

Systematic Studies On Track Reconstruction Efficiency At Belle II

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Outline

- Overview on the Belle II experiment
- Bhabha kinematics at Belle II
- Preparation for calculating the tracking efficiency
- Phase2 tracking efficiency
- Phase3 tracking efficiency
- Comparing phase2 with phase3
- Conclusion

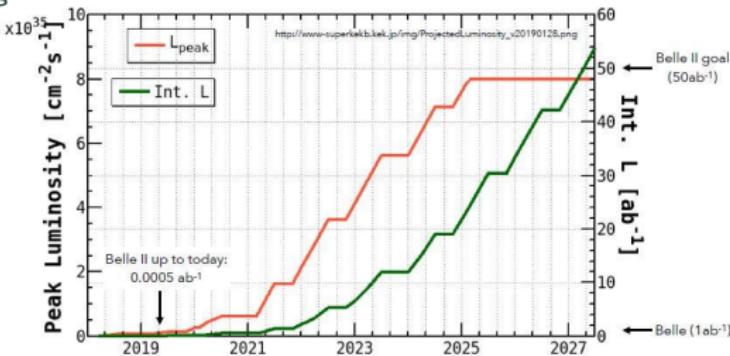
Motivation

- At an electron-positron accelerator most outgoing particles are again electrons and positrons (these events are called Bhabha events)
- These events can be used to estimate the performance of the tracking detectors
- If the *tag* particle in a Bhabha event has a track than the *probe* particle also should have a track associated
→ a tracking efficiency can be calculated

Overview Of The Belle II Experiment

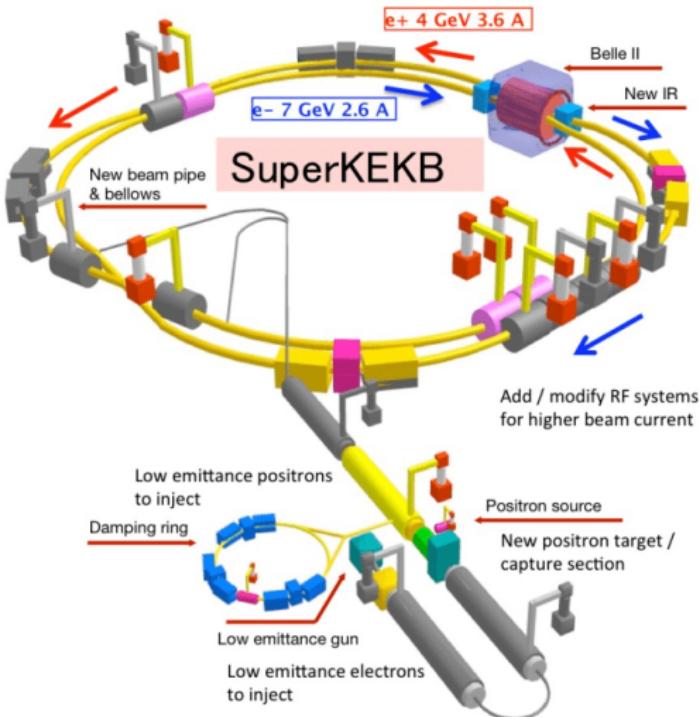
Belle II Schedule And Luminosity Goals

- Phase1: accelerator commissioning and background estimation (completed in 2016)
- Phase2: collision runs and background studies with partially installed detector (completed in 2018)
- Phase3: data taking with the whole detector (started in April 2019)



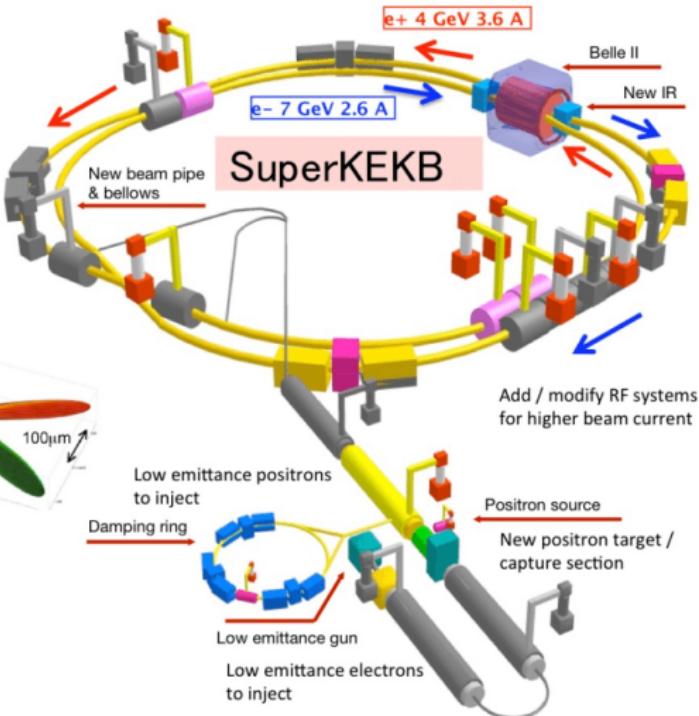
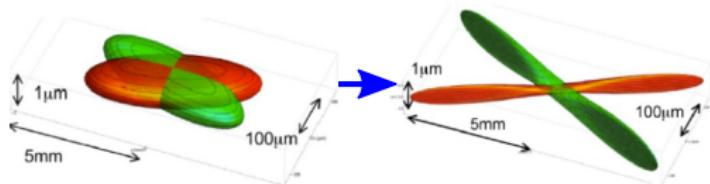
The SuperKEKB e^+e^- collider

- Asymmetric B -factory
- Center-of-mass close to $\Upsilon(4S)$
 ~ 10.5 GeV
- Upgrade of the KEKB collider:
 - Larger beam current
 - Reduced beam size



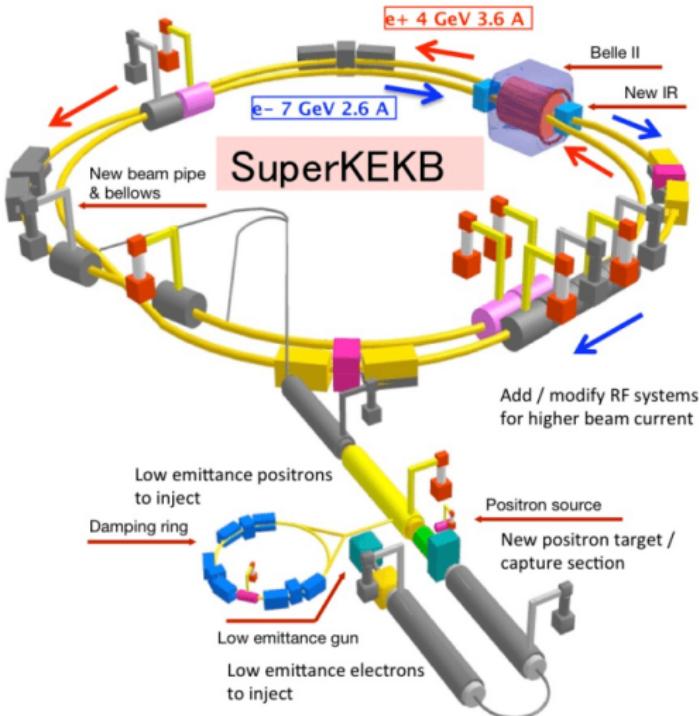
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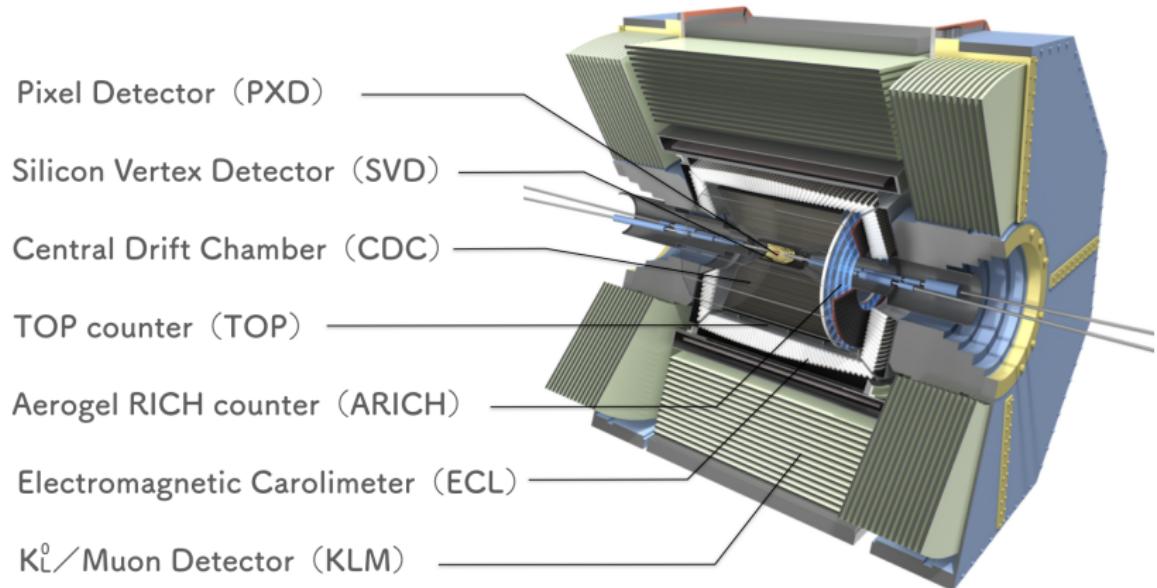


The SuperKEKB e^+e^- collider

- Asymmetric B -factory
- Center-of-mass close to $\Upsilon(4S)$
 ~ 10.5 GeV
- Upgrade of the KEKB collider:
 - Larger beam current
 - Reduced beam size
- \rightarrow Luminosity increase $\times 40$
- Designed peak luminosity of
 $8 \cdot 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
- Planned data sample corresponding to a recorded integrated luminosity of
 $\sim 50 \text{ ab}^{-1}$



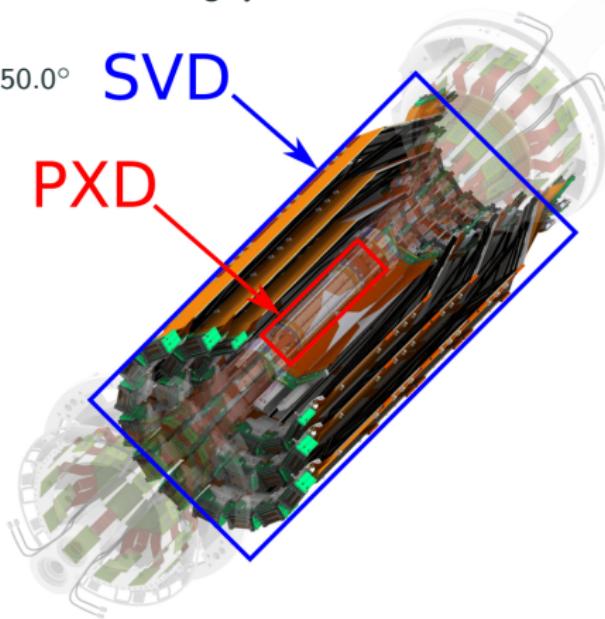
The Belle II Detector



Vertex Detectors

Vertex Detectors:

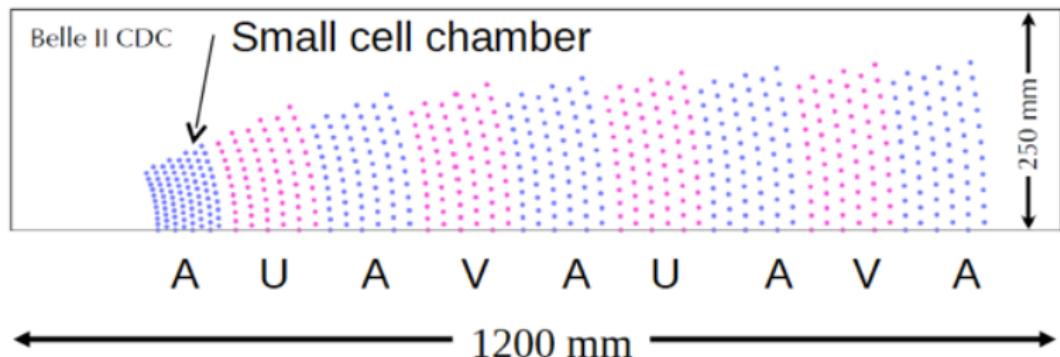
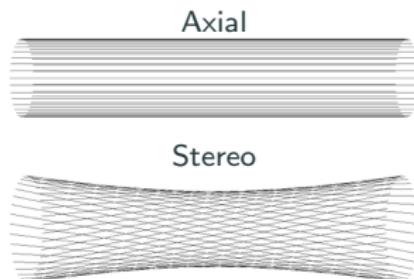
- Consists of Pixel Detector (PXD) and Silicon Vertex Detector (SVD)
- Both detectors consist of multiple ladders of strip detectors
- During phase2, only a fraction of the VXD detectors were installed
- During phase3, the complete SVD and roughly half of the PXD were installed
- Acceptance: $17.0^\circ < \theta < 150.0^\circ$



Central Drift Chamber

Central Drift Chamber:

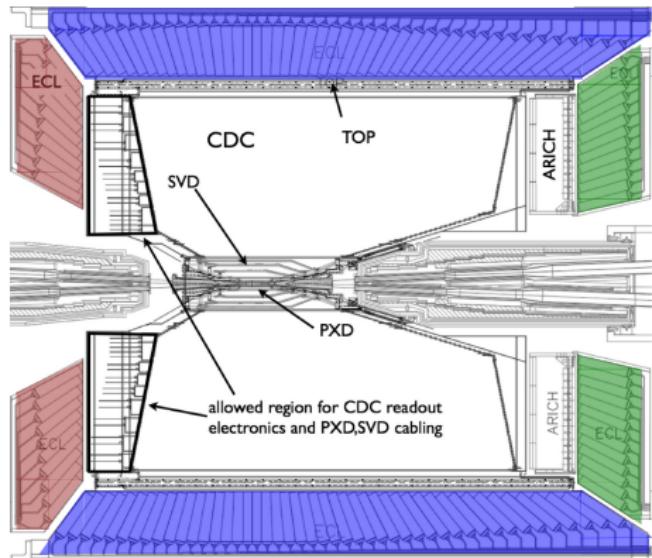
- Consists of 14336 sense wires arranged in 56 layers
- 6 layers are combined to a superlayer (with an exception to innermost superlayer)
- There are 5 axial and 4 stereo superlayers
- The electric field is provided by 42240 field wires
- Charged particles ionize the gas.
The signal is then read out by the sense wires
- Acceptance: $17.0^\circ < \theta < 150.0^\circ$



Electromagnetic Calorimeter

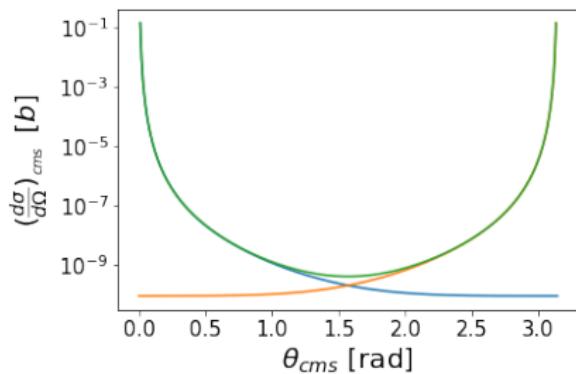
Electromagnetic Calorimeter:

- Consists of 8936 CsI(Tl) crystals
- Separation in **barrel**, **forward end cap** and **backward end cap**
- There are two $\sim 1^\circ$ wide gaps at transition between the regions
- Main tasks:
 - High efficiency photon detection, plus determination of their energy and angular coordinates
 - Electron identification
 - Generation of a proper signal for the trigger
- Acceptance: $12.4^\circ < \theta < 155.1^\circ$

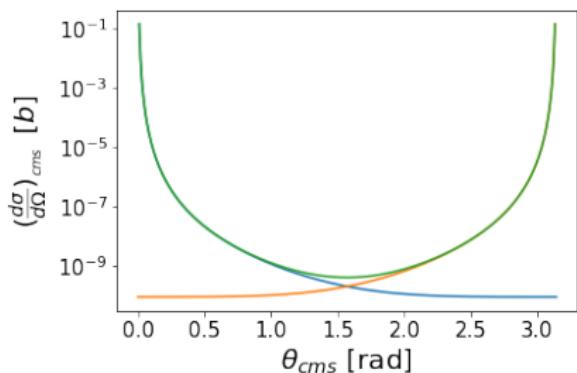


Bhabha Kinematics At Belle II

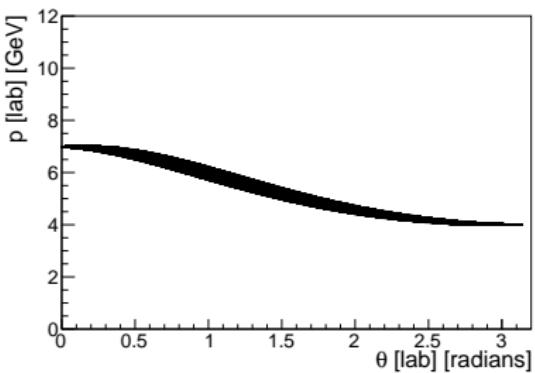
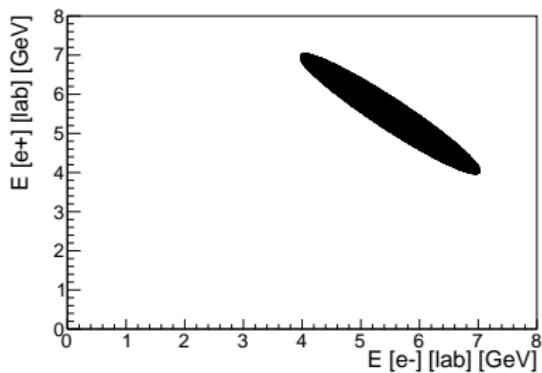
Bhabha Kinematics At Belle II



Bhabha Kinematics At Belle II



- The beams have asymmetric energies
- The beams are hitting each other under an angle of 1.26°



Preparation For Calculating The Tracking Efficiency

Introducing Cuts

Goal: Reconstruct Bhabha events using only ECL information

$$\text{vpho-Bhabha} \rightarrow \text{ECL-Object(HcIE)} + \text{ECL-Object(LcIE)}$$

HcIE: particle with higher cluster Energy; LcIE: particle with lower cluster Energy

Introducing Cuts

Goal: Reconstruct Bhabha events using only ECL information

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- The particles have to pass the tracking detectors

$$\rightarrow 17.0^\circ < \theta_{\text{ECL-Object}} < 150.0^\circ$$

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- The particles have to pass the tracking detectors
 $\rightarrow 17.0^\circ < \theta_{\text{ECL-Object}} < 150.0^\circ$
- $8 \text{ GeV} < M_{v\text{pho}} < 12 \text{ GeV}$
- 2 clusters with at least 3.5 GeV per event; One cluster has to have at least 4.5 GeV
- Number of reconstructed tracks per event < 7
- Total energy in the ECL $< 15 \text{ GeV}$

Introducing Cuts

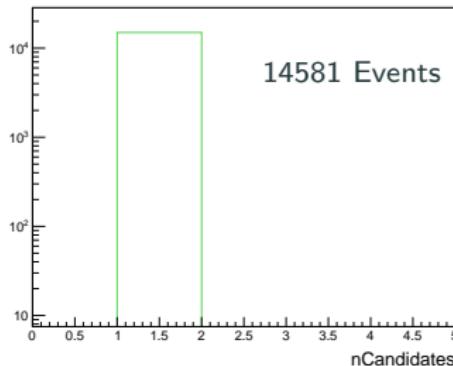
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Single phase2 MC10 Bhabha file



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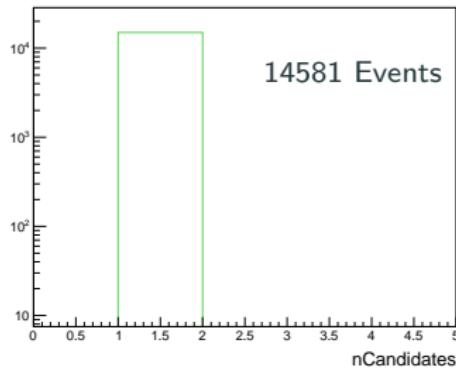
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- The particles have to pass the tracking detectors

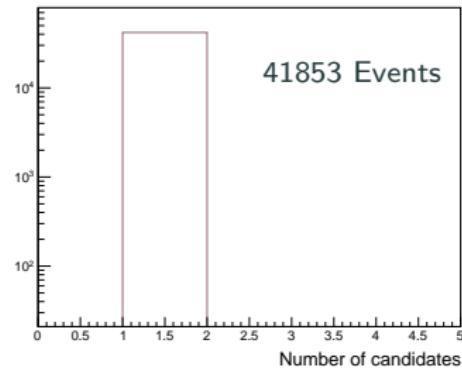
$$\rightarrow 17.0^\circ < \theta_{\text{ECL-Object}} < 150.0^\circ$$

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Single phase2 MC10 Bhabha file



Single phase2 data file



Introducing Cuts

Goal: Reconstruct Bhabha events using only ECL information

$$\text{vpho-Bhabha} \rightarrow \text{ECL-Object(HcIE)} + \text{ECL-Object(LcIE)}$$

HcIE: particle with higher cluster Energy; LcIE: particle with lower cluster Energy

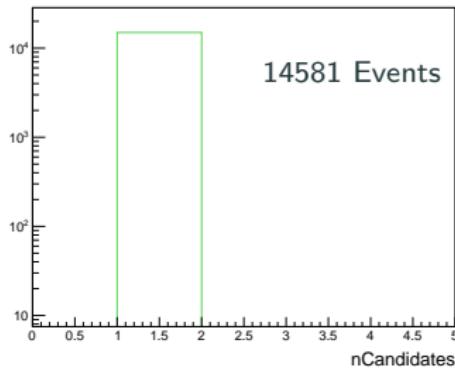
- The particles have to pass the tracking detectors

$$\rightarrow 17.0^\circ < \theta_{\text{ECL-Object}} < 150.0^\circ$$

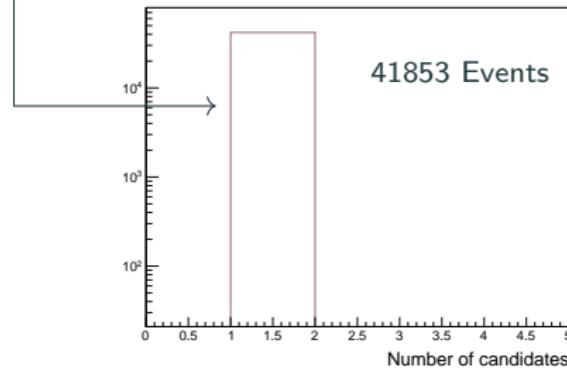
- $8 \text{ GeV} < M_{\text{vpho}} < 12 \text{ GeV}$
- 2 clusters with at least 3.5 GeV per event; One cluster has to have at least 4.5 GeV
- Number of reconstructed candidates
- Total energy in the ECL objects

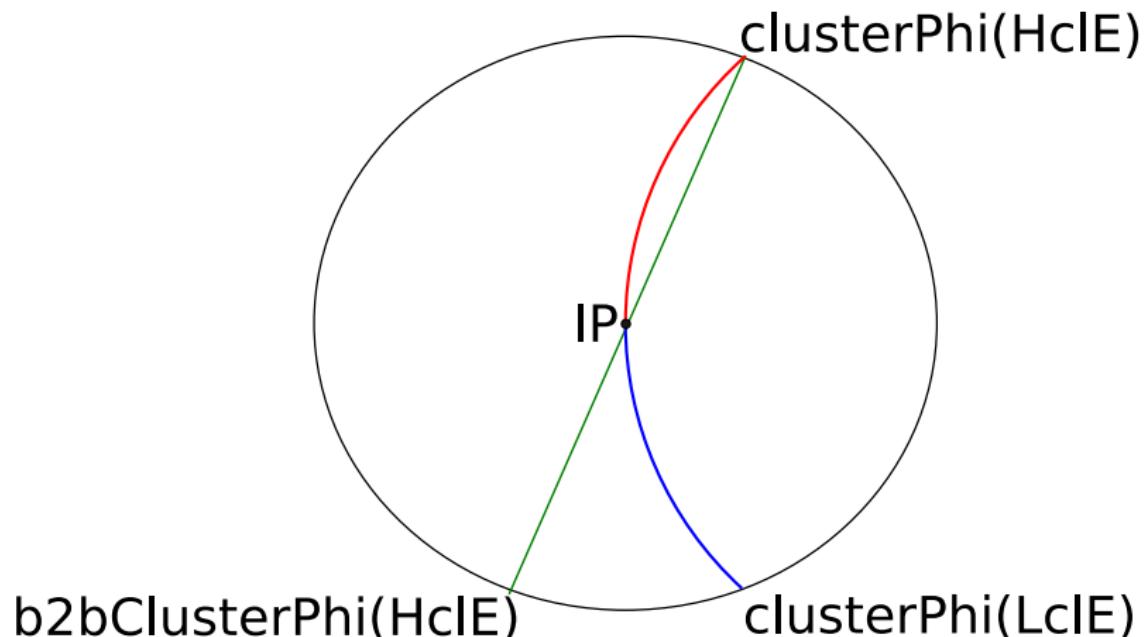
Also contains $e^+e^- \rightarrow \gamma\gamma$ events

Single phase2 MC10 Bhabha file

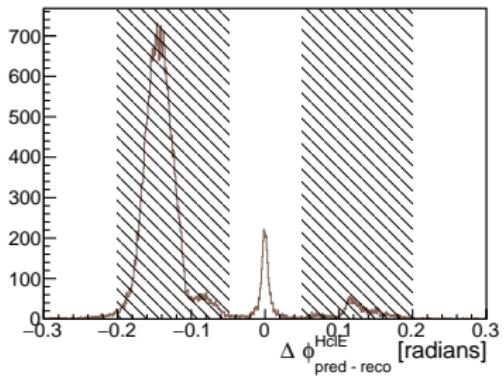
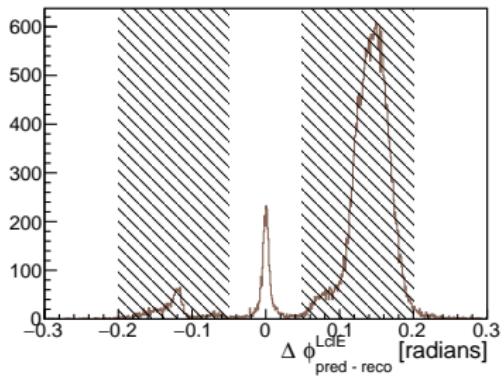
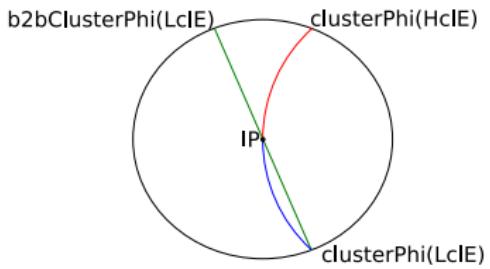
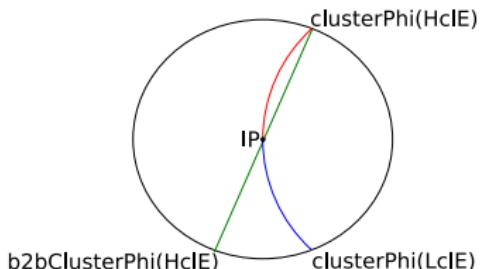


Single phase2 data file

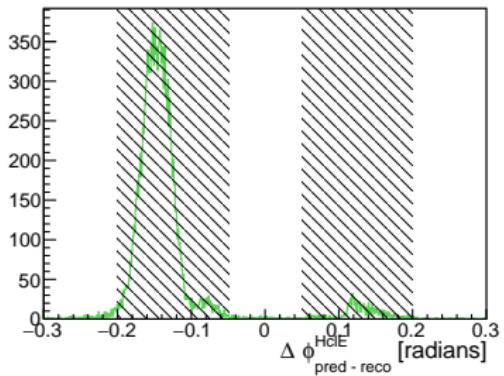
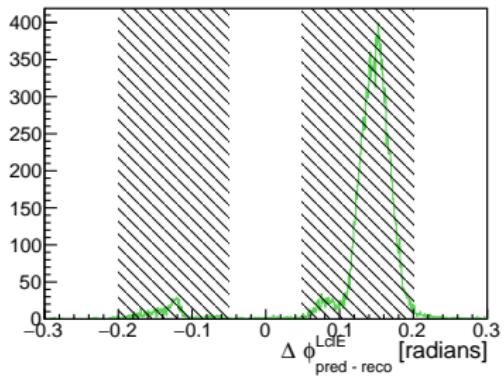
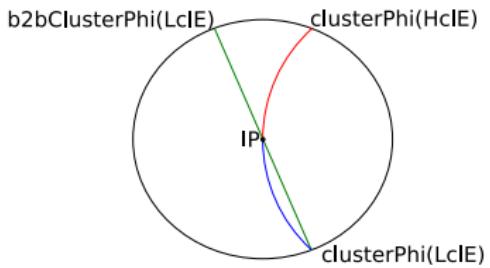
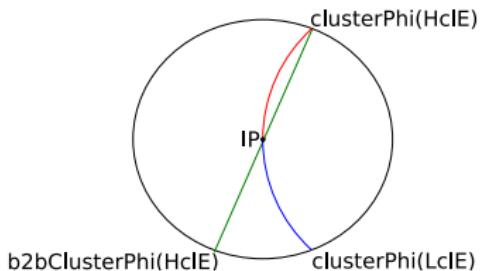




Bhabha Event Selection



Bhabha Event Selection



Trigger

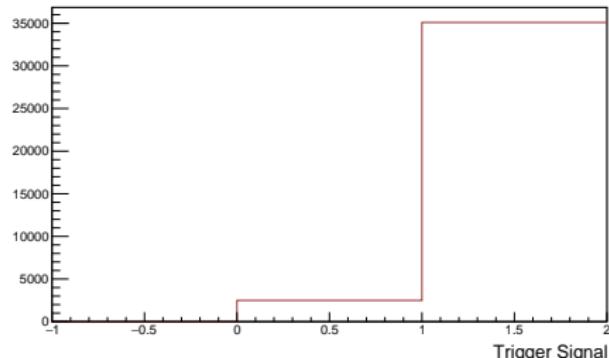
We need to be sure that a trigger signal is coming from the ECL. Otherwise there could be a bias

→ The bhabha trigger bit is used

This trigger requires several conditions:

- Trigger signal coming from the ECL
- Both reconstructed particles have to have a cluster energy of 2.5 GeV each and one has to have at least 4 GeV
- $160^\circ < \sum \theta_{cms} < 200^\circ$
- $140^\circ < \Delta\phi_{cms} < 220^\circ$

The trigger cut is only applied on phase2 data (and phase3 data later on) since the trigger simulation does not work reliably on MC



Dividing The ECL In Areas Of Interest

As function of azimuthal angle

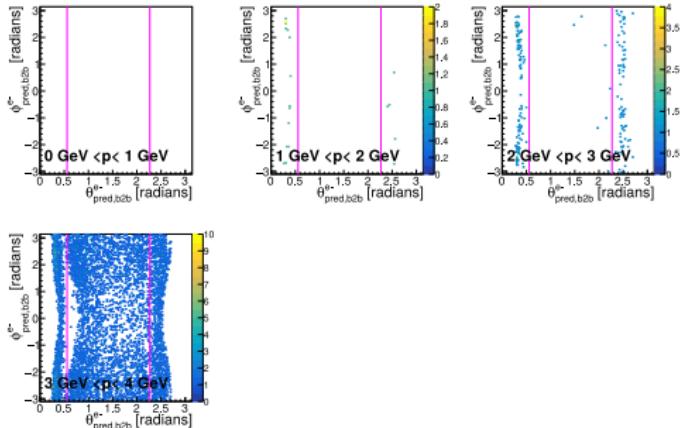
$\phi_{\text{pred,b2b}}$

$p(e^-)$

Forward End-Cap

Barrel

Backward End-Cap



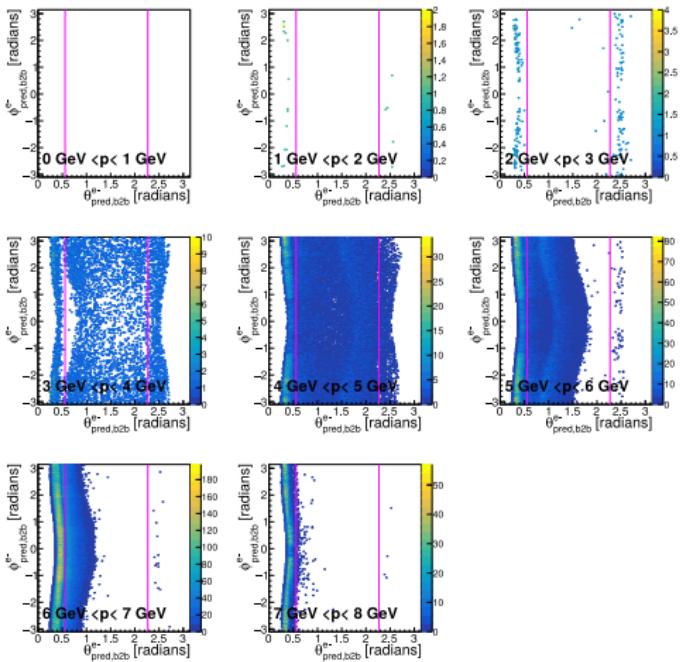
Dividing The ECL In Areas Of Interest

As function of azimuthal angle

$\phi_{\text{pred,b2b}}$

$$p(e^-)$$

Forward End-Cap	4 GeV – 8 GeV
Barrel	4 GeV – 7 GeV
Backward End-Cap	/

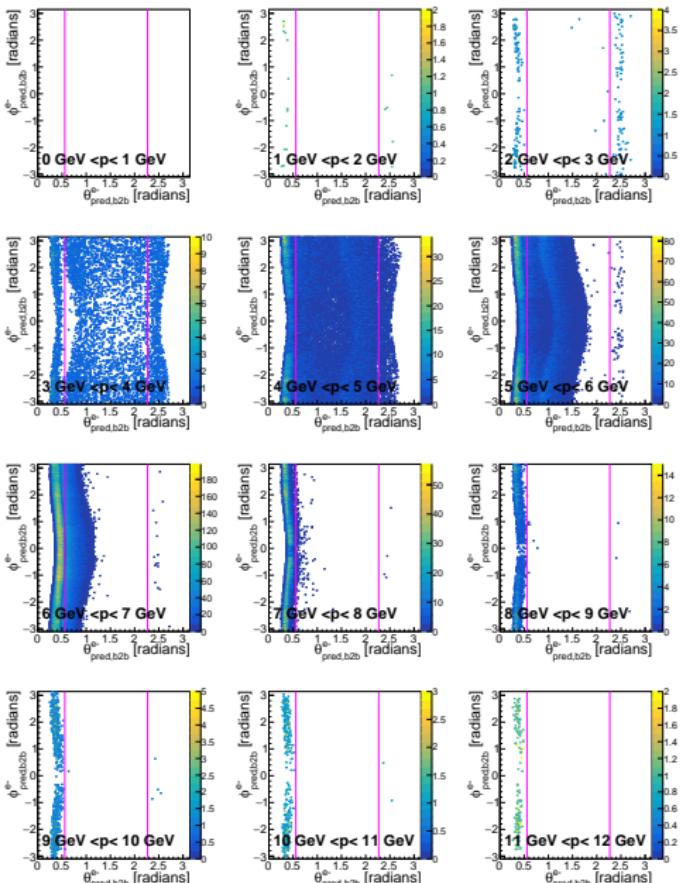


Dividing The ECL In Areas Of Interest

As function of azimuthal angle

$\phi_{\text{pred,b2b}}$

Forward End-Cap	4 GeV – 8 GeV
Barrel	4 GeV – 7 GeV
Backward End-Cap	/

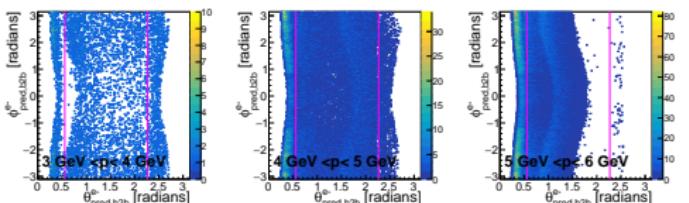
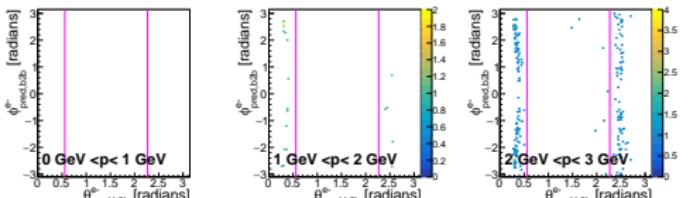


Dividing The ECL In Areas Of Interest

As function of azimuthal angle

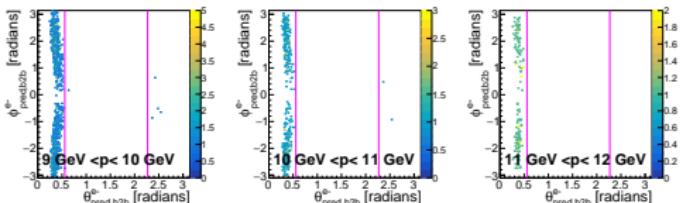
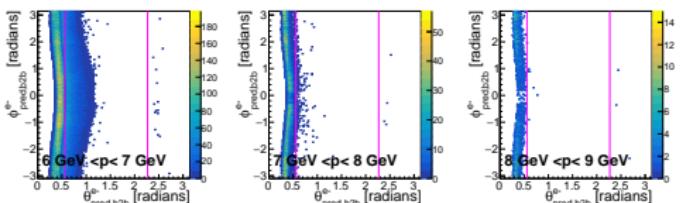
$$\phi_{\text{pred},\text{b2b}}$$

Forward End-Cap	4 GeV – 8 GeV
Barrel	4 GeV – 7 GeV
Backward End-Cap	/



As function of polar angle $\theta_{\text{pred},\text{b2b}}$

$$p \quad \text{e}^- \quad 4 \text{ GeV} - 9 \text{ GeV}$$



Dividing The ECL In Areas Of Interest

As function of azimuthal angle

$$\phi_{\text{pred},\text{b2b}}$$

$$p(e^-)$$

Forward End-Cap 4 GeV – 8 GeV

Barrel 4 GeV – 7 GeV

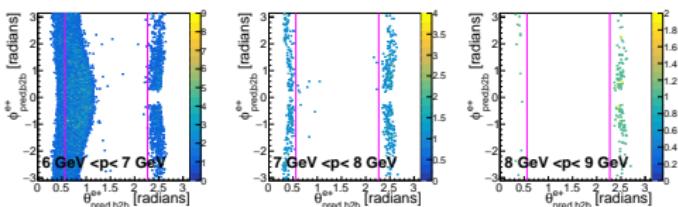
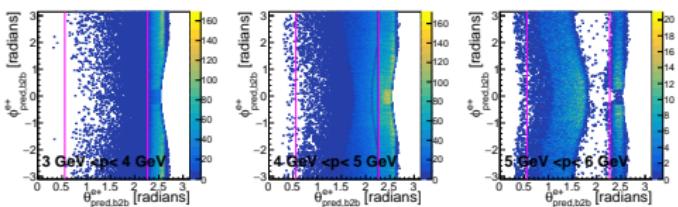
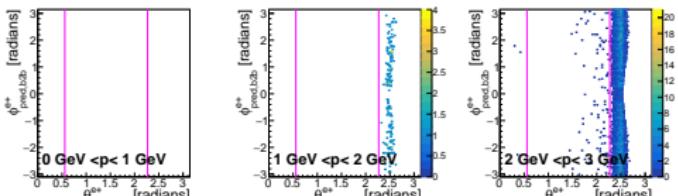
Backward End-Cap /

$$p(e^+)$$

Forward End-Cap /

Barrel 3 GeV – 7 GeV

Backward End-Cap 2 GeV – 6 GeV

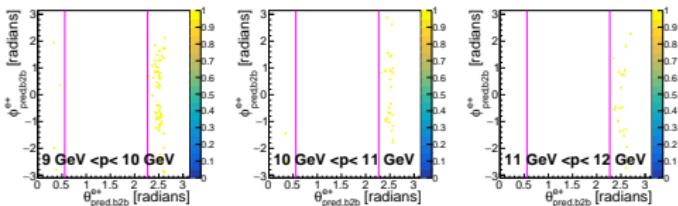


As function of polar angle $\theta_{\text{pred},\text{b2b}}$

$$p$$

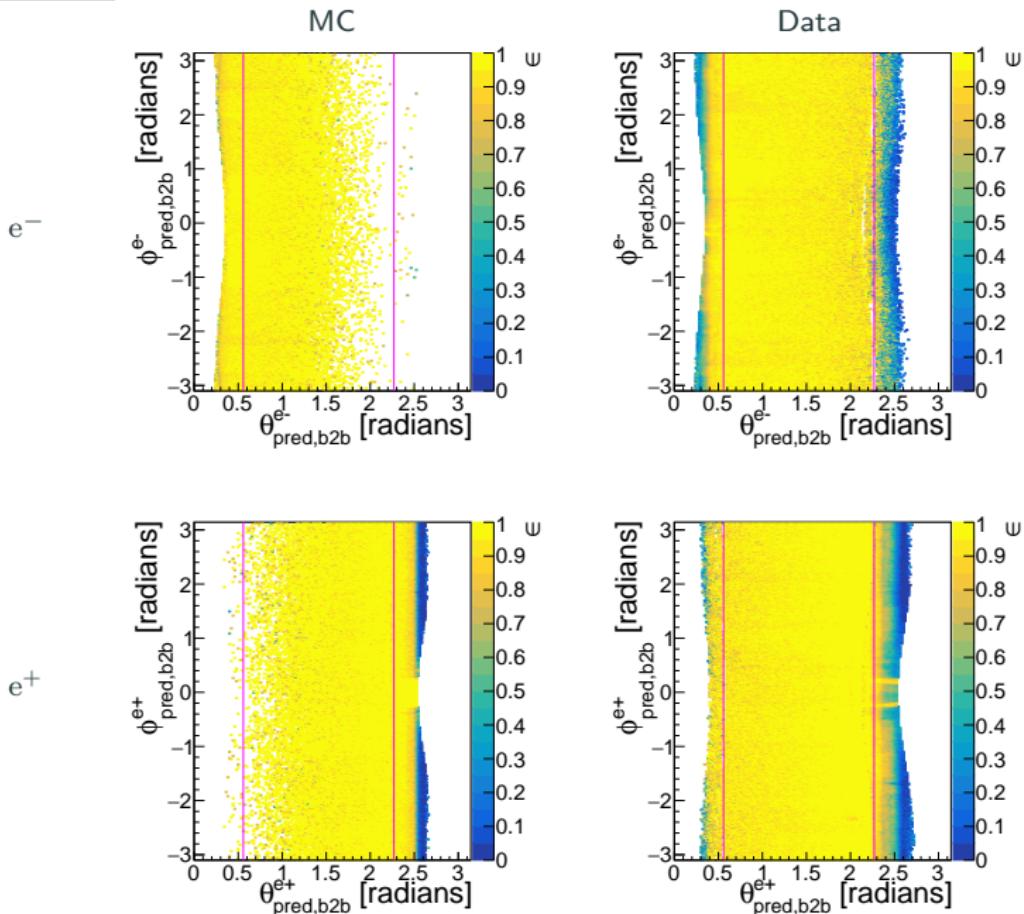
e^- 4 GeV – 9 GeV

e^+ 2 GeV – 7 GeV

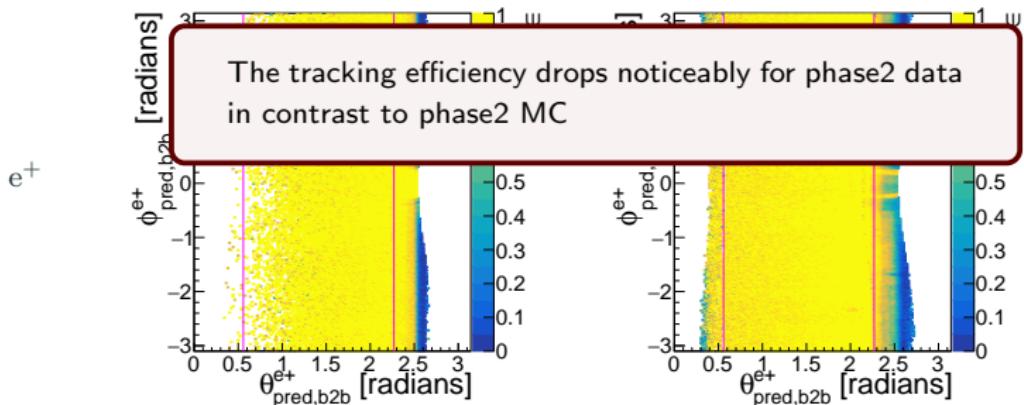
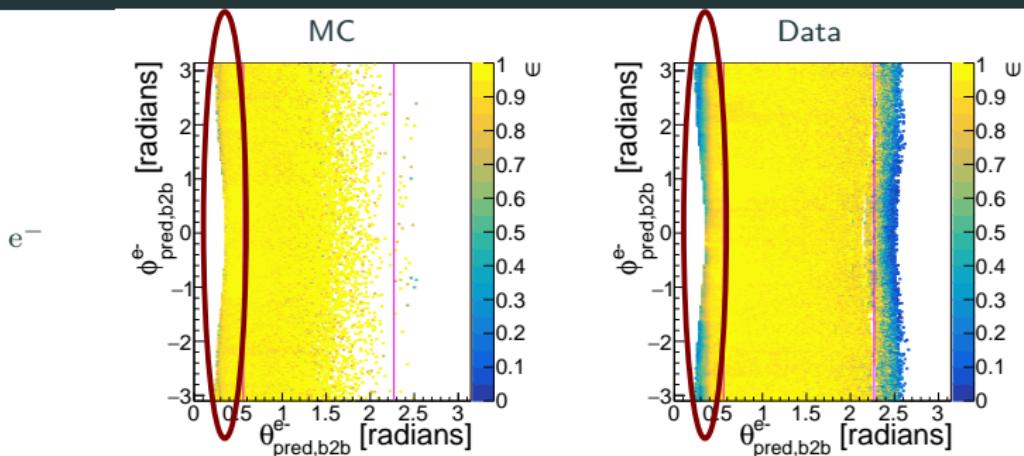


Phase2 Tracking Efficiencies

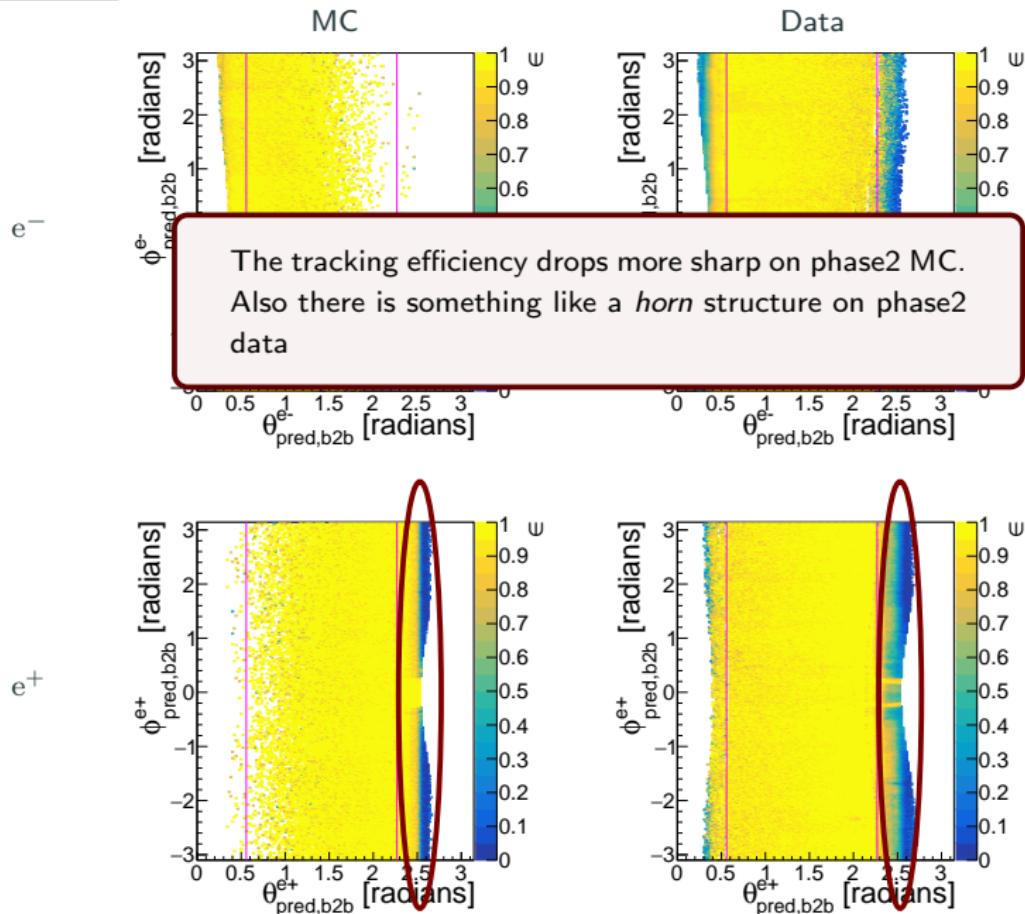
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$

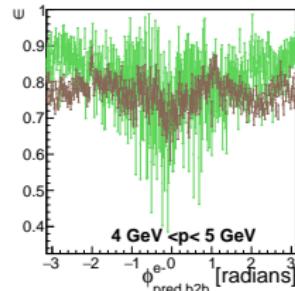


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

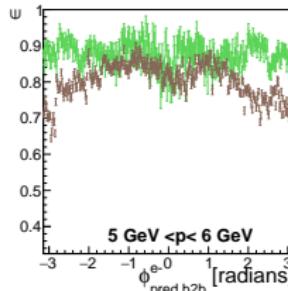
Phase2 MC10

Phase2 Data

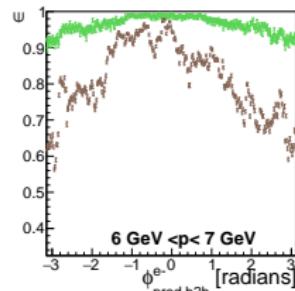
e^-



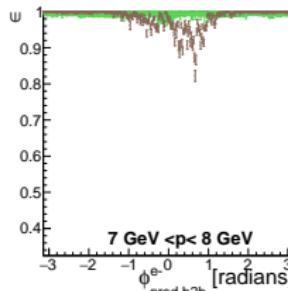
$4 \text{ GeV} < p < 5 \text{ GeV}$



$5 \text{ GeV} < p < 6 \text{ GeV}$

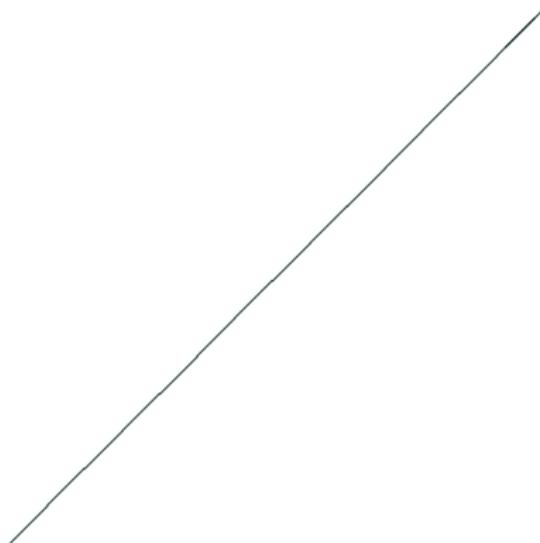


$6 \text{ GeV} < p < 7 \text{ GeV}$



$7 \text{ GeV} < p < 8 \text{ GeV}$

e^+

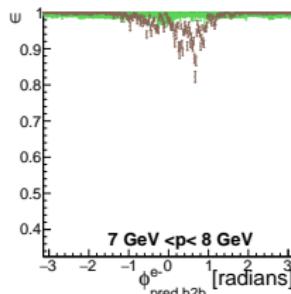
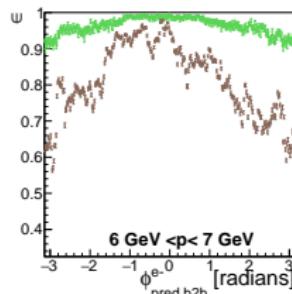
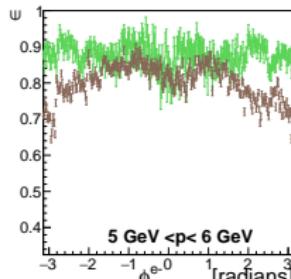
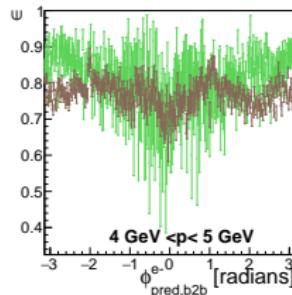


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase2 MC10

Phase2 Data

e⁻



Electron Tracking Efficiency:

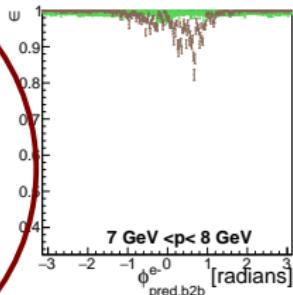
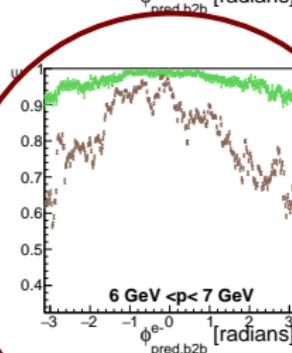
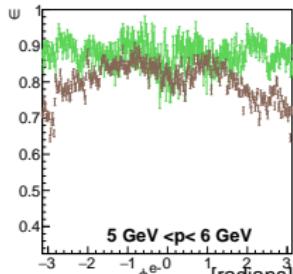
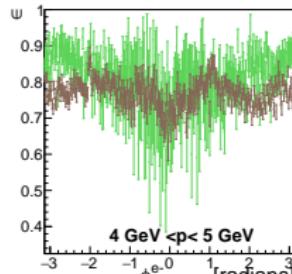
- Phase2 MC has almost always a higher tracking efficiency compared to phase2 data
- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\text{pred,b2b}}| \gtrsim 2$

Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase2 MC10

Phase2 Data

e⁻



Electron Tracking Efficiency:

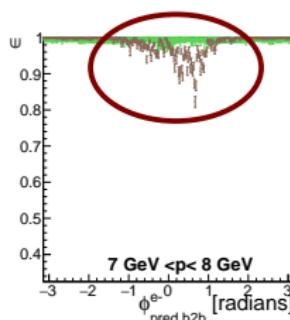
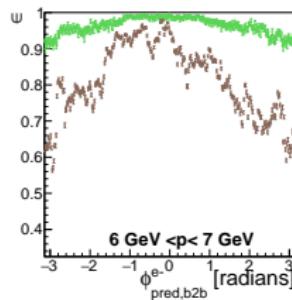
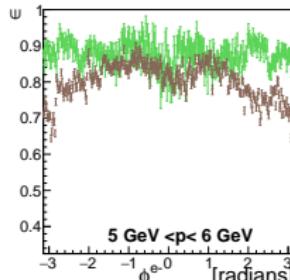
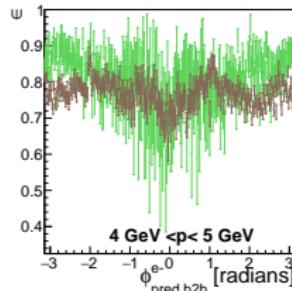
- Phase2 MC has almost always a higher tracking efficiency compared to phase2 data
- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\text{pred,b2b}}| \gtrsim 2$
- There is no similarity in the structure for momenta between 6 GeV and 7 GeV

Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase2 MC10

Phase2 Data

e⁻



Electron Tracking Efficiency:

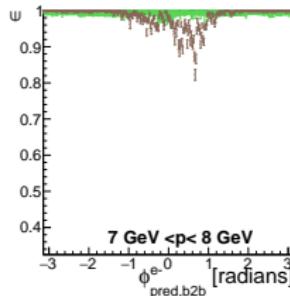
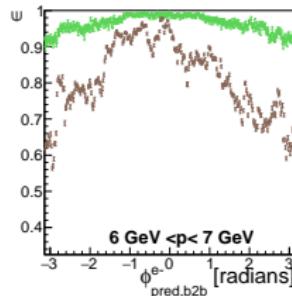
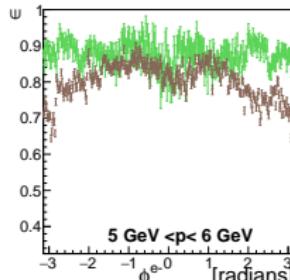
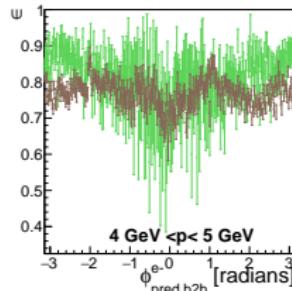
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- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\text{pred,b2b}}| \gtrsim 2$
- There is no similarity in the structure for momenta between 6 GeV and 7 GeV
- Highest tracking efficiency occurs for momenta between 7 GeV and 8 GeV. But there is also an efficiency drop at $\phi_{\text{pred,b2b}} \gtrsim 0$

Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase2 MC10

Phase2 Data

e⁻



Electron Tracking Efficiency:

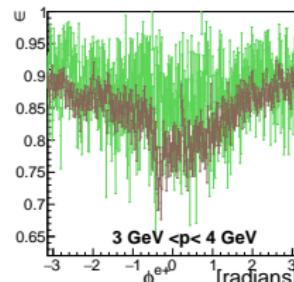
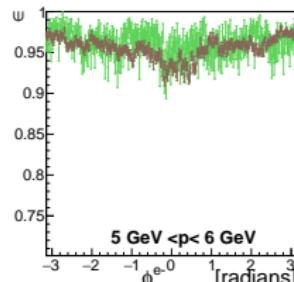
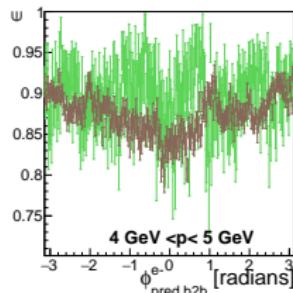
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- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\text{pred,b2b}}| \gtrsim 2$
- There is no similarity in the structure for momenta between 6 GeV and 7 GeV
- Highest tracking efficiency occurs for momenta between 7 GeV and 8 GeV. But there is also an efficiency drop at $\phi_{\text{pred,b2b}} \gtrsim 0$

Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

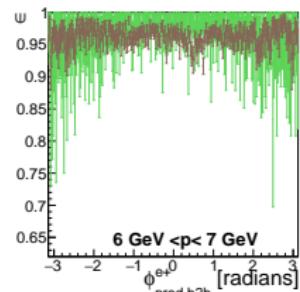
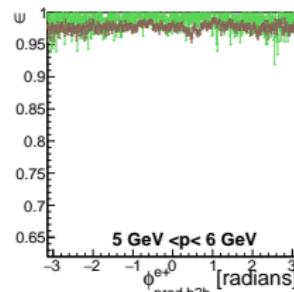
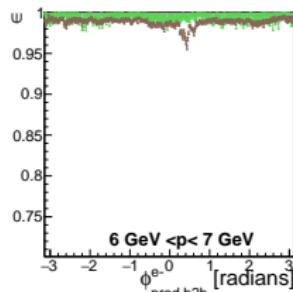
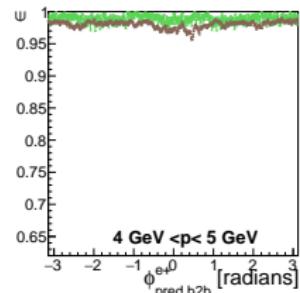
Phase2 MC10

e⁻

Phase2 Data



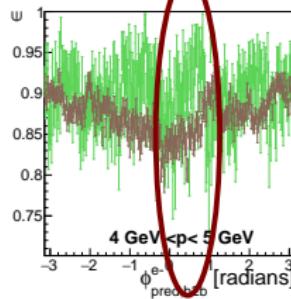
e⁺



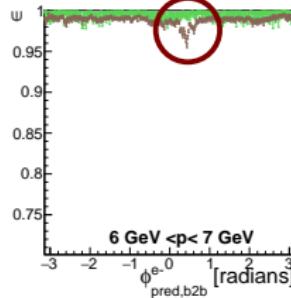
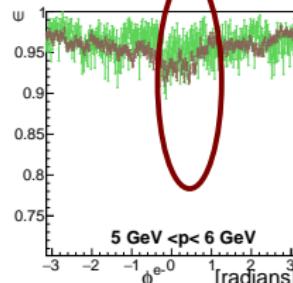
Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase2 MC10

Phase2 Data

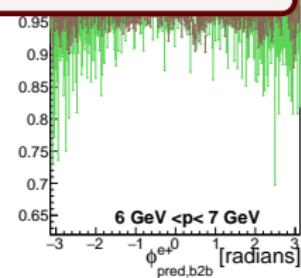
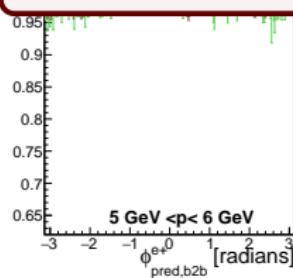


e^-



Electron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 6 GeV and 7 GeV
- There is a slope at $\phi_{\text{pred,b2b}} \gtrsim 0$ for phase2 MC and phase2 data

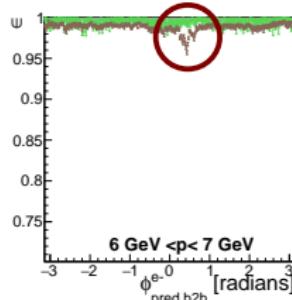
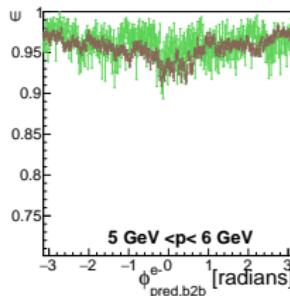
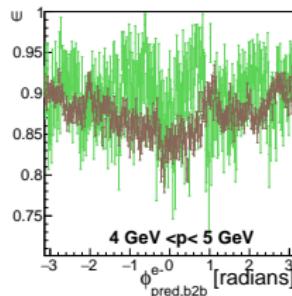


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase2 MC10

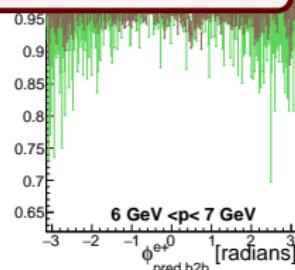
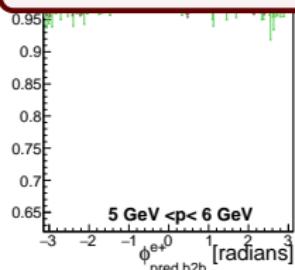
e⁻

Phase2 Data



Electron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 6 GeV and 7 GeV
- There is a slope at $\phi_{\text{pred,b2b}} \gtrsim 0$ for phase2 MC and phase2 data
- This kind of drop we also saw in the forward end-cap for momenta between 7 GeV and 8 GeV

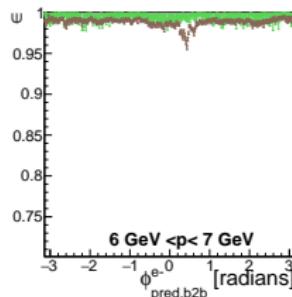
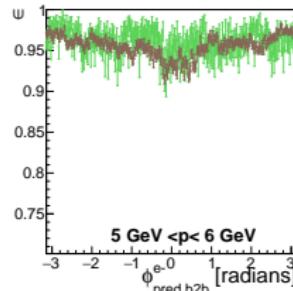
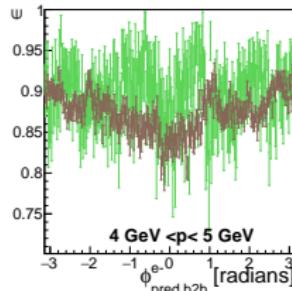


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase2 MC10

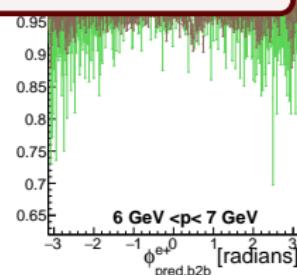
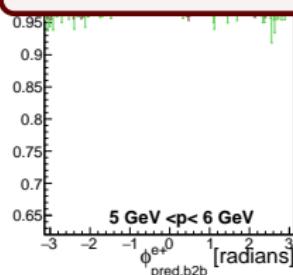
e⁻

Phase2 Data



Electron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 6 GeV and 7 GeV
- There is a slope at $\phi_{\text{pred,b2b}} \gtrsim 0$ for phase2 MC and phase2 data
- This kind of drop we also saw in the forward end-cap for momenta between 7 GeV and 8 GeV

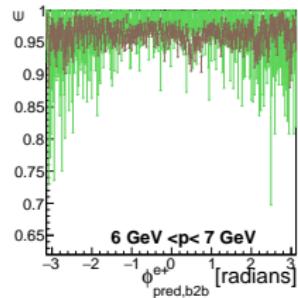
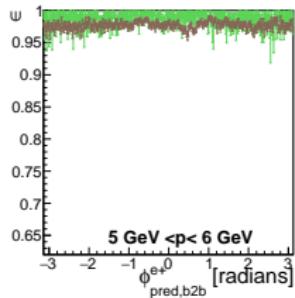
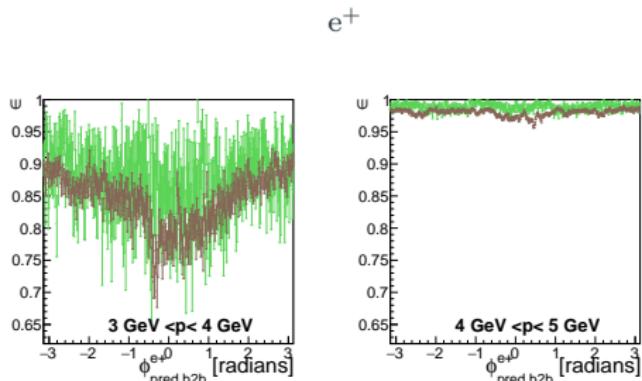
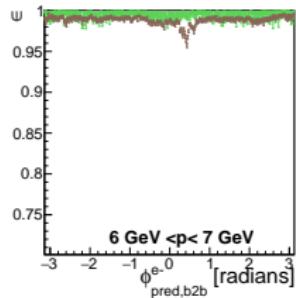


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase2 MC10

Positron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 4 GeV and 5 GeV
- The lowest tracking efficiency occurs for momenta between 3 GeV and 4 GeV with a minima at $\phi_{\text{pred,b2b}} \approx 0$

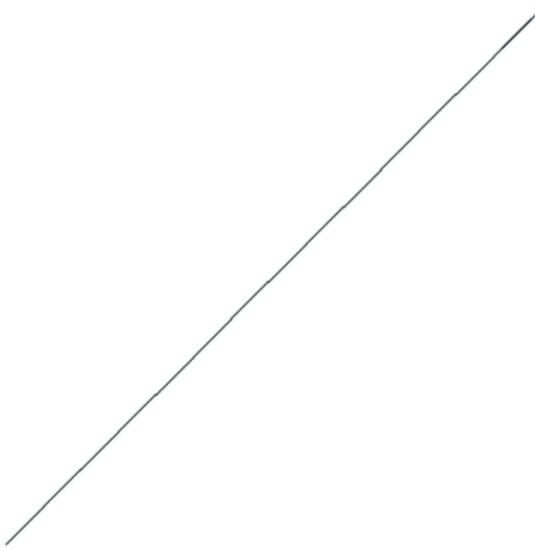


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

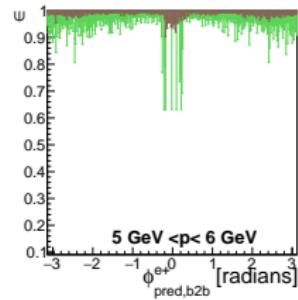
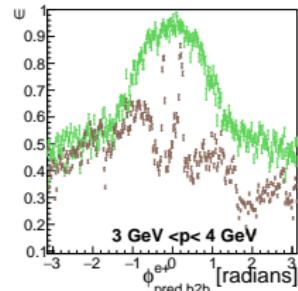
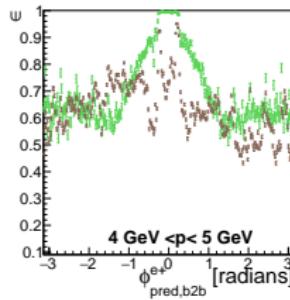
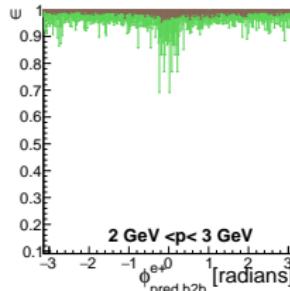
Phase2 MC10

e^-

Phase2 Data



e^+



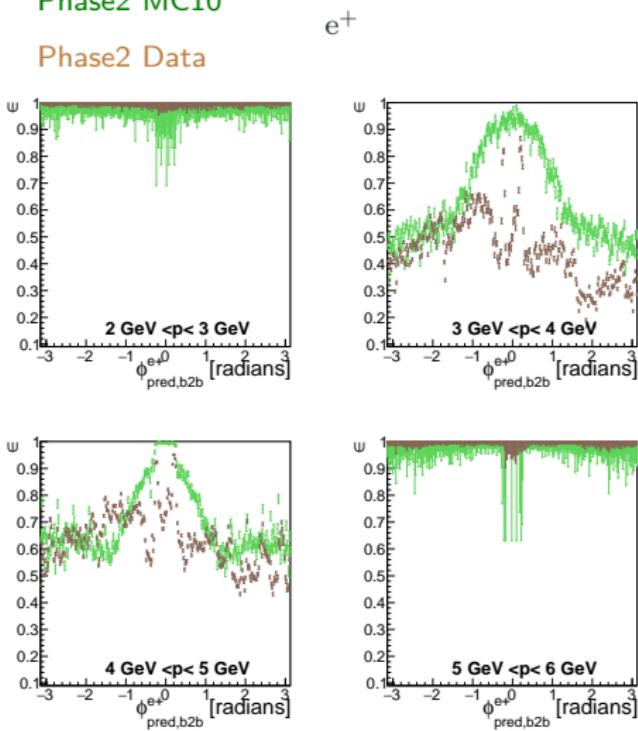
Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

Positron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 2 GeV and 3 GeV and 5 GeV and 6 GeV

Phase2 MC10

Phase2 Data



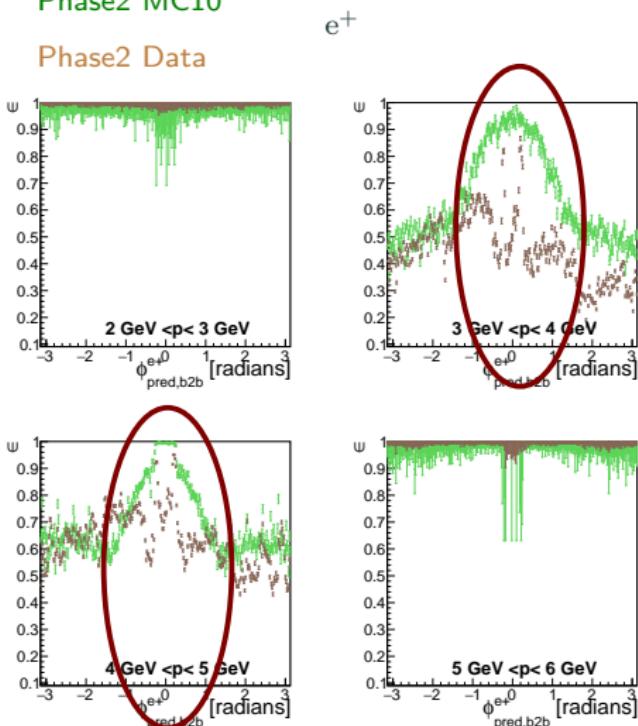
Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

Positron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 2 GeV and 3 GeV and 5 GeV and 6 GeV
- Weird *horn* structure we saw earlier
- Phase2 MC tracking efficiency peaks at $\phi_{\text{pred,b2b}} \approx 0$

Phase2 MC10

Phase2 Data



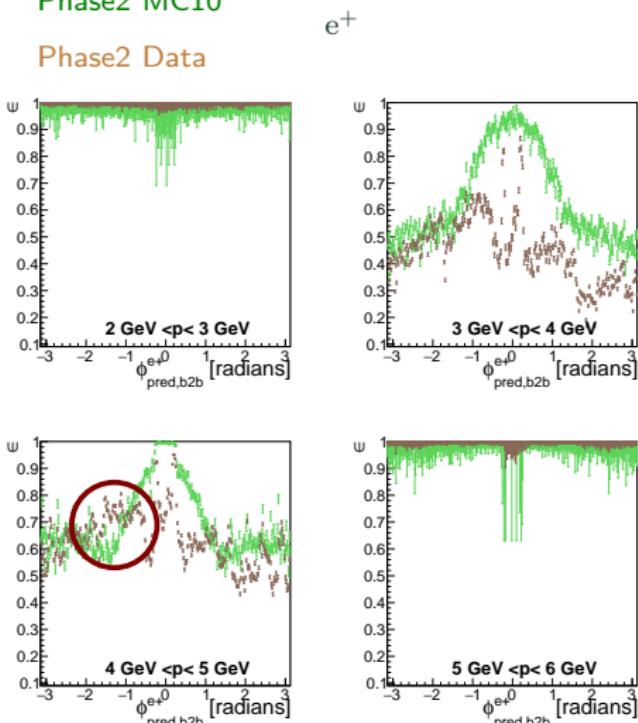
Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

Positron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between 2 GeV and 3 GeV and 5 GeV and 6 GeV
- Weird *horn* structure we saw earlier
- Phase2 MC tracking efficiency peaks at $\phi_{\text{pred,b2b}} \approx 0$
- For momenta between 4 GeV and 5 GeV phase2 data appears to have a higher tracking efficiency compared to phase2 MC at $\phi_{\text{pred,b2b}} \approx -1$

Phase2 MC10

Phase2 Data

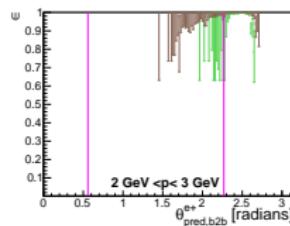
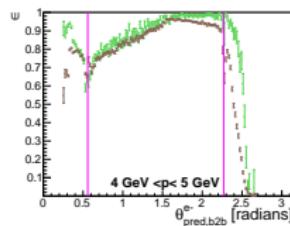
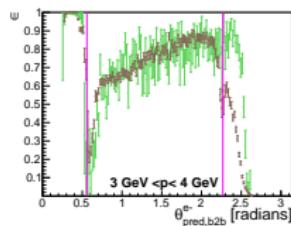


Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

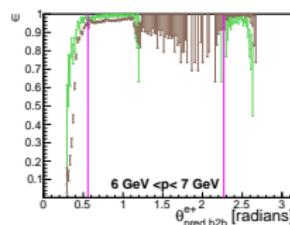
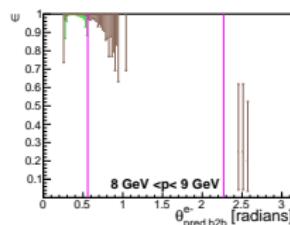
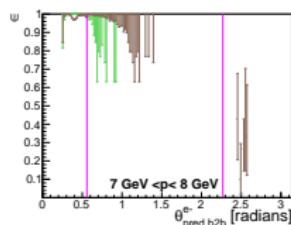
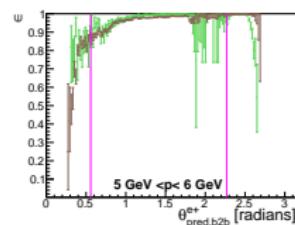
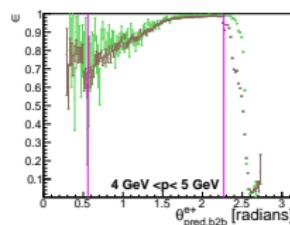
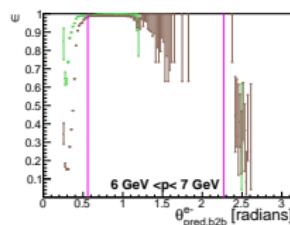
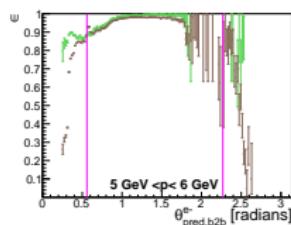
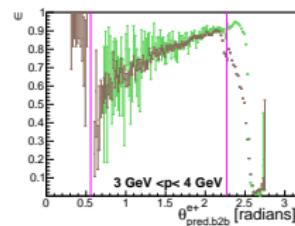
Phase2 MC10

e^-

Phase2 Data



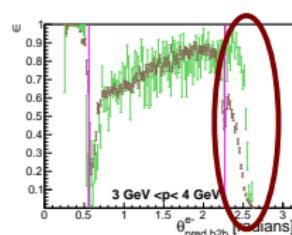
e^+



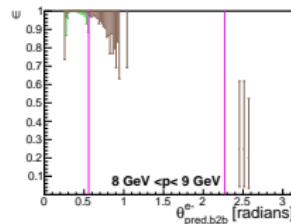
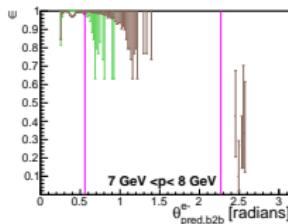
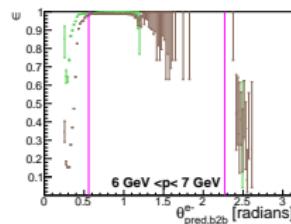
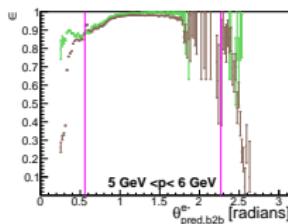
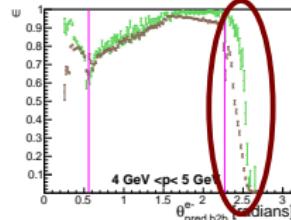
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data



e^-



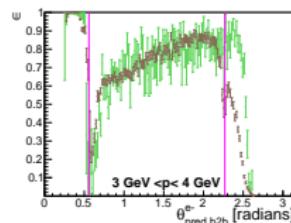
Electron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC

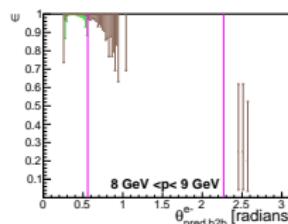
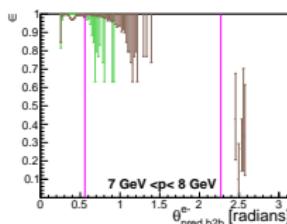
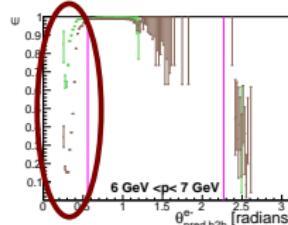
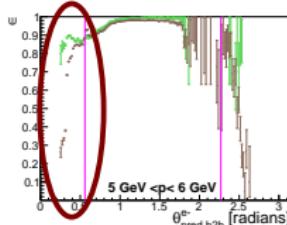
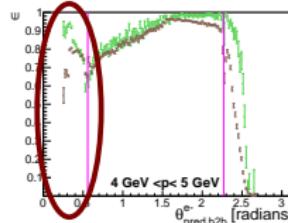
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data



e^-



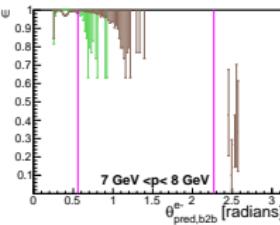
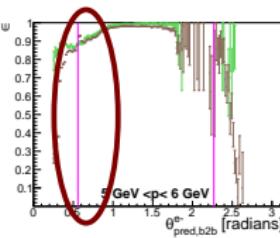
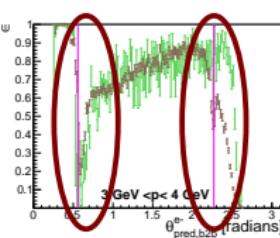
Electron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC

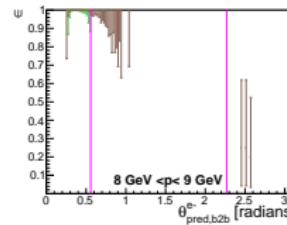
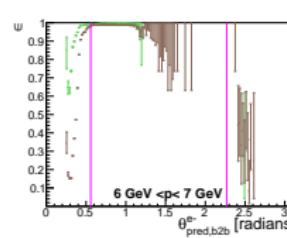
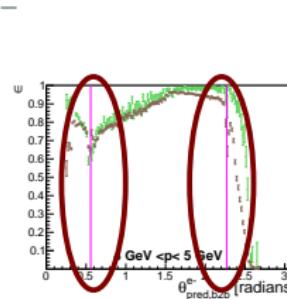
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data



e^-



Electron Tracking Efficiency:

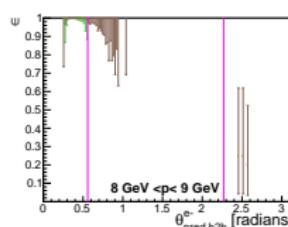
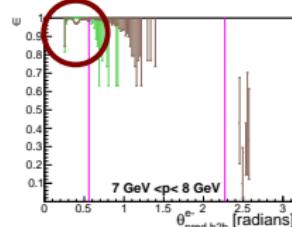
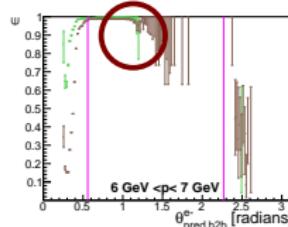
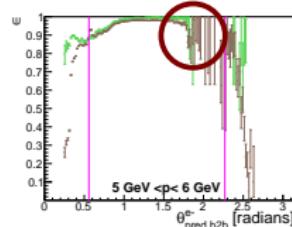
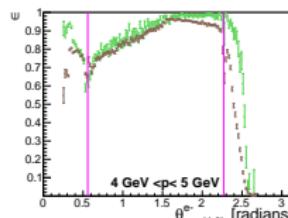
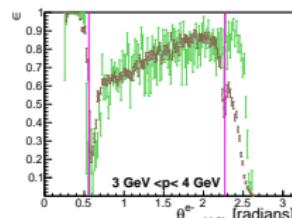
- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC
- Drops in efficiency at transition between barrel and end-caps

Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data

e⁻



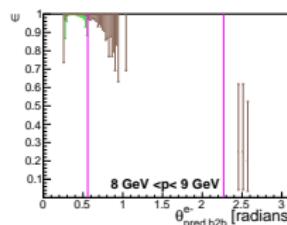
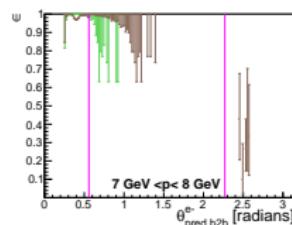
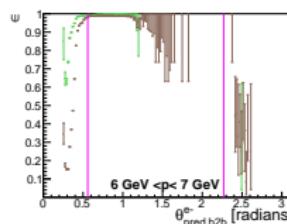
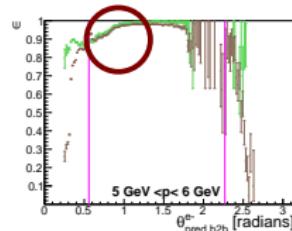
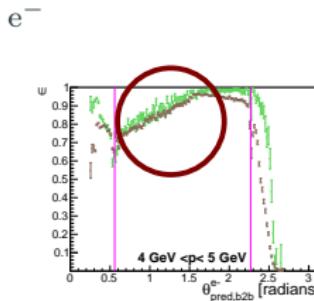
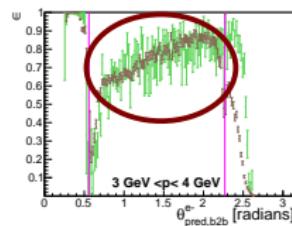
Electron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC
- Drops in efficiency at transition between barrel and end-caps
- A efficiency drop appears to propagate for momenta between 5 GeV and 7 GeV for phase2 data

Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data



Electron Tracking Efficiency:

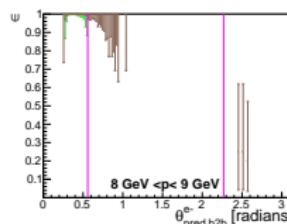
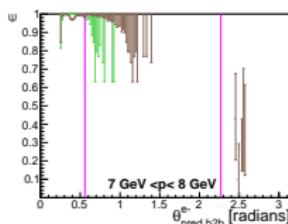
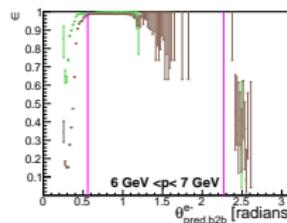
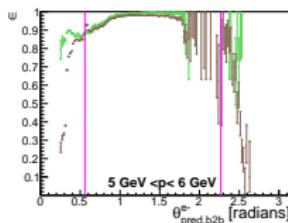
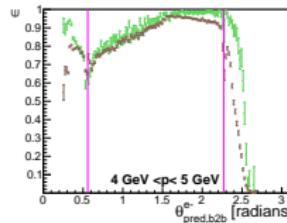
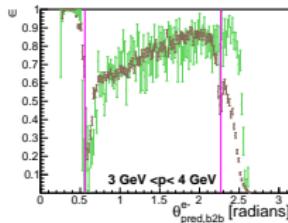
- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC
- Drops in efficiency at transition between barrel and end-caps
- A efficiency drop appears to propagate for momenta between 5 GeV and 7 GeV for phase2 data
- There is a slope in the barrel

Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase2 MC10

Phase2 Data

e⁻



Electron Tracking Efficiency:

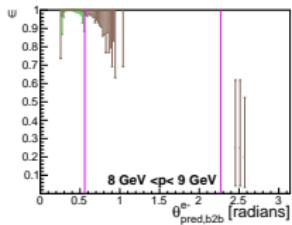
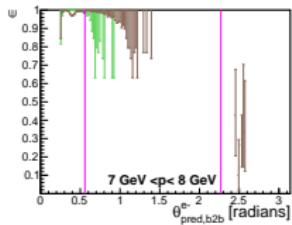
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Positron Tracking Efficiency:

Phase2 MC10

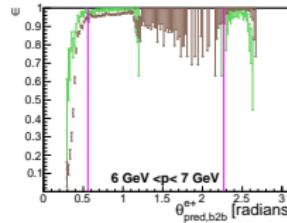
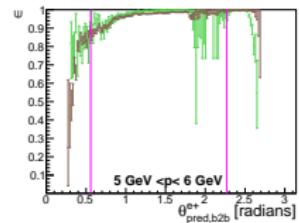
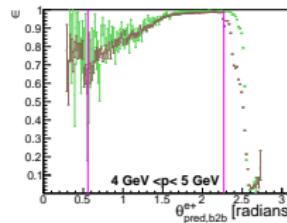
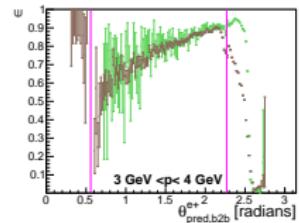
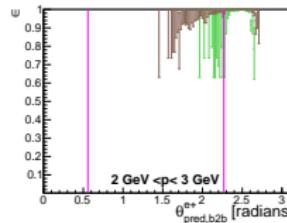
Phase2 Data

e⁺



Phase2 MC10

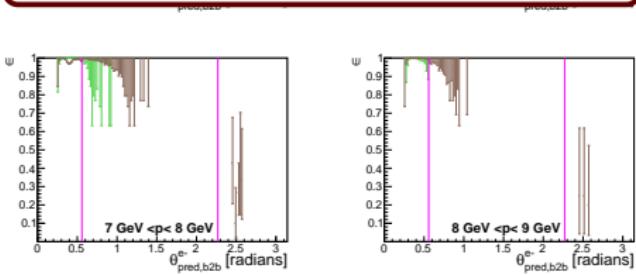
Phase2 Data



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

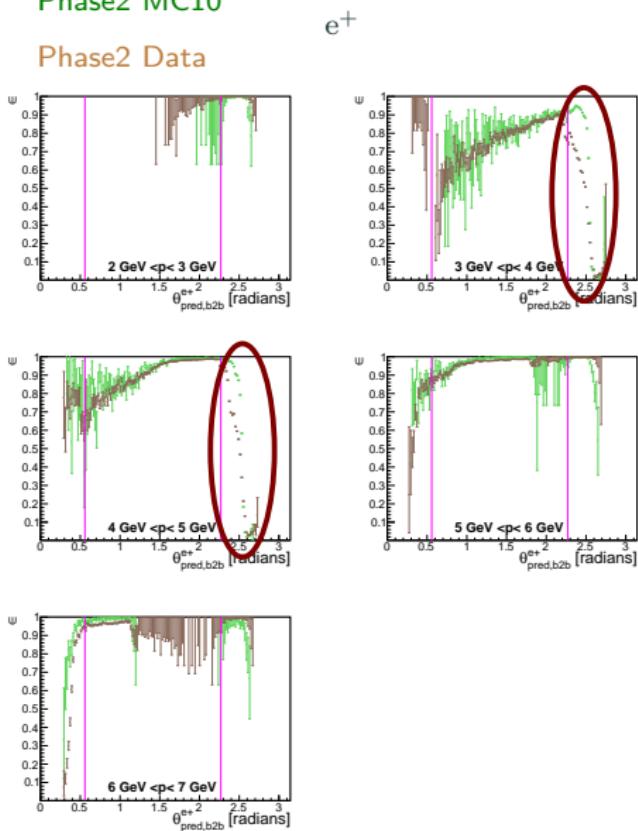
Positron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap



Phase2 MC10

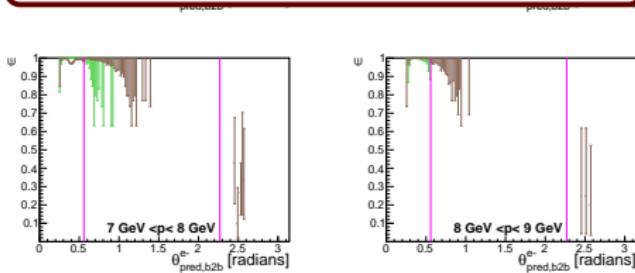
Phase2 Data



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

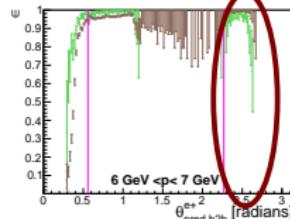
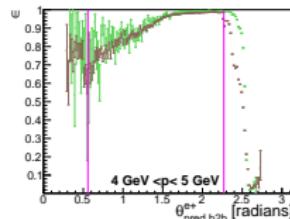
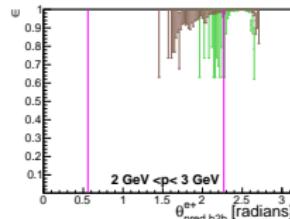
Positron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa

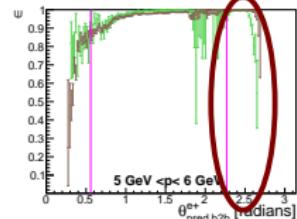
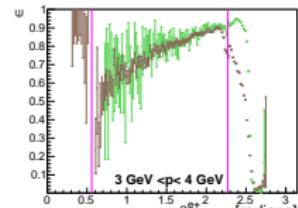


Phase2 MC10

Phase2 Data



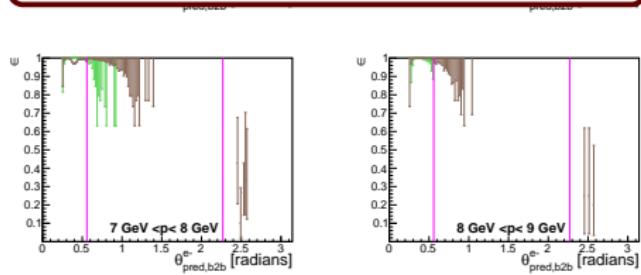
e⁺



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

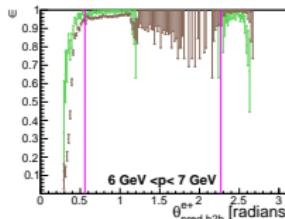
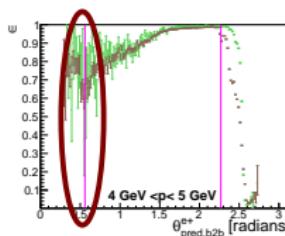
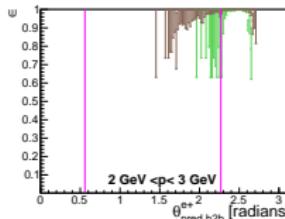
Positron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa
- Efficiency drop at transition between barrel and end-caps

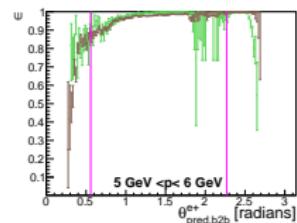
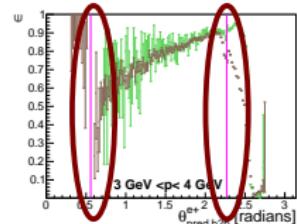


Phase2 MC10

Phase2 Data



e⁺



Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Positron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa
- Efficiency drop at transition between barrel and end-caps
- There is a slope in the barrel again

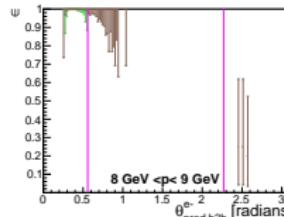
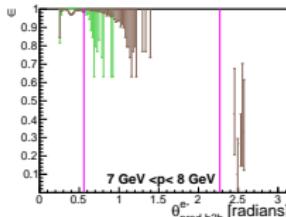
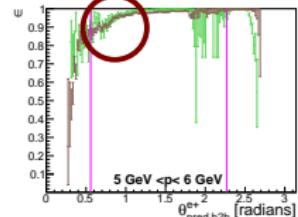
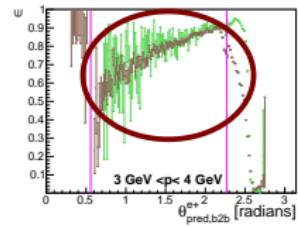
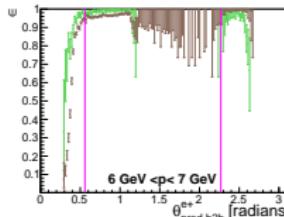
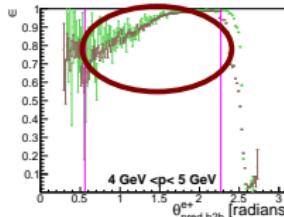
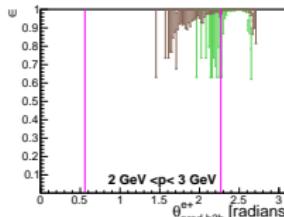
Phase2 MC10

Phase2 Data

e⁺

Phase2 MC10

Phase2 Data



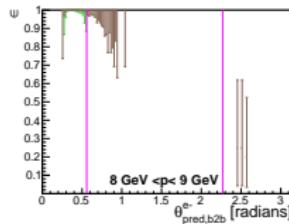
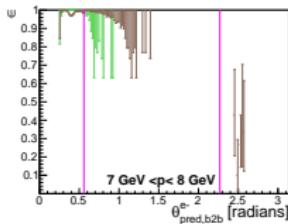
Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Positron Tracking Efficiency:

- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa
- Efficiency drop at transition between barrel and end-caps
- There is a slope in the barrel again

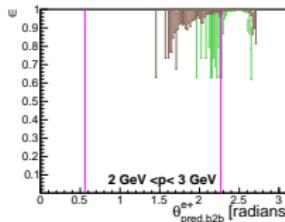
phase2MC

phase2Data

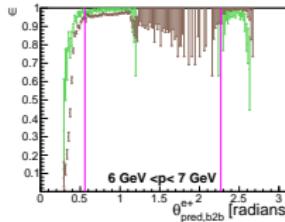
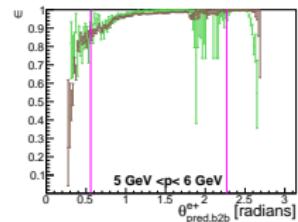
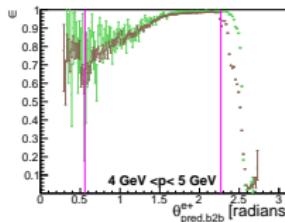
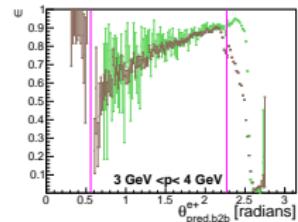


Phase2 MC10

Phase2 Data

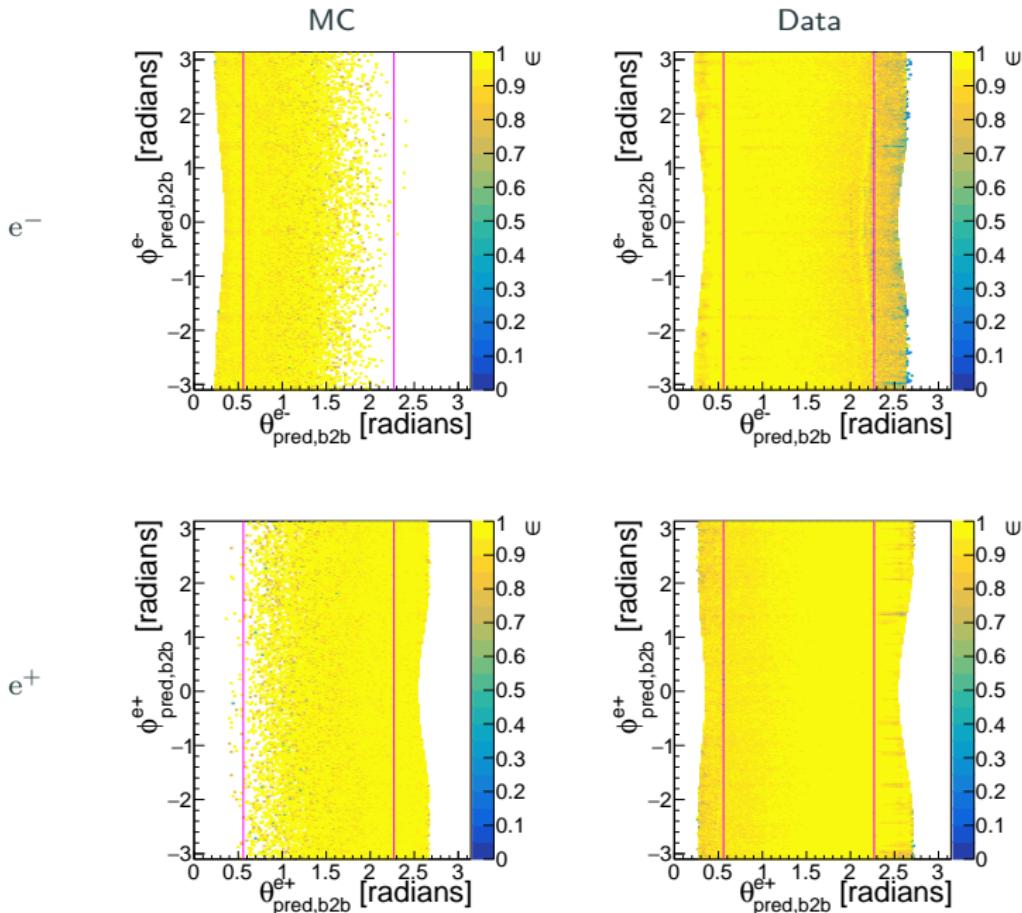


e⁺

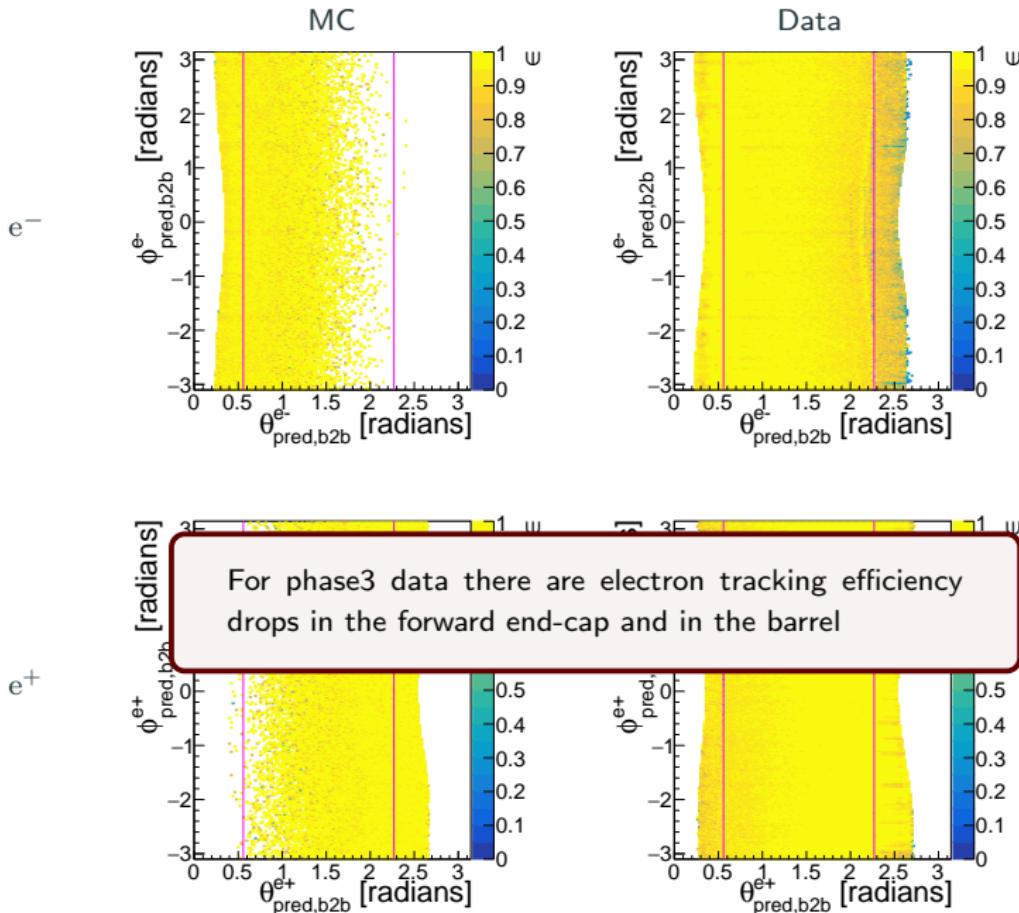


Phase3 Tracking Efficiencies

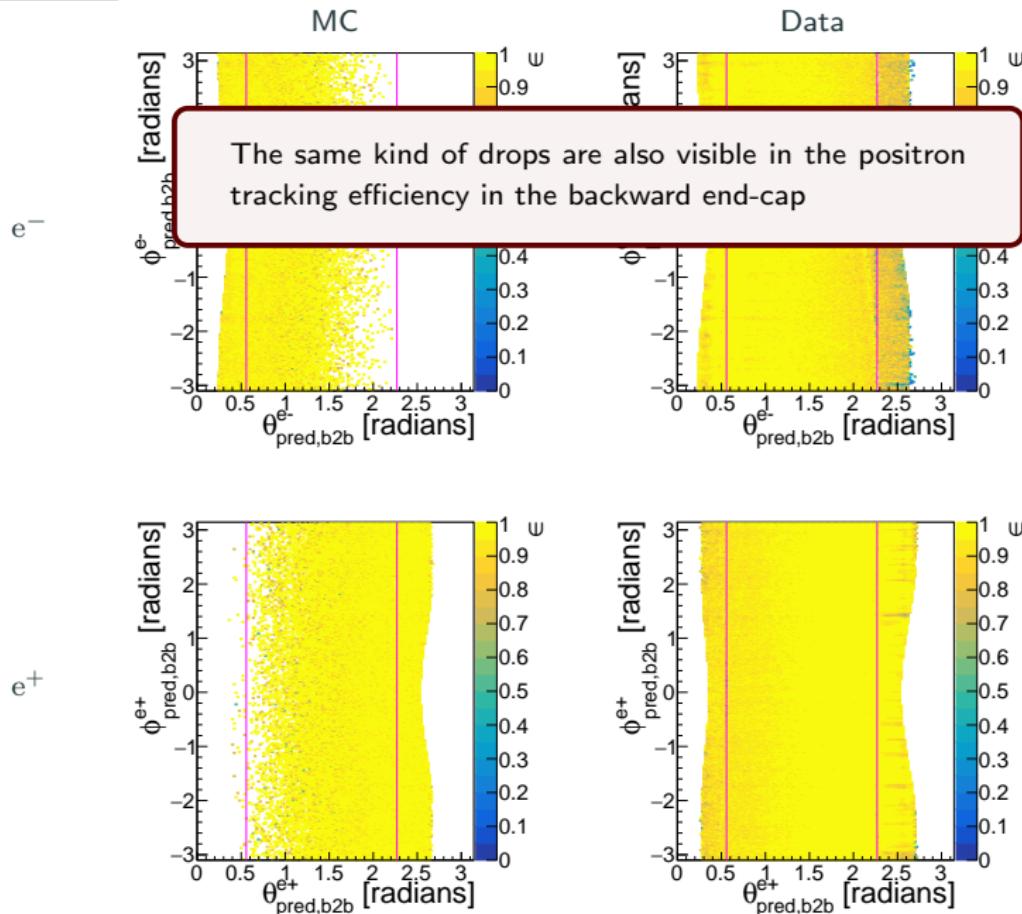
Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}} - \phi_{\text{pred,b2b}}$

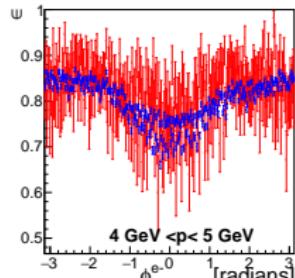


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

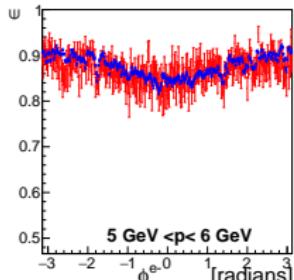
Phase3 MC10

Phase3 Data

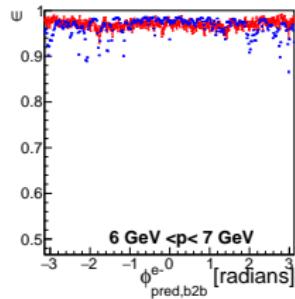
e⁻



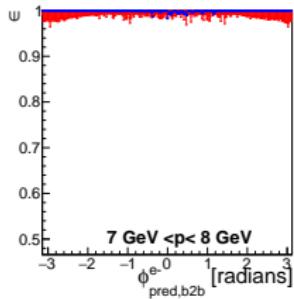
$4 \text{ GeV} < p < 5 \text{ GeV}$



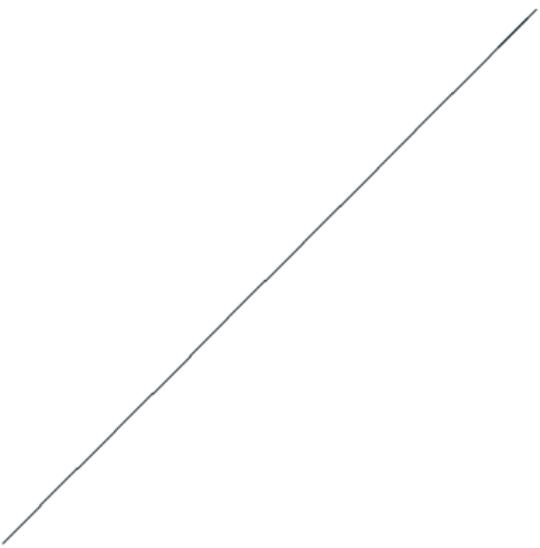
$5 \text{ GeV} < p < 6 \text{ GeV}$



$6 \text{ GeV} < p < 7 \text{ GeV}$



e⁺

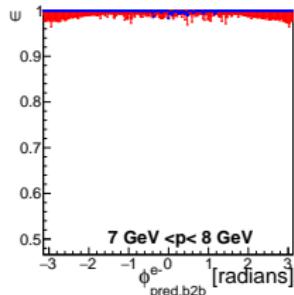
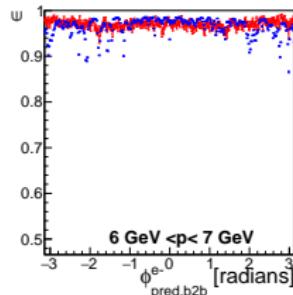
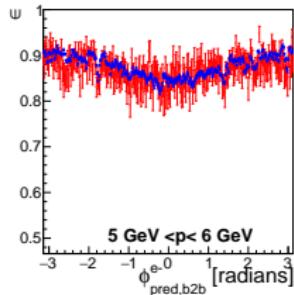
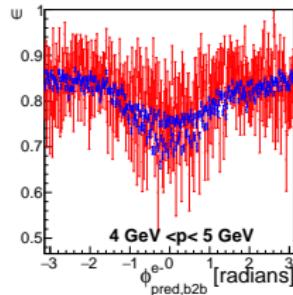


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase3 MC10

Phase3 Data

e⁻



Electron Tracking Efficiency:

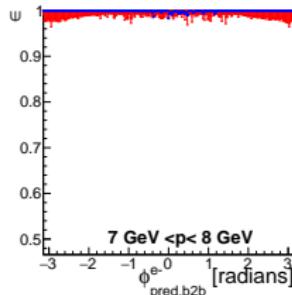
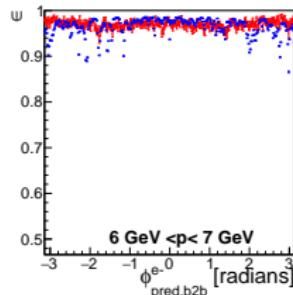
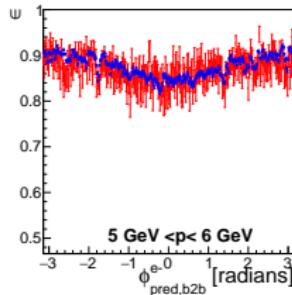
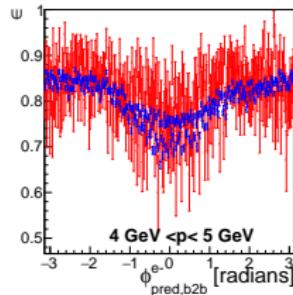
- Highest tracking efficiency at momenta between 7 GeV and 8 GeV

Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase3 MC10

Phase3 Data

e⁻



Electron Tracking Efficiency:

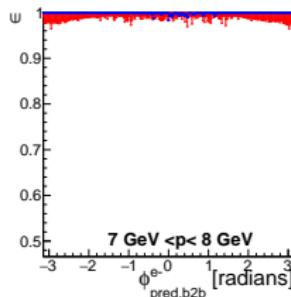
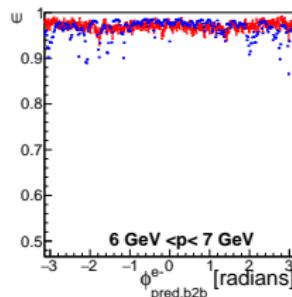
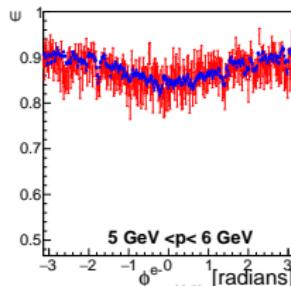
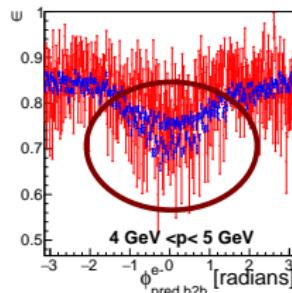
- Highest tracking efficiency at forward momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV

Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase3 MC10

Phase3 Data

e⁻



Electron Tracking Efficiency:

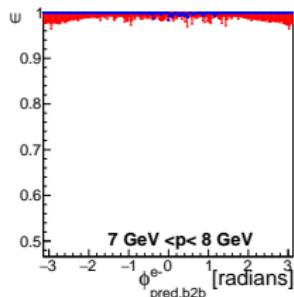
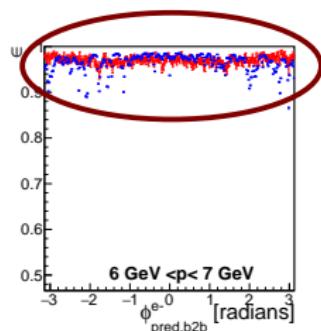
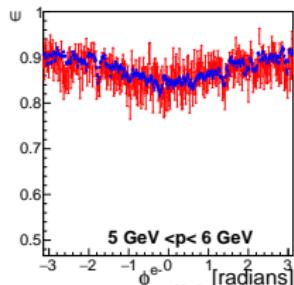
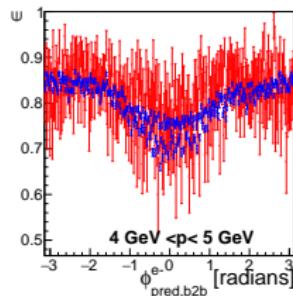
- Highest tracking efficiency at forward momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV

Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase3 MC10

e⁻

Phase3 Data



Electron Tracking Efficiency:

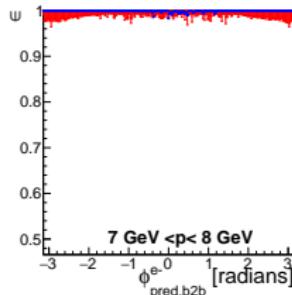
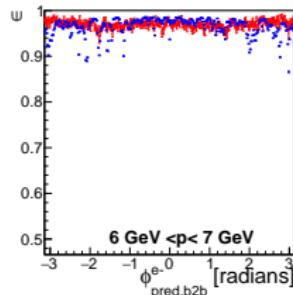
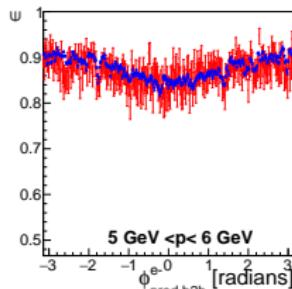
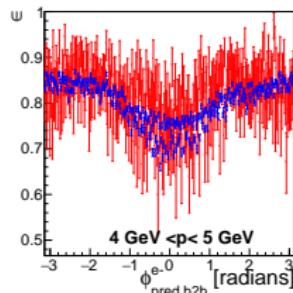
- Highest tracking efficiency at forward momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV
- Weird efficiency drops in phase3 data for momenta between 6 GeV and 7 GeV

Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

Phase3 MC10

e⁻

Phase3 Data



Electron Tracking Efficiency:

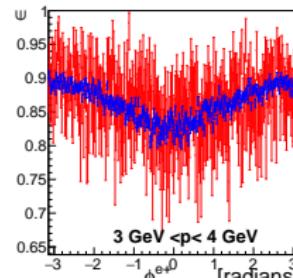
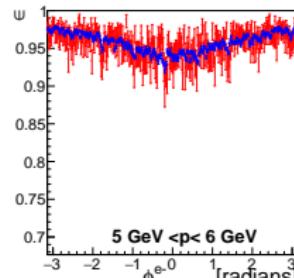
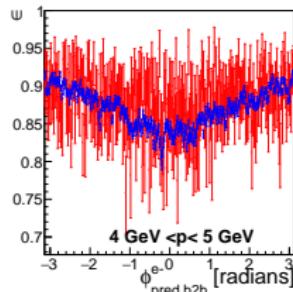
- Highest tracking efficiency at momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV
- Weird efficiency drops in phase3 data for momenta between 6 GeV and 7 GeV

Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

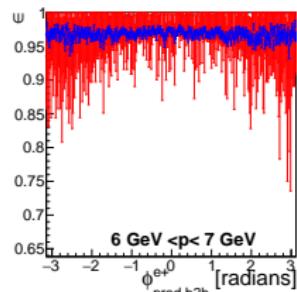
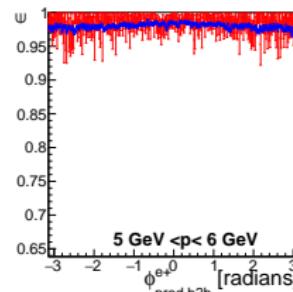
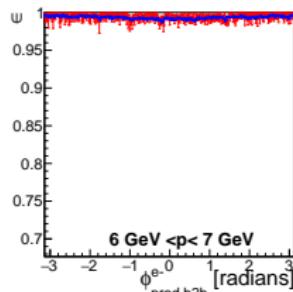
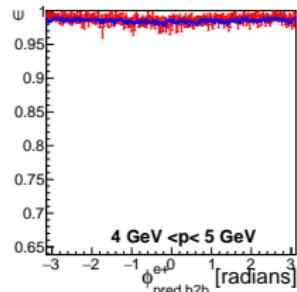
Phase3 MC10

e⁻

Phase3 Data



e⁺

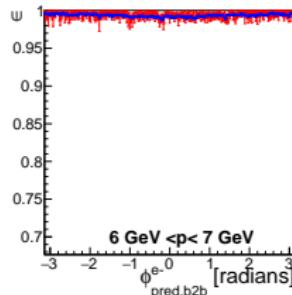
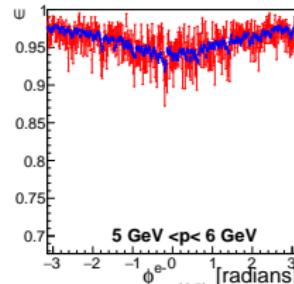
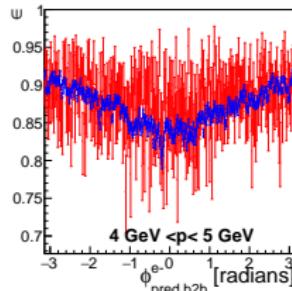


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase3 MC10

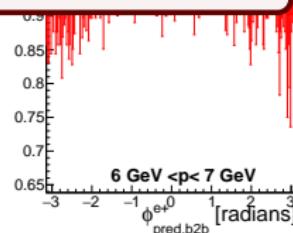
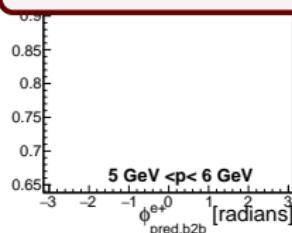
e⁻

Phase3 Data



Electron Tracking Efficiency:

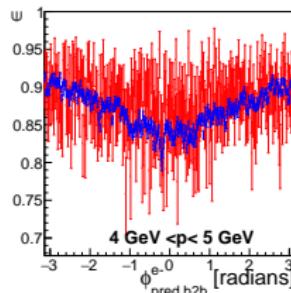
- Highest tracking efficiency at momenta between 6 GeV and 7 GeV
- Lowest tracking efficiency at momenta between 4 GeV and 5 GeV



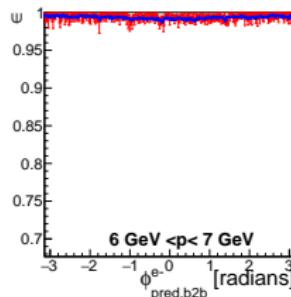
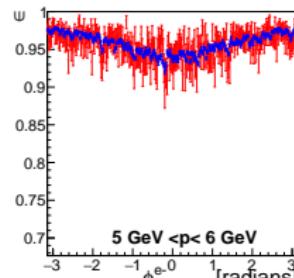
Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Phase3 MC10

Phase3 Data

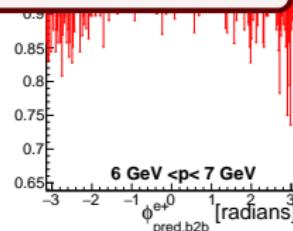
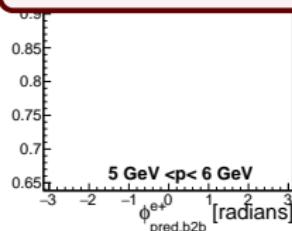


e^-



Electron Tracking Efficiency:

- Highest tracking efficiency at momenta between 6 GeV and 7 GeV
- Lowest tracking efficiency at momenta between 4 GeV and 5 GeV
- Minimum at $\phi_{\text{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV

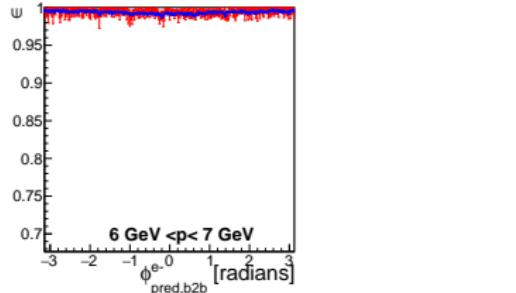


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

Positron Tracking Efficiency:

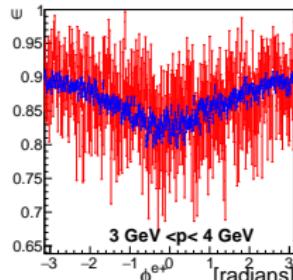
- Highest tracking efficiency at for momenta between 4 GeV and 6 GeV
- Lowest tracking efficiency at for momenta between 3 GeV and 4 GeV

$\psi_{\text{pred,b2b}}$ $\psi_{\text{pred,b2b}}$

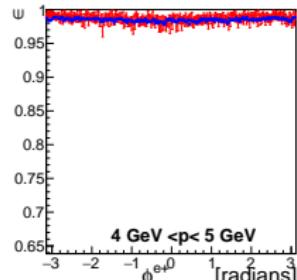
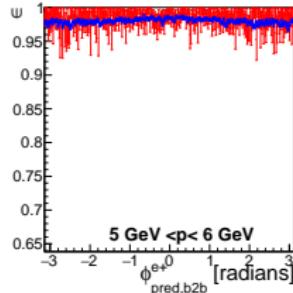
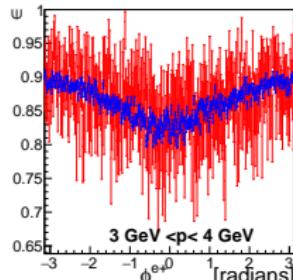


Phase3 MC10

Phase3 Data



e⁺

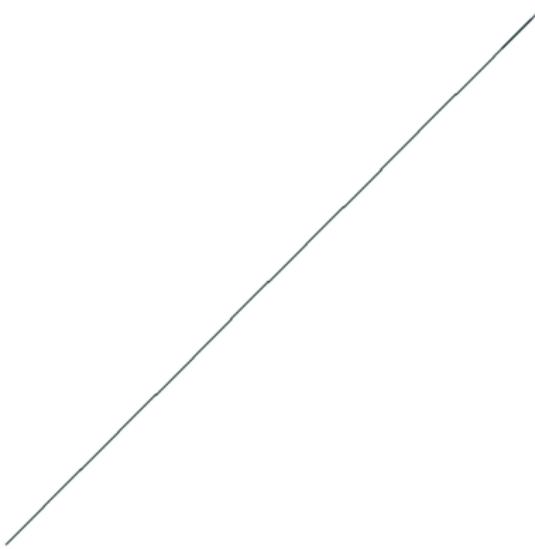


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

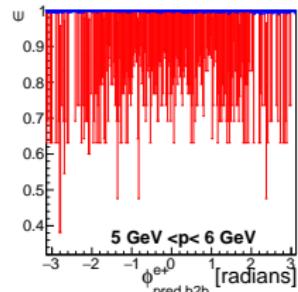
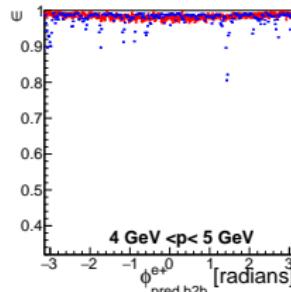
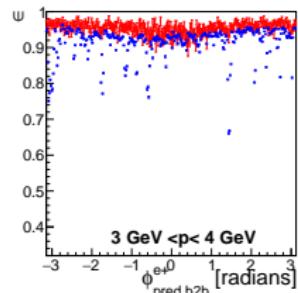
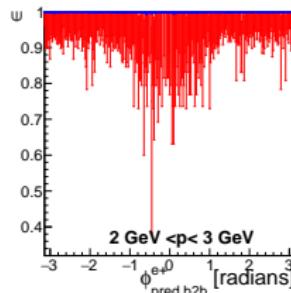
Phase3 MC10

Phase3 Data

e^-



e^+



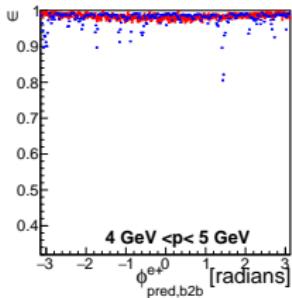
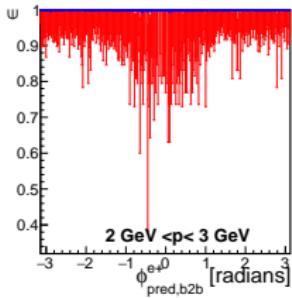
Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

Positron Tracking Efficiency:

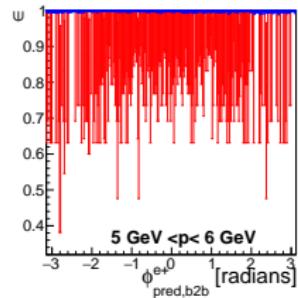
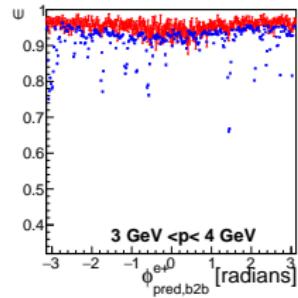
- The highest tracking efficiency occurs for momenta between 2 GeV and 3 GeV and 5 GeV and 6 GeV

Phase3 MC10

Phase3 Data



e^+



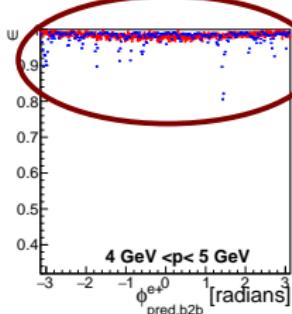
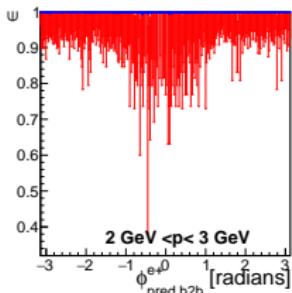
Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

Positron Tracking Efficiency:

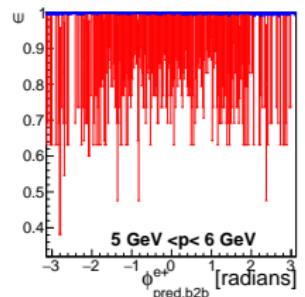
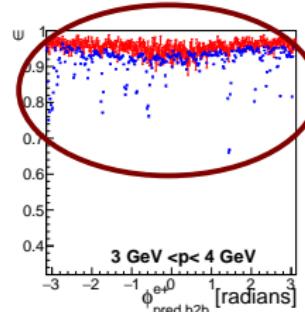
- The highest tracking efficiency occurs for momenta between 2 GeV and 3 GeV and 5 GeV and 6 GeV
- Weird efficiency drops in the phase3 data tracking efficiency for momenta between 3 GeV and 5 GeV

Phase3 MC10

Phase3 Data



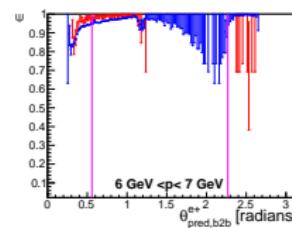
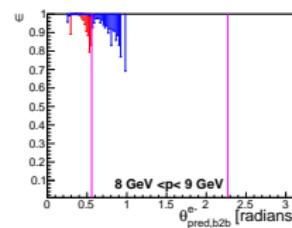
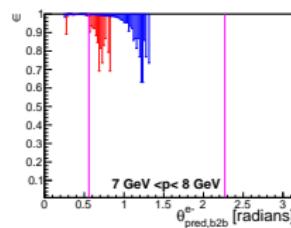
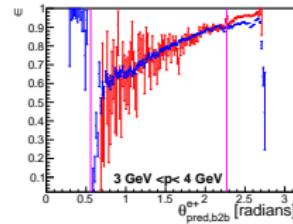
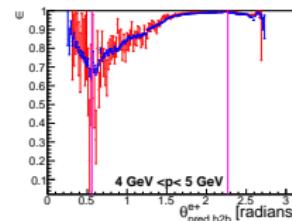
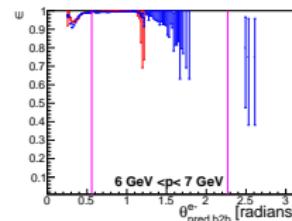
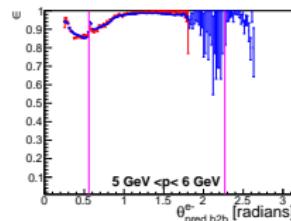
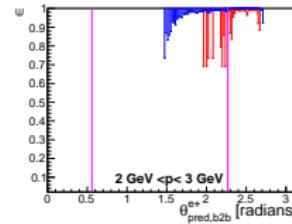
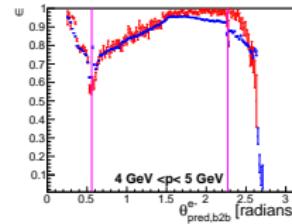
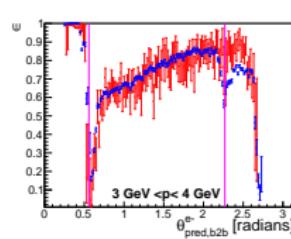
e^+



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

Phase3 Data

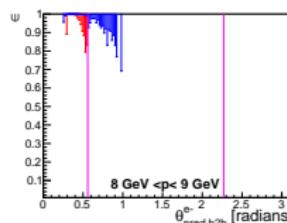
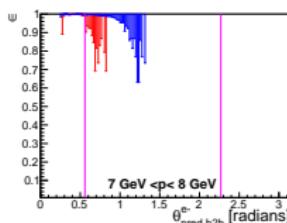
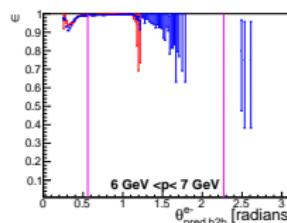
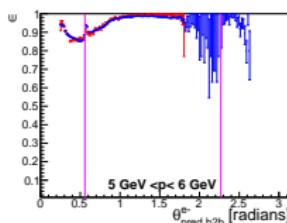
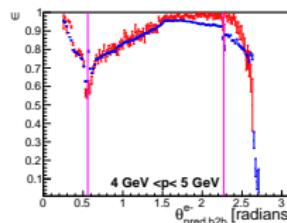
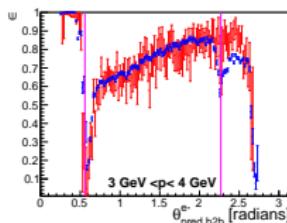


Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

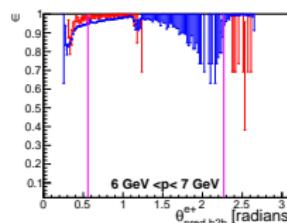
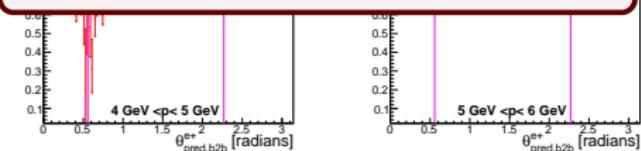
Phase3 Data

e⁻



Electron Tracking Efficiency:

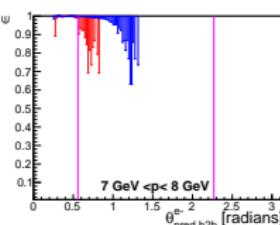
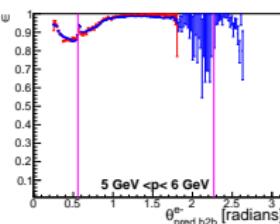
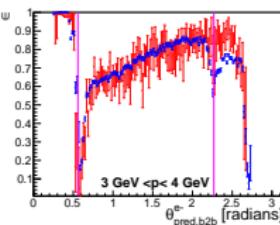
- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between 4 GeV and 5 GeV)



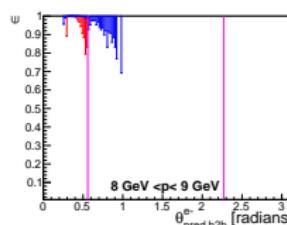
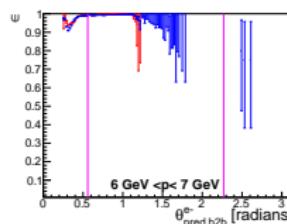
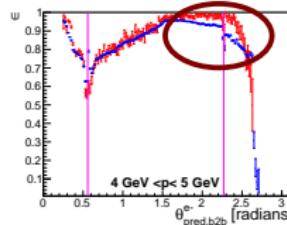
Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

Phase3 Data

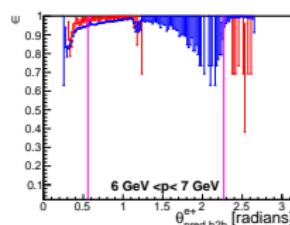
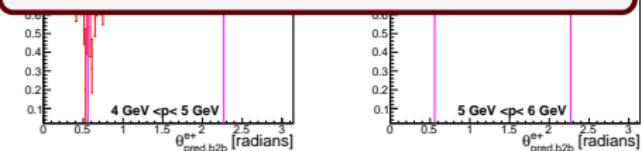


e^-



Electron Tracking Efficiency:

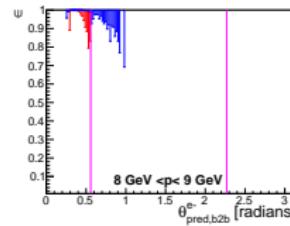
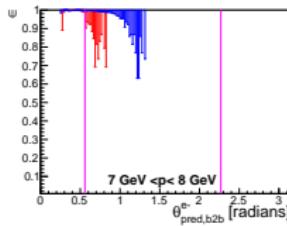
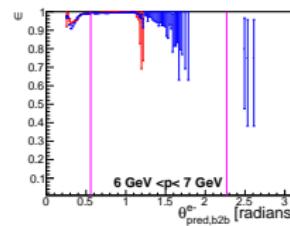
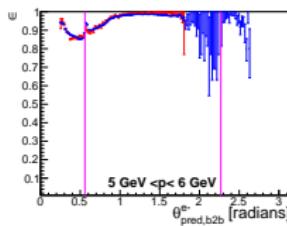
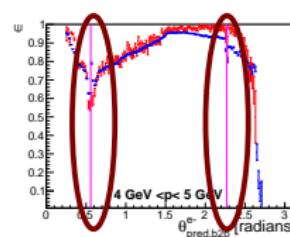
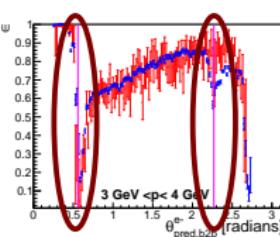
- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between 4 GeV and 5 GeV)



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

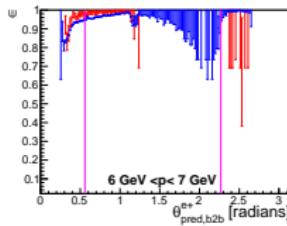
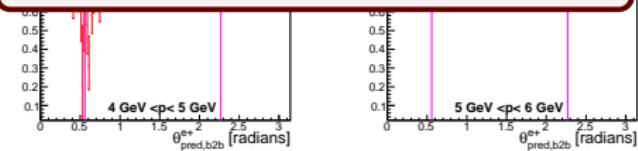
Phase3 MC10

Phase3 Data



Electron Tracking Efficiency:

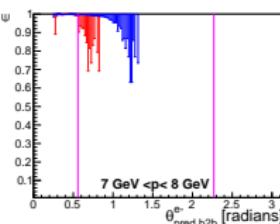
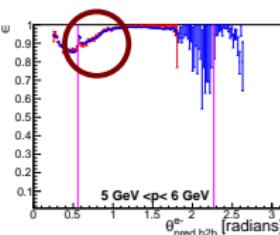
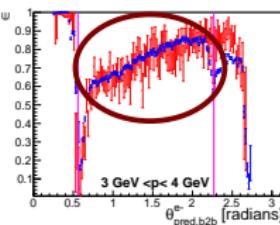
- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between 4 GeV and 5 GeV)
- Efficiency drops at transition between barrel and end-caps



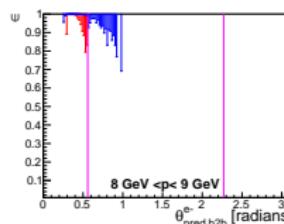
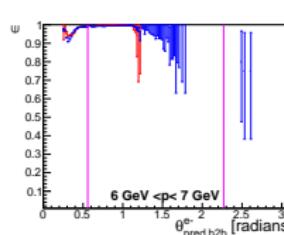
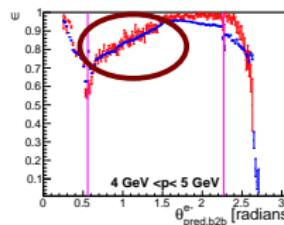
Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

Phase3 Data

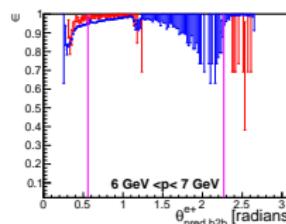
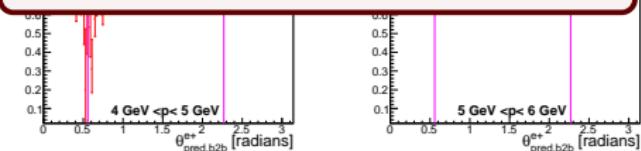


e^-



Electron Tracking Efficiency:

- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between 4 GeV and 5 GeV)
- Efficiency drops at transition between barrel and end-caps
- There is a slope in the barrel

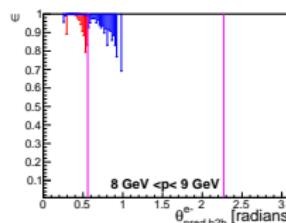
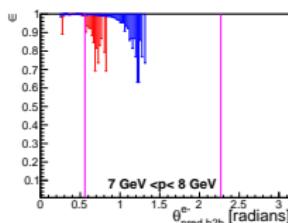
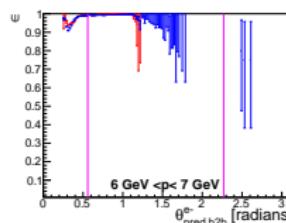
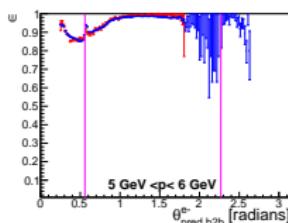
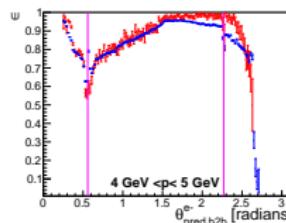
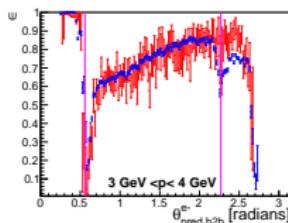


Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

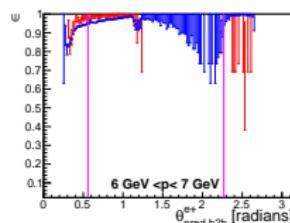
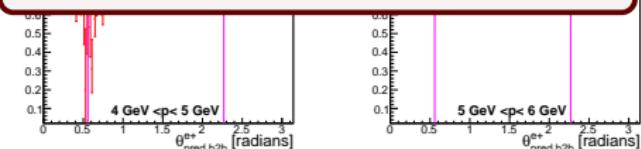
Phase3 Data

e^-



Electron Tracking Efficiency:

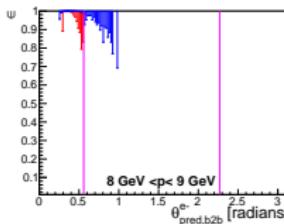
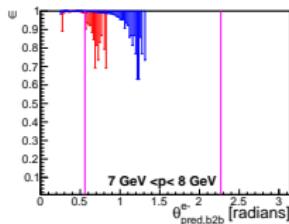
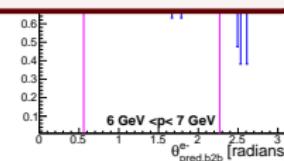
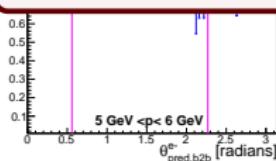
- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between 4 GeV and 5 GeV)
- Efficiency drops at transition between barrel and end-caps
- There is a slope in the barrel



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

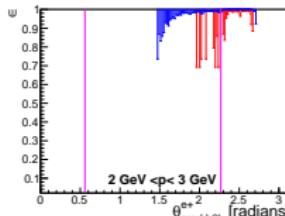
Positron Tracking Efficiency:

- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between 3 GeV and 4 GeV)

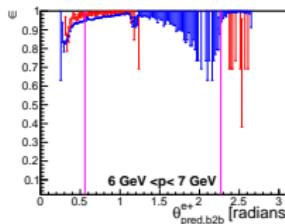
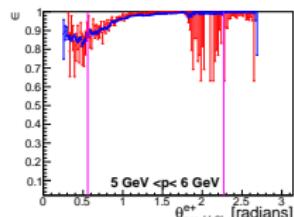
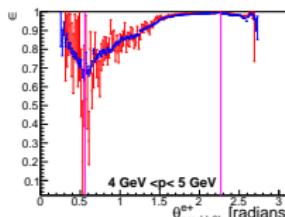
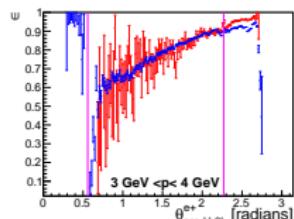


Phase3 MC10

Phase3 Data



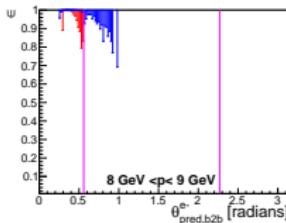
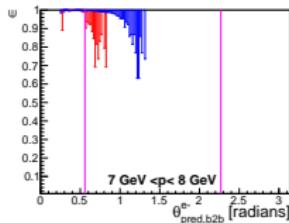
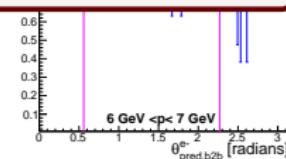
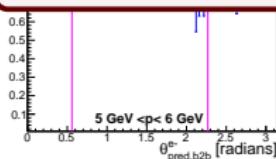
e⁺



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

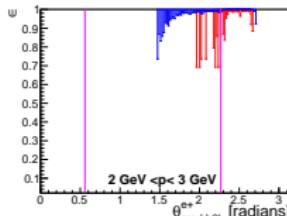
Positron Tracking Efficiency:

- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between 3 GeV and 4 GeV)

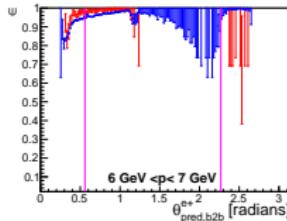
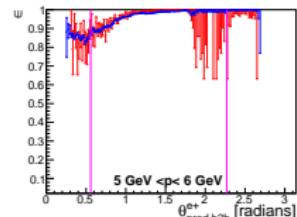
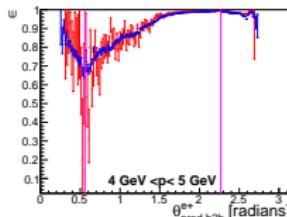
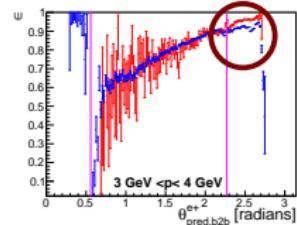


Phase3 MC10

Phase3 Data



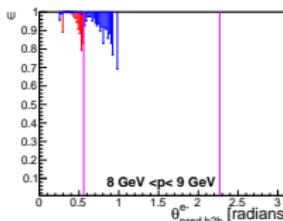
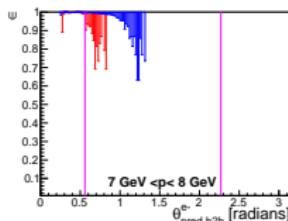
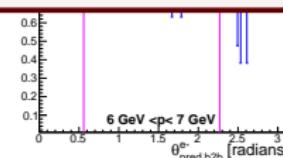
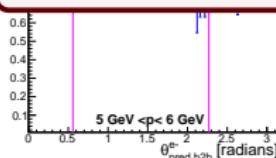
e⁺



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

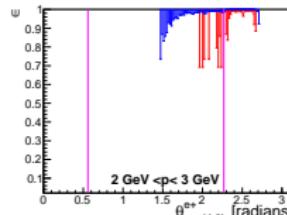
Positron Tracking Efficiency:

- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between 3 GeV and 4 GeV)
- There is a slope in the barrel

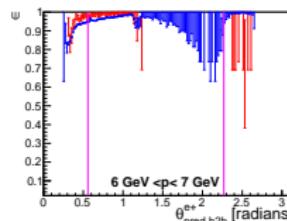
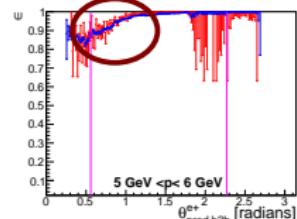
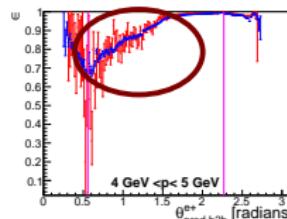
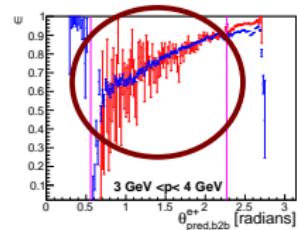


Phase3 MC10

Phase3 Data



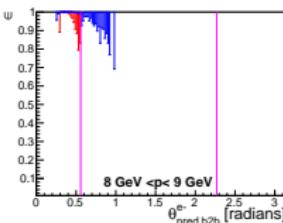
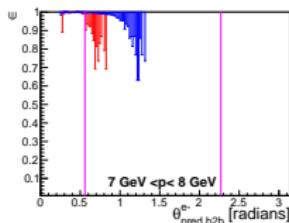
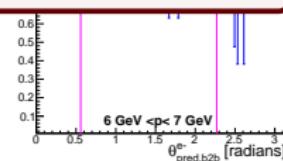
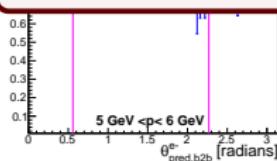
e⁺



Phase3 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

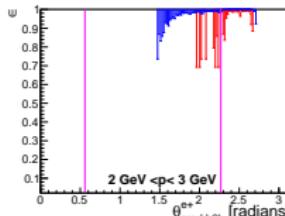
Positron Tracking Efficiency:

- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between 3 GeV and 4 GeV)
- There is a slope in the barrel

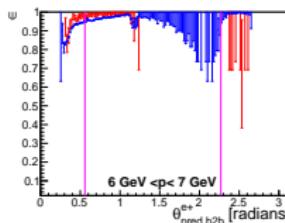
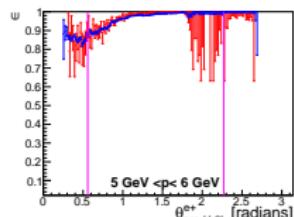
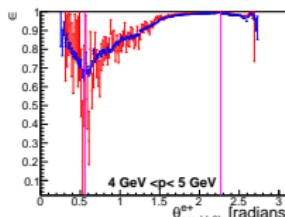
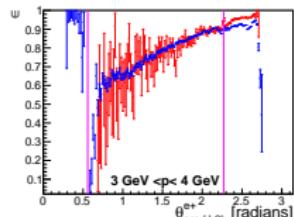


Phase3 MC10

Phase3 Data



e⁺



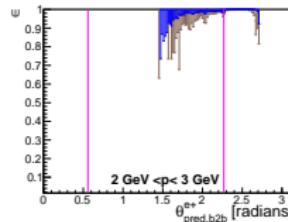
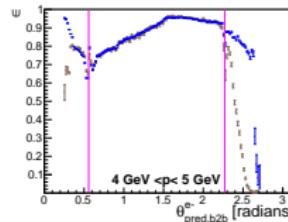
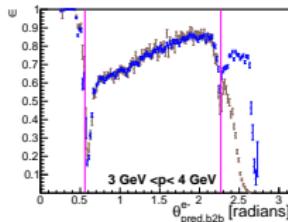
Comparing The Tracking Efficiency Of Phase2 Data with Phase3 Data

Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

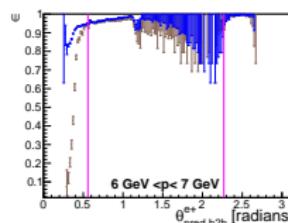
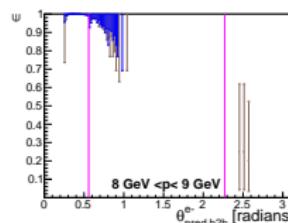
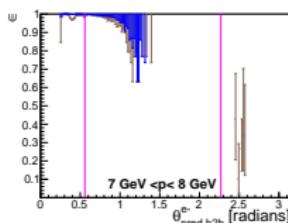
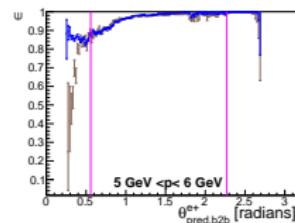
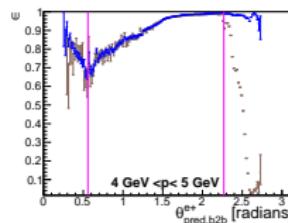
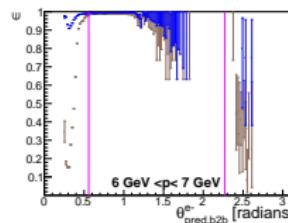
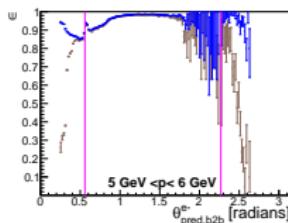
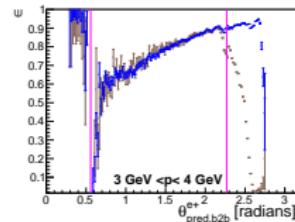
Phase2 Data

e^-

Phase3 Data



e^+

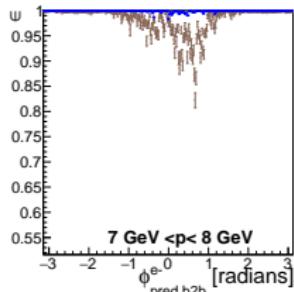
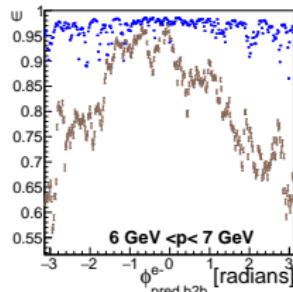
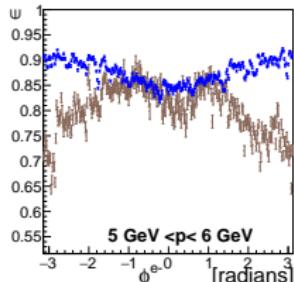
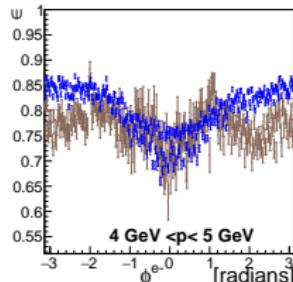


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

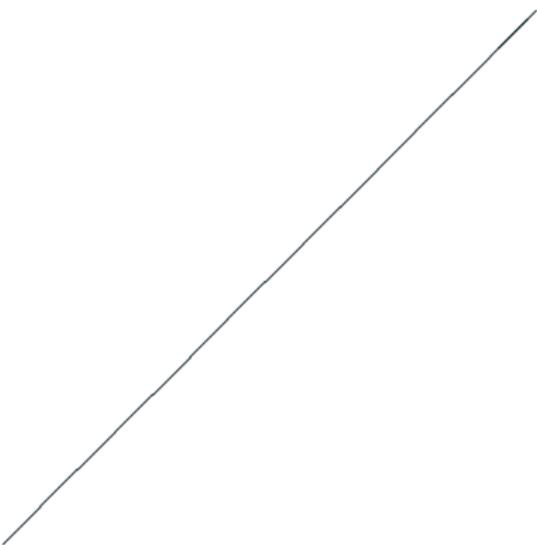
Phase2 Data

Phase3 Data

e^-



e^+

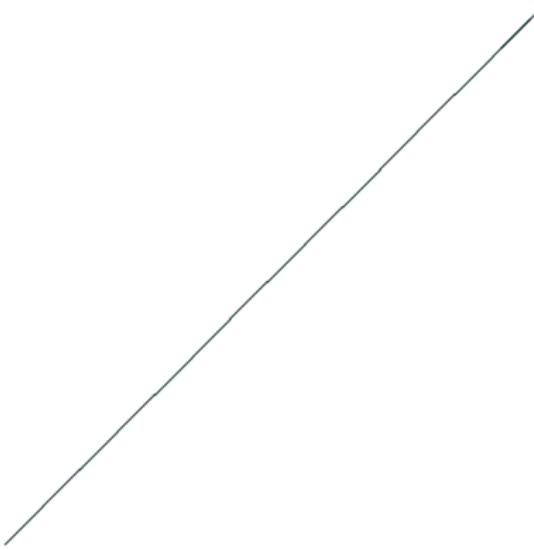


Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

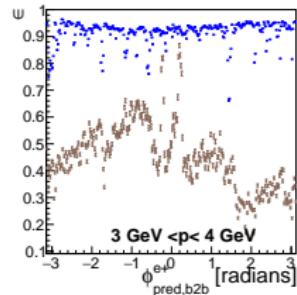
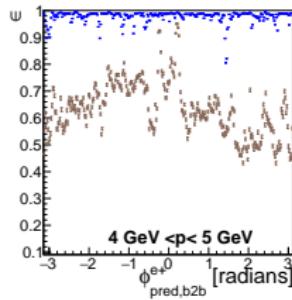
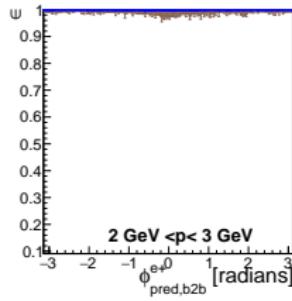
Phase2 Data

e^-

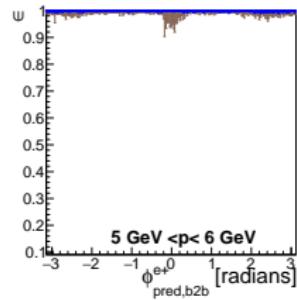
Phase3 Data



e^+



$3 \text{ GeV} < p < 4 \text{ GeV}$



$5 \text{ GeV} < p < 6 \text{ GeV}$

Conclusion

Conclusion

Appendix

Code

```
1 fillParticleList('gamma:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path  
    ↪ =mypath)  
fillParticleList('e+:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path=  
    ↪ mypath)  
3  
reconstructDecay('vpho:gamma -> gamma:all', '', path=mypath)  
5 reconstructDecay('vpho:elec -> e+:all', '', path=mypath)  
7 copyLists(outputListName = 'vpho:ECLObjectUnranked', inputListNames=['vpho:elec  
    ↪ ', 'vpho:gamma'], path=mypath)  
9 rankByHighest('vpho:ECLObjectUnranked', 'daughter(0,clusterE)', path=mypath)  
cutAndCopyList('vpho:ECLObject', 'vpho:ECLObjectUnranked', '', path=mypath)  
11 reconstructDecay('vpho:bhabha -> vpho:ECLObject vpho:ECLObject', '', path=  
    ↪ mypath)  
13 variablesToNtuple('vpho:bhabha', variables, treename = 'vpho_bhabha', filename =  
    ↪ output.root, path=mypath)
```

More Events

Phase2 data:

- /ghi/fs01/belle2/bdata//Data/release-03-00-03/
DB00000528/proc00000008/e0003/4S/r0*/all/mdst/sub00/*.root
- proc9

Phase2 MC:

- /belle/MC/release-01-00-02/DB00000294/MC10/
prod00004668/s00/e1002/4S/r00000/3600520000/mdst/sub00

Phase3 data:

- Exp7: /group/belle2/dataprod/Data/release-03-02-
02/DB00000654/proc9/e0007/4S/r0*/all/mdst/sub00/*.root
- Exp8: /group/belle2/dataprod/Data/release-03-02-
02/DB00000654/proc9/e0008/4S/r0*/all/mdst/sub00/*.root
- proc9

Phase3 MC:

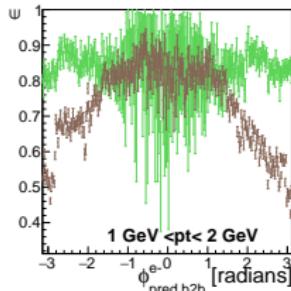
- /belle/MC/release-01-00-02/DB00000294/MC10/
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Phase2 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

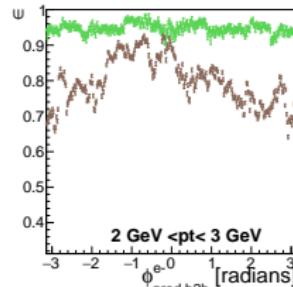
Phase2 MC10

Phase2 Data

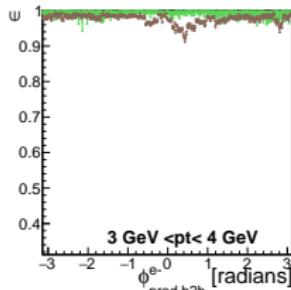
e^-



$1 \text{ GeV} < p_t < 2 \text{ GeV}$

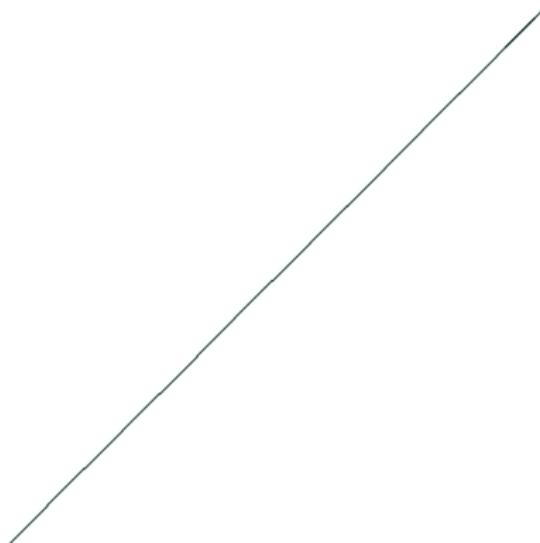


$2 \text{ GeV} < p_t < 3 \text{ GeV}$



$3 \text{ GeV} < p_t < 4 \text{ GeV}$

e^+

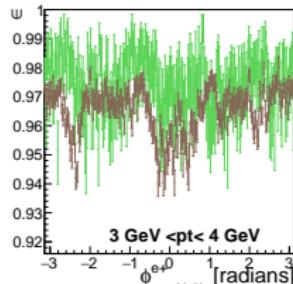
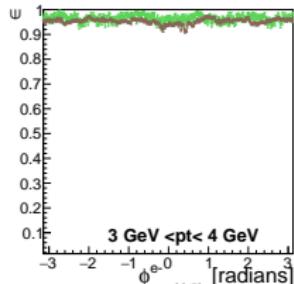
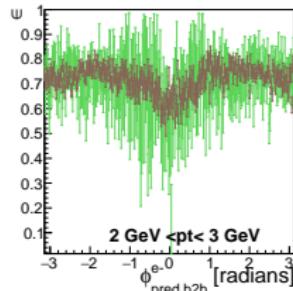


Phase2 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

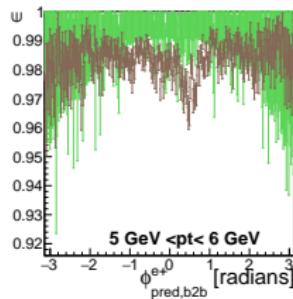
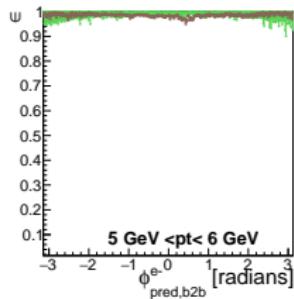
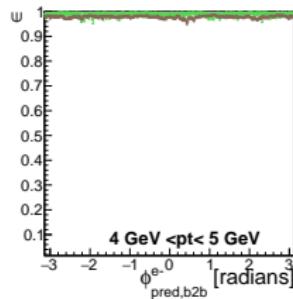
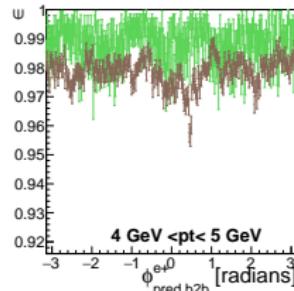
Phase2 MC10

e^-

Phase2 Data



e^+

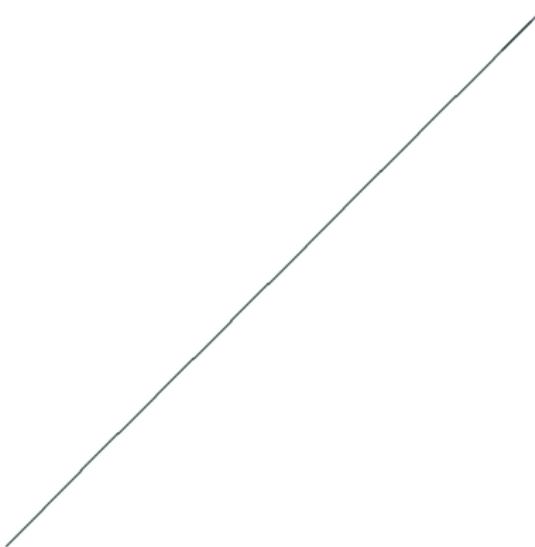


Phase2 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

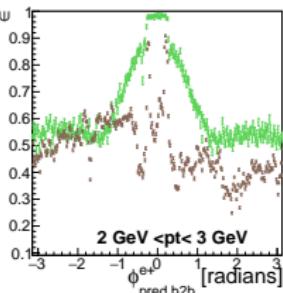
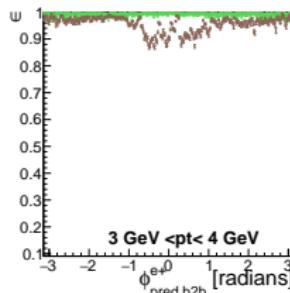
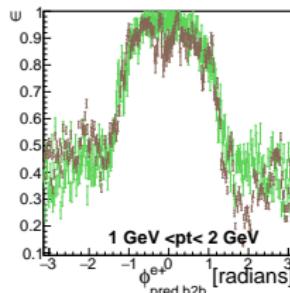
Phase2 MC10

e^-

Phase2 Data



e^+

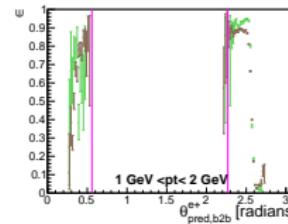
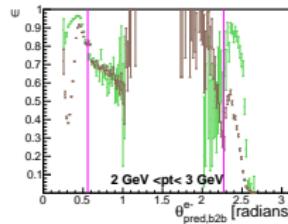
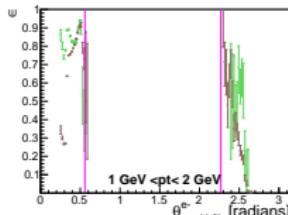


Phase2 pt Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

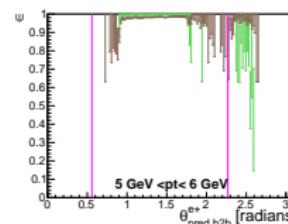
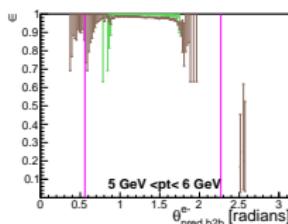
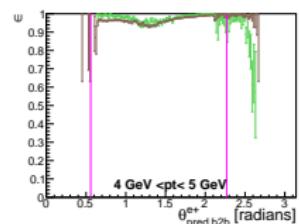
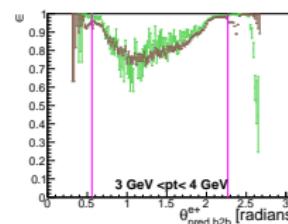
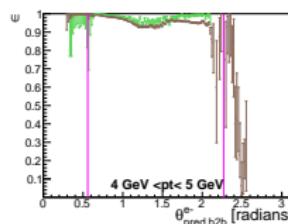
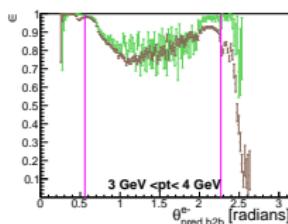
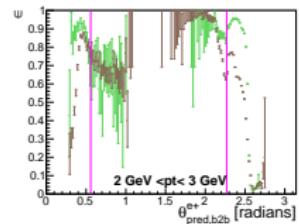
Phase2 MC10

e^-

Phase2 Data



e^+

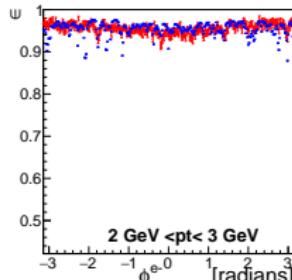
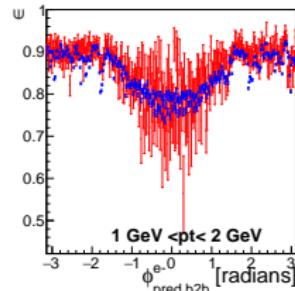


Phase3 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

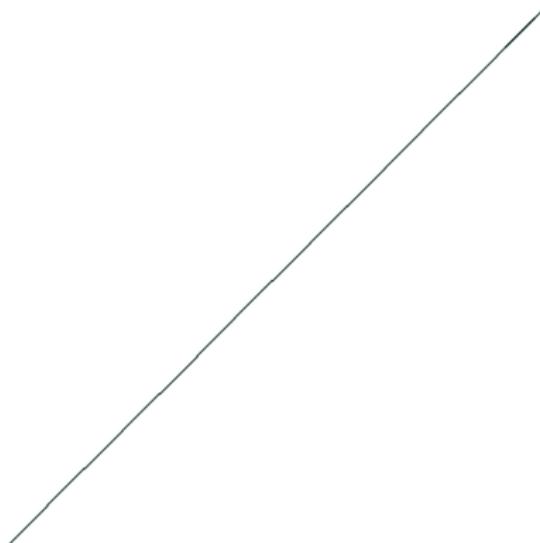
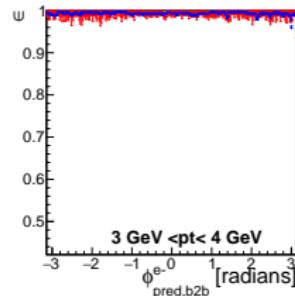
Phase3 MC10

Phase3 Data

e⁻



e⁺

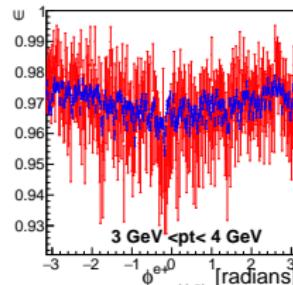
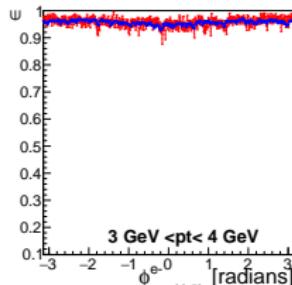
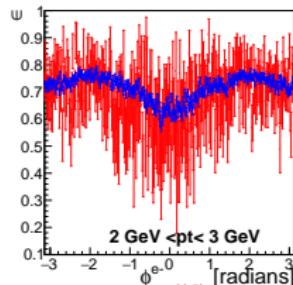


Phase3 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

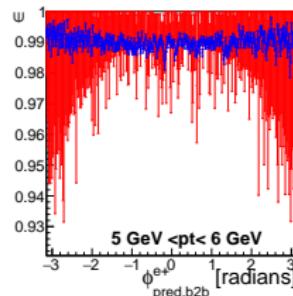
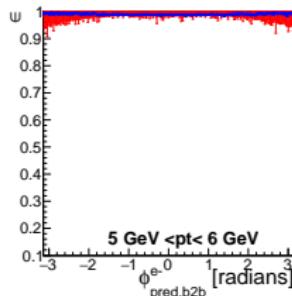
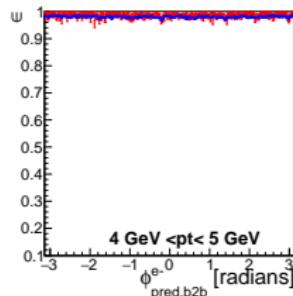
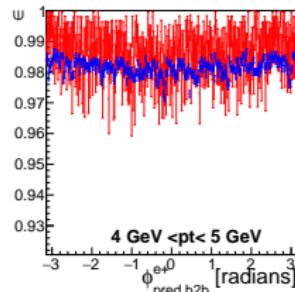
Phase3 MC10

e⁻

Phase3 Data



e⁺

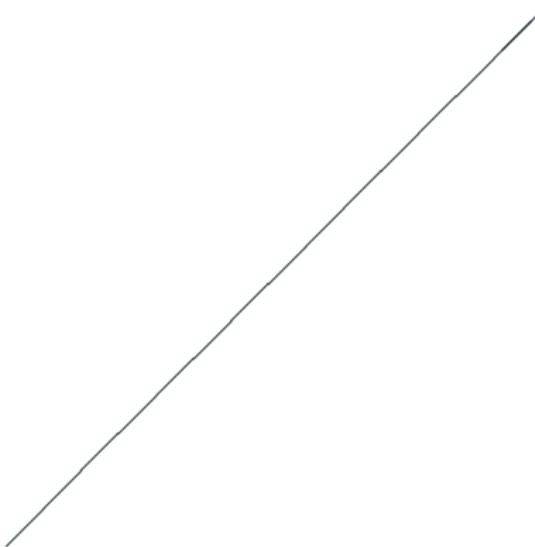


Phase3 pt Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

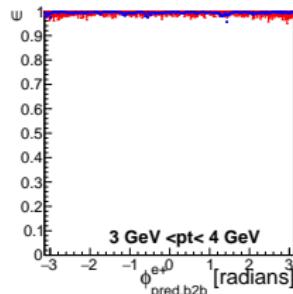
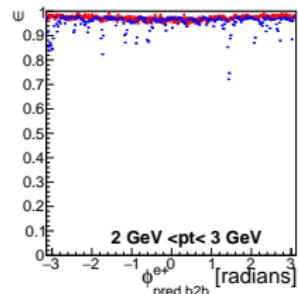
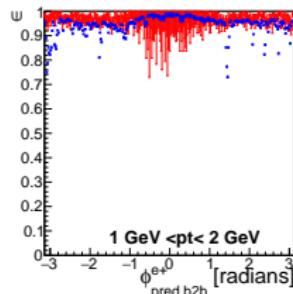
Phase3 MC10

e^-

Phase3 Data



e^+

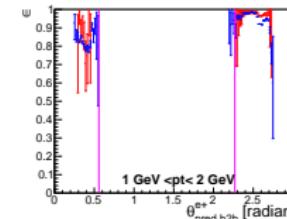
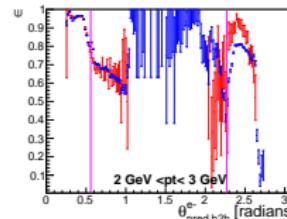
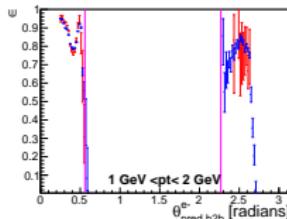


Phase3 pt Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

Phase3 MC10

e⁻

Phase3 Data



e⁺

