Systematic Studies On Track Reconstruction Efficiency At Belle II

Martin Sobotzik (msobotzi@students.uni-mainz.de)
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Johannes Gutenberg-Universität Mainz

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

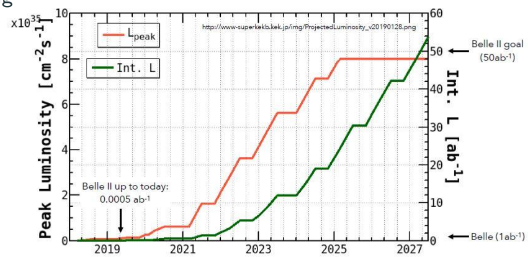
Motivation

- 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
  $\rightarrow$ a tracking efficiency can be calculated

Overview Of The Belle II Experiment

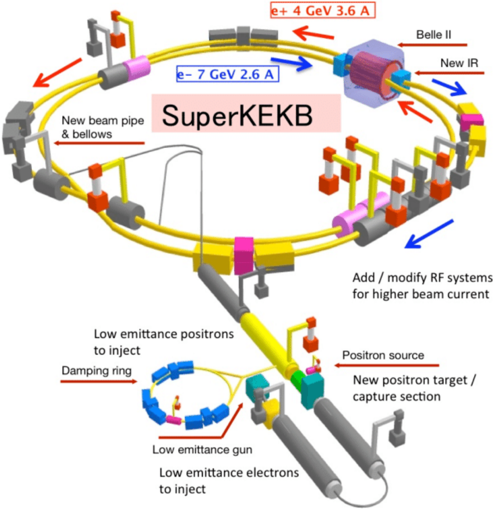
Belle II Schedule And Luminosity Goals

- 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 $\Upsilon(4S)$ $\sim 10.5\,\mathrm{GeV}$
- Upgrade of the KEKB collider:
  - Larger beam current
  - Reduced beam size



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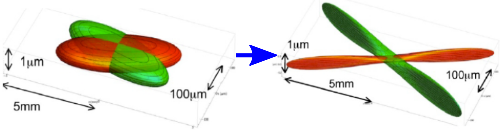

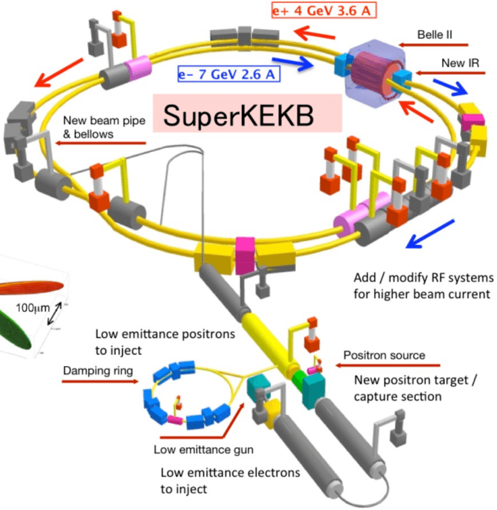

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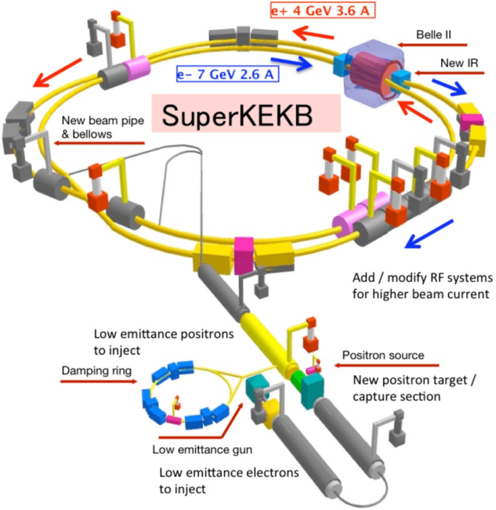
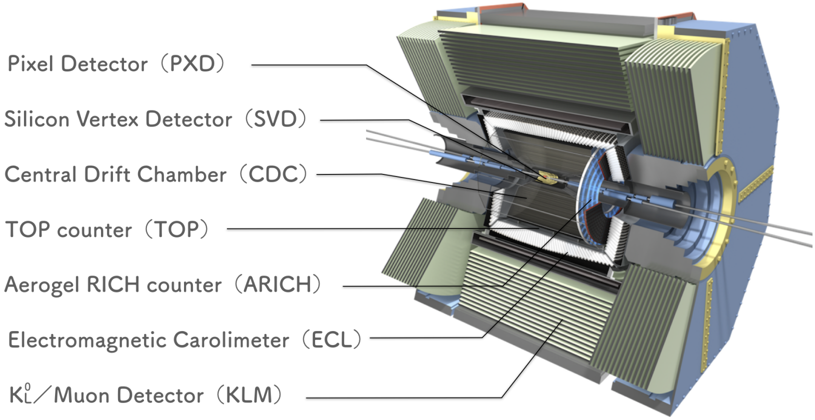
- Upgrade of the KEKB collider:
  - Larger beam current
  - Reduced beam size
- $\rightarrow$ Luminosity increase x40
- Designed peak luminosity of $8 \cdot 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Planned data sample corresponding to a recorded integrated luminosity of $\sim 50\,\mathrm{ab}^{-1}$



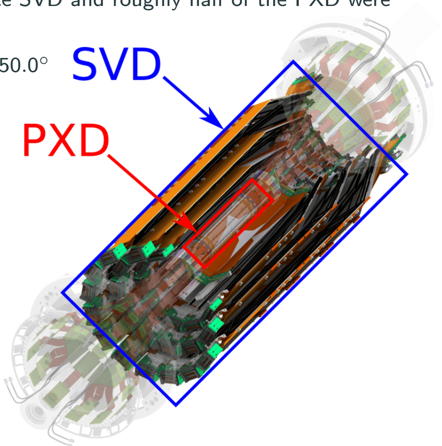
The Belle II Detector



Vertex Detectors

Vertex Detectors:

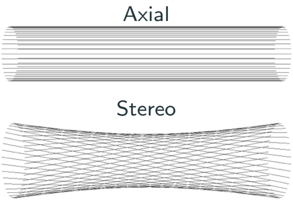
- Consists of Pixel Detector (PXD) and Silicon Vertex Detector (SVD)
- Both detectors consist of multiple ladders of strip detectors
- During phase2, only a fraction of the VXD detectors were installed
- During phase3, the complete SVD and roughly half of the PXD were installed
- Acceptance: $17.0^\circ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

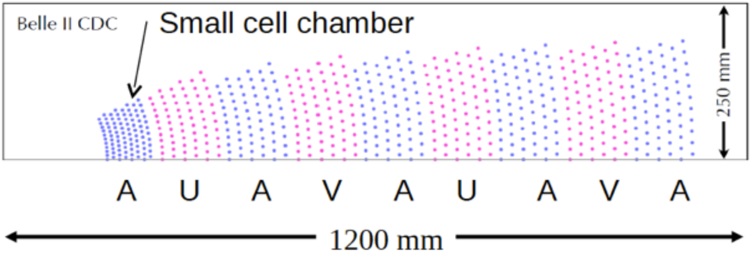


Central Drift Chamber

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: $17.0^\circ < \theta < 150.0^\circ$

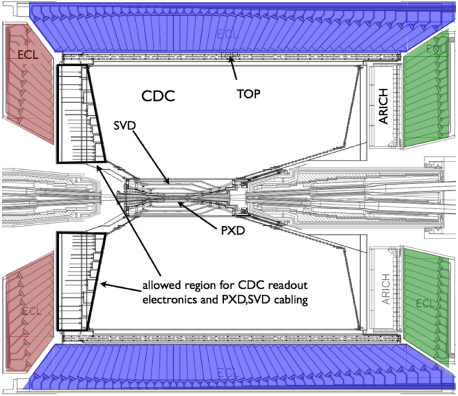




Electromagnetic Calorimeter

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

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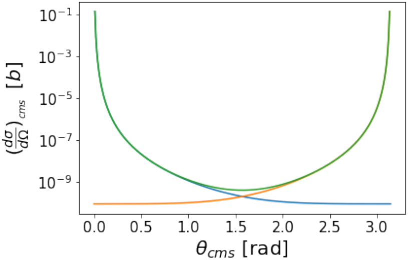

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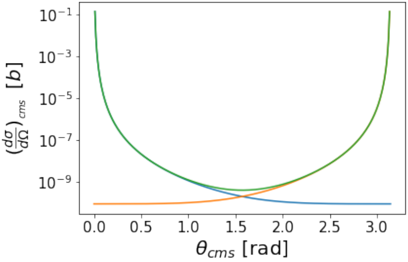
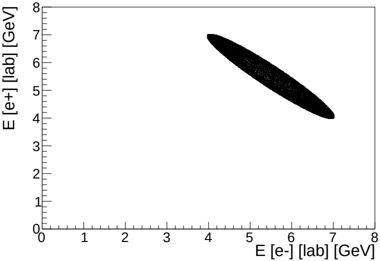
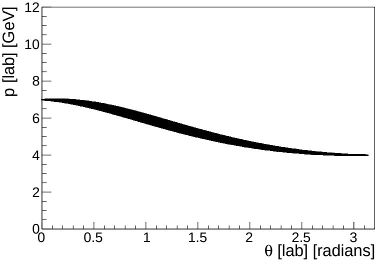


- The beams have asymmetric energies
- The beams are hitting each other under an angle of 1.26°





Preparation For Calculating The Tracking Efficiency

Introducing Cuts

Goal: Reconstruct Bhabha events using only ECL information

$$\text{vpho-Bhabha} \rightarrow \text{ECL-Object(HclE)} + \text{ECL-Object(LclE)}$$

HclE: particle with higher cluster Energy; LclE: particle with lower cluster Energy

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

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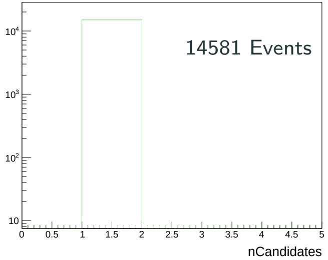
Single phase2 MC10 Bhabha file



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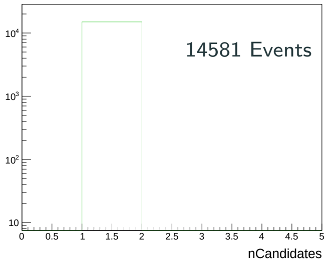
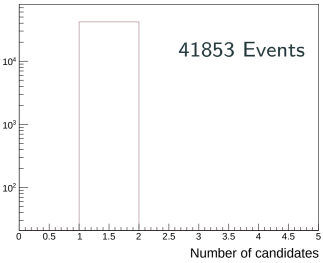


Single phase2 data file



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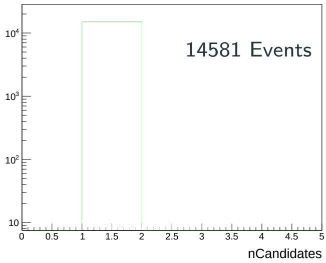
- The particles have to pass the tracking detectors
  $\rightarrow 17.0^\circ < \theta_{\mathrm{ECL\text{-}Object}} < 150.0^\circ$
- $8\,\mathrm{GeV} < \mathrm{M_{vpho}} < 12\,\mathrm{GeV}$
- 2 clusters with at least $3.5\,\mathrm{GeV}$ per event; One cluster has to have at least $4.5\,\mathrm{GeV}$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

Also contains $\mathrm{ee} \rightarrow \gamma\gamma$ events

Single phase2 MC10 Bhabha file



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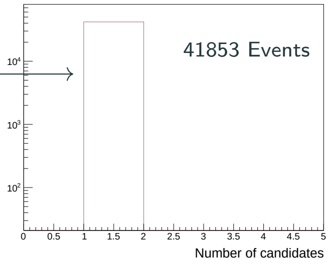
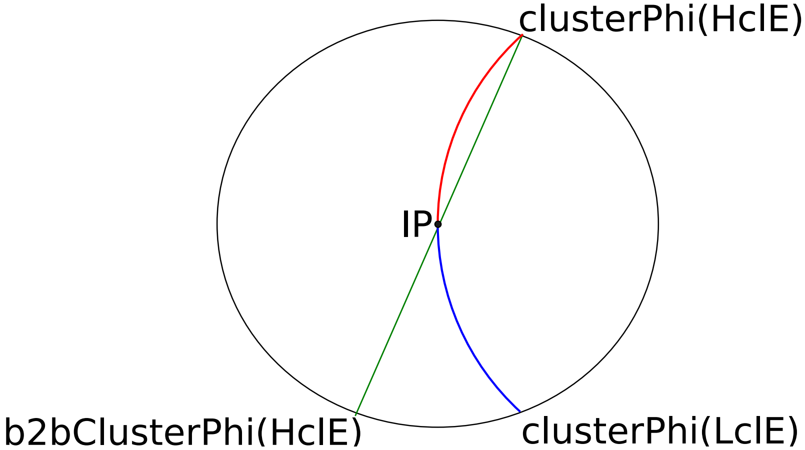
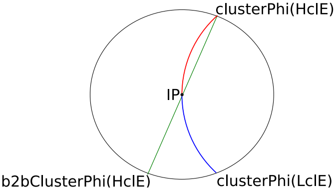
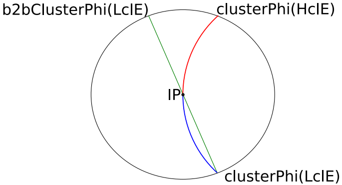
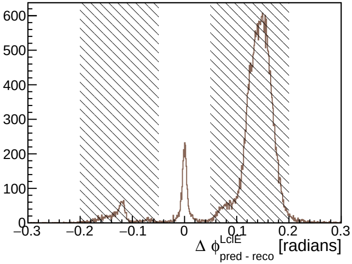


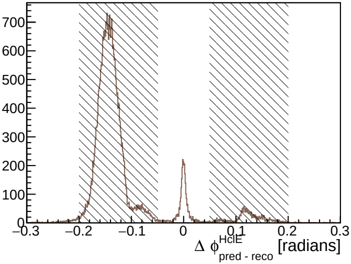

clusterPhi(HclE)
IP
b2bClusterPhi(HclE)
clusterPhi(LclE)

Bhabha Event Selection









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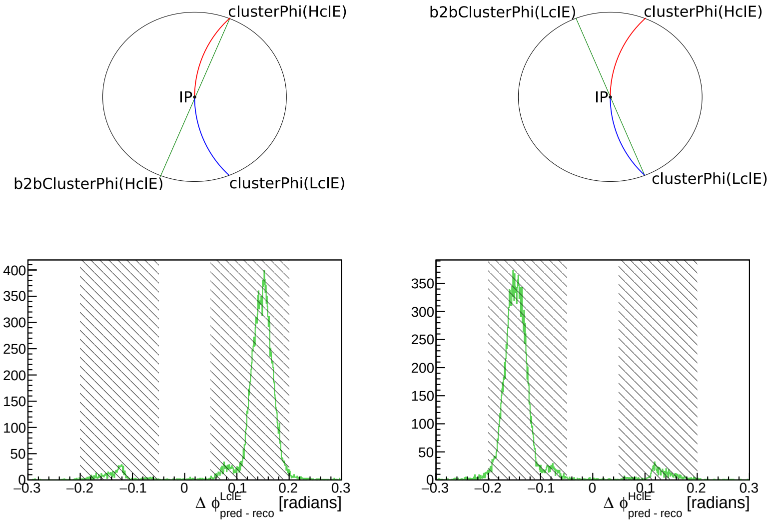


Trigger

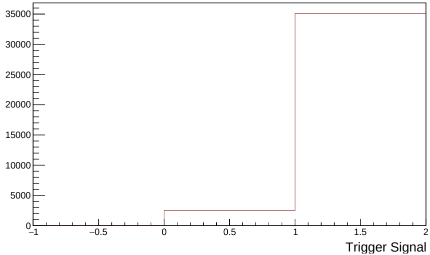
We need to be sure that a trigger signal is coming from the ECL. Otherwise there could be a bias

→ 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
- $160° < \sum \theta_{cms} < 200°$
- $140° < \Delta\phi_{cms} < 220°$

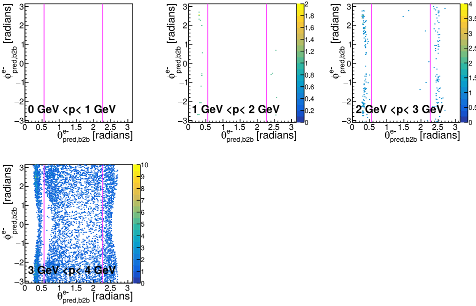
The trigger cut is only applied on phase2 data (and phase3 data later on) since the trigger simulation does not work reliably on MC



Dividing The ECL In Areas Of Interest

As function of azimuthal angle $\phi_{\mathrm{pred,b2b}}$

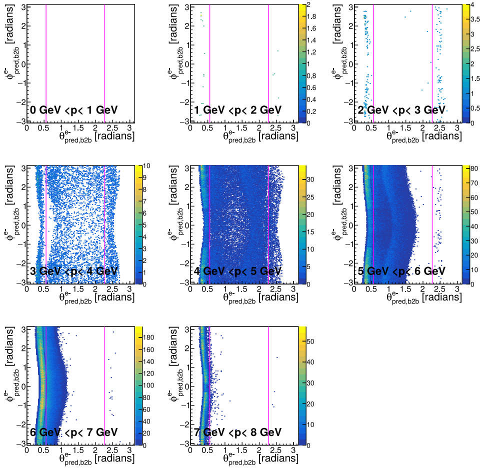
	$\mathrm{p(e^-)}$
Forward End-Cap	
Barrel	
Backward End-Cap	



Dividing The ECL In Areas Of Interest

As function of azimuthal angle $\phi_{\text{pred,b2b}}$

	$p(e^-)$
Forward End-Cap	$4\,\text{GeV} - 8\,\text{GeV}$
Barrel	$4\,\text{GeV} - 7\,\text{GeV}$
Backward End-Cap	/



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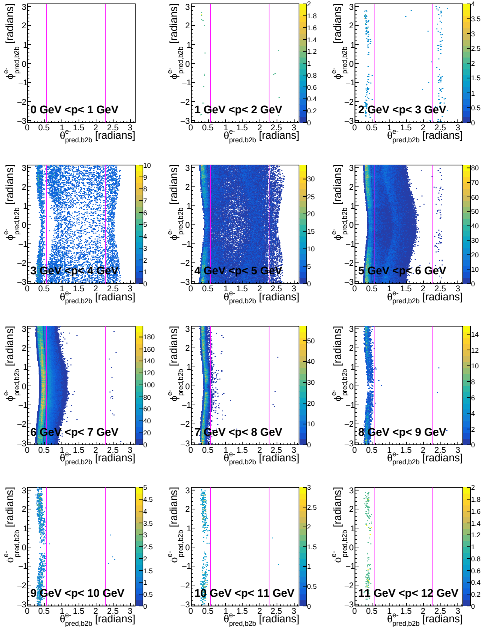

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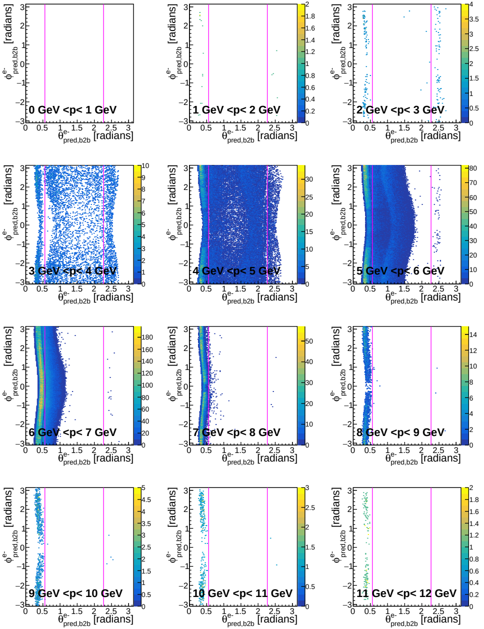
	p(e^-)
Forward End-Cap	$4\,\mathrm{GeV} - 8\,\mathrm{GeV}$
Barrel	$4\,\mathrm{GeV} - 7\,\mathrm{GeV}$
Backward End-Cap	/

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

	p
e^-	$4\,\mathrm{GeV} - 9\,\mathrm{GeV}$



Dividing The ECL In Areas Of Interest

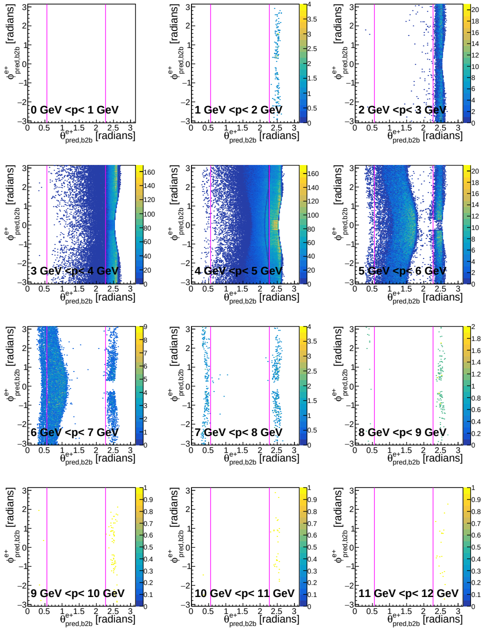
As function of azimuthal angle $\phi_{\text{pred,b2b}}$

	$p(e^-)$
Forward End-Cap	$4\,\text{GeV} - 8\,\text{GeV}$
Barrel	$4\,\text{GeV} - 7\,\text{GeV}$
Backward End-Cap	/

	$p(e^+)$
Forward End-Cap	/
Barrel	$3\,\text{GeV} - 7\,\text{GeV}$
Backward End-Cap	$2\,\text{GeV} - 6\,\text{GeV}$

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

	p
e^-	$4\,\text{GeV} - 9\,\text{GeV}$
e^+	$2\,\text{GeV} - 7\,\text{GeV}$



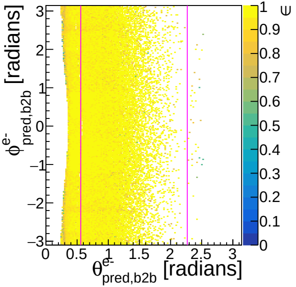
Phase2 Tracking Efficiencies

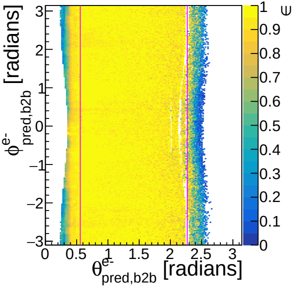
Phase2 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}} - \phi_{\mathbf{pred,b2b}}$

MC

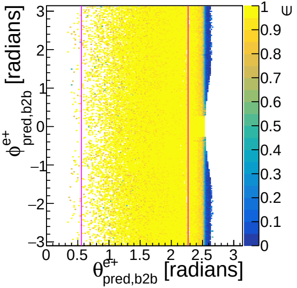
Data

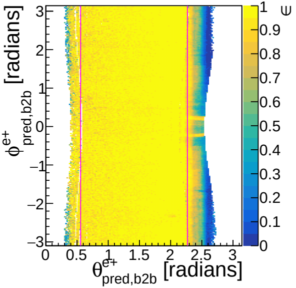
e^-



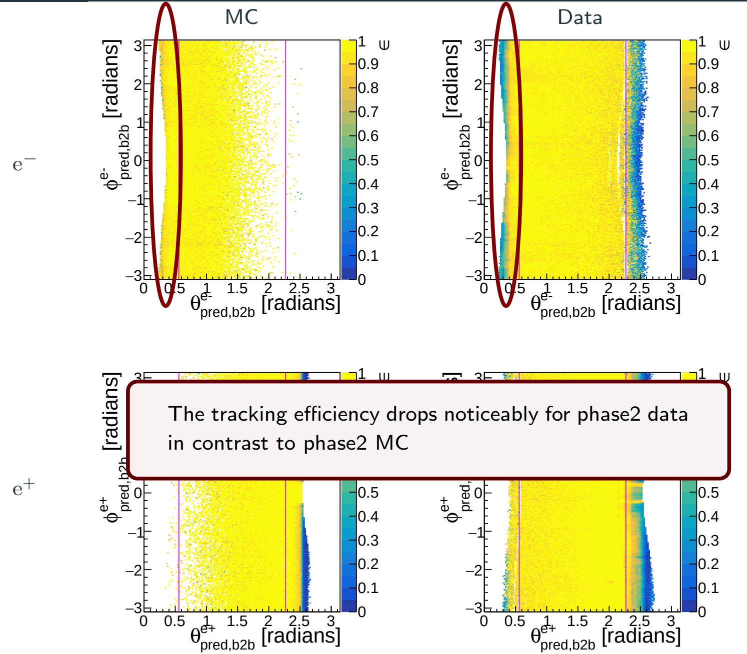


e^+



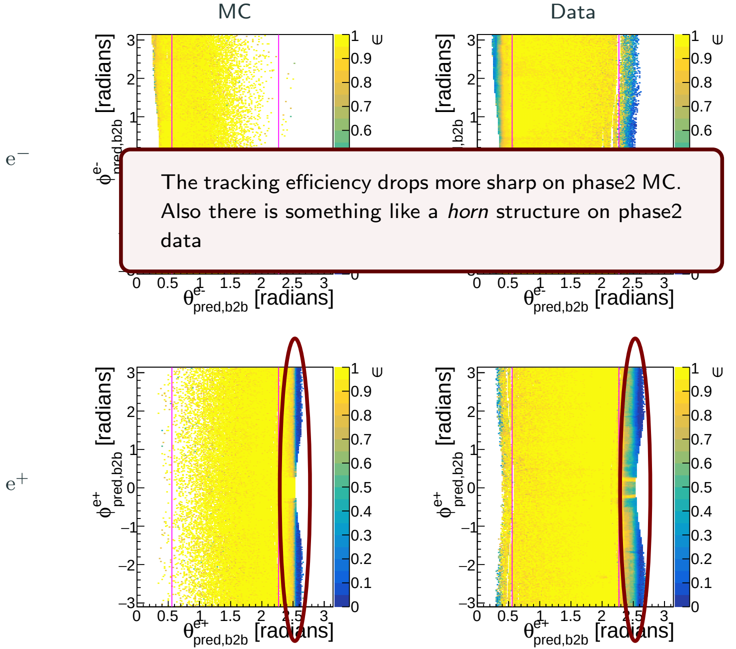


Phase2 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}} - \phi_{\mathbf{pred,b2b}}$



The tracking efficiency drops noticeably for phase2 data in contrast to phase2 MC

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



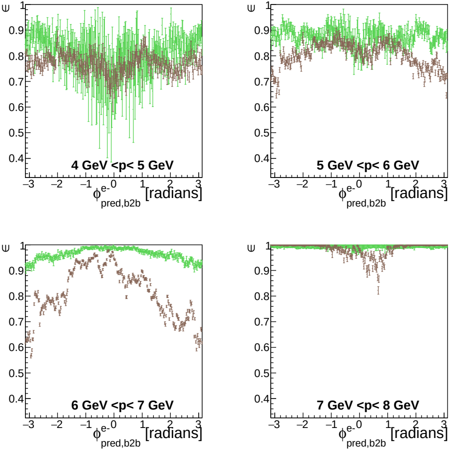
The tracking efficiency drops more sharp on phase2 MC. Also there is something like a *horn* structure on phase2 data

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

Phase2 MC10

Phase2 Data

e^-



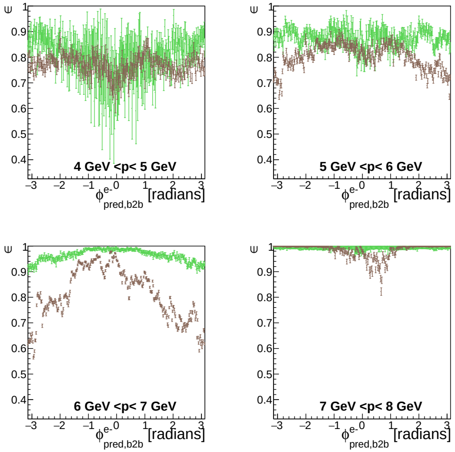
e^+

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

Phase2 MC10

Phase2 Data

e^-



Electron Tracking Efficiency:

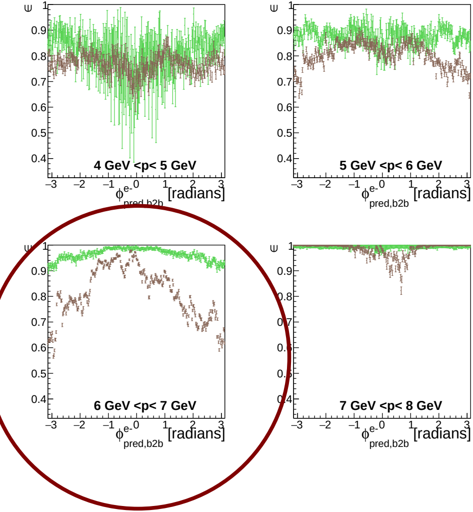
- Phase2 MC has almost always a higher tracking efficiency compared to phase2 data
- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\mathrm{pred,b2b}}| \gtrsim 2$

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

Phase2 MC10

Phase2 Data

e^-



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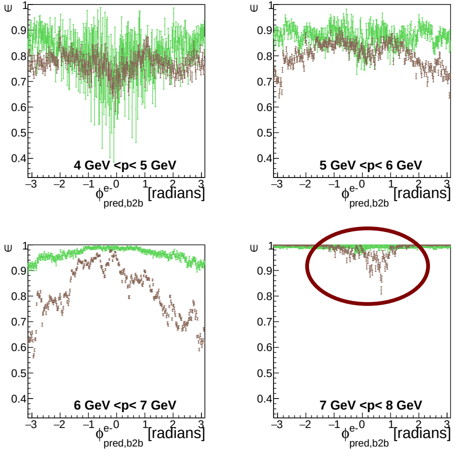
- There is no similarity in the structure for momenta between 6 GeV and 7 GeV

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

Phase2 MC10

Phase2 Data

e^{-}



Electron Tracking Efficiency:

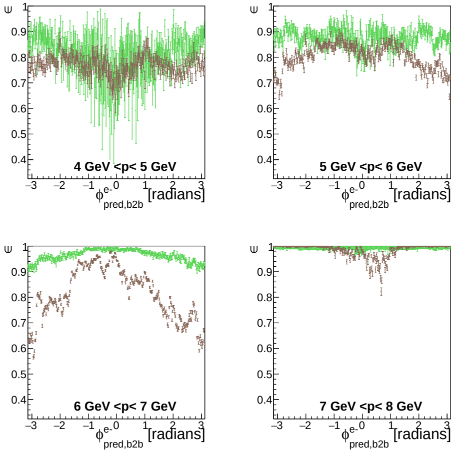
- Phase2 MC has almost always a higher tracking efficiency compared to phase2 data
- For most momenta the biggest difference between phase2 MC and phase2 data occurs for $|\phi_{\mathrm{pred,b2b}}| \gtrsim 2$
- There is no similarity in the structure for momenta between $6\,\mathrm{GeV}$ and $7\,\mathrm{GeV}$
- Highest tracking efficiency occurs for momenta between $7\,\mathrm{GeV}$ and $8\,\mathrm{GeV}$. But there is also an efficiency drop at $\phi_{\mathrm{pred,b2b}} \gtrsim 0$

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

Phase2 MC10

Phase2 Data

e^-



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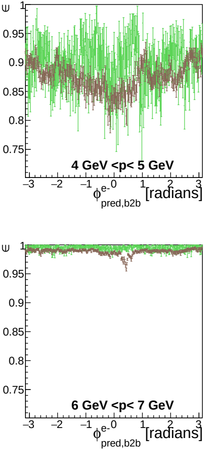
- Highest tracking efficiency occurs for momenta between $7\,\mathrm{GeV}$ and $8\,\mathrm{GeV}$. But there is also an efficiency drop at $\phi_{\mathrm{pred,b2b}} \gtrsim 0$

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

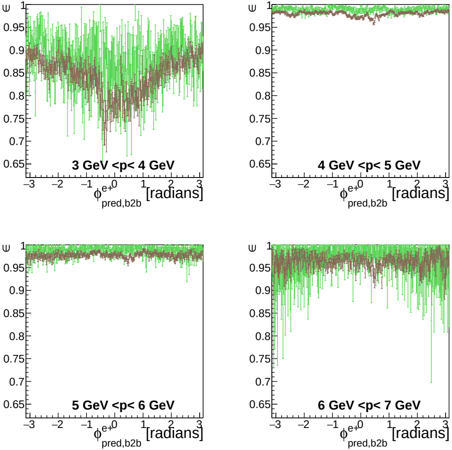
Phase2 MC10

Phase2 Data

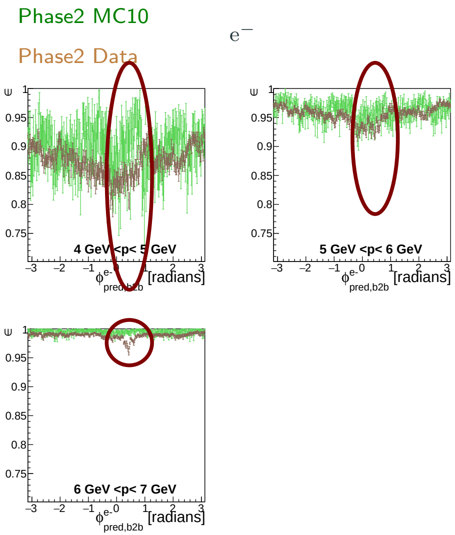
e^-



e^+

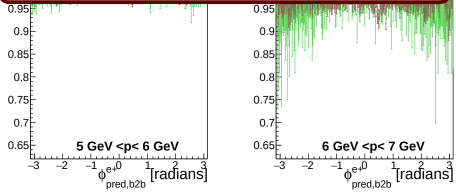


Phase2 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Barrel



Electron Tracking Efficiency:

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

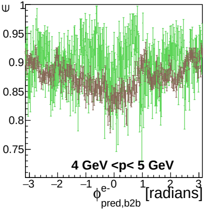


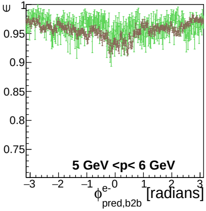
Phase2 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Barrel

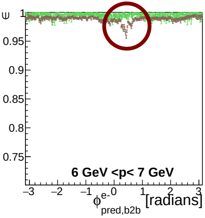
Phase2 MC10

Phase2 Data

e^-

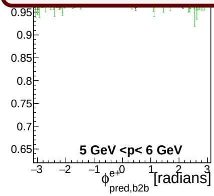


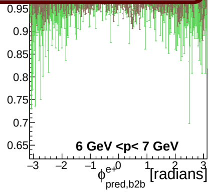




Electron Tracking Efficiency:

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



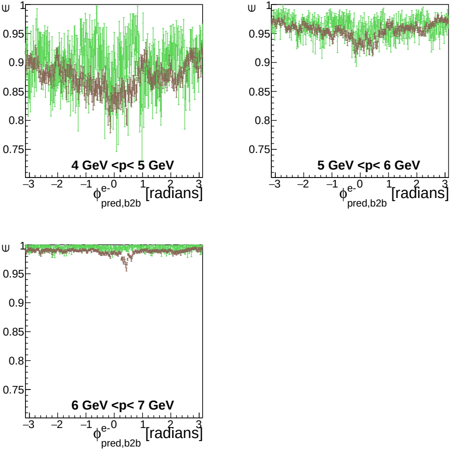


Phase2 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Barrel

Phase2 MC10

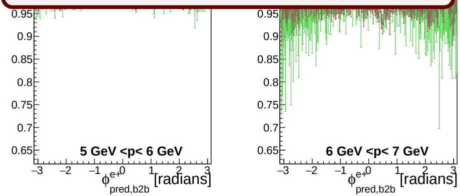
Phase2 Data

e^-



Electron Tracking Efficiency:

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

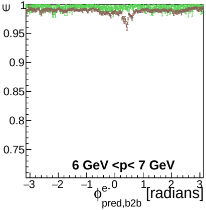


Phase2 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Barrel

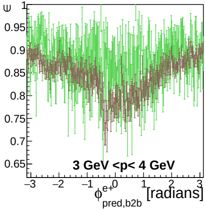
Phase2 MC10

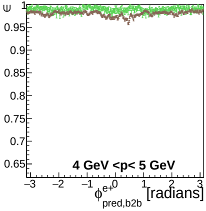
Positron Tracking Efficiency:

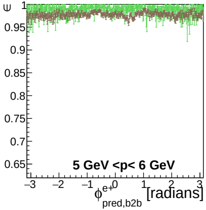
- The highest tracking efficiency occurs for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$
- The lowest tracking efficiency occurs for momenta between $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$ with a minima at $\phi_{\mathrm{pred,b2b}} \approx 0$

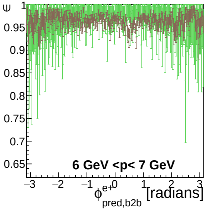


e^{+}









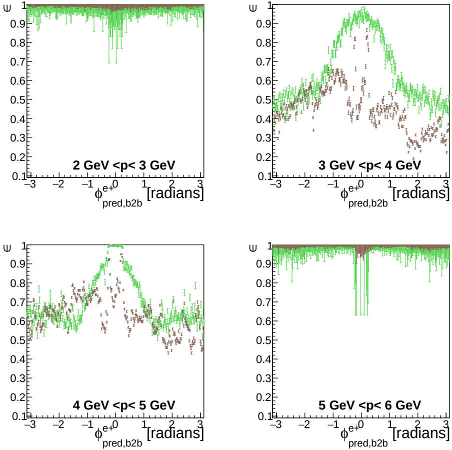
Phase2 Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Backward End-Cap

Phase2 MC10

Phase2 Data

e^-

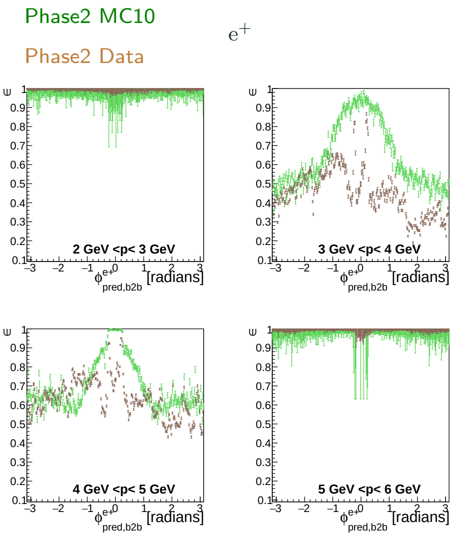
e^+



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

Positron Tracking Efficiency:

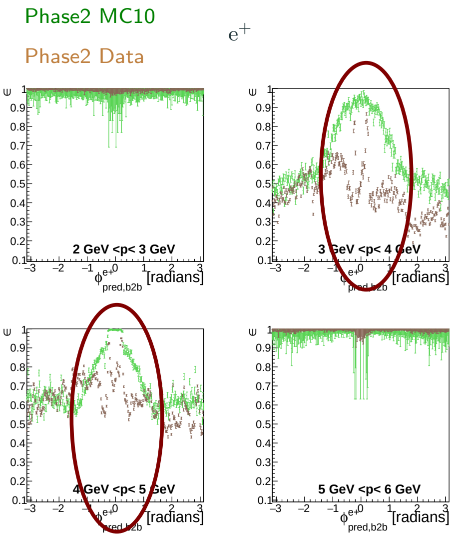
- The highest tracking efficiency occurs for momenta between $2\,\mathrm{GeV}$ and $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$



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

Positron Tracking Efficiency:

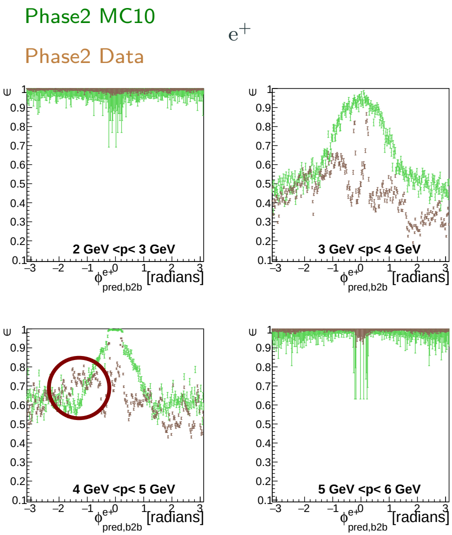
- The highest tracking efficiency occurs for momenta between $2\,\mathrm{GeV}$ and $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$
- Weird *horn* structure we saw earlier
- Phase2 MC tracking efficiency peaks at $\phi_{\mathrm{pred,b2b}} \approx 0$



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

Positron Tracking Efficiency:

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

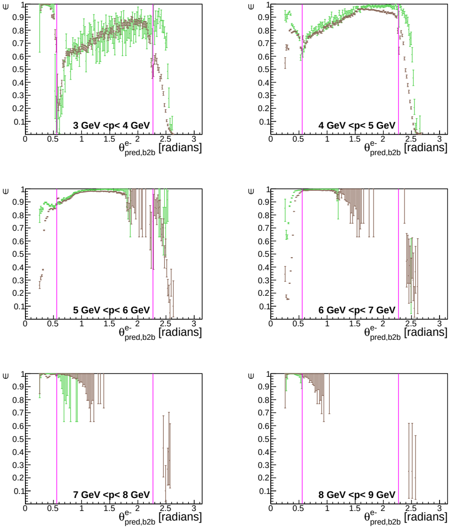


Phase2 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

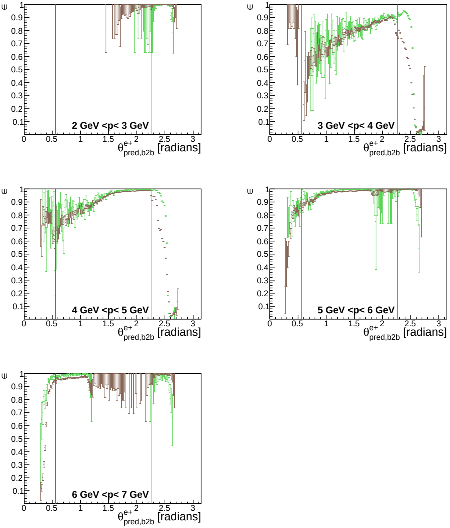
Phase2 MC10

Phase2 Data

e^-



e^+

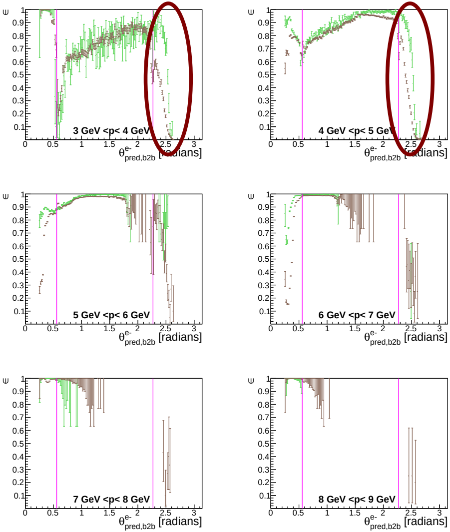


Phase2 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

Phase2 MC10

Phase2 Data

e^{-}



Electron Tracking Efficiency:

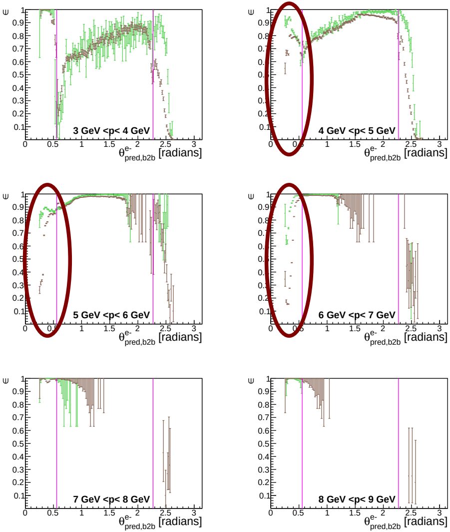
- For momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC

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

Phase2 MC10

Phase2 Data

e^-



Electron Tracking Efficiency:

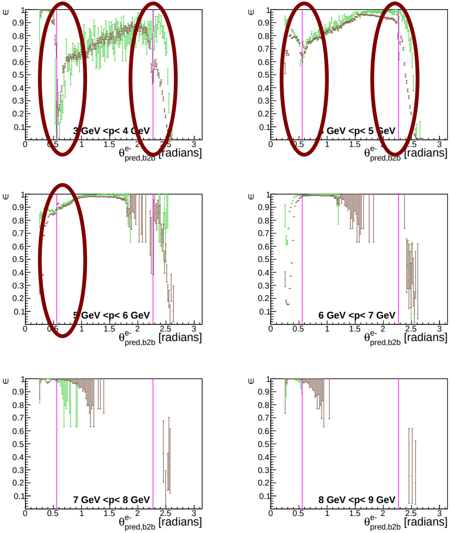
- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC

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

Phase2 MC10

Phase2 Data

e^-



Electron Tracking Efficiency:

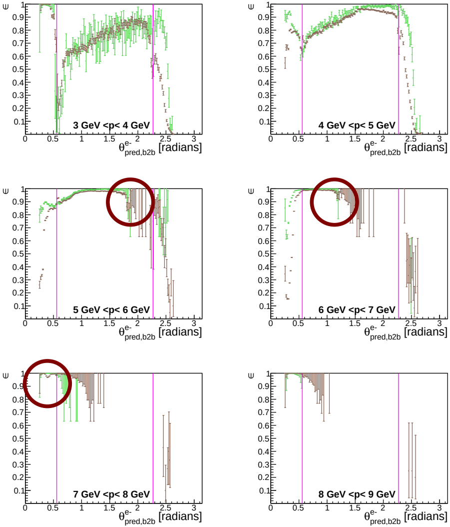
- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC
- Drops in efficiency at transition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

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

Phase2 MC10

Phase2 Data

e^-



Electron Tracking Efficiency:

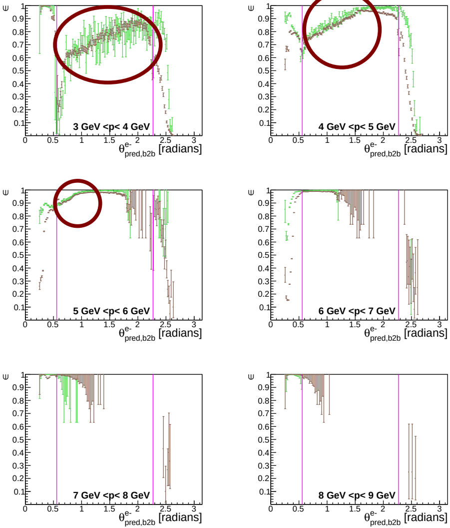
- For momenta between 3 GeV and 5 GeV the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between 4 GeV and 6 GeV the tracking efficiency in the forward end-cap is worse for phase2 data compared to phase2 MC
- Drops in efficiency at transition 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 $\theta_{\mathrm{pred,b2b}}$

Phase2 MC10

Phase2 Data

e^-



Electron Tracking Efficiency:

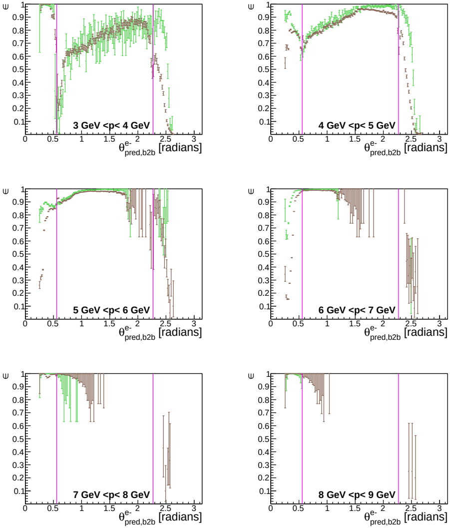
- For momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ the tracking efficiency in the backward end-cap is worse for phase2 data compared to phase2 MC
- For momenta between $4\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$ the tracking efficiency in the forward end-cap is worse for phase2 data compared to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

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

Phase2 MC10

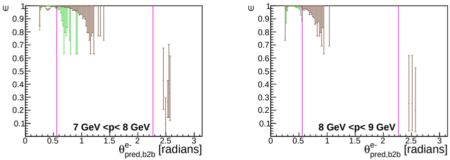
Phase2 Data

e^{-}



Electron Tracking Efficiency:

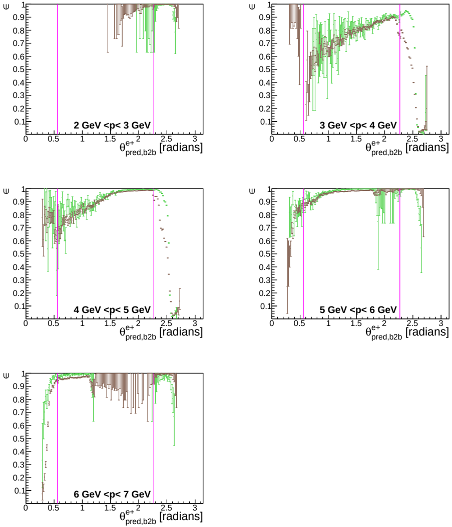
Positron Tracking Efficiency:



Phase2 MC10

Phase2 Data

e^+



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

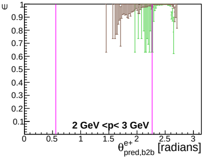
Positron Tracking Efficiency:

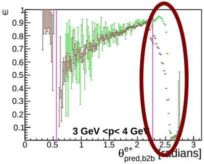
- For momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap

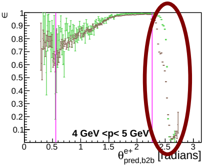
Phase2 MC10

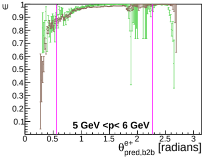
Phase2 Data

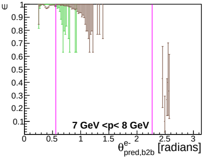
e^{+}

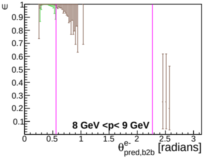


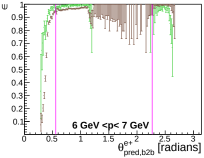








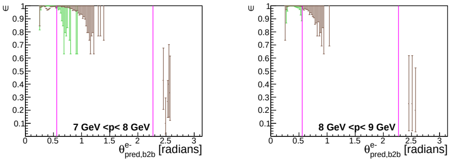




Phase2 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

Positron Tracking Efficiency:

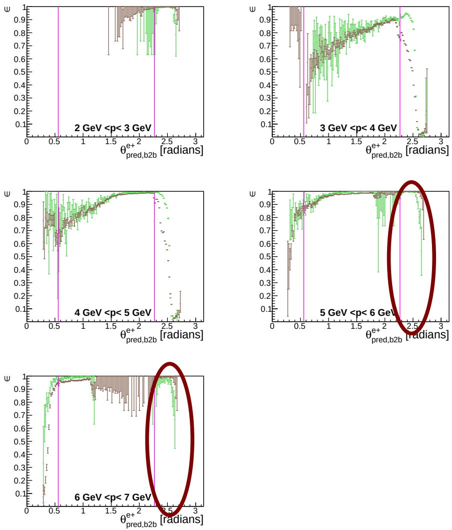
- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa



Phase2 MC10

Phase2 Data

e^+



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

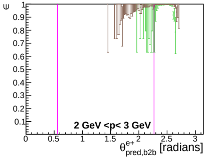
Positron Tracking Efficiency:

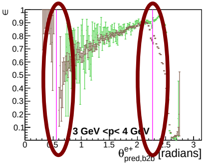
- For momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between $5\,\mathrm{GeV}$ and $7\,\mathrm{GeV}$ it is vice versa
- Efficiency drop at transition between barrel and end-caps

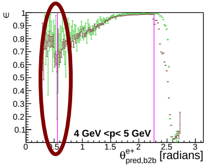
Phase2 MC10

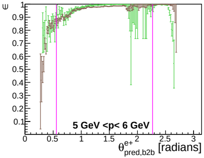
Phase2 Data

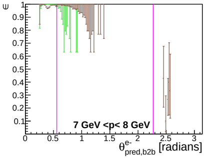
e^+

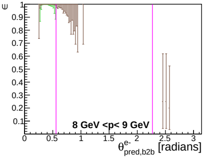


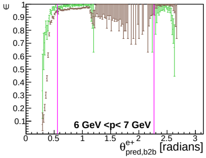












Phase2 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

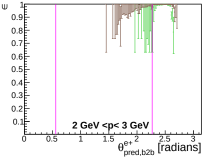
Positron Tracking Efficiency:

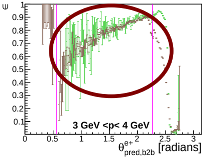
- For momenta between 3 GeV and 5 GeV the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between 5 GeV and 7 GeV it is vice versa
- Efficiency drop at transition between barrel and end-caps
- There is a slope in the barrel again

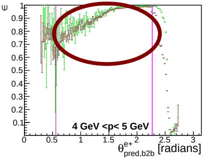
Phase2 MC10

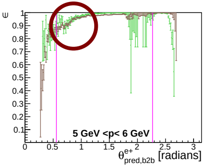
Phase2 Data

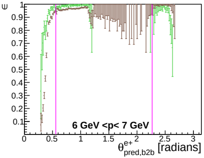
e^+

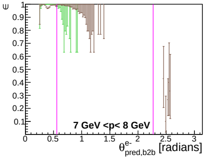


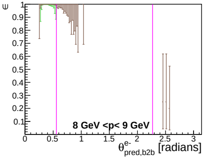












Phase2 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

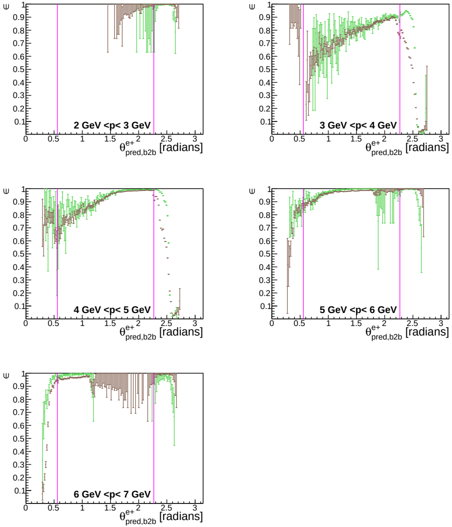
Positron Tracking Efficiency:

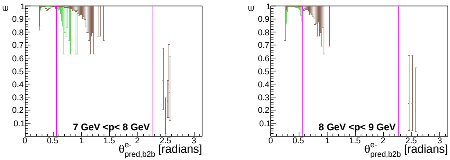
- For momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ the phase2 data tracking efficiency is lower compared to phase2 MC in the backward end-cap
- For momenta between $5\,\mathrm{GeV}$ and $7\,\mathrm{GeV}$ it is vice versa
- Efficiency drop at transition between barrel and end-caps
- There is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

Phase2 MC10

Phase2 Data

e^{+}



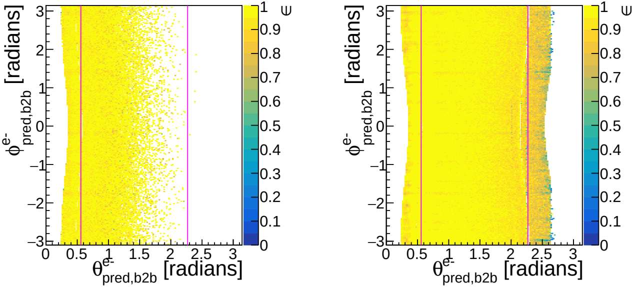


Phase3 Tracking Efficiencies

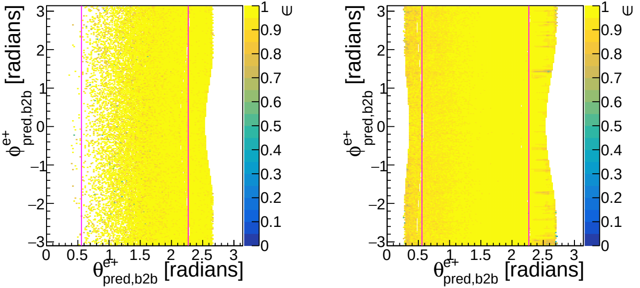
Phase3 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}} - \phi_{\mathbf{pred,b2b}}$

MC | Data

e^-



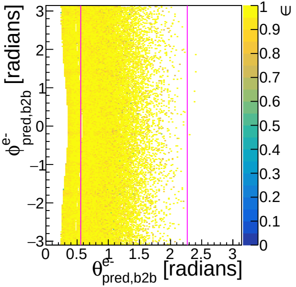
e^+

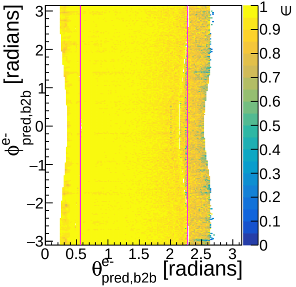


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}} - \phi_{\mathbf{pred,b2b}}$

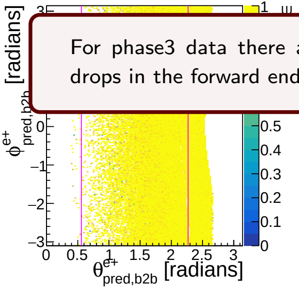
MC | Data

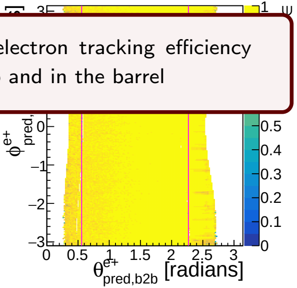
e^-





e^+





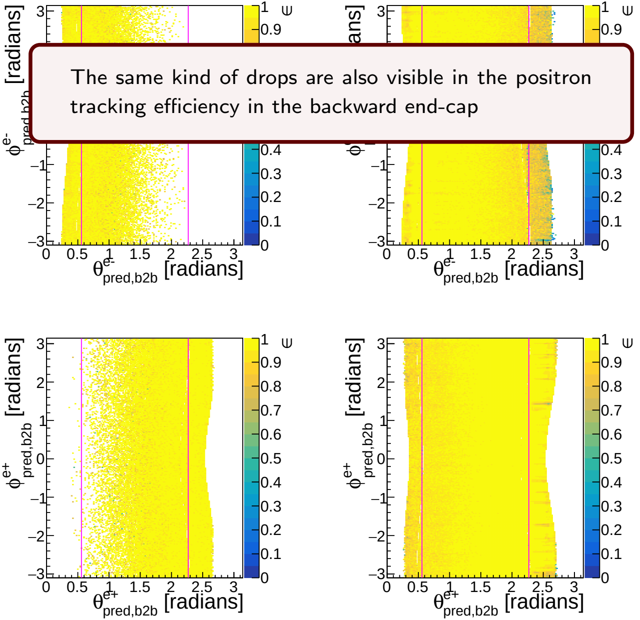
For phase3 data there are electron tracking efficiency drops in the forward end-cap and in the barrel

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

MC | Data

e^-

e^+



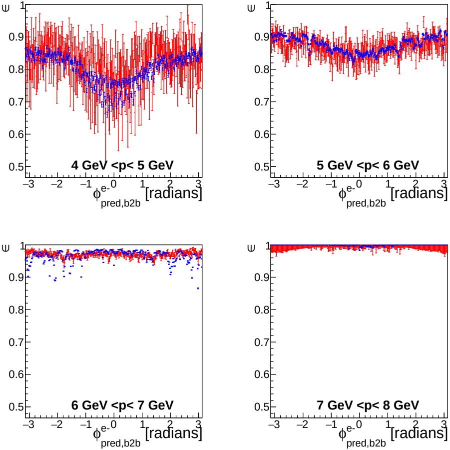
The same kind of drops are also visible in the positron tracking efficiency in the backward end-cap

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

Phase3 MC10

Phase3 Data

e^{-}



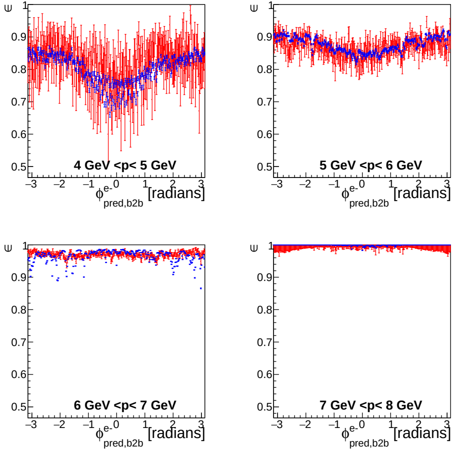
e^{+}

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

Phase3 MC10

Phase3 Data

e^{-}



Electron Tracking Efficiency:

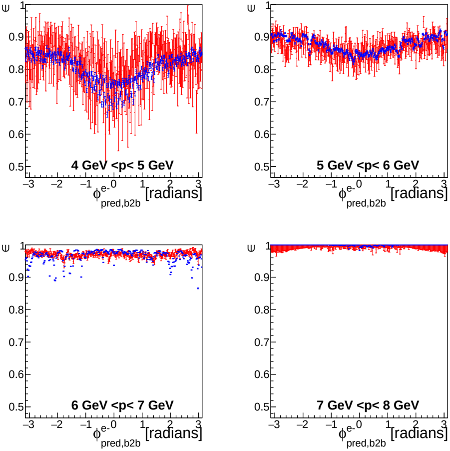
- Highest tracking efficiency at for momenta between 7 GeV and 8 GeV

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

Phase3 MC10

Phase3 Data

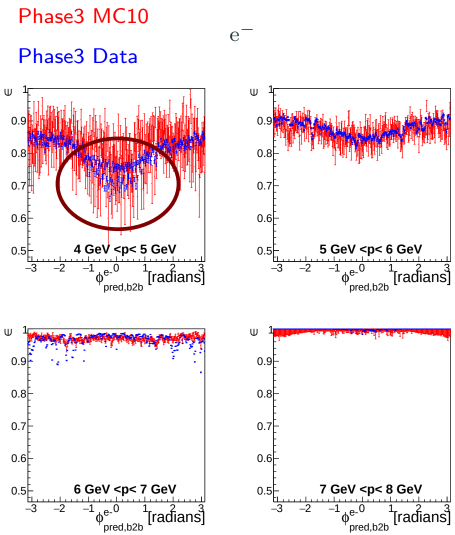
e^-



Electron Tracking Efficiency:

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

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



Electron Tracking Efficiency:

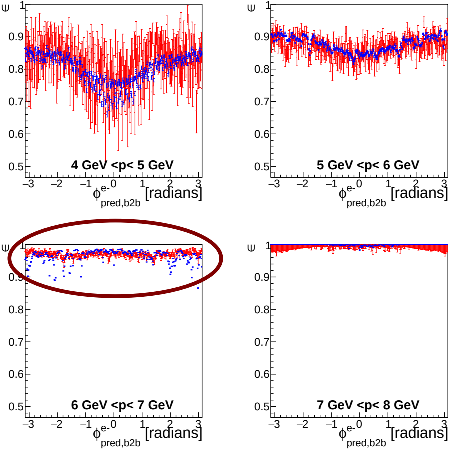
- Highest tracking efficiency at for momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV

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

Phase3 MC10

Phase3 Data

e^-



Electron Tracking Efficiency:

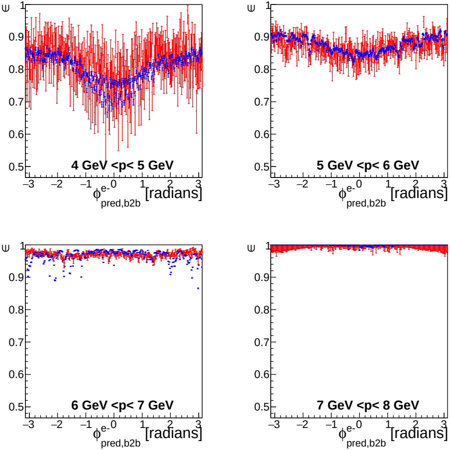
- Highest tracking efficiency at for momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV
- Weird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

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

Phase3 MC10

Phase3 Data

e^{-}



Electron Tracking Efficiency:

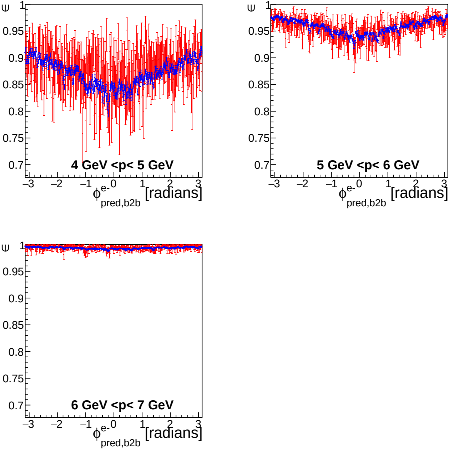
- Highest tracking efficiency at for momenta between 7 GeV and 8 GeV
- Minimum at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV
- Weird *ribbon* structure in the phase3 data tracking efficiency at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 5 GeV
- Weird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

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

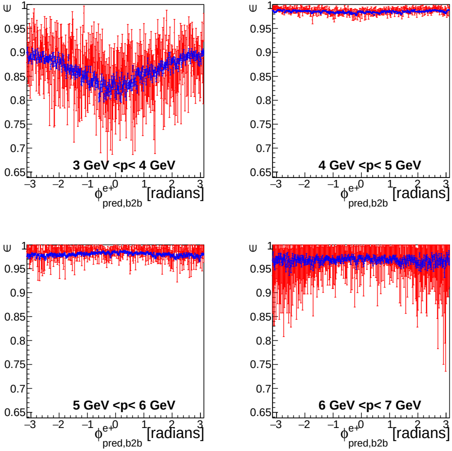
Phase3 MC10

Phase3 Data

e^-



e^+

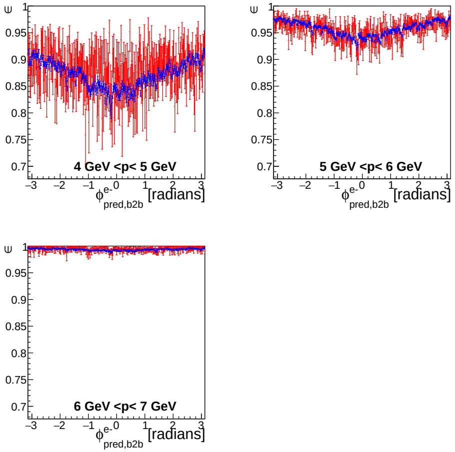


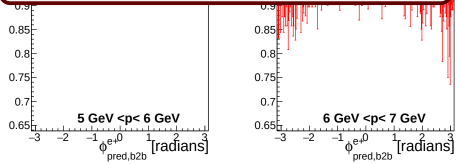
Phase3 Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Barrel

Phase3 MC10

Phase3 Data

e^-





Electron Tracking Efficiency:

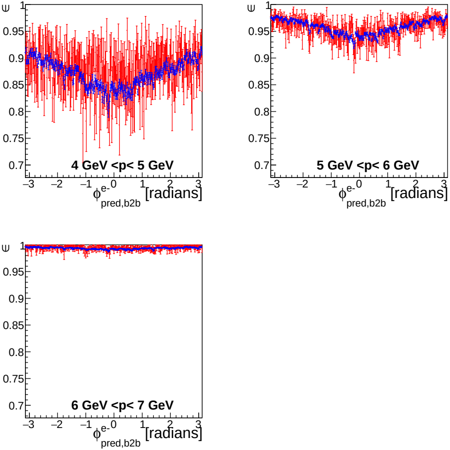
- Highest tracking efficiency at for momenta between 6 GeV and 7 GeV
- Lowest tracking efficiency at for momenta between 4 GeV and 5 GeV

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

Phase3 MC10

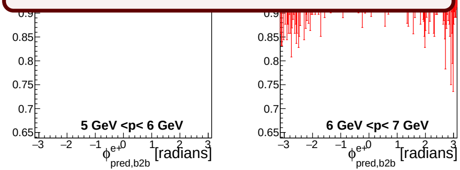
Phase3 Data

e^-



Electron Tracking Efficiency:

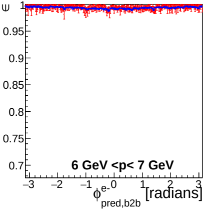
- Highest tracking efficiency at for momenta between 6 GeV and 7 GeV
- Lowest tracking efficiency at for momenta between 4 GeV and 5 GeV
- Minimum at $\phi_{\mathrm{pred,b2b}} \approx 0$ for momenta between 4 GeV and 6 GeV

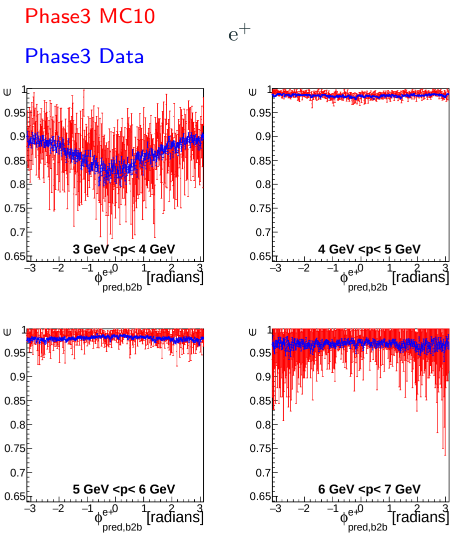


Phase3 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Barrel

Positron Tracking Efficiency:

- Highest tracking efficiency at for momenta between $4\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$
- Lowest tracking efficiency at for momenta between $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$





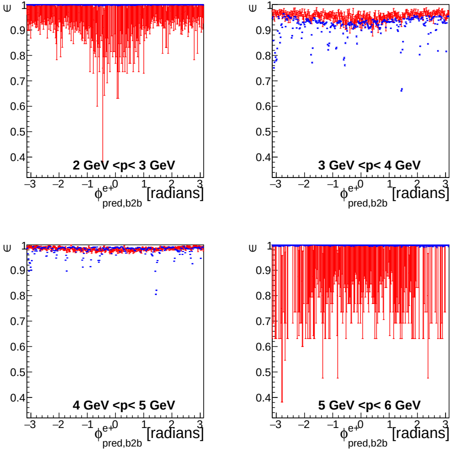
Phase3 Tracking Efficiencies As Function Of $\phi_{\mathrm{pred,b2b}}$; Backward End-Cap

Phase3 MC10

Phase3 Data

e^-

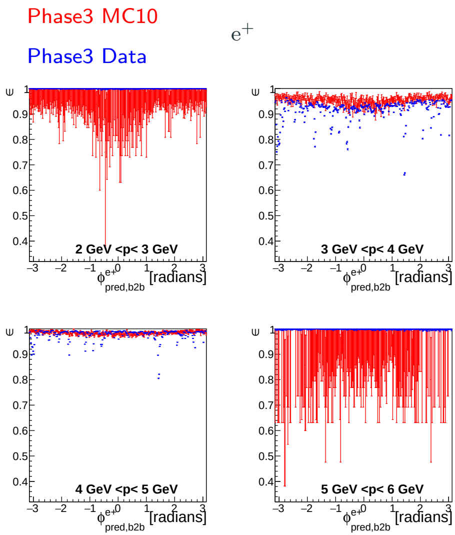
e^+



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

Positron Tracking Efficiency:

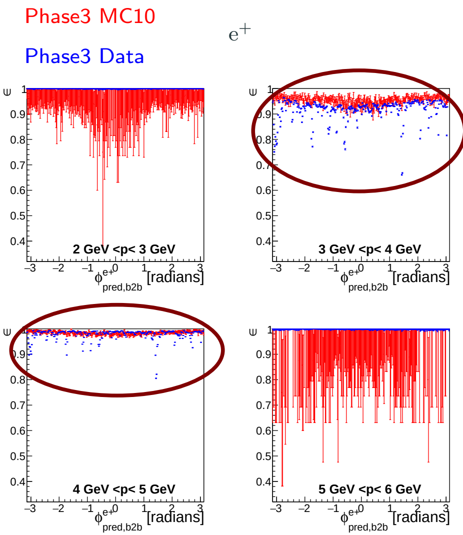
- The highest tracking efficiency occurs for momenta between $2\,\mathrm{GeV}$ and $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$



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

Positron Tracking Efficiency:

- The highest tracking efficiency occurs for momenta between $2\,\mathrm{GeV}$ and $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$ and $6\,\mathrm{GeV}$
- Weird efficiency drops in the phase3 data tracking efficiency for momenta between $3\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$

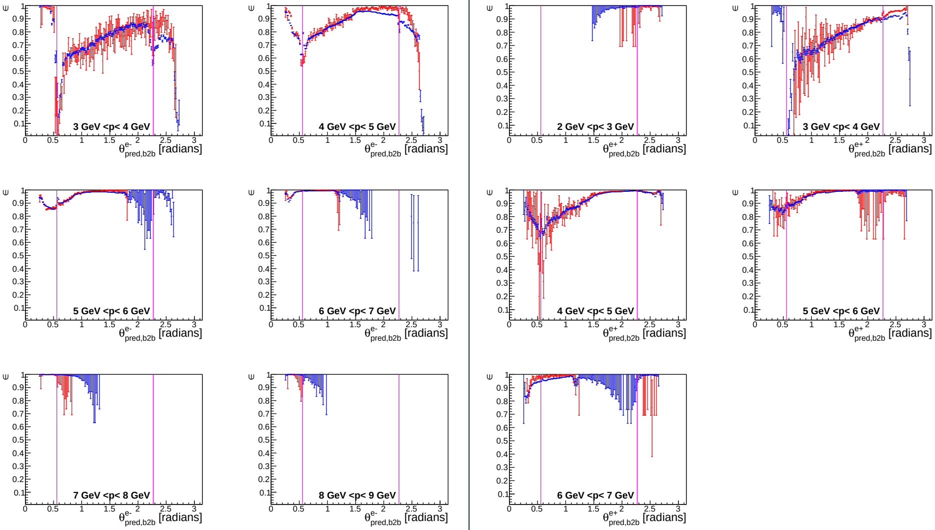


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase3 MC10

Phase3 Data

e^- e^+

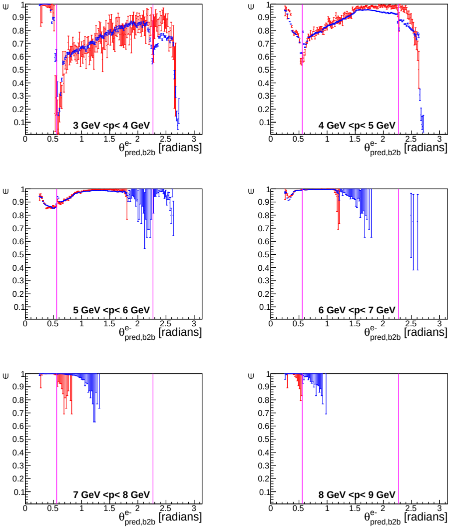


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase3 MC10

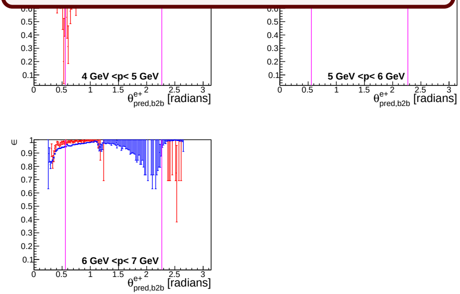
Phase3 Data

e^-



Electron Tracking Efficiency:

- Phase3 MC and phase3 data are very close to each other (exception occurs for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$)

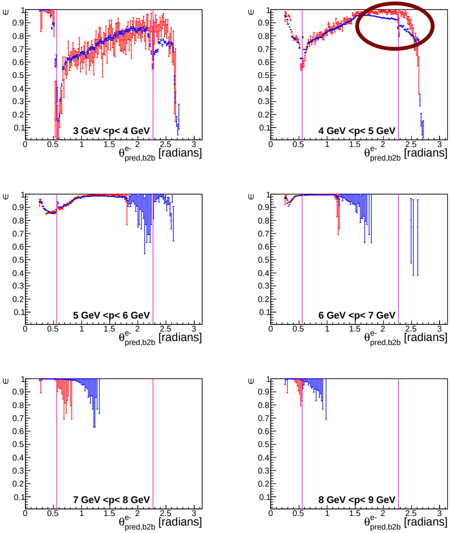


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase3 MC10

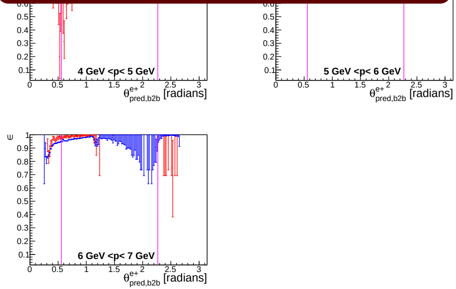
Phase3 Data

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)

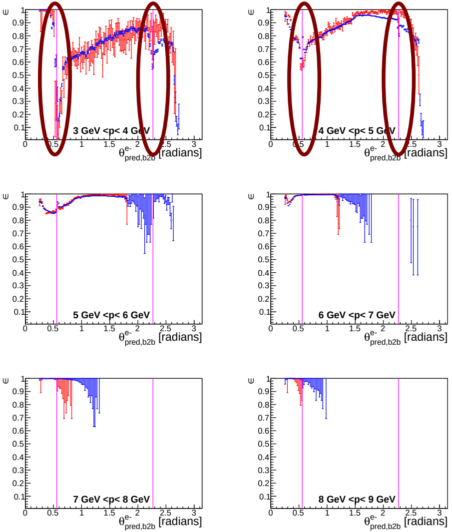


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase3 MC10

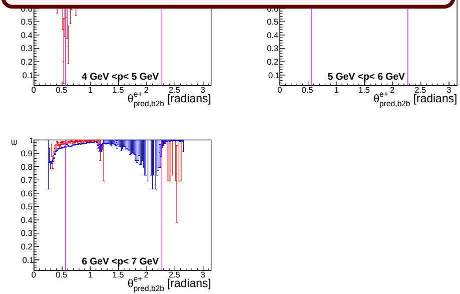
Phase3 Data

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

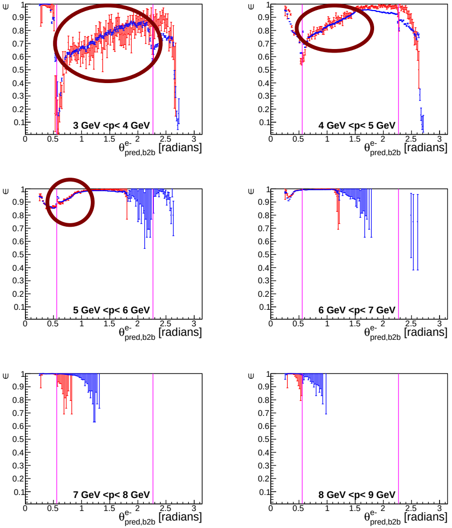


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase3 MC10

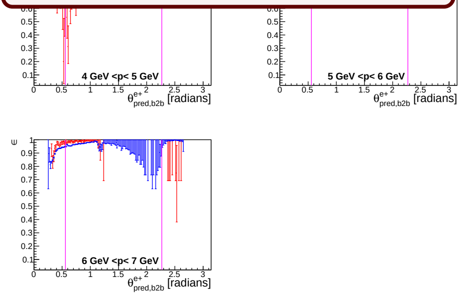
Phase3 Data

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

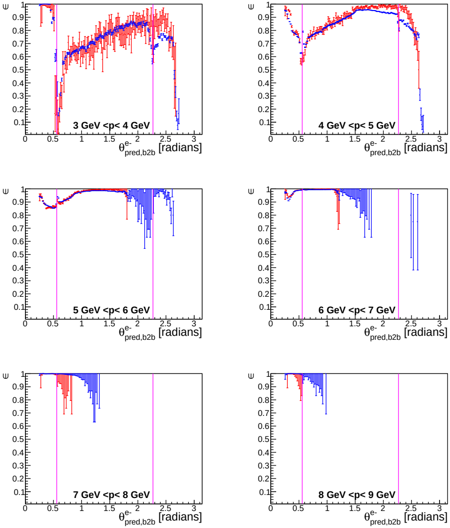


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

Phase3 MC10

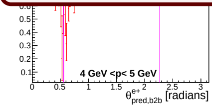
Phase3 Data

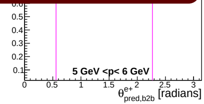
e^-

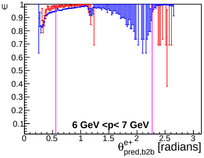


Electron Tracking Efficiency:

- 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



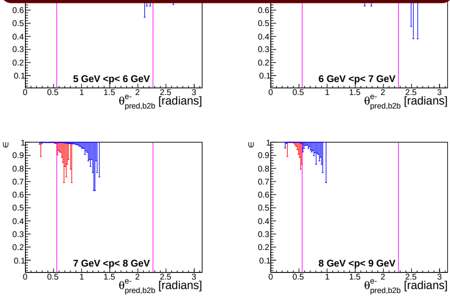


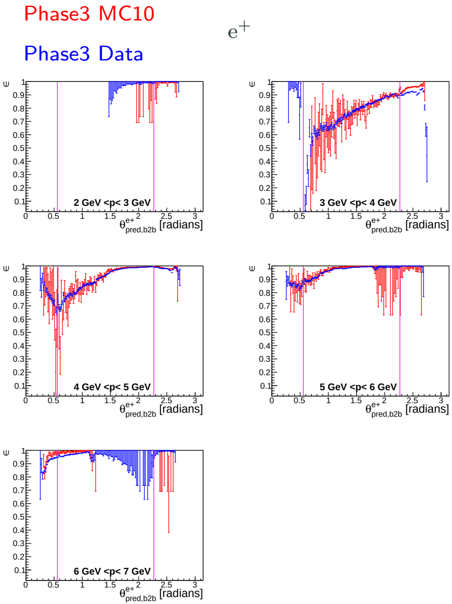


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

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 $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$)

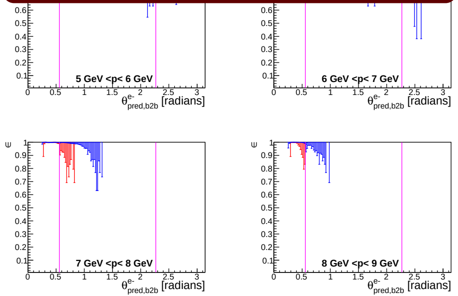




Phase3 Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

Positron Tracking Efficiency:

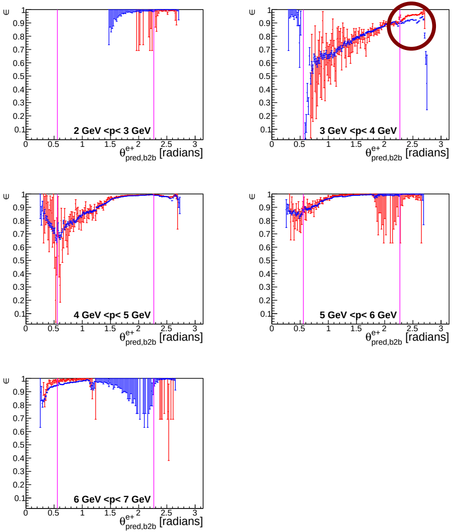
- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$)



Phase3 MC10

Phase3 Data

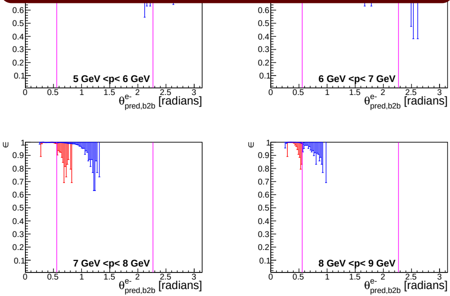
e^+



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

Positron Tracking Efficiency:

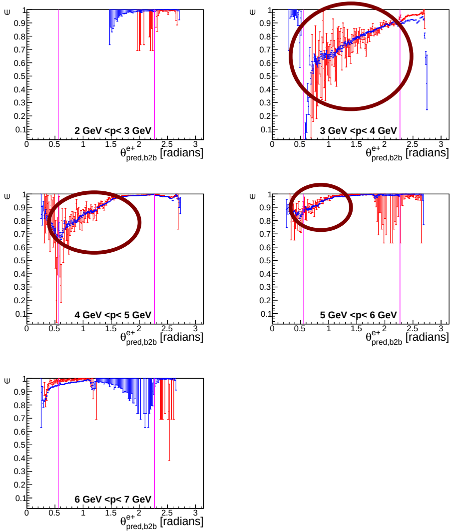
- The tracking efficiency pf phase3 MC and phase3 data are close to each other (exception occurs in the backward end-cap for momenta between $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$)
- There is a slope in the barrel



Phase3 MC10

Phase3 Data

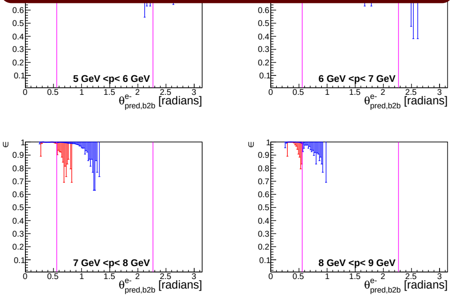
e^+

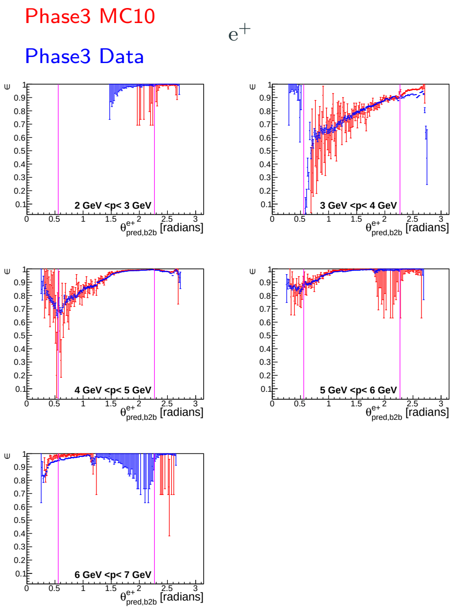


Phase3 Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

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 $3\,\mathrm{GeV}$ and $4\,\mathrm{GeV}$)
- There is a slope in the barrel





Comparing The Tracking Efficiency Of Phase2 Data with Phase3 Data

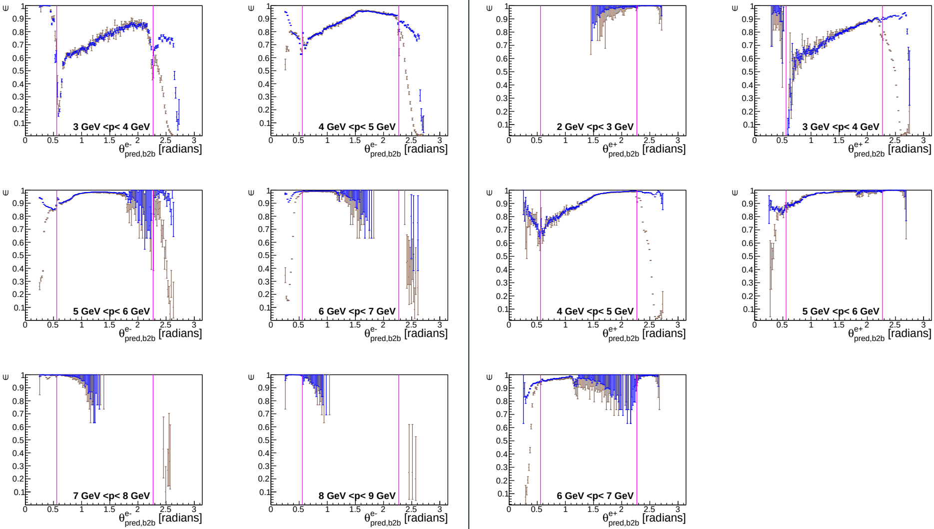
Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase2 Data

Phase3 Data

e^-

e^+

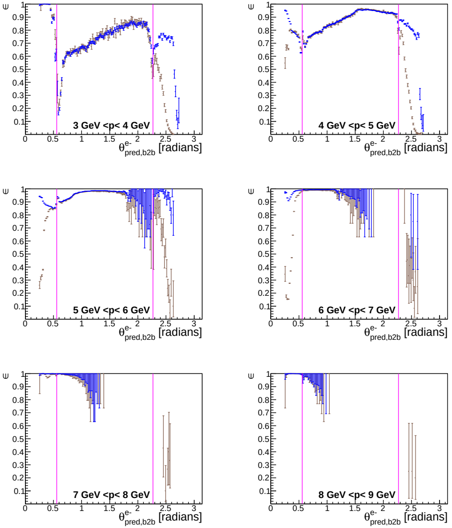


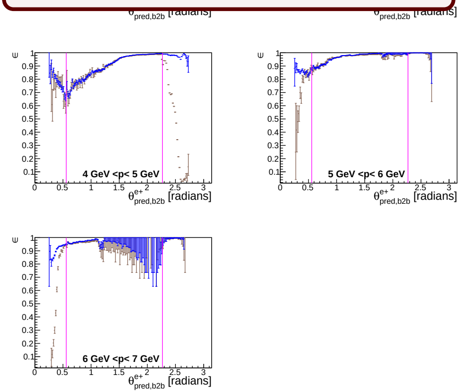
Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

Phase2 Data

Phase3 Data

e^-





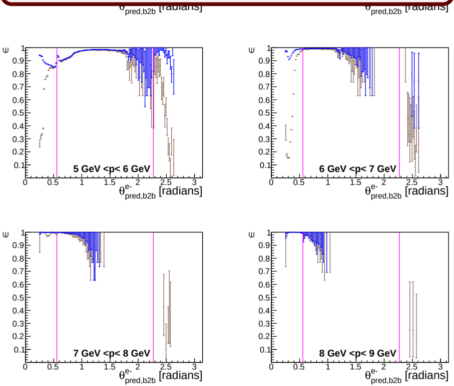
Electron Tracking Efficiency:

- Drastic improvement in the end-caps
- Tracking efficiency in the barrel stayed more or less the same

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

Positron Tracking Efficiency:

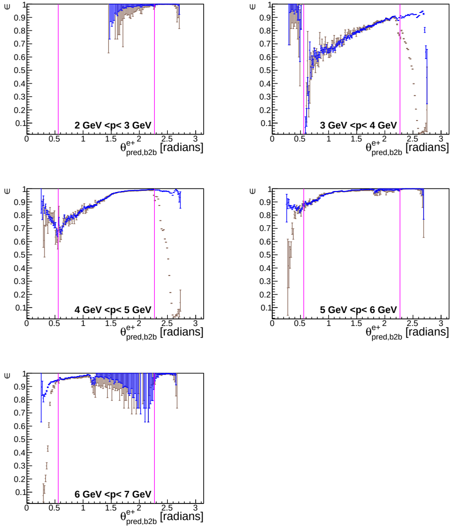
- Drastic improvement in the end-caps
- Tracking efficiency in the barrel stayed more or less the same



Phase2 Data

Phase3 Data

e^+

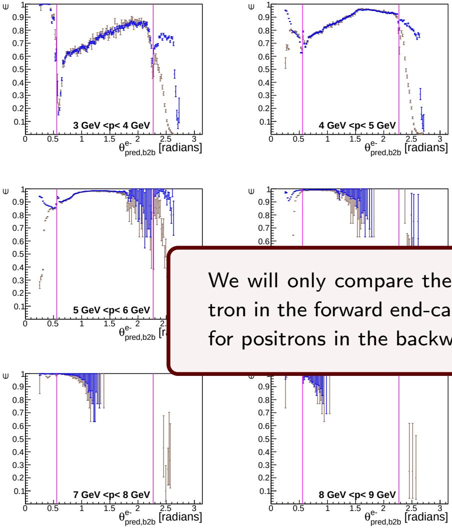


Tracking Efficiencies As Function Of $\theta_{\mathrm{pred,b2b}}$

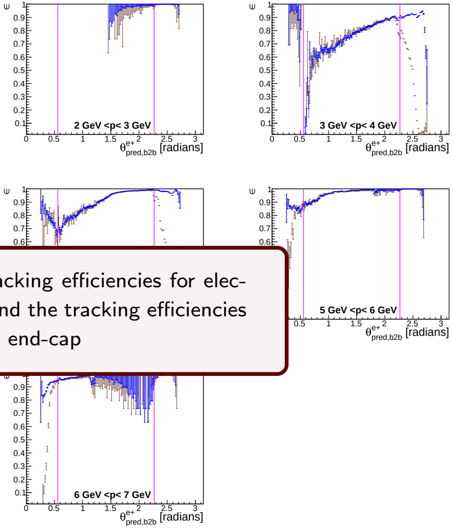
Phase2 Data

Phase3 Data

e^-



e^+



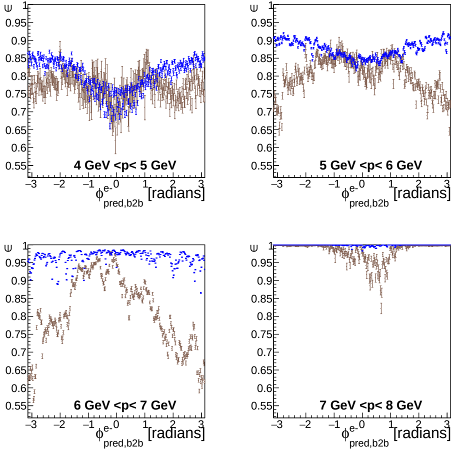
We will only compare the tracking efficiencies for electron in the forward end-cap and the tracking efficiencies for positrons in the backward end-cap

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

Phase2 Data

e^{-}

Phase3 Data



Electron Tracking Efficiency:

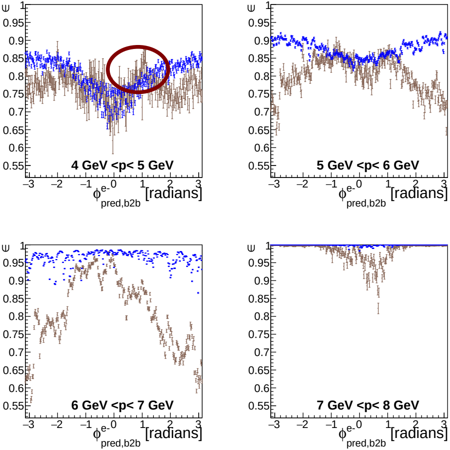
- The tracking efficiency improved over almost all $\phi_{\mathrm{pred,b2b}}$ (exception occurs for $\phi_{\mathrm{pred,b2b}} \approx 1$ for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$)

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

Phase2 Data

Phase3 Data

e^-



Electron Tracking Efficiency:

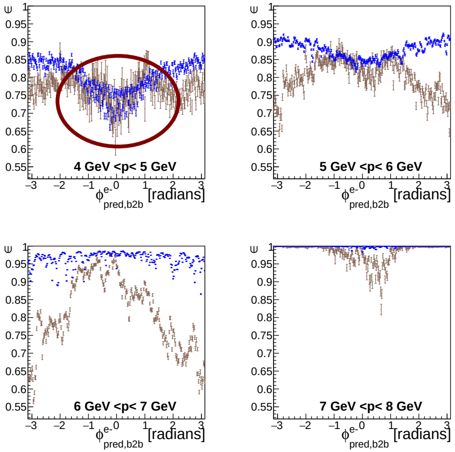
- The tracking efficiency improved over almost all $\phi_{\mathrm{pred,b2b}}$ (exception occurs for $\phi_{\mathrm{pred,b2b}} \approx 1$ for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$)

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

Phase2 Data

Phase3 Data

e^-



Electron Tracking Efficiency:

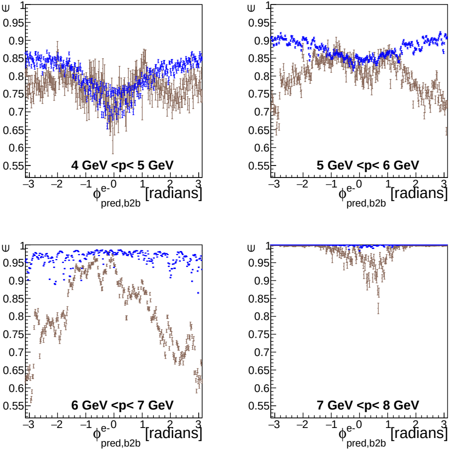
- The tracking efficiency improved over almost all $\phi_{\mathrm{pred,b2b}}$ (exception occurs for $\phi_{\mathrm{pred,b2b}} \approx 1$ for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$)
- The lower *ribbon* of phase3 data seems to follow the phase2 data structure

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

Phase2 Data

e^-

Phase3 Data



Electron Tracking Efficiency:

- The tracking efficiency improved over almost all $\phi_{\mathrm{pred,b2b}}$ (exception occurs for $\phi_{\mathrm{pred,b2b}} \approx 1$ for momenta between $4\,\mathrm{GeV}$ and $5\,\mathrm{GeV}$)
- The lower *ribbon* of phase3 data seems to follow the phase2 data structure

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

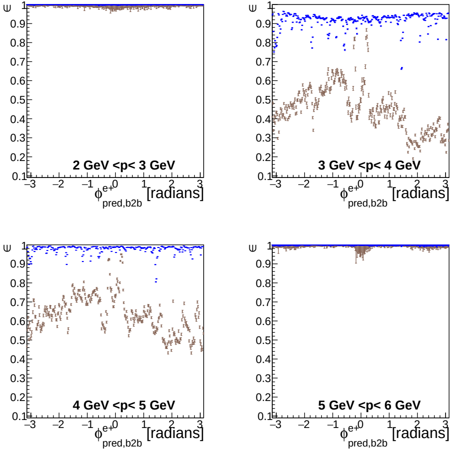
Positron Tracking Efficiency:

-

Phase2 Data

Phase3 Data

e^{+}



Conclusion

Conclusion

Appendix

Code

```
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)

reconstructDecay('vpho:gamma -> gamma:all', '', path=mypath)
reconstructDecay('vpho:elec -> e+:all', '', path=mypath)

copyLists(outputListName = 'vpho:ECLObjectUnranked', inputListNames=['vpho:elec', 'vpho:gamma'], path=mypath)

rankByHighest('vpho:ECLObjectUnranked', 'daughter(0,clusterE)', path=mypath)
cutAndCopyList('vpho:ECLObject', 'vpho:ECLObjectUnranked', '', path=mypath)

reconstructDecay('vpho:bhabha -> vpho:ECLObject vpho:ECLObject', '', path=mypath)

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:

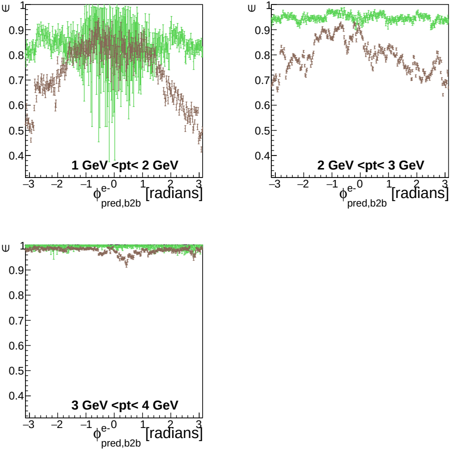
- /belle/MC/release-01-00-02/DB00000294/MC10/ prod00004664/s00/e0000/4S/r00000/3600520000/mdst/sub00

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

Phase2 MC10

Phase2 Data

e^{-}



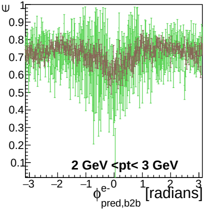
e^{+}

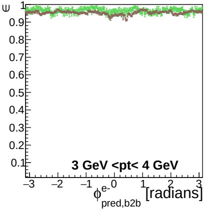
Phase2 pt Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Barrel

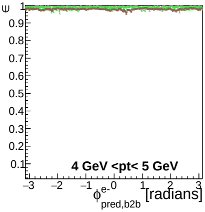
Phase2 MC10

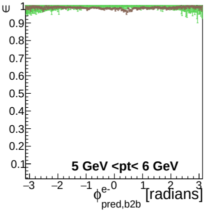
Phase2 Data

e^-

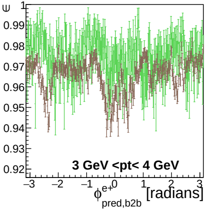


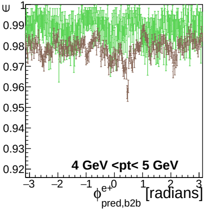


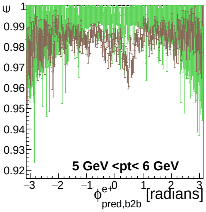




e^+







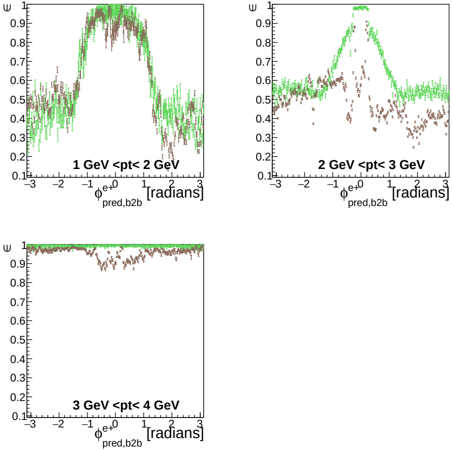
Phase2 pt Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Backward End-Cap

Phase2 MC10

Phase2 Data

e^-

e^+

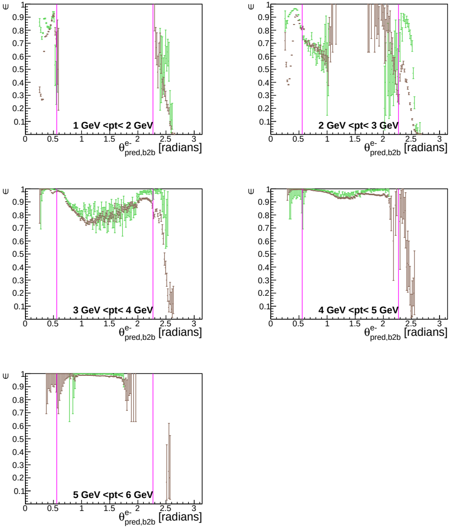


Phase2 pt Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

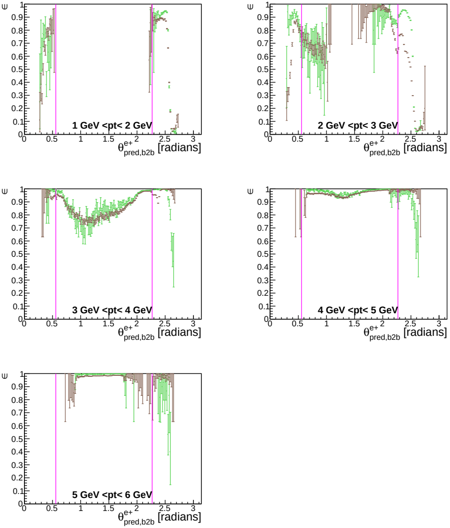
Phase2 MC10

Phase2 Data

e^-



e^+

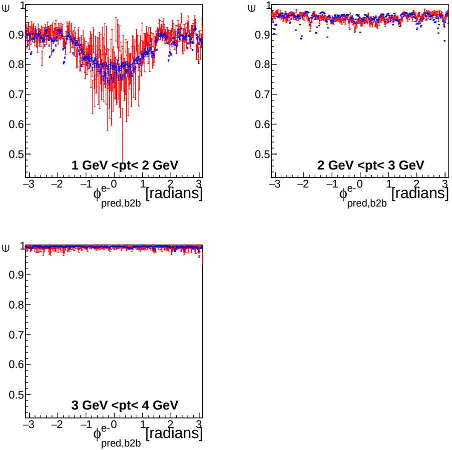


Phase3 pt Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Forward End-Cap

Phase3 MC10

Phase3 Data

e^-



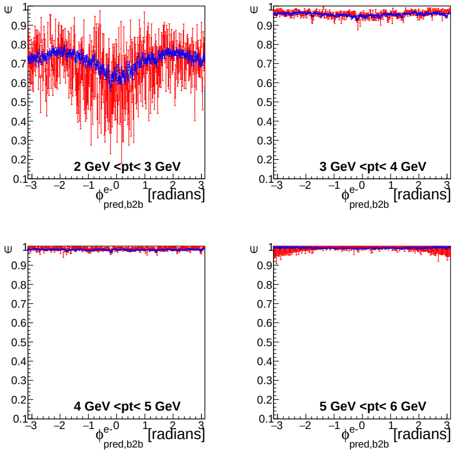
e^+

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

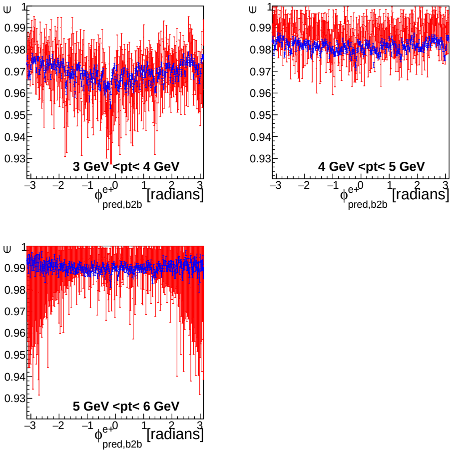
Phase3 MC10

Phase3 Data

e^{-}



e^{+}



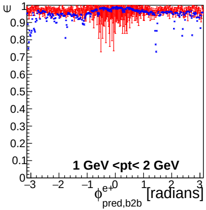
Phase3 pt Tracking Efficiencies As Function Of $\phi_{\mathbf{pred,b2b}}$; Backward End-Cap

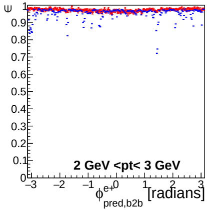
Phase3 MC10

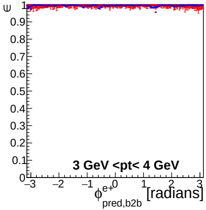
Phase3 Data

e^-

e^+





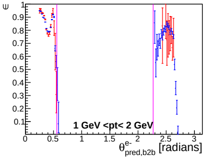


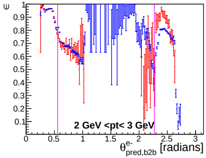
Phase3 pt Tracking Efficiencies As Function Of $\theta_{\mathbf{pred,b2b}}$

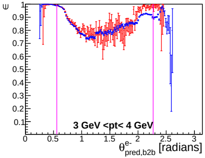
Phase3 MC10

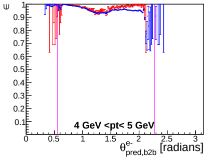
Phase3 Data

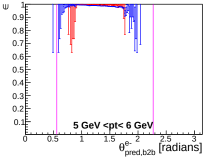
e^-











e^+