

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

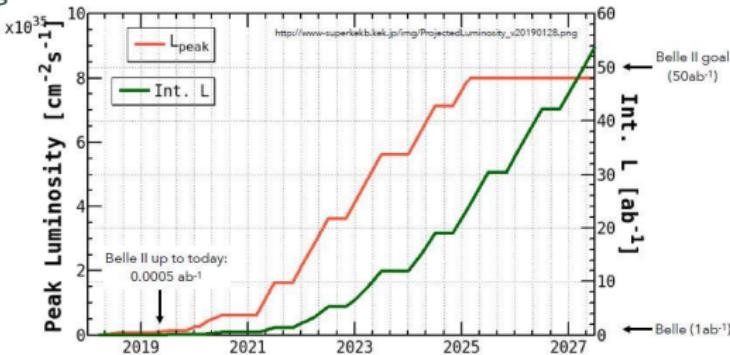
Motivation

- 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

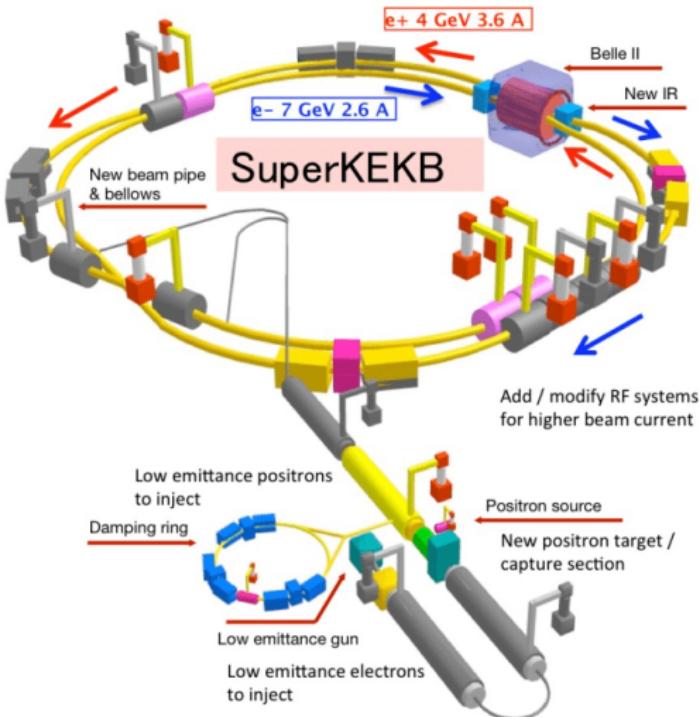
Belle II Schedule And Luminosity Goals

- 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)



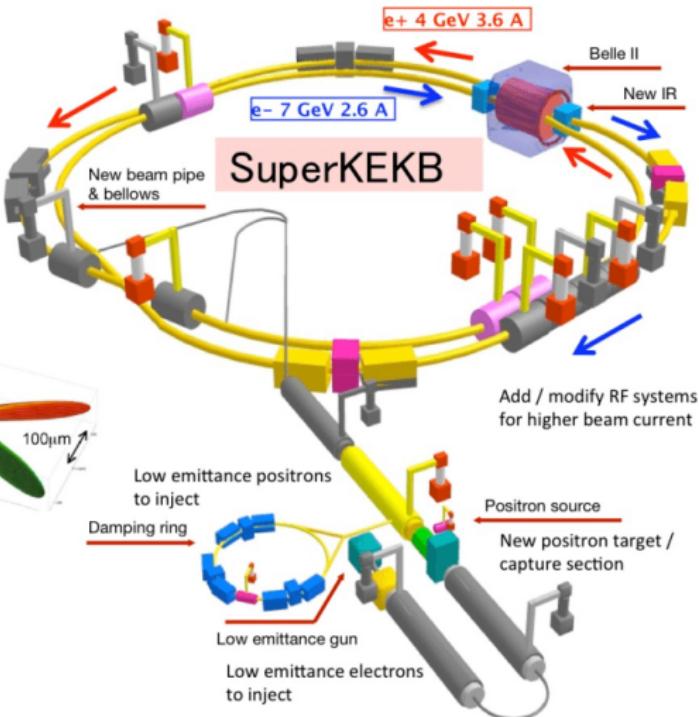
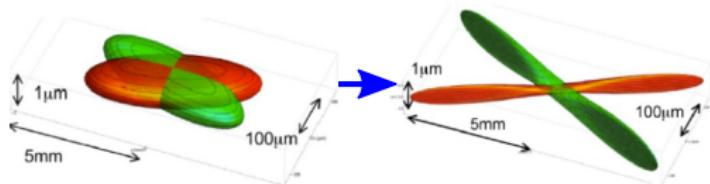
The SuperKEKB e^+e^- collider

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



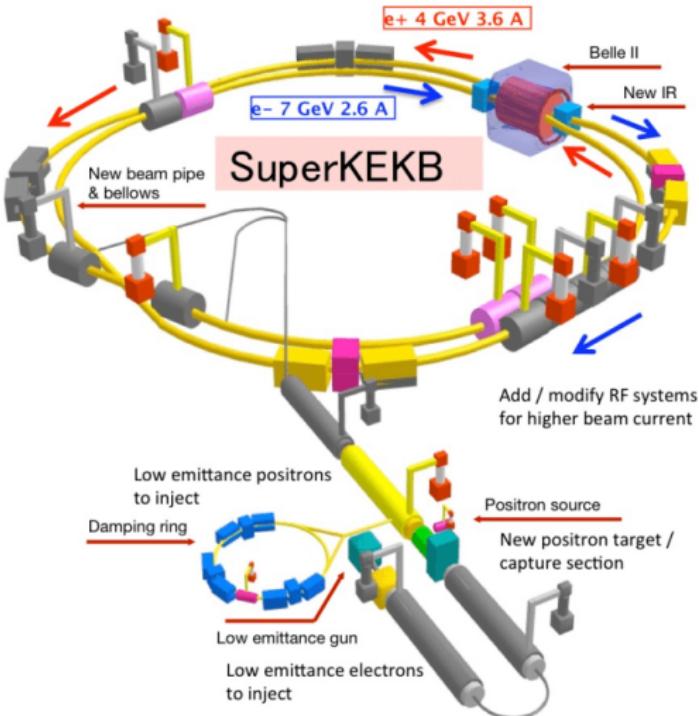
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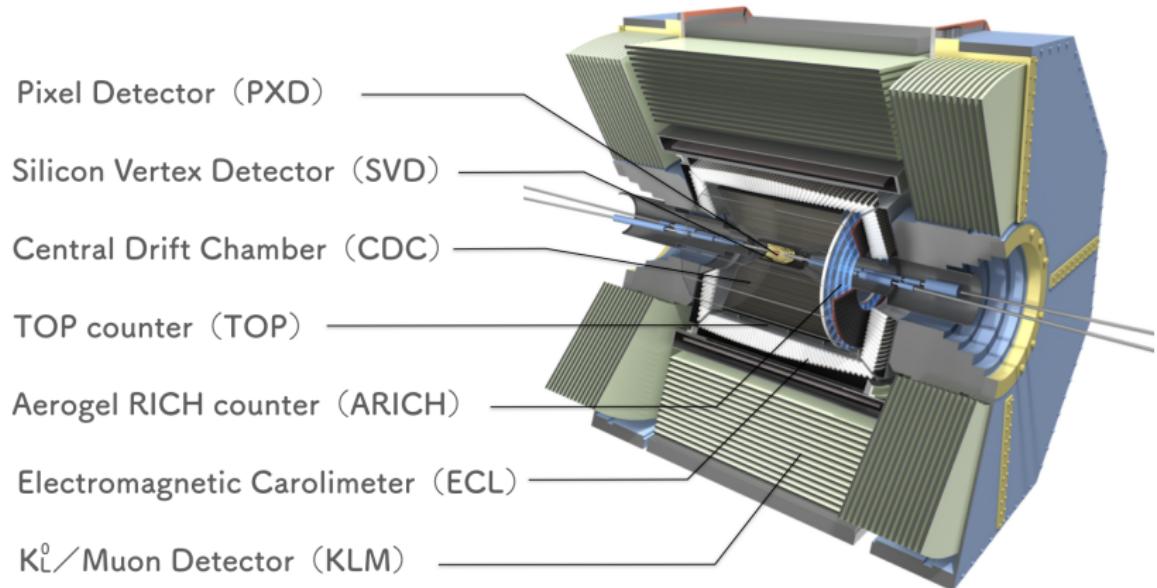


The SuperKEKB e^+e^- collider

- 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
 $\sim 50 \text{ ab}^{-1}$



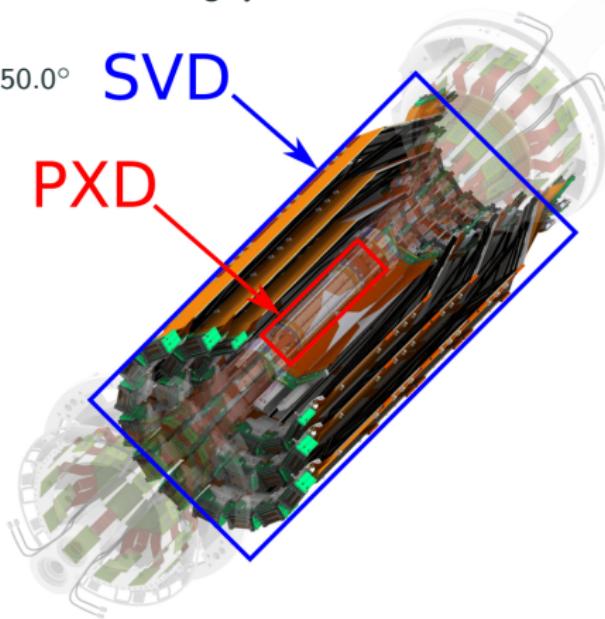
The Belle II Detector



Vertex Detectors

Vertex Detectors:

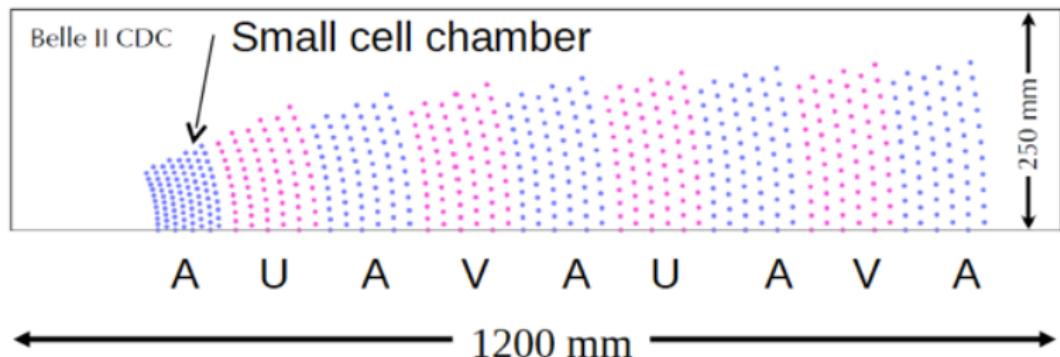
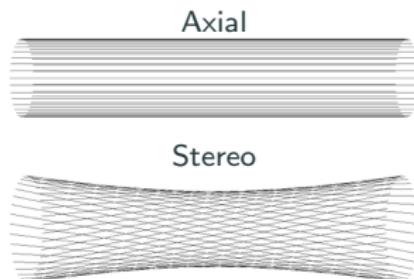
- Consists of Pixel Detector (PXD) and Silicon Vertex Detector (SVD)
- Both detectors consist of multiple ladders of strip detectors
- During phase2, only a fraction of the VXD detectors were installed
- During phase3, the complete SVD and roughly half of the PXD were installed
- Acceptance: $17.0^\circ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



Central Drift Chamber

Central Drift Chamber:

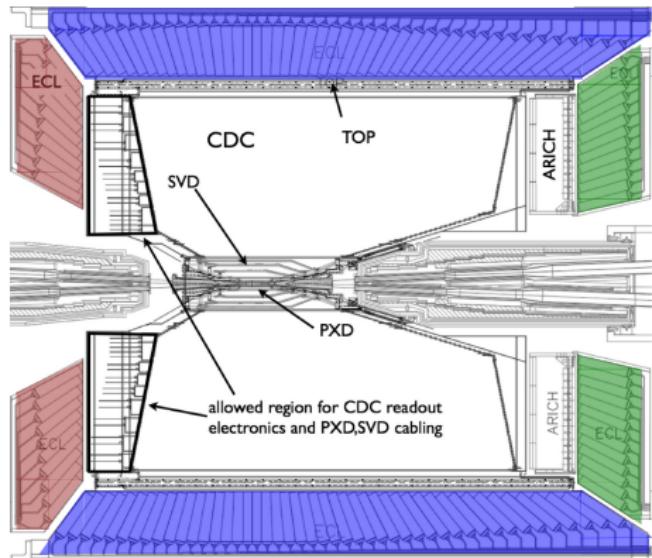
- Consists of 14336 sense wires arranged in 56 layers
- 6 layers are combined to a superlayer (with an exception to innermost superlayer)
- There are 5 axial and 4 stereo superlayers
- The electric field is provided by 42240 field wires
- Charged particles ionize the gas.
The signal is then read out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



Electromagnetic Calorimeter

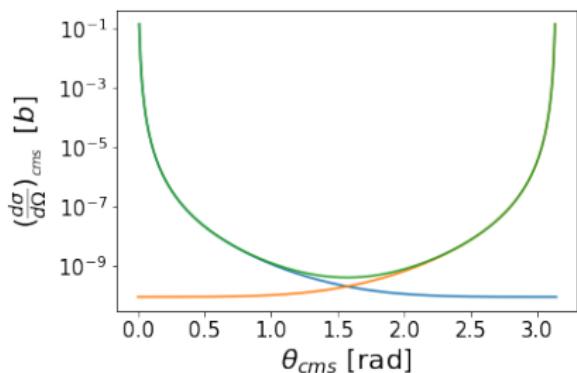
Electromagnetic Calorimeter:

- 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: $12.4^\circ < \theta < 155.1^\circ$

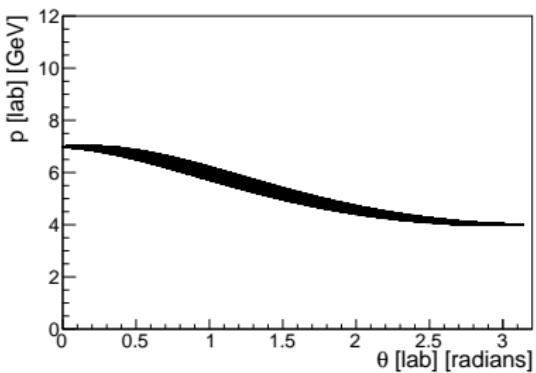
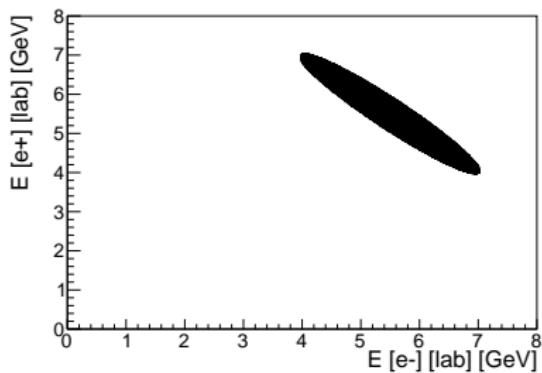


Bhabha Kinematics At Belle II

Bhabha Kinematics At Belle II



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

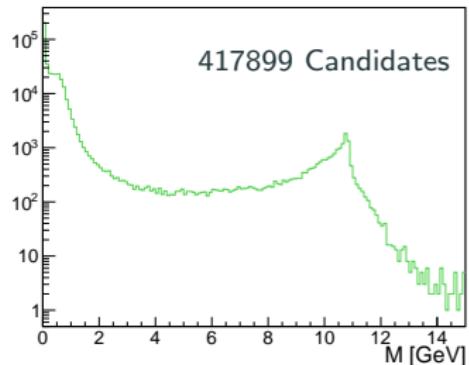
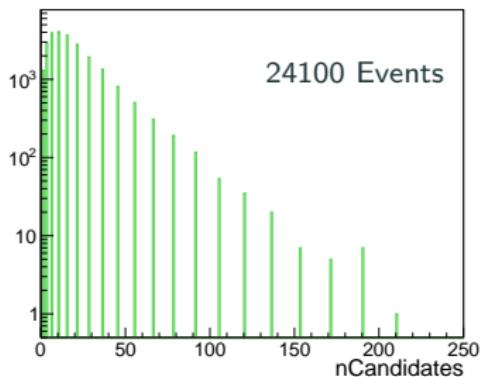


Preparation For Calculating The Tracking Efficiency

Reconstruction Bhabha Events With Basf2

```
1 fillParticleList('gamma:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path=mypath)
2 fillParticleList('e+:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path=mypath)
3
4 reconstructDecay('vpho:gamma -> gamma:all', "", path=mypath)
5 reconstructDecay('vpho:elec -> e+:all', "", path=mypath)
6
7 copyLists(outputListName = 'vpho:ECLObjectUnranked', inputListNames=['vpho:elec', 'vpho:gamma'], path=mypath)
8
9 rankByHighest('vpho:ECLObjectUnranked', 'daughter(0,clusterE)', path=mypath)
10 cutAndCopyList('vpho:ECLObject', 'vpho:ECLObjectUnranked', "", path=mypath)
11
12 reconstructDecay('vpho:bhabha -> vpho:ECLObject vpho:ECLObject', "", path=mypath)
13
14 variablesToNtuple('vpho:bhabha', variables, treename = 'vpho.bhabha', filename = output.root, path=mypath)
```

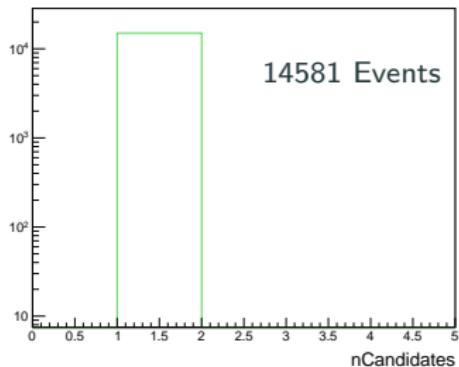
Single phase2 MC10 Bhabha file



Introducing Cuts

- $8 \text{ GeV} < M < 12 \text{ GeV}$
- Exactly 2 clusters with at least 3.5 GeV per event and one cluster has to have at least 4.5 GeV
- Number of reconstructed tracks per event < 7
- Total energy in the ECL $< 15 \text{ GeV}$

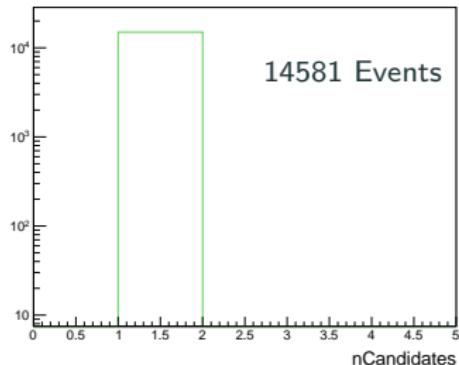
Single phase2 MC10 Bhabha file



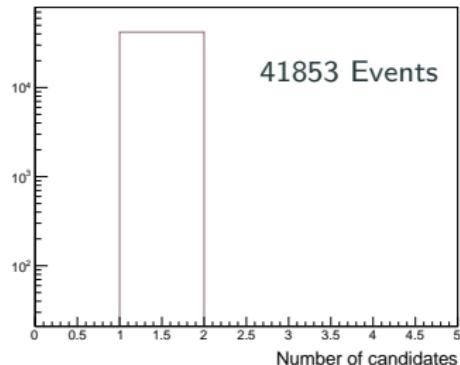
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Single phase2 MC10 Bhabha file



Single phase2 data file

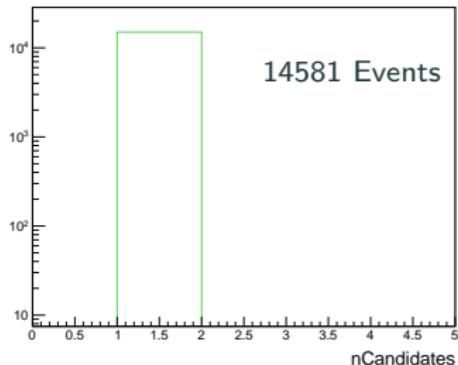


Introducing Cuts

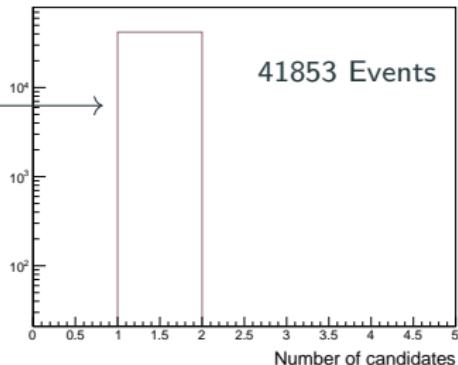
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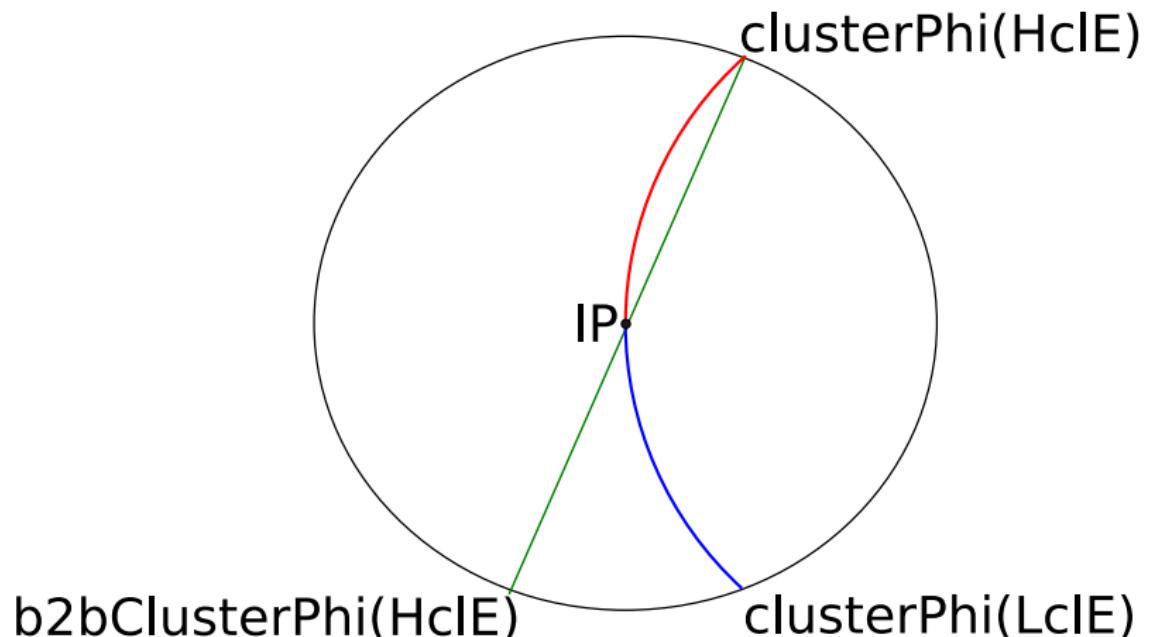
Also contains $ee \rightarrow \gamma\gamma$ events

Single phase2 MC10 Bhabha file

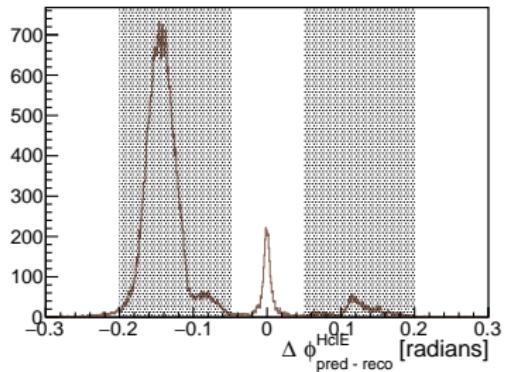
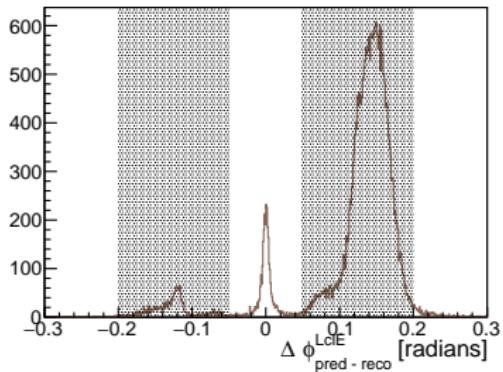
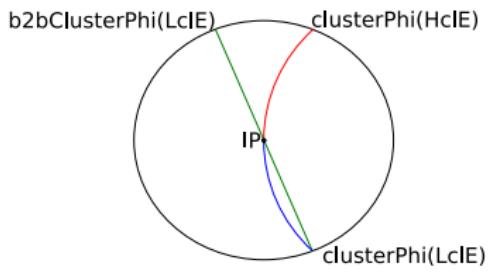
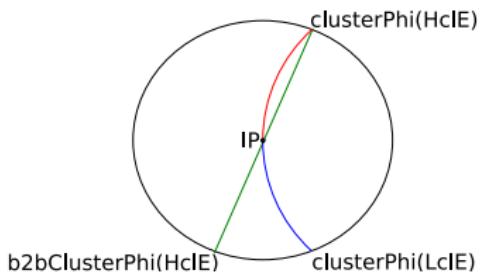


Single phase2 data file

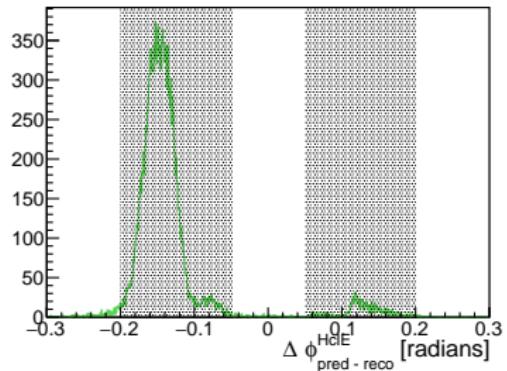
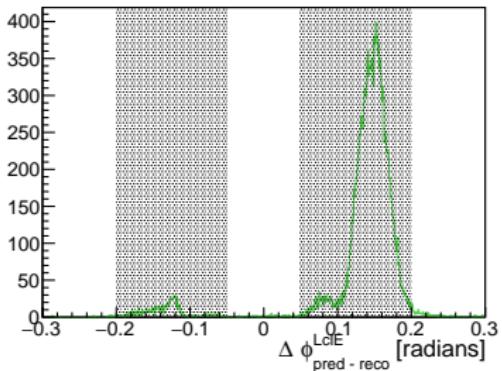
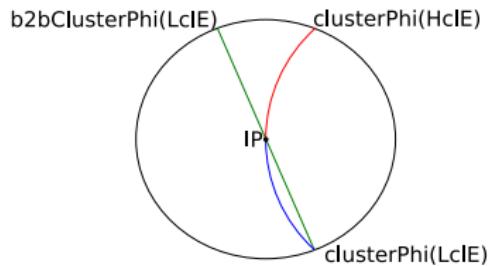
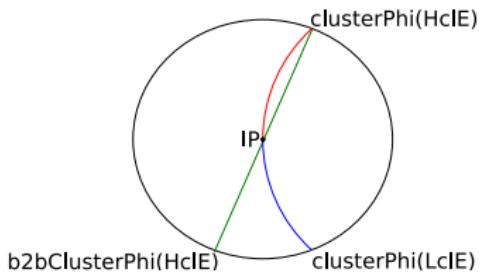




Bhabha Event Selection



Bhabha Event Selection



Trigger

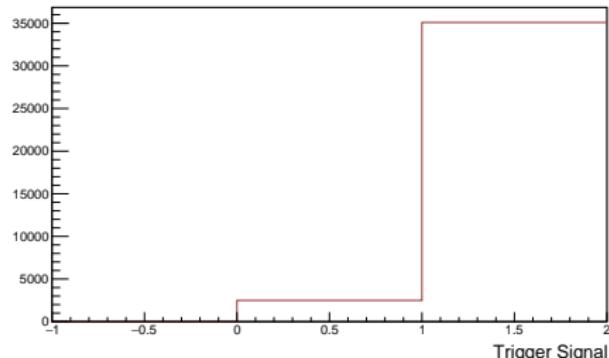
We need to be sure that a trigger signal is coming from the ECL. Otherwise there could be a bias

→ 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



More Events

Dividing The ECL In Areas Of Interest

As function of azimuthal angle

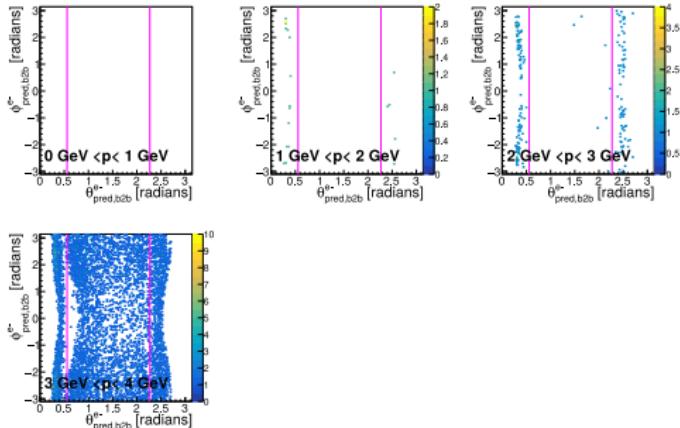
$\phi_{\text{pred},\text{b2b}}$

$p(e^-)$

Forward End-Cap

Barrel

Backward End-Cap



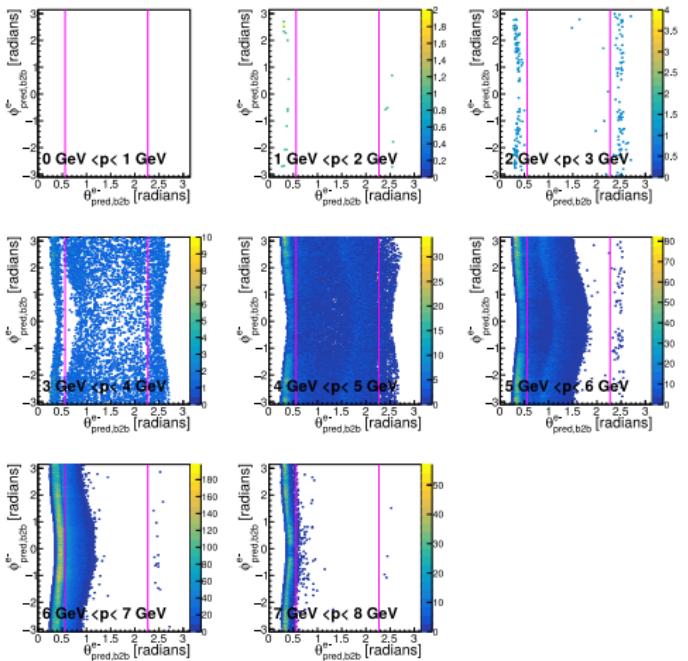
Dividing The ECL In Areas Of Interest

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	/



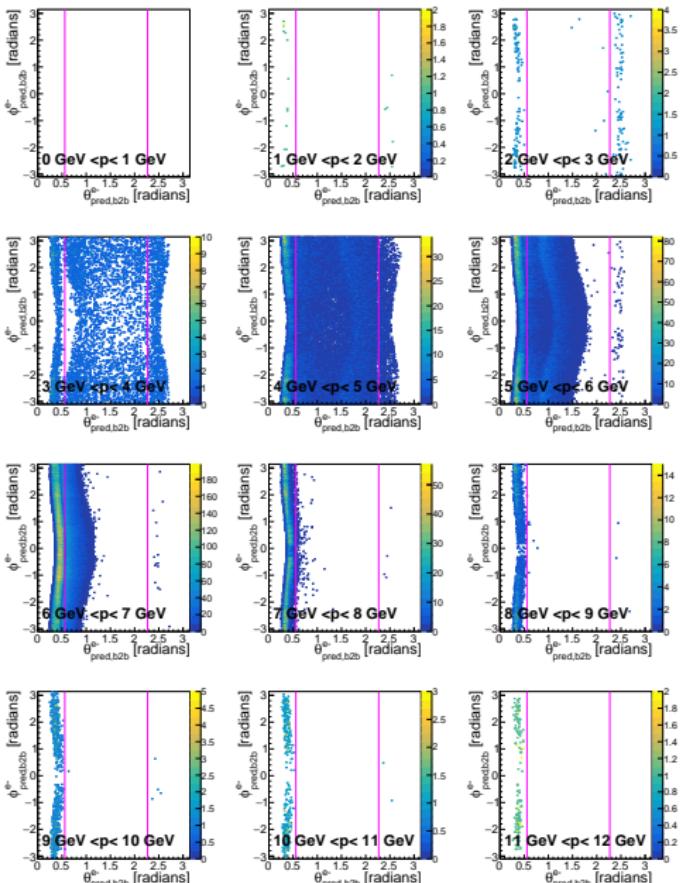
Dividing The ECL In Areas Of Interest

As function of azimuthal angle

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

$p(e^-)$

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

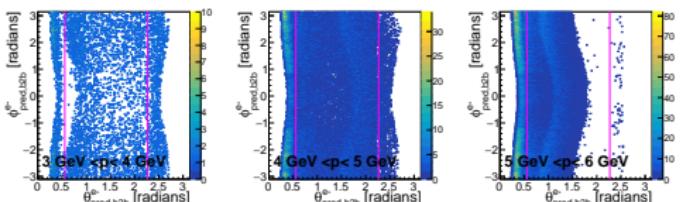
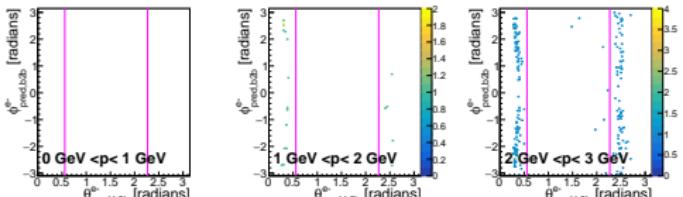


Dividing The ECL In Areas Of Interest

As function of azimuthal angle

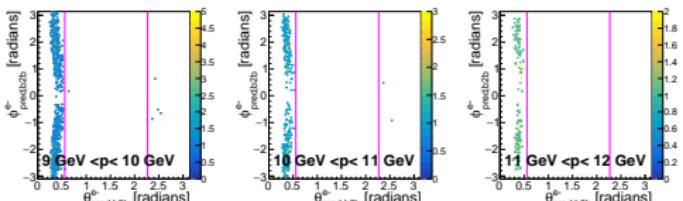
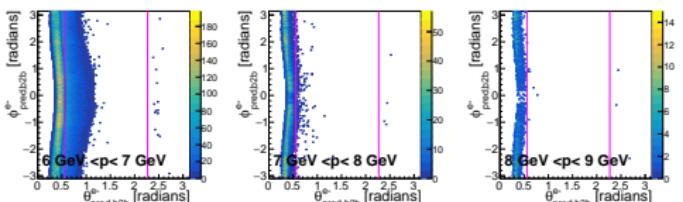
$$\phi_{\text{pred},\text{b2b}}$$

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

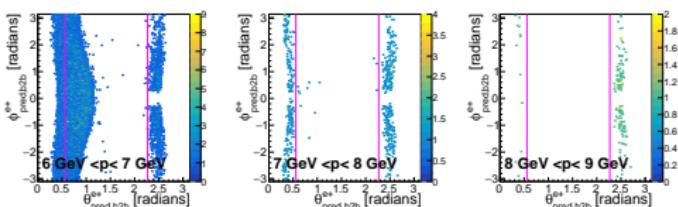
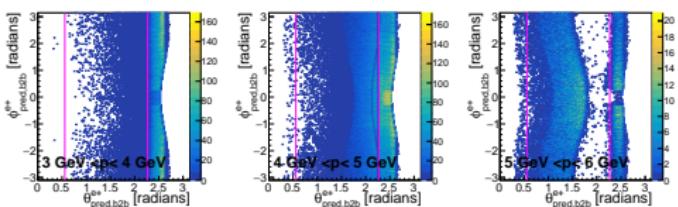
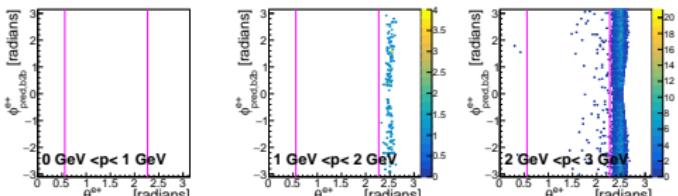
$$\phi_{\text{pred},\text{b2b}}$$

$$p(e^-)$$

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

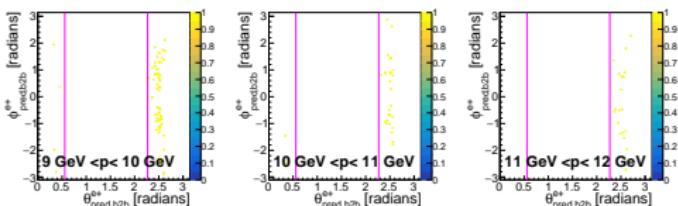


As function of polar angle $\theta_{\text{pred},\text{b2b}}$

$$p$$

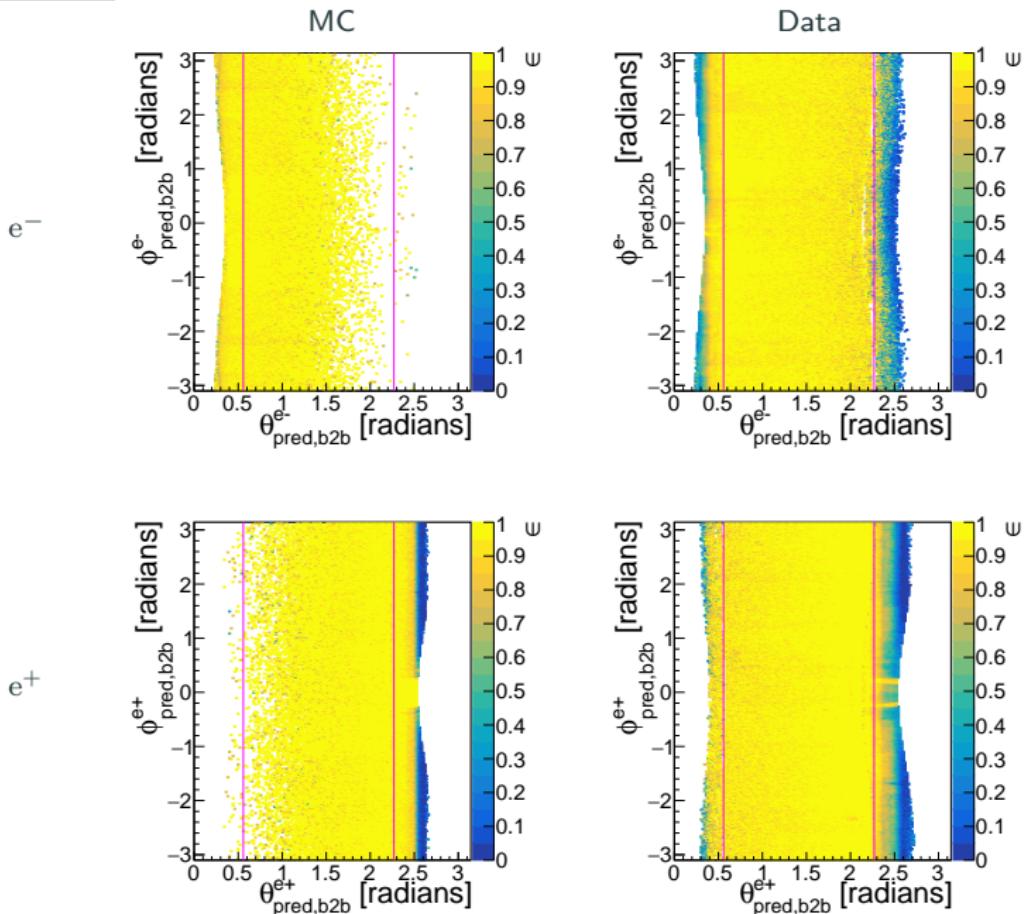
$$e^- \quad 4 \text{ GeV} - 9 \text{ GeV}$$

$$e^+ \quad 2 \text{ GeV} - 7 \text{ GeV}$$



Phase2 Tracking Efficiencies

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

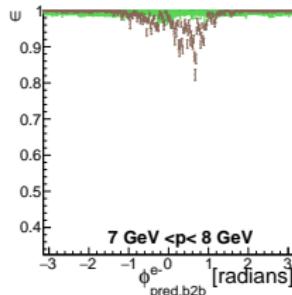
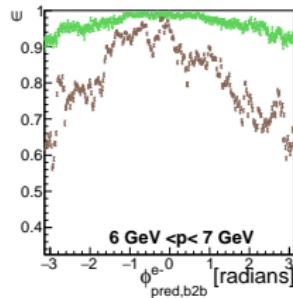
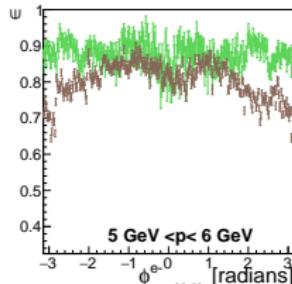
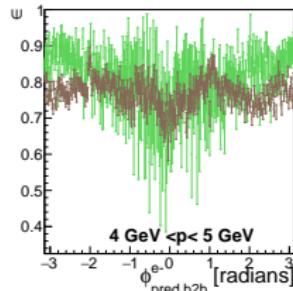


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

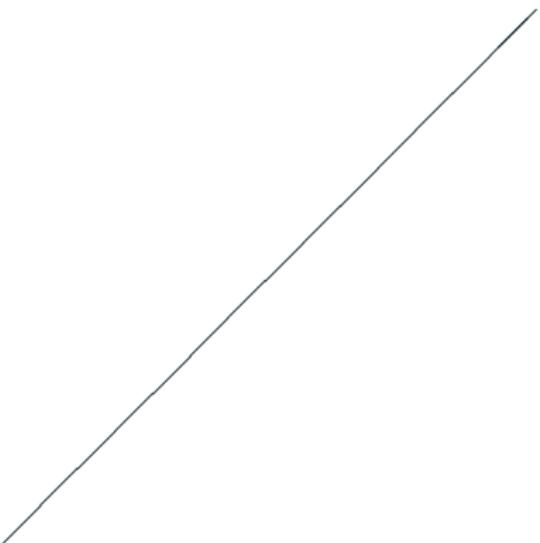
Phase2 MC10

Phase2 Data

e⁻



e⁺

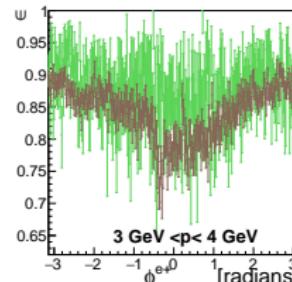
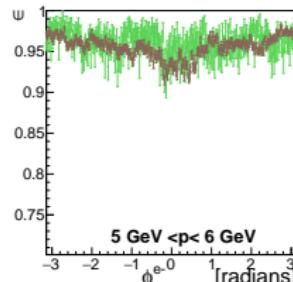
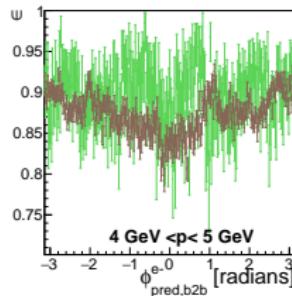


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

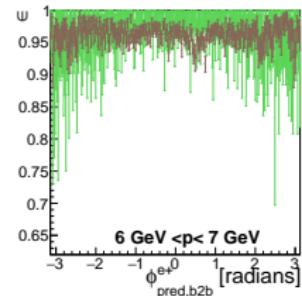
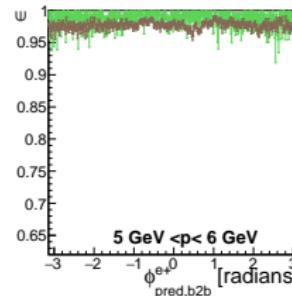
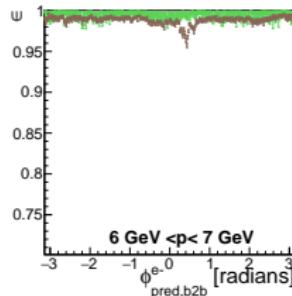
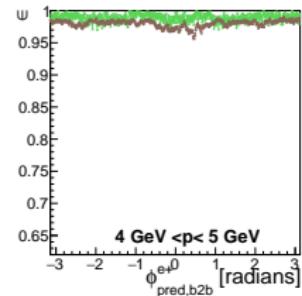
Phase2 MC10

e⁻

Phase2 Data



e⁺

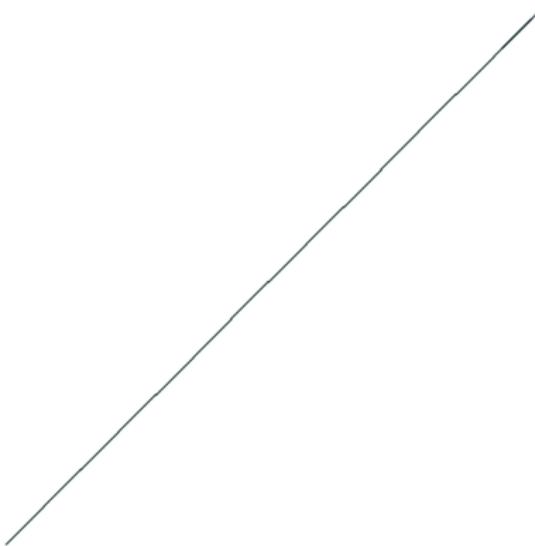


Phase2 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

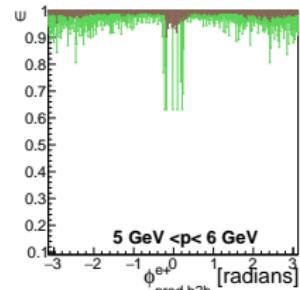
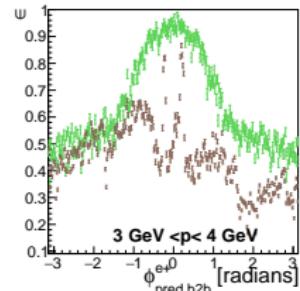
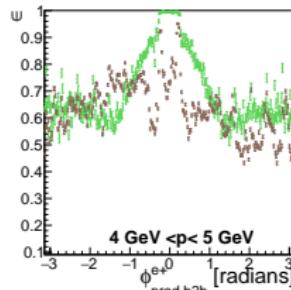
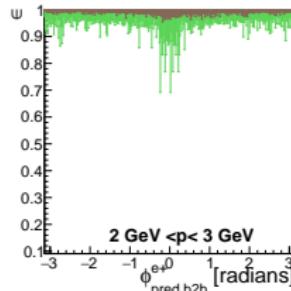
Phase2 MC10

e^-

Phase2 Data



e^+

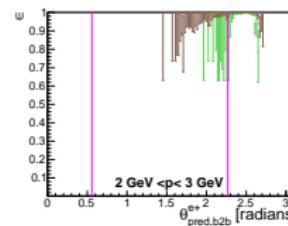
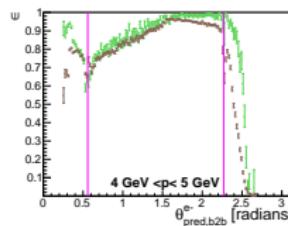
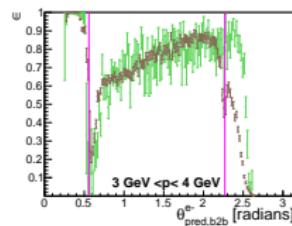


Phase2 Tracking Efficiencies As Function Of $\theta_{\text{pred,b2b}}$

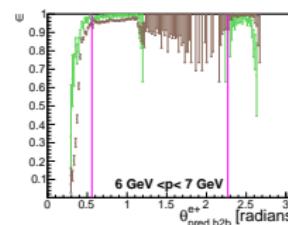
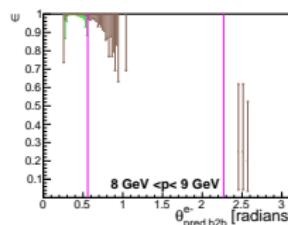
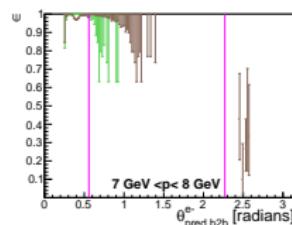
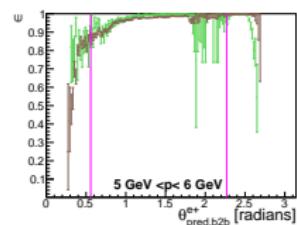
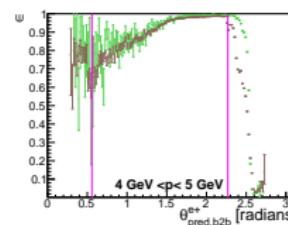
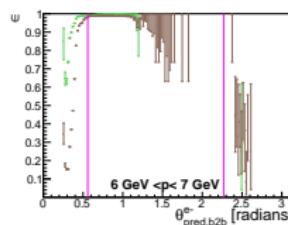
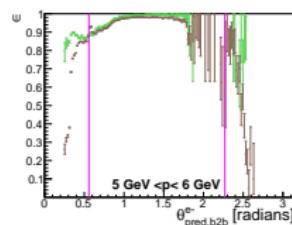
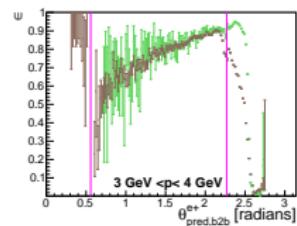
Phase2 MC10

e^-

Phase2 Data

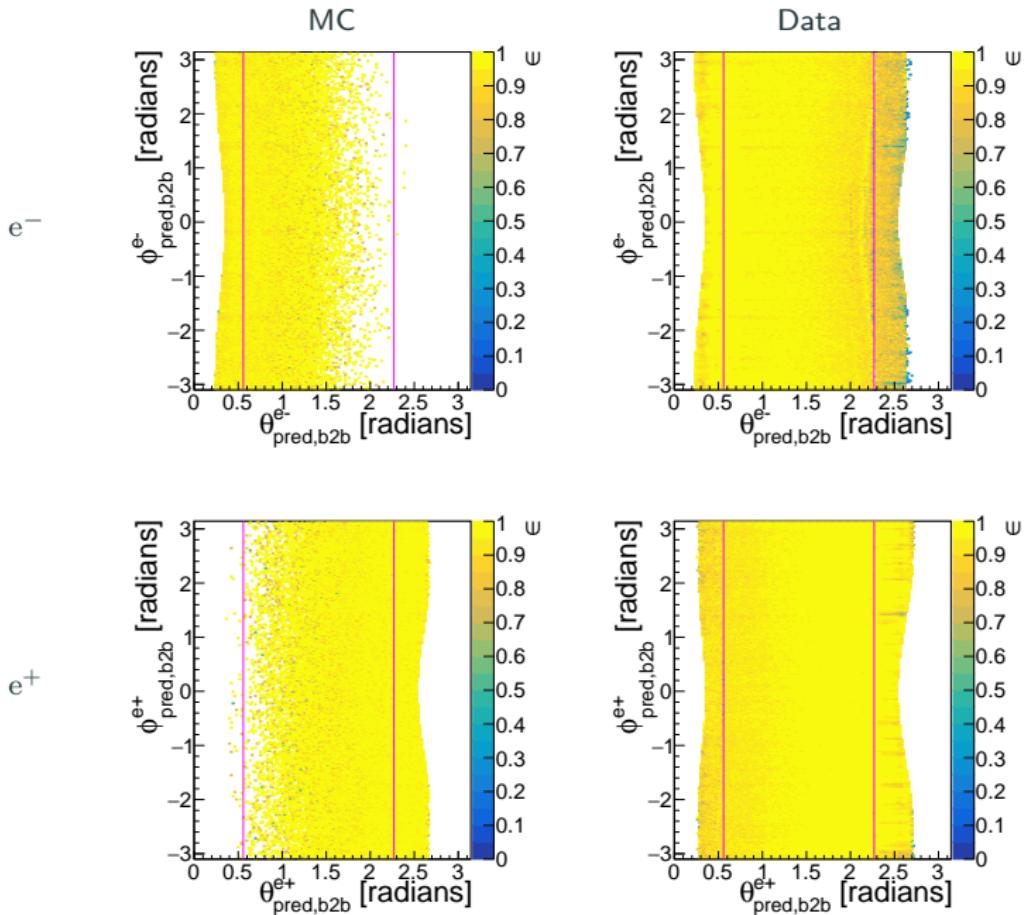


e^+



Phase3 Tracking Efficiencies

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

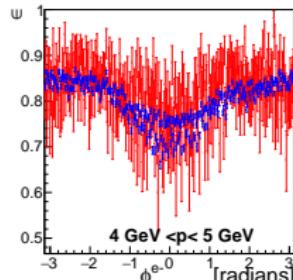


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Forward End-Cap

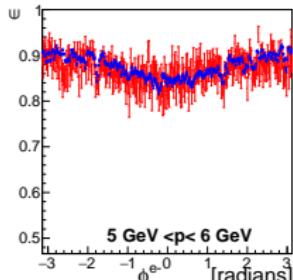
Phase3 MC10

Phase3 Data

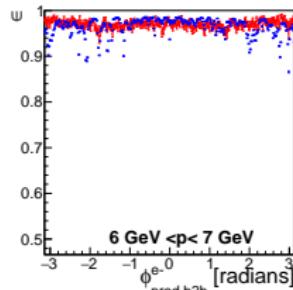
e⁻



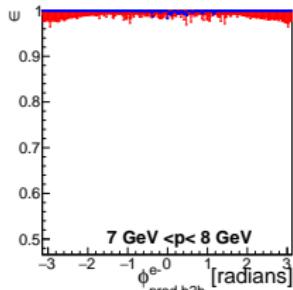
$4 \text{ GeV} < p < 5 \text{ GeV}$



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

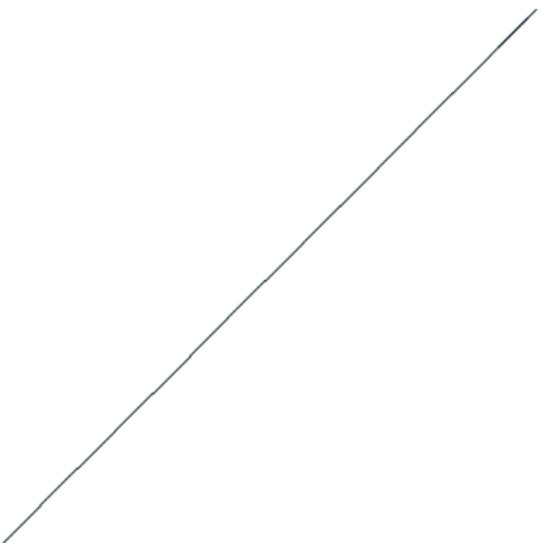


$6 \text{ GeV} < p < 7 \text{ GeV}$



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

e⁺

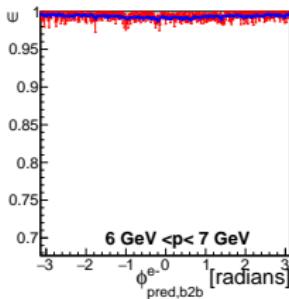
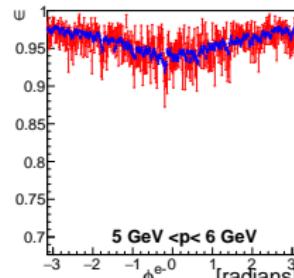
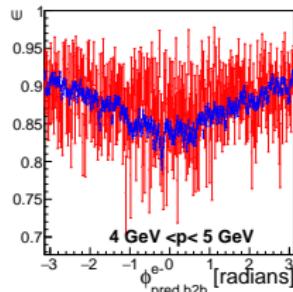


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Barrel

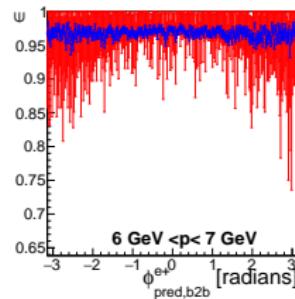
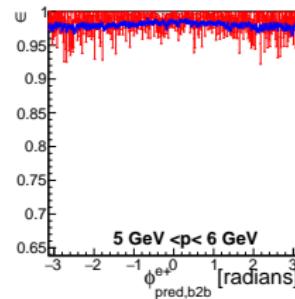
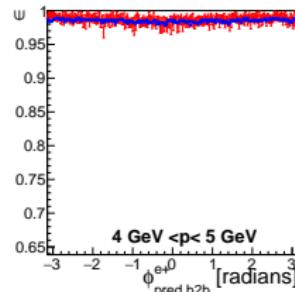
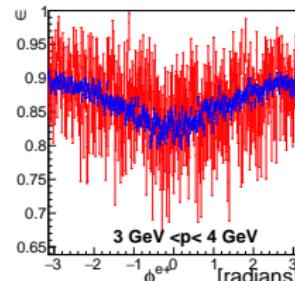
Phase3 MC10

e⁻

Phase3 Data



e⁺

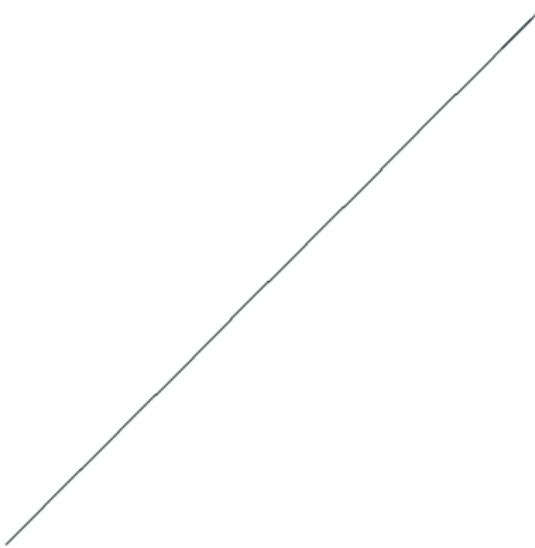


Phase3 Tracking Efficiencies As Function Of $\phi_{\text{pred,b2b}}$; Backward End-Cap

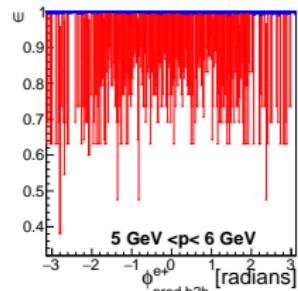
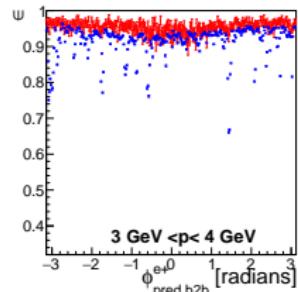
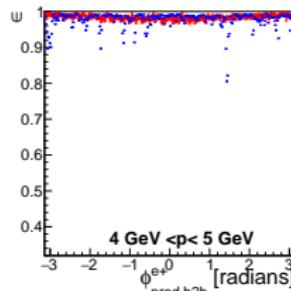
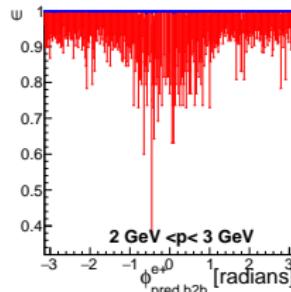
Phase3 MC10

Phase3 Data

e^-



e^+



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

Phase3 MC10

Phase3 Data

