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

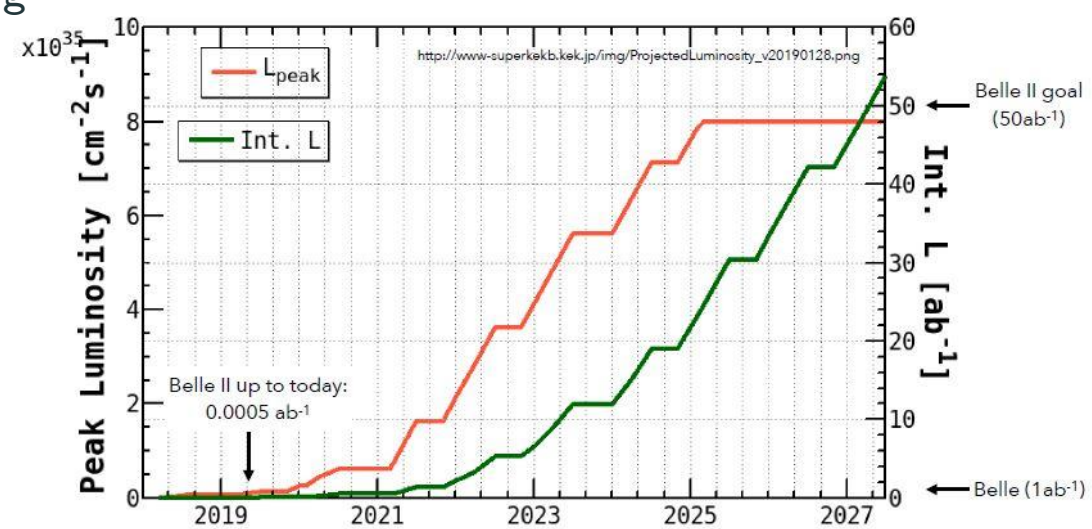
Motivation

- 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
  $\rightarrow$ a tracking efficiency can be calculated

Overview Of The Belle II Experiment

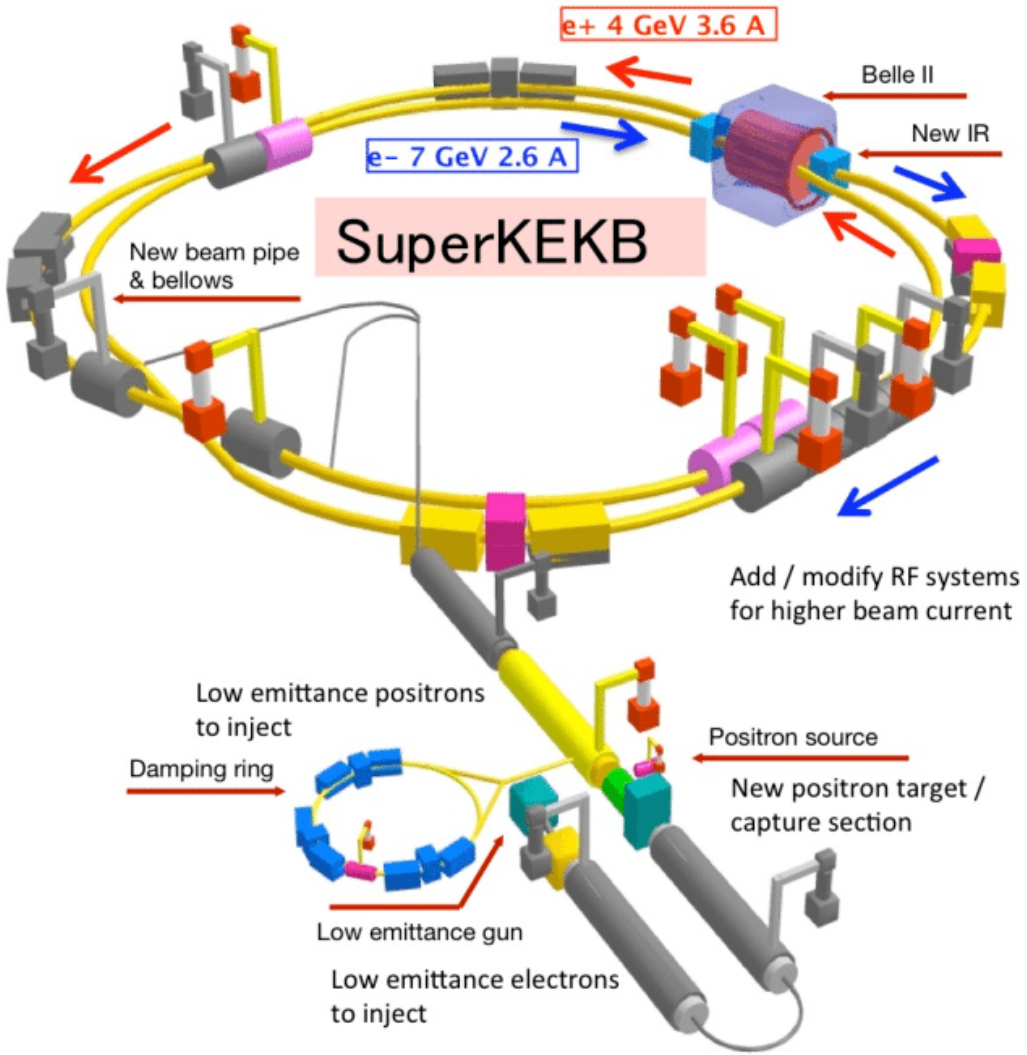
Belle II Schedule And Luminosity Goals

- 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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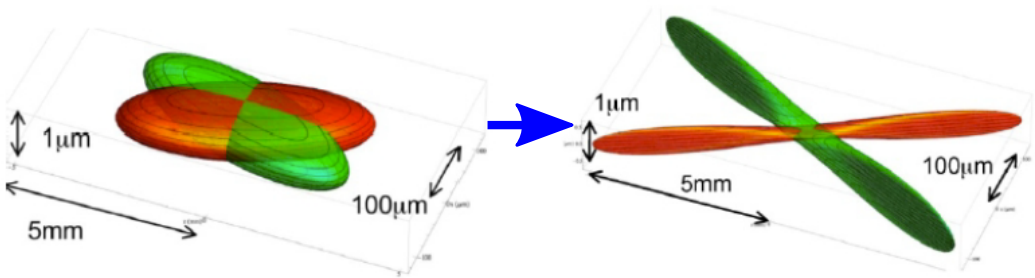

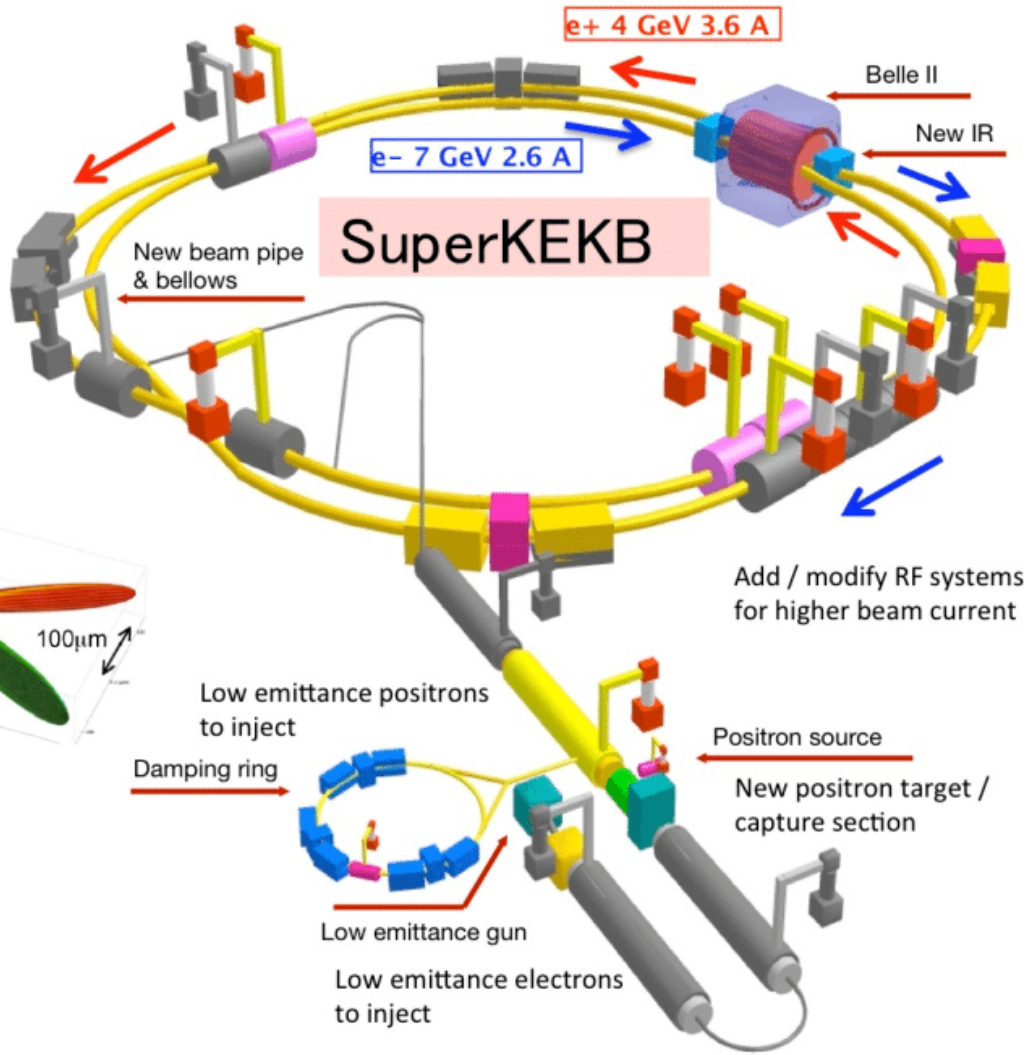

The SuperKEKB $\mathrm{e^+e^-}$ collider

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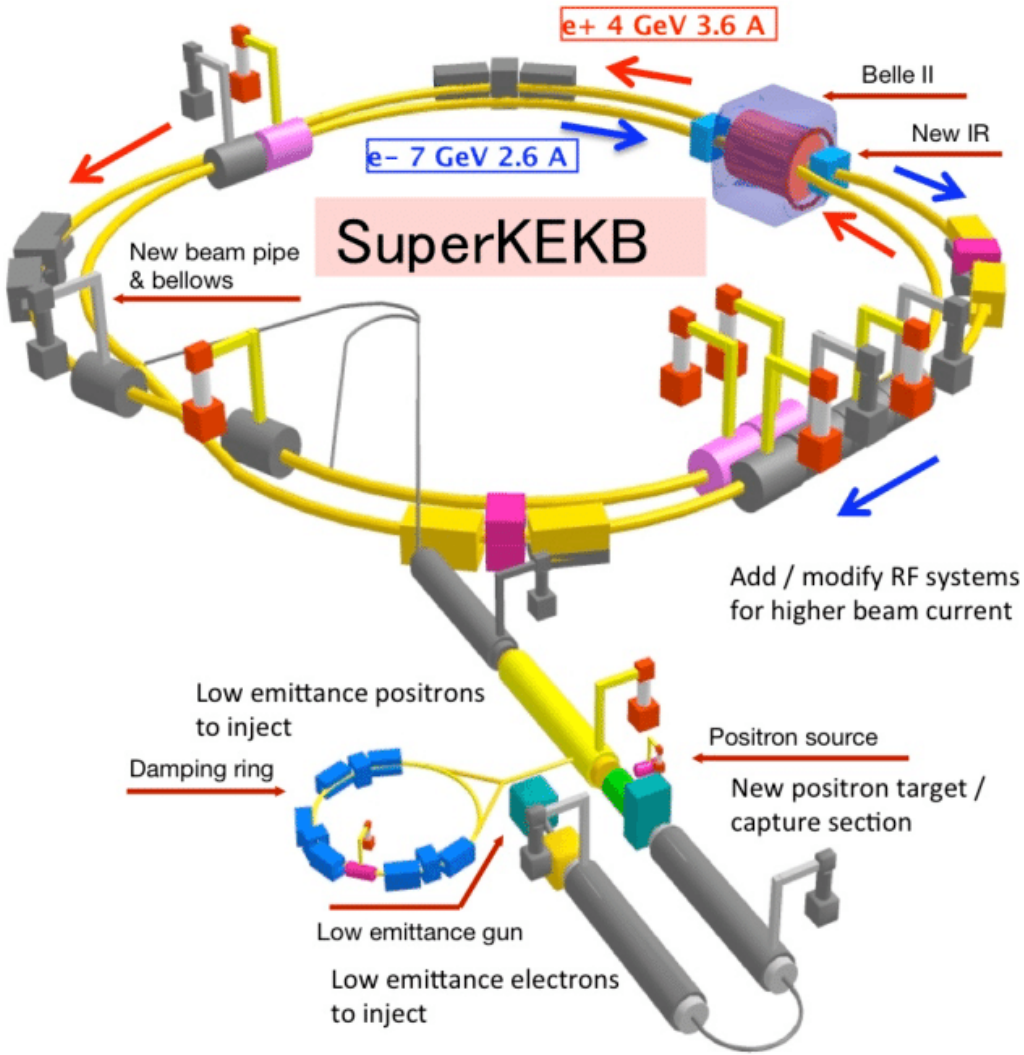
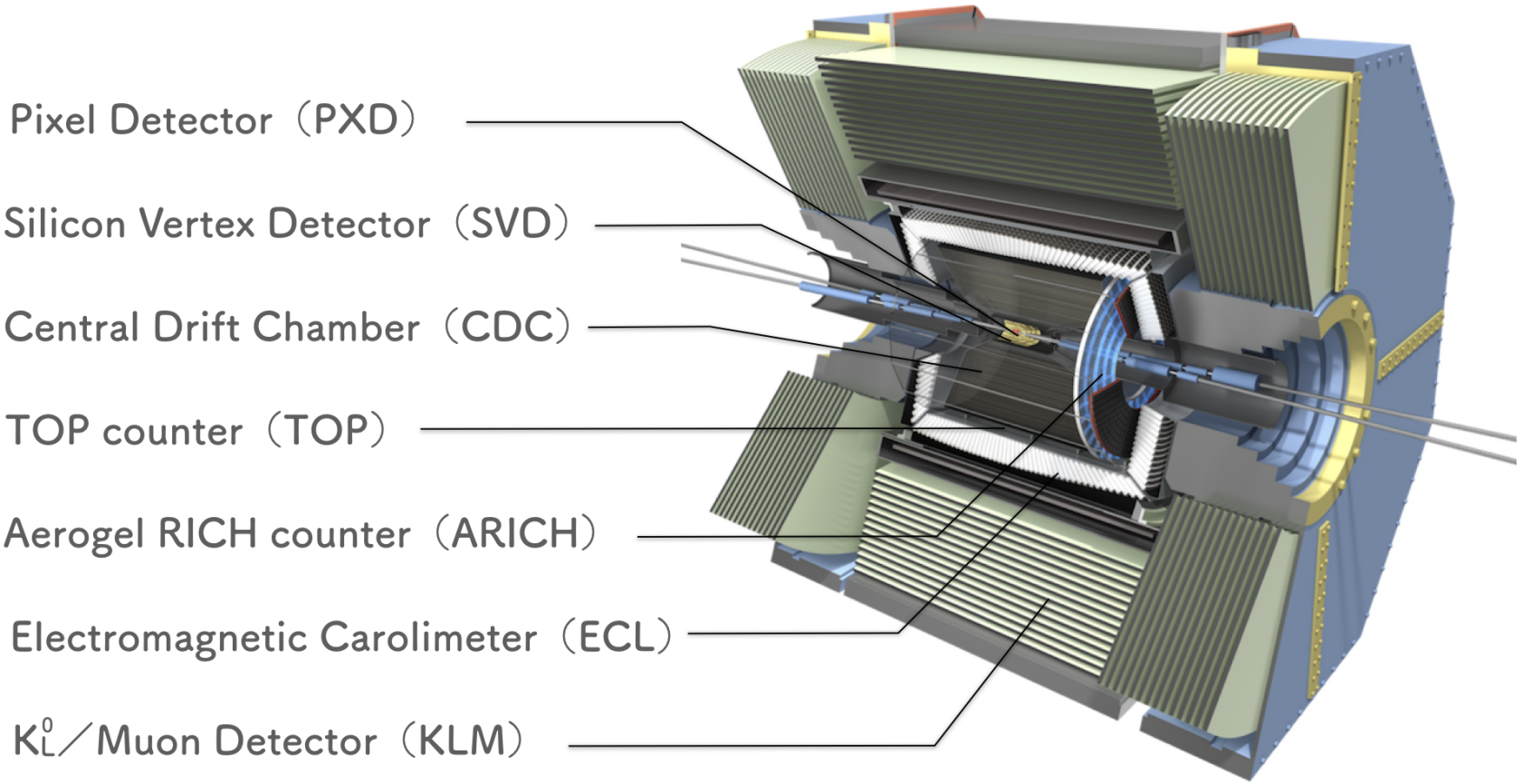
- Center-of-mass close to $\Upsilon(4\mathrm{S})$ $\sim 10.5\,\mathrm{GeV}$
- Upgrade of the KEKB collider:
  - Larger beam current
  - Reduced beam size
- $\rightarrow$ Luminosity increase x40
- Designed peak luminosity of $8 \cdot 10^{35}\,\mathrm{cm^{-2}s^{-1}}$
- Planned data sample corresponding to a recorded integrated luminosity of $\sim 50\,\mathrm{ab^{-1}}$



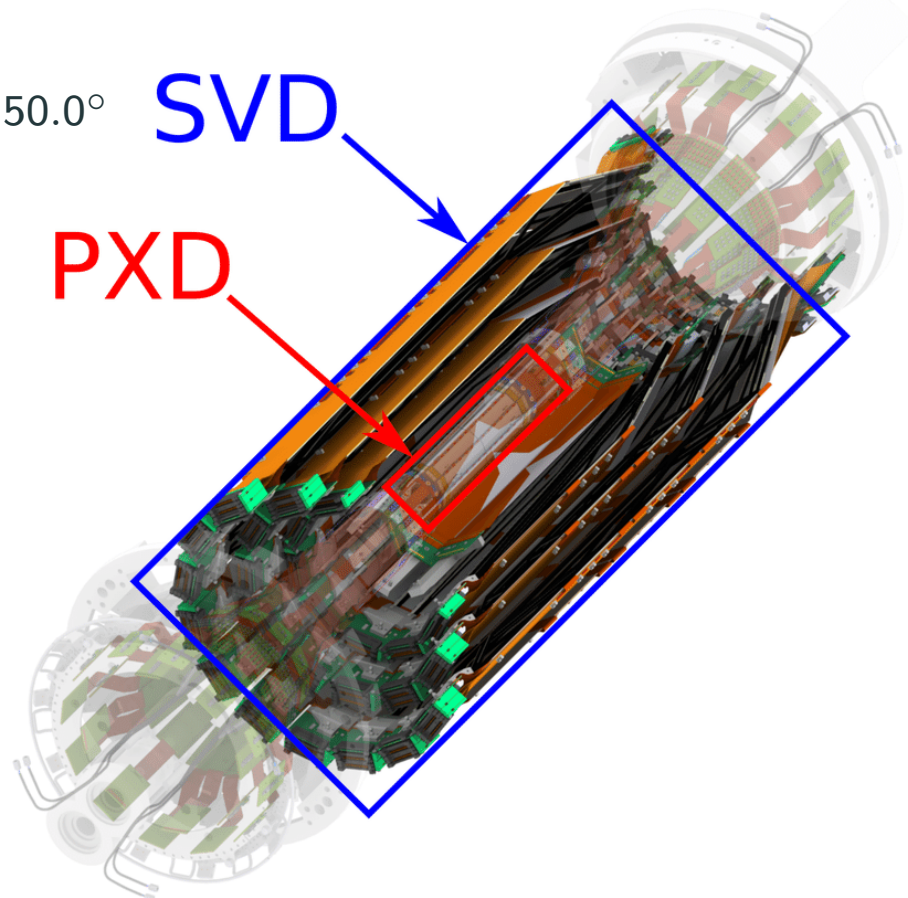
The Belle II Detector



Vertex Detectors

Vertex Detectors:

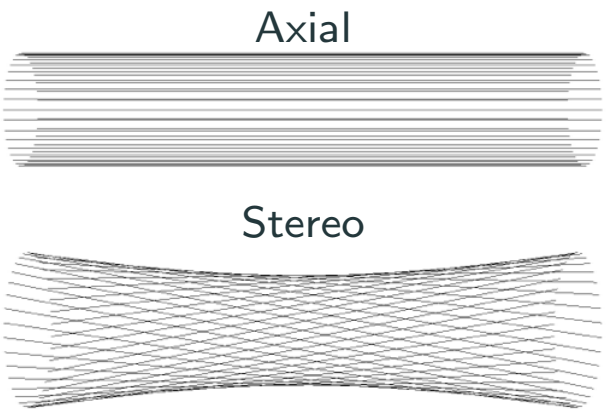
- Consists of Pixel Detector (PXD) and Silicon Vertex Detector (SVD)
- Both detectors consist of multiple ladders of strip detectors
- During phase2, only a fraction of the VXD detectors were installed
- During phase3, the complete SVD and roughly half of the PXD were installed
- Acceptance: $17.0° 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

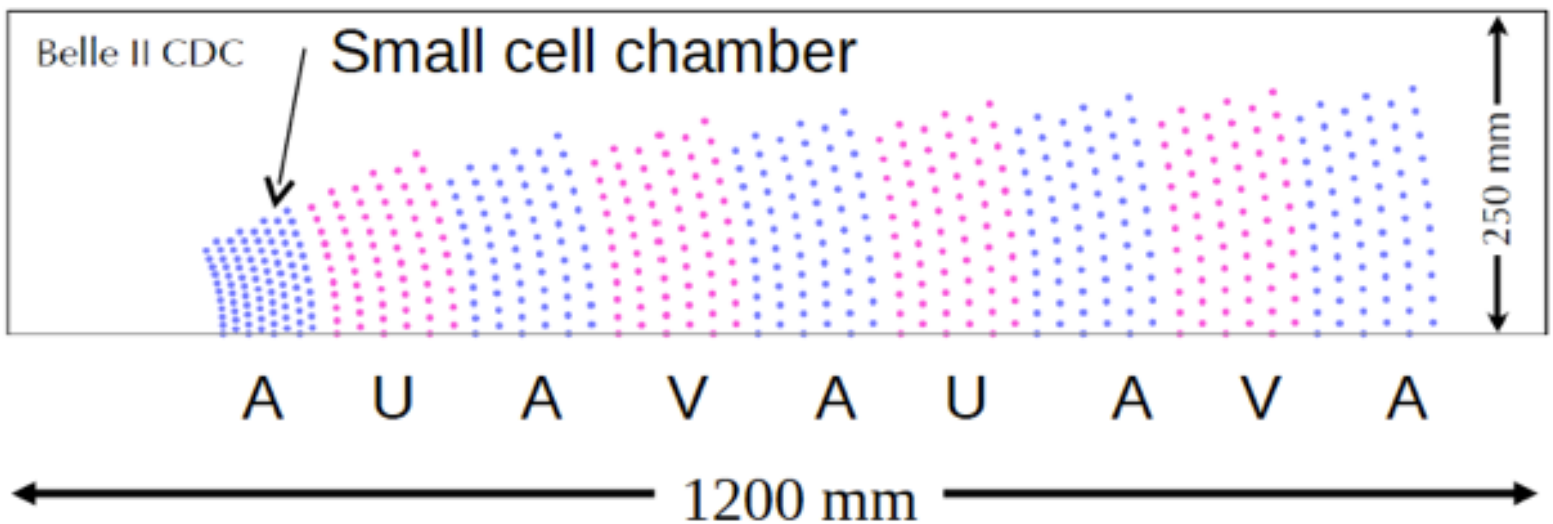


Central Drift Chamber

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 sens wires
- Acceptance: $17.0° < \theta < 150.0°$

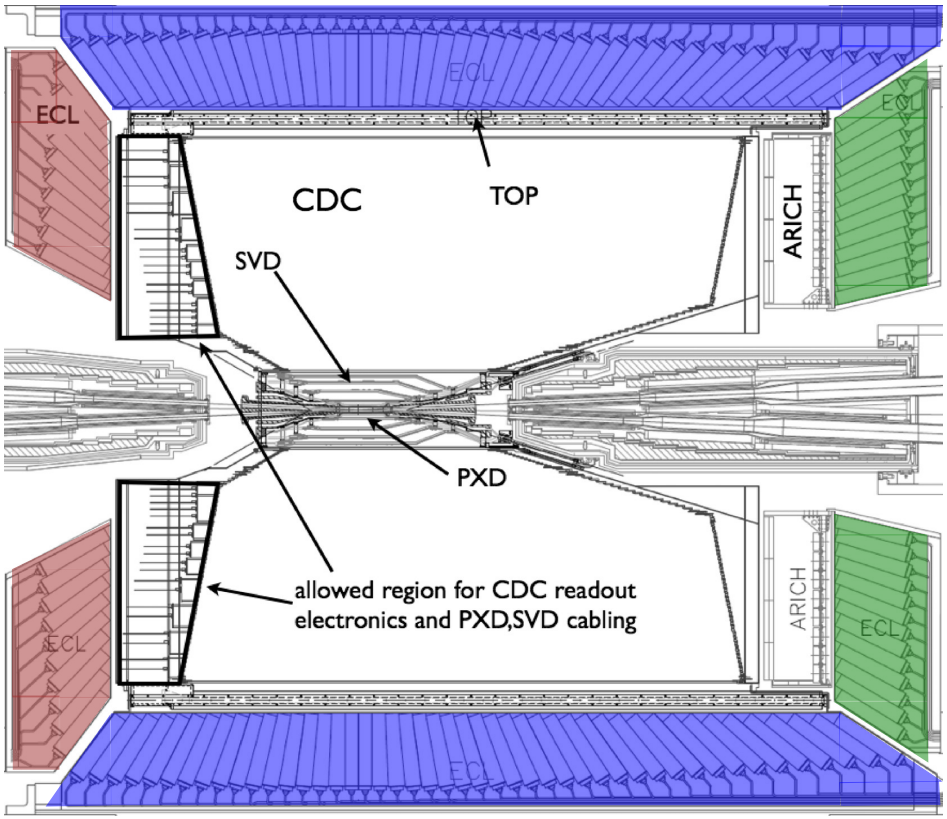




Electromagnetic Calorimeter

Electromagnetic Calorimeter:

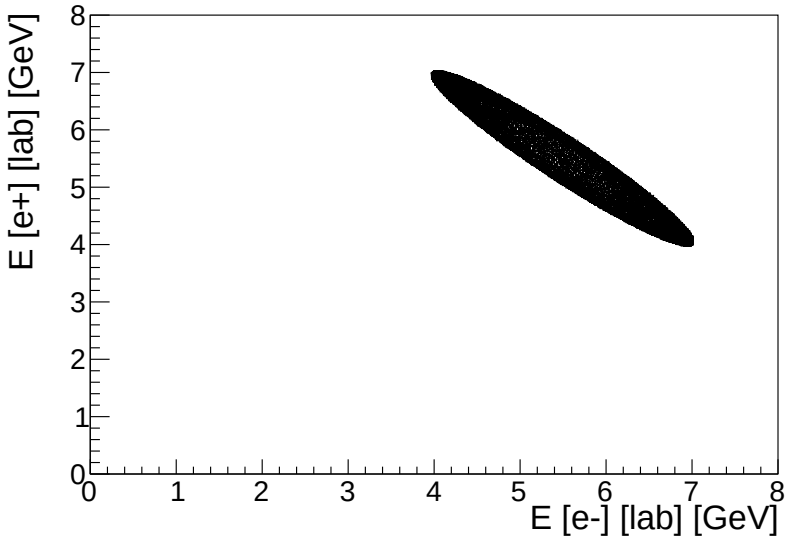
- Consists of 8936 CsI(Tl) crystals
- Separation in barrel, forward end cap and backward end cap
- There are two $\sim 1^\circ$ wide gaps at transition between the regions
- Main tasks:
  - High efficiency photon detection, plus determination of their energy and angular coordinates
  - Electron identification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

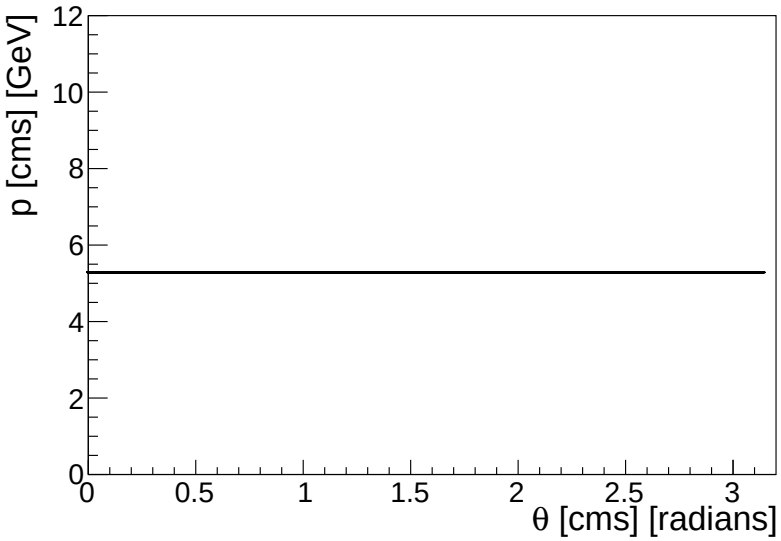


Bhabha Kinematics At Belle II

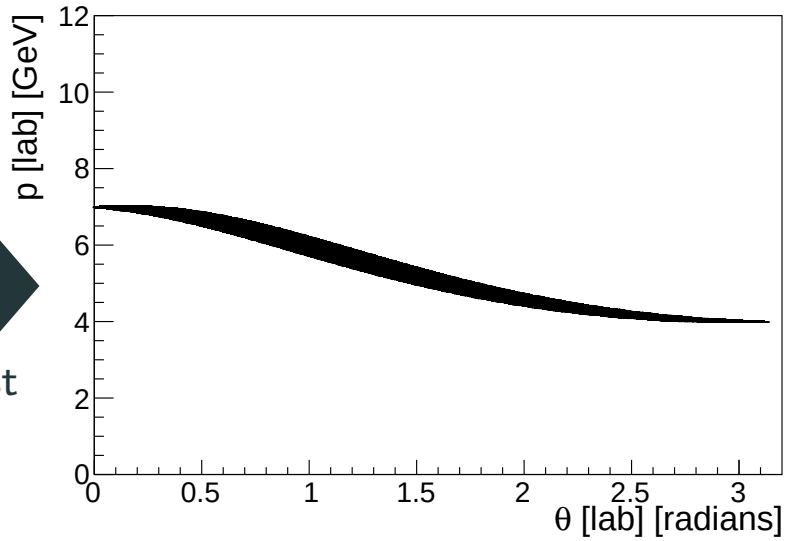
Bhabha Kinematics At Belle II

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





Boost



Preparation For Calculating The Tracking Efficiency

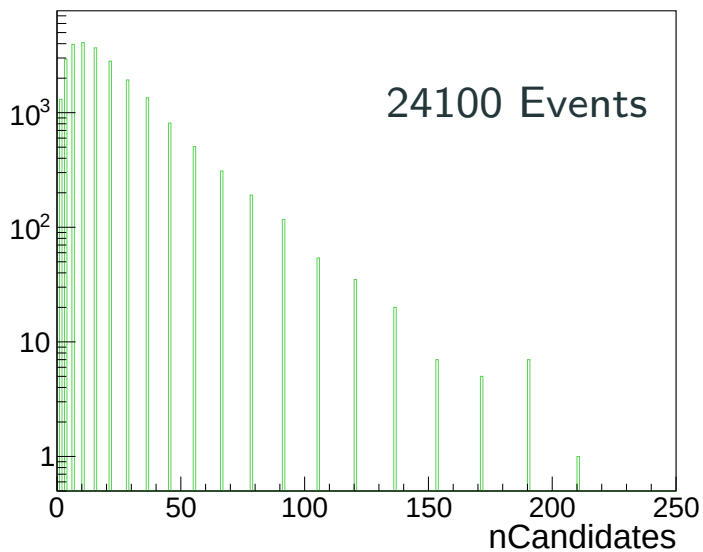
Reconstruction Bhabha Events With Basf2

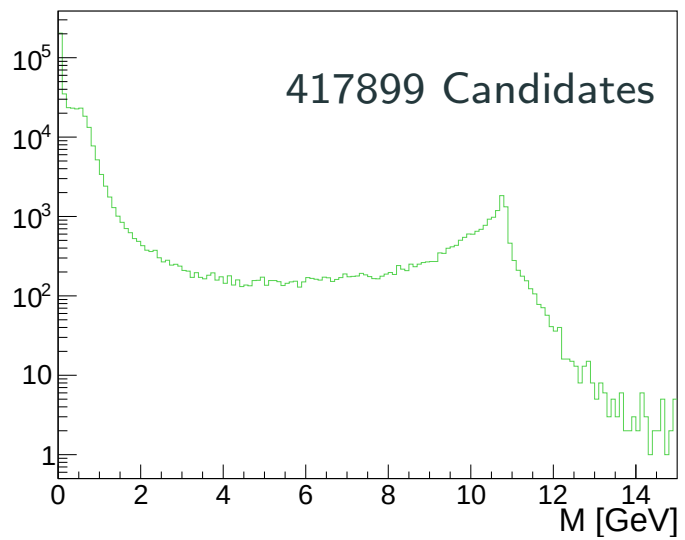
```
1  fillParticleList('gamma:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path=mypath)
   fillParticleList('e+:all', 'clusterE > 0.01 and 0.296706 < theta < 2.61799', path=mypath)
3
   reconstructDecay('vpho:gamma -> gamma:all', '', path=mypath)
5  reconstructDecay('vpho:elec -> e+:all', '', path=mypath)

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

9  rankByHighest('vpho:ECLObjectUnranked', 'daughter(0,clusterE)', path=mypath)
   cutAndCopyList('vpho:ECLObject', 'vpho:ECLObjectUnranked', '', path=mypath)
11
   reconstructDecay('vpho:bhabha -> vpho:ECLObject vpho:ECLObject', '', path=mypath)
13
   variablesToNtuple('vpho:bhabha', variables, treename = 'vpho_bhabha', filename = output.root, path=mypath)
```

Single phase2 MC10 Bhabha file

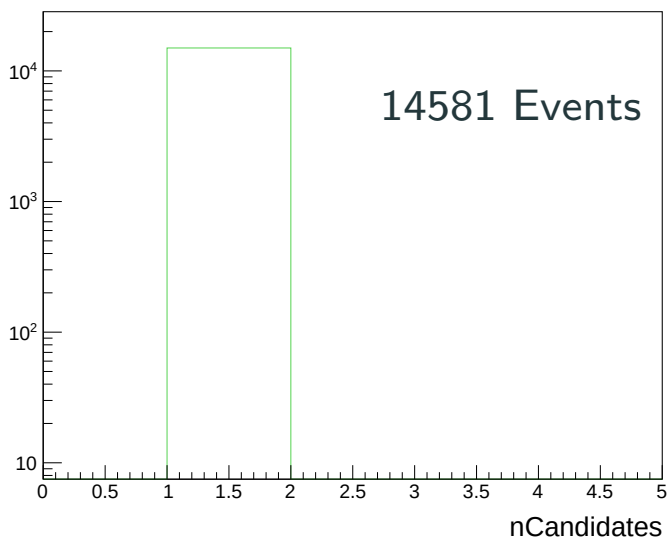




Introducing Cuts

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

Single phase2 MC10 Bhabha file



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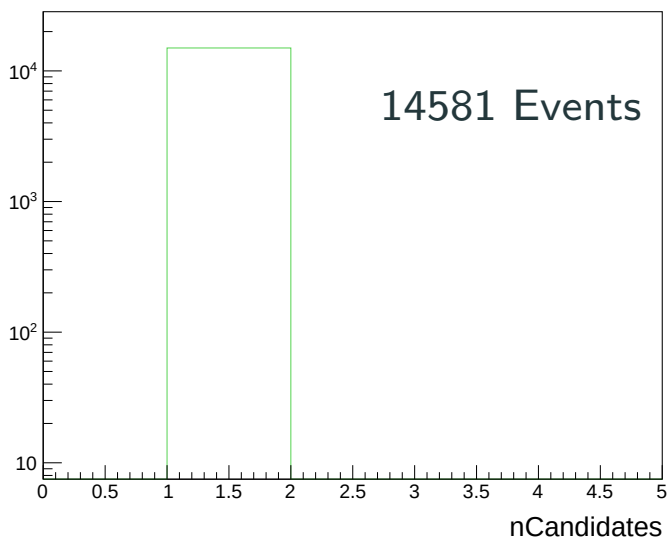
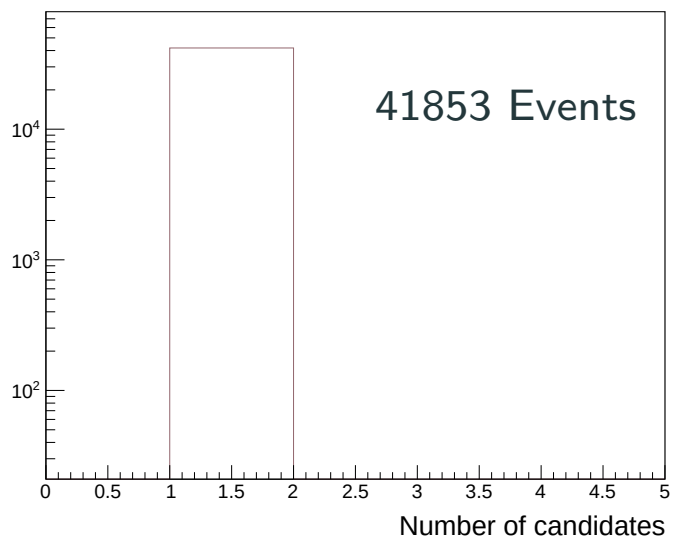


Single phase2 data file



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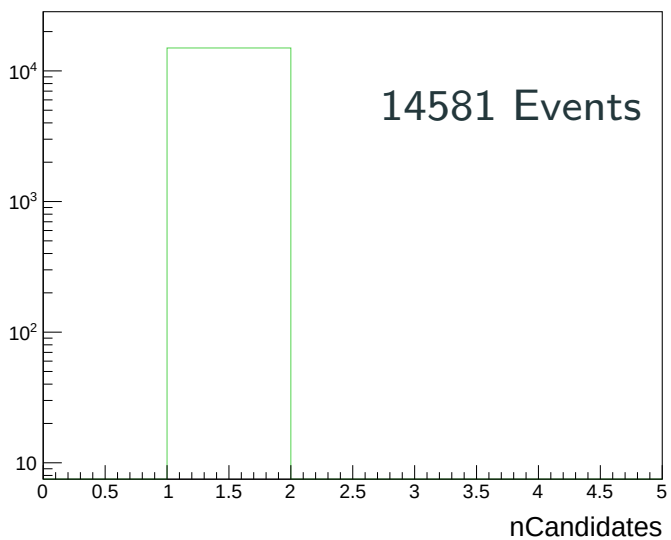
Also contains $\mathrm{ee} \to \gamma\gamma$ events

Single phase2 MC10 Bhabha file



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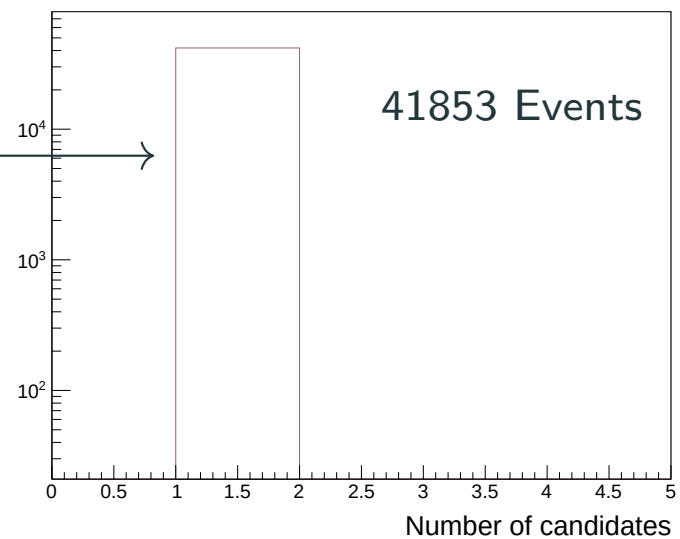
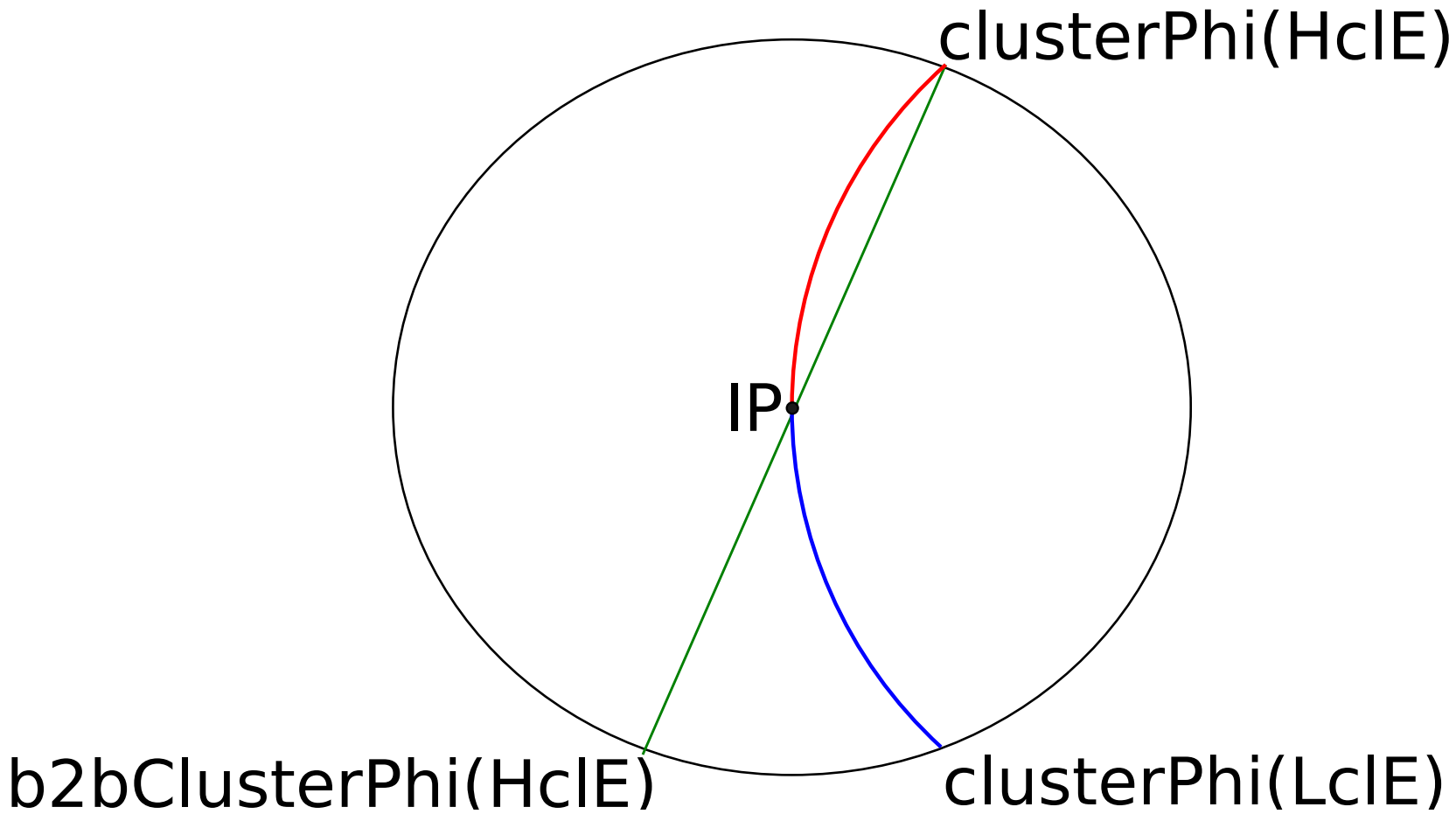


Bhabha Event Selection



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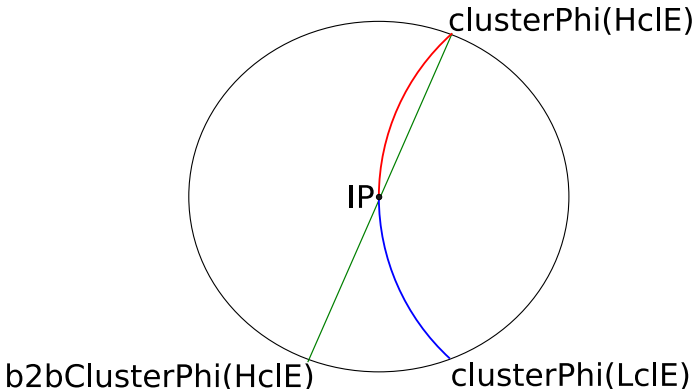

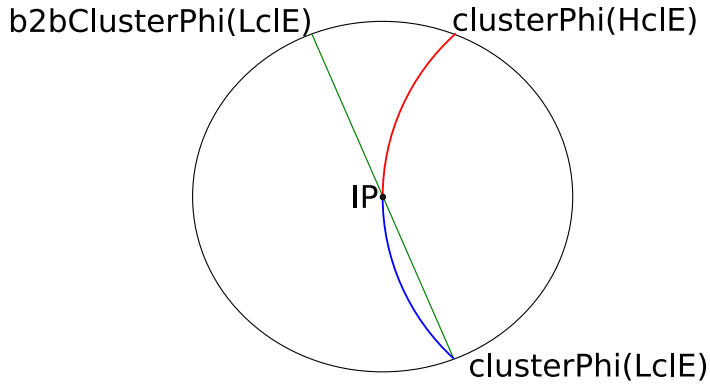

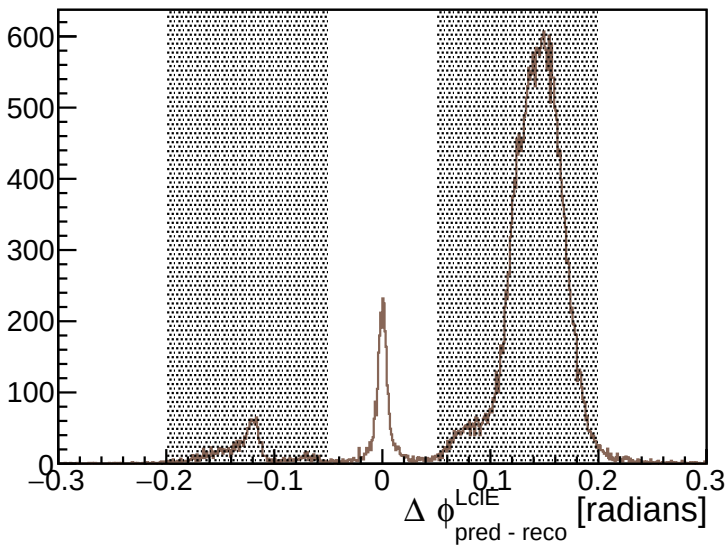

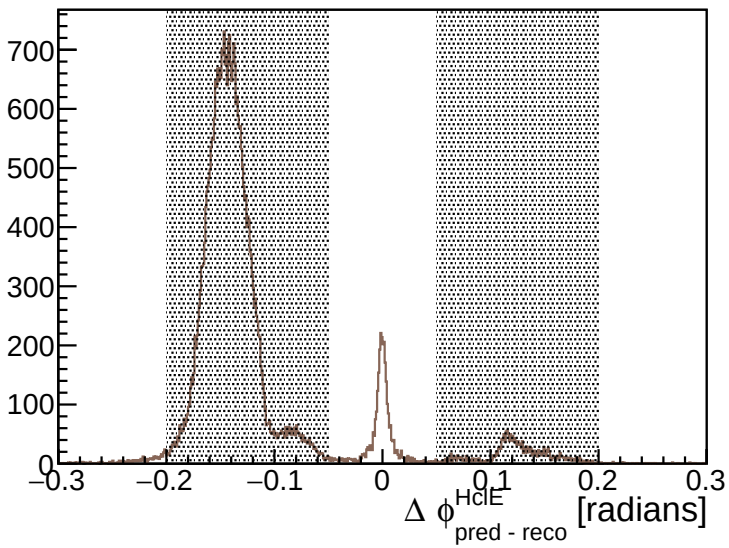

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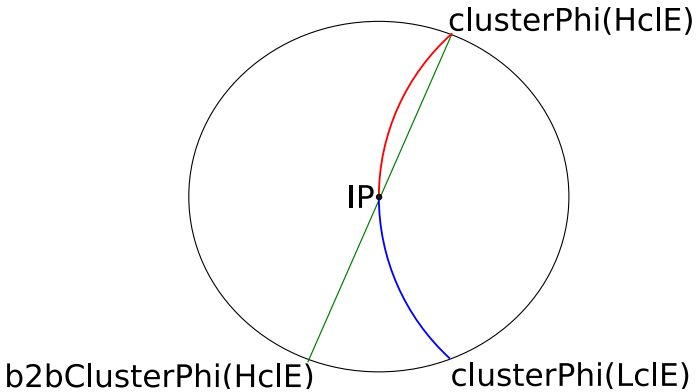
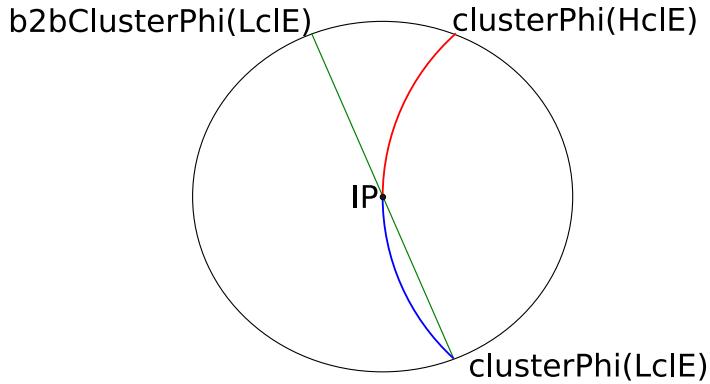
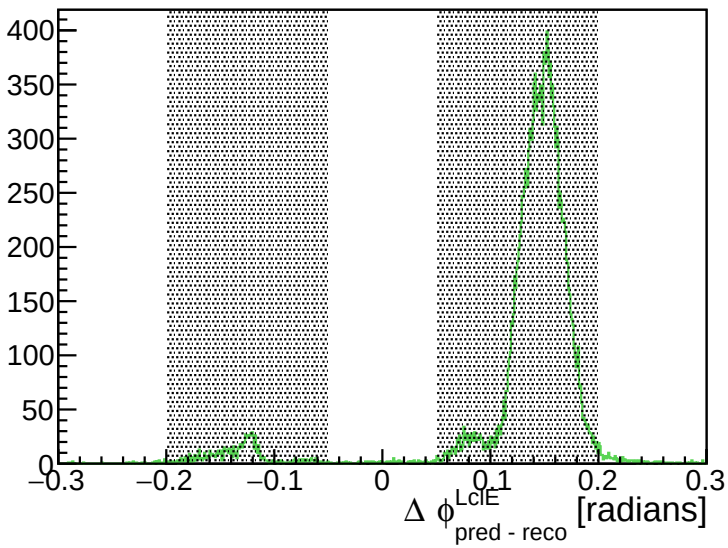
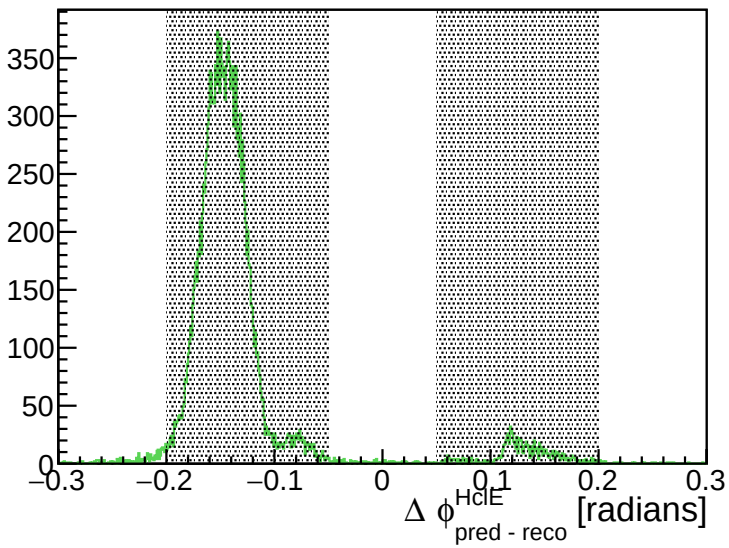








Trigger

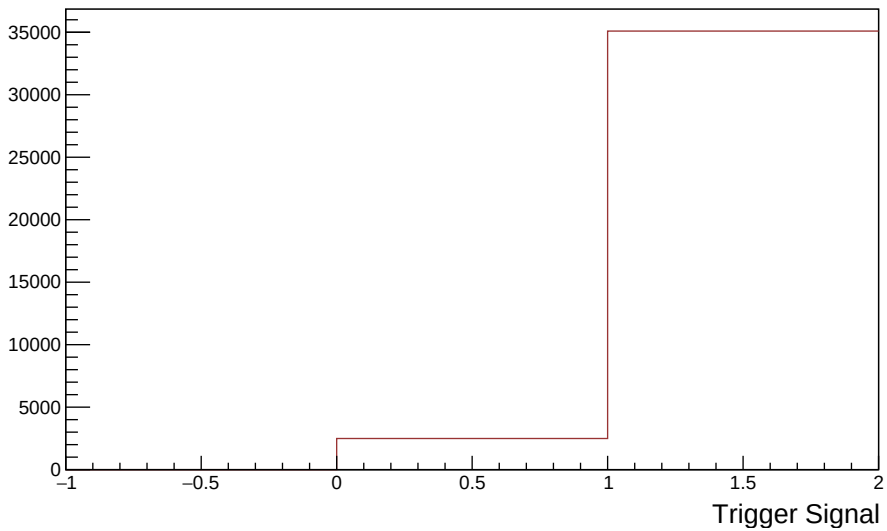
We need to be sure that a trigger signal is coming from the ECL. Otherwise there could be a bias

$\rightarrow$ 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 $2.5\,\mathrm{GeV}$ each and one has to have at least $4\,\mathrm{GeV}$
- $160^\circ < \sum \theta_{cms} < 200^\circ$
- $140^\circ < \Delta\phi_{cms} < 220^\circ$

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



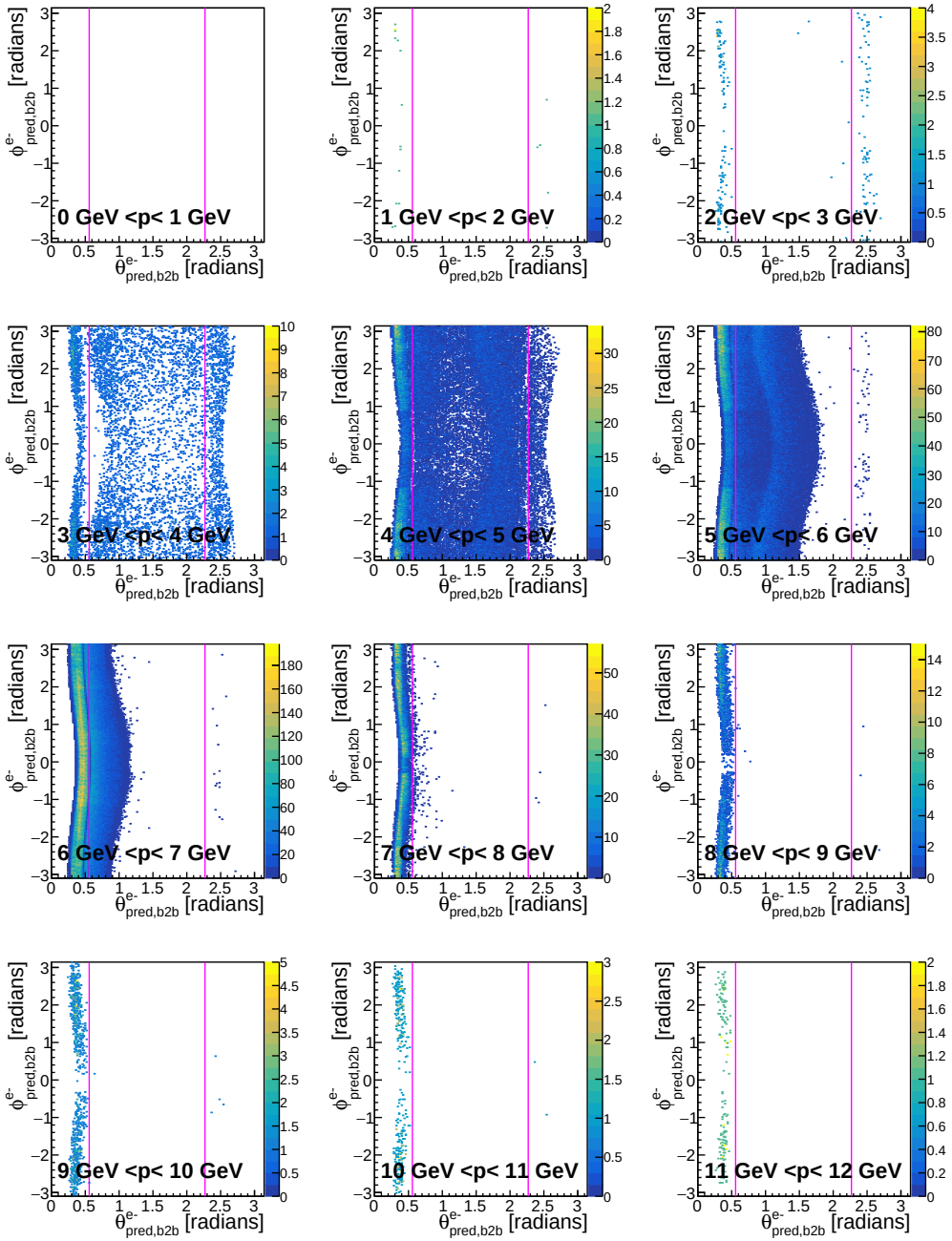
Dividing The ECL In Areas Of Interest

As function of azimuthal angle ϕ

	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 θ

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



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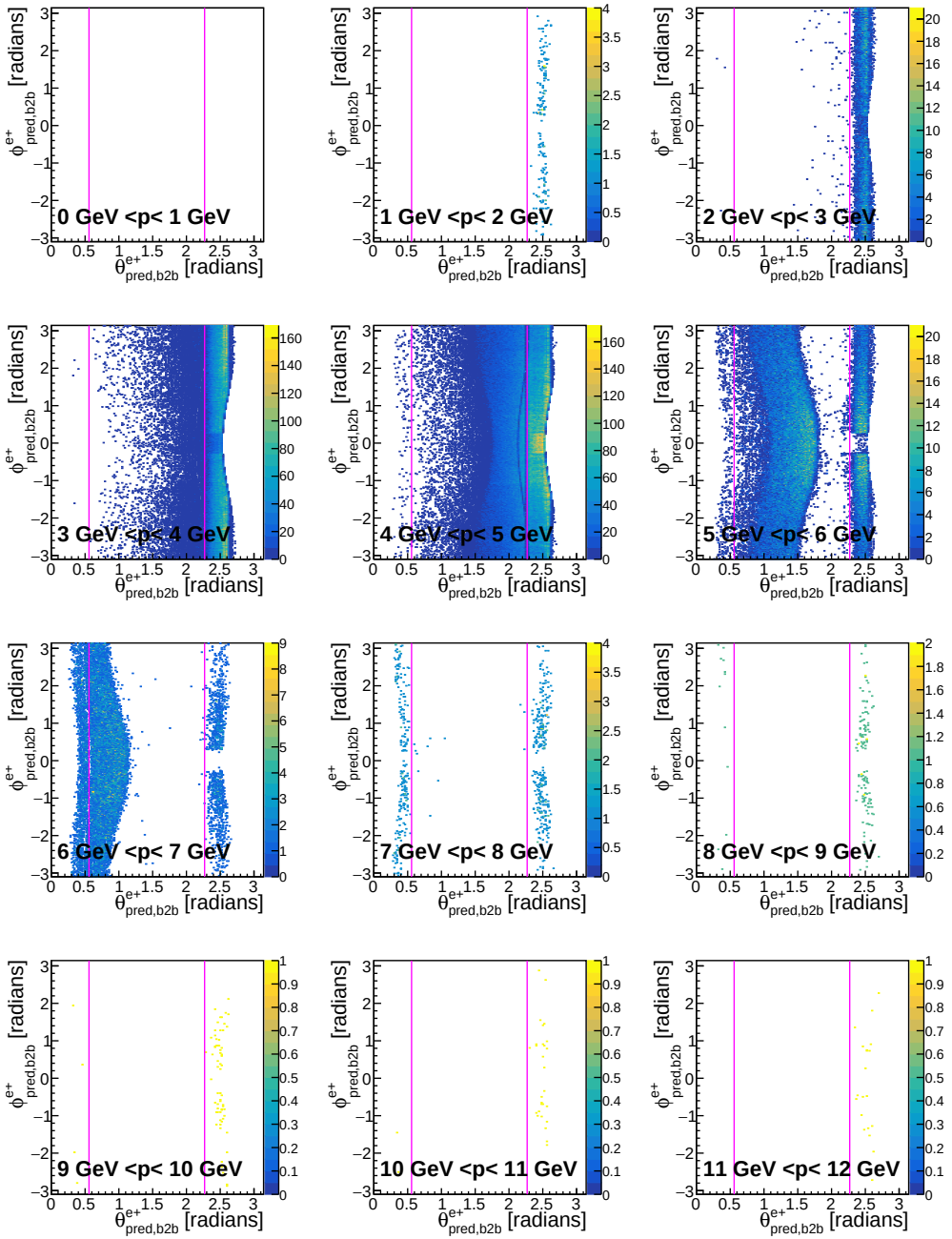
As function of azimuthal angle ϕ

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

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

As function of polar angle θ

	Momentum
e^-	$4\,\mathrm{GeV} - 9\,\mathrm{GeV}$
e^+	$2\,\mathrm{GeV} - 7\,\mathrm{GeV}$



Motivation

- I am performing an analysis to estimate the tracking efficiency on phase 2 data
- The process I am considering is Bhabha events $\mathrm{e}^+ + \mathrm{e}^- \rightarrow \mathrm{e}^+ + \mathrm{e}^-$
- The definition of efficiency I am going to use is:

$$\epsilon = \frac{\text{Number of Bhabha events with exactly 2 tracks}}{\text{Number of Bhabha events with 1 or more tracks}}$$

- After selecting Bhabha events where at least one of the tracks was detected, one can look how many times the second one is found
- This idea comes from some plots presented by Sam Cunliffe in previous tracking and ECL meetings.

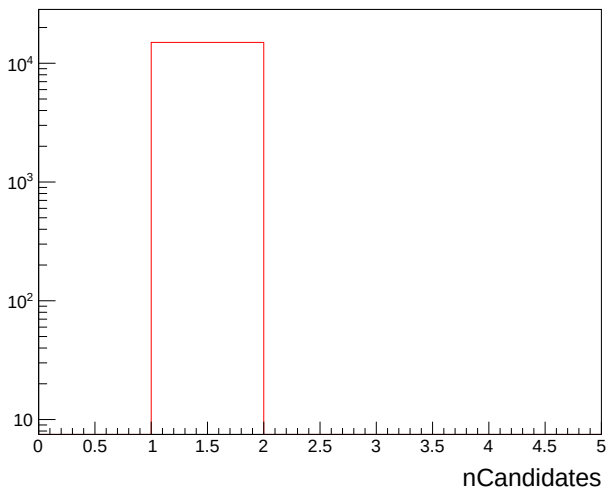
Best Candidate Selection

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

HcLE: particle with the higher cluster Energy; LclE: particle with the lower cluster Energy

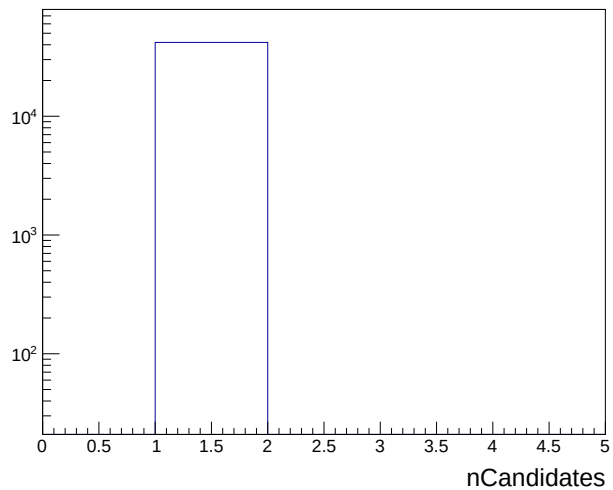
- $0.296706 < \theta_{\text{ECL Object}} < 2.61799 \rightarrow$ It has to hit the ECL
- Exactly two clusters with at least 3.5 GeV per event and one cluster has to have at least 4.5 Ge
- $8\,\text{GeV} < \text{M}_{\text{vpho}} < 12\,\text{GeV}$
- $\text{nTracks} < 7$
- $\text{Total Energy in the ECL} < 15\,\text{GeV}$

1 MC ee $\rightarrow$ ee File

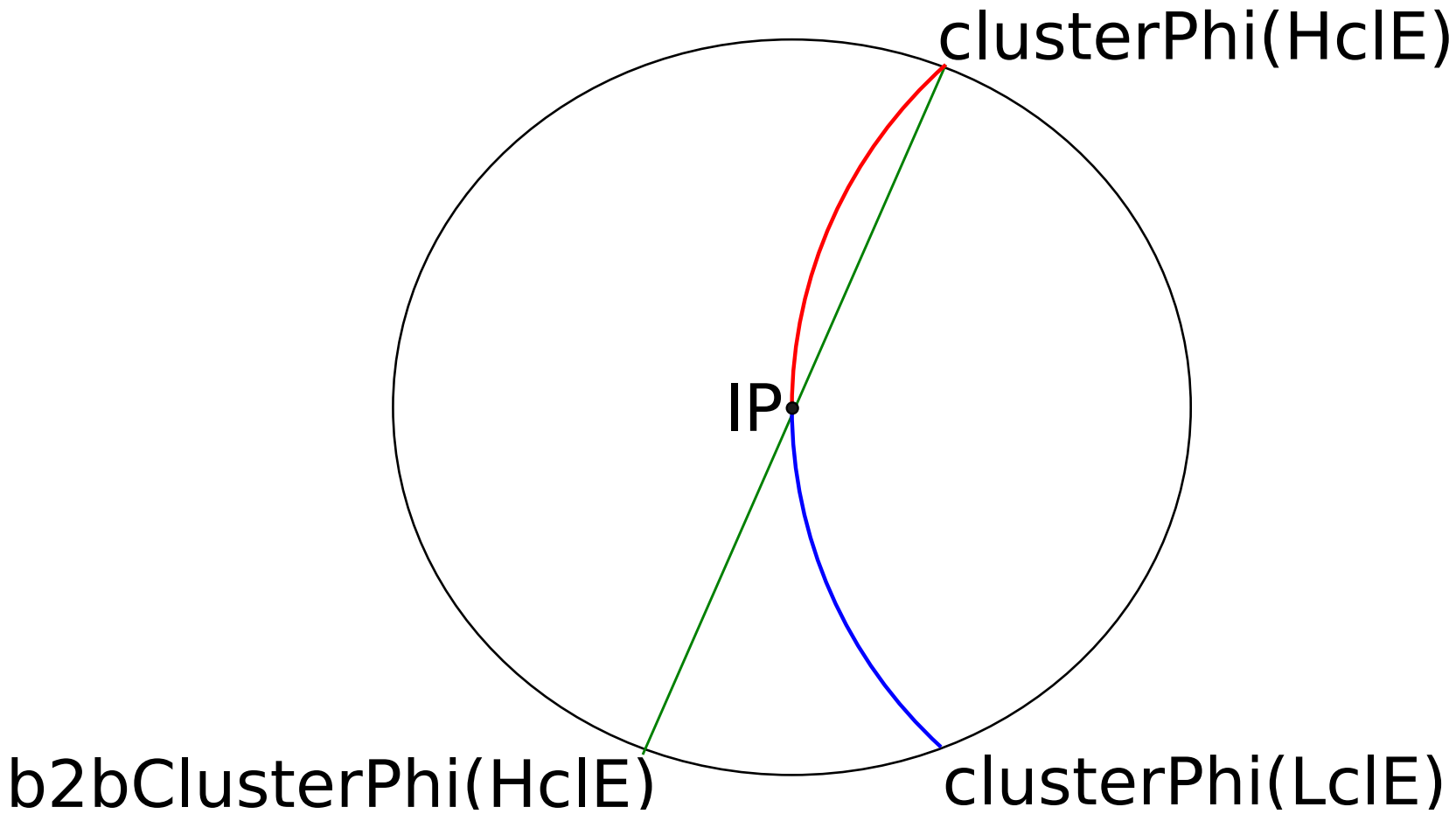


Phase 2 data

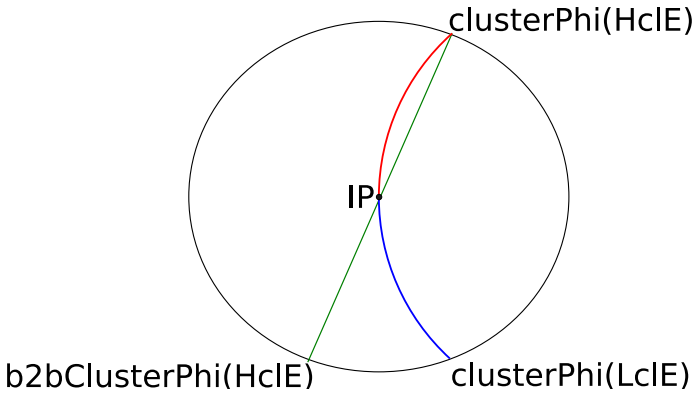
r02608/all/mdst/sub00/*.root

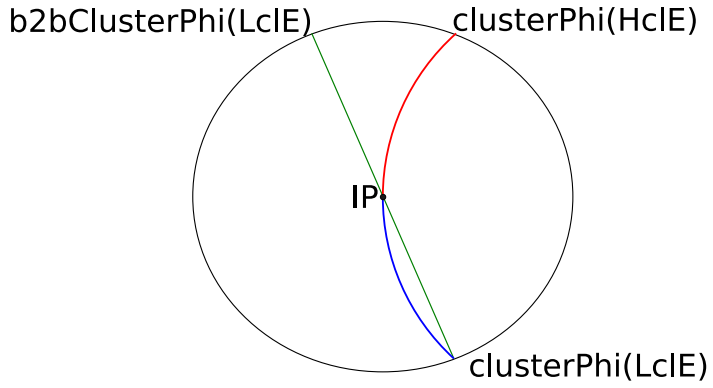


Bhabha Event Selection

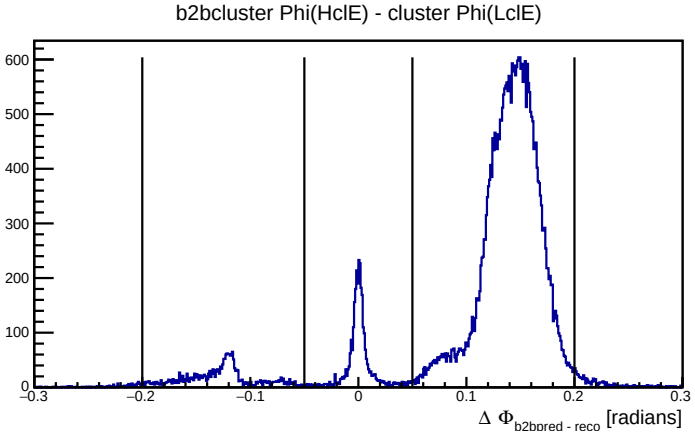


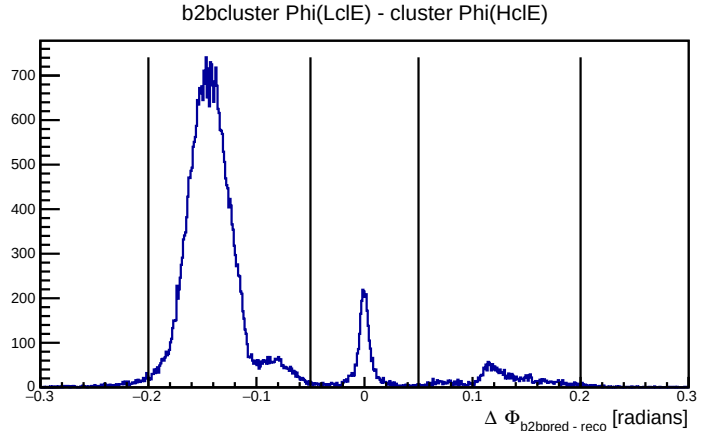
Bhabha Event Selection (Phase 2 data)



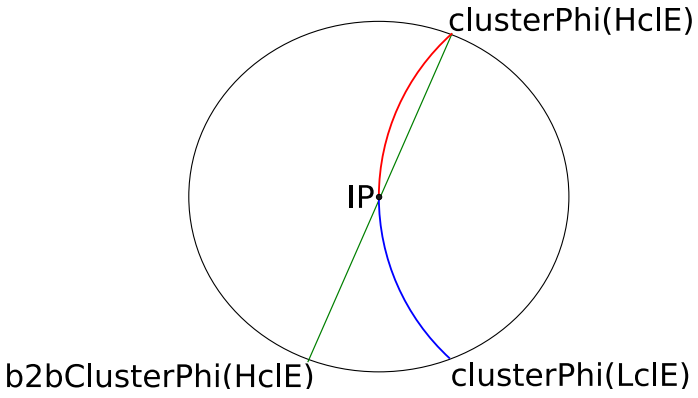


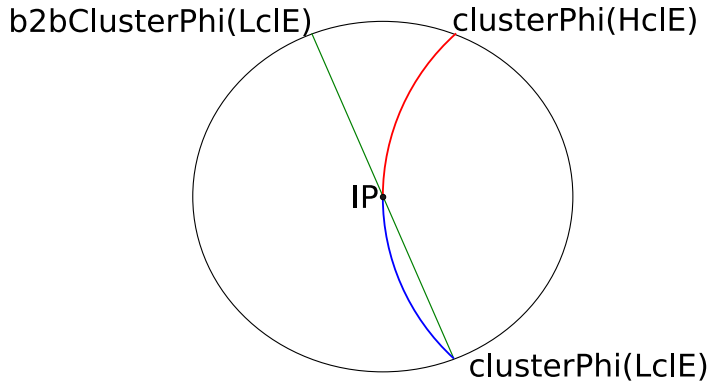
Phase 2 data r02608



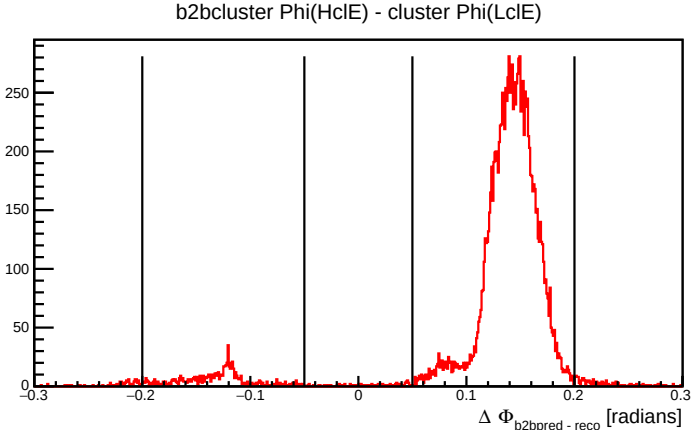


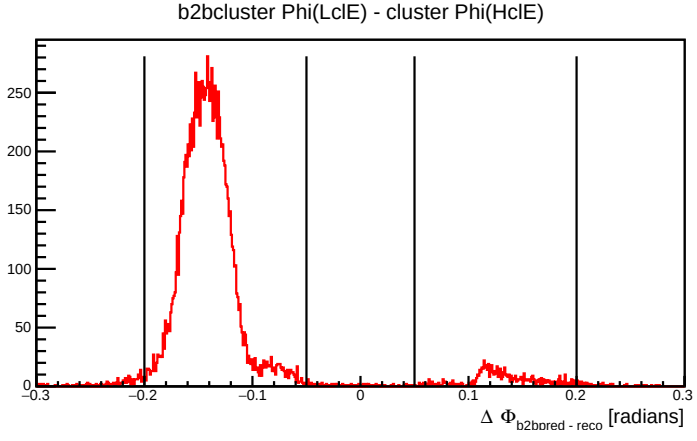
Bhabha Event Selection (MC)





MC: $ee \to ee$





More Events

MC:

- /belle/MC/release-02-00-01/DB00000411/MC11/prod00006731/s00/e1002/4S/r00000/3600520000/mdst/sub00
- 5272146 candidates selected

Phase 2 data:

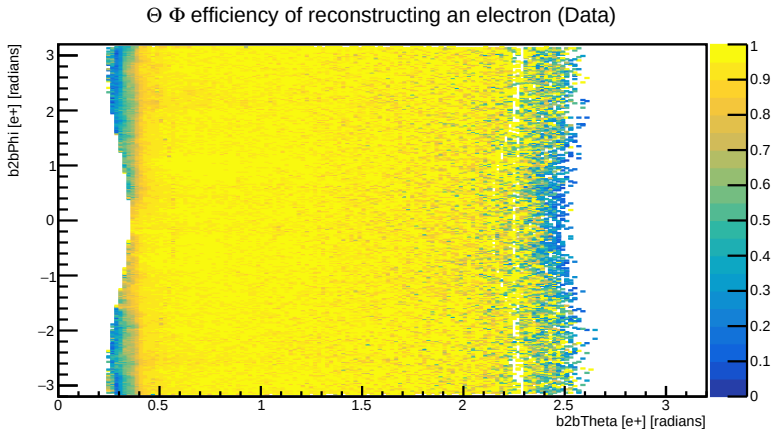
- /ghi/fs01/belle2/bdata//Data/release-03-00-03/DB00000528/proc00000008/e0003/4S/r02*/all/mdst/sub00/*.root
- proc8
- 3669759 candidates selected

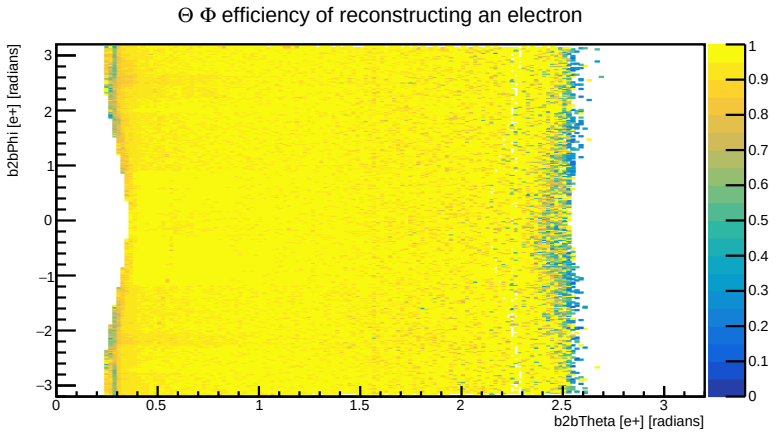
Compare MC And Phase 2 data Efficiency

Phase 2 data

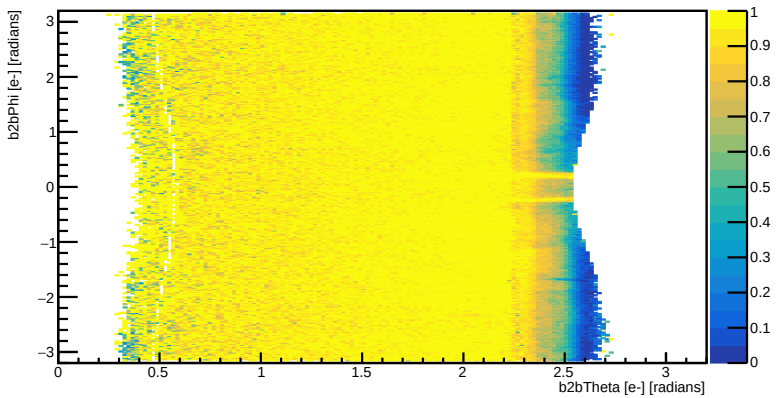
MC

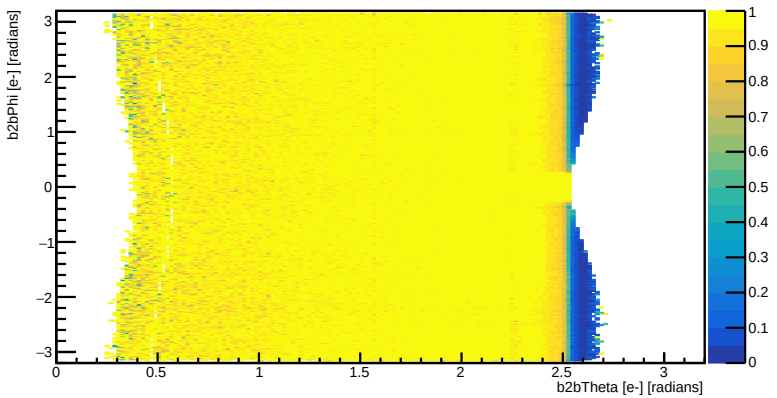
e^-





e^+





Theta And Phi Projection

Φ

Θ

e^-

e^+