LumiCal and BeamCal Reconstruction

André Sailer

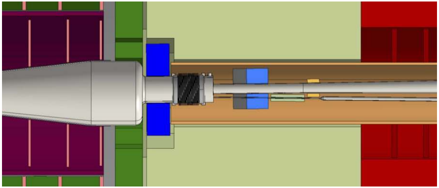
CERN-EP-LCD

32nd FCAL Workshop
May 11, 2018

Table of Contents

Forward Calorimeters

- Performance studies of the LumiCal and BeamCal detector and reconstruction software



	Z_{start} [mm]	Z_{end} [mm]	R_{in} [mm]	R_{out} [mm]	θ_{min} [mrad]	θ_{max} [mrad]
LumiCal	2539	2710	100	340	39	134
BeamCal	3181	3441	32	150	10	46

Reconstruction Software

LumiCalClusterer

- Nearest-neighbour clustering, optimised to separate Bhabha electrons from nearby final state radiation photons

BeamCalClusterReco

- Two reconstruction approaches: Nearest-neighbour clustering; shower fitting
- Different methods of generating incoherent pair background: Simulated bunch crossings, averages, Gaussian, parametrisation, *None*
- Subtraction of incoherent pair background

Repository on Github http://github.com/FCalSW/FCalClusterer.git

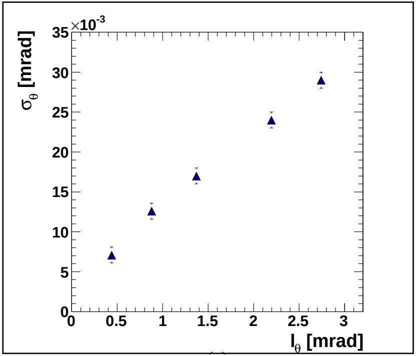
More Tests

- More automatic tests to ensure proper position reconstruction

```
    Start 1: t_BeamCalReco
1/4 Test #1: t_BeamCalReco ...........  Passed    4.88 sec
    Start 2: t_LumiCalReco
2/4 Test #2: t_LumiCalReco ...........  Passed    0.79 sec
    Start 3: t_TestLumi2Clu
3/4 Test #3: t_TestLumi2Clu ..........  Passed    0.82 sec
    Start 4: t_NewLumimCalReco
4/4 Test #4: t_NewLumimCalReco .......  Passed    2.41 sec
```

LumiCal Parameters, Expected Performance

- Z: 2539 mm
- Inner Radius: 100 mm, 40 mrad
- Outer Radius: 340 mm, 134 mrad
- Radial cells: 64, 1.47 mrad
- Expect polar angle resolution of about 0.020 mrad



From LCD-Note-2009-002, 1.5 TeV electrons, optimised log constant

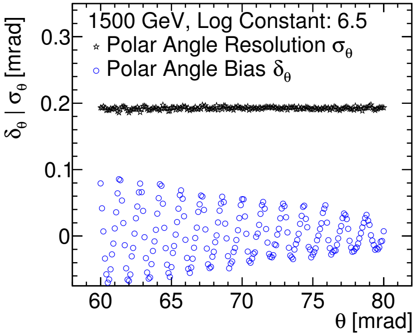
Polar Angle Resolution: Previously

- Simulating at fixed polar angle in 0.1 mrad steps
- Polar angle resolution 10 times worse than previously estimated
- Theta calculated from x/y/z average.

$$\vec{x} = \frac{\sum\limits_{\text{Hits}} w_{\text{Hit}} \vec{x}_{\text{Hit}}}{\sum\limits_{\text{Hits}} w_{\text{Hit}}}$$

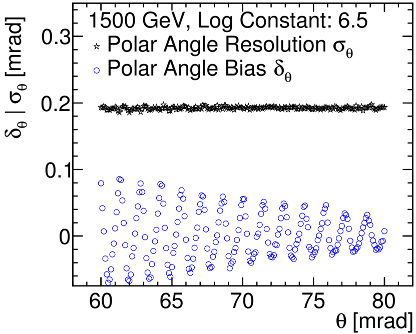
Energy weighted by

$$w_{\text{Hit}} = \max\left(0.0, \log\left(C + \frac{E_{\text{Hit}}}{E_{\text{Cluster}}}\right)\right)$$



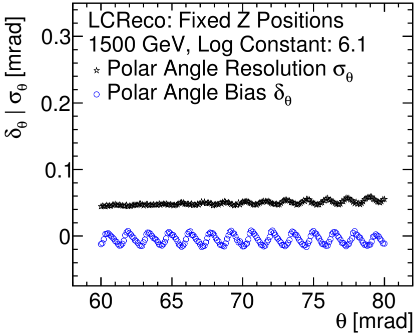
Bugs, Fixes, and Resolutions

- Previous bad reconstruction



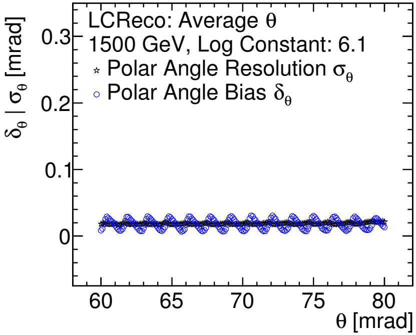
Bugs, Fixes, and Resolutions

- Previous bad reconstruction
- Fix Z-position of layers, fix layer starting with 0, place hit in middle of sensitive



Bugs, Fixes, and Resolutions

- Previous bad reconstruction
- Fix Z-position of layers, fix layer starting with 0, place hit in middle of sensitive
- Average over polar angle instead of Cartesian coordinates. **Recovered previously estimated polar angle resolutions**



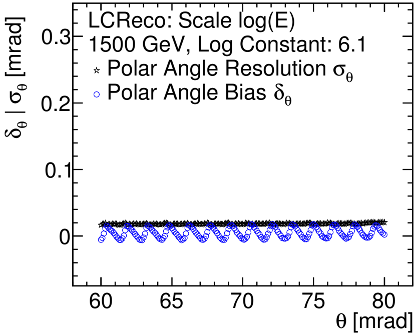
Weighting Cells by Cell Area

- Cell area grows by radius, larger cells receive larger energy deposit

$$A = R_{\text{cell}} \Delta\phi \Delta R \qquad (1)$$

ΔR and $\Delta\phi$ are constant, area only scales by R. Neglecting $(\Delta R)^2$ term for arc segments.

- Scale cell weights with $R_{\text{min}}/R_{\text{cell}}$
$w_{\text{Hit}} =$
$\max\left(0.0, \log\left(C + \frac{E_{\text{Hit}}}{E_{\text{Cluster}}}\right) \frac{R_{\text{min}}}{R_{\text{cell}}}\right)$



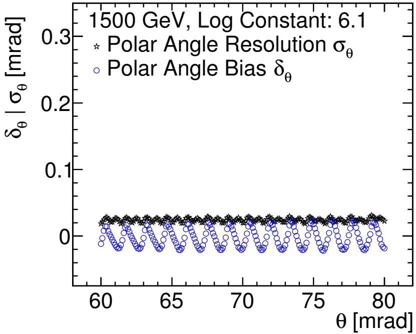
Weighting Cells by Cell Area

- Cell area grows by radius, larger cells receive larger energy deposit

$$A = R_{\text{cell}} \Delta\phi \Delta R \qquad (1)$$

  ΔR and $\Delta\phi$ are constant, area only scales by R. Neglecting $(\Delta R)^2$ term for arc segments.

- Scale cell weights with $R_{\text{min}}/R_{\text{cell}}$
  $w_{\text{Hit}} =$
  $\max\left(0.0, \log\left(C + \frac{E_{\text{Hit}}}{E_{\text{Cluster}}} \frac{R_{\text{min}}}{R_{\text{cell}}}\right)\right)$



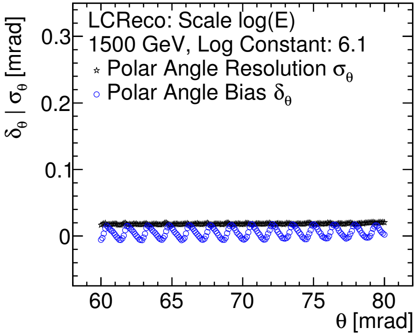
Weighting Cells by Cell Area

- Cell area grows by radius, larger cells receive larger energy deposit

$$A = R_{\text{cell}} \Delta\phi \Delta R \qquad (1)$$

  ΔR and $\Delta\phi$ are constant, area only scales by R. Neglecting $(\Delta R)^2$ term for arc segments.

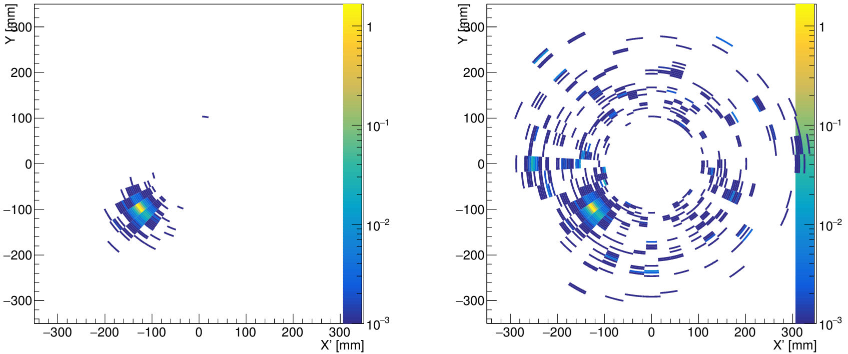
- Scale cell weights with $R_{\text{min}}/R_{\text{cell}}$
  $w_{\text{Hit}} =$
  $\max\left(0.0, \log\left(C + \frac{E_{\text{Hit}}}{E_{\text{Cluster}}}\right)\frac{R_{\text{min}}}{R_{\text{cell}}}\right)$
- Chose to keep this scaling implemented



LumiCal Reconstruction with Background

- Many particles from $\gamma\gamma \to$ hadrons impact the LumiCal

No background — 30 BX $\gamma\gamma \to$ hadrons background



- LumiCal clustering does not gracefully handle more than 2 showers, merges them all in to a single cluster
  - Very hard to disentangle

$\to$ Apply reconstruction for BeamCal to LumiCal: better control over cluster merging

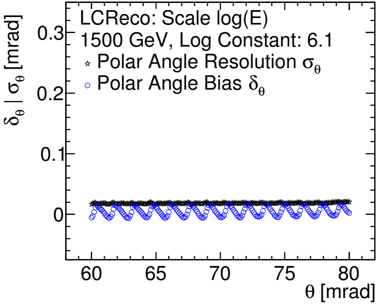
BeamCal Clustering for the LumiCal

Use the BeamCal clustering algorithm for the energy deposits in the LumiCal

- Improve polar angle reconstruction in BeamCal Reco: log-weighting
- Implement reading segmentation class of LumiCal
- Add maximum distance cut for pad merging

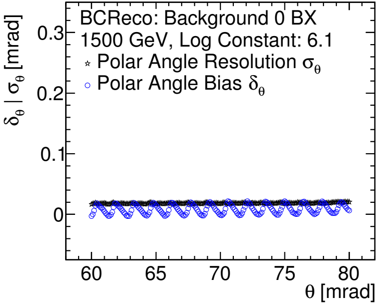
Polar Angle Resolutions

- Polar angle with LumiCal reconstruction



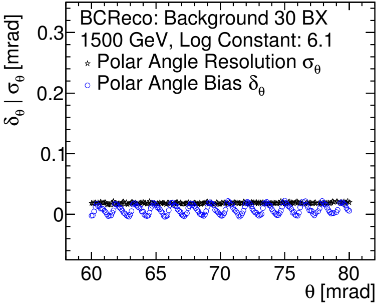
Polar Angle Resolutions

- Polar angle with BeamCal reconstruction



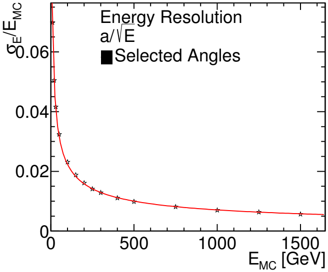
Polar Angle Resolutions

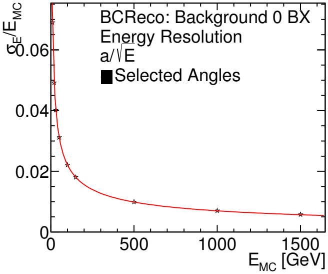
- Polar angle with BeamCal reconstruction and background overlaid



Energy Resolution

- Same energy resolution with LCReco (top) or BCReco (bottom) without background
  - $\sigma E/E = a/\sqrt{E[\mathrm{GeV}]}$
  - $a = 0.22$, constant term negligible, no gaps or noise
- With $\gamma\gamma \rightarrow$ hadron backgrounds (not shown) worse energy resolution, larger bias
  - need to recalibrate
  - Also add incoherent pair background





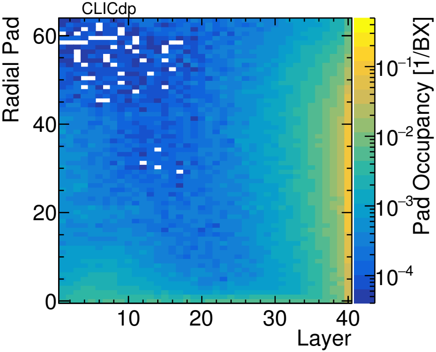
Simulation and Reconstruction Parameters

- Simulated 10 25 50 100 190 250 500 750 1000 1000 1250 1500 [GeV] electrons over the BeamCal and LumiCal angular acceptance
- 20k for each energy point
- Reconstructed with BeamCalClusterReco for LumiCal and BeamCal with 40 BX of 3 TeV and 380 GeV incoherent pair background for $L^{\star} = 6\ m$ simulated by Dominik Arominski.
  - 10σ of background as threshold for LumiCal reconstruction
  - 3σ of background as threshold for BeamCal reconstruction
- $\gamma\gamma \rightarrow$ hadron background not included

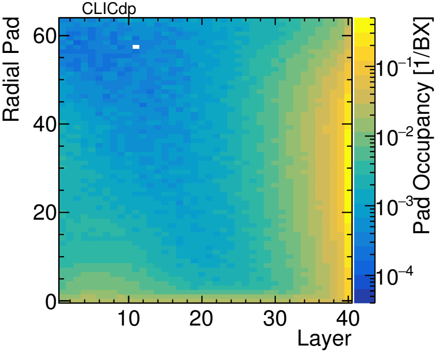
LumiCal Occupancy

- Occupancies for the LumiCal from incoherent pairs

380 GeV

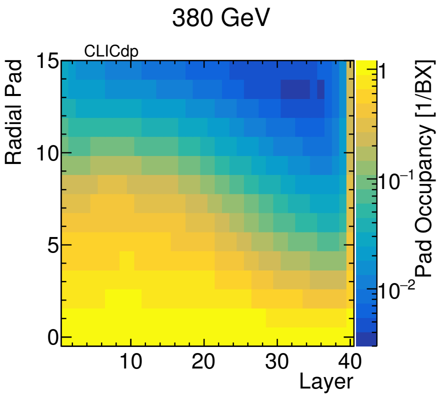


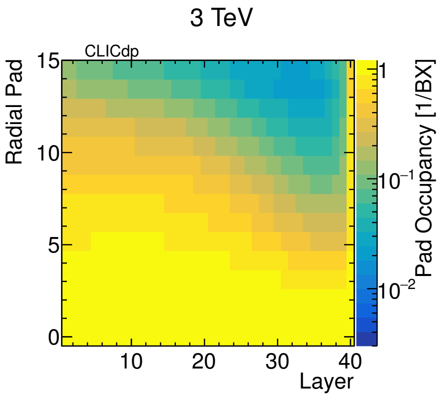
3 TeV



BeamCal Occupancy

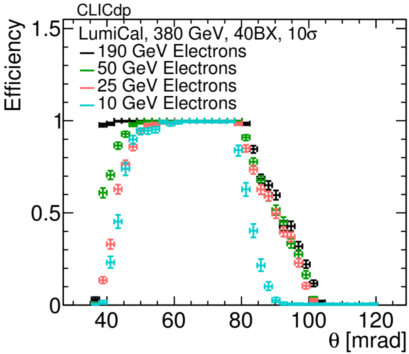
- Occupancies for the BeamCal from incoherent pairs





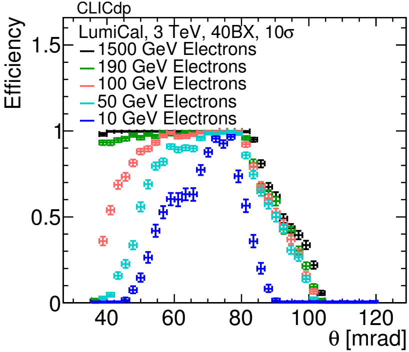
LumiCal Efficiency at 380 GeV

- LumiCal reconstruction efficiency for different energy primary particles
- Matching particles in angle and energy
- Slight loss at the inner edge of the LumiCal
- When LumiCal comes into the shadow of the beam pipe all particles are lost



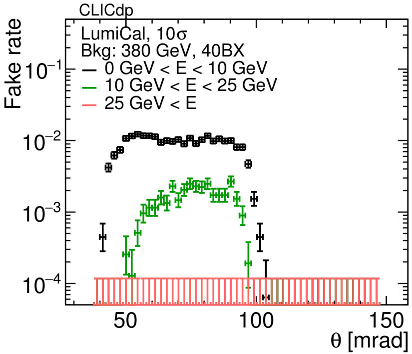
LumiCal Efficiency at 3 TeV

- LumiCal reconstruction efficiency for different energy primary particles
- Matching particles in angle and energy
- Good reconstruction between 1.5 TeV and 190 GeV
- Losses at the inner edge of the LumiCal
- When LumiCal comes into the shadow of the beam pipe all particles are lost
- Not sure about the “saddle” at 60 mrad



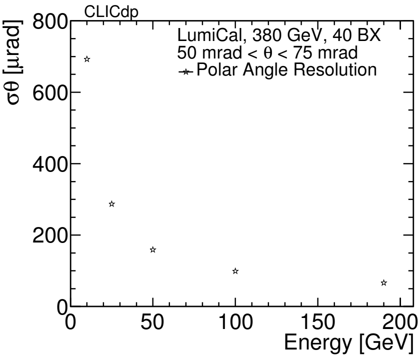
LumiCal Fake Rate

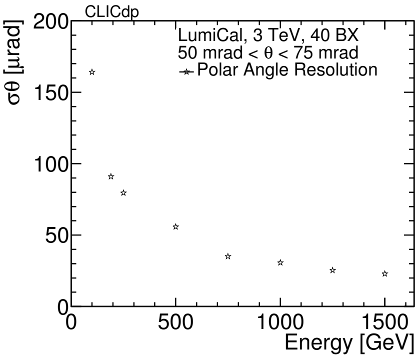
- Fake cluster: not matched to the primary MCParticle in angle and energy
- Fake rate per 40 BX of background



LumiCal Polar Angle Resolution

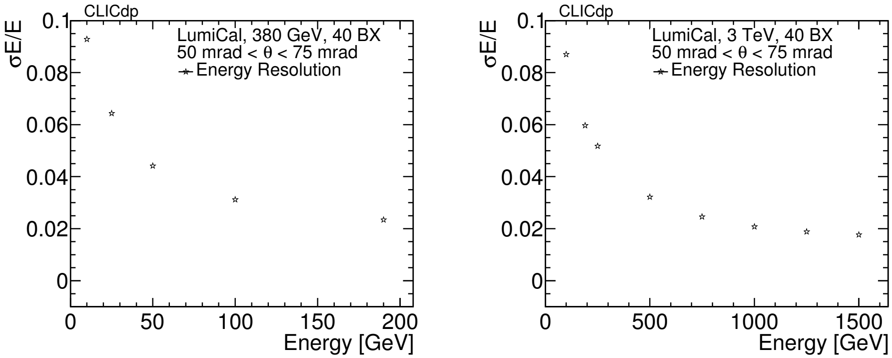
- Polar angle resolution unaffected by incoherent pair background





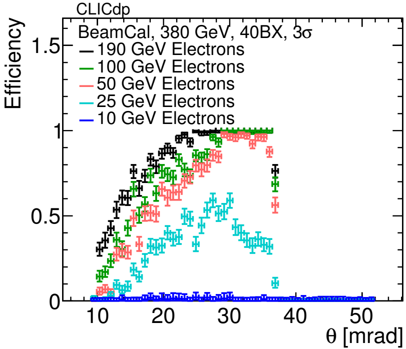
LumiCal Energy Resolution

- Energy resolution worse with incoherent pair background
- Depends on the background level (380 GeV or 3 TeV)
  - E.g., 190 GeV has much worse resolution at 3 TeV than at 380 GeV due to different backgrounds



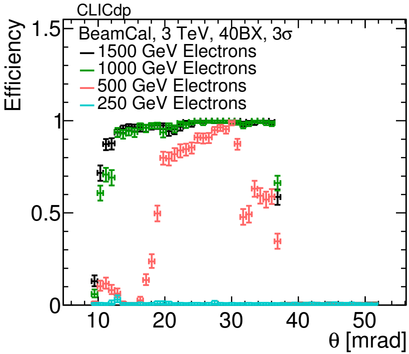
BeamCal Efficiency at 380 GeV

- BeamCal reconstruction efficiency for different energy primary particles
- Matching particles in angle and energy
- Large losses at lower radii for all energies
- Basically impossible to see anything below 20 GeV



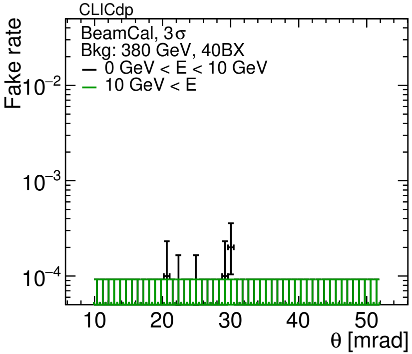
BeamCal Efficiency at 3 TeV

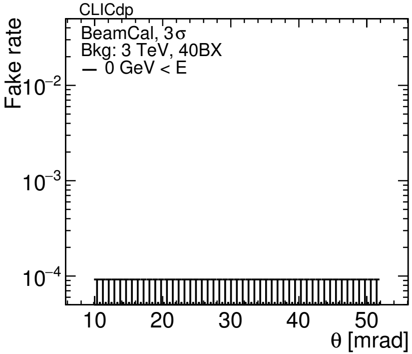
- BeamCal reconstruction efficiency for different energy primary particles
- High efficiencies down to 1 TeV
- At the lower edge the high background pushes some clusters into the matching criteria
- Matching particles in angle and energy



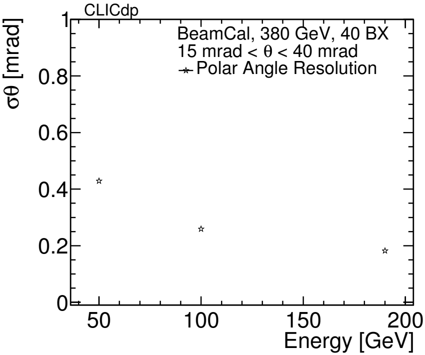
BeamCal Fake Rate

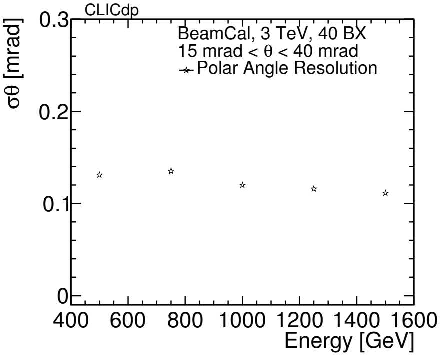
- With the used reconstruction parameters, very low fake rate in the BeamCal
- Can reduce cluster selection to increase efficiencies



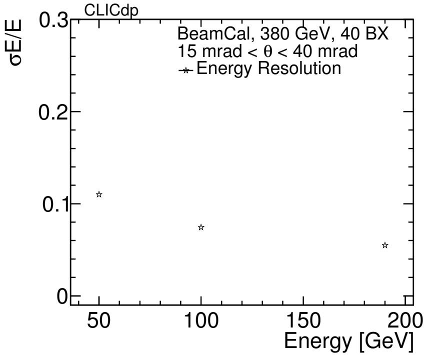


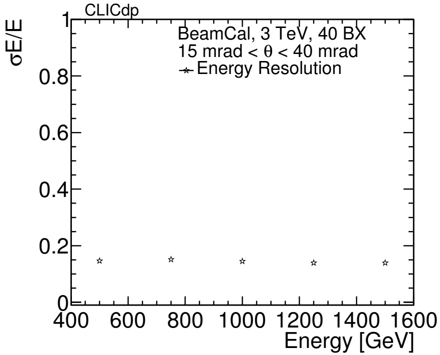
BeamCal Polar Angle Resolution





BeamCal Energy Resolution





Summary

- The long-standing issue of the polar angle resolution in LumiCalClusterer has been re-solved
- The LumiCalClusterer cannot be used with background
- The BeamCal reconstruction has been adapted to also run on the LumiCal and obtains the same resolutions under the same conditions
- Performance of the LumiCal and BeamCal with incoherent pair background was shown