Far-Forward detectors with ePIC simulation - toward preTDR

24 September 2024

Zvi Citron[1], Eden Mautner[1], Valeriy Zhezher[1], Michael Pitt[1,2]

[1]*Ben Gurion University of the Negev (IL)*
[2]*The University of Kansas (US)*

אוניברסיטת בן-גוריון בנגב
جامعة بن غوريون في النقب
Ben-Gurion University of the Negev

Outline

Updates

B0 detector geometry was updated and will be requested to be merged with the main branch (New_B0ECAL_geo)

- ✓ B0 ECAL geometry is fully configurable and matches the CAD and shifted by 15 cm
- ➢ Consequence: B0 Tracker layers were rearranged to match new B0ECAL position

Analysis

- B0 detector performance for photons / neutrons / protons with a new branch
- Interplay with the rest of the Far-Forward detectors

Simulation update - geometry

Simulation status – B0 geometry

- Default geometry (master branch on Aug 19):

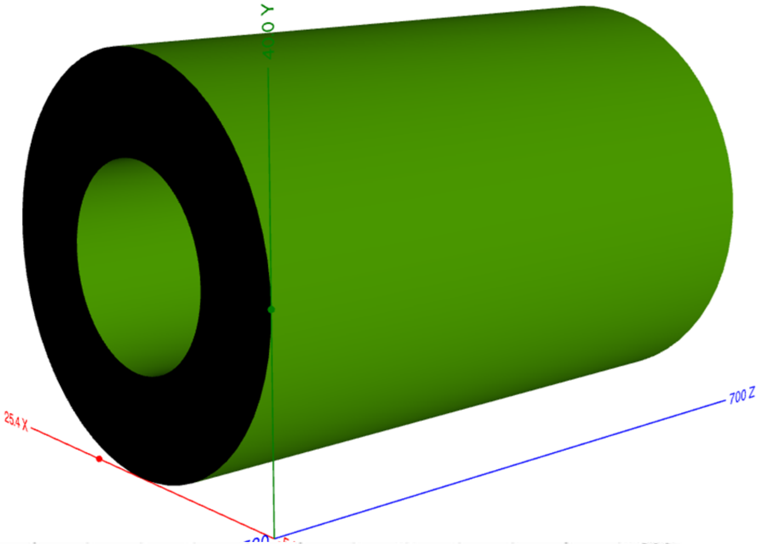
B0 magnet:

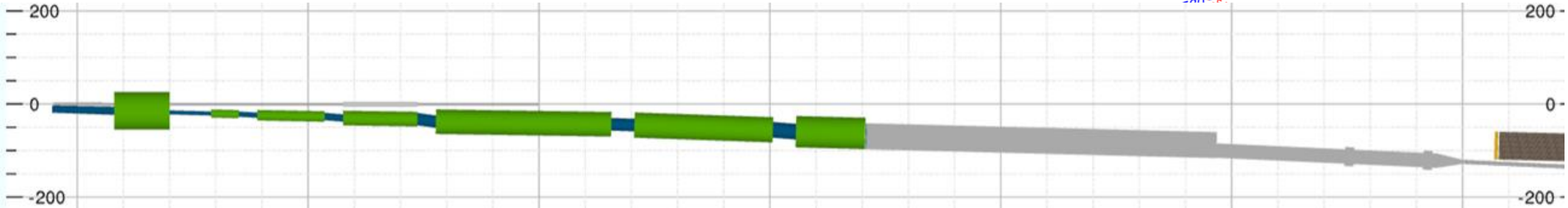
Length = 1.2m

Positioned at (-0.14578, 0, 6.4) meter

Distance from IP 580 cm, r = 20 cm

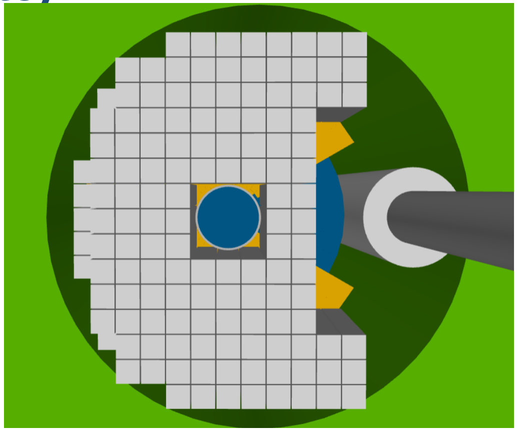
Aligned with respect to the electron beam





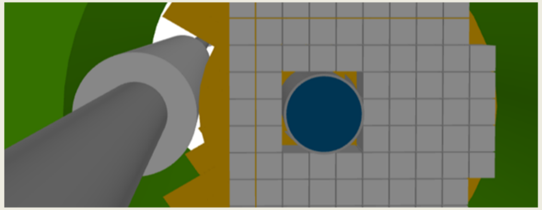
Simulation update - geometry

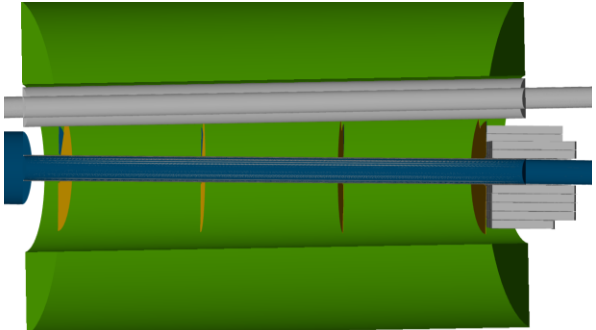
Simulation status – B0 geometry (pending update)



- https://github.com/eic/epic/tree/New_B0ECAL_geo
- ECAL Crystal matrix and position (692 - 712 cm from IP)
  - B0 ECAL customized matrix (close to CAD drawing)
  - Small fixes related to the coordinate system

Shift EMCAL to front of the magnet

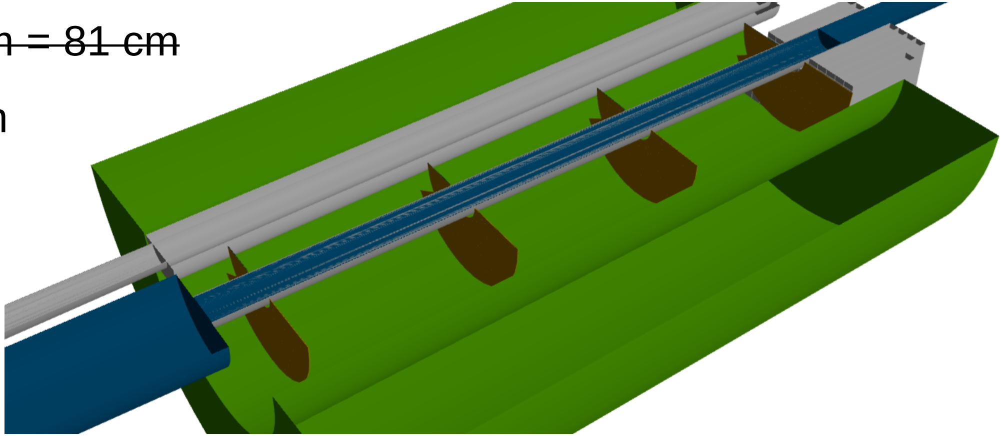




Simulation update - geometry

Simulation status – B0 geometry (pending update)

- https://github.com/eic/epic/tree/New_B0ECAL_geo
- ECAL Tracker layers are adjusted accordingly
  - B0 tracker: ~~z=6.3m, length 27*3 cm = 81 cm~~
  - z=6.39m, length 34*3 cm = 102 cm
    - 1st tracker layer = 588 cm
    - 2nd tracker layer = 622 cm
    - 3rd tracker layer = 656 cm
    - 4th tracker layer = 690 cm



4th layer is 2cm from EMCAL

B0ECAL performance - photons

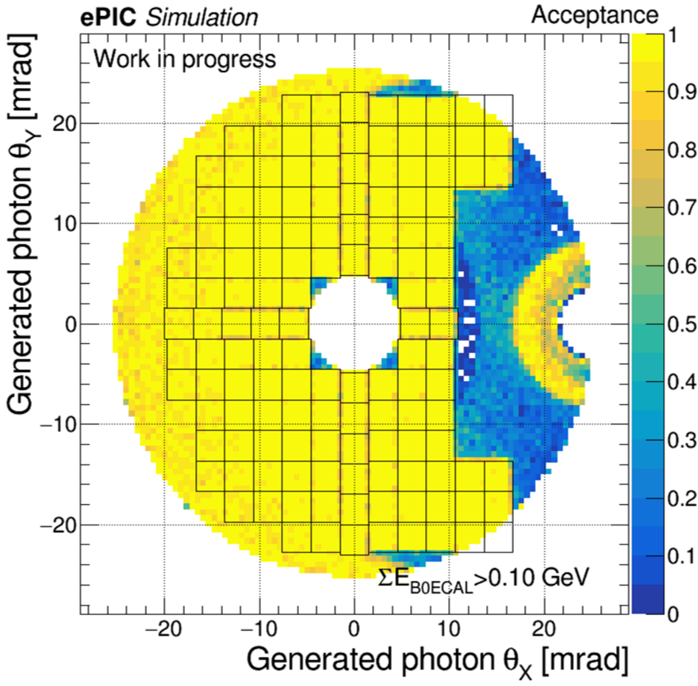
Acceptance in B0 X-Y plane

- Photon gun with E<110GeV and 5<θ/mrad<25
- Spatial photon acceptance defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$
- Set energy threshold in EMCAL > 100 MeV

Observations

- Photon out-of-fiducial region deposit energy in EMCAL
- Caused by photon conversion in earlier detector's material



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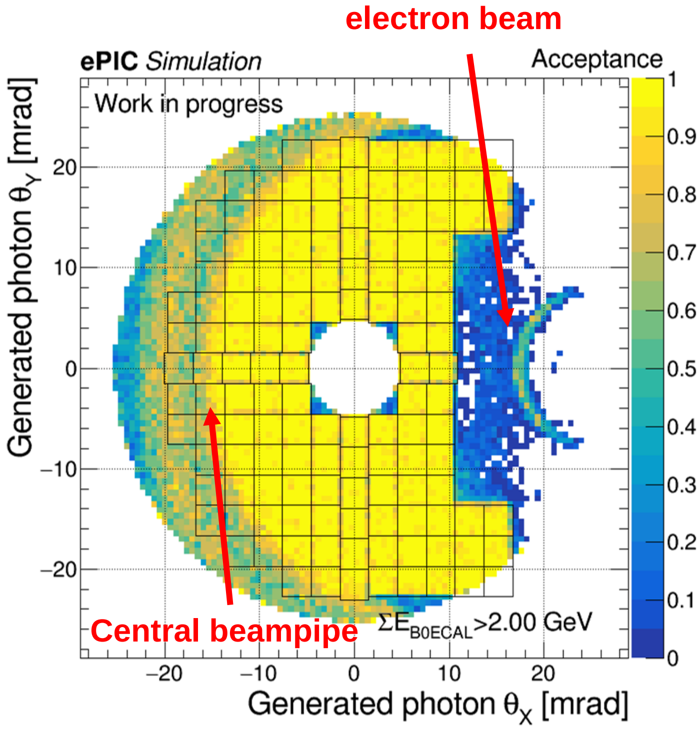


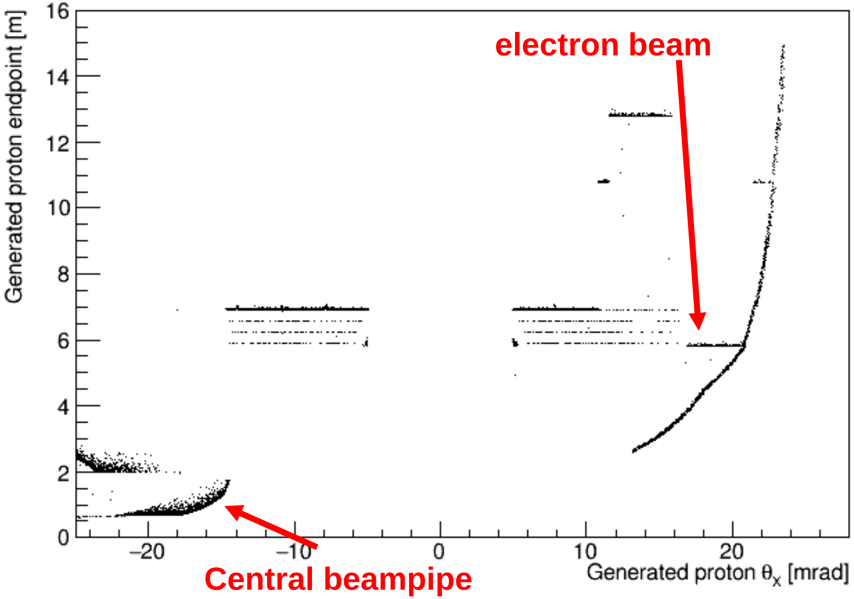
Observations

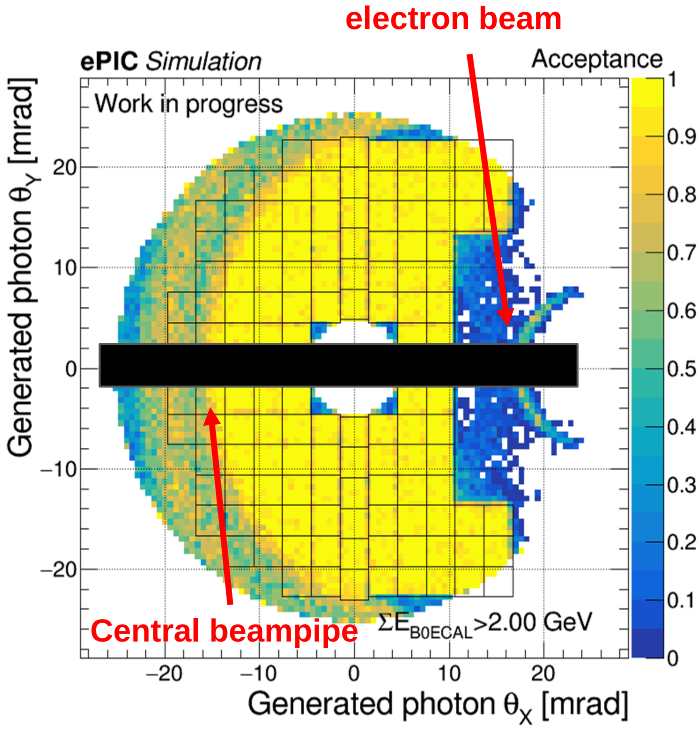
- Photon out-of-fiducial region deposit energy in EMCAL
- Caused by photon conversion in earlier detector's material

B0ECAL performance - photons

Acceptance in B0 X-Y plane

- G4 simulation provides information of the photon endpoint (photon conversion), issue with the central beam pipe persist





B0ECAL performance - photons

Acceptance in B0 X-Y plane

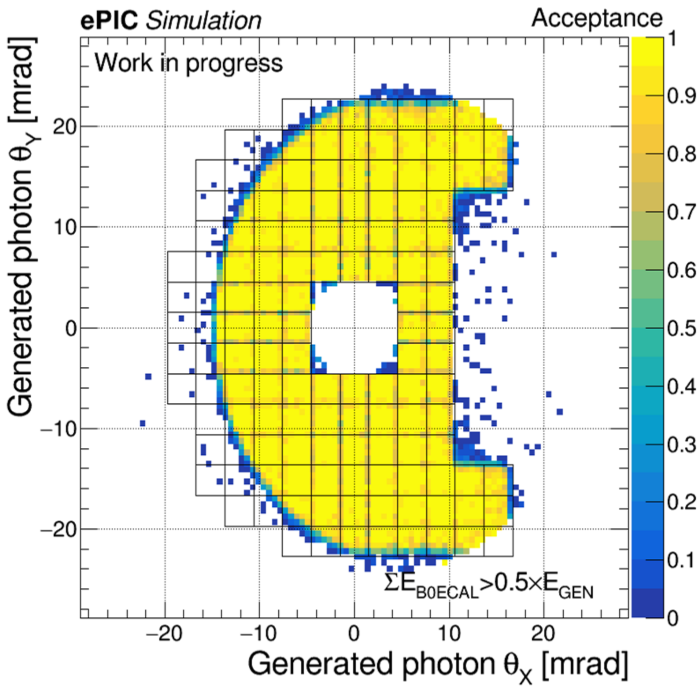
- Photon gun with E<110GeV and 5<θ/mrad<25
- Spatial photon acceptance defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$

- Set energy threshold in EMCAL > 0.5 E_{GEN}

Observations

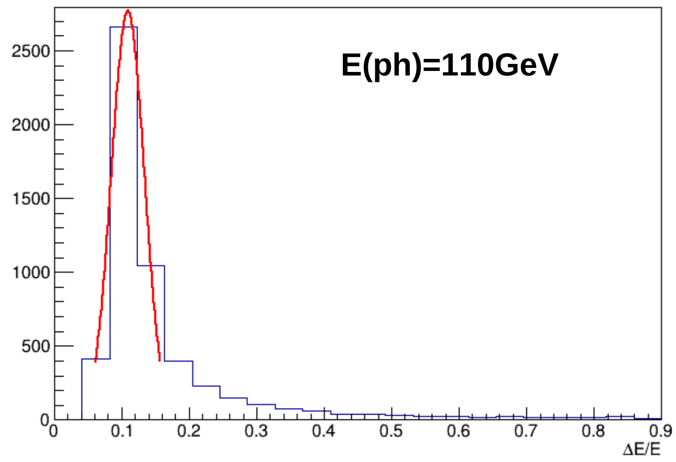
- High acceptance for photons that not intersect the central beampipe

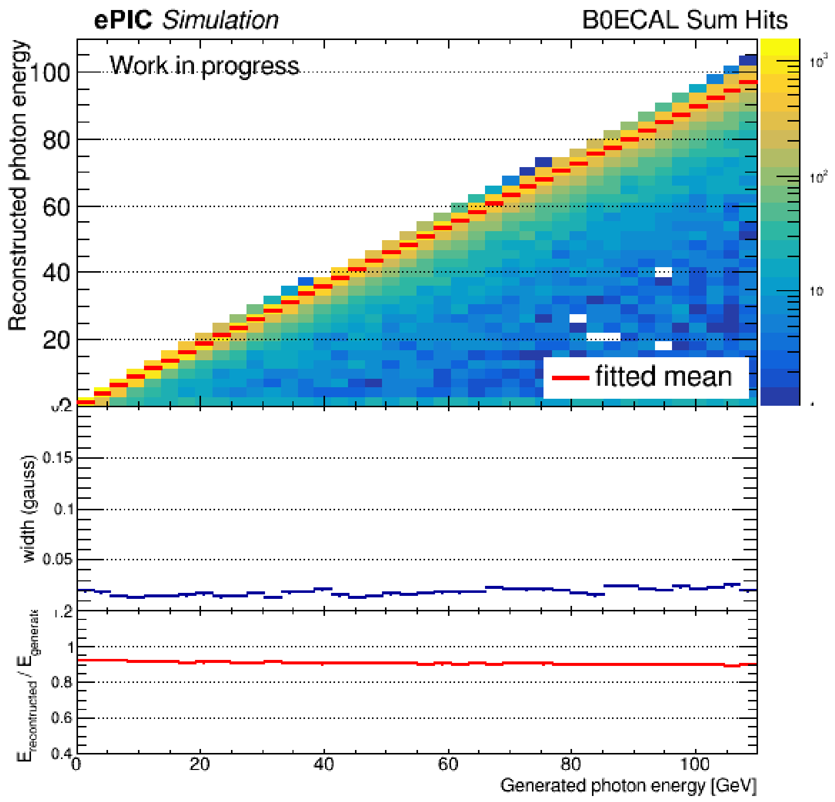


B0ECAL performance - photons

Energy response for θ<13mrad

- To study the entire detector's sensitive area, consider only photons interacting within the B0ECAL crystals
- NOTE: light yields are not included in the reconstruction





B0ECAL performance - photons

Energy response for θ<13mrad

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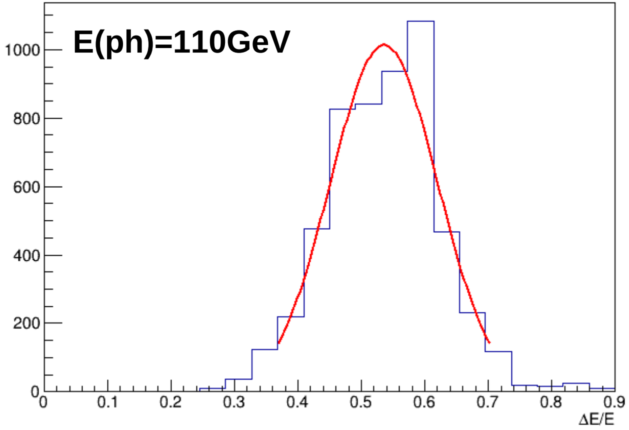
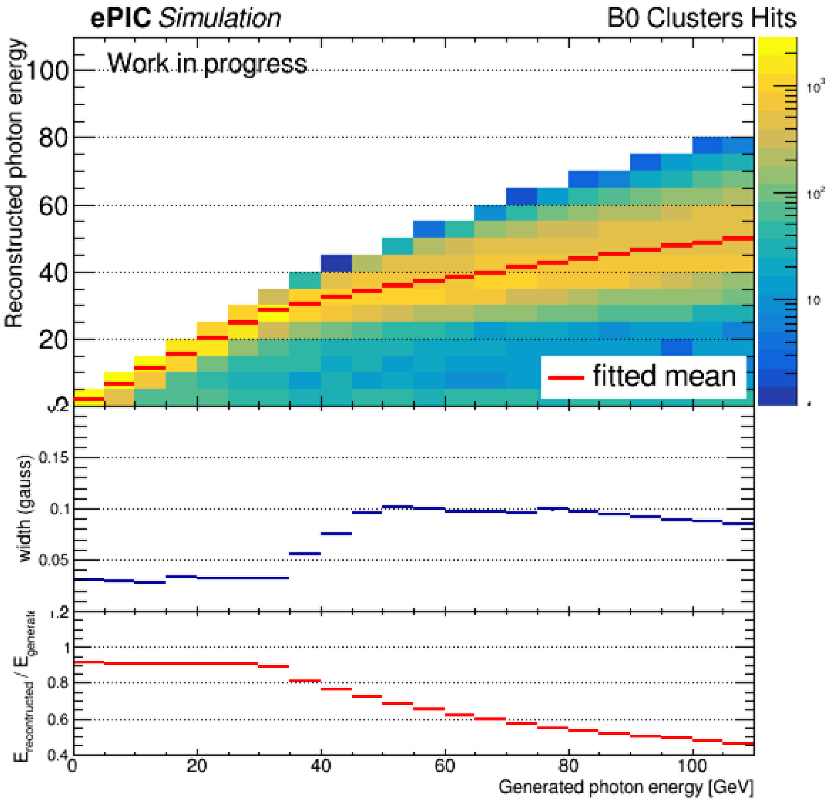
- Clustering algorithm shows saturation (**FIXME**)





B0ECAL performance - photons

Energy response for θ<13mrad

For each 2x2 cm^2 crystal we use 3+1 sensors of different pitch size

- Realistic energy response is given by the following sequence:

  N photons in PbOW crystal / mm^2 = 145.75 / GeV [1]*

  1. Sample N photons from Poi(N_{SiPM}=145.75*400), randomly distribute among the four sensors, with 6x6mm^2 SiPM: n~Binomial(N*PDE,0.09) (the largest effect on the resolution)
  2. Apply PDE of 18% for 10PS, 32% for 15PS, and saturation: ADC = $N_{MAX}(1-EXP(-n*pde/N_{MAX}))$, $N_{MAX}=(6/PS)^2$

     E_{MAX}(15PS) = N_{MAX}/(145.75*36*0.32) = 95 GeV

     E_{MAX}(10PS) = N_{MAX}/(145.75*36*0.18) = 170 GeV

  1. Apply calibration factor ADC → GeV

     C_10PS = ADC * (1 / 145.75*36*0.18)

Total number of photons in the crystal: N=(E/GeV)*145.75*400

⇩

Number of photons hit the sensor times PDE (effective area is 9%)

⇩

Convert Nph in sensor to ADC including saturation effects
Veto hits with Nph<10

*** Expected reflectivity 99% (93% in LY)**
*** Expected LY 200ph/MeV**

[1] 100% reflectivity, 100ph/MeV, https://indico.bnl.gov/event/24129/contributions/93860/attachments/55755/95323/VZhezher_20240709.pdf

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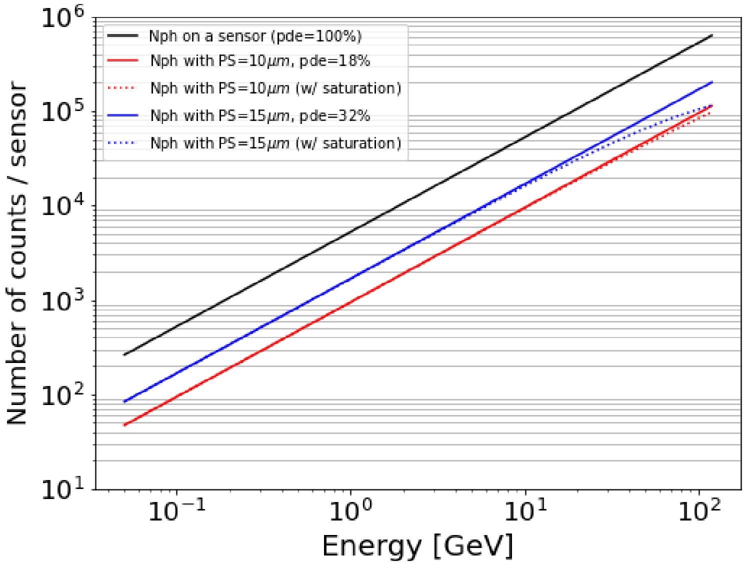

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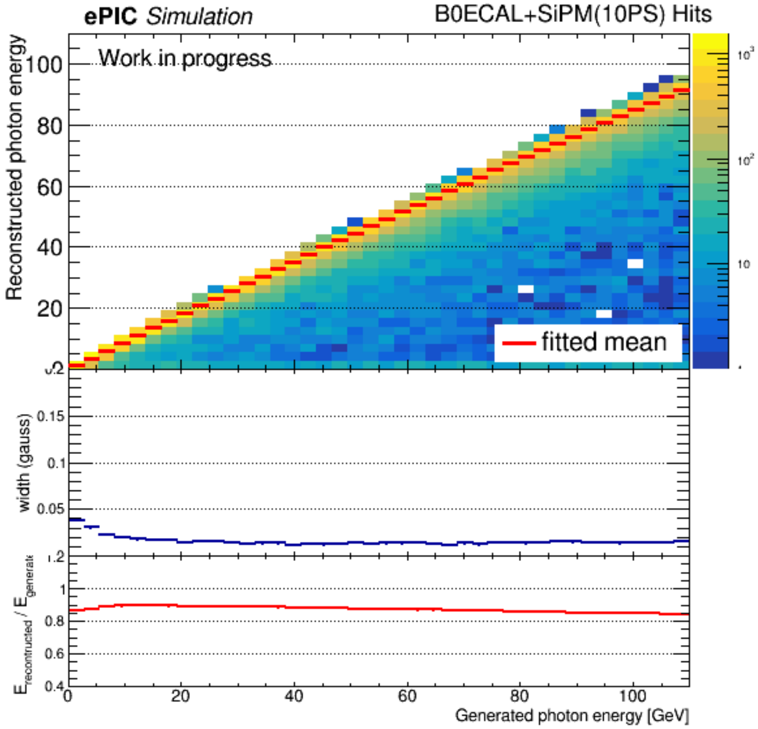

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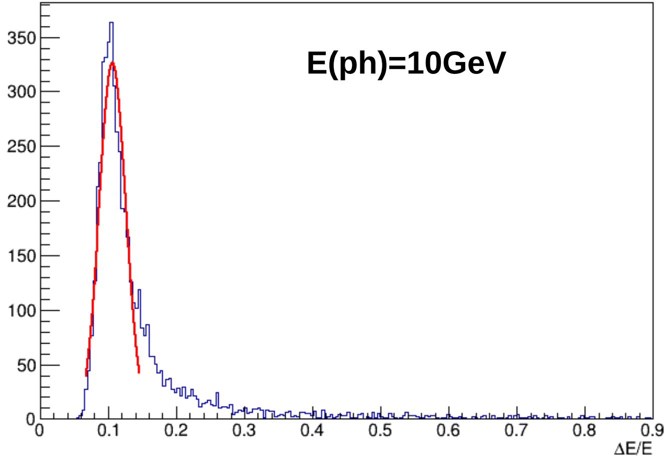
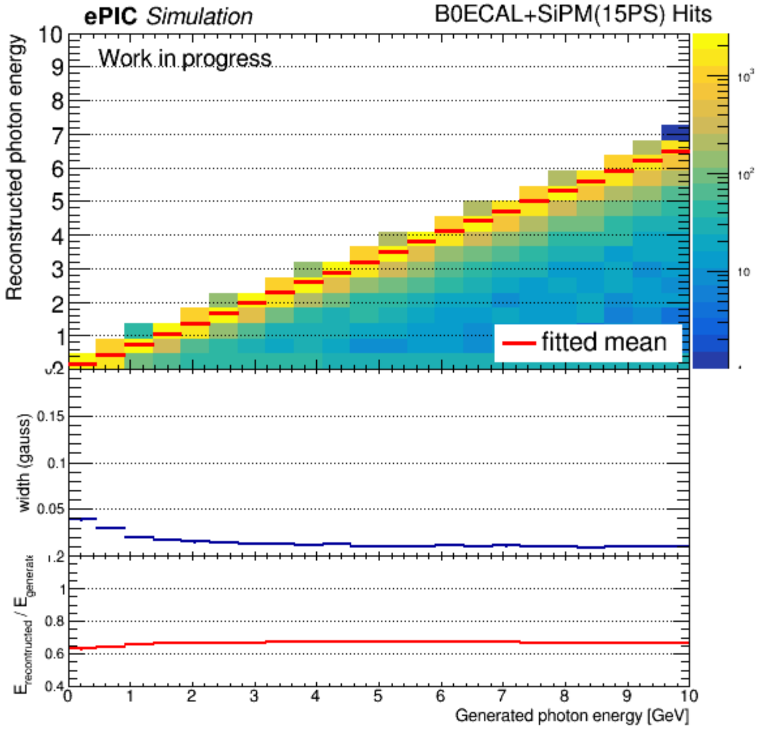
B0ECAL performance - photons

Energy response for θ<13mrad

For each 2x2 cm^2 crystal we use 3+1 sensors of different pitch size

- Non gaussian shape





ZDC performance - photons

Acceptance in ZDC X-Y plane

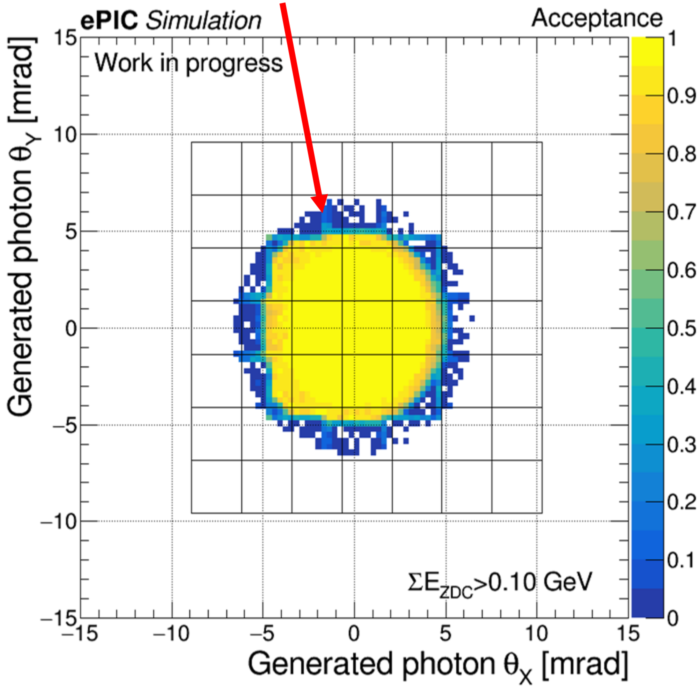
- Photon gun with E<110GeV and θ<5mrad
- Spatial photon acceptance defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$
- Set energy threshold in ZDC > 100 MeV

Observations

- All detected photons contained within the hadron beampipe inside the B0 magnet

Exit window from hadron beam



ZDC performance - photons

Acceptance in ZDC X-Y plane

- Photon gun with E<110GeV and θ<5mrad
- Spatial photon acceptance defined as:

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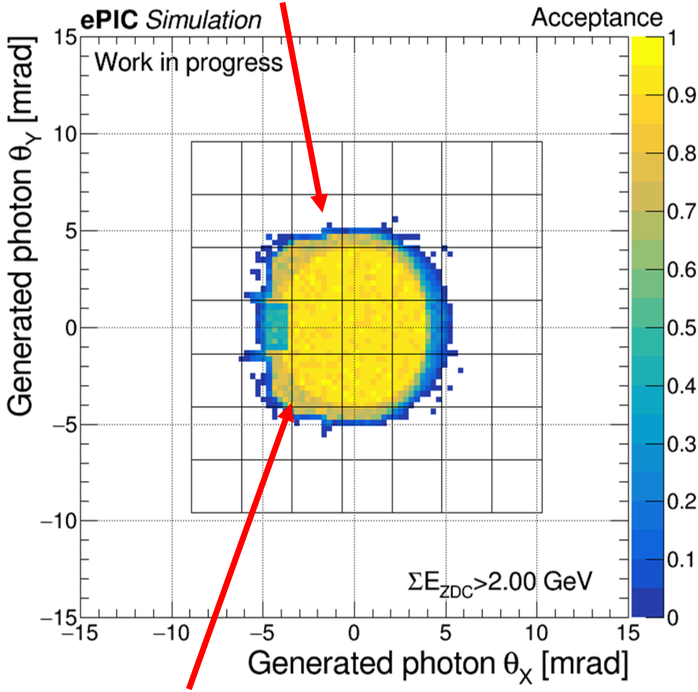
- Set energy threshold in ZDC > 2 GeV

Observations

- All detected photons contained within the hadron beampipe inside the B0 magnet
- Small overlap with RP boxes

Exit window from hadron beam

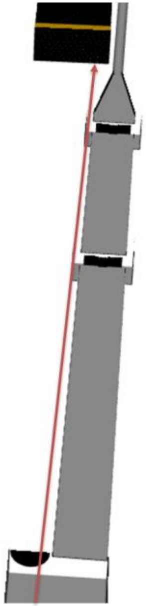


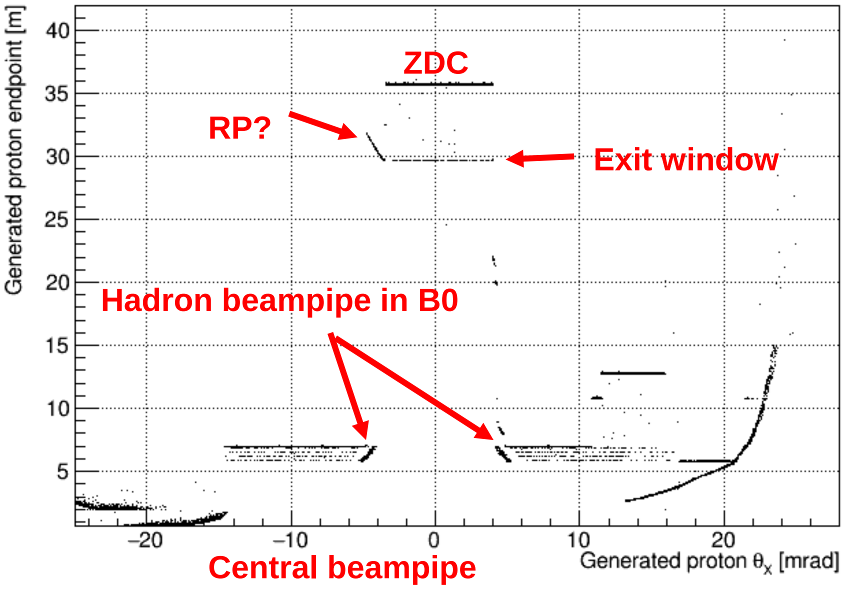
Hadron beampipe in B0

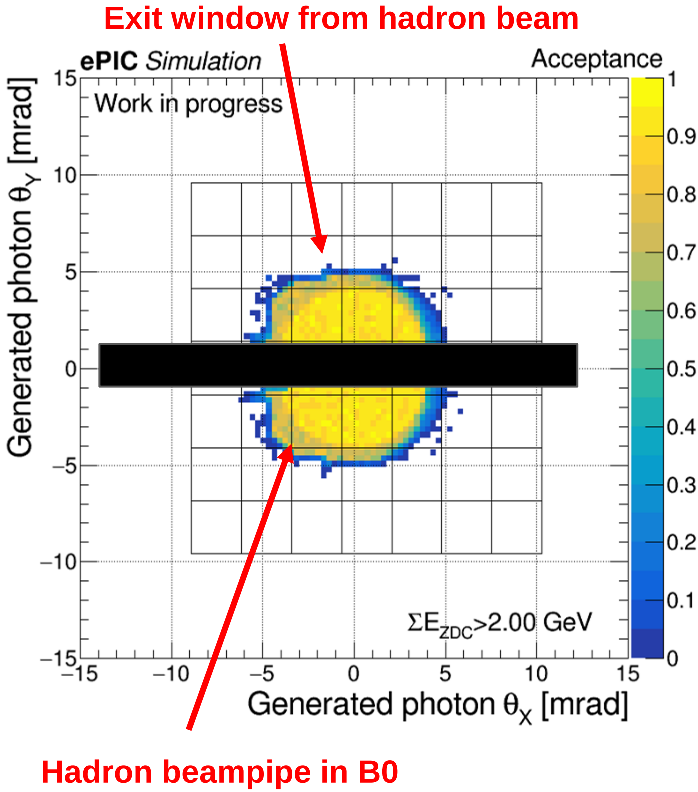
ZDC performance - photons

Acceptance in ZDC X-Y plane

- G4 simulation provides information of the photon endpoint (photon conversion), photons blocked by B0 beampipe



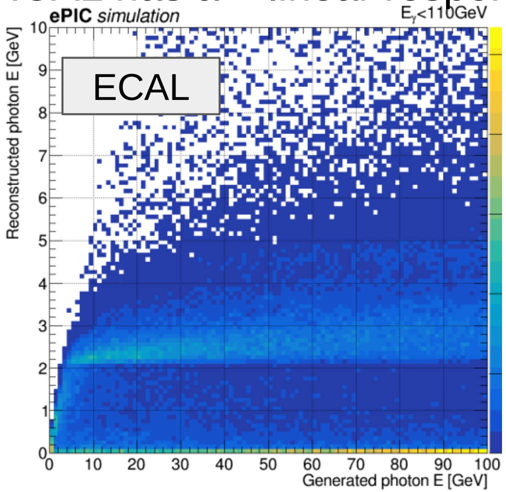


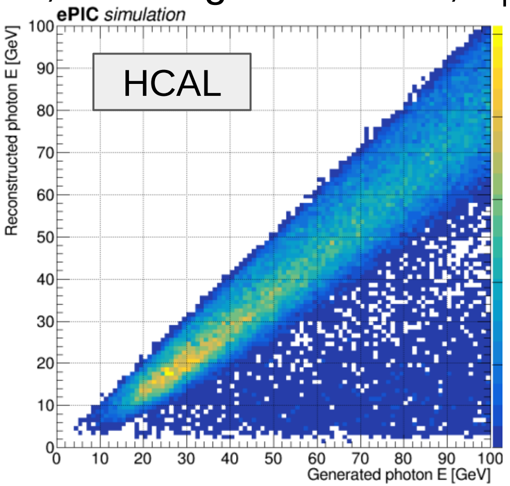


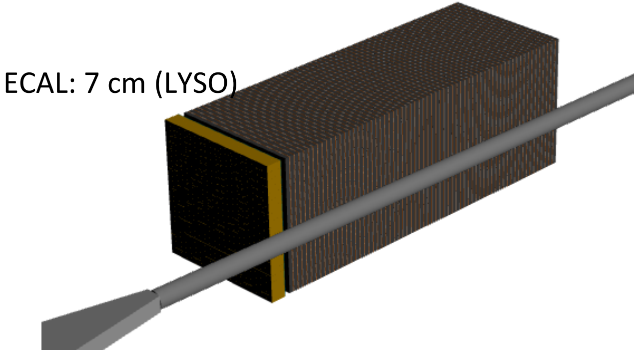
ZDC performance - photons

Energy response in ZDC:

- ECAL layer has low containment for large energy range
- Same issue as B0? (energy truncation)
- HCAL has a ~ linear response, with large resolution, $E_{RECO} \sim 0.75*E_{GEN}$







ZDC performance - photons

Acceptance in ZDC X-Y plane

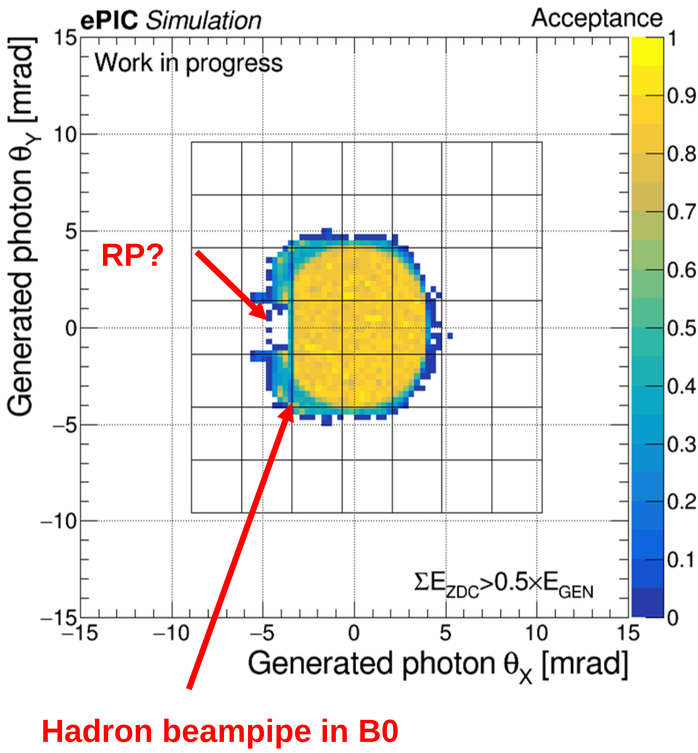
- Photon gun with E<110GeV and θ<5mrad
- Spatial photon acceptance defined as:

$$N(E_{B0ECAL}>E_{threshold})/N$$

- Set energy threshold in ZDC > 0.5 E_{GEN}

Observations

- All detected photons contained within the hadron beampipe inside the B0 magnet
- Small overlap with RP boxes
- Energy containment (7cm LYSO?)



Photon detection

Joint acceptance in B0+ZDC

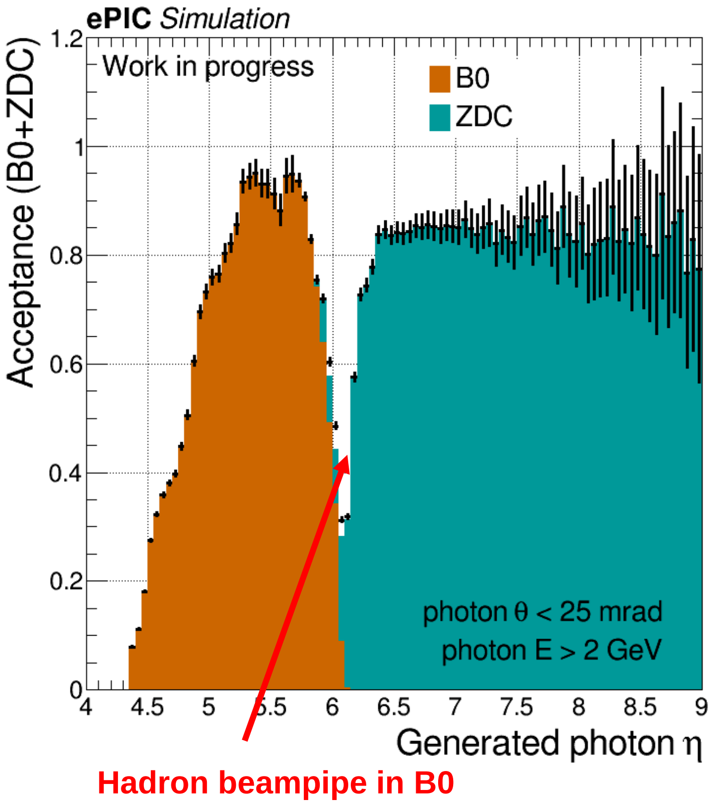
- Photon gun with E<110GeV and θ<25mrad
- Photon acceptance defined as:

  $N(E_{CAL}>E_{threshold})/N$

- Set energy threshold in the calorimeters > 0.5 E_{GEN}

Observations

- In overall a good coverage of the forward region
- Some loss in acceptance around hadron beampipe in B0 detector



B0ECAL performance - neutrons

Acceptance in B0 X-Y plane

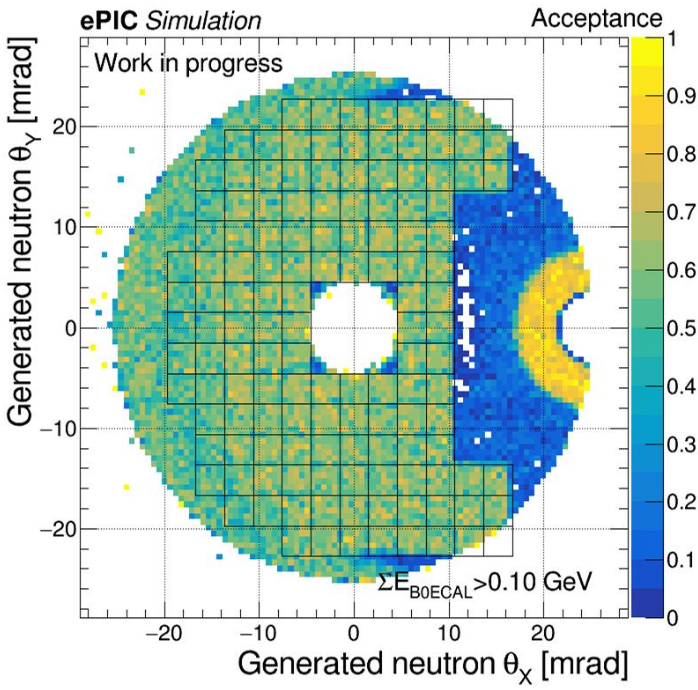
- Neutron gun with E<100GeV and 5<θ/mrad<25
- Spatial photon acceptance defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$

- Set energy threshold in B0EMCAL > 100 MeV

Observations

- Neutrons out-of-fiducial region deposit energy in the EMCAL, specially from the electron beampipe



B0ECAL performance - neutrons

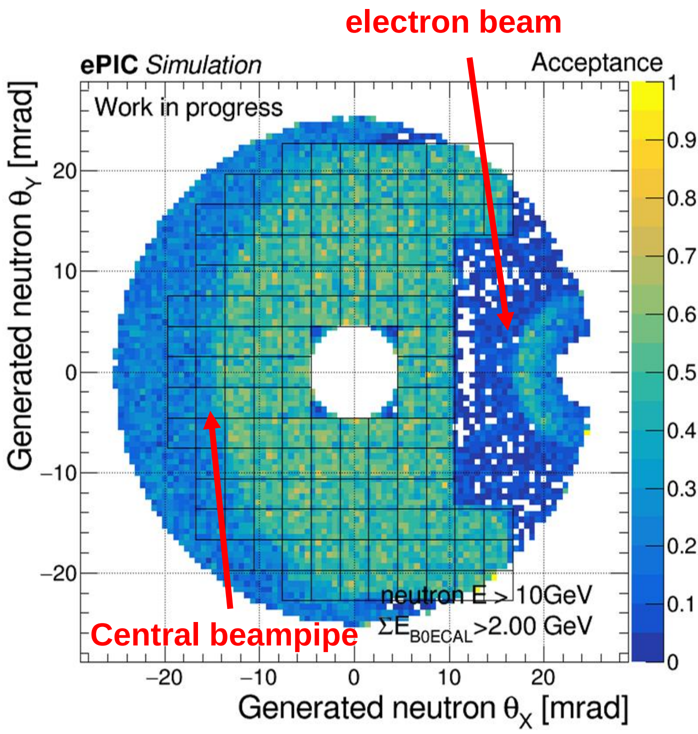
Acceptance in B0 X-Y plane

- Neutron gun with E<100GeV and 5<θ/mrad<25
- Spatial photon acceptance defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$
- Set energy threshold in B0EMCAL > 2 GeV

Observations

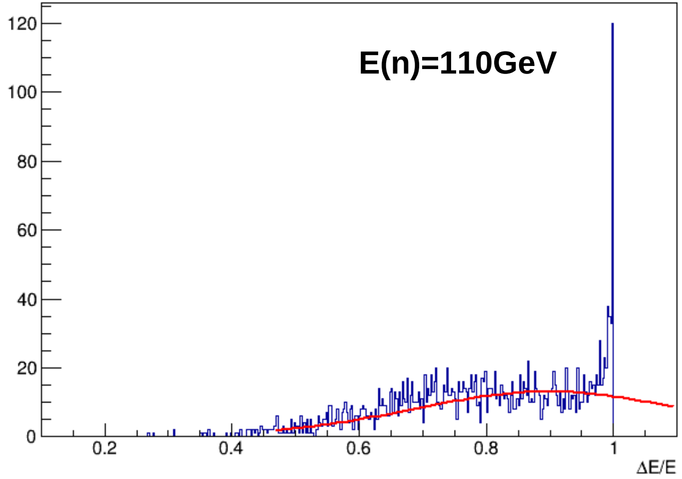
- Neutrons out-of-fiducial region deposit energy in the EMCAL, specially from the electron beampipe
- Overlap with central beampipe is also visible

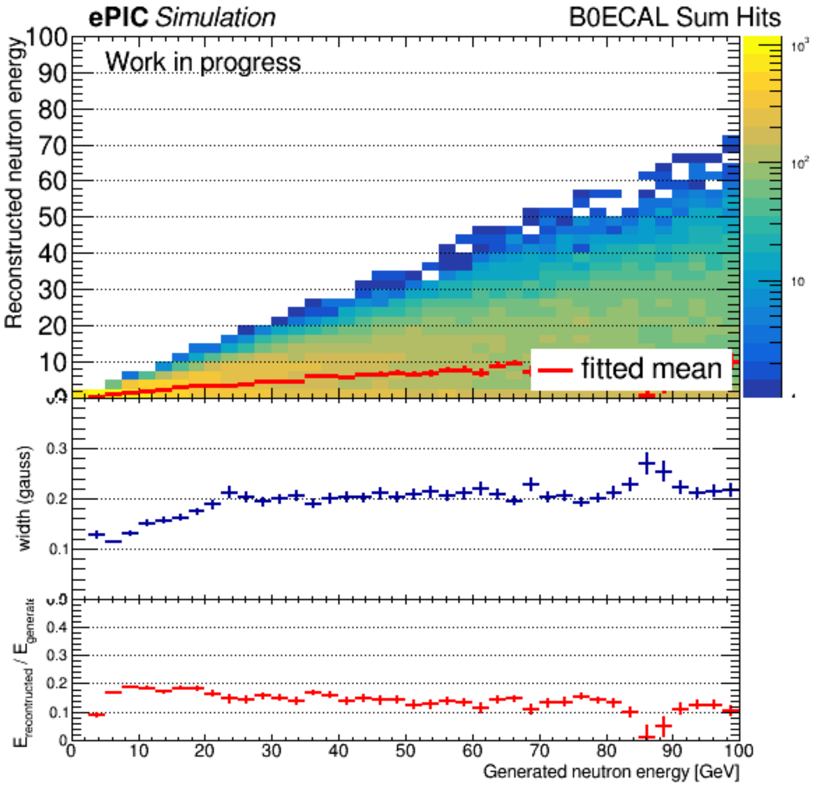


B0ECAL performance - neutrons

Energy response for θ<13mrad

- To study the entire detector's sensitive area, consider only neutrons interacting within the B0ECAL crystals (40%)
- NOTE: light yields are not included in the reconstruction





ZDC performance - neutrons

Acceptance in ZDC X-Y plane

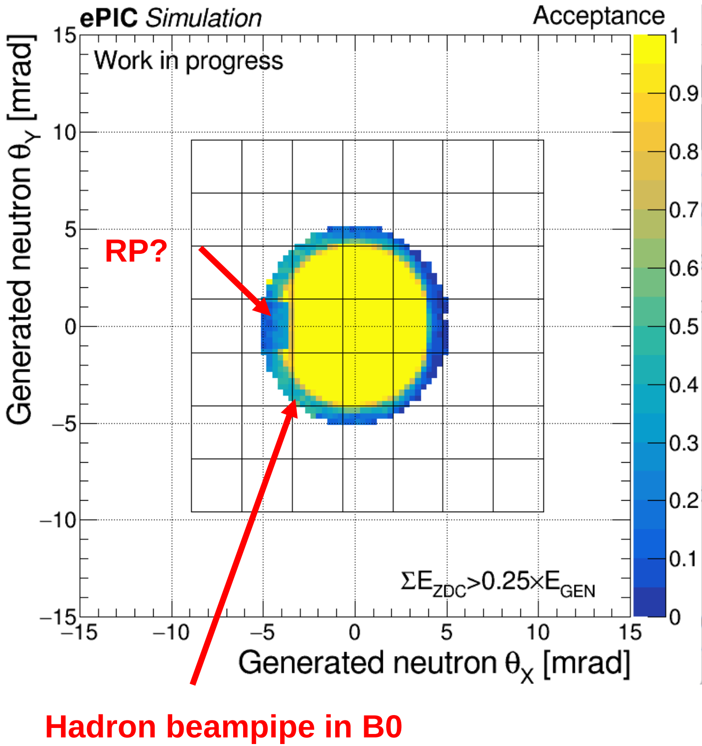
- Neutron gun with E=110GeV and θ<5mrad
- Spatial photon acceptance defined as:

  $N(E_{ZDC}>E_{threshold})/N$

- Set energy threshold in ZDC > 0.25 E_{GEN}

Observations

- All detected photons contained within the hadron beampipe inside the B0 magnet
- Small overlap with RP boxes



Neutron detection

Joint acceptance in B0+ZDC

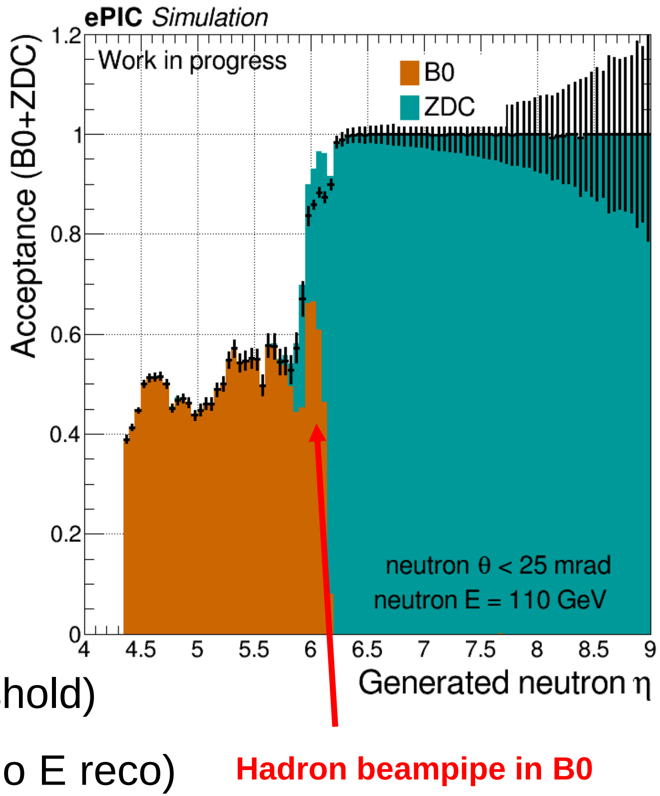
- Photon gun with E=110GeV and θ<25mrad
- Photon acceptance defined as:

  $N(E_{CAL}>E_{threshold})/N$

- Set energy threshold in the calorimeters > 2GeV

Observations

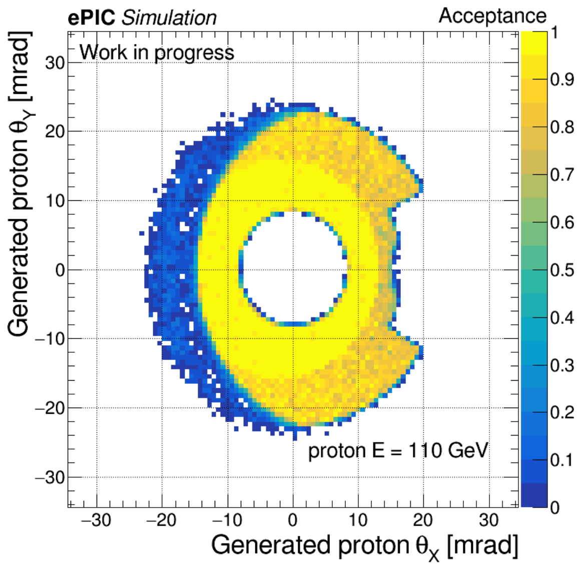
- In overall a good coverage of the forward region
- Energy reconstructed in B0 is limited (use loose threshold)
- Some neutron tagging can be done in B0 detector (*no E reco)

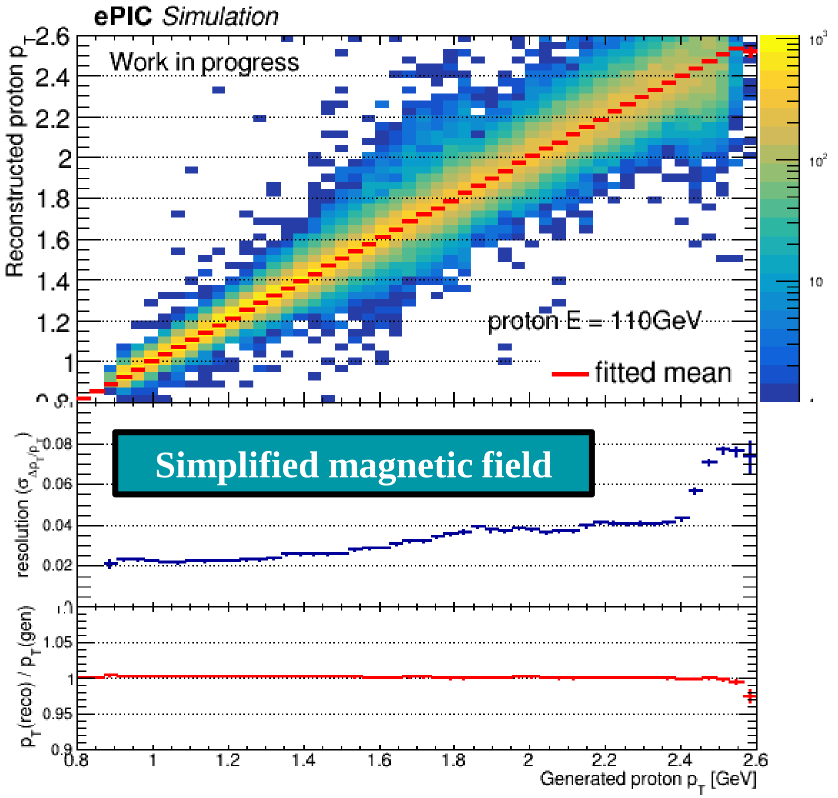


B0Tracker performance - protons

Track reconstruction

- 110 GeV protons generated with 5 < θ/mrad < 25.
- Overlap with central beampipe causes large losses in the acceptance



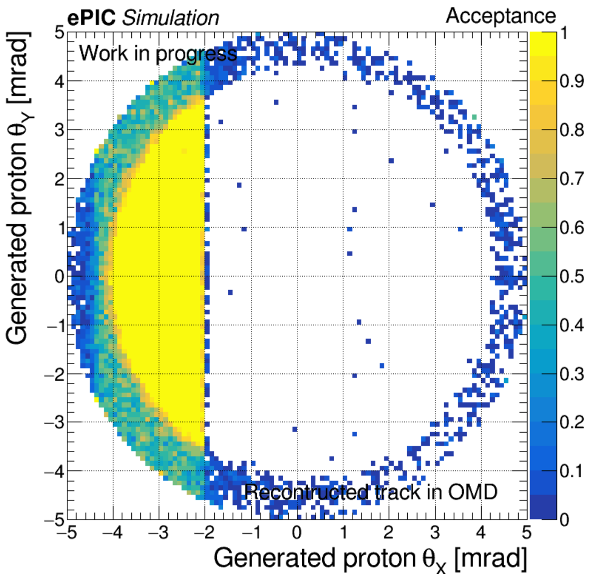


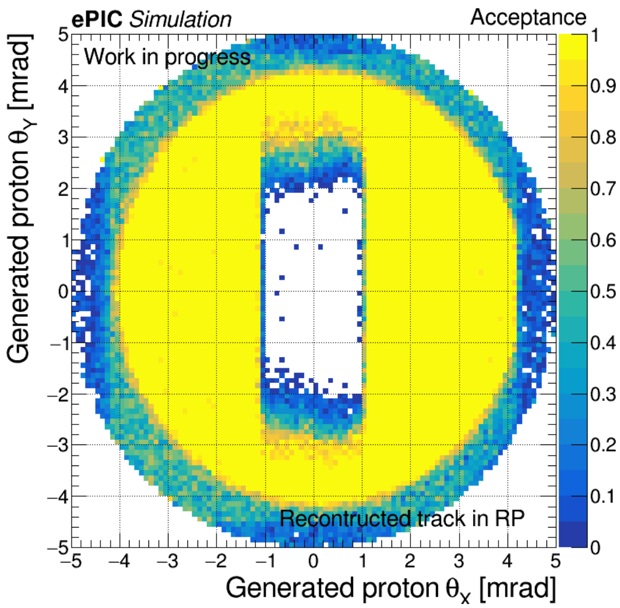
NEW: **Resolution pT ~ 2-4%** (default was 4-6%)

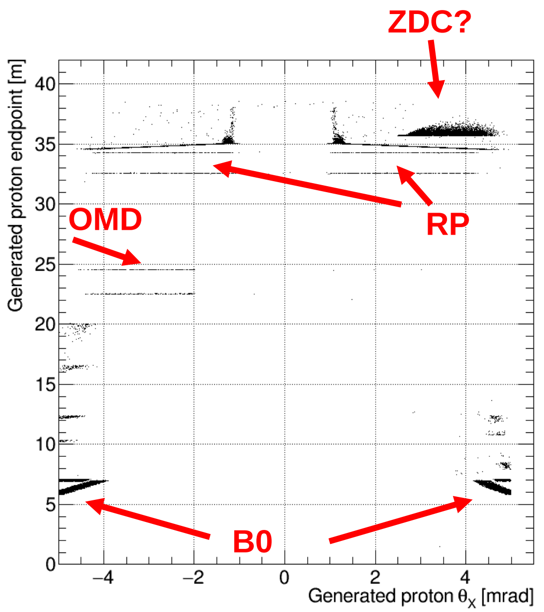
RP+OMD performance - protons

Track reconstruction in the forward tracker

- 275 GeV protons generated with θ < 5 mrad
- Acceptance: N(reco track)/N



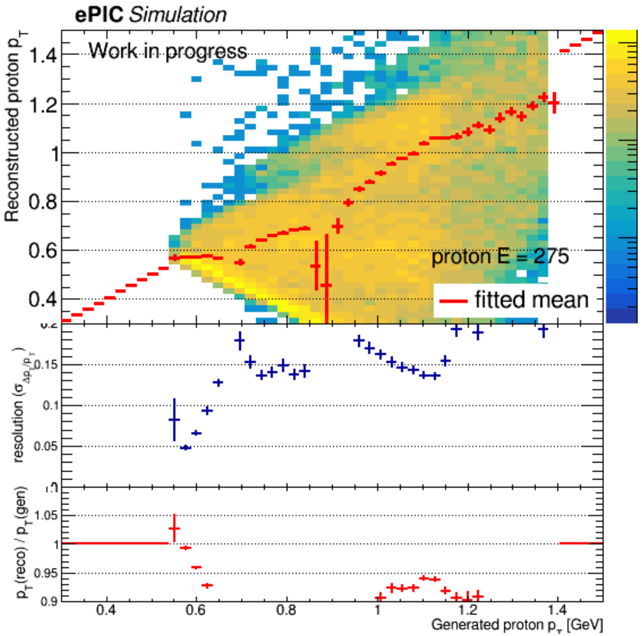


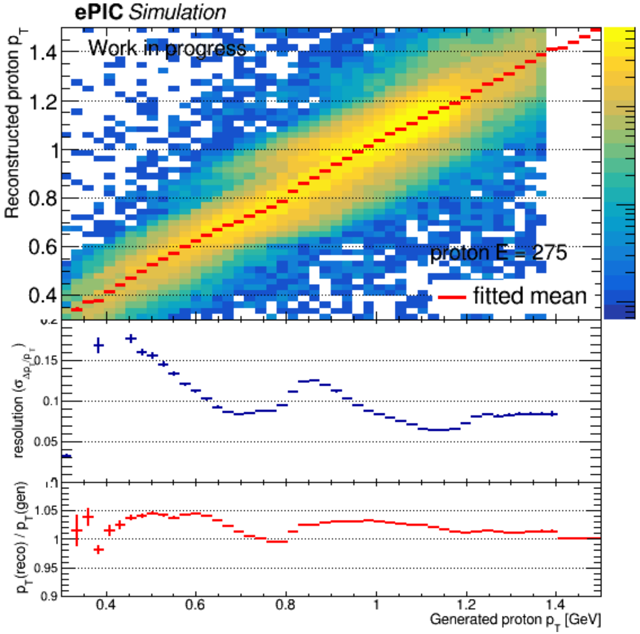


RP+OMD performance - protons

Track reconstruction in the forward tracker

- 275 GeV protons generated with θ < 5 mrad
- Acceptance: N(reco track)/N
- Test both OMD/RP





RP+OMD performance - protons

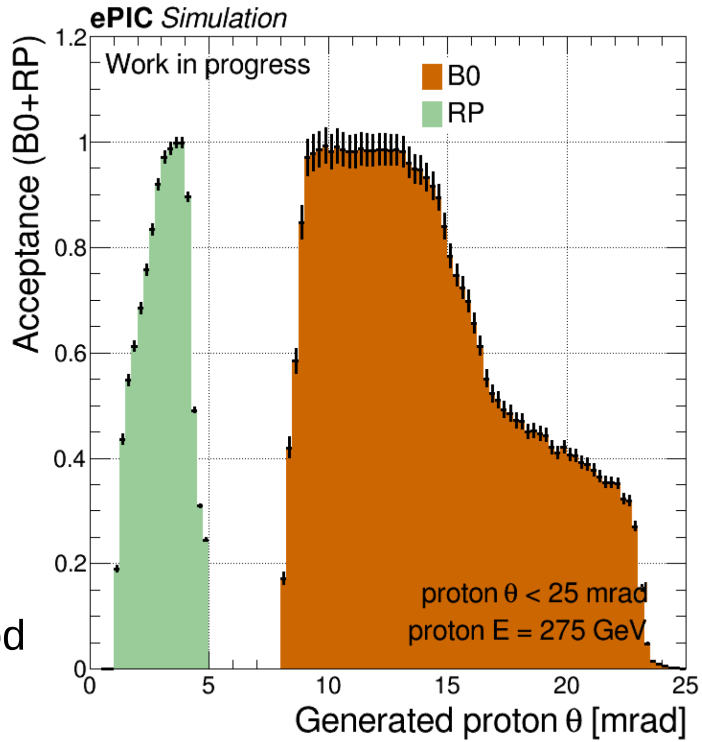
Joint acceptance in B0+RP

- Proton gun with E=275 GeV and θ<25mrad
- Photon acceptance defined as:

$$N(N_{TRK}>0)/N$$

Observations

- B0 tracking acceptance starts at θ~8 mrad
- The coverage of the forward region expected to be good
- PT reconstructed works for both subsystems



Summary

Summary

- B0ECAL geometry is fully configurable and is ready to be merged with the main branch
- The interplay with all Far-Forward detectors was studied (can be added to pre-TDR plots)

Results for B0 detectors

- Some overlap with the central beampipe FIXME
- Clustering algorithm for Crystals show saturation, need to be fixed (EICRECON) FIXME

Photons: good acceptance down to low energy thresholds, impact on the resolution from the light yields only effects low energy region (up to a few GeV)

Charged particles (protons): improved resolution with increased space between the layers

Neutrons: 50% detection efficiency, with challenging tagging (Pulse/Cluster shapes?)

Backup

Technical info

Branches used in the analysis:

MCParticles: Particle gun - generator information

B0ECalHits: B0 EMCAL hits

B0ECalClusters: B0 ECAL Clusters (EICRECON)

ReconstructedChargedParticles: Charged particles. After rotation particles with eta>4 are assigned to B0 tracker

ForwardOffMRecParticles: OMD tracks

ForwardRomanPotRecParticles: RP tracks

EcalFarForwardZDCClusters: ZDC ECAL

HcalFarForwardZDCClusters: ZDC HCAL

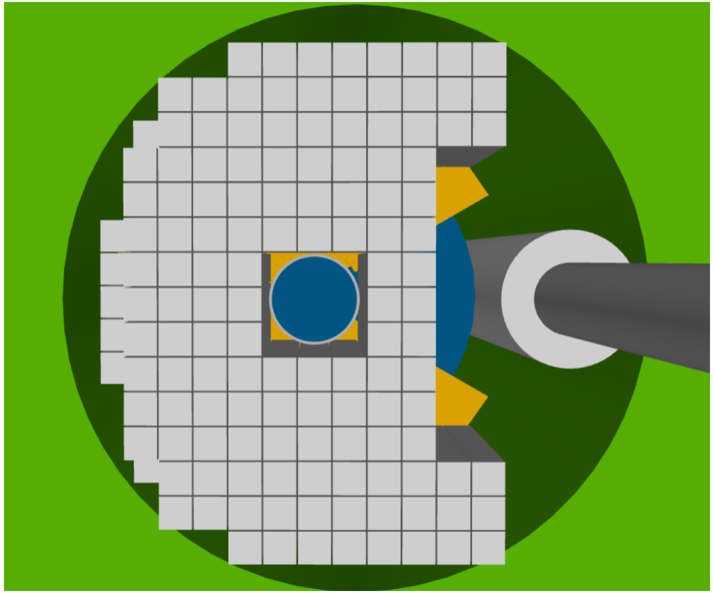
Simulation status – B0 geometry

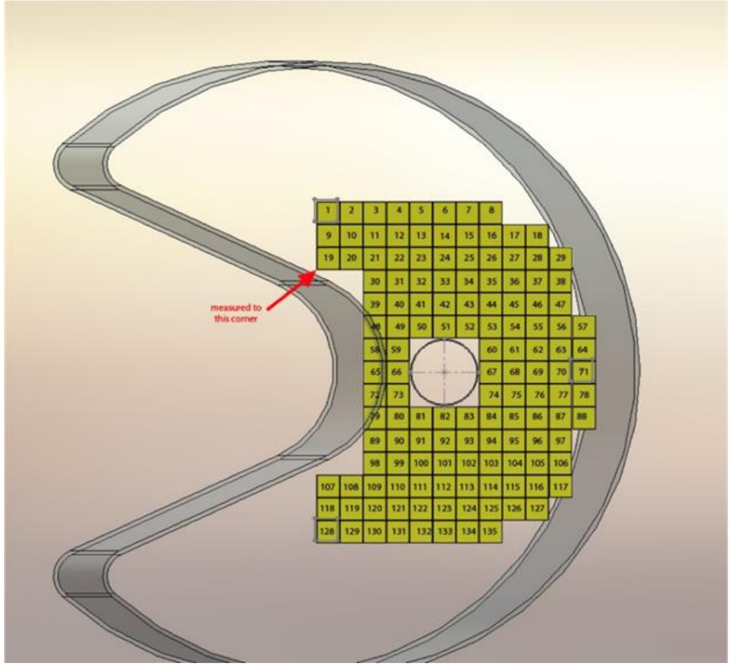
- Default geometry (master branch on Aug 19):

```
        Hadron magnets -- with BIG FLIP and 50cm shift

        ##
    ##   name     center_x center_y center_z rin(z-in) rin(z-out)  dout    length   angle      B       gradient
    ##              [m]      [m]      [m]      [m]        [m]       [m]      [m]   [mrad]     [T]      [T/m]
    ##

         B0PF     -0.145779265   0.0     6.400000000   0.2000    0.2000    0.5000   1.200   0.00      1.1840539      0.000
        B0PFq     -0.145779265   0.0     6.400000000   0.2000    0.2000    0.5000   1.200   0.00      0.0000000      -8.12238283
            B0APF     -0.210480535   0.0     8.198946015   0.0430    0.0430    0.1860   0.600   -25.0     3.4314469      0.000
        Q1APF     -0.254342857   0.0     9.628296939   0.0560    0.0560    0.2120   1.460   -19.5     0.0000000    -72.608
        Q1BPF     -0.312840809   0.0     11.56243847   0.0780    0.0780    0.2560   1.610   -15.0     0.0000000    -63.24525402
         Q2PF     -0.407362293    0.0    14.66604545   0.1315    0.1315    0.3620   3.800   -14.8     0.0000000     36.88301623
         B1PF     -0.503165042   0.0     18.56486896   0.1350    0.1350    0.3700   3.000   -34.0     3.4479890      0.000
        B1APF     -0.612903791   0.0     21.31298439   0.1680    0.1680    0.4360   1.500   -25.0     2.7000000      0.000
        B2APF     -1.491239596   0.0     40.74293743   0.2       0.2       0.5      4.4    -28.22    -4.7890142      0.000
```

Simulation status – B0 geometry

- Matching CAD drawing





Photon detection

Joint acceptance in B0+ZDC

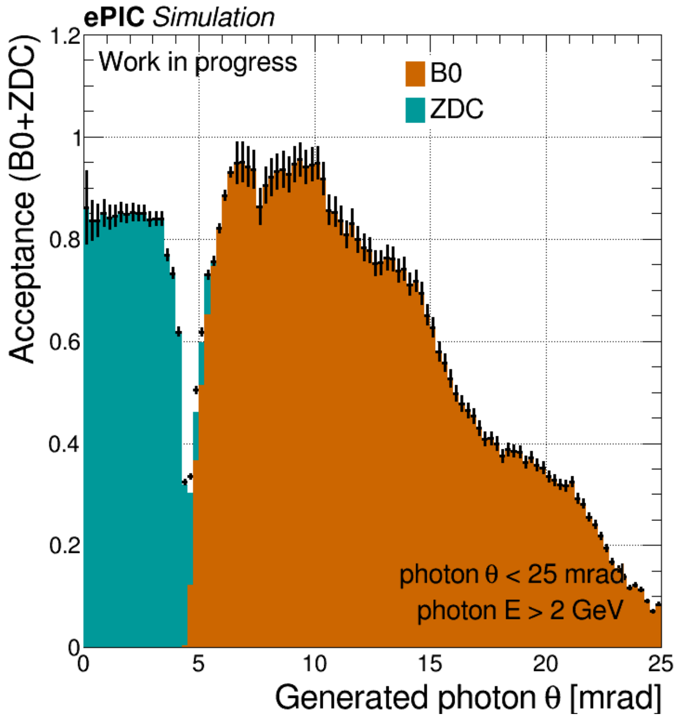
- Photon gun with E<110GeV and θ<25mrad
- Photon acceptance defined as:

  $N(E_{B0ECAL} > E_{threshold})/N$

- Set energy threshold in EMCAL > 0.5 E_{GEN}

Observations

- In overall a good coverage of forward region
- Some loss in acceptance around hadron beampipe in B0 detector



B0ECAL performance - photons

Energy response for θ<13mrad

For each 2x2 cm^2 crystal we use 3+1 sensors of different pitch size

- Realistic energy response is given by the following sequence:

  N photons in PbOW crystal / mm^2 = 145.75 / GeV [1]

  1. Sample N photons from Poi(N_{SiPM}=145.75*400), randomly distribute among the four sensors, with 6x6mm^2 SiPM: n~Binomial(N*PDE,0.09) (the largest effect on the resolution)
  2. Apply PDE of 18% for 10PS, 32% for 15PS, and saturation: ADC = N_{MAX}(1-EXP(-n*pde/N_{MAX})), N_{MAX}=$(6/PS)^2$

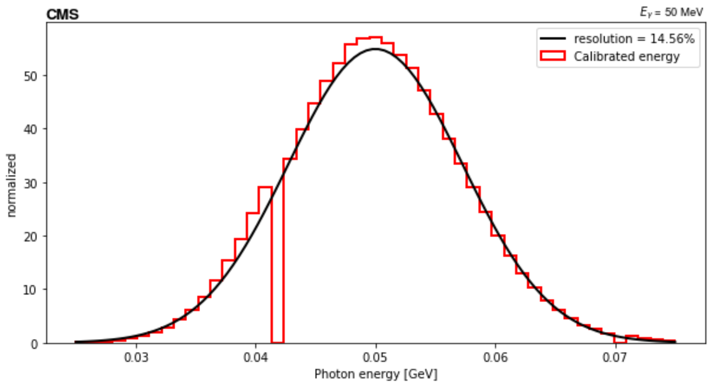
     E_{MAX}(15PS) = N_{MAX}/(145.75*36*0.32) = 95 GeV

     E_{MAX}(10PS) = N_{MAX}/(145.75*36*0.18) = 170 GeV

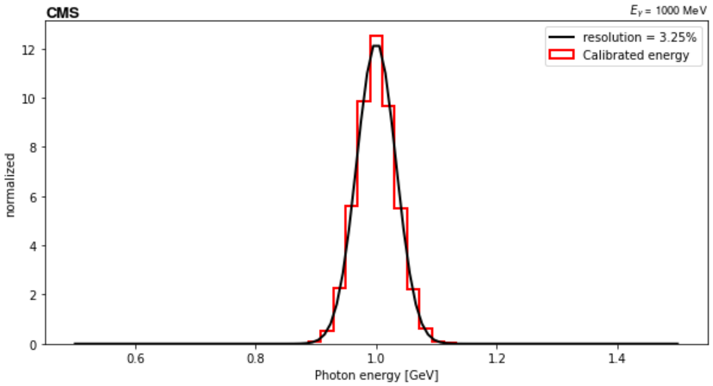
  1. Apply calibration factor ADC → GeV

     C_10PS = ADC * (1 / 145.75*36*0.18)

number of photons / sensor = 47.22



number of photons / sensor = 944.46



[1] 100% reflectivity, 100ph/MeV, https://indico.bnl.gov/event/24129/contributions/93860/attachments/55755/95323/VZhezher_20240709.pdf

B0ECAL performance - photons

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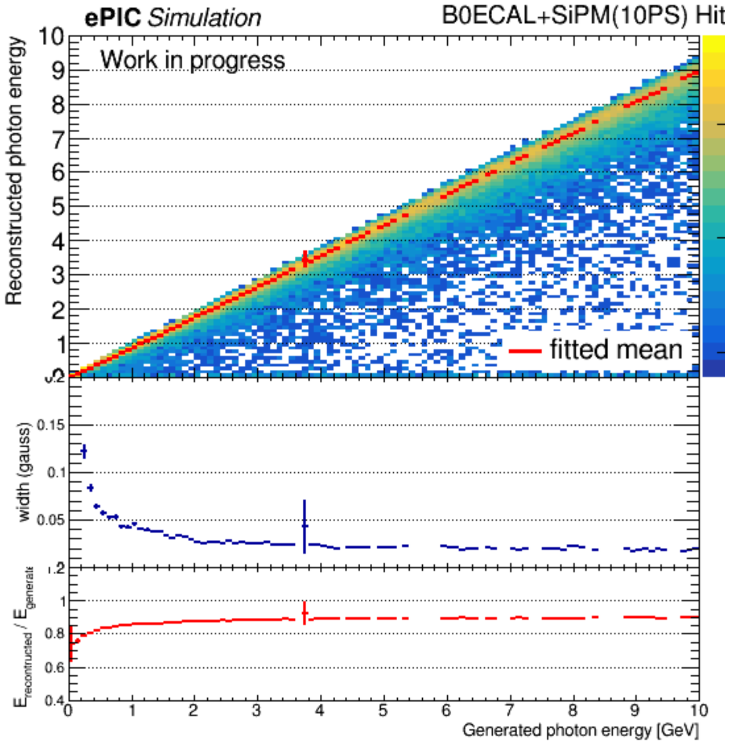

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B0ECAL performance - photons

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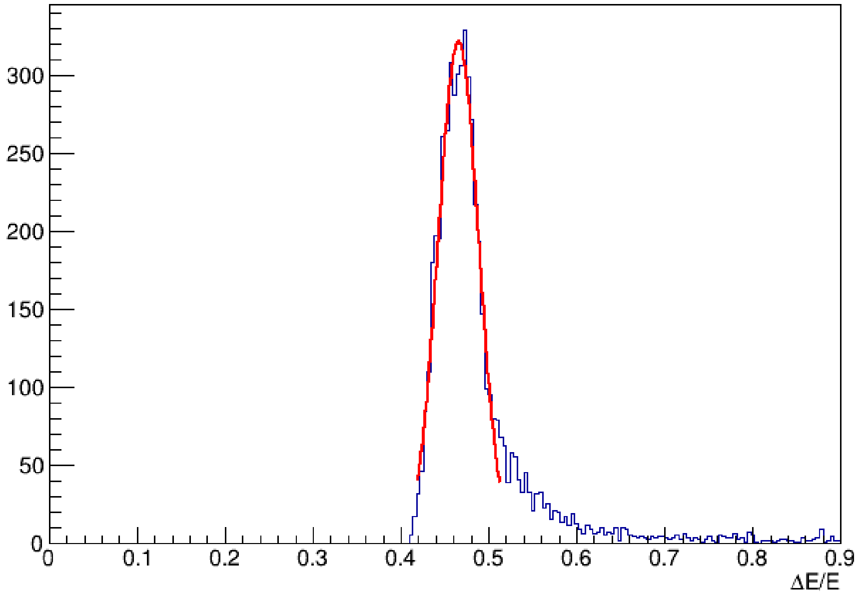
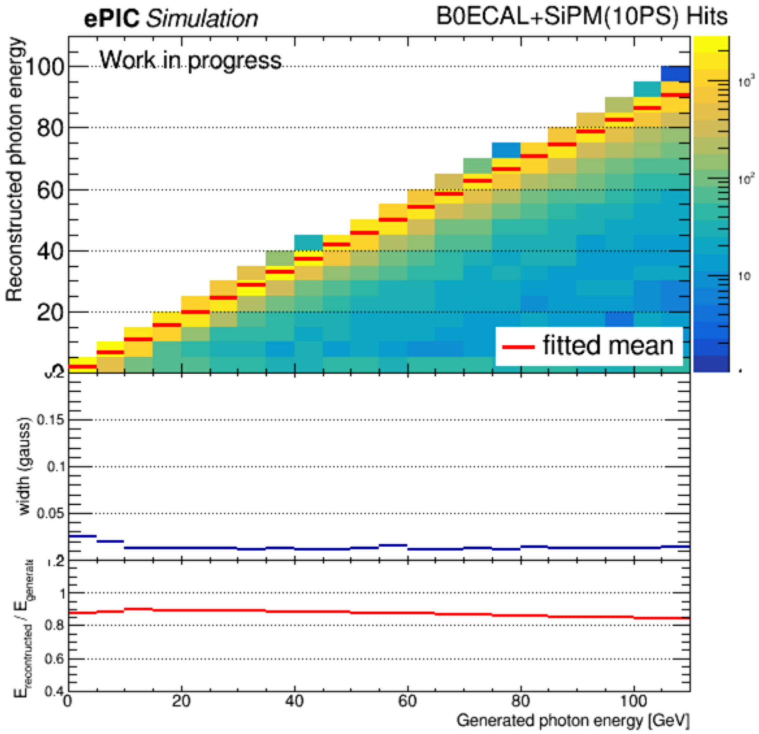


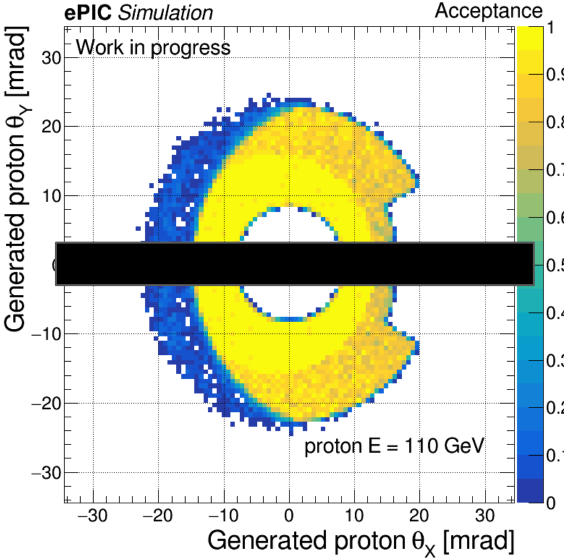


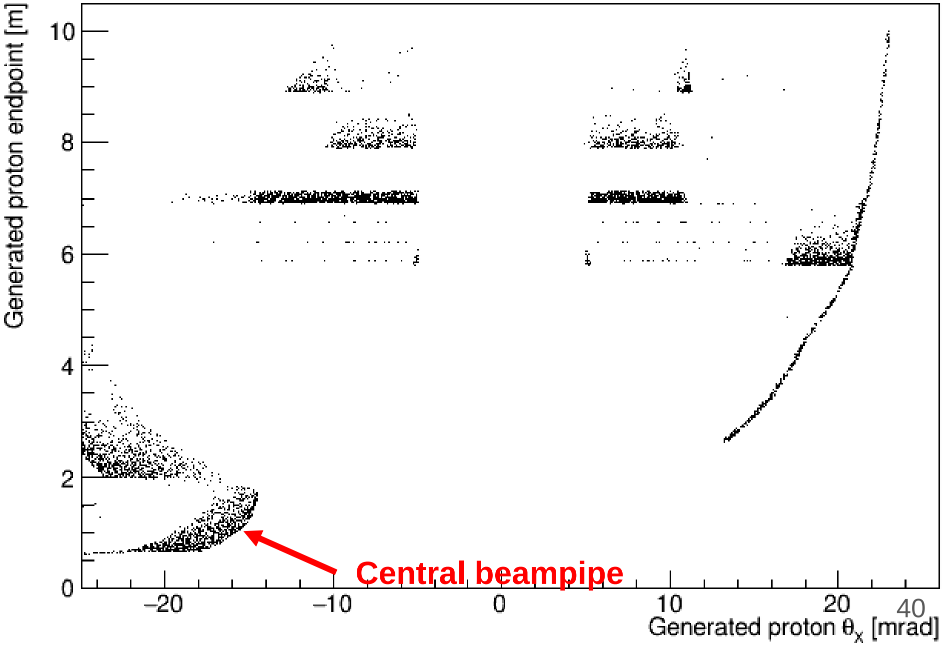
[1] 100% reflectivity, 100ph/MeV, https://indico.bnl.gov/event/24129/contributions/93860/attachments/55755/95323/VZhezher_20240709.pdf

B0Tracker performance - protons

Momentum resolution

- 110 GeV protons generated with 5 < θ/mrad < 25.
- Overlap with central beampipe causes large losses in acceptance





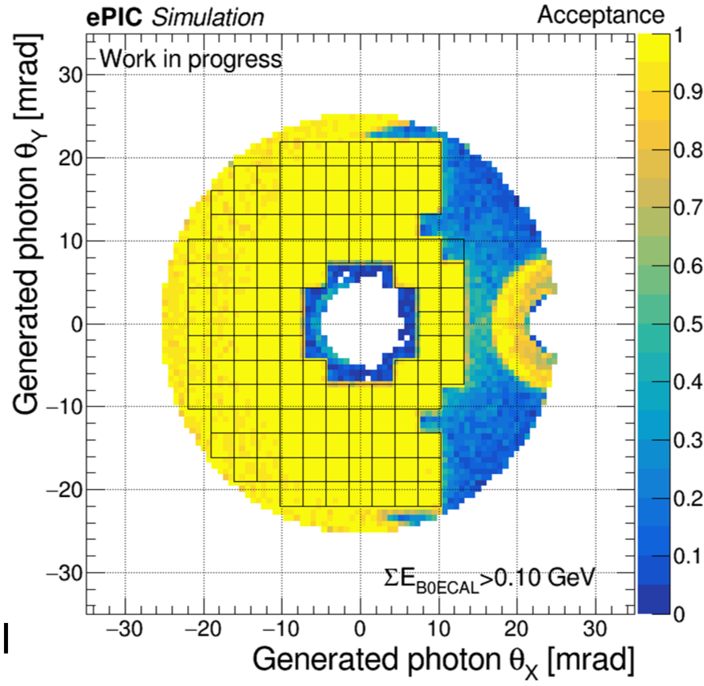
B0 performance - photons

Acceptance in B0 X-Y plane

- Spatial photon acceptance tested with particle gun, and defined as:

  $N(E_{B0ECAL}>E_{threshold})/N$

- Set energy threshold in EMCAL > 100 MeV



Observations

- Photon out-of-fiducial region deposit energy in EMCAL
- Caused by photon conversion in earlier detector's material

B0 performance - photons

Acceptance in B0 X-Y plane

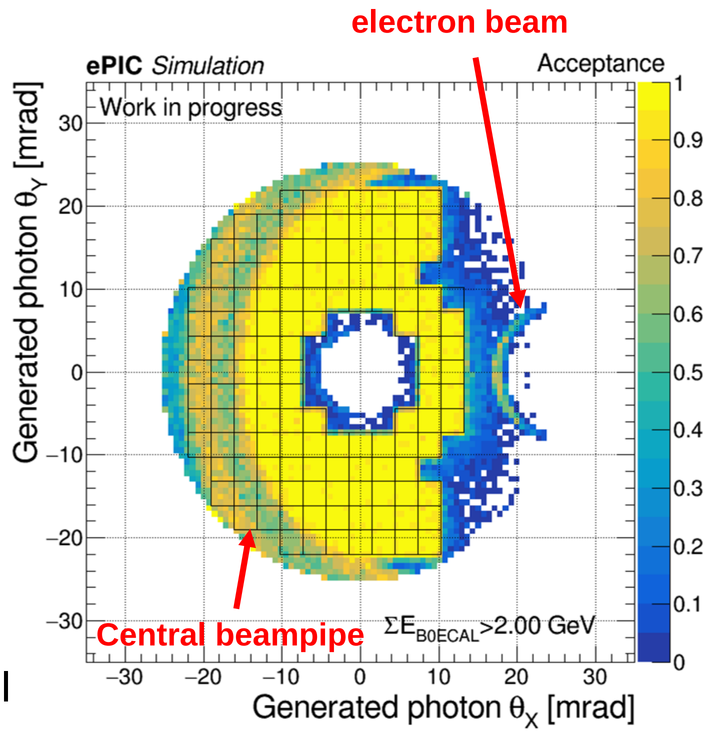
- Spatial photon acceptance tested with particle gun, and defined as:

  $N(E_{B0ECAL} > E_{threshold})/N$

- Set energy threshold in EMCAL > 2 GeV

Observations

- Photon out-of-fiducial region deposit energy in EMCAL
- Caused by photon conversion in earlier detector's material



B0 performance - photons

Acceptance in B0 X-Y plane

- G4 simulation provides information of the photon endpoint (photon conversion), issue with the central beampipe persist