Forward detectors with ePIC simulation (updates)

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Ben-Gurion University of the Negev

Motivation

- In the past few month a few updates were made with the FF simulations, which impacts many processes studied at the EIC, which some of our interests:
  - Background vetoing program (veto incoherent VM processes by tagging ion decay fragments)
  - Soft photons (photons from ion deexcitation in quasi-coherent scattering)
  - Nucleon tagging (proton in ep and protons/neutrons in eA)
- Today we provide a feedback on single particle response of the Far-Forward detector array in ePIC simulation (B0, RP, ZDC, OMD)

Main updates

- New ZDC geometry (PR610+ PR534)
- Forward beampipe + ZDC exit window (PR665)
- Beampipe is filled with vacuum (PR492 + **NEW UPDATE**)
- B0 detector crystals being harmonized with CAD drawing (**NEW UPDATE**)

+ Updates that I'm not aware of …

Beampipe with vacuum

Code

Far-Forward detector array components are defined in

https://github.com/eic/epic/blob/main/compact/far_forward/default.xml

```
<lccdd>

  <include ref="ion_beamline.xml" />
  <include ref="beampipe_hadron_B0.xml" />
  <include ref="electron_beamline.xml" />
  <include ref="B0_tracker.xml"/>
  <include ref="B0_ECal.xml"/>
  <include ref="offM_tracker.xml"/>
  <include ref="ZDC_SiPMonTile.xml"/>
  <include ref="ZDC_Crystal_LYSO.xml"/>
  <include ref="roman_pots_eRD24_design.xml"/>
  <include ref="vacuum.xml"/>
  <include ref="magnets.xml"/>

</lccdd>
```

[ion_beamline.xml]:

Forward Magnets, with coordinates defined in [definitions.xml]

[beampipe_hadron_B0.xml]:

beampipe in B0 + FF beampipe from B1APF to B2PF, filled with vacuum, with ZDC exit window.

[vacuum.xml]:

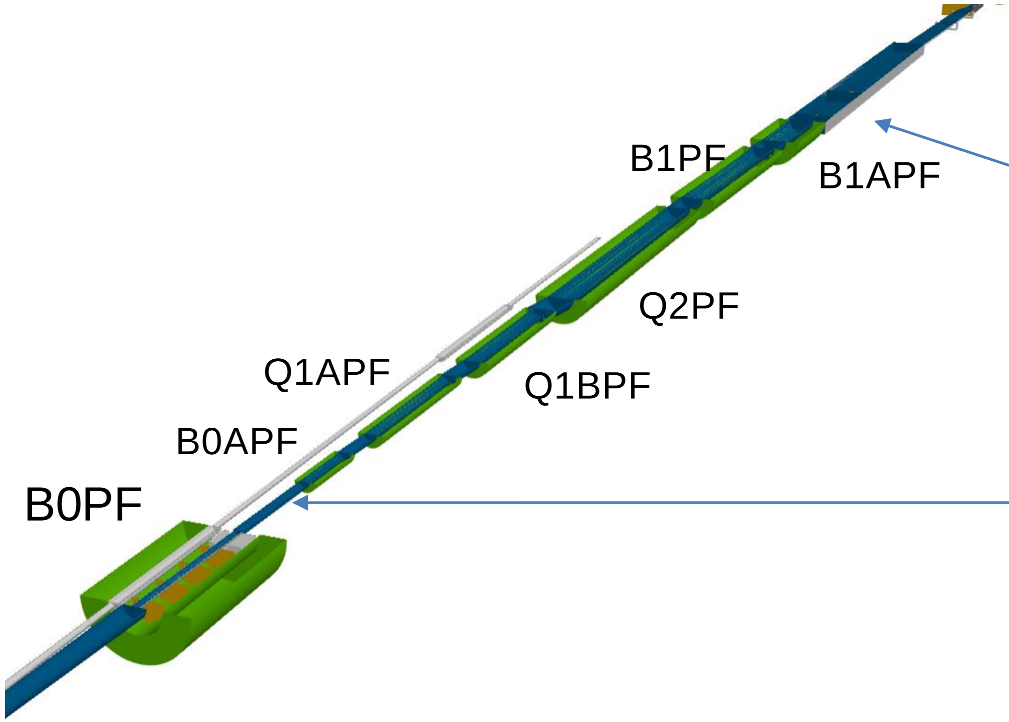
vacuum between forward insert and B1APF

Beampipe with vacuum

Code

Far-Forward detector array components are defined in

https://github.com/eic/epic/blob/main/compact/far_forward/default.xml



[ion_beamline.xml]:

Forward Magnets, with coordinates defined in [definitions.xml]

B0PF, B0APF, Q1APF, Q2BPF, Q2PF, B1PF, B1APF, B2PF

[beampipe_hadron_B0.xml]:

beampipe in B0 + FF beampipe from B1APF to B2PF, filled with vacuum, with ZDC exit window.

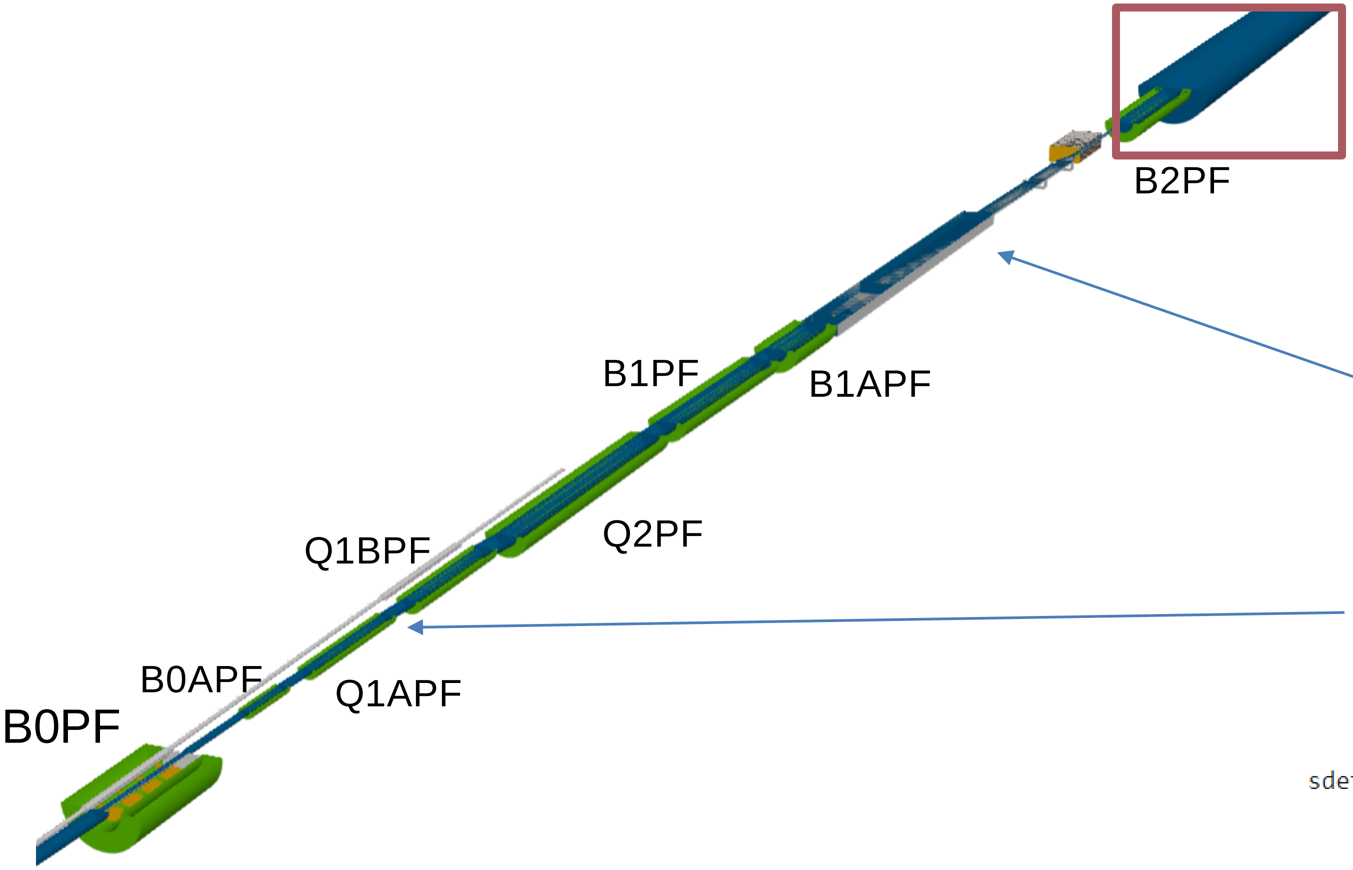
[vacuum.xml → magnetVacuumFF.cpp]:

vacuum between forward insert and B1APF

Beampipe with vacuum

Code (updated)

New PR with vacuum filled from z~40 to 100 m (https://github.com/eic/epic/pull/720)



[ion_beamline.xml]:

Forward Magnets, with coordinates defined in [definitions.xml]

B0PF, B0APF, Q1APF, Q2BPF, Q2PF, B1PF, B1APF, B2PF

[beampipe_hadron_B0.xml]:

beampipe in B0 + FF beampipe from B1APF to B2PF, filled with vacuum, with ZDC exit window.

[vacuum.xml → magnetVacuumFF.cpp]:

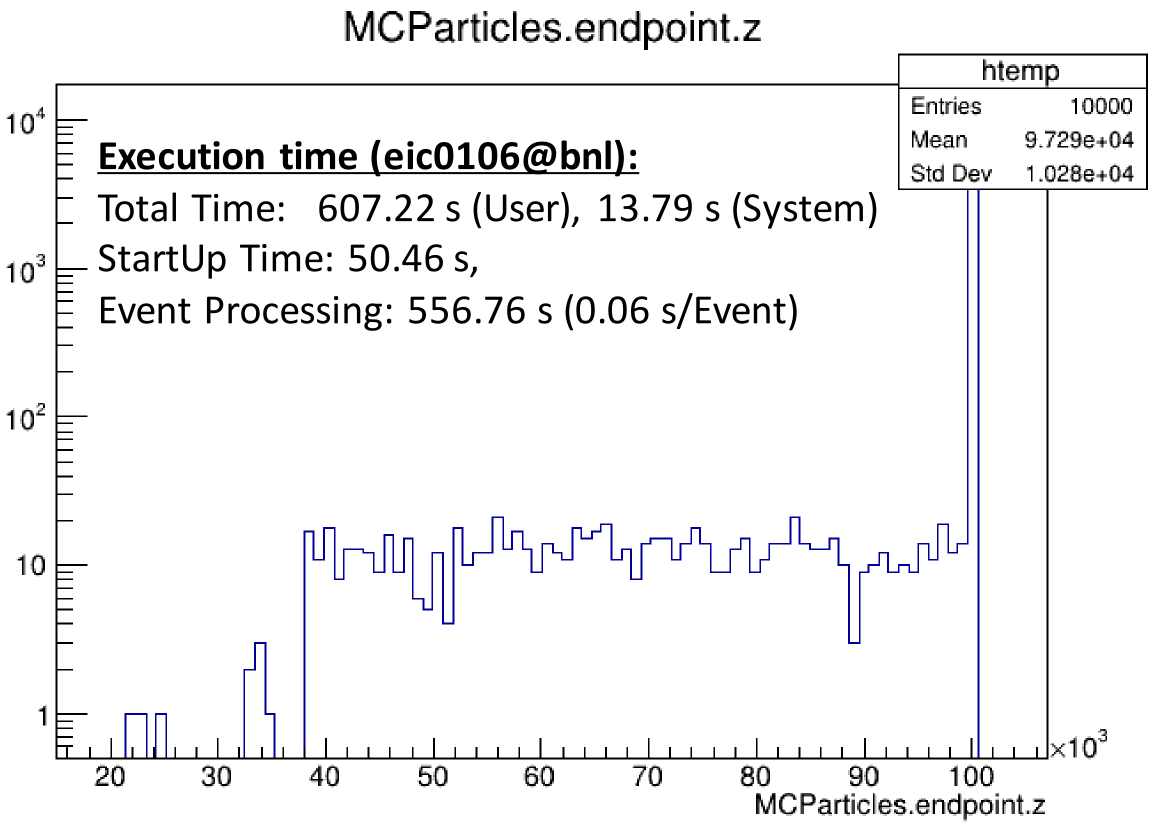
vacuum between forward insert and B1APF **+ new vacuum from B2PF (including) until Z=100m**

```
sdet.setAttributes(det, vpiece, x_det.regionStr(), x_det.limitsStr(),
                   "InvisibleNoDaughters"); // make invisible instead of AnlBlue
```

Execution time

- Generate 41GeV protons, (the steering file shown in the backup)

ddsim --steeringFile test.py -N 10000 --compactFile $DETECTOR_PATH/$DETECTOR_CONFIG.xml --outputFile edm4hep.root

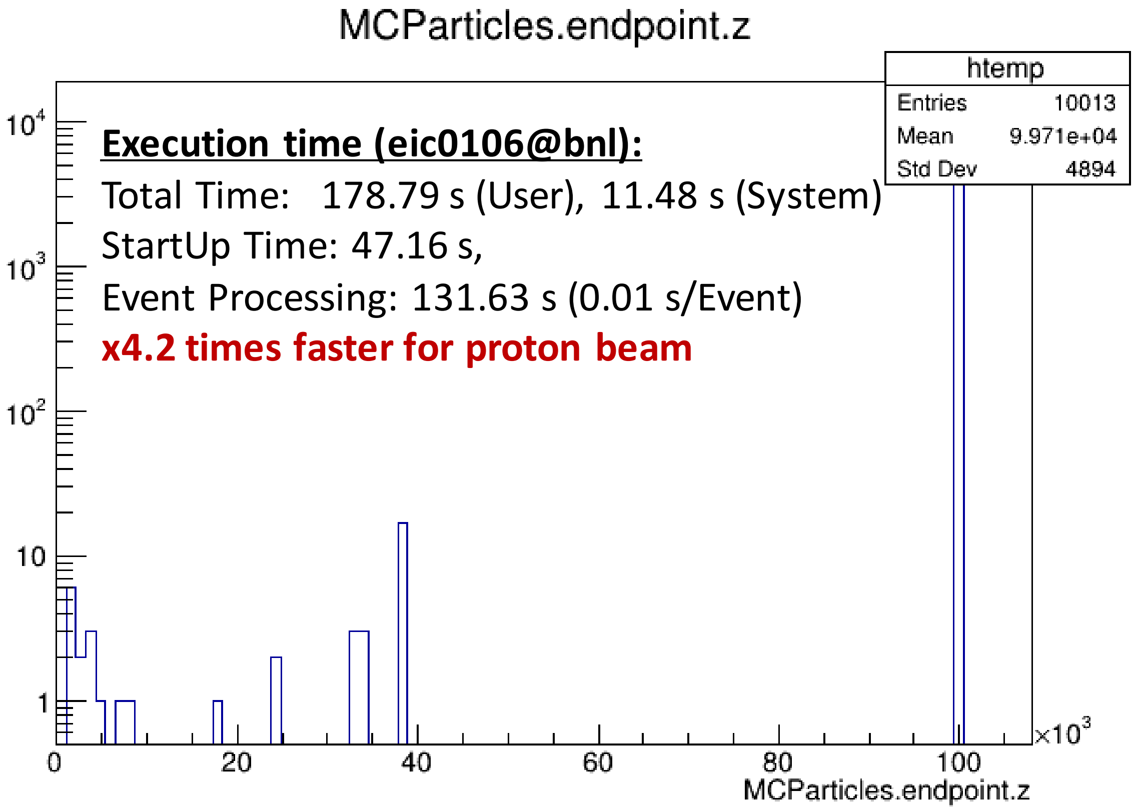


Execution time (eic0106@bnl):

Total Time: 607.22 s (User), 13.79 s (System)

StartUp Time: 50.46 s,

Event Processing: 556.76 s (0.06 s/Event)



Execution time (eic0106@bnl):

Total Time: 178.79 s (User), 11.48 s (System)

StartUp Time: 47.16 s,

Event Processing: 131.63 s (0.01 s/Event)

x4.2 times faster for proton beam

Execution time

- Generate 41GeV protons, (the steering file shown in the backup)

x4.2 times faster for proton beam

- Coherent J/psi in ePb

No ions: 2 s/Event, Standard: 180 s/Event, this RP: 15 sEvent

- Incoherent J/psi in ePb (ion dissociation)

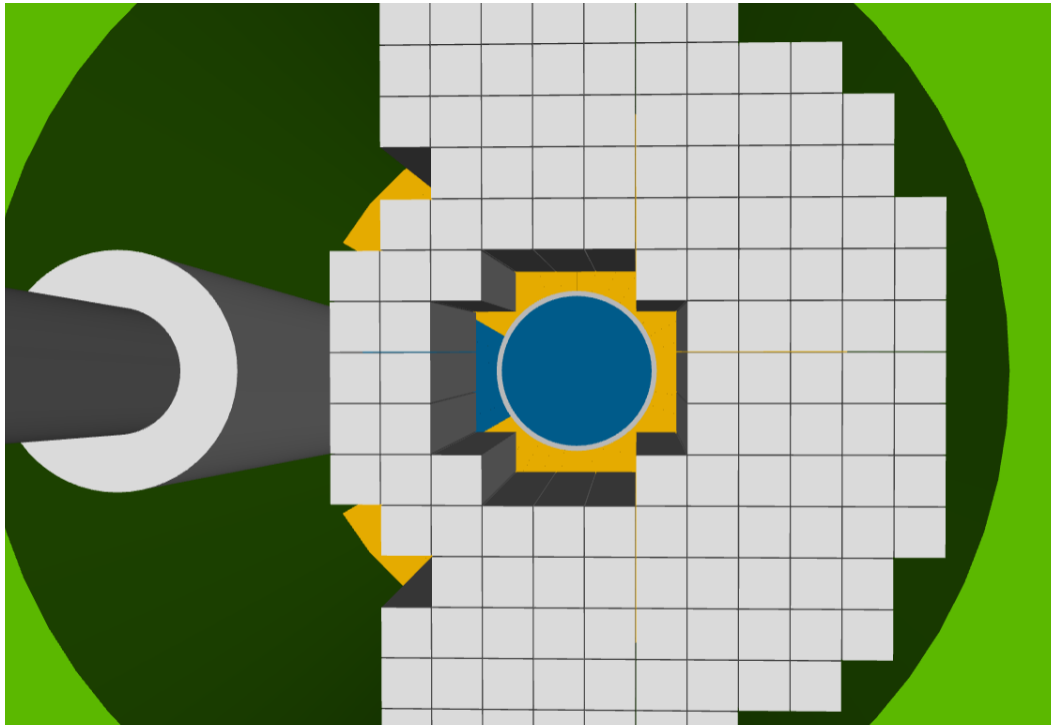
Standard: 310 s/Event, this RP: 30 sEvent

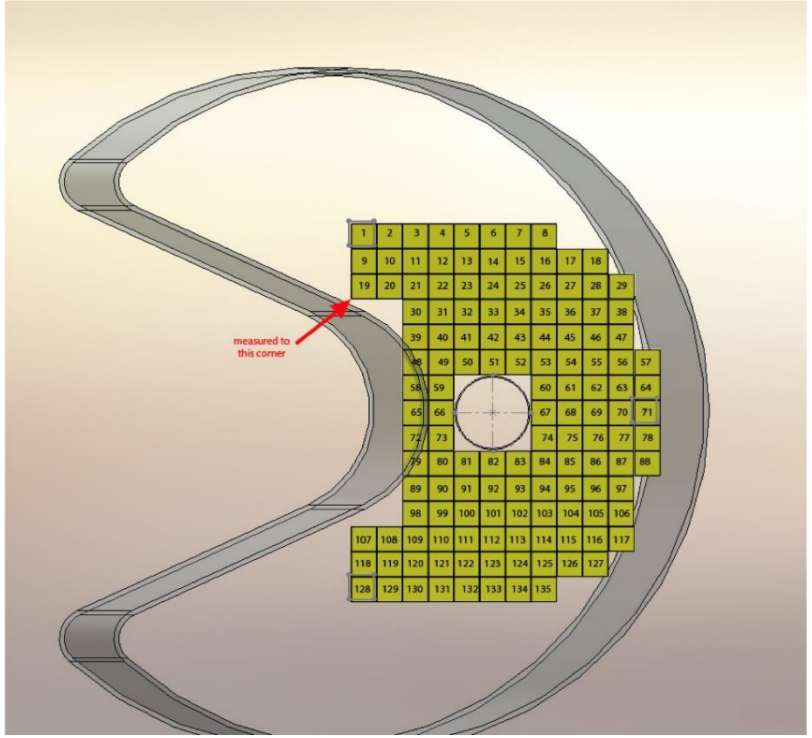
x10 times faster for Pb beam

- We like to merge this PR as it improves simulation execution time for physics studies https://github.com/eic/epic/pull/720

B0 geometry update

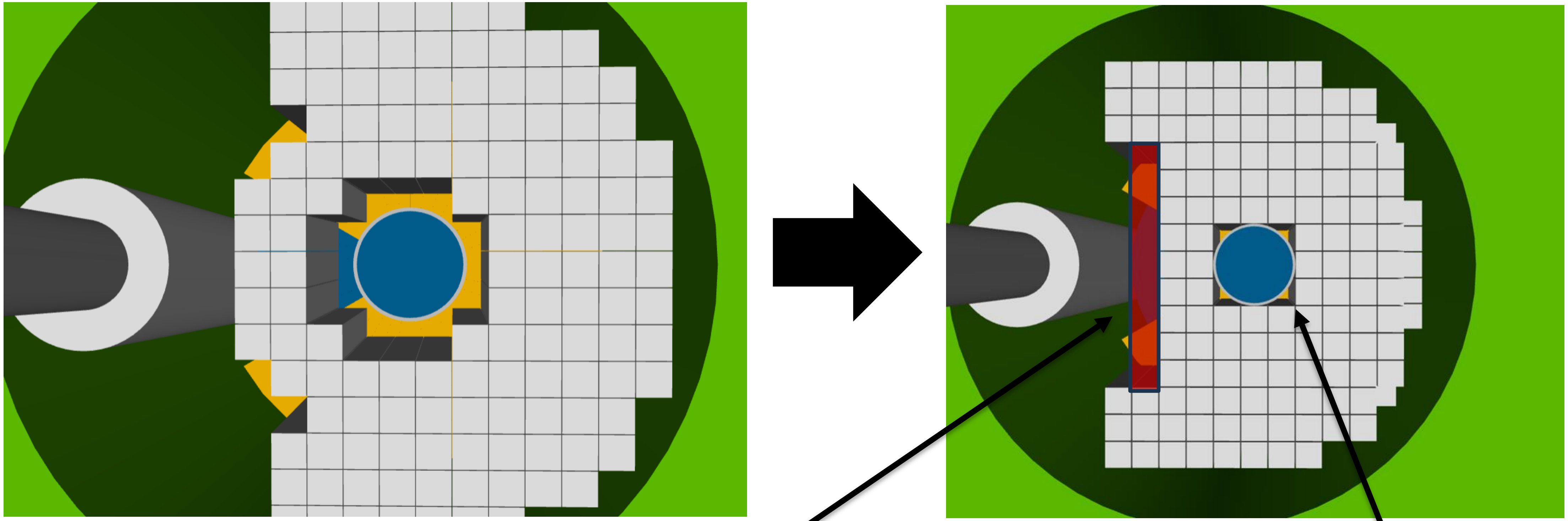
- Harmonization of the simulation geometry with the CAD drawing





B0 geometry update

- Harmonization of the simulation geometry with the CAD drawing

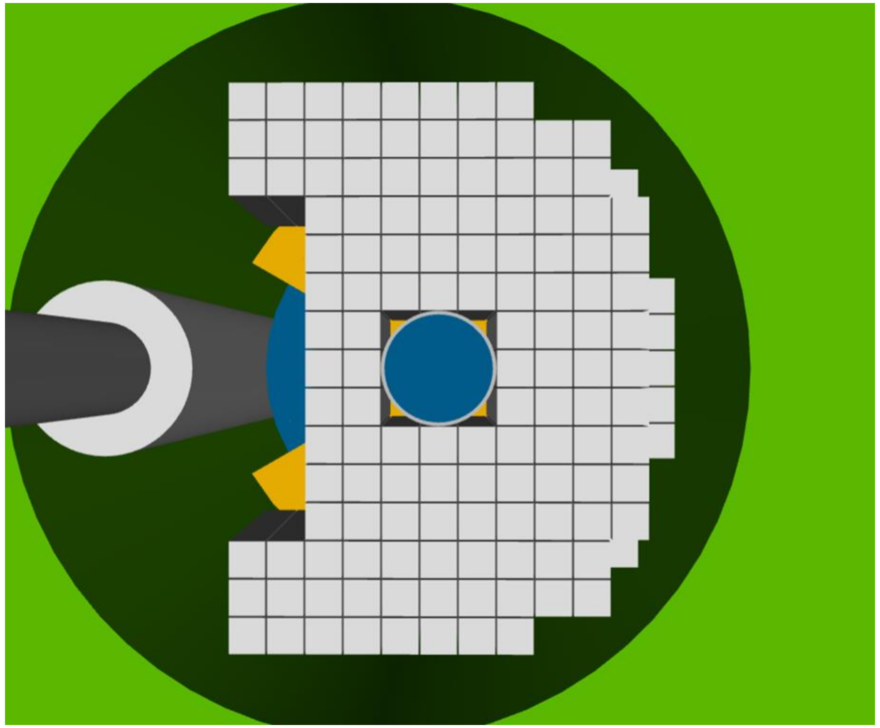


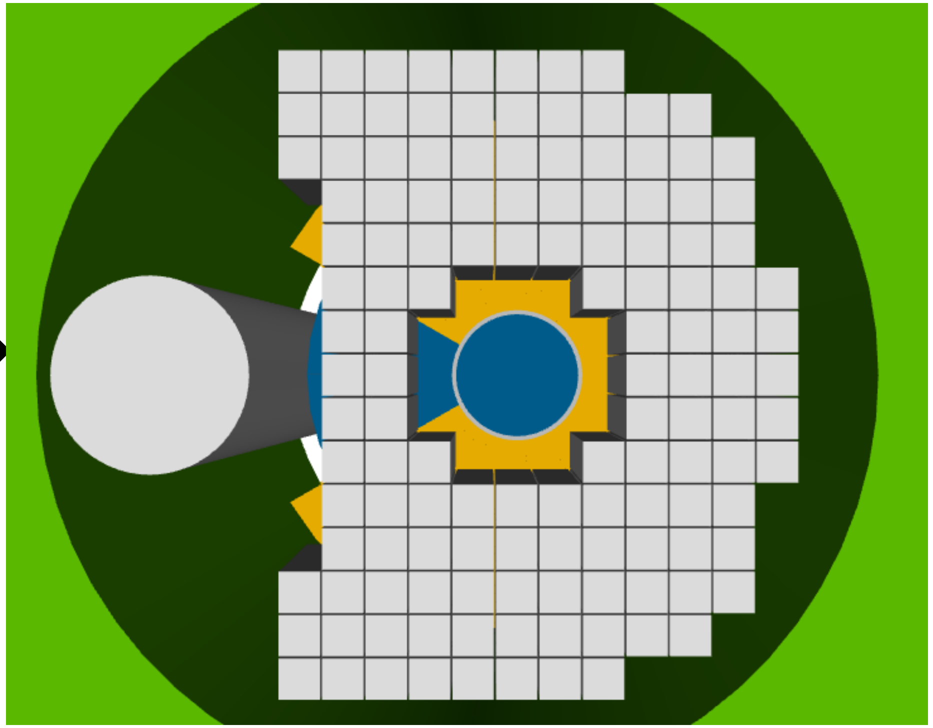
Additional space that can be filled with crystals

0.5mm between hadron beampipe (r=3.1cm) and crystal edge (crystal = 2cm + 0.5mm wrapper)

B0 geometry update

- Harmonization of the simulation geometry with the CAD drawing

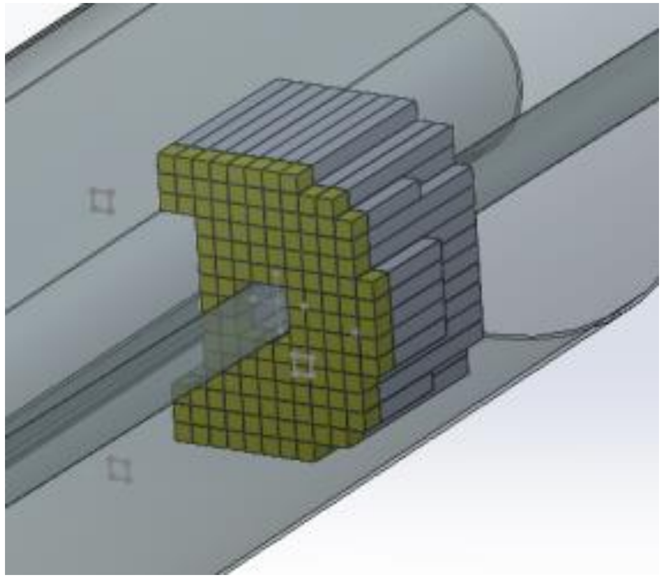


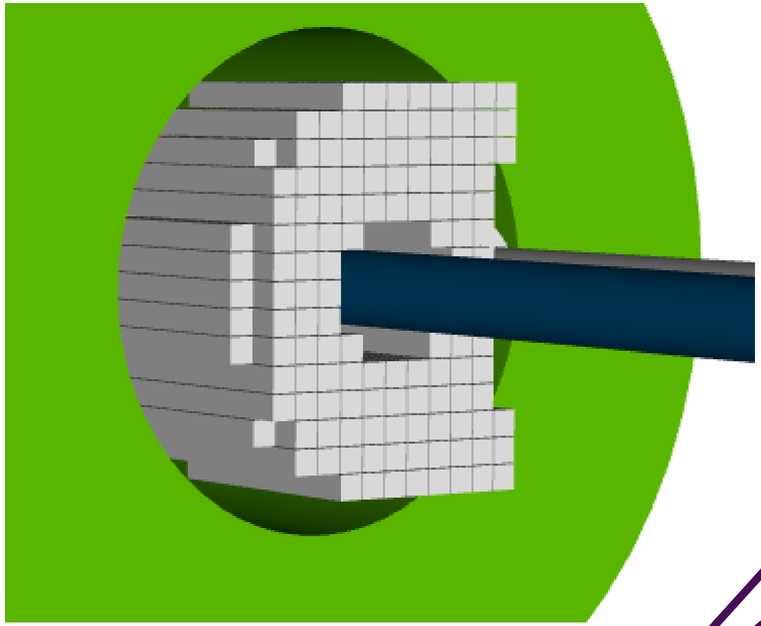


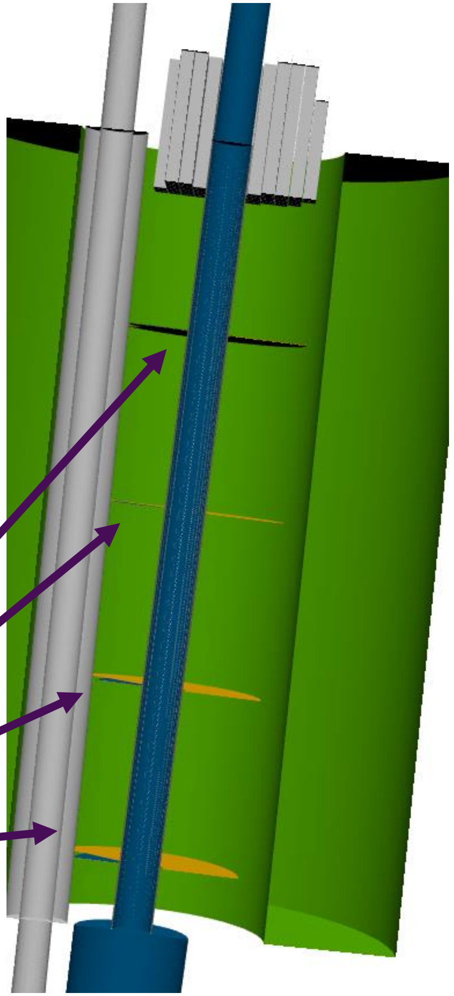
- Large tolerance between hadron beampipe and the detector
- Added more crystals on the electron side

B0 geometry update

- CAD drawing was studied to identify which crystals need to be shorten in case detector is pulled backwards







- B0ECAL moved 15cm forward, this allows more space for tracking planes

B0Trk

Photons in B0

Acceptance in B0 X-Y plane

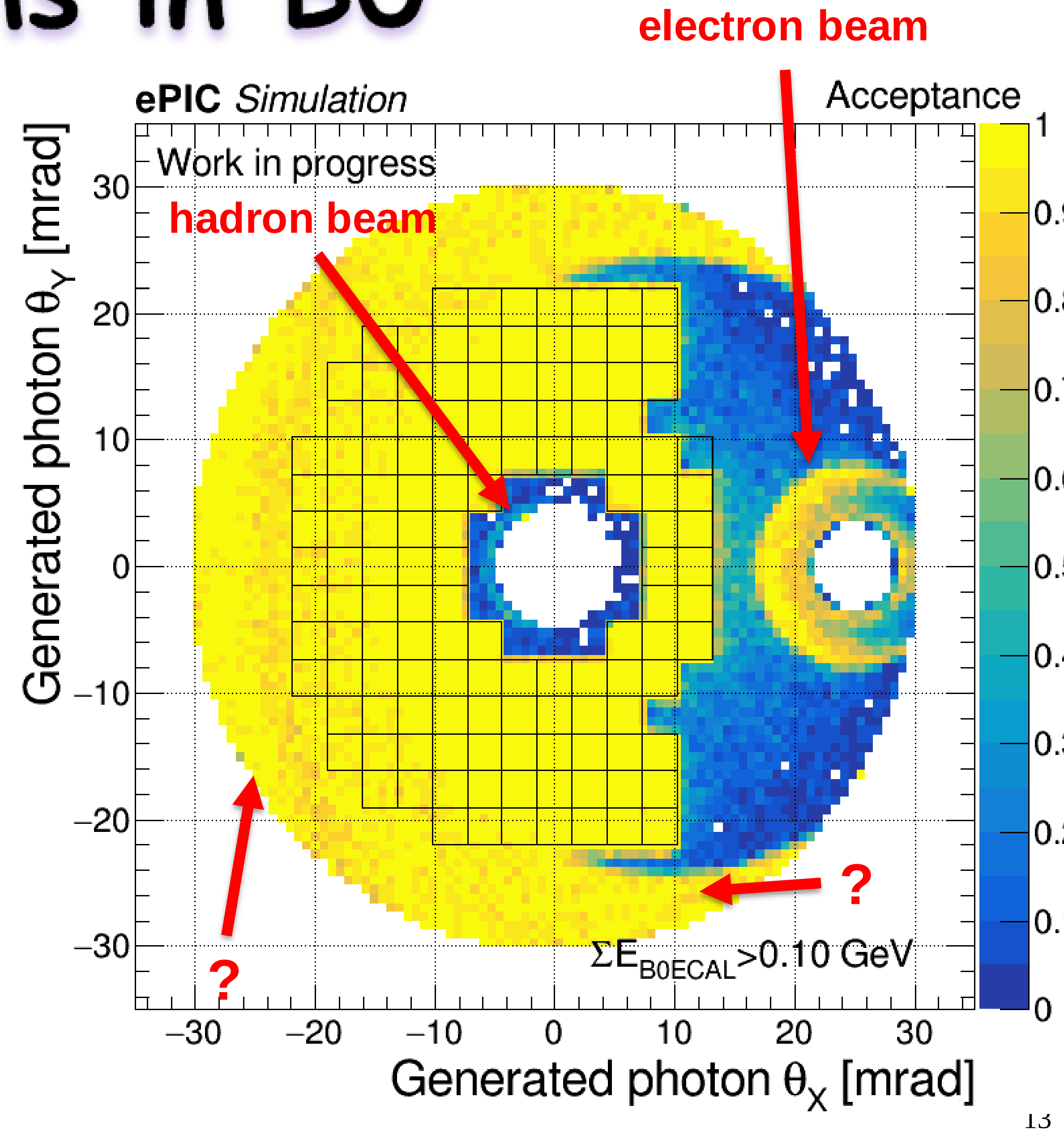
- Spatial photon acceptance tested with particle gun, and defined as:

$$A = \frac{N(\theta_X^*, \theta_Y^* | E_{B0ECAL} > E_{th})}{N(\theta_X^*, \theta_Y^*)}$$

- Set energy threshold in EMCAL> 0.5 GeV

Observations

- Photons out-of-fiducial region (outside EMCAL) deposit energy in EMCAL.
- Caused by photon conversion in earlier detector's material



Photons in B0

Acceptance in B0 X-Y plane

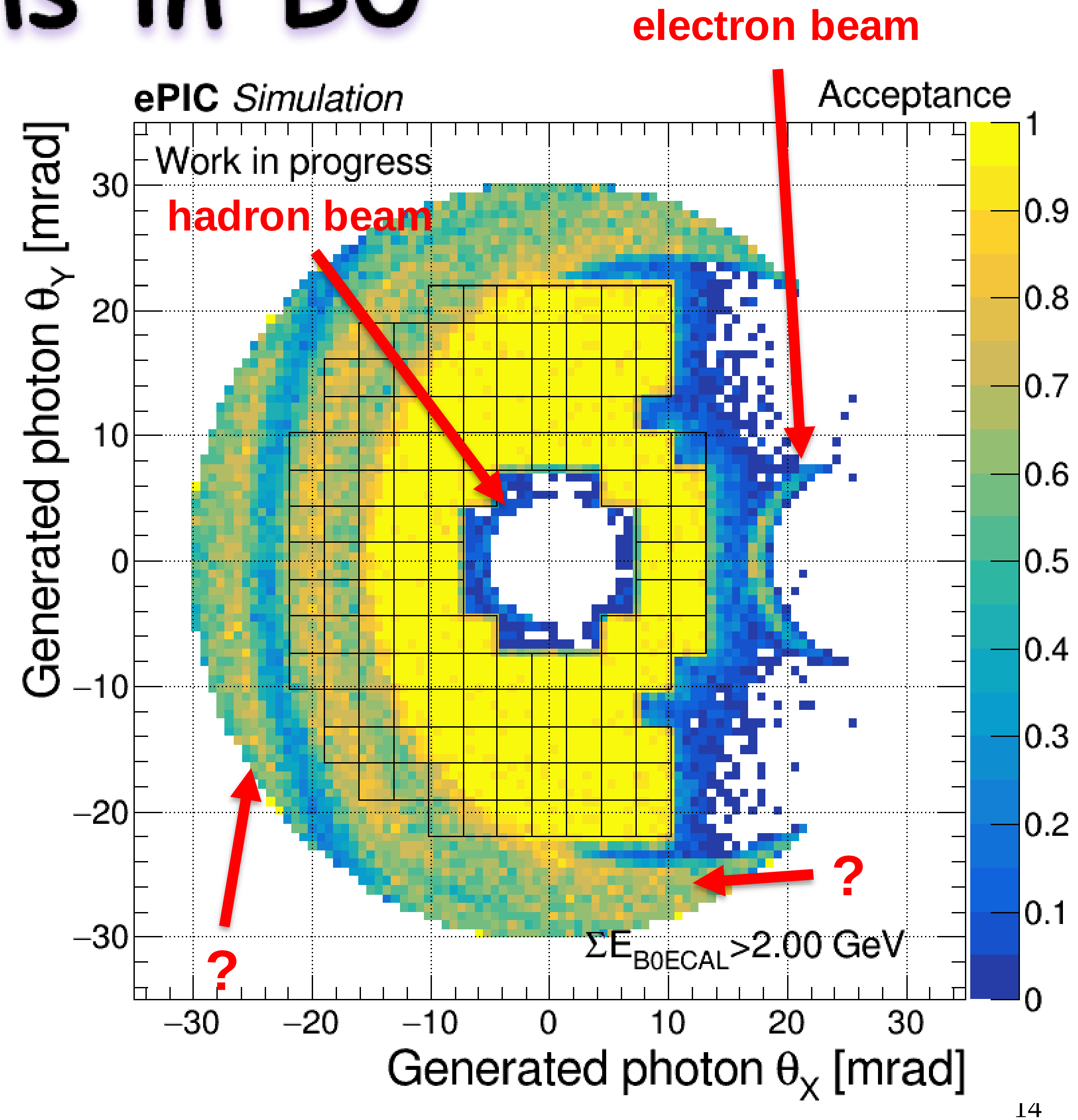
- Spatial photon acceptance tested with particle gun, and defined as:

$$A = \frac{N(\theta_X^*, \theta_Y^* | E_{B0ECAL} > E_{th})}{N(\theta_X^*, \theta_Y^*)}$$

- Set energy threshold in EMCAL> 20 GeV

Observations

- Photons out-of-fiducial region (outside EMCAL) deposit energy in EMCAL.
- Caused by photon conversion in earlier detector's material

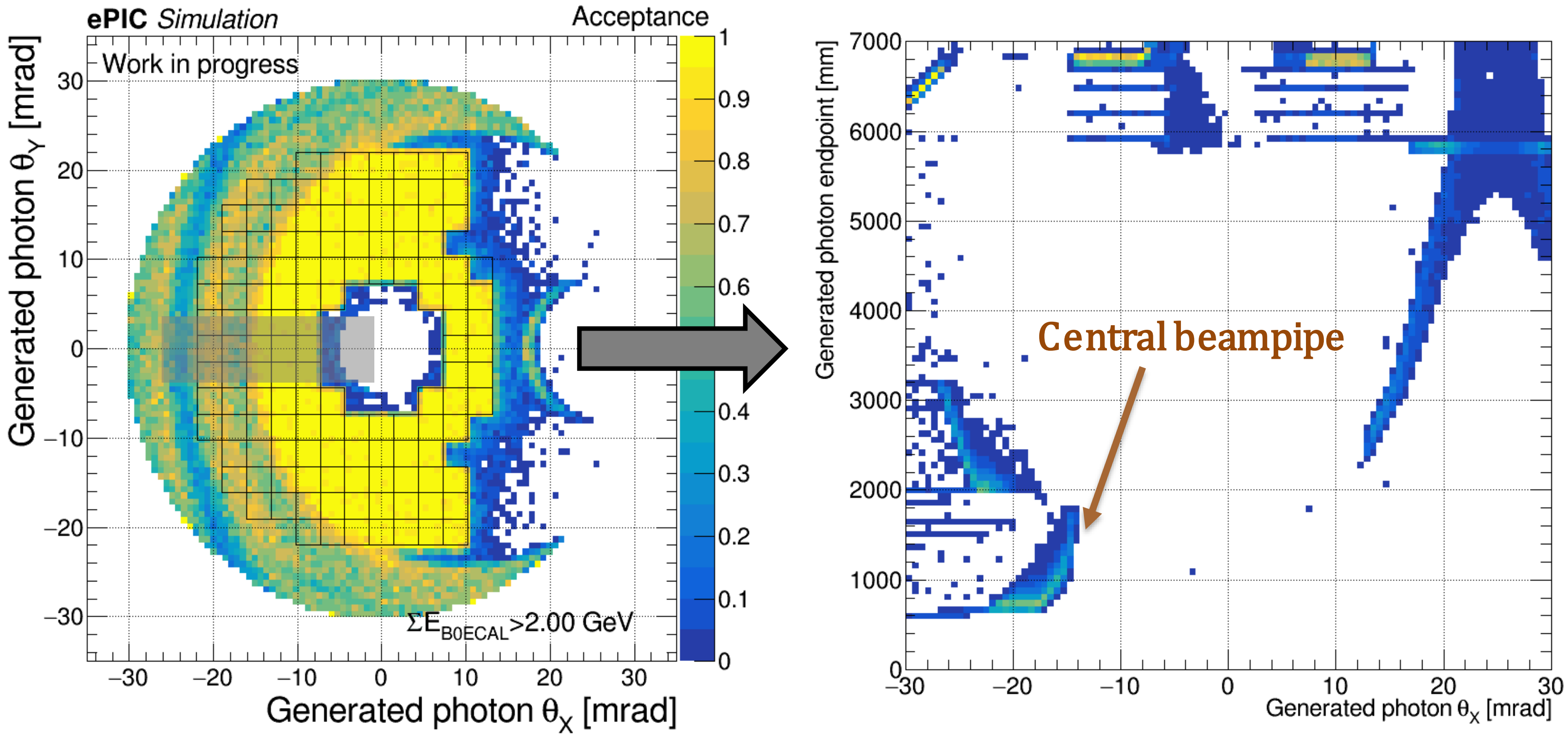


Photons in B0

Acceptance in B0 X-Y plane

- G4 simulation provides information of the photon endpoint (where $\gamma \rightarrow ee$ starts)
- Issue with the central beampipe is persist

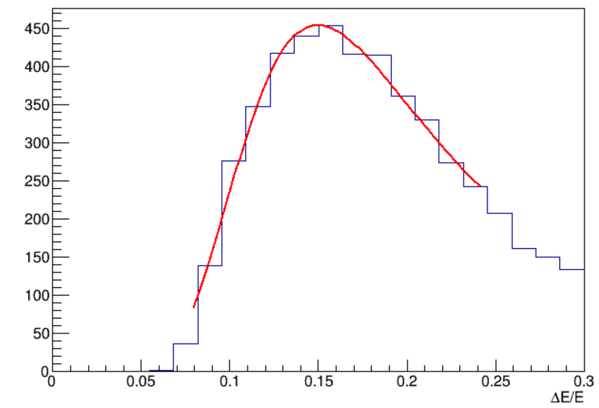
Plot photon endpoint along the X axis (θ_Y~0)



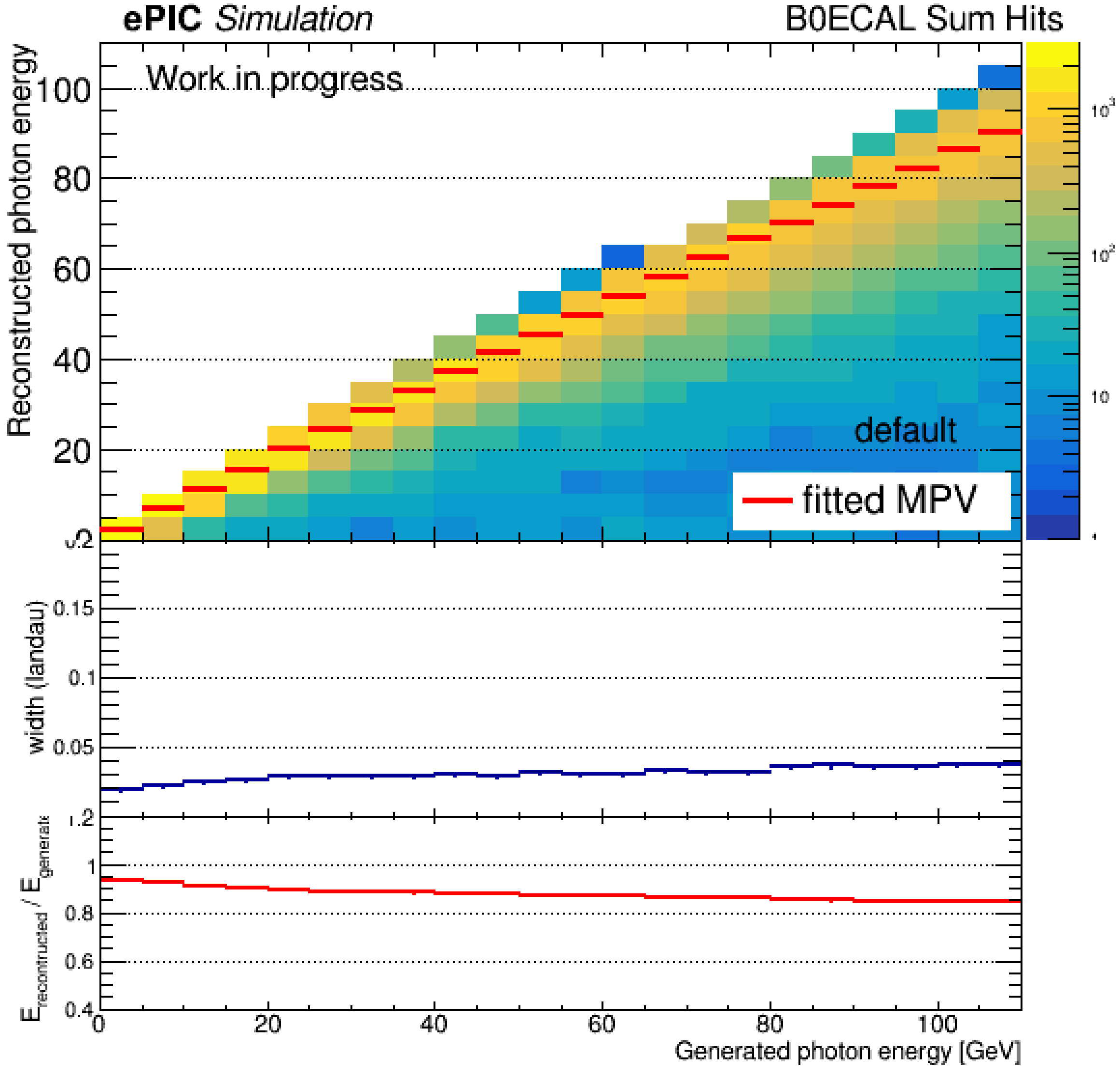
B0 detector performance (ddsim)

Energy response for θ<13mrad

- To study the entire detector's sensitive area beampipe was removed from the simulation.
- When photons interact before the B0ECAL energy response is not defined (fluctuations and bias)
- NOTE: light yields are not included yet (reco level)



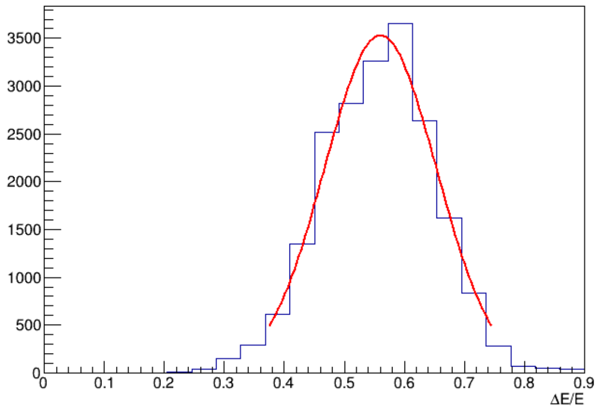
E(ph)=110GeV



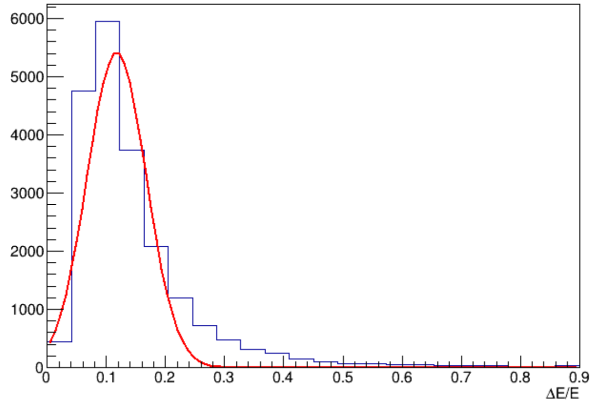
B0 detector performance (EICRecon)

Energy response for θ<13mrad

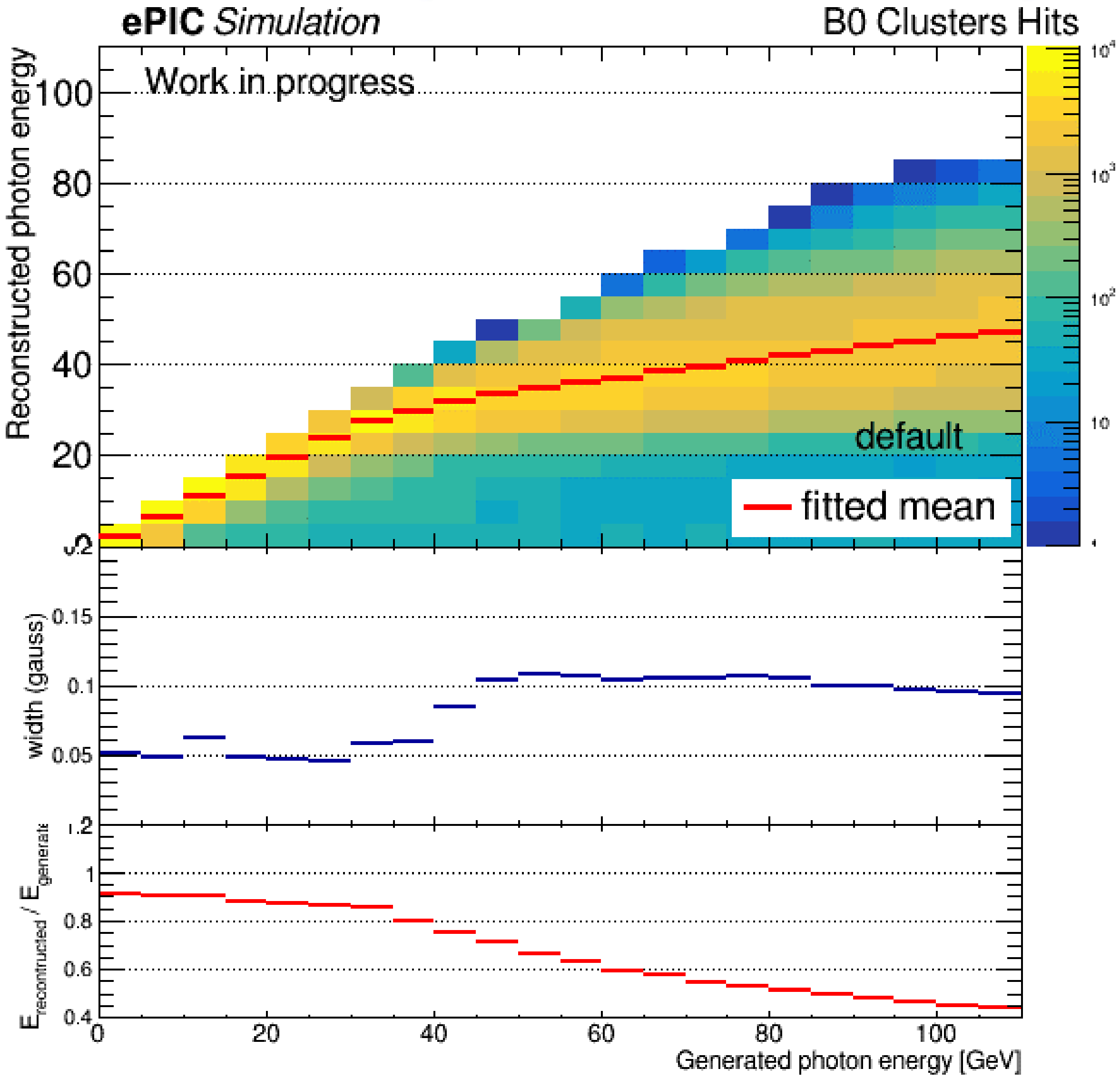
- To study the entire detector's sensitive area beampipe was removed from the simulation.
- When photons interact before the B0ECAL energy response is not defined (fluctuations and bias)
- NOTE: light yields are not included yet (reco level)



E(ph)=110GeV



E(ph)=10GeV



Photons in ZDC

Acceptance in ZDC X-Y plane

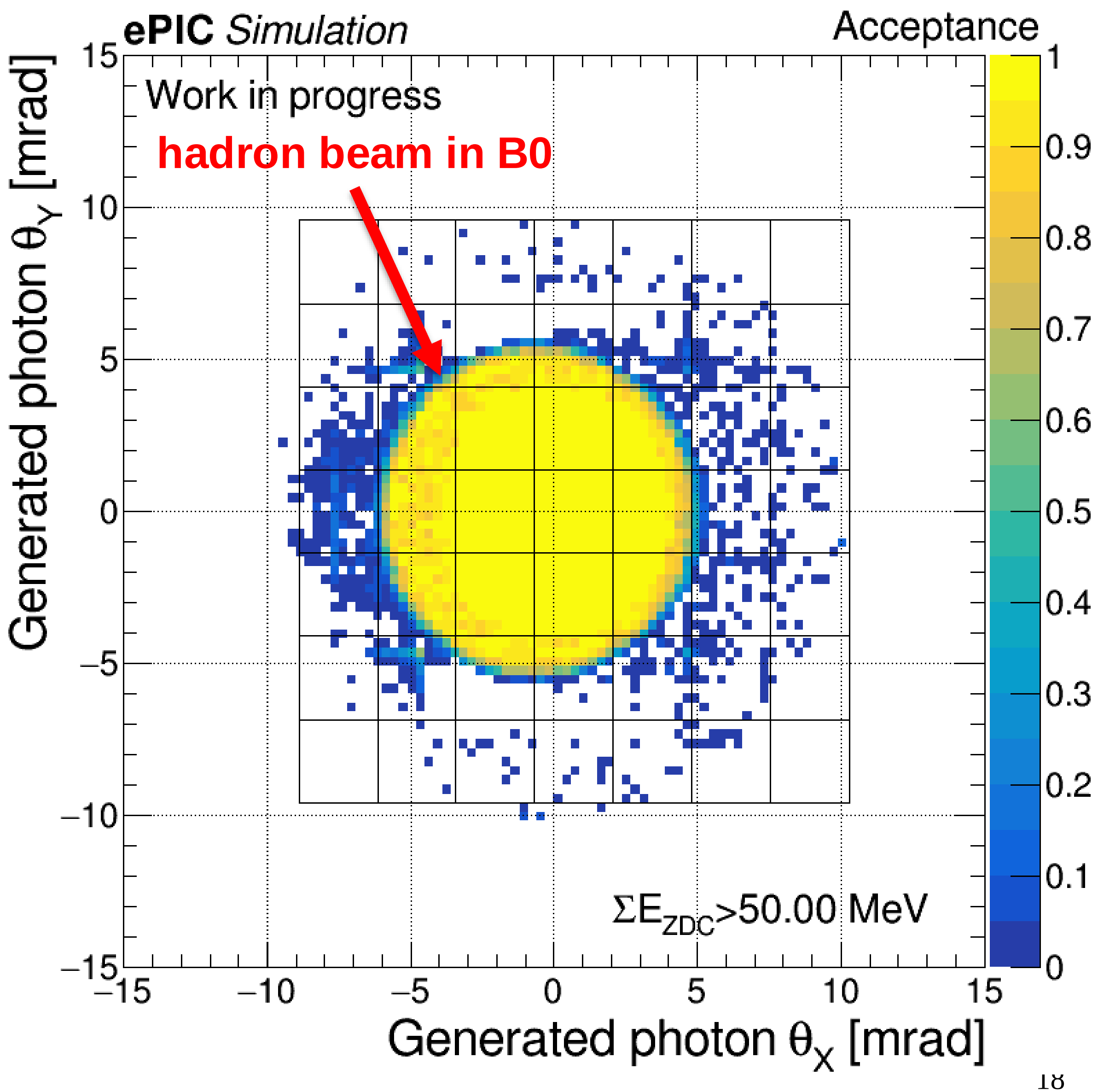
- Spatial photon acceptance tested with particle gun, and defined as:

$$A = \frac{N(\theta_X^*, \theta_Y^* | E_{ZDC} > E_{th})}{N(\theta_X^*, \theta_Y^*)}$$

- Set energy threshold in ZDC > 0.05 GeV

Observations

- Photons contained within the hadron beampipe inside the B0 magnet.



Photons in ZDC

Acceptance in ZDC X-Y plane

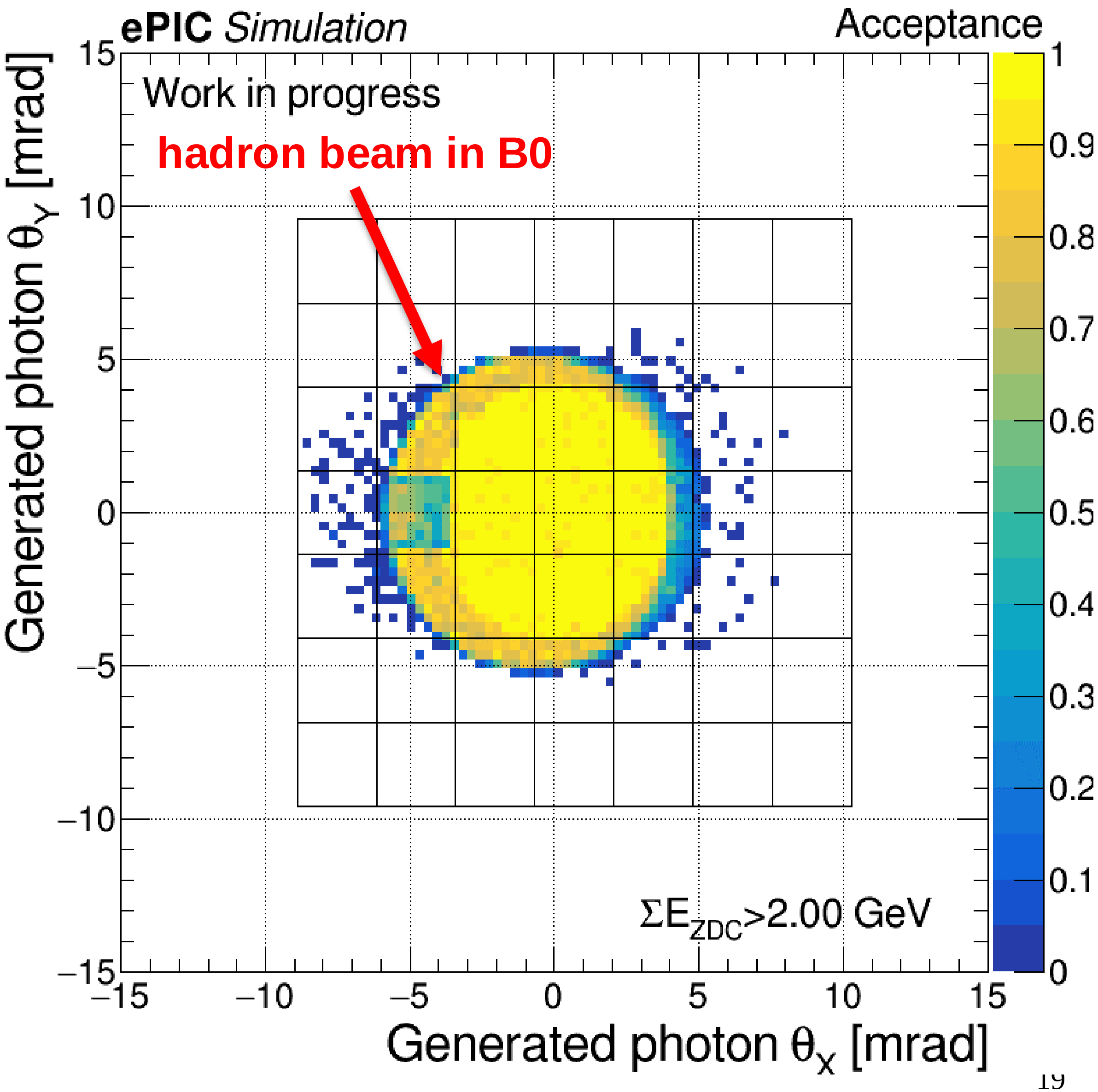
- Spatial photon acceptance tested with particle gun, and defined as:

$$A = \frac{N(\theta_X^*, \theta_Y^* | E_{ZDC} > E_{th})}{N(\theta_X^*, \theta_Y^*)}$$

- Set energy threshold in ZDC > 2 GeV

Observations

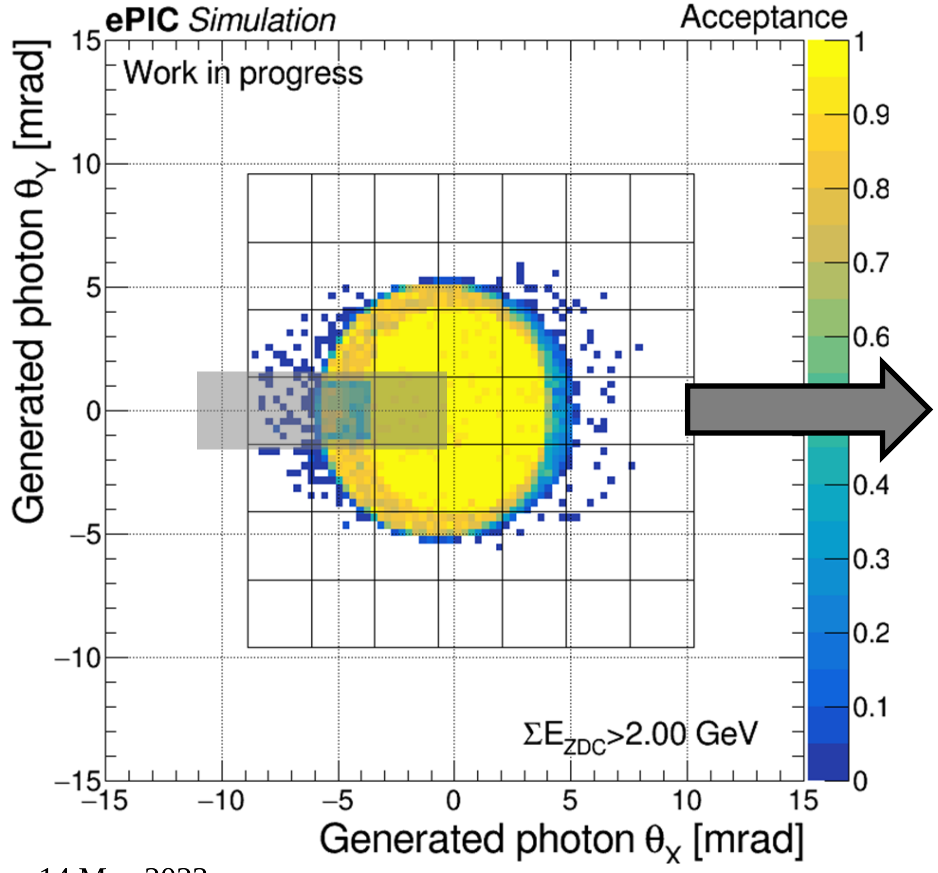
- Photons contained within the hadron beampipe inside the B0 magnet.
- Small overlap with RP boxes?

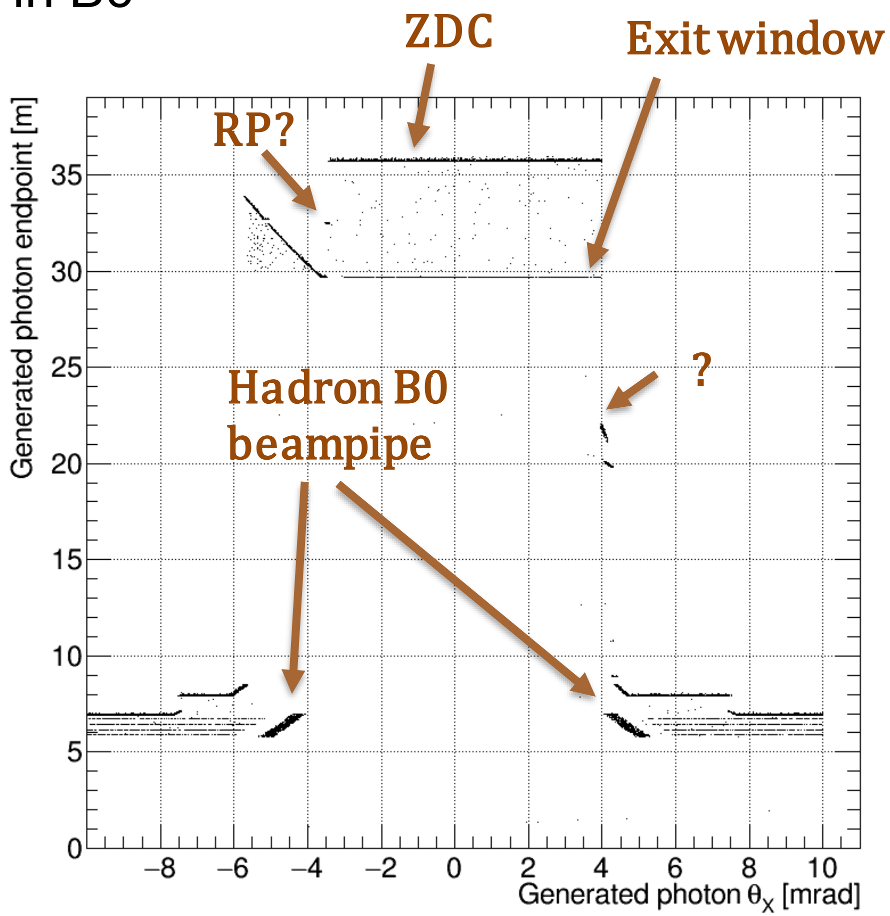


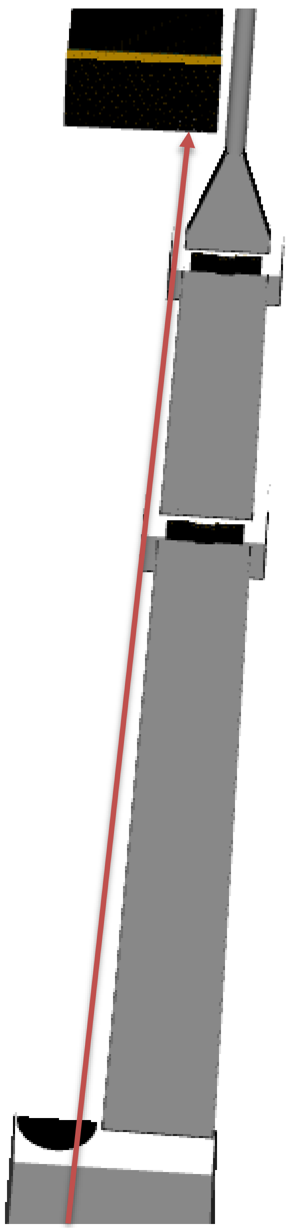
Photons in ZDC

Acceptance in B0 X-Y plane

- G4 simulation provides information of the photon endpoint (where $\gamma \rightarrow ee$ starts)
- Photons blocked by the hadron beampipe in B0





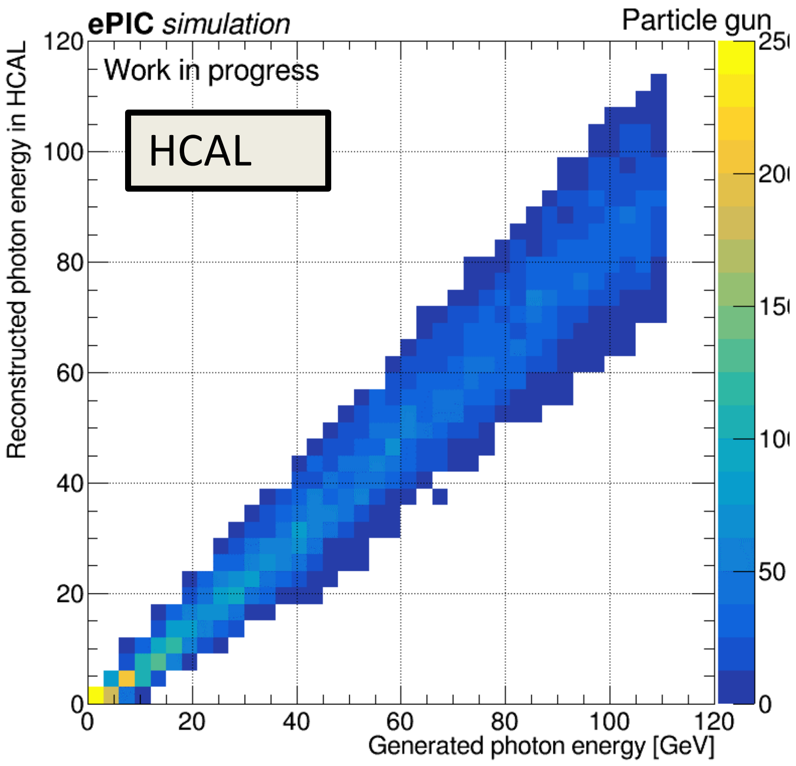


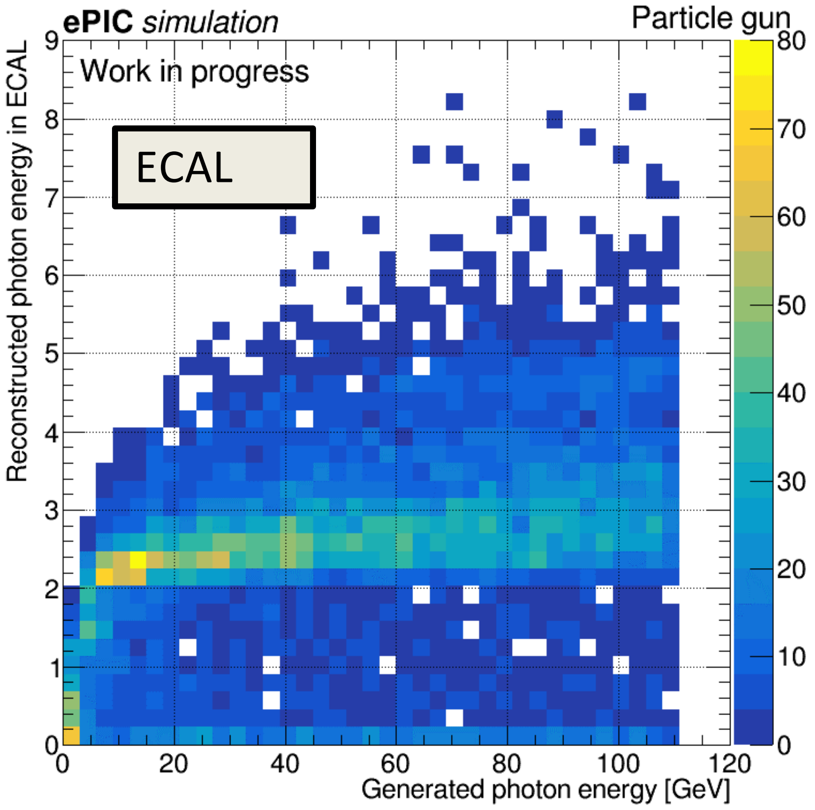
ZDC detector performance (EICRecon)

Particle gun with photons

- Photons with θ<2mrad, endpoint>35m.
- Photon energy response from ECAL + HCAL

Similar saturation in ZDC ECAL for reconstructed clusters



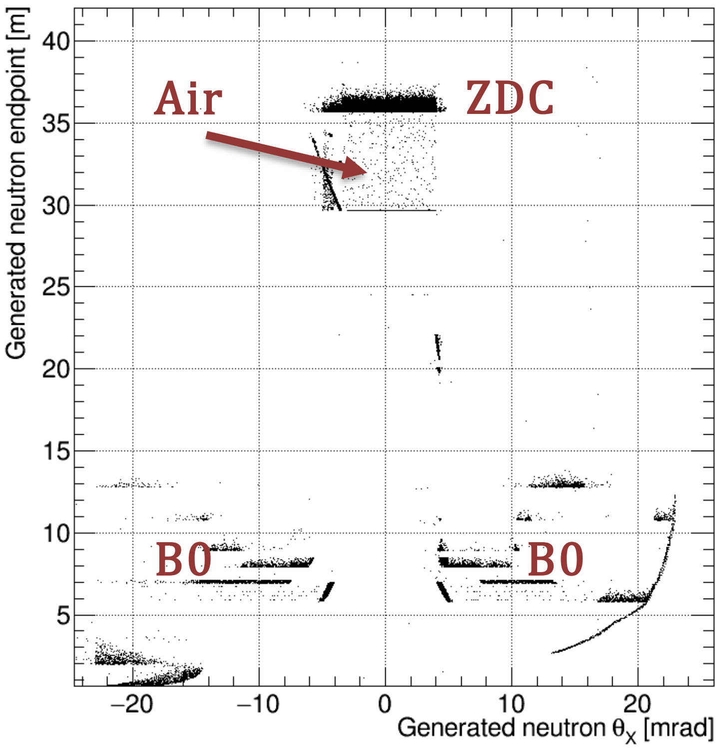


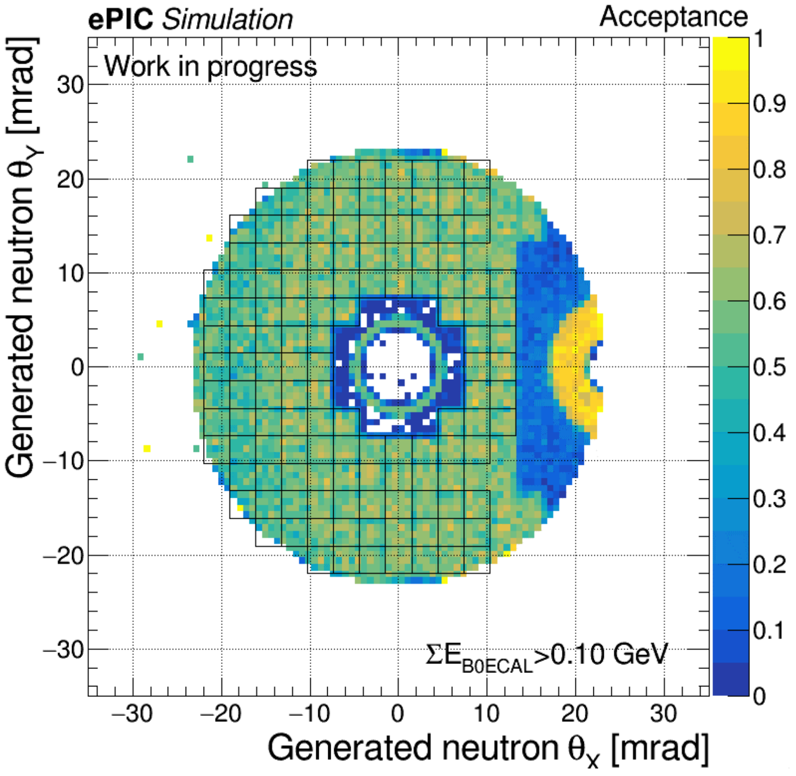
Forward neutrons

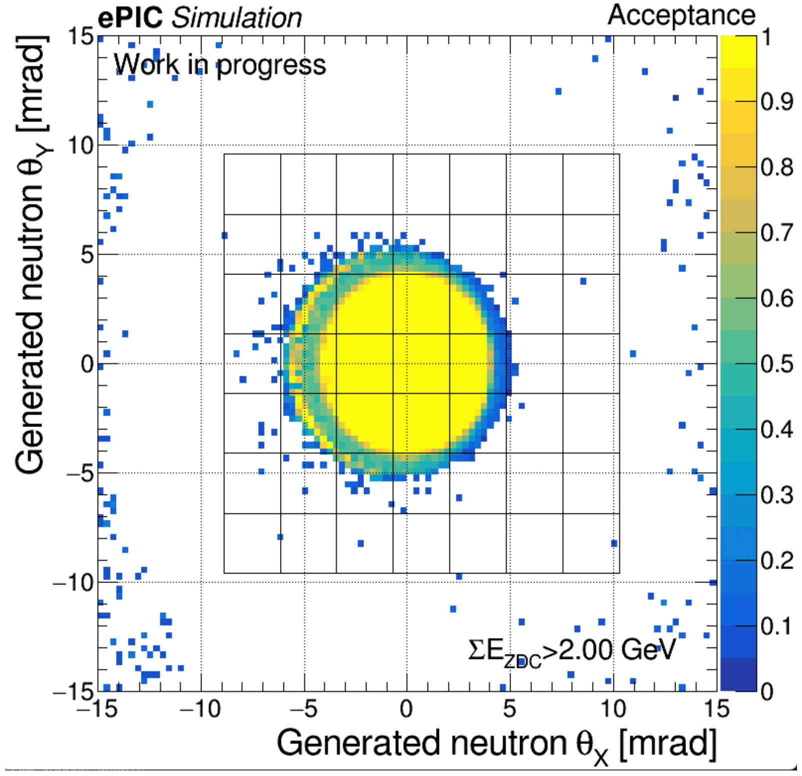
For θ > 5 mrad: B0 – detection efficiency of 50% (B0 ECAL λ is larger than 1)

For θ < 5 mrad: all neutrons measured in the ZDC

Neutron with θ~0



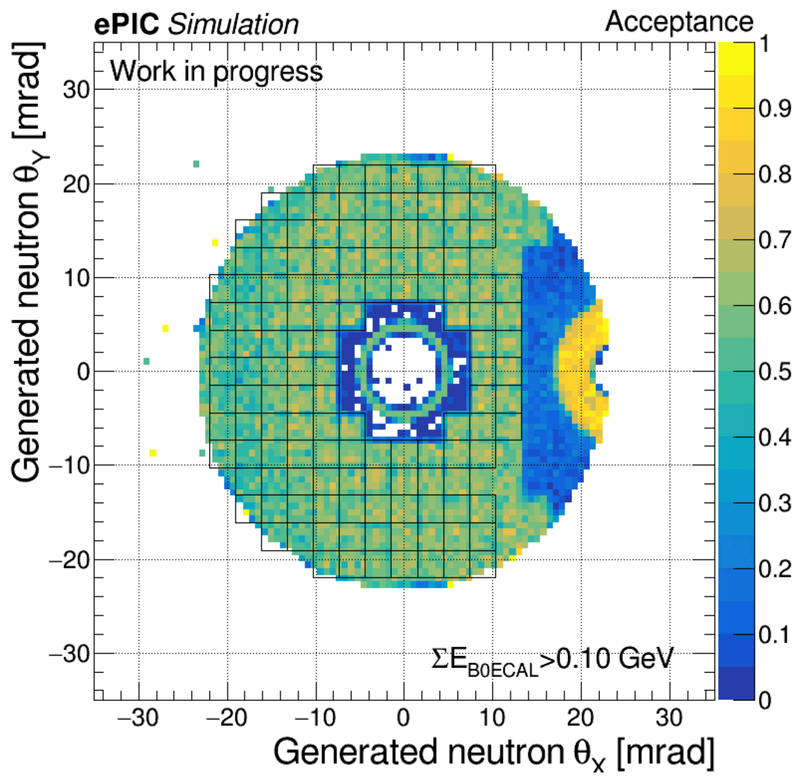


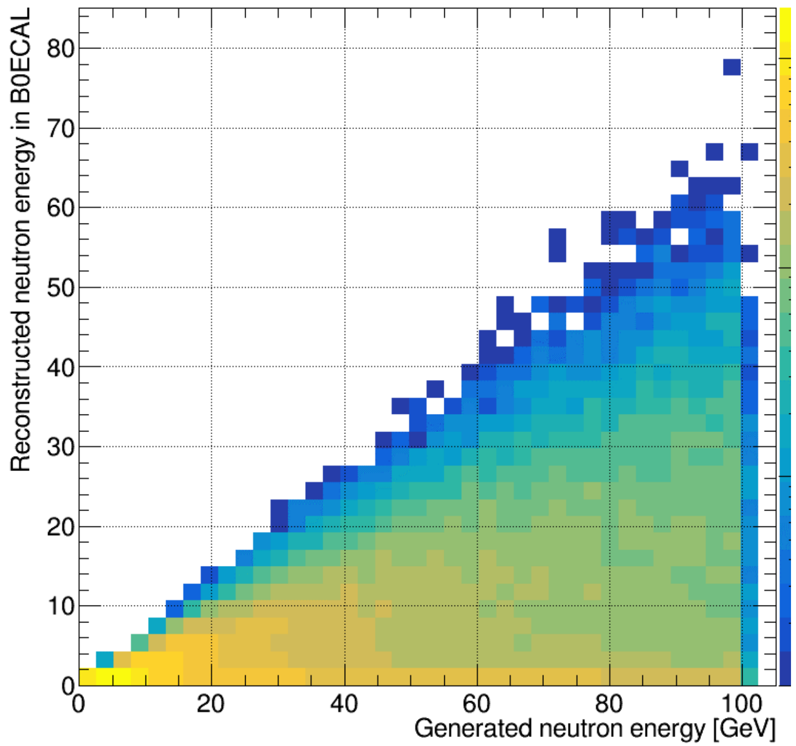


Forward neutrons

For θ > 5 mrad: B0 – detection efficiency of 50% (B0 ECAL λ is larger than 1)

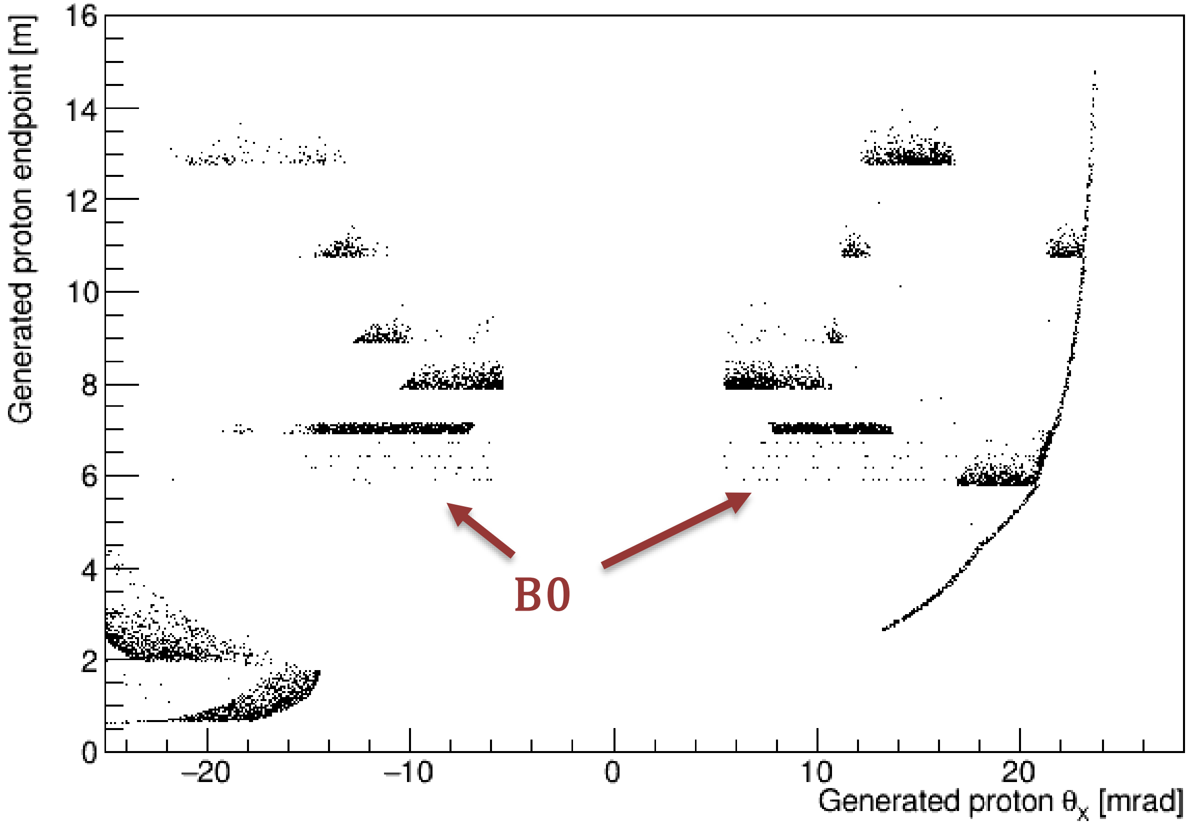
Energy resolution for neutron in B0 is very poor, not clear at all if we can aim detecting neutrons

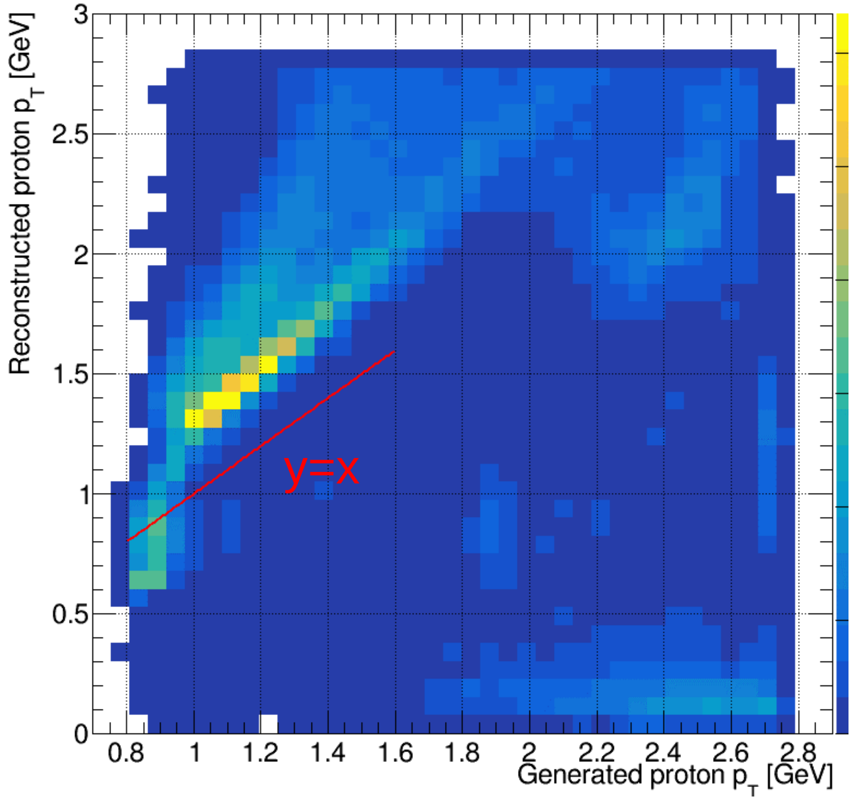




Forward protons

- Protons with θ>5 mrad and E = 110 GeV were generated in 18x275 configuration.
- All protons end up < 10 meter, many in the B0 detector
- 110 GeV protons (from Pb) have bias in B0 tracker



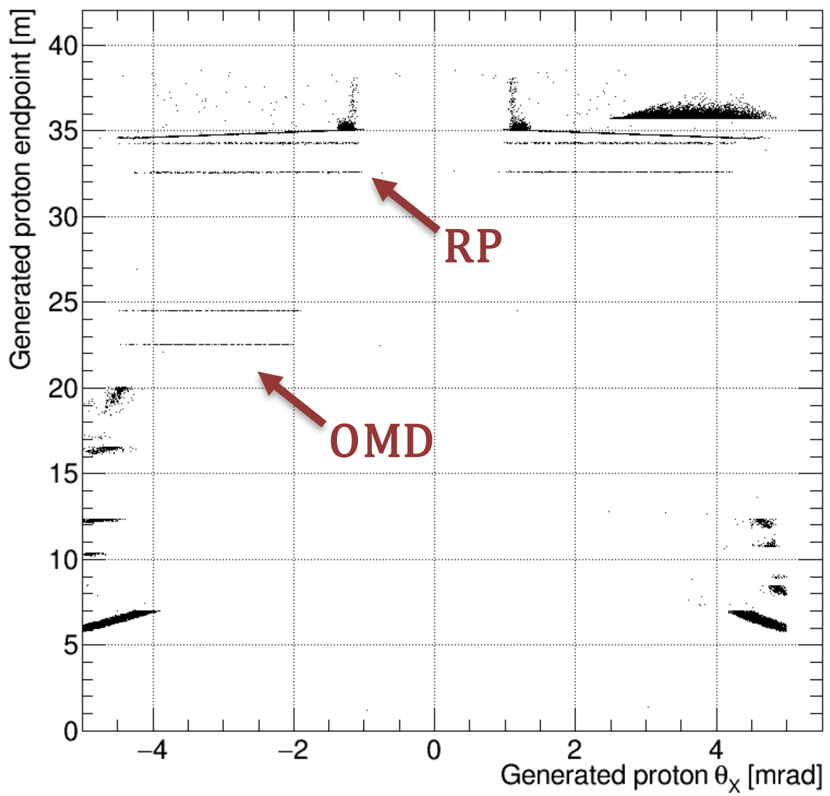


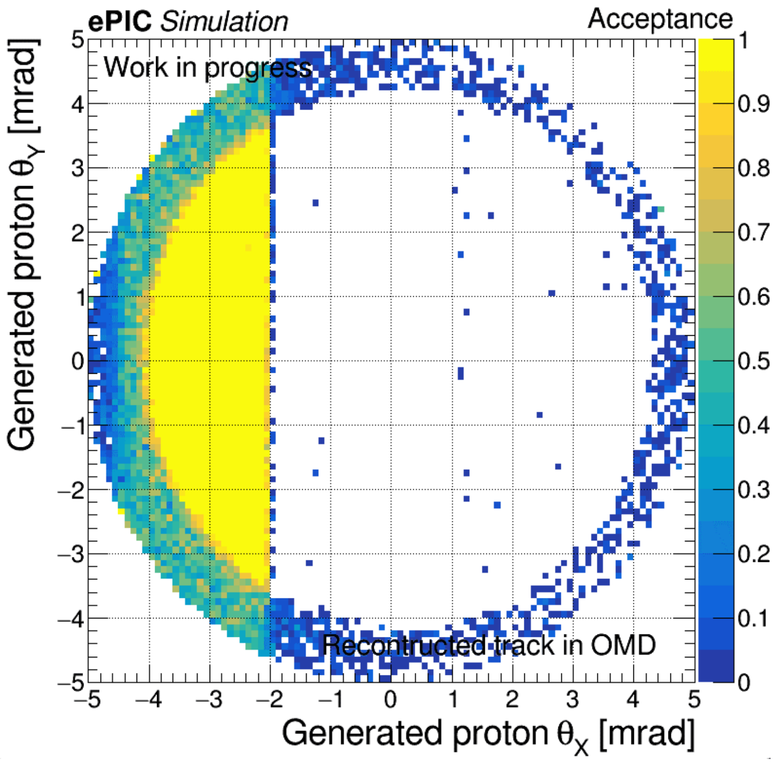
Forward protons

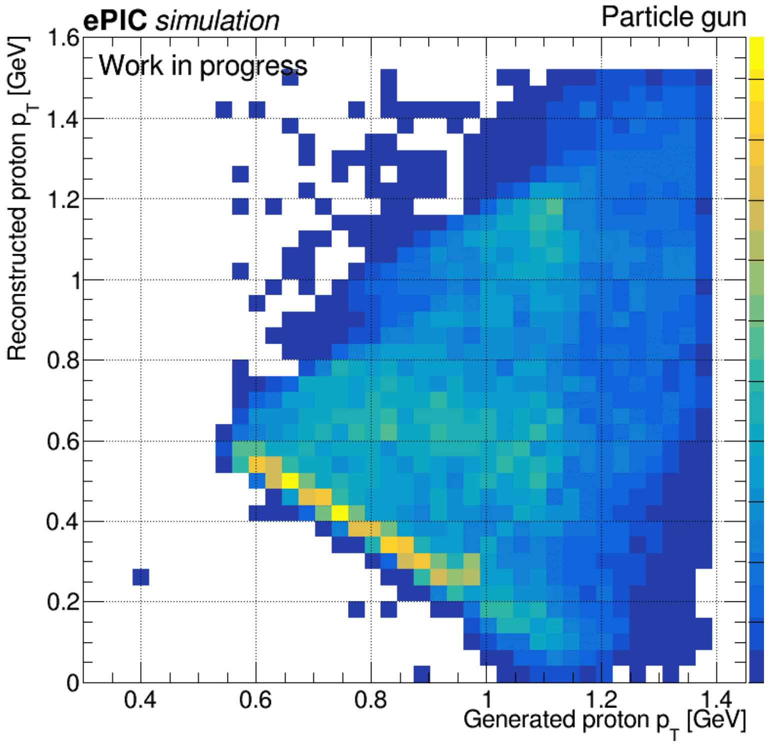
Protons with θ<5 mrad and E = 275 GeV were generated in 18x275 configuration.

Overlap between RP and OMD? No recontacted protons in RP (investigating)

Using momentum of *ForwardOffMRecParticles* and *ForwardRomanPotRecParticles*





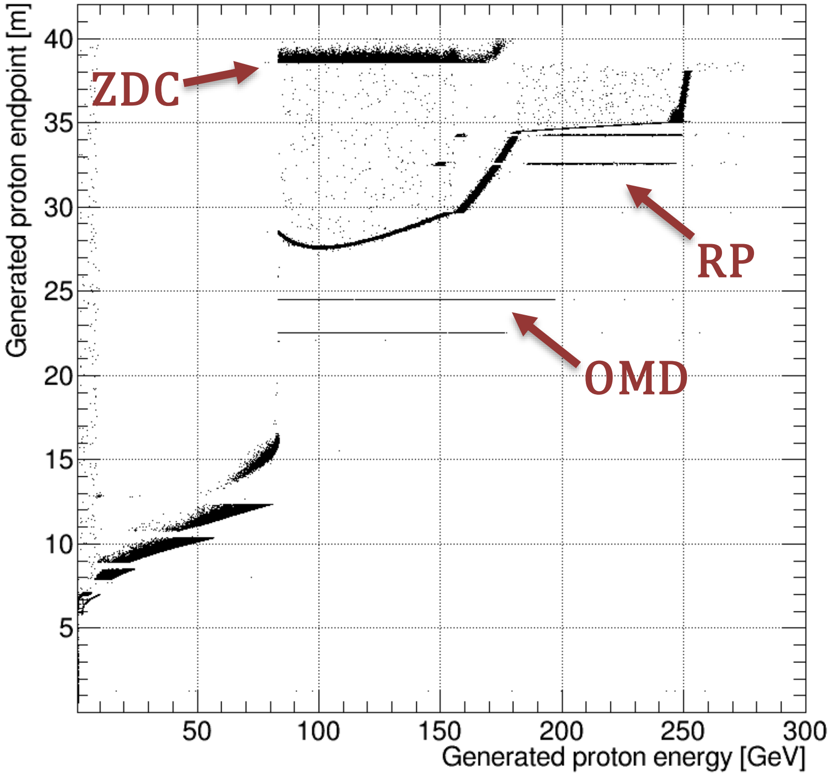


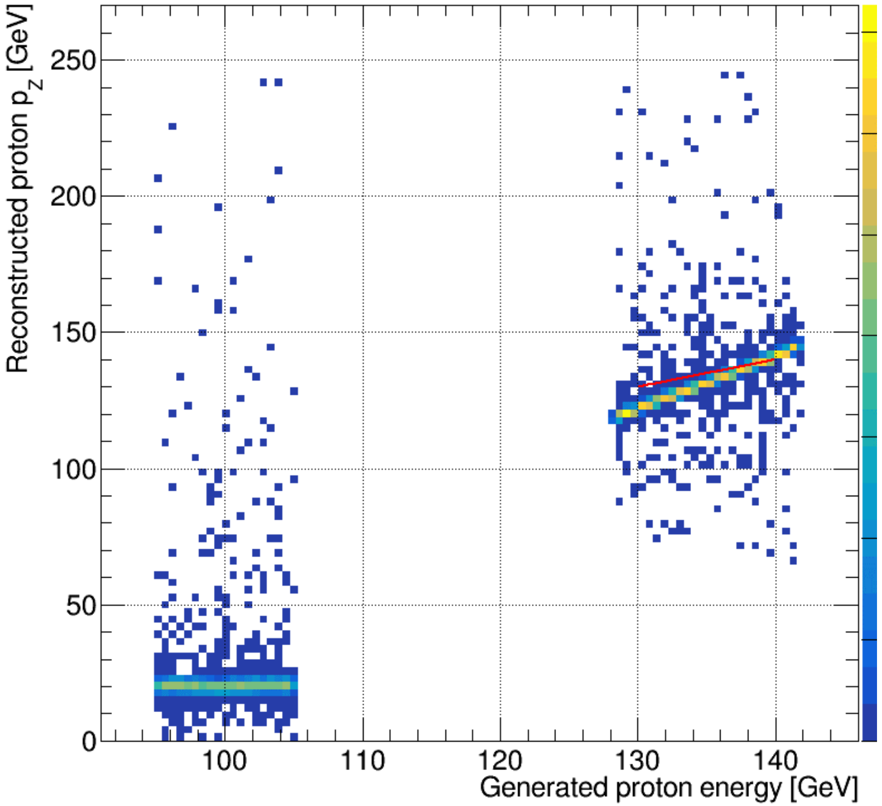
Forward protons

Protons with θ=0 mrad and E < 275 GeV were generated in 18x275 configuration.

Protons with energy from 130 to 140 GeV measured with the OMD ($0.45<x_L<0.5$)

Protons with energy within 90 – 105 GeV get to OMD





Summary

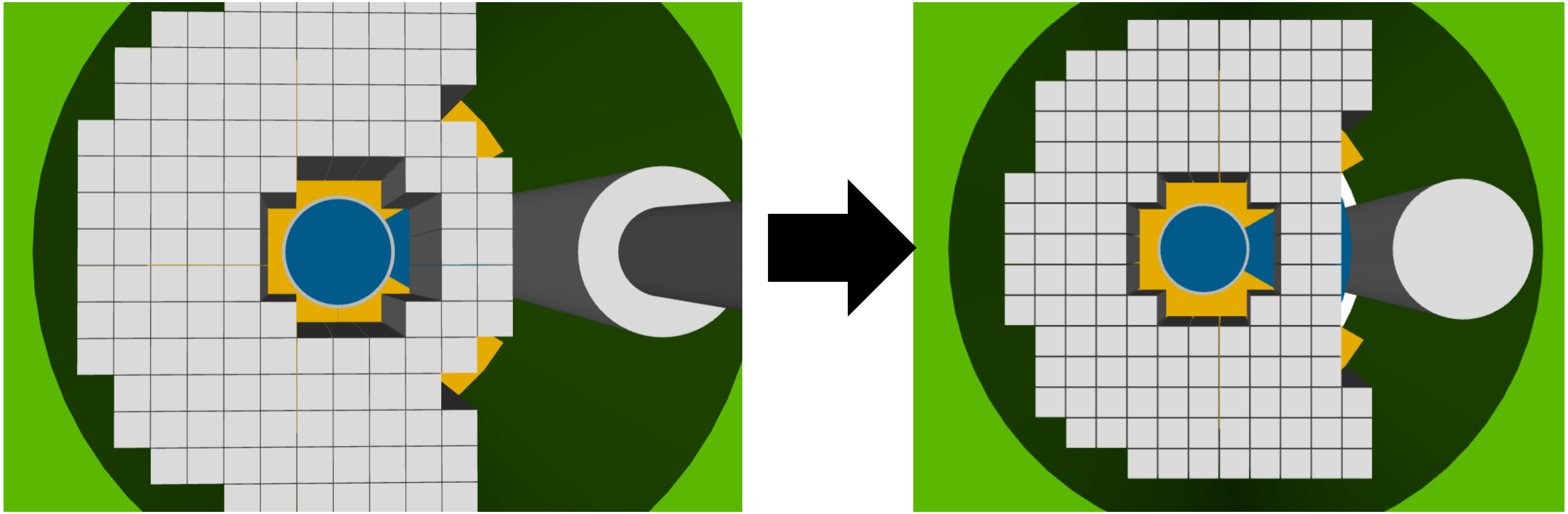
Summary:

- Vacuum was extended until the end of the physical volume
- B0 geometry harmonization with CAD + optimization is ongoing
  - We need to agree on the geometry
  - The position of the crystals can be further optimized.
- New exit window allow photons to reach the ZDC
- Charged particle propagation looks OK, but we have some issues at the reconstruction (branches, settings…)
- Reconstructed energy in crystals (B0, ZDC) – needs further investigation

Backup

B0 geometry update

- Harmonization of the simulation geometry with the CAD drawing



Possible bugs

OD(z=670mm) = 63.5mm (θ-25mrad/2=35mrad)

OD(z=1750mm) = 92.06mm (θ-25mrad/2=13.7mrad)

OD(z=4455) = 258mm (θ-25mrad/2=16.5mrad)

https://github.com/eic/epic/blob/New_B0ECAL_geo/compact/central_beampipe.xml

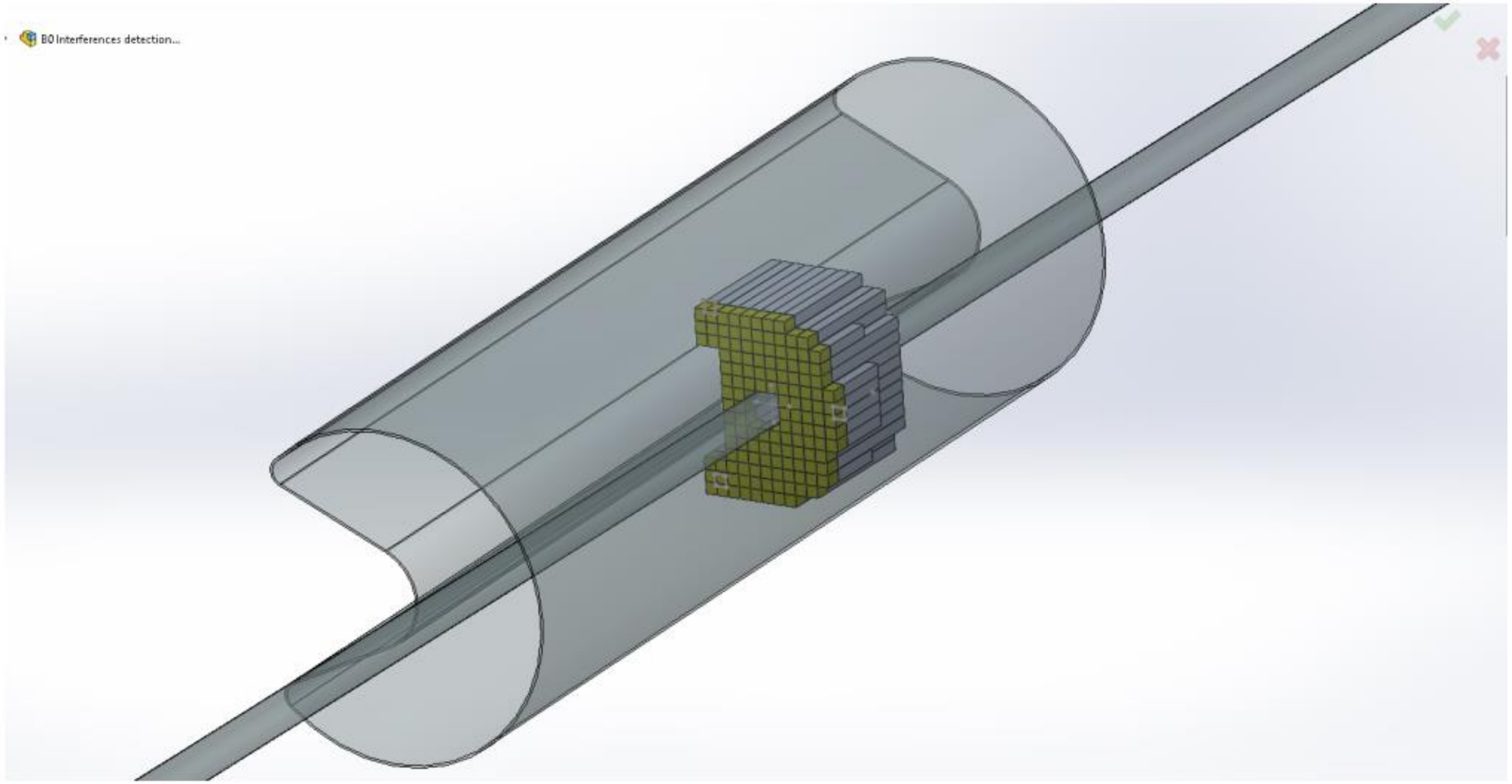
```
<zplane z="BeampipeDownstreamStraightLength + 0.5 * BeampipeOD * tan(abs(CrossingAngle))" OD="BeampipeOD"/>
<zplane z="1750.00 * mm" OD=" 92.06 * mm"/>
<zplane z="4455.80 * mm" OD="257.92 * mm"/>
```

Inflating these numbers allow photons with 15mrad < θ < 23 reach the B0ECAL

B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 0cm

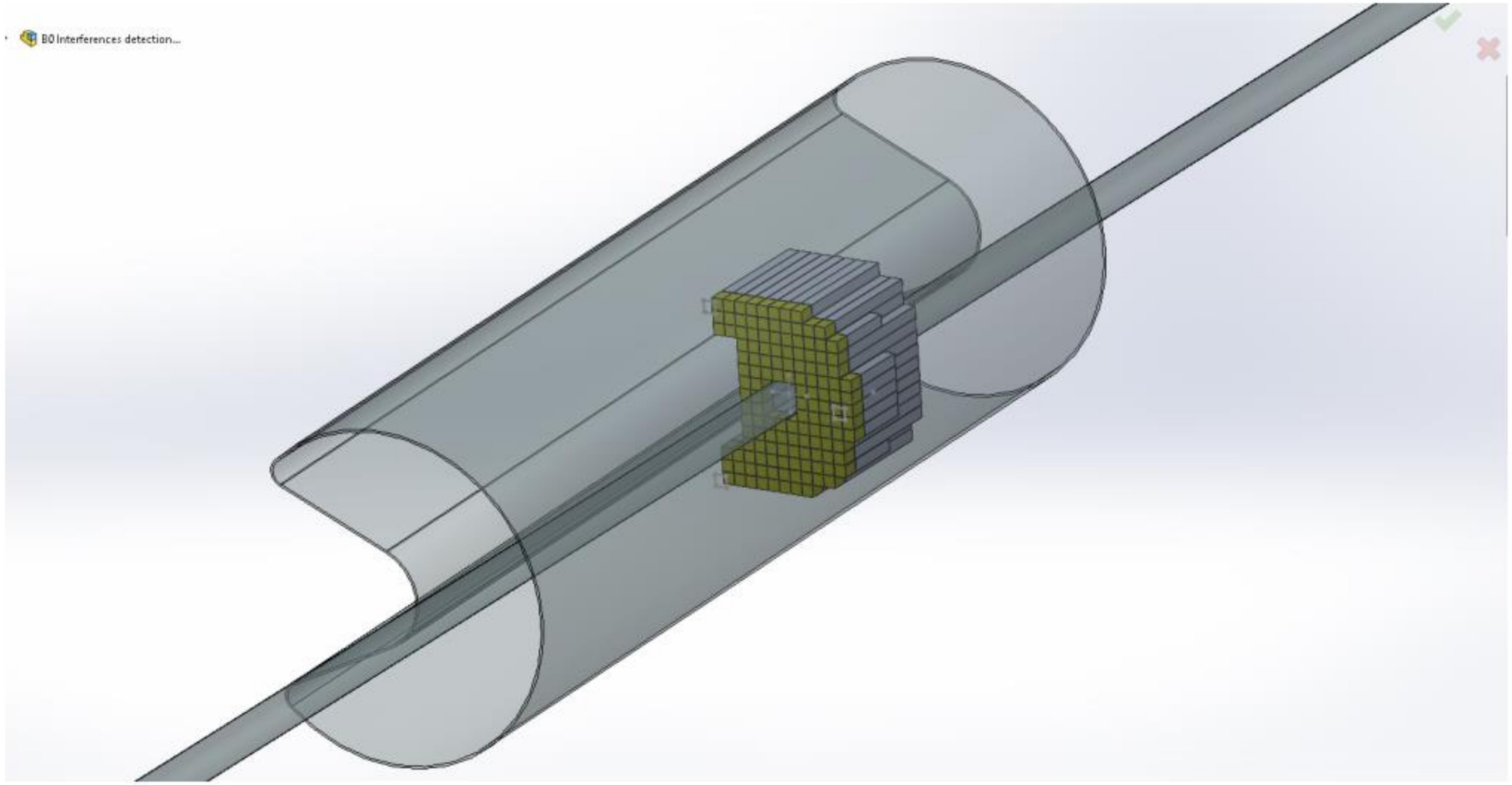
At the current position of the calorimeter there is no collision with the magnet



B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 5cm

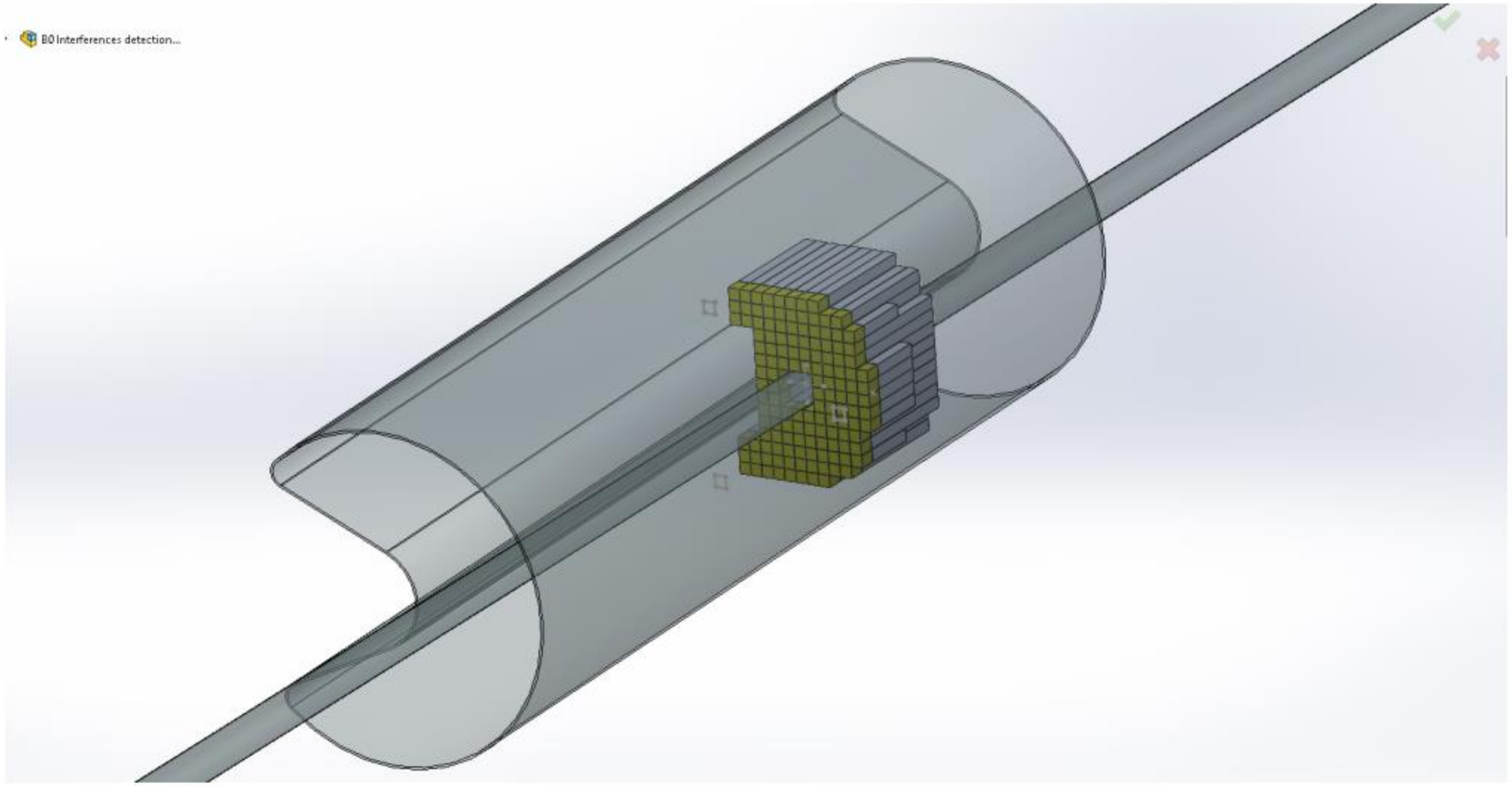
No collision with the magnet



B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 10cm

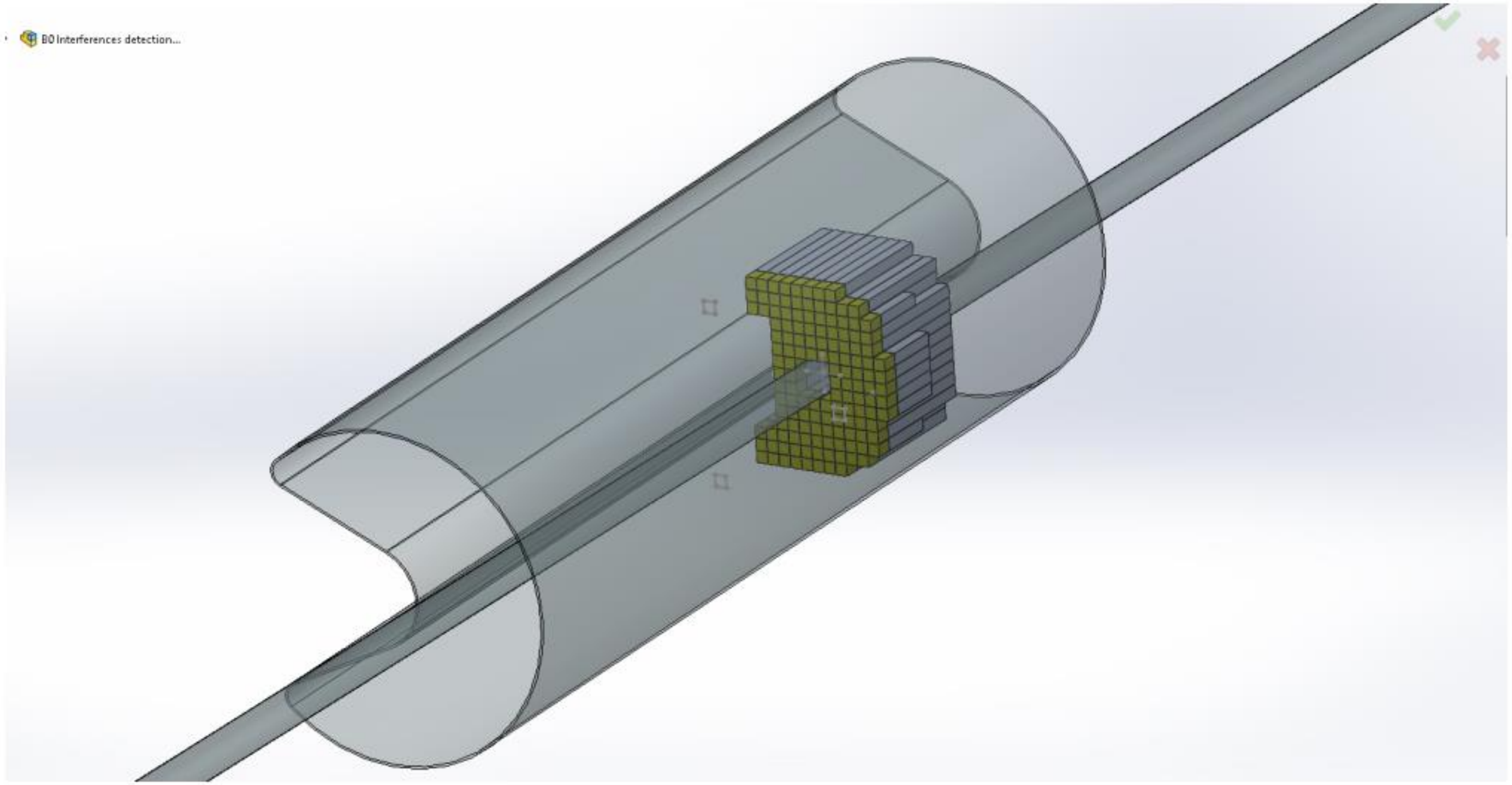
No collision with the magnet



B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 15cm

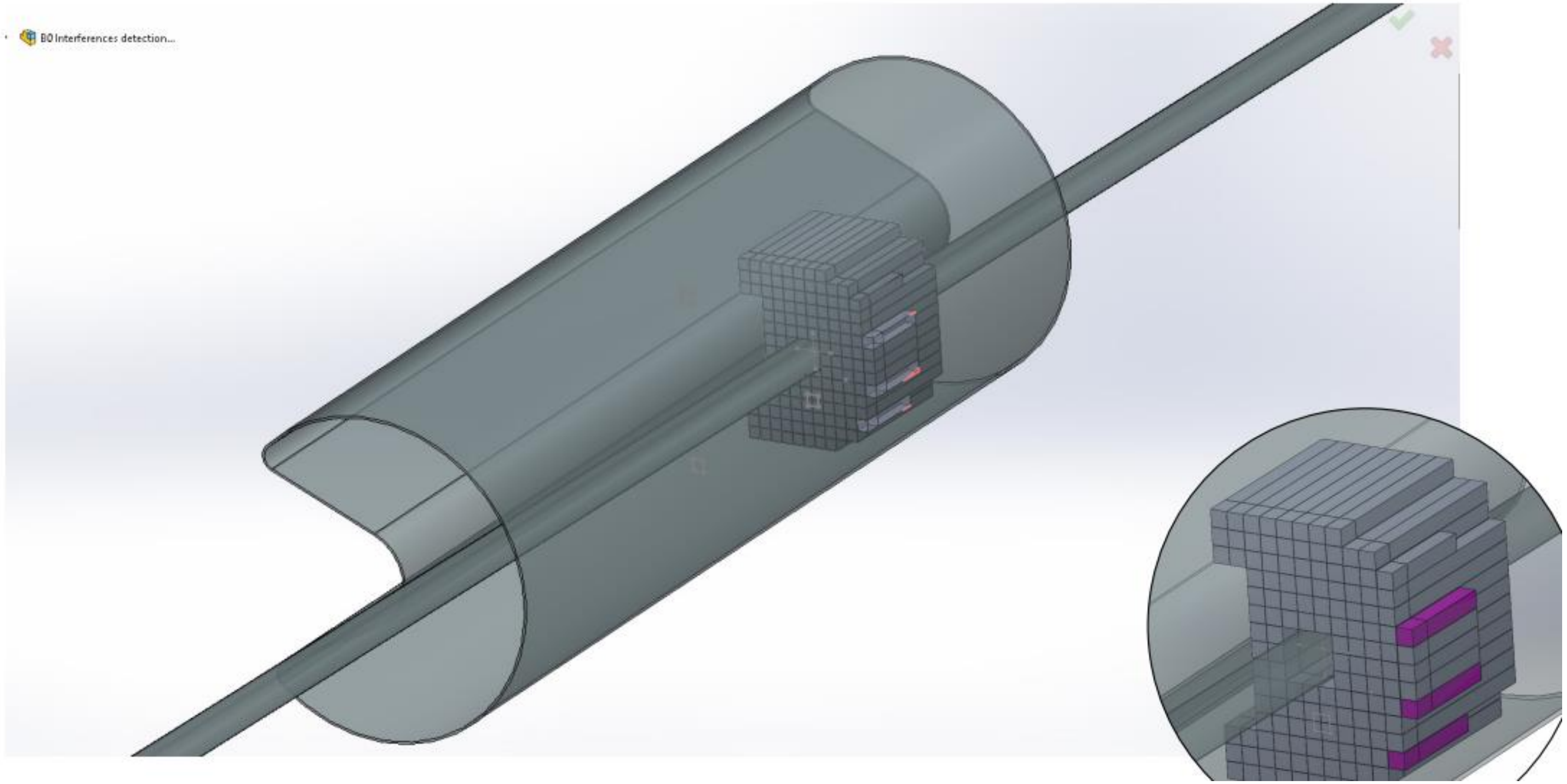
No collision with the magnet



B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 20cm

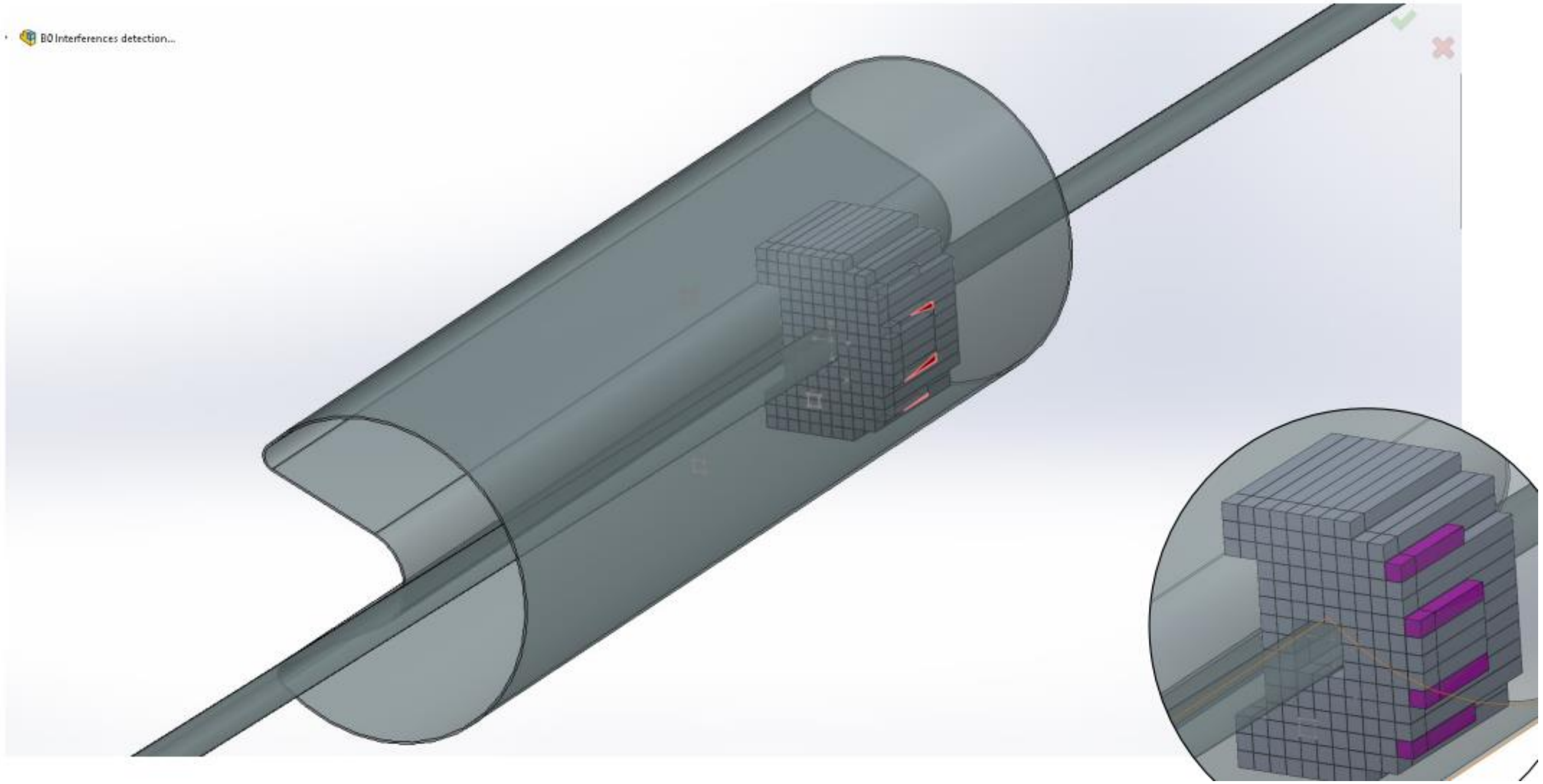
In the P5 state there are 3 collisions with the magnet located in the shortened crystals.



B0 geometry update

- Moving the B0ECAL 5cm forward, Z = 25cm

In the P6 state there are 4 collisions with the magnet located in the shortened crystals.



Technical details

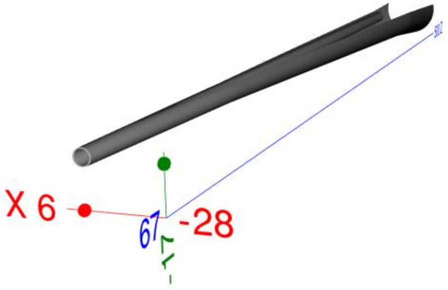
ddsim setup:

```
ddsim --steeringFile job.py -G -N 100 \
  --compactFile $DETECTOR_PATH/epic_craterlake_18x275.xml  \
  --outputFile edm4hep.root --random.seed 624
```

EICRecon setup:

```
source /opt/detector/setup.sh
export DETECTOR_CONFIG=epic_craterlake_18x275
eicrecon -Pjana:nevents=-1
 -Ppodio:output_include_collections=MCParticles, ReconstructedChargedParticles, B0ECalClusters,
ForwardOffMRecParticles, ForwardRomanPotRecParticles, EcalFarForwardZDCClusters,
HcalFarForwardZDCClusters, B0ECalHits \
 edm4hep.root
```

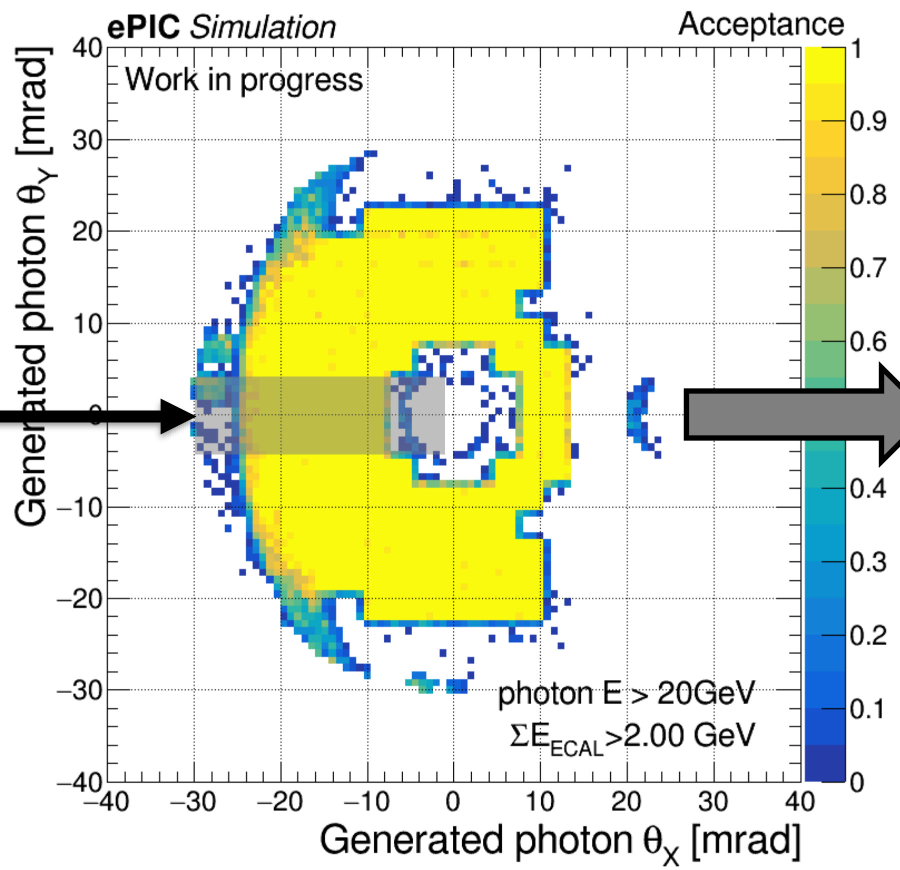
Forward photons

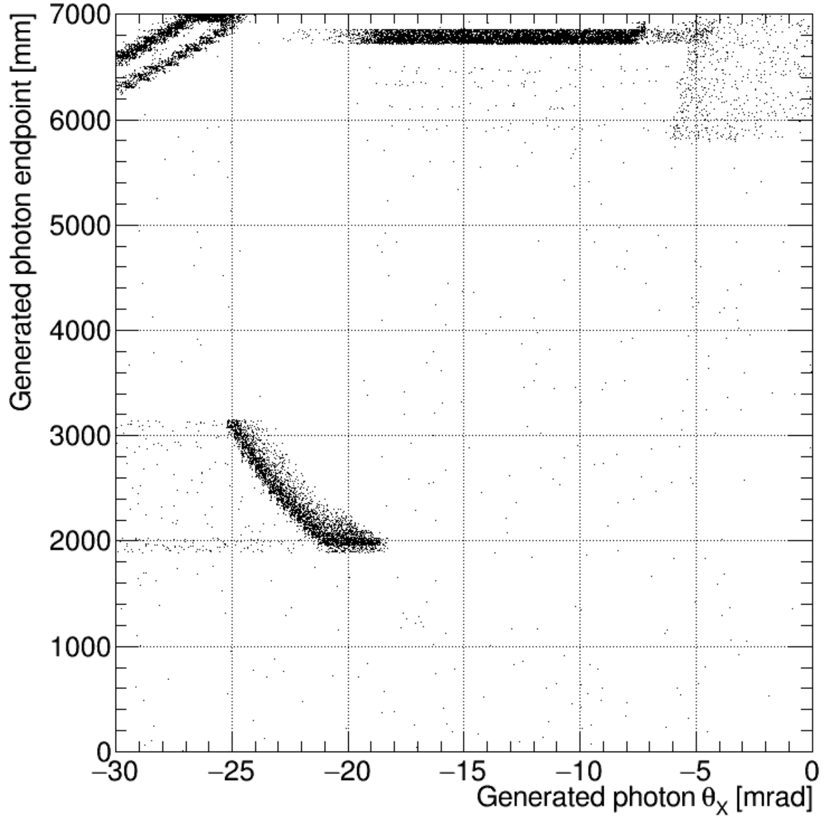


Acceptance in B0 X-Y plane

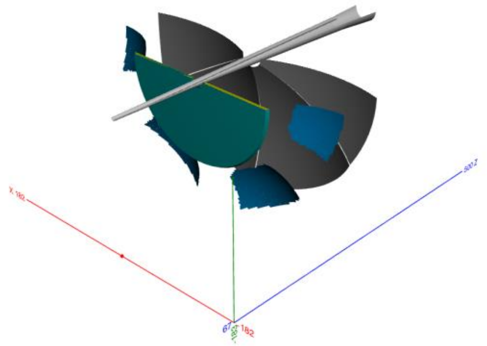
- G4 simulation provides information of the photon endpoint (where $\gamma \rightarrow ee$ starts)
- Remove central beampipe (${DETECTOR_PATH}/compact/central_beampipe.xml)

Plot photon endpoint along the X axis (θ_Y~0)





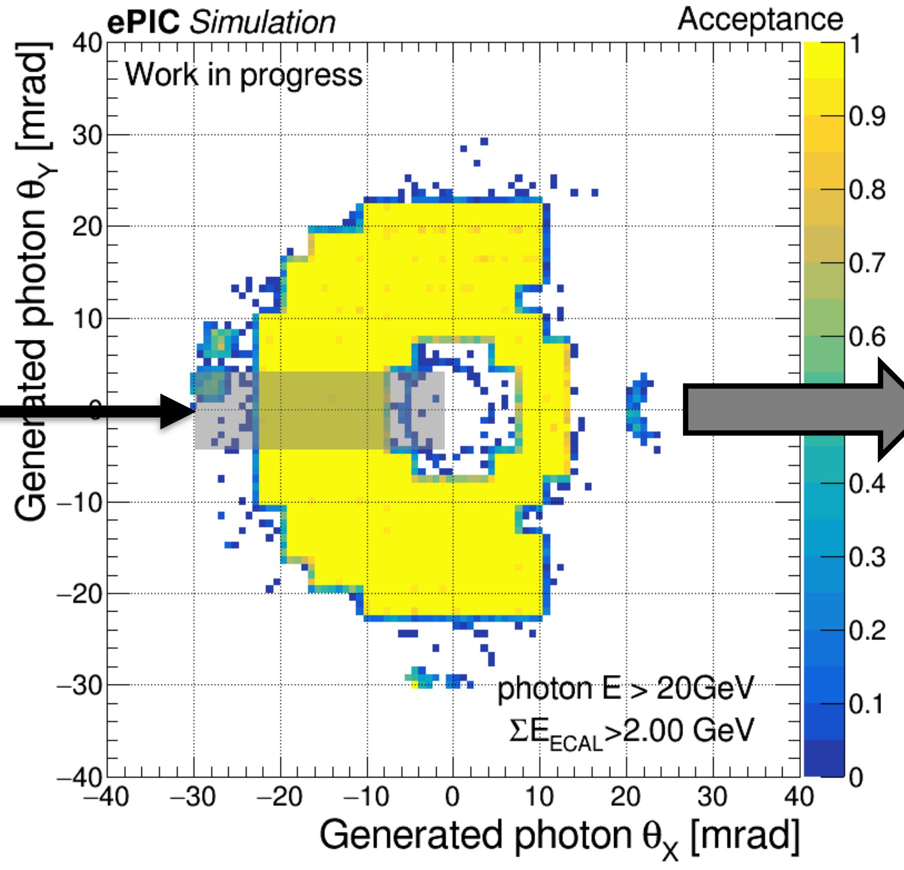
Forward photons

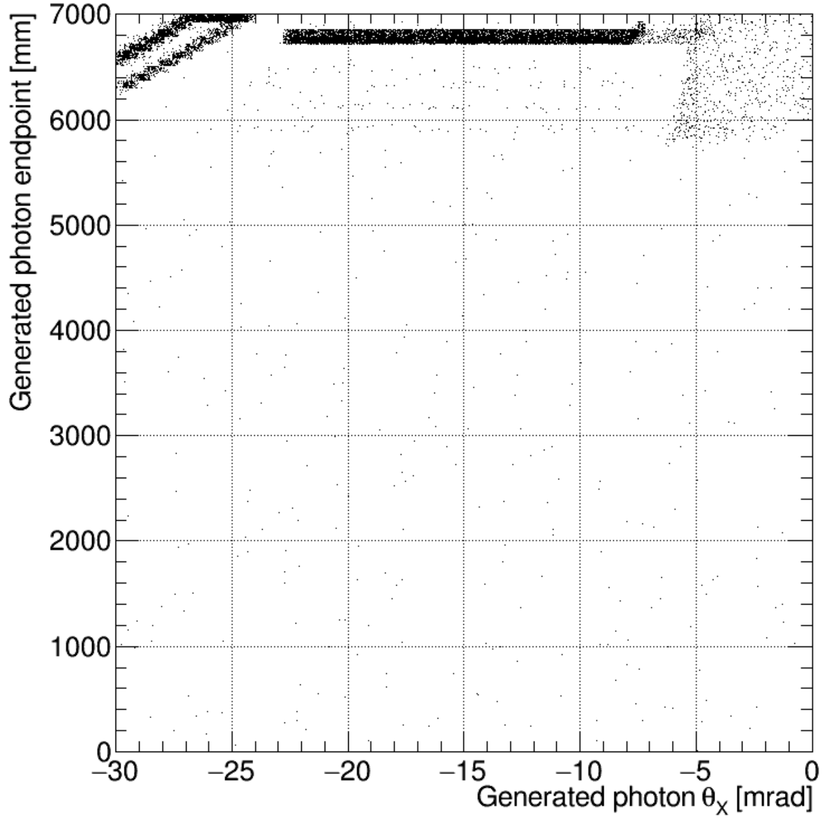


Acceptance in B0 X-Y plane

- G4 simulation provides information of the photon endpoint (where $\gamma \rightarrow ee$ starts)
- Remove central beampipe (${DETECTOR_PATH}/compact/central_beampipe.xm.,
- Remove dRICH (${DETECTOR_PATH}/compact/pid/drich.xml)

Plot photon endpoint along the X axis (θ_Y~0)





Steering file

```
from DDSim.DD4hepSimulation import DD4hepSimulation
from g4units import mm, GeV, MeV, mrad
SIM = DD4hepSimulation()

################################################################################
## Configuration for the DDG4 ParticleGun
################################################################################
SIM.enableGun = True

## Lorentz boost for the crossing angle (a boost along the X coordinate)
SIM.crossingAngleBoost = -25.0*mrad

SIM.gun.momentumMin = 41*GeV
SIM.gun.momentumMax = 41*GeV
SIM.gun.particle = 'proton'

## MinimalKineticEnergy to store particles created in the tracking region
SIM.part.minimalKineticEnergy = 1.0*GeV
```