

Low energy photons in B0

27 June 2023

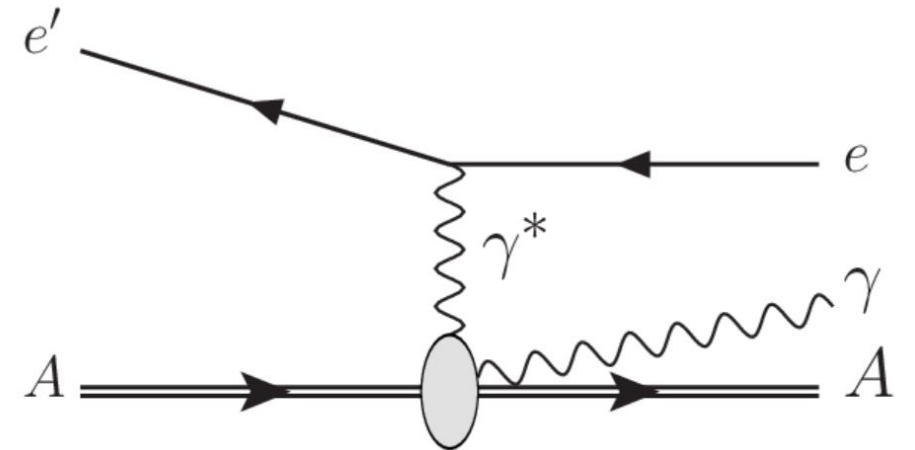
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Motivation and strategy

- In many eA interactions, ion emits a photon via the deexcitation mechanism.
- Due to the boost of the ions ($\gamma_A = E_h \cdot Z / m_A$, where E_h is hadron beam energy), forward photons are produced.
- Photon were generated isotopically ($\cos\theta \sim \text{Uni}[-1,1]$, $\phi \sim \text{Uni}[0,2\pi]$), at discrete energies in ion rest frame, and were boosted in the electron-ion lab frame.
- Events of the form of $e + A \rightarrow e' + A + \gamma$ are written in hepMC format, storing the beam energy configuration, and were propagated through the ePIC detector simulation and reconstruction.
- Ions and electrons were disabled in simulation



Photon spectra

- Photons with two energies were generated: 5 MeV and 7 MeV, with $P(5\text{MeV}) = P(7\text{MeV}) = 0.5$. Motivated by the energy range of excited ions in PbPb collisions at the LHC, [Eur. Phys. J. A \(2021\)](#)
- Two hadron beam energies were considered¹: 108 and 39.4 GeV/n

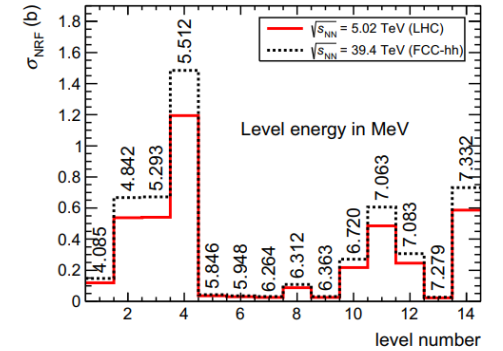
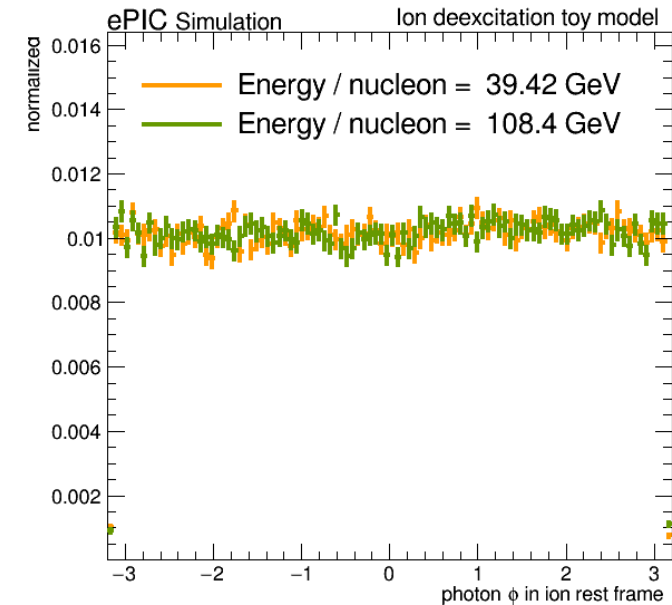
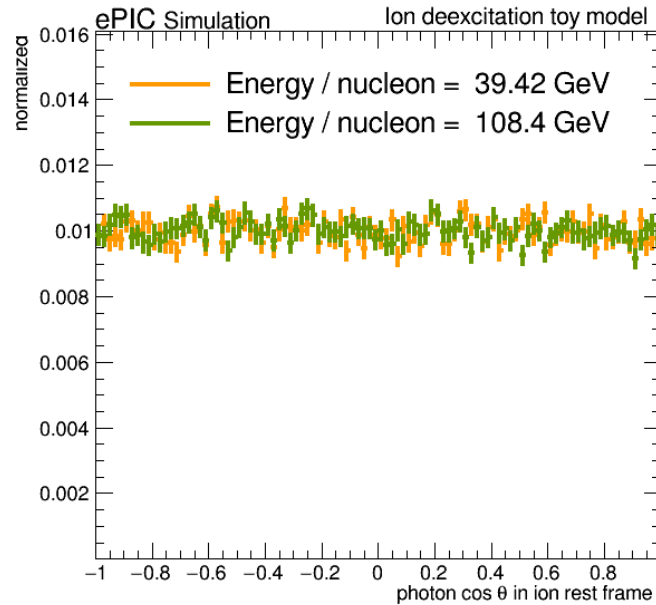
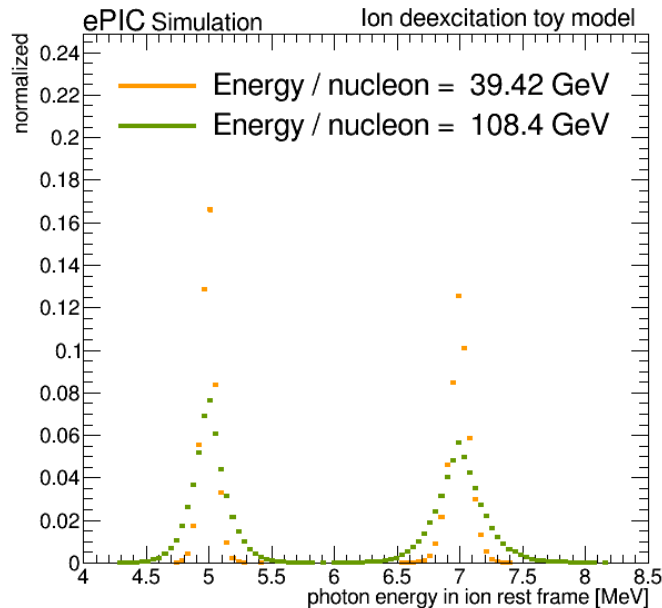


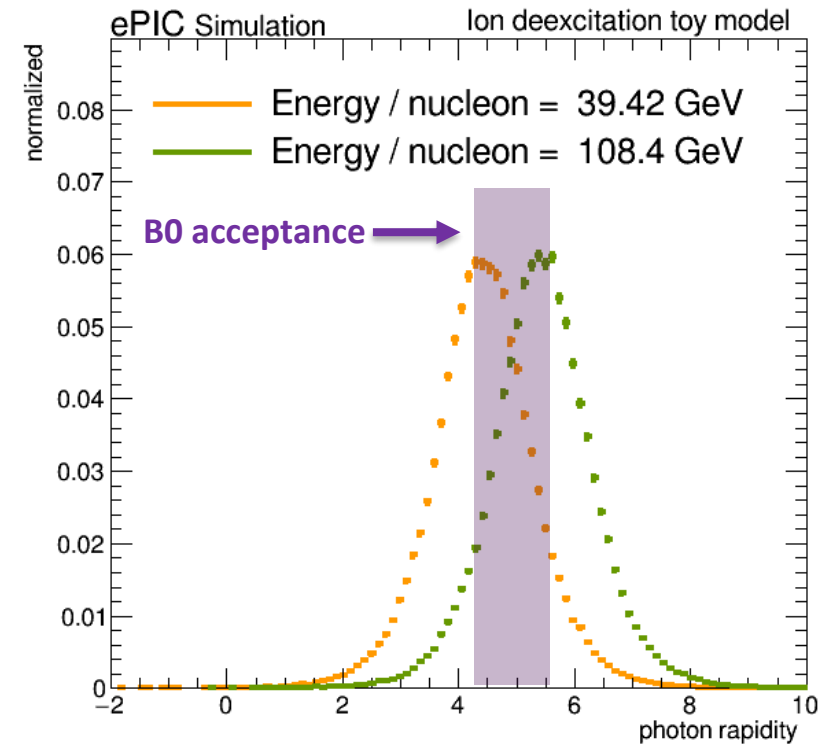
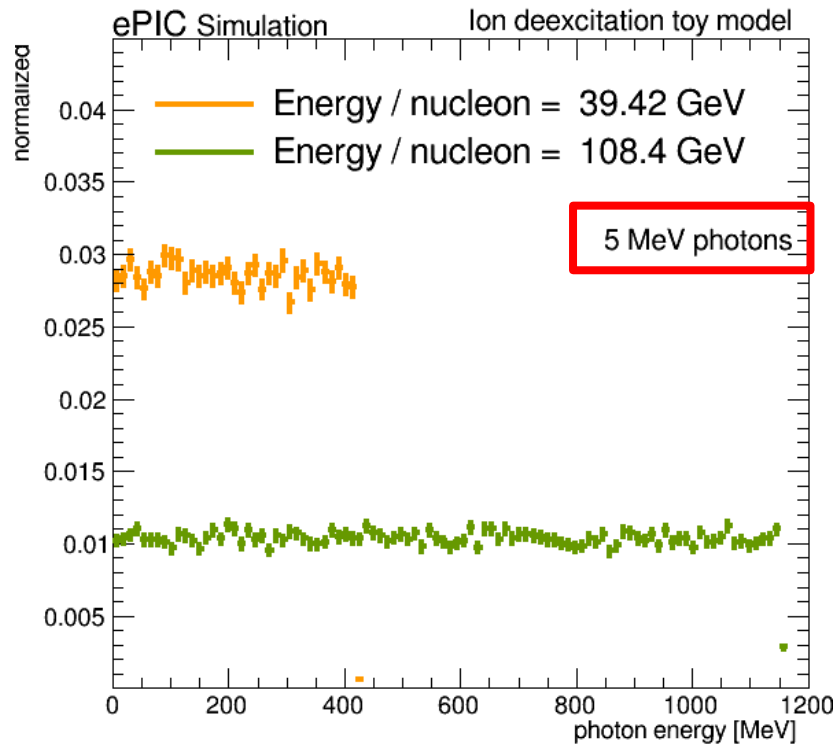
Fig. 2 NRF cross sections for ultraperipheral ^{208}Pb - ^{208}Pb collisions at the LHC and FCC-hh, respectively, at $\sqrt{s_{\text{NN}}} = 5.02$ TeV (solid histogram) and at $\sqrt{s_{\text{NN}}} = 39.4$ TeV (dashed histogram)



¹ Limited range constrained by the [Afterburner](#), discussed here: <https://github.com/eic/afterburner/issues/5>

Photon boost

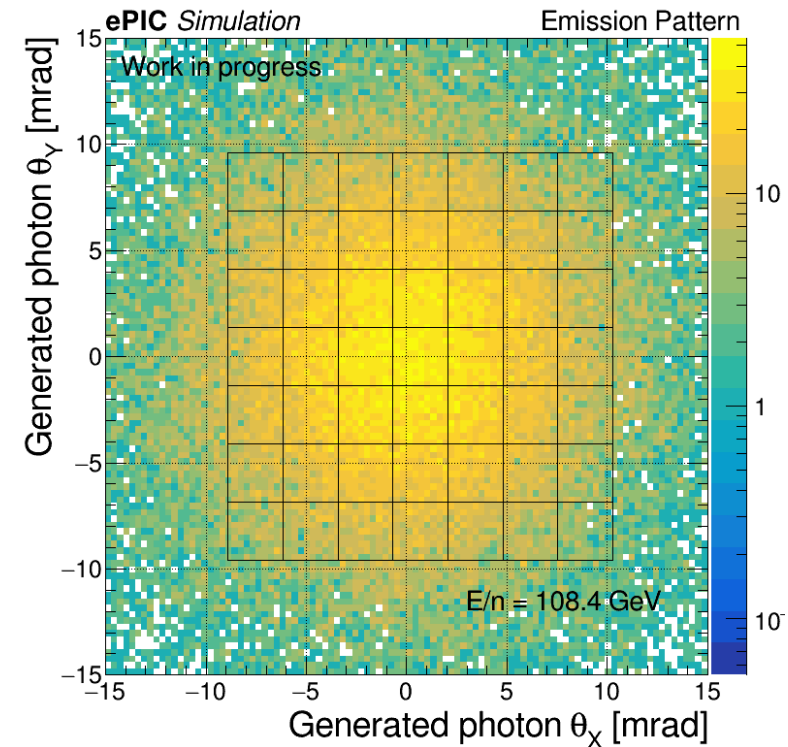
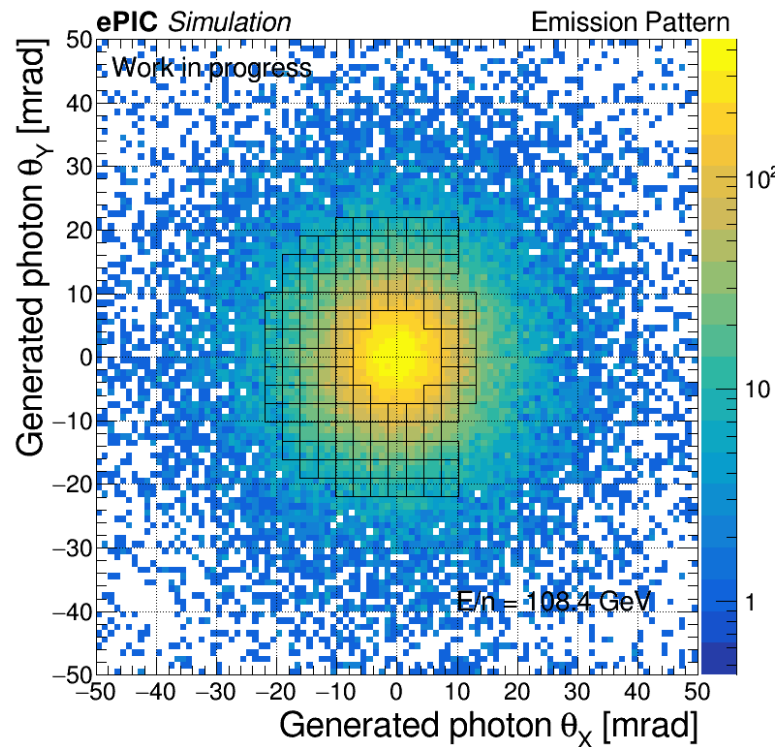
- In lab frame and hadron beam coordinate system¹, photons are boosted, acquiring higher energies resulting in large rapidity distribution



¹ use `tlv.RotateY(Xangle)` ROOT function to move to hadron coordinate system, $Xangle=25e-3$ rad

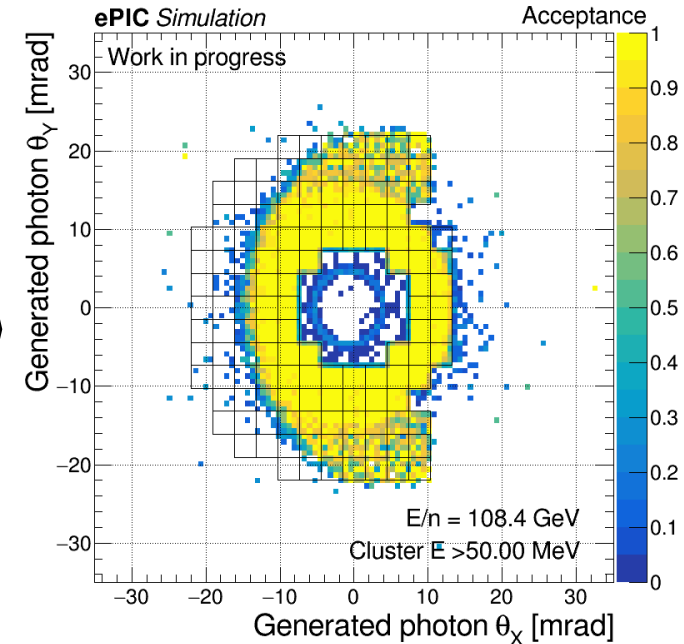
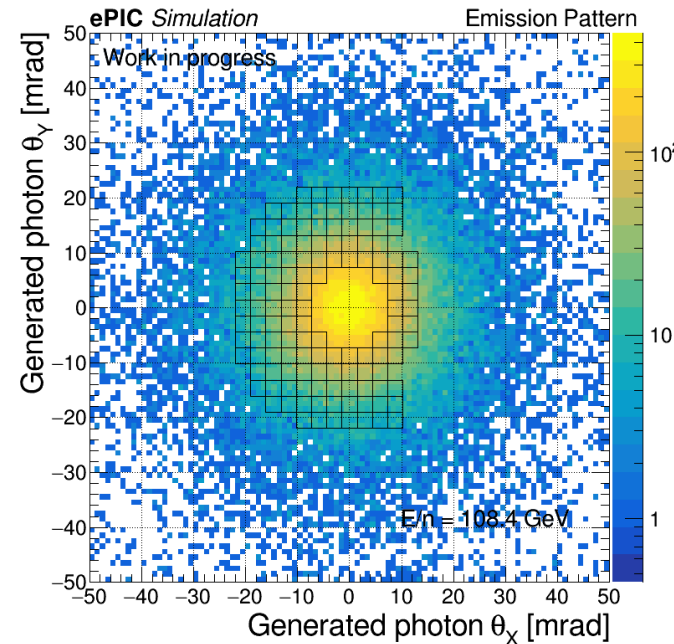
Simulation results

- In the forward region, the ZDC and the B0 detectors can measure forward photons.
- Photon spatial distribution at the interaction point for 108 GeV/n Pb beam.
- B0 and ZDC detector contours are shown in top of the distributions.



Simulation results

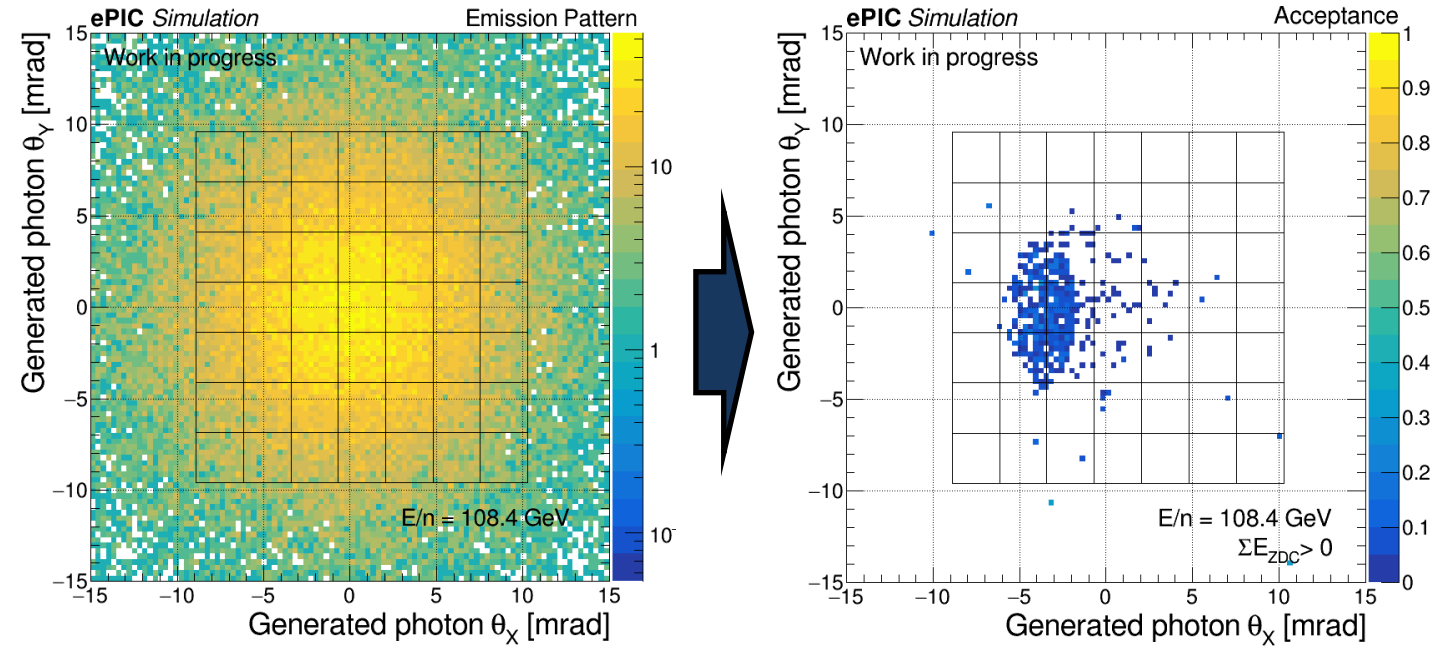
- Geometrical acceptance of B0 detector for 108 GeV/n Pb beam
- Clusters in B0 detector above a certain thresholds are considered



γ energy in A rest frame	Within B0 acceptance	B0 acceptance + At least one cluster in B0 with $E > 50$ MeV
5 MeV	40%	33%
7 MeV	40%	33%

Simulation results

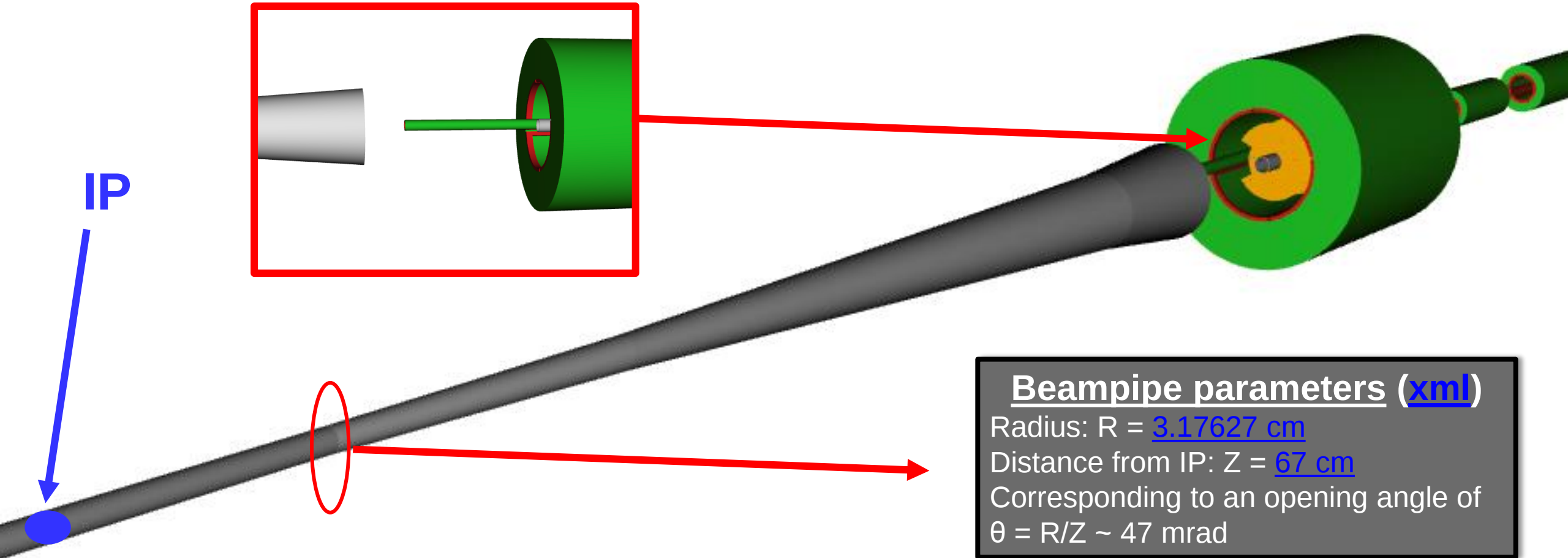
- Geometrical acceptance of ZDC detector for 108 GeV/n Pb beam
- Consider detected photons if any hit in ZDC detector was reconstructed.



γ energy in A rest frame	Within ZDC acceptance	ZDC acceptance + Signal in ZDC above 0
5 MeV	60%	<1%
7 MeV	60%	<1%

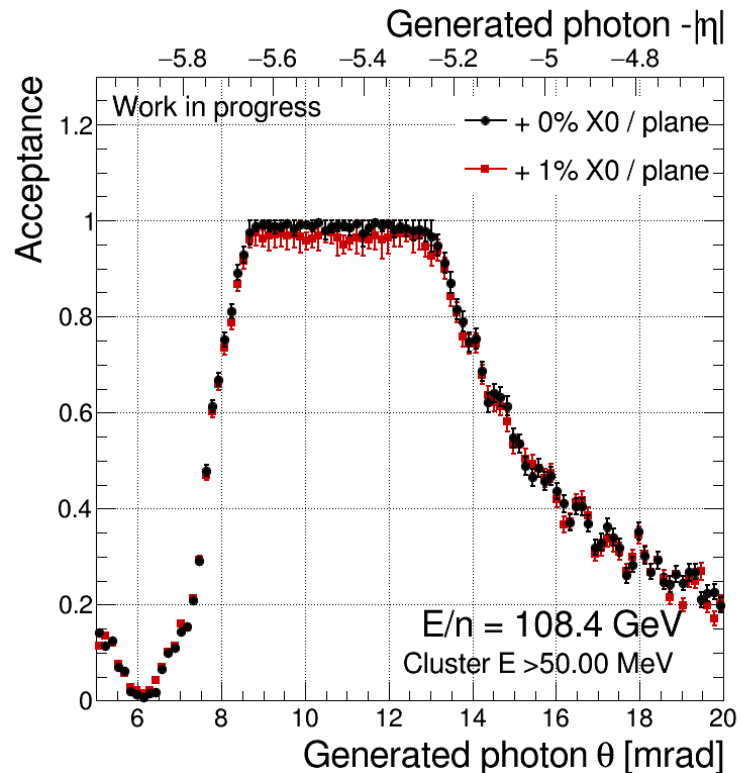
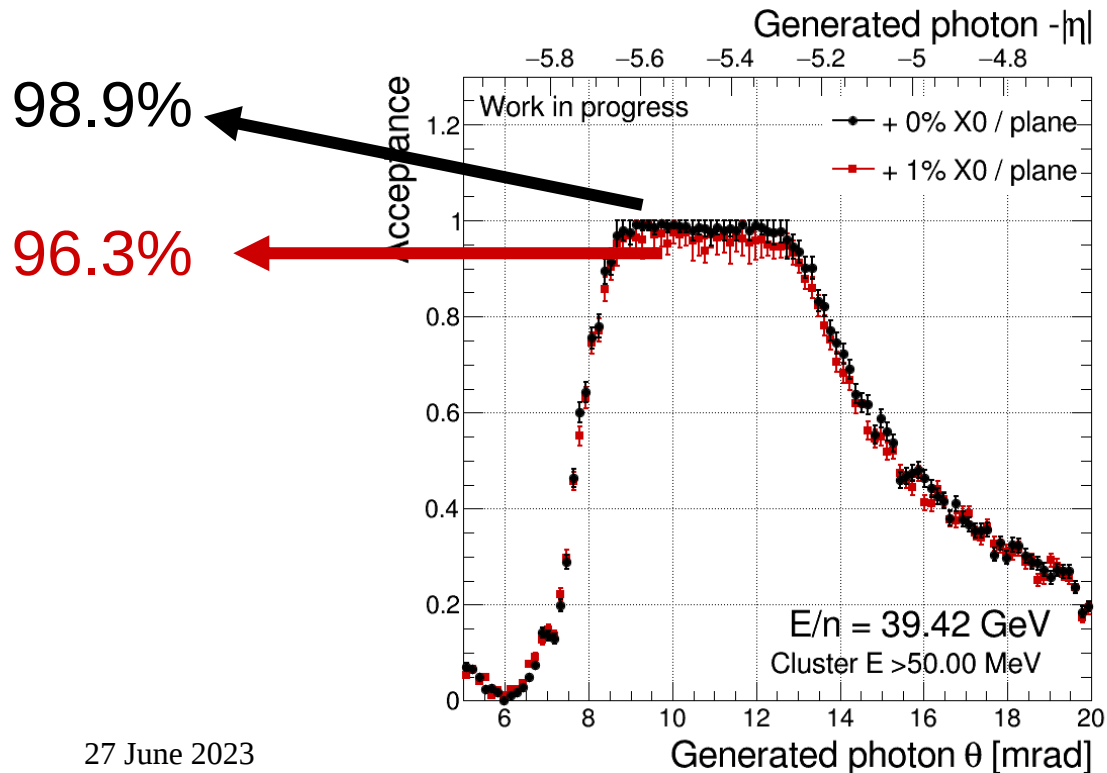
ePIC detector geometry

- Photons up to ~ 15 mrad don't cross the beampipe resulting in high acceptance in B0 detector.



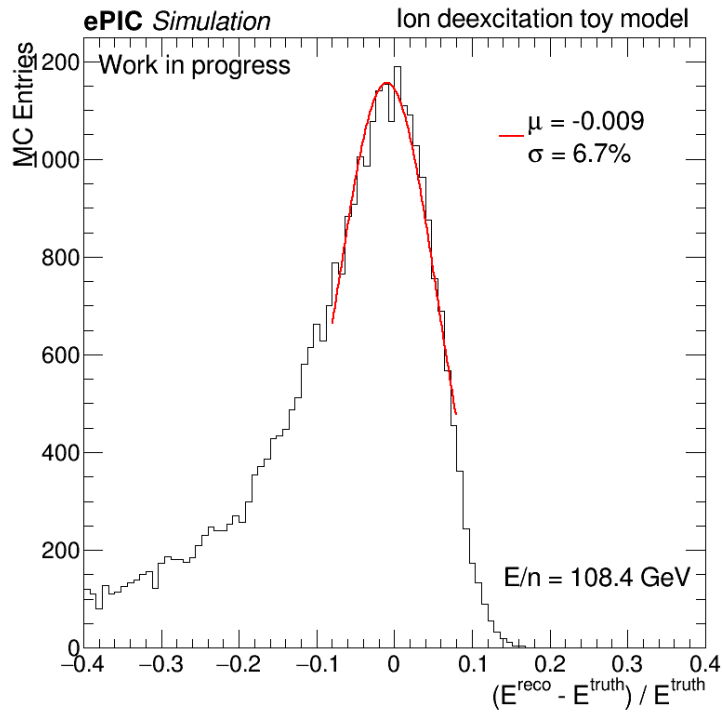
ePIC detector geometry

- The only material photons with $\theta < 15 \text{ mrad}$ see is the B0 Tracking detectors.
- B0 tracker = 0.3 mm of SiOxide and 0.12 mm of CarbonFiber ([link](#))
- To check the effect of additional material, a 0.1436 mm of Cu was added to each layer resulting in 1%X0 / tracking station = 4%X0 additional material budget before the B0ECAL

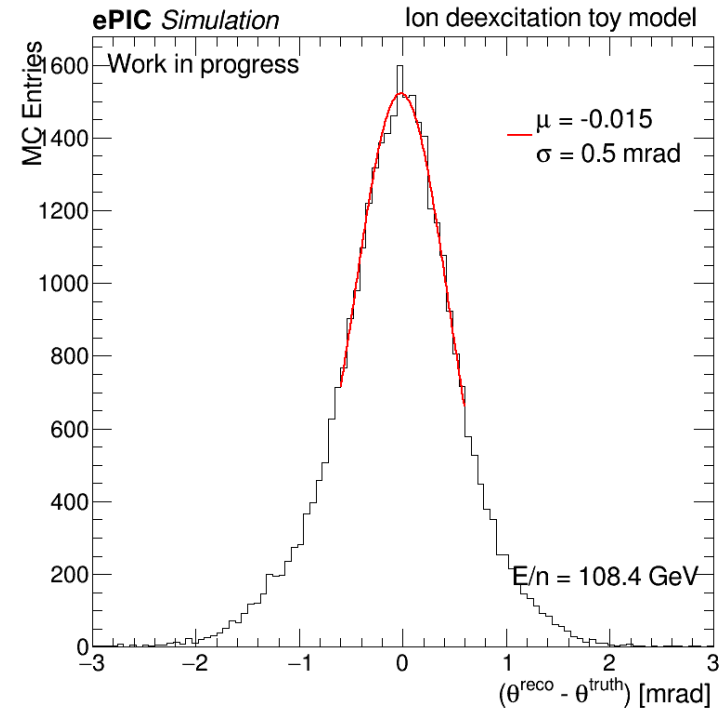


Simulation results

- Reconstruction of photon energy in the ion rest frame requires good position and energy resolution
- Using reconstructed clusters (EICRecon) to determine photon 4-momentum



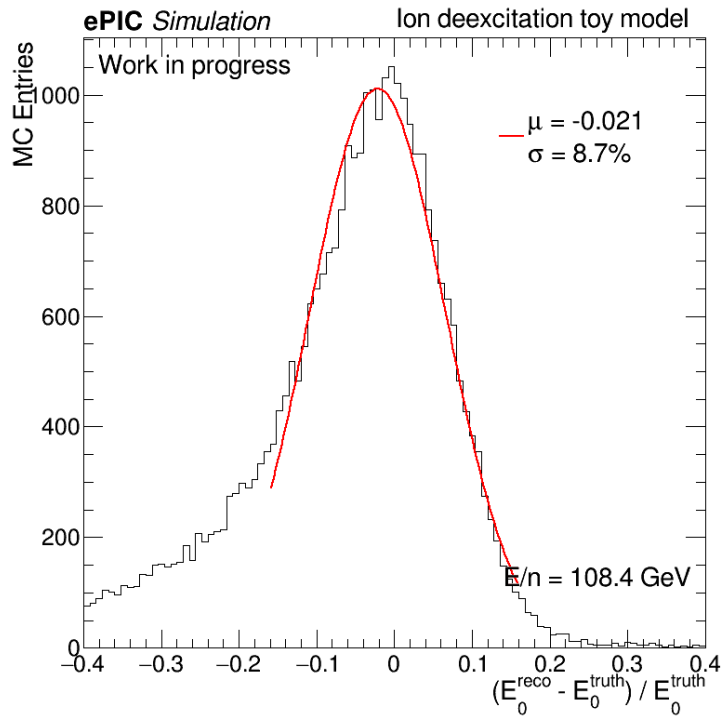
**$\sigma/E \sim 6.7\%$
with long tail**



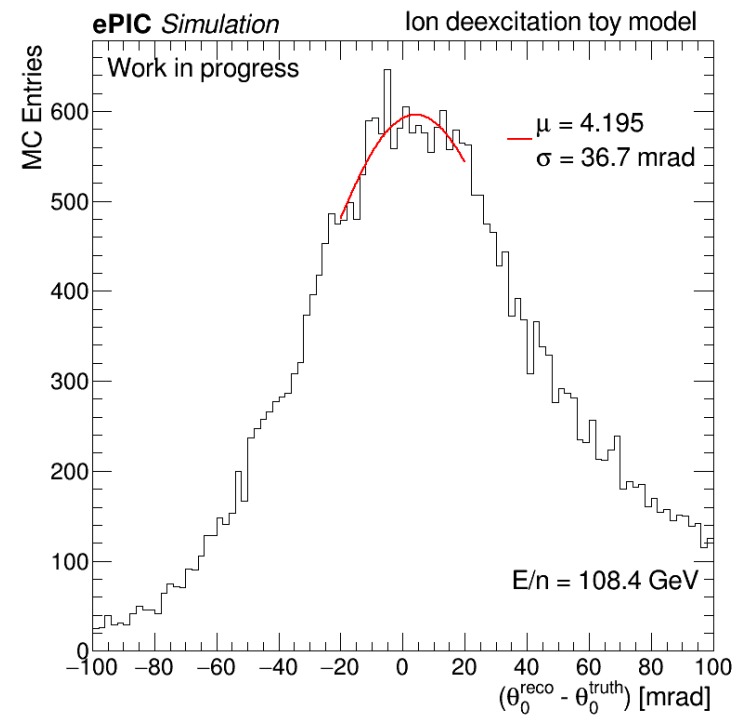
$\sigma \sim 0.5 \text{ mrad} = 3.2 \text{ mm}$

Simulation results

- Reconstruction of photon energy in the ion rest frame requires good position and energy resolution
- Using reconstructed clusters (EICRecon) to determine photon 4-momentum
- Reconstructed photons are boosted to ion rest frame



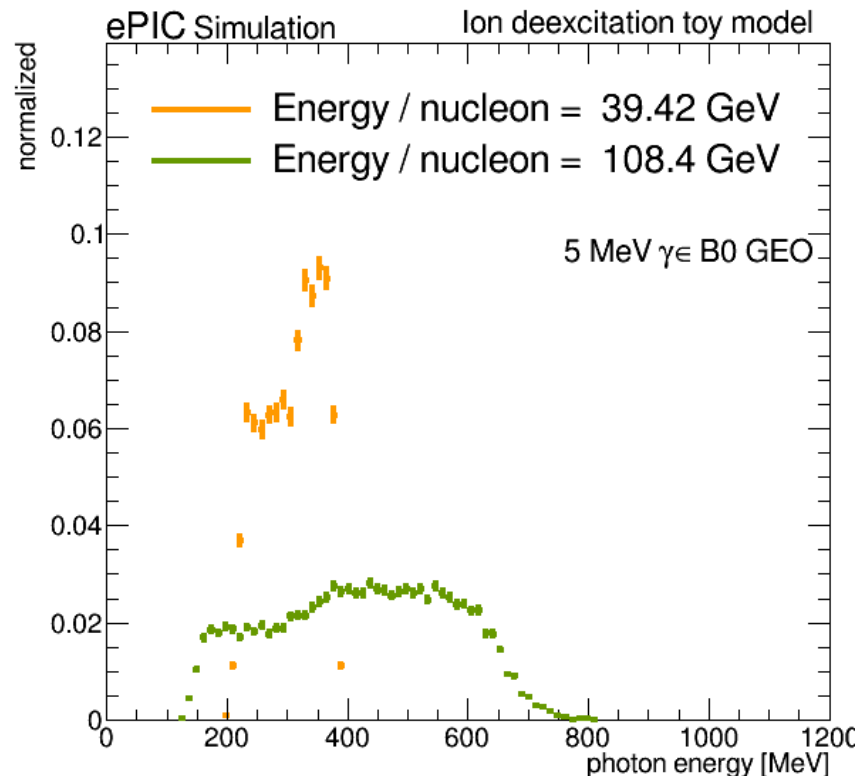
$\sigma/E \sim 9\%$



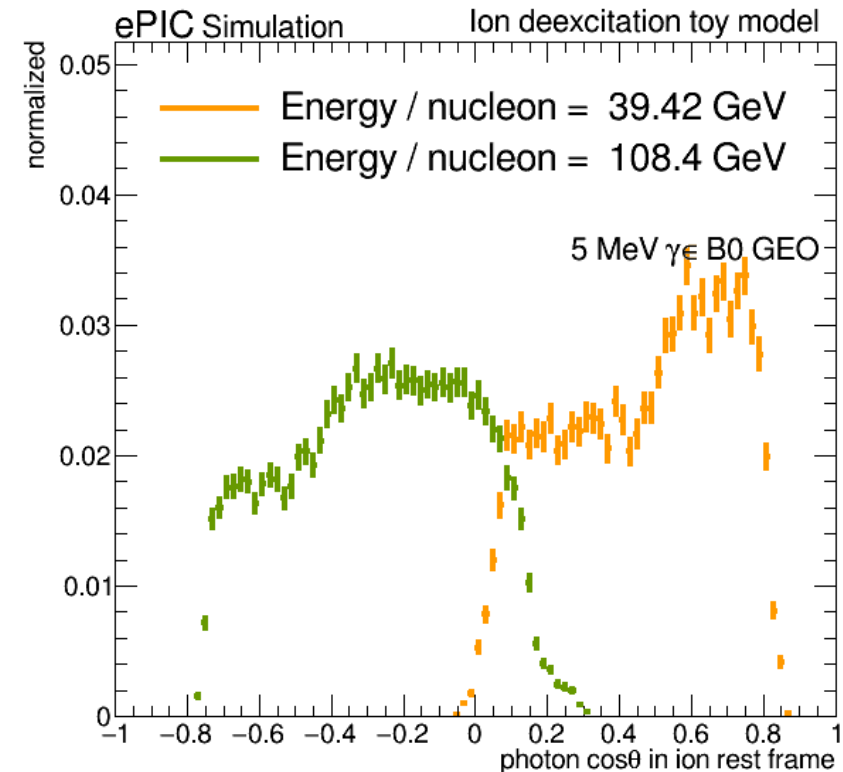
**Can resolve
directionality**

Simulation results

- The B0 geometrical acceptance forces detectable photons to be at higher energies and biases the angular distribution in ion rest frame.
- Energy and angular distribution for photons emitted within the B0 geometrical acceptance:



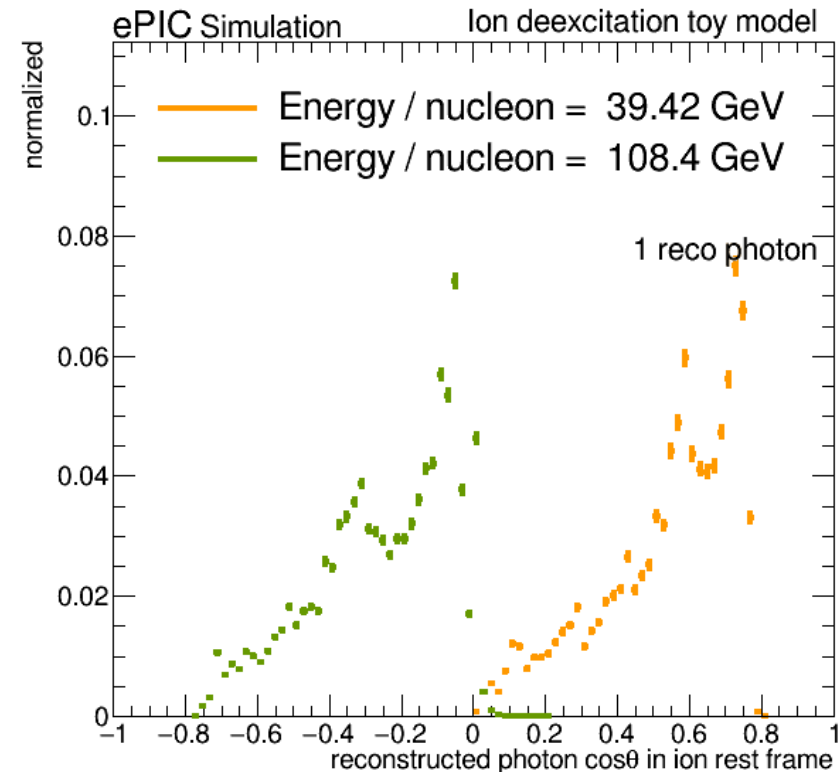
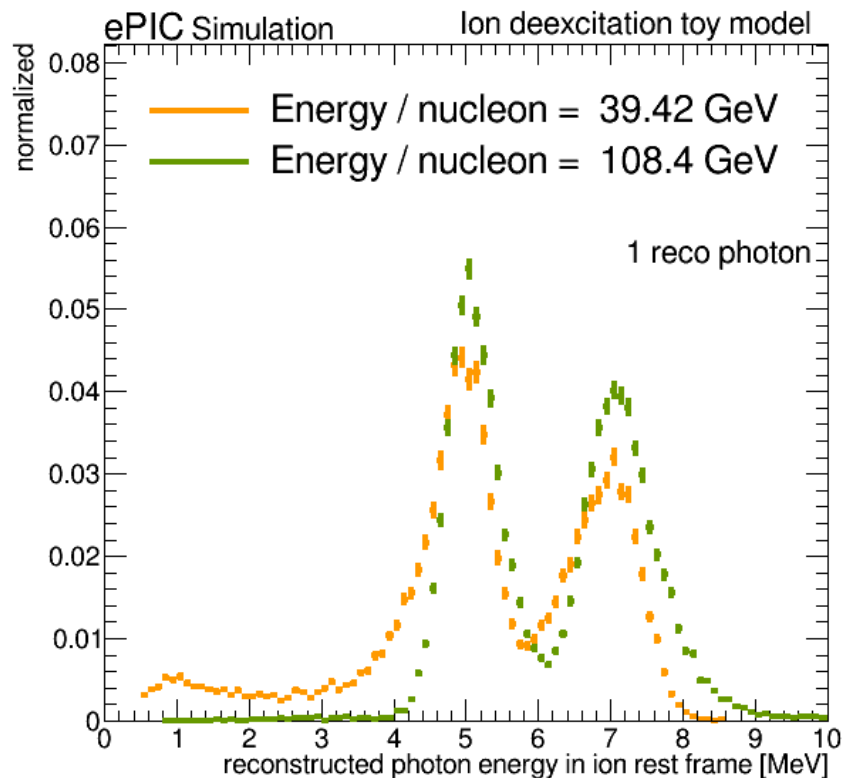
$\theta > 2.5 \text{ mrad} \rightarrow E > 150 \text{ MeV}$



Distorted cos θ^* distribution

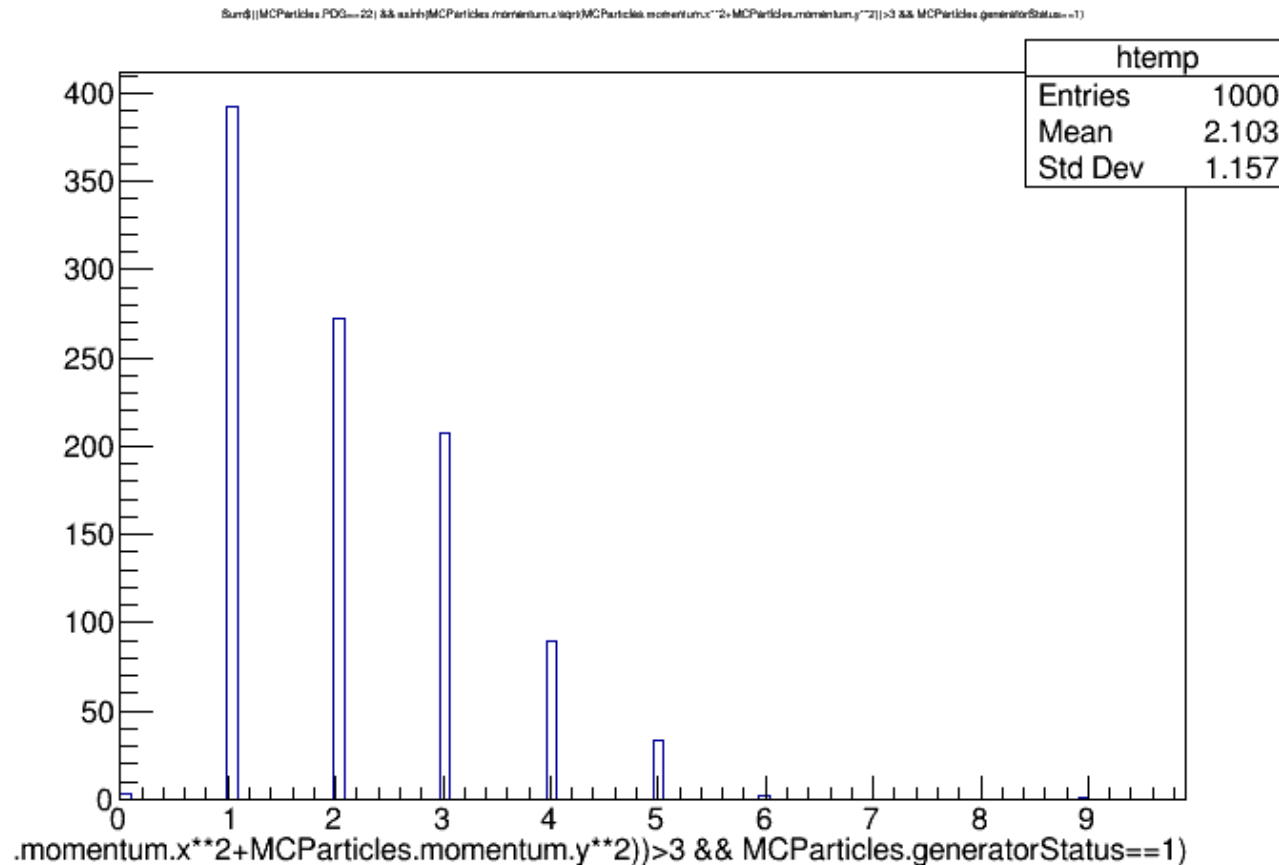
Simulation results

- Photons are reconstructed from the calibrated B0ECAL clusters.
 - Energy reconstruction – good separation for the toy model ($\Delta E = 2$ MeV)
 - Angular reconstruction – large bias due to geometrical acceptance and resolution



Next steps

- We plan to look at incoherent VM events.
 - Develop filter to store only $ePb \rightarrow ePb + X$ events (3% from all incoherent)



- Number of final state photons with $\eta > 3$ in $J/\psi \rightarrow ee$ events
- We switch to $J/\psi \rightarrow \mu\mu$ events to avoid brem. photons

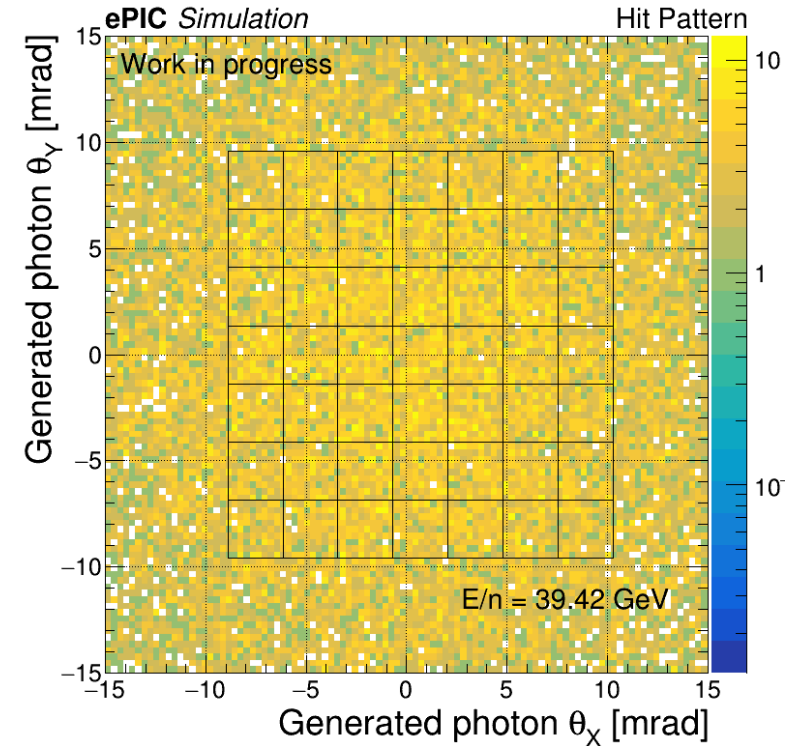
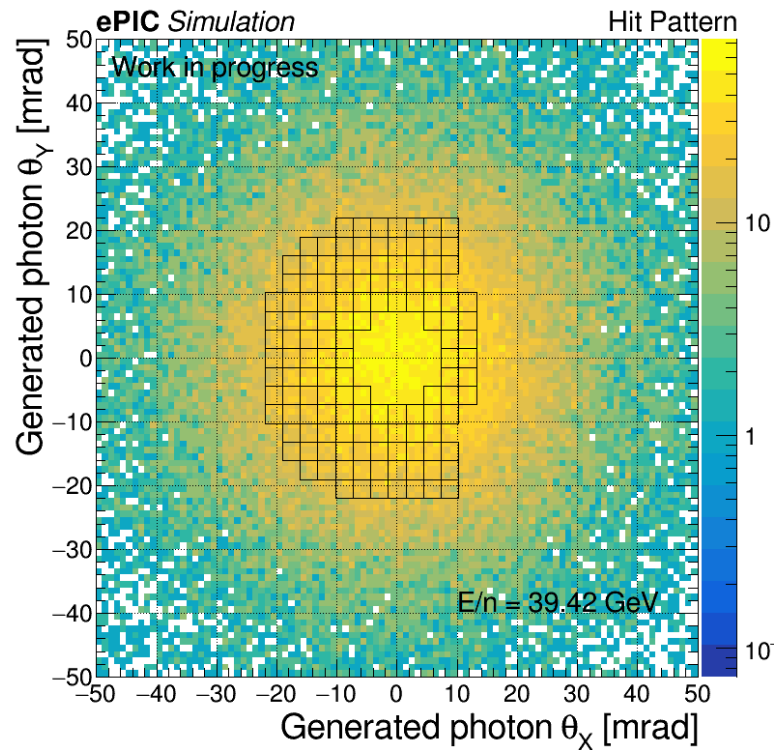
Summary

- Feasibility study for $\sim$ MeV photons from ion deexcitation has been performed for ePb beam energies
- Geometrical acceptance of $\sim$ 40% in B0 detector for forward photons was computed
- B0 ECAL cells with energy thresholds above 50 MeV result in $\sim$ 30% photon detection efficiency (the main loss is due to intersect with the beampipe).
- B0 is the only detector with high efficiency for $O(100\text{MeV})$ photons in $|\eta| > 4.5$
- Photon energy resolution in ion rest frame $< 10\%$ (!)
- Photon spatial resolution in lab frame – 3.3 mm (B0 crystal size is $20 \times 20 \text{ mm}^2$)
- Further studies including realistic physics model are ongoing

Backup

Simulation results

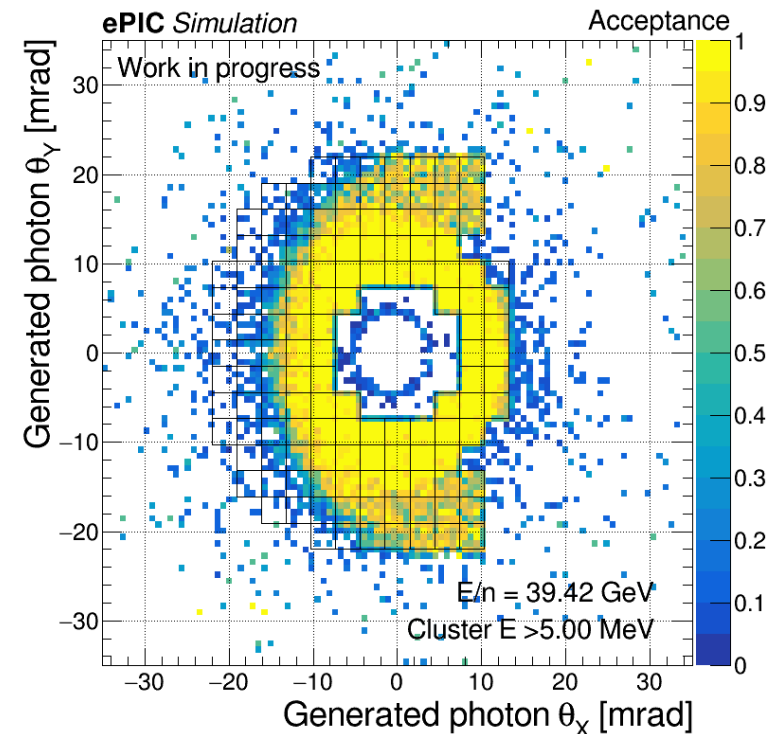
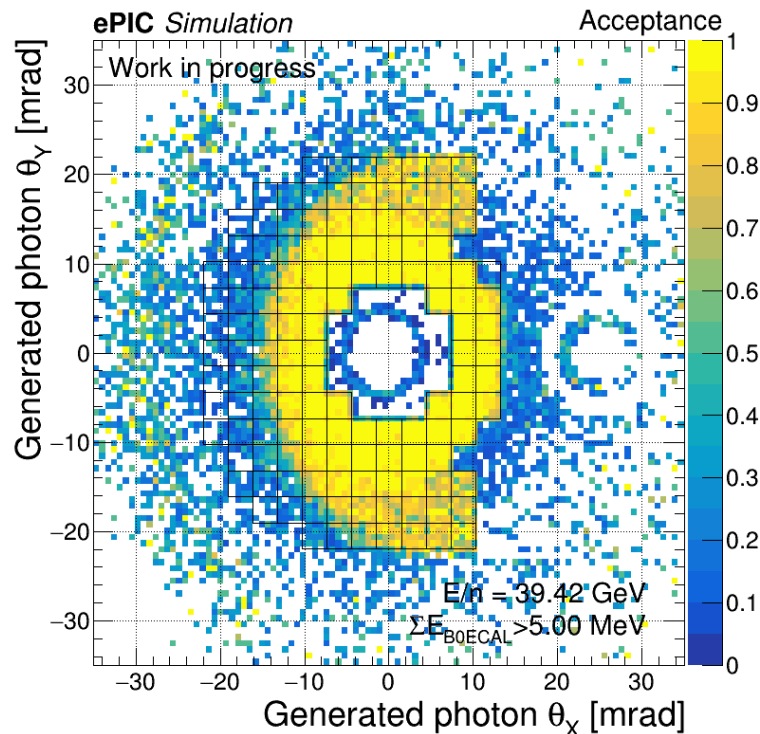
- In the forward region, the ZDC and the B0 detectors can measure forward photons.
- Hit pattern for 39.4 GeV/n Pb beam in B0 and ZDC detectors :



Simulation results

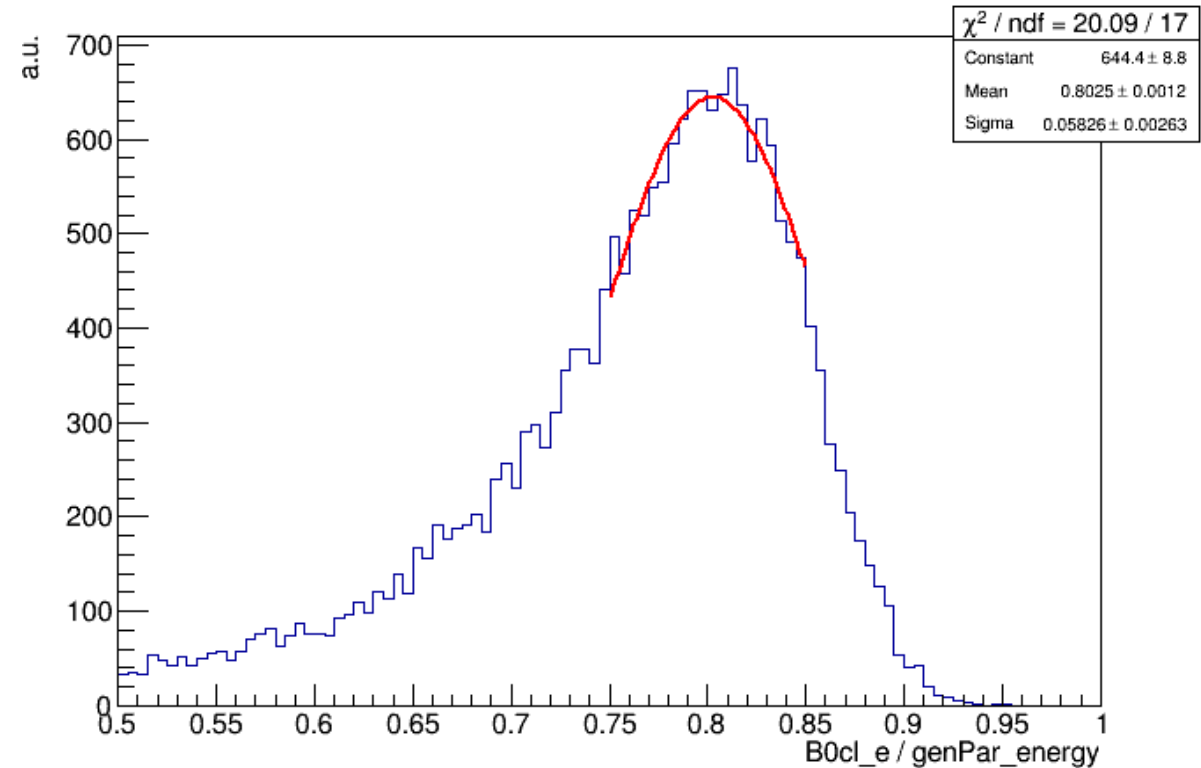
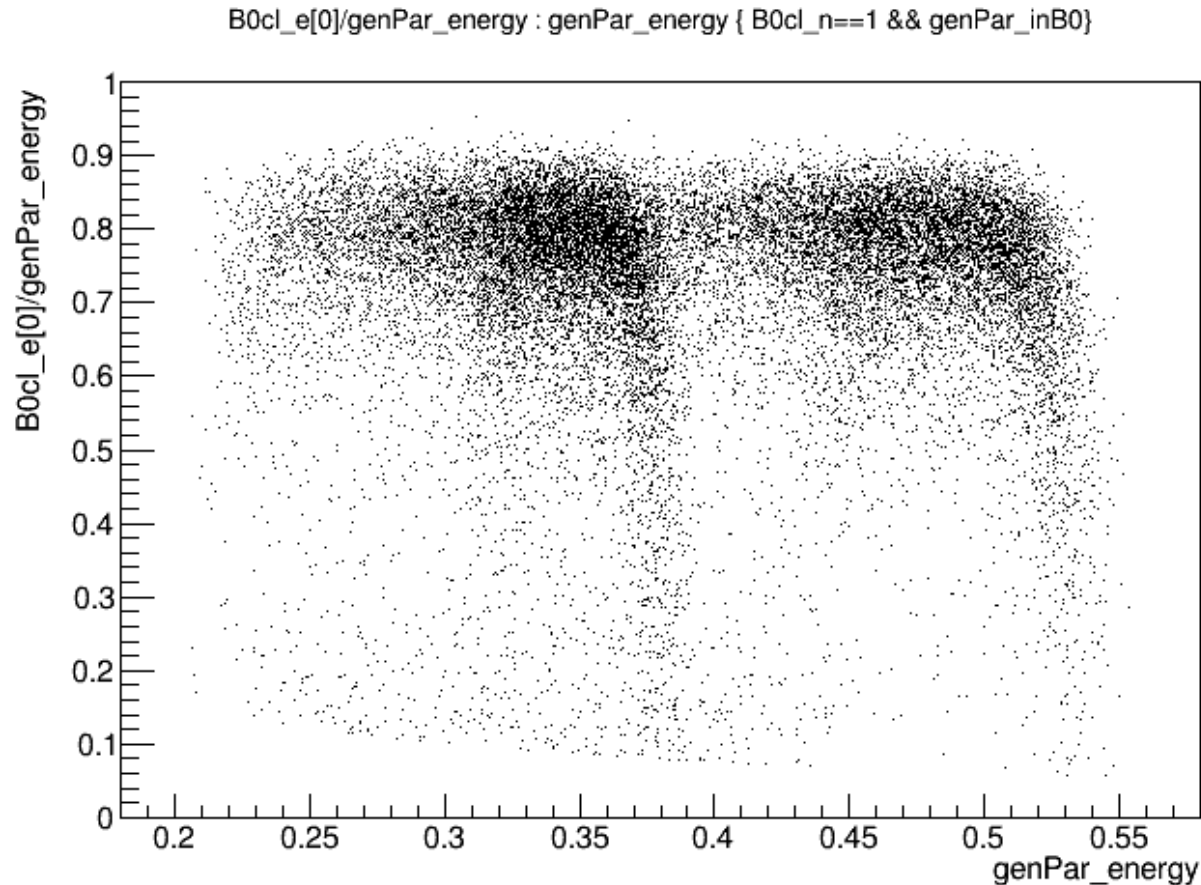
- Geometrical acceptance of B0 detector for 39.4 GeV/n Pb beam:

γ energy in A rest frame	Within B0 acceptance	B0 acceptance + At least one hit in B0 with $E > 5$ MeV	B0 acceptance + At least one cluster in B0 with $E > 5$ MeV	B0 acceptance + At least one hit in B0 with $E > 10$ MeV	B0 acceptance + At least one cluster in B0 with $E > 10$ MeV
5 MeV	31.5%	23.4%	22.6%	23.4%	22.6%
7 MeV	31.8%	24.3%	23.3%	24.2%	23.3%



Photon calibration

- Due to a constant response vs photon energy the calibration factor computed for the inclusive sample. Calibration factor $C = 1.2461090$



Photon reconstruction

- In most of the events we have only 1 energy cluster

