ZDC EMCAL Resolution for Λ^0 Reconstruction

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ePIC TIC Meeting
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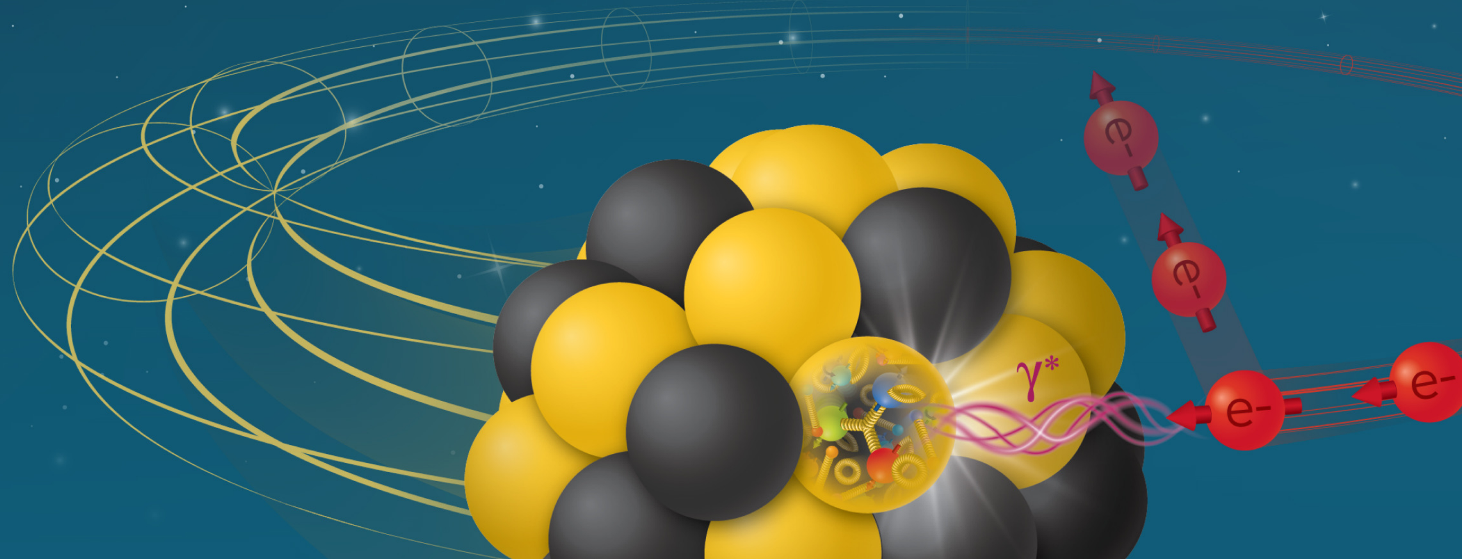
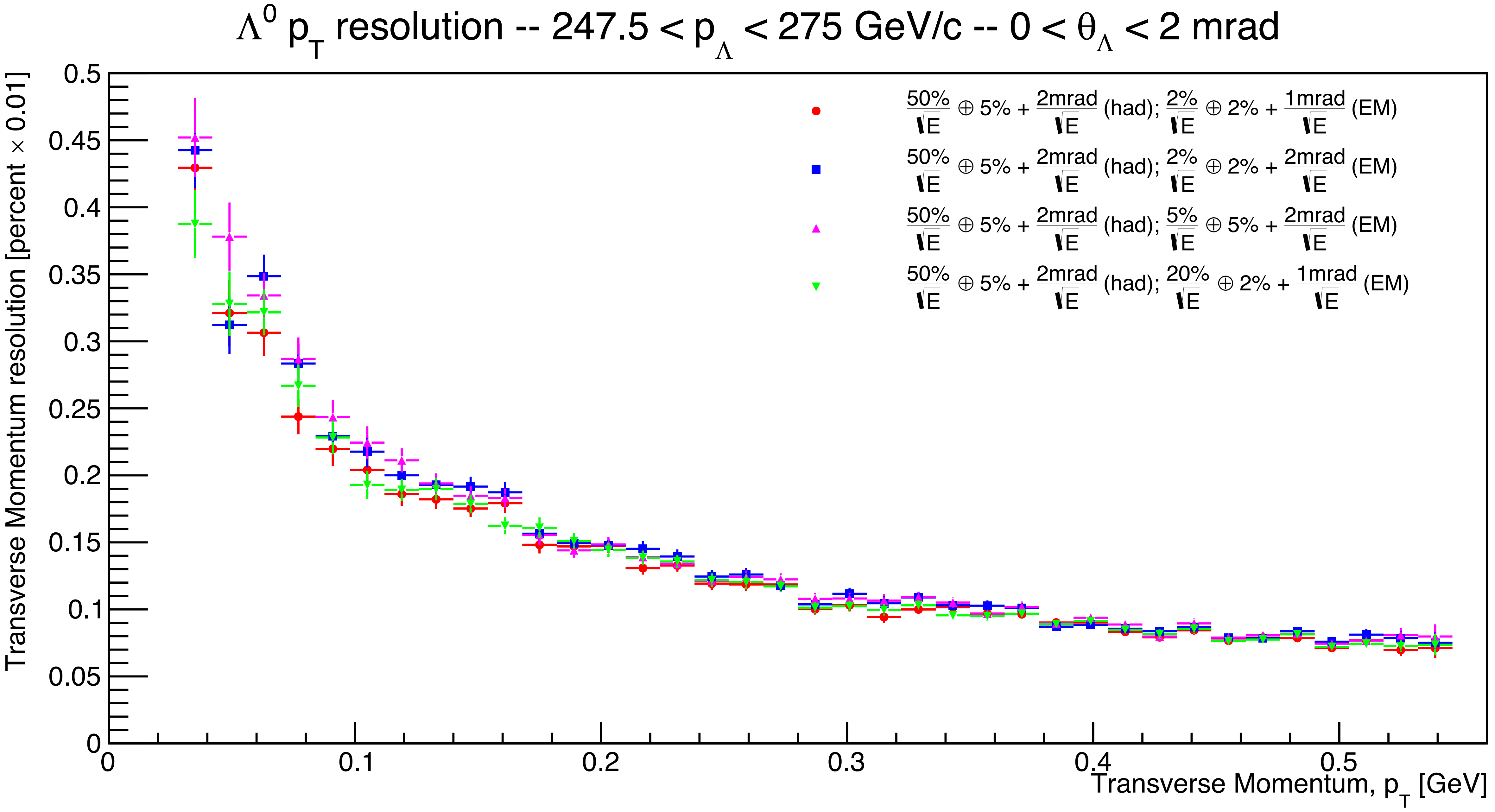
Electron-Ion Collider



Preliminaries

- Using particle gun to rule out any issues with generator:
  - Sample I had on-hand was with crossing angle with wrong sign.
- Shooting Λ^0 with:
  - 247.5 < p < 275 GeV (90% beam energy to 100%).
  - $0 < \theta < 2$ mrad
- GEANT handles the decay → confirmed proper branching fractions:
  - $\Lambda^0 \rightarrow p + \pi^- \ (\sim 67\%)$
  - $\Lambda^0 \rightarrow n + \pi^0 \rightarrow \gamma\gamma \ (\sim 33\%)$
- Particles shot through magnets for proper aperture, but with beampipe “off” and no real ZDC – just using for acceptance.
  - Acceptance of $\Lambda^0 \rightarrow n + \pi^0 \rightarrow \gamma\gamma$ in this study is around ~65%.
- Smearing applied “by-hand” and ignoring reconstruction itself – only looking at effect of resolution assumptions for energy and angle.
  - Specifically, $n\gamma\gamma$ final-states which successfully arrive at the ZDC have their MC truth vectors smeared by various energy/angular resolution values → **assumes nothing about *how* the reconstruction is carried-out.**
- **Note:** This study does not answer the question of what Λ^0 p_T (which leads to the Kaon t) resolution is *__required__*, just how this depends on the energy and angular resolutions of the ZDC

Results



Λ^0 p_T resolution -- 247.5 < p_Λ < 275 GeV/c -- 0 < θ_Λ < 2 mrad
Transverse Momentum resolution [percent × 0.01]
Transverse Momentum, p_T [GeV]
$\frac{50\%}{\sqrt{E}} \oplus 5\% + \frac{2mrad}{\sqrt{E}}$ (had); $\frac{2\%}{\sqrt{E}} \oplus 2\% + \frac{1mrad}{\sqrt{E}}$ (EM)
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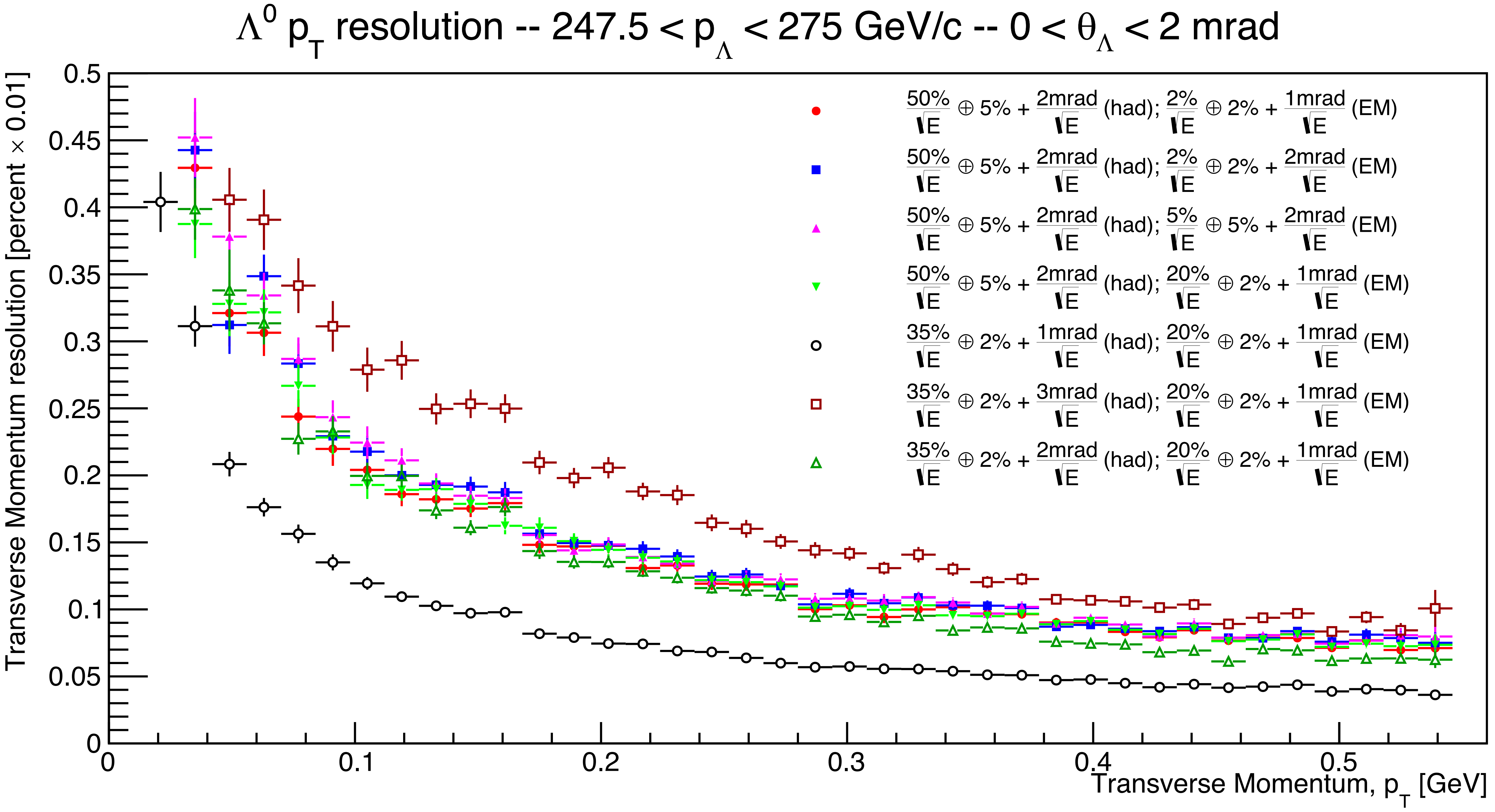
Results



Λ^0 p_T resolution -- 247.5 < p_Λ < 275 GeV/c -- 0 < θ_Λ < 2 mrad
Transverse Momentum resolution [percent × 0.01]
Transverse Momentum, p_T [GeV]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.1
0.2
0.3
0.4
0.5
$\frac{50\%}{\sqrt{E}} \oplus 5\% + \frac{2mrad}{\sqrt{E}}$ (had); $\frac{2\%}{\sqrt{E}} \oplus 2\% + \frac{1mrad}{\sqrt{E}}$ (EM)
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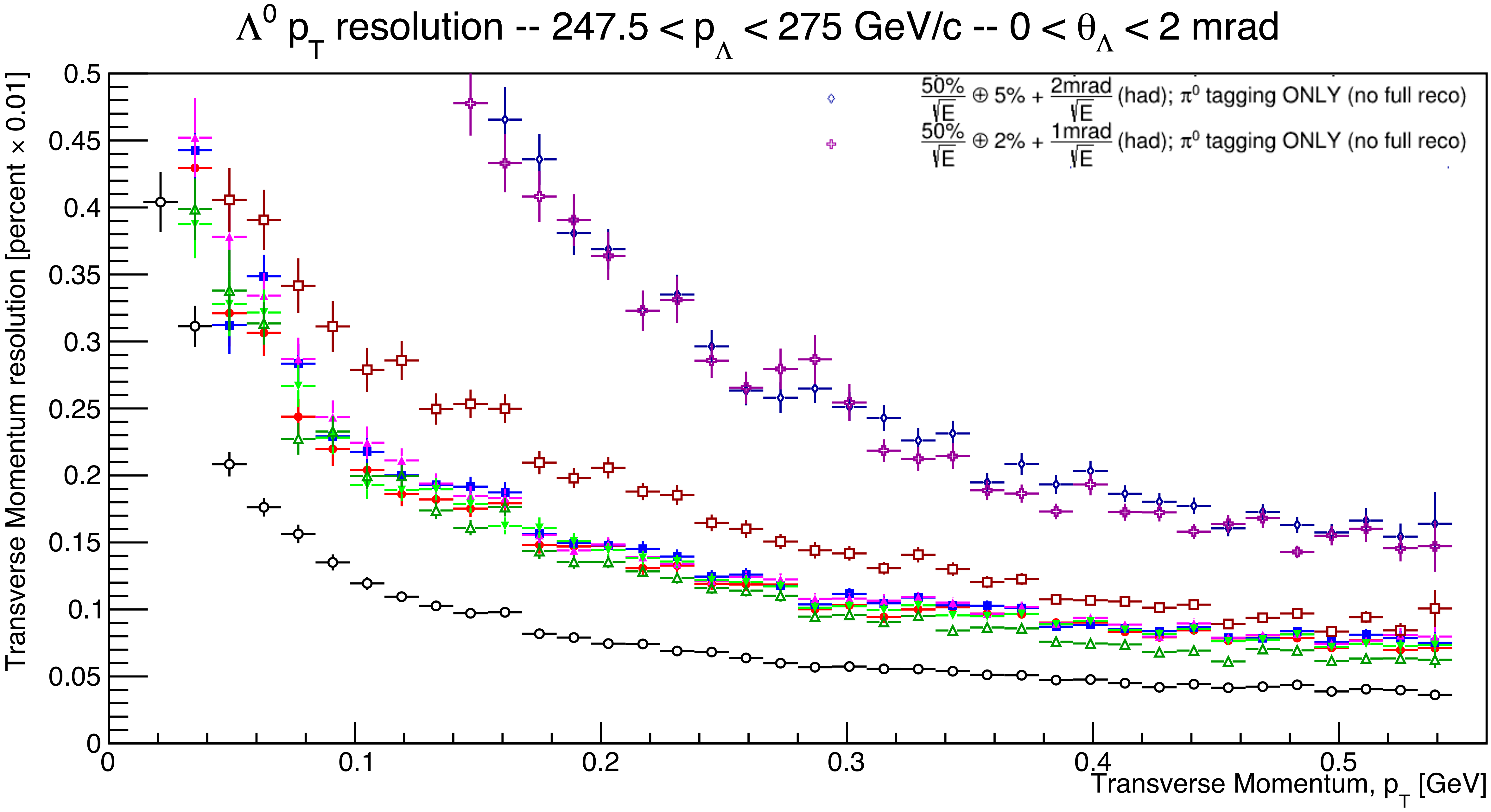
Results



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$\frac{50\%}{\sqrt{E}} \oplus 5\% + \frac{2mrad}{\sqrt{E}}$ (had); π^0 tagging ONLY (no full reco)
$\frac{50\%}{\sqrt{E}} \oplus 2\% + \frac{1mrad}{\sqrt{E}}$ (had); π^0 tagging ONLY (no full reco)
Transverse Momentum resolution [percent × 0.01]
Transverse Momentum, p_T [GeV]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5

Initial Conclusions

- Performance for neutron reconstruction plays the dominant role in Λ^0 reconstruction.
  - Results do not indicate that 20cm long PbWO4/LYSO crystals are *needed* for reconstruction of the Λ^0 (via the $\pi^0 \rightarrow \gamma\gamma$).
- Angular resolution plays the dominant role in pT reconstruction.
  - This is clear from the results on the neutron, where the angular resolution is more-important than the energy resolution.

Important Discussion/Considerations

- *How* do we carry-out the reconstruction?
  - We *do not* a priori know the vertex for the Λ^0 decay → this causes a problem for reconstructing the π^0.
    - **For crystals:** We will know the positions with ~1-2mm resolution, but we will ***not*** have the angular information needed to measure the 4-vector (cannot assume photons originate at IP).
    - **For imaging via SiPM-on-Tile:** We have enough information about the spatial extent of the showers to extract the incident angle of the photons on the EMCAL → this will enable full 4-vector reconstruction of the π^0 **(but how good will it be??).**

Some options to consider

1. **20cm long crystals + SiPM-on-Tile:**
   - E-resolution is very good, but we lose the benefit of the SiPM-on-Tile for the shower angles for photons.
   - This study indicates very high energy resolution for photons *not required.*
   - 20cm long crystals mean ~ full absorption of photon energy, and loss of angular information needed to fully reconstruct the π^0, and therefore to fully reconstruct the Λ^0.

PbWO4 radiation length: ~ 0.92cm
LYSO radiation length: ~ 1.1cm

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2. **~10cm long crystals + SiPM-on-Tile:**
   - Crystals can act as a sort of "pre-shower", while still enabling usage of the information in the SiPM-on-Tile.
   - Crystals still usable to tag events with low-energy photons (e.g. e+A incoherent).
   - **How well will this really work? A study is needed here!**

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Some options to consider

1. 20cm long crystals + SiPM-on-Tile:

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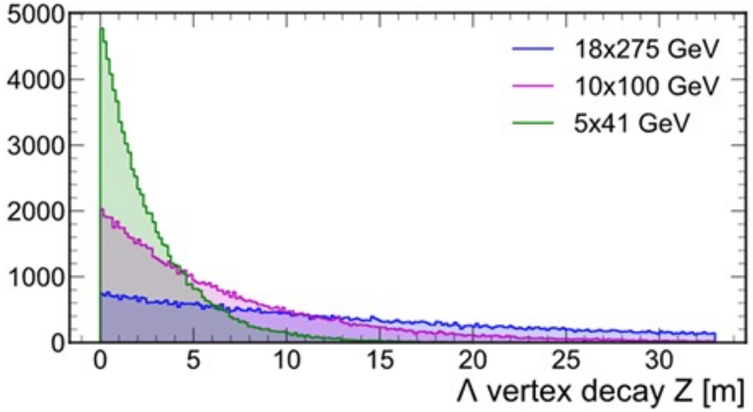
3. SiPM-on-Tile ONLY:

- Allows best option for angular reconstruction of shower.
- *Might* lose low-E photon capability (need to show it works with SiPM-on-Tile **only**).
- Potentially more-difficult hadronic/EM shower separation.

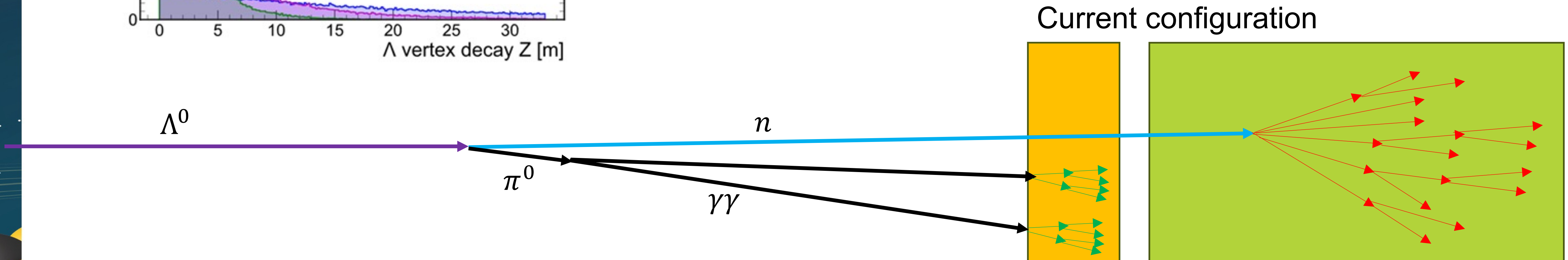
PbWO4 radiation length: ~ 0.92cm
LYSO radiation length: ~ 1.1cm

Pictorial view of neutral decay into ZDC

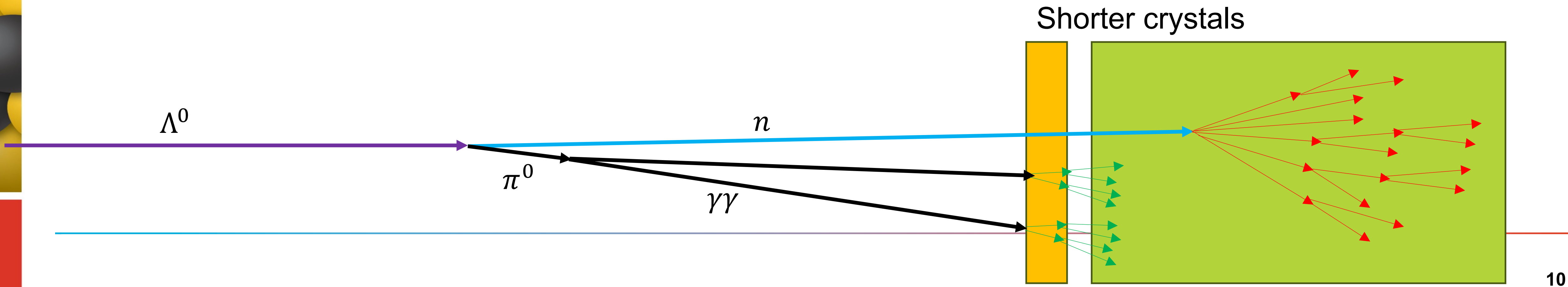


From: J Arrington *et al* 2021 *J. Phys. G: Nucl. Part. Phys.* **48** 075106

Yellow: crystal EMCAL
Blue: SiPM-on-Tile



$$\Lambda^0 \rightarrow n + \pi^0 \rightarrow \gamma\gamma$$



Conclusions

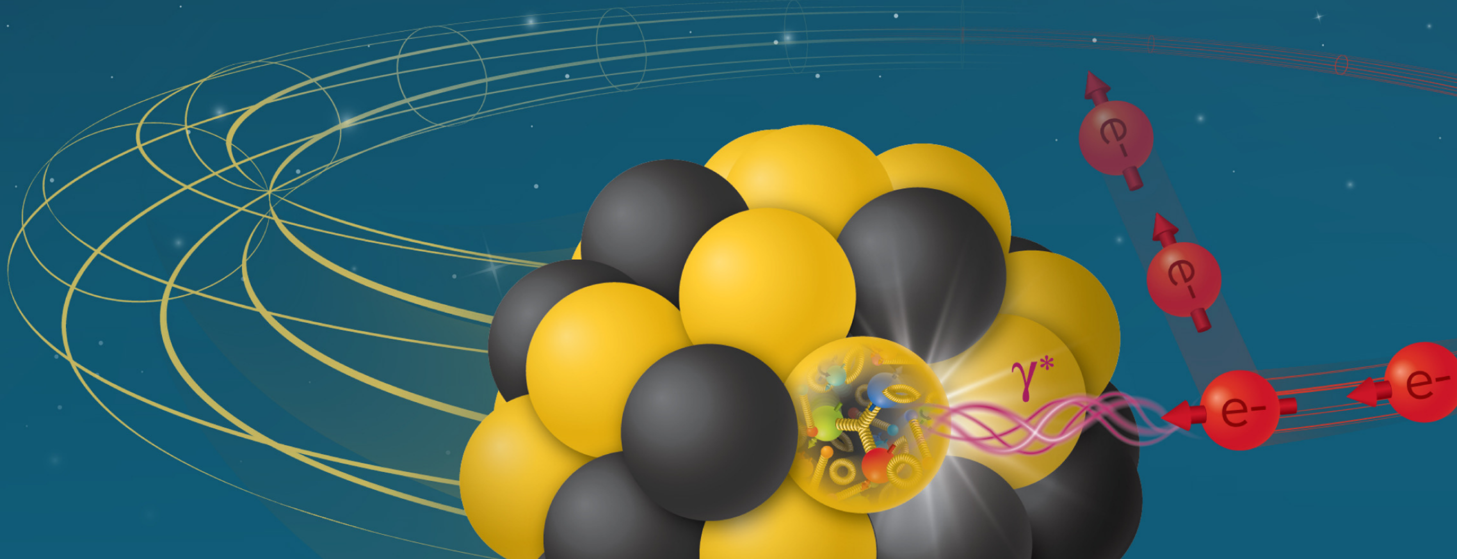
- The p_T resolution of the Λ^0 is dominated by the reconstruction of the neutron (and the HCAL *angular resolution, primarily*), which carries most of the momentum. The energy resolution of the EM section and the impact on $\pi^0 \rightarrow \gamma\gamma$ reco is sub-dominant.

- This study makes the assumption that the ZDC EM section can reconstruct the *vector* direction of the $\pi^0 \rightarrow \gamma\gamma$ (the 4-vector of the photons) with good resolution. **It's not clear this could be achieved with long crystals only.**

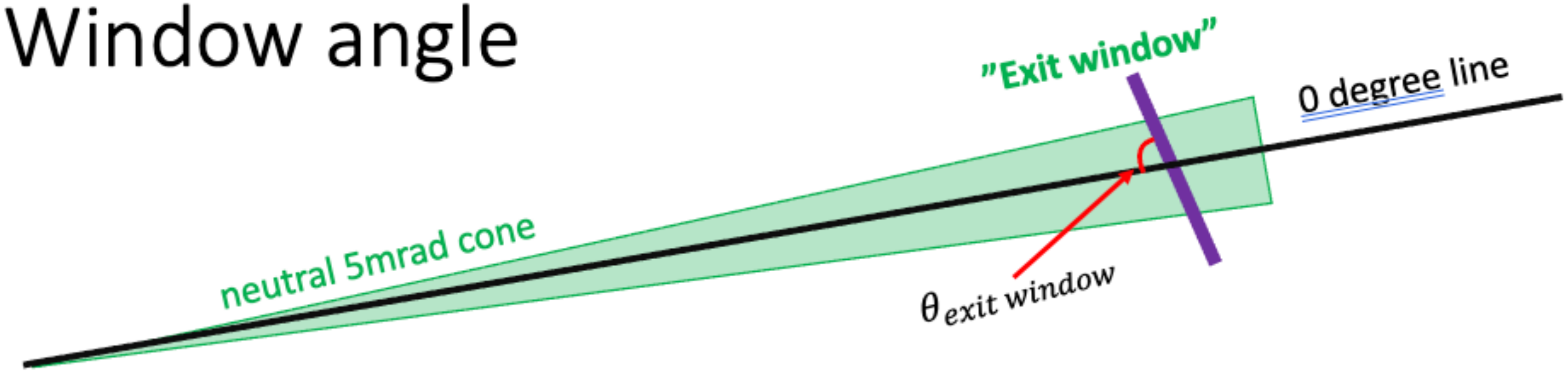
- The angular resolution for $\pi^0 \rightarrow \gamma\gamma$ EM showers should be studied in the SiPM-on-tile ZDC using full simulations to see how the imaging capabilities would perform. Ideally, full reconstruction of the Λ^0 should be used to extract the resolution on the Λ^0 p_T (and its relationship to the Kaon t understood).

Neutral exit window

Electron-Ion Collider



Window angle



Notes:

- Angles are between the center of the neutral cone and the window.
- Material is stainless steel.
- "survival probability" refers to particles which travserse the window with no interaction with the material - they would arrive "intact" at the detector.

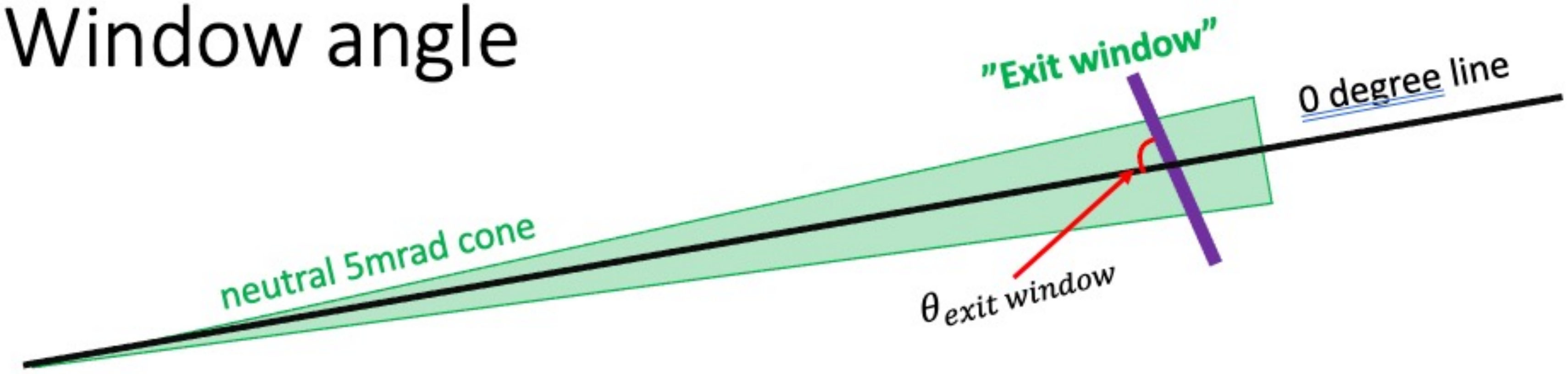
Particle	Energy	Window tilt	thickness	survival probability
neutron	100 to 135 GeV	90 degrees	2 mm	98.8%
neutron	100 to 135 GeV	90 degrees	5 mm	96.9%
neutron	100 to 135 GeV	90 degrees	10 mm	93.8%
neutron	100 to 135 GeV	60 degrees	2 mm	98.4%
neutron	100 to 135 GeV	60 degrees	5 mm	96.3%
neutron	100 to 135 GeV	60 degrees	10 mm	92.6%
neutron	100 to 135 GeV	45 degrees	2 mm	98.1%
neutron	100 to 135 GeV	45 degrees	5 mm	95.8%
neutron	100 to 135 GeV	45 degrees	10 mm	91.6%
neutron	100 to 135 GeV	20 degrees	2 mm	96.4%
neutron	100 to 135 GeV	20 degrees	5 mm	90.7%
neutron	100 to 135 GeV	20 degrees	10 mm	82.7%

Neutrons

Stainless Steel

1

Window angle



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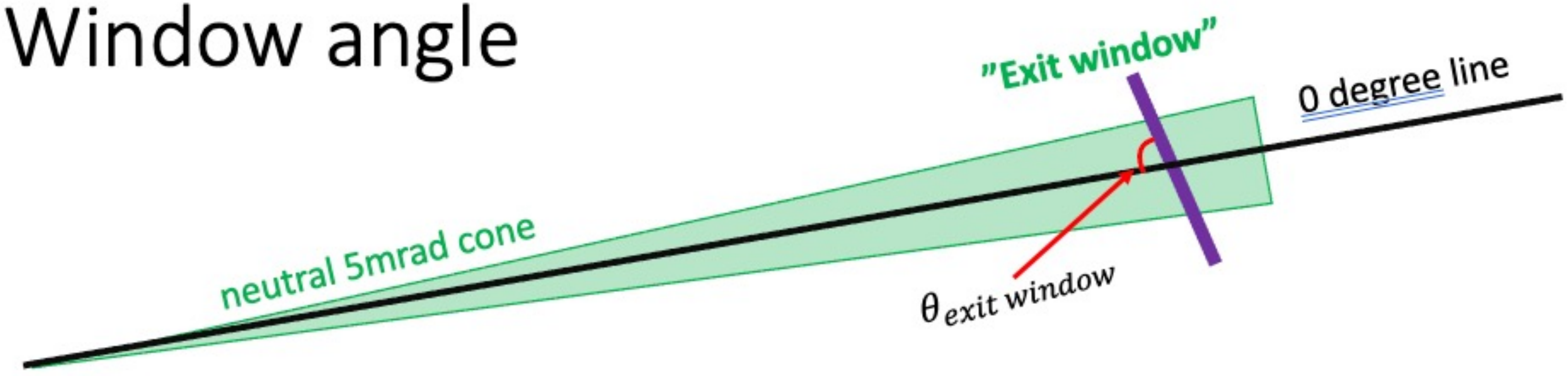
photon	200 to 275 GeV	90 degrees	2 mm	91.8%
photon	200 to 275 GeV	90 degrees	5 mm	81.3%
photon	200 to 275 GeV	90 degrees	10 mm	66.9%
photon	200 to 275 GeV	60 degrees	2 mm	90.6%
photon	200 to 275 GeV	60 degrees	5 mm	78.9%
photon	200 to 275 GeV	60 degrees	10 mm	62.1%
photon	200 to 275 GeV	45 degrees	2 mm	88.6%
photon	200 to 275 GeV	45 degrees	5 mm	74.0%
photon	200 to 275 GeV	45 degrees	10 mm	56.6%
photon	200 to 275 GeV	20 degrees	2 mm	78.8%
photon	200 to 275 GeV	20 degrees	5 mm	55.1%
photon	200 to 275 GeV	20 degrees	10 mm	31.9%

Particle	Energy	Window tilt	thickness	survival probability
photon	0.01 to 1 GeV	90 degrees	2 mm	92.5%
photon	0.01 to 1 GeV	90 degrees	5 mm	84.0%
photon	0.01 to 1 GeV	90 degrees	10 mm	68.7%
photon	0.01 to 1 GeV	60 degrees	2 mm	91.2%
photon	0.01 to 1 GeV	60 degrees	5 mm	81.2%
photon	0.01 to 1 GeV	60 degrees	10 mm	65.4%
photon	0.01 to 1 GeV	45 degrees	2 mm	90.0%
photon	0.01 to 1 GeV	45 degrees	5 mm	76.1%
photon	0.01 to 1 GeV	45 degrees	10 mm	60.2%
photon	0.01 to 1 GeV	20 degrees	2 mm	80.4%
photon	0.01 to 1 GeV	20 degrees	5 mm	59.1%
photon	0.01 to 1 GeV	20 degrees	10 mm	35.4%

Photons

Stainless Steel

Window angle



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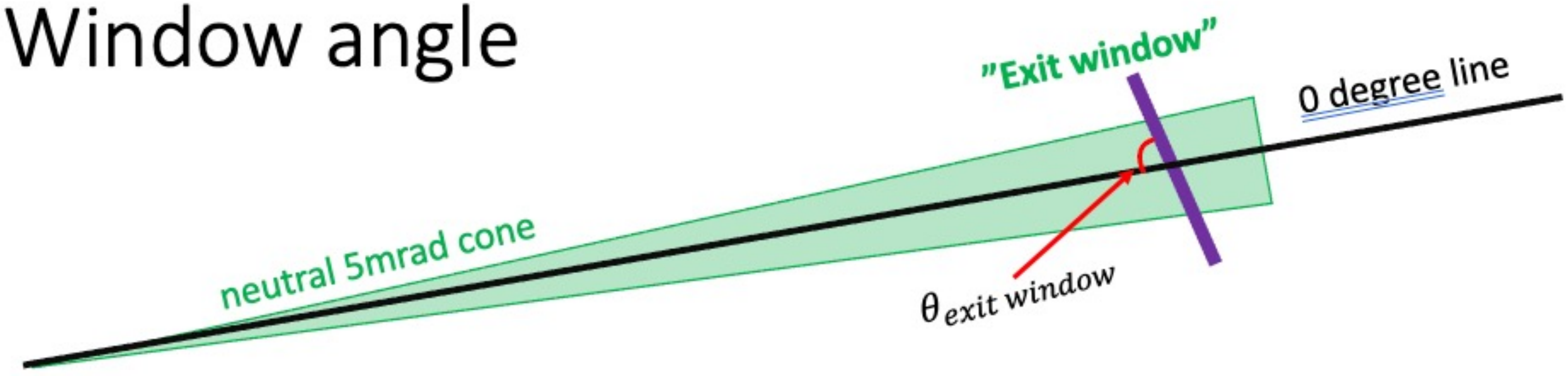
neutron	100 to 135 GeV	90 degrees	10 mm	96.9%
neutron	100 to 135 GeV	60 degrees	2 mm	99.2%
neutron	100 to 135 GeV	60 degrees	5 mm	98.2%
neutron	100 to 135 GeV	60 degrees	10 mm	96.7%
neutron	100 to 135 GeV	45 degrees	2 mm	99.0%
neutron	100 to 135 GeV	45 degrees	5 mm	97.5%
neutron	100 to 135 GeV	45 degrees	10 mm	95.6%
neutron	100 to 135 GeV	20 degrees	2 mm	98.0%
neutron	100 to 135 GeV	20 degrees	5 mm	95.4%
neutron	100 to 135 GeV	20 degrees	10 mm	90.8%

Neutrons

Aluminum

3

Window angle



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photon	200 to 275 GeV	60 degrees	10 mm	91.0%
photon	200 to 275 GeV	45 degrees	2 mm	97.6%
photon	200 to 275 GeV	45 degrees	5 mm	94.2%
photon	200 to 275 GeV	45 degrees	10 mm	88.6%
photon	200 to 275 GeV	20 degrees	2 mm	95.6%
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photon	200 to 275 GeV	20 degrees	10 mm	78.6%

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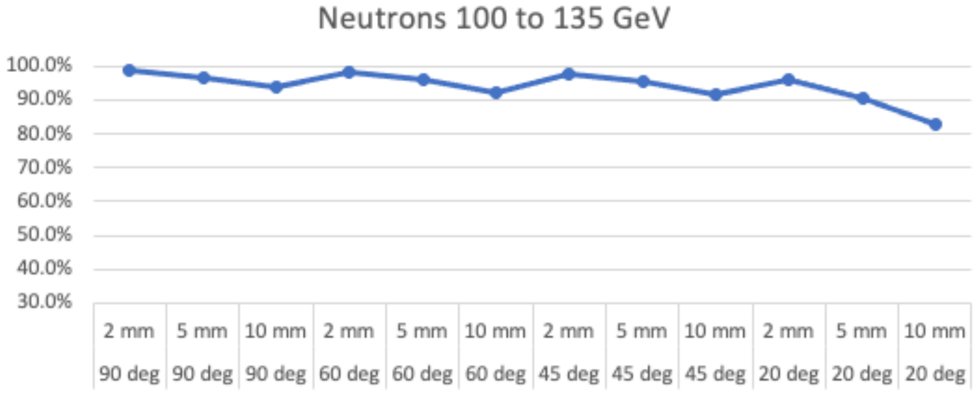
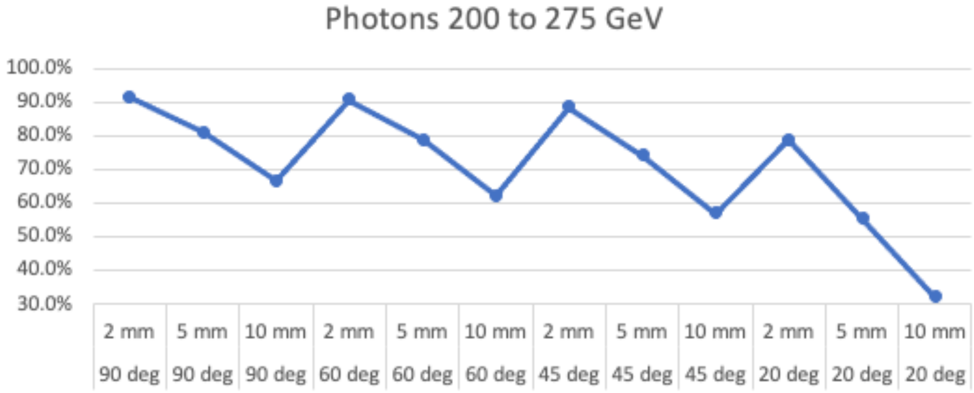
photon	0.01 to 1 GeV	90 degrees	10 mm	93.0%
photon	0.01 to 1 GeV	60 degrees	2 mm	98.2%
photon	0.01 to 1 GeV	60 degrees	5 mm	95.8%
photon	0.01 to 1 GeV	60 degrees	10 mm	91.4%
photon	0.01 to 1 GeV	45 degrees	2 mm	97.6%
photon	0.01 to 1 GeV	45 degrees	5 mm	95.2%
photon	0.01 to 1 GeV	45 degrees	10 mm	89.8%
photon	0.01 to 1 GeV	20 degrees	2 mm	95.4%
photon	0.01 to 1 GeV	20 degrees	5 mm	89.4%
photon	0.01 to 1 GeV	20 degrees	10 mm	80.9%

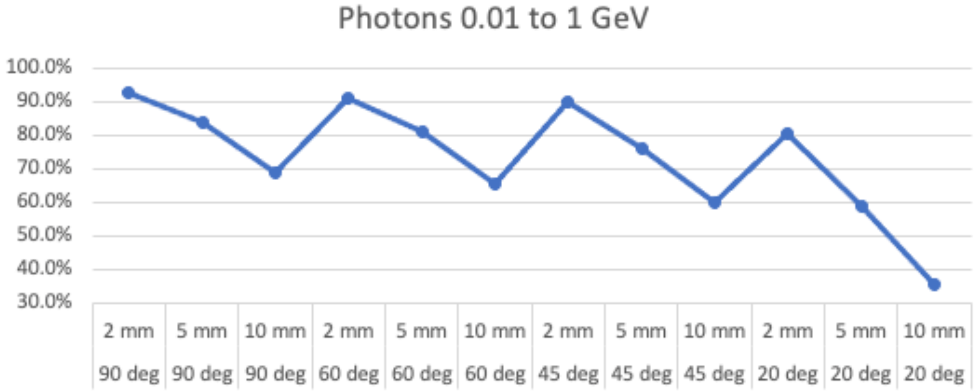
Photons

Aluminum

Stainless Steel







Aluminum