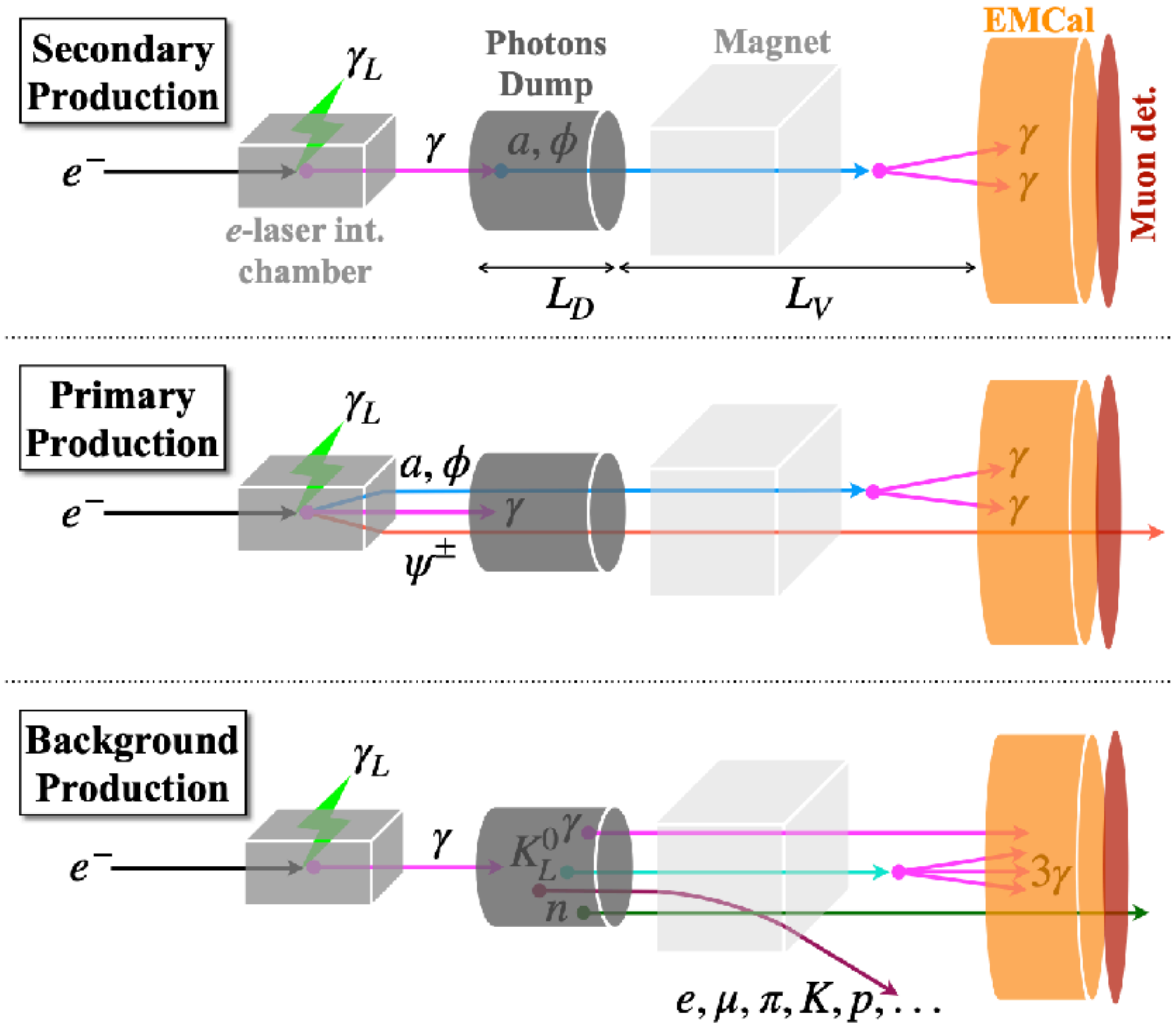
Feasibility Study of H1 SPACAL for New Physics Searches at LUXE-NPOD

Marcus Mähring

The NPOD Project

- Downstream from main experiment
- Use Compton photons to induce Primakoff production: $\gamma + N \rightarrow N + X$
- Focus on ALPs but potentially also other U(1) mediators / “dark” particles
- Signal: two photos reconstructable to common vertex after the photon dump



arXiv:2107.13554v1

Current Goals of My Internship

1. Characterize signal from ALP decays

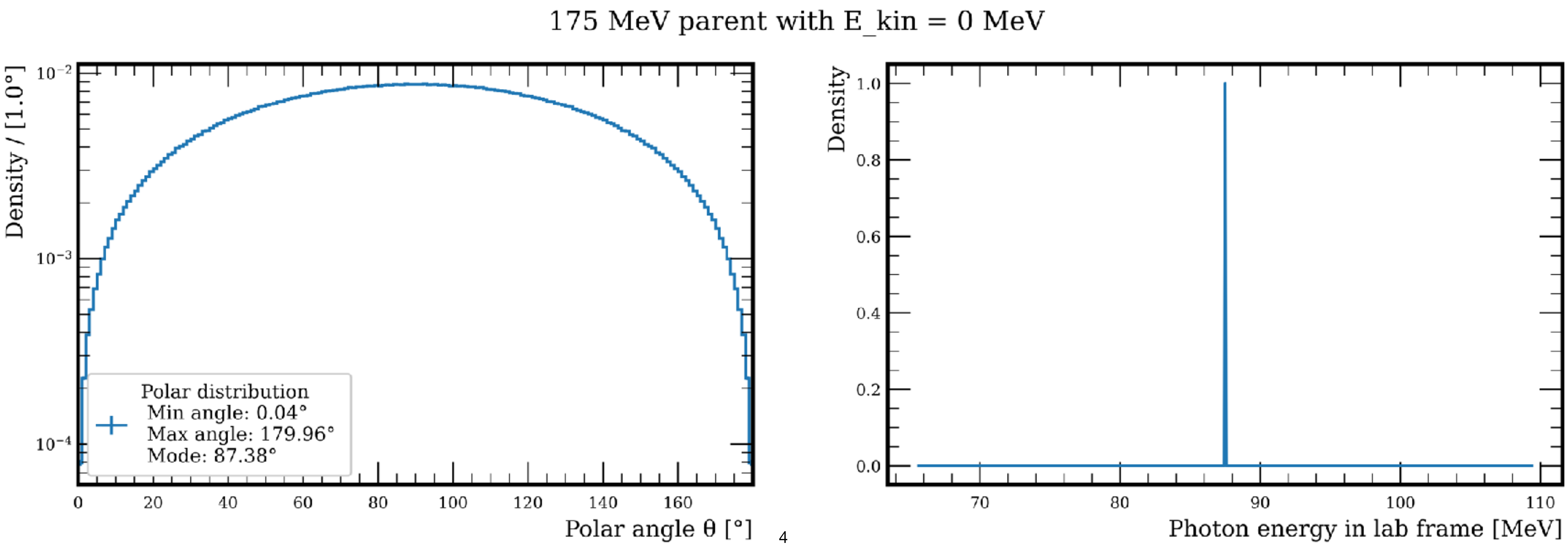
2. Build G4 simulation implementing ALPs with adjustable characteristics of ALPs

3. From technical conditions imposed for background mitigation purposes: determine whether the H1 SPACAL calorimeter could be used in PHASE 0 as a “drop in” alternative

4. Investigate other technologies to supplement or substitute the SPACAL if it’s insufficient

Signal Characterization

- ALPs are (pseudo)scalars, meaning they decay isotropically in their rest frame
- At rest, cosine distribution of polar angles, delta distribution for energy. Smearing from boost.
- Simulation confirmed three different ways by taking π^0 as reference (MC, G4, G4beamline)



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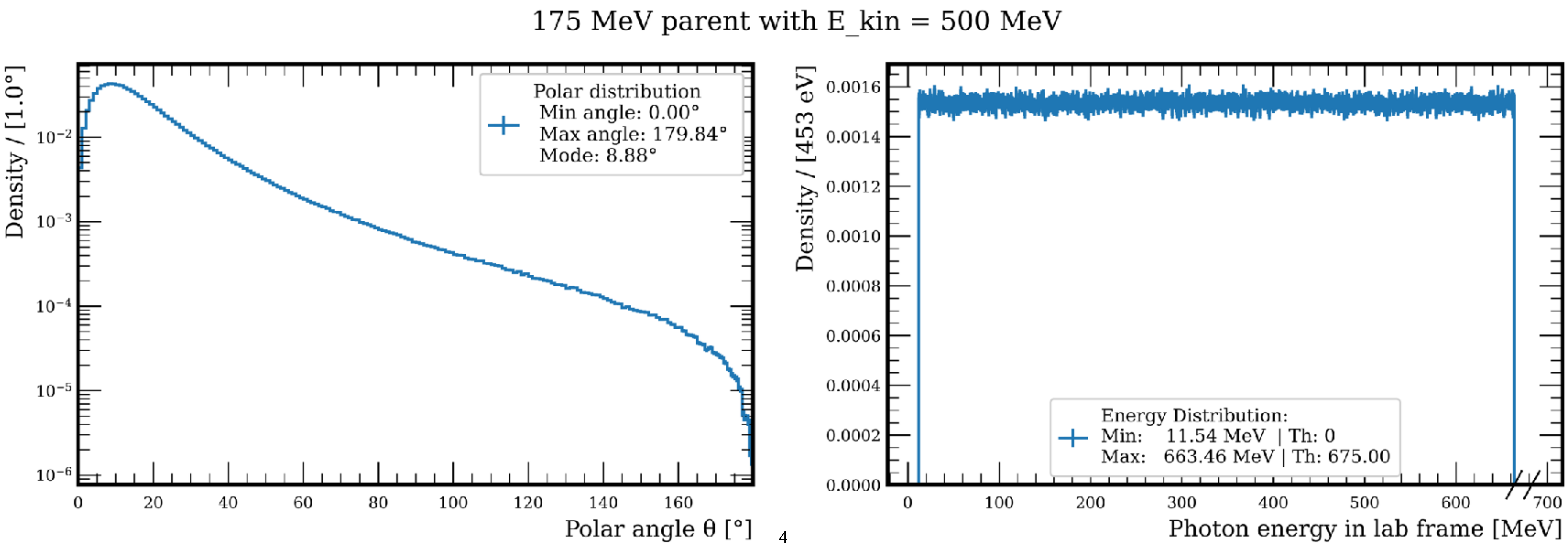

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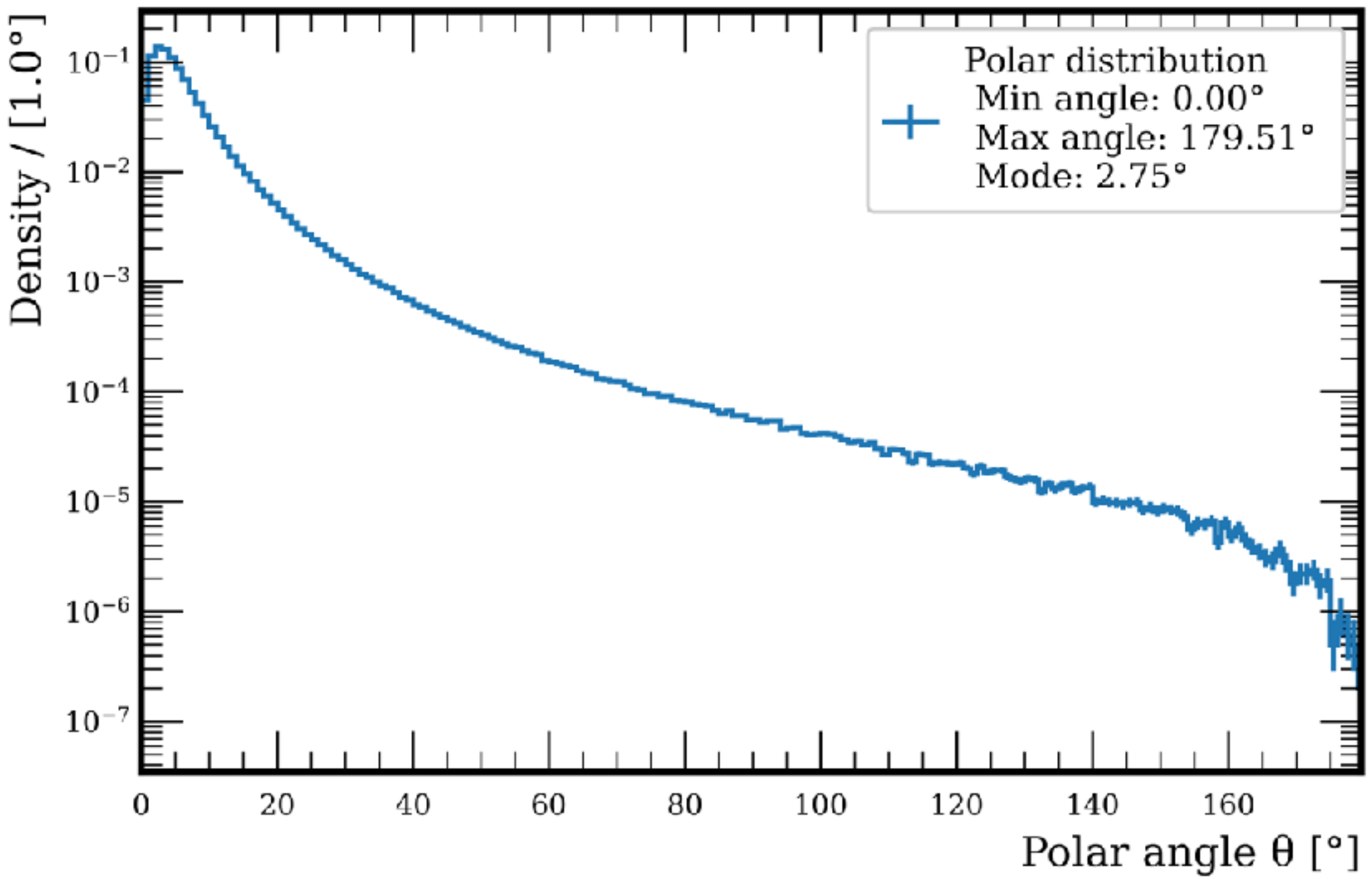
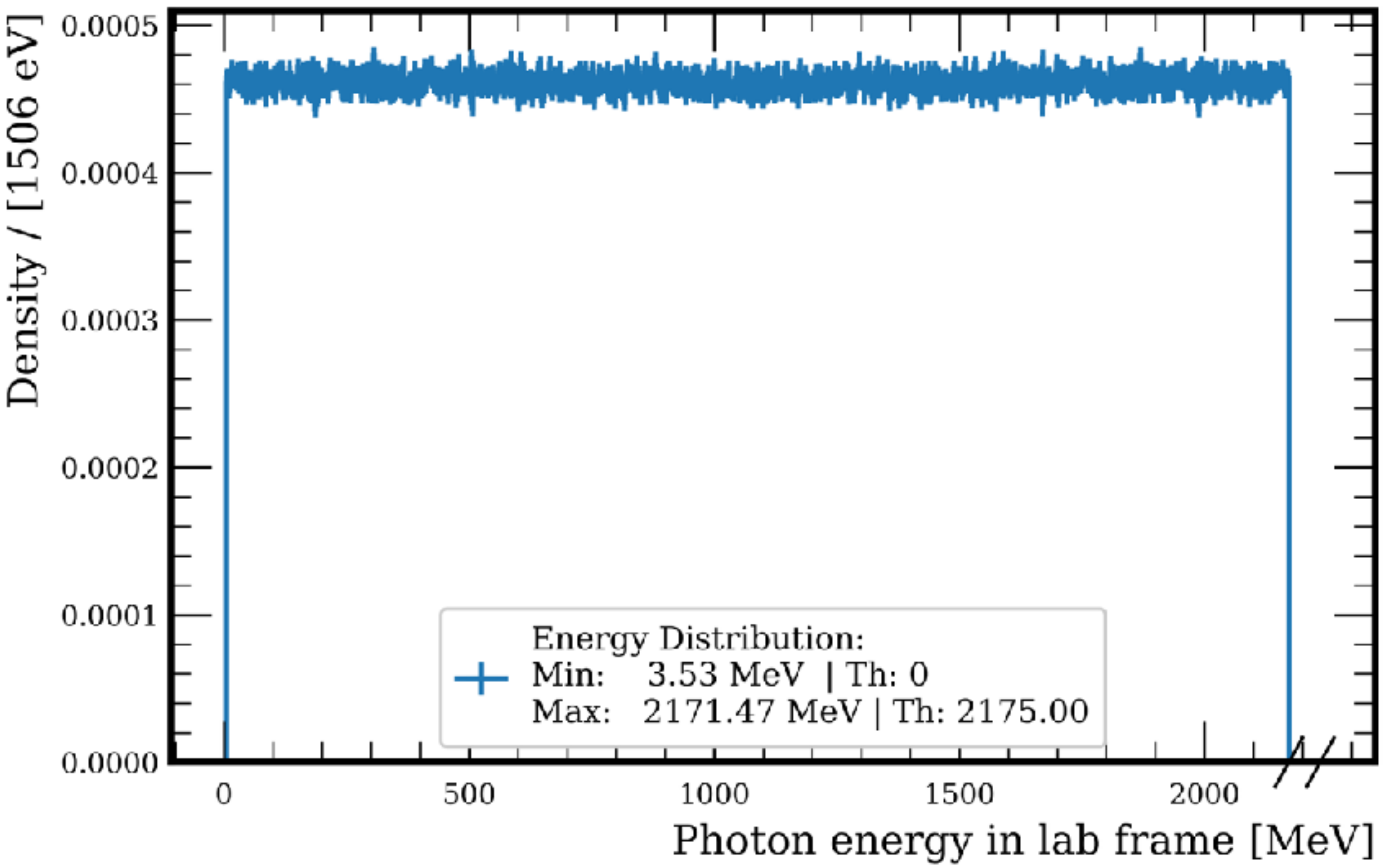
175 MeV parent with E_kin = 2 GeV





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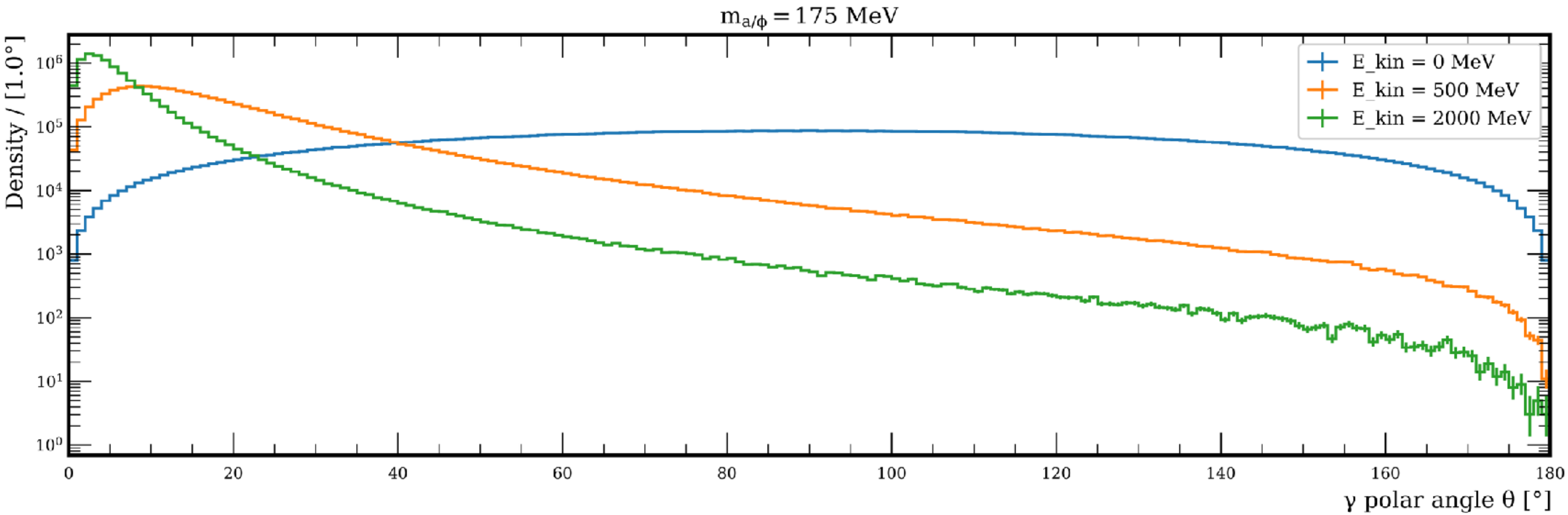
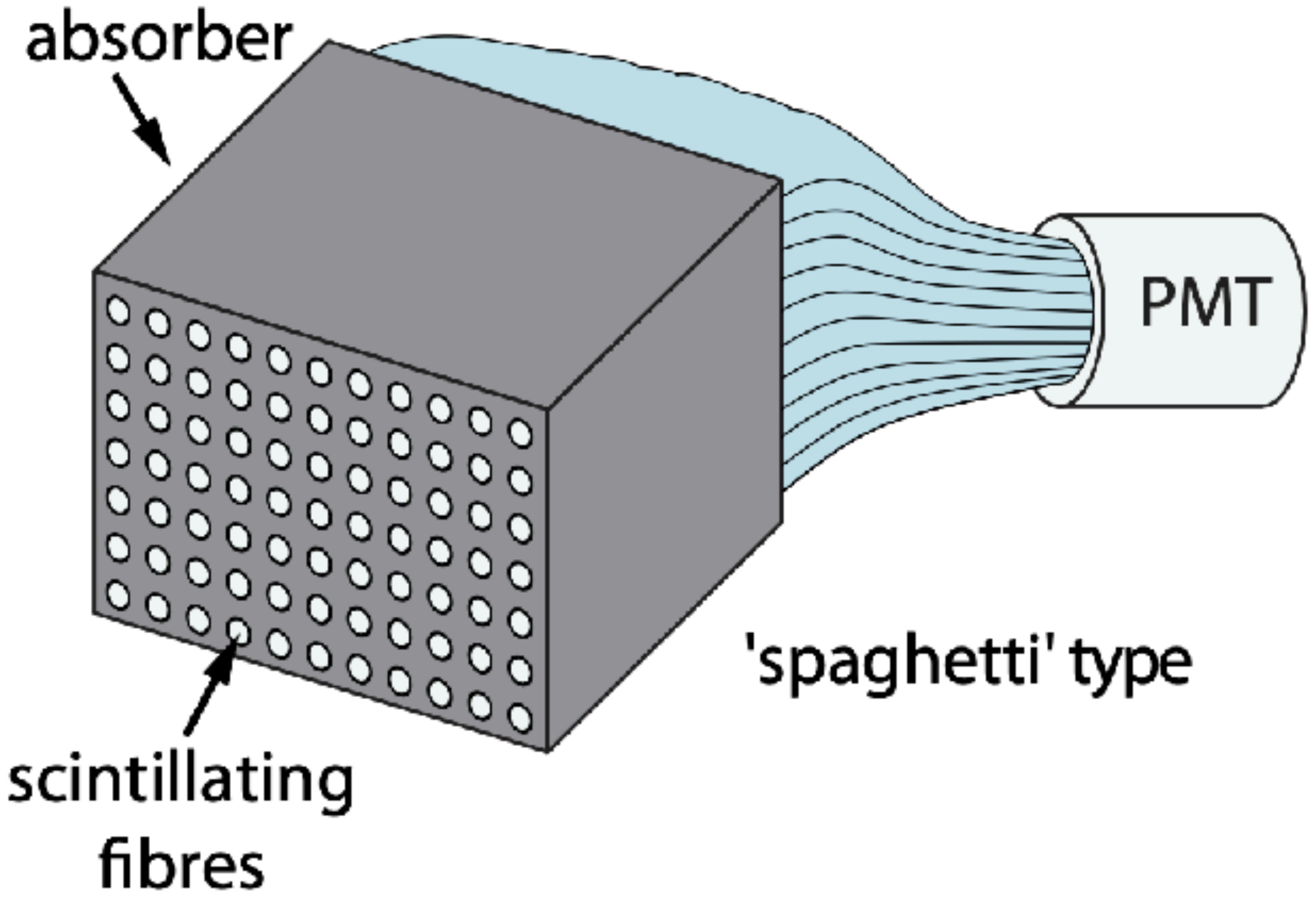
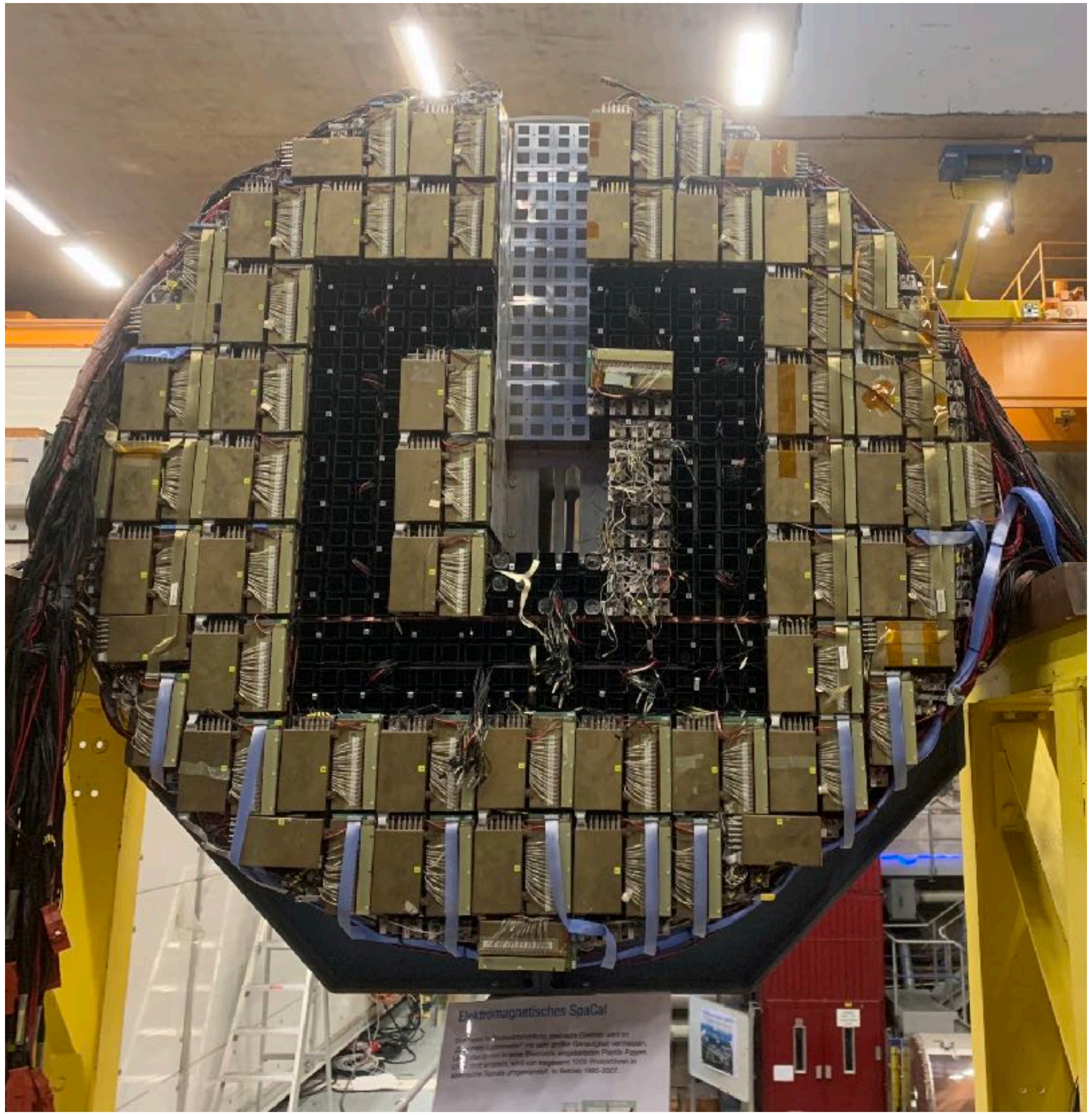


The SPACAL

- Longitudinal depth $28X_0$
- Energy resolution:
$\sigma_E = (7.1 \pm 0.2)\,\% / \sqrt{E[\mathrm{GeV}]} \oplus (1 \pm 0.1)\,\%$



From Kolanoski, H., & Wermes, N. (2020).
Particle Detectors: Fundamentals and Applications.
Page 616



Technical Considerations

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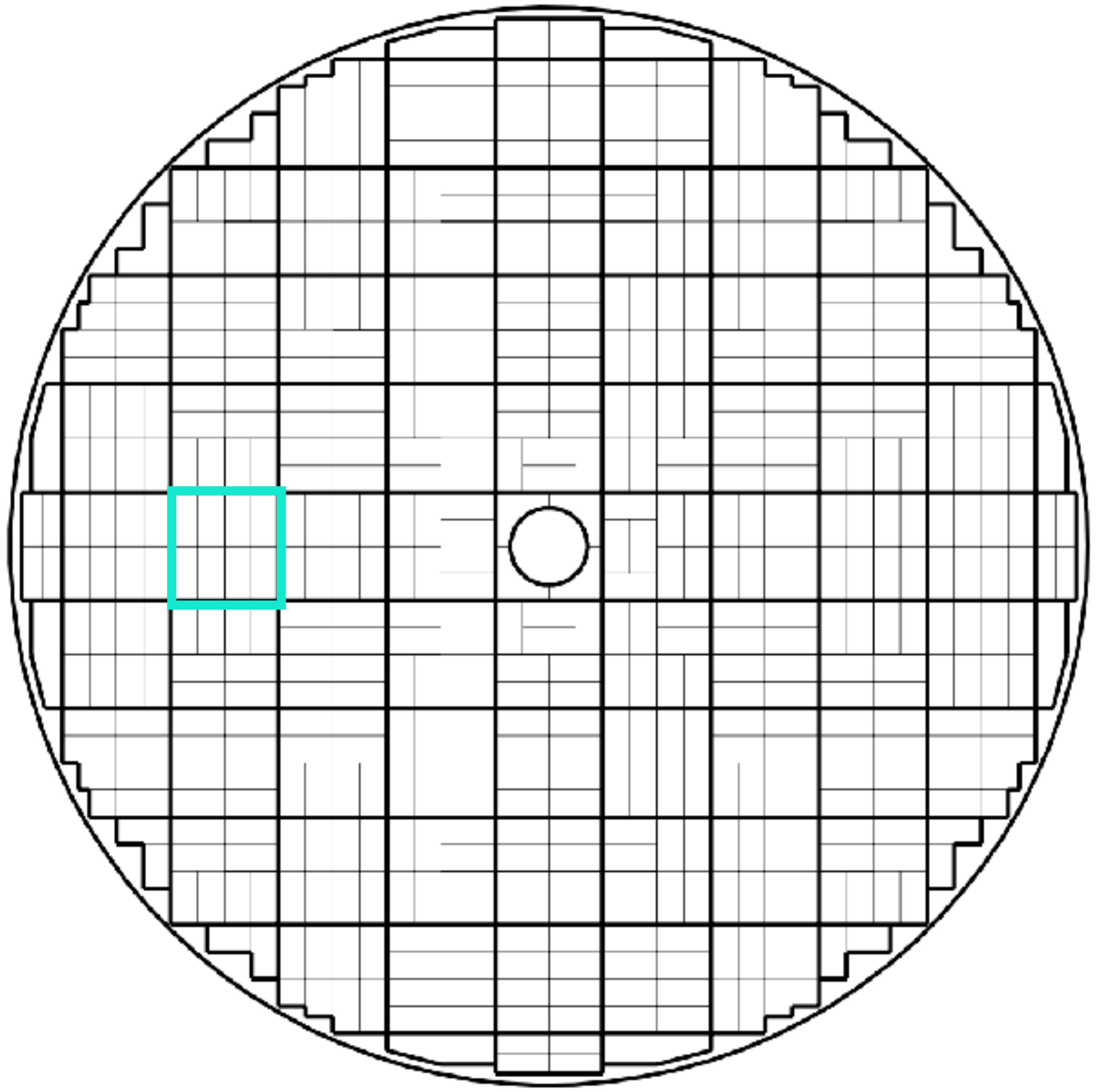
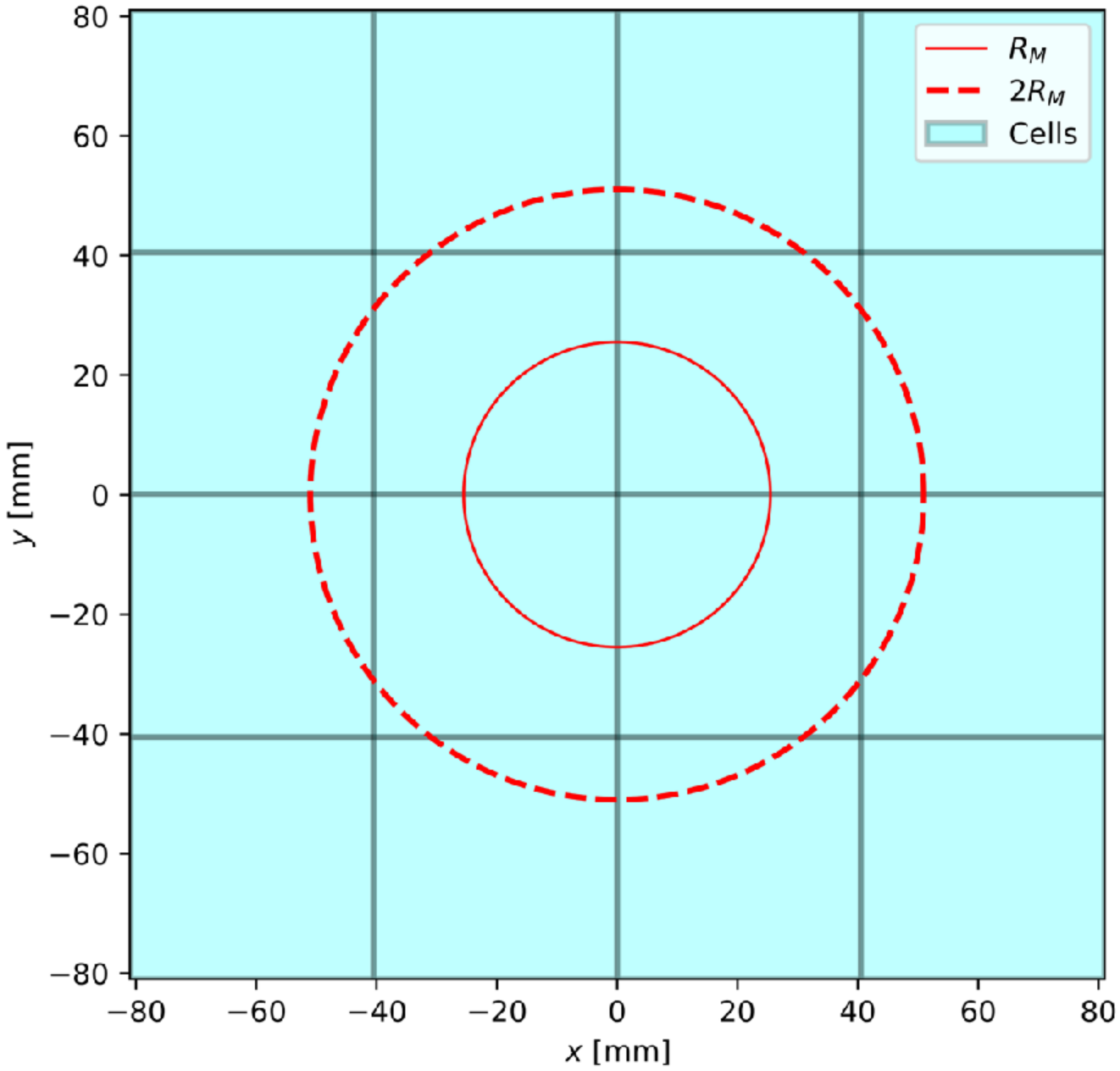


rϕ view. Rectangles represent 2x1 cell submodules

Appuhn, R-D., et al. "The H1 lead/scintillating-fibre calorimeter." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 386.2-3 (1997)



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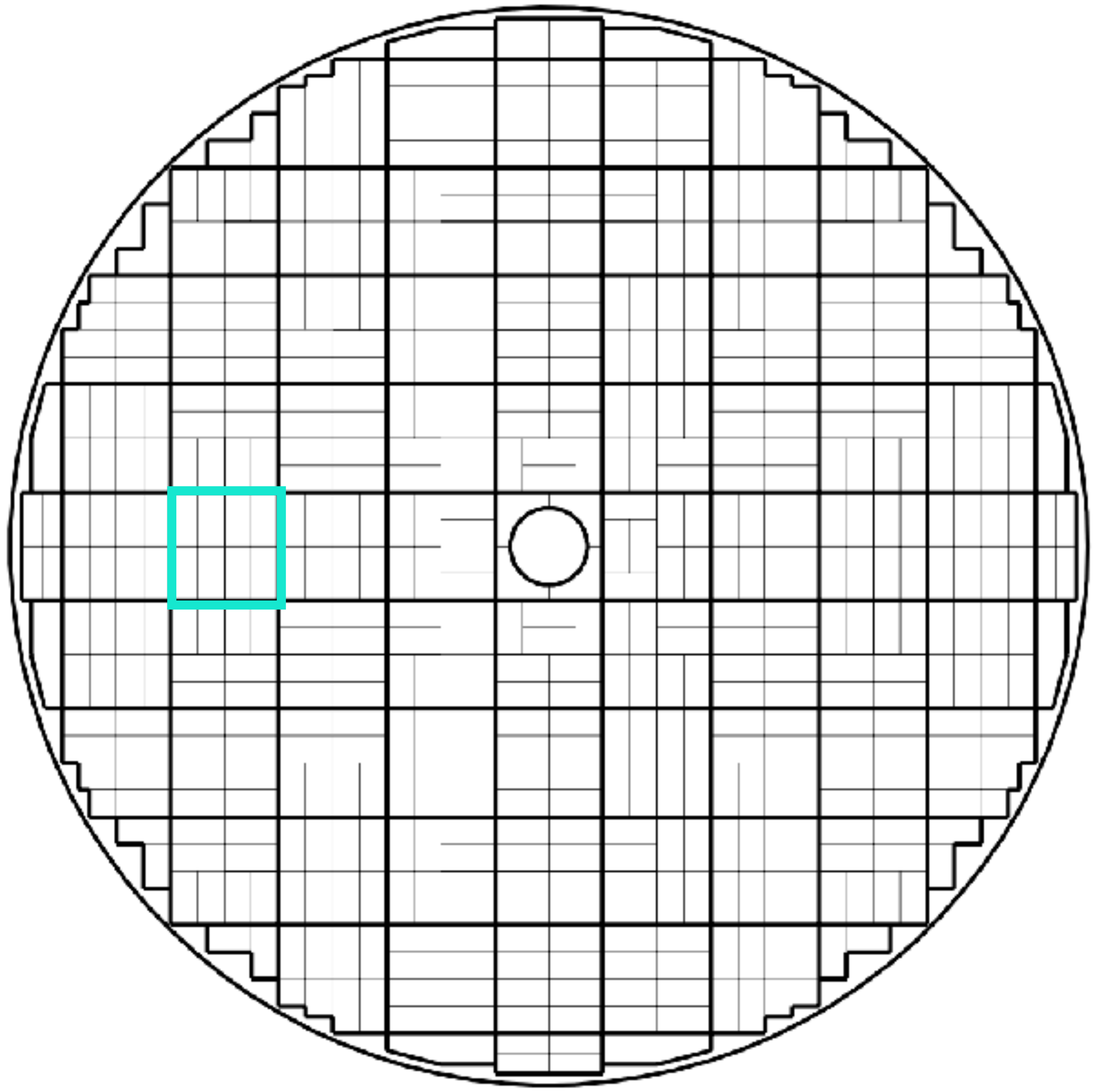

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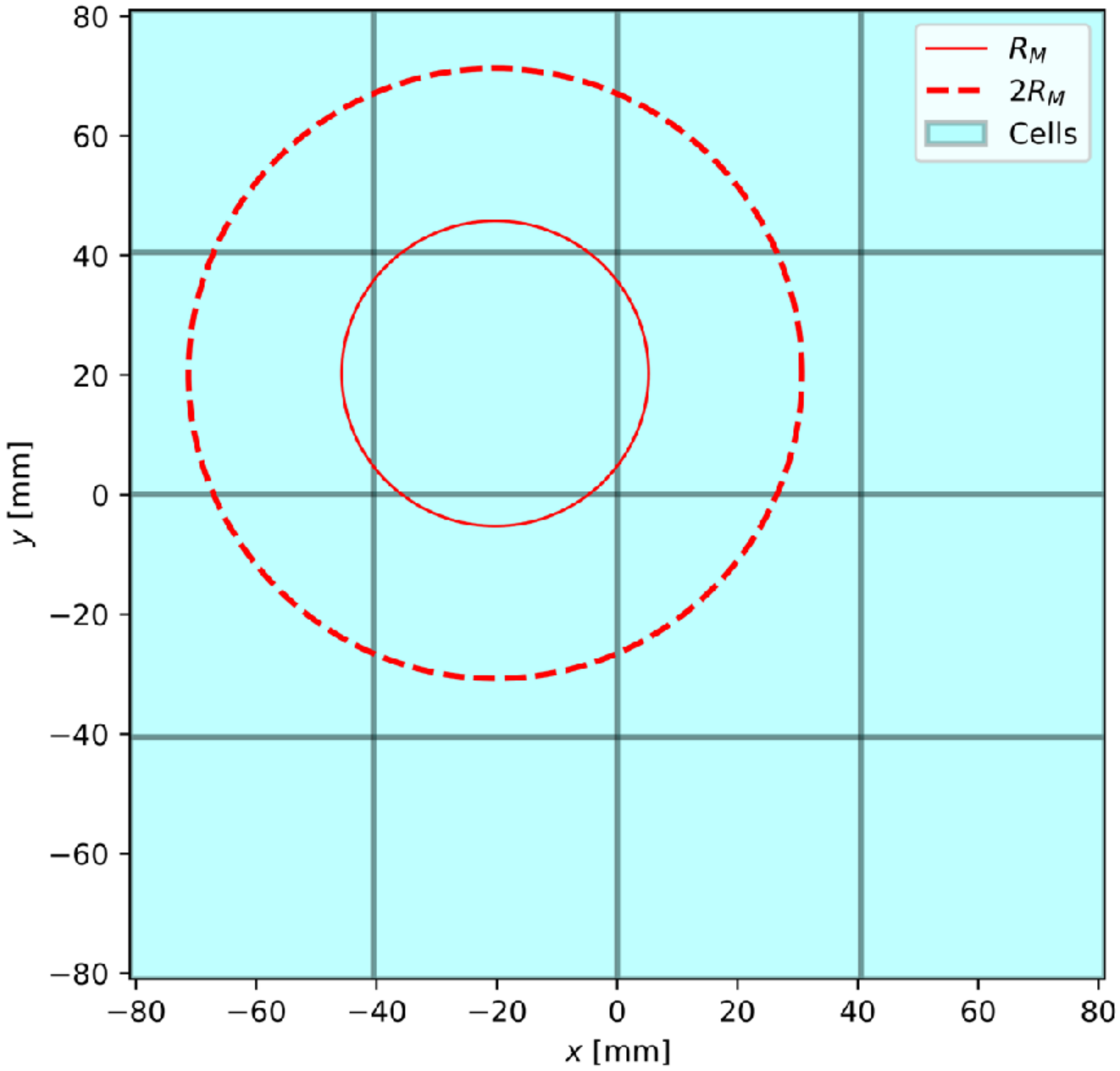

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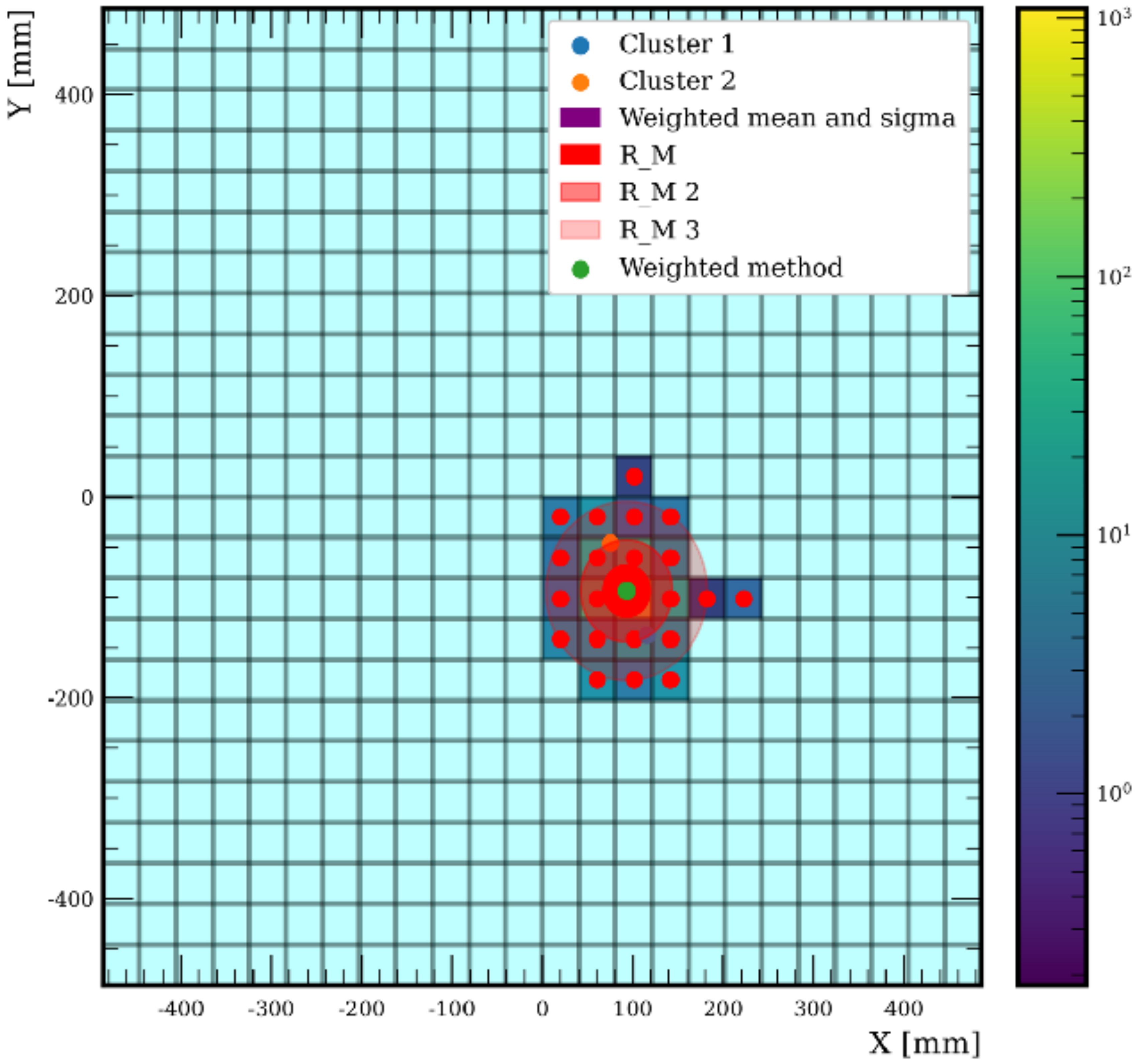
Angle	No longitudinal segmentation…	Maybe we can say something anyway?	$\mathcal{O}$ (~100 mrad)

Shower Characteristics and Summary Statistics

- Current challenge: possible to get some angular resolution?



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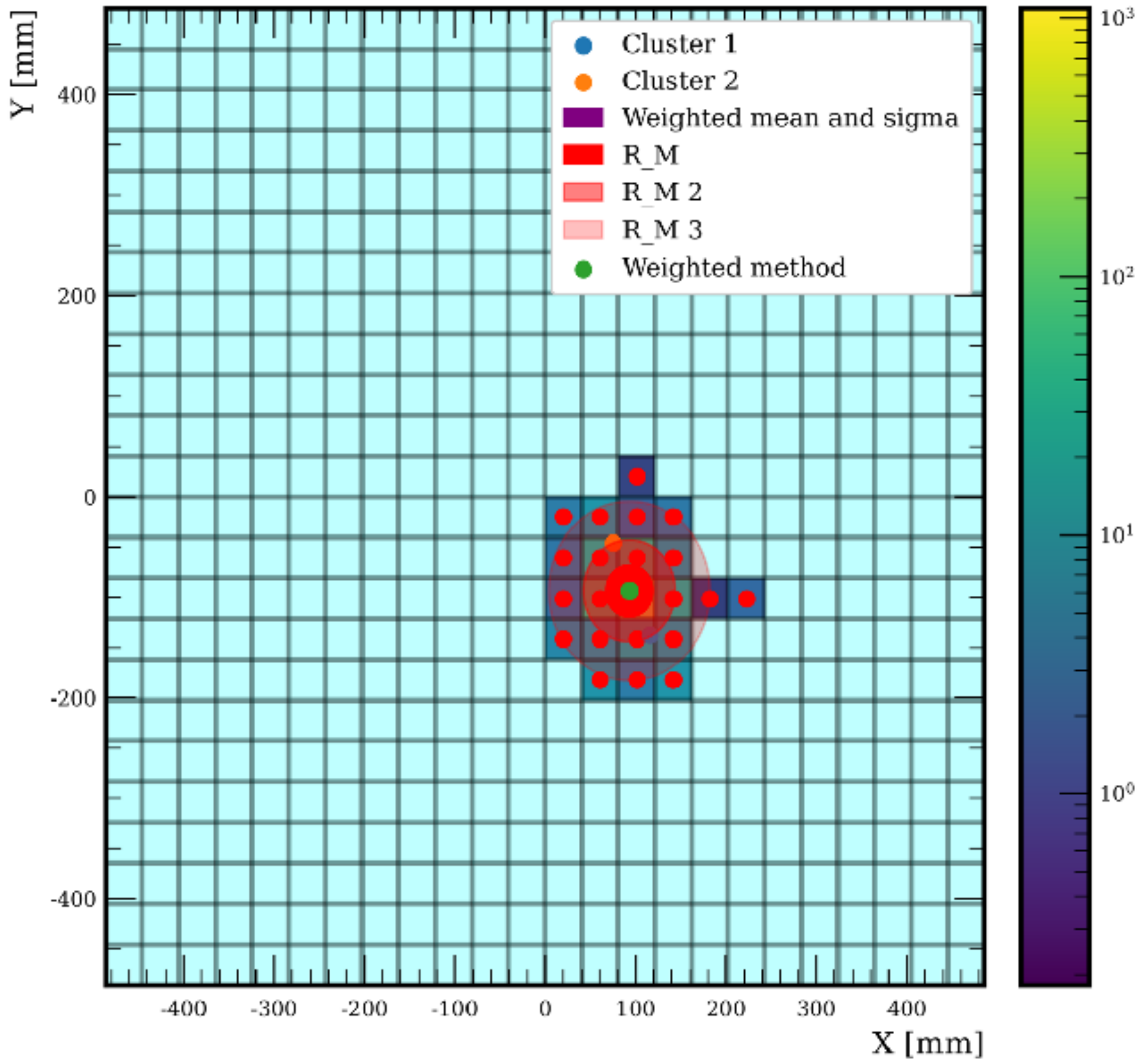

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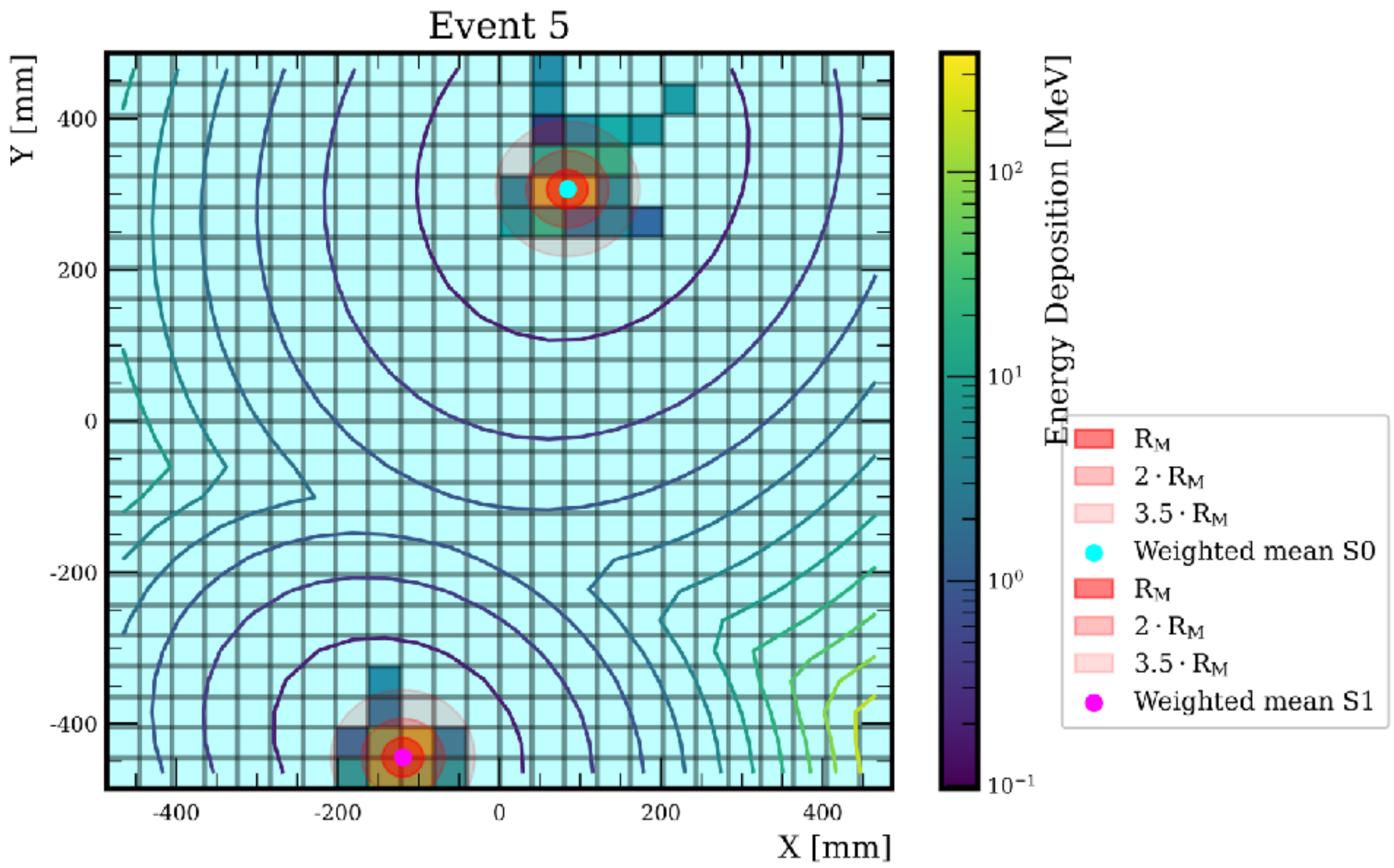

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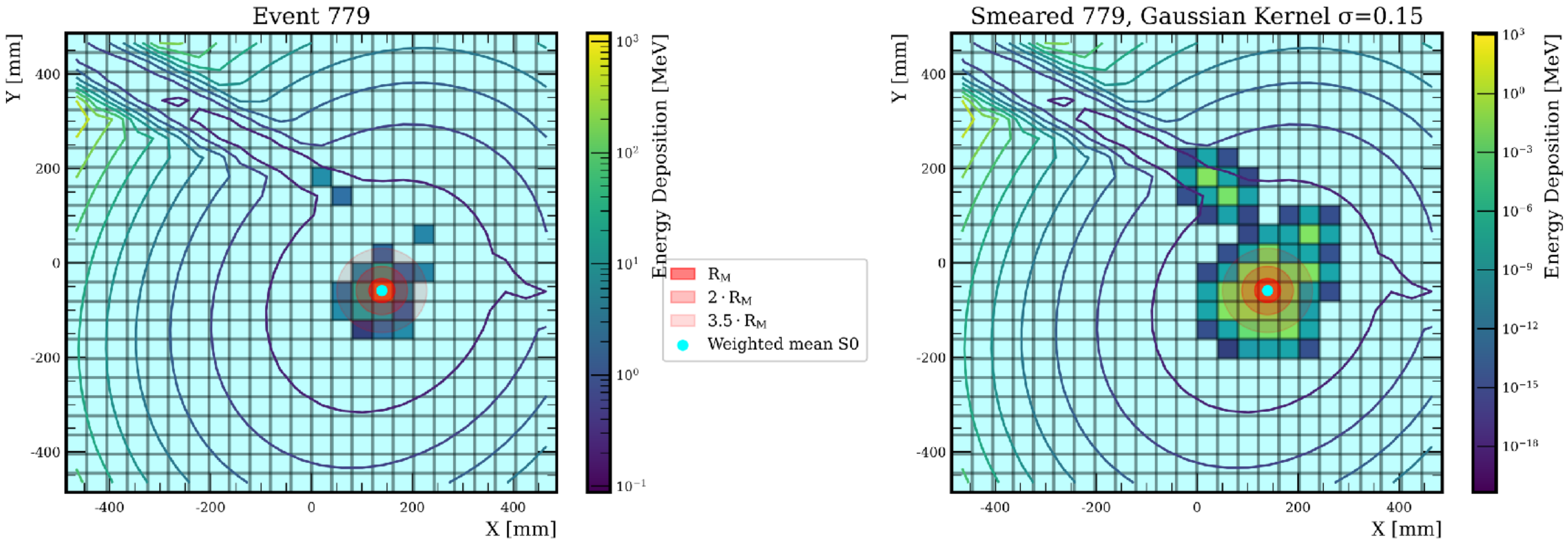
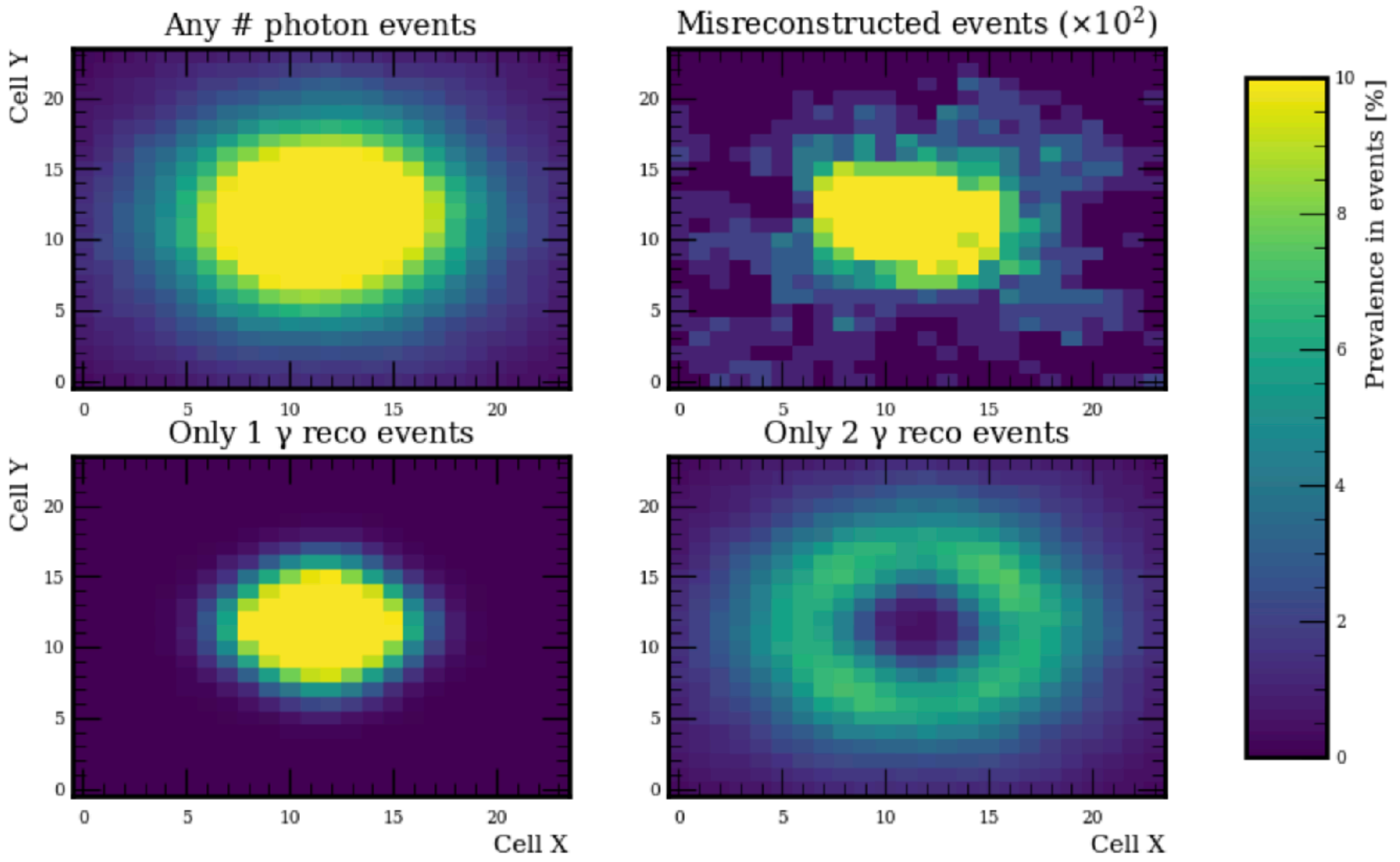


A Sampler: Some Energy Deposition Distributions



From simulation of 1 GeV ALP with 500 MeV mass and a scale of 100 GeV

Summary

- Characterized / confirmed signal type
- Completed backbone of simulation for ALPs with G4
- Implementing analysis framework (some python classes) to streamline extraction of summary statistics from simulations
- Currently working on angular reconstruction and investigating alternative / supplementary technologies

Next steps:

- Use more summary statistics and see if I can perform some smart fit to the incoming angle
- Try a CNN to extract a summary score / angle
- BDT to combine summary statistics?
- Improve shower recognition —> “jet fitting” algorithm? Testing for bimodality?

Backup Slides

Lifetime of ALP

- Given by formulae:

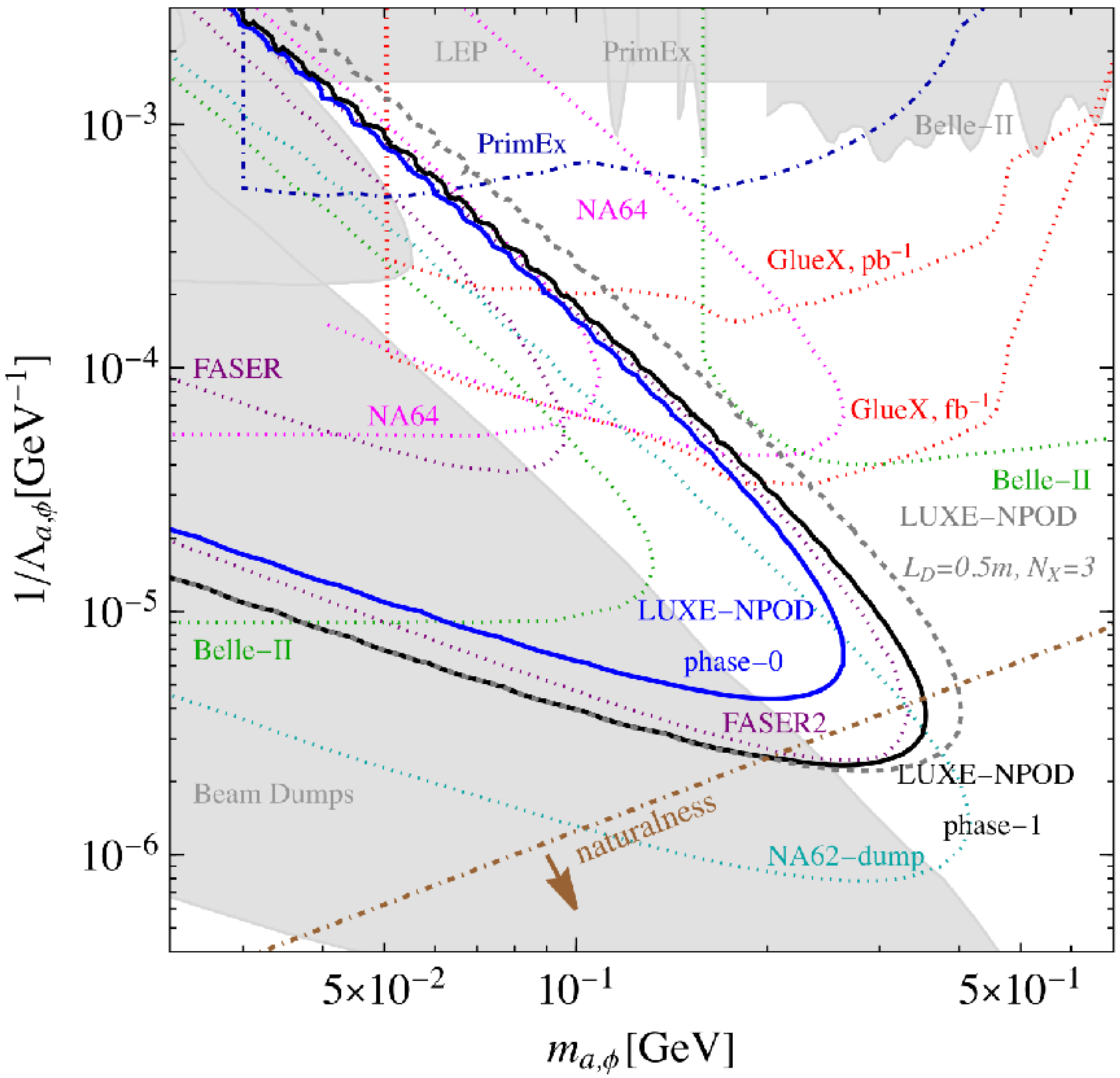
  - $\Gamma = \dfrac{m_{a/\phi}^3}{64\pi\Lambda_{a/\phi}^2}$

  - $\tau = \hbar/\Gamma$

- Example: $m_{a/\phi} = 500$ GeV & $\Lambda_{a/\phi} = 100$ GeV, lifetime of 1e-5 ps…

- Not excludable at NPOD

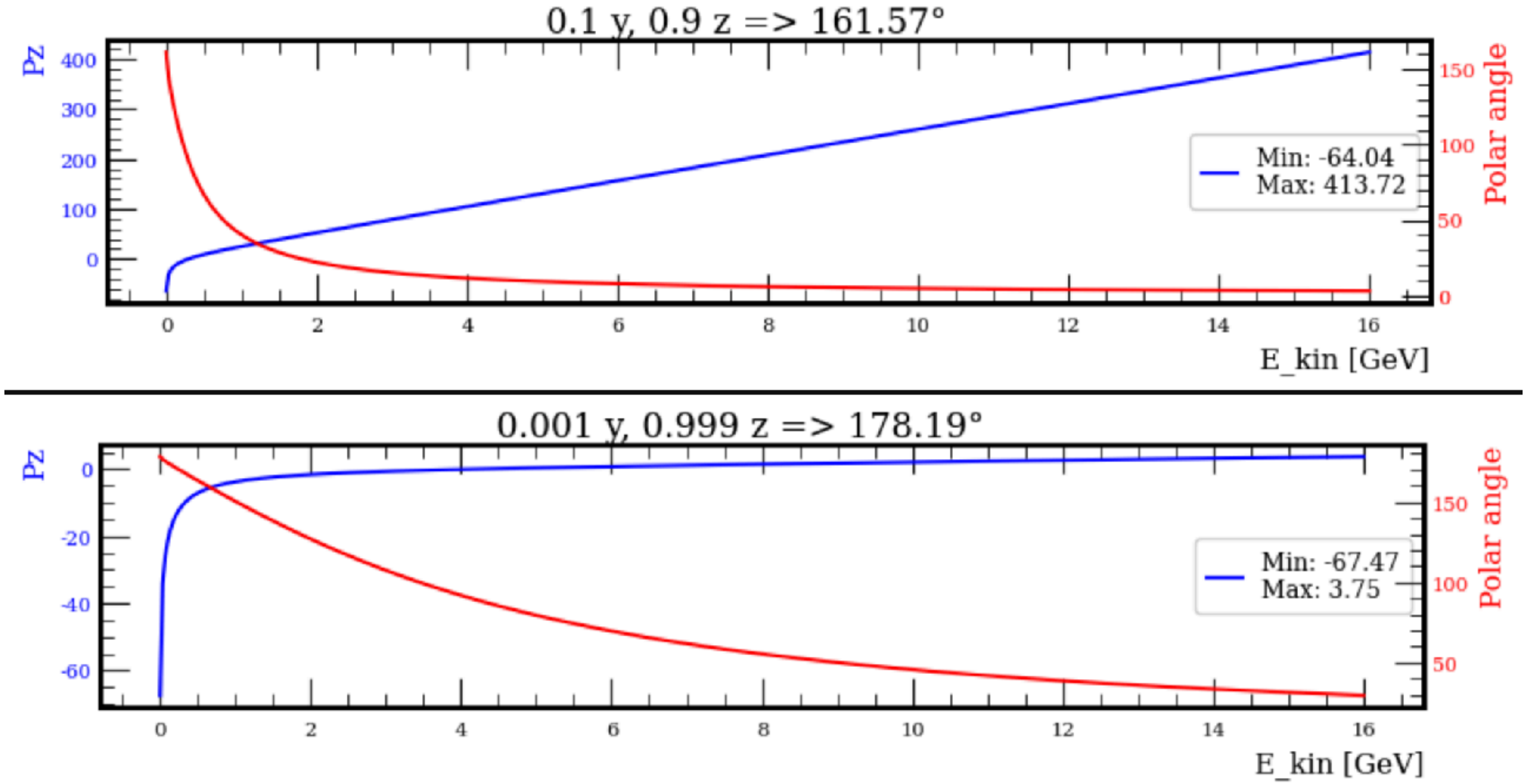
Exclusions



LEP
PrimEx
Belle−II
PrimEx
NA64
GlueX, pb^{-1}
FASER
NA64
GlueX, fb^{-1}
Belle−II
LUXE−NPOD
L_D=0.5m, N_X=3
LUXE−NPOD
phase−0
Belle−II
FASER2
LUXE−NPOD
phase−1
Beam Dumps
naturalness
NA62−dump
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$1/\Lambda_{a,\phi}$[GeV^{-1}]
5×10^{-2}
10^{-1}
5×10^{-1}
$m_{a,\phi}$[GeV]

Stragglers in Angular Distributions

- Comes from the fact that we can't boost with the speed of light

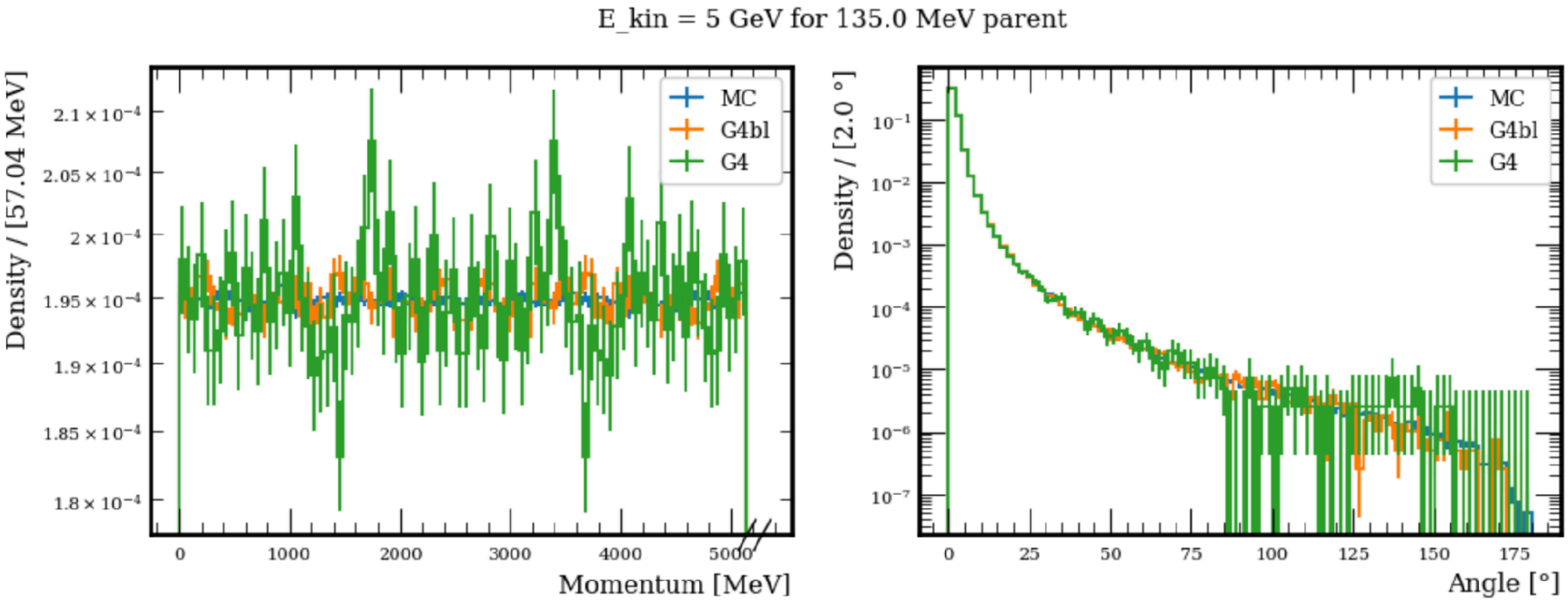


Parent mass: 135 MeV

- For all boost velocities, there is a cutoff angle after which photons decayed at this angle will *not* change the sign of their momentum

- Leads to large angles still represented, even for large boosts

Simulation Comparisons



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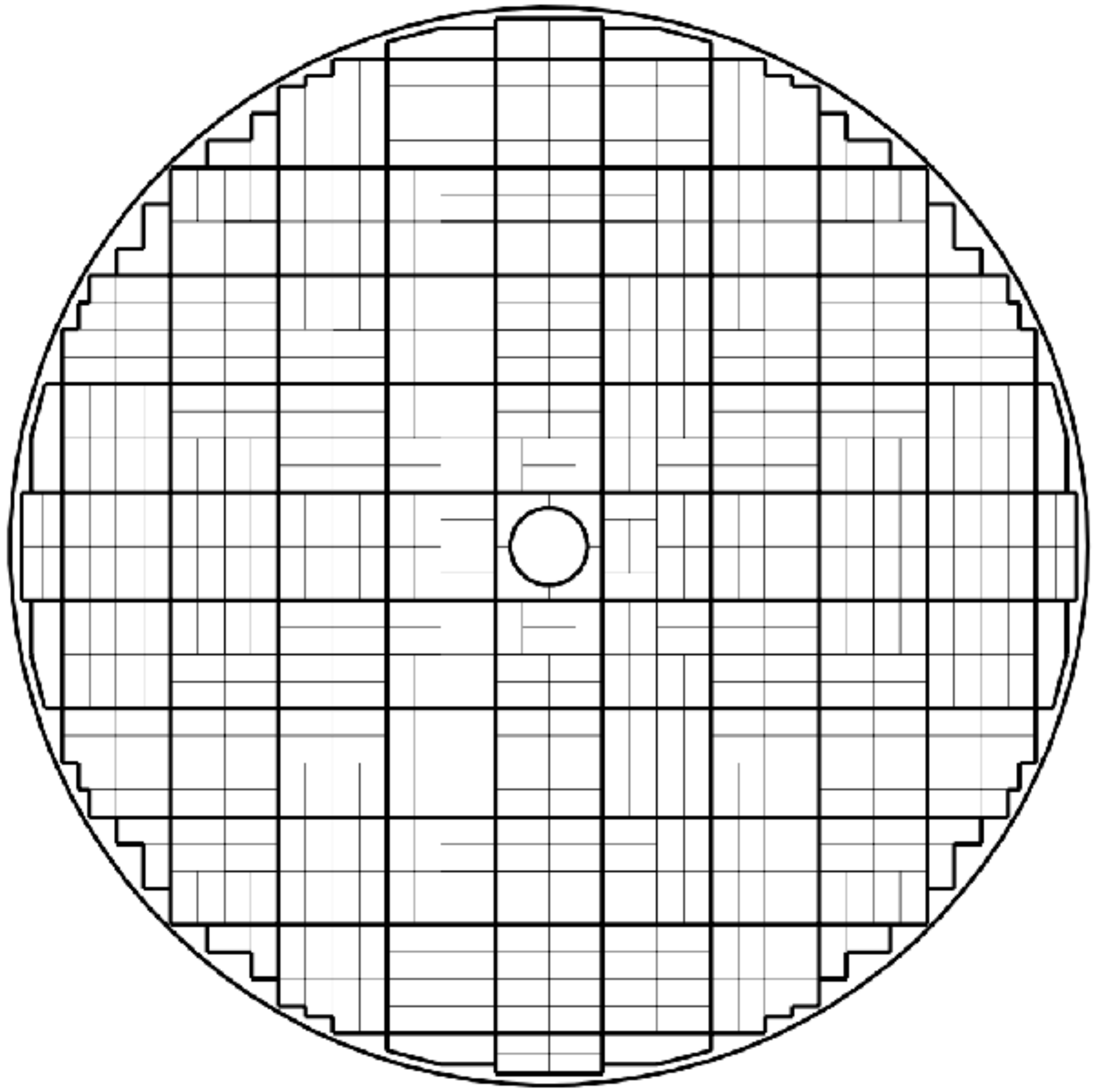

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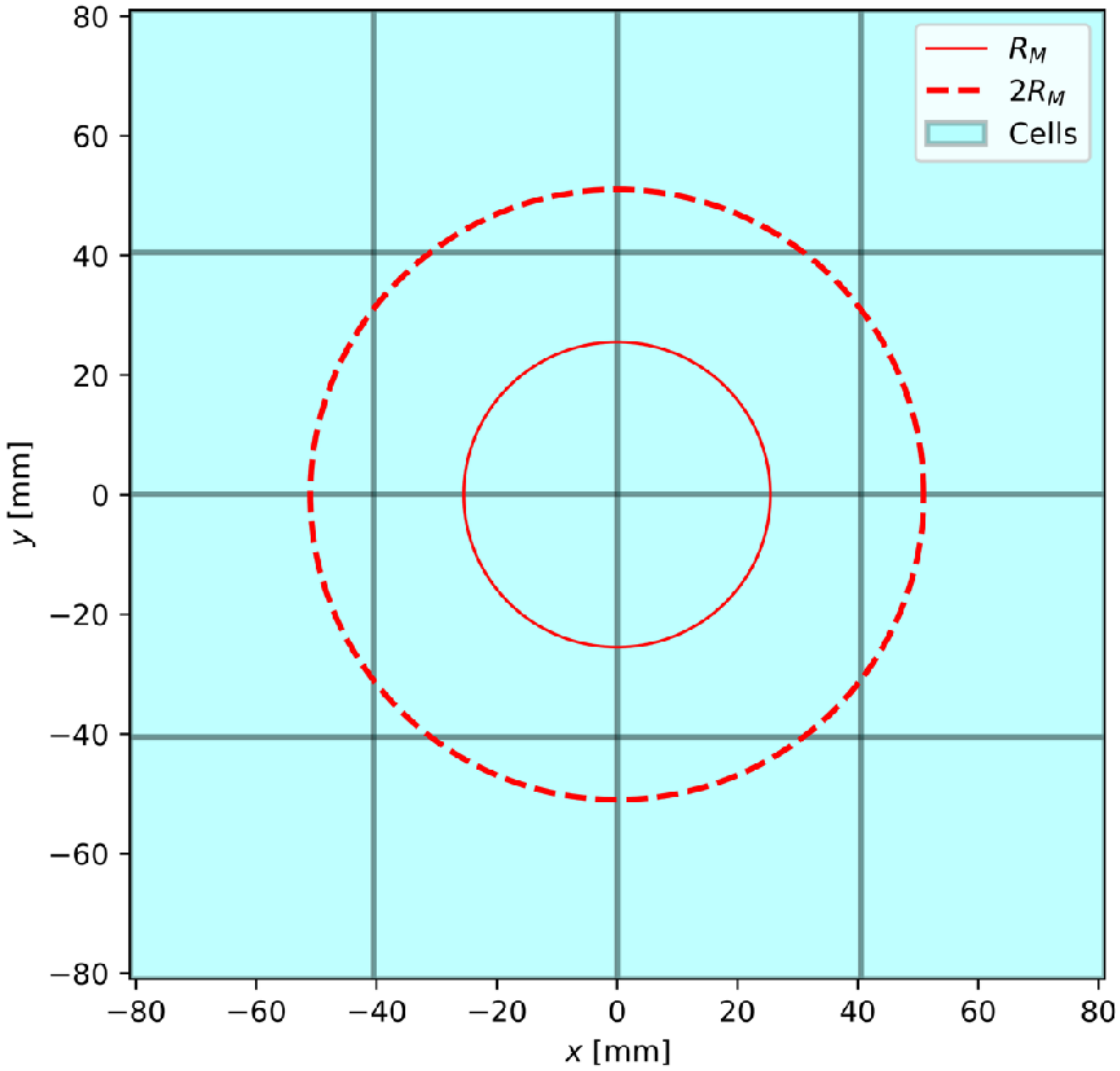

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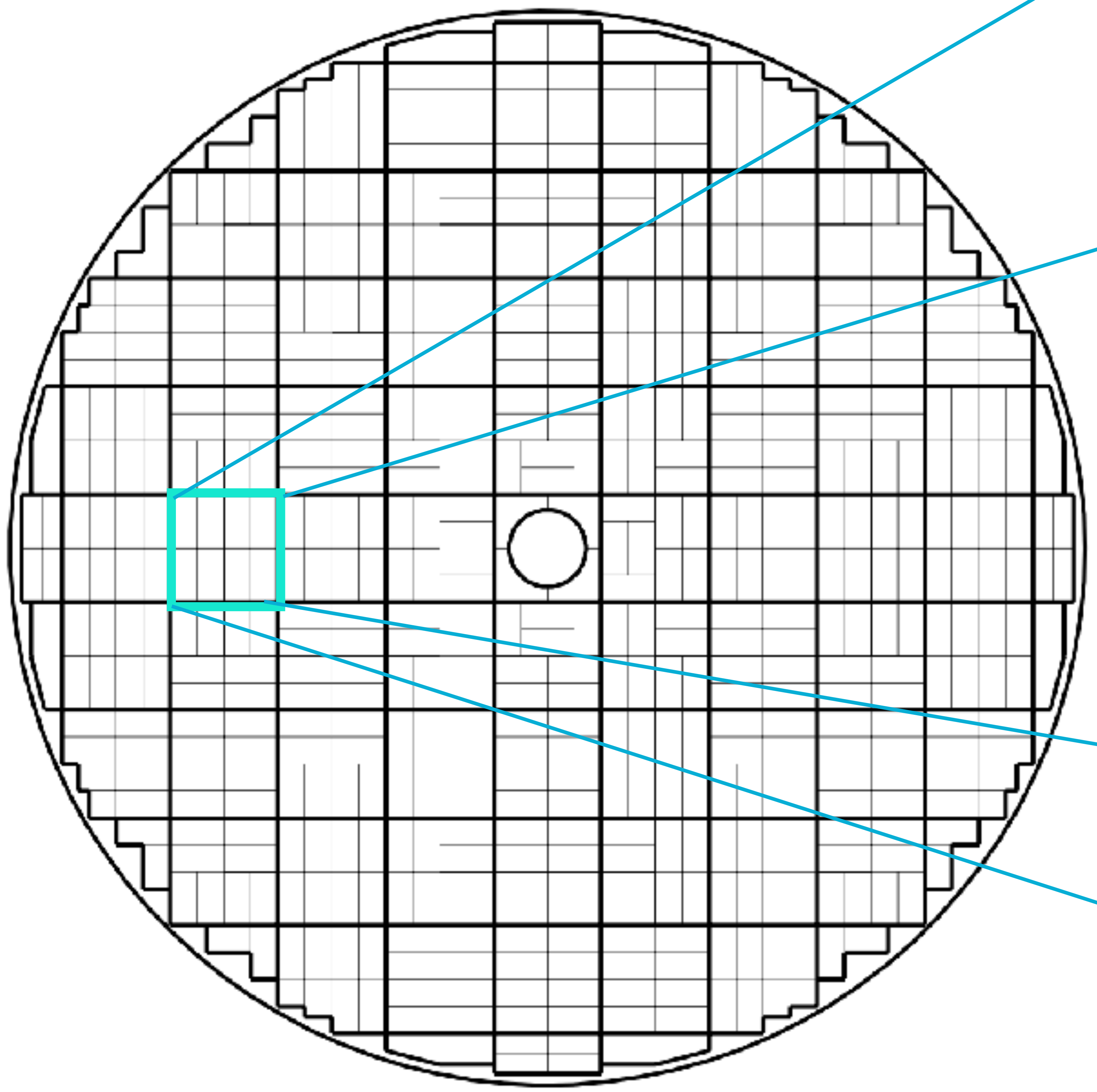

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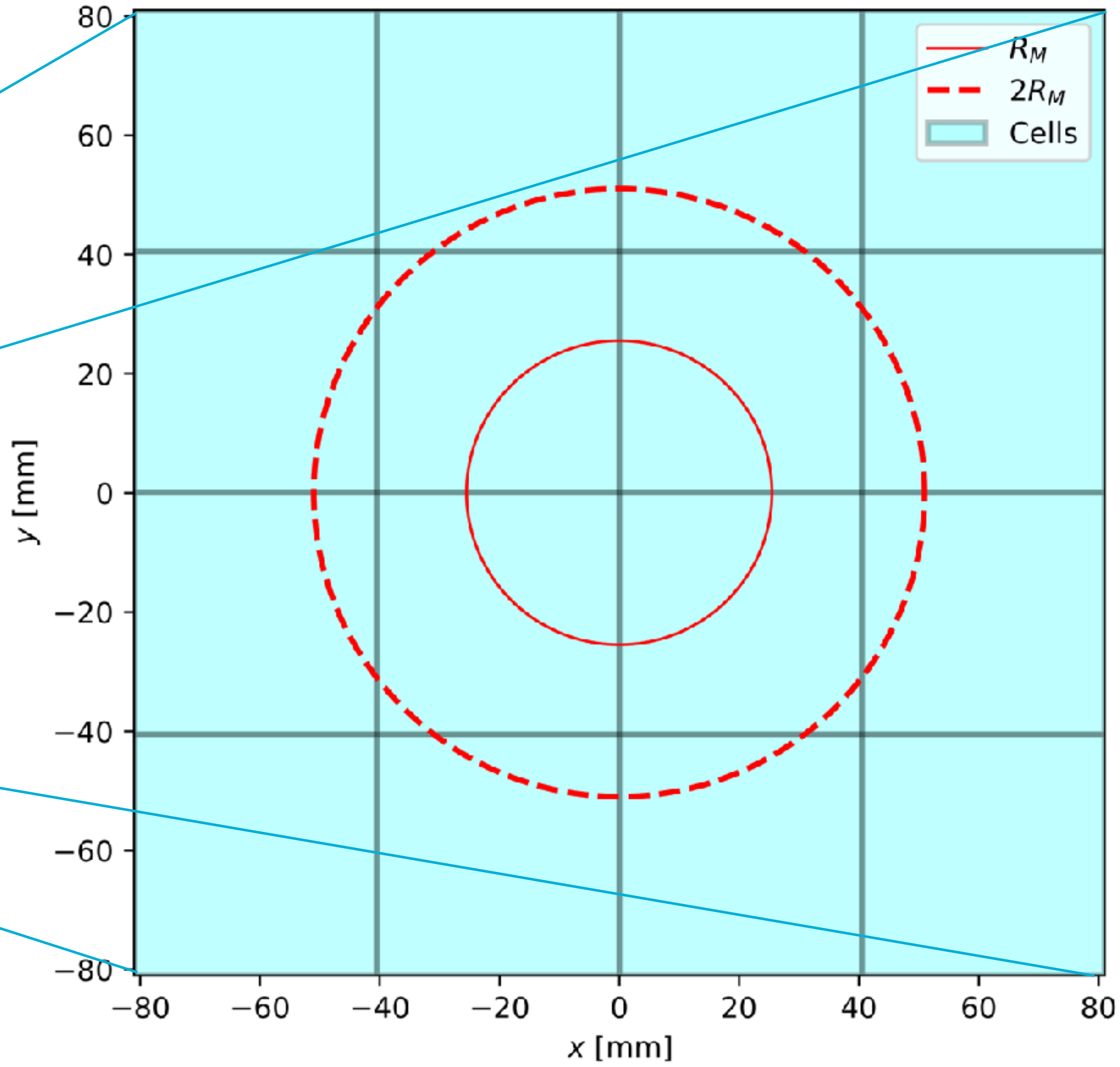

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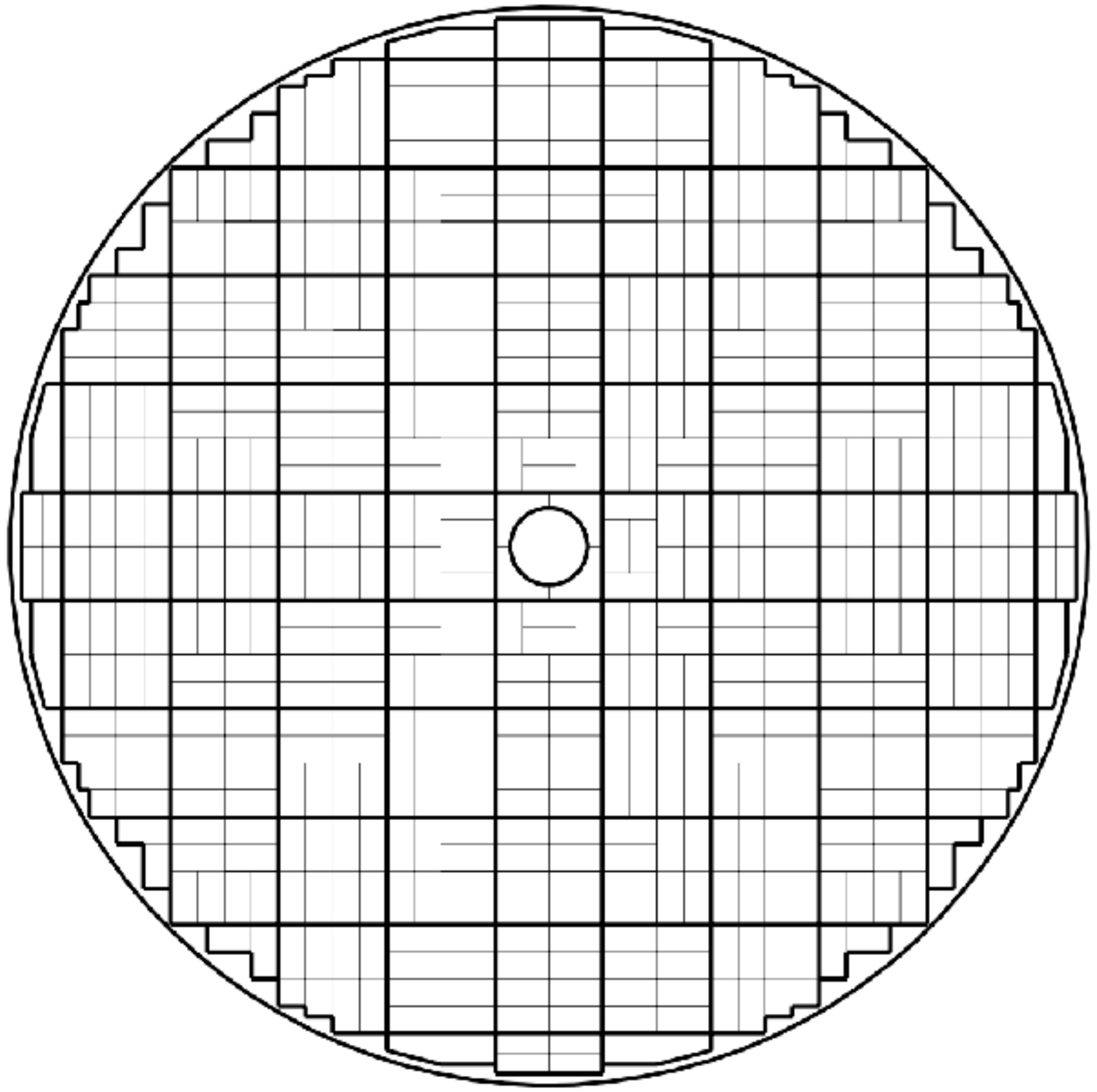

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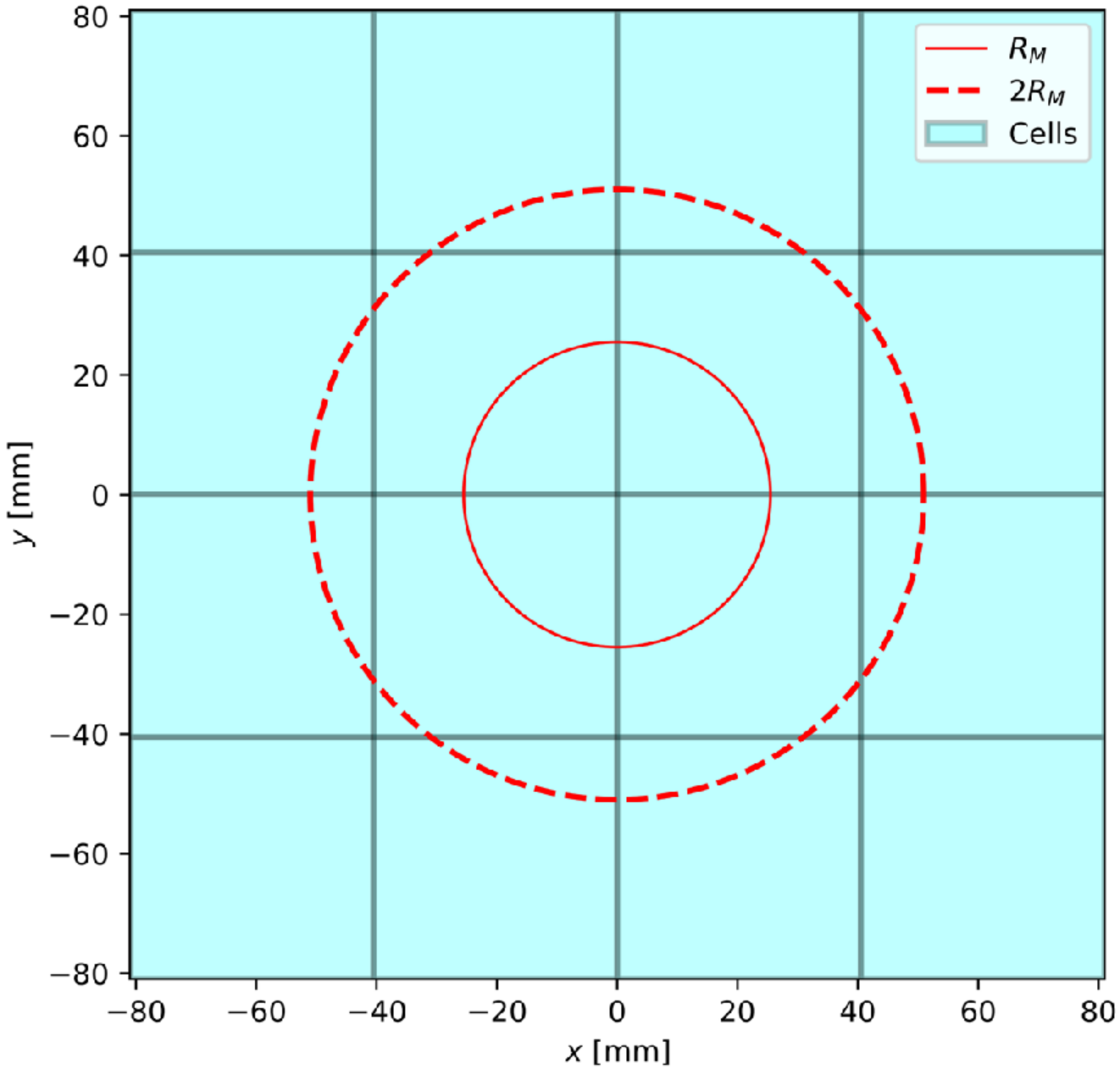

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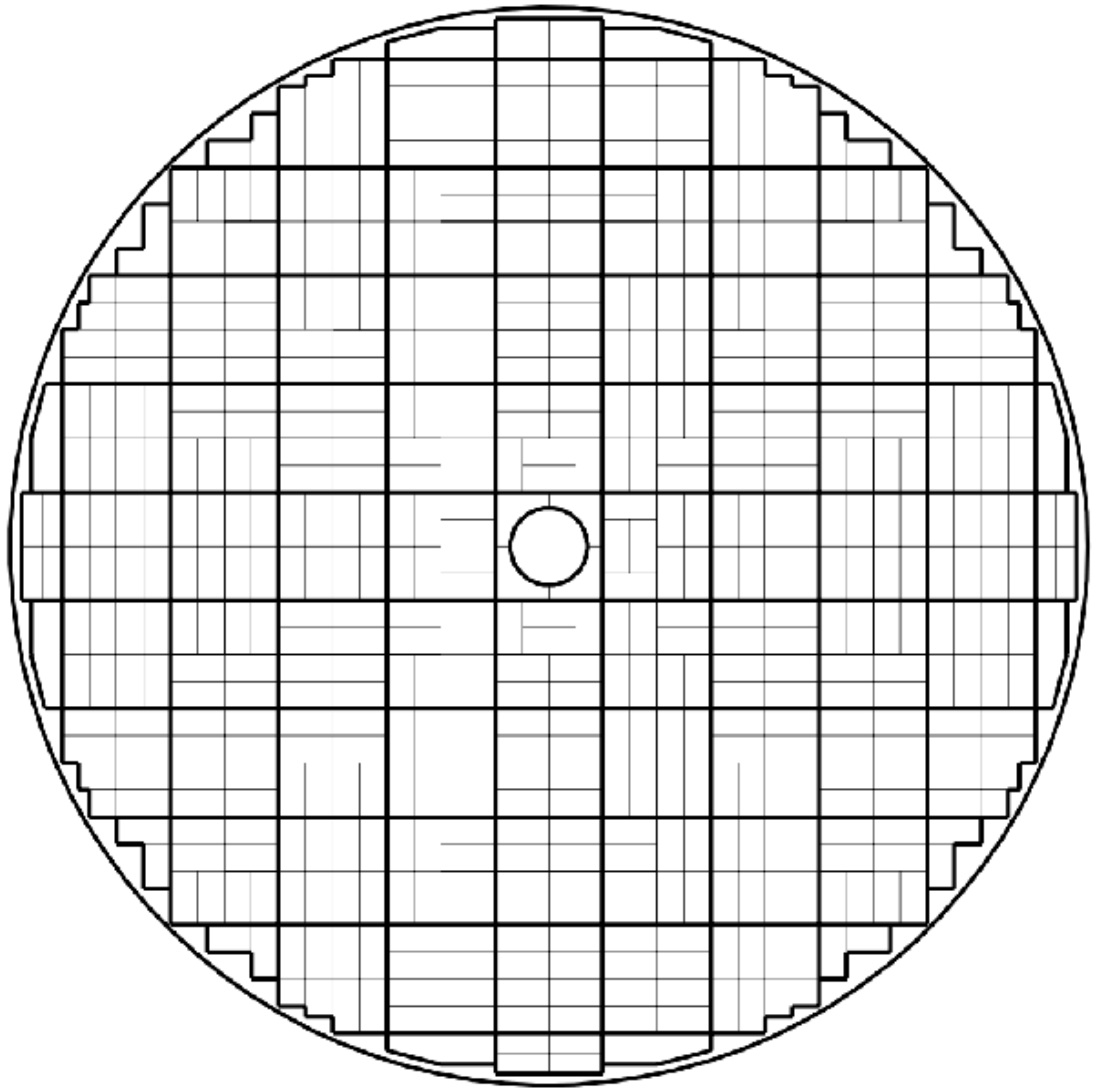

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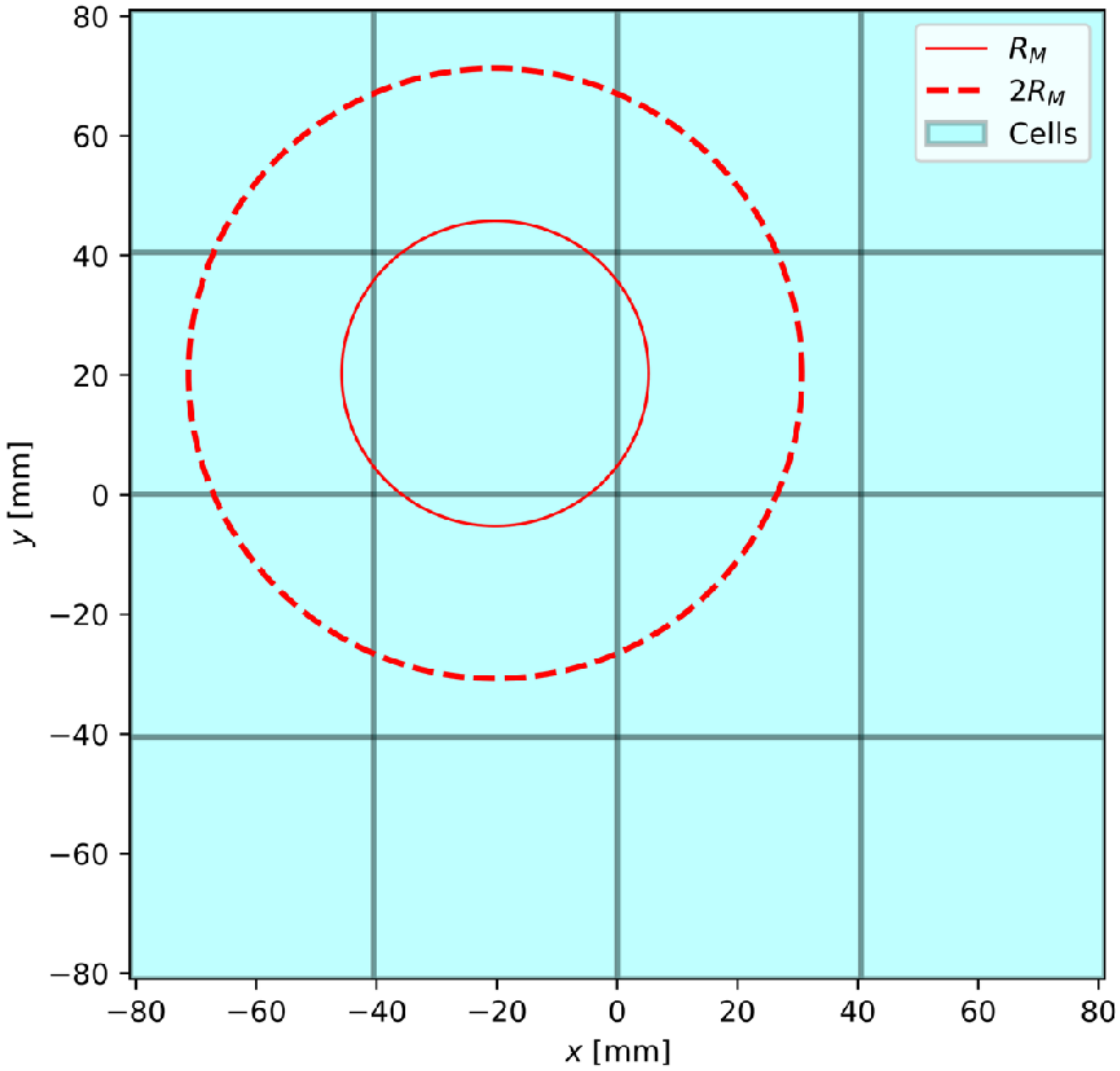

Technical Challenges for Better Position Resolution

- Wires not inside lead itself, but inside milled “notches”.
- Scintillating wires affixed by pressing
- Makes subdivision beyond singular cells difficult…

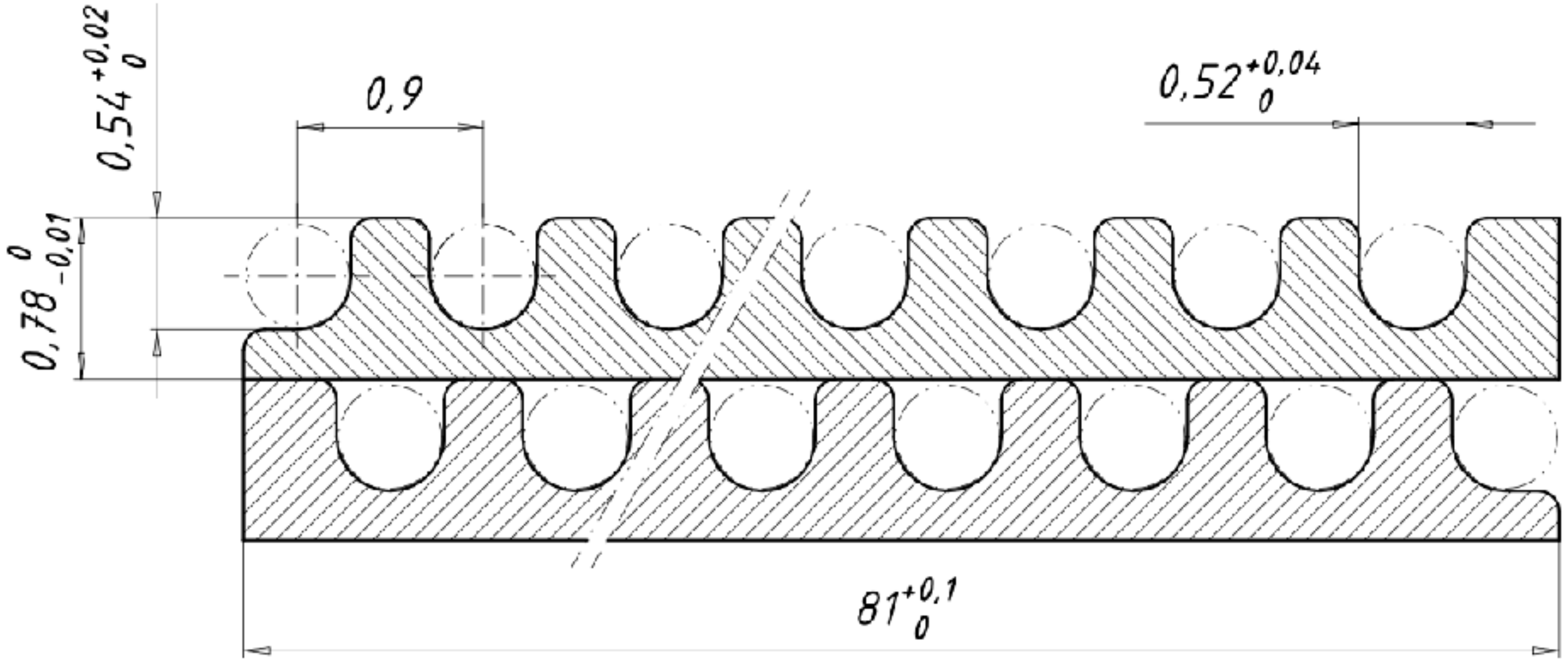

Figure 4: Cross section of two lead plates.