Pion Detector Simulations

MOLLER Collaboration Meeting - December 2021

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Goal: Correction of A^e for pion background $f^\pi A^\pi$

Method: Range out e and measure f^π, A^π in π-enriched sample

- Expect **$f^\pi \approx$ 0.13%**, **$A^\pi \approx$ 500 ppb**; need $f^\pi A^\pi$ to 20% relative precision
- Absorber: showermax ($10X_0$) + 20 cm thick pion lead donut ($36X_0$)
- Detector: acrylic "lucite" Cherenkov integrating detectors
- **A^π** measurement:
  - Anticipate 100 MHz total pion rate in all sectors
  - Both A^π_{PV} and $A^\pi_T \cos\varphi$ must be measured:
    - A^π_T is parity-conserving and could be of order 20 ppm
    - Requires array of detectors around azimuthal acceptance
- **f^π** measurement:
  - MIP pion signal in two sectors (open and closed) during low-current counting-mode data-taking periods
    - f^π unlikely to change around acceptance

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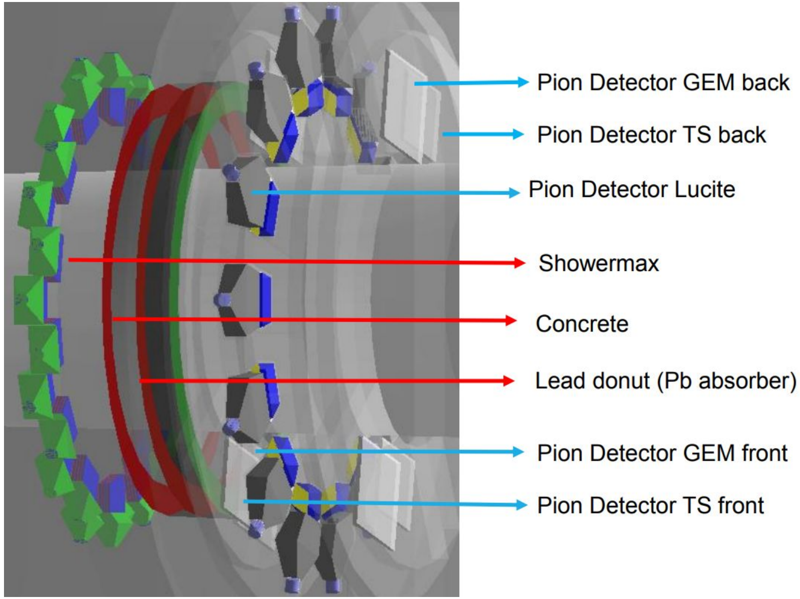
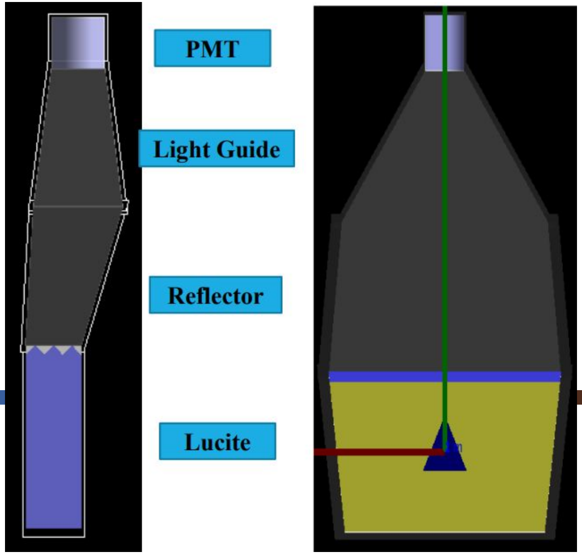
Detector Design Evolution (2010-2020)

Conceptual design: Original lucite detector dimensions



- 3 x 1" layer stack of lucite planes
- Wedge for coupling light out
- Reflecting air-core lightguide
- Light direct to 3" PMT



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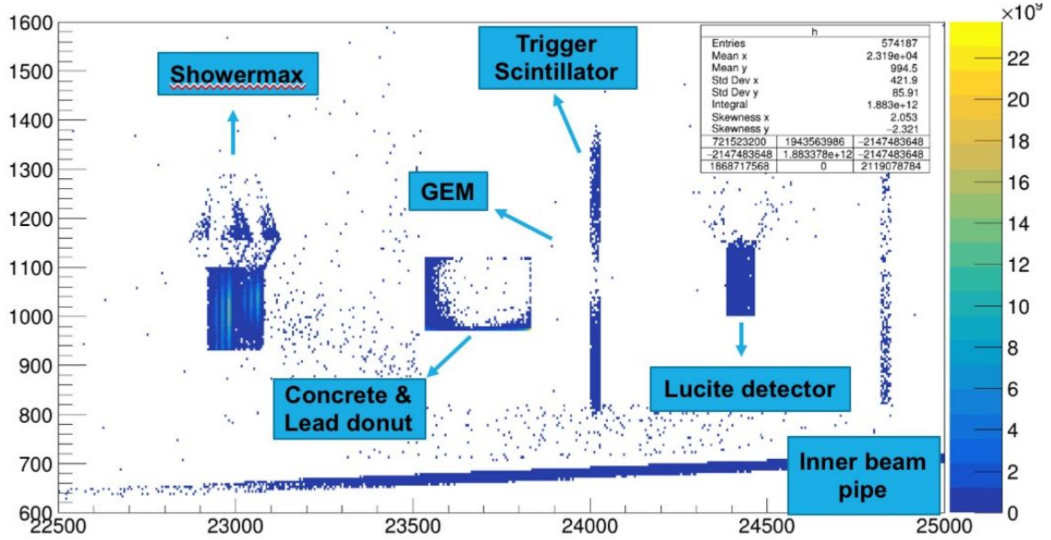
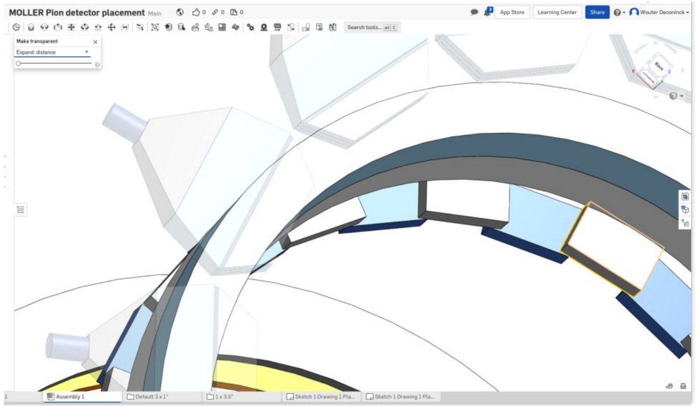
Detector Design Evolution (August 2020)

Conceptual design: The pitfalls of single-sector thinking

- Lucite detectors in the shadow of showermax
- “Surely” no electrons will be able to punch through the $36X_0$ lead donut…
- π/e p.e. ratio ~10^{-3} due to showermax secondaries

Origin location (r, z) of secondaries that hit Pion detector, Moller generator



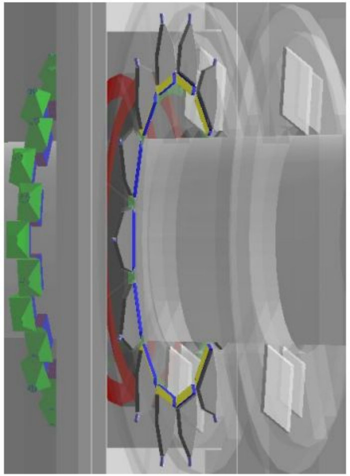


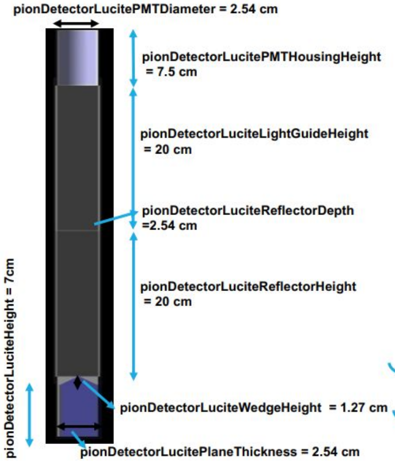
Detector Design Evolution (2021)

Improved design: Lucite much closer to the pion lead donut

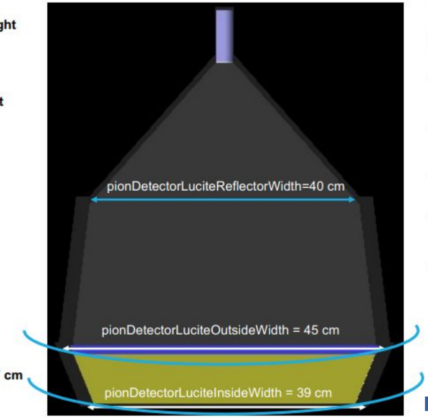
- Thinner (3” → 1”) lucite, **against pion lead donut** to avoid secondaries
- 0.5” to 1” lead-shielded at inner radius and back face
- Only unshielded at outer radius (lightguide)

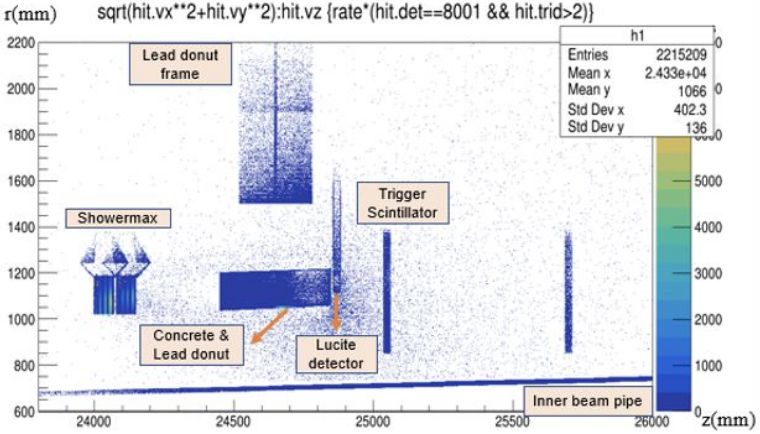
PionDetectorSystem geometry





PionDetectorLucite geometry





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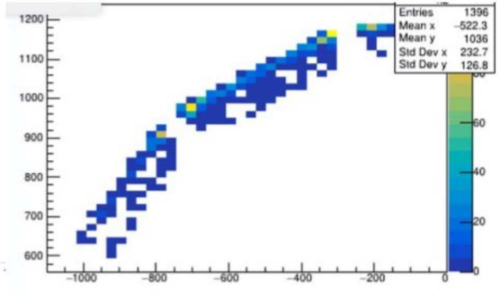
Detector Design Evolution (2021)

Low pion/electron ratio due to low energy electrons

June 2021: Showermax secondaries at large radius make it past lead donut and into corners of the lucite detectors



Even after tilting showermax, staggering in radius:

- π/e p.e. ratio in detector remains low, ~2.5%
- low energy electrons from unshielded lightguide side, which often range out in the lucite (more isotropic)

Conclusion in July 2021:

- optimize optical design of lucite to maximize π/e ratio by using pion directionality, and allow for shielding at outer radial side

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Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify

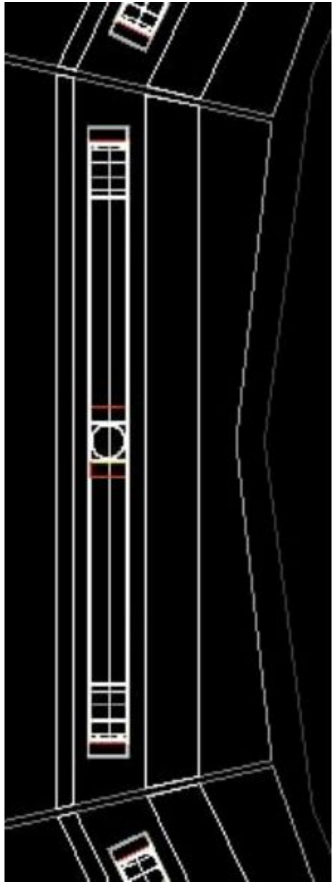
New 90° rotated design (different from quartz and showermax):

- 1” lucite layers (one or multiple)
- PMT downstream, direct coupling to lucite
- No more wedge, no more lightguide
- Shielding on all sides, including outer radial side

π/e p.e. ratio is much improved, **~50% to ~60%** (finally)

Remaining improvements to include in geant4 model:

- Direct PMT coupling (currently still assumes air gap)
- Multiple PMTs in azimuthal direction (θ_c = 45°, Δz = 7 cm)



Detector Design Evolution (2022)

Redesign: Exploit pion directionality

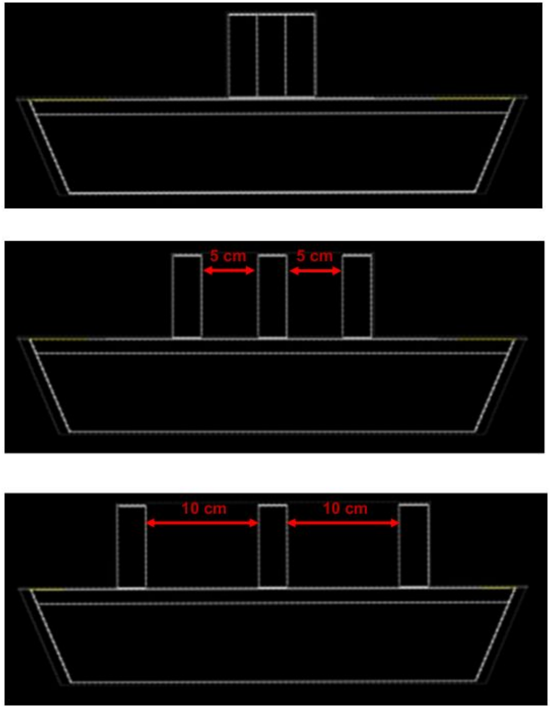
Directionality benefits:

- Pions (signal) is going towards PMT
- Electrons (background) is angled up/down, or even going backwards

Shielding benefits:

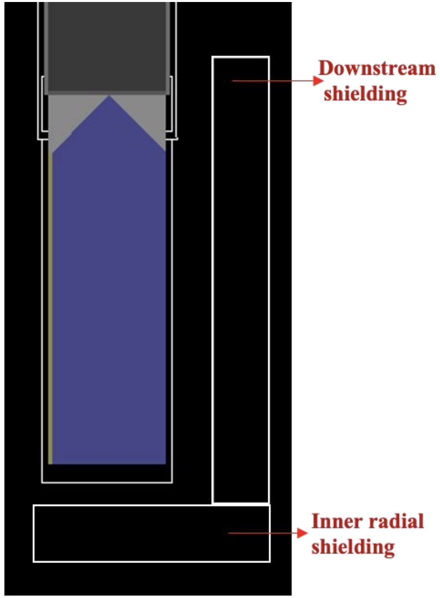
- Shielded from sector-to-sector showermax spray
- Shielded from diffuse low energy background electrons coming in from the outer radial direction

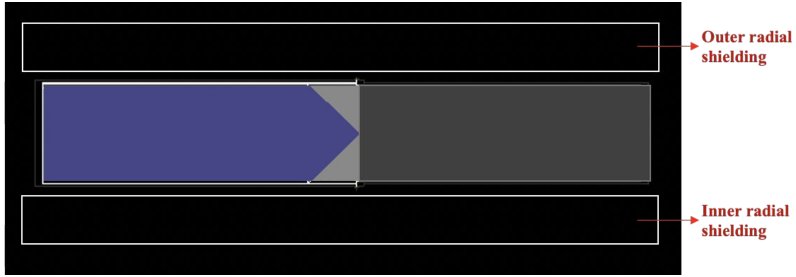
(Note: we are using rectangular design, not trapezoid)



Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify





Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify

Table.1: Comparison of the results for the rotated pion detector system. The second column in the table is the ratio of the rate from pions to Møller electrons and the third column is the ratio of the rate from photoelectrons of the pion generator to the photoelectrons of the Møller electron generator.

	Optimization	Pi/e	Pi/e (photoelectrons)
2021 design →	New geometry	4.9%	2.5%
	New geometry with shielding	16.8%	4.7%
	Moving showermax outward radially	13.7%	5.5%
	Rotating the pion detector system and removing the lightguide	13.8%	16.8%
2022 design →	Increase the thickness of the inner radial shielding	44.2%	49.0%
	Chang the radial position of lucite	69.8%	51.0%
	Decrease the azimuthal thickness of the lucite	69.6%	55.8%
	Using 3 PMTs instead of 1 PMT	70.0%	61.5%

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Prototype Construction (2022)

U Manitoba: Simplified design means easier testing

Plan for January/February 2022:

- Multiple bars of 1.5” x 10 cm x 20 cm and 1.5” x 10 cm x 30 cm Eljen UVA
- Optical grease (instead of glue) coupling to one or more PMT (1”, 1.5”)
- Directionality, p.e. yield testing with cosmic rays

Structural design:

- Anticipate simplification: no lightguide, reduced requirements on rigidity
- New design is essentially a stack of lead-lucite-lead slabs
- Nevertheless, showermax design cannot be reused as planned

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Summary

Pion detector design has reached 60% (... in π/e p.e. ratio)

- Original design had to be modified because of showermax spray
- Incremental changes were not sufficient to enrich π/e sufficiently
- Rotated design indicates performance of up to 60% π/e p.e. ratio
- Planned studies of rotated design:
    - Improved modeling of coupling to PMT
    - Optimization of length/thickness of lucite/shielding
    - Radiation at PMT (shielded from all sides)
- Next steps:
    - Prototype tests: winter/spring 2022
    - Structural design: winter 2022

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Lead Donut: Aluminum Plate

6” stiffener plate, 56” radius hole

Current design is likely to use different solution, but this is considered to be equivalent for now.