Pion Detector Simulations

MOLLER Collaboration Meeting - June 2022

David Armstrong, Wouter Deconinck,
Elham Gorgannejad, Raj Seehra

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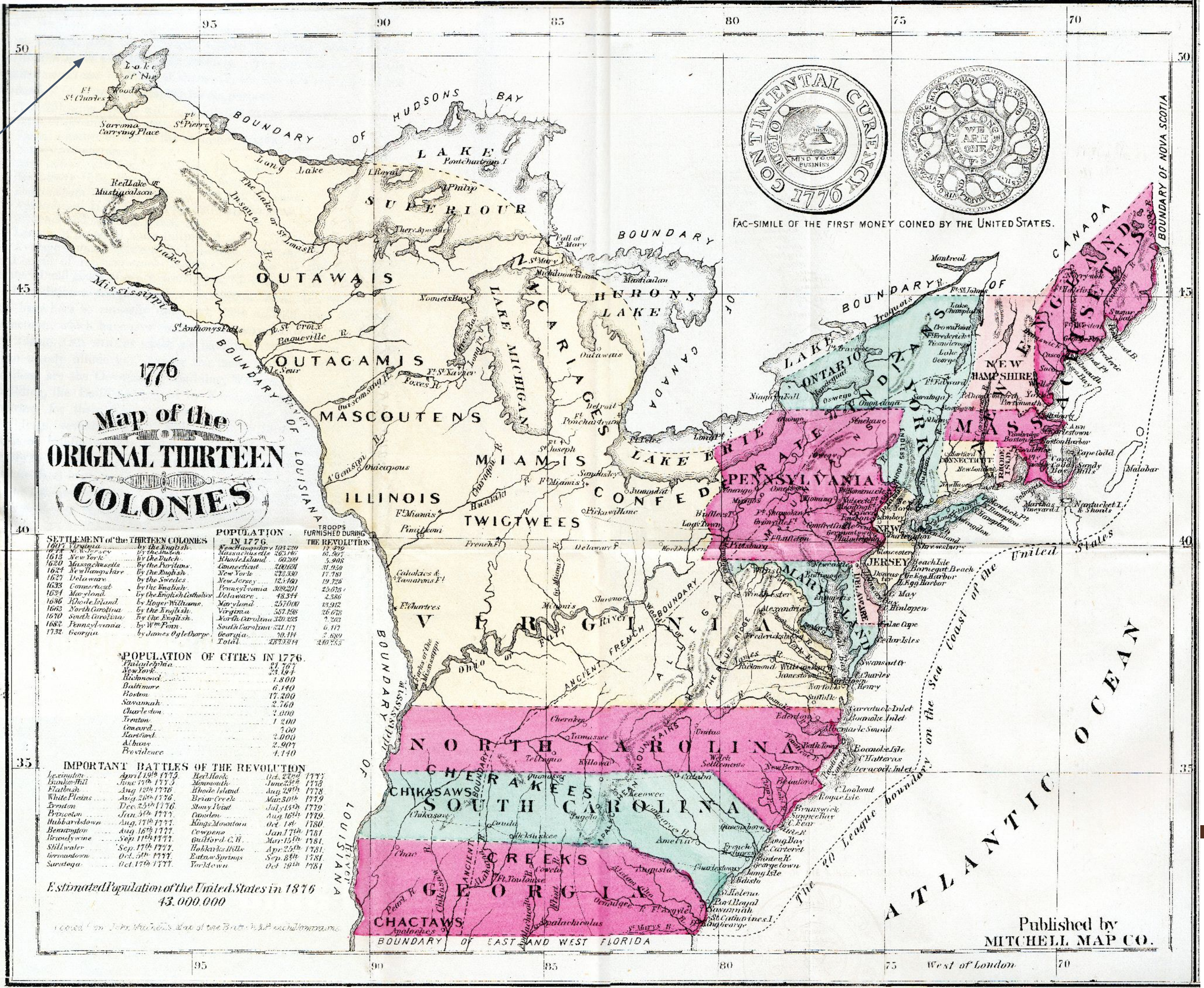
June 21: Indigenous Peoples Day

The University of Manitoba campuses are located on original lands of Anishinaabeg, Cree, Oji-Cree, Dakota and Dene peoples, and on the homeland of the Métis Nation.

We respect the Treaties that were made on these territories, we acknowledge the harms and mistakes of the past, and we dedicate ourselves to move forward in partnership with Indigenous communities in a spirit of reconciliation and collaboration.

Winnipeg (estd. 1873)



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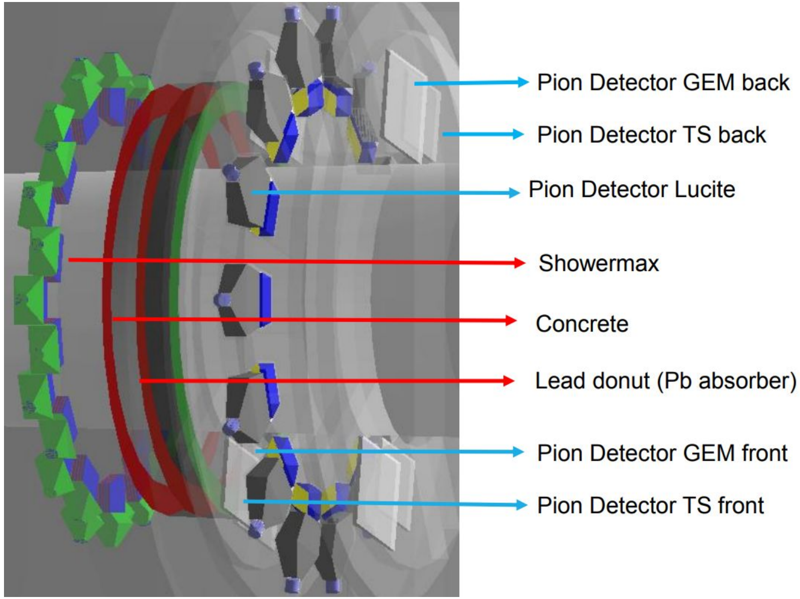
Goal: Correction of A^e for pion background $f^\pi A^\pi$

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

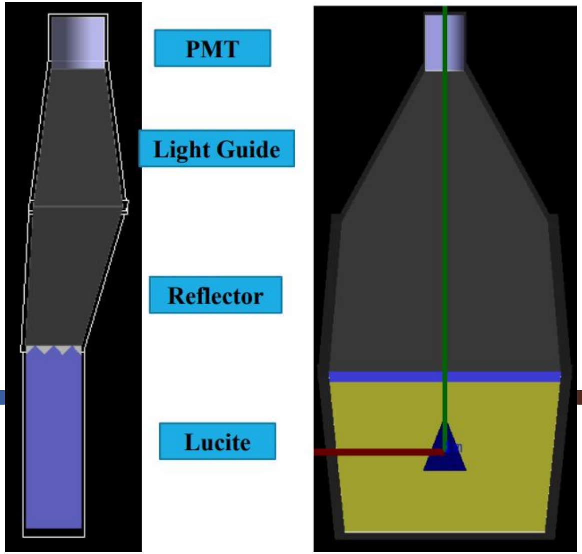
- Expect **$f^\pi \approx 0.13\%$**, **$A^\pi \approx 500$ ppb**; need $f^\pi A^\pi$ to 20% relative precision
- Absorber: showermax ($10X_0$) + 20 cm thick pion lead donut ($36X_0$)
- Detector: acrylic "lucite" Cherenkov integrating detectors
- **A^π** measurement:
    - Anticipate 100 MHz total pion 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 φ acceptance

Detector Design Evolution (2010-2020)

Conceptual design: Original lucite detector dimensions



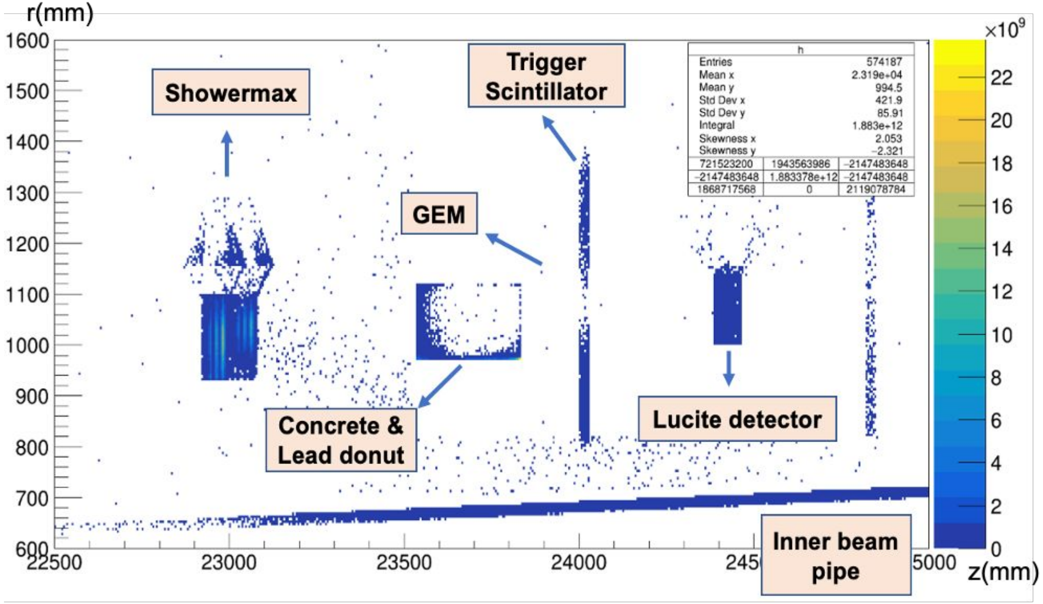
- 3 x 1” layer stack of lucite planes
- Wedge for coupling light out
- Reflecting air-core lightguide
- Light direct to 3” PMT

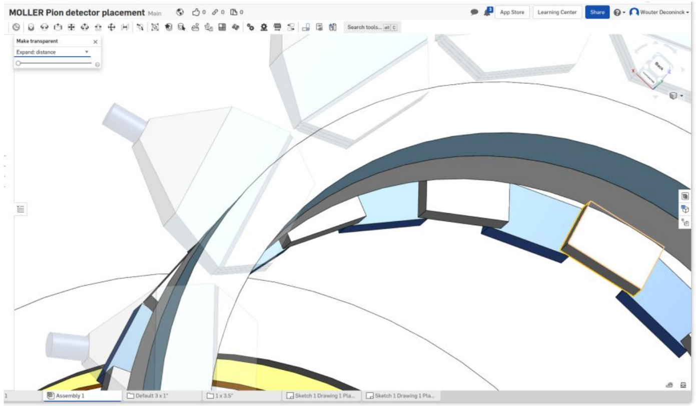


Detector Design Evolution (August 2020)

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



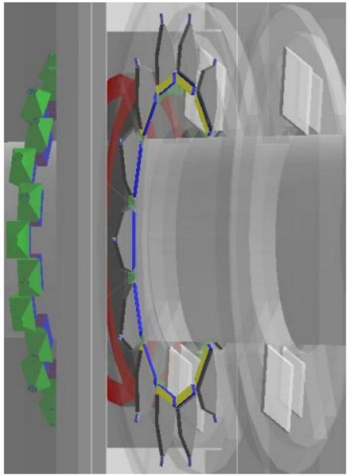


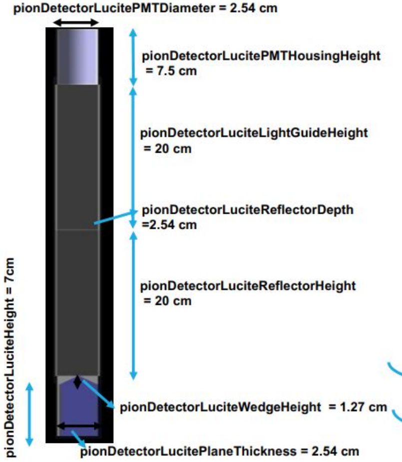
Detector Design Evolution (2021)

Improved design: Lucite much closer to the pion lead donut

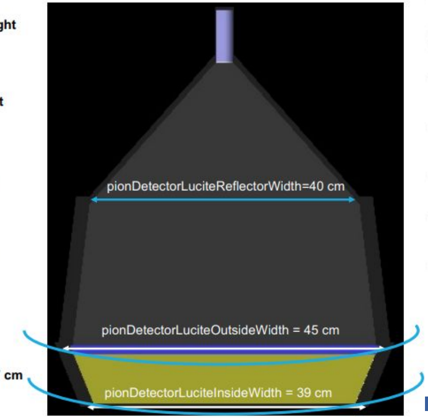
- Thinner (3” → 1”) lucite, **against pion lead donut** to avoid secondaries
- 0.5” to 1” lead-shielded at inner radius and back face
- Only unshielded at outer radius (lightguide)

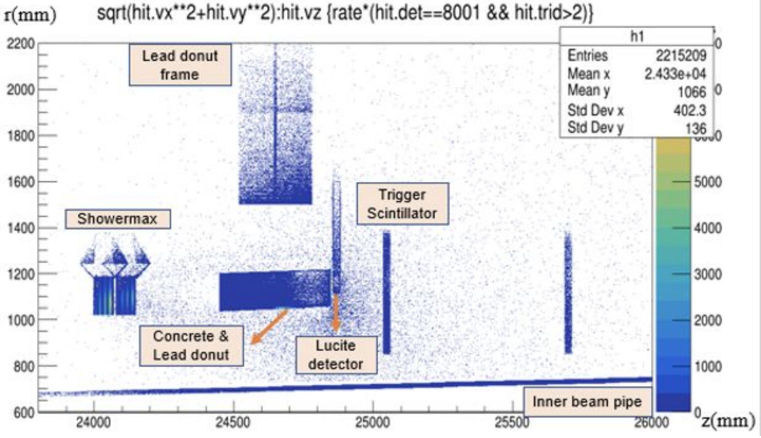
PionDetectorSystem geometry





PionDetectorLucite geometry

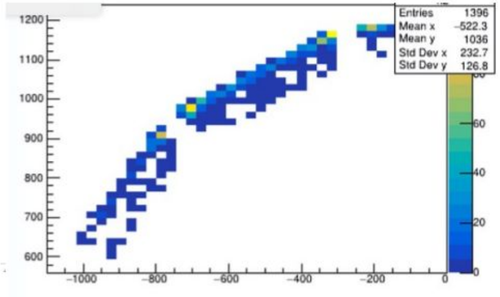




Detector Design Evolution (2021)

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

Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify

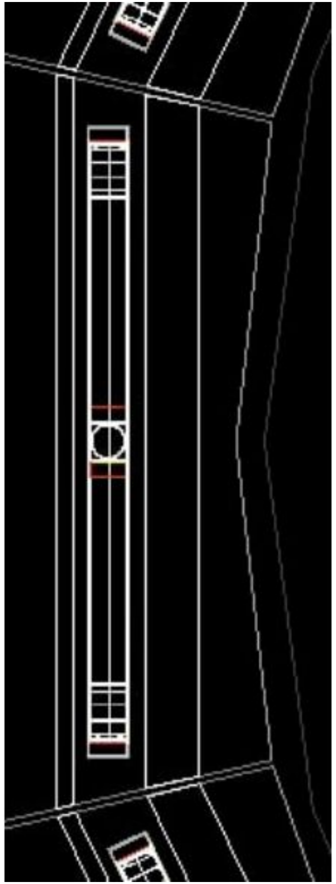
New 90° rotated design (different from quartz and showermax):

- 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)

Improvements added to geant4 model since last meeting:

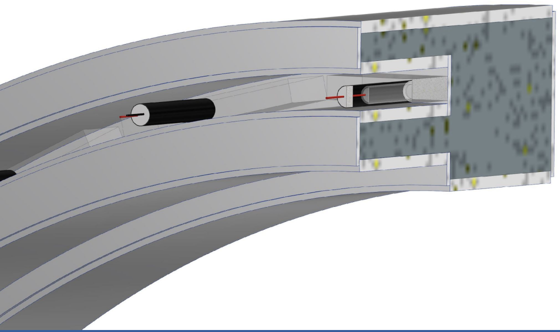
- Direct coupling between lucite and lucite (no wedge)
- Improved shielding, narrower detectors (28 sectors)

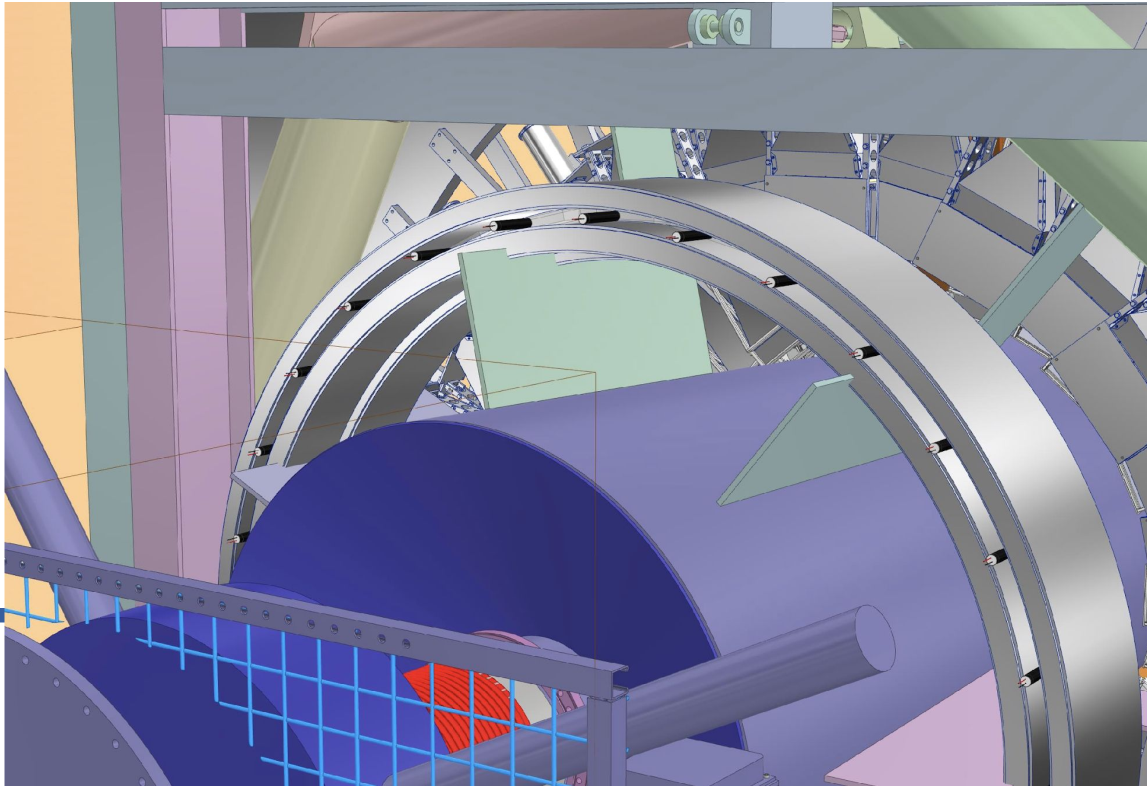


Detector Design Evolution (2022)

Redesign: Integration in Lead Donut

- 28 narrower sectors
- Rectangular lucite





Detector Design Evolution (2022)

Redesign: Exploit pion directionality

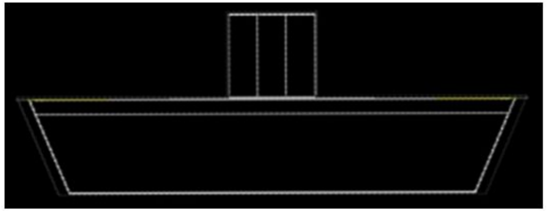
Directionality benefits:

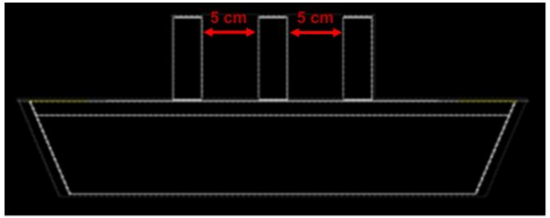
- Pions (signal) is going towards PMT
- Electrons (background) is angled up/down, or even going backwards

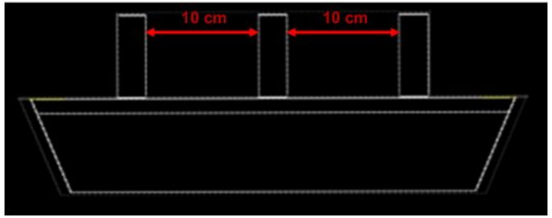
Shielding benefits:

- 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)

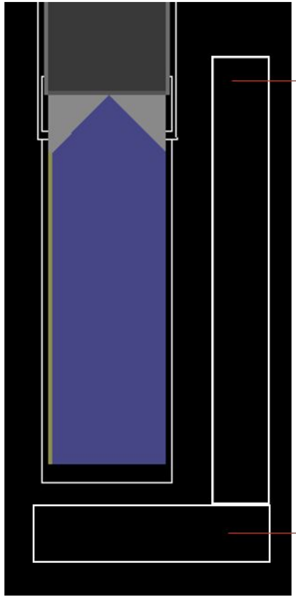


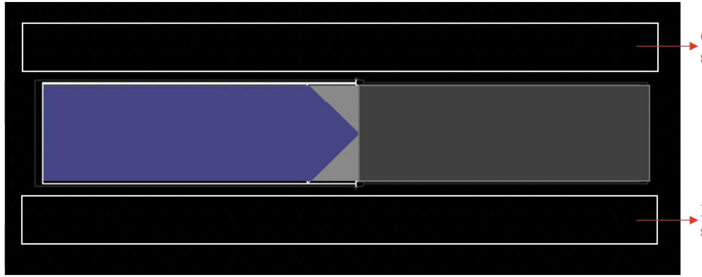




Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify





Detector Design Evolution (2022)

Redesign: Exploit pion directionality and simplify

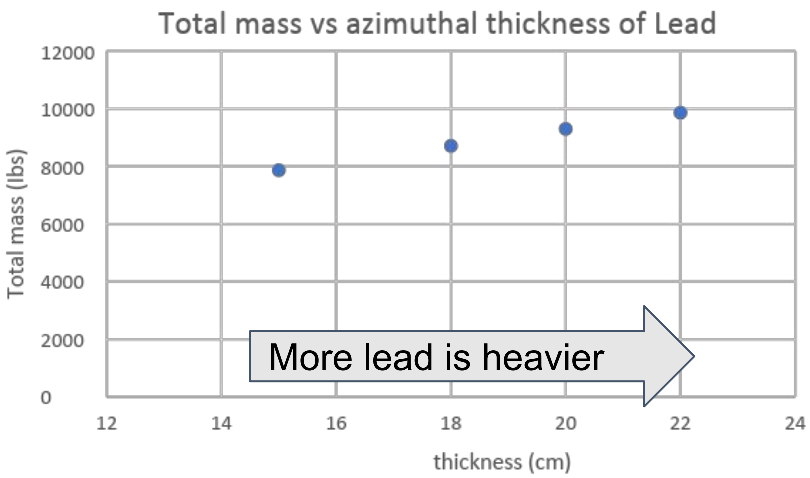
Table.1: Comparison of the results for the rotated pion detector system. The second column in the table is the ratio of the rate from pions to Møller electrons and the third column is the ratio of the rate from photoelectrons of the pion generator to the photoelectrons of the Møller electron generator.

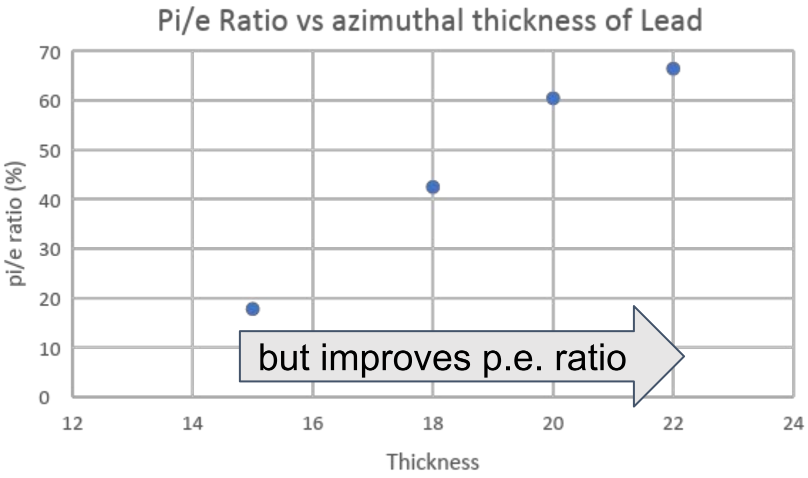
	Optimization	Pi/e	Pi/e (photoelectrons)
2021 design →	New geometry	4.9%	2.5%
	New geometry with shielding	16.8%	4.7%
	Moving showermax outward radially	13.7%	5.5%
	Rotating the pion detector system and removing the lightguide	13.8%	16.8%
2022 design →	Increase the thickness of the inner radial shielding	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%

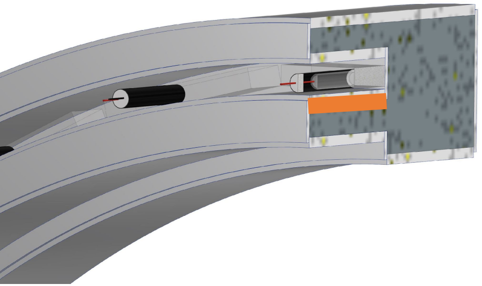
More inner radial shielding and lead donut improves to 100% π/e p.e. ratio

Detector Design Evolution (2022)

Increasing inner radial shielding has impact on π/e p.e. ratio







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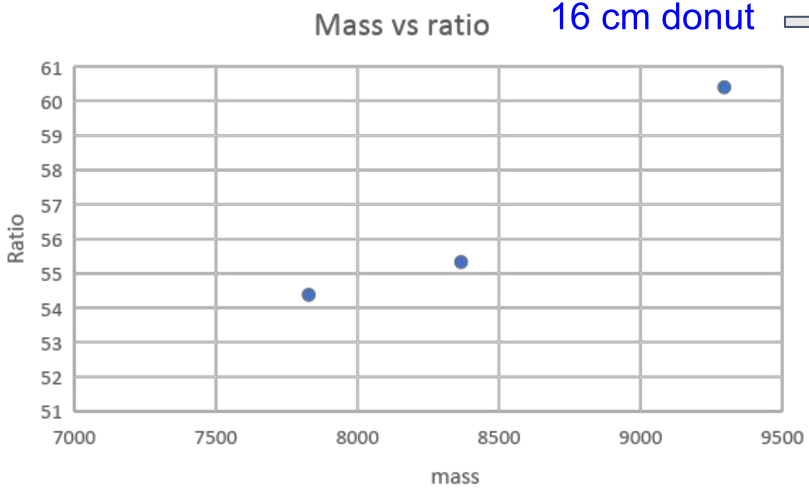
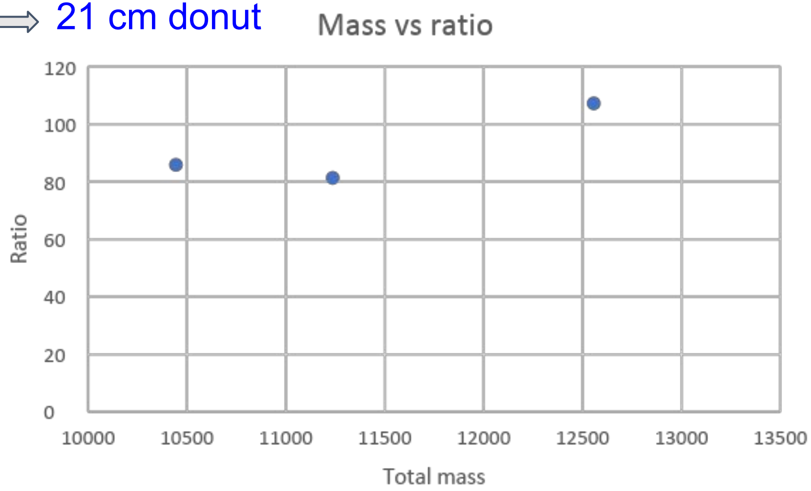
Detector Design Evolution (2022)

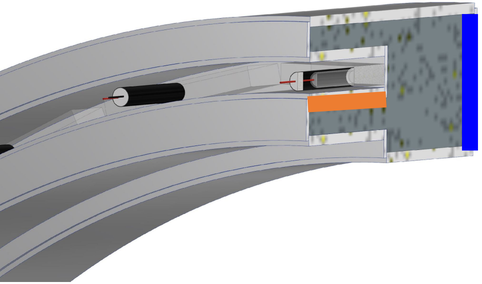
Increasing donut radial thickness has impact on π/e p.e. ratio

but improves p.e. ratio

16 cm donut → 21 cm donut







thicker lead is heavy

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Prototype Construction (2022)

U Manitoba: Simplified design means easier testing

Prototype design:

- 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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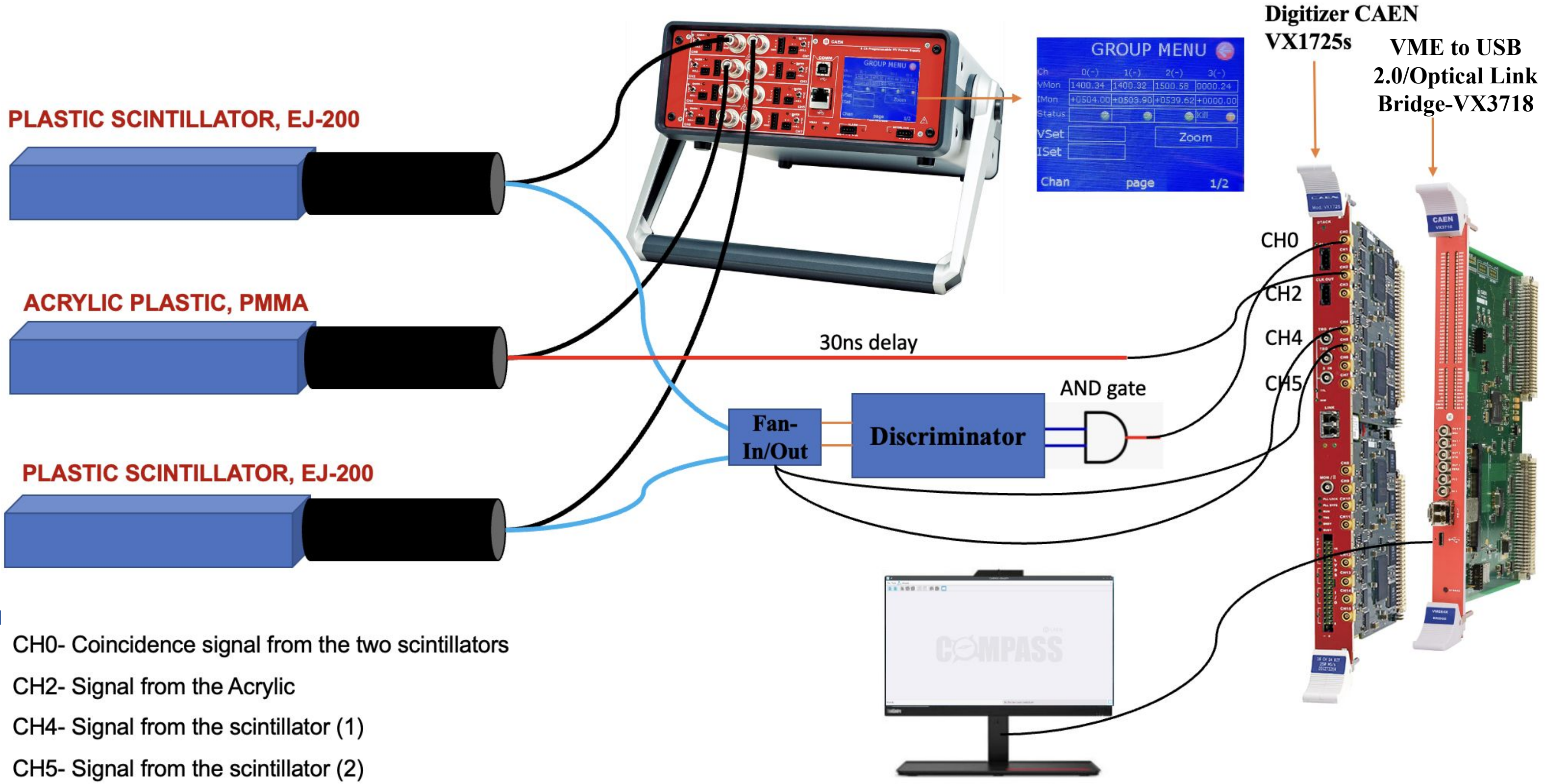
Prototype Construction (2022)

Cosmic Ray Telescope



CH0- Coincidence signal from the two scintillators

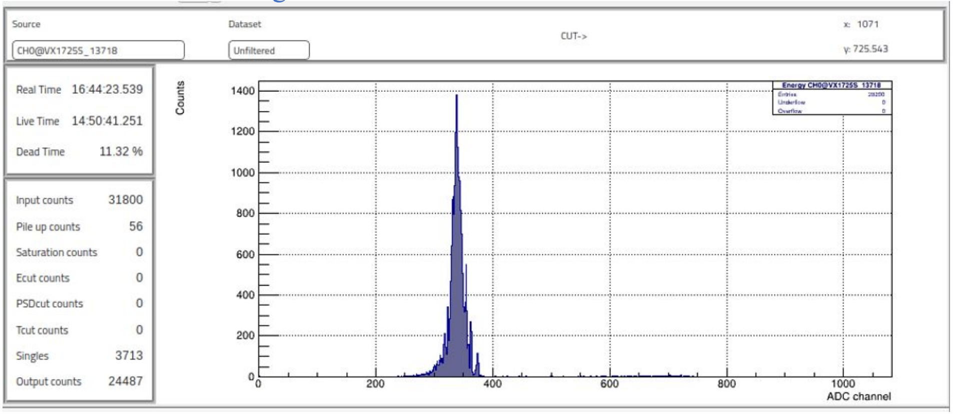
CH2- Signal from the Acrylic

CH4- Signal from the scintillator (1)

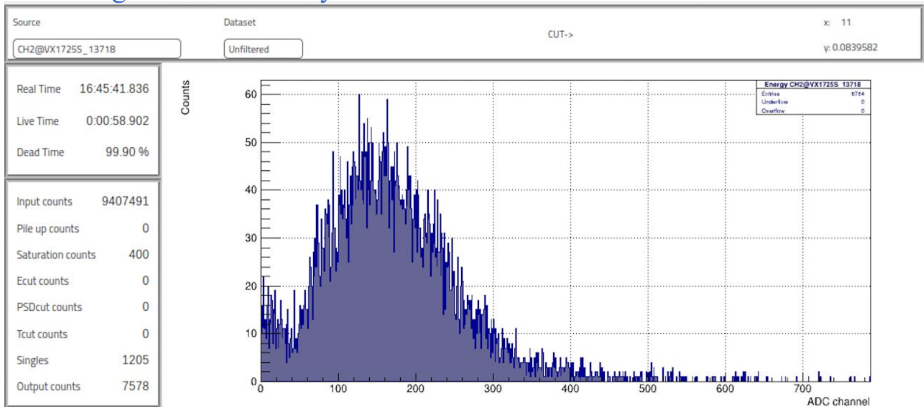
CH5- Signal from the scintillator (2)

Prototype Construction (2022)

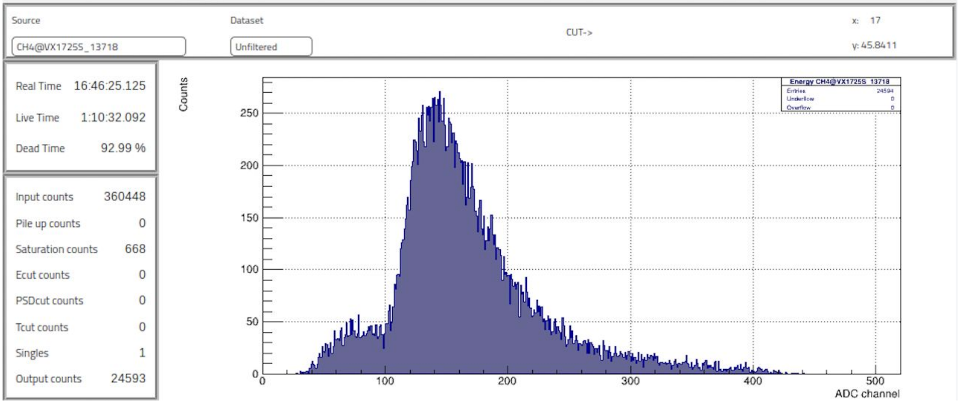
CH0 : Coincidence signal from the scintillators



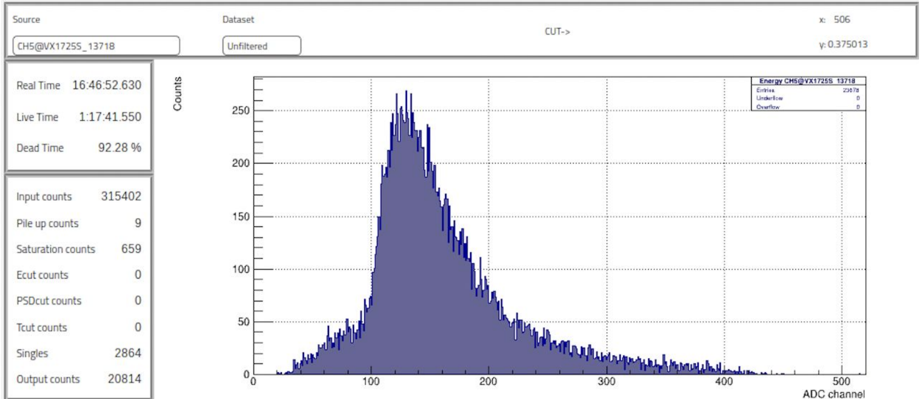
CH2: Signal from the Acrylic



CH4: Signal from scintillator (1)

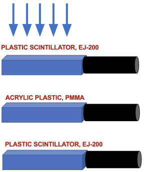


CH5: Signal from scintillator (2)



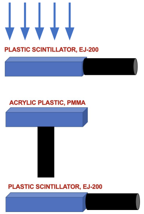
Prototype Construction (2022)

Photo-Electron Yields



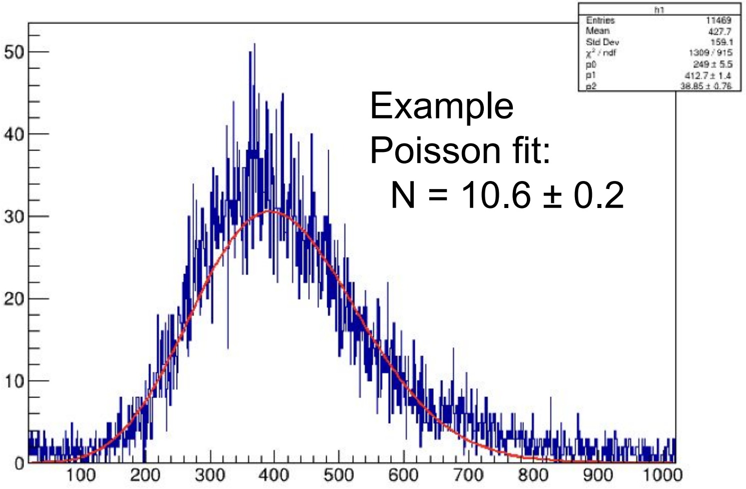
Horizontal orientation of lucite (i.e. how sensitive is the lucite to what we think background looks like)

- Test bench measurements: 10.6 ± 0.2
- Remoll simulation of test setup: 77 ± 2



Vertical orientation of lucite (i.e. how sensitive is the lucite to what we think pion signal looks like)

- Test bench measurements: in progress (slower)
- Remoll simulation of test setup: 412 ± few



Simulation assumptions under evaluation: QE, eff ∅ PMT, n(λ), polish, etc

Number of p.e.s not critical to measuring asymmetry

Summary

Pion detector design has reached 100% (... in π/e p.e. ratio)

- Original design had to be modified because of showermax spray
- Rotated design has performance of 60% π/e p.e. ratio and better
- More inner radial shielding and lead donut improves to 100% π/e p.e. ratio
- Other studies not discussed:
  - Optimization of length/thickness of lucite/shielding
  - Radiation from dump at PMT (shielding from backside)
  - Radiation dose studies in progress by LATech
- Next steps:
  - Increased donut support: discussions ongoing with engineers
  - Support structure design: ideas under discussion with engineers
- Aim for 90% review by end of summer

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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.