Pion Detectors – ERR 2 July 2025

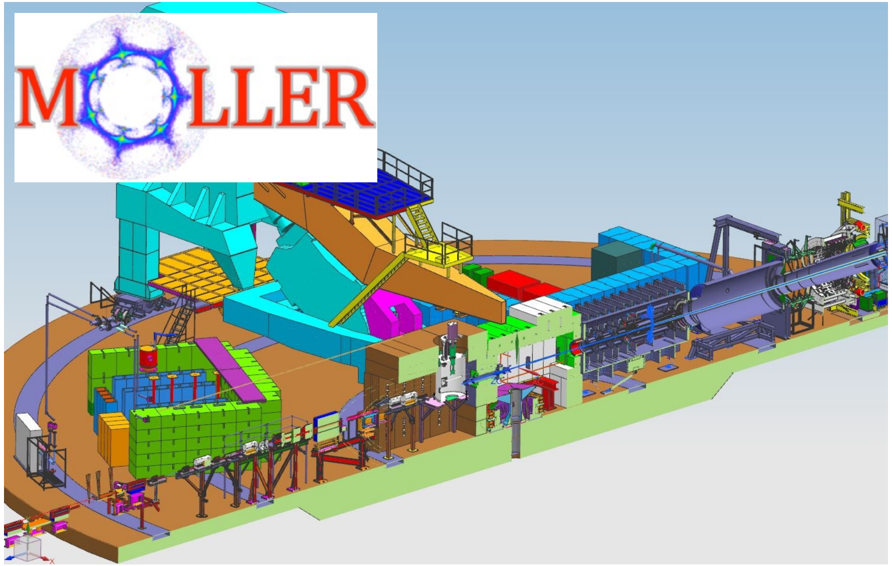
Personnel

Pion background determination

System overview

Prototyping

Summary & To Do



David Armstrong William & Mary

July 30 2025

Personnel

- Wouter Deconinck, U. Manitoba
- Elham Gorgannajed, U. Manitoba
- Jie Pan, U. Manitoba
- David Armstrong, W&M
- Kate Evans, W&M
- Tasneem Raza, W&M
- Simona Malace, JLab

Pion Detectors – Background evaluation and subtraction

Committee questions:

"How is the pion background evaluated and subtracted?"

"Does the pion detector meet the needs to implement the pion background subtraction?"

Answer: see next 6 slides

Note: the pion background for the Moller signal (Ring 5) is determined independently and subtracted separately from the multi-ring Moller/e-p/inelastic deconvolution procedure

Pion Background

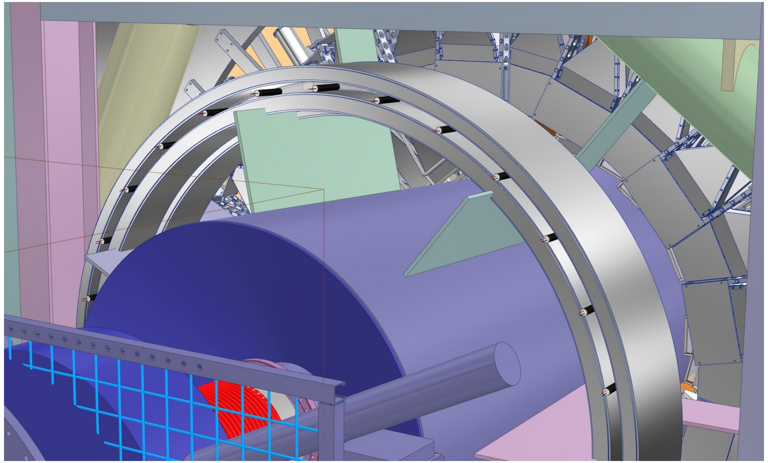
- Need to determine, for Ring 5,

  i) asymmetry: A_{PV}^{π}

  ii) $f^{\pi} = \frac{R^{\pi}}{R^{\pi} + R^{e}}$

- Estimate: f^{π} ~0.13% with A_{PV}^{π} ~500 ppb

  Need to determine $f^{\pi} A_{PV}^{\pi}$ to 20% relative precision



- Range out majority of electrons with Pb absorber (donut)
- A_{PV}^{π} measurement from 20 MHz total pion rate over full azimuth
  - during main asymmetry data-taking
    - moderately radiation-hard integrating detectors

      ∴ Acrylic Cerenkov detectors

- f^{π} measurement of MIP pion signal during Counting-Mode data-taking (supplemented by ShowerMax, Ring 5, GEMs, Trigger Scintillators)

Pion Detectors: Integrating Mode data-taking

- 1 GeV forward-angle pions from 3 GeV beam have huge parity-conserving transverse asymmetries (~ 20 ppm) A_T^{π} (Qweak)*   ∴ Full azimuthal coverage
- Measure separately in open (5-8 GeV), closed (3-5 GeV) and transitions sectors to get handle on pion energy dependence of A_{PV}^{π}

  ∴ 28-fold segmentation (matches ShowerMax segmentation)
- Pion flux:

  GEANT 4/Wiser model: $2.0\times10^{-5}\,\frac{\text{GHz}}{\mu A}/\text{detector}$ (over 28 detectors) = 24 MHz total at 65 μA
- ~ 0.8 MHz/detector   (28 detectors)
  - δA_{π} = 0.83 ppm/day →

    100 ppb (20% relative to expected asymmetry) in 60 days
  - Use same ADCs as main detectors
  - Run continuously during main asymmetry measurement
  - Want > 20 PEs/pion, so asymmetry width not significantly broadened by detector resolution

    Prototype: 65 PEs/per cosmic muon

*Phys. Rev. C 101 (2020)055503

Pion Detectors – Integrating Mode signal

- GEANT 4 simulation indicates π/e ratio of photoelectrons in pion detector = 1.07. *Why?*
  - Copious flux of few-MeV e^-, e^+ and γ's from tail of ranged-out Moller shower, a few of which each make 1 or 2 PEs

    +

  - Relatively smaller flux of π^-/μ^-, each of which generates 60 PEs*

- Need to correct measured asymmetry from pion detectors for Moller asymmetry to get A_{PV}^{π}

- Check π/e ratio of photoelectrons in pion detector with counting mode data

$*$ μ^- are from π^- decay, for our purposes can treat as π^-

Pion Flux measurement

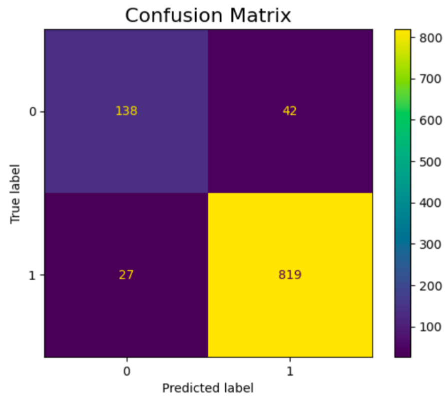
- Determine f^{π} in thin quartz detectors in Counting Mode:
  - Trigger on pion detector signal.
  - see MIP in Shower-max:

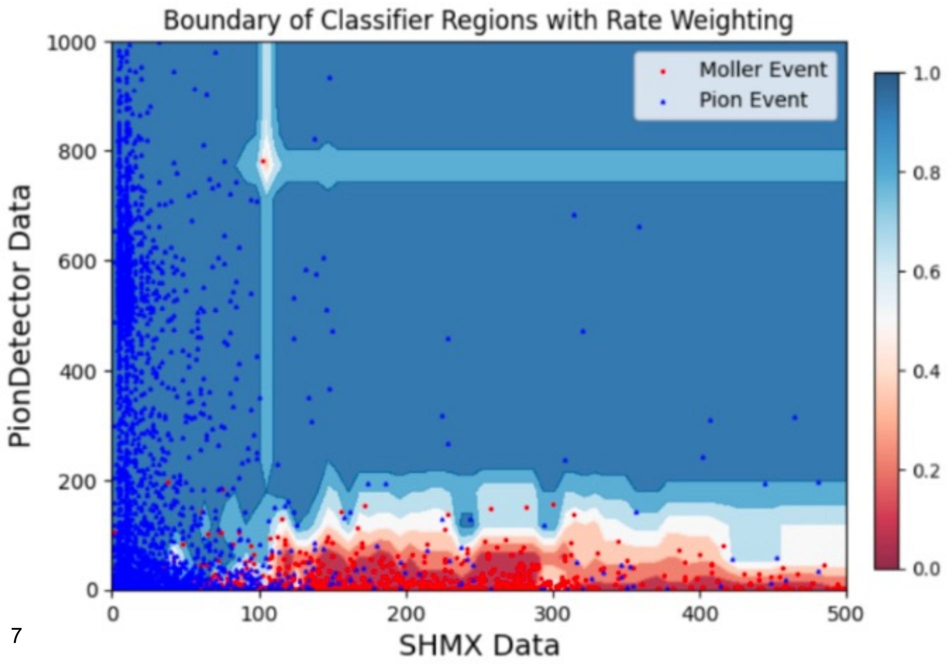
    Software requirement: (Tracking GEMs)·(Tracking Scints)·(thin quartz)·(ShowerMax MIP)·(Pion Detector)

- GEANT 4 simulations

  + MLL (Random Forest Classifier)

  correct identification score: 95.1%

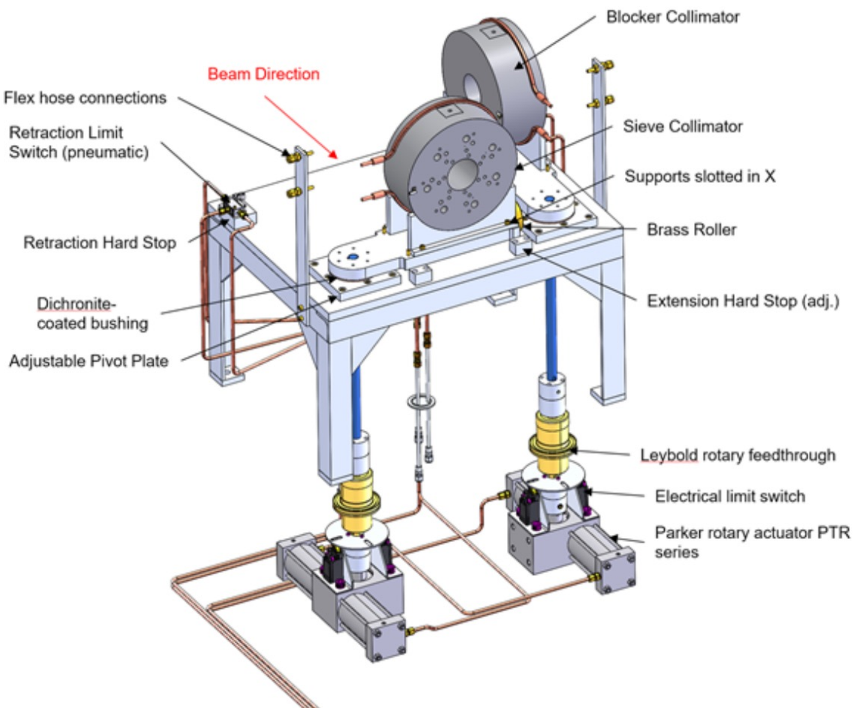




Pion Flux measurement – Blocker enhancement

- Additional mode to verify response of Pion Detector and Shower-max to pions:
  - insert Blocker collimator (20 X_0 W/Cu)
  - Suppress π^- flux at main detectors by $\times 0.55$
  - Suppress e^- flux at main detectors by $\times 10^{-4}$
- Shower-max signal: roughly equal mix of π^-/μ^- and e^-
- Pion Detector: essentially pure π^-/μ^-

- Not yet studied in detail in simulation



Pion Detectors – Radiation tolerance

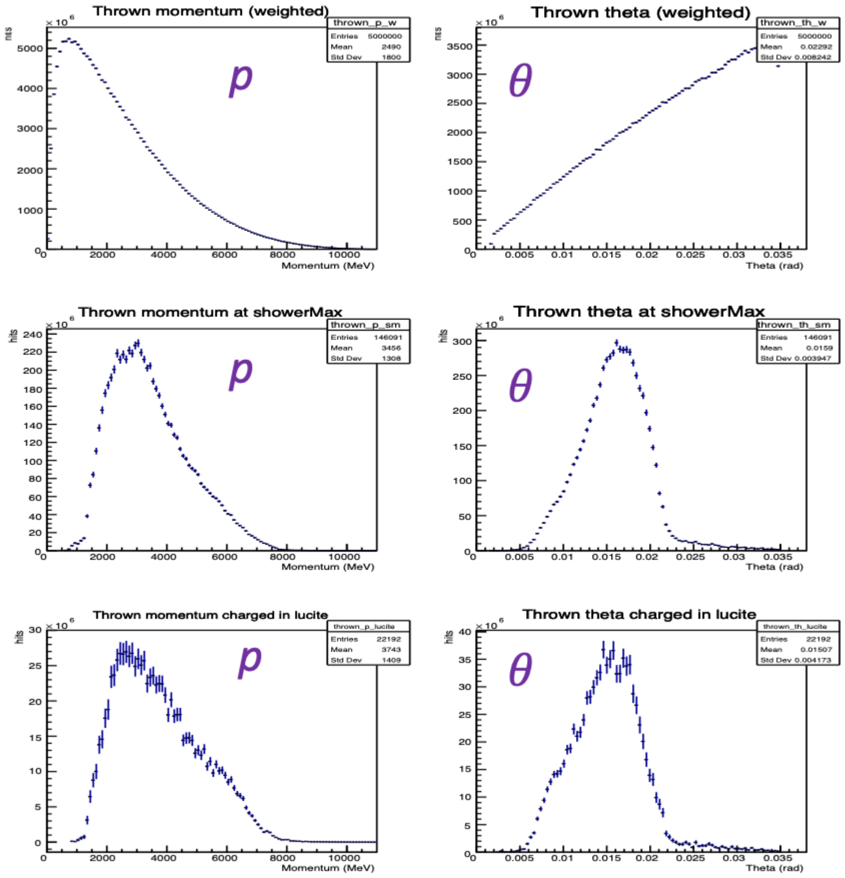
Committee question: "*Has the radiation tolerance of the pion detectors been demonstrated over the full experimental run?*"

Answer: The simulated total dose (integrated over full run) to pion detectors 200 kRad
(remember – detectors well-shielded inside pion donut)

Literature: UVT acrylic optical properties good to >1 MRad.

HAPPEX-I both HAPPEX-3 used the same pair of acrylic detectors, no degradation seen in light output at end of HAPPEX-3.

Pion Detector: Fair sampling of pion kinematics?

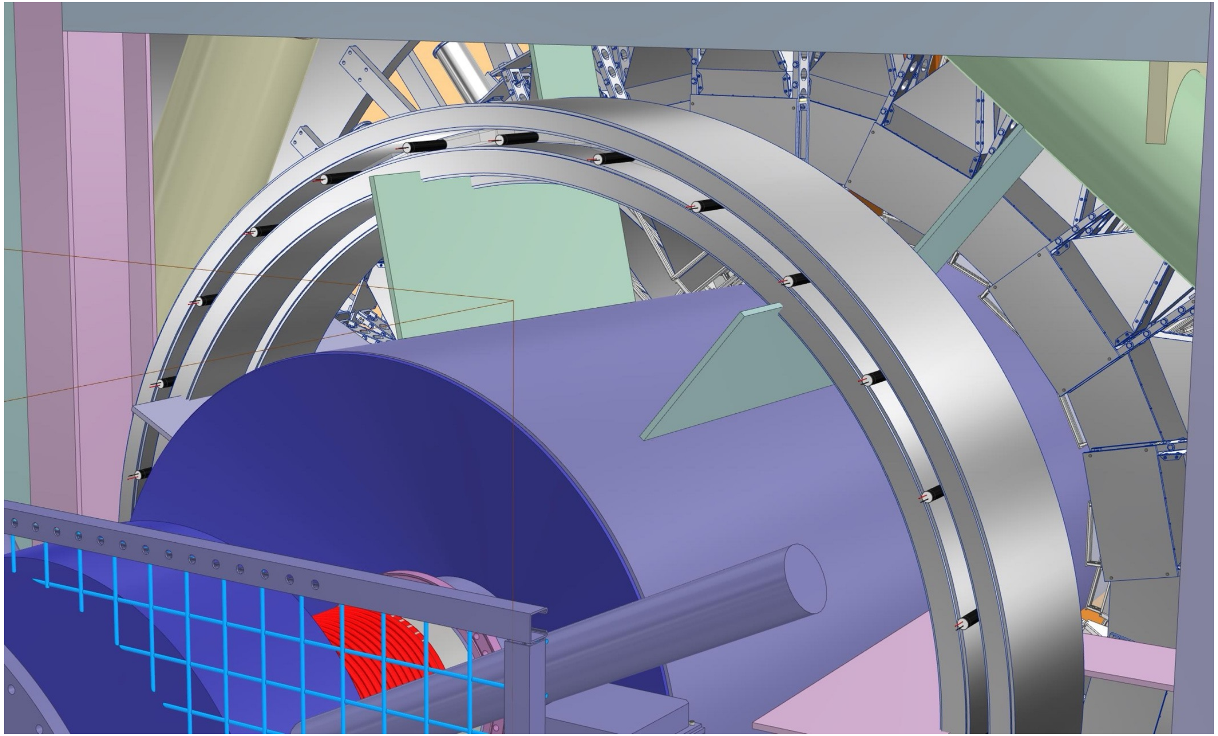


Thrown Kinematics (Wiser model)

Kinematics seen by Ring 5 & ShowerMax

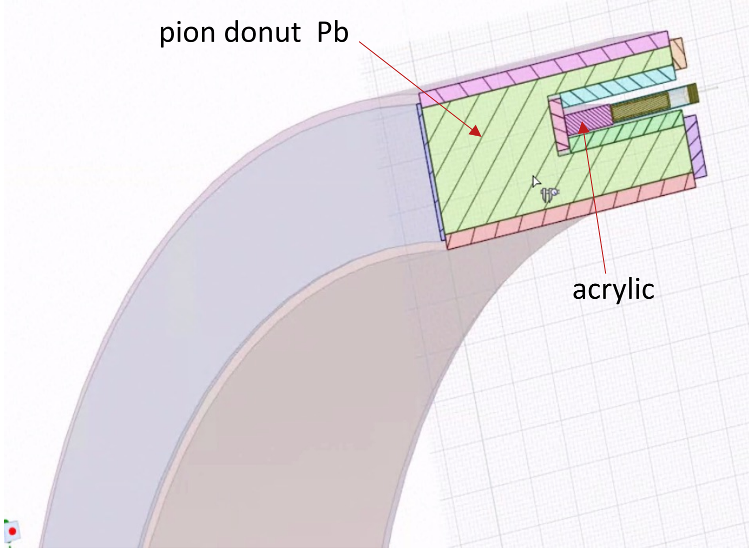
Kinematics seen by Pion Detectors

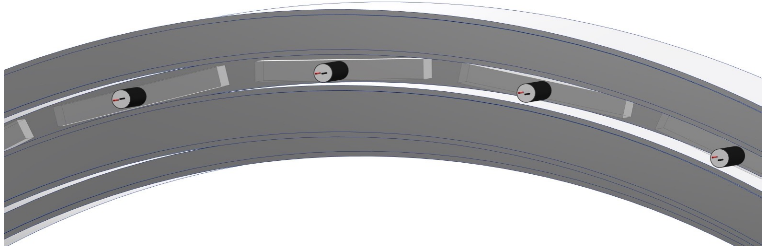
Pion Detector – system overview



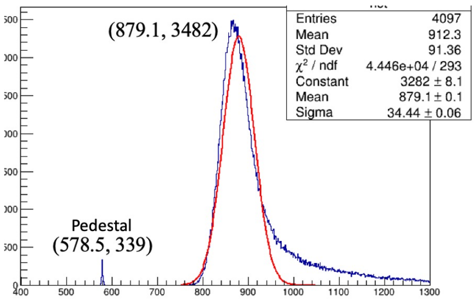
- 28 identical acrylic detectors (7 cm deep, 21 cm wide, 1” thick)
- Read out via 1” diameter directly-coupled PMT at rear (no lightguide)
- Encased in Pb donut

Pion Detector





- $45\ X_0$ in direction of scattered Moller electrons
- π/e ratio of photoelectrons in pion detector = 107%
  (design goal: > 50%)
- simulated light yield: > 50 pe's/pion
- loose tolerance (±5 mm) on location of acrylic



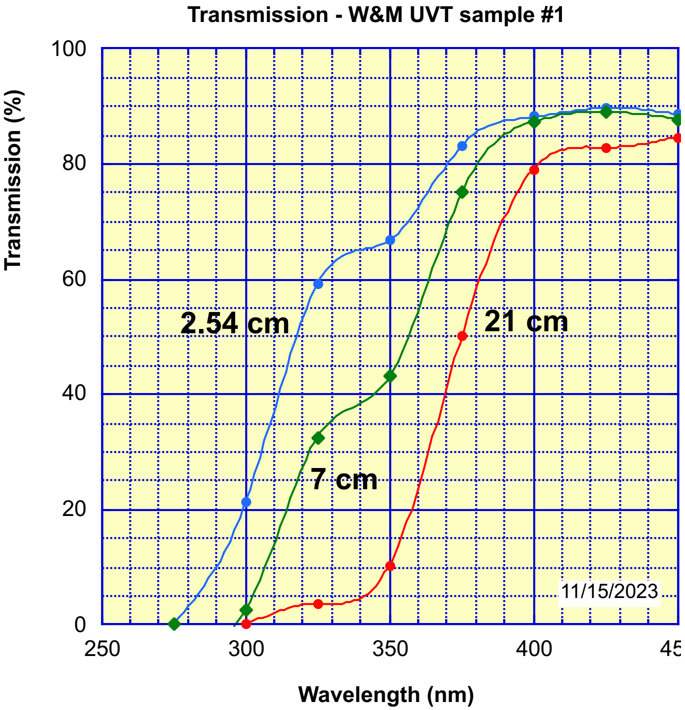
σ/peak = 11.3%

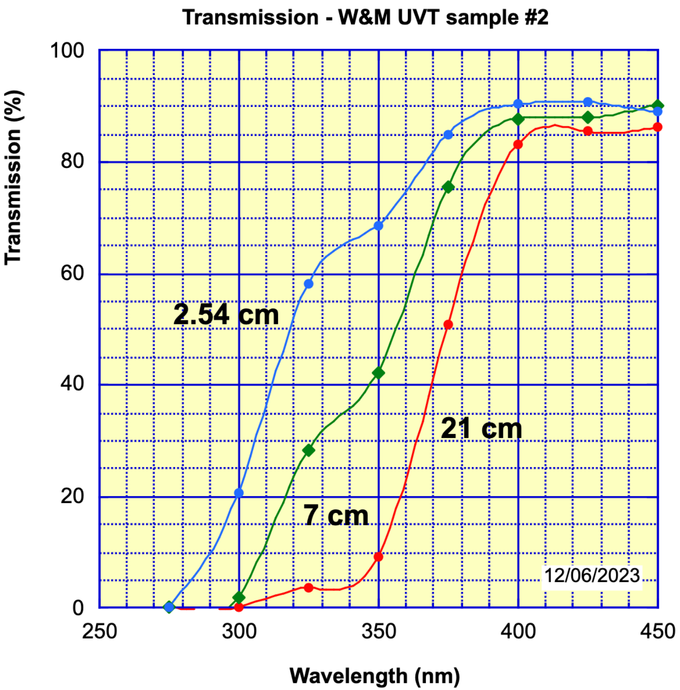
- Material selected: Eljen UVT acrylic
- Benchmarked GEANT4 optical response with electrons at MAMI/Mainz: Nov. '22
- Tested optical response using cosmic muons at Test Lab exceeded simulated light yield (see slides 16 and 17)

Pion Detectors – Acrylic

Eljen PMMA UVT acrylic
Dimensions: 21 cm x 2.54 cm x 7 cm.
Diamond-milled edges. As-cast faces.

Optical transmission verified (Carl Zorn).
Matches what we have been using in our simulations.



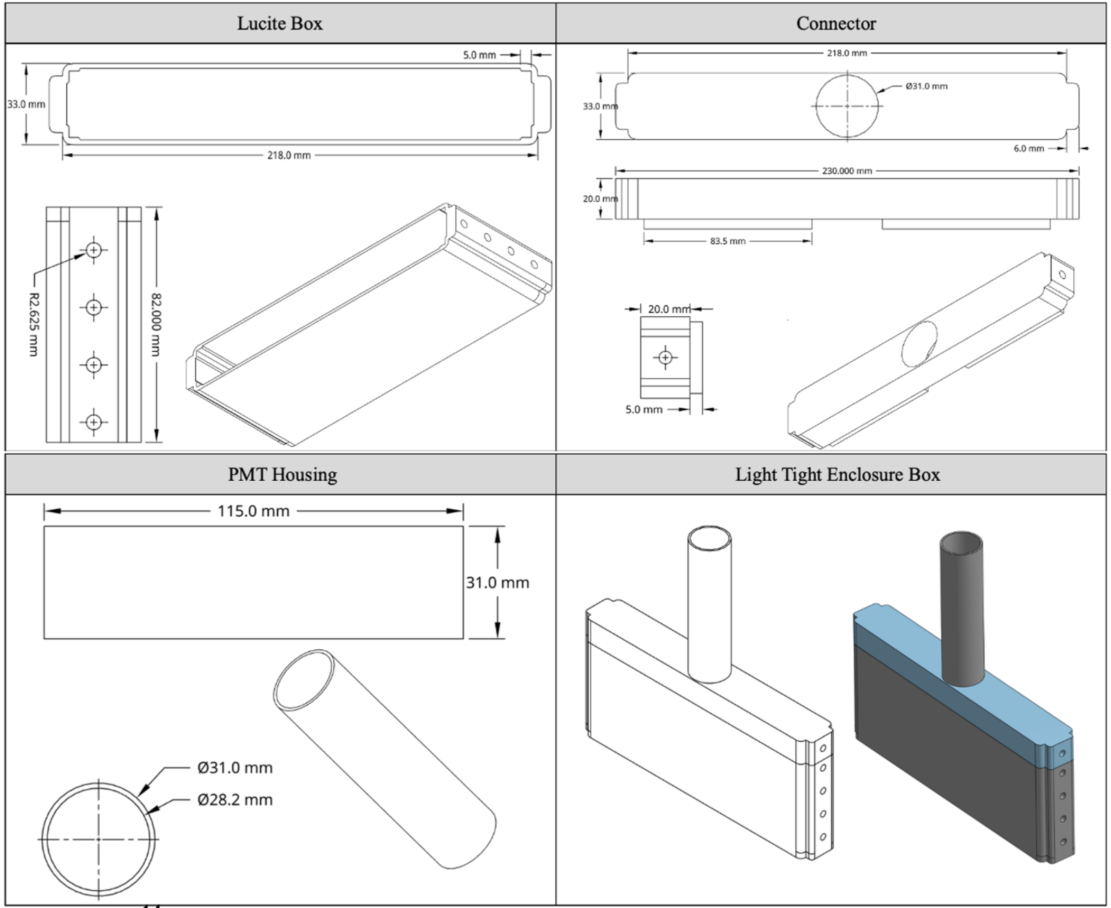


Pion Detectors – Light Tight housing

3D-printed light-tight housing design

- Elham Gorganazed

Prototyped at U. Manitoba

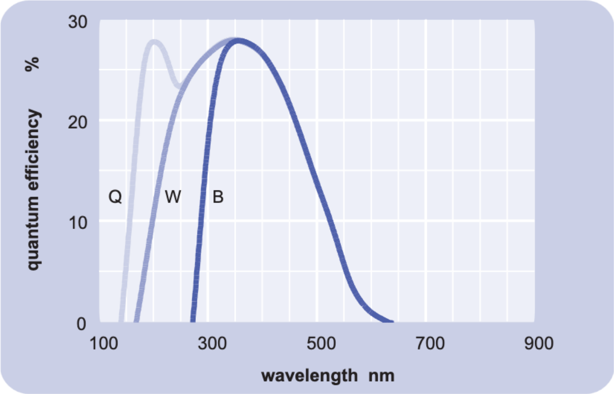


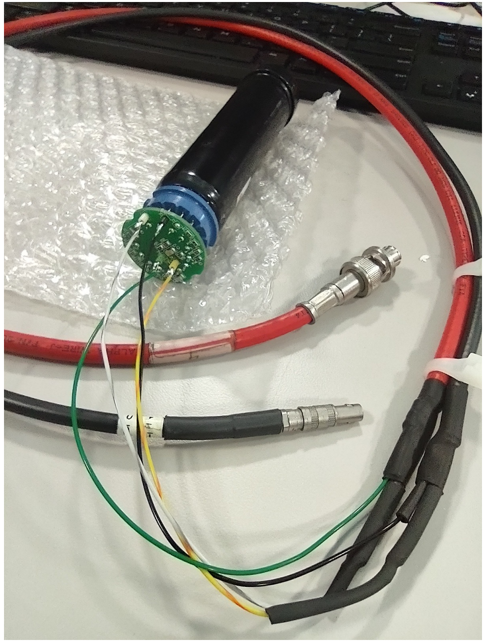
Pion Detectors – PMTs

The ET 9125BQ

29 mm (1.13") diameter, blue-green sensitive bialkali photocathode

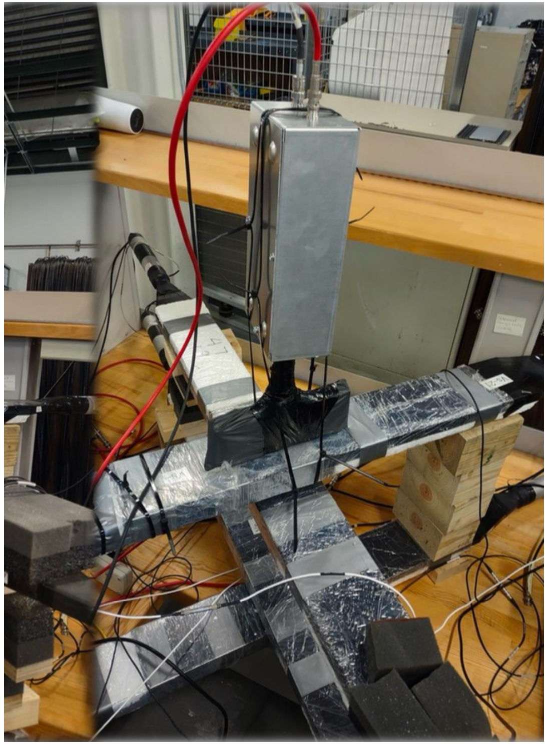
11 high gain, high stability, SbCs dynodes of linear focused design.
Photocathode active diameter: 1”

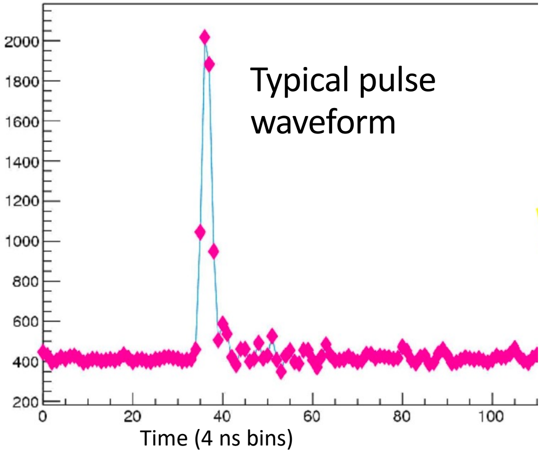


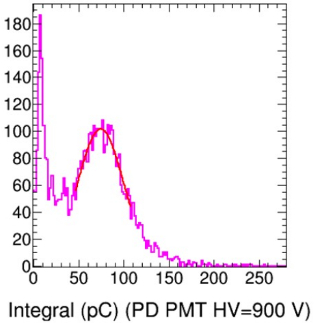


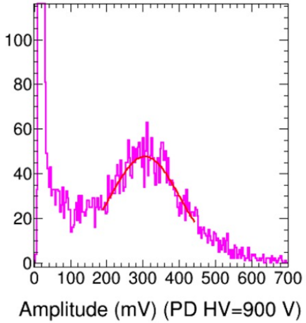
Prototype PMT
with temporary HV divider
(initial testing)

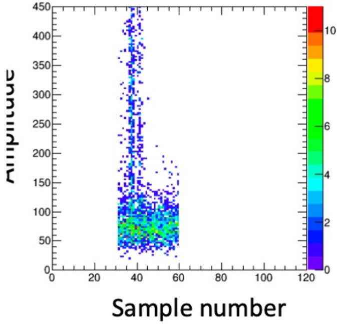
Pion Detector – Prototype testing with cosmics









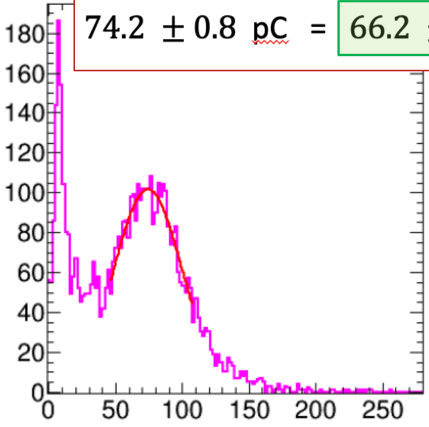


Pion detector prototype
- Acrylic and PMT: as designed
- *not* final detector enclosure
- *not* final PMT base (commercial base)

- 4 scintillator paddles stand at JLab
- Detector read out via fADC250, VTP trigger (same as for counting mode in experiment)

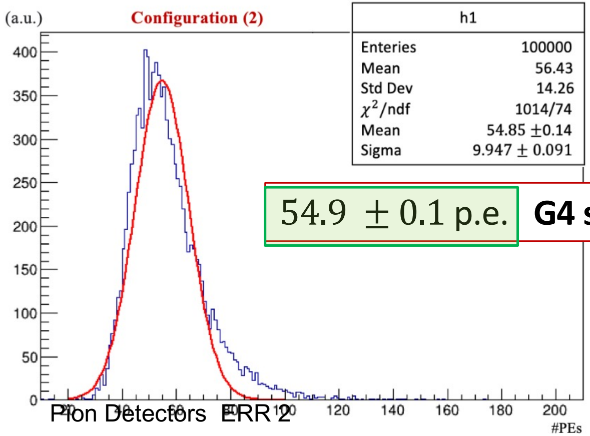
Pion Detector – Prototype: cosmics vs. simulation; status

74.2 ± 0.8 pC = 66.2 ± 0.7 p.e. **Prototype**



Our acceptance criteria: > 30 pe

- Acrylic, PMTs, base sockets: all procured
- PMT Q/A testing: about to start
- Prototyped 3D-printed enclosure
- Prototyped PMT base/HV divider, fast amplifier
    - testing underway
- All assembled detectors to be cosmic tested



54.9 ± 0.1 p.e. **G4 simulation**

Acrylic modules

Prototype fast amplifier

Prototype base/divider

Pion Detectors – PMT Base & amplifier

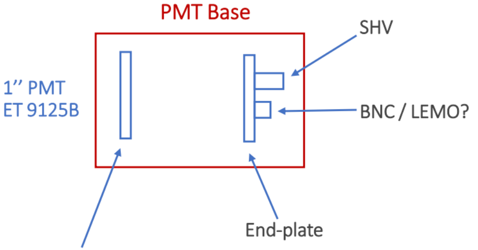
Unlike Main Detectors, ShowerMax, and other auxiliary detectors, we don't need to switch the number of dynode stages read between integrating mode & counting mode operation – simply change the HV. Use 9 stages.

Still need to switch between I-to-V and the $\times 10$ Fast Amp

Integrating mode: 16 pA photcathode current
: need gain of 4×10^5
: HV = 800 V

Counting mode : need gain of 2×10^7
: HV = 1350 V

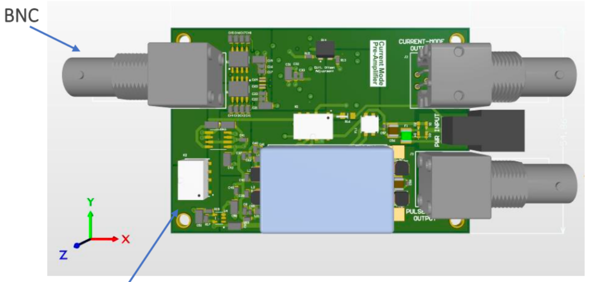
Switching Base Design for Pion Detectors



Voltage divider:

Current mode & Event mode - 10 /11 stages
(no switch needed on this PCB)

Dual-mode Amplifiers



Mode switching – I-to-V Amp / Fast Amp

Default gain for the fast Amp – x10

Use C637C parameters for voltage divider design?

12 voltage dividers

The standard voltage dividers available for all variants of this pmt are tabulated below:

	k d_1	d_1 d_2	d_2 ··· d_7	d_7 d_8	d_8 d_9	d_9 d_{10}	d_{10} d_{11}	d_{11} a
C637A	2R	R	-------------	R	R	R	R	R
C637B	2R	R	-------------	R	2R	3R	4R	3R
C637C	150 V	R	-------------	R	R	R	R	R

4

Have prototype pion detector base and prototype fast amplifier (Jie Pan, U. Manitoba) - testing underway.

Summary

- Acrylic, PMTs: procured
- Prototyped detector tested with cosmics

To do:

- Complete the testing of PMT base/fast amplifier, procure full run
- Production 3-D printing of detector housing
- Assembly of detectors (W&M)
- Cosmic testing in parallel with assembly (Test Lab cosmic stand)

Backup

Pion detector tests at Mainz

- Data taking at MAMI-B microtron Nov. 23 - 26 2022
- 855 MeV e^- beam, 5 kHz rate, pencil beam
- Commercial QDC readout (CAEN V965)
- 2 Acrylic detectors studied:

  Det. A: $3.8\text{ cm} \times 10.2\text{ cm} \times 30\text{ cm}$ with $1.5''$ PMT

  Det. B: $3.8\text{ cm} \times 10.2\text{ cm} \times 20\text{ cm}$ with $1.5''$ PMT

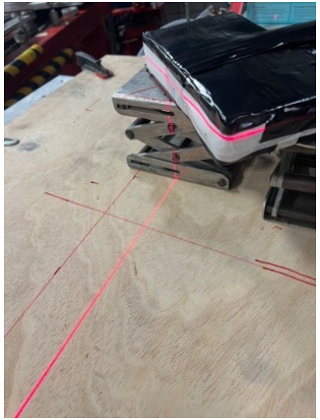
  c.f.   Design Pion detector:

  $2.5\text{ cm} \times 7.0\text{ cm} \times 23\text{ cm}$ with $1.0''$ PMT

  GEANT 4 scaling of photoelectron signal:
  Design/Det. B = 0.65

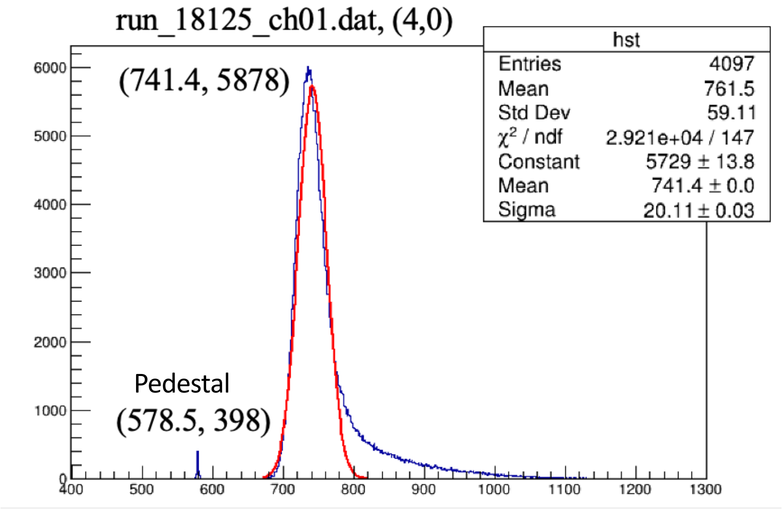
- Measured: detector response vs. position along detector width for both detectors, vs. high voltage, and at different incident angles. Still to do: calibrate PMT gain.

- Will use to benchmark the GEANT 4 simulations of optical response & compare to cosmic muon results.



Pion detector tests at Mainz – typical spectra

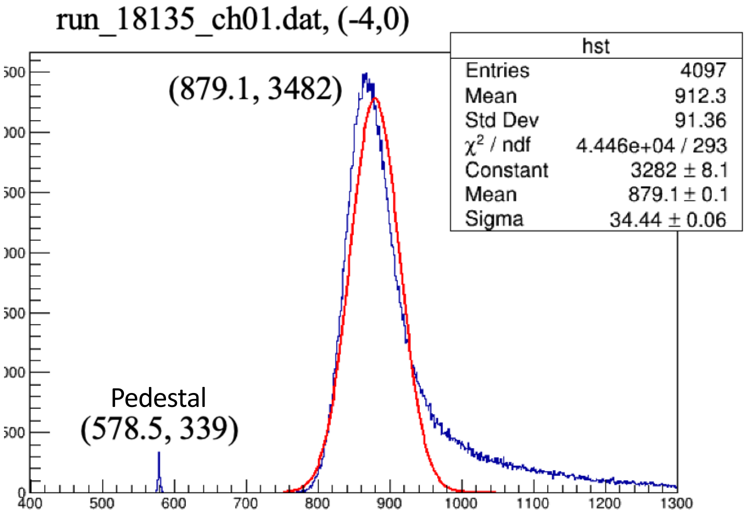
Det. A: 30 cm wide



σ/peak = 12.4%

Implied min. # pes (Poisson stats): 65

Det. B: 20 cm wide



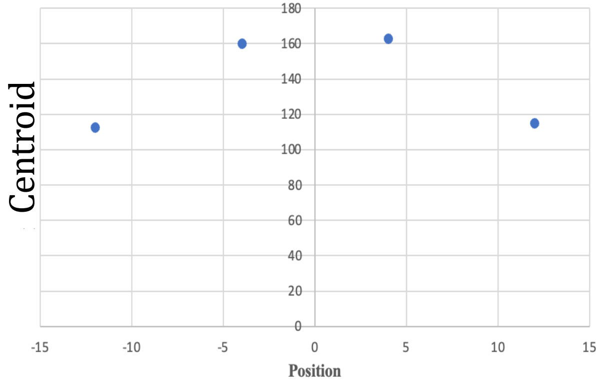
σ/peak = 11.3%

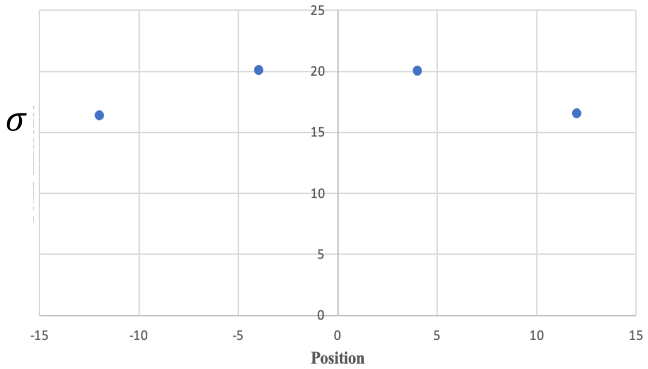
Implied min. # pes (Poisson stats): 78

Design goal: σ/peak < 25 %

Pion detector tests at Mainz

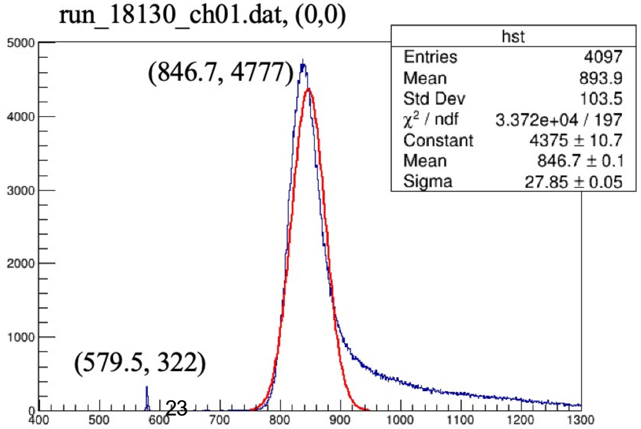
Variation of response across detector width: (Det. A)



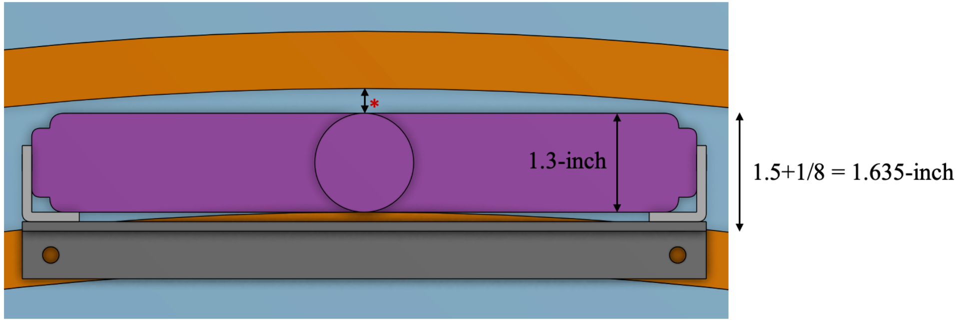


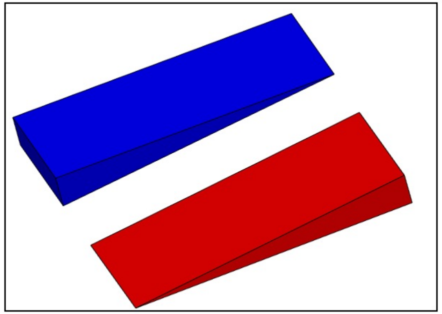
Response with beam directly incident on PMT: (Det. A)

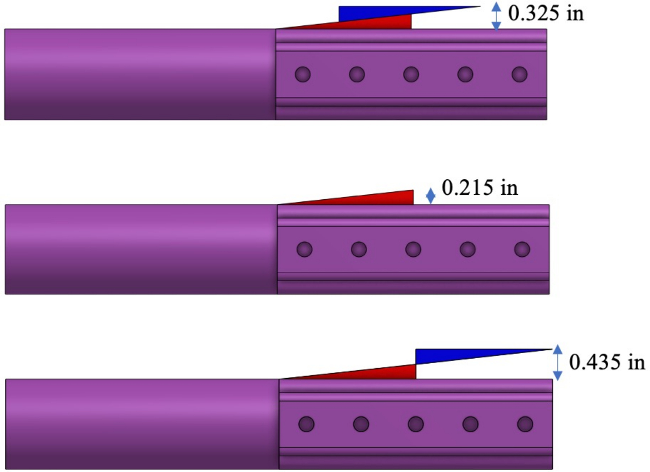
σ/peak = 10.4%



Pion Detectors – Insertion into Pion Donut

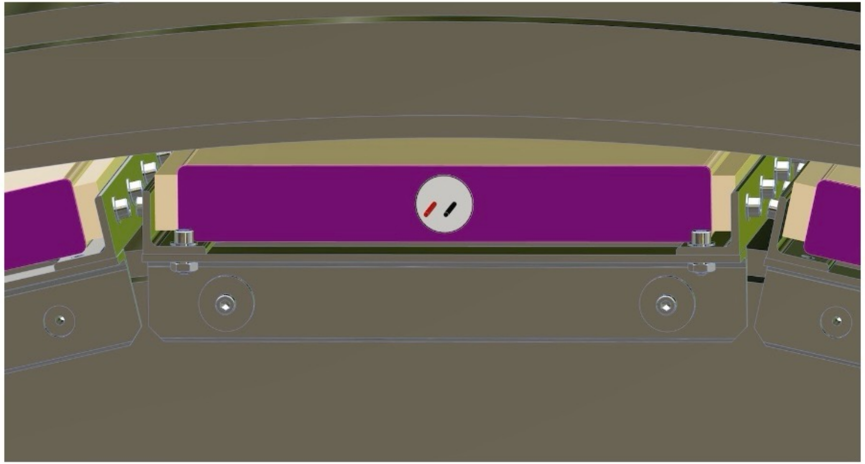






Plastic wedges to adjust detectors individually to fit.

Pion Detectors – Insertion into Pion Donut



Pion Detectors – Initial PMT testing

Gain vs. HV for ET 9125BQ
using single photoelectron response
(Simona M.)

Here, using all 11 dynodes & commercial high voltage divider. Matches vendor specs.