SAND2020-11894C

Overview

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- Neutron image concept
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  - single-bar measurements
- Position calibrations
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  - with muons
- Energy calibrations
- Conclusions

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Motivation

- Detection and imaging of neutrons
  - Special nuclear material detection
  - Nuclear waste handling
  - Fundamental particle physics
  - Astronomy

- Fast neutrons:

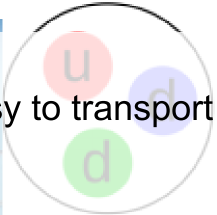
-Aren’t easily shielded.

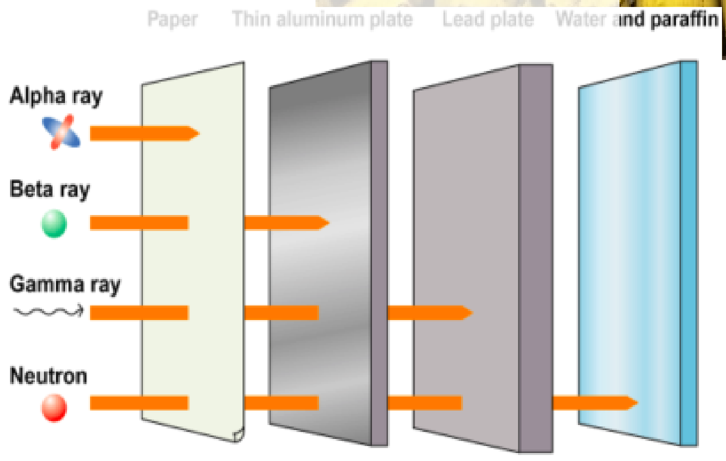
-Low natural backgrounds

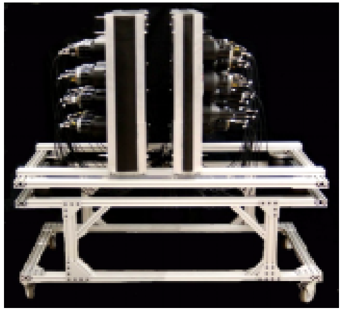
- Desirable:

compact imager, easy to transport and deploy, with a hig

efficiency.



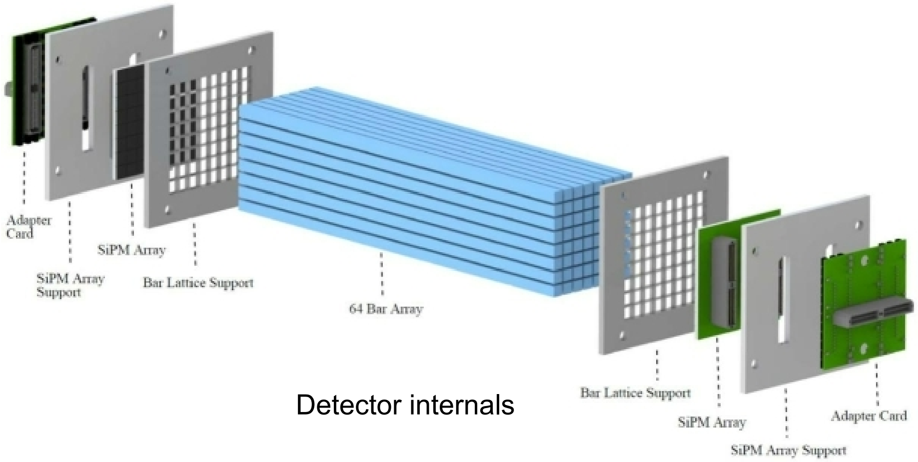




One of the first neutron scatter camera

Detector description

- 64 5x5x200 mm^3 bars of EJ-204 plastic scintillator material, wrapped in Teflon
- Two SensL J-series 6x6 mm^2 silicon photomultiplier (SiPM) arrays
- Customized DAQ, which uses 16 IRS3d ASICs, developed at UH



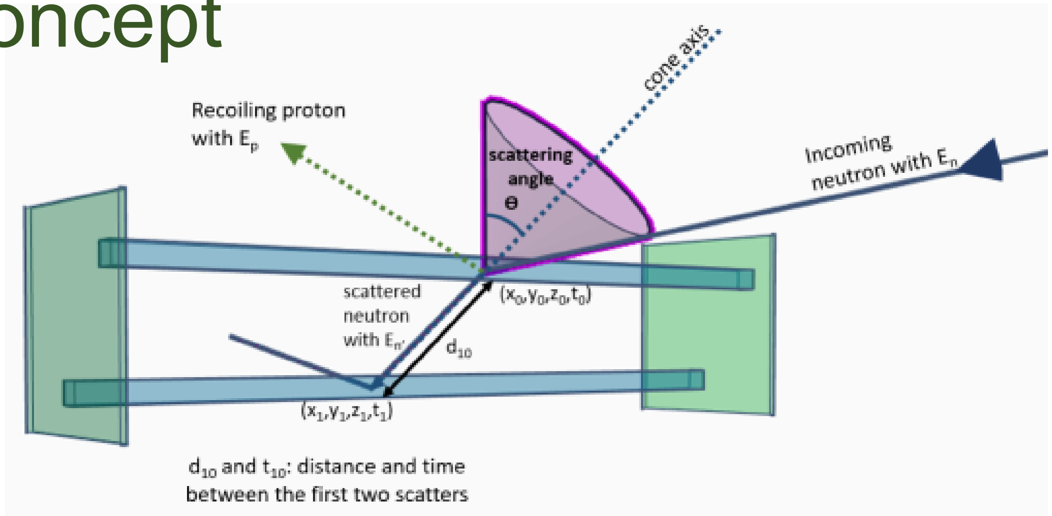
Detector internals

IRS PARAMETERS

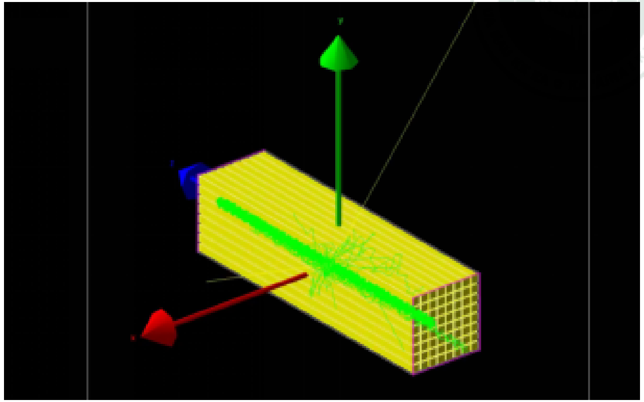
Parameter	Table Column Head
Channels	8
Sampling cells	128
Storage depth	32,786
Digitization	on-chip Wilkilson
Quantization	12(9)-bits logged (effective)
Dynamic range	~ 2 V
Typical noise	$\sim 1\ mV_{RMS}$
Sampling rate	1-4 GSa/s
Buffer time	(8-32)μs
Conversion time	>2μs


Disassembled OS-SVAC prototype

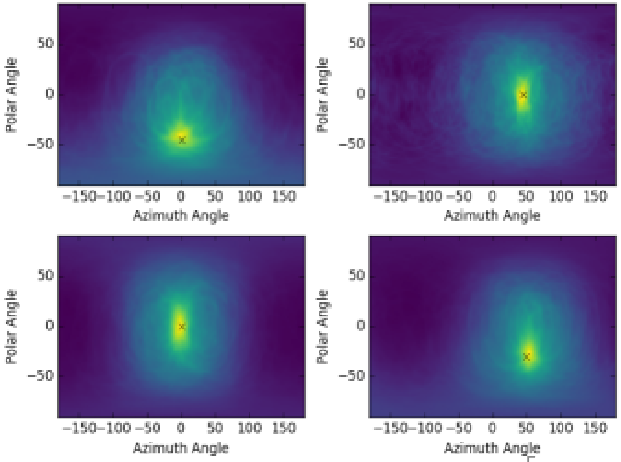
Double-scatter neutrons image reconstruction concept



Neutron double-scatter event illustration



Neutron double-scatter event simulation



$$E_n = E_{n'} + E_p$$

$$E_{n'} = \frac{1}{2} m_n v^2 = \frac{1}{2} m_n \left(\frac{d}{\Delta t} \right)^2$$

Direction reconstruction via cone back-projection accurately determines simulated source location:

$$\cos\theta = \sqrt{\frac{E_{n'}}{E_n}}$$

(NIM A doi:10.1016/j.nima.2017.11.025)

Single-bar measurements

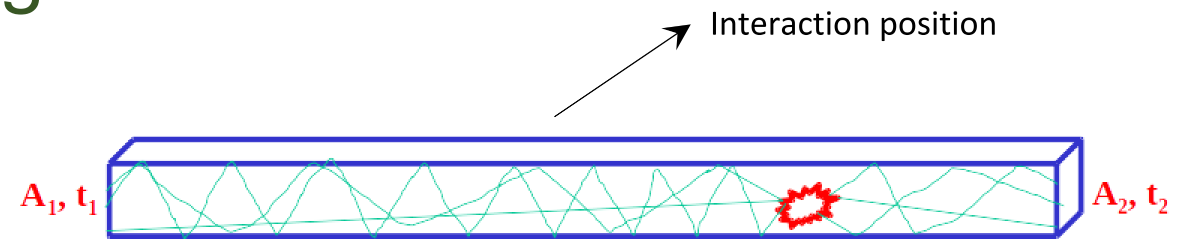


Illustration of a particle interaction in a bar

$$E \sim \sqrt{A_1 A_2}$$

$$t \sim \tfrac{t_1+t_2}{2}$$

$z \sim t_1 - t_2$ or $z \sim \log(A_1/A_2)$

$$\begin{aligned} t_1 - t_2 &= \frac{z}{v} - \frac{L-z}{v} \\ &= \frac{2z}{v} - \frac{L}{v}. \end{aligned}$$

$$\begin{aligned} \ln\frac{A_1}{A_2} &= \ln\frac{e^{-z/\lambda}}{e^{-(L-z)/\lambda}} \\ &= \frac{L}{\lambda} - \frac{2z}{\lambda}, \end{aligned}$$

Lineal, if λλ¿ vv re constants in the material

where:
A_i - Pulse amplitude
t_i - Pulse arrival time
λ- attenuation length
L - bar length
v - speed of light in the scintillator

Position calibrations

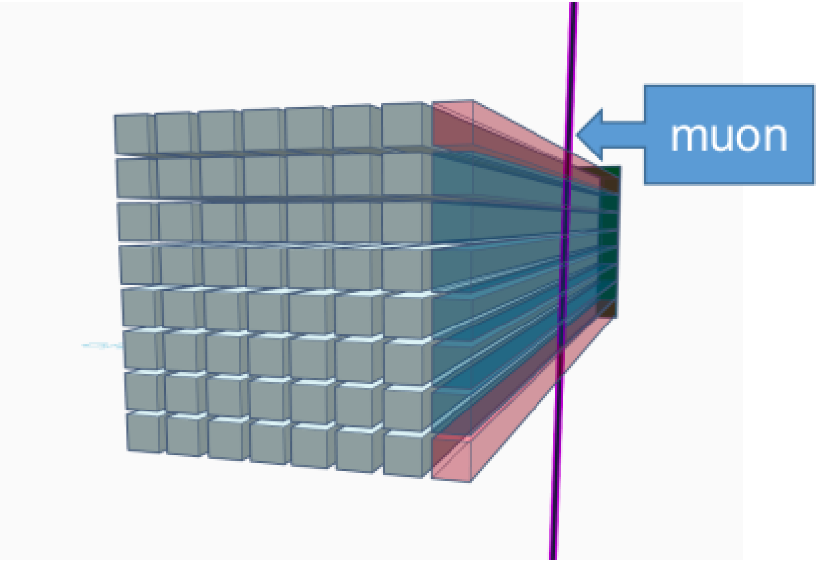
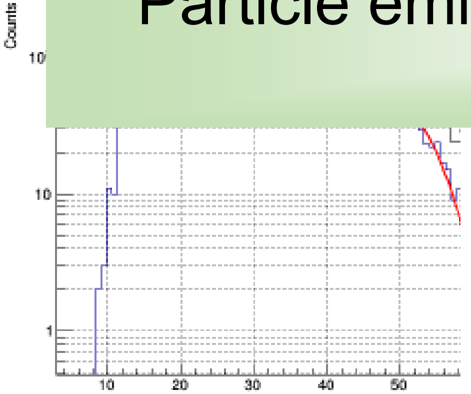


Illustration of a muon passing through a edge column of bars

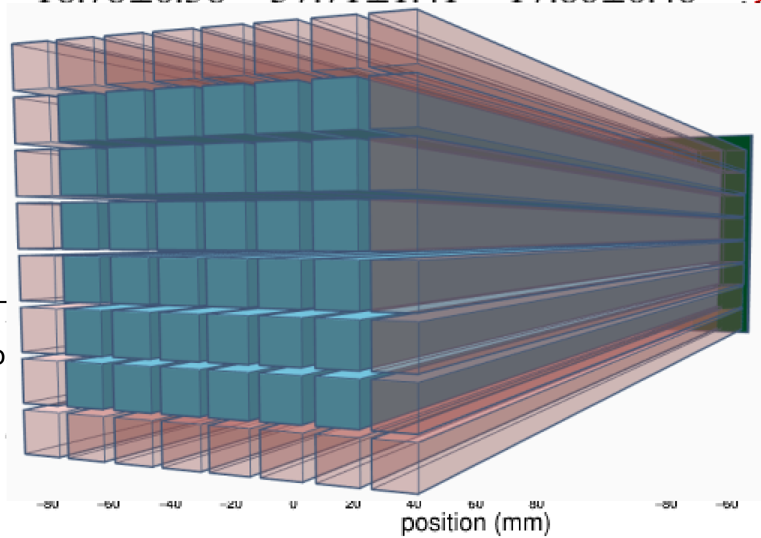
- To access inner bars, we set up the prototype as a “muon telescope”.
- The interaction position of the top and bottom bars were used to recreate the muon track.
- A single row of outer bars was calibrated with both, muons and particle sources, to verify the validity of the technique

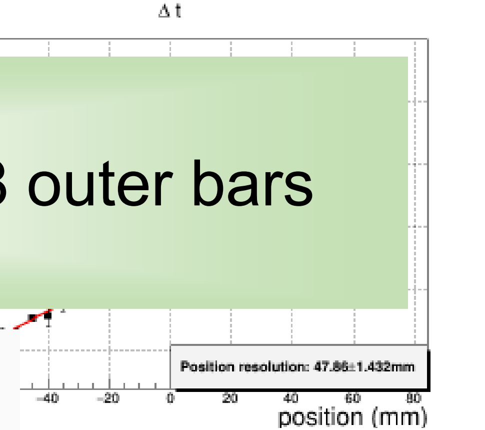
Calibration with particle emission sources

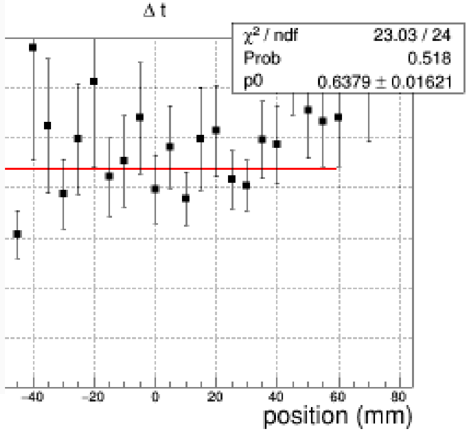
Particle emission calibration valid for the 28 outer bars



24	18.78±0.38	57.71±1.41	17.86±0.46
32			
40			
48			
56			
64			







Energy calibration example f

position resolution= $\frac{\sigma_{avg}(z)}{m(z)}$

Po

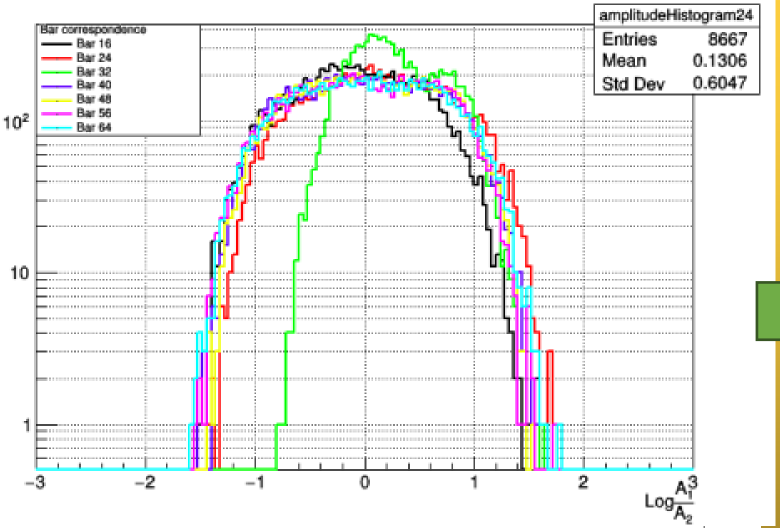
where $\sigma_{avg}(z)$ the average of the std-dev
and $m(z)$ slope value.

Calibration example for amplitude- and time-based position resolutions.

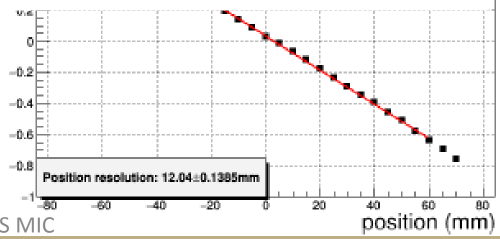
Position calibration using muons

Use the values from the slopes (particle source calibration) to obtain the interaction position of **top** and **bottom** bars

SOURCE CALIBRATIONS

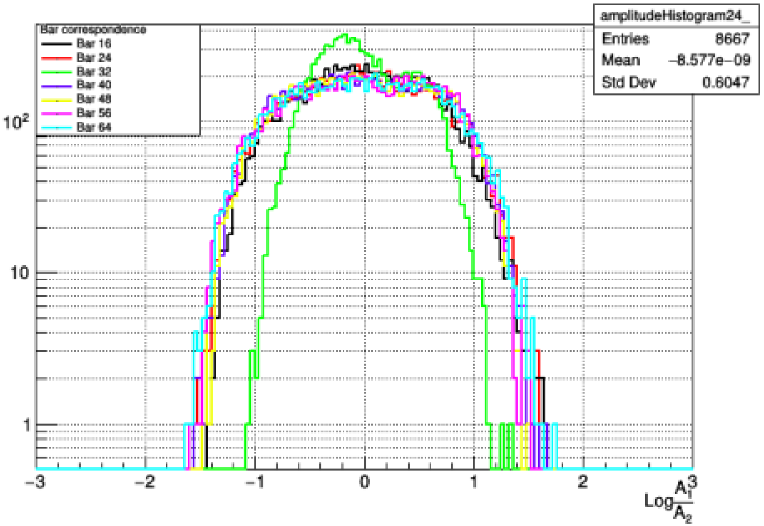


Log of the amplitudes ratio before align correction

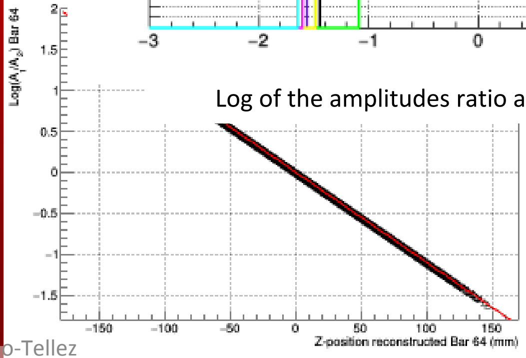


Amplitude-based position calibration from bar 64 (bottom)

MUONS



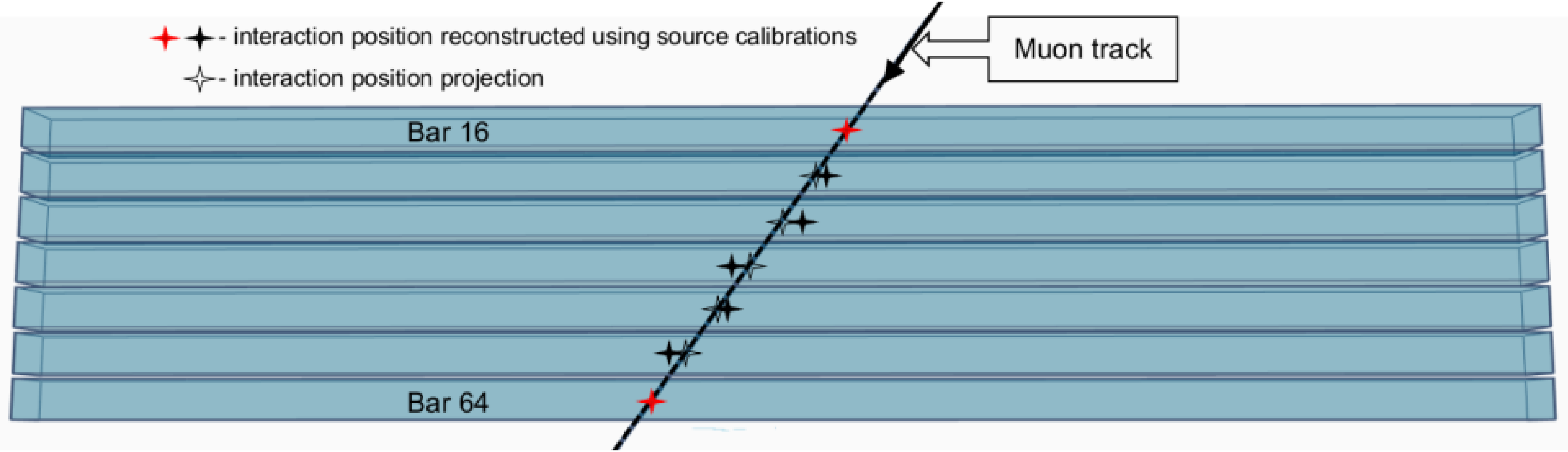
Log of the amplitudes ratio after align correction



Interaction position reconstruction using amplitudes for bar 64

Position calibration using muons

Utilize the two reconstruction points to fit a line and recreate the muon track. Interpolate for inner bars and relate the interaction position withe amplitude measurements



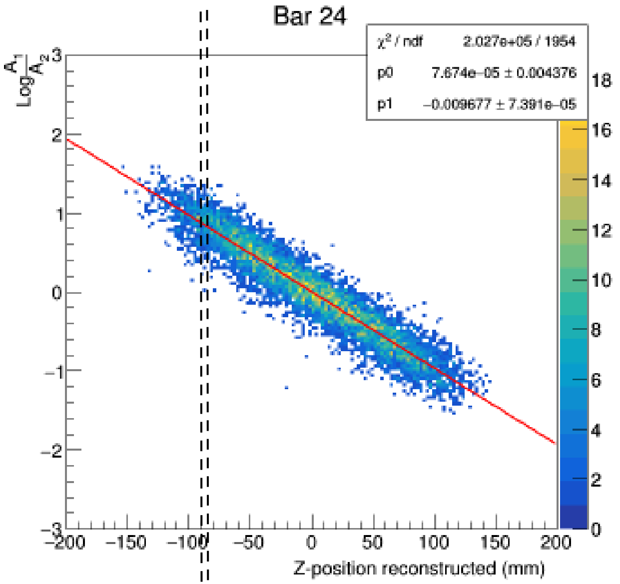
Position calibration using amplitudes

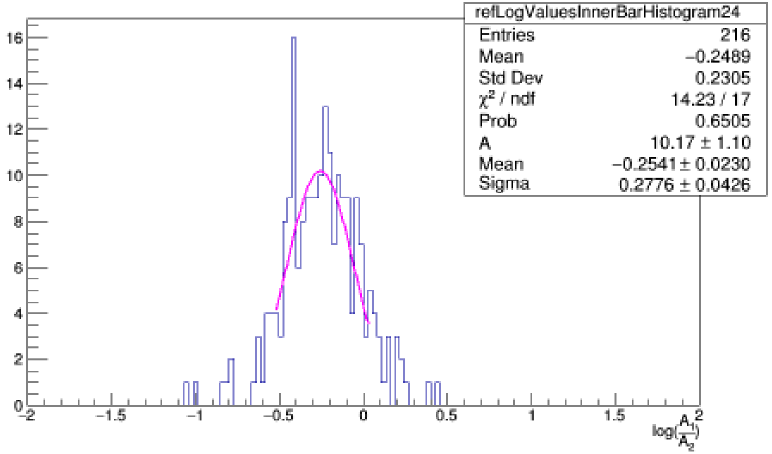
- Relate the reconstructed poisition and the log(A1/A2) measured values
- Group the reconstructed Z-position in bin size of 5 mm
- Obtain distributions of the log(A1/A2) values.

position resolution= $\frac{\sigma_{avg}(z)}{m(z)}$

where $\sigma_{avg}(z)$ the average of the std-dev and $m(z)$ slope value.

Relation between the reconstructed z-value and the log(A1/A2) for bar 24

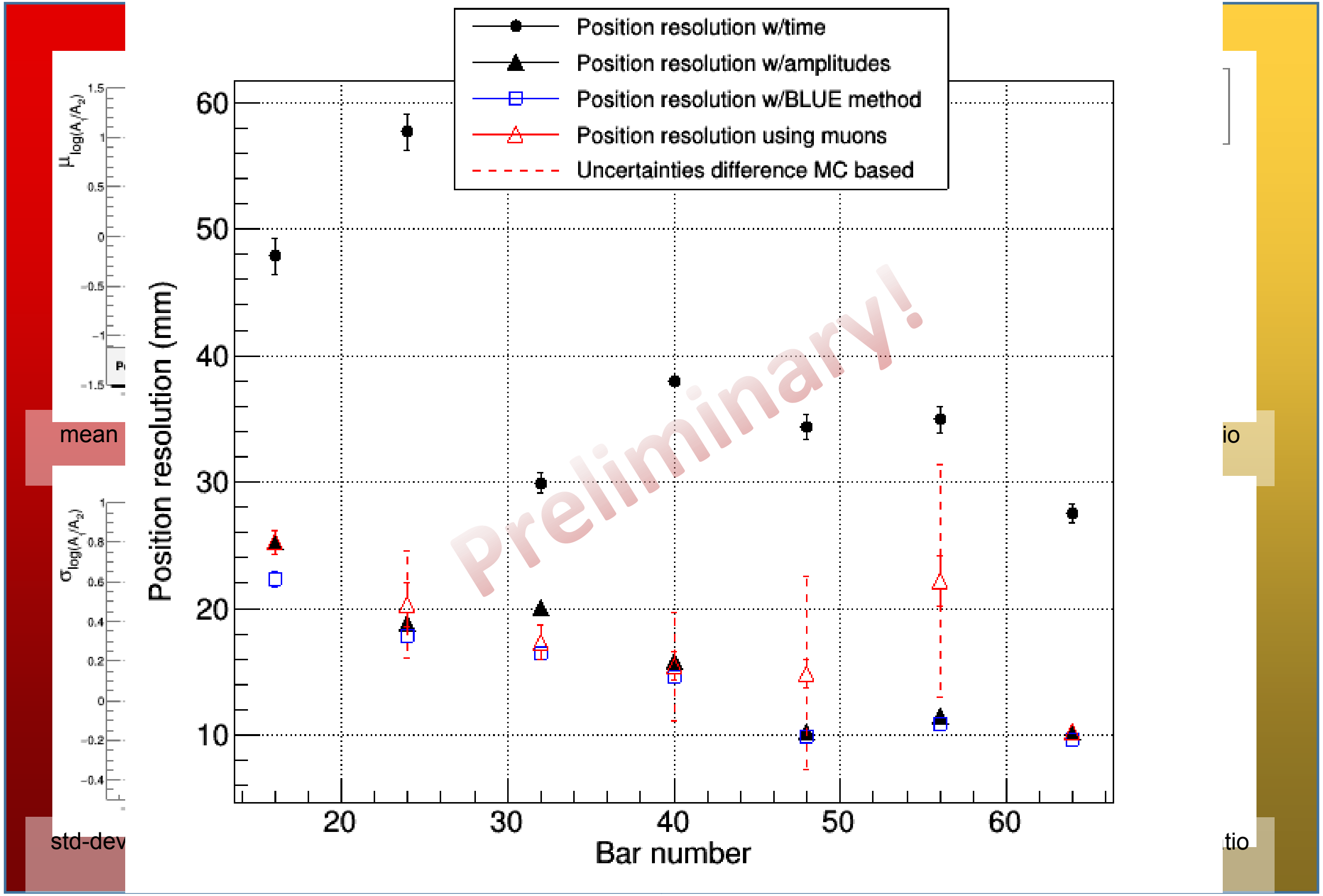




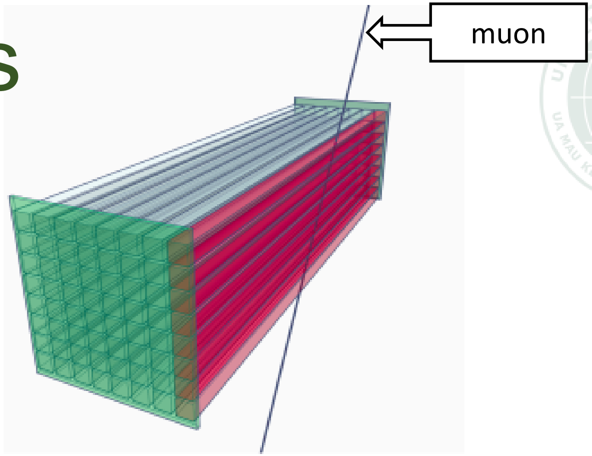
Distribution taken from a bin of the 2D histogram

Amplitude-based position calibrations

Generate plots of the mean and std-dev for each bar

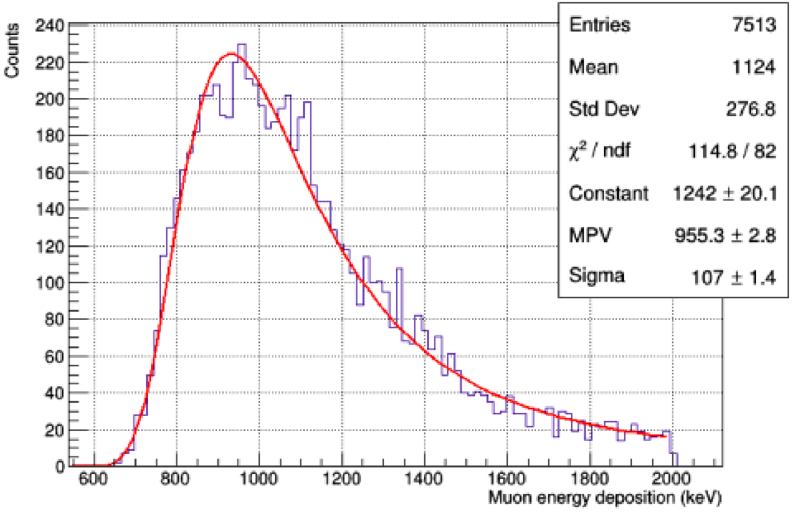


Energy calibration with muons



Muon acquisition

- The condition for the acquisition was to trigger the outer row of bars previously calibrated with the particle souces.
- ~8,000 muon events acquired
- Energy deposition obtained from each bar

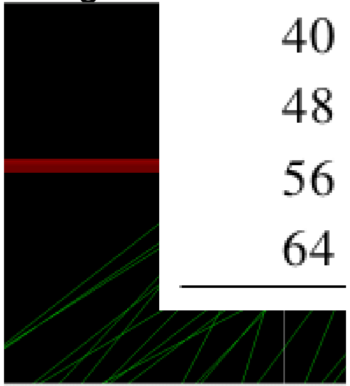


Muon energy spectra distribution for real data

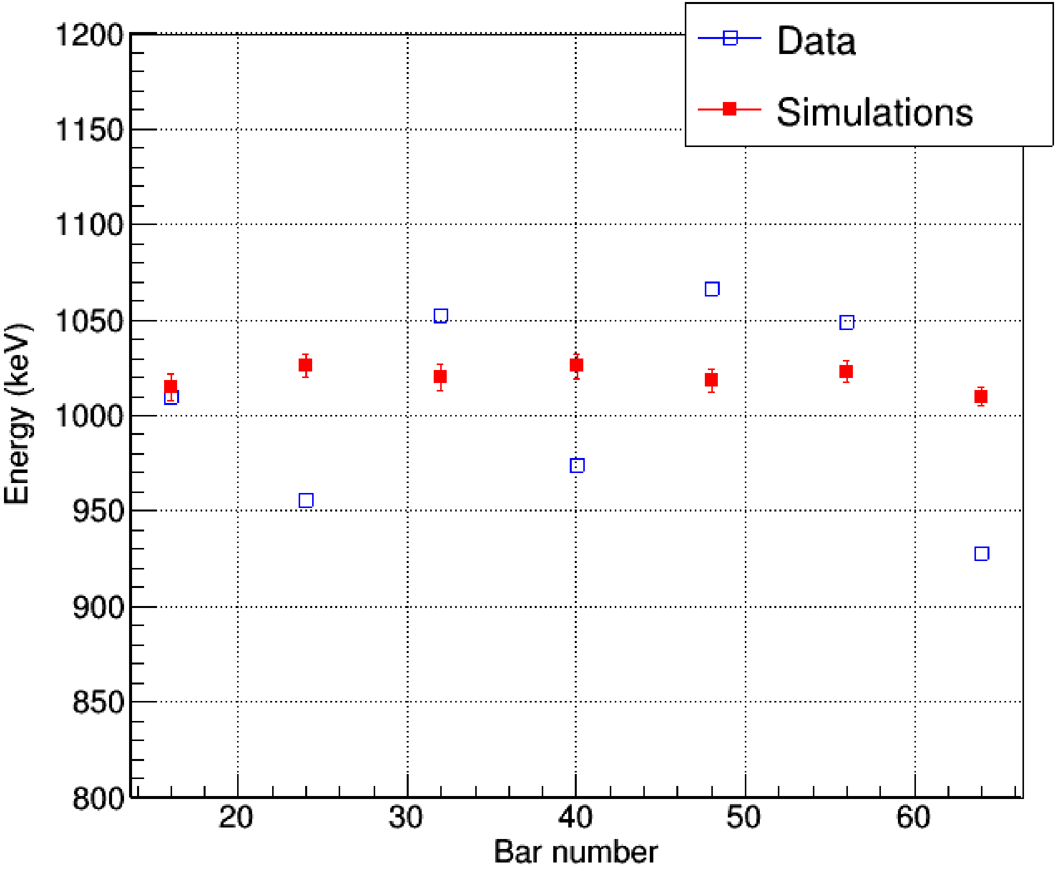
Energy calibration

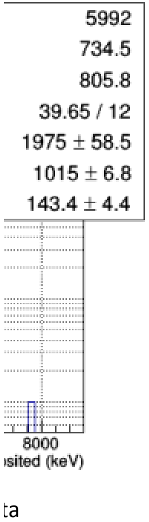
Muon si

- ~6,000
- random mm × 3
- 20 mm row.
- The inp version zenith a angle s



Bar numb		eV)
		ns
16		
24		
32		
40		
48		
56		
64		





Conclusions

- Position calibrations using particles are, in general, worse than the results obtained in previous investigations (doi.org/10.1016/j.nima.2019.02.063). It may be attributed to some factors.
- Degradation for position resolutions values for muons expected due to the spreading of errors from the pre-calibrated bars.
- Consistency found between the position resolutions using particles and muon methods indicate a promising path toward full detector calibration.
- Position resolutions when using particles reported an average of 16±0.18 mm, when using muons reported an average of 17.97±0.50 mm.
- Energy calibration measurements are in good agreement, with variations of 8% or lower.
- Time, energy, and position calibrations for the rest of the bars are undergoing.
- The lessons learned from this prototype motivated design changes for our next prototype, currently under construction.

The OS team

Thank you