Developing the Next Generation Neutron Detector

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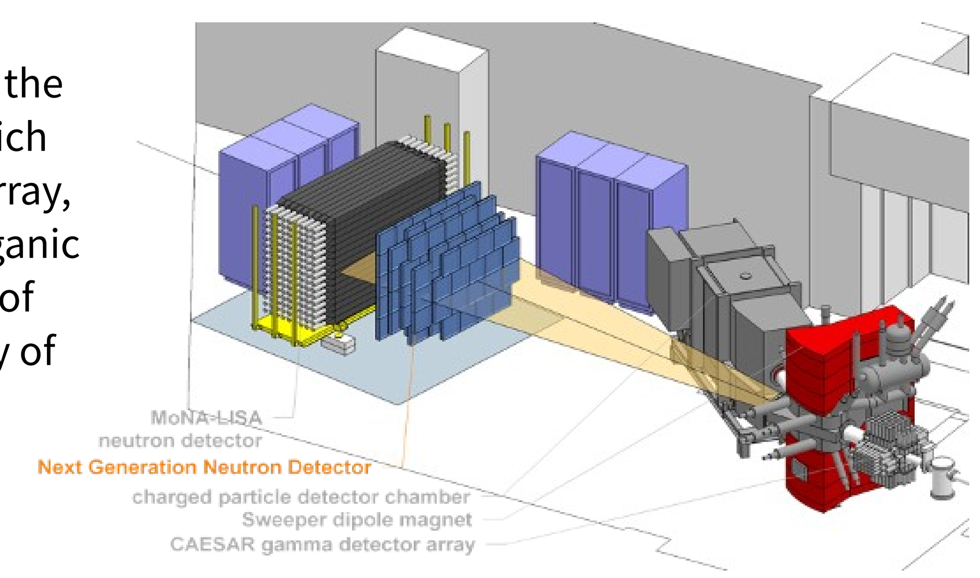
Introduction to MoNA

The Modular Neutron Array (MoNA) Collaboration studies the properties of exotic neutron rich nuclei using the MoNA-LISA array, which consists of 288 long organic scintillator bars for detection of neutrons resulting from decay of unbound states.

Decay energy resolution for unbound states is limited by detector resolution, σ = ~5 cm.

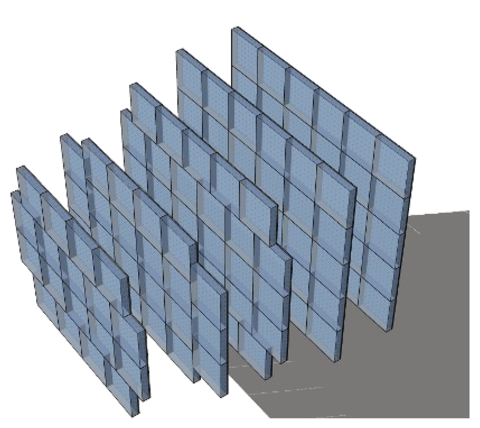


MoNA and NGn in S2 experimental hall at FRIB.

The Next Generation Array

In order to extend decay measurements to heavier neutron-rich nuclei at FRIB, higher neutron position resolution is needed. The proposed design of the Next-Generation Neutron array (NGn) will increase resolution from ~5 cm (MoNA) to ~1 cm (NGn), a factor of 5 increase in resolution.

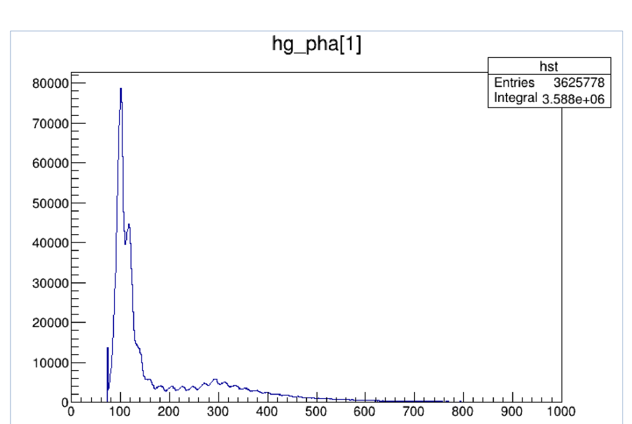
NGn will consist of 128 EJ-200 organic scintillator tiles each with dimension 32cm×32cm×2.5cm with 64 SiPMs distributed over one face of the plate to measure the light distribution produced by scattered neutrons.



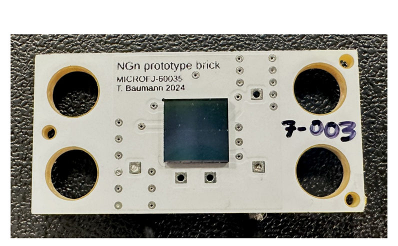
Proposed NGn tile design arranged in layers.

SiPMs and Prototype Detectors

We used 16 Onsemi FJ-60035 Silicon Photomultiers (SiPMs) to detect light intensity produced in the plate. These SiPMs have single photon detection capablities.



Typical cosmic muon energy spectra in a SiPM, exhibiting single photon peaks.



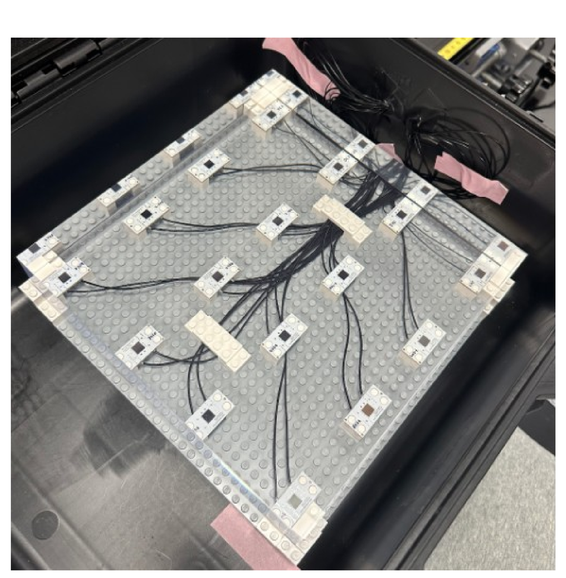
SiPM (4mmx4mm) mounted on a LEGO-ready PCB

I assembled 26 of these LEGO-mountable PC-board SiPMs at FRIB for use in our prototype detector testing.

We found that factors affecting light collection and position determination include:

- Scintillator plate area and thickness
- Whether SiPMs are mounted to the plate using optical coupling or an air gap)
- Reflectivity of the face opposite the SiPMs

High ***detection efficiency*** results from coupled SiPMS and high reflectivity on the plate backside. High ***position resolution*** results from uncoupled SiPMs and low plate reflectivity. Our goal is to find the right balance between these two.

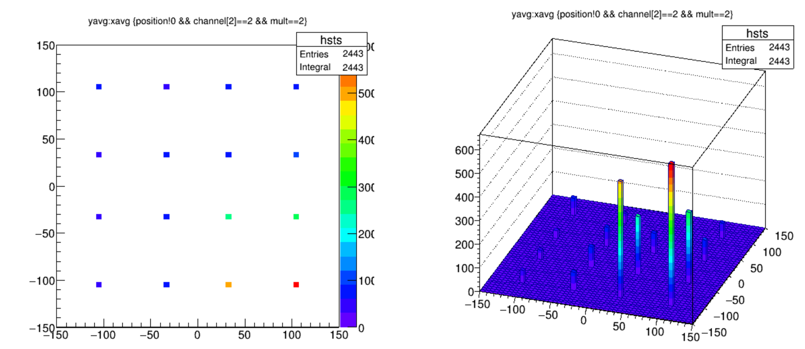


SiPM 4x4 array on a 24x24x5cm scintillator tile.

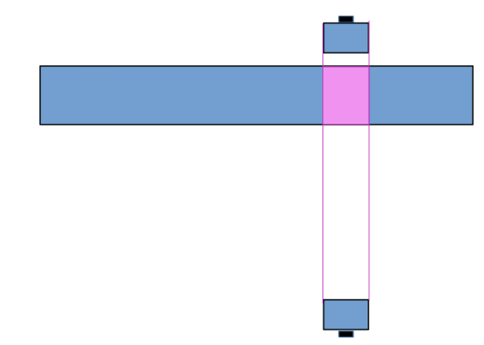
Position Reconstruction

Neutron scattering produces photons in the scintillator volume which propagate by critical reflection and trigger a subset of SiPM detectors. Our goal is to reconstruct event positions accurately using the SiPM signal distribution.

We began testing position reconstruction by illuminating the plate with a well-defined beam of muons using tracking detectors above and below the plate.



2D histogram of weighted x and y positions, showing the SiPM firing pattern in the vicinity of the muon-tracker beam.



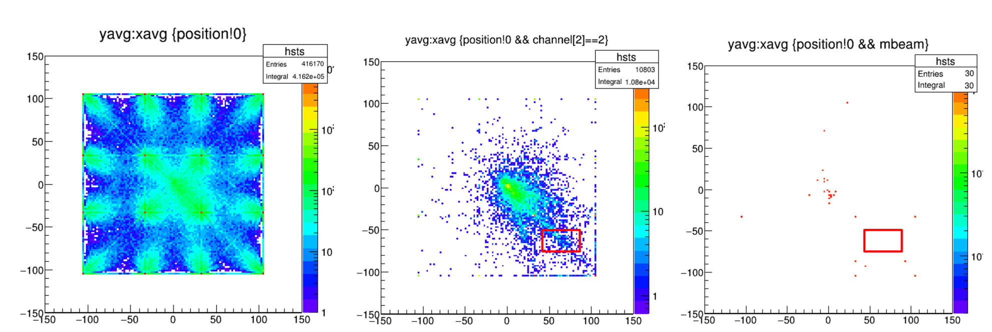
We test position determination using a localized muon "beam" obtained by filtering only on events that include both trackers placed above and below the plate.

We then determine event position using a weighted sum over all SiPMs:

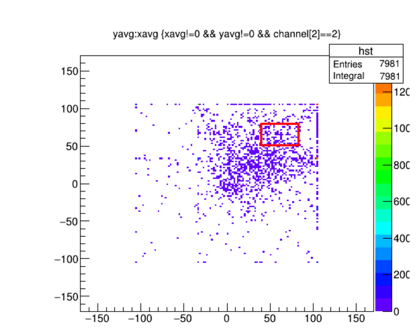
$$x_{event} = \frac{\sum e_i^p x_i}{\sum e_i^p} \qquad y_{event} = \frac{\sum e_i^p y_i}{\sum e_i^p} \qquad (1)$$

where e_i = signal amplitude in SiPM i, p = energy weight exponent, and x_i (y_i) is the SiPM x (y) position on the detector plate.

Test on an unwrapped (no reflectivity added) and uncoupled SiPM configuration. Left pane shows position reconstruction for all events, middle pane shows data gated on the upper muon tracker, and right pane shows events gated on both trackers. The calculated location of events appear in the correct plate quadrant, but positions are biased toward the plate center.

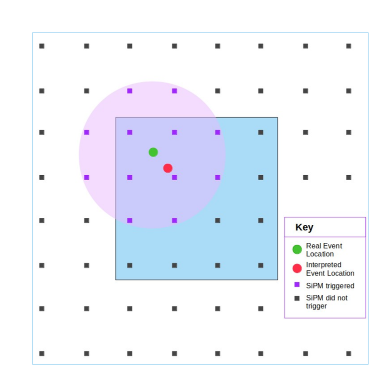


5 cm plate: 2D histogram of reconstructed y vs. x positions, gated using outer tracking detector(s). *Left:* full plate illumination; Middle: gated on upper muon tracker; *Right:* gated on both upper and lower trackers. Red boxes mark the location of tracker(s).

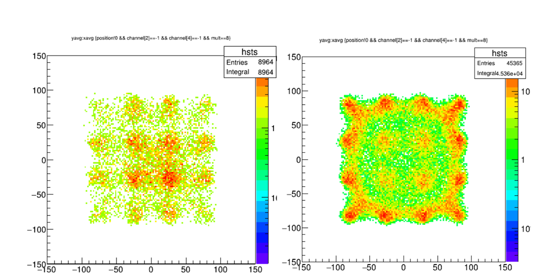


2.5 cm plate: Reconstructed event locations gated on upper tracker, which are in general closer to actual event locations compared with 5 cm plate.

This center shifting is due to the geometry of our SiPM array. A muon scattering at the green spot triggers all twelve SiPMs (pink circle) in a hypothetical larger plane of detectors (outer square), whereas only 8 SiPMs are triggered in our detector tile (blue shaded region). Much of the undetected light will be lost through the top and left side-plate surfaces.



The resulting position reconstruction for events near the plate edges biases locations toward the plate's center, locating the green event closer toward the center at the red. On the right are two plots of multiplicity 8 events using 5% (left) and 50% (right) reflectivity. Note the very different location patterns.



Reconstructed positions for ~5% (left) and ~50% (right) reflectivity, gated on multiplicity 8 events.

Data and Simulation

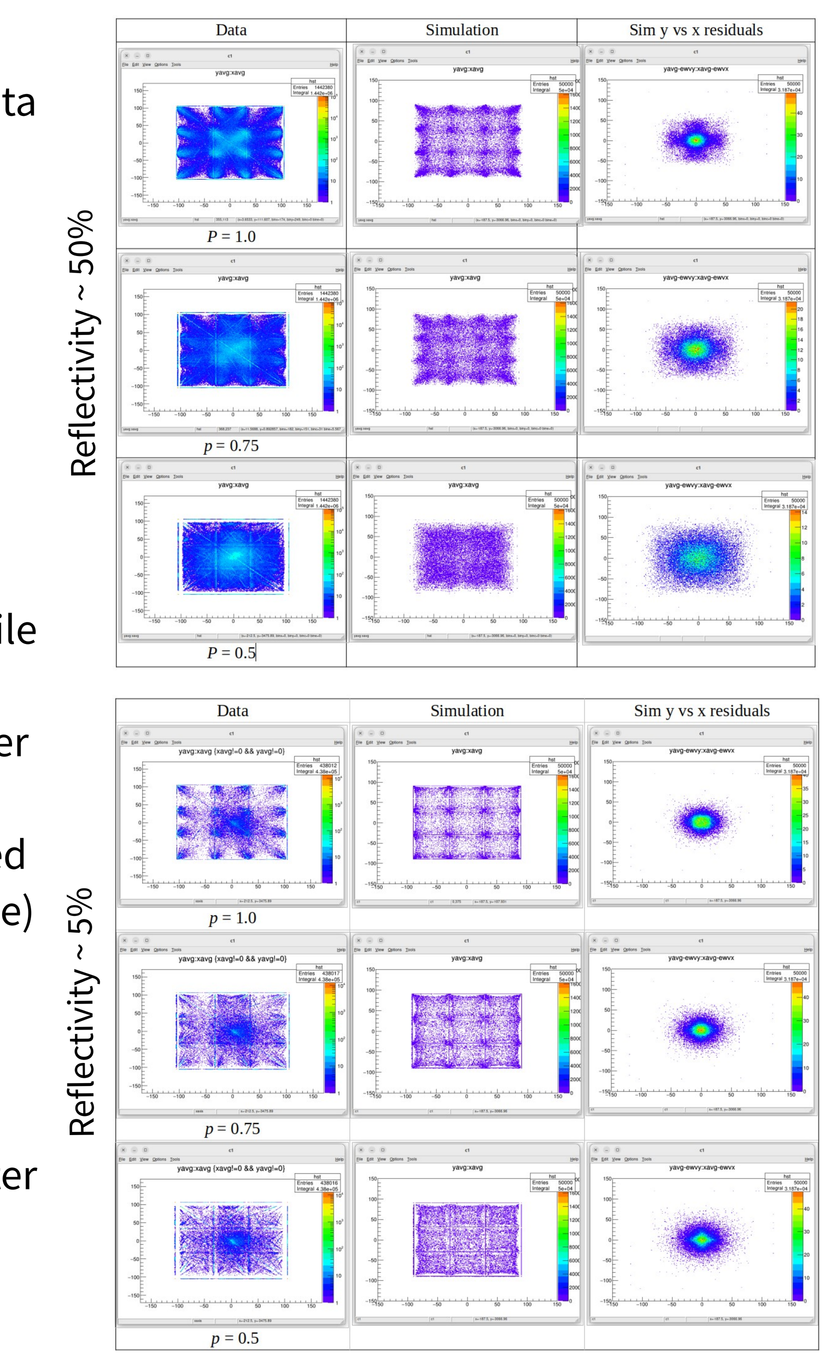
Position reconstruction for muons illuminating the whole plate area for data and simulation are shown to the right.

Reconstruction using Equation (1) will always result in events being located *within the SiPM perimeter*, including those events occurring outside the perimeter.

We tested reflective (~50%) and non-reflective (~5%) configurations for the tile surface opposite the SiPMs. For experimental data a sheet of white paper was positioned on the face to create medium reflectivity (~50%) and removed (leaving just the scintillator plate surface) for low reflectivity (~5%).

Position reconstruction for **data**:

- a sizable fraction of events are incorrectly located near the plate center (not seen in simulation)
- Reconstructed events also cluster strongly around SiPM locations



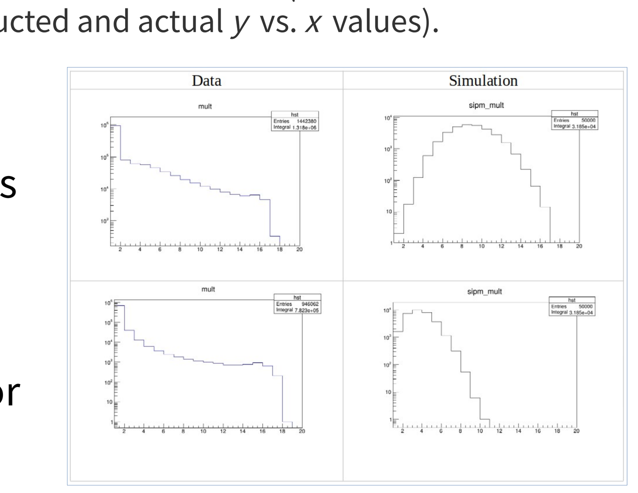
Comparing data and simulation for a 4x4 SiPM array on one side of 2.5 cm thick plate, and reflectivity R = ~0.5 (upper 9 panes) and R = ~0.05 (lower 9 panes) on the opposite side. Position reconstruction using three different energy weight exponents (p = 1.0, 0.75, and 0.5) are shown for each reflectivity, along with the simulation residuals (differences between reconstructed and actual y vs. x values).

Position reconstruction for **simulation:**

- Simulation residuals seem best for lower the reflectivity configuration and using weighting exponent p = 0.5 for energy.

Agreement between data and simulation is generally *marginal*. **Improvement in simulation** is needed to better account for features seen in data to develop a better reconstruction algorithm.

Multiplicity plots shown to the right highlight major differences between data and simulation, both in terms of spectrum shape and behavior at low multiplicity.



Multiplicity plots for data (left) and simulation (right) for reflectivities ~50% (top) and ~5% (bottom)

Future Work

Our current position reconstruction algorithm is limited to locating events to within the SiPM perimeter. Improvement in simulation is necessary to reproduce features seen in data. We will then explore position reconstruction using **machine learning**, where the improved simulation would provide training for events over the entire plate.

Acknowledgments

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