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Neutron Scatter Camera Materials for poster for RadSensing 2011

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General information

- Project title: A High-Sensitivity Fast Neutron Imager
- Key technical staff (all SNL):
  - James Brennan
  - Erik Brubaker (PI)
  - Robert Cooper
  - Mark Gerling
  - Peter Marleau
  - Nick Mascarenhas (was PI, now @ IAEA)
  - Stan Mrowka

Project goals

- The neutron scatter camera is a relatively mature R&D detector technology. It has been shown that fast neutrons can be detected and imaged using two separated planes of liquid scintillator detector elements. Standoff passive detection of SNM was the primary motivation for developing this system, and remains the flagship application. Other applications of interest involving SNM are warhead counting, or more generically treaty verification; emergency response diagnostics; active interrogation for search or screening; and enrichment measurements, or more generically nuclear safeguards.
- Over time, the neutron scatter camera research activities have shifted from detector development to tests and deployments. While this is appropriate for a maturing technology, we will maintain a base level of effort directed toward detector improvements and the exploration of new ideas big and small. This should be around 1/3 of the project effort and budget. The remaining 2/3 will go toward testing and characterizing the existing detector in a variety of potential applications.

Office of Nonproliferation and Verification Research and Development

RadSensing 2011

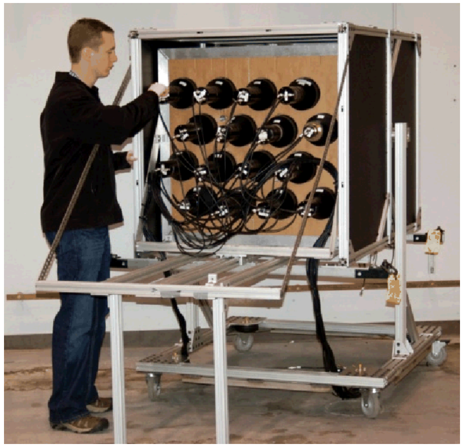
A High-Sensitivity Fast Neutron Imager

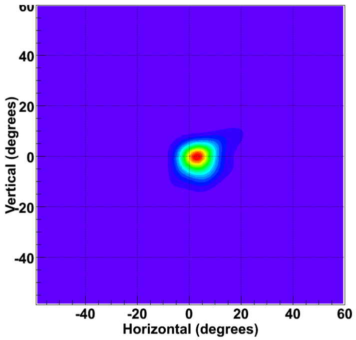
Principal Investigator: Erik Brubaker

Supporting Team: Brennan, Cooper, Gerling, Marleau

Prior Results

- Demonstrated the ability to identify a point source of fast neutrons and its location in numerous settings.
- Resolved multiple fast neutron point sources in a scenario relevant to arms control treaty verification.
- Demonstrated the ability to resolve extended sources, clearly distinguishing a 2-d line source from a point.
- Demonstrated ability to distinguish Cf-252 from AmBe using the measured neutron energy spectrum.





The 32-element scatter camera and an MLEM-reconstructed neutron point source image.

Technical Challenges

- The scatter camera concept requires two neutron elastic scatters in the detector, putting a fundamental limitation on detection efficiency.
  - Can trade off efficiency and angular resolution.
- Non-orthogonality of response to nearby source positions makes extended source imaging difficult.
  - Investigated alternative imaging concepts for high-resolution imaging in e.g. treaty contexts.

Planned Accomplishments

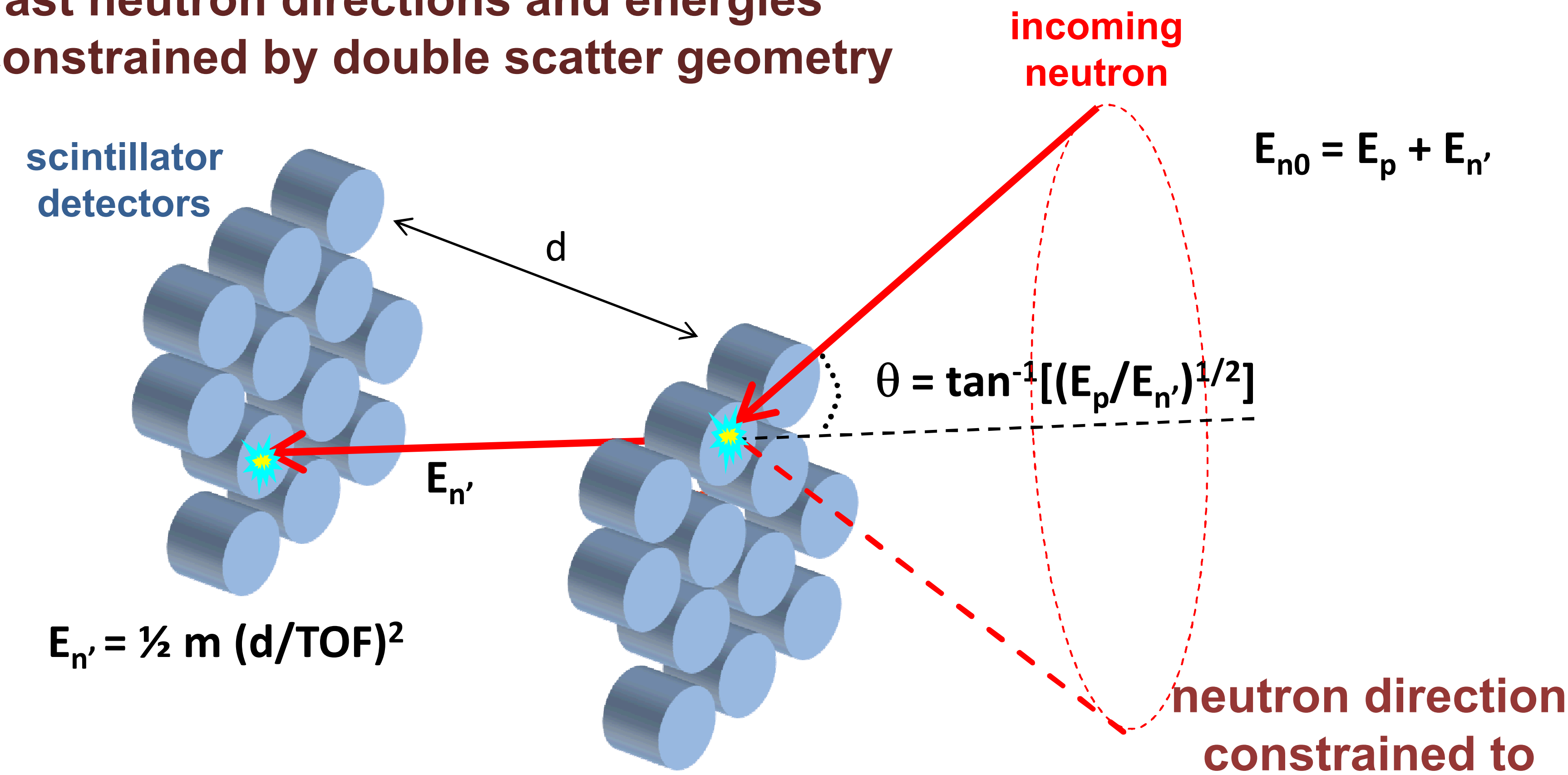
- Continue to measure extended sources in 2-d and 3-d.
- Characterize performance quantitatively for large standoff (low S:B) source detection and localization.
- Continue to deploy the scatter camera as opportunities arise for testing in new scenarios or with different target objects.

Detector development

- FY11:
  - Improvements to detector frame.
  - Bubble-free cell design.
  - Improve energy resolution.
- Possible future tasks:
  - Explore alternate detector geometries: cylindrical, spherical, amorphous cell arrangements; position-sensitive detectors; etc.
  - Replace analog electronics with fast digitizers. More compact electronics and improved PSD.
  - Eliminate energy measurements for sensitive applications.

Neutron Scatter Camera

Fast neutron directions and energies constrained by double scatter geometry



Multimode capability includes

- ***Neutron energy spectrum.***
- ***Compton imaging.***

Testing and Characterization

- Focus on metrics, quantitative performance measurement, and comparison to other detector systems where possible.
- Test against a range of scenarios, even if not optimized for a given application. Provide a baseline against which other systems can be compared.
- Develop a set of benchmark scenarios representing reasonable performance tests in a variety of application spaces.

Neutron imaging applications and scenarios

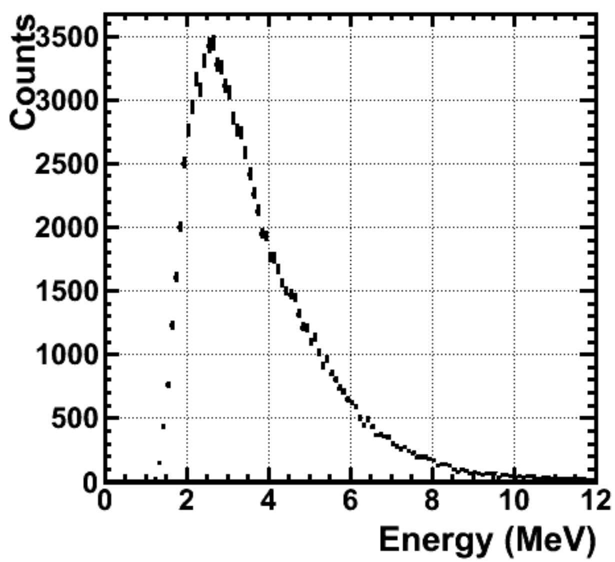
- **Standoff detection of weapons-grade plutonium**
  - Determine the presence or absence of a source within some spatial footprint.
- **Emergency response**
  - Distinguish Pu from AmBe inside plastic box.
  - Determine size, mass, and/or composition of moderating material.
- **Treaty verification**
  - Count neutron sources in MIRV-like configuration.
  - Track warhead dismantlement through concrete wall.
- **Active interrogation**
  - Distinguish nat U from Pb under brem source interrogation.
  - Same with neutron interrogation source.

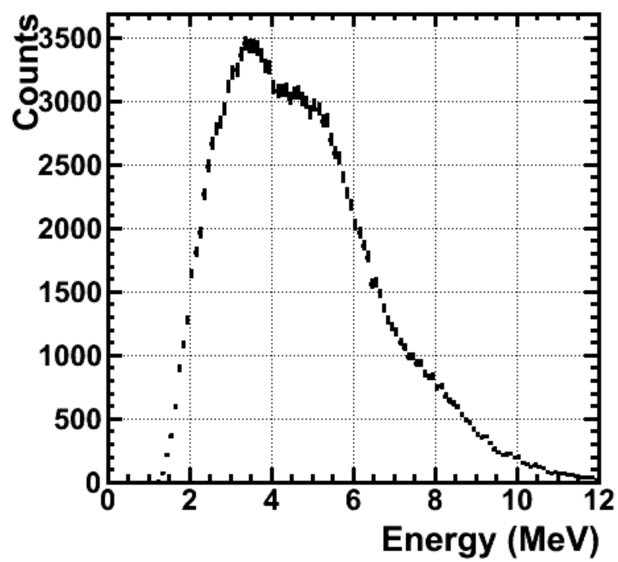
Neutron spectroscopy

- "Measurement of the Fast Neutron Energy Spectrum of an ^{241}Am-Be source using a Neutron Scatter Camera": submitted to IEEE Trans. Nucl. Sci.
- Took many hours of data using a Cf-252 source and an AmBe source.
- Compared the two spectra to evaluate ability to discriminate between them.
- Unfolded resolution effects to get a direct measurement of AmBe spectrum; compared to published results.

Raw measured energy spectra

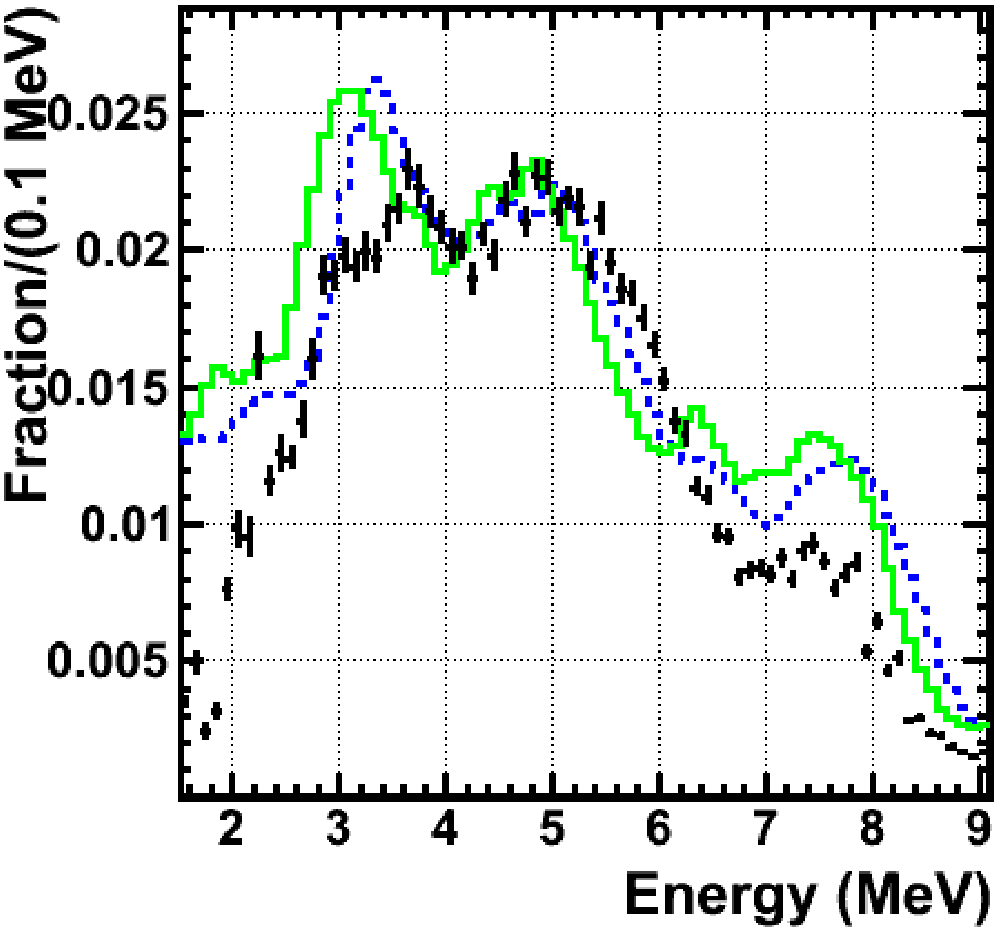
- Neutron energy spectra observed by NSC:
  - Left: Cf-252
  - Right: AmBe





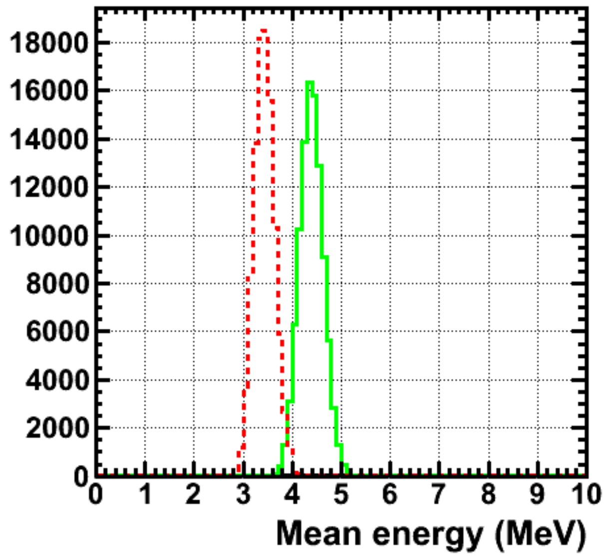
Unfolded AmBe spectrum

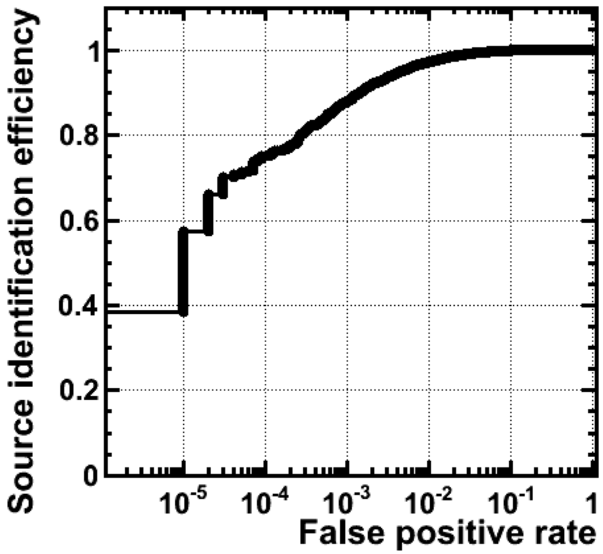
- Points: our data after ML-based unfolding
- Green solid line: ISO 8529-1 standard
- Blue dashed line: measurement from Geiger
- Energy-dependent efficiency not corrected



Fission source vs AmBe, ROC curve

- Excellent discrimination for 50-event samples even using a simple test statistic: mean raw energy.
- Note these are bare sources.



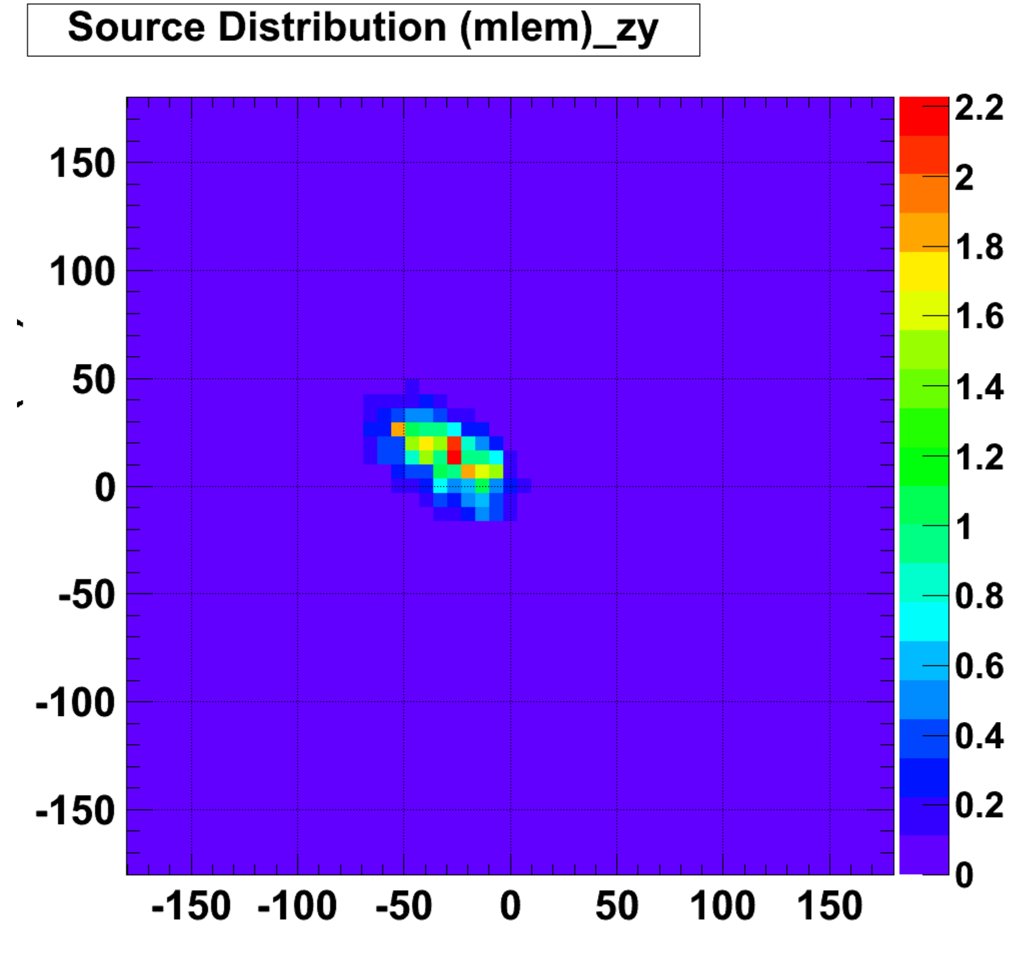


Extended source imaging

- For treaty verification scenarios, the ability to distinguish an extended source from a point source is valuable.
- Additionally, resolving nearby extended sources is more difficult than similarly situated point sources.
- Investigate the scatter camera’s imaging performance for extended sources—a follow-on to last summer’s warhead counting exercise.

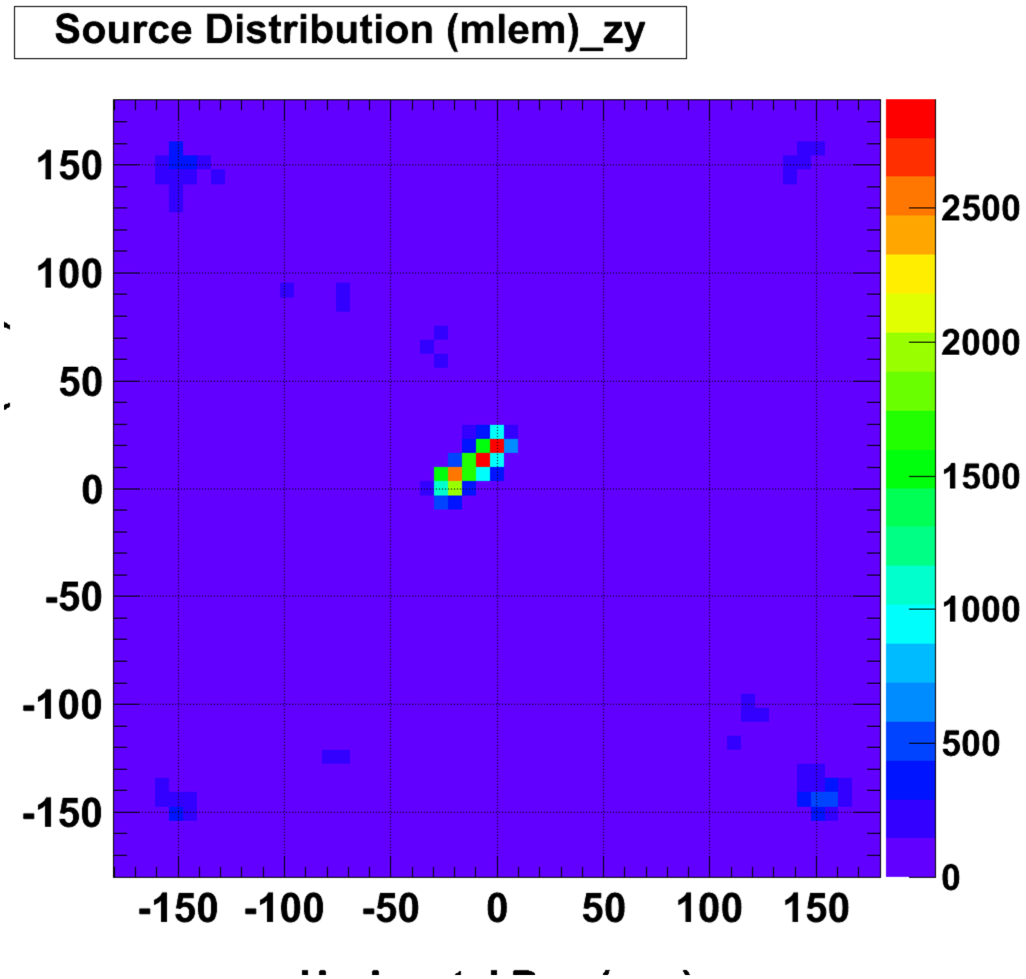
NSC: extended source

- 50 cm diagonal line source
- 96 hour run
- 16+16 NSC 3 m away
- 25” plane separation



NSC: extended source

- 50 cm diagonal line source
- 96 hour run
- 16+16 NSC 3 m away
- 50” plane separation



Extended source imaging: NSC

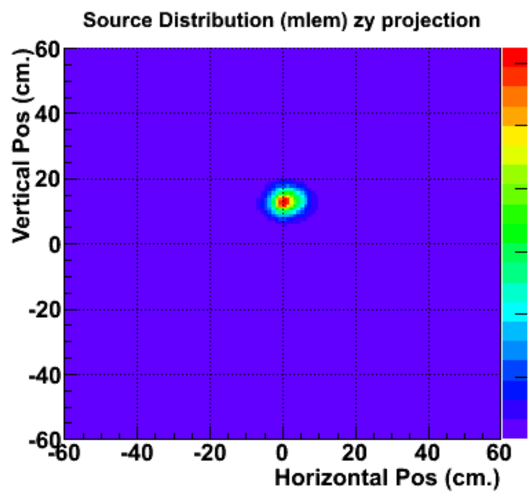
- The neutron scatter camera is designed/optimized for enhancing S:B in low-signal environments (standoff detection, heavily shielded sources), not for high-resolution imaging.
- By increasing plane separation, we improve the NSC resolution and enhance the extended source reconstruction.

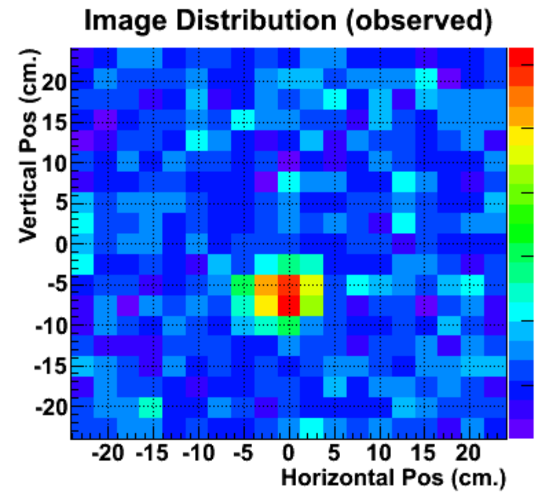
Pinhole imager

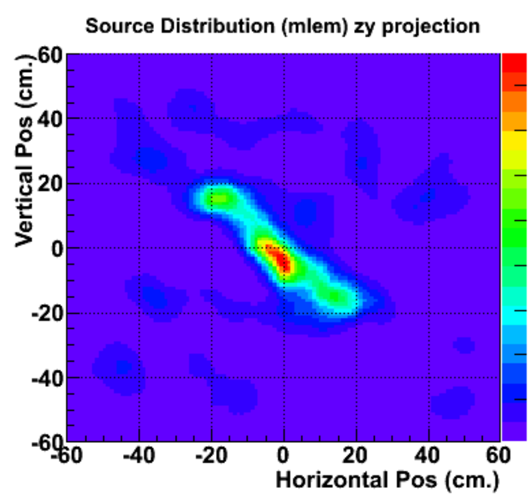
- Explored an alternative fast neutron imager concept: pinhole imaging.
- Suited for high-resolution, high-S:B scenario.
- 4” HDPE mask, 2” dia. pinhole
- Raster single 2” dia. LS cell across the image plane
  - Cheap but slow.
  - Avoid calibration issues.

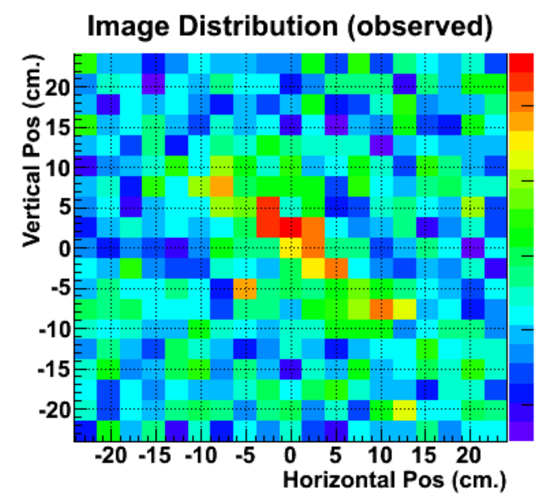
Pinhole imager: extended source

- Top: point source; bottom: 50 cm diagonal line source
- Mask/pinhole 1.5 m from source, image plane 3 m from source
- 2 min exposure, 2” dia. cell rastered through 1” grid.



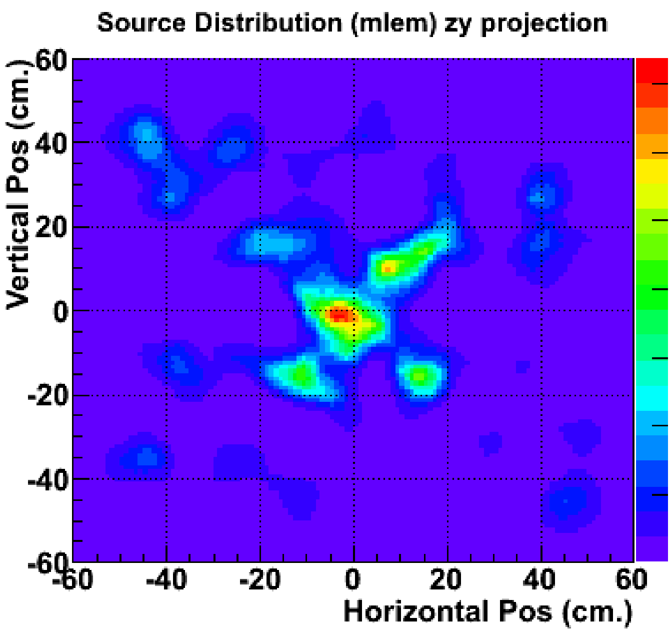


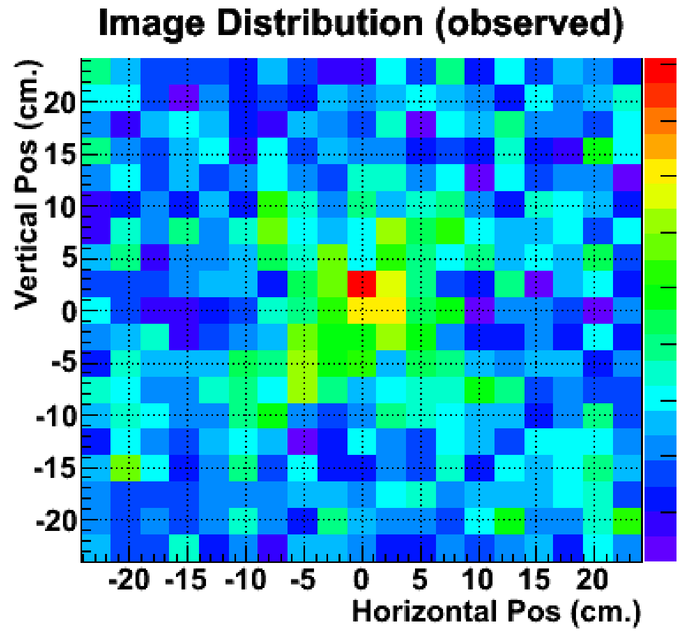




Pinhole imager: extended source

- Combine two 2-min diagonal runs to make an "X".
- Significantly more difficult than a single diagonal!





Extended source imaging: pinhole

- The pinhole imager is a simple system that has good resolution and orthogonal response ideal for extended source distributions.
- Our rastered image plane does not fully capture the difficulty of position-sensitive detection and channel-to-channel calibrations.
- But image performance is promising: successfully resolve diagonal line sources and “X” source in few-minute runs.