Advanced Neutron Detectors with Pad Readout

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Motivation and Overview

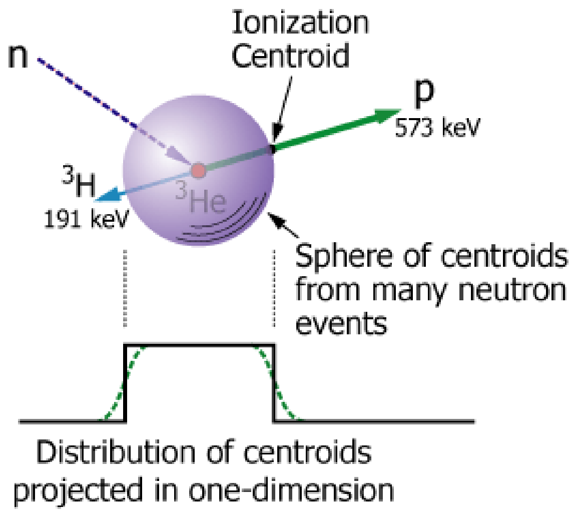
- Next generation detectors for SNS and other neutron facilities
- Thermal neutron imaging based on conversion in ^{3}He (and BF_3)
- Operation in the ionization mode, i.e. gas gain of unity
- One-dimensional device verified initially
- This project, focused on Small Angle Neutron Scattering, has generated a prototype of 1/16 typical size (24cm $\times$ 24cm)
- Ultimate goal: 1m $\times$ 1m area, 2.5mm resolution, 10^8 Hz

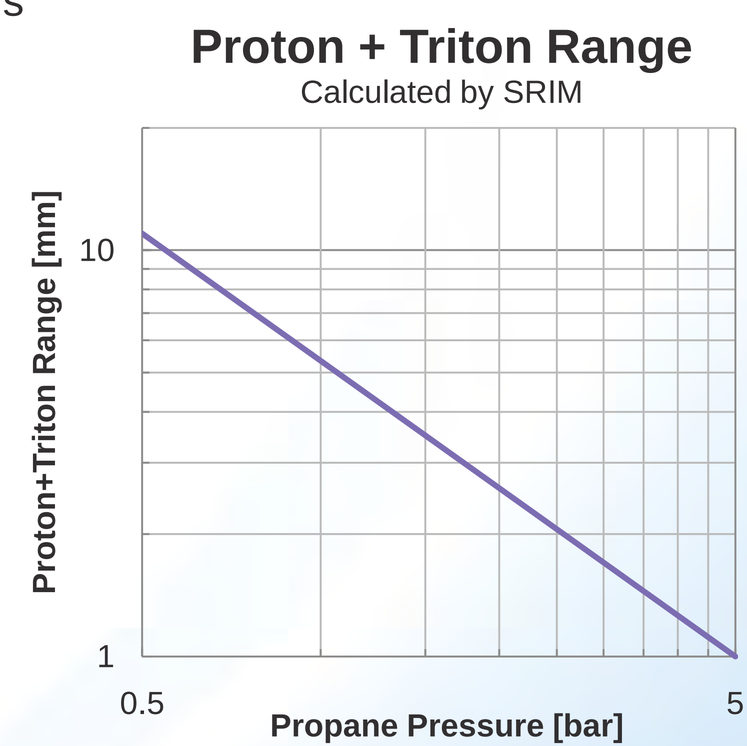
  (Typical device now: 1m $\times$ 1m area, 5mm resolution, 10^5 Hz)
- Strong reliance upon Application Specific Integrated Circuits (ASICs)

Signal Formation on a Pixel

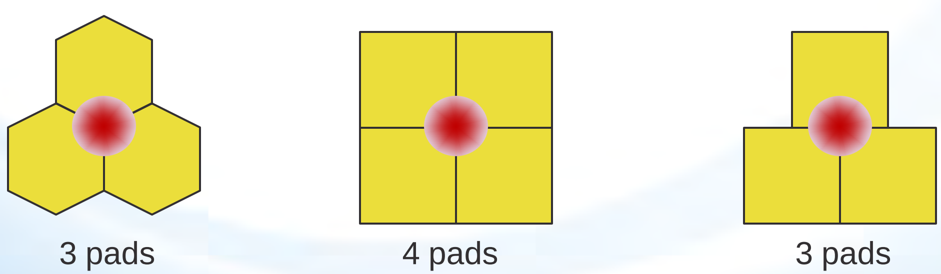
$n + {}^3He \rightarrow p + {}^3H + 764\ keV$

~30,000 electrons





Charge Sharing among Pixels



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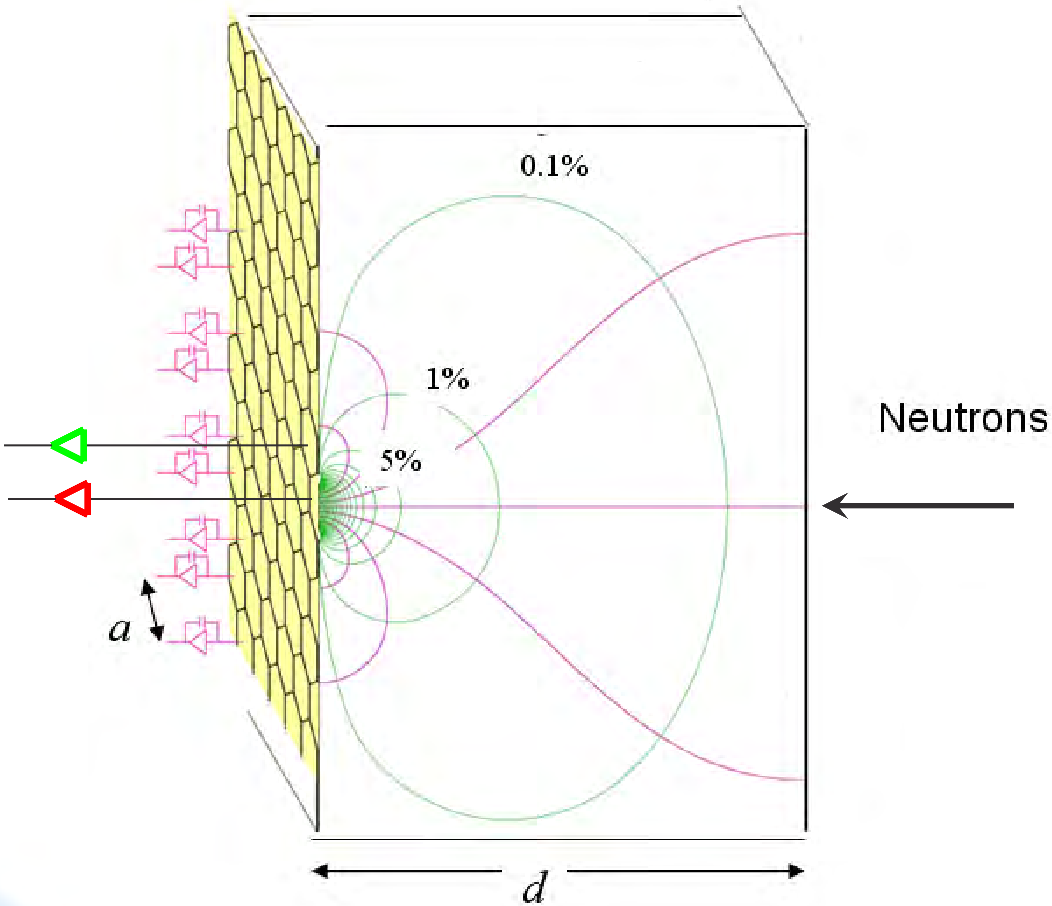
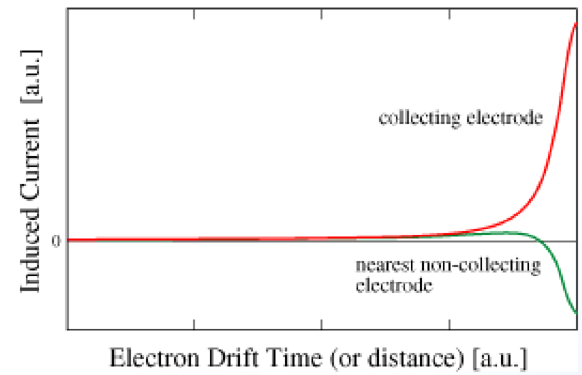
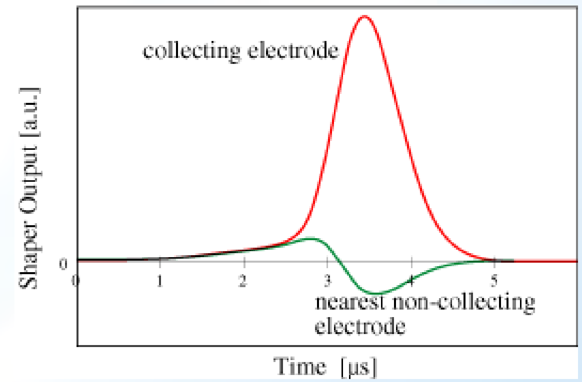
Charge Induction on Strip/Pixel Electrodes

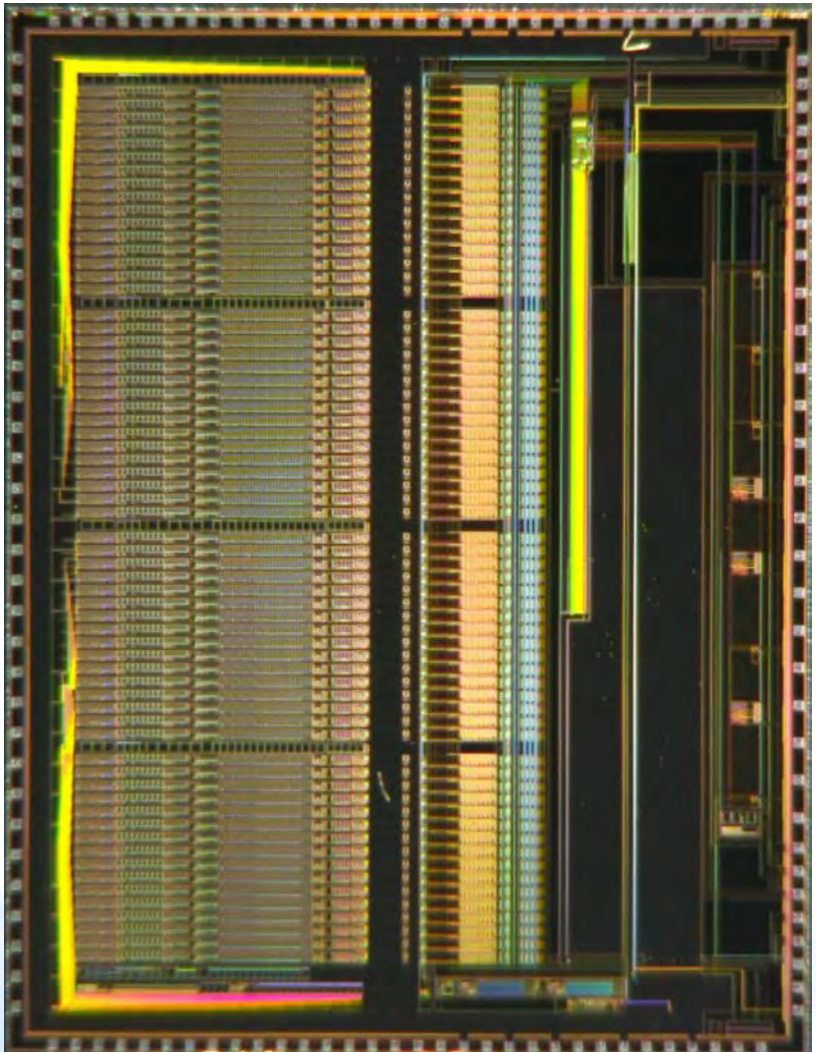


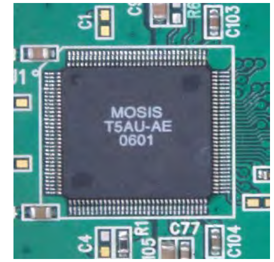




Weighting potentials (green lines) and weighting field (red lines) calculated following Ramo's theorem

Custom ASIC Chip for the Ionization Chamber

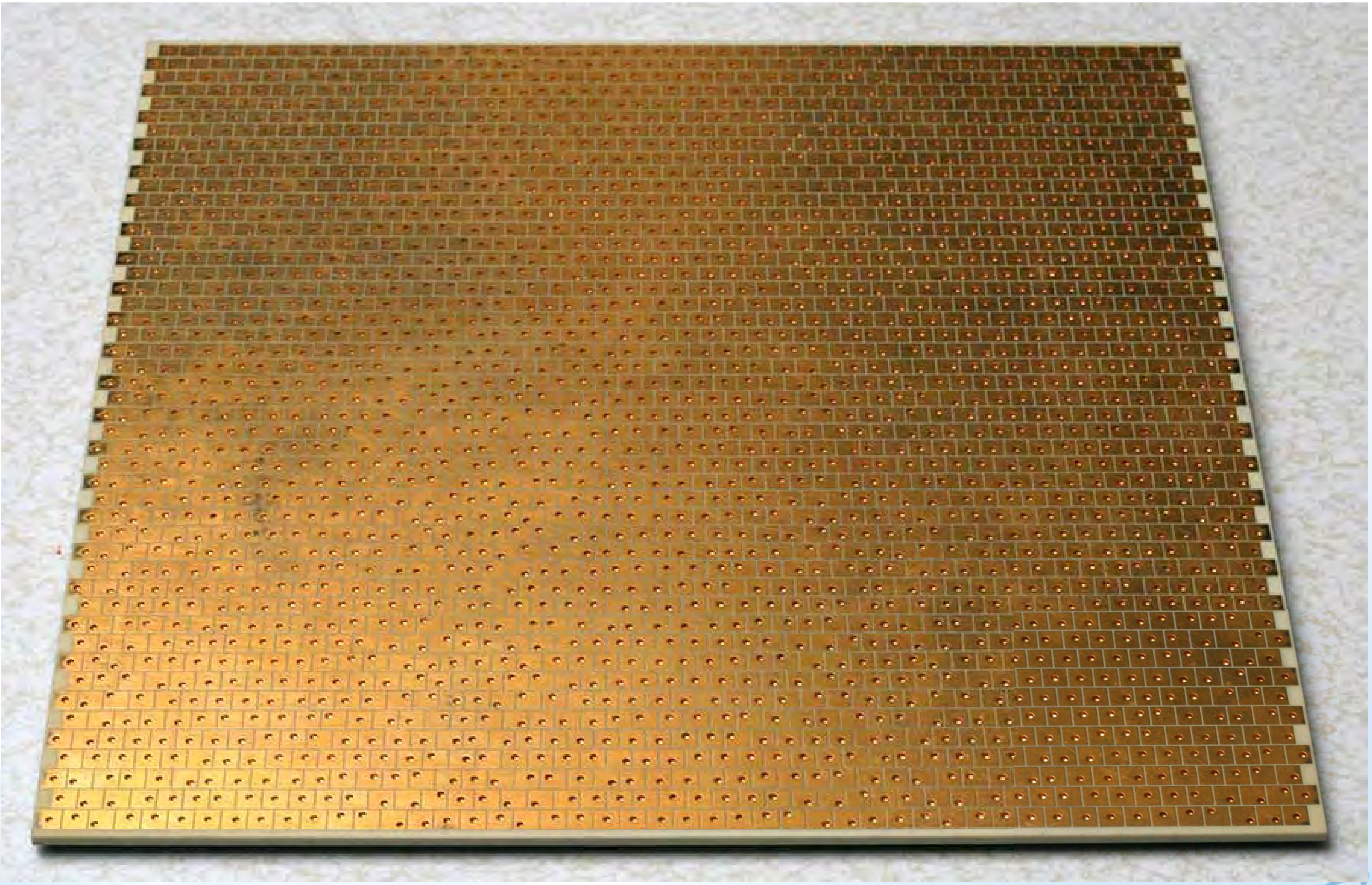




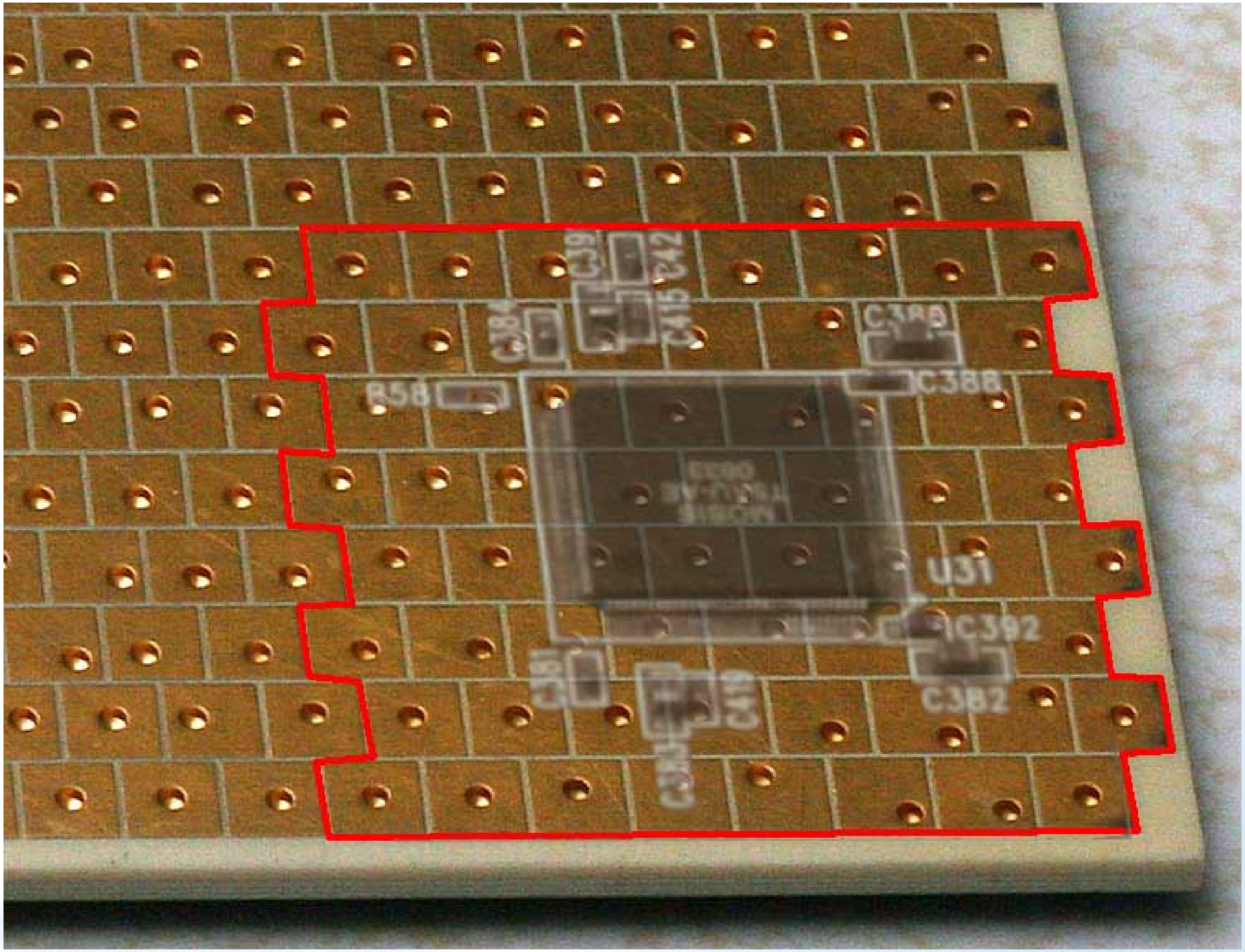
- **64-channel ASIC** for SANS experiments at SNS, **2.3 mW/ch.**
- 6.65x8.53=56mm^2, 315k MOSFETs
- **fabricated in CMOS 2.5V 0.25 µm**
- Electronic resolution **below 120 electrons rms at 5 pF @ 1µs peaking time**
- **Energy, timing, address per event**
- **Simultaneous measurement and readout**
- Current mode peak detector and digitizer (**PDAD**)
  - **peak-detection and A/D conversion**
  - in **real-time,** with **no clock,** at **low-power**

De Geronimo, G, et al., IEEE Trans. on Nucl. Sci., v54, pp541-548

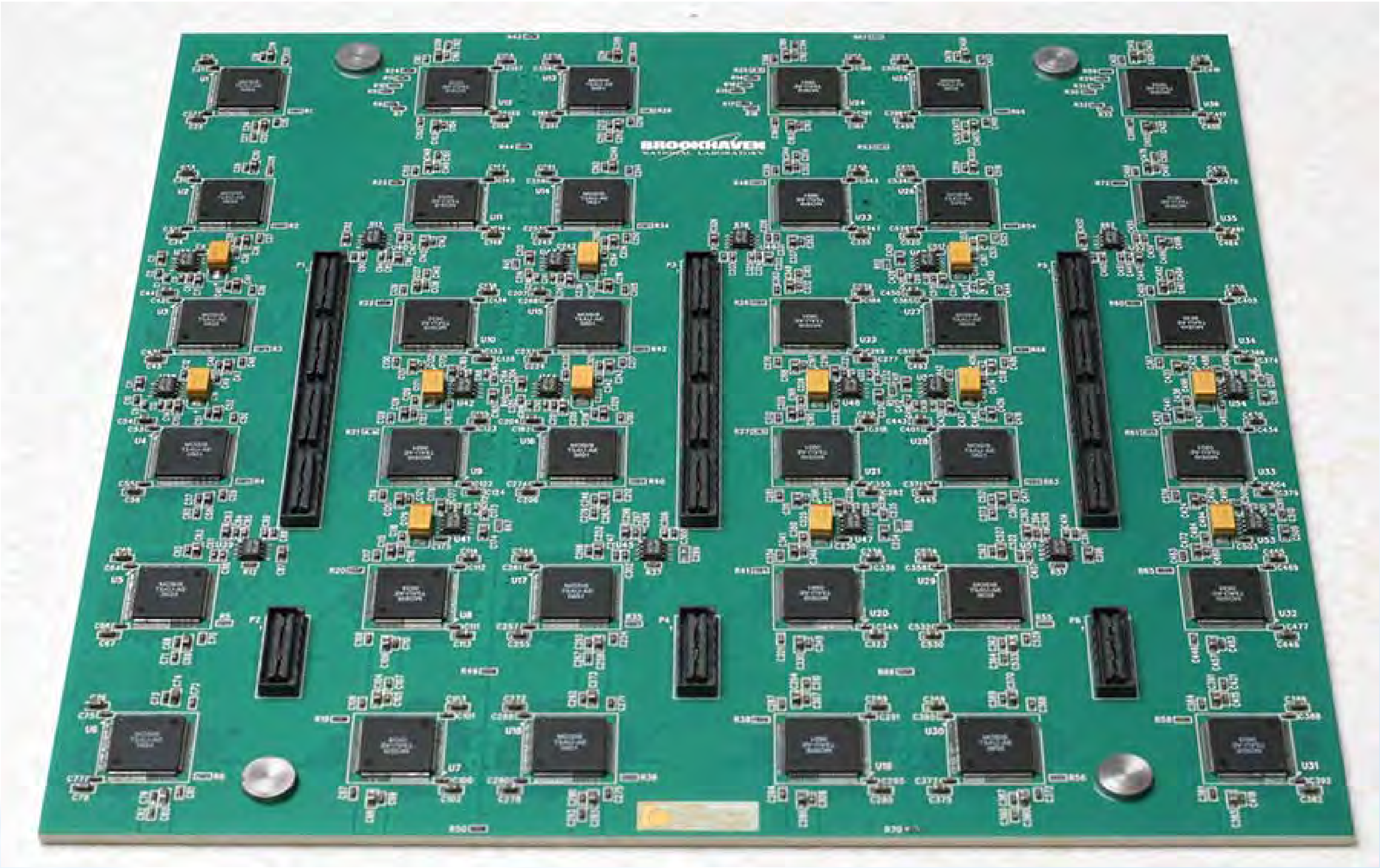
Pad side of the ASIC Board



Pad side of the ASIC Board

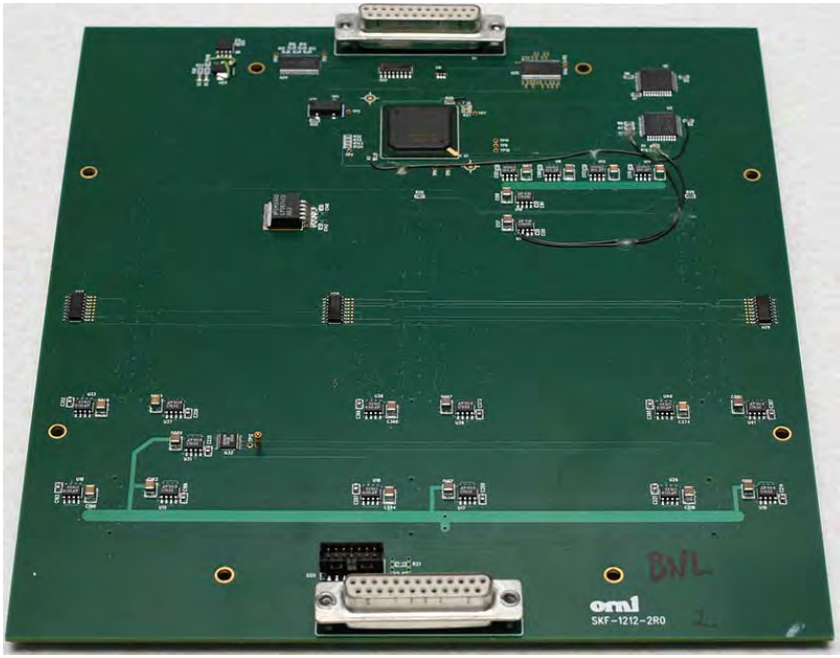


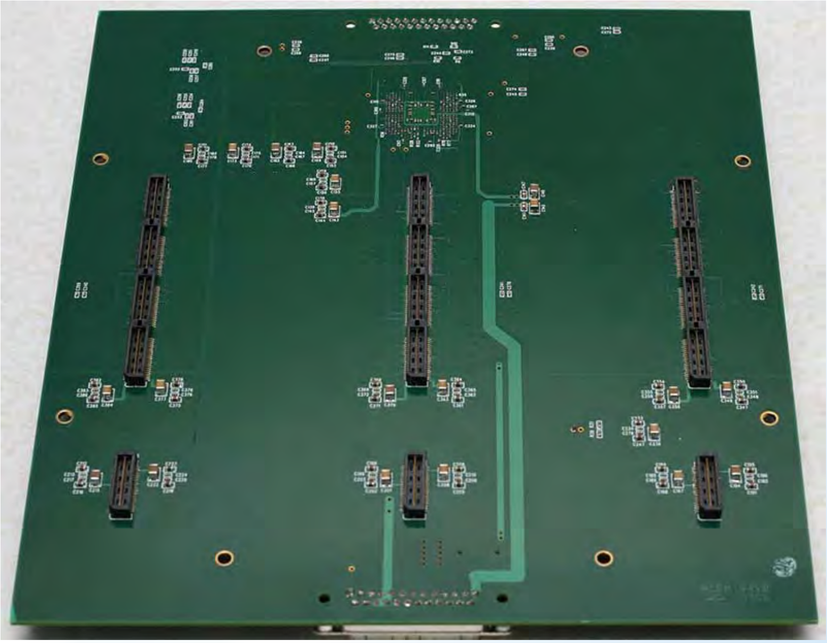
Component side of the ASIC Board (9 layer PCB)



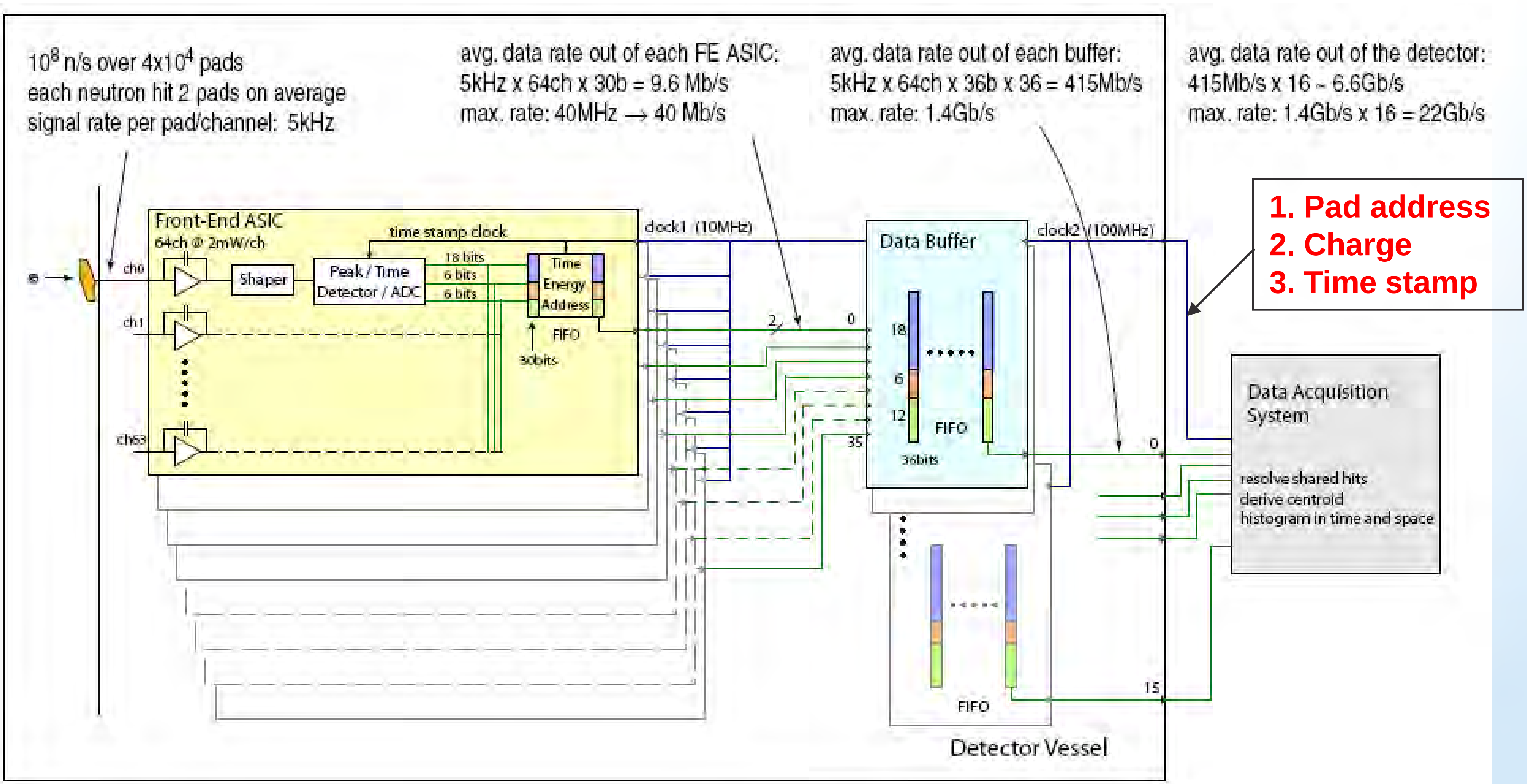
Most measurements presented today were from a 16 chip configuration highlighted here.

SANSROC Board





Signal Readout (for a large detector)

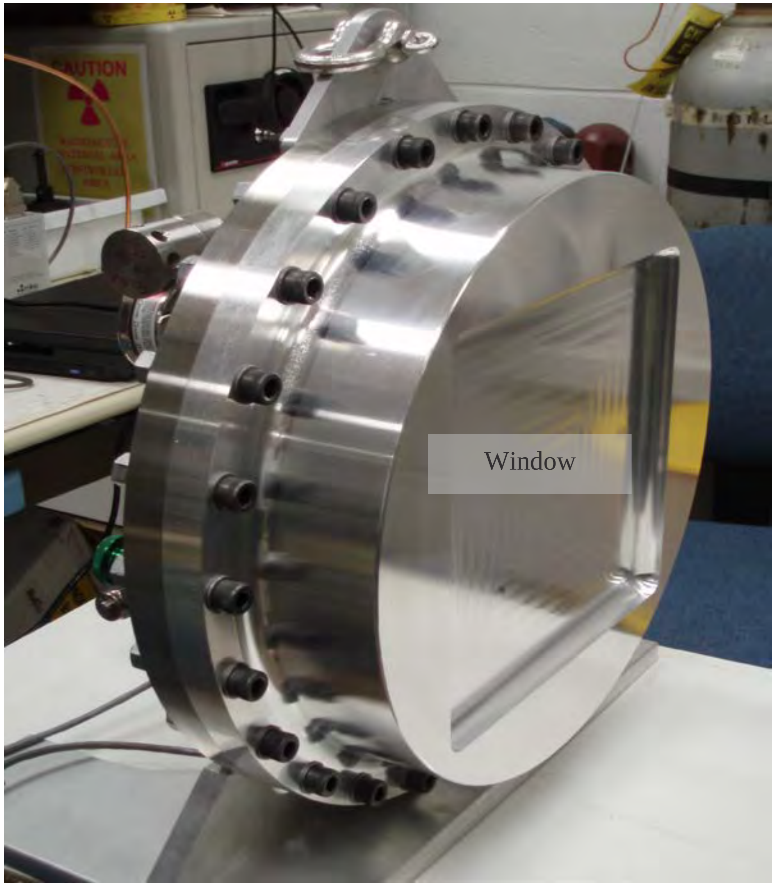


Pad Plane

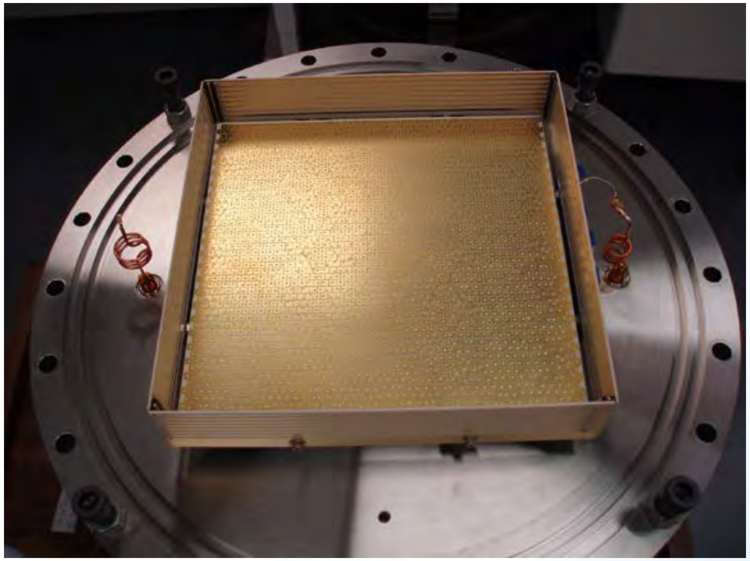
ASIC

SANSROC

Completed Detector

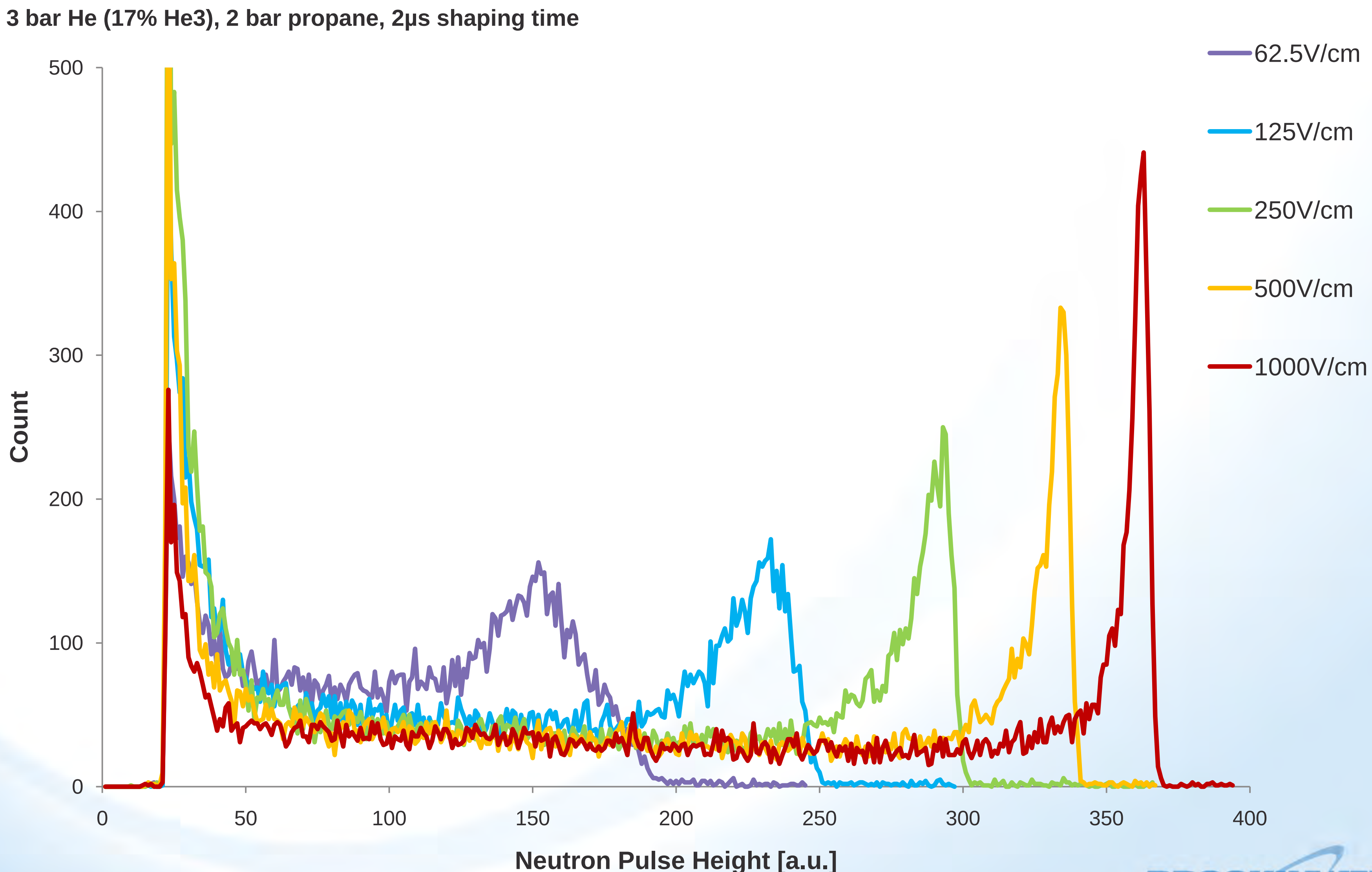


Completely assembled detector. Window defines sensitive area of 24 cm × 24 cm. Detector is sealed, with gas filling of ^{3}He plus propane. Pump/puriifer maintains sufficient gas purity for long term operation.

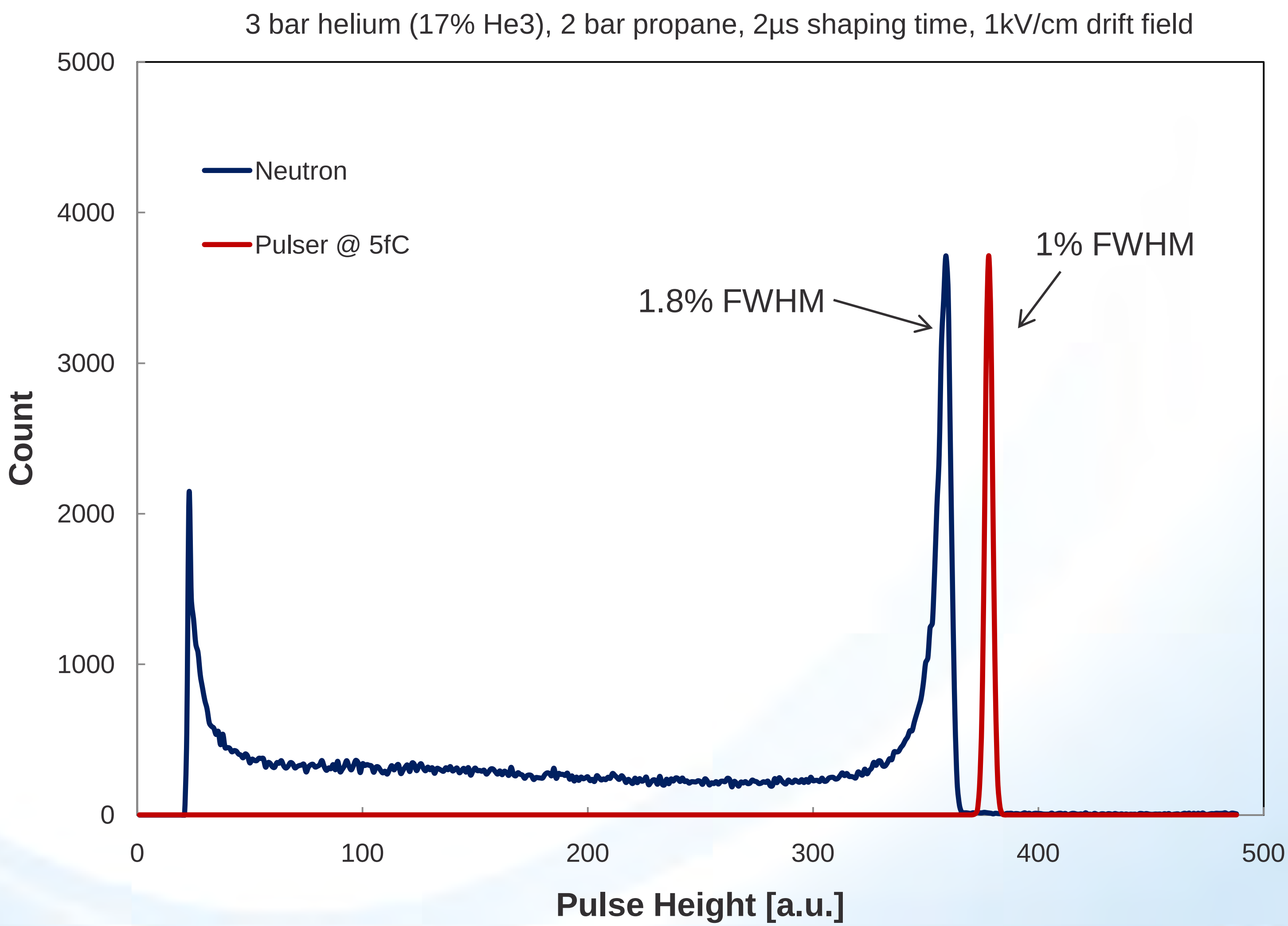


View of detector with window removed. Anode pad board and SANSROC are mounted on rear stainless steel flange, with drift field defining electrodes at edges

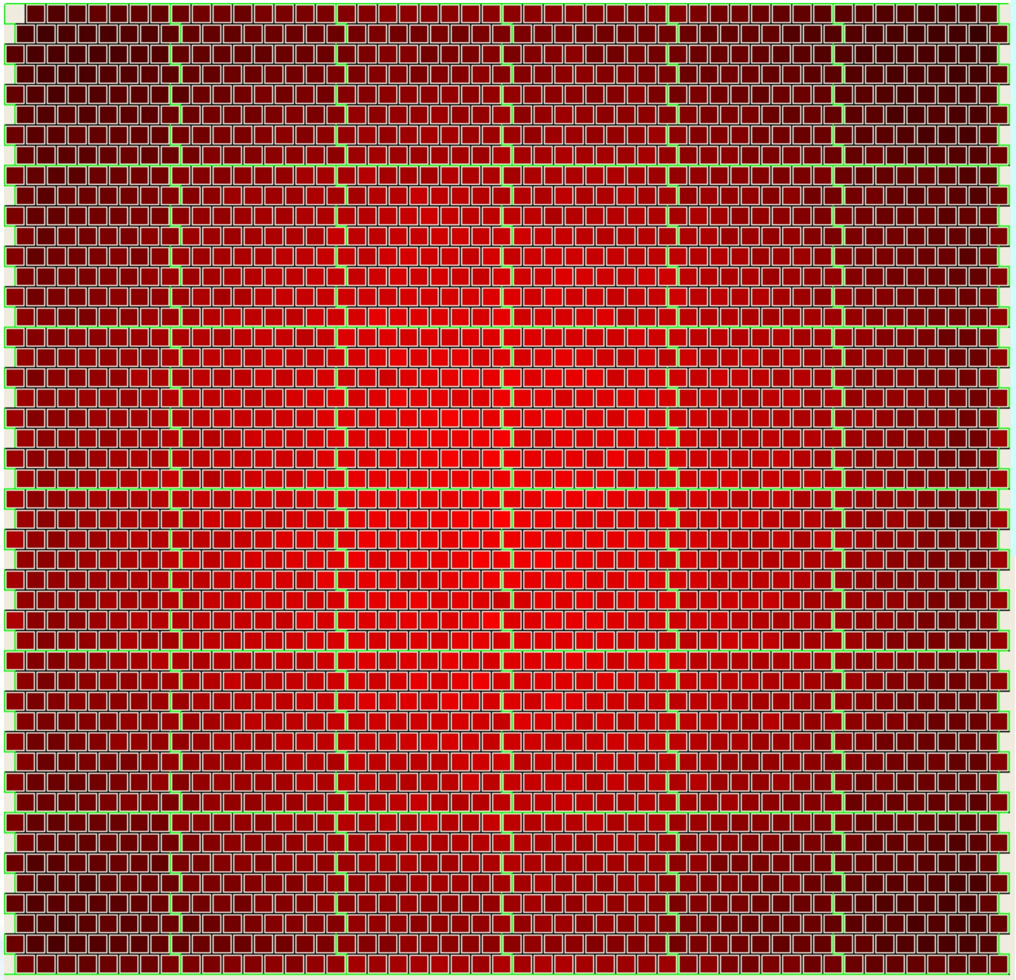
Neutron Pulse Height vs. Drift Field



Energy Resolution of the Thermal Neutron Peak

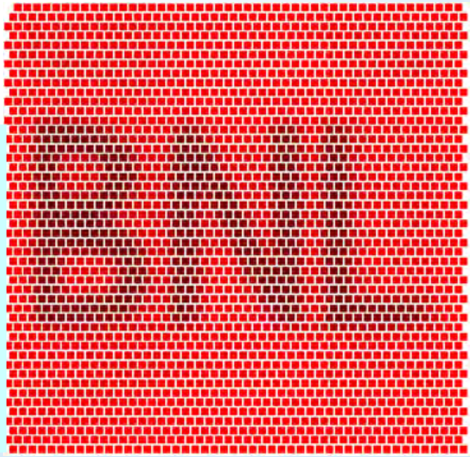


2D Histogram from Uniform Neutron Flux



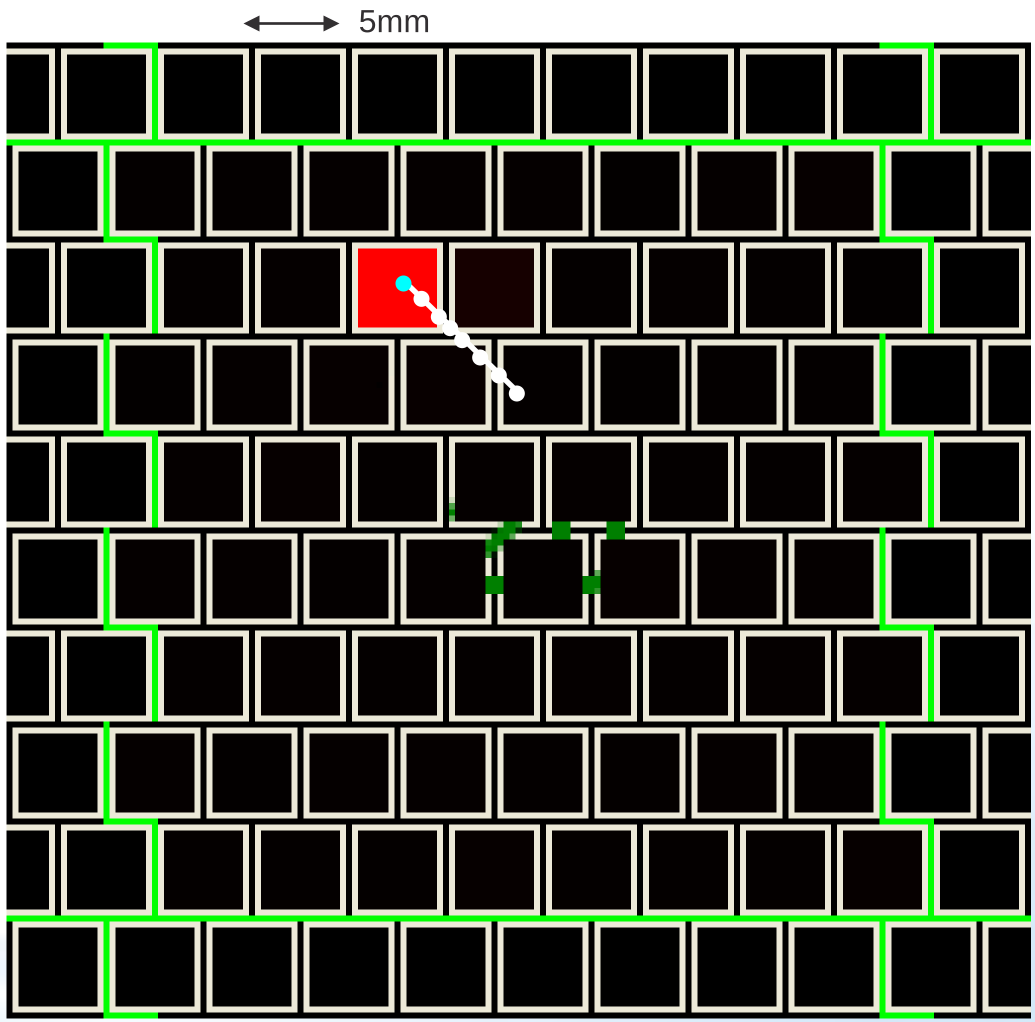
Response of entire 48 × 48 pad detector and full acquisition system to uniform illumination with thermal neutrons. Neutron source is very close to detector window, *d* ~10cm, and thus there is a fall off of neutron intensity from center to the sides.

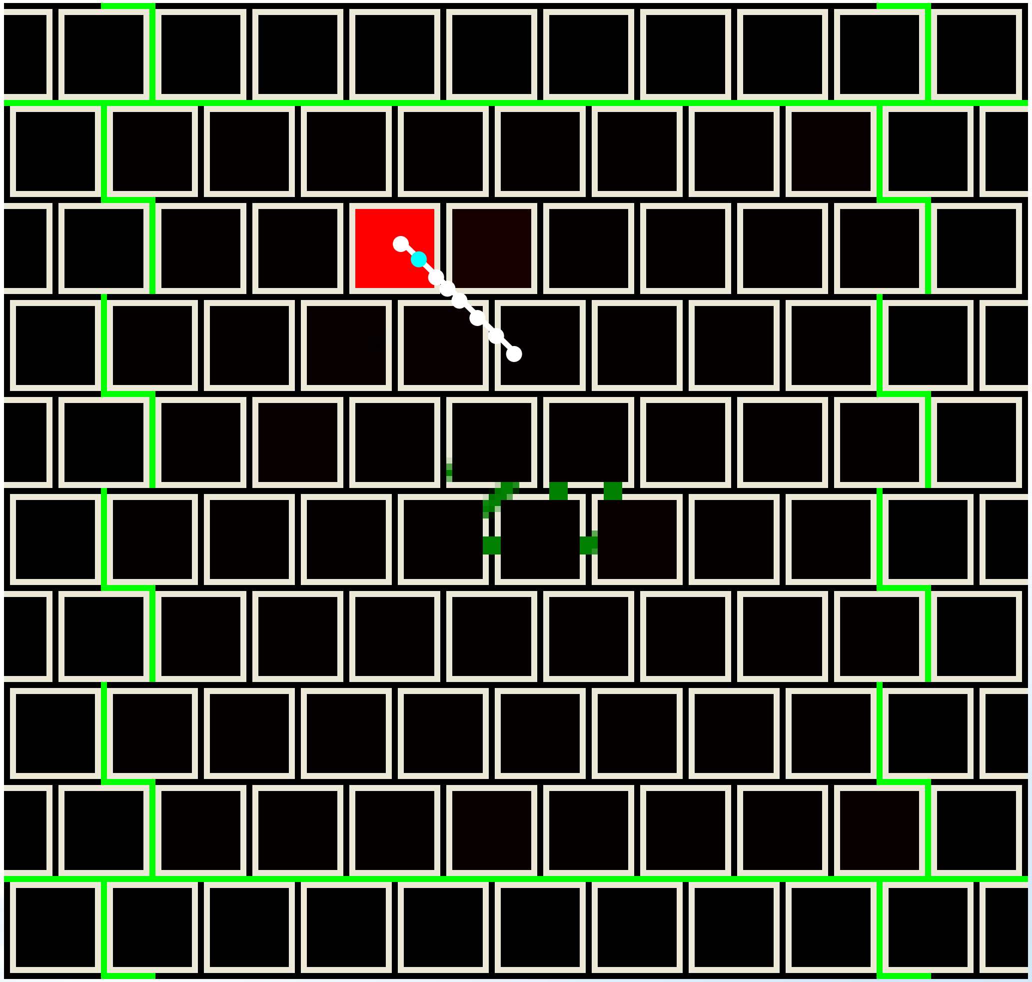
Image of "BNL" letters formed from Cd. Measurements were made with *d* ~5m to reduce parallax.

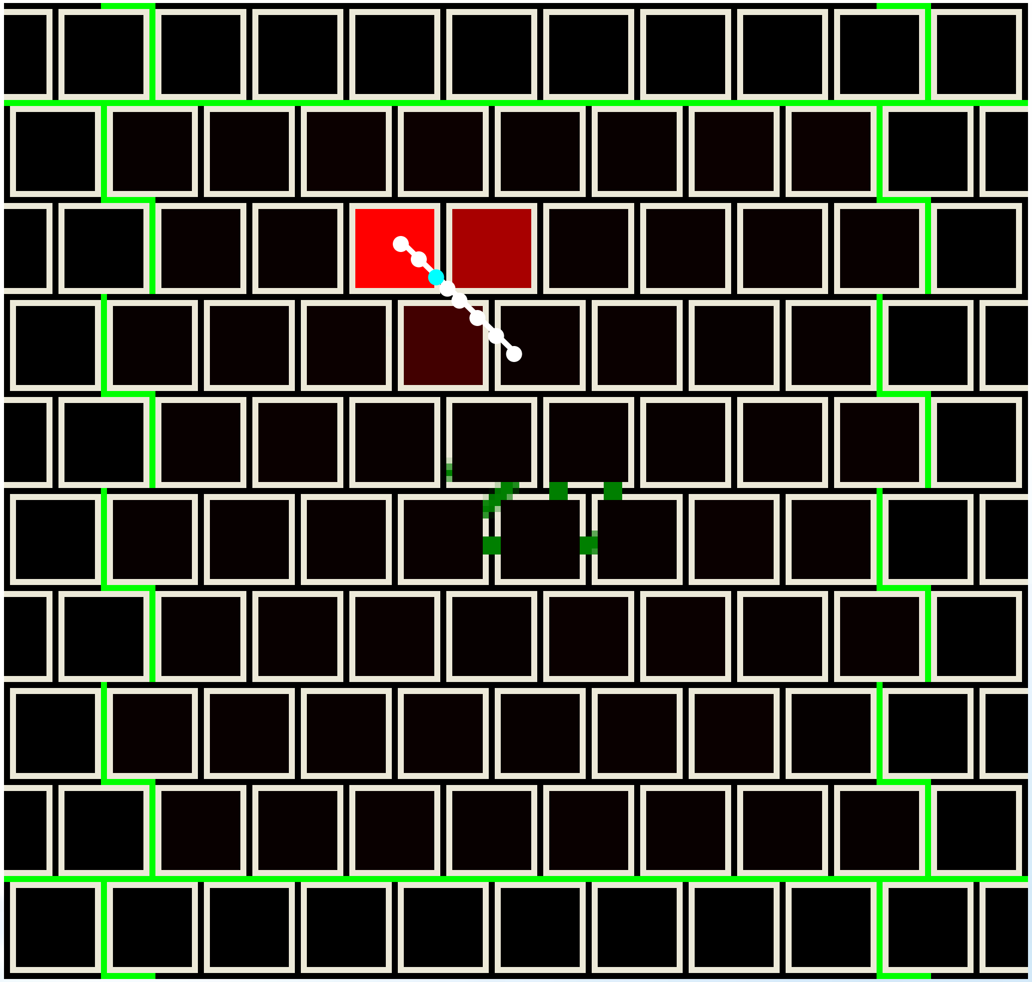


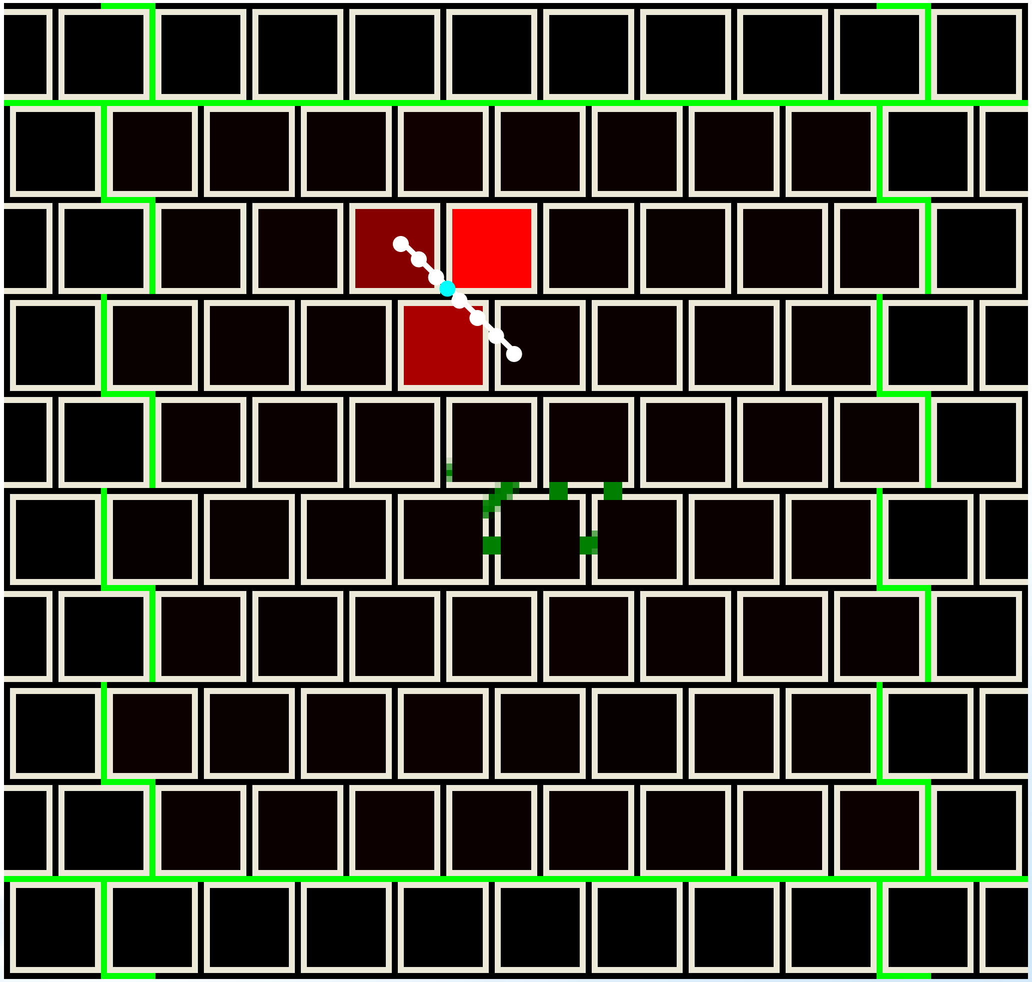
Measurements at CG1D at HFIR
(Instrument Development Beamline, Lowell Crow)

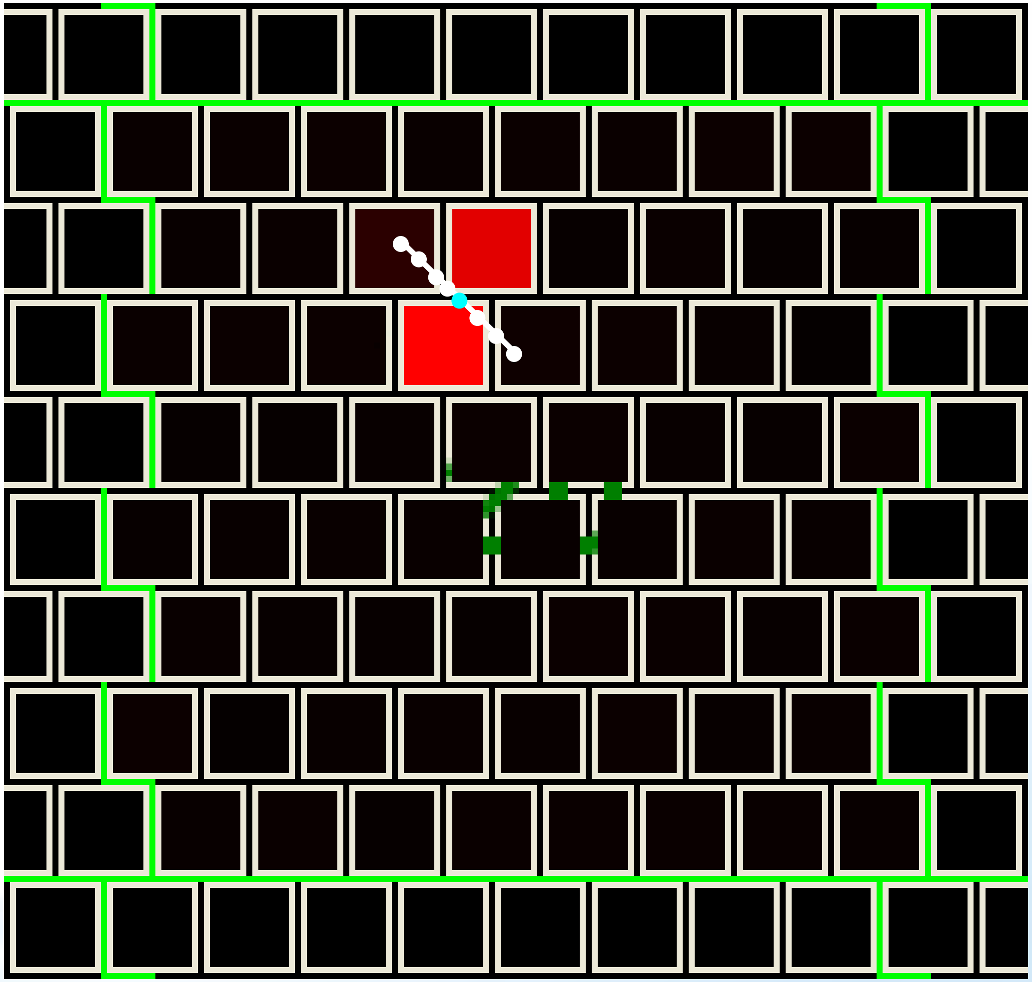
Scanning 1 mm diameter beam diagonally from one pad row to the next

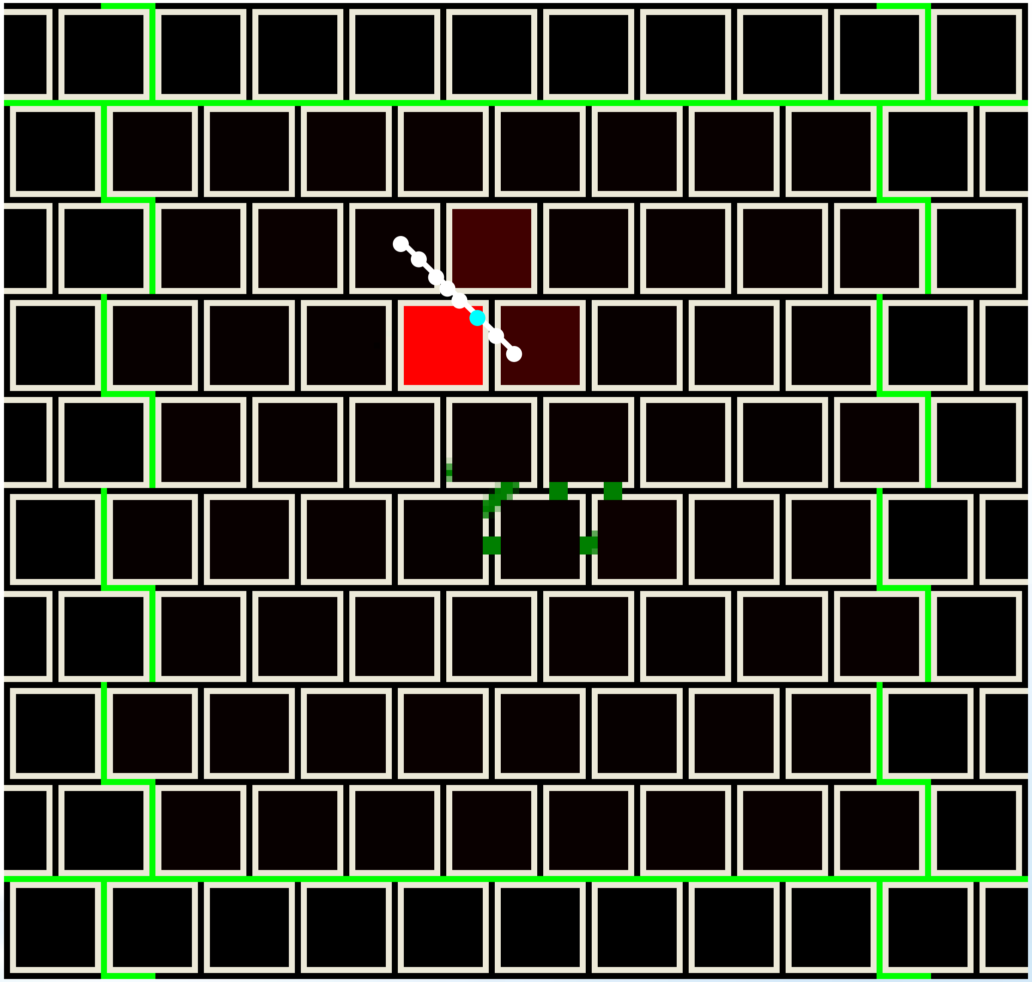


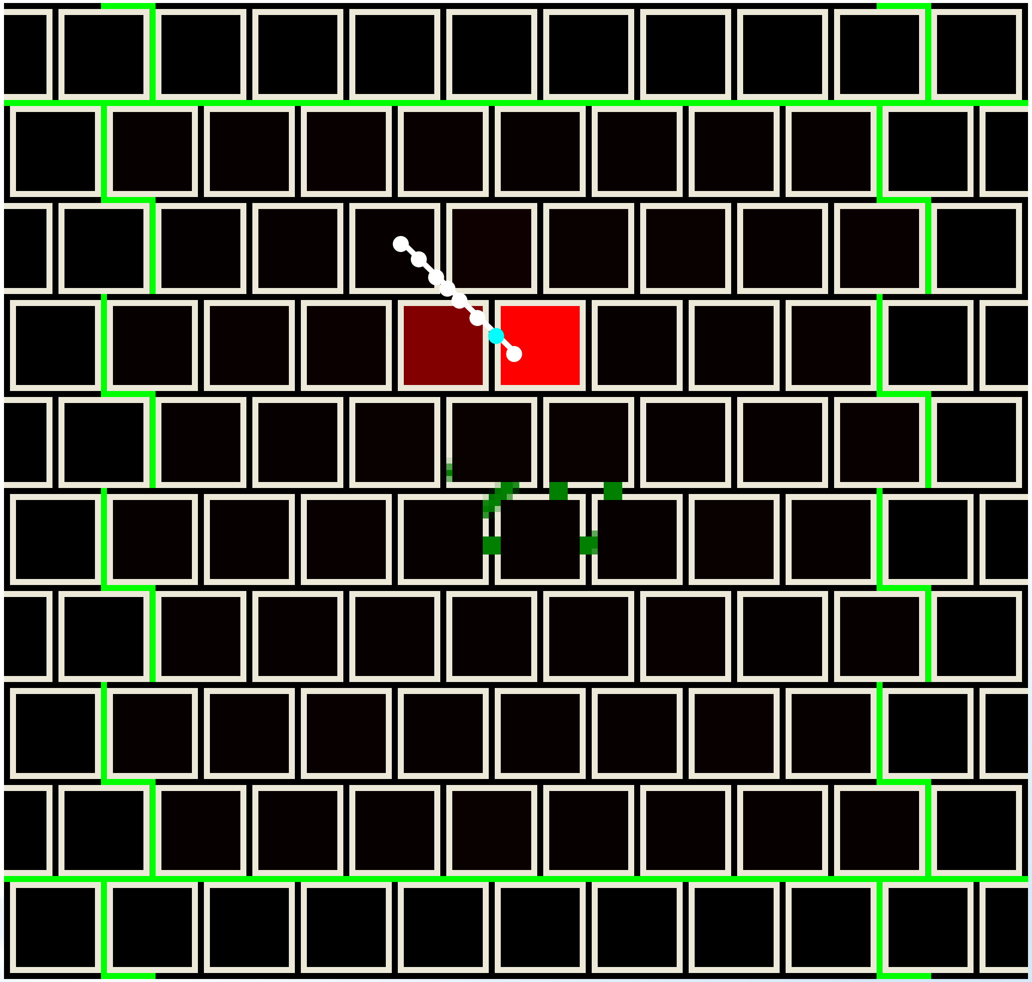


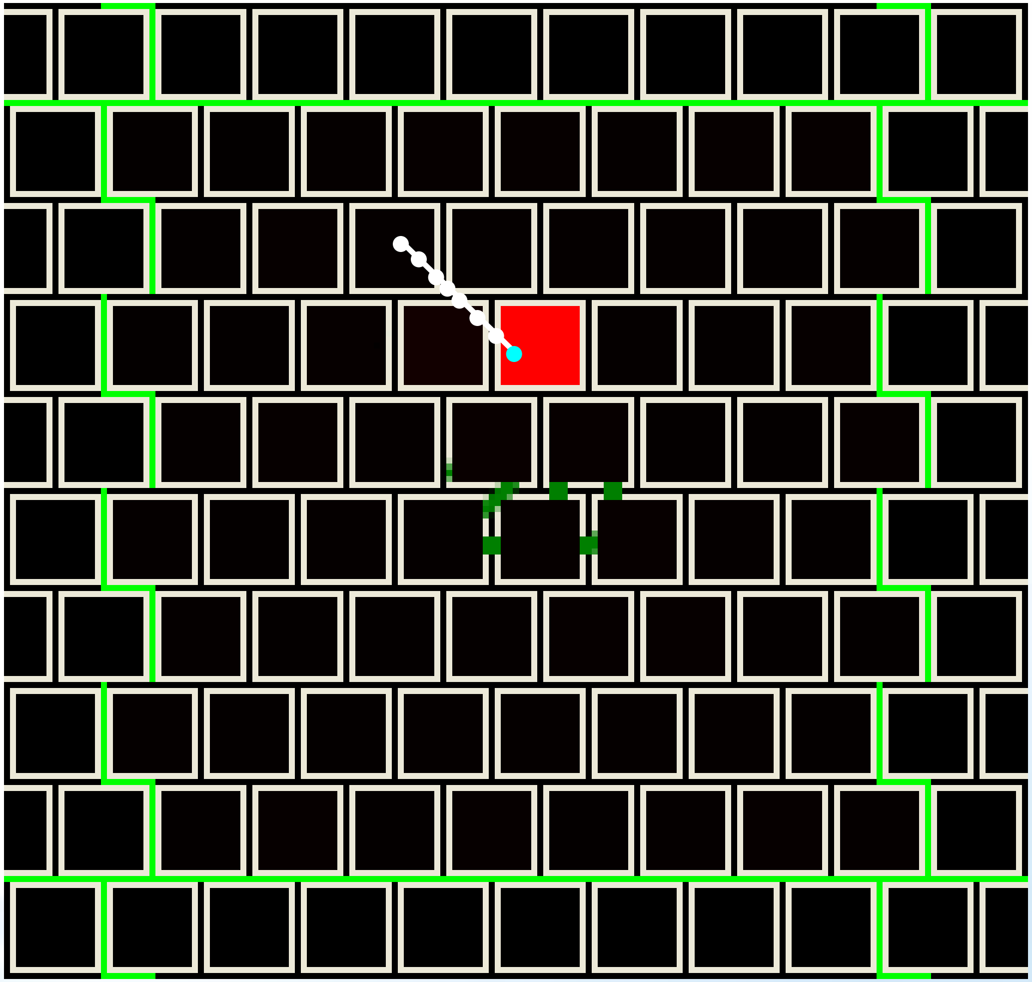










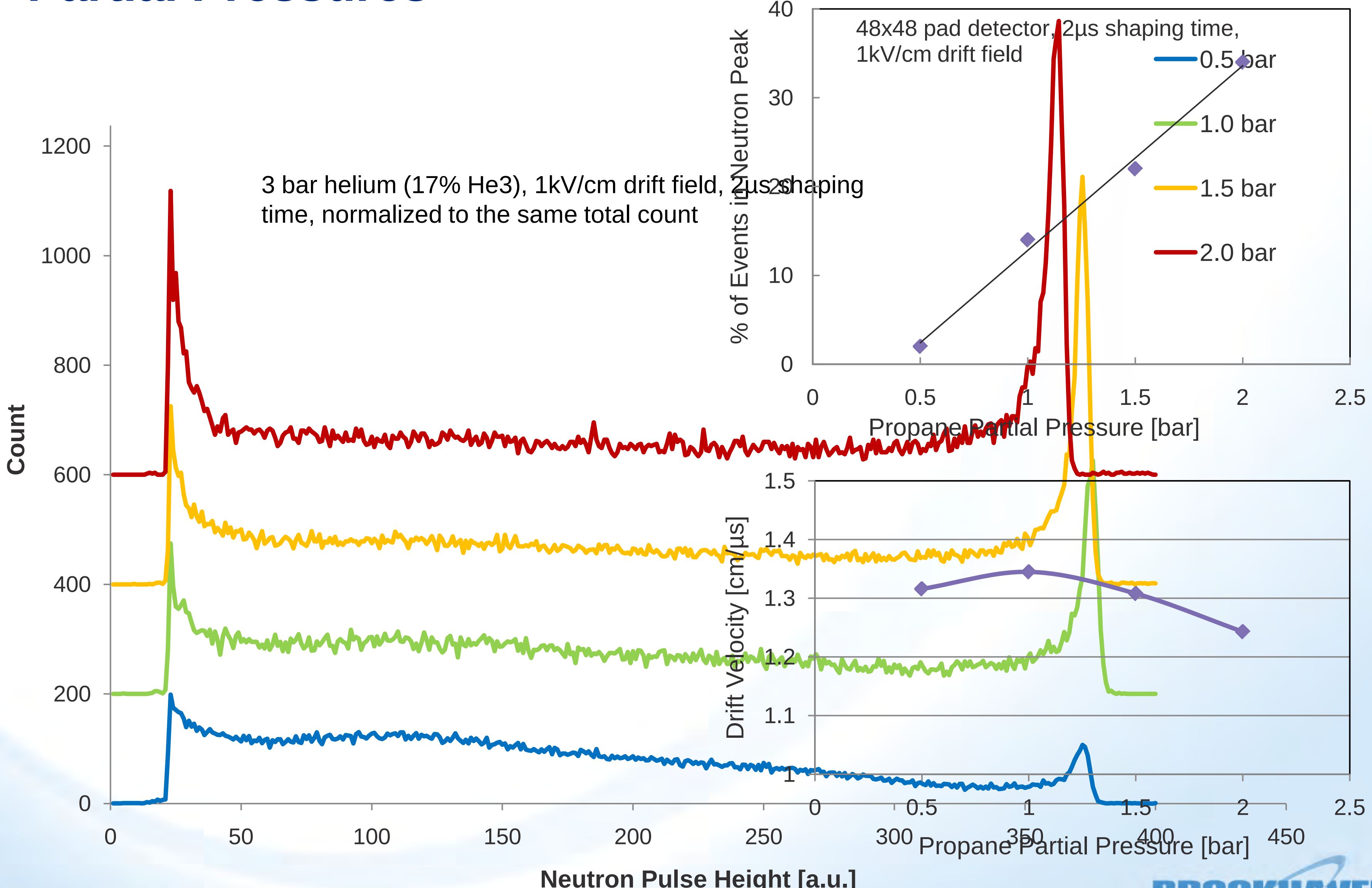


Concluding Remarks

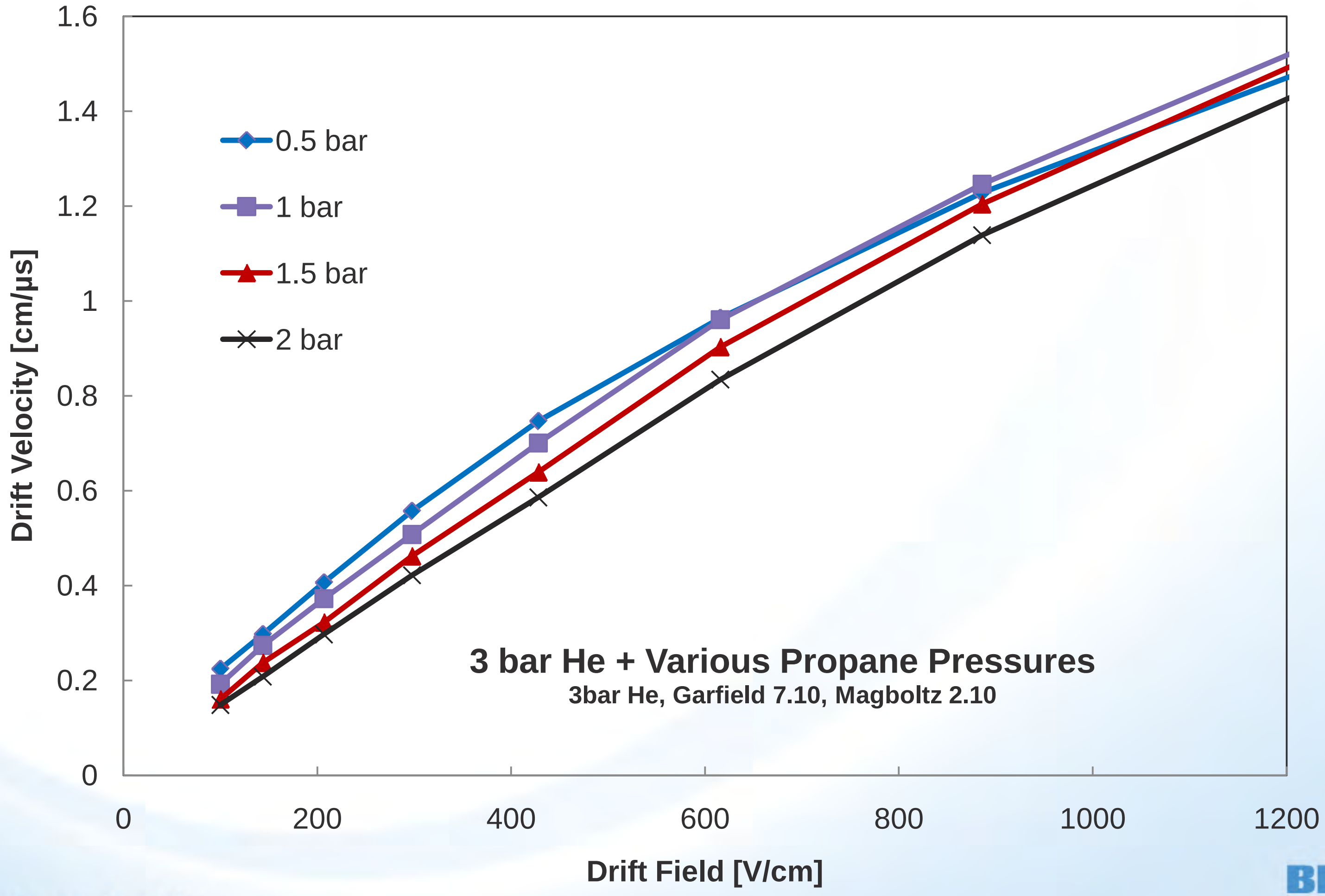
- 24cm × 24cm, 2304 channel neutron detector for SANS
  ultimately a detector: 1m × 1m, 40,000 channels, 10^8 s^{-1}
- High throughput: 5kHz per channel, 2.5 mm position resolution
- Ionization mode: no Frisch grid, no wires planes, extremely stable
- High efficiency for thermal neutrons, >50% for 2 – 10 Å
- Electronics inside gas volume – power supply/computer on outside
- Not feasible without ASICs
- Future efforts will explore limits of pad and ASIC density, with even higher throughput and better position resolution. Also possible use of BF_3 ($n + {}^{10}B \rightarrow {}^{7}Li + \alpha + 2.3$ MeV)
- This technology has ~ two orders of magnitude higher rate capability than existing technologies, and is extremely stable in the long term

Back-Up Slides

Neutron Pulse Height Spectra at Different Propane Partial Pressures



Electron Drift Velocity in These Gas Mixtures



Ultimate Energy Resolution for Thermal Neutron Peak

Let P = pulse amplitude, N = # electron/ion pairs, M = gain

Relative variance in P is $(\sigma_P / P)^2$, and its FWHM is given by:

$$\Delta E / E = 2.36\,(\sigma_P / P)$$

$$= 2.36\,[(\sigma_N / N)^2 + N^{-1}[(\sigma_M / M)^2]^{1/2}$$

$\sigma_N = (FN)^{1/2}$, where F = Fano Factor

$b = (\sigma_M / M)^2$ is the relative variance in gain (sometimes denoted as f):

$$\therefore \quad \Delta E / E = 2.36\, N^{-1}\,[(F + b]^{1/2}$$

1. Ionization Mode: $b = 0$

$$\Delta E / E = 2.36\,(0.2 + 0)^{1/2} / 3.10^4$$

$$\sim 0.6\%$$

2. With Gas Gain: $b \sim 0.6$

$$\Delta E / E = 2.36\,(0.2 + 0.6)^{1/2} / 3.10^4$$

$$\sim 1.2\%$$

3. Preamplifier noise also sets a lower limit to energy resolution:

ENC ~ 150 e rms = 353 e FWHM

$$\Delta E / E_{noise} = 353/(3.\,10^4) \sim 1.2\%$$