Advanced Neutron Detectors with Pad Readout

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KEY FEATURES OF ANODE PAD AND IONIZATION MODE

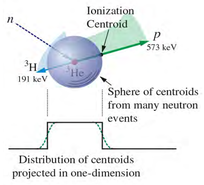
- High throughput: 5×10^3 n s^{-1} per channel, 1 → 2.5 mm position resolution
- Ionization mode: no Frisch grid, no wire planes, extremely stable
- Gas mixture of ^{3}He plus C_3H_8 (for stopping proton/triton)
- High efficiency for thermal neutrons, >50% for 2 – 10 Å
- Electronics inside gas volume. Only external equipment are power supplies and computer.
- Technique capitalizes on low-noise ASICs - not feasible without them
- Initial goal: 24cm × 24cm, 2304 channel neutron detector for SANS
- Ultimately a detector: 1m × 1m, 40,000 channels, 10^8 n s^{-1}
- Explore limits of pad & ASIC density for even higher throughput and resolution (use C_4H_{10})
- Work supported by DOE BES for Spallation Neutron Source

PRINCIPLE OF OPERATION

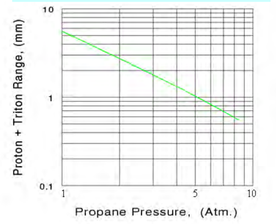
n + ^{3}He → p + ^{3}H + 764 keV

→ ~25,000-30,000 electron-ion pairs

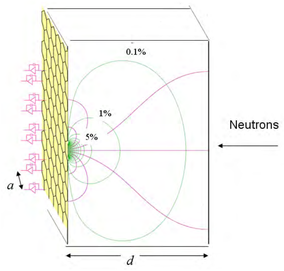
Neutron interaction



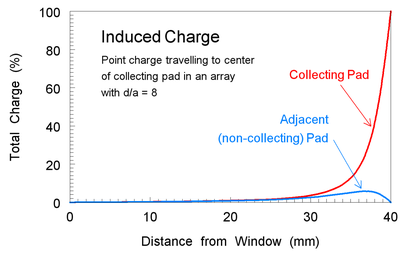
Combined Proton/Triton Range



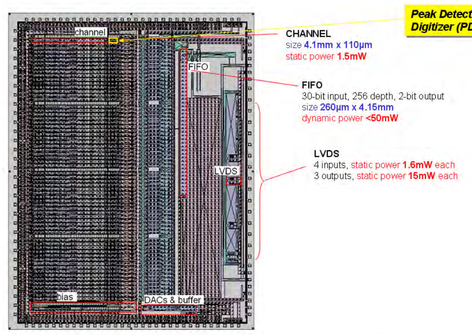
Contour plot of weighting field (red lines) and weighting potentials (green lines) for geometry in which pad spacing, *a*, is much smaller than conversion depth, *d*.



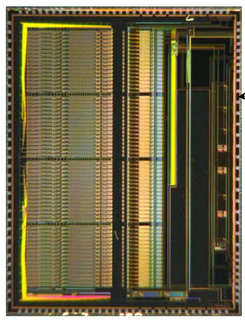
Induced charge on collecting and non-collecting pads for our geometry:
a = 5mm, d = 40mm.

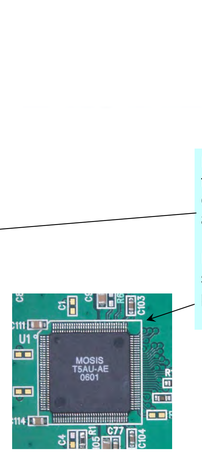


ASIC DESIGN AND PERFORMANCE



Final circuit layout of one ASIC, as viewed with software design tools:
- 64 channels
- transistors: 315,000
- 110 e^- rms noise
- 18 bit timing
- 8.5mm × 6.6mm
- static power: 150mW
- dev. time: 20 months

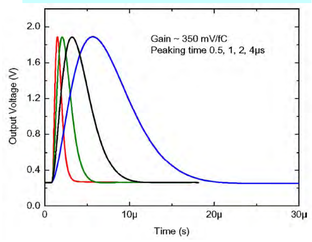




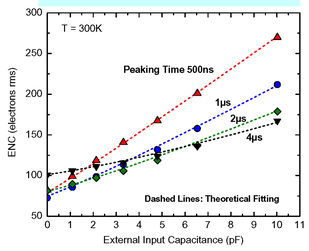
Photograph of silicon die, fabricated in 0.35μm CMOS. Die size: 8.5mm × 6.6mm

Die is encapsulated in a standard low profile quad package, 20mm × 20mm

Output waveform from one channel for input charge of 5 fC



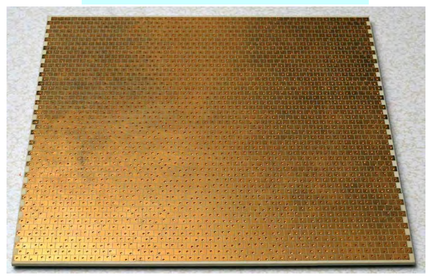
Electronic noise as function of load capacitance (~5pF per pad)



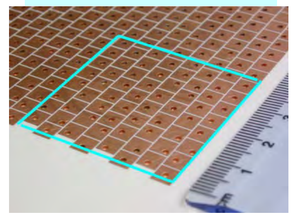
ANODE PAD BOARD

Examples of charge sharing between adjacent pads. Pads can have either hexagonal or square geometry. A choice of *square pads* with every other row *displaced by half a pitch* has been chosen to make tiling of sub-units the most practical

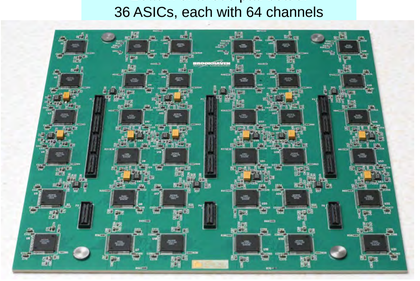
Top of anode pad board:
48 × 48 pads, or 2304 channels



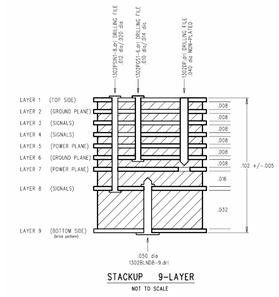
One corner of anode pad board, with outline of 8×8 pads that are connected to one ASIC

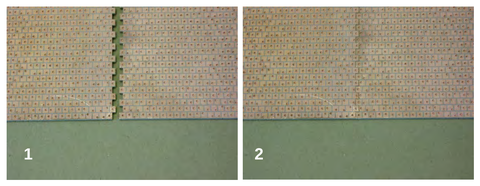


Bottom of anode pad board:
36 ASICs, each with 64 channels



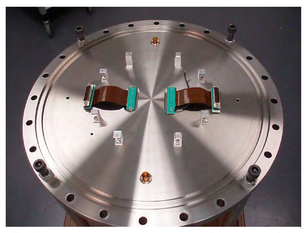
This electrode is a 9-layer board, fabricated by state-of-the-art printed circuit techniques



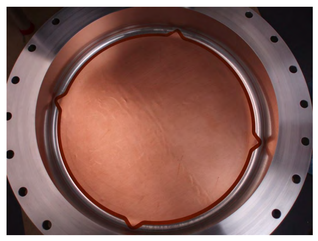


Tiling for larger areas has been demonstrated:
#1 shows laser-machined step-edges of two 48 × 48 pad boards, about to be interlocked.
#2 the two edges have been interlocked, yielding a smooth transition with connections intact.

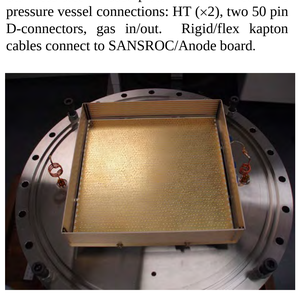
DETECTOR ASSEMBLY



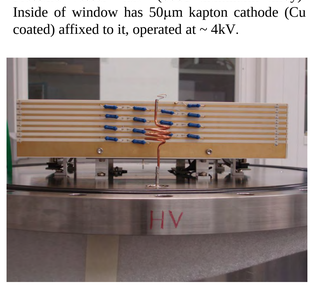
Stainless-steel base-plate which contains pressure vessel connections: HT (×2), two 50 pin D-connectors, gas in/out. Rigid/flex kapton cables connect to SANSROC/Anode board.



Pressure vessel "hat" (6061 aluminum alloy). Inside of window has 50μm kapton cathode (Cu coated) affixed to it, operated at ~ 4kV.



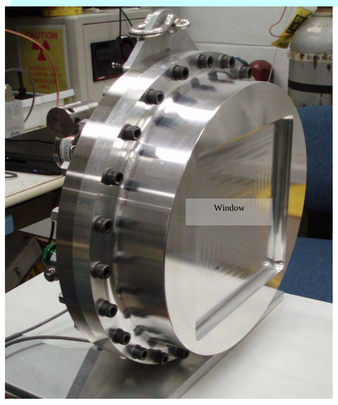
SANSROC (not visible) and anode boards in place, with field-defining electrodes on all four sides.



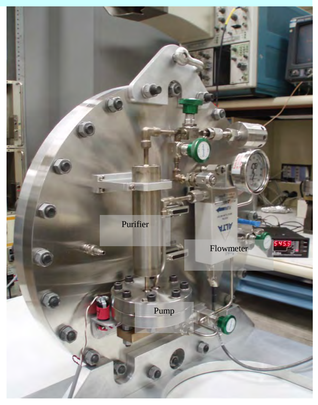
Side view, one field-defining electrode. Blue resistor chain provides voltage steps to each strip. Coiled copper wire provides electrical contact to Cu-coated kapton cathode.

Fully Assembled Detector

Front of Detector



Rear of detector



Sensitive Area = 24 cm × 24 cm

SYSTEM OPERATION

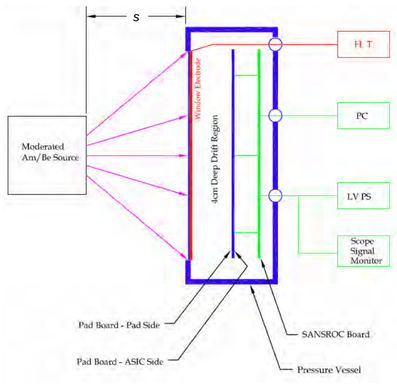
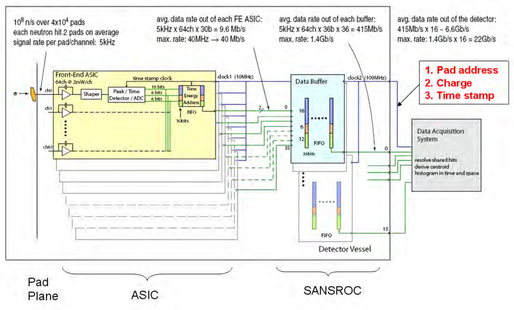
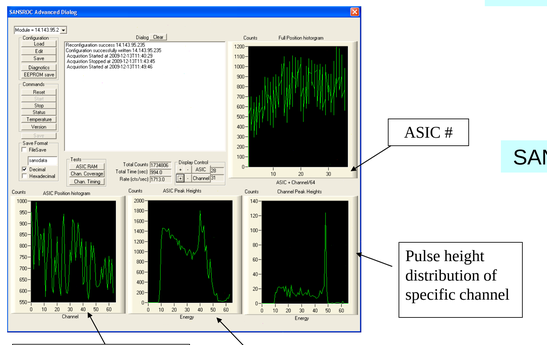


Diagram shows neutrons from moderated Am/Be source uniformly illuminating the full sensitive area of the detector, 24cm × 24cm. Distance "s " adjustable from ~ 0.1m to ~ 5m. Note minimal volume of equipment required outside the detector.

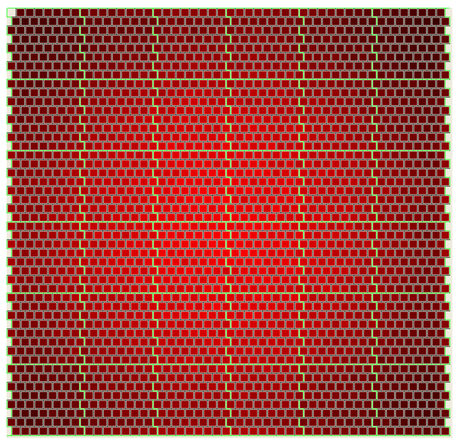


This diagram illustrates the flow of information from neutron conversion (~ 5fC) to data capture in data acquisition. System is shown in 64-channel groups. Locations of anode pad plane, ASICs and SANSROC are indicated. Each pad hit generates a 30 bit word containing:
1. Time Stamp (100ns)
2. Total Charge
3. Address

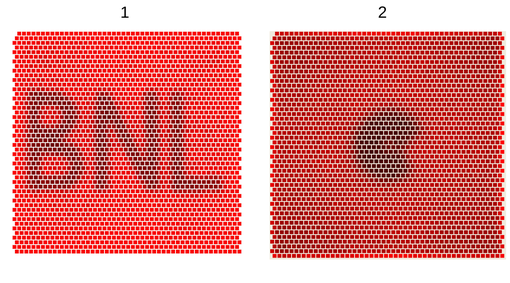


SANSROC Control

SOME KEY RESULTS

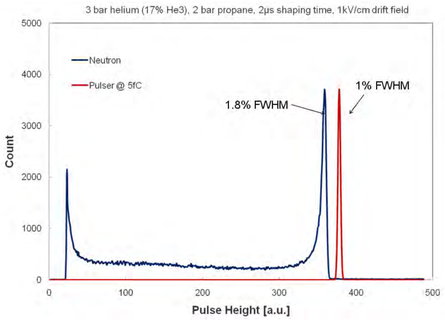


Response of entire 48 × 48 pad detector and full acquisition system to uniform illumination with thermal neutrons. Neutron source is very close to detector window, *s* ~10cm, and thus there is a fall off of neutron intensity from center to the sides.

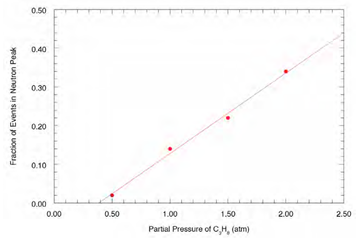


Same image area as above.
#1 shows image of "BNL" letters formed from Cd.
#2 shows image of Cd disc, with 90º sector removed.
Measurements were made with s ~ 5m to reduce parallax.

Pulse height distribution, from one pad, of thermal neutron signals. Energy resolution (1.8% FWHM) is the best ever measured in a gas-filled detector operating without a Frisch grid



Fraction of events in the full neutron peak as function of propane partial pressure



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