Neutron Imaging Camera

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Neutron Imaging Camera

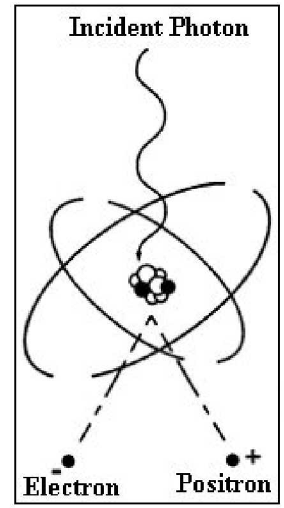
- Basis of NIC technology is 3-D tracking of charged particles in a gaseous medium.
  - Comprised of a Time Projection Chamber (TPC) with 2-D Micro-well readout (MWD).
- Unique technology; distinct from traditional methods for neutron imaging.
- Versatile Applications
  - Passive and active standoff interrogation
  - Space/Solar physics
  - Neutron, gamma, & charged particle detection

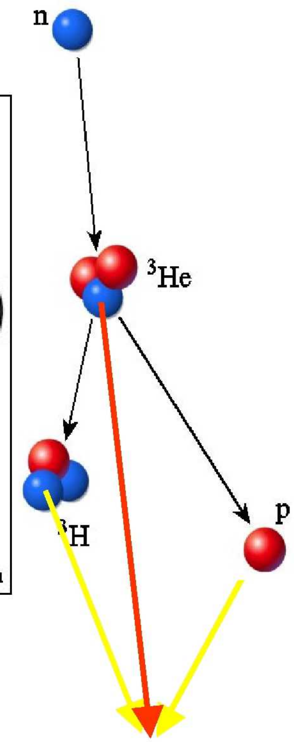
Methods of Neutron Imaging

- As with gamma-ray imaging, neutron imaging relies on the detection of secondary products of neutron interactions in matter.
- Take advantage of interactions with large cross sections:
  - Inelastic : $^3He(n,p)^3H$
  - Elastic : (n,p)
- Use measured quantities from secondary tracks (arrival time, (x,y,z),$\vec{p}$,E) to reconstruct initial direction & energy of neutron.

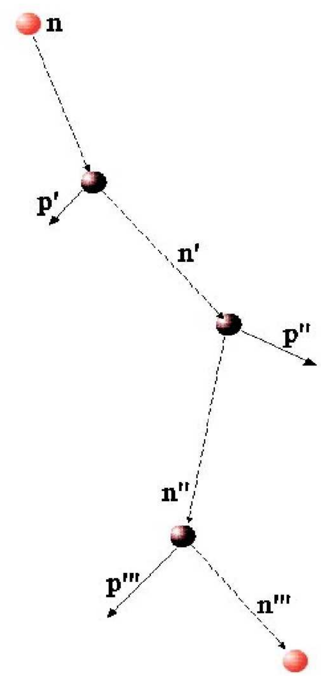
Neutron Interactions

- $^3He(n,p)^3H$
  - Track p & ^3H
  - Vertex identification allows for reconstruction of *initial neutron momentum vector*





- Elastic (n,p) scatter
  - Track single & multiple scatter protons
  - Use $\vec{p}_p$ to reconstruct initial neutron momentum vector
- Key to NIC technology is measuring secondary by-product *momentum vectors*.



NIC Advantage for (n,p) tracking

- Measure proton energy, Ep_1 & Ep_2
  + Interaction locations, L_1 & L_2
  - 1 scatter → neutron detection
  - 2 scatters → 2π sr location, En > Ep1+Ep2

  + Momenta of scattered protons
    → Energy and direction of neutron

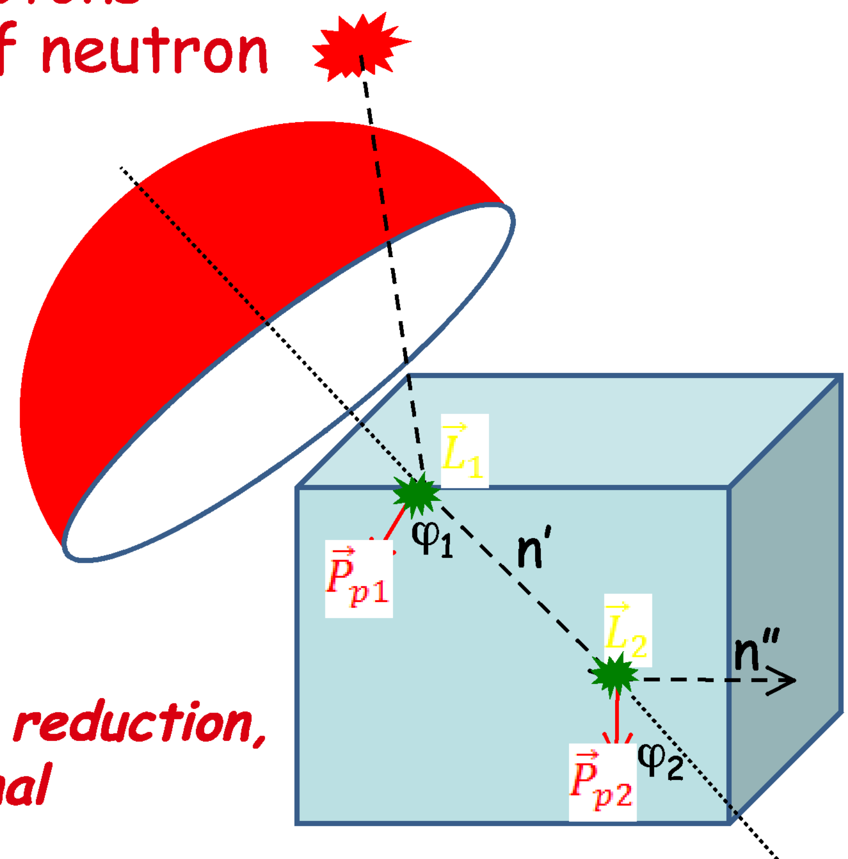
$$\cos\varphi_2 = \vec{P}_{p2} \cdot \vec{P}_{n'}$$

$$E_{n'} = E_{p2}/cos^2\varphi_2$$

$$\vec{P}_{n'} = \sqrt{2m_n E_{n'}}\,(\vec{L}_2 - \vec{L}_1)$$

$$\vec{P}_n = \vec{P}_{p1} + \vec{P}_{n'}$$

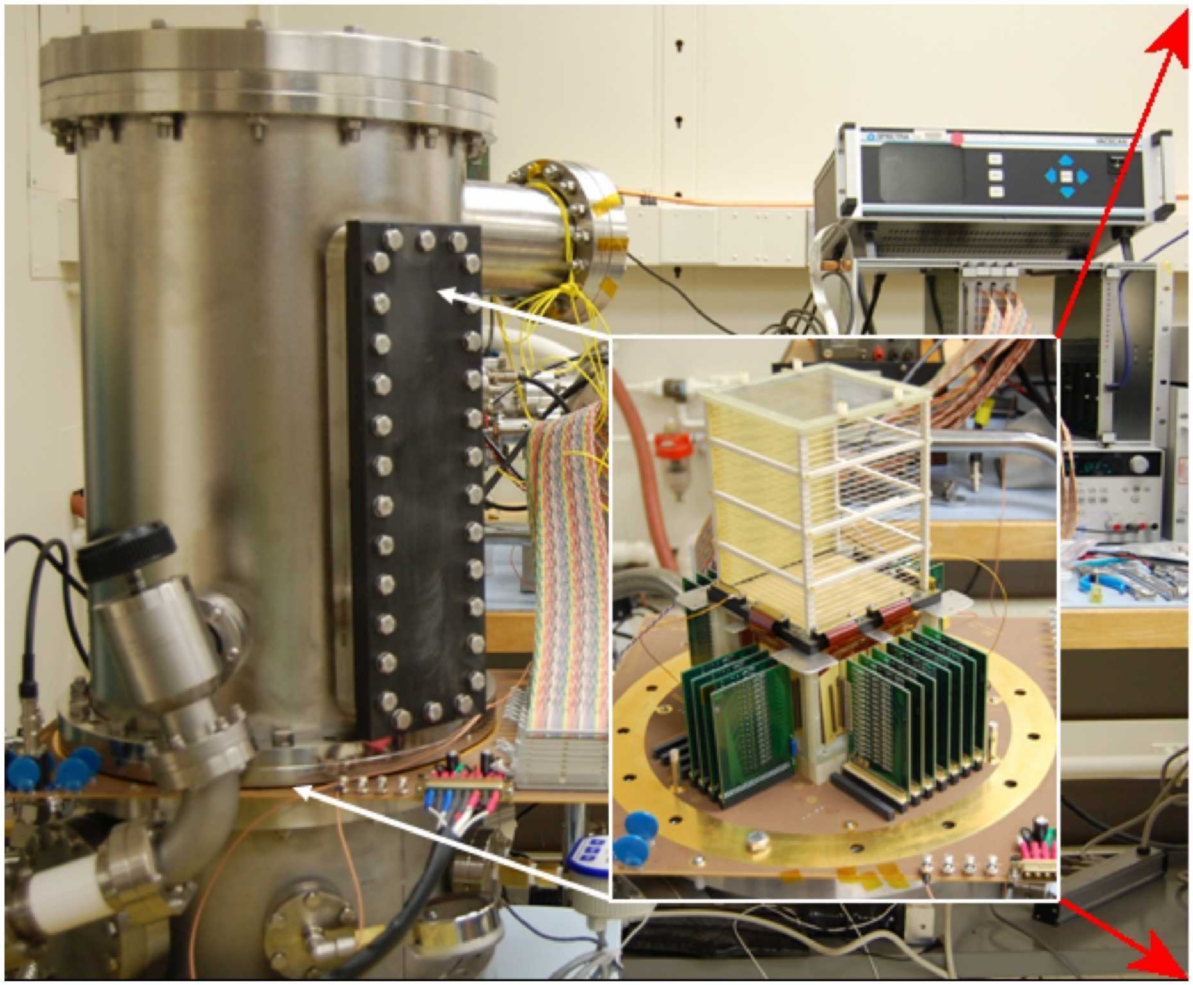
$$E_n = (\vec{P}_n \cdot \vec{P}_n)/2m_n$$

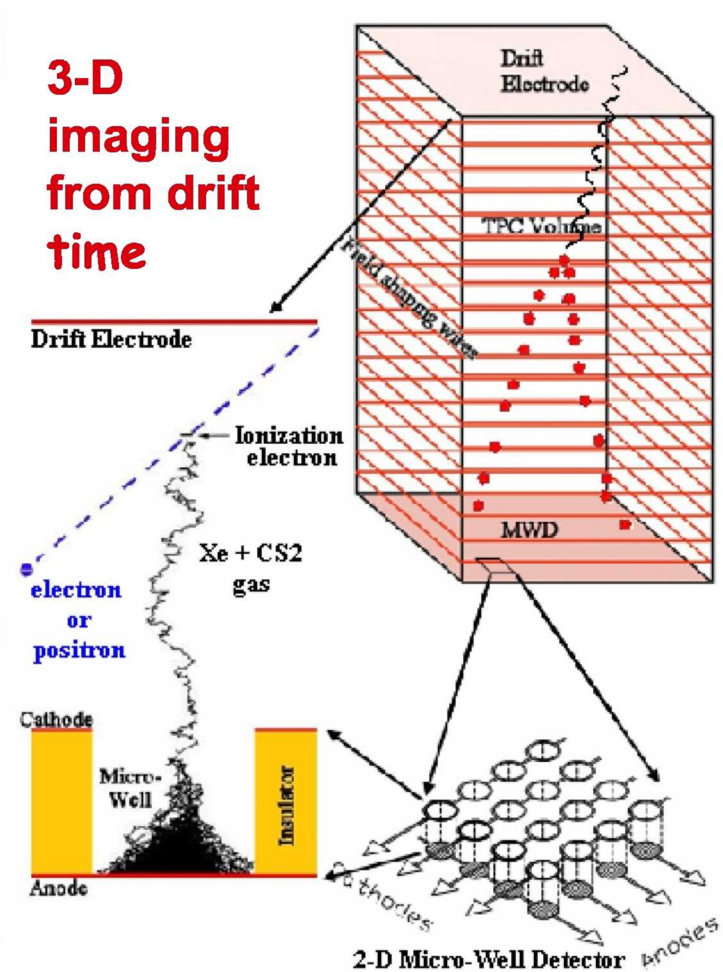


Increase in sensitivity, background reduction, and angular resolution, omnidirectional

NIC/3-DTI Theory of Operation

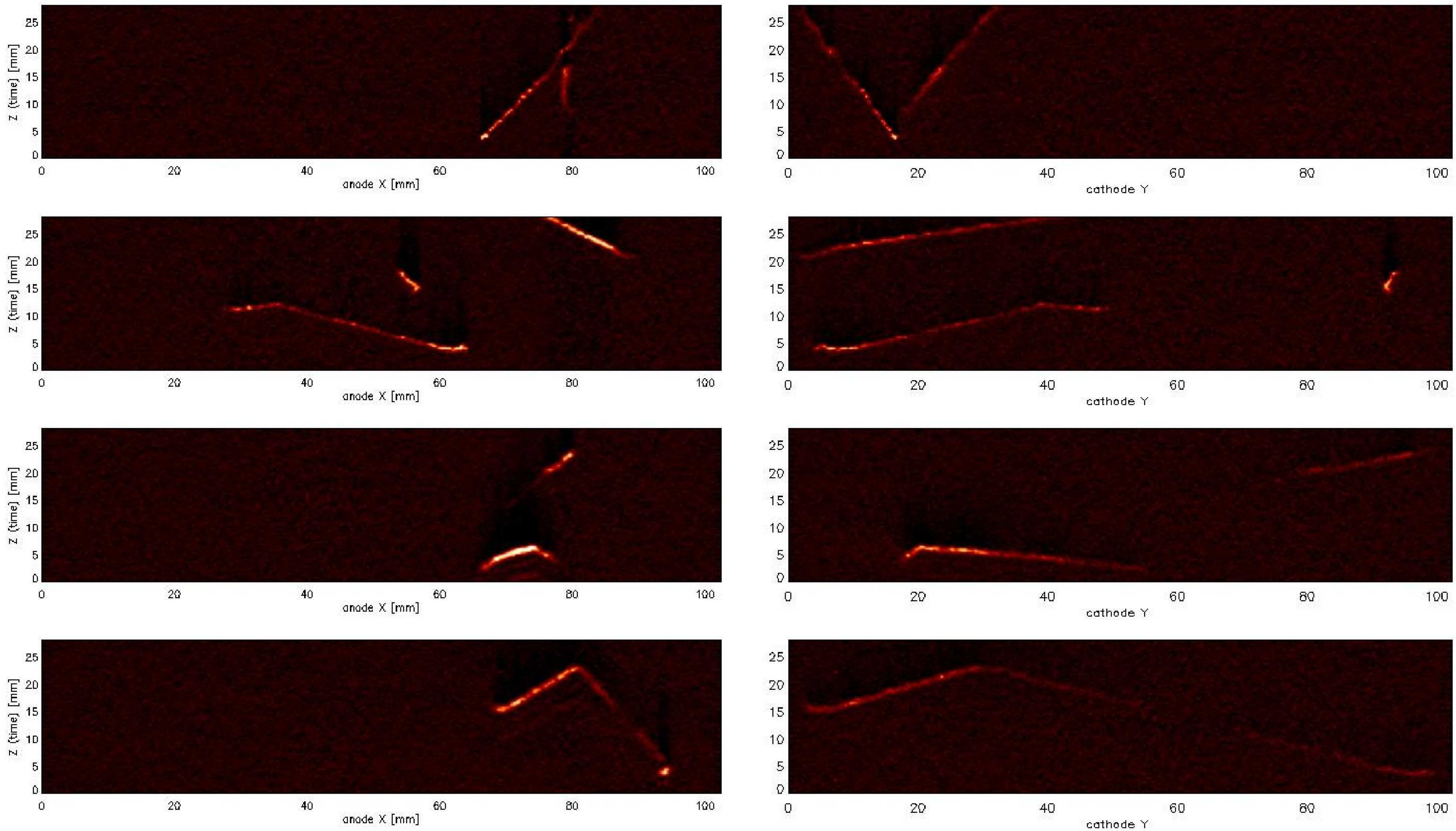
- **Ionization chamber**: Large-volume time projection chamber (TPC)
- **Proportional counter**: 2-D gas micro-well detector (MWD) readout
  - Low density, homogenous medium (low energy particle tracking)
  - 100 % active detector volume (no scattering in passive material)





Successful NIC Demonstration

^{3}He based NIC



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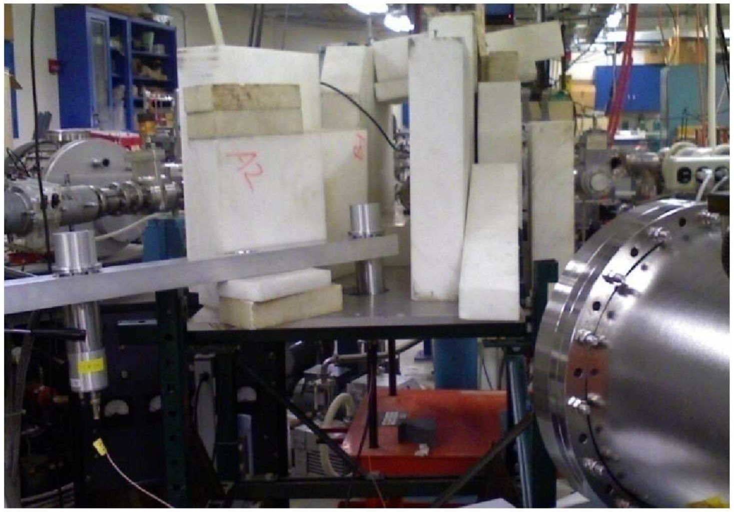
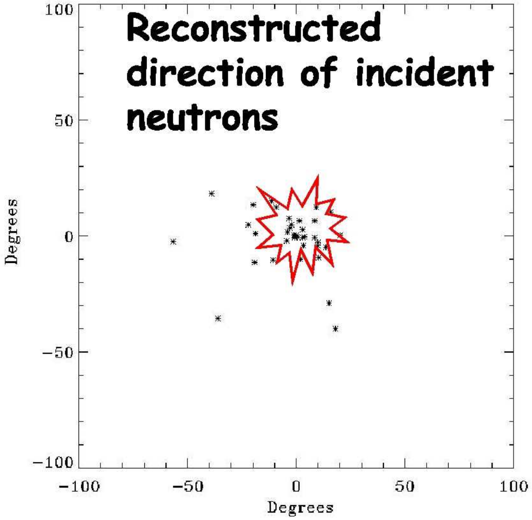
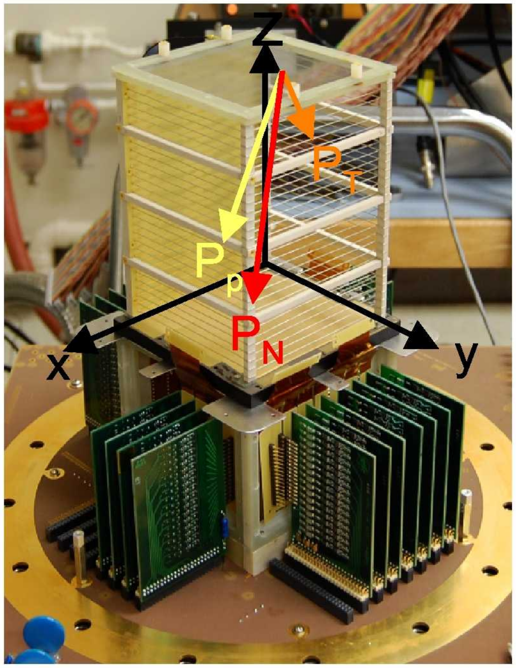
Neutron Imaging

- Imaged 1 MeV neutrons at the NSWC PIAF
- Neutron momentum reconstructed from p,T fragments
- Angular resolution θ_{68}=~8 deg

➢ **We are looking at alternatives to ^{3}He including H_2 & Methane-based NIC**







MWD Construction

MWDs are "double sided flex circuit boards" with orthogonal (2-D) traces on top & bottom.

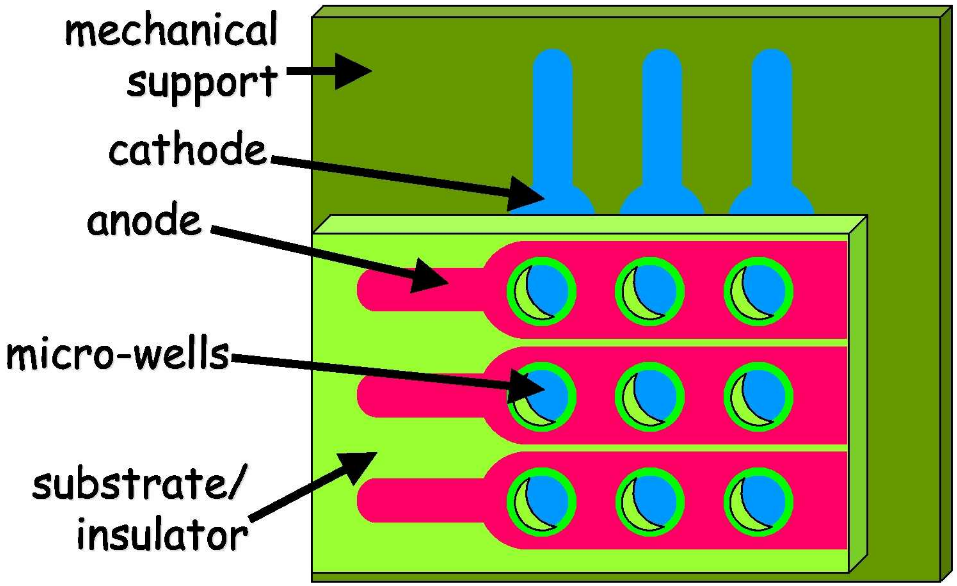
Micro-wells are holes, machined through substrate concentric with openings in cathodes.

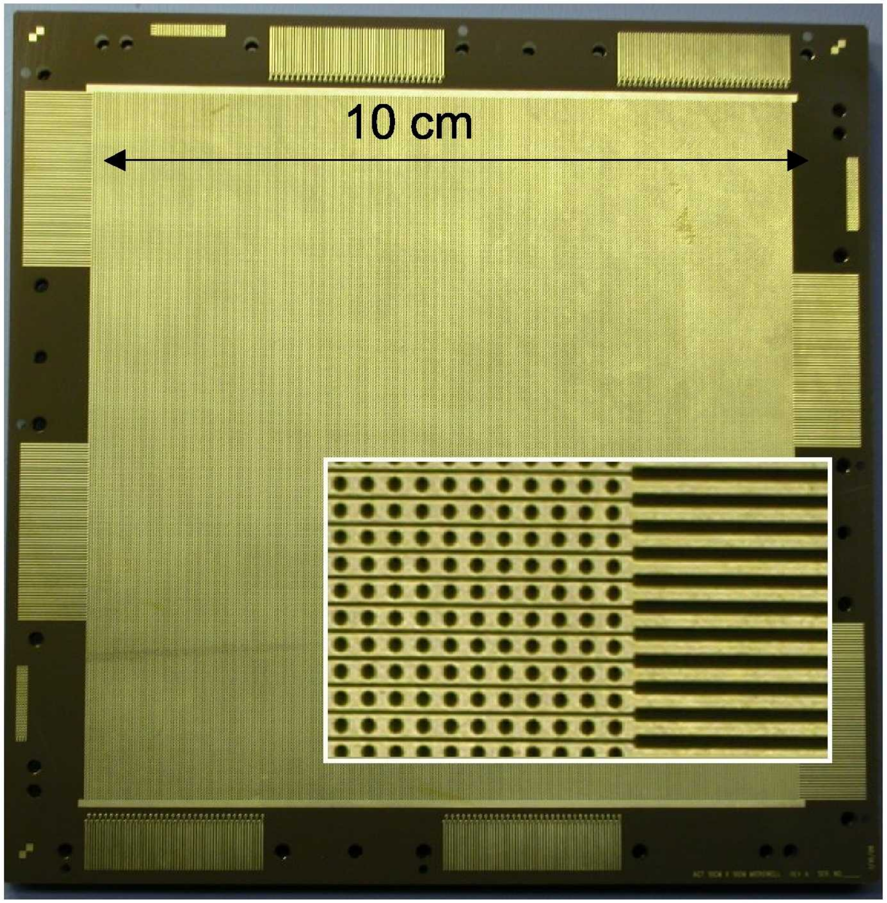
Well Pitch: 400μm (16 mil)

Well Diam: 200μm (8 mil)

Well Depth: 200μm (8 mil)

Cathode Gap: 50μm (2 mil)
goal 12μm (0.5 mil)



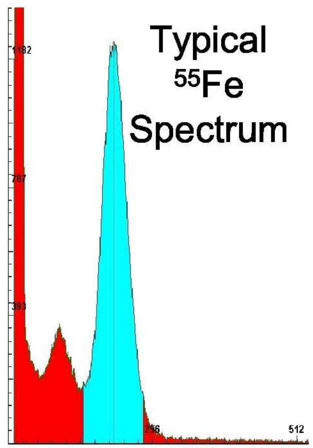


MWD Fabrication

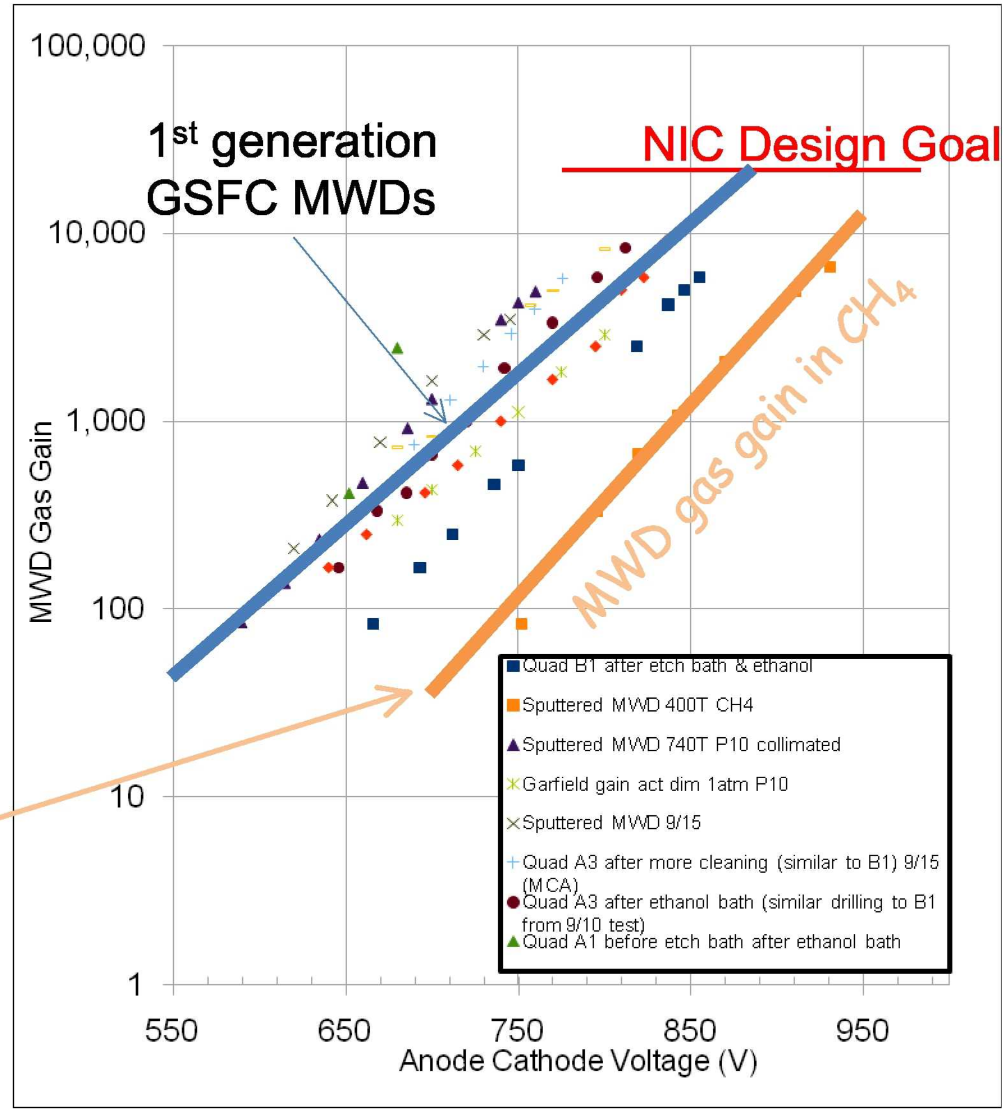
- Laser micro-machining facility is fully functional
- Machining sections of 10×10 cm^2 substrate area to optimize technique
  - Many aspects of fabrication effect MWD performance (gas gain)
    - Laser ablation technique
    - Surface cleaning
    - Well diameter wrt to cathode hole diameter
    - Well aspect ratio
- 1 Day turn-around
  - Rapid testing of techniques

GSFC MWD Performance

- 2nd gen GSFC MWDs
- Gain measurement
  - Collimated ^{55}Fe source, P-10 at 1 atm
- Max gain limited by breakdown

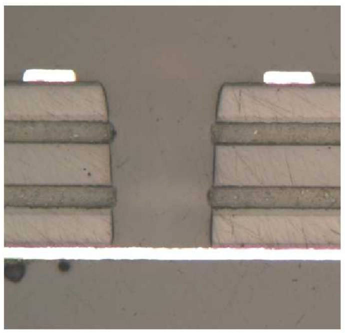


- **Works with CH_4**
  V_{AC} higher
  - CH_4+CS_2 tests soon

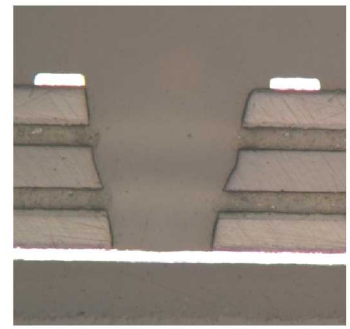


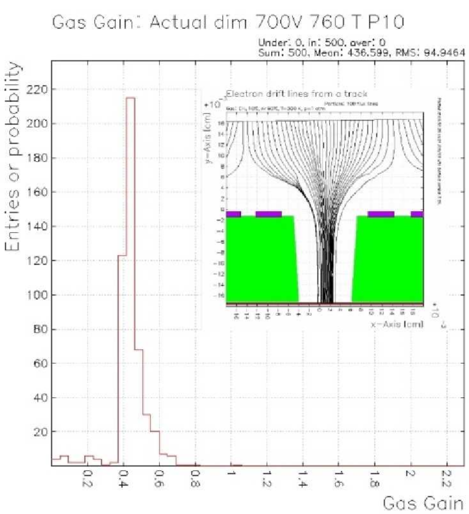
GARFIELD Simulations

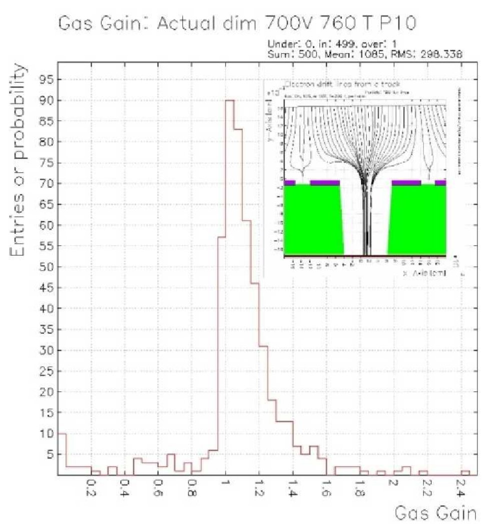
- Model various gas mixtures and well geometries to optimize MWD performance and fabrication
- Results indicate strong dependence on well shape

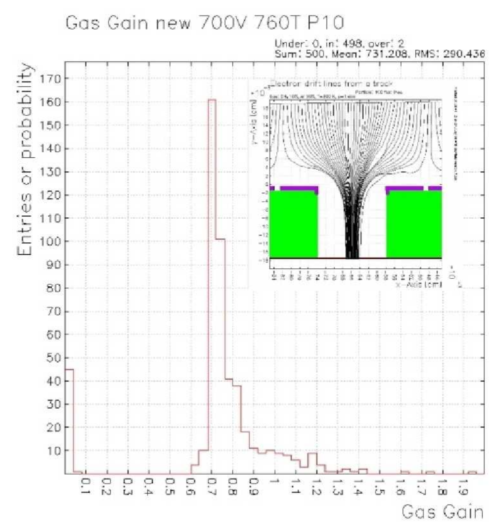


P-10 at 760 torr, V_{Bias}=700V
400V drift potential
Histograms from 500 Monte-Carlo electrons drifted from a line 200 mm above the center of the well









30x30 cm^2 NIC Development

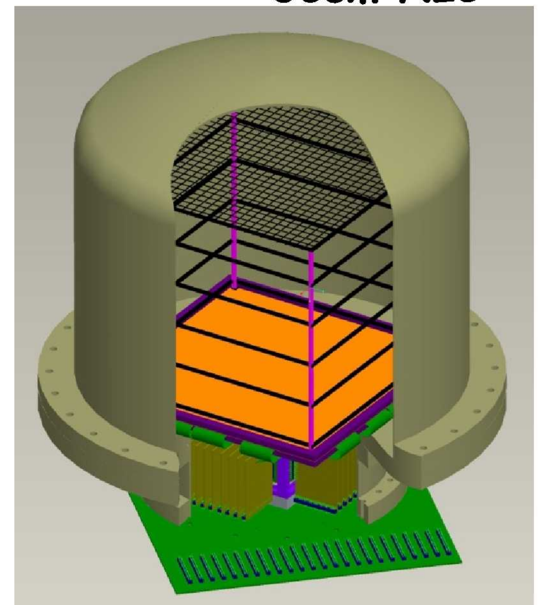
- Produce 30x30 cm^2 NIC for field testing by early 2010.

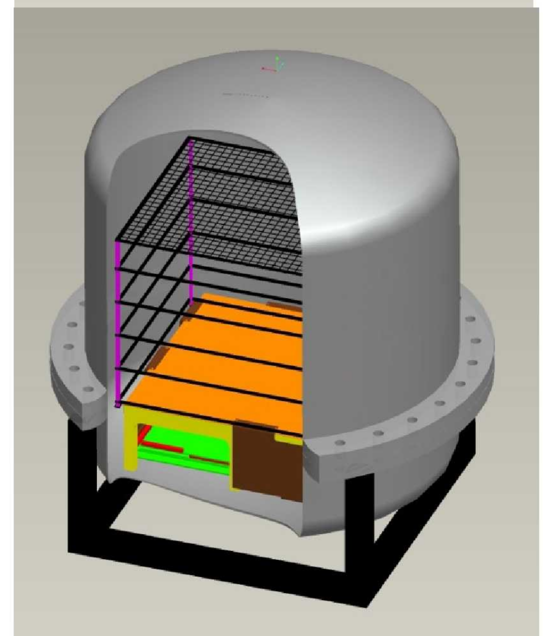
- 30 cm MWD with 10 cm electronics
  - 1/3 resolution readout (512 channels)
    - Gang 3 electrodes to one FEE channel
  - Snapshot and semi-streaming data mode

- 30 cm MWD with 30 cm electronics
  - 1/2 resolution readout (768 channels)
    - Every other electrode read out, limited by number of ASICs
  - Streaming data mode

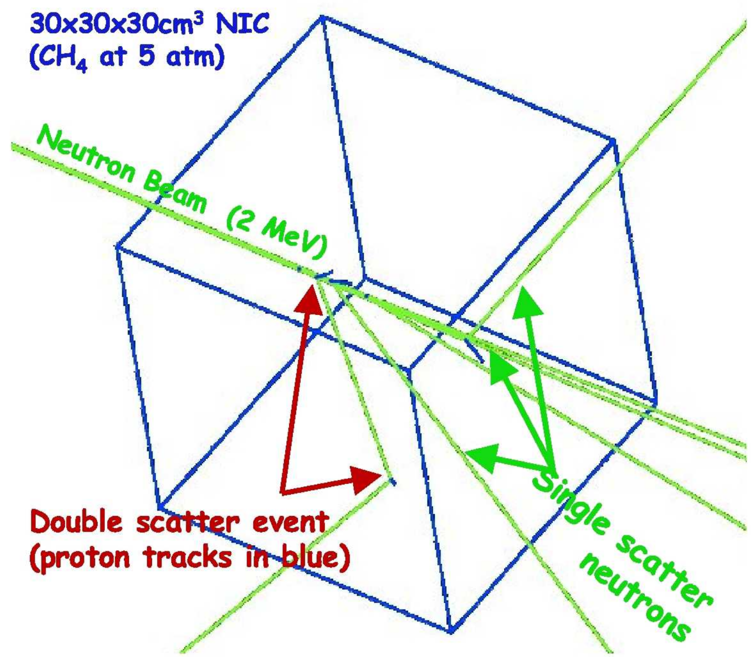
- Full resolution readout (1536 channels)
  - Additional ASICs, not before Jan 2010

30cm NIC





GEANT4 Simulations



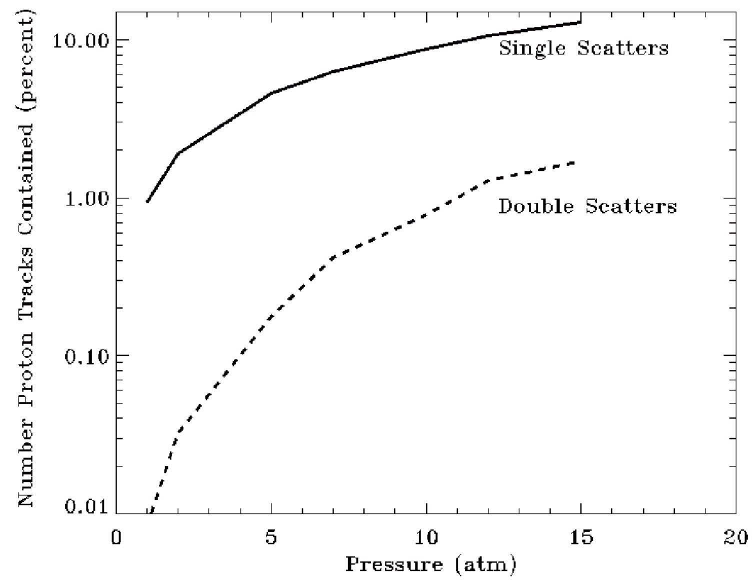
- Simulate (n,p) double scatter events within NIC
  - Assume NIC is filled with CH_4
  - Neutron beam:
    - Point source or uniform illumination
    - Mono-energetic or representative of a radioactive source, e.g. ^{252}Cf
  - Track all single & double scatter events
- Generate simulated events for image reconstruction software development
- Reconstruct image plane using simulated events
  - Add instrument response

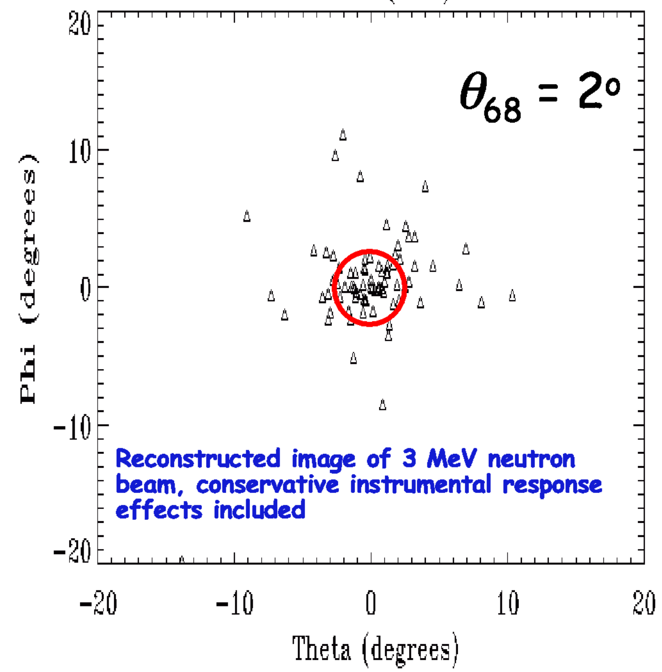
NIC Efficiency Estimate

30 cm NIC, 3 MeV neutrons

- Probability of interaction ~0.5%
- ^{3}He at 3 atm
  - Single interaction, PSF: θ_{68} = ~5°
- CH_4 at 5 atm
  - Double scatter, PSF: θ_{68} = ~2°

- Imaging reduces contribution of the background
- Improves sensitivity

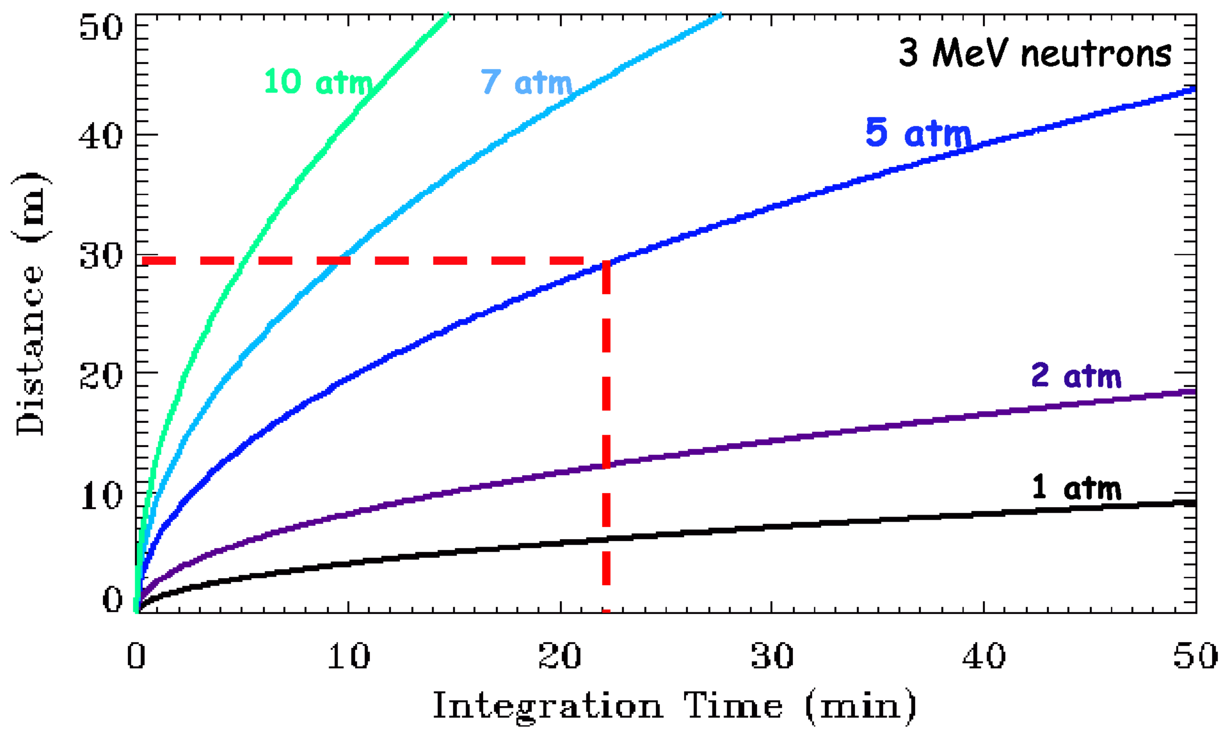




NIC Sensitivity

- Evaluate NIC sensitivity to 20 microCi ^{252}Cf source.
- Consider Omnidirectional NIC (all four sides of square 30x30x30 cm^2 active volume).
  - Compute cosmic ray background intensity accounting for zenith dependence (Moser et al. 2005).
  - Assume 25 square degree resolution within field of view, resulting in ~1100 pixels over entire field of view
  - Assume NIC properly identifies every interacting neutron and choose only proton tracks that are fully contained with NIC
- ***Determine the integration time versus source location such that NIC identifies a source with a 1/1000 probability for false positive.***

* Trade Study underway to optimize NIC Sensitivity



NIC Field Testing

- NIC 30 cm prototype completed in early 2010
  - MWD Optimization (GARFIELD and empirical studies)
  - Gas studies for methane-based NIC
  - NIC design optimization based on GEANT4 simulations
- GSFC Field Tests
  - D-T generator
  - 10 mCi ^{252}Cf source
- NSWC Field Tests
  - D-T generator field tests
  - NSWC/PIAF tests
- ONR funding to investigate active and passive integration of NIC on Naval platforms