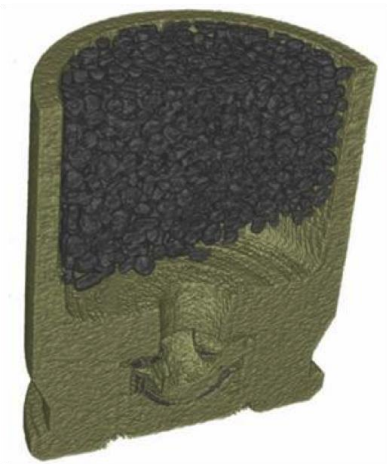
Development of a high resolution position sensitive MCP-PMT detector

National Nuclear Security Administration

Personnel : Mr. Blake Wiggins (fourth year graduate student), Dr. Davinder Siwal (postdoc), Romualdo deSouza (PI)

Neutron imaging

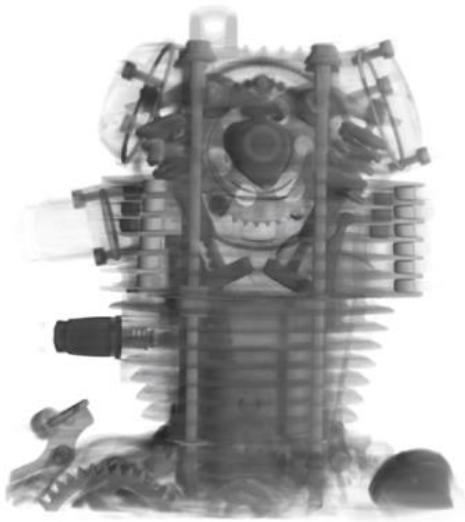


Individual gunpowder grains inside a bullet

W.B. Feller

Neutron and Photon Detector Workshop 2012

Good position and time resolution are necessary in high quality imaging!



A motorcycle engine

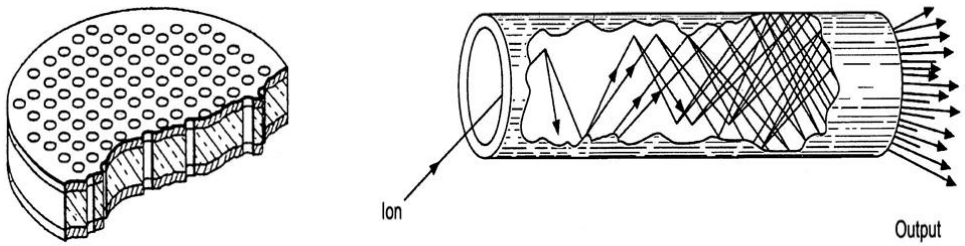
Courtesy of PSI

Whether detecting photons, electrons, or ions ultimately one is inevitably dealing with electrons.

Goal: Develop a detector with single electron sensitivity that has sub-millimeter position resolution, sub-nanosecond time resolution and the capability of resolving two spatially separated, simultaneous electrons.

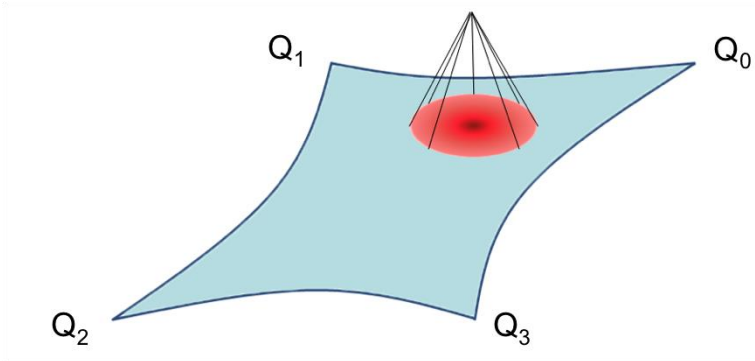
Existing technologies

Due to its large amplification and nanosecond time response the microchannel plate detector is an ideal tool for realizing this goal.



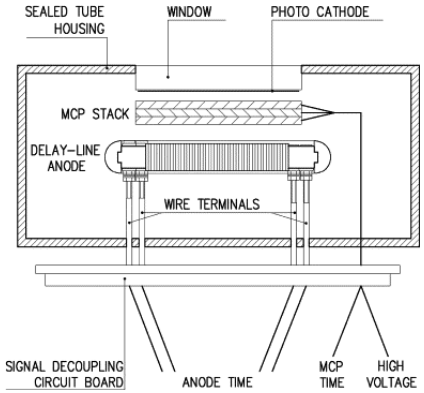
- Millions of leaded glass tubes 2-10 μm in diameter act as secondary electron emitters
- Applied voltage results in an electron producing an avalanche with typical amplification of approximately10^3 per plate

Resistive anode approach



Charge cloud from MCP is deposited on a resistive sheet (Quantar Technology). The charge is readout from the four corners, which provides a measure of the position ("charge centroiding").

Helical delay line approach



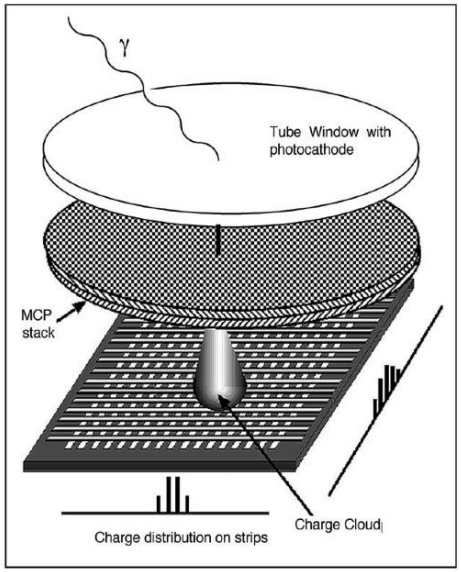
A. Czasch, J. Milnes, N. Hay, W. Wicking, O. Jagutzi, Nucl. Instr. Meth A 580 1066 (2007)

A helical delay line acts as the **anode** providing a measure of the position in one dimension.

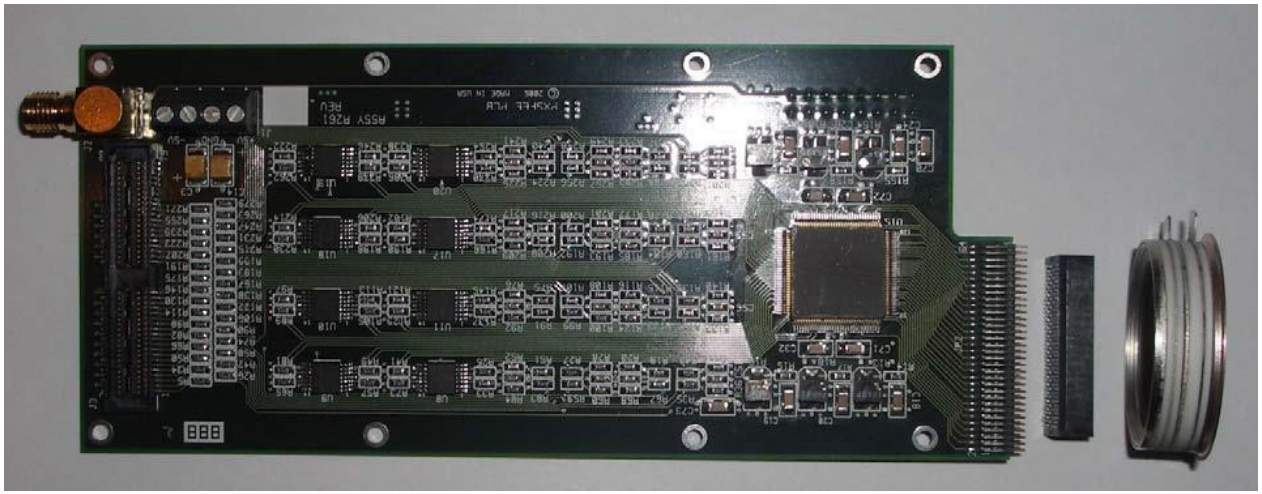
Existing PS-MCP technologies

Cross strip anode approach

O. Siegmund et al., Proc. Adv. Maui Optical and Space Surveillance Technolgies Conf. E69 (2010)



O. Siegmund et al, NIM A**610** 118 (2009)



While this approach achieves a resolution of 10-20 μm FWHM, it has the disadvantages of:

- Complex readout electronics (16 strips shown above)
- High power consumption

In contrast, the approach we will pursue (using induced signals) is characterized by:

- Fast signal
- Simple readout
- Multi-hit capability
- Low power consumption
- Senses (does not collect) the electron cloud

Signal to background (S/B)

- Typical measurements of position resolution involve use of large incident signals e.g. 1,000 incident photons [Floryan Rev. Sci. Instr. 60 (1989) 339.] to achieve a resolution of 50-70 μm.

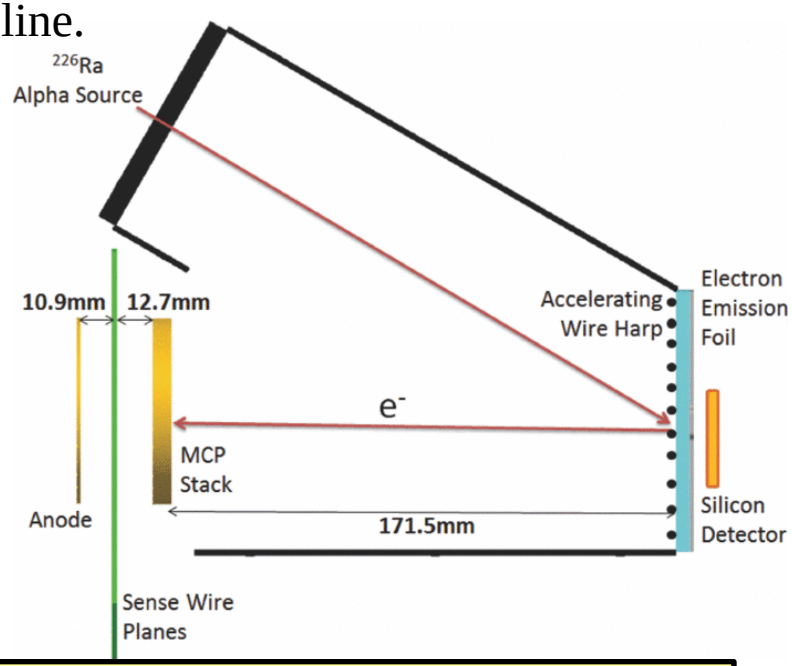
- Detection at low S/B is important because:
  - Enables imaging of faint images (e.g. astronomy)
  - Reduces radiation exposure (e.g. medical imaging)
  - Improves sample processing time (e.g. neutron radiography)

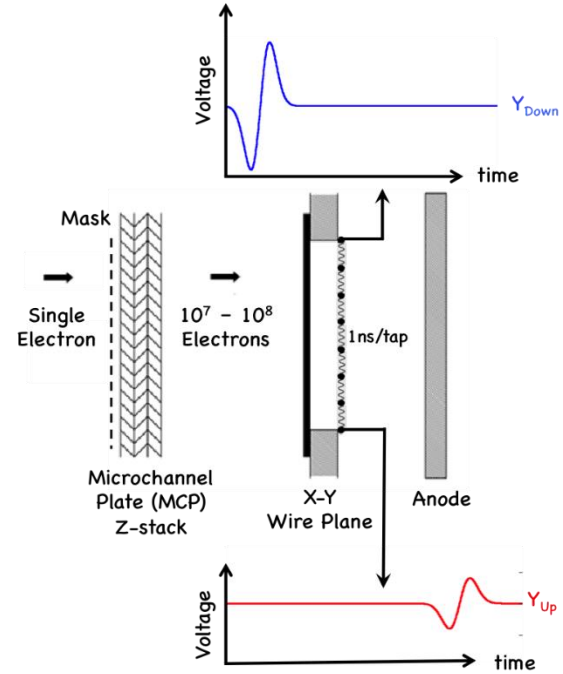
What position resolution is achievable at low S/B?

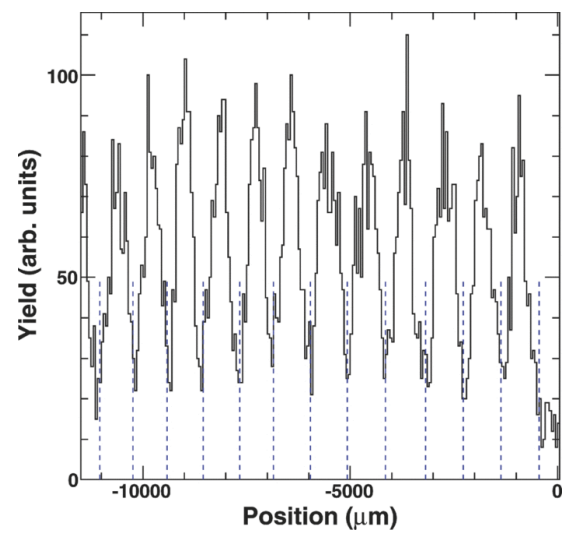
After considering other approaches we decided that the approach of generating an electron via bombardment of a foil by an α particle is a good approach since the distribution of ejected electrons is peaked at a single electron.

Introduction to the induced signal approach

- Amplification of a single electron to a pulse of 10^7 or 10^8 electrons is sensed by a wire plane (2 orthogonal planes can provide 2D).
- Wires in the sense wire plane on a 1 mm pitch are connected to taps in a delay line.
- Position is related to the time difference of the signal arriving at the two ends of the delay line.



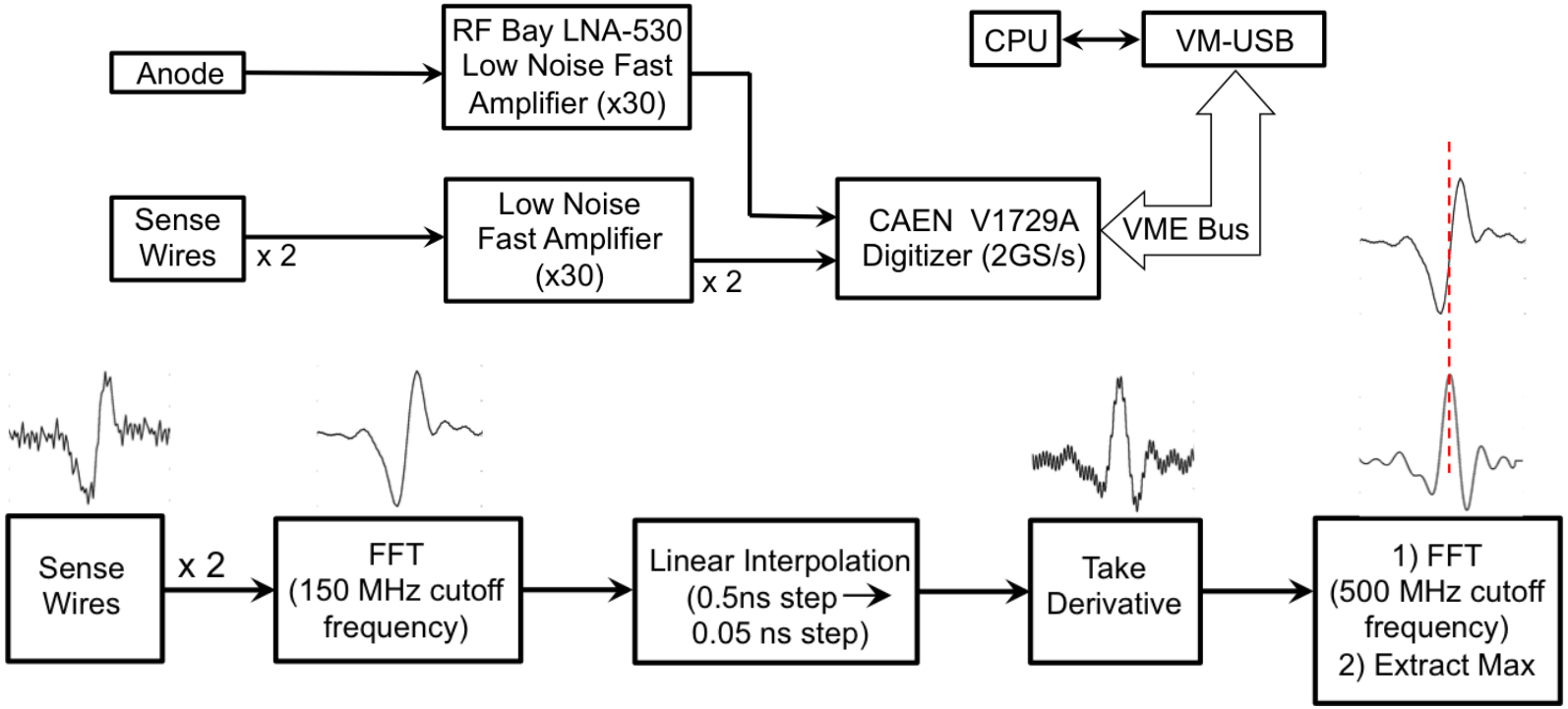




Using this approach a position resolution of 466 um (FWHM) was initially realized

R.T. Desouza et al., Rev. Sci. Instr **83** 053305 (2012)

Improving the induced signal approach with Digital Signal Processing (DSP)



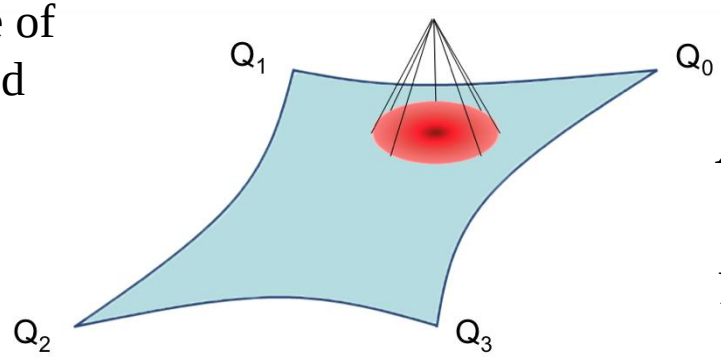
With better signal analysis (DSP)

- a position resolution of **115 μm (FWHM)** is achieved (just in the last couple of months!).
- To date only the zero crossing point in the induced signal has been utilized. However, the entire pulse shape contains information. Can this be exploited? **To accomplish this requires an understanding of the dependence of the detailed shape of the induced signal on position.**

Implementing a Resistive Anode (RA) to characterize the induced signal

Idea: use independent measure of position to characterize induced signal

Replaced sense wires and metal anode with a resistive anode (Quantar Technology)



$$X = \frac{Q_0 + Q_2}{Q_0 + Q_1 + Q_2 + Q_3}$$

$$Y = \frac{Q_0 + Q_1}{Q_0 + Q_1 + Q_2 + Q_3}$$

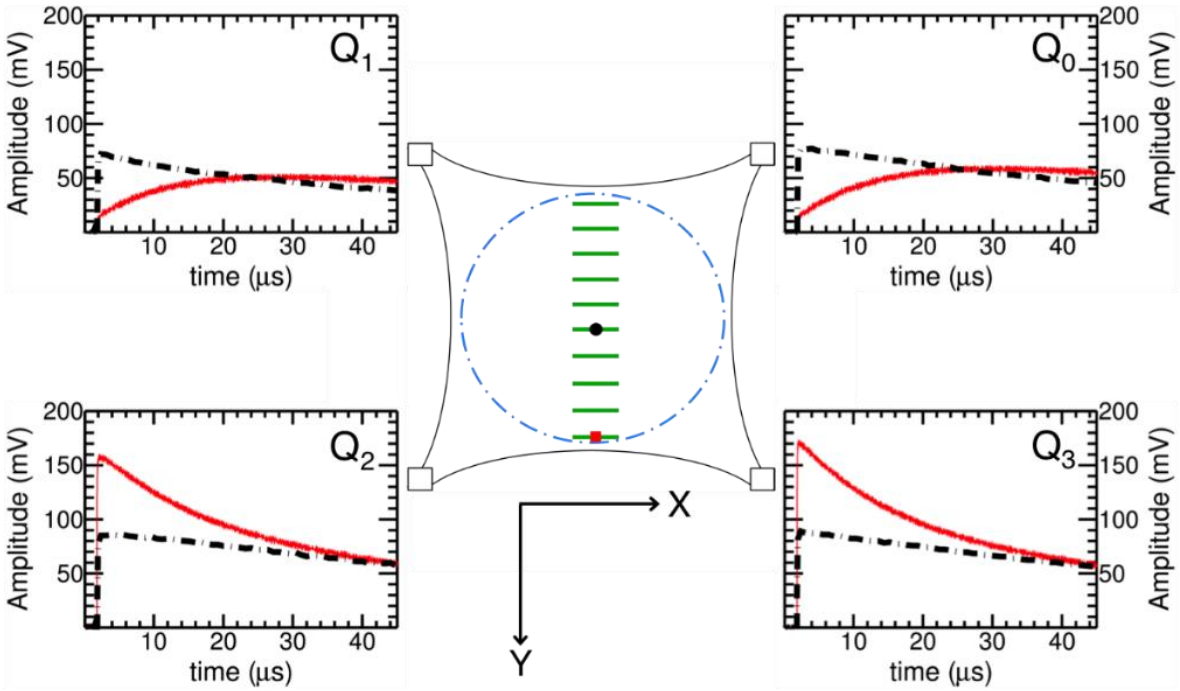
- DAQ triggered by MCP timing signal
- Total charge of event is measured from MCP
- Position is derived from four corners of resistive anode using conventional electronics: charge sensitive amplifiers, shaping amplifiers, and peak sensing ADC (Caen V785).

Using just charge division : Position resolution achieved is **157 μm** FWHM. This is comparable to what is typically achieved with this approach.

B.B. Wiggins et al., Rev. Sci. Instr. **86** 083303 (2015)

Can the joint use of the charge division and pulse shape information improve the spatial resolution?

Improving the position resolution of the RA with pulse shape analysis



D. Siwal, B. B. Wiggins, R. T. deSouza, NIM A **804**, 144 (2015).

- A clear correlation is evident between the signal risetime and $Y_{position}$.
- Use of the signal risetime in addition to the charge division method results in a significantly improved resolution.

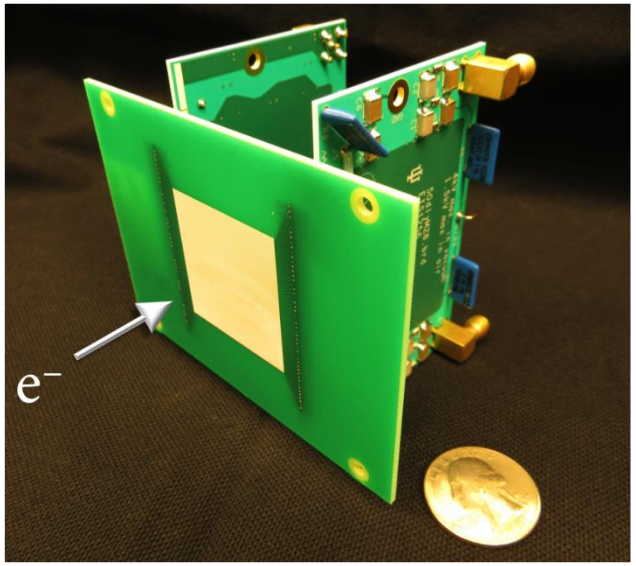
Resolution obtained is 64 μm (FWHM), significantly better than what is achieved for comparable configurations

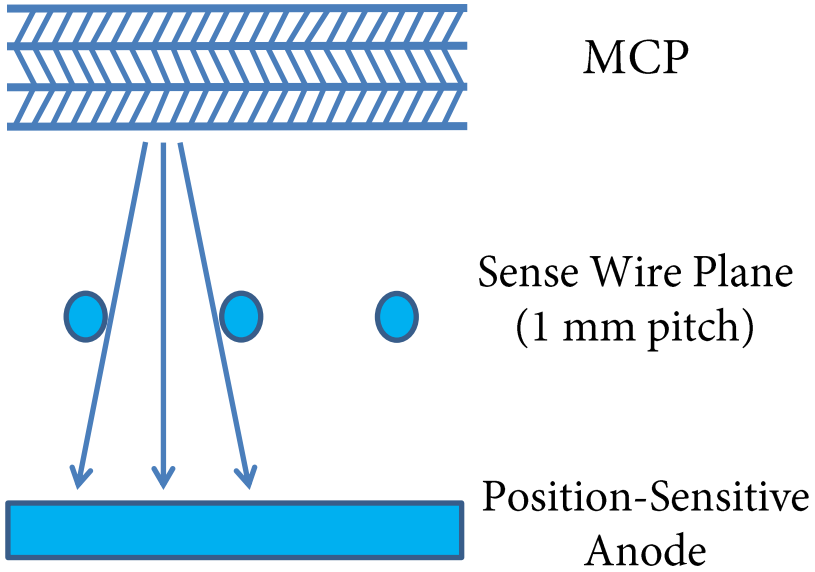
However, insertion of a sense wire plane prior to the RA resulted in large coupling of RA to the sense wire plane. Thus it is not feasible to use the RA to characterize the induced signals.

Implementing a multi-strip anode to characterize the induced signal

- Anode strips are 250 µm wide with 75 µm inter-strip isolation
- Active area is approximately 3 cm x 3 cm
- Even and odd strips are independently coupled to the taps of a delay line board
- Signals from the delay board are processed in a similar fashion to the induced signal approach

Resolution obtained is 94 µm (FWHM).





Can correlating the induced signal shape with the position measured by the multi-strip anode be used to improve the position resolution achievable with the sense wires?

Romualdo T. deSouza, Indiana University

Accomplishments

- For a **single** incident electron
- Over 80% of the 40 mm diameter detector

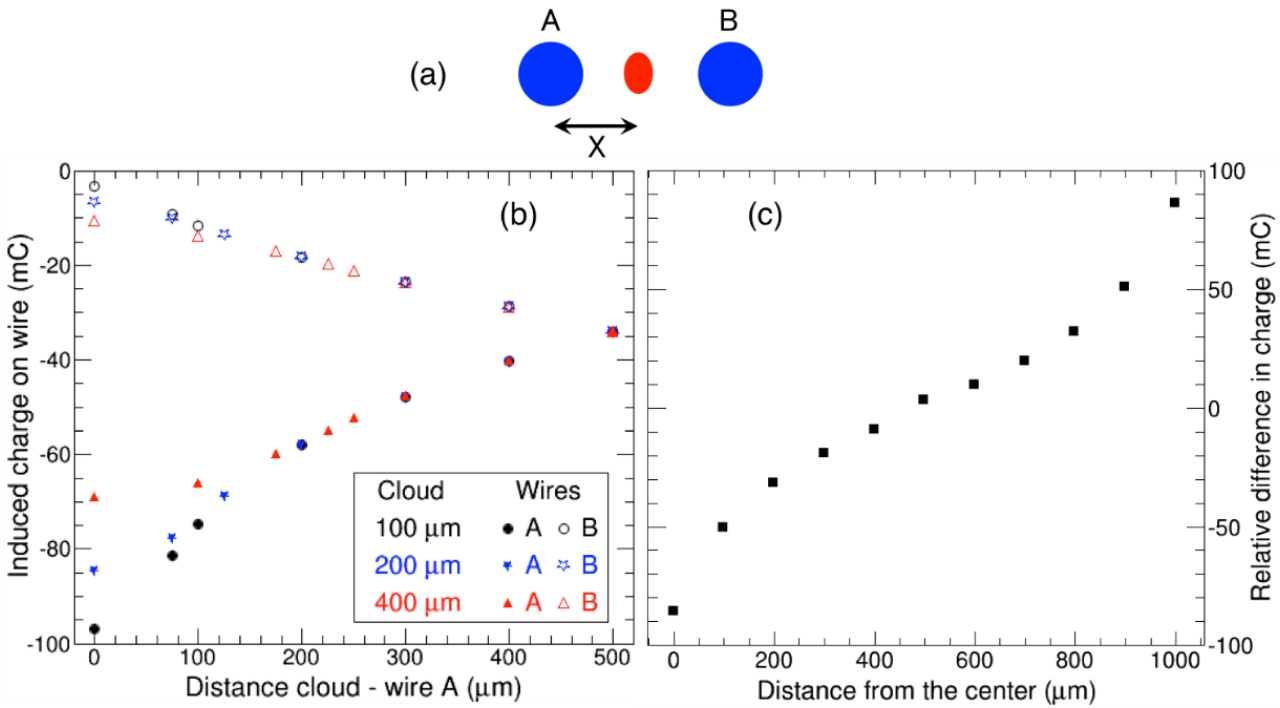
Position-Sensitive MCP Detector	Spatial Resolution FWHM (µm)
Resistive Anode with Charge Division (CD)	157
Resistive Anode- CD + Risetime Analysis	64
Multi-Anode (delay line readout)	94
First Generation Induced Signal (delay line)	466
Induced Signal with DSP	115

1) We have achieved a resolution with a resistive anode that is a factor of two better than previously obtained by utilizing pulse shape (risetime) analysis.
2) With delay line readout and a multi-anode we achieve a sub 100 µm resolution typically obtained only with high density, complex charge sensitive readout.
3) For the induced signal detector we have obtained a resolution of 115 µm using only the zero crossing point of the signal and are now poised to characterize and make use of the entire signal shape.

Accomplishments

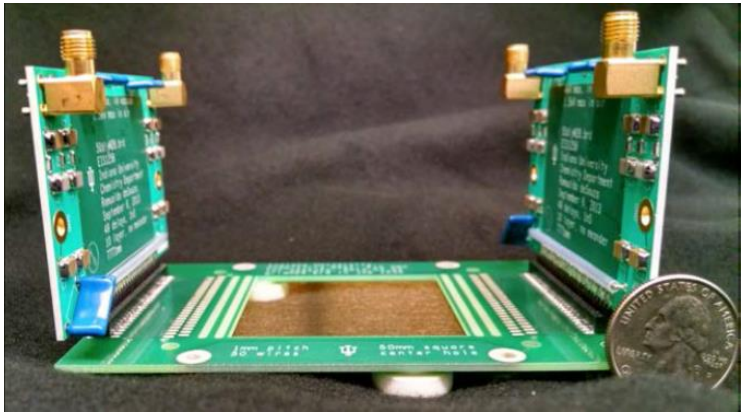
- **Optimizing the position resolution of a Z-stack microchannel plate resistive anode detector for low intensity signals**, B.B. Wiggins, E. Richardson, D. Siwal, S. Hudan, R.T. deSouza, Rev. Sci. Instrum. 86, 083303 (2015) (157 um for Resistive anode with charge division only)
- **Using pulse shape analysis to improve the position resolution of a resistive anode microchannel plate detector**, D. Siwal, B. B. Wiggins, R.T. deSouza, Nucl. Instr. Meth. In Phys. Res. A804, 144 (2015). (64 um for RA using DSP)
- **Sensing an electron cloud emanating from a microchannel plate stack**, R.T. deSouza, B. B. Wiggins, D. Siwal, (Accepted in IEEE Proceedings of NSS-MIC 2015)

Outlook : Implementing a differential readout



We anticipate use of a differential readout will result in improved position resolution for the induced signal.

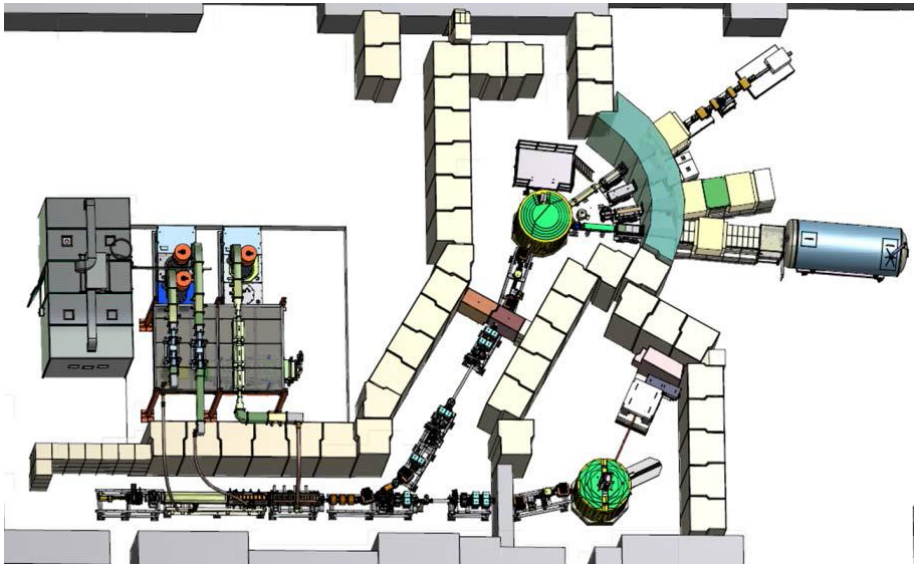
Designed and fabricated the mechanical assembly for testing the second generation detector with differential signal readout.



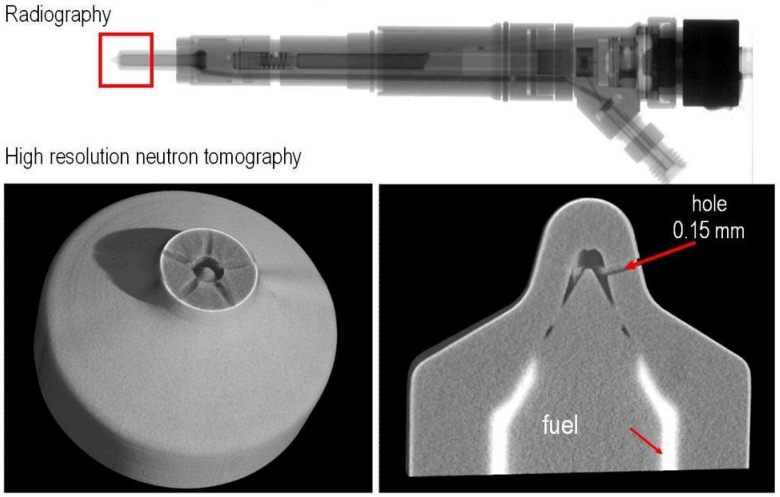
Romualdo T. deSouza, Indiana University

Outlook : Neutron Imaging

Low Energy Neutron Source (LENS) at Indiana University

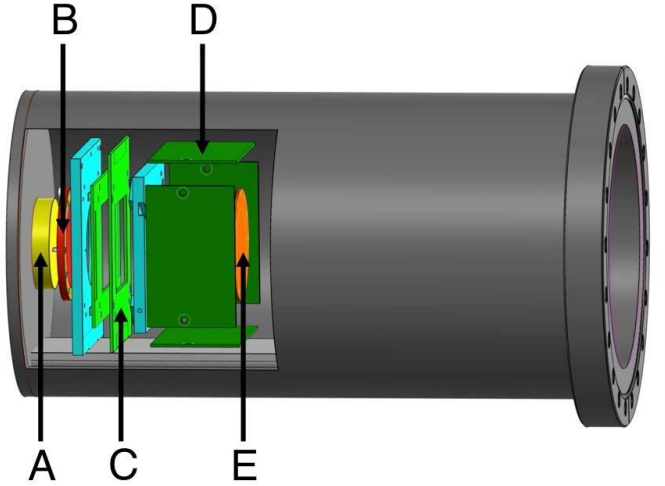


- 13 MeV proton linac driver
- $^{9}Be(p,n)$ to produce neutrons
- Thermalization (polyethylene, solid CH_4 @ 6.5K)
- 100 n/(ms.cm^2)



Courtesy of PSI

By inserting a neutron sensitive MCP (B-doped) in front of the detector we will be sensitive to thermal neutrons.



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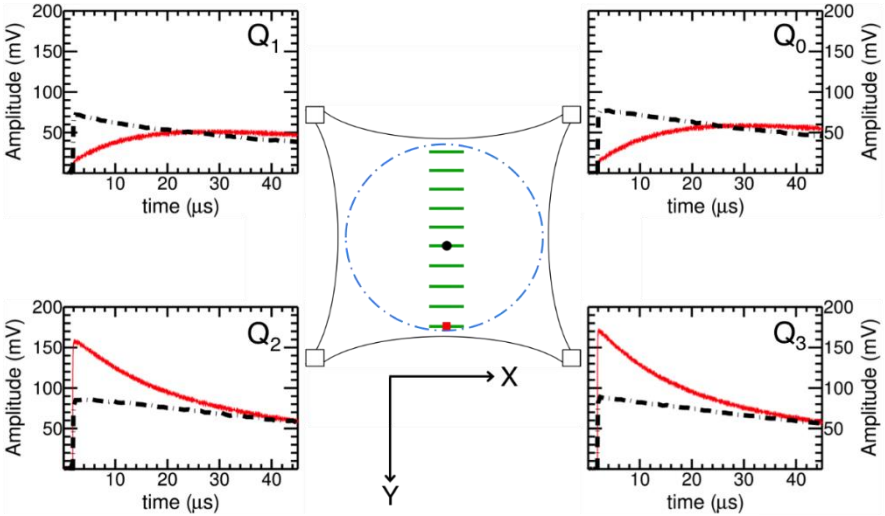
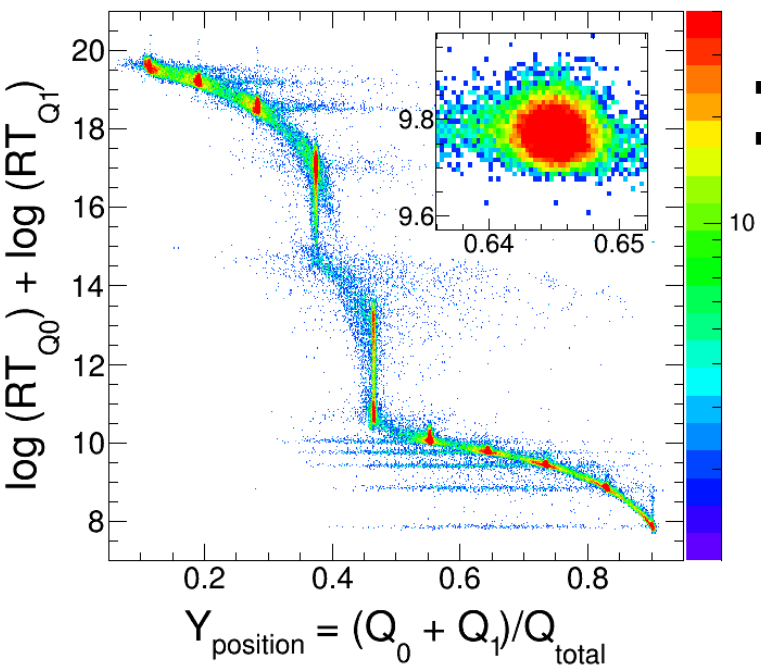
Assessment of existing approaches

Position-Sensitive MCP Detector	Advantages	Disadvantages
Multi-Anode (charge readout)	Fast signal Can distinguish multi-hit events Spatial resolution ~ 25-50 µm	Cost of readout electronics Cross-talk between anodes
Resistive Anode	Relatively slow signal Simplicity of readout Low power consumption Spatial resolution ~ 100 µm	Limited to count rates <100kHz Cannot distinguish multi-hit events
Helical Delay Line Anode	Fast signal Low power and electronic cost Can distinguish multi-hits at 10 MHz Spatial resolution ~ 60 µm	Attenuation and dispersion of signal in delay line Difficult fabrication process Fragility of a single wound wire
Cross-Strip Anode	Fast signal Spatial resolution 10 – 20 µm Chevron MCP (less charge spreading) Can distinguish multi-hit events	Cost of readout electronics High power consumption
Induced Signal	Fast signal Simplicity of readout Can distinguish multi-hit events Low power consumption	Attenuation and dispersion of signal in delay line

Improving the position resolution of the RA with pulse shape analysis





- A clear correlation is evident between the summed risetime and $Y_{position}$.
- Pileup is also evident.
- Use of the signal risetime in addition to the charge division method results in a significantly improved resolution.

Resolution = 64 μm FWHM

D. Siwal, B. B. Wiggins, R. T. deSouza, NIM A **804**, 144 (2015).

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