Status

ALD Secondary Electron Emission Program

Delivered to PSEC Collaboration Meeting
Neal Sullivan
October 15, 2009

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Outline

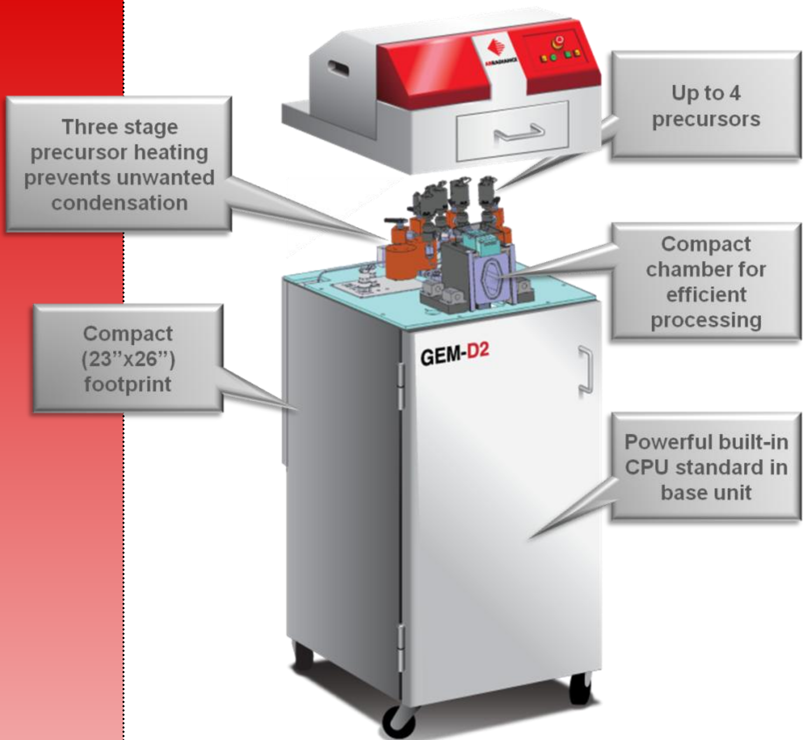
- Status and Summary of Contract
- Progress on MCP ALD equipment
- Progress on MCP Emissive film performance
- Progress on MCP Resistive film performance
- New MCP Application: Special Nuclear Material Detection – Fast Neutron Detector
  - Plastic MCP ALD films development
  - Fast Neutron Detection Simulation development
  - Plastic MCP performance
  - Neutron Detection Experimental Results
    - University of New Hampshire (UNH)
    - Massachusetts Institute of Technology (MIT)
- Summary

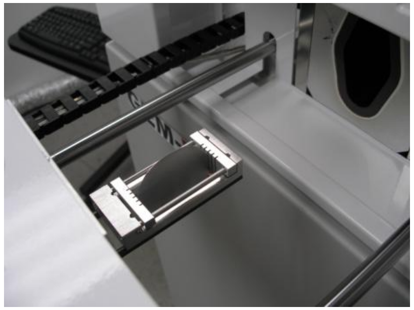
1 Year Contract No. 9F-32341 (Oct 1, 2009): $120,434.00

- ***Objective***: Optimize Arradiance thin film technology process & process equipment to meet performance requirements for LAPR-TOF glass and small sample AAO substrate development.
- Work Plan Detail (Glass and AAO substrates):
  - MCP manufacturing & performance requirements definition: Inputs from program & Arradiance simulation driven film parameter determination
  - Film optimization on 33 mm capillary glass substrates: resistance and emission optimization; process integration and functionality
- Work Plan Deliverables:
  - Development of ALD emissive & resistive films which meet gain, resistance & uniformity specifications on glass & AAO substrates.
  - Process and test of up to 20 capillary glass and 20 AAO functionalized prototype MCPs.
  - Proof of Principle Report to the project

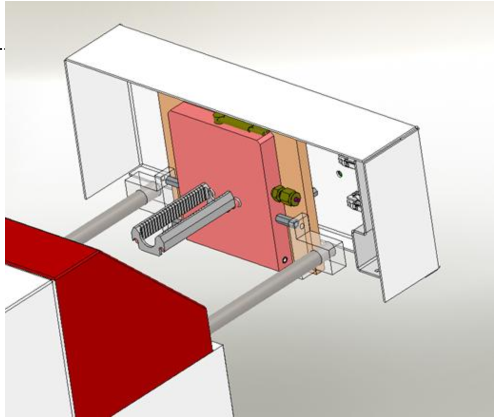
- ***Status***: Awaiting funding for ALD and Test fixture build to accommodate 33mm samples

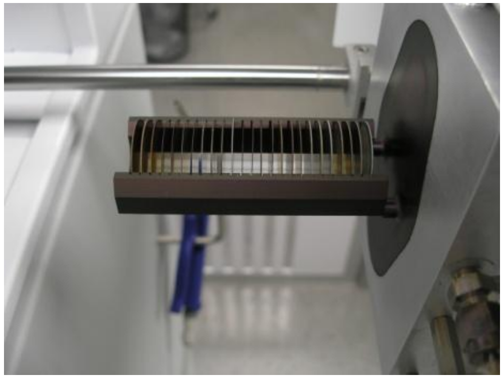
Arradiance GEM ALD Equipment – 2nd Generation MCP ALD processing





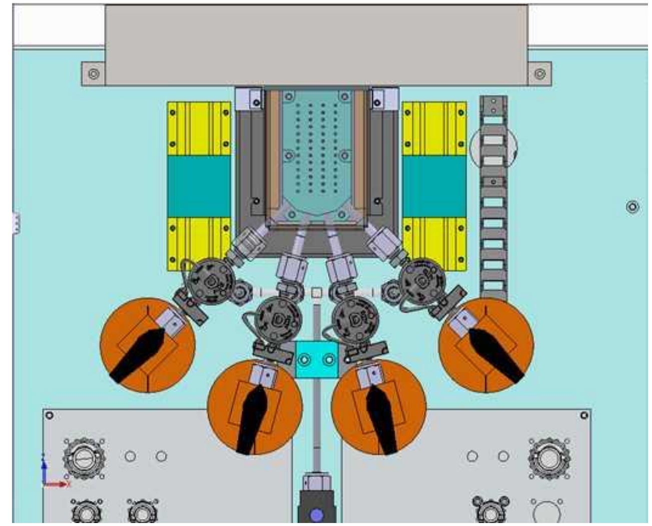
- Chamber door pulls out for easy load and unload of door-mounted substrate holder.
- Easy to reach batch boat design to hold up to twenty-five 1” diameter MCP substrates.
- Larger dia substrates (up to 76mm) can be loaded in smaller quantities.
- Holder positions substrates such that all substrates see uniform gas flow over entire surface area.

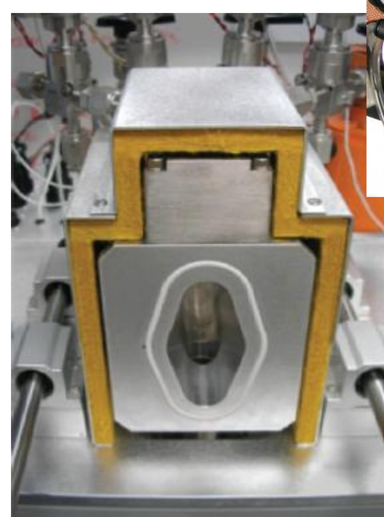


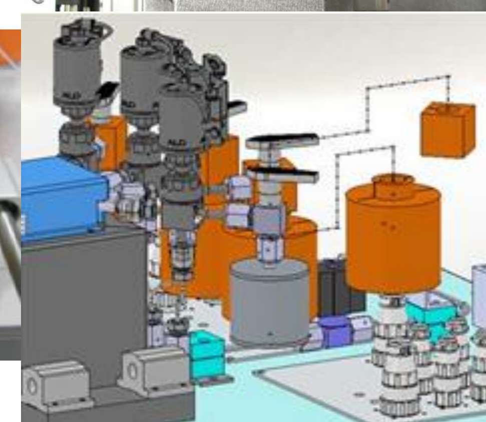


Uniformity for MCPs:
High Aspect Ratio & High Surface Area

- Separate gas delivery lines to avoid precursor mixing and contamination.
- Showerhead precursor delivery isolates & distributes uniform gas flow to all MCP substrates.
- Convective, rather than conductive, heating assures uniform temperature across reaction chamber.
- Chamber geometry accommodates MCP structures with uniform heating and gas flow.
- Minimum chamber volume for faster heating, cool-down, pumping times and minimal precursor usage.
- Chamber geometry designed for optimum pressure control.

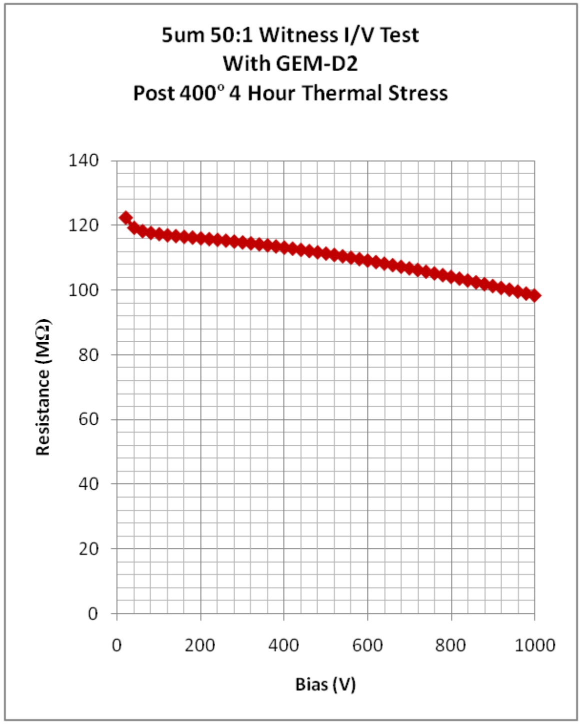


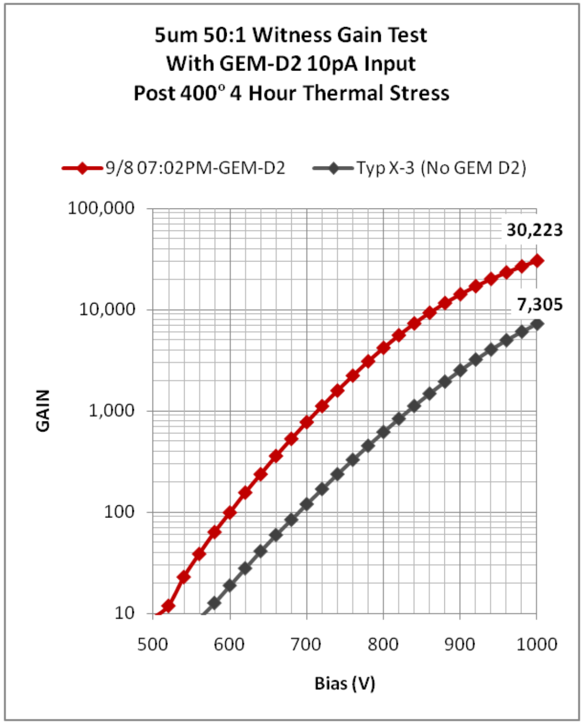


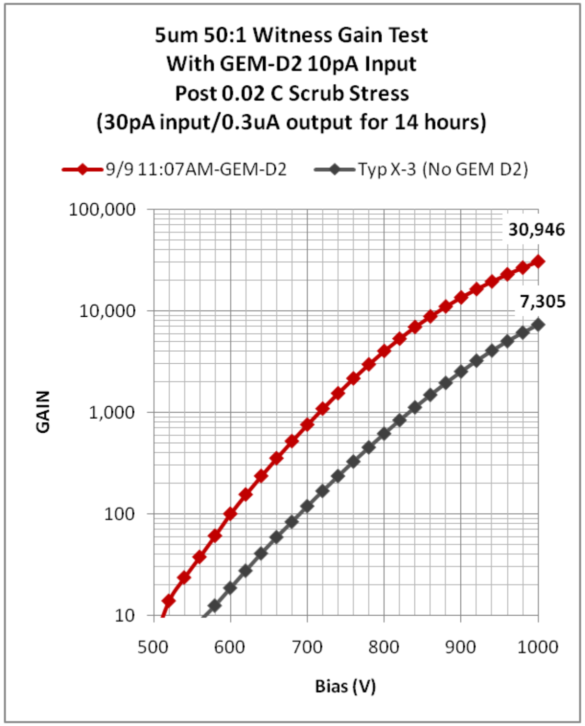


Commercial GEM-D2 Application I

- Commercial MCP base resistance of ~100MΩ at 1000V.
- Increased SEY of GEM-D2 film
- Short term scrub, extracting 0.02 C at I_{out}=0.3uA (14 hrs), did not degrade gain.

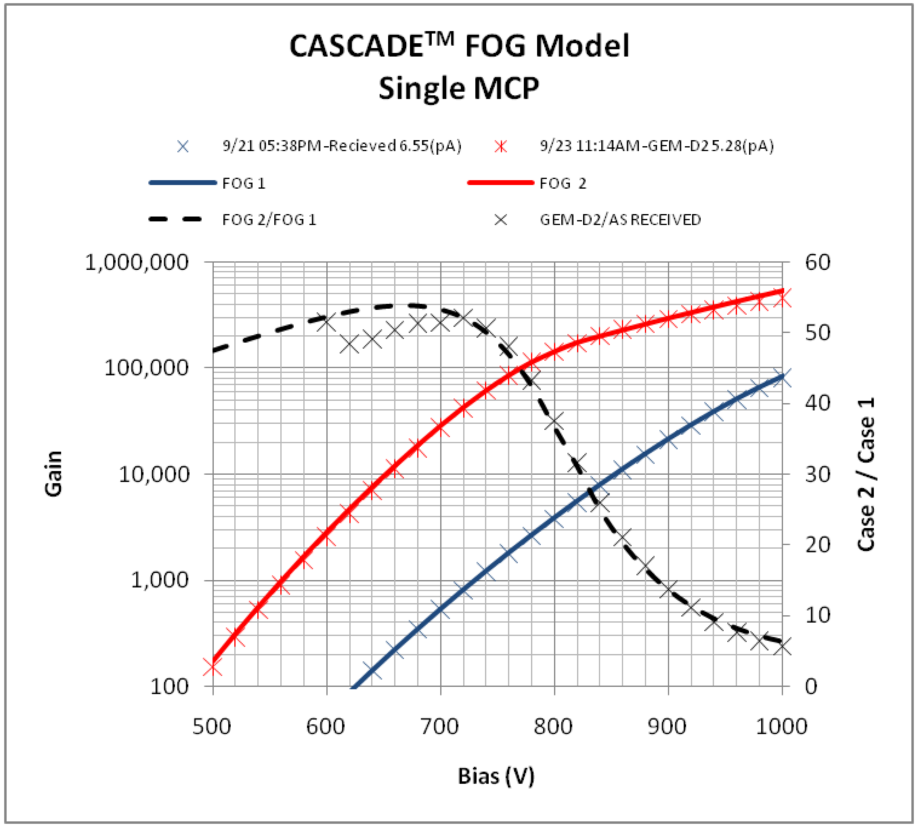






Commercial GEM-D2 Application II: CASCADE First Order Gain (FOG) Analysis

- Before and After GEM-D2 Emissive Coating - 60:1 LD 12um Pitch 12 Degree Bias



FOG Model results fitting measured before and after GEM-D2 data (Solid line is modeled)

Change Model with Yellow Columns 9/23/2009

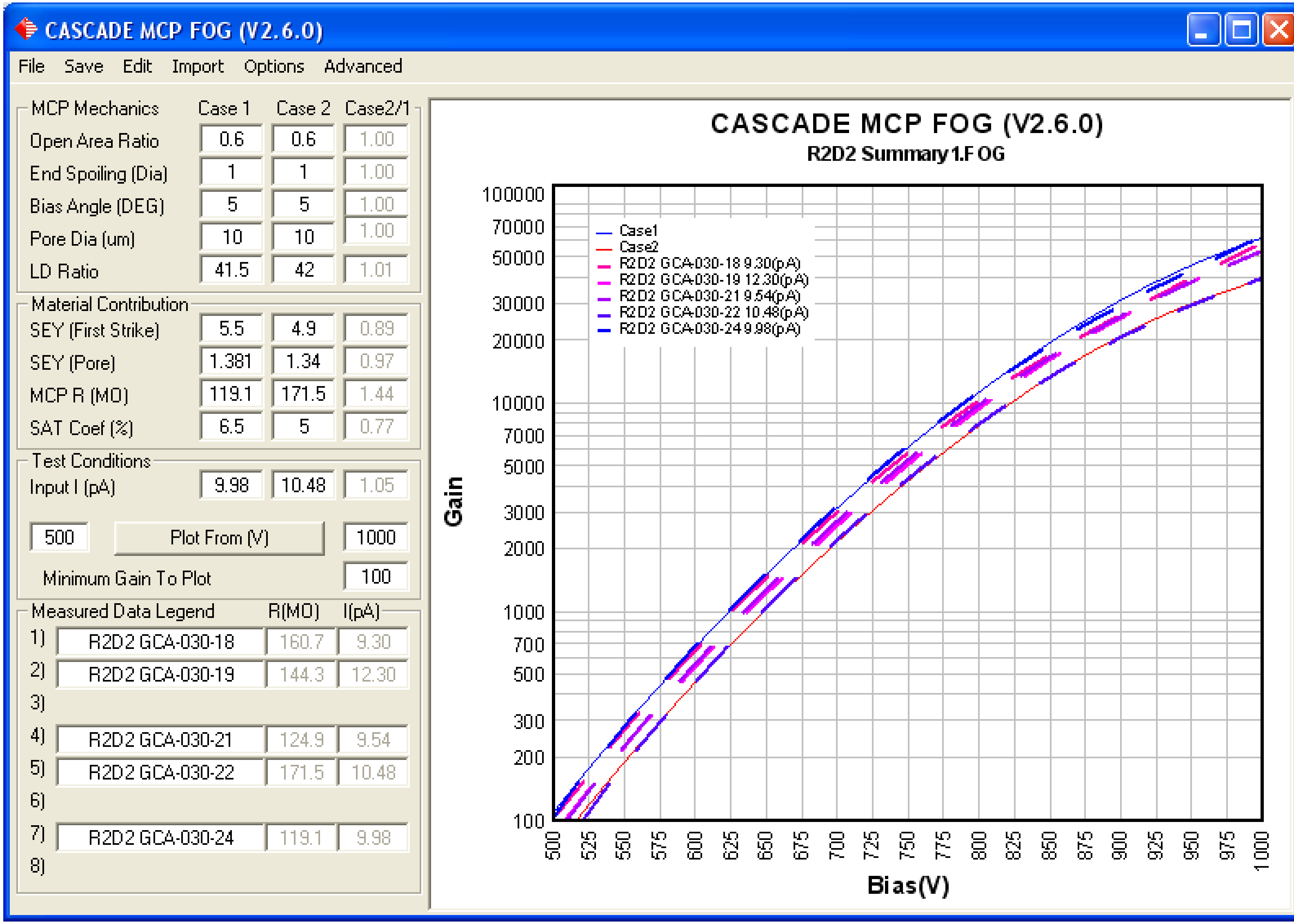
Does not include tilt angle, Pore Dia, I/O Field, Charging effects

	FOG 1	FOG 2	FOG 2/FOG 1	Description
Changeable Parameters	0.6	0.6	1.00	*Open Area Ratio*
	5	7	1.40	*SEY Constant (First Impact)*
	0.5	0.5	1.00	*End Spoiling in Diameters*
	60	62	1.03	*L/D Ratio*
	1.04	1.35	1.30	*SEY Constant (Relative to D2)*
	12	12	1.00	*Bias Angle (Degrees)*
	120	100	0.83	*MCP R (M Ω)*
	6.55	5.28	0.81	*Input I(pA)*
	8.0%	8.0%	1.00	*SAT Coefficient (% Strip)*

FOG Analysis Results For GEM-D2

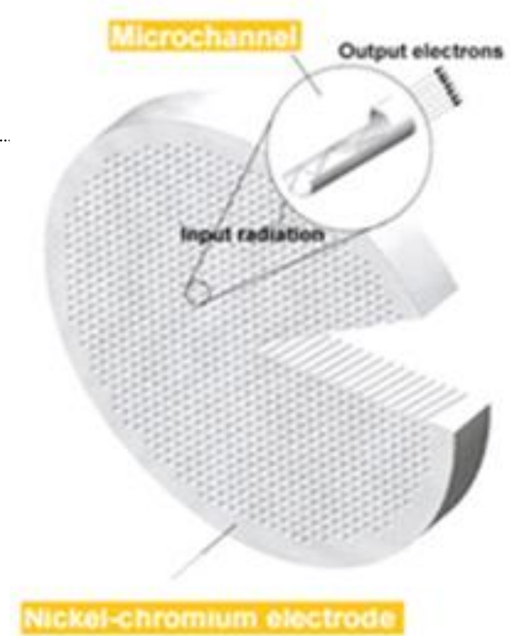
1. 40% increase in first strike SEY
2. 30% increase in pore cascade SEY
3. 3 % increase in apparent LD ratio

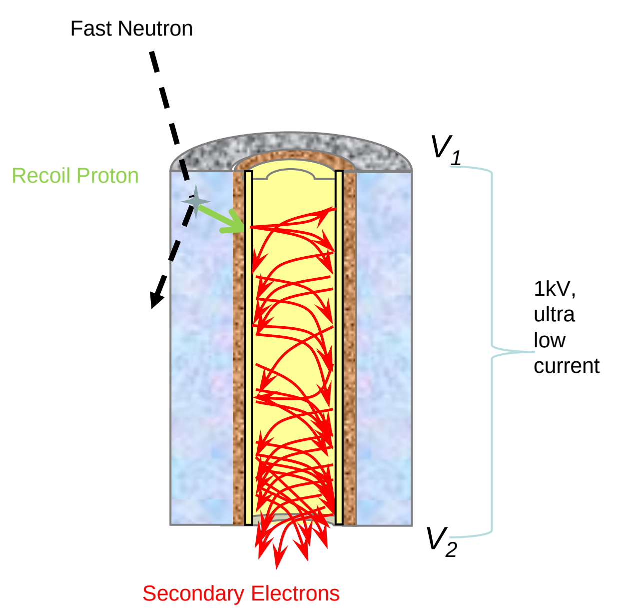
R2D2 Lot to Lot Repeatability
40:1 LD 10 um Pore Micro Channel Substrate



SNM detection technology overview

- Hydrogen-rich PMMA microchannel structure
- Graded Temperature ALD deposition
  - Active films deposition at 140C
- Neutron-proton recoil reaction within plastic at better than 1% efficiency
- Proton initiated secondary electron cascade
- Output pulse 10^3 – 10^6 electrons
- Standard readout electronics
- Technology is scalable to large format



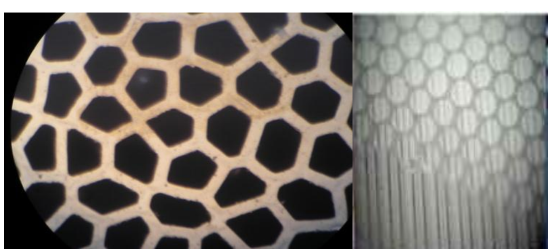


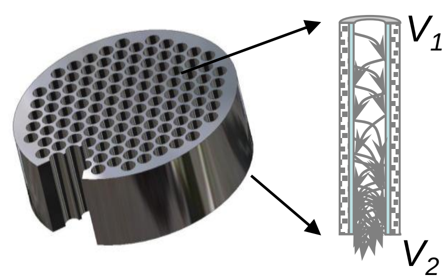
Summer 2009 Experimental Data Collected

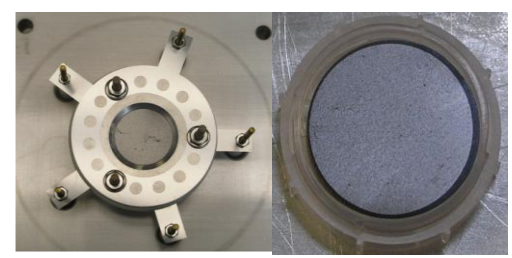
- Prof. Jim Ryan UNH - Space Science Center
  - 06/04/2009
  - PMMA, 2mm, > 40k 50um Pores, 20um wall
- Isotope sources: Cf-252 (n, γ), Am-241/Be (n, γ), Cs-137 (γ), Co-60 (γ), Am-241 (γ)
- Results

γ QE	=	8.85E-04
n QE	=	3.28E-03

- Dr. Dick Lanza MIT - Nuclear Science & Eng.
  - 08/19/2009
  - PMMA, 5mm, > 40k 50um Pores, 20um wall,
- Thermo Scientific 300 series D-T source (14MeV - pulsed)
- Results
  - nQE ~1.2%
  - Source limited t<1.5 us
  - dark count ~0.3 c/cm^2/s







SNM Neutron detection simulation overview

$$P_{detection} = P_1 * P_2 * P_3$$

P_1 – n-p recoil within the MCP substrate

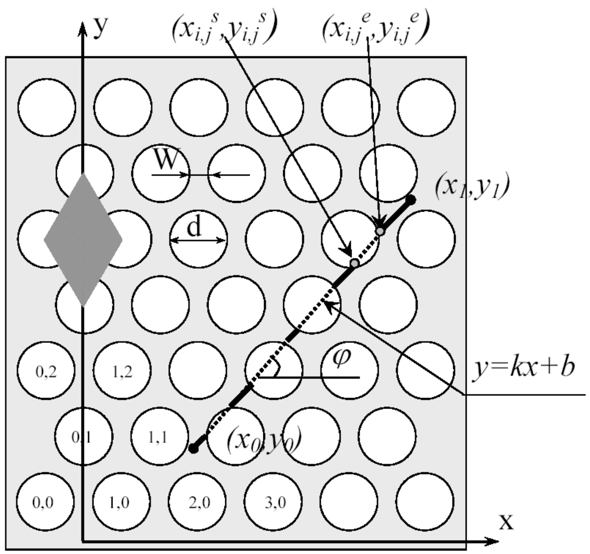
P_2 – proton escape into MCP pore

P_3 – electron avalanche is formed (MCP ~1)

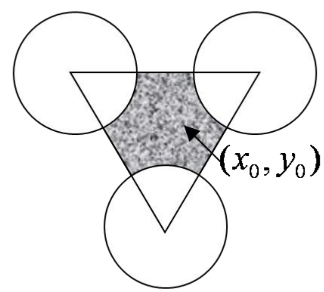
$$P_1 = 1 - \exp\left(-N_H \sigma_n L_{eff}\right)$$

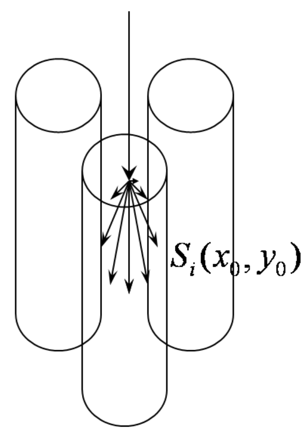
$$L_{eff} = L_{eff}(x_0, y_0, \theta, \varphi)$$

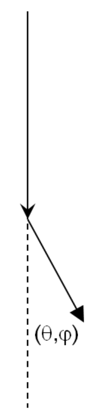
$$N_x = 2\frac{\rho_{MCP} m_x \mu_x}{M_x \sum_i m_i \mu_i}$$



P_2







$$\cos(\theta) = \sqrt{\frac{E_p}{E_n}}$$

$E_p \in [0, E_n]$

$$S_i(x_0, y_0) < R(E_p(\theta))$$

$$S_i(x_0, y_0) = \frac{\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2}}{\sin(\theta)}; \theta \neq 0, \pi$$

$$(x_1 - x_0)^2 = \left[\min\left|\left\{-\left(tg(\varphi)\cdot\xi - 0_{i,x}\right) \pm \sqrt{D}\right\}\cos^2(\varphi) - x_0\right|\right]^2 \quad \xi = y_0 - tg(\varphi)x_0 - O_{i,y}$$

$$y_1 = tg(\varphi)\cdot x_1 + \left(y_0 - tg(\varphi)x_0\right)$$

$$D = \left(tg(\varphi)\cdot\xi - O_{i,x}\right)^2 - \left(O_{i,x} + \xi^2 - \frac{d^2}{4}\right)^2 \frac{1}{\cos^2(\varphi)}$$

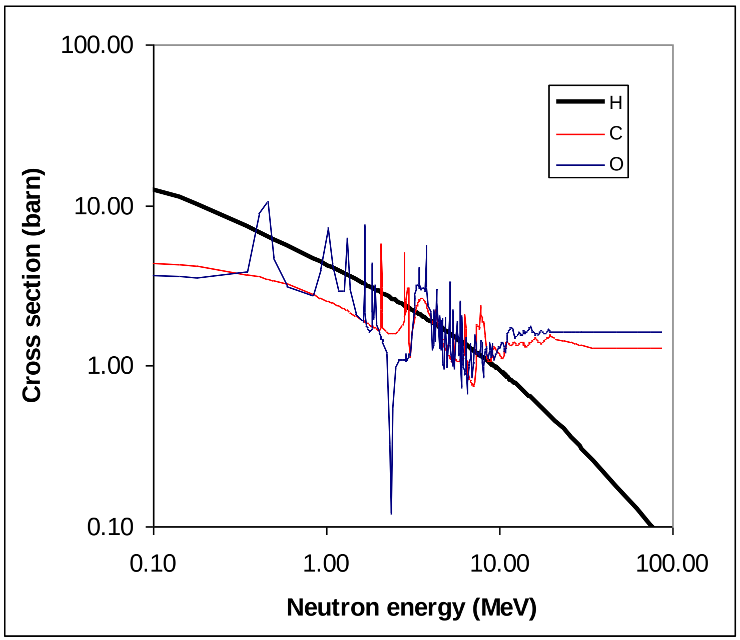
Neutron detection simulation: proton recoil - P1

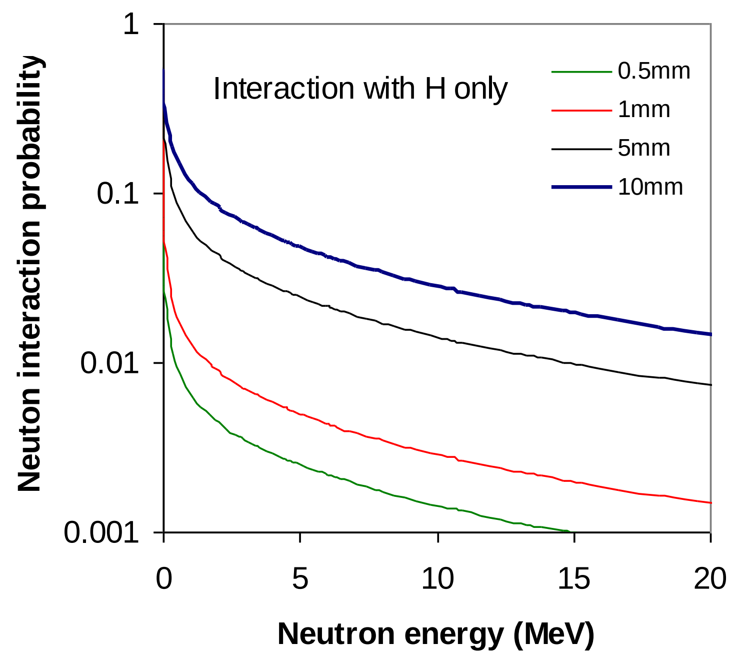
PMMA $(C_5\text{-}O_2\text{-}H_8)_n$

monomers / cm^3	7.16×10^{21}
H atoms / cm^3	**5.73×10^{22}**
C atoms / cm^3	3.58×10^{22}
O atoms / cm^3	1.43×10^{22}

Cross section of neutron interaction

$P = [1 - \exp(-N_i \sigma_i L)](1-A)$





50 µm circular pores, 20 µm walls, 1.19 g/cm^3

Neutron detection simulation results – P1 and P2

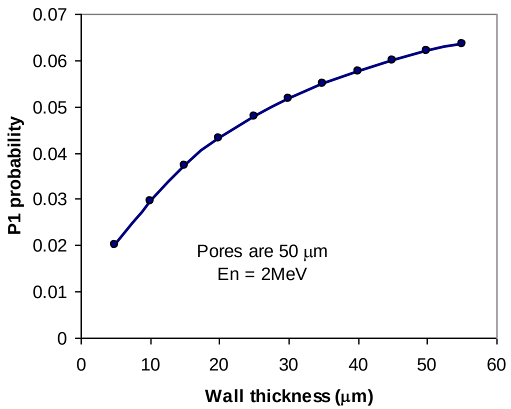
$$P_{detection} = P_1 * P_2 * P_3$$

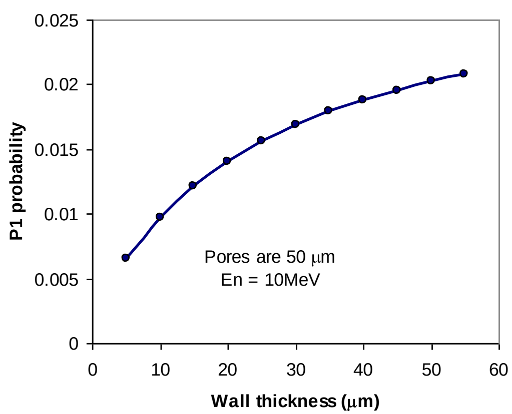
P_1 – n-p recoil within the MCP substrate

P_2 – proton escape into MCP pore

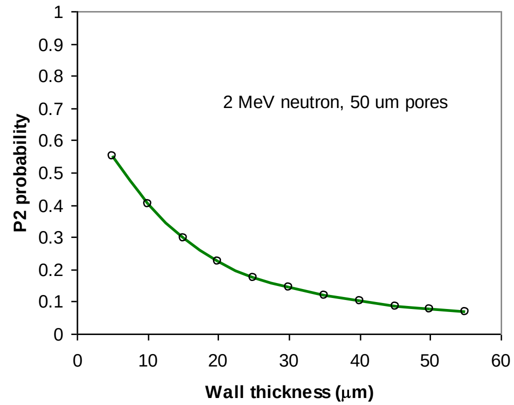
P_3 – electron avalanche is formed (MCP ~1)

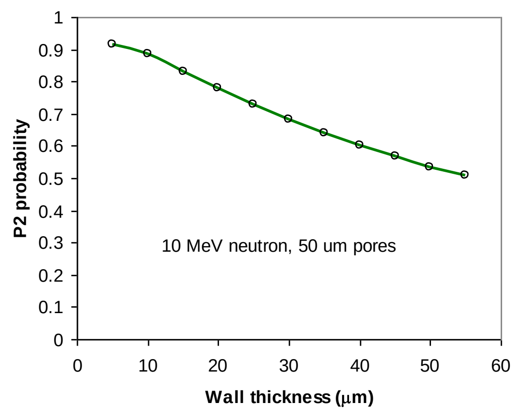
P1



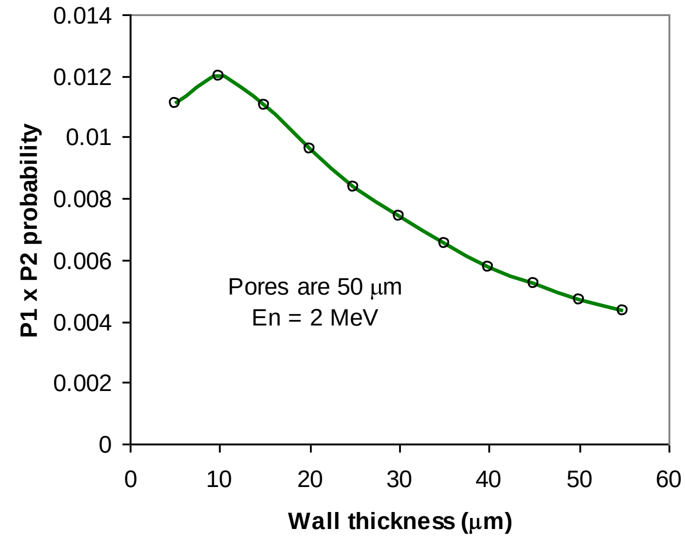


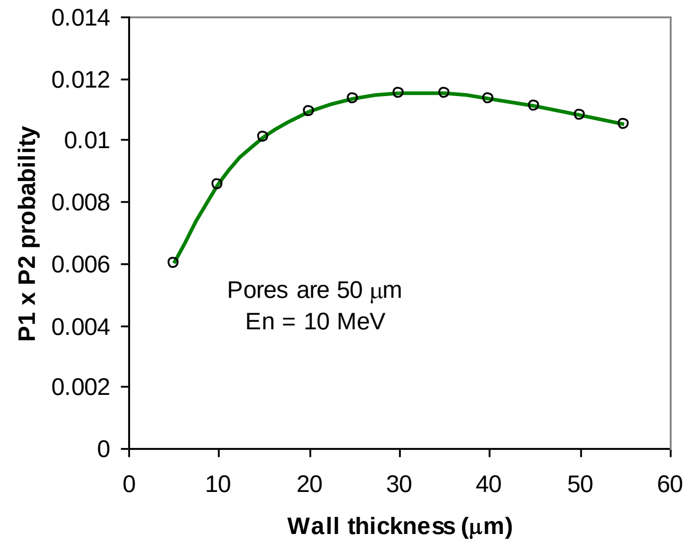
P2





P1*P2*P3





Neutron detection simulation: P3 Probability and Event Timing Simulation

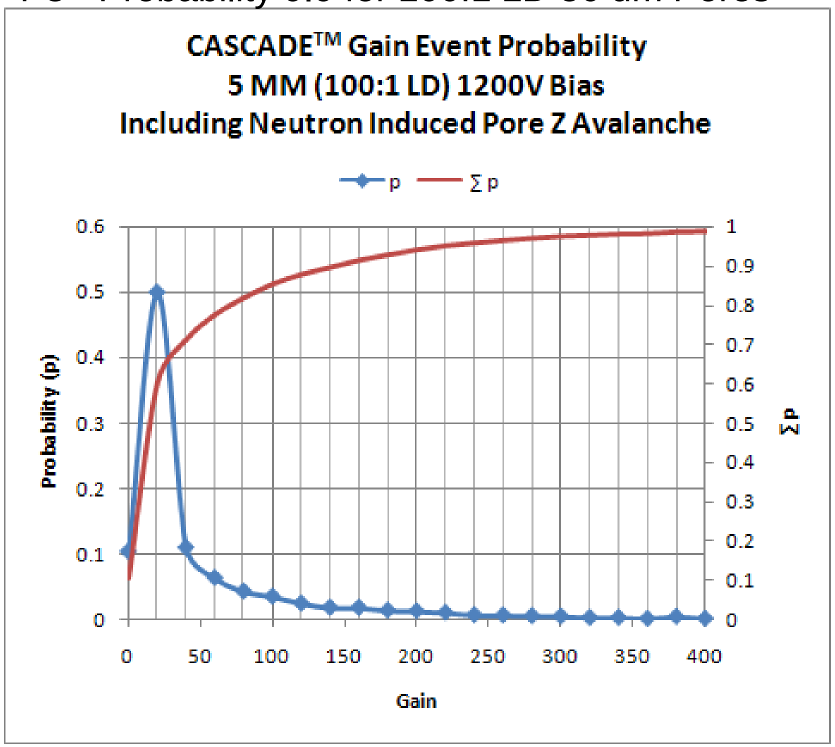
Neutron Detection Stage

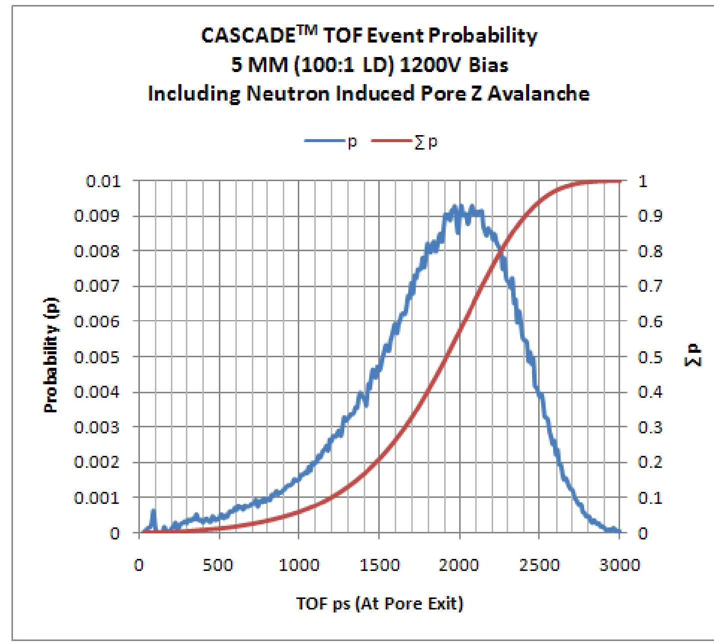
Signal Amplification Stage

Note:
P3 – Probability for Amplification Stage is 1.0

Timing for Amplification Stage is < 200 ps

Operating at 1200V Bias (Average Gain 47)
P3 - Probability 0.9 for 100:1 LD 50 um Pores

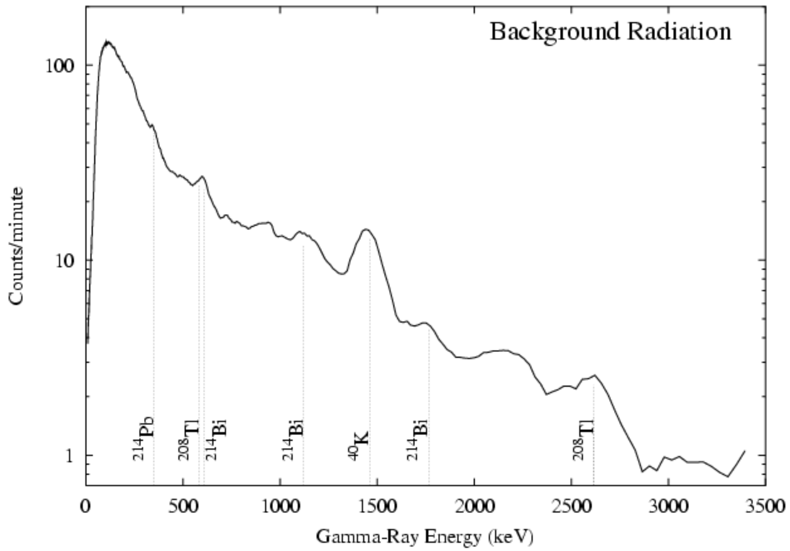




For 99.9% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of +- 1.5 ns

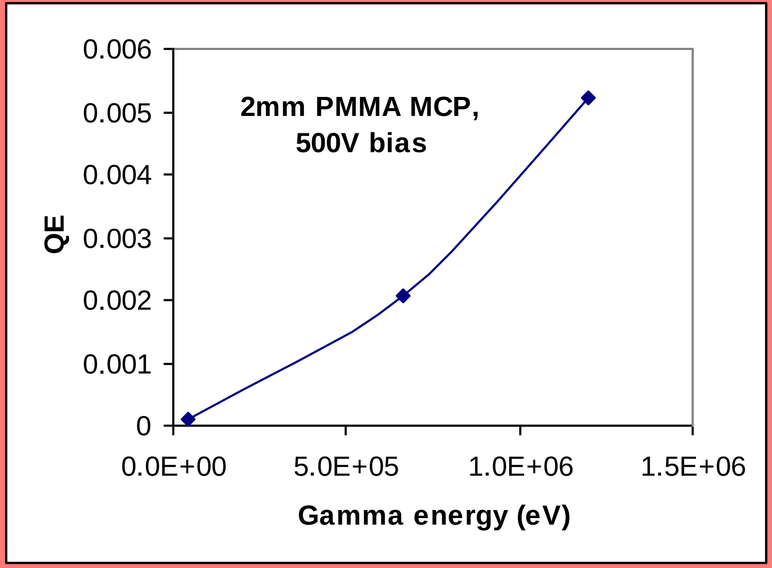
For 90% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of < +- 1.0 ns

UNH Experimental Summary



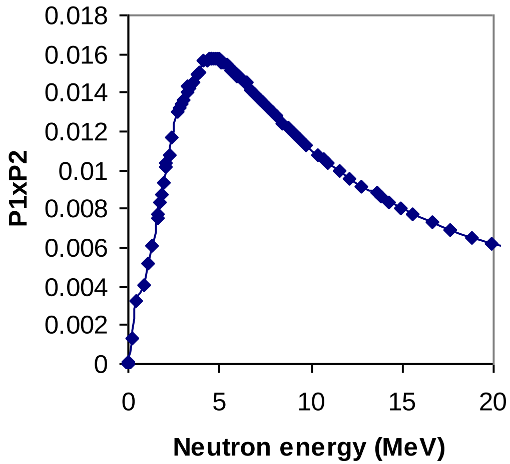
γ isotopic sources

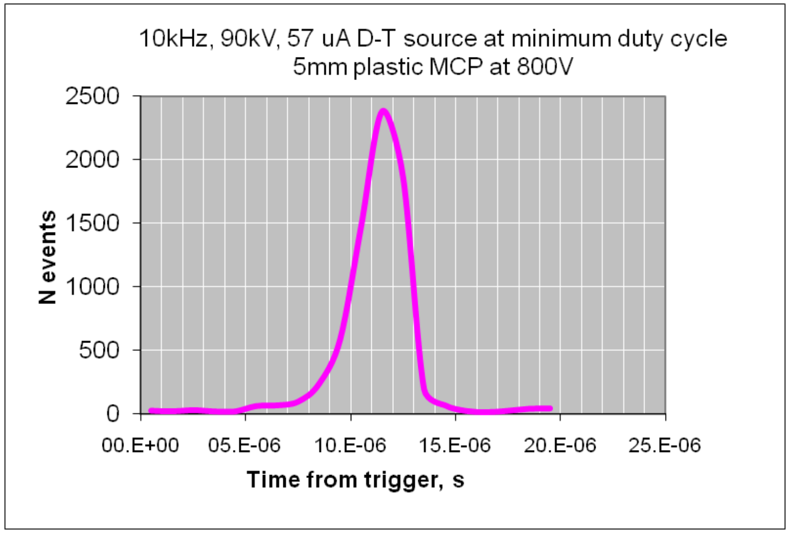
Gamma E (eV)	QE
4.00E+04	9.26E-05
6.61E+05	2.06E-03
1.20E+06	5.22E-03



Pulse source: timing performance MIT measurements with a pulsed source

Predicted QE ~0.8%



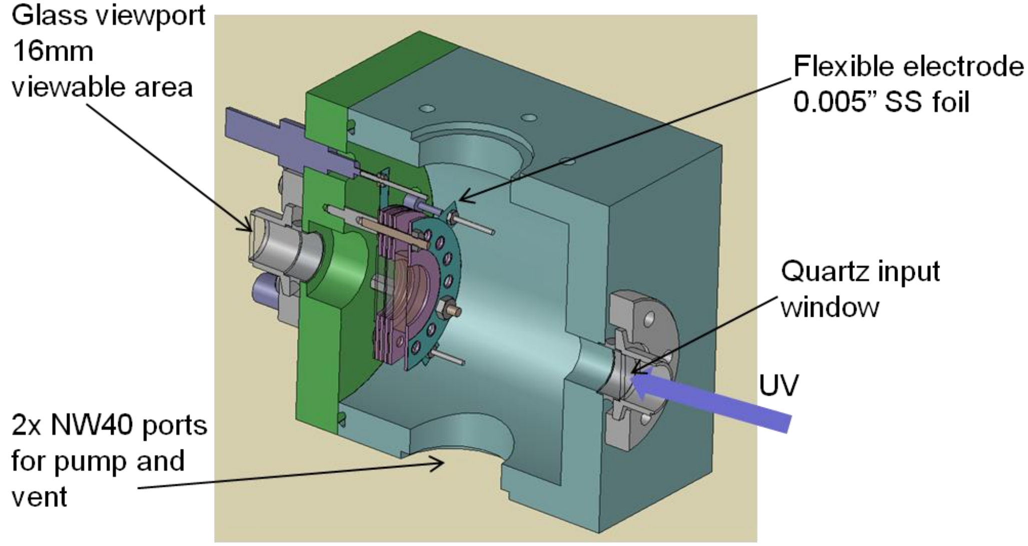


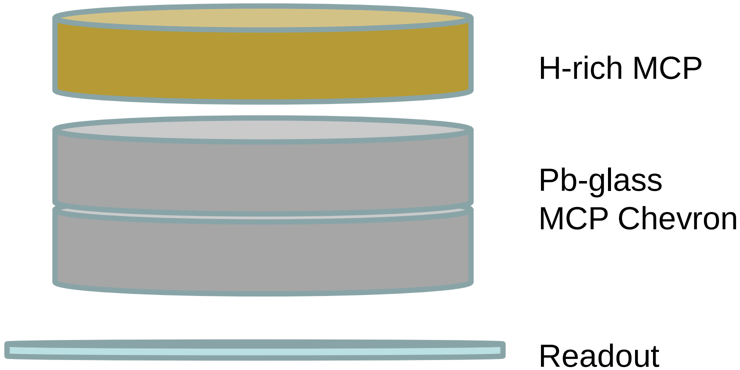
Conclusions:

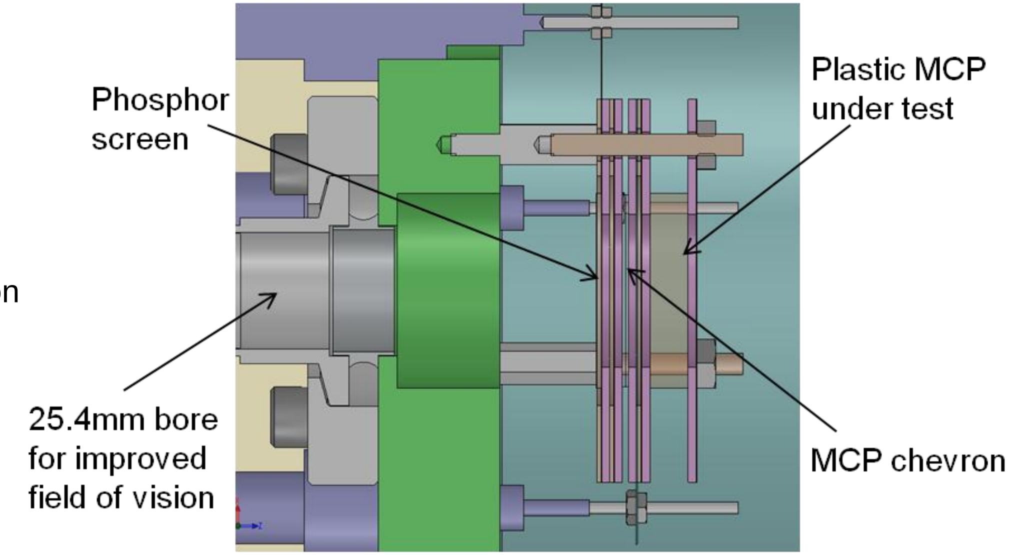
1. QE to 14 MeV neutrons is ~1.2%
2. n and γ counts are comparable at this source settings
3. Timing better than 1.5 μs (measurement limited by the source)
4. MCP dark count very low (~0.3 c/cm^2/s)

Hardware Experimental setup

- 5 mm PMMA MCP, ~50 um pores, 20 um walls, 5º bias angle
- installed above a chevron stack of 50:1 L/D MCPs
- Phosphor screen readout
- Canberra preamp and postamplifier







Summary

- Contract signed – Await funding release
- 2nd Generation ALD Process Equipment ready for PSEC MCP substrates
- Simulation support for SE yield determination from MCP measurements is complete.
- High performance MCP active film results demonstrate success
  - High secondary electron yield results in high gain MCPs
  - Targeted and Repeatable MCP device resistance
- Novel MCP application demonstrated: Fast neutron detector, implemented in high H plastic substrate, with low noise and high efficiency demonstrated
  - ~1% Neutron detection efficiency target
  - $< 0.1\%$ Gamma detection efficiency
  - < 0.3 C/s-cm^2 Noise