ARRADIANCE®

Novel Plastic Microchannel-Based Direct Fast Neutron Detection

D. Beaulieu, P. de Rouffignac, D. Gorelikov, H. Klotzsch, J. Legere*, J. Ryan*, K. Saadatmand, K. Stenton, N. Sullivan, A. Tremsin
Arradiance Inc., Sudbury MA
* UNH EOS, Durham, NH

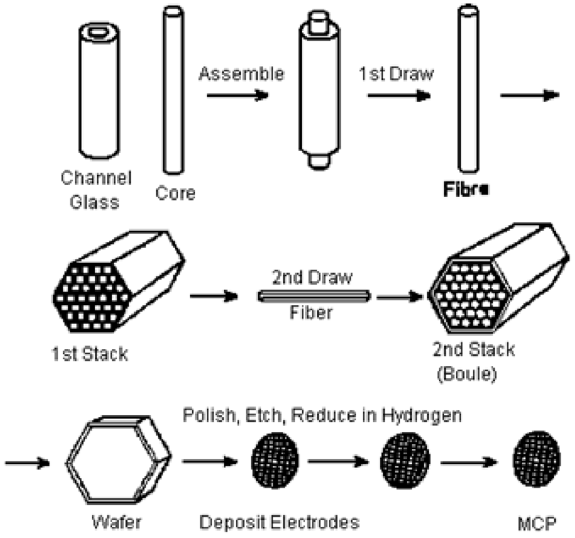
Arradiance Inc.
142 North Road, Suite F-150
Sudbury, MA 01776
(800) 659-2970 Tel and Fax
www.arradiance.com

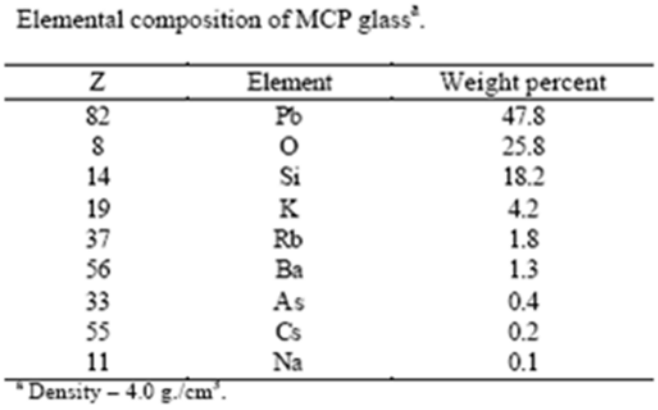
Outline

- Microchannel plate (MCP) background
- Arradiance functional thin film technology
  - Atomic Layer Deposition (ALD)
- Substrate independent MCP technology
  - Secondary electron emissive films
  - Conductive films
- Fast neutron MCP detector
  - Concept
  - Functionality
  - Simulation
- Fast neutron MCP detector experimental
- Fast neutron MCP detector results
- Summary and Future Work

MicroChannel Plate (MCP) Technology

- Mature (1960s) MFG, Expensive, *Bulk materials determine performance*, High Z content, limited size (<10cm), difficult process control
- Event counting: $>10^7$ gain, <0.01 c/cm^2-s noise, high efficiency, <10µm spatial resolution, <50ps rms temporal resolution

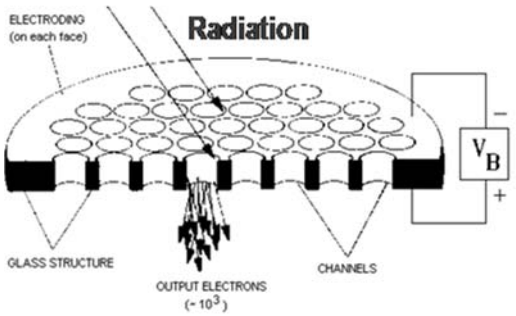


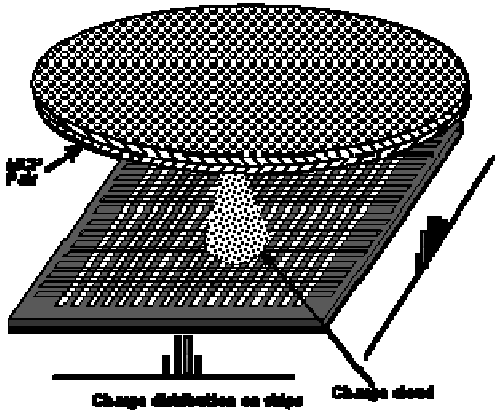


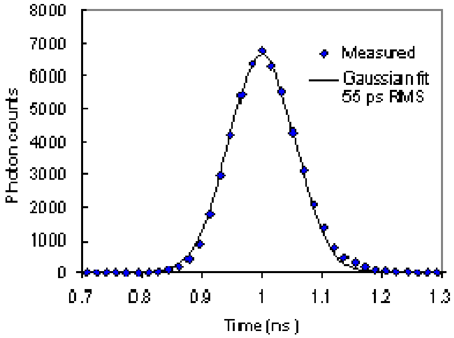
Elemental composition of MCP glass[a].

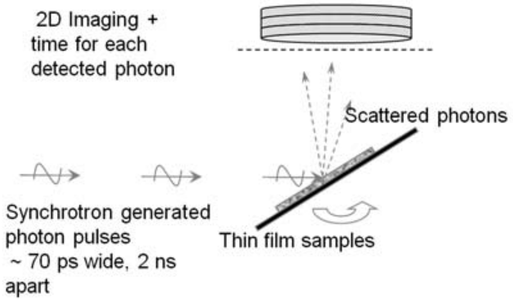
Z	Element	Weight percent
82	Pb	47.8
8	O	25.8
14	Si	18.2
19	K	4.2
37	Rb	1.8
56	Ba	1.3
33	As	0.4
55	Cs	0.2
11	Na	0.1

[a] Density – 4.0 g./cm^3.





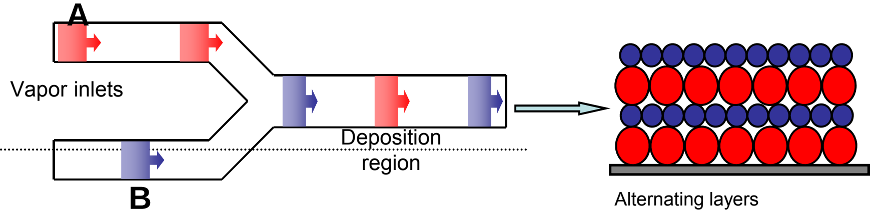




A. S. Tremsin, et al., Nucl. Instr. Meth. A 580, pp.853-857 (2007)

Wiza, Nuclear Inst. & Meth., Vol 162, 1979, 587

ALD MCP Technology

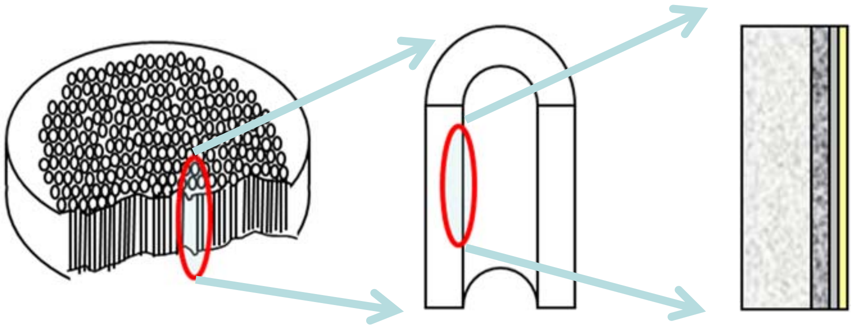


- MCP performance tied to glass composition

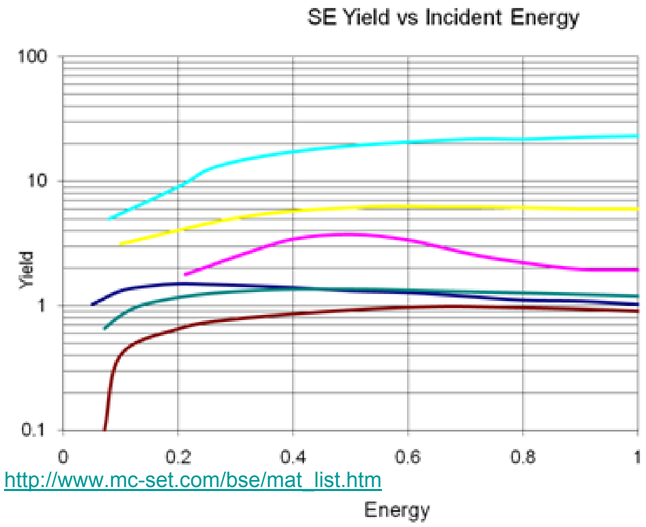
ALD:

- Device optimization is de-coupled from substrate.
- Semiconductor processes & process control.
- Materials engineering at the nanoscale
- Functional films composed of abundant,non-toxic materials.
- Advantages:
  - High conformality (>500:1)
  - Scalable to large areas
  - Digital thickness control
  - Pure films
  - Control over film composition
  - Low deposition temperatures (50-300°C)

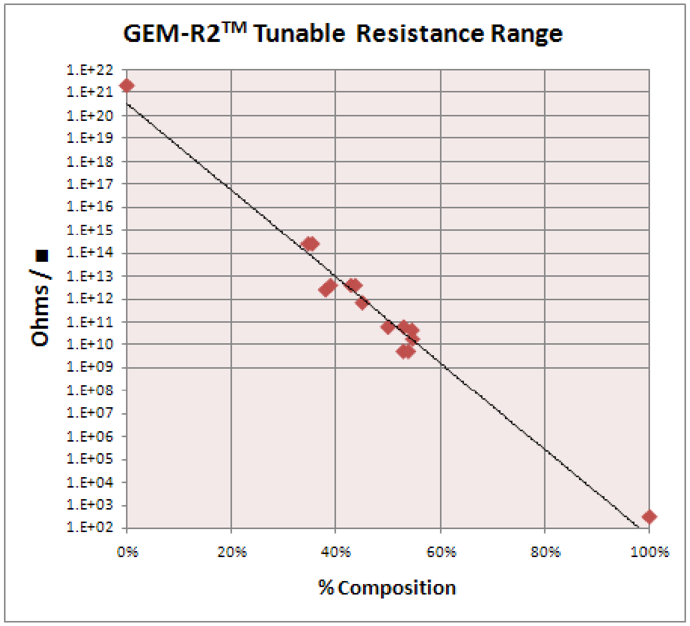
- Thin film growth that relies on self-limiting surface reactions
- Gas A reacts with a surface
  - excess precursor & reaction by-product removed.
- Gas B is introduced to the evacuated chamber – reacts with surface bound A
  - excess precursor & reaction by-product removed.
- Repetition of A – B pulse sequence to build film layer-by-layer



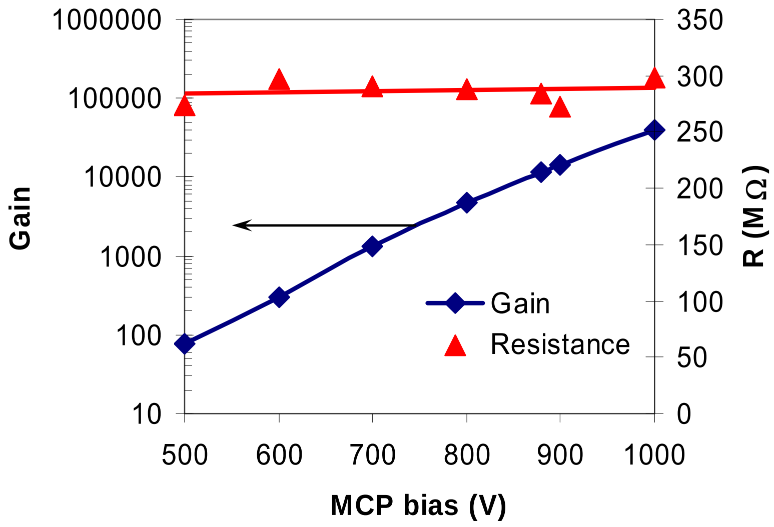
ALD Functional Films: Substrate Independent MCP



http://www.mc-set.com/bse/mat_list.htm

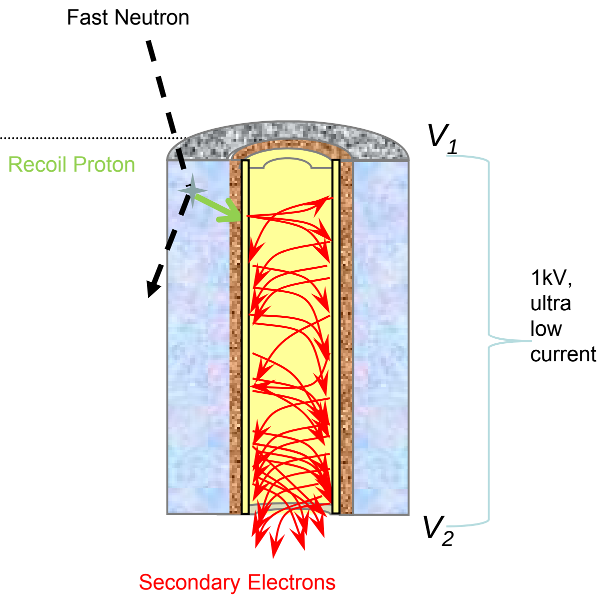


- SE yields >5 possible vs MCP < 3
- Conductivity range > 7 orders of magnitude
- Ohmic conduction, Stable in applied E field, TCR < 1%

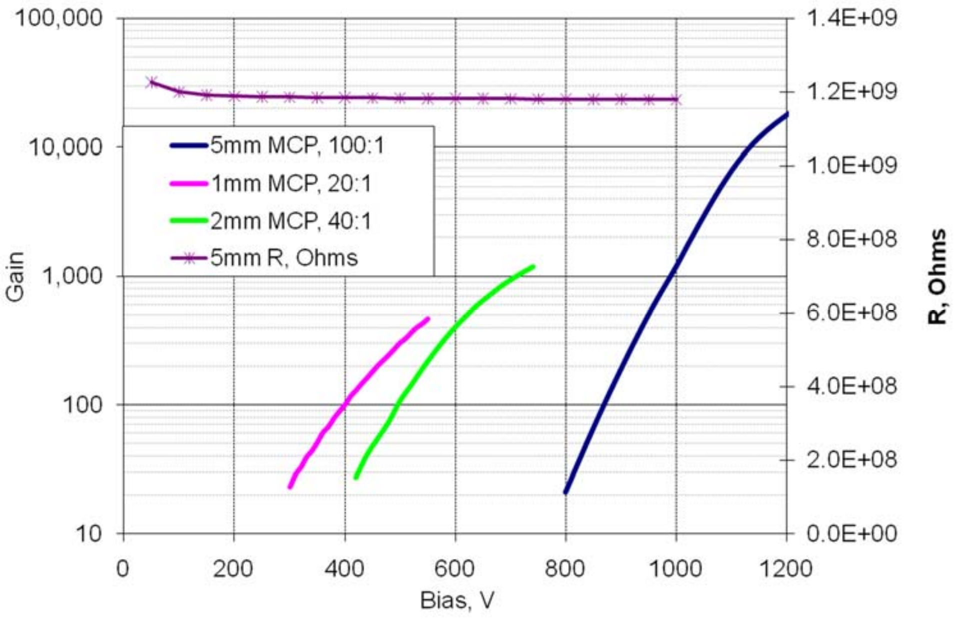


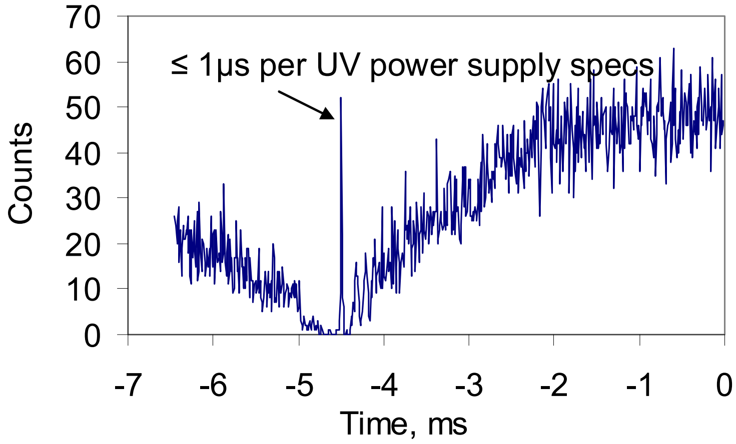
- 10 µm pore, Soda Lime glass substrate, 40:1 L/D, R~280 MW
- 5-10x gain increase vs. commercial MCPs

Fast Neutron Detection Technology



- Hydrogen-rich PMMA MCP
- Graded Temperature ALD
  - Active films deposition at 140C
- Proton initiated electron cascade
- Output pulse $10^3 – 10^6$ electrons
- Standard readout electronics





Timing histogram of events detected under 120Hz-modulated UV illumination.

Fast Neutron Detection Simulation: P1 and P2 Probabilities

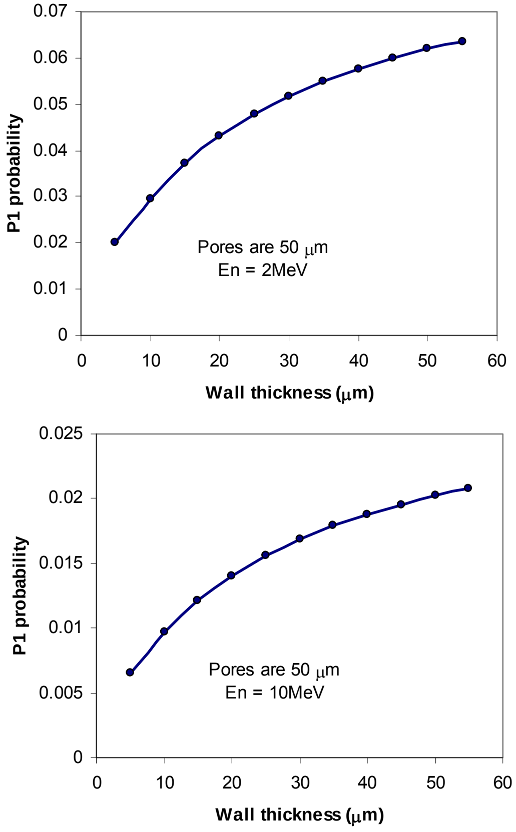
$P_{detection} = P_1 * P_2 * P_3$

P_1 – n-p recoil within the MCP substrate

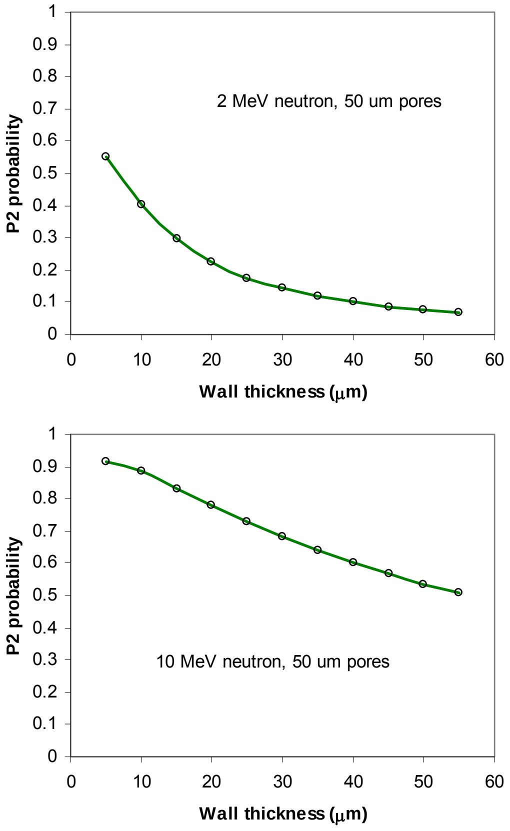
P_2 – proton escape into MCP pore

P_3 – electron avalanche is formed (MCP ~1)

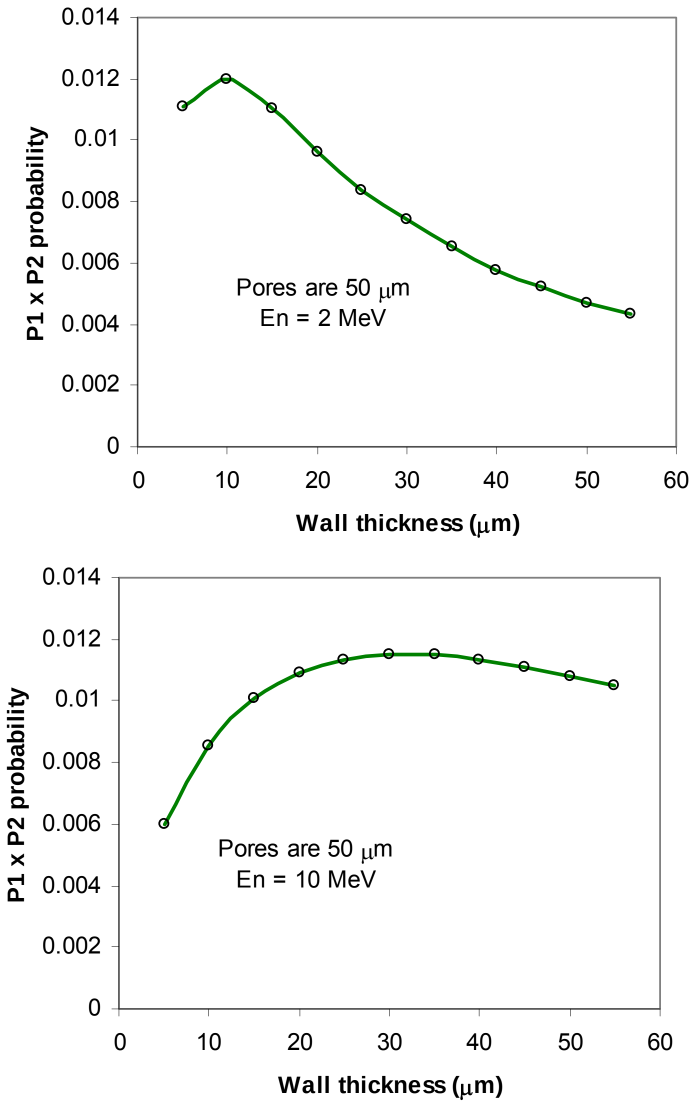
P1



P2



P1*P2*P3



Fast Neutron Detection Simulation: P3 Probability and Event Timing

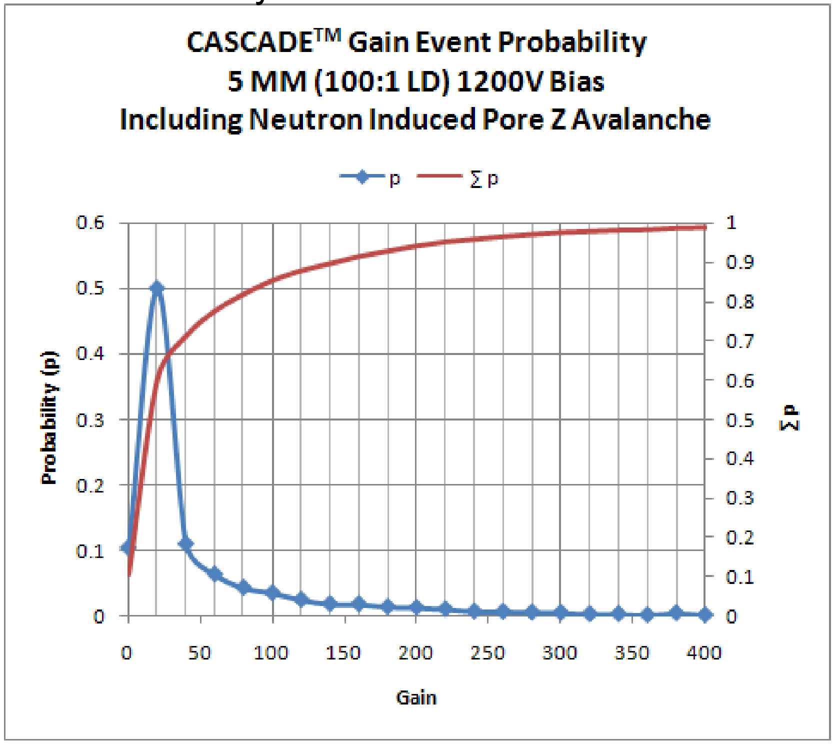
Neutron Detection Stage

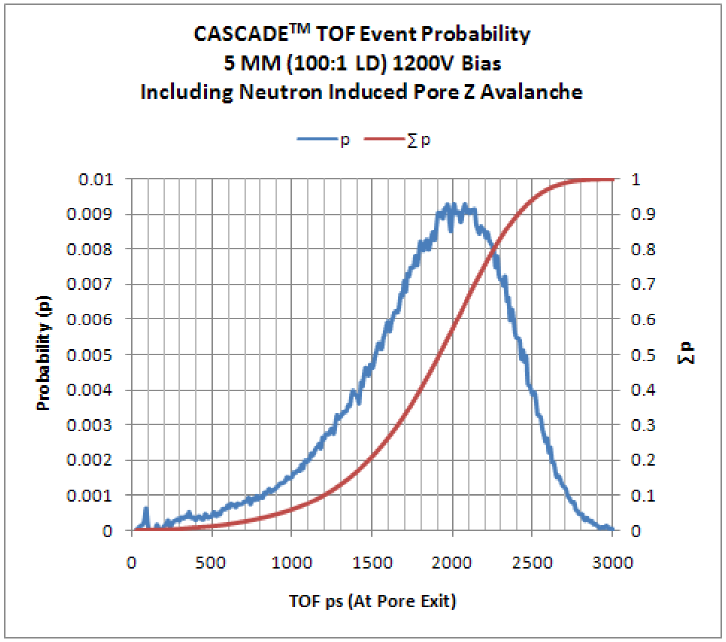
Signal Amplification Stage

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



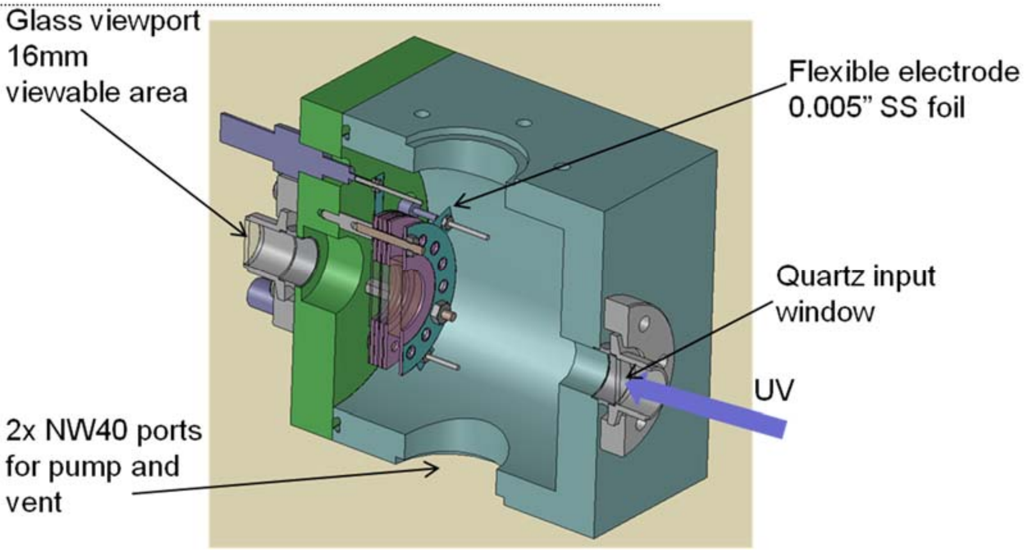


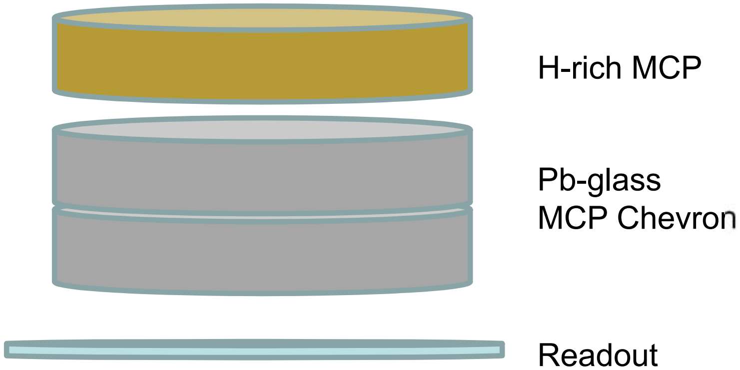
For 99.9% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of ±1.5 ns

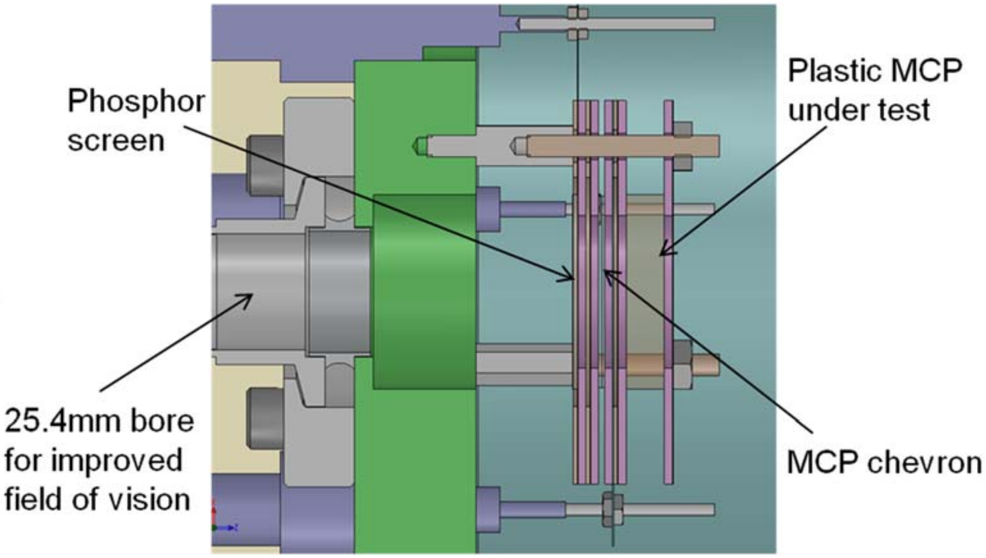
For 90% of events, we should expect a pulse timing uncertainty in coincidence mode of operation of < ± 1.0 ns

Detector Hardware Experimental Setup

- 2 & 5 mm PMMA MCP, ~50 µm pores, 20 µm walls, 5º bias angle
- installed above a chevron stack of 50:1 L/D MCPs
- Phosphor screen readout
- Canberra preamp and postamplifier



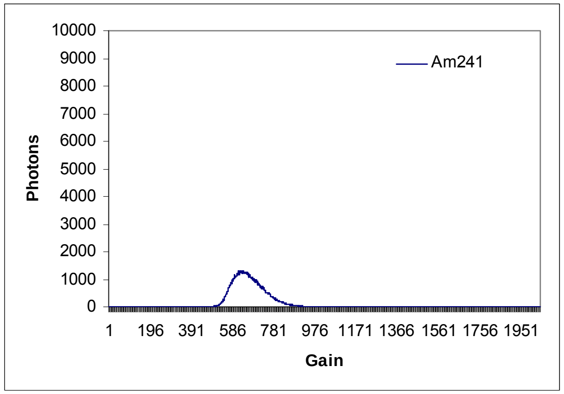


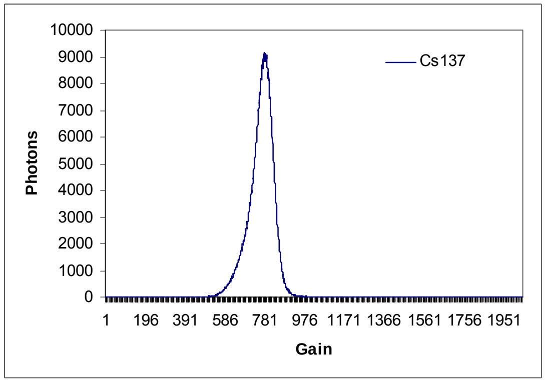


Isotope Sources: Experimental Setup

	Am-241	Cs-137	C-60	Cf-252
	1.9 mQ	760 µQ	43.7 µQ	
Gamma (keV)	36% @ 60, 38% @ 12-22	661	1.17; 1.33	
Flux MCP/s	1.76x10^5	7.03x10^4	8.08x10^3	~10^7

- Isotopes ~15cm from liquid scintillator detector spectra collected over 110s (real time).
- Mesytec MPD-4. is used to record PMT data





Reduction of flux by filters

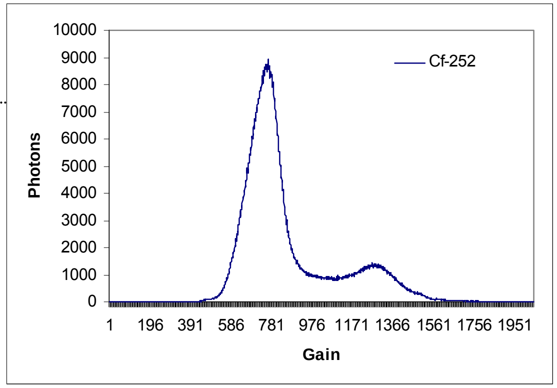
Pb

Gamma	Neutron
0.251328	0.778787

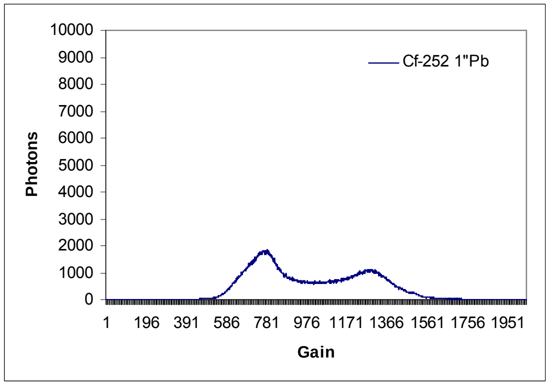
Wax

Gamma	Neutron
0.697481	0.384746

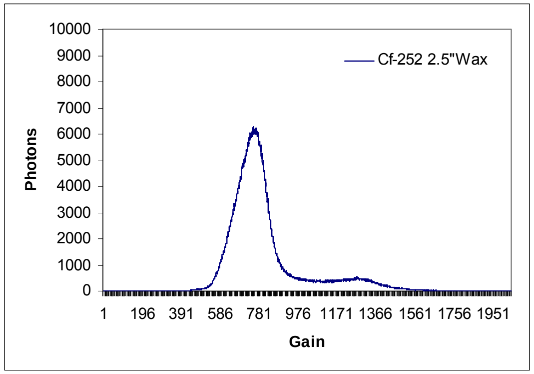
No filters



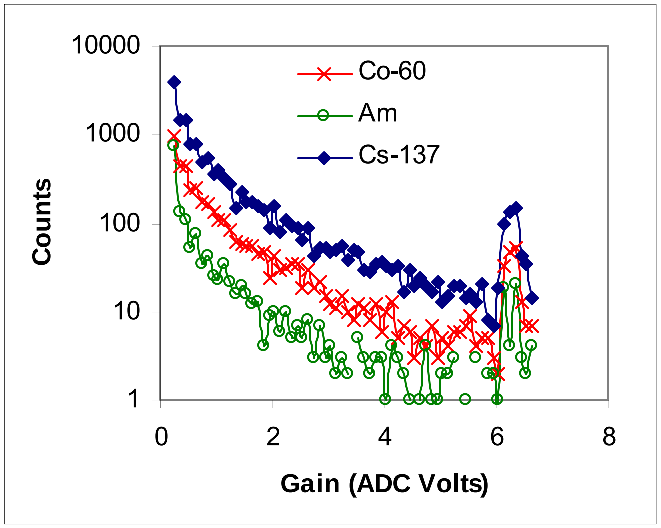
1” Pb



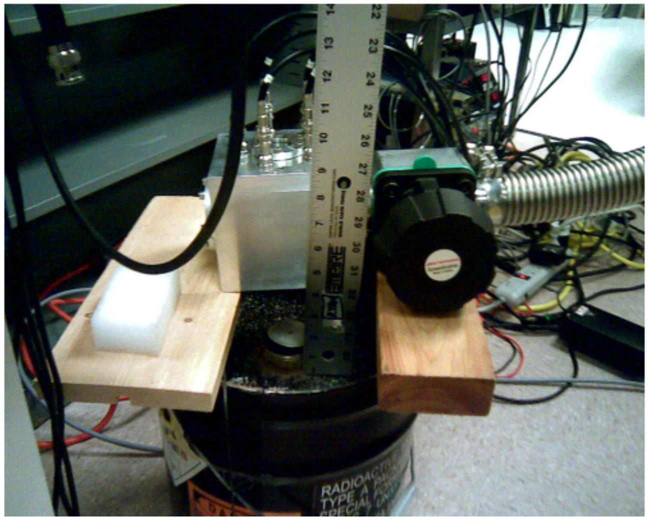
2.5” Wax



Gamma Isotope Sources MCP Results Summary

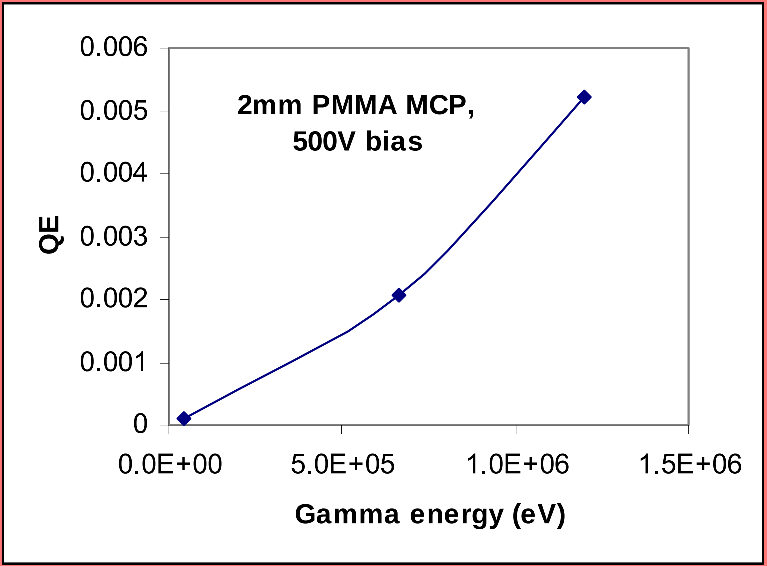


- PMMA, 2mm, > 100k 50 µm Pores, 20µm wall



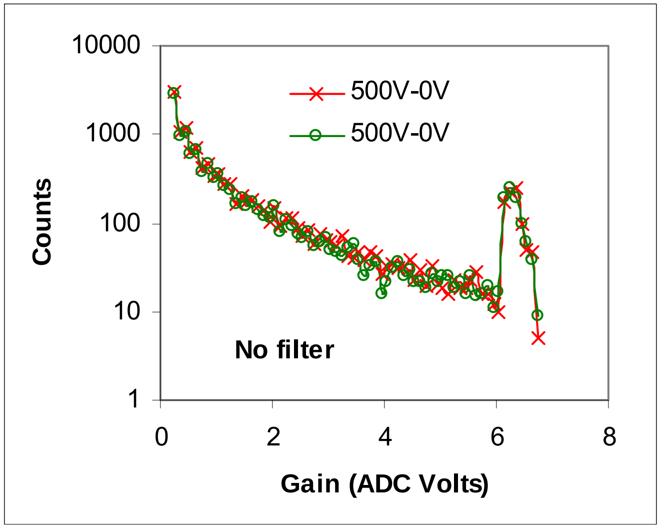
γ isotopic sources

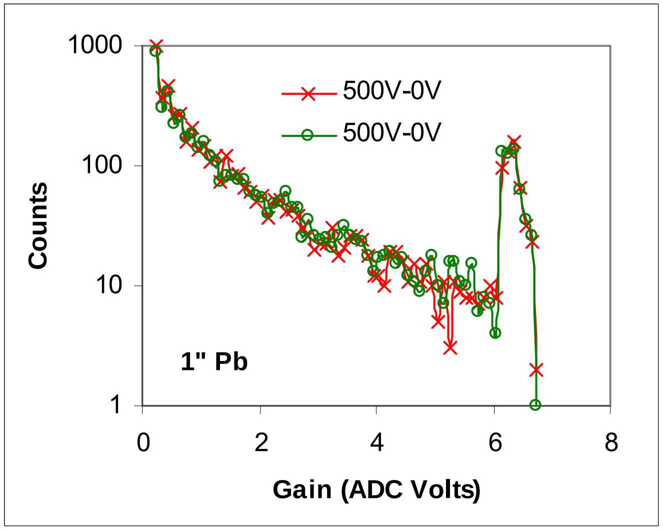
Gamma E (eV)	QE
4.00E+04	9.26E-05
6.61E+05	2.06E-03
1.20E+06	5.22E-03



Cf-252 MCP Experimental Results Summary

Counts in 96 seconds detected by PMMA MCP only (chevron subtracted)



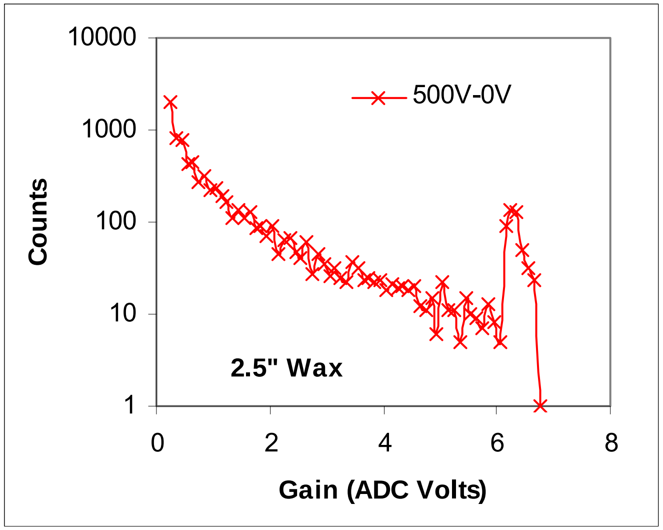


Filter	Count rate (cps/detector)
no	125
1” Pb	52
2.5” wax	83

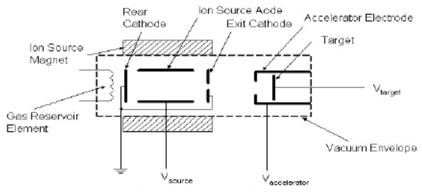
γ QE = 0.000885

n QE = 3.28E-03

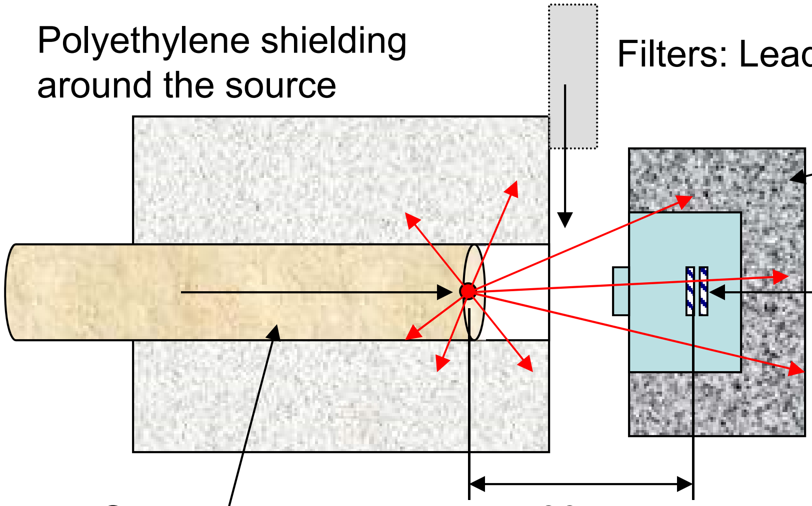
n QE well matched to simulation



D-T Source (Thermo 320) Experimental Setup



NEUTRON TUBE SCHEMATIC



Polyethylene shielding around the source

Filters: Lead (2”), polyethylene (1”, 2”), borated plastic (1”)

Lead shielding around the detector

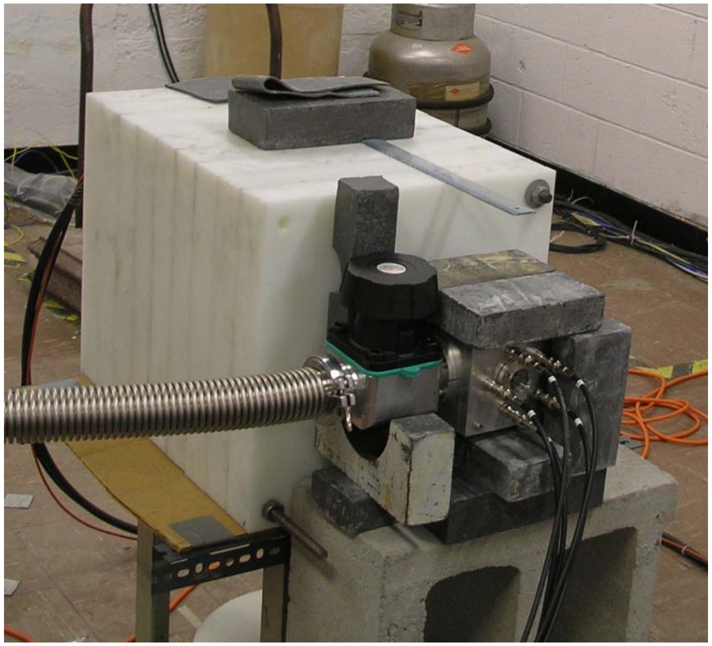
MCPs

5 mm PMMA MCP,
~50 µm pores, 20 µm walls, 5° bias angle
installed above a chevron stack
of 50:1 L/D MCPs

Source

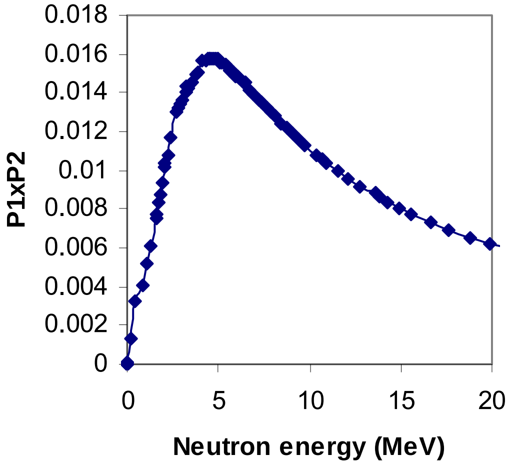
~30 cm

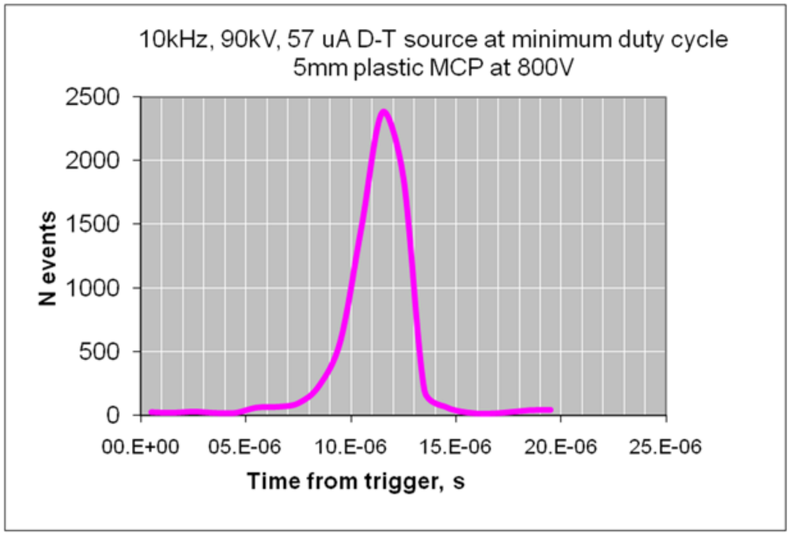
Technical Specifications	
Neutron Yield	1.0E+08 n/s
Neutron Energy	14 MeV
Typical Lifetime	1,200 hours @ 1x10⁸ n/s
Pulse Rate	250 Hz to 20 kHz, continuous
Duty Factor	5% to 100%
Minimum Pulse Width	5 µsec
Pulse Rise Time	Less than 1.5 µsec
Pulse Fall Time	Less than 1.5 µsec
Maximum Accelerator Voltage	95 kV
Beam Current	60 µamps



D-T Source Experimental Results Summary

Predicted QE ~0.8%





Conclusions:

1. QE to 14 MeV neutrons is ~1.2%
2. Believe n and γ counts are comparable at 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)

Conclusions and Future Work

- Functional films – Improved performance, substrate independence
  - Emissive Layer - Optimized SE yield and tailored conductivity
  - Conductive layer - “Ohmic” conduction, Low TCR
- First Plastic MCP results demonstrated
- Fast neutron detector demonstration
  - > 1% Neutron detection simulation target
    - 2mm MCP QE=0.003
    - 5mm MCP QE=0.012
  - < 0.1% Gamma detection “simulation” target
    - Energy dependence QE=$9.26\text{x}10^{-5}$ – $5.22\text{x}10^{-3}$
- Future Work
  - Optimization for Neutron QE > 10%
  - Gamma Sensitivity
  - Energy Sensitivity < 500 keV
  - Demonstrate timing < 1.5ns

Acknowledgements

- Prof. James Ryan

- Dr. Richard Lanza