ALD Nanofilm microchannel plate Technology

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Outline

- Microchannel plate (MCP) background
- Key MCP film performance Metrics
- MCP functional thin film technology
  - Secondary electron emissive films
  - Conductive films
- Application examples
  - Large area, high aspect ratio detectors
  - High Energy Physics
  - Fast neutron detection
- Summary

What is a Micro Channel Amplifier?

Very Fast – Very Low Noise - Charged Particle Amplifier

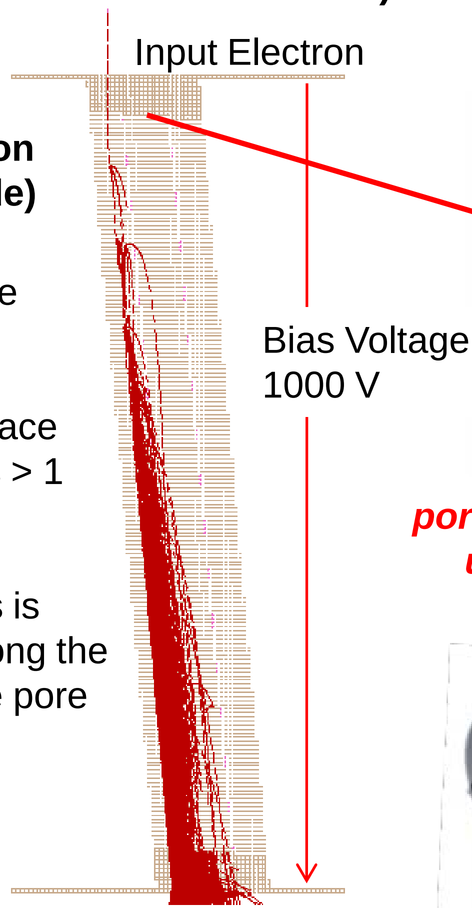
Single Micro Channel Amplifier
(Pore ~ 0.002 mm in diameter)

Amplification
(SE Cascade)

Electrons are accelerated

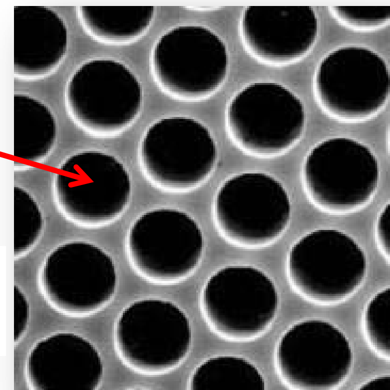
Strike a surface
This creates > 1 electron

The process is repeated along the length of the pore



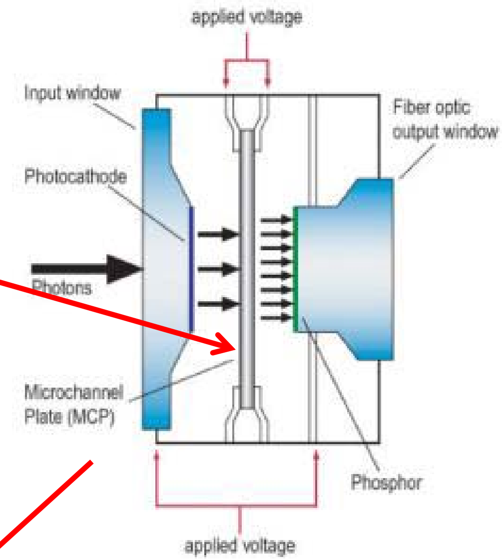
High Gain up to 1e6
Low noise – Very fast pico second response

Micro Channel Plate
(MCP -Array of pores)



pore diameter ranges from 5-10 um in with an AR of >50:1

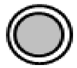
Micro Channel Plate
Used In Light Amplification



Finished NV Tube

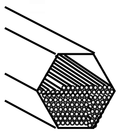
NV Application

Critical MCP processing

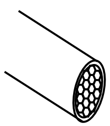


1” Etch-able Core
Lead Glass Rod

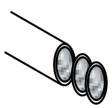
Draw Tower



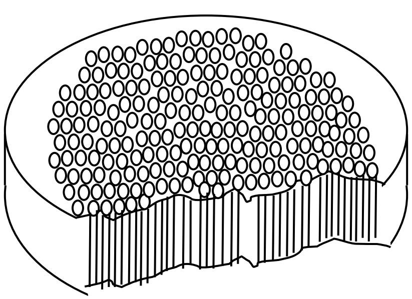
Stacked
Draw Tower
Repeated



Boule
5-100mm Dia



Diced
0.2-0.3 mm thick



Etched
Producing >5M
2-10 um pores

TABLE 2

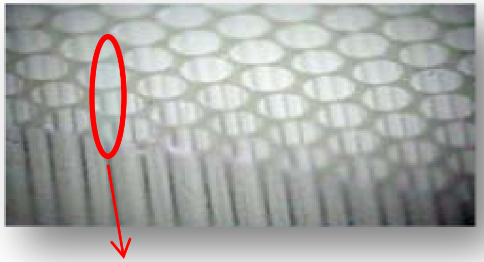
Elemental composition of MCP glass[a].

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

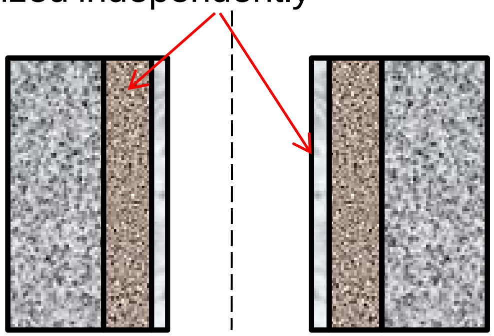
[a] Density – 4.0 g./cm^3.

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

Substrate Functionalize



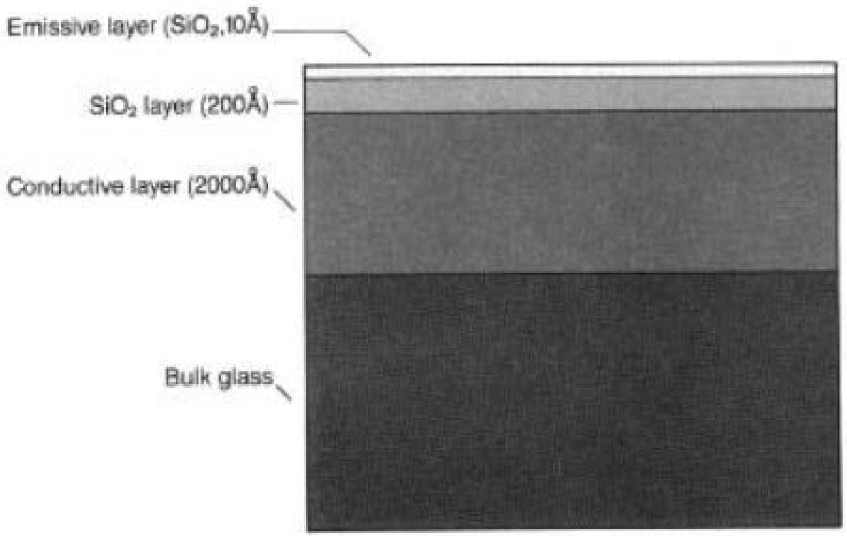
H_2 Reduction conduction & emission layers produced simultaneously & cannot be optimized independently



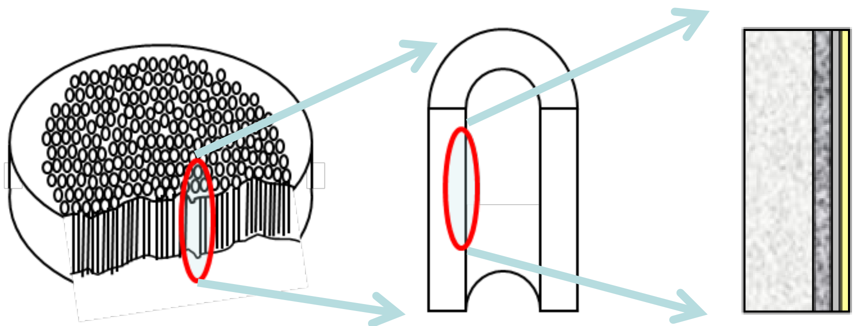
Alternative MCP Substrates: Key Findings

- Substrate
  - Mechanical structure
  - Electrically insulating
- Conductive layer
  - Conformal & uniform
  - ~10^{14} Ohms/Sq
  - Low field effect
- Emissive layer
  - Conformal & uniform
  - High secondary yield
- MCP Device
  - High Gain
  - Resistance stability and matching
  - Stable gain following "scrub"

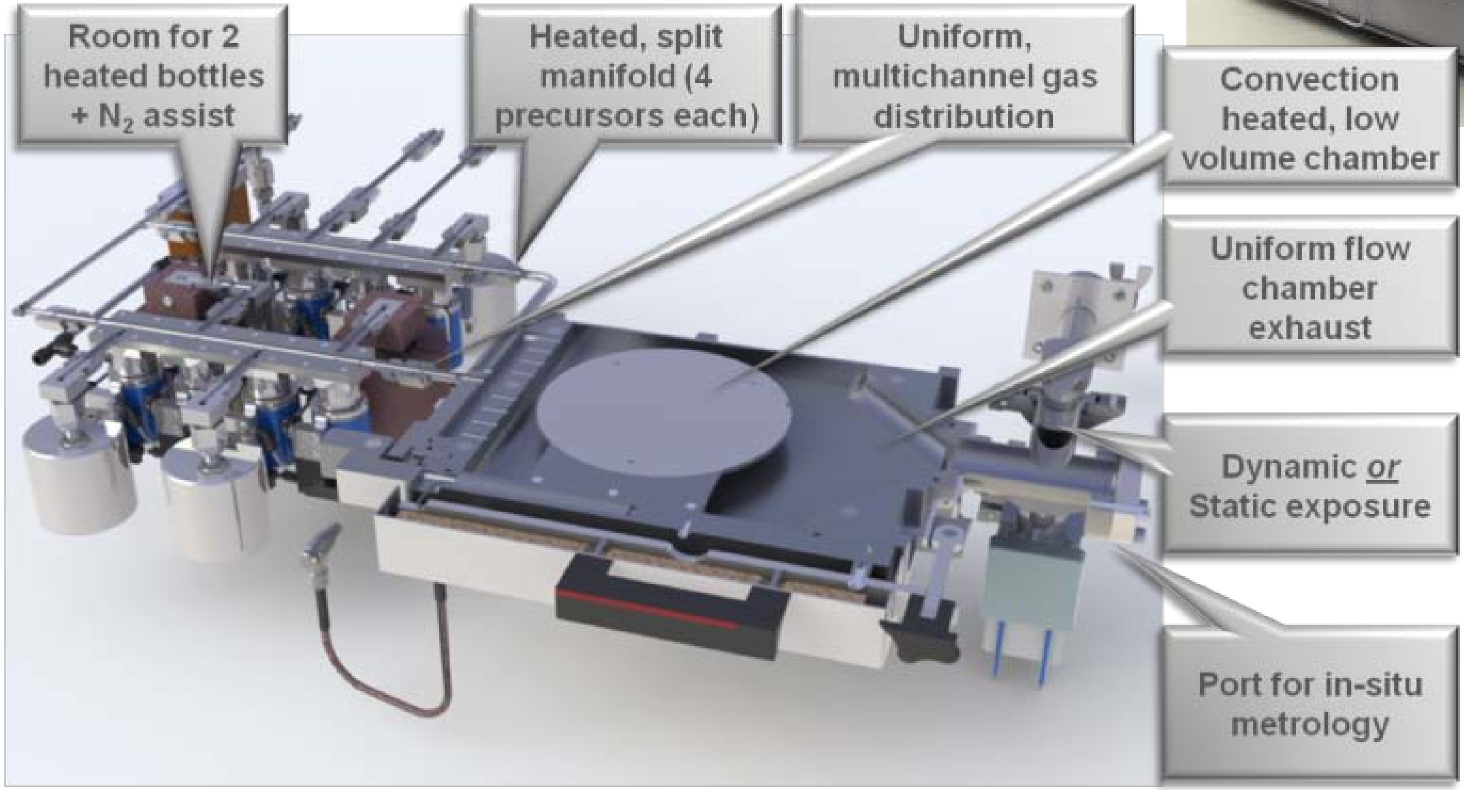
MCP performance tied to glass composition



Channeltron electron multiplier handbook (Burle)

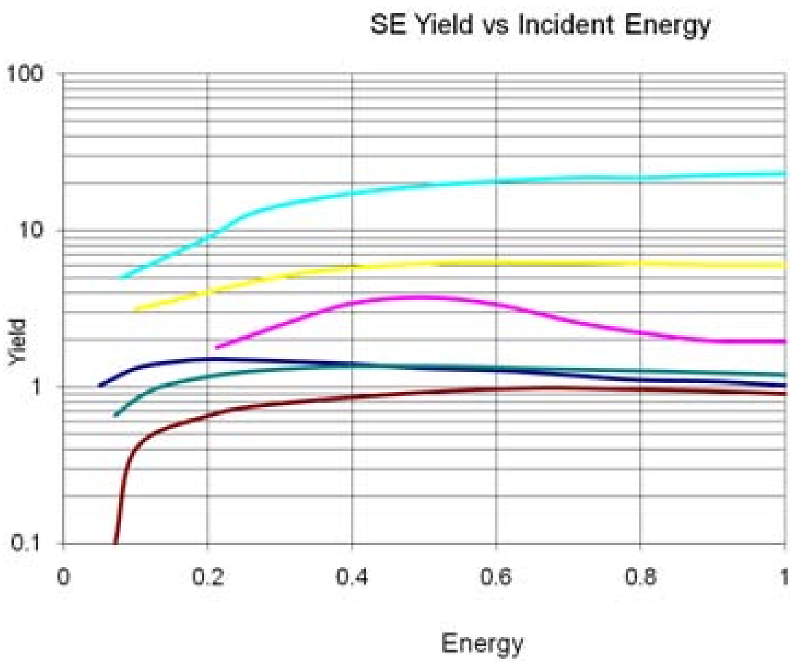


Experimental: GEMStar 8 Equipment

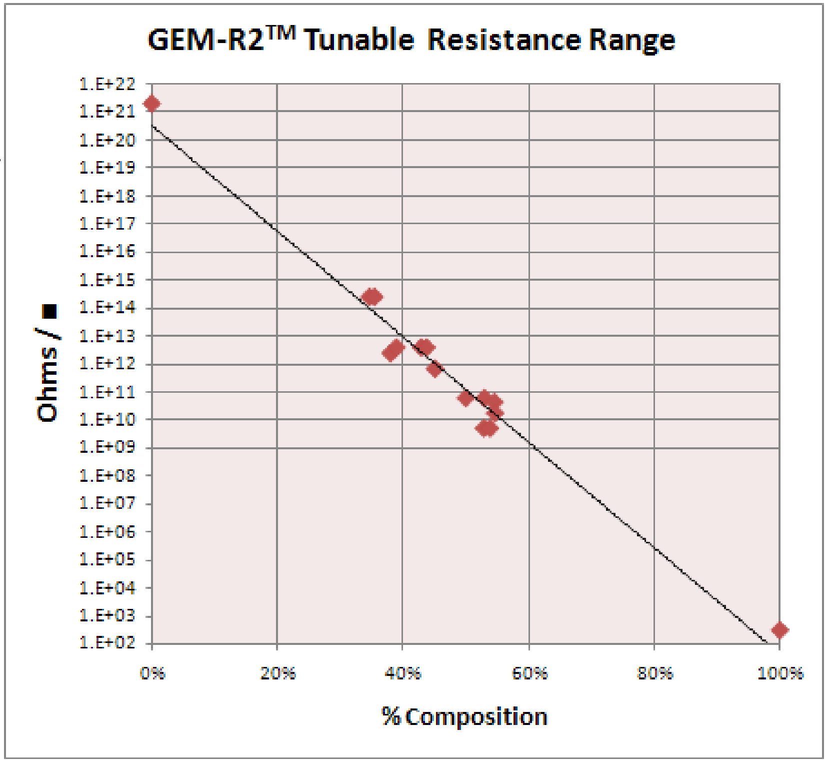


- Designed for extreme surface area, high aspect ratio structures: Multi-channel precursor delivery system isolates & distributes precursors combine with a tapered exhaust to provide exceptional nanofilm uniformity.
- Differentially pumped system seals eliminate gas permeation which along with separate and actively heated Oxidant and Metal-Organic manifolds eliminate parasitic nanofilm production.
- Metrology Interface for QCM, ellipsometry , FTIR, OES and room for up to six high capacity precursor cylinders (2 heated) with 2 independent gas lines, maximizes system productivity.

Layer materials and properties



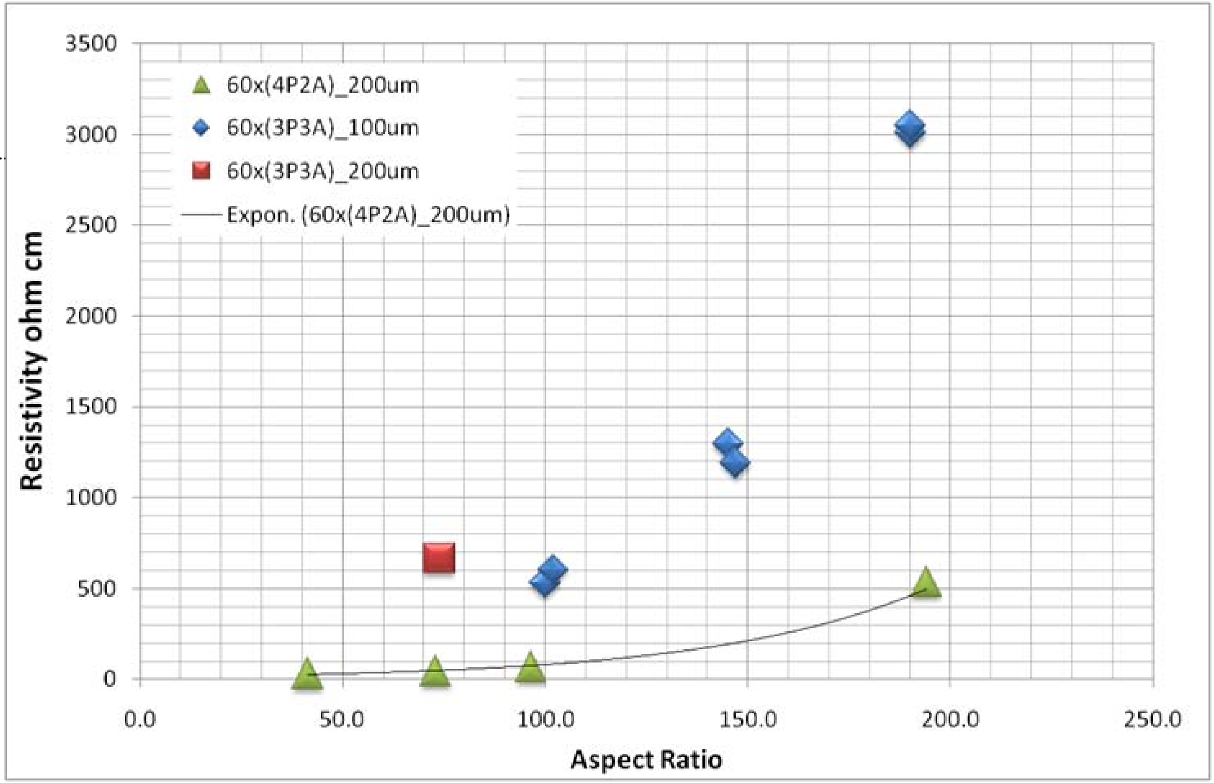
- Emissive nanofilms
  - Thin, conductively doped Al_2O_3
  - Thin MgO
  - Thin MgO – TiO_2 nanolaminate
- ALD enables wide range of material selection
- SE yields range from ~1 to ~ 5 in energy region of interest
- MCP Pb-glass SE yield ~1-2



- Conductive nanofilms
  - Zn doped CuO nanolaminate with alternating layers of Al_2O_3
  - Pt nanoclusters formed within an Al_2O_3 nanoalloy
- Conductivity control over 7 orders
- Ohmic conduction
- Stable resistance in the presence of applied field
- TCR < 1% - comparable to Pb-glass MCP values

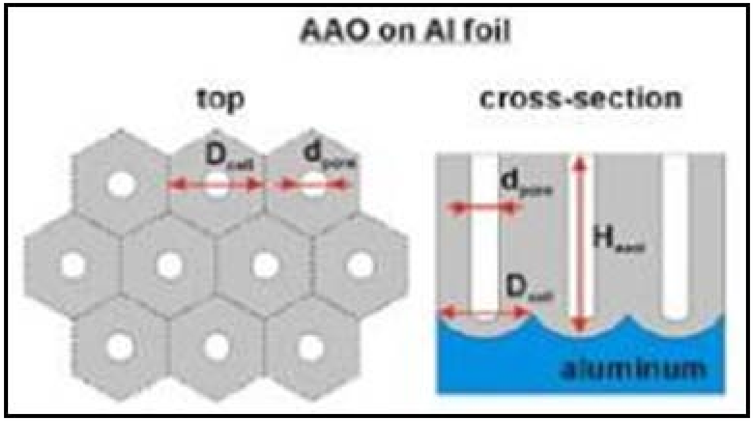
Process characterization

- Electrical - AR Penetration of conducting film into fiber optic structures of constant diameter & varying length.

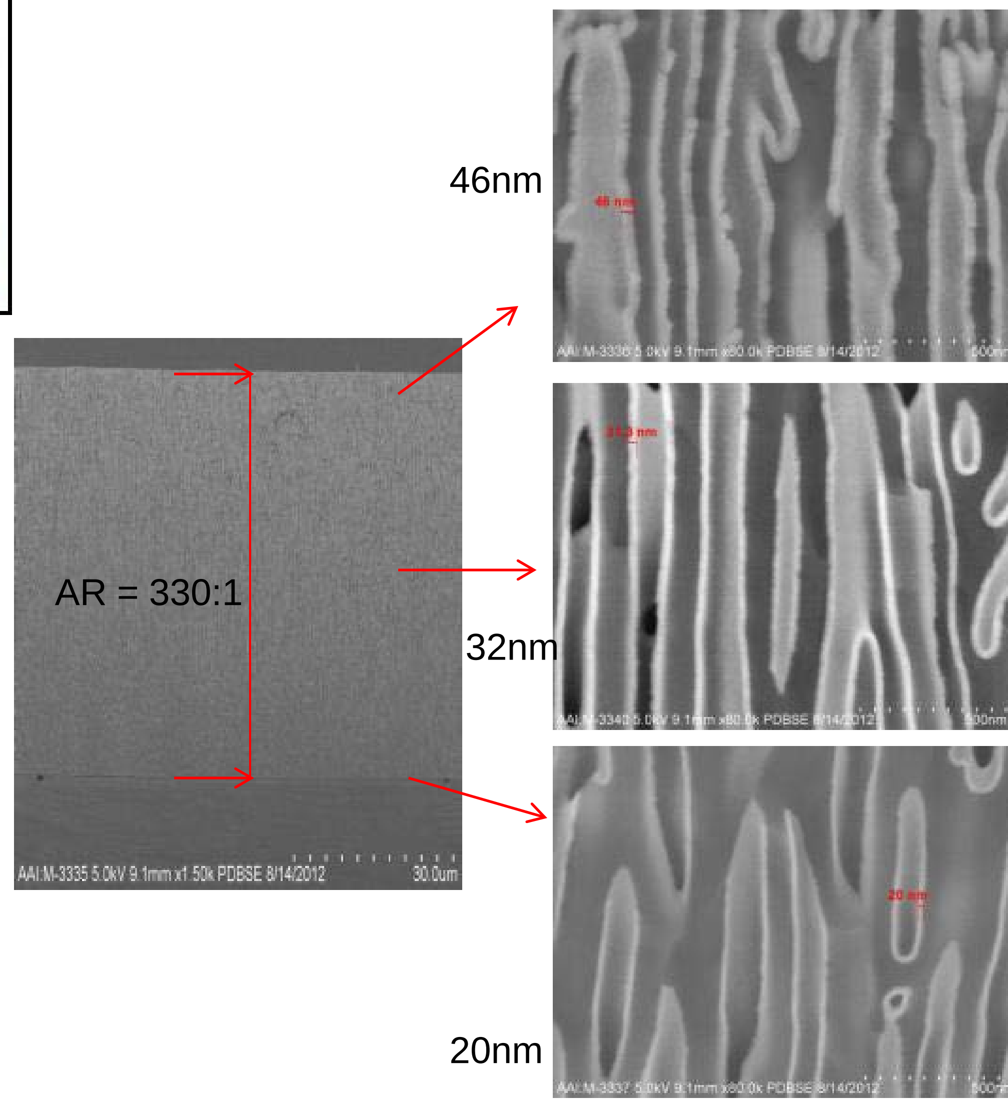


- Mechanical - using specialized fiber optics and index matching, optically locating the depth of penetration. Internal fiber diameter (pore width) is 14.9µm and the length of penetration is measured to be 4803µm, resulting in AR coverage of 322:1.

Nanofilm on AAO test structure



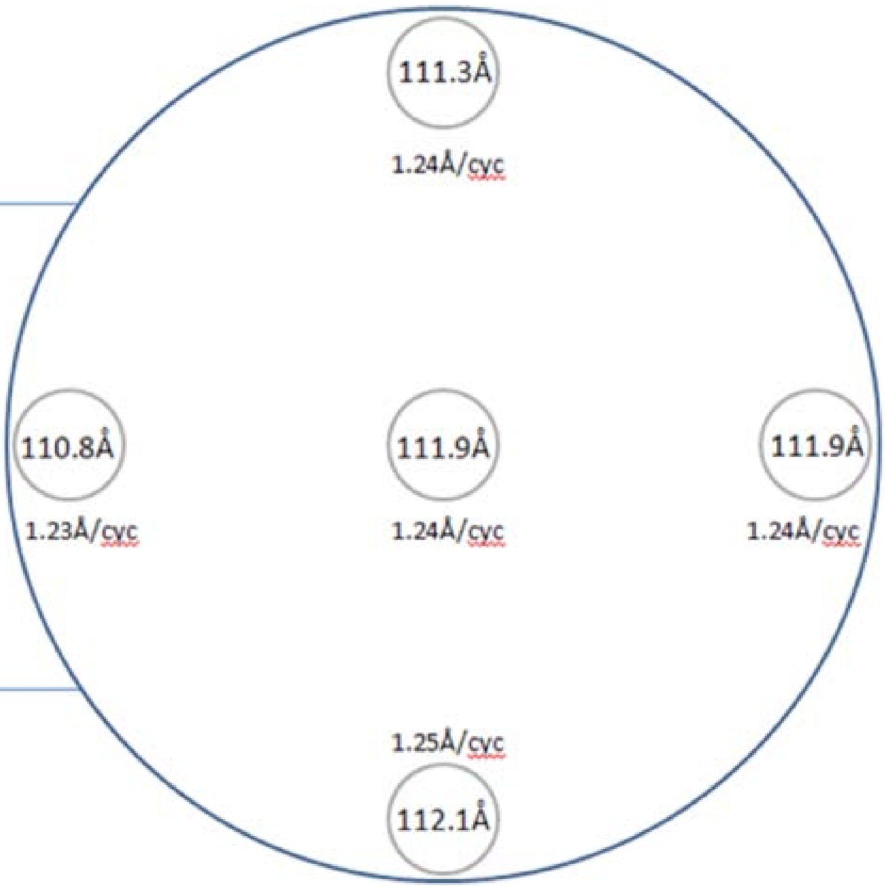
Backscatter SEM – nanofilm highlighted on AAO

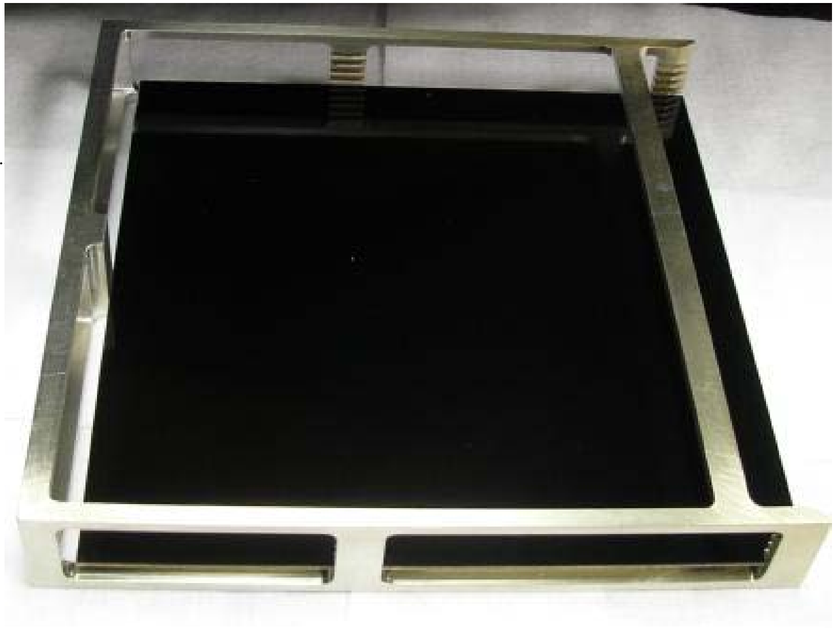


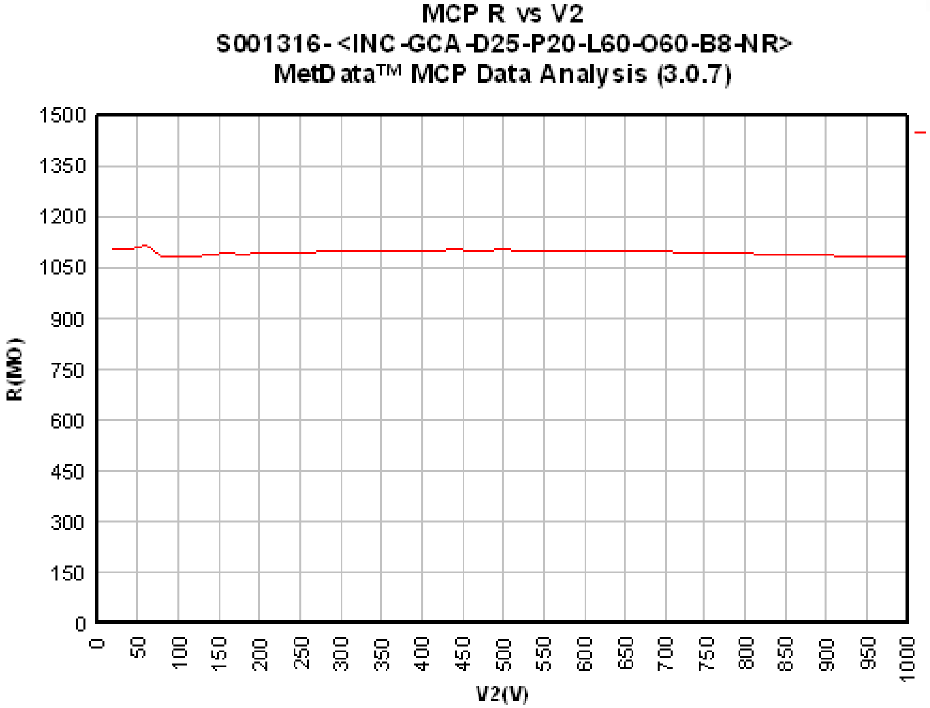
AAO:

- Pores 50 µm x 150nm double sided
- Surface area 1.3 m^2

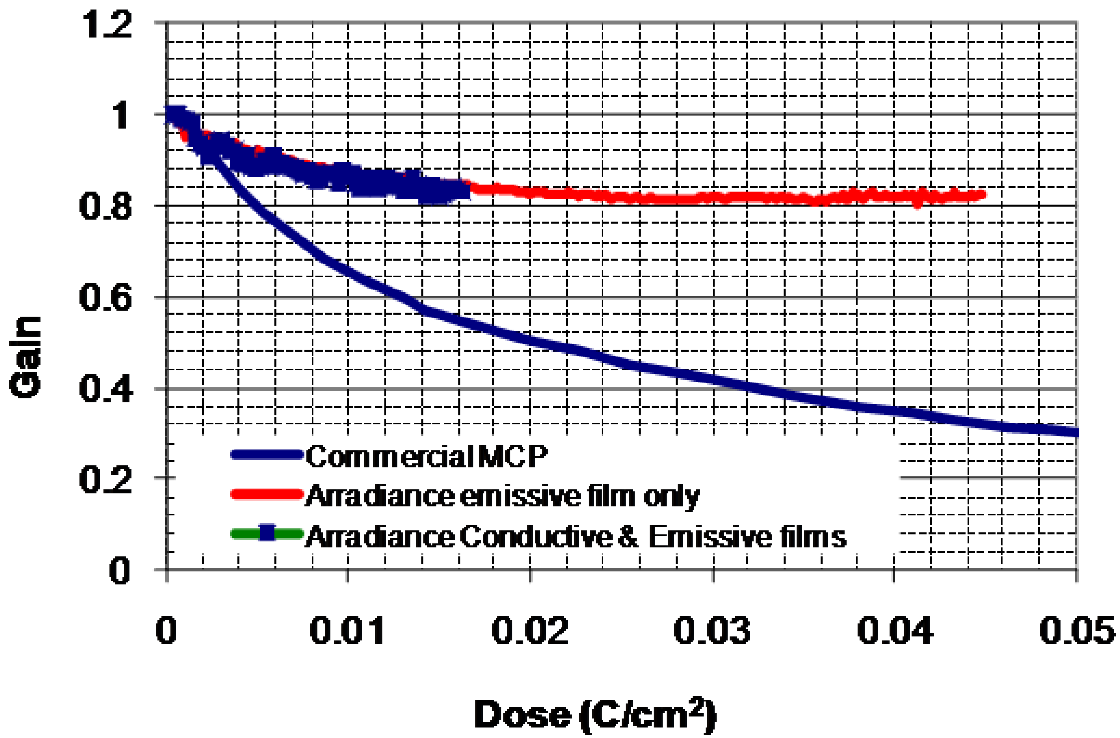
Large Area MCP results







MCP Gain Lifetime



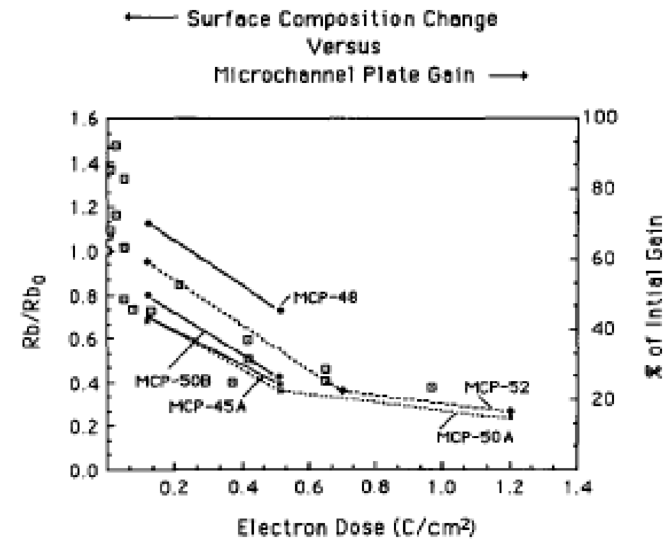
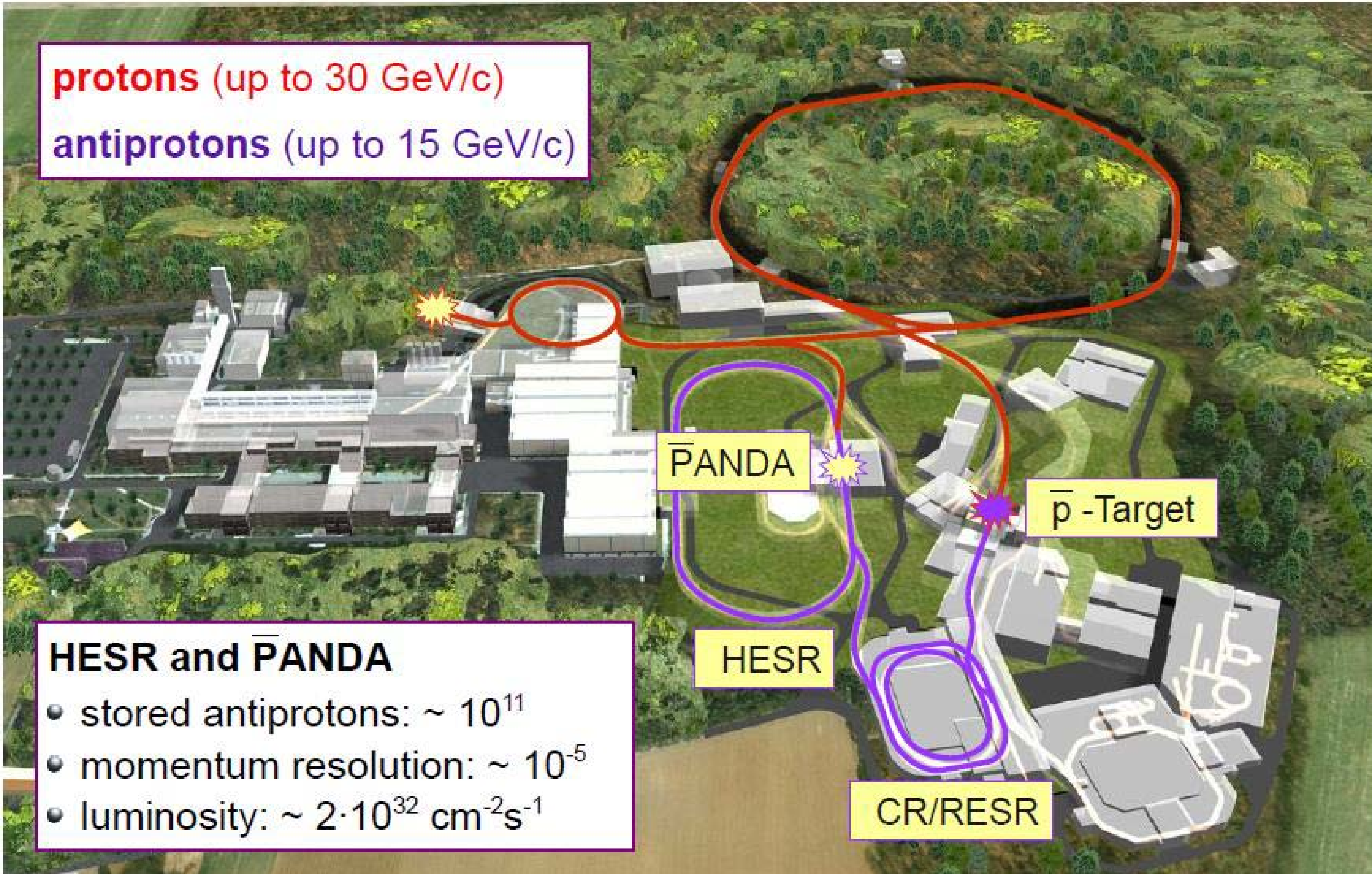


Fig. 7. The dose-dependent changes in the gain of various MCP devices (solid connected points), and the Rb surface concentration on acid-etched and reduced fracture surfaces (open points); the MCPs and the fracture surfaces are (Cs, Rb)–lead silicate.

A.M. THEN and C.G. PANTANO Journal of Non-Crystalline Solids 120 (1990) 178-187

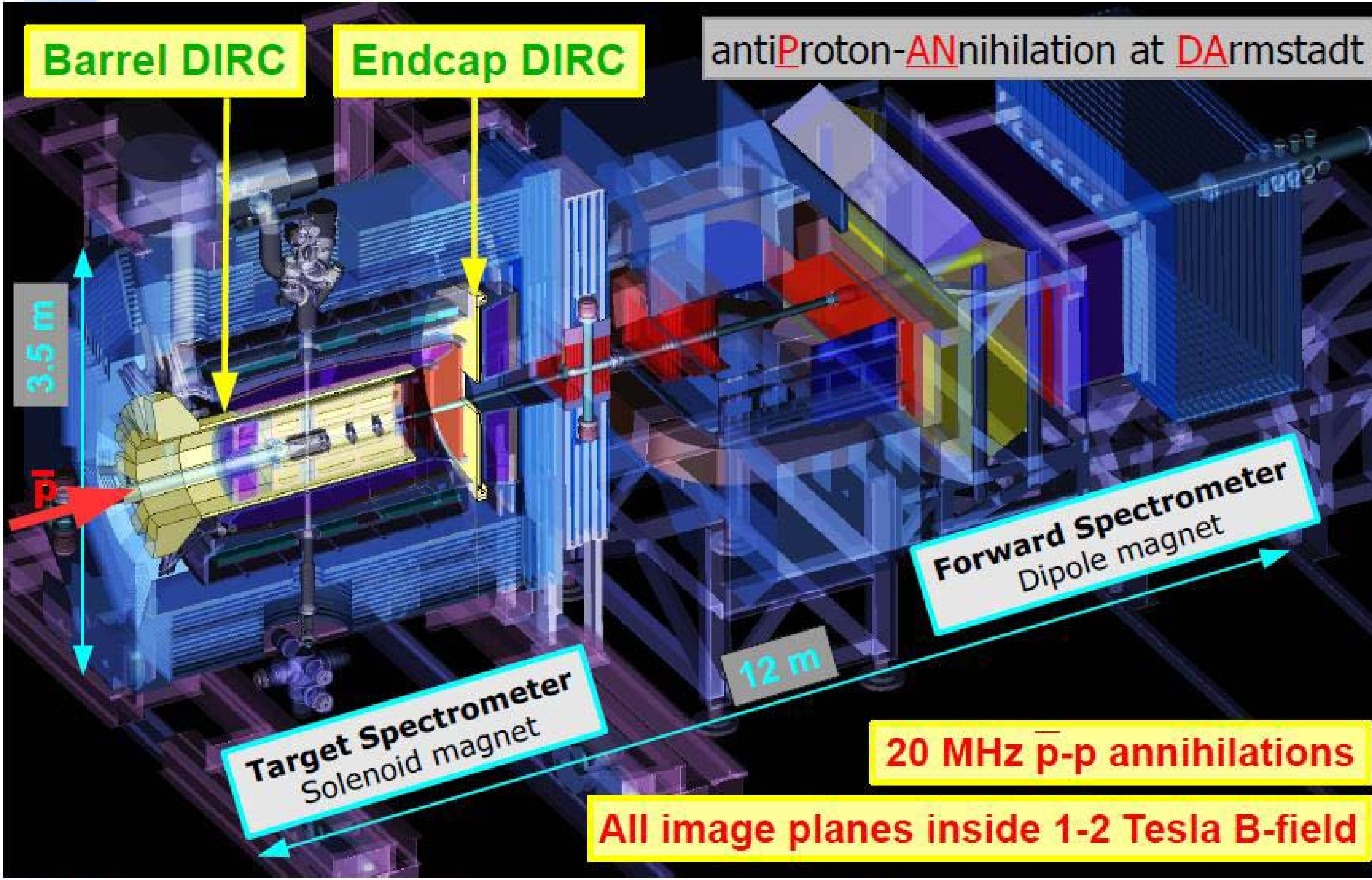
Antiproton Facility HESR at FAIR



HESR and $\overline{\text{P}}$ANDA

- stored antiprotons: ~ 10^{11}
- momentum resolution: ~ 10^{-5}
- luminosity: ~ $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$

$\overline{\text{P}}$ANDA Detector at FAIR

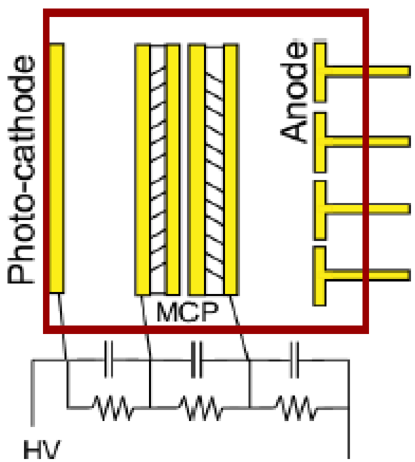


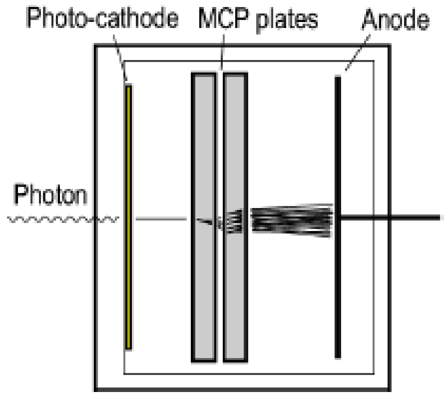
Challenges to Photon Sensors

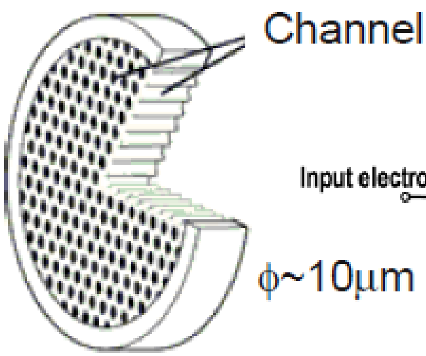
- Good geometrical resolution over a large surface
  - multi-pixel sensors with ~5x5 mm^2 anodes
- Single photon detection inside B-field
  - high gain (> $5*10^5$) in up to 2 Tesla
- Time resolution for ToP and/or dispersion correction
  - very good time resolution of < 100 ps for single photons
- Few photons per track
  - high detection efficiency η = QE * CE * GE
    [QE = quantum efficiency; CE = collection efficiency; GE = geometrical efficiency]
  - low dark count rate
- Photon rates in the MHz regime
  - **high rate capability** with rates of several MHz/cm^2
  - **long lifetime** with integrated anode charge of 1-5 $C/cm^2/y$)

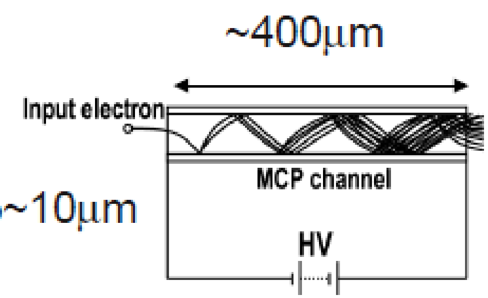
Microchannel-Plate PMT

electron multiplication in glass capillaries ($\varnothing \approx$ 10-25 μm)



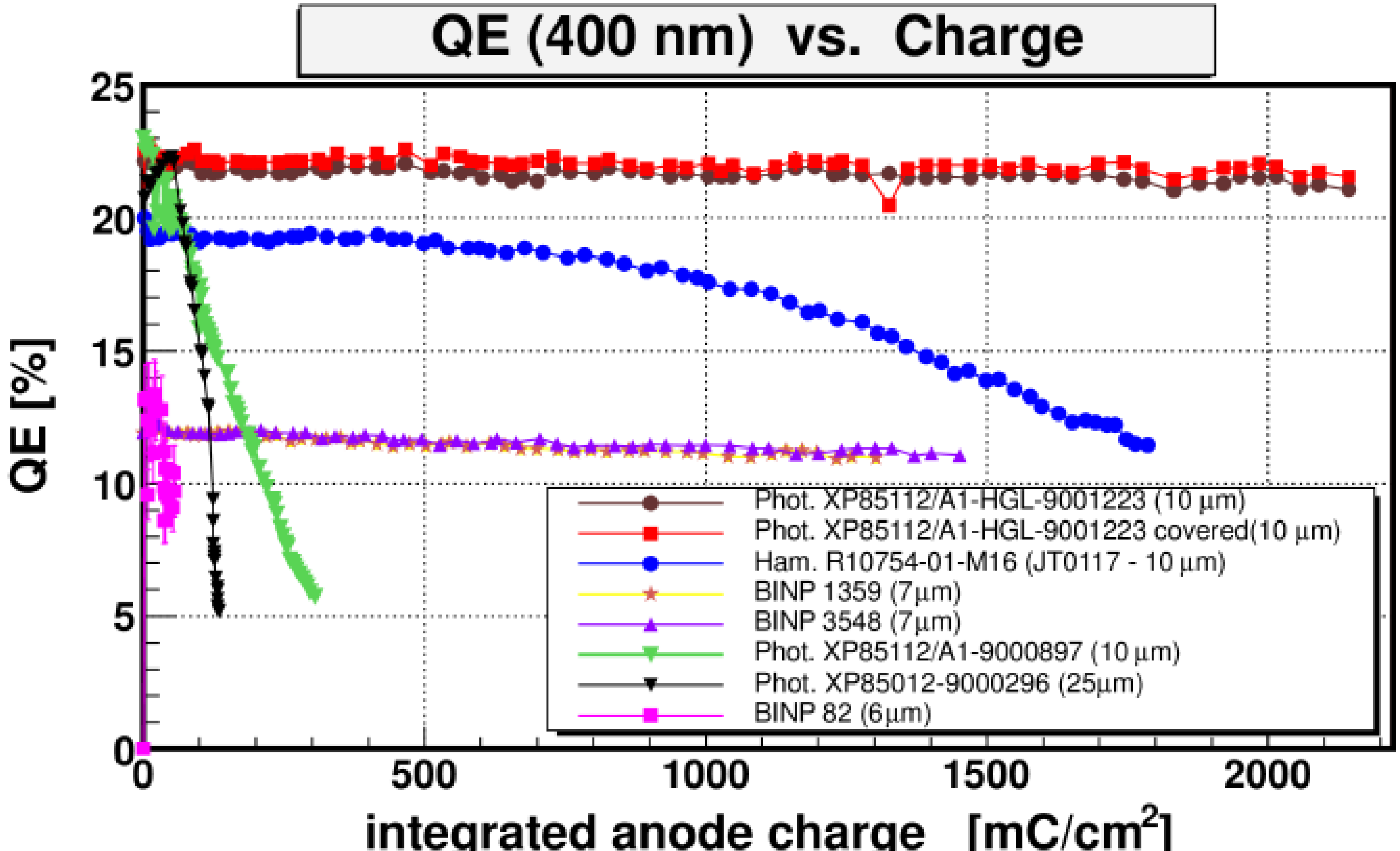






- usable in high magnetic fields
- high gain:
  - $>10^6$ with 2 MCP stages
  - single photon sensitivity
- very fast time response:
  - signal rise time = 0.3 – 1.0 ns
  - TTS < 50 ps
- low dark count rate
- quantum efficiency comparable to that of standard vacuum PMTs
- multi-anode PMTs available
- caveats:
  - lifetime (QE drops)
  - price

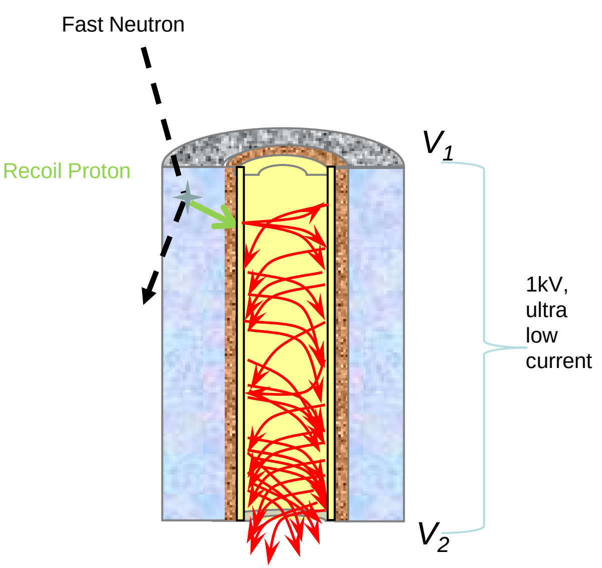
Lifetime of Different MCP-PMTs



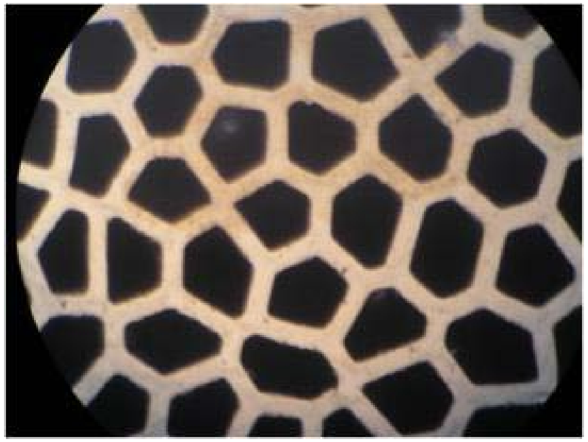
- older BINP and PHOTONIS MCP-PMTs: rapid Q.E. degradation
- new PHOTONIS XP85112: **still no Q.E. drop at >2 C/cm^2**

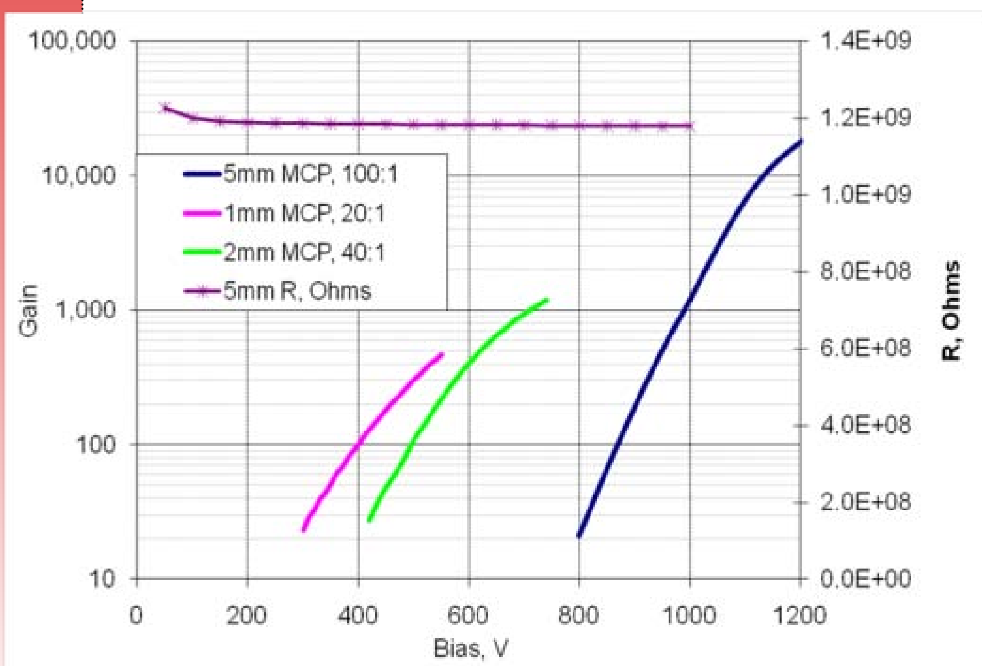
SNM detection technology overview

- 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

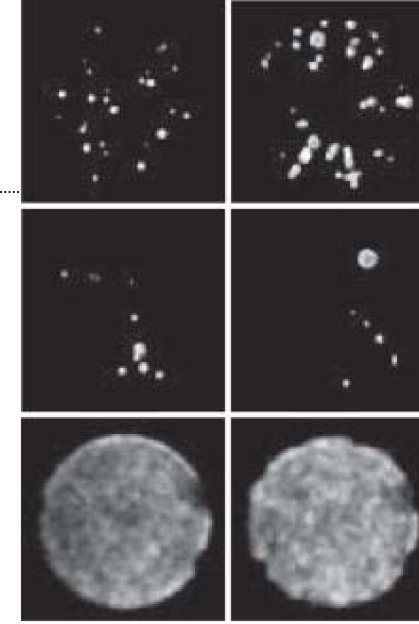


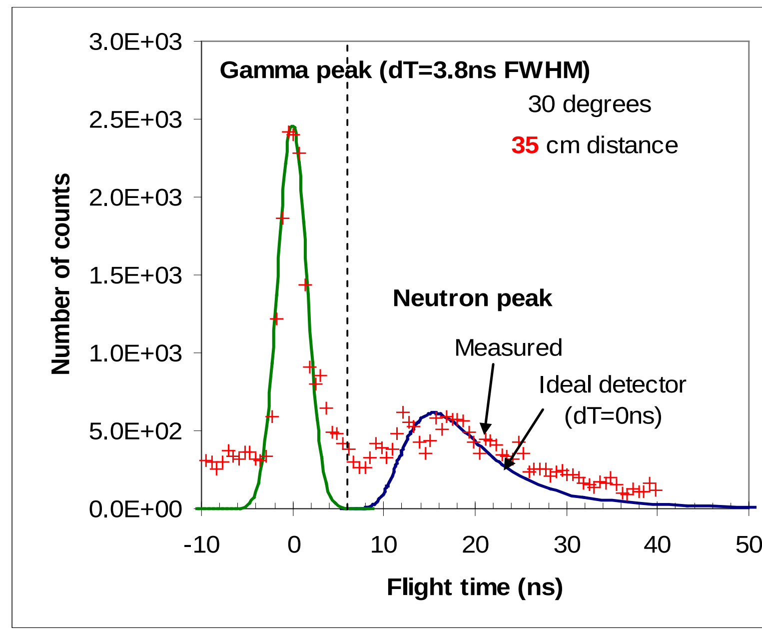
Plastic substrate MCP





Phosphor screen images of events detected with Co-60 gamma source (left) and Cf-252 gamma and neutron source (right).





Timing histogram of time delta between two detectors in response to Co-60 and Cf-252 sources.

Summary

- Emission and conduction layers for MCP technology have been developed
- Emission layer improves the performance of glass MCPs
  - High gain
  - Longer lifetime
  - Reduced outgassing / ion feedback
- Substrate independent conduction and emission films open new possibilities
  - Large area micromachined and plastic substrates
  - Temperature compatibility over a wide range
  - Novel photocathode materials/configurations
  - Low noise – no radioactive traces
  - Better uniformity / reproducibility / spatial resolution