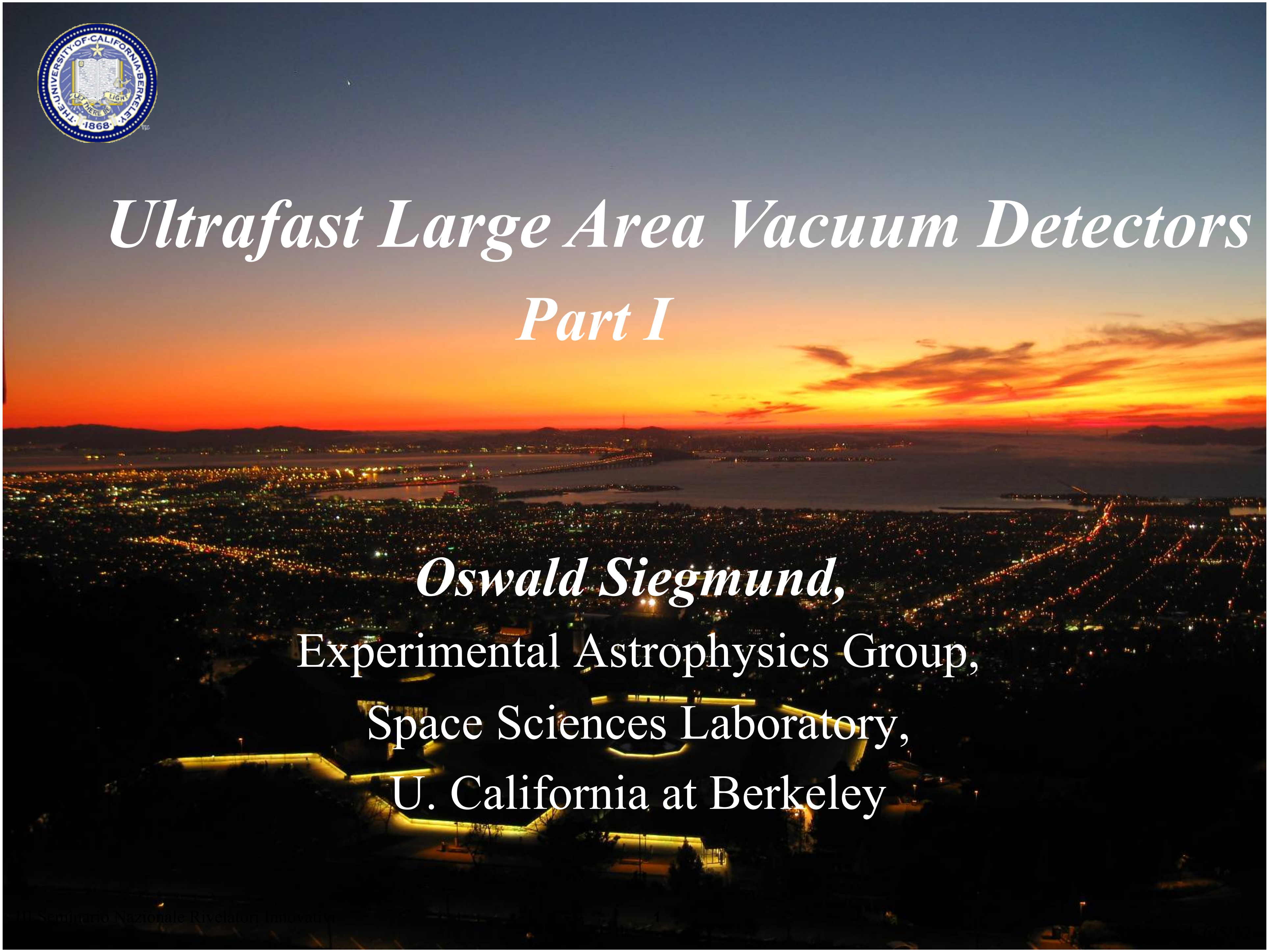


Ultrafast Large Area Vacuum Detectors

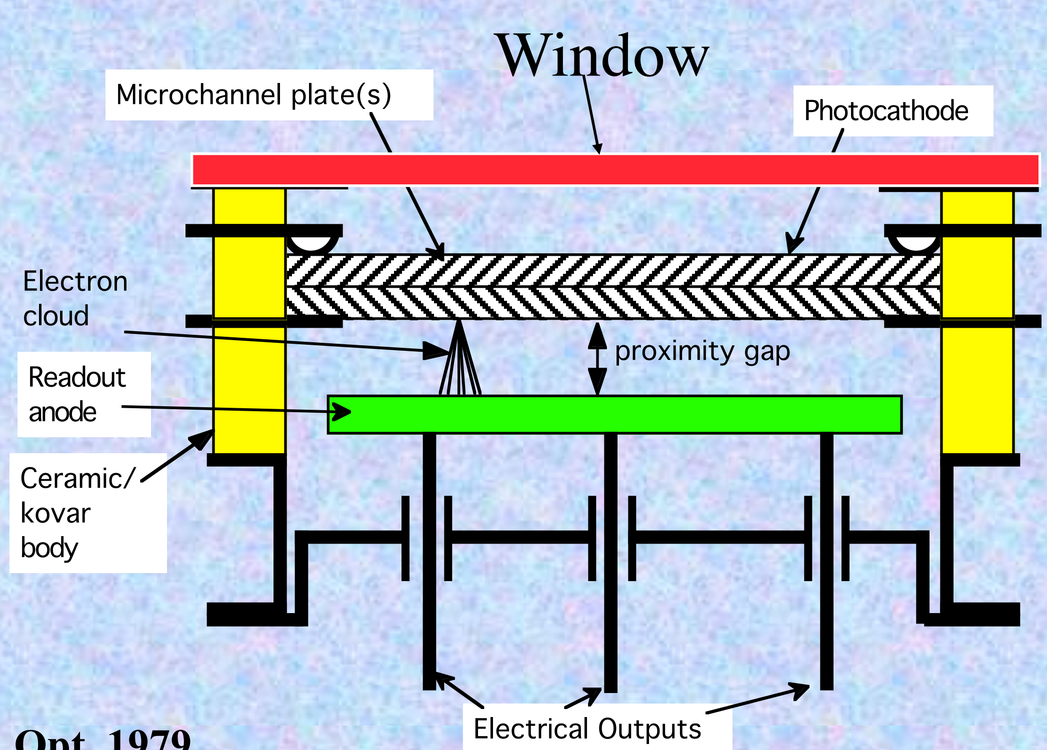
Part I

Oswald Siegmund,
Experimental Astrophysics Group,
Space Sciences Laboratory,
U. California at Berkeley

Microchannel Plate Detector Schemes

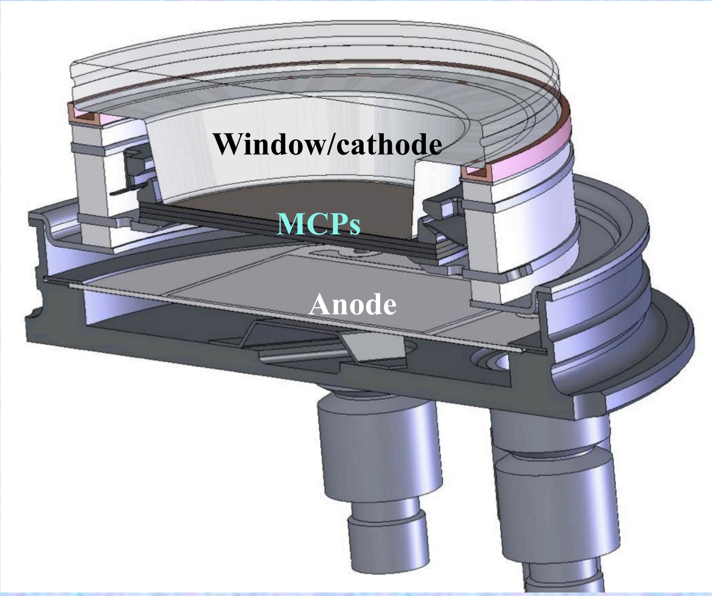
The general scheme of microchannel plate sensors was set decades ago by the night vision industry. Since then a very large number of variations have been developed.

- Detector scheme
  - *Radiation detected by photocathode on window or MCP*
  - *MCP(s) amplify signal*
  - *Electronic encoding anode or phosphor screen & sensor convert signal to image data*



See Wiza NIM 1979, Eberhart Appl. Opt. 1979

Microchannel Plate Detectors



There are many MCP detector schemes each with specific advantages/problems. General scheme is photon detection (photocathode), 1, 2 or 3 MCPs to provide gain, and then some type of readout.

Photocathodes

Alkali halides
Multi-alkalis
GaAs (P/In)
GaN
CsTe / RbTe
Diamond

Microchannel plates

Glass
- **low noise**
- **curved**

Si - lithiographic
Ceramic – lithographic
Borosilicate-ALD

Readouts

Resistive anode
Wedge and strip
Phosphor/CCD
Codacon/Mama
Delay line
Cross strip
Strip-line
ASIC/APS

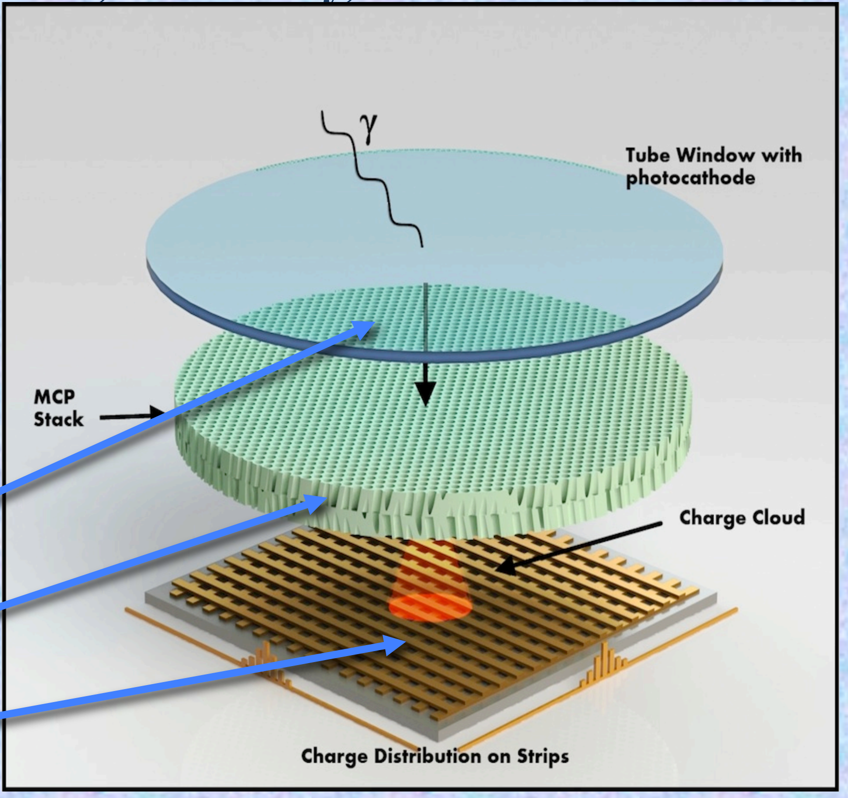
Large Area Sealed Tube Photon Counters Driving areas of new development.

Large Area Picosecond Photodetector Program (DOE)

Major effort at Argonne National Lab., U. Chicago, UC Berkeley and several other National Labs, Universities and Industry to develop large area (20cm) sealed tube sensors with optical photo-cathodes and novel microchannel plates and employ them for high speed timing/imaging applications in High Energy Physics, RICH, Astronomy, etc.

Concept

Proximity focused bialkali cathode, borosilicate micro-capillary array with atomic layer deposited resistive layer and secondary electron emissive layer to make a microchannel plate, strip-line anode with ASIC amp/disc for picosecond resolution.

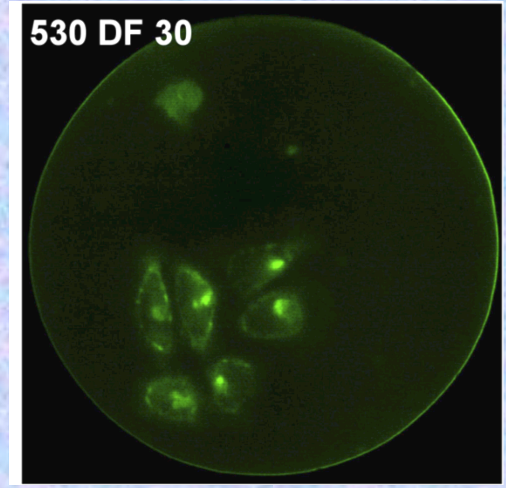


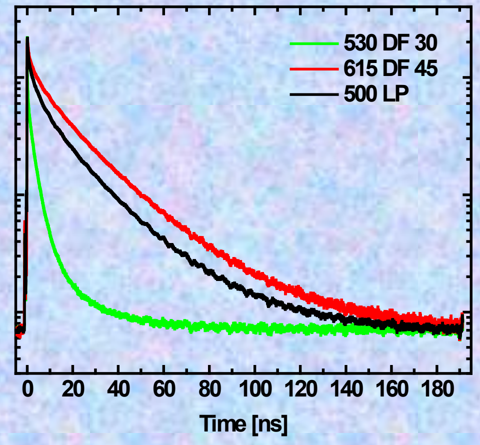
Photocathode on window or MCP converts photon to electron

MCP(s) amplify electron by 10^4 to 10^7

Strip-line anode measures charge position

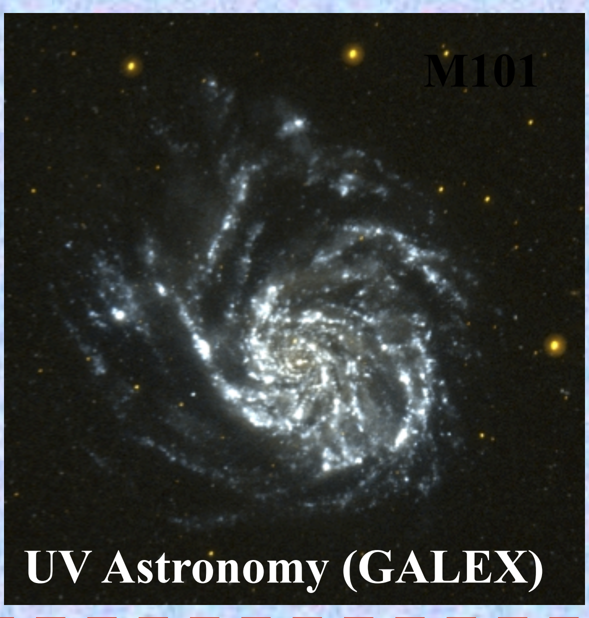
Microchannel Plate Sensor Applications





Fluorescent dye decay time

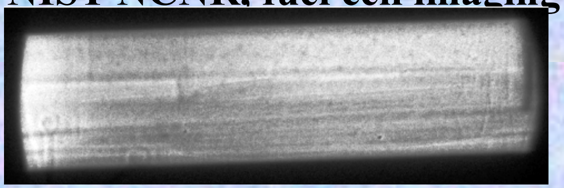
Biological lifetime fluorescence imaging



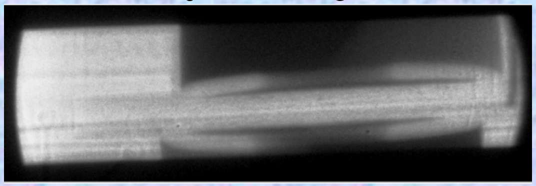
UV Astronomy (GALEX)

Thermal Neutron imaging

NIST NCNR, fuel cell imaging



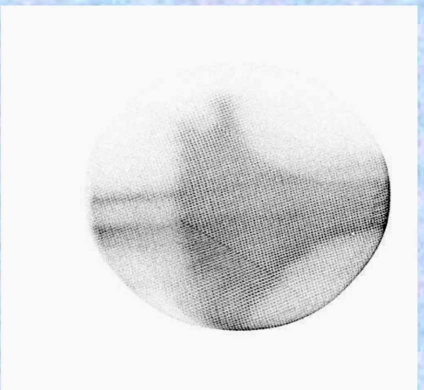
Dry test object

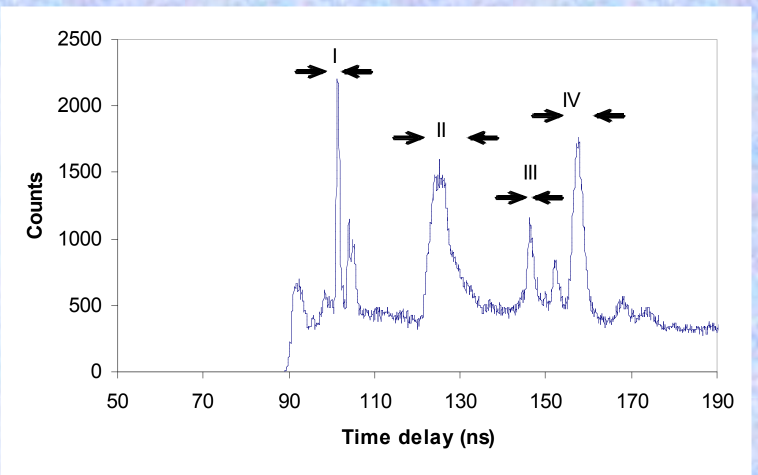


Water flow initiated

ALS Synchrotron time of flight photoelectron spectroscopy

Electron image

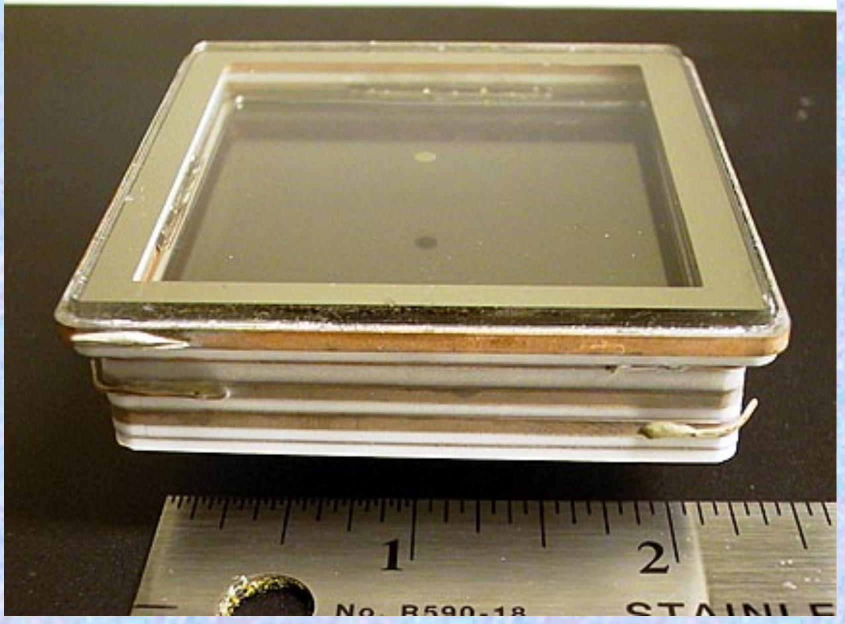




Sealed tube detectors

65mm sealed tube GALEX, CsI, CsTe, delay line, MCP Z.

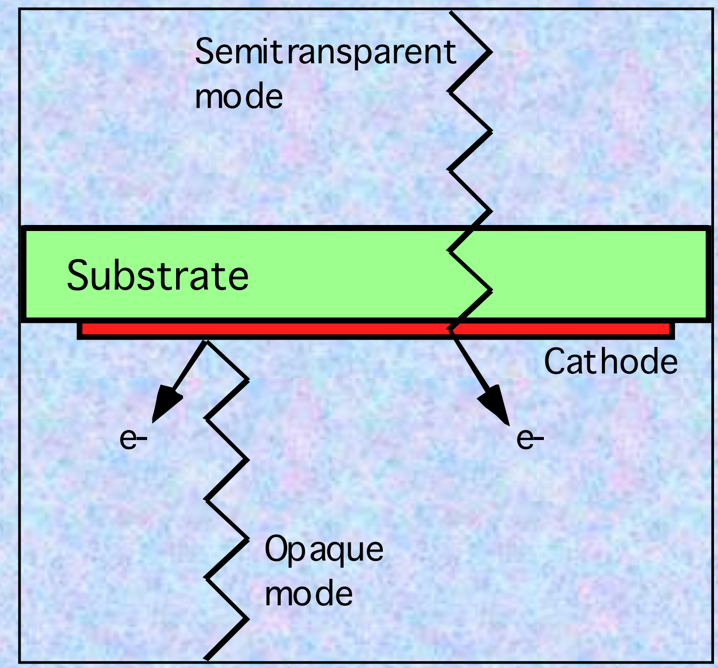
50mm square sealed tube Photonis Planacon, 2 MCPs



Photocathode Overview

Semi-transparent cathodes
(thin film on entrance window) are commonly used in the visible/NIR (night vision, etc).

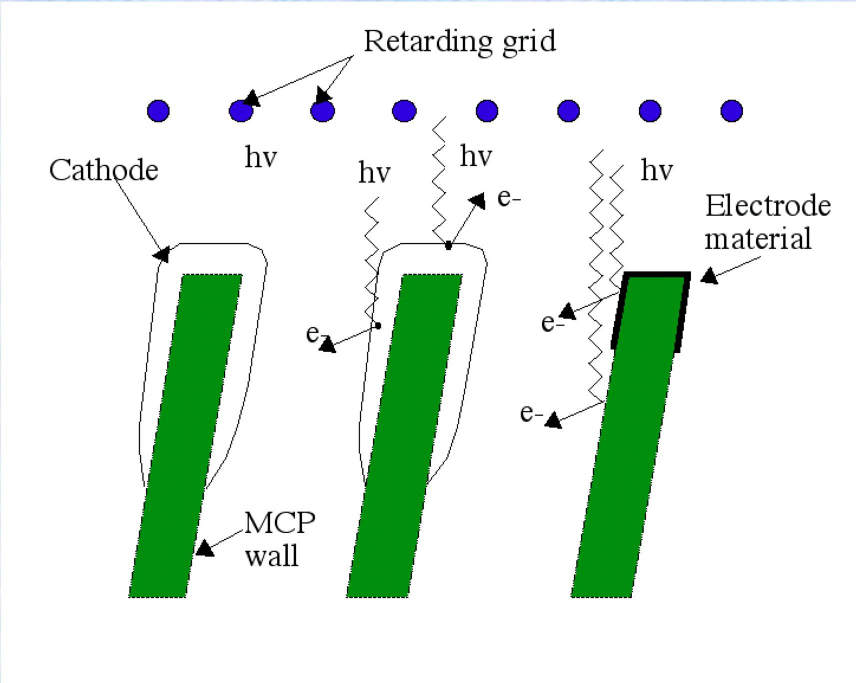
Opaque cathodes **are often used in the UV (astronomy) for large area detectors and are deposited onto microchannel plates.**



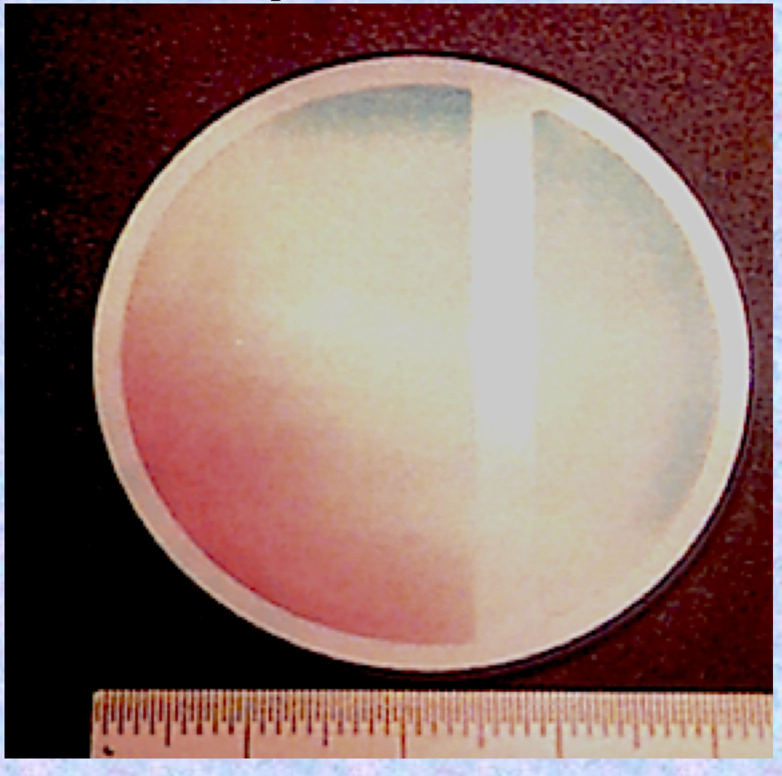
Photocathode	Wavelength	QE	Environment
CsI (alkali halides)	10-150 nm	high	Somewhat stable in dry air
CsTe/RbTe	100-300 nm	modest	Ultra high vacuum (UHV)

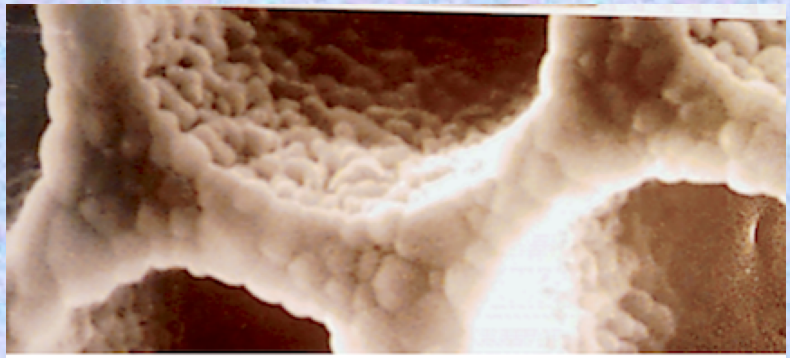
Photocathode Quantum Efficiencies - Opaque

Alkali Halide Opaque Photocathode Scheme



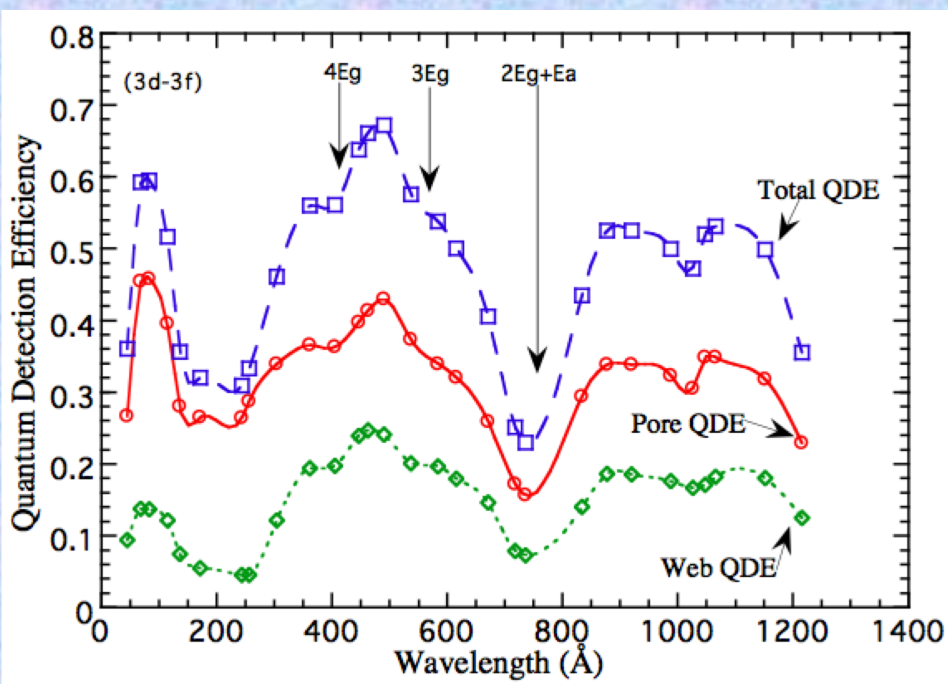
Photocathode Deposited on Microchannel Plate





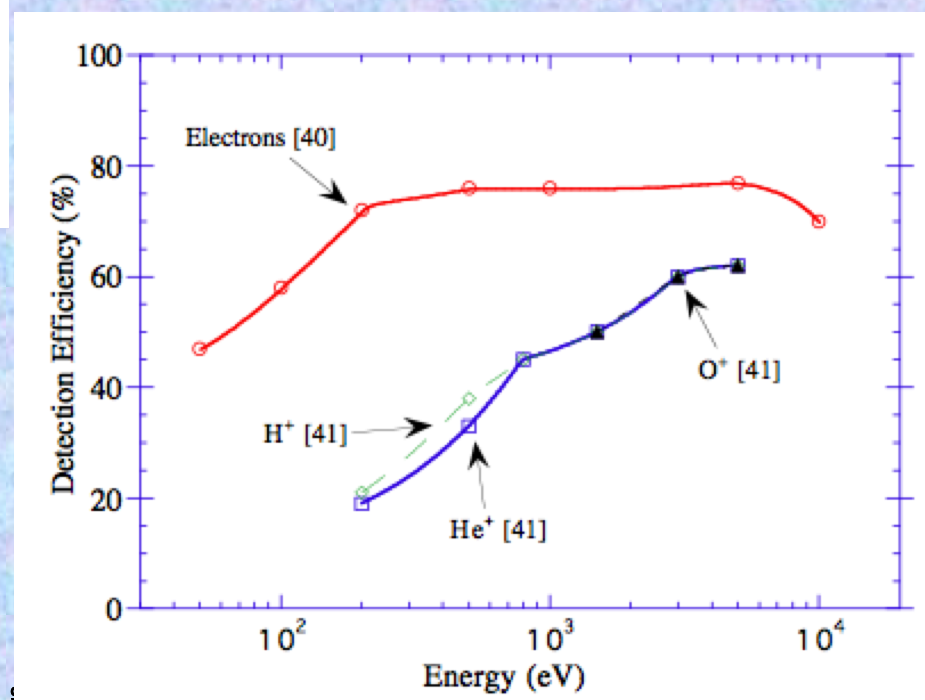
Opaque photocathode layer structure deposited onto microchannel plate

Photocathode Quantum Efficiencies - Opaque



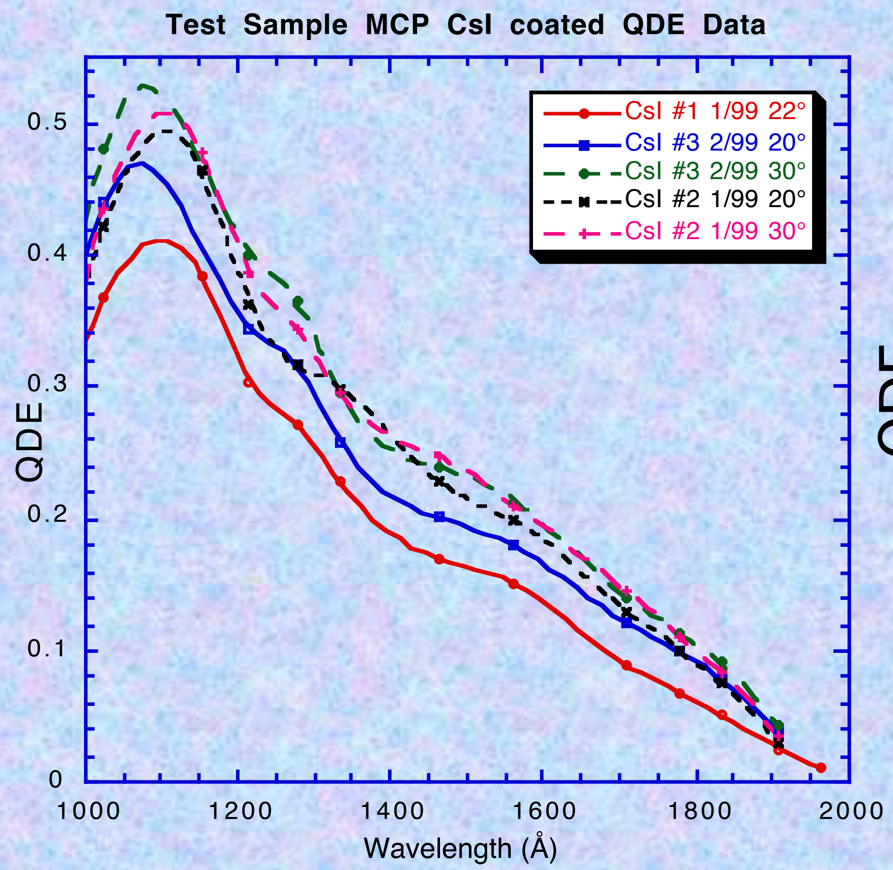
KBr opaque photocathode QDE measurements on the Microchannel Plate surfaces.

Microchannel Plate Electron and Ion Detection Efficiencies

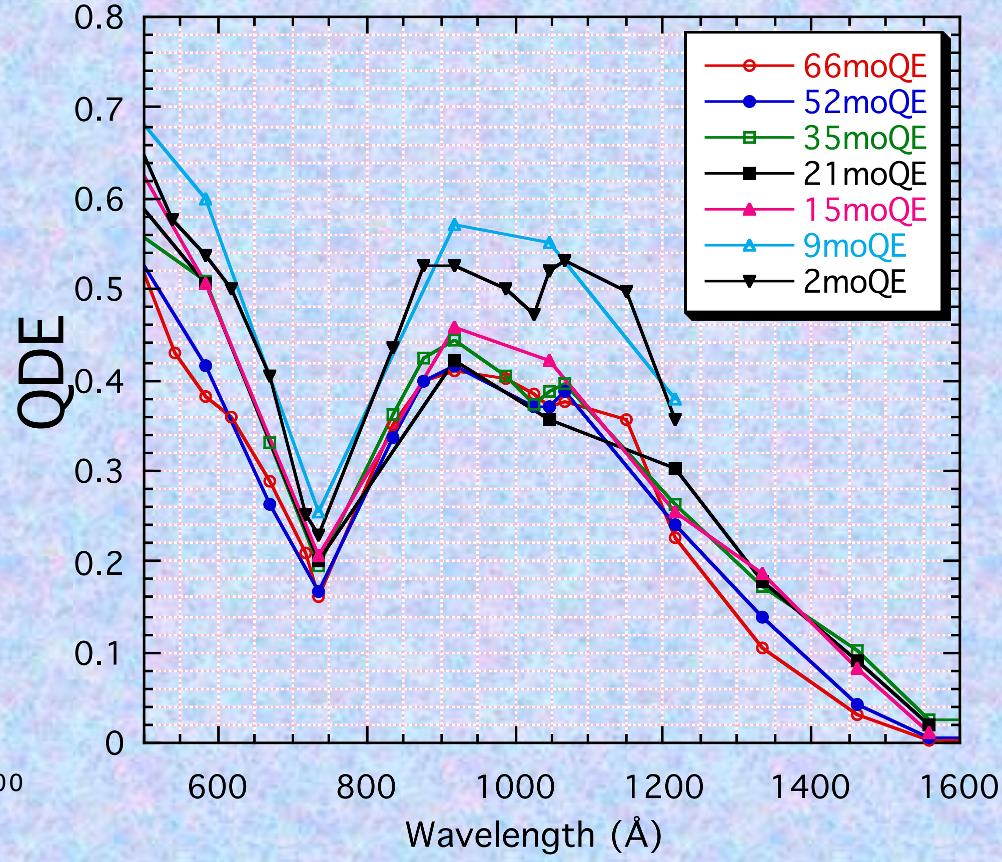


Photocathode Quantum Efficiencies - Opaque

CsI opaque photocathode QDE measurements

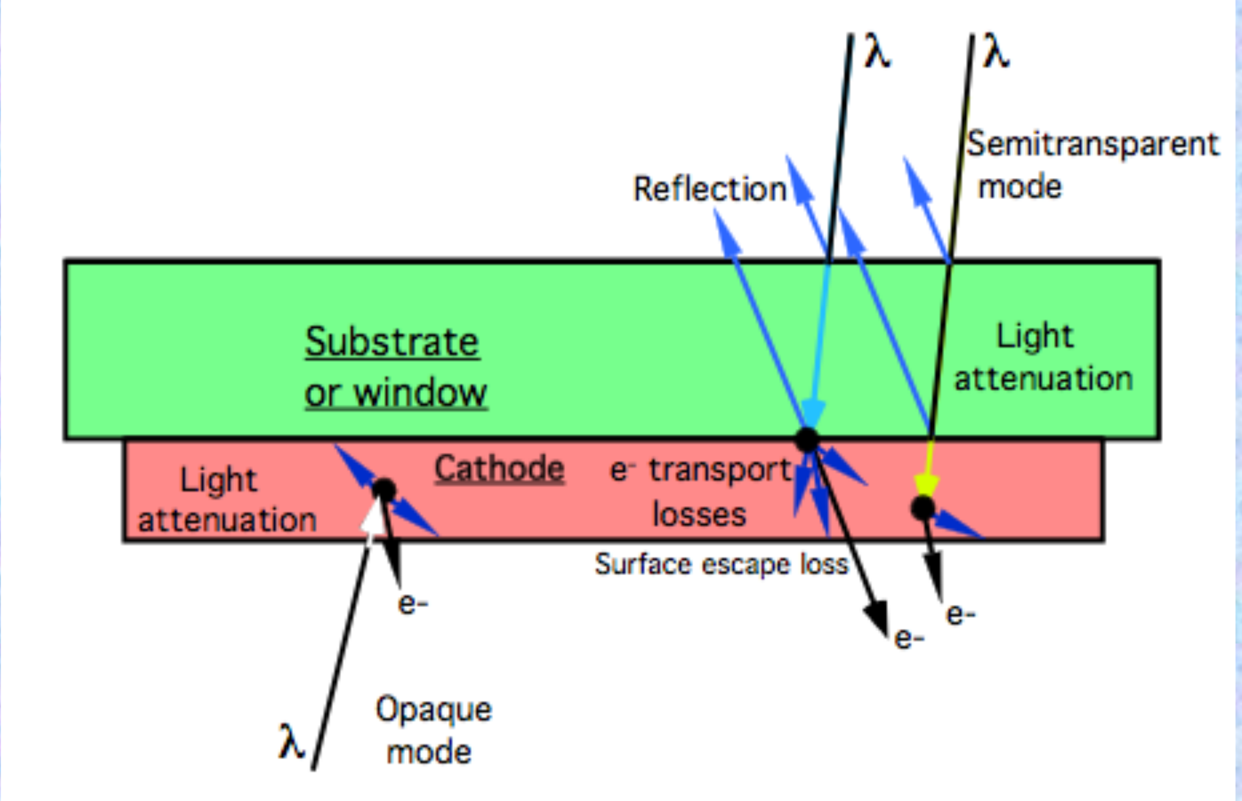


KBr opaque photocathode QDE lifetest measurements



Visible Photocathode Configuration

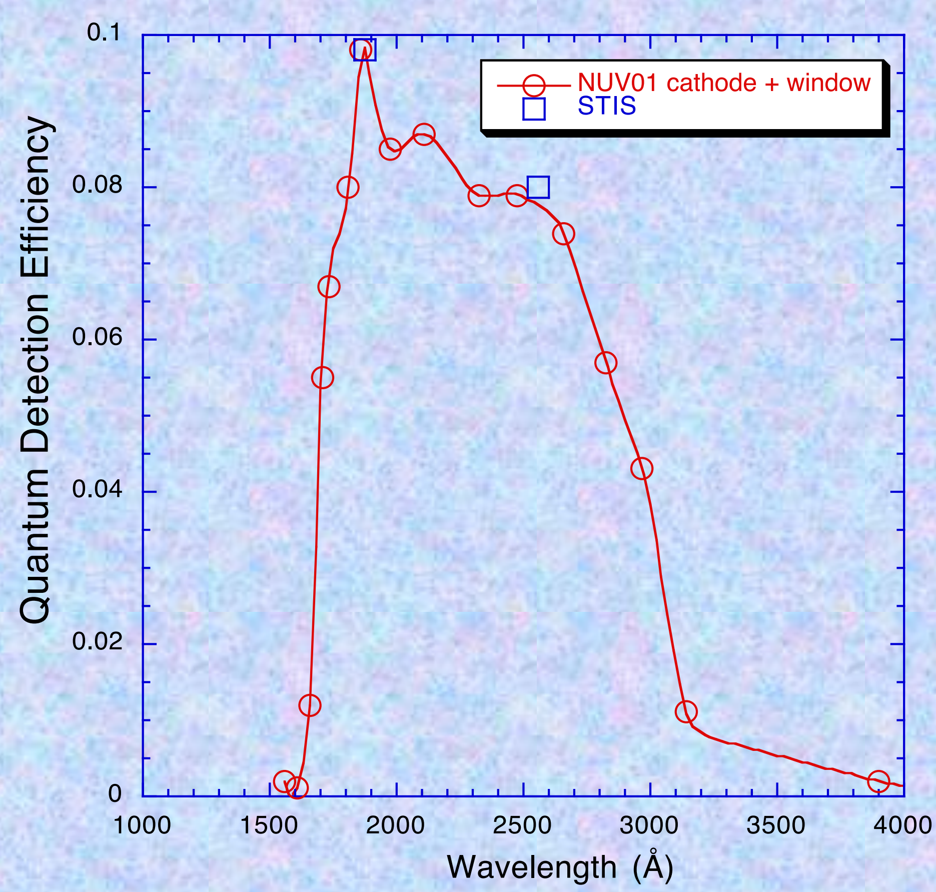
Numerous processes affect the QE



Bialkali is a few 100Å thick, and is compatible with deposition as semitransparent on the window, but is very difficult to achieve as an opaque cathode on the MCP surface.

Photocathode Quantum Efficiencies - Transmission

CsTe Semitransparent Photocathode Data for MCP Detectors



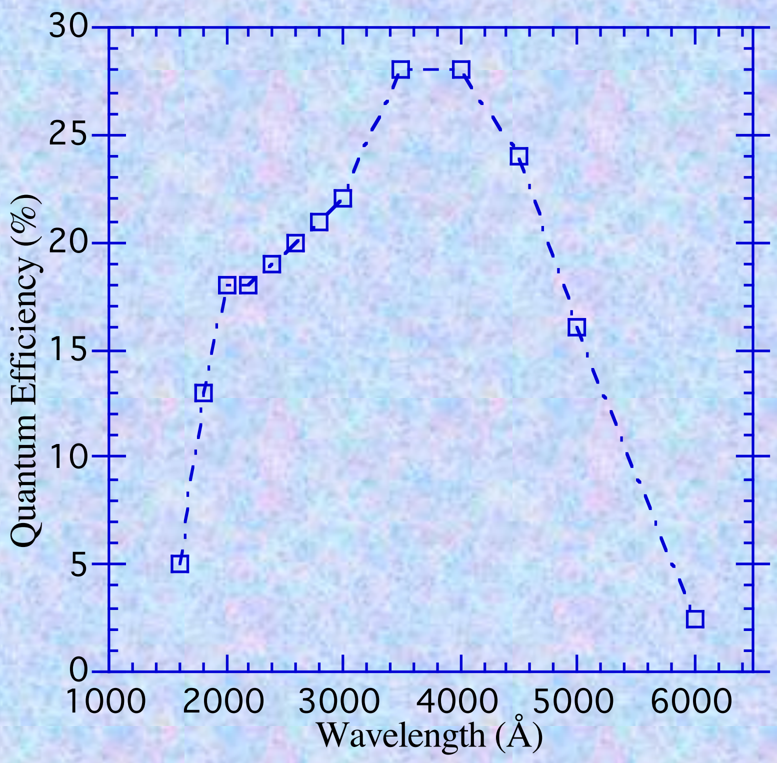
CsTe must be in a sealed tube device due to extreme contamination sensitivity.

We have produced CsTe for NIST CsTe standard photodiodes, and MCP detectors in 25mm, 40mm, 60mm formats.

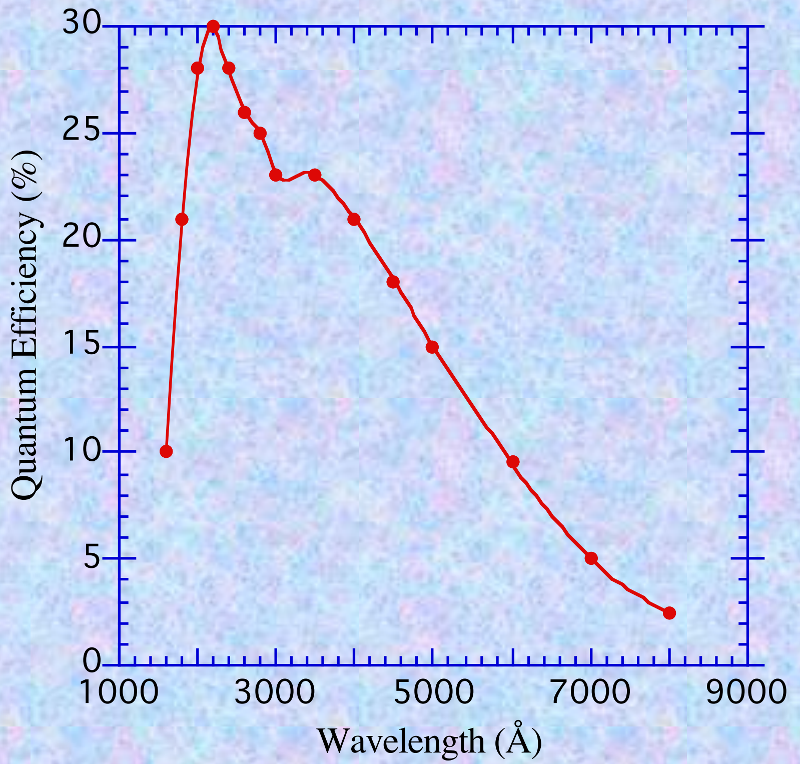
Semitransparent cathodes on the entrance window are standard, but do limit the spatial resolution due to proximity spreading of photoelectrons

We have done opaque cathodes but they are still developmental.

Photocathode Quantum Efficiencies - Visible



Bialkali - semitransparent with Quartz window

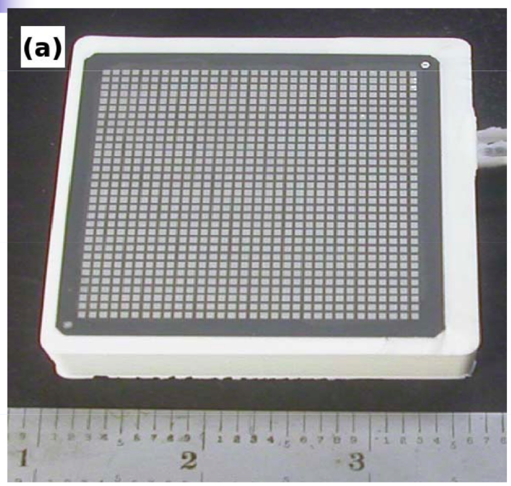


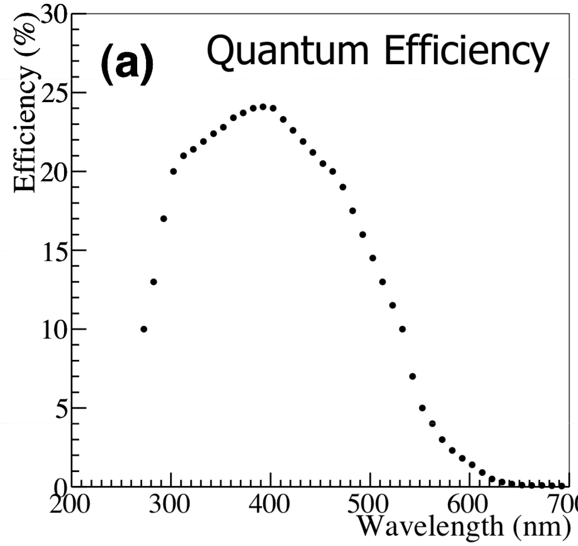
S20 - Opaque with Quartz window

Visible photocathodes require more stringent processing conditions than Alkali Halides or CsTe photocathodes. The window type also has an effect on the efficiency. Our transfer chamber for multialkali cathodes has produced some quite high efficiency S20 and S25 cathodes.

Current Technology – Photonis Planacon.

Photonis Planacon MCP-PMT (XP85022)

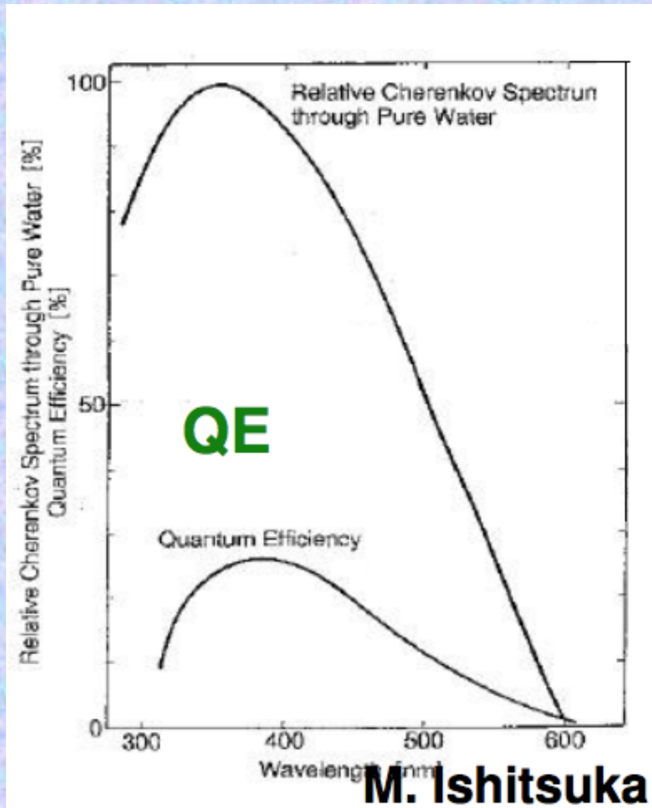




Window material	Borosilicate, Corning 7056 or equivalent
Photocathode	Bialkali
Multiplier structure	MCP chevron (2), 25 μm pore, 40:1 L:D ratio
Anode structure	32×32 array, 1.1 / 1.6 mm (size /pitch)
Active area	53×53 mm
Open-area-ratio	80%

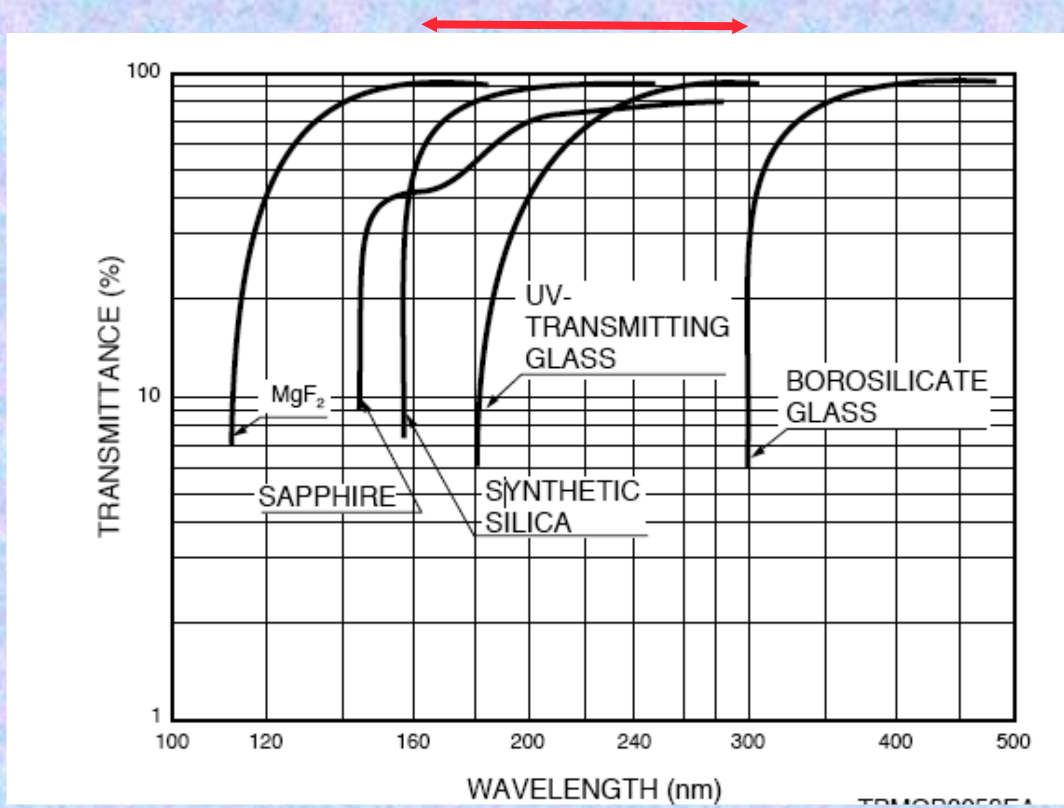
Heejong Kim
U. Chicago

Cathode Bandpass and Windows



Nominal Cherenkov emission spectrum compared with bialkali

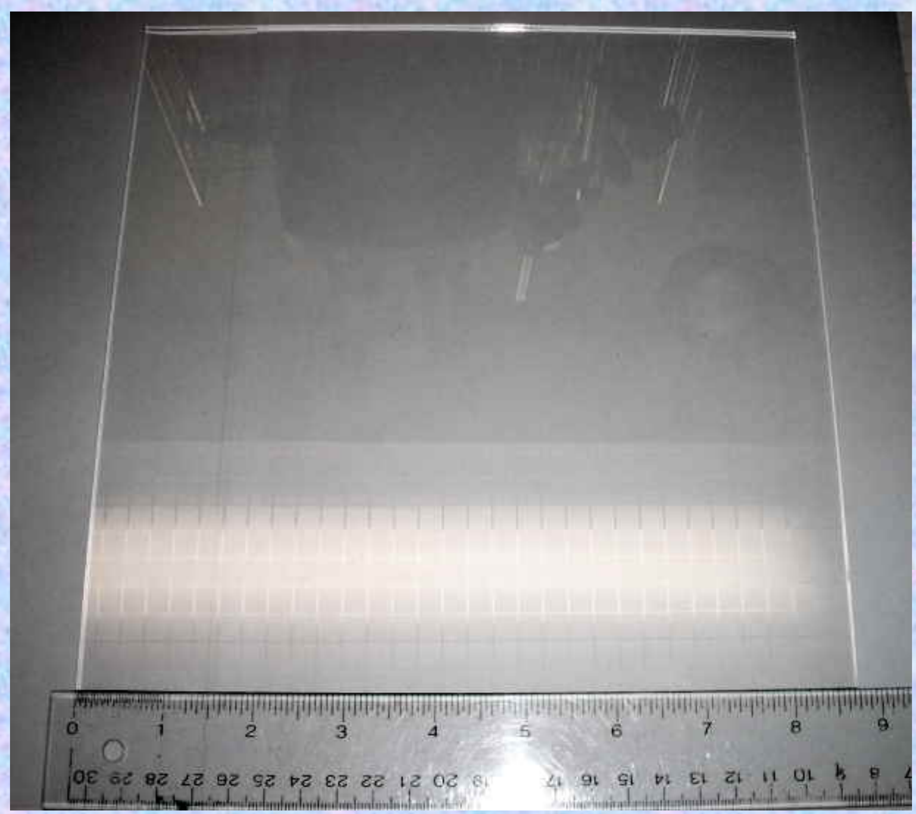
Acceptable cutoff range



Typical window transmission curves

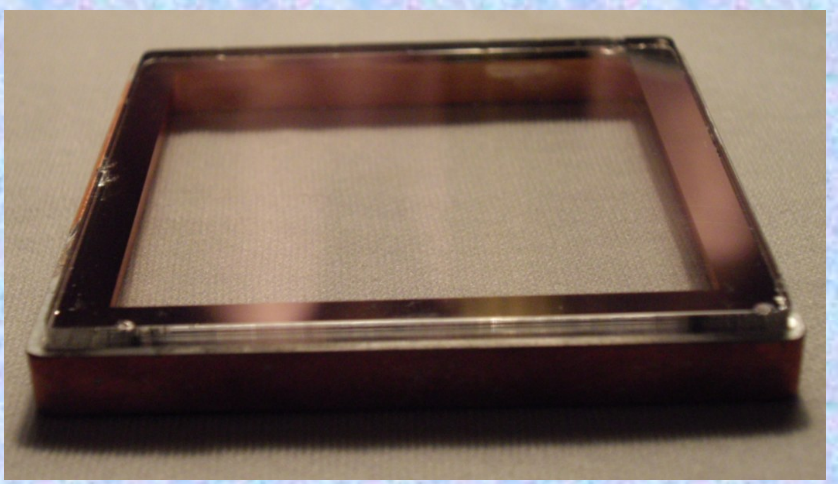
Window Selection and Sealing Technique

Schott Borofloat 33 has been identified as a cheap and effective potential window material for very large area devices.



Borofloat 33, 22 x 22cm window

Hot indium seals are the method of choice for a UHV device



Test sample indium seal

Window Seal Development on Full 20cm Detector Format

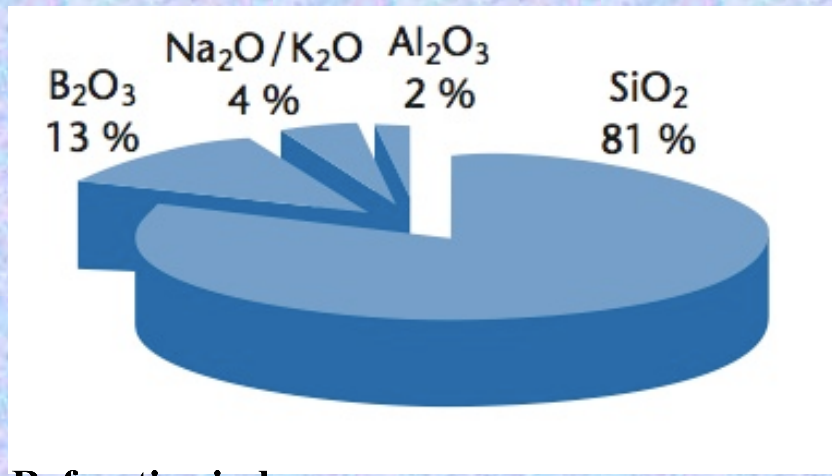
Indium seal well

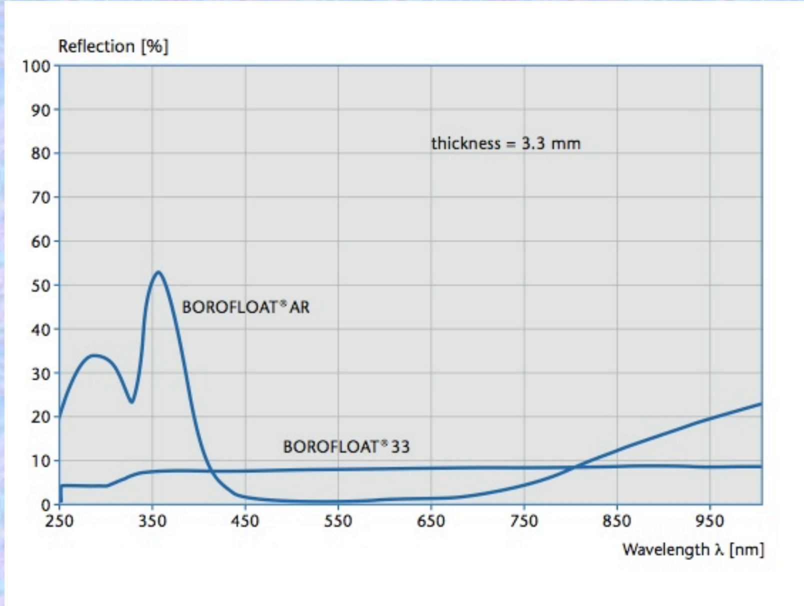
Ceramic body with Cu Indium well, 5mm B33 window and "dummy" anode.

Schott Borofloat 33 General Parameters

The cathode substrate, window or window coating, affects the photocathode performance. Quartz, fiber optics, 7056 glass are common. Borofloat B33 Borosilicate is not, and also has Tin diffused into one side from the float process.

B33 Composition





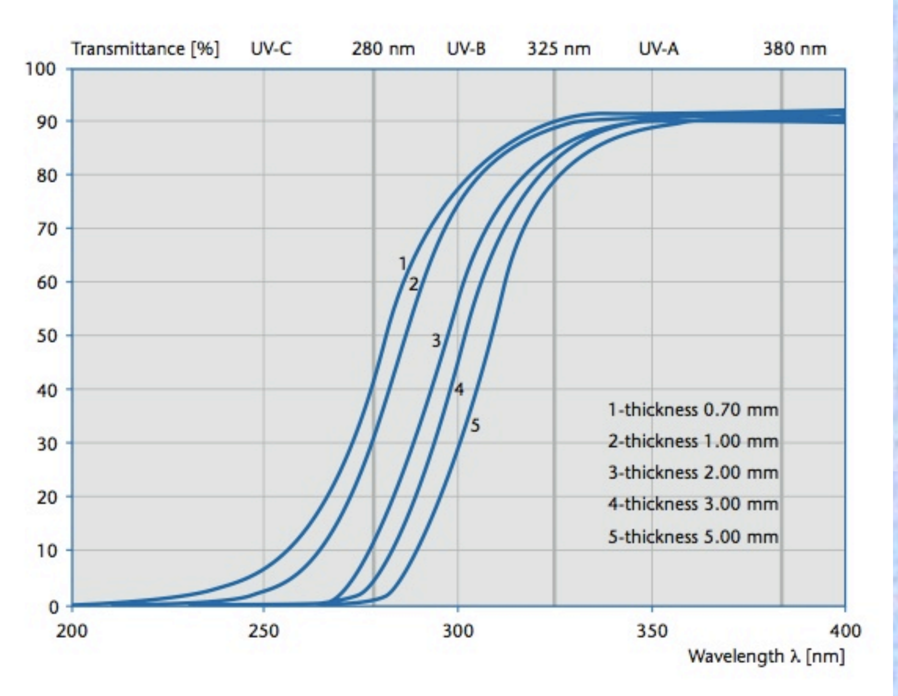
Refractive index
@400nm

B33	**1.47**
Air	**~1.0**
Water	**~1.32**

Standard AR coating is bad for Bialkali - most likely don't need AR coating for water/B33 interface

Transmittance & Conductive Layers for Windows

Large photocathodes can be resistive so sometimes a conductive under layer or zoning is needed. Large windows must also be made thicker so lose the short wavelengths.



B33 Transmittance is typical for borosilicate glasses

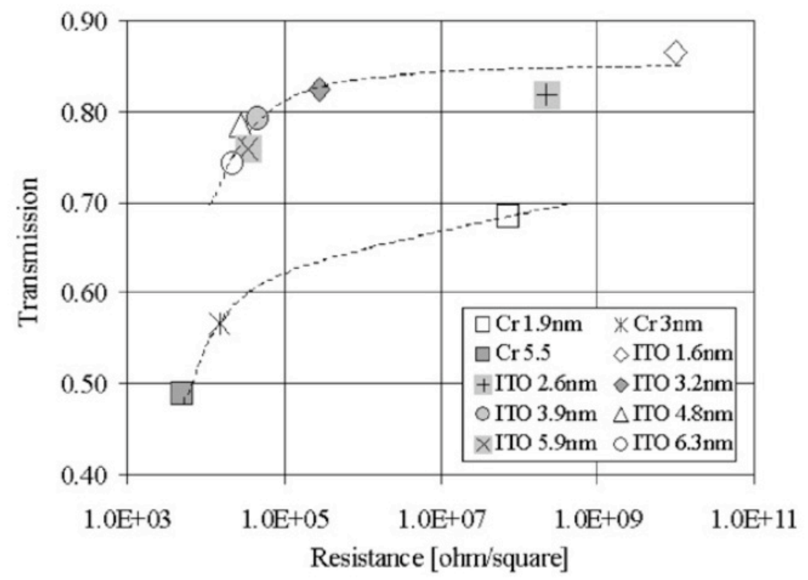
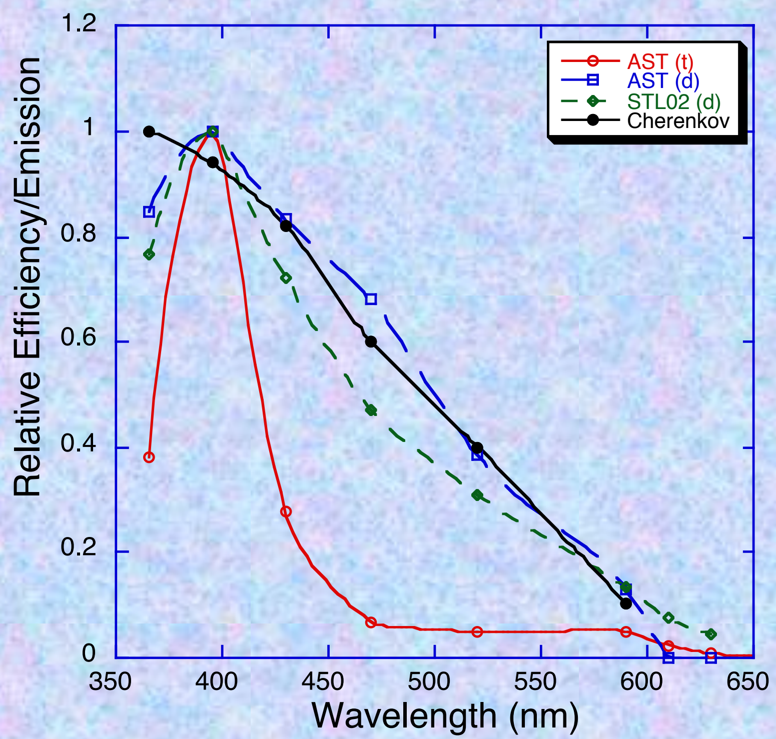


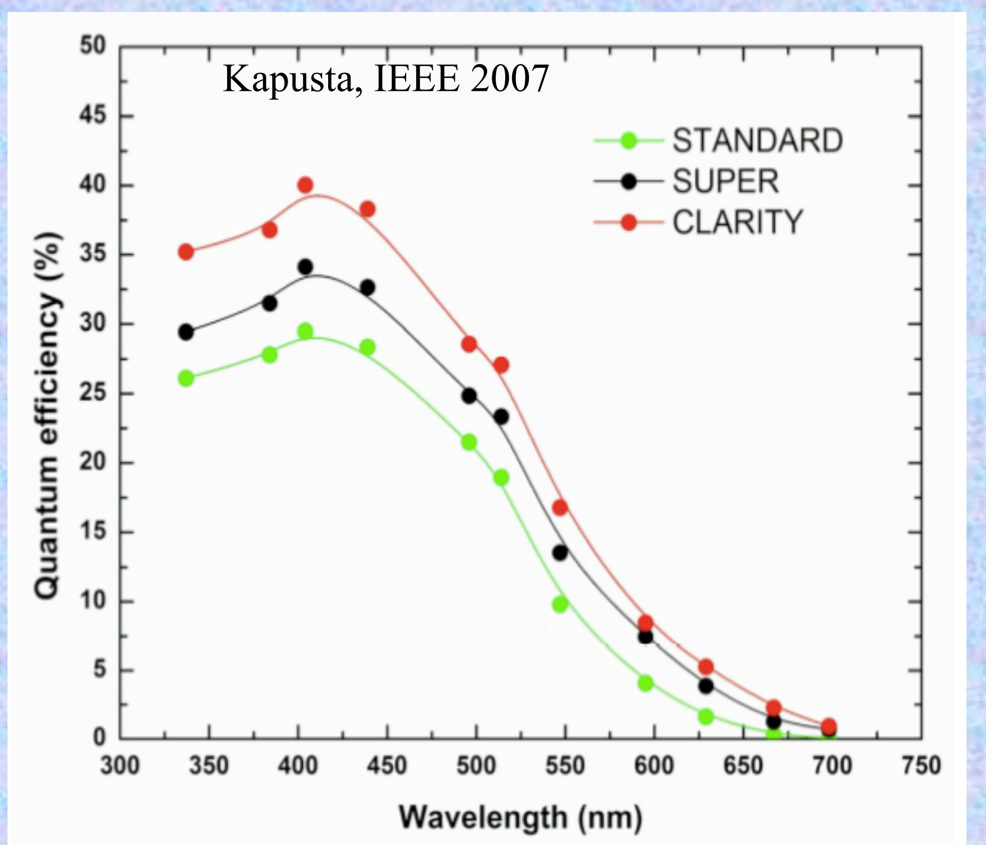
Fig. 4. Measured surface resistance versus average transmission (200–400 nm) of ITO and Cr thin films of various thickness on quartz substrates.

Braem, NIMA 2003

Bialkali Photocathode Optimizations



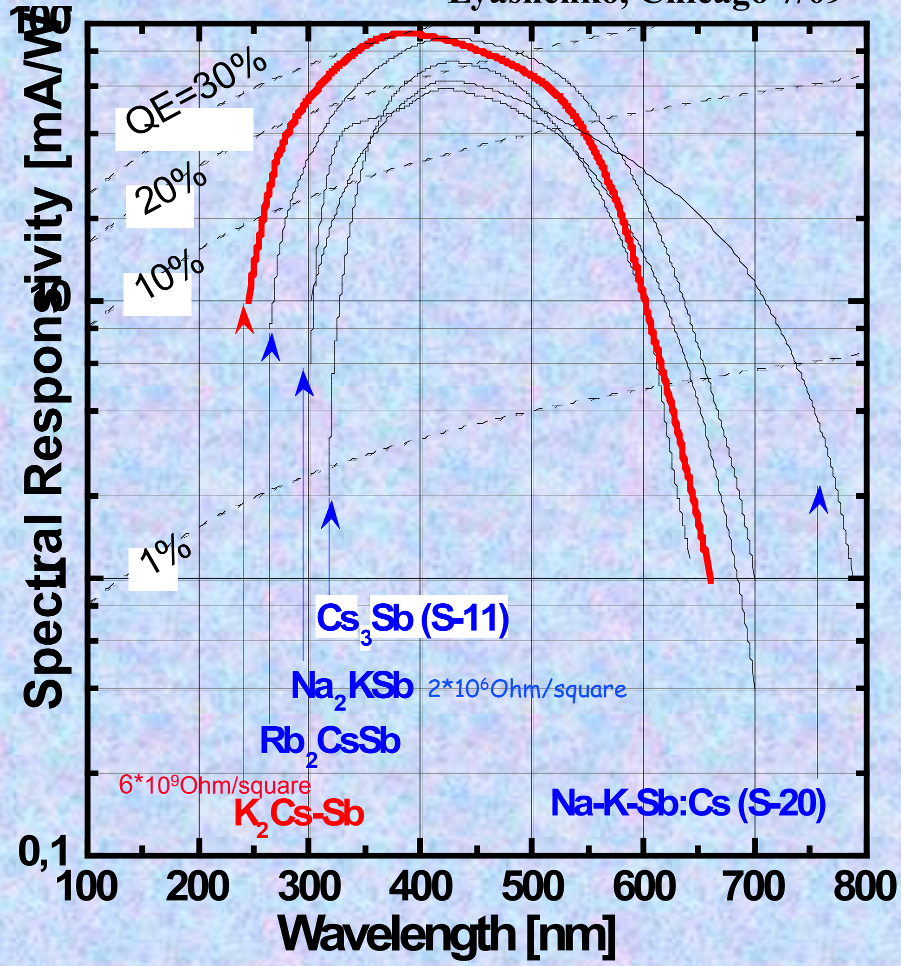
Examples of bialkali photocathode depositions with different wavelength optimizations (on fiber optics).



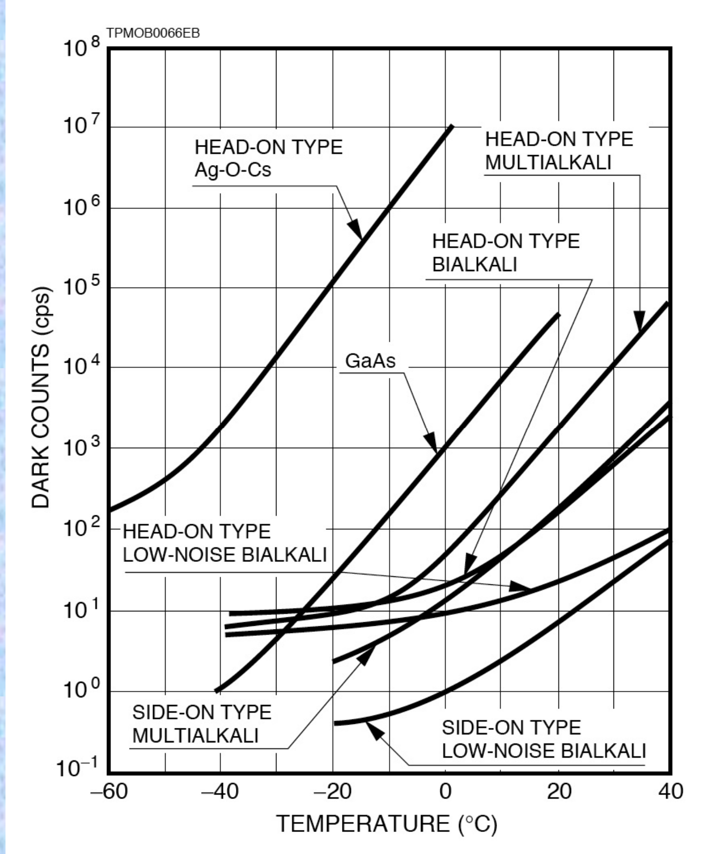
Comparison of high efficiency Bialkali PMT cathodes, to be considered for LAPD!

Bi-Alkali Cathode Characteristics

Lyashenko, Chicago 7/09

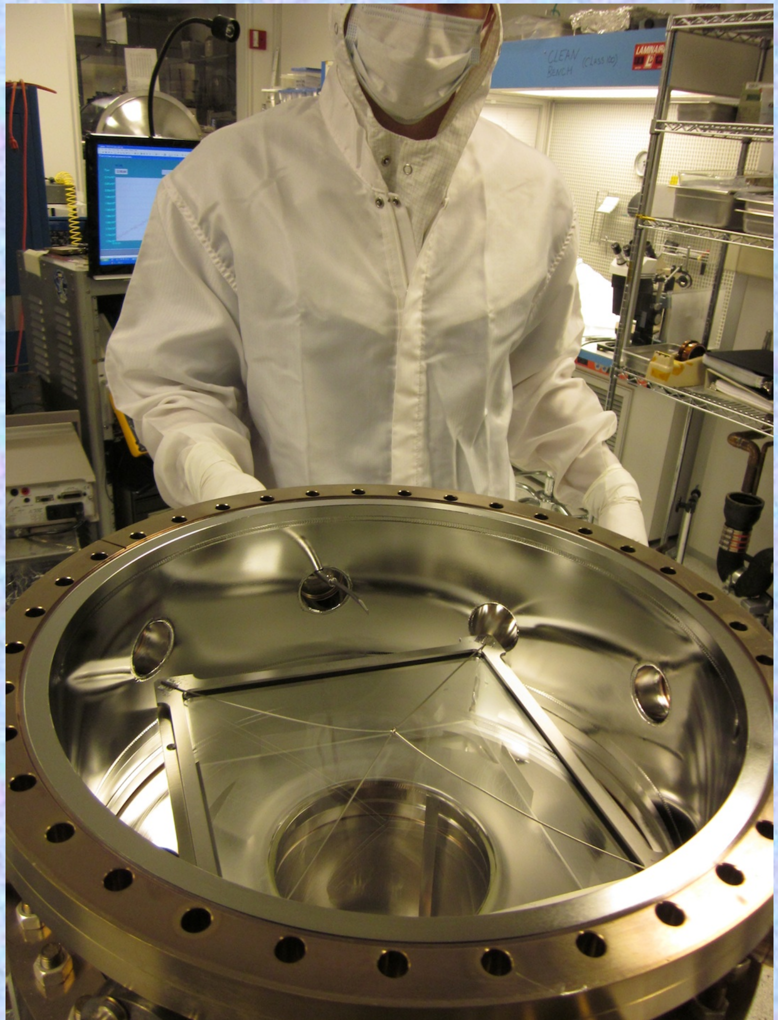


QE and resistivity for various bialkalis



Cathode Noise vs Temp

20cm Bialkali Photocathode - System Load

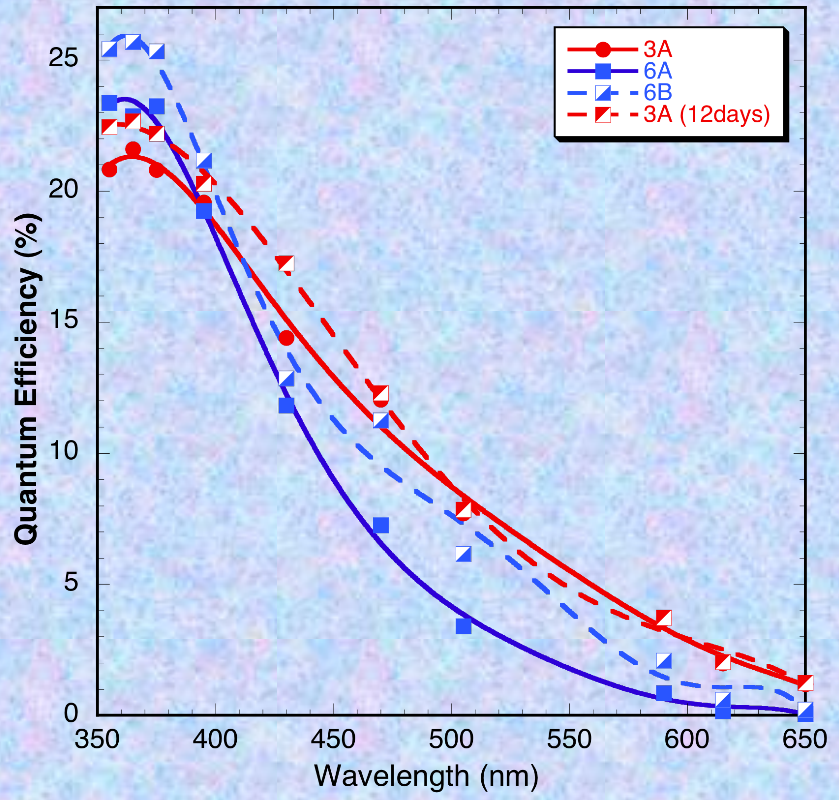


22cm window loaded

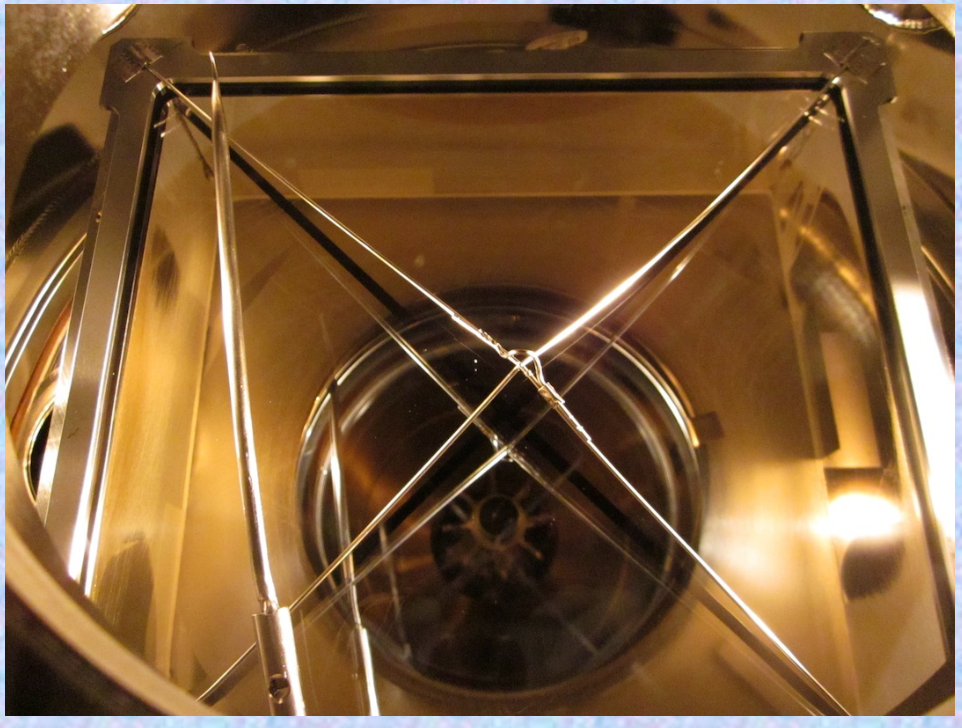
Some final window adjustments

Bialkali Photocathode Sample Tests

Cathode test runs with Na_2KSb cathodes on B33 borosilicate windows
>20% QE achieved, QE uniformity better than ± 15% on 8" substrates.



Bialkali test cathodes made on 31mm (6A,B) and 20cm (3A) B33 windows. Quantum efficiency measurement of cathode efficiency plus window attenuation.

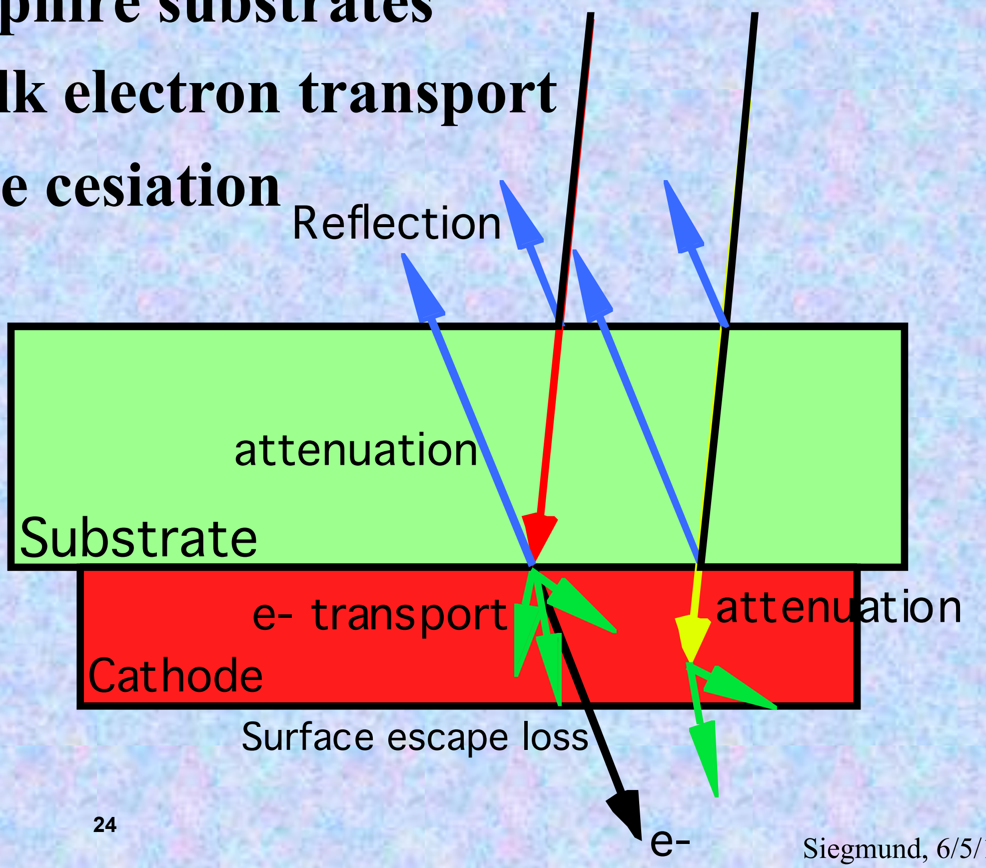


20 cm B33 window inside the processing chamber showing the photocathode area. The extreme corners are not coated in this setup.

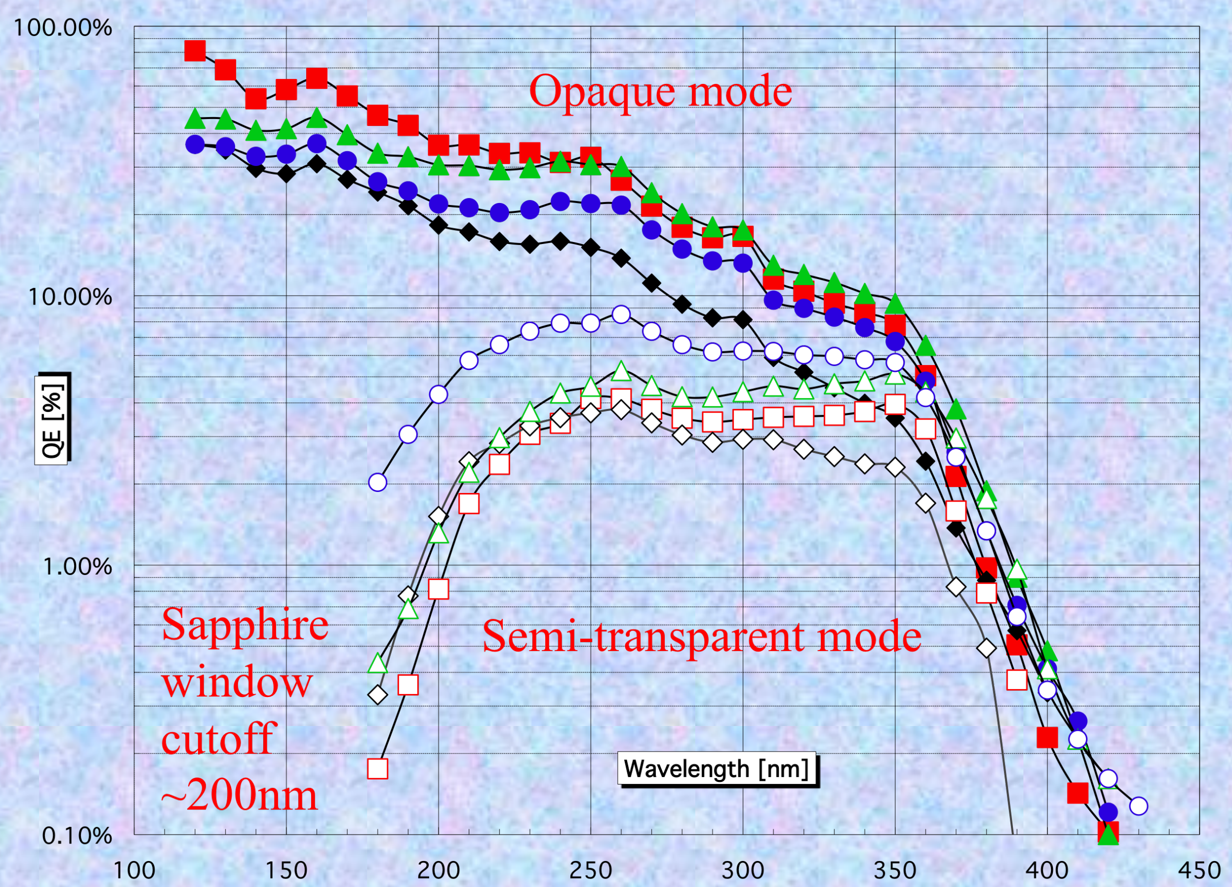
GaN Photocathode Prospects

- "Solar blind" efficient cathode for 100nm-400nm
- Band gap energy 3.5 eV, (~355nm)
- Alloys ($Al_xGa_{1-x}N$, $In_xGa_{1-x}N$) can change the bandgap
- Robust, compatible with sapphire substrates
- p (Mg) doped to promote bulk electron transport
- NEA is established by surface cesiation
- ~100nm GaN layers typical

- Numerous processes affect the QE

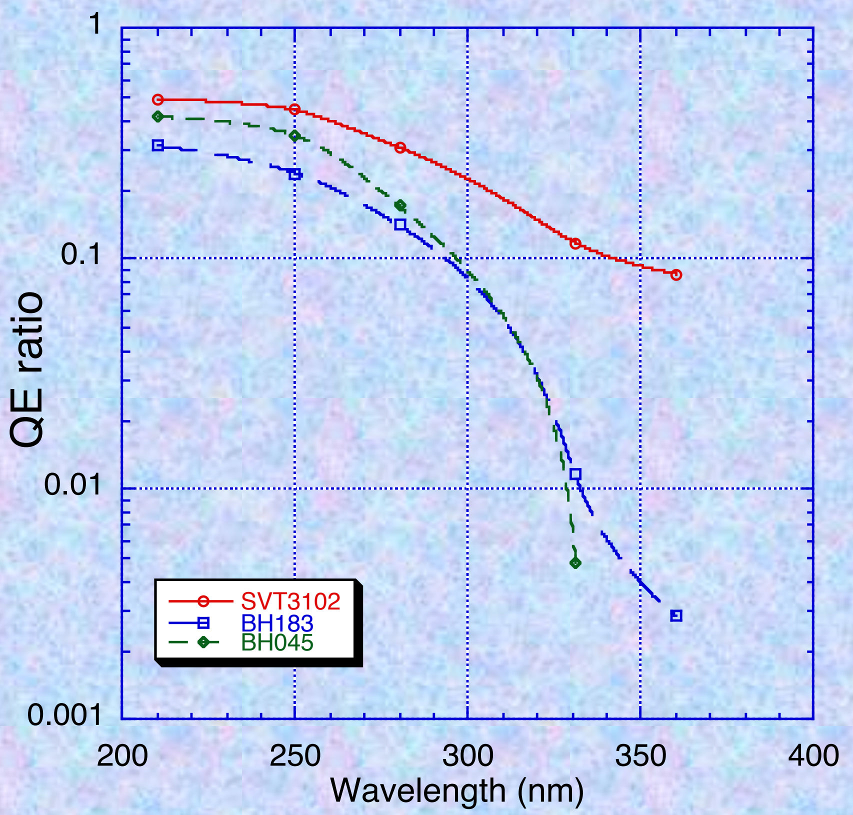


Opaque GaN Deposited on Sapphire



GaN semitransparent and opaque photocathode quantum efficiencies. The GaN is 150nm to 100nm thick with depth graded Mg concentration. The best semitransparent QE is for a substrate with only 50% GaN coverage - hence the achievable efficiency is probably closer to twice the measured values.

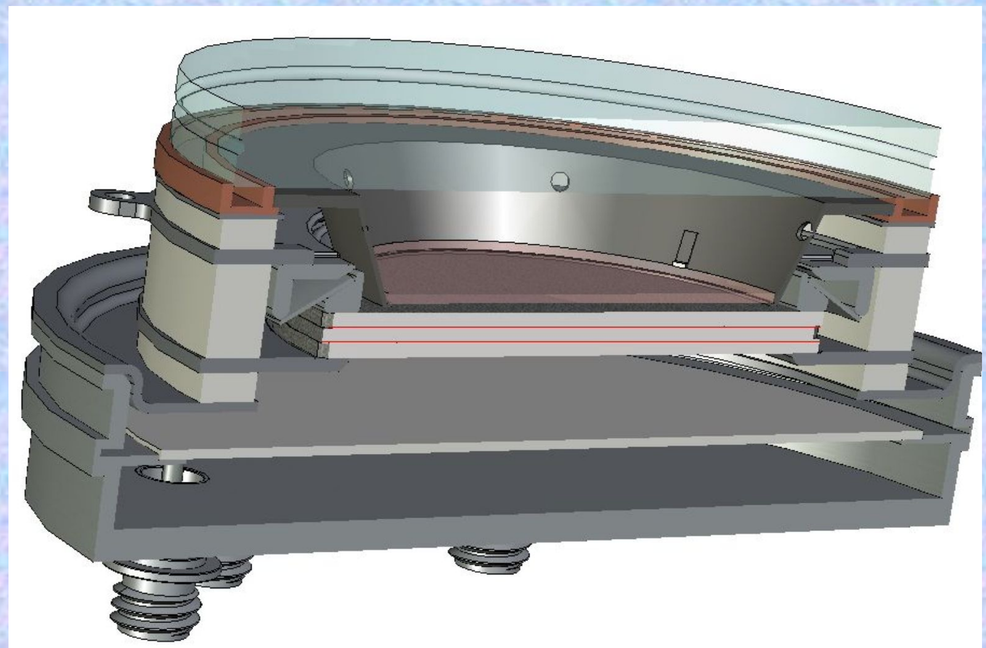
GaN Photocathode Stability

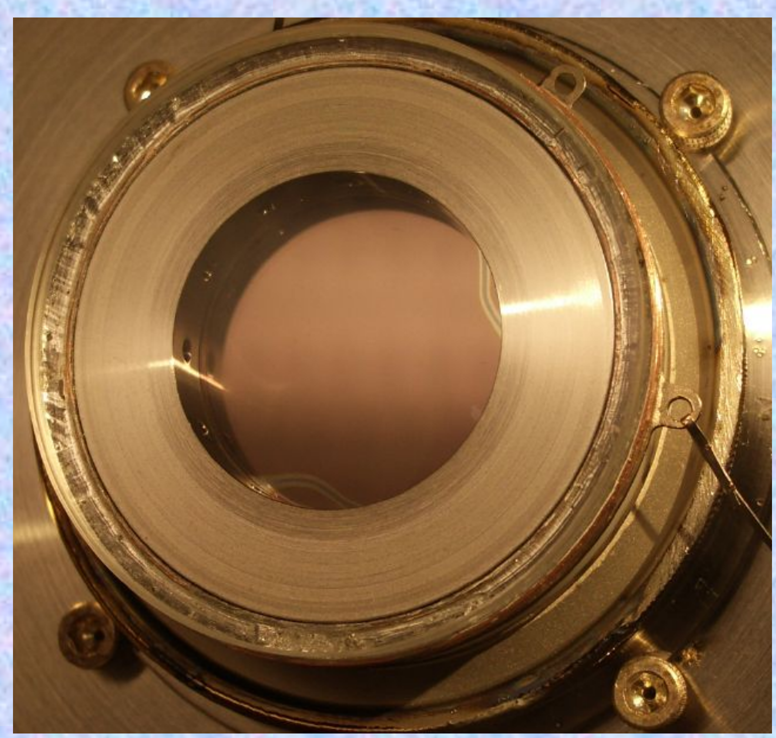


Relative degradation of cesiated GaN samples before and after exposure to *700 torr nitrogen* (!) and a 250C vacuum bake. Back to full QE after re-cesiation!

- **GaN is a robust material with good handling properties.**
- **Samples have been fully re-cleaned and reprocessed many times with no reduction in the QE reached.**
- **GaN sample in a sealed tube has not changed in QE measurably in over three years.**
- **Exposure to pressures of 10^{-7} torr for about one day do reduce the QE by 30% at 200nm, and a factor of 10 at 350nm. This strongly suggests surface NEA impairment.**

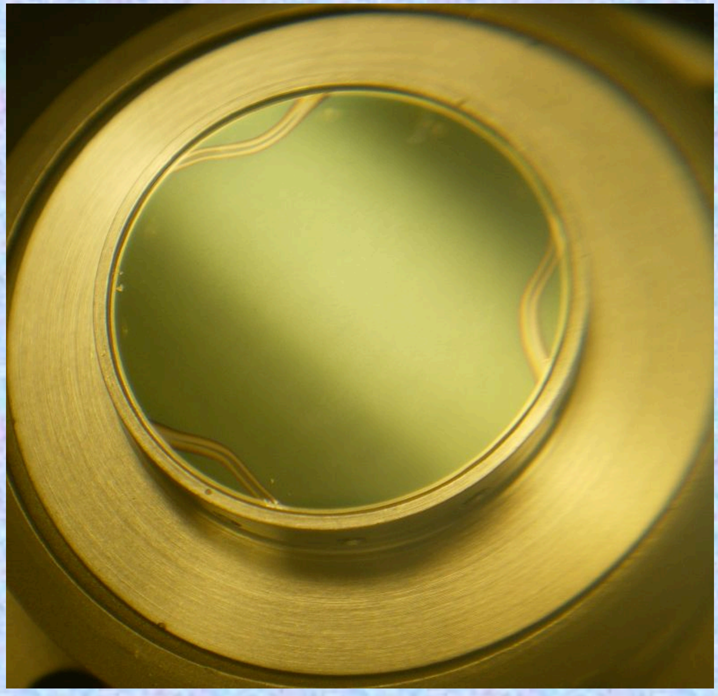
GaN Imaging Detectors



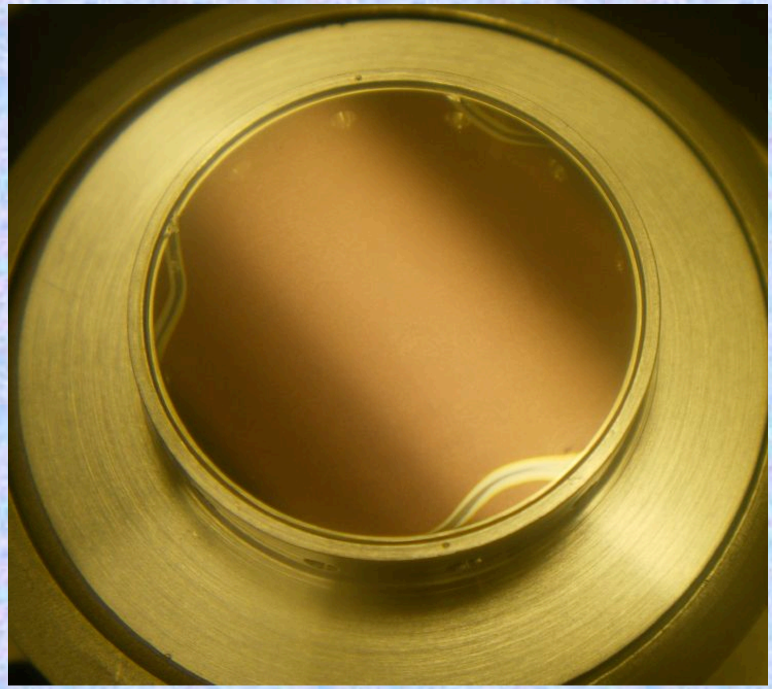


- **We have built an imaging detector using semitransparent GaN on sapphire**
- **Uses a cross delay line anode and a MCP triplet to image individual photon events**
- **Several GaN cathodes have been evaluated for their imaging properties**

GaN Cathodes for Image Tubes



0.15μm GaN



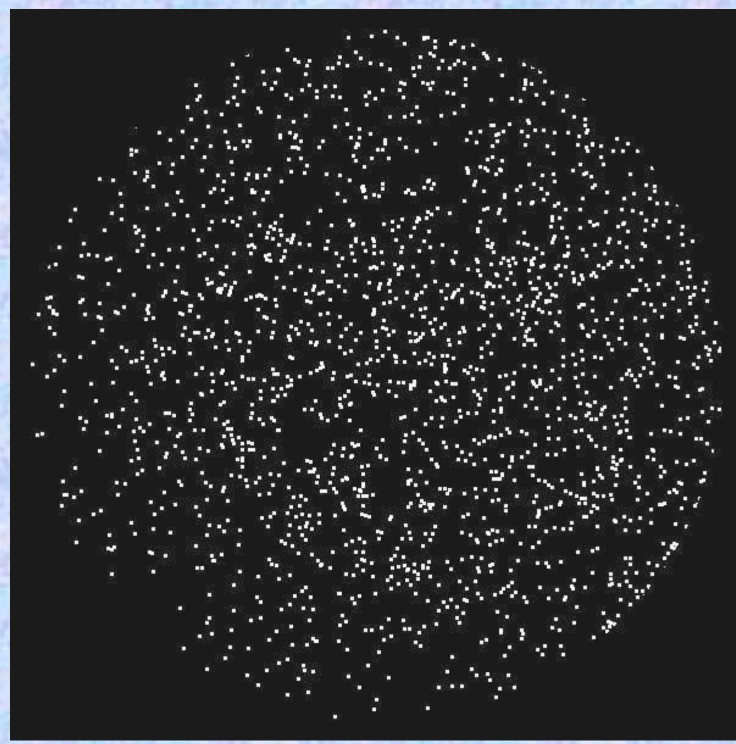
0.10μm GaN

- 1” diameter semi-transparent GaN (0.1μm and 0.15μm thick) on sapphire
- Mounts in holder to place cathode close (<0.5mm) to MCP surface
- Same GaN fabrication method with AlN layer and highly P doped GaN
- Wire clip shadows, that hold down substrate during GaN deposition, can be seen

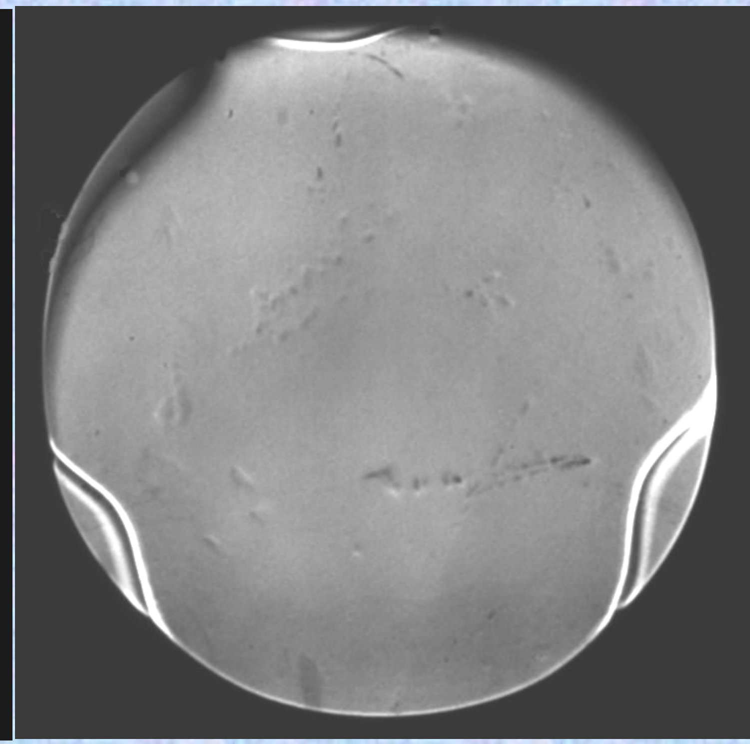
Semitransparent GaN Cathode Imaging

0.1μm GaN

120v GaN bias



Background image ~0.9 events cm^{-2} sec^{-1}, 600 sec integration

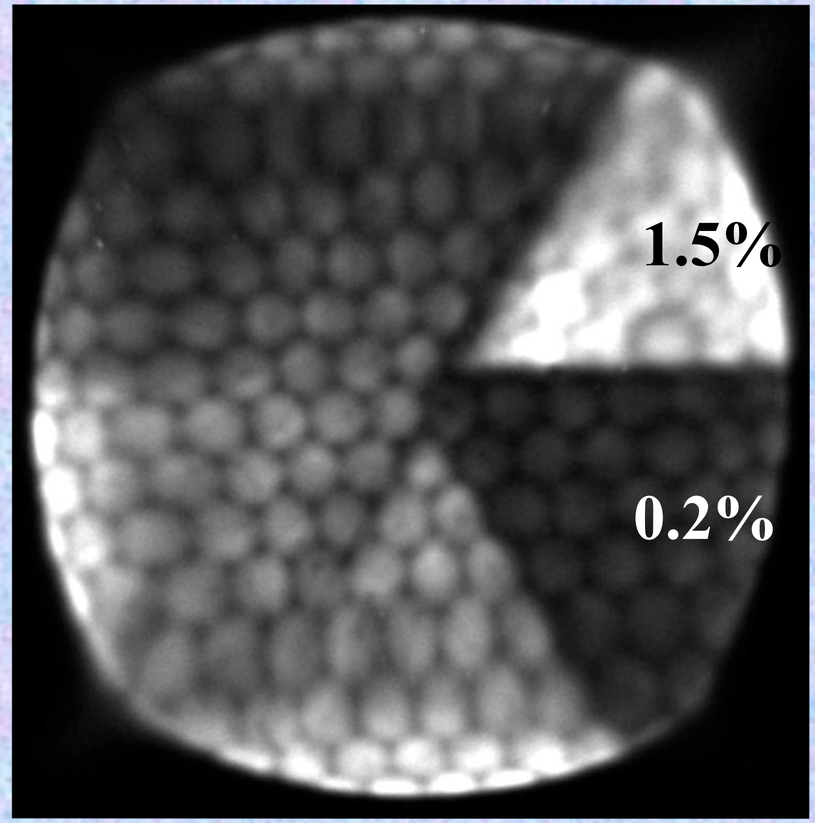


Flood illumination with 185nm 10^8 events

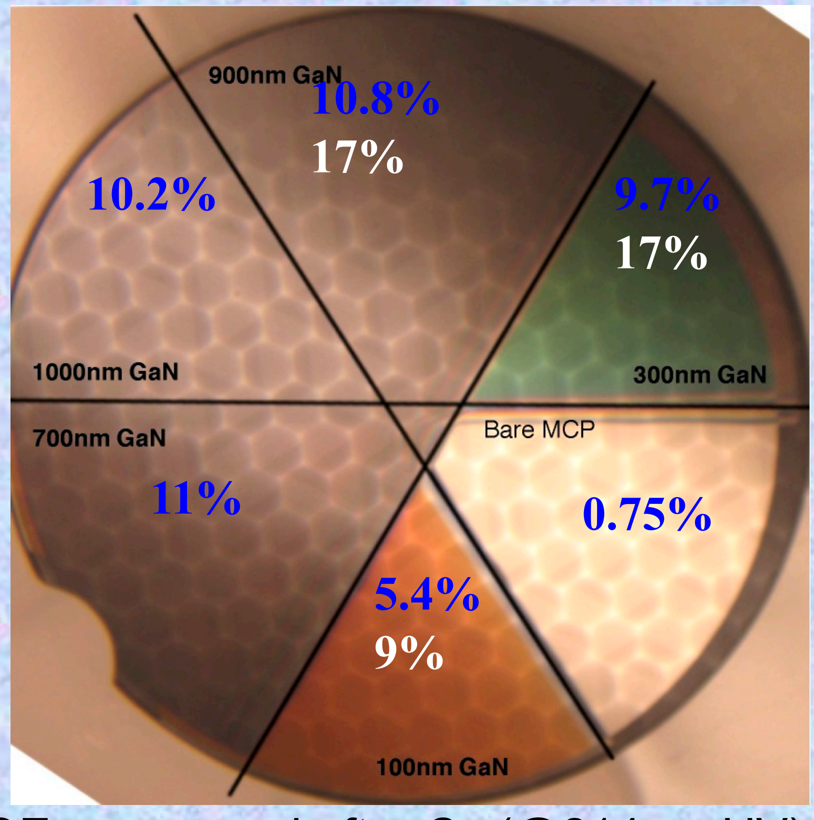
- The 0.1μm GaN gives OK overall response, but GaN defects / scratches on sample show up
- There are edge shadows due to mounting hardware at the edges
- Much higher QE at the edges of the deposition wire shadows
- Background rate of 0.9 cm^{-2} sec^{-1} with GaN bias, 0.45 cm^{-2} sec^{-1} without bias

Opaque GaN Deposited on ALD MCPs

Borosilicate/ALD MCP coated by MBE with P-doped GaN/AlN (amorphous/polycrystalline) and tested in a photon counting imaging detector



Integrated photon counting image using 184 nm UV shows unprocessed GaN layer response vs bare MCP.

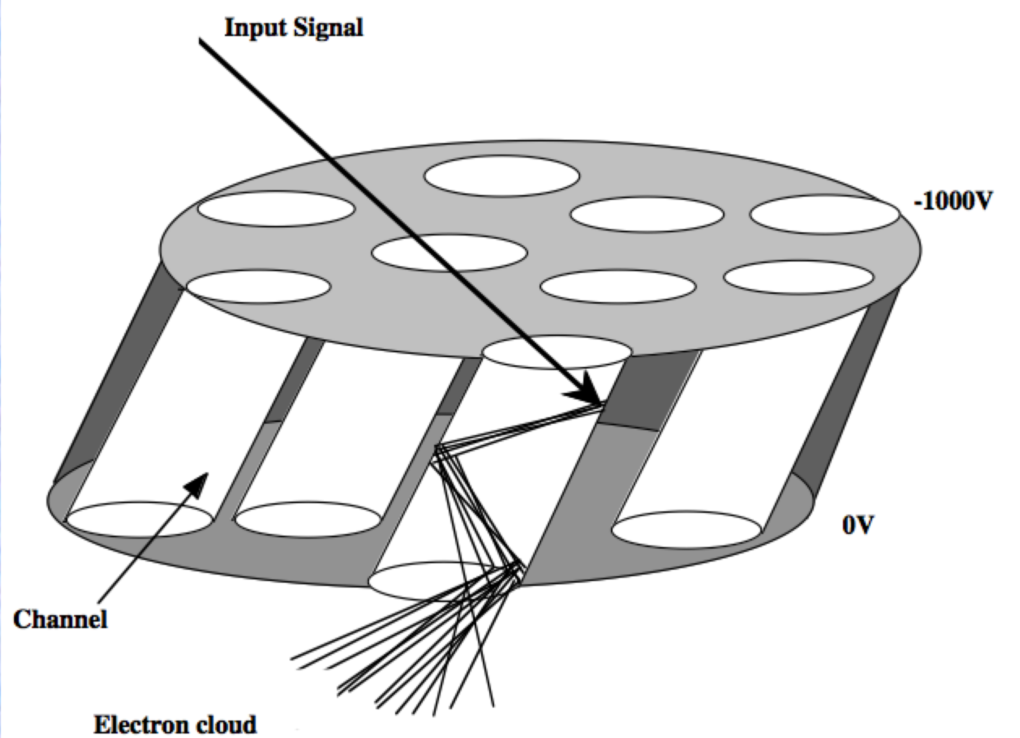


QEs measured after Cs (@214nm UV) 10º (blue) or 45º (white) graze angle.
Typical QE- thickness asymptote for opaque cathode

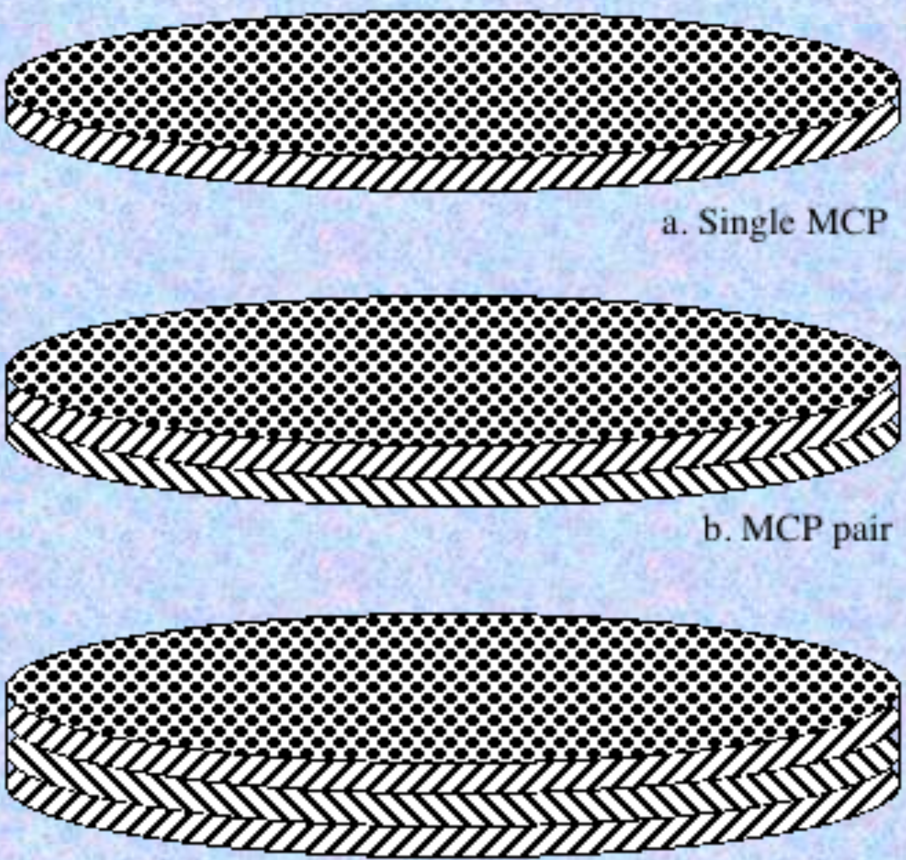
Deposited by SVT associates (A. Dabiran).

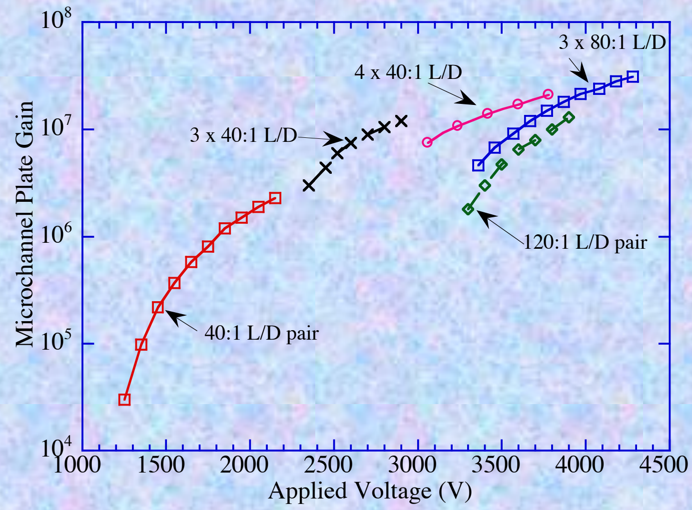
Basic MCP Fabrication Processing Steps

- Start with core glass cylinder inside clad glass tube
- Draw fibers, cut and stack into hexagonal “multi’s”
- Stack multi’s into large block or small boule
- Second draw to final size.
- Slice and polish wafers - (cut to bias angle)
- Etch out core glass
- Reduce in high temperature hydrogen to get conductive pore surfaces.
- Apply electrodes on surfaces.

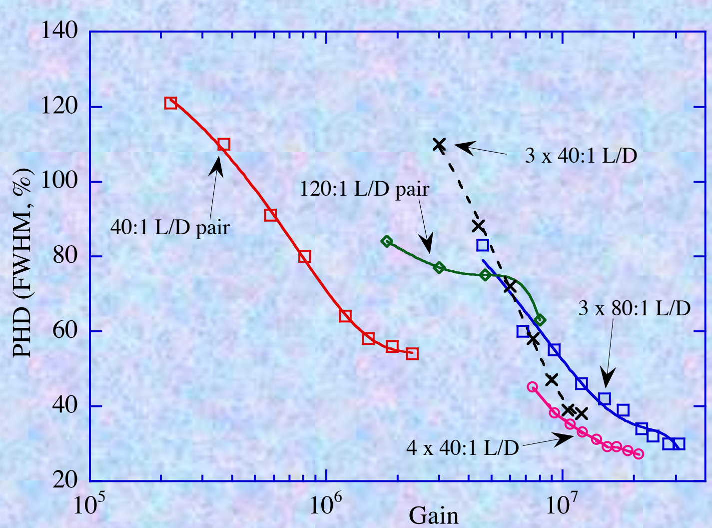


Basic MCP Configurations





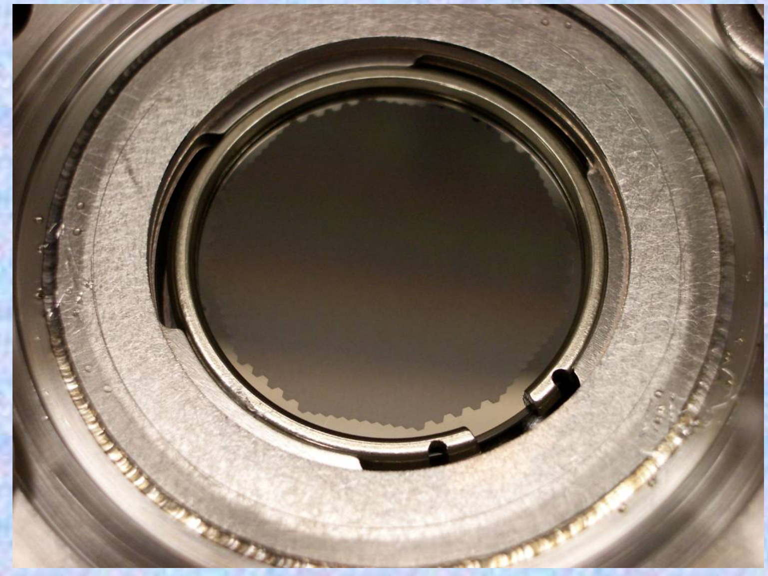
MCP Gain vs V for stacks



MCP pulse height distributions

Common MCP Use - Intensifier Application

Solid Edge MCP



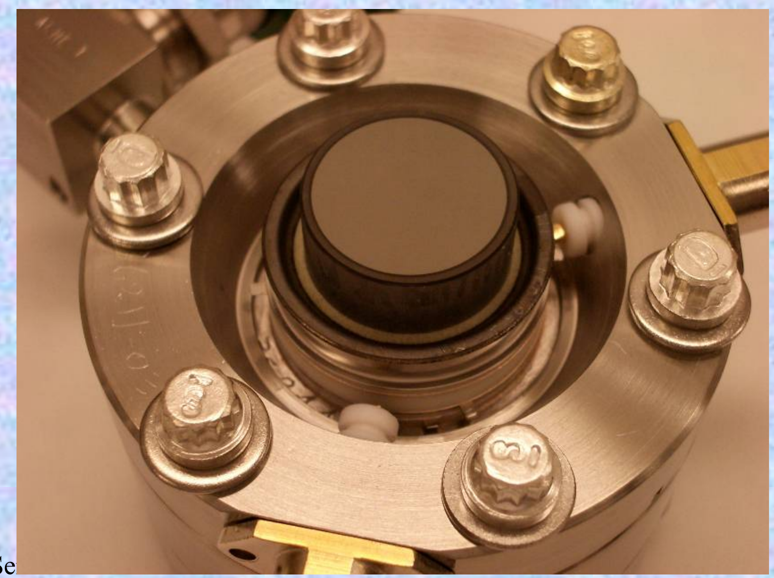
Single MCP

Multialkali cathode

Or GaAs

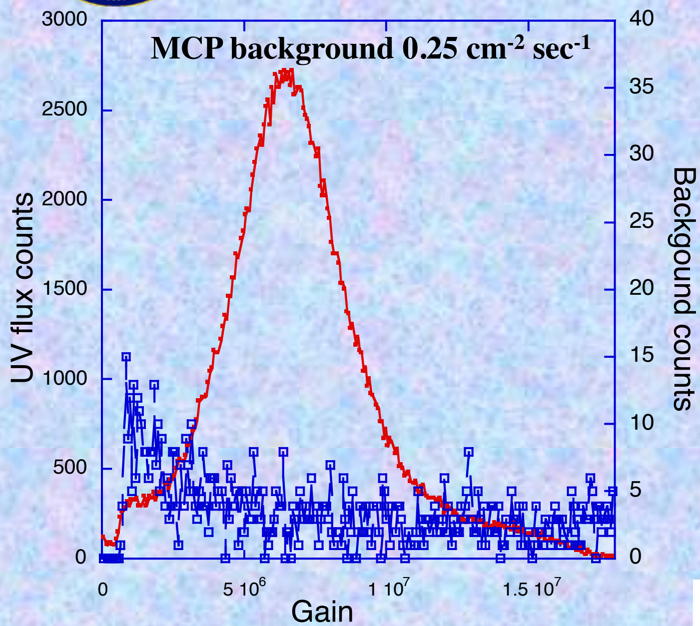
Phosphor on FO

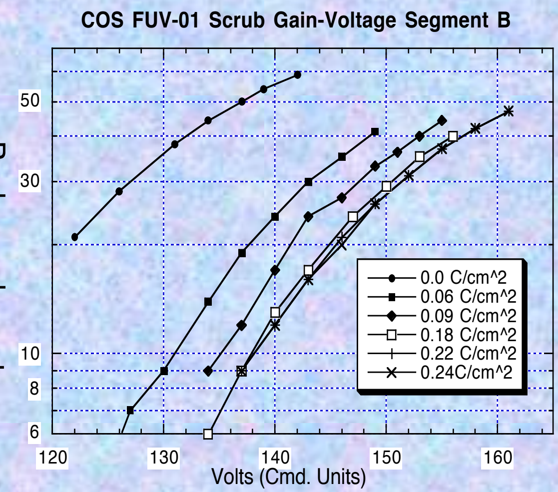
Fiber optic output



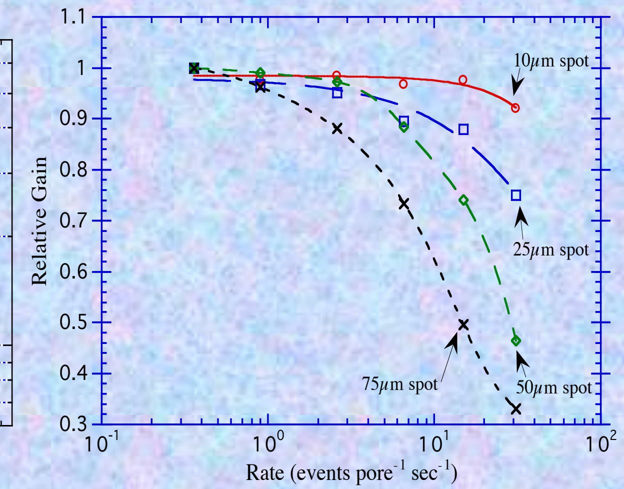
Phosphor screen

Glass Microchannel Plate Performance

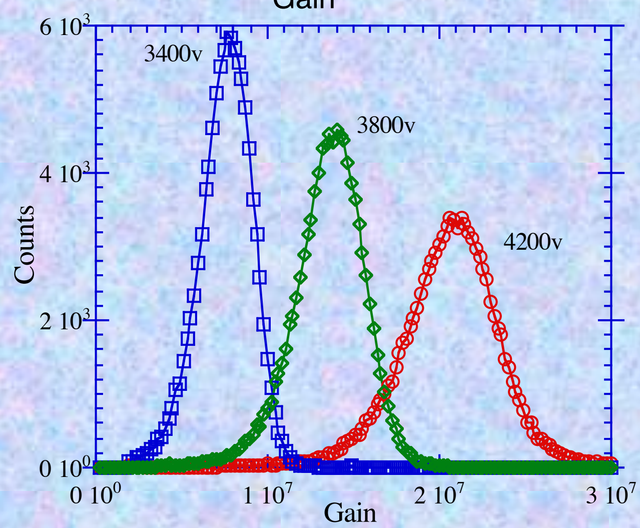




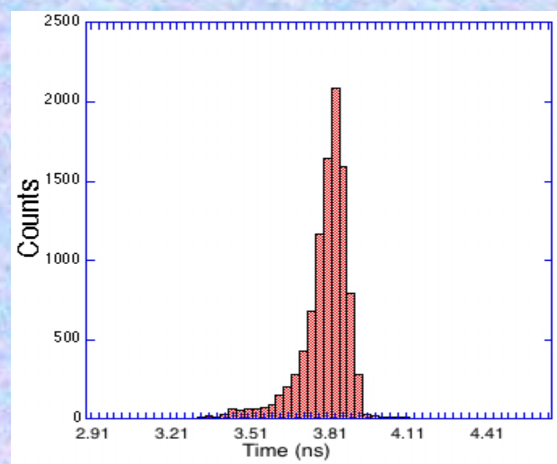
MCP scrubbing reduces gain



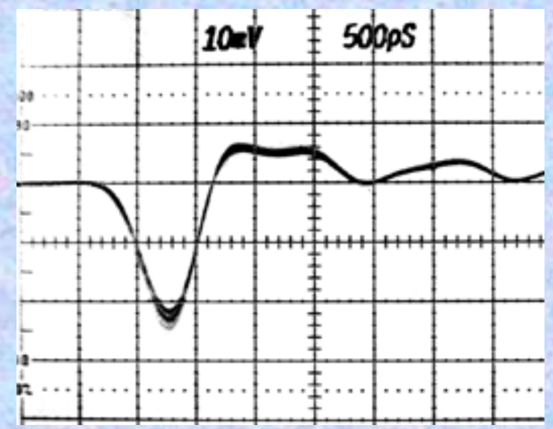
MCP local rate vs gain



MCP event pulse height distributions



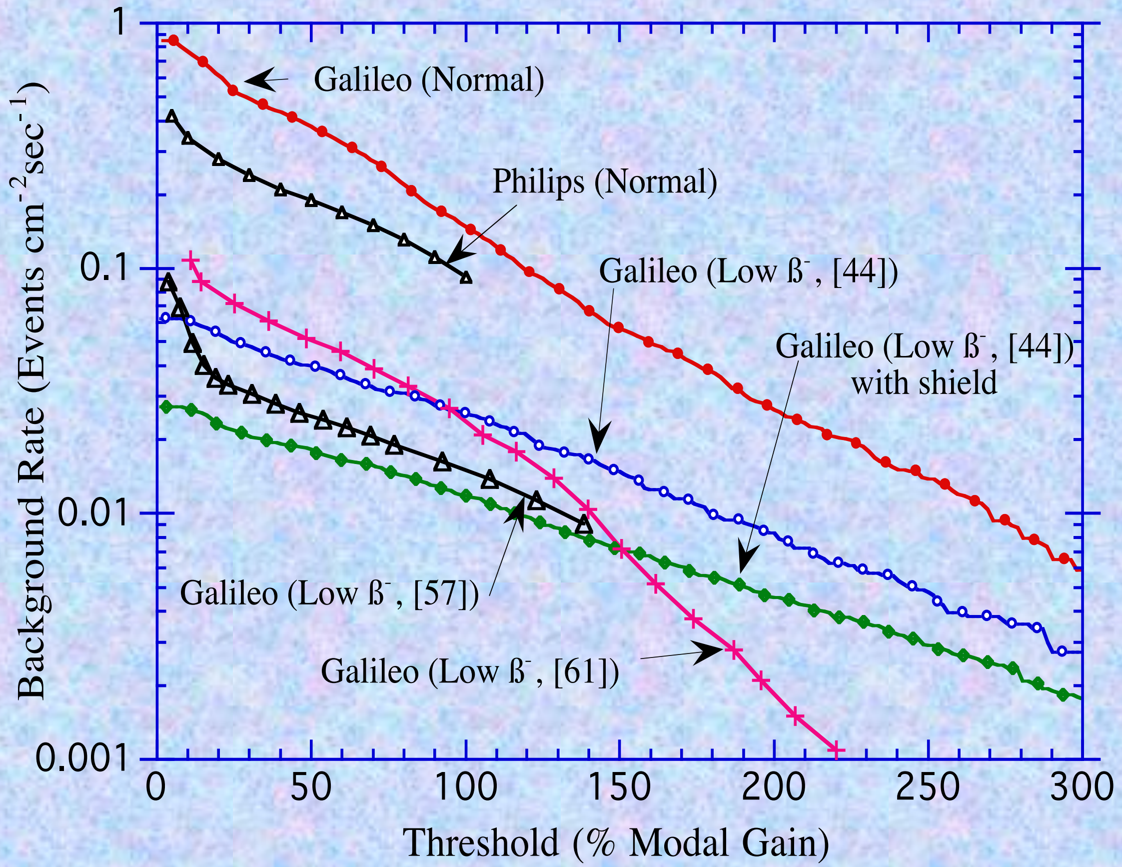
Laser (~80 ps) measurements of timing jitter show 100ps time spread, 3 x 10μm pore, sealed tube, S20 cathode.



Measured FWHM on 1GHz scope is ~500ps, risetime ~400ps. Indicates <250ps FWHM for detector response.

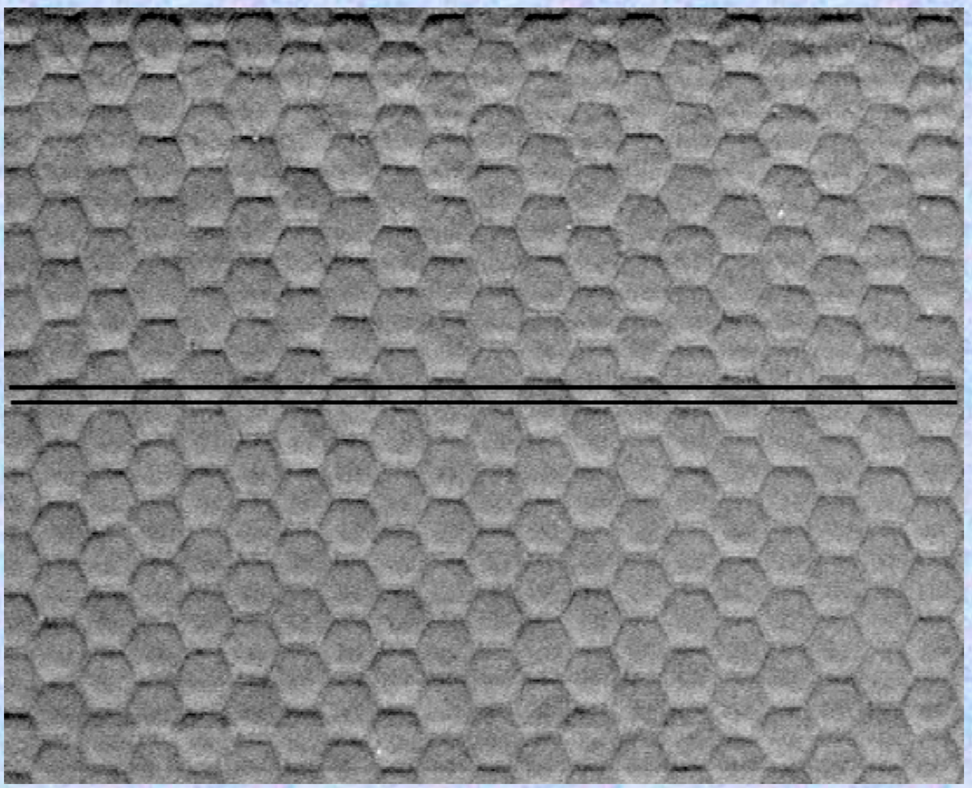
MCP Background Rates

Background is dominated by beta decay in normal glass MCPs due to K or Rb.

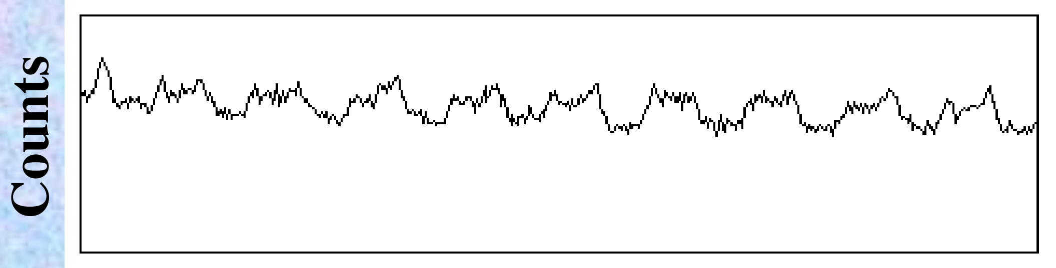


Normal and low noise glass MCP stack background rates as a function of threshold

MCP Flat Field Response



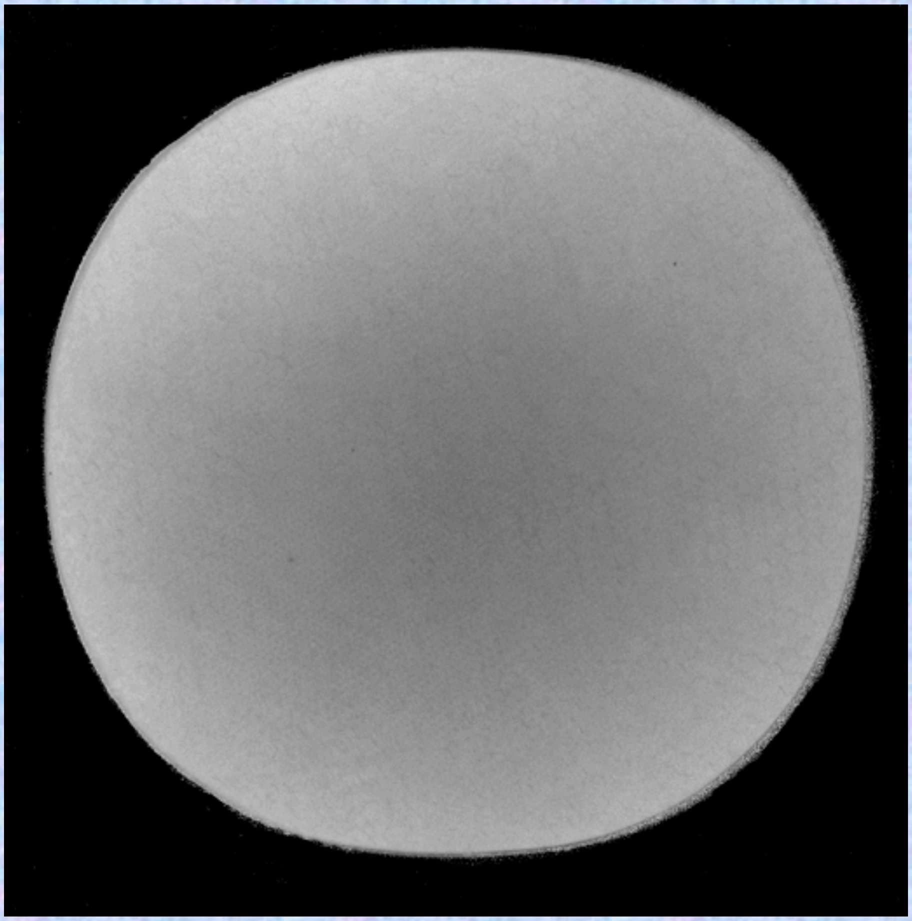
Deep flat field image of a section of a HST detector showing MCP multifiber modulation. Individual multifibers are about 0.8mm wide and show gain changes and position shifts at multifiber boundaries.



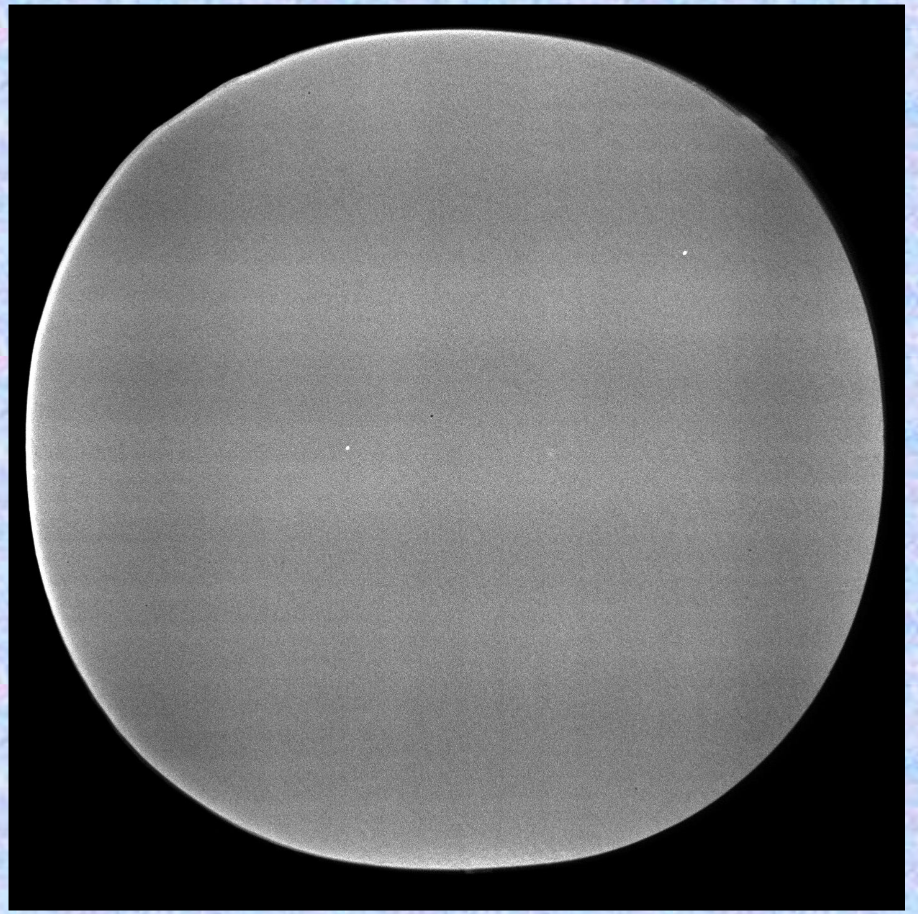
Position Histogram of image slice

Newer 25mm MCP 3 x 60:1 Z stack

Performance of MCP "Z" stack with Photonis (Brive) MCP Z stack (10µm pores). Cross delay line readout.



Gain map image shows extremely faint multifiber edge gain modulation and slight global variation.



Intensity image shows no multifiber modulation. Just two "warm spots", and some global variation due to electronics.