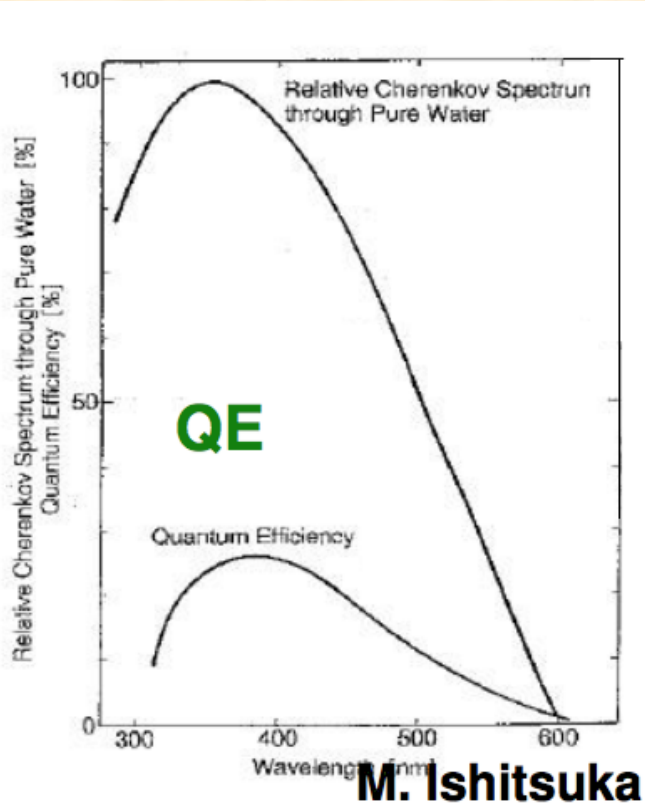
LAPPD Bialkali Photocathode Development

Ossy Siegmund, Sharon Jelinsky, Jason McPhate, Joe Tedesco
Experimental Astrophysics Group, Space Sciences Laboratory, U. California at Berkeley

Junqi Xie, Klaus Attenkofer, Zikri Yusof, Bob Wagner, Ed May, Carla Pilcher, Joe Gregar, Sasha Paramonov, Marcel Demarteau
Argonne National Lab.

LAPPD Photocathode Development

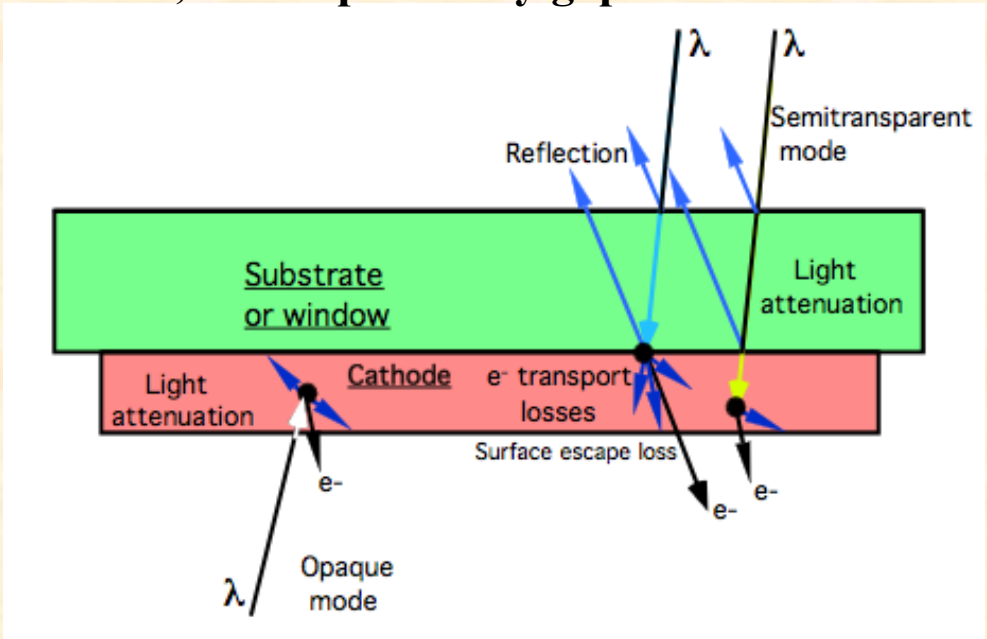
Goals: establish a photocathode/window baseline and fabrication processes compatible with processing 20cm LAPPD tubes.



Nominal Cherenkov emission spectrum compared with bialkali

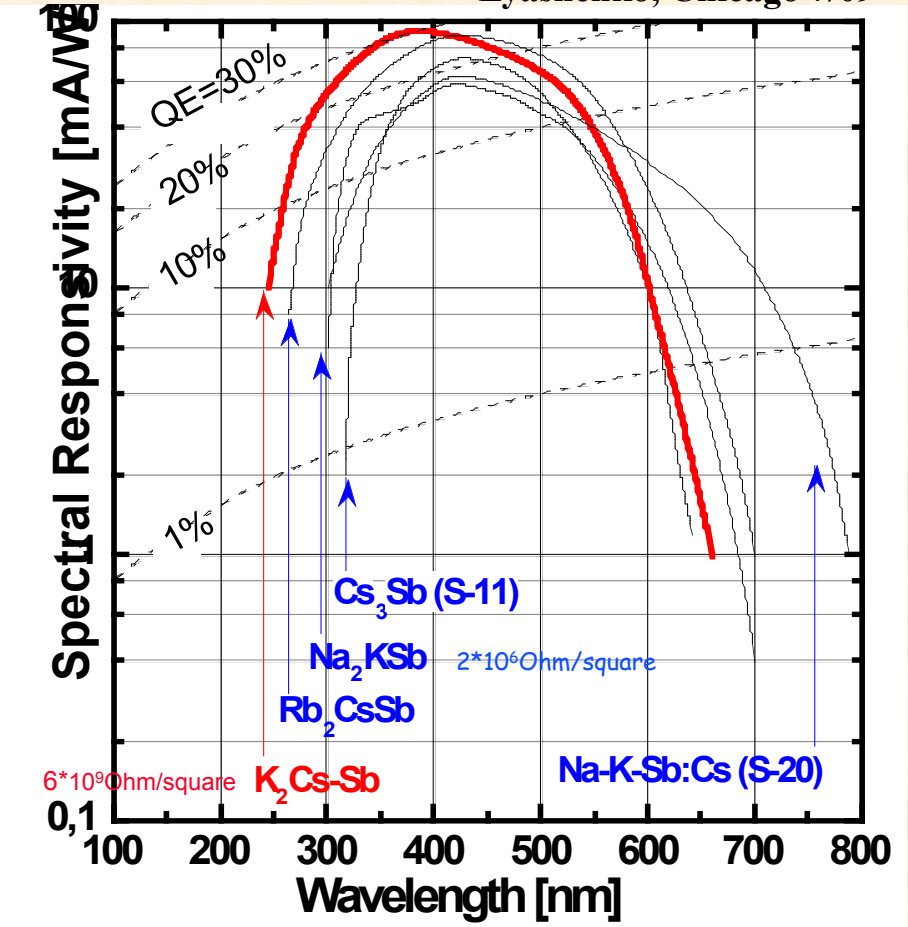
Photocathode Operation Schemes

Bialkali is a few 100Å thick, and is nominally a deposition as a semitransparent layer on the window, with a proximity gap to the first MCP.

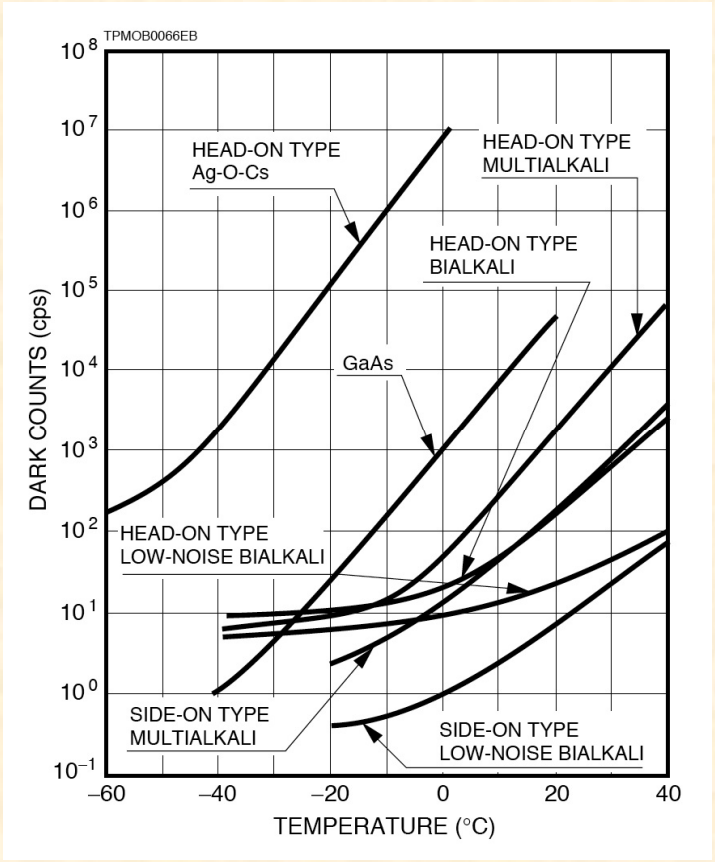


Typical Bi-Alkali Cathode Characteristics

Lyashenko, Chicago 7/09



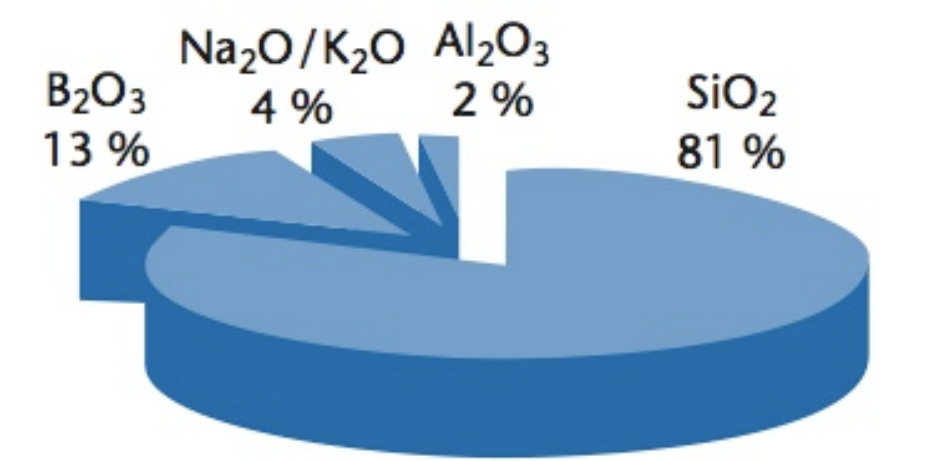
QE and resistivity for various bialkali's
We have used Na_2KSb and K_2CsSb.



Cathode Noise vs Temp.
Expect 10,000 to 40,000 events/ sec for 8" tube bialkali!

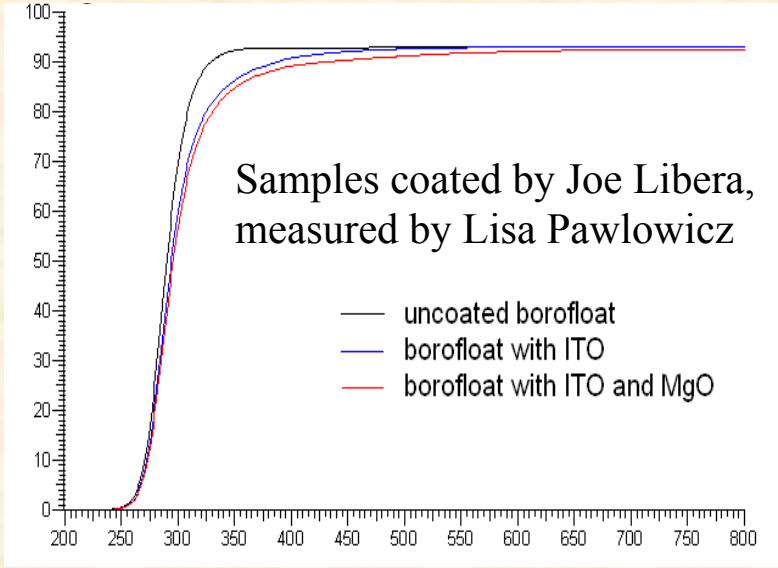
Window of choice B33 - General Parameters

The cathode substrate, window or window coating, affects the photocathode performance. Borofloat B33 Borosilicate has been tested, and it is a good photocathode substrate. BUT - it has Tin diffused into one side, so we polish it. Anti-reflection coatings not baselined, (5 to 9% reflectance in bandpass).



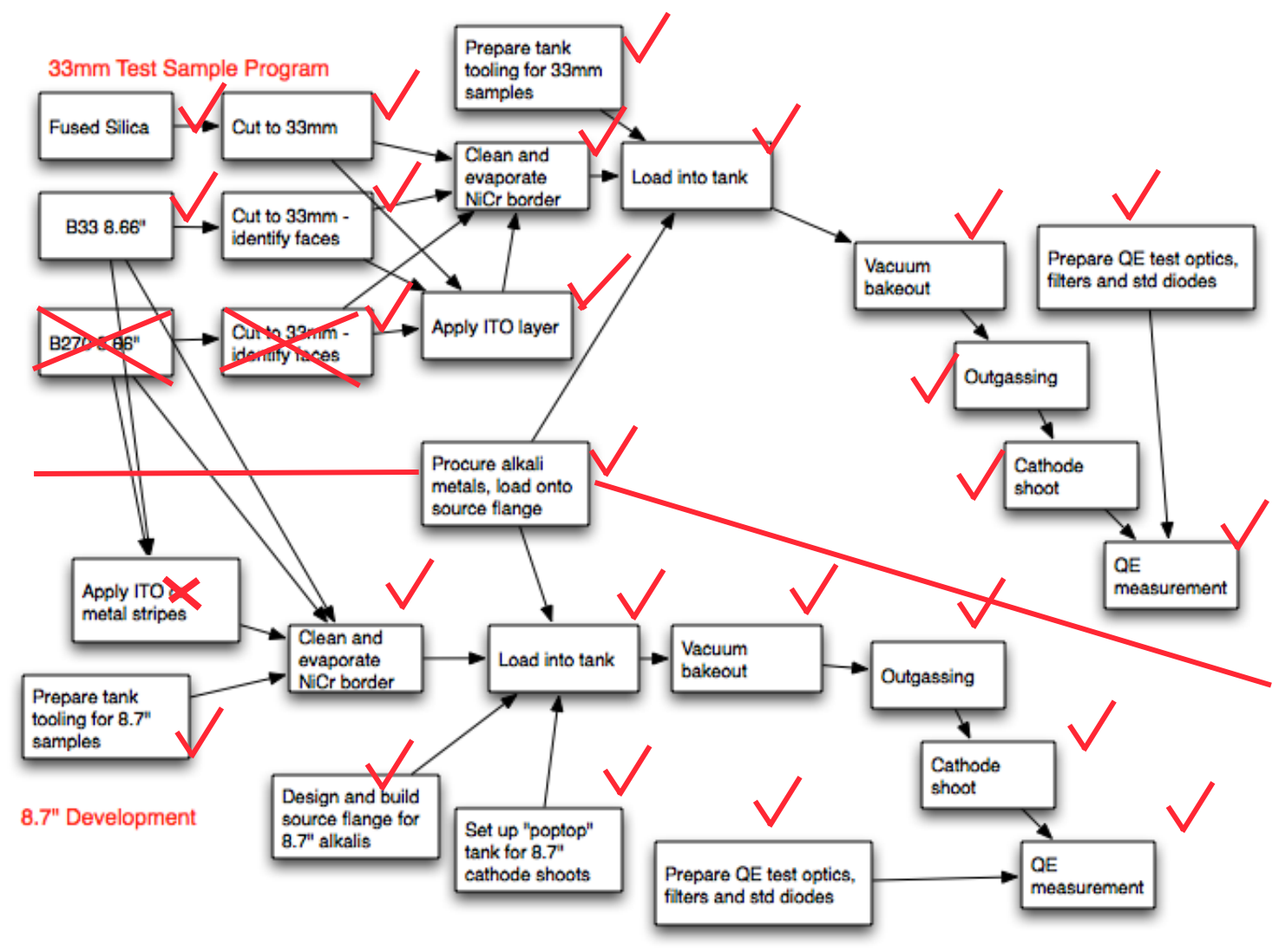
B33 Composition

Refractive index—@400nm	
B33	1.47
Air	~1.0
Water	~1.32



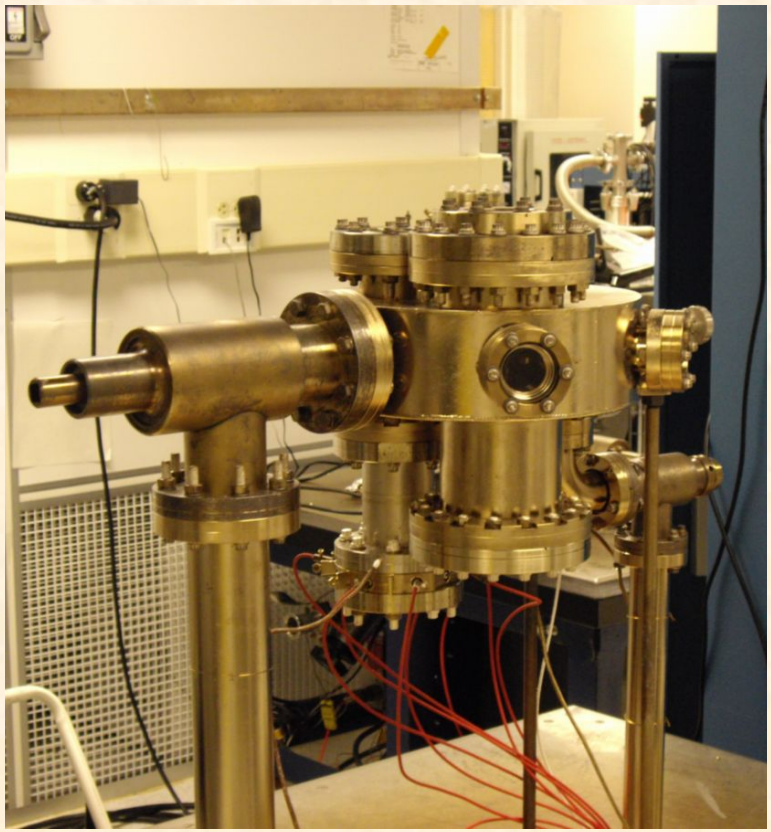
B33 Transmittance is typical for boro-silicate glasses.

UCB Work Flow for Bialkali Cathode Development



We have run the processes for both small and 20cm depositions successfully. Now we are establishing the process in the large tube process tank.

UCB Tube Lab, 1.2” old sample test/process station.



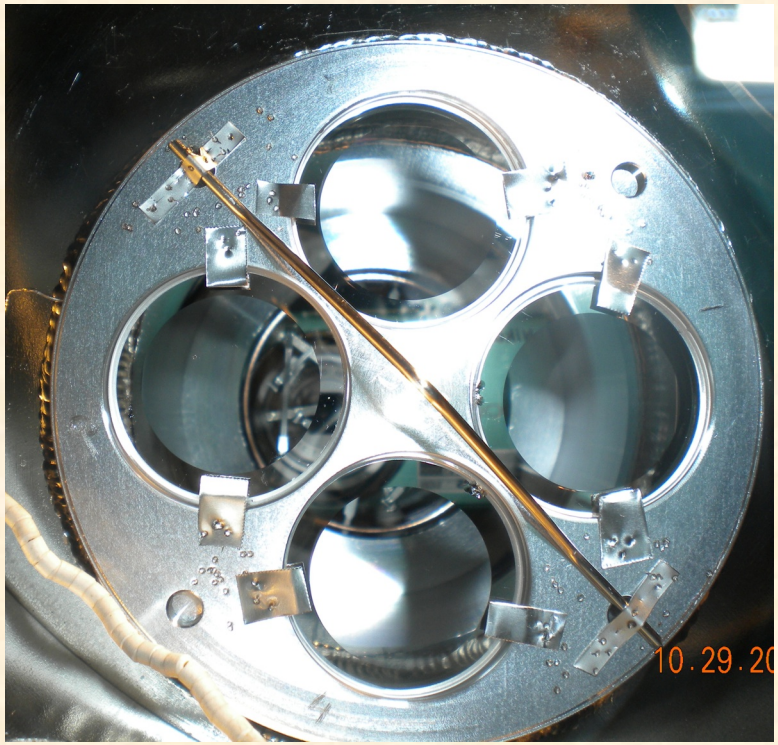
Small tank used to process alkali cathodes (33mm) and tubes of small area.
Can take 4-8 samples/run. 7 runs done, more than 30 substrate coatings.

- **Small sample test runs**
- **Substrate material tests**

UCB Bialkali Process Development Program

Small window cathode development, 1.22” samples
- Processed samples to optimize QE and bandpass

Window holder inside tank

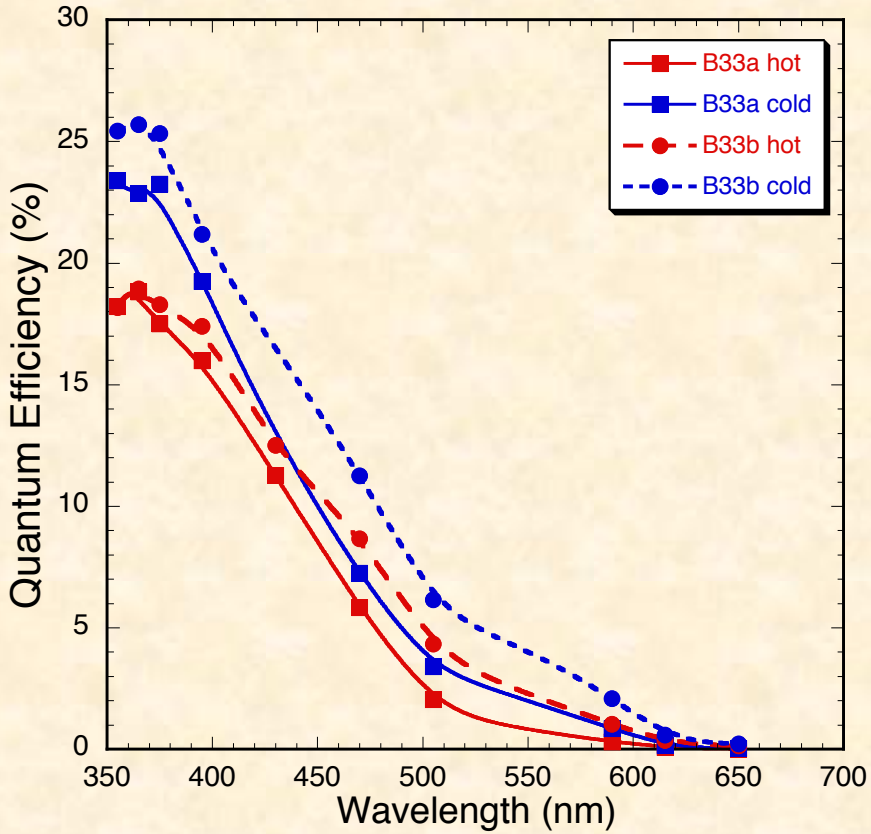


Window holders and mask

We cut up 8.7” B33 windows to make ~50 ea 1.22” test samples.
Inconel annular electrodes were evaporated just as they would be for In seals

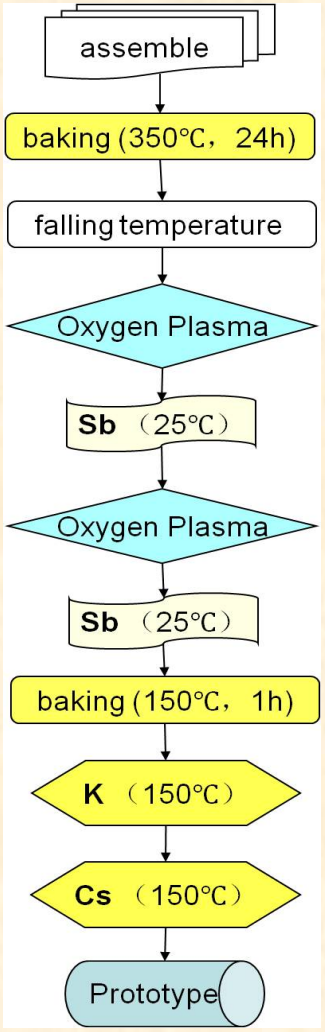
UCB Bialkali Photocathode Sample Tests

Cathode test runs with K_2CsSb and Na_2KSb cathodes on borofloat-33 windows. Na_2KSb ~25% QE achieved, QE uniformity better than ± 15%.



Bialkali test cathodes made on polished 31mm B33 windows gave the best results. Na_2KSb measured hot, right after deposition, always improves after cool down. Have been able to repeat the process a number of times in different process tanks.

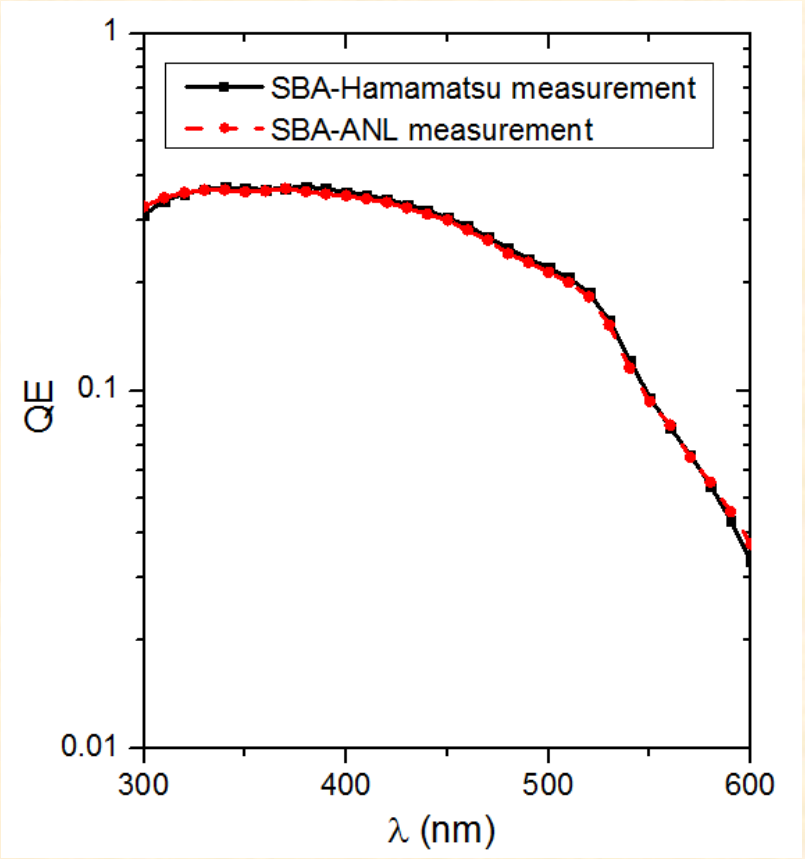
Argonne Bi-Alkali Photocathode Deposition Process



Uses Burle PMT processing station and photocathode process to deposit small area K_2CsSb bialkali photocathodes.

Optimize & apply this to the fabrication of large area photocathodes.

ANL Optical Measurement Station Commissioning

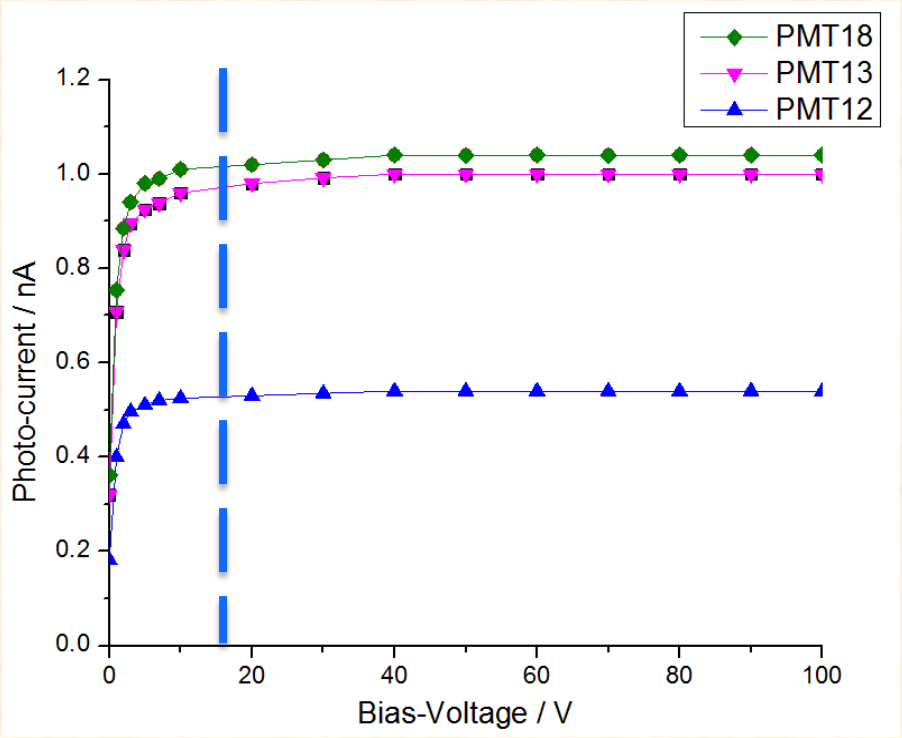


Movable optical station can be shared by different growth facilities in the lab. QE measurement of PMTs by Hamamatsu and ANL optical station agree well with each other indicating the home-built optical station is accurate.

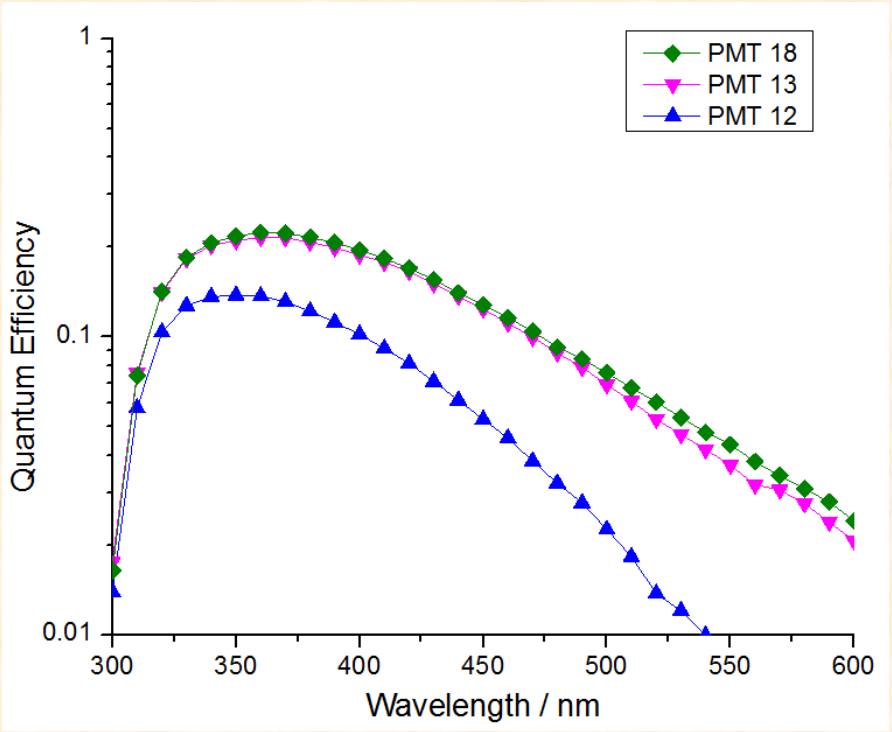
ANL Small PMT Photocathode Characterization

Have deposited a number of cathodes & established a baseline process

I-V Characteristic



QE Measurement



Cathodes exhibit characteristic I-V behavior,
QE as high as 24% at 370 nm.
The quick drop at short wavelength is due to glass absorption.

Argonne NATIONAL LABORATORY

Small Bialkali Cathode Development Summary

UCB small window cathode development, 1.2" samples, 4 per run

- Studied Na_2KSb, K_2CsSb cathodes made by co-evaporation
- Processed samples to optimize QE and bandpass
- Used several substrate materials, SiO_2, B270, and B33
  - B33 has best QE and is a good substrate material
- Inconel evaporated borders established with good adhesion/conduction
- Tested MgO/ITO/conductor underlayer for cathodes – poor QE
- Na_2KSb ~25% QE achieved repeatably on B33 substrates
- QE uniformity better than ± 15% over 3" x 3" (2 x2 substrates).
- Work with Na_2KSb and B33 as 8" baseline, and use Inconel border
  - good QE, high temp stability, uniform, high conductivity, low background

Argonne small cathode development, "PMT" samples

- Photocathode growth and characterization instruments were set up.
- K_2CsSb cathode fabrication with conventional "PMT" process
- Standard bandpass characteristics and QE achieved
- PMT photocathodes with QE as high as 24% have been produced.

8” Photocathode Process Development

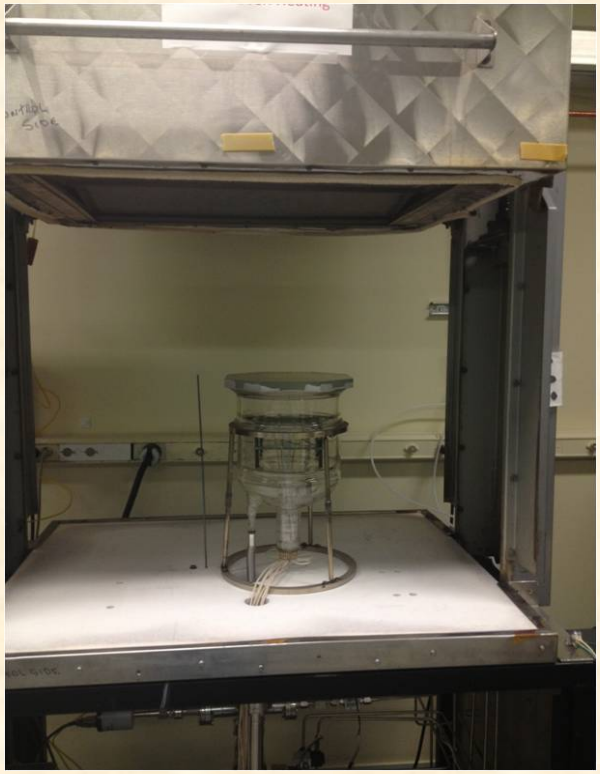
UCB Objectives for 8” window/cathode development:-

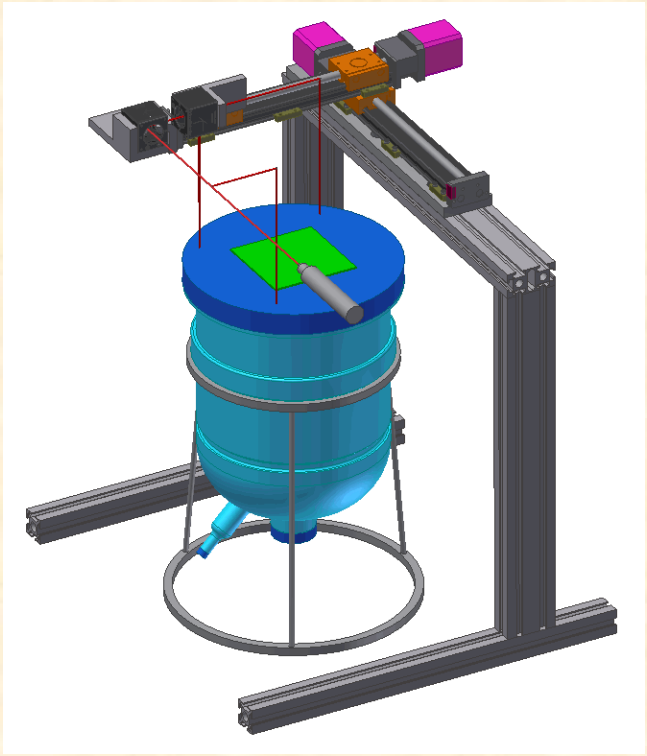
- Commission 8” cathode & seal process development tank
- Verify small sample deposition method for 8” cathodes
- Optimize alkali sources for large Na_2KSb cathode areas
- Confirm 8” wet cleaning and plasma cleaning processes
- Optimize cathode QE levels and test stability and uniformity
- Trial window seals on 8.7” Indium wells
- Transfer processes to large sealed tube vacuum tank

ANL Objectives for 8” window/cathode development:-

- Commission “Chalice” large area PMT cathode testbed
- Verify small PMT deposition method for 8” cathodes
- Optimize alkali & Sb sources for large K_2CsSb cathode areas
- Establish optimal Sb layer thickness

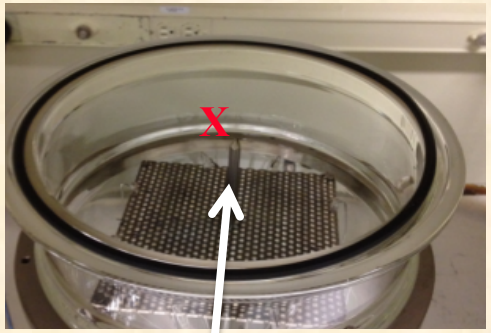
The ANL Chalice Large Area Photocathode Testbed





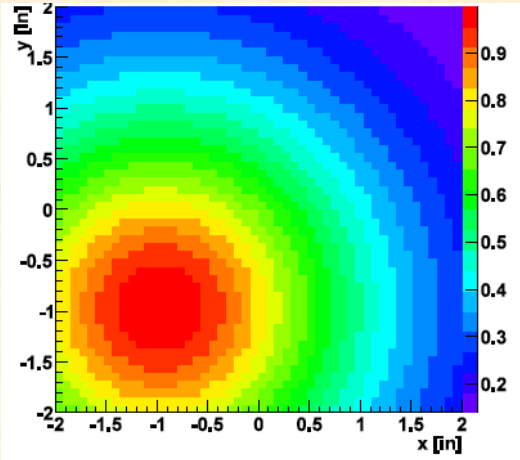
Design is based on the small PMT tube experiences
The chalice can be visualized as a LARGE PMT tube.
Top glass plate is replaceable for reuse.
Chalice structure is supported by external legs.
An X-Y scanner was designed and built for QE scan.

Comparison of QE Map & Sb Transmission Map

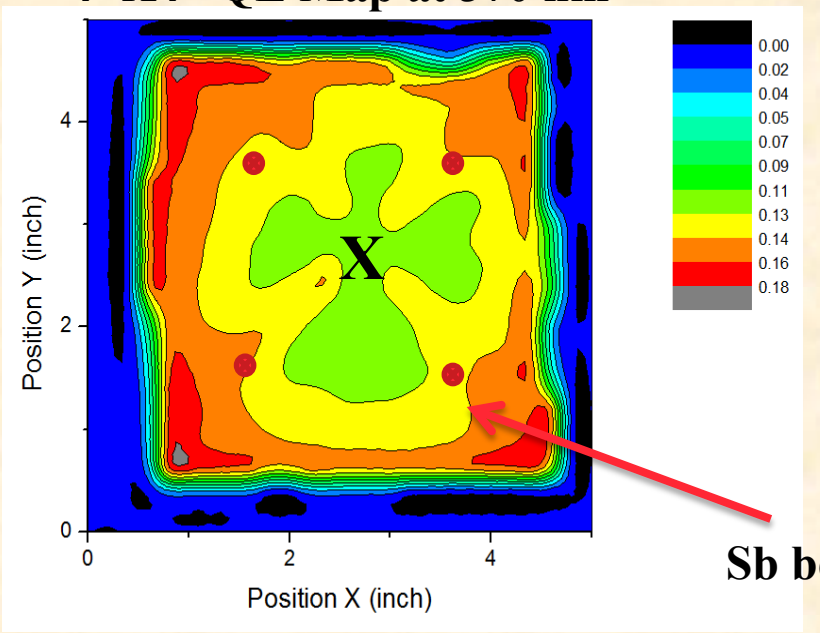


Center nail ("lightning rod") for plasma cleaning

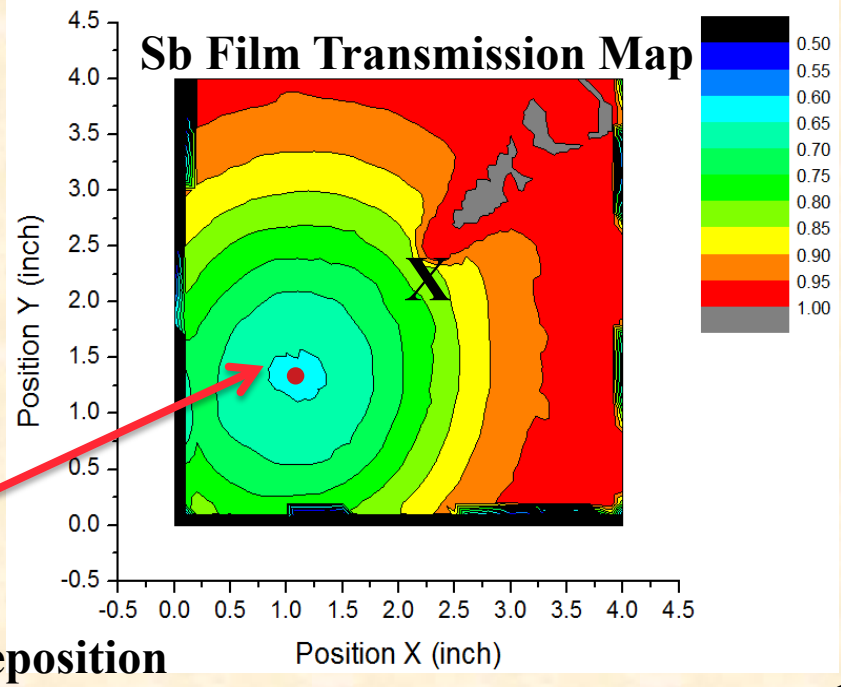
Simulation of relative Sb thickness



4"X4" QE Map at 370 nm



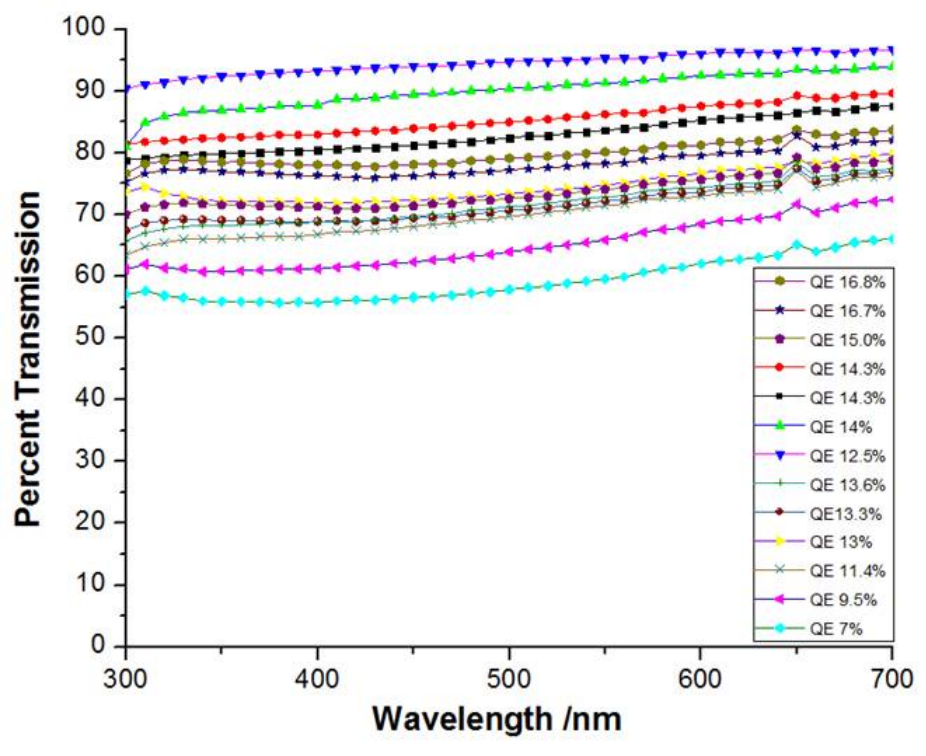
Sb Film Transmission Map

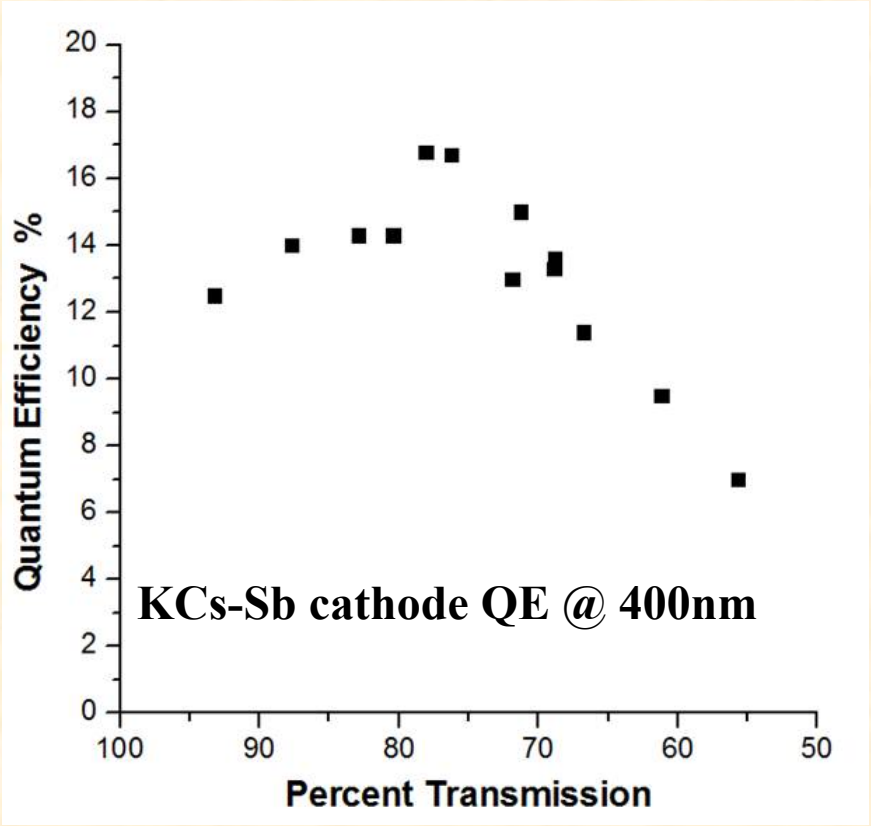


Sb bead

Center X: Lightning rod, affects the Sb film deposition

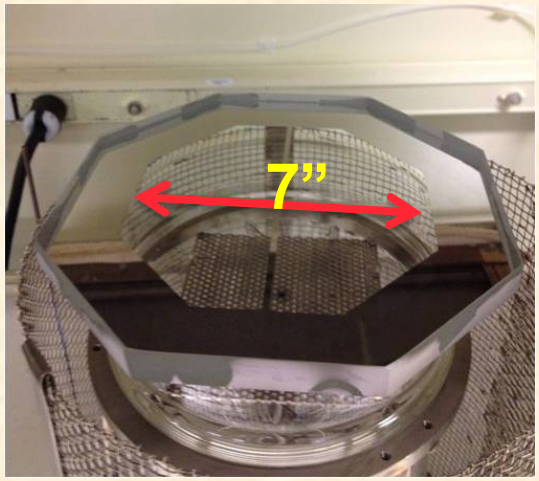
Sb Film Transmission v.s Photocathode QE



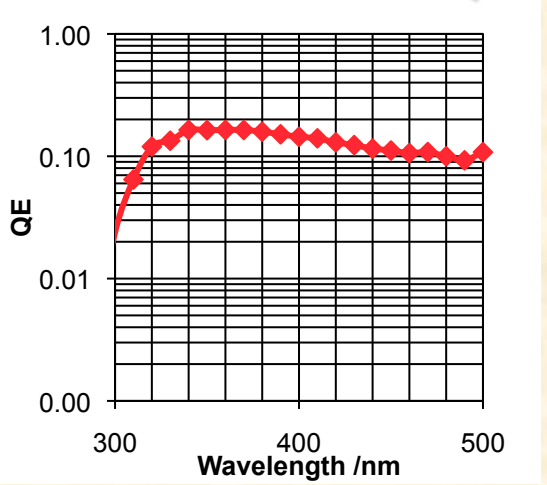


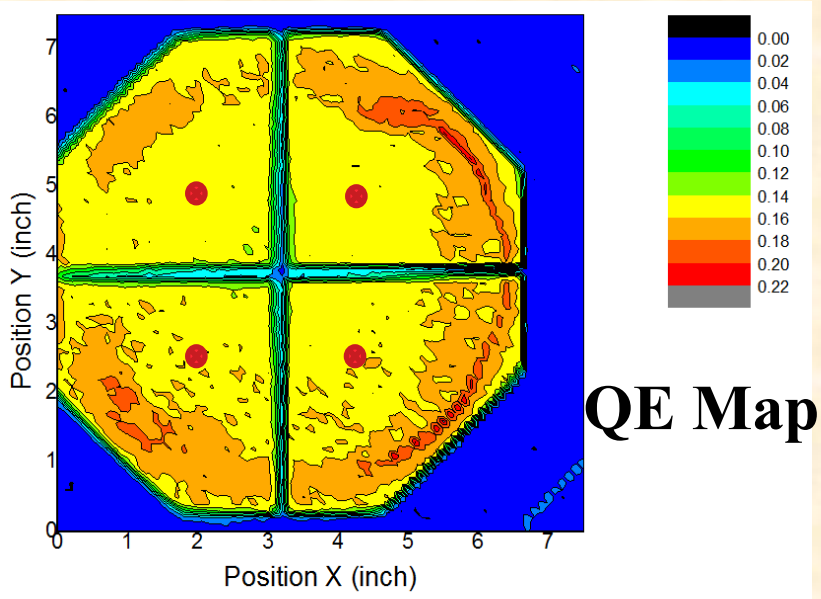
Sb film transmission with and cathode QE were measured.
Film transmission generally increases with wavelength
The highest QE occurs for ~78% Sb transmission layers(at 400nm).

ANL Chalice Photocathode Characterization (7”)



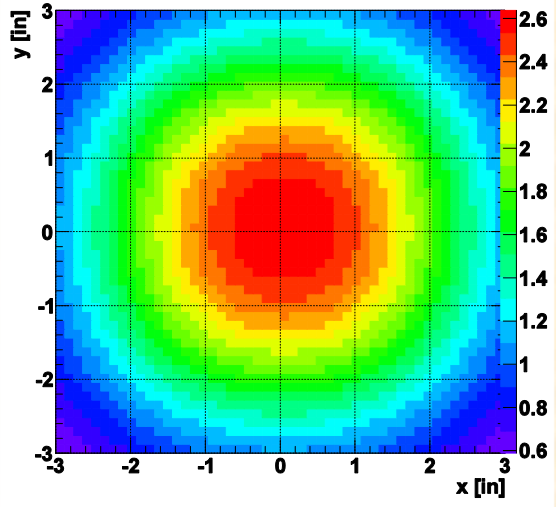
Average measured QE





QE Map

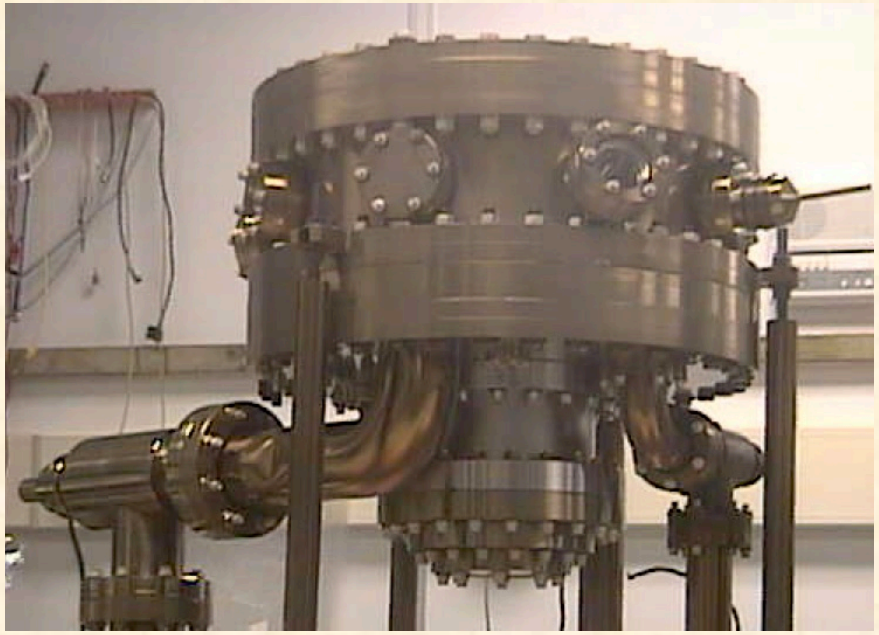
Simulation of Sb layer thickness

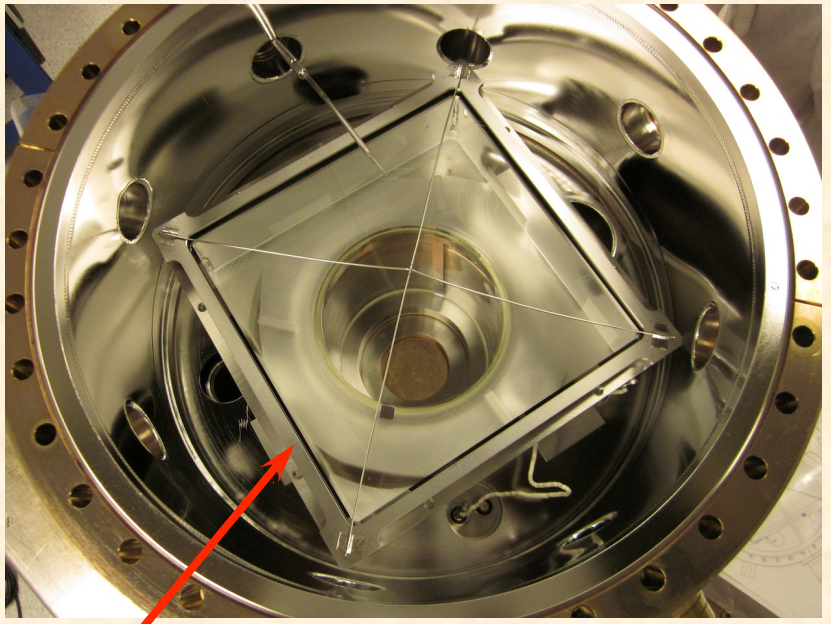


Flat cathode with average QE (~16%), the highest QE spot reaches over 22%, and the higher QE is at the corner area, which is the thinner Sb area.

UCB 8.7” PhotoCathode / Seal test Chamber

8.7” Square PC/seal test process chamber with 14” internal Diameter.





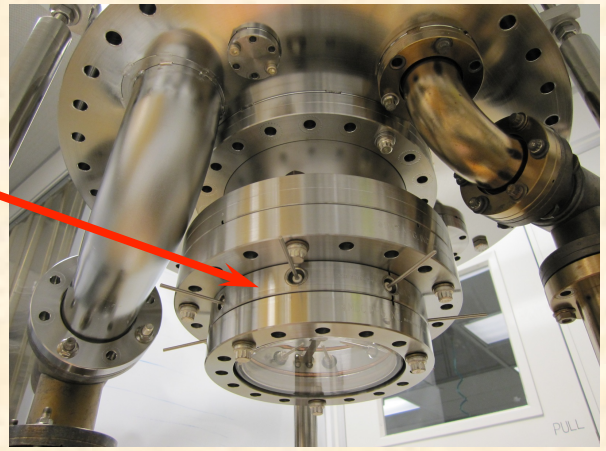
Larger 16” flange tank, for testing

- **-Quantum efficiency**
- **-QE Uniformity**
- **-Seal tests**

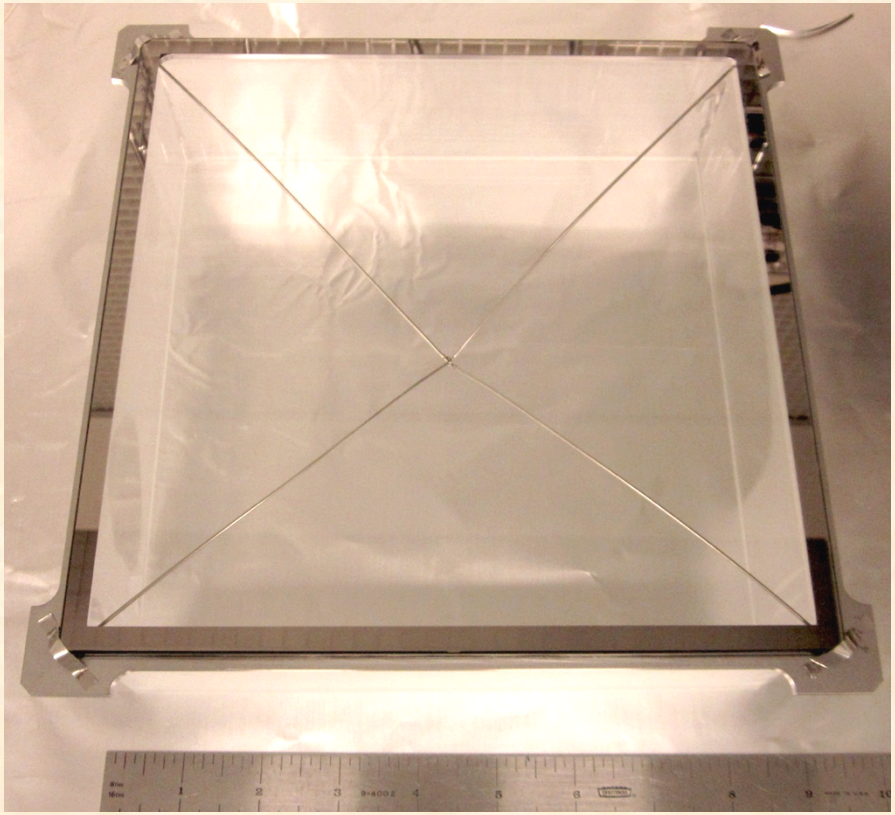
Bakeout up to 375°C to get the chamber conditioned. Used SAES alkalis & SbPt beads. Employed new larger sources for large cathode area.

8.7” square B33 window in holder

Alkali sources

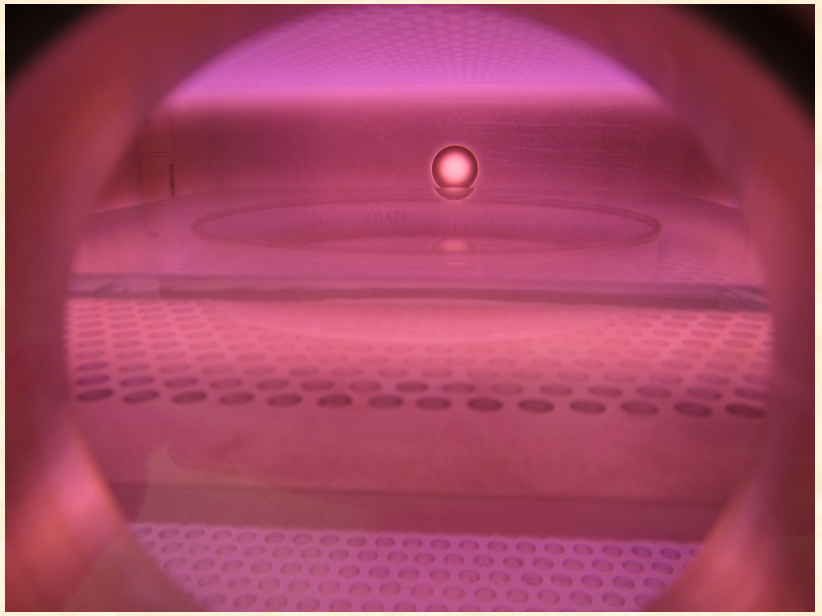


Preparation of 8.7” B33 Windows for Cathodes



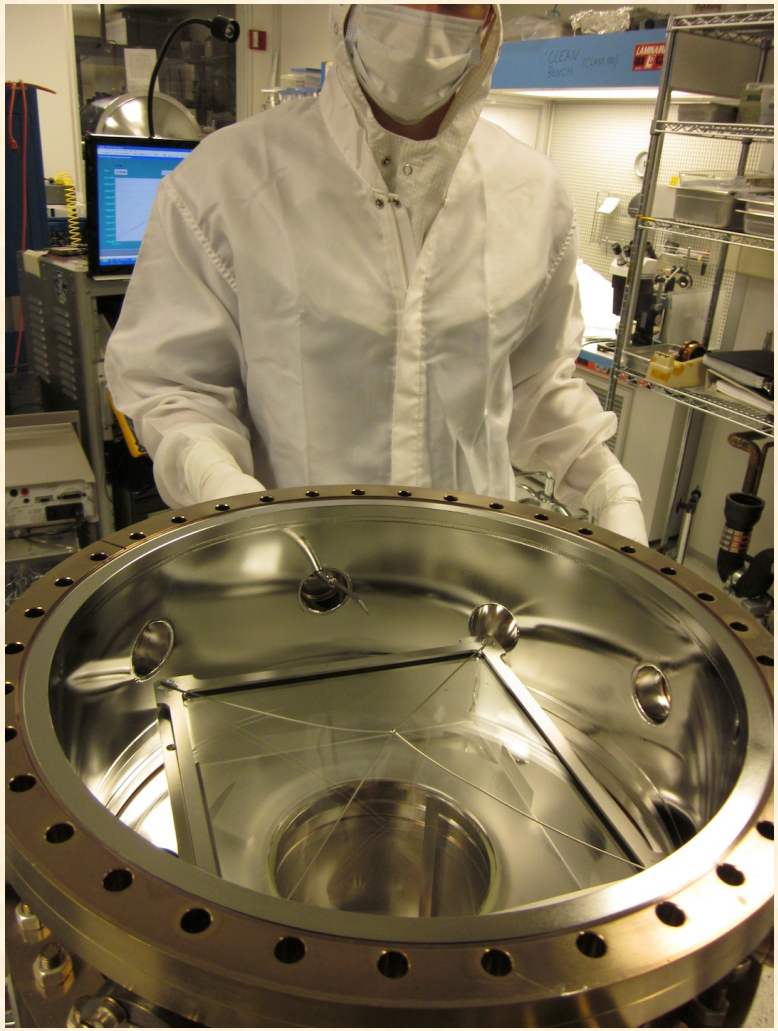
NiCr electrode border on B33. Corner to corner “X” is also applied to ensure conductivity.

All the tooling is in place. We wet clean, plasma clean, and evaporate NiCr on a window, and load into a holder for photocathode processing.



Plasma cleaning

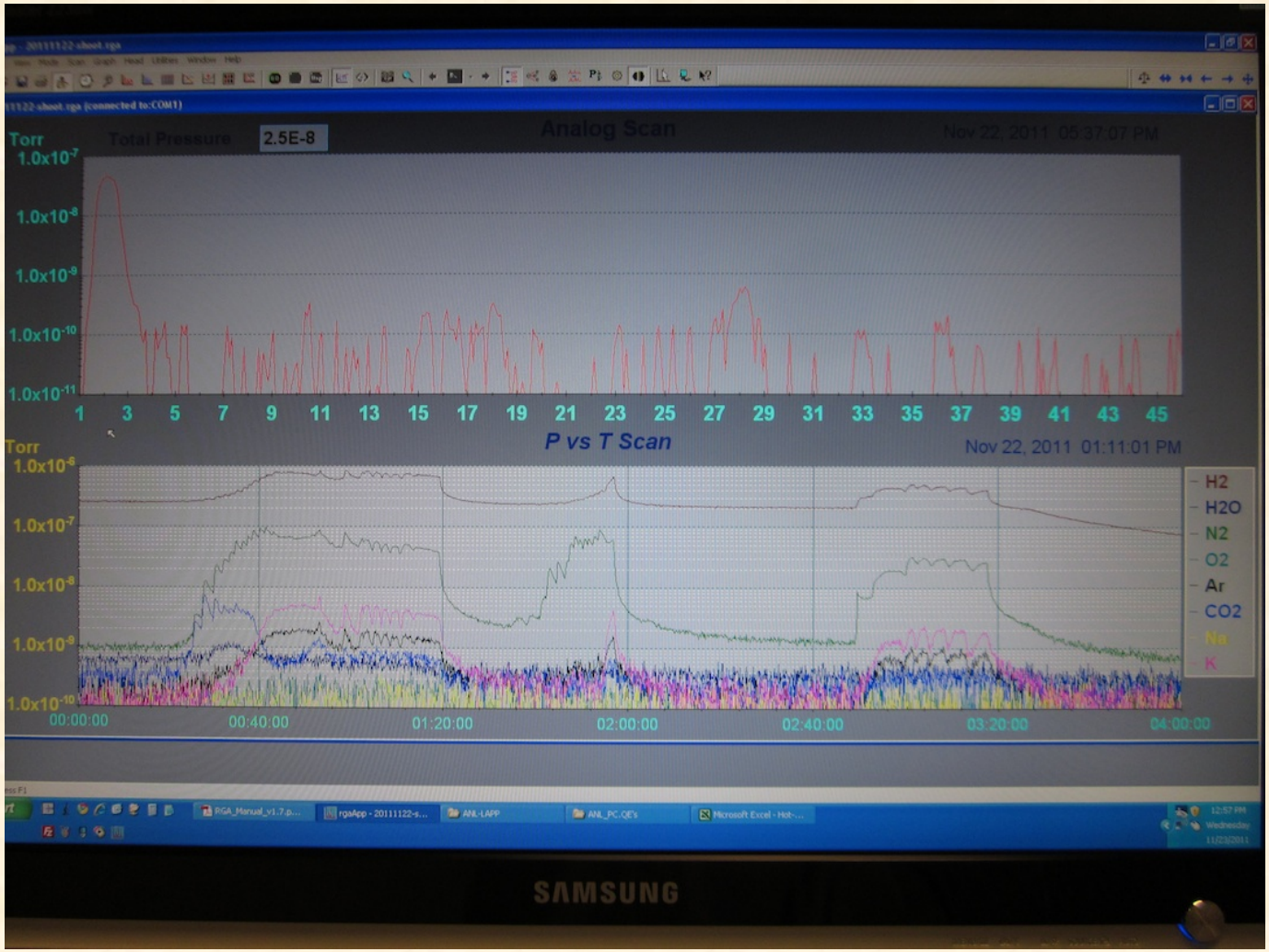
8” Photocathode Processing & System Load

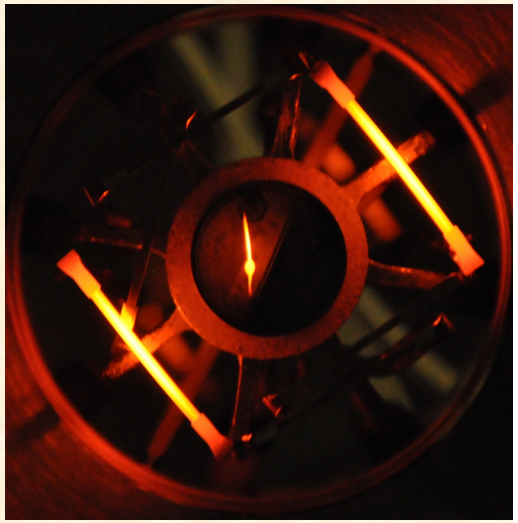


8.7” window loaded

- 8” PC/Seal Test Chamber
  - *<10^{-9} Torr base vacuum,*
  - *RGA operational, fully baked*
- 5mm thick, 8.7” polished B33 window
  - *NiCr border*
  - *electroded with “X” pattern*
- Oxygen plasma clean,
- Baked at 365°C for 16 hrs
- Used large 40mm alkali sources.
- Deposited Na_2KSb photocathode
- RGA records for entire process
- Cathode everywhere
  - except extreme corners

Na_2KSb Photocathode Deposition

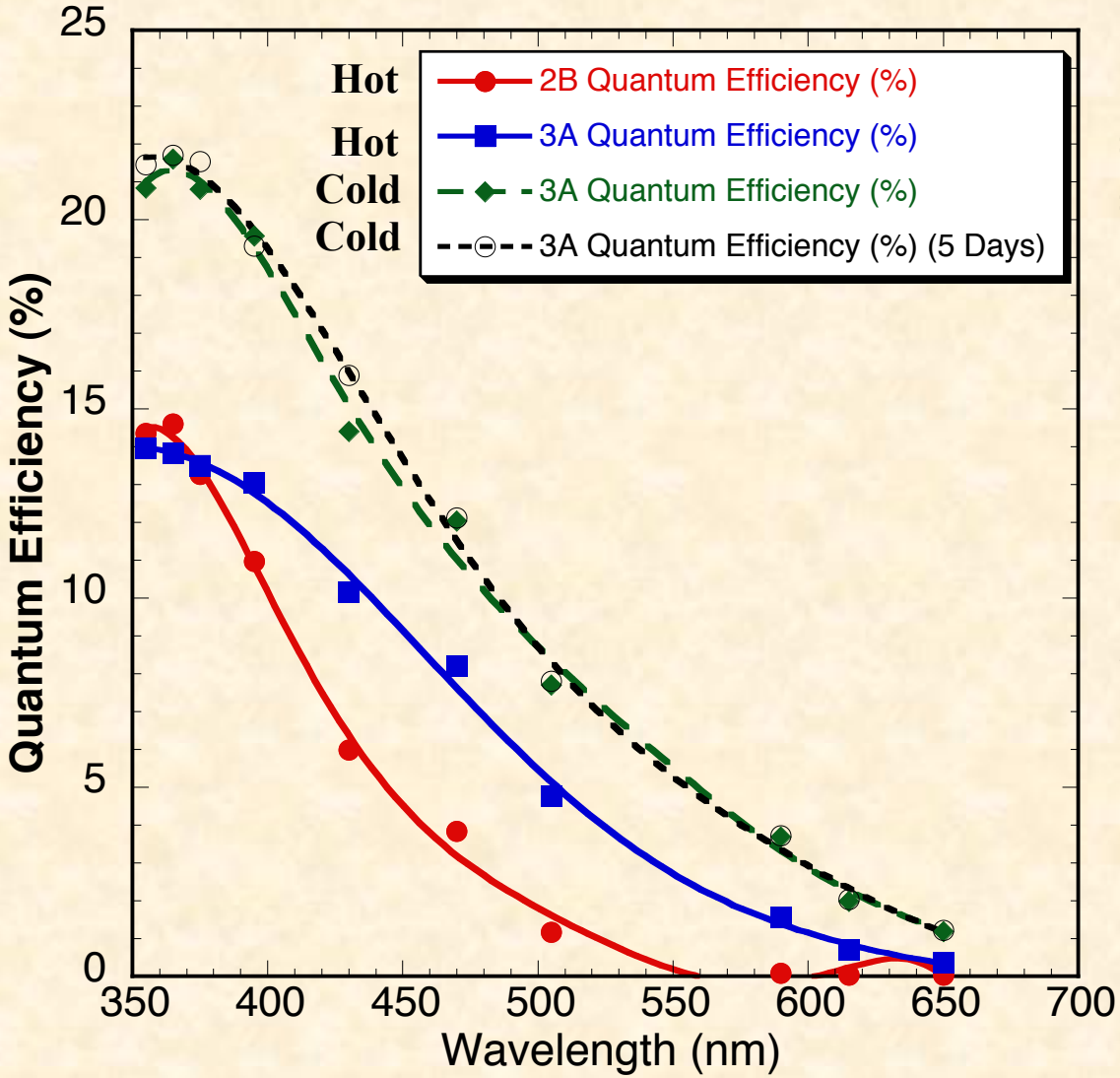




Alkali / Sb sources in action

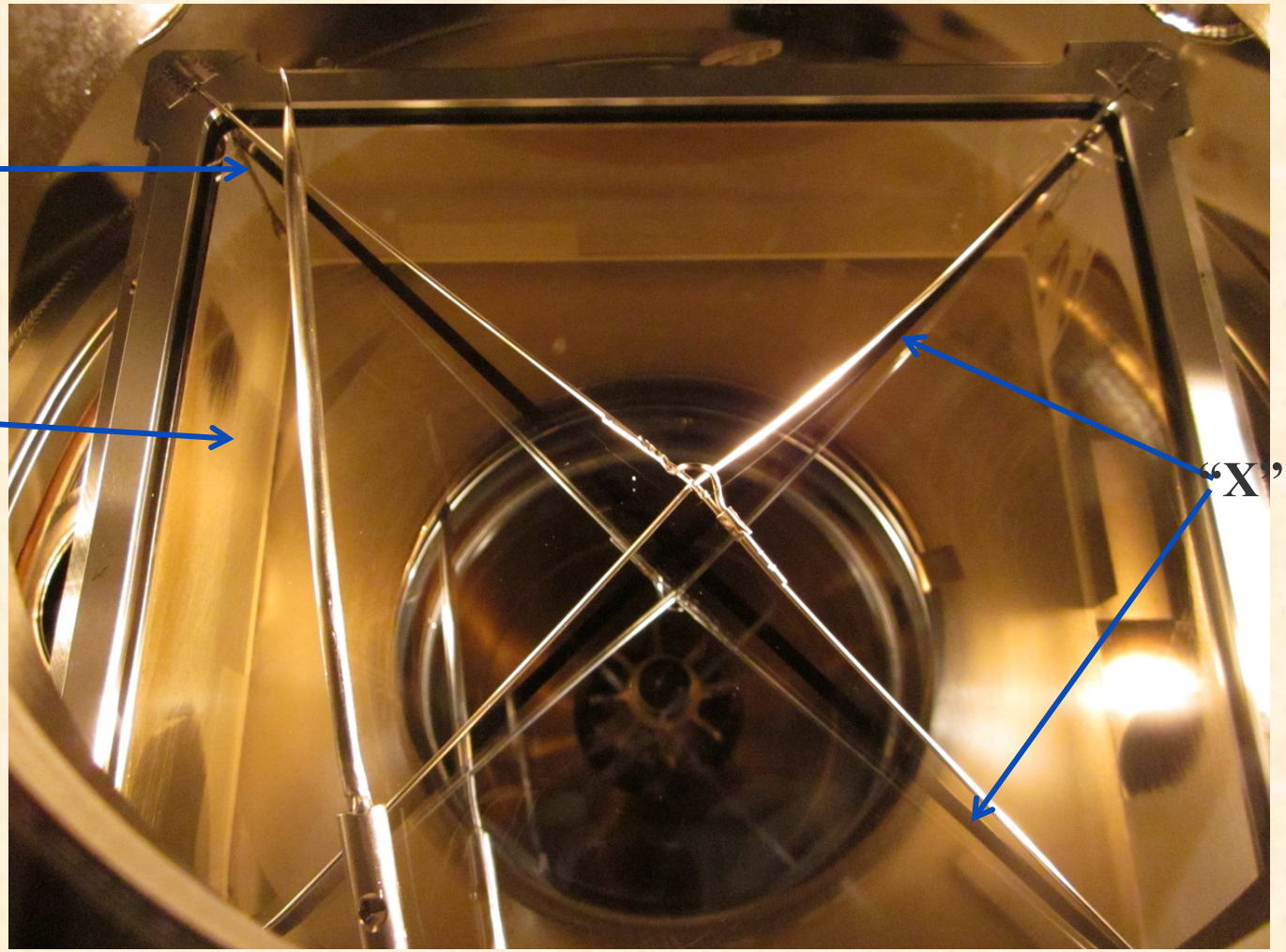
K Sb Na K Sb

8” Na_2KSb Bialkali Results



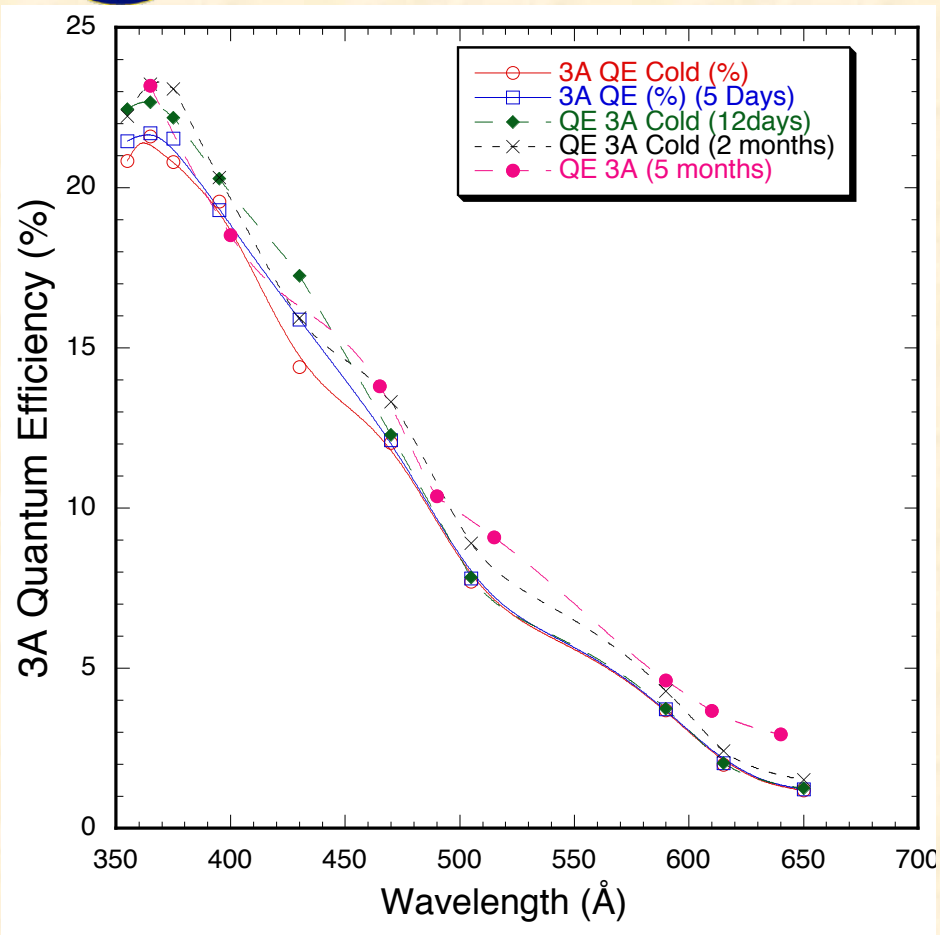
#3 is a redder cathode than #2. #3 is much thicker, which can be seen in the opacity of the cathode. We get a typical enhancement of the QE after cool-down. The QE remained stable over the 5 days after deposition. This is not corrected for the 5mm thick window transmission which we expect to be about 90%. Average PMT cathodes of this type peak at about 18% so we are above that.

8” Na_2KSb Process #3A

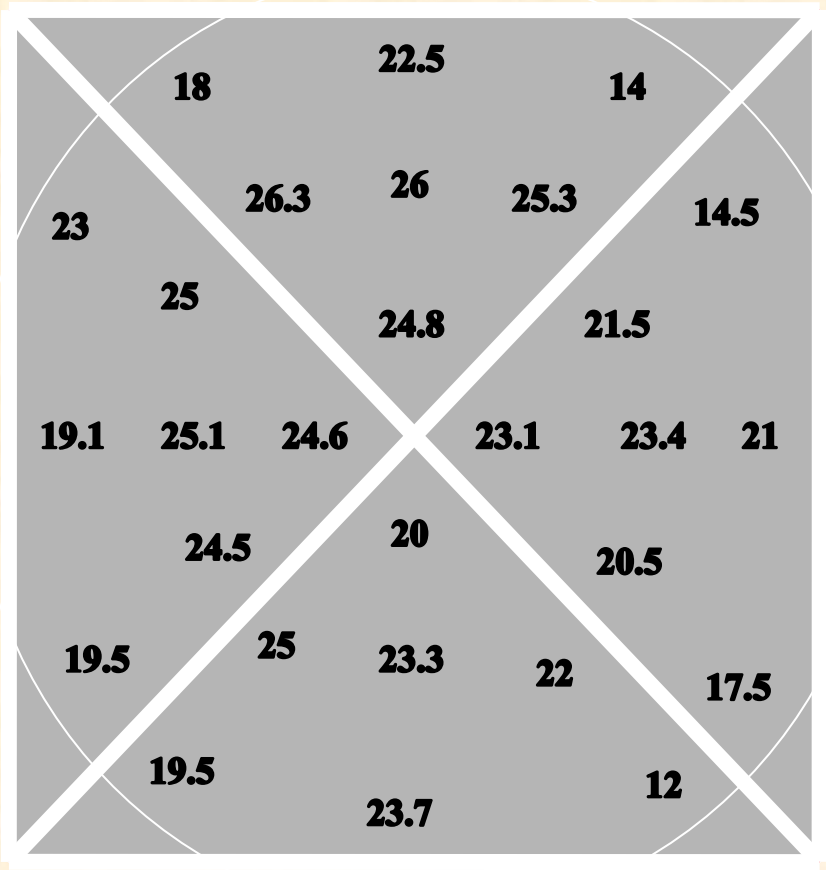


Window (hot) was lifted after process to simulate an indium hot seal procedure. We have also since done a leak tight hot/vacuum Indium seal (McPhate talk).

8in #3A Photocathode Uniformity/Stability



Basic process is a co-evap technique. We get an enhancement of the QE after cool-down. The QE remained stable over the 5 months after deposition.



Cathode Uniformity. Majority of the area is within ±15% of the average QE. There is some obscuration by tooling in some places.

UCB 8” PhotoCathode Sealed Tube Device Process Tank

Process tank commissioned & ready for tube process. First 8” cathode process done, standard optimizations in progress.

Process tank for sealed tube processing, photocathode deposition and transfer seal.

Argonne 8” PhotoCathode Progress Summary

- Large area (7’’X7’’) flat photocathode with average QE (~16%) was produced,
- Highest QE value was 22%. QE of the photocathode is directly related to base Sb layer thickness.
- The optimized Sb thickness for KCs-Sb photocathode is around 78% transmission (@400nm).
- In related studies we used the BNL Synchrotron light source experiment and successfully saw the K diffusion process and K_2CsSb crystalline growth with X ray reflection/diffraction.

Next Steps

- More Reflection data on Sb films to calibrate the transmission
- Optimize the cathode recipe for higher QE cathode based on parameter studies & X ray reflection/diffraction data.
- Input findings into LAPPD sealed tube fabrication program

UCB 8” PhotoCathode Progress Summary

8” PC/Seal Test Chamber

- <10^{-9} Torr base vacuum, RGA operational, fully baked
- 5mm thick, 8.7” polished B33 windows, NiCr border with “X”
- Successfully hot/vacuum sealed window to tube indium well.
- Deposited Na_2KSb photocathodes on 8” windows
  - *~25% QE with good uniformity (±15%) and stability (>5 Mo)*
  - *Can repeat successful process in different vacuum tanks*
  - *RGA/pressure/temp/response record for entire process*

8” Sealed Tube Process Tank

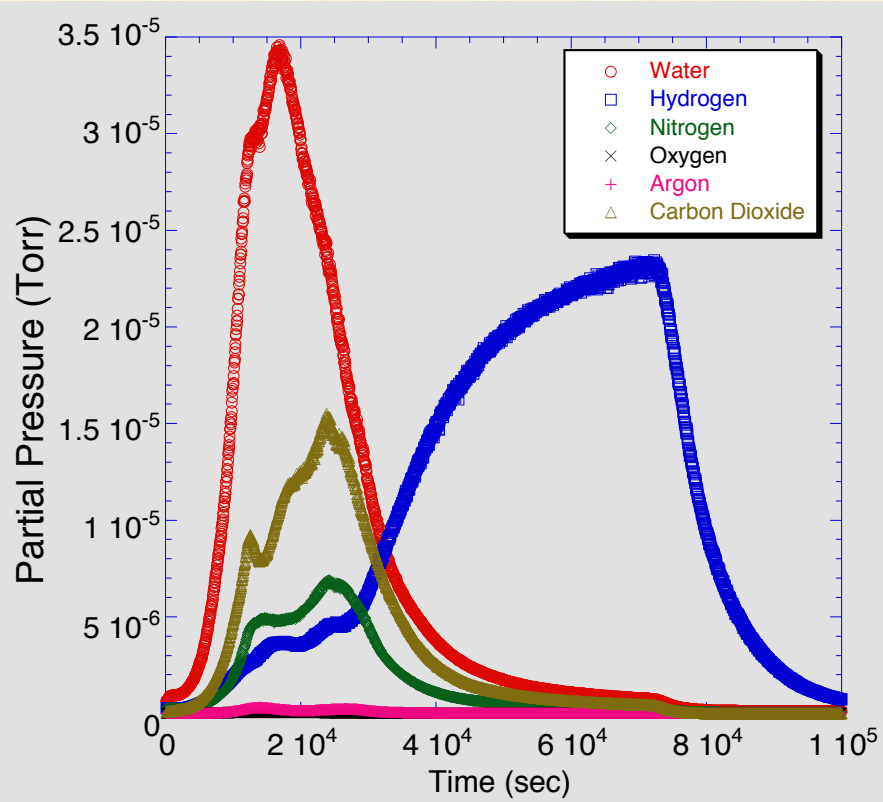
- *<10^{-9} Torr base vacuum, RGA operational, fully baked*
- *Deposited 1st cathode, optimization process underway*

Next Steps

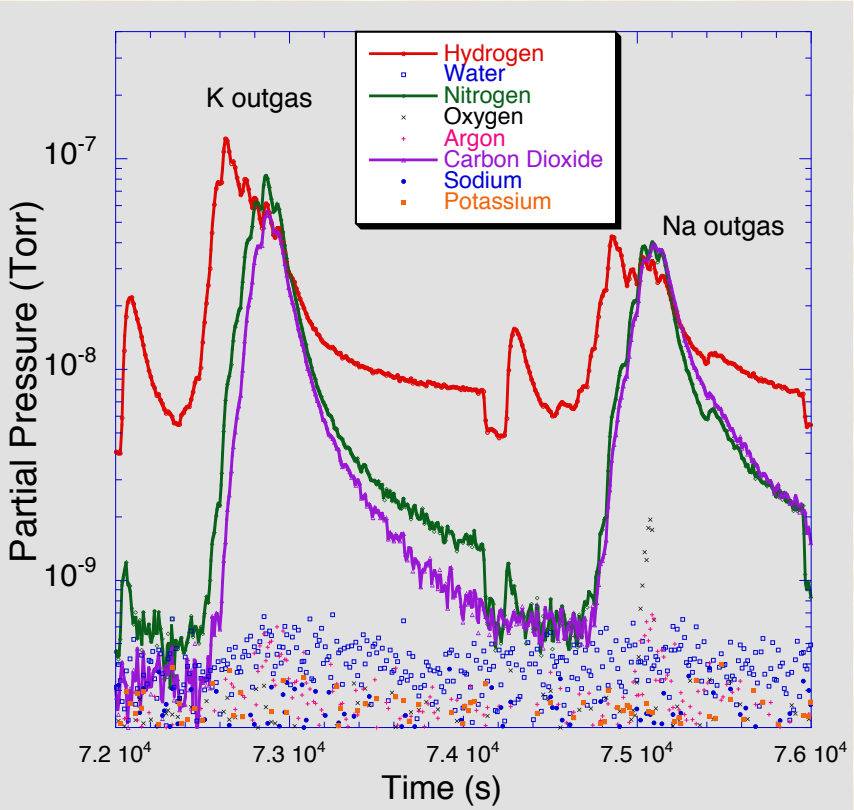
- *Optimize cathode process in 8” Sealed Tube Tank*
- *Seal Na_2KSb photocathodes onto LAPPD devices*

Backup Slides

8” Na_2KSb Process #3A Preparations



Bakeout

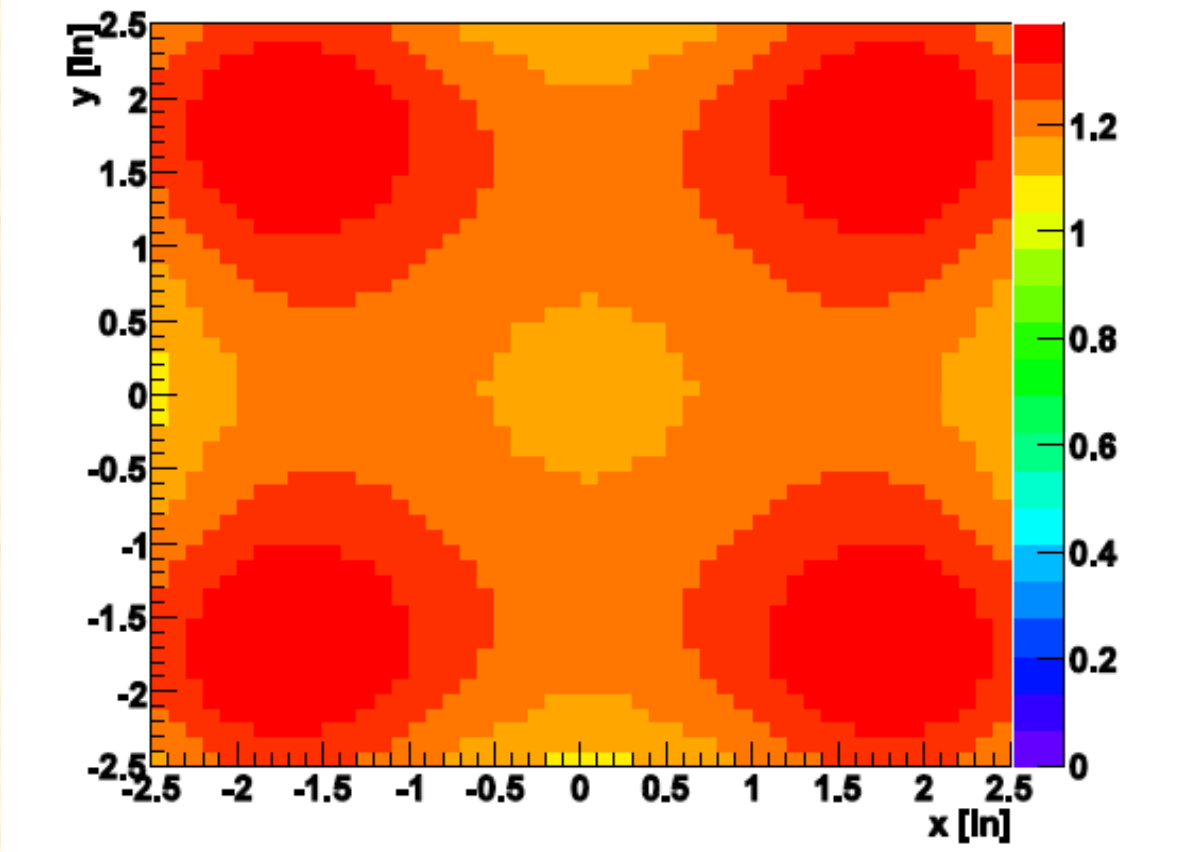


Alkali Outgas

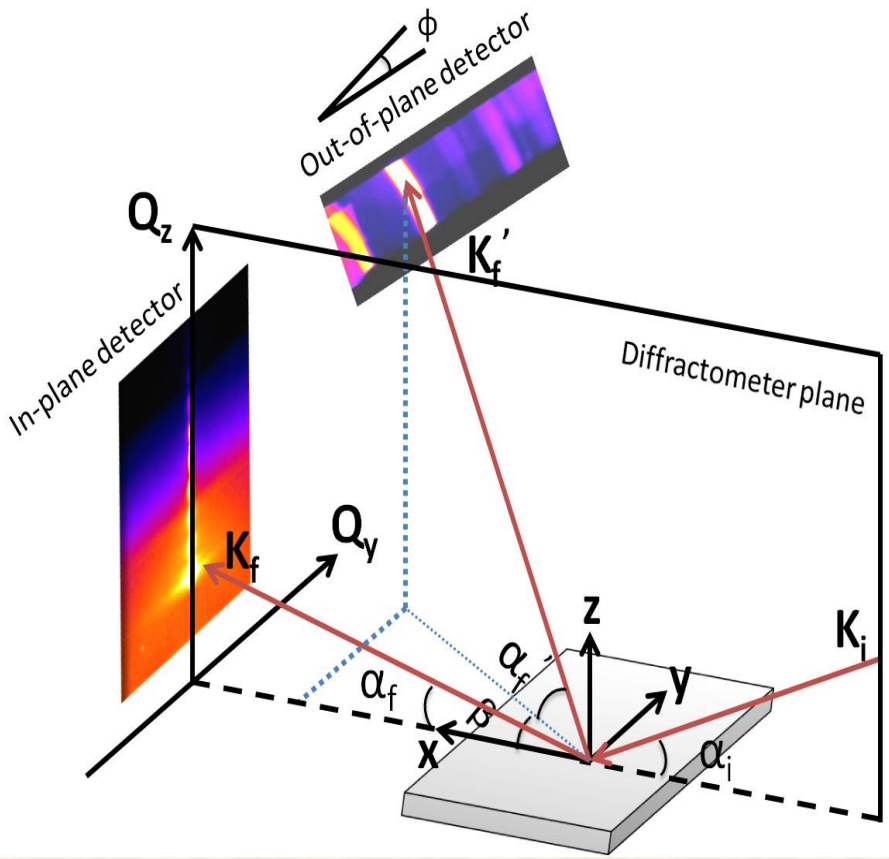
Sb Bead Arrangement for the Chalice (4”X4”)

- Numerical simulation of Sb thickness as a function of Sb bead arrangement and distance from window;
- 4 Sb bead arrangement
- 2.5” distance from the window
- This arrangement produces sufficient uniformity on a 4”x4” window as our starting point;
- This assumes all the beads perform identically.

Simulation of relative Sb thickness



In-situ Analysis of Cathode Growth with Synchrotron - Collaboration with BNL



In-situ X-ray scattering measurements

Movie like characterization during the growth:

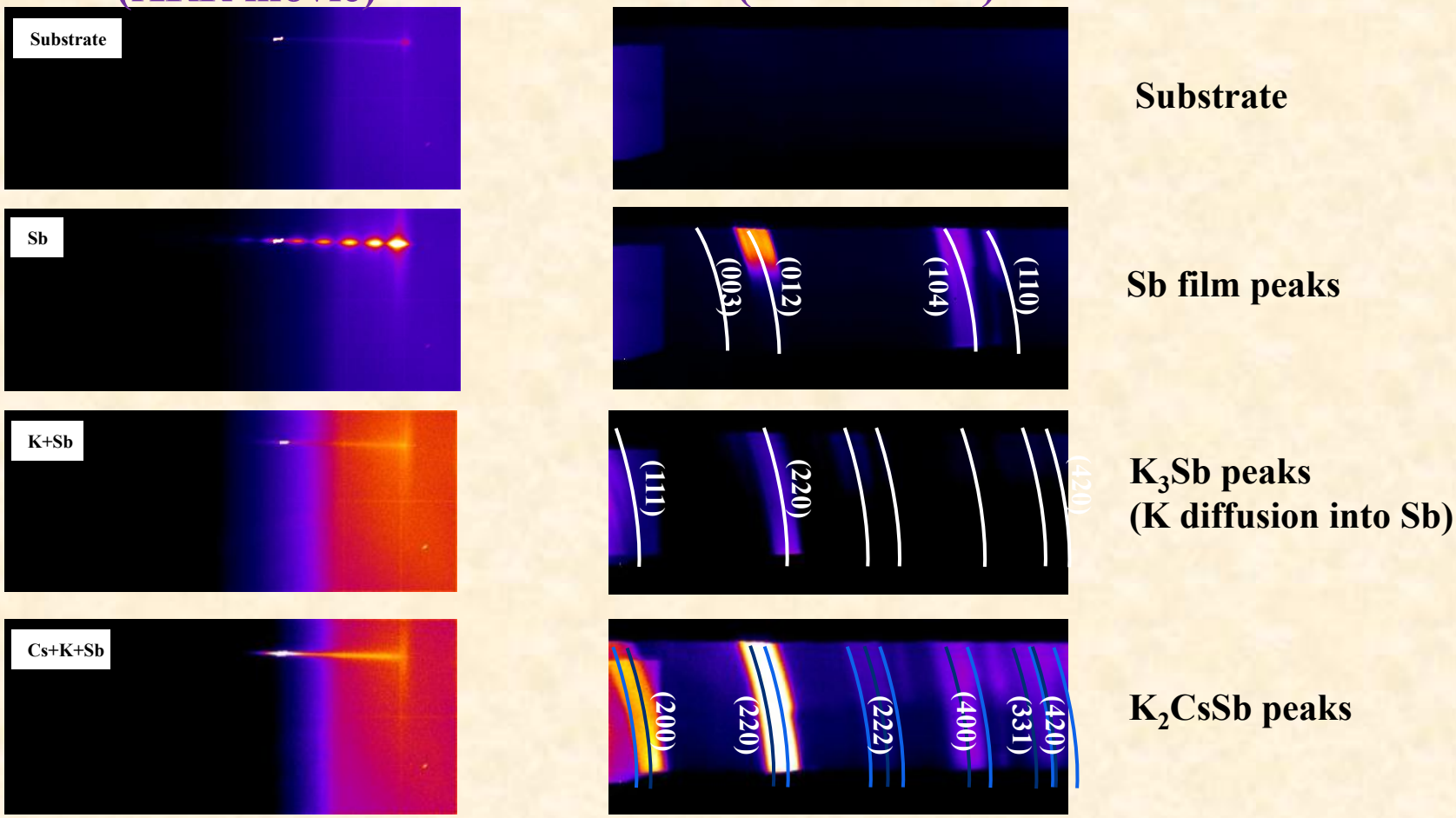
- **In-plane detector (X-ray Reflection)**
  Macroscopic film properties:
  - Film thickness
  - Roughness

- **Out-of-plane detector (X-ray Diffraction)**
  Microscopic composition :
  - Which phases are present
  - Lateral and transversal and homogeneity
  - Crystalline size
  - Preferential crystal growth

Evolution of Cathode Structure during Growth

Scan in diffractometer plane (XRR movie)

Scan out of diffractometer plane (XRD movie)



Substrate

Sb film peaks

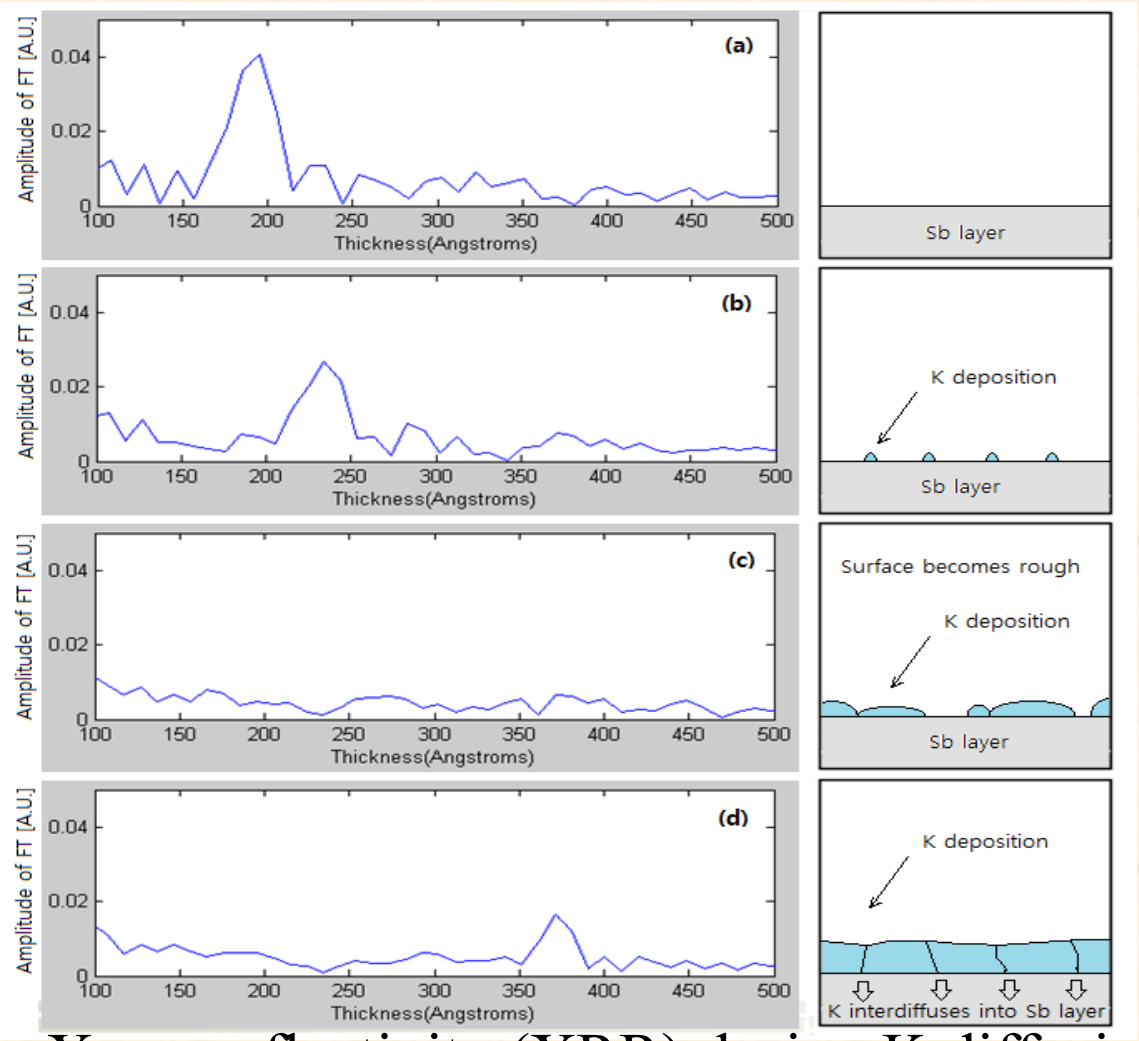
K_3Sb peaks
(K diffusion into Sb)

K_2CsSb peaks

X-ray scattering recorded the whole growth process like a movie, above figures show the movie frames at critical points

Ref: Photocathode Physics for Photoinjectors , Connell, 2012

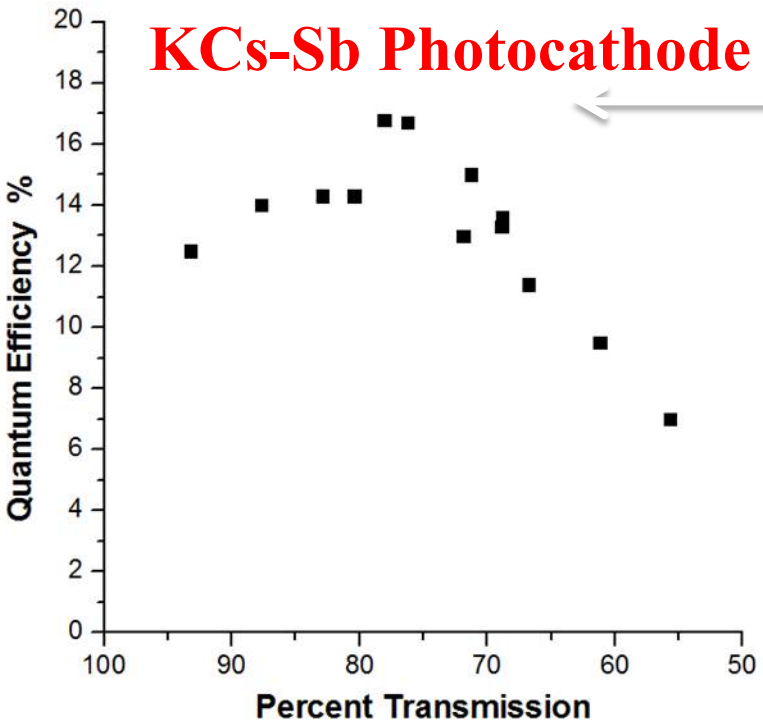
Visualization of K Diffusion Process with XRR



Real-time X-ray reflectivity (XRR) during K diffusion process
Peak position corresponds to the thickness of the layer
Surface roughness is correlated with the peak broadening

Cathode QE and Sb Film Transmission

KCs-Sb Photocathode



Cs-Sb Photocathode

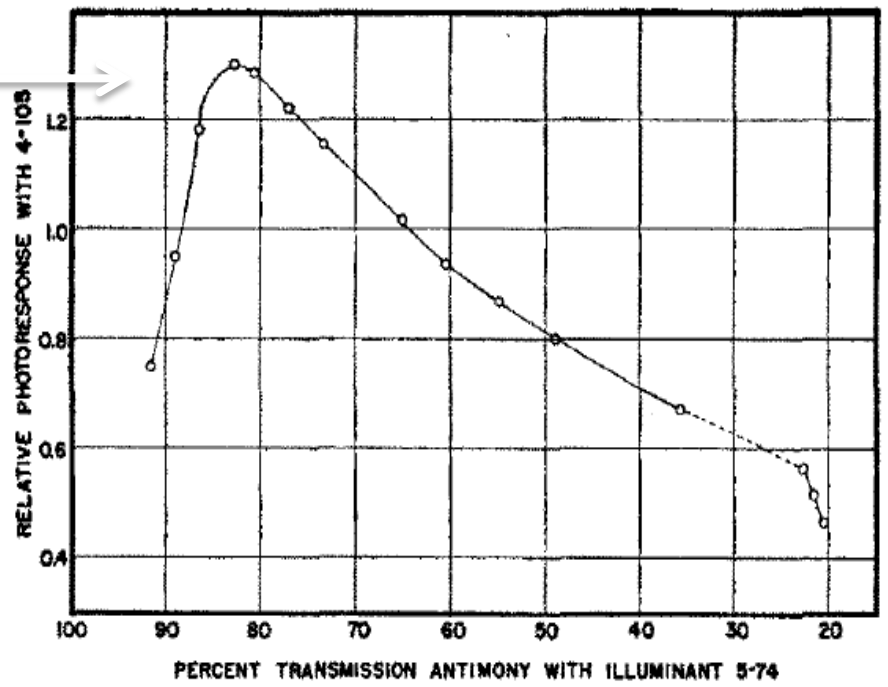


FIG. 5. Photoresponse in arbitrary units of Cs—Sb under reverse illumination *vs* transmission in percent of the original antimony

Relate the QE of the KCs-Sb cathodes with the Sb film transmission at 400 nm.

MARTIN ROME, *J. Appl. Phys*, 26, 166, 1955

- **Note that the highest QE is around 78% Sb transmission (400nm beam), similar to that of Cs-Sb cathode at around 82% Sb transmission (blue light) as reported.**