Large-Area Picosecond Photo-Detectors

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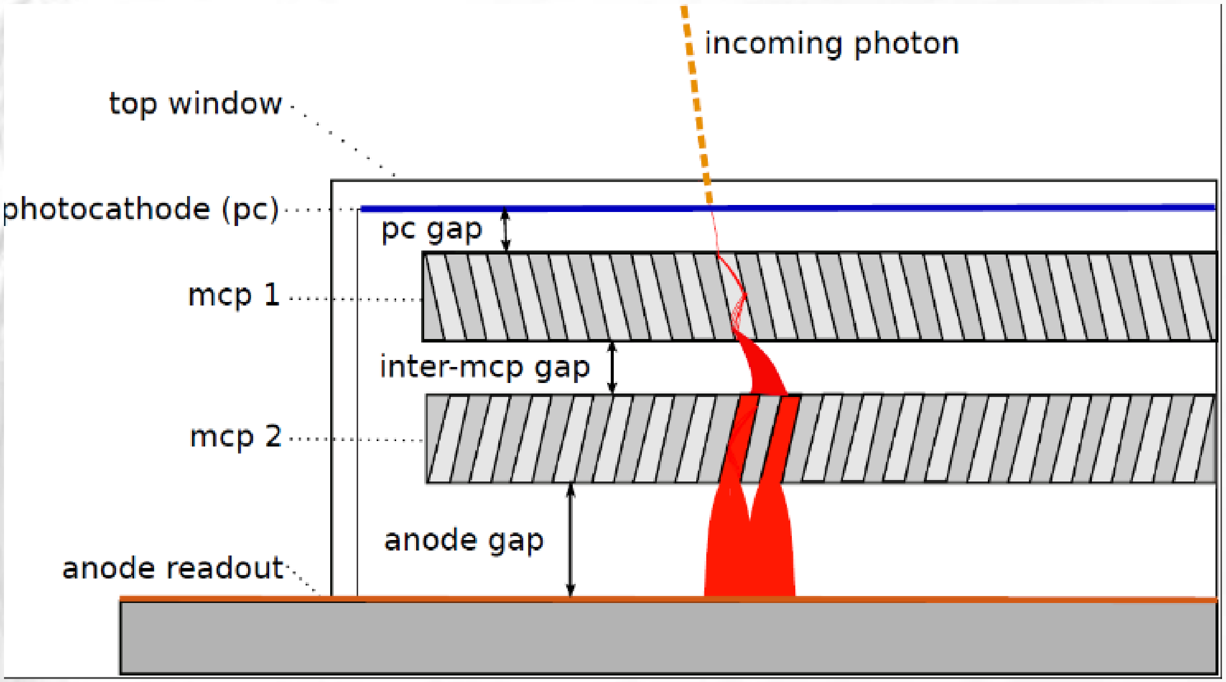
University of Chicago

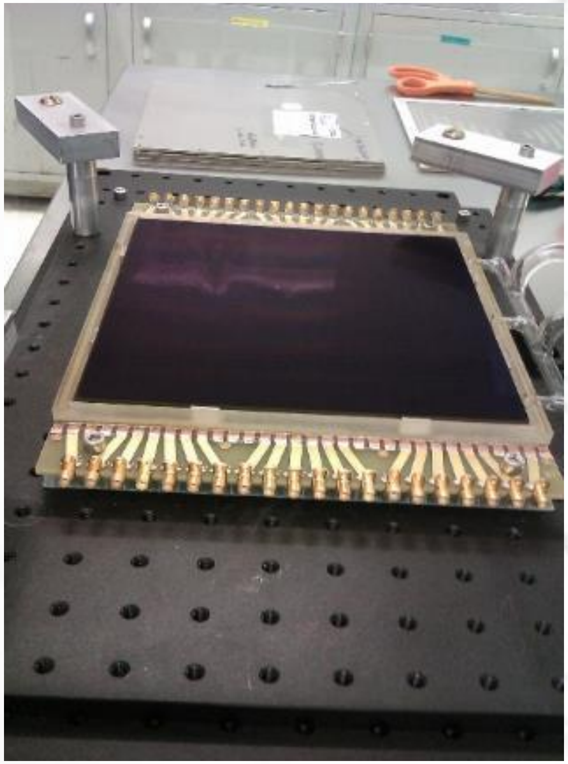
FroST-II Workshop, Mainz, October 23, 2016

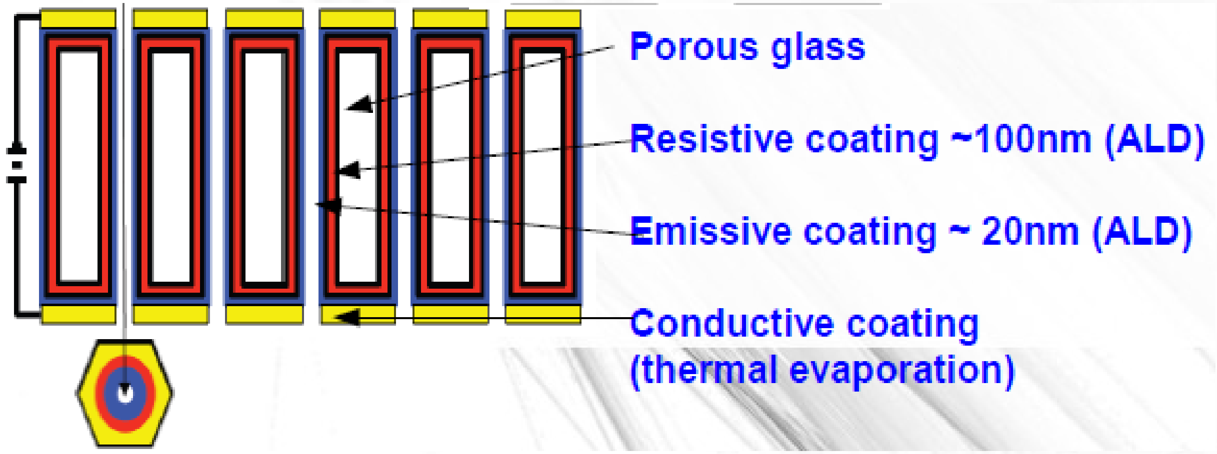
Outline

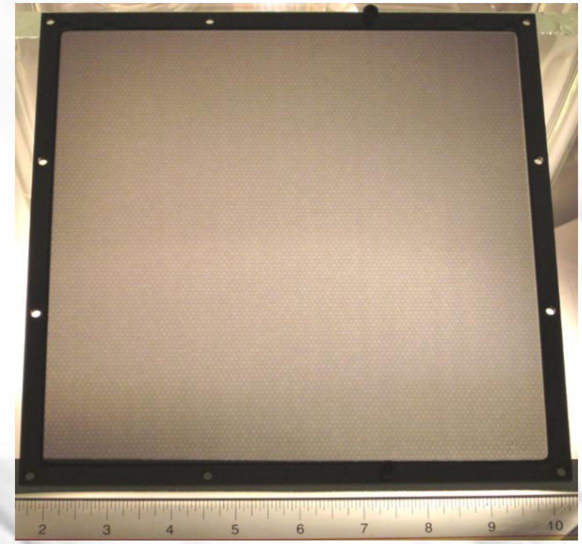
- LAPPD Overview
- Commercialization status at Incom Inc.
- R&D Towards Volume Production
  - development of in-situ assembly process at UChicago
  - Gen-II LAPPD

LAPPD

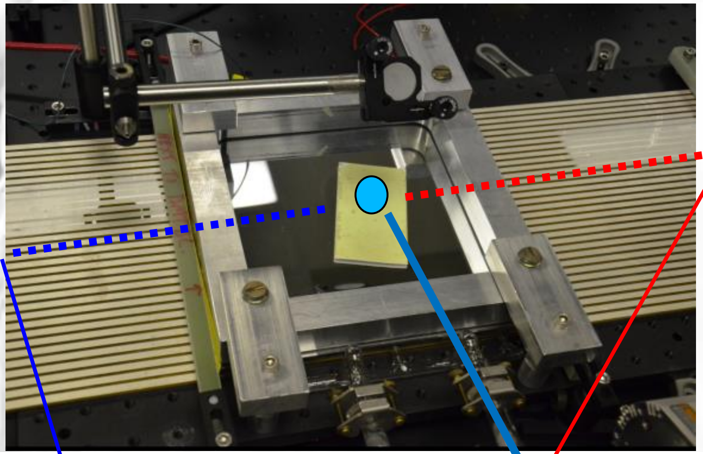

incoming photon
top window
photocathode (pc)
pc gap
mcp 1
inter-mcp gap
mcp 2
anode gap
anode readout

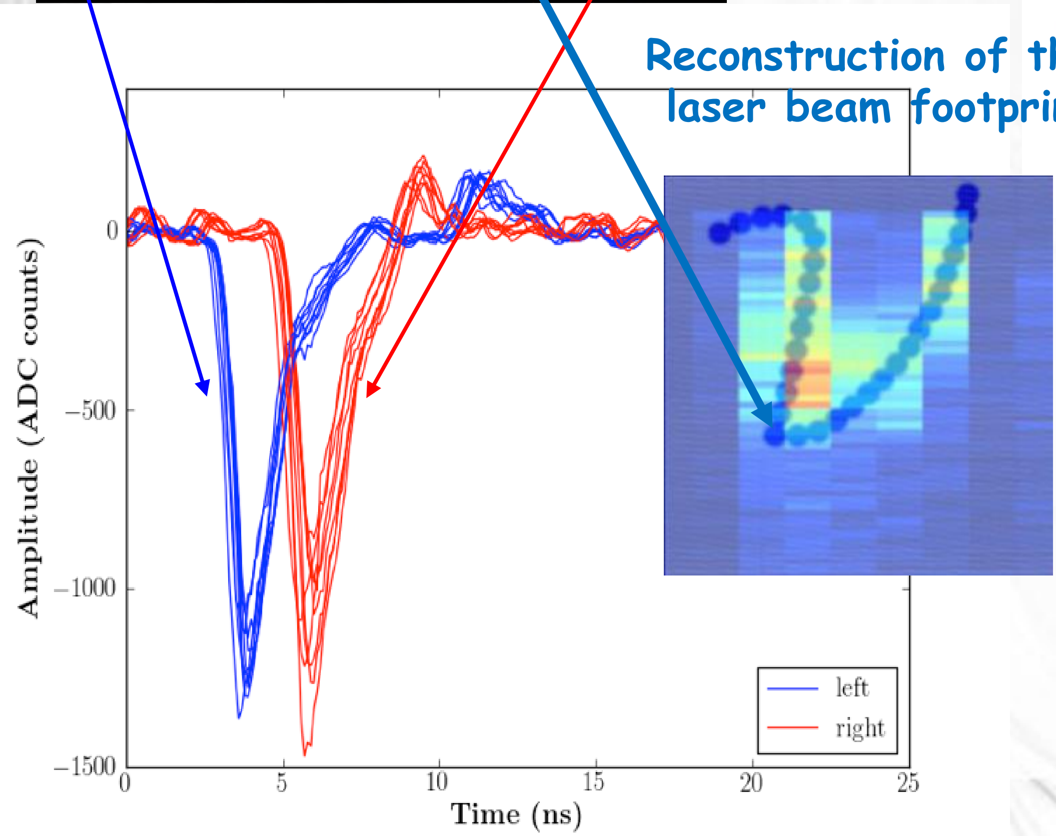



Porous glass
Resistive coating ~100nm (ALD)
Emissive coating ~ 20nm (ALD)
Conductive coating
(thermal evaporation)

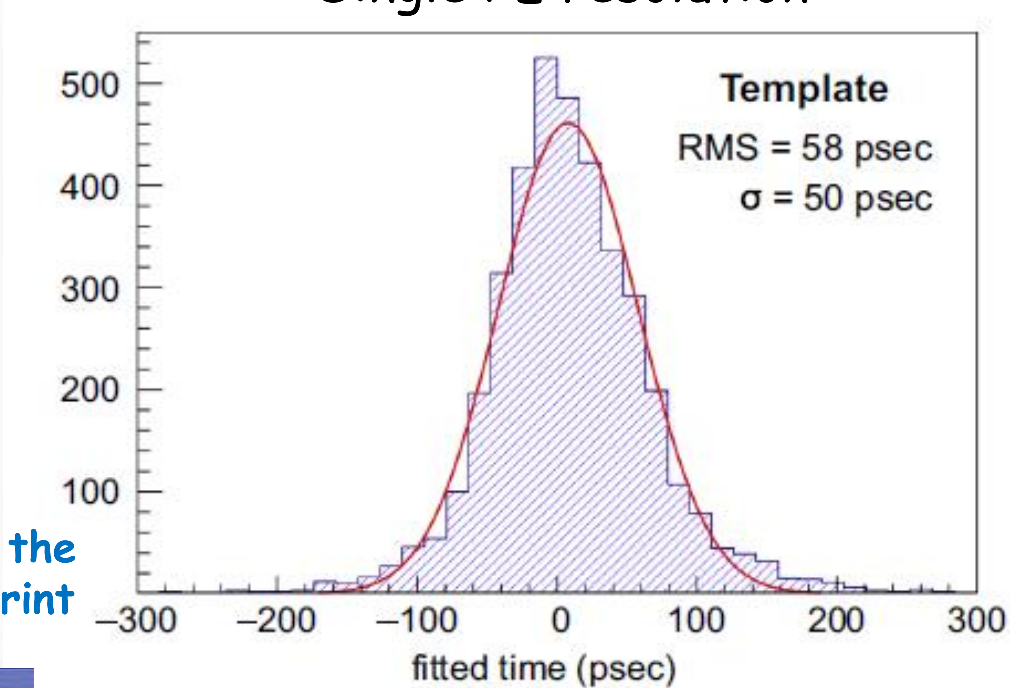


LAPPD Prototype Testing Results





Single PE resolution



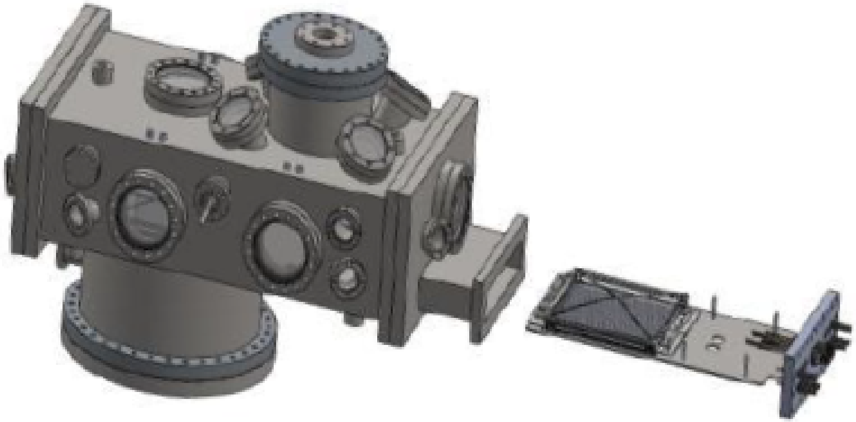
Demonstrated characteristics:
single PE timing ~50ps
multi PE timing ~35 ps
differential timing ~5 ps
position resolution < 1 mm
gain >10^7

RSI 84, 061301 (2013),
NIMA 732, (2013) 392
NIMA 795, (2015) 1
See arXiv:1603.01843
for a complete LAPPD bibliography

Commercialization Status

Incom V2.0 LAPPD Integration & Sealing

Process & Hardware



Process:

- UHV – with Conflat seals, scroll, turbo and ion pump.
- Tile kit components pre-assembled & locked in place .
- Baked @ 350C to low 10^{-10} torr range
- In-tank scrubbing
- Window Transfer Process
- Na_2KSb Photocathode deposition @ 190C using SAES beads.
- Hot Indium Seal – with grooved sidewalls

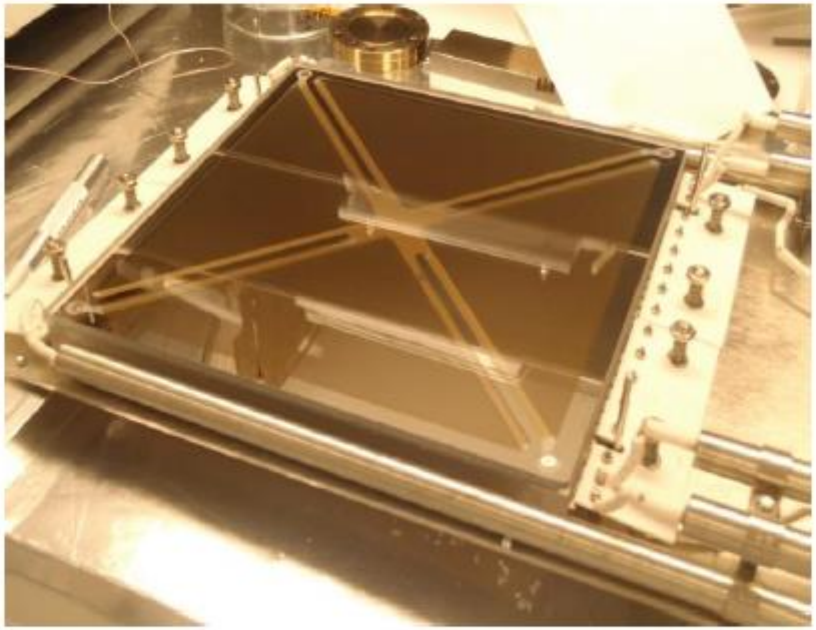
Hardware:

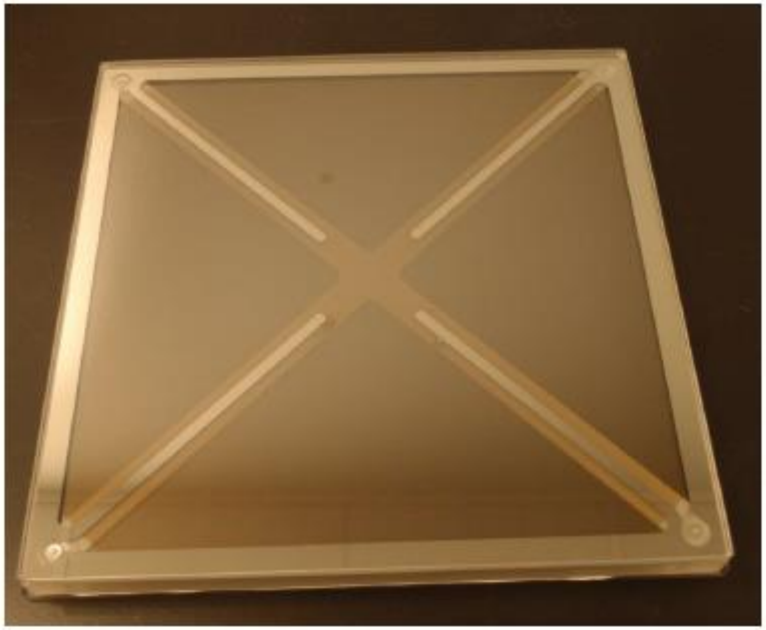
- Single "Fully Bakeable" Chamber: 30"L X 16"W X 8"H
- Simple window transfer between photocathode deposition & sealing.
- Electrical interconnects for in-process monitoring
- Readily expandable for volume production

Slide courtesy of Incom Inc.

Commercialization Status

LAPPD #10 @STP

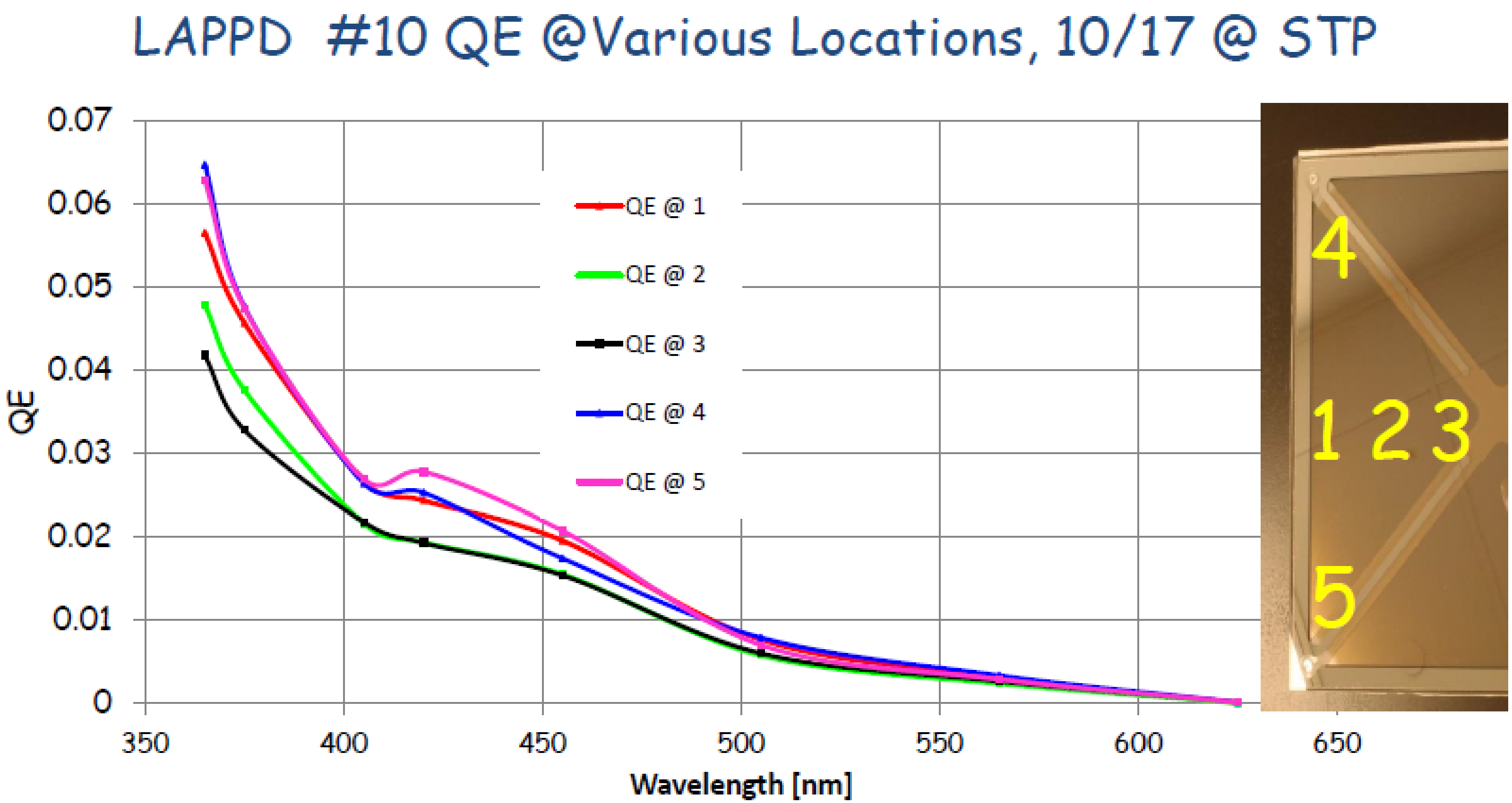




- LAPPD #10 Sealed, October 11, 2016
- No color change in PC upon venting UHV tank to STP
- Window deflection, characteristic of tile under vacuum.

Slide courtesy of Incom Inc.

Commercialization Status

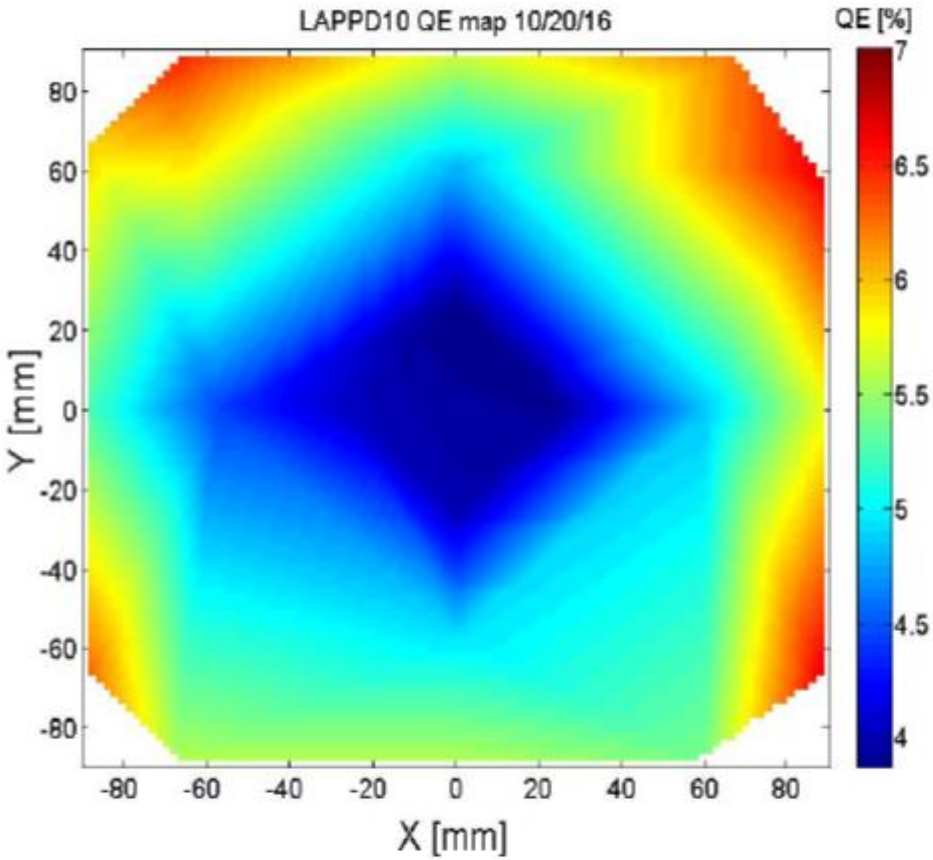


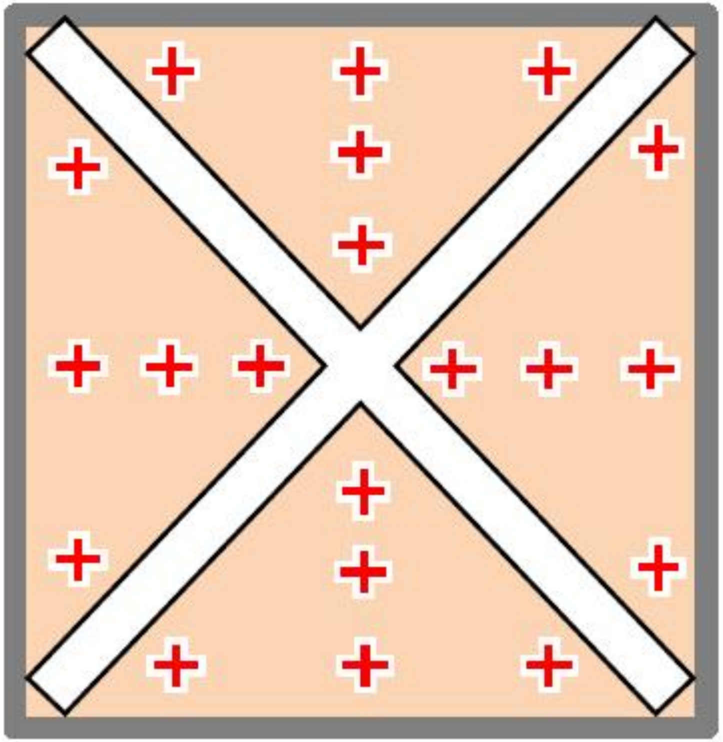
- Center QE is lower vs. edges,
- Bigger variation at short wavelengths Suggests >>Sb center thickness.
- QE (range) @365nm = (4.2 % - 6.5%)
- QE (Avg) @365nm = 5.35%

Slide courtesy of Incom Inc.

Commercialization Status

LAPPD #10 QE map @ 365nm



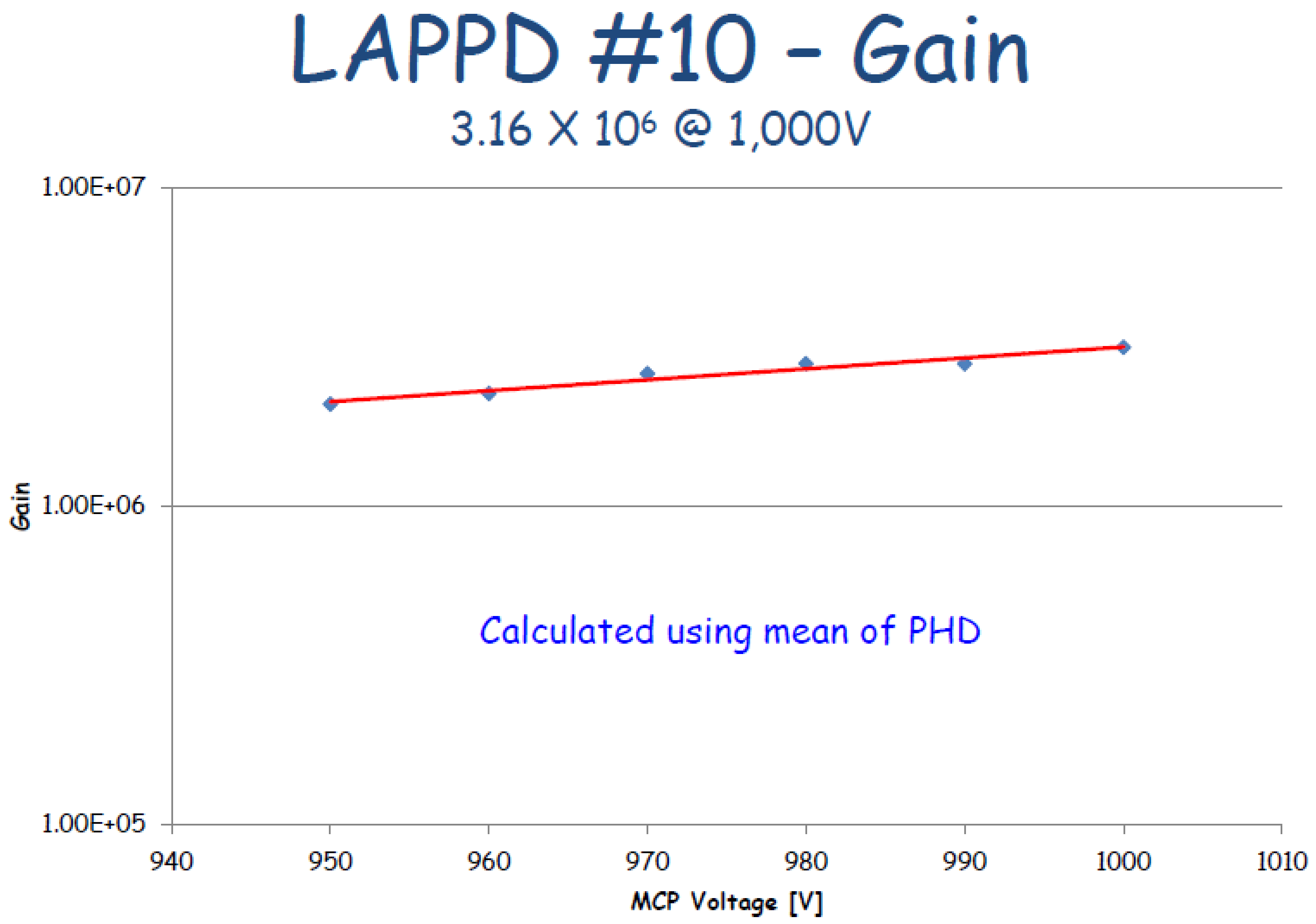


Interpolated using QE measurements at 20 locations across the window area

QE (range) @365nm = (4% - 7%) QE (Avg) @365nm = 5.5 %

Slide courtesy of Incom Inc.

Commercialization Status



Slide courtesy of Incom Inc.

Commercialization Status

LAPPD # 10 - Status and Conclusions

- Breakthrough! First demonstration of fully functional LAPPD!
- World largest flat panel MCP-PMTs with bi-alkali photocathode
- No detectible leaks since sealing 10/11/2016
- Stable operation at a gain of $3X10^6$ → single photon sensitivity
- QE ~ 5.5%, aiming at >20% in future devices
- Remarkably low noise ~12Hz @ 1000V across MCPs with 50mV threshold after preamp
- A transition from pilot production "commissioning" to "exploitation stage" and routine fabrication of detector tiles is expected shortly!
- Incom is on plan to deliver prototype "all glass" LAPPDs in QIV 2016
- Advanced LAPPD Development targets application specific needs, and reduced cost

Slide courtesy of Incom Inc.

Commercialization Status

Incom LAPPD Price?

Current pricing is intended to provide cost recovery for unfunded R&D expenses.

Grant money helps offset some of these costs, making LAPPD™ available at a reduced cost for promising early adopter applications.

Incom is committed to working with early adopters to insure that LAPPD can be evaluated for appropriate applications and not allowing cost to be a barrier for that assessment.

Current process technology is scalable, and pending design changes are expected to significantly streamline fabrication and further reduce manufacturing costs.

In a recently awarded DOE GEN II LAPPD grant, Incom Inc. projected a unit cost of **$10,000** each, with high volume (1,000 units) orders.

Slide courtesy of Incom Inc.

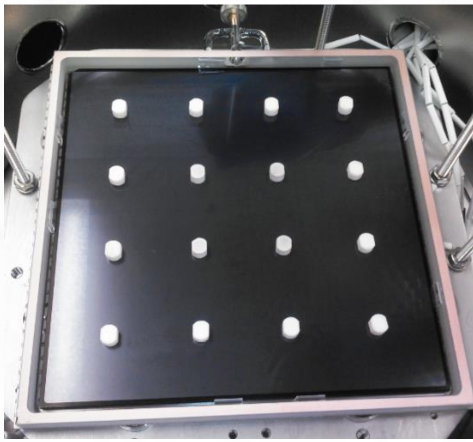
Commercialization Status

Slide courtesy of Incom Inc.

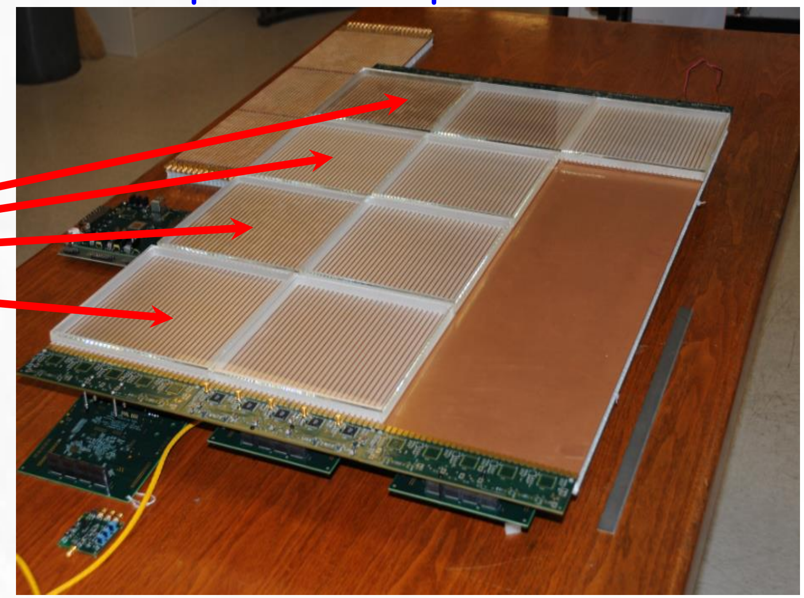
Goal of the R&D Effort at UChicago

<u>Affordable</u> large-area many-pixel photo-detector systems
with picosecond time resolution

LAPPD module 20x20 cm



Example of a Super Module



A production rate of 50 LAPPDs/week
would deliver 20,000 LAPPDs in ~7.5 years

- High volume production can be challenging
- We are exploring if a non-vacuum transfer process can be inexpensive and easier for a very high volume production

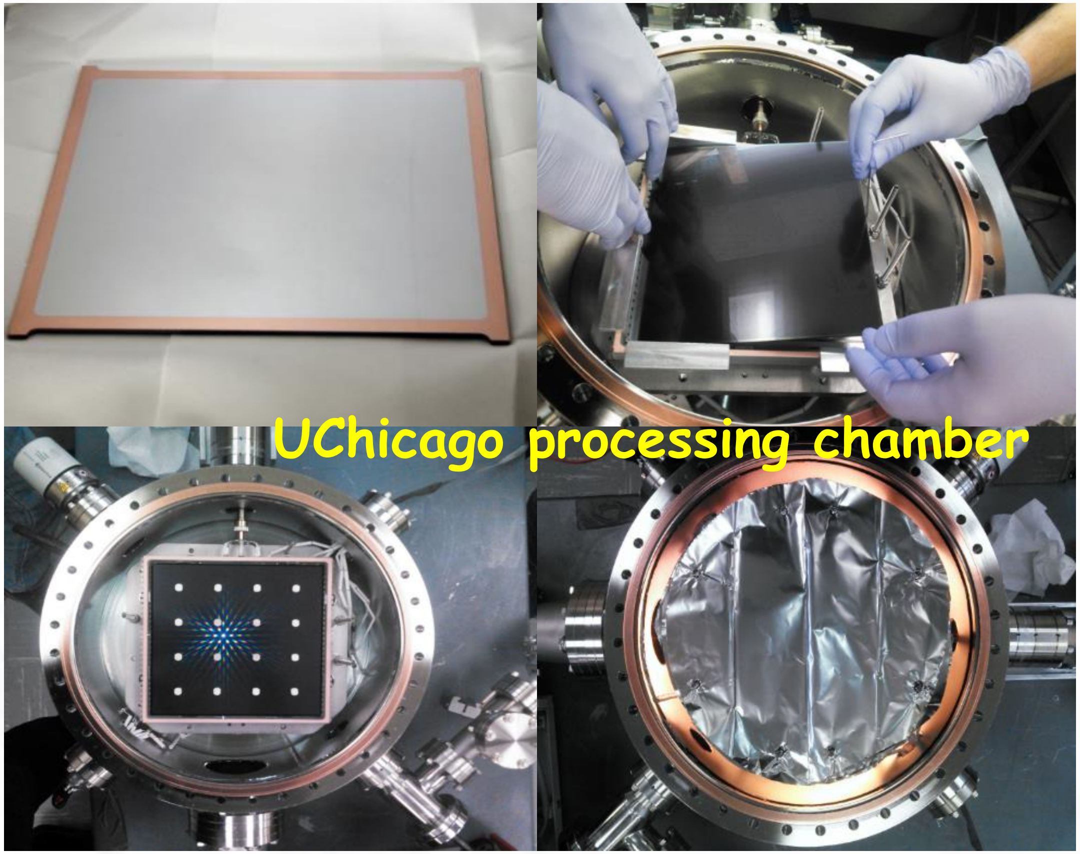
UChicago goal is to enable high volume production at Incom so we can do physics using LAPPD™

In-Situ Assembly Strategy

Simplify the assembly process by avoiding vacuum transfer:
make photo-cathode after the top seal
(PMT-like batch production)

Heat only the tile
not the vacuum vessel

Intended for
parallelization



Step 1: pre-deposit Sb on the top window prior to assembly
Step 2: pre-assemble MCP stack in the tile-base
Step 3: **do top seal and bake in the same heat cycle using dual vacuum system**
Step 4: bring alkali vapors inside the tile to make photo-cathode
Step 5: flame seal the glass tube or crimp the copper tube

In-Situ Assembly Facility UChicago

The idea is to achieve volume production by operating many small-size vacuum processing chambers at the same time

Looking forward towards transferring the in-situ process to industry

In-Situ Process Pre-requisite

Reliable hermetic seal over a 90-cm long perimeter

Indium Solder Flat Seal Recipe

Input:

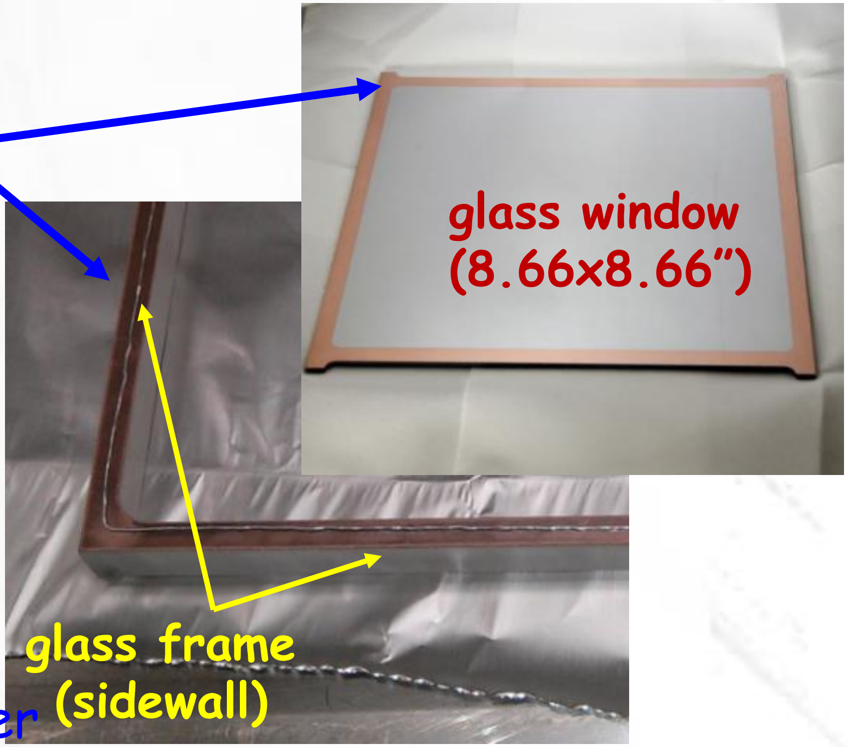
- Two glass parts with flat contact surfaces

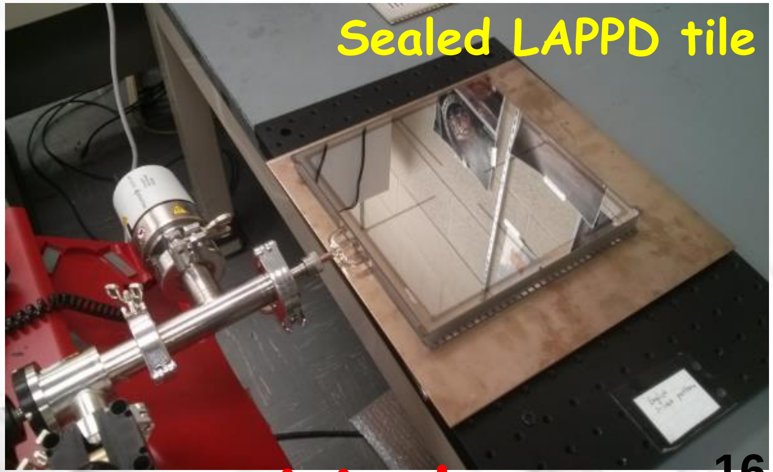
Process:

- Coat 200 nm of NiCr and 200 nm of Cu on each contact surface (adapted from seals by O.Siegmund at SSL UC Berkeley)
- Make a sandwich with indium wire
- Bake in vacuum at 250-300C for 24hrs

Key features:

- A good compression over the entire perimeter is needed to compensate for non-flatness and to ensure a good contact
- In good seals indium penetrates through entire NiCr layer (Cu always "dissolves")





This recipe is now understood

It works well over large perimeters

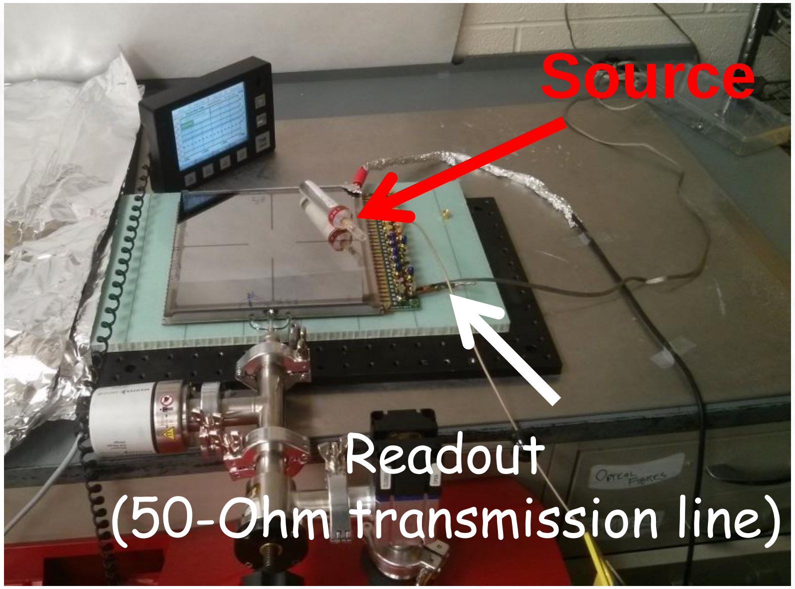
Metallization and compression are critical

First Signals from an In-Situ LAPPD

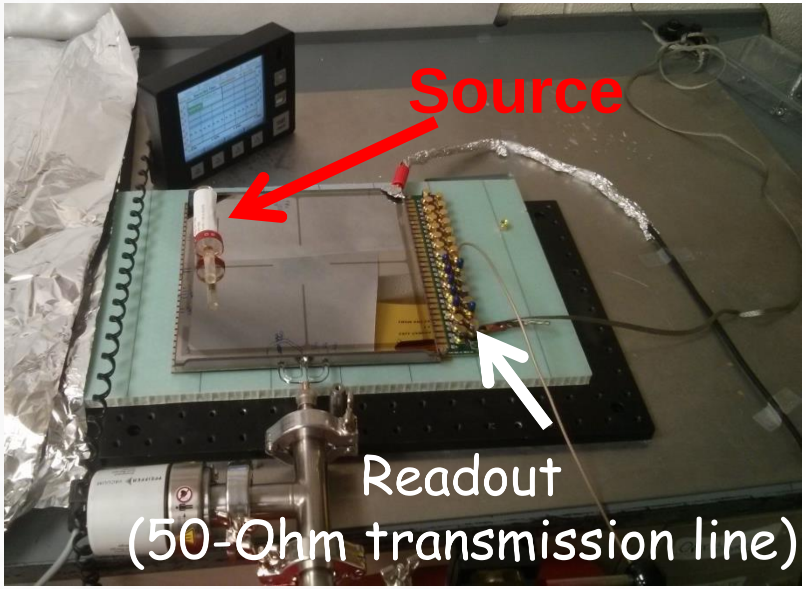
April, 2016

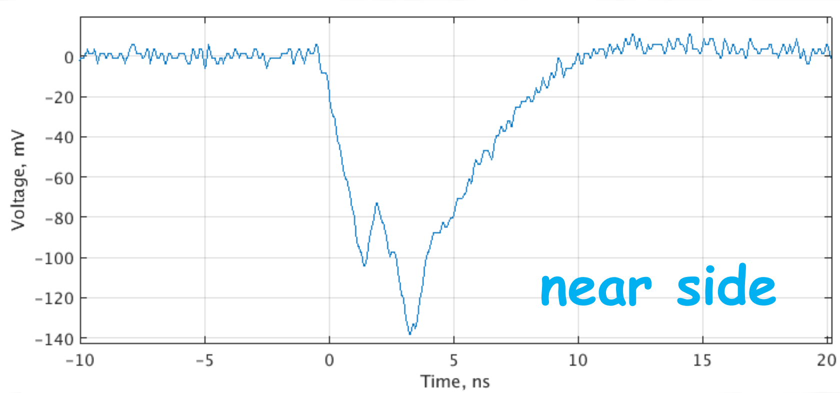
(Sb cathode)

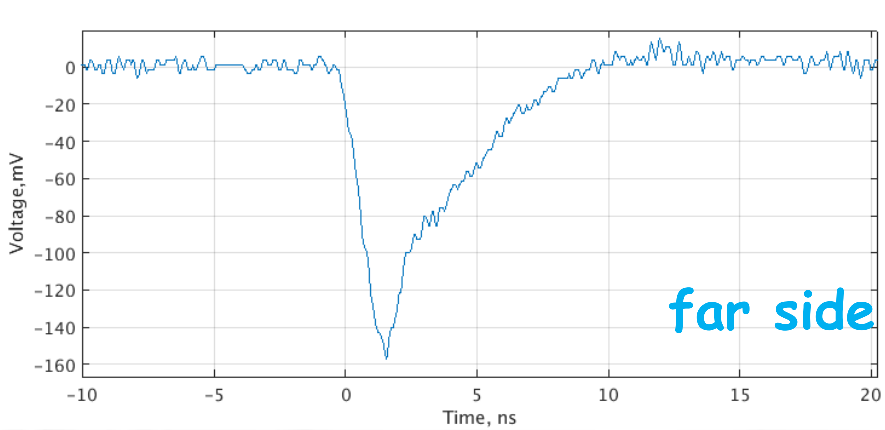
Near side: reflection from unterminated far end



Far side: reflection is superimposed on prompt



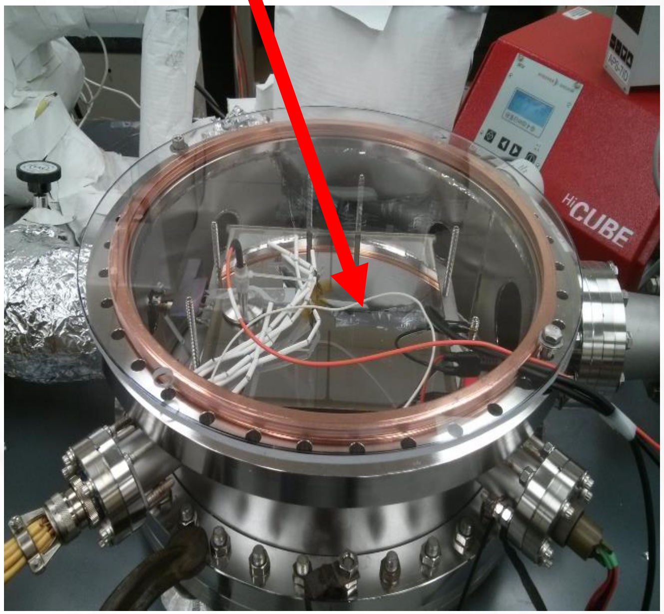


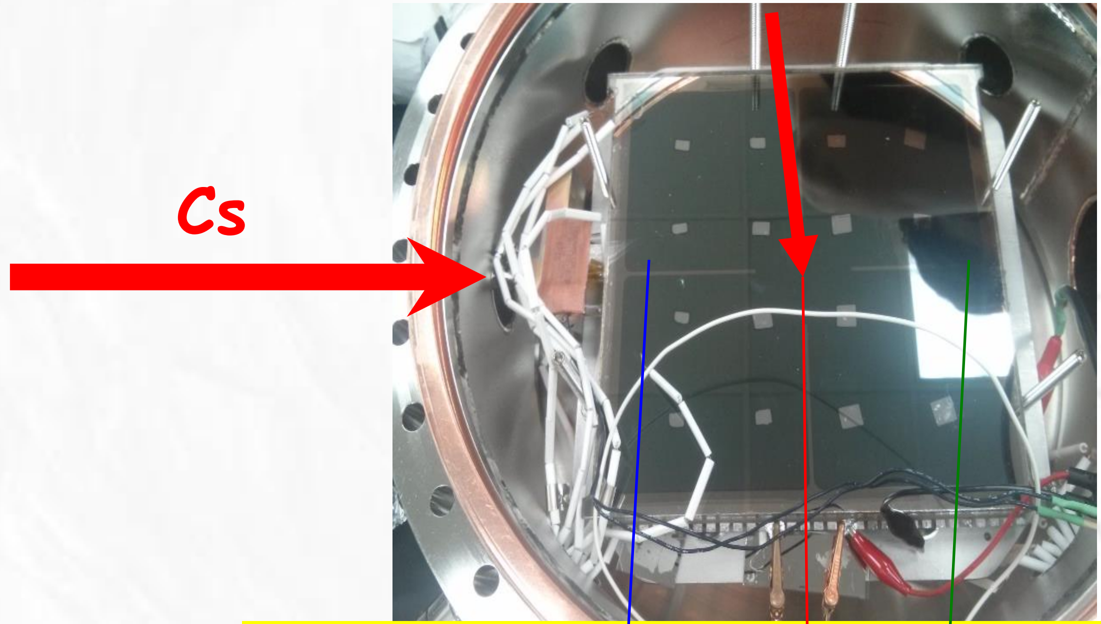


The tile is accessible for QC before photo-cathode shot
Could help the production yield

In-Situ Photo-Cathode

July, 2016

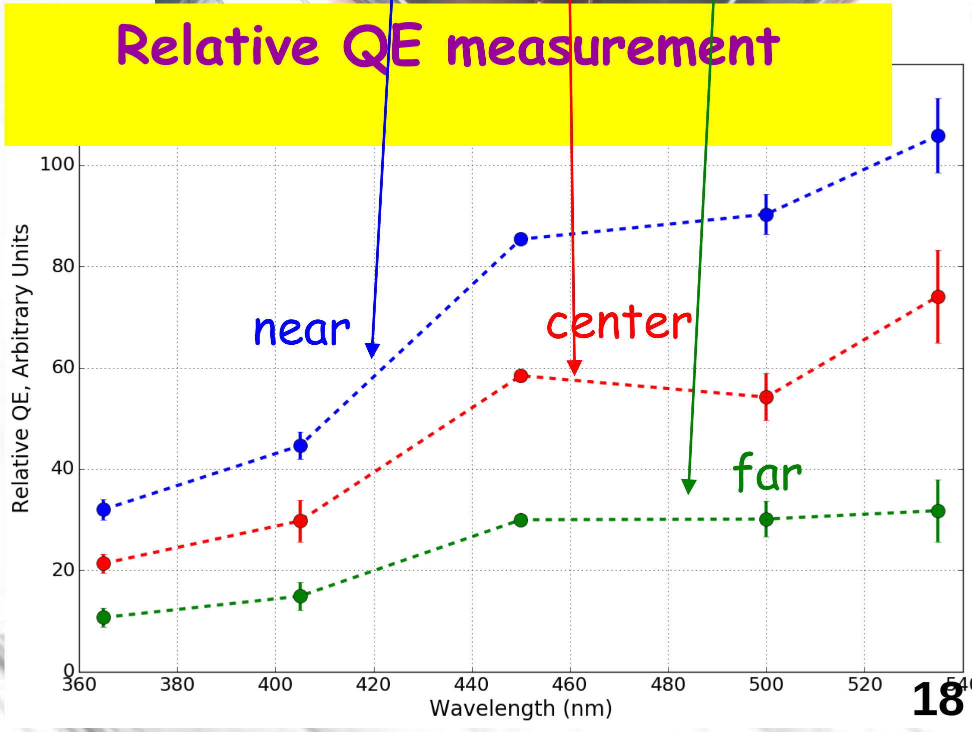




First in-situ commissioning run (Summer 2016)

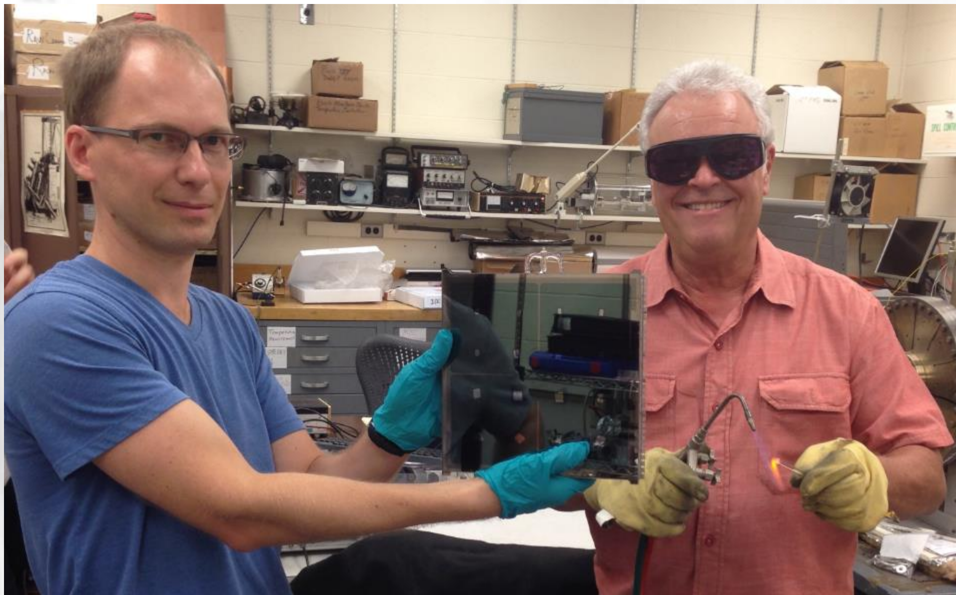
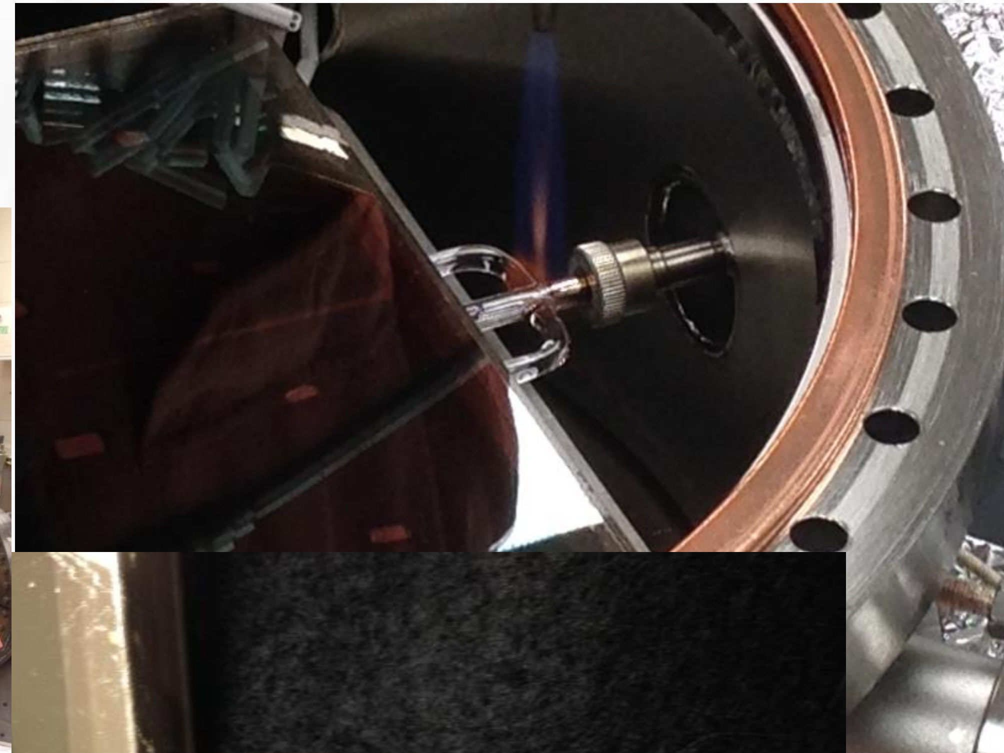
- saw the first photo-current response from in-situ photo-cathode
- measured relative QE (absolute QE is tricky due to DC current through the whole stack)
- demonstrated a <u>sealed tile</u> configuration
  - no QE drop for 2 weeks after the valve to the pump was closed
  - no QE drop for 3 weeks after flame seal

Note on this commissioning run:
PC is very thick for transmission mode operation
(initial 20nm of Sb translates into ~80nm of Cs-Sb)



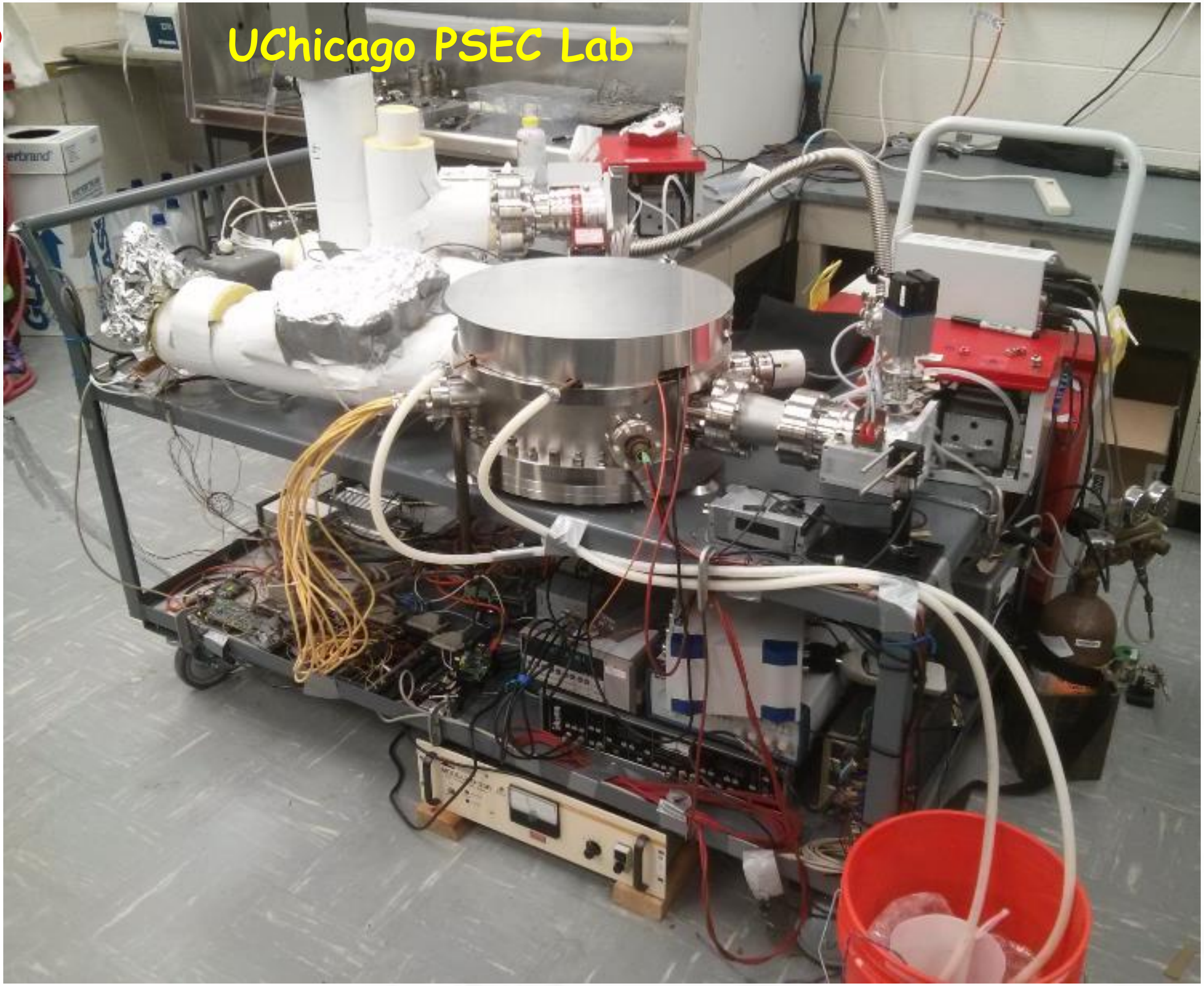
Flame Seal – Final In-Situ Step

August 18, 2016


Current Status of the In-Situ

October, 2016

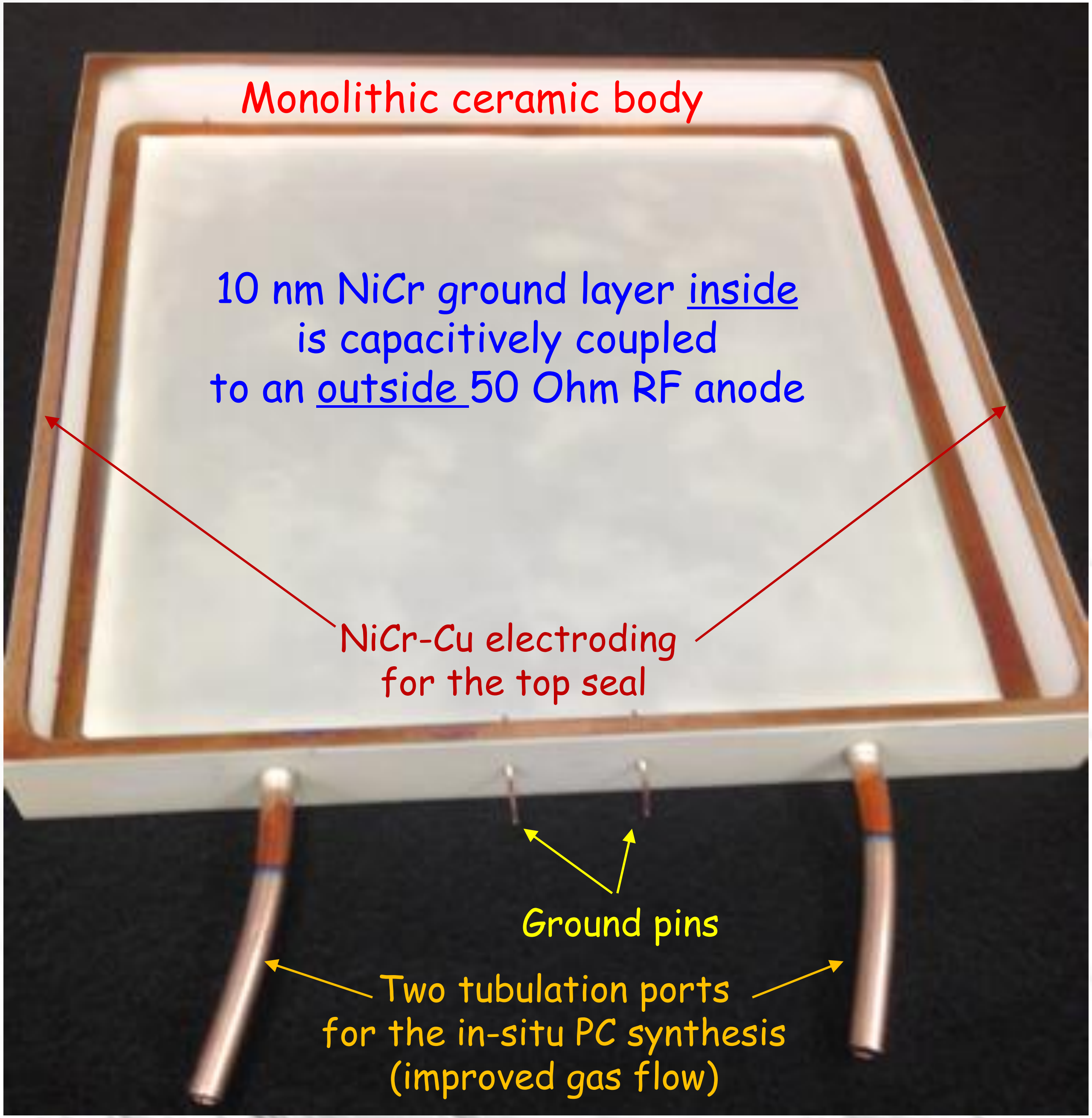


Improved instrumentation for process control

(Hard work by Evan Angelico and Eric Spieglan)

Gen-II LAPPD

- Robust ceramic body
- Anode is not a part of the vacuum package
- Enables fabrication of a generic tile for different applications
- Compatible with in-situ and vacuum transfer assembly processes

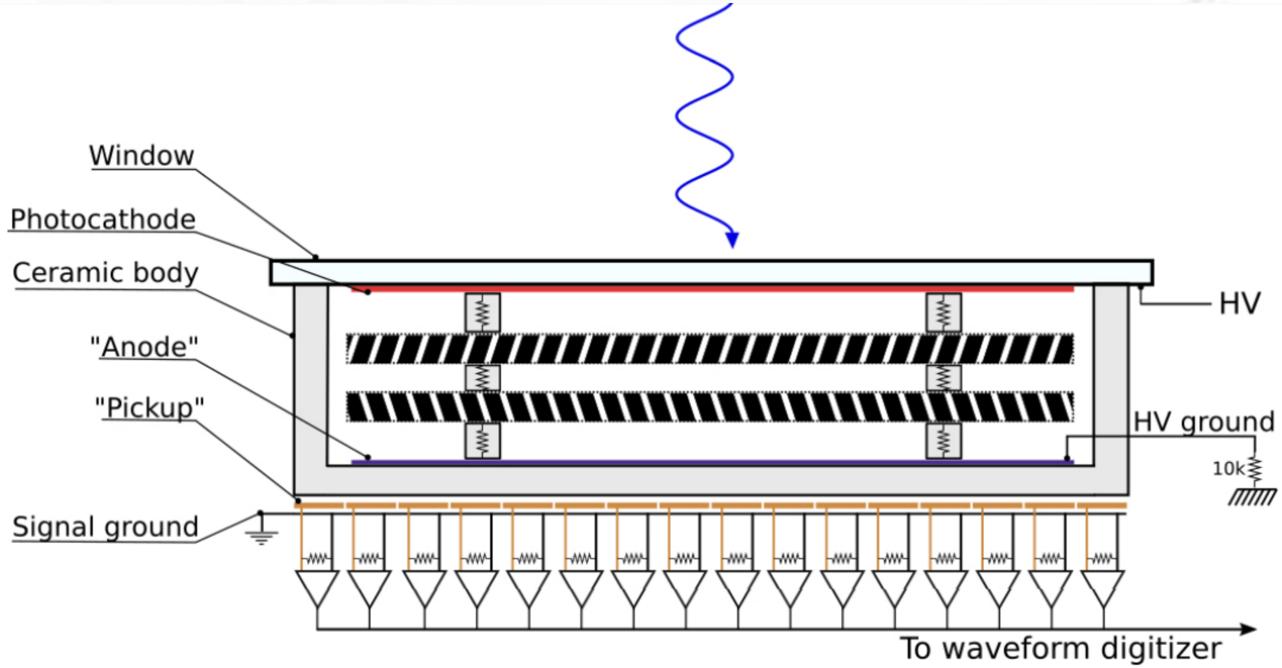


Joint effort with Incom Inc. via DOE NP SBIR Phase-I

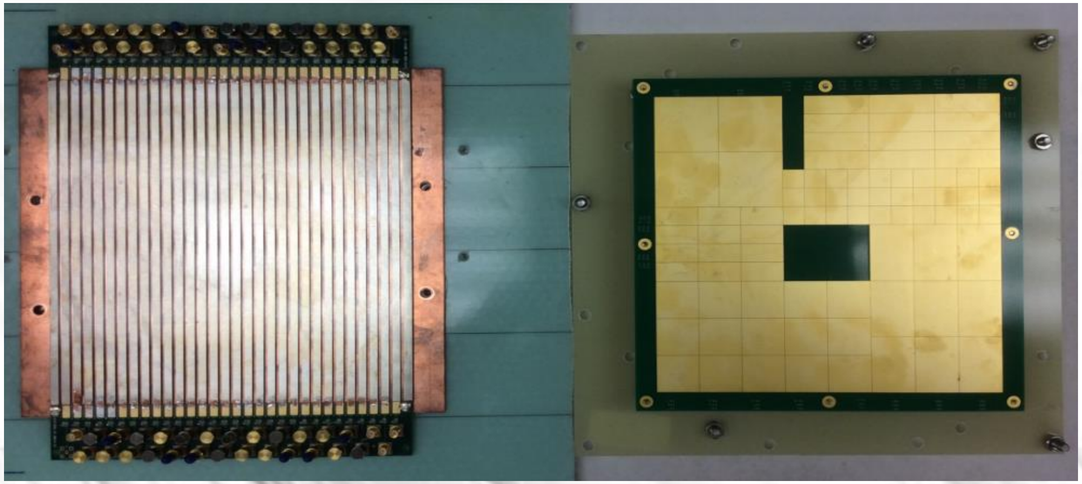
Gen-II LAPPD: "inside-out" anode

Custom anode is outside

Compatible with high rate applications

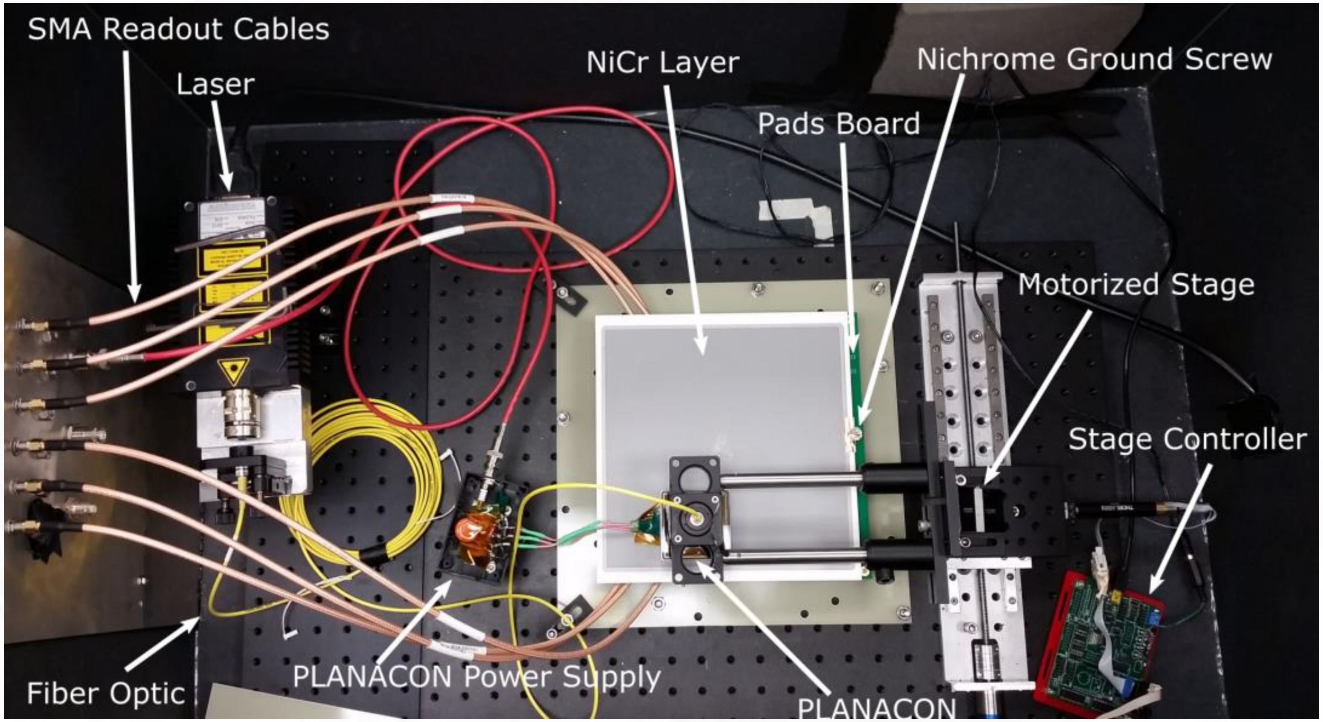


Choose your own readout pattern



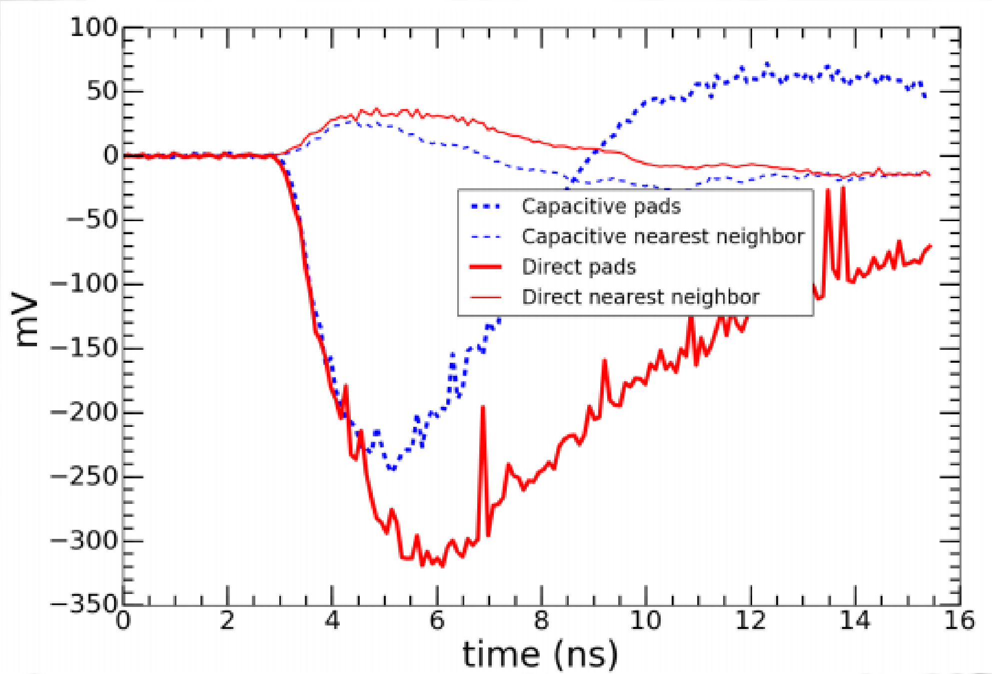
For details see arXiv:1610.01434 (submitted to NIM)

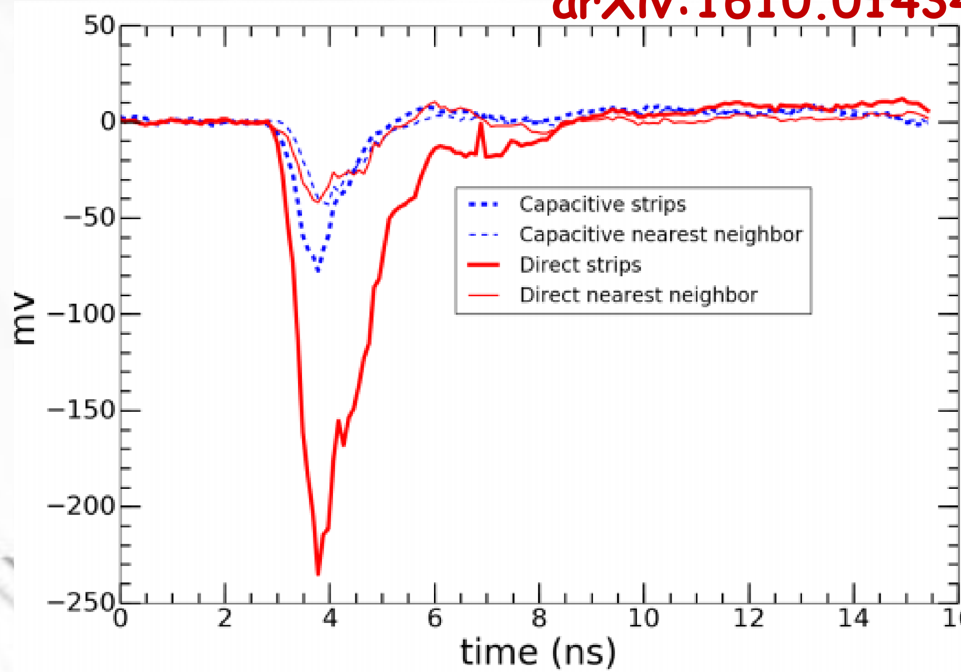
Inside-out Anode Testing



Evan Angelico
And
Todd Seiss

arXiv:1610.01434





Summary

- Commercialization at Incom Inc. goes well
- They would like to keep close contact with early adopters
- With the goal to use LAPPDs in large experiments

  UChicago group is focused on R&D for high volume production process
- Making photo-cathode in-situ as a final step is very attractive

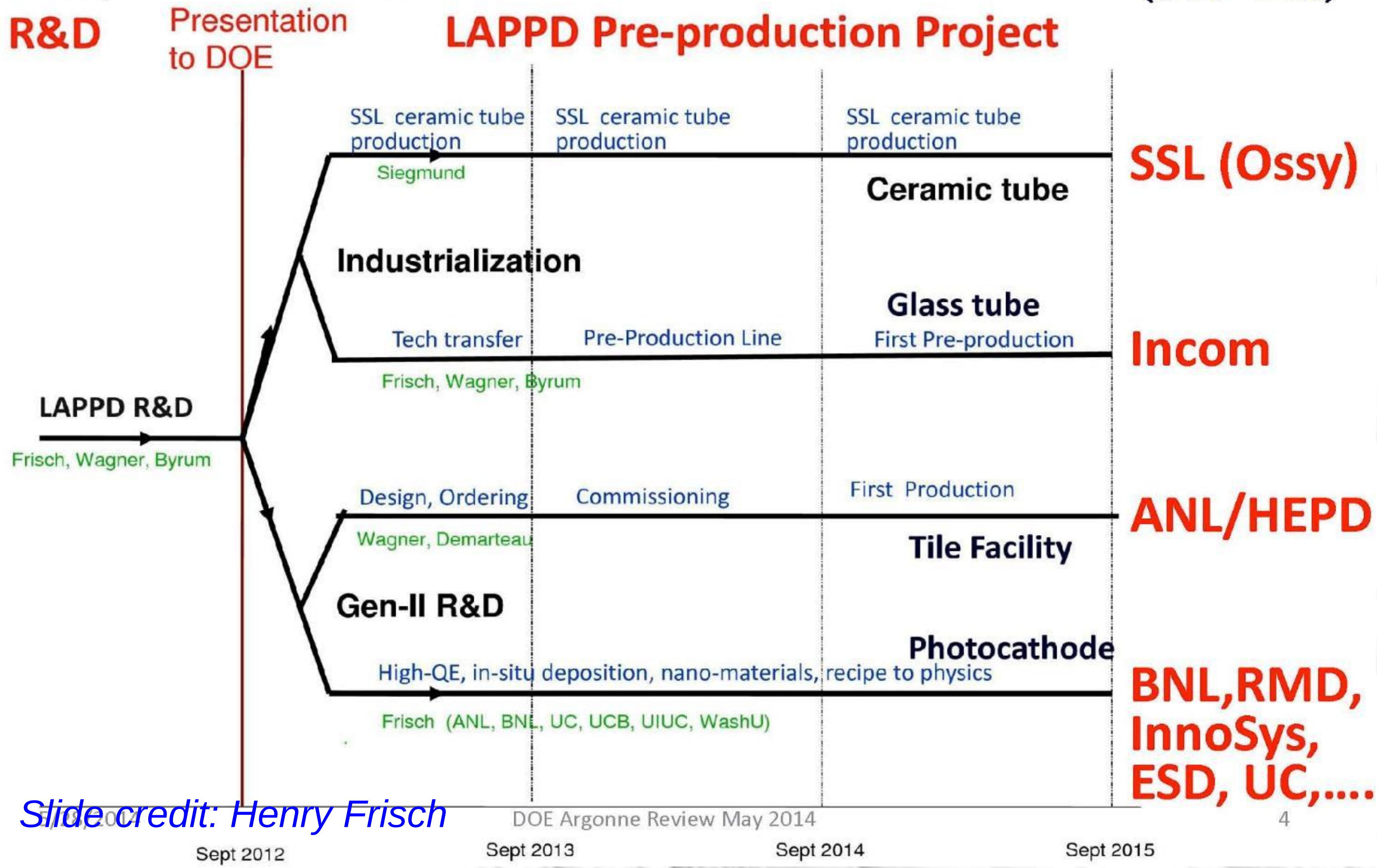
  - leak check before PC-synthesis

  - real-time tuning and optimization of PC is possible
- Right at the moment we are working on photo-cathode optimization and Gen-II LAPPD vacuum packaging

Back-up

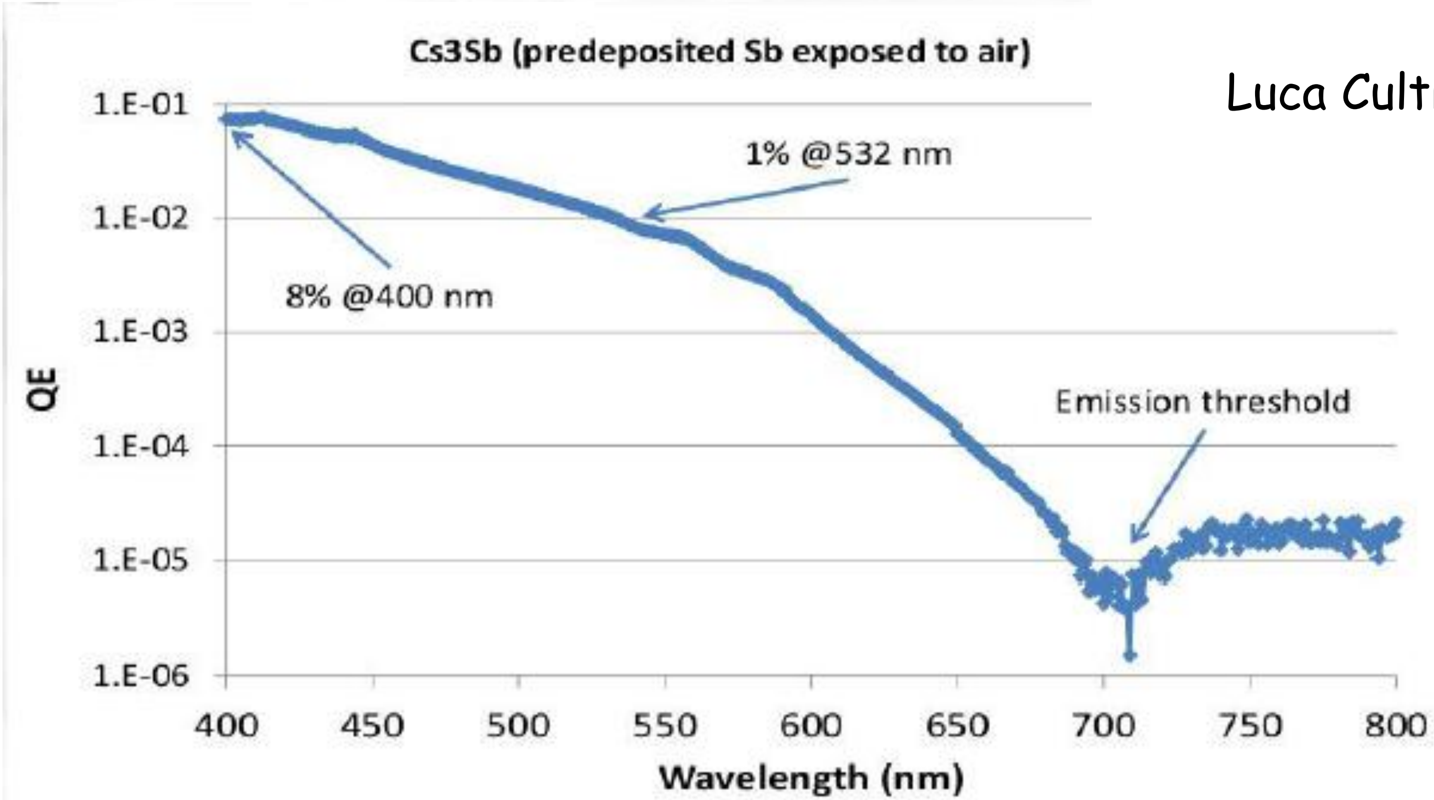
The 2013 Transition from LAPPD to Production: The 4 Parallel Paths

Dec 12, 2012 Presentation to DOE (a UC view)



Slide credit: Henry Frisch

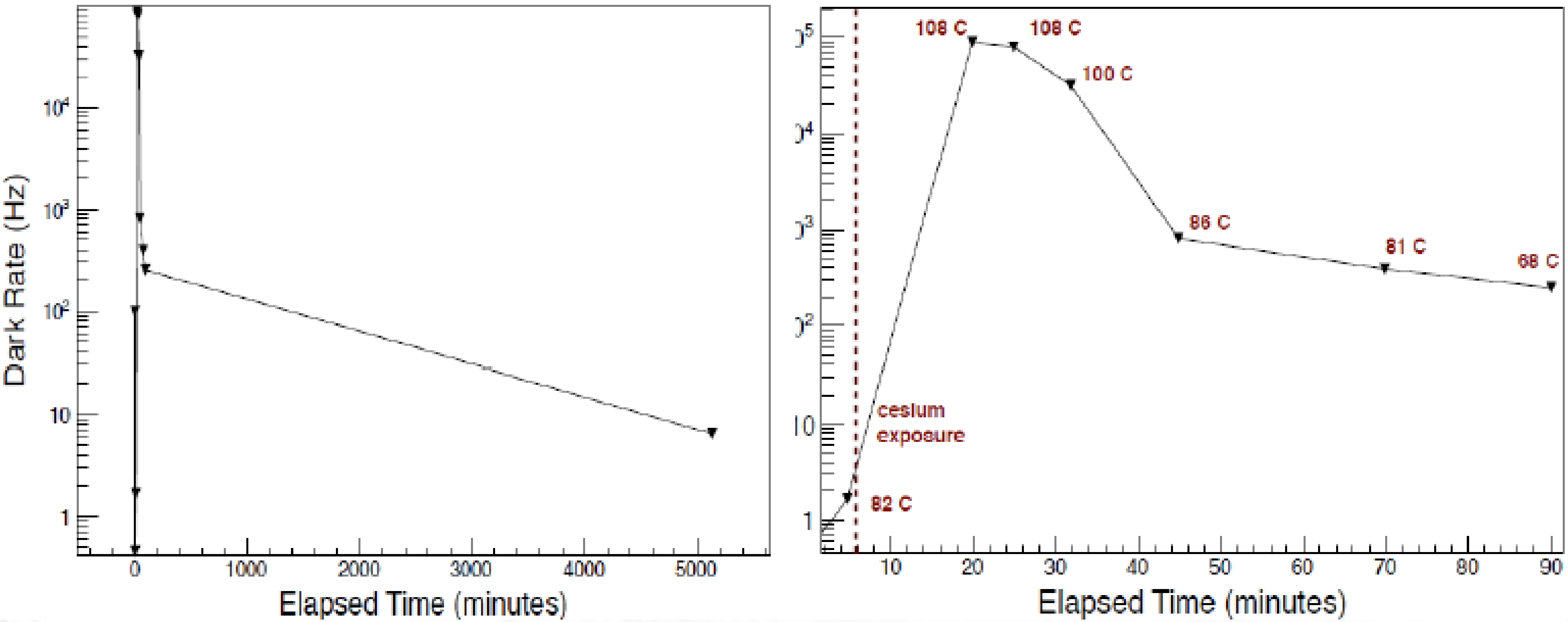
Can you make PC after Sb was exposed to air?



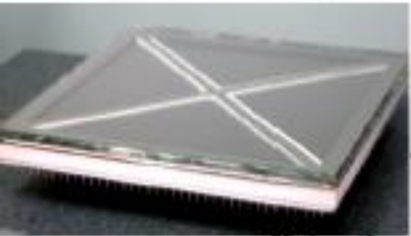
Luca Cultrera at Cornell

What about noise in the MCPs after Cs-ation?

Matt Wetstein

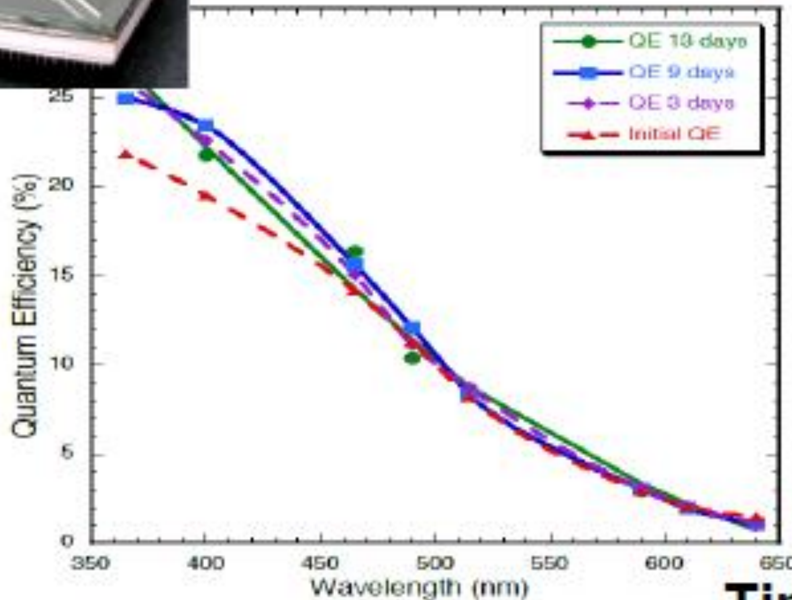


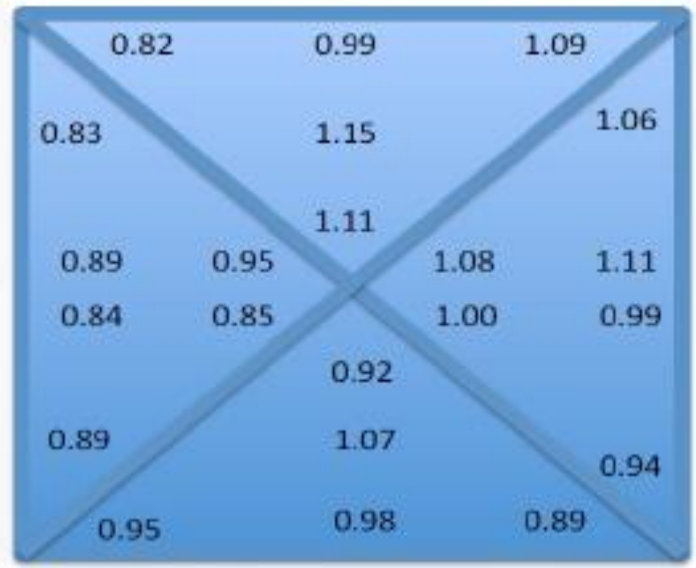
SSL Ceramic LAPPD Tile Results



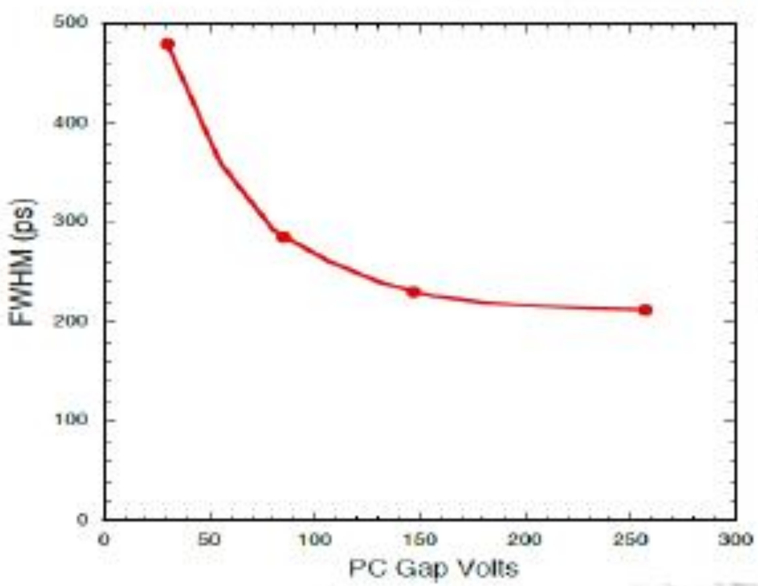
Measurements after full processing cycle inside the vacuum chamber

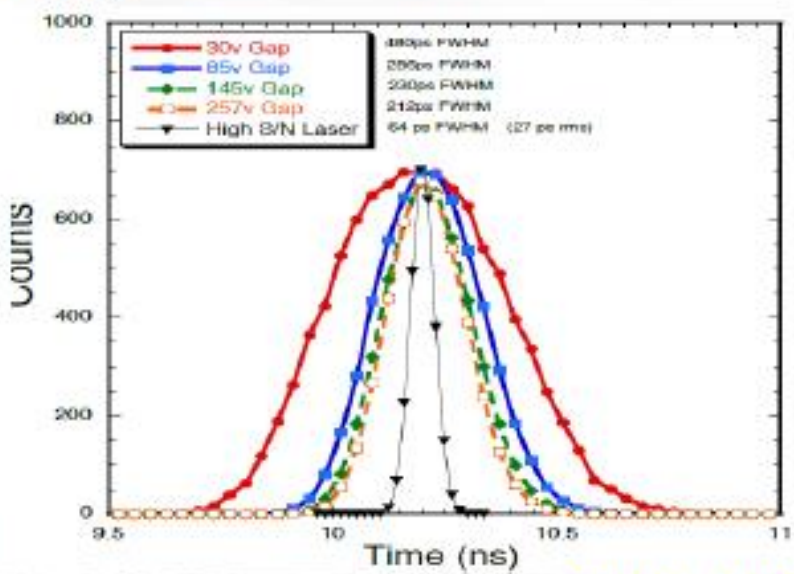
QE





Timing

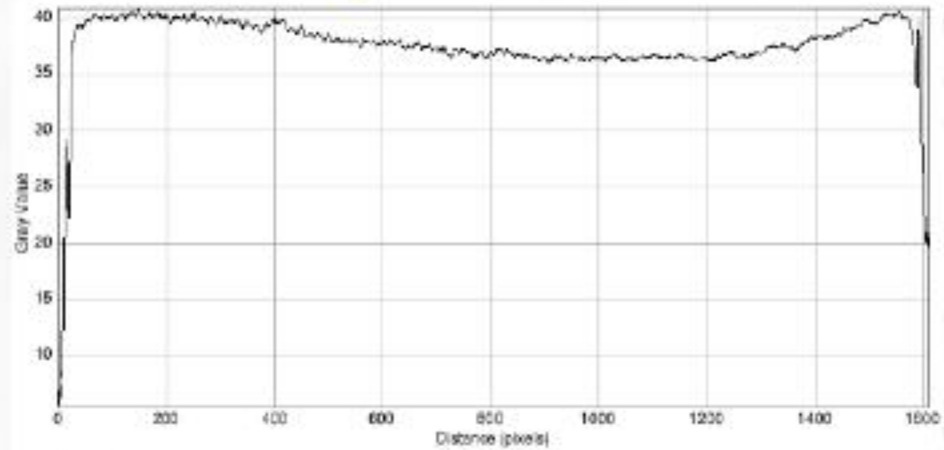


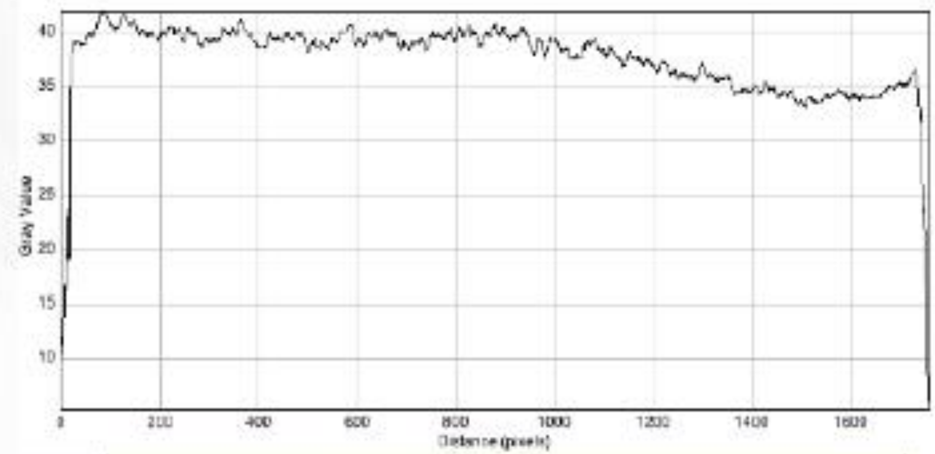


2014 JINST 9 C04002

Gain Uniformity

Gain map image for a pair of 20 µm pore, 60:1 L/D, ALD borosilicate MCPs, 950 V per MCP, 184 nm UV





Gain is uniform within ~15% across full 20 x 20 cm² area

O.H.W. Siegmund, N. Richner, G. Gunjala, J.B. McPhate, A.S. Tremsin, H.J. Frisch, J. Elam, A. Mane, R. Wagner, C.A. Craven, M.J. Minot, "Performance Characteristics of Atomic Layer Functionalized Microchannel Plates" Proc. SPIE 8859-34, in press (2013).

Noise <0.1 counts cm^{-2} s^{-1}

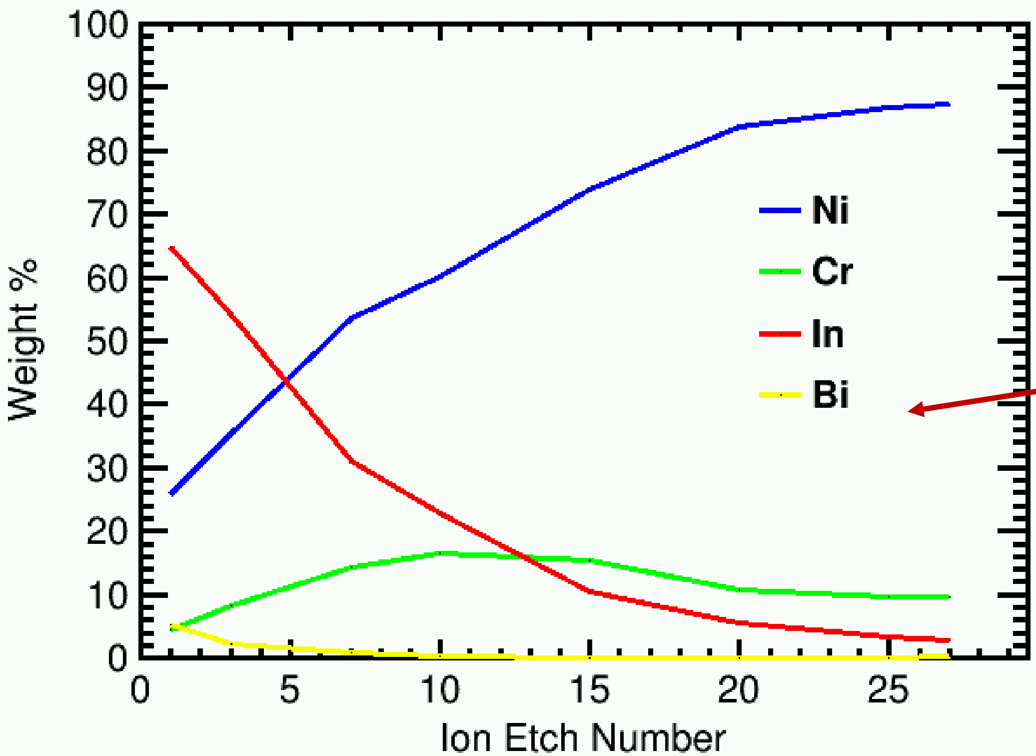
Metallurgy of the Seal

Moderate temperatures and short exposure time:

- A thin layer of copper quickly dissolves in molten indium
- Indium diffuses into the NiCr layer

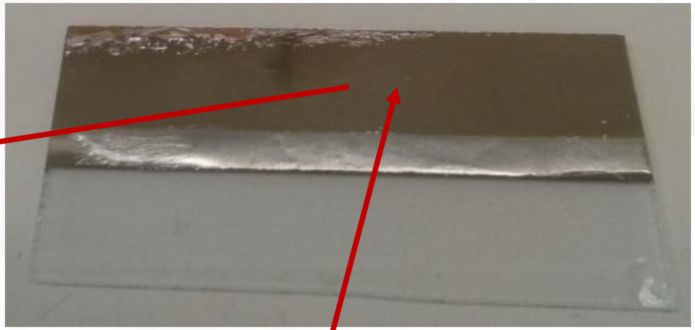
Low melting InBi alloy allows to explore temperatures below melting of pure In (157C)

Depth profile XPS



Layer depth (uncalibrated)

Glass with NiCr-Cu metallization exposed to **InBi** at ~100C for <1hrs (it seals at these conditions)



InBi was scraped when still above melting (72C)

The ion etch number is a measure for the depth of each XPS run

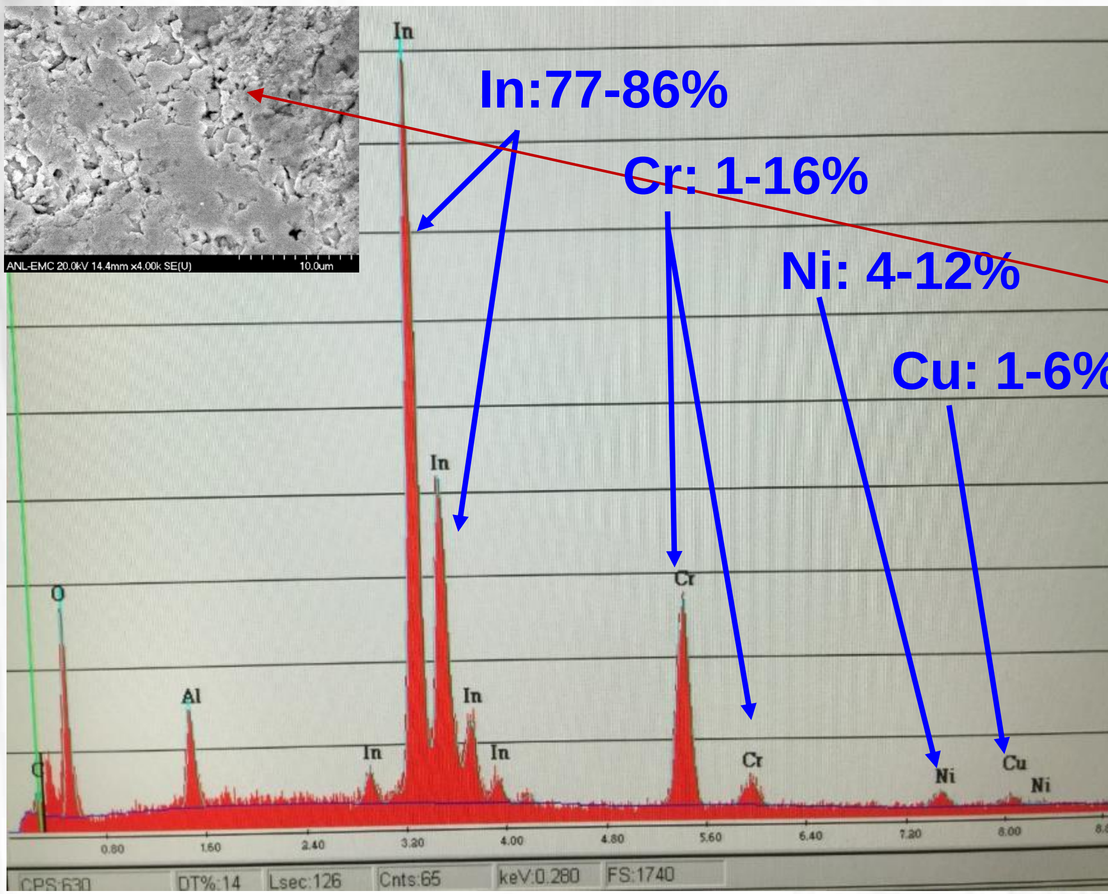
XPS access courtesy of J. Kurley and A. Filatov at UChicago

Metallurgy of the Seal

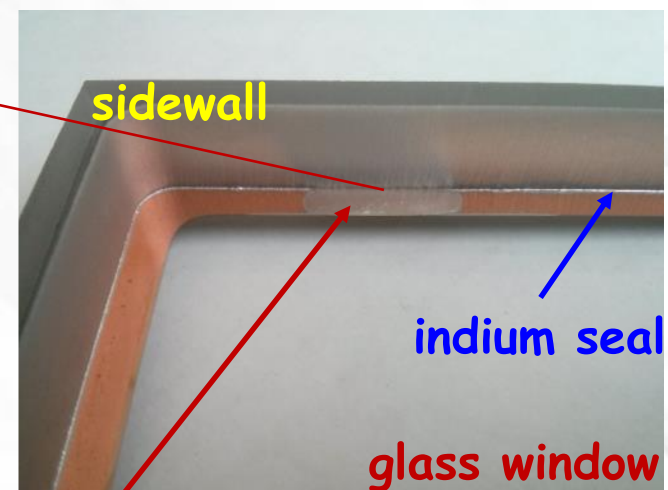
High temperatures and long exposure time

- Indium penetrates through entire NiCr layer

SEM and EDAX of the metal surface scraped at the interface



Glass with NiCr-Cu metallization bonded by **pure In** at ~250C for 2hrs (it seals at these conditions)



Cut and scrape at the metal-glass interface

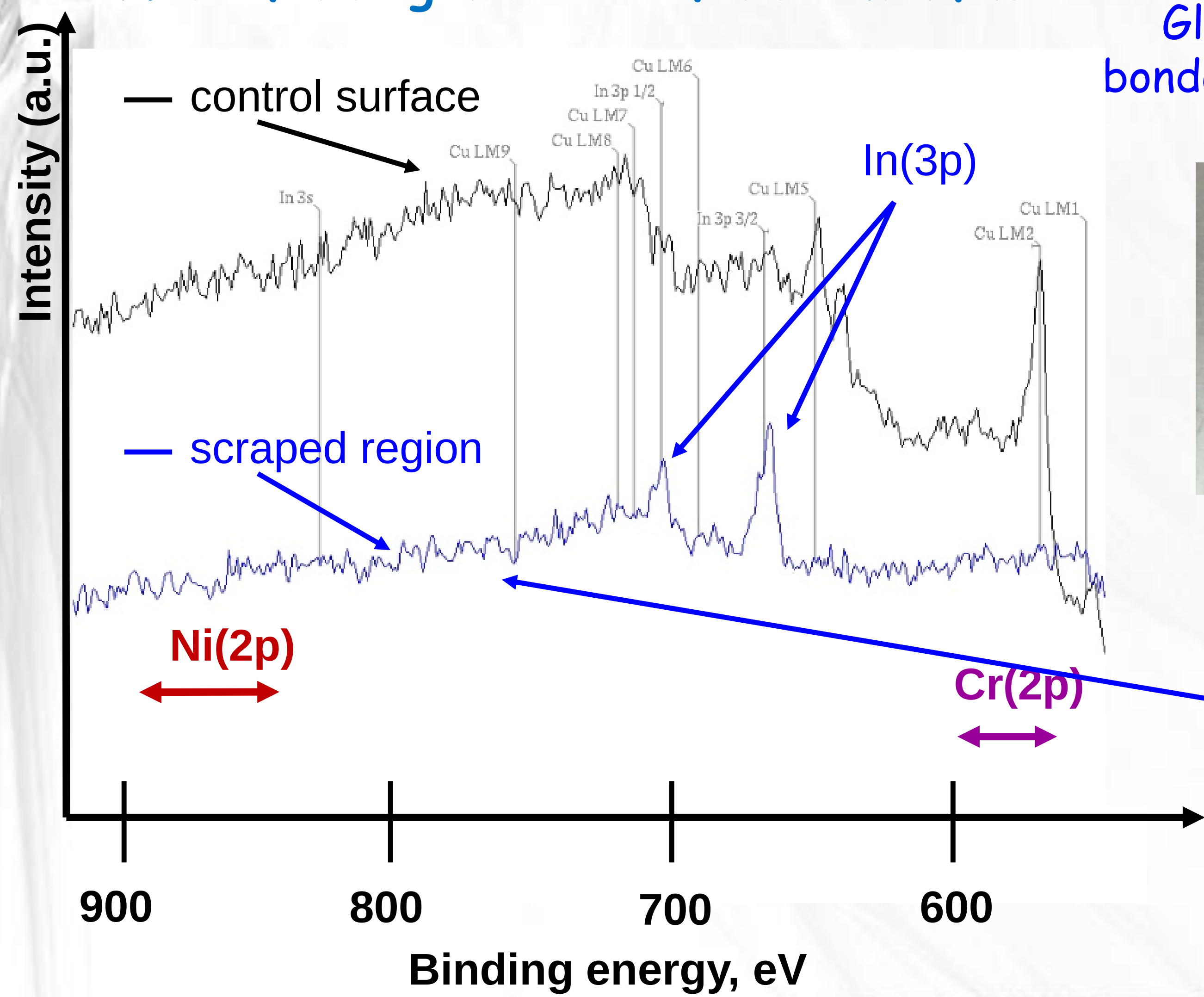
SEM/EDAX data courtesy of J. Elam at Argonne

Metallurgy of a Good Seal

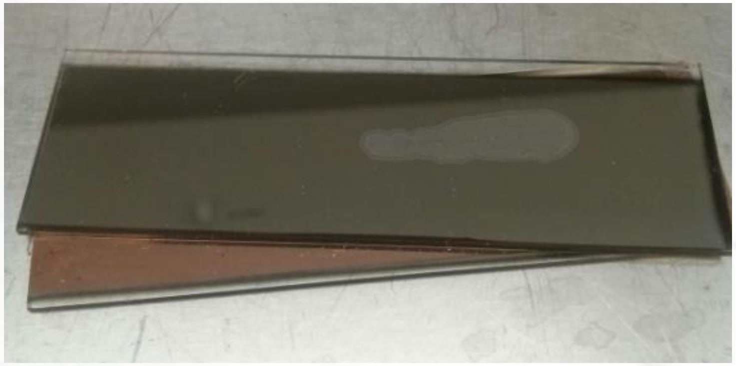
Higher temperatures and longer exposure time

- Indium penetrates through entire NiCr layer

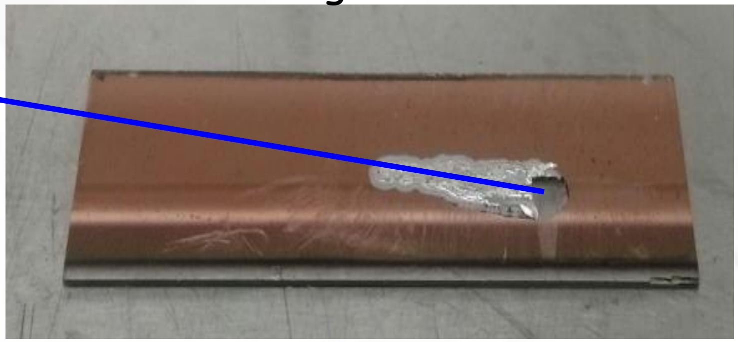
XPS of the glass side of the interface



Glass with NiCr-Cu metallization bonded by **pure In** at ~350C for 24hrs (it seals at these conditions)



Cut and scrape at the metal-glass interface



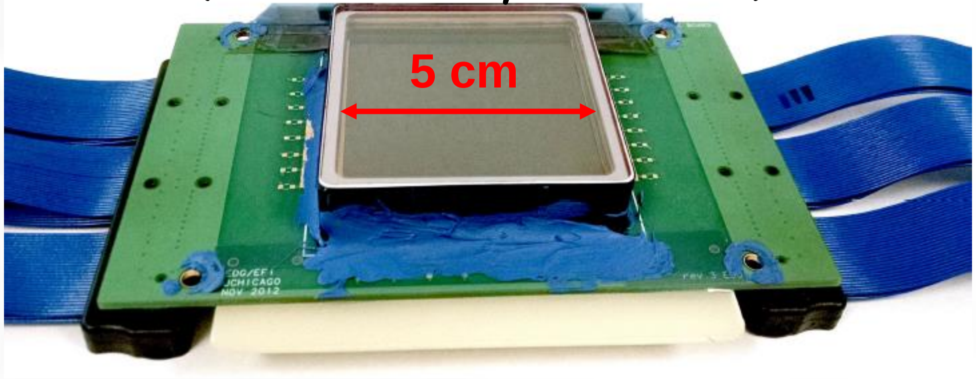
We now reliably seal at 250-300C for 12-24hrs

XPS data courtesy of A. Filatov at UChicago

Indium seal recipes exist for a long time

We adapted NiCr-Cu scheme
from O.Siegmund at SSL UC Berkeley

PLANACON™
(MCP-PMT by Photonis)



Why do we need another indium seal recipe?

Make larger photo-detectors
Our recipe scales well to large perimeter

Simplify the assembly process
Our recipe is compatible with PMT-like batch production