An Indium Solder Flat Seal for the Assembly of Large-Area Planar MCP-based Detectors Without Vacuum Transfer of the Window

Andrey Elagin
University of Chicago

for the UChicago PSEC group:
Evan Angelico, Andrey Elagin, Henry Frisch, Eric Spieglan,
and summer students: Madeline Bernstein and Hayward Melton,
and Bernhard Adams at Incom Inc.,
and Robert Jarrett at Indium Corporation

ICHEP 2016, August 05, 2016, Chicago

Outline

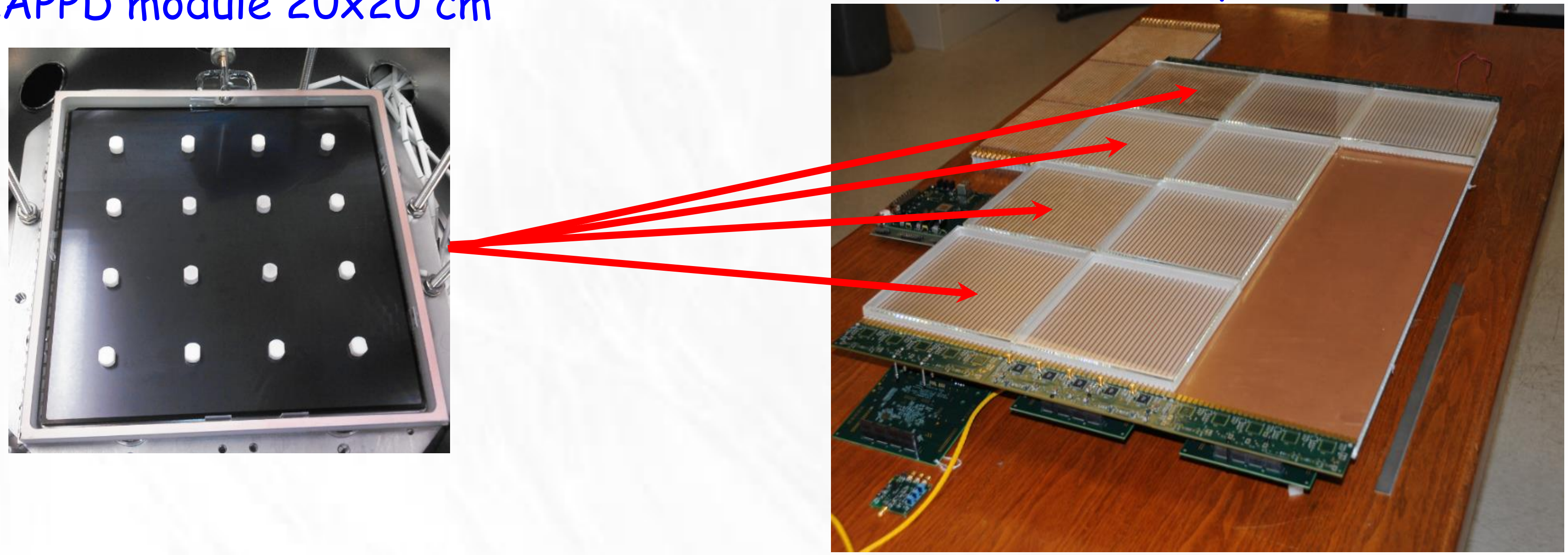
- Motivation for a Non-Vacuum Transfer Process
- In-Situ Assembly Strategy
- Current Status
- In-Situ Assembly Pre-requisite: Indium Seal
- Next Steps: Gen-II LAPPD
- Summary

Our Goal

Affordable large-area many-pixel photo-detector systems with picosecond time resolution

LAPPD module 20x20 cm

Example of a Super Module



LAPPD™ is now being commercialized by Incom Inc. (talk by M.Minot)

We would like to go after new discoveries that could be within the reach of this technology

We need LAPPDs to be available in very large quantities

The goal of our detector R&D is to enable high volume production at Incom so we can do physics using LAPPD™

Need for High Volume Production

Key applications

- Particle identification by time-of-flight (colliders and fixed-target experiments)
- Optical tracking (see Optical TPC talk by Eric Oberla tomorrow)
- Cherenkov/scintillation light separation to reconstruct $0\nu\beta\beta$-decay event topology (see poster 1452 on directional liquid scintillator tomorrow)
- Medical imaging, proton therapy, nonproliferation, quantum imaging (see poster by Bernhard Adams on Monday)

How many LAPPDs are needed?

- NuDot needs up to 72 LAPPDs (small-scale prototype with a path to a very large directional liquid scintillator detector for $0\nu\beta\beta$-decay)
- ANNIE needs 20-100 LAPPDs (see ANNIE poster by Carrie McGivern tomorrow)
- KamLAND-Zen and SNO+ may benefit from LAPPDs but would need thousands of LAPPDs
- THEIA would need over 20,000 LAPPDs for just a 10% photo-coverage

(a combination of regular PMTs and LAPPDs is a possible option for THEIA, optimization is ongoing)

Production rate of 50 LAPPDs/week would cover 100 m^2 in one year

High volume production can be challenging for conventional vacuum transfer techniques

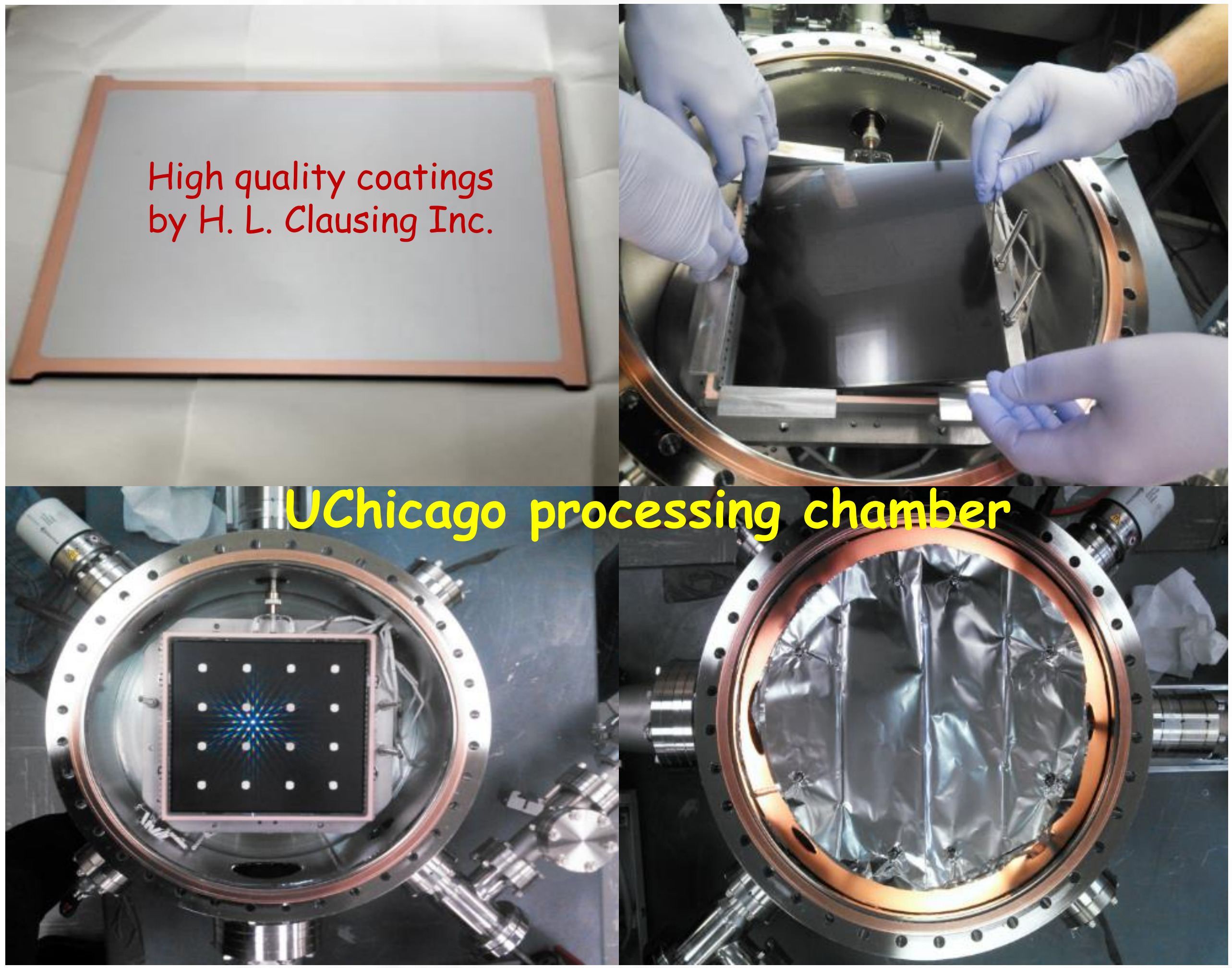
In-Situ Assembly Strategy

Simplify the assembly process by avoiding vacuum transfer:
make photo-cathode after the top seal

Ultimate goal: PMT-like batch production of LAPPD (50/week)

Glassblowing by Joe Gregar at Argonne

Engineering support by Richard Northrop at UChicago



8x8" MCPs by A.Mane and J.Elam at Argonne

8x8" MCPs were also provided by Arradiance

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**
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

Dual vacuum for the seal and bake-out

Then open outside vacuum for photo-cathode synthesis with window accessible

Heat only the tile (not the vacuum vessel)

Intended for parallelization

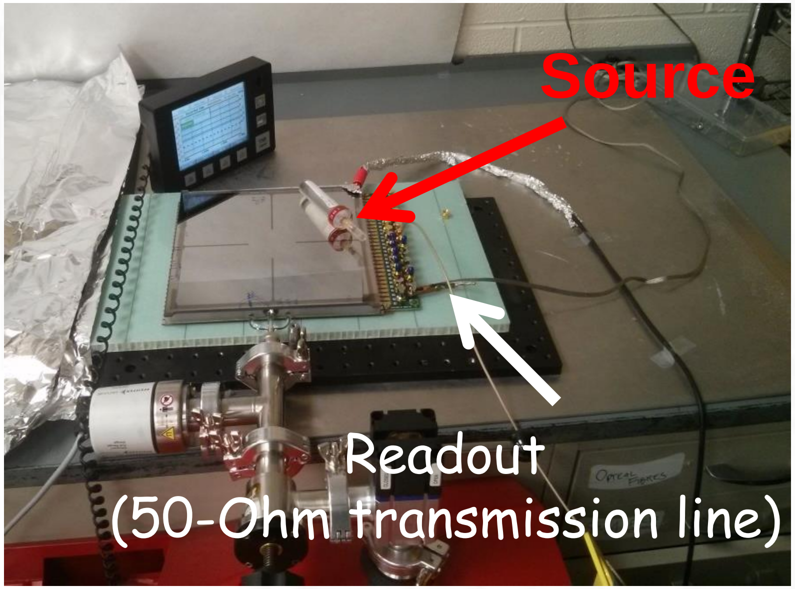
All machining is a magic touch by Bob Metz, UChicago

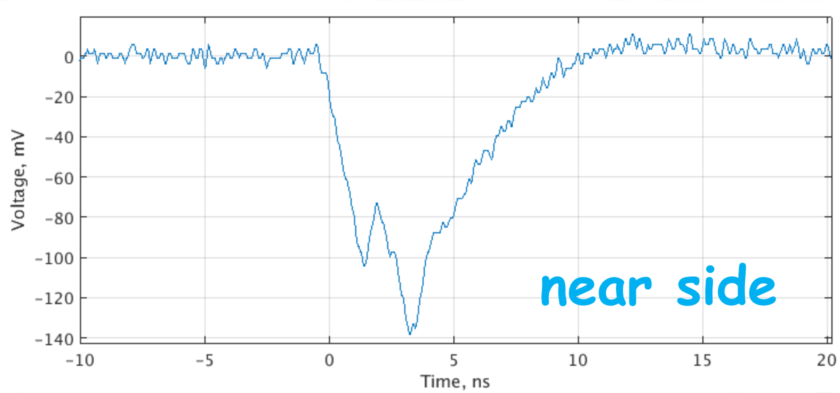
Looking forward towards transferring the in-situ process to industry

First Signals from an In-Situ LAPPD

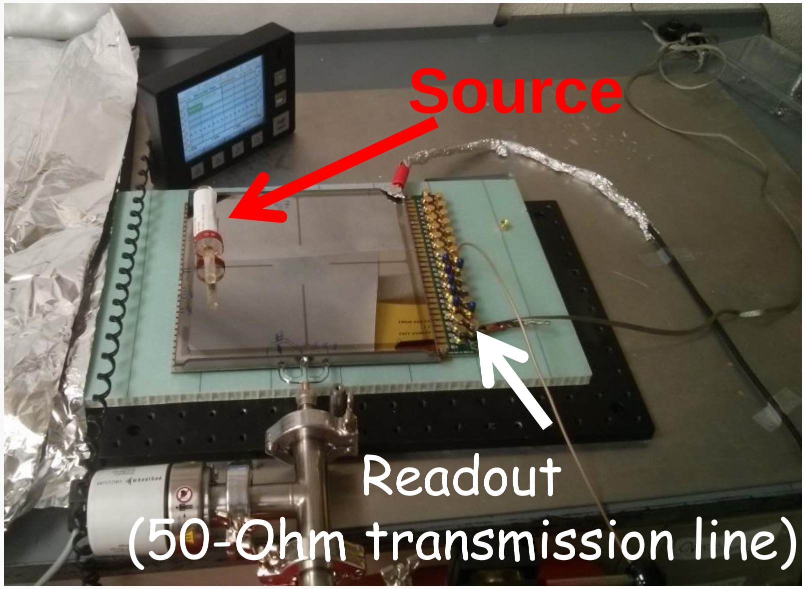
(Sb cathode)

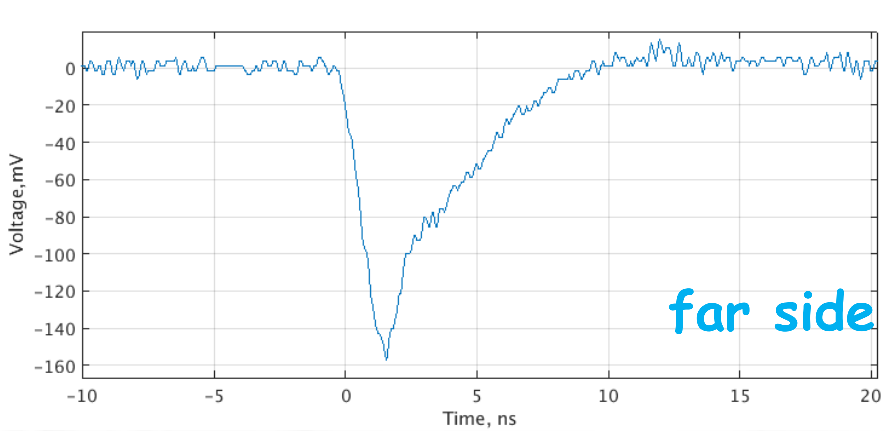
Near side: reflection from unterminated far end





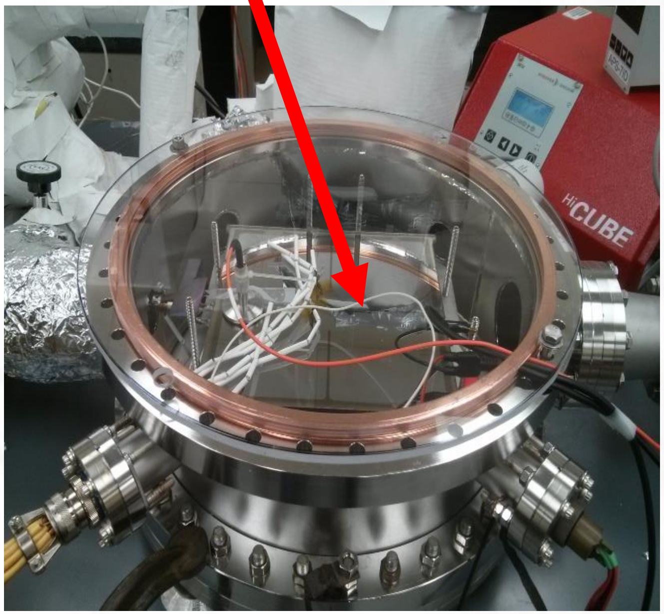
Far side: reflection is superimposed on prompt





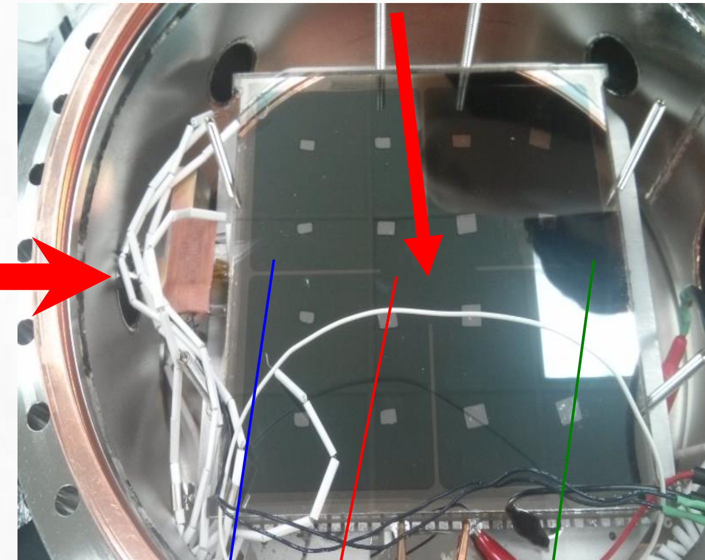
Current Status

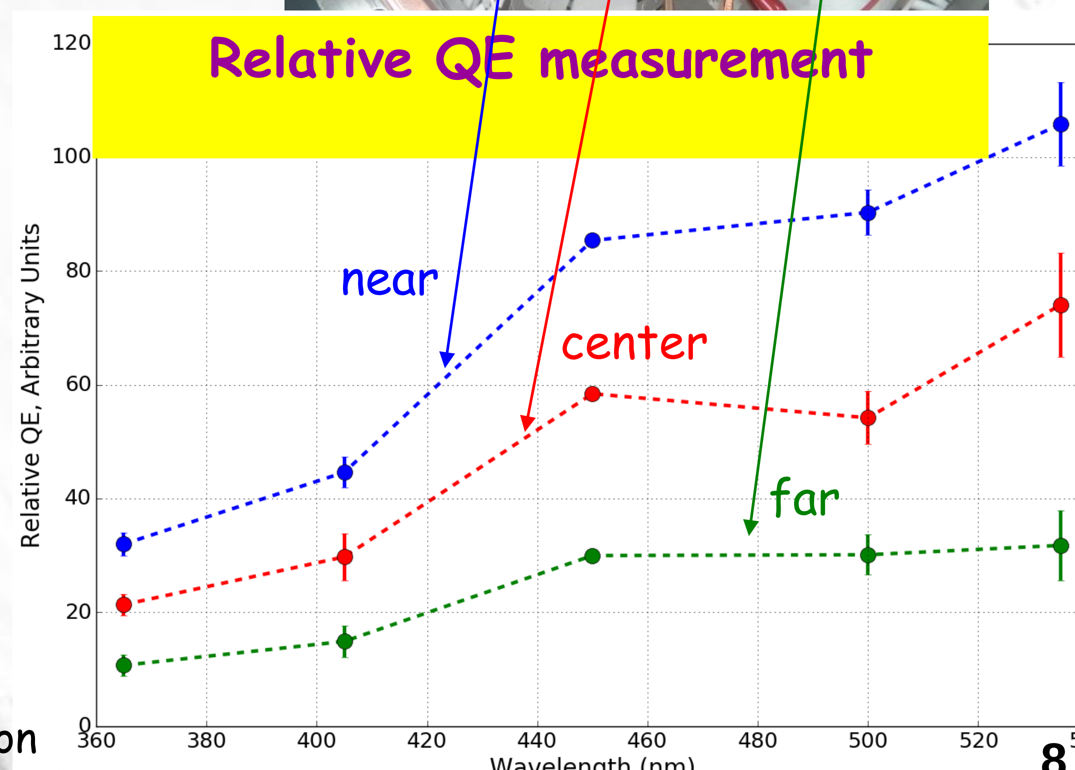
Sb layer only



Cs

Cs-Sb photo-cathode





First in-situ commissioning run is complete

- saw the first photo-current response
- measured relative QE

Demonstrated a "sealed tile" configuration

- so far no drop in QE after 5 days with a closed valve between the tile and the pump

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

In-Situ Process Pre-requisite:

Reliable hermetic seal over a 90-cm long perimeter

Indium Solder Flat Seal Recipe

Input:

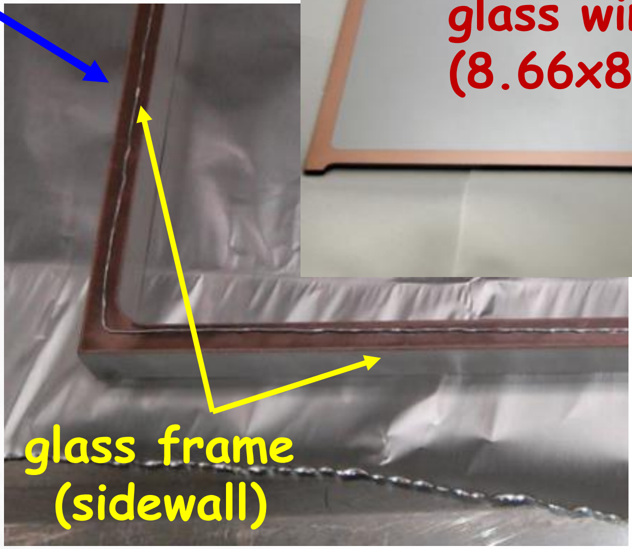
- Two glass parts with flat contact surfaces

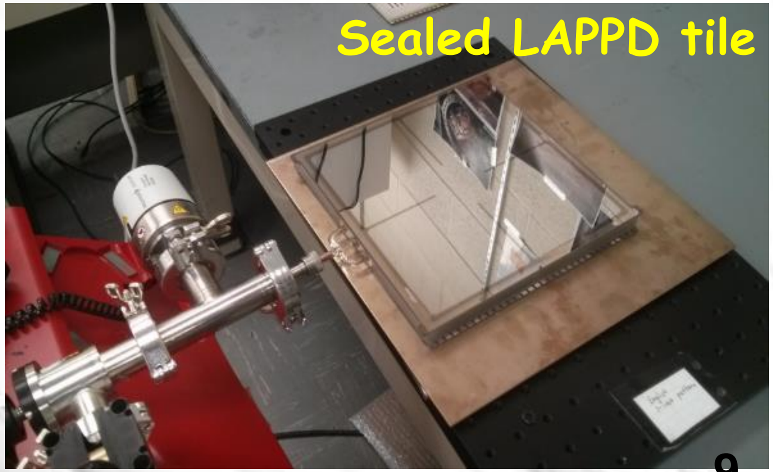
Process:

- 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

Next Step: Gen-II LAPPD

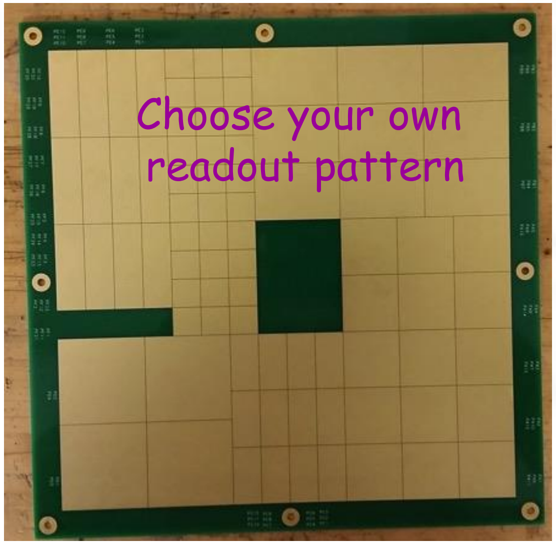
From glass to ceramic

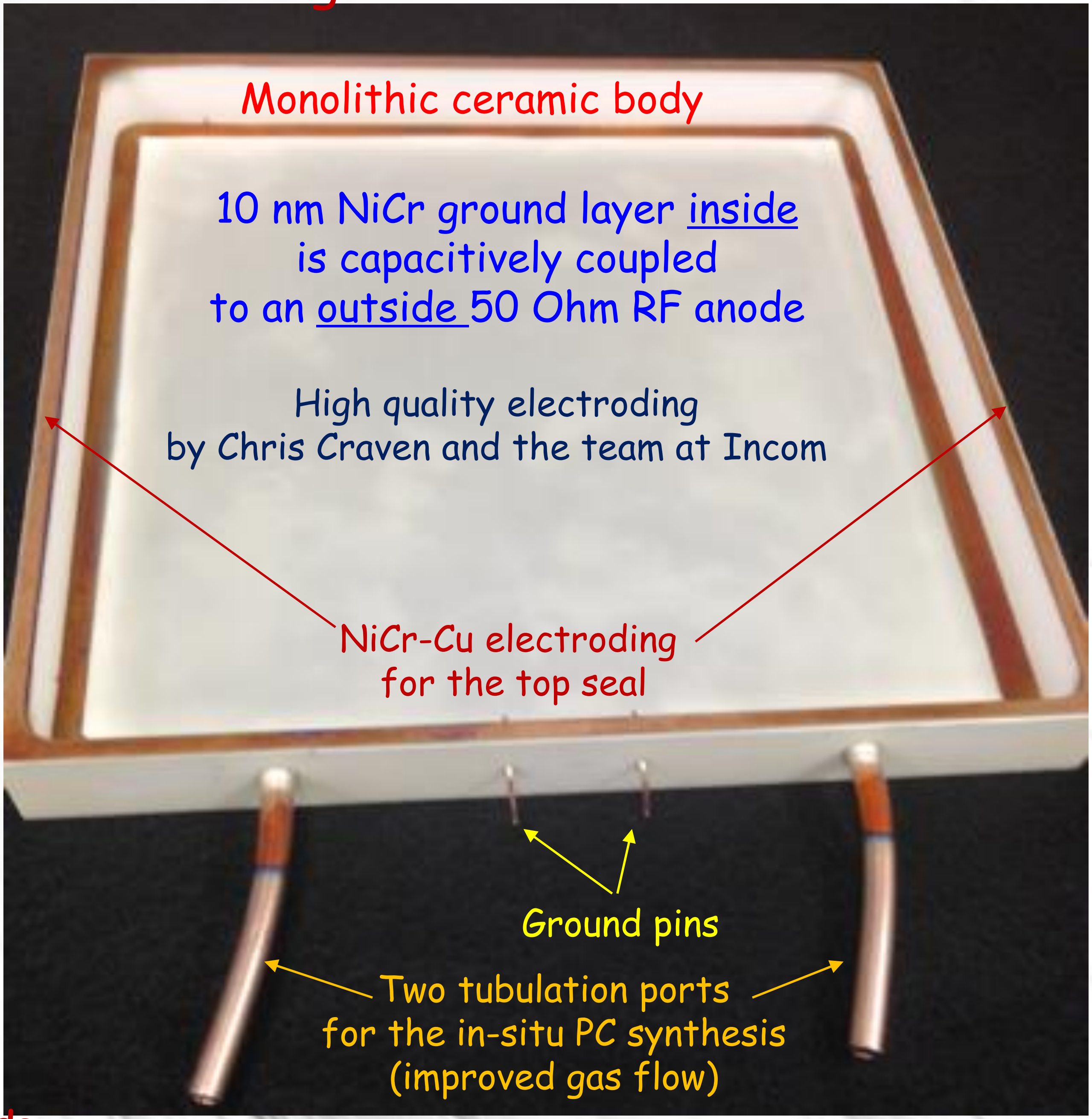
Custom anode is outside

Compatible with high rate applications

Supports large-area super-module panels

Anode is not a part of the vacuum package





See posters on the "inside-out" anode by Evan Angelico and Todd Seiss on Monday

Stop by Incom Inc. booth #314

Acknowledgements

We a grateful for in-depth discussions to the following experts:
Oswald Siegmund, Jason McPhate, Qiti Guo, Chian Liu, Bing Shi, Howard Clausing, Alexander Filatov, James Kurley, Jeffrey Elam, Anil Mane, Dean Walters, Alexander Zinovev, Ian Steel, Klaus Attenkofer, John Smedley, Alexey Lyashenko, Gary Varner, Charles Sinclair, Luca Cultrera, Matt Poelker, Michael Pellin

These people made the development possible at early stage:
Matthew Wetstein, Eric Oberla, Razib Obaid, Mary Heintz, Richard Northrop, Robert Metz, Joe Gregar, Alexander Vostrikov, Brendan Murphy, Robert Wagner, Marc Kupfer, Jeffrey Williams

We thank our colleagues at Incom Inc. for the joint effort on Gen-II LAPPD:
Michael Foley, Michael Minot, Chris Craven, Mark Popecki
We thank Michael Detarando at Incom for moral support of our in-situ effort

The activities at the University of Chicago were supported by the Department of Energy under DE-SC-0008172, the National Science Foundation under grant PHY-1066014, and the Driskill Foundation

Summary

LAPPD™ is being commercialized by Incom Inc

With the goal to use LAPPDs in a large experiments
we focused on R&D for high volume production process
understood and solved the hermetic seal problem
made over 20 indium seals with a 90-cm-long perimeter each

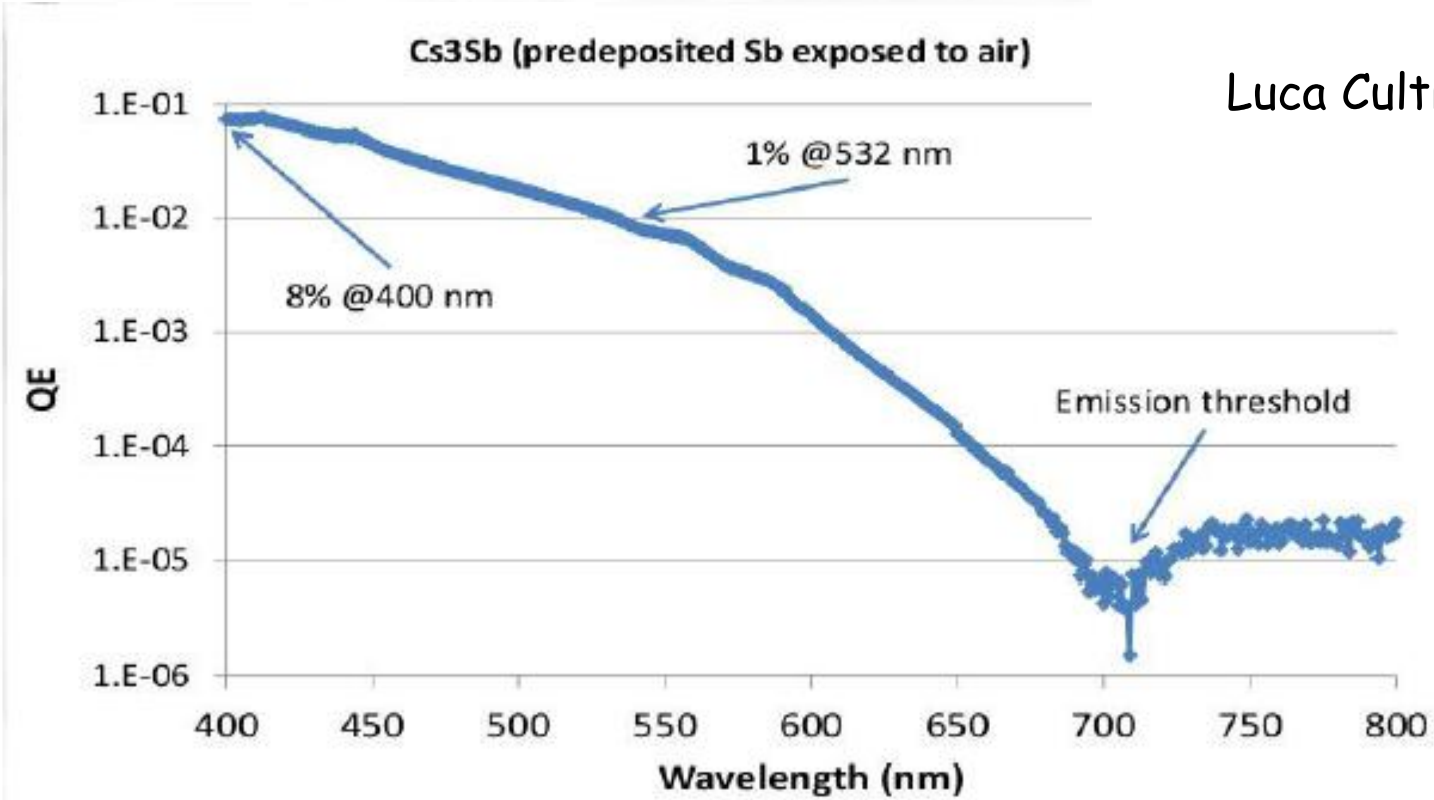
Making photo-cathode as a final step is very attractive
leak check before PC-synthesis
real-time tuning and optimization of PC is possible

Right at the moment we are working on photo-cathode
commissioning run demonstrated in-situ PC-synthesis
PC characterization is ongoing in a sealed tile

Next run is to go for Gen-II LAPPD in-situ assembly

Back-up

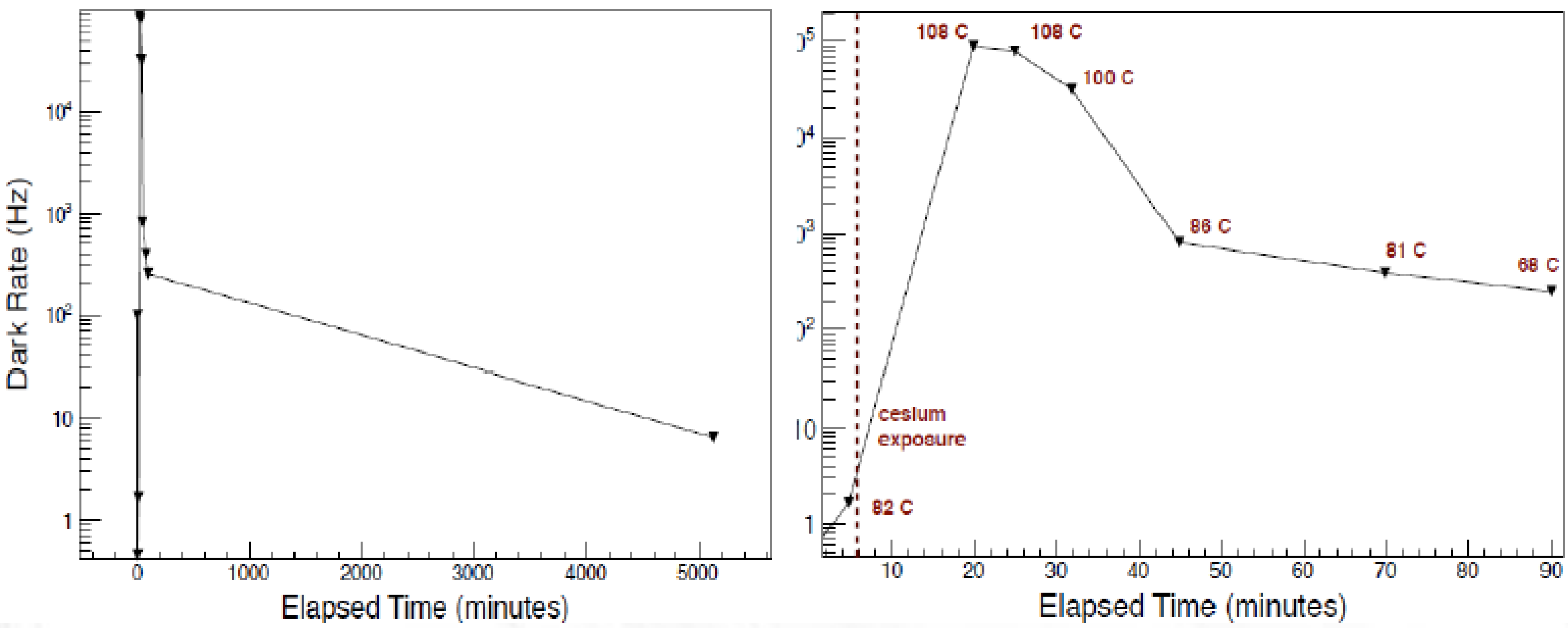
Can you make PC after Sb was exposed to air?



Luca Cultrera at Cornell

What about noise in the MCPs after Cs-ation?

Matt Wetstein

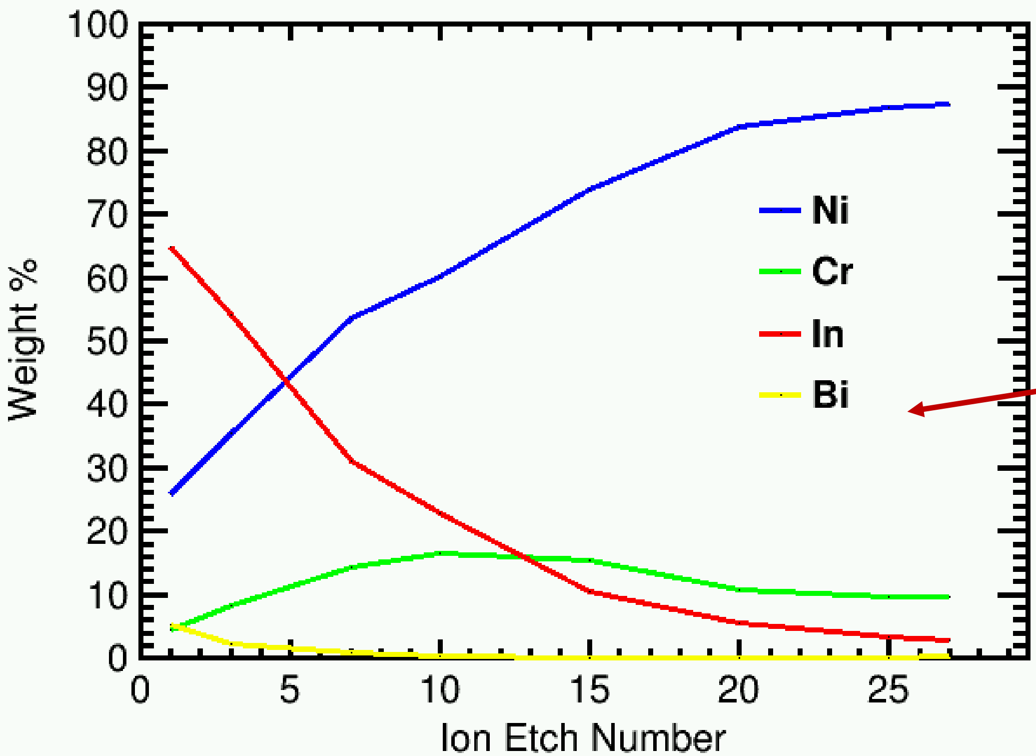


Metallurgy of the Seal

Moderate temperatures and short exposure time:

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

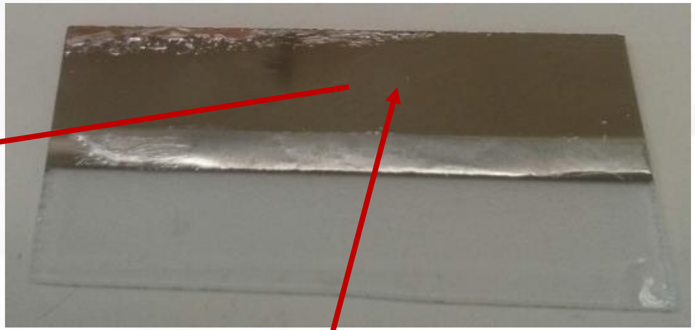
Depth profile XPS



Layer depth (uncalibrated)

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

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

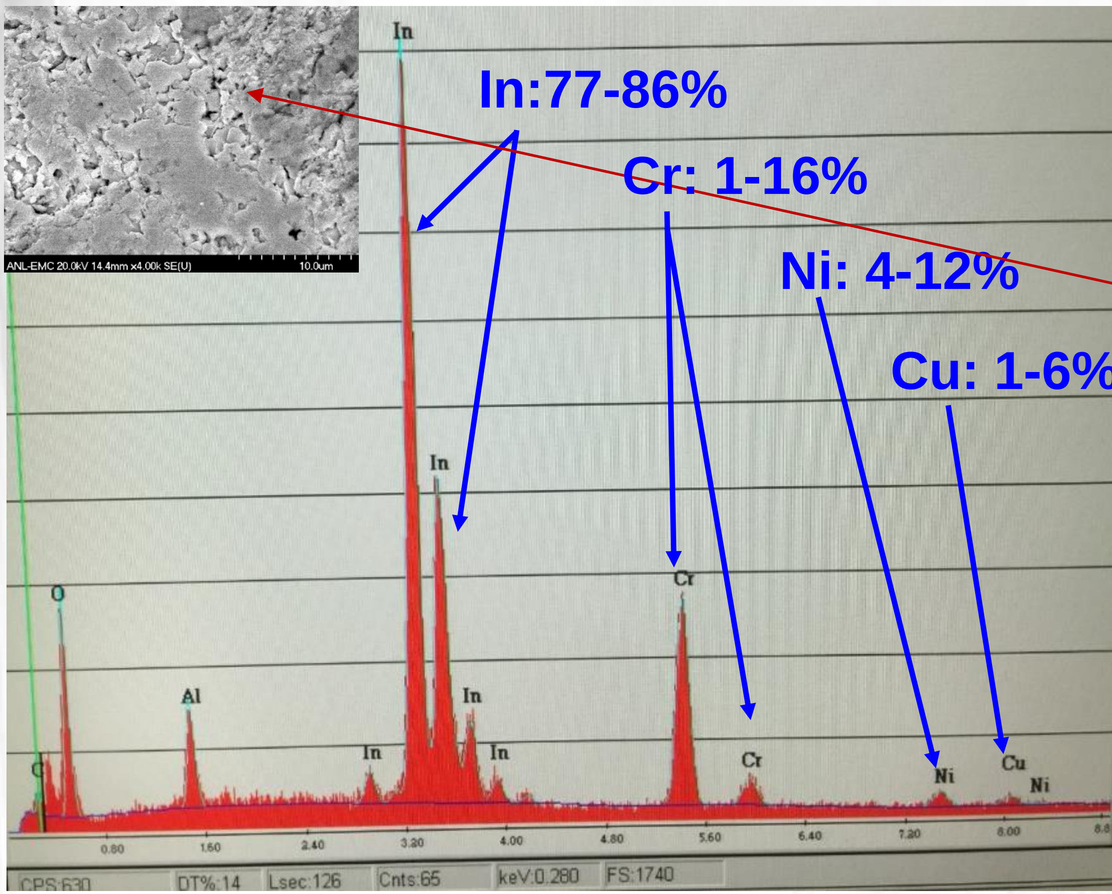
XPS access courtesy of J. Kurley and A. Filatov at UChicago

Metallurgy of the Seal

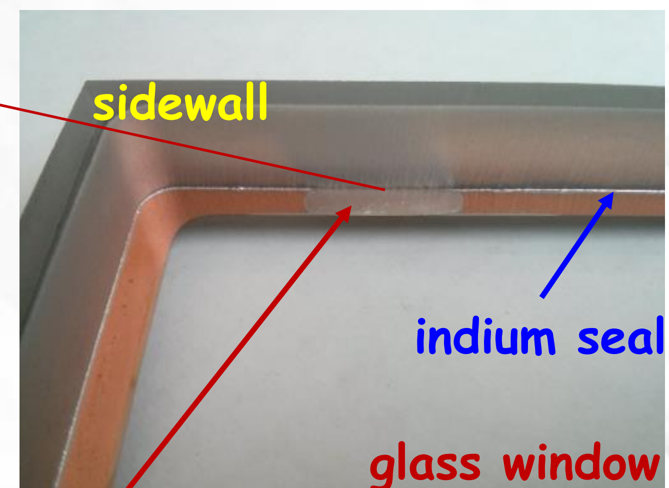
High temperatures and long exposure time

- 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

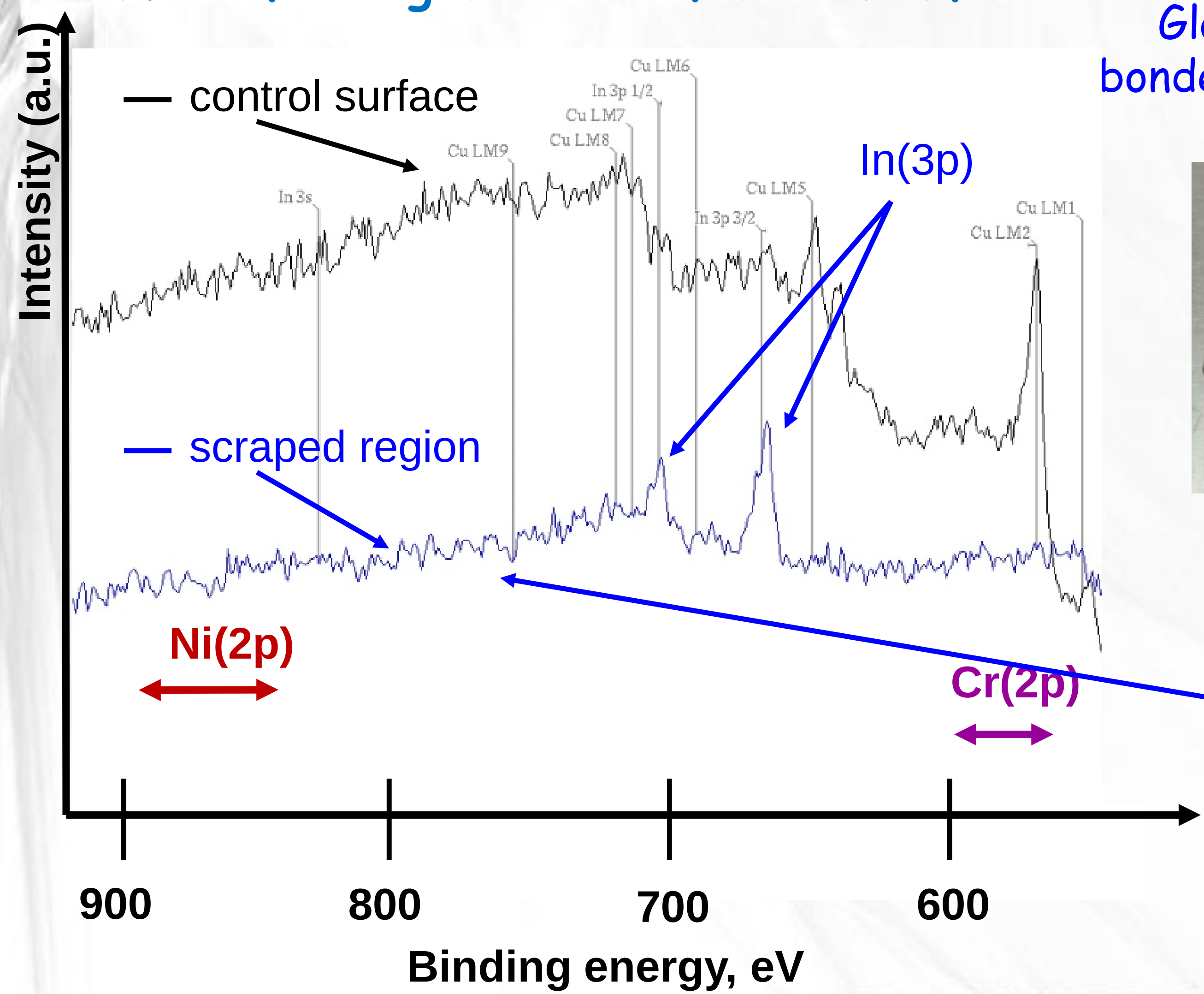
SEM/EDAX data courtesy of J. Elam at Argonne

Metallurgy of a Good Seal

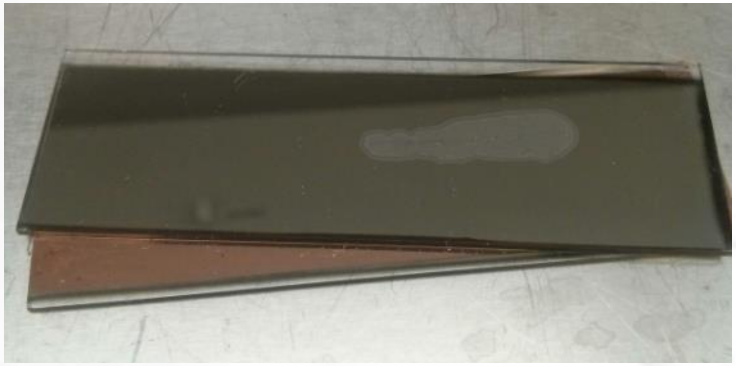
Higher temperatures and longer exposure time

- Indium penetrates through entire NiCr layer

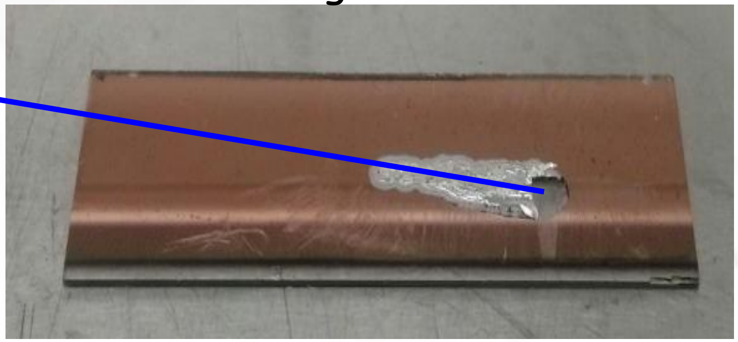
XPS of the glass side of the interface



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



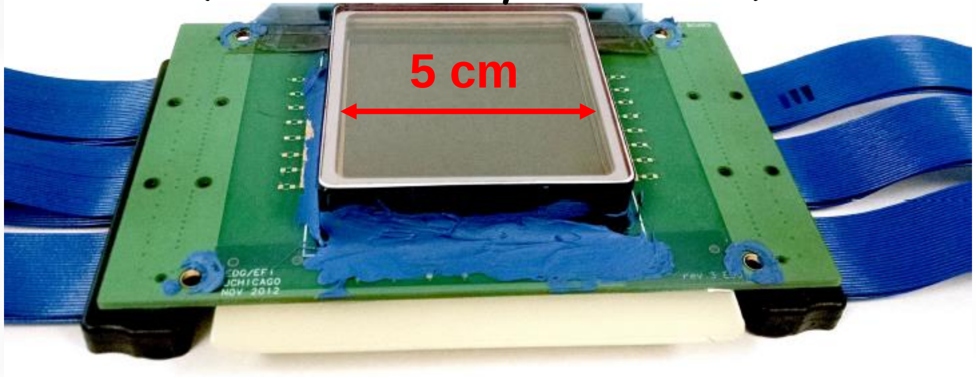
We now reliably seal at 250-300C for 12-24hrs

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)

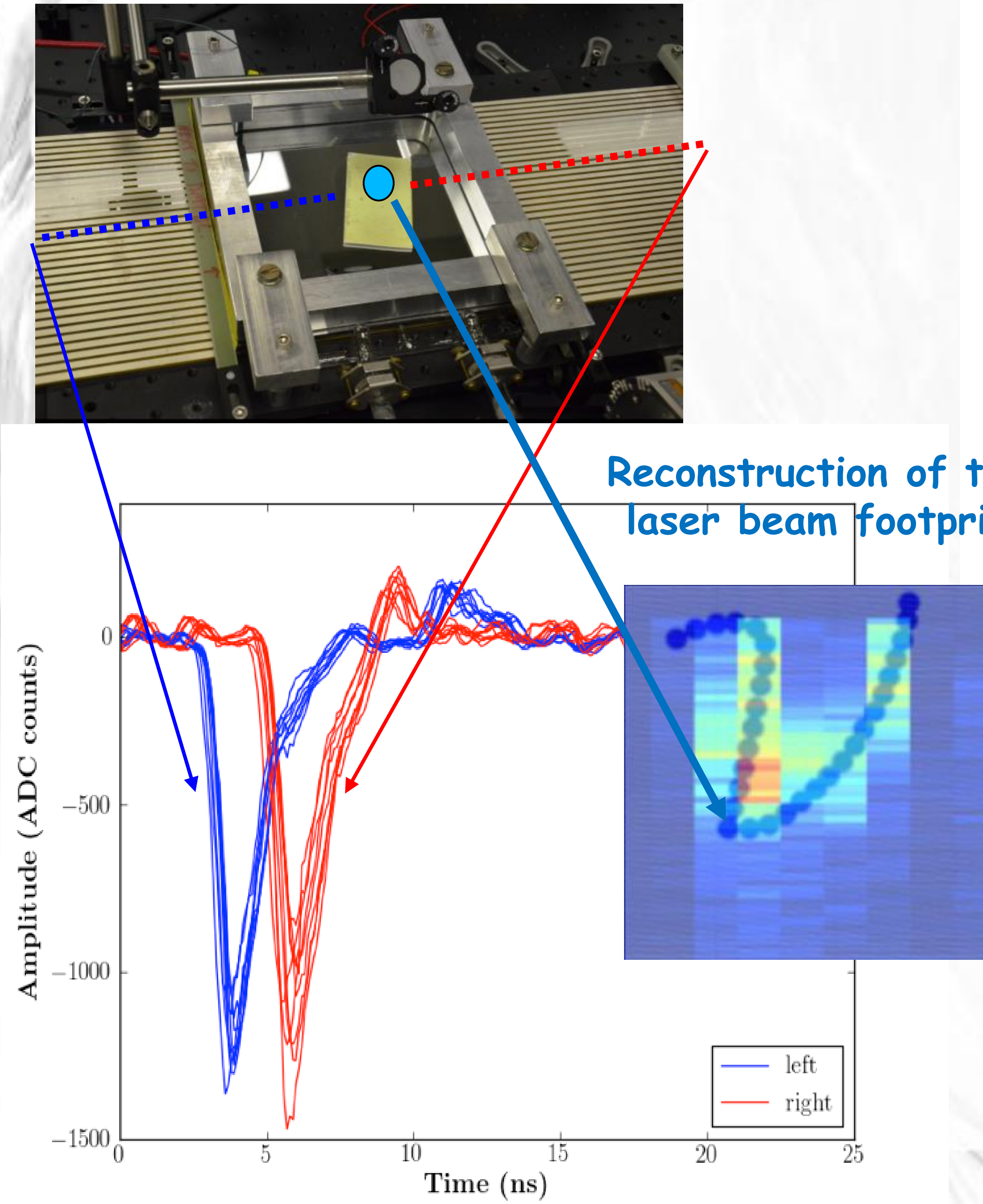


Why do we need another indium seal recipe?

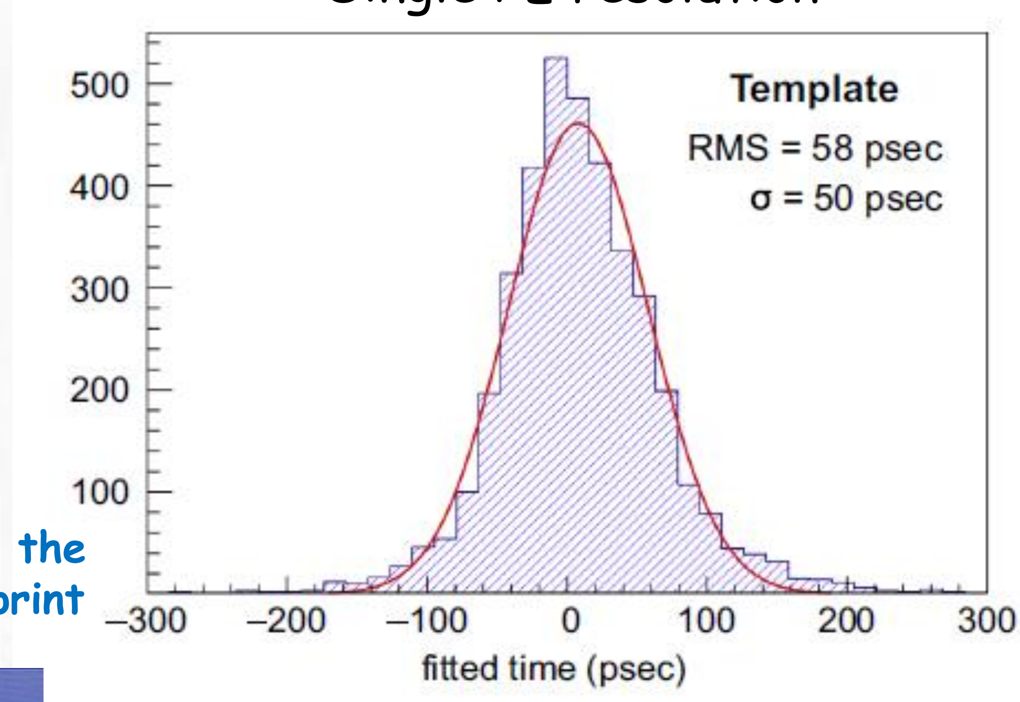
Make larger photo-detectors
Our recipe scales well to large perimeter

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

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