Development of the Large-Area Picosecond Photo-Detectors

Andrey Elagin
University of Chicago

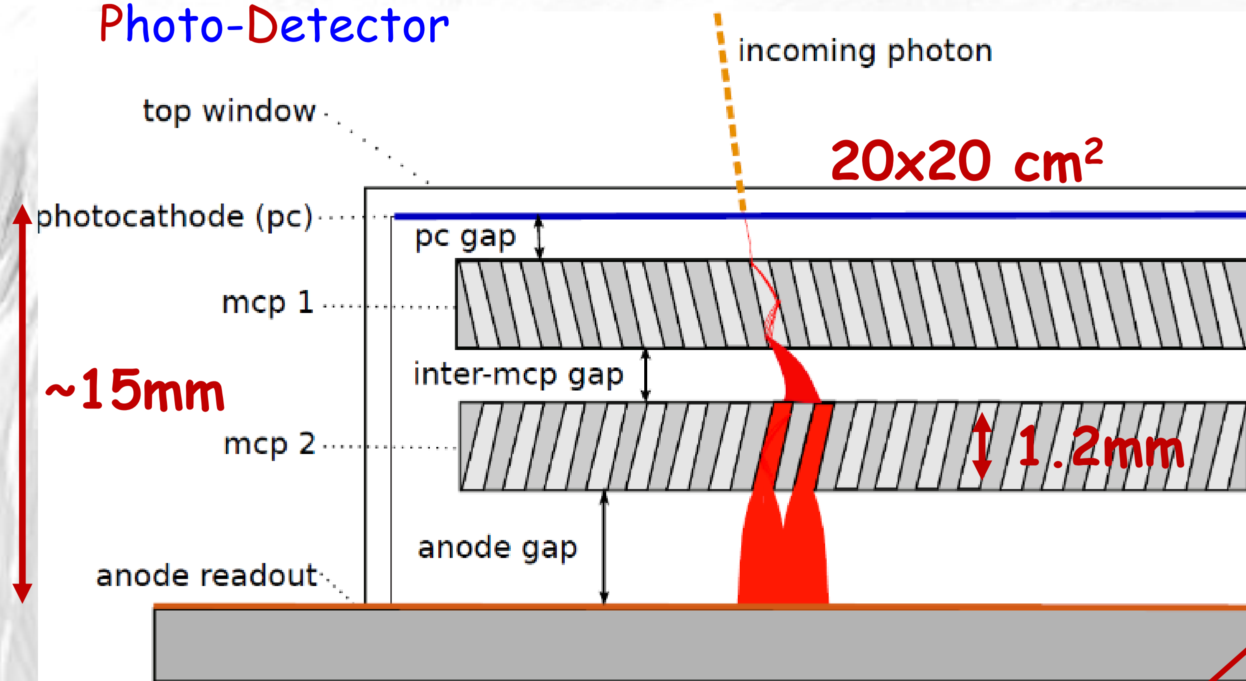
DUNE Near Detector Workshop
Fermilab, March 28, 2017

Outline

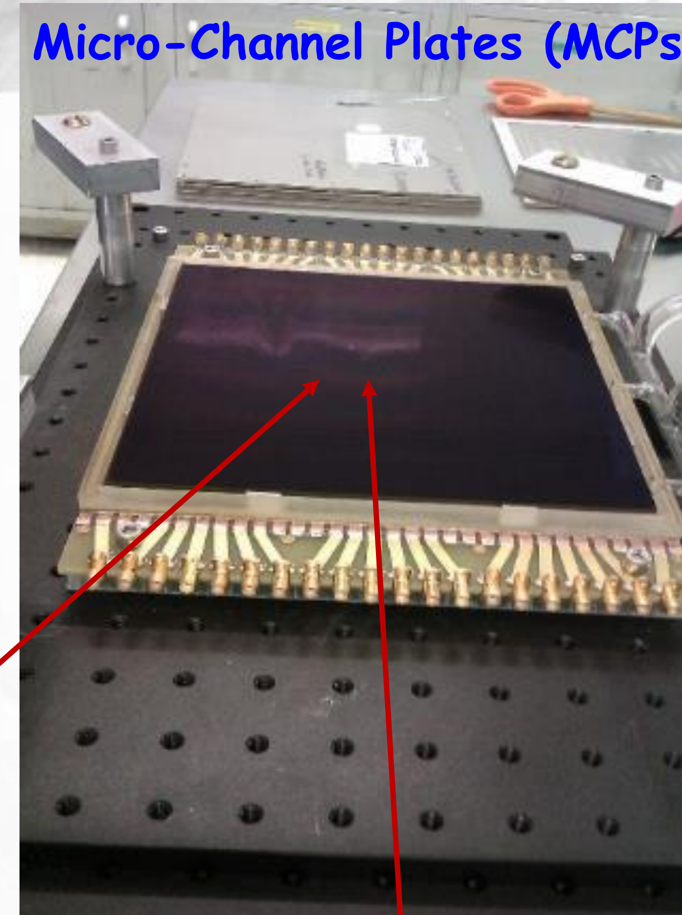
- LAPPD Overview
- Commercialization status at Incom Inc.
- R&D Towards Volume Production
  - development of in-situ assembly process at UChicago
  - Gen-II LAPPD

LAPPD

Large-Area Picosecond Photo-Detector

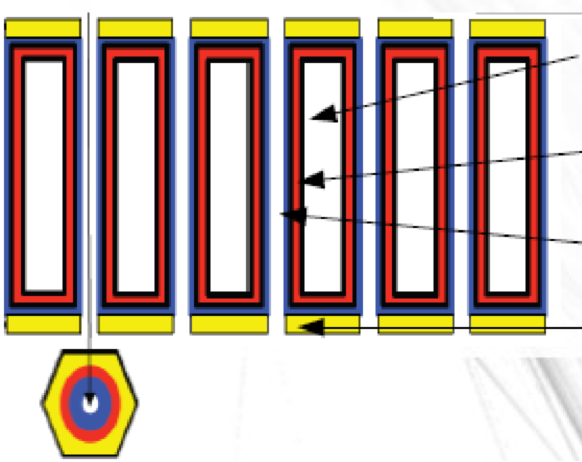


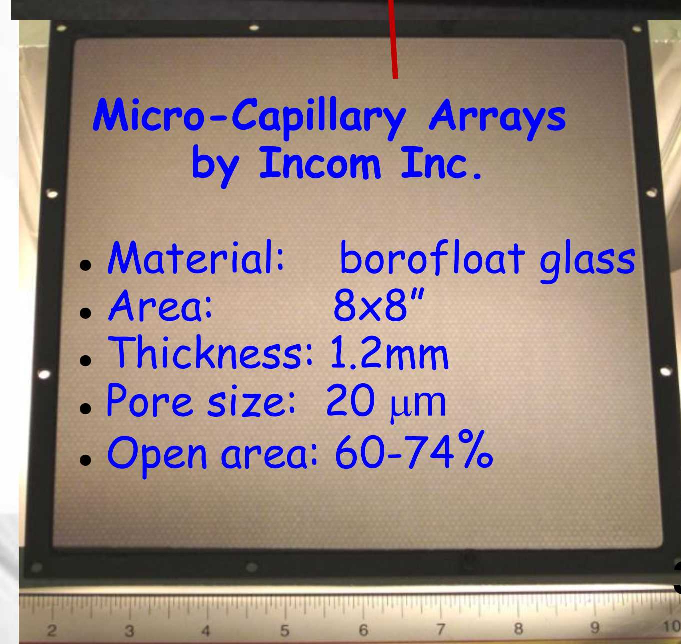
Micro-Channel Plates (MCPs)



Atomic Layer Deposition (ALD)

- J.Elam and A.Mane at Argonne (process is now licensed to Incom Inc.)
- Arradiance Inc. (independent process)

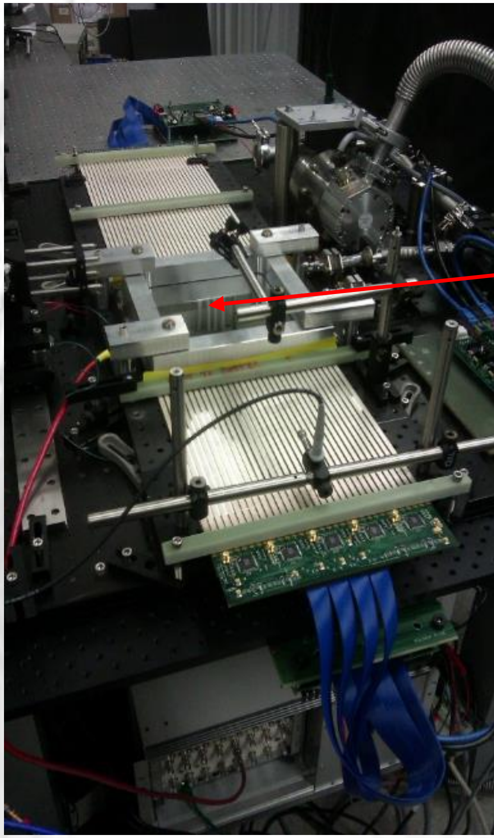


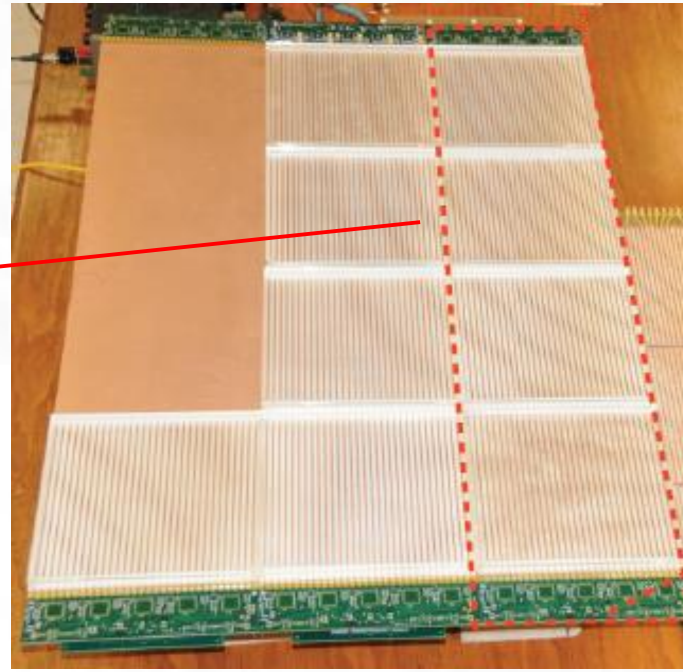


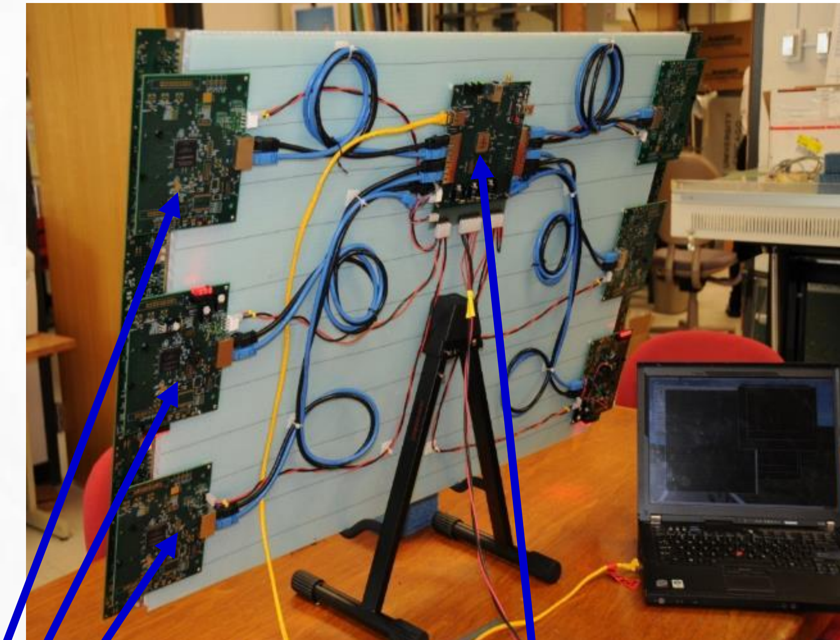
Micro-Capillary Arrays by Incom Inc.

- Material: borofloat glass
- Area: 8x8"
- Thickness: 1.2mm
- Pore size: 20 μm
- Open area: 60-74%

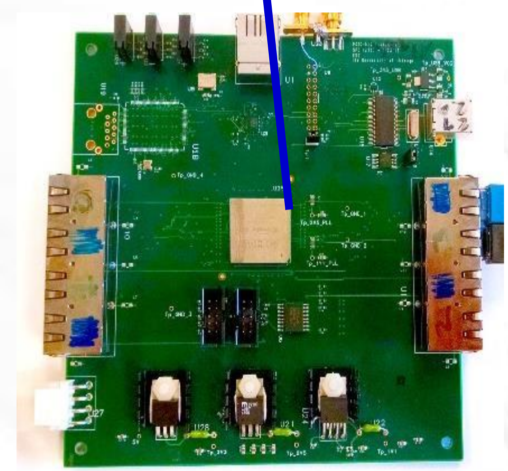
LAPPD Electronics







30-Channel ACDC Card
(5 PSEC-4)



Central Card
(4-ACDC;120ch)

NIM 711 (2013) 124

Delay-line anode
- 1.6 GHz bandwidth
- number of channels
  scales linearly with area

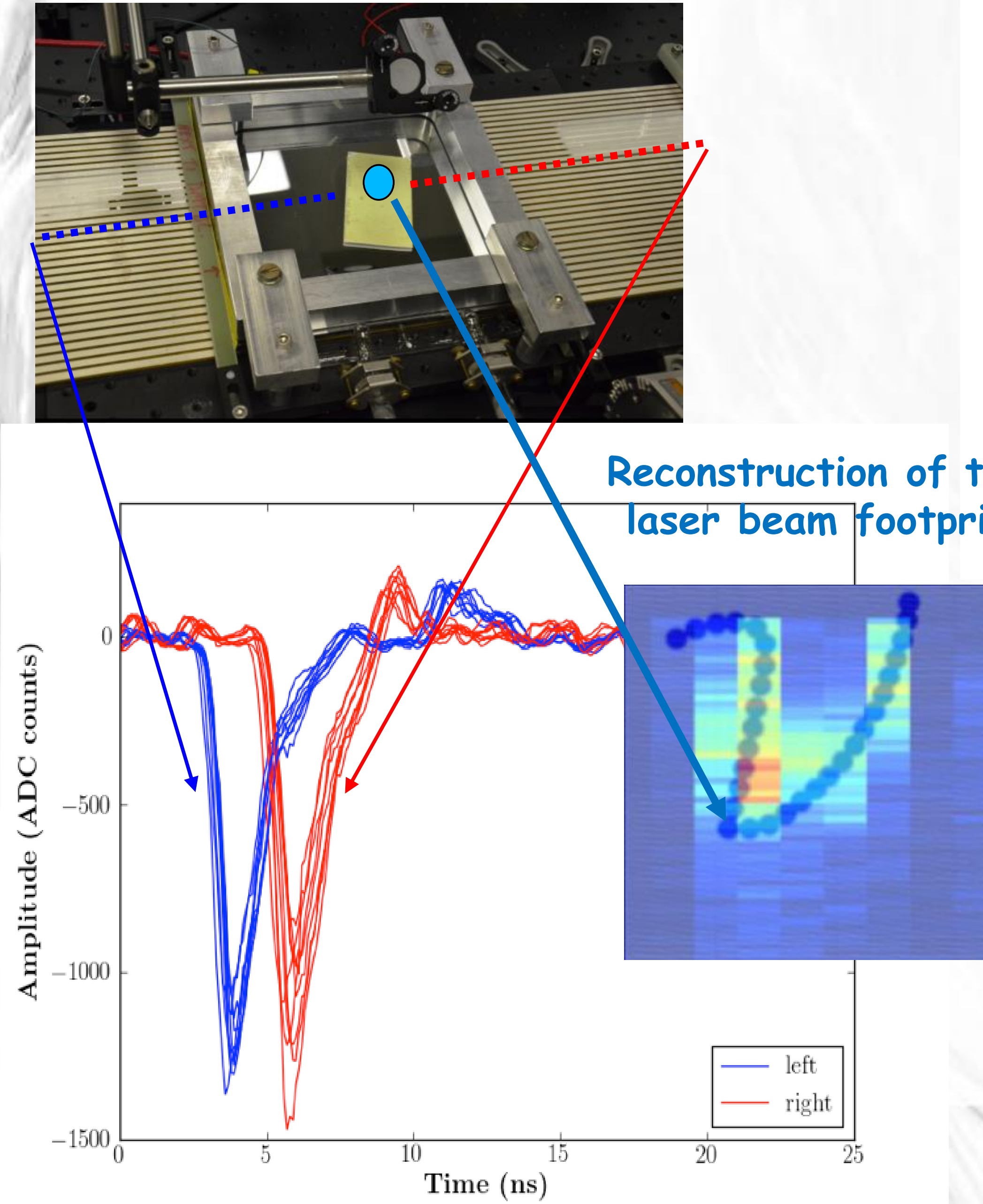
NIM 735 (2014) 452

PSEC4 ASIC chip
- 6-channels, 1.5 GHz, 10-15 GS/s, 256 samples/ch

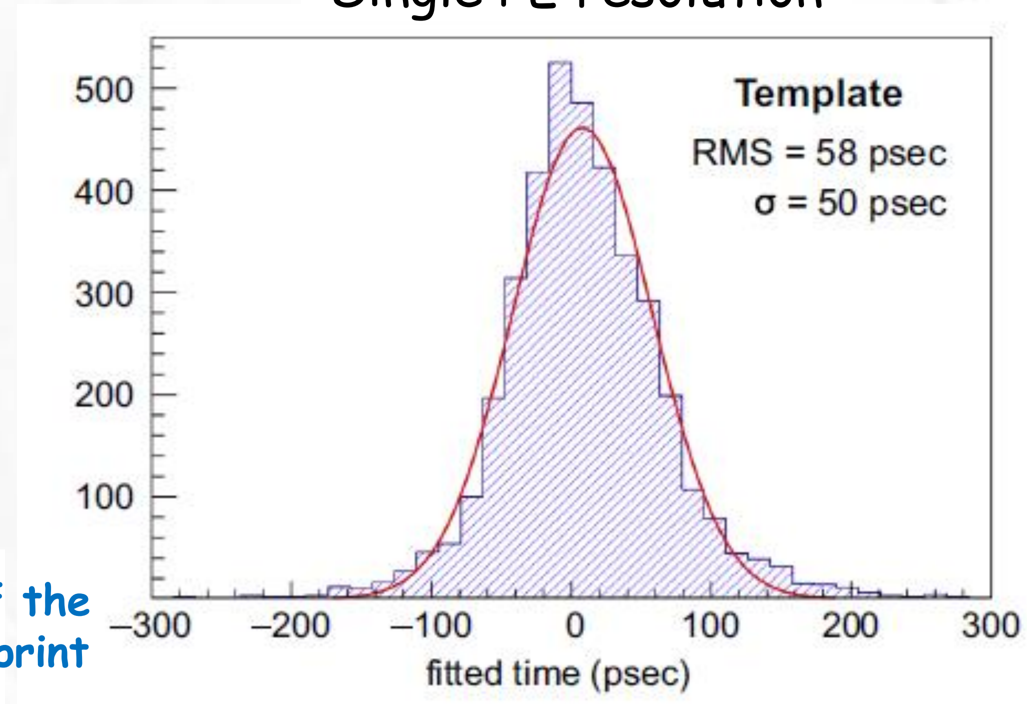
PSEC4a: 8-chs, 1.6GHz, 1056 samples/ch (randomly accessible in blocks of 132)

Early Testing Results

LAPPD "demountable" prototype testing by the Chicago-Argonne group in 2012-2013



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

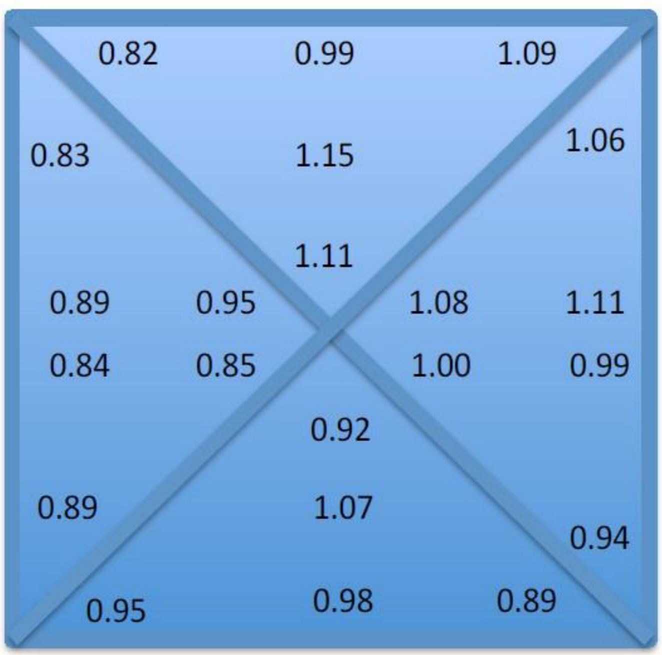
LAPPD Sealing Attempt @ SSL Berkeley

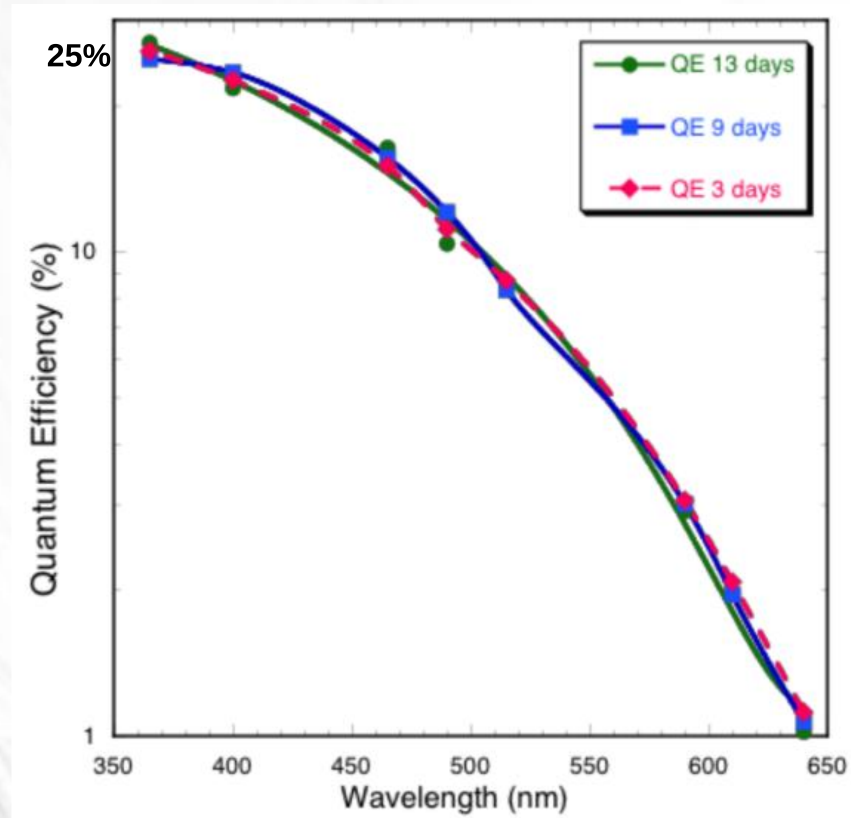
August 2013

A fully processed ceramic LAPPD tile was tested while still in the vacuum chamber

- Peak QE ~25%
- QE non-uniformity +/-15% over 20x20 cm^2 area
- No change in QE after 2 weeks
- TTS ~ 200 ps (FWHM, using 80ps laser and ad-hoc connectors to get signal out of the vacuum chamber)
- Unfortunately, this first tile leaked

QE uniformity map





2014 JINST 9 C04002

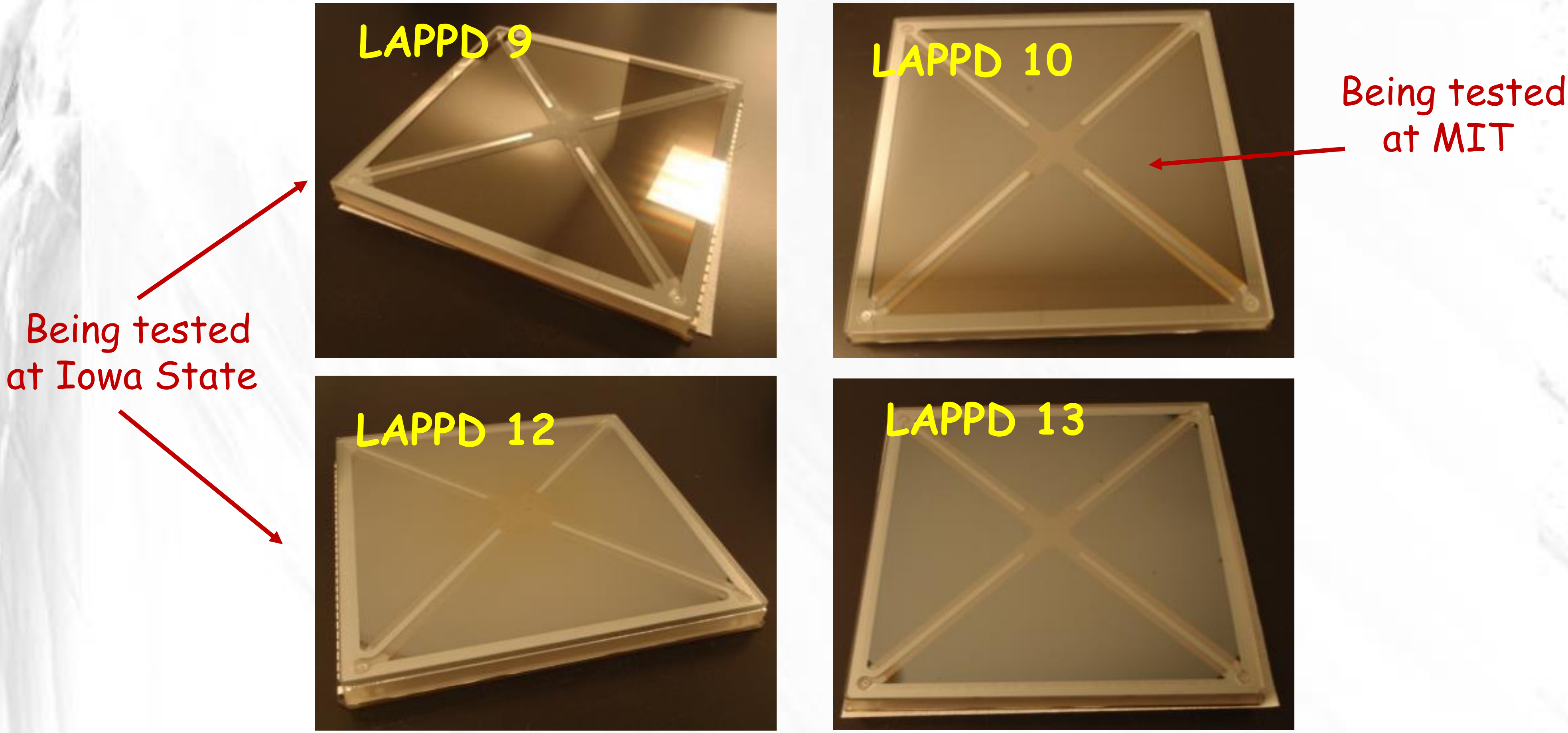
Commercialization Status

Incom Inc. (Charlton, MA) is working on making LAPPD™ commercially available

Supported by DOE via SBIR grant

- April 2014 - DOE funding to create infrastructure and demonstrate a pathway towards pilot production
- November 2015 – Facility operational
- December 2015 – Commissioning trial initiated
- October 2016 – First Sealed Tile with Bialkali Photocathode
- Now transitioning from "commissioning" to "exploitation" stage

Commercialization Status



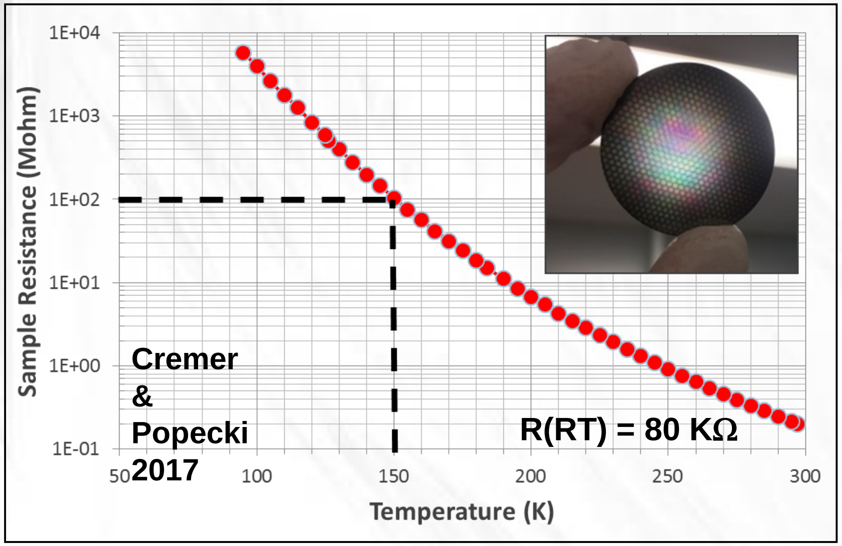
- Functional, sealed LAPPDs, are now being fabricated
- These early prototypes are facilitating evolutionary optimization of the fabrication process and tile design
- Early Adopters are being engaged for preliminary trials

Cryogenic MCP Development at Incom

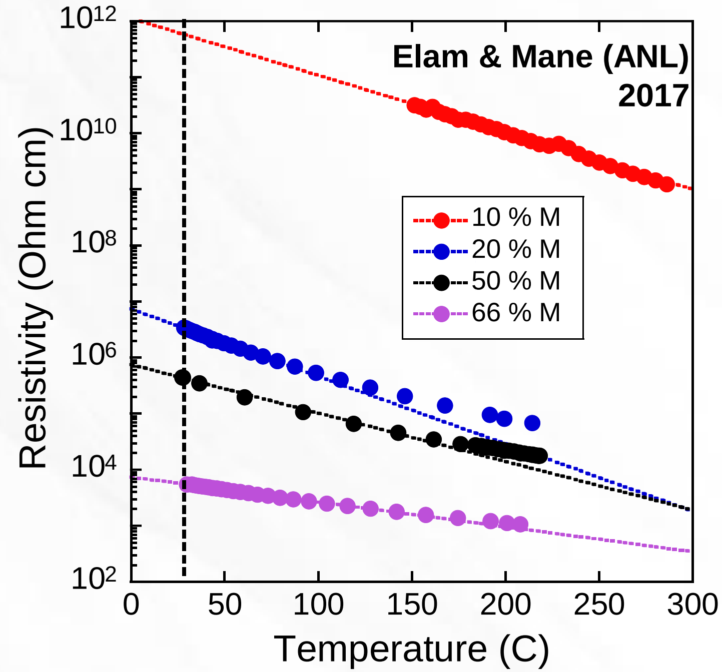
Incom is working on resistive ALD coatings with improved thermoelectrical properties to develop ALD-MCPs that are optimized for detector operation at cryogenic temperatures

- Resistive ALD film has semiconductor-like thermoelectrical properties
- Temperature dependency is described by negative thermal coefficient of resistance (TCR)

Resistance vs T for an ALD MCP with adjusted R



Resistivity vs T for different ALD film compositions



- R changes by 10^4-10^5 when going from RT to cryogenic temperatures (TCR = -0.03)
- ALD allows resistance tuning over much wider range than conventional MCPs

→ Enabling technology to achieve acceptably high counting MCPs. cryogenic temperatures.

- Slope = thermal coefficient of resistance (TCR)
- Can lower TCR by changing film composition

Looking for early adopters to test 33mm dia MCP detector assembly in cryogenic environment at end of Phase II SBIR in 2019

Slide courtesy of Till Cremer, Incom Inc.

LAPPD™ @ Incom

For more information

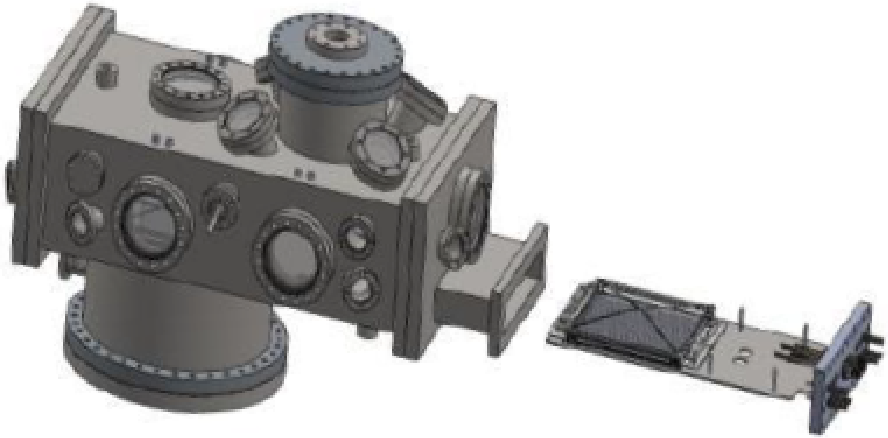
Michael Minot
Director R&D, Incom Inc.
mjm@incomusa.com
Office - 508-909-2369
Cell – **978-852-4942**

For more details on commercialization status see talk by M.Minot at RD51 meeting at CERN: https://indico.cern.ch/event/607147/

LAPPD™ @ Incom

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 to low 10^{-10} torr range
- In-tank operation of tile / scrubbing
- Window Transfer Process
- Multi-alkali Photocathode deposited on underside of window.
- Hot Indium Seal - with grooved sidewalls

Hardware:

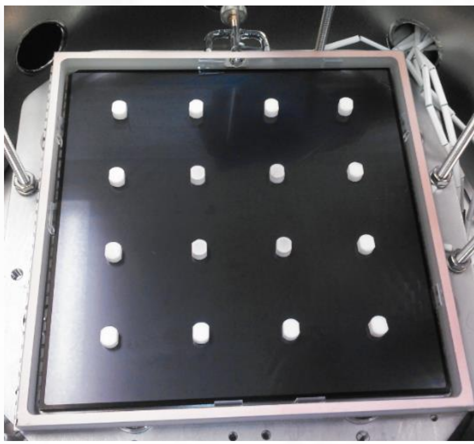
- Single "Fully Bakeable" Chamber: 30"L X 16"W X 8"H
- Simple window transfer between photocathode deposition & sealing.
- Electrical interconnects for in-process monitoring
- Readily expandable for volume production

Slide courtesy of Incom Inc.

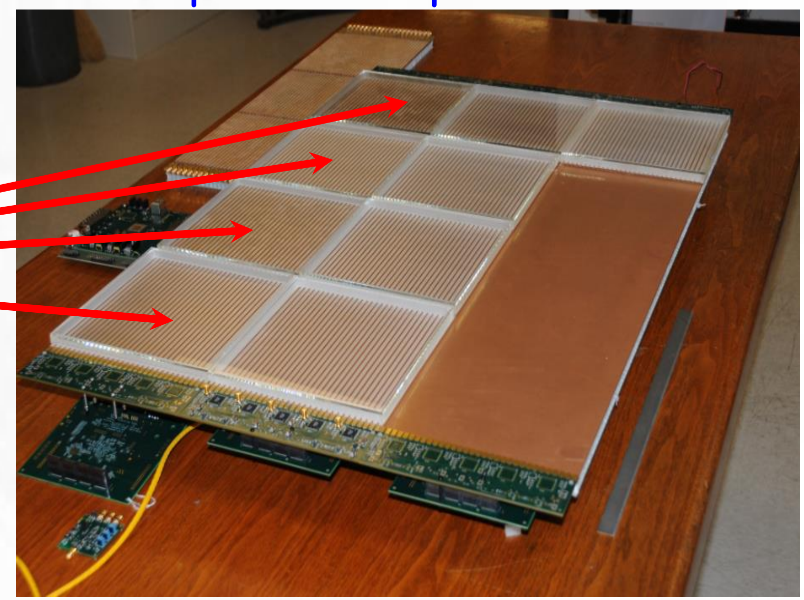
Goal of the R&D Effort at UChicago

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

LAPPD module 20x20 cm^2



Example of a Super Module



We are exploring if an <u>*In-Situ*</u> process (without vacuum transfer) can be inexpensive and easier to scale for a very high volume production

UChicago goal is to develop alternative high volume,
scalable, low cost processing options
(in close collaboration with Incom)

Need for High Volume Production

Key applications

- Cherenkov/scintillation light separation (e.g. $0\nu\beta\beta$-decay event topology)
- Optical tracking (e.g. Eric Oberla PhD thesis experiment at the Fermilab Test Beam)
- Particle identification by time-of-flight (colliders and fixed-target experiments)
- Medical imaging, proton therapy, nonproliferation

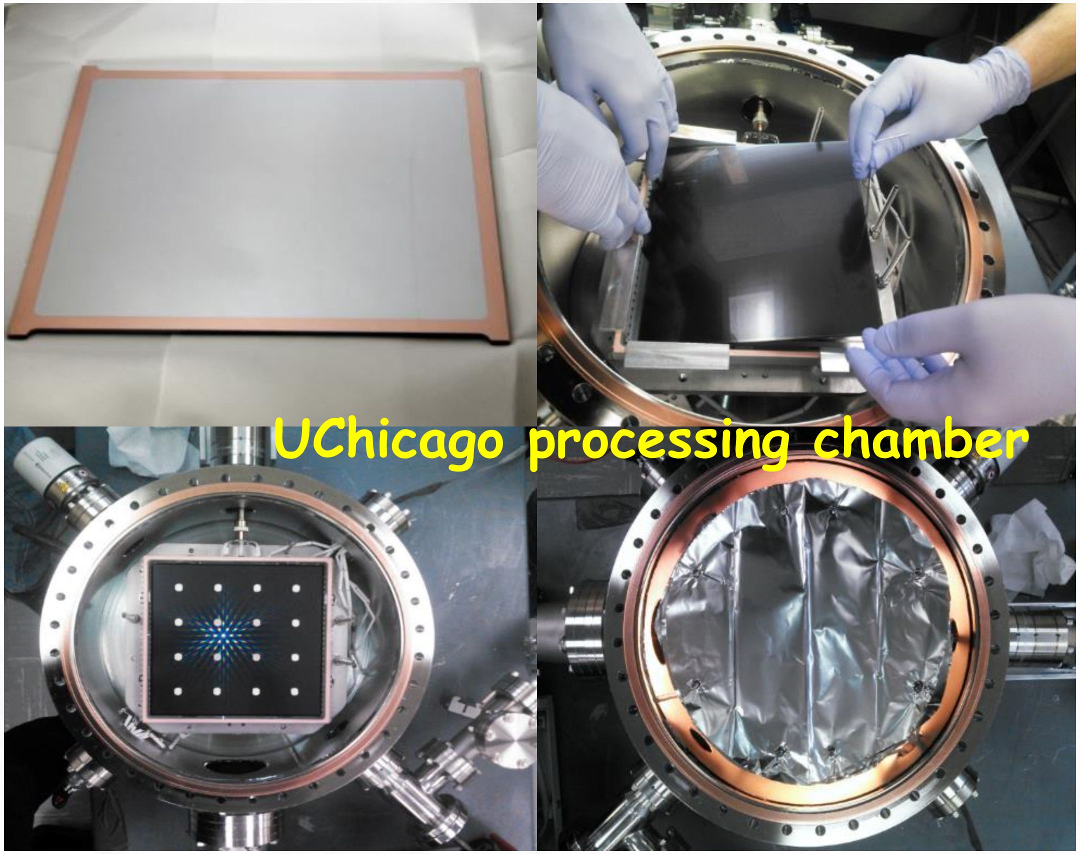
How many LAPPDs are needed?

- 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 experiment at Fermilab needs 20-100 LAPPDs
- 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

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

In-Situ Assembly Strategy

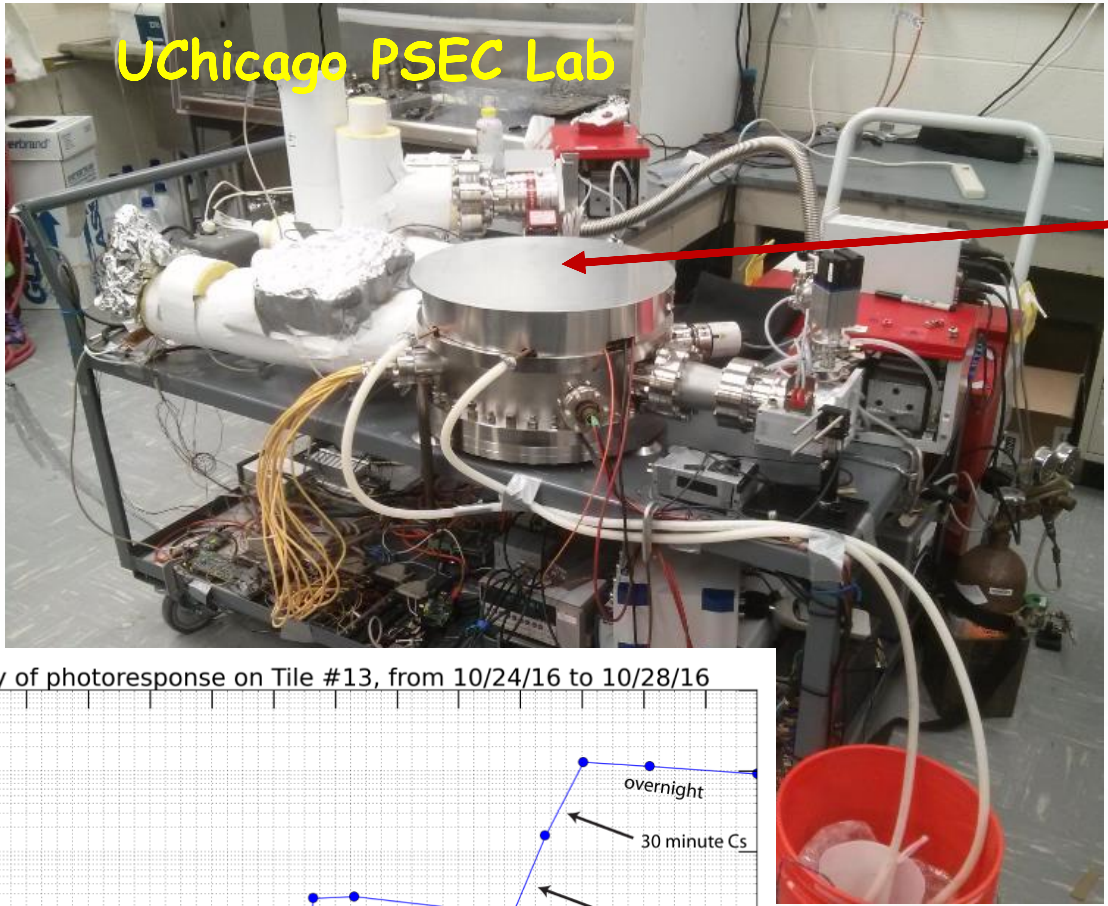
Simplify the assembly process by avoiding vacuum transfer:
make photo-cathode after the top seal
(PMT-like batch production)

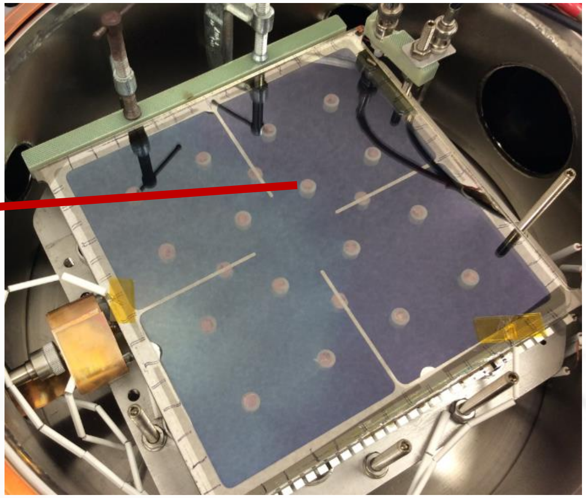


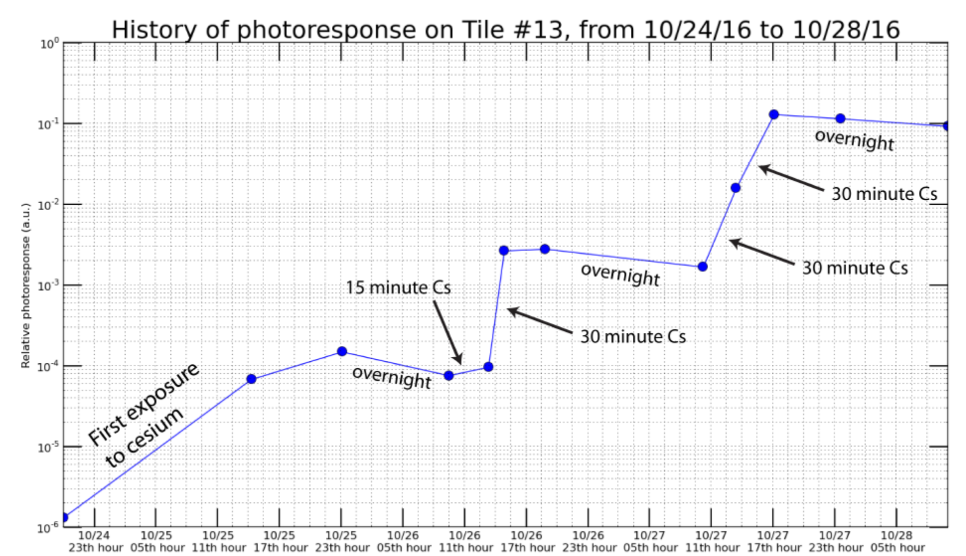
Step 1: pre-deposit Sb on the top window prior to assembly
Step 2: pre-assemble MCP stack in the tile-base
Step 3: do top seal and bake in the same heat cycle using dual vacuum system
Step 4: bring alkali vapors inside the tile to make photo-cathode
Step 5: flame seal the glass tube or crimp the copper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

In-Situ LAPPD Fabrication

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







Heat only the tile not the vacuum vessel

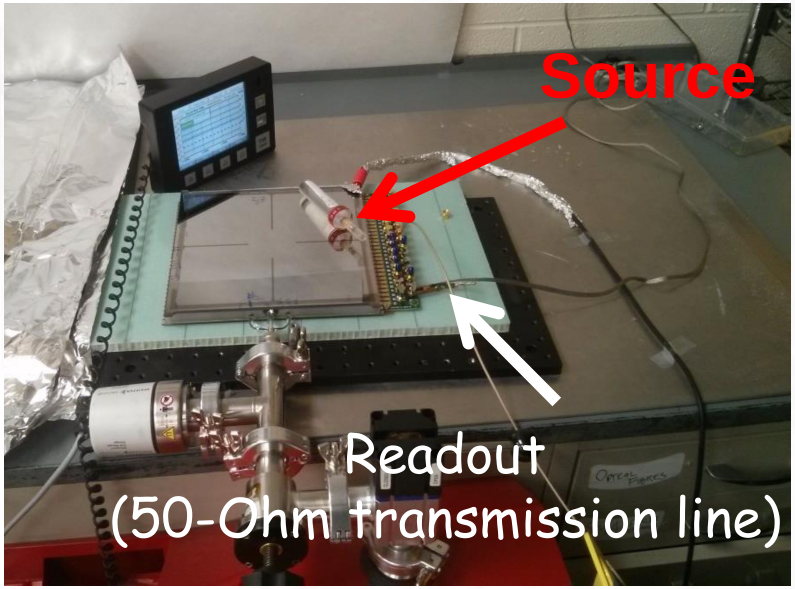
Intended for parallelization

First Signals from an In-Situ LAPPD

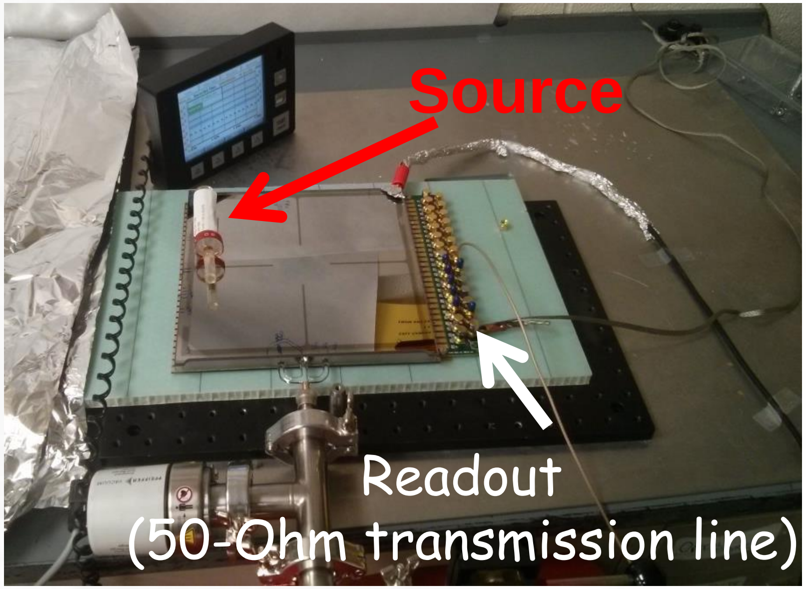
April, 2016

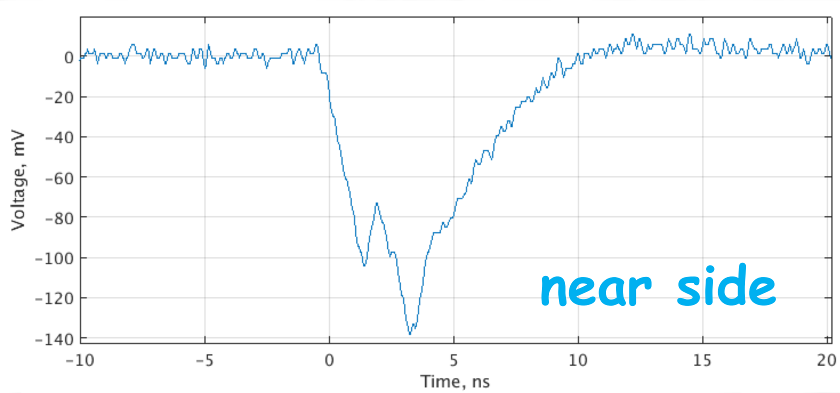
(Sb cathode)

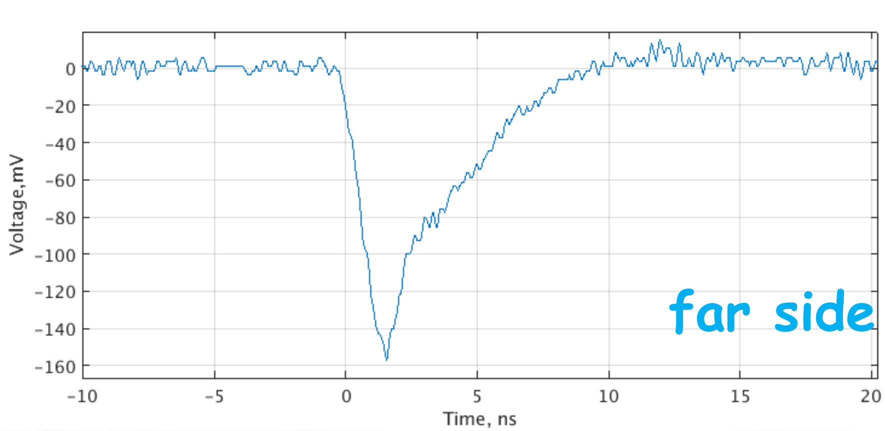
Near side: reflection from unterminated far end



Far side: reflection is superimposed on prompt





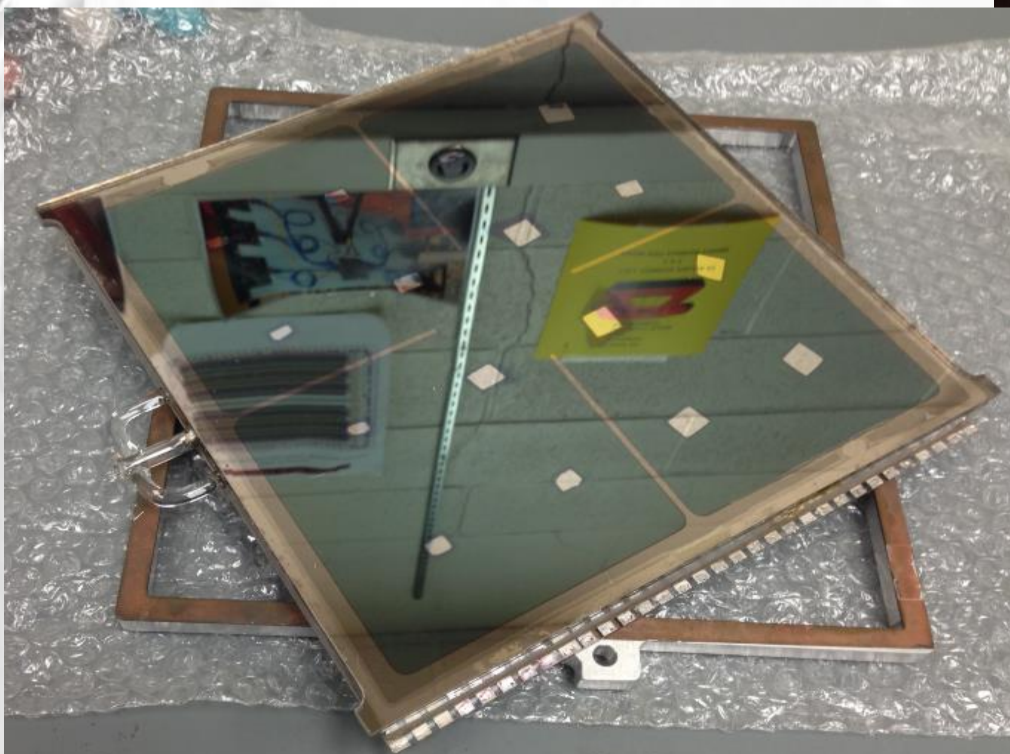


The tile is accessible for QC before photo-cathode shot
This is helpful for the production yield

First Sealed In-Situ LAPPD

August 18, 2016

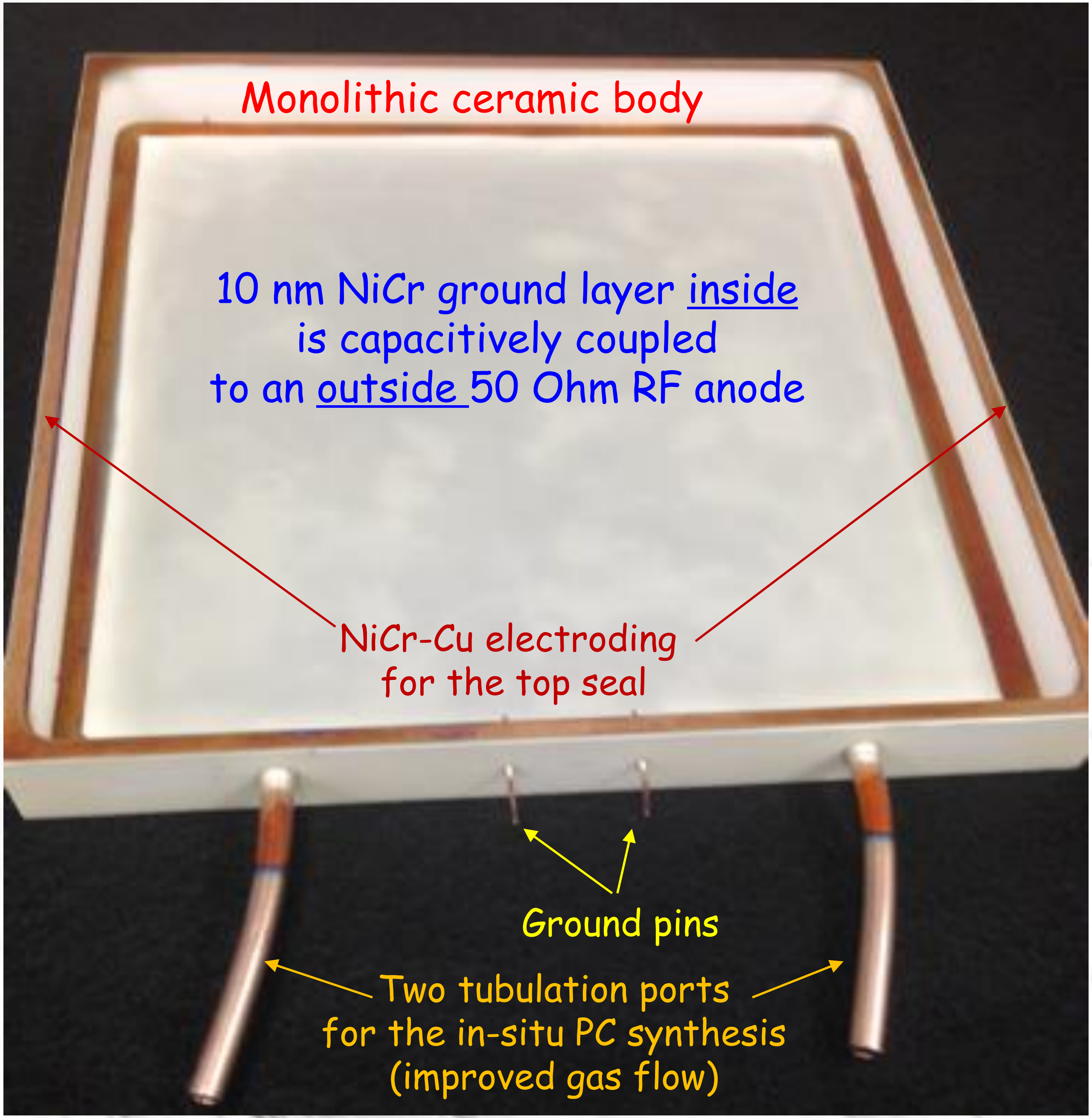
(Cs_3Sb photo-cathode)



Gen-II LAPPD

- Robust ceramic body
- Fused silica window
- 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

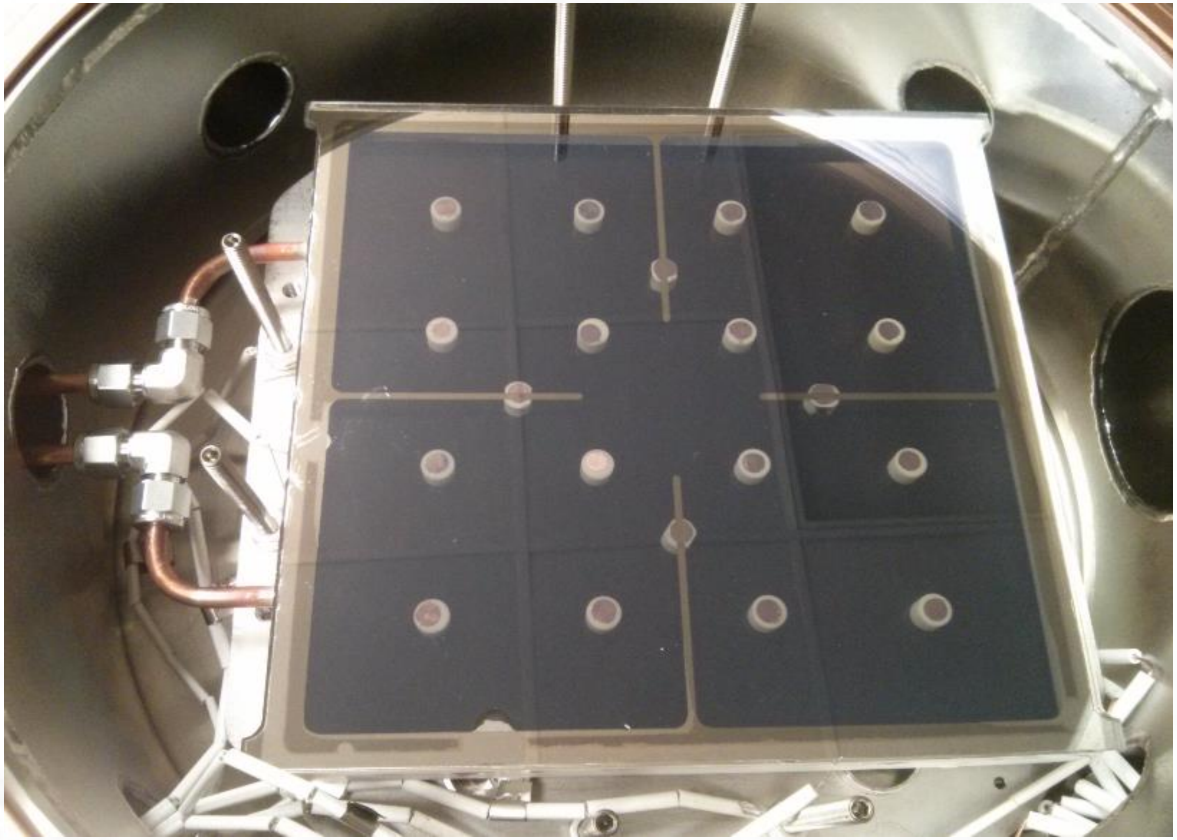
For details on capacitively coupled anode see NIMA 846 (2016) 75



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

Gen-II LAPPD: work in progress

January, 2017



In-Situ LAPPD milestones:

- Developed a robust metallurgy scheme for hermetic packaging
- Demonstrated 8x8" PC made through a ¼" tube on a pre-deposited Sb layer
- Showed that Cs doesn't alter the resistive layer of the MCPs

Next steps:

- Improved bake-out procedure for stable MCP operation
  - residual water vapor is the main factor contributing to unstable performance of the MCPs after their exposure to Cs

Summary

- Commercialization at Incom Inc. goes well
  - early LAPPD tiles are out for testing
  - transitioning from “commissioning” to “exploitation” stage
- With the goal to use LAPPDs in large experiments the UChicago group is focused on R&D for high volume production process
  - optimizing *In-Situ* photo-cathode synthesis
  - moving towards Gen-II LAPPD
  - building 2nd vacuum processing chamber -> parallelization

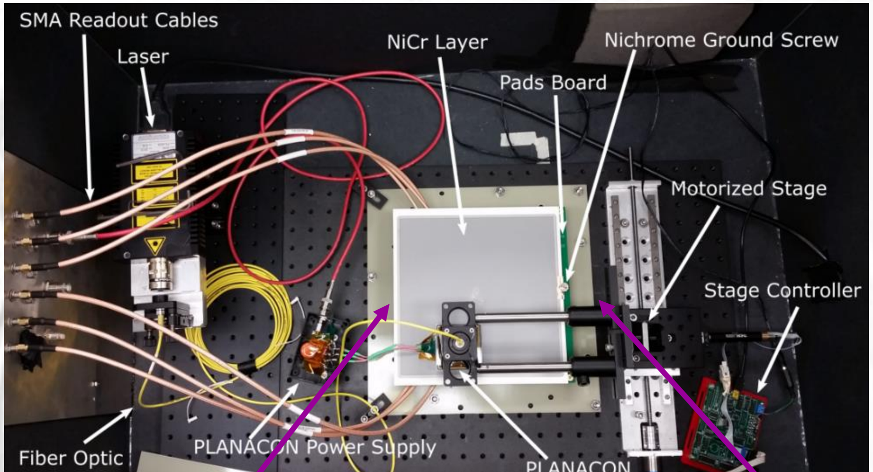
UChicago Team:
Evan Angelico
Andrey Elagin
Henry Frisch
Eric Spieglan

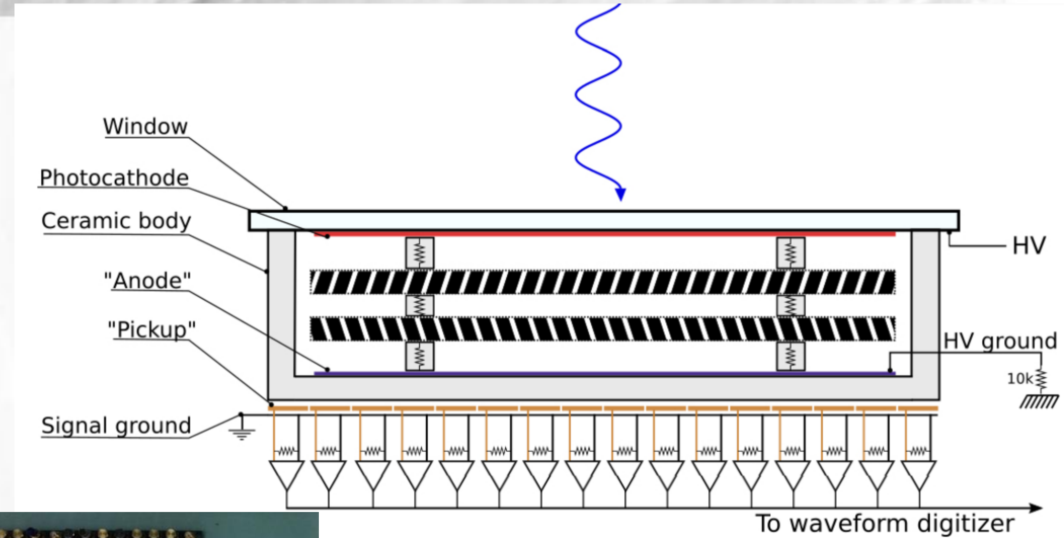
with engineering support by
Richard Northrop

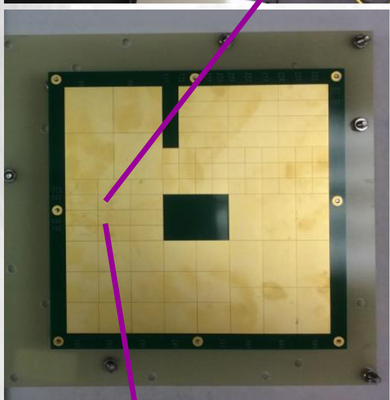
and lots of help from undergraduates and summer students

Back-up

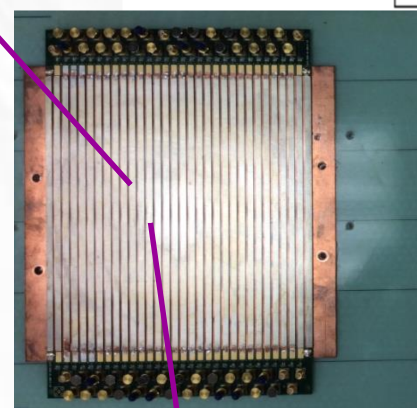
Gen-II LAPPD: "inside-out" anode



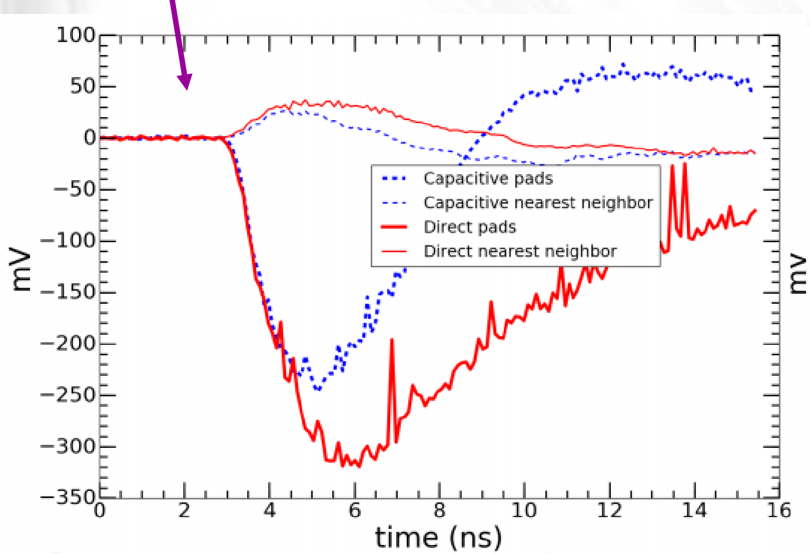


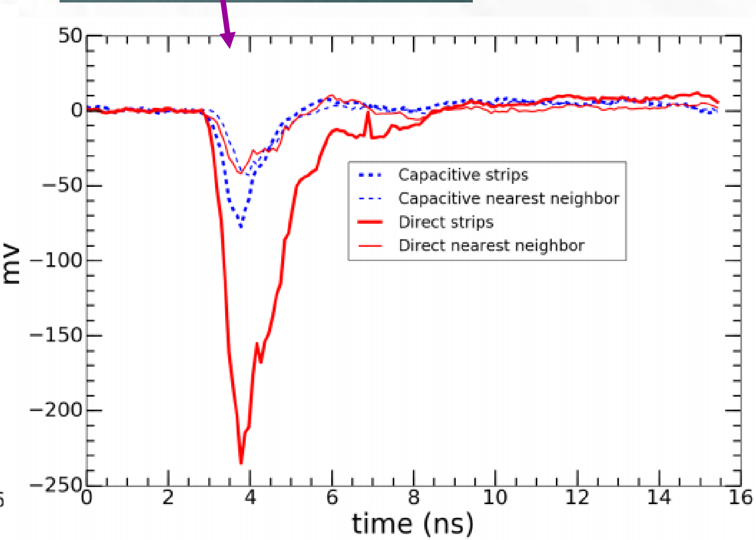


Chose your own readout pattern



- Custom anode is outside
- Capacitively coupled
- Compatible with high rate applications

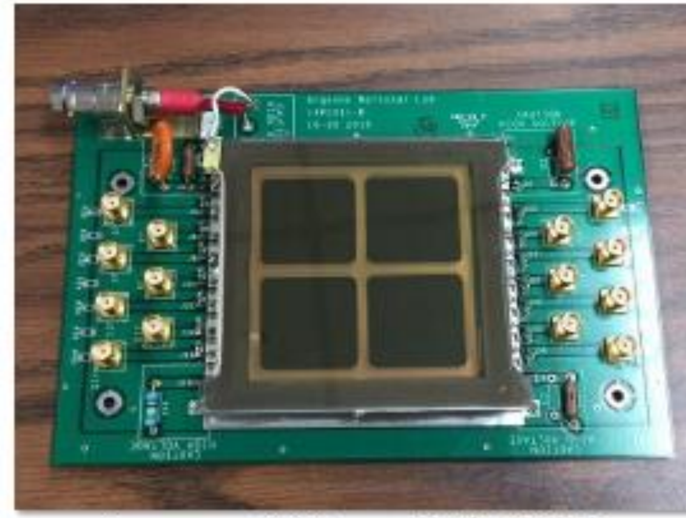




For details see NIMA 846 (2016) 75

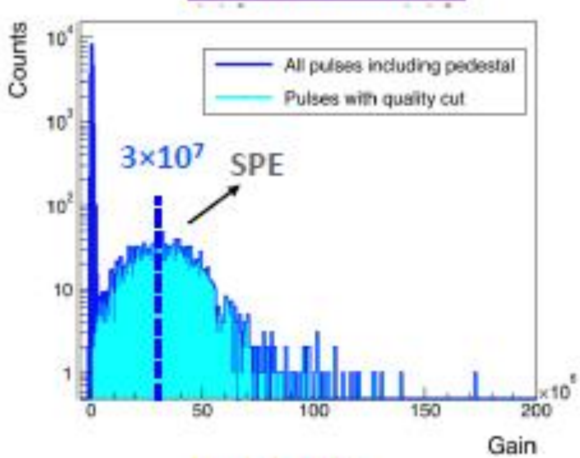
Argonne 6x6 cm^2 Photo-Detectors

- Argonne routinely producing 6X6 cm^2 functional detectors with K_2CsSb photocathode
- New IBD-1 design allows HV optimization, as biasing individual components possible
- In addition to assembly of photo-detectors, laser testing facility available and photocathode research ongoing.
- Performance:
  - Gain > 10^7
  - Quantum efficiency ~ 15%
  - Time resolution including the laser jitter: σ ~ 35 ps
  - Position resolution along anode strip: < 1 mm
  - Rate capability > 1 MHz/cm^2 for single photoelectrons



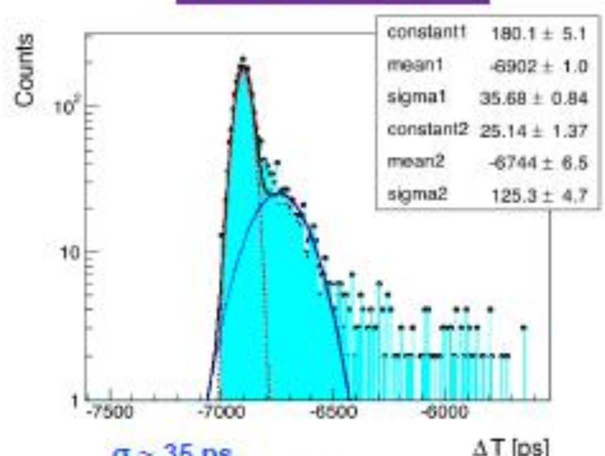
Argonne 6X6 cm MCP-PMT on custom readout board

Gain distribution



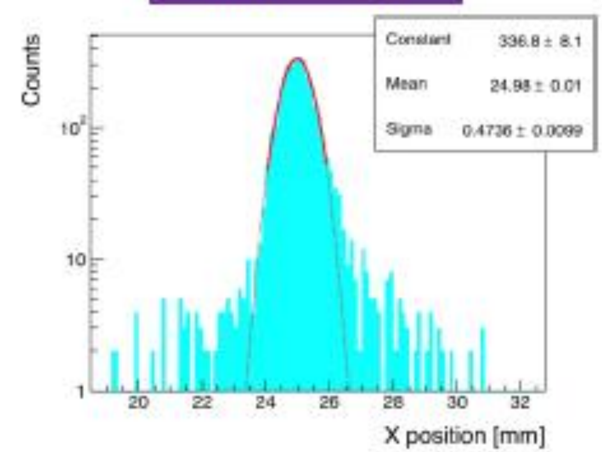
Gain > 10^7

Timing distribution

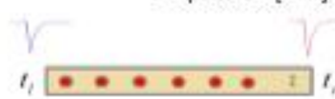


σ ~ 35 ps for SPE, including Laser jitter

Position resolution



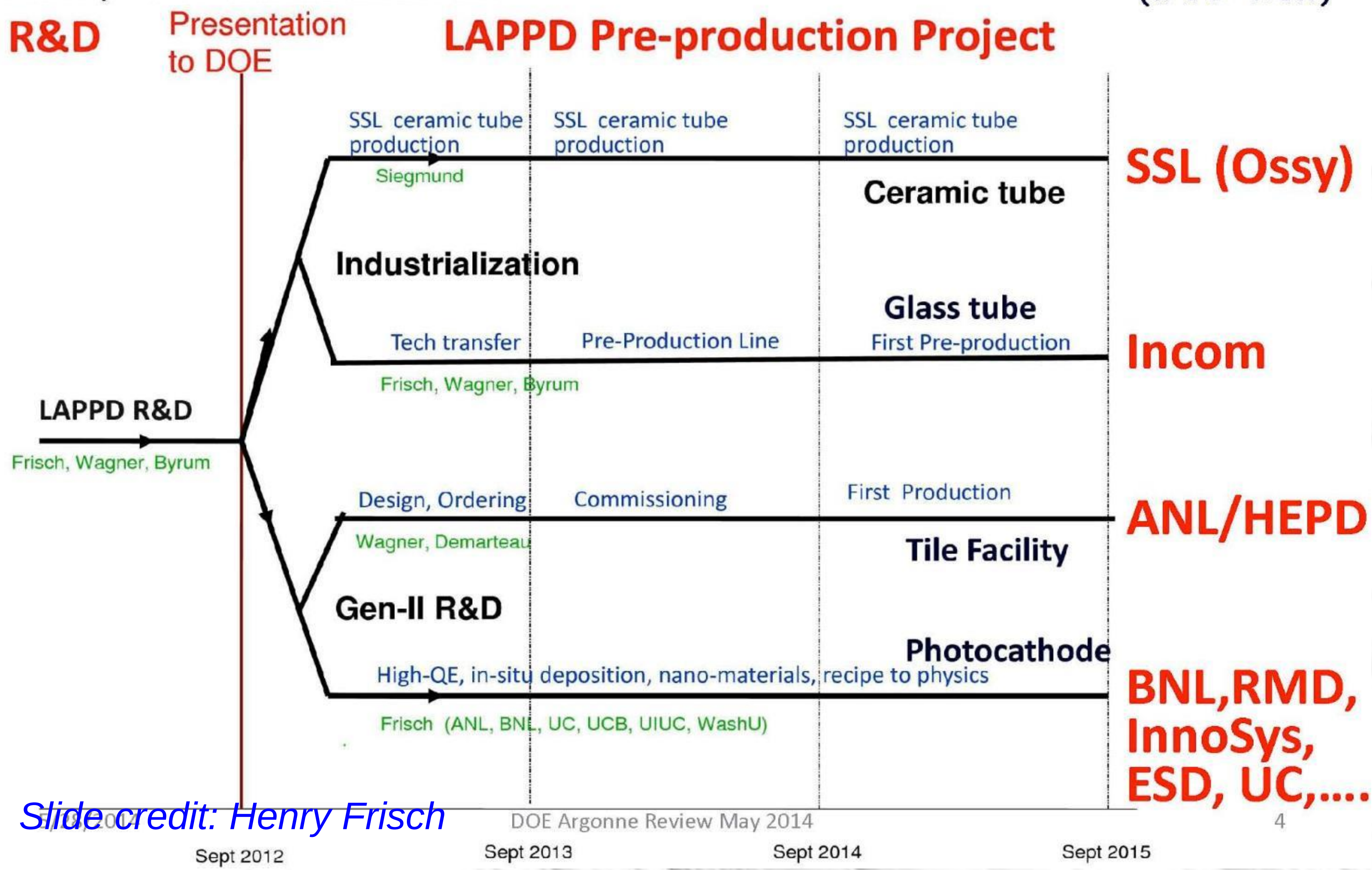
σ < 1 mm for SPE



Slide courtesy of R. Darmapalan and R. Wagner

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

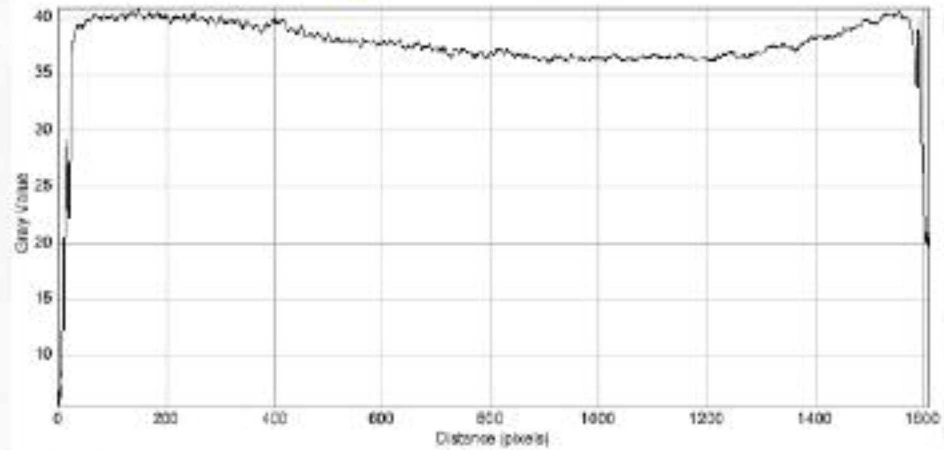
Dec 12, 2012 Presentation to DOE (a UC view)

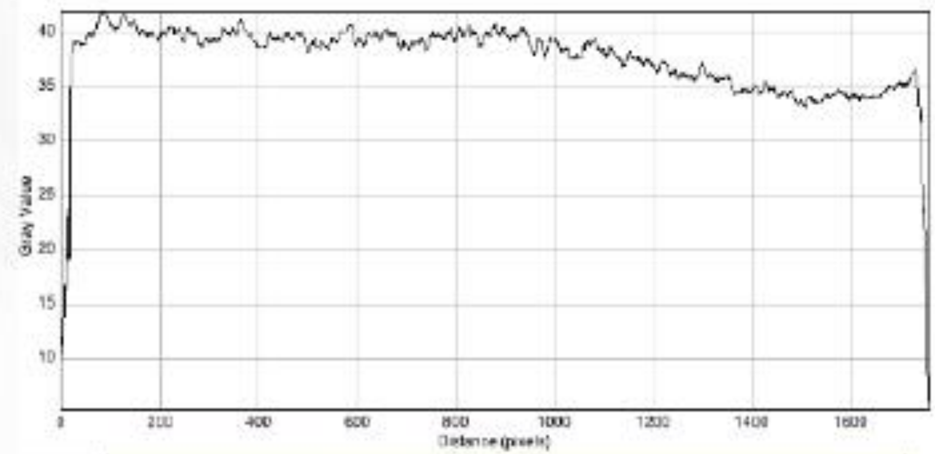


Slide credit: Henry Frisch

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 cm^2 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).

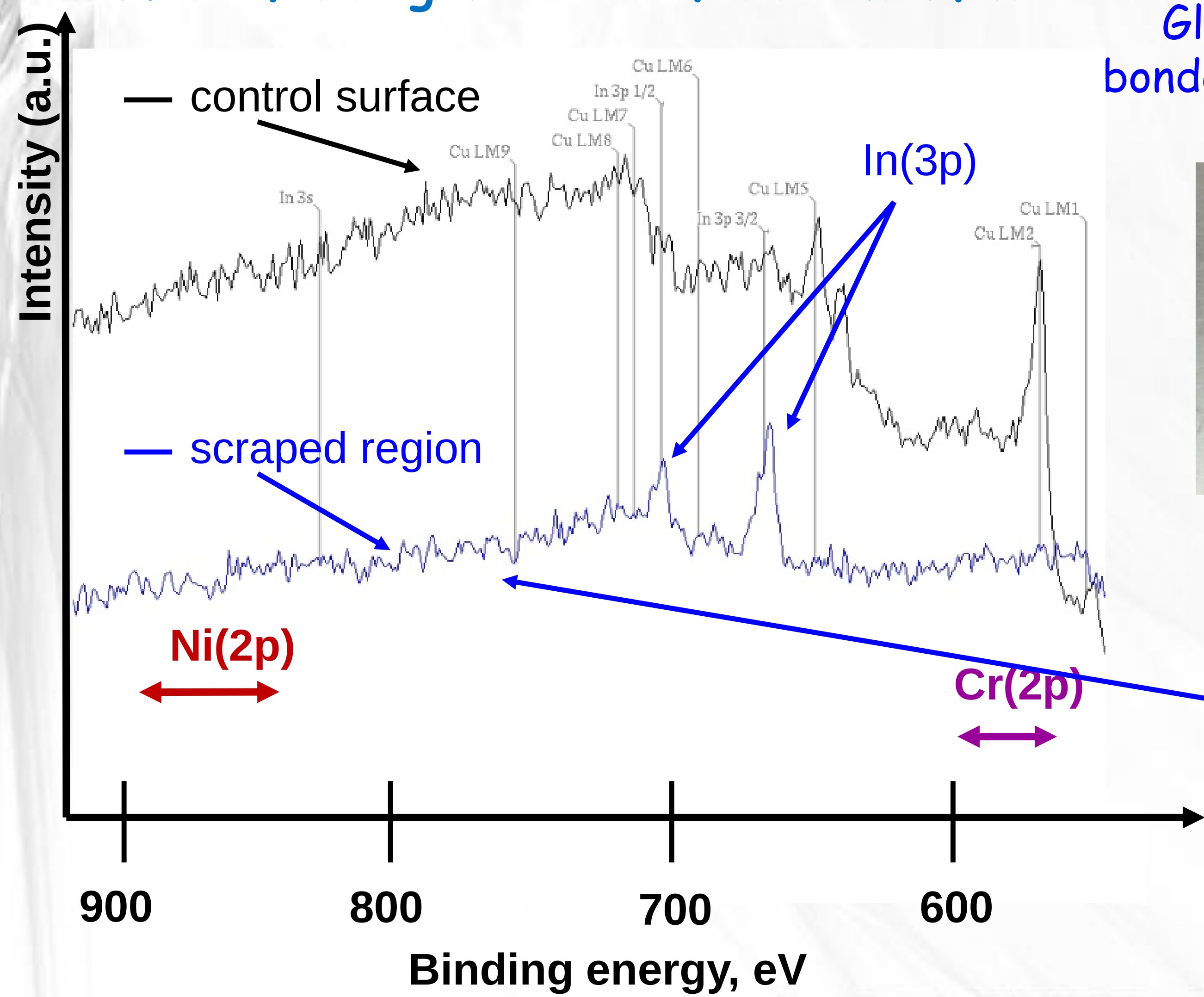
Noise <0.1 counts cm^{-2} s^{-1}

Metallurgy of a Good Seal

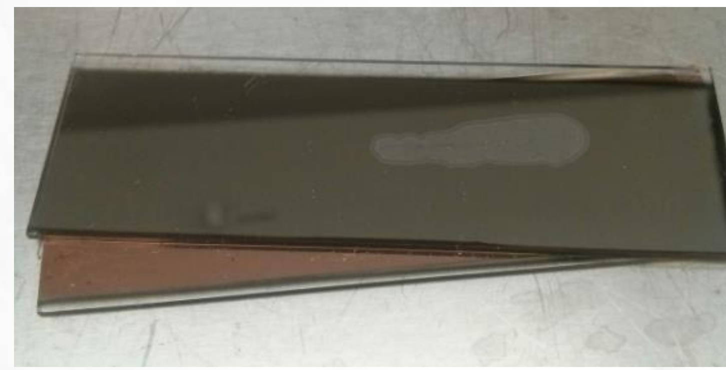
Higher temperatures and longer exposure time

- Indium penetrates through entire NiCr layer

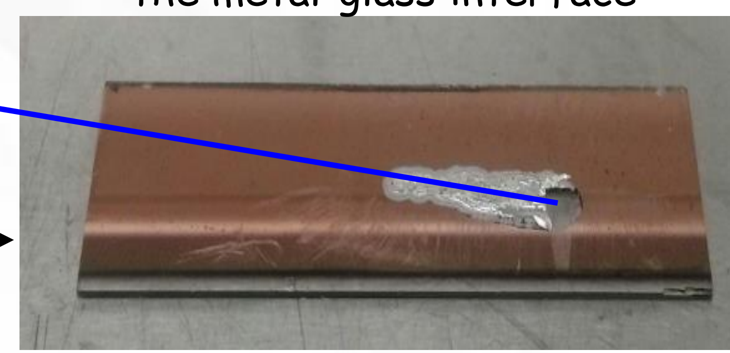
XPS of the glass side of the interface



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

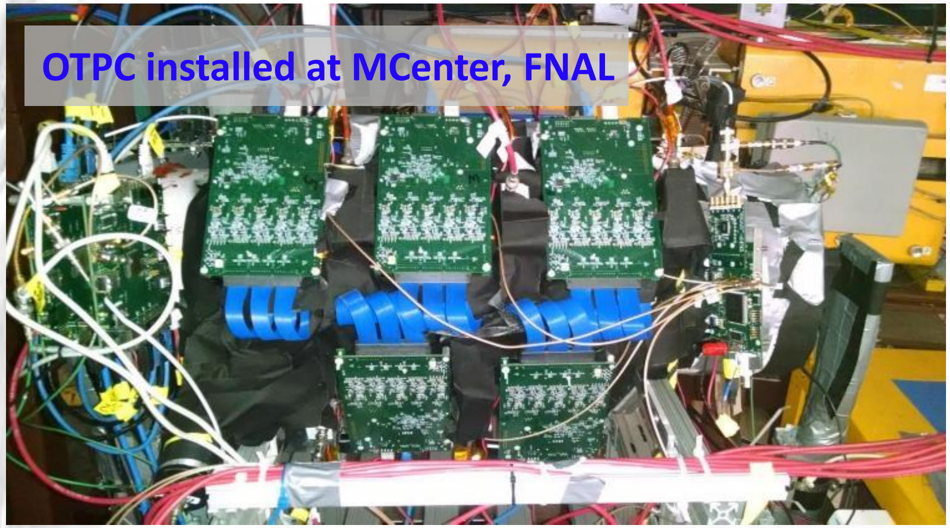
XPS data courtesy of A. Filatov at UChicago

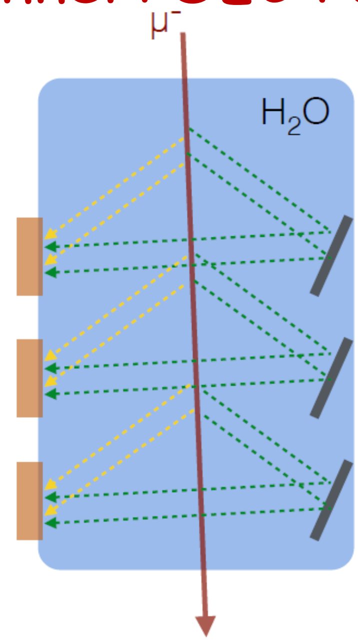
Optical Tracking Demonstration

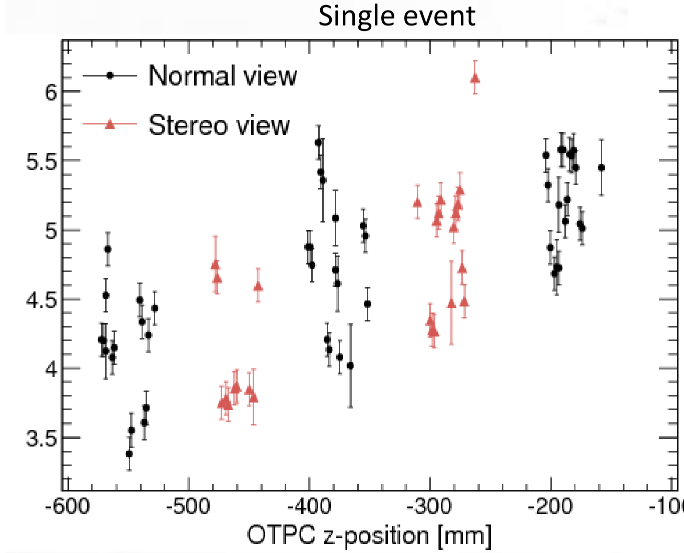
Eric Oberla PhD thesis

NIM A814 (2016) 19

180-channel PSEC4 system



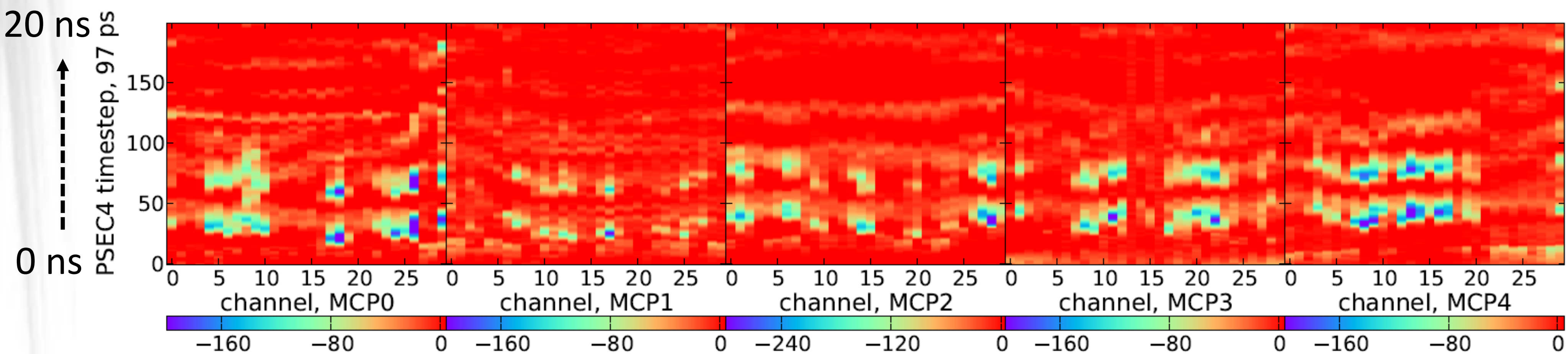




Example event

Typical event (thru-going μ)

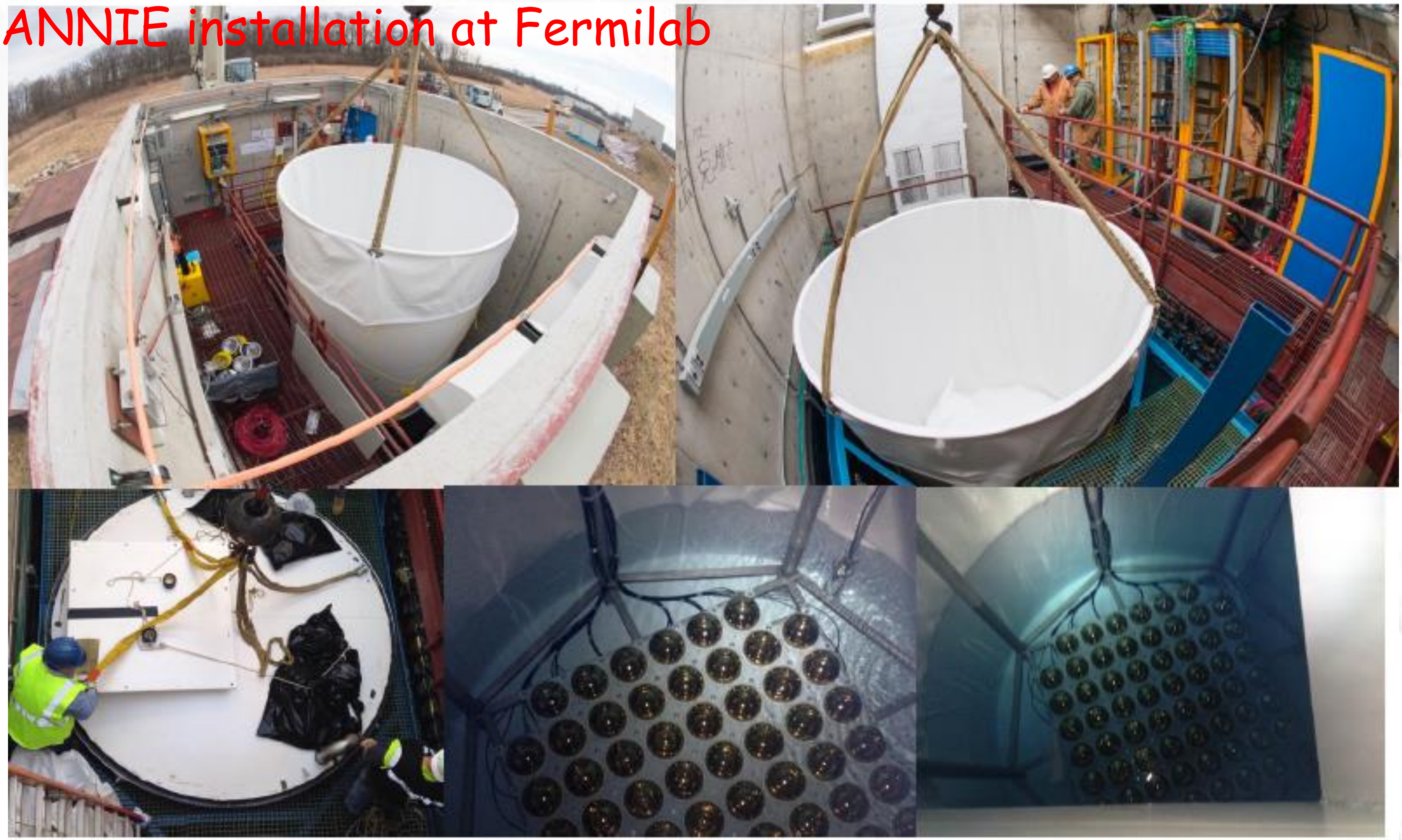
-570 mm - → -160 mm



The ANNIE Experiment

- Measure neutron multiplicity in neutrino-nucleus interactions
- R&D towards water-based neutrino detection technology
- Explore optical tracking using novel photo-detectors

ANNIE installation at Fermilab



Data taking is ongoing