LAPPD™

Large-Area Picosecond Photo-Detectors

Andrey Elagin
University of Chicago

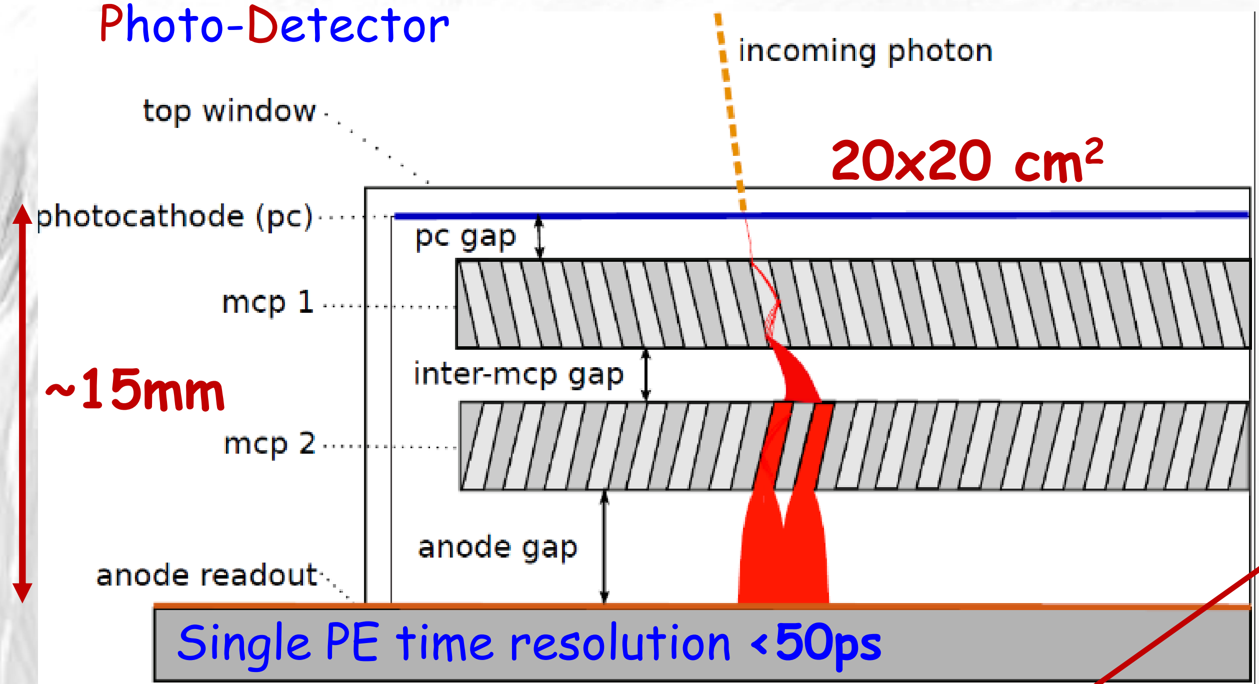
Research Techniques Seminar, Fermilab, November 28, 2017

Outline

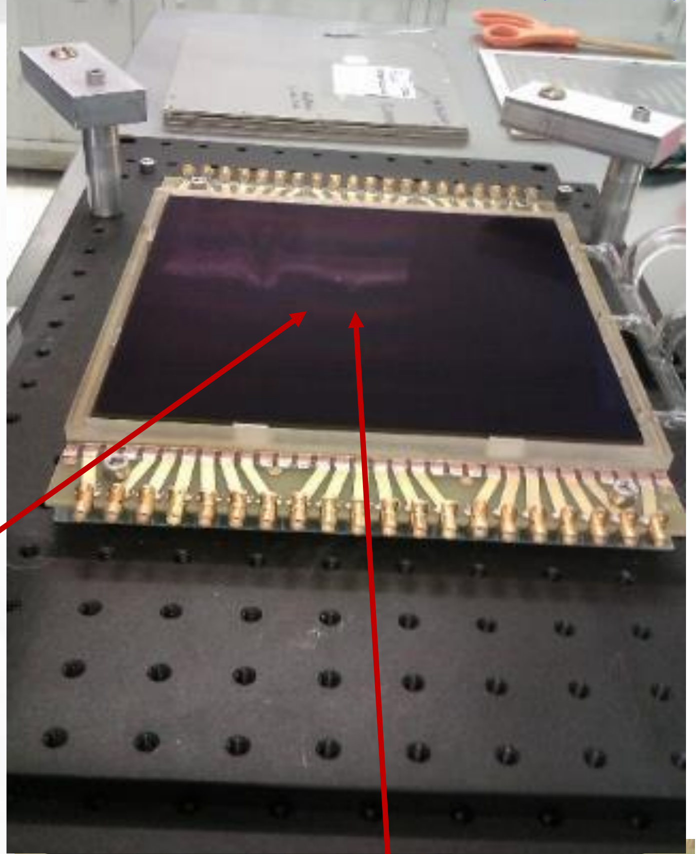
- Introduction to LAPPD^{TM} and potential applications
- LAPPD^{TM} commercialization status
- R&D towards a batch production process

LAPPD™

Large-Area Picosecond Photo-Detector

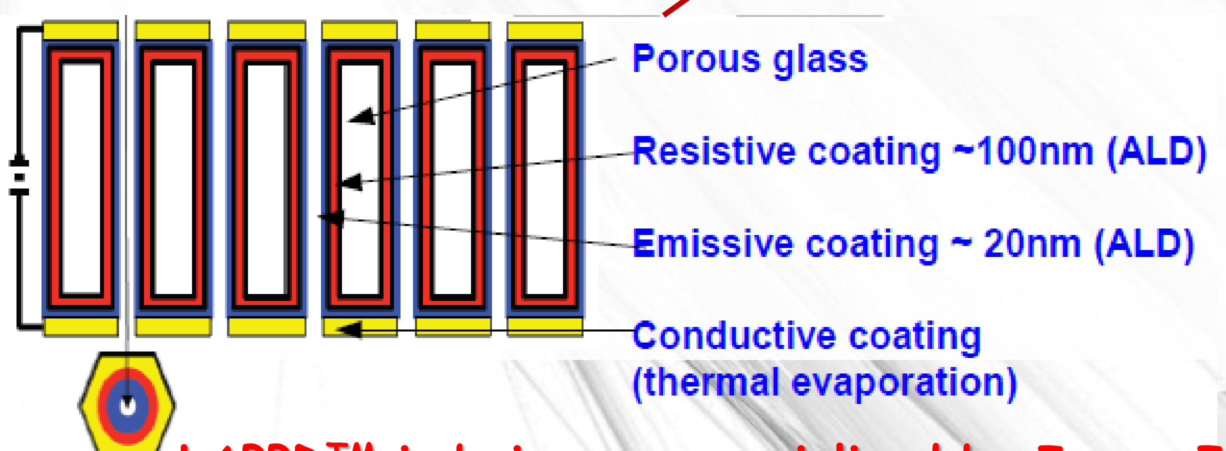


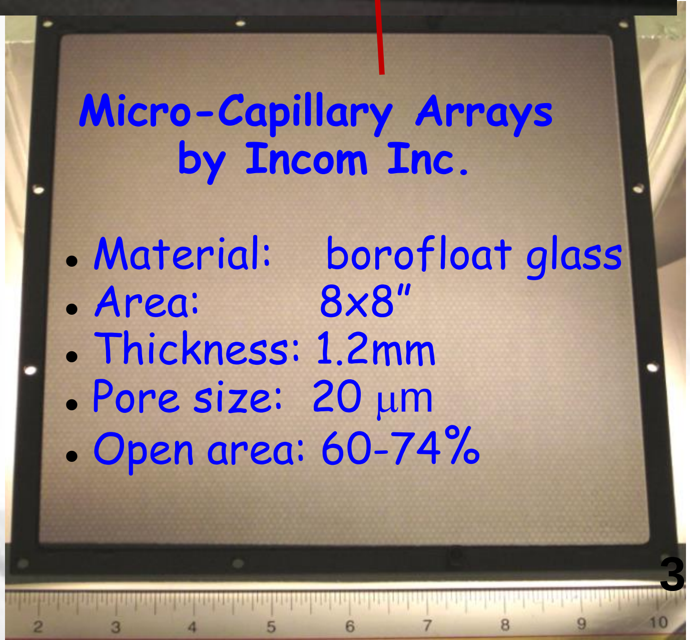
Micro-Channel Plates (MCPs)



Atomic Layer Deposition (ALD)

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

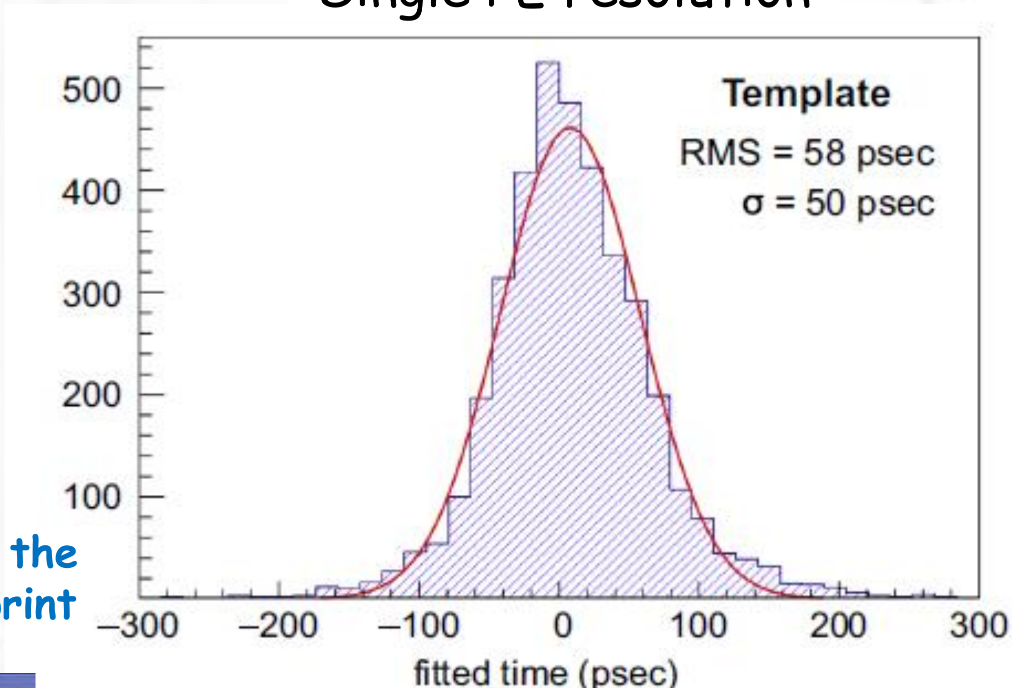


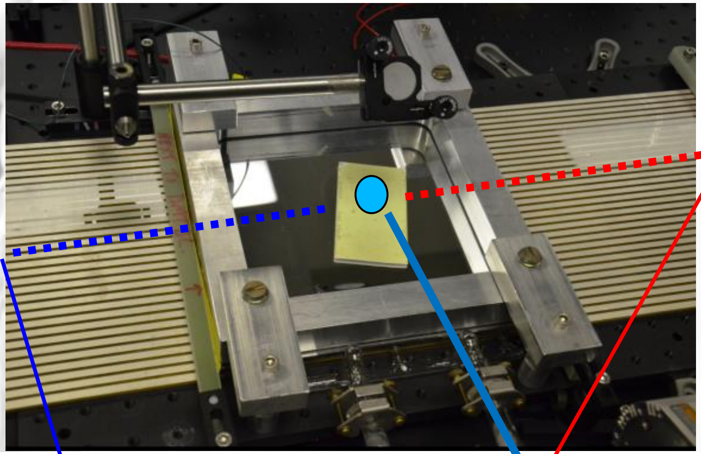


LAPPD™ is being commercialized by Incom Inc.

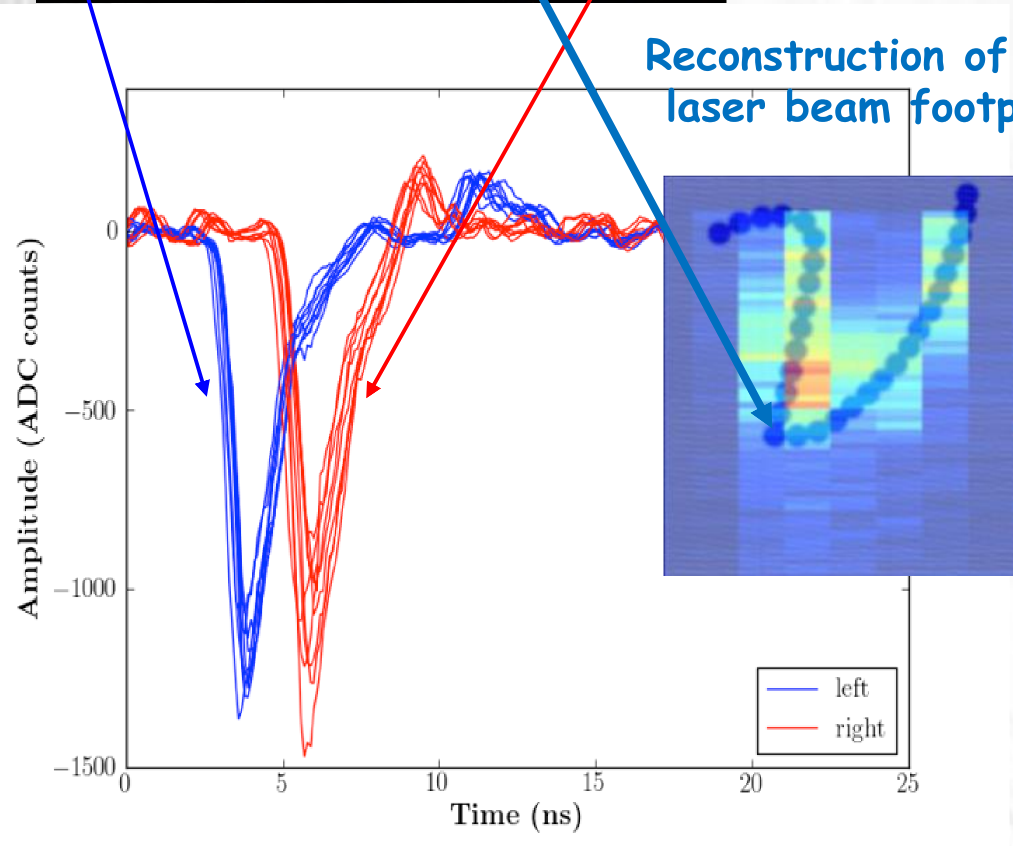
LAPPD Prototype Testing Results

Single PE resolution





Reconstruction of the laser beam footprint



Demonstrated characteristics:

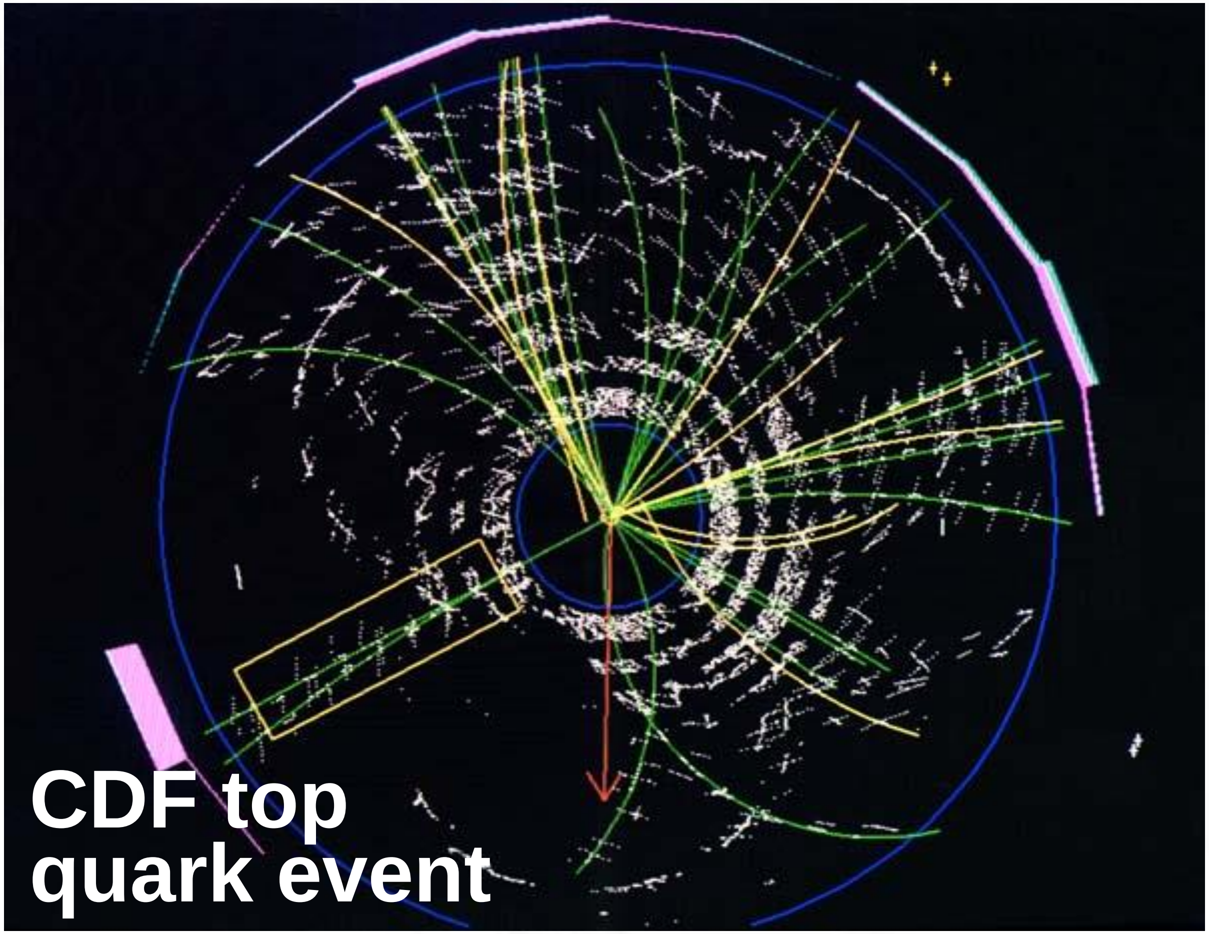
single PE timing ~50ps
multi PE timing ~35 ps
differential timing ~5 ps
position resolution < 1 mm
gain >10^7

RSI 84, 061301 (2013),
NIMA 732, (2013) 392
NIMA 795, (2015) 1
arXiv:1603.01843

See our doc library at:
http://lappddocs.uchicago.edu/

Colliders

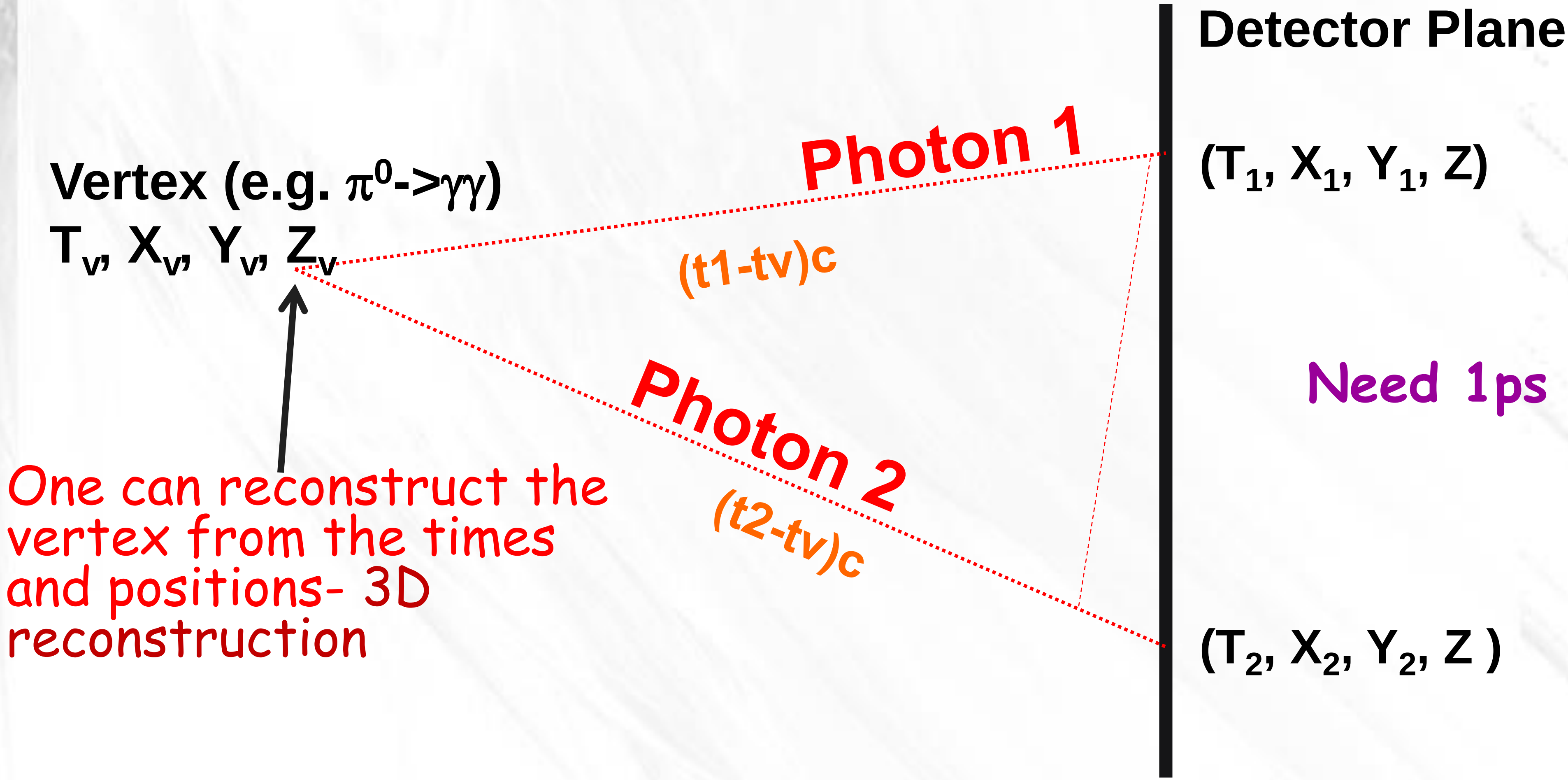
- Identify the quark content of charged particles
- Assign tracks and photons to vertices



Need 1ps

Vertexing Using Arrival 4D-points

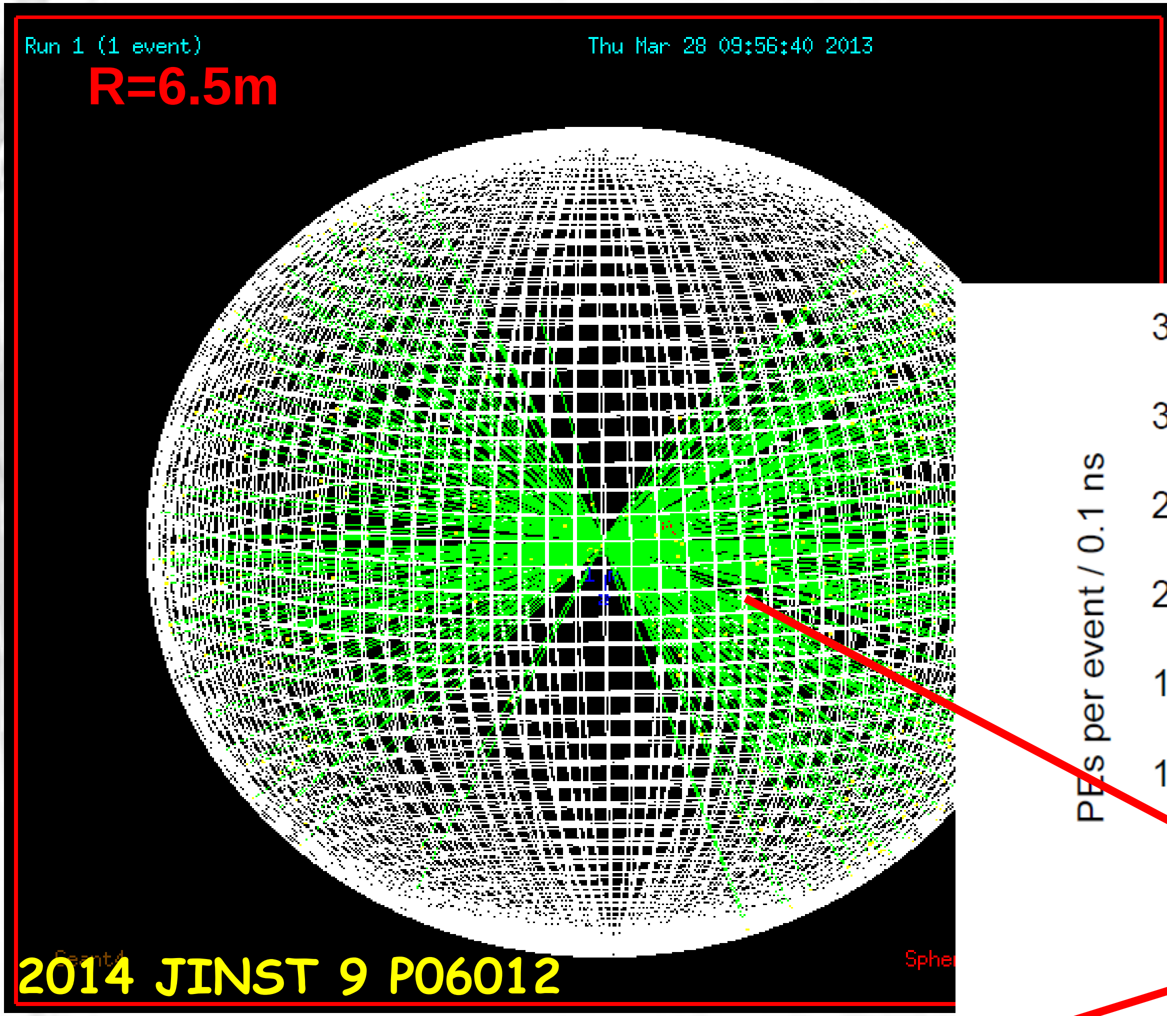
E.g. rare Kaon decays (KOTO at JPARC): background rejection by reconstructing π^0 vertex space point (beat combinatorics background)



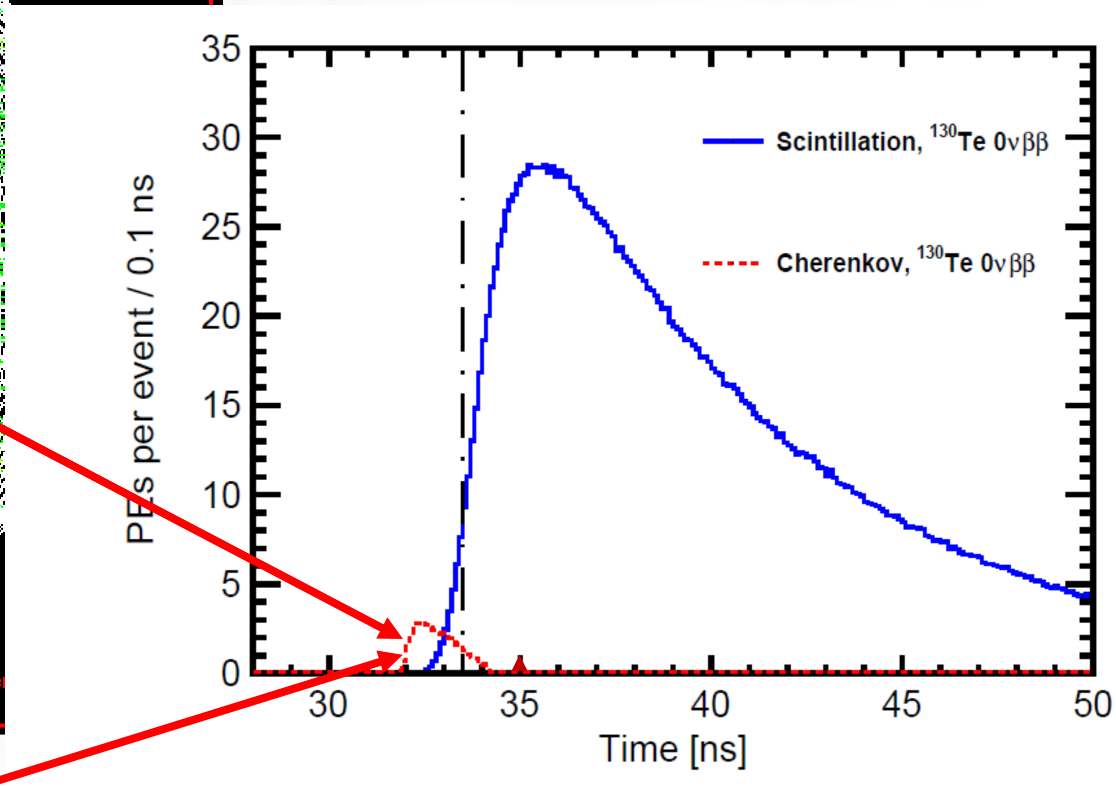
Large Directional Liquid Scintillator

Simulation of a $0\nu\beta\beta$ event
(selected event with large angle between electrons)

- Distinct two-track topology with preference to be "back-to-back"
- Most of electrons are above Cherenkov threshold



PE arrival times, TTS=100 ps

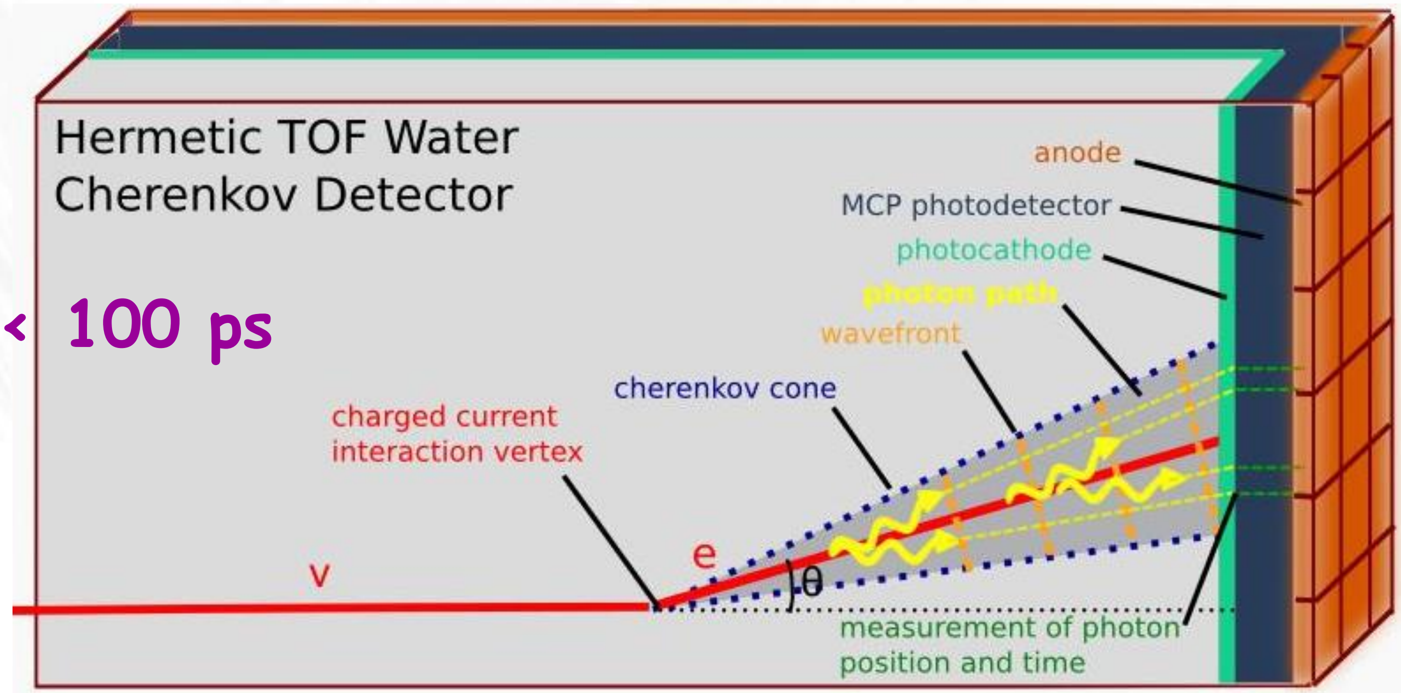


Fast (arrives early) and directional
- directionality reconstruction
- event topology reconstruction (e.g., 2-track vs 1-track)

Optical Time Projection Chamber

- Like a TPC but drifts photons instead of electrons
- Exploits precise location and time for each detected photon
- Would allow track /vertex reconstruction in large liquid counters

Need < 100 ps

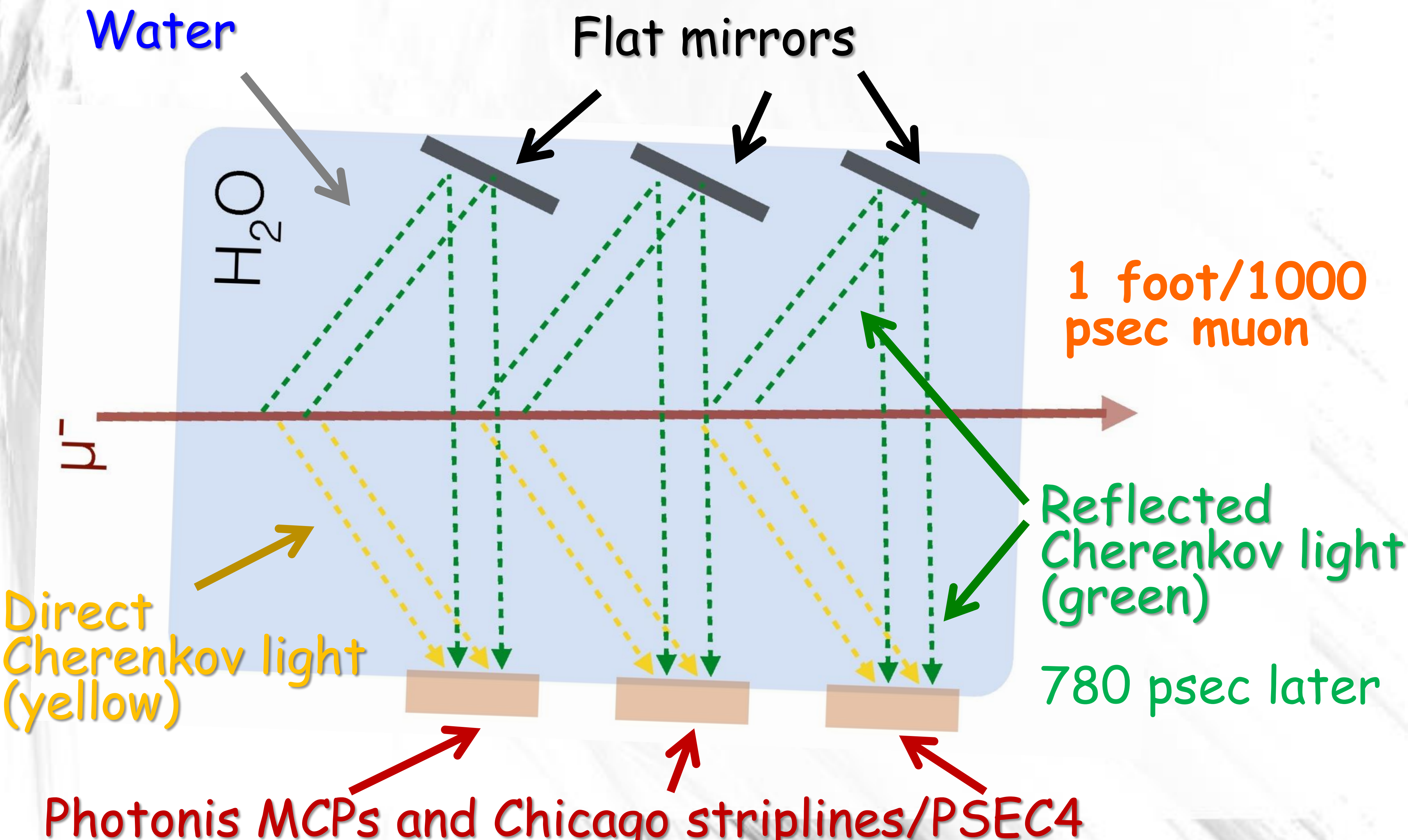


Suggestion to use LAPPD's for DUSEL and the name (OTPC) due to Howard Nicholson

- It doesn't have to be water (use prompt Cherenkov light that arrives early)
- In fact, for long tracks optical tracking should also work using just scintillation

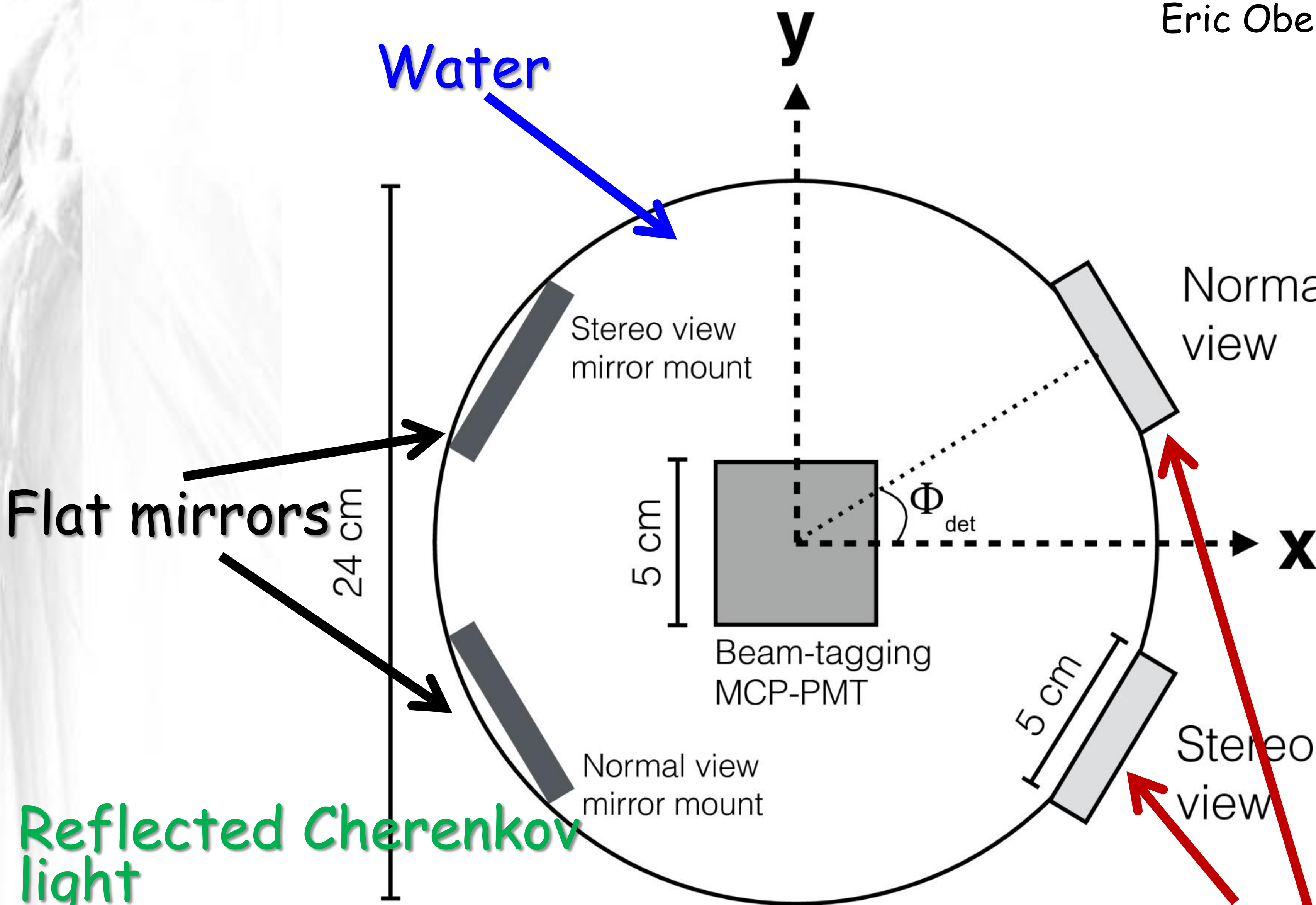
Eric Oberla's Optical TPC

Eric Oberla's Ph.D thesis



Beam's Eye View of the OTPC

Eric Oberla's Ph.D thesis

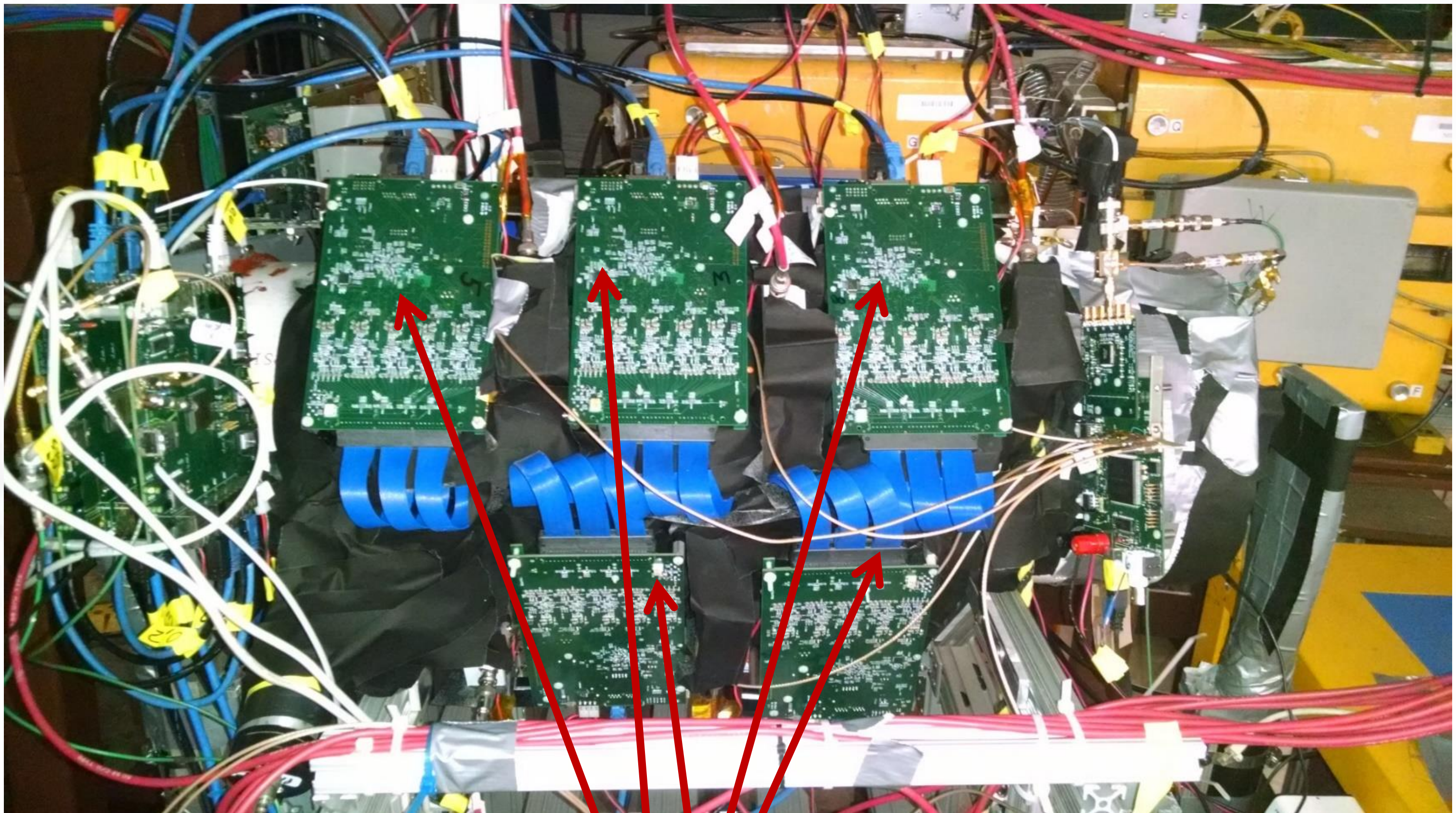


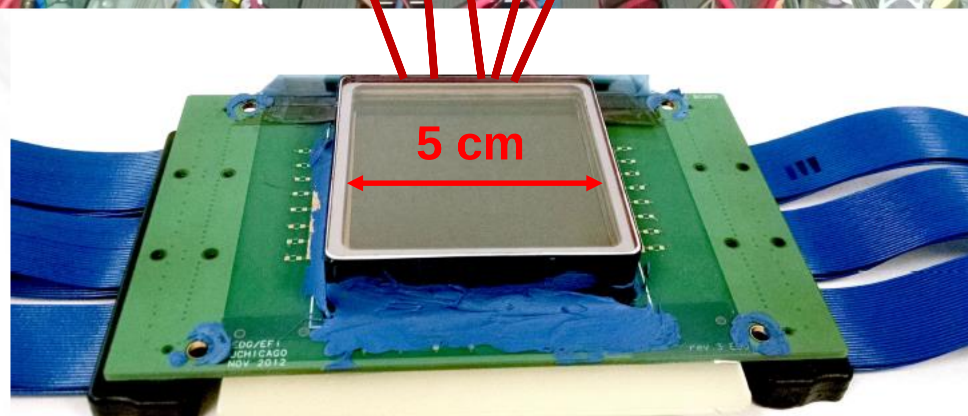
Reflected Cherenkov light arrives 780 psec later depending on position and angle

Photonis MCPs and Chicago striplines/PSEC4

OTPC at Fermilab Test Beam

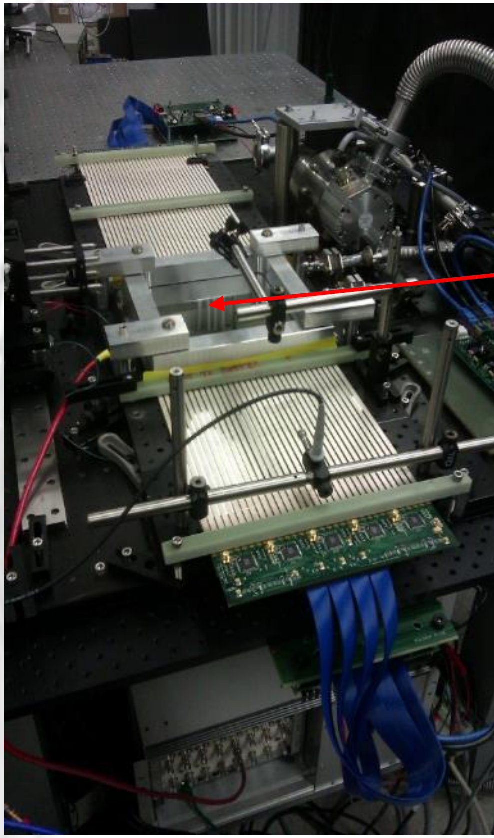
Eric Oberla's Ph.D thesis

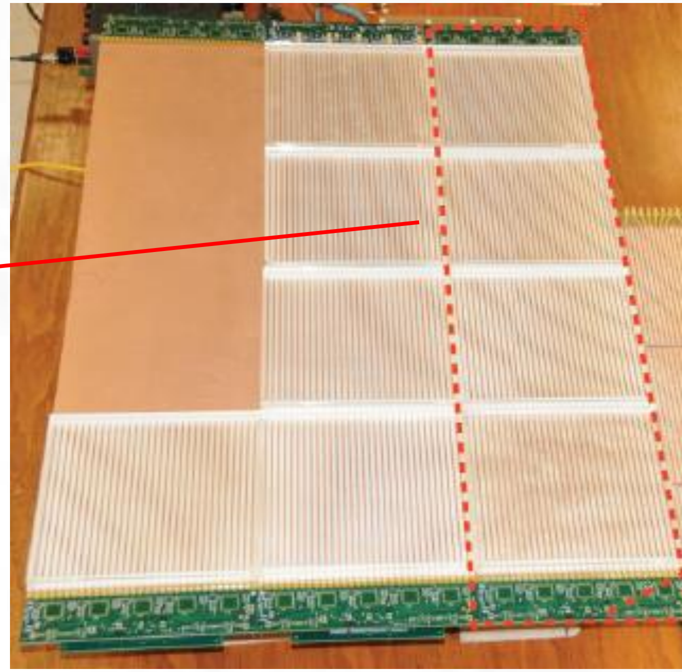


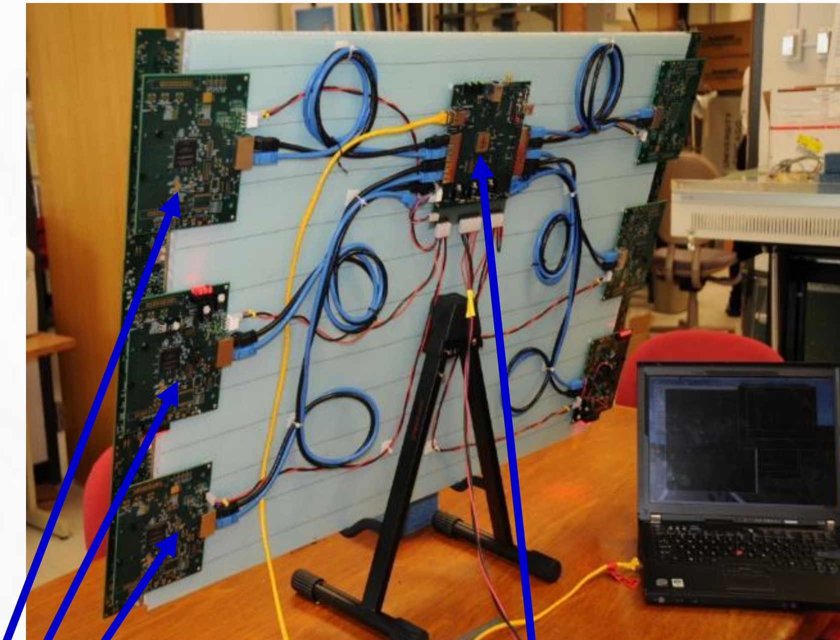


Five Photonis Planacons

LAPPD Electronics at Chicago







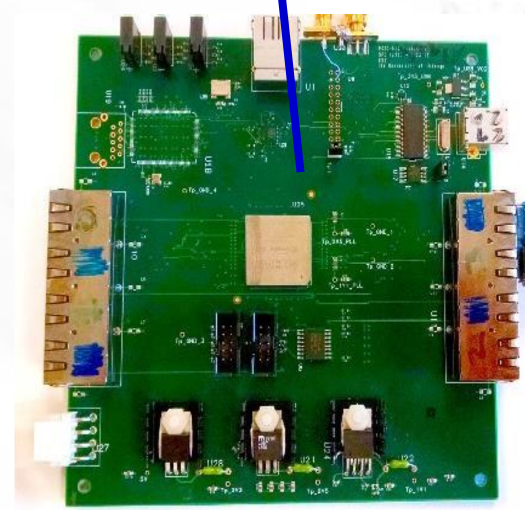
NIM 711 (2013) 124

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

NIM 735 (2014) 452

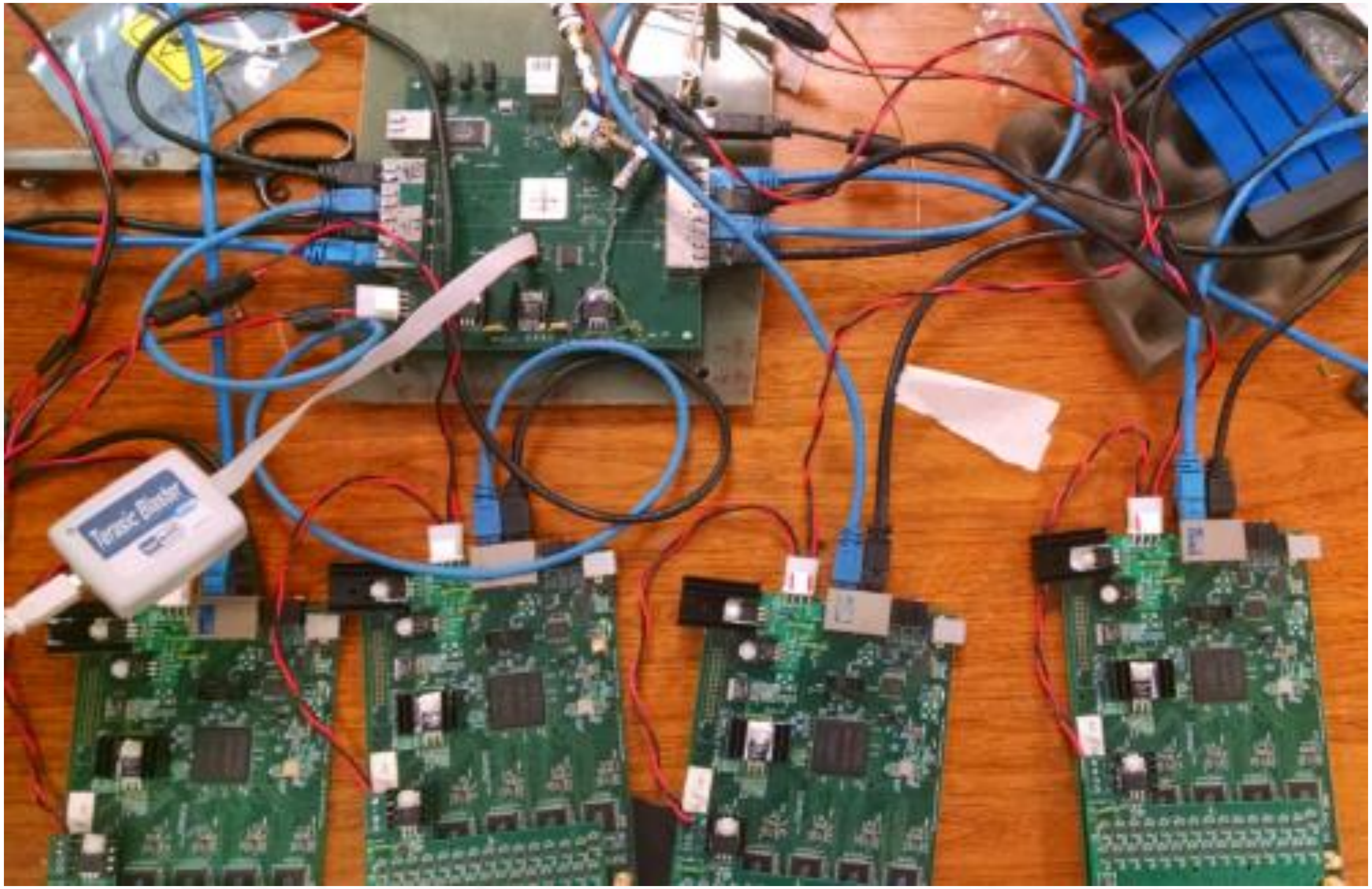
PSEC-4 ASIC chip
- 6-channel, 1.5 GHz, 10-15 GS/s

30-Channel ACDC Card
(5 PSEC-4)



Central Card
(4-ACDC;120ch)

Multichannel Systems



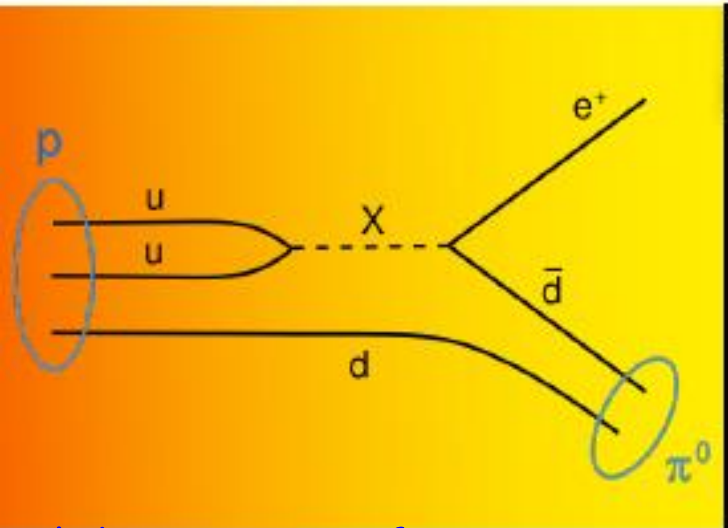
- 60-channel LAPPD prototype at the ANL Laser Lab
- 180-channel self-triggered Optical TPC at Fermilab
- Central card controls several front end boards
- New central cards by Mircea Bogdan handles 1920 channels
- PSEC4A is back from Mosis (funded by Sandia, work by E.Oberla)

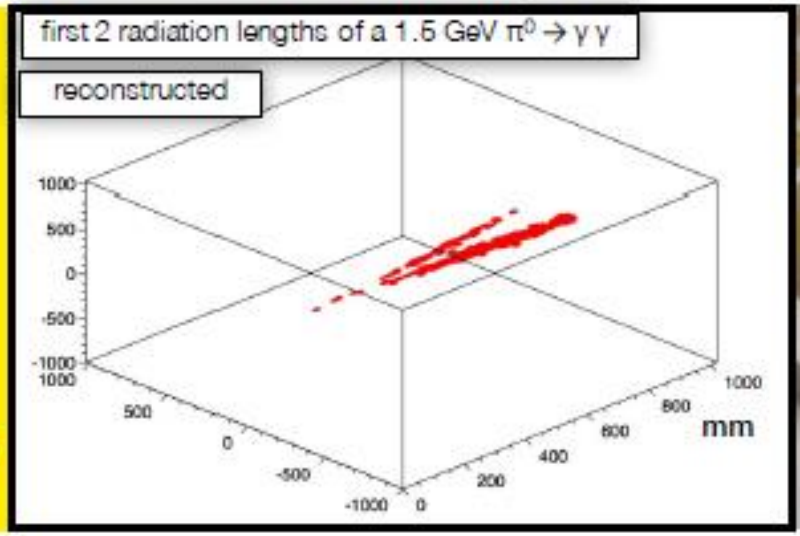
ANNIE Experiment at Fermilab

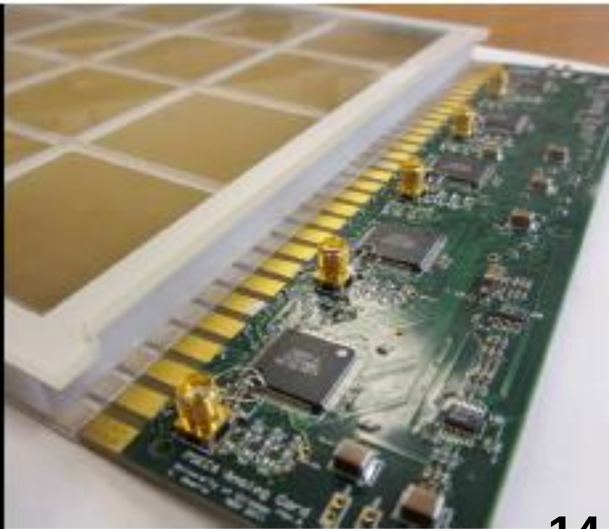
What is ANNIE?

The Accelerator Neutrino Neutron Interaction Experiment

- A measurement of the abundance of final state neutrons from neutrino interactions to aid in understanding neutrino-nucleus interactions.
- An R&D effort to further water-based neutrino detection technology.





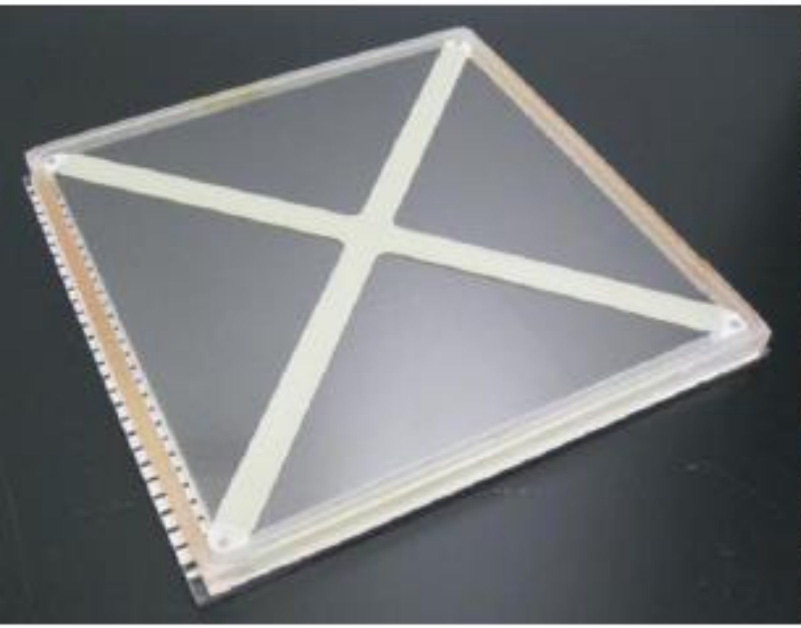


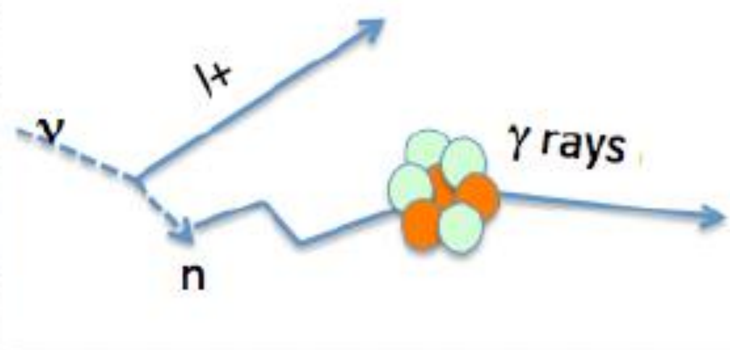
Slide courtesy of M.Wetstein

ANNIE and LAPPD™

ANNIE R&D

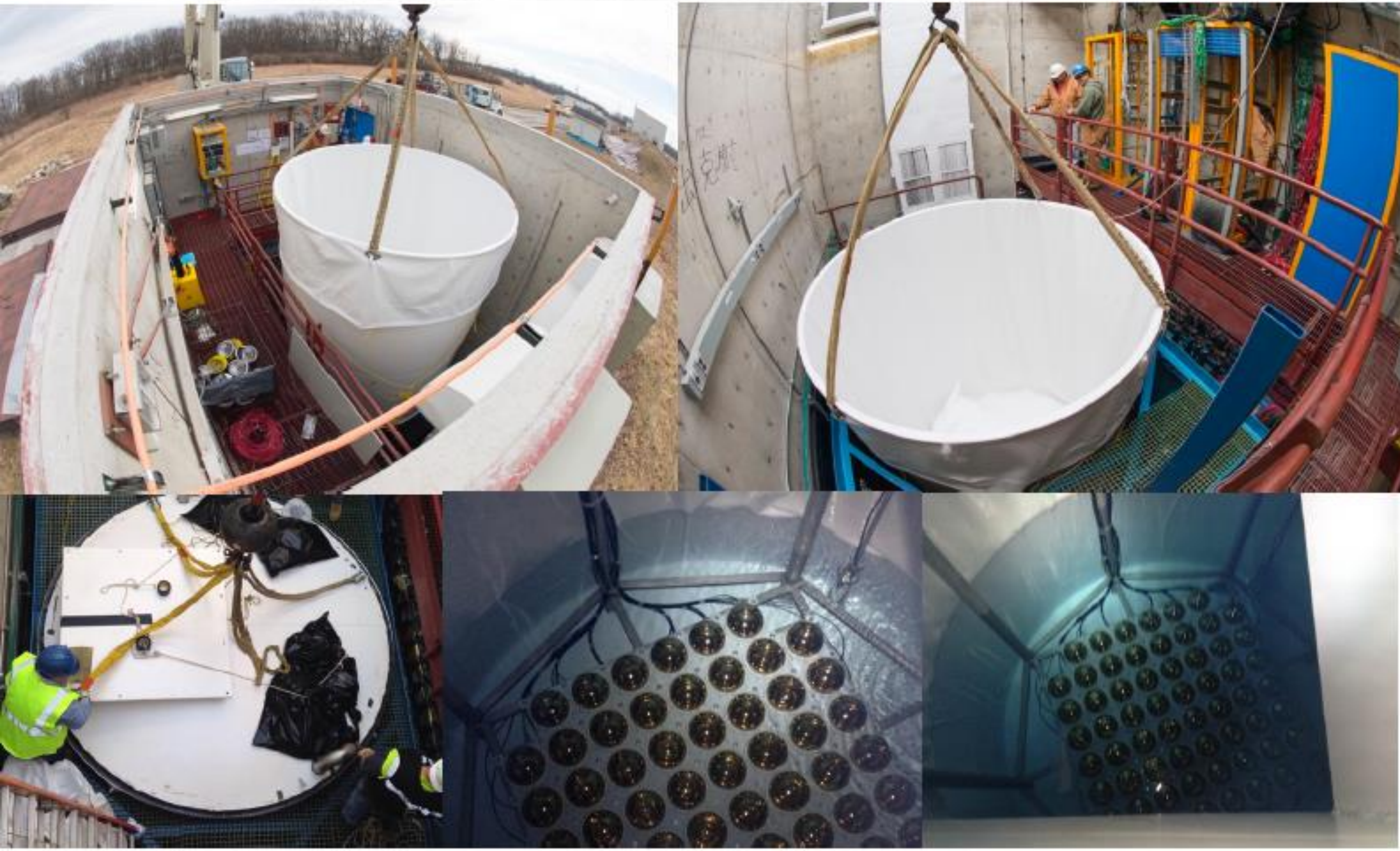
- Demonstration of LAPPDs in a neutrino experiment
- Application of fast, waveform sampling (PSEC) electronics
- First use of Gd on a neutrino beam





- A test bed for other novel photosensors
- Possible later addition of water-based liquid scintillator

ANNIE Completed Phase I



Slide courtesy of M.Wetstein

Incom LAPPD "Preliminary" Results & Timeline

- DOE Pilot Production Facility Funding - April 2014
- Incom Pilot Production Facility - November 2015
- LAPPD Commissioning Trials Initiated - December 2015

  #1 -> #8 - Dec. 2015 to Aug. 2016, Seal & Connectivity Trials

  #9 – 9/14/2016, First Sealed Tile – Aluminum Photocathode

  #12 – 12/21/2016, QE (365nm Max/Avg/Min) = 16.5% /11.1% /6.7%

  #15 – 03/31/2017, QE 365nm (Max/Avg/Min) = 35.1% /30.3% /21.6%

  #22 – 10/10/2017, QE 365nm (Max/Avg) = 14.7% / 12.6%, High Gain MCPs, Peaked SPE PHD

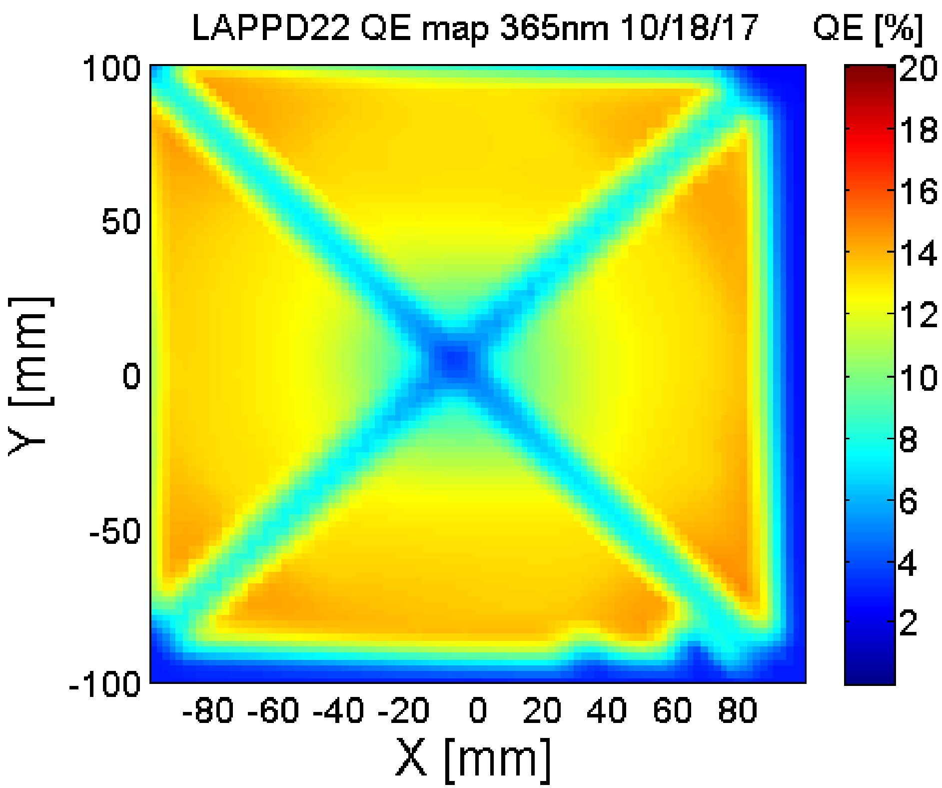
- Exploitation Phase Begins - QI 2018

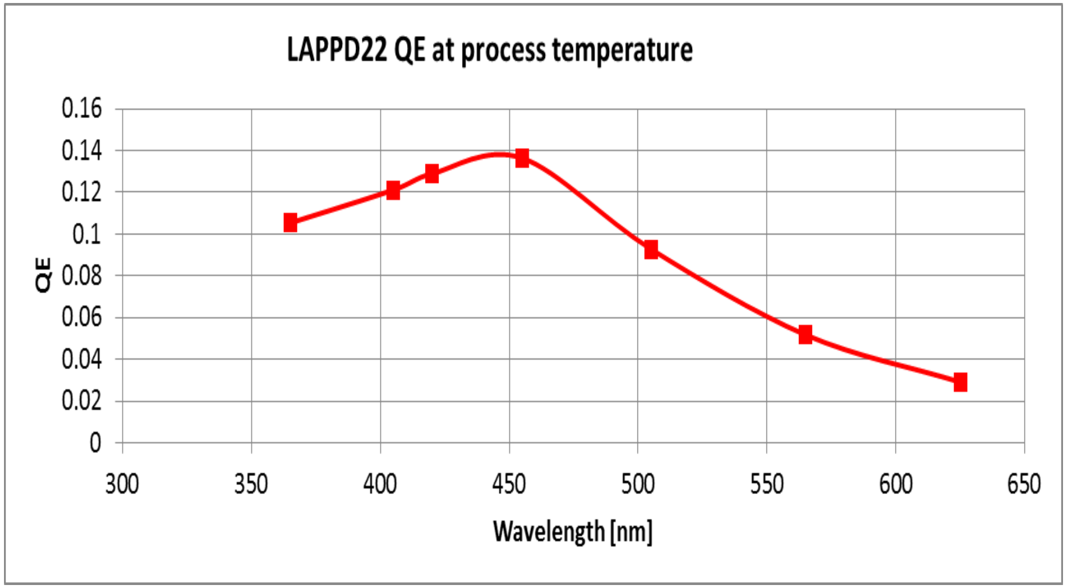
  Operate Pilot Production on a routine basis

  Produce prototypes for early adopters

Slide courtesy of M. Minot at Incom Inc.

LAPPD #22 - QE Scan

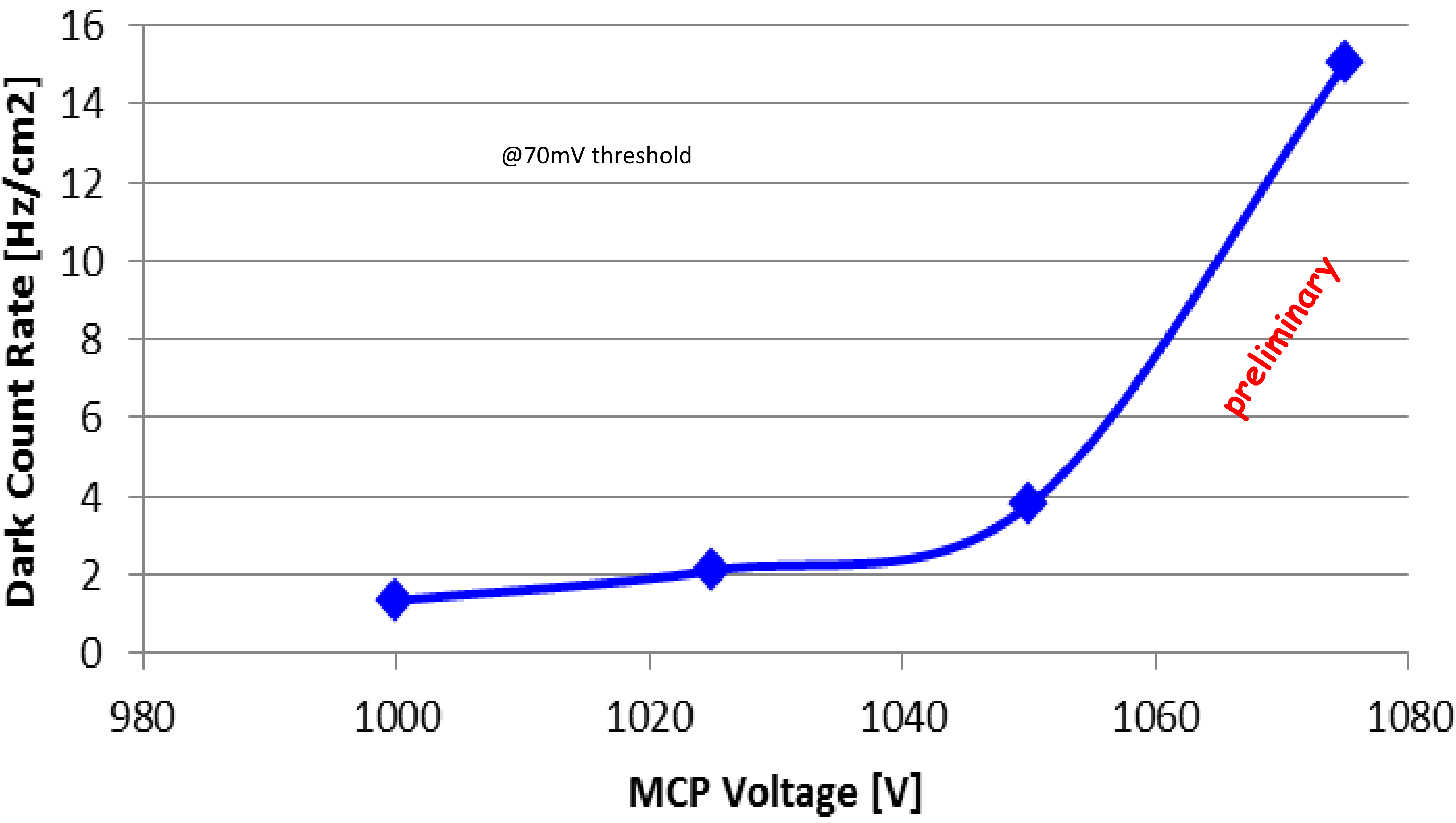




With X-Spacers Excluded:
Mean QE=12.58, QE_{max}: 14.74%
Standard Deviation (σ): 1.18 or 9.4% of mean

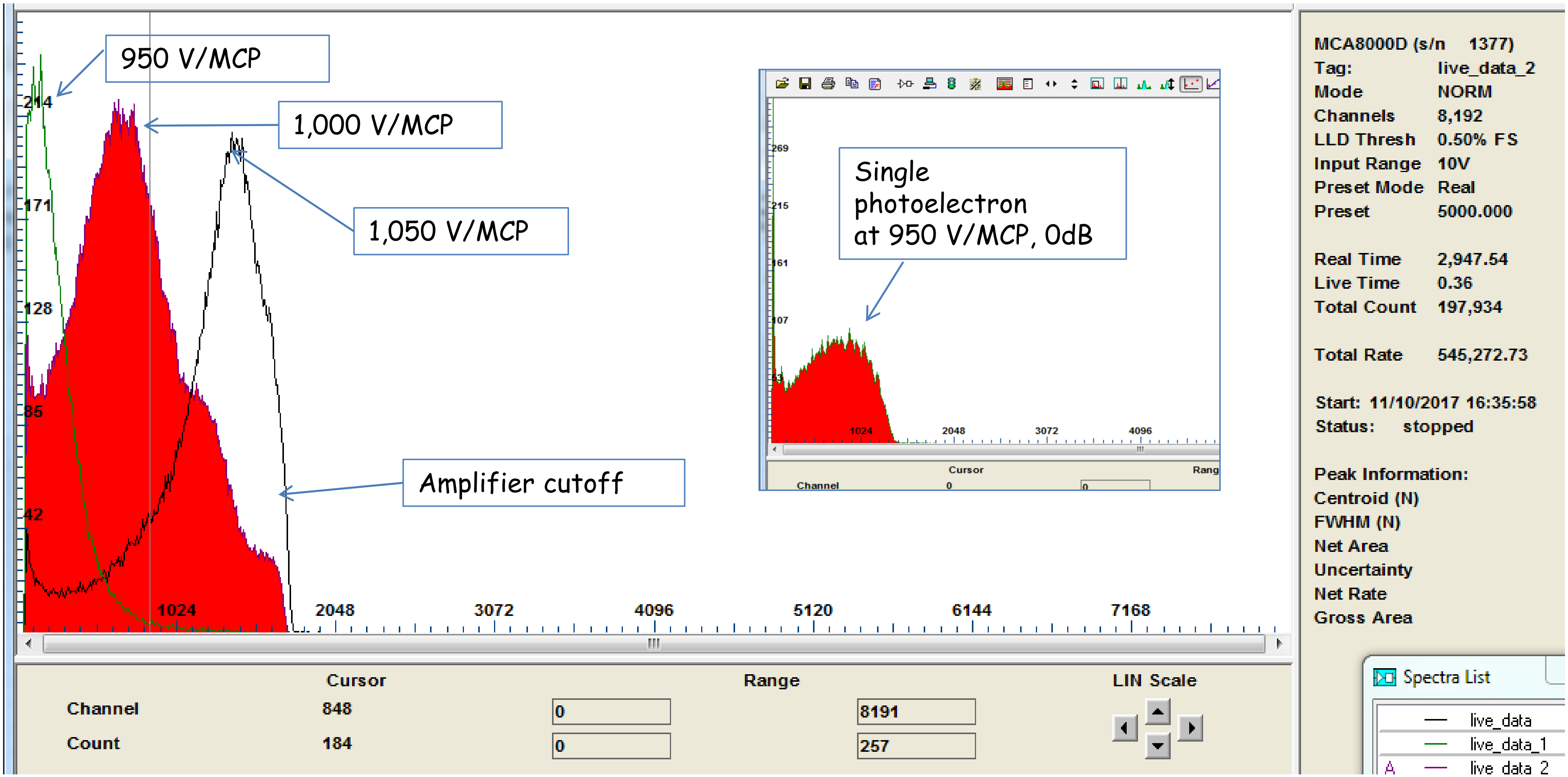
Slide courtesy of M. Minot at Incom Inc.

LAPPD #22 Dark Count Rate – PC On (-50V)



Slide courtesy of M. Minot at Incom Inc.

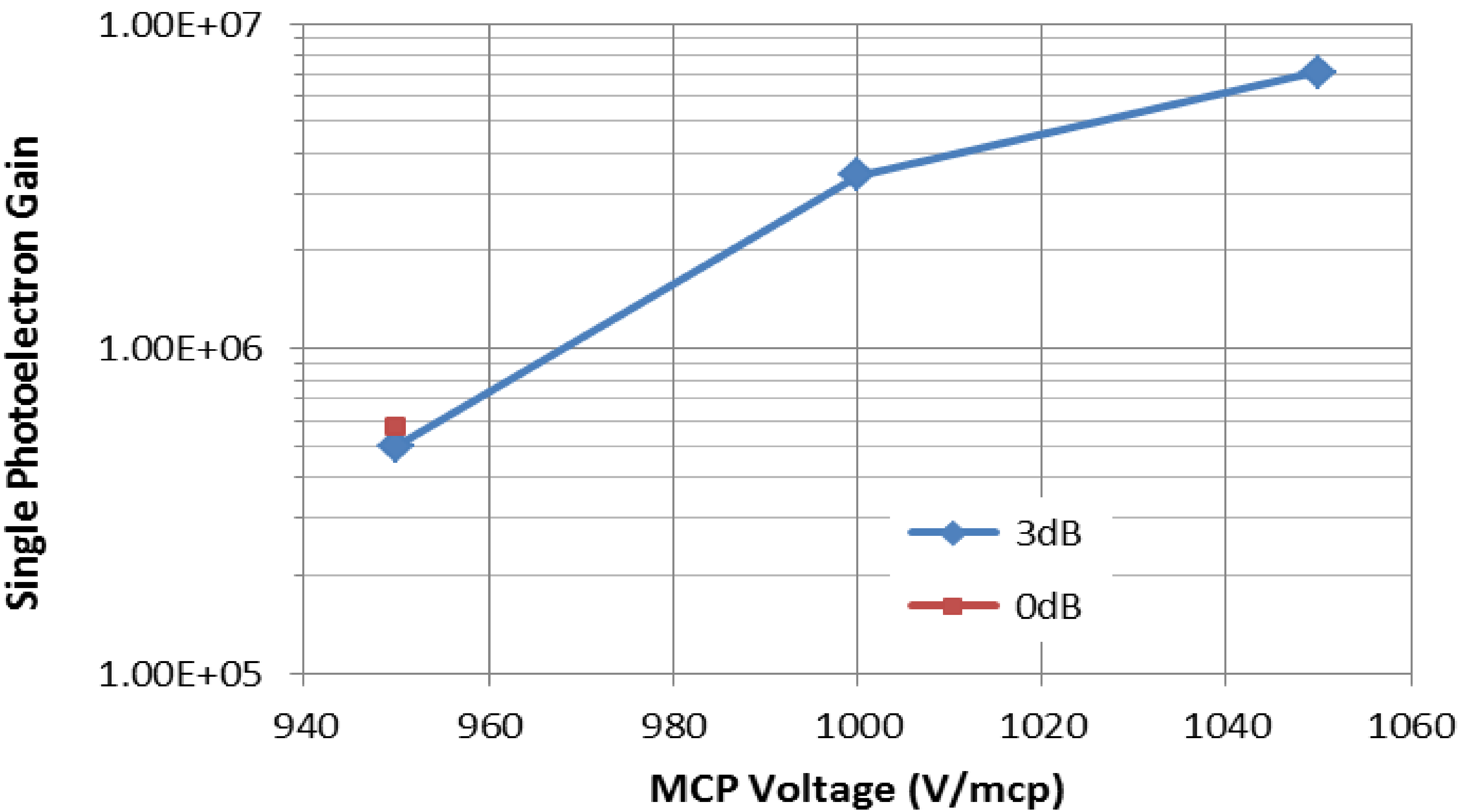
LAPPD #22 - PHDs for Single Photoelectrons



Data collected with 3dB attenuation at the Amptek amplifier input
Insert: Single photoelectron at 950 V/MCP, 0dB

Slide courtesy of M. Minot at Incom Inc.

LAPPD #22 - Single PE Gain

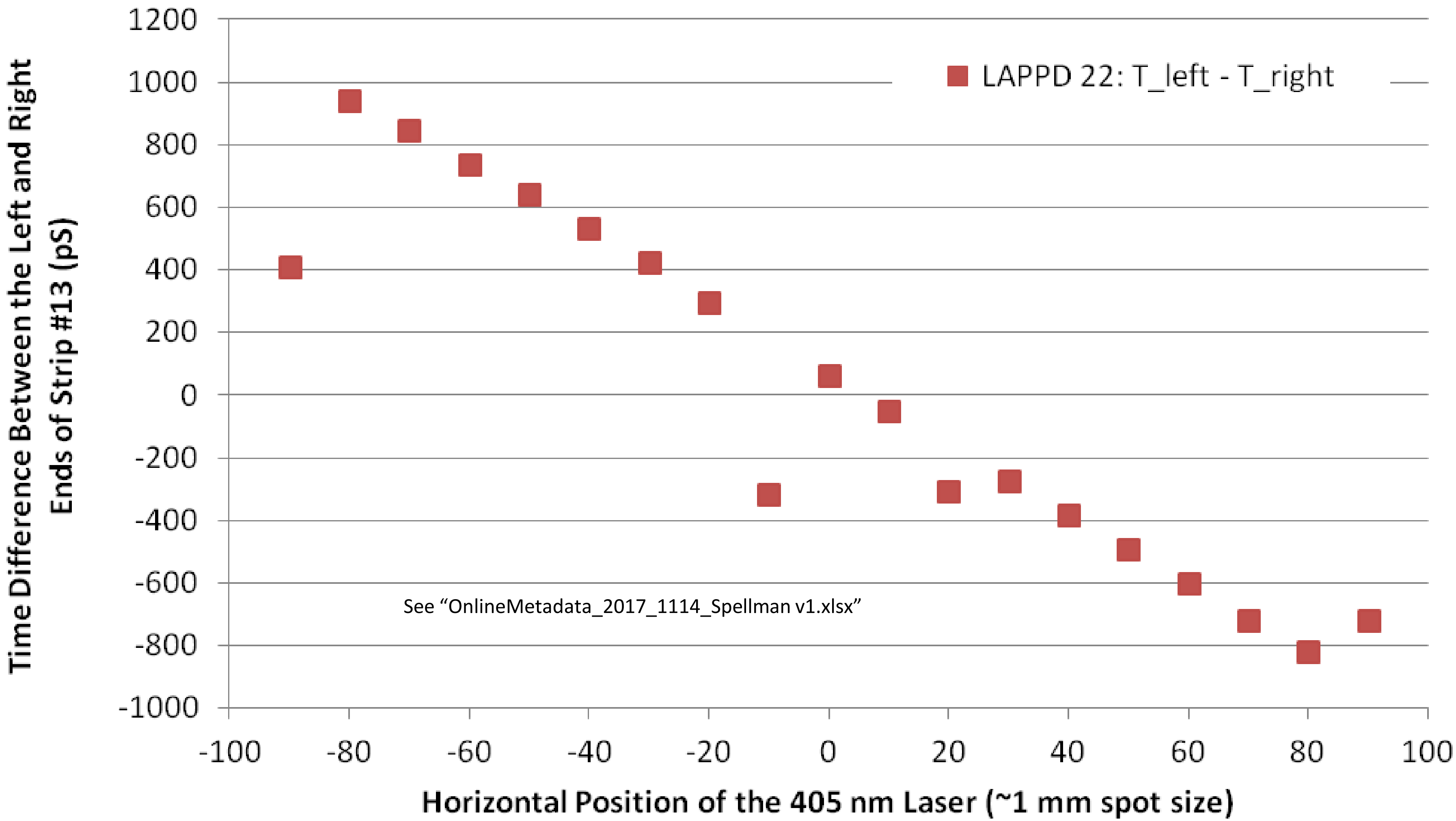


Filename	MCP V	(10V, 8192 ch) MCA Centroid (ch)	Attenuation	Amplifier voltage (mV)	Charge (fC)	Gain
2017-11-10 1609	950	850	0	1038	92	5.74E+05
2017-11-10 1630	950	132	3	161	80	5.02E+05
2017-11-10 1725	1000	690	3	842	545	3.41E+06
2017-11-10 1806	1050	1401	3	1710	1138	7.11E+06

See file “Onlinemetadata_20171110_Spellman with plots.xlsx”

Slide courtesy of M. Minot at Incom Inc.

LAPPD 22 - Timing and Derived Position Along a Single Strip



A ~1mm diameter 405 nm 60 pS laser spot was moved laterally along an anode strip:

- Laser spot position is derived by measuring the time of arrival of the MCP pulse at each end of the strip and knowing the time a pulse takes to propagate across the entire strip.
- Linearity deviations occur at the ends, and at the transit across the X-spacer, where dark pulses are included in the measurement.

Slide courtesy of M. Minot at Incom Inc.

Innovators & Early Adopters

- Collaborators with an expressed willingness to evaluate early LAPPD prototypes, sharing round-robin test results and technical performance feedback.
  - Opinion leaders able to influence the adoption of LAPPD for established or future technical programs.
  - Ability to evaluate prototype performance under practical conditions or facilities not available to Incom Inc. Examples: magnetic fields, neutron beam, Cherenkov light, Fermi Lab Particle Beams, Neutrino-less Double-Beta Decay, life testing, etc.
- Incom is committed to working with early adopters to insure that LAPPD are available to be evaluated for appropriate applications.
  - Measurement & Test Workshop to facilitate hands on experience with LAPPD, and establish standardized M&T procedures.
  - Short term loan & leasing agreements
  - Purchase with discounts to Early Adopters with DOE funded programs.

Slide courtesy of M. Minot at Incom Inc.

LAPPD™ Early Adopter Programs – **What About Your Program?**

PRINCIPAL INVESTIGATOR & SPONSOR	PROGRAM TITLE
Bill Worstell, Incom Inc.	TOF Proton Radiography for Proton Therapy
Henry Frisch (U of Chicago)	LaRiaT (Liquid Argon Beam-line Experiment, Fermi Lab)
	Sub-psec TOF for collider vertex and particle ID
	Track reconstruction in a small water Cherenkov counter
	Double-beta decay development
Mayly Sanchez, Matthew Wetstein, Iowa State	ANNIE - Atmospheric Neutrino Neutron Interaction Experiment
Mickey Chiu (BNL)	Phenix Project - "eIC Fast TOF"
Erik Brubaker, Sandia National Lab/CA	Neutron Imaging Camera
John Learned, U. of Hawaii, and Virginia Tech	Short Baseline Neutrino (NuLat)
Lindley Winslow (MIT)	Search for Neutrino-less Double-Beta Decay (NuDot) Using Fast Timing Detectors
Andrey Elagin (U of Chicago)	Neutrino-less Double-Beta Decay
Bill Worstell, Incom Inc, Bob Wagner & Junqi Xie. ANL, Jefferson Laboratory	Magnetic Field Tolerant Large Area Picosecond Photon Detectors for Particle Identification
Andrew Brandt, University of Texas, Arlington	Life Testing of LAPPD
Dr Matthew Malek, The University of Sheffield	Hyper-Kamiokande Upgrade (~10,000 LAPPD in 10 years)

Slide courtesy of M. Minot at Incom Inc.

LAPPD Measurement & Test Workshop

- Familiarize early adopters with the LAPPD, and provide early access.
- Provide researchers with raw data for their own evaluation and use, which might include using the data to evaluate LAPPD readiness for their program applications.
- Establish standardized measurement protocols.
- Evaluate alternative electronic readout options; examples include PSI DRS4 Evaluation Boards, Ultralytics LAPPD Readout Card, PSEC4 Eval boards, CAEN DRS4 Readout, other.
- First Ever Workshop - November 13-16, 2017
  - Kurtis Nishimura (U of Hawaii, working with John Learned, and Erik Brubaker, Sandia)
  - Josh Brown (Berkeley, working with Erik Brubaker, Sandia)
  - Julieta Gruszko (MIT, working with Lindley Winslow)
- Data Collected - Analysis underway, results expected in early December
  - Pulse height vs. laser trigger rate at fixed MCP voltages
  - Scans along and across strips for position and crosstalk assessment
  - Photocathode scans with 42 volts and 10 volts between the photocathode and MCP
  - 160,000 single photoelectron waveforms using DRS4 evaluation boards
- **Next Workshop – January 22 – 26, 2018 Spaces Available**

Slide courtesy of M. Minot at Incom Inc.

For more information

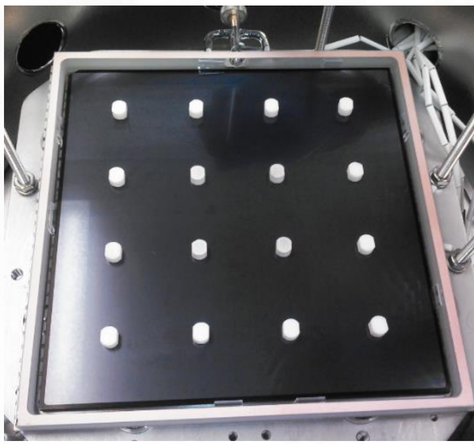
Michael Minot
Director R&D, Incom Inc.
mjm@incomusa.com
Office - 508-909-2369
Cell – **978-852-4942**

Slide courtesy of M. Minot at Incom Inc.

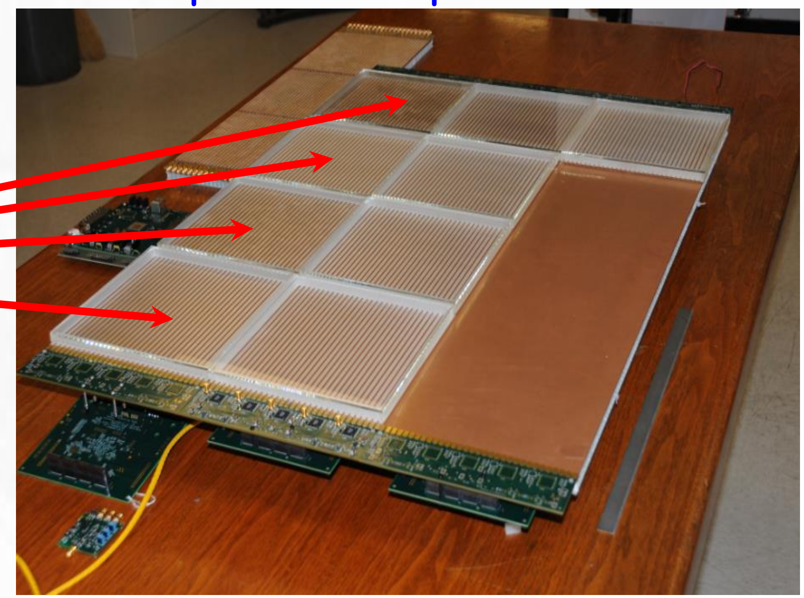
Goal of the R&D Effort at UChicago

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

LAPPD module 20x20 cm^2



Example of a Super Module

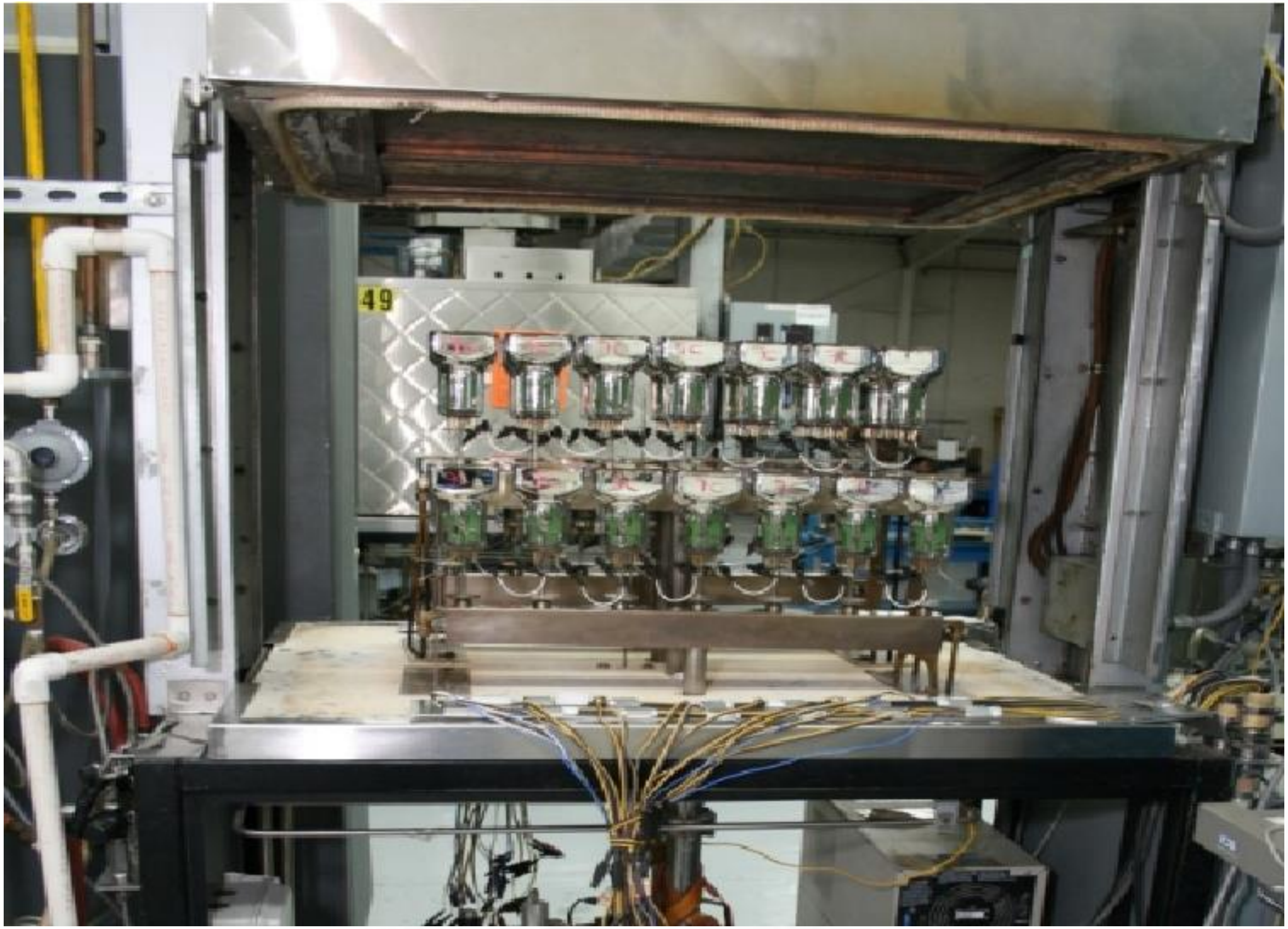


We are exploring if an *<u>In-Situ</u>* process (without vacuum transfer) can be inexpensive and easier to scale for a very high volume production

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

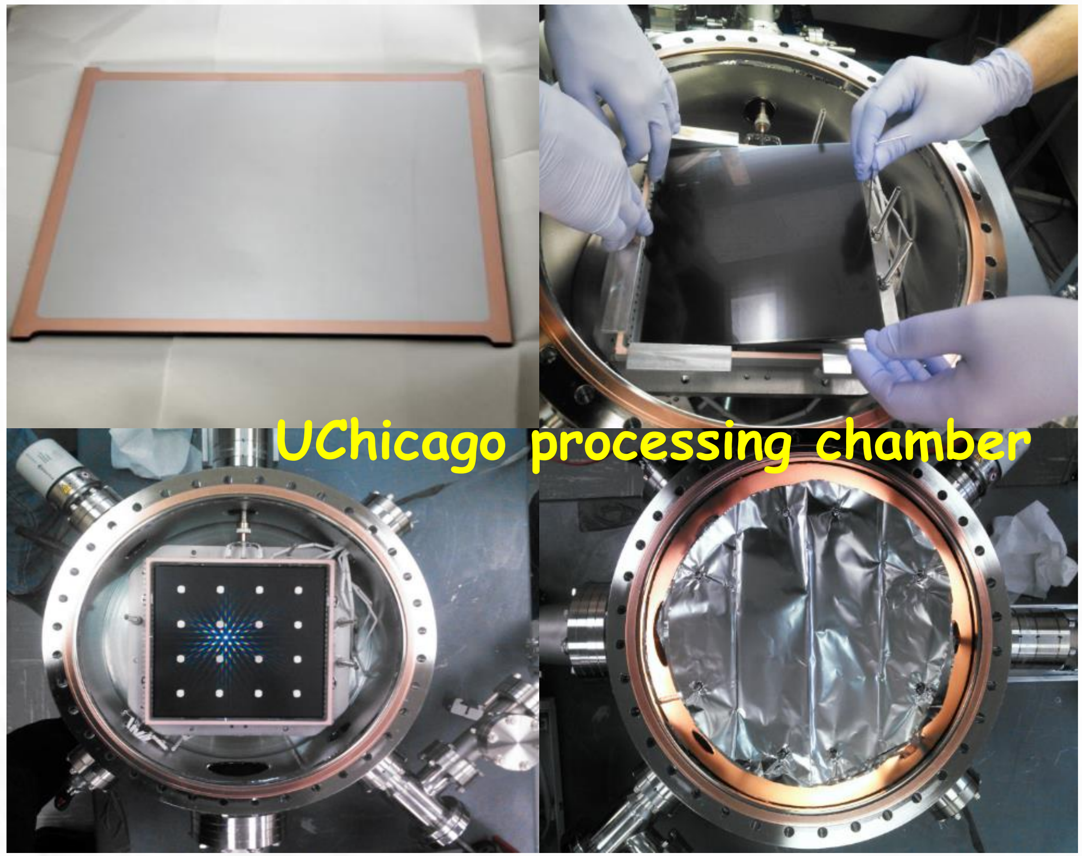
UChicago goal is to develop alternative high volume, scalable, low cost processing options (in close collaboration with Incom Inc.)

Can We Make LAPPDs in Batches Like PMTs?



In-Situ Assembly Strategy

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
can vent the outer vacuum and access the detector
prior to PC synthesis
Step 4: bring alkali vapors inside the tile to make photo-cathode
Step 5: flame seal the glass tube or pinch the copper tube

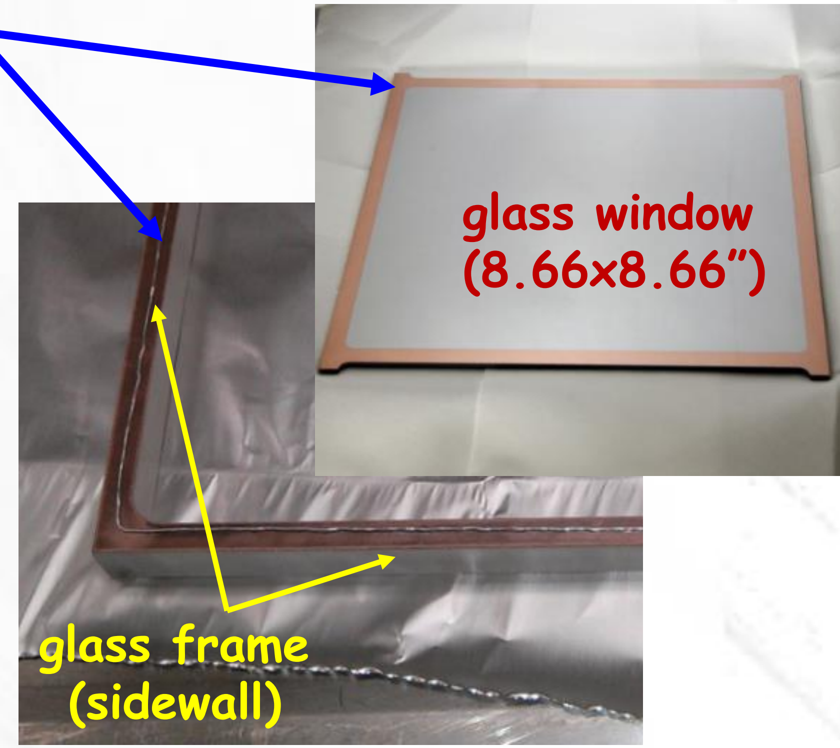
Indium Solder Flat Seal Recipe

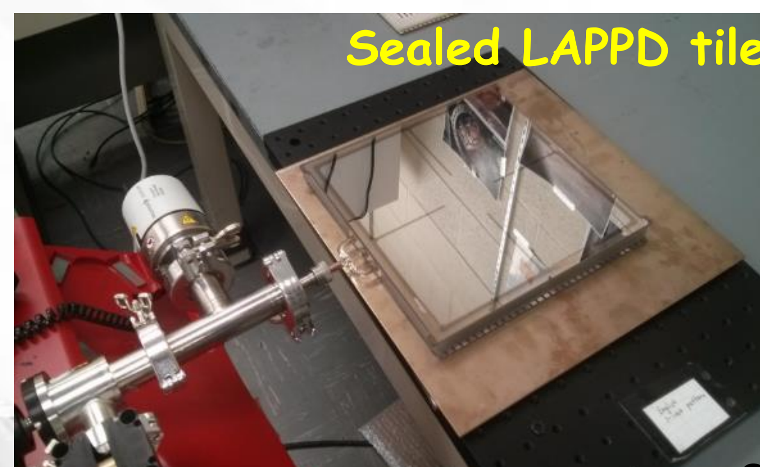
Input:

- Two glass parts with flat contact surfaces (also trying to seal ceramic + fused silica)

Process:

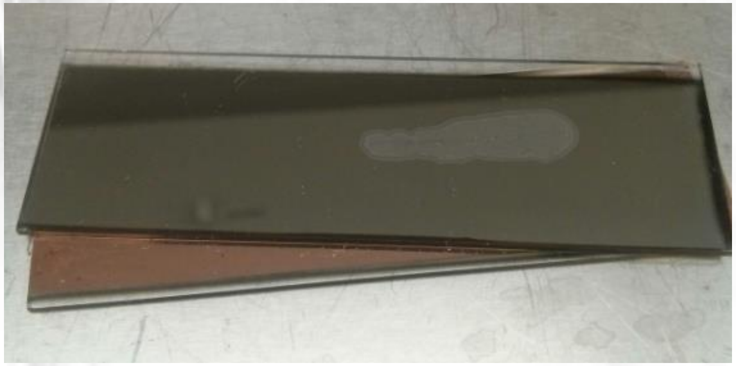
- Coat 200 nm of NiCr and 200 nm of Cu on each contact surface (no vacuum break in between NiCr and Cu depositions)
- Make a sandwich with 99.995% pure indium wire (etch the In wire 5% HCl just before assembly)
- Bake in vacuum at 250-300C for 24hrs (go significantly above melting – known as "superheat" in soldering industry)
- A good compression over the entire perimeter is needed to compensate for non-flatness and to ensure a good contact (no seal without a press on the edges!)





Metallization pattern is based on SSL seal by O. Siegmund et. al.

Understanding the Seal Recipe



Here is what we know about the seal:

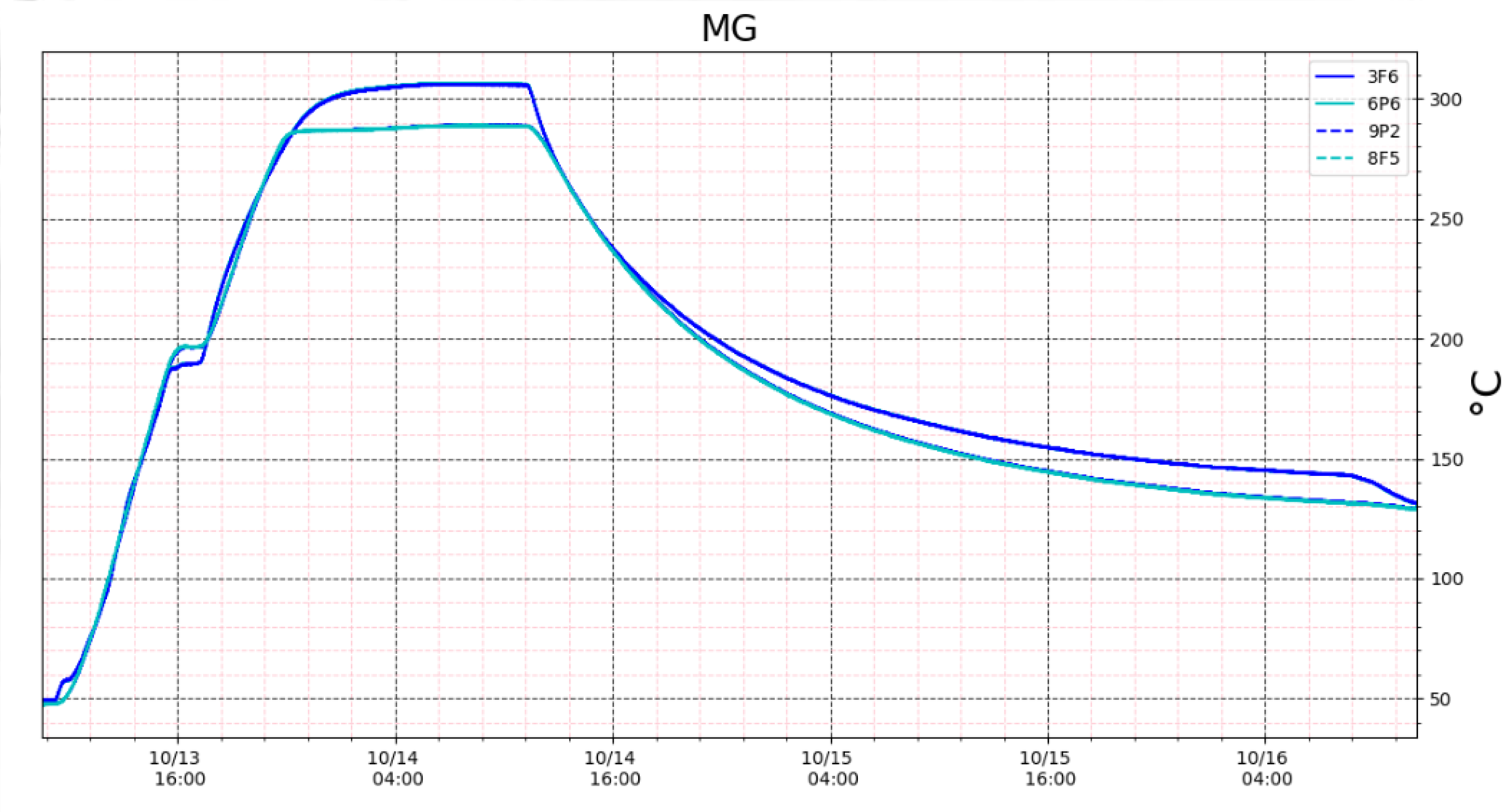
(XPS with depth profile was used to characterize the seal)

- NiCr layer will provide tie layer
- Cu provides protection against oxide on NiCr
- Indium wire gets squished--oxide broken

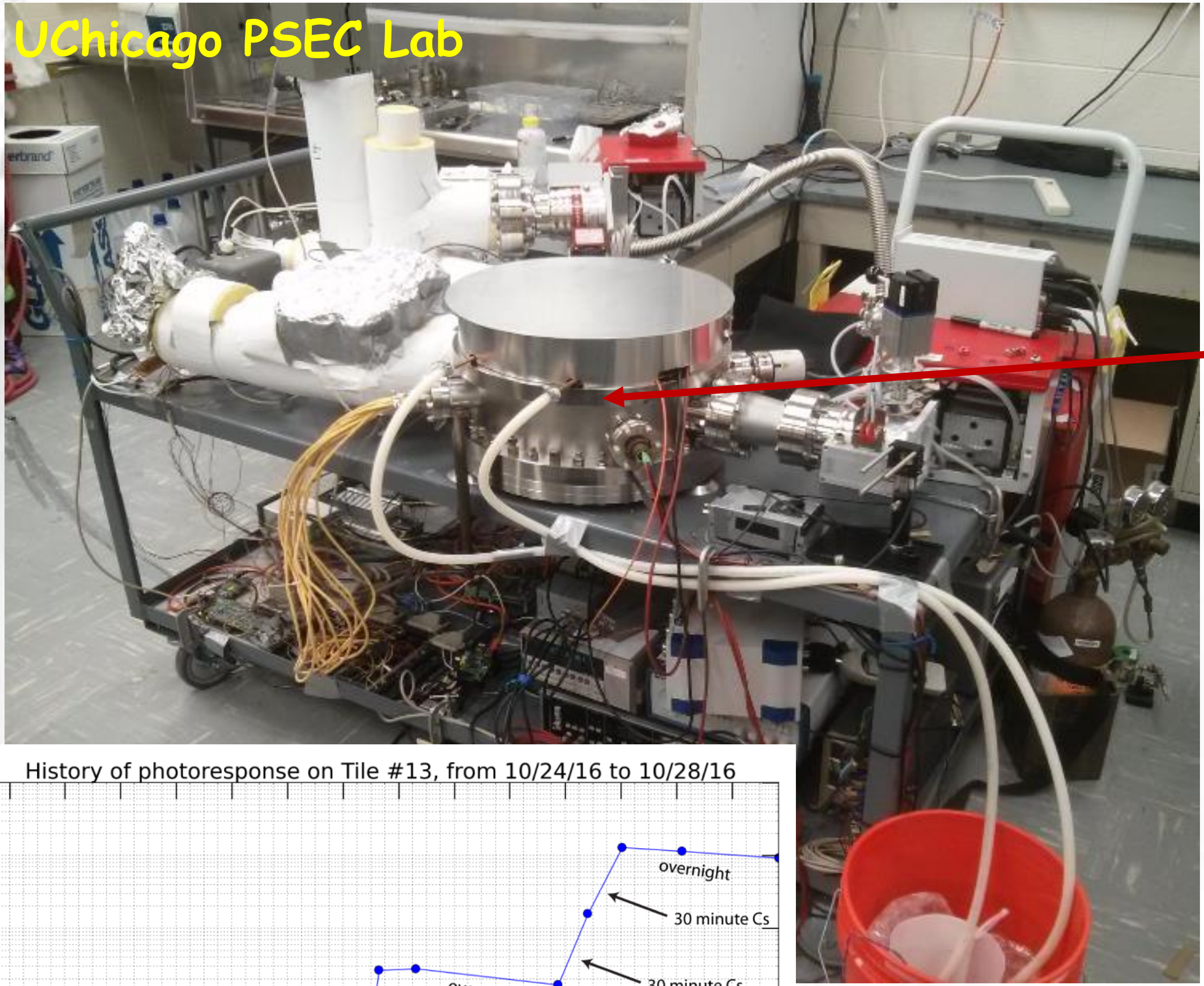
  (this principle is also used in cold seal by D. Walters at ANL)
- Cu diffuses into bulk Indium
- Ni and Cr diffuse into bulk Indium
- Indium bonds to the glass (presumably through a very thin layer of Cr – this is on the edge of sensitivity)

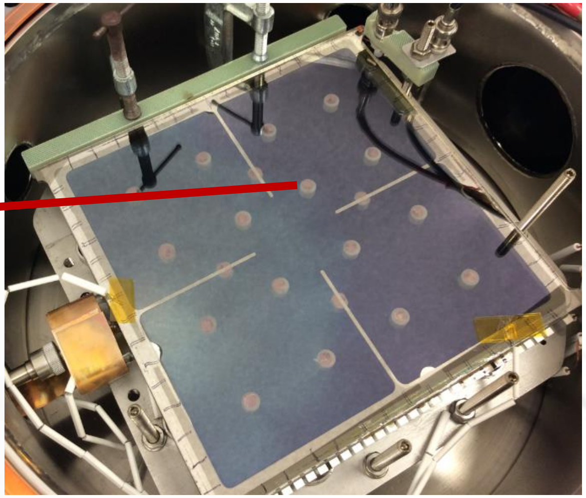
Many thanks to R. Jarrett at Indium Corp. for expert advice on indium metallurgy

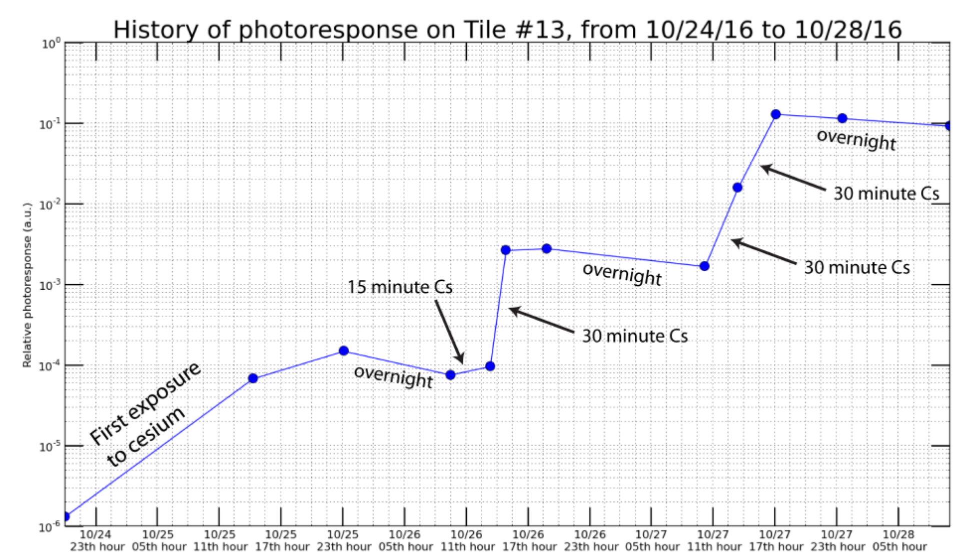
Heat Cycle


MG
3F6
6P6
9P2
8F5
300
250
200
150
100
50
°C
10/13 16:00
10/14 04:00
10/14 16:00
10/15 04:00
10/15 16:00
10/16 04:00

In-Situ LAPPD Fabrication







Heat only the tile not the vacuum vessel

Intended for parallelization

In-Situ Assembly Facility UChicago

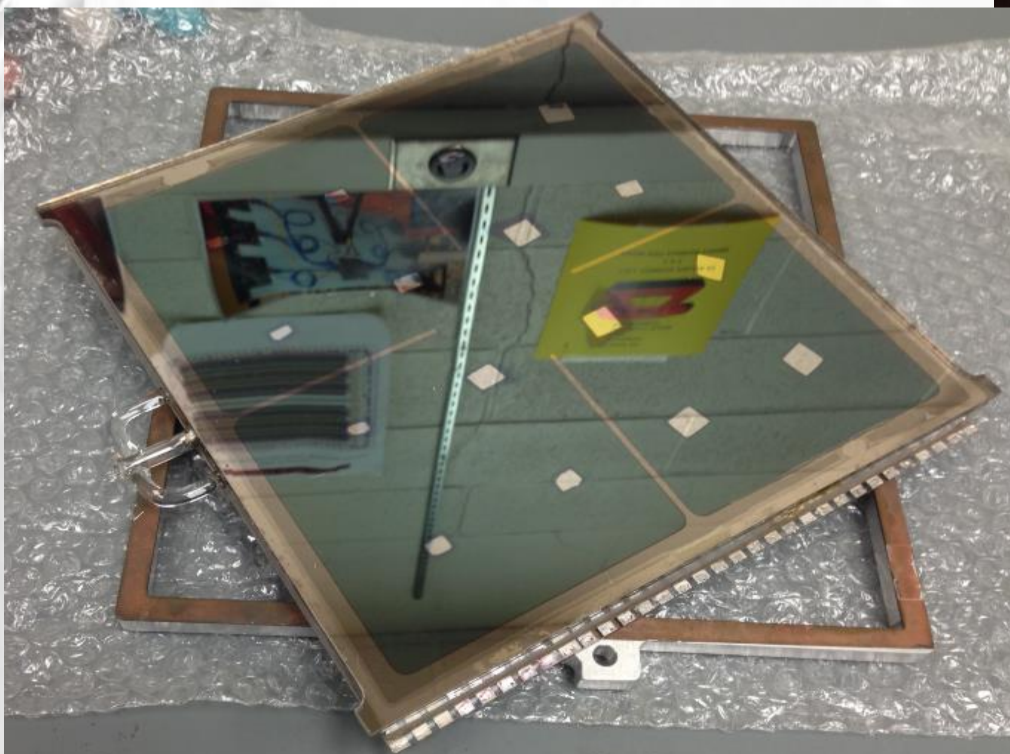
The idea is to achieve volume production by operating many small-size vacuum processing chambers at the same time
or/and make several tiles in bigger chambers

Looking forward towards transferring the in-situ process to industry

First Sealed In-Situ Glass LAPPD

August 18, 2016

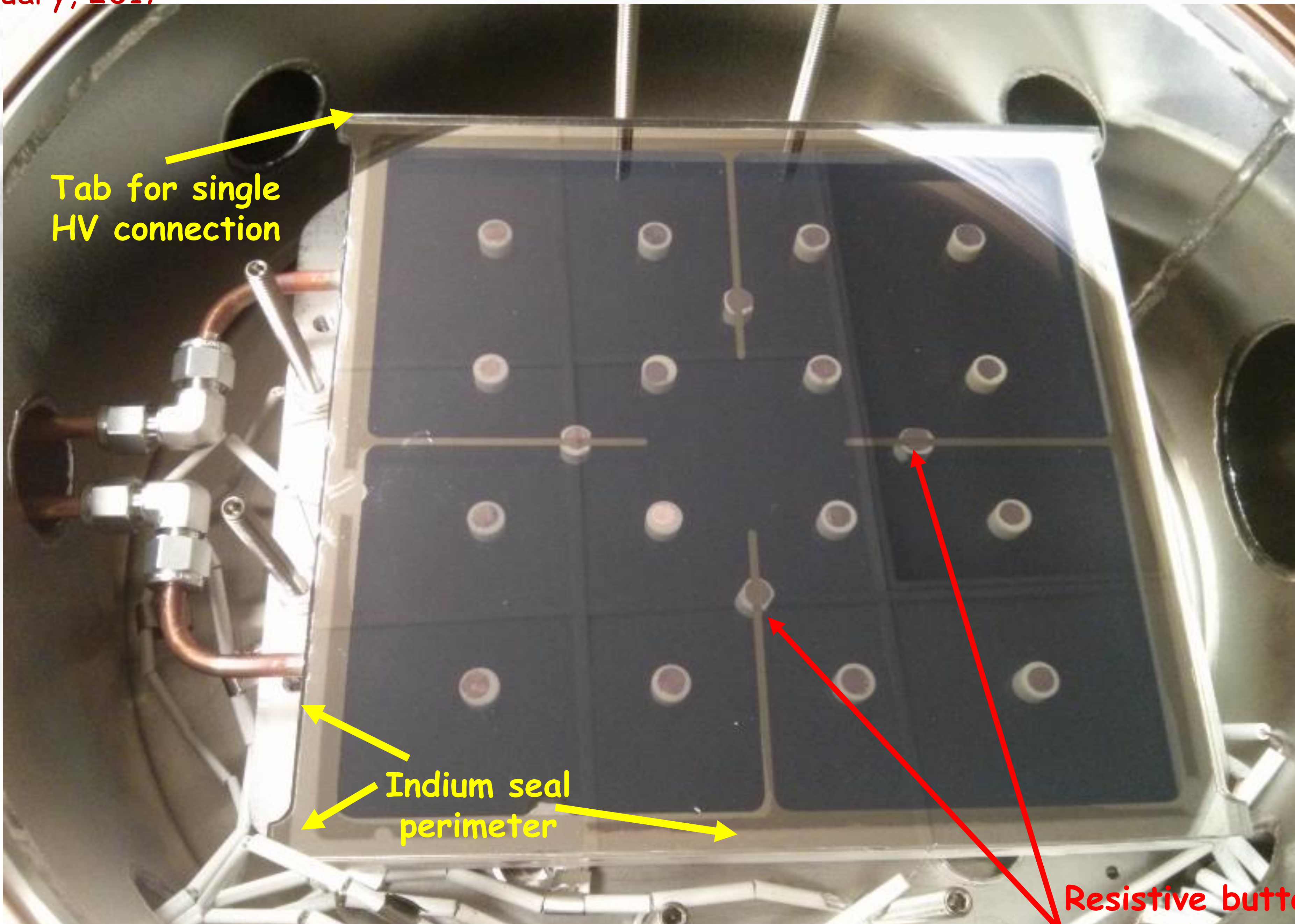
(Cs-Sb photo-cathode)



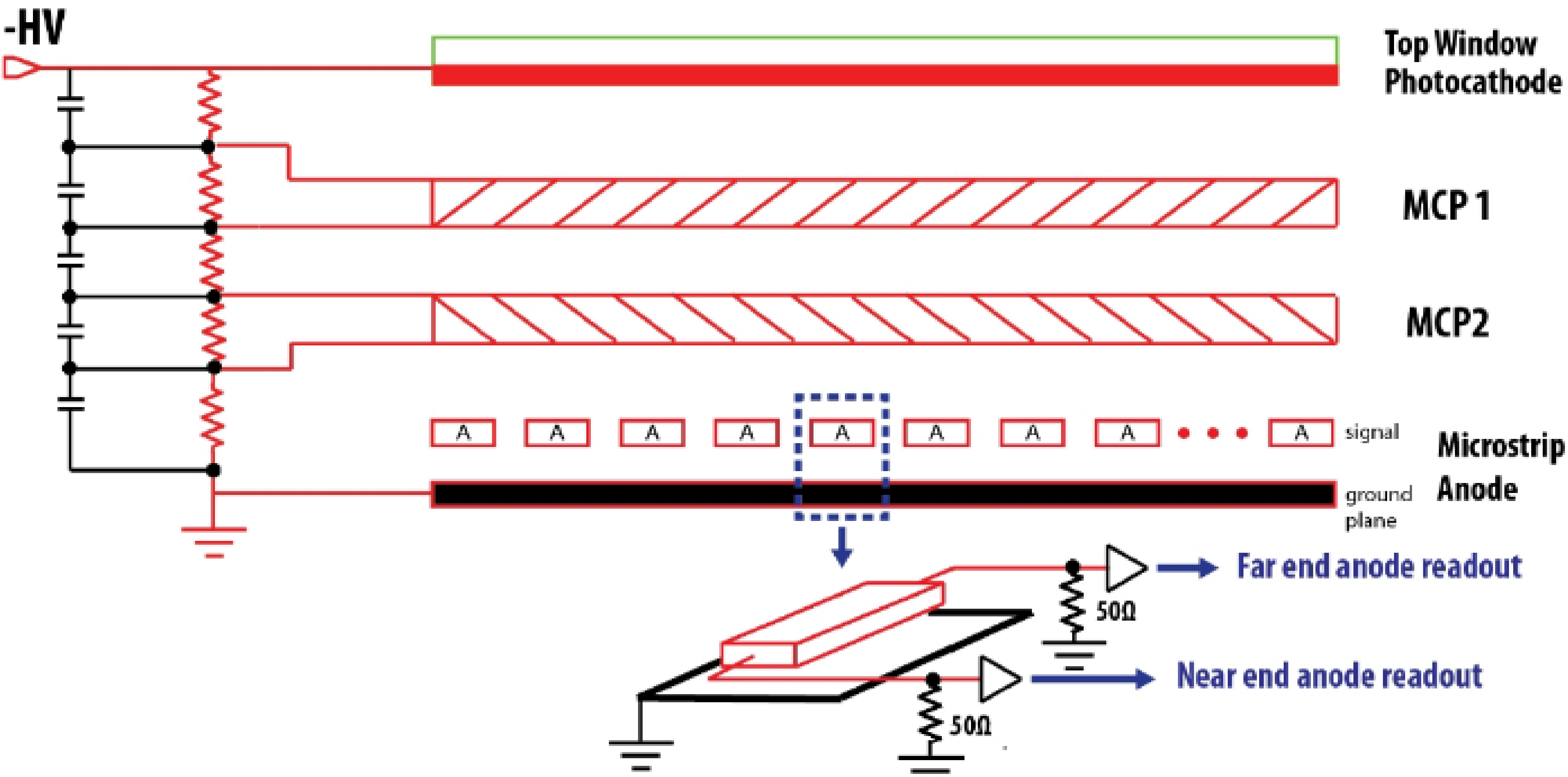
Flame seal by
J.Gregar, Argonne

Ceramic Gen-II LAPPD

January, 2017

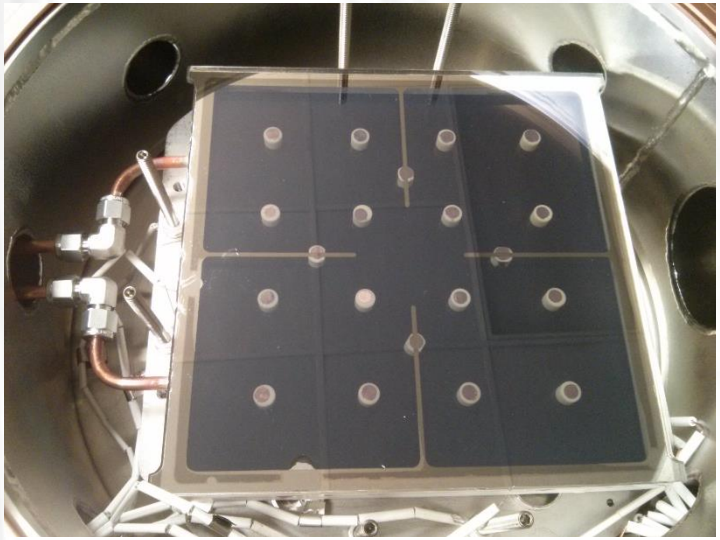


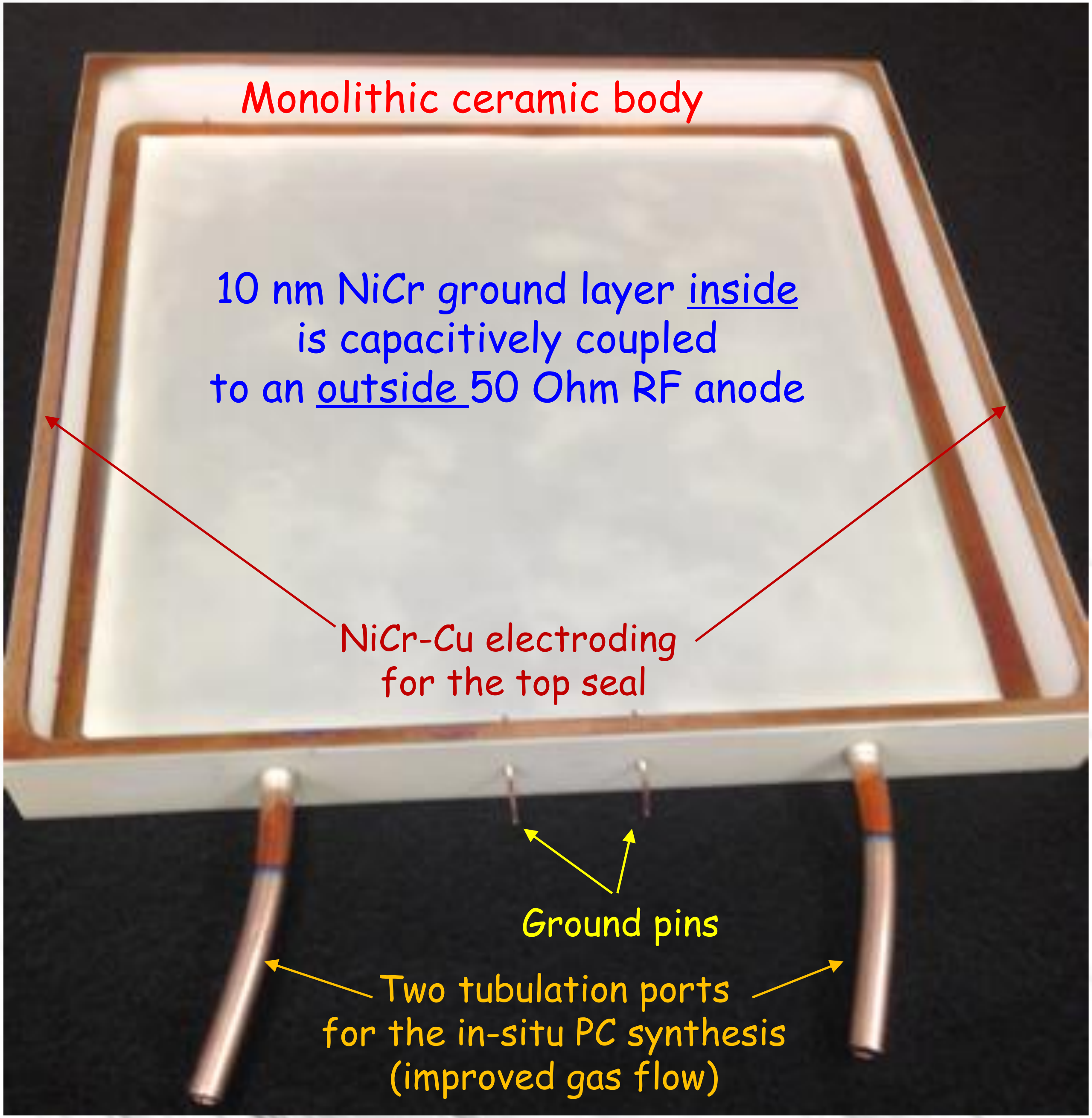
Internal HV Divider



Gen-II LAPPD

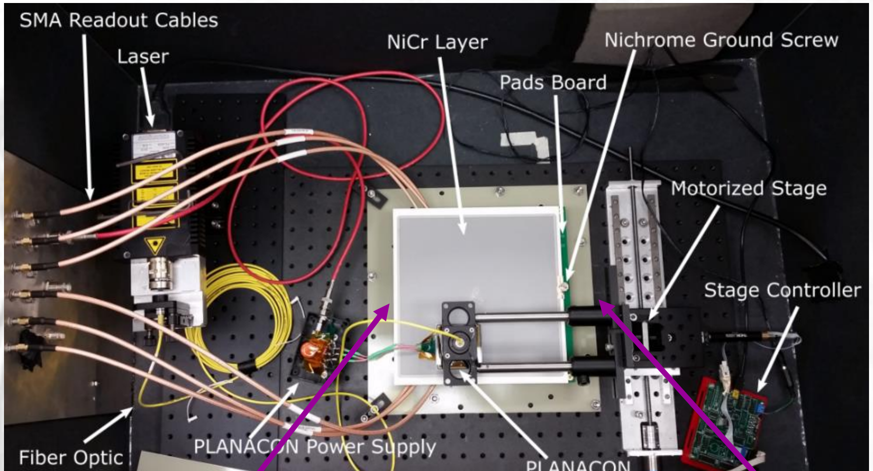
- Robust ceramic body
- Anode is not a part of the sealed detector package
- Enables fabrication of a generic tile for different applications
- Compatible with in-situ and vacuum transfer assembly processes

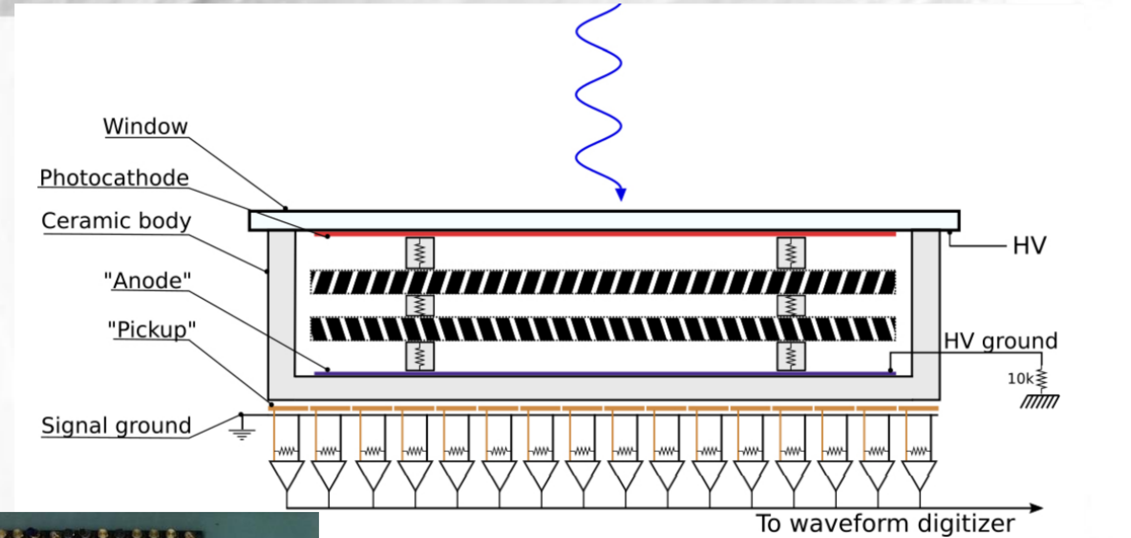


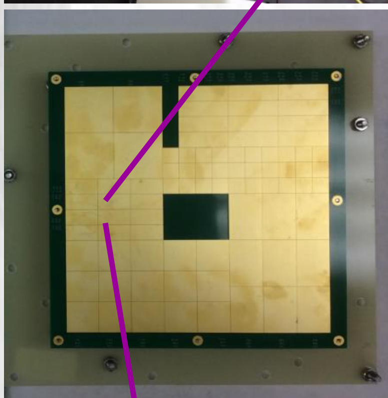


Joint effort with Incom Inc. via DOE SBIR

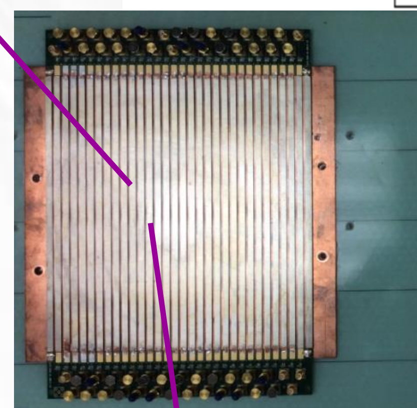
Gen-II LAPPD: "inside-out" anode



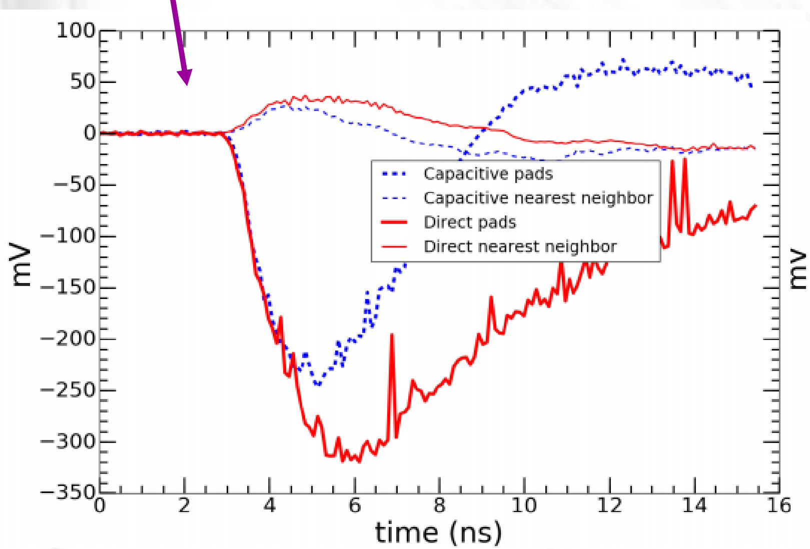


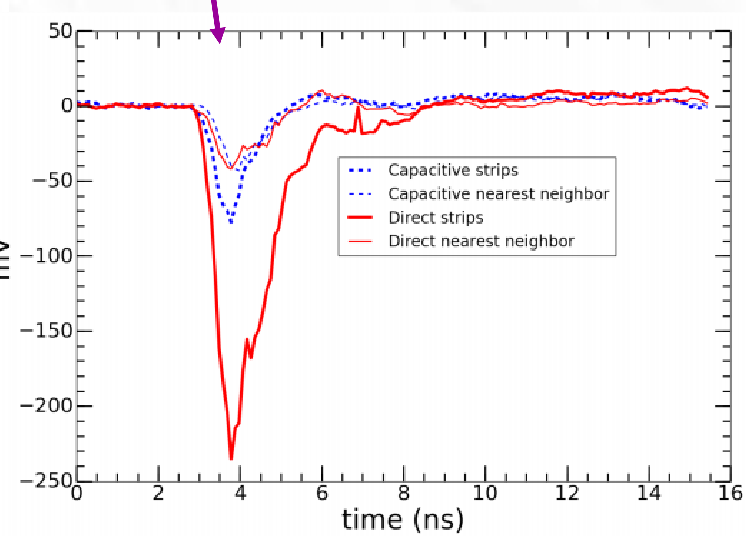


Chose your own readout pattern



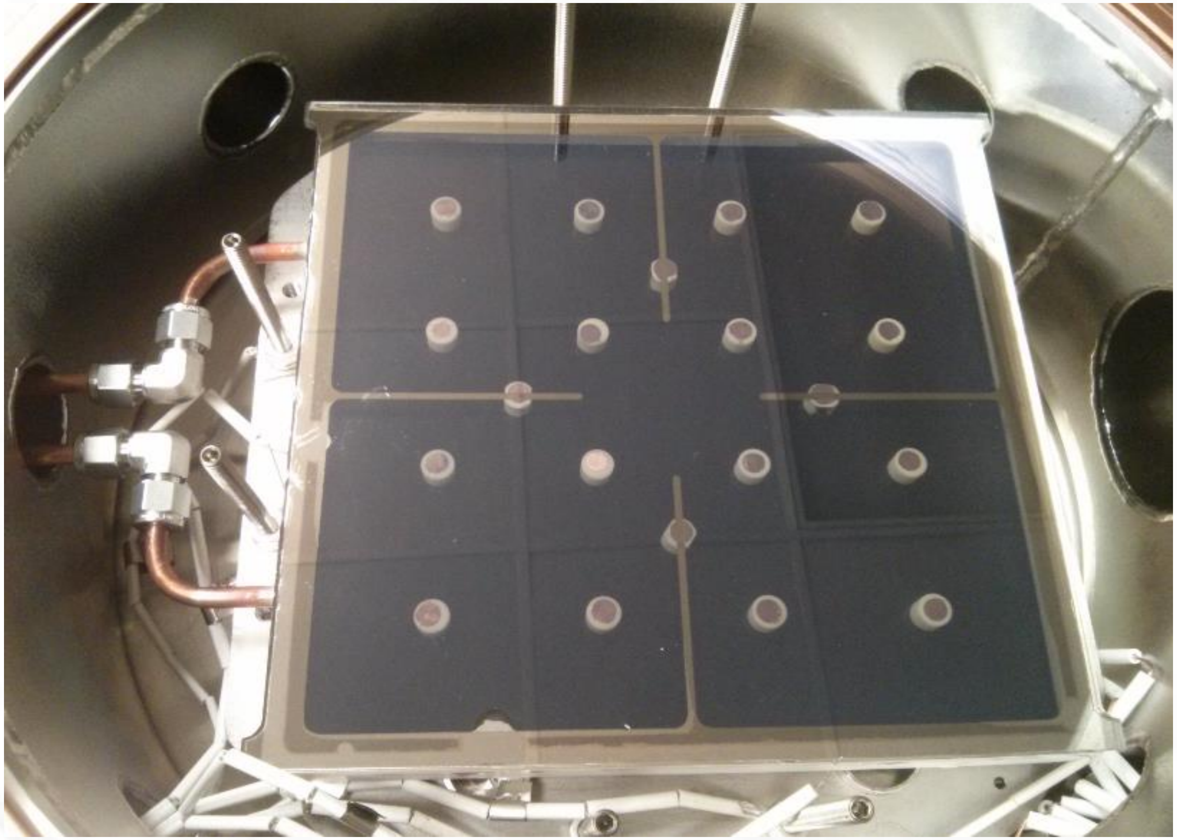
- Custom anode is outside
- Capacitively coupled
- Compatible with high rate applications





For details see NIMA 846 (2016) 75

In-Situ LAPPD: work in progress



LAPPD batch production milestones:

- Developed a robust metallurgy scheme for hermetic packaging
- Demonstrated Cs transport from a source outside of the detector package to the entire 20x20 cm^2 window surface in the presence of full size MCPs (we did made Cs-Sb photo-cathode)
- Showed that MCP initial resistance can be recovered after Cs-ation (MCPs are NOT permanently damaged or changed)
- Confirmed that capacitively coupled readout works well

Challenges for In-Situ Process

List of problems discovered so far:

- MCP plates go to lower resistance (recoverable in air)
- We had exposed Cu on the window- Indium wets it. Cs interacts with Indium to forms a flakes/powder inside the entire volume.
- Resistive buttons interact with Cs (now use new buttons)
- Measuring QE is made more difficult by our internal HV divider (can't get current across the PC-MCP gap directly).

Cs-In-(X?) Flakes/Powder Story

Ongoing investigation

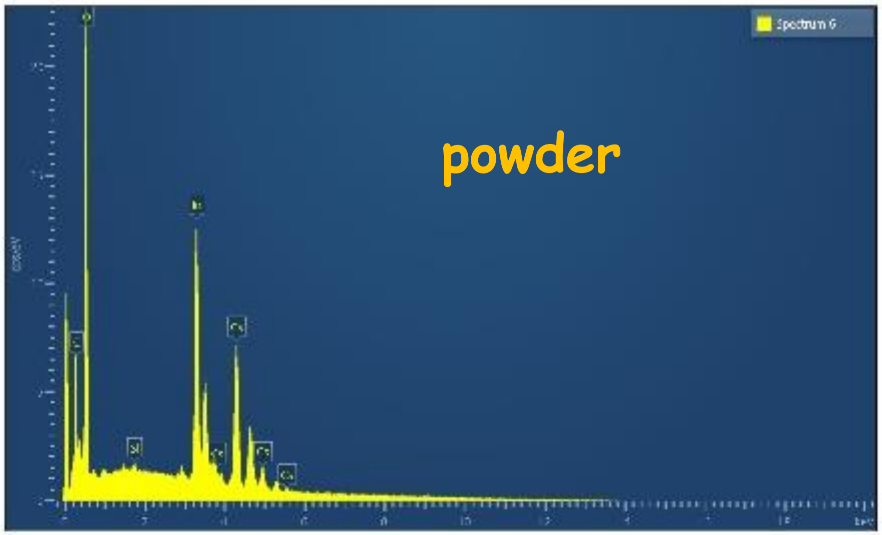


Figure 4: A spectrum from a **dust** fleck shown in the SEM picture above. The peaks indicate the existence of indium and Cs, and not their quantitative relative composition.

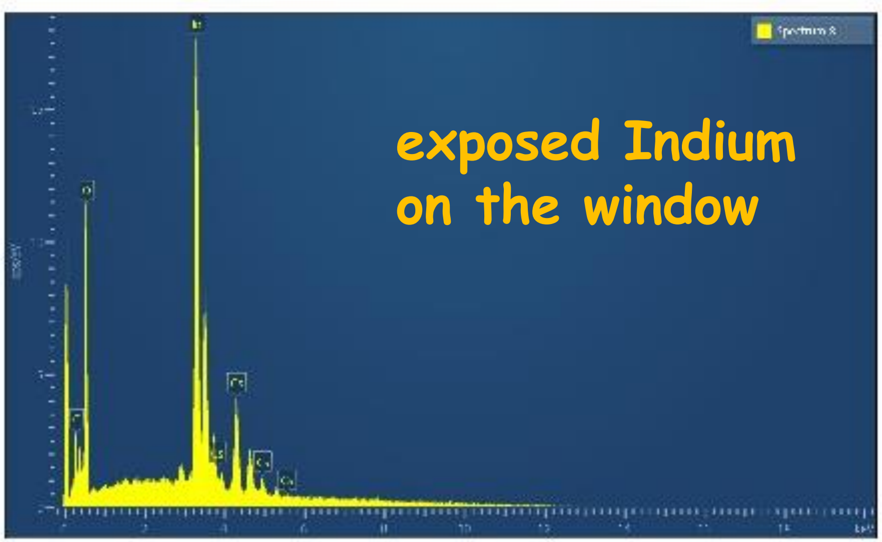
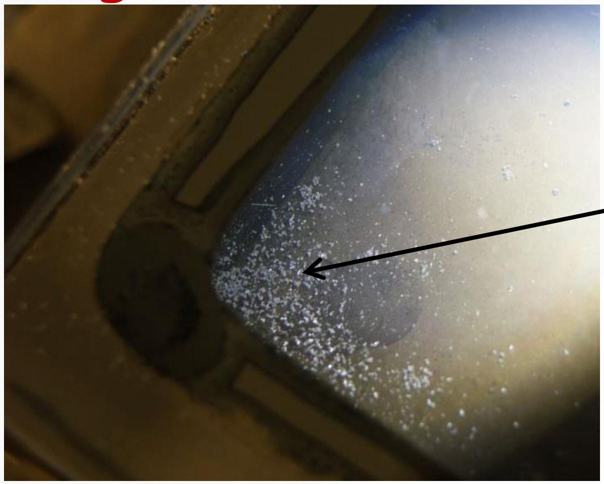


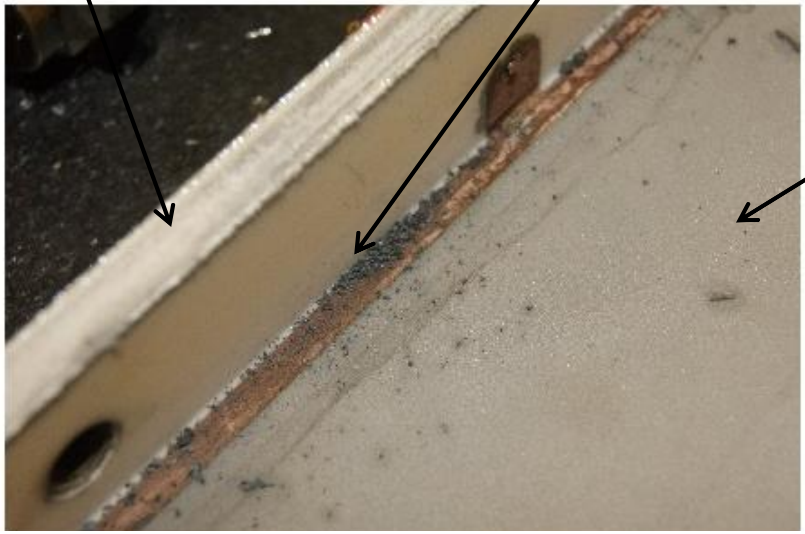
Figure 5: This spectrum is taken from the layer on the **window** that had turned black and flaky. The spectrum looks almost identical to that of the dust flecks.



Powder while still in vacuum

Sealing surface on top of sidewall

Powder after exposure to air



NiCr anode

We are getting new windows with improved metallization to avoid/limit In “seen” by Cs

Sb Story

We start with 10nm of Sb on the window –
this layer could be sitting in air for months before assembly

Photo-cathode experts were/are worried…
Sb oxidation is the main concern

Things to consider:

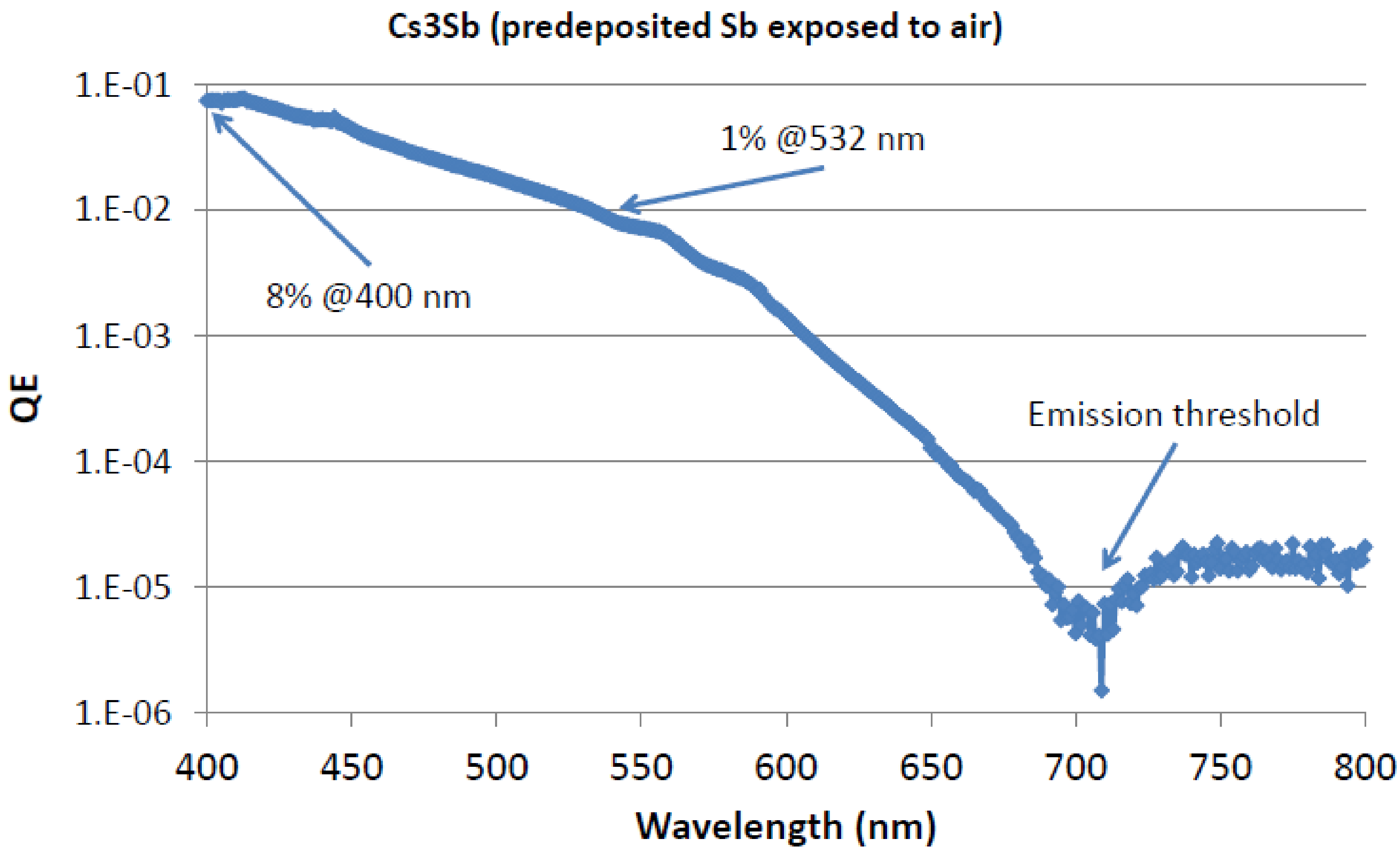
- We bake the whole detector including window at 300C for 16hrs and we do see reduction in the original Sb layer thickness (are we getting rid of oxide by long heating?)

- Eventually we have to characterize the Sb layer after the bake (may have to adjust original thickness or heat cycle)

- We have done XPS studies of the Sb layer as received from vendor (air exposed for 3 months)

Can we make PC after Sb was exposed to air?

Luca Cultrera at Cornell



Sb XPS Studies

Sb test coupon:
fused silica microscope slied with
200nm of NiCr + 200nm of Cu + 10nm of Sb

UChicago XPS details

(XPS expert support by Alexander Filatov at UChicago)

X-ray gun:

- 10 mA at 15 kV
- high resolution mode step size 0.1 eV
- area of the analyzed spot 300x700 mum

Ar ion beam (for depth profiling):

- beam size 6x6 mm
- beam energy 2 kV
- beam density 7.78 A/cm2

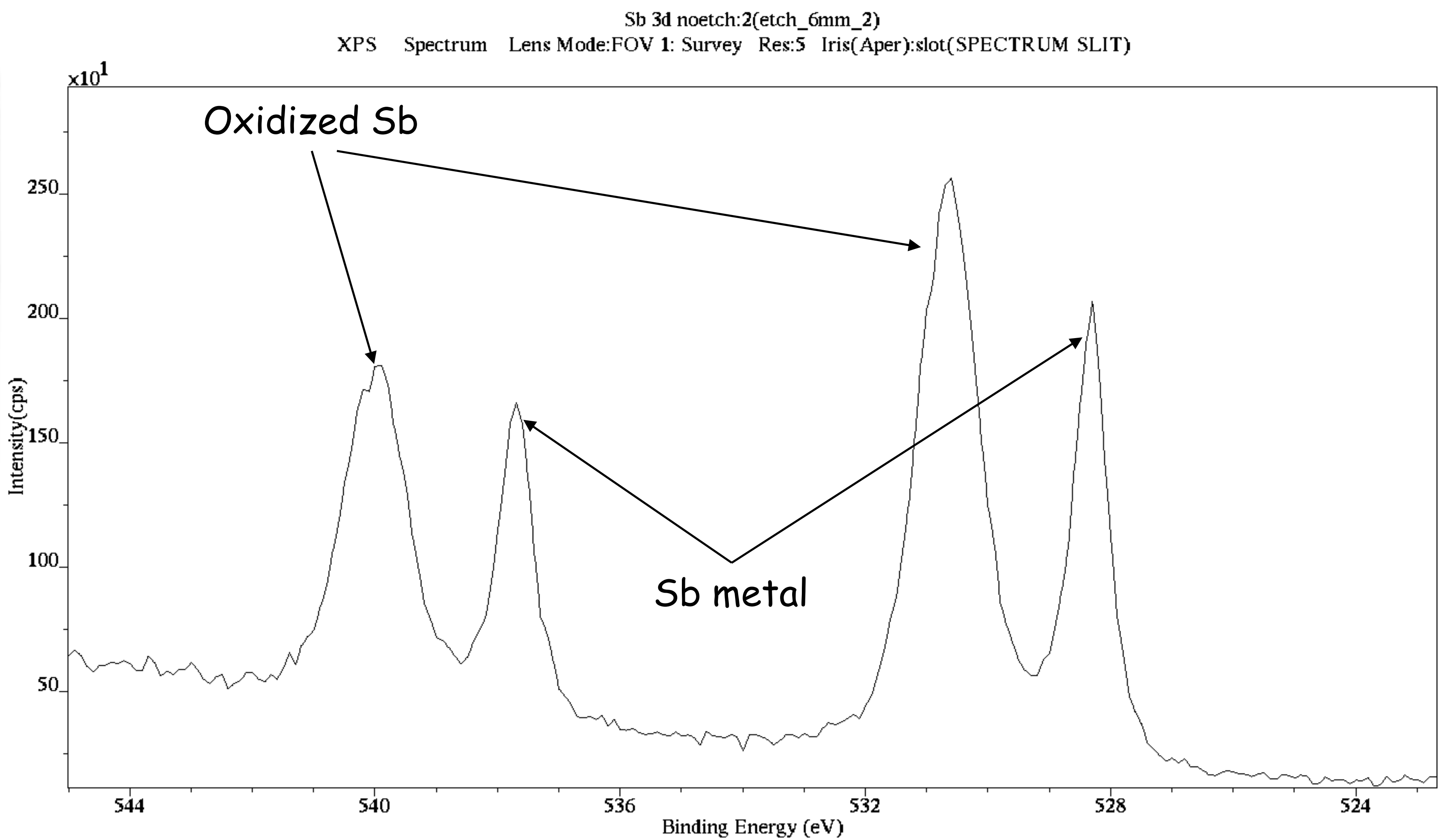
Side note on thin film coatings

- Good quality films are expert's territory
- Sb deposition in particular:
  - H.L. Clausing Inc.,
  - Bing Shi at the Argonne Thin Film Deposition Lab
- NiCr-Cu isn't easy, but we have one more commercial vendor for that

Depth profiling was performed using 5 sec etches by the Ar ion beam.
We estimated that a 5 sec etch removes on average 0.25 nm
of the surface material.

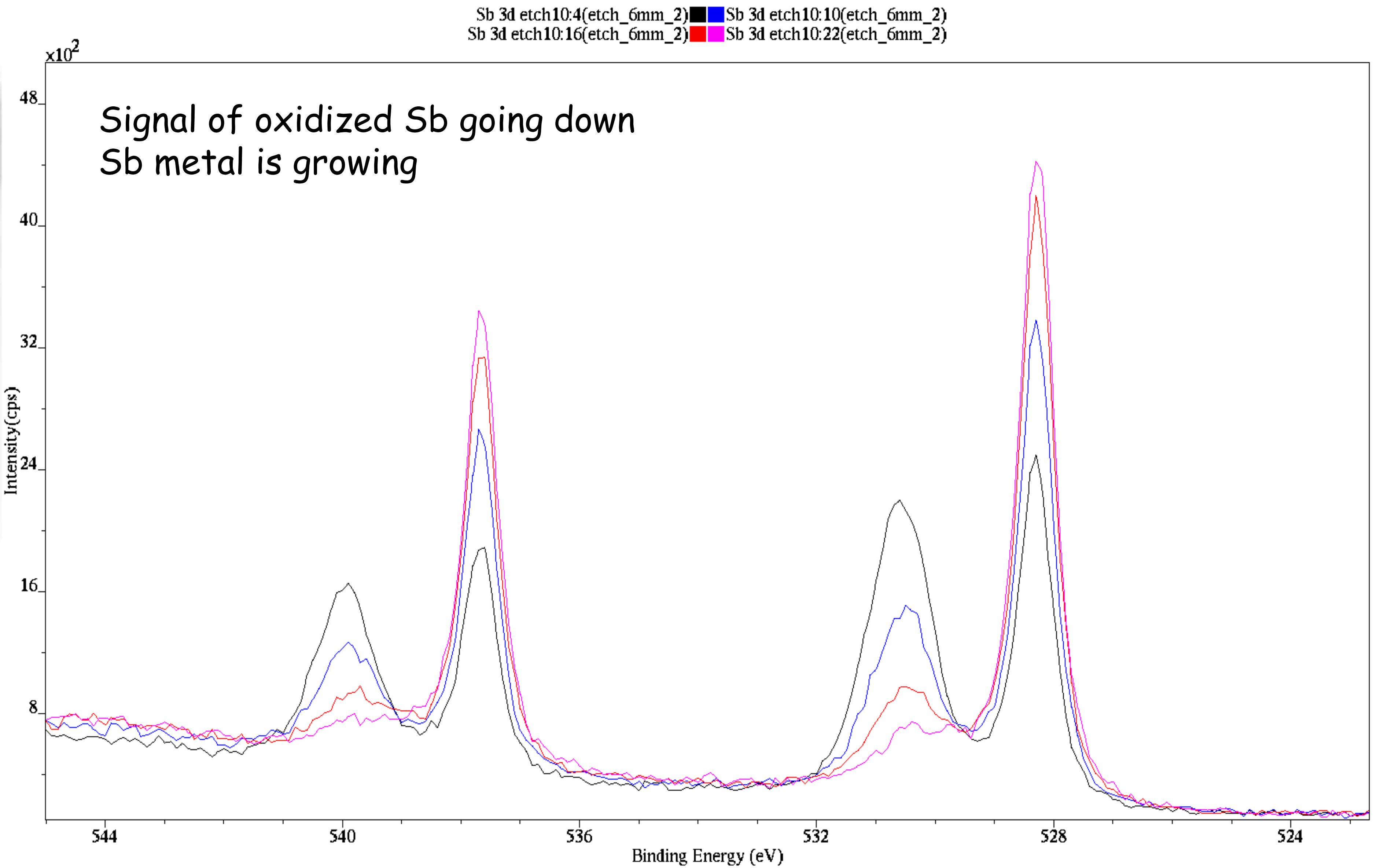
Sb XPS Studies

XPS scan before any ion etching



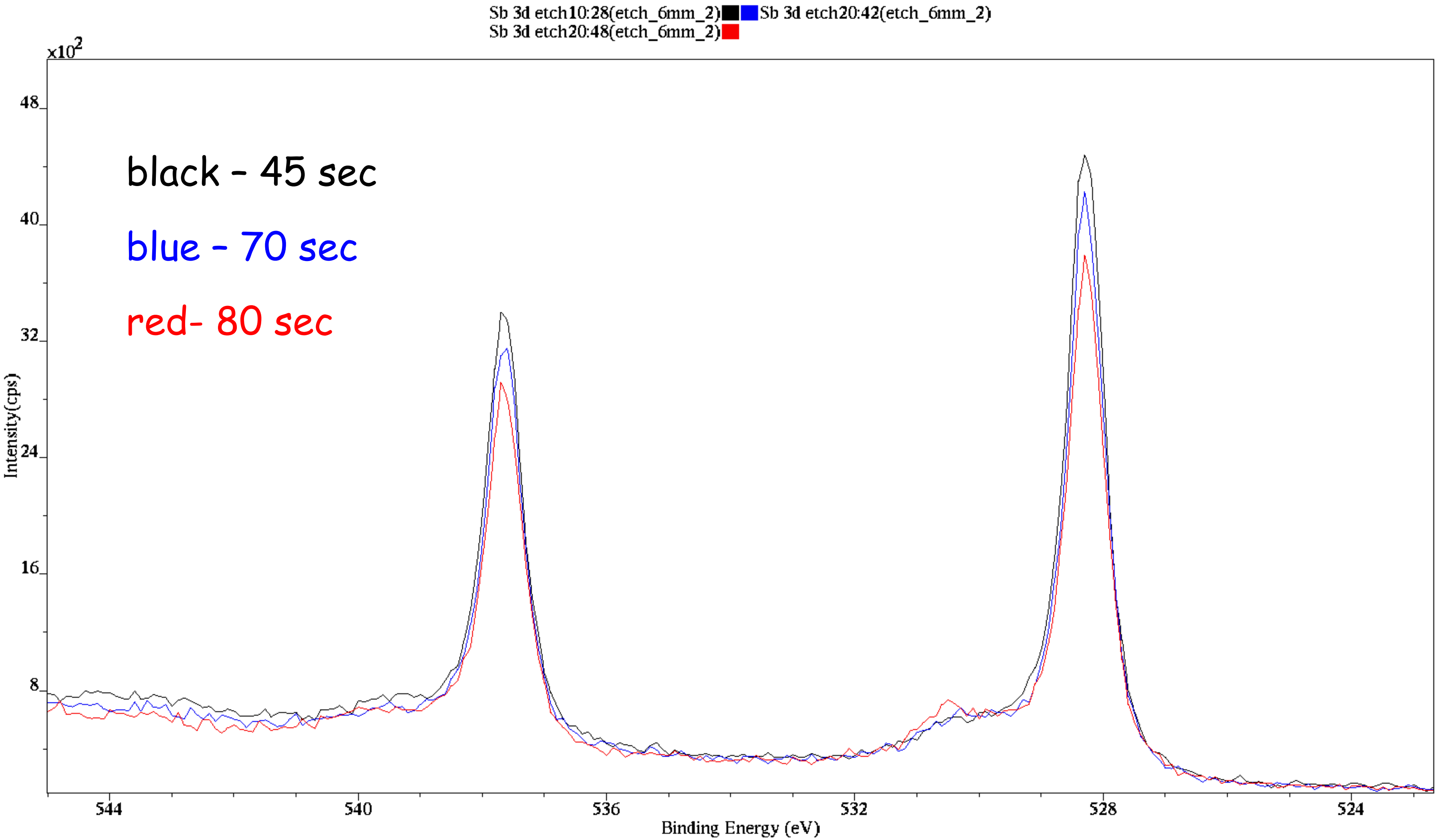
Sb XPS Studies

Intermediate scans within first 35 seconds of etching



Sb XPS Studies

After 40 seconds we see pure Sb metal (preferential sputtering of oxygen is not completely excluded, but it would have to be very strong)



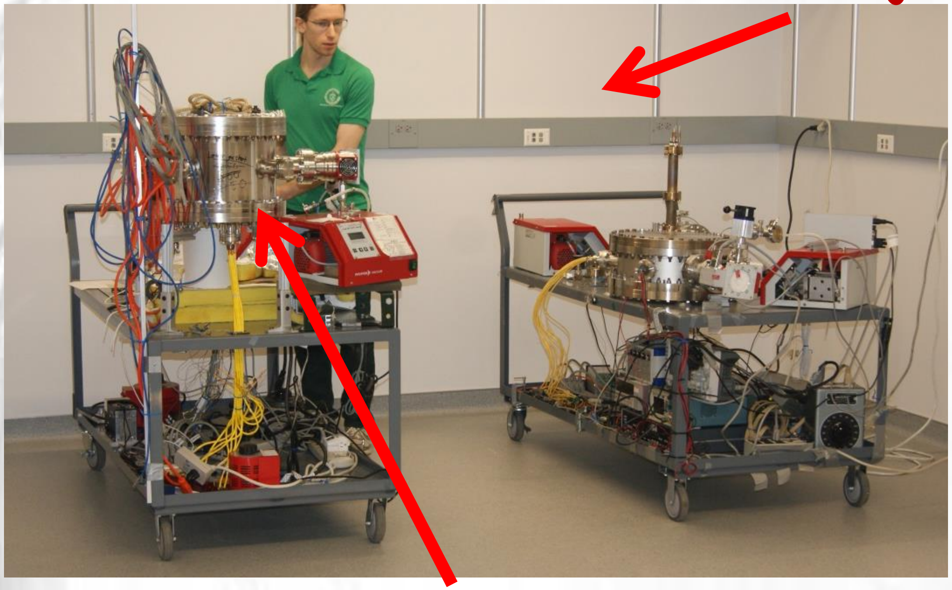
No Sb metal is seen after 200s

Assuming initial 10nm Sb thickness the average etch rate is 0.5A/sec

Therefore Sb-oxide thickness is ~40sec x 0.5A/sec = 2nm

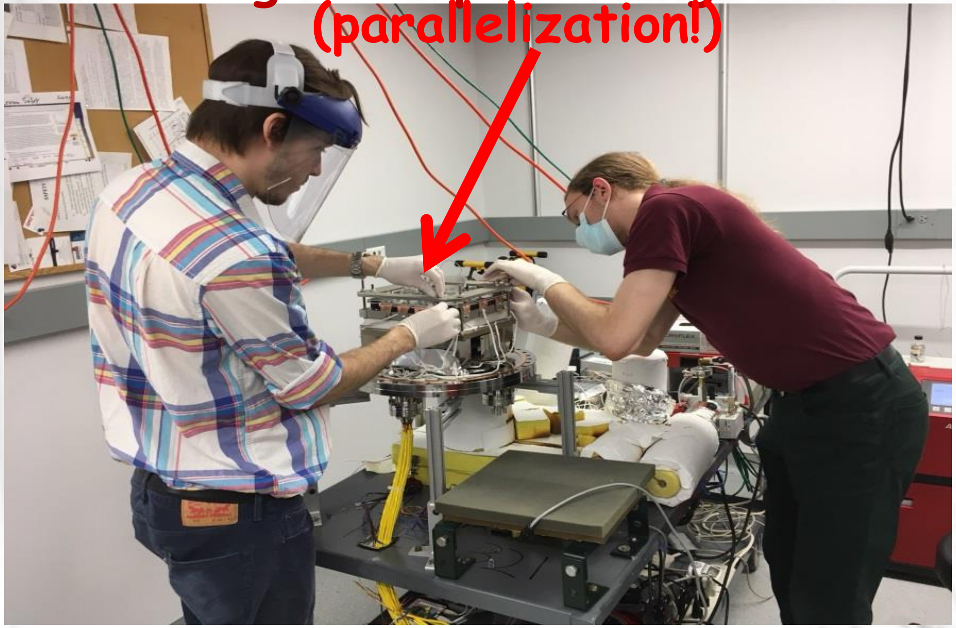
What's Next?

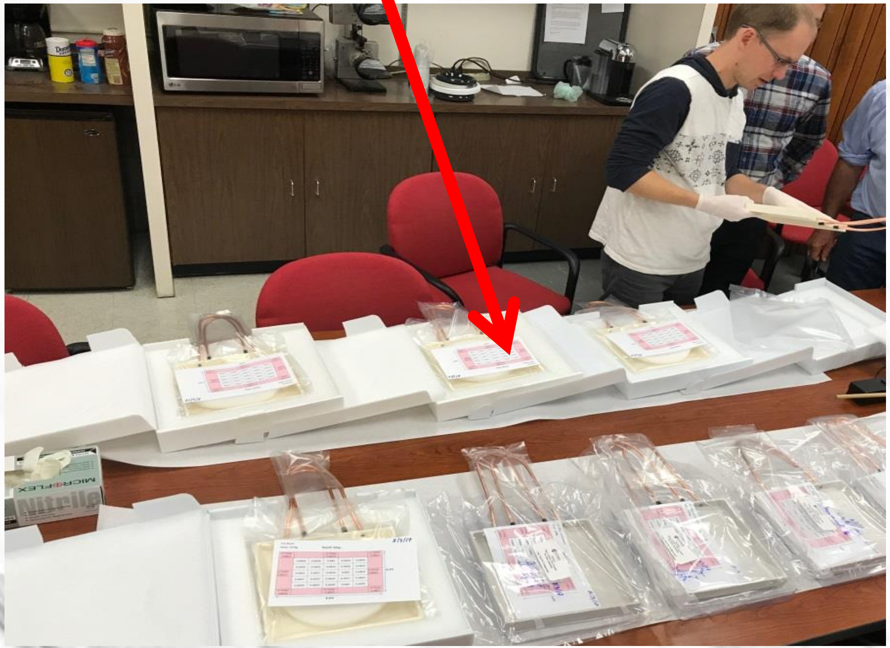
We've just got a new lab



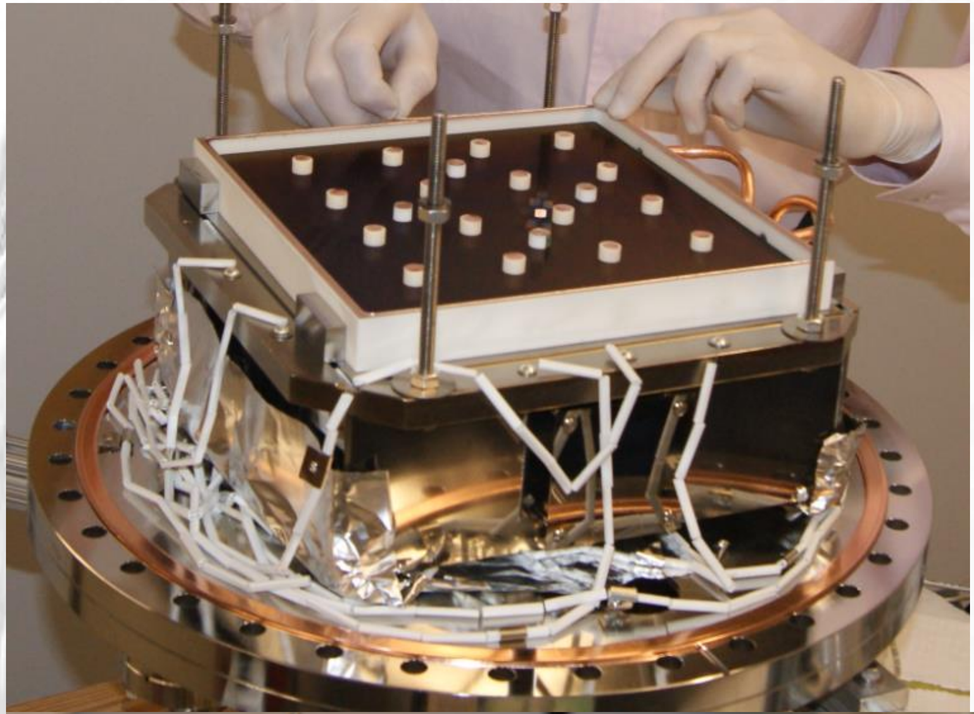
We've got 2nd processing chamber (parallelization!)

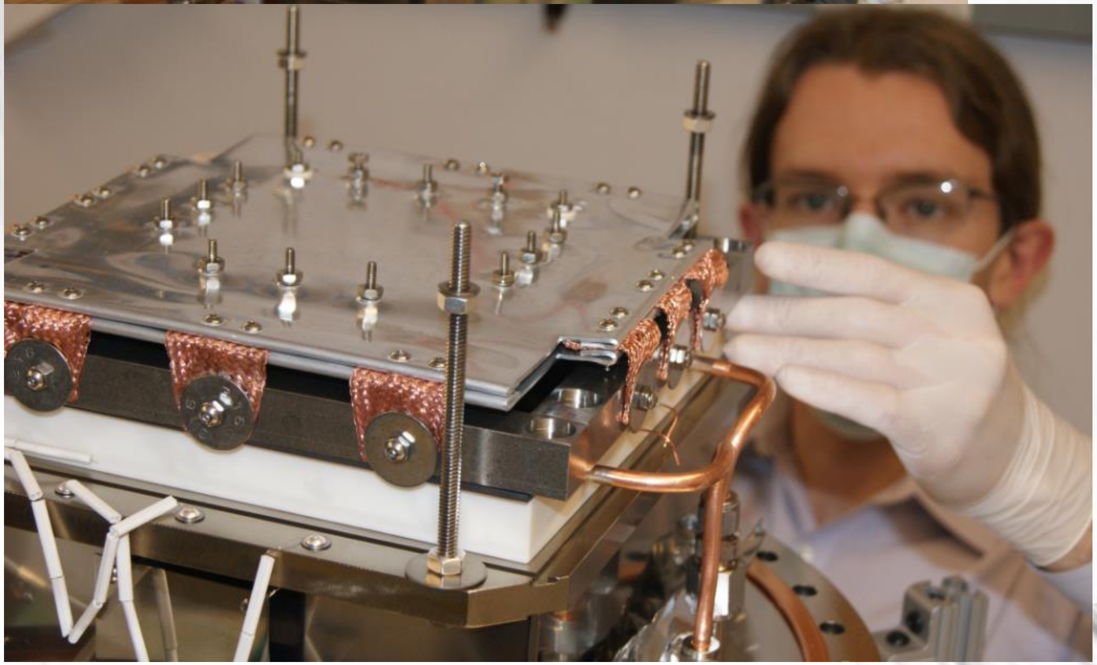
We are getting lots of components





In-Situ Tile #21





Assembled, sealed, and baked.
Now preparing for the "In-Situ" photocathode shot.

Summary

- Lots of fast timing applications including Fermilab experiments
- Large-Area Picosecond Photo-Detectors are being commercialized by Incom Inc.
    - Incom is transitioning from commissioning to exploitation
    - Let them know about your application and become an early adopter of LAPPD
- Chicago group is exploring if an In-Situ, PMT-like, process can be used to manufacture LAPPDs without vacuum transfer of the window
    - We consider this as a high risk R&D where success is not guaranteed but the pay-of is attractive enough to try
    - So far we don't see obvious show-stoppers
    - Lots of technical challenges
- We would like to build a stronger Fermilab-Chicago connection

Acknowledgements

UChicago PSEC Team
Evan Angelico, AE, Henry Frisch, Rich Northrop,
Carla Pilcher, Eric Spieglan
plus Eric Oberla and Mircea Bogdan on electronics
plus 12 high school and undergrad students last summer

Chicago group is supported by U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences and Offices of High Energy Physics and Nuclear Physics under contracts DE-SC0008172 and DE-SC0015367; the National Science Foundation under grant PHY-1066014; and the Physical Sciences Division of the University of Chicago.

We are grateful for in-depth discussions to the following experts:
Oswald Siegmund, Jason McPhate, Qiti Guo, Chian Liu, Bing Shi,
Howard Clausing, Alexander Filatov, Jeffrey Elam, Anil Mane,
Dean Walters, Alexander Zinovev, Ian Steel, Klaus Attenkofer,
John Smedley, Joe Gregar, Eileen Hahn

Acknowledgements

Incom Research and Development Team

Michael Minot, Michael R. Foley, Mark A. Popecki, William A. Worstell, Christopher A. Craven, Alexey Lyashenko, Bernhard W. Adams, Till Cremer, Justin L. Bond, Michael E. Stochaj, Melvin Aviles

Current Funding & Personnel Acknowledgements

- DOE, DE-SC0009717 ""Phase IIA TTO" - LAPPD Commercialization - Fully Integrated Sealed Detector Devices
- DOE, DE-SC0011262 Phase IIA - "Further Development of Large-Area Micro-channel Plates for a Broad Range of Commercial Applications"
- DOE, DE-SC0015267, Development of Gen-II LAPPDTM Systems For Nuclear Physics Experiments
- DOE DE-SC0017929, Phase I - "High Gain MCP ALD Film" (Alternative SEE Materials)
- NIH 1R43CA213581-01A Phase I - Time-of-Flight Proton Radiography for Proton Therapy
- DOE (HEP, NP, NNSA) Personnel: Dr. Alan L. Stone, Dr. Helmut Marsiske, Dr. Manouchehr Farkhondeh, Dr. Michelle Shinn, Carl C. Hebron, Dr. Kenneth R. Marken Jr, Dr. Manny Oliver, Dr. Donald Hornback and many others.

Back-up

OTPC

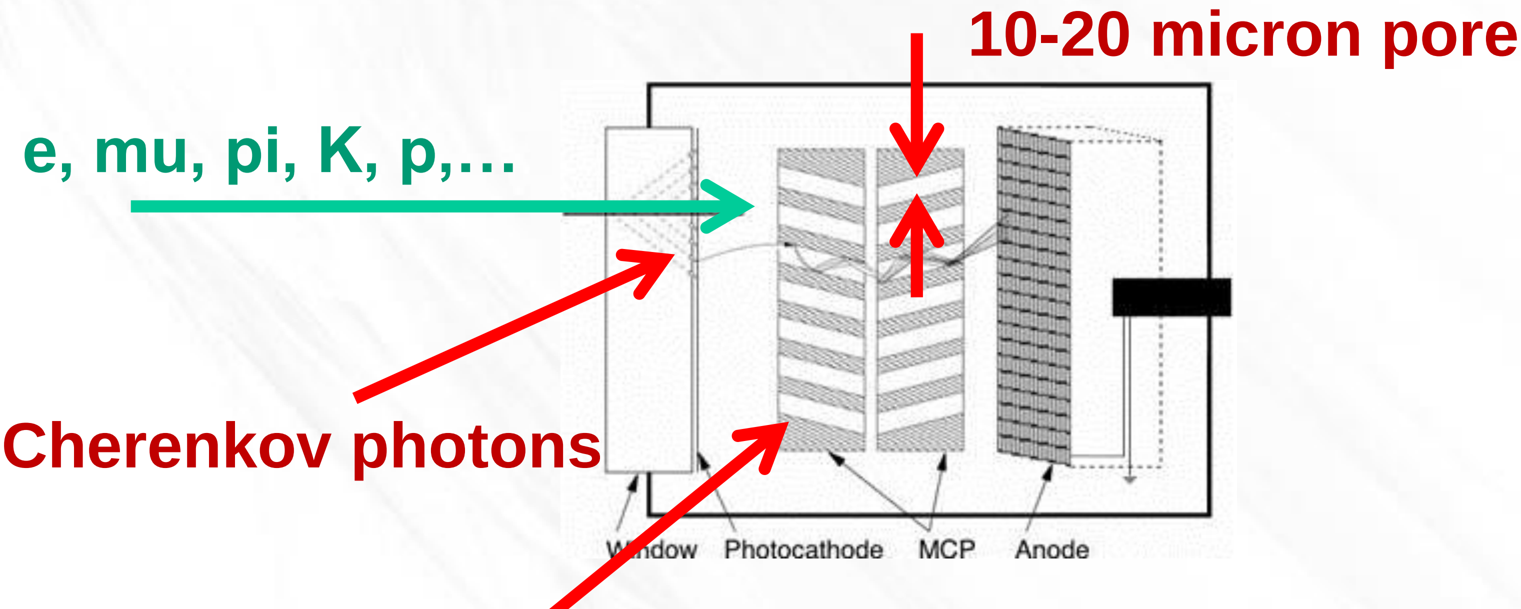
A B S T R A C T

A first experimental test of tracking relativistic charged particles by 'drifting' Cherenkov photons in a water-based optical time-projection chamber (OTPC) has been performed at the Fermilab Test Beam Facility. The prototype OTPC detector consists of a 77 cm long, 28 cm diameter, 40 kg cylindrical water mass instrumented with a combination of commercial $5.1 \times 5.1\ \mathrm{cm}^2$ micro-channel plate photo-multipliers (MCP-PMT) and $6.7 \times 6.7\ \mathrm{cm}^2$ mirrors. Five MCP-PMTs are installed in two columns along the OTPC cylinder in a small-angle stereo configuration. A mirror is mounted opposite each MCP-PMT on the inner surface of the detector cylinder, effectively increasing the photo-detection efficiency and providing a time-resolved image of the Cherenkov light on the opposing wall. Each MCP-PMT is coupled to an anode readout consisting of thirty $50\ \Omega$ microstrips. A 180-channel data acquisition system digitizes the MCP-PMT signals on one end of the microstrips using the PSEC4 waveform sampling-and-digitizing chip operating at a sampling rate of 10.24 Gigasamples-per-second. The single-ended microstrip readout determines the time and position of a photon arrival at the face of the MCP-PMT by recording both the direct signal and the pulse reflected from the unterminated far end of the strip. The detector was installed on the Fermilab MCenter secondary beam-line behind a steel absorber where the primary flux is multi-GeV muons. Approximately 80 Cherenkov photons are detected for a through-going muon track in a total event duration of $\sim$2 ns. By measuring the time-of-arrival and the position of individual photons at the surface of the detector to $\leq$100 ps and a few mm, respectively, we have measured a spatial resolution of $\sim$15 mm for each MCP-PMT track segment, and, from linear fits over the entire track length of $\sim$40 cm, an angular resolution on the track direction of $\sim$60 mrad.

Fast Timing Pre-requisites

1) Fast source (e.g. prompt Cherenkov light)
2) Psec-level pixel size (e.g. MCP pores)
3) High gain (e.g. MgO ALD MCPs give >10^7)
4) Low noise

Schematic of an MCP-based Photo-Detector



Amplification section: Gain-bandwidth, Signal-to-Noise, Power, Cost

Timing Limits

Can we achieve sub-picoseconds?

Stefan Ritt slide

2nd Chicago Photocathode Workshop

How is timing resolution affected?

$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

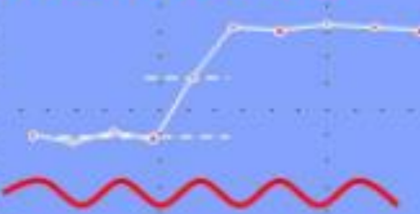
•Assumes zero aperture jitter

	U	Δu	f_s	f_{3dB}	Δt
•today:	100 mV	1 mV	2 GSPS	300 MHz	~10 ps
•optimized SNR:	1 V	1 mV	2 GSPS	300 MHz	1 ps
•next generation:	100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
•next generation •optimized SNR:	1V	1 mV	10 GSPS	3 GHz	0.1 ps

•How to achieve this?

•includes detector noise in the frequency region of the rise time

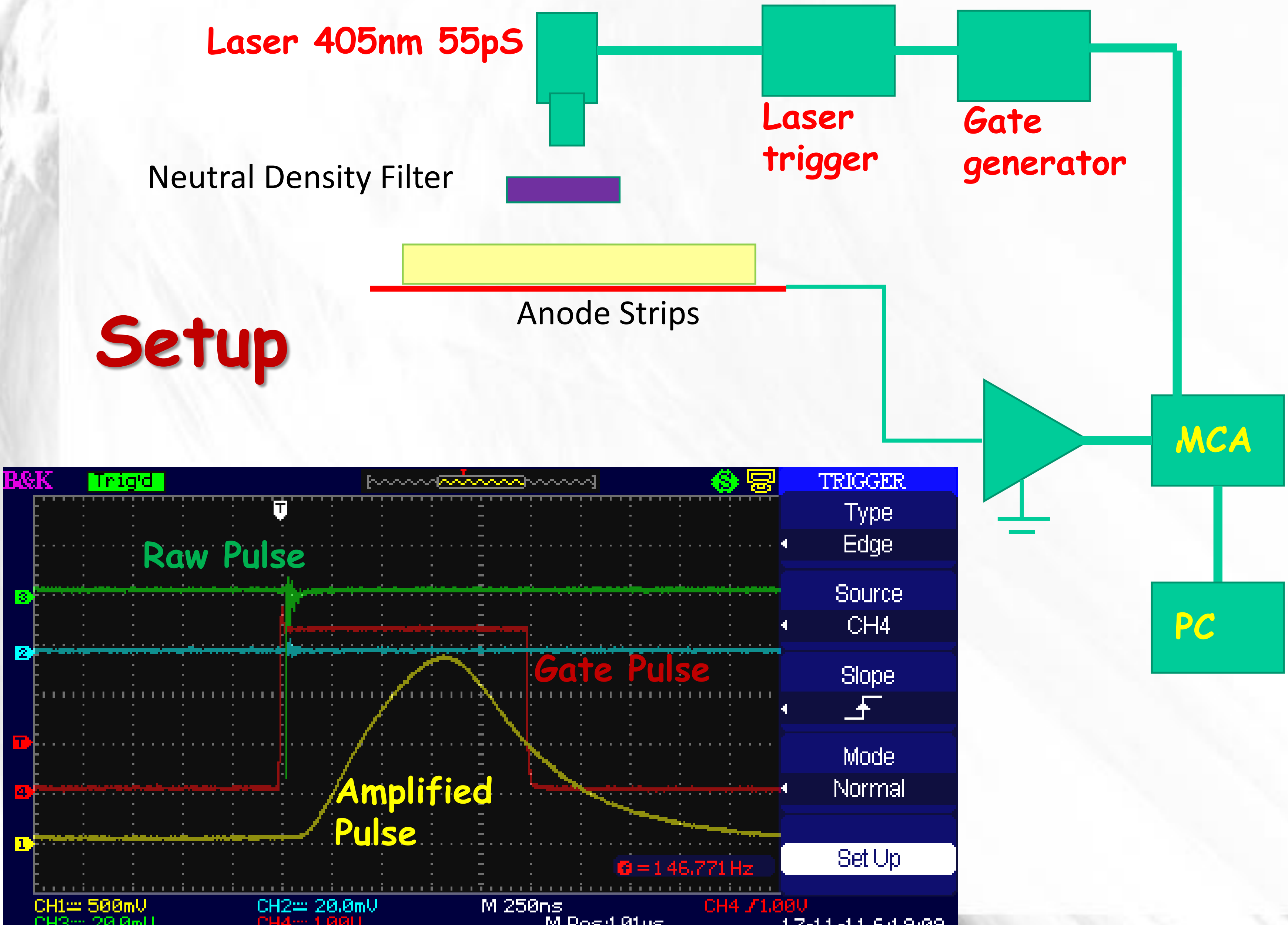
•and aperture jitter



Stefan Ritt slide

Getting to 100 fs won't be that easy but it's a nice goal to have

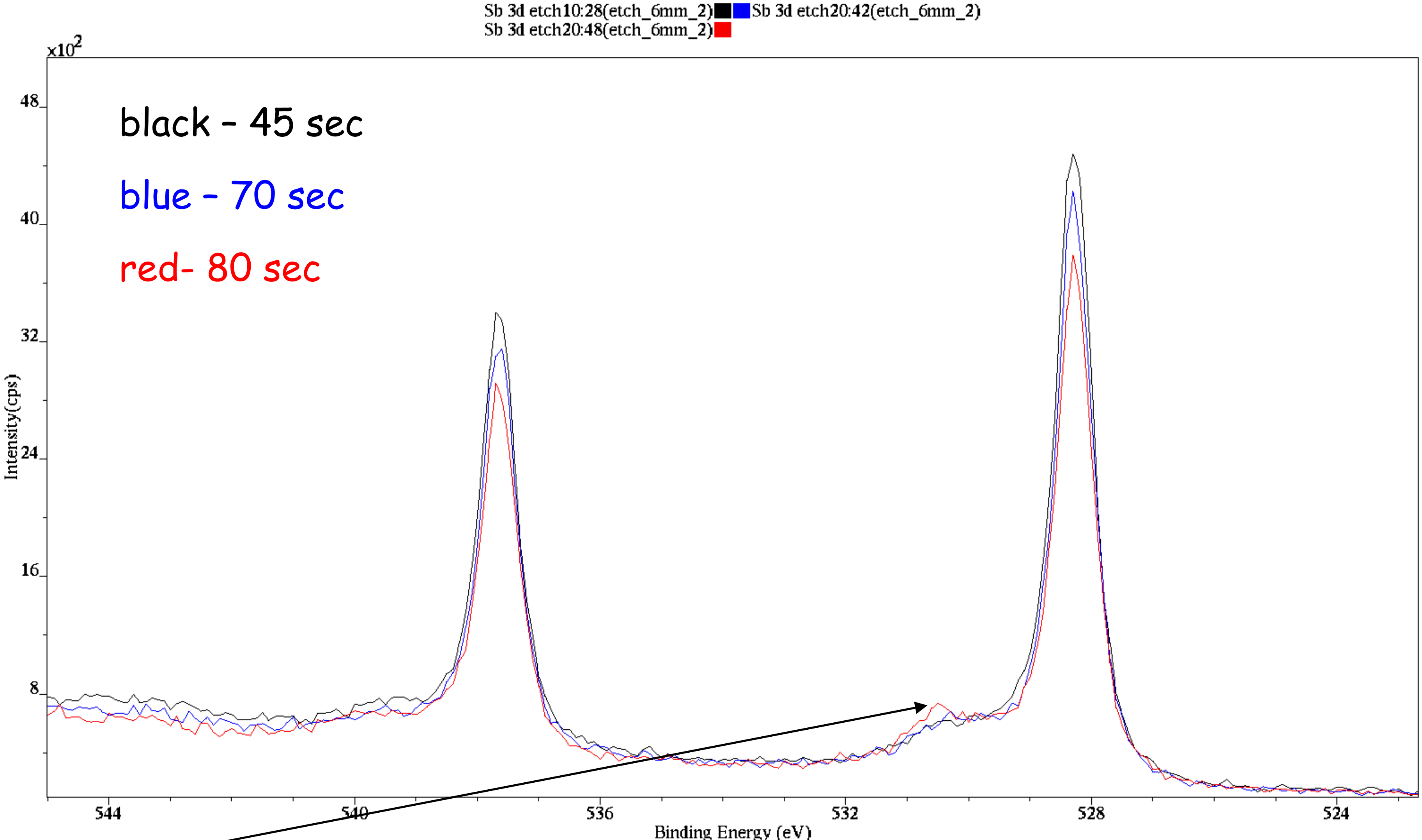
PHDs measurement scheme



Slide courtesy of M. Minot at Incom Inc.

Sb XPS Studies

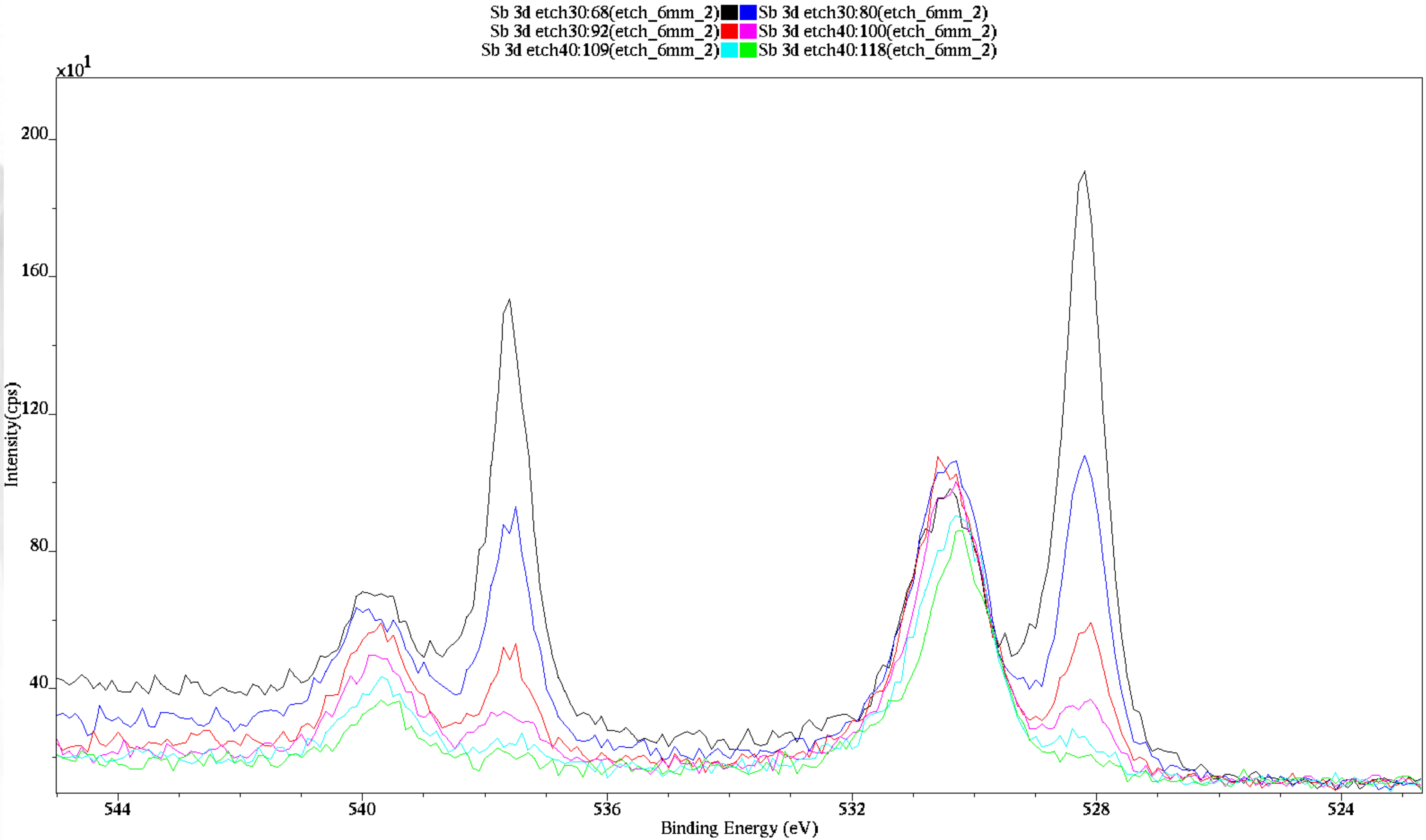
Between 45 seconds and 80 seconds we see pure Sb metal (preferential sputtering of oxygen is not completely excluded, but it has to be very strong)



Peak at 530.4 eV belongs to Auger signals of a Cu metal underlayer

Sb XPS Studies

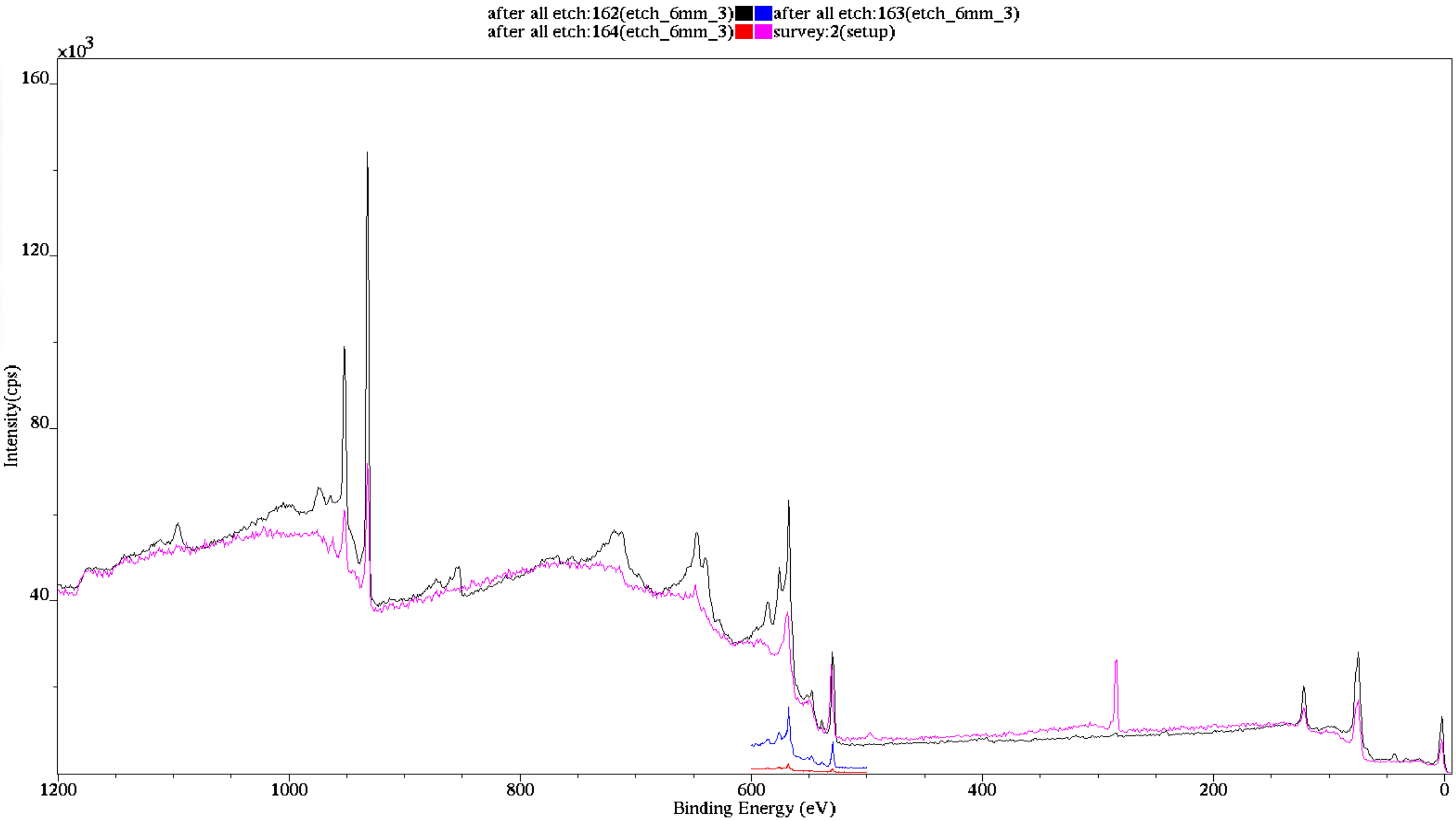
Continue ion etch: Sb metal goes down, Auger Cu goes up



No Sb metal is seen after 200s
Assuming initial 10nm Sb thickness the average etch rate is 0.5A/sec

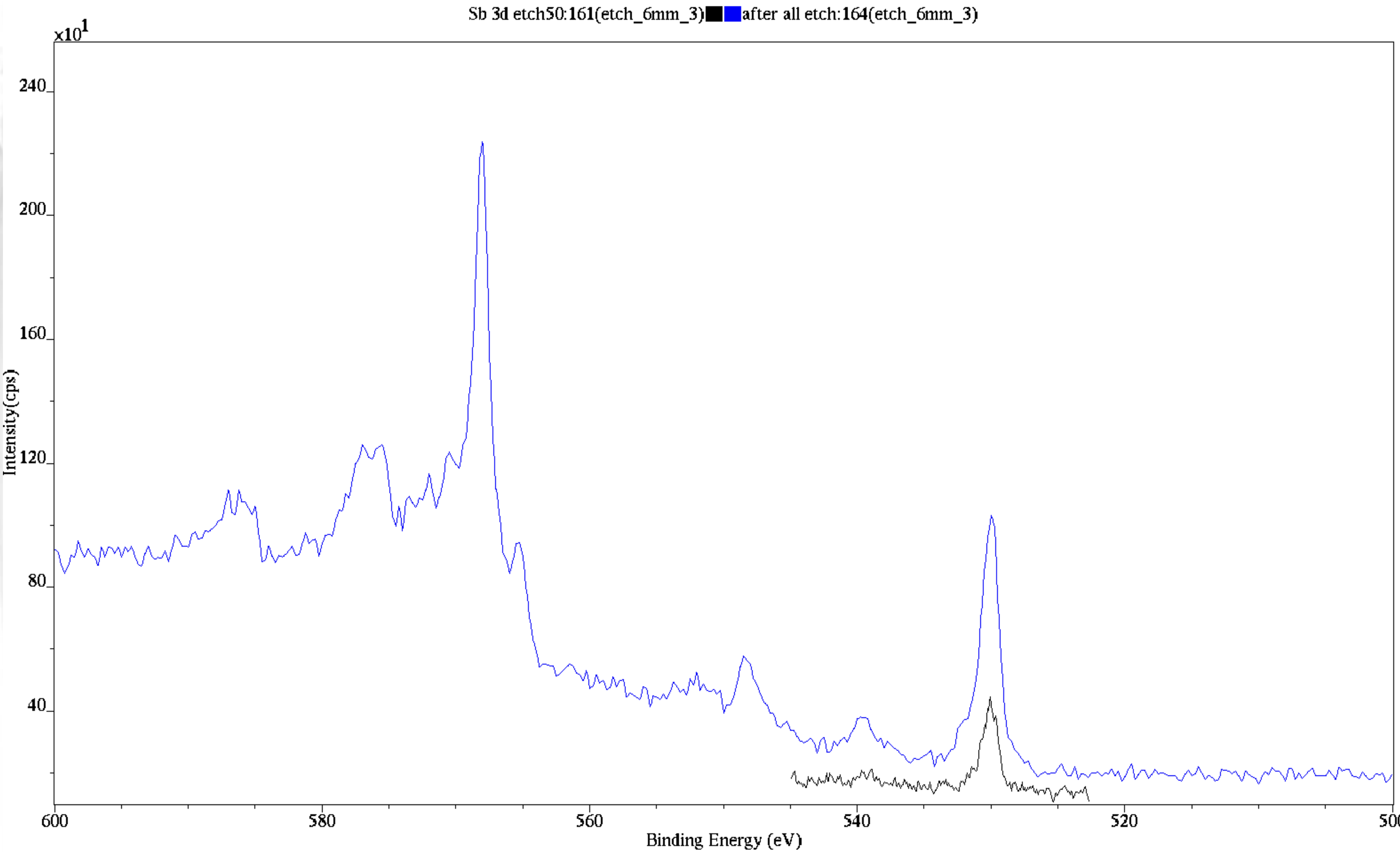
Sb XPS Studies

Assigning the ~530eV and 540eV peaks to Auger Cu



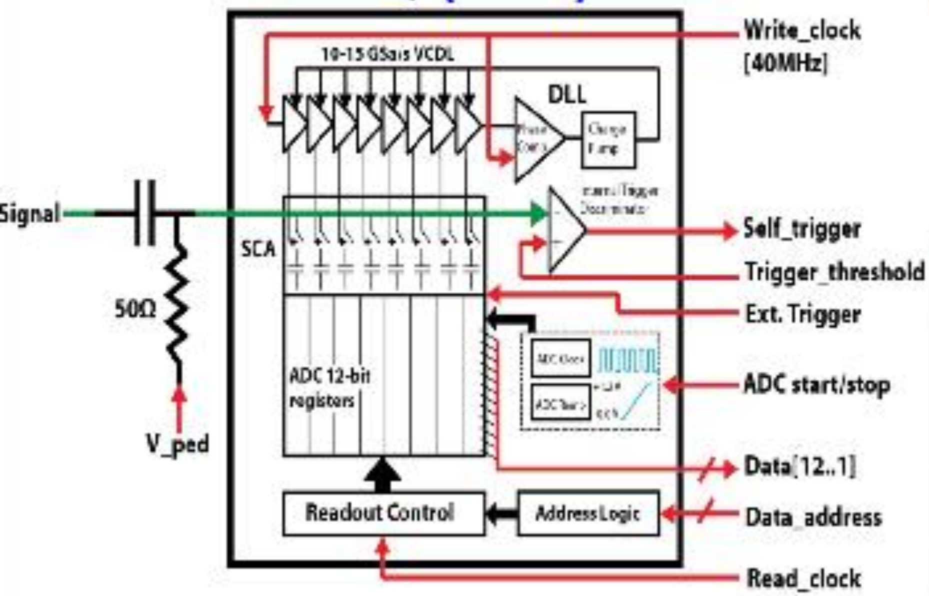
Sb XPS Studies

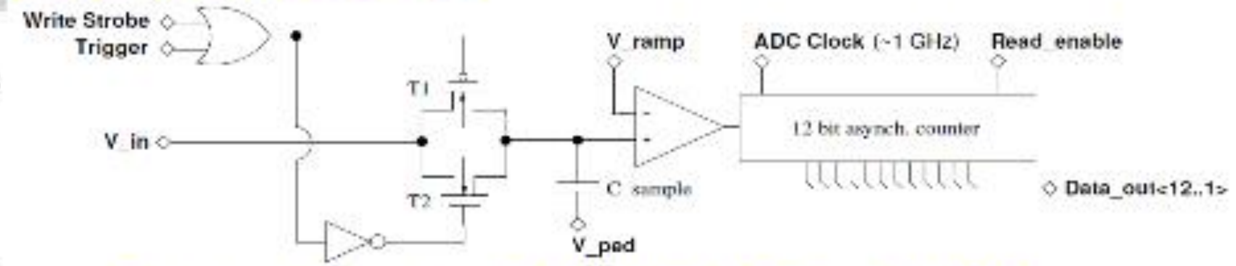
Assigning the ~530eV and 540eV peaks to Auger Cu



PSEC4 ASIC

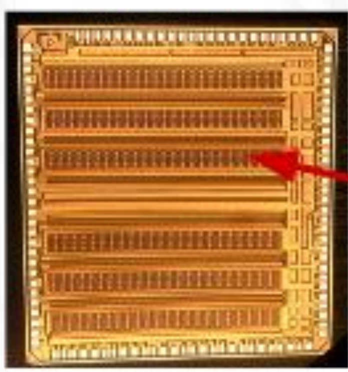
NIMA 735, (2014) 452-461





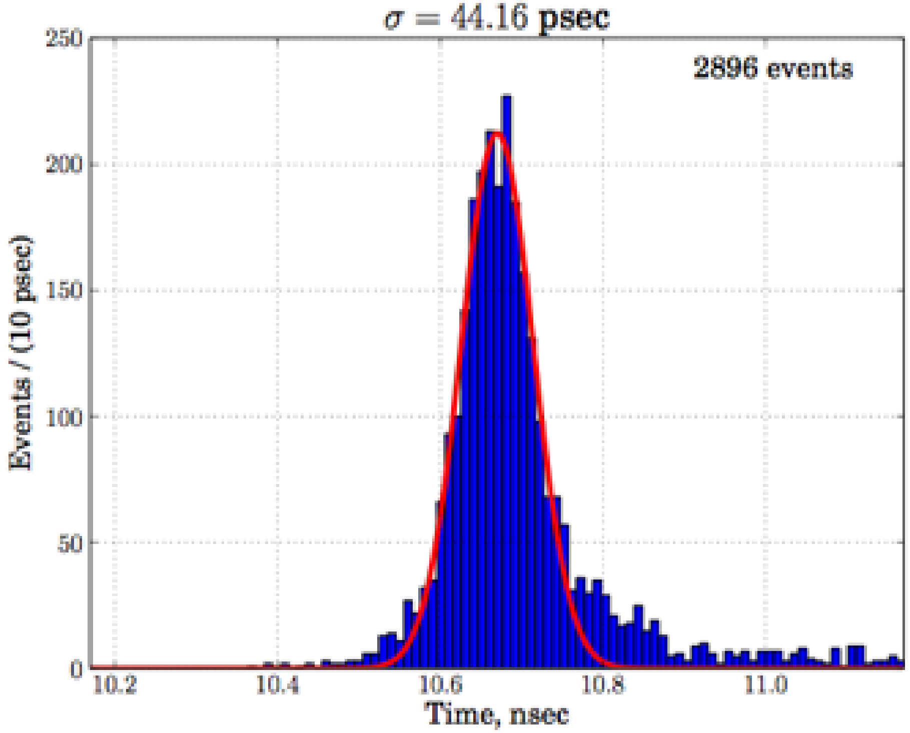
- Fabricated using IBM-8RF 130nm CMOS process
- Each of 6 channels is a switch capacitor array
  - 256 samples deep
  - on-chip ADC
  - sampled of 10's MHz clock using VCDL
- 10Gs/s, 1.5GHz
- Controlled by FPGA

PSEC4 die

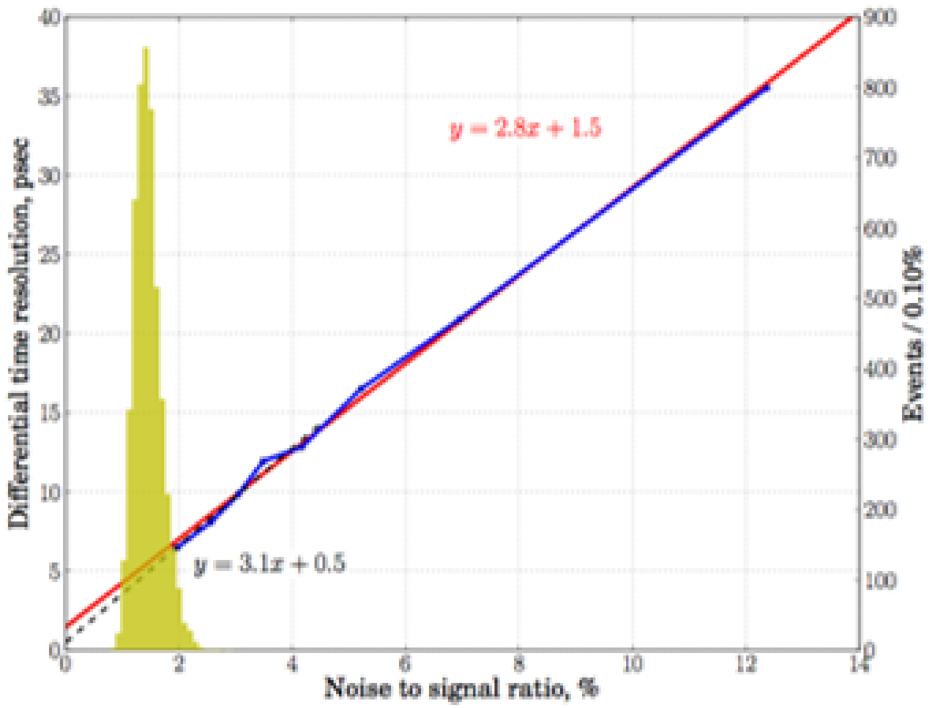


Evaluation board

Present (now old) Time Resolution



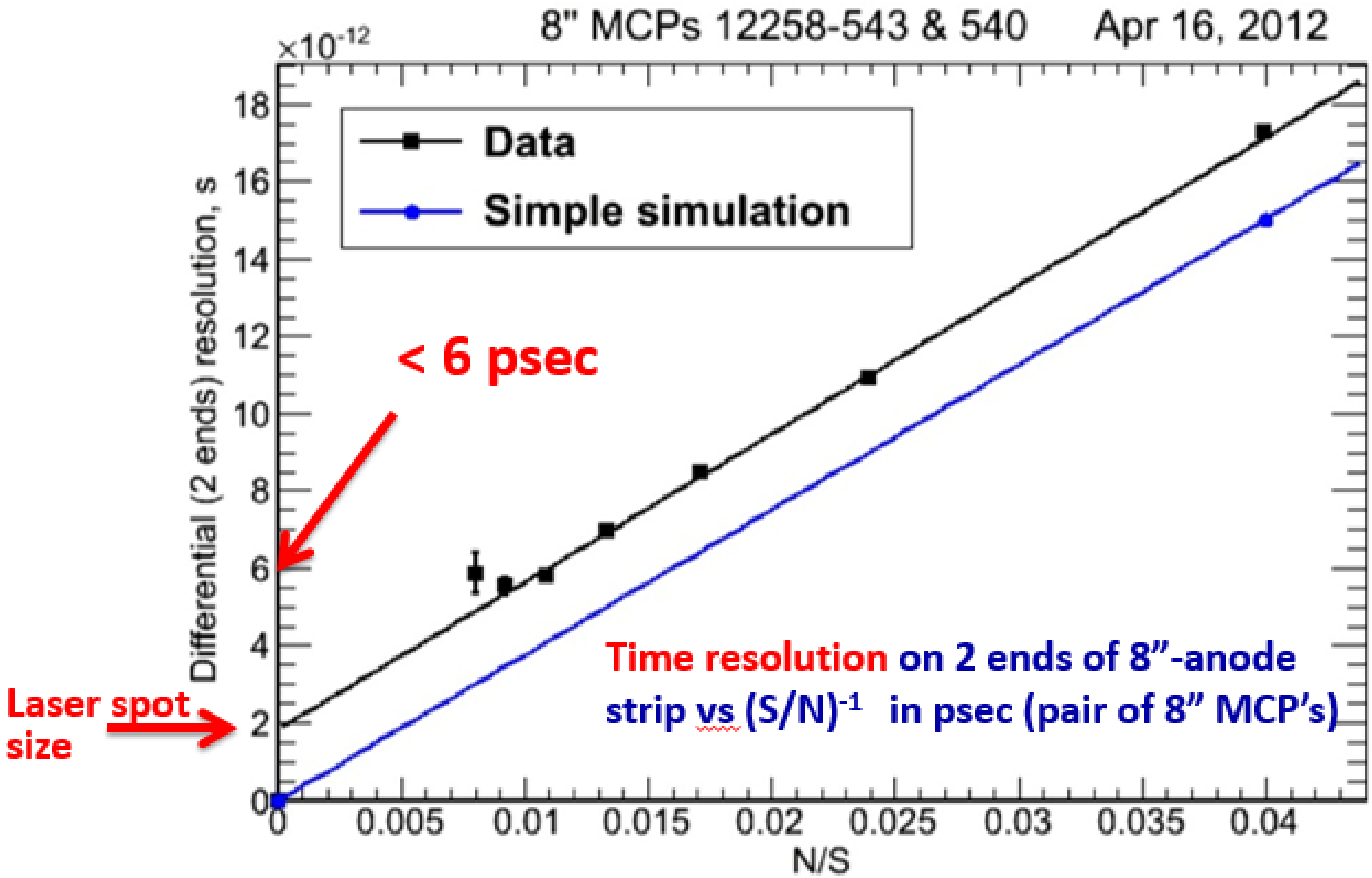
Single Photo-electron
PSEC4 Waveform sampling
Sigma=44 psec



Differential Time Resolution
Large signal Limit
Oscilloscope Readout
Black line is y=3.1x+0.5 (ps)
Red line is y=2.8x +1.5 (ps)
Where the constant term represents the large S/N limit (0.5-1.5 ps)

Highly non-optimized system (!)- could do much better

Timing res. agrees with MC



N = RMS of the noise; S = signal amplitude

M. Wetstein, B. Adams, A. Elagin, R. Obaid, A. Vostrikov, ...

PSEC4

ABSTRACT

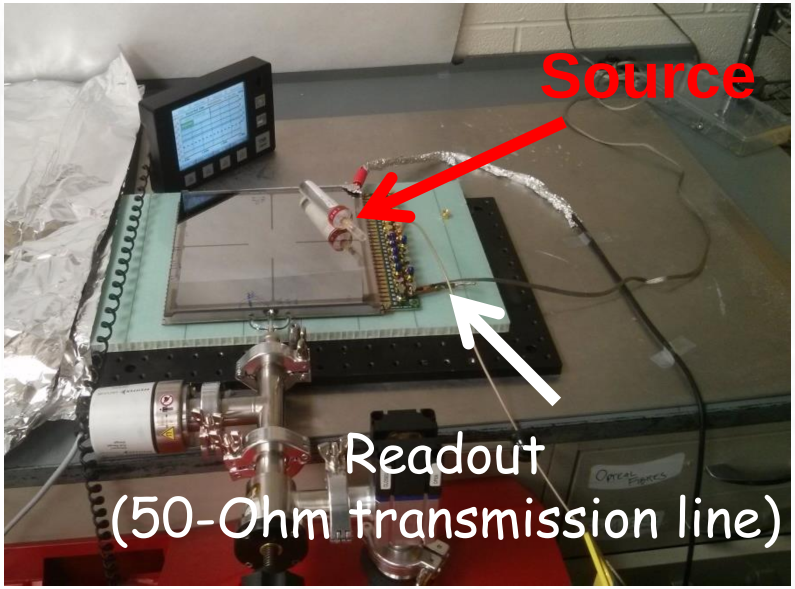
The PSEC4 custom integrated circuit was designed for the recording of fast waveforms for use in large-area time-of-flight detector systems. The ASIC has been fabricated using the IBM-8RF 0.13 μm CMOS process. On each of the six analog channels, PSEC4 employs a switched capacitor array (SCA) of 256 samples deep, a ramp-compare ADC with 10.5 bits of DC dynamic range, and a serial data readout with the capability of region-of-interest windowing to reduce dead time. The sampling rate can be adjusted between 4 and 15 Gigasamples/second (GSa/s) on all channels and is servo-controlled on-chip with a low-jitter delay-locked loop (DLL). The input signals are passively coupled on-chip with a −3 dB analog bandwidth of 1.5 GHz. The power consumption in quiescent sampling mode is less than 50 mW/chip; at a sustained trigger and a readout rate of 50 kHz the chip draws 100 mW. After fixed-pattern pedestal subtraction, the uncorrected integral non-linearity is 0.15% over a 750 mV dynamic range. With a linearity correction, a full 1 V signal voltage range is available. The sampling timebase has a fixed-pattern non-linearity with an RMS of 13%, which can be corrected for precision waveform feature extraction and timing.

First Signals from an In-Situ LAPPD

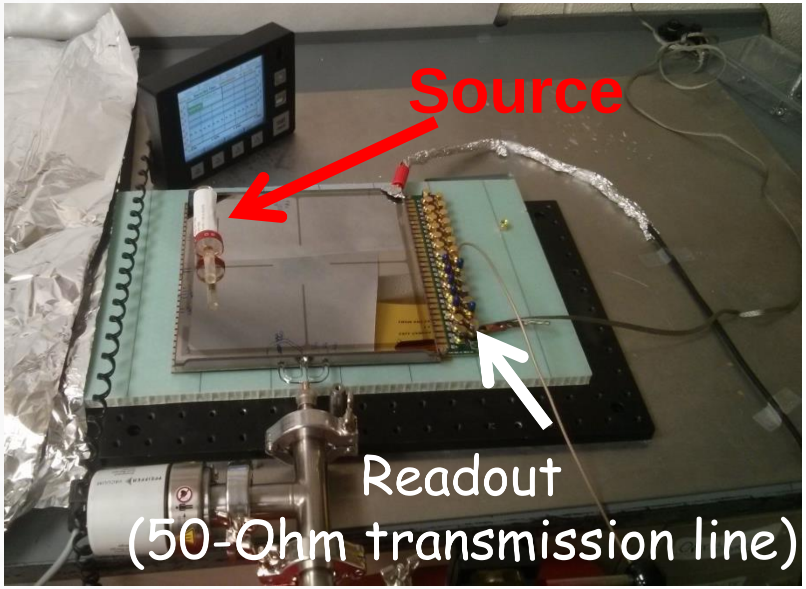
April, 2016

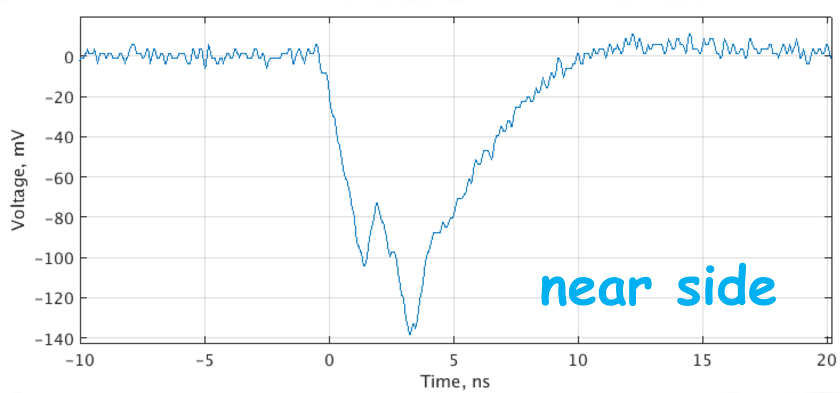
(Sb cathode)

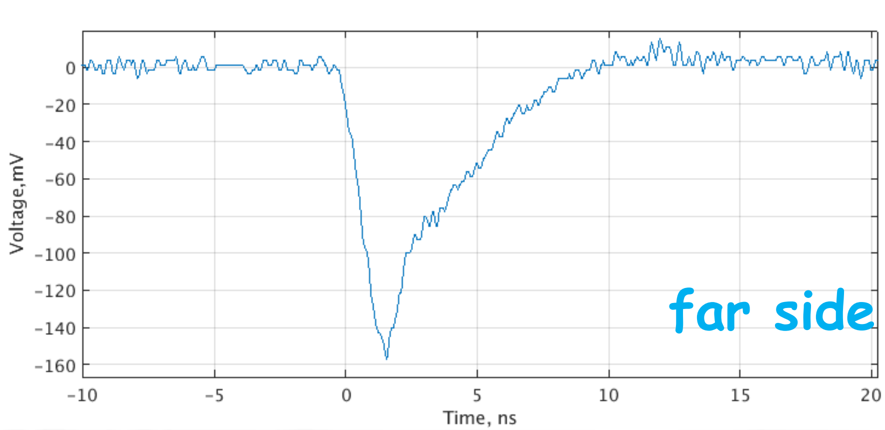
Near side: reflection from unterminated far end



Far side: reflection is superimposed on prompt







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

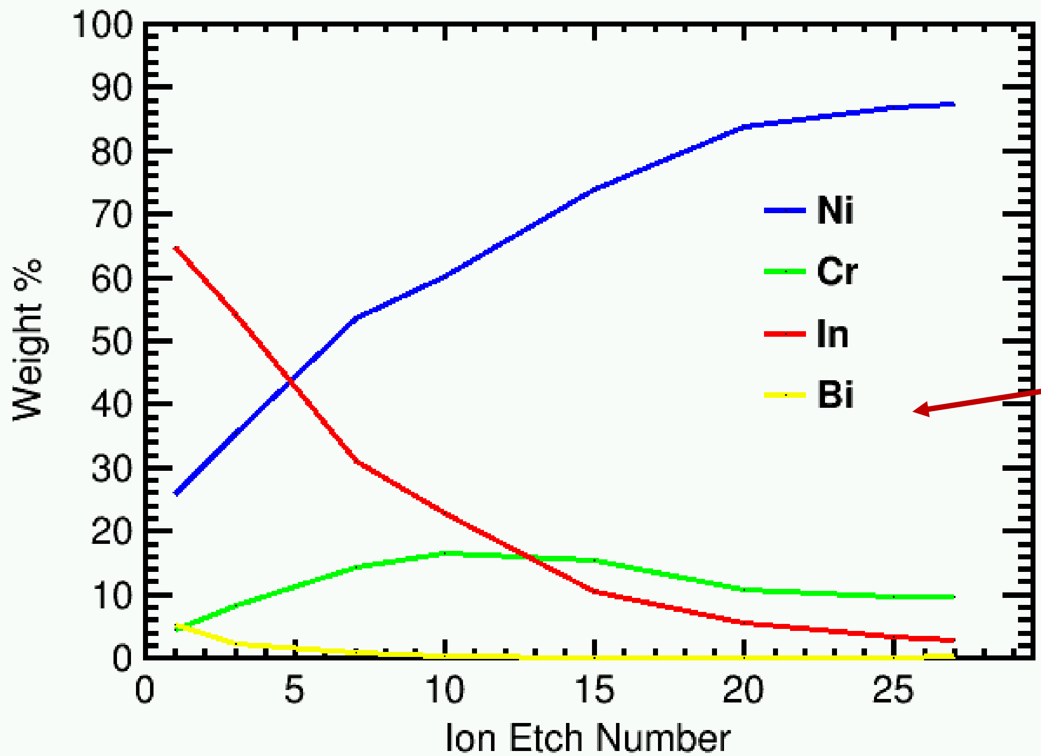
Metallurgy of the Seal

Moderate temperatures and short exposure time:

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

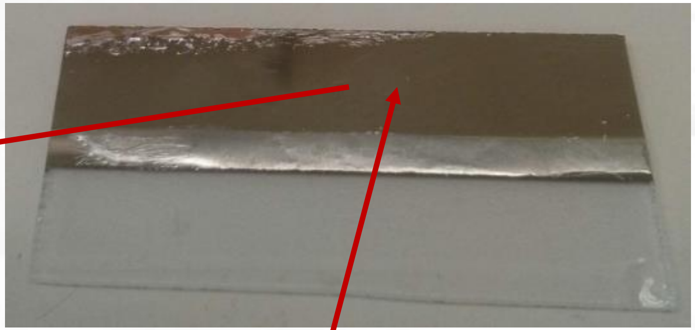
Low melting InBi alloy allows to explore temperatures below melting of pure In (157C)

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

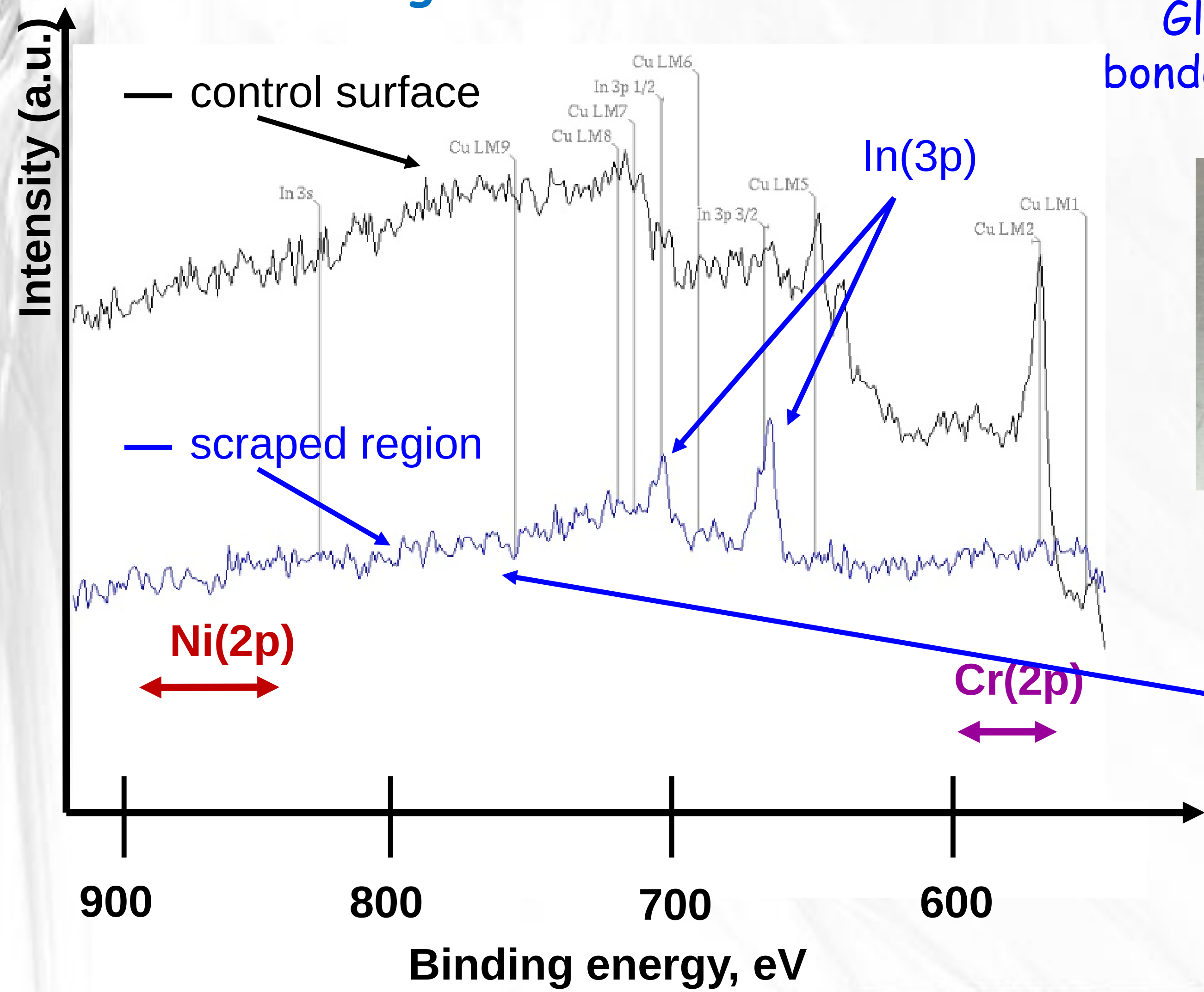
XPS access courtesy of J. Kurley and A. Filatov at UChicago

Metallurgy of a Good Seal

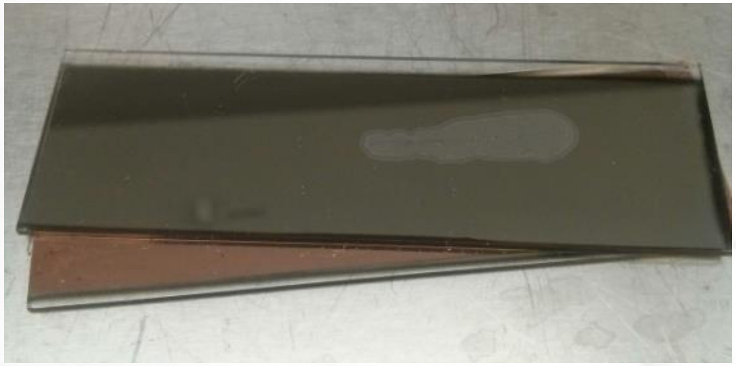
Higher temperatures and longer exposure time

- Indium penetrates through entire NiCr layer

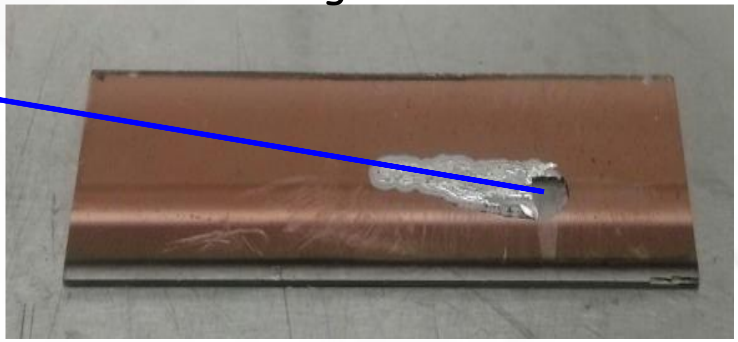
XPS of the glass side of the interface



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

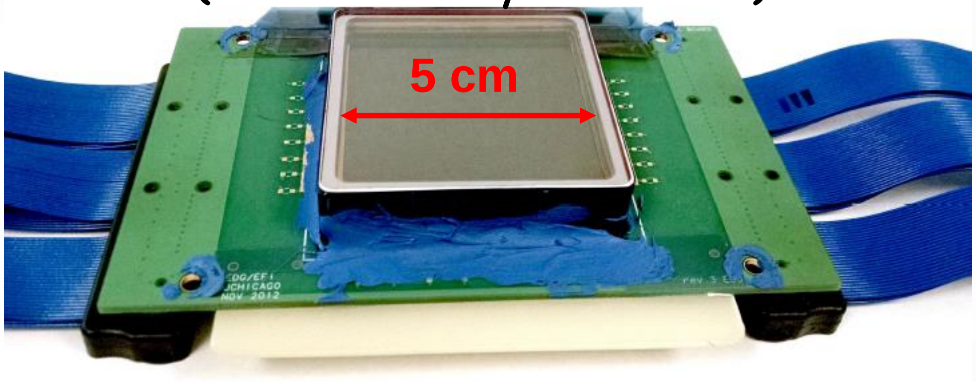
XPS data courtesy of A. Filatov at UChicago

Indium seal recipes exist for a long time

Why do we need another indium seal recipe?

PLANACON™

(MCP-PMT by Photonis)



Make larger photo-detectors

Our recipe scales well to large perimeter

Simplify the assembly process

Our recipe is compatible with PMT-like batch production

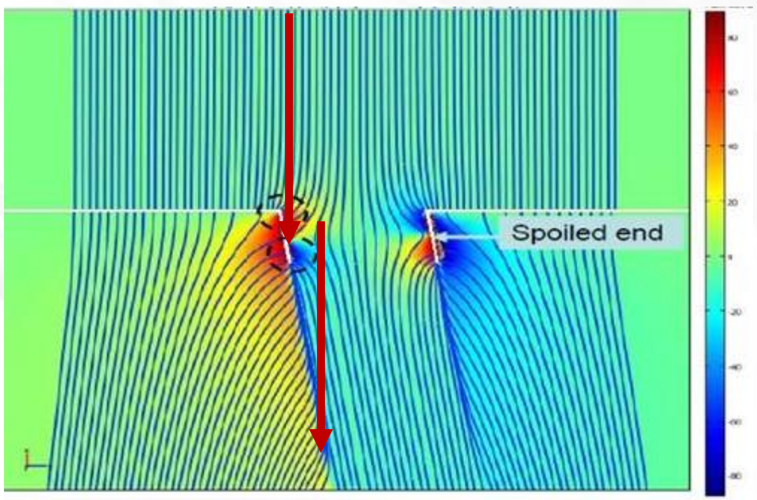
Large-signal Limit Dependence

Does the time resolution go as 1/N or 1/root-N photo-electrons?

Hypothesis:

- In an MCP-PMT the time jitter is dominated by the 1st strike: path length to the 1st strike varies
- Smaller pores, increased bias angle are better
- "IF gain is such that a single photon shower makes the pulse (e.g. 10^7), time jitter is set by the probability that NO photon has arrived in interval δt" - H. Frisch

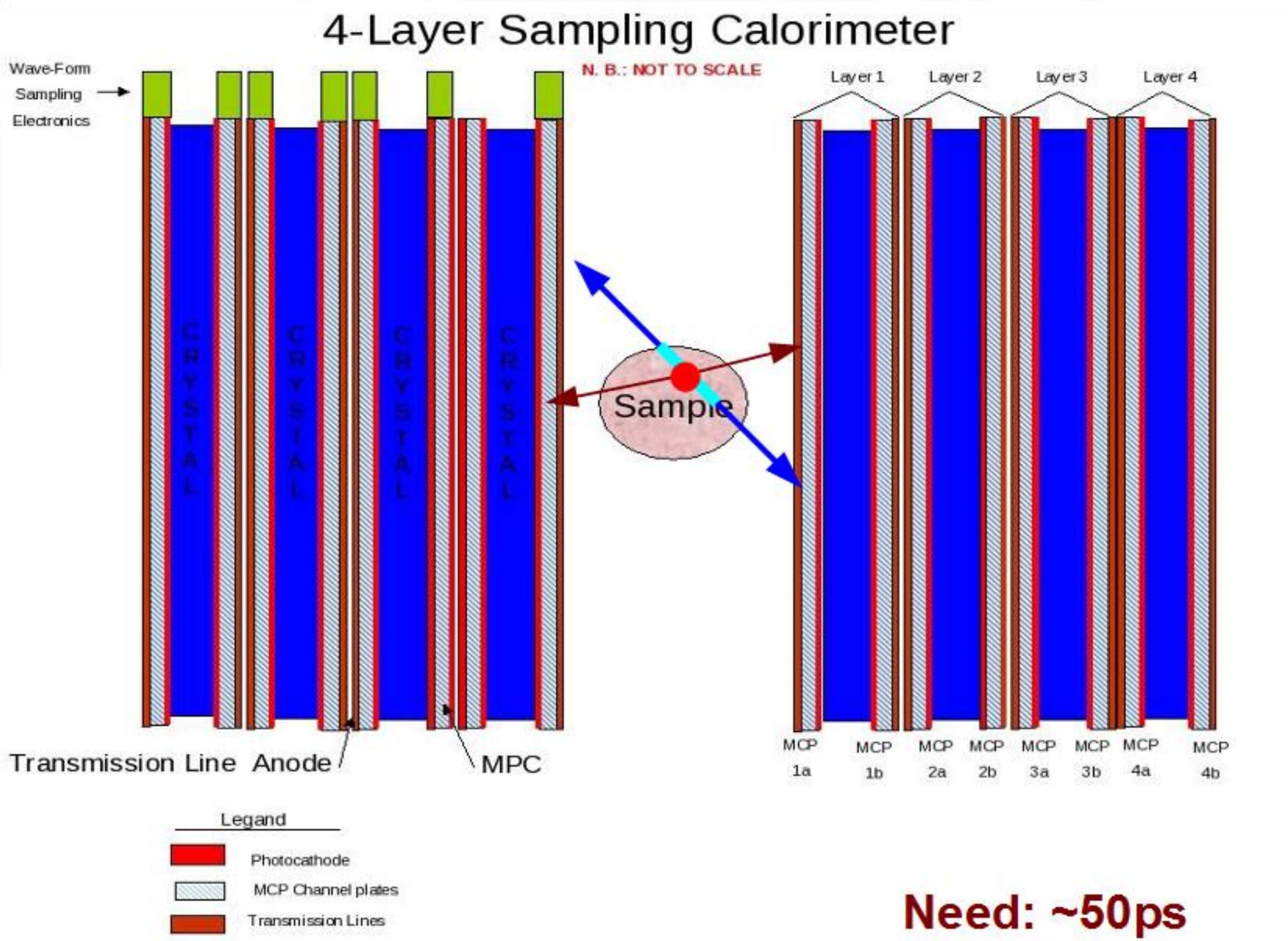
This assumes that one fits the waveform to determine pulse T_0



E.g. if 50 photoelectrons (from Cherenkov light in a window) arrive within 50 psec, the probability that one goes for T psec with NO photon making a first strike goes as e^{-T} => a 1/N dependence

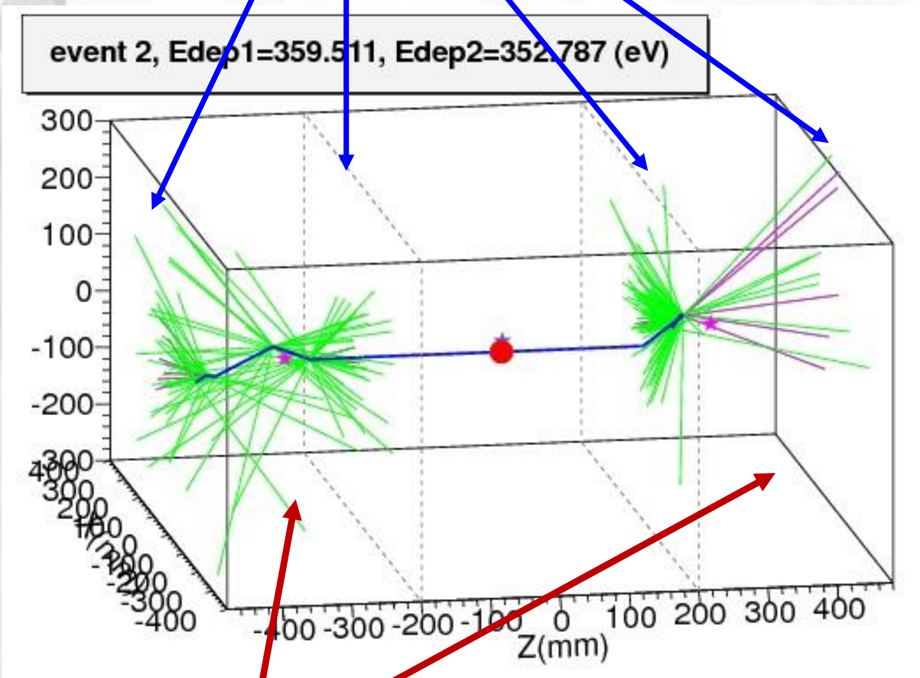
Low-Dose Whole-Body PET Camera

Chin-Tu Chen, Henry Frisch, Chien-Min Kao, and Heejong Kim

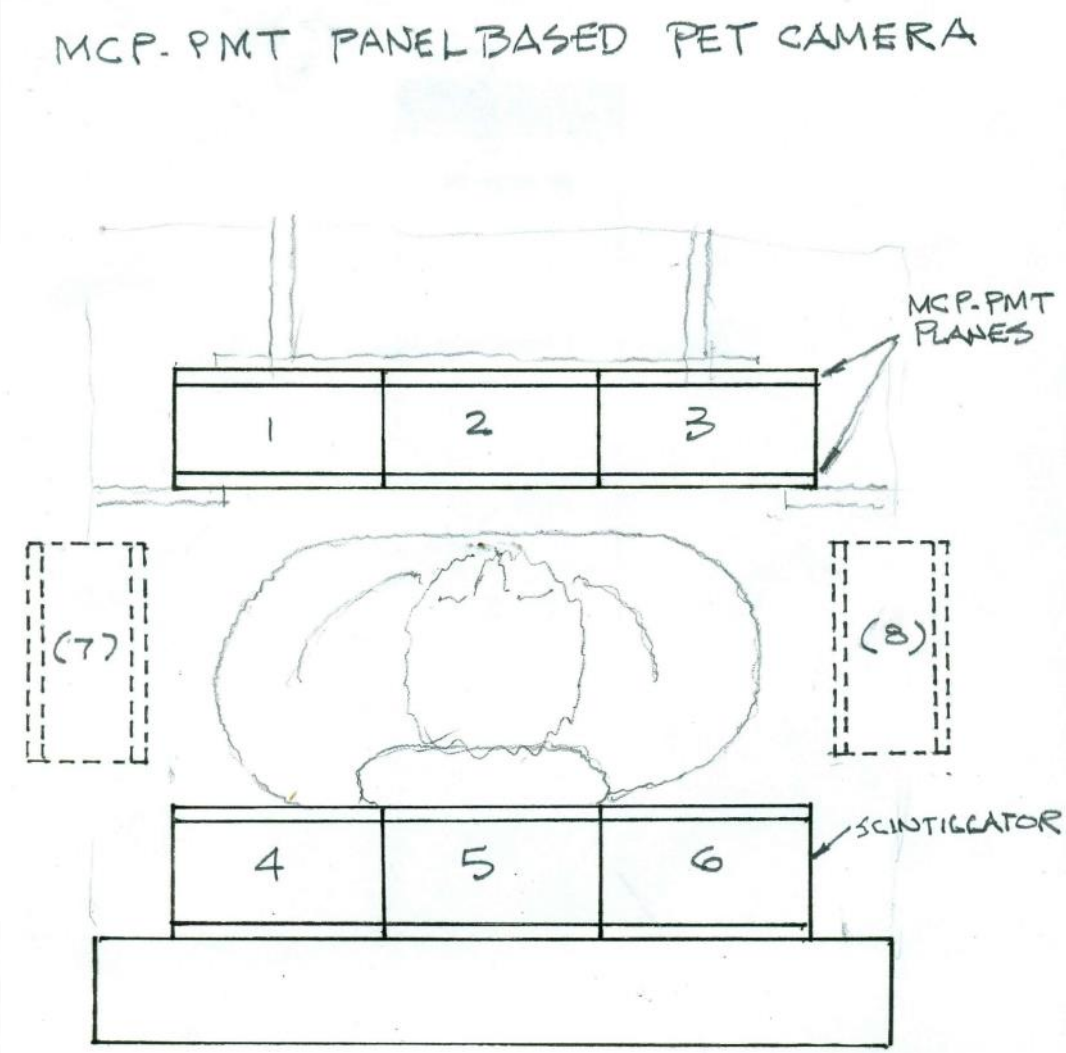


Low-Dose Whole-Body PET Camera

photo-detector planes



water-based liquid scintillator



Simulation and reconstruction work by Carla Grosso-Pilcher