Air-Transfer High-Volume Production of Large-area MCP-based Photodetectors

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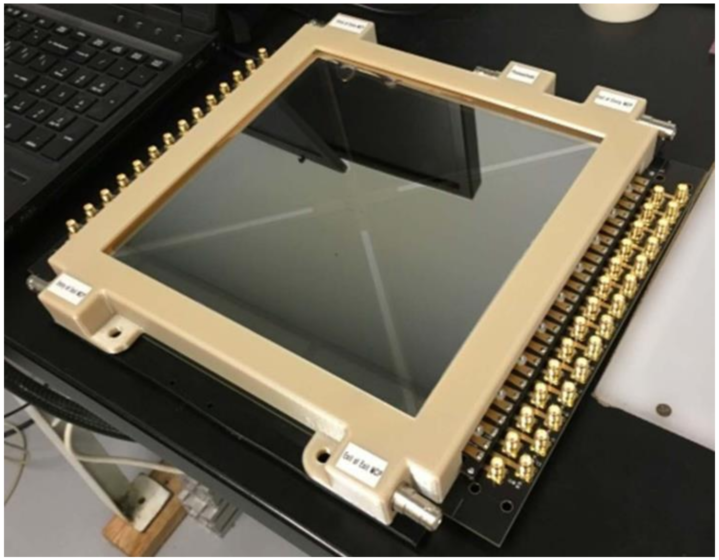
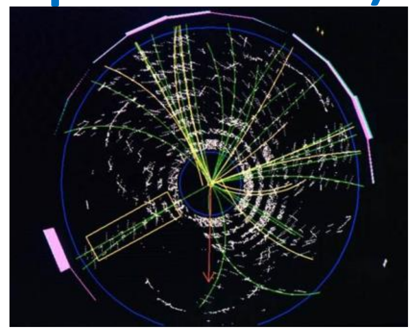
We describe the design of a **facility** for the **batch** production of **large numbers** of micro-channel-plate photomultipliers using the ``**air-transfer'' photocathode process** we have demonstrated on single LAPPD™ modules at the University of Chicago. The proposed facility uses **dual nested low-vacuum (LV)** and **ultra-high-vacuum (UHV) systems in a rapid-cycling, small-footprint batch production system** capable of producing 100 8" x 8" photodetectors per week, scalable to larger numbers. The system allows the use of **O-rings or rubber gaskets** rather than the usual UHV metal seals, **full access for leak-checking before synthesizing the photocathode,** and **real-time photocathode optimization with feedback.**

Applying Large-Area Fast Timing in the Field

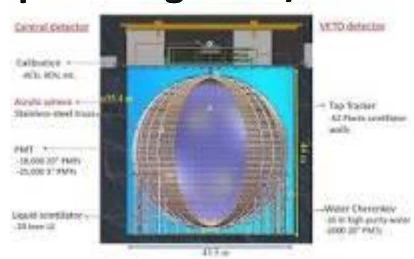
(<<10 psec for charged particles, < 50 psec for single photons)



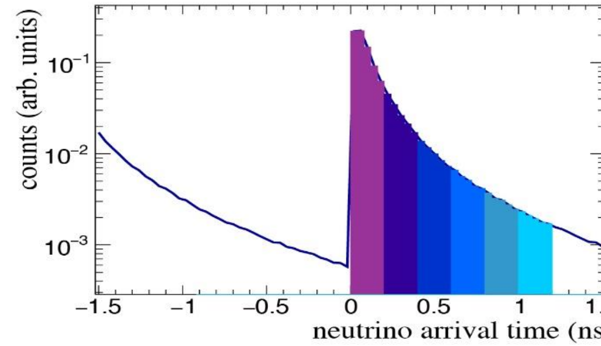
INCOM TILE 41

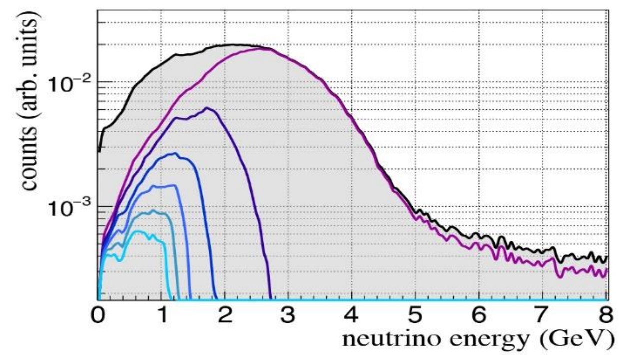


Hep.uchicago.edu/~frisch



Eric Spieglan talk





Evan Angelico talk

NOW:

Incom –6 (8)/ month, linearly expandable…

IN 10-20 YEARS:

would like numbers comparable to current PMT use:

TOF-PET: 10's of thousands

Colliders: 10's of square meters;

Neutrinos: JUNO has 18,000 20" and 25,000 3"

(A. Giaz, arXiv1804.03575)

Q:How Are PMT's Made in Batches?

LAPPD Collab purchase of Burle (RC) system (DOE funding)

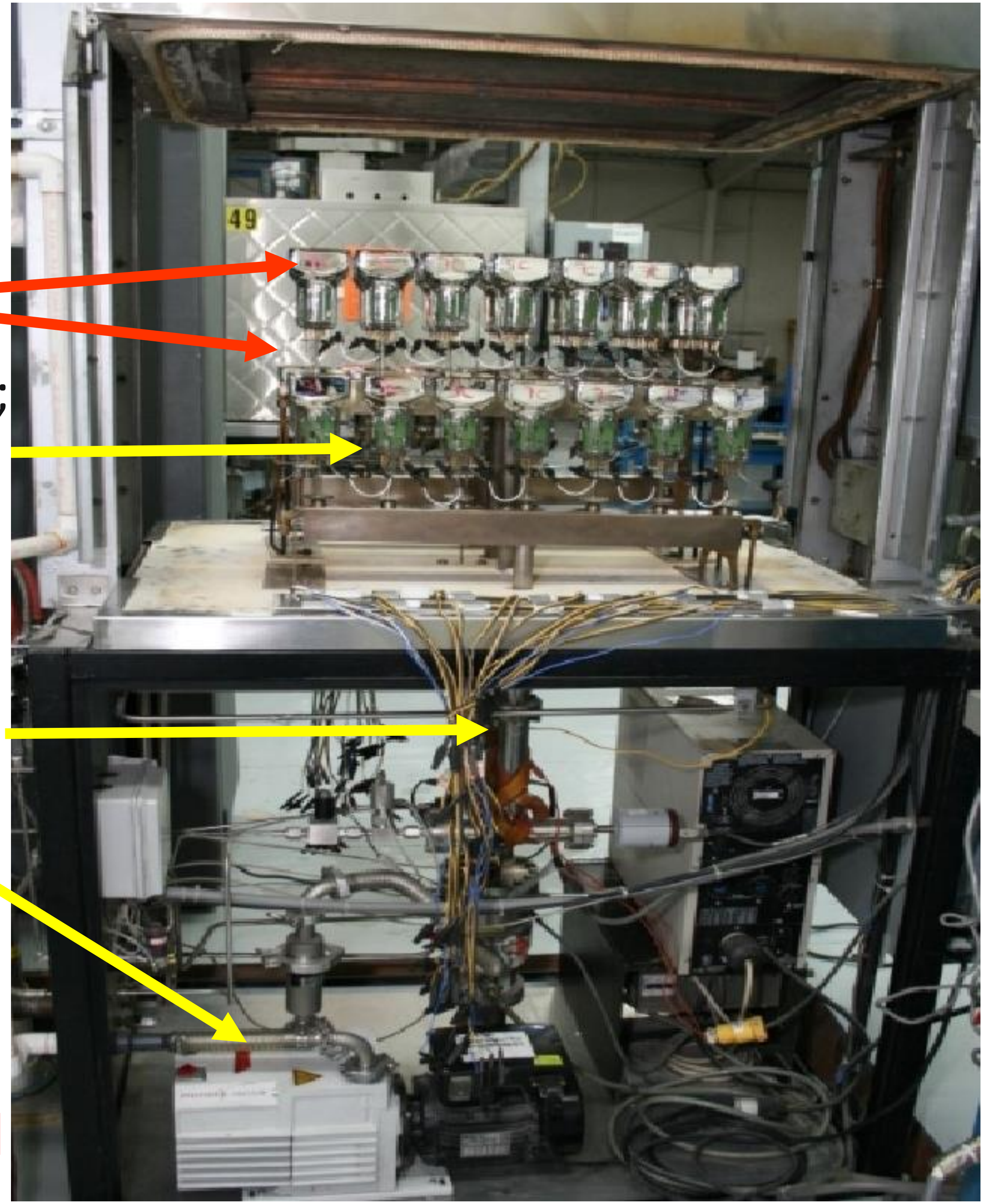
Batch of 30? tubes

Pumped via **a thin tubulation**; Pinched off **after** cathode synthesis

Simple oven (Low Vac=air)

Low conductance manifold

Low vacuum (LV) pump

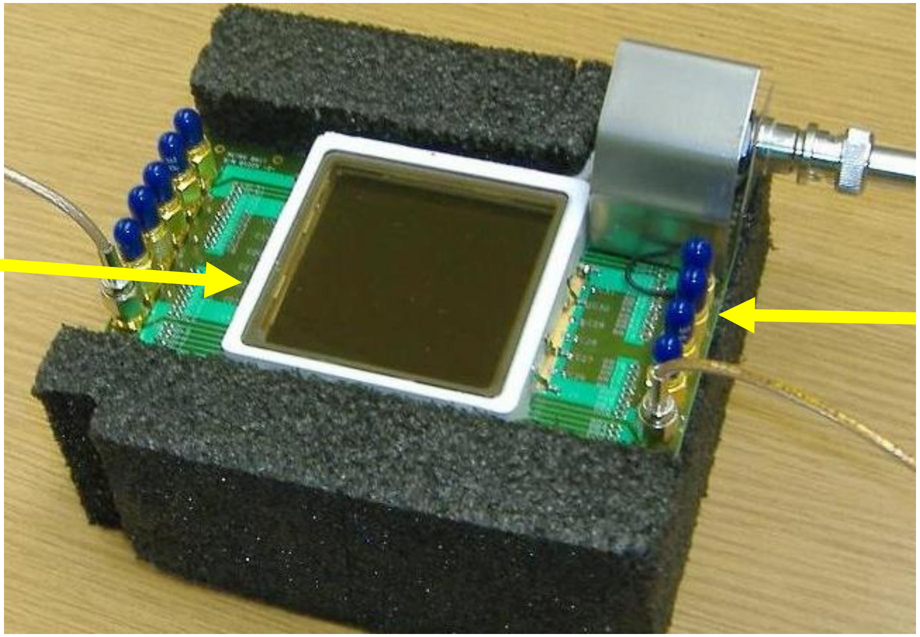


Ans: UHV **inside** tube; cathode synthesized in situ

Prior Unsolved Problems with Large-area Flat Panel Packages

The aspect ratio of a flat-panel large-area package makes the PMT-like photocathode evaporation process difficult.

Photonis Planacon (~10K$)

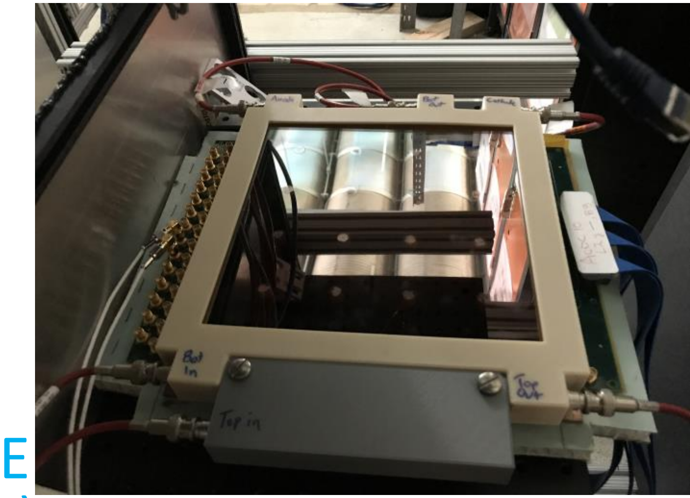


Chicago 32-stripline readout card

Micro-channel PMTs (MCP-PMT) are made via "vacuum transfer", in which the photocathode is evaporated separately on the inside of the entrance window, and then transferred in UHV to the detector body, where it is sealed. This requires: a large UHV volume, relatively large thermal mass cycled through bake-out. The hermiticity of the seal and the cathode quality (QE, uniformity, lifetime) are difficult to access.

Evan Angelico Slide Nov. 3. 2019 at Incom -- HJF edits

The four historical show-stoppers" have been proven viable :



UC Tile 31 at test-beam

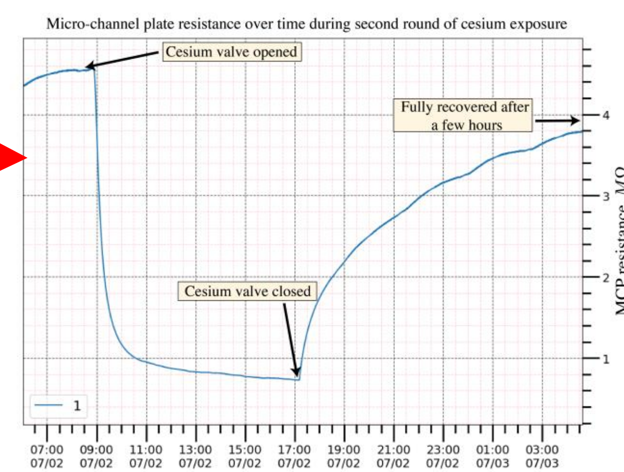
- **Ceramic/glass hermetic seal** in batch production style chamber (solved, US Provisional patent 15/468,371)

Challenges: indium oxide, metallization quality, surface quality

- **Air-transfer photocathode** growth Demonstrated photocurrent spreads across full area; industry to optimize process for QE from 4% to 25-35% (**see Barois quote slide 7**)

Challenges: quality and thickness of antimony precursor, temperature uniformity during formation

- **MCPs recover after multiple cesiations,** are HV stable at fields with reasonable gain



Evan Angelico

Challenges: explore in multiple trials, in progress

- **Consistent production of ceramic inside-out bodies** We have a full supply chain for LAPPD materials, have made a Gen-II LAPPD and used at the test-beam – top right

R&D for industrialization of in-situ method is done

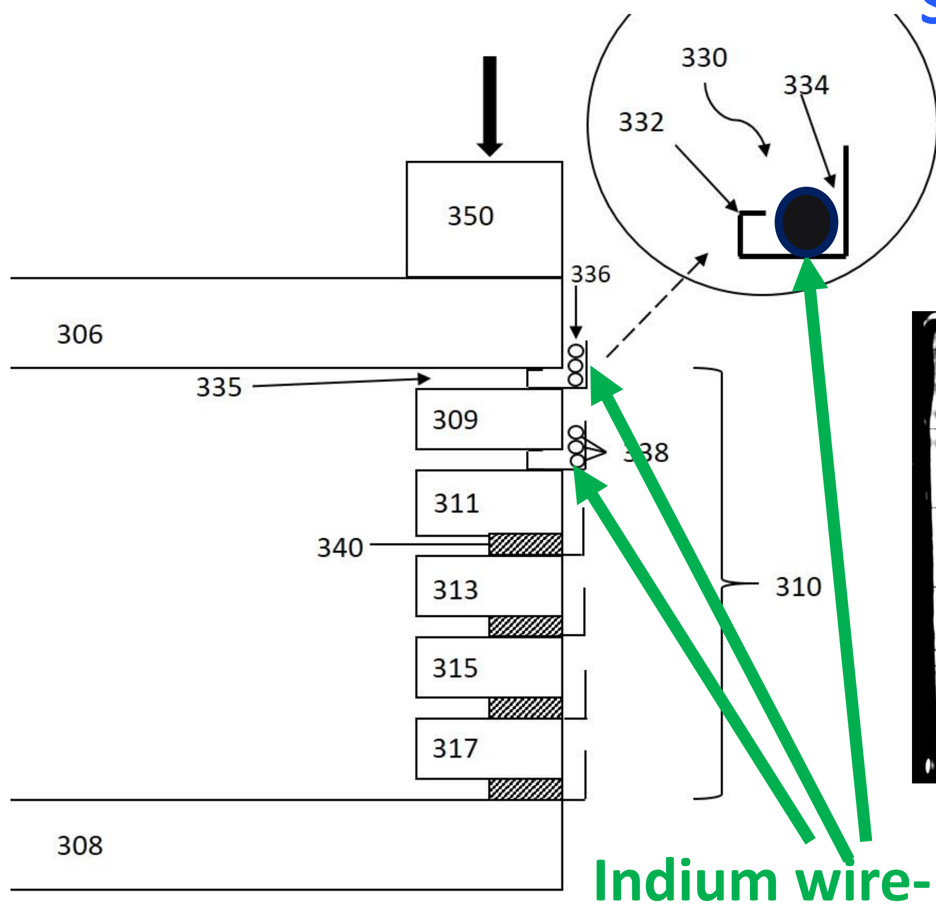
Capillary Hermetic Indium Seal

FINALLY, we have a solution to the window-body seal problems.

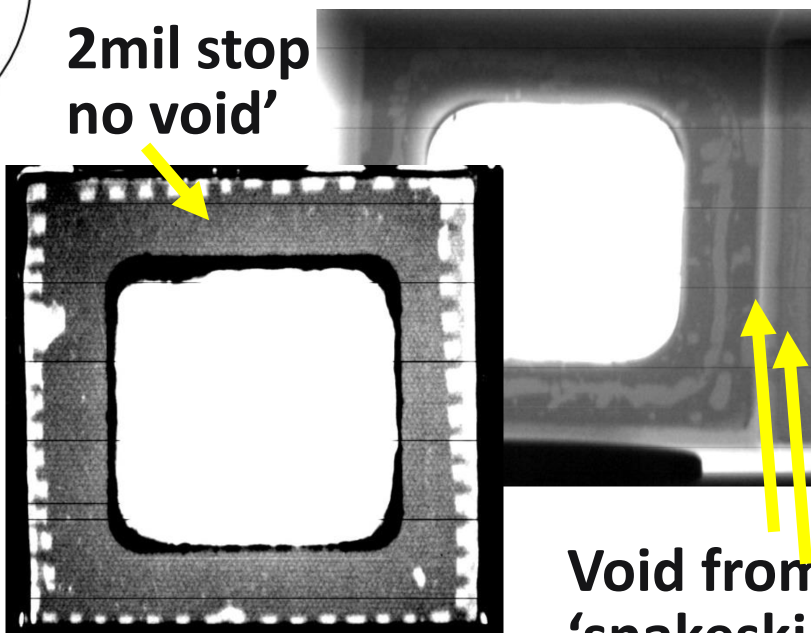
Was not– the square corners
Was not- the large size
Was not- arcane metallurgy

Problem is– the oxide in the gap
Soln: gap defined by hard-stop
Soln: No oxide initially in gap
Soln: essential X-ray diagnostics

US Provisional patent 15/468,371



2mil stop no void'

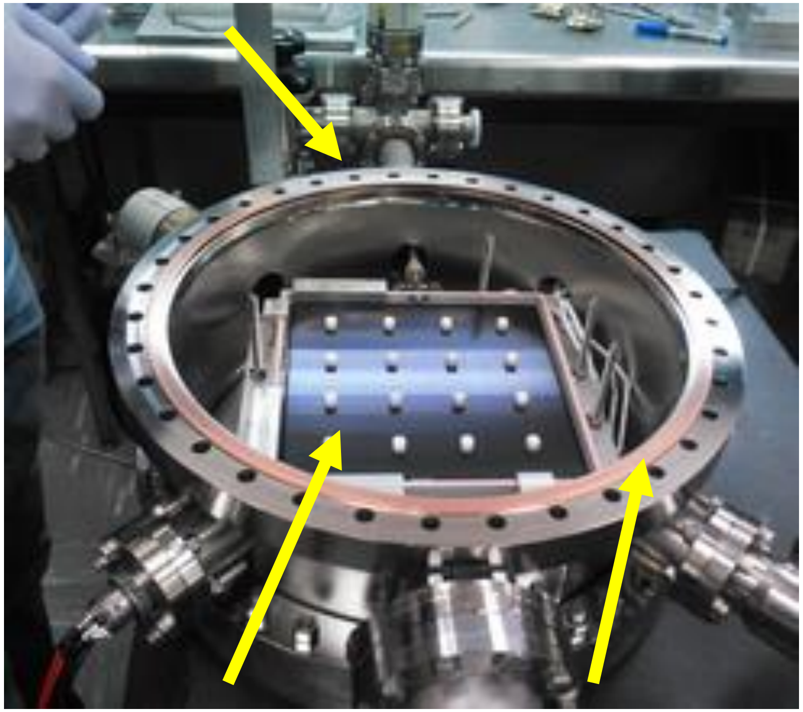


Void from In 'snakeskin'

Indium wire- molten In is wick'd into gap (E.S.)

The Air Transfer Photocathode Process

Margherita UHV outer vessel



MCP inside tile base

Conflat 16.5" metal seal

Emulate PMT process:

1. LV outer, UHV inside tube due to high-temp baking, getter, alkali vapors
2. Photocathode synthesized inside volume
3. Low conductance UHV to LV through thin tubulation

Differences from PMT process:

1. Antimony layer pre-deposited on window; seal before alkali
2. Work in LV instead of air
3. Heat only the tube- no outer oven (reason for LV)

Air Transfer Is Not New

Eric Spieglan found these (obscure) papers:

1. B. Tanguy, J. M. Barois and M. Onillon; Experimental Study of the Equilibria of Cesium Potassium Antimonides with Alkali Vapours; Materials Chemistry and Physics, 30 (1991) 7-12
2. Jean Marc Barois, Claude Fouassier, Marc Onillon. and Bernard Tanguy; Experimental Study of the Non-Stoichiometry of Cesium Antimonide: Cs$_3$Sb; Materials Chemistry and Physics, 24 (1989) 189-197

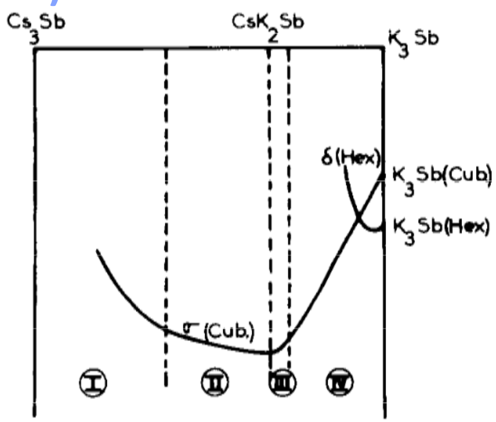


Fig. 8. Isothermal Gibbs-energy composition curves for nearly stoichiometric $(Cs_{1-x}K_x)_3Sb$ (*i.e.* nearly quasi binary system Cs_3Sb-K_3Sb).

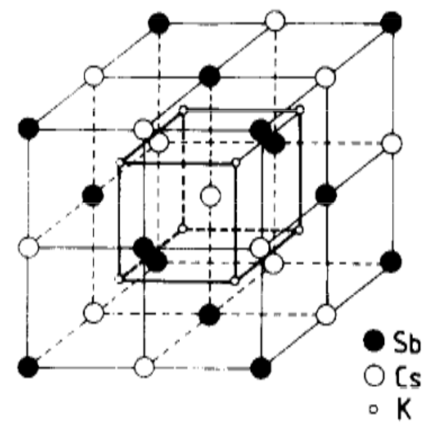


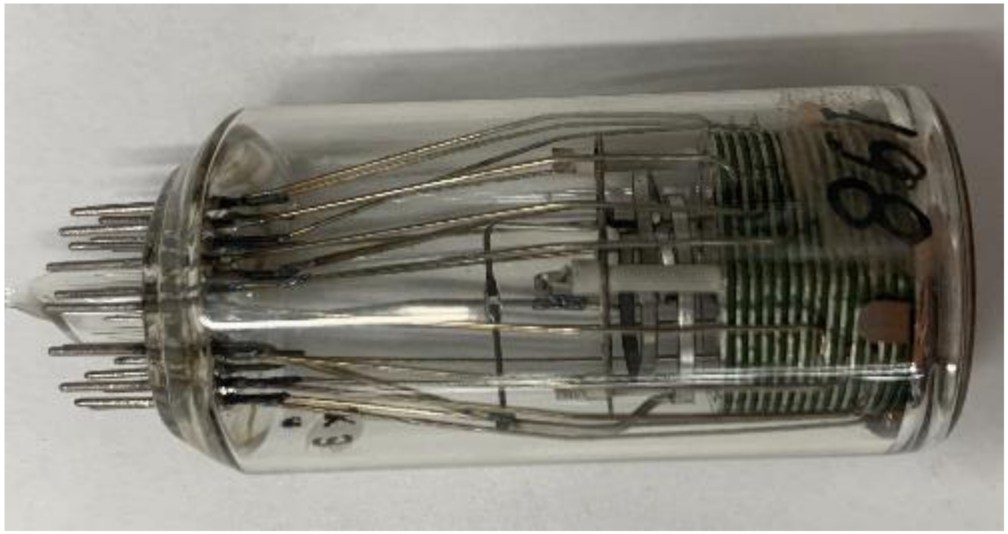
Fig. 1. Crystal structure of CsK_2Sb [5].

Last sentence of Ref. 1 above:

"Manufacturing photoemissive layers by equilibrating the antimonides with binary alkali vapours would lead to a product with better definition than those obtained through the dynamic process used at present"

Air Transfer Is Not New-cont.

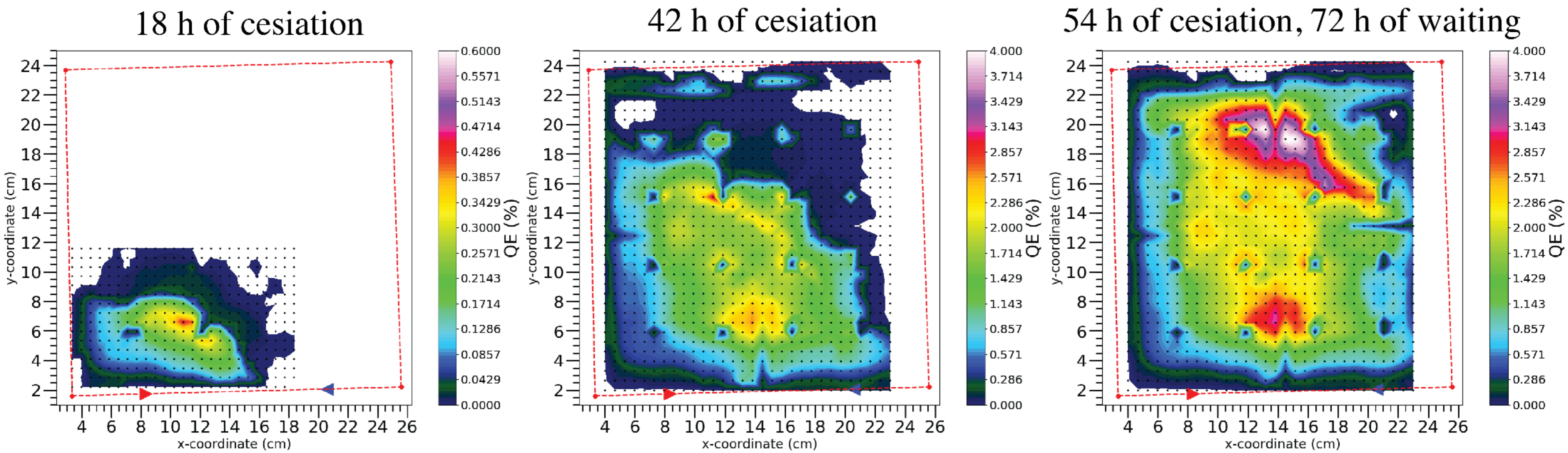
Andrey Elagin found a Russian PMT manufacturer who sent us PMT's made by air-transfer



Naixin Liang and Vasily Soloview (Chicago undergrads) measured the QE- not great (~15%), but this was a one-off tube made just for us (gratis).

See PSEC Document Library #345 "Testing the Quantum Efficiency of MELZ Photo-Multiplier Tubes", at **lappddocs.uchicago.edu**

In-Situ Cathode Synthesis



Cs transport over Time

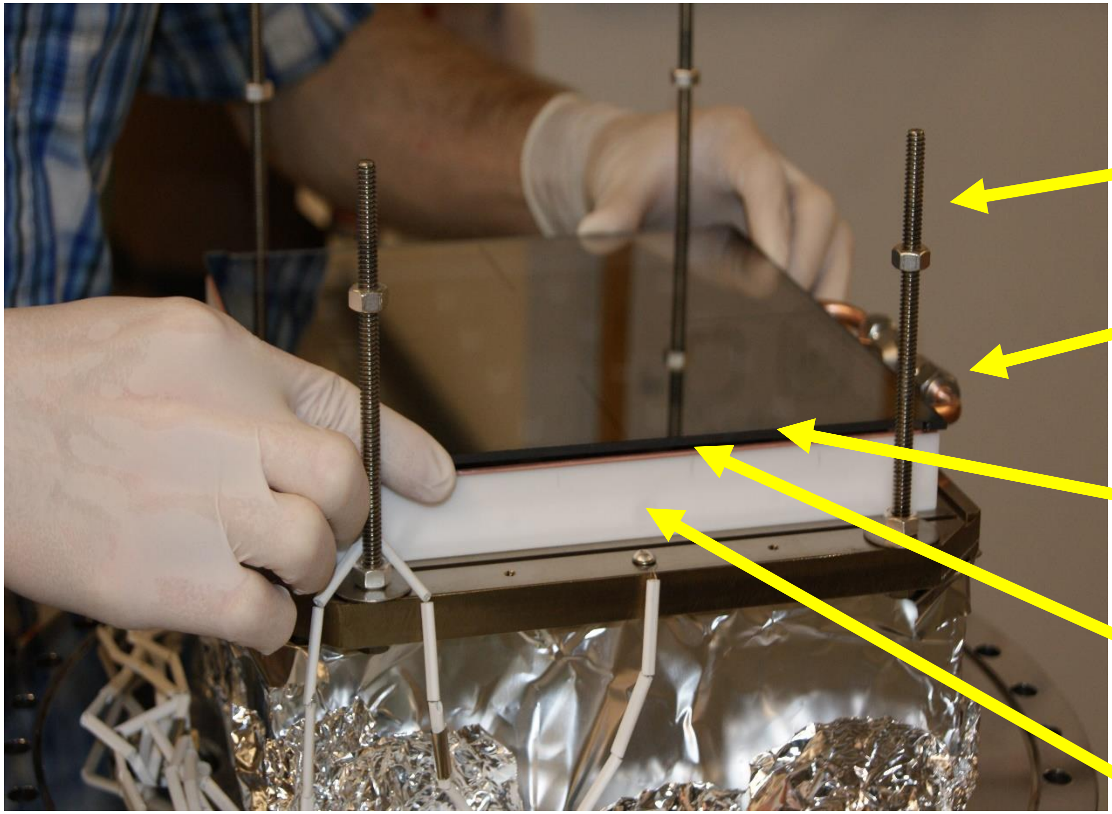
Start with a 10nm predeposited layer of Sb; bring in Cs through two tubulations on lower side (marked).

QE is below expected ~4% rather than 15-20%; most likely due to Sb layer too thick.
Non-uniformity probably largely due to thermal non-uniformity (open to room air, heated in the middle below).

However: Cs transports over whole face; plates recover; Tile31 now at Fermilab Test Beam Facility with Evan. Leave to industry to optimize.

A Large Batch Proposal

We realized that all the current steps can be straight-forwardly parallelized as in the Photonis PMT stand



Support fixture

UHV Manifold

Window

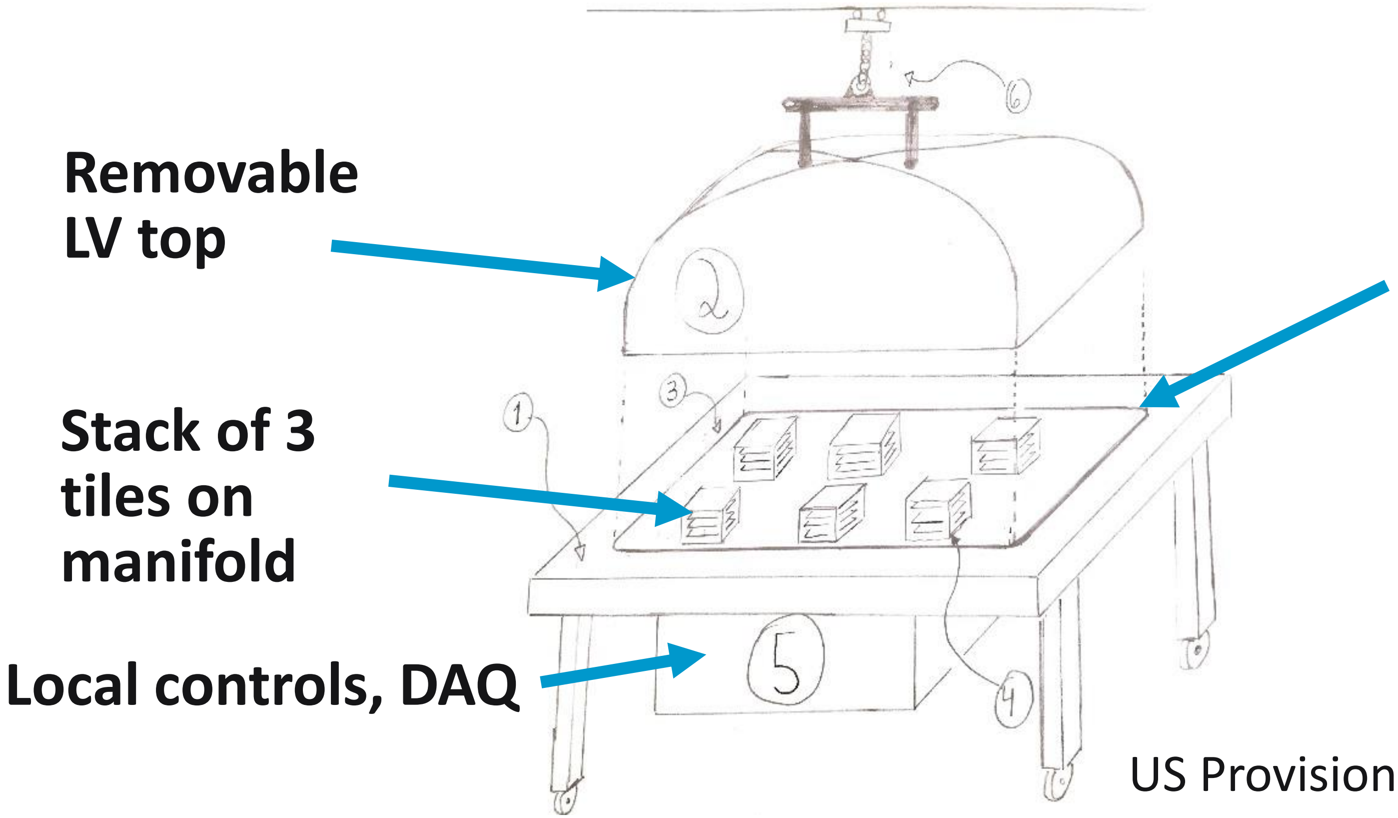
Seal

Ceramic base

Stack modules 3-high on one fixture, separately valved

A Large Batch Proposal- cont.

We realized that our dual UHV system is overkill - one needs only LV for the sealing process and thermal insulation

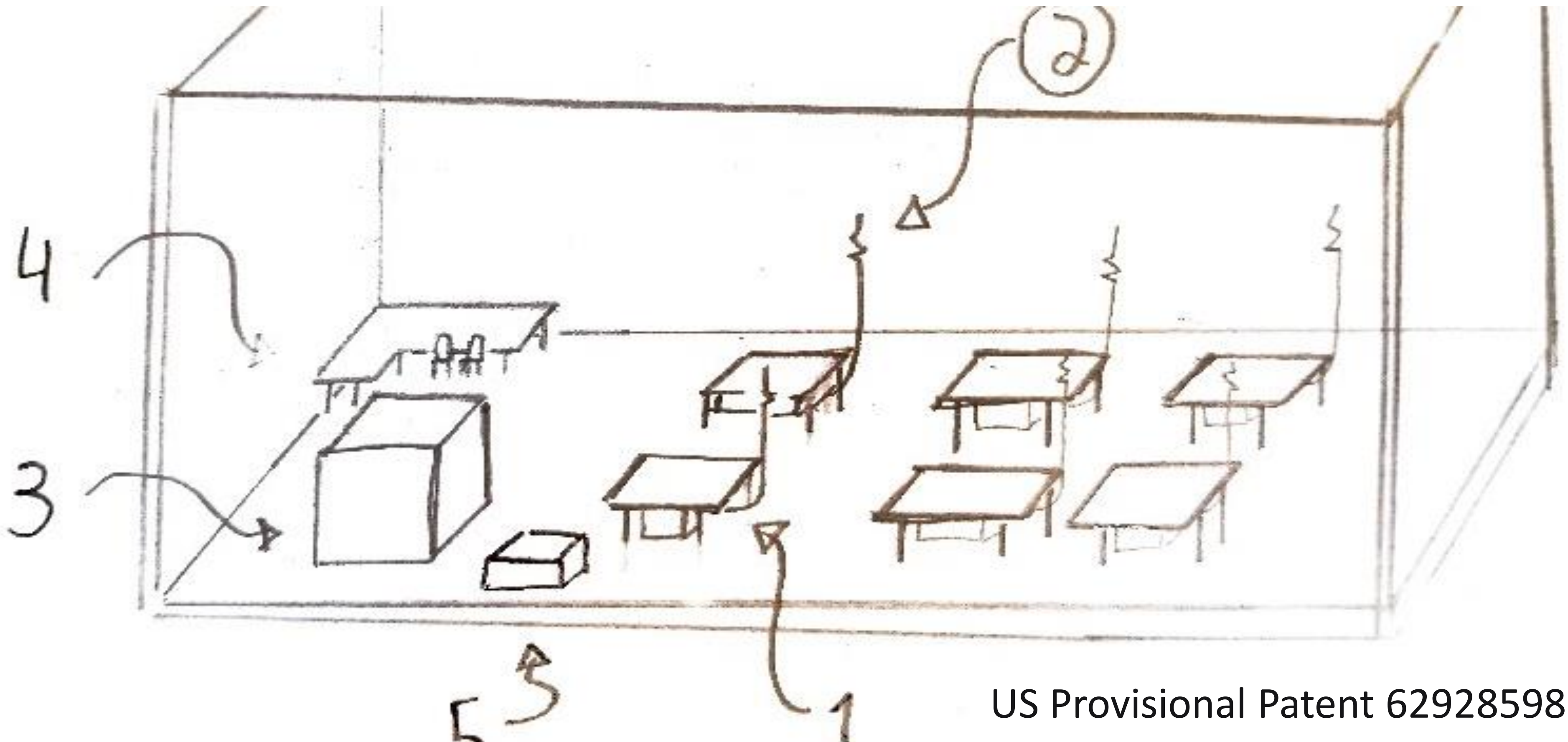


US Provisional Patent 62928598

Means we can use gaskets or O-rings- not restricted to 16.5" Conflat metal seals– can have multiple stacks on one system; i.e. a faster batch cycle and a larger batch.

A Multi-cart Batch Facility

The small footprint (cart or table) allows multiple units on a common vacuum, slow-control, and system.

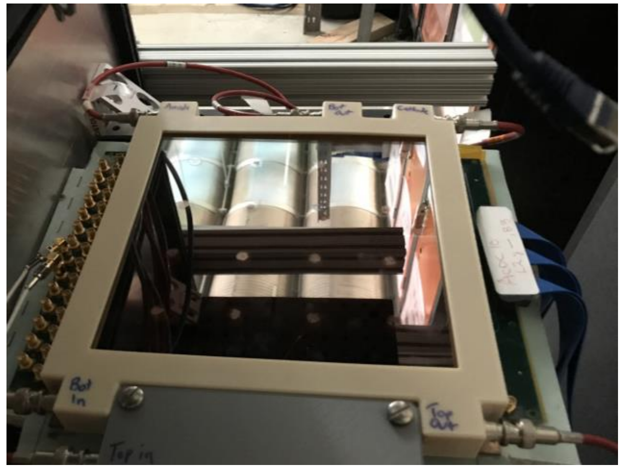


US Provisional Patent 62928598

3 modules /manifold x 6 manifolds/cart x 6 carts = 108 8” modules/week, scalable

Conclusions – such as they are

We believe that the R&D for industrialization of the in-situ method is done



UC Tile 31 at the Fermilab test-beam (Evan Angelico)

We believe that the hermetic seal is in good shape, the mechanical stack-up also Thermal cycle also

Photocathode synthesis method is well-founded and acts as expected, but needs optimization (Sb thickness, temperature control)- leave to industry as it's going to be tied into their own process

Acknowledgements

Special thanks to Ossie Sigmund, Michael Minot, Klaus Attenkofer, Joe Gregar, Neal Sullivan, Bob Fefferman, Michael Grosse, Michael Detarando, Howard Nicholson, and Helmut Marsiske, without whom LAPPDs wouldn't have happened.

We thank those listed below for essential technical contributions and good company. Apologies for those I've inadvertently left off…

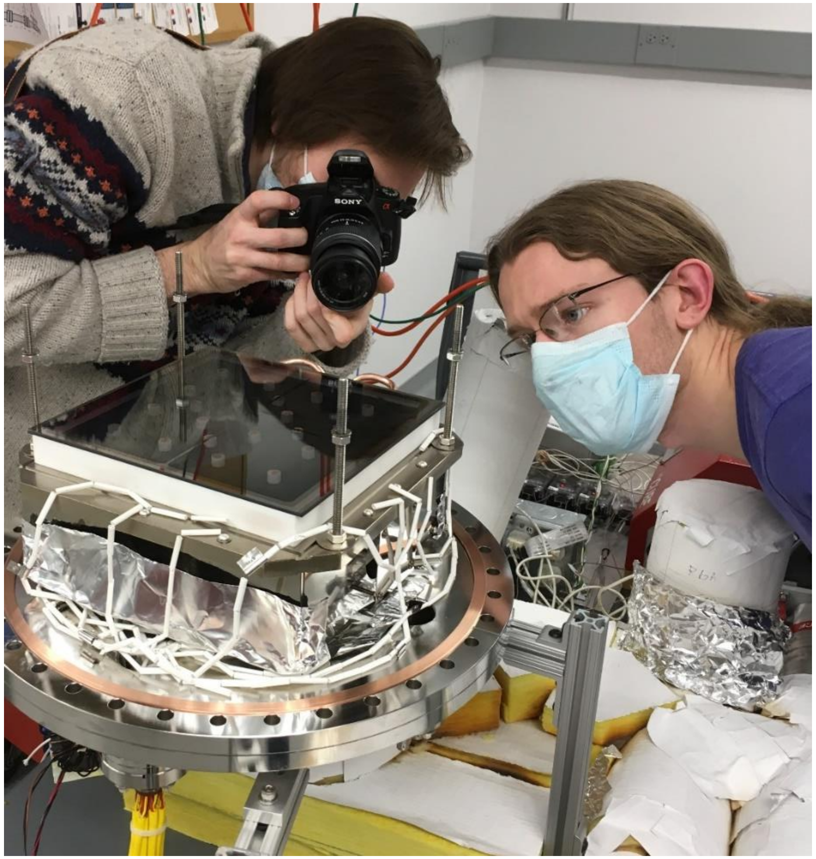
- Mary Heintz, Rich Northrop, Ben Stillwell, Mircea Bogdan, Fukun Tang (Chicago engineering staff); Greg Sellberg (FNAL)
- Michael Foley, Alexey Lyashenko, Camden Ertley, Mark Popecki (Incom)
- Jeff Elam and Anil Mane (ANL ALD group)
- The LAPPD Collaboration
- The many Chicago undergraduates and high school students
- Sergei Belyanchenko (MELZ), Giles Humpston (seal expert), and Bob Jarrett (Indium Corp.)

Reference Bibliography

1. PSEC papers, internal notes, and student reports are available from the PSEC Document Library:
   lappddocs.uchicago.edu

2. The PSEC archive of papers on photocathodes, anodes, micro-channel plates, etc. is available at https://psec.uchicago.edu/library/index.php

The End

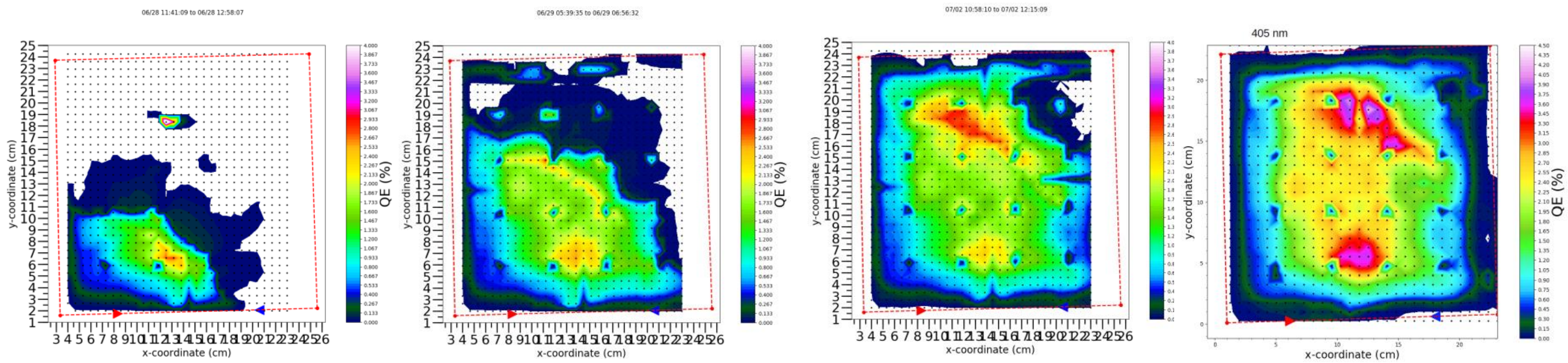


Backup Slides

UC Patents/Registered Trademark

UCHI No.	Application No.	Patent No.	Application Type	Country	Status	Filing Date	Issue Date	Title
1345/05-T-070	11/583,299	7,485,872	US Utility	United States	Issued	10/19/2006	02/03/2009	Large Area, Pico-Second Resolution, Time of Flight Detectors
1902/10-T-008	13/044,442	8,604,440	US Utility	United States	Issued	3/9/2011	12/10/2013	Use of Flat Panel Microchannel Photomultipliers in Sampling Calorimeters with Timing
1902/10-T-008	14/090,647	9,244,180	Continuation	United States	Issued	11/26/2013	01/26/2016	Use of Flat Panel Microchannel Photomultipliers in Sampling Calorimeters with Timing
1902/10-T-008	14/982,387	9,625,588	Continuation	United States	Issued	12/29/2015	04/18/2017	Use of Flat Panel Microchannel Photomultipliers in Sampling Calorimeters with Timing
2304/14-T-024	86246181	5375546	Trademark Application	United States	Registered	4/8/2014	01/09/2018	LAPPD
2308/14-T-029	14/608,777	9,916,958	US Utility	United States	Issued	1/29/2015	03/13/2018	Alkali Semi-Metal Films and Method and Apparatus for Fabricating Them
2308/14-T-029	15/884,947		Divisional	United States	Pending	01/31/2018		Alkali Semi-Metal Films and Method and Apparatus for Fabricating Them
2331/14-T-058	15/553,275	10,132,942	US Utility	United States	Issued	4/8/2016	11/20/2018	Positron-emission Tomography Detector Systems Based on Low-Density Liquid Scintillators

In-Situ Cathode Synthesis



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