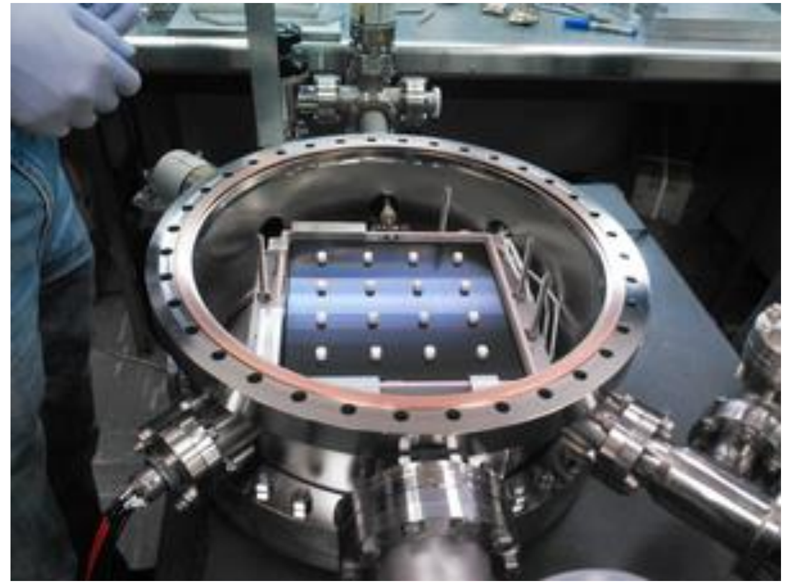
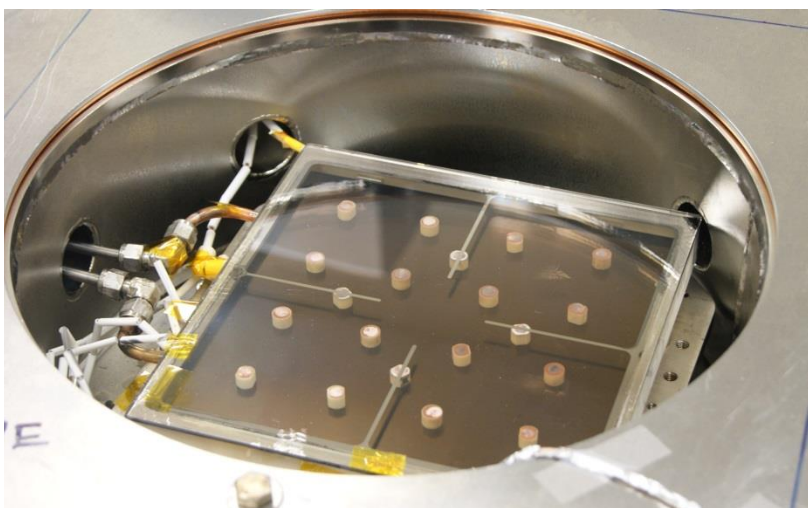
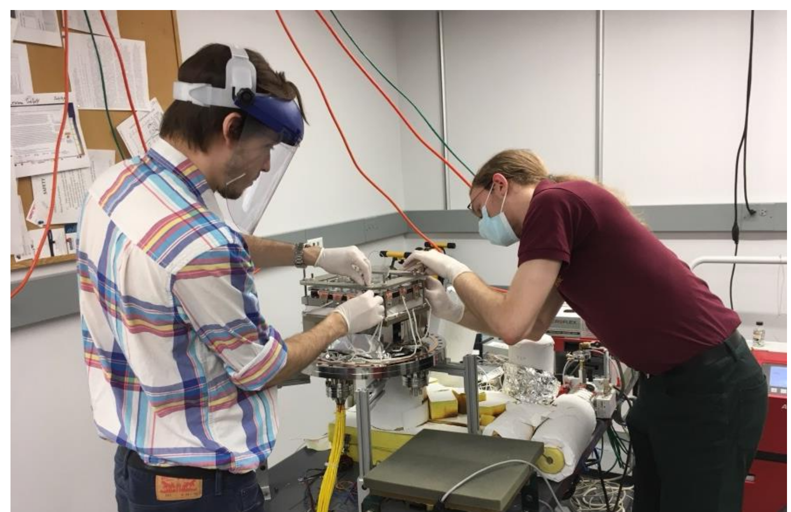
Psec timing/LAPPD program at Chicago

Evan Angelico, Andrey Elagin, HJF, Rich Northrop, Carla Pilcher, Eric Spieglan
plus Eric Oberla (emeritus) and Mircea Bogdan on electronics
plus 12 (!) HS and undergrad students last summer

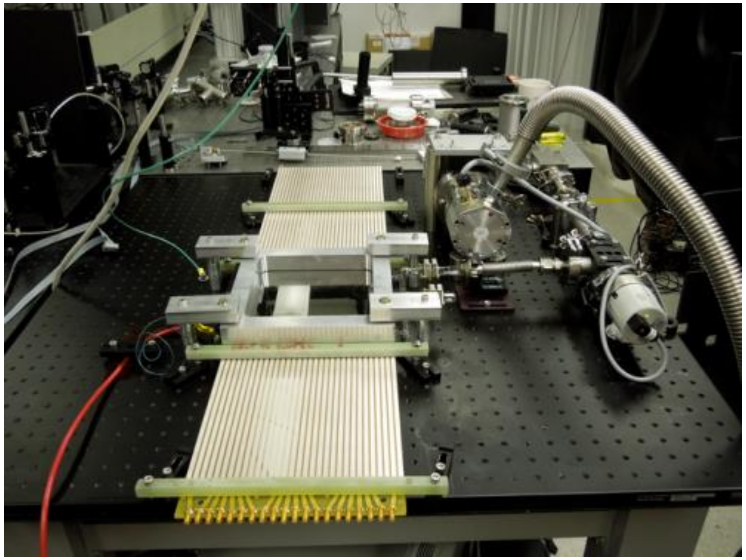


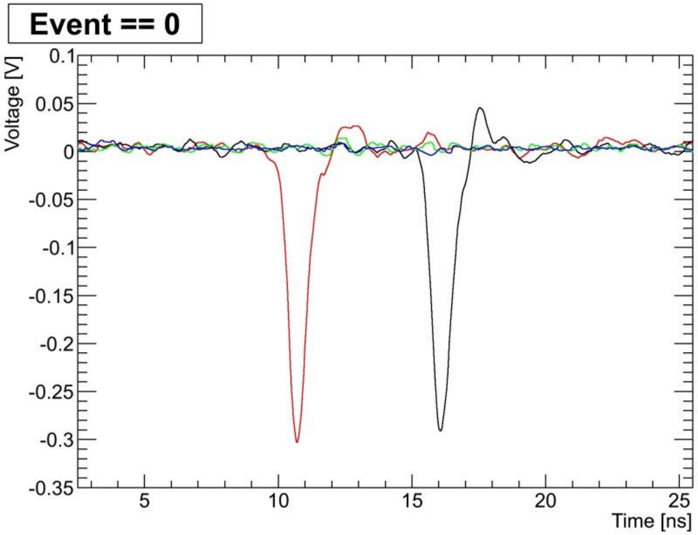




Our (UC) LAPPD™ 'Tile'

1. 8" x 8" active area (MCP size)
2. Amplification: a pair of MgO MCPs in a chevron config.
3. Measured gain typically $\geq 10^7$
4. Space resolution 700 microns in 2D (strips); 300 microns with ½" pads if signals are shared
5. Time resolution: < 50 psec single photon measured, goal of a < a few (or one) for charged particles traversing window (50 PE) or high energy photons (i.e. large pulses)





B.W. Adams, A. Elagin, H. Frisch, R. Obaid,E. Oberla, A. Vostrikov, R. Wagner, J. Wang, M. Wetstein;{\it Timing Characteristics of Large Area Picosecond Photodetectors};Nucl. Inst. Meth. Phys. Res. A. , Vol. 795, pp 1-11 (Sept. 2015);

Topics

1. Photodetector development (R&D with Incom Inc)
   a) Indium window-to-tilebase seal
   b) Application-independent anode (pads or strips)– metal resistive capacitive coupling
   c) Ceramic robust high-bandwidth 1-piece body
   d) PMT-process batch production: facilities, process
   e) Theory-based photocathodes (with RMD, Smedley, Attenkofer)

2. Electronics (Eric Oberla, Mircea Bogdan, ANNIE)
   a) Multibuffer 130nm CMOS 10 GS/sec ASIC developmnt
   b) Scalable FPGA-based DAQ readout/control for ANNIE

3. Goals- expand physics reach via psec timing frontier: testbeam and simulation studies (PhD students, Elagin):
   a) Optical Time Project Chamber for double-beta decay
   b) Collider photon/ch vertexing and track quark content

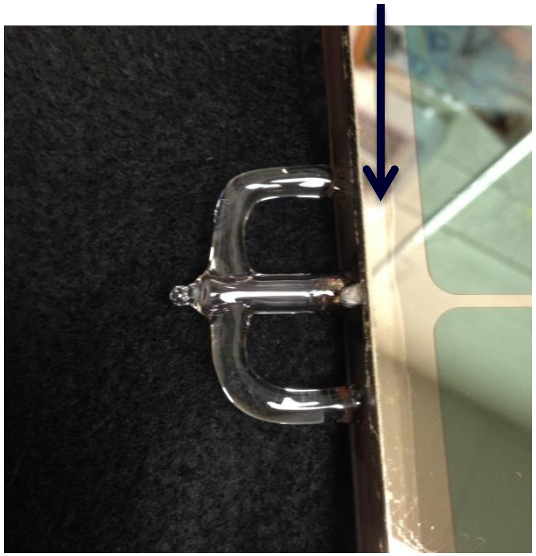
Recent papers (see lappddocs.uchicago.edu)

- **E. Angelico, T. Seiss, B. W, Adams, A. Elagin, H. J. Frisch, E. Spieglan;\\{\it Capacitively coupled pickup in MCP-based photo-detectors using a conductive, metallic anode};\\Nucl. Inst. Meth. Phys. Res. A. (Oct. 2016)**
- **A. Elagin, H. J. Frisch, B. Naranjo, J. Ouellet, L. Winslow, T. Wongjirad;\\{\it Separating Double-Beta Decay Events from Solar NeutrinoInteractions in a Kiloton-Scale Liquid Scintillator Detector By Fast Timing};Nucl. Inst. Meth. Phys. Res. A. (Sept. 2016)**
- **E. Oberla and H.J. Frisch;\\ {\it Charged particle tracking in a water Cherenkov optical time-projection chamber};\\ Nucl. Inst. Meth. Phys. Res. A. Volume 814, 19-32, (April 2016)% ISSN 0168-9002. arXiv:1510.00947**

Andrey and Evan will give talks at Light 2017 next week on tile production and OTPC.

Photodetector Development

1: TOP SEAL: glass sidewall to window- consider proven



Recipe (lots of characterization, vendor/Ossy input)

1. Very clean glass surfaces
2. 200 nm of Nichrome
3. 200 nm of Cu w no vacuum break
4. .9999 Indium wire sized for volume
5. Etch Indium wire in 5% HCl
6. Thermal cycle 100C above melting
7. Press down on window edges w DOF

What happens: (Andrey Elagin FIB/SEM/ studies) (ITT story)

1. Nichrome layer will provide tie layer
2. Cu provides protection against oxide on NiCr
3. Indium wire gets squished--oxide broken (Walters)
4. Cu diffuses into bulk Indium (Ossy said so)
5. Nickel and Chrome diffuse into bulk Indium (!)
6. A very thin layer containing chrome on the glass forms the bond to the indium.

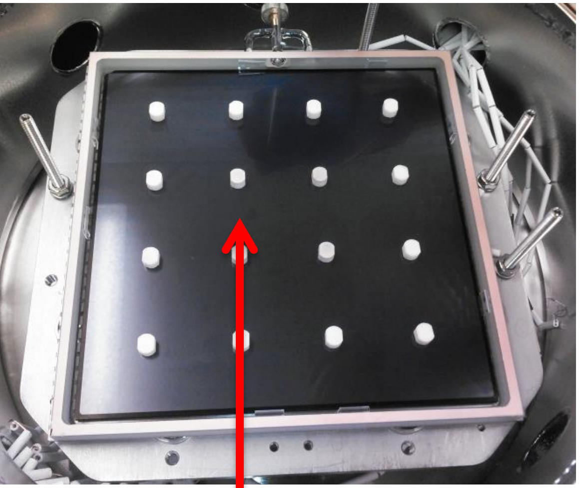
Photodetector Development

TOP SEAL- continued

The LAPPD size introduces 3 serious problems not experienced in making smaller tubes:

1. Uniform metalization, indium distribution, and cleanliness over a much longer length (~36")
2. Uniform pressure and heating over that length
3. In a transfer process base sealing surface level to a mil or less (?-number I don't know, as we use wire captured in place between the window and sidewall)

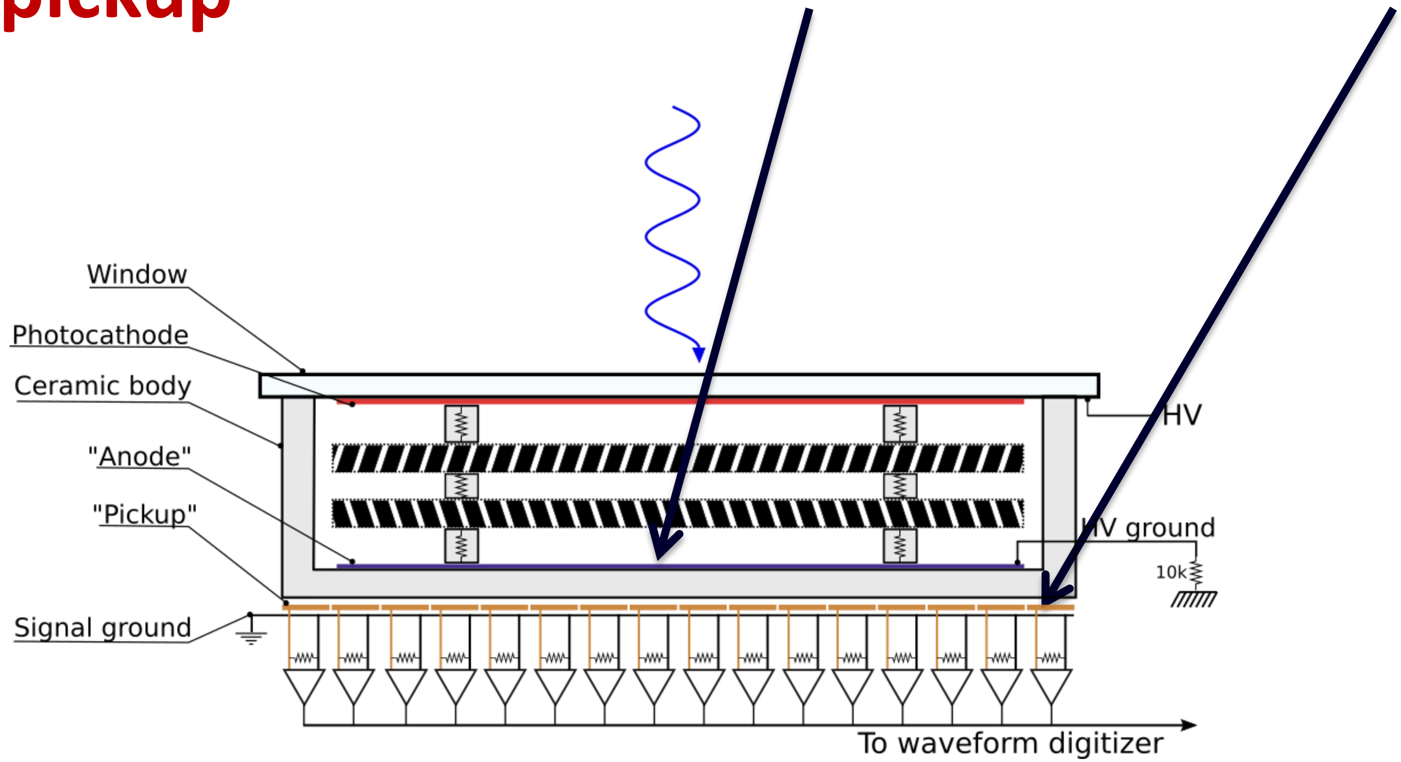
And, a precise STACK HEIGHT over entire tile.



Note buttons make stack height a discrete problem

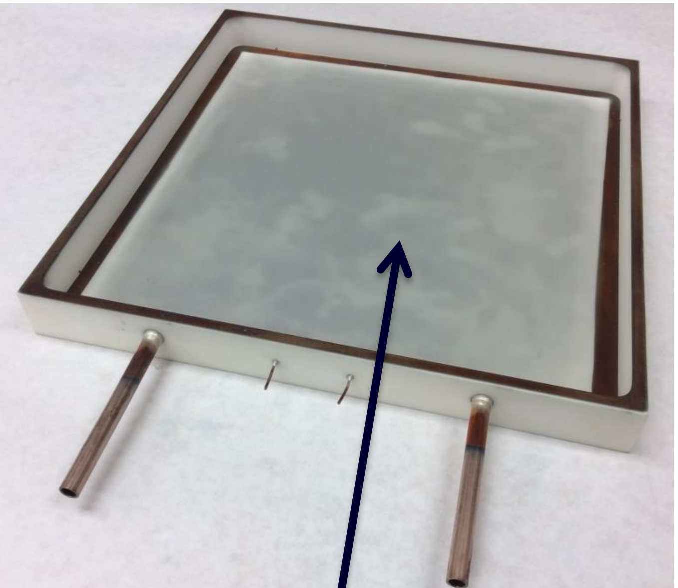
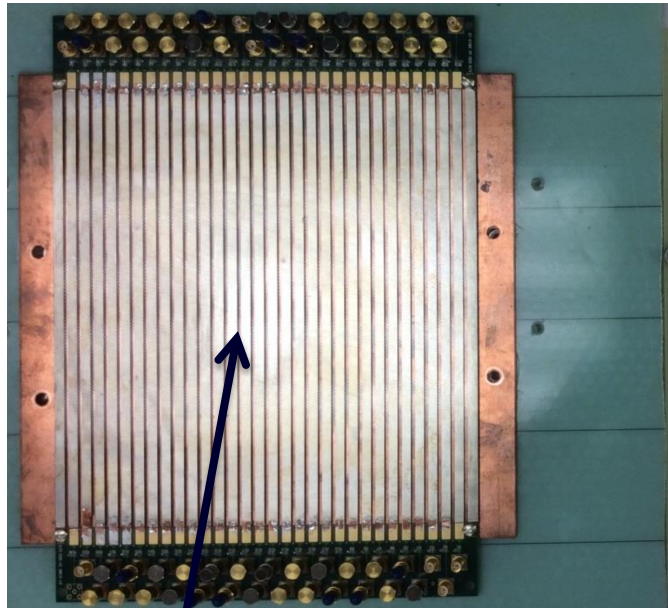
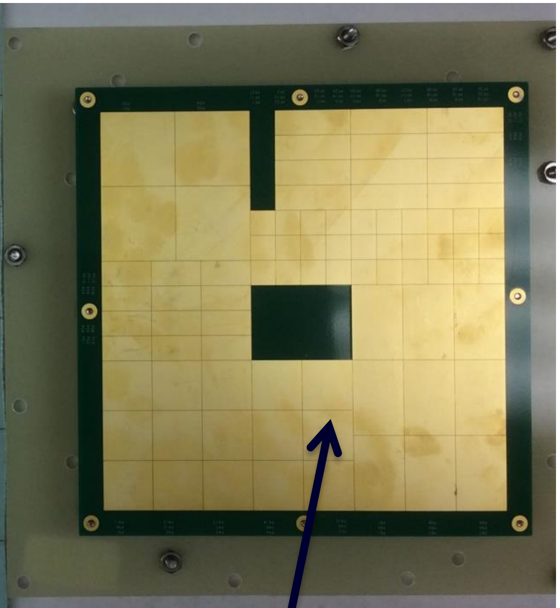
1. FEA and many trials dictate a stack height low by 0.002±0.0005" over the tile interior
2. Each button spacer has to be custom shimmed to meet the above
3. Pressing uniformly on the edges over the seal area on all 4 sides is essential

2: Capacitively coupled anode w. external signal pickup



1. **Metal layer rather than thick-film for production during seal layer coating (also realities of thick-film)**
2. **10nm of NiCr is resistive enough for RC (capacitive) coupling**

Photodetector Development
2: Capacitively coupled anode w. extrnl signal pickup

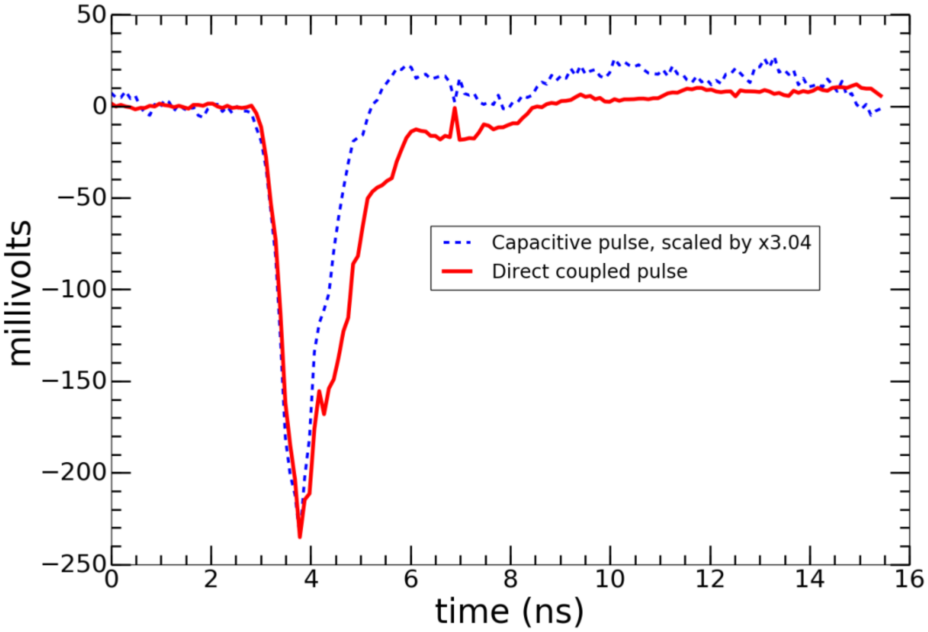
10 nm-thick NiCr anode plane (DC ground)

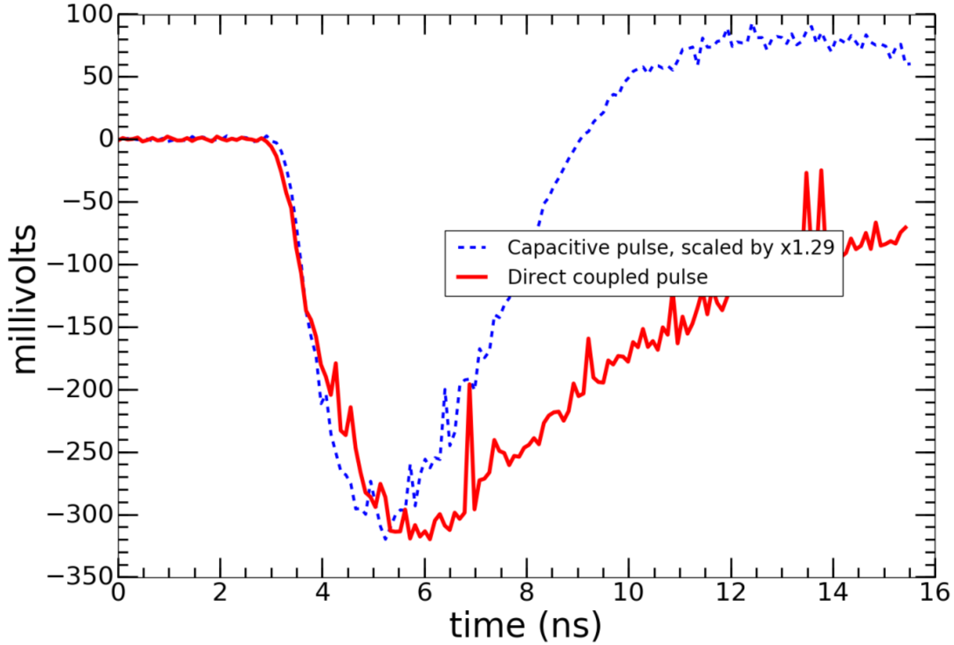
50-ohm stripline readout (E. Angelico)

LHC Pad test pattern readout (T. Seiss)

Photodetector Development

Capacitively coupled anode w. extrnl signal pickup



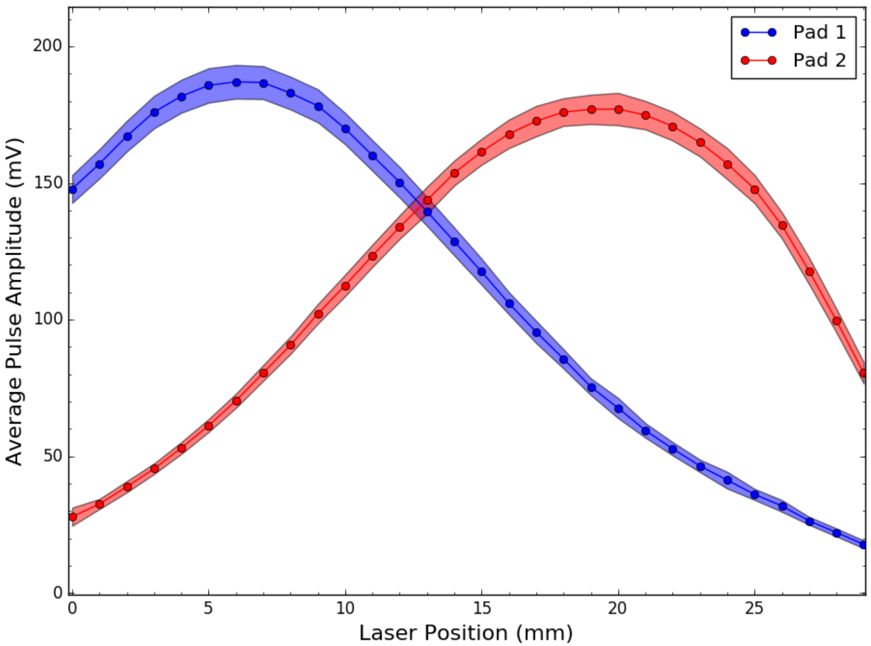


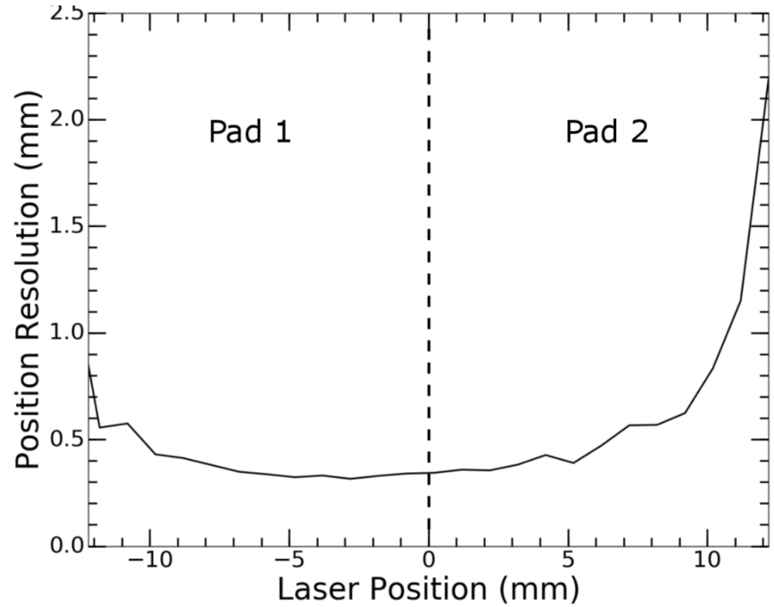
Comparison of risetimes direct vs capacitively coupled on strip readout PC-card

Comparison of risetimes direct vs capacitively coupled on pad readout PC-card

Photodetector Development

Capacitively coupled anode w. extrnl signal pickup





Sharing of the signal across two adjacent ½" pads

Position resolution with ½" pads and large signals (256 pads per LAPPD).

Advantage for Incom in they make 1-design tube; user defines readout pattern, resolution, band-width on card

3: Ceramic robust high-bandwidth 1-piece tile base

1. Our university group complement s Incom's commercial focus on production of their glass tile design in 2 ways:
   1. Develop physics applications (e.g. OTPC; later in talk)
   2. Evolutionary design options- (but don't get in their way on the Gen-I glass tile while working on Gen-II!)

2. Have developed a `Green-trimmed' ceramic tile base with the following advantages:
   1. One piece- no assembly of sidewall and base w. frit
   2. Hotter bake-out possible as no frit or silver ink anode
   3. Higher bandwidth than glass (also no ion migration)
   4. More robust than glass
   5. Working closely with Mike Foley of Incom under a DOE Nuclear Physics SBIR

   Disadvantages: long lead-times, no experience (vs glass)

3: Ceramic robust high-bandwidth 1-piece tile base

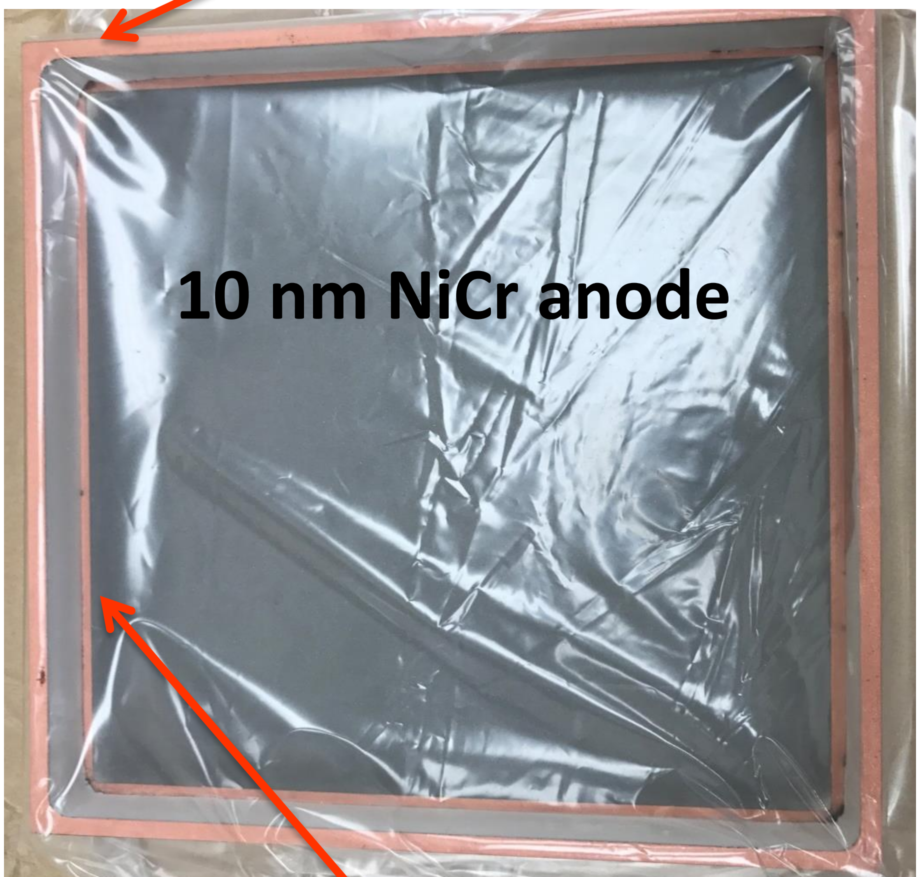
Sidewall and anode plane are green-trimmed and then ground to spec after full fire- no fritted or brazed large (long) joint

Ceramic tile bases from 4 vendors- have 5 from each

Photodetector Development

3: Ceramic robust high-bandwidth 1-piece tile base
Multipurpose metallizing (‘coating’) glass or ceramic

200/200 nm NiCr/Cu seal surface



NiCr/Cu anode border

1. Major roadblock for both glass and ceramic (surprise!)- source of a lot of delay working out
2. Expert territory only: Eileen Hahn (Fermilab), Sharon Jelinsky (SSL), Bing Xu (ANL), commercial precision optical coaters (2 vendors)
3. Here we use coating for sealing surfaces, capacitively-coupled anode, and connection to pins to interior- single process (no vacuum break between sealing layers)
4. Now have 2 good vendors+

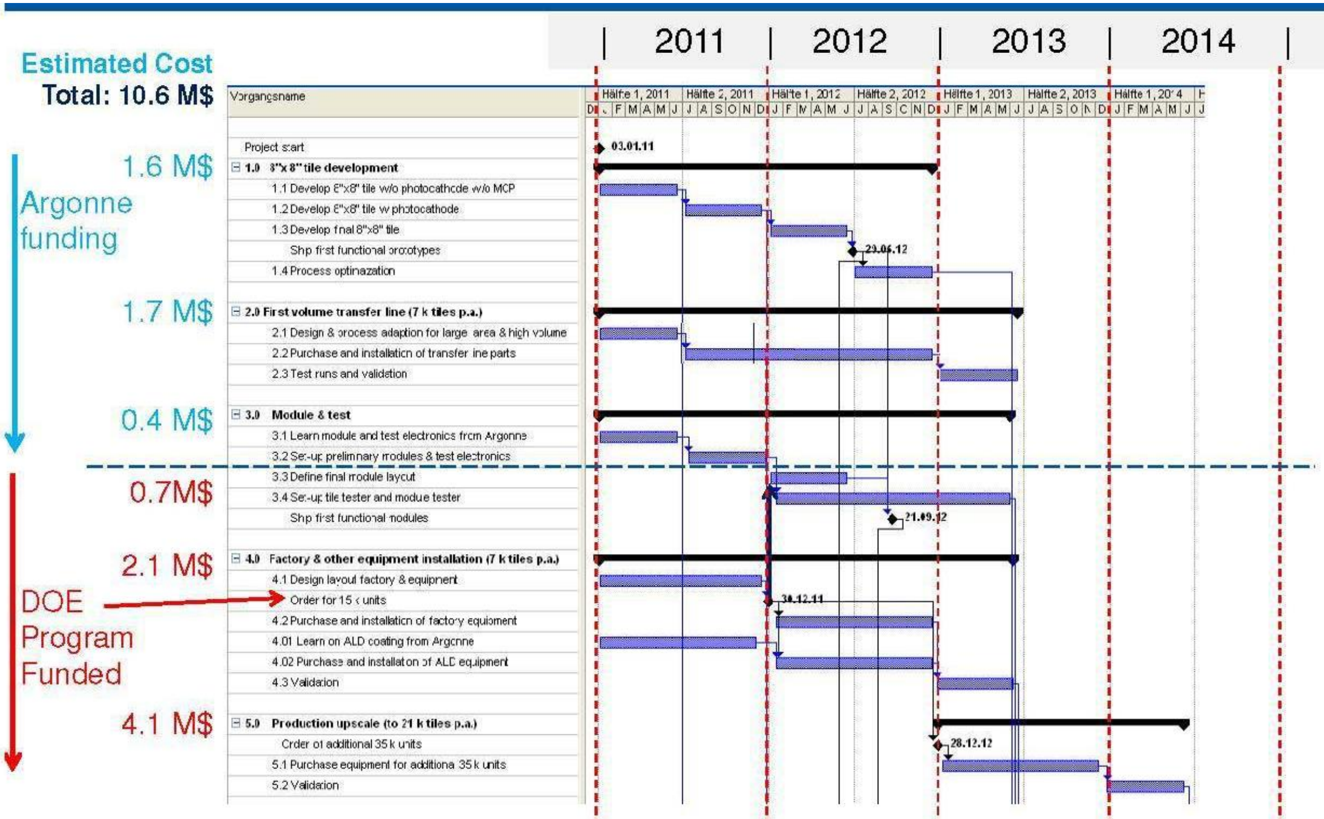
4: Batch production process/facility development (w. Incom)

Conventional PMTs are (usually) made in batches, using the hermetic package as the UHV environment

PMT Process Characteristics

1. Many tubes on one pump
2. Very poor external vacuum- Oring seal on tubulation, small long path to small pump. Internal getter+alkali provide the UHV pumping
3. External oven heating only tube (not vessel)
4. Alkali source internal or external (Brits)
5. Tubes are accessible during photocathod synthesis

Batch production process/facility development (w. Incom)

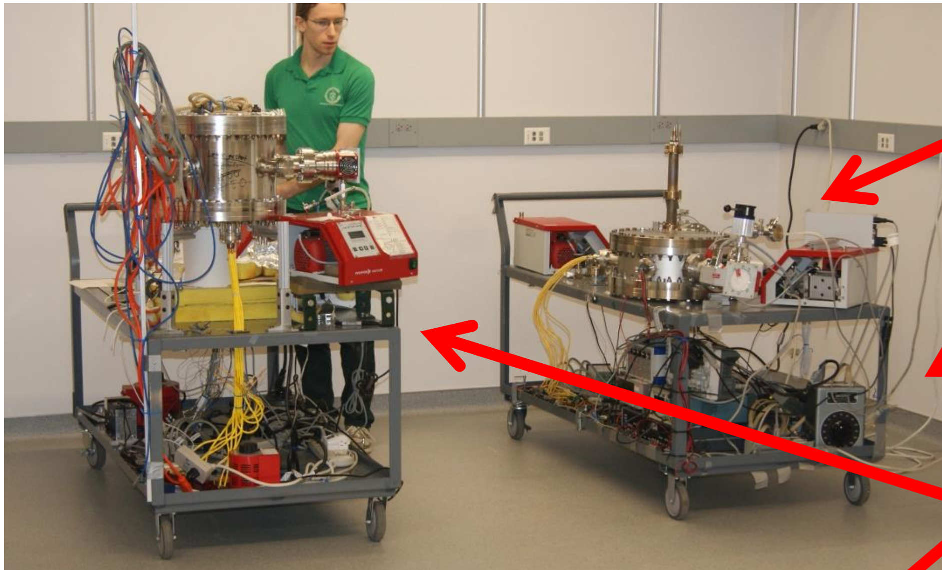


Schedule from a serious proposal by industry at the time of DUSEL

For HEP use we estimate industry needs to make 50/week (2000/yr; 6000/postdoc). Not nuts- had a serious proposal for DUSEL-from a large company making a similar photodevice . However went down with DUSEL as well. Necessary to get price down, adequate availablity.

Photodetector Development

Batch production process/scaleable facility development (w. Incom NP SBIR)- replicable

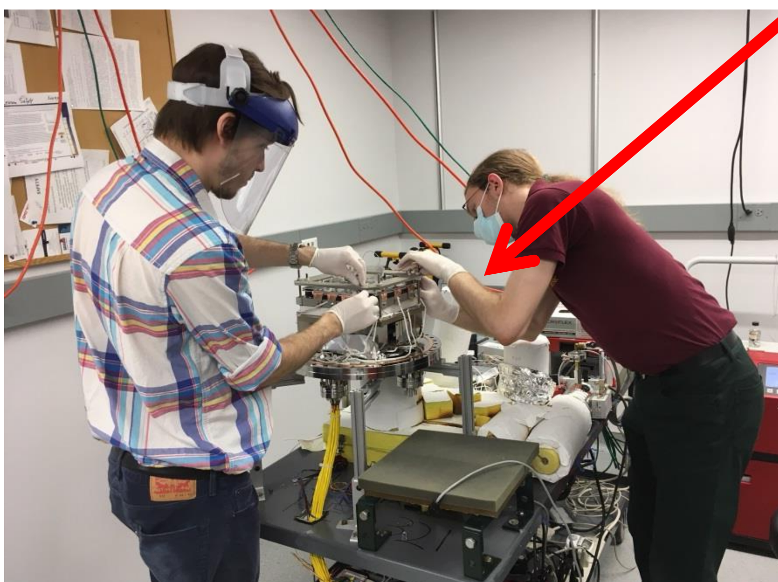


Margherita I

New lab (!)

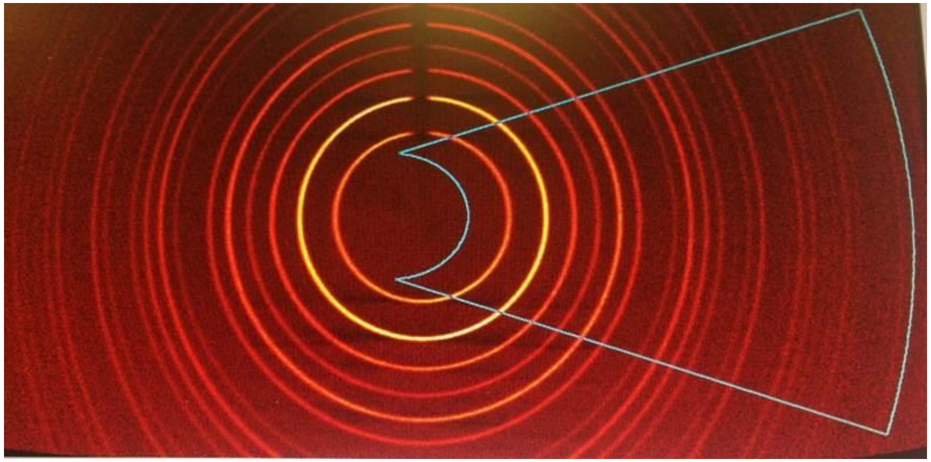
Wet lab (!!)

Margherita II (improved)



Photodetector Development

5: Theory-based photocathodes (w. RMD, Smedley, Attenkofer ; Luca Cultrera)



K2CsSb powder diffraction of RMD cathode material taken at UC

Second Workshop on Photocathodes: 300nm-500nm

Photocathode Workshop: agenda, talks

June 29-30, 2012 at The University of Chicago

Day 1

Speaker	Title
Karen Byrum (ANL-HEPD) Henry Frisch (UC)	Goals of the Workshop
Razmik Mirzoyan (MPI-Munich)	What Are the Highest QE's Measured So Far?
John Smedley (BNL)	Determining Parameters in the Spicer-Model and Predicted Maximum QE
Inés Montaño (Sandia)	Minimizing Negative and Maximizing Positive Effects of Electron Scattering
Xiuling Li (UIUC)	Influence of Structure and Composition on Conductivity and Optical Properties
Andy Cormack (ET Enterprises)	Overview and Critique on Design Concepts for Sources
Charles Sinclair (Cornell)	Getter Sources Versus Metallic Evaporation Sources
Oswald Siegmund	Challenges in Photocathode Deposition for Large-Area MCP Proximity-Focus Devices
Ray Conley (BNL)	Comparison of Evaporation, Sputtering and CVD Techniques for Growth of Multi-Component Systems

Day 2

Speaker	Title
Sen Qian (IHEP)	Cathode Development in China
Matthew Highland (ANL-MSD)	Solid State Solutions, Phase Diagrams and Phase Transitions
Jeffrey Elam (ANL-ESD)	In situ Measurement Tools
Miguel Ruiz Osés (Stony Brook)	Visualizing Crystal Growth and Solid State Chemistry During the Recipe
Zikri Yusof (ANL-HEPD)	Changes In Cs_2Te Photocathode Fermi Level Due to Heating

Conference Home | Agenda | Talks | Travel & Parking | Accommodations | Participants

Agenda of 2nd cathode workshop at UC

Collaboration with BNL and RMD, and also Cornell, on `theory-based' cathodes and workshops led to: a) ties to the cathode community , and the in-situ initiative

Photodetector Development

In-situ photocathode synthesis (Springer, Sinclair)

Idea is to emulate RCA/Burle PMT production

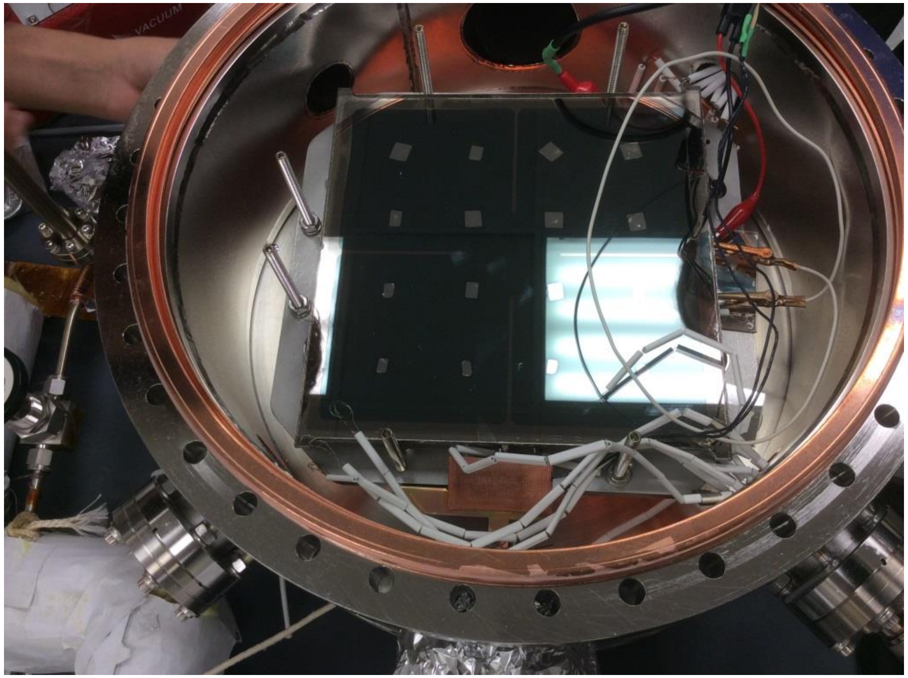
Steps:

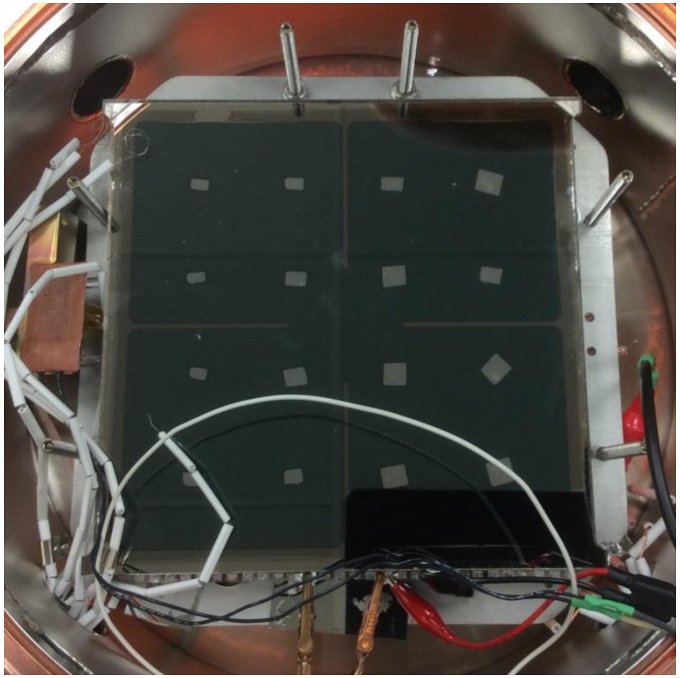
1. Coat (NiCr/Cu) border and electrode fingers on window
2. Pre-deposit a 10nm Antimony (Sb) layer overlapping border and fingers
3. Seal window to tile base with a bake-out/sealing thermal cycle: dual vacuum- 1) tile and 2) vessel
4. Bring vessel to air, leaving sealed tile on its pump
5. Introduce alkali vapor through tubulation while measuring QE of (exposed) window and resistance of MCP plates and stack
6. Pinch off tubulation when photocathode is done

We have used a `GodParent Committee' (CDF) to guide us: Klaus Attenkofer (BNL), Luca Cultrera (Cornell), Jeff Elam (ANL), Mike Pellin (ANL), Matt Poelker (JLAB), Charlie Sinclair (Cornell, SLAC), John Smedley (BNL),Gary Varner (Hawaii, Chair)

Photodetector Development

In-situ photocathode synthesis (Springer, Sinclair)





- GPs recommended doing only Cs first
- Expect uniformity to be determined by thickness of Sb layer- should very uniform

In-situ photocathode synthesis (Springer, Sinclair)

Successes

- We have learned how to manipulatethe movement of Cs around inside the system (remember we're beginners)
- Vapor reached everywhere on the window- uniform
- Chemical reaction between Cs and Sb seems to be `self-limiting' as expected- reaches a defined end-point
- QE seems to be consistent with reasonable Cs3Sb cathode, but we cannot measure it precisely yet (subtlety I missed completely- can explain if asked in questions)
- MCP plates are not permanently damaged/changed

Problems discovered:

- MCP plates go to lower resistance (recoverable in air)
- We had exposed Cu on the window- Indium wet it. Cs interacts with Indium to form a black powder.
- Resistive buttons interact with Cs (new buttons yesterday)
- Measuring QE is made more difficult by our internal HV divider (can't get current across first gap directly).

In-Situ Cathode Synthesis Trials in Progress

E.g. The black powder from cesiating excess indium

Sealing surface on top of sidewall

Black powder

NiCr anode

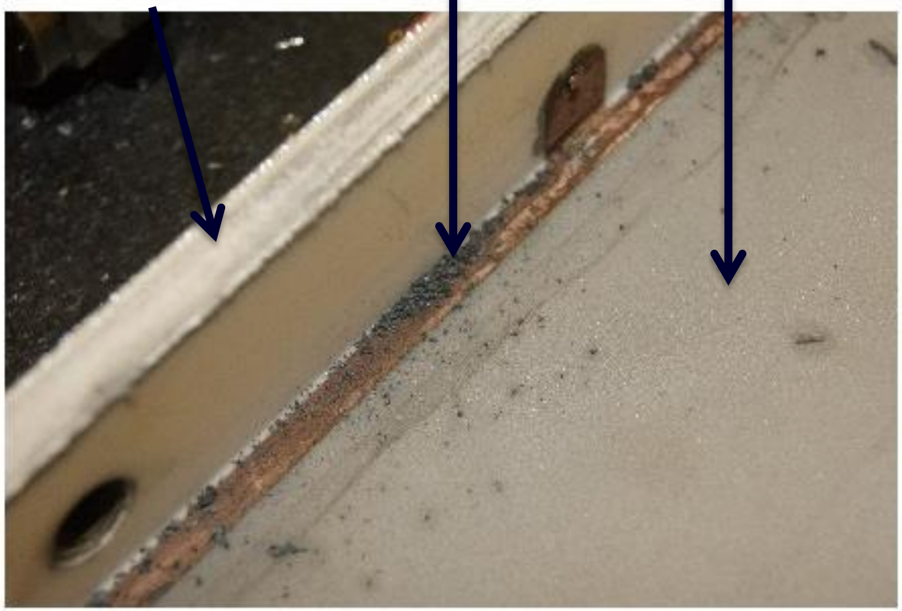
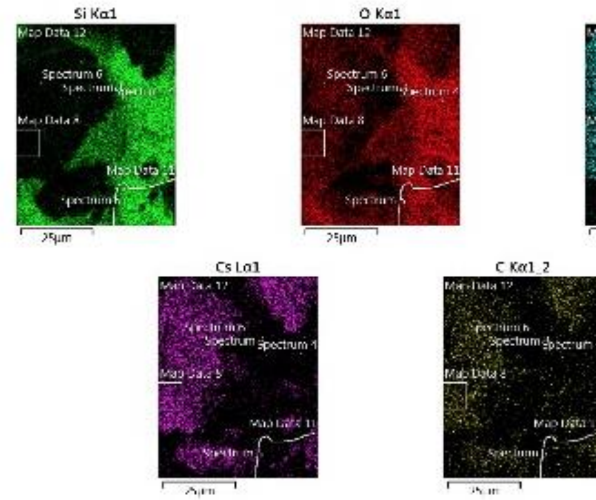


Figure 1: This black dust was found thrown throughout the tile, in crevices and on MCPs and on glass beads. We presume that it came from the window. It was collected from multiple locations and analyzed. This dust is from the window, and flaked everywhere.

(New windows will have no exposed Cu- few weeks away)



Evan (FIB/SEM) and Andrey (SEM)

Figure 3: The individual chemical maps from the Figure 2. Notice that the dust specs are mostly Cs and Indium, and the empty space is Si and O. This only confirms that the black dust is some mixture of Cs and Indium, and not its relative composition or homogeneity.

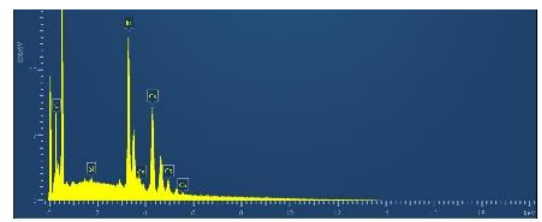


Figure 4: A spectrum from a dust fleck shown in the SEM picture above. The peaks indicate the existence of indium and Cs, and not their quantitative relative composition.

Analysis showing it's a CsIn compound

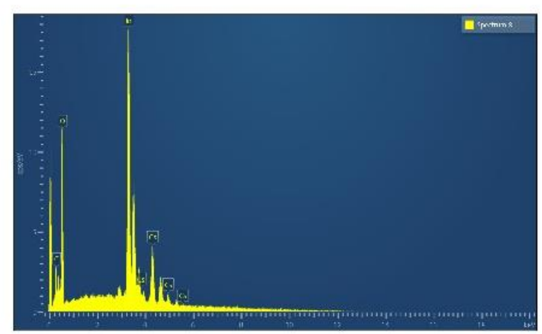
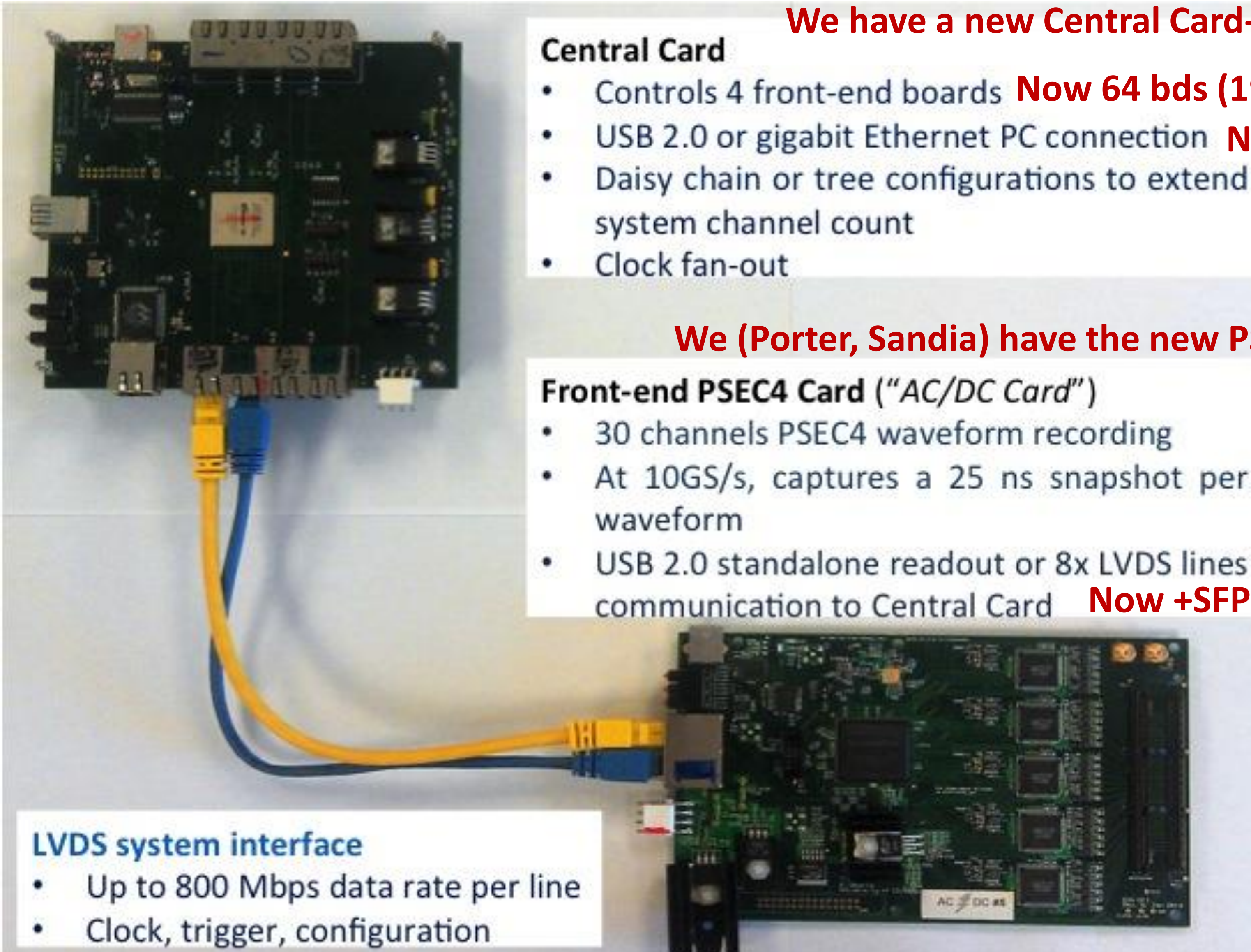


Figure 5: This spectrum is taken from the layer on the window that had turned black and flaky. The spectrum looks almost identical to that of the dust flecks.

Electronics

Eric Oberla's Ph.D thesis; Mircea Bogdan, John Podczerwinski, Horatio Li, Evan Angelico; John Porter of Sandia funded PSEC4A Mosis run; Jonathan Eisch, Miles Lucas,, .. (ANNIE)



We have a new Central Card- Mircea Bogdan

Now 64 bds (1920 channels)

Now +SFP and VME

We (Porter, Sandia) have the new PSEC4A ASIC

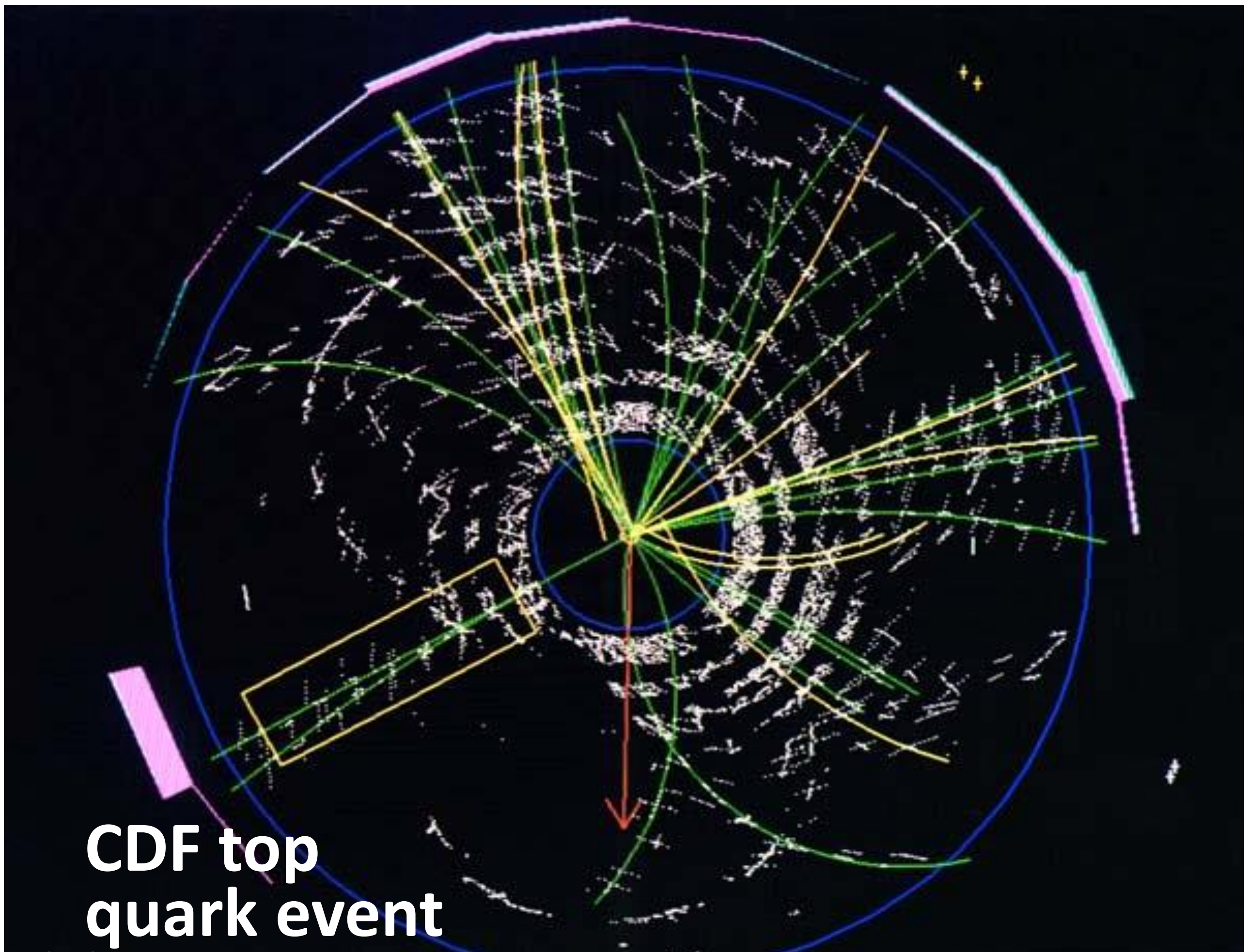
Now +SFP and VME

The Original Motivation: I GotTired of @#$! Jets

Goals: 1) Measure all 4-vectors– can reconstruct masses

2) assign tracks to vertices (e.g. CMS forward Ecal.)

3) vertex photons at colliders (4-vectors!) ;



Aside: Use photons (and electrons) as reference time- i.e. do differential timing of tracks from the same vertex to eliminate external clock jitter

See Aspen talk, Jan 2003 (hep.uchicago.edu/~frisch

Three Timing Cases to Distinguish

The factors limiting the ultimate timing resolution are different in each of the following cases:

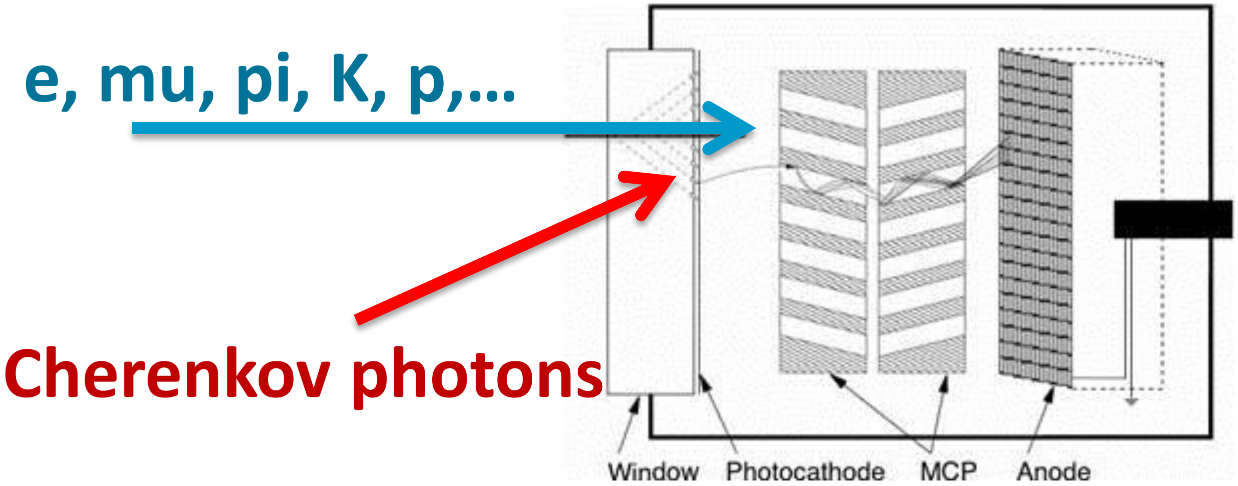
1. Single optical photons (Scintillation or Cherenkov)
2. Charged Particles above Cherenkov Threshold(H2O,glass)
3. Electromagnetic showers from High Energy photons

I will focus on #2 and #3, relativistic charged particles and high energy photons, for which psec or sub-psec time resolutions I believe are plausible given certain detection criteria are met.

Note: In what follows I treat time and space distances in the same units, i.e. c=1, and 1 psec =300 microns; 1 nsec =1000 psec; 1 nsec =1 foot

Criteria for Sub-Psec Timing-1

Fast Source: A psec source in time-space of many photons in a time-space interval (example: Cherenkov light from a charged particle traversing a radiator or the entrance window of a photodetector);

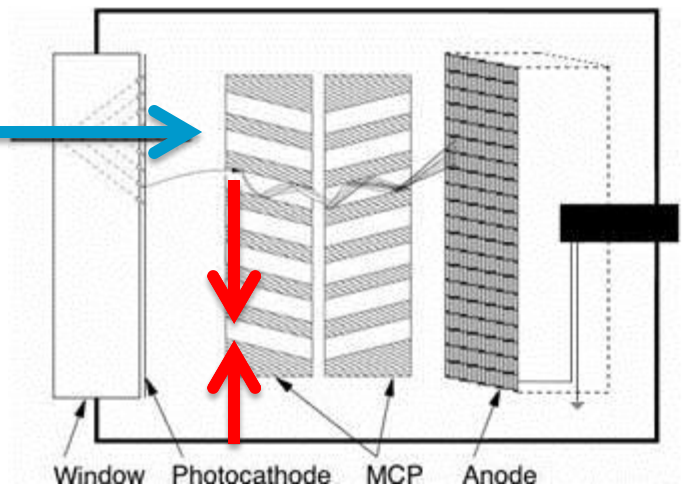


(Or early in an electromagnetic shower such as in a pre-radiator or EM calorimeter (separate discussion));

Criteria for Sub-Psec Timing-2

Psec-level pixel size (example: 10-20 micron pores in an MCP plate)

e, mu, pi, K, p,...



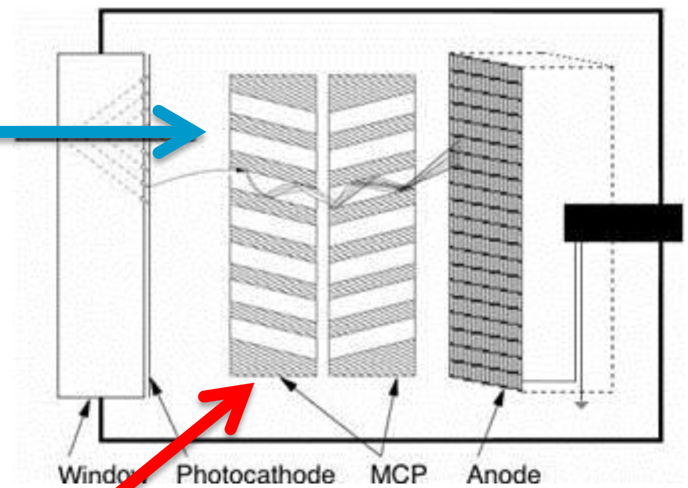
10-20 micron pore

Criteria for Sub-Psec Timing-3

High gain: The gain has to be high enough that **a single photon triggers,** i.e. t**he first photon 'in' determines the leading edge of the pulse** and consequently the timing.

N.B. NOT 1/sqrt(N)

e, mu, pi, K, p,...



Amplification section: Gain-bandwidth, Signal-to-Noise, Power, Cost (eg: two-stages of MgO MCPs give gain $>10^7$)

Signal-to-Noise, Rise-time Dependences

Long discussions at UC/ANL /France workshops of dependence on analog bandwidth, gain, noise, digitization methods, etc. ;

Answer (S. Ritt) is that at the level of present performance, using waveform sampling, the achievable time resolution is well-described by three parameters: 1) analog band-width (aka rise-time); 2) signal-to-noise; and 3) the sampling rate (assuming sufficient number of bits not to limit).

- Show Stefan Ritt's Rule-of-Thumb. For a sampling rate proportional to analog bandwidth it's only 2 parameters.

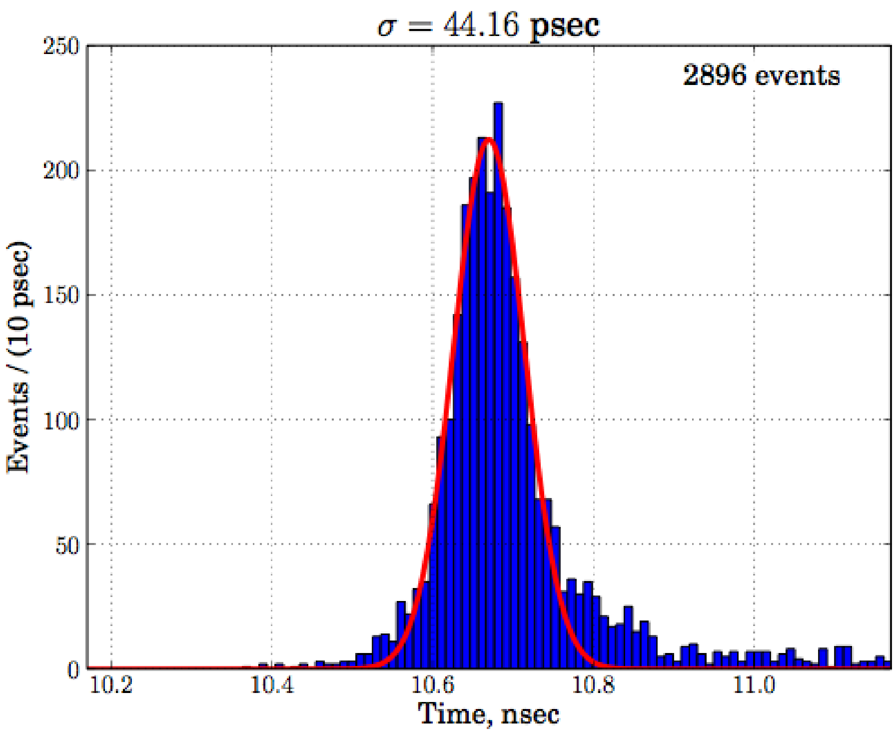
Breaking the 1-Psec Barrier?

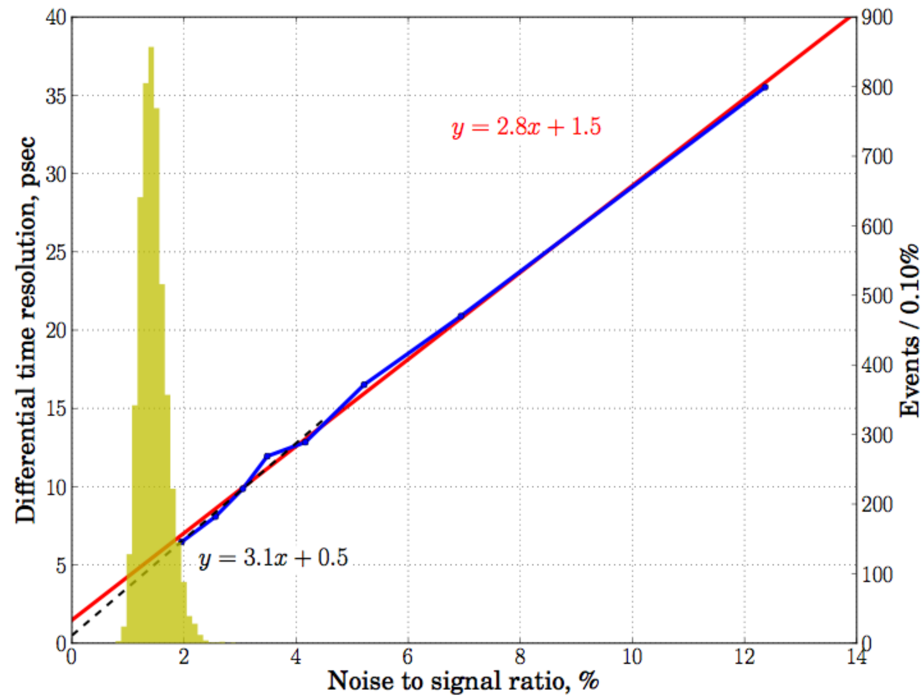
Stefan Ritt (PSI) table from 2nd Chicago Photocathode Workshop (annotated) (see psec.uchicago/edu/library)

Signal	Noise	Sampling	Bandwidth	Resolution
U	Δu	f_s	f_{3db}	Δt
100 mV	1 mV	2 GSPS	300 MHz	~10 ps
1 V	1 mV	2 GSPS	300 MHz	1 ps
100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
1V	1 mV	10 GSPS	3 GHz	0.1 ps !
LAPPD: 1V	**0.7 mv**	**15 GS/sec**	**1.5 GHz**	**??**

Before 100 fsec something else will surely bite us, but still…

Present (now old) Time Resolution



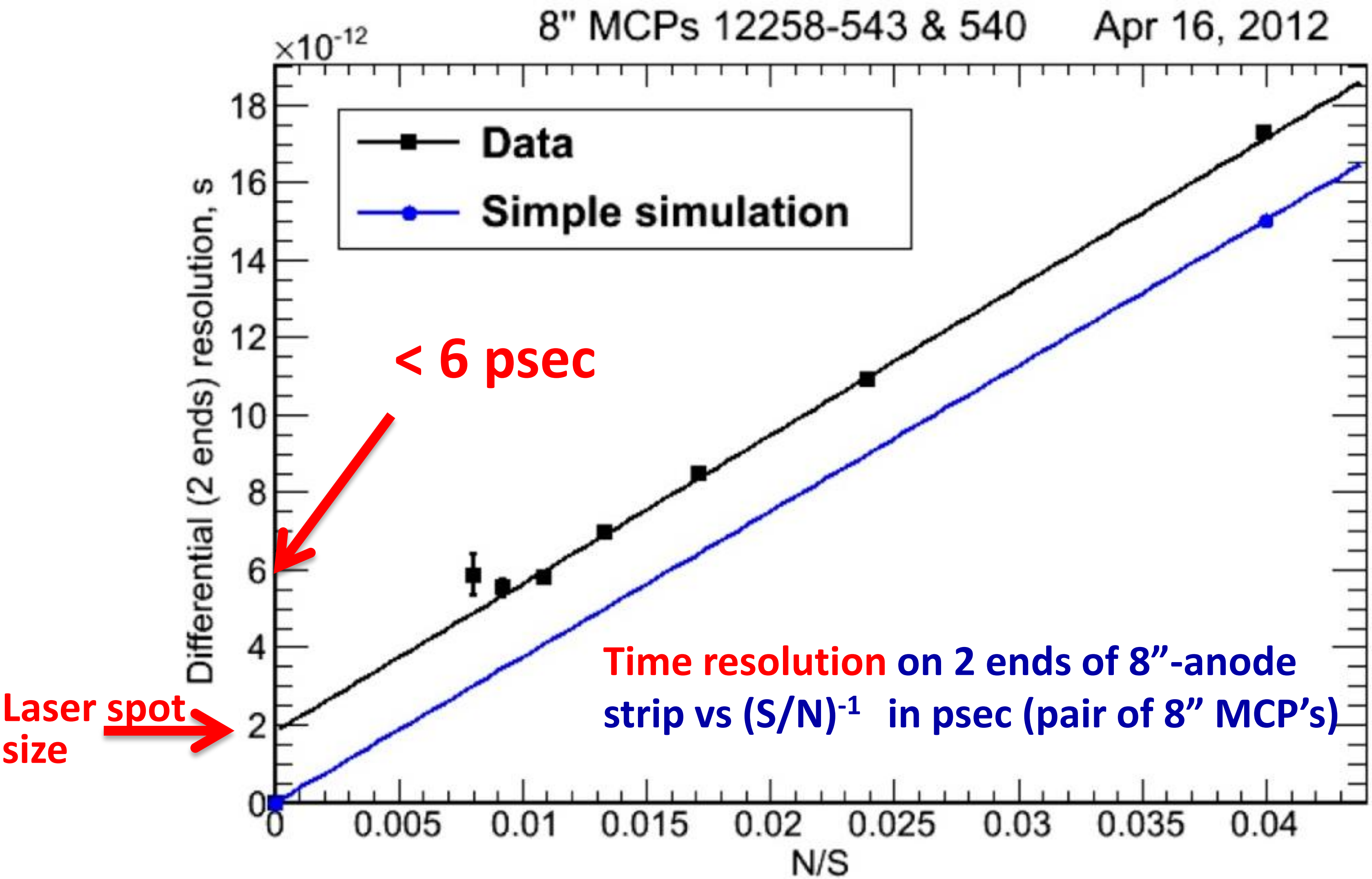


Single Photo-electron
PSEC4 Waveform sampling
Sigma=44 psec

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, …

Opinion, pure and simple (why not)

Next round of big collider detectors

- Should measure 4-vectors of all tracks up to (say) P_T= 25 GeV using ultra-fast TOF
- Should vertex all particles using ultra-fast TOF, including photons
- For ultra-fast TOF need small pixels, high gain, and lots of photons in a coherent localized pulse.

John Lindsley (air-shower array pioneer, with Bruno Rossi at MIT). Volcanos in background. Very primitive and wonderful- amazing summer for a 15-yr old

Volcano ranch group car: predecessor of the WWII Navy Weapons carrier we drove out in the morning (summer, 1960)

The End

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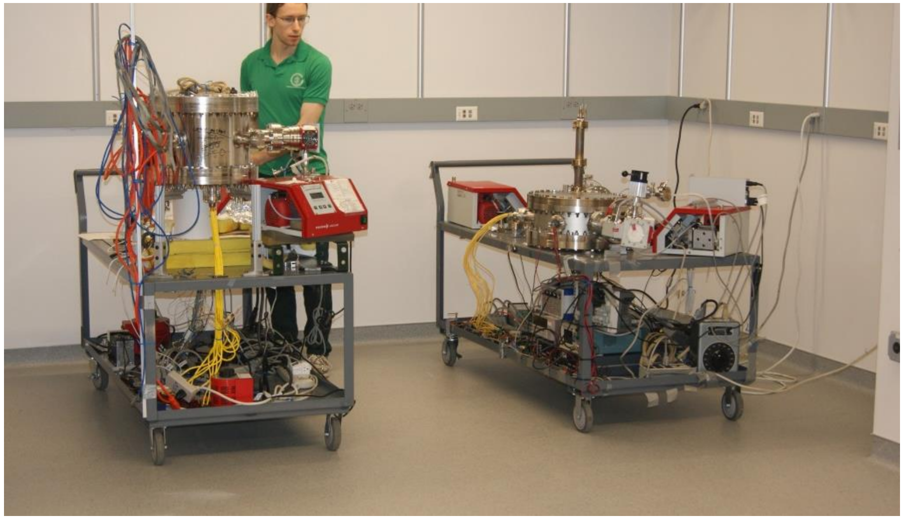
Backup Slides

Photodetector Development

Joe Gregar (master glassblower Argonne) and Andrey

Ceramic tile bases from 4 vendors



Second Margherita for ceramic in our brand-new lab; new wet lab (!)

A Plea

As money gets tight we naturally pull back from risk and disruptive technologies. However the big gains in our exploratory capabilities have come from new things- often not easy- e.g. the TPC and silicon vertex detectors (I was on a godparent committee that approved Aldo Menzione's for CDF). We should aim for 'a portfolio' of risk'– judiciously and thoughtfully chosen; but we should fight the shutting down either new initiatives or career paths for young physicists interested in new ideas.

(N.B. not a plea for my program per se- much broader and more important to the future of US basic science)