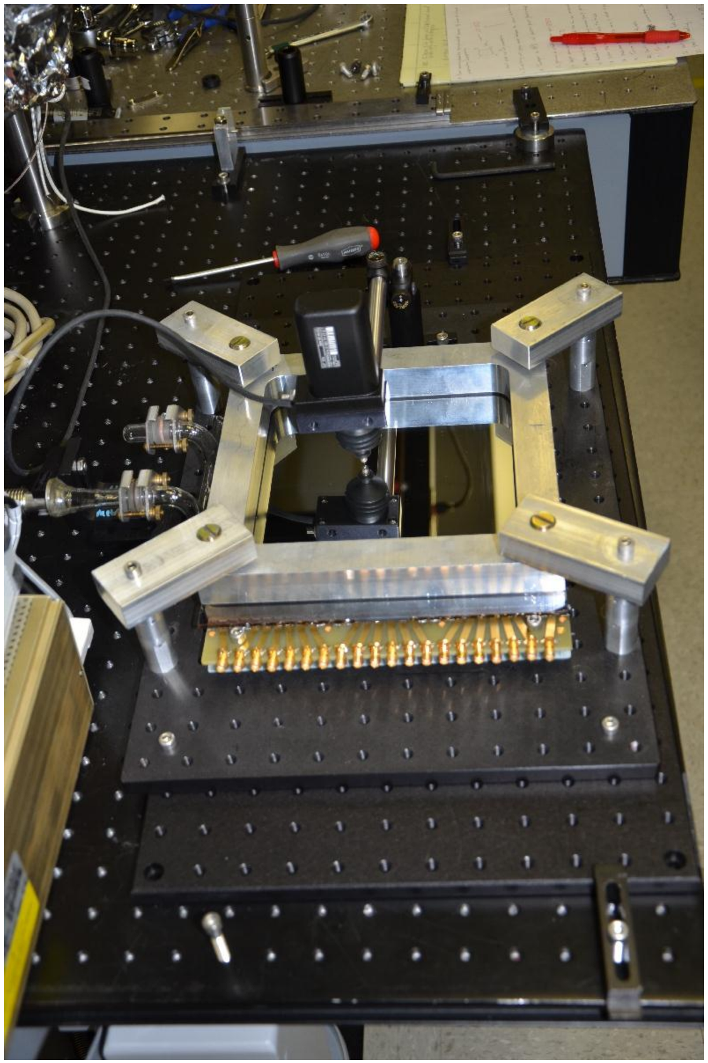
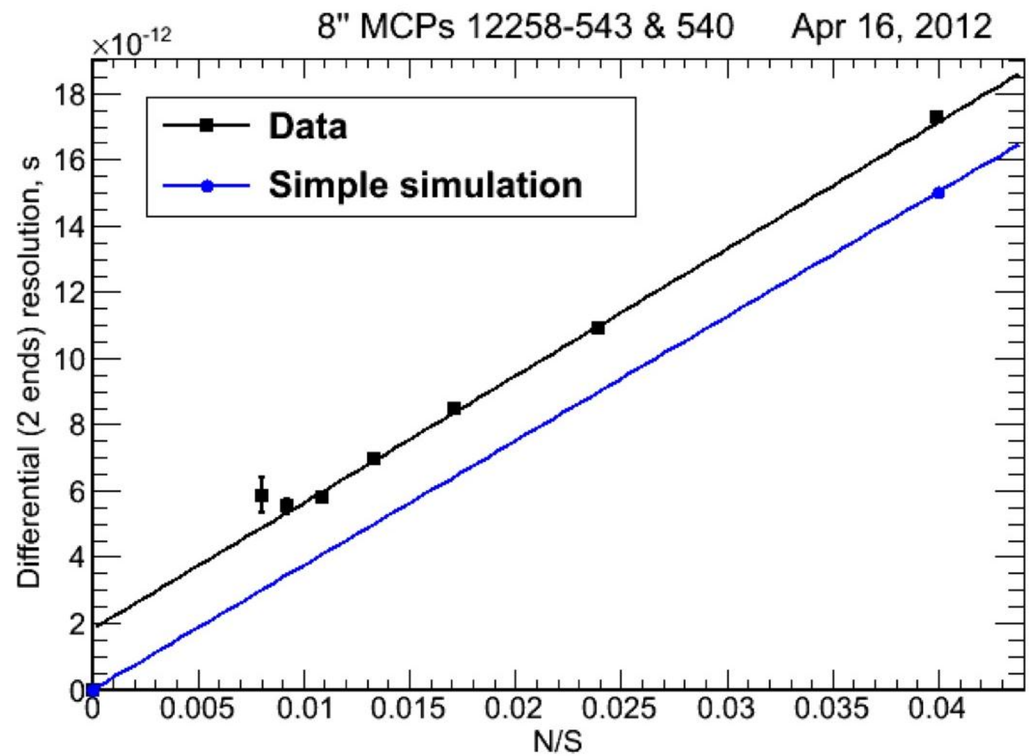
# The Development of Large-Area Pico-second Photodetectors

Henry Frisch, Enrico Fermi Institute, Univ. of Chicago
**For the LAPPD Collaboration**






**N = RMS of the noise; S = signal amplitude**

# Outline

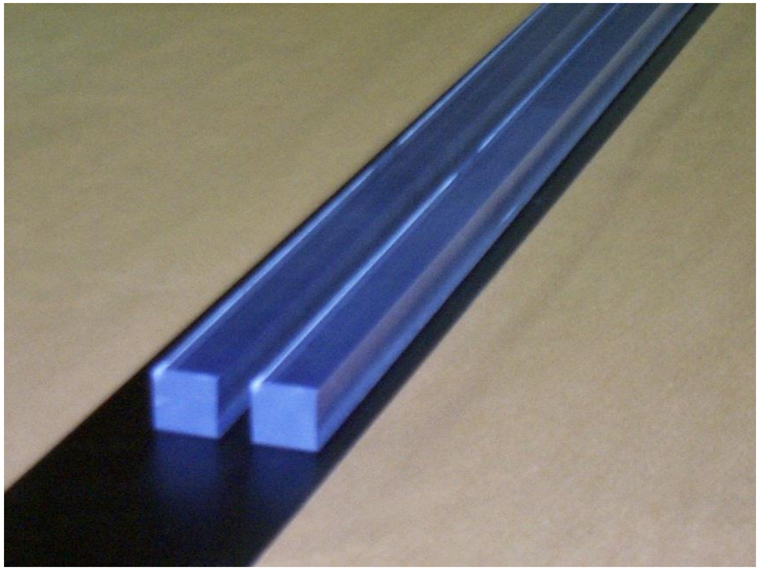
- New Types of Detectors Can Change Whole Areas of Science, Medical Imaging, Nuclear Non-proliferation
- Technical details of LAPPD: Surface Physics, GigaHz E&M, Glass, Circuit (ASIC) design, Tech Transfer to Industry
- Photocathodes- learning SS physics (!)
- Opportunities – many PhD theses in many fields- a broad collaborative effort, including industry

Acknowledgements- LAPPD collaborators, Howard Nicholson and the DOE HEP, ANL Management, and the NSF.

# Why has 100 psec been the # for 60 yrs?

**Typical path lengths for light and electrons are set by physical dimensions of the light collection and amplifying device.**

**These are on the order of  an inch. One inch is 100 psec. That' what we measure- no surprise!** (LH picture from T. Credo)



Typical Light Source (With Bounces)

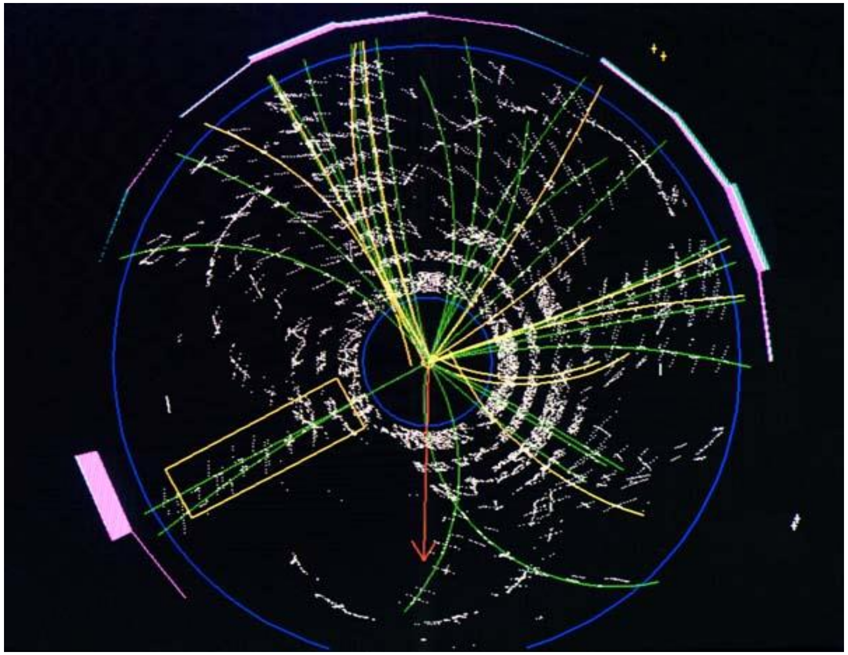
Typical PMT's  (With Long Path Lengths)

# Colliders:

**1) Identify the quark content of charged particles;**

**2) Vertex photons ; 3) Separate vertices; 4) Discovery**

**Extract *all* the information in each event** (4-vectors) – only spins remain…



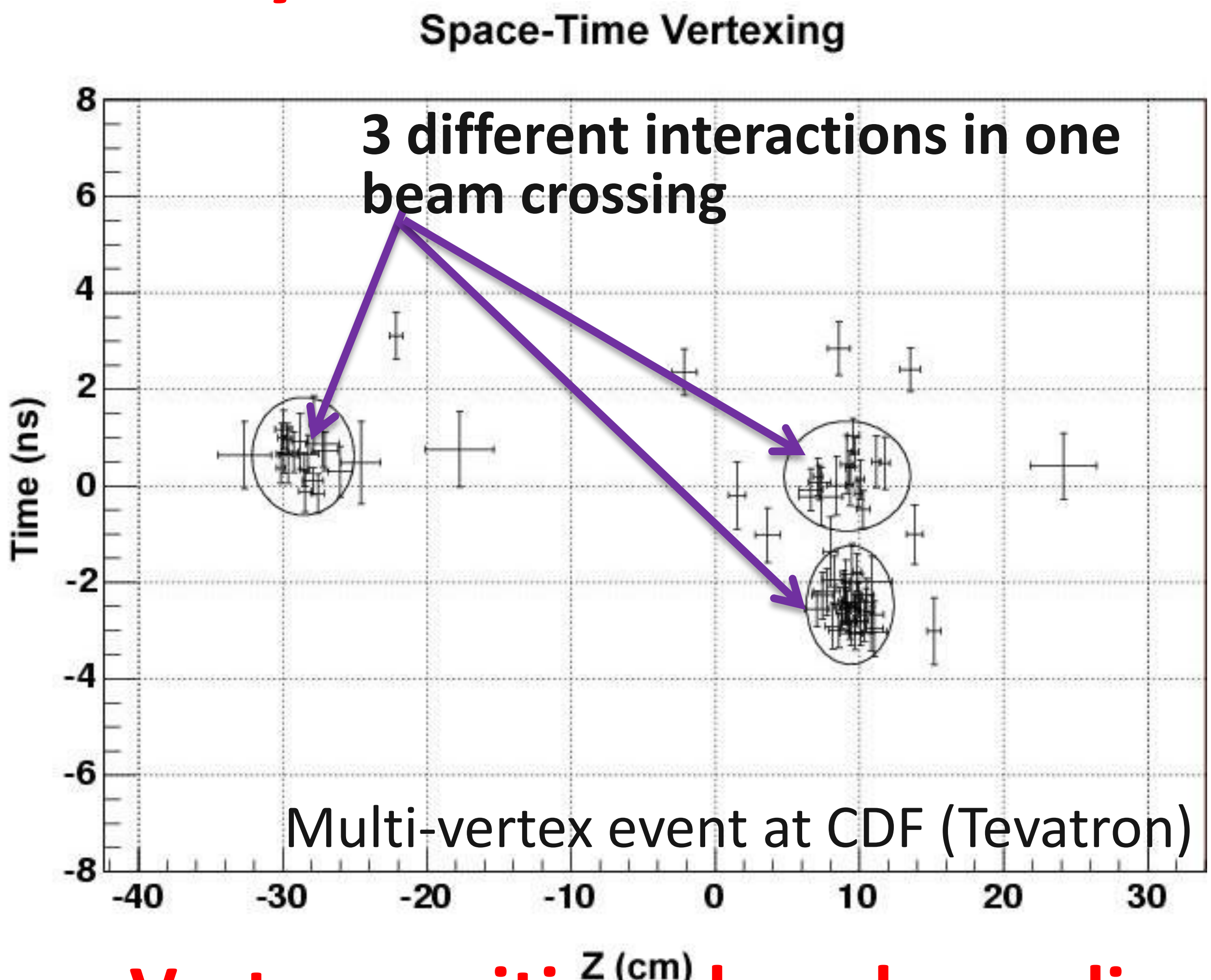
**Light source is Cherenkov light in the window or radiator.**

**Differential TOF: measure the difference in arrival times of photons and charged particles which arrive a few psec later (gives precise local time-dependent calibration**

**Will come back to this at the end…**

# Major problem coming up at LHC- vertexing at high luminosity (e.g. Joe Incandela's UC seminar on CMS)

Time (ns)

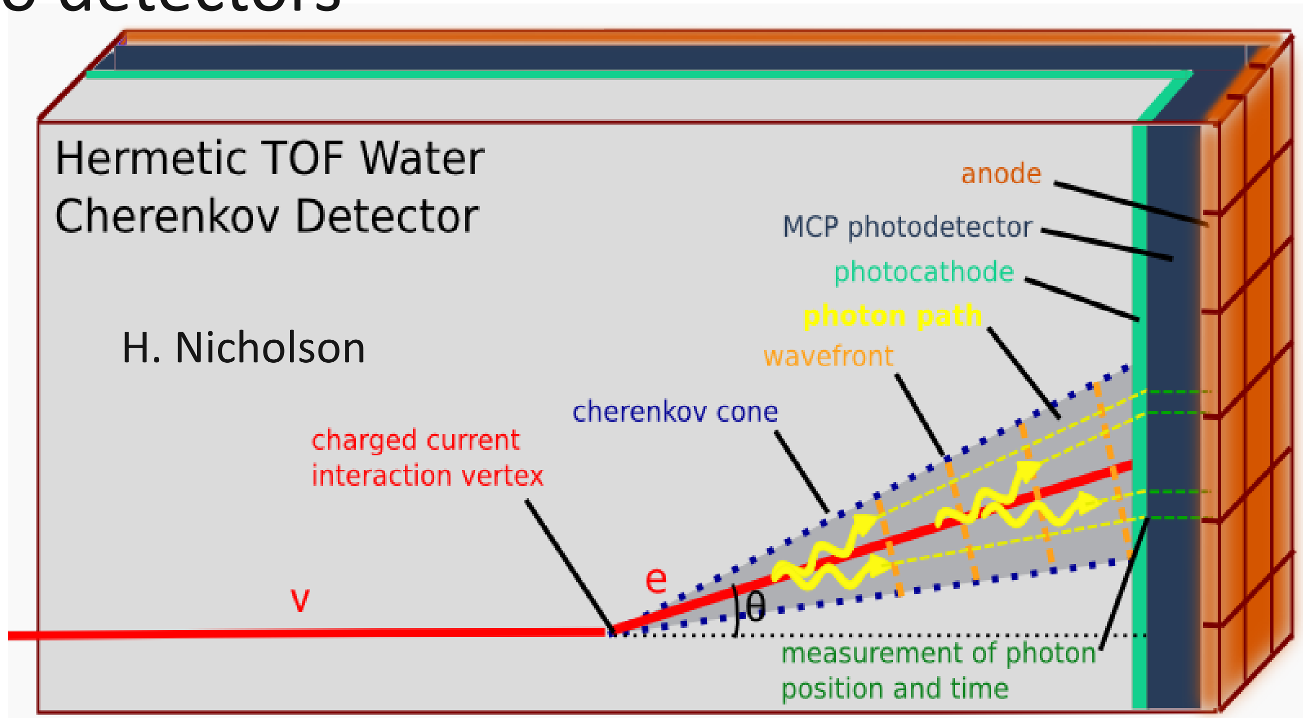



Vertex position along beam line (cm)

**Need, e.g.- Higgs to gamma-gamma at the LHC - tie the photons to the correct vertex, and more precisely reconstruct the mass of the pair**

# Neutrino Physics

**Need**: lower the cost and extend the reach of large neutrino detectors




**Approach:** measure the arrival times and positions of photons and reconstruct tracks in water

**Benefit:** Factor of 5 less volume needed, cost.

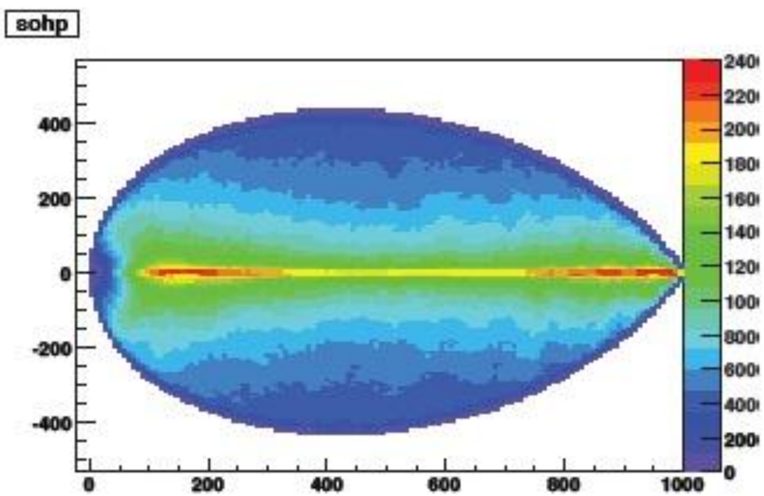
**Competition-** large PMT's, Liquid Argon

# A Photon Time-Projection Chamber

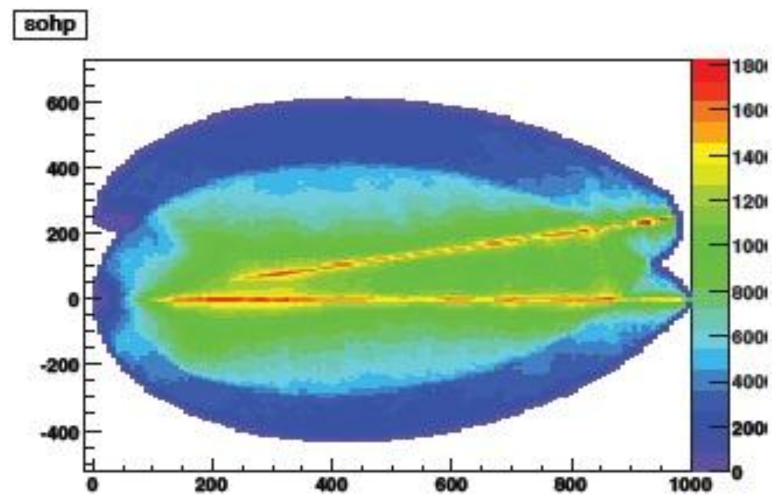
## Track Reconstruction Using an "Isochron Transform"

Results of a toy Monte Carlo with perfect resolution

Color scale shows the likelihood that light on the Cherenkov ring came from a particular point in space. Concentration of red and yellow pixels cluster around likely tracks




Single track



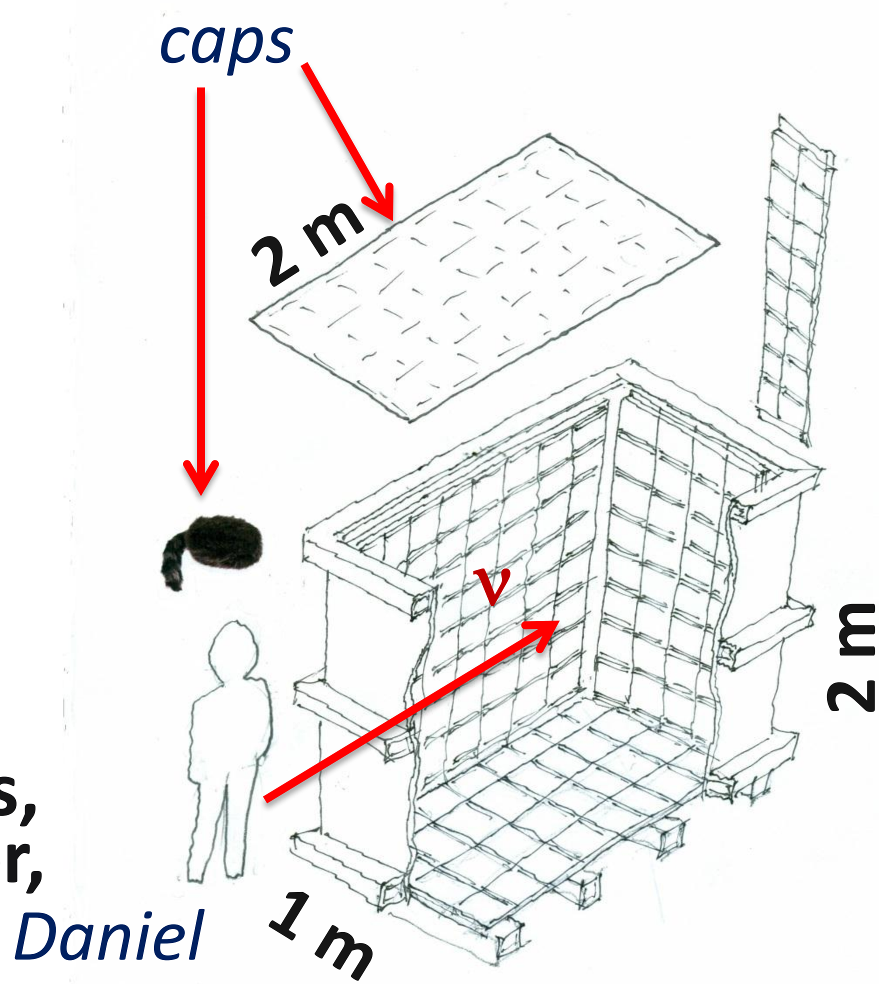

Two tracks displaced from a common vertex

**Work of Matt Wetstein (Argonne,&Chicago) in his spare time (sic)**

# Daniel Boone*

- Proposal (LDRD) to build a little proto-type to test photon-TPC ideas and as a simulation testbed
- `Book-on-end' geometry- long, higher than wide
- Close to 100% coverage so bigger Fid/Tot volume
- Δx, Δy << 1 cm
- Δt < 100 psec
- Magnetic field in volume
- Idea: to reconstruct vertices, tracks, events as in a TPC (or, as in LiA).

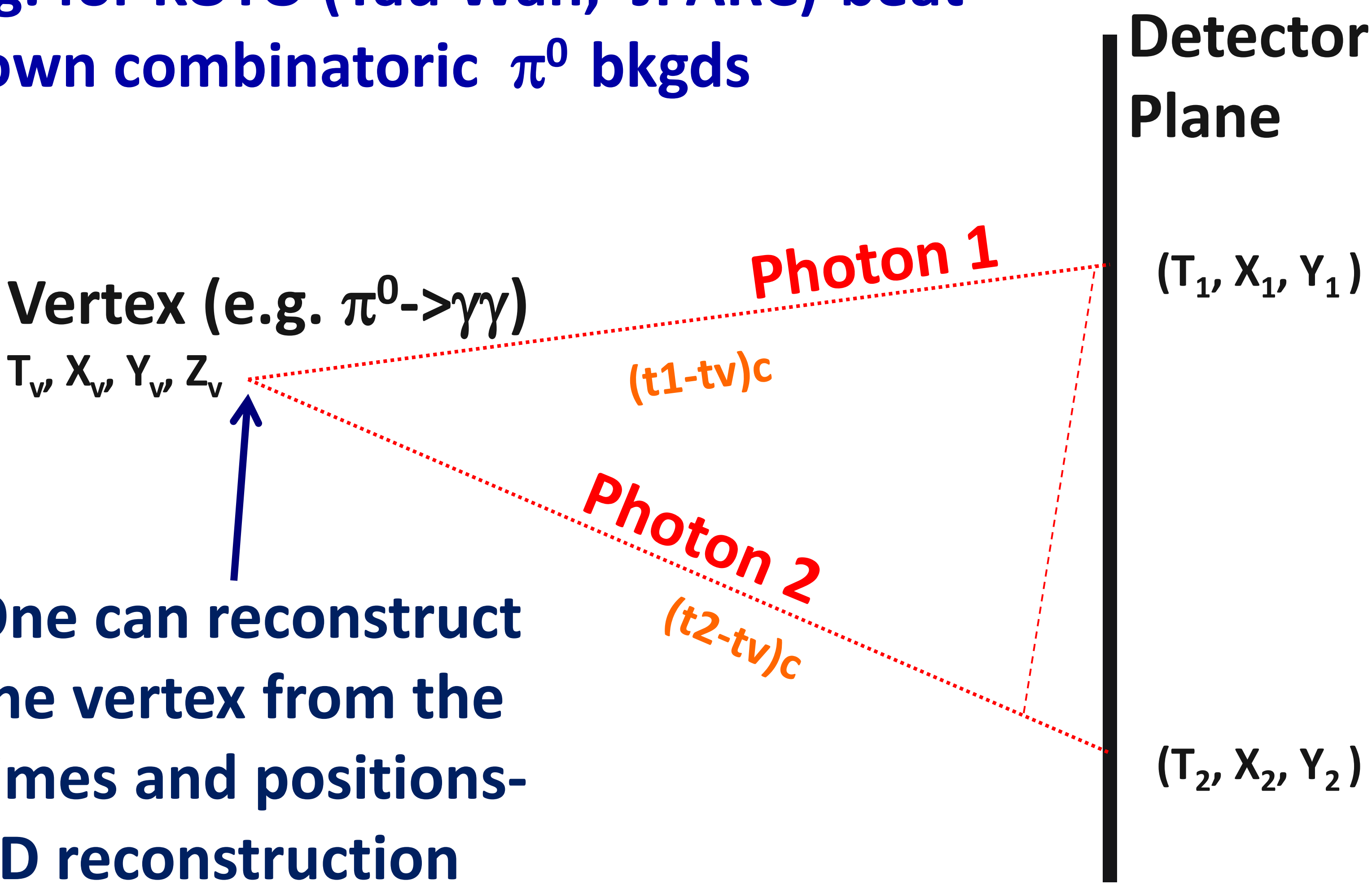
* Think MiniBoone, etc




Also ANNIE- Bob Svoboda

# Rare Kaon Decays- backgd rejection by reconstructing $\pi^0$ vertex space point:

**E.g. for KOTO (Yau Wah, JPARC)-beat down combinatoric $\pi^0$ bkgds**

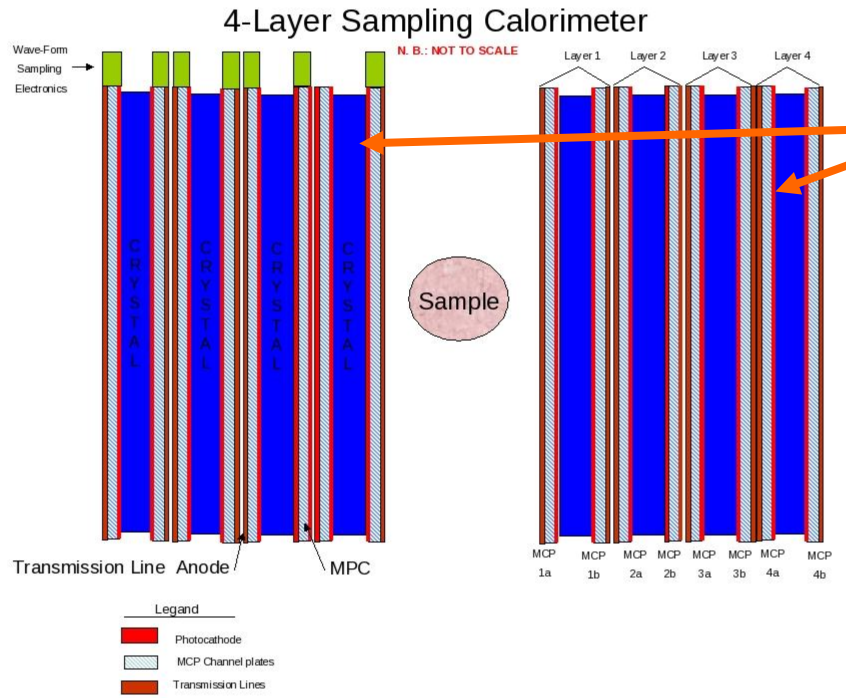



**One can reconstruct the vertex from the times and positions- 3D reconstruction**

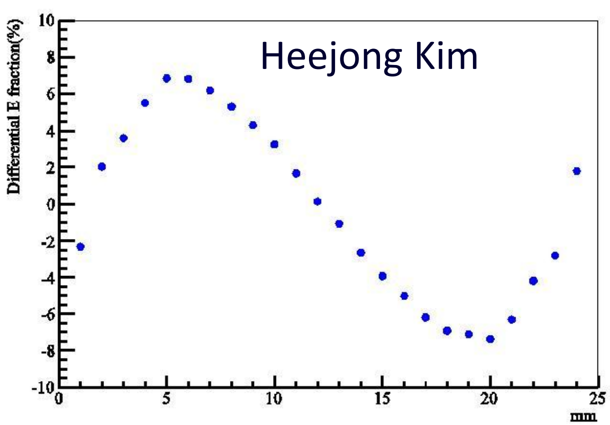
# Sampling Calorimetry in PET (1B$ Mkt)

Can we solve the depth-of-interaction problem and also use cheaper faster radiators?

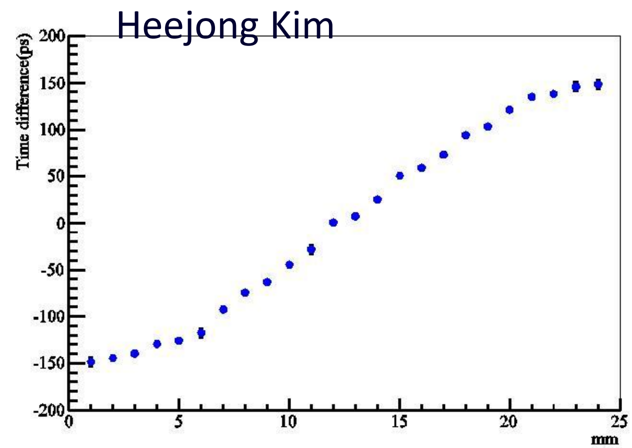
Simulations by Heejong Kim (Chicago)




Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side




Depth in crystal by time-difference




Depth in crystal by energy-asymmetry

# Cherenkov-sensitive Sampling Quasi- Digital EM/Had-separating Calorimeters

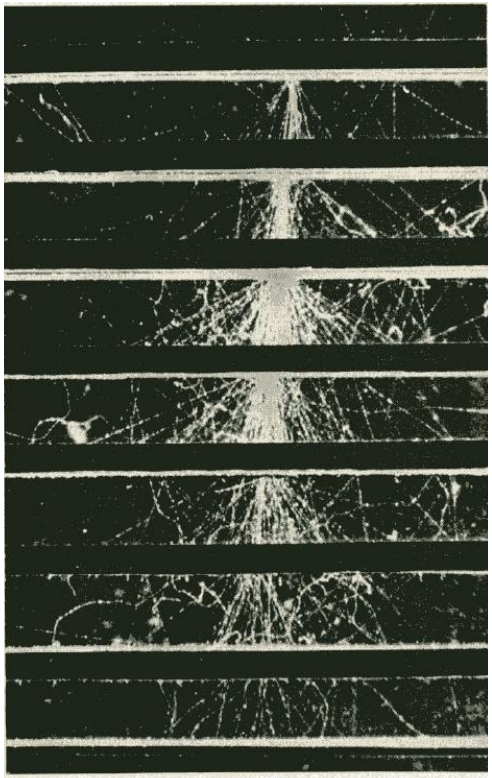
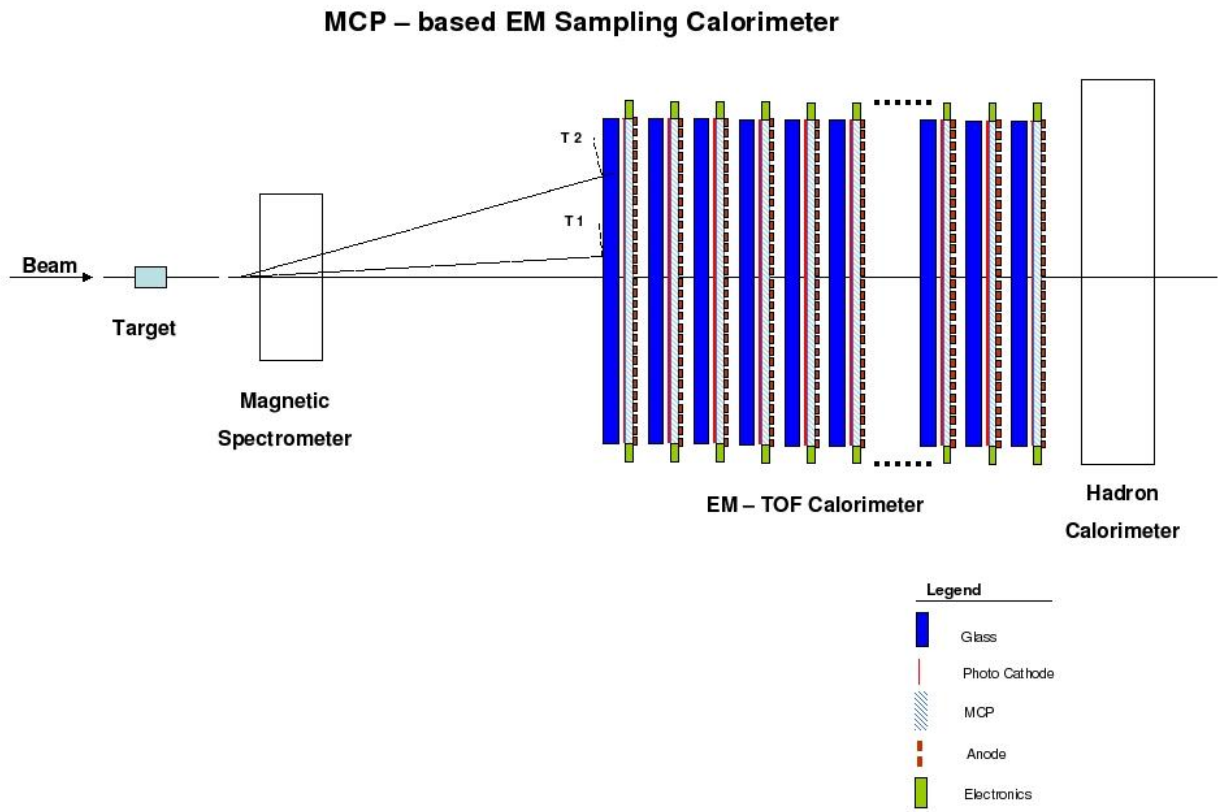


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.



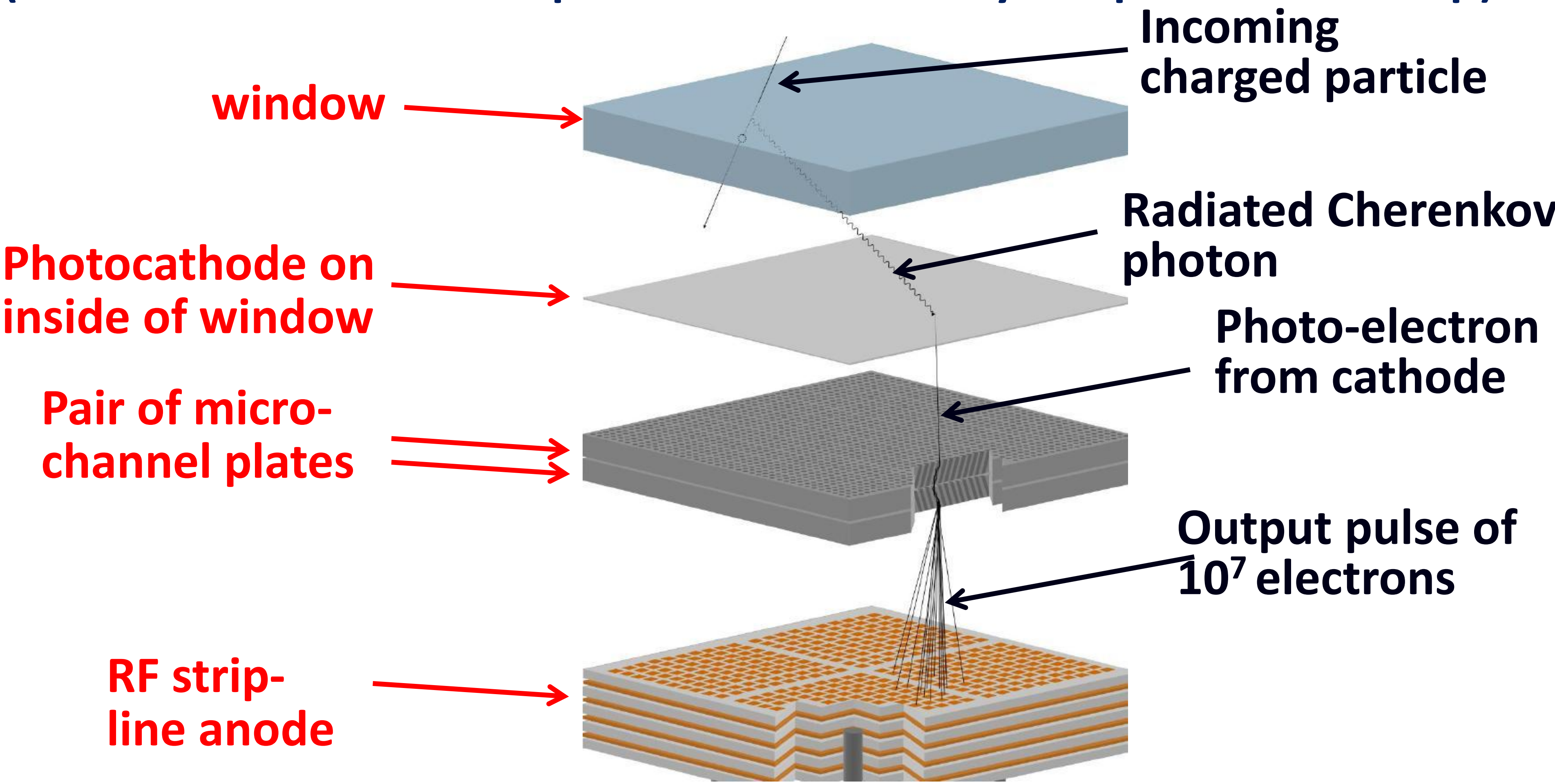

A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

A `cartoon' of a fixed target geometry such as for JPARC's KL-> pizero nunubar (at UC, Yao Wah) or LHCb

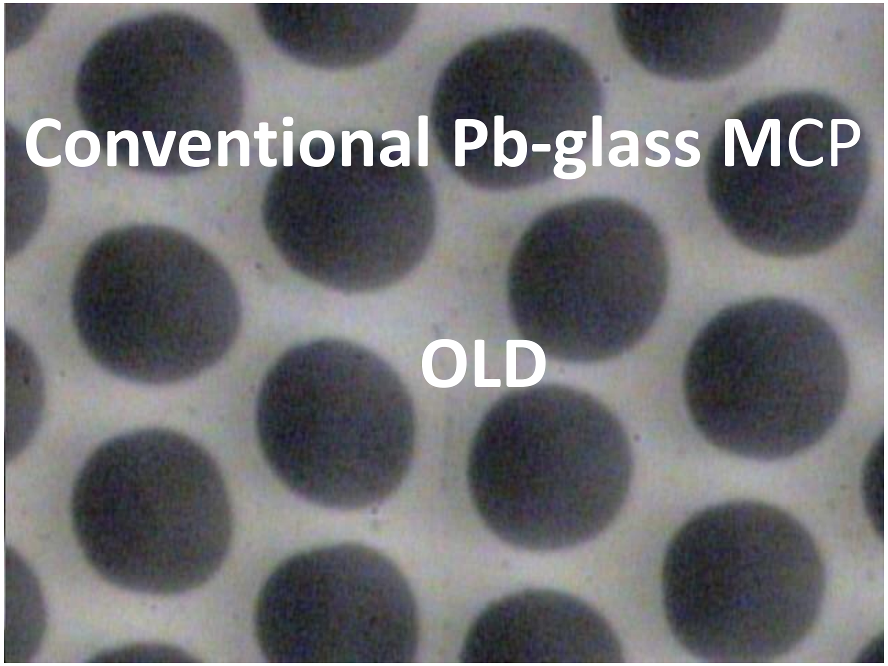
# How Does it Work?

**Requires large-area, gain > $10^7$, low noise, low-power, long life, $\sigma(t)$<10 psec, $\sigma(x)$ < 1mm, and low large-area system cost**

**Realized that an MCP-PMT has all these but large-area, low-cost: (since intrinsic time and space scales are set by the pore sizes- 2-20µ)**



# Simplifying MCP Construction





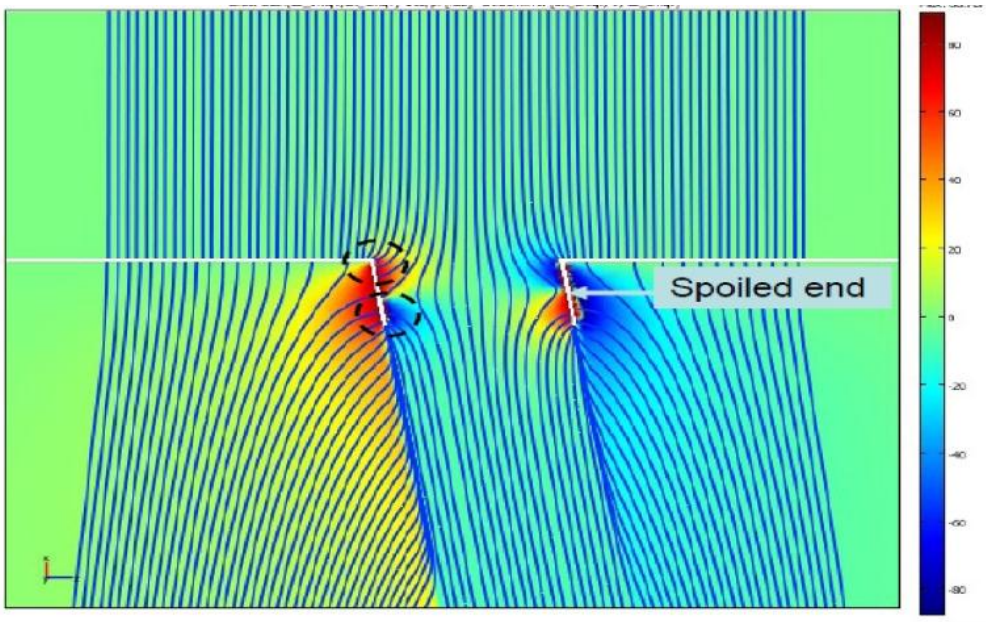
**Chemically produced and treated Pb-glass does 3-functions:**

1. **Provide pores**
2. **Resistive layer supplies electric field in the pore**
3. **Pb-oxide layer provides secondary electron emission**

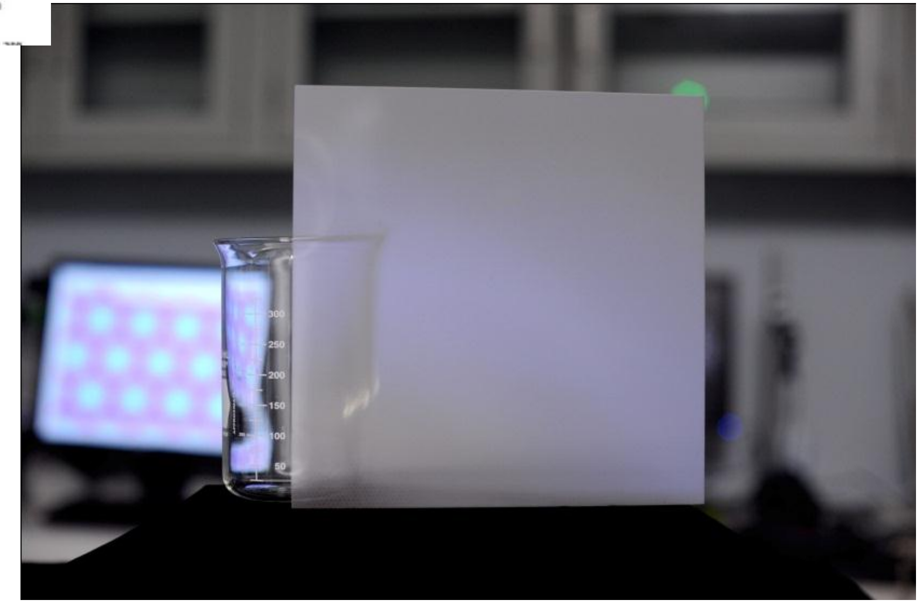
Separate the three functions:

1. Hard glass substrate provides pores;
2. Tuned Resistive Layer (ALD) provides current for electric field (possible NTC?);
3. Specific Emitting layer provides SEE

# Micro-Channel Plate Development

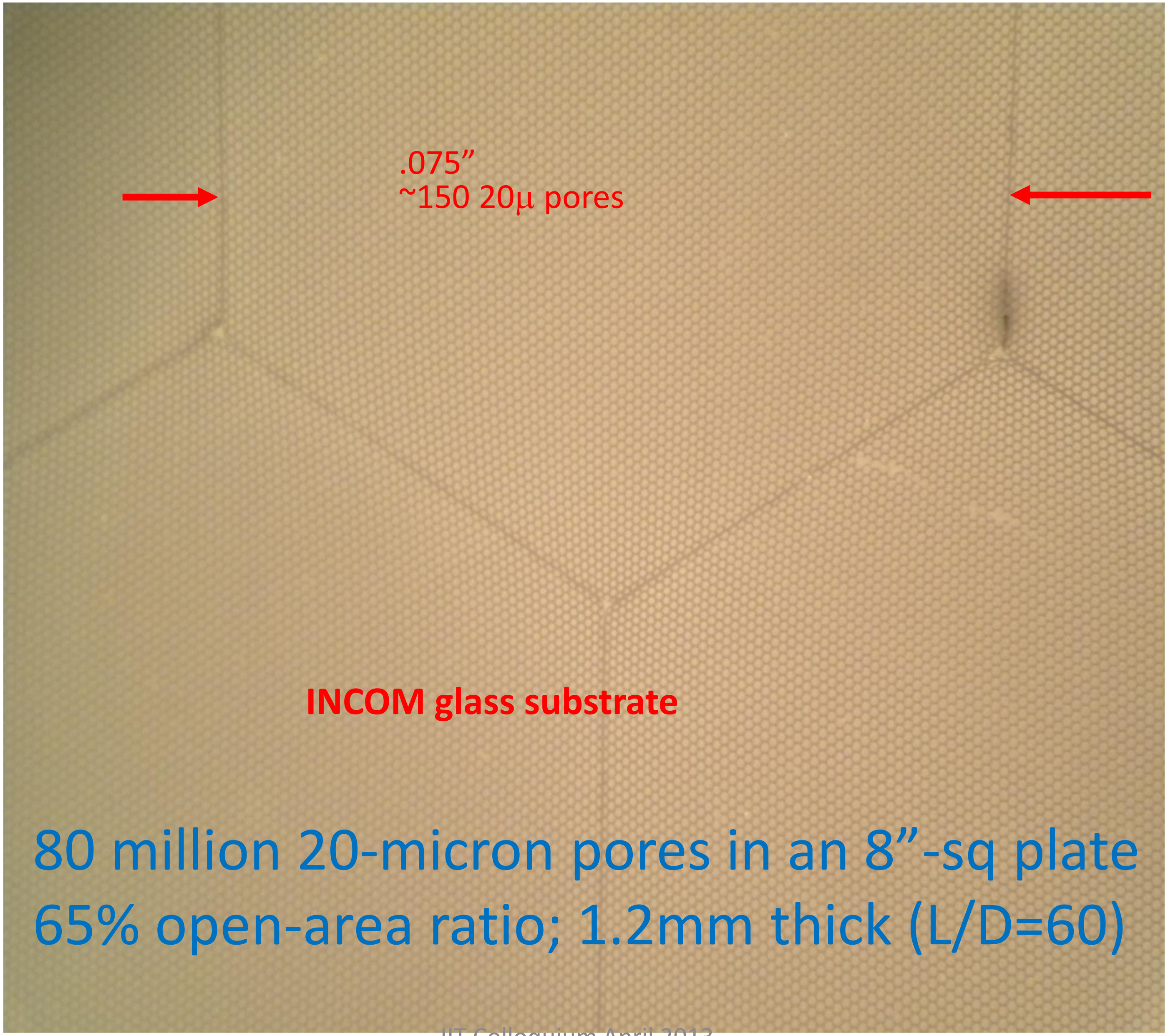



Simulation of electric field in 1 or several pores- with endspoiling; (attempted) comparison with data



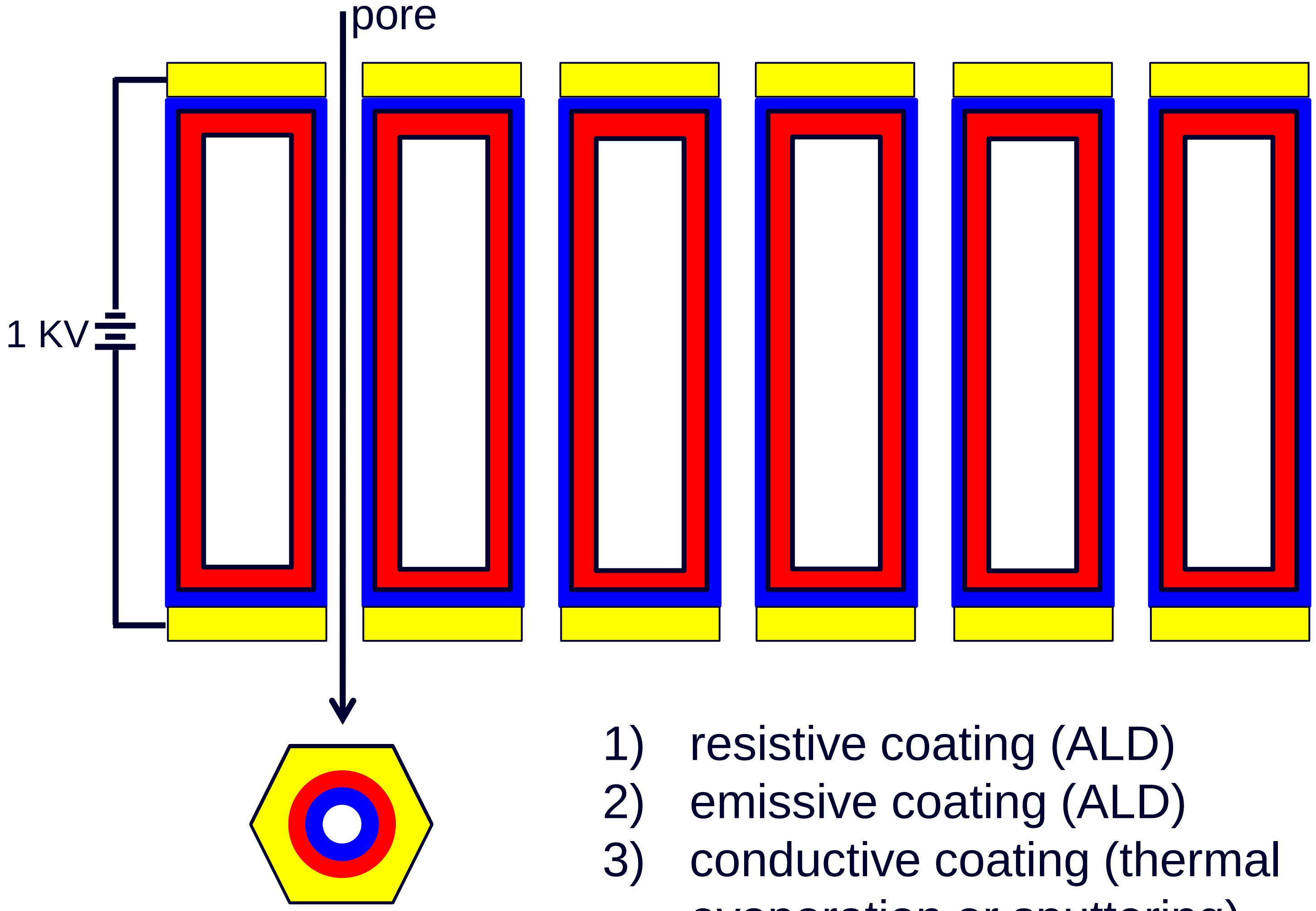
Incom 8"-sq high-quality MCP plate with > 65% OAR

# Incom Micropore Substrate




**Incom.inc, Charlton Mass**

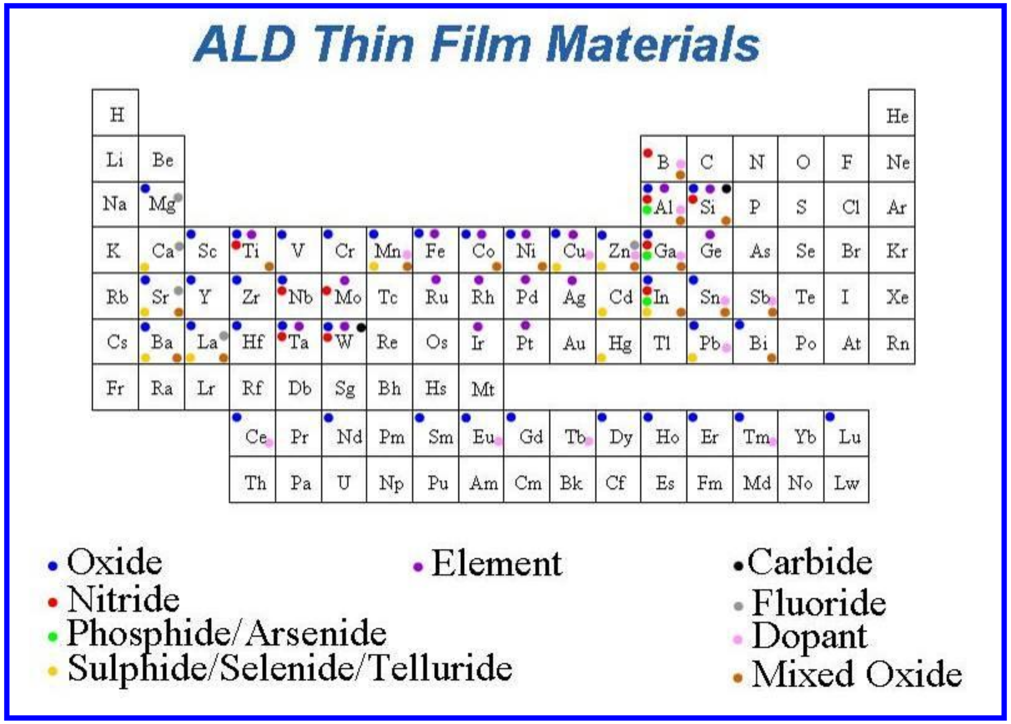
# New MCP Structure (not to scale)

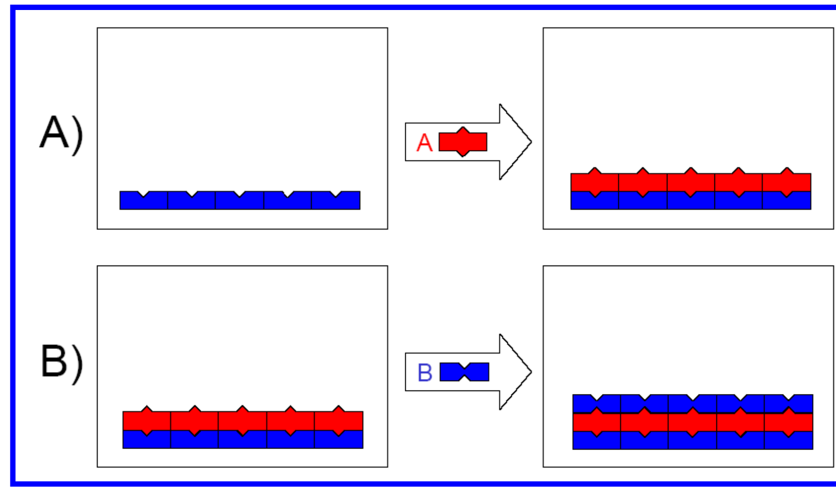



1) resistive coating (ALD)
2) emissive coating (ALD)
3) conductive coating (thermal evaporation or sputtering)

Jeff Elam

# Atomic Layer Deposition (ALD) Thin Film Coating Technology

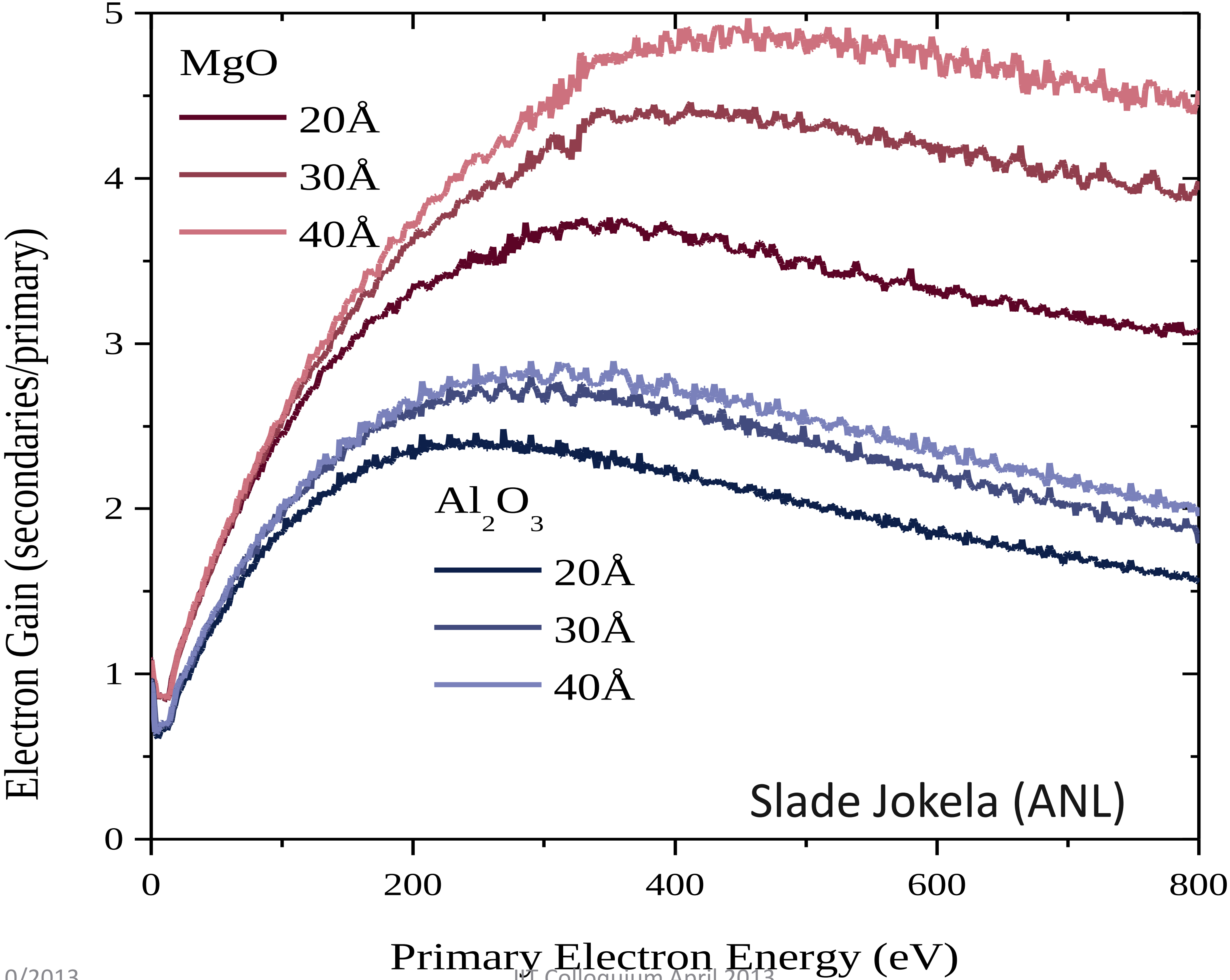



- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

**Lots of possible materials => much room for higher performance**

Jeff Elam pictures


MgO
20Å
30Å
40Å
$Al_2O_3$
20Å
30Å
40Å
Slade Jokela (ANL)
Electron Gain (secondaries/primary)
Primary Electron Energy (eV)
0
1
2
3
4
5
0
200
400
600
800

# ALD-Coated Incom 8” by 8” Microchannel Plate

**80,000,000 pores**

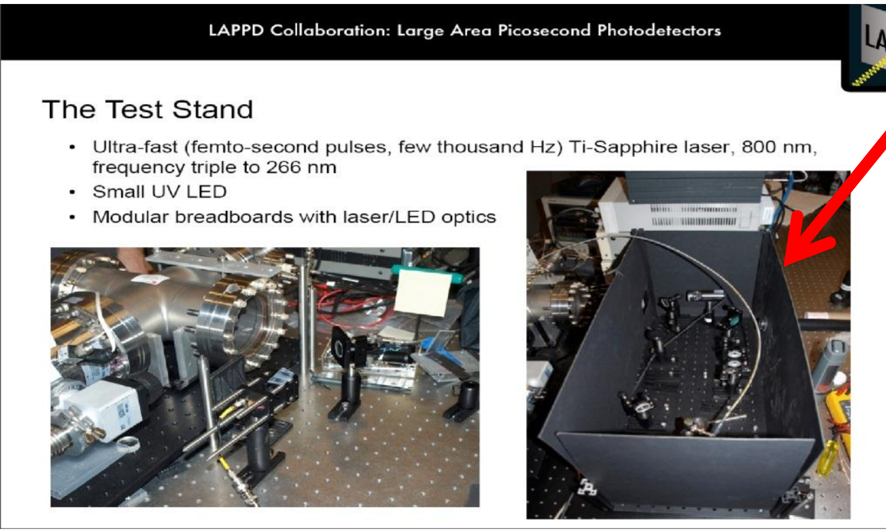
**Anil Mane and Jeff Elam (ANL)**

**A commercial 2”-square plate is more than $1000 and isn’t as good in *many* ways**

# ALD &Integration tests at ANL

Bernhard Adams, Andrei Elagin, Razib Obaid, Eric Oberla, Matt Wetstein

**Using <100 Femtosec laser, lots of vacuum (sic)**


LAPPD Collaboration: Large Area Picosecond Photodetectors

The Test Stand

- Ultra-fast (femto-second pulses, few thousand Hz) Ti-Sapphire laser, 800 nm, frequency triple to 266 nm
- Small UV LED
- Modular breadboards with laser/LED optics

ALD-coated MCP plate (Anil)

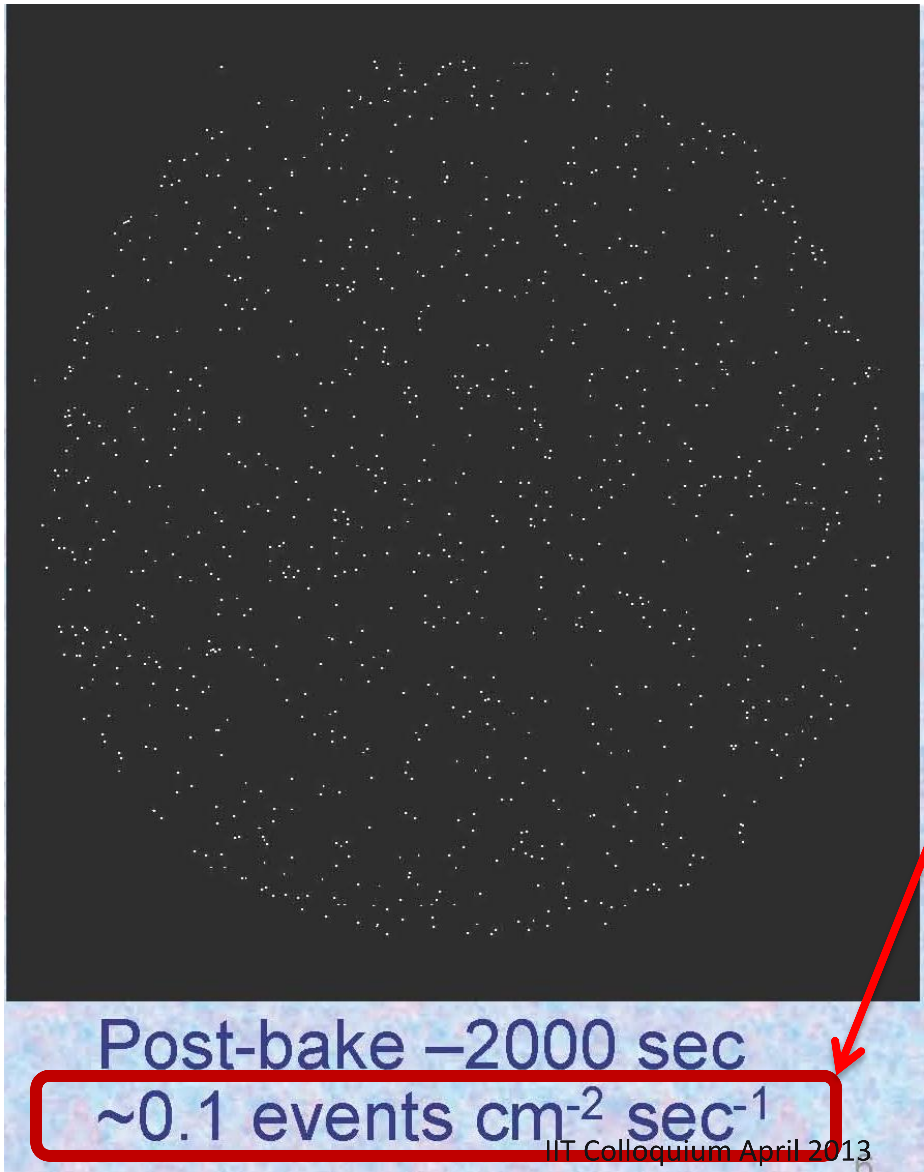
Anil Mani and Bob Wagner

Razib Obaid and Matt Wetstein

# Microchannel Plates-4b

## Performance:

Ossy Siegmund,
Jason McPhate,
Sharon Jelinsky,
SSL/UCB



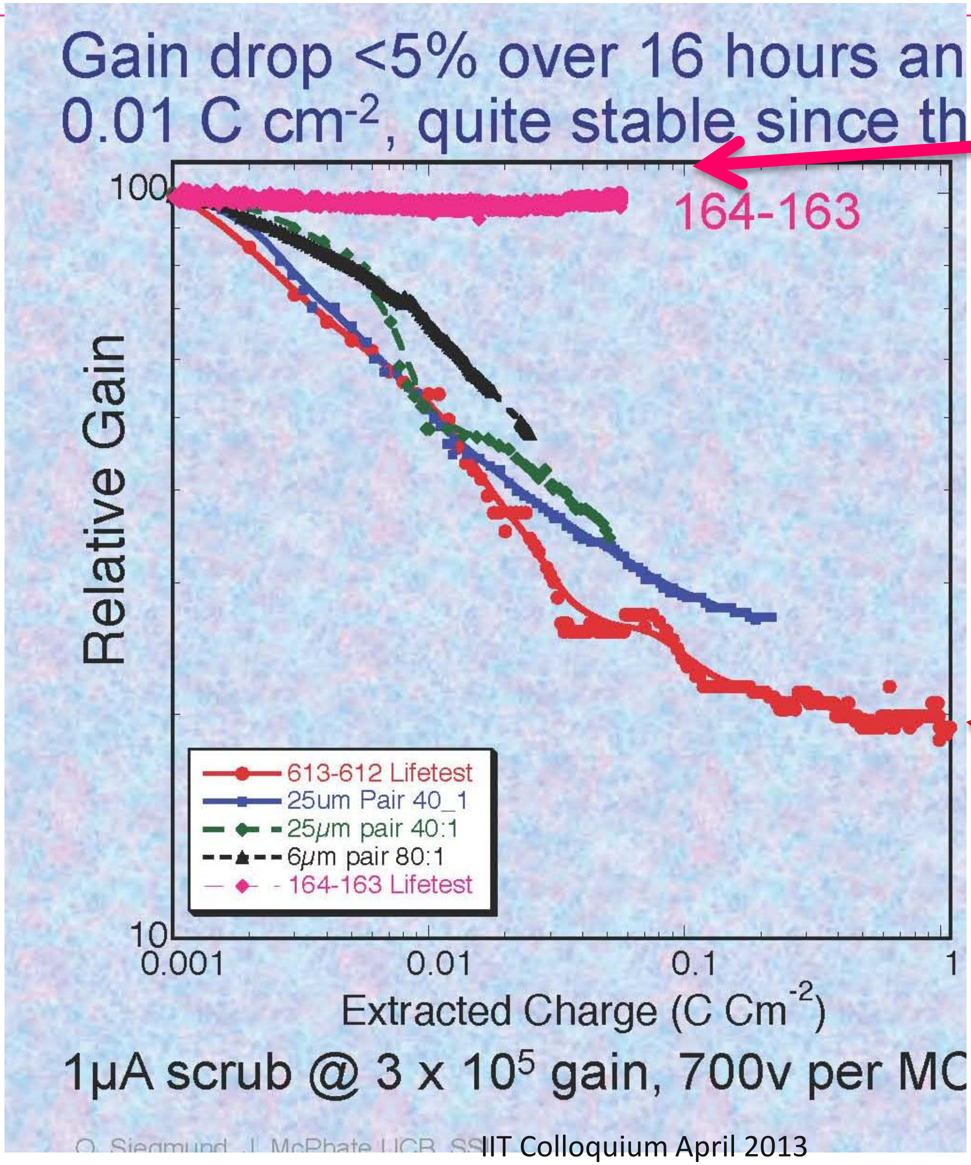

**Noise (bkgd rate). <=0.1 counts/cm$^2$/sec; factors of few > cosmics (!)**

# Microchannel Plates-4d

## Performance: burn-in (aka `scrub')

**Measurements by Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB**

(Big deal commercially?)




**Measured ANL ALD-MCP behavior**

**(ALD by Anil Mane, Jeff Elam, ANL)**

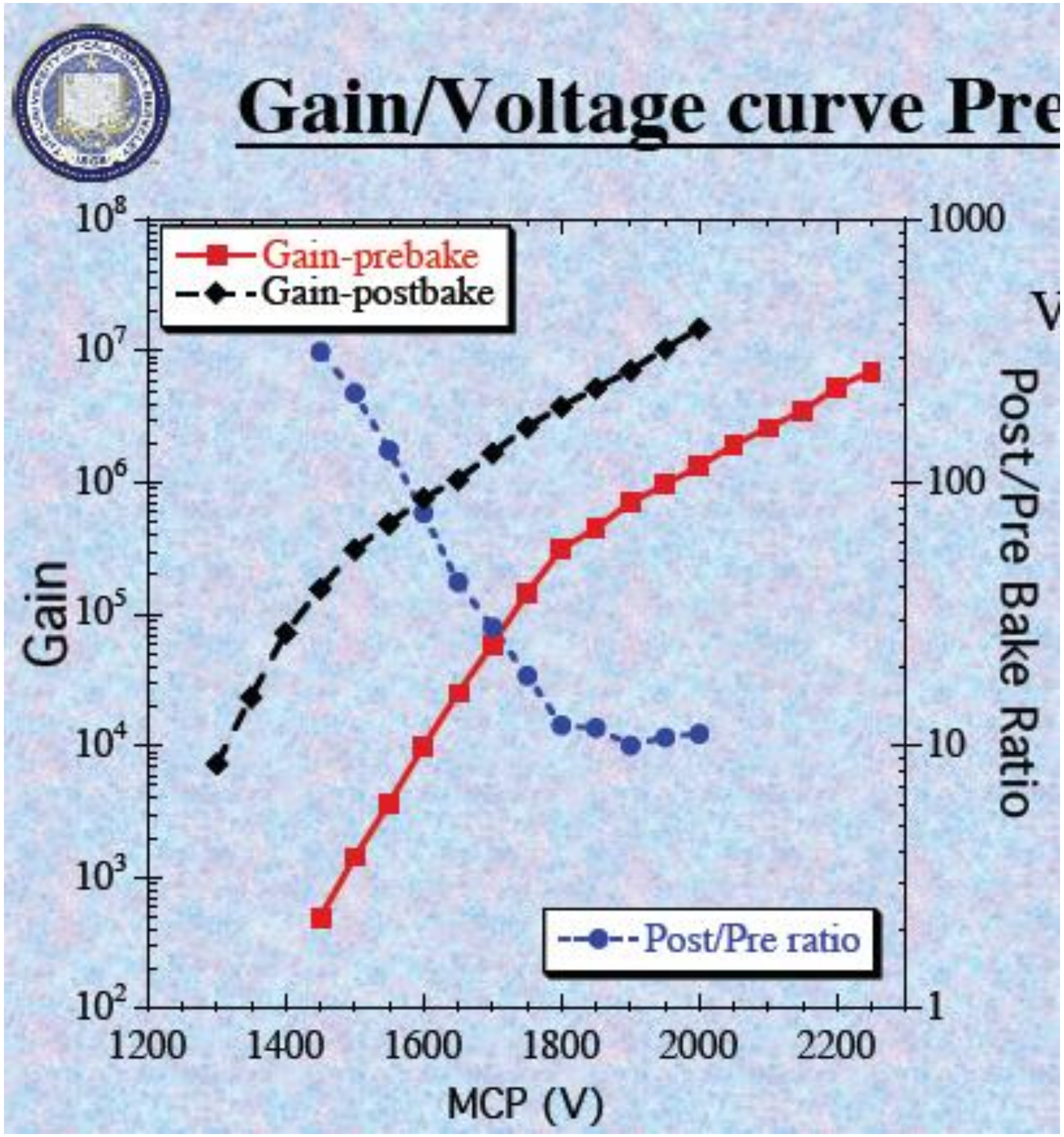
**Typical MCP behavior- long scrub-times**

# Signal- want large for S/N

## *We see gains > $10^7$ in a chevron-pair*

**Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB**

**ALD by Anil Mane and Jeff Elam, ANL**

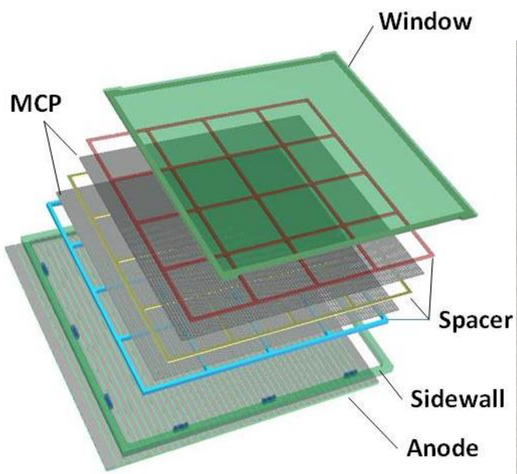


# The Half-Meter-Squared SuperModule

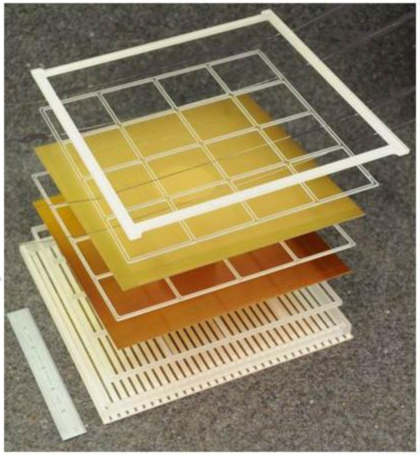
A SuperModule holds 12 tiles in 3 tile-rows.  15 waveform sampling ASICS on each end  of the tray digitize 90 strips. 2 layers of local processing (Altera) measure  extract charge, time,  position, goodness-of-fit

A `tile' is a sealed vacuum-tube with cathode, 2 MCP's, RF-strip anode, and internal voltage divider

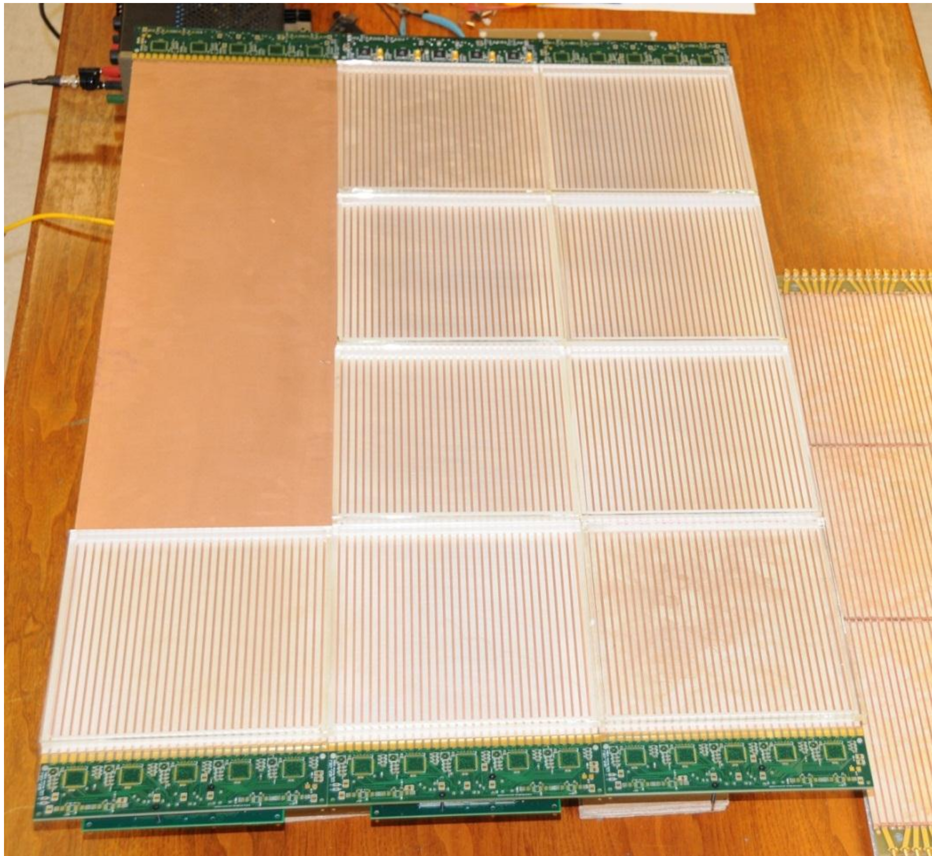
HV string is made with ALD




Design Drawing  -  September 2010

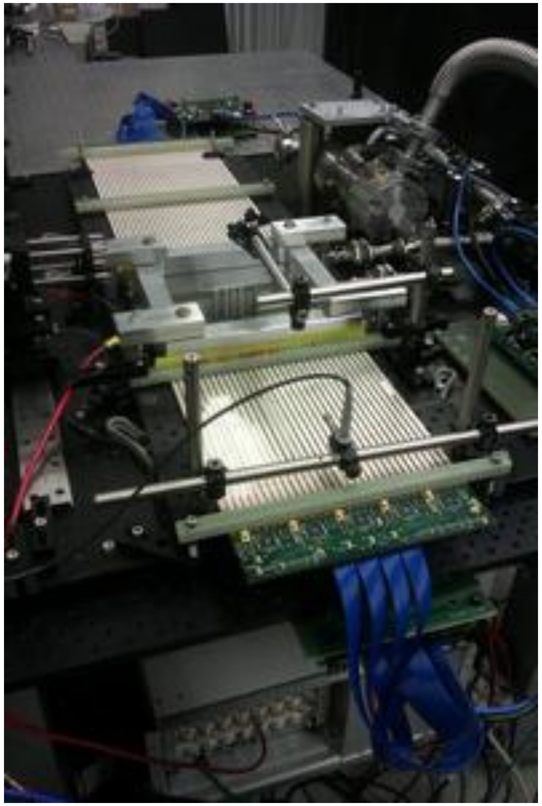


Actual Glass Parts  -  April 2012

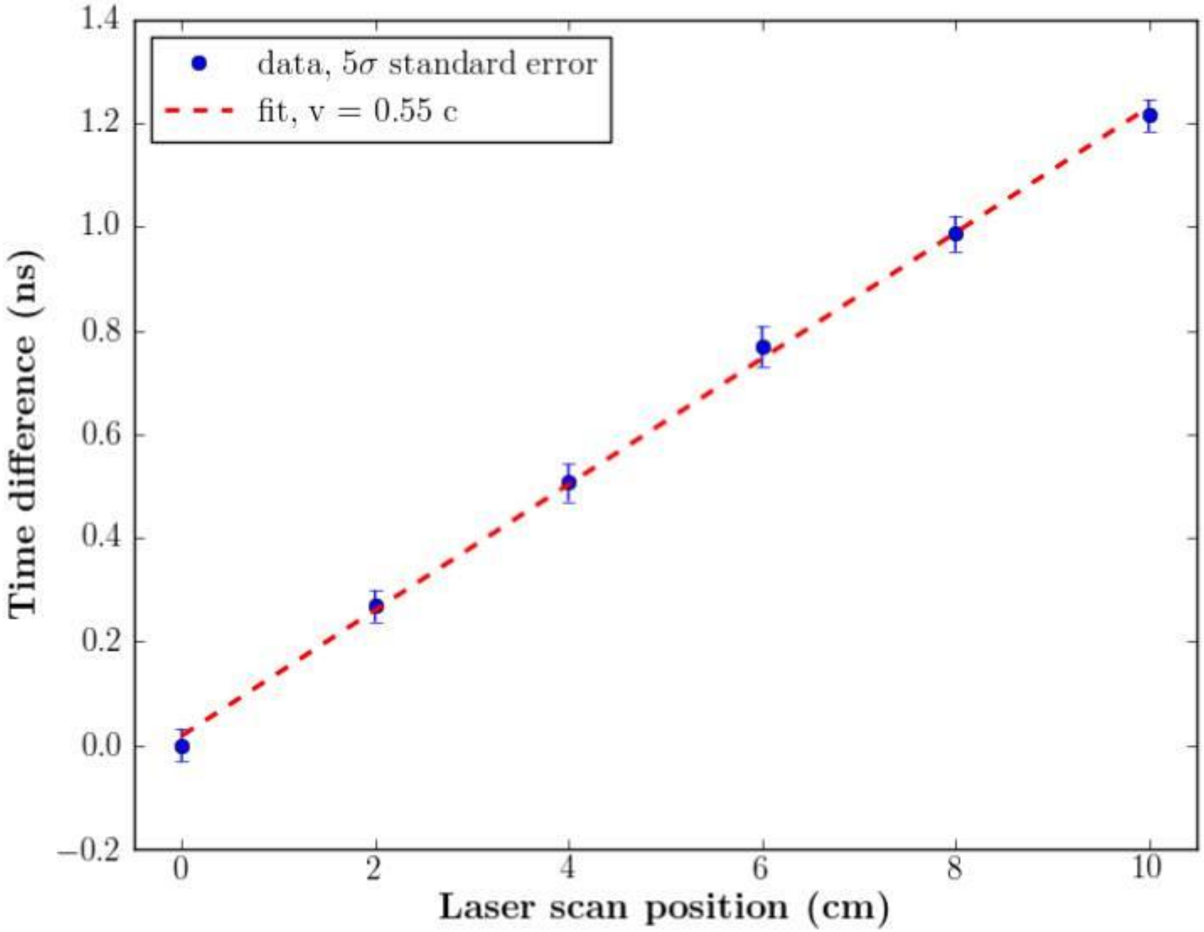


# Demonstrated Position Sensitivity

**Razib's scanning stage**

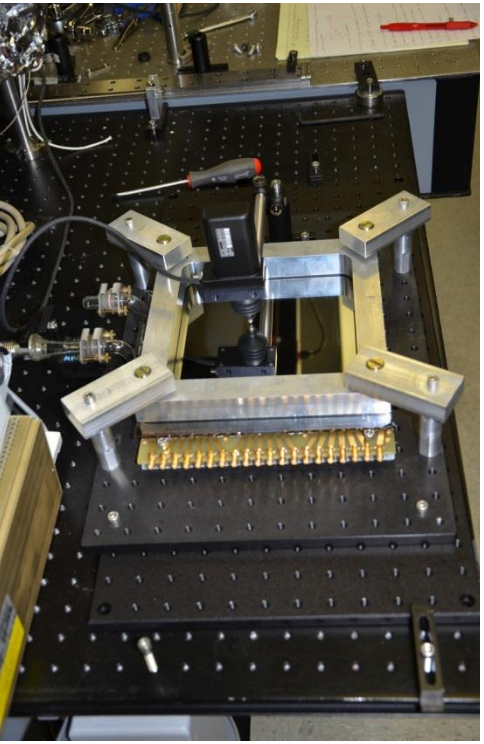


**4-tile `tile-row' of Supermodule**

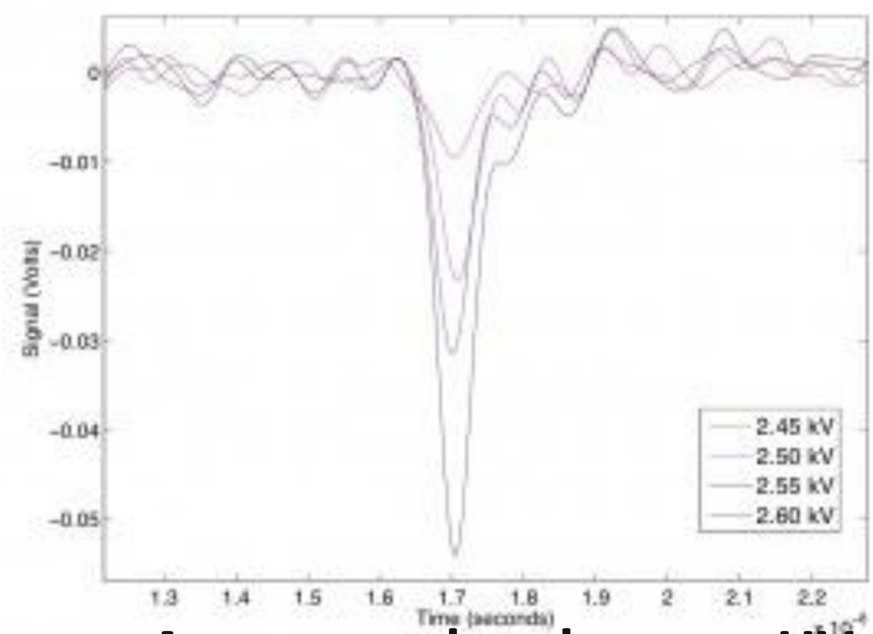



**Time difference of 2 ends vs laser position**

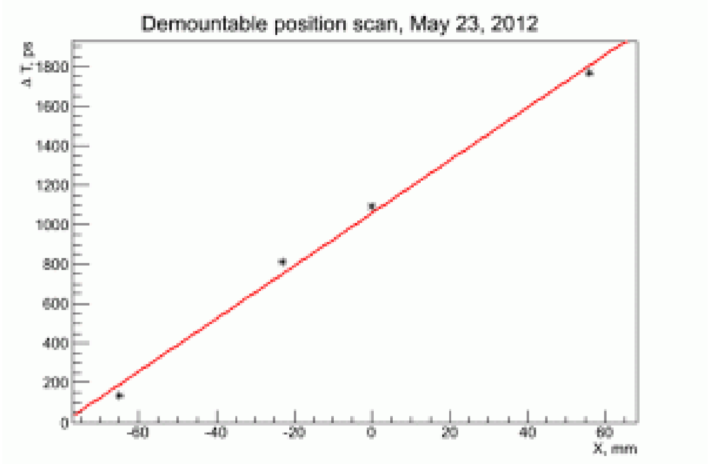
# Demonstration of the Internal ALD HV Divider in the Demountable Tile



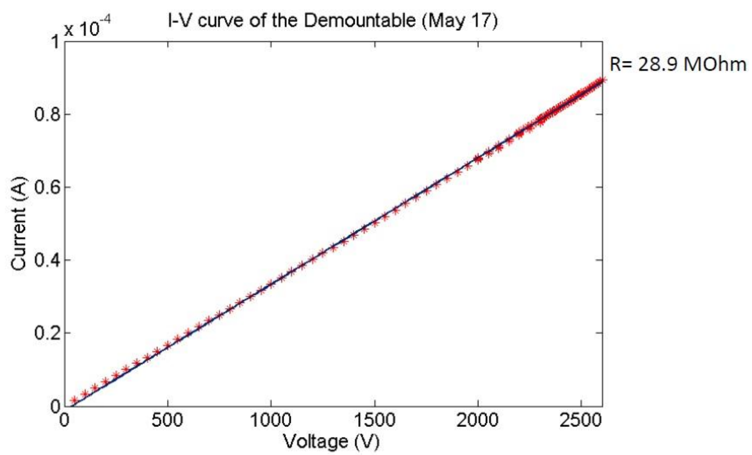
**Demountable at APS**




**Average pulse shape vs HV**

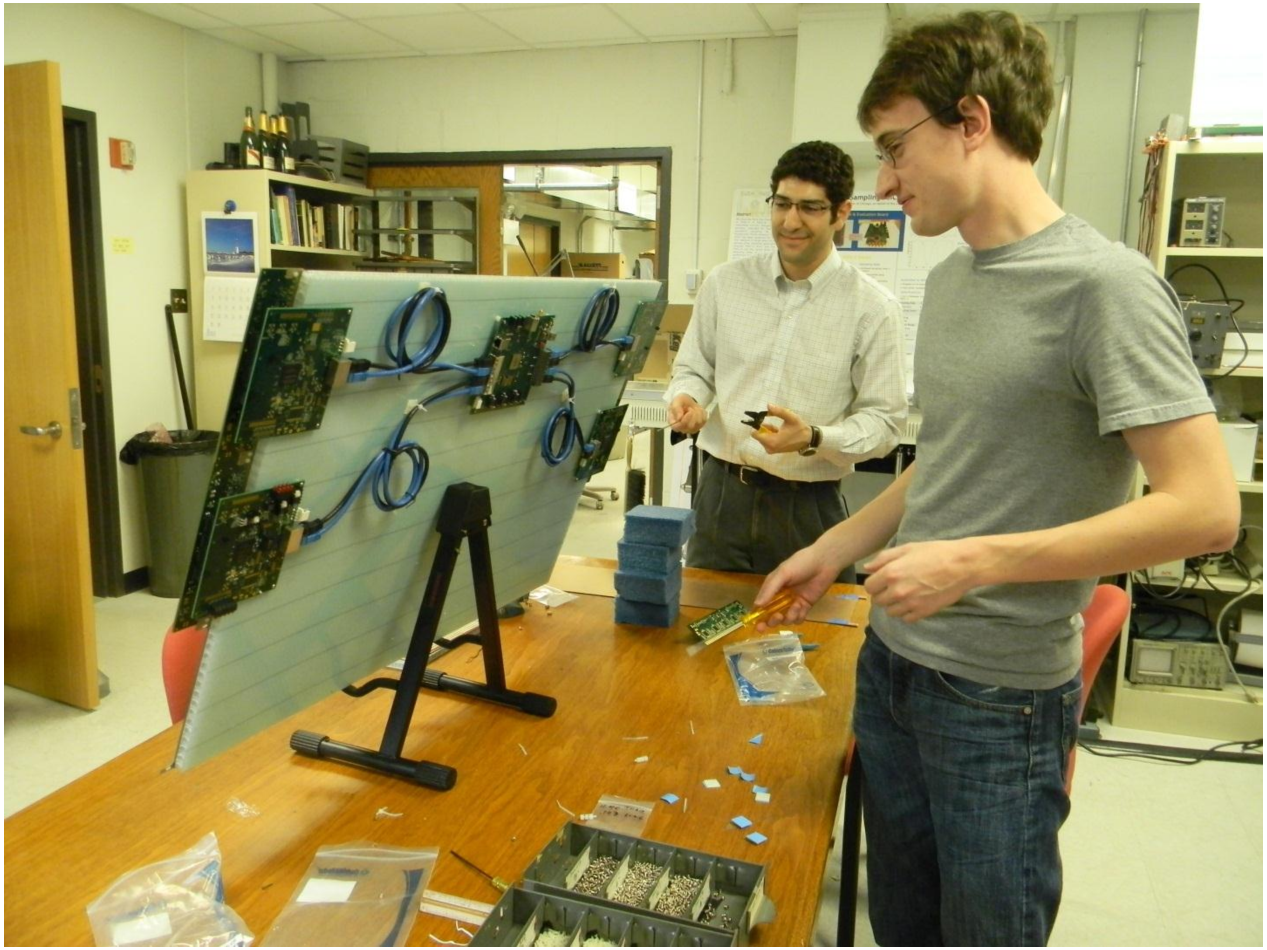



**Scanning the laser: t vs x**




**IV Curve (expected 32 Megs)**

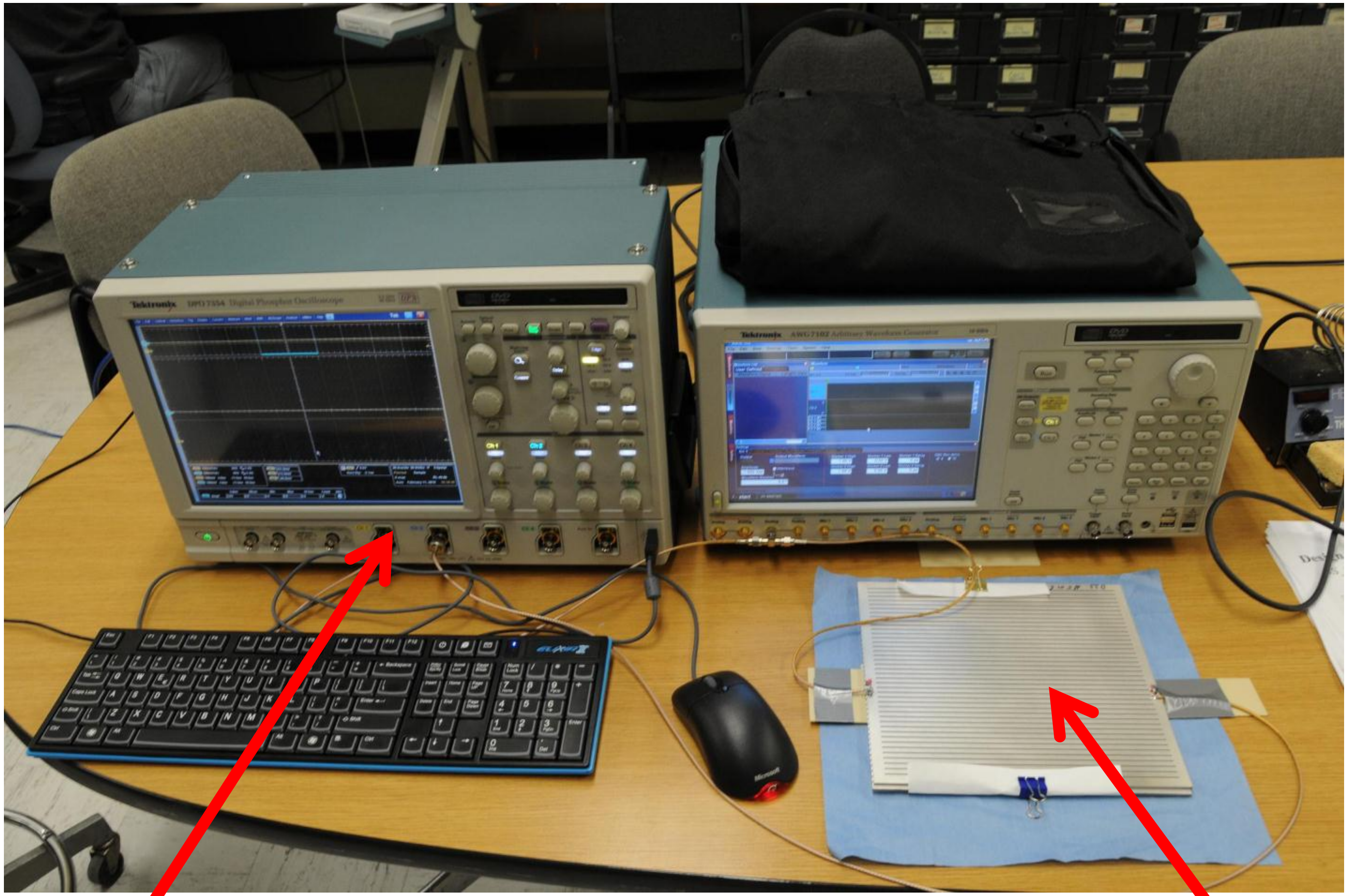
# Developing and Testing the Electronics, Anodes, and DAQ



**Eric Oberla (grad student) and Craig Harabedian (engineer) working on the Tray layout and cabling**

# Anode Testing for ABW, Crosstalk,..

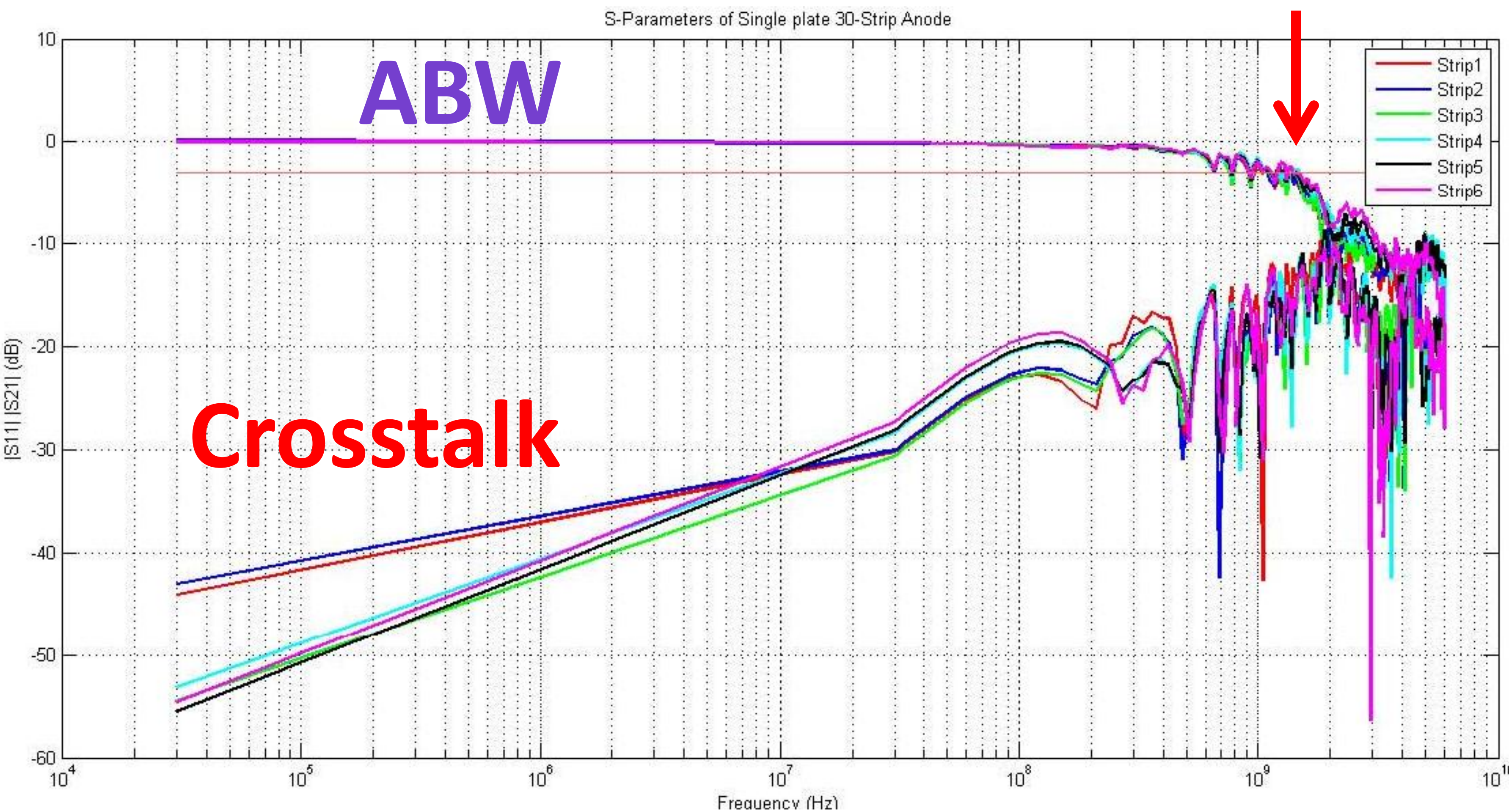
Herve' Grabas, Razib Obaid, Dave McGinnis



Network Analyzer

Tile Anode

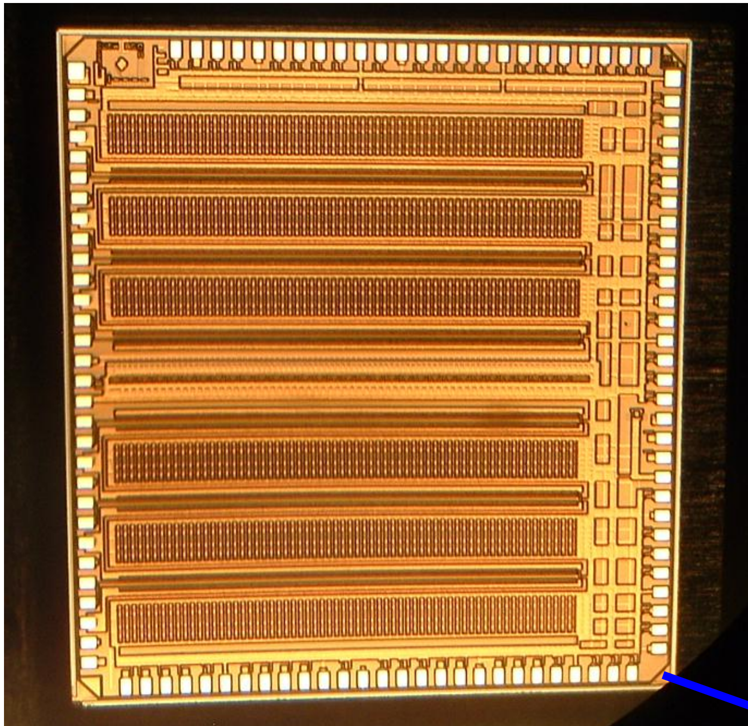
# Anode Testing for ABW, Crosstalk,..

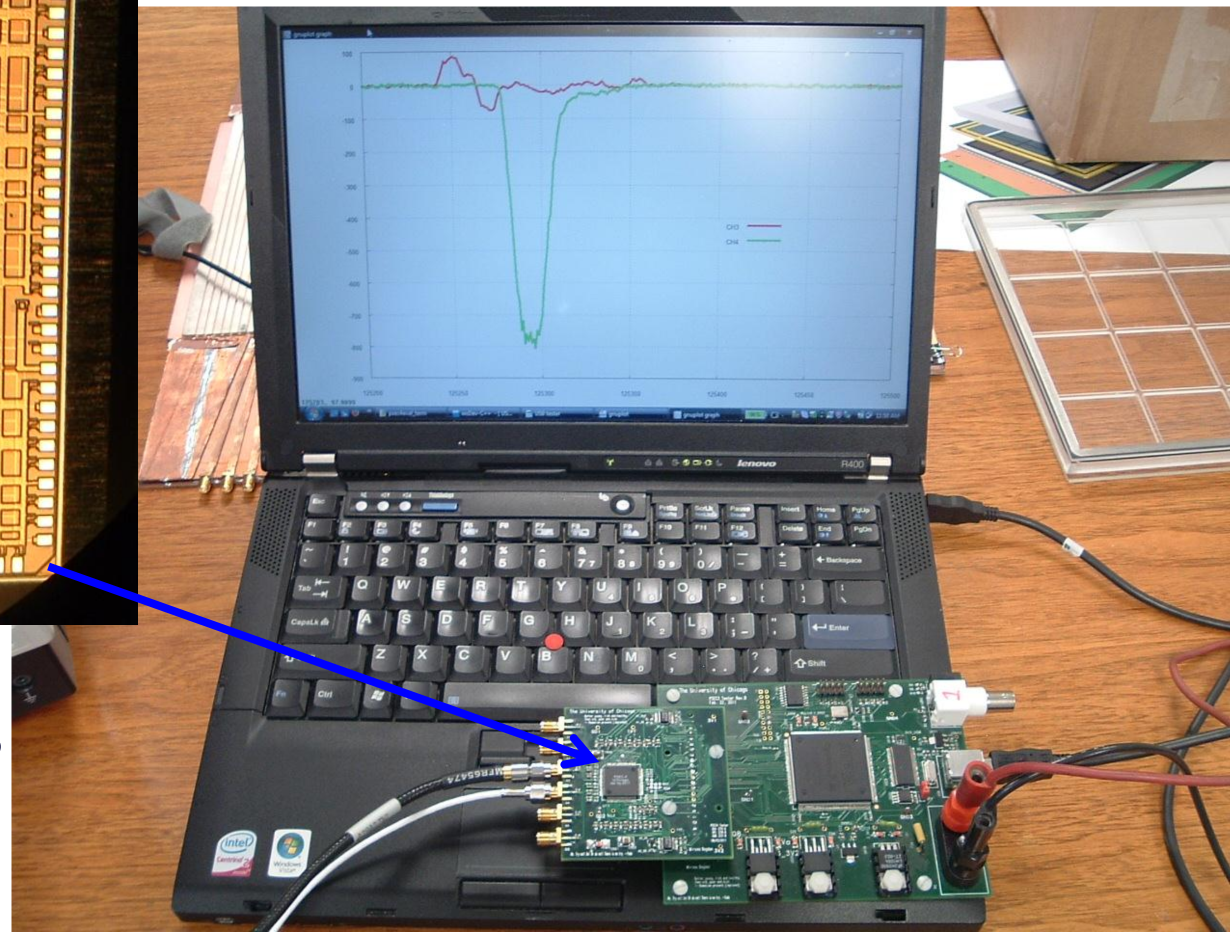



**Razib Obaid**

# PSEC-4 ASIC

Eric Oberla, ANT11

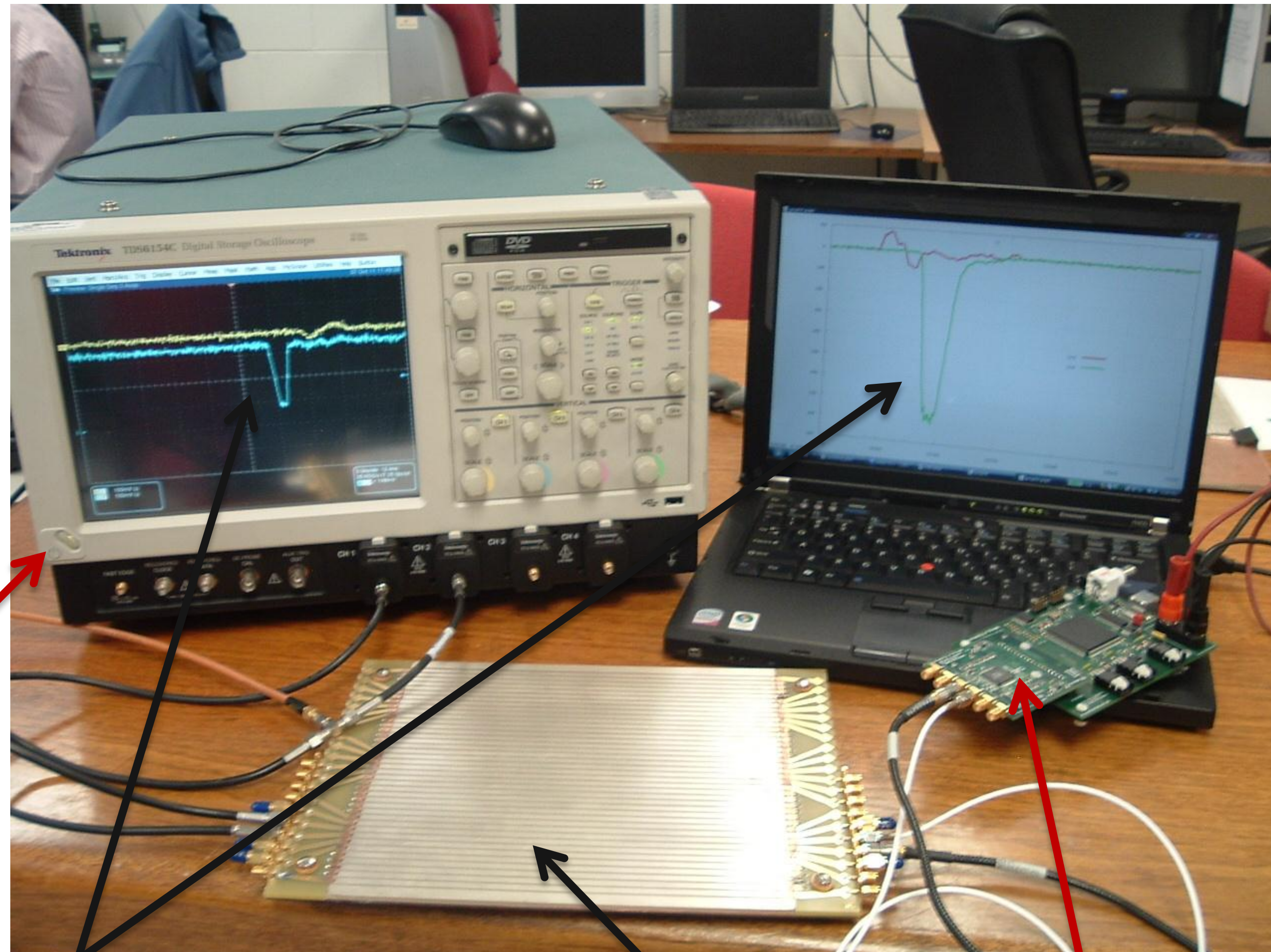




- 6-channel “**oscilloscope on a chip**” (1.6 GHz,10-15 GS/s)
- Evaluation board uses USB 2.0 interface + PC data acquisition software

# 6-channel `Scope-on-a-chip'

Designed by Eric Oberla (UC grad student) working in EDG with EDG tools and engineers (H. Grabas, J.F. Genat)



Real digitized traces from anode

**20 GS/scope**
**4-channels (142K$)**

**17 GS/PSEC-4 chip**
**6-channels ($130 ?!)**

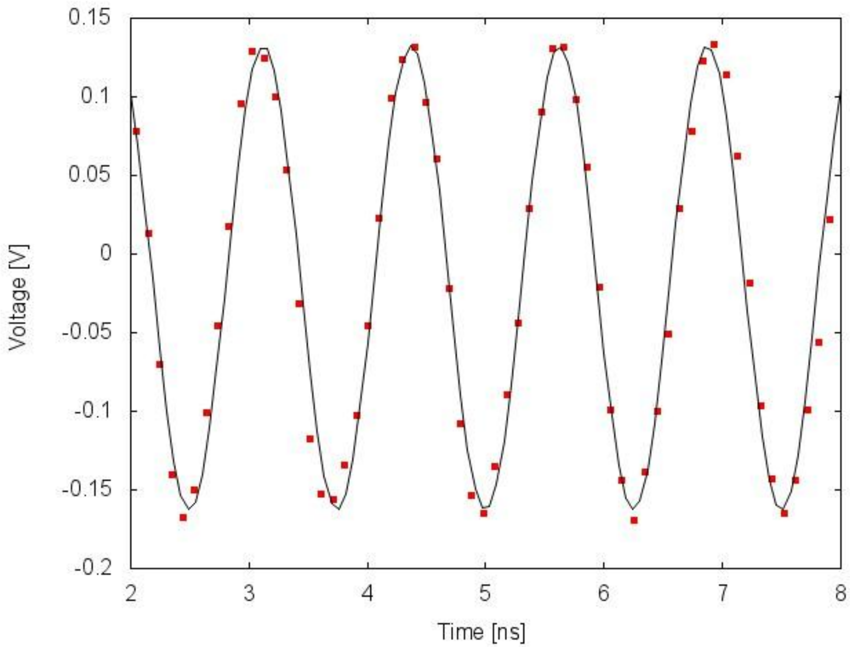
# PSEC-4 Performance

Eric Oberla, ANT11

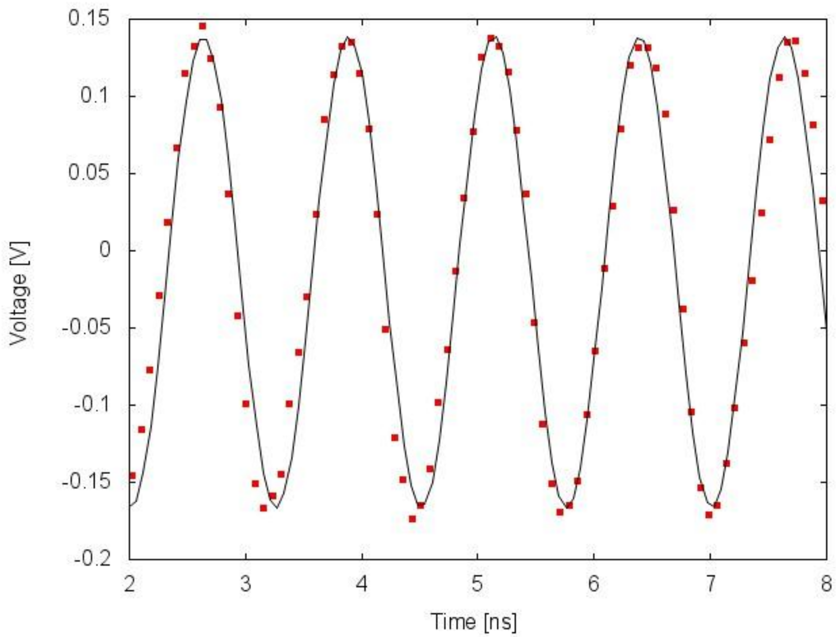
## Digitized Waveforms

**Input: 800MHz, 300 $mV_{pp}$ sine**

**Sampling rate : 10 GSa/s**




**Sampling rate : 13.3 GSa/s**

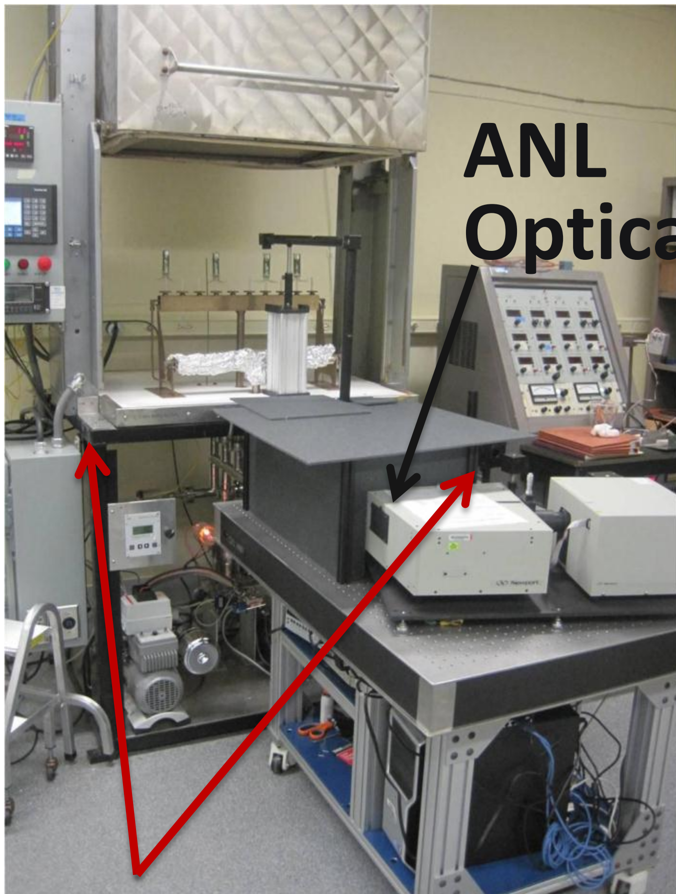



- **Only simple pedestal correction to data**
- **As the sampling rate-to-input frequency ratio decreases, the need for time-base calibration becomes more apparent (depending on necessary timing resolution)**

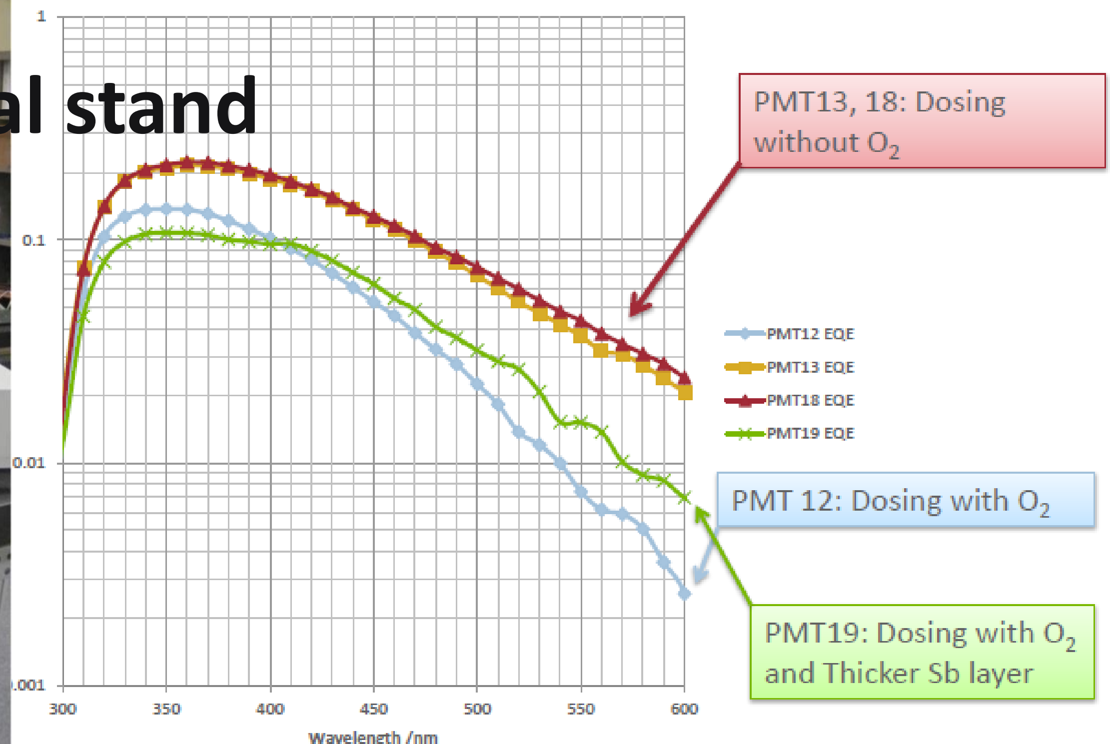
# Photocathodes

## LAPPD goal- 20-25% QE, 8”-square- conv. alkali

## 2 parallel efforts: SSL (knows how), and ANL (learning)



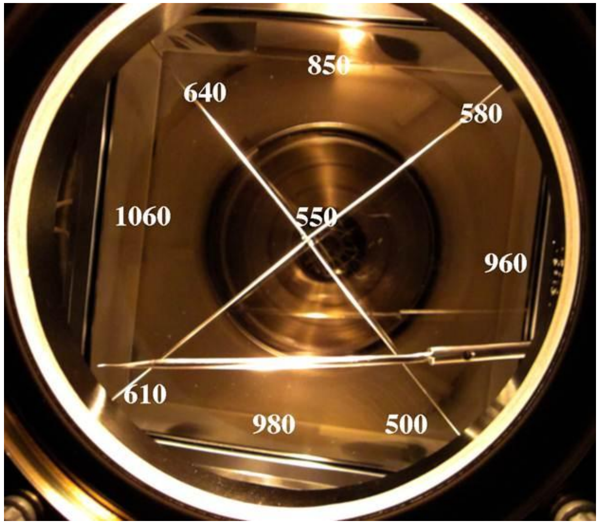

**Burle commercial equipment**



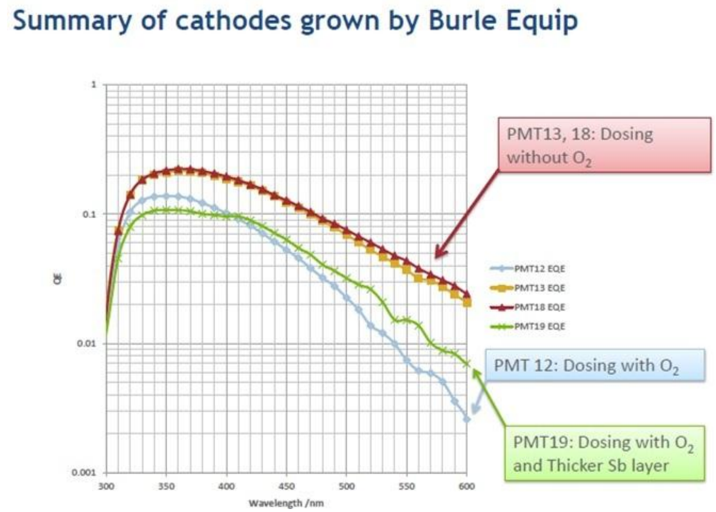

**First cathodes made at ANL**

# Status of PhotoCathodes

Have made >20% 8"PC at SSL; 25% small PC's at ANL, 18% 4" (larger underway)

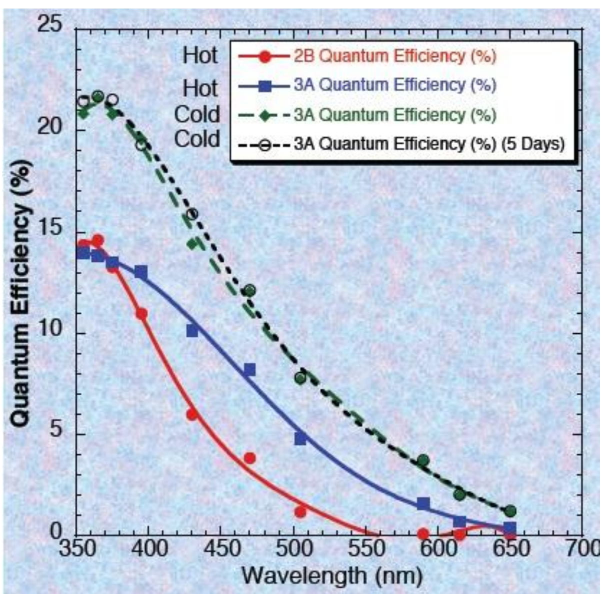



SSL 8" SbNaK cathode

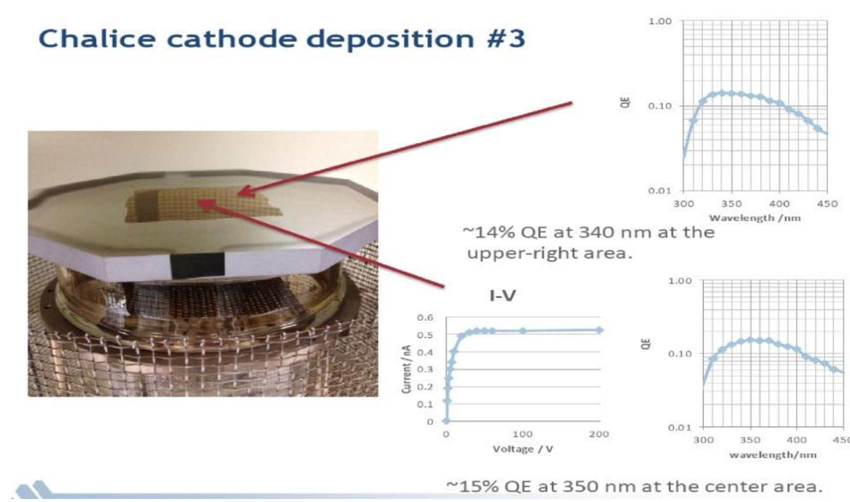



ANL

QE of ANL small SbKCs cathodes




QE of SSL 8" SbNaK cathode

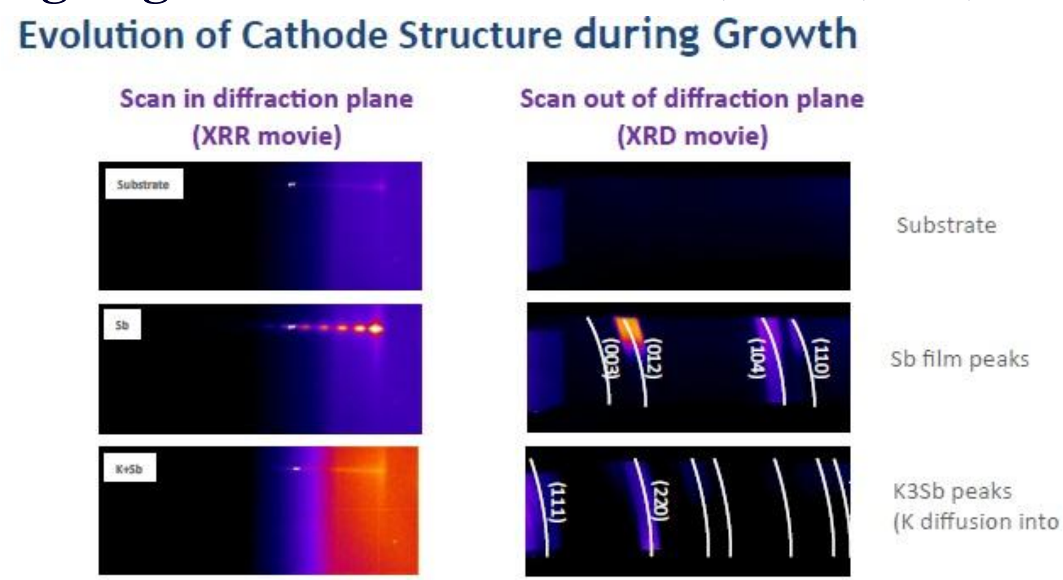



4" cathode: Chalice in Burle oven ANL

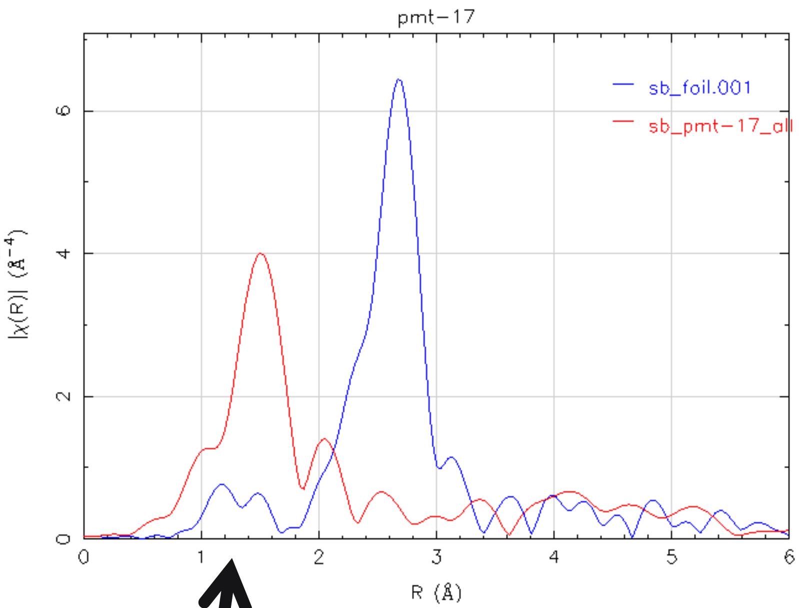
# PhotoCathode Research

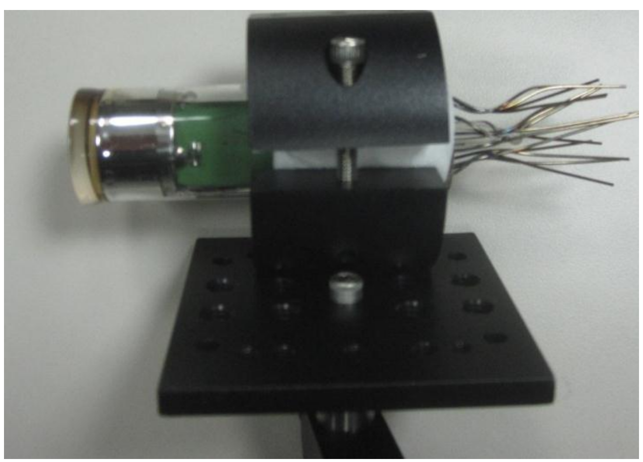
4/10/2013

**Ongoing collaboration with BNL, UCB, UC, ANL for `Theory-Based Photocathodes**




**Xray diffraction while growing**

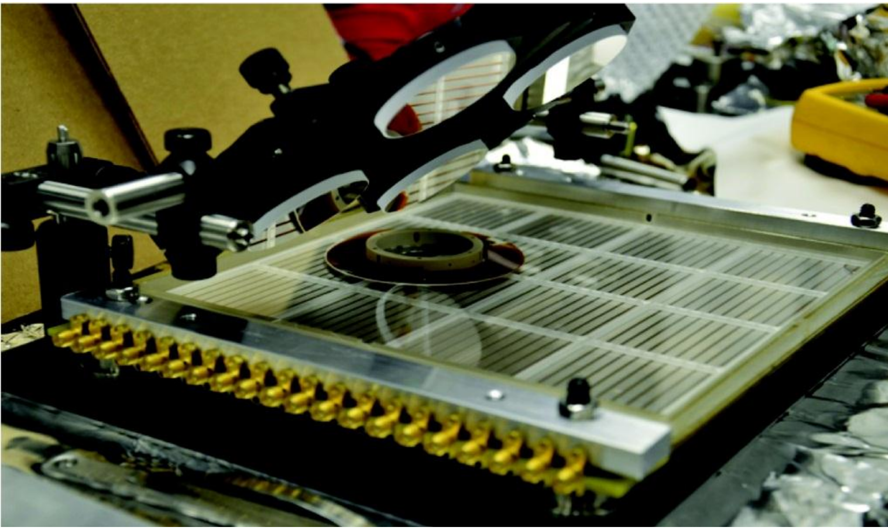


**Razib, Carlos, and Junqi put a PMT into an APS Xray beam (you should ask them any questions…)**

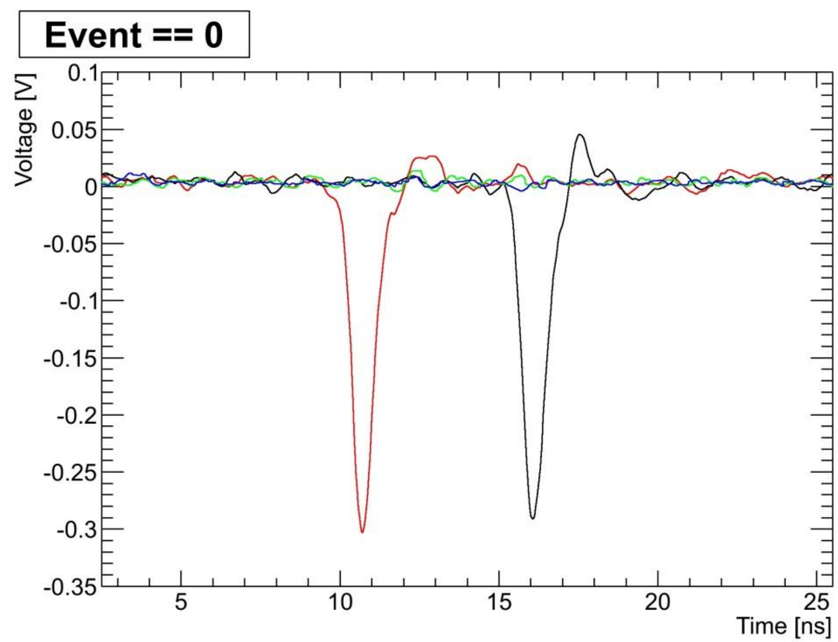
# Conclusions

# 8”-MCP Pair and Strip Anode Work



Laser mirrors and 8” anode for 8” MCP tests

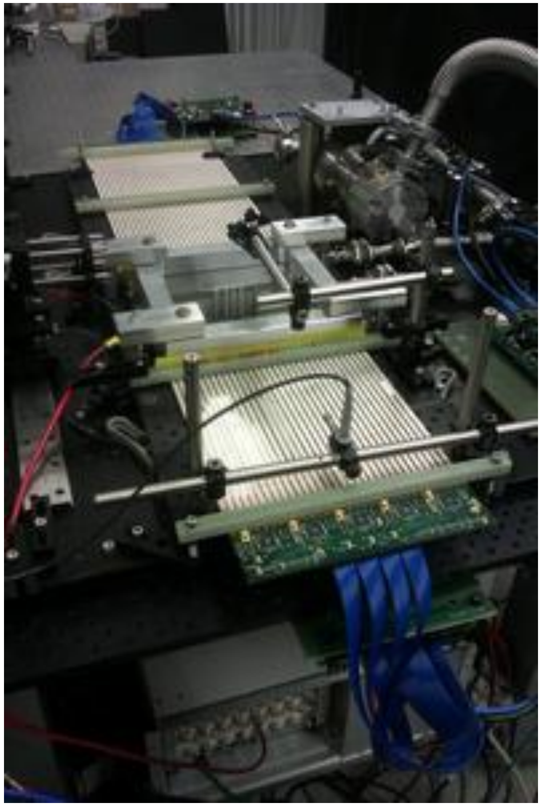
Pulses from one strip of 8” anode with 8” MCP pair



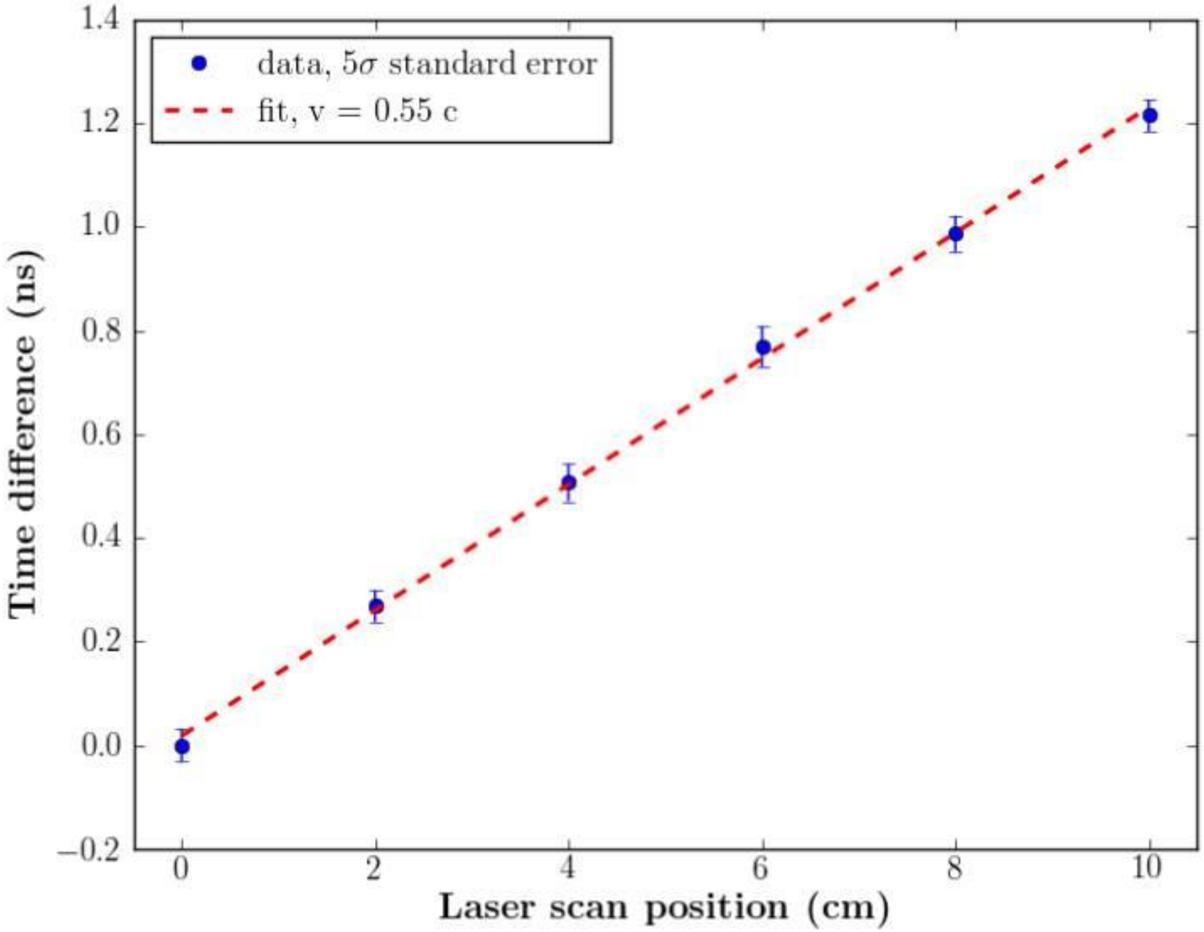

Matt Wetstein, Bernhard Adams, Andrey Elagin, Razib Obaid, Sasha Vostrikov, Bob Wagner

# Demonstrated Position Sensitivity

**Razib's scanning stage**

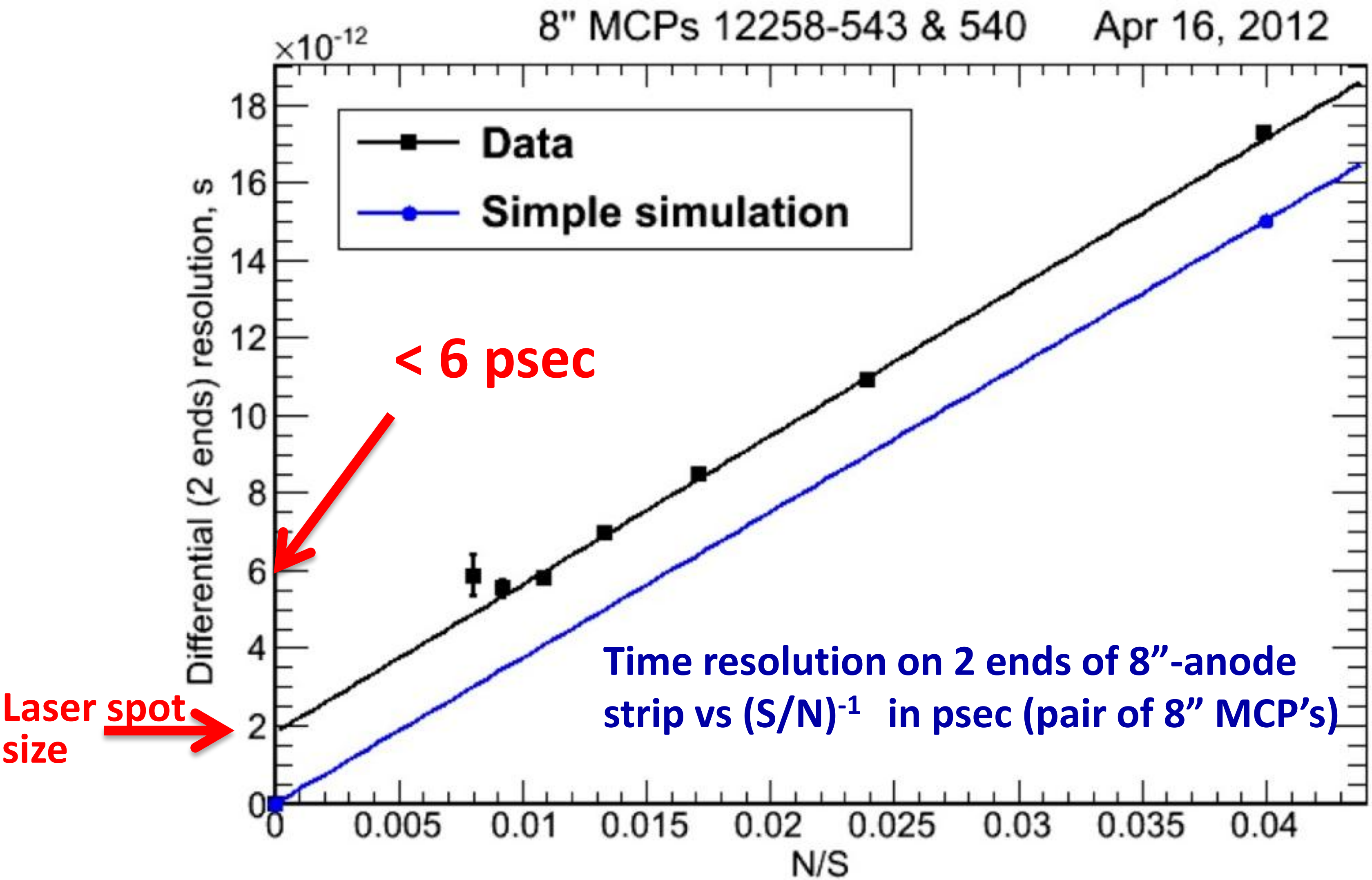


**4-tile `tile-row' of Supermodule**




**Time difference of 2 ends vs laser position**

# Timing res agrees with MC




**N = RMS of the noise; S = signal amplitude**

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

# Going Another Order-of-Magnitude

Stefan Ritt slide, doctored

(agrees with JF MC)

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

•Assumes zero aperture jitter

| $U$ | $\Delta u$ | $f_s$ | $f_{3db}$ | $\Delta t$ |
|---|---|---|---|---|
| 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 |
| 1.0 | 0.7 | 17 | 1.6 | |

For 100 fsec →

Achieved by LAPPD

100 Femtosec (!)

Subject of a 2013 SBIR with Innosys, SLC

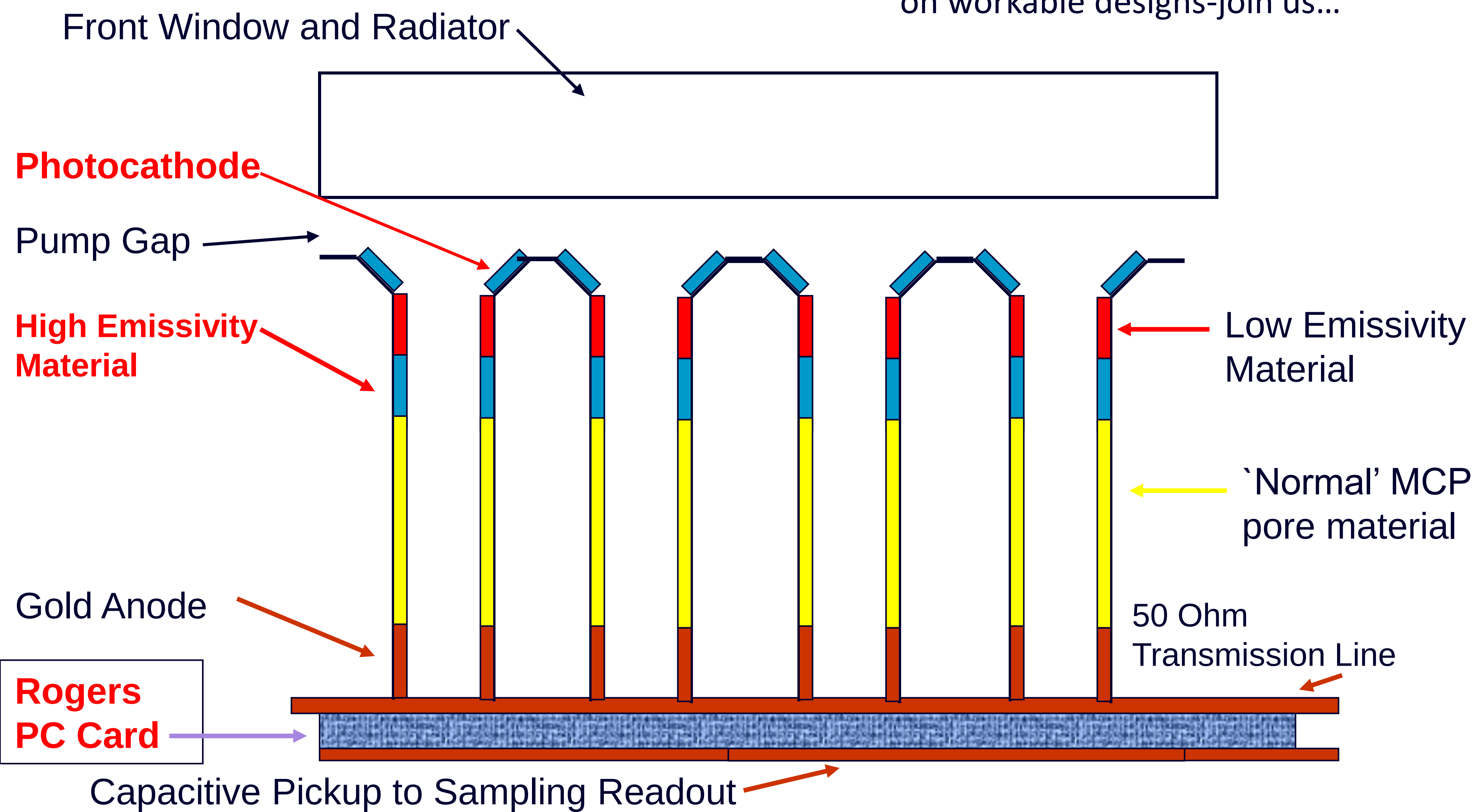
Differential TOF: 1.5m path

| $\Delta t$: | $\gamma$ | e | $\pi$ | K | p |
|---|---|---|---|---|---|
| (ps) | 0 | $10^{-6}$ | 0.13 | 1.6 | 6.25 |

# What’s the limit? (2009 cartoon)

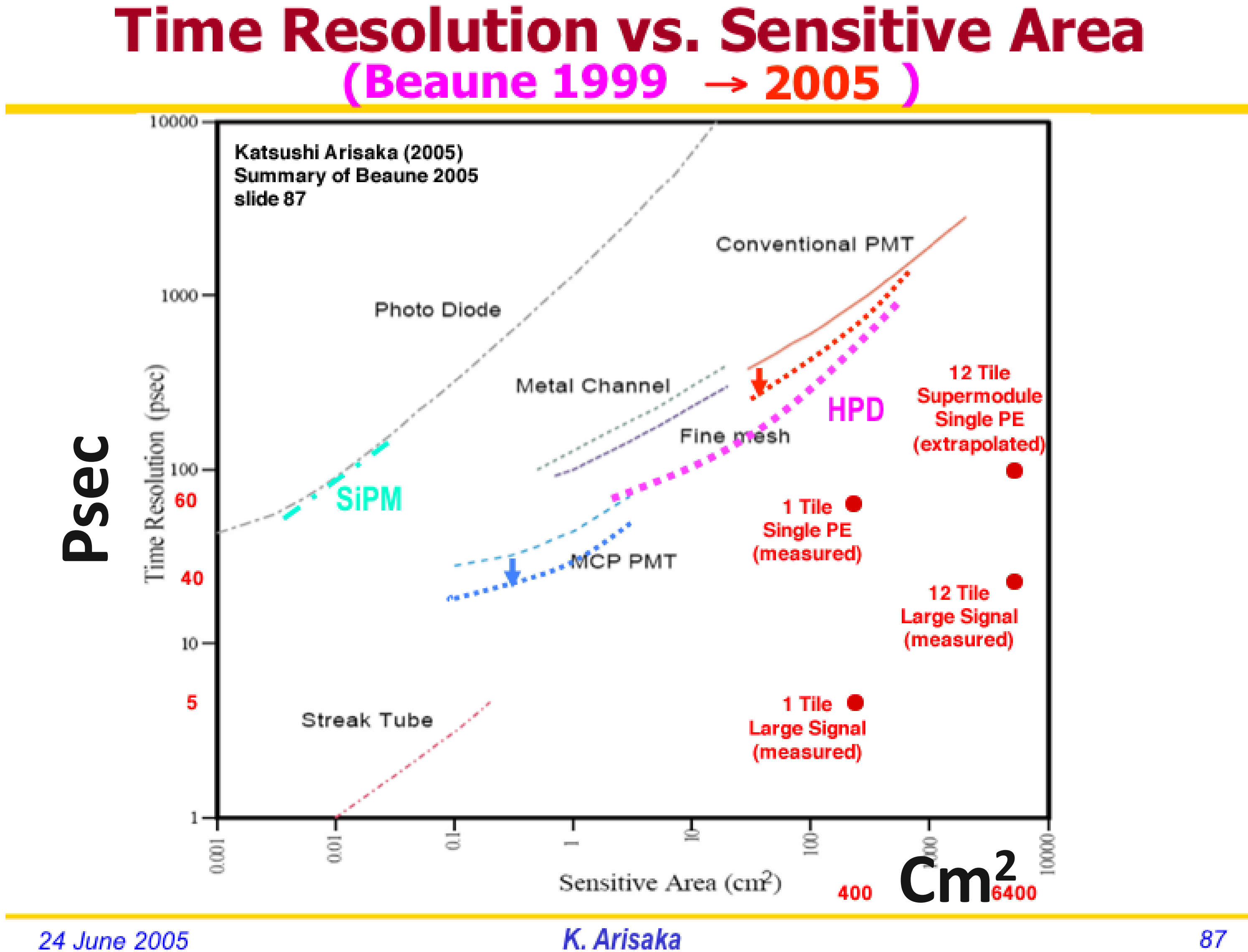
**Funnel pore with reflection cathode, dynode rings, ceramic anode,…**

N.B.- this is a `cartoon’- working on workable designs-join us…



# Comparison with existing detectors

**K. Arisaka; UCLA**



# More Information on LAPPD:

- **Main Page: http://psec.uchicago.edu (has the links to the Library and Blogs)**
- **Library: Workshops, Godparent Reviews, Image Library, Document Library, Links to MCP, Photocathode, Materials Literature, etc.;**
- **Blog: Our log-book- open to all (say yes to certificate Cerberus, etc.)- can keep track of us (at least several companies do);**

# The End