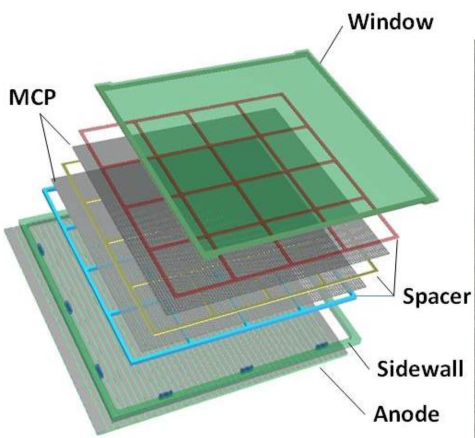
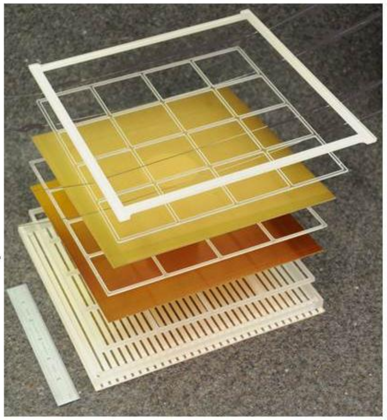
The Development of Large-Area Pico-second Photodetectors

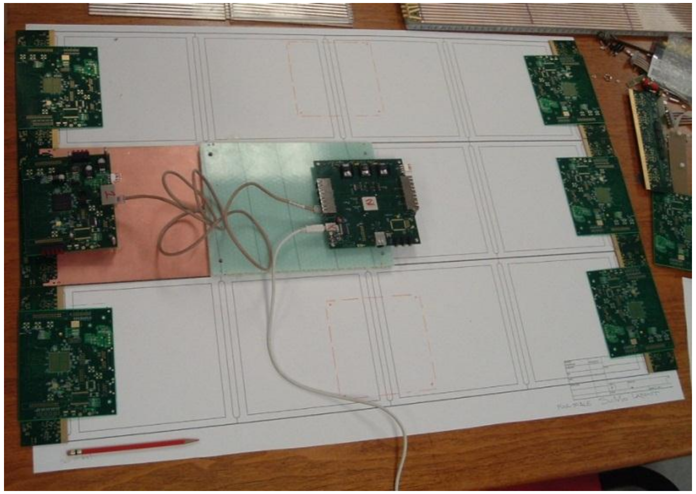
Henry Frisch, Enrico Fermi Institute, Univ. of Chicago
For the LAPPD Collaboration

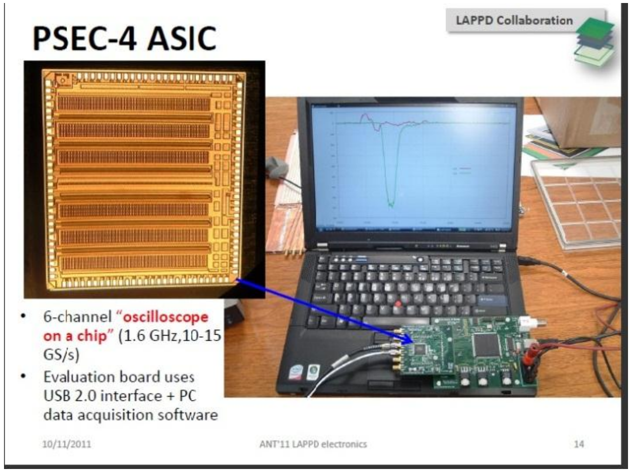


Design Drawing - September 2010



Actual Glass Parts - April 2012





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

Outline

- Motivation(s) and Applications
- LAPPD
- Micro Channel Plates
- Hermetic Packaging, signal and HV circuits
- Electronics and DAQ (plug-and-play)
- Photocathodes
- Results
- Opportunities and Challenges

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

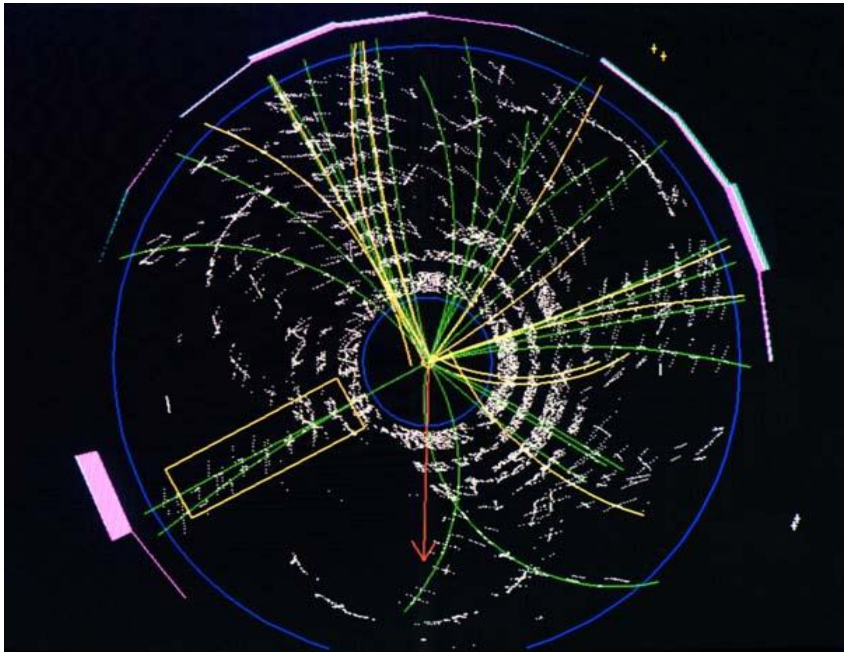
Motivation

Colliders:

Need: 1) identify the quark content of charged particles

2) vertex photons

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

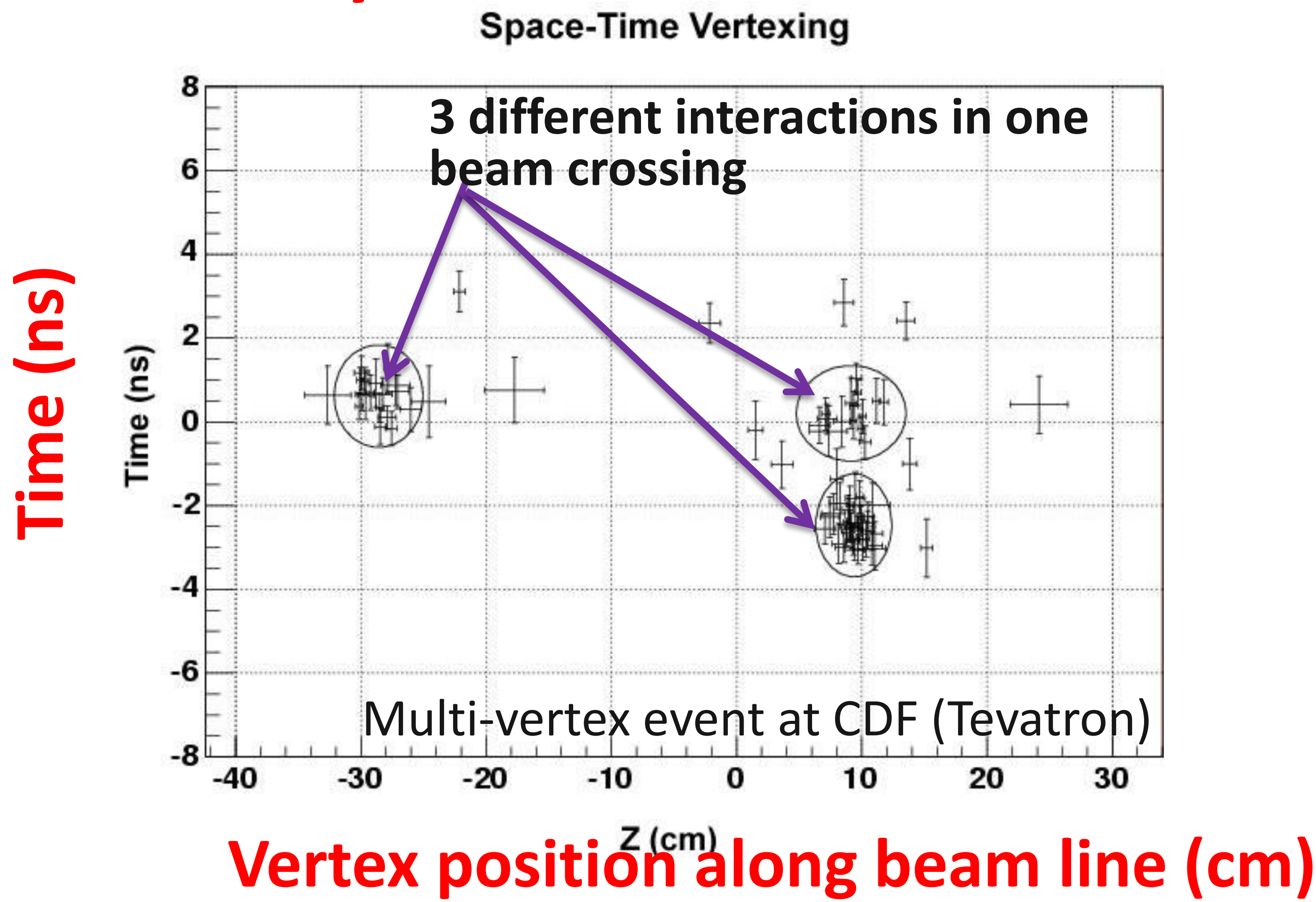


Approach: measure the difference in arrival times of photons and charged particles which arrive a few psec later. Light source is Cherenkov light in the window/radiator.

Benefit: Discoveries in signatures not possible now

(Note: conventional TOF resolution is 100 psec -factor of 100 worse than our goal= 1" is 100 psec, so need a small scale-length).

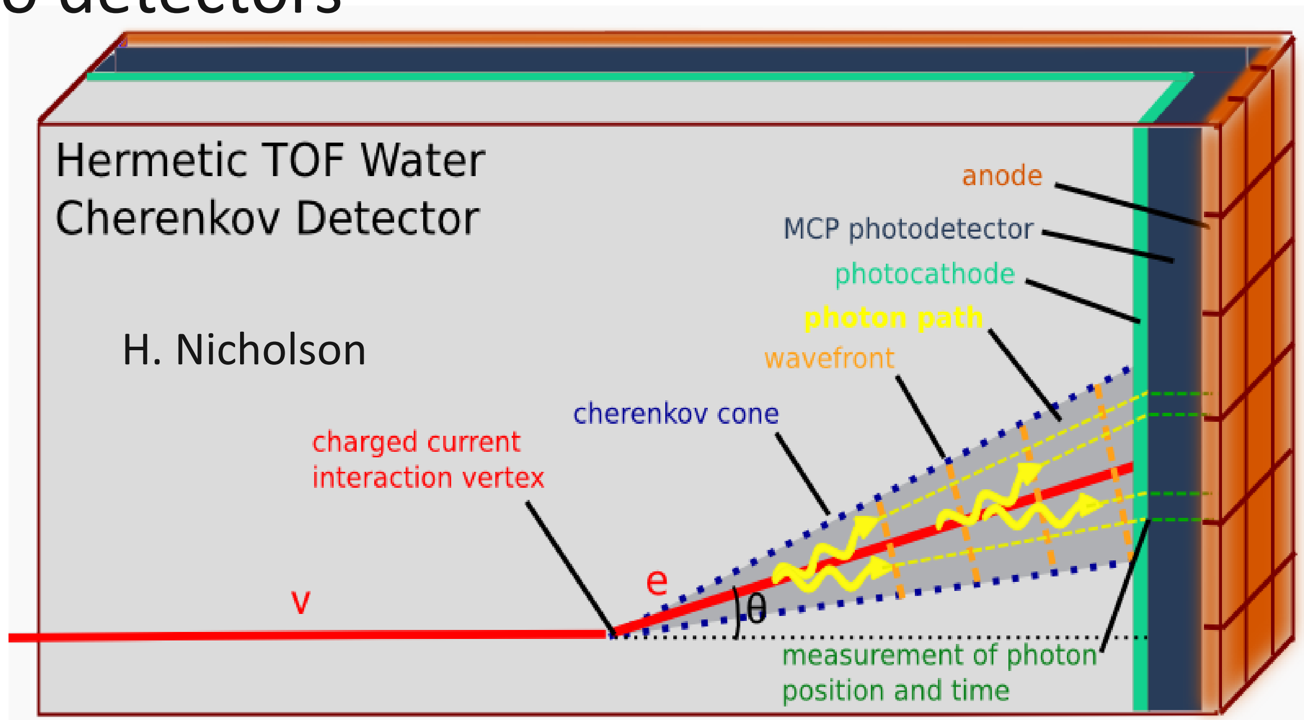
Major problem coming up at LHC- vertexing at high luminosity (e.g. Joe Incandela's UC seminar on CMS)



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.

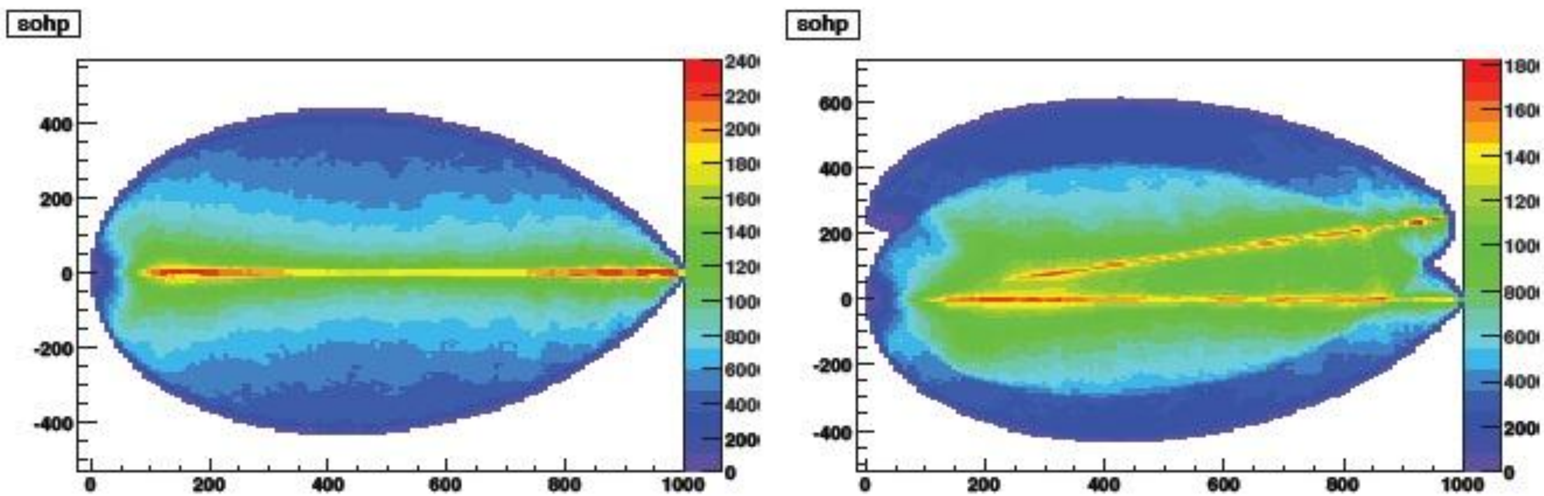
Competition- large PMT's, Liquid Argon

Can we build a photon TPC?

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

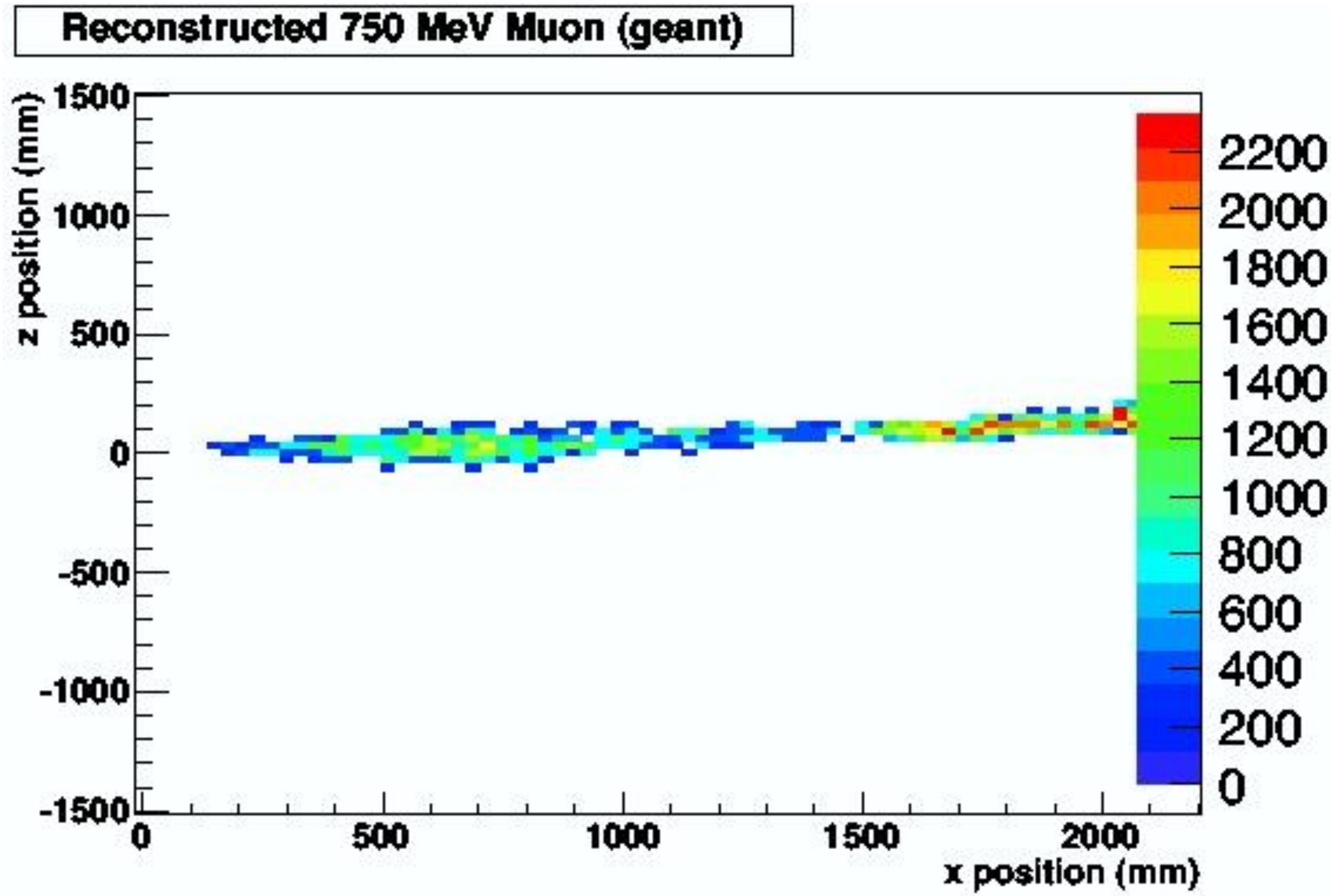


Single track

Two tracks displaced from a common vertex

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

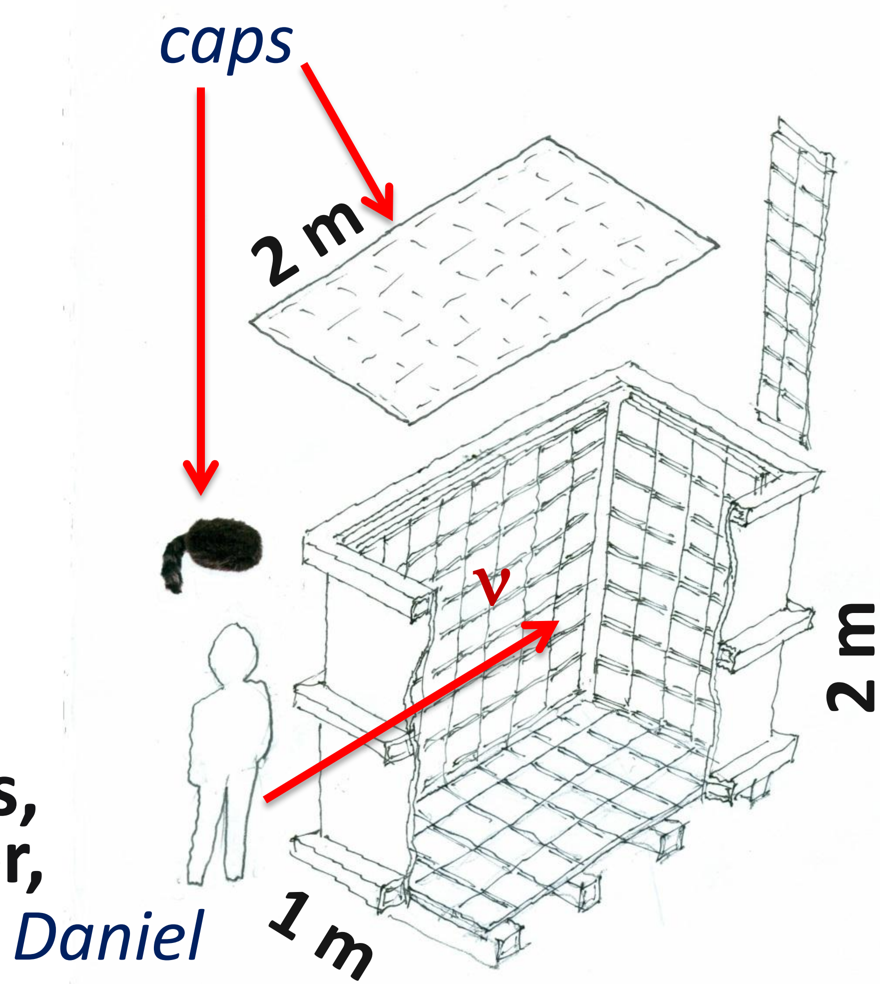
Works on GEANT events too



Matt Wetstein; ANL&UC

Daniel Boone

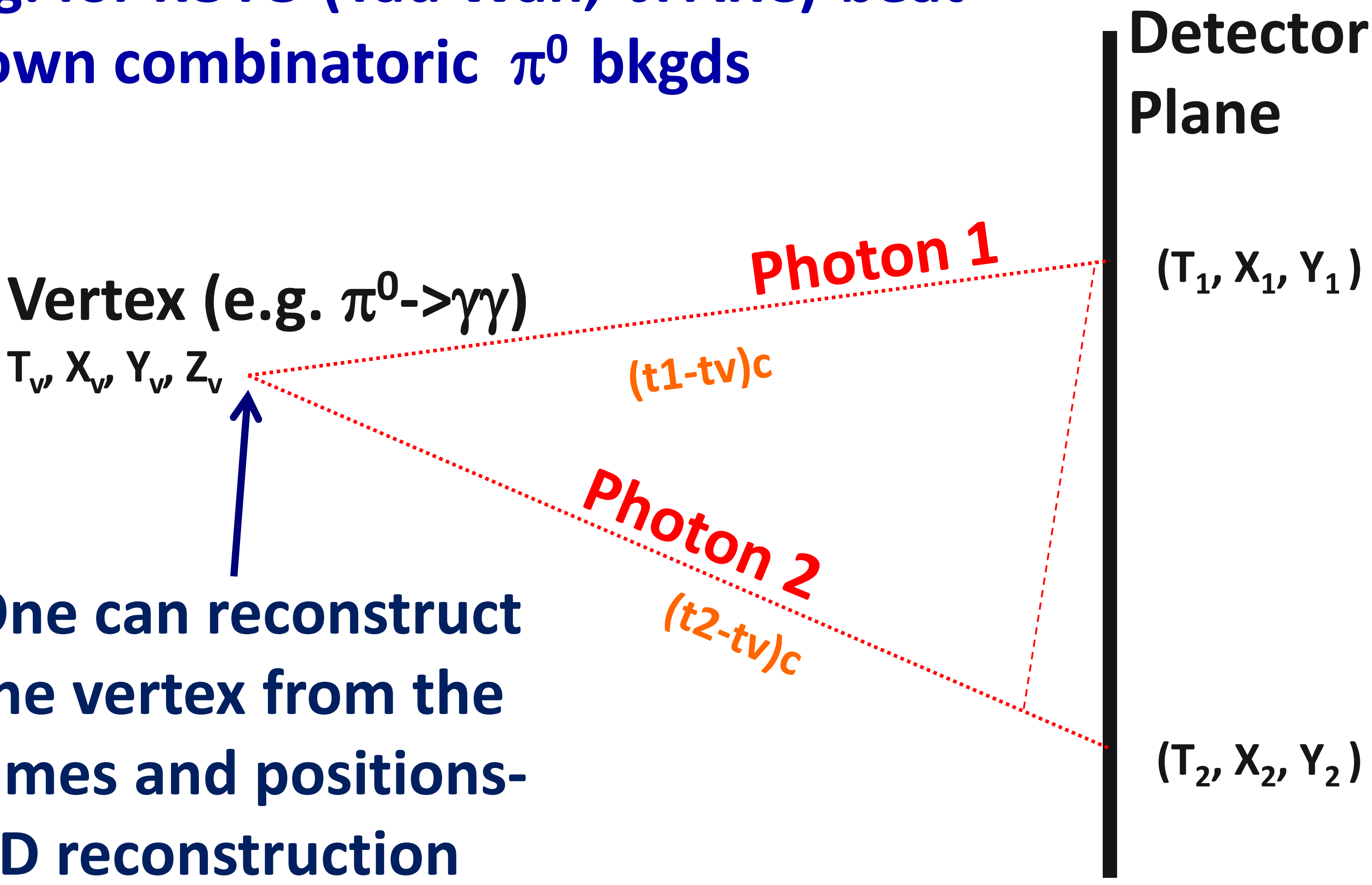
- Proposal (LDRD) to build a little proto-type to test photon-TPC ideas and as a simulation testbed
- `Book-on-end' geometry- long, higher than wide
- Close to 100% coverage so bigger Fid/Tot volume
- Δx, Δy << 1 cm
- Δt < 100 psec
- Magnetic field in volume
- Idea: to reconstruct vertices, tracks, events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



Also ANNIE- Bob Svoboda

Rare Kaon Decays- backgd rejection by reconstructing π^0 vertex space point:

E.g. for KOTO (Yau Wah, JPARC)-beat down combinatoric π^0 bkgds



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

Good timing alone doesn't do it-

The ALICE TPC: Drift electrons onto wires that measure *where* and *when* for *each* electron.

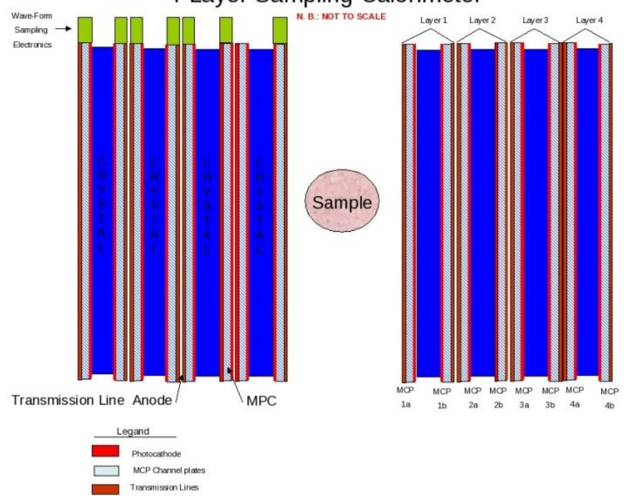
Good time resolution would buy nothing if one integrated over a whole (blue) TPC sector- ie didn't correlate *when* and *where*

Correlated time and space points allow 3D reconstructions

Medical Imaging (PET)

Need: 1) much lower dose rate
2) faster through-put
3) real-time feedback (therapy as well as diagnosis)

4-Layer Sampling Calorimeter

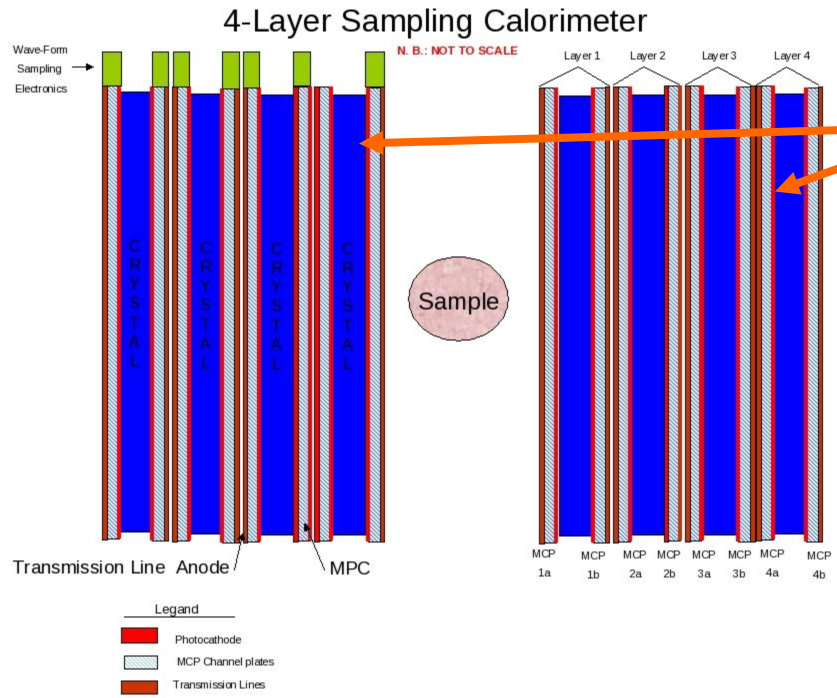


Approach: precise Time-of-Flight, sampling, real-time adaptive algorithms in local distributed computing, use much larger fraction of events and information

Benefit: higher resolution, lower dose to patient, less tracer production and distribution, new hadron therapy capabilities

Competition: Silicon PMT's

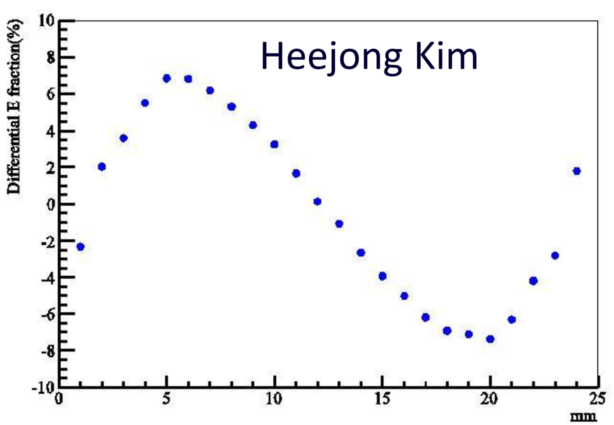
Sampling Calorimetry in PET?



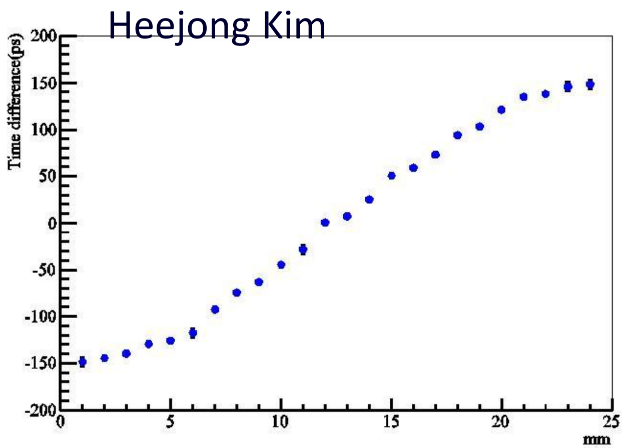
Can we solve the depth-of-interaction problem and also use cheaper faster radiators?

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

Simulations by Heejong Kim (Chicago)



Depth in crystal by time-difference

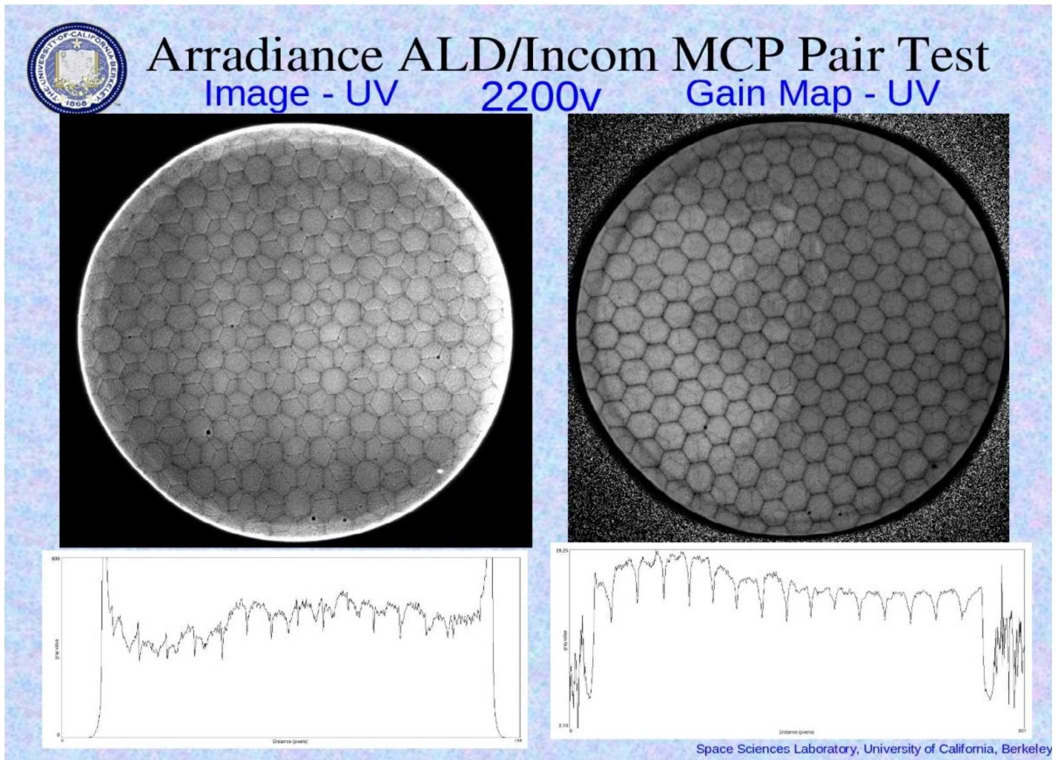


Depth in crystal by energy-asymmetry

An Energy-Flow MCP-based Calorimeter?

Pores saturate => output is proportional to number of pores.?Transmission line readout gives a cheap way to sample the whole plane with pulse height and time- get energy flow.

Oswald Siegmund, Jason McPhate, Sharon Jelinsky, SSL (UCB)



Note- at high gain the boundaries of the multi's go away

Electron pattern (not a picture of the plate!)- SSL test, Incom substrate, Arradiance ALD. Note you can see the multi's in both plates => ~50 micron resolution

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

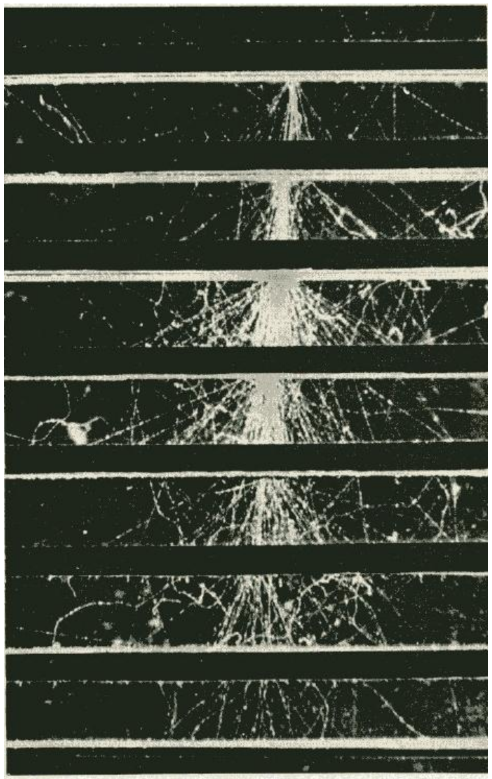
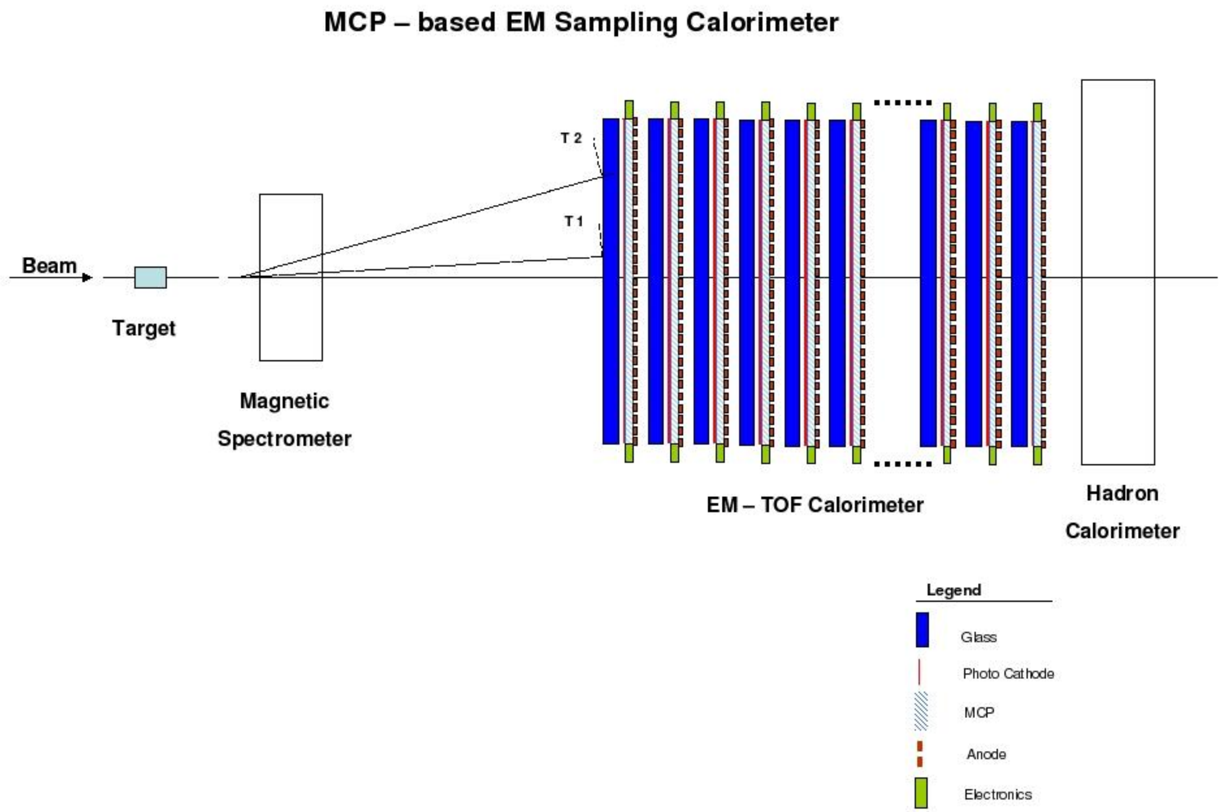


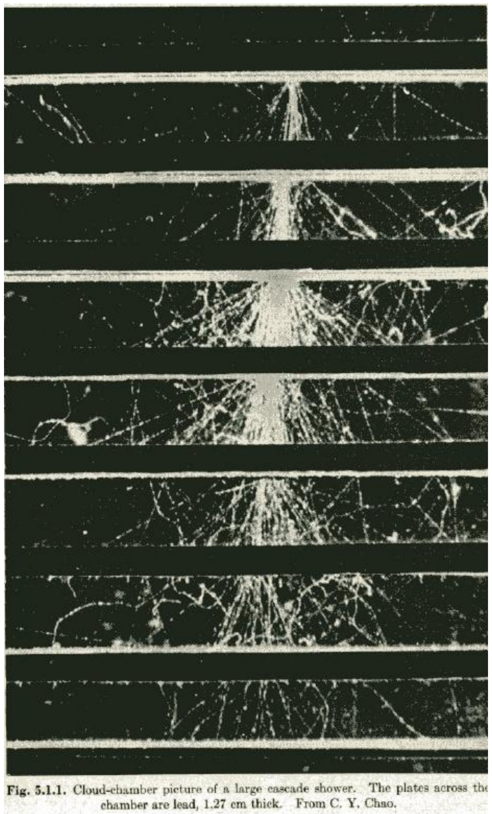
Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.

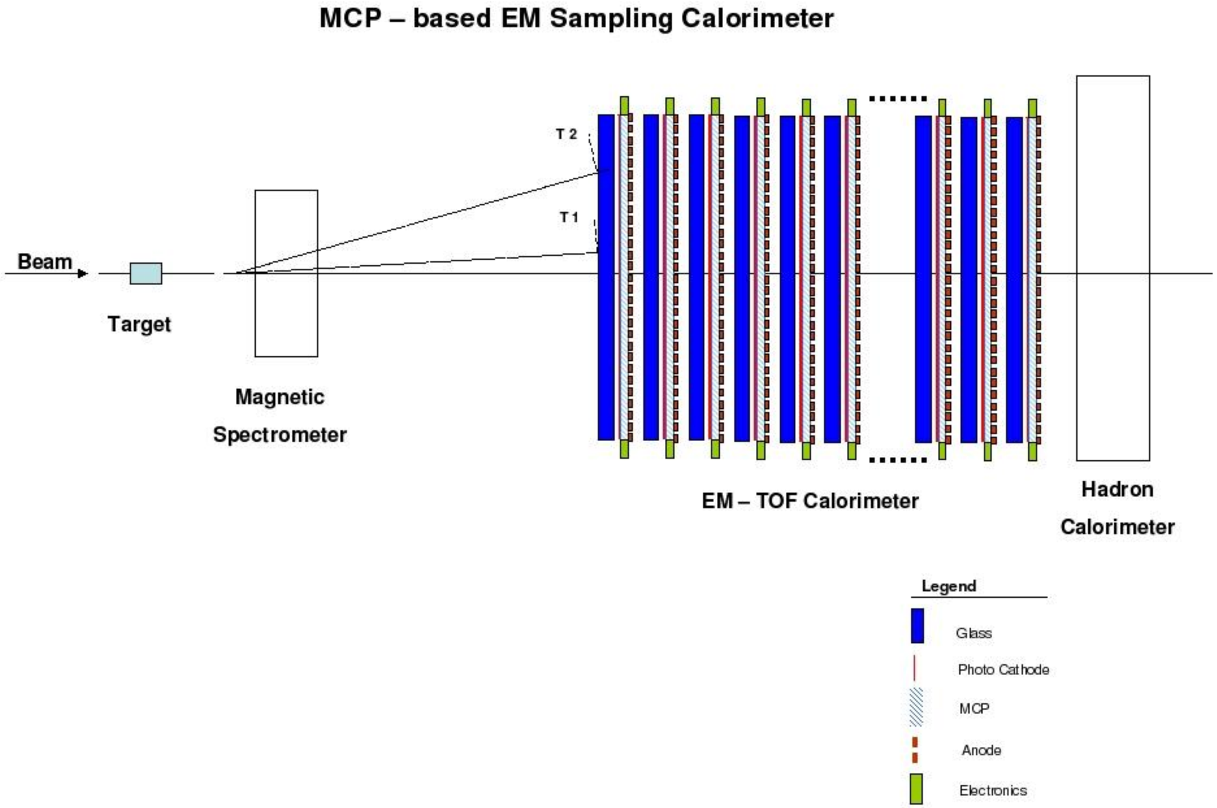


A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

Cherenkov-sensitive Sampling Quasi- Digital Calorimeters





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

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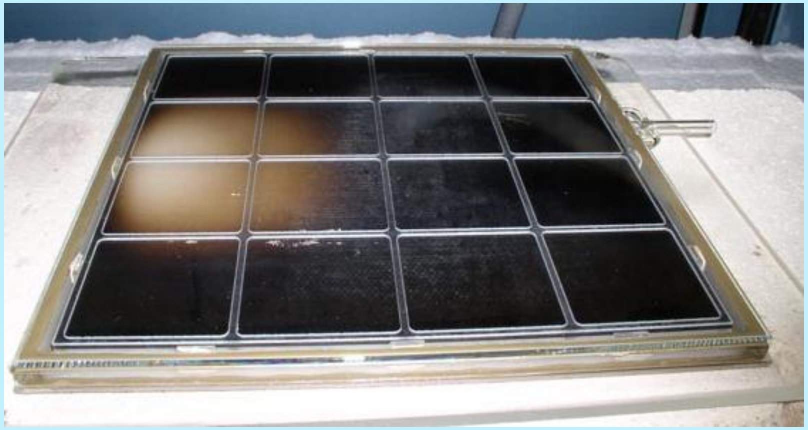
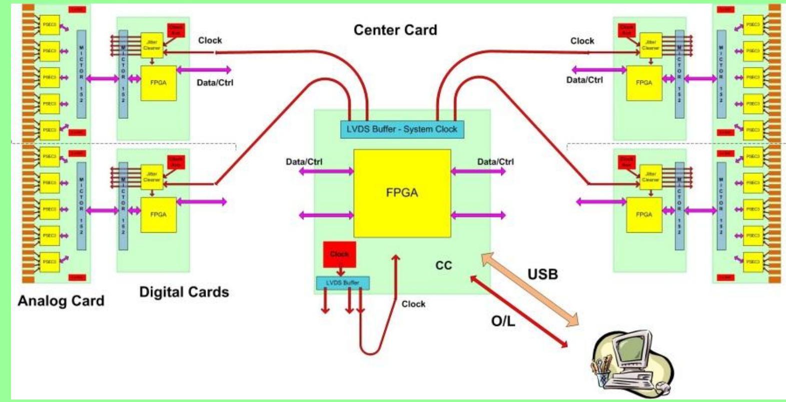
LAPPD

The 4 `Divisions' of glass LAPPD

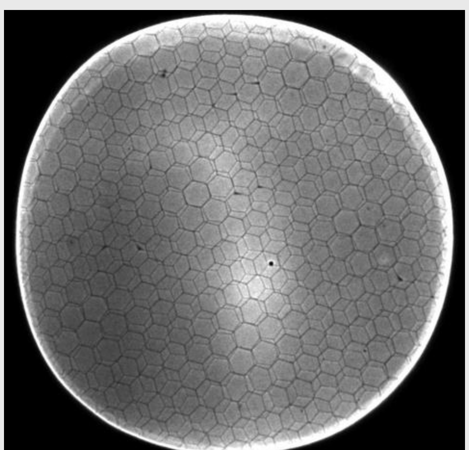
Hermetic Packaging



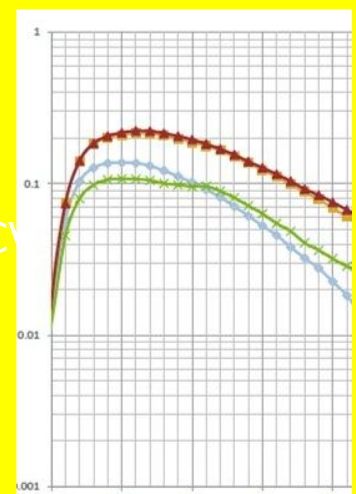
Electronics/Integration



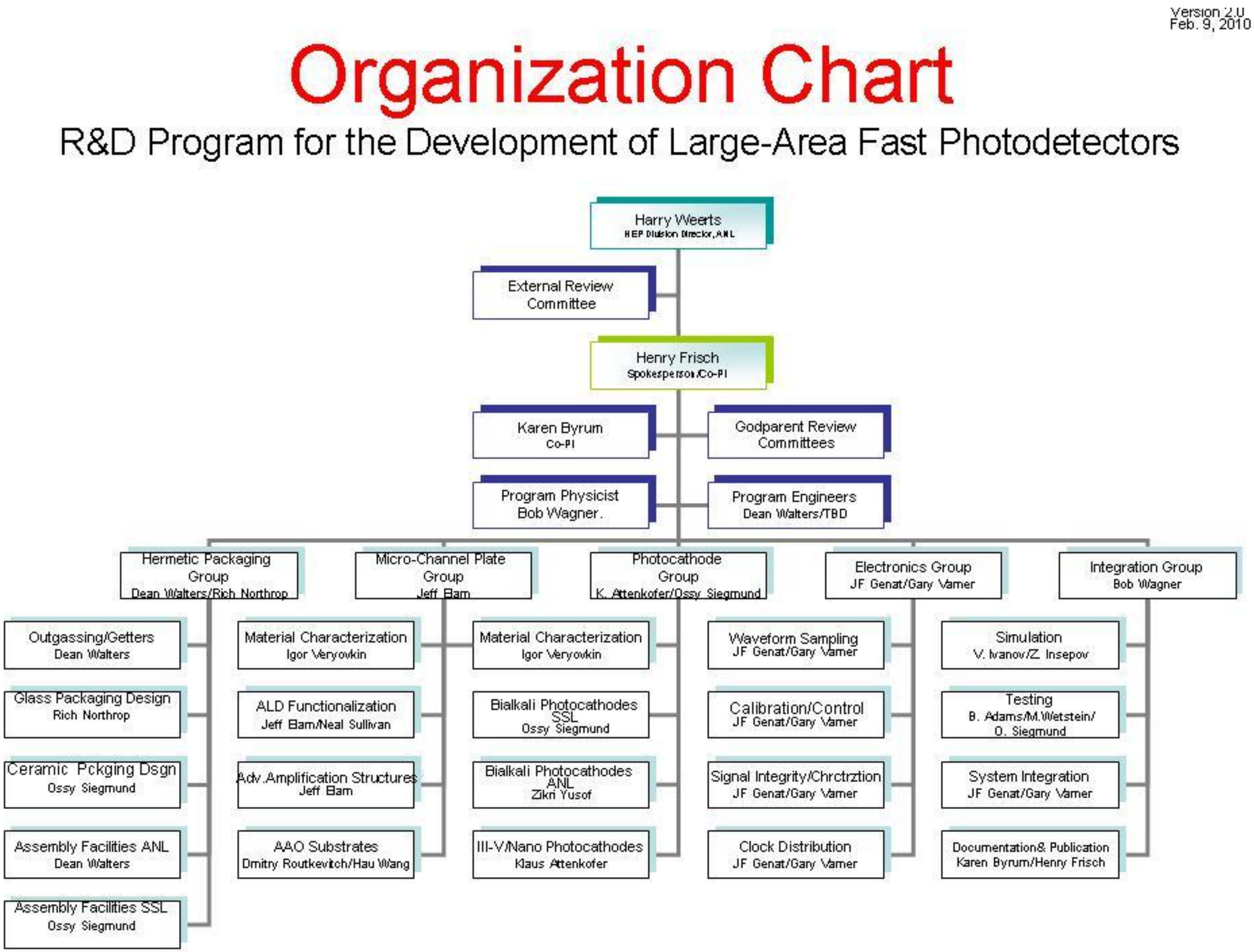
MicroChannel Plates



Photocathodes



The Large-Area Psec Photo-Detector Collaboration-2010



Portfolio of Risk- Parallel Efforts

- **Two parallel but intertwined efforts at different levels of risk, reward:**
  - **SSL/Hawaii** (Siegmund)- ceramic package based on Planacon experience, NaKSb cathode, higher cost, smaller area, lower throughput, **lower risk due to fewer innovations, more experience;**
  - **ANL/UC** (Wagner, Byrum,Frisch)- glass package, KCsSb cathode, lower cost, larger area, higher throughput, **higher risk, but more innovation and use of new technologies.**
- **Reduce risk and enhance reward by diversification onto the 2 paths.** Has proved very beneficial to both efforts (much cross-fertilization, and shared MCP development)

Parallel Efforts on Specific Applications

Explicit strategy for staying on task- Multiple parallel cooperative efforts

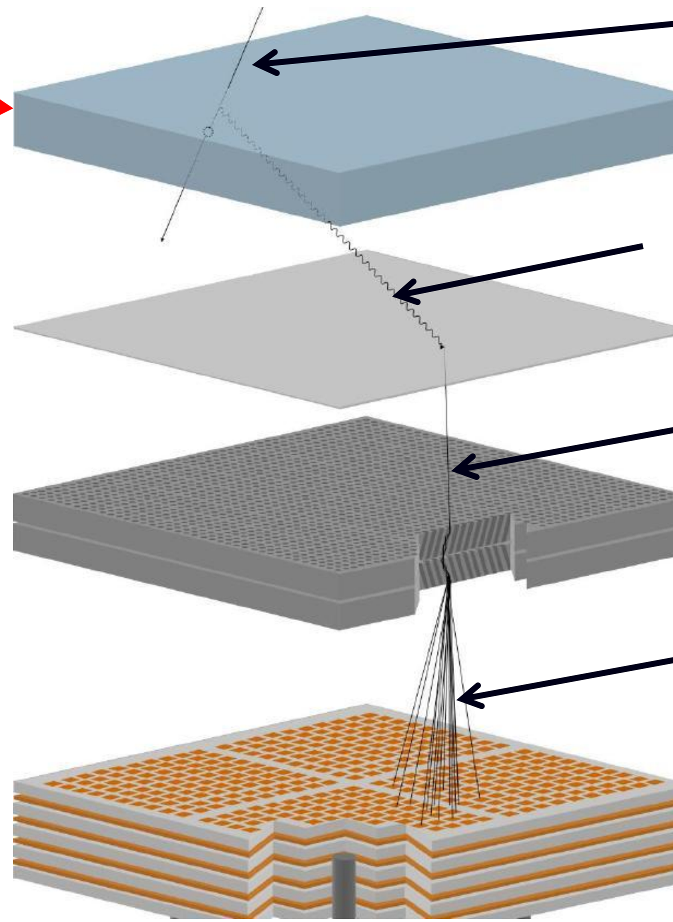
All these need work- naturally tend to lag the reality of the detector development

MCP's

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)



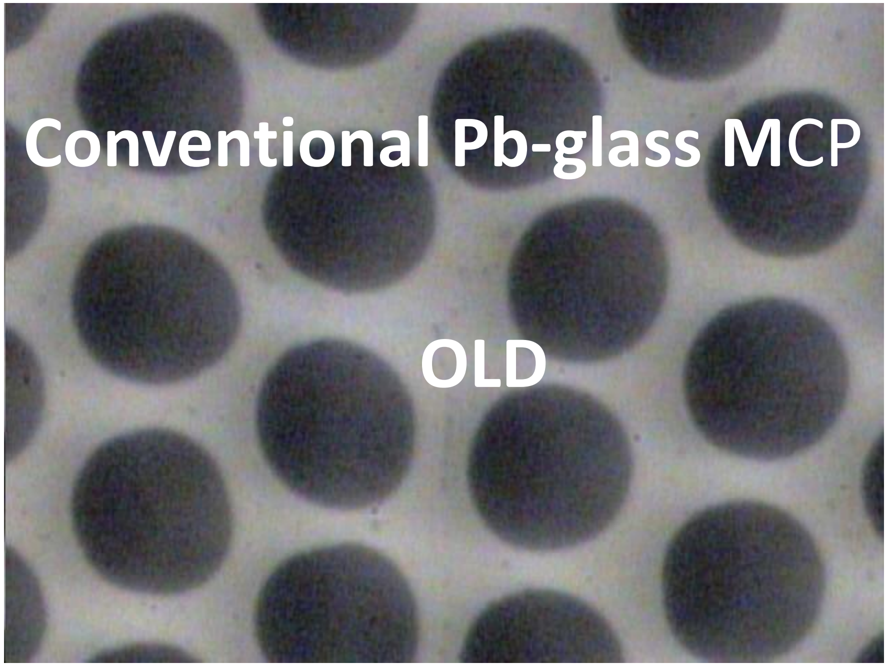
So what are the new technologies?

- Glass capillary substrates (Incom)
- Atomic Layer Deposition (Arradiance, ANL)
- RF transmission line anodes (Tang, UC..)
- Waveform Sampling (Hawaii, MPI, Orsay,Saclay, UC)
- Cheap plate glass, frit seals, silk-screened anodes, home-brew indium seals, …

However- there are areas where we have only old technologies and need new ones-

Challenges and opportunities (have some fun while you’re mostly typing in deathless C++)

Simplifying MCP Construction



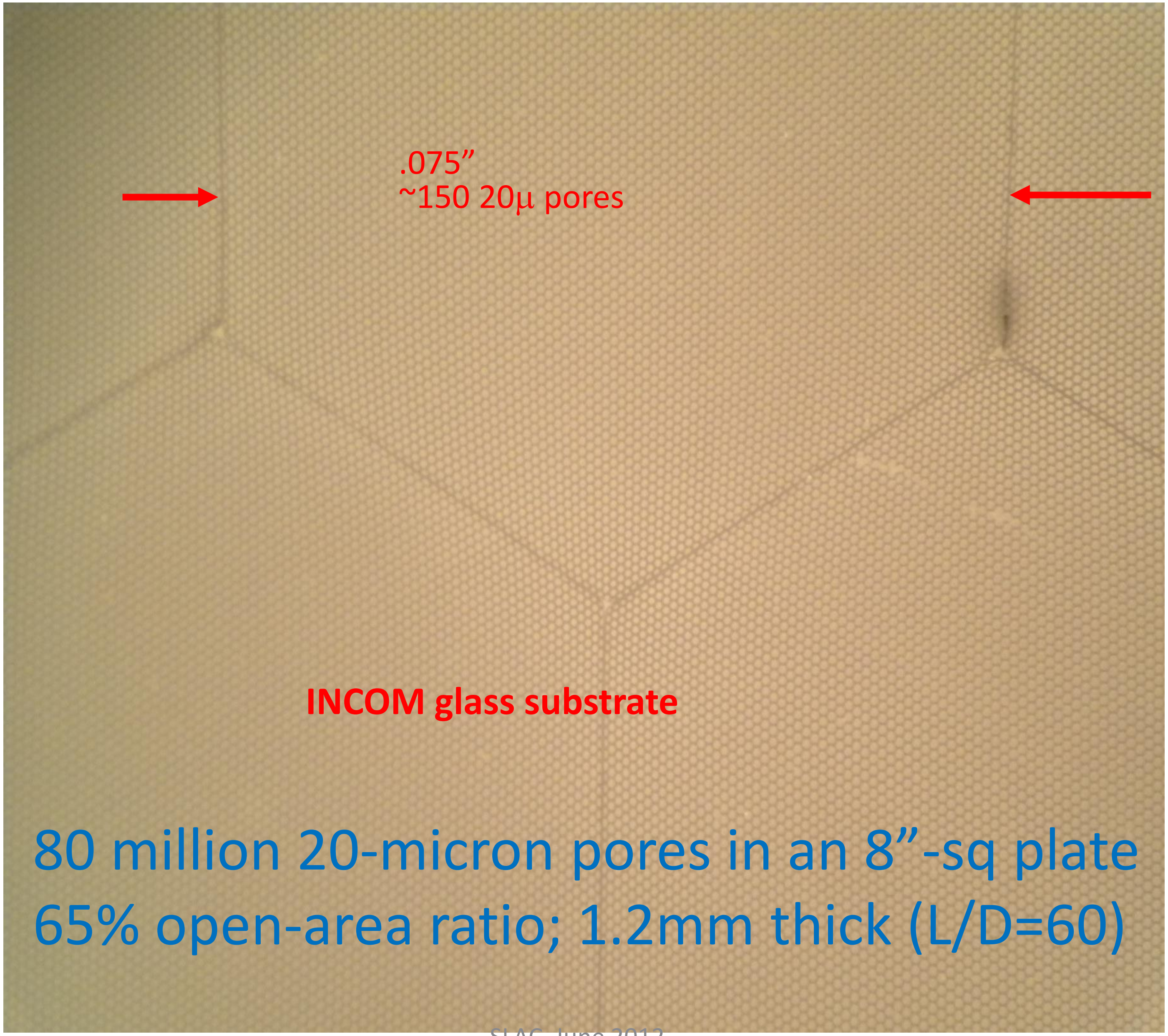
Chemically produced and treated Pb-glass does 3-functions:

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

Latest Incom Micropore Substrate

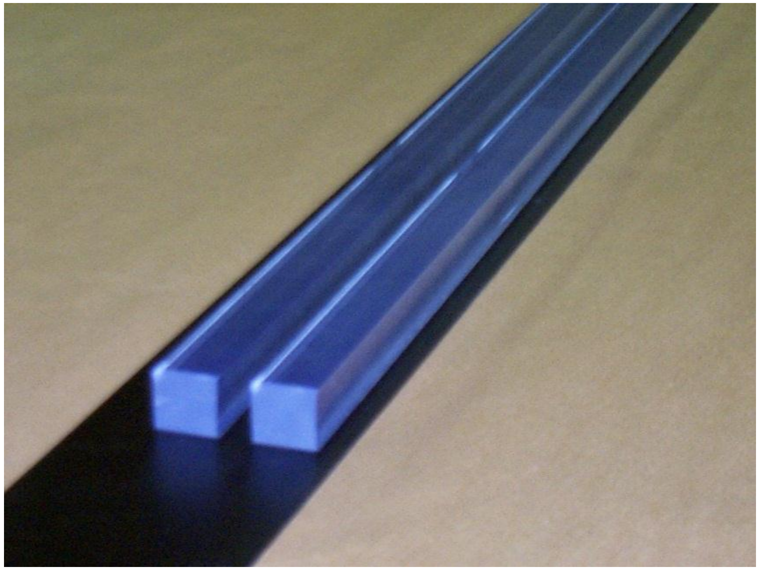


Incom.inc, Charlton Mass

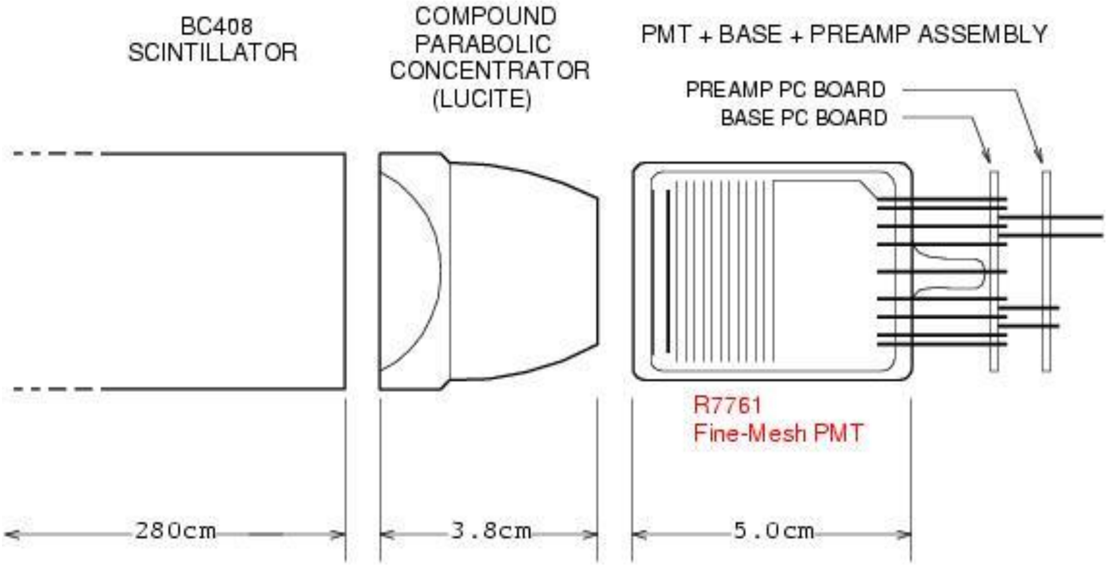
Why has 100 psec been the # for 60 yrs?

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's what we measure- no surprise! (pictures from T. Credo)

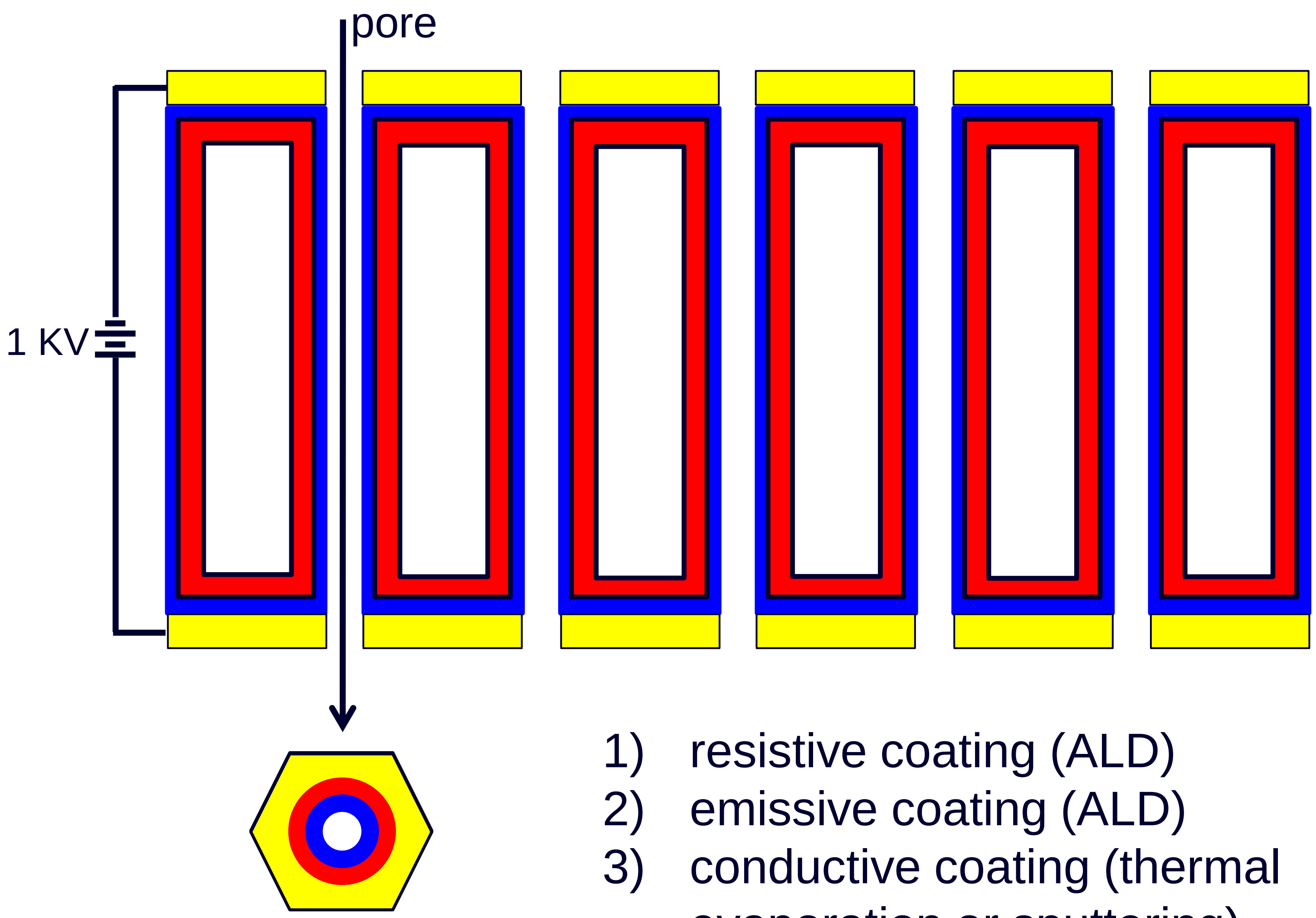


Typical Light Source (With Bounces)



Typical Detection Device (With Long Path Lengths)

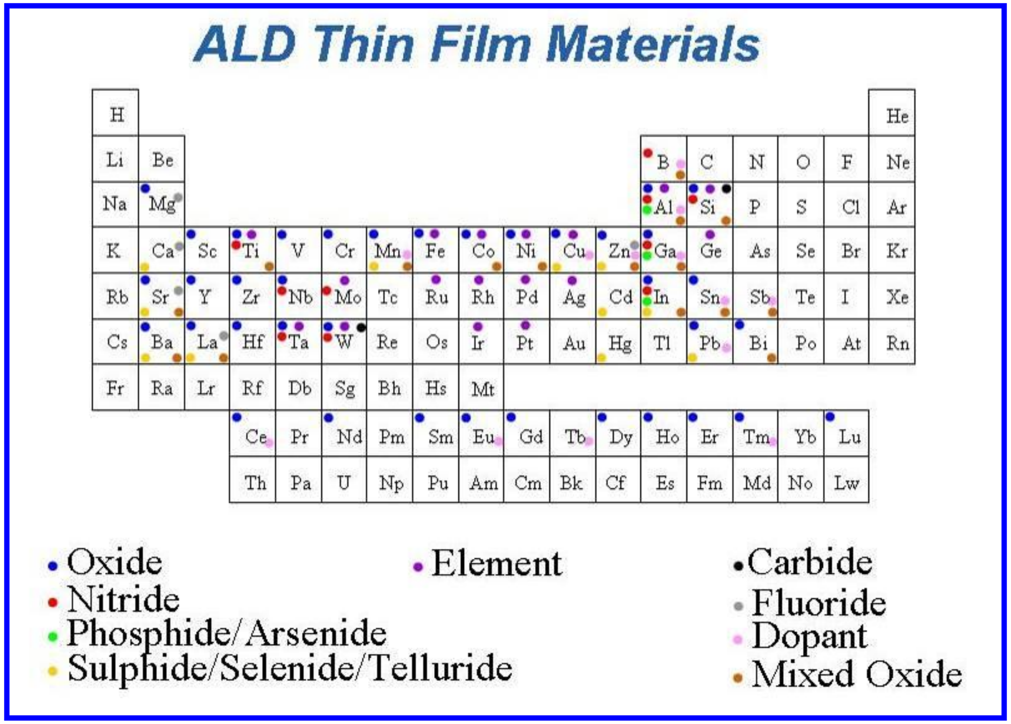
New MCP Structure (not to scale)



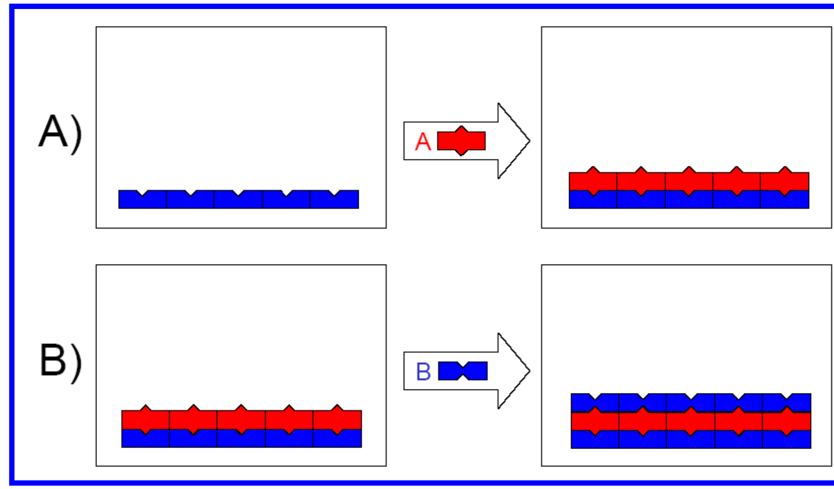
1) resistive coating (ALD)
2) emissive coating (ALD)
3) conductive coating (thermal evaporation or sputtering)

Jeff Elam

Atomic Layer Deposition (ALD) Thin Film Coating Technology

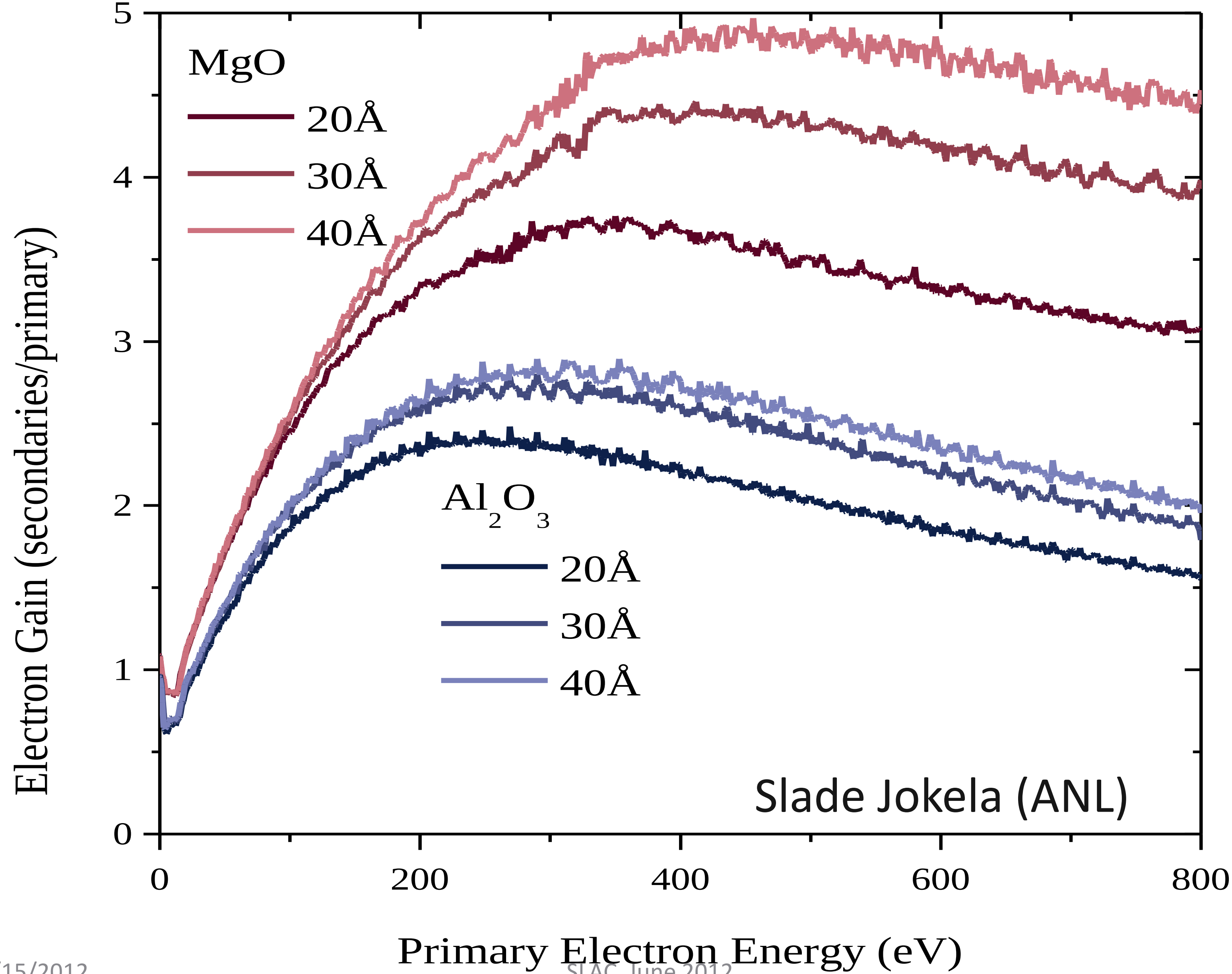


Lots of possible materials => much room for higher performance



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

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 &Integration tests at ANL

Argonne Atomic Layer Deposition and Test Facilities

- In situ measurements of R (Anil)
- Femto-second laser time/position measurements (Matt, Bernhard, Andrey, Razib, Sasha, Bob, Eric)
- 33 mm development program
- 8” anode injection measurements

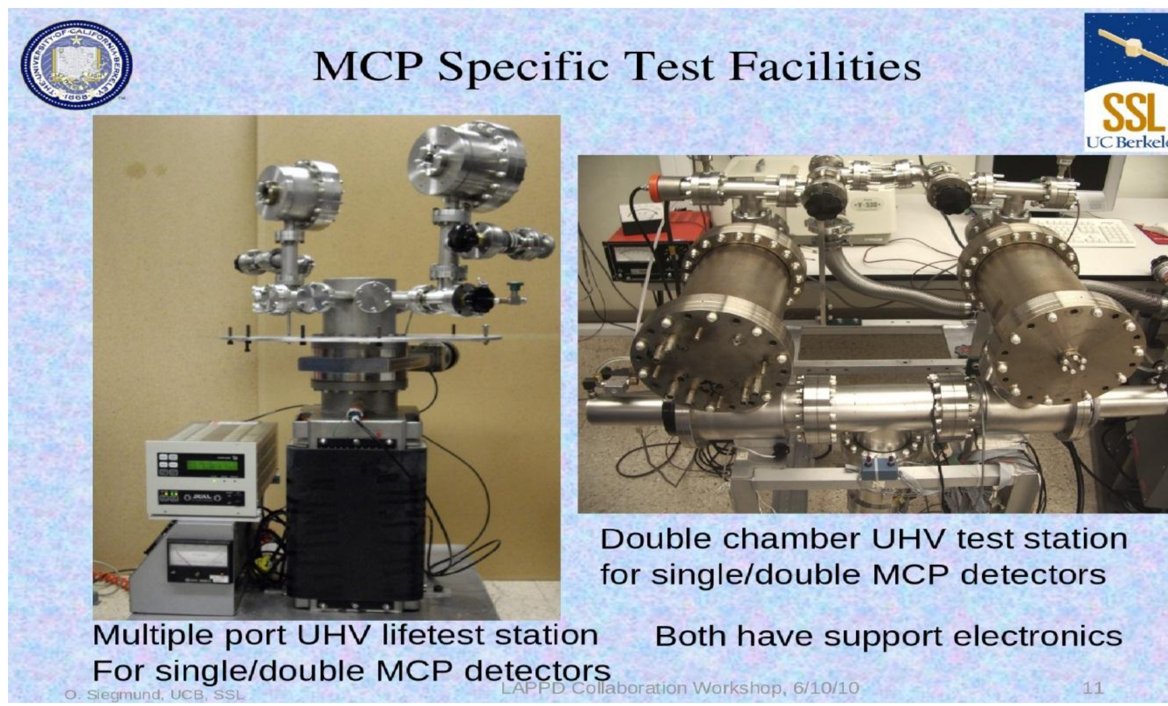
Anil Mani and Bob Wagner

SSL (Berkeley) Test/Fab Facilities

Ossy Siegmund, Jason McPhate, Sharon Jelenski, and Anton Tremsin-

Decades of experience

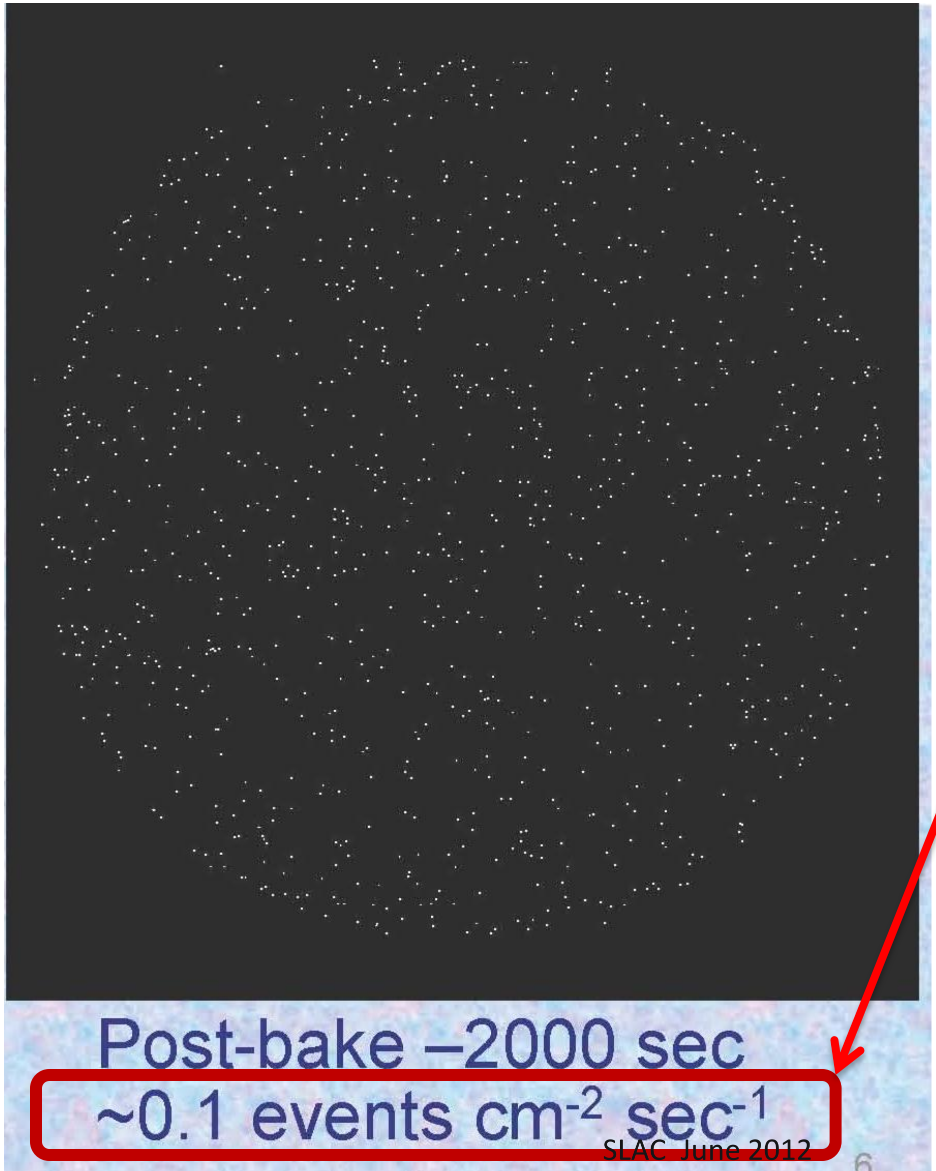
(some of us have decades of inexperience?)



Microchannel Plates-4b

Performance:

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



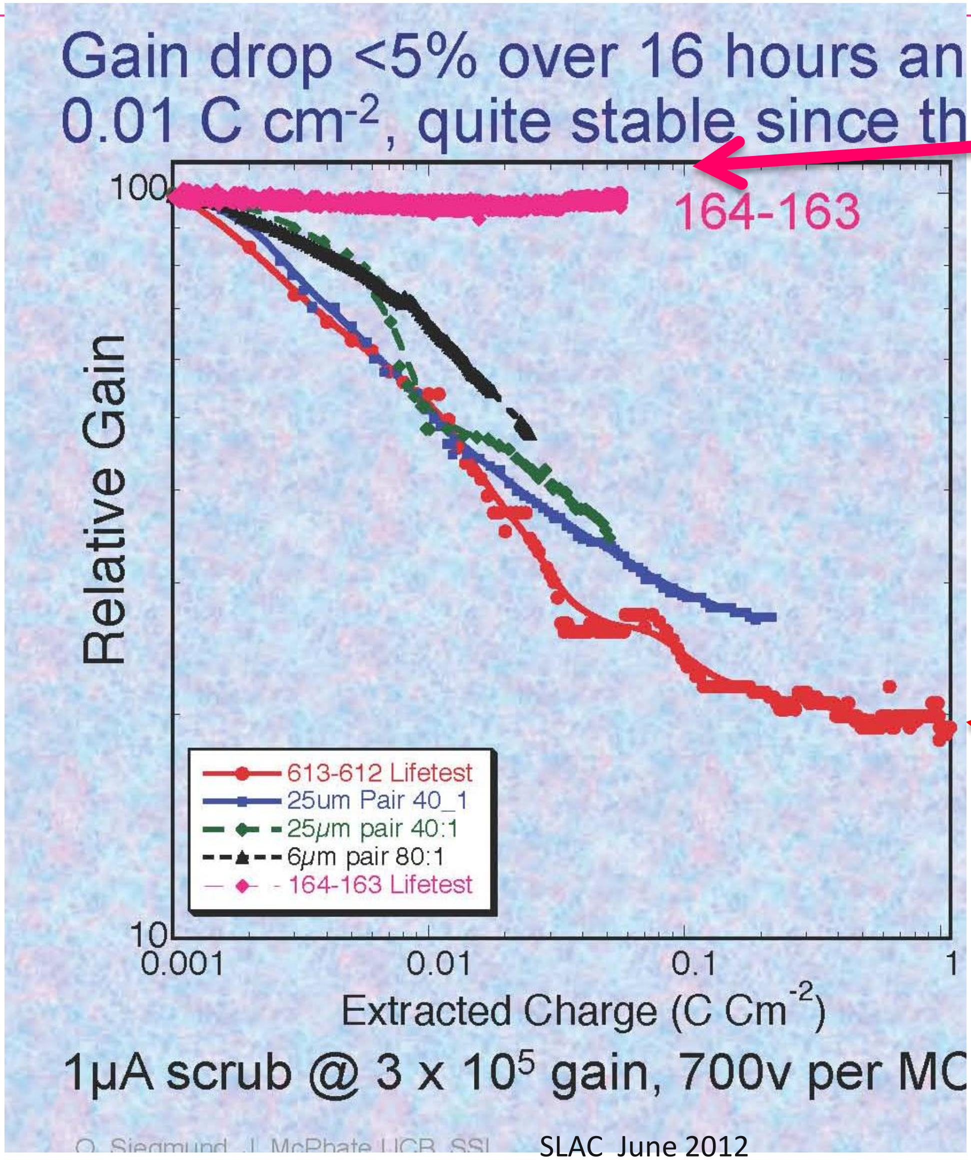
Noise (bkgd rate). <=0.1 counts/cm^2/sec; factors of few > cosmics (!)

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)

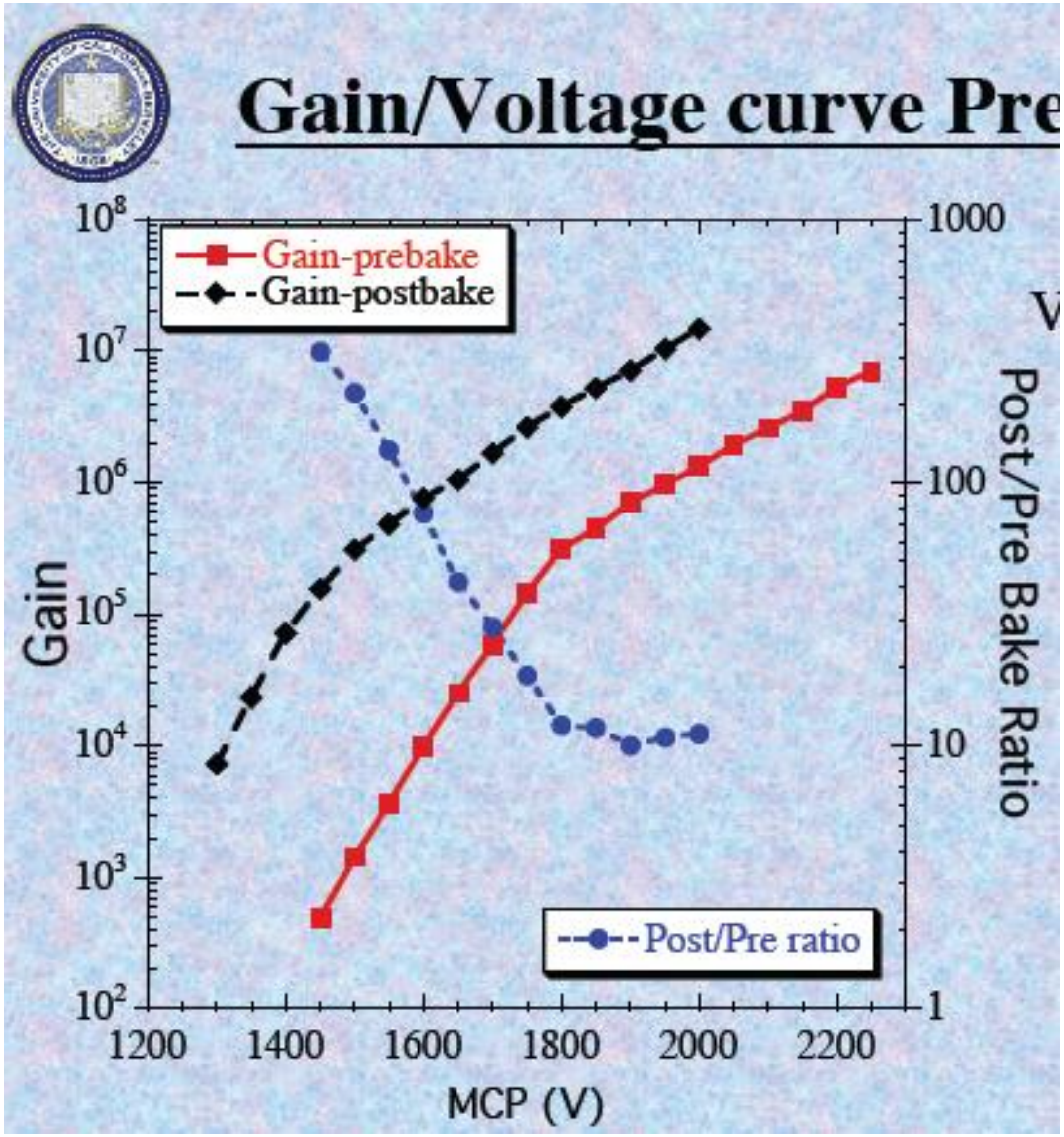
Typical MCP behavior- long scrub-times

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

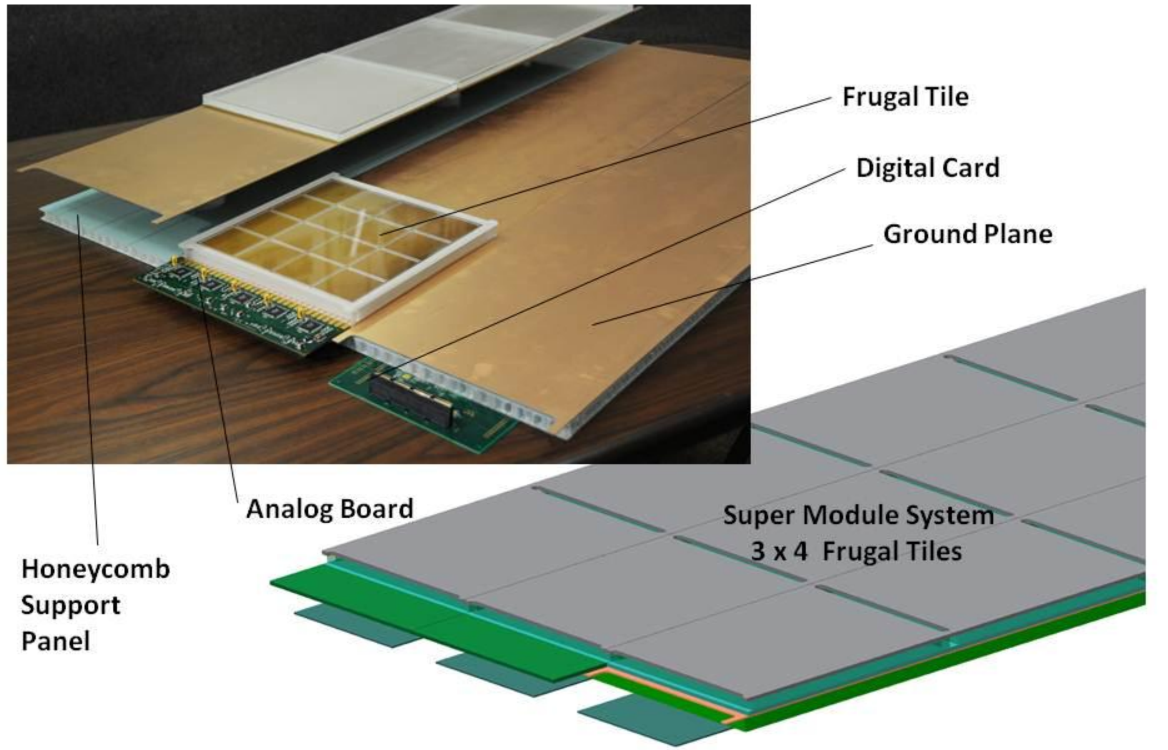


Hermetic Packaging

Internal HV circuit, capacitively coupled signal circuit (no penetrations through glass)- the `frugal tile'

Tile-Tray Integrated Design

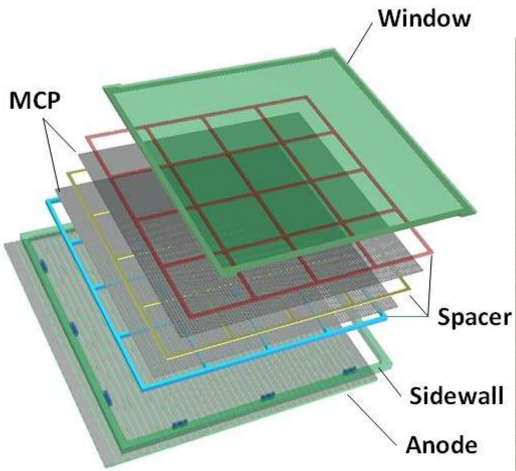
Because this is an RF-based readout system, the geometry and packaging are an integral part of the electronic design



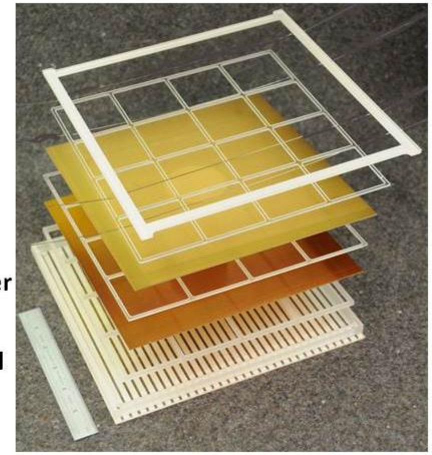
Tray and Tiles - The Super Module System

The design is modular, with 8"-square MCP sealed vacuum tubes (`tiles') with internal strip-lines capacitively coupled to a ground plane (tray) that also holds the electronics.

The Half-Meter-Squared SuperModule



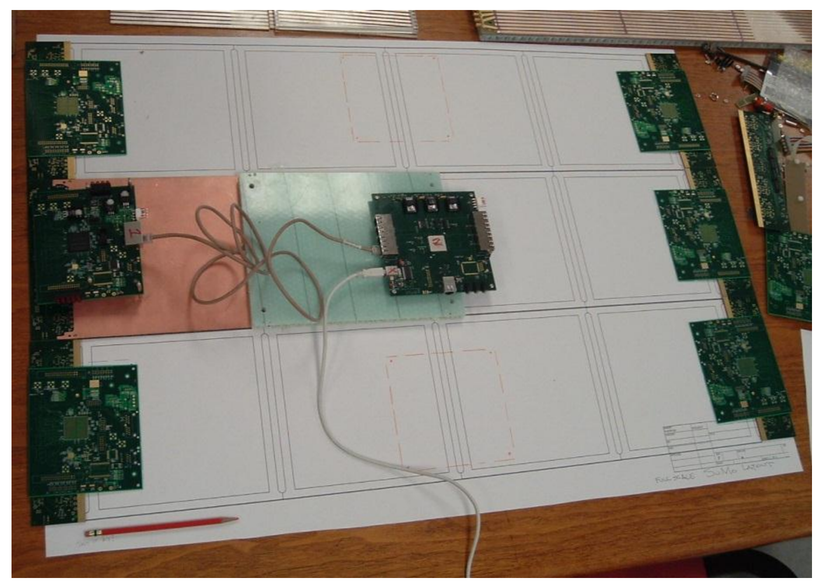
Design Drawing - September 2010


Actual Glass Parts - April 2012

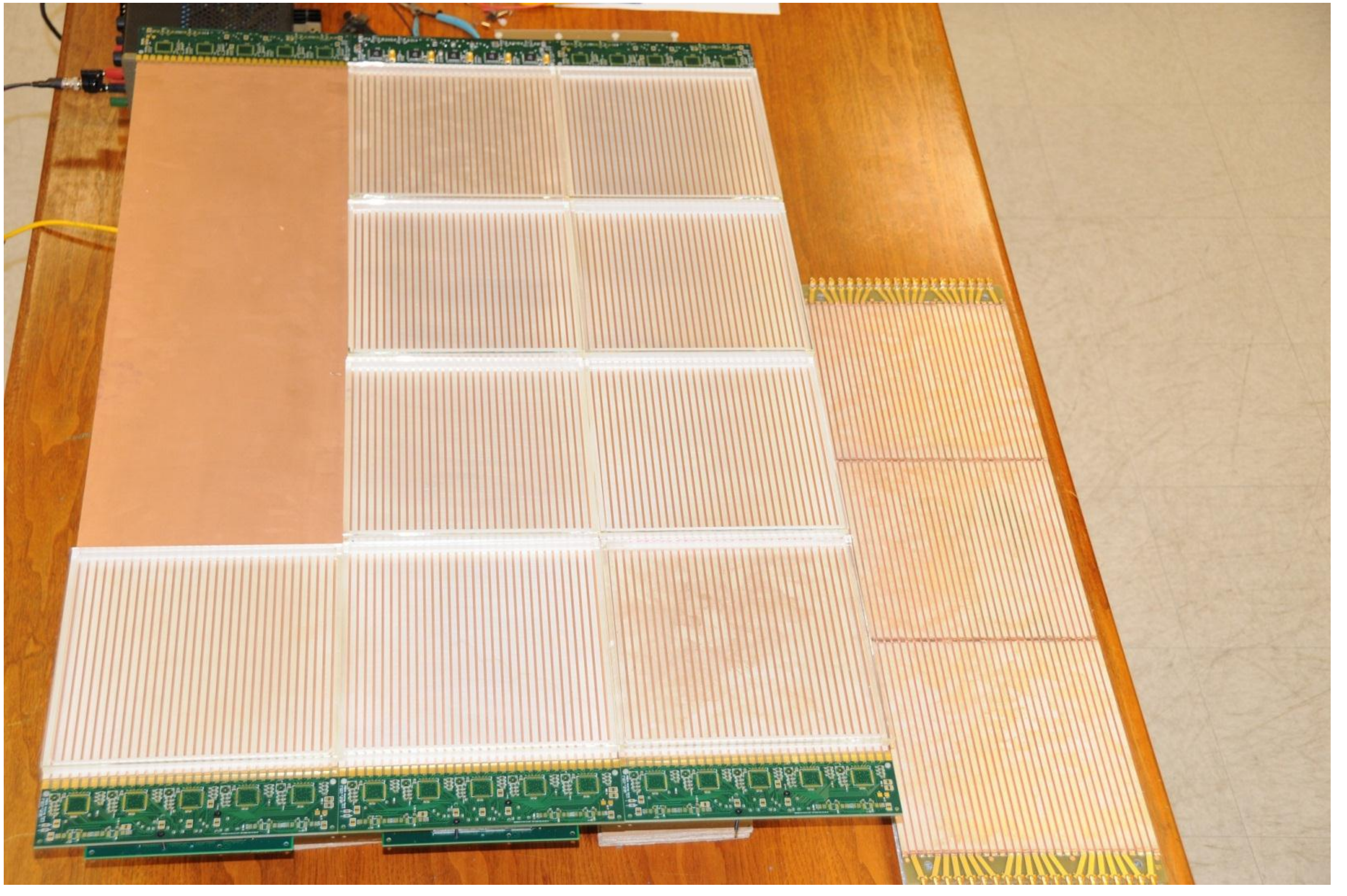
A `tile' is a sealed vacuum-tube with cathode, 2 MCP's, RF-strip anode, and internal voltage divider

HV string is made with ALD

A `tray' 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

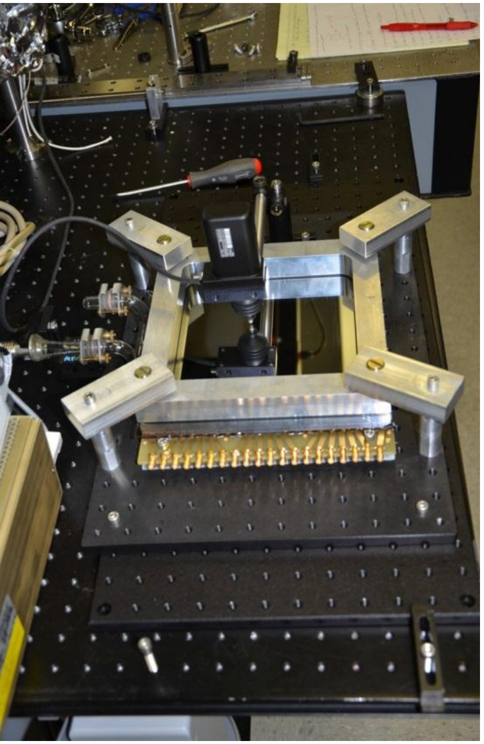


SuperModule Mockup: ½-m^2 of cathode

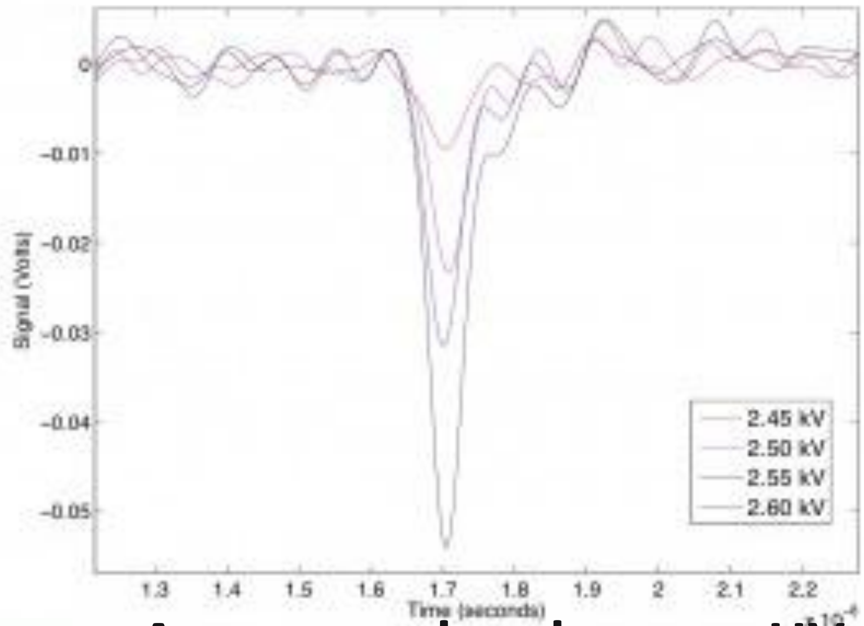


- Real 8" glass tile package parts- anode, side-wall, window (sic)
- `Innards' stack of 2 MCP's +3 spacers+anode+window under test
- Have read out through from AC card through full DAQ chain to PC

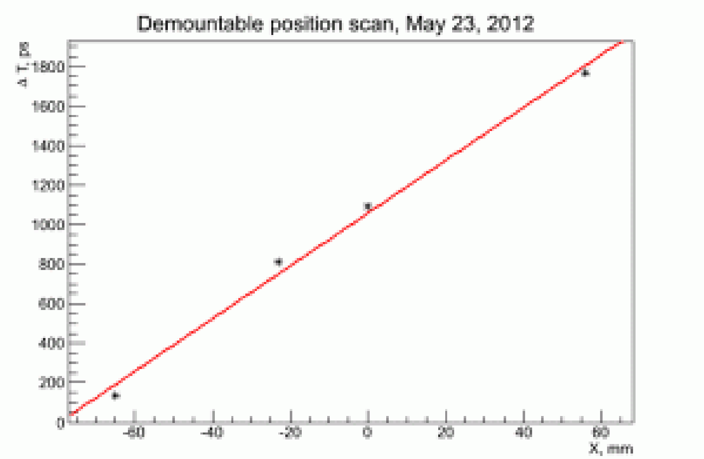
Demonstration of the Internal ALD HV Divider in the Demountable Tile



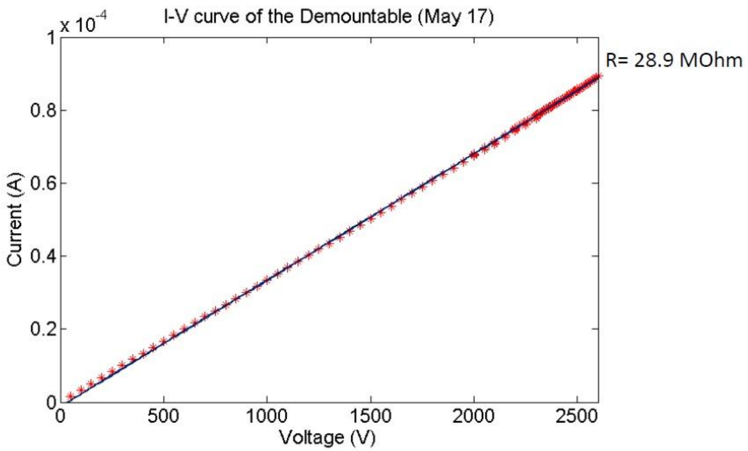
Demountable at APS



Average pulse shape vs HV



Scanning the laser: t vs x

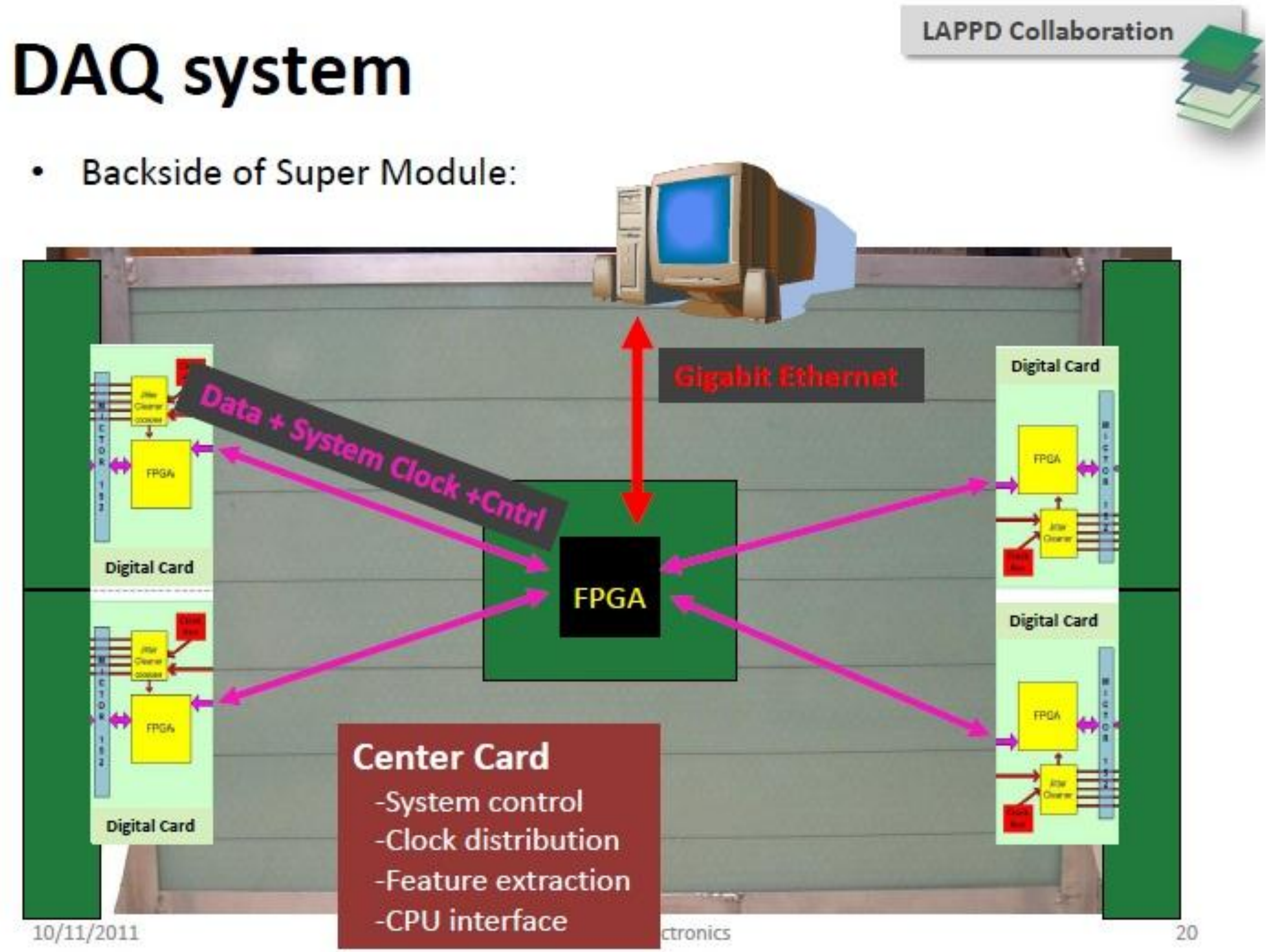


IV Curve (expected 32 Megs)

Electronics and DAQ

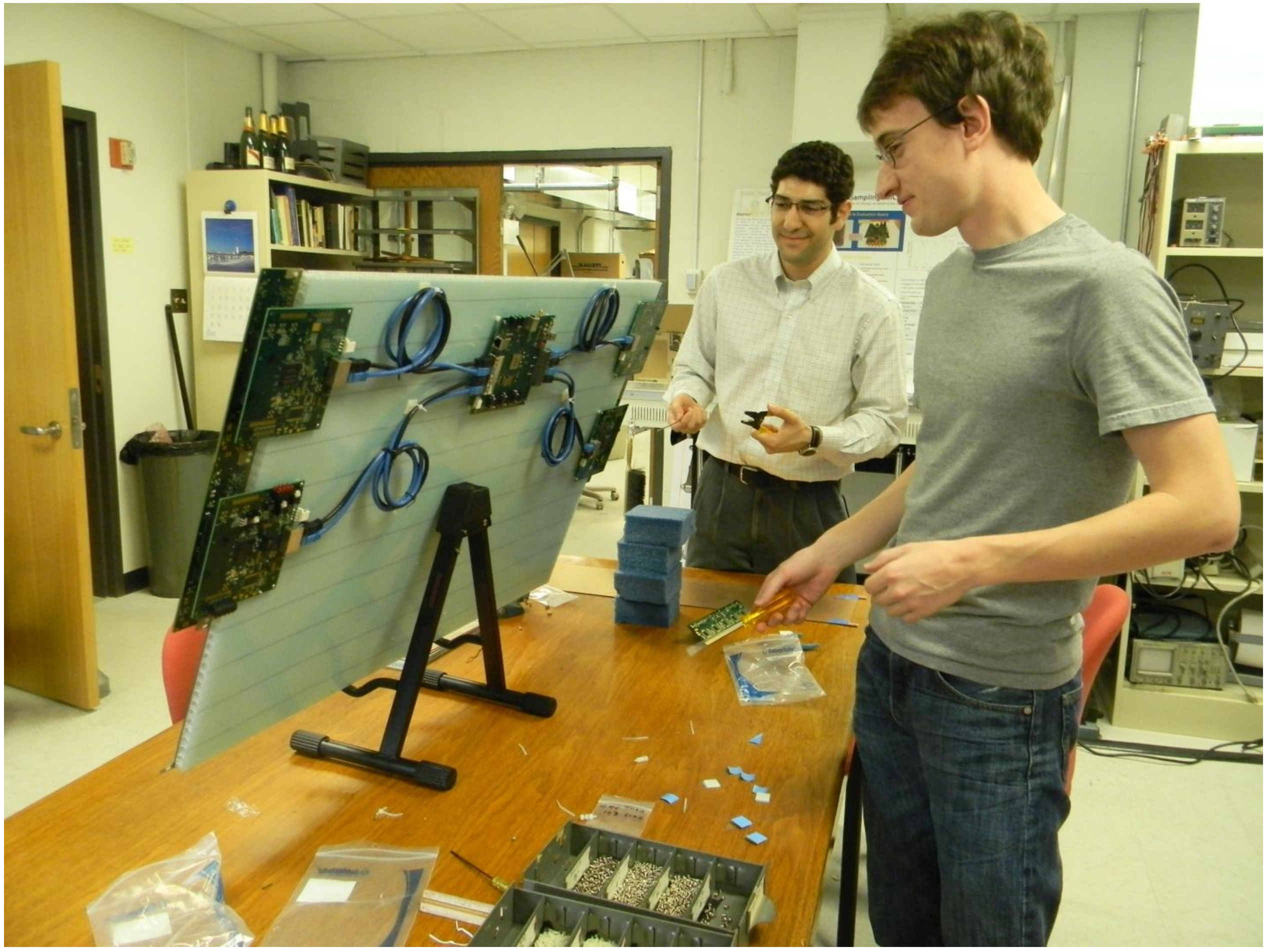
The plug-and-play goal for the supermodule

Extract time, position of pulse using time from both ends



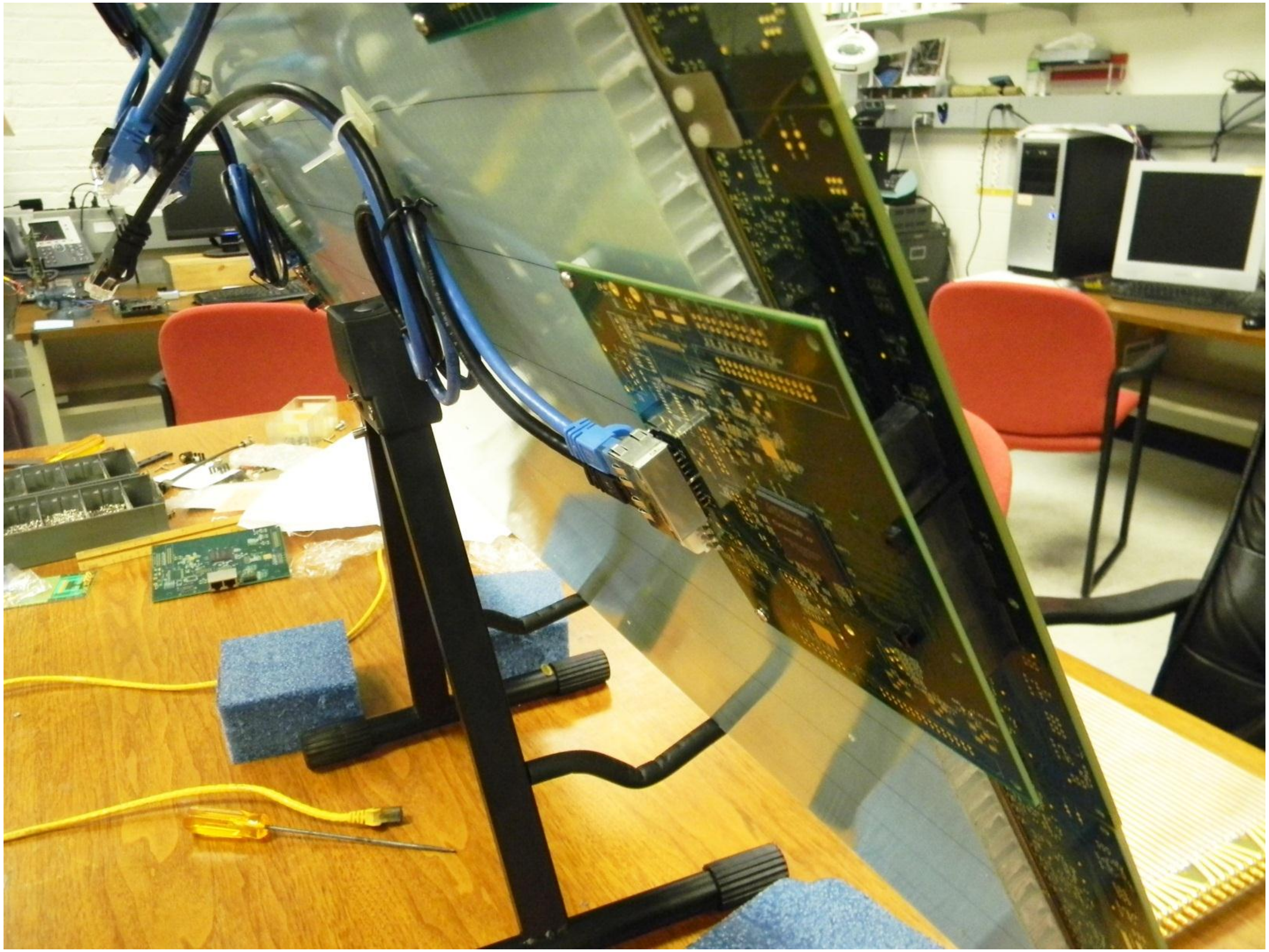
Eric Oberla slide from ANT11

Developing and Testing the Electronics, Anodes, and DAQ



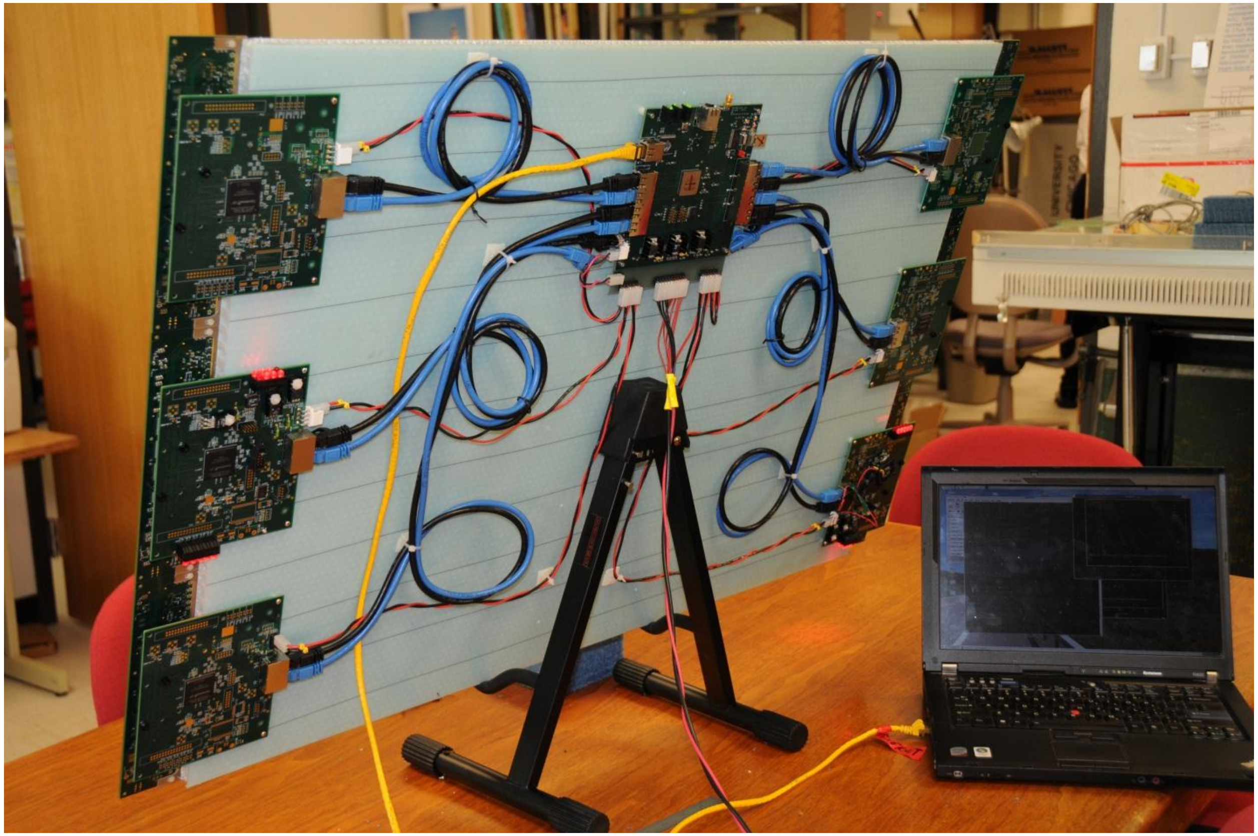
Eric Oberla (grad student) and Craig Harabedian (engineer) working on the Tray layout and cabling

Analog Card to Digital Card



Can be direct connection (shown) or cable

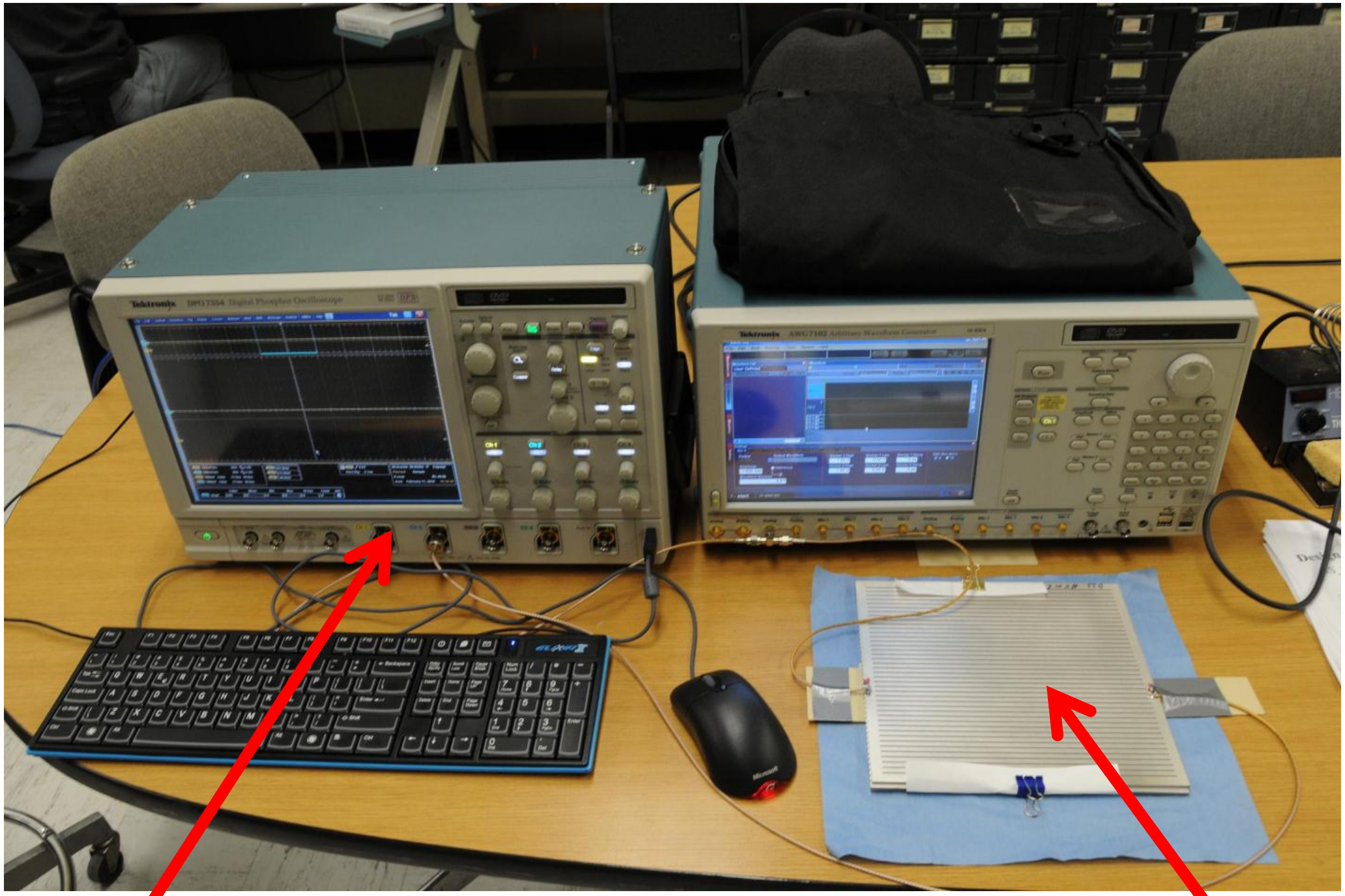
Digital Cards and Central Card



Present readout to PC and Nvidia GPU is via USB; Ethernet hardware is on boards- later

Anode Testing for ABW, Crosstalk,..

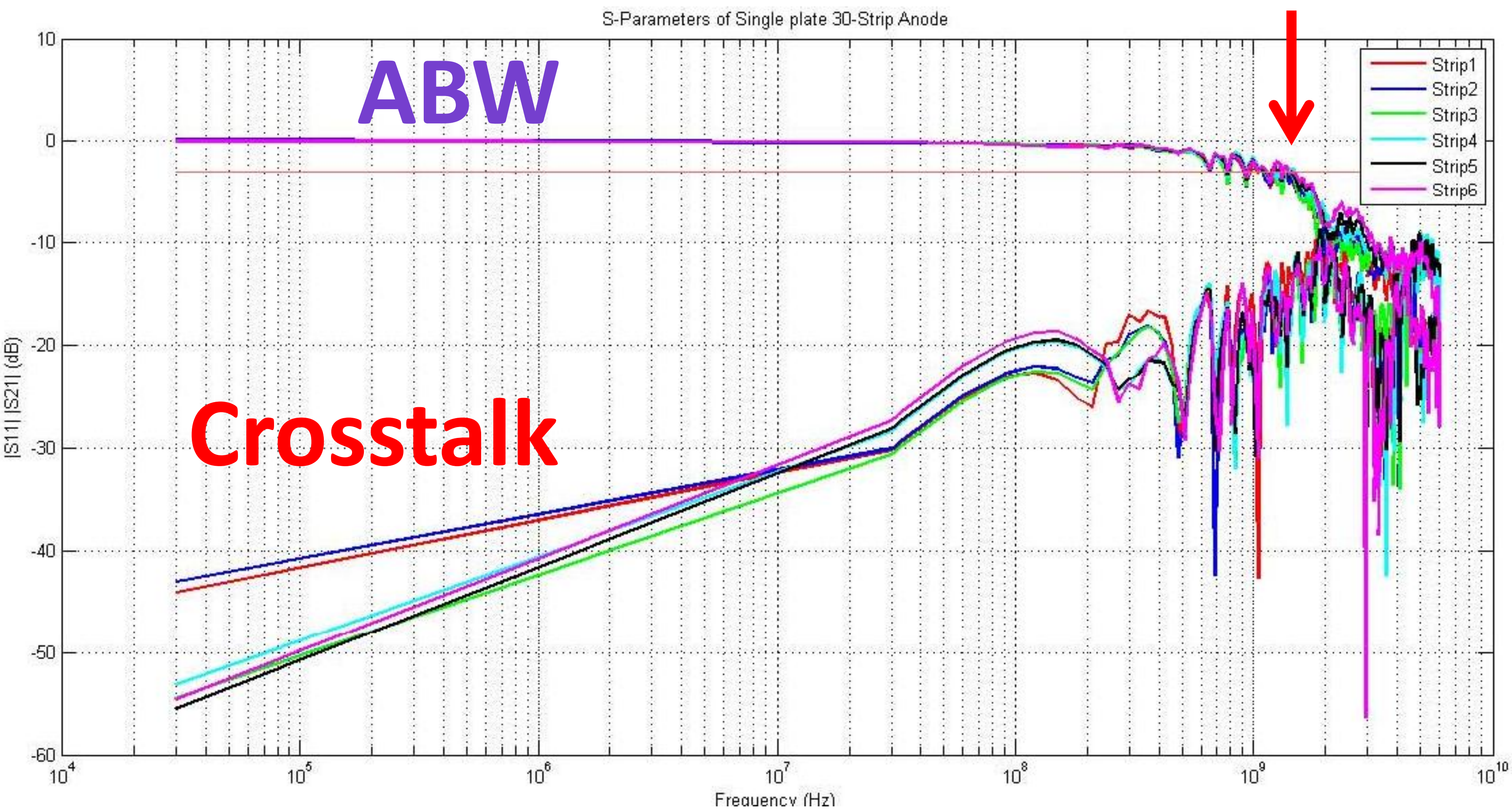
Herve' Grabas, Razib Obaid, Dave McGinnis



Network Analyzer

Tile Anode

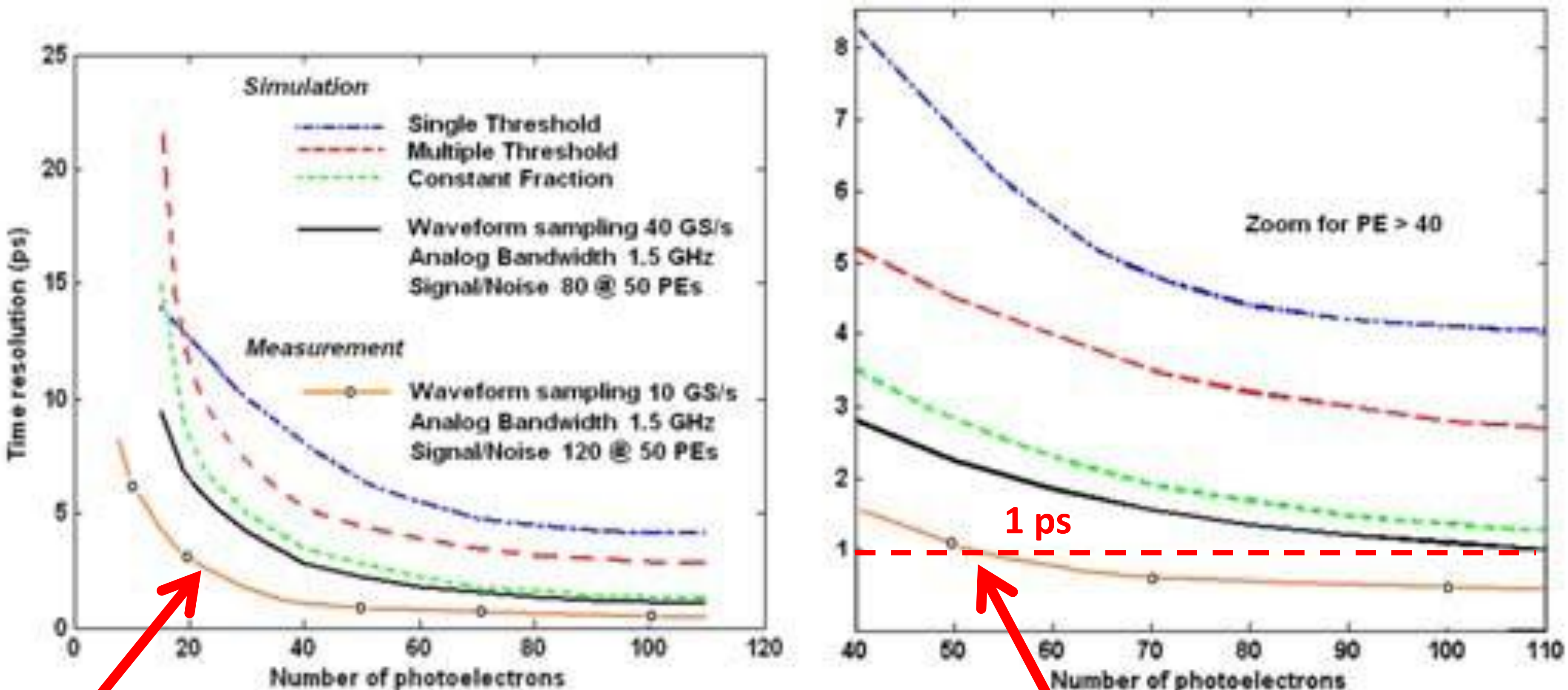
Anode Testing for ABW, Crosstalk,..



Razib Obaid

Simulation of Resolution vs abw

Jean-Francois Genat (NIM)



This (brown) line

This (brown) line

Brown line: 10 Gs/sec (we've done >15);

1.5 GHz abw (we've done 1.6); S/N 120 (N=0.75mv, S is app specific)

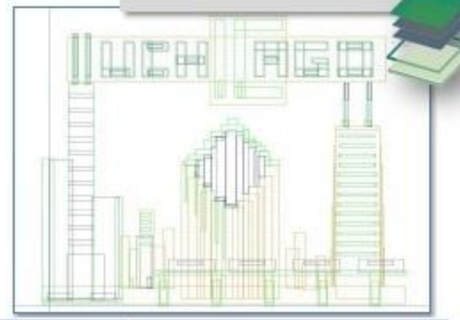
The PSEC4 Waveform Sampling ASIC

PSEC4: Eric Oberla and Herve Grabas; and friends…

PSEC-4 ASIC

LAPPD Collaboration

Designed to sample & digitize fast pulses (MCPs):



- Sampling rate capability > 10GSa/s
- Analog bandwidth > 1 GHz (challenge!)
- Relatively short buffer size
- Medium event-rate capability (up to 100 KHz)

→ *130 nm CMOS*

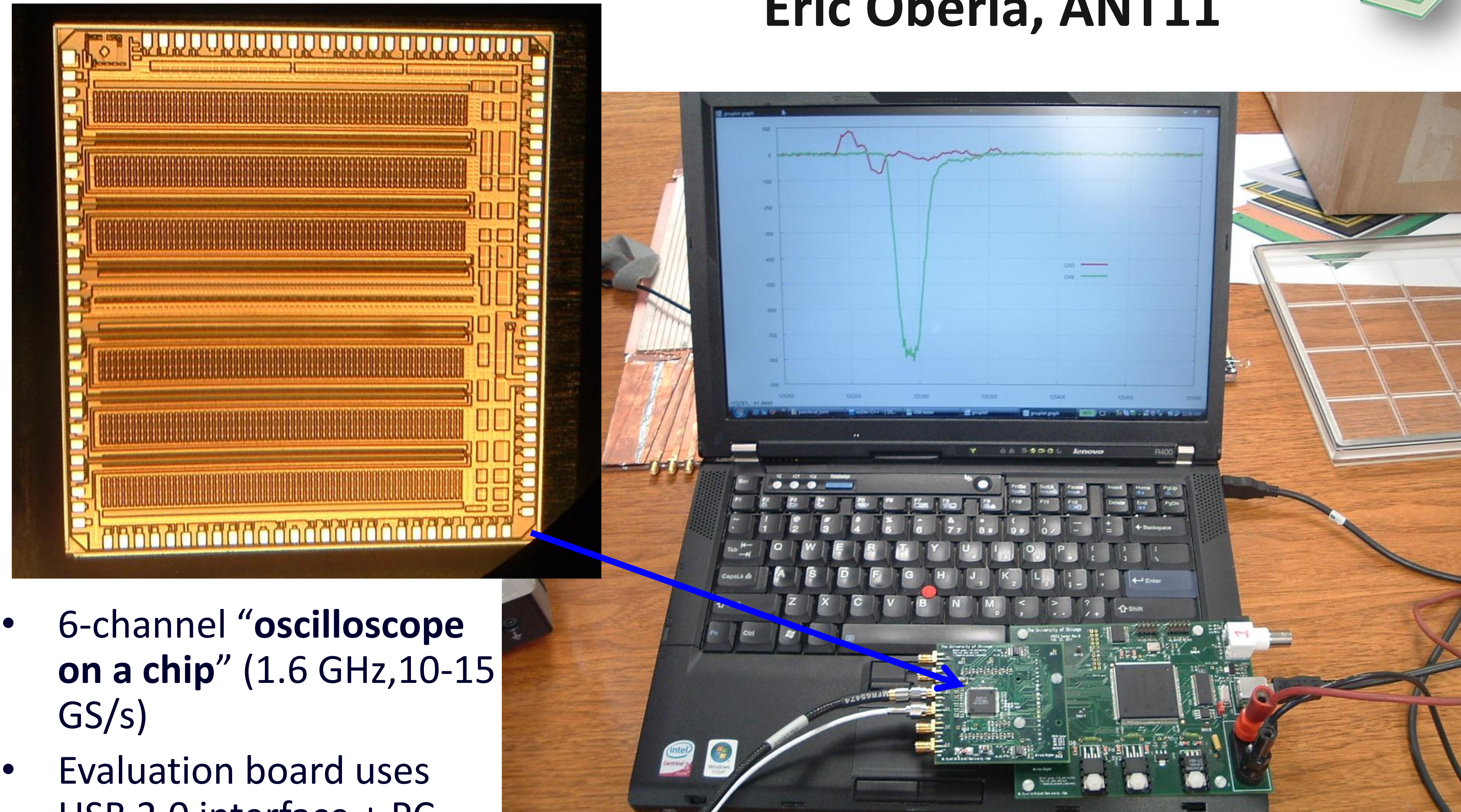
	SPECIFICATION
Sampling Rate	2.5-15 GSa/s
# Channels	6 (or 2)
Sampling Depth	256 (or 768) points
Sampling Window	Depth*(Sampling Rate)$^{-1}$
Input Noise	<1 mV RMS
Analog Bandwidth	1.5 GHz
ADC conversion	Up to 12 bit @ 2GHz
Dynamic Range	0.1-1.1 V
Latency	2 µs (min) – 16 µs (max)
Internal Trigger	yes

10/11/2011 ANT'11 LAPPD electronics 13

Eric Oberla, ANT11

PSEC-4 ASIC

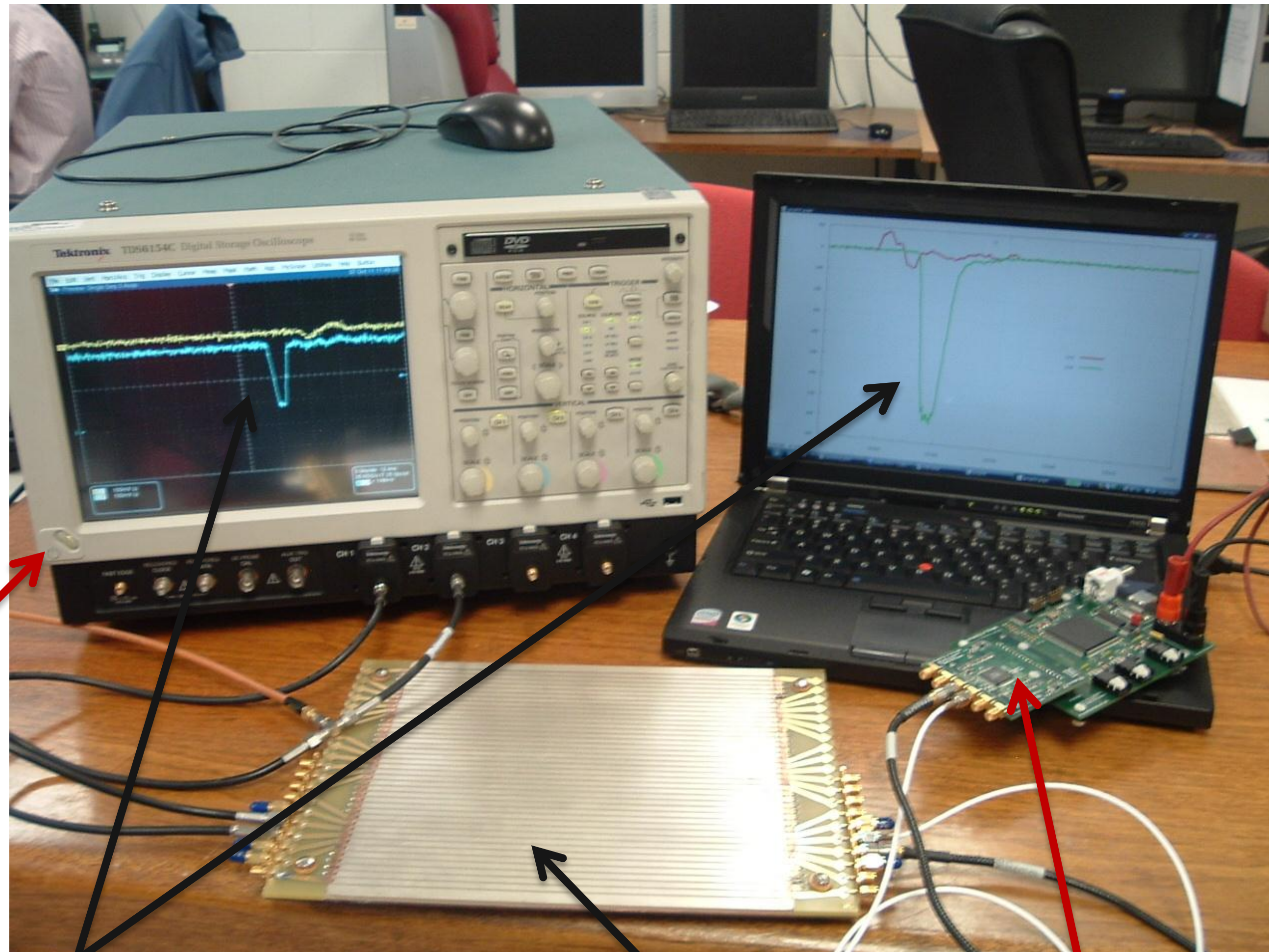
Eric Oberla, ANT11



- 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 ?!)

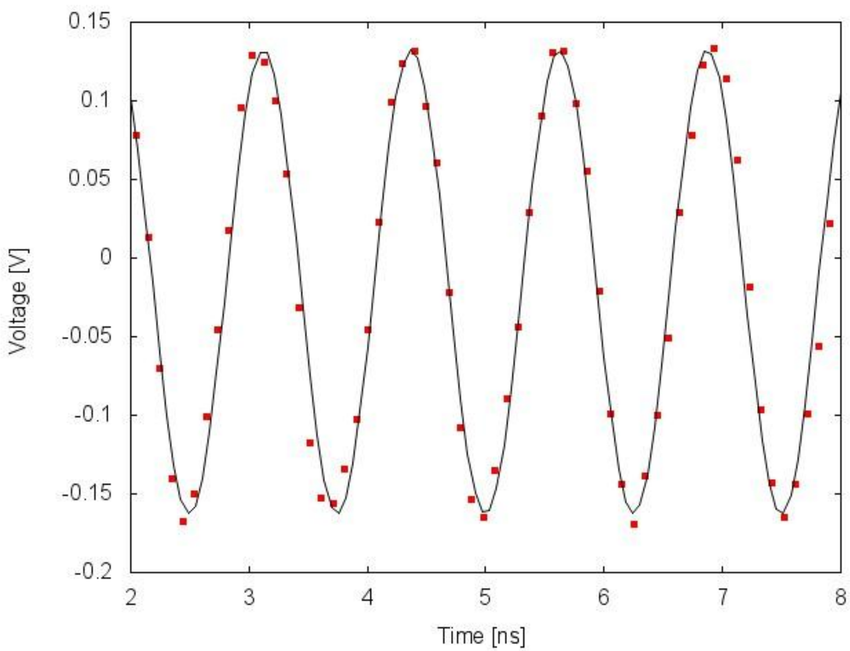
PSEC-4 Performance

Eric Oberla, ANT11

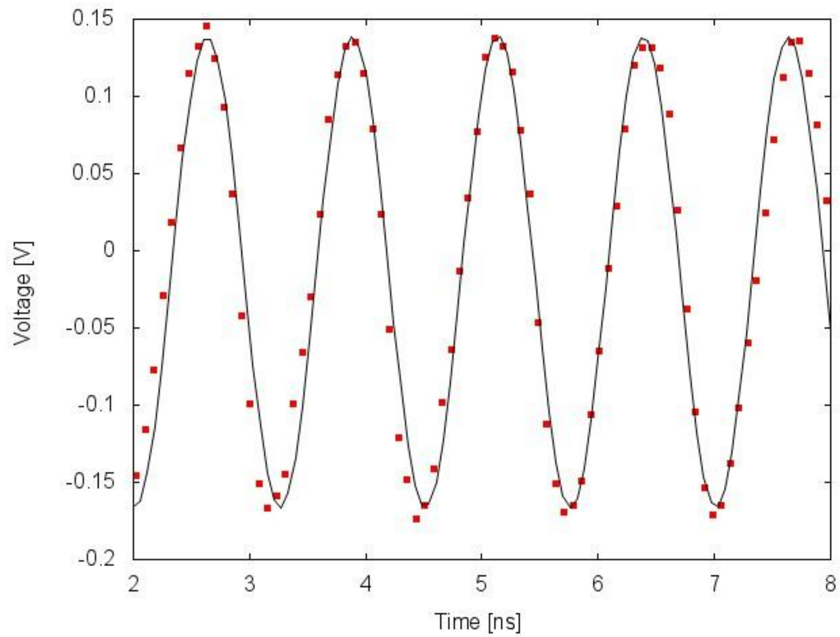
Digitized Waveforms

Input: 800MHz, 300 mV_{pp} sine

Sampling rate : 10 GSa/s



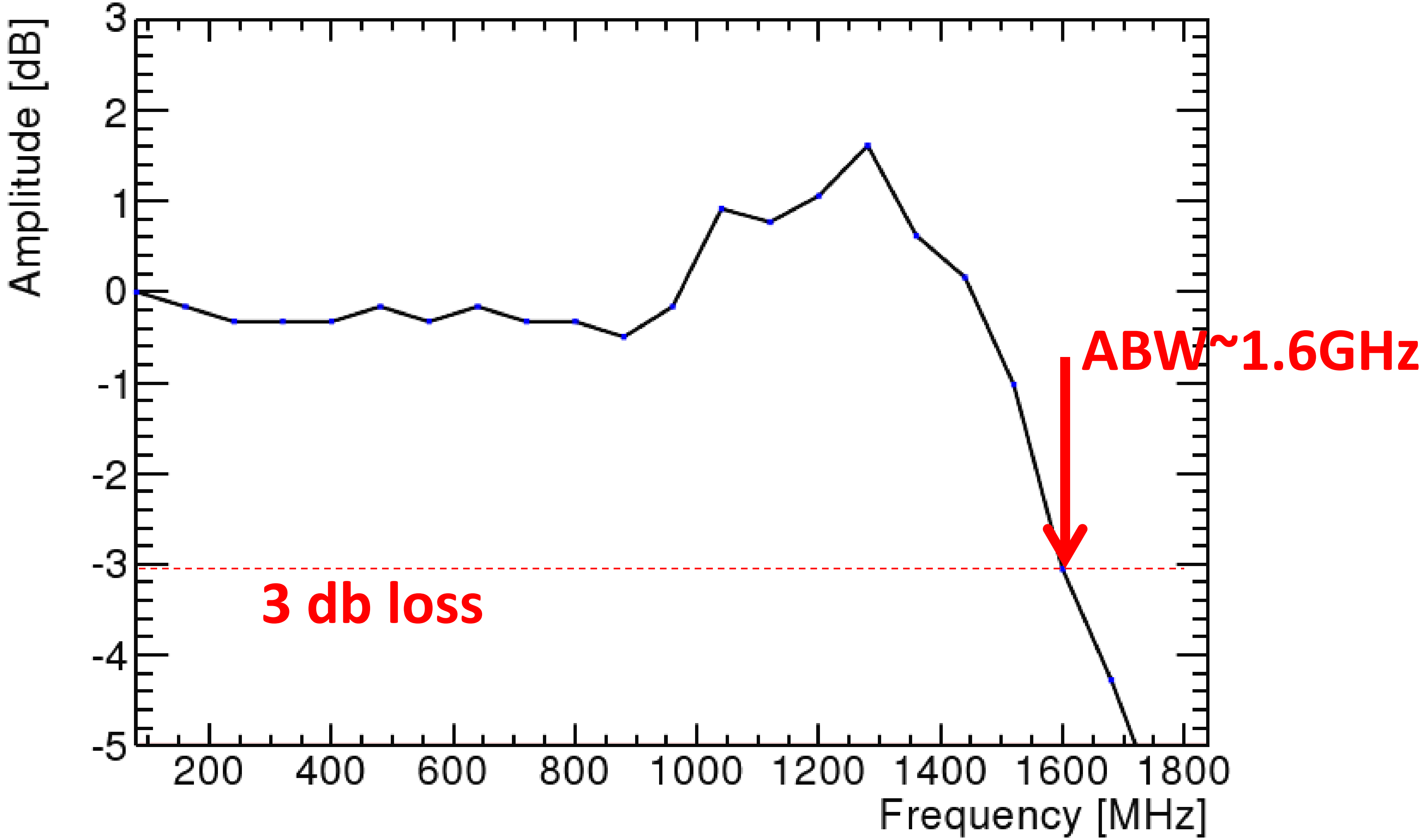
Sampling rate : 13.3 GSa/s



- 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)

Digitization Analog Bandwith

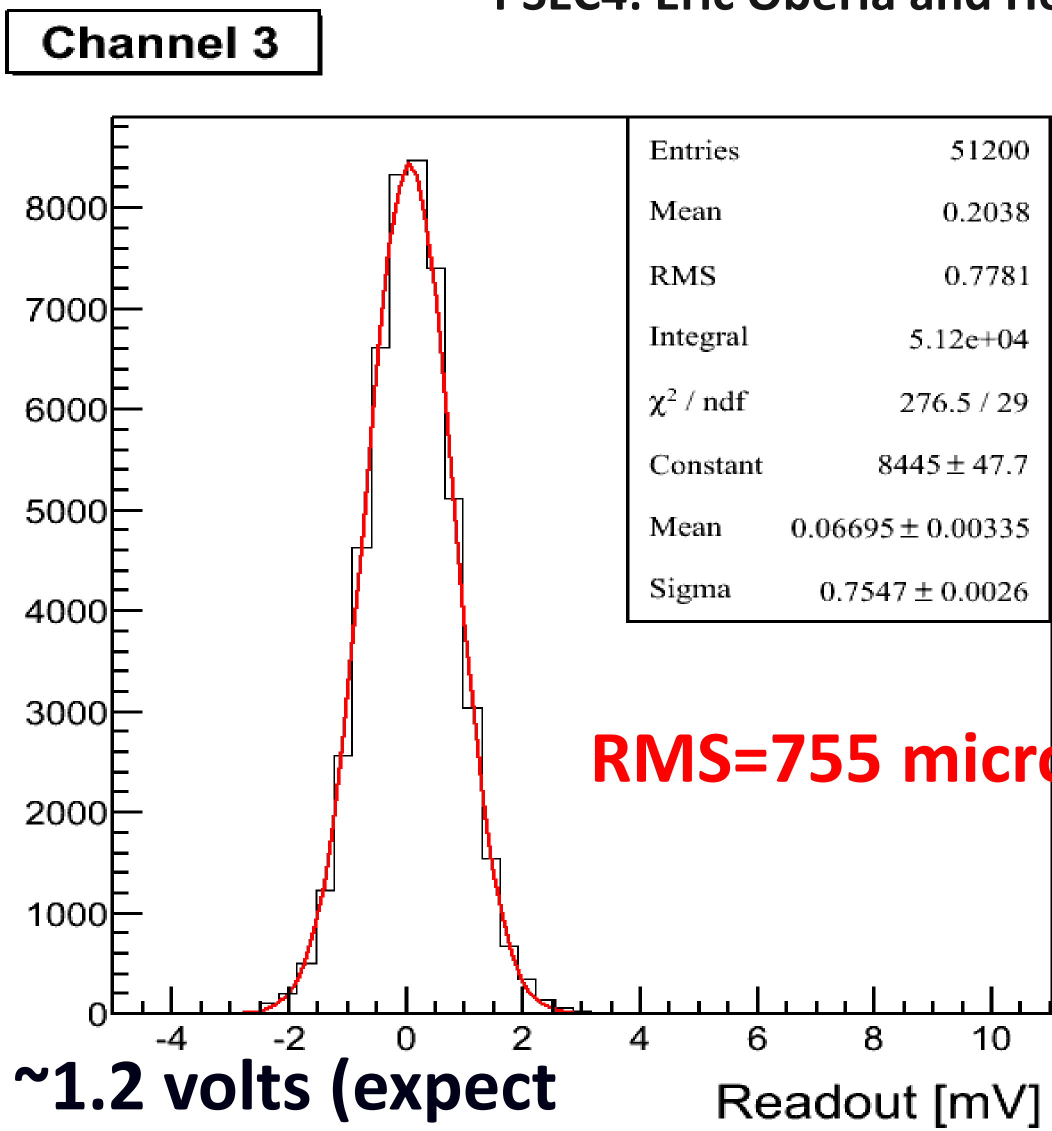
Eric Oberla, ANT11



PSEC4: Eric Oberla and Herve Grabas+ friends…

Noise (unshielded)

PSEC4: Eric Oberla and Herve Grabas+ friends…



RMS=755 microvolts

Full-Scale ~1.2 volts (expect S/N>=100, conservatively)

Eric Oberla, ANT11

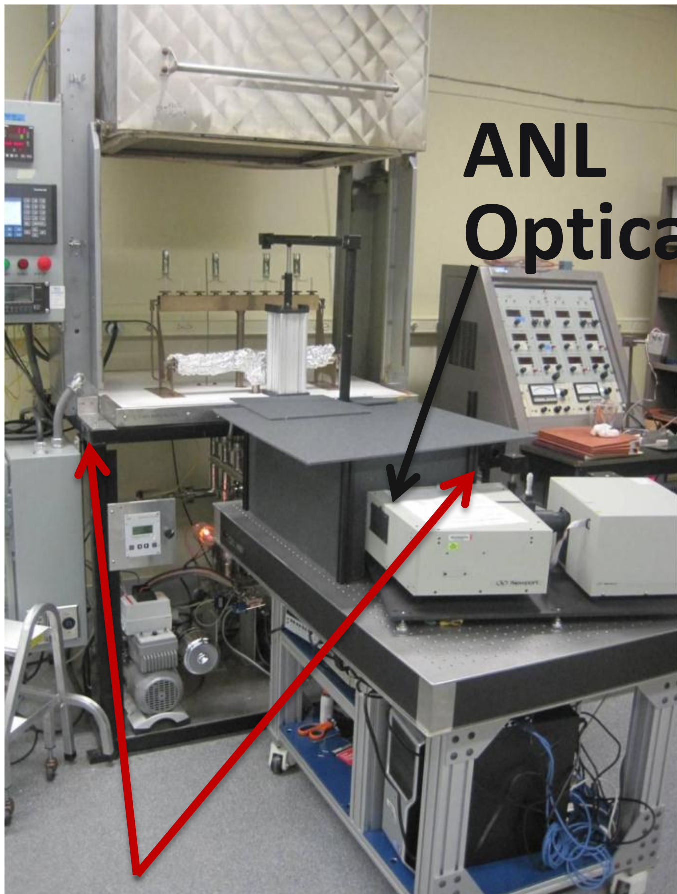
Photocathodes

oy- chemistry…

Photocathodes

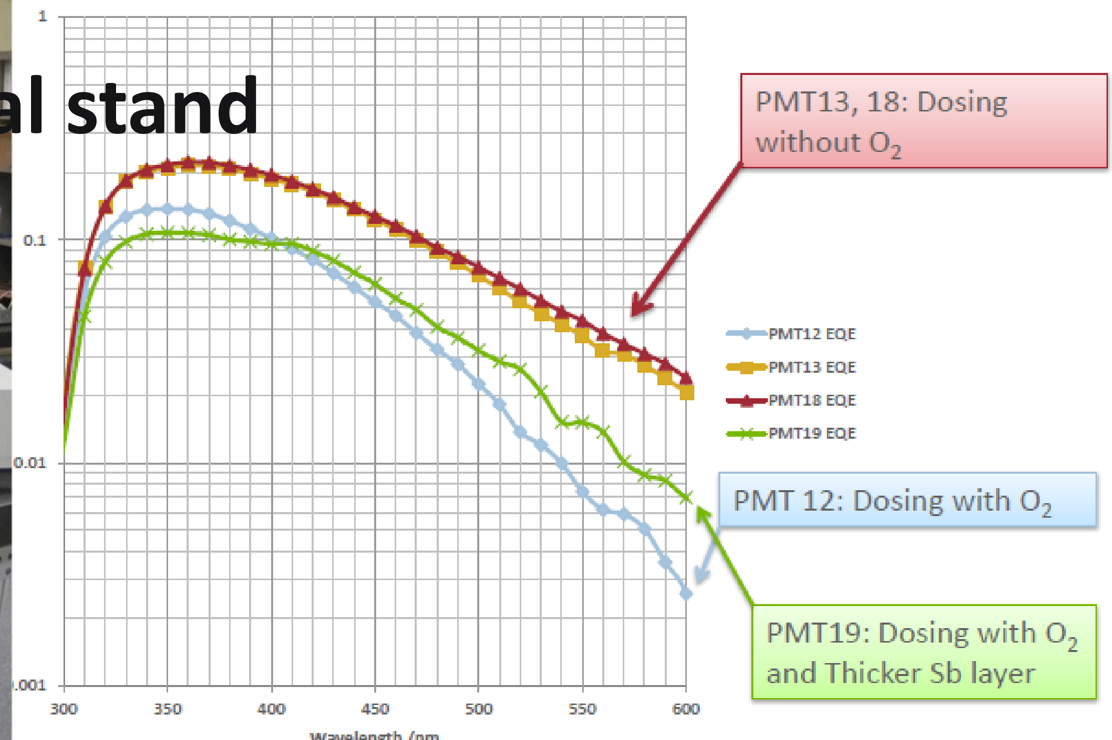
LAPPD goal- 20-25% QE, 8”-square- conv. alkali

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



ANL Optical stand

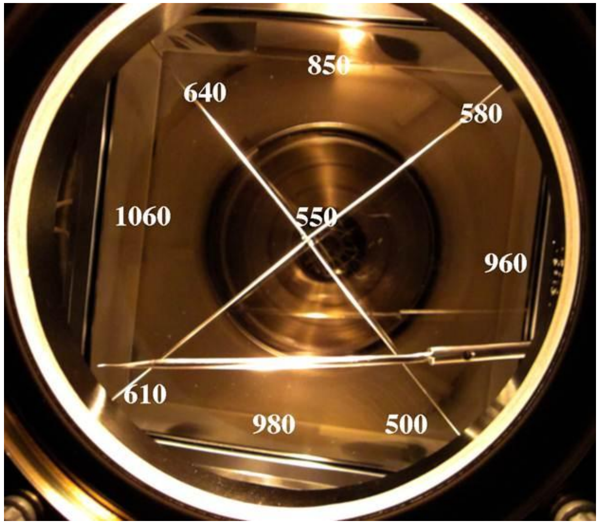
Burle commercial equipment



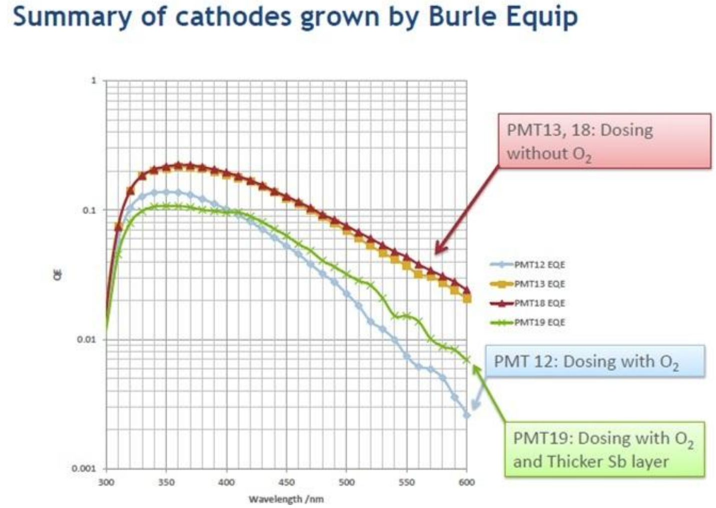
First cathodes made at ANL

Status of PhotoCathodes

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

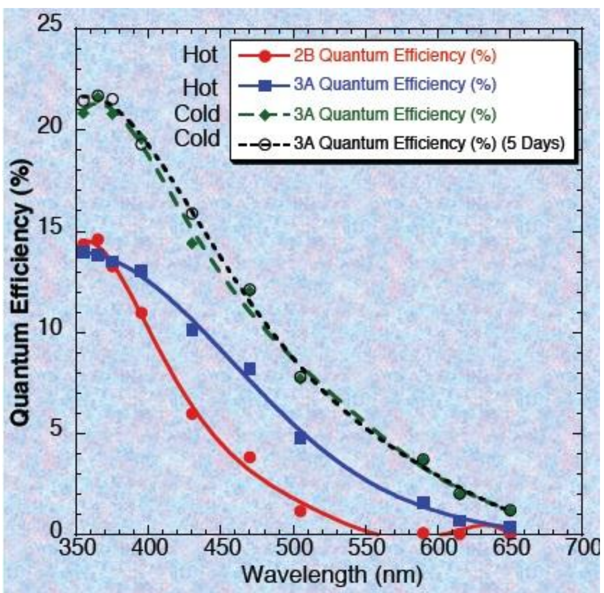


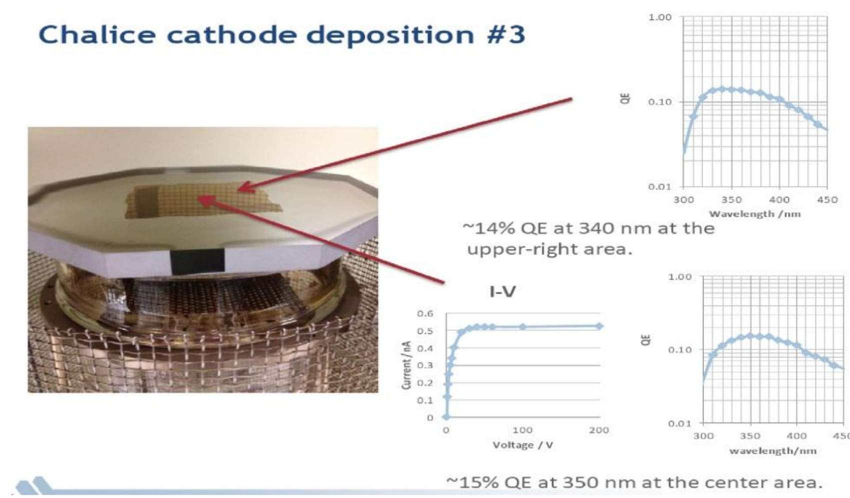
SSL 8" SbNaK cathode



ANL

QE of ANL small SbKCs cathodes



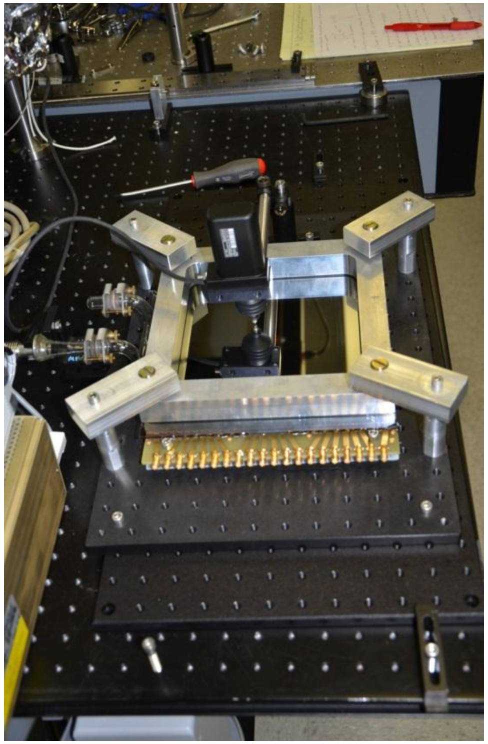


4" cathode: Chalice in Burle oven ANL

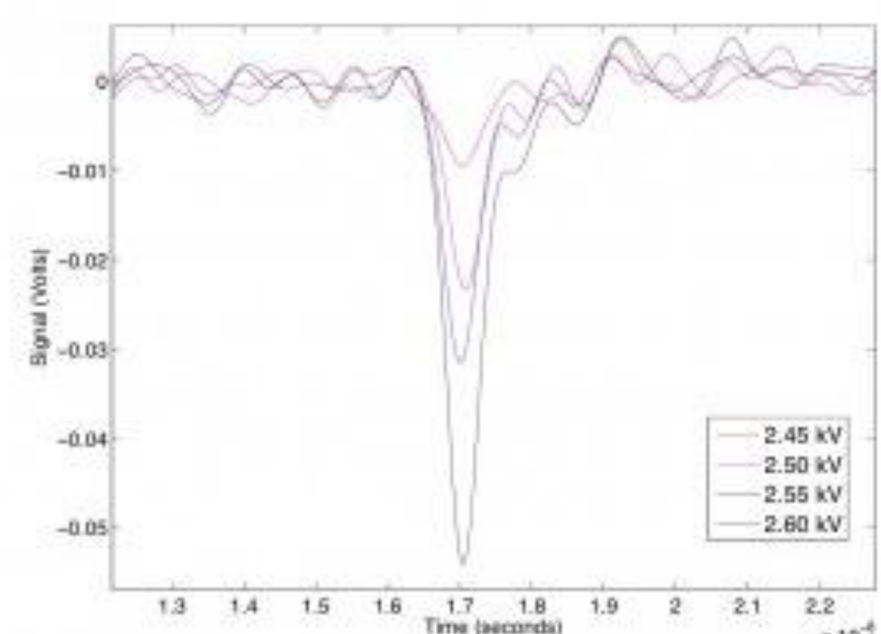
QE of SSL 8" SbNaK cathode

Results and Summary

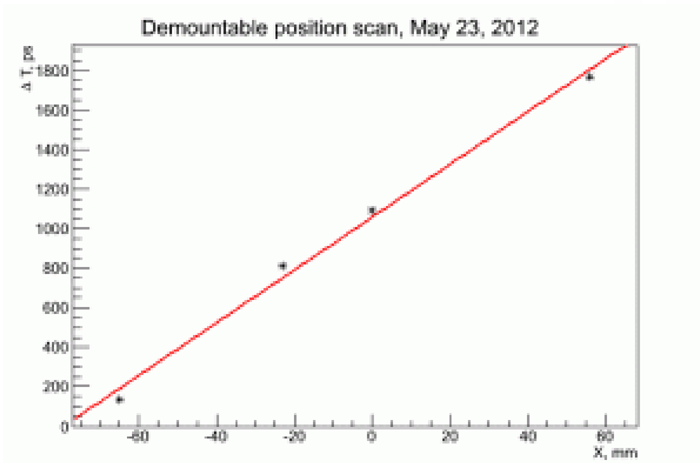
Demonstration of The Internal ALD HV Divider in the Demountable



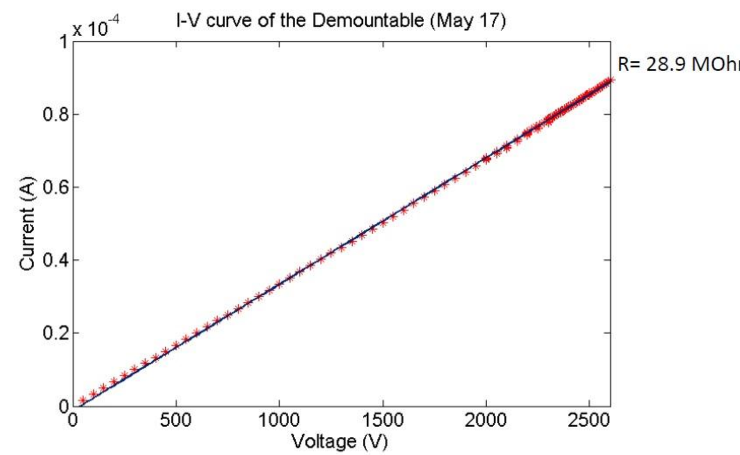
Demountable at APS



Average pulse shape vs HV



Scanning the laser: t vs x



IV Curve (expected 32 Megs)

Internal ALD HV Divider Scheme works?

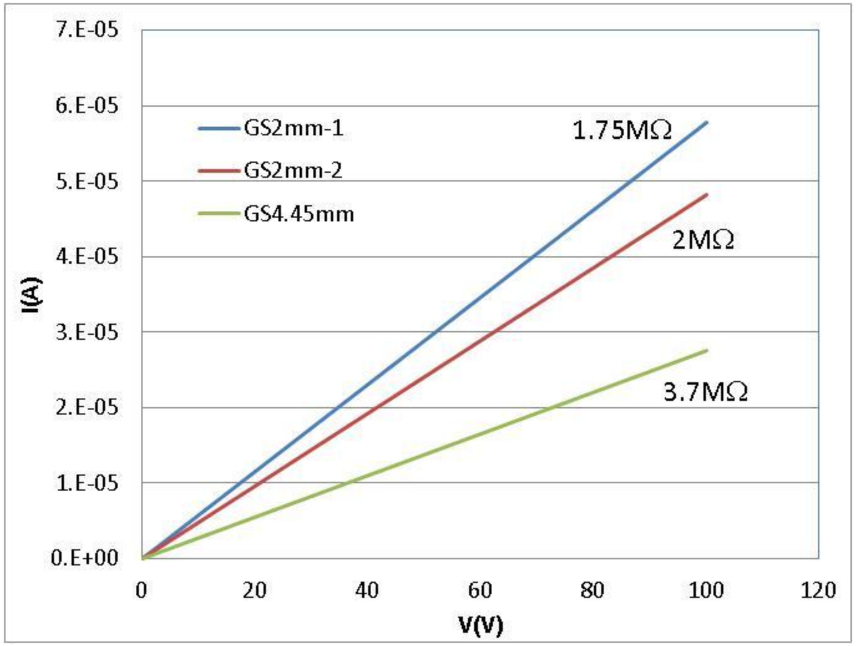
- Coat MCP's *and* spacers with ALD to form a completely internal resistive divider string-no pins

Anil Mane, Jeff Elam (ANL/ESD)

Layer	Thickness (mm)	R Layer(MOhm)	V(V)	I(μA)
grid A	2	1.7	170.0	100
MCP 1	1.2	8	800.0	100
grid B	2	2.0	200.0	100
MCP 2	1.2	10.0	1000.0	100
grid C	4.45	3.6	360.0	100
Total	10.85	25.3	2530.0	100

Resistances and voltages for the stack

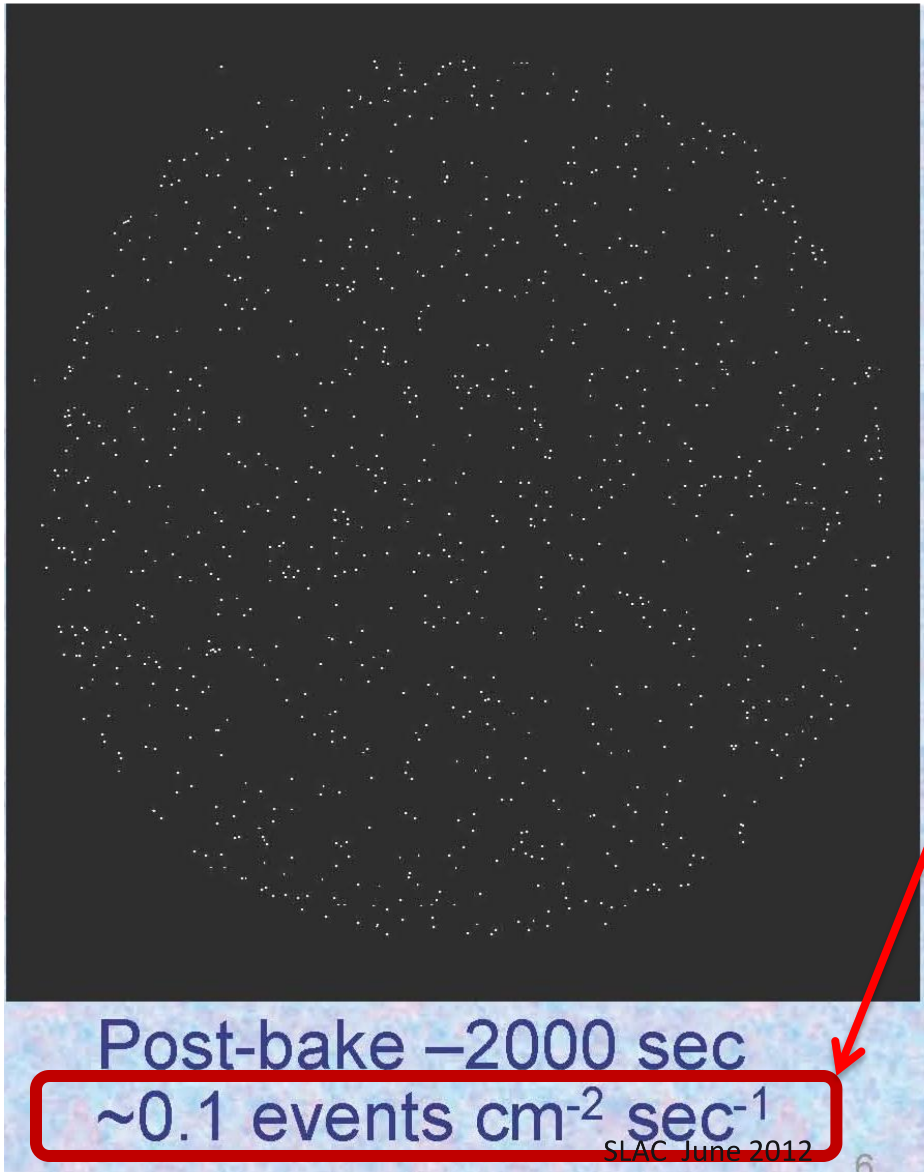
I-V Curves for the stack



Microchannel Plates-4b

Performance:

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



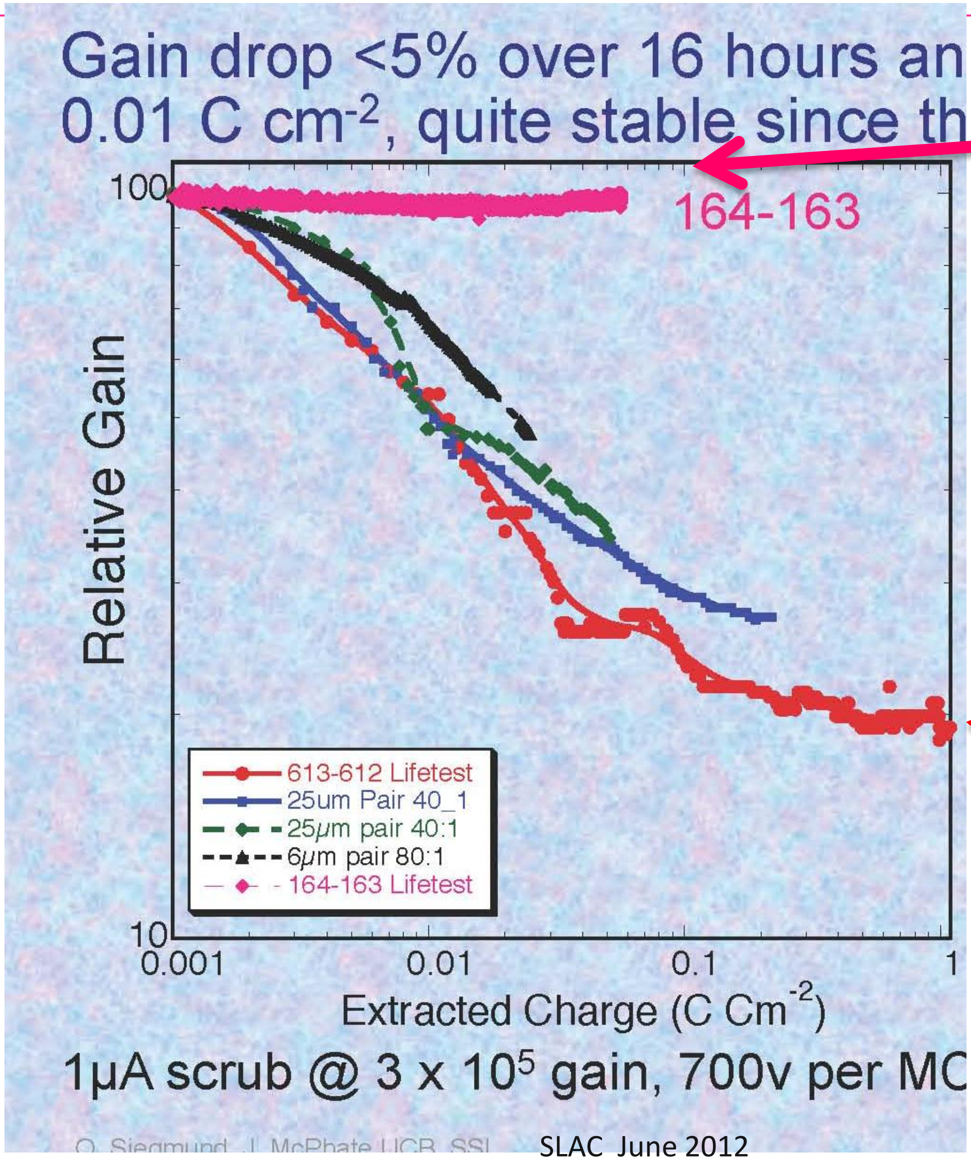
Noise (bkgd rate). <=0.1 counts/cm^2/sec; factors of few > cosmics (!)

Microchannel Plates-4d

Performance: burn-in (aka `scrub')

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

(Big deal commercially?)



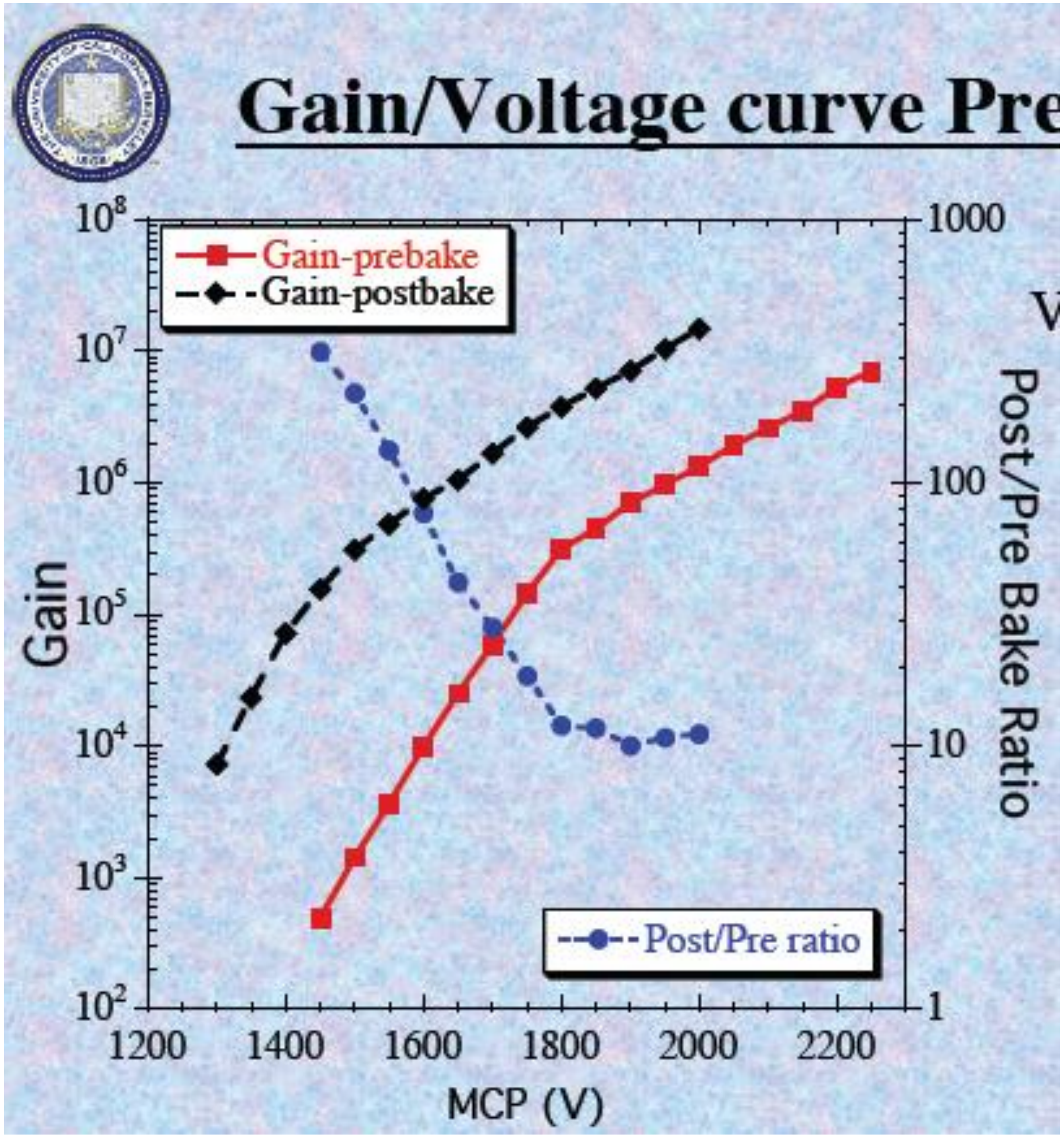
Measured ANL ALD-MCP behavior

(ALD by Anil Mane, Jeff Elam, ANL)

Typical MCP behavior- long scrub-times

Signal- want large for S/N

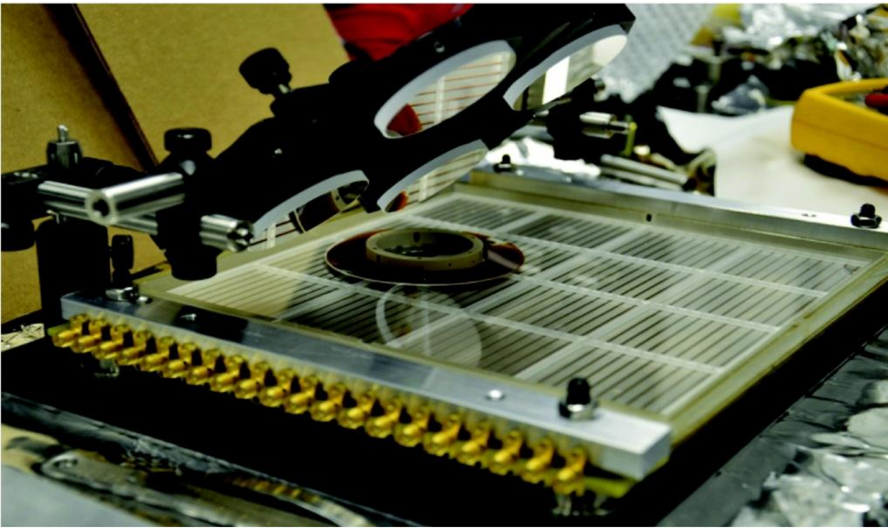
We see gains > 10^7 in a chevron-pair



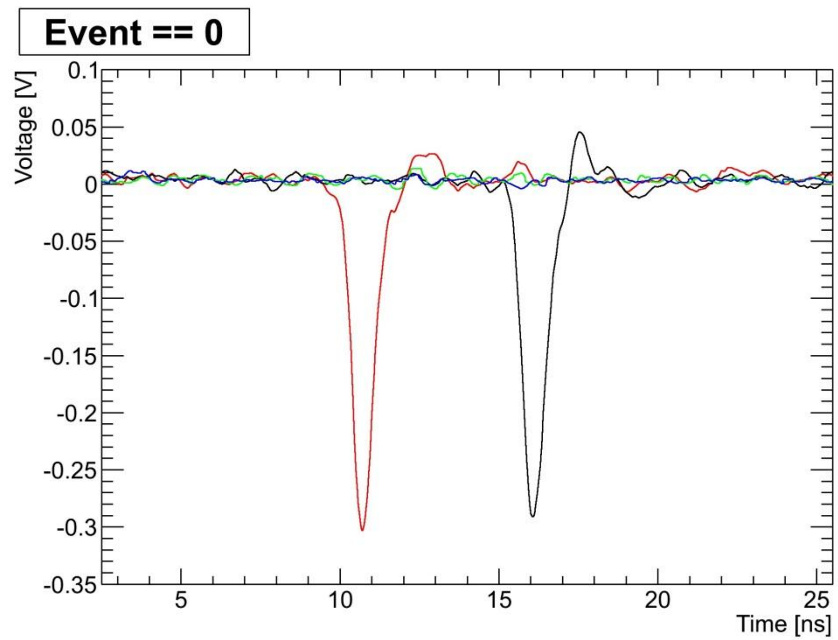
Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB

ALD by Anil Mane and Jeff Elam, ANL

Results From 8”-MCP Pair and Anode



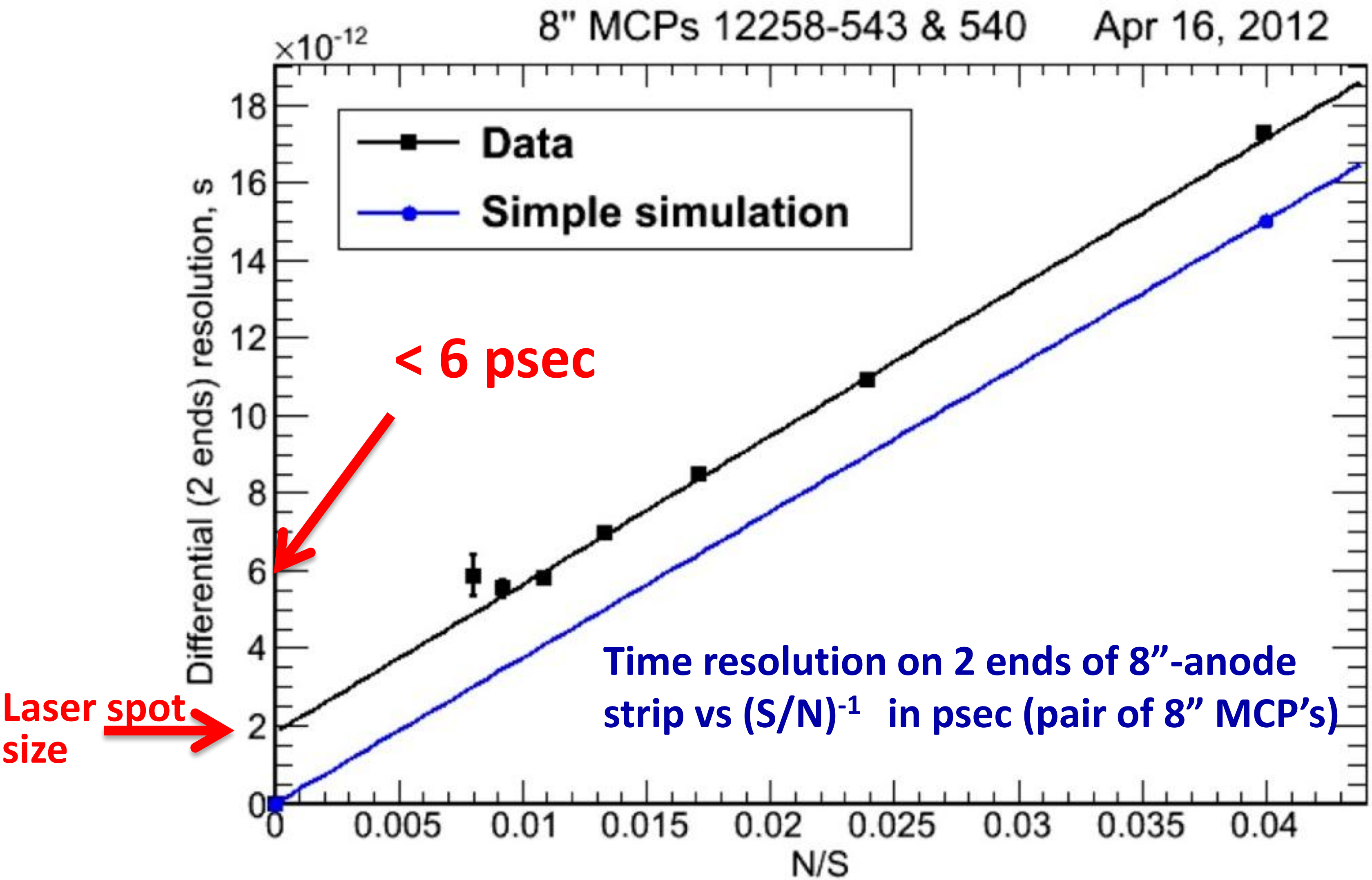
Laser mirrors and 8” anode for 8” MCP tests



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

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

Preview- LAPPD (rel) timing



N = RMS of the noise; S = signal amplitude

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

Opportunities and Challenges

(euphemism for problems)

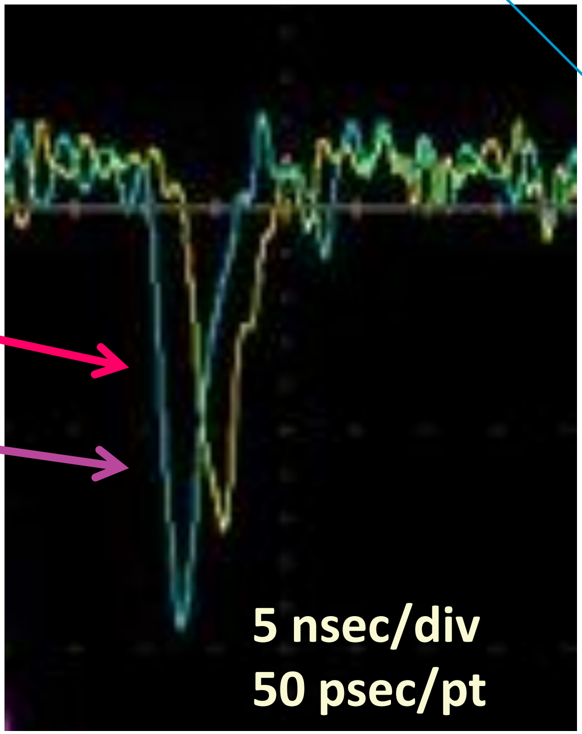
The 4 Determinants of Time Resolution

a) Signal/Noise (S/N)

b) Analog Band-width (ABW)

c) Sampling Rate

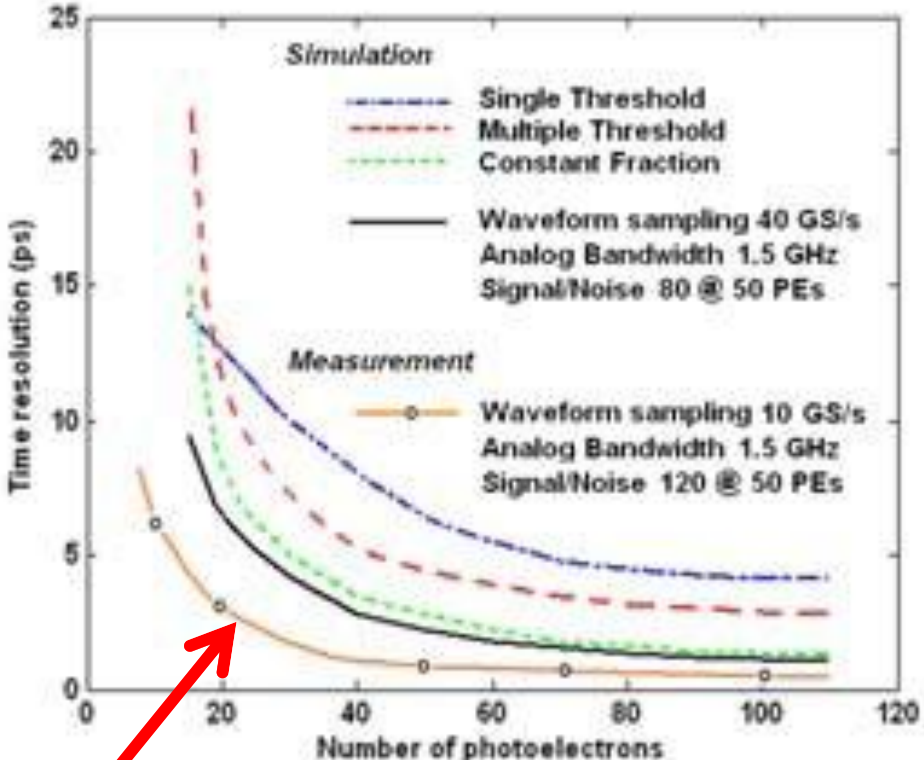
d) Signal statistics

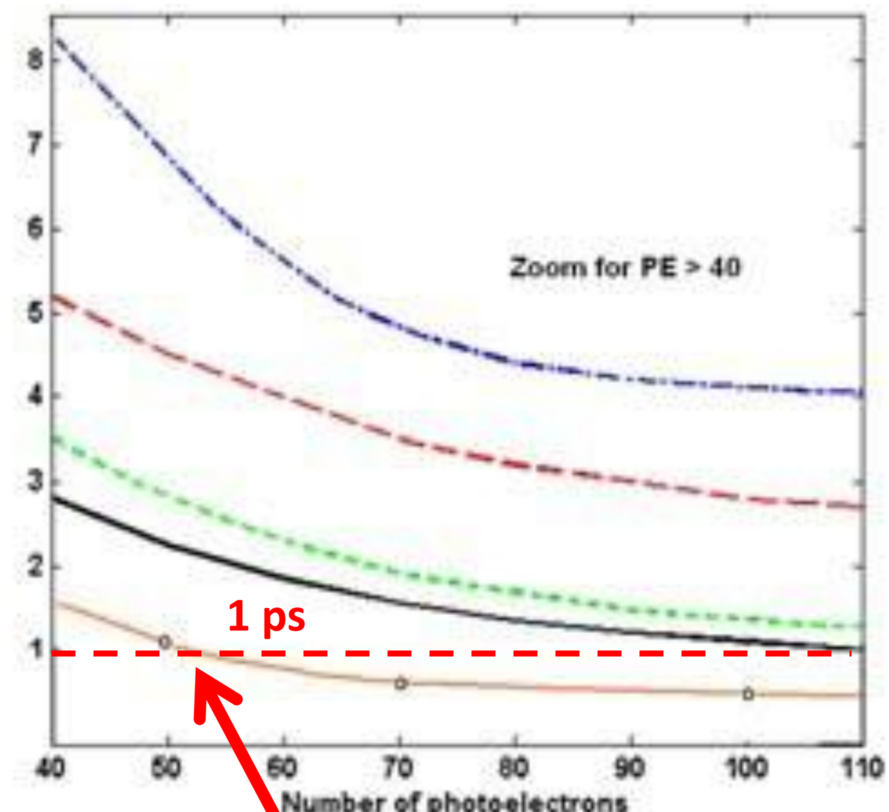


J.F. Genat, F. Tang, H. Frisch, and G. Varner; *Picosecond Resolution Timing Measurements,* Nucl. Instr. Meth A607, 387 (2009); Workshop on *The Factors that Limit Time Resolution in Photo-detectors,* University of Chicago, April 28-29, 2011

Simulation of Resolution vs abw

Jean-Francois Genat





This (brown) line

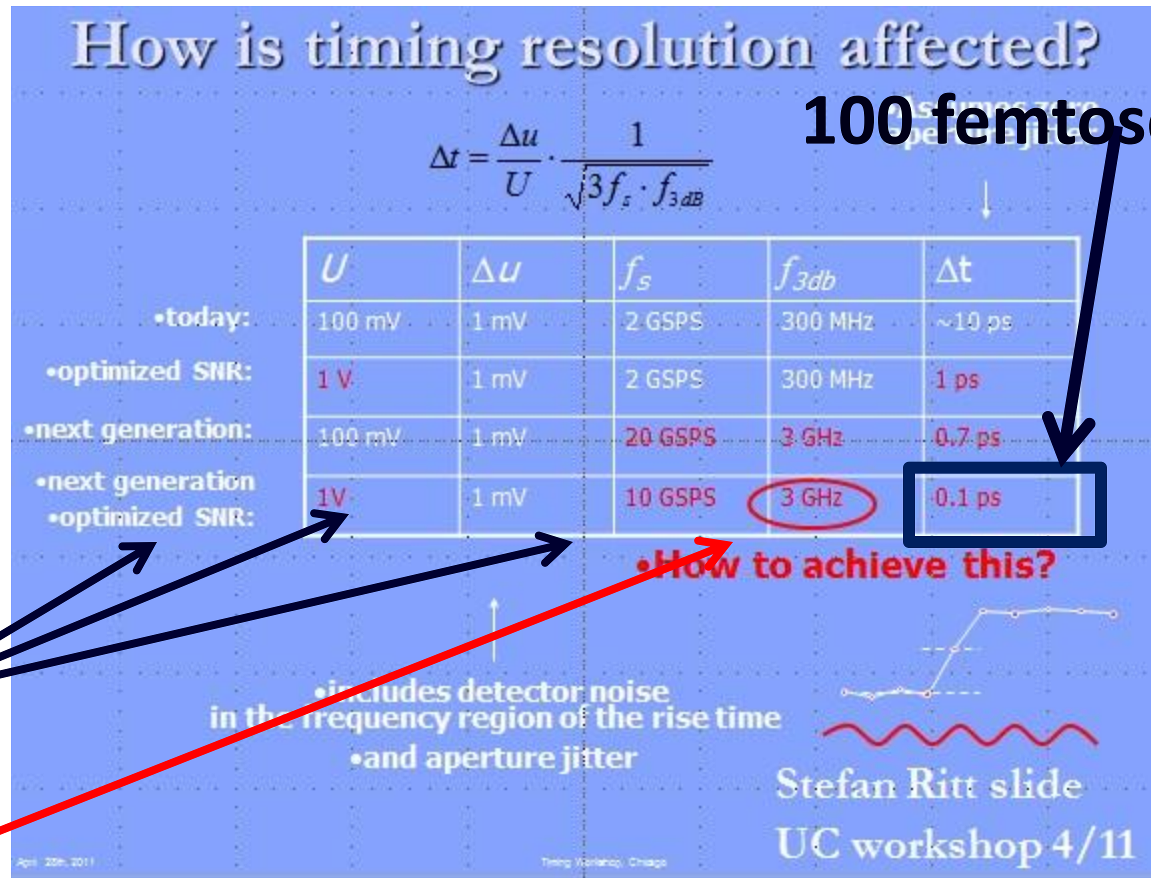
This (brown) line

Brown line: 10 Gs/sec (we've done >15);
1.5 GHz abw (we've done 1.6); S/N 120 (N=0.75mv, S is app specific)

Opportunities:Can we go deep sub-picosec?: the Ritt Parameterization

(agrees with JF MC)

Stefan Ritt slide, doctored



	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

100 femtosec

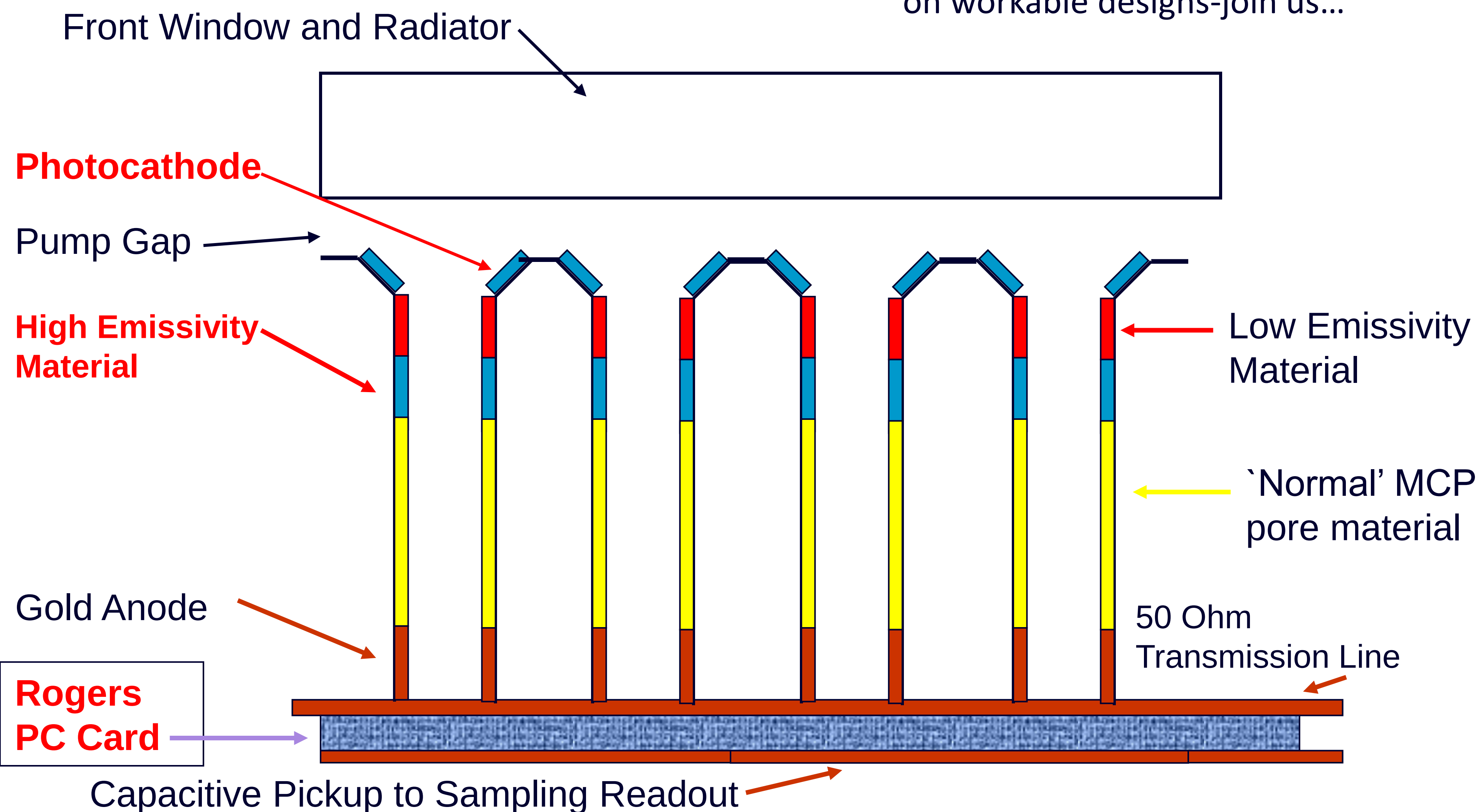
S/N, f_Z: DONE

abw: NOT YET

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…



Opportunities

- Sub psec timing –e.g. Ritt 100 fsec extrp.
- Tight pulse height (high SEY 1st strike)
- Photocathodes- QE's >45% (?)
- Non-vacuum transfer assembly
- Simpler top seal- (incl. metal for neutrons)
- Commercialization (SBIR/STTR)

Truth in Advertising- Current Problems

(remember we're only in 3rd yr)

- Uniformity of ALD (parallel efforts at ANL, Arradiance)- will be solved…
- Vacuum transfer assembly- ceramic in progress (SSL); several years for glass package most likely…
- `Frugal' top seal for glass package (progress)
- Optimization for specific applications (e.g. Collider, KOTO, HE and LE neutrinos, PET
- Lack of simulation for applications (help?)

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

oy- chemistry

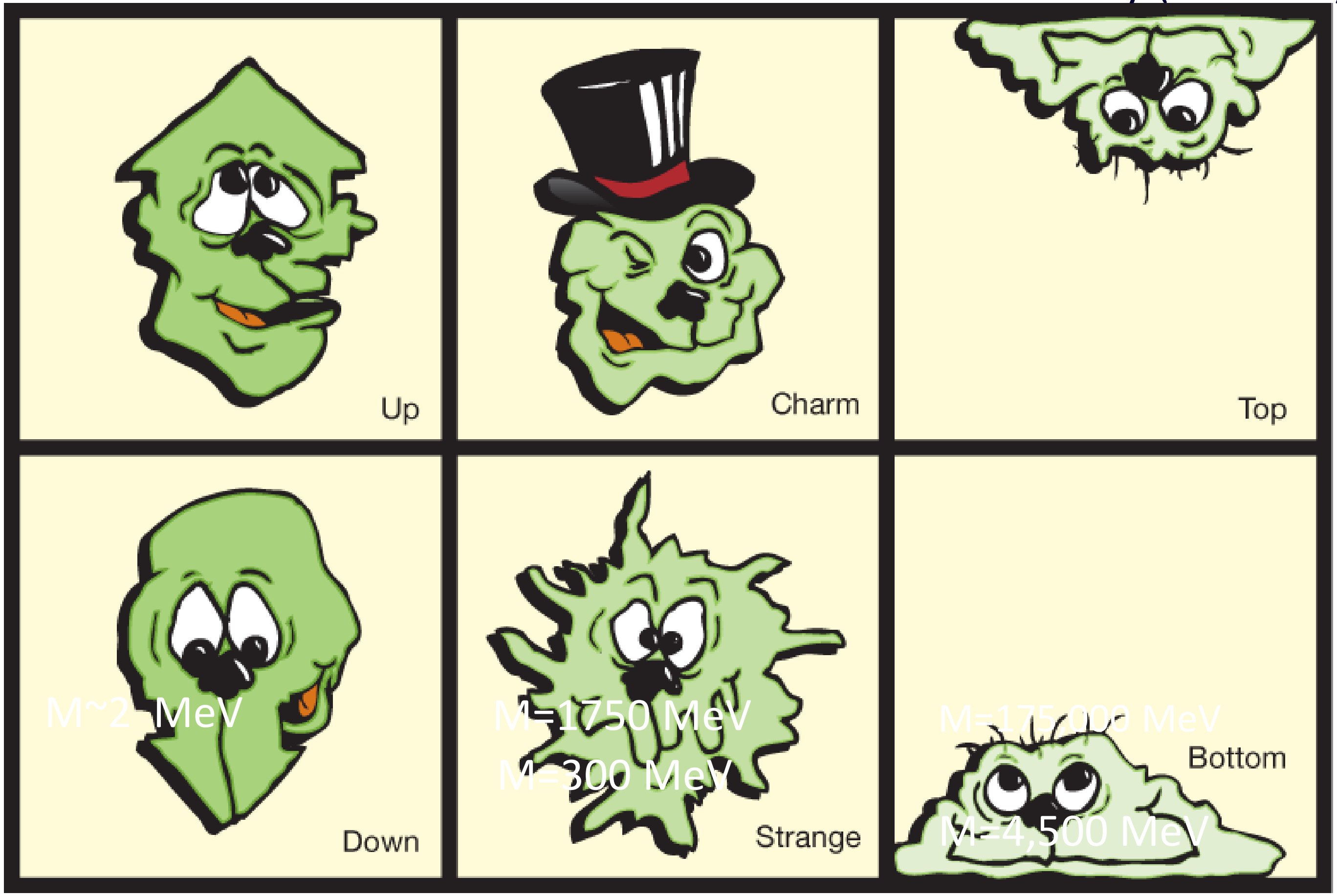
BACKUP SLIDES

The bizarre structure of basic matter

Nico Berry (nicoberry.com)

Charge +2/3e

Charge -1/3e

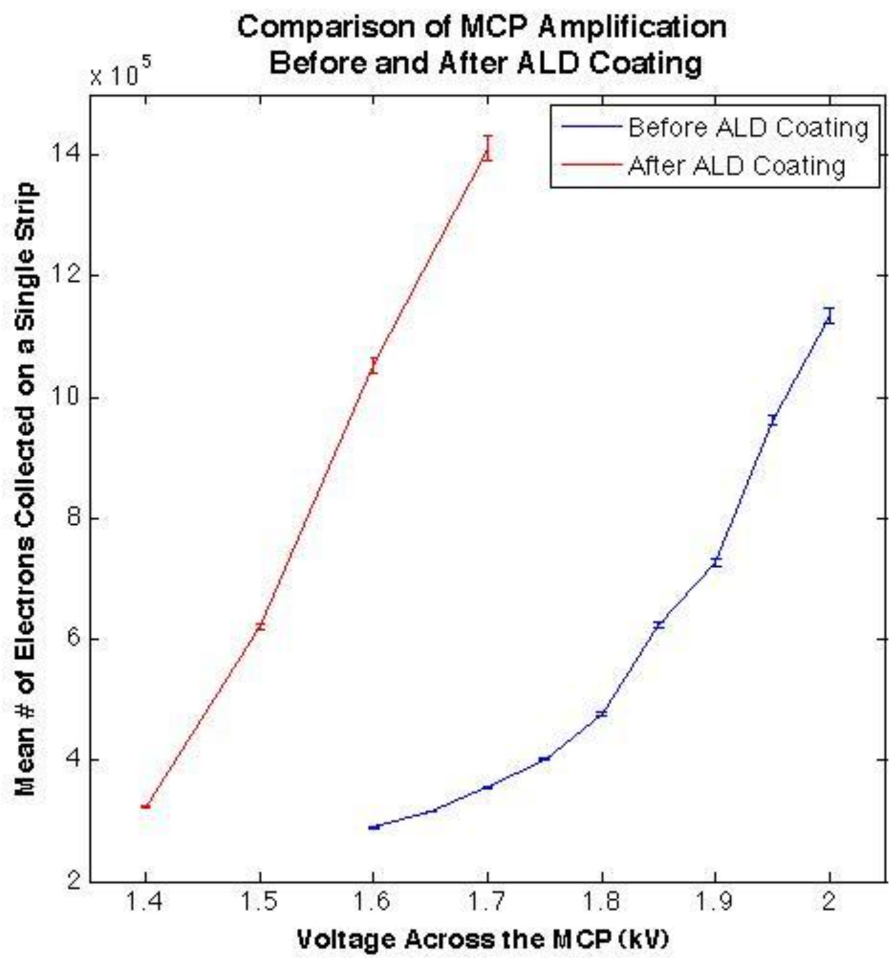


Distinguishable only by mass (and possibly lifetime)- hence measure velocity (v) and momentum (gmv) of the parent particle to find out m and thus the quark content.

MCP and Photocathode Testing

Testing Group: Bernhard Adams, Matthieu Cholet, and Matt Wetstein at the APS, Ossy Siegmund's group at SSL

N. B.!



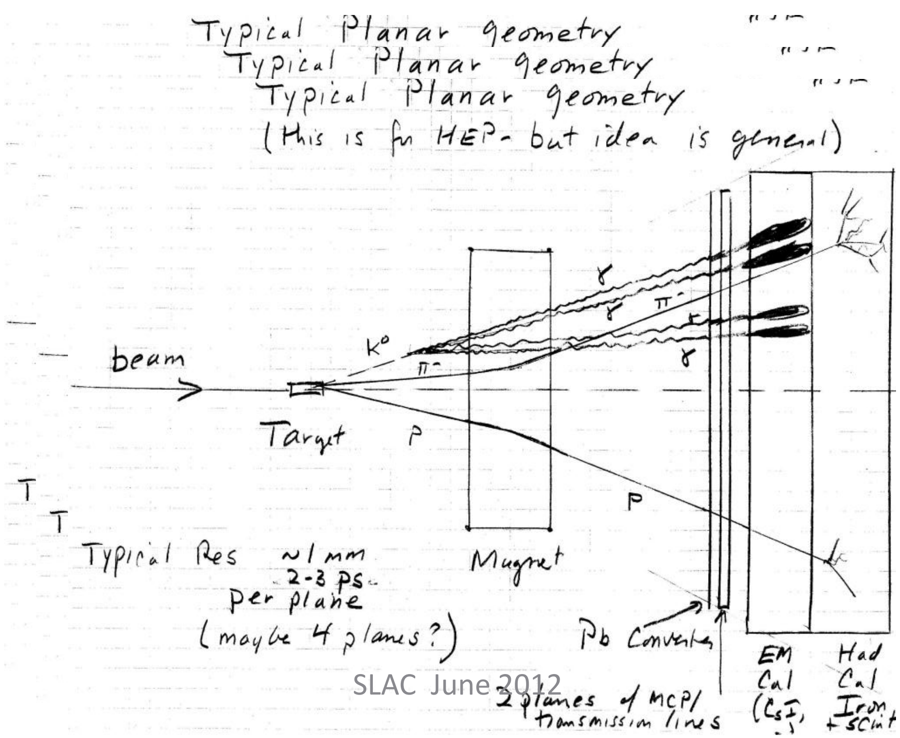
LAPPD Preliminary

(very)

First measurements of gain in an ALD SEE layer at the APS laser test setup

(Bernhard Adams, Matthieu Cholet, and Matt Wetstein)

K_L to pizero nu-nubar



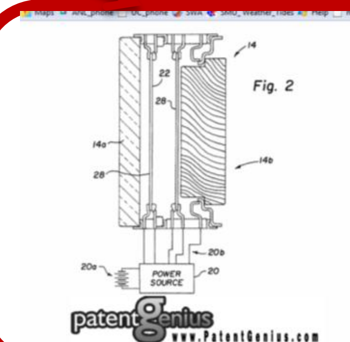
Hermetic Packaging

- Top Seal and Photocathode- this year's priority

3 parallel paths

Tile Development Facility at ANL

Production Facility at SSL/UCB

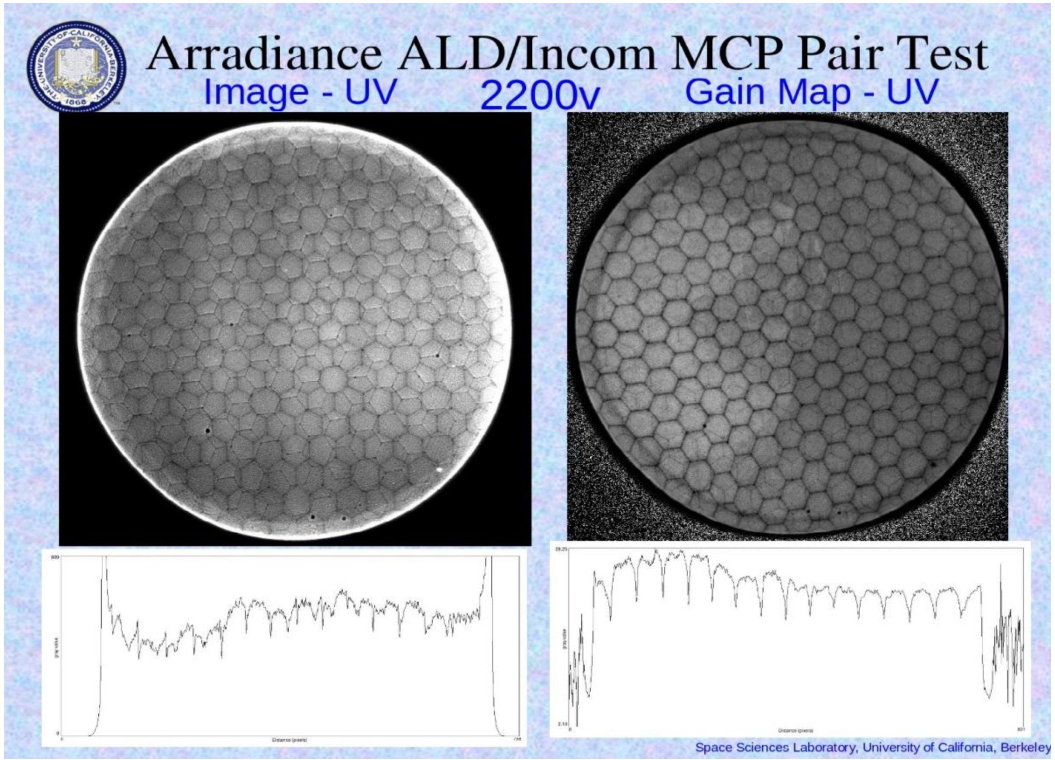


Commercial RFI for 100 tiles
(Have had one proposal for 7K-21K tiles/yr)

A `Quasi-digital' MCP-based Calorimeter

Idea: can one saturate pores in the the MCP plate s.t.output is proportional to number of pores. Transmission line readout gives a cheap way to sample the whole lane with pulse height and time- get energy flow.

Oswald Siegmund, Jason McPhate, Sharon Jelinsky, SSL (UCB)



Note- at high gain the boundaries of the multi's go away

Electron pattern (not a picture of the plate!)- SSL test, Incom substrate, Arradiance ALD. Note you can see the multi's in both plates => ~50 micron resolution

II STATE OF THE ART

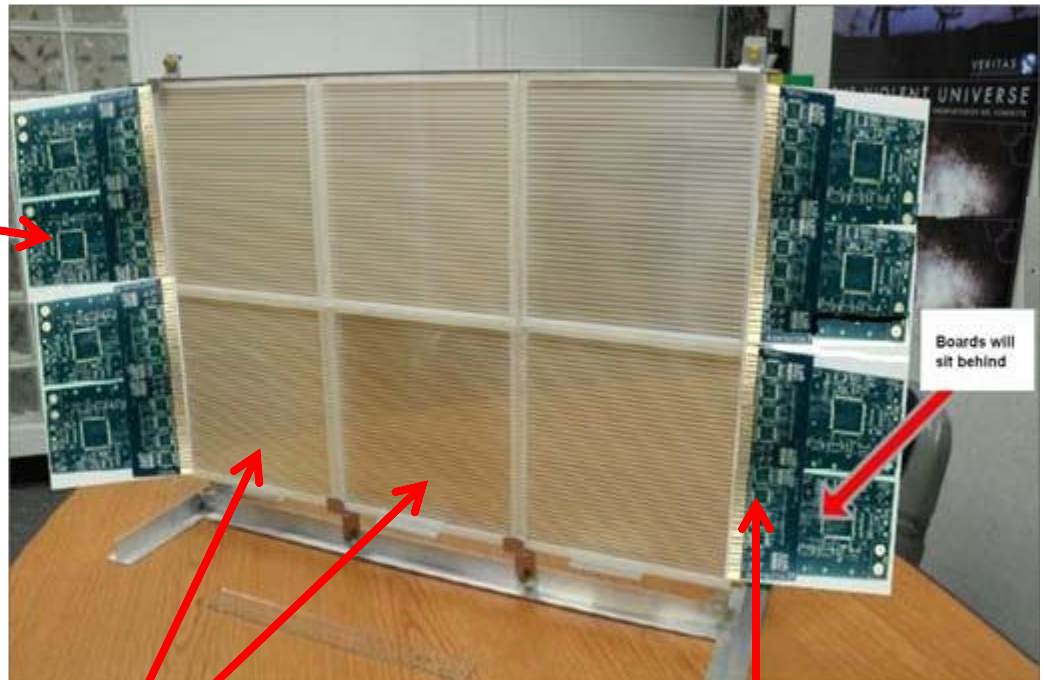
Several circuits have already been designed in the HEP community for fast pulse sampling, mainly to record photo-multipliers pulse shapes. As detailed in section I, fast timing requires higher sampling rates, but smaller dynamics ranges.

	Hawaii		Orsay/Saclay		PSI		PSEC
	Lab 3	Planned Blab2	Sam	Planned	DRS3	Planned DRS4	This proposal
Sampling frequency	20 MHz-3.7 GHz	1-10 GHz	0.7-2.5 GHz	10 GHz	10 MHz-5 GHz	5 GHz	40 GHz
Analog bandwidth	900 MHz	850 MHz	300 MHz	650 MHz	450 MHz	> DRS3	> 1 GHz
Number of Channels	9	16	2		12/6/2/1	8/4/2/1	16
Triggered mode	Common Stop	Channel trigger on sums	Common Stop		Common Stop	Common Stop	Channel trigger
Resolution		10 bit	11.6 bit		11.6 bit	11.5 bit	8-10 bit
Samples	256	4/8 rows of 512	256	2048	1024-12288	1024-8192	64
Clock	33 MHz	33 MHz	66 MHz		20 MHz	fsamp/2048	60 MHz
Max latency			5ms		0.6 ms		
Input Buffers		TIA (5kOhm gain)	Yes	No	No	No	Yes
Differential Inputs	No	Pseudo-diff	Yes		Yes	Yes	Pseudo diff
Input impedance	50 Ohms Ext	30-70Ohms adjustable	> 10 MOhm			7-11pF	
Readout clock		1 GHz Wilkinson	16 MHz		33 MHz	33 MHz	60 MHz
Readout time	150µs	512µs	< 2 µs		30ns * n samples	30ns * n samples	< 1 µs
Locked delays	Ext DAC	Ext DLL	Int DLL		Ext PLL	Int PLL	
On-chip ADC	Yes	1 GHz Wilkinson	No		No	No	Yes
R/W simultaneous		Yes	No		No	Yes	No
Power/ch	50mW	20mW/sample 0.2W/read	150 mW		1-13mW	2-20mW	
Dynamic range		1mV/1V	0.65mV-2V		0.35mV/1.1V	0.35/1V	1V
Xtalk	Average << 10%	< 0.1%	0.30%		<0.5%	<0.5%	
Sampling jitter		TBD	40ps		200ps (Ext PLL)	Ext PLL	10ps
Power supplies	2.5V	2.5V	0-3.3V		2.5V	2.5 V	1.8V
Process	TSMC 0.25	TSMC 0.25	AMS 0.35	AMS 0.18	UMC 0.25	UMC 0.25	CMOS 0.13
Chip area	2.5 mm2	12 mm2	10 mm2		25 mm2	25 mm2	1 mm2
Cost/channel		500$/40 10$/2k	15.7$/12k			10-15$	

Table 1. State of the art, this proposal. The yellow column is from Gary Varner's group at the University of Hawaii (USA) [12], the light blue from Dominique Breton from the University of Paris-Sud (Orsay) [10] and Eric Delagnes from CEA (Saclay), (France) [11]. The orange column from Stefan Ritt at PSI (Switzerland) [13]. The dark blue is this proposal.

MCP+Transmission Lines Sampled at Both Ends Provide Time and 2D Space

Field Programable Gate Arrays (not as shown- PC cards will be folded behind the panel- not this ugly…



Single serial Gbit connection will come out of panel with time and positions from center of back of panel

8" Tiles

10-15 GS/sec Waveform Sampling ASICS

Applications

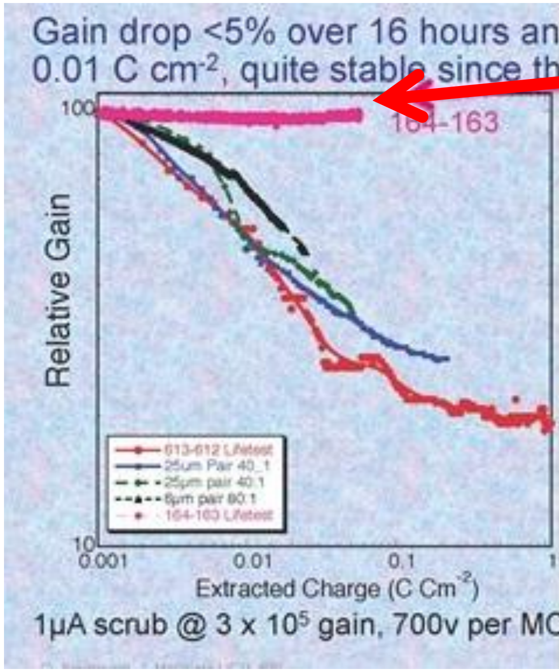
LAPPD Markets: Need. Applications. Benefit. and Competition

Application	Market Need	Approach	Benefit	Competition
Non-cryogenic Tracking Neutrino Detectors	HEP-Fermilab	Very-large-area, bialkali-cathode	Bkgd rejection, Cost, Readiness	Liquid Argon
LE Neutron Detection	Neutron Diffraction	B or Gd Glass, no cathode	Time and Position resolution, pulse shape γ/n differentiation, Large area	He3, B tubes
LE Neutron Detection	Transportation Security	B or Gd Glass, no cathode	Large area pulse shape γ/n differentiation, Large area	He3, B tubes
LE Anti-Neutrino Detection	Reactor Monitoring	Large-area, bialkali-cathode	Efficiency, Cost	PMT's, SiPMs
HE Collider Vertex Separation	CERN	Psec TOF	Resolution, Radiation-Hard	Silicon Vertex
HE Collider Particle ID	CERN, Future Lepton Collider	Psec TOF	Resolution, Reach in P_T	None
π^0/η Reconstruction and ID	Rare K Decays (JPARC), Fermilab	Psec TOF	Combinatoric Bkgd Rejection	Conventional TOF
Strange Quark ID	RHIC (BNL), ALICE (LHC) Collider	Psec TOF	Resolution, Reach in P_T	dE/dx
Positron-Emission Tomography	Clinical Medical Imaging	TOF, Large Area	Lower Dose Rate, Faster throughput	SiPM

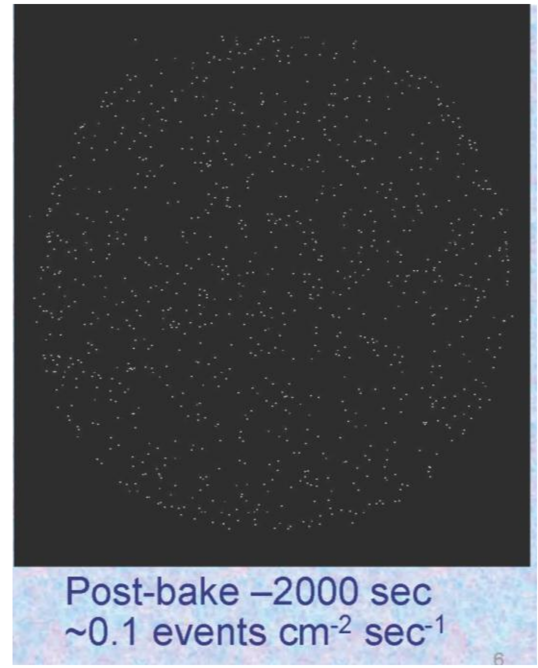
SRI's NABC Approach http: //www.itu.dk/~jeppeh/DIKP/NABC.pdf (sic- Denmark?)

LAPPD Performance

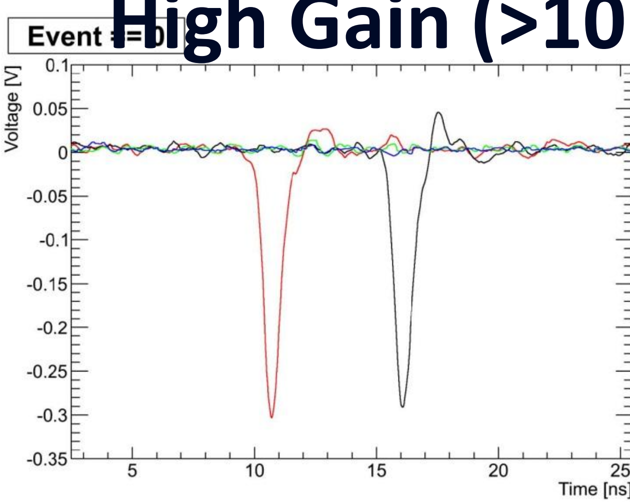
Fast Preconditioning



Low noise

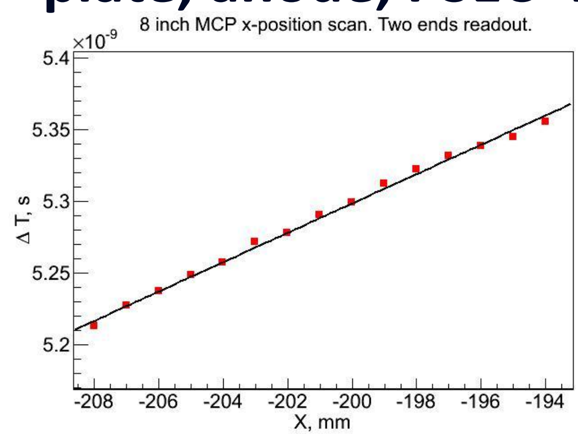


High Gain (>10⁷)



400 micron resolution

(8" plate, anode, PSEC-4)



Application 4-
Cherenkov-sensitive Sampling Calorimeters

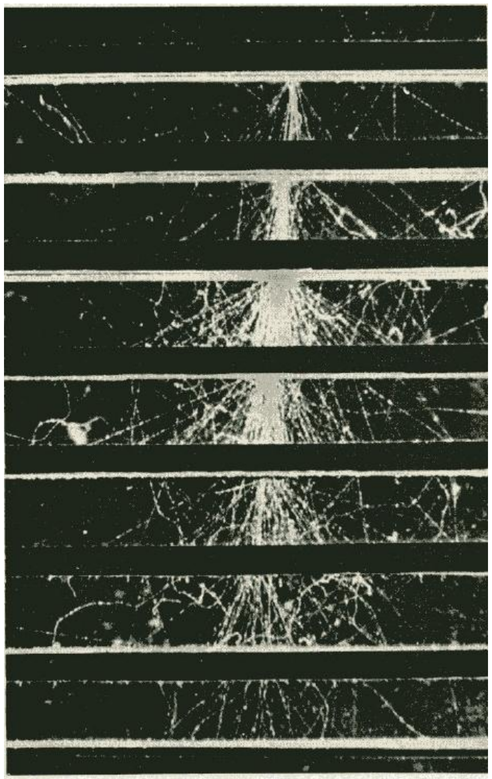
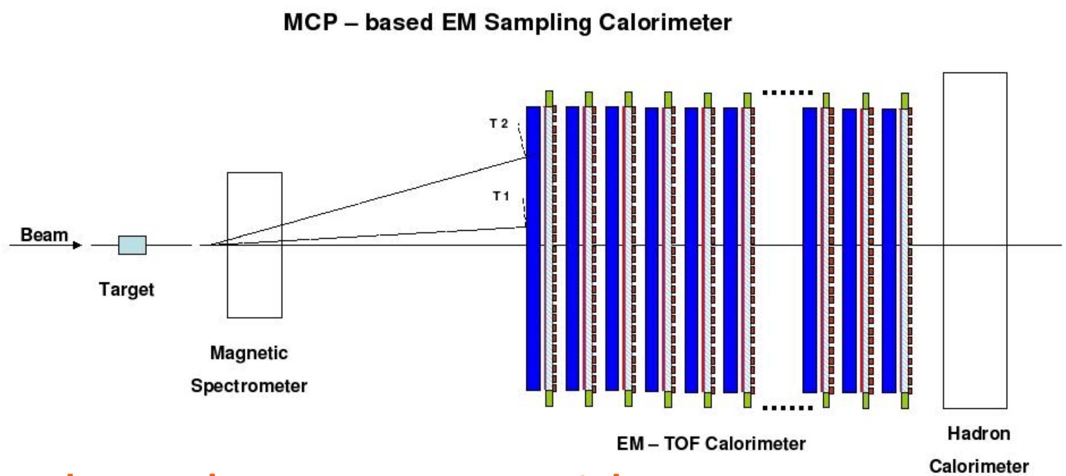
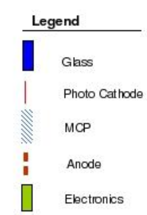


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.

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



Idea: planes on one side read both Cherenkov and scintillation light- on other only scintillation.



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

Detector Development- 3 Prongs

MCP development- use modern fabrication processes to control emissivities, resistivities, out-gassing

Use Atomic Layer Deposition for emissive material

(amplification) on cheap inert substrates (glass capillary arrays, AAO). Scalable to large sizes; economical; pure – i.e. chemically robust and (it seems- see below) stable

Readout: Use transmission lines and modern chip technologies for high speed cheap low-power high-density readout.

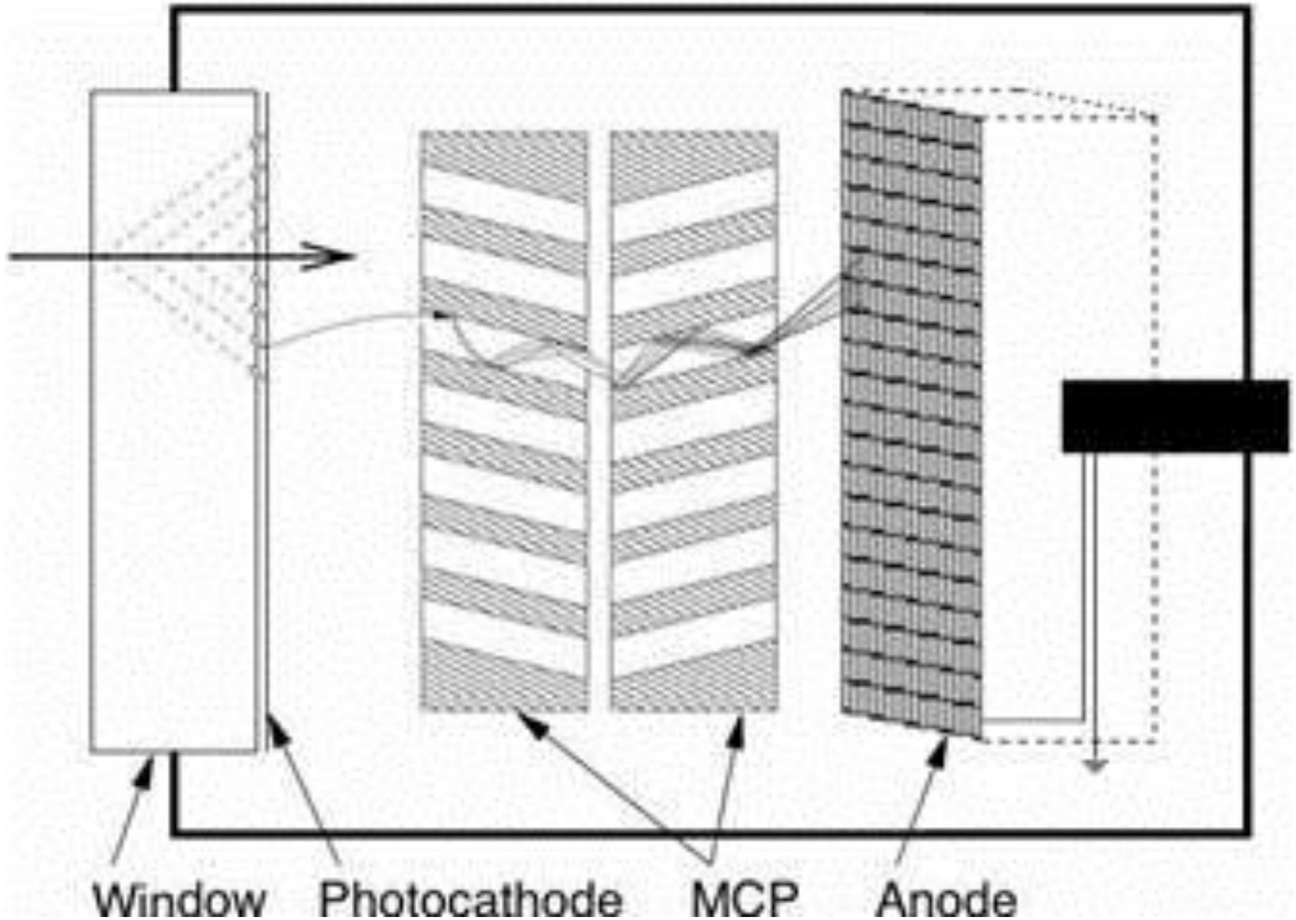
Anode is a 50-ohm stripline. Scalable up to many feet in length ; readout 2 ends; CMOS sampling onto capacitors- fast, cheap, low-power (New idea- make MCP-PMT tiles on single PC-card readout- see below)

Use computational advances -simulation as basis for design

Modern computing tools allow simulation at level of basic processes- validate with data. Use for `rational design' (Klaus Attenkofer's phrase).

Micro-channel Plates PMTs

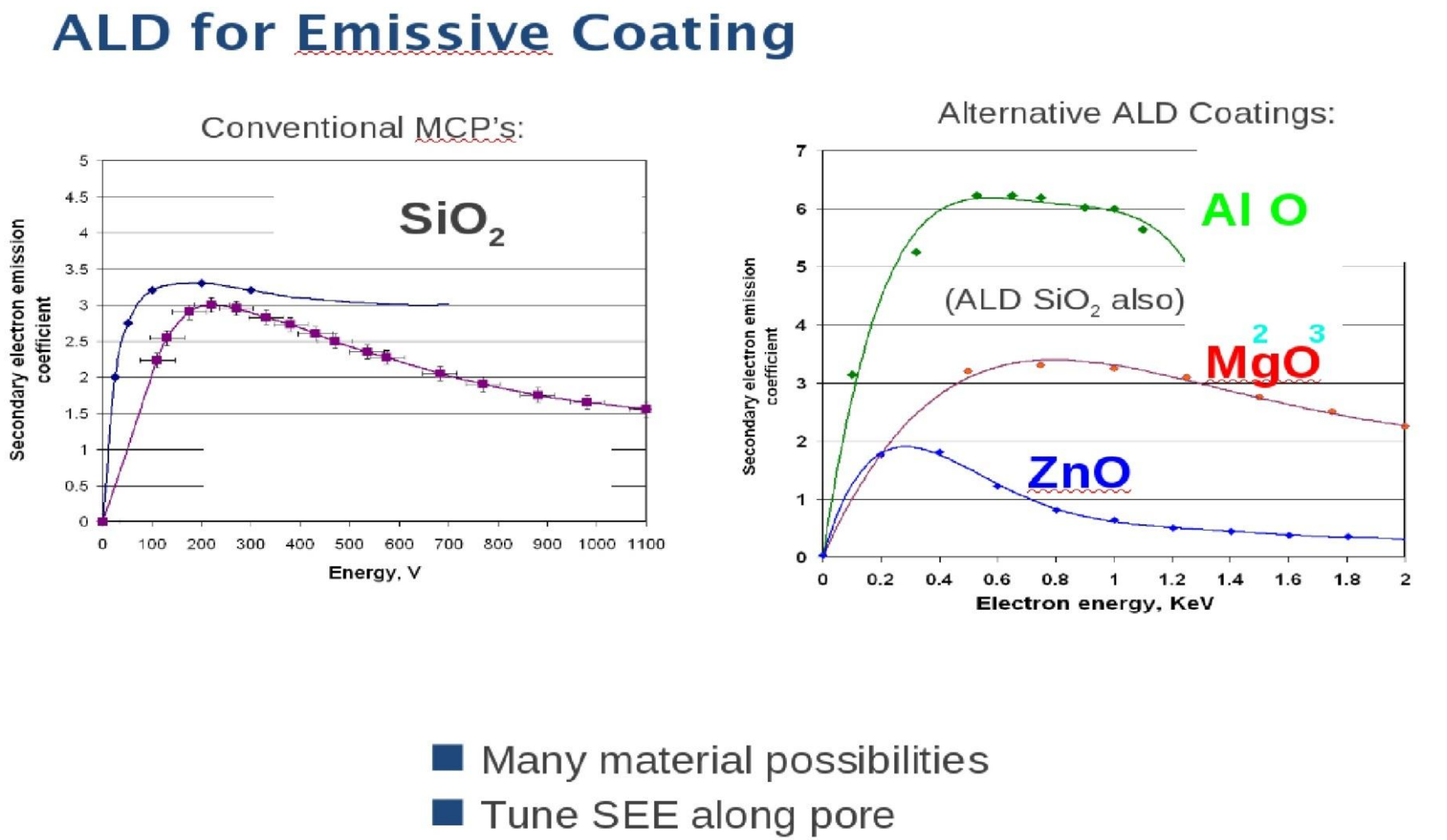
Satisfies small feature size and homogeneity



Photon and electron paths are short- few mm to microns=>fast, uniform Planar geometry=>scalable to large areas

ALD for Emissive Coating

Conventional MCP's: Alternative ALD Coatings: (ALD SiO_2 also)



- Many material possibilities
- Tune SEE along pore (HF- possible discrete dynode structure (speed!)

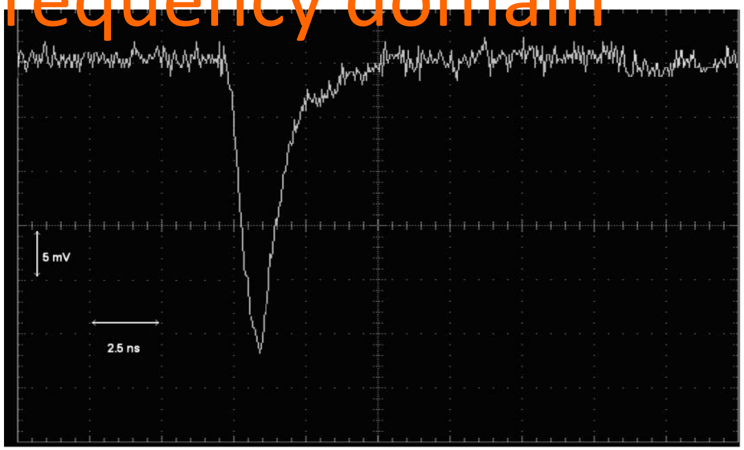
Jeff Elam ,
Zeke Insepov,
Slade Jokela

Front-end Electronics/Readout

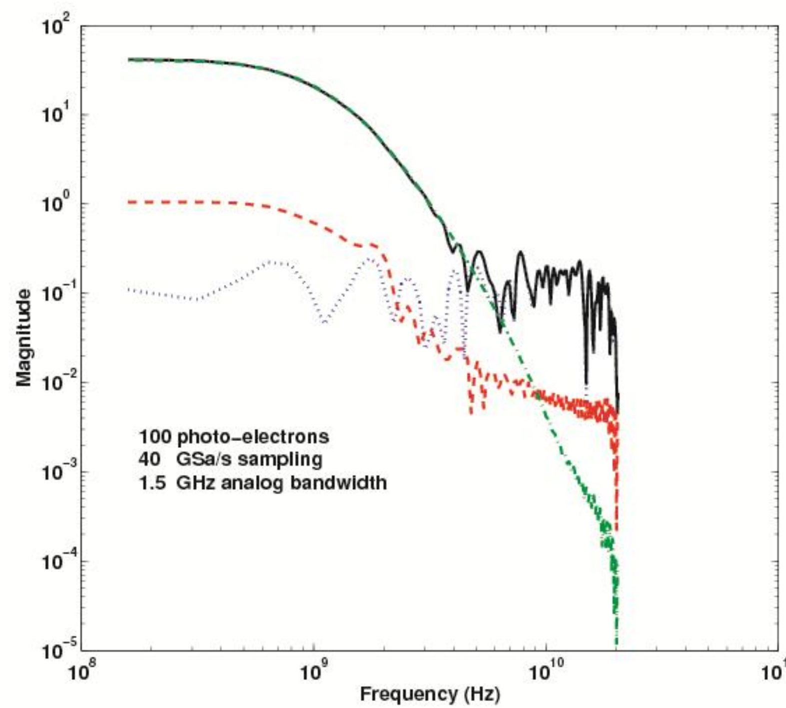
Waveform sampling ASIC

Electronics Group: Jean-Francois Genat, Gary Varner, Mircea Bogdan, Michael Baumer, Michael Cooney, Zhongtian Dai, Herve Grabas, Mary Heintz, James Kennedy, Sam Meehan, Kurtis Nishimura, Eric Oberla, Larry Ruckman, Fukun Tang

First have to understand signal and noise in the frequency domain



A typical MCP signal (Planacon)



Frequency spectra of signal and noise (JF Genat)

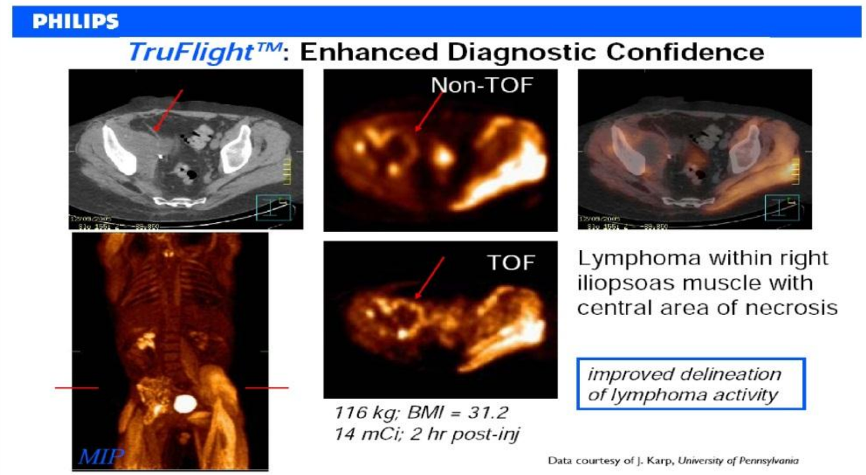
Application 3- Medical Imaging (PET)

TOF adds 3rd dimension to Positron-Emission Tomography

TOF (Effective Efficiency) Gain for Whole-Body PET (35 cm)

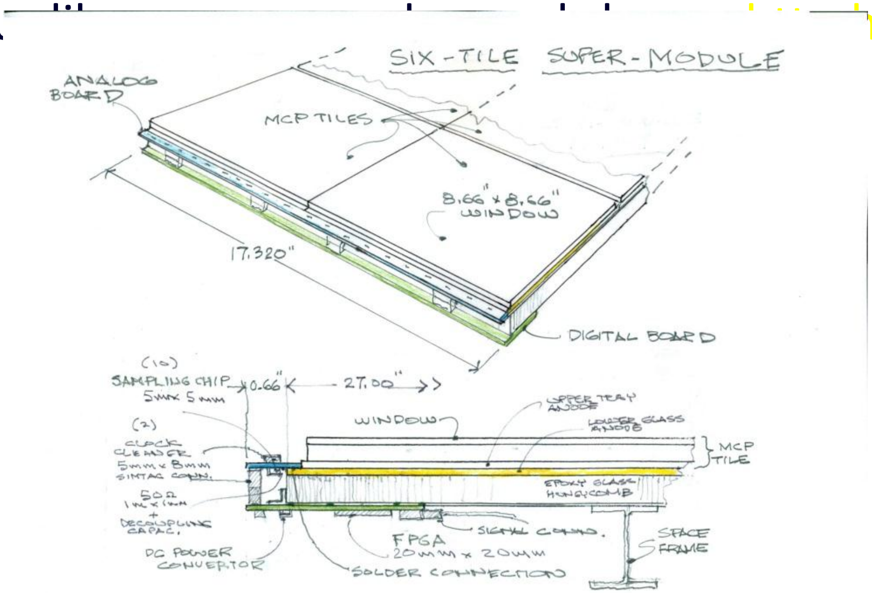
Hardware	Δt (ps)	TOF Gain
BGO Block Detector	3000	0.8
LSO Block (non-TOF)	1400	1.7
LSO Block (TOF)	550	4.2
$LaBr_3$ Block	350	6.7
LSO Side Coupled	250	9.3
LSO Small Crystal	210	11.1
LuI_3 Small Crystal	125	18.7
$LaBr_3$ Small Crystal	70	33.3

- ***Incredible*** **Gains Predicted**
- ***Nothing*** **Else Can Give Us Gains of This Size!**



Slides from Bill Moses's talk at the Clermont Workshop

(see ou ... hep.uchicago.edu/psec)

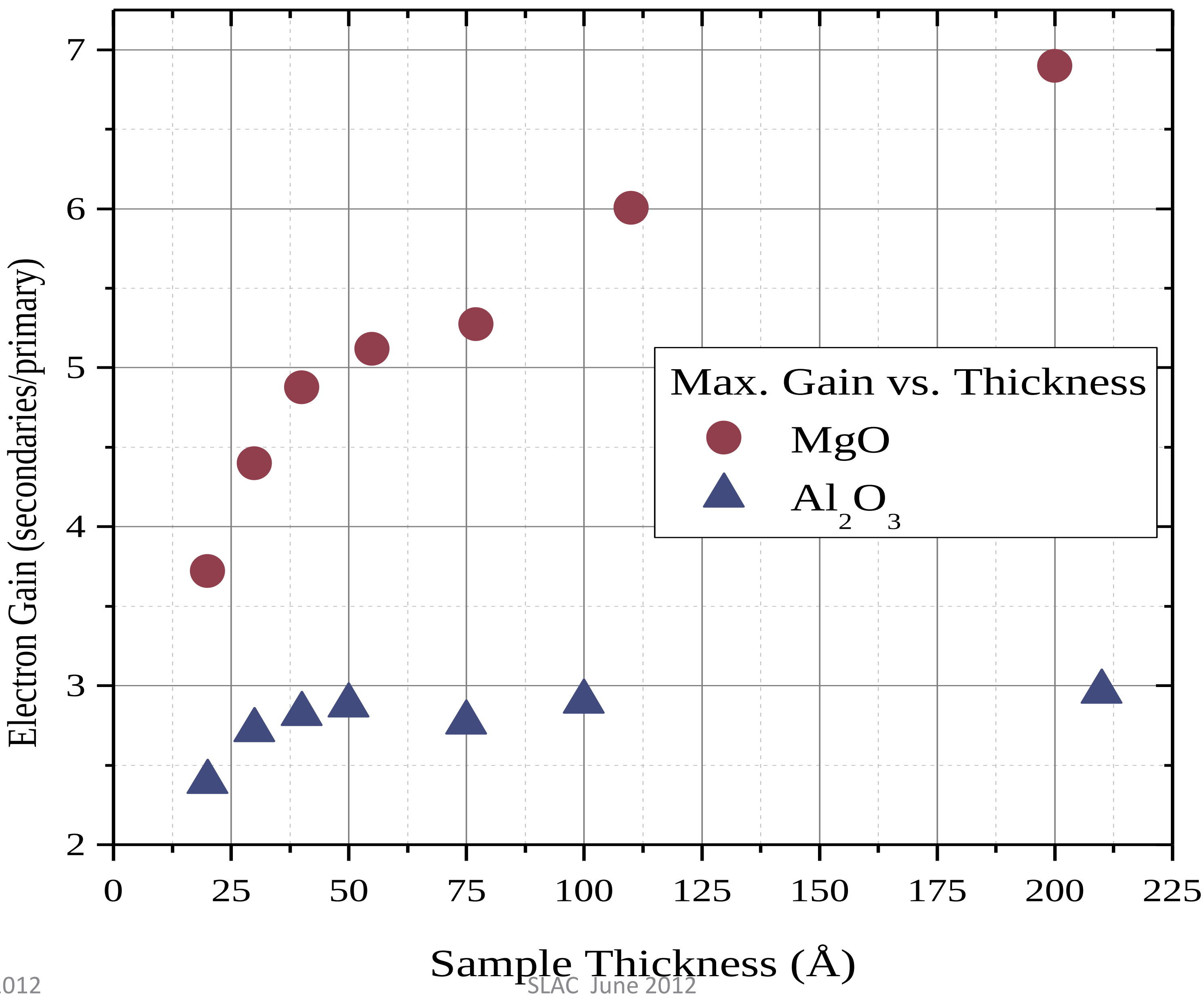


Clinical flat-bed scanner?

Low-density multi-layer sampling gamma detectors?

Cheap robust electronics

Real-time imaging?



Max. Gain vs. Thickness
MgO
Al2O3
Electron Gain (secondaries/primary)
Sample Thickness (Å)
2
3
4
5
6
7
0
25
50
75
100
125
150
175
200
225

What sets the 1 psec goal for HEP?

Separation with a 1.5-m Radius Solenoid (CDF)

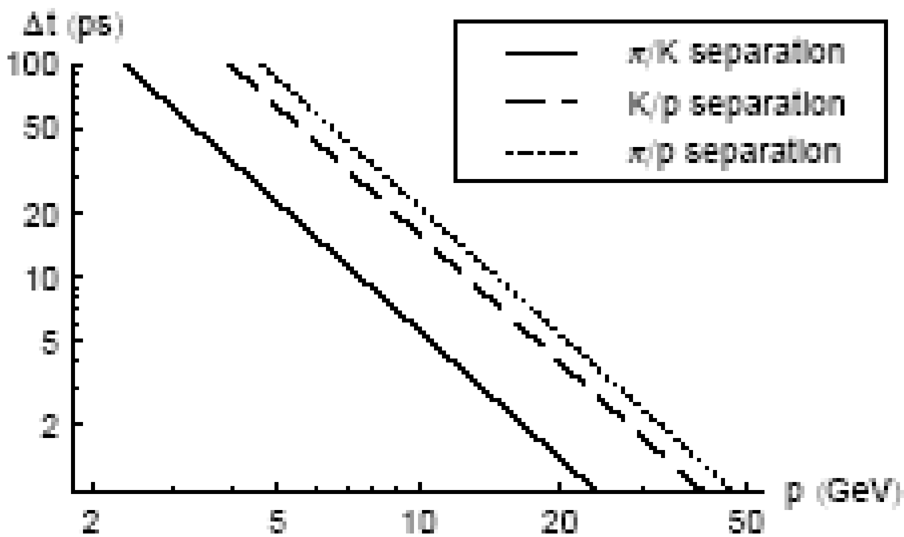


Figure 4: Contours of 1-sigma separation for pions, kaons, and protons versus the time resolution of the particle flight time over a 1.5-meter path for a detector with 1psec resolution.

Getting the Start Time: t_0.

Collisions at the Tevatron (e.g.) have a distribution in times with a sigma of ≈ 1.4 nsec (1.4 thousand psec's). Rather than measure the start time, t_0, at the origin, we fit the tracks from a single vertex for the t_0. At present we do this with the tracking chamber (COT), with a resolution on the order of a nsec. At CDF: t_0 is correlated with z_{vertex}! (From the new TAMU EM timing system in CDF (Goncharov, Krutelyov, Toback)).

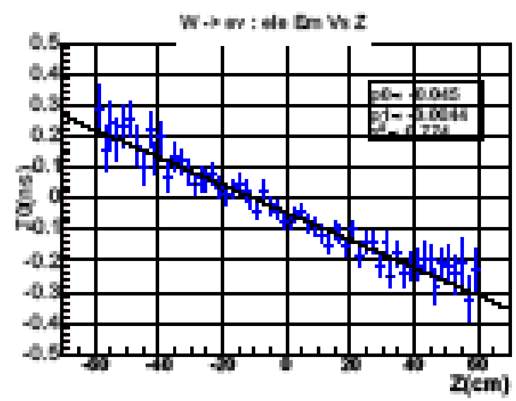
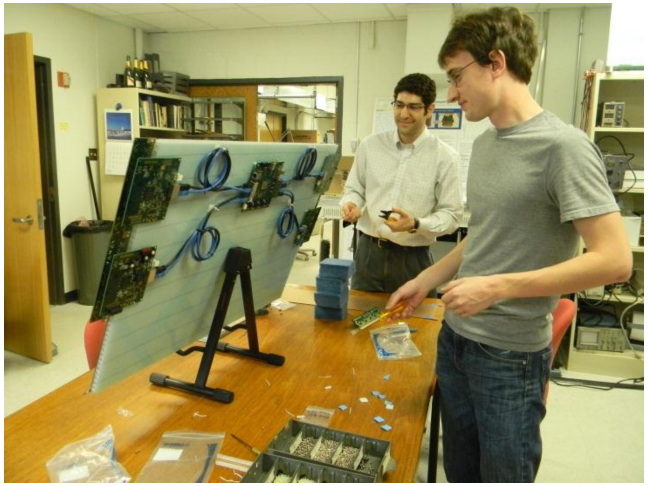


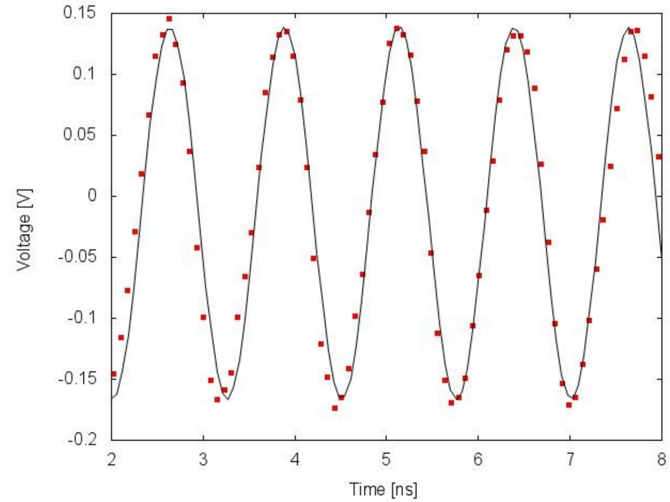
Figure 5:

Point is that each vertex has a time– fitting the tracks can tie charged particles to vertices. Fitting photons likewise is also possible if we know L, as we know beta.

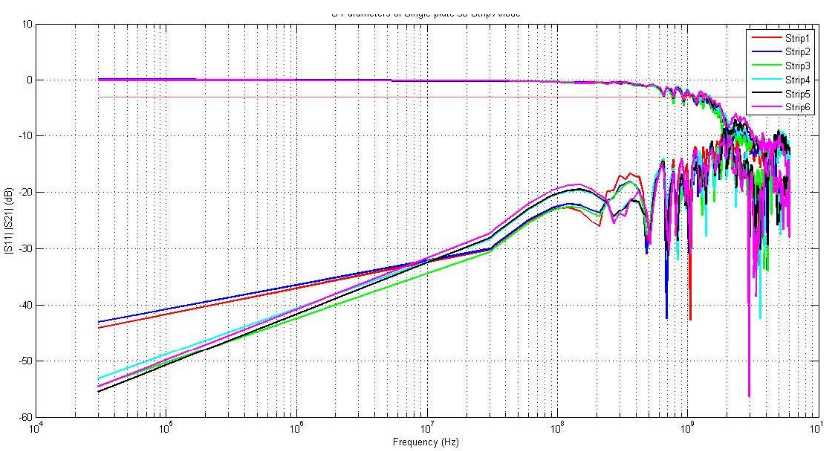
Electronics- Integration & Performance



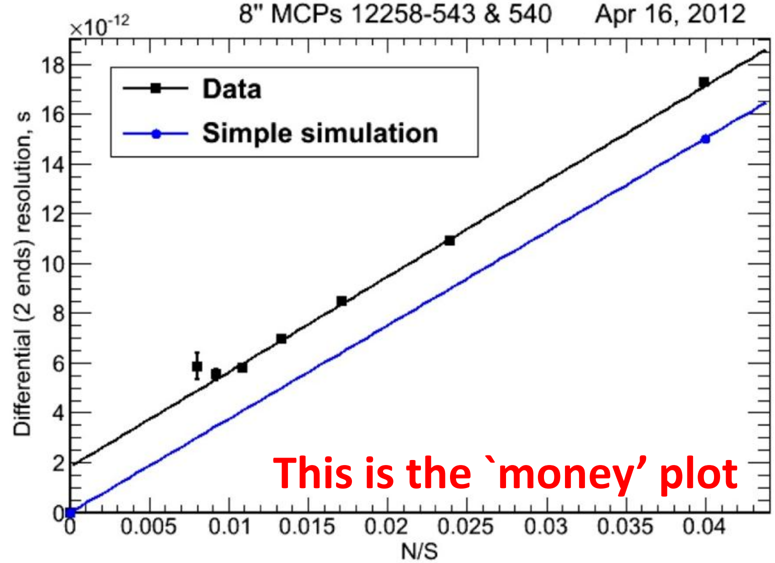
Eric Oberla and Craig Harabedian cabling SuMo digital and central FPGA cards



PSEC-4 sampling at 13.3 Gsamples/sec



Analog Bandwidth of strip-line anode

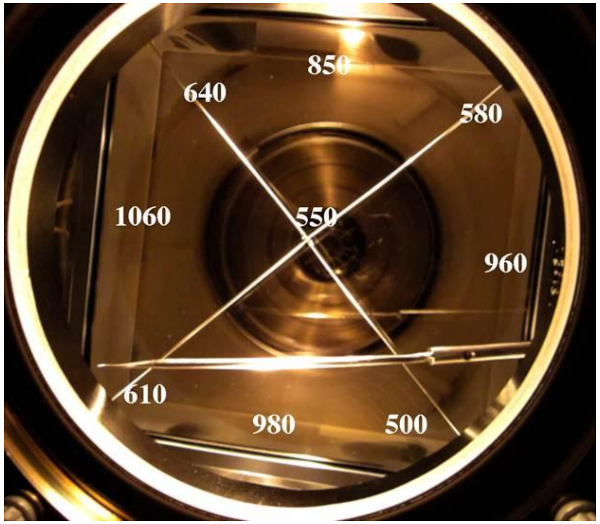


N = RMS of the noise; S = signal amplitude

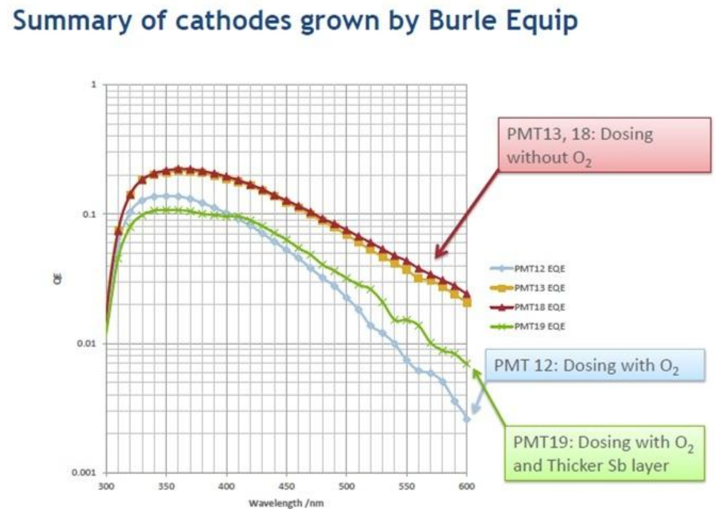
Time resolution on 2 ends of anode strip vs $(S/N)^{-1}$ in psec

Achievements: PhotoCathodes

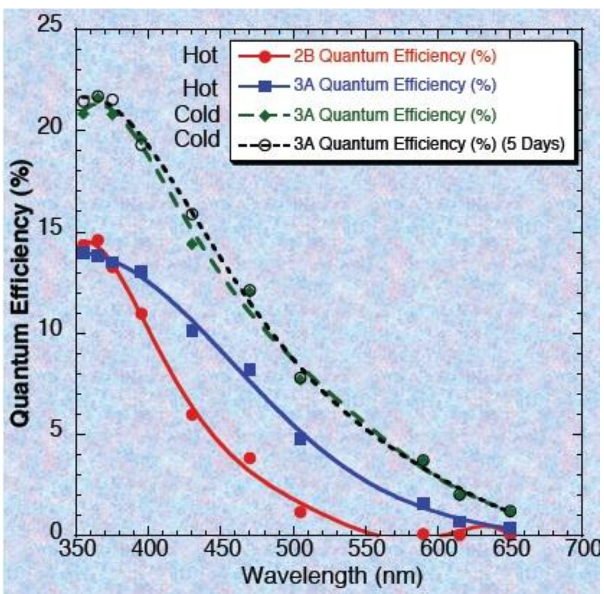
Have made >20% 8"PC at SSL; 25% small PC's at ANL, 18% 4" (larger underway)



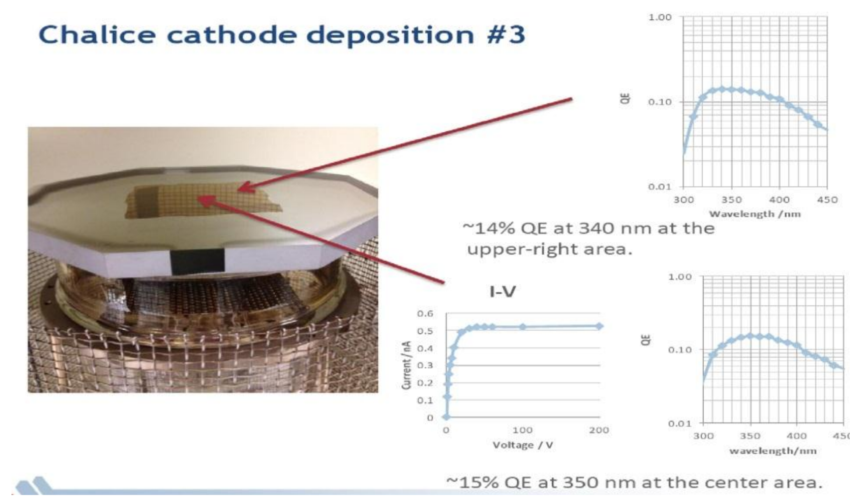
SSL 8" SbNaK cathode



QE of ANL small SbKCs cathodes



QE of SSL 8" SbNaK cathode



4" cathode: Chalice in Burle oven ANL

8” Glass Package Component Costs

Rich Northrop

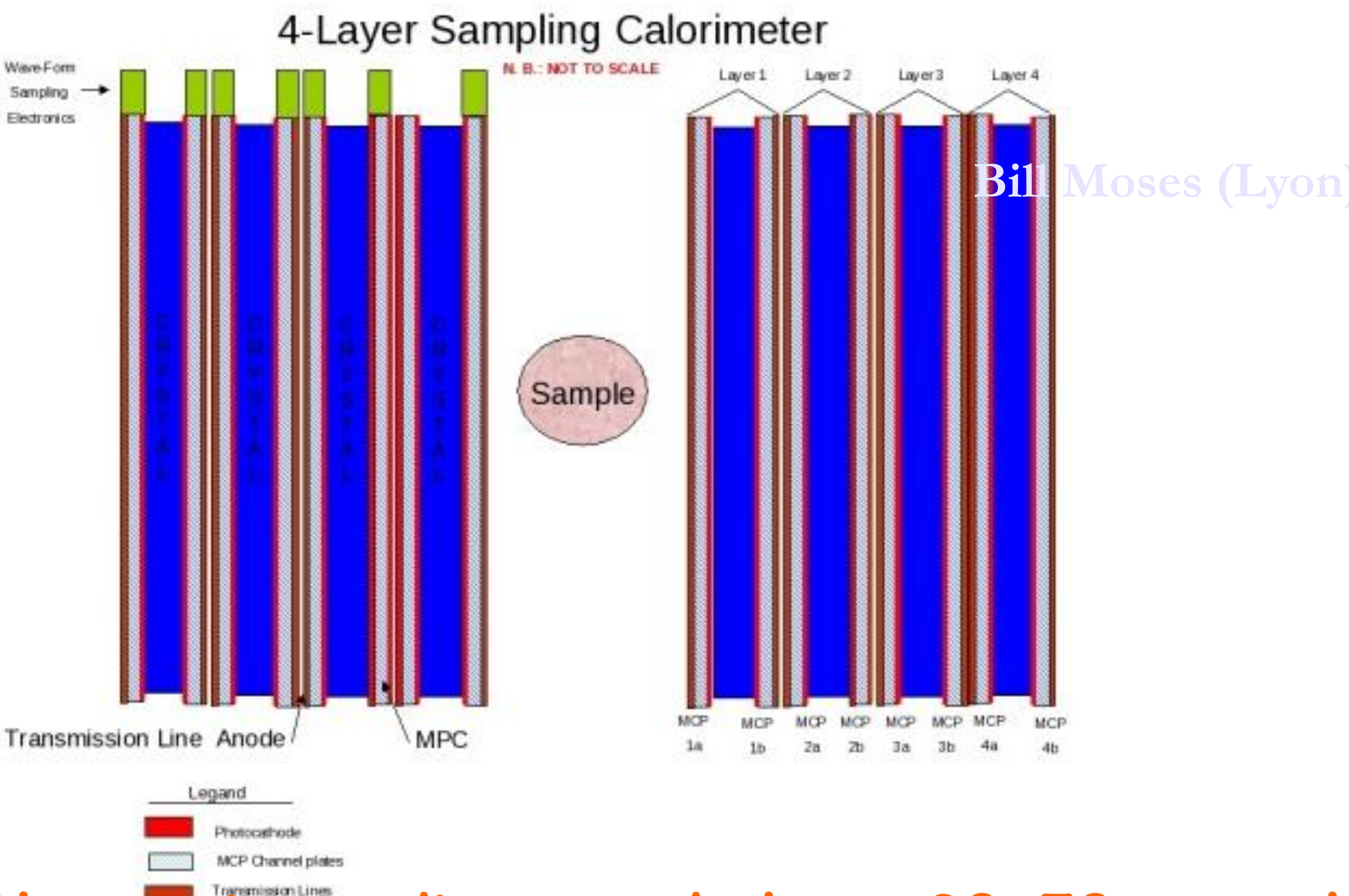
Fabricated per unit cost estimates

	---------Quotations---------		----------------------Cost estimates----------------------		
	30	**1000**	**3000**	**10,000**	**100,000**
Window (1@)	**$18**	**13**	**11**	**10**	**8**
Side wall (1@)	**$78**	**55**	**52**	**48**	**40**
Base plate (1@)	**$20**	**13**	**11**	**10**	**8**
Rod Spacers (75@)	**$7**	**3**	**2**	**1.20**	**.80**
Total	**$641**	**$306**	**$224**	**$158**	**$116**

The above prices are for water jet cut B33 glass, tol. +- 0.010, except rod spacers +000 -0.004

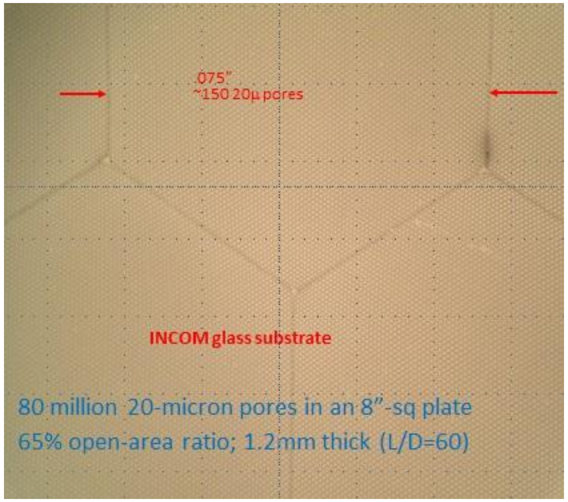
To this add 2 8” plates (@250?), ALD (Bulk), PC, assembly

Sampling calorimeters based on thin cheap photodetectors with correlated time and space waveform sampling

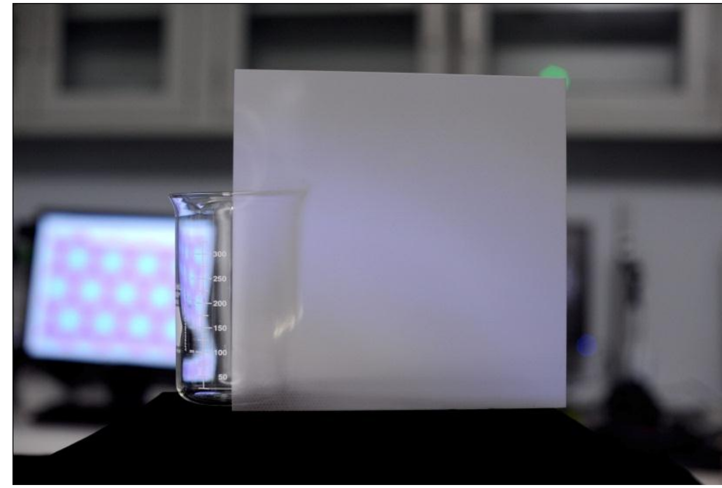


Proposal: Alternating radiator and cheap 30-50 psec thin planar mcp-pmt's on each side (needs simulation work)

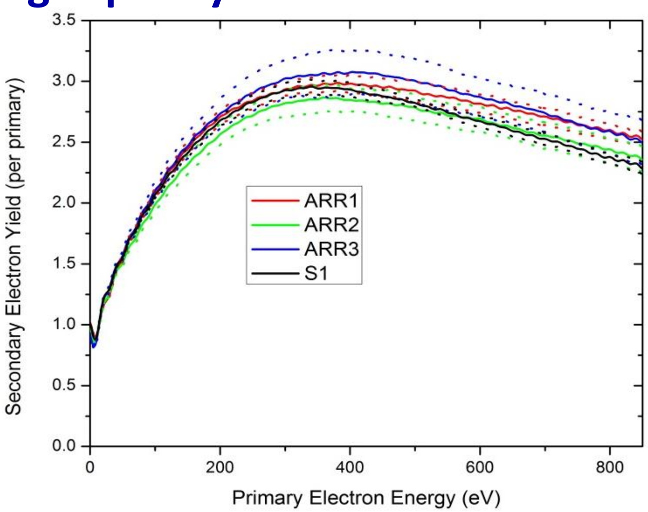
Micro-Channel Plate Development



Incom with SSL testing developed 8"-sq high-quality MCP Plates

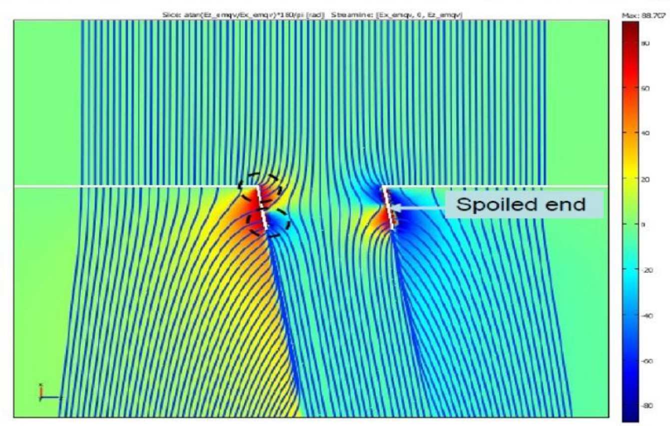


Incom 8"-sq high-quality MCP plate with > 65% OAR



Characterization of SEY of emitting materials (ANL/MSD, here for Arradiance)

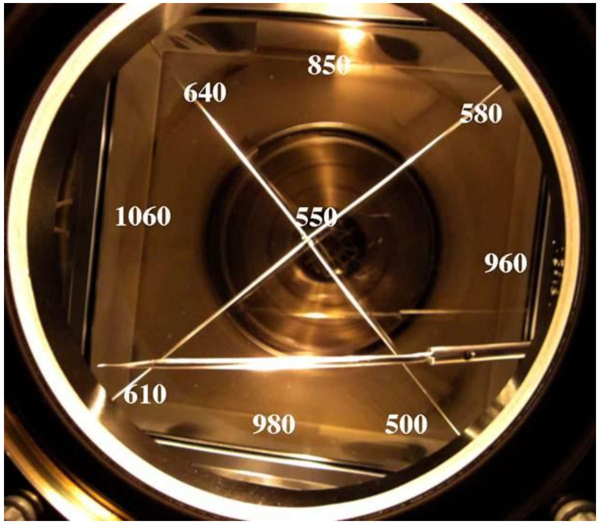
Spoiled end. Color: field angle



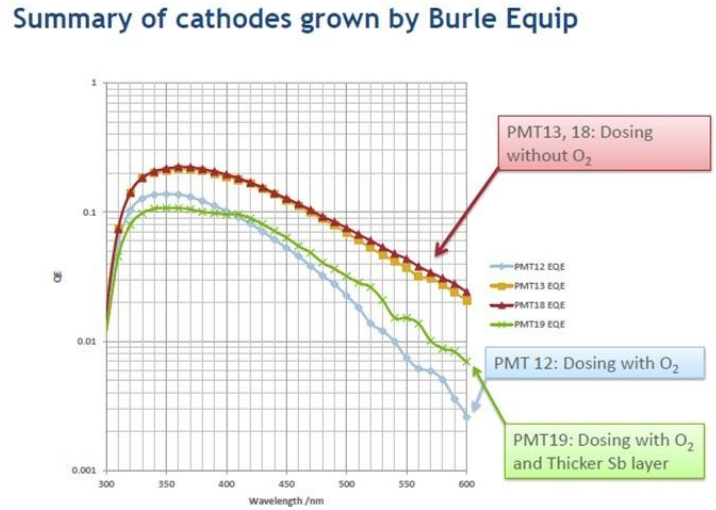
Detailed simulation of MCP's and materials; comparison with data

Achievements: PhotoCathodes

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

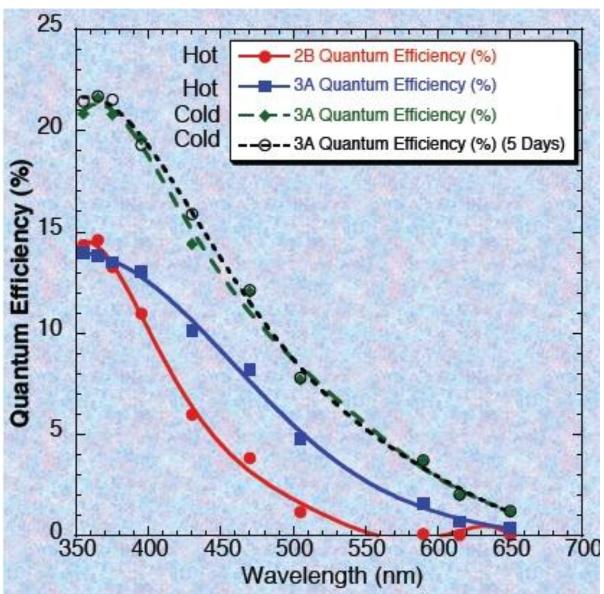


SSL 8" SbNaK cathode

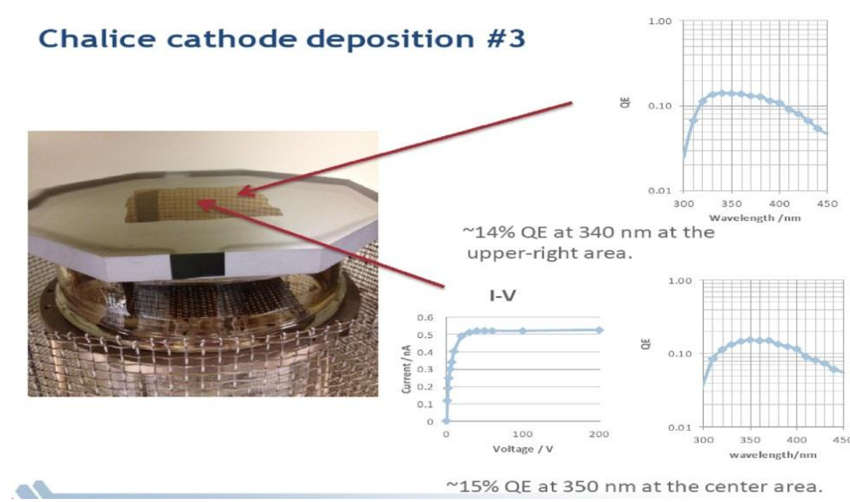


ANL

QE of ANL small SbKCs cathodes

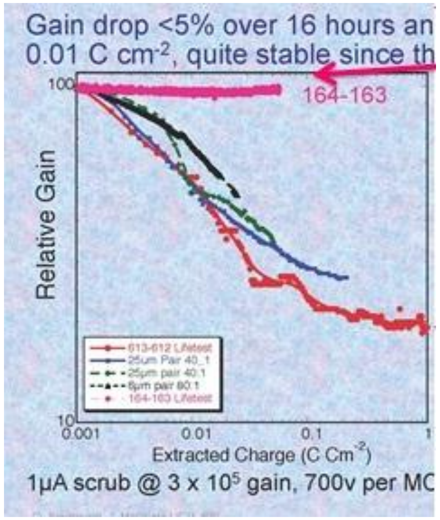


QE of SSL 8" SbNaK cathode



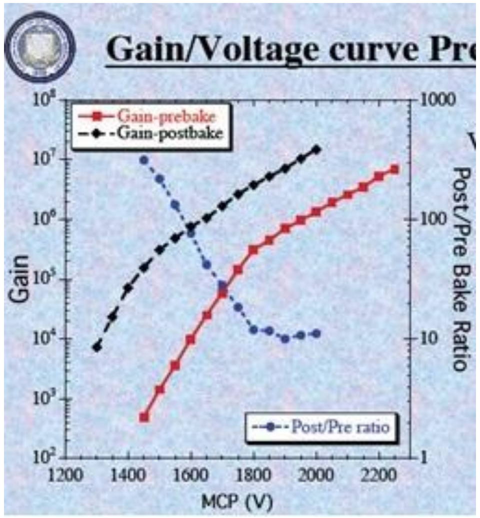
4" cathode: Chalice in Burle oven ANL

Micro-Channel Plate Performance



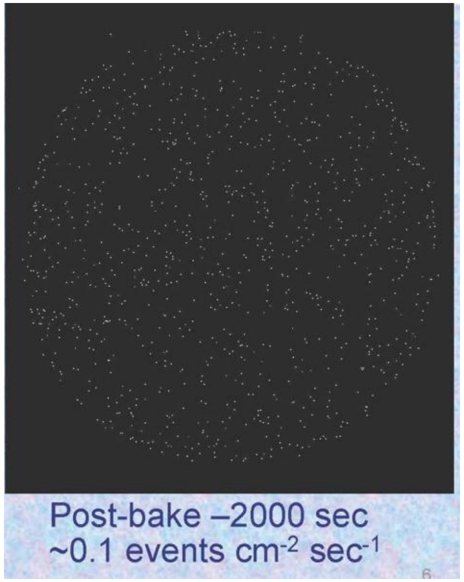
SSL

ALD plates show no aging



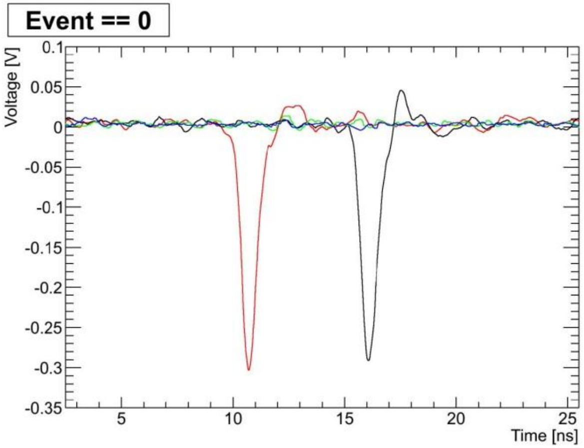
SSL

Gains are as good or better than commercial



SSL

Noise is <0.1 cts/cm^2-sec (very good)



ANL

Pulses from two ALD-functionalized MCP's measured on 2 ends of an 8" anode RF strip