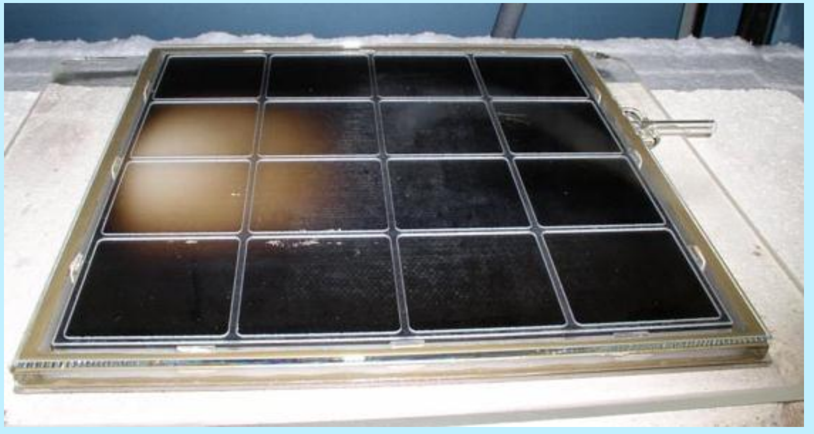
Large-area MCP-based Photo-detectors, Ultra-fast timing, and sub-mm Spatial Resolution (LAPPD)

Henry Frisch
Enrico Fermi Institute, Univ. of Chicago
and HEPD, Argonne National Laboratory

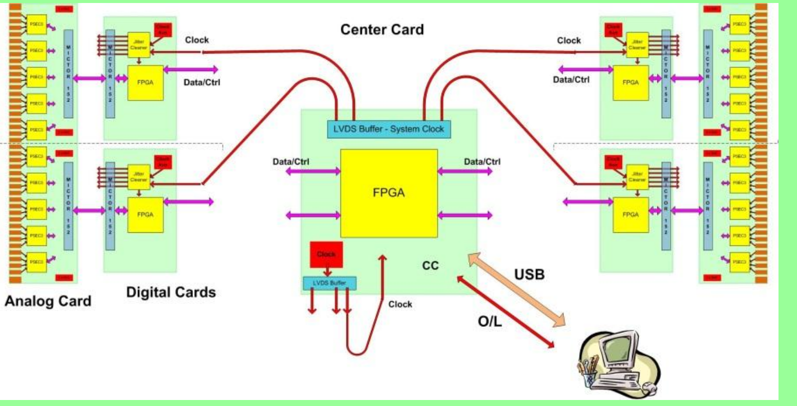
The 4 `Divisions' of LAPPD

Hermetic Packaging



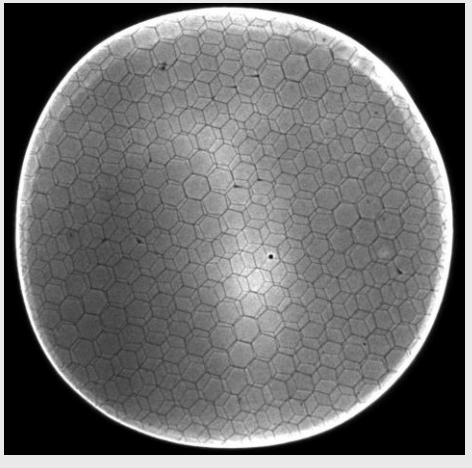
See Bob Wagner's talk

Electronics/Integration



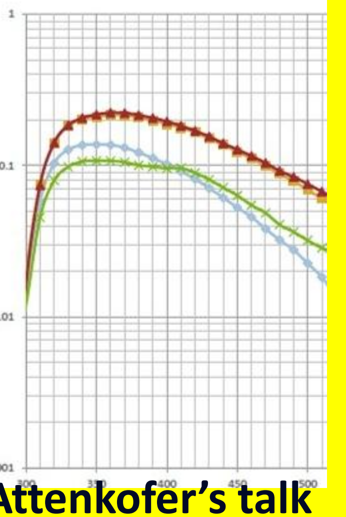
This talk

MicroChannel Plates



See Ossy's talk

Photocathodes



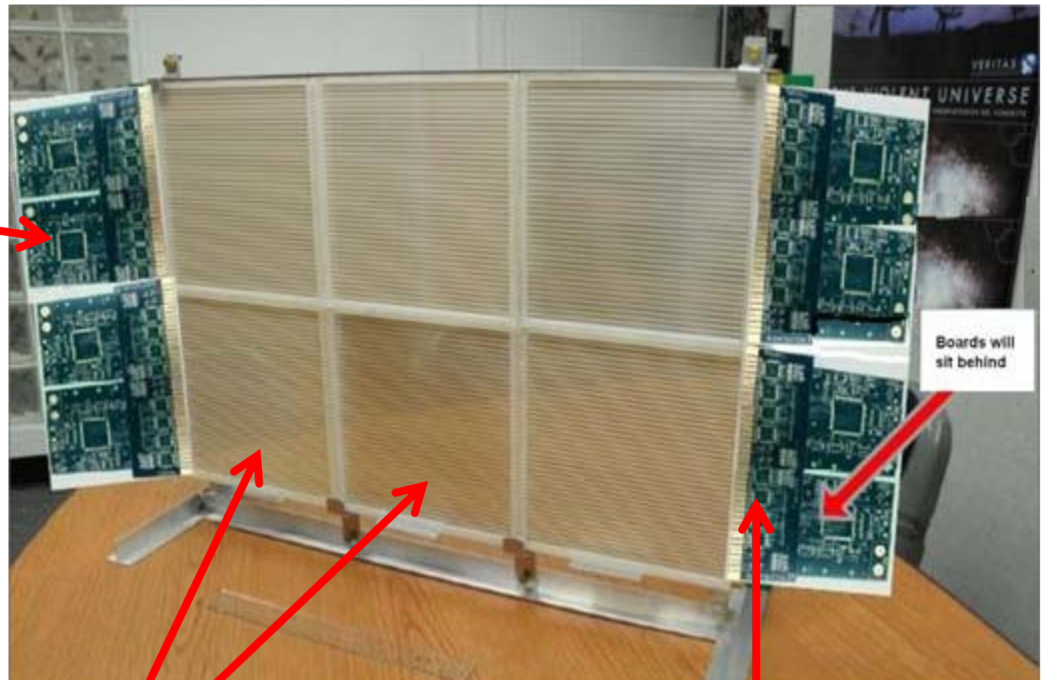
See (hear) Klaus Attenkofer's talk

Outline

1. The Power of Correlated Time/Space Points
2. MCP's, Transmission Lines, and Waveform Sampling
3. The 4 Determinants of Time Resolution
   a) Signal/Noise (S/N)
   b) Analog Band-width (ABW)
   c) Sampling Rate
   d) Signal statistics
4. What is the ultimate resolution at decent area & cost?
5. Water Cherenkov Counters; PET Cameras; TOF at Colliders; TOF for Fixed Target; Security; and New Ideas

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...

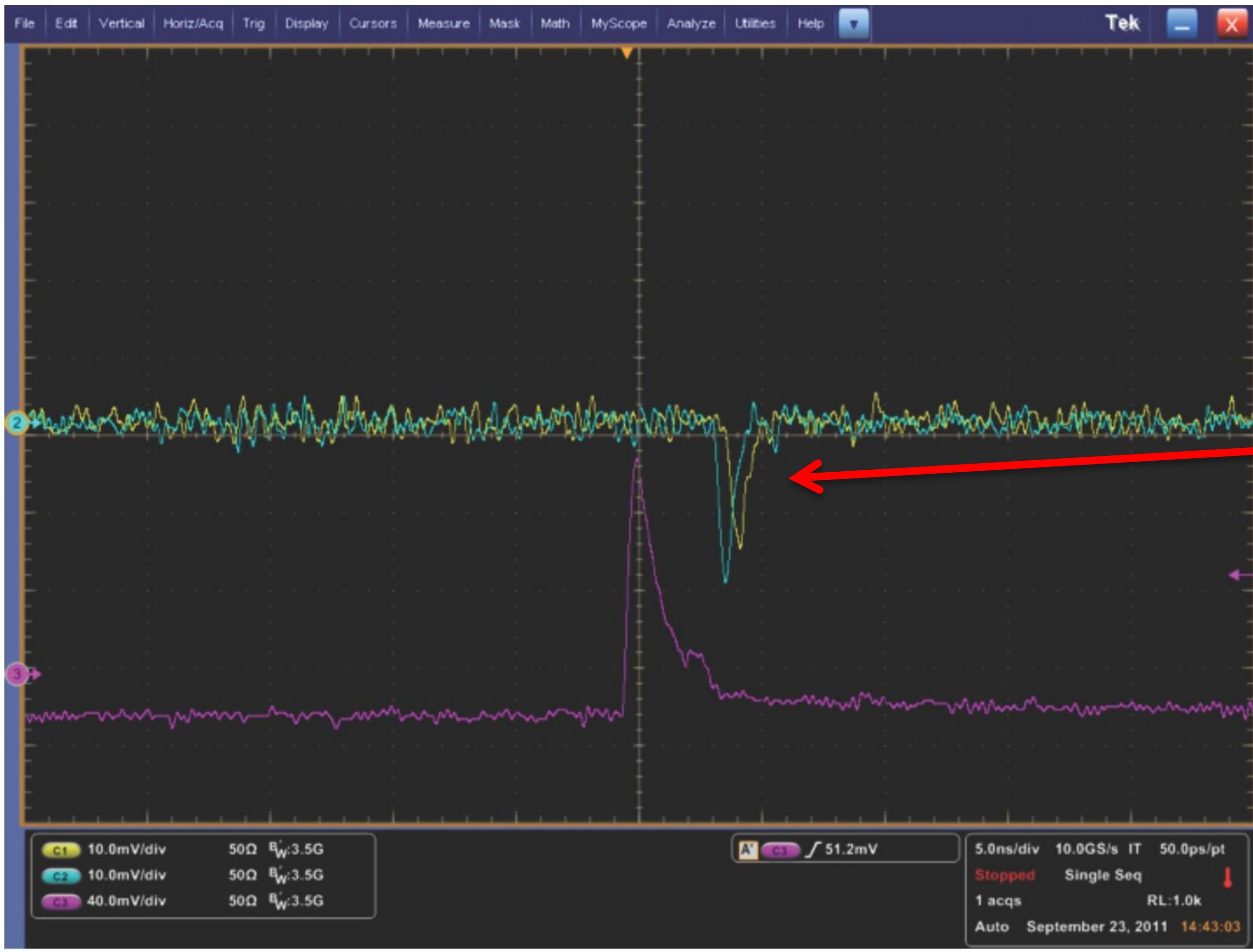


Single serial Gbit connection will come out of panel with time and positions from center of back of panel

8" Tiles

10-15 GS/sec Waveform Sampling ASICS

Time and Space Points

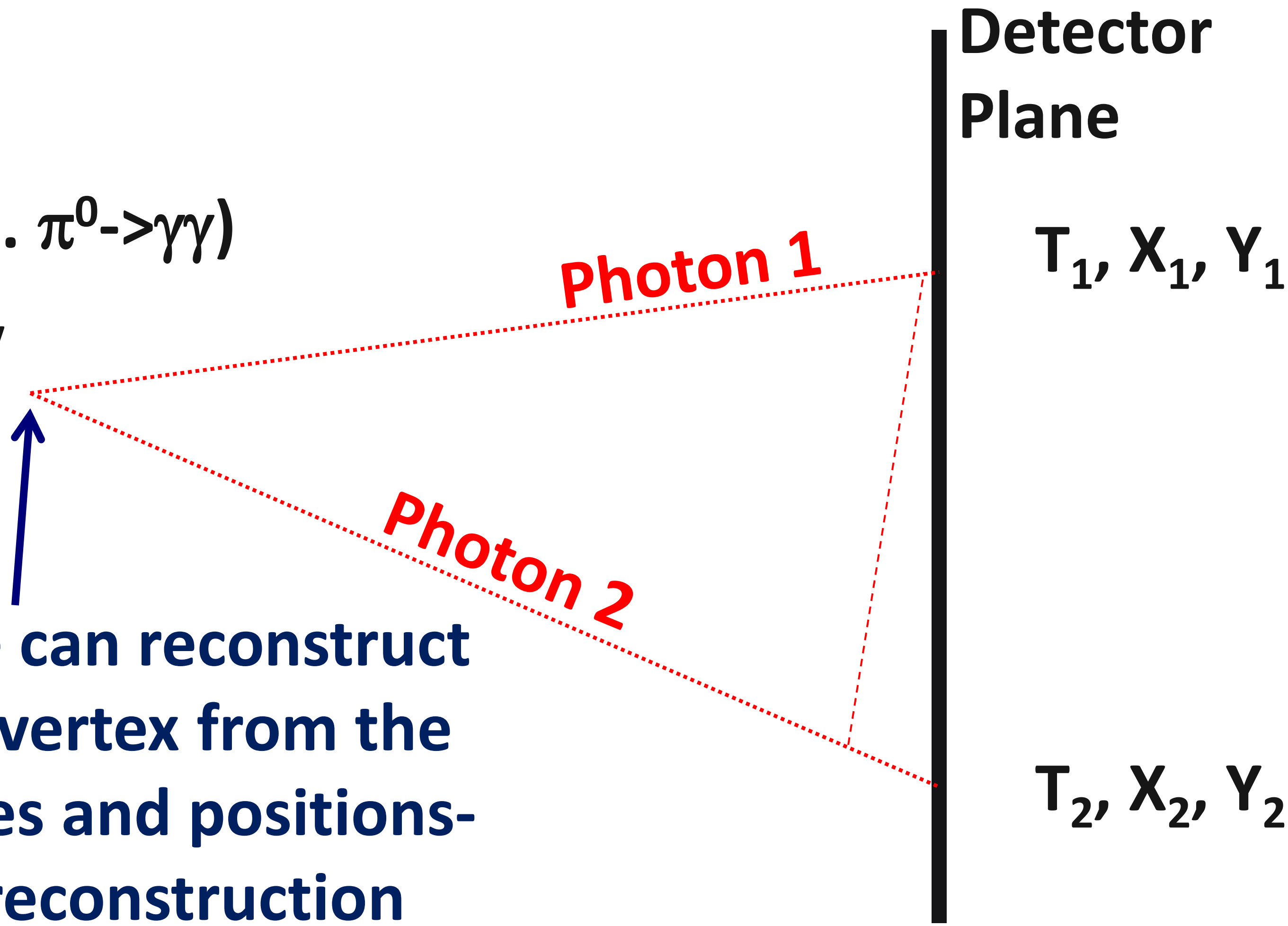


Pulses from the 2 ends of an 8” silk-screened cheap-glass anode strip

5 nsec/div
50 psec/pt

Reconstructing the vertex space point: Simplest case- 2 hits (x,y) at wall

Vertex (e.g. π^0->$\gamma\gamma$)
T_v, X_v, Y_v, Z_v



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*

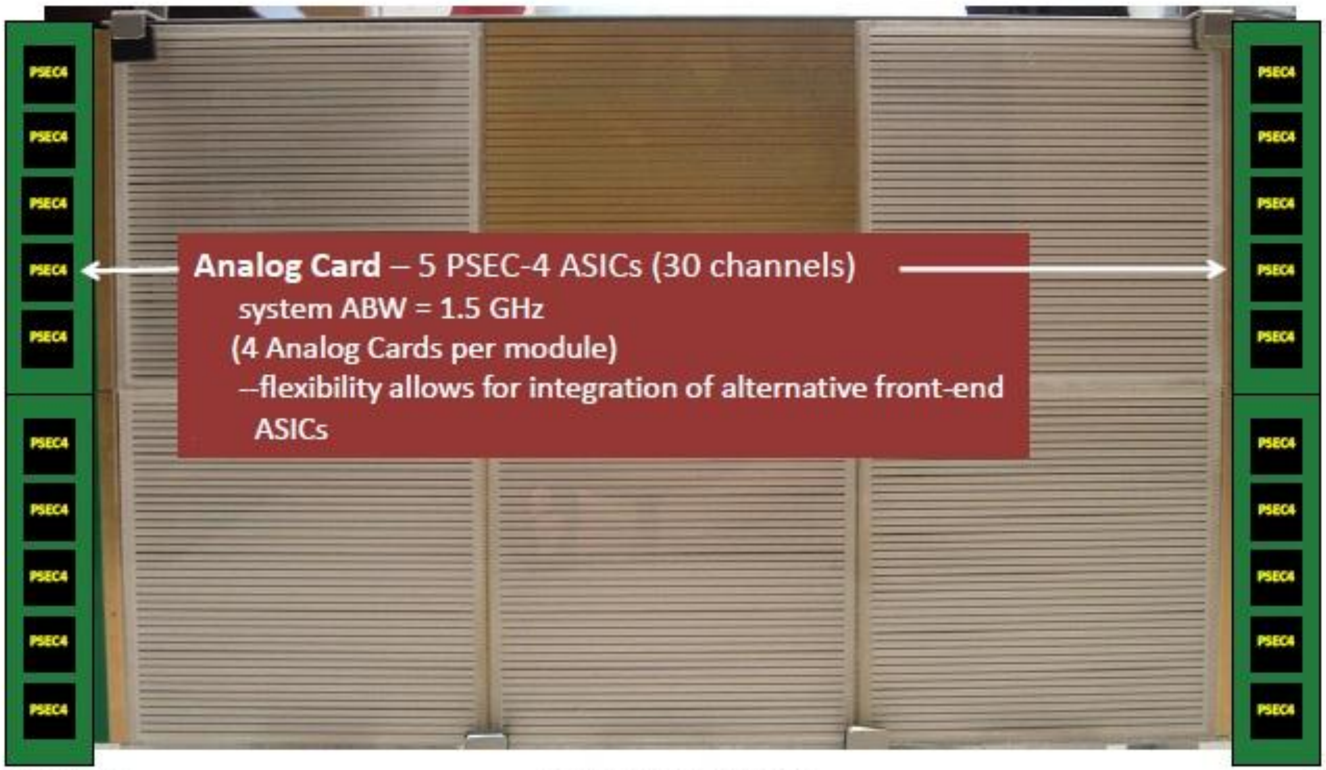
Correlated time and space points allow 3D reconstructions

Waveform Sample On Ends of Strips

LAPPD Collaboration

DAQ system

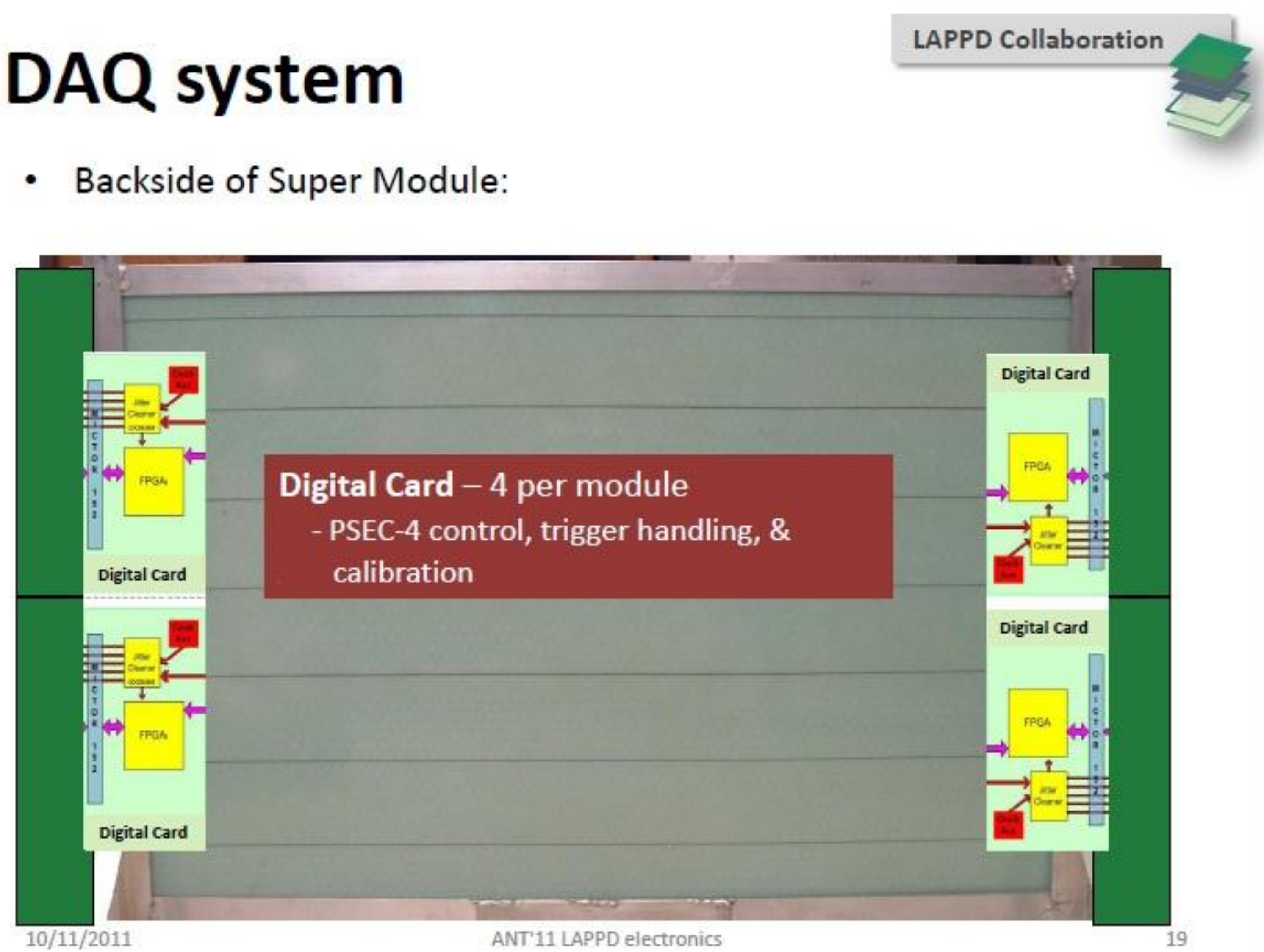
- Targeted to Super Module readout



10/11/2011 ANT'11 LAPPD electronics 18

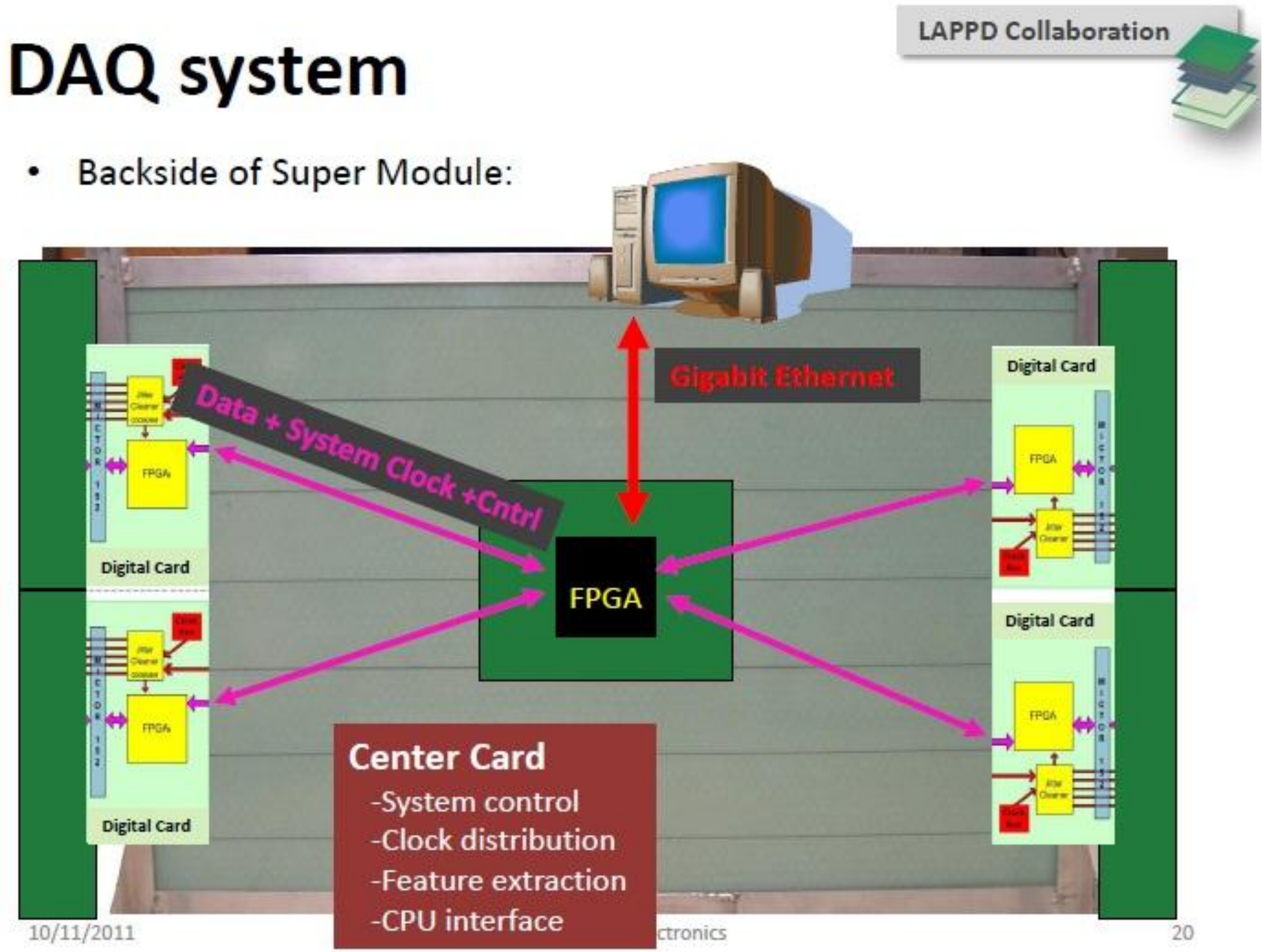
Eric Oberla slide from ANT11

Extract time, charge, shape each end



Eric Oberla slide from ANT11

Extract time, position of pulse using time from both ends



Eric Oberla slide from ANT11

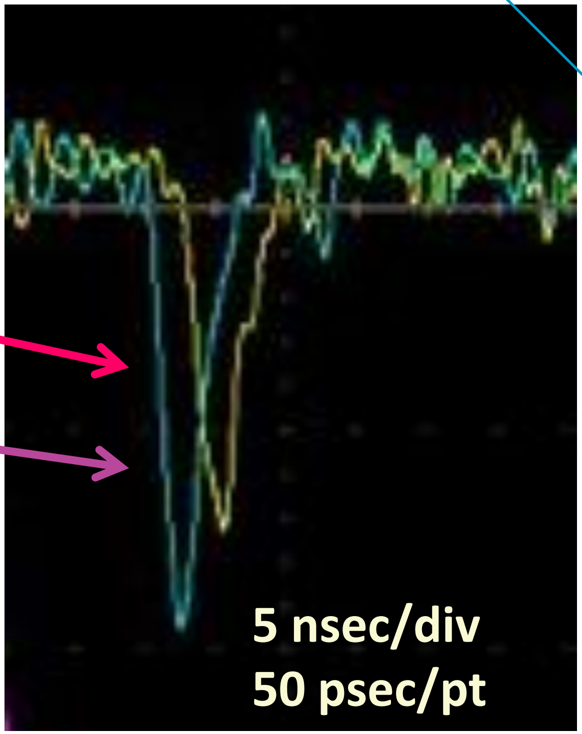
The 4 Determinants of Time Resolution

a) Signal/Noise (S/N)

b) Analog Band-width (ABW)

c) Sampling Rate

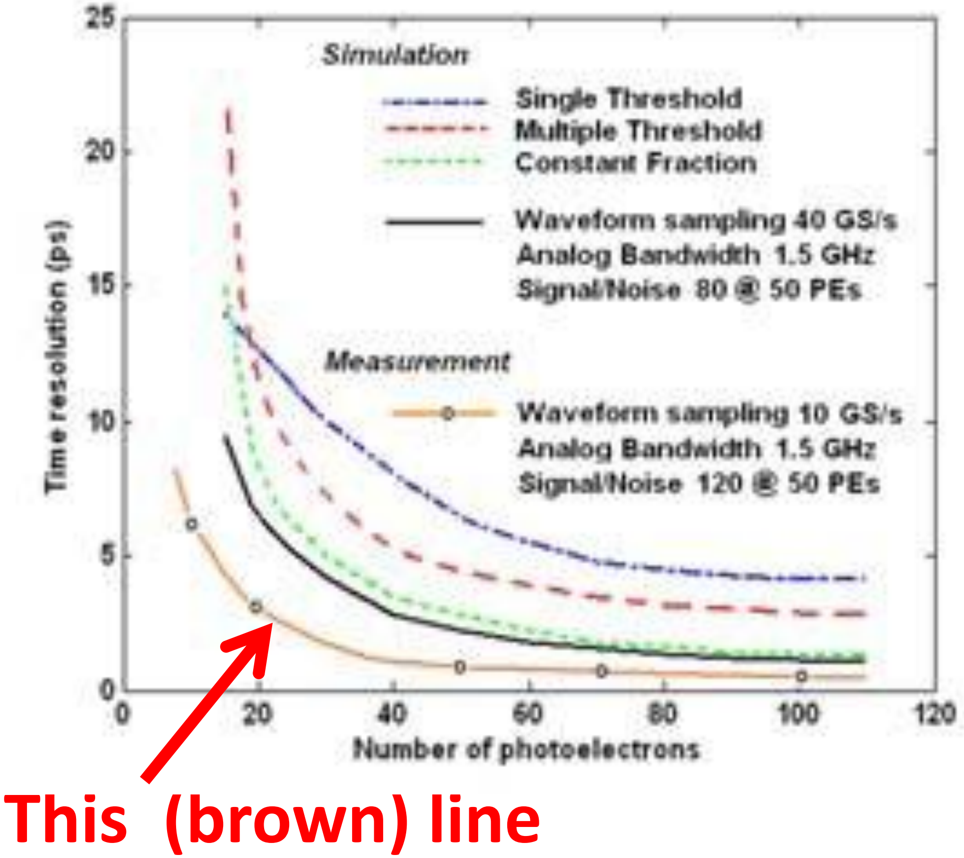
d) Signal statistics

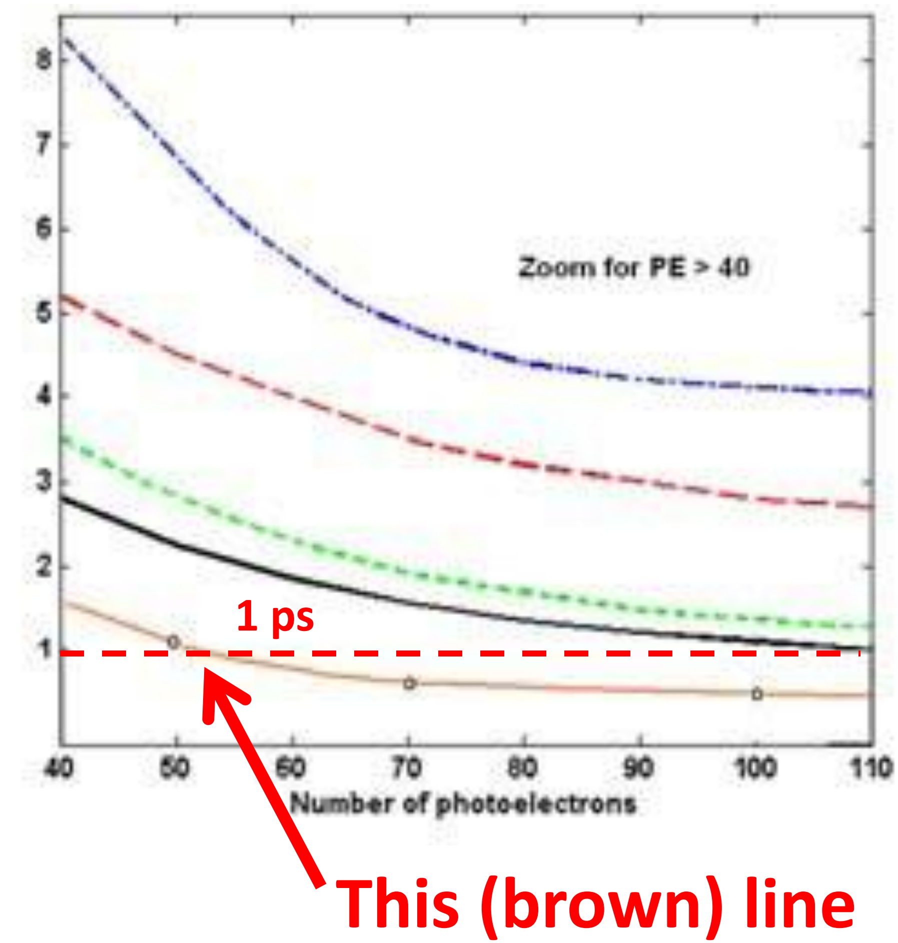


J.F. Genat, F. Tang, H. Frisch, and G. Varner; *Picosecond Resolution Timing Measurements,* Nucl. Instr. Meth A607, 387 (2009); Workshop on *The Factors that Limit Time Resolution in Photo-detectors,* University of Chicago, April 28-29, 2011

Simulation of Resolution vs abw

Jean-Francois Genat



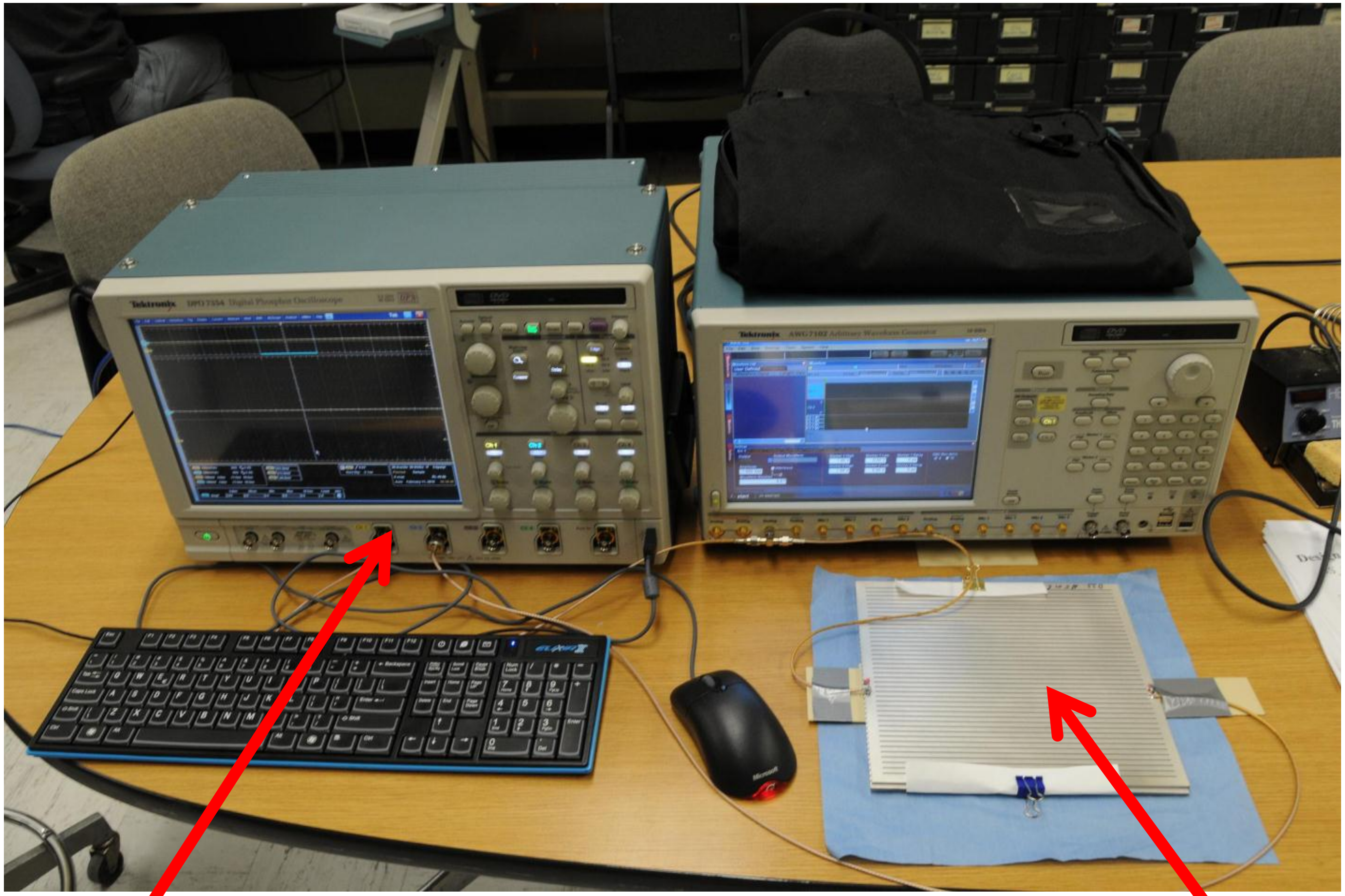


Brown line: 10 Gs/sec (we've done >15);

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

Anode Testing for ABW, Crosstalk,..

Herve' Grabas, Razib Obaid, Dave McGinnis



Network Analyzer

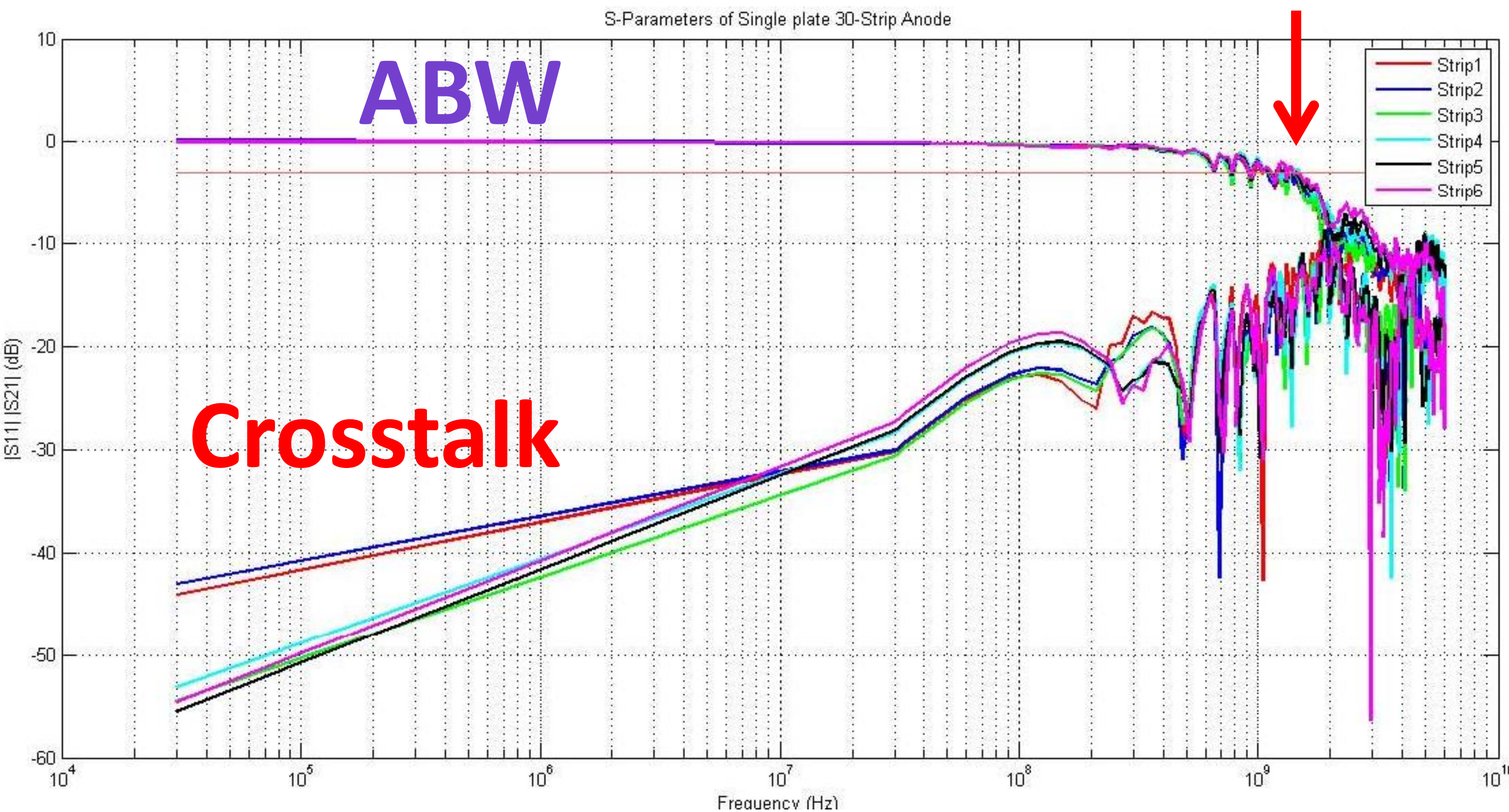
Tile Anode

Anode Testing for ABW, Crosstalk,..

Herve’ Grabas, Razib Obaid, Dave McGinnis

Tile row assembly of 3 tile anodes – abw >500 MHz

Anode Testing for ABW, Crosstalk,..



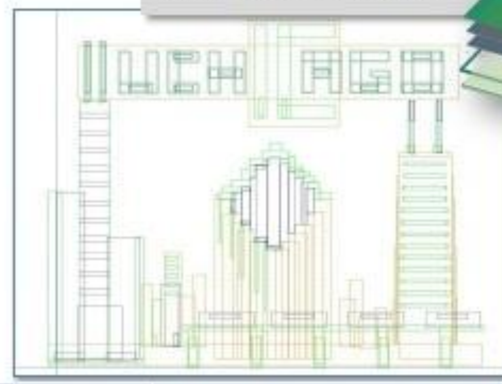
Razib Obaid

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***

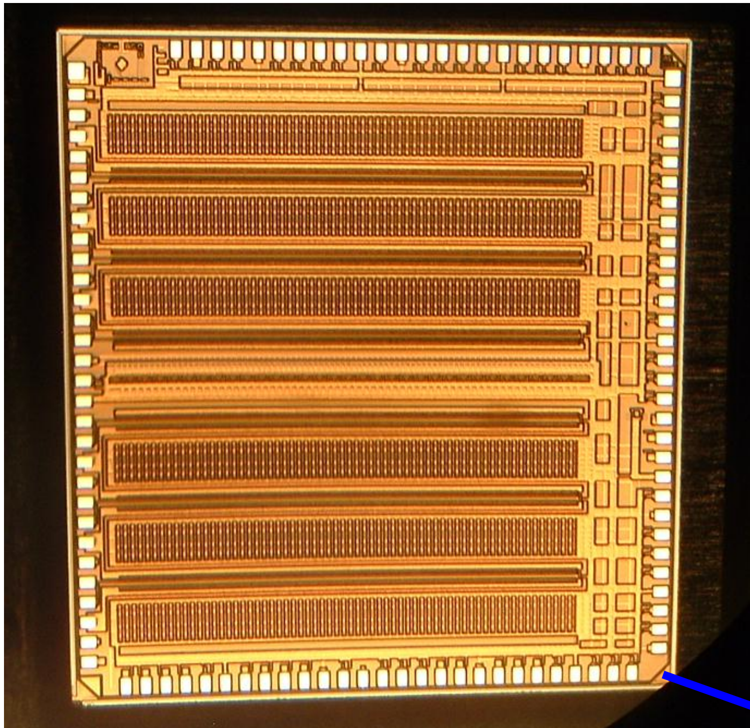
	SPECIFICATION
Sampling Rate	2.5-15 GSa/s
# Channels	6 (or 2)
Sampling Depth	256 (or 768) points
Sampling Window	Depth*(Sampling Rate)$^{-1}$
Input Noise	<1 mV RMS
Analog Bandwidth	1.5 GHz
ADC conversion	Up to 12 bit @ 2GHz
Dynamic Range	0.1-1.1 V
Latency	2 μs (min) – 16 μs (max)
Internal Trigger	yes

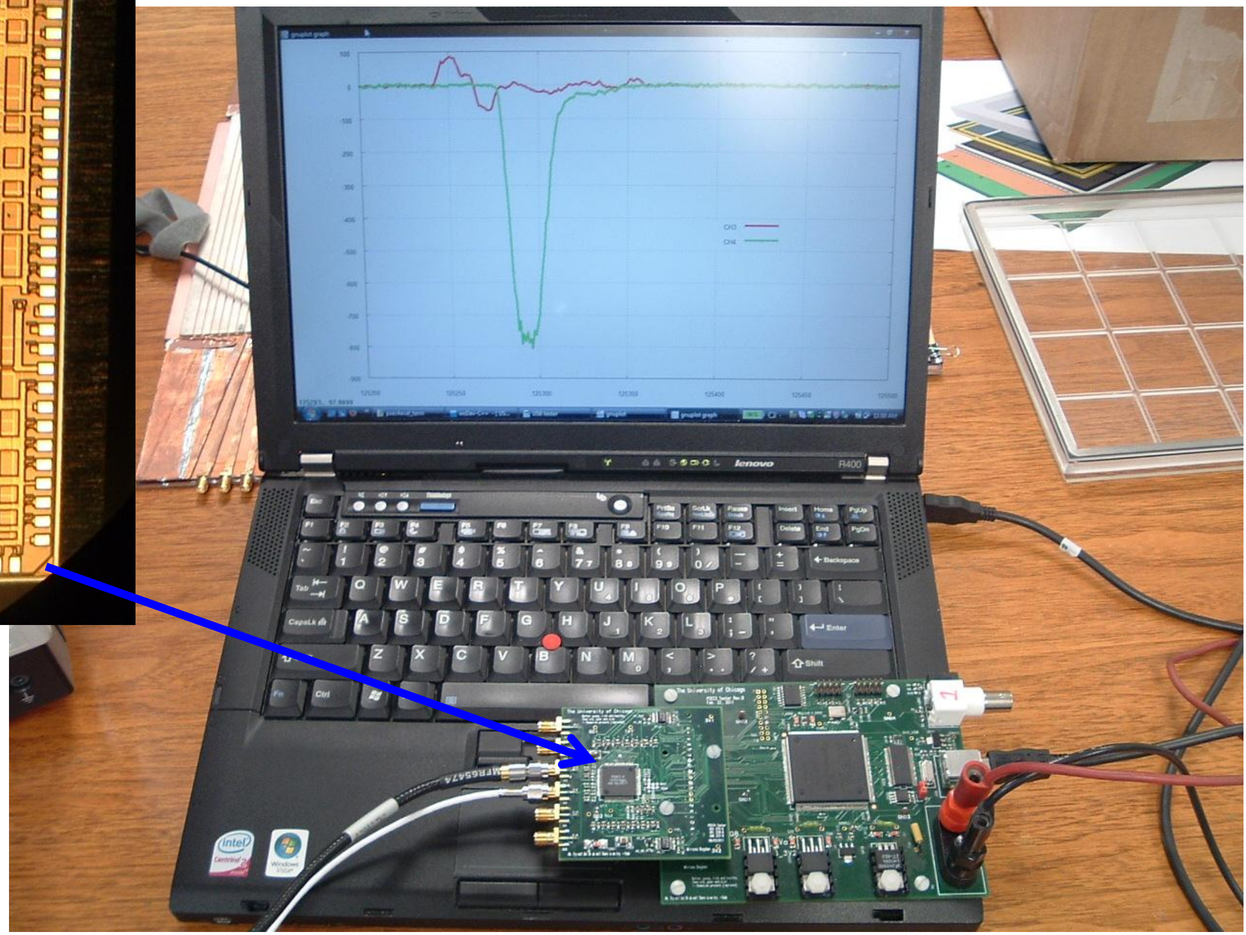
10/11/2011 ANT'11 LAPPD electronics

Eric Oberla, ANT11

PSEC-4 ASIC

Eric Oberla, ANT11

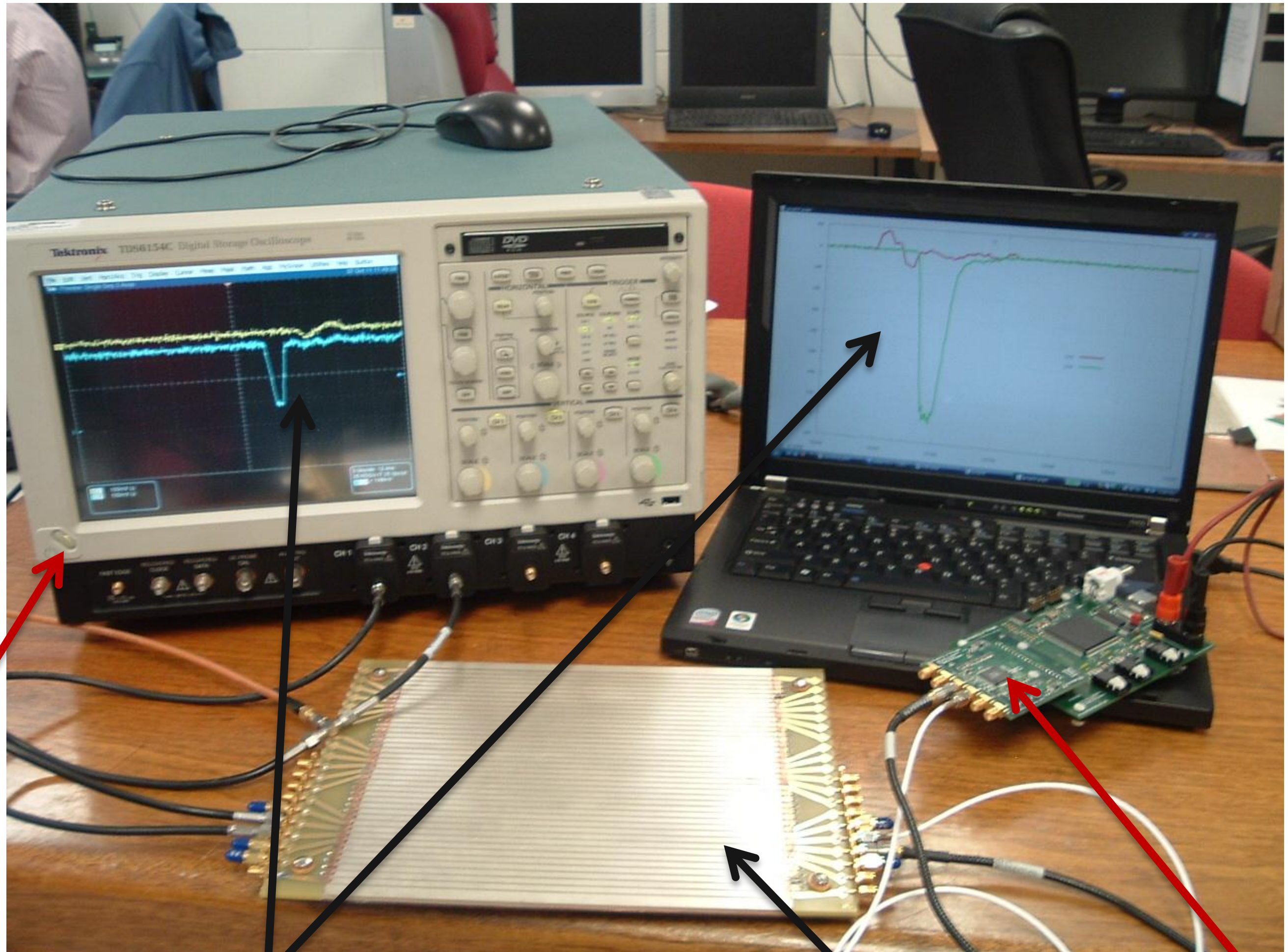




- 6-channel “**oscilloscope on a chip**” (1.6 GHz,10-15 GS/s)
- Evaluation board uses USB 2.0 interface + PC data acquisition software

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

Eric Oberla (grad student)



Real digitized traces from anode

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

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

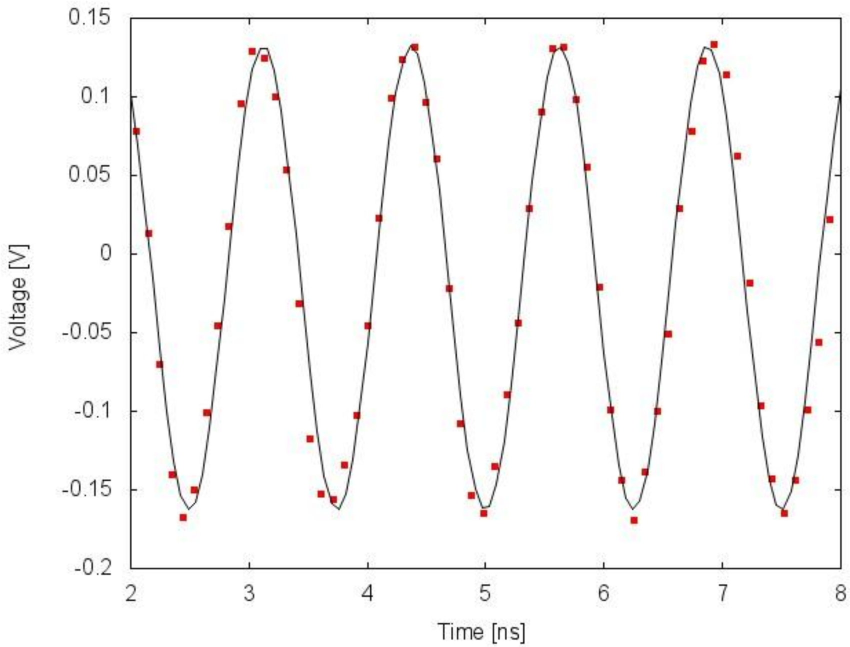
PSEC-4 Performance

Eric Oberla, ANT11

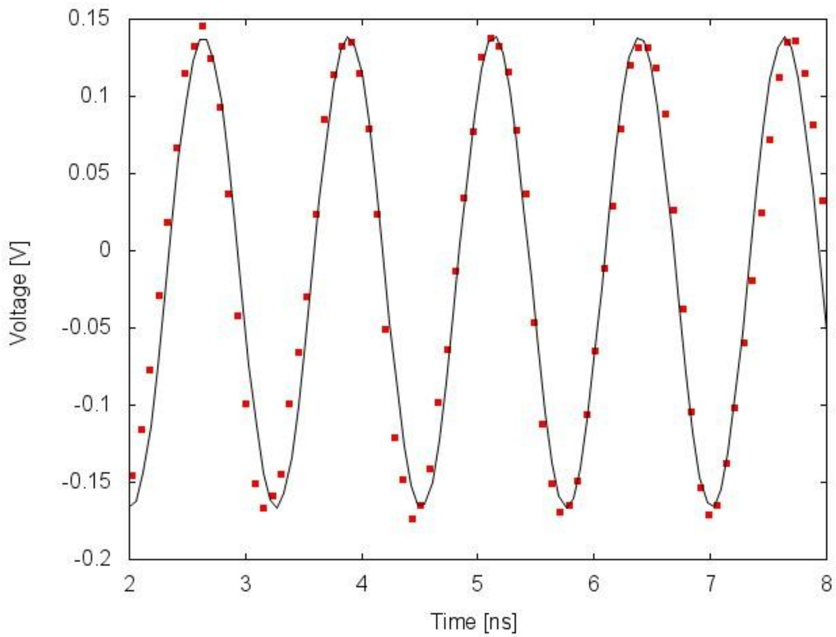
Digitized Waveforms

Input: 800MHz, 300 mV_{pp} sine

Sampling rate : 10 GSa/s



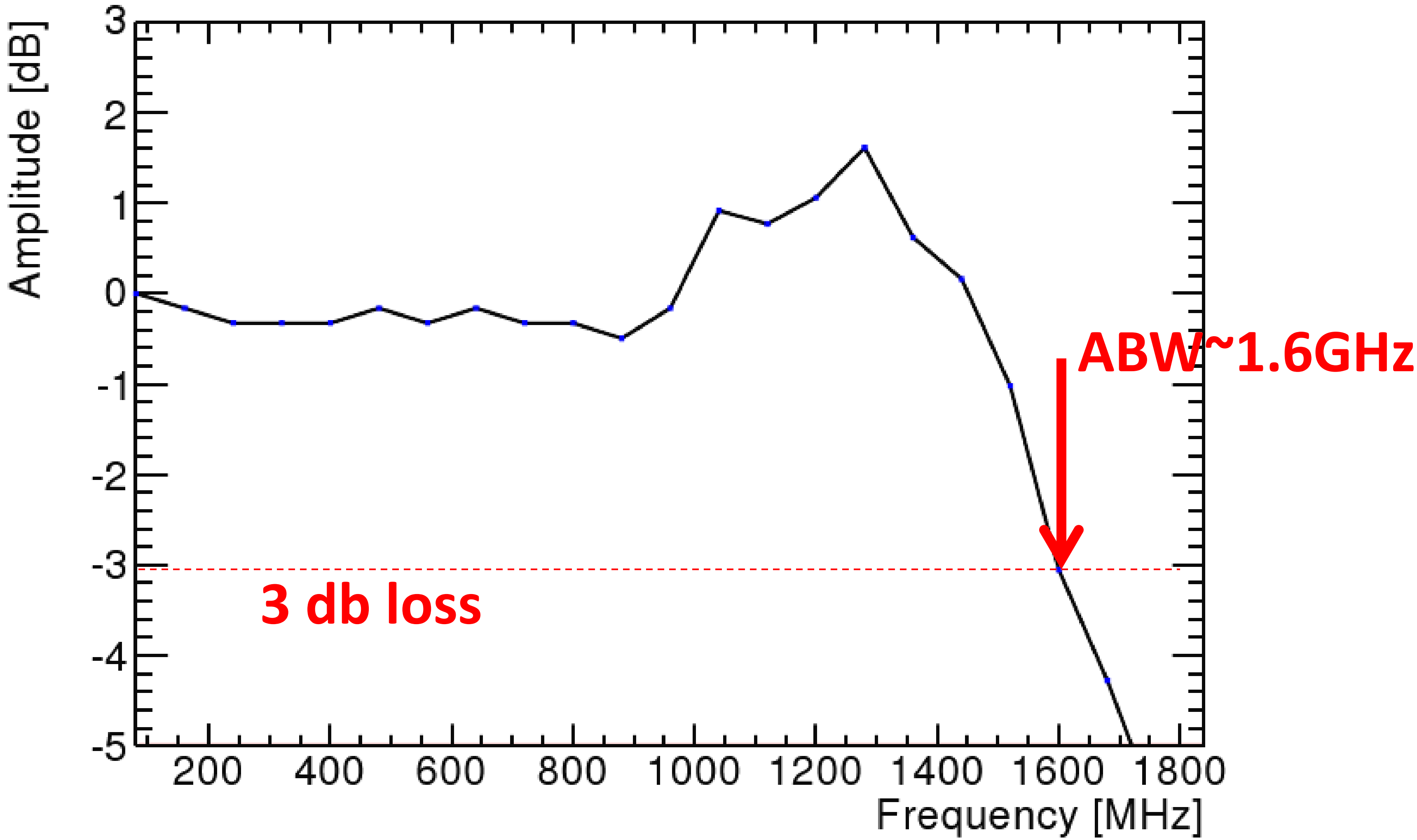
Sampling rate : 13.3 GSa/s



- 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

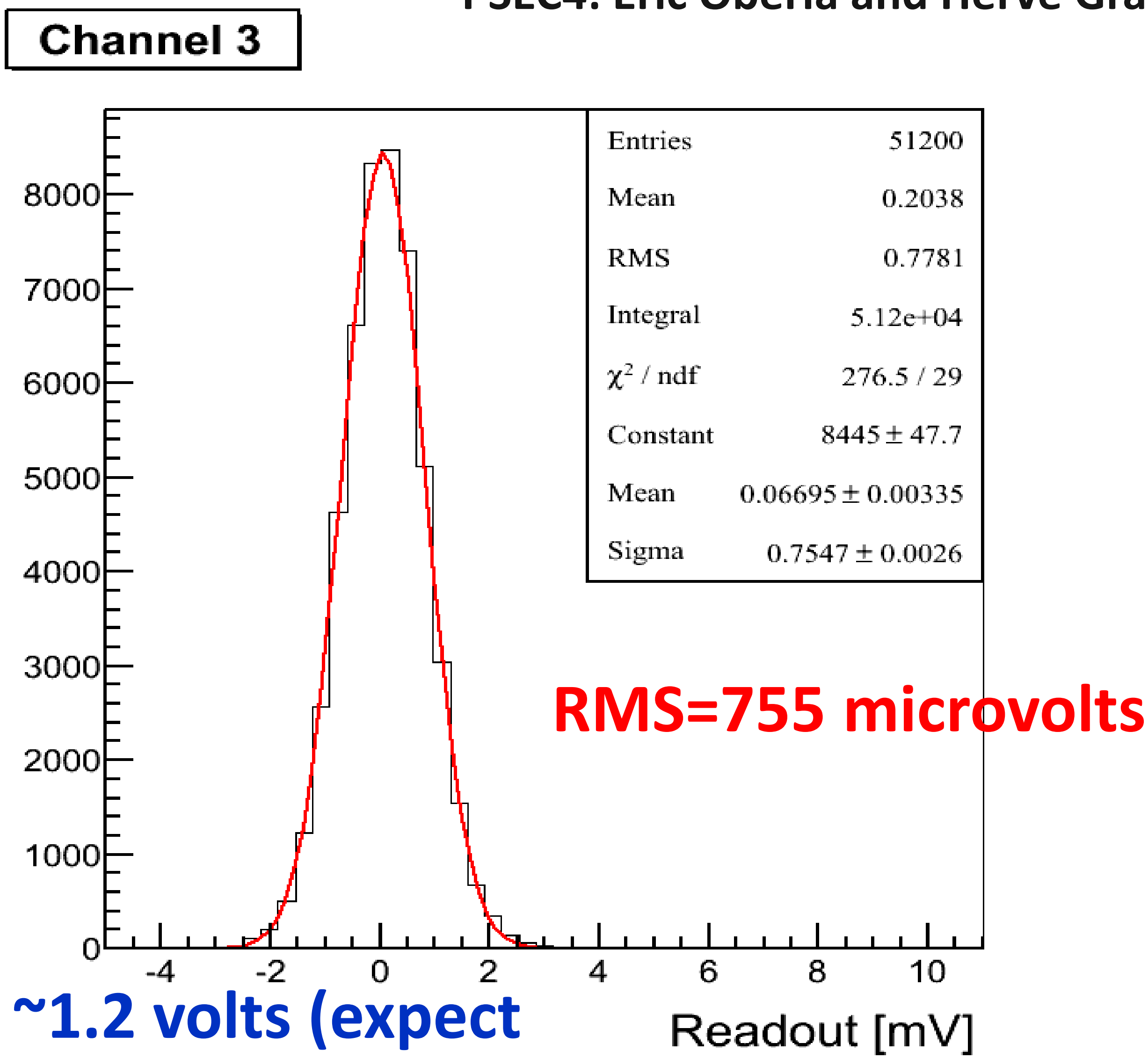
Eric Oberla, ANT11



PSEC4: Eric Oberla and Herve Grabas+ friends…

Noise (unshielded)

PSEC4: Eric Oberla and Herve Grabas+ friends…



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

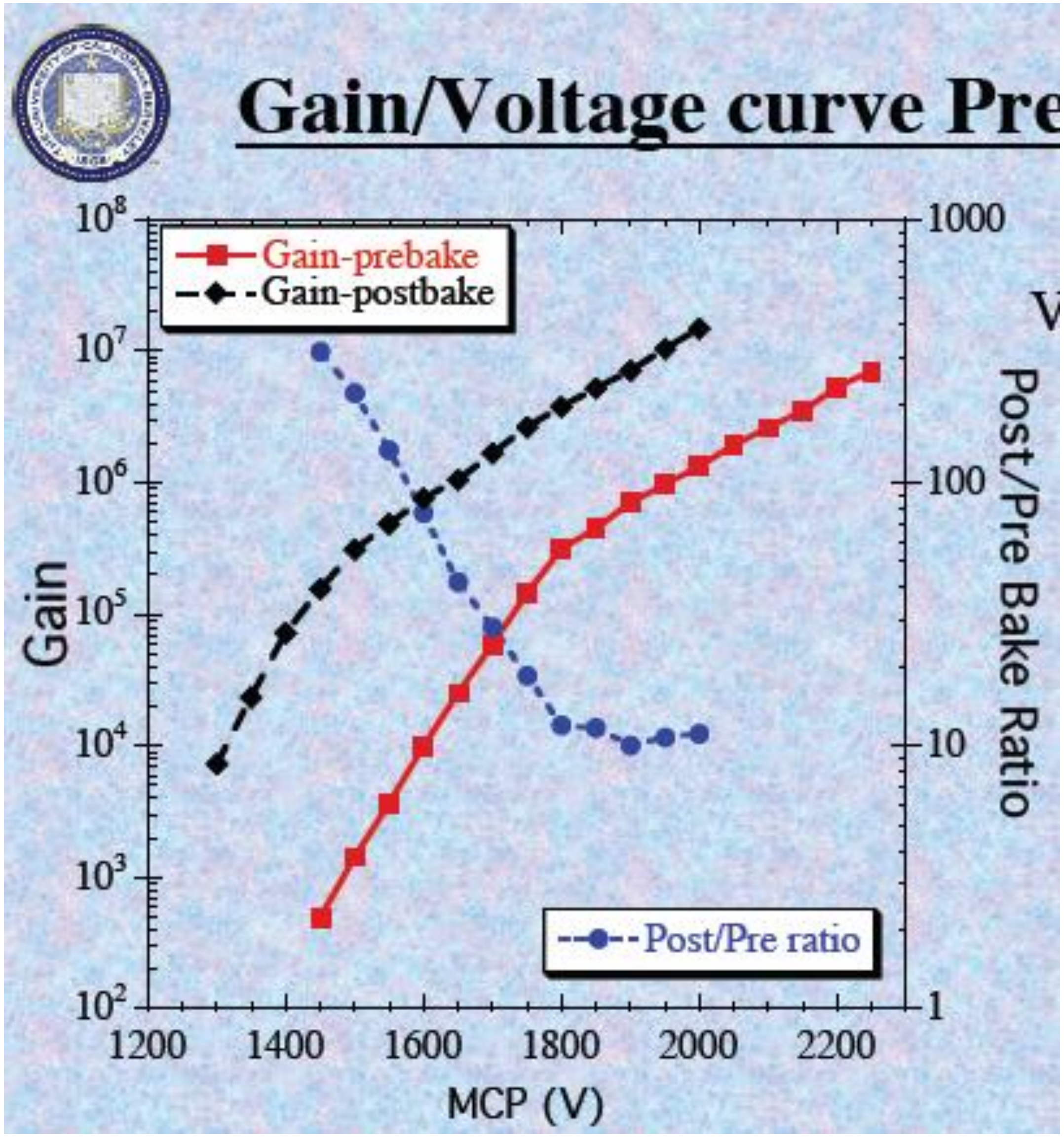
Eric Oberla, ANT11

Signal- want large for S/N

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

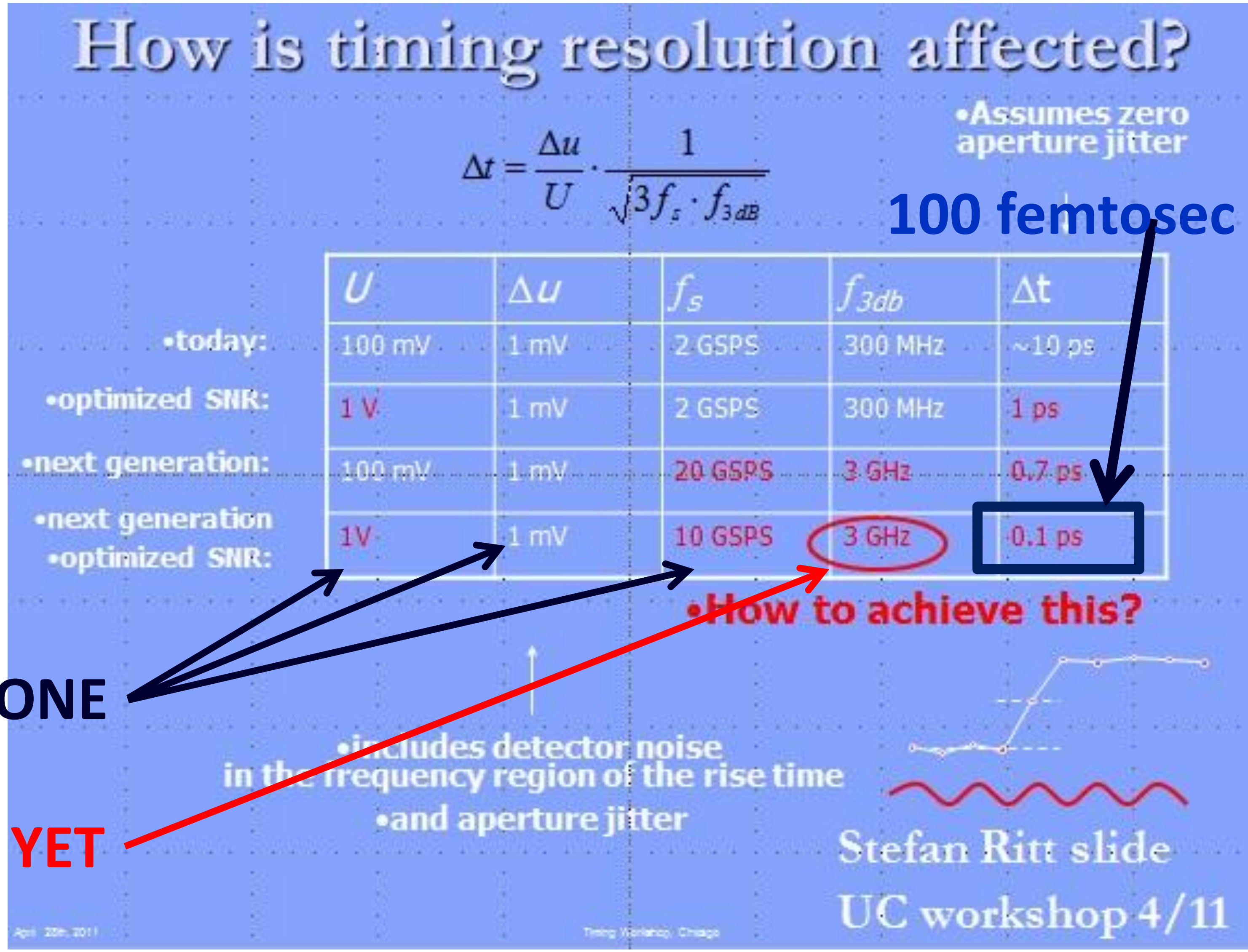
Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB

ALD by Anil Mane and Jeff Elam, ANL



Can we go deep sub-picosec?:
the Ritt Parameterization (agrees with JF MC)

Stefan Ritt slide, doctored



How is timing resolution affected?

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

•Assumes zero aperture jitter

100 femtosec

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

•How to achieve this?

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

•and aperture jitter

Stefan Ritt slide

UC workshop 4/11

S/N, f_Z: DONE

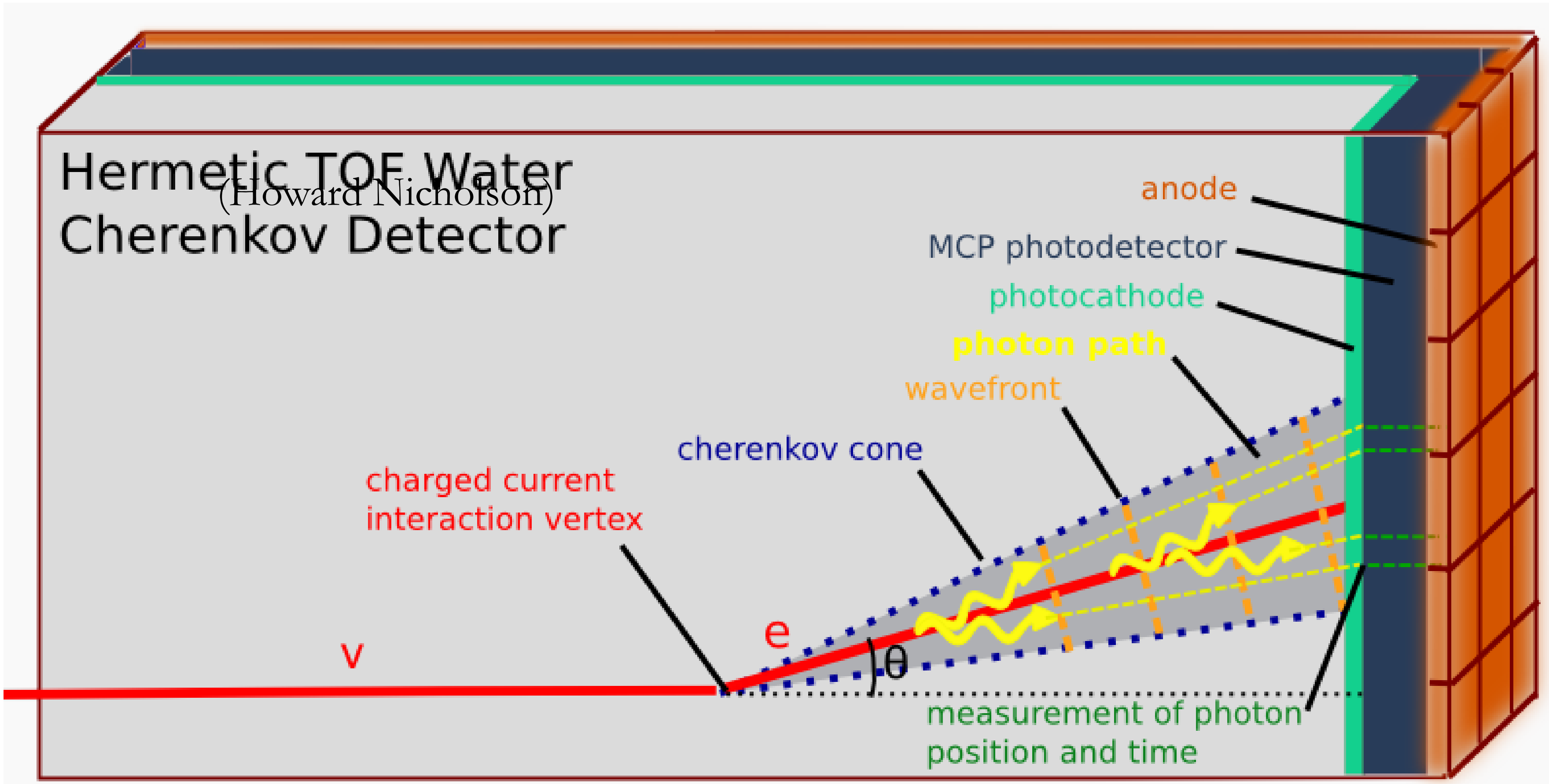
abw: NOT YET

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

Neutrino Physics

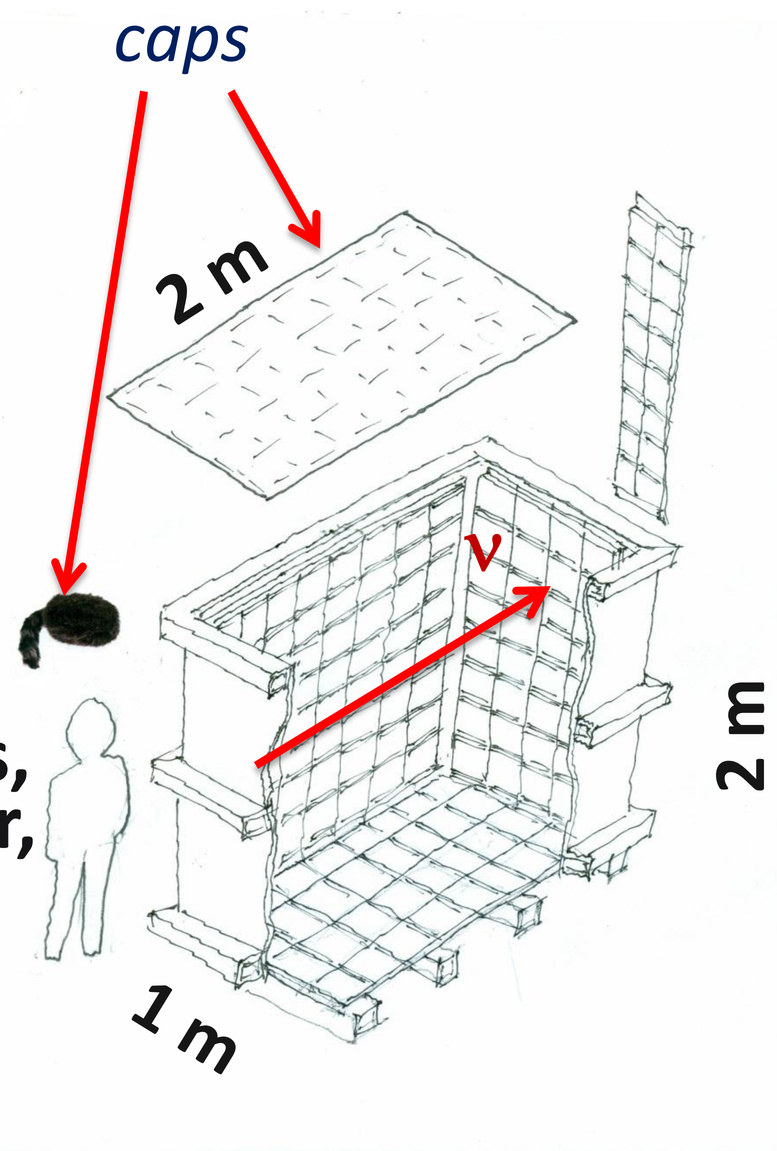


(Howard Nicholson)

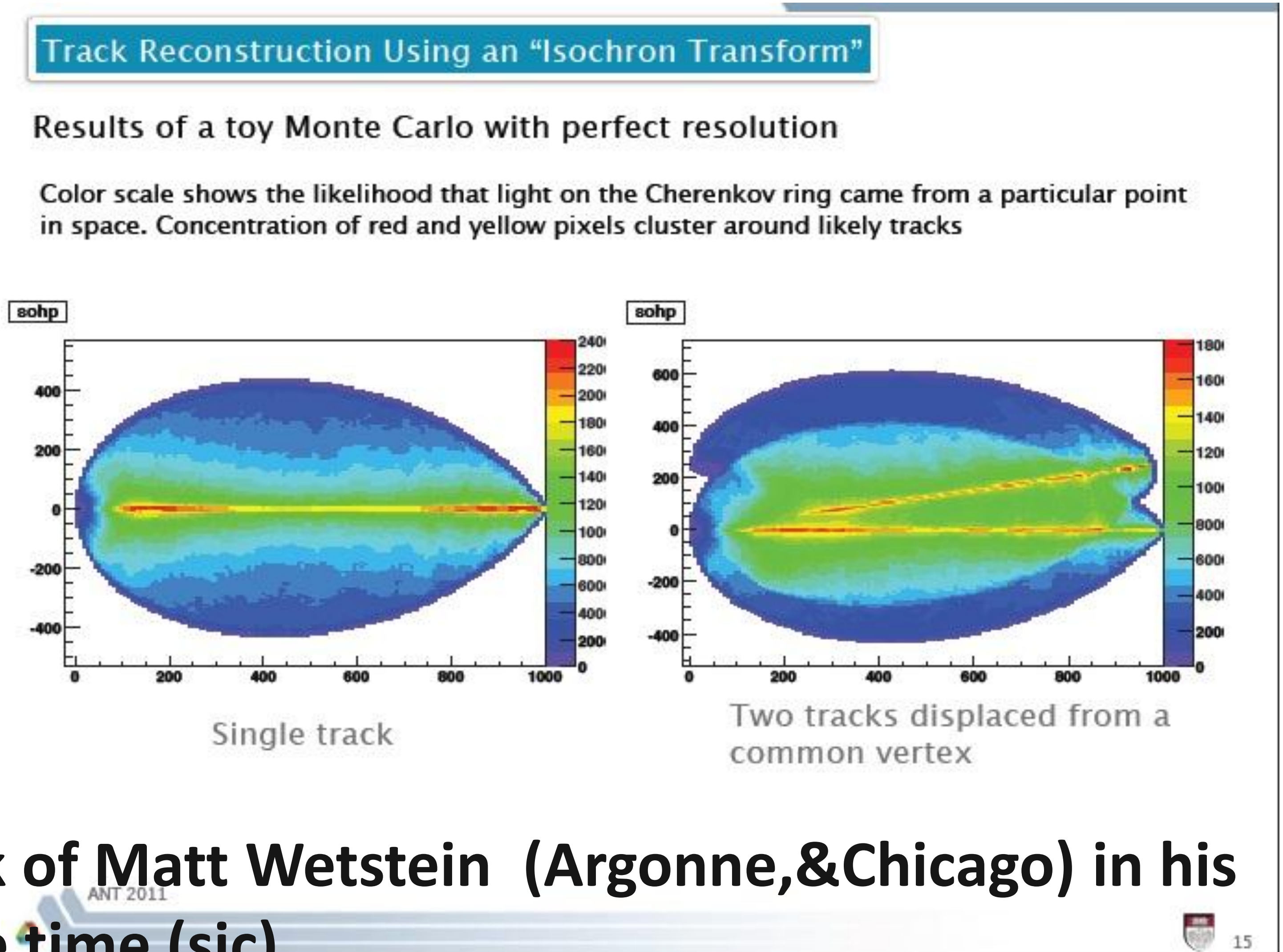
Spec: signal single photon, 100 ps time, 1 cm space, low cost/m2 (5-10K$/m2)*

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).

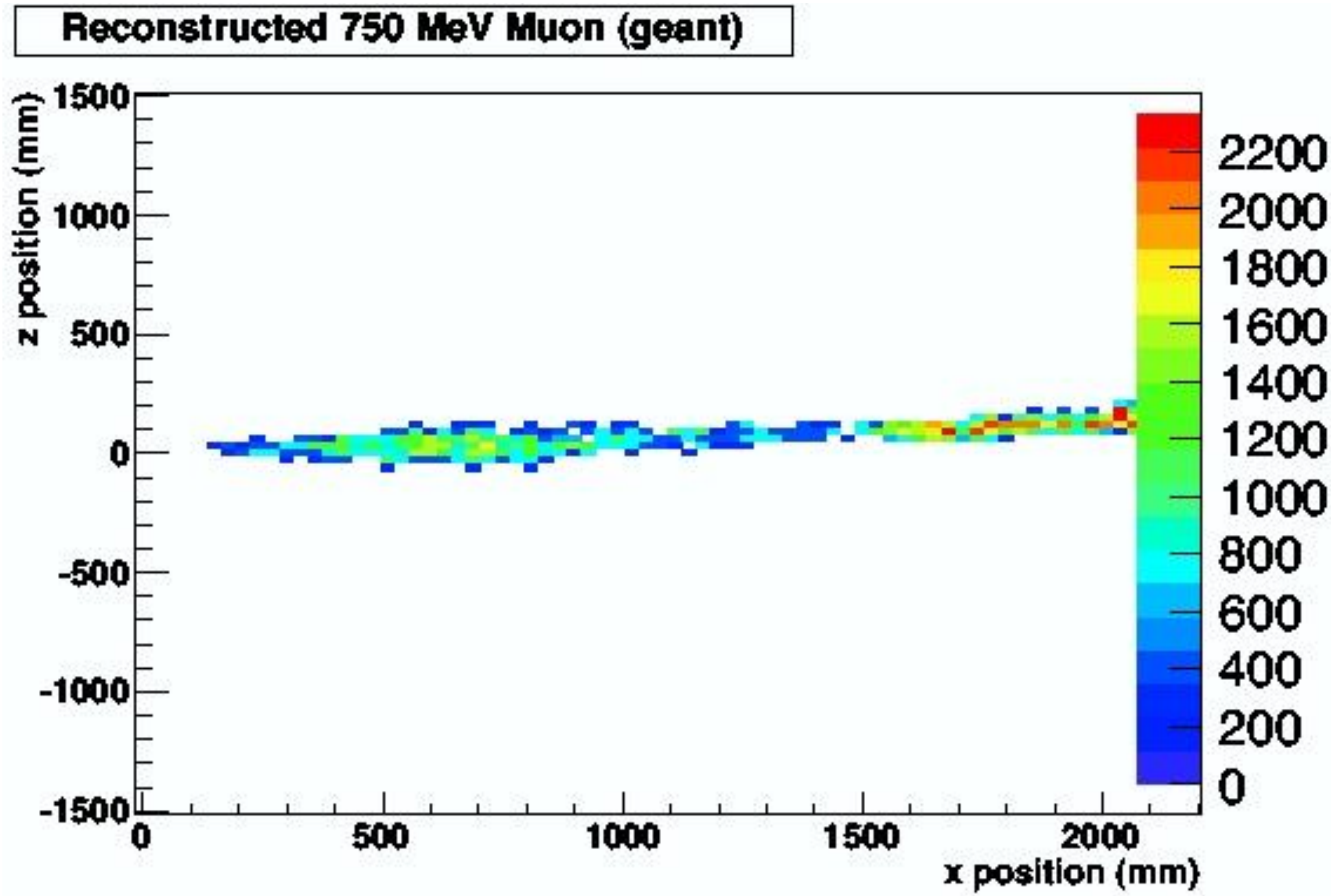


Can we build a photon TPC?



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

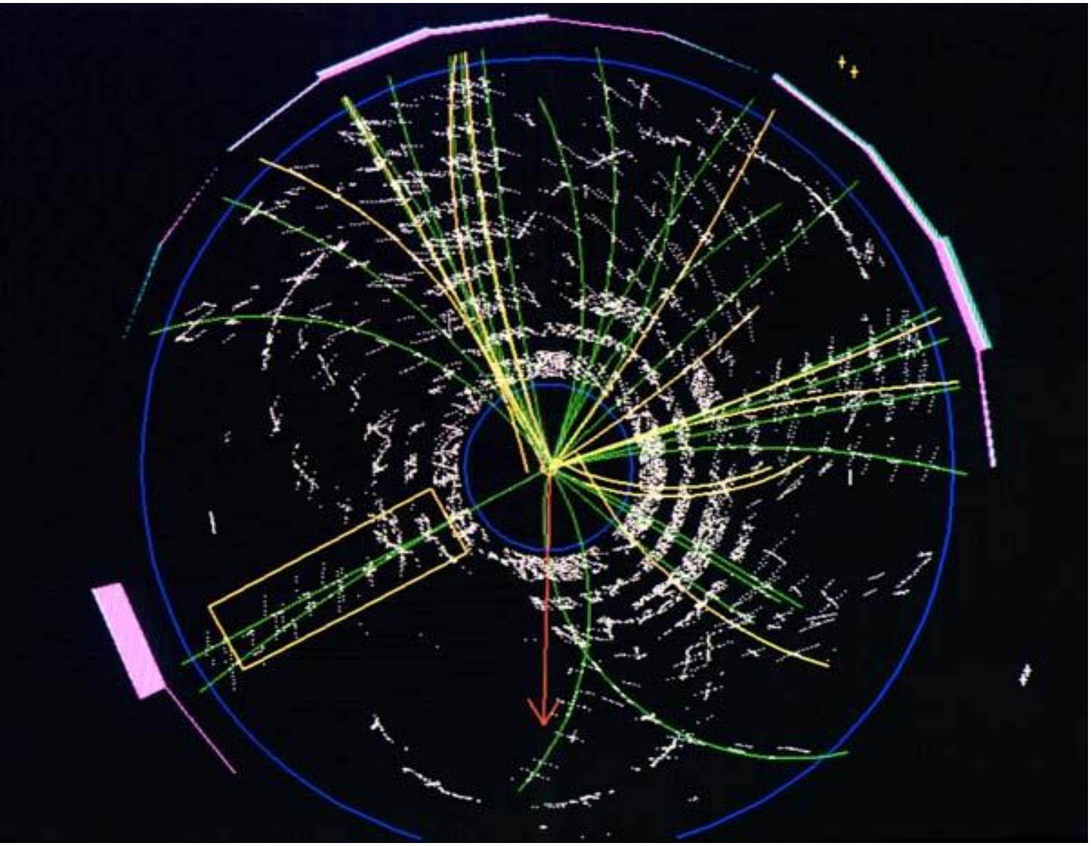
Works on GEANT events too



Matt Wetstein; ANL&UC

Application to Colliders

At colliders we measure the 3-momenta of hadrons, but can't follow the flavor-flow of quarks, the primary objects that are colliding. 2-orders-of-magnitude in time resolution would all us to measure ALL the information=>greatly enhanced discovery potential.



t-tbar -> W^+bW^-bbar->
e+ nu+c+sbar+b+bbar

A top candidate event from CDF- has top, antitop, each decaying into a W-boson and a b or antib. Goal- identify the quarks that make the jets.

Specs:
Signal: 50-10,000 photons
Space resolution: 1 mm
Time resolution 1 psec
Cost: <100K$/m2:

2003- Aspen Exptl Summary Talk

Visions of Where Are We Going In Experimental Particle Physics

Detectors Continued

My choice for development is time-of-flight (!?). Precise measurement of the 3-vector, the point of origin, and the particle type gives *all the information possible about each particle.*

If we could measure with $\sigma = 1$ psec (yes) in a path length of 1.5m (e.g. CDF), get 1 σ $\pi - K$ separation at $p_T = 25$ GeV.

Is this crazy?

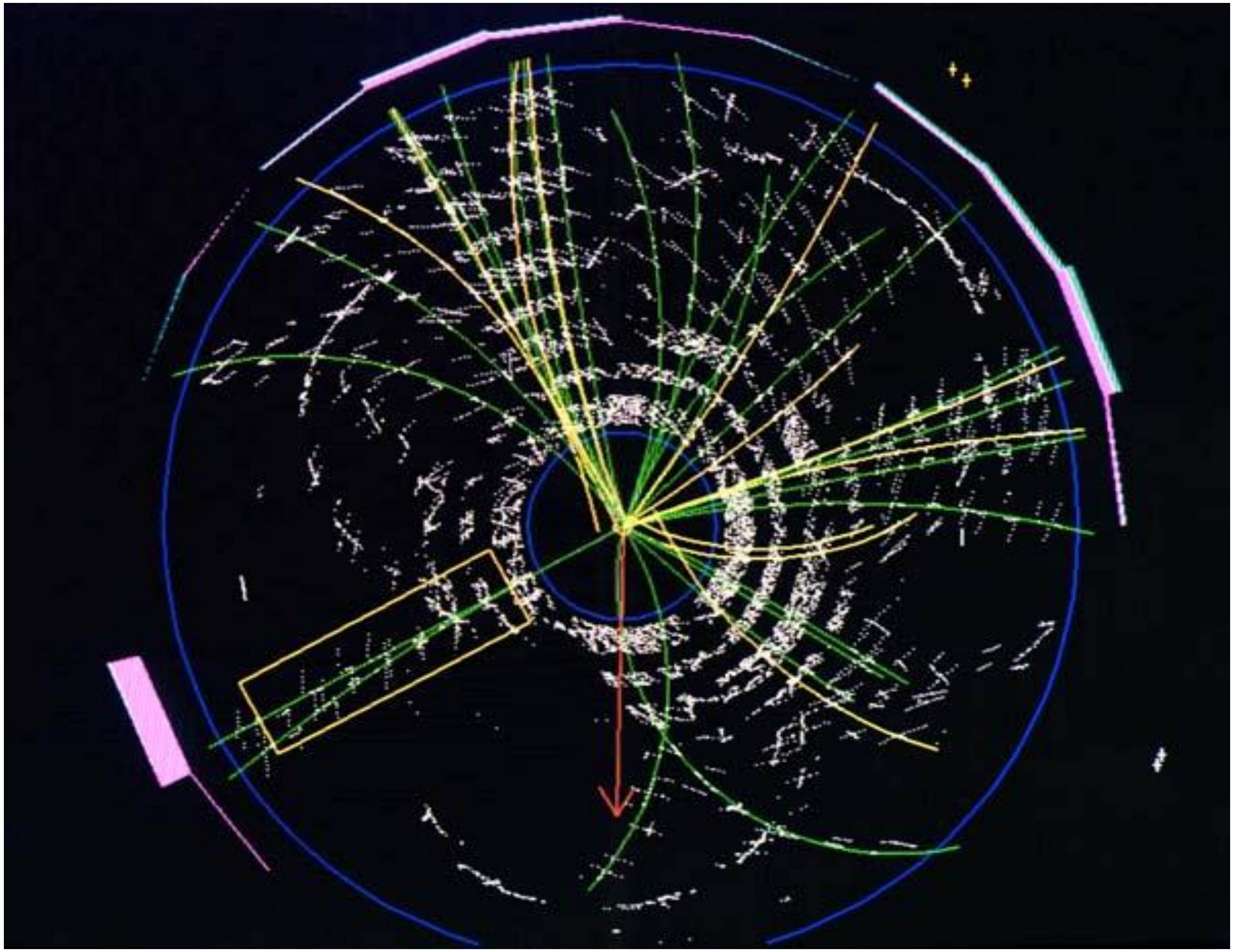
- There exist GaAs Schottky photodiodes with $\sigma \sim 1$ psec, so no law of nature precludes it.
- Need a fast source of light- e.g. Cherenkov radiation.
- Light cannot bounce- has to go straight in.
- Need spatial resolution $< 300\mu$m for $\delta t = 1$ psec.
- Find the collision 'start' time by measuring the time of tracks relative to each other.
- Have to calibrate entire volume *in situ*- need lots of π, K, p,...

So, could we build an outer layer for a central (solenoidal) detector with good spatial resolution and segmentation such that **for every track with $p_T < 25$ GeV we measure not only p_x, p_y, p_z, but also its flavor content?**

HJF Aspen Winter Conference Jan. 19-26, 2003

Invitation from Joe Lykken and Maria Spiropulu- led to psec TOF

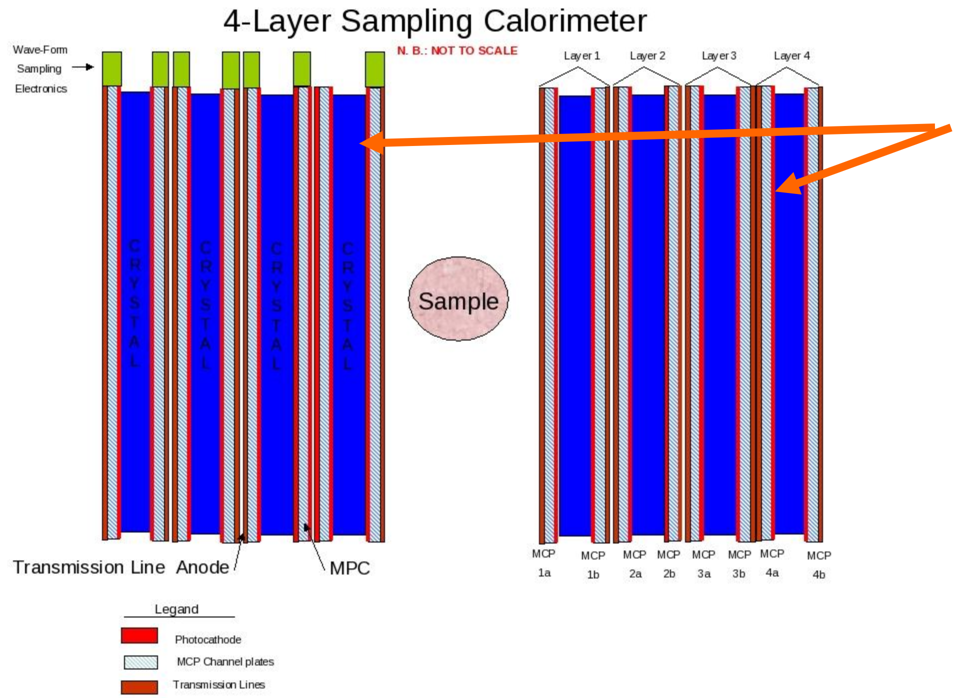
Colliders: Differential TOF



Rather than use the Start time of the collision, measure the difference in arrival times at the beta=c particles (photons, electrons and identified muons) and the hadrons, which arrive a few psec later.

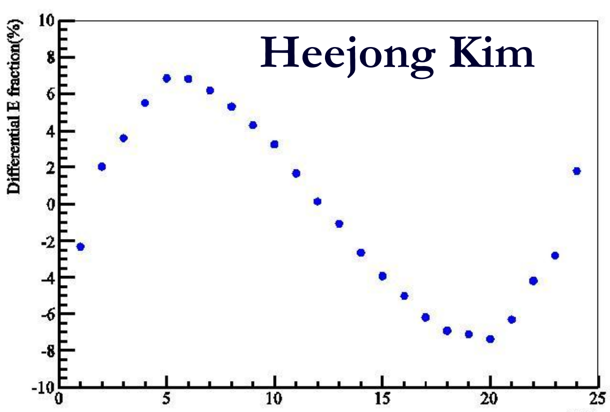
Medical Imaging (PET)

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

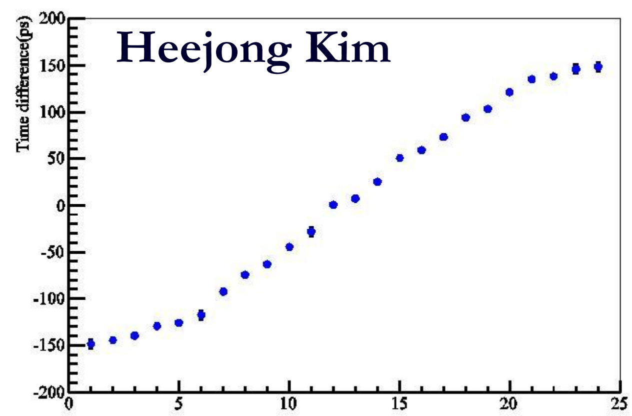


Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side

Simulations by Heejong Kim (Chicago)

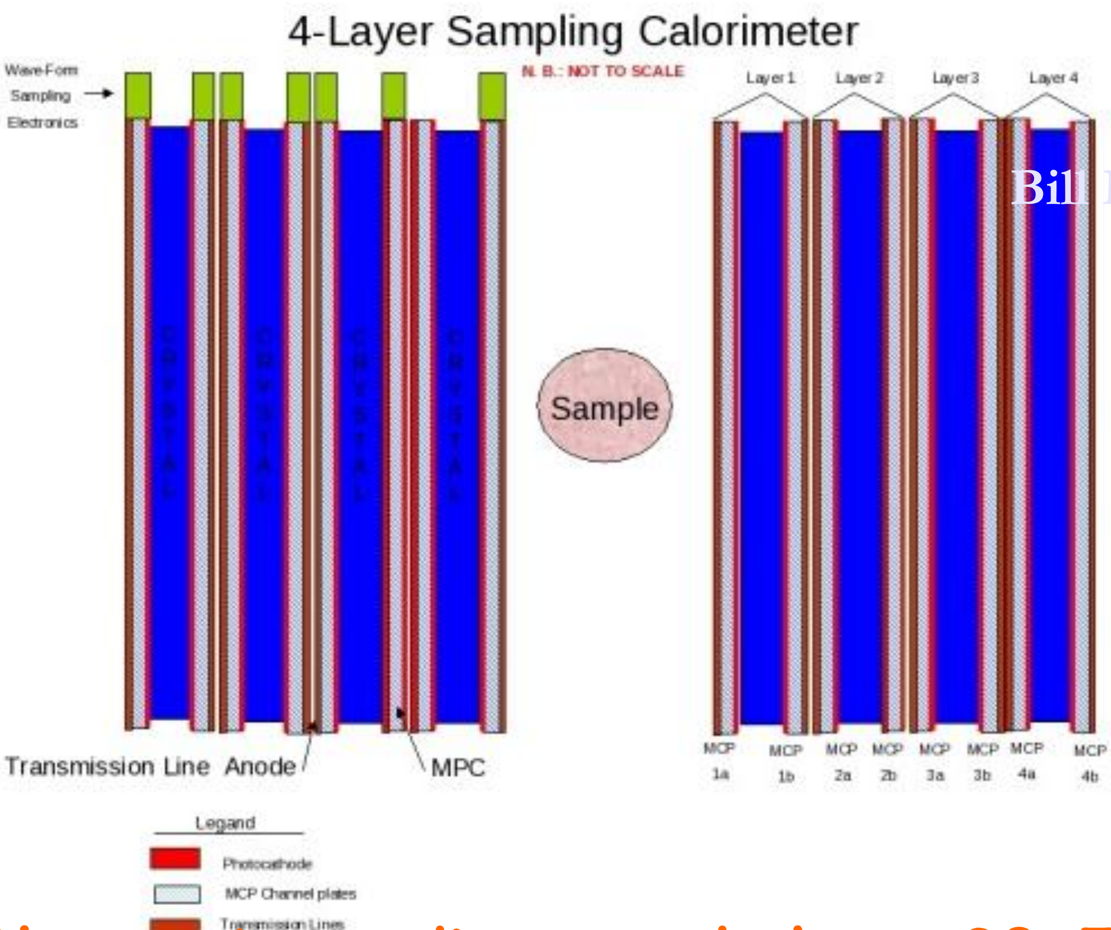


Depth in crystal by energy- asymmetry



Depth in crystal by time-difference

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)

Cherenkov-sensitive Sampling Quasi- Digital Calorimeters

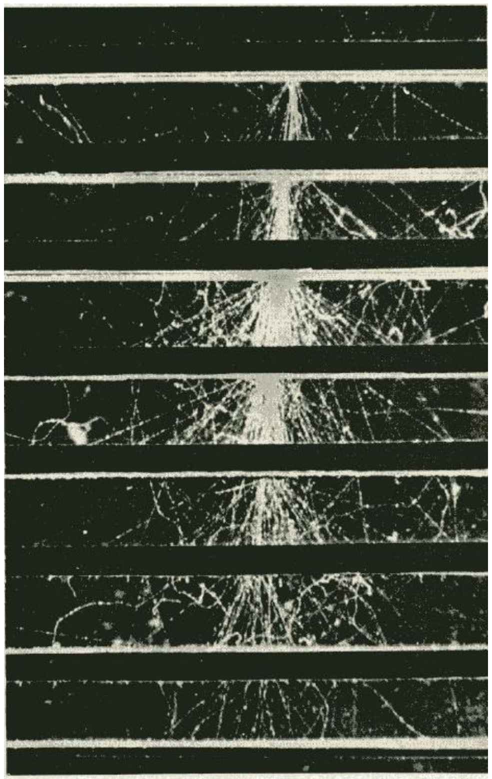
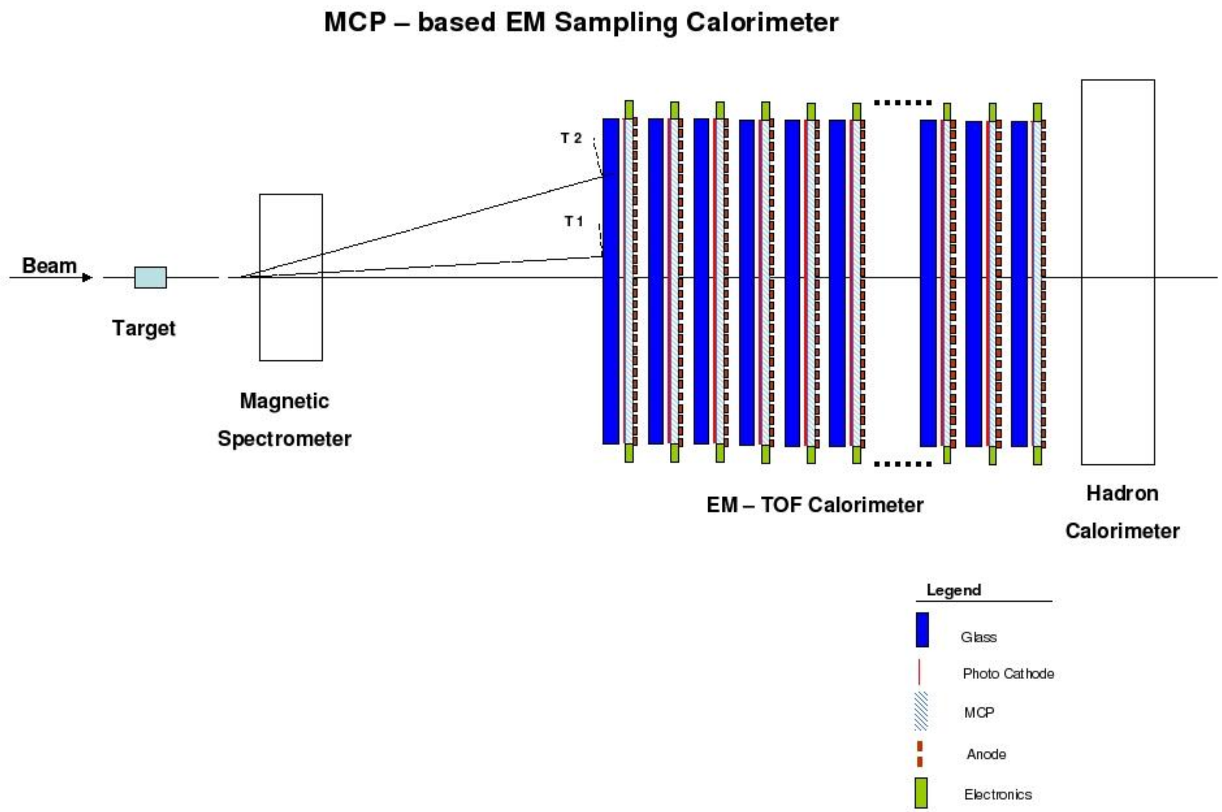


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.



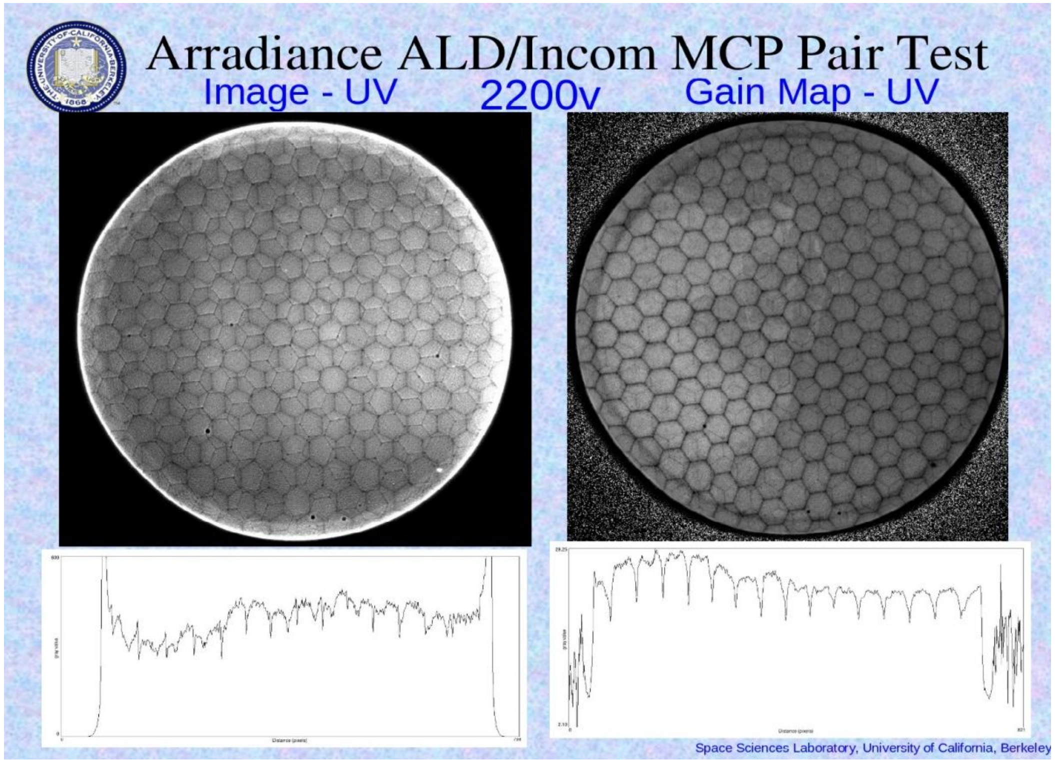
A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

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

More Information:

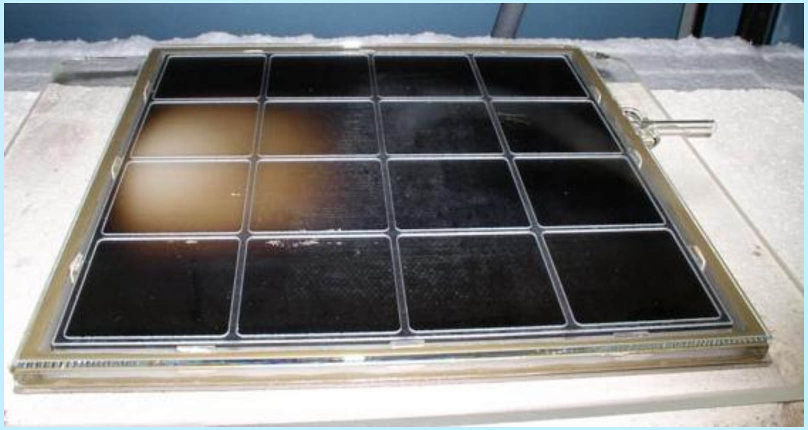
- **Main Page: http://psec.uchicago.edu**
- **Library: Workshops, Godparent Reviews, Image Library, Document Library, Links to MCP, Photocathode, Materials Literature, etc.;**
- **Blog: Our log-book- open to all (say yes to certificate Cerberus, etc.)- can keep track of us (at least several companies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

The End

BACKUP SLIDES

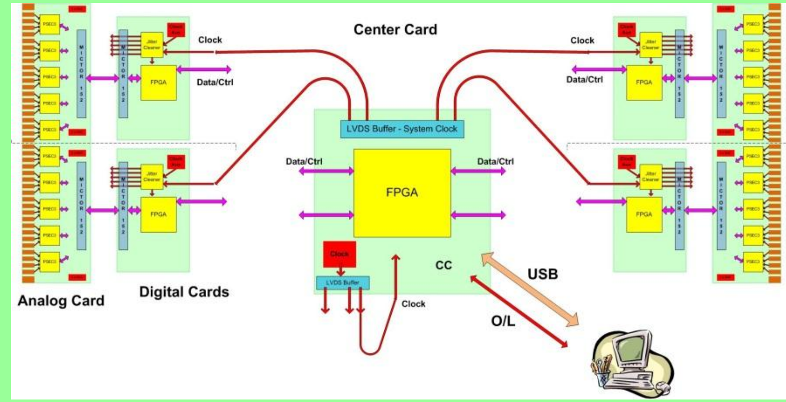
The 4 `Divisions' of LAPPD

Hermetic Packaging



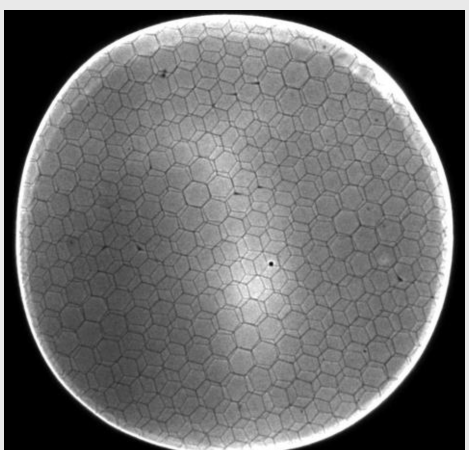
See Bob Wagner's talk

Electronics/Integration



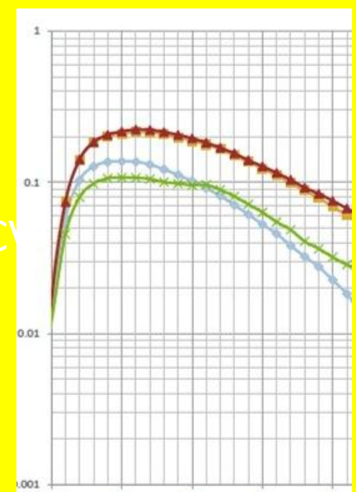
This talk

MicroChannel Plates



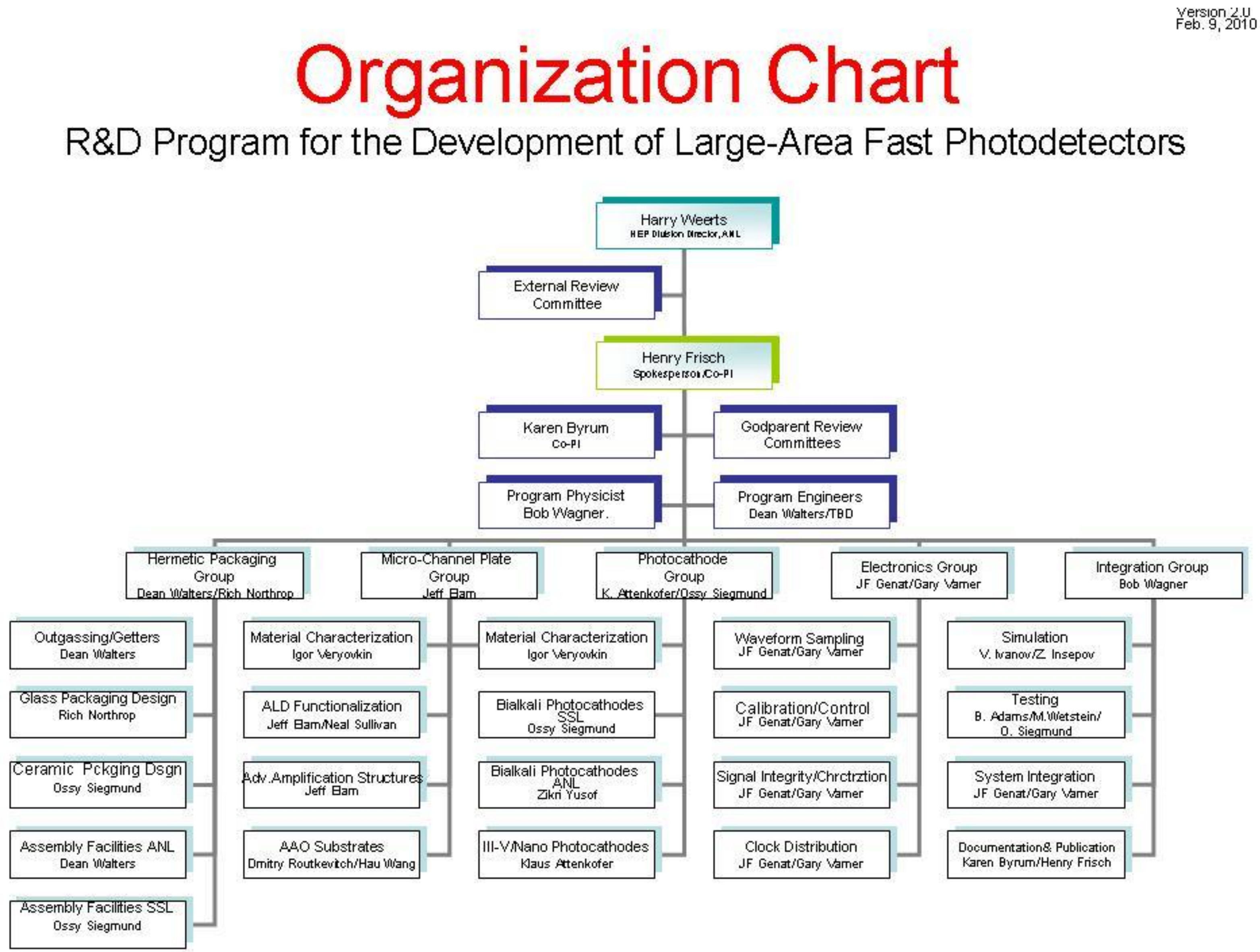
See (hear) Bob Wagner's talk

Photocathodes



See (hear) Klaus Attenkofer's talk

The Large-Area Psec Photo-Detector Collaboration



Microchannel Plates-2

- **Argonne ALD and test Facilities**

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

Anil Mani and Bob Wagner

Razib Obaid and Matt Wetstein

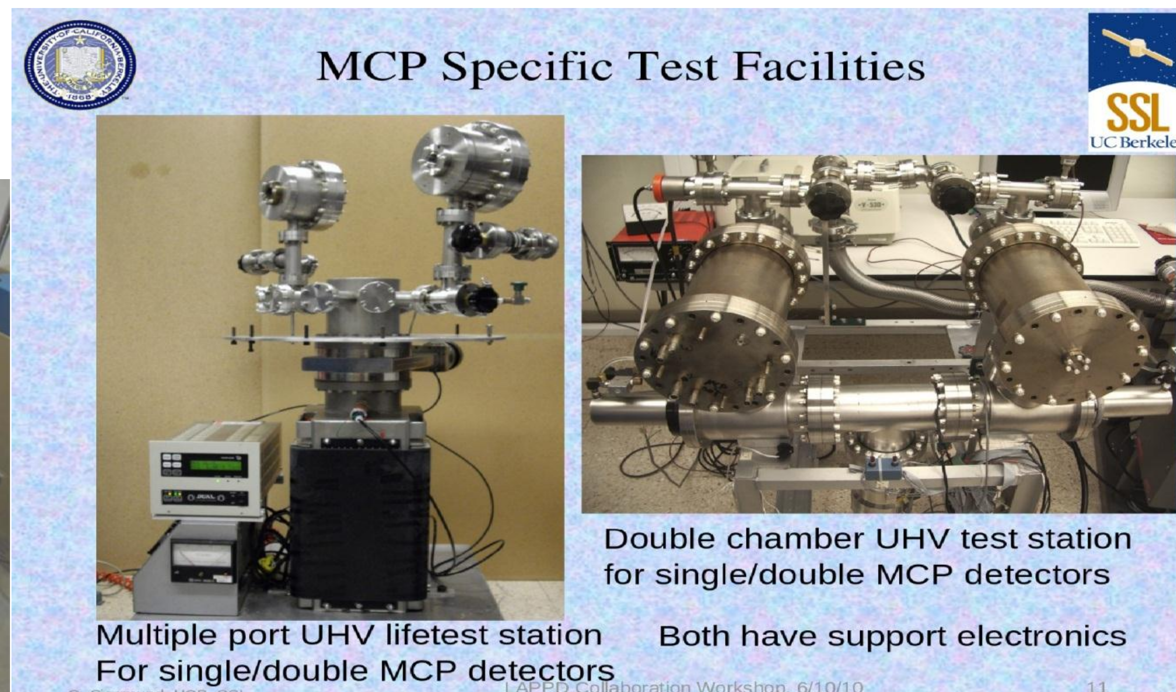
Microchannel Plates-3

- **SSL (Berkeley) Test/Fab Facilities**

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

Decades of experience

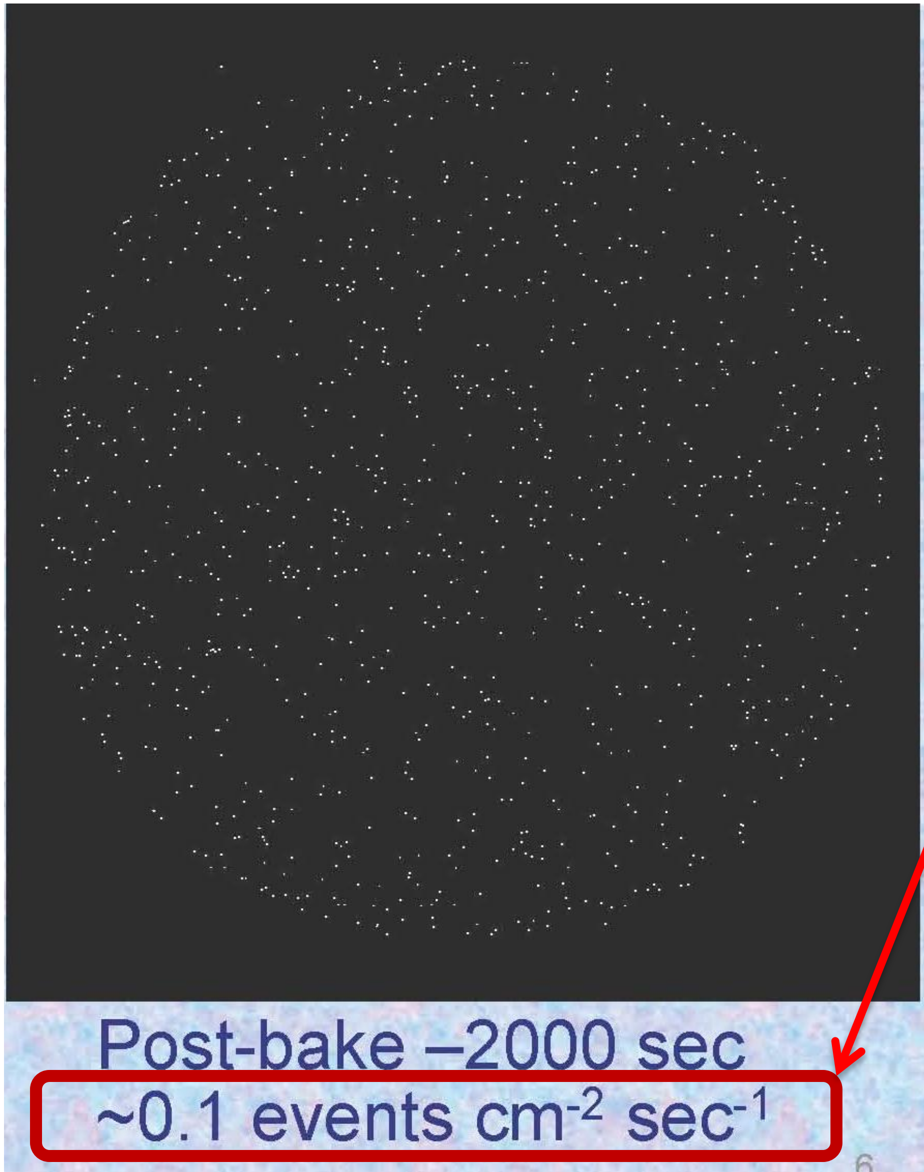
(some of us have decades of inexperience?)



Microchannel Plates-4b

Performance:

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

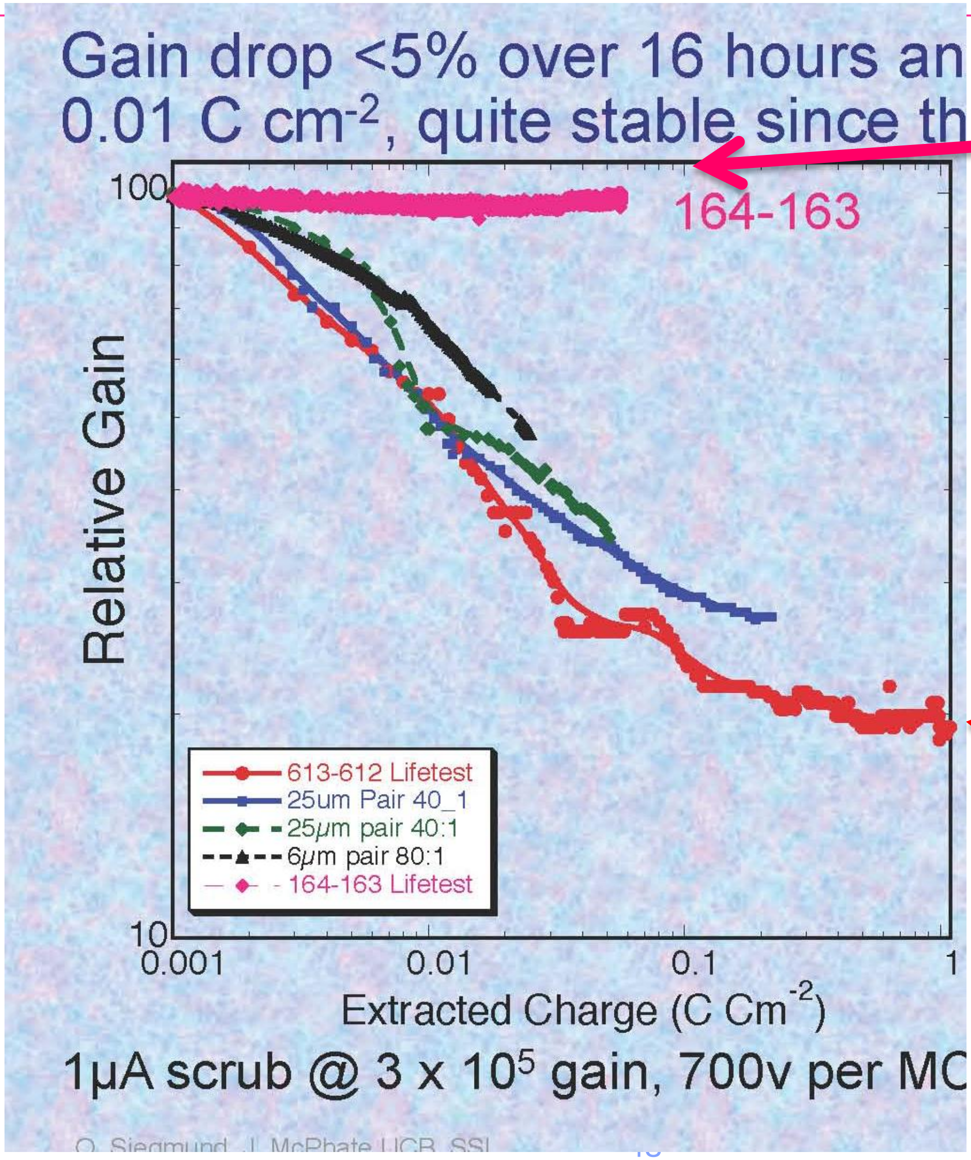


Noise (bkgd rate). <=0.1 counts/cm^2/sec; factors of few > cosmics (!)

Microchannel Plates-4d

Performance: burn-in (aka `scrub')

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



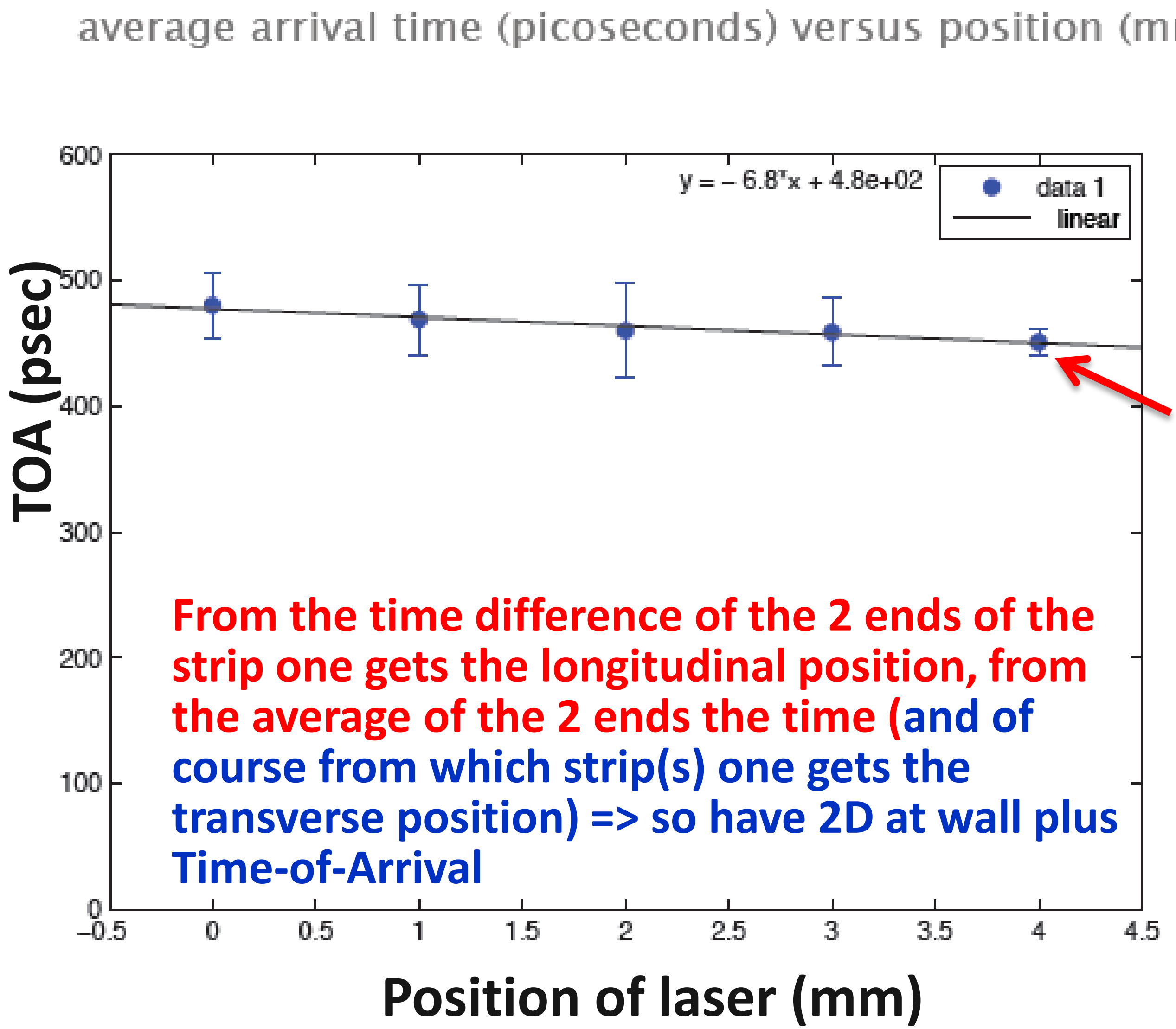
Measured ANL ALD-MCP behavior

(ALD by Anil Mane, Jeff Elam, ANL)

Typical MCP behavior- long scrub-times

First Pulses From an 8” MCP

Matt Wetstein, Bernhard Adams, Razib Obaid, Sasha Vostrikov (ANL and UC)



From the time difference of the 2 ends of the strip one gets the longitudinal position, from the average of the 2 ends the time (and of course from which strip(s) one gets the transverse position) => so have 2D at wall plus Time-of-Arrival

TrueError bar prob.
like this
(ask Matt)

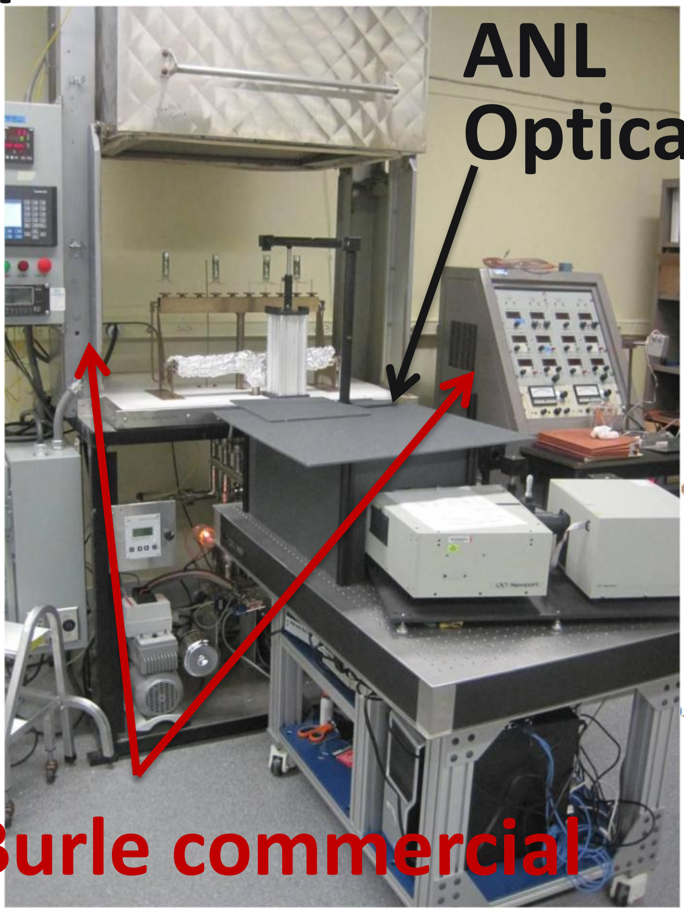
Note
c= 0.3mm/ps
1/c=3.3 psec/mm

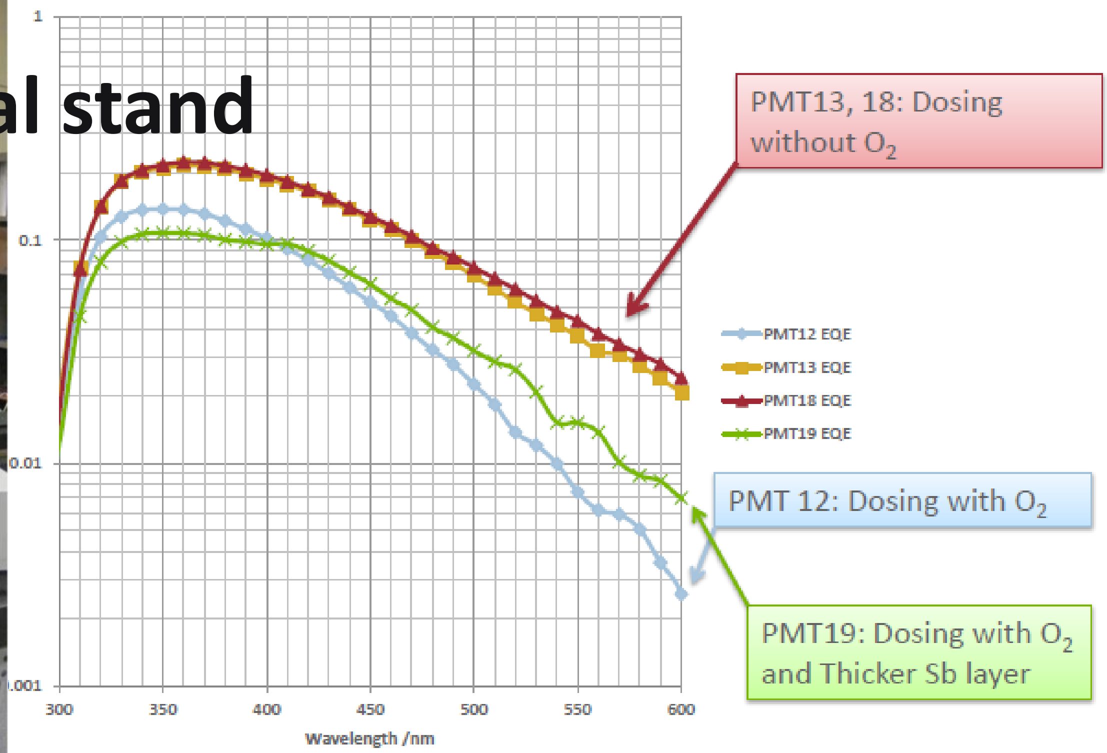
Photocathodes

Subject of next talk by Klaus- touch on here only briefly

LAPPD goal- 20-25% QE, 8"-square

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





First cathodes made at ANL

Photocathodes- 2

Subject of next talk by Klaus

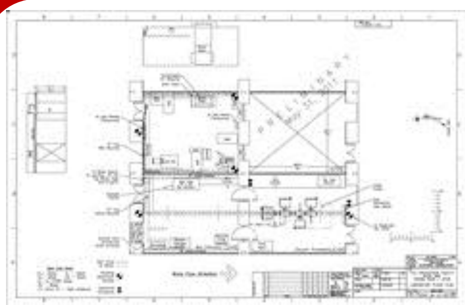
**SSL has years of experience making bialkali photocathodes-
They are our treasury bonds (Swiss francs?) in the LAPPD `portfolio of risk'**

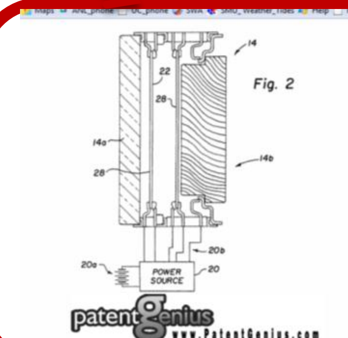
8" Photocathode Chamber

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)

The End