Large-area MCP-based Photo-detectors

Henry Frisch
Enrico Fermi Institute, Univ. of Chicago
and HEPD, Argonne National Laboratory
For the LAPPD Collaboration

Outline

1. A little history and thanks to all 3 institutions
2. MCP's, Transmission Lines, and Waveform Sampling; Time and Space Resolution Determinants (TMI- transparencies can be viewed later if you're interested)
3. Applications: Water Cherenkov Counters; PET Cameras; TOF at Colliders; TOF for Fixed Target; Security (ditto)

(way too many slides- will skip- but you're welcome to look on web)

A little history

All started with seed funding (golden money):

1. First Funding from Dean Fefferman (UC)
2. Then LDRD (3-Year) with Karen Byrum and Gary Drake (ANL)
3. 2007 FRA (1st round) with Karen (ANL) and Eric Ramberg (FNAL)
4. 2009 DOE substantial funding => LAPPD

2007 letter from Don Levy

Date: Wed, 5 Sep 2007 15:27:29 -0500

To: University Faculty and Staff

From: Donald Levy, Vice President for Research and for National Laboratories

Re: Announcement

$225,000 awarded for joint University-Fermilab Strategic Collaborative Initiatives projects

I am pleased to announce that researchers and scientists at the University and Fermi National Accelerator Laboratory have been awarded $225,000 ($75,000 each) for new joint research projects through the University's new Strategic Collaborative Initiatives (SCI) program for Fermilab. The research projects cover a broad range of studies from chemistry to high energy particle physics to computational cosmology. Proposals for collaborative projects that included researchers from Argonne National Laboratory were also considered and one was selected for funding.

New proposals receiving SCI grants and their principal investigators are:

* "Fundamental studies of the interfacial oxidation chemistry of Niobium and the influence such oxidation has on high-performance superconducting RF materials," Steven J. Sibener, Carl William Eisendrath Professor in Chemistry and Director, The James Franck Institute, and Lance Cooley, SRF Materials Group Leader at Fermilab

* "High energy particle physics time-of-flight detectors," Henry Frisch, Professor in Physics, Erik Ramberg, Scientist II, Particle Physics Division at Fermilab, and Karen Byrum, Scientist, High Energy Physics Division at Argonne

* "Numerical Cosmology at Fermilab and the University of Chicago," Nick Gnedin, Associate Professor, Department of Astronomy and Astrophysics, Fermilab Theoretical Astrophysics Group, and Kavli Institute for Cosmological Physics; Scott Dodelson, Associate Professor, Department of Astronomy and Astrophysics and Head of Fermilab Theoretical Astrophysics Group, Kavli Institute for Cosmological Physics; and Andrey Kravtsov, Associate Professor, Department of Astronomy and Astrophysics, Kavli Institute for Cosmological Physics, and The Enrico Fermi Institute.

The above proposals were selected on the basis of the importance of the work; whether the collaboration creates a more powerful or convincing research program than could be achieved by working independently; and potential to achieve an ongoing collaboration.

2009 Slide

Thoughts on Role of FRA Funding

- Allowed crucial proto-typing of ASICs and transmission lines, acquisition of commercial MCP's and electronics, visiting students
- Not large- 75K$ first yr; 90K$ 2nd yr, so only 25-30K$/institution/yr. Not enough alone...
- Consequently should be spent at FNAL and ANL on things that are hard for a national lab, and at UC on things that are hard for a university group (i.e. use it for items not easily supported by federal spending).
- In our case, being able to order expensive instrumentation and have foreign visitors made a huge difference (2-ledger accounts are worth their weight in gold).

The Large-Area Psec Photo-detector Collaboration

2009 Slide

The Development of Large-Area Fast Photo-detectors

April 15, 2009

John Anderson, Karen Byrum, Gary Drake, Edward May, Alexander Paramonov, Mayly Sanchez, Robert Stanek, Hendrik Weerts, Matthew Wetstein[1], Zikri Yusof
High Energy Physics Division
Argonne National Laboratory, Argonne, Illinois 60439

Bernhard Adams, Klaus Attenkofer
Advanced Photon Source Division
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Zeke Insepov
Mathematics and Computer Sciences Division
Argonne National Laboratory, Argonne, Illinois 60439

Jeffrey Elam, Joseph Libera
Energy Systems Division
Argonne National Laboratory, Argonne, Illinois 60439

Michael Pellin, Igor Veryovkin, Hau Wang, Alexander Zinovev
Materials Science Division
Argonne National Laboratory, Argonne, Illinois 60439

David Beaulieu, Neal Sullivan, Ken Stenton
Arradiance Inc., Sudbury, MA 01776

Mircea Bogdan, Henry Frisch[1], Jean-Francois Genat, Mary Heintz, Richard Northrop, Fukun Tang
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

Erik Ramberg, Anatoly Ronzhin, Greg Sellberg
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Ruckman, Gary Varner
University of Hawaii, 2505 Correa Road, Honolulu, HI, 96822

Robert Abrams, Valentin Ivanov, Thomas Roberts
Muons,Inc 552 N. Batavia Avenue, Batavia, IL 60510

Jerry Va'vra
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

Oswald Siegmund, Anton Tremsin
Space Sciences Laboratory, University of California, Berkeley, CA 94720

Dmitri Routkevitch
Synkera Technologies Inc., Longmont, CO 80501

David Forbush, Tianchi Zhao
Department of Physics, University of Washington, Seattle, WA 98195

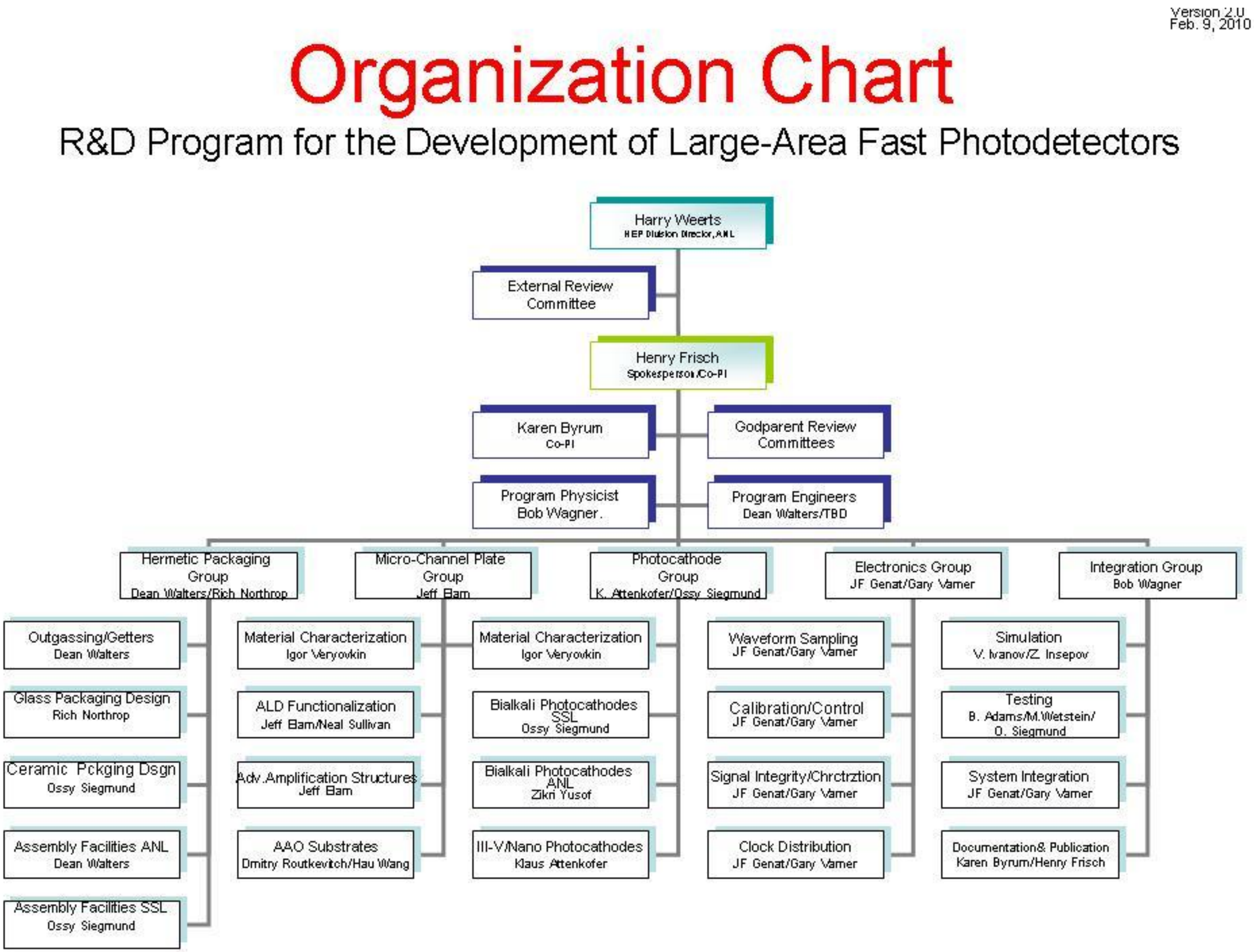
[1] Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

Henry Frisch
Enrico Fermi Institute and Argonne National Laboratory

4 National Labs, 5 Divisions at Argonne, 3 US small companies; electronics expertise at Universities of Chicago and Hawaii

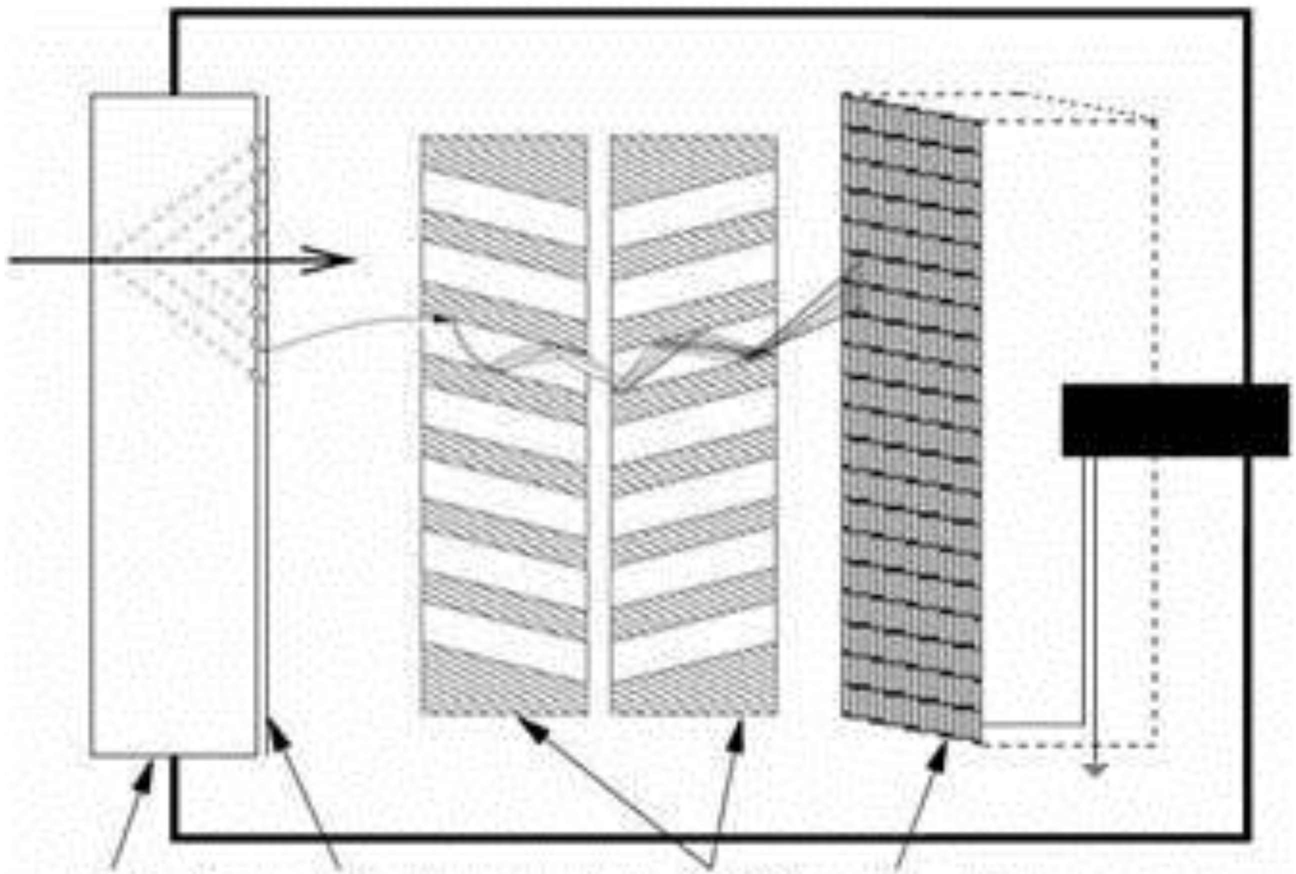
Goal of 3-year R&D- commercializable modules.

The Large-Area Psec Photo-Detector Collaboration



Brief Intro to MCP's, Transmission Lines, and Waveform Sampling

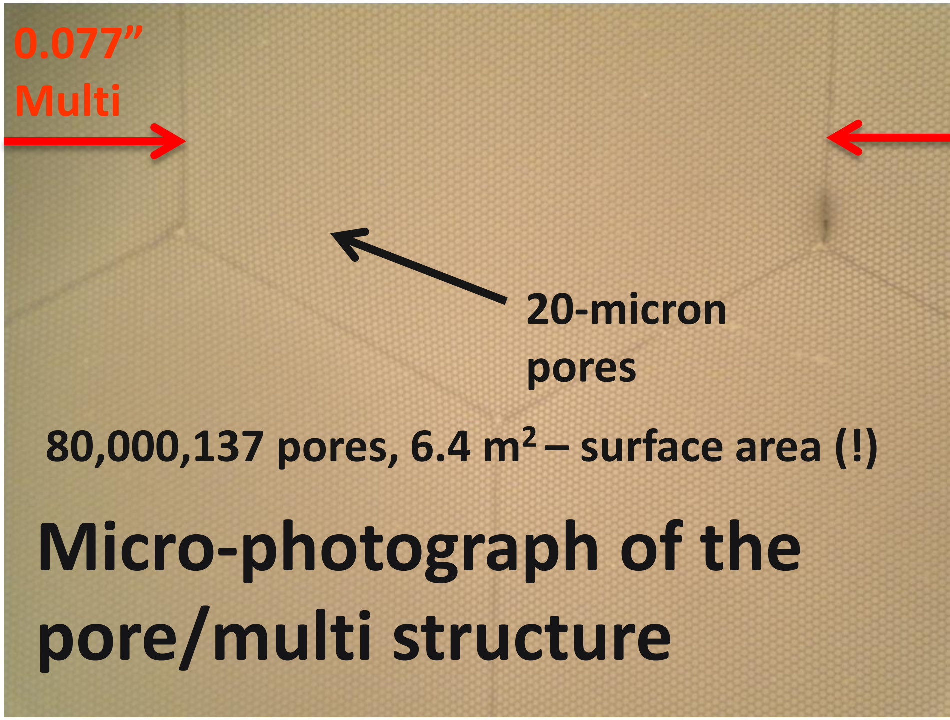
Satisfies small feature size and homogeneity



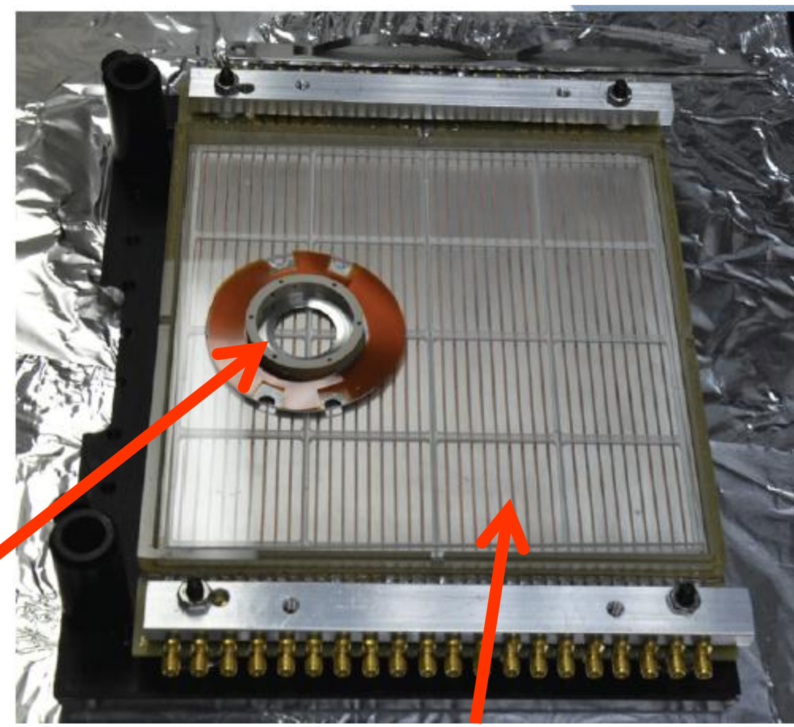
Photon and electron paths are short- few mm to microns=>fast, uniform Planar geometry=>scalable to large areas

We now have 8" MCP's

- **Incom Glass Substrates- Hard (untreated) glass**



2 working formats:



33mm Disc (Development)

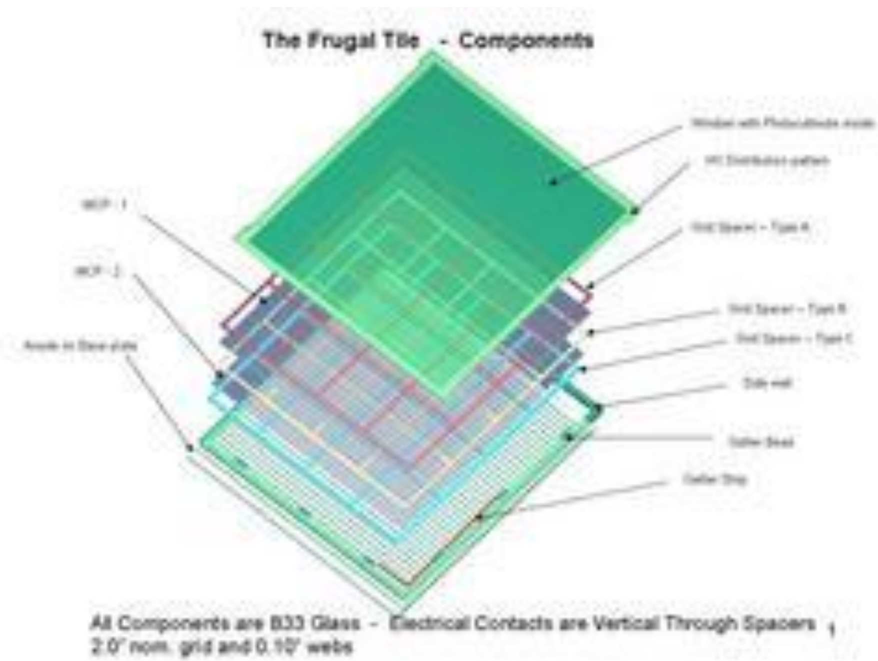
8"-square (the `Tile')

Large Area Design- 8" `tiles'

- Have moved to a tile/tray design: tray has all the electronics; only connections to tiles are HV and ground
- Tiles are glued with spray glue to tray
- HV divider chain is made with ALD
- No pins through glass
- Tile is plate glass
- Anode strips connect
- Modular; simple
- Top seal is cold (ANL) Hot (SSL)

Hermetic Packaging

- **ANL/UC Glass Package**

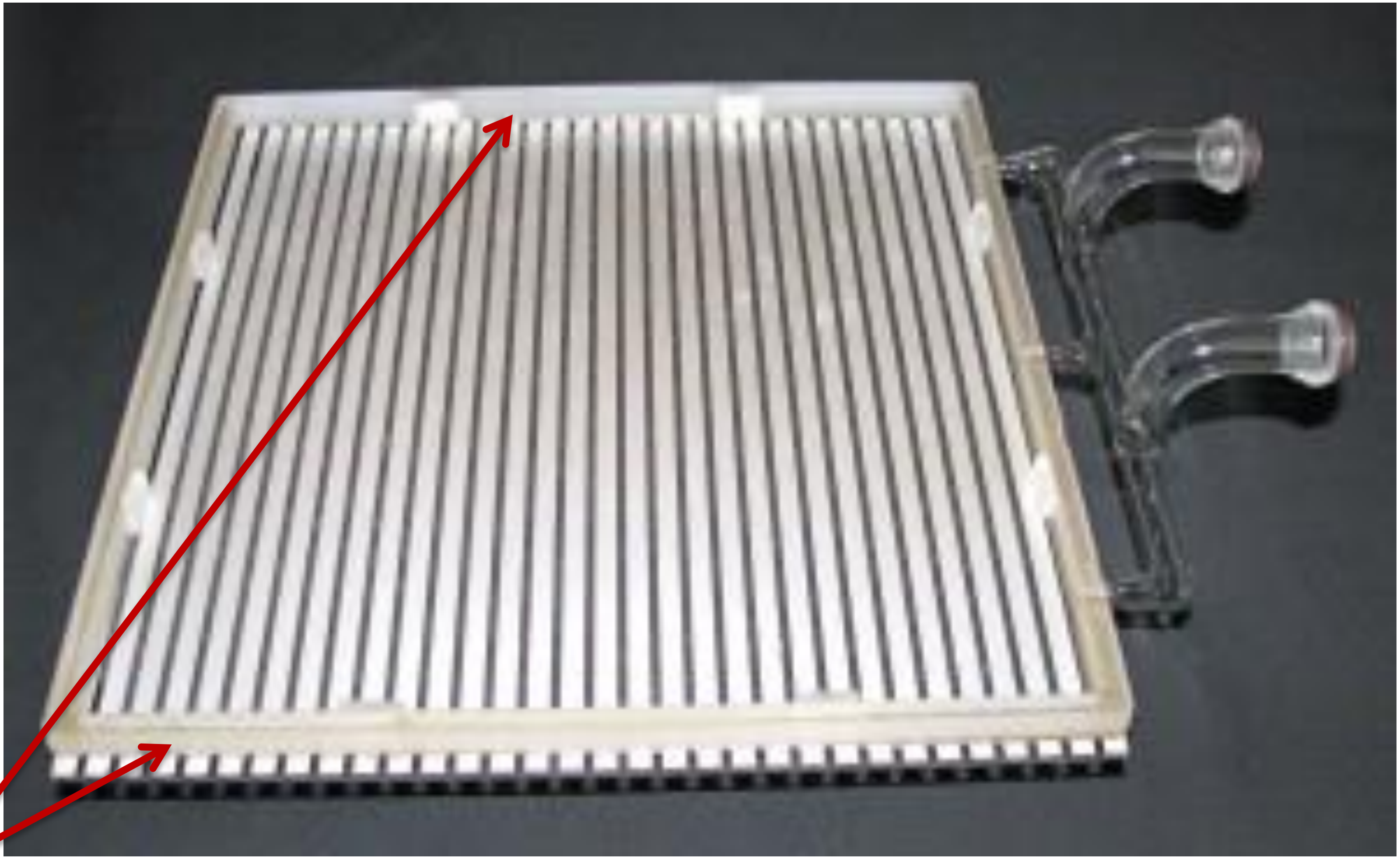


Glass package showing ALD-coated 8" MCP, grid spacer, bottom seal

(apologies for blurriness)

Hermetic Packaging

We have solved sealing over the anode strips



Bottom seal by Joe Gregar, ANL master glass-blower with help from Michael Minot (Minotech, Incom) and Ferro Corp

Fermilab Electroding Facility

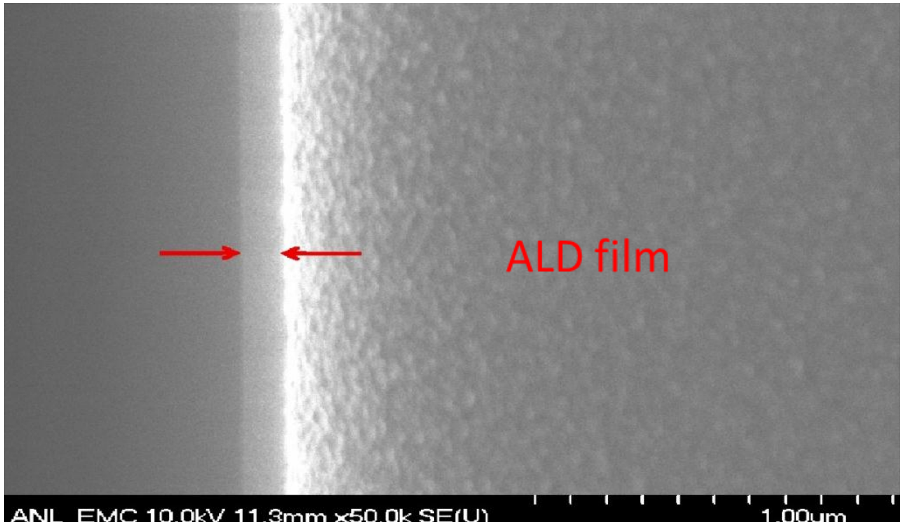
Total view of system with top bell open for mounting MCP frame

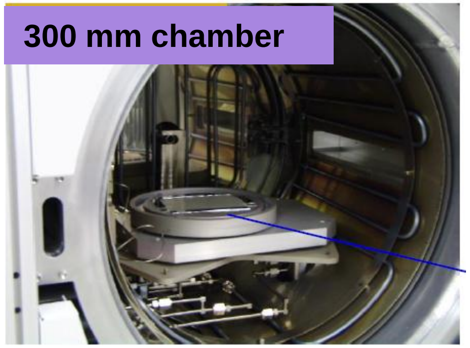
Slide from Eileen Hahn, Group Leader Thin Film Facility; 3rd LAPPD Collaboration Meeting, Dec 9, 2011
Fermilab Group: Erik Ramberg, Greg Sellberg, Anatoly Ronzhin, Pasha Murat

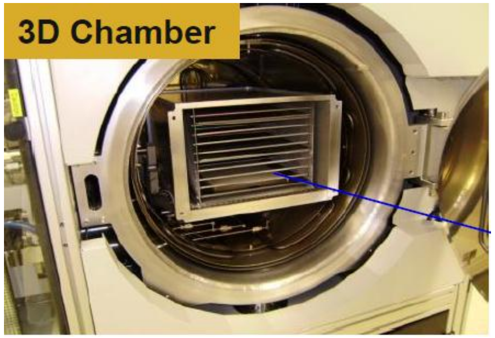
ALD Coating 8” MCPs in Beneq

Jeff Elam, Anil Mane, Joe Libera (Qing Peng) , (Thomas Proslier) (ANL:ESD/HEP); Neal Sullivan (Arradiance), Anton Tremsin (Arradiance, SSL)

All pictures swiped from Jeff’s talks- invite him and Anil to talk (!)







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 Mane and Bob Wagner

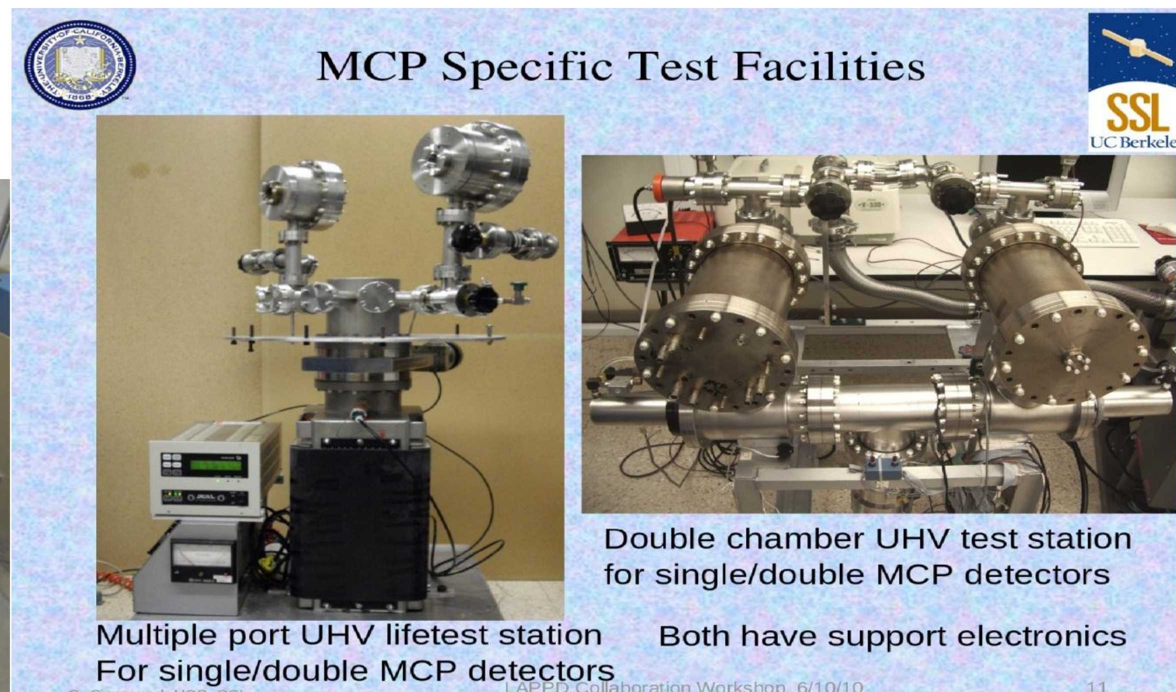
SSL (Berkeley) Test/Fab Facilities

(tests ANL ALD-coated MCP's; parallel MCP design- will be first to produce (why I show it))

Ossy Siegmund, Jason McPhate, Sharon Jelenski, and Anton Tremsin (also Arradiance)

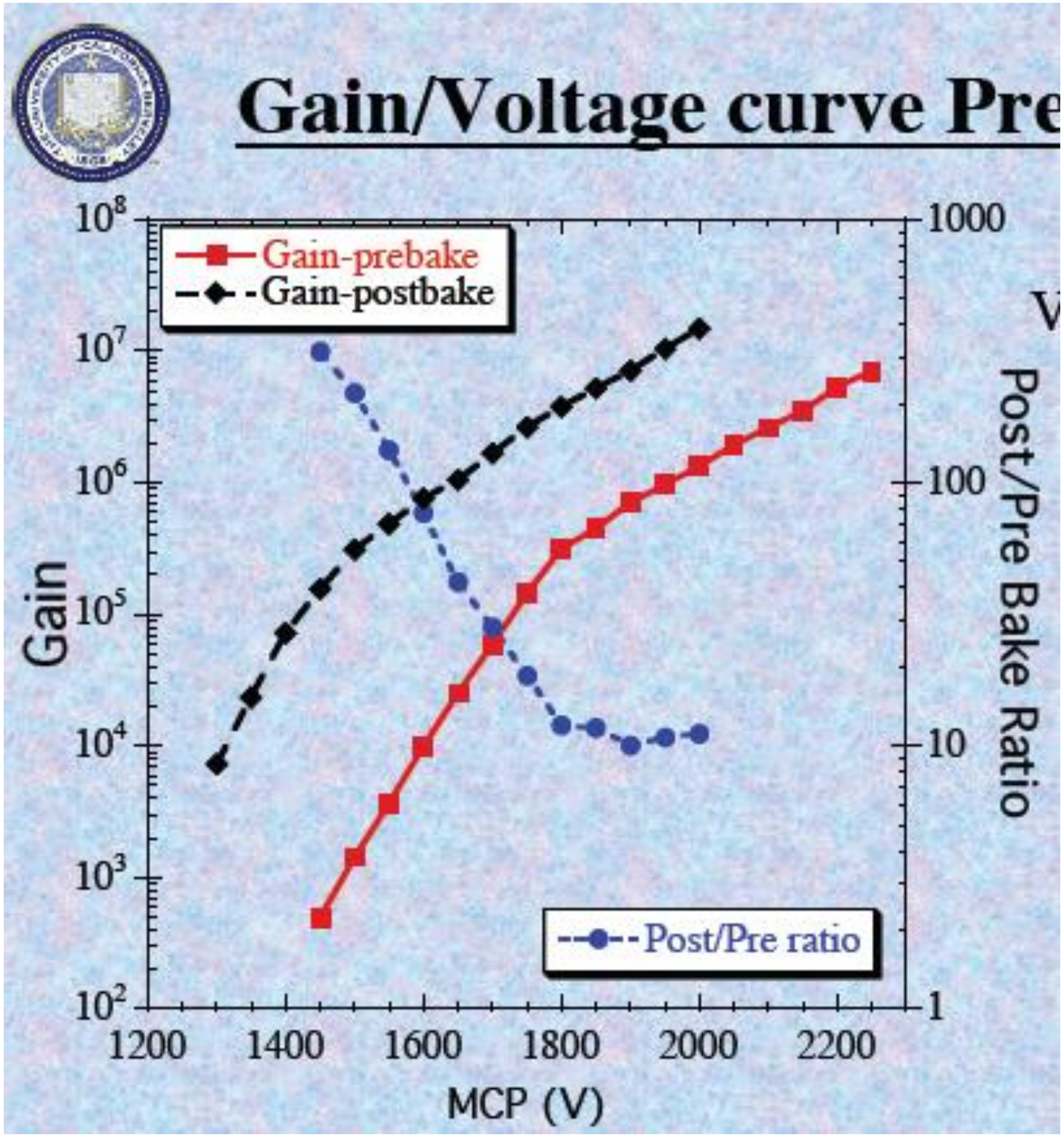
Decades of experience

(some of us have decades of inexperience?)



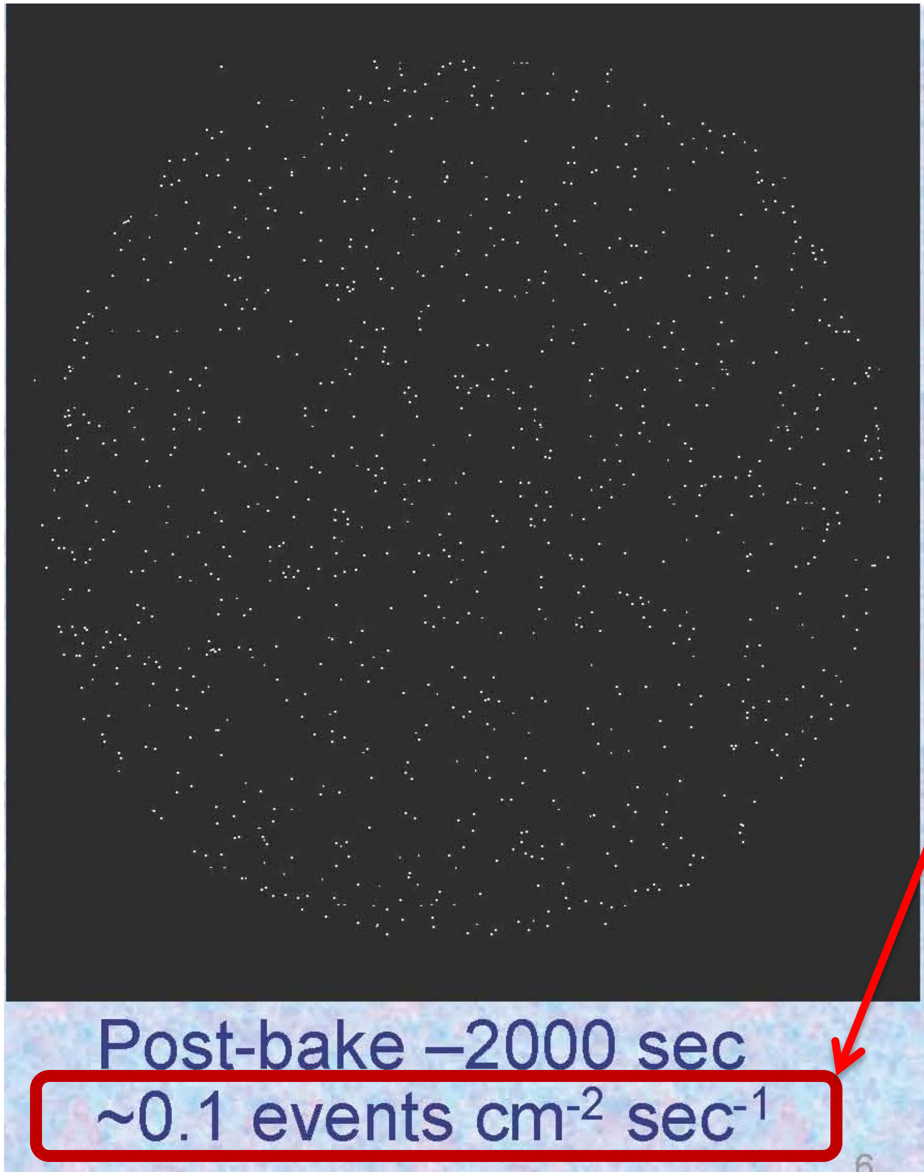
Performance: First, the gain. We see gains > 10^7 in a chevron-pair; > 10^5 in a single plate (attractive possibility for cost/simplicity)

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



Performance- noise.

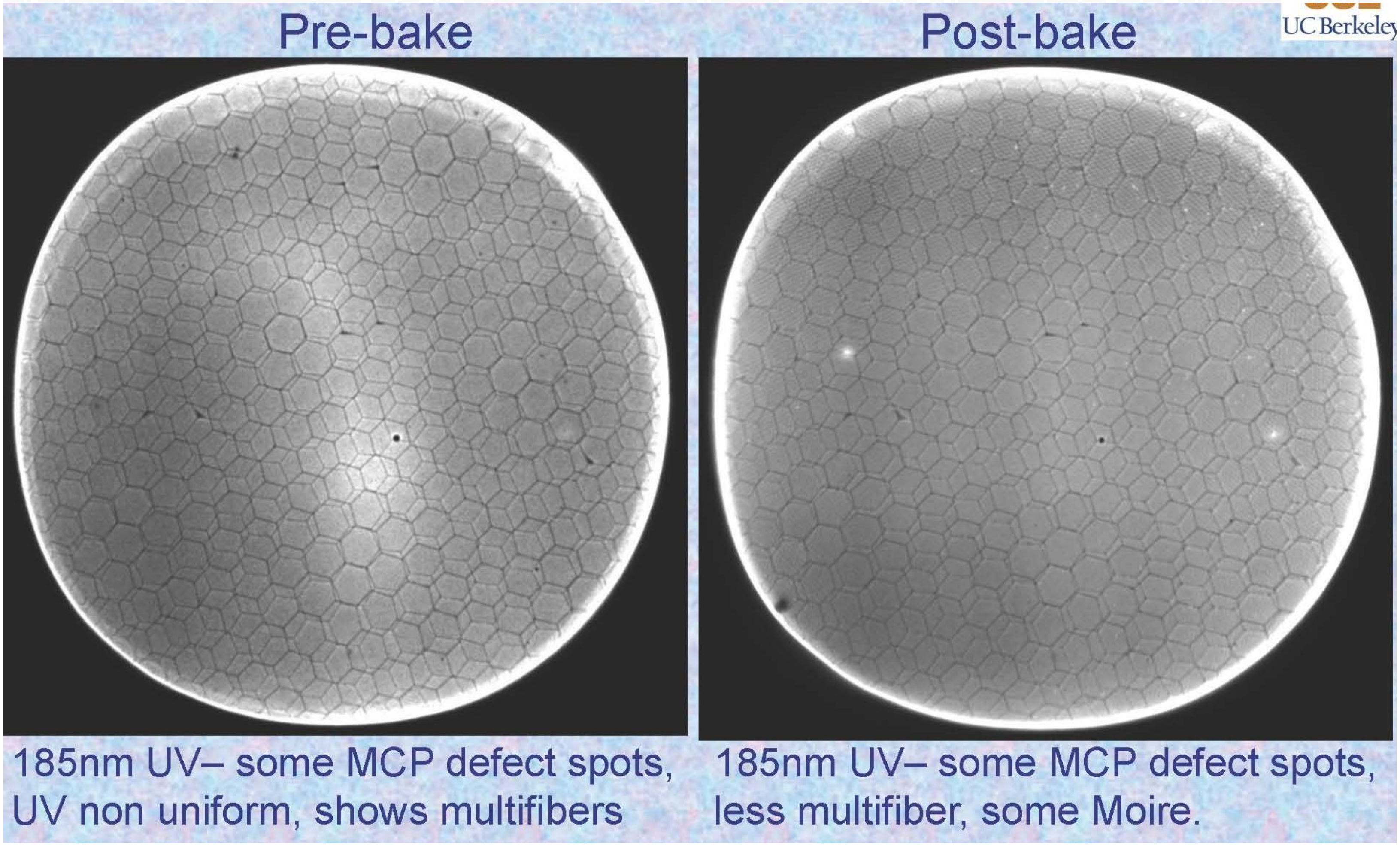
Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB



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

Comparable to the very best (boutique) conventional MCP's

Performance: Image quality, spatial resolution, uniformity: Good uniformity; can resolve the multi boundaries in top plate (20microns)

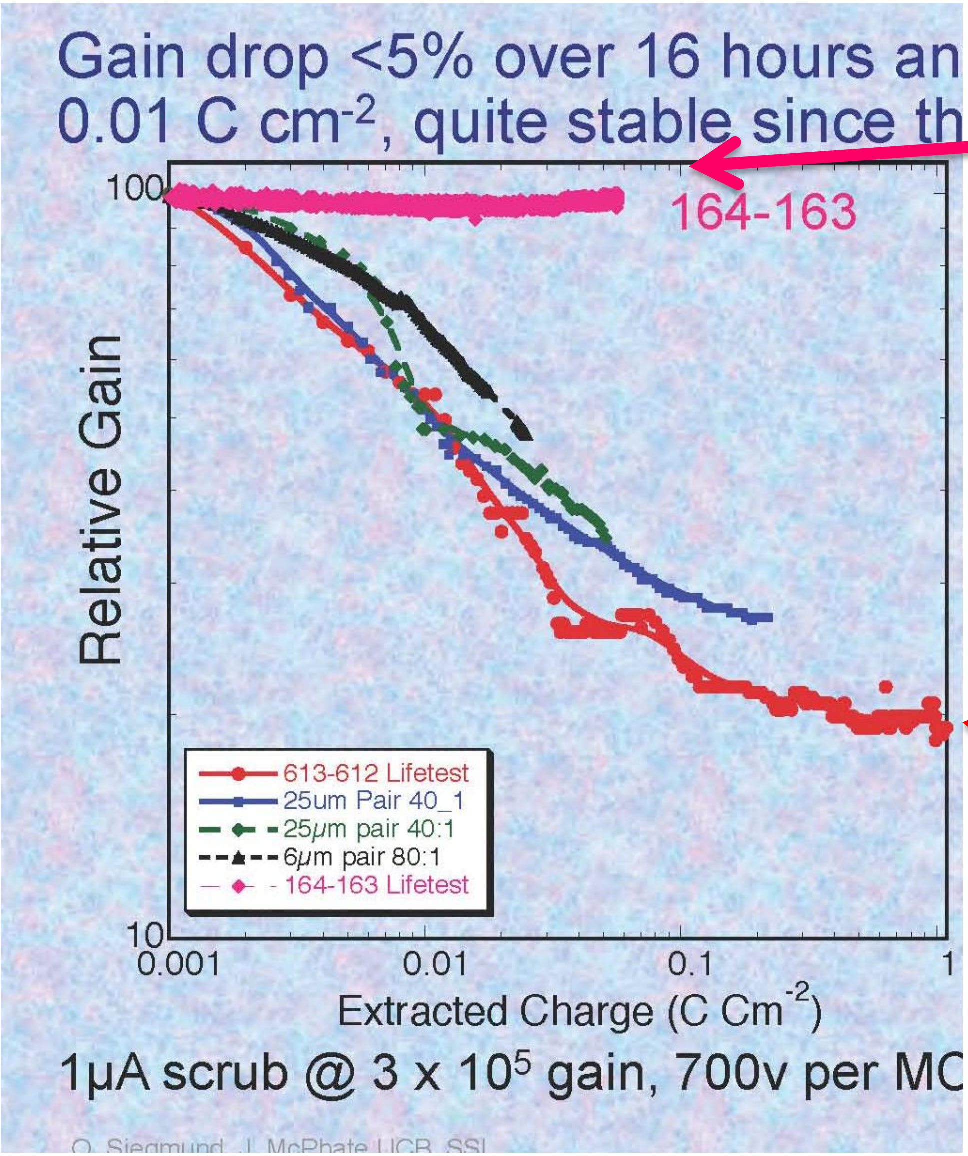


Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB

Performance: burn-in (aka `scrub')

(Probably the most important slide of the talk)

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

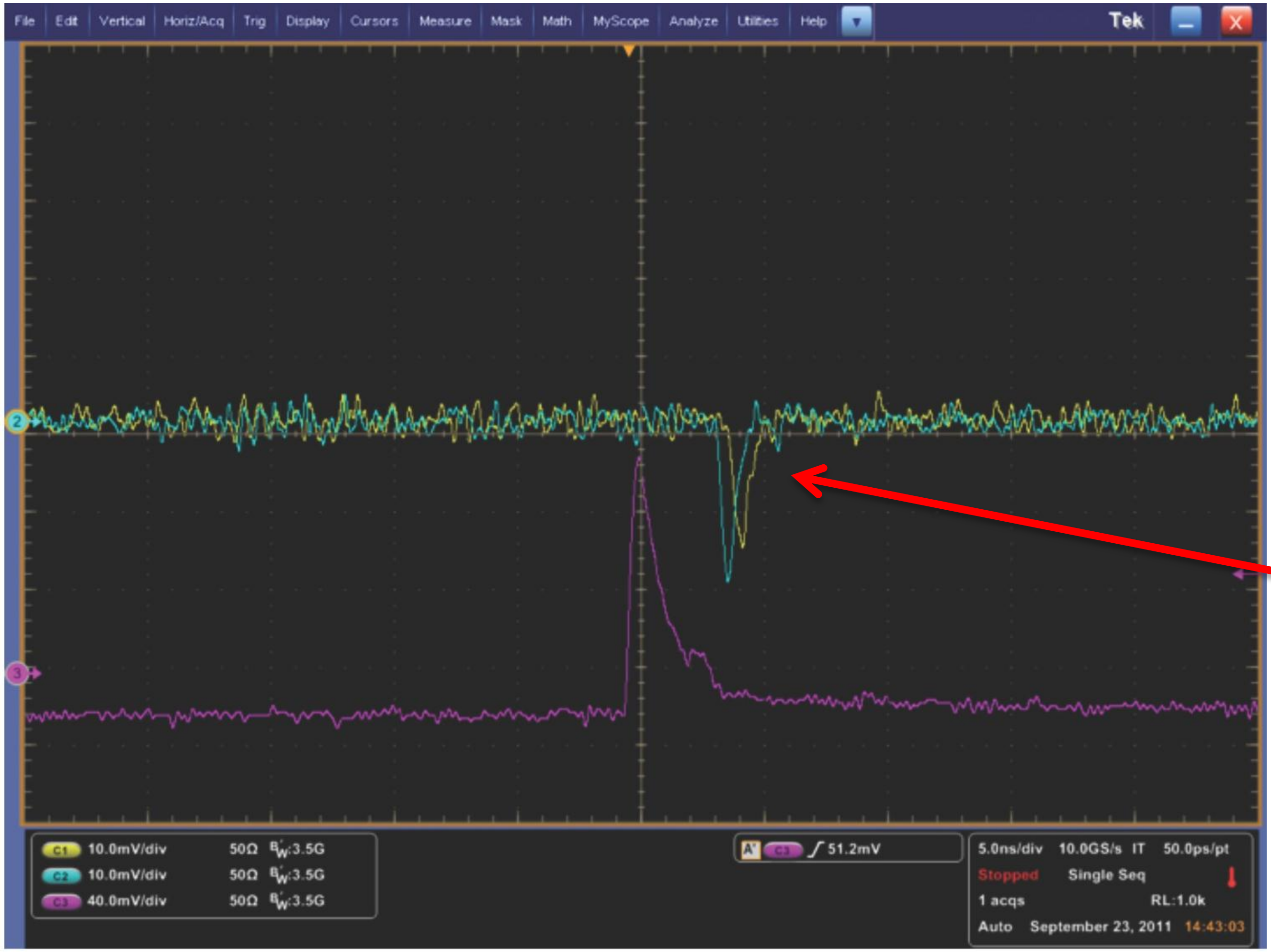


Measured ANL ALD-MCP behavior

(ALD by Anil Mane, Jeff Elam, ANL)

Typical MCP behavior- long scrub-times

First Pulses From an 8” MCP (!)



Caveats- this is the first time… TDIITDs- don’t over analyze this

Pulses from the 2 ends of an 8” anode strip

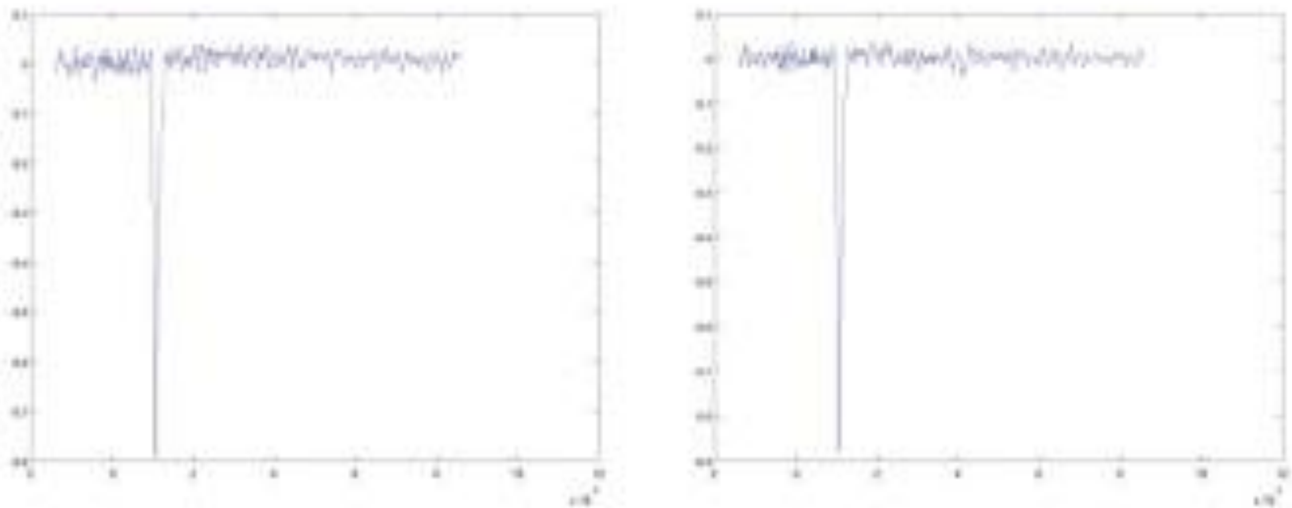
Matt Wetstein, Bernhard Adams, Razib Obaid, Sasha Vostrikov (ANL and UC)

Exciting time- first pulses from 8” plates (sub-psec laser at the APS)

The 8" Chamber - results

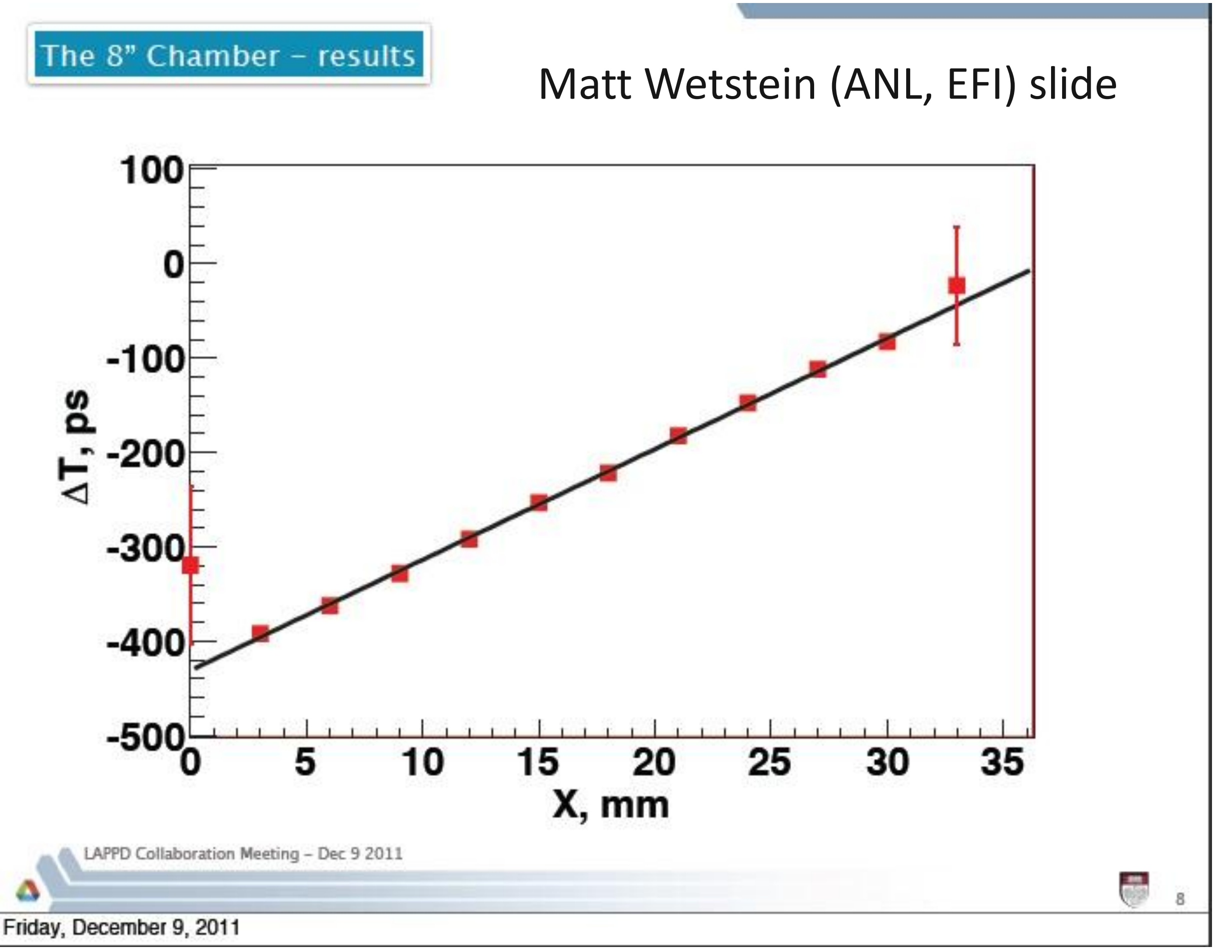
Matt Wetstein (ANL, EFI) slide

New pulses from a pair of 8" MCPs!



Matt Wetstein (ANL, EFI), Bernhard Adams (ANL, XPSD), Andrei Elagin, Razib Obaid, Sasha Vostrikov (UC)

Measuring time and Position on 8" plates (sub-psec laser at the APS)



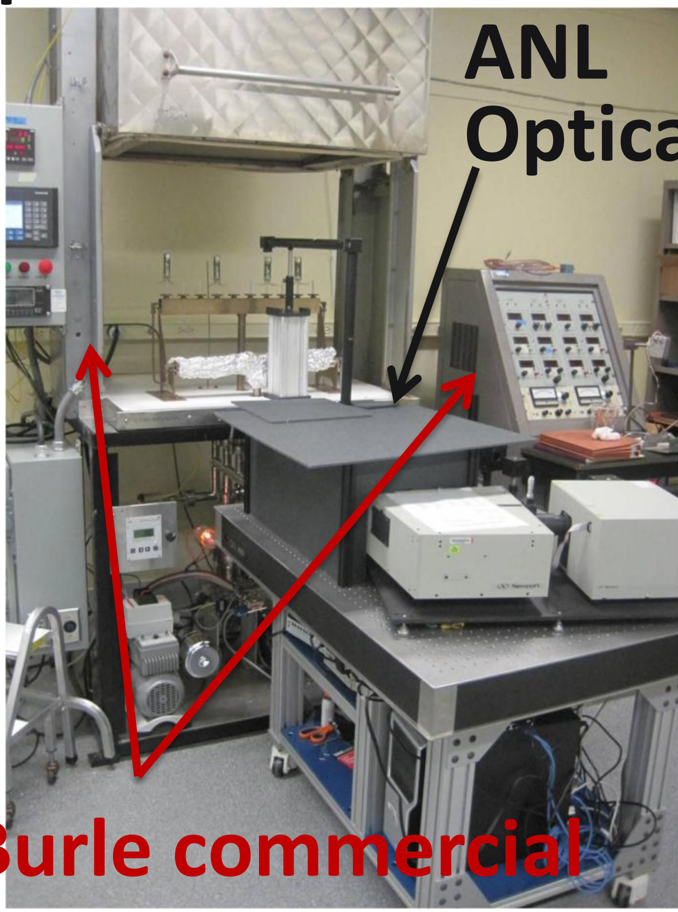
From the time difference of the 2 ends of the strip one gets the longitudinal position, from the average of the 2 ends the time (and of course from which strip(s) one gets the transverse position) => so have 2D at wall plus Time-of-Arrival

Matt Wetstein (ANL, EFI), Bernhard Adams (ANL, XPSD), Andrei Elagin, Razib Obaid, Sasha Vostrikov (UC)

Photocathodes

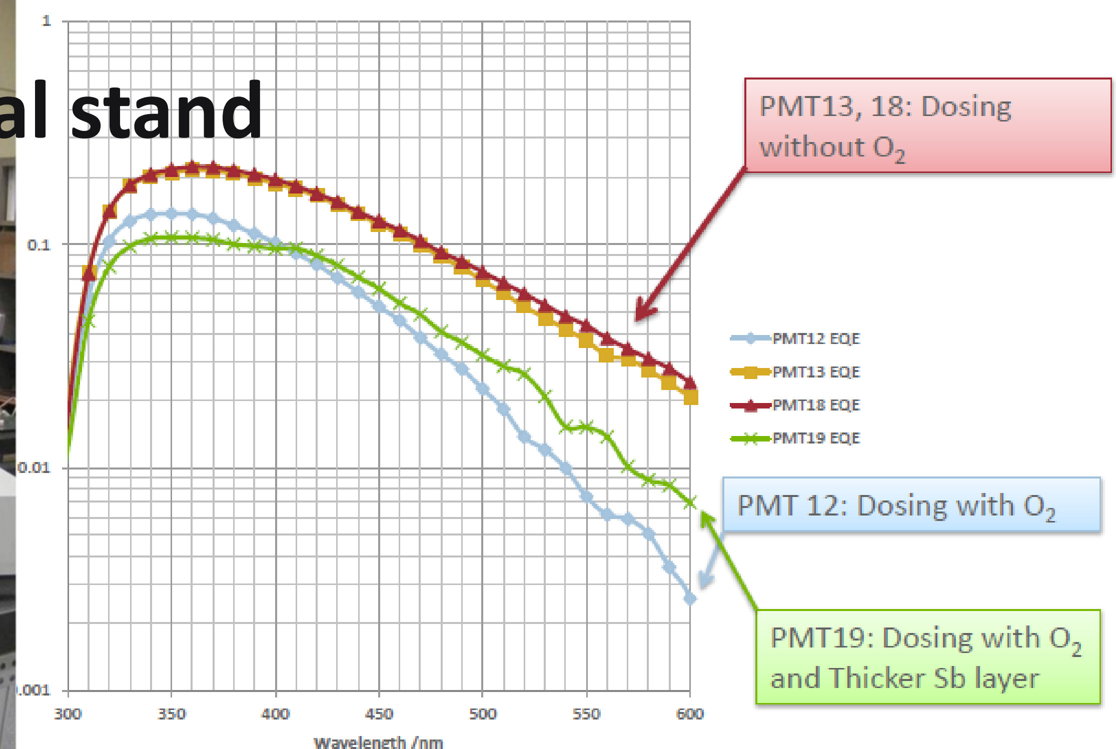
LAPPD goal- 20-25% QE, 8”-square

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



ANL Optical stand

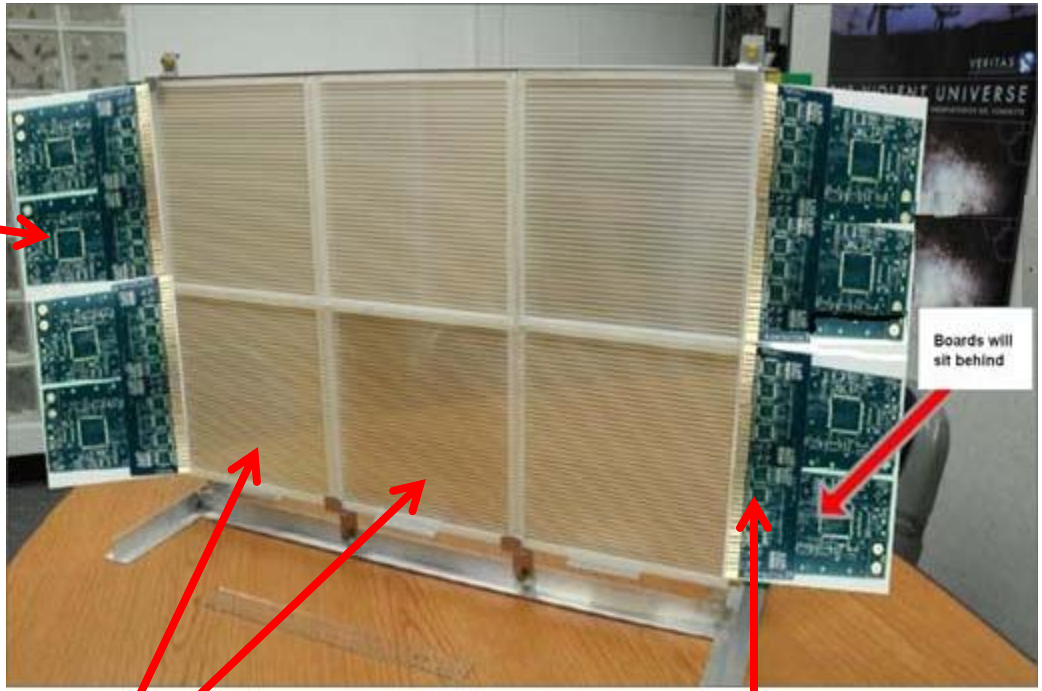
Burle commercial equipment



First cathodes made at ANL

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

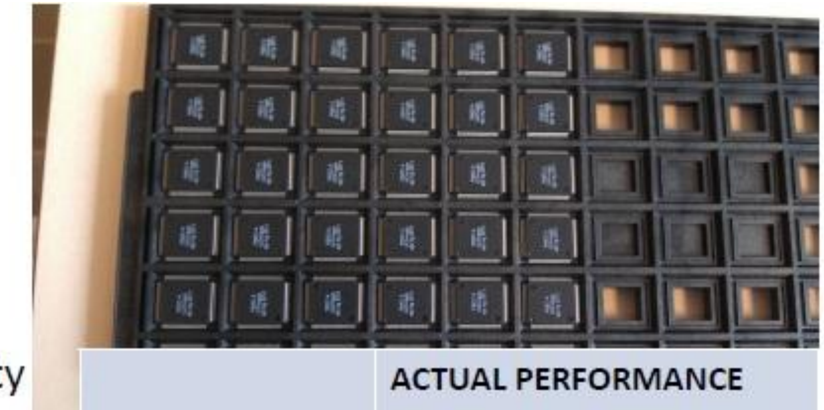
8” Tiles

10-15 GS/sec Waveform Sampling ASICS

The PSEC4 Waveform Sampling ASIC

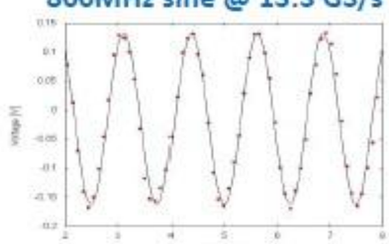
PSEC4: Eric Oberla and Herve Grabas; and friends…

PSEC-4



- Waveform digitizing ASIC
- Sampling rate capability > 10GSa/s
- Analog bandwidth > 1 GHz
- Medium event-rate capability (up to ~100 KHz)

800MHz sine @ 13.3 GS/s

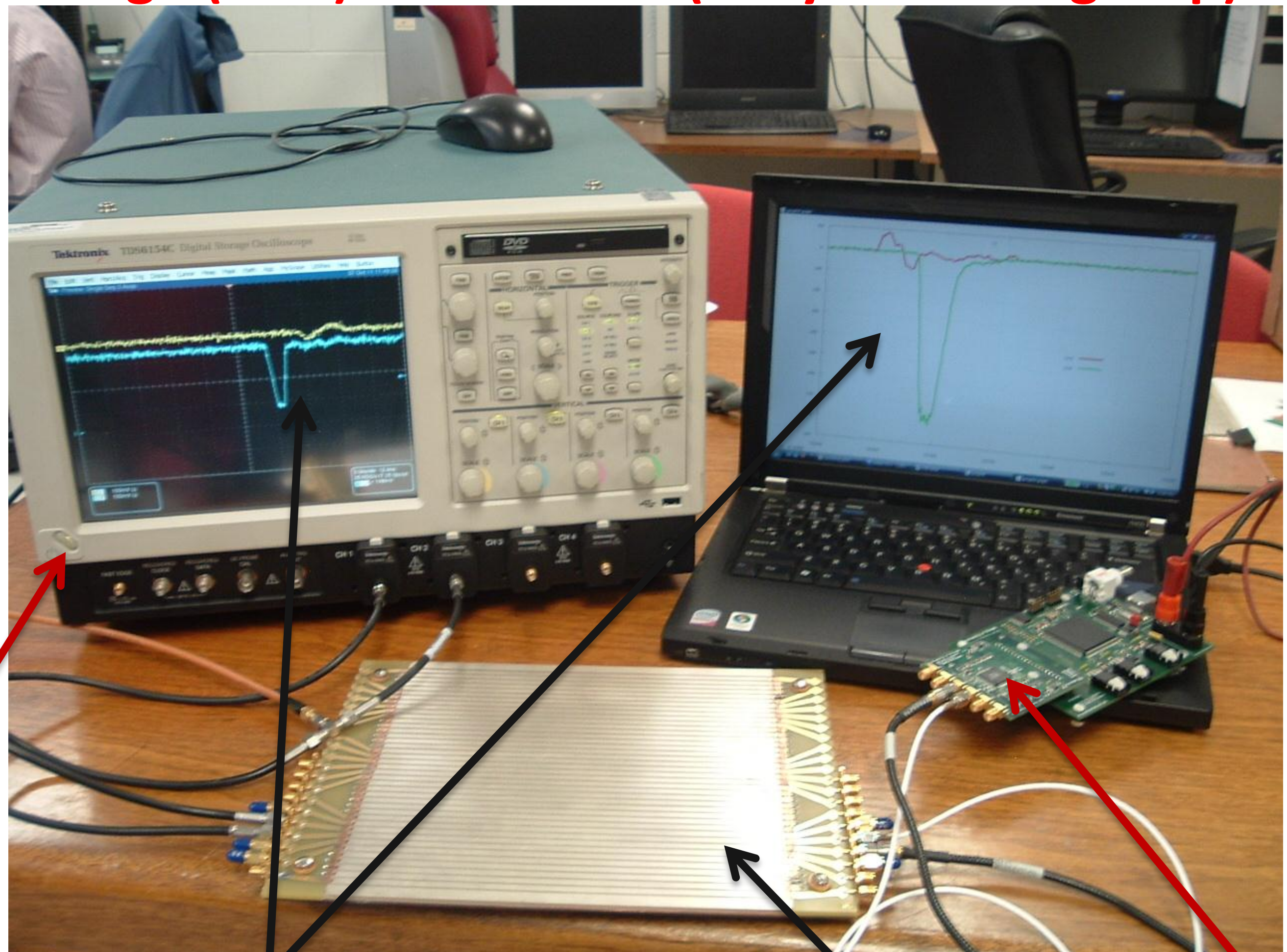


	ACTUAL PERFORMANCE
Sampling Rate	2.5-15 GSa/s
# Channels	6
Sampling Depth	256 points (17-100 ns)
Input Noise	<1 mV RMS
Analog Bandwidth	1.6 GHz
ADC conversion	Up to 12 bit @ 1.5 GHz
Dynamic Range	0.1-1.1 V
Latency	2 μs (min) – 16 μs (max)
Internal Trigger	yes

Eric Oberla, 3rd LAPPD Collaboration Meeting

`6-channel Scope on a Chip'

Chicago (EDG) and Hawaii (Gary Varner's group)



Real digitized traces from anode

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

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

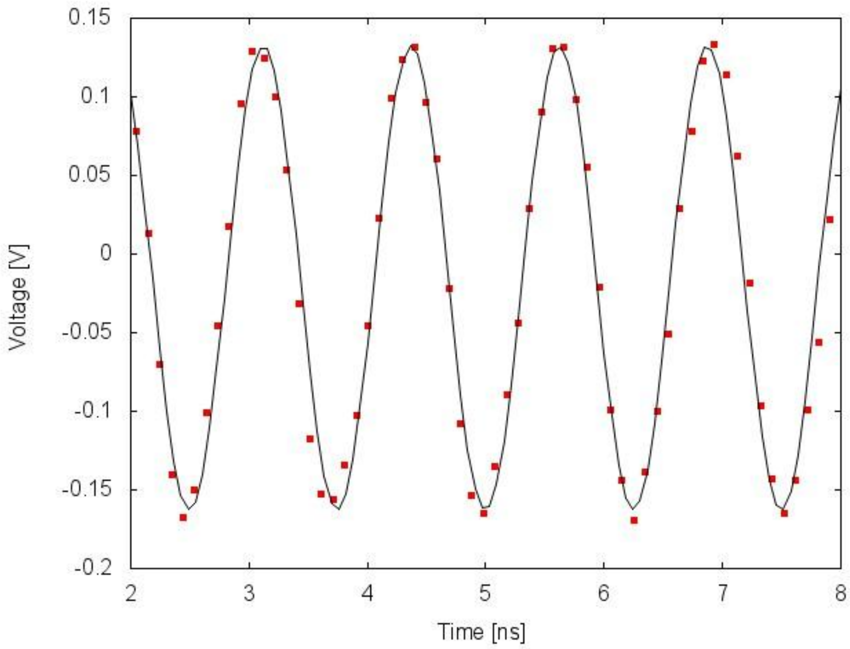
PSEC-4 Performance

Eric Oberla, ANT11

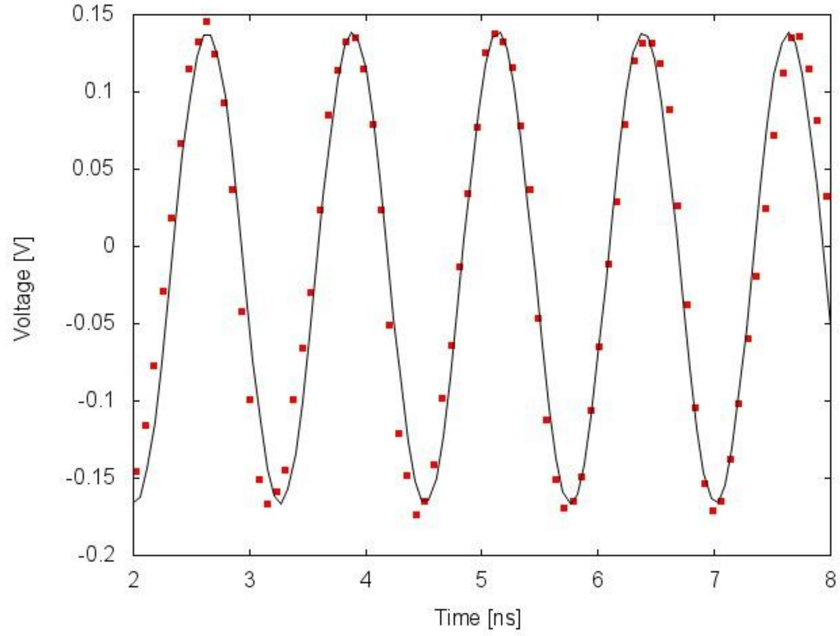
Digitized Waveforms

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)

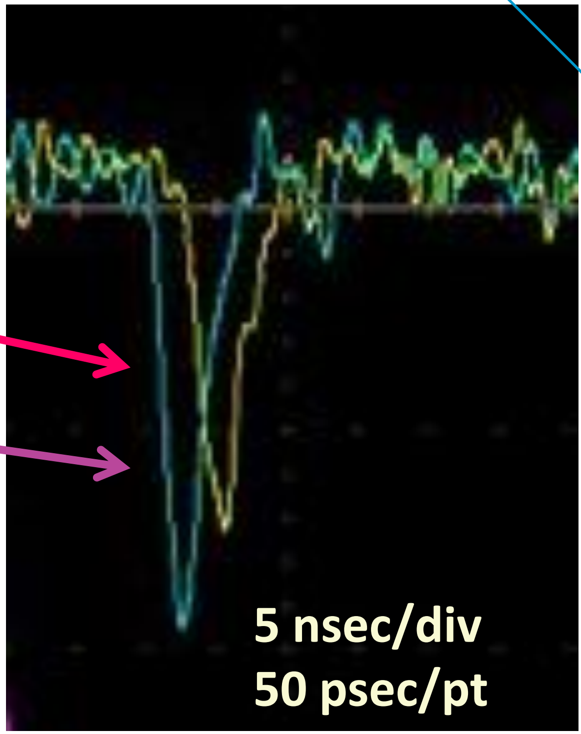
The 4 Determinants of Time Resolution

a) Signal/Noise (S/N)

b) Analog Band-width (ABW)

c) Sampling Rate

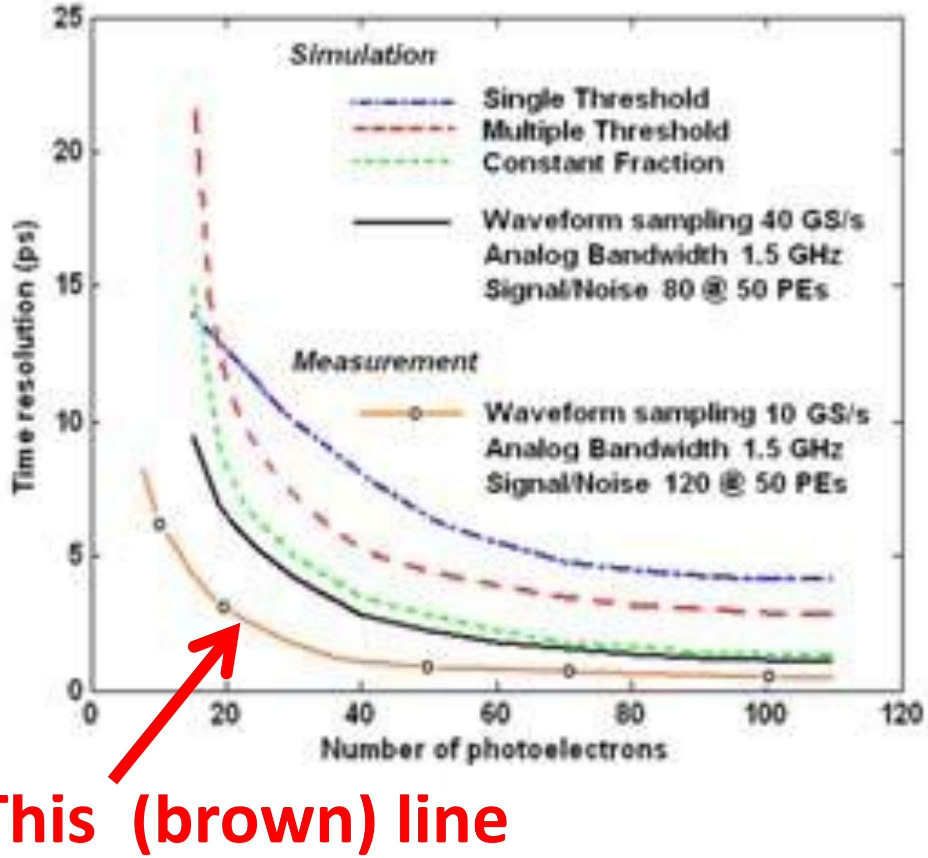
d) Signal statistics

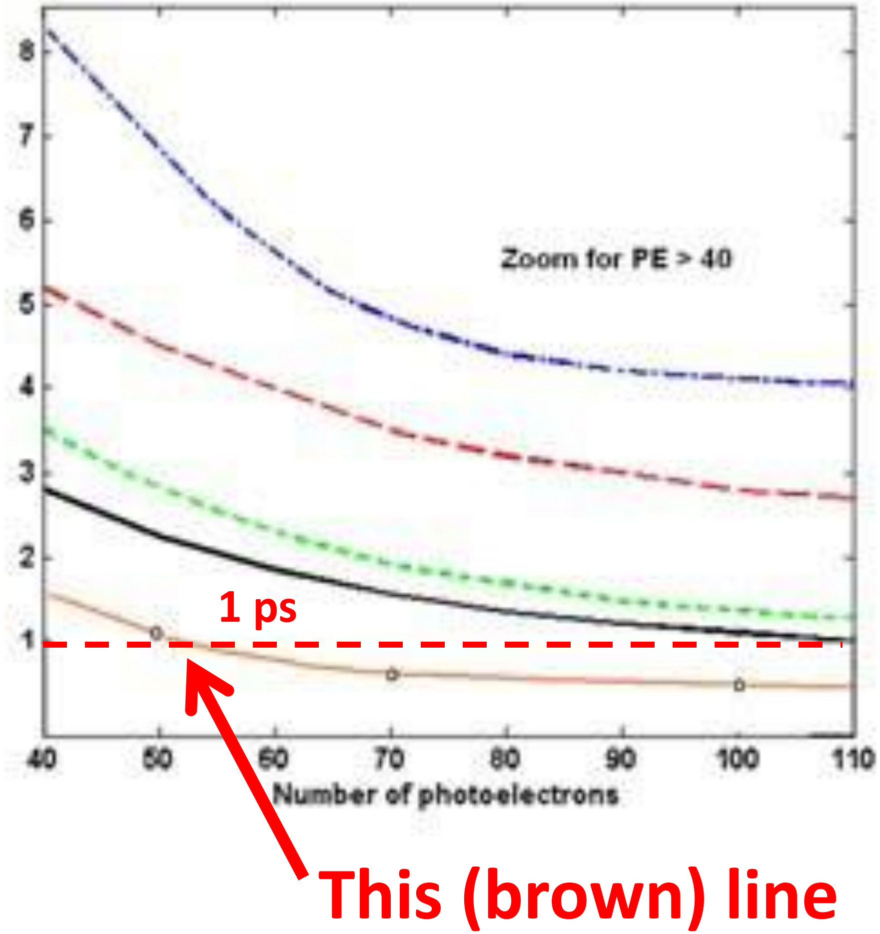


J.F. Genat, F. Tang, H. Frisch, and G. Varner; *Picosecond Resolution Timing Measurements,* Nucl. Instr. Meth A607, 387 (2009); Workshop on *The Factors that Limit Time Resolution in Photo-detectors,* University of Chicago, April 28-29, 2011

Simulation of Resolution vs abw

Jean-Francois Genat





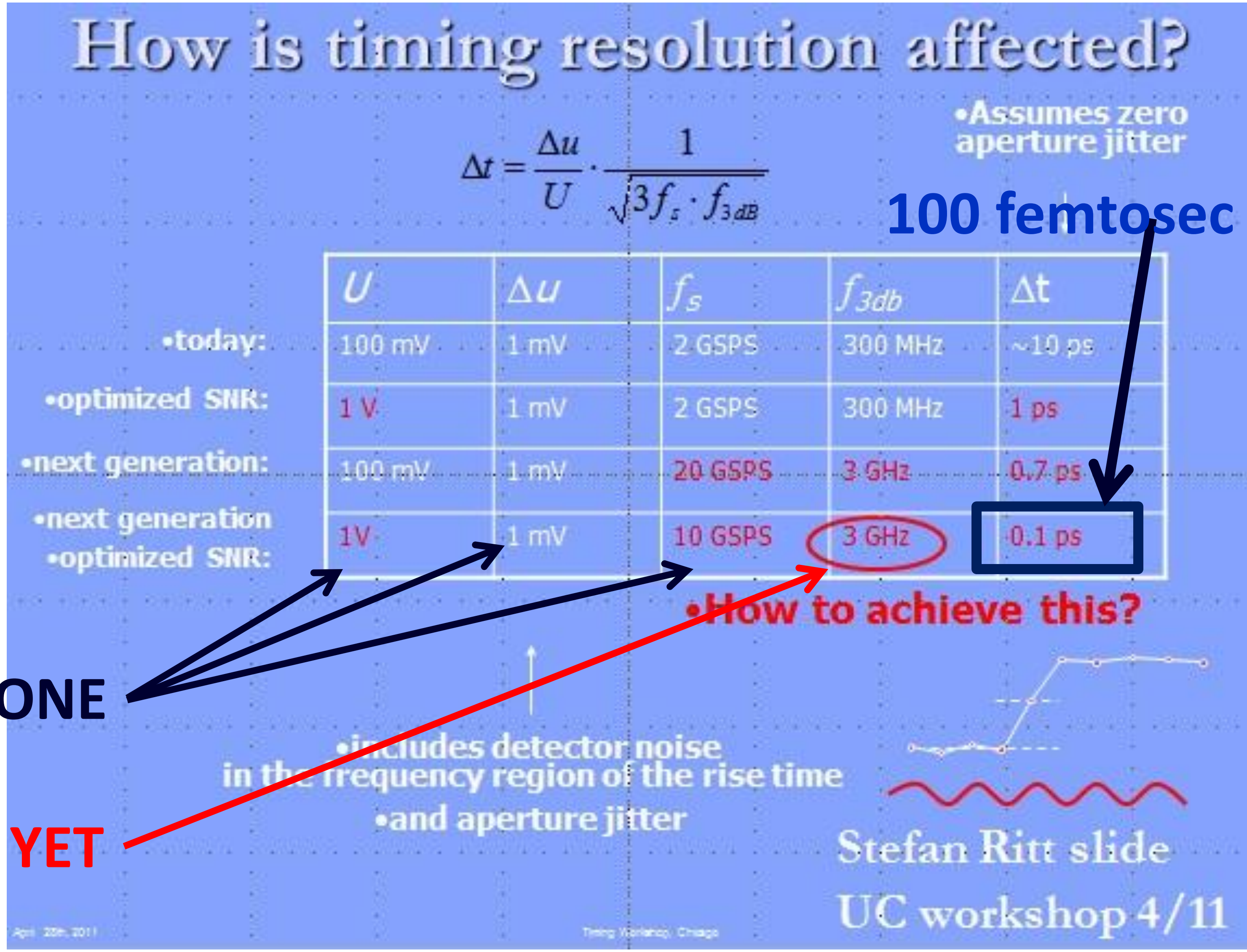
Brown line: 10 Gs/sec (we've done >15);

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

Can we go deep sub-picosec?:

the Ritt Parameterization (agrees with JF MC)

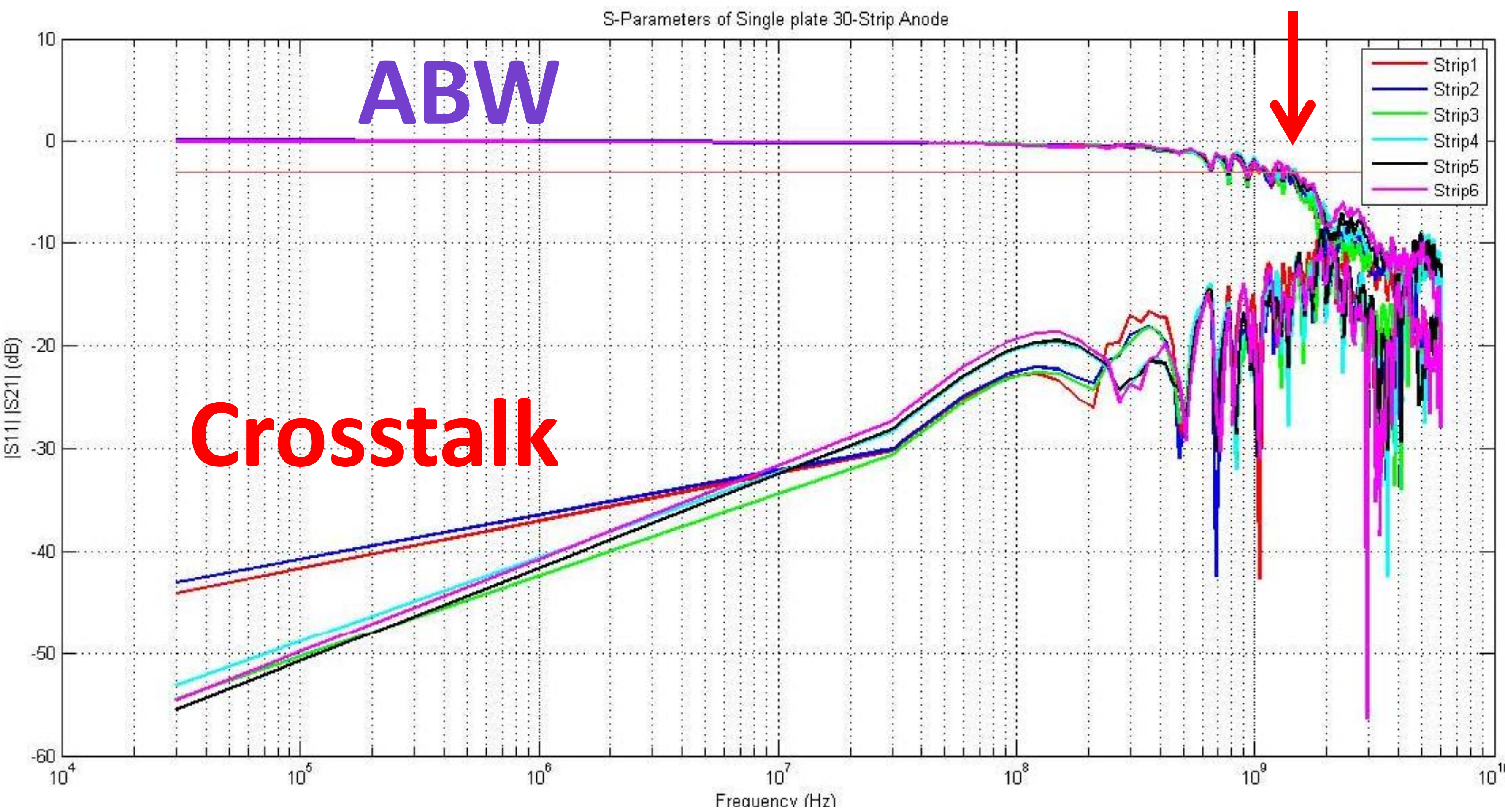
Stefan Ritt slide, doctored



S/N, f_Z: DONE

abw: NOT YET

Anode Testing for ABW, Crosstalk,..



Herve Grabas (EFI, Saclay), Razib Obaid (EFI), Dave McGinnis (Fermilab) (having three RF-groups within driving distance is truly wonderful!)

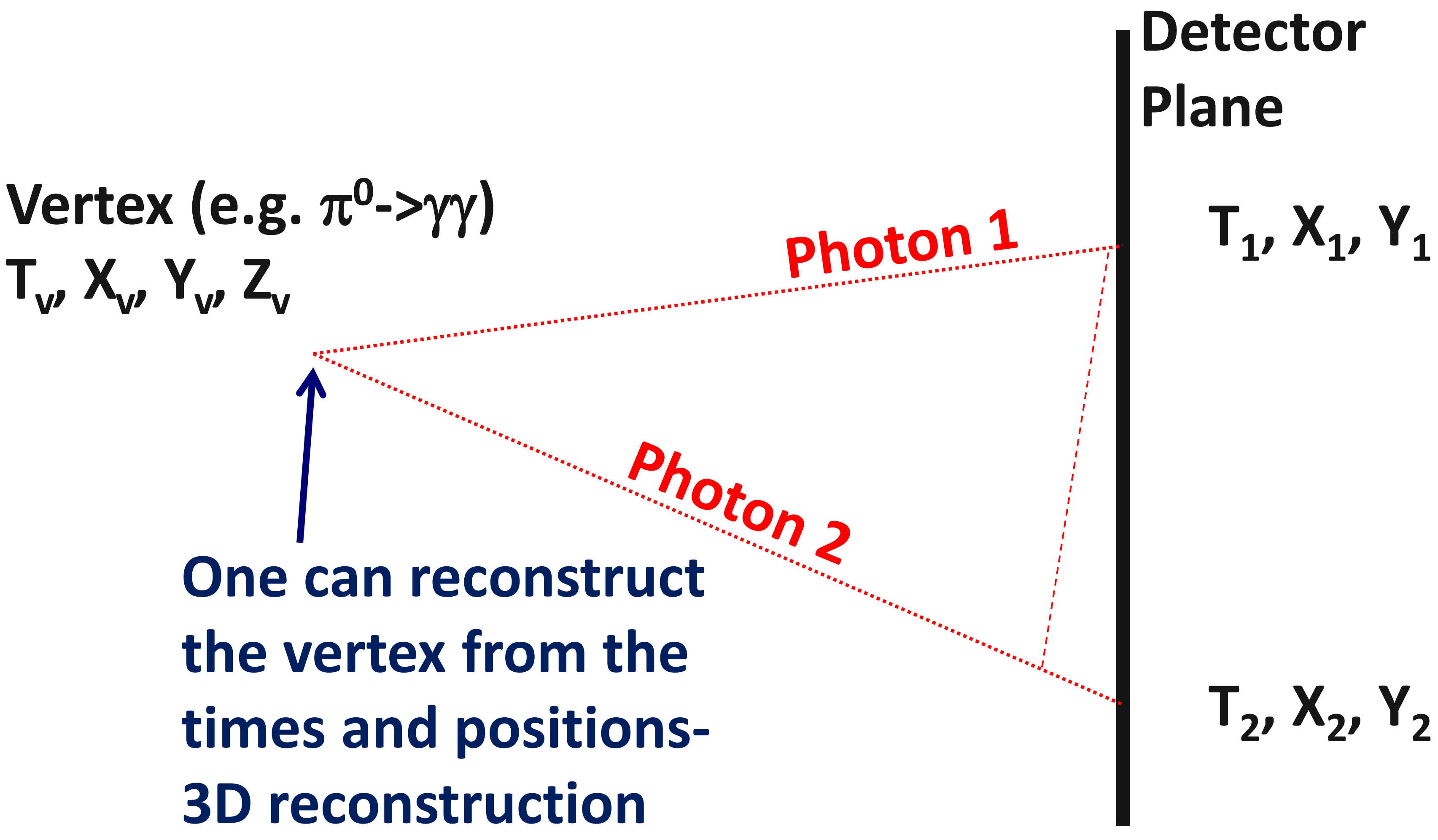
First Adopters

Identifying first-adopters and identifying and establishing markets- some candidates (nothing yet is formal)-

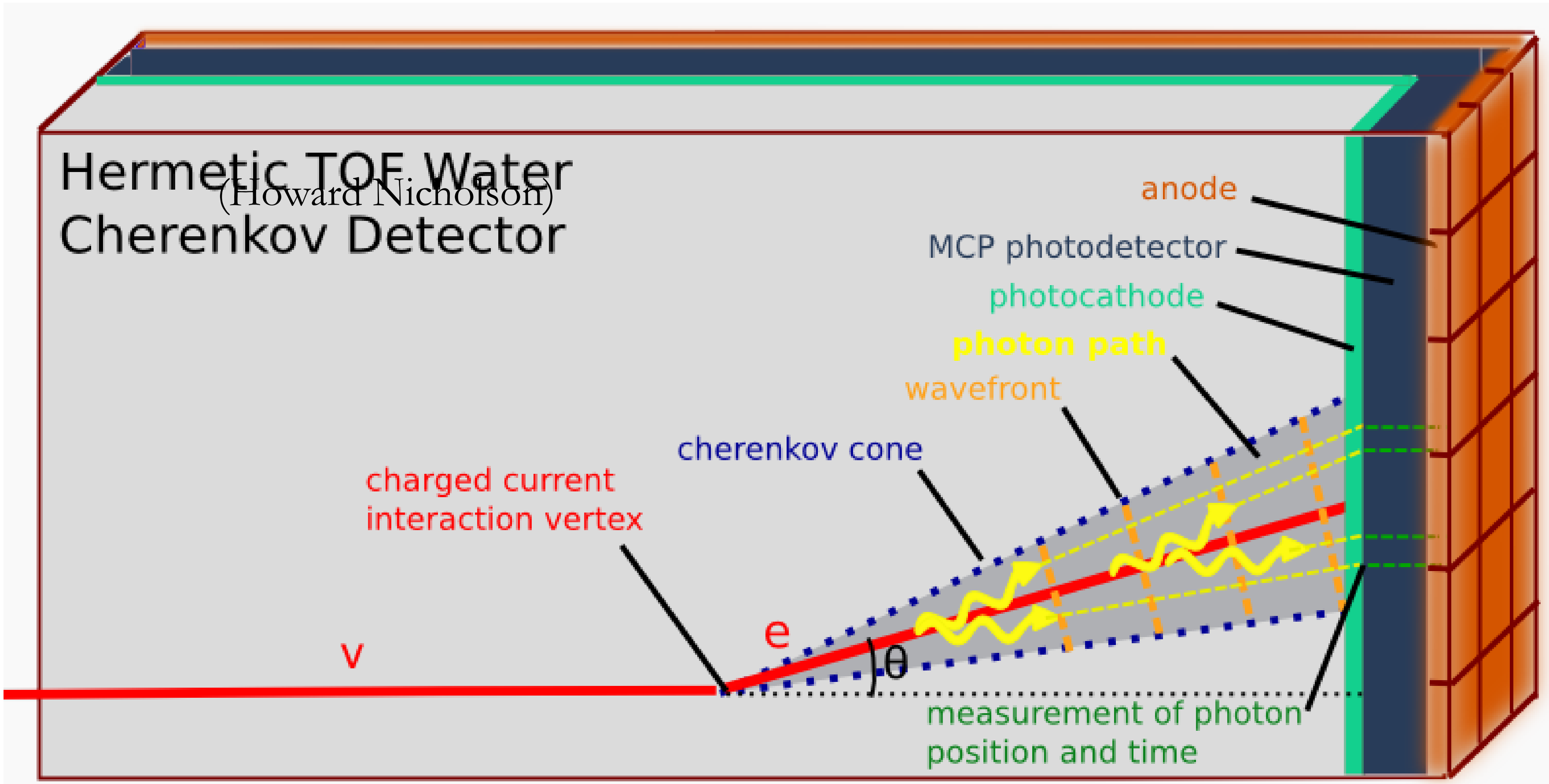
1. Medical Imaging- Chicago, Strasbourg,.
2. HEP neutrinos- Daniel Boone
3. Non-proliferation/Security- LBNL, Sandia
4. Fixed target TOF- KOTO (JParc, JLAB)
5. Muon cooling- Muons,Inc
6. Colliders- STAR, ALICE,…

Parallel Efforts on Specific Applications

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



Neutrino Physics



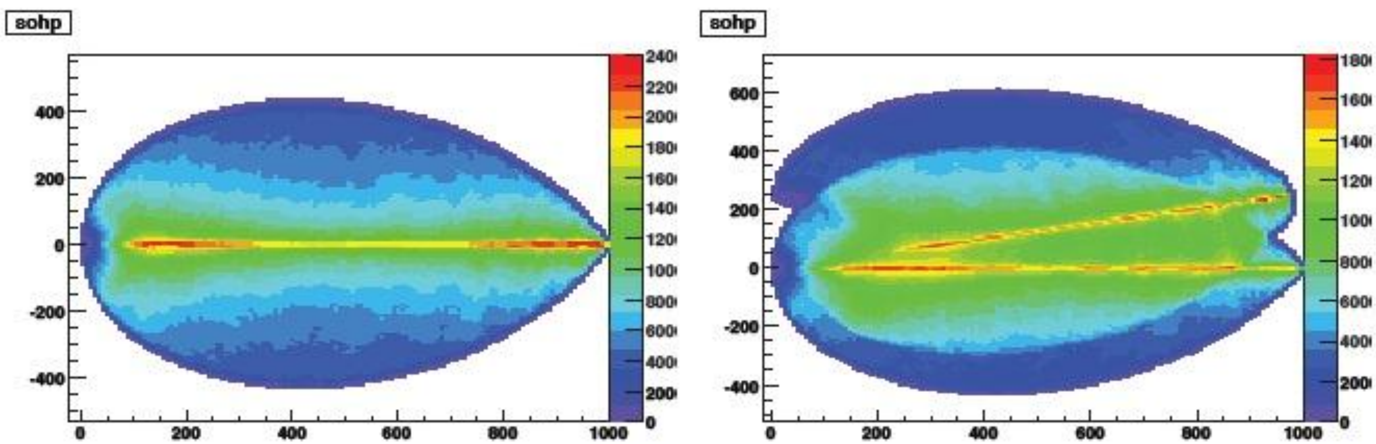
Spec: signal single photon, 100 ps time, 1 cm space, low cost/m2 (5-10K$/m2)*

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

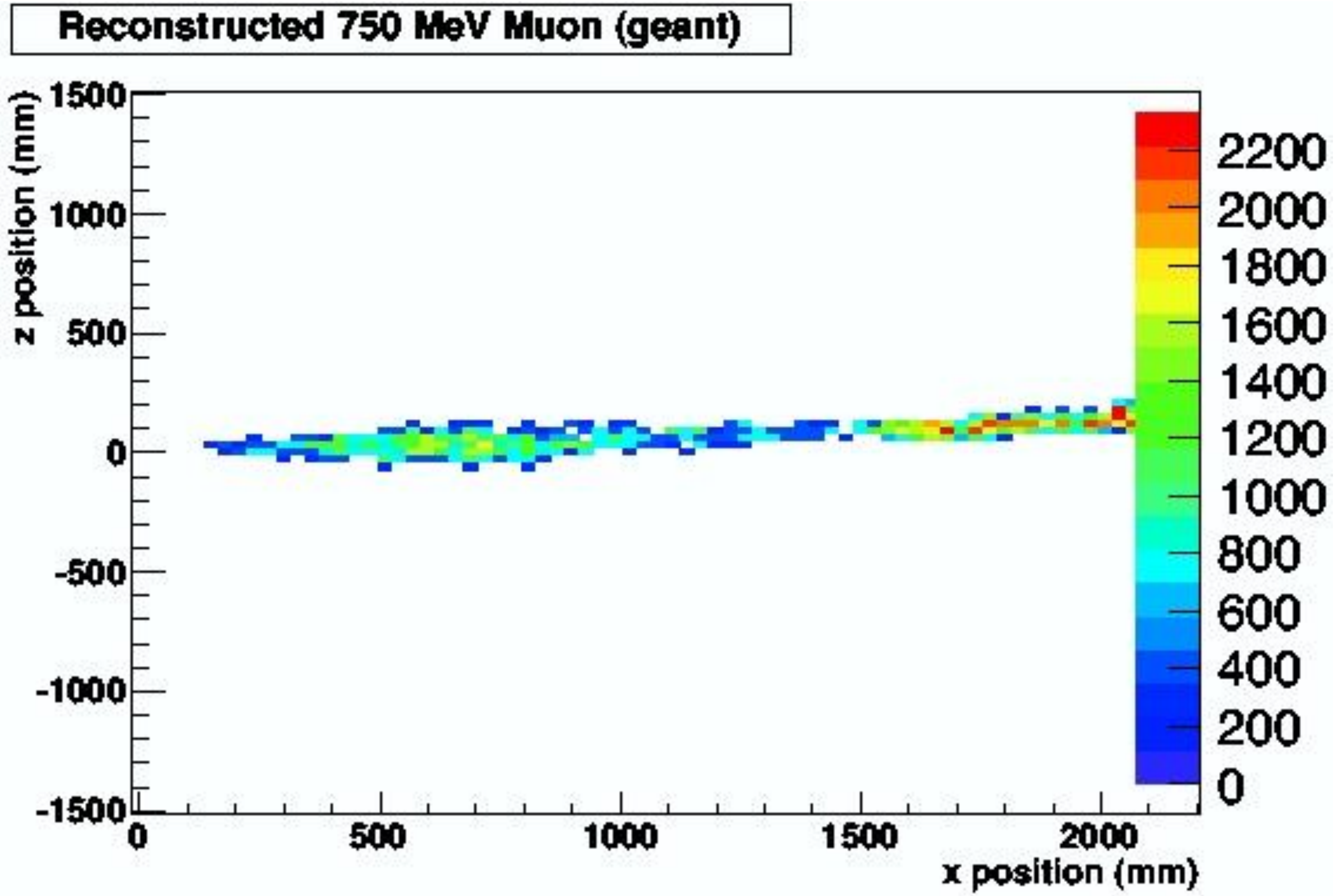
Two tracks displaced from a common vertex

ANT 2011

15

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

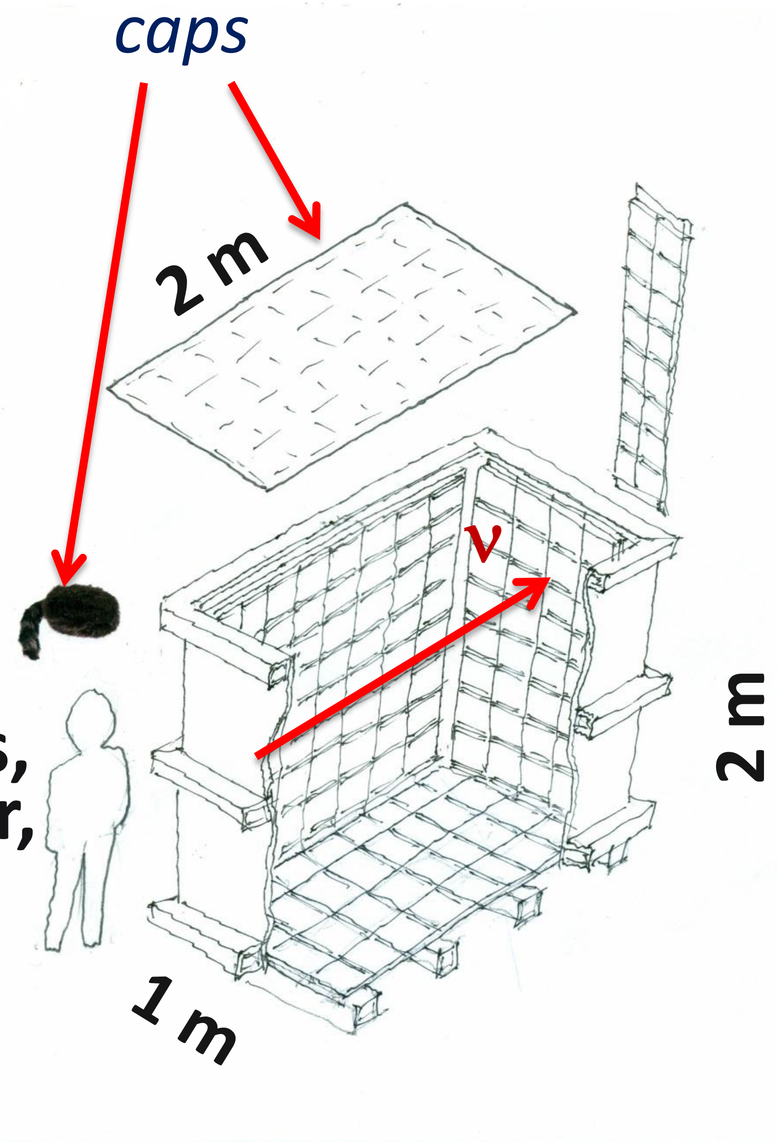
Works on GEANT events too



Matt Wetstein; ANL&UC

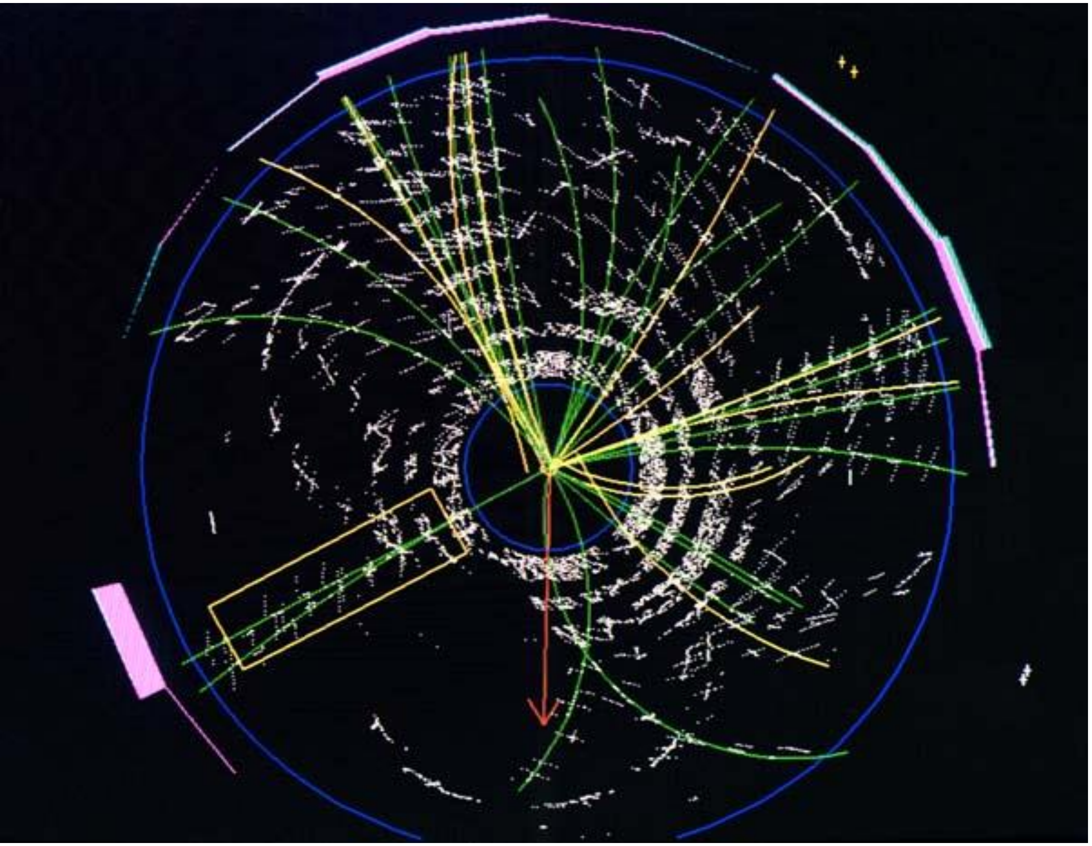
Daniel Boone

- 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).



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.

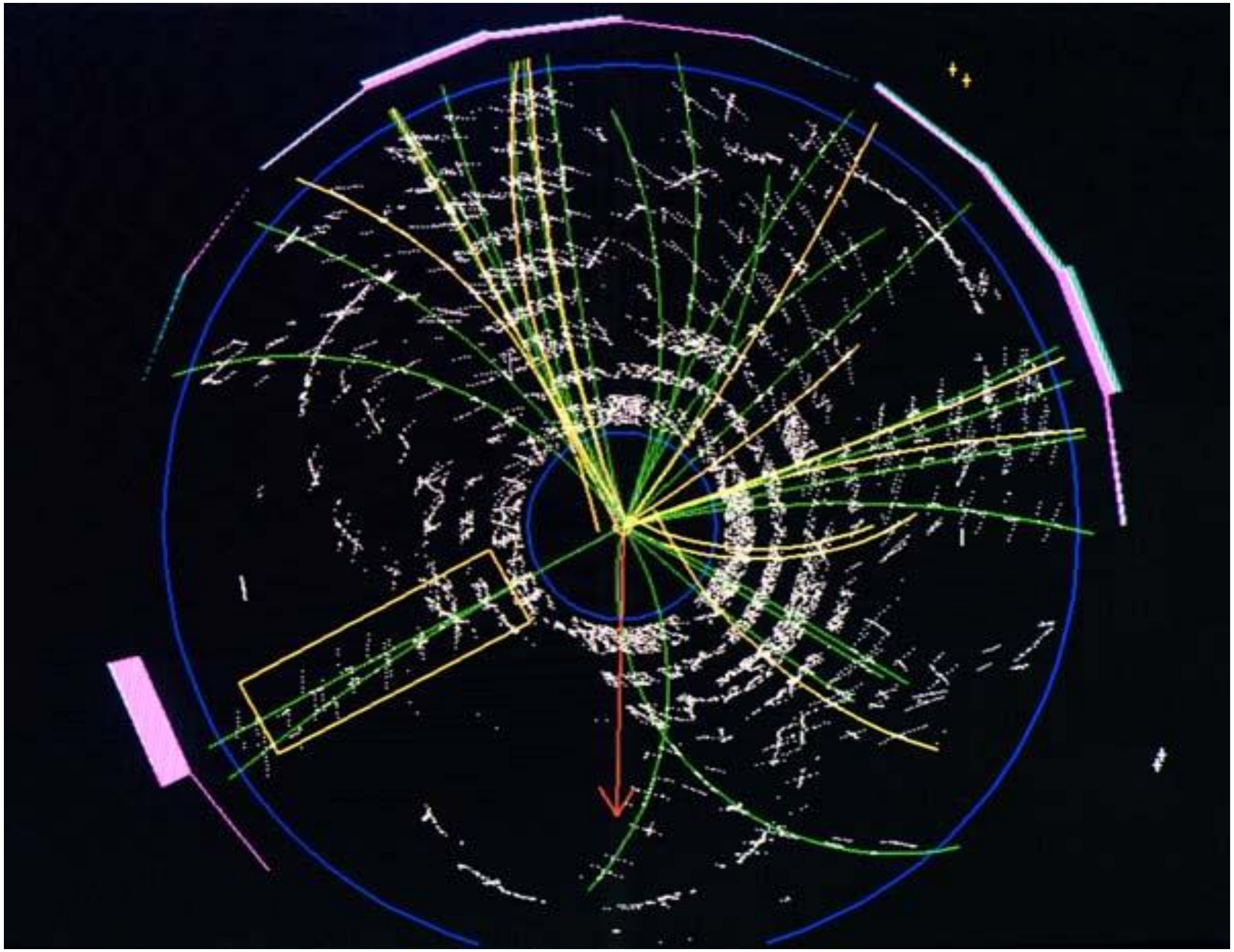


t-tbar -> W^+bW^-bbar->
e+ nu+c+sbar+b+bbar

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.

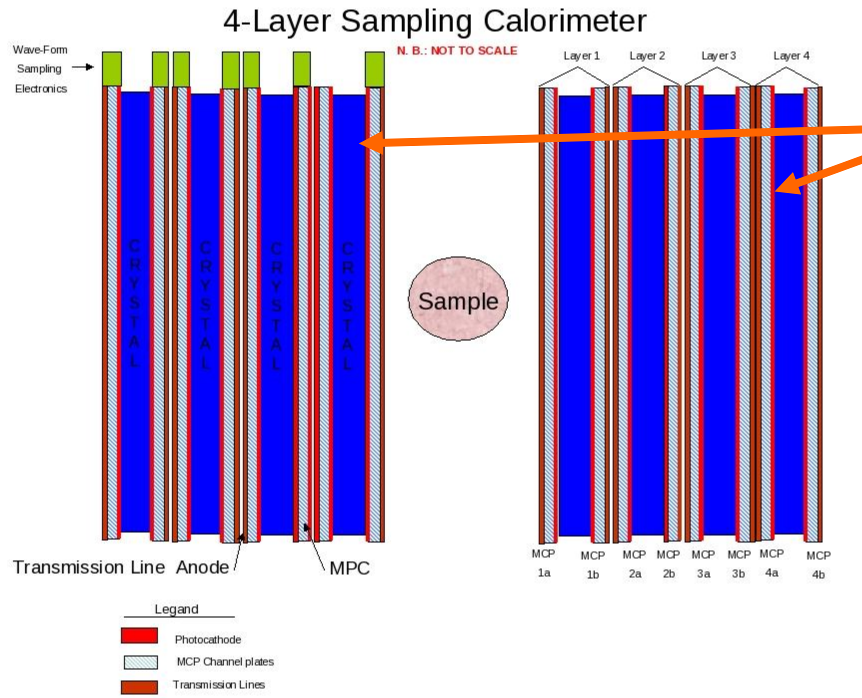
Specs:
Signal: 50-10,000 photons
Space resolution: 1 mm
Time resolution 1 psec
Cost: <100K$/m2:

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.

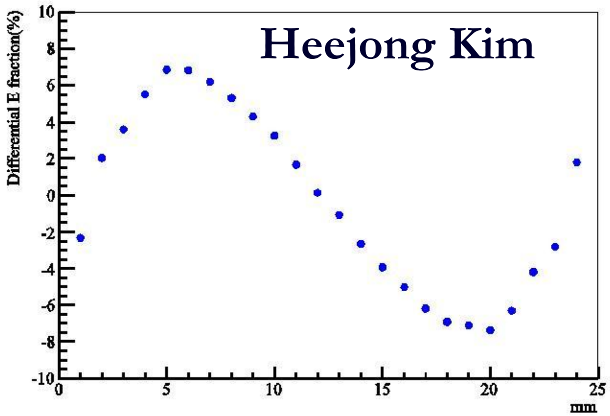
Medical Imaging (PET)



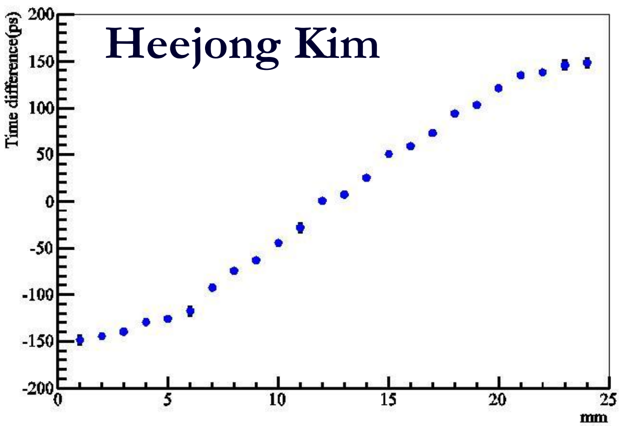
Can we solve the depth-of-interaction problem and also use cheaper faster radiators?

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

Simulations by Heejong Kim (Chicago)

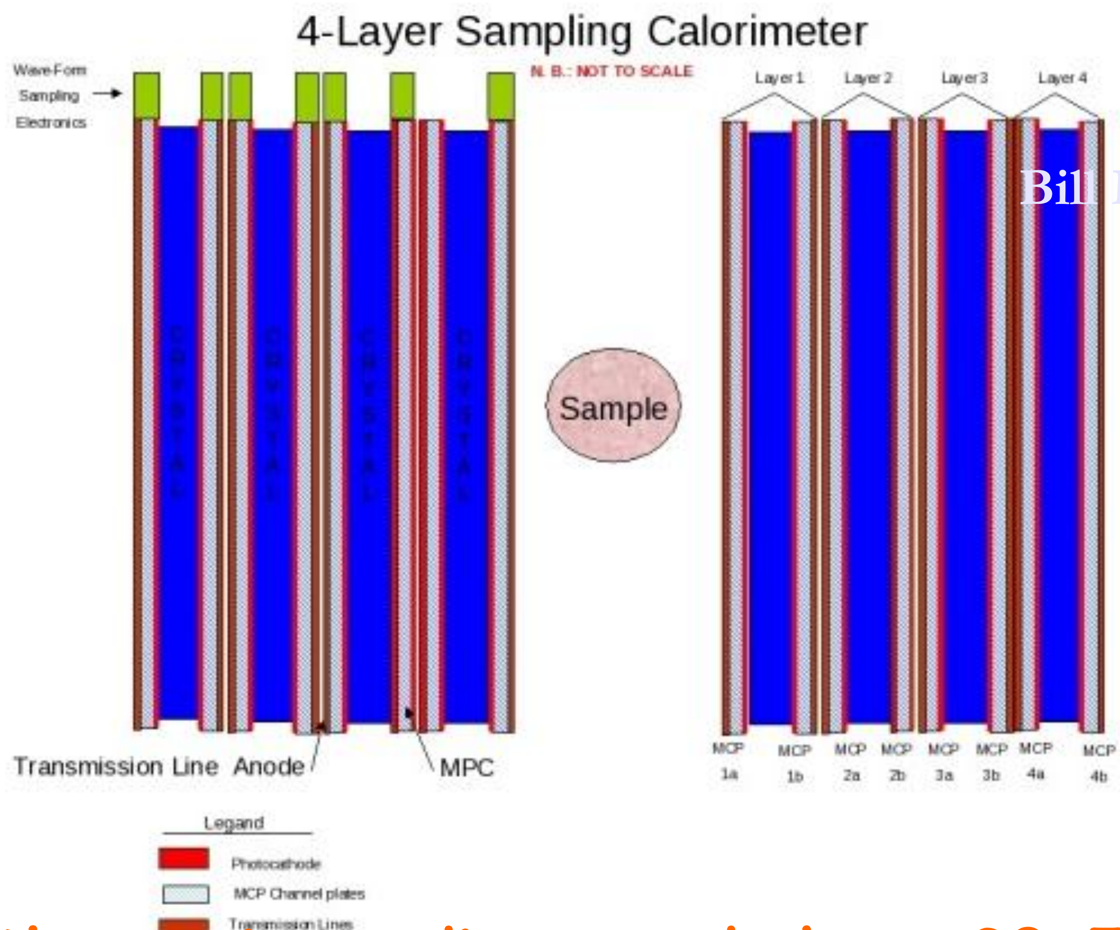


Depth in crystal by energy- asymmetry



Depth in crystal by time-difference

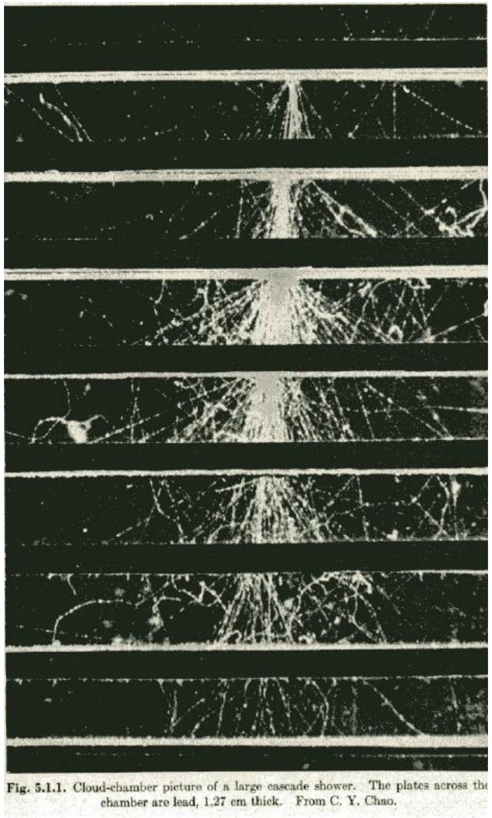
Sampling calorimeters based on thin cheap photodetectors with correlated time and space waveform sampling

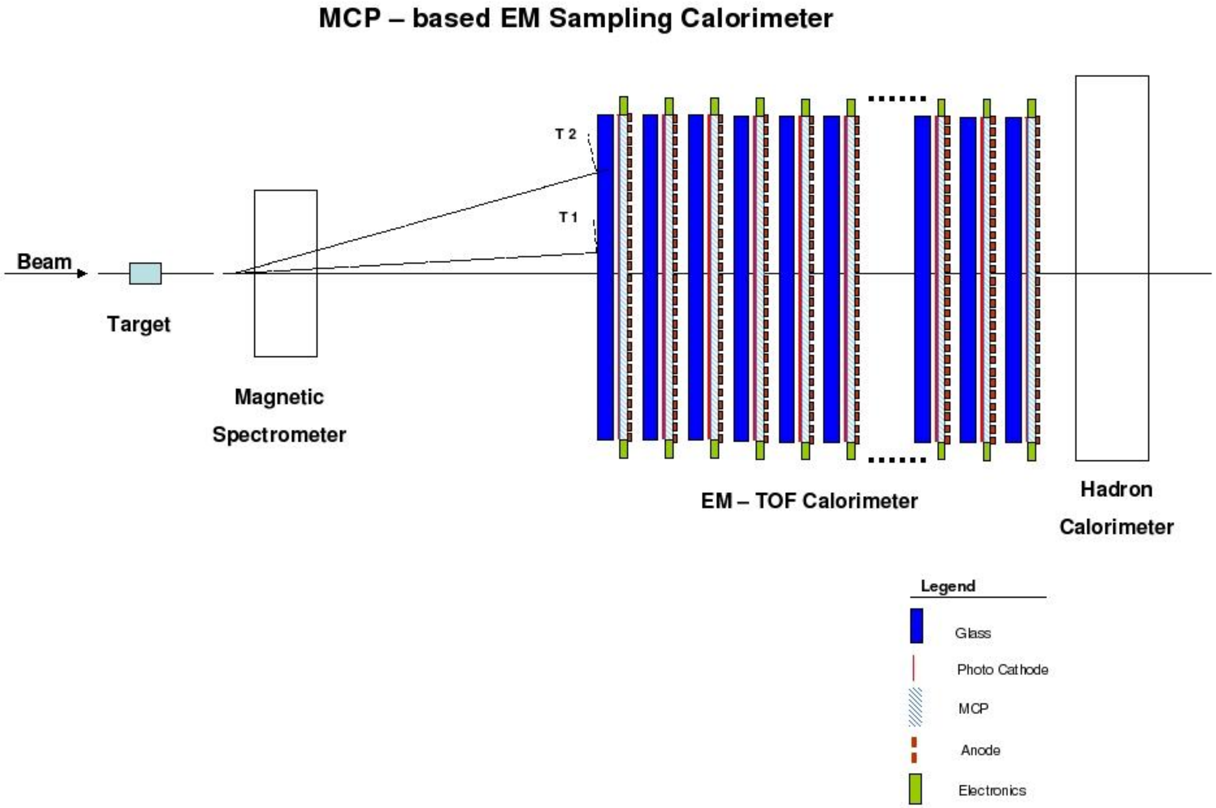


Bill Moses (Lyon)

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





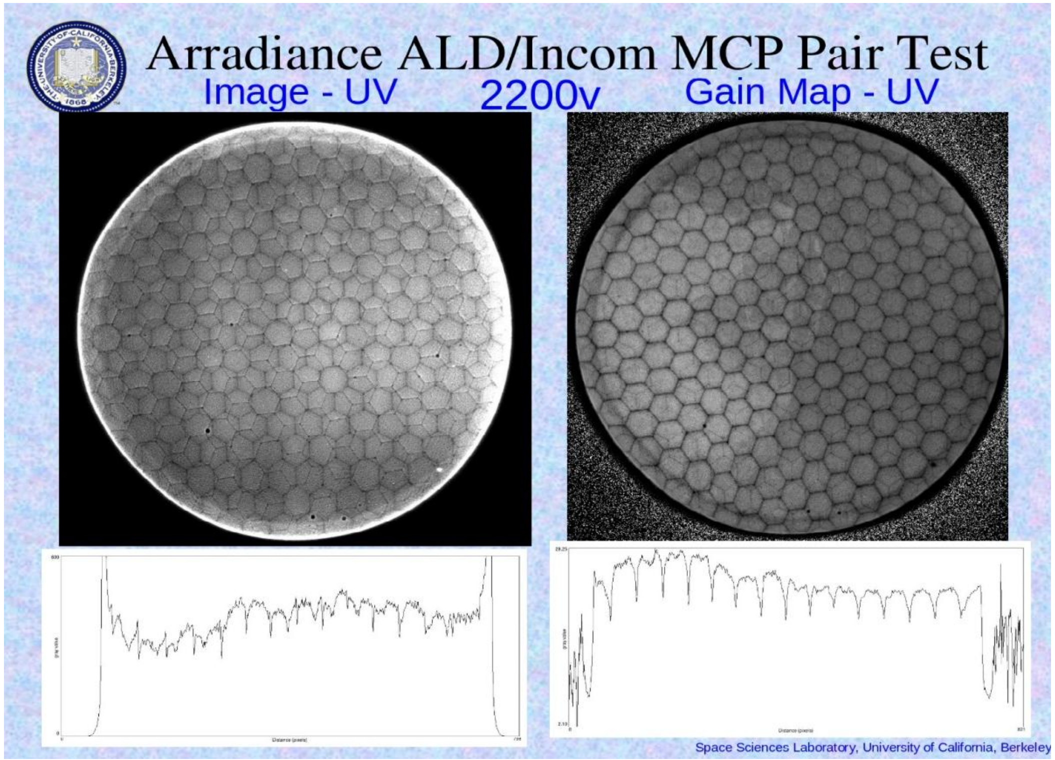
A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

If I had to summarize*:

- There are remarkable opportunities using the collaborative resources of Argonne, Fermilab and UC available to us (latter isn't trivial).
- Seed funding such as the FRA funding is really golden money-

* Not easy…

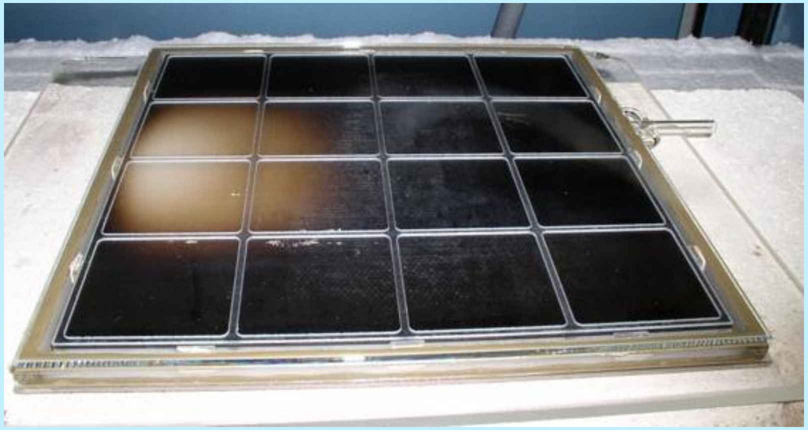
More Information:

- **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 (a number of companies do);**

BACKUP SLIDES

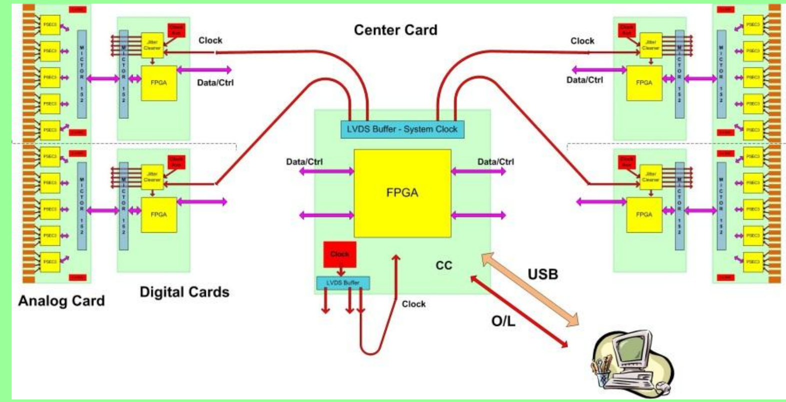
The 4 `Divisions' of LAPPD

Hermetic Packaging



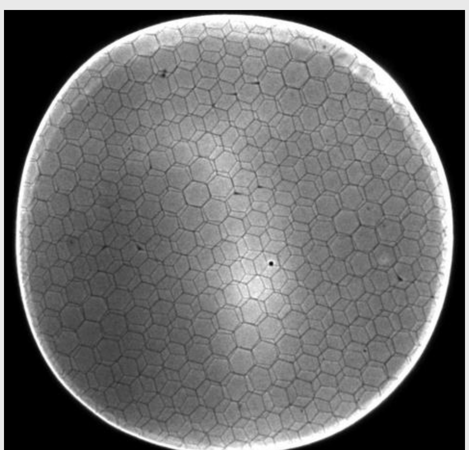
See   Bob Wagner's talk

Electronics/Integration



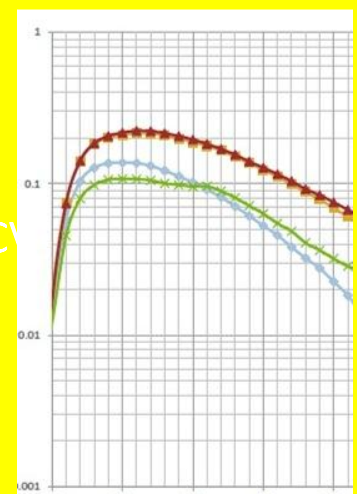
This talk

MicroChannel Plates



See   Ossy's talk

Photocathodes



See (hear) Klaus Attenkofer's talk

2003- Aspen Exptl Summary Talk

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.

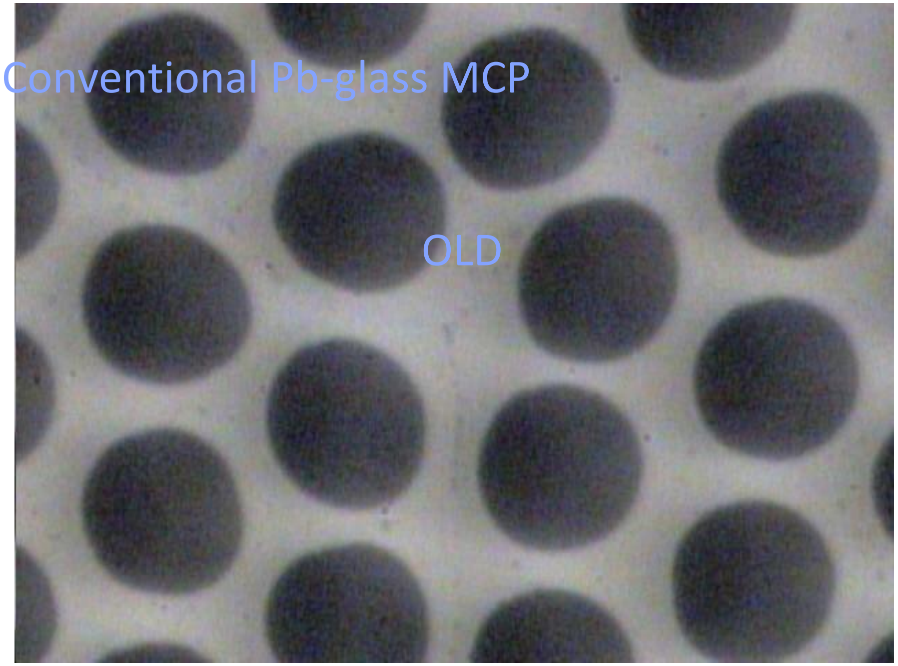
Is this crazy?

- 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?**

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

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

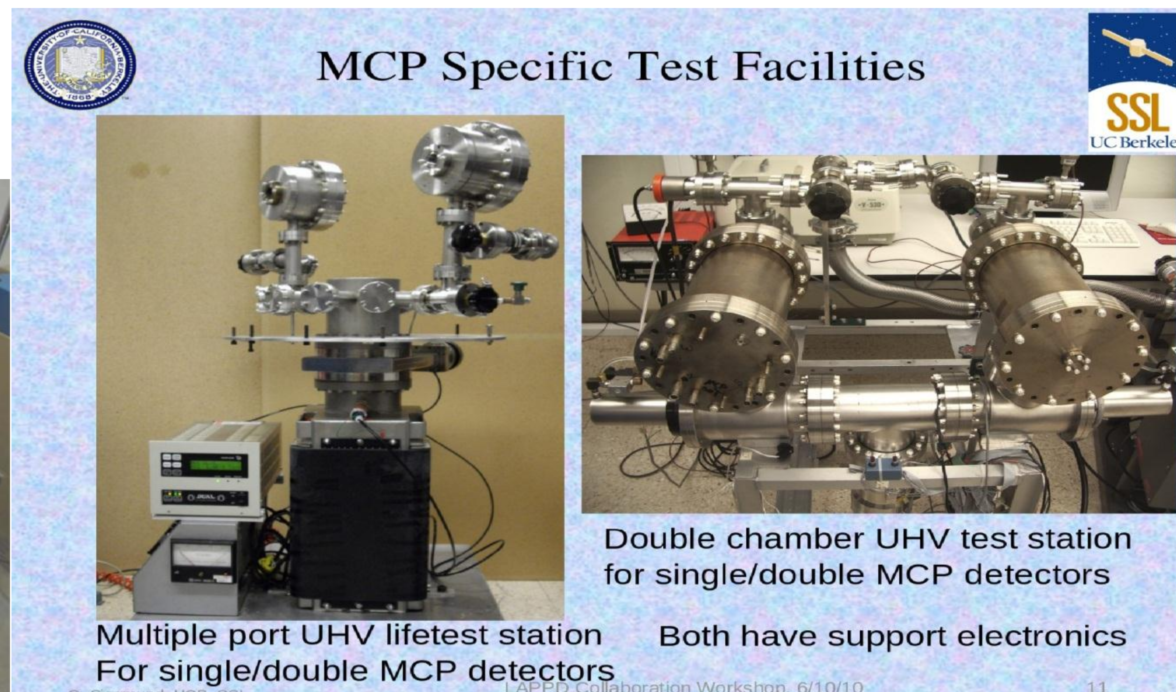
Microchannel Plates-3

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

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

Decades of experience

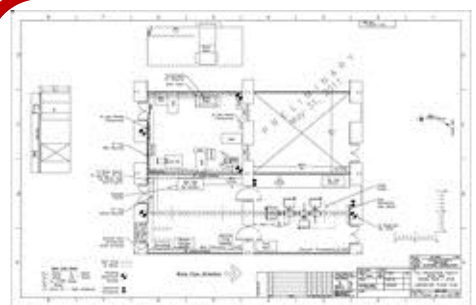
(some of us have decades of inexperience?)



Hermetic Packaging

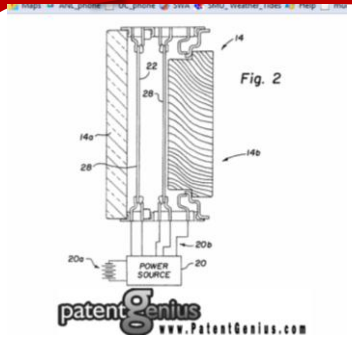
- Top Seal and Photocathode- this year's priority

3 parallel paths



Tile Development Facility at ANL

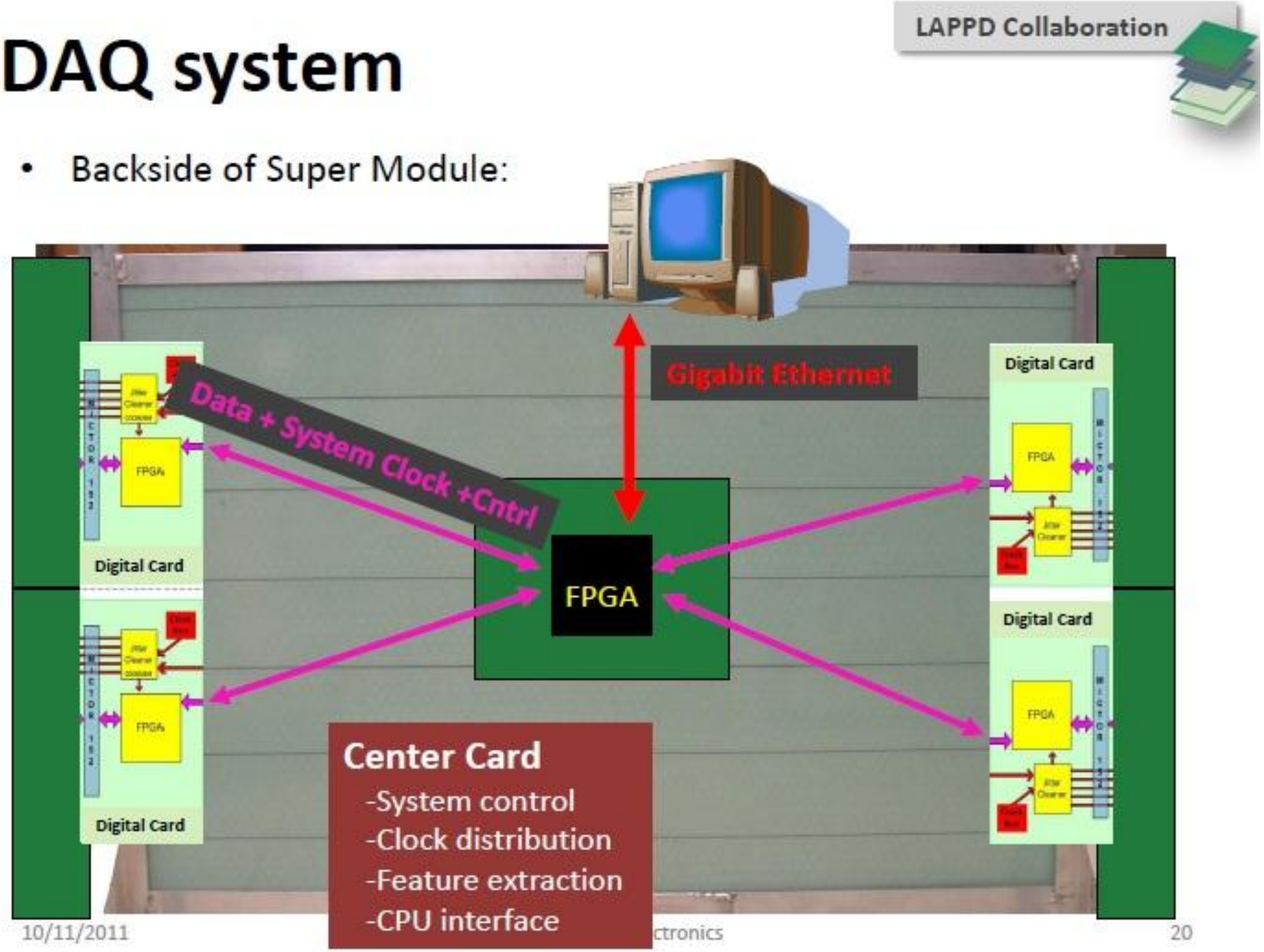
Production Facility at SSL/UCB



Commercial RFI for 100 tiles

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

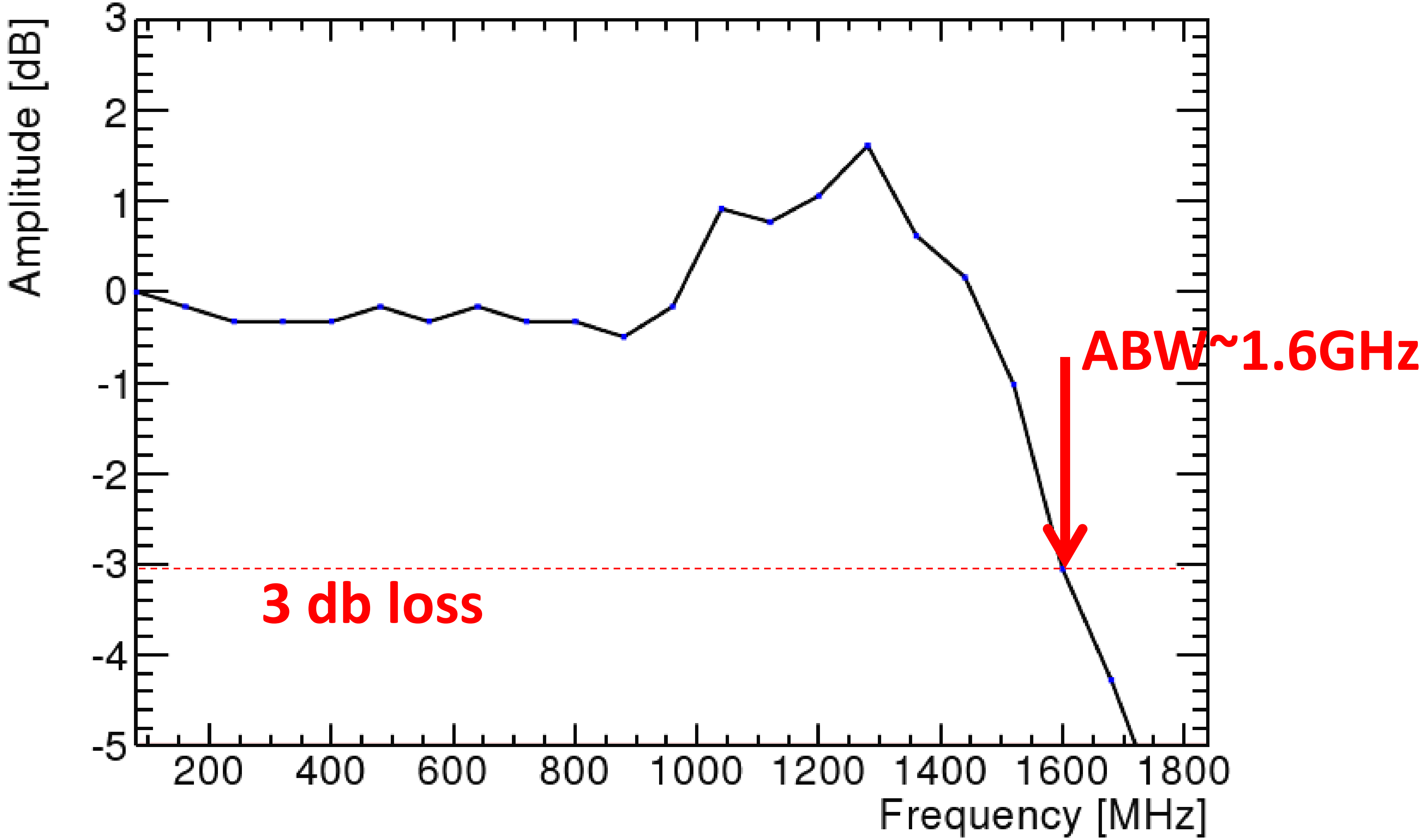
Extract time, position of pulse using time from both ends



Eric Oberla slide from ANT11

Digitization Analog Bandwith

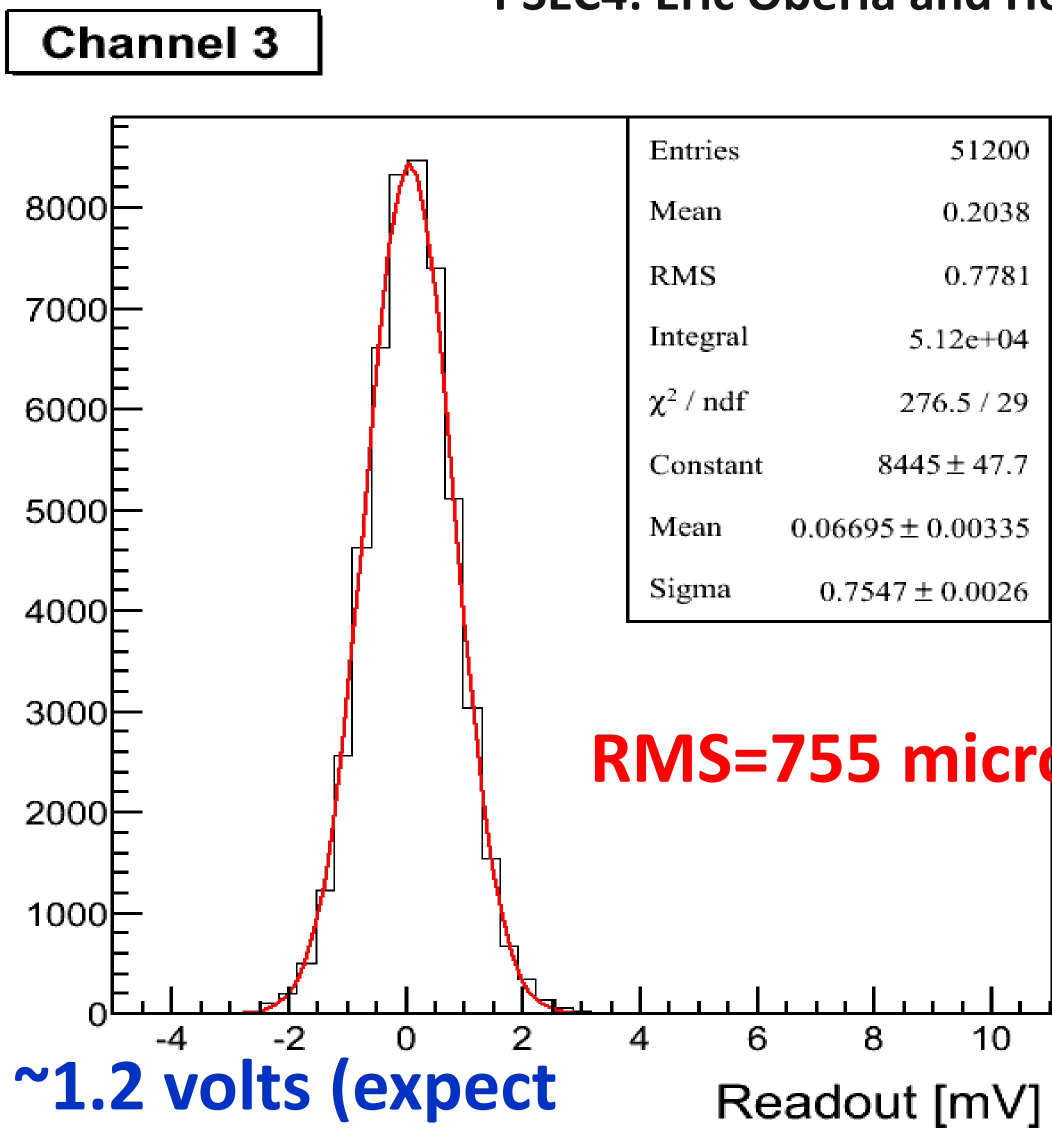
Eric Oberla, ANT11



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

Good timing alone doesn't do it-

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

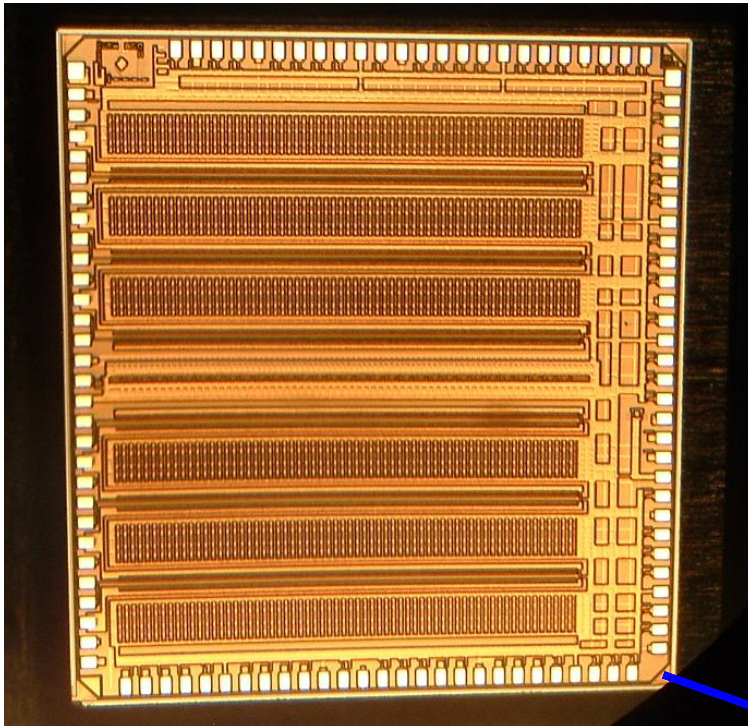
Good time resolution would buy nothing if one integrated over a whole (blue) TPC sector- ie didn't correlate *when* and *where*

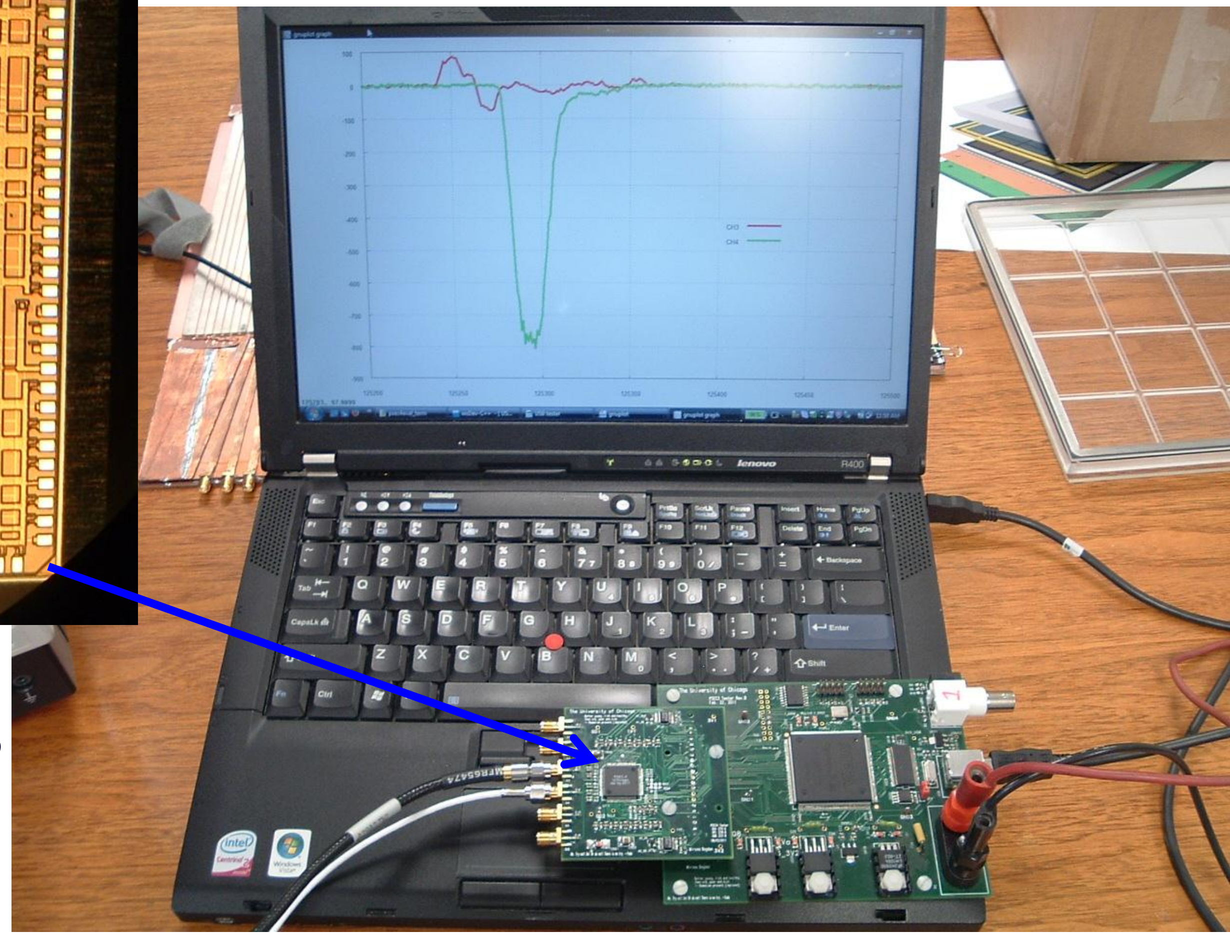
Correlated time and space points allow 3D reconstructions

PSEC-4 ASIC

LAPPD Collaboration

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