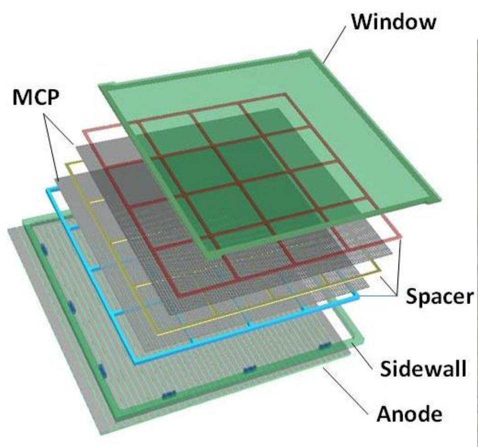
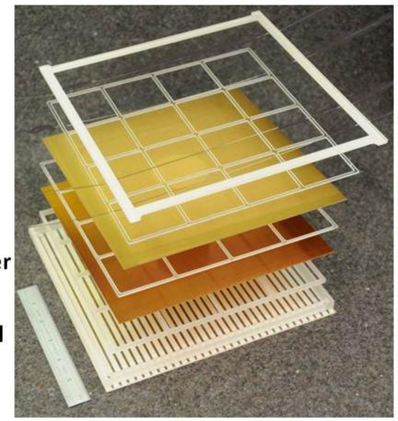
Electronics and System Integration for Large-Area Pico-second Photodetectors

Henry Frisch, Enrico Fermi Institute, Univ. of Chicago

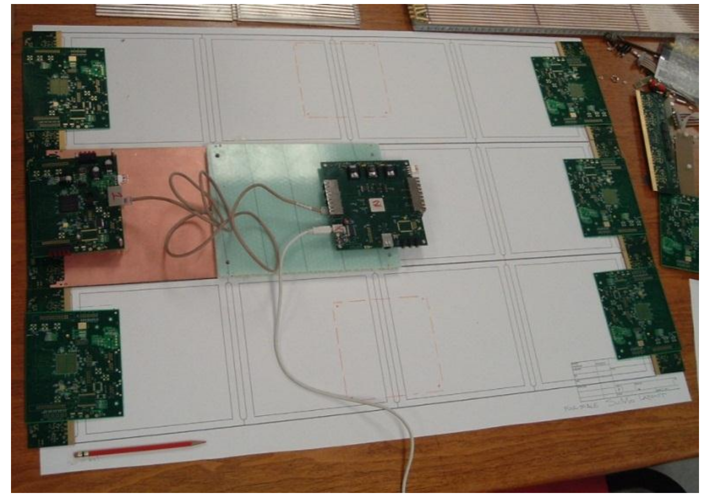
For Eric Oberla and the LAPPD Collaboration

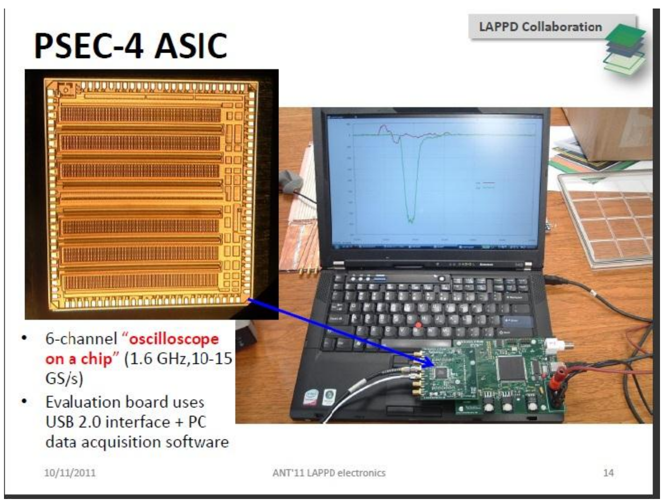


Design Drawing - September 2010



Actual Glass Parts - April 2012





See also the talks by Andrey Elagin, Ossie Siegmund, and Junqi Xie

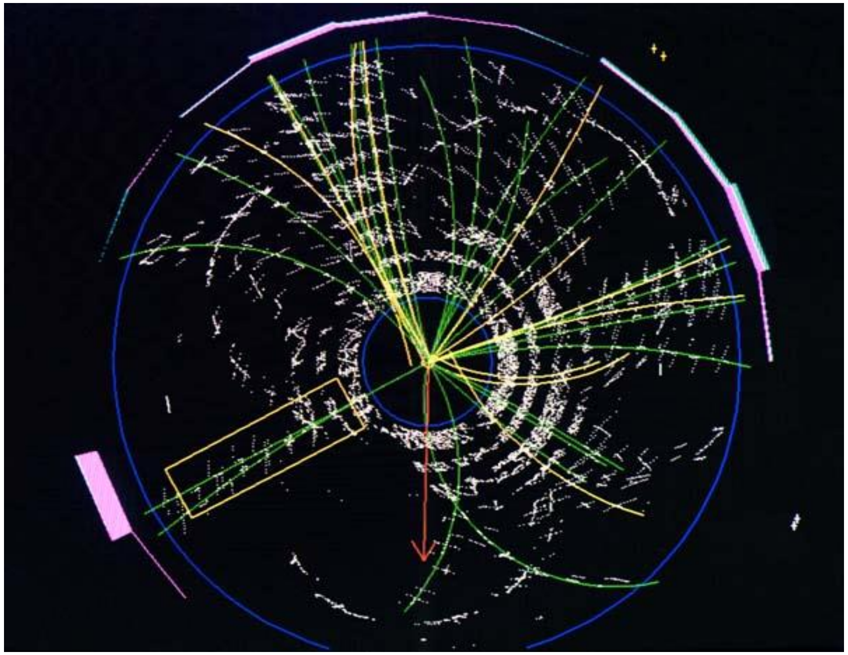
Outline

- Motivation for fast-timing and large area (Need) (4 min)
- MCP Package as integrated HV DC electrical circuit; anode and waveform sampling as integrated RF electrical circuit (4 min)
- Waveform sampling and Anode Details (6 min)
- Outlook- challenges and Opportunities (1 min)

Acknowledgements- Eric Oberla for the opportunity to talk, LAPPD collaborators, Howard Nicholson and the DOE HEP, ANL Management, and the NSF.

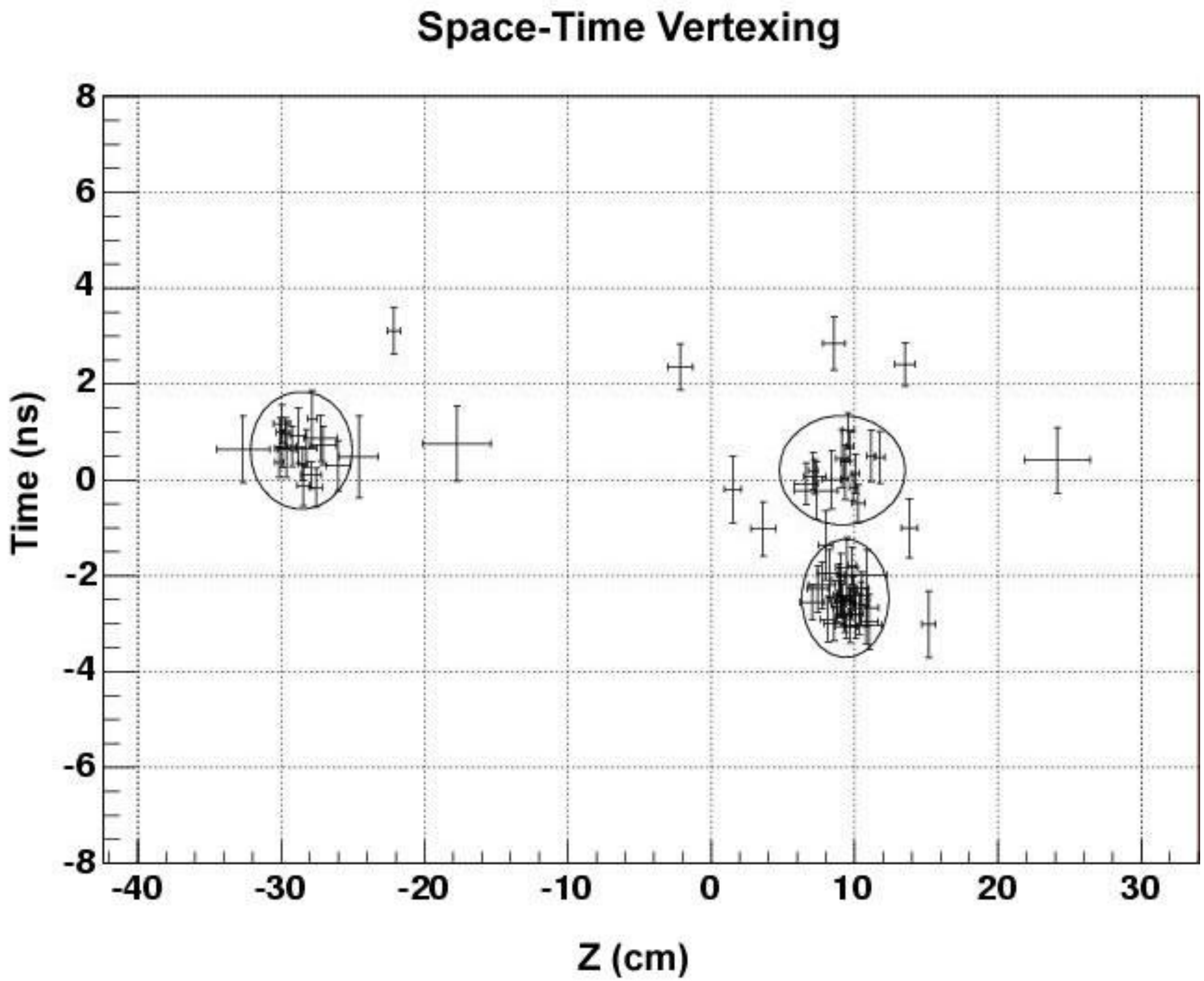
Colliders:

Need: 1) identify the quark content of charged particles
2) vertex photons



Theme: extract *all* the information in each event (4-vectors)

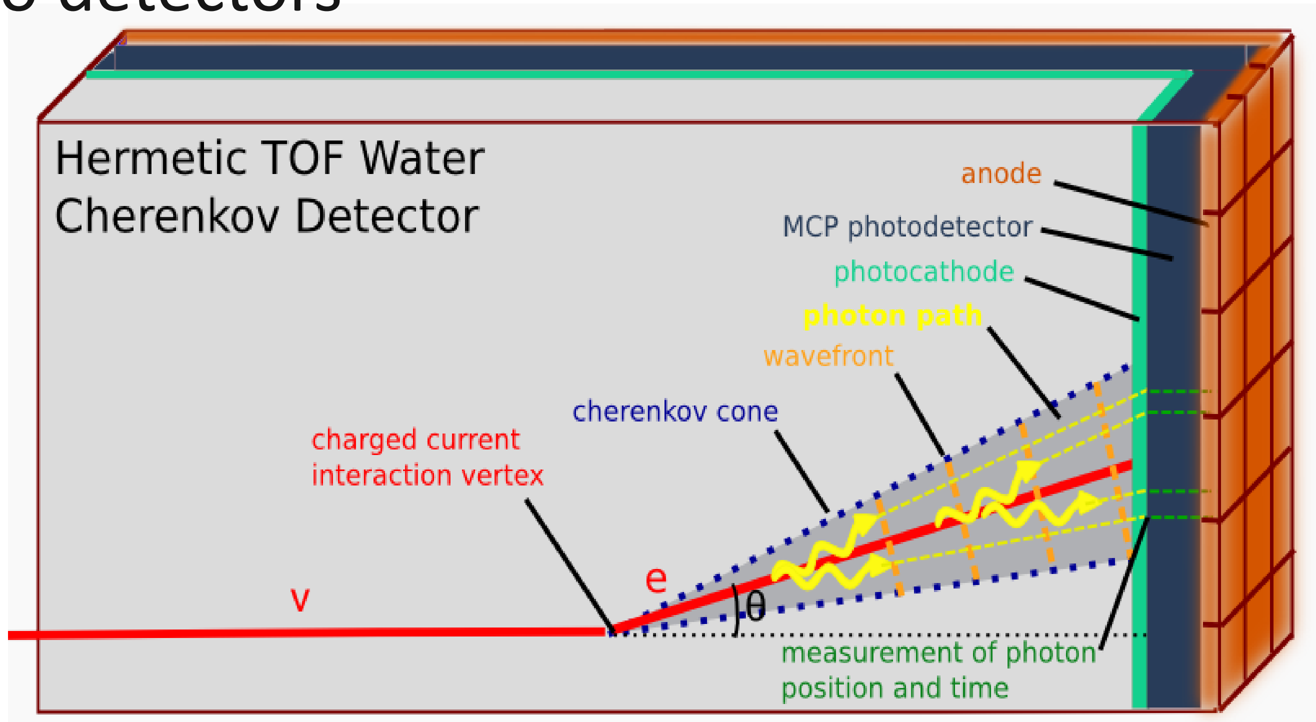
Approach: measure the difference in arrival times of photons and charged particles which arrive a few psec later. Light source is Cherenkov light in the window/radiator.
Benefit: Discoveries in signatures not possible now
(Note: conventional TOF resolution is 100 psec -factor of 100 worse than our goal= 1" is 100 psec, so need a small scale-length).



Example need- 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.

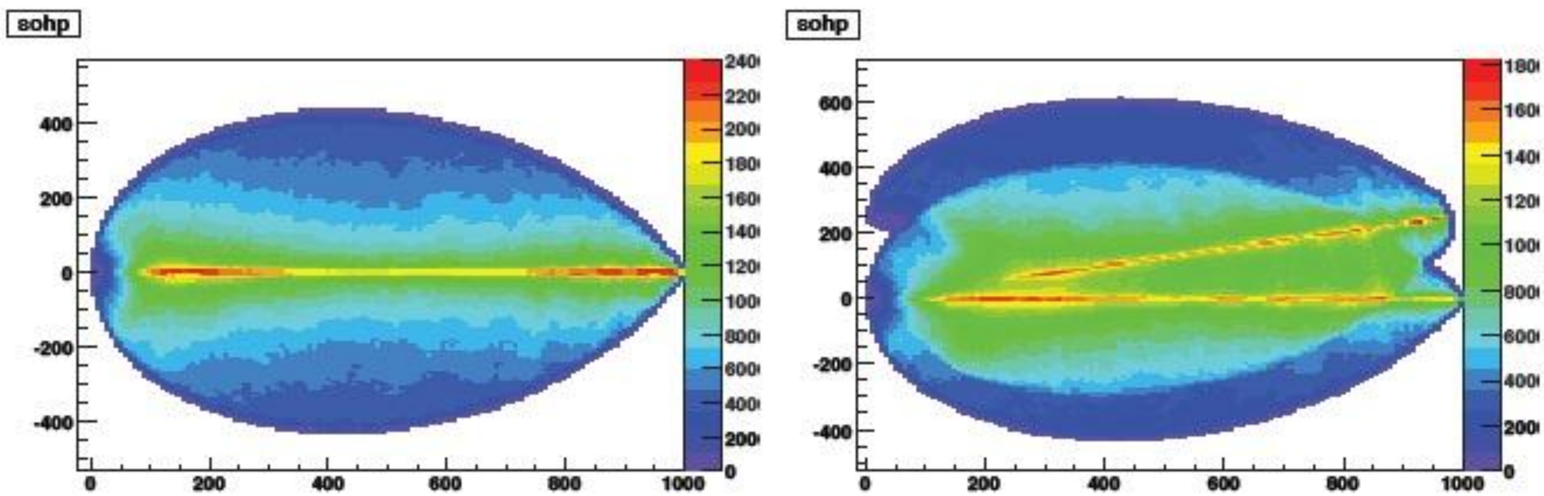
Competition- large PMT's, Liquid Argon

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



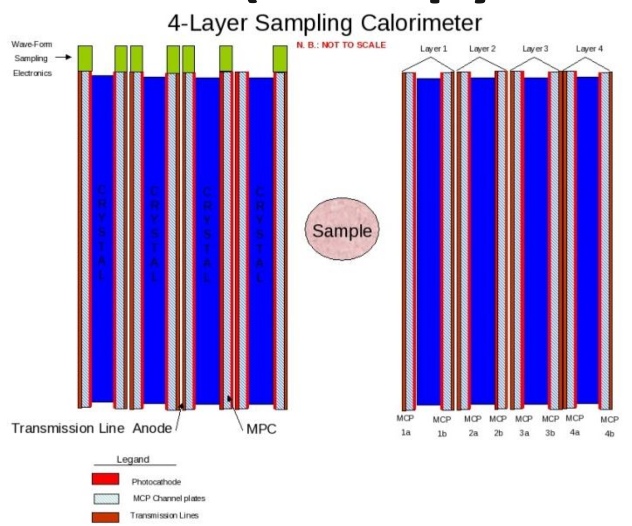
Single track

Two tracks displaced from a common vertex

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

Medical Imaging (PET)

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



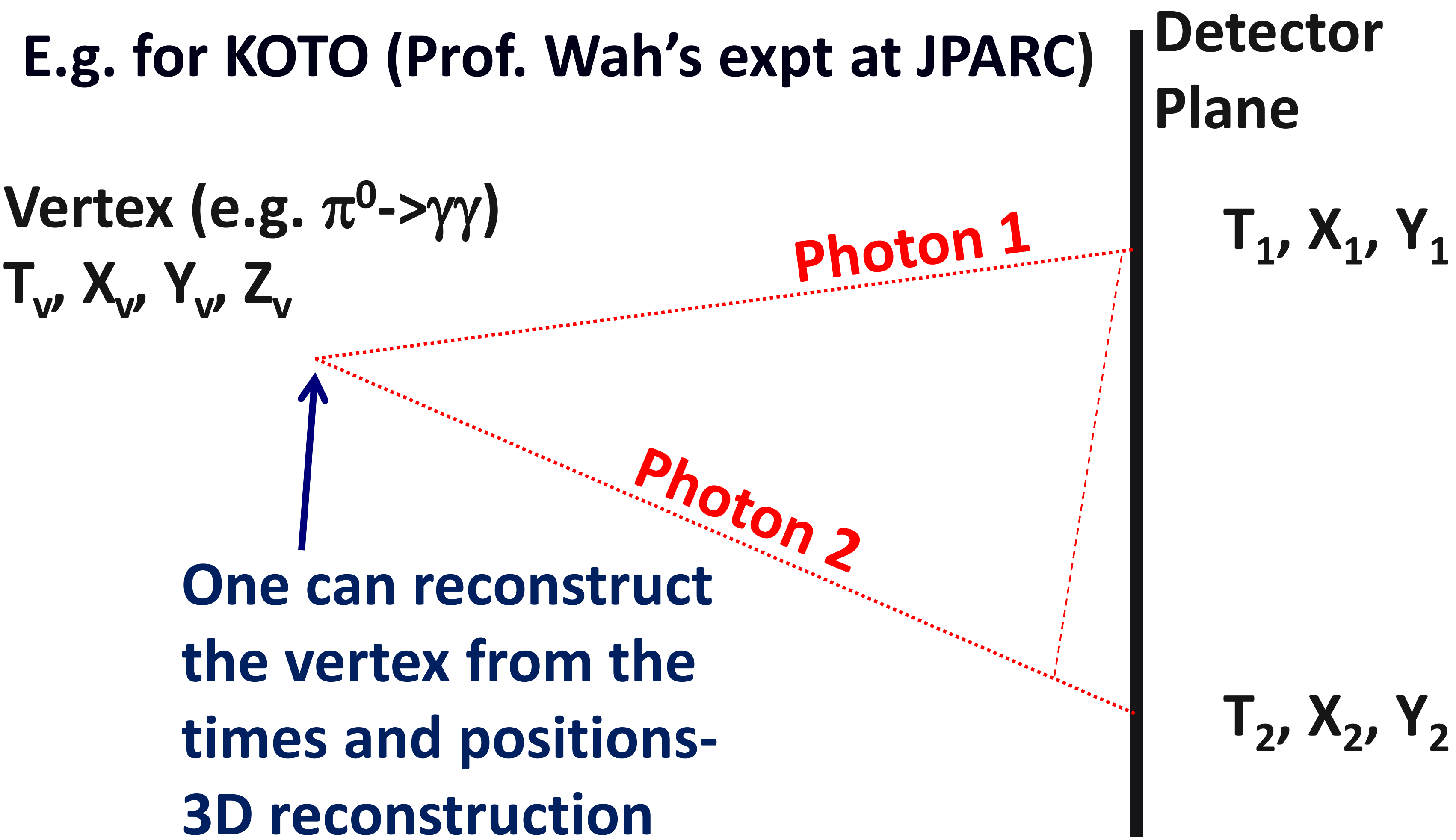
Approach: precise Time-of-Flight, sampling, real-time adaptive algorithms in local distributed computing, use much larger fraction of events and information

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

Competition: Silicon PMT's

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

E.g. for KOTO (Prof. Wah's expt at JPARC)



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

Cherenkov-sensitive Sampling Quasi- Digital Calorimeters

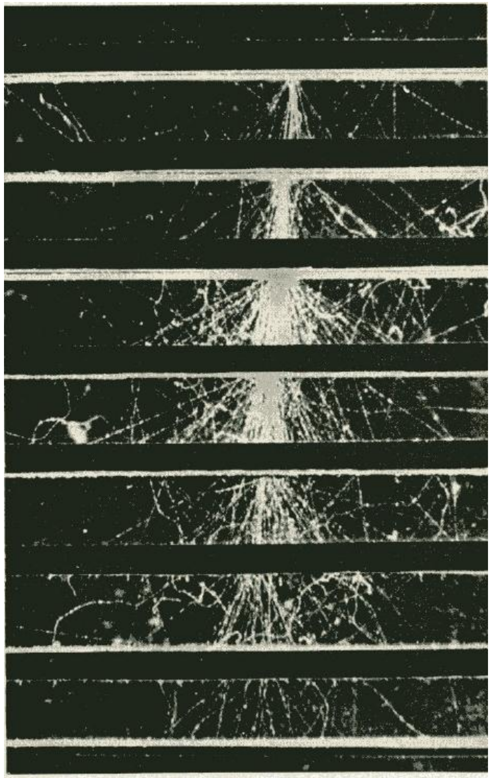
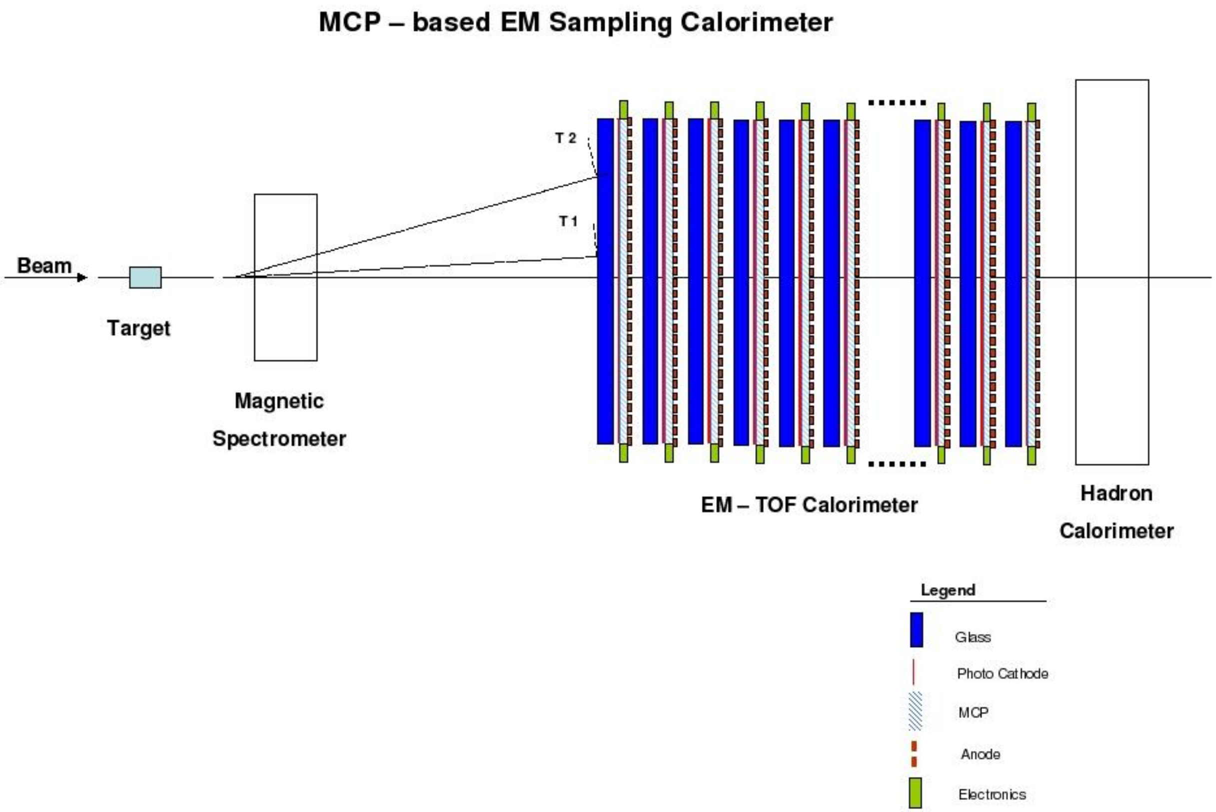


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.

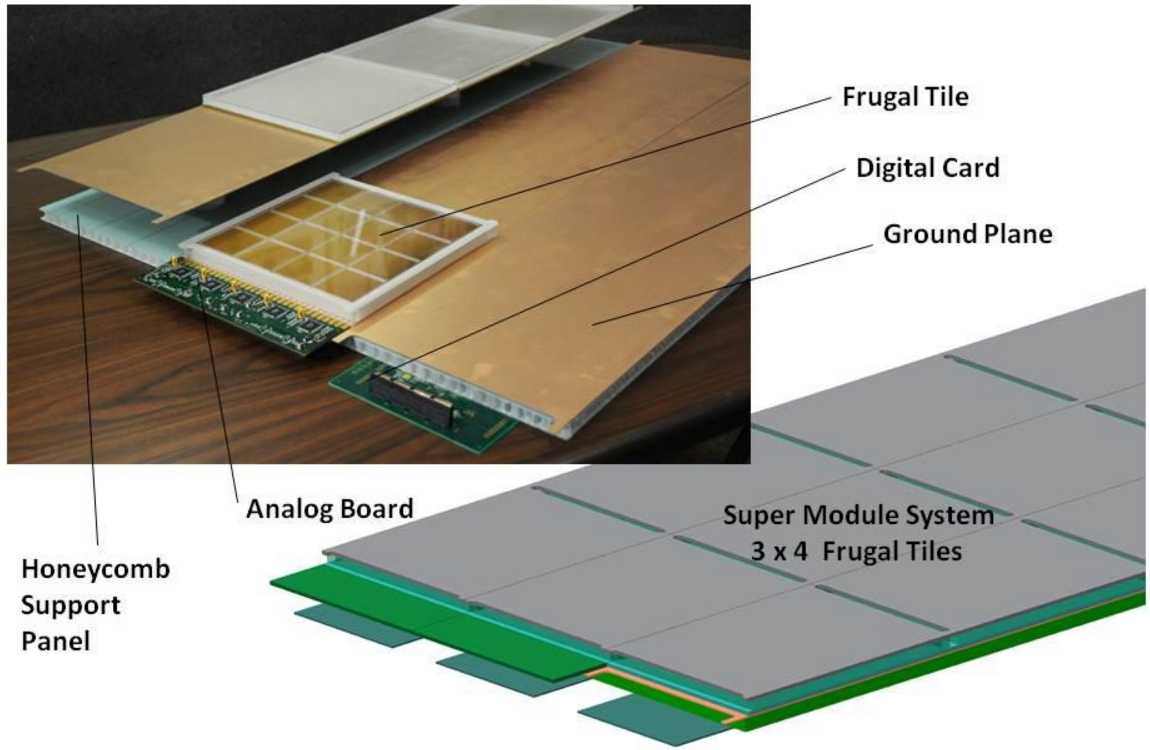


A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

Tile-Tray Integrated Design

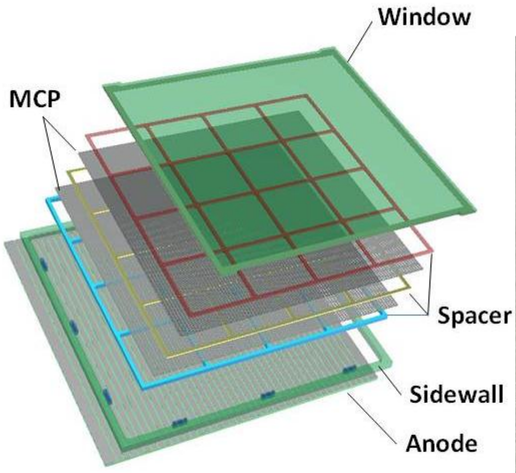
Because this is an RF-based readout system, the geometry and packaging are an integral part of the electronic design



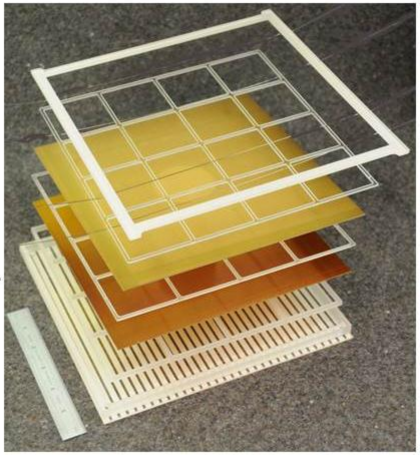
Tray and Tiles - The Super Module System

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

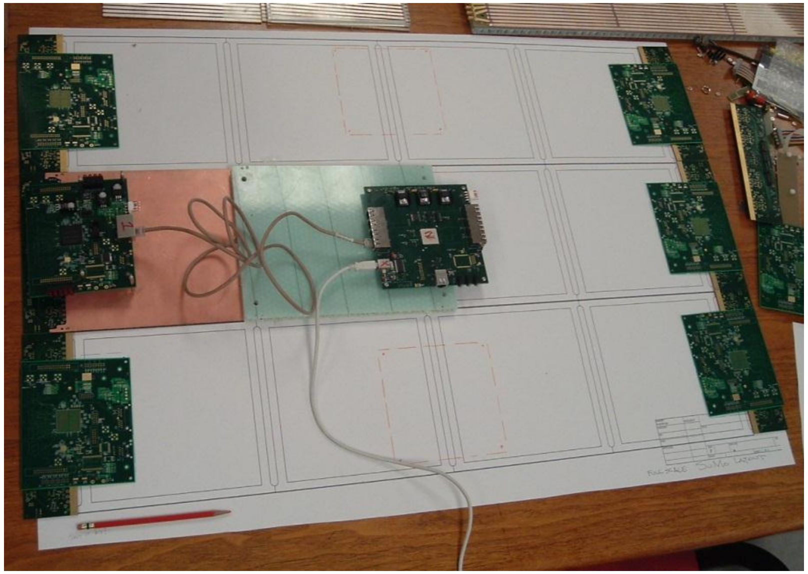
A `tile' is a sealed vacuum-tube with cathode, 2 MCP's, RF-strip anode, and internal voltage divider

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

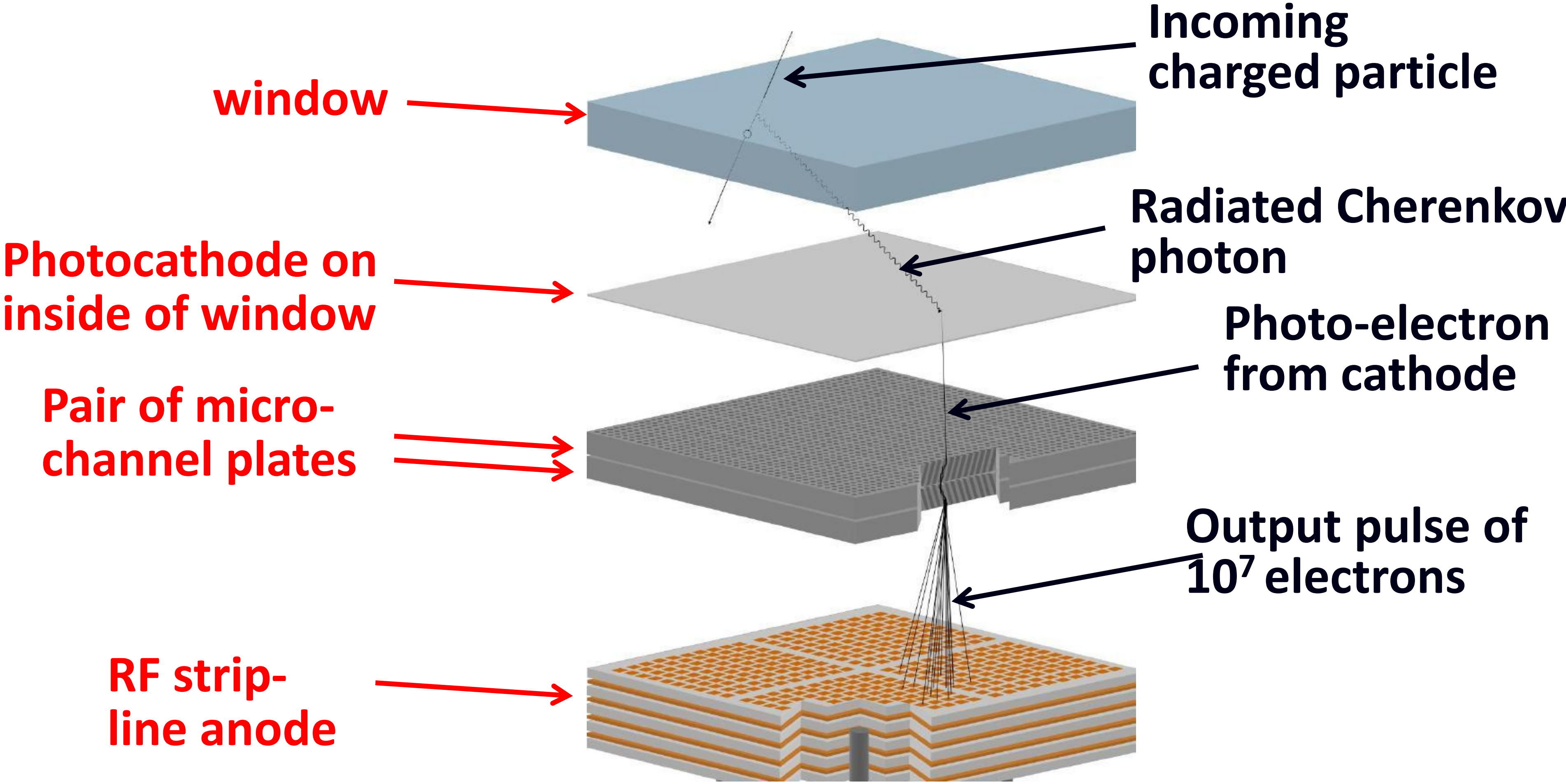
2 layers of local processing (Altera) measure extract charge, time, position, goodness-of-fit



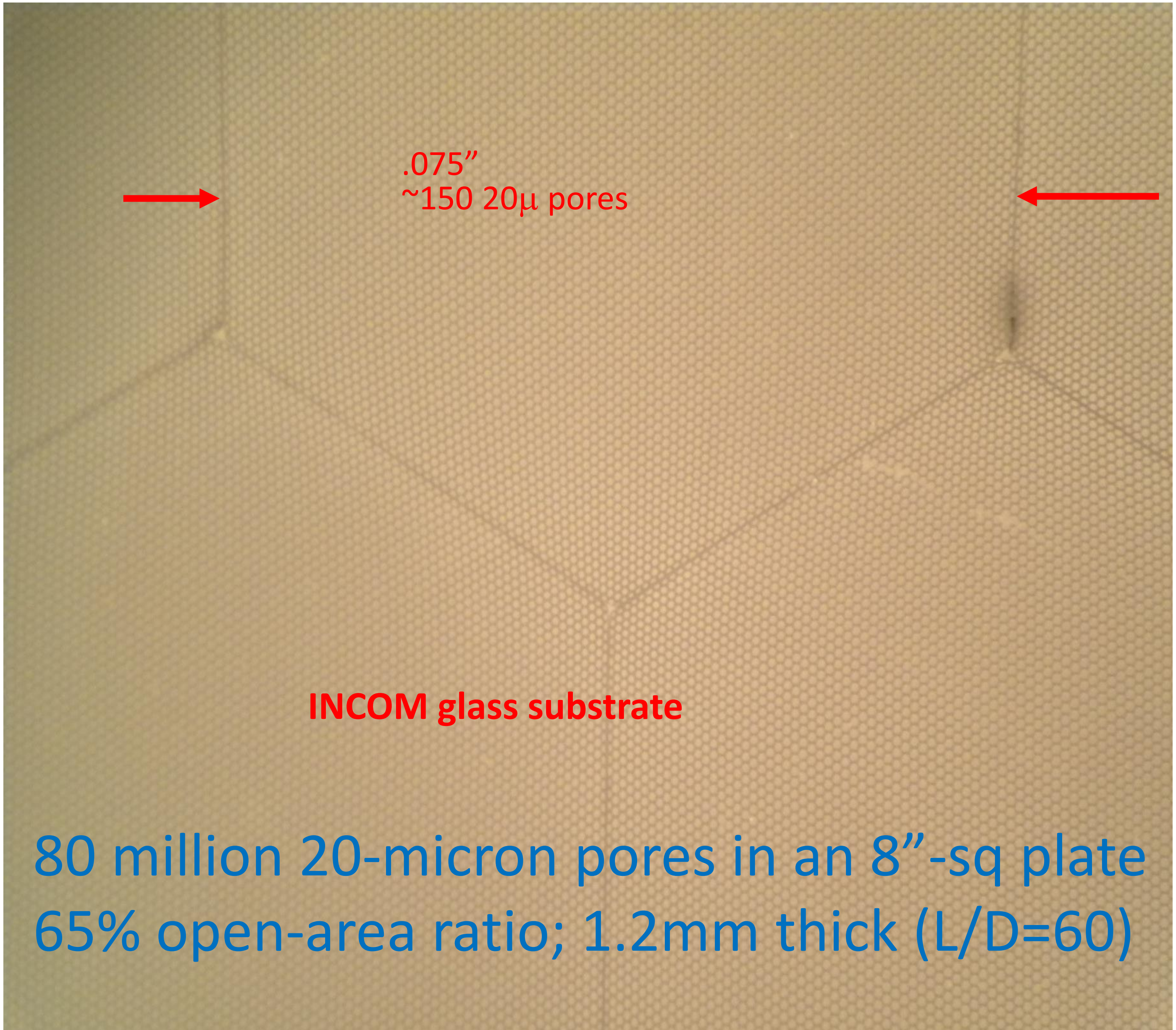
How Does it Work?

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)

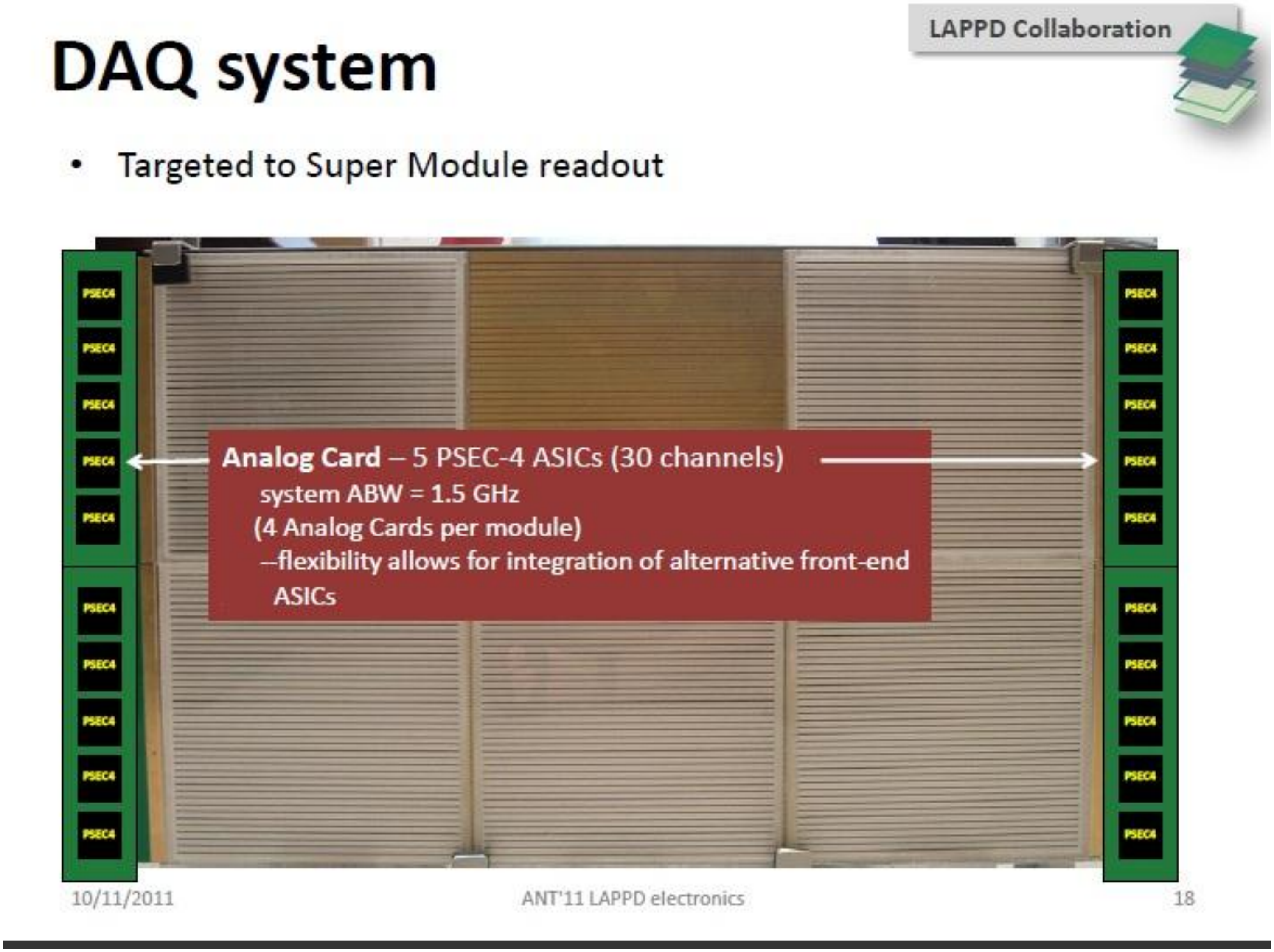


Incom Micropore Substrate



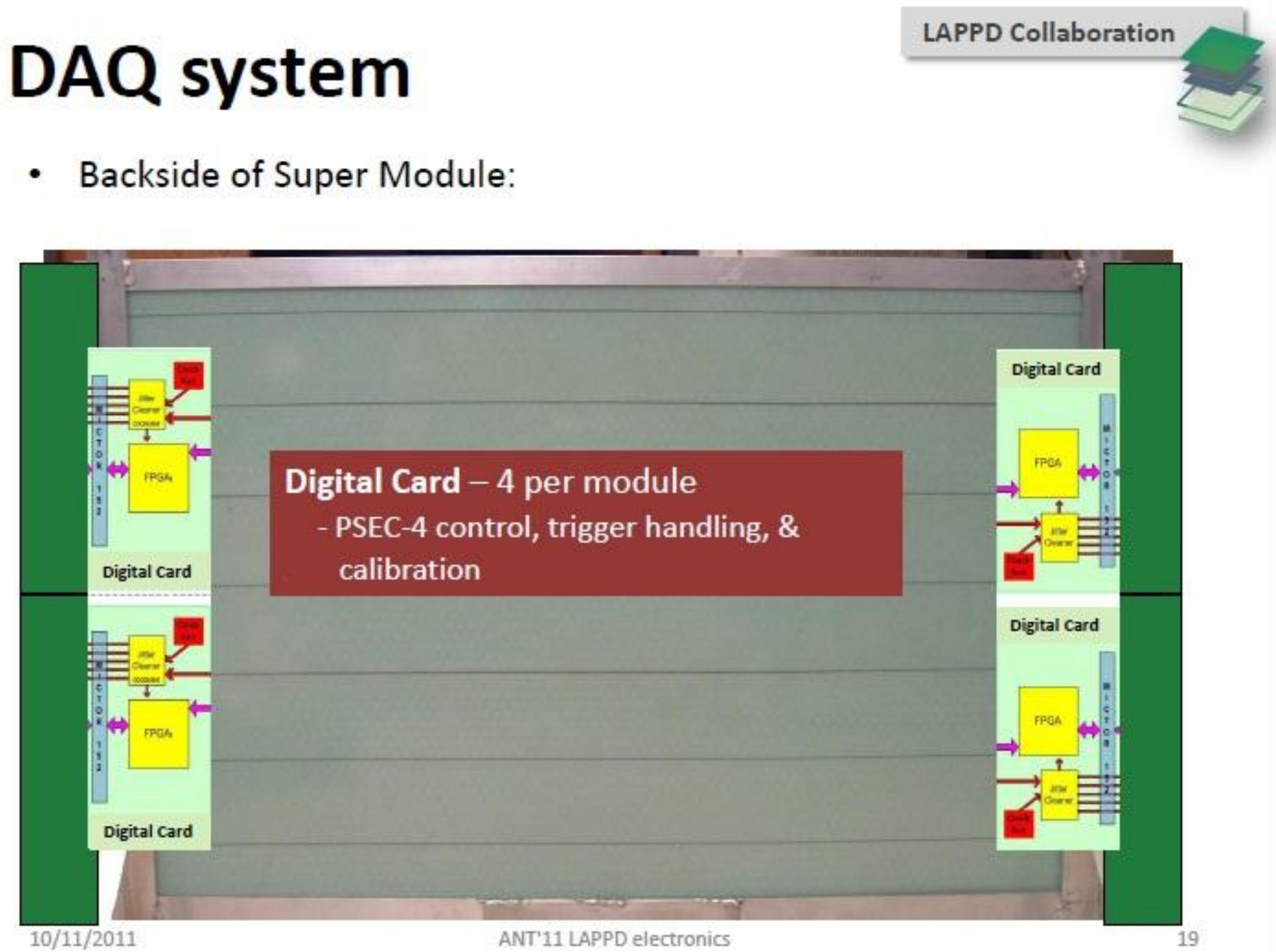
Incom.inc, Charlton Mass

Waveform Sample On Ends of Strips



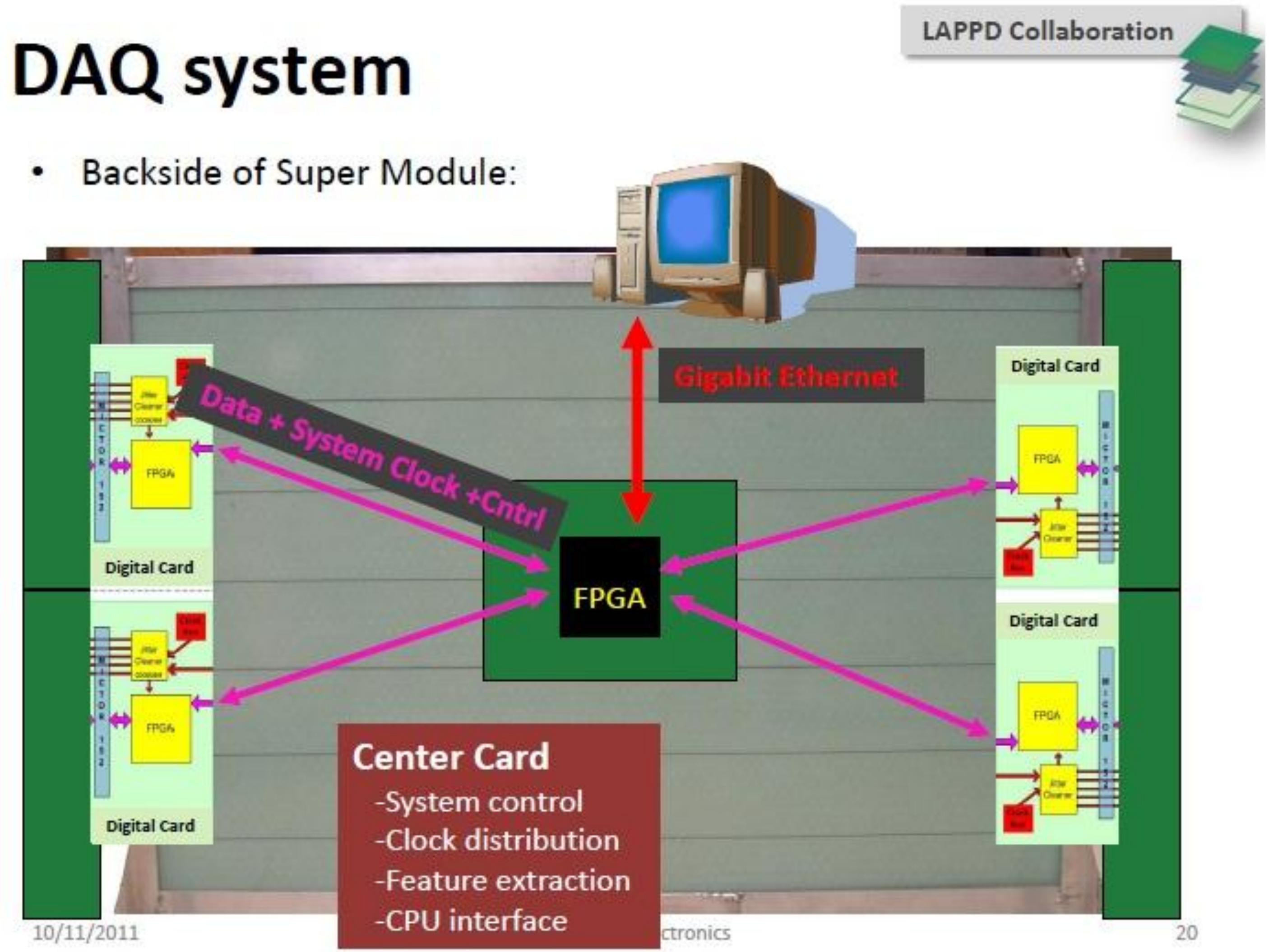
Eric Oberla slide from ANT11

Extract time, charge, shape each end



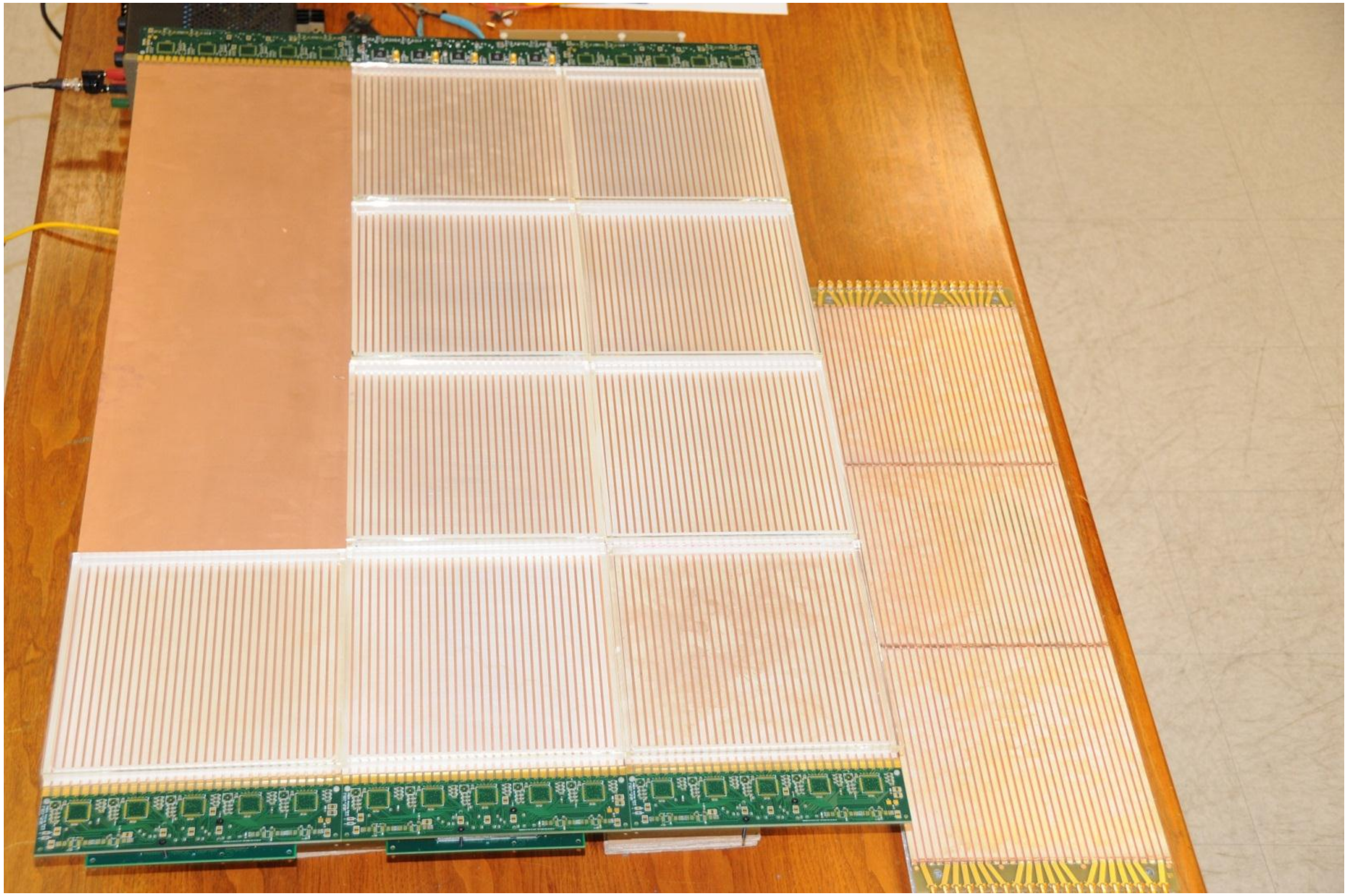
Eric Oberla slide from ANT11

Extract time, position of pulse using time from both ends



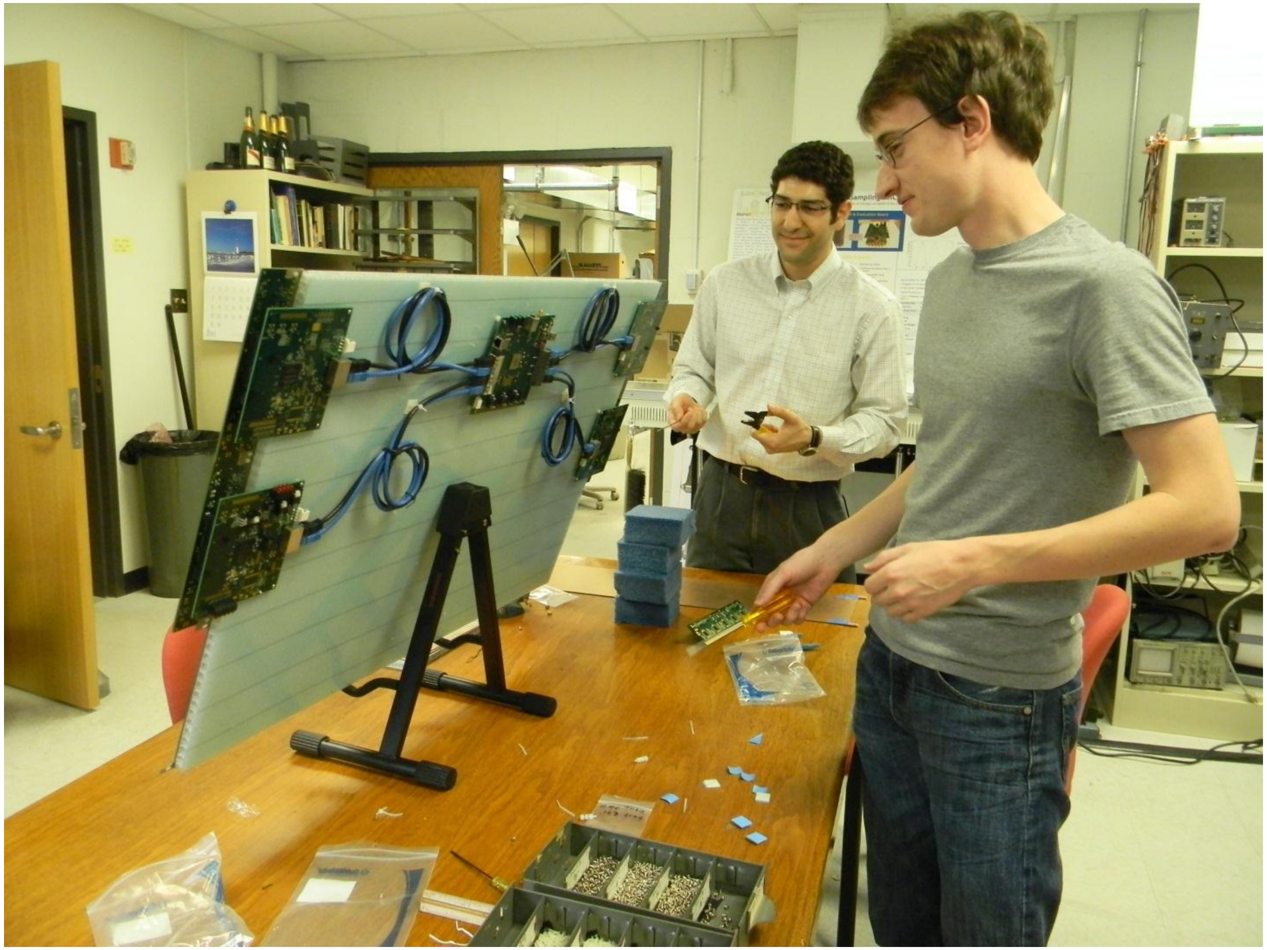
Eric Oberla slide from ANT11

SuperModule Mockup



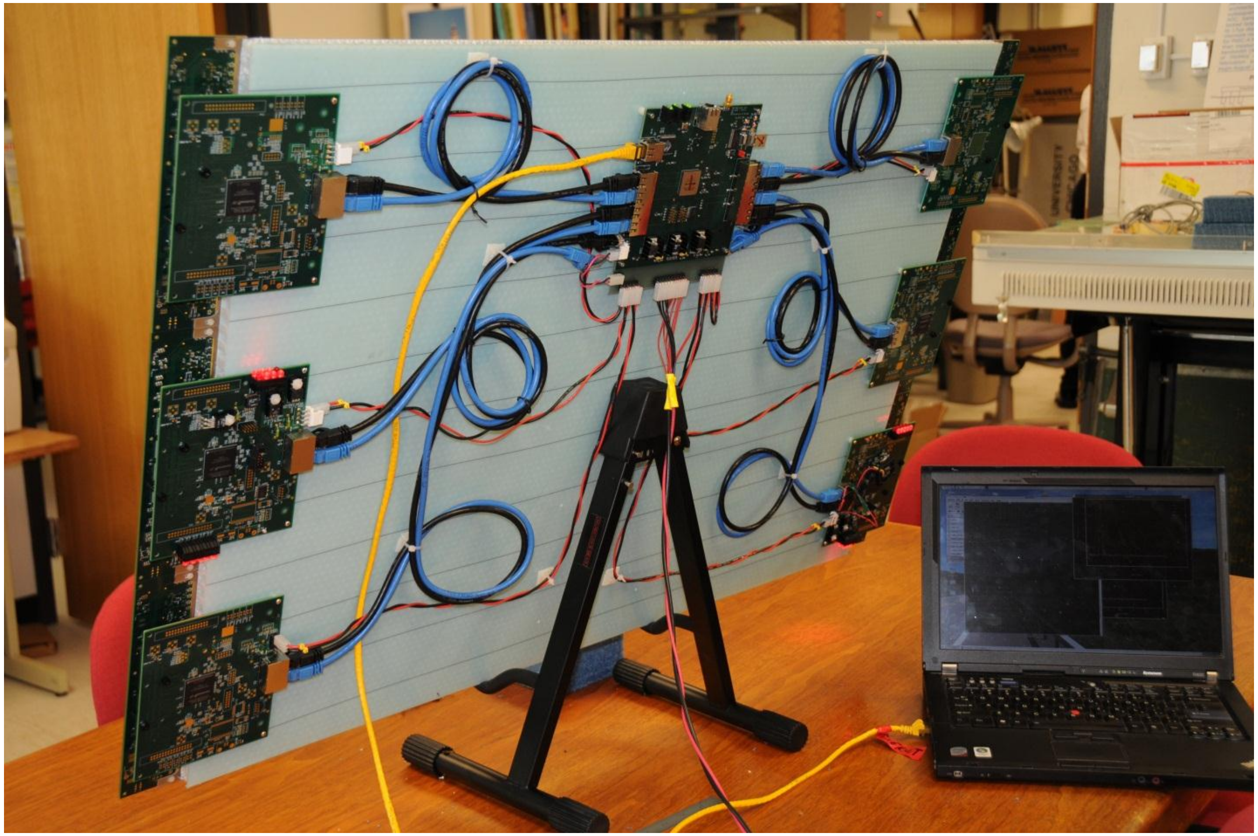
- Real 8” glass tile package parts- anode, side-wall, window (sic)
- `Innards’ stack of 2 MCP’s +3 spacers+anode+window under test
- Have read out through from AC card through full DAQ chain to PC

Developing and Testing the Electronics, Anodes, and DAQ



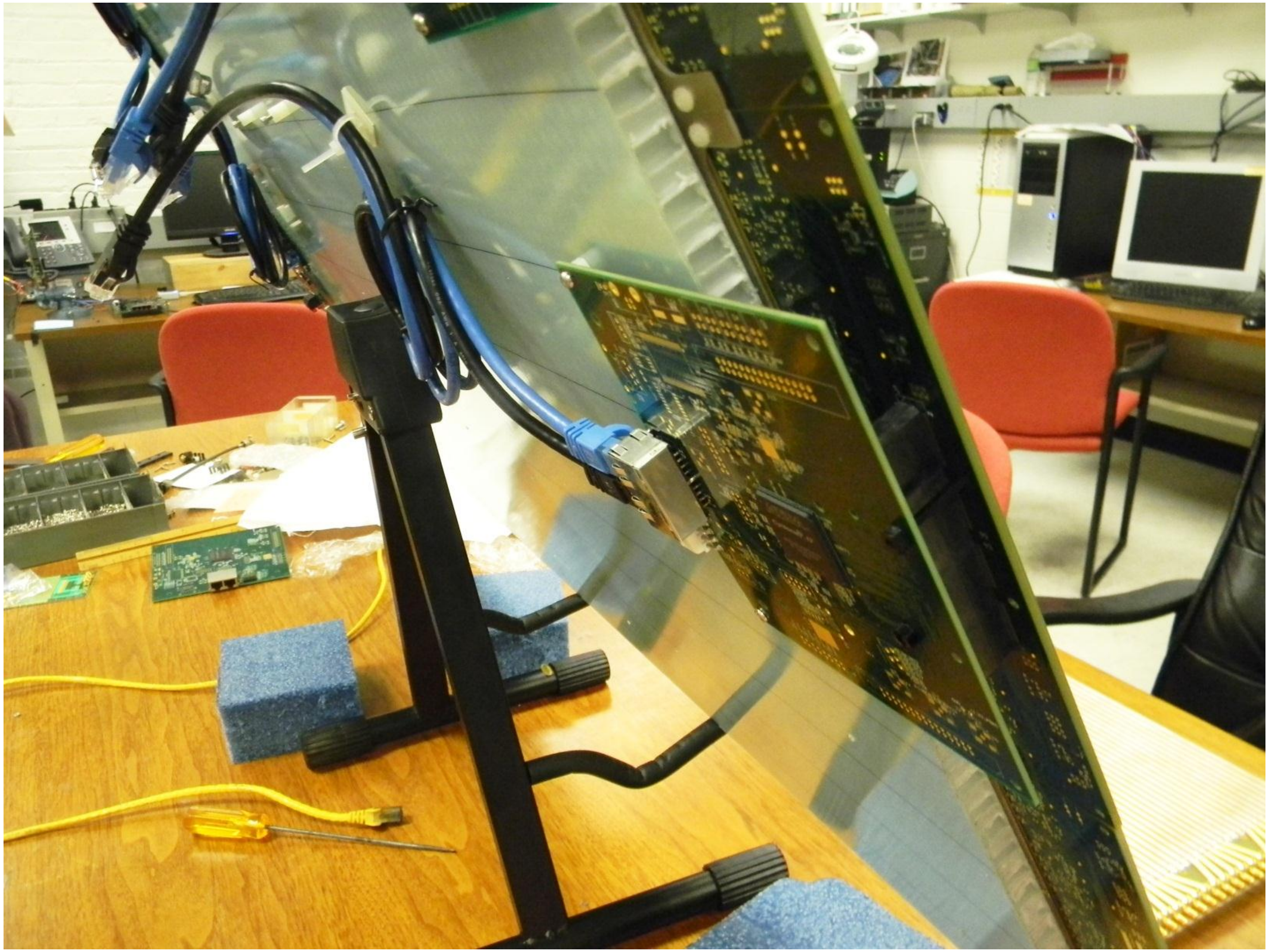
Eric Oberla (grad student) and Craig Harabedian (engineer) working on the Tray layout and cabling

Digital Cards and Central Card



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

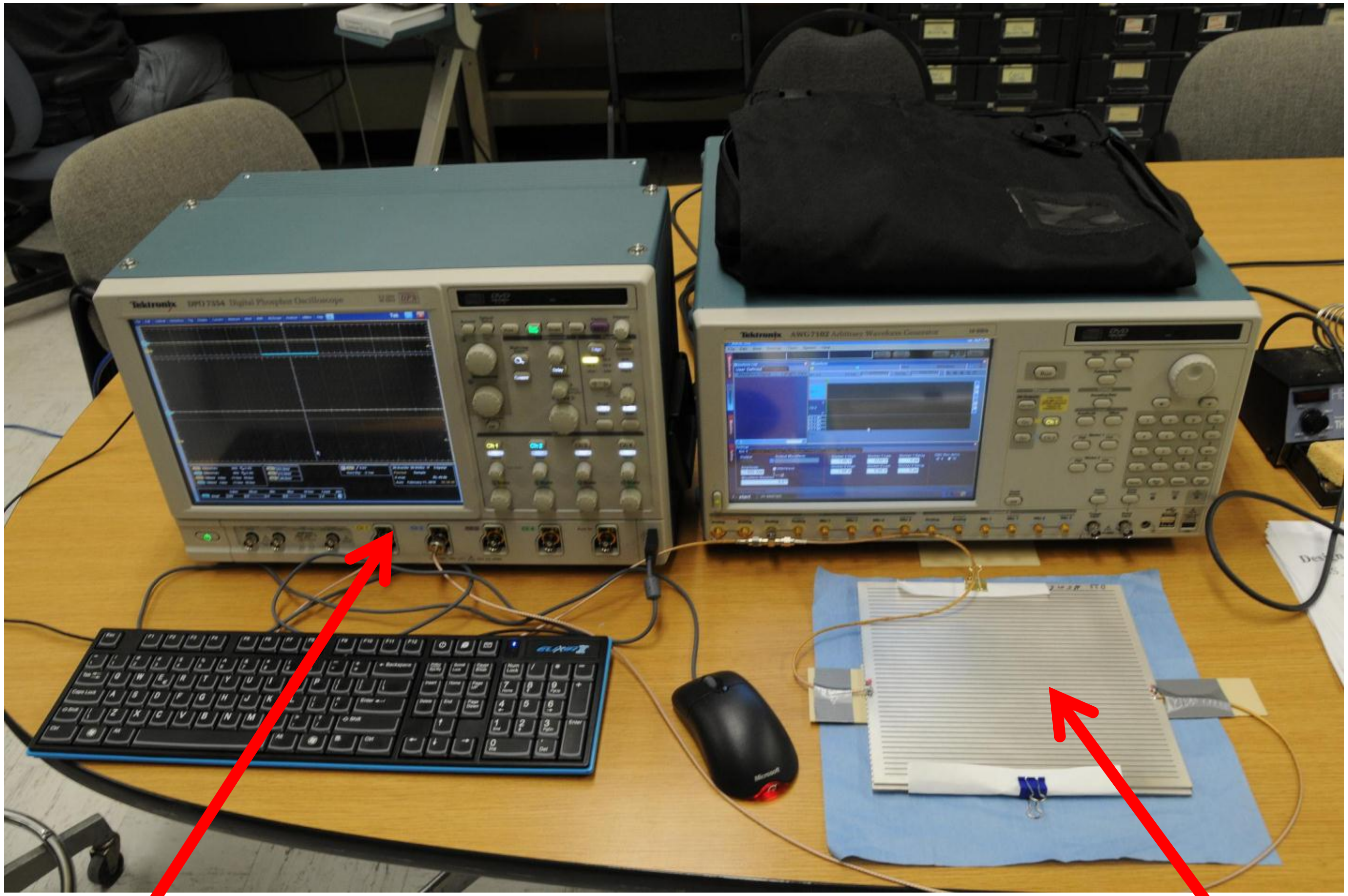
Analog Card to Digital Card



Can be direct connection (shown) or cable

Anode Testing for ABW, Crosstalk,..

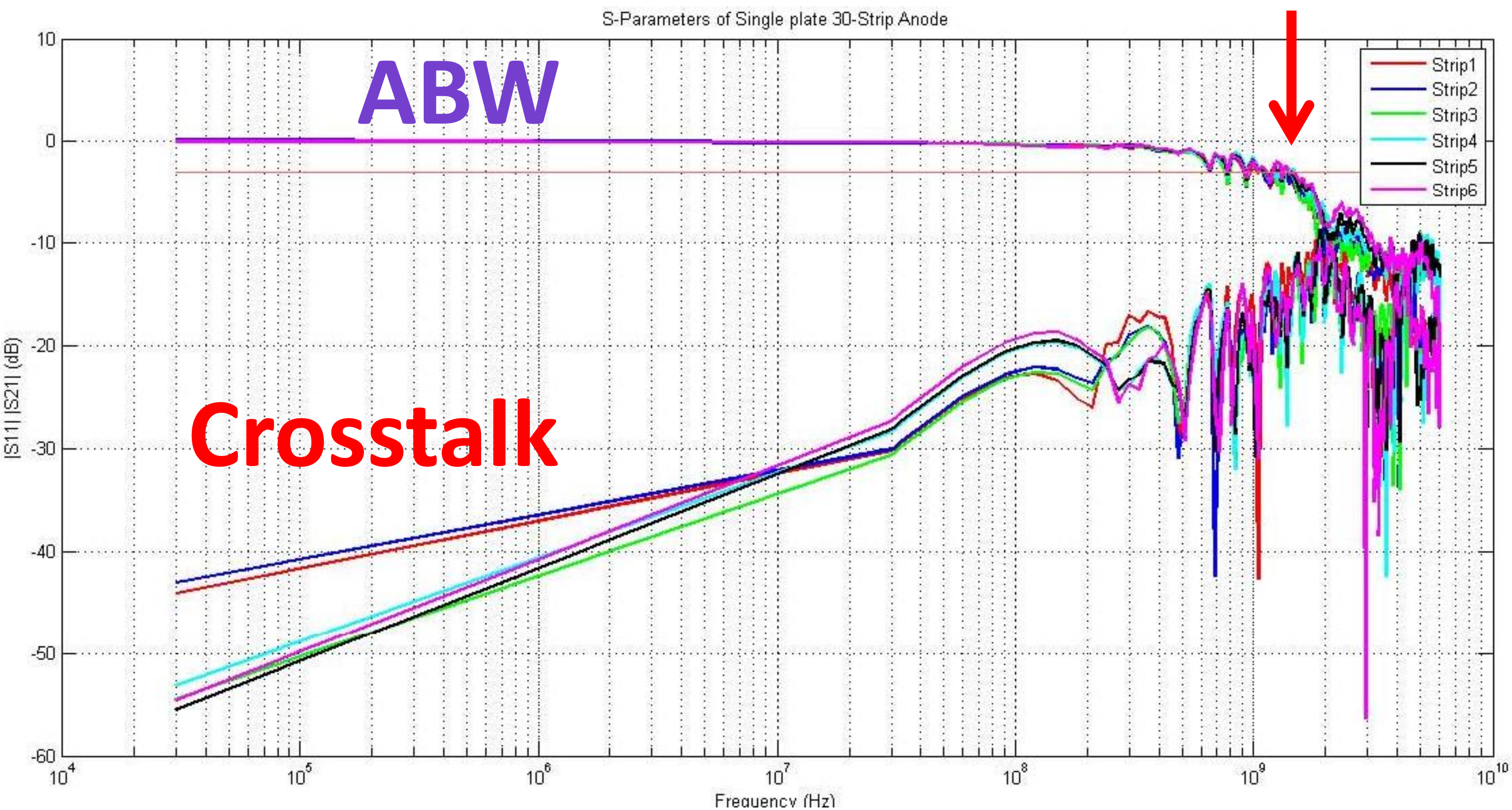
Herve' Grabas, Razib Obaid, Dave McGinnis



Network Analyzer

Tile Anode

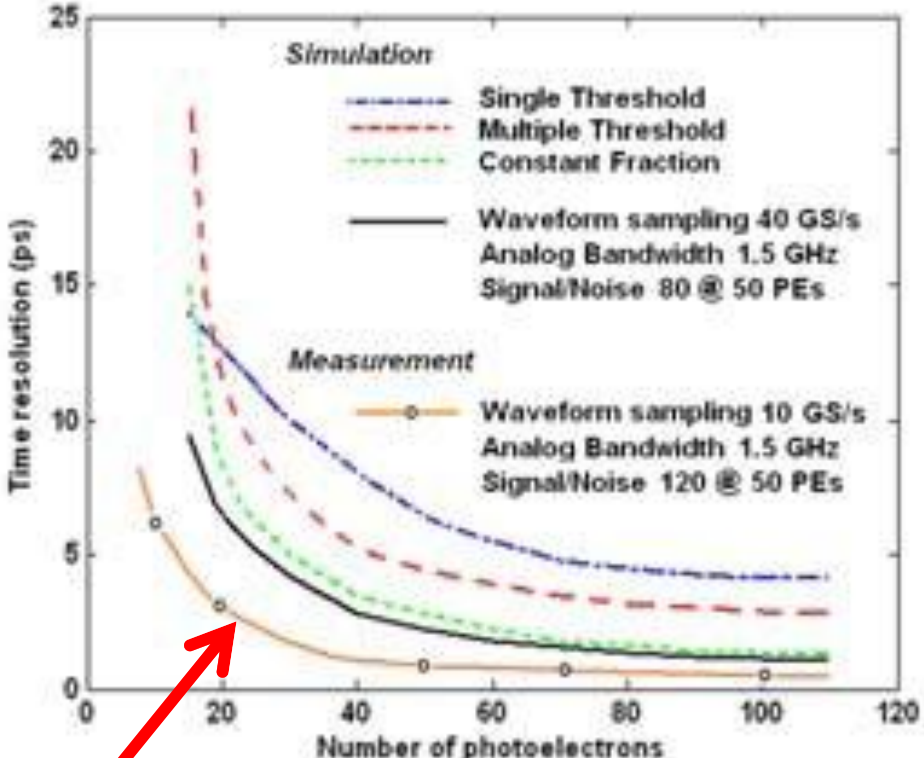
Anode Testing for ABW, Crosstalk,..

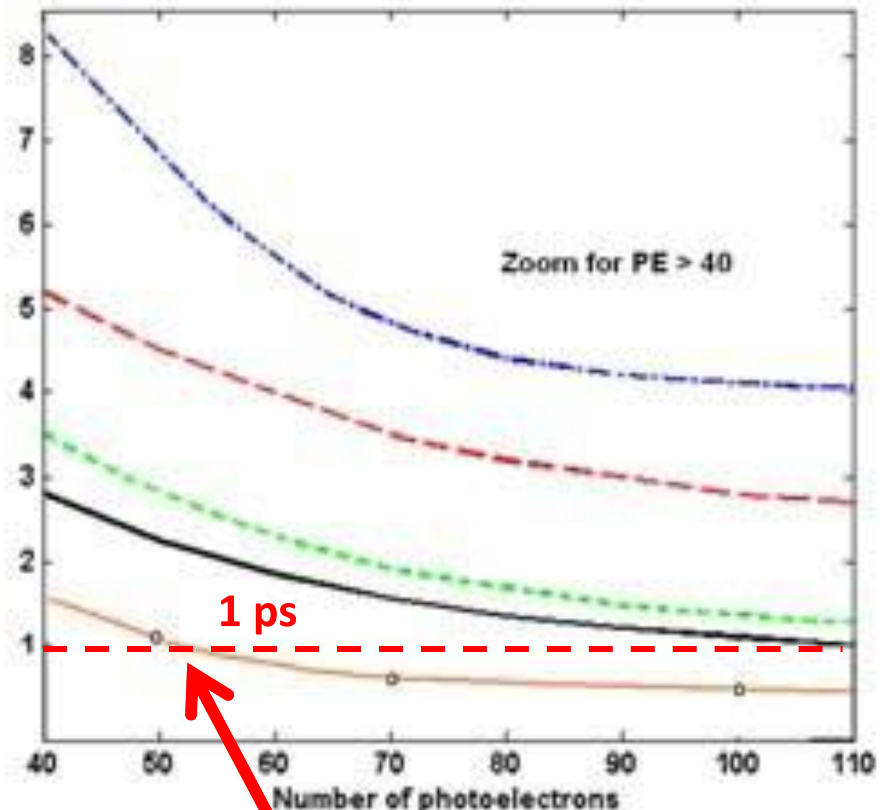


Razib Obaid

Simulation of Resolution vs abw

Jean-Francois Genat (NIM)





This (brown) line

This (brown) line

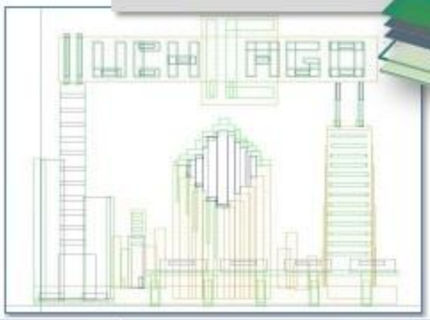
Brown line: 10 Gs/sec (we've done >15);
1.5 GHz abw (we've done 1.6); S/N 120 (N=0.75mv, S is app specific)

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***

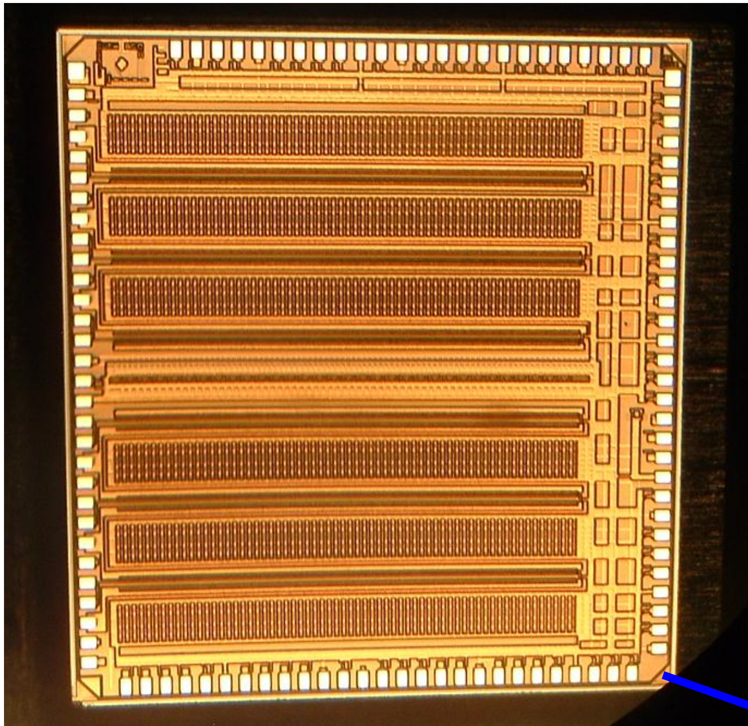
	SPECIFICATION
Sampling Rate	2.5-15 GSa/s
# Channels	6 (or 2)
Sampling Depth	256 (or 768) points
Sampling Window	Depth*(Sampling Rate)$^{-1}$
Input Noise	<1 mV RMS
Analog Bandwidth	1.5 GHz
ADC conversion	Up to 12 bit @ 2GHz
Dynamic Range	0.1-1.1 V
Latency	2 μs (min) – 16 μs (max)
Internal Trigger	yes

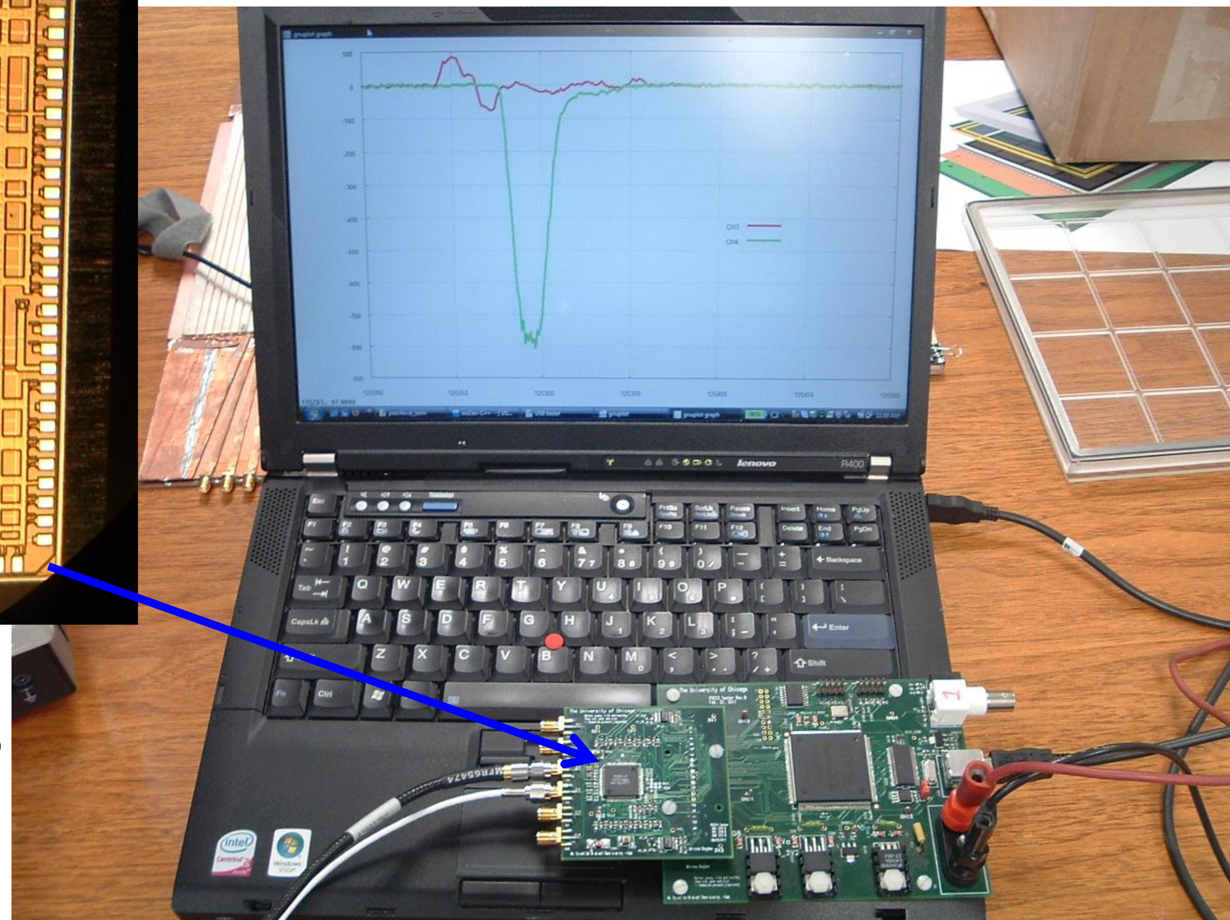
10/11/2011 ANT'11 LAPPD electronics 13

Eric Oberla, ANT11

PSEC-4 ASIC

Eric Oberla, ANT11

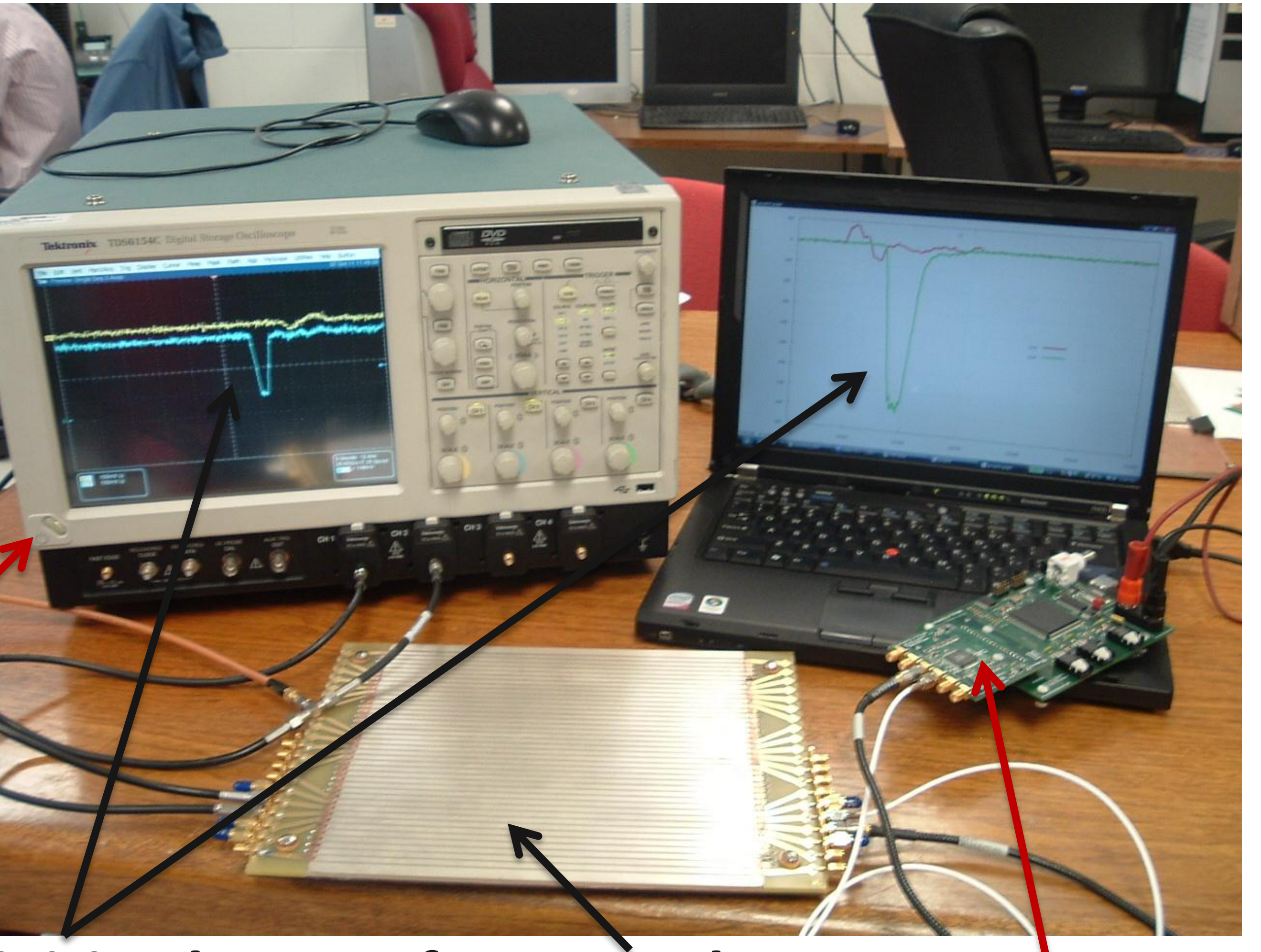




- 6-channel “**oscilloscope on a chip**” (1.6 GHz,10-15 GS/s)
- Evaluation board uses USB 2.0 interface + PC data acquisition software

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

Designed by Eric Oberla (UC grad student) working in EDG with EDG tools and zeitgeist



Real digitized traces from anode

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

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

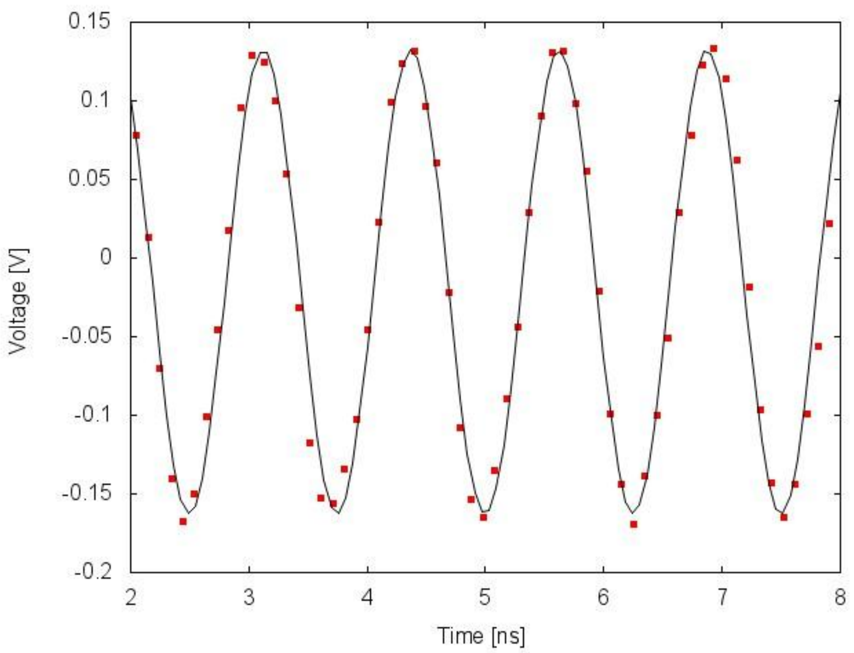
PSEC-4 Performance

Eric Oberla, ANT11

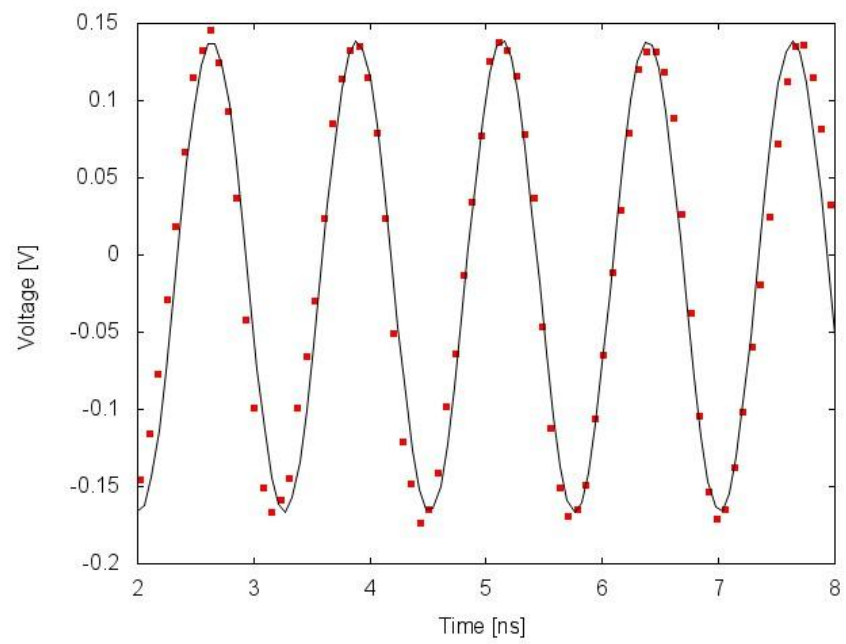
Digitized Waveforms

Input: 800MHz, 300 mV_{pp} sine

Sampling rate : 10 GSa/s



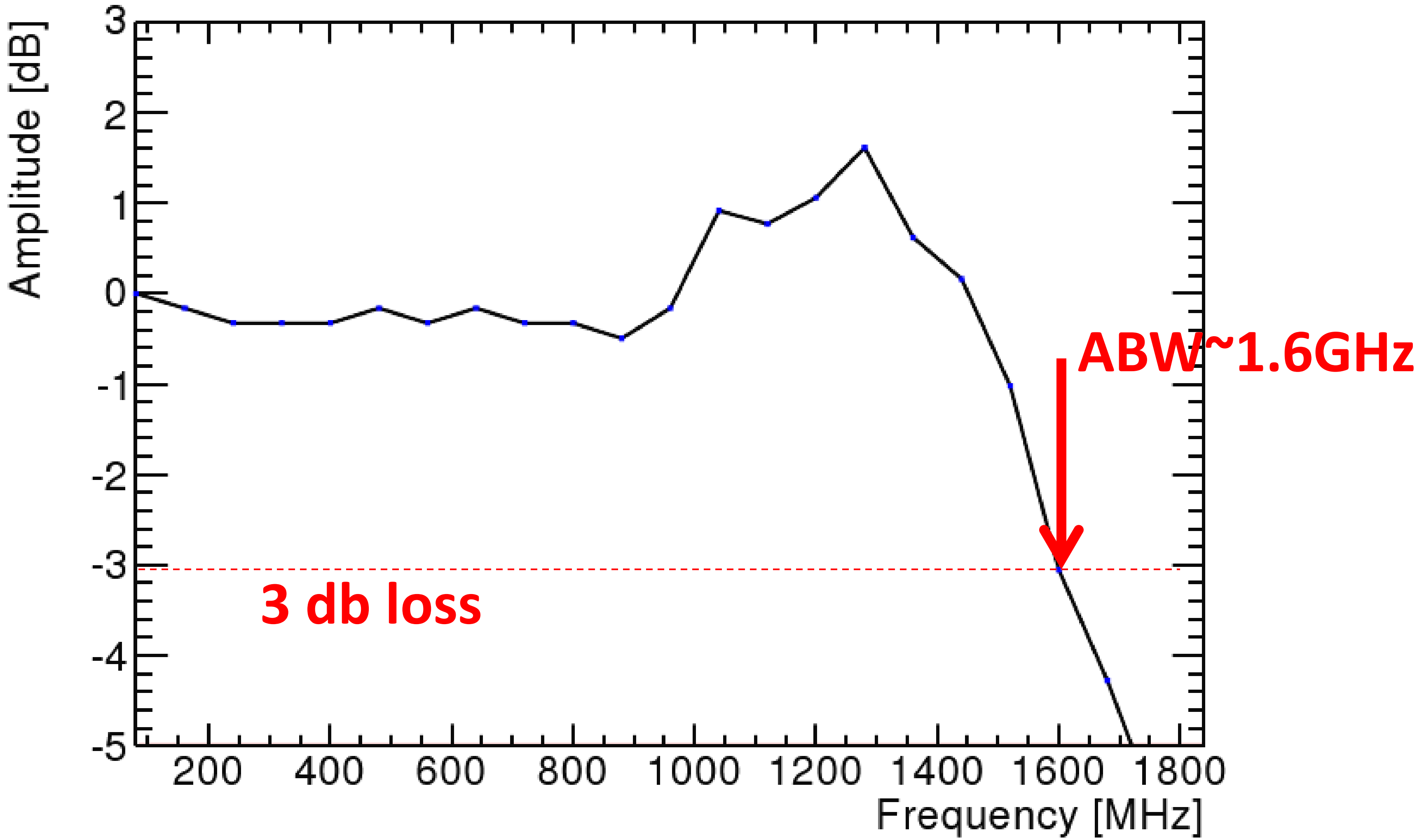
Sampling rate : 13.3 GSa/s



- 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

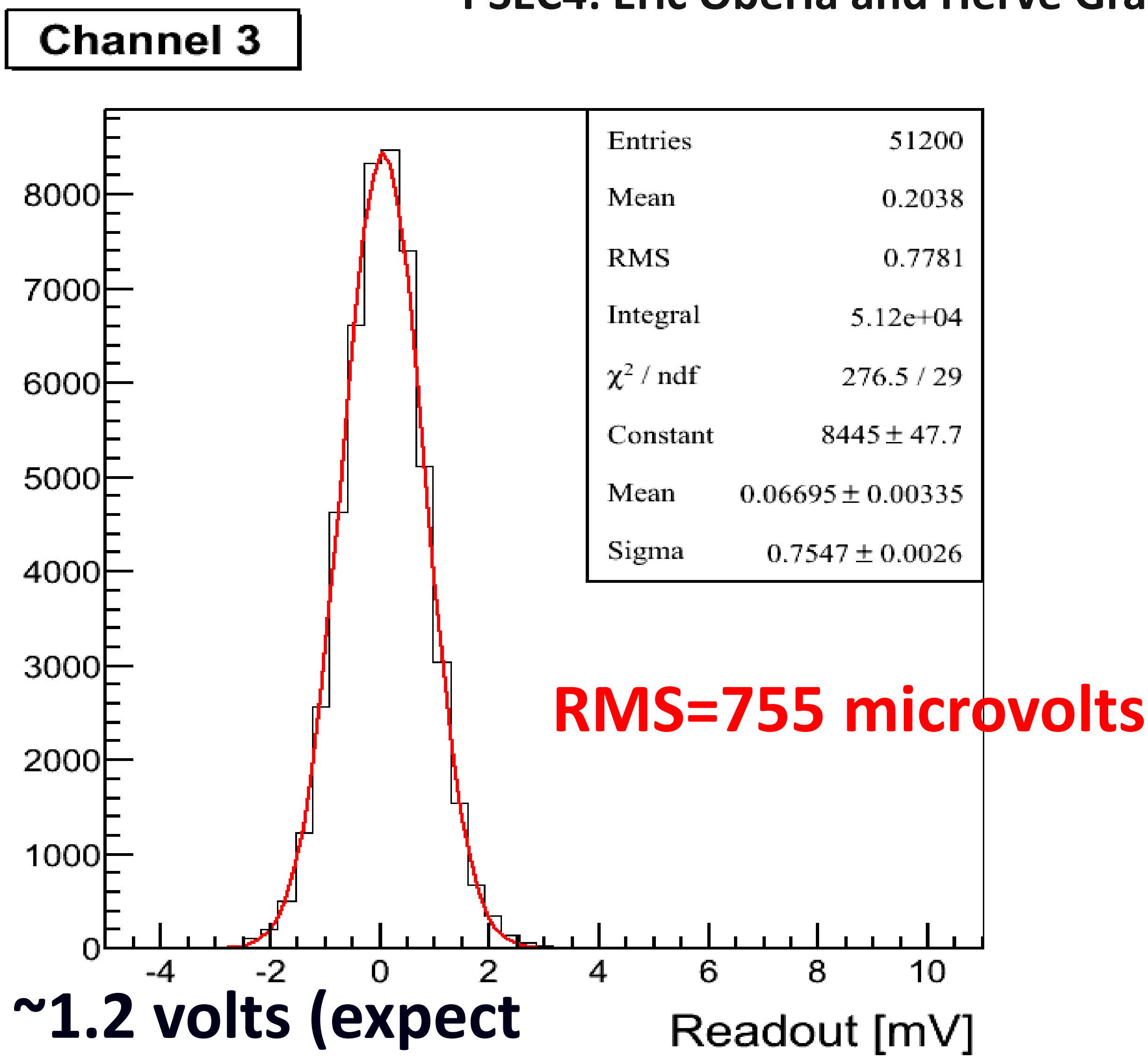
Eric Oberla, ANT11



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)

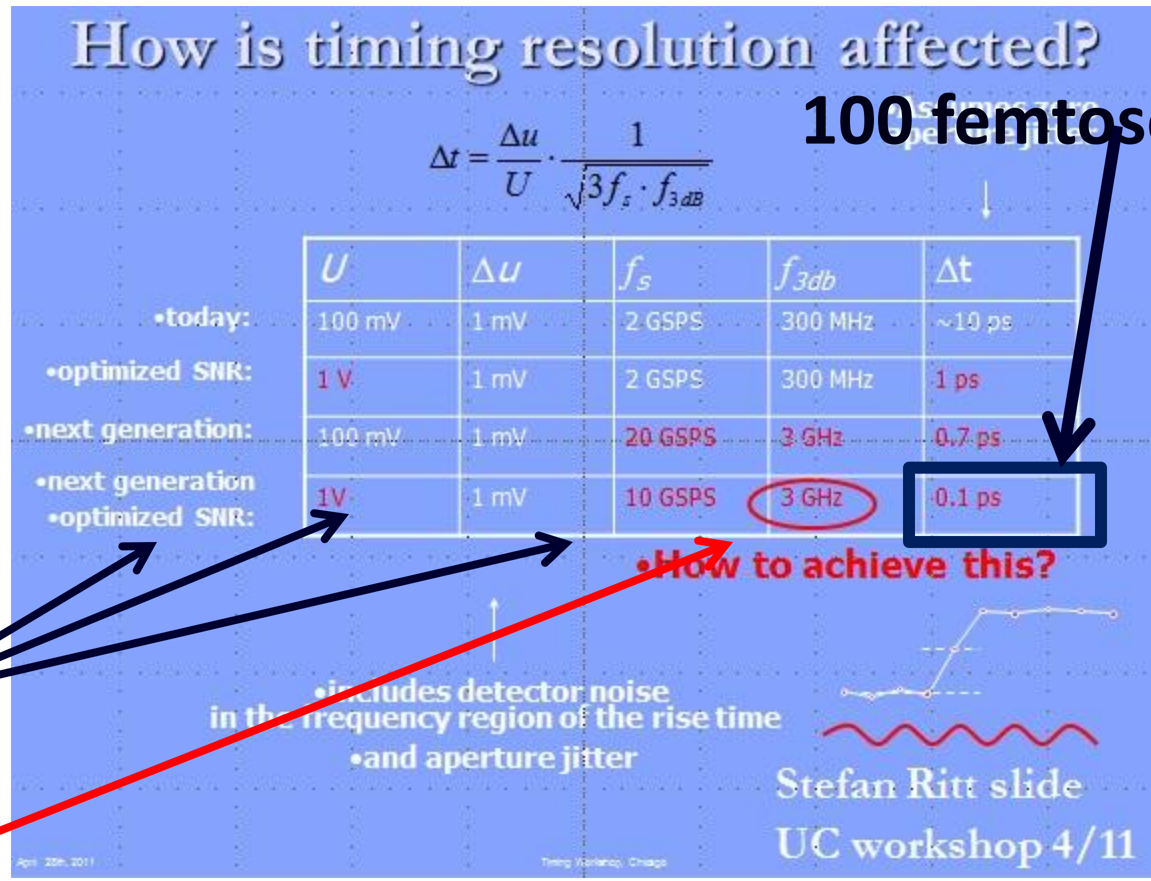
Eric Oberla, ANT11

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

(agrees with JF MC)

Stefan Ritt slide, doctored

100 femtosec



S/N, f_Z: DONE

abw: NOT YET

Challenges

- **Photocathode- vacuum transfer (vs not)**
- **Top seal- indium (vs frit, other, metal for neutrons)**
- **Getter, long-time vacuum (6.4 m^2/plate)**
- **Commercialization (risk abatement=$$)**
- **Talent- esp. career paths for young ones (anything that takes more than 3 yrs is a major problem)**
- **Identifying the first adopters**
- **Continued funding**

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

BACKUP SLIDES

Parallel Efforts on Specific Applications

Explicit strategy for staying on task-
Multiple parallel cooperative efforts

PET
(UC/BSD, UCB, Lyon)

Collider
(UC, ANL,Saclay.

LAPD Detector Development
ANL,Arradiance,Chicago,Fermilab, Hawaii,Muons,Inc,SLAC,SSL/UCB, UIUC, Wash. U
Drawing Not To Scale (!)

Muon Cooling
Muons,Inc
(SBIR)

K->πνν
JPARC

Neutrinos
(Matt, Mayly, Bob, John, ..; Zelimir)

Non-proliferation
LLNL,ANL,UC

Mass Spec
Andy Davis, Mike Pellin, Eric Oberla

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

The unexplained structure of basic building blocks-e.g. quarks

The up and down quarks are light (few MeV), but one can trace the others by measuring the mass of the particles containing them. Different models of the forces and symmetries predict different processes that are distinguishable by identifying the quarks. Hence my own interest.

Q=2/3

Q=-1/3

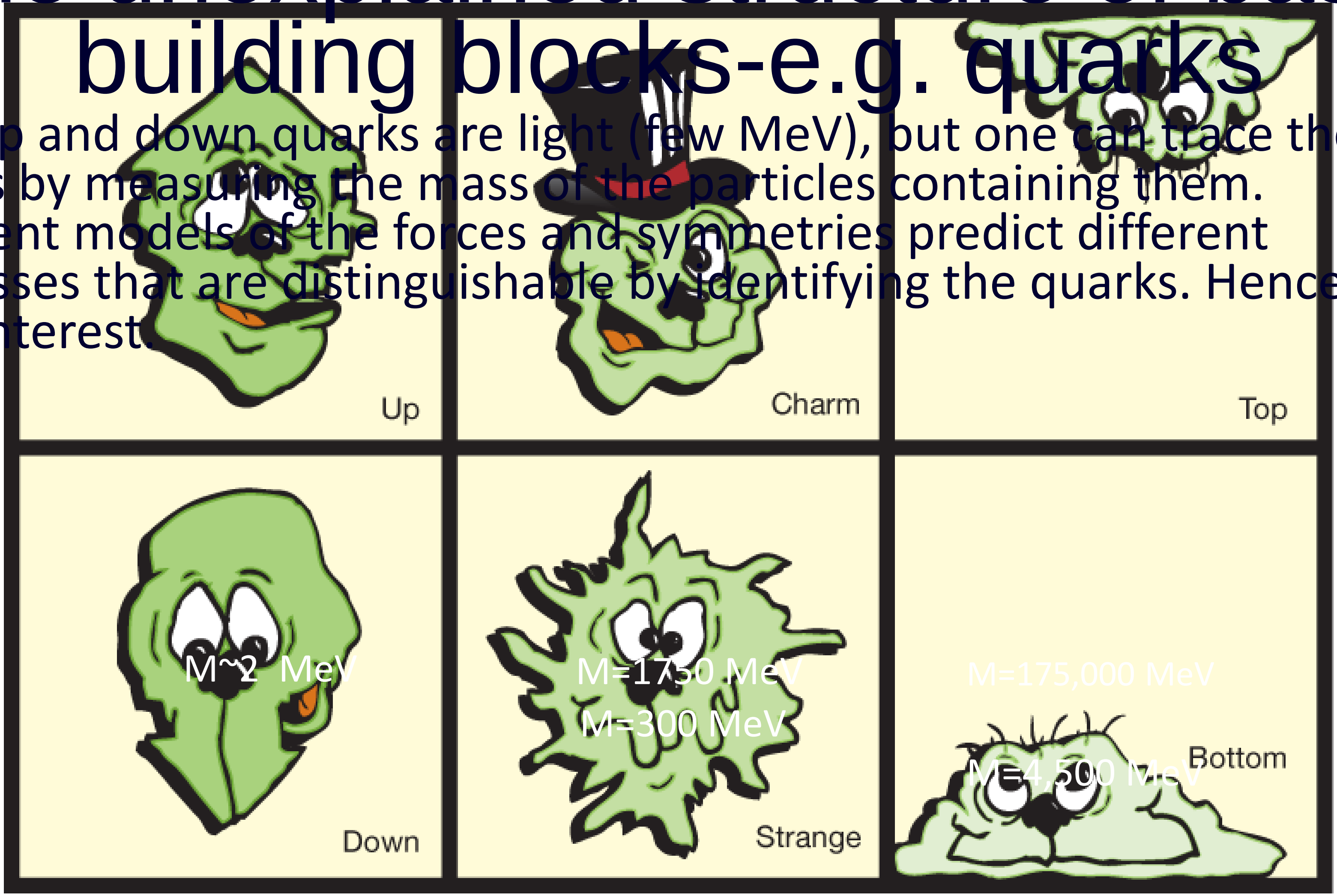


fig.1 **Quarks**

Nico Berry (nicoberry.com)

ALD &Integration tests at ANL

Argonne Atomic Layer Deposition and Test Facilities

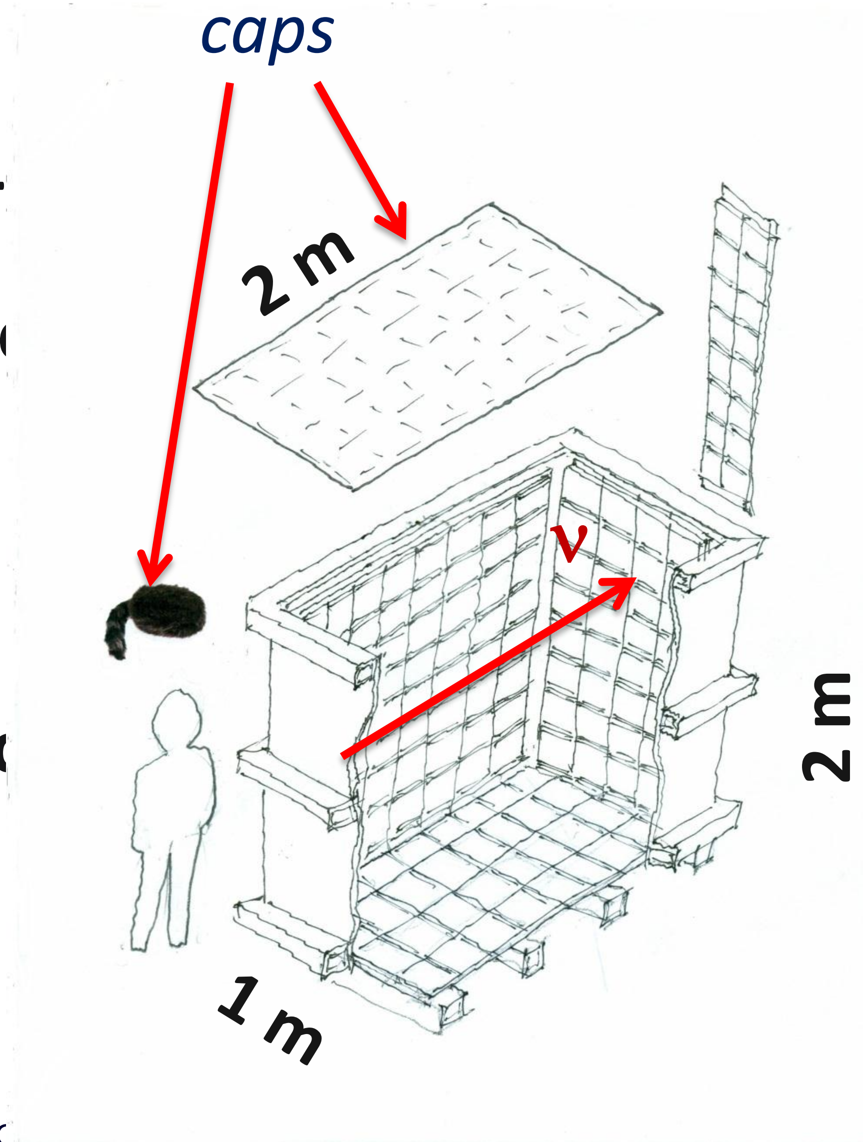
- In situ measurements of R (Anil)
- Femto-second laser time/position measurements (Matt, Bernhard, Razib, Sasha)
- 33 mm development program
- 8" anode injection measurements

Anil Mani and Bob Wagner

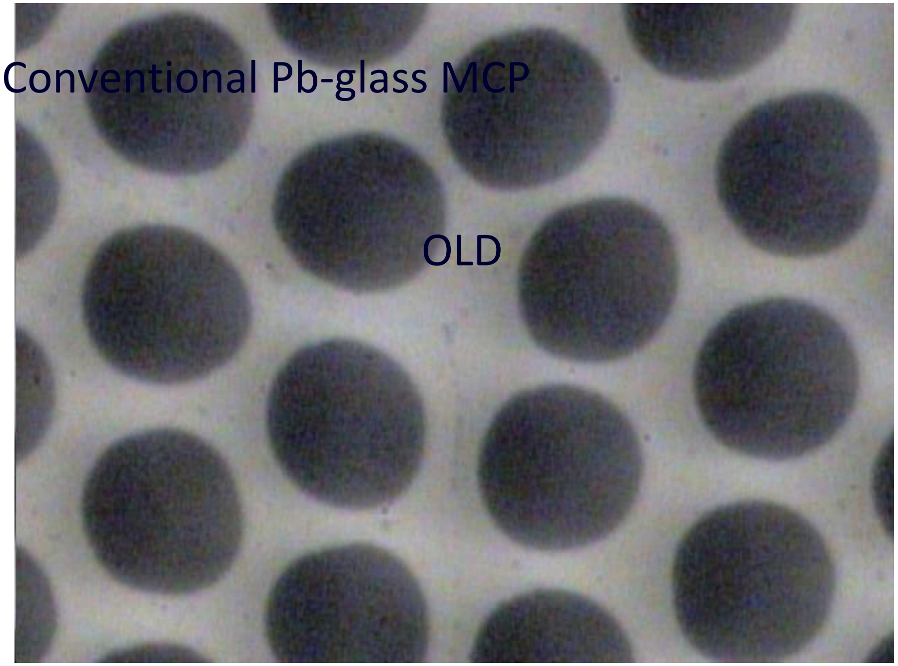
Razib Obaid and Matt Wetstein

Daniel Boone

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



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**

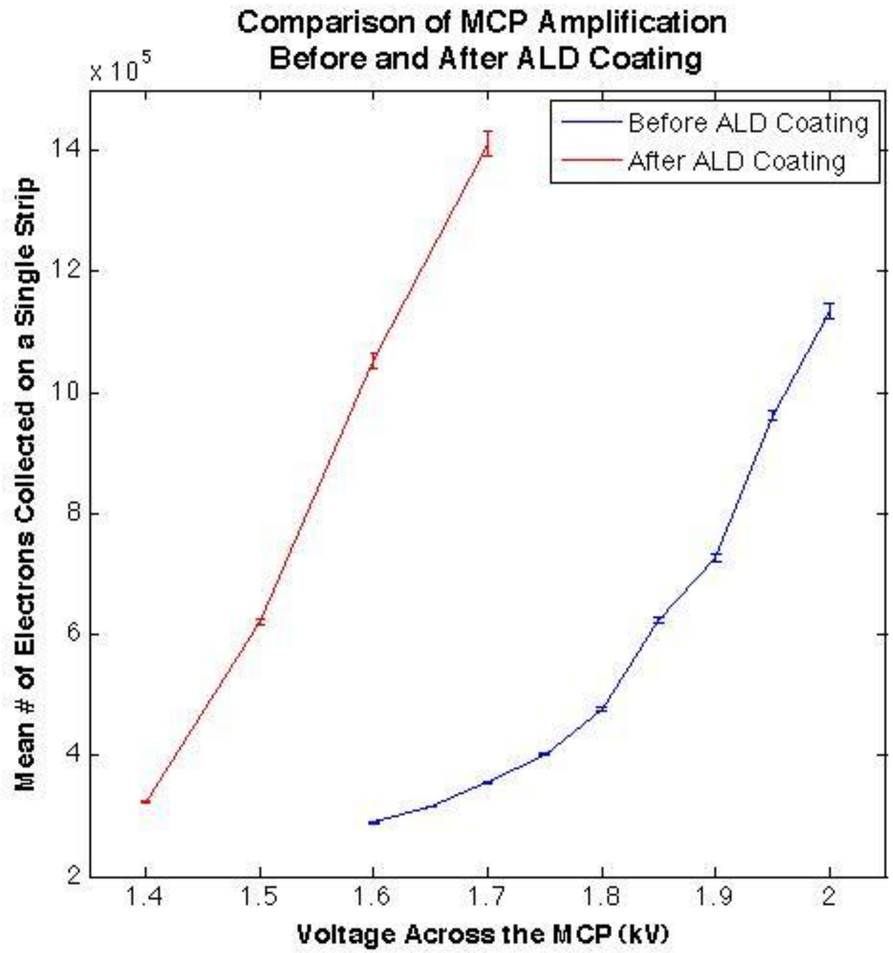
Separate the three functions:

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

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

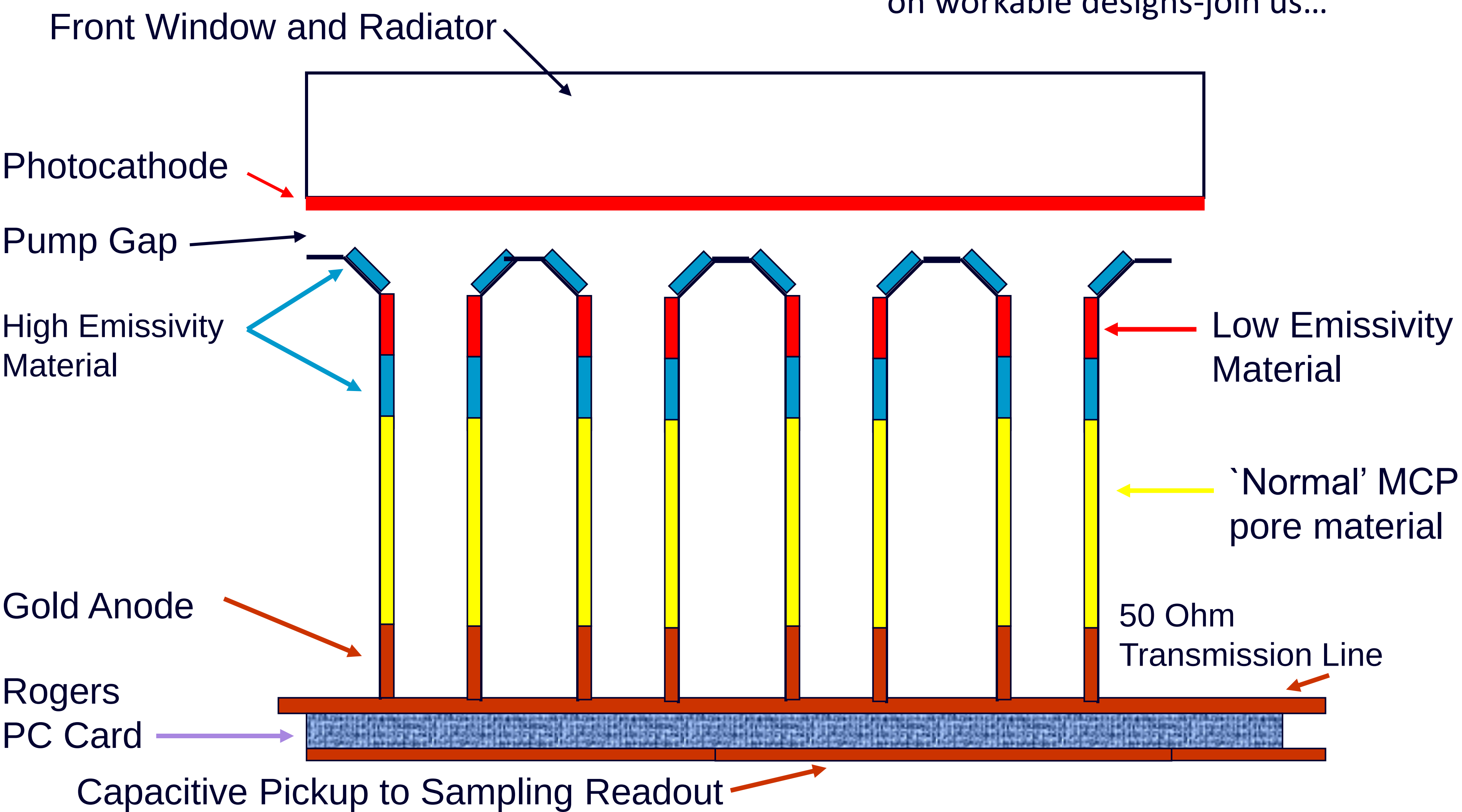
(very)

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

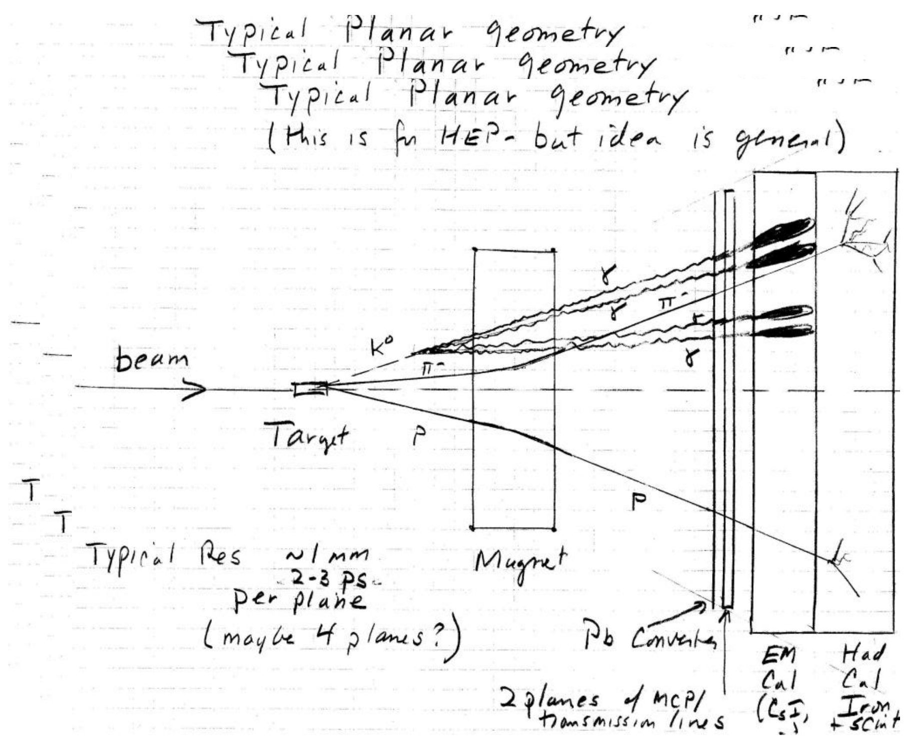
(Bernhard Adams, Matthieu Cholet, and Matt Wetstein)

Psec Large-area Micro-Channel Plate Panel (MCPP) LDRD proposal to ANL (with Mike Pellin/MSD)

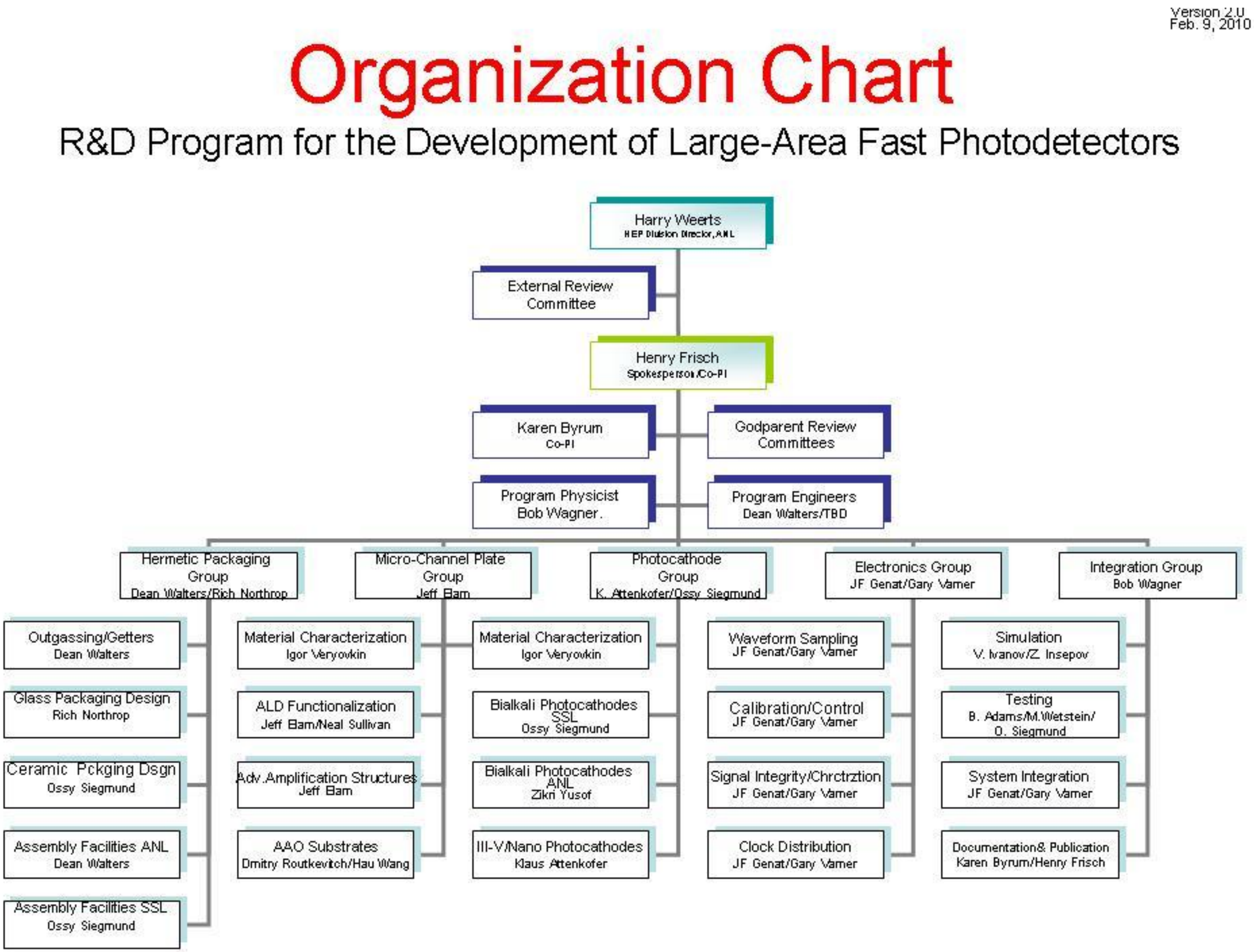
N.B.- this is a `cartoon'- working on workable designs-join us…



K_L to pizero nu-nubar



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

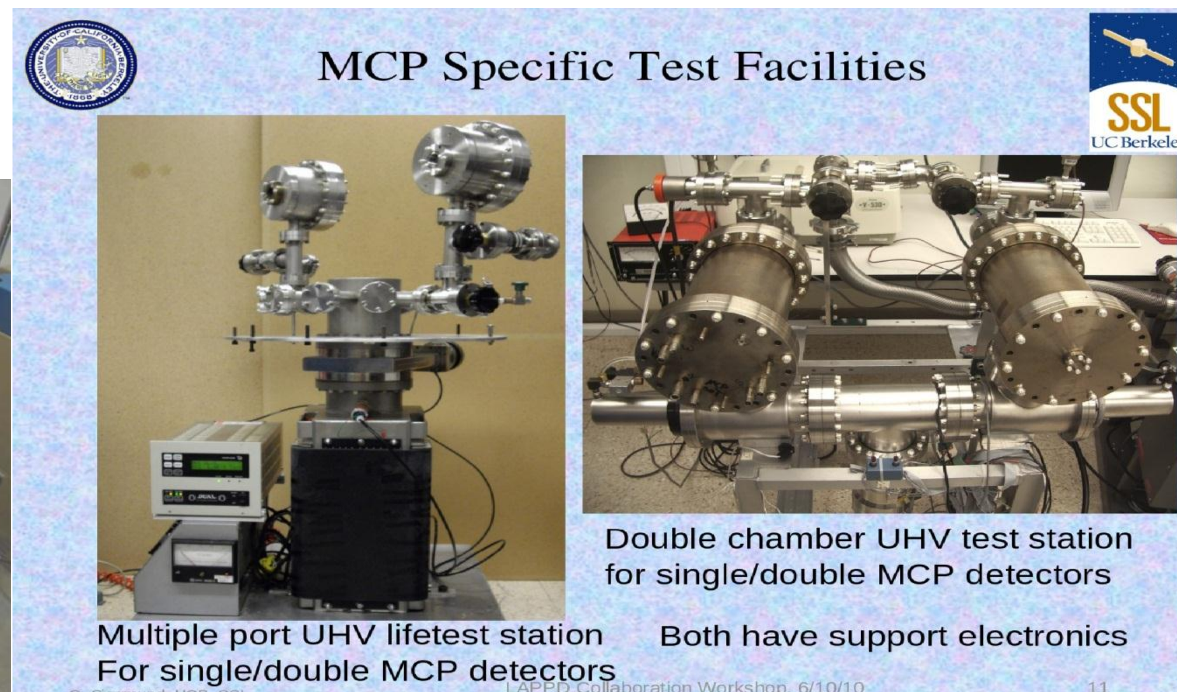
Anil Mani and Bob Wagner

Razib Obaid and Matt Wetstein

Microchannel Plates-3

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

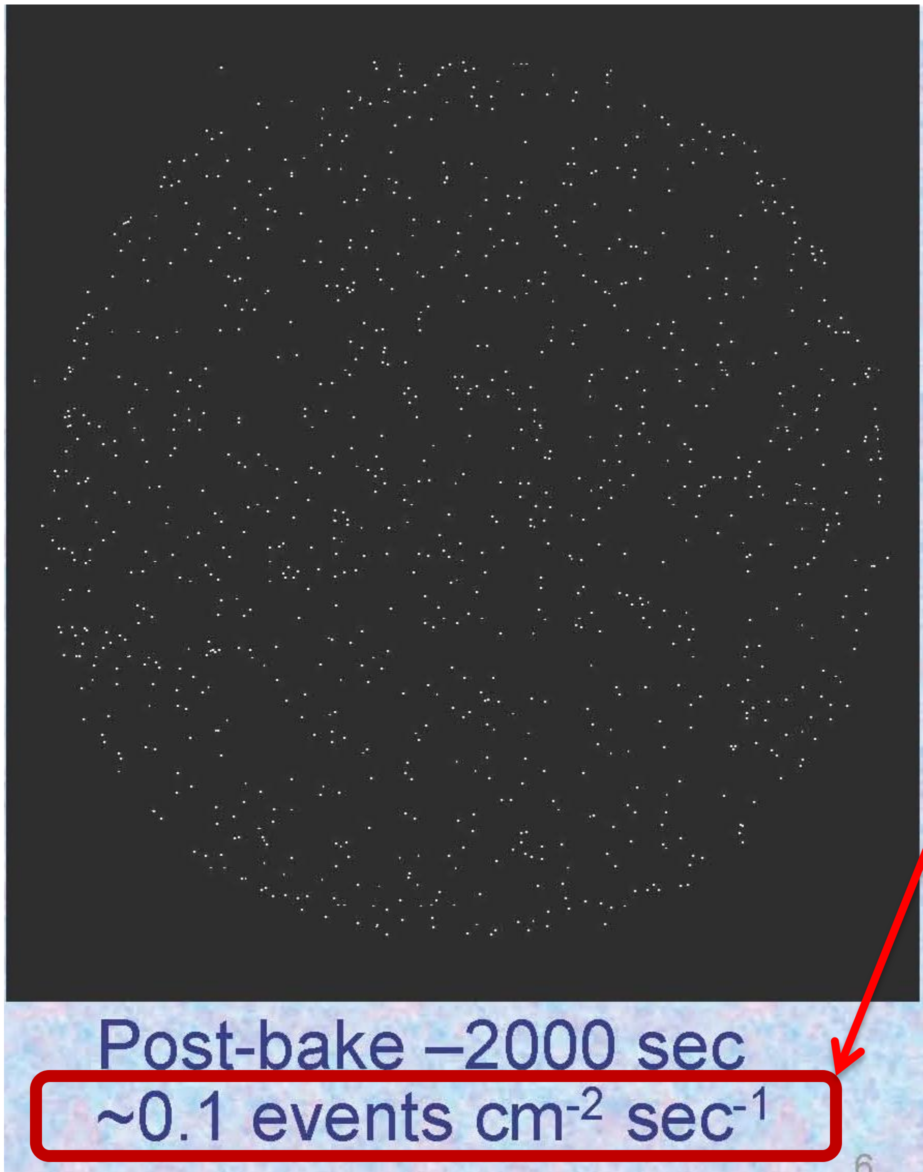
Ossy Siegmund, Jason McPhate, Sharon Jelenski, and Anton Tremsin-
Decades of experience
(some of us have decades of inexperience?)



Microchannel Plates-4b

Performance:

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

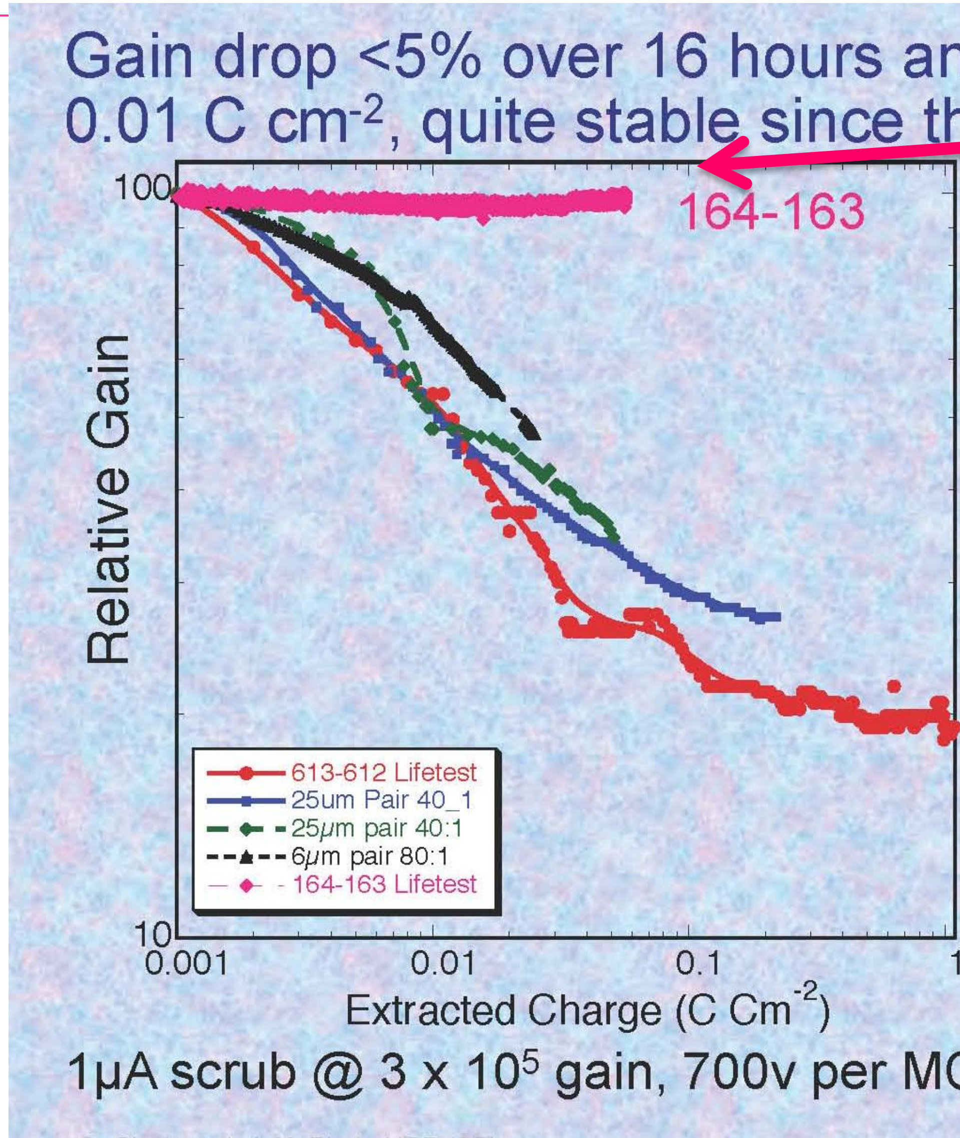


**Noise (bkgd rate).
<=0.1 counts/cm^2/sec;
factors of few >
cosmics (!)**

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

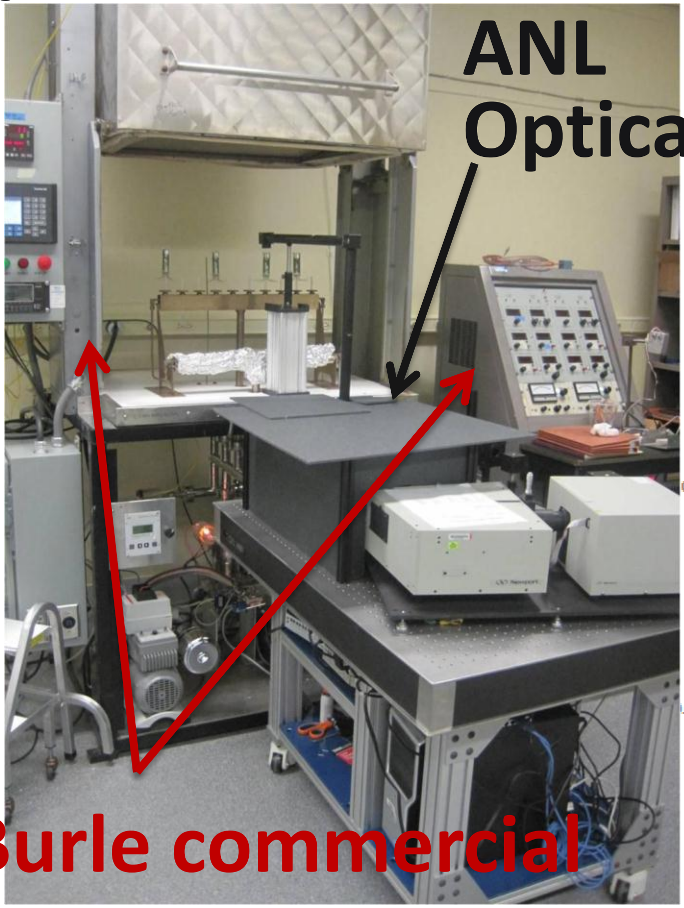
Photocathodes

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

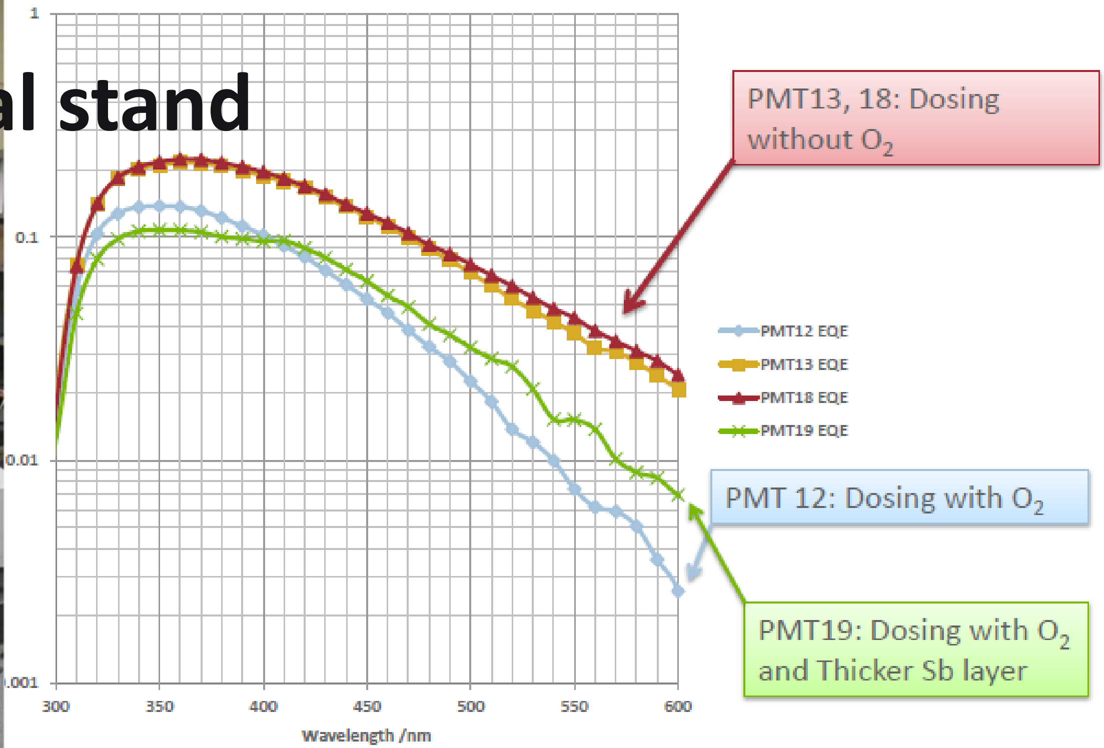
LAPPD goal- 20-25% QE, 8”-square

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

ANL Optical stand



Burle commercial equipment

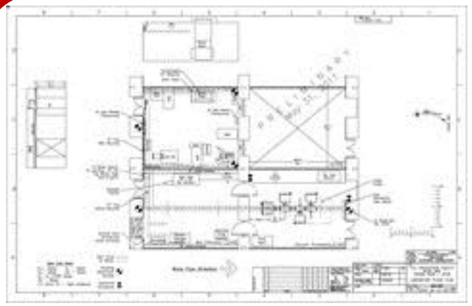


First cathodes made at ANL

Hermetic Packaging

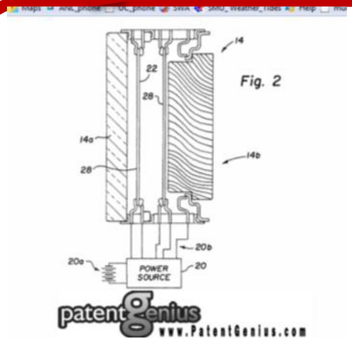
- **Top Seal and Photocathode- this year's priority**

3 parallel paths



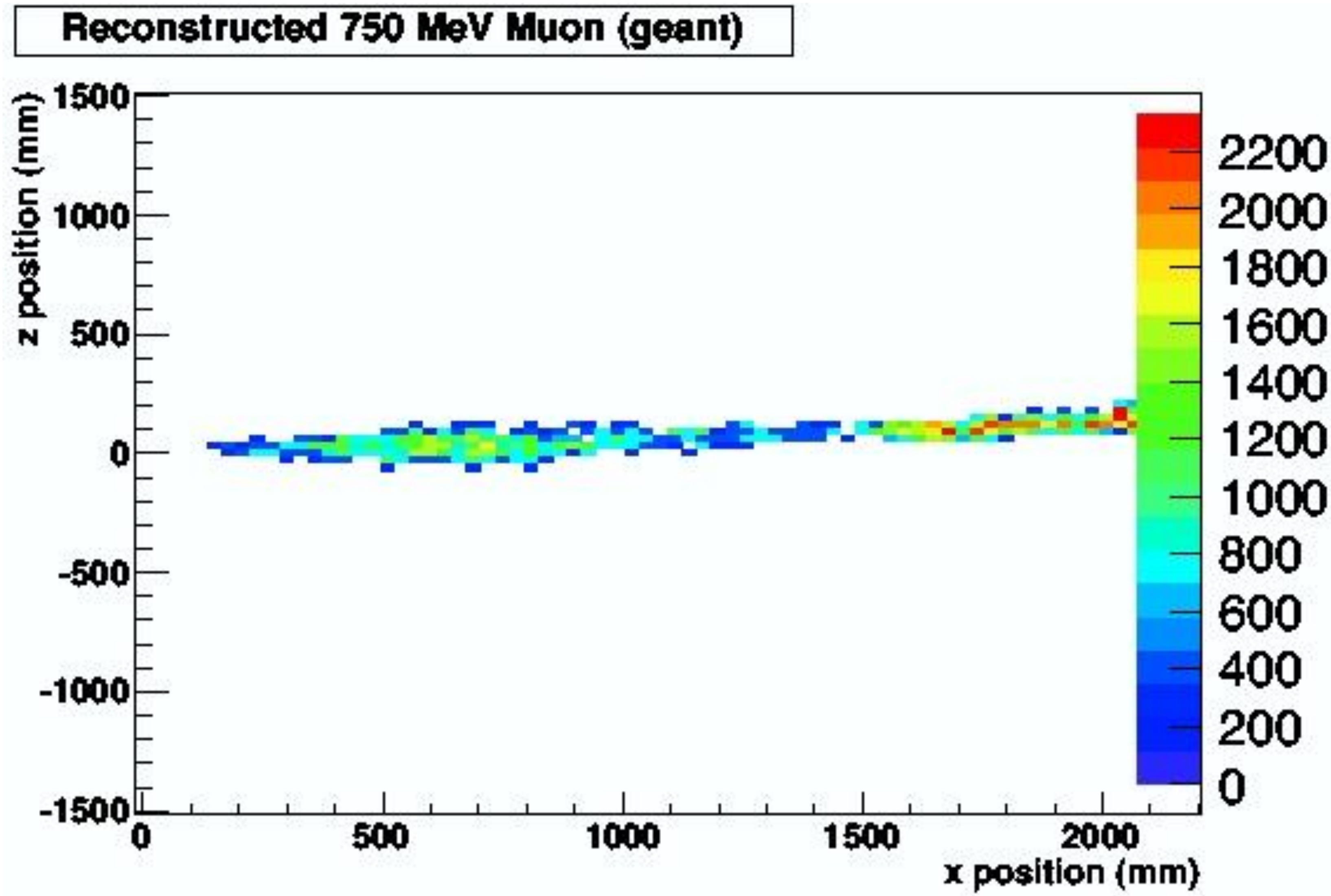
Tile Development Facility at ANL

Production Facility at SSL/UCB



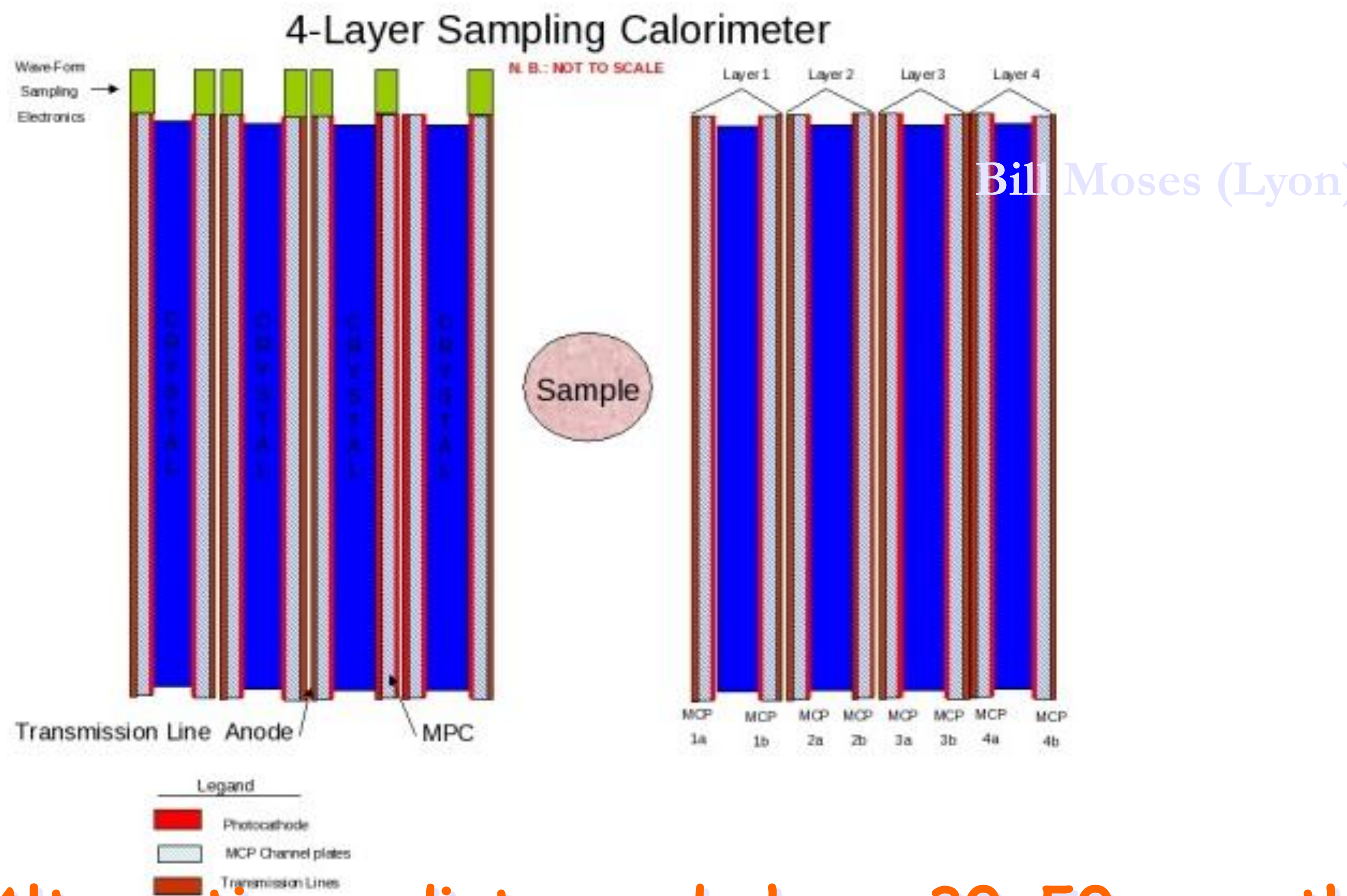
Commercial RFI for 100 tiles
(Have had one proposal for 7K-21K tiles/yr)

Works on GEANT events too



Matt Wetstein; ANL&UC

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

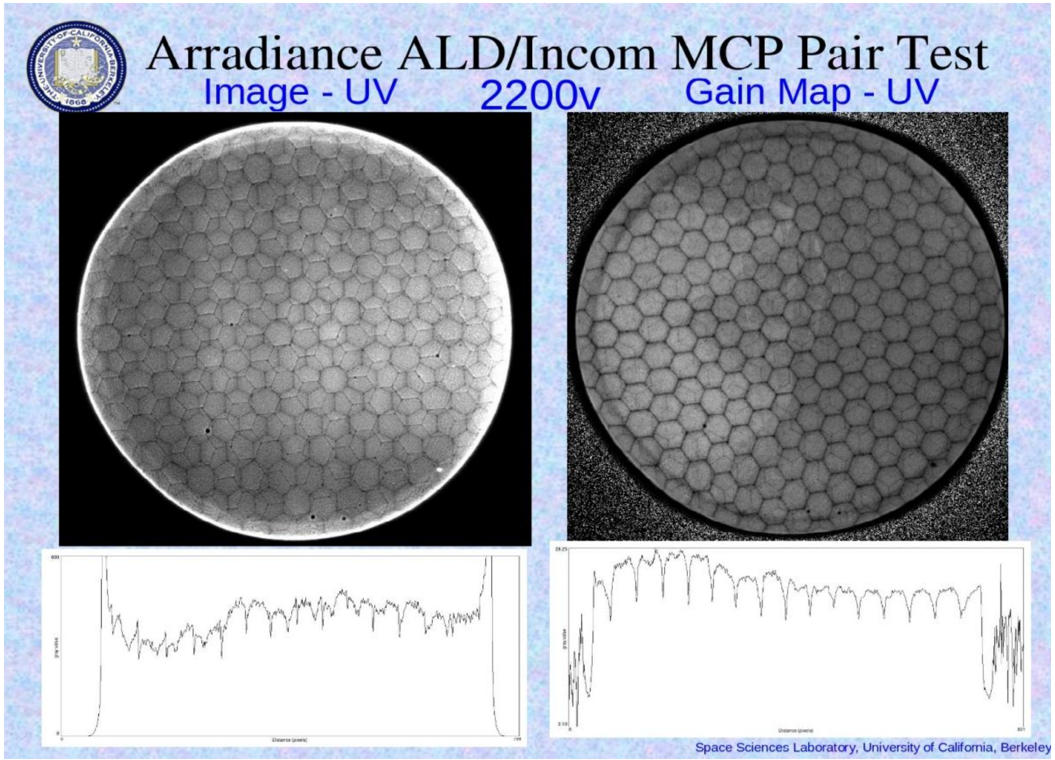


Proposal: Alternating radiator and cheap 30-50 psec thin planar mcp-pmt's on each side (needs simulation work)

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

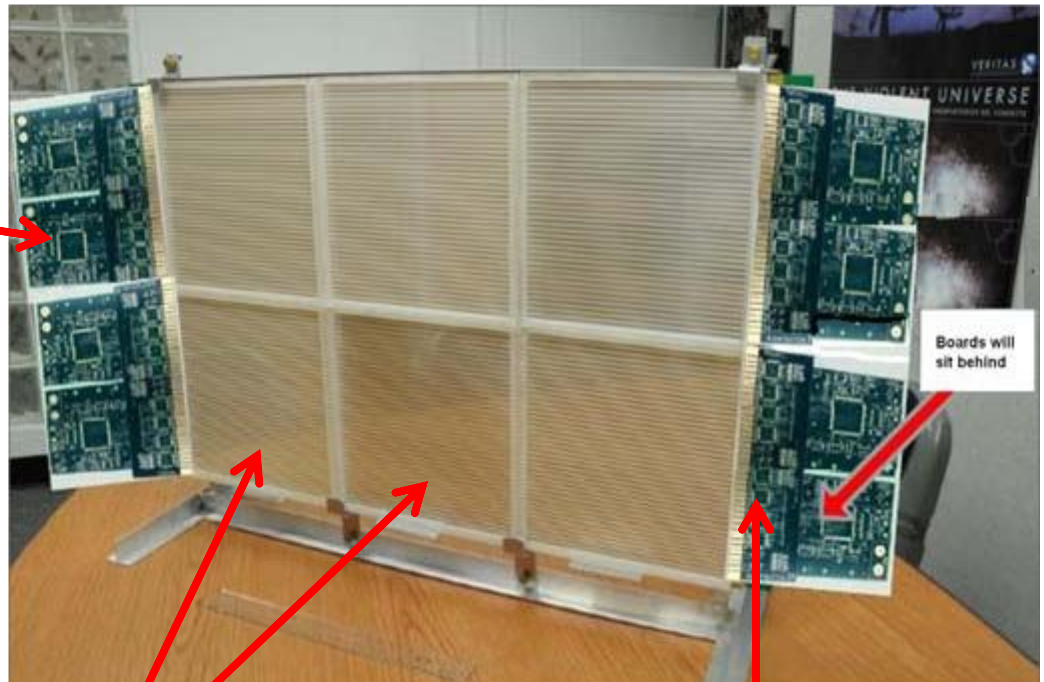
Several circuits have already been designed in the HEP community for fast pulse sampling, mainly to record photo-multipliers pulse shapes. As detailed in section I, fast timing requires higher sampling rates, but smaller dynamics ranges.

	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

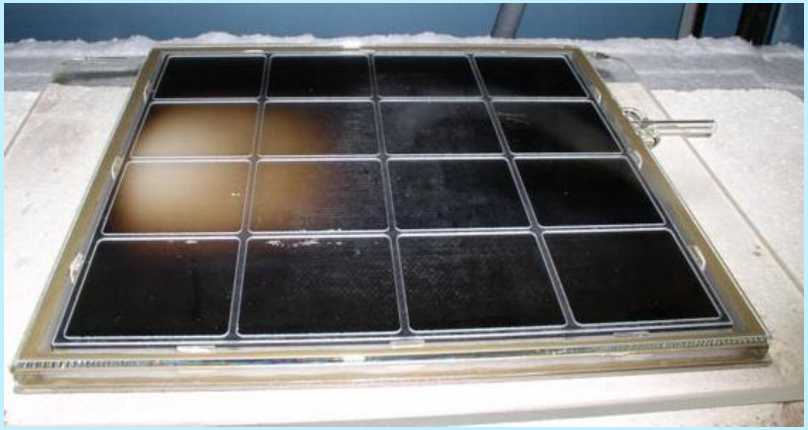
LAPPD Markets: Need. Applications. Benefit. and Competition

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?)**

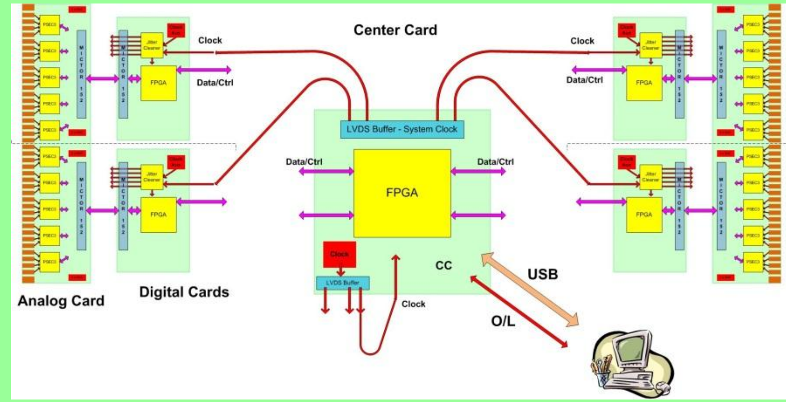
The 4 `Divisions' of glass LAPPD

Hermetic Packaging



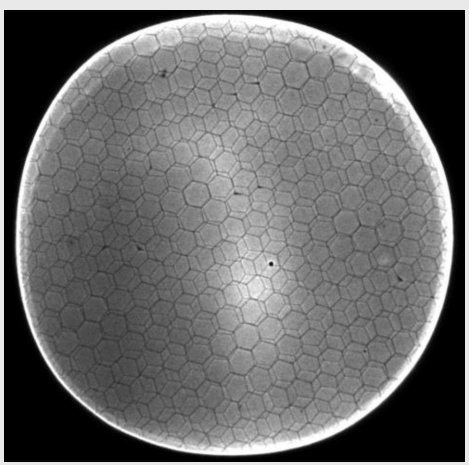
See Bob Wagner's talk

Electronics/Integration



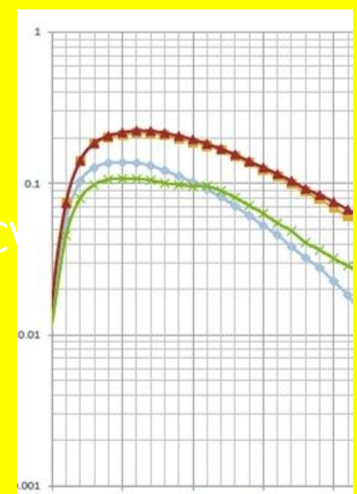
This talk

MicroChannel Plates



See Ossy's talk

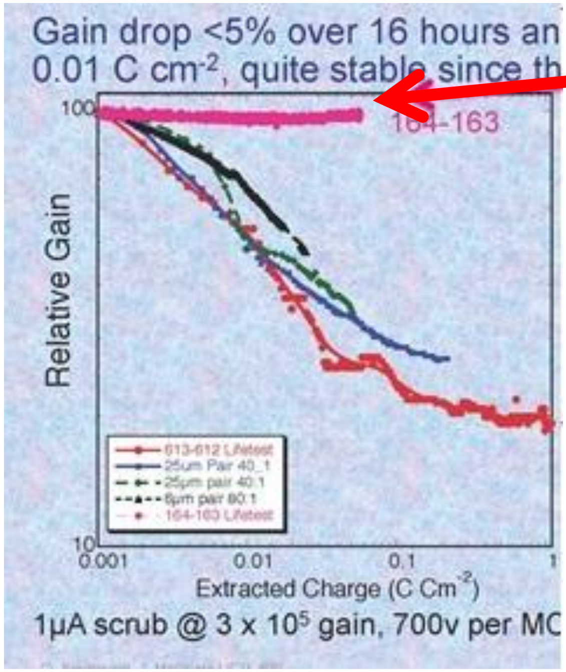
Photocathodes



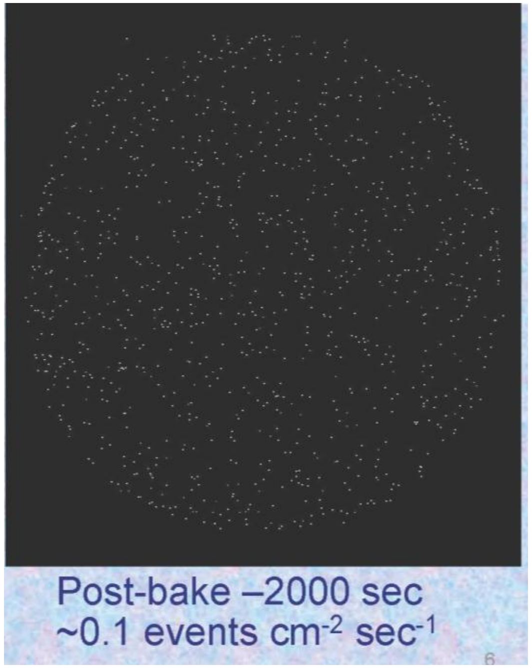
See (hear) Klaus Attenkofer's talk

LAPPD Performance

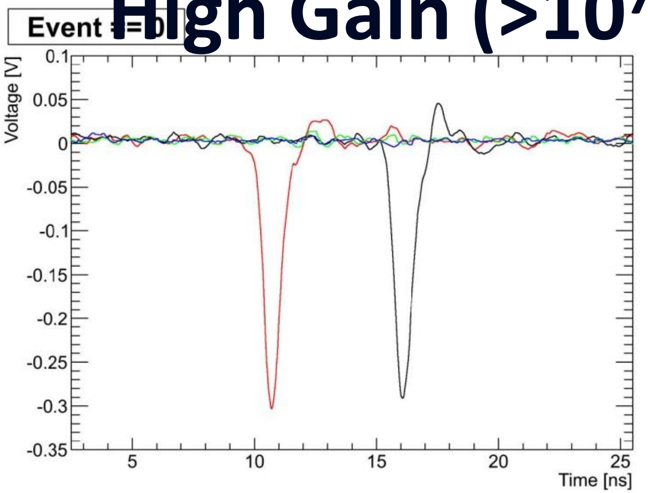
Fast Preconditioning



Low noise

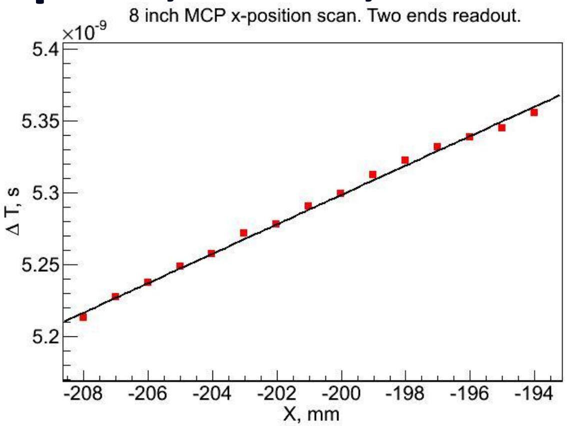


High Gain (>10^7)



400 micron resolution

(8" plate, anode, PSEC-4)

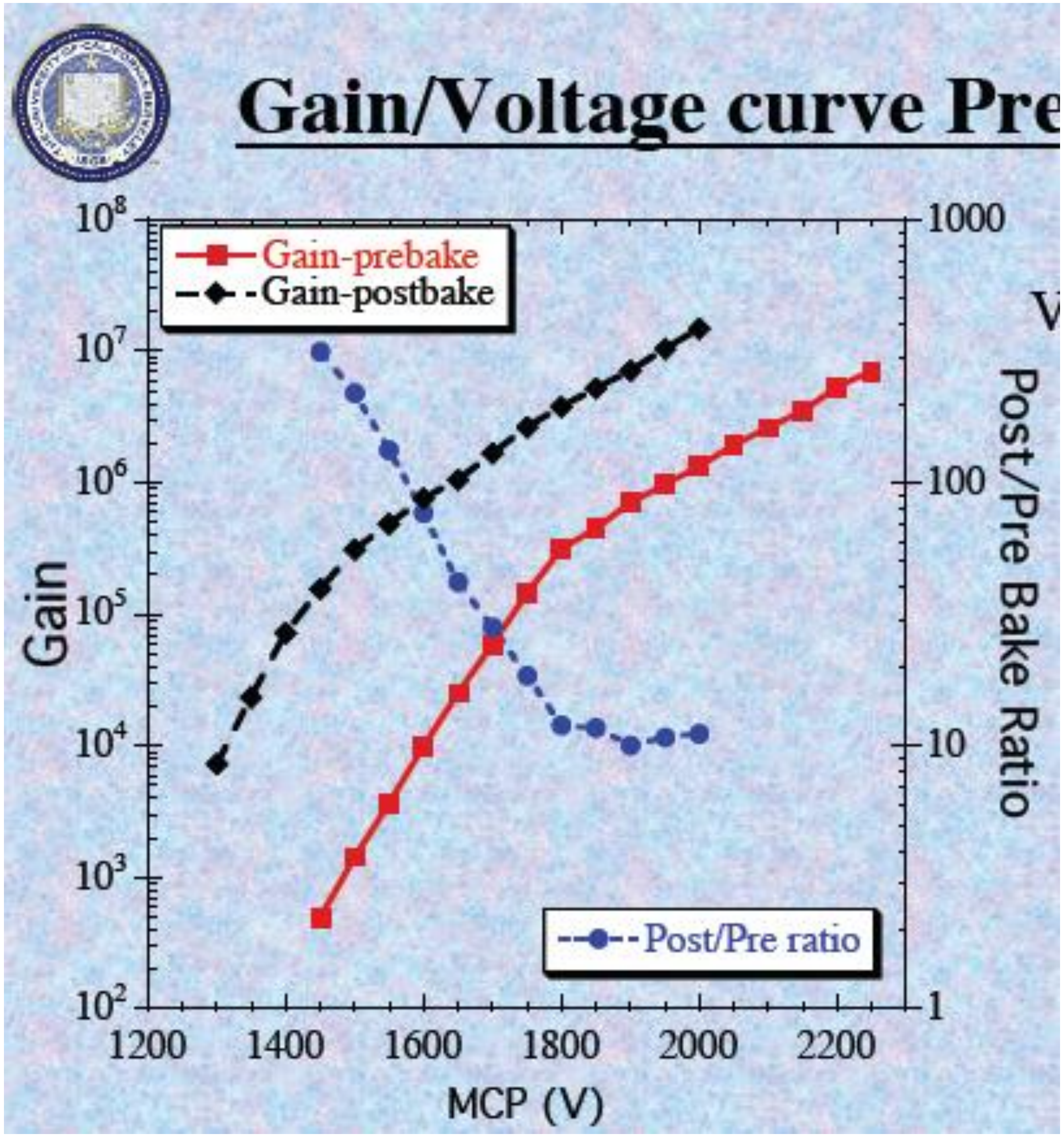


Signal- want large for S/N

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



SS

- SS