The Challenges and Applications of Sub-Psec Large-area Detectors

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Abstract

The precision of large-area spatial measurements has improved dramatically over the last 50 years due to the invention of silicon strip and pixel detectors. The ultimate time resolution of large-area devices is not yet known, but can be much better than the 1" (100 psec) resolution typical of large time-of-flight sensors or the 12" (1 nsec) typical of large neutrino detectors. I will discuss the status of the development of large-area micro-channel-plate-based photodetectors, for which the characteristic distance scale that determines the time resolution is 10's of microns. There is good reason to believe that time resolutions well below 1 psec are achievable with developments currently underway.

Outline

I. Quick Survey of Unique Applications
   a. The Optical Time Projection Chamber (OTPC)
   b. Directionality in Neutrinoless Double Beta Decay
   c. Low-Energy Antineutrino Reconstruction (Reactors)
   d. Pizero Vertexing in K^0->$\pi^0\nu\nu$ (e.g. KOTO at JPARC)
   e. Vertexing at High Luminosity at the LHC
   f. TOF in the Central Region at the LHC (BSM, PID)
   g. Medical Imaging (e.g. PET, Proton Therapy)

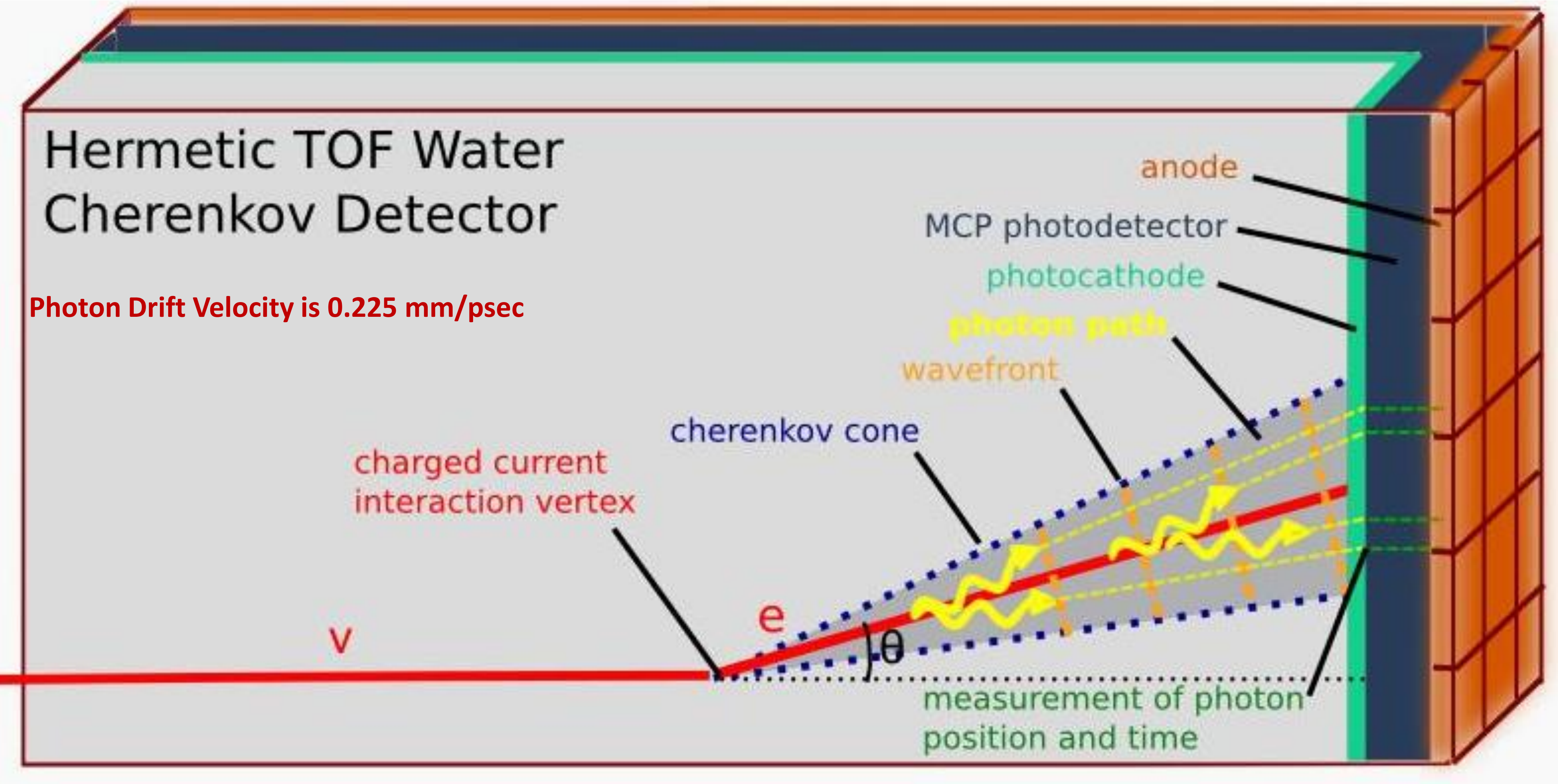
II. Basic Principles and the Limiting Factors

III. Some Details of an Example- the LAPPD `tile/tray'

IV. Some efforts towards 1-psec/sub-psec timing

The Optical Time Projection Chamber (OTPC)

- **Like a TPC but drift photons instead of electrons (no B needed)**
- **Exploits precise location and time for each detected photon**
- **Would allow track /vertex reconstruction in large liquid counters**

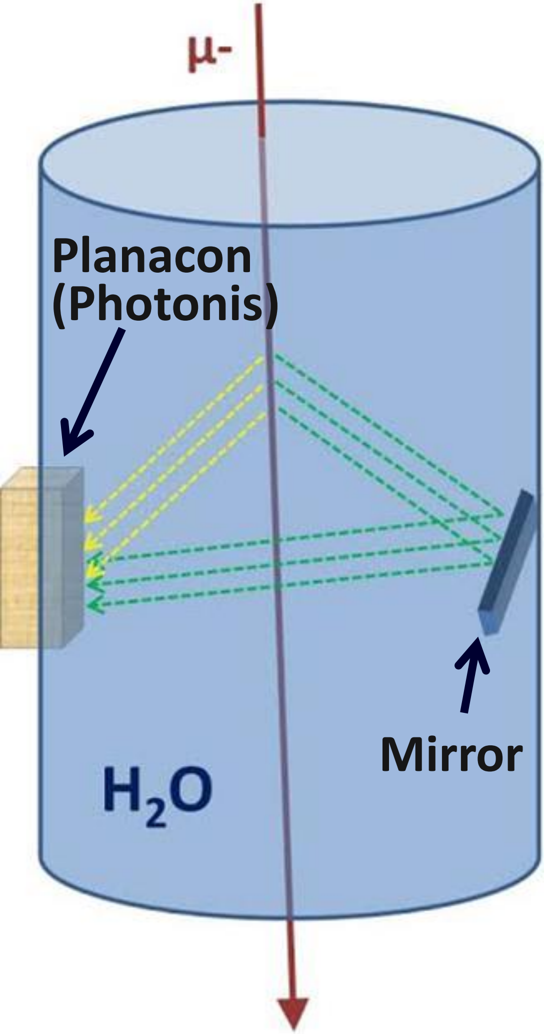


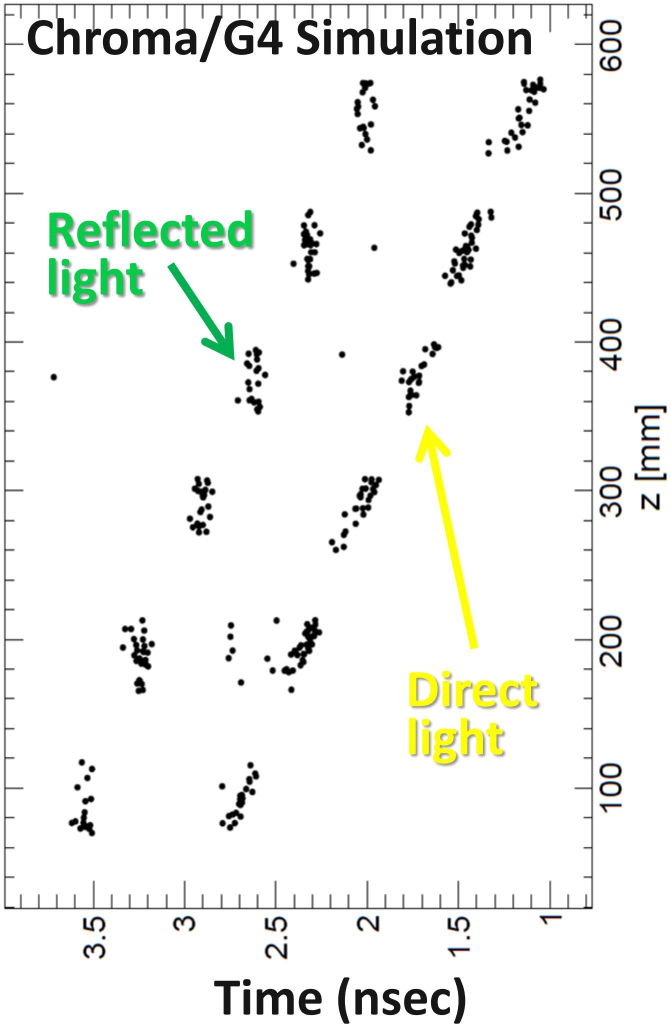
Photon Drift Velocity is 0.225 mm/psec

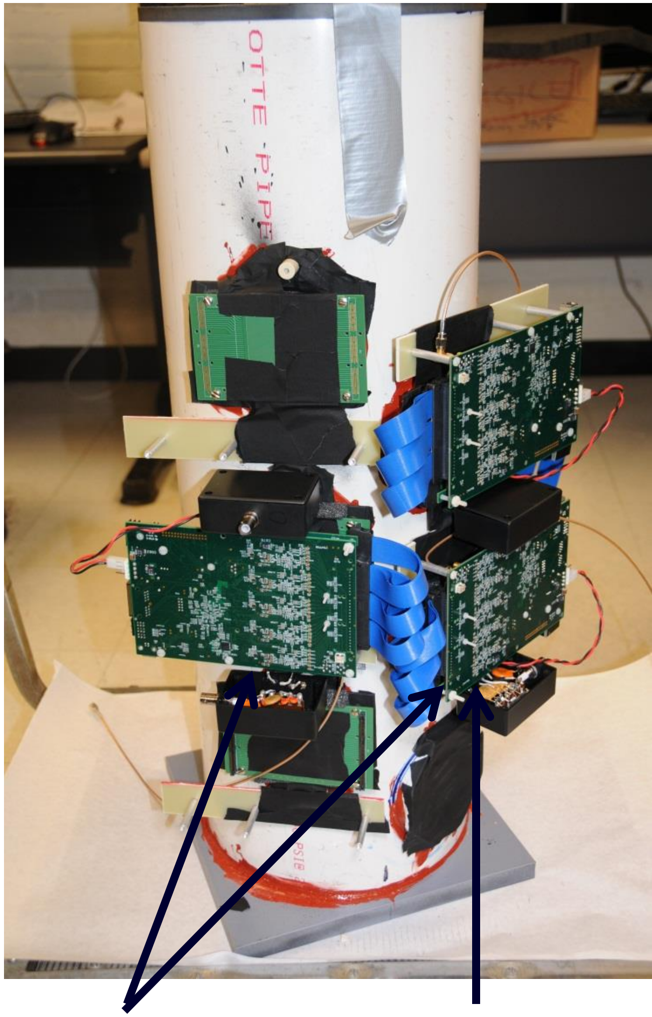
First suggestion of LAPPD’s for DUSEL and the name (OTPC) due to Howard Nicholson

The Optical Time Projection Chamber (OTPC)

- **Eric Oberla's thesis (see his talk)-** proof-of-principle 1D-OTPC
- Uses mirrors (yes!) to exploit time resolving to increase coverage





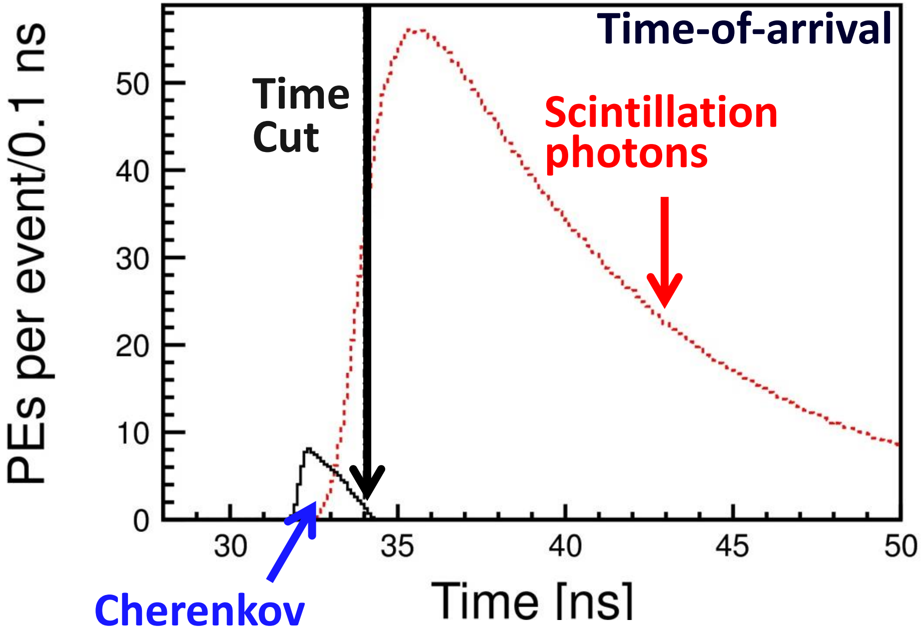


Planacons (Photonis)

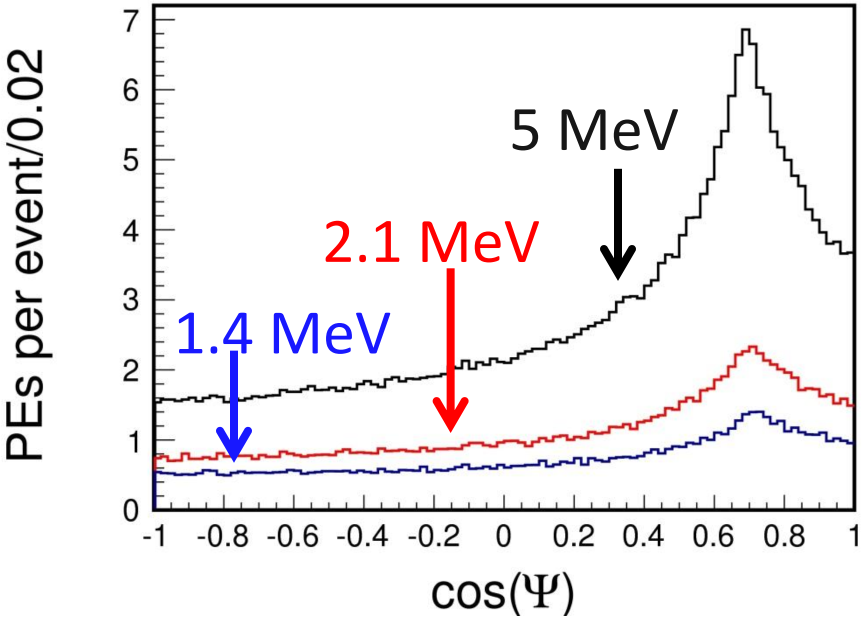
1-15 GS/sec 120-channel PSEC4 readout

Measuring Directionality in Neutrinoless Double-β Decay

- **Signal has 2 electrons; dominant (non-intrinsic) backgrounds have 1**
- **Cherenkov light retains (some) directionality**
- **Cherenkov light arrives before scintillation, as it's redder (really)**
- **Fast-timing allows selection on the early photons**



Cherenkov photons from center of 6.5m-radius sphere: TTS=100 psec

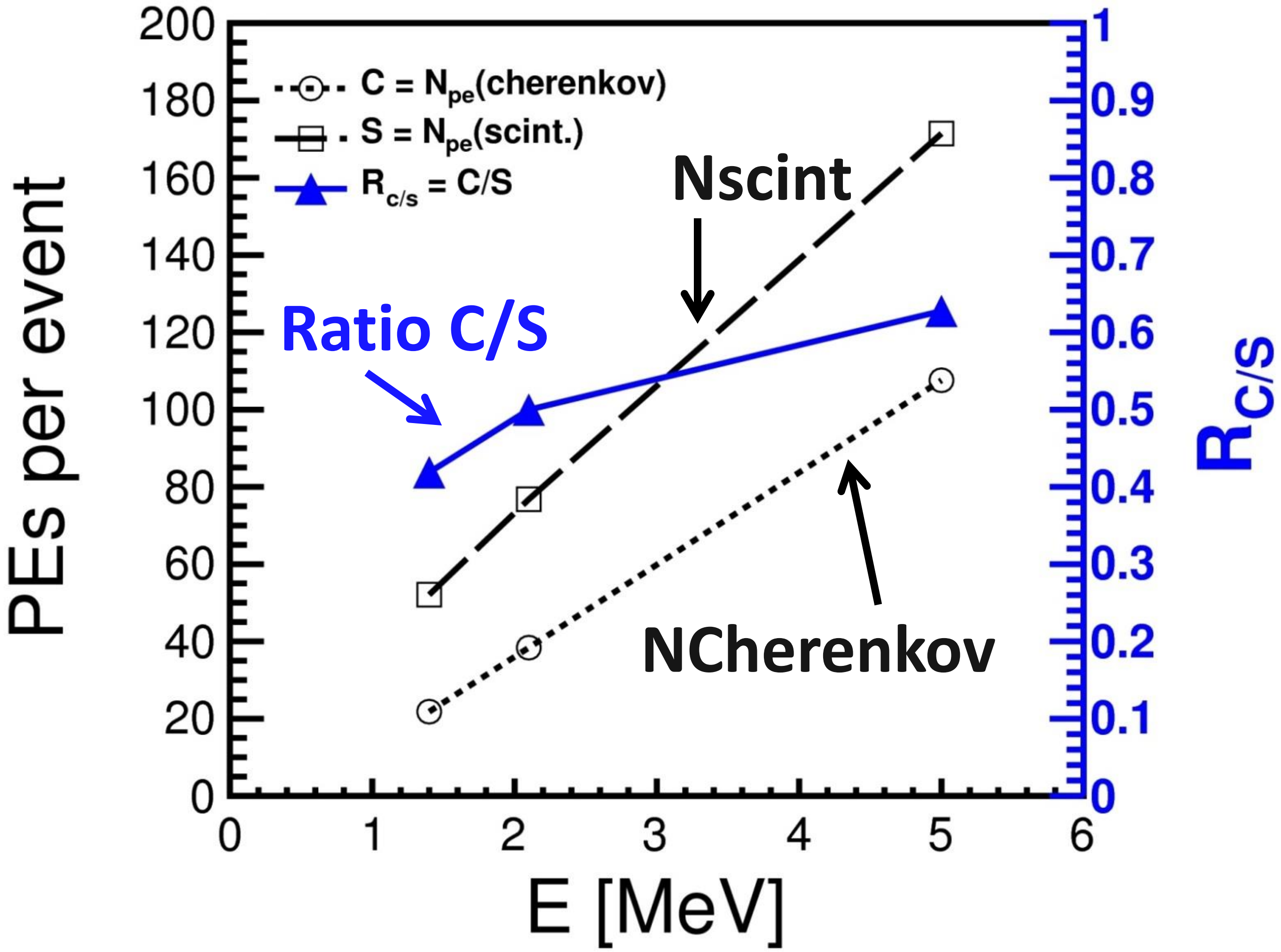


Cosine of angle between the photoelectron hit and the original electron direction after the 34 ns cut. Both Cherenkov and scintillation light are included. Note the peak at the Cherenkov angle.

Christof Aberle, Andrey Elagin, Matt Wetstein, Lindley Winslow, HJF; arXiv:1307.5813 (TBP JINST)

(see Andre Elagin's talk)

Number of PhotoElectrons After Time Cut

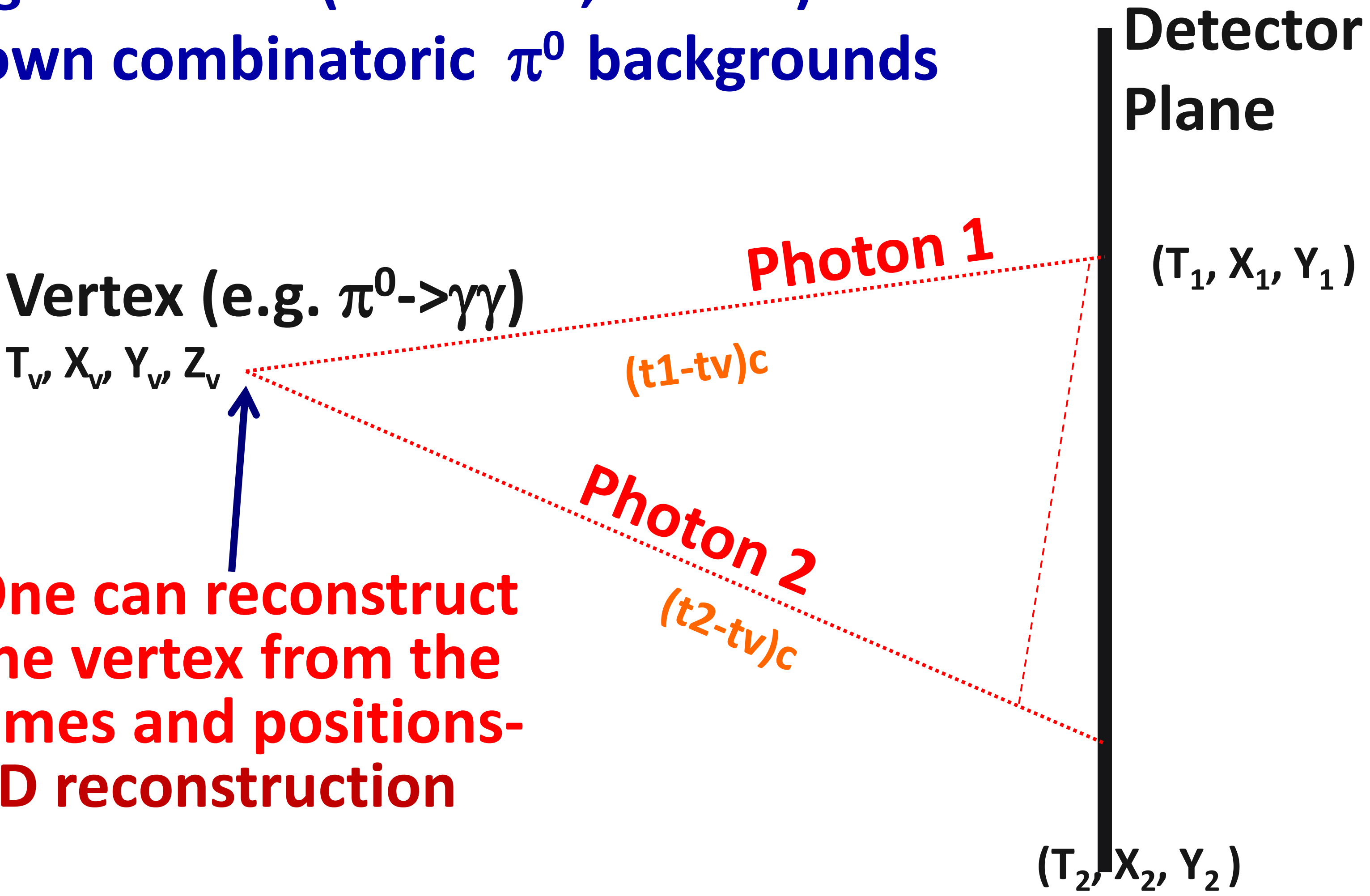


The expected number of photo-electrons (PE) from Cherenkov (C) and Scintillation (S) light after the 34 nsec time cut, for electron energies of 1.4, 2.1, and 5 MeV, generated at the center of the 6.5m-radius liquid scintillator detector. The right-hand ordinate is the ratio C/S.

Christof Aberle, Andrey Elagin, Matt Wetstein, Lindley Winslow, HJF; arXiv:1307.5813 (TBP JINST)

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

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



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

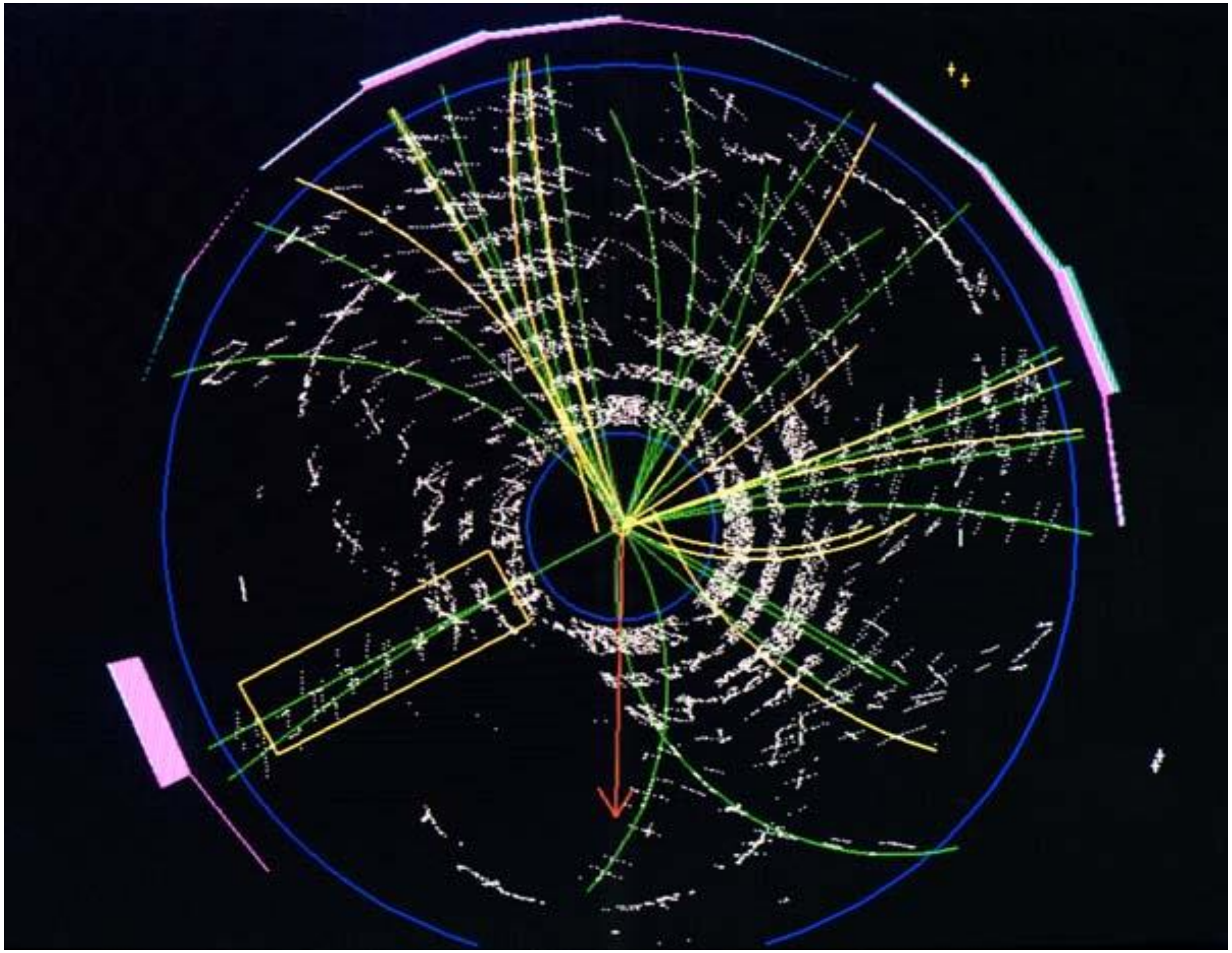
N.B. Photon Drift Velocity is 0.298 mm/psec

Colliders:

Goals: 1) identify the quark content of charged particles

2) separate vertices

3) vertex photons



CDF top quark event

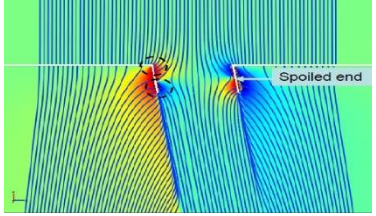
See Snowmass white paper

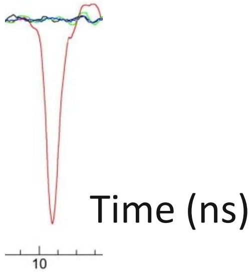
A Brief Tour of MCP-based Fast Timing

What determines the time resolution?

A. Pulse Generation – from photon to fast current pulse

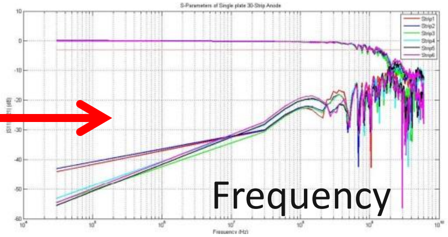
Transit-Time Spread (TTS) is determined by geometry, fields, and secondary-emission





B. Getting the fast pulse to the time-measuring place

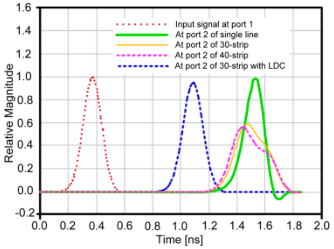
80 million pores need to be reduced to a small # (e.g. 30) of electronics channels while preserving the Analog BandWidth(ABW)

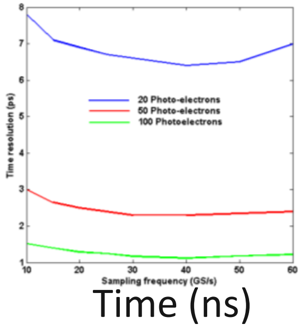


C. Determining `the time' of the pulse

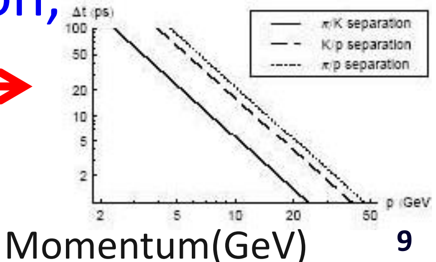
Problems are Noise and Pulse Shape (no noise, no problem, if all shapes the same)

Waveform sampling, Constant-Fraction-Disc, Single Threshold Disc., Multiple Threshold..





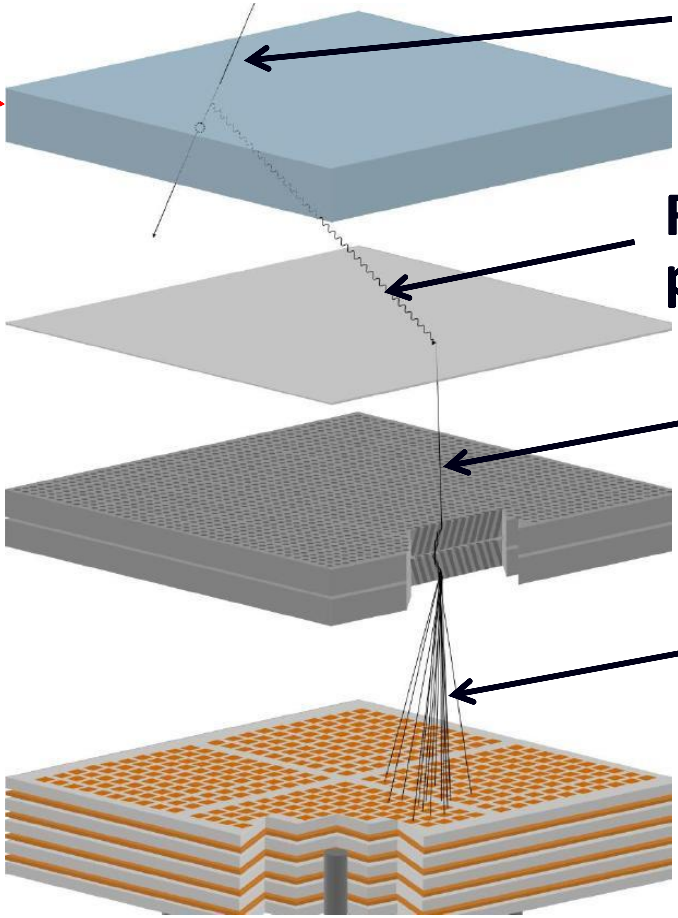
D. System Considerations: Clock Distribution, Calibration,



How Does it Work?

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



Incoming charged particle

window

Radiated Cherenkov photon

Photocathode on inside of window

Photo-electron from cathode

Pair of micro-channel plates

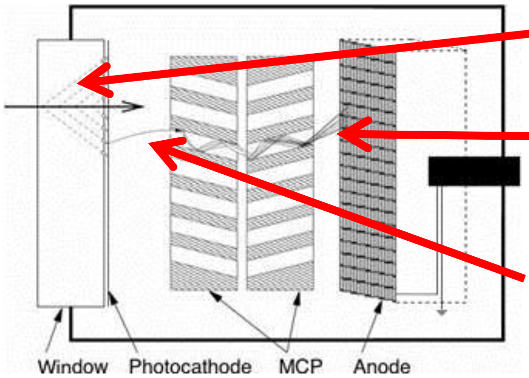
Output pulse of 10^7 electrons

RF strip-line anode (old-version- now we use microstrips)

Key parameters: Number of Photons and Transit-Time Spread

Pulse Generation – from photon to fast current pulse

A: Timing will depend on light source: Cherenkov light in 8mm radiator (window) gives ~50 PE’s; many applications are single photons



400 Cherenkov optical photons

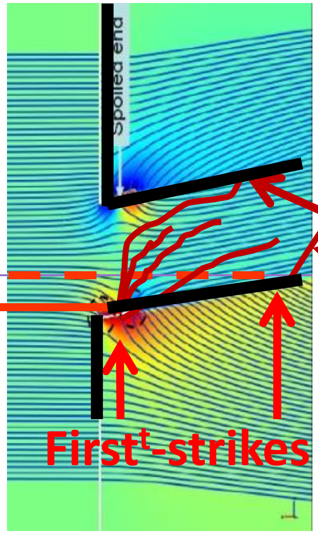
Incoming charged particle

10^6 to 10^8 electrons in current pulse

50 photo-electrons from cathode

B: Transit-Time Spread (TTS) depends on geometry, electric field, and first-strike secondary-emission coefficient;

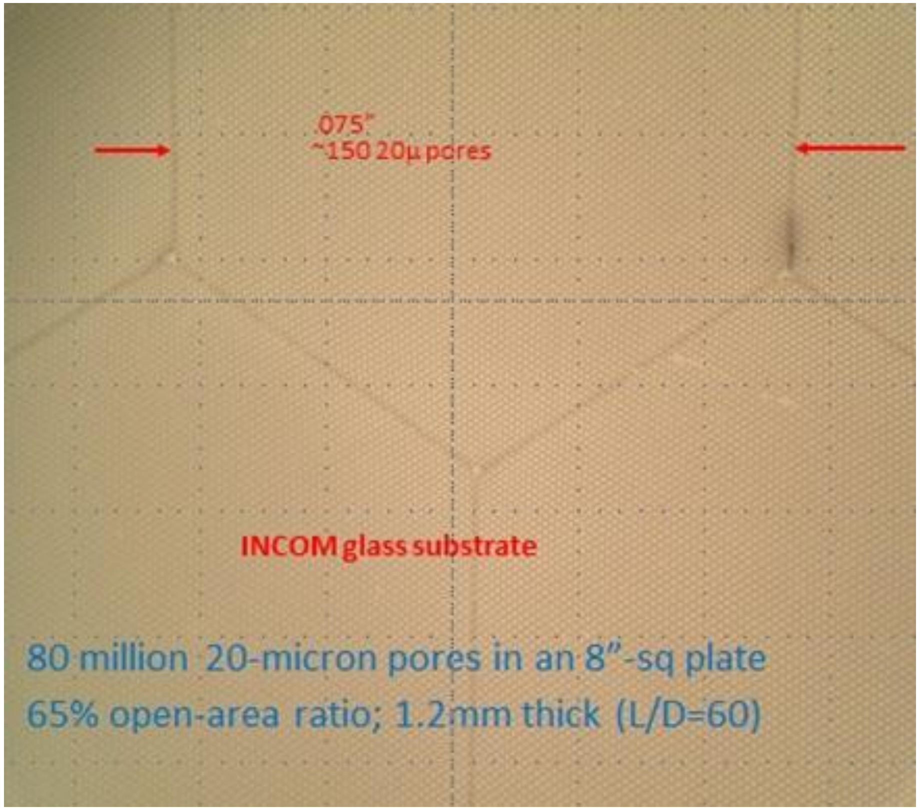
Picture of 1 pore
(currently L/D=60, 8^o)



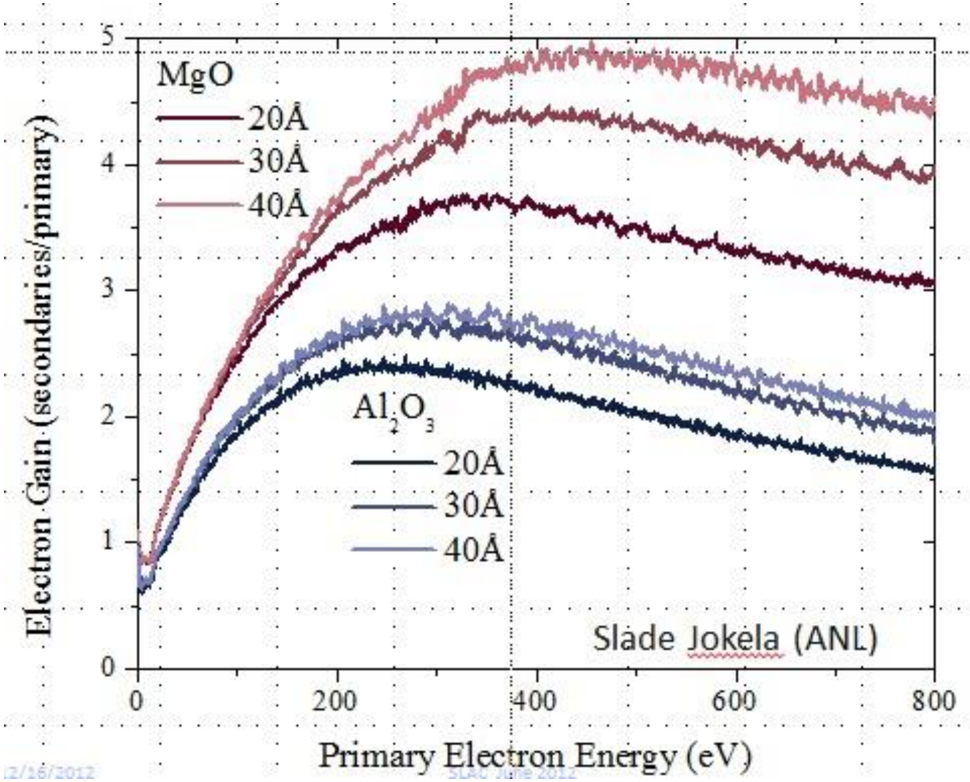
Incoming photo-electrons
From photocathode (only 1/pore)

secondary emission (SEY) electrons

`First-Strike' Parameters to play with



Pore size and angle



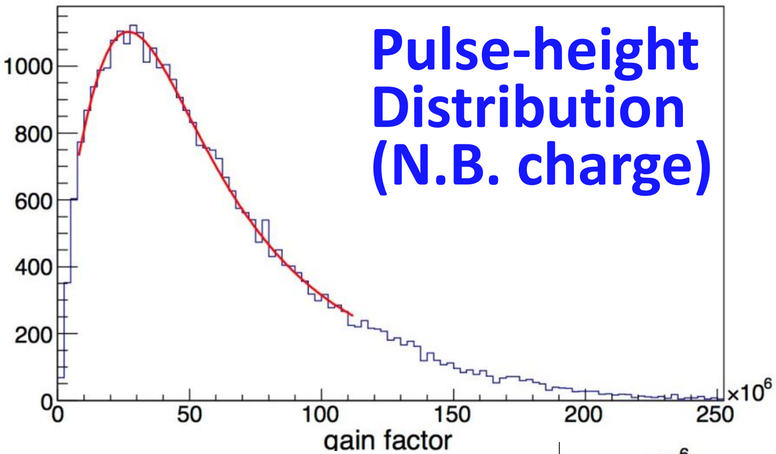
Higher SEY Materials
Optimized voltages

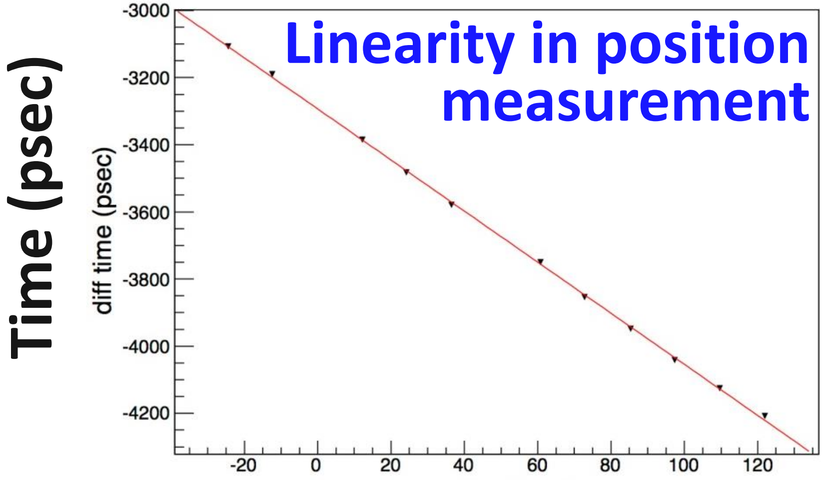
Other:

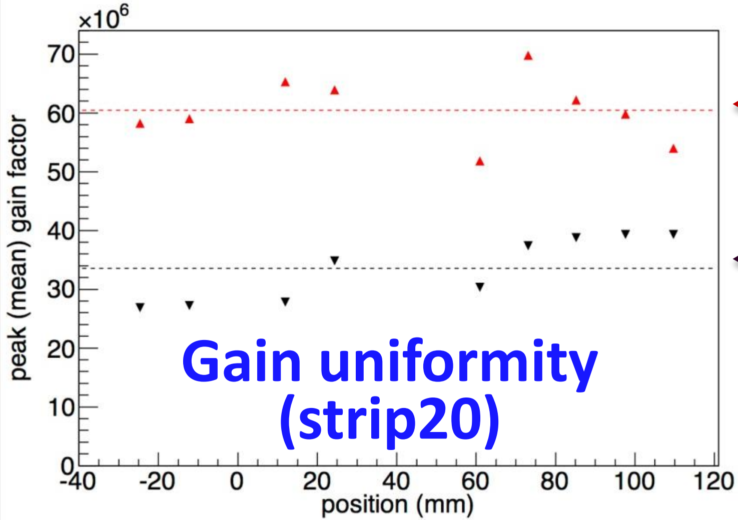
- Cathode-MCP gap size and shape
- Discrete dynode structure (Elam)
- Reflection-mode photocathode on MCP
- Tailoring Efield for equal times
- Other voltages, geometries…

Arradiance, Inc
MgO-coated ALD-functionalized MCPs

Arradiance delivered 2 matched, stable, MgO-coated plates. They have been operated in the full 8”-tile Demountable test facility.







Av gain

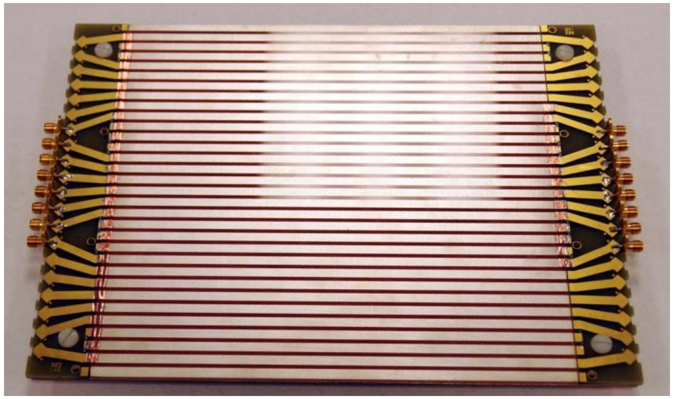
Peak gain (3.4E7)

Fermilab, CalTech &UC are in the process of ordering 6 more plates thru Incom (Incom PO) for a sampling calorimeter beam test.

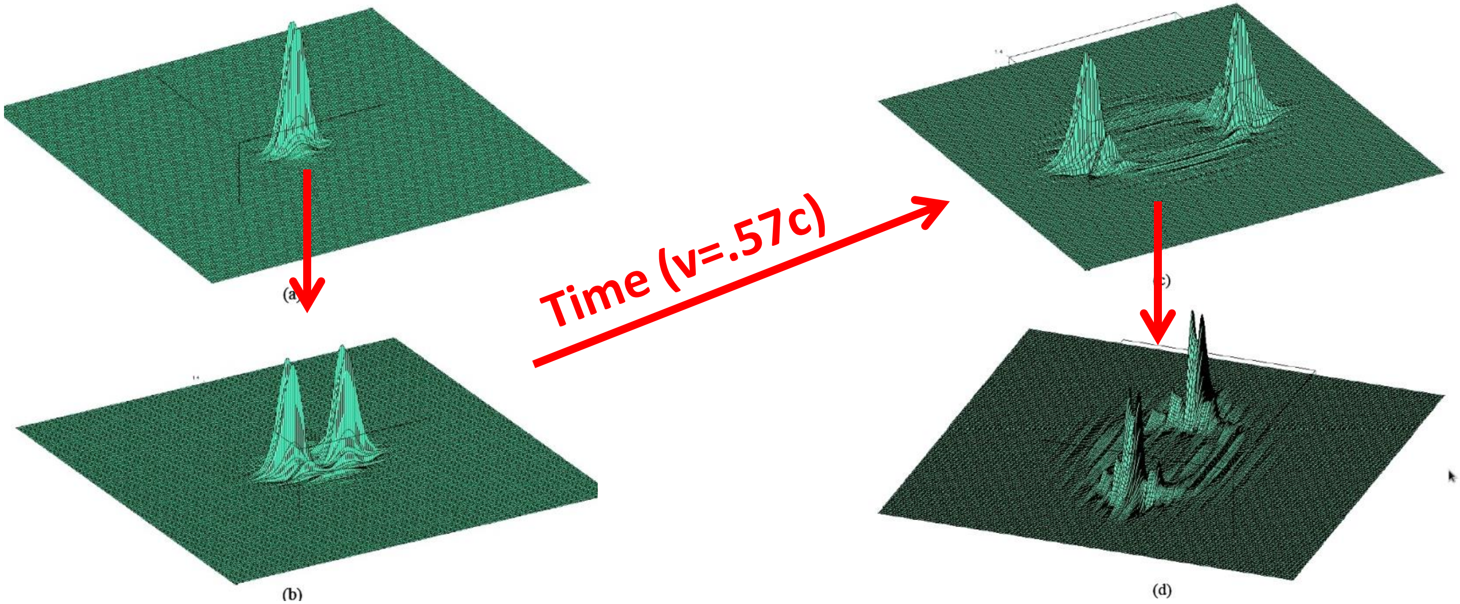
Getting the fast pulse to the digitizer

80 million pores need to be reduced to a small # (e.g. 30) of electronics channels while preserving the Analog BandWidth(ABW)

Early 30-strip test anode, each strip is 50 Ohms, read out on both ends

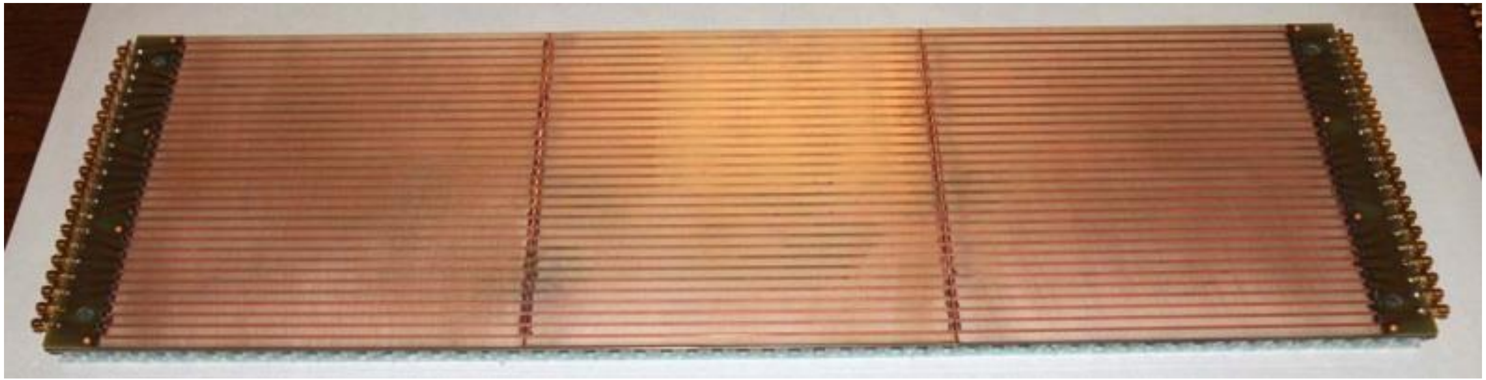


Simulated time evolution of pulse on 30-strip anode- note the growing crosstalk in neighboring strips as the pulse propagates toward both ends



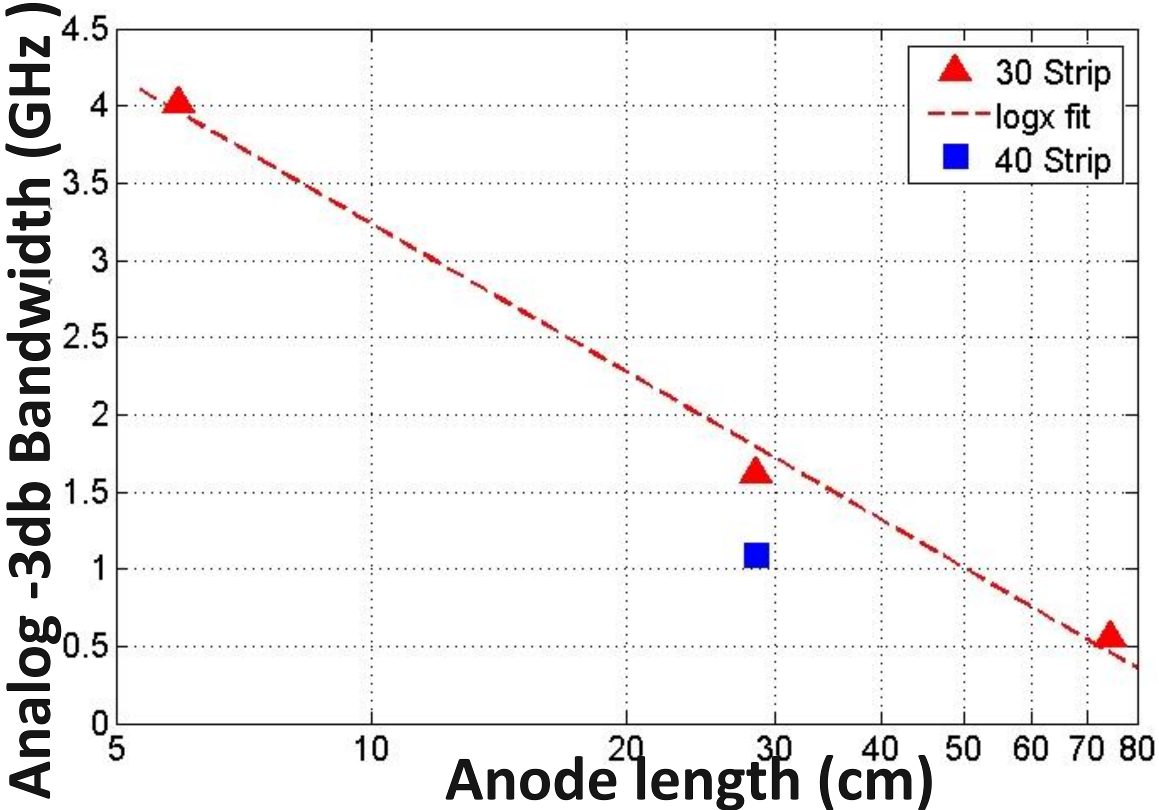
(time-domain simulation with proprietary FE code by InnoSys, Inc)

Daisy-chaining tile modules



Cover large areas at low electronics channel count by daisy-chaining RF striplines across MCP-PMT modules

But one loses bandwidth as the strips get longer, largely due to crosstalk. →

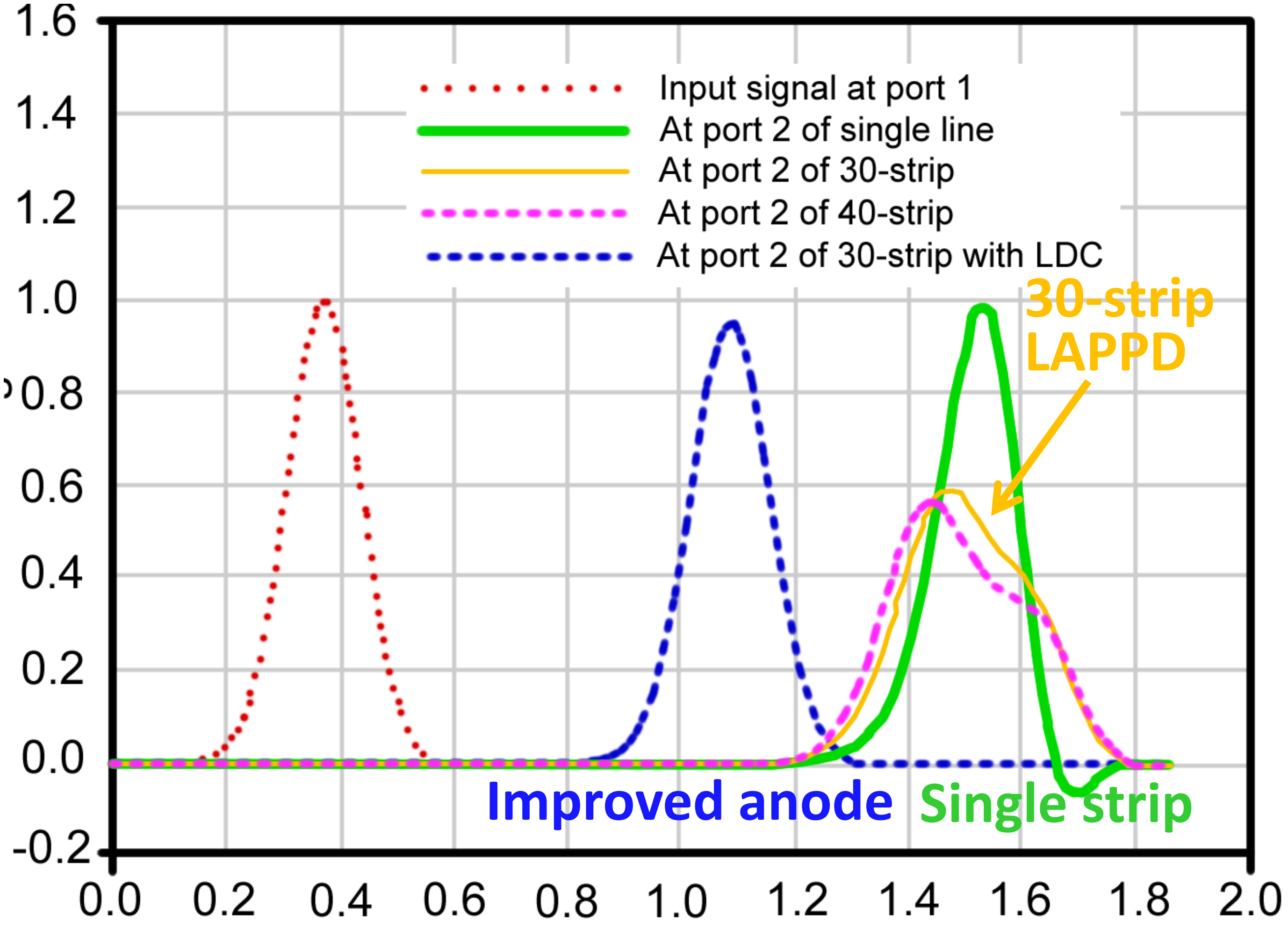


Effect of Crosstalk on Pulse Shape (Timing)

Crosstalk also affects the pulse shape, making the time measurement dependent on distance along the μstrip line

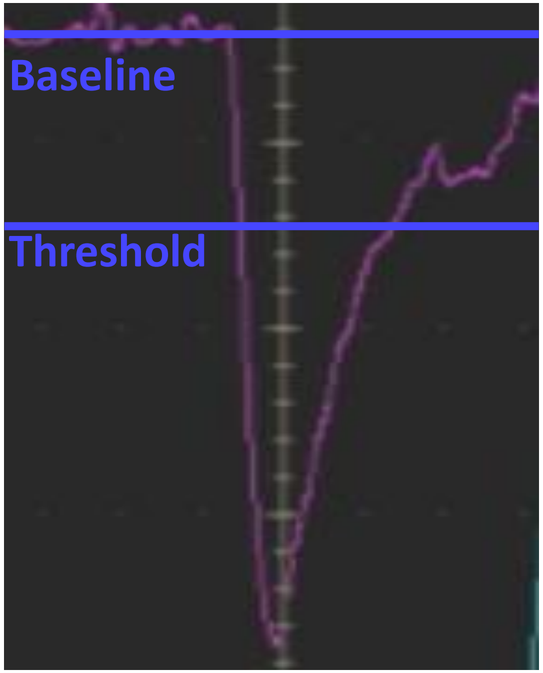
Time-domain simulation with proprietary FE code by InnoSys, Inc)

Note distortion in leading edge in the 30-strip LAPPD anode (in yellow-apologies)

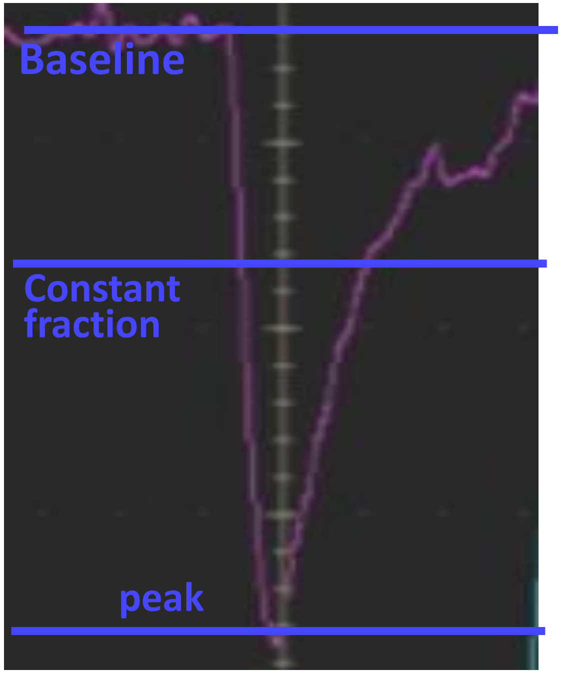


Time measured across 8" anode (nsec)

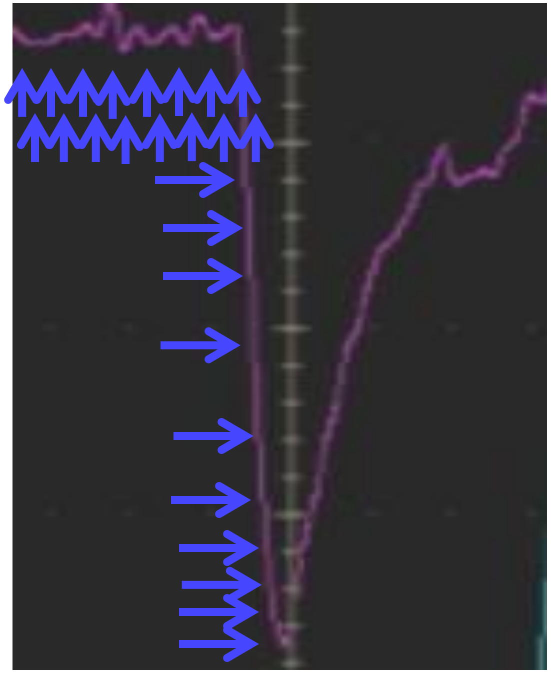
Measuring time t_0 from a pulse



Simple discriminator (single threshold)



Constant Fraction discriminator (CFD)



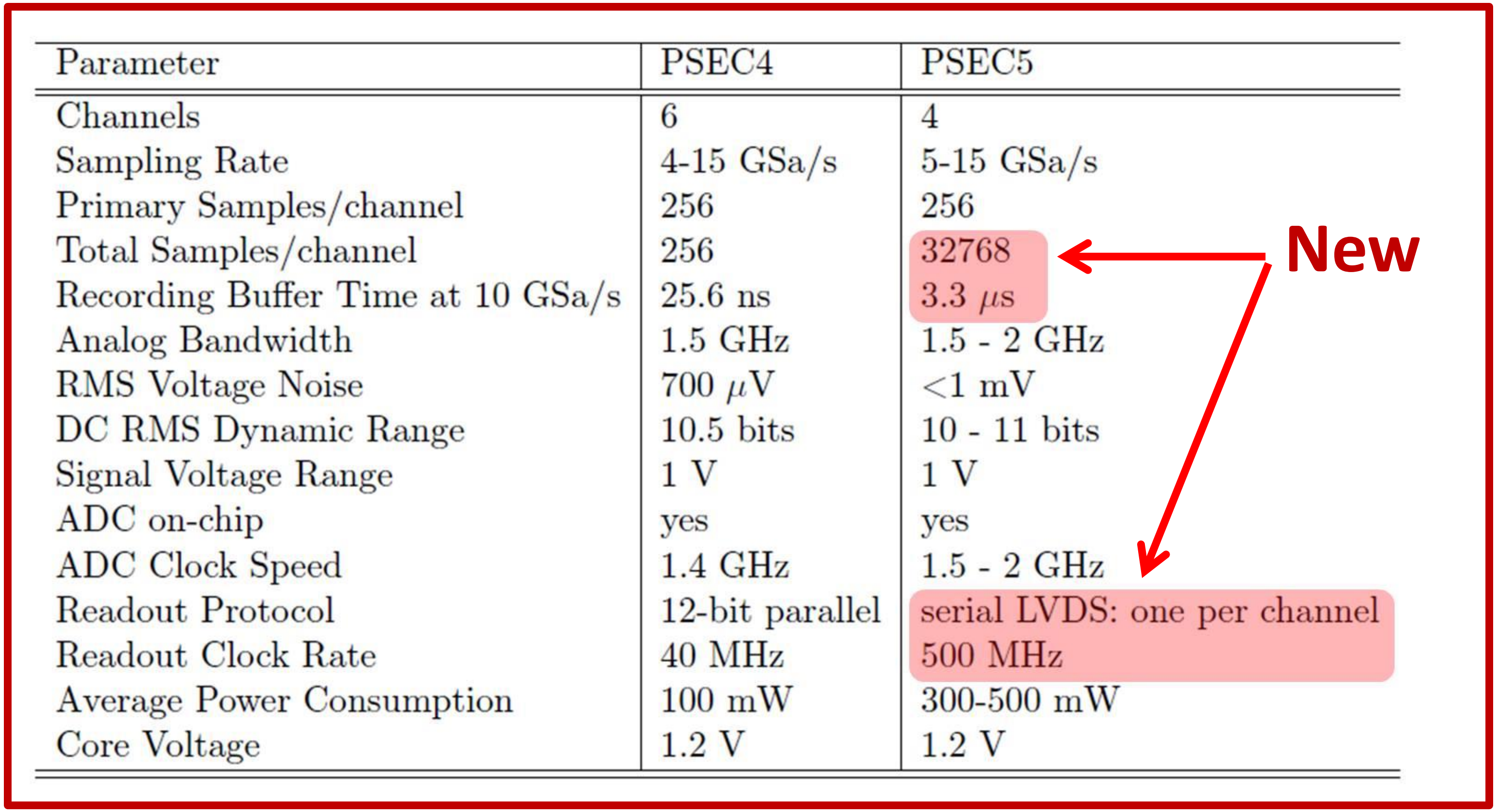
10 GS/sec Waveform Sampling (10 bits/pt PSEC4)

Waveform sampling is basically a fast digital scope on each channel- measures the baseline, pulse shape, pile-up, and allows averaging the noise with N samples on the leading edge (noise can have higher bandwidth than signal, unfortunately)- see E. Oberla's talk

J.-F. Genat, G.Varner, F. Tang, HJF; *Pico-second Resolution Timing Measurements*; Nucl.Instrum.Meth.A607:387-393,2009; arXiv:0810.5590

Waveform Samplng-PSEC4&5

PSEC5 is based on PSEC4 but with a deeper buffer for LHC, KOTO, Annie, …i.e. HEP experiments with trigger latency



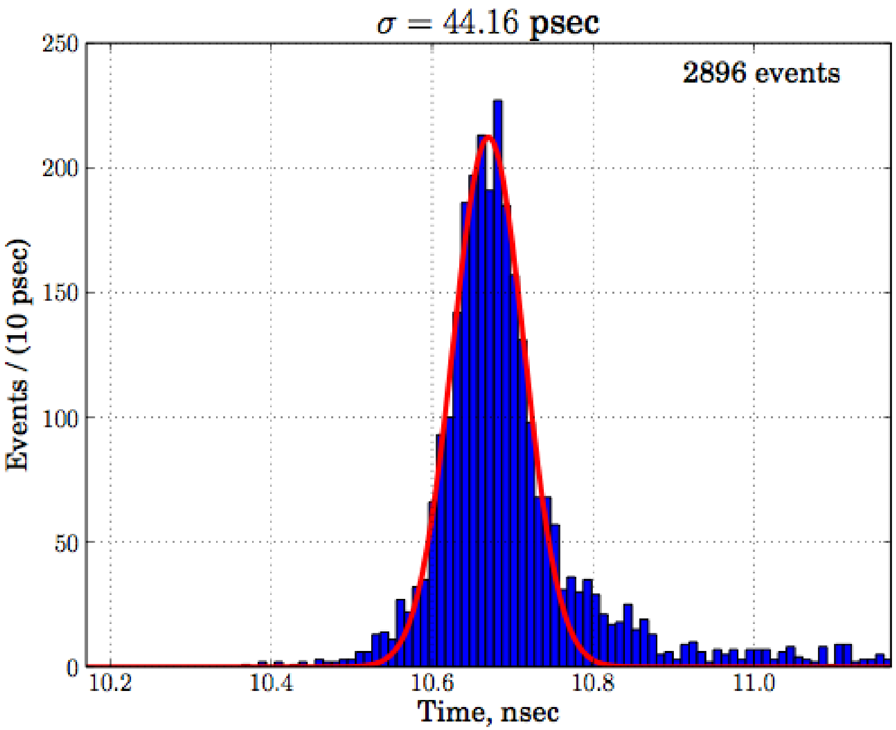
Parameter	PSEC4	PSEC5
Channels	6	4
Sampling Rate	4-15 GSa/s	5-15 GSa/s
Primary Samples/channel	256	256
Total Samples/channel	256	32768
Recording Buffer Time at 10 GSa/s	25.6 ns	3.3 μs
Analog Bandwidth	1.5 GHz	1.5 - 2 GHz
RMS Voltage Noise	700 μV	<1 mV
DC RMS Dynamic Range	10.5 bits	10 - 11 bits
Signal Voltage Range	1 V	1 V
ADC on-chip	yes	yes
ADC Clock Speed	1.4 GHz	1.5 - 2 GHz
Readout Protocol	12-bit parallel	serial LVDS: one per channel
Readout Clock Rate	40 MHz	500 MHz
Average Power Consumption	100 mW	300-500 mW
Core Voltage	1.2 V	1.2 V

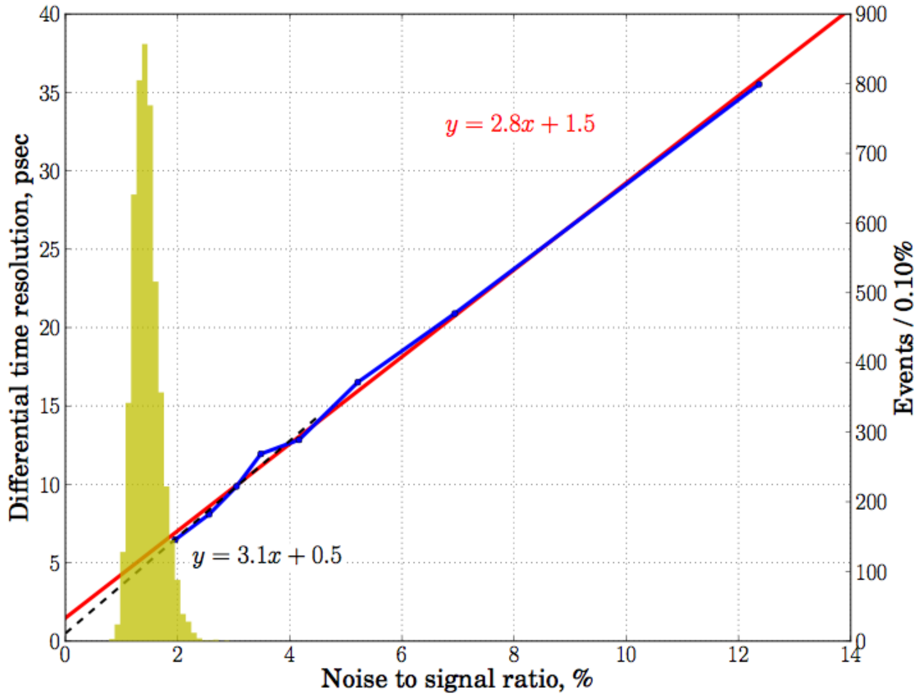
New

Joint Hawaii UC effort: M. Bogdan, E. Oberla, I. Mostafanezhad, G. Varner, HJF

See poster by M. Bogdan

Present Time Resolution





Single Photo-electron
PSEC4 Waveform sampling
Sigma=44 psec

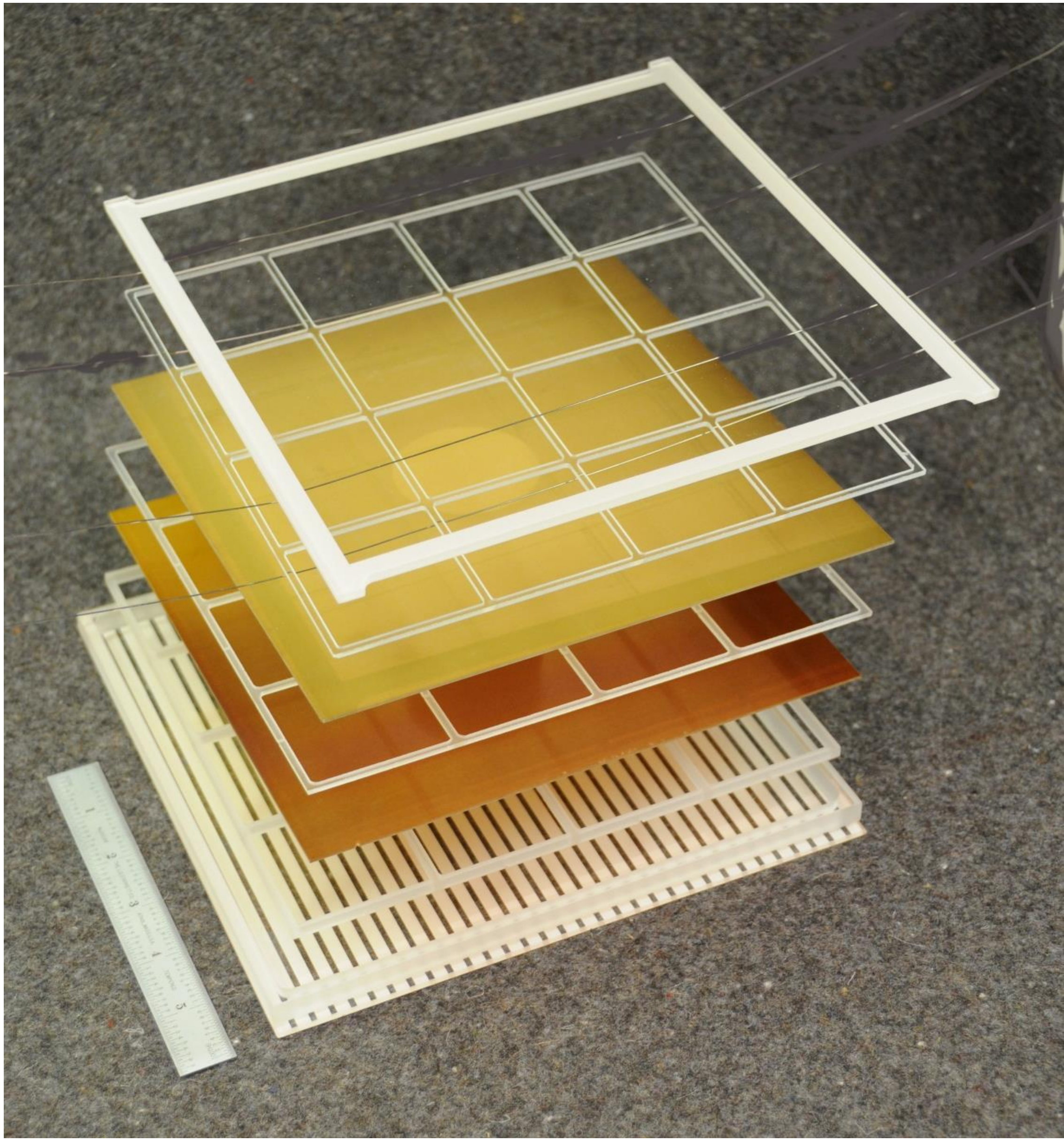
Differential Time Resolution
Large signal Limit
Oscilloscope Readout
Black line is y=3.1x+0.5 (ps)
Red line is y=2.8x +1.5 (ps)
Where the constant term represents the large S/N limit (0.5-1.5 ps)

Highly non-optimized system (!)- could do much better

Keep It Simple- 8 parts

1 topwindow
2 MCP's
3 Spacers
1 Tilebase
1 Getter Necklace
TOTAL: 8 parts

I (strongly) recommend using the ALD internal HV divider- the Arradiance plates are matched, we can make matched plates, the plates are stable,…it's a proven technology.



Indium-Bismuth Window Solder Seal

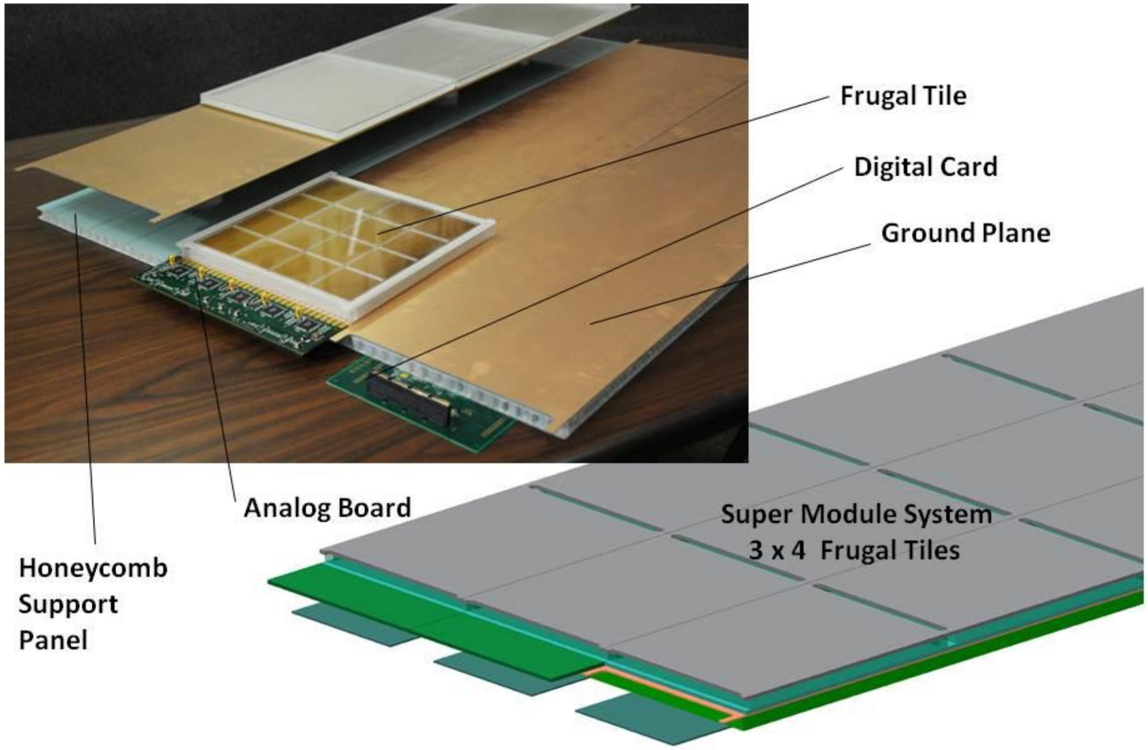
- First try at SSL proved principle- only needed finesse (didn't expect this much success first try, frankly- it looks really good, though not an industrial production method)
- Had a full 8" cathode with good QE
- Tube was operational in tank- looked very good

(O. Siegmund, J. McPhate, ...)

8" metallized window hermetically sealed to sidewall (now 4 successful seals in a row in glove box by Elagin- exact same chemistry and solder as SSL seal) (see his talk)

Tile-Tray Integrated Design

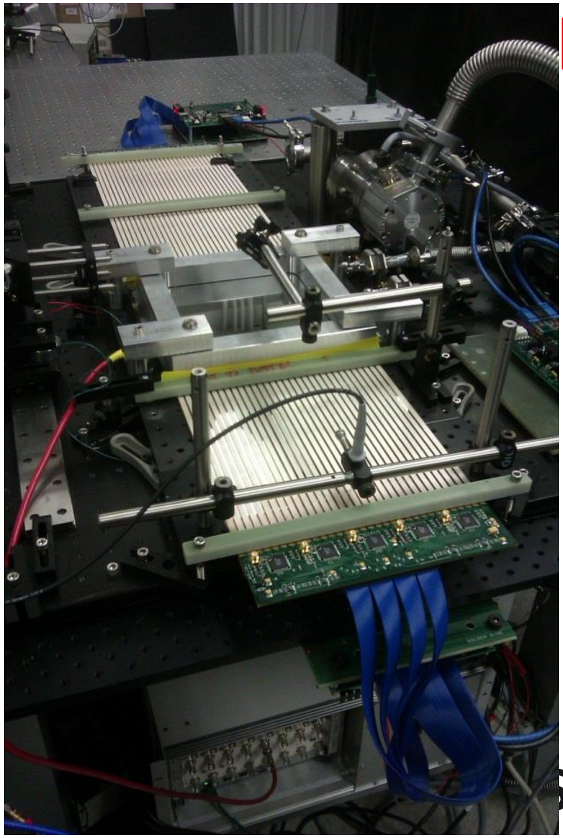
Because this is an RF-based readout system, the geometry and packaging are an integral part of the electronic design

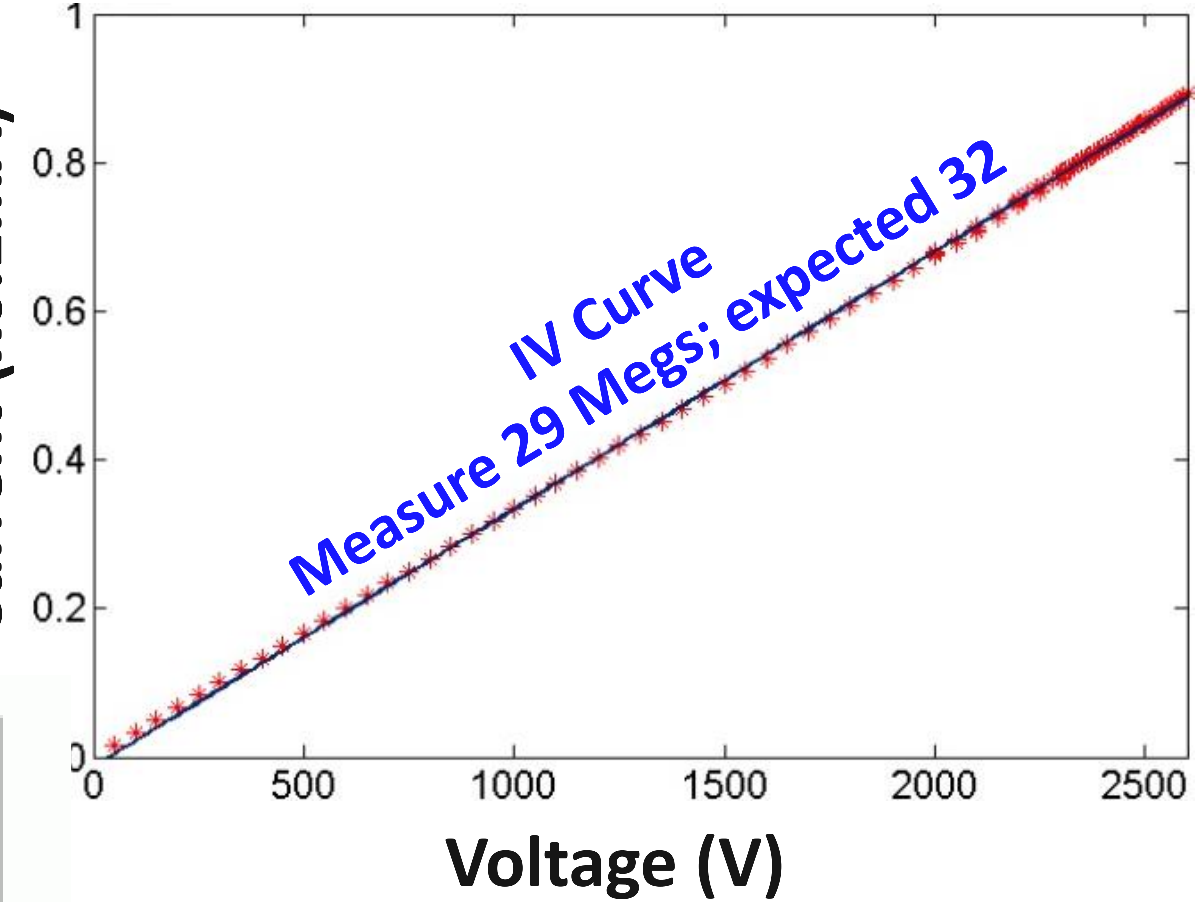


Tray and Tiles - The Super Module System

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.

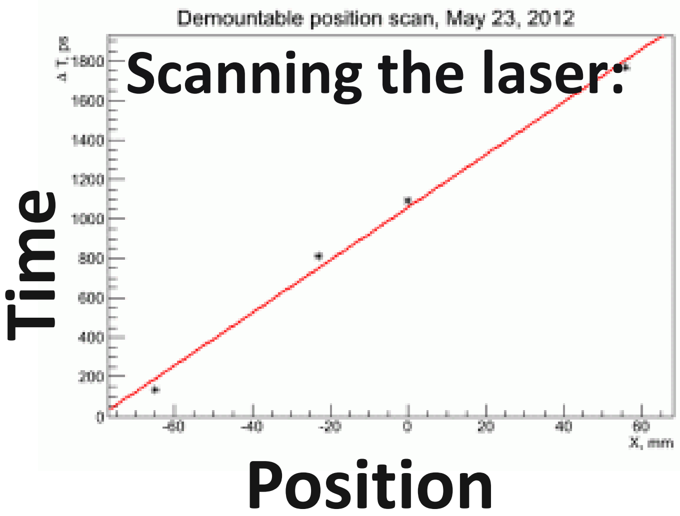
Demonstration of the Internal ALD HV Divider in the Demountable Tile





IV Curve

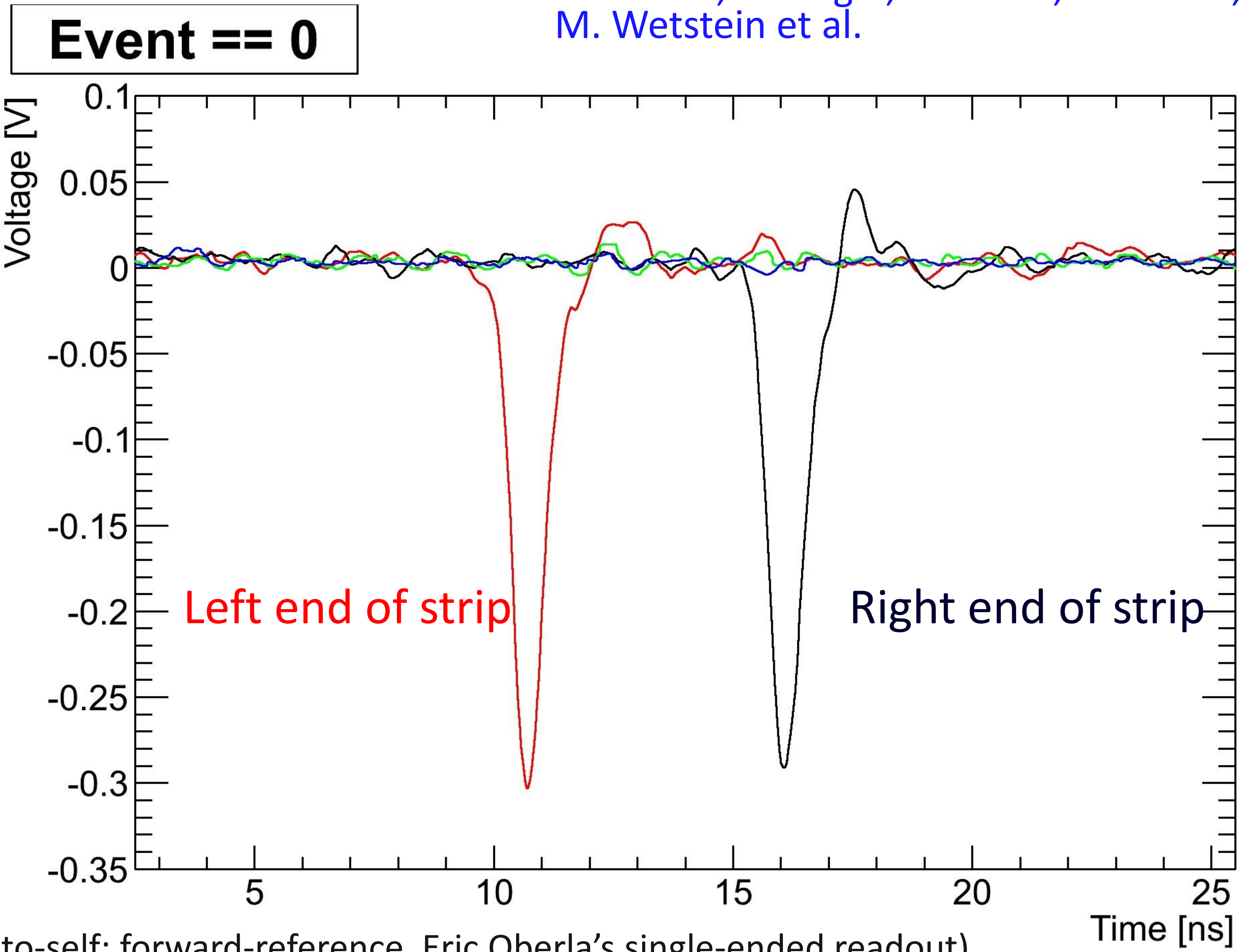
Measure 29 Megs; expected 32



Scanning the laser:

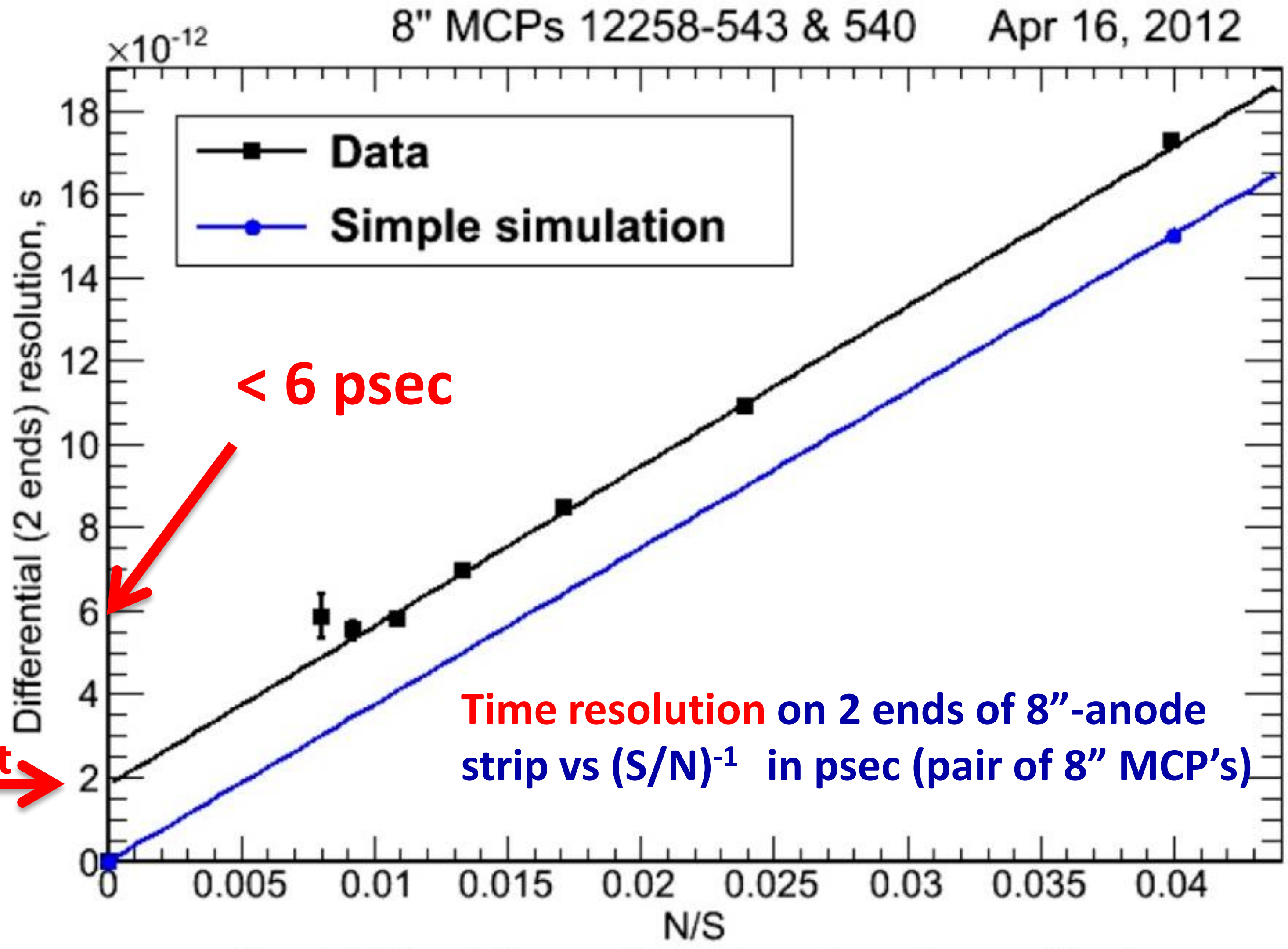
Pulses from a pair of 8” MCP Al2O3 plates

B. Adams, A. Elagin, R. Obaid, E. Oberla,
M. Wetstein et al.



(Note-to-self: forward-reference Eric Oberla’s single-ended readout)

Timing res. agrees with MC



< 6 psec

Laser spot size

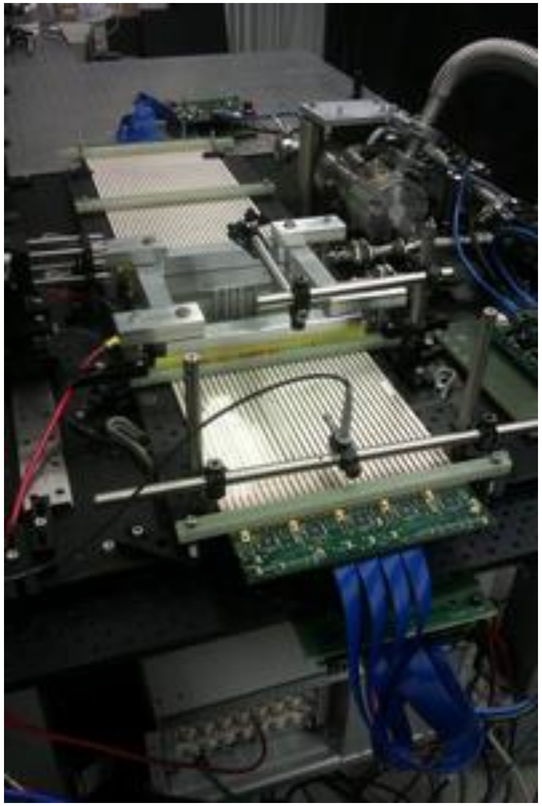
Time resolution on 2 ends of 8”-anode strip vs $(S/N)^{-1}$ in psec (pair of 8” MCP’s)

N = RMS of the noise; S = signal amplitude

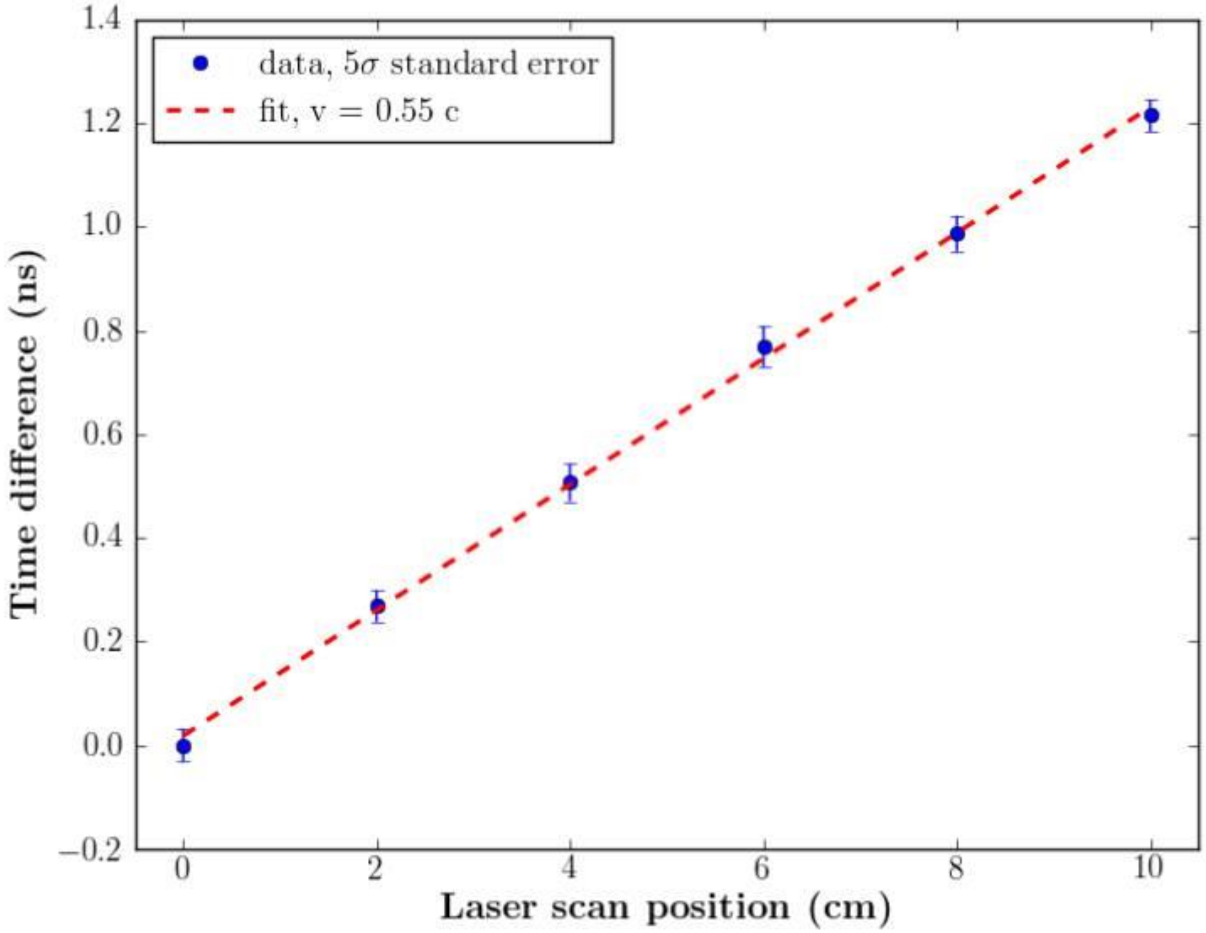
M. Wetstein, B. Adams, A. Elagin, R. Obaid, A. Vostrikov, …

Demonstrated Position Sensitivity

Razib's scanning stage



4-tile `tile-row'
of Supermodule

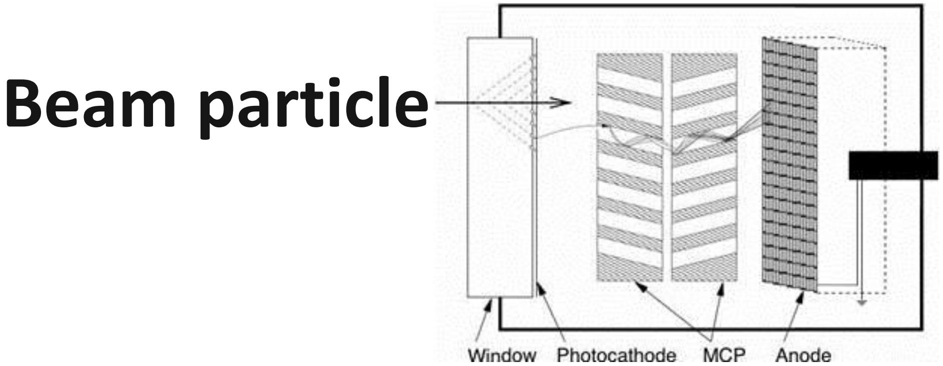


Time difference of 2 ends vs laser position

Breaking the 1-Psec Barrier

Summarize where are we now:

- The TTS (Transit-Time-Spread: FWHM) ~50psec for large pulses



- We measured in the Fermilab Test Beam (T979, 2008) that a Photonis Planicon with an 8-mm quartz radiator produces ~50 PEs (Photo-Electrons) when a charged particle traverses the radiator and window

- The present precision is completely dominated by the measuring setups and not the intrinsic resolution of the pulse generation or time measurement

Breaking the 1-Psec Barrier

Make a simple-minded `guesstimate' of resolution:

- Get a mean of 50 PE's in a TTS of 50psec
- Mean # of PE's per psec is 1 (1PE/psec)
- Probability of getting n PE's expecting m is
- $P_m(n)=m^n e^{-m}/n!$, so prob of 0 is e^{-1}
- Probability of 0 PEs in 1st 3 psec is e^{-3}=10%
- The prob. of >=1 in the 1st 3 psec is flat; σ=3/sqrt(12)=0.9 psec
- And if, with smaller pores, higher secondary emission for first strike, and better focusing we can get a TTS of 25psec, the probability of 0 PEs in 1st 3 psec is e^{-6}=1%

Not proven, but not nuts

What about measuring the pulse?

Stefan Ritt's 'Rule-of-Thumb (see "The Factors that Limit Time Resolution in Photodetectors, Workshop, Univ. of Chicago, Chicago, IL; 28-29 April 2011 **)**

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

3 parameters: Signal-to-Noise (U/dU), sampling rate (f_s), and analog bandwidth (f_{3db}). Analog bandwidth is related inversely to pulse risetime: 350 MHz corresponds to 1 nsec.

Simplified version of Stefan's Rule:

For a fixed number of samples on the rising edge (e.g. between 10% and 90%), the resolution is inversely proportional to the S/N ratio and the analog bandwidth.

So What Does Stefan's ROT Predict?

Stefan Ritt slide from 2nd Photocathode Workshop* (annotated)

U	Δu	f_s	f_{3db}	Δt
100 mV	1 mV	2 GSPS	300 MHz	~10 ps
1 V	1 mV	2 GSPS	300 MHz	1 ps
100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
1V	1 mV	10 GSPS	3 GHz	0.1 ps
LAPPD:1V	**0.7 mv**	**15 GS/sec**	**1.6 GHz**	**20??**

- **Measured differential (1 end to another) resolution is ~5 psec: a measure of how well we are doing on the pulses**
- **I suspect most of the rest is in the test setup, but there may be other effects we don't yet know. Needs effort**

---

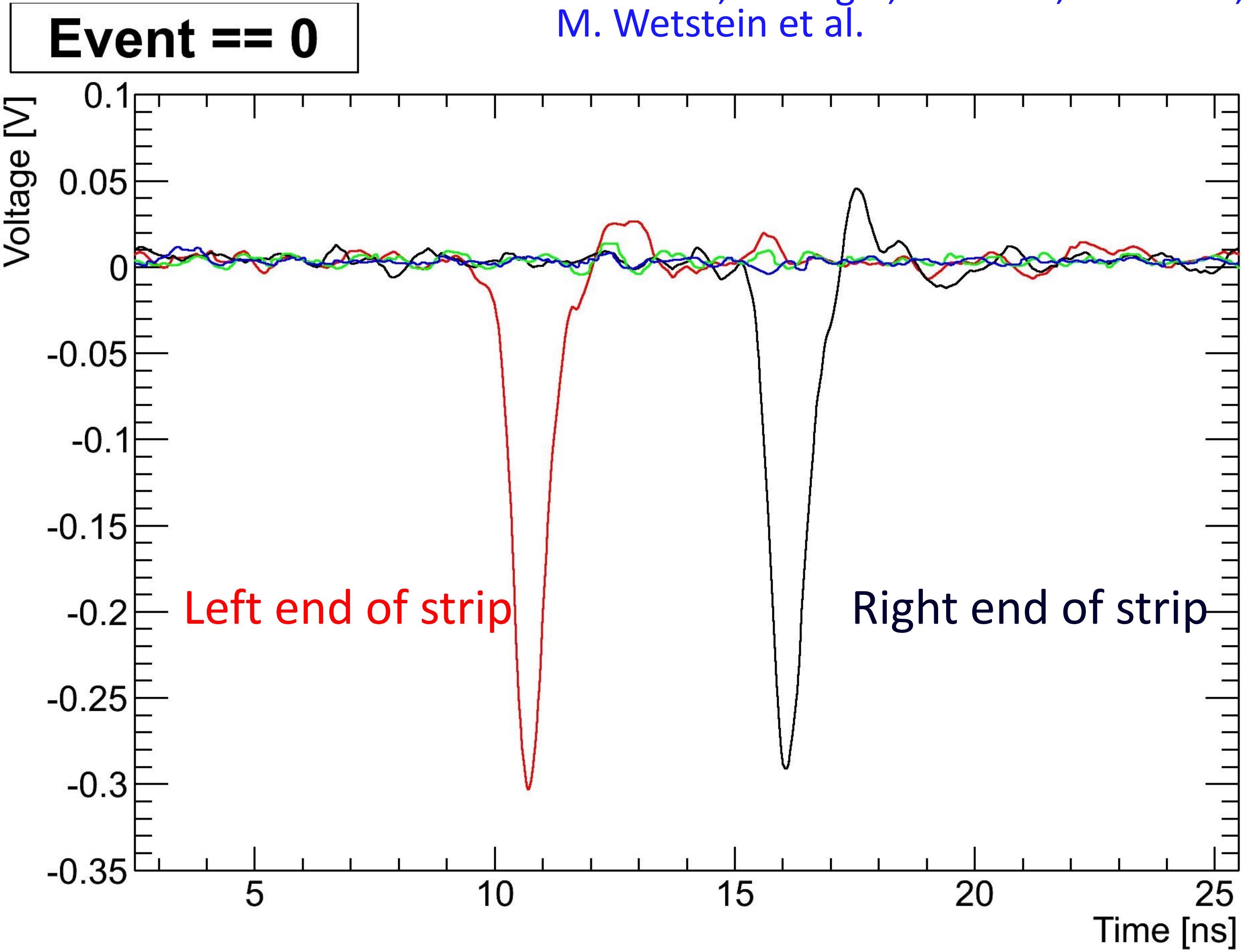
*see psec library web page

Sub-psec Front End Prospects

- E. Oberla invented a sweet idea- read out only one end of the 50Ohm lines, and leave the other unterminated=> one reads the near end directly and the far end `on the bounce' in the same electronics channel. He then uses the digital waveform to autocorrelate the two pulses to get the position.
- This suggests an answer to the problem of holding the number of samples constant as the risetime decreases (see C. Craven talk on faster substrates at Incom). Photek (Howorth et al.) have already achieved 60 psec risetimes- to get 10 samples on the leading edge need to sample at 160 GHz. Sampling is not a well-matched solution.
- One solution, for low occupancy settings (e.g. large neutrino detectors, lepton colliders), would be to do the time and position analysis analog in a front-end ASIC. Postion from analog autocorrelation; time from a `Chronotron'- exploit the constant length (time) of the tile.

Reminder of the Pulses from a pair of 8” MCP Al2O3 plates

B. Adams, A. Elagin, R. Obaid, E. Oberla, M. Wetstein et al.



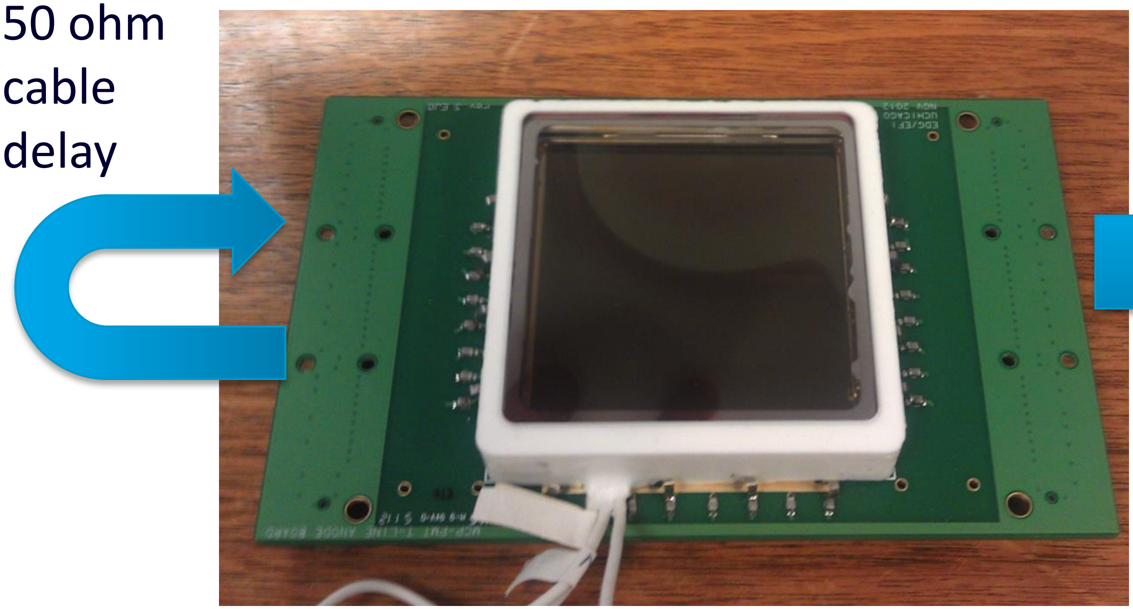
Left end of strip

Right end of strip

Transmission line single-ended readout

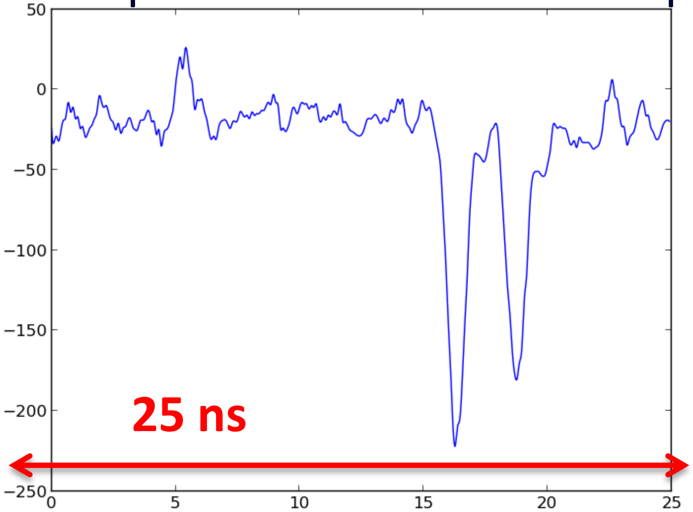
E. Oberla slide

50 ohm
cable
delay



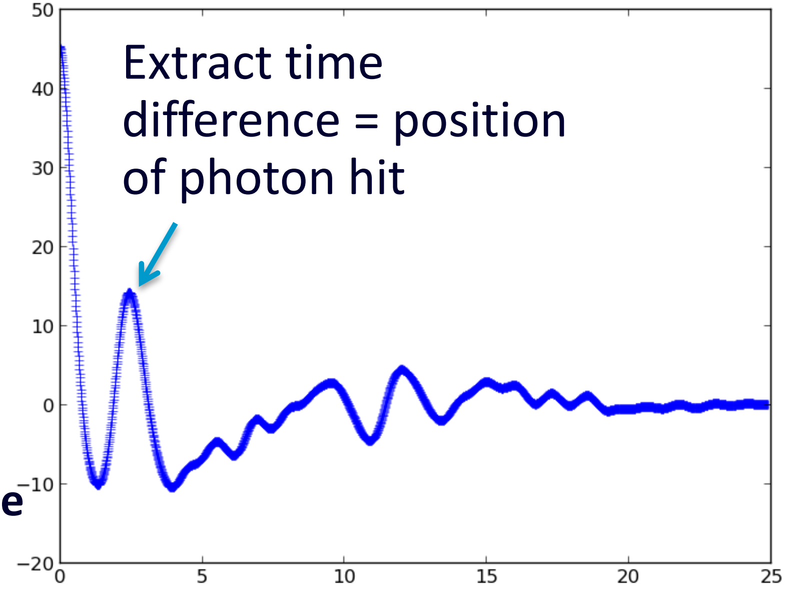
30 channels PSEC4
readout

Record pulse and reflection on open end:



25 ns

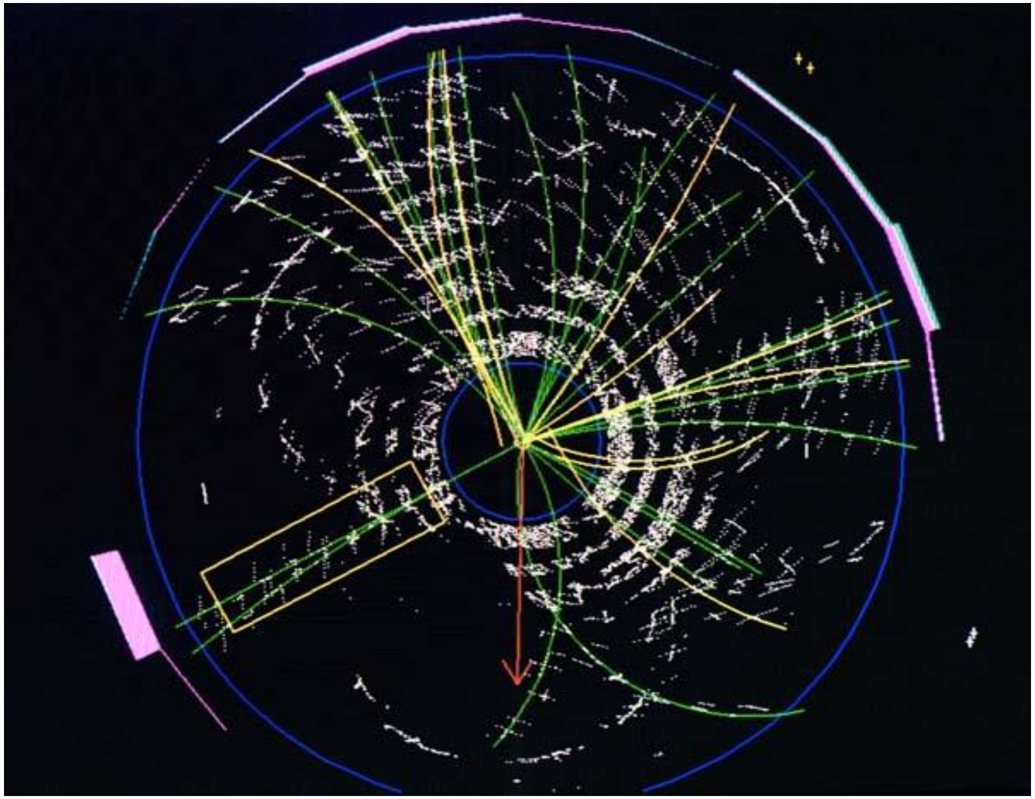
1)Interpolate
2)Resample timebase
3)**Autocorrelate**



Extract time
difference = position
of photon hit

A Comment on Calibration

With jitter cleaners one can distribute a clock with psec-level stability. However, the task of holding calibrations to better than a psec over long-time scales is formidable.

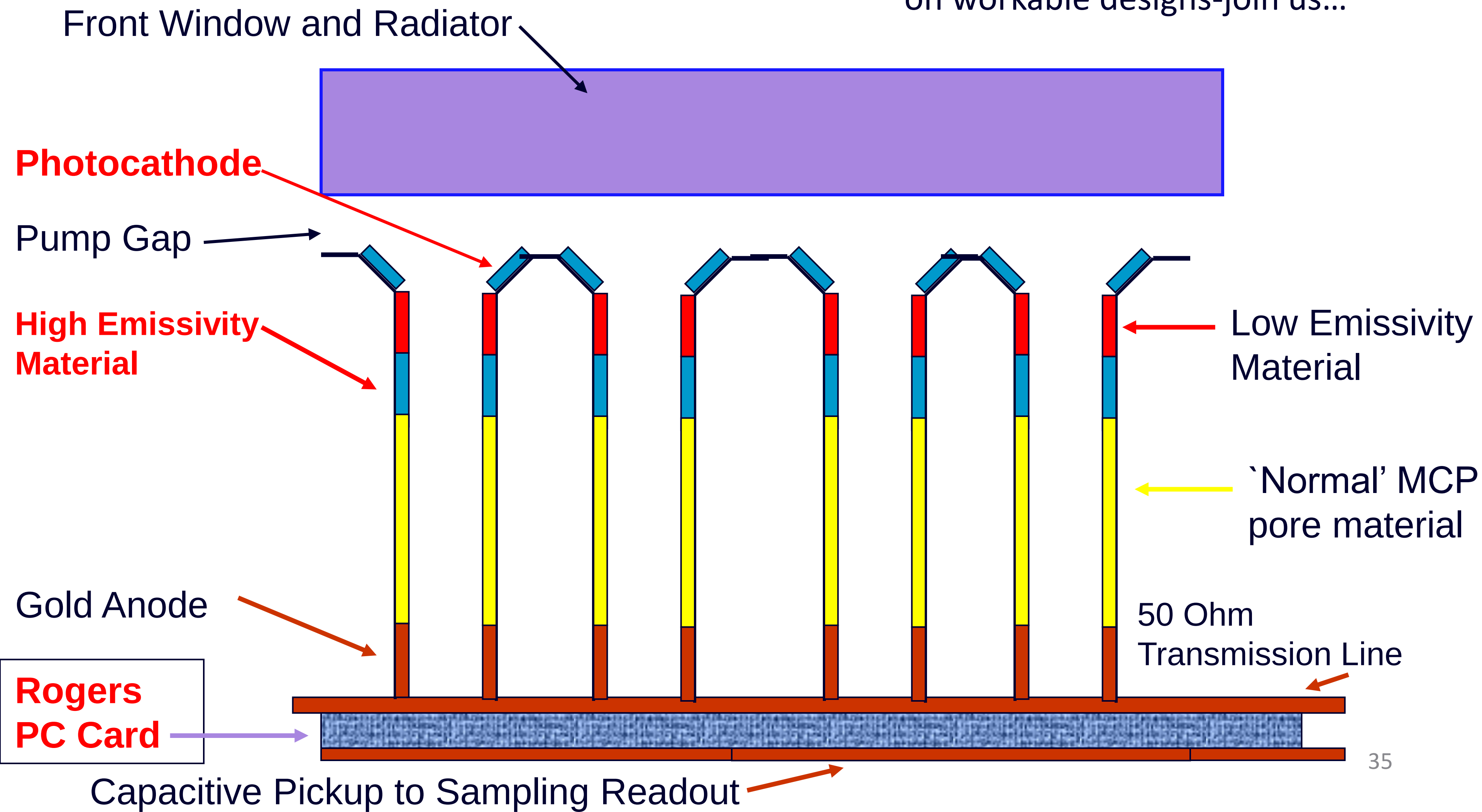


Proposal: Measure the difference in arrival times of photons and charged particles which arrive a few psec later.

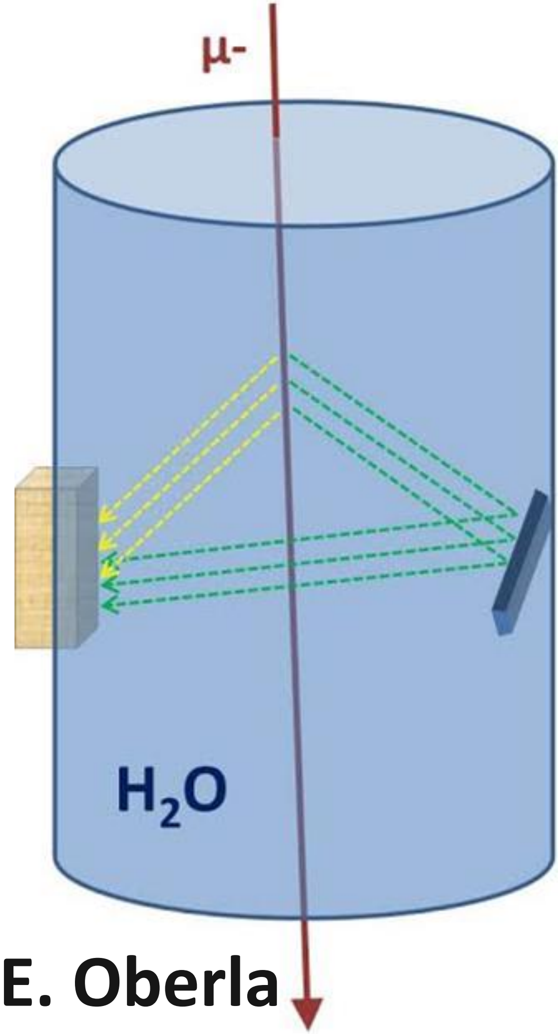
What’s the limit? (2009 cartoon)

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

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



Lastly, let's come back to mirrors and the Optical TPC



E. Oberla

Homage to T. Ypsilantis

Adding psec-resolution changes the space in which considerations of Liouville's Theorem operates from 3dimensional to 4dimensional. In analogy with accelerator physics, we can exchange transverse emittance to longitudinal emittance.

There may be interesting and clever ways to exploit this in large water/scint Cherenkov counters.

Some References

MCP Testing and Pulse Performance : B. Adams, M. Chollet, A. Elagin, A. Vostrikov, M. Wetstein, R. Obaid, and P. Webster
A Test-facility for Large-Area Microchannel Plate Detector Assemblies using a Pulse Sub-picosecond Laser;
Review of Scientific Instruments **84**, 061301 (2013)

PSEC-4 Waveform Sampling Chip E. Oberla, J.-F. Genat, H. Grabas, H. Frisch, K. Nishimura, and G Varner
A 15 GSa/s, 1.5 GHz Bandwidth Waveform Digitizing ASIC;
Nucl. Instr. Meth. A735, Jan., 2014, http://dx.doi.org/10.1016/j.nima.2013.09.042;
http://arxiv.org/abs/1309.4397

Microstrip Anode Performance H. Grabas, R. Obaid, E. Oberla, H. Frisch J.-F. Genat, R. Northrop, F. Tang, D. McGinnis, B. Adams, and M. Wetstein;
RF Strip-line Anodes for Psec Large-area MCP-based Photodetectors,
Nucl. Instr. Meth. A71, pp124-131, May 2013

SSL MCP Performance, Testing and Ceramic Tile Program O.H.W. Siegmund,*, J.B. McPhate, J.V. Vallerga, A.S. Tremsin, H. Frisch, J. Elam, A. Mane, and R. Wagner; *Large Area Event Counting Detectors with High Spatial and*
Temporal Resolution, submitted to JINST; Dec, 2013

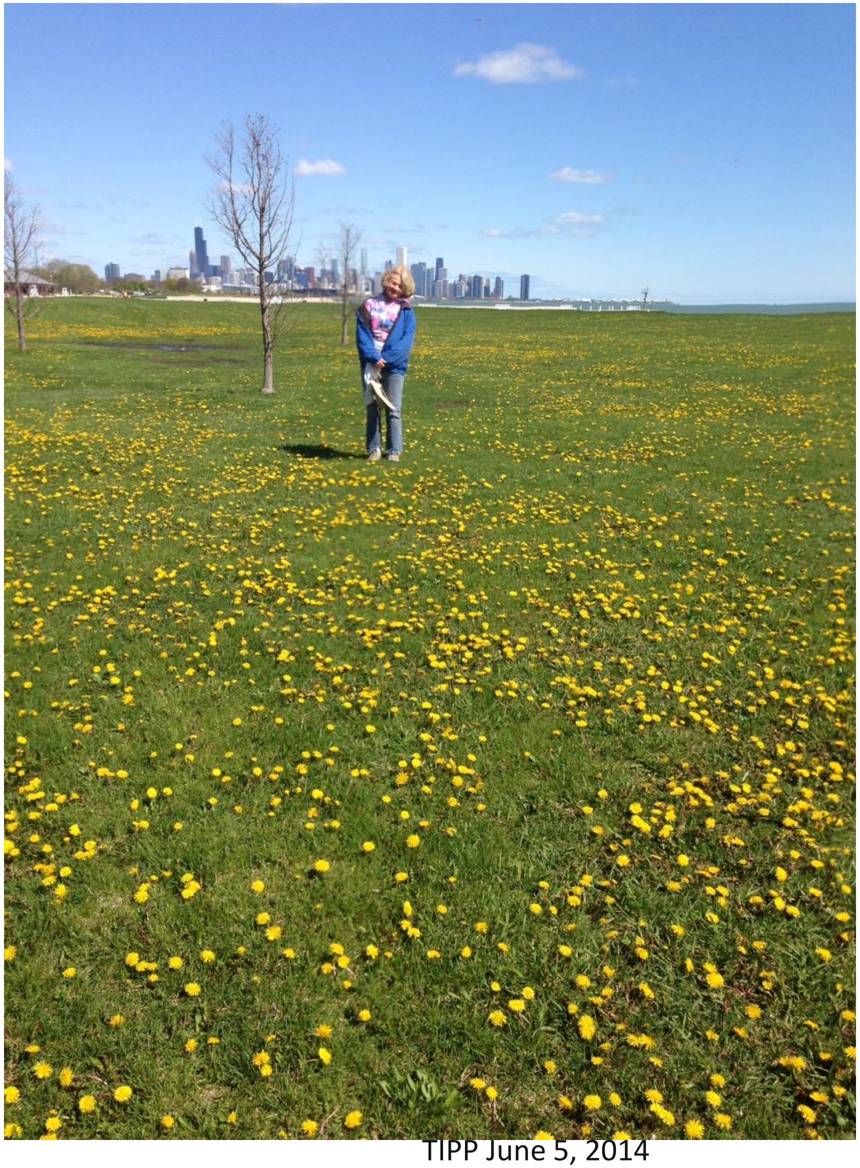
Fast Timing in Searches for Double Beta Decay C. Aberle, A. Elagin, H.J. Frisch, M. Wetstein, L. Winslow.
Measuring Directionality in Double-Beta Decay and Neutrino Interactions with Kiloton-Scale Scintillation Detectors; Jul 22, 2013. To Be Published in JINST; e-Print: arXiv:1307.5813

LAPPD documentation can be found at
http://psec.uchicago.edu/library/doclib/
(thanks to Mary Heintz, system administrator)

Many Thanks to:

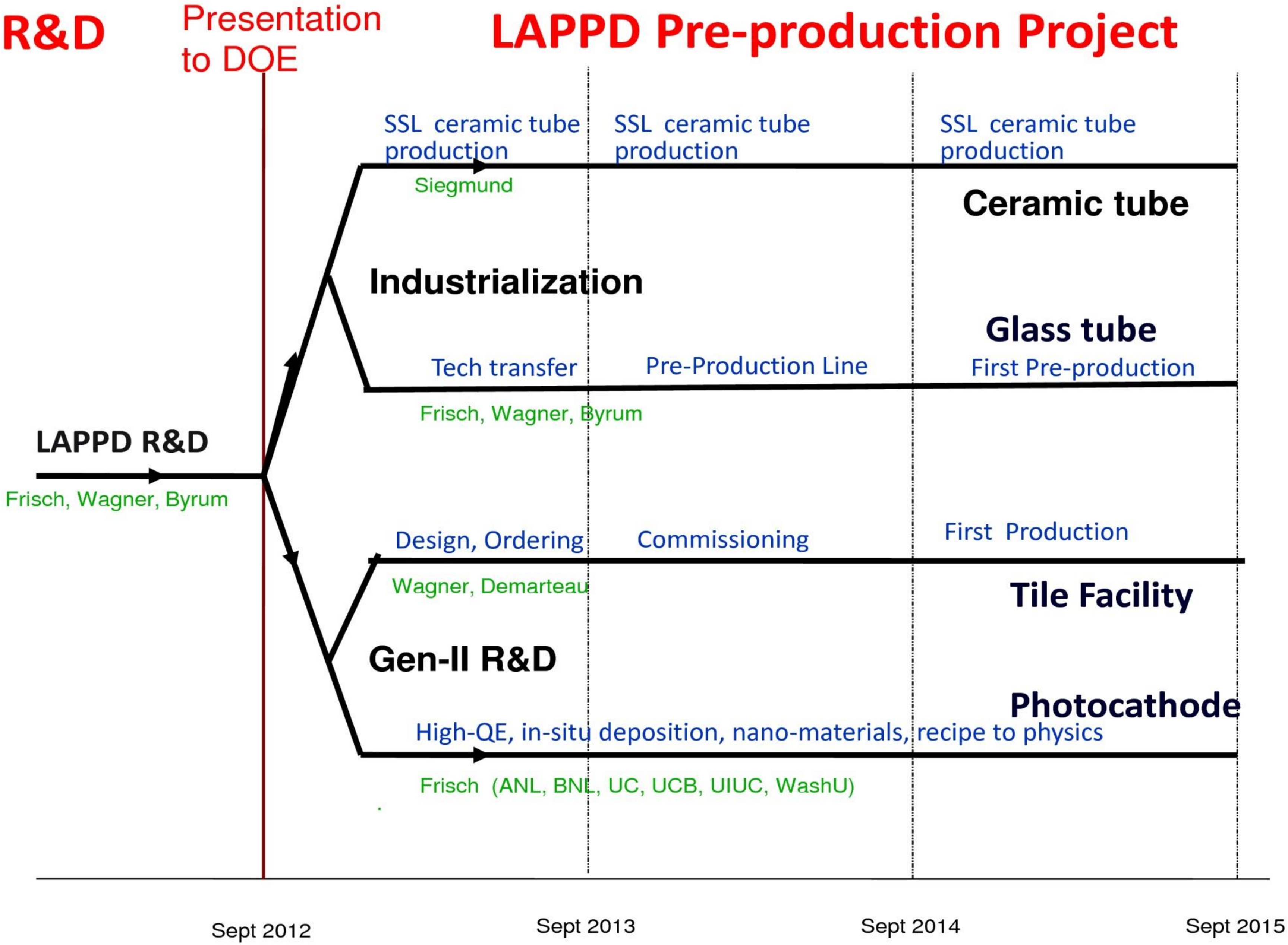
- My LAPPD Collaborators at ANL, UC-Berkeley SSL, Uchicago, Hawaii, and Washington University
- Staff and management at Incom, Arradiance, and InnoSys
- Others in the field of fast-timing , with special thanks to T. Ohshima and J. Vavra; and waveform sampling, (special thanks here to D. Breton, E. Delagnes, J.F.-Genat, S. Ritt, and G. Varner)
- Howard Nicholson and the US DOE Office of HEP
- The organizers, staff, and students of TIPP2014 (!)

The End



Backup Slides

Dec.12,2012 Proposed Plan



R&D

Presentation to DOE

LAPPD Pre-production Project

LAPPD R&D

Frisch, Wagner, Byrum

Industrialization

SSL ceramic tube production

Siegmund

SSL ceramic tube production

SSL ceramic tube production

Ceramic tube

Tech transfer

Frisch, Wagner, Byrum

Pre-Production Line

Glass tube

First Pre-production

Gen-II R&D

Design, Ordering

Wagner, Demarteau

Commissioning

First Production

Tile Facility

Photocathode

High-QE, in-situ deposition, nano-materials, recipe to physics

Frisch (ANL, BNL, UC, UCB, UIUC, WashU)

Sept 2012

Sept 2013

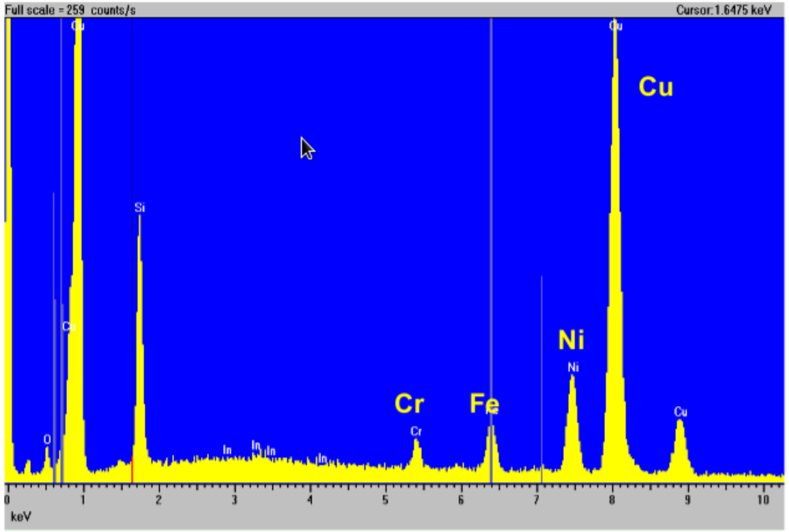
Sept 2014

Sept 2015

Getting Quantitative on the Solder Seal

Andrei, Ian Steele

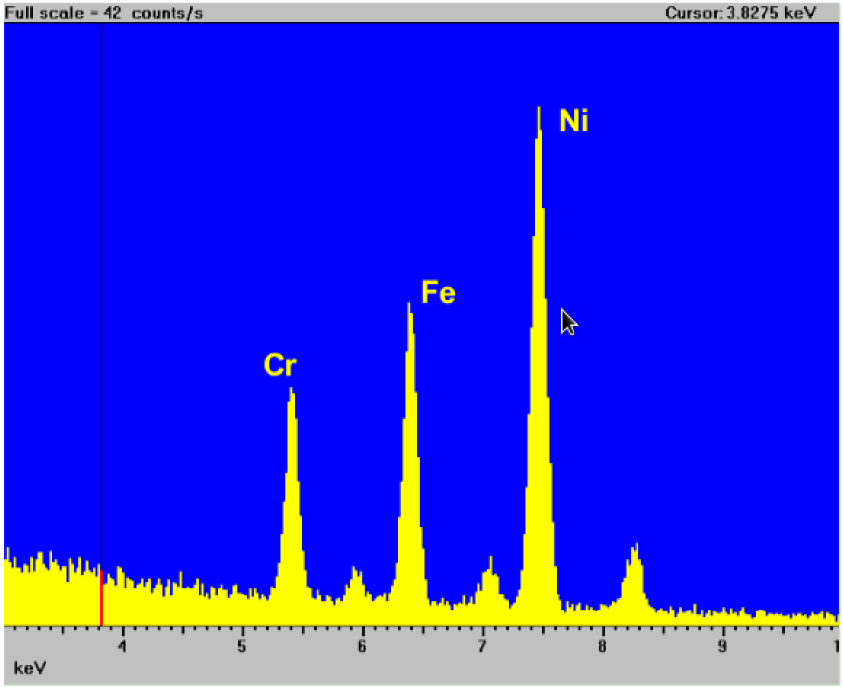
Good sample by Clausing, looking on NiCr layer through 200nn



ı Steele, UChicago

Use same recipe as SSL- main difference is flat vs groove, and thickness of Cu on sidewall (window is the same)

Bad sample by Clausing, looking directly on NiCr layer

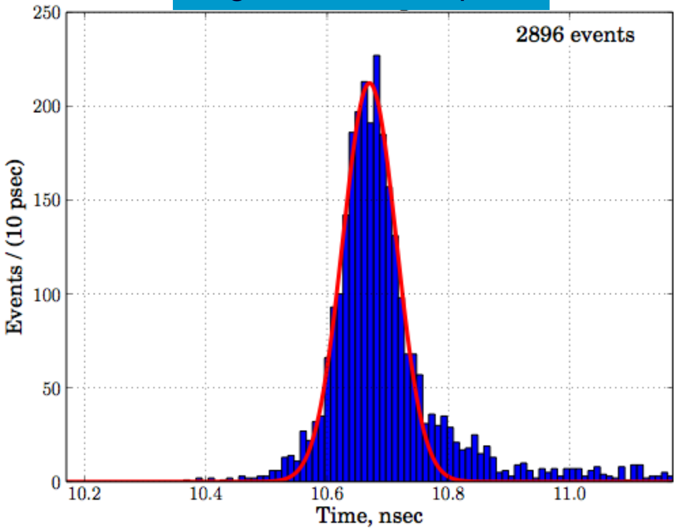


Chicago

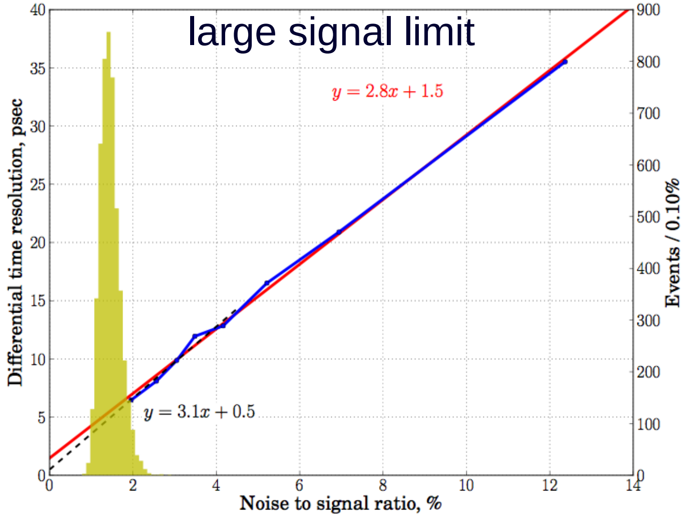
Still some parameter we don’t understand- evap rate, temp, OH, H, …

LAPPD - Last Review

single PE: σ ~ 44 psec

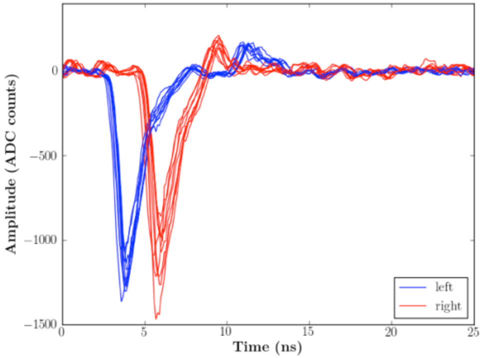


large signal limit



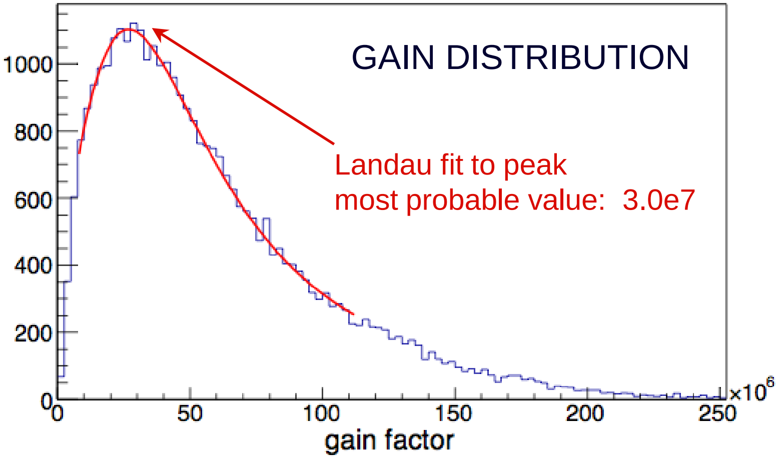
complete system testing with PSEC electronics

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

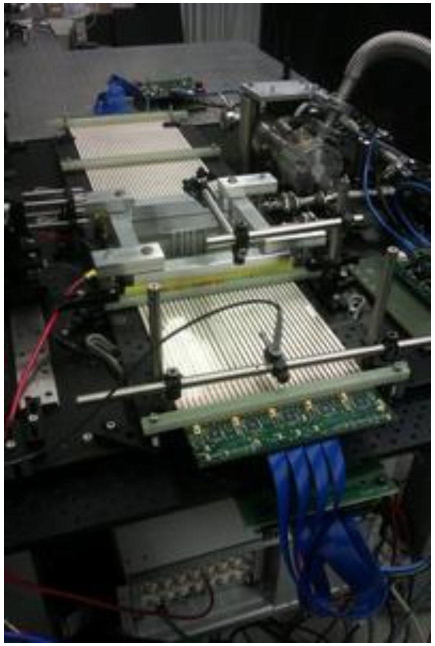


GAIN DISTRIBUTION

Landau fit to peak
most probable value: 3.0e7

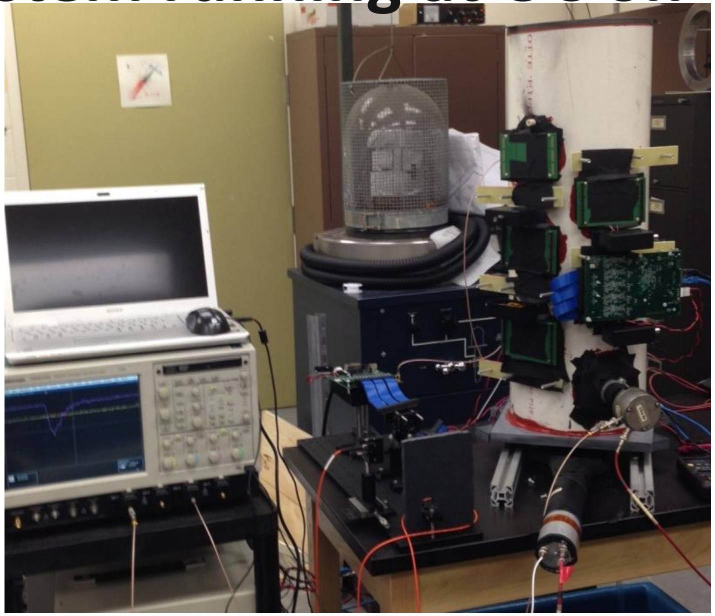


Electronics-PSEC4



60-channel system running at APS Teststand

120-channel system running at UC on the OTPC (Eric)

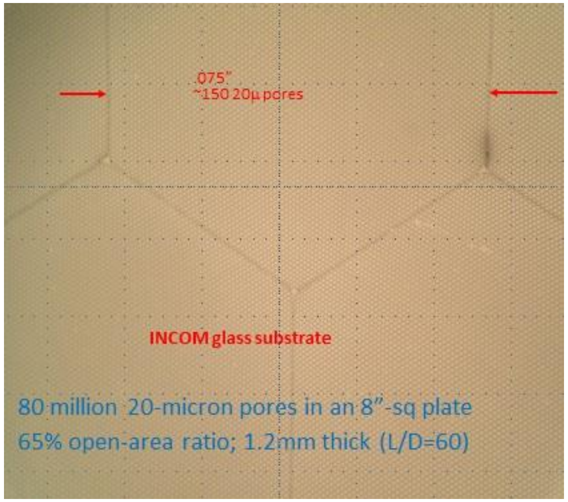


U. Of Vermont has 6 -channel system running (not shown)

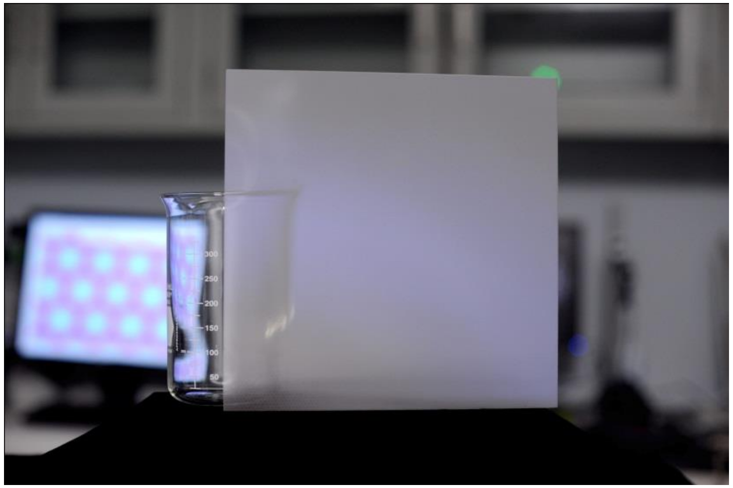
And Sandia ordered 120 PSEC4 (720 channels); we piggy-backed 80 (480 channels)

Huston, D.R., et al, "Concrete bridge deck condition assessment with automated multisensor techniques", Structure and Infrastructure Engineering , Sept. 2010

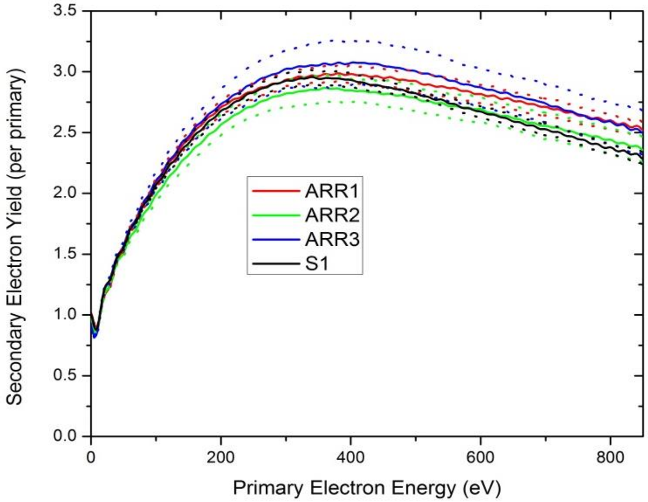
Micro-Channel Plate Development



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

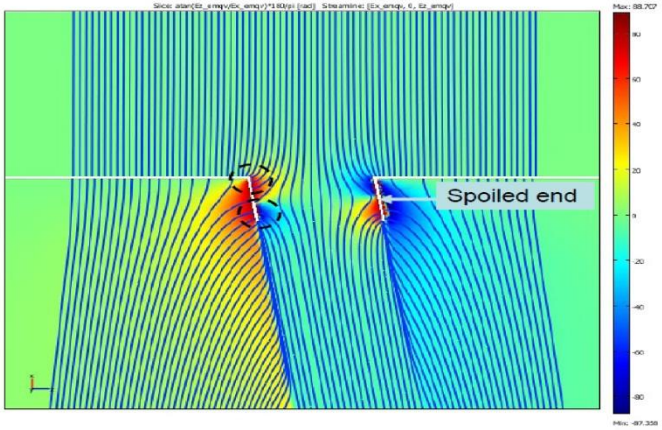


Incom 8"-sq high-quality MCP plate with > 65% OAR



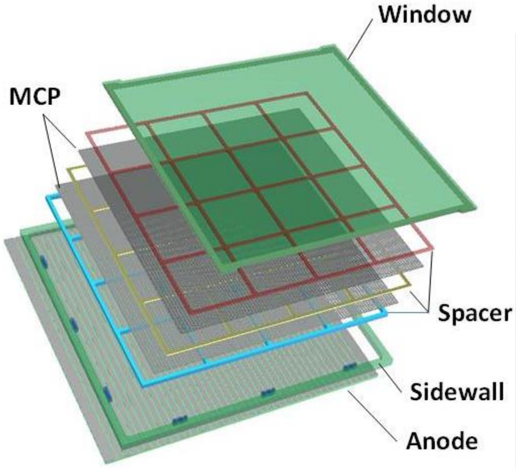
Characterization of SEY of emitting materials (ANL/MSD, here for Arradiance)

Spoiled end. Color: field angle

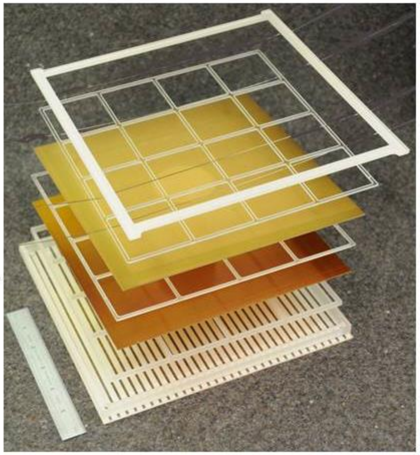


Detailed simulation of MCP's and materials; comparison with data

The Half-Meter-Squared SuperModule



Design Drawing - September 2010



Actual Glass Parts - April 2012

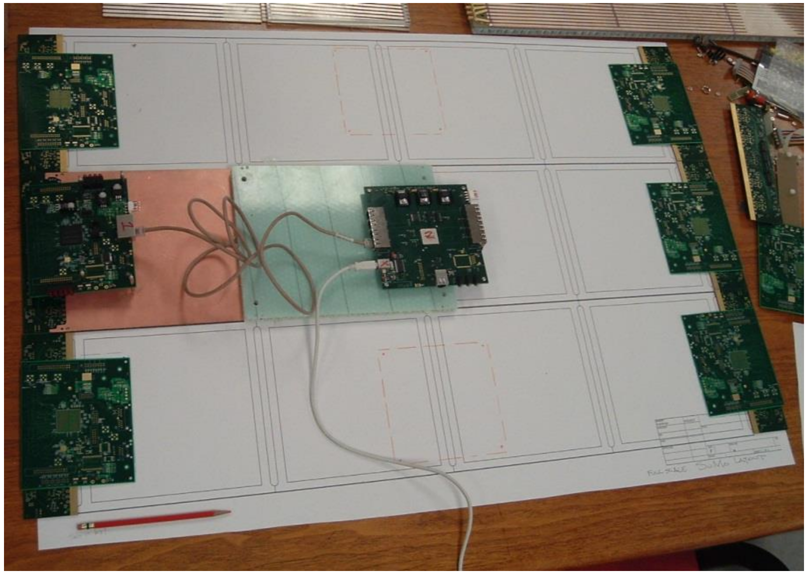
A `tile' is a sealed vacuum-tube with cathode, 2 MCP's, RF-strip anode, and internal voltage divider

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



Looking beyond first tiles: high performance photodetectors

1. High QE- photocathodes-
2. High volume/lower cost --innovative production techniques (both assembly and design)
3. Application-specific anodes: pads, patterns, crossed-delay lines, …
4. Electronics, complete systems, packaging

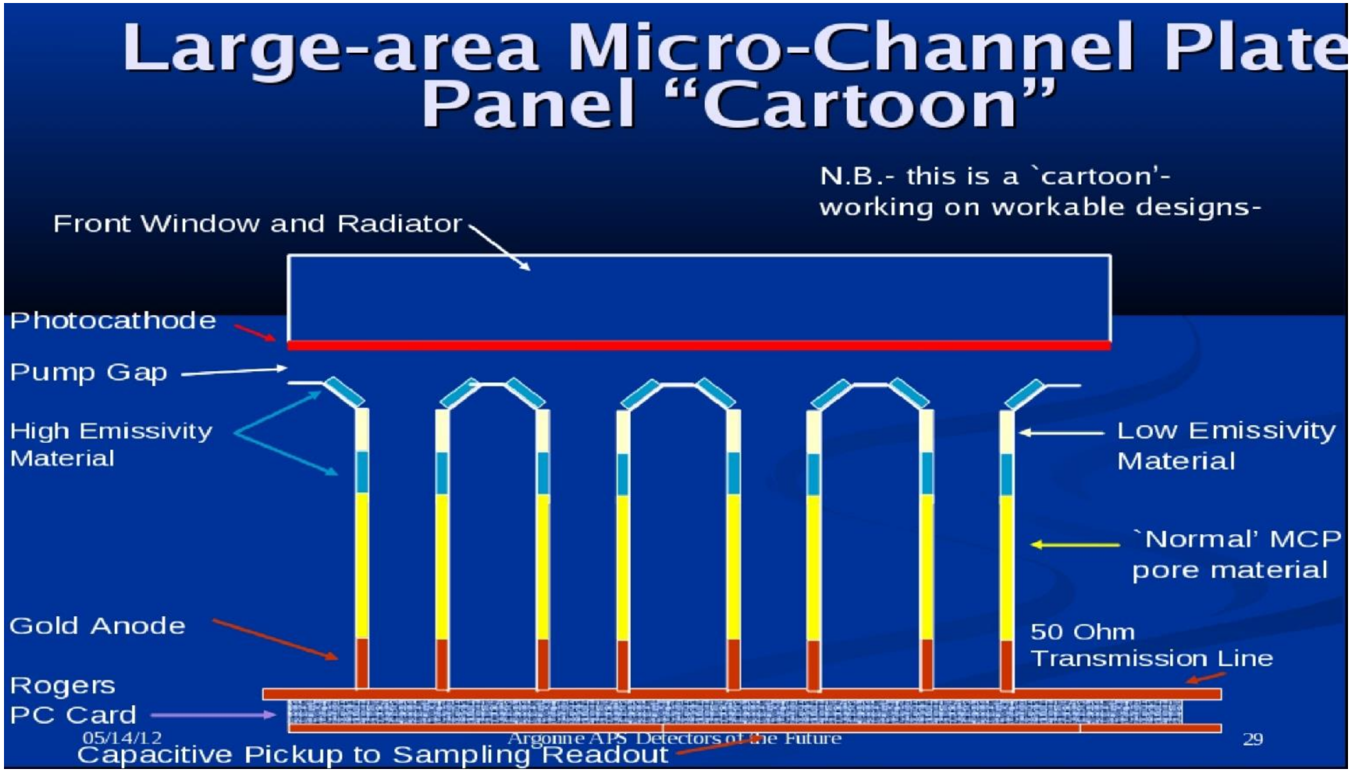
Need a coherent effort, with an eye on the competition.

Essential Innovations from conventional MCP-PMT’s

- 8” hardglass (`pyrex’) substrates (Incom)
- Proprietary resistive layer (ANL/ESD)
- `Frugal’ plate-glass body, water-jet cut
- Glass frit bottom seal over anode traces
- Silk-screened frugal transmission line anodes
- No-pin ALD-based resistive HV divider
- >15 GS/sec waveform-sampling ASICs
- Local analysis FPGA-based DAQ->time,space
- Modular design for large-area coverage
- `Femtosec’ laser testing (ANL/XSD)

Looking beyond first tiles: high performance photodetectors

1. Sub-psec time resolution: Ritt extrapolation gives 100 fsec at 3GHz (but settle for 500)
2. Funnels, reflective geometry, high-ABW anodes

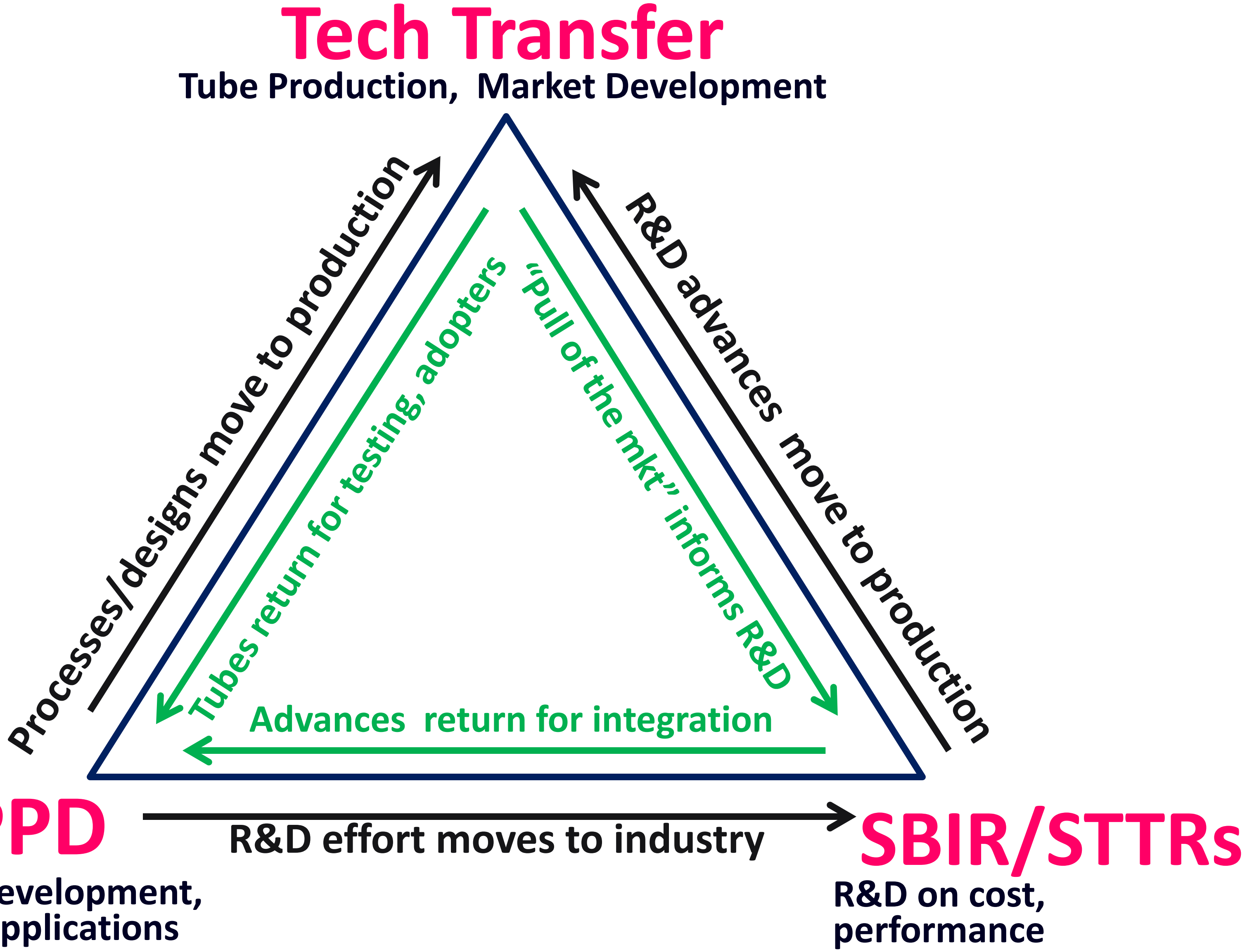


Large-area Micro-Channel Plate Panel "Cartoon"

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

Sub-psec is possible (I'm willing To bet $)

The Transition from 3 Years of R&D to Applications: Roles of SBIR/STTR and TTO



Tech Transfer

Tube Production, Market Development

Processes/designs move to production

Tubes return for testing, adopters

"Pull of the mkt" informs R&D

R&D advances move to production

Advances return for integration

LAPPD

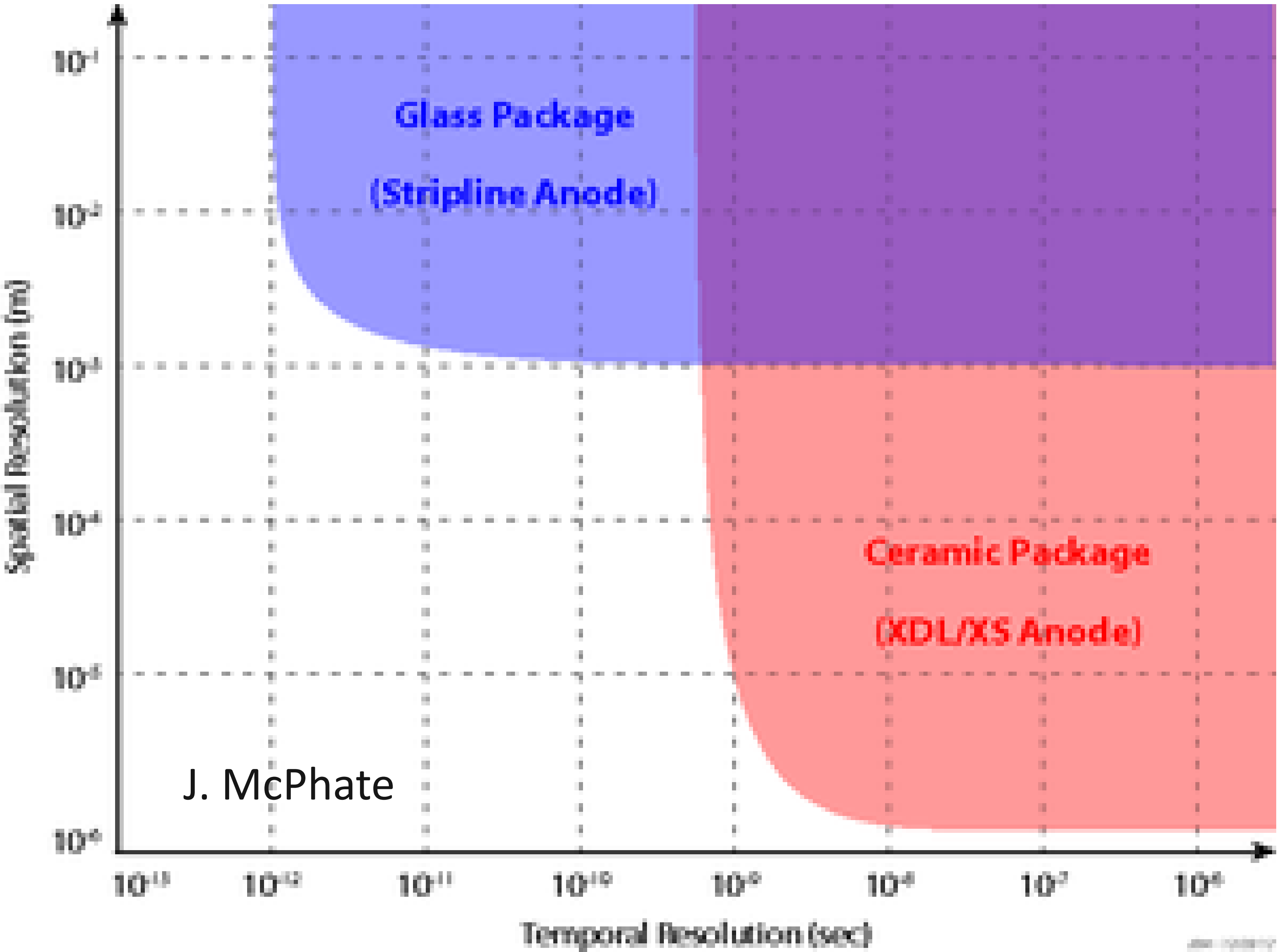
Process development,
Testing, Applications

R&D effort moves to industry

SBIR/STTRs

R&D on cost,
performance

Complementarity of 2 Packages



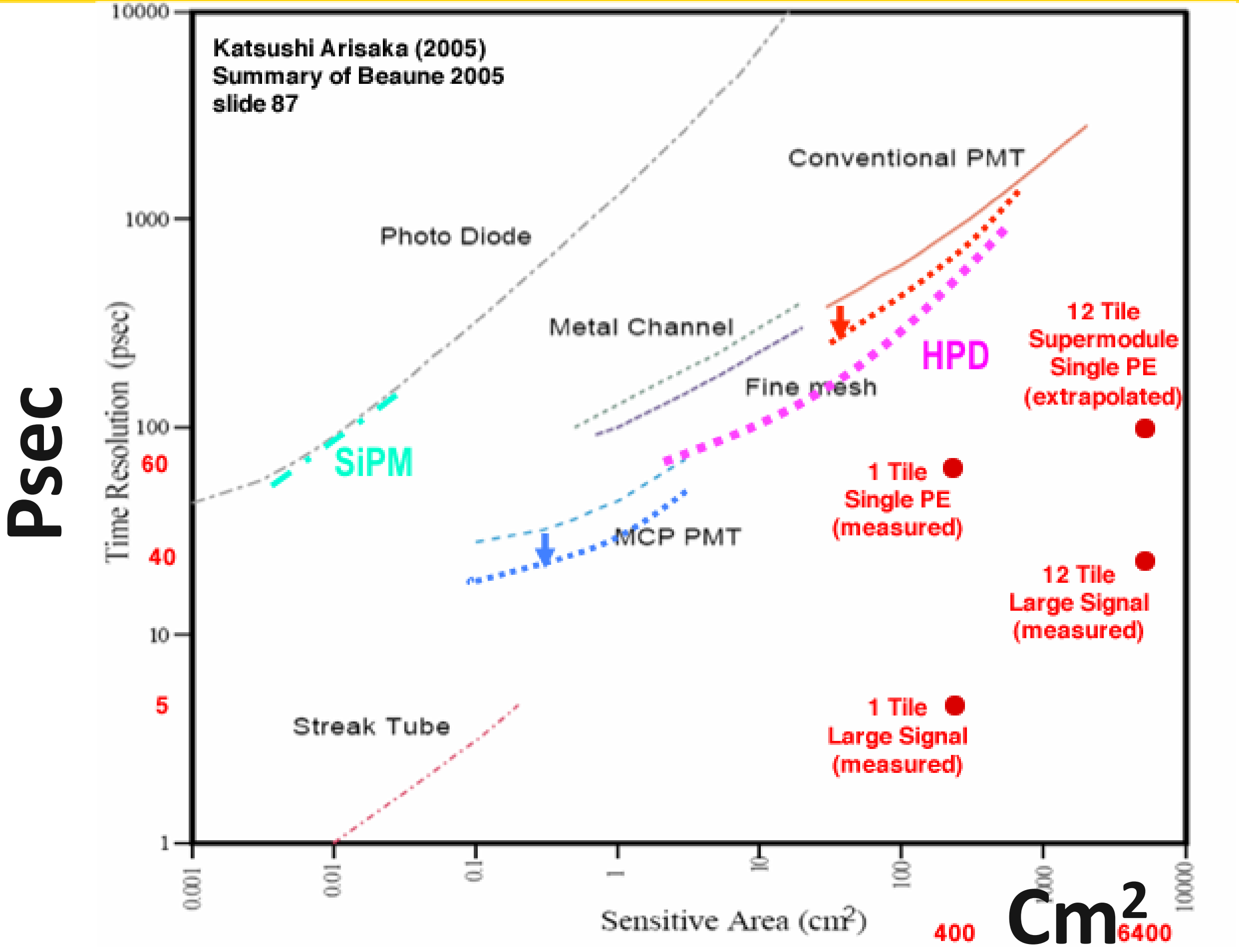
J. McPhate

Comparison with existing detectors

K. Arisaka; UCLA

Time Resolution vs. Sensitive Area

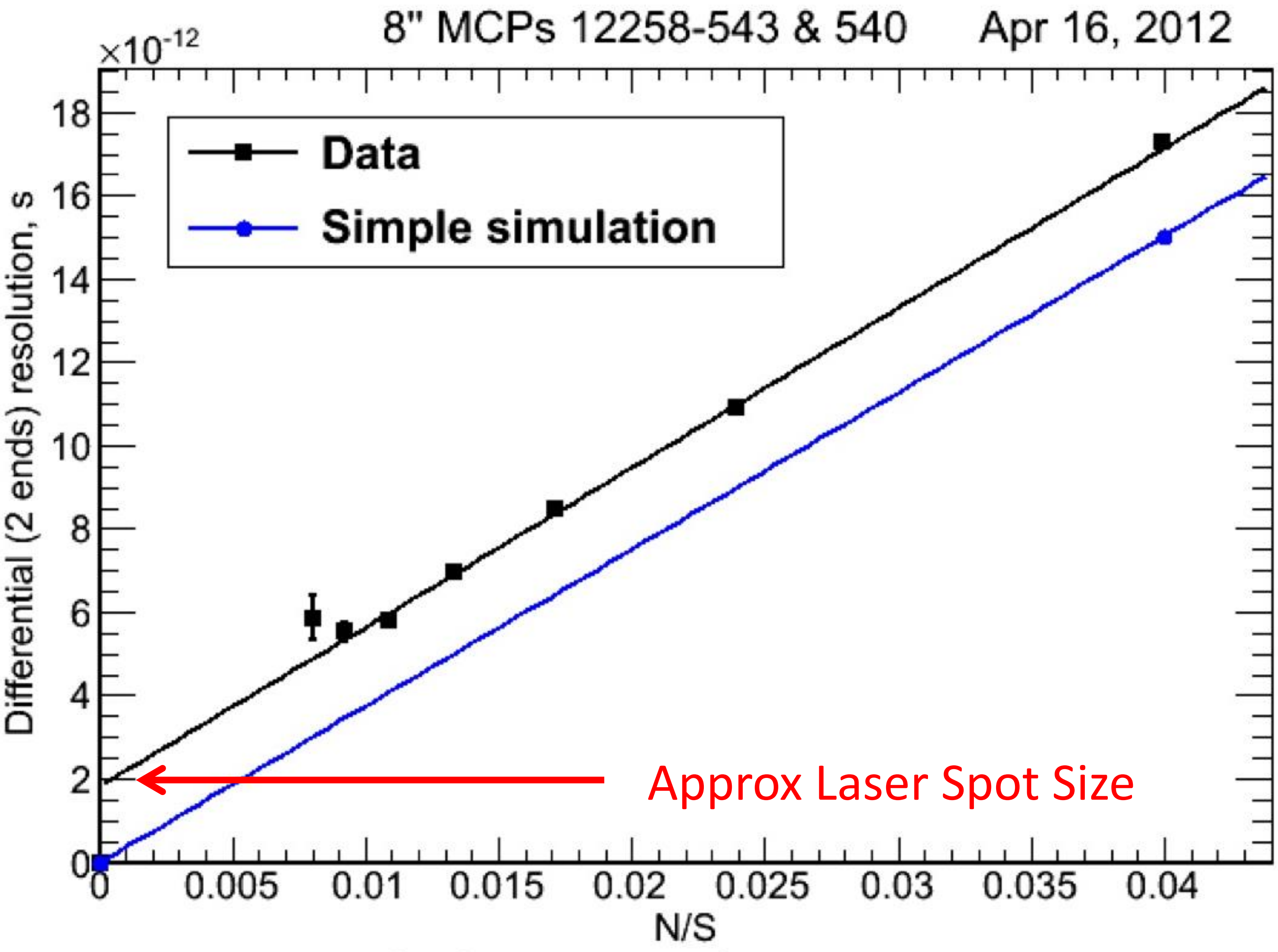
(Beaune 1999 → 2005)



24 June 2005 *K. Arisaka* *87*

Measured Timing Resolution on 8” Pair

pico-seconds



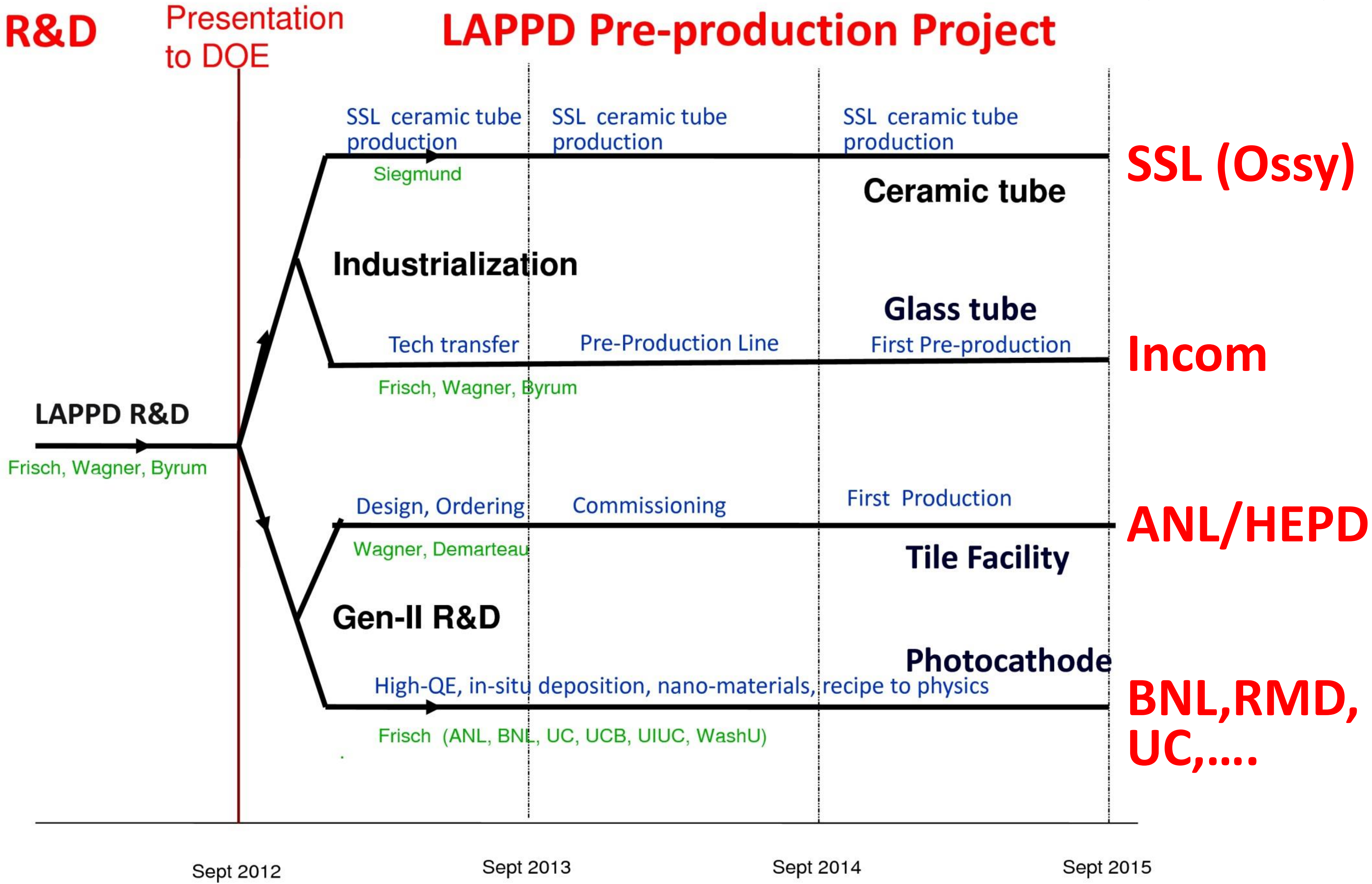
Approx Laser Spot Size

N = RMS of the noise; S = signal amplitude

The 2013 Transition from LAPPD to Production: The 4 Parallel Paths

Dec 12, 2012 Presentation to DOE

(a UC view)



R&D

Presentation to DOE

LAPPD Pre-production Project

SSL ceramic tube production

SSL ceramic tube production

SSL ceramic tube production

Siegmund

Ceramic tube

SSL (Ossy)

Industrialization

Glass tube

Tech transfer

Pre-Production Line

First Pre-production

Incom

Frisch, Wagner, Byrum

LAPPD R&D

Frisch, Wagner, Byrum

Design, Ordering

Commissioning

First Production

ANL/HEPD

Wagner, Demarteau

Tile Facility

Gen-II R&D

Photocathode

High-QE, in-situ deposition, nano-materials, recipe to physics

BNL,RMD, UC,….

Frisch (ANL, BNL, UC, UCB, UIUC, WashU)

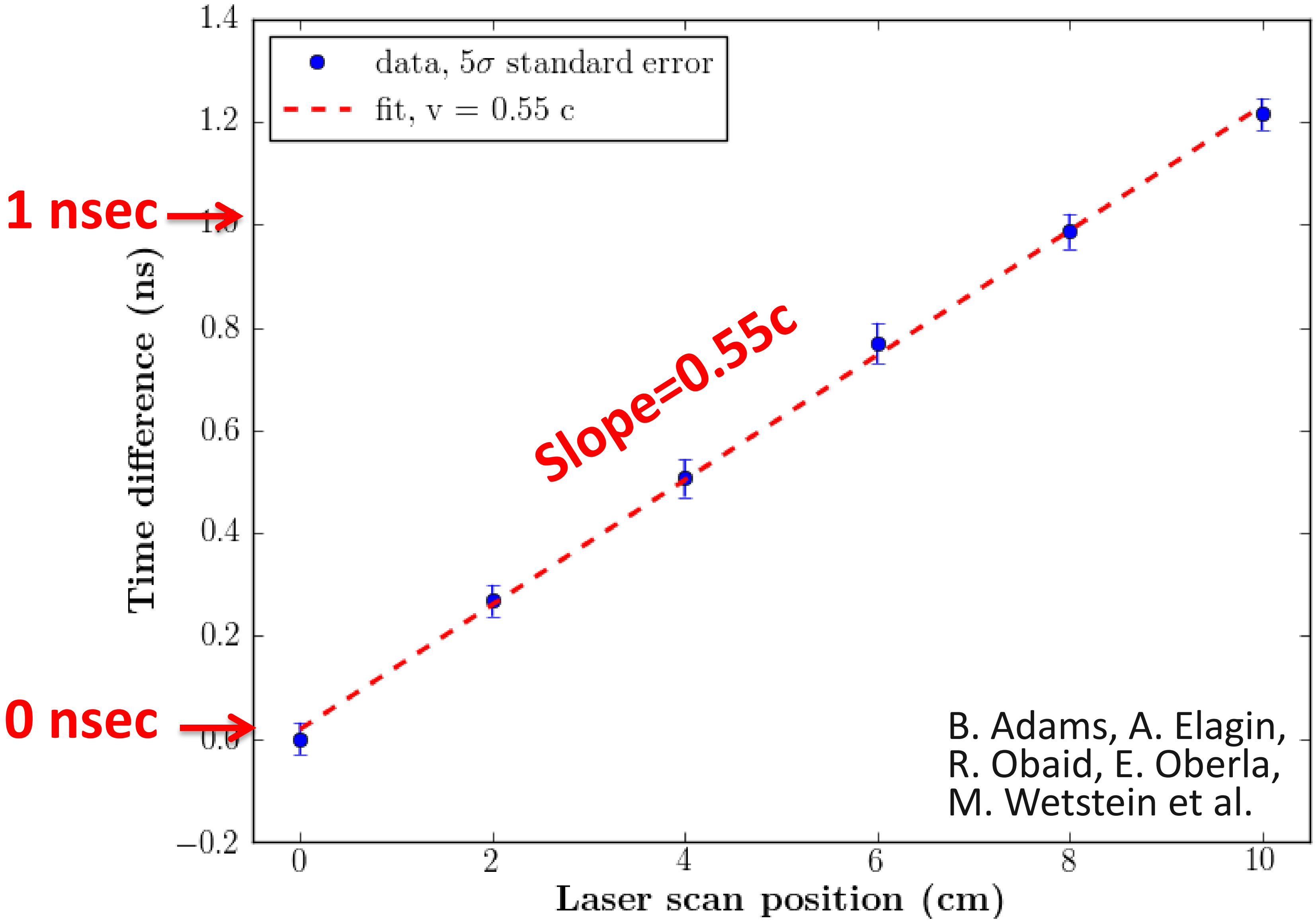
Sept 2012

Sept 2013

Sept 2014

Sept 2015

Position Measuring ANL APS Demountable Tile



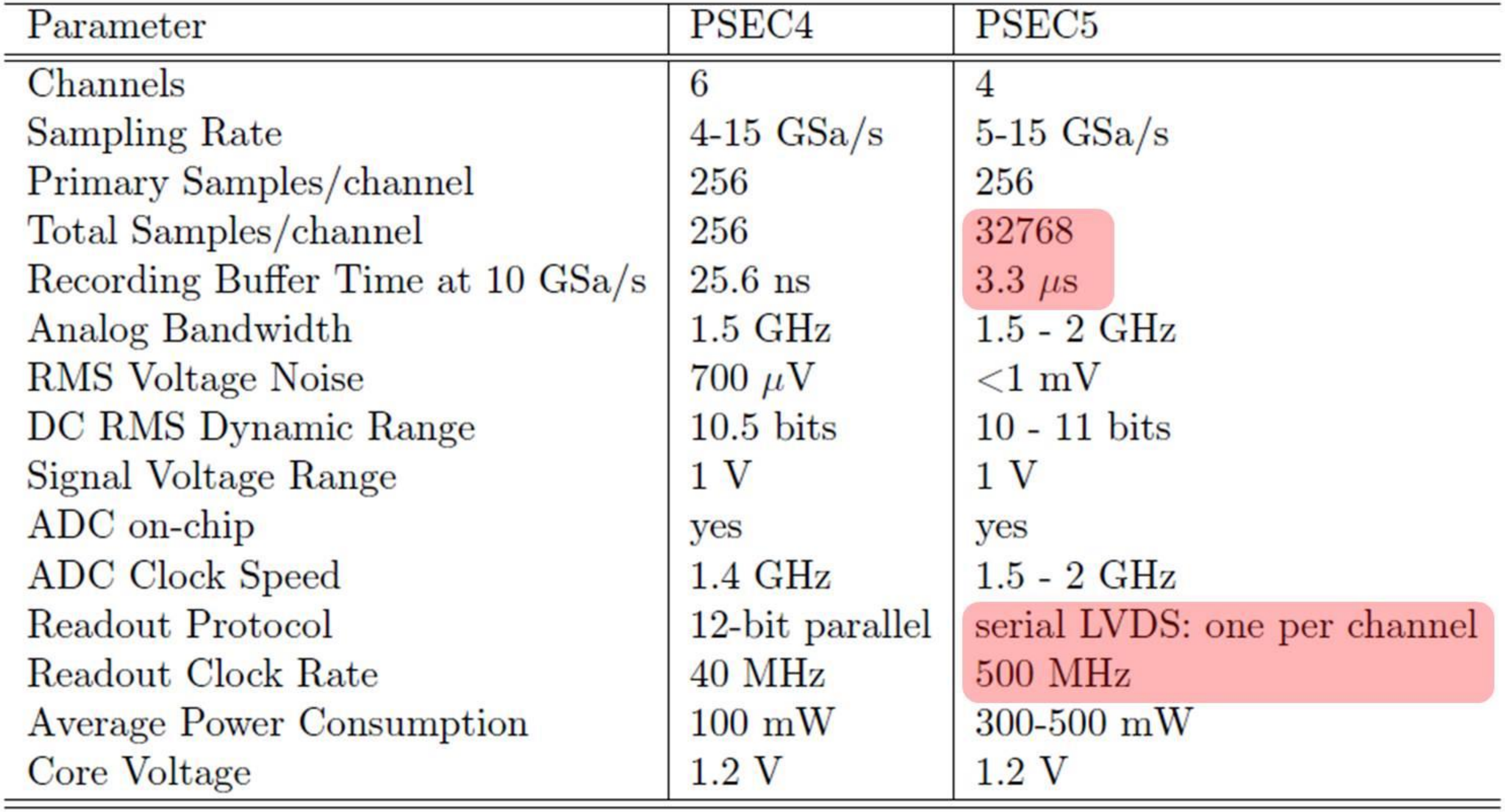
1 nsec

0 nsec

Slope=0.55c

B. Adams, A. Elagin,
R. Obaid, E. Oberla,
M. Wetstein et al.

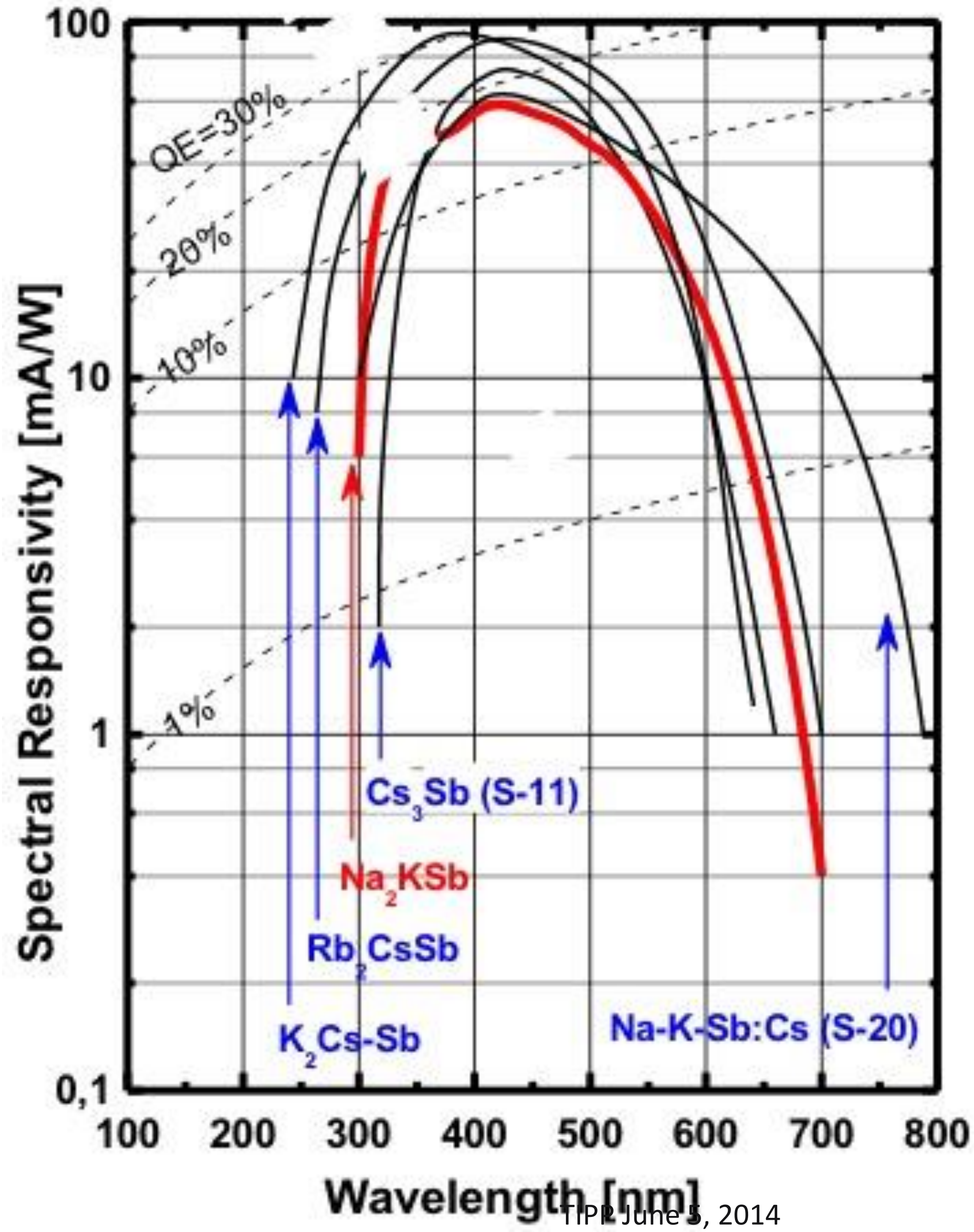
Next Gen Waveform Sampling PSEC5 specs (Hawaii, Innosys, and Chicago)



Parameter	PSEC4	PSEC5
Channels	6	4
Sampling Rate	4-15 GSa/s	5-15 GSa/s
Primary Samples/channel	256	256
Total Samples/channel	256	32768
Recording Buffer Time at 10 GSa/s	25.6 ns	3.3 μs
Analog Bandwidth	1.5 GHz	1.5 - 2 GHz
RMS Voltage Noise	700 μV	<1 mV
DC RMS Dynamic Range	10.5 bits	10 - 11 bits
Signal Voltage Range	1 V	1 V
ADC on-chip	yes	yes
ADC Clock Speed	1.4 GHz	1.5 - 2 GHz
Readout Protocol	12-bit parallel	serial LVDS: one per channel
Readout Clock Rate	40 MHz	500 MHz
Average Power Consumption	100 mW	300-500 mW
Core Voltage	1.2 V	1.2 V

Eric Oberla table

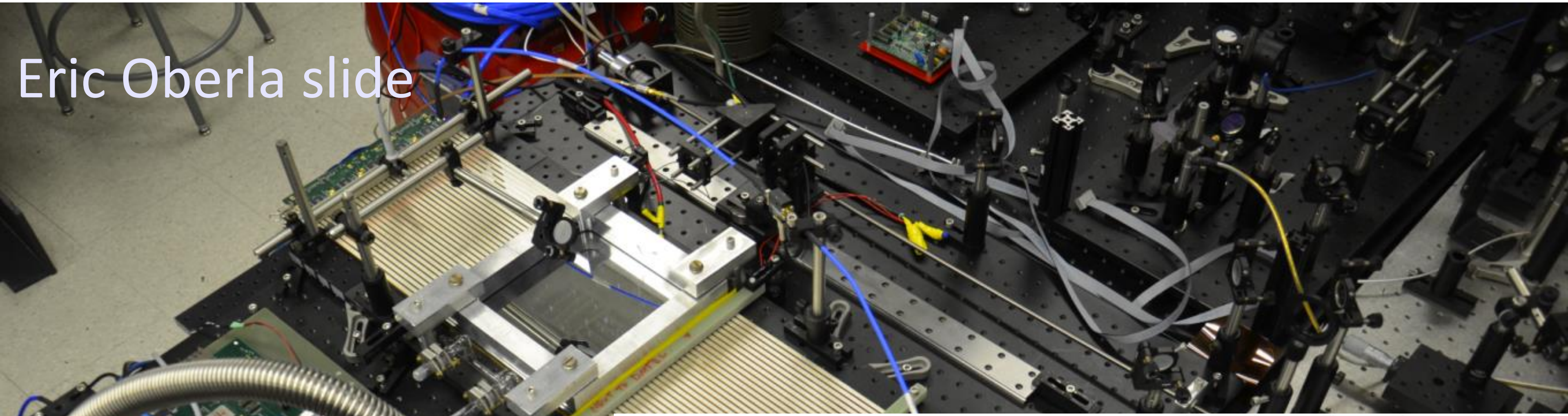
Alkali Cathode Spectral Responses

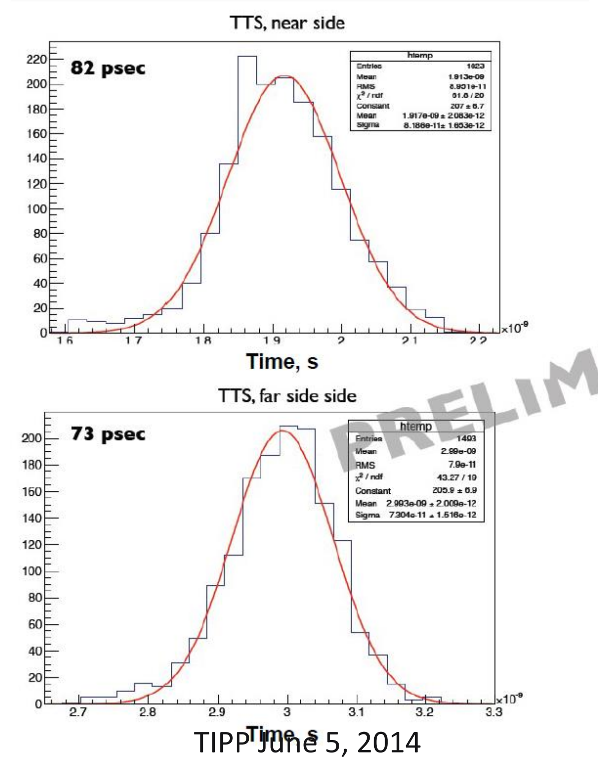


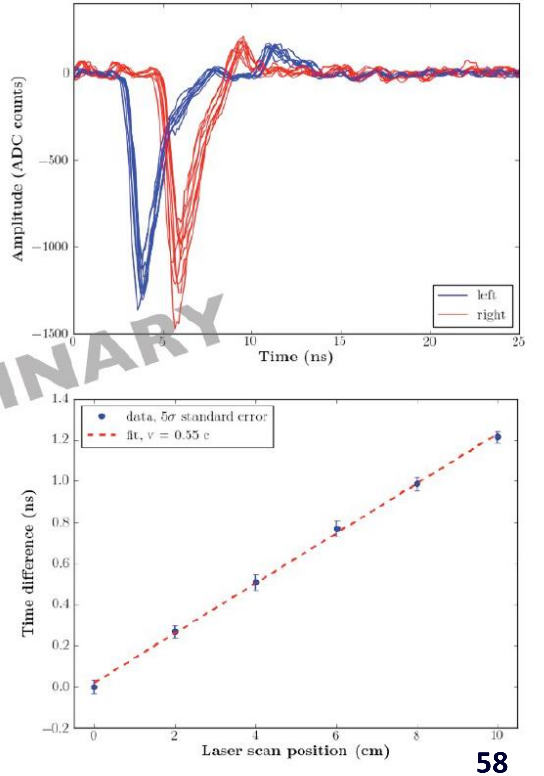
From A. Lyashenko
First Photocathode
Workshop
UC July 2009

LAPPD system example: The ‘supermodule’: APS testing (many thanks to Bernhard Adams, ANL+ others- see RSI paper)

Eric Oberla slide



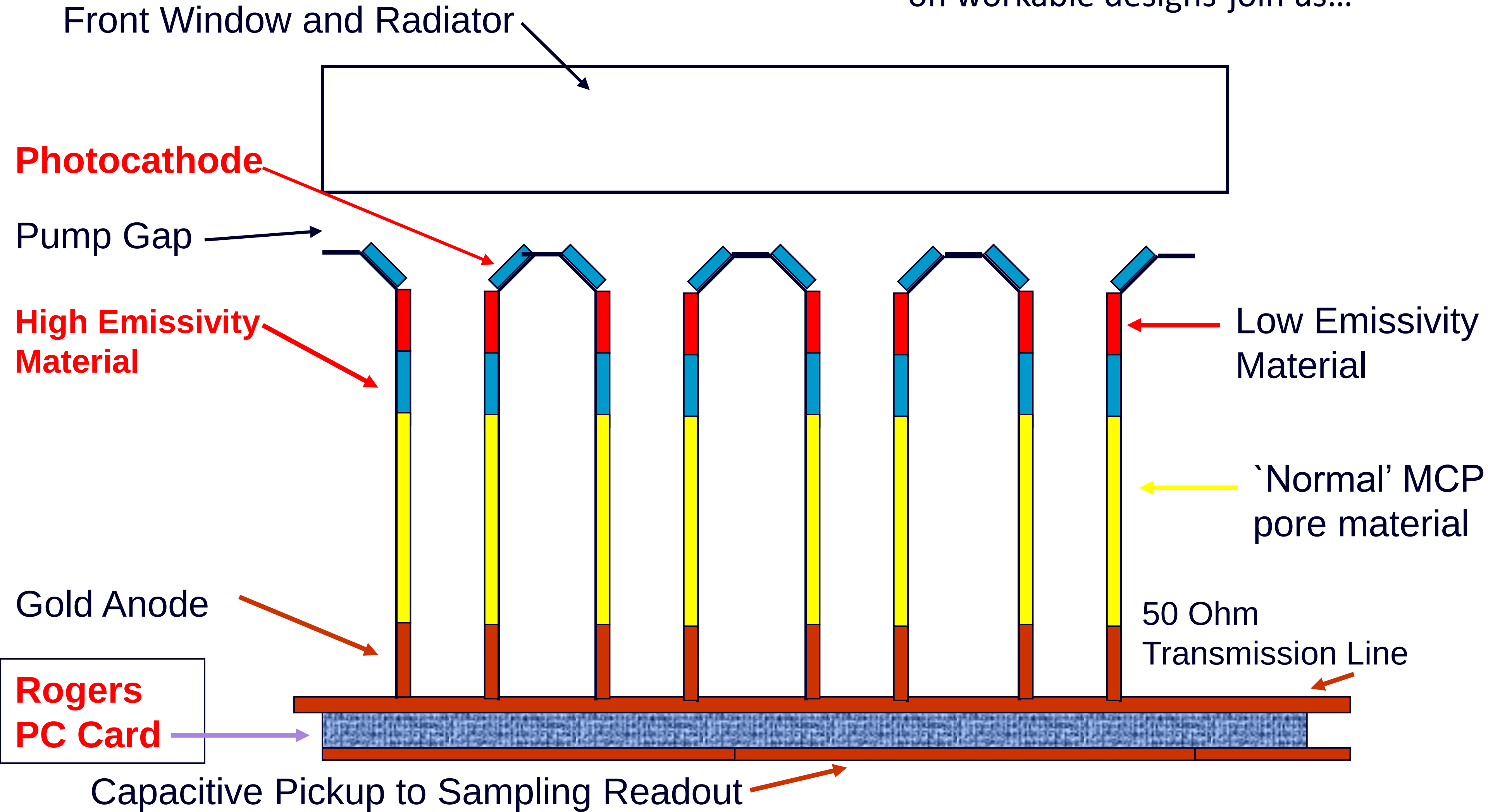




What’s the limit? (2009 cartoon)

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

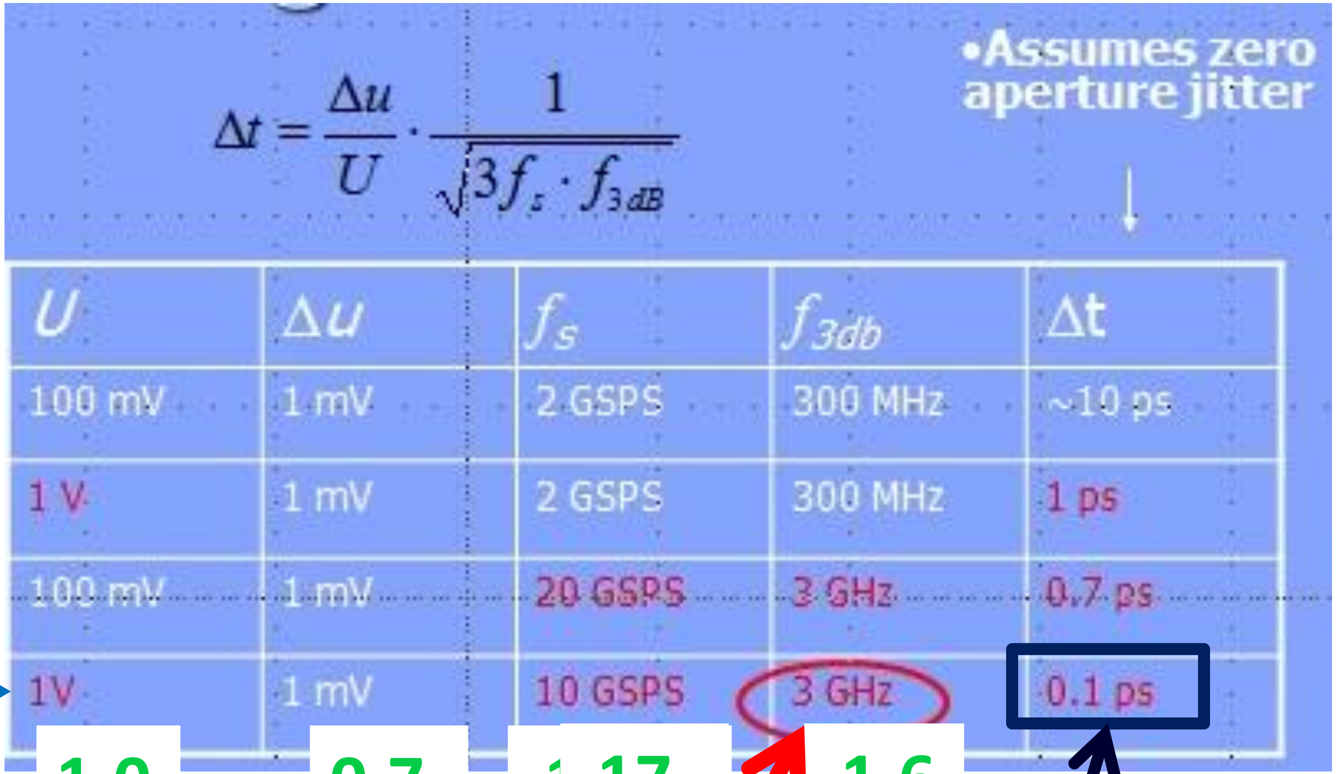
N.B.- this is a `cartoon’- working on workable designs-join us…



Going Another Order-of-Magnitude

Stefan Ritt slide, doctored

(agrees with JF MC)



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

- Assumes zero aperture jitter

U	Δu	f_s	f_{3db}	Δt
100 mV	1 mV	2 GSPS	300 MHz	~10 ps
1 V	1 mV	2 GSPS	300 MHz	1 ps
100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
1V	1 mV	10 GSPS	3 GHz	0.1 ps

For 100 fsec →

1.0 0.7 1 17 1.6

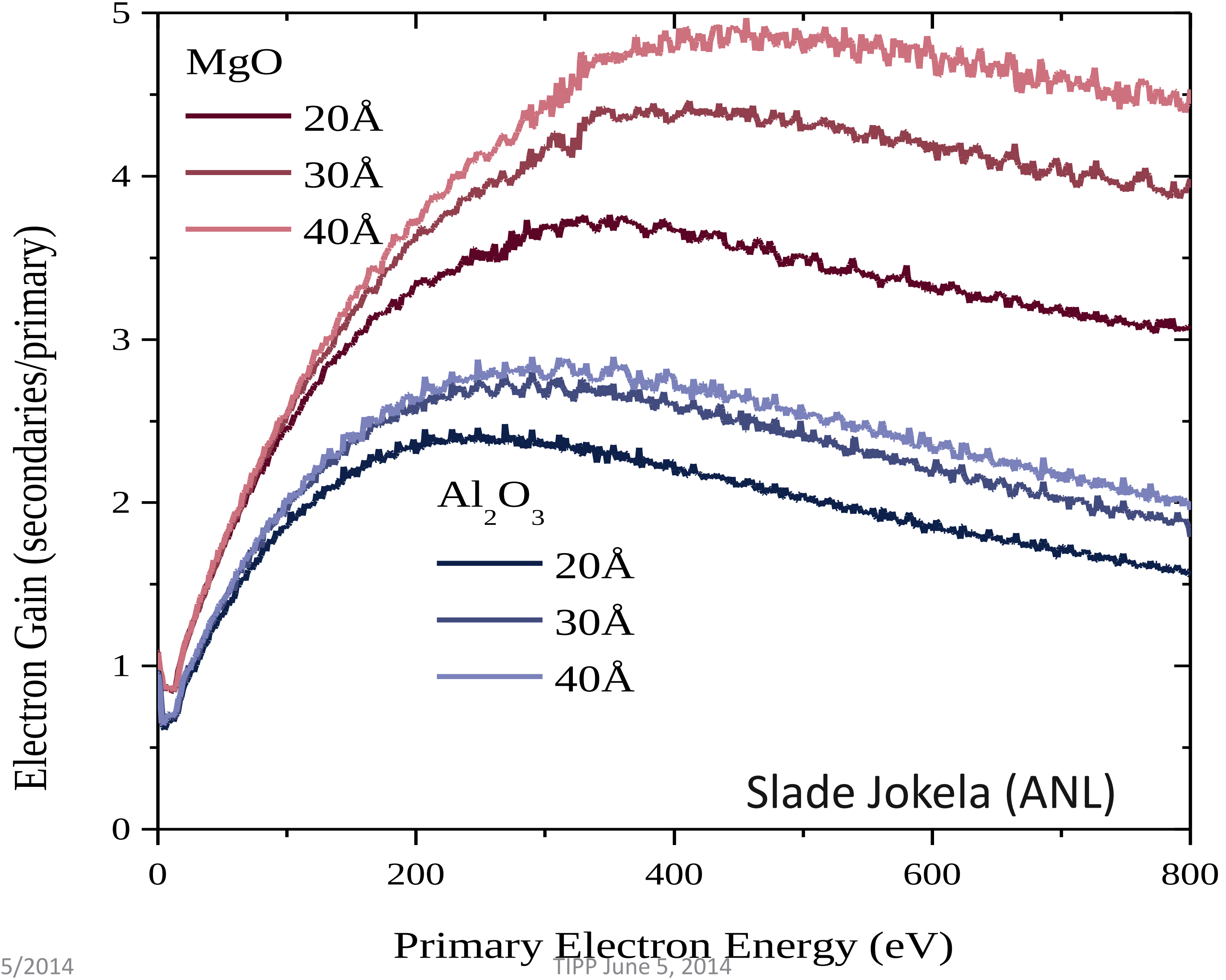
Achieved by LAPPD

100 Femtosec (!)

Subject of a 2013 SBIR with Innosys, SLC

Differential TOF: 1.5m path

Δt:	γ	e	π	K	p
(ps)	0	10^{-6}	0.13	1.6	6.25

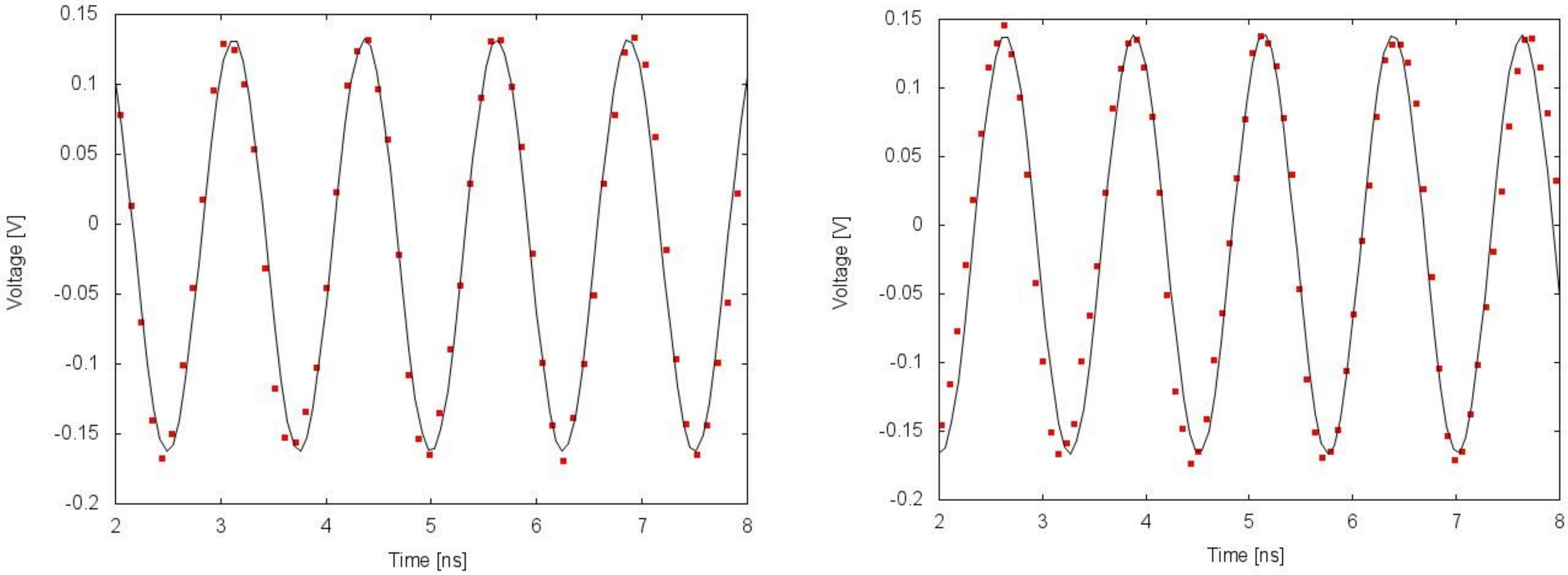

Electron Gain (secondaries/primary)
0
1
2
3
4
5
MgO
20Å
30Å
40Å
Al_2O_3
20Å
30Å
40Å
Slade Jokela (ANL)
0
200
400
600
800
Primary Electron Energy (eV)

PSEC-4 Performance

Eric Oberla, ANT11

Digitized Waveforms

Input: 800MHz, 300 mV$_{pp}$ sine



Sampling rate : 10 GSa/s

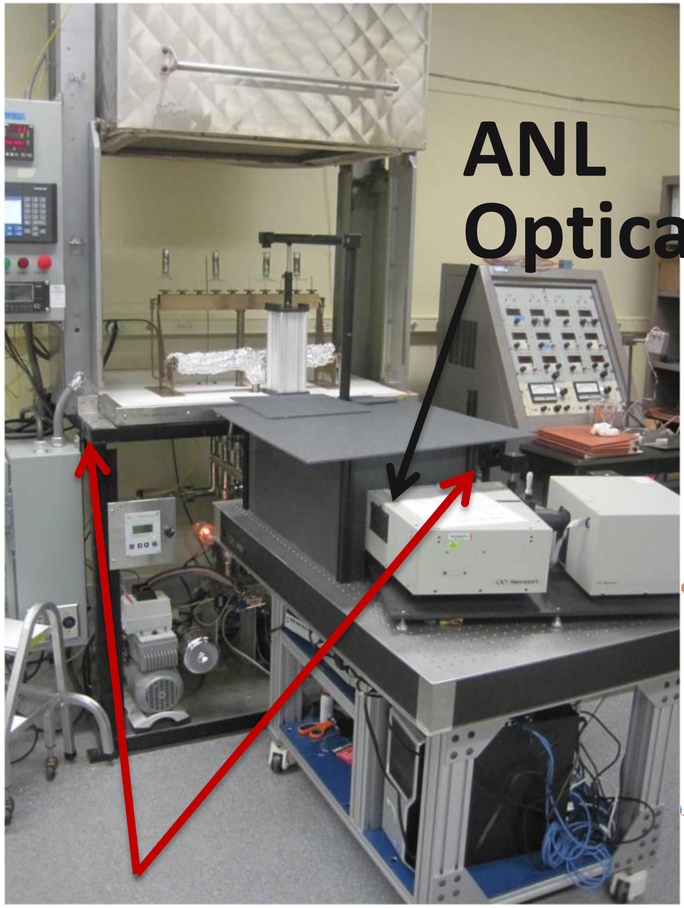
Sampling rate : 13.3 GSa/s

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

Photocathodes

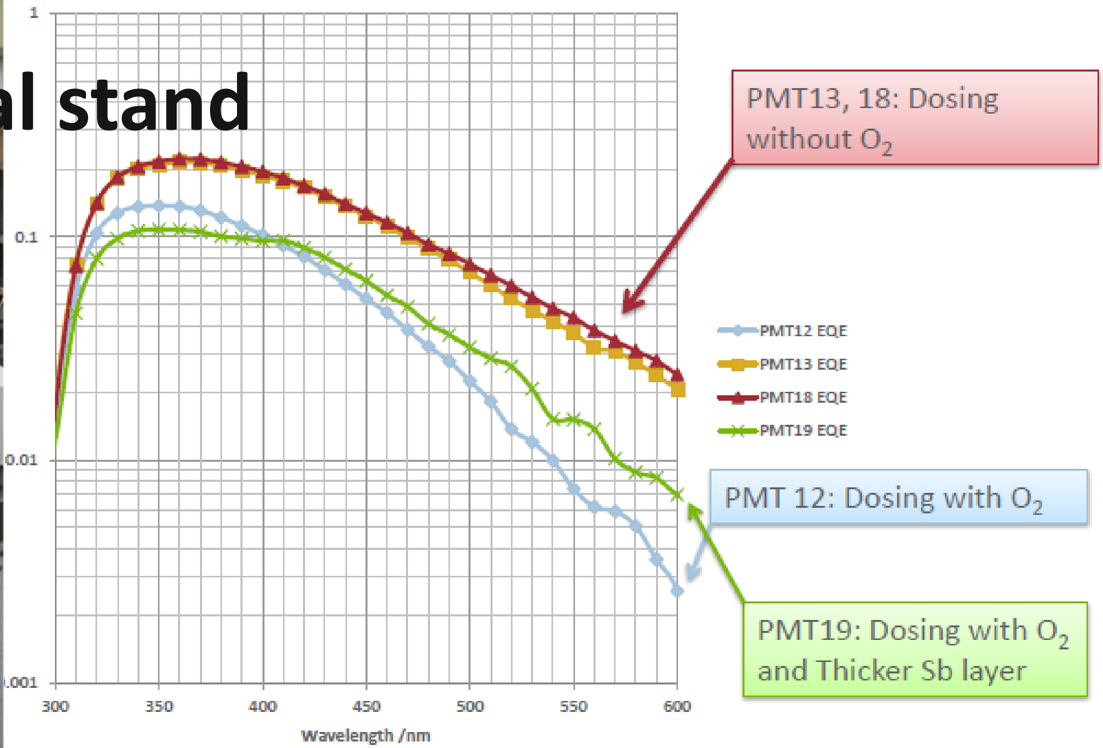
LAPPD goal- 20-25% QE, 8”-square- conv. alkali

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



ANL Optical stand

Burle commercial equipment



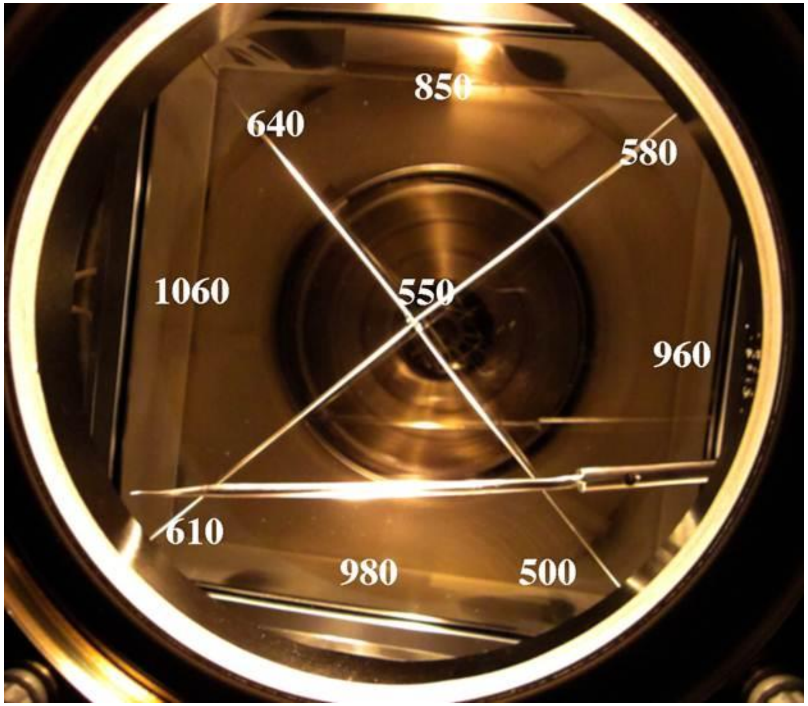
PMT13, 18: Dosing without O_2

PMT 12: Dosing with O_2

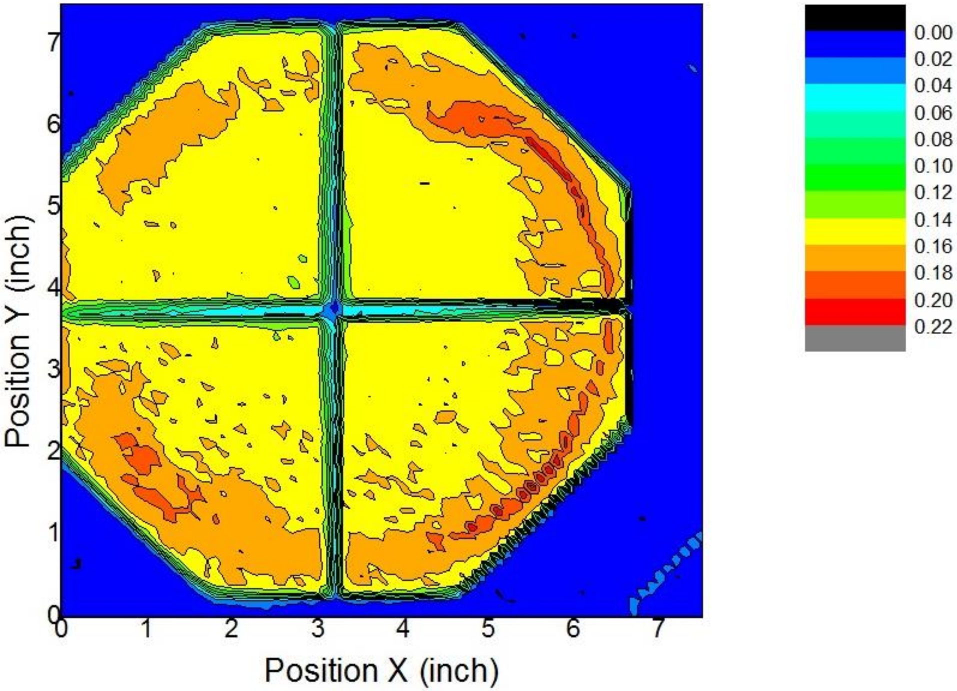
PMT19: Dosing with O_2 and Thicker Sb layer

First cathodes made at ANL

Cathode Major Achievements

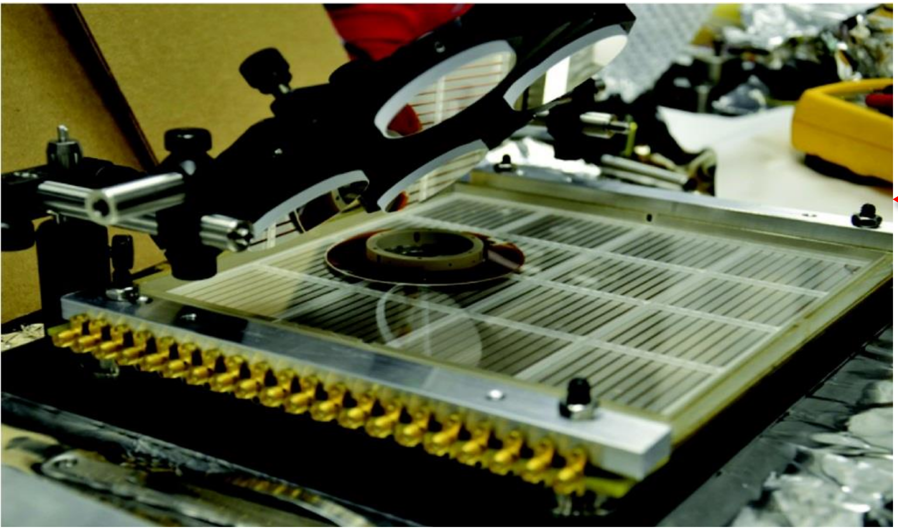


A successful 8” Bialkali Cathode (Ossy’s Talk)

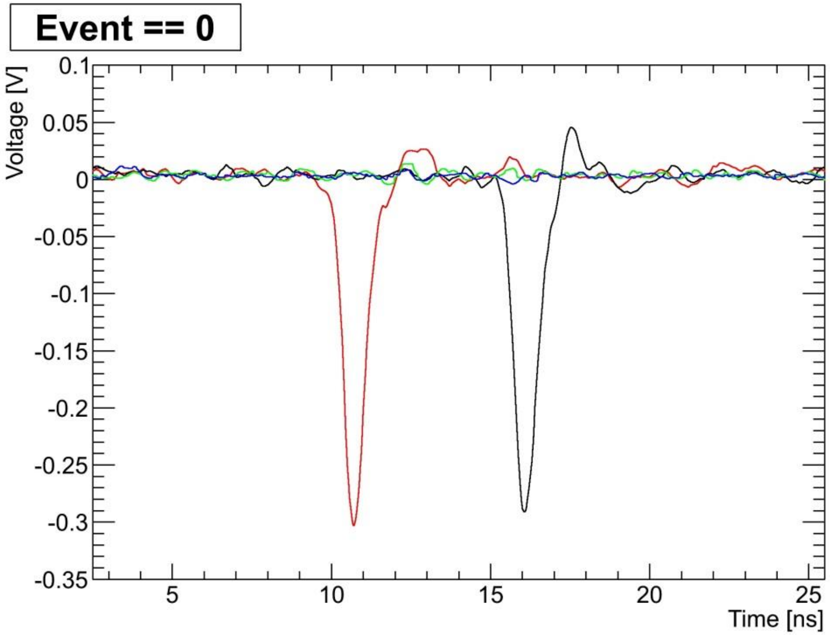


A 8” Bialkali made in the Burle Equip at ANL (Ossy’s Talk)

8”-MCP Pair and Strip Anode Work



Laser mirrors and 8” anode for 8” MCP tests



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

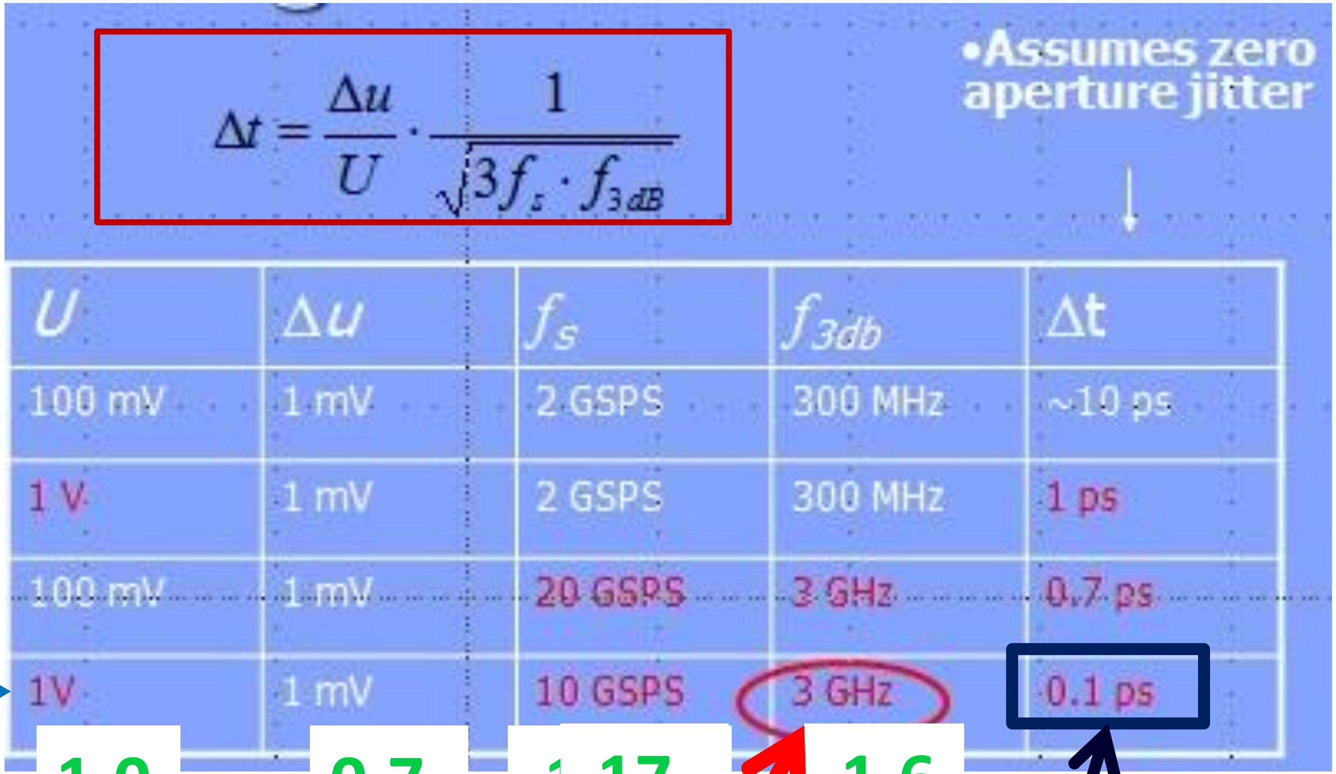
Matt Wetstein, Bernhard Adams, Andrey Elagin, Razib Obaid, Sasha Vostrikov, Bob Wagner

Going Another Order-of-Magnitude

Stefan Ritt slide from 2nd Photocathode Workshop*

(annotated by HJF)

*see psec library web page



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

•Assumes zero aperture jitter

U	Δu	f_s	f_{3db}	Δt
100 mV	1 mV	2 GSPS	300 MHz	~10 ps
1 V	1 mV	2 GSPS	300 MHz	1 ps
100 mV	1 mV	20 GSPS	3 GHz	0.7 ps
1V	1 mV	10 GSPS	3 GHz	0.1 ps
	1.0	0.7	1 17	1.6

For 100 fsec →

Achieved by LAPPD

100 Femtosec (!)

(Yes, but… But, quantitatively, what are the reasons why not?) Needs a dedicated simulation program

Differential TOF: 1.5m path

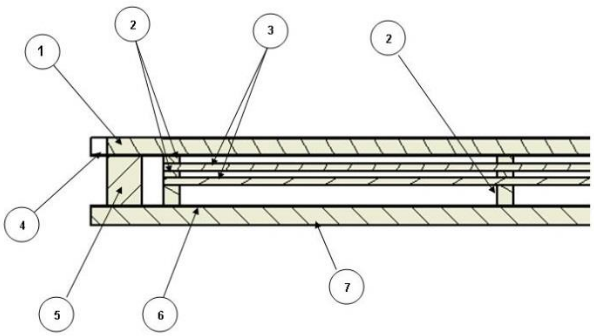
Δt:	γ	e	π	K	p
(ps)	0	10^{-6}	0.13	1.6	6.25

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);**

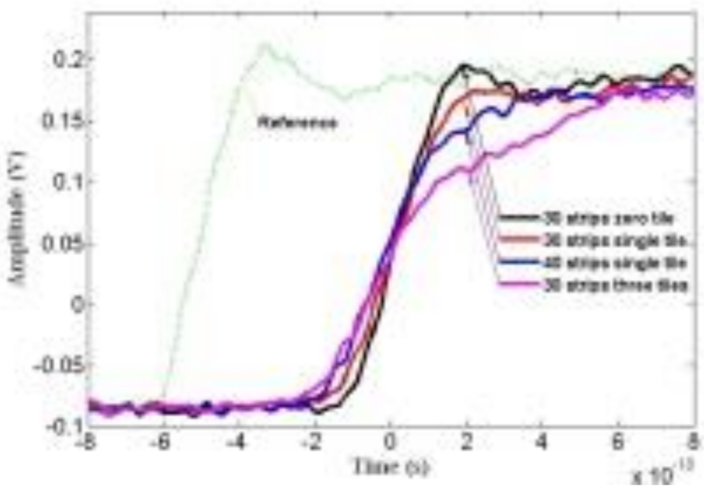
37b Needs: Bandwidth > 3 GHz for Δt < 1 psec

MCP-PMT as 3D waveguide

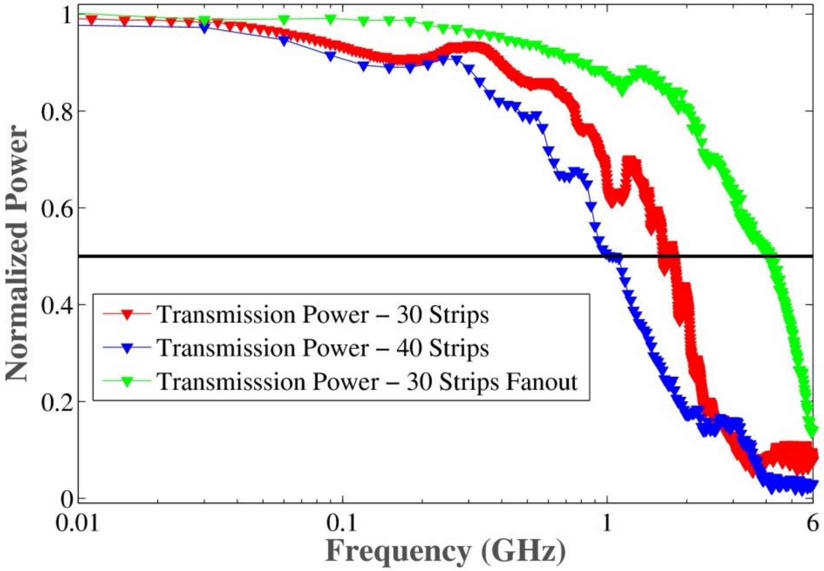


1. Top window with photocathode on inside
2. Grid spacers
3. Microchannel plates
4. HV contact
5. Side wall
6. Anode transmission lines
7. Bottom window

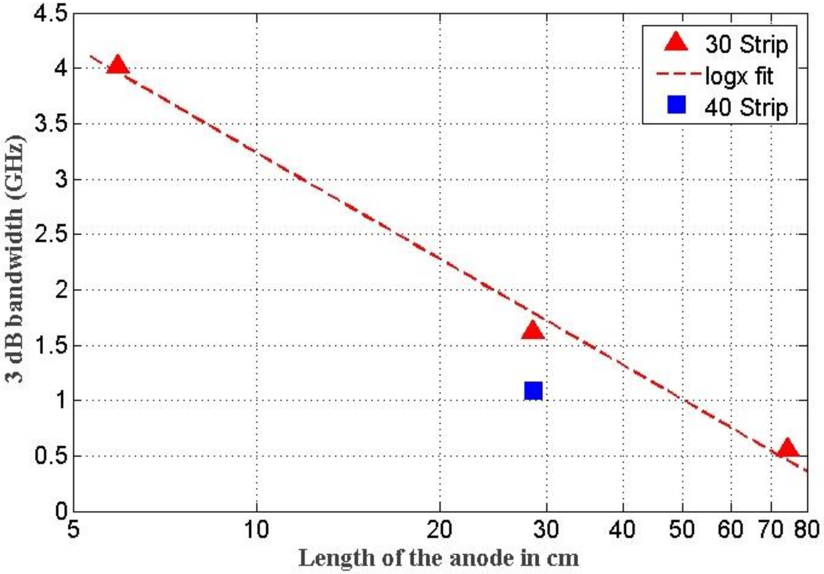
Anode risetimes (step function)



Analog bandwidth of `frugal' anode



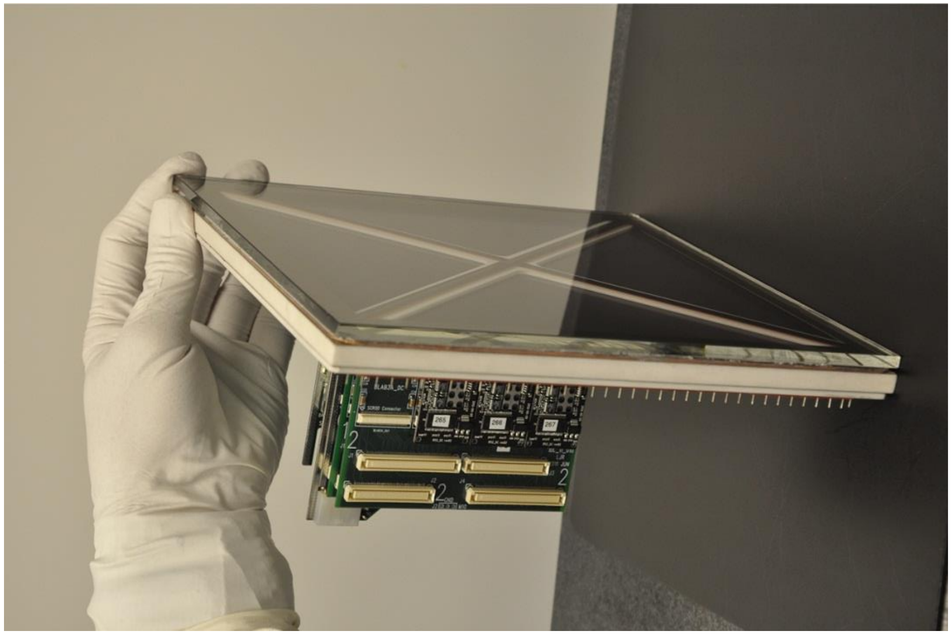
Bandwidth 3db point vs Anode length



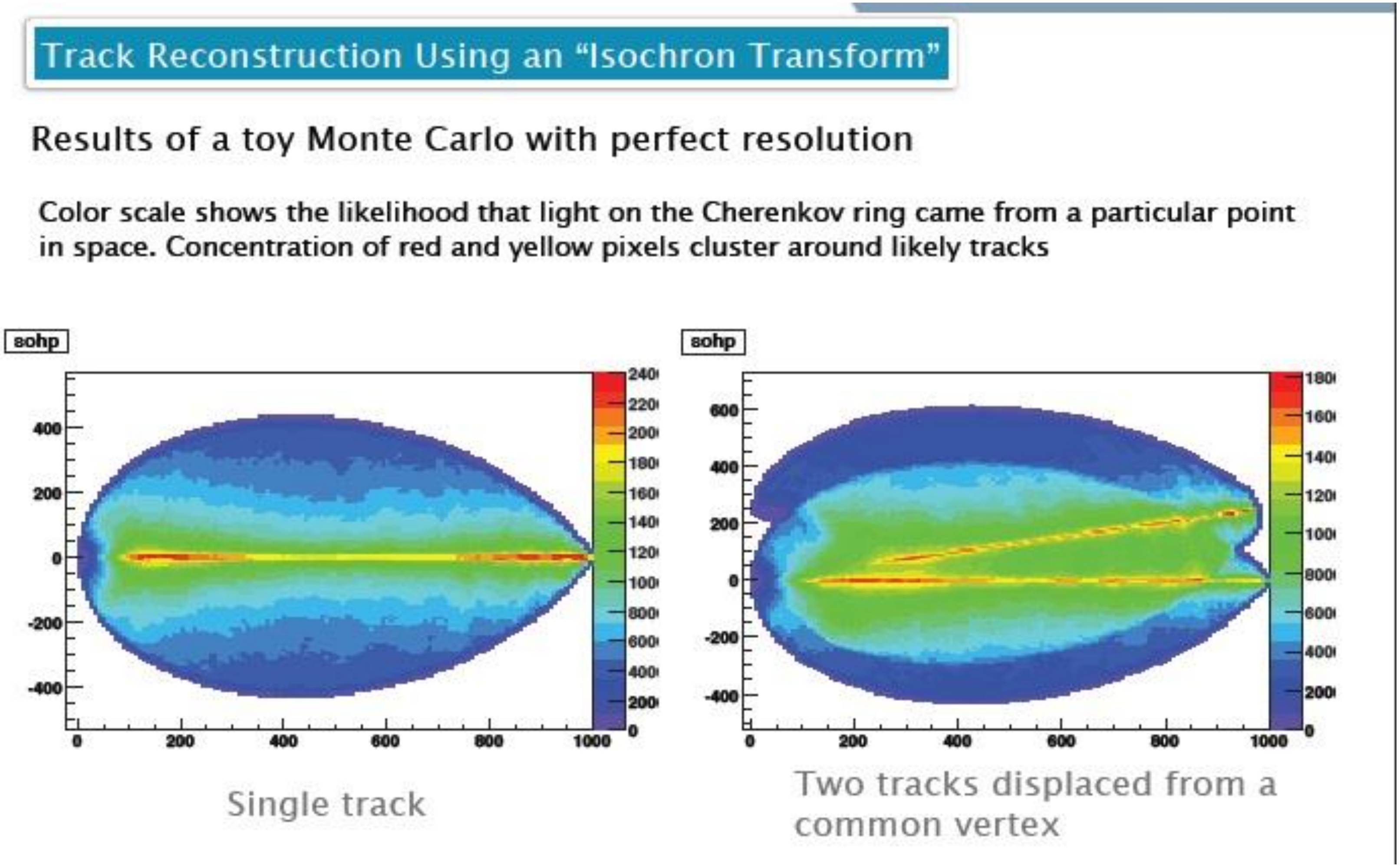
Packaging Major Achievements

Development of a `frugal' glass tile package with internal HV divider, capacitive GHz readout (Andrey's and Matt's Talks)

Development of a complete ceramic package system design (Jason's and Ossy's talks)



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

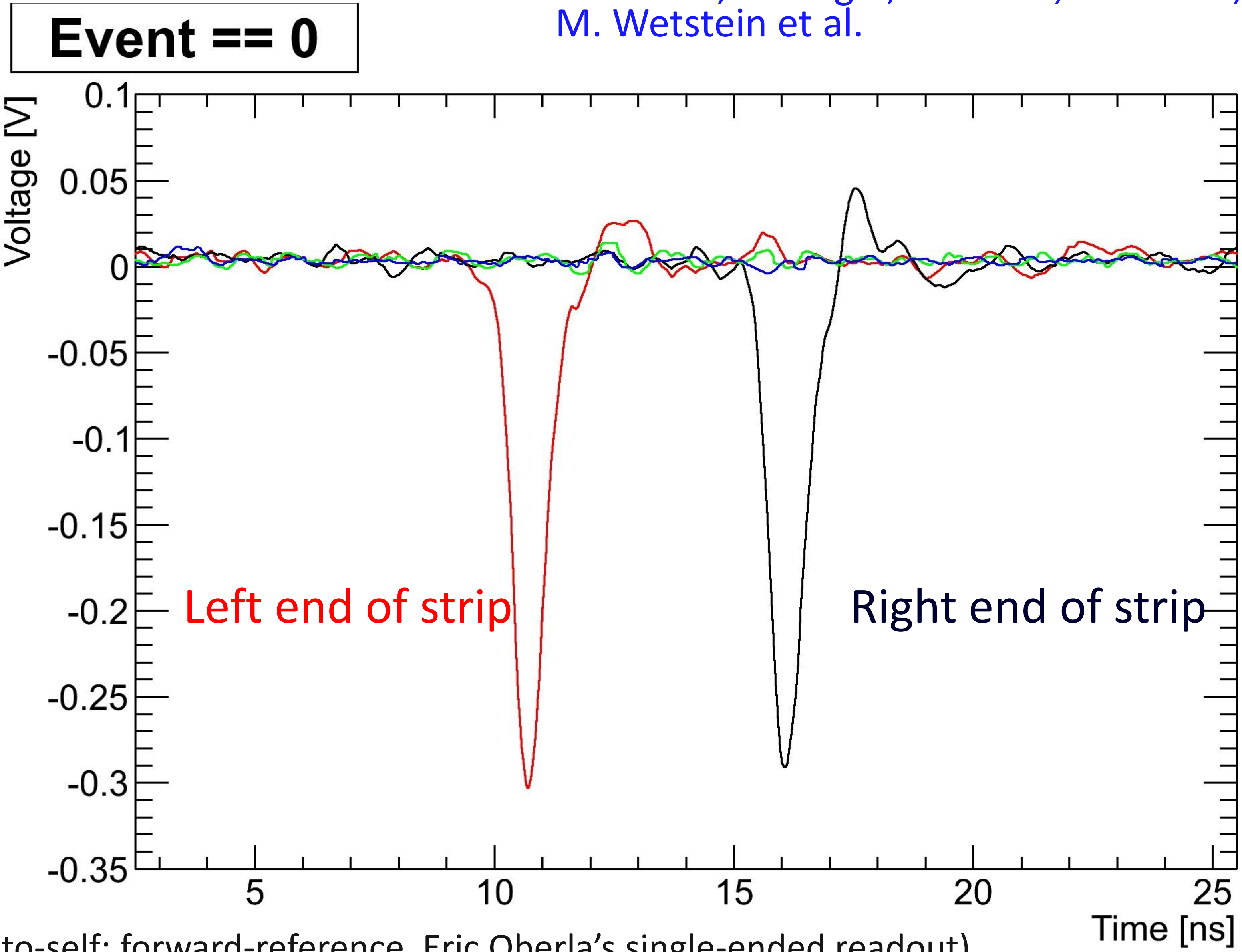
Single track

Two tracks displaced from a common vertex

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

Pulses from a pair of 8” MCP Al2O3 plates

B. Adams, A. Elagin, R. Obaid, E. Oberla, M. Wetstein et al.



(Note-to-self: forward-reference Eric Oberla’s single-ended readout)