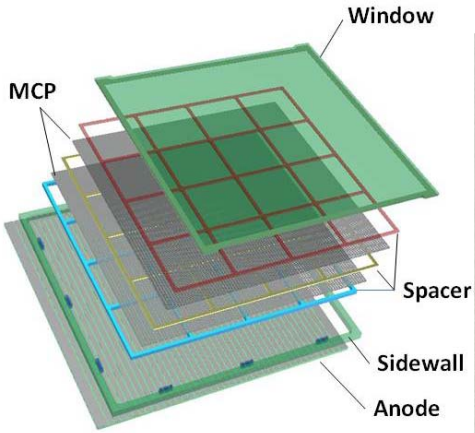
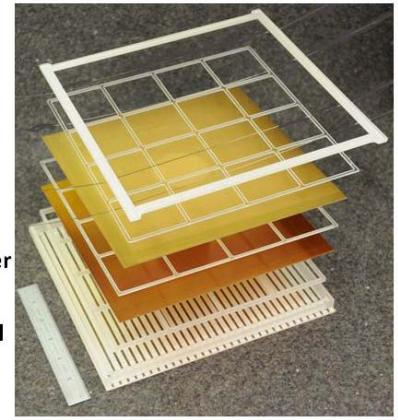
Developing Large-Area Pico-second Photodetectors

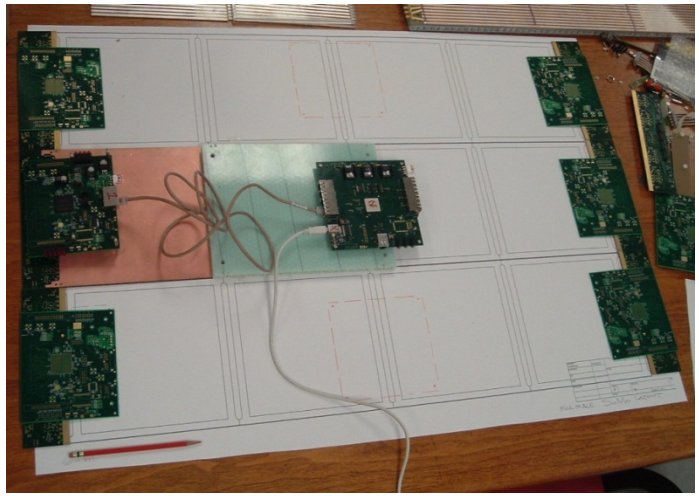
HJF for the LAPPD Collaboration

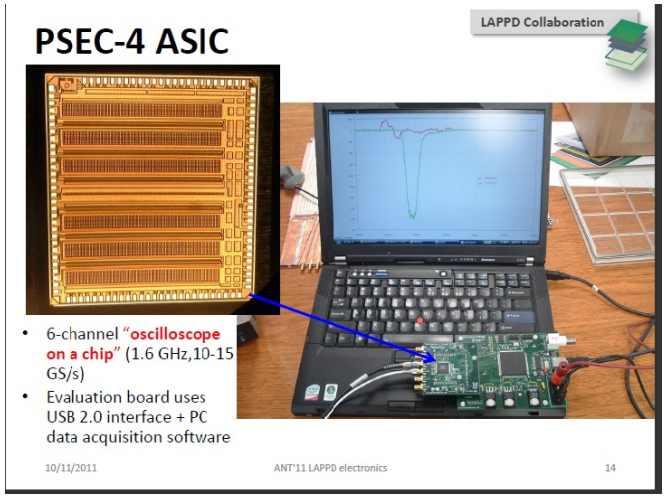


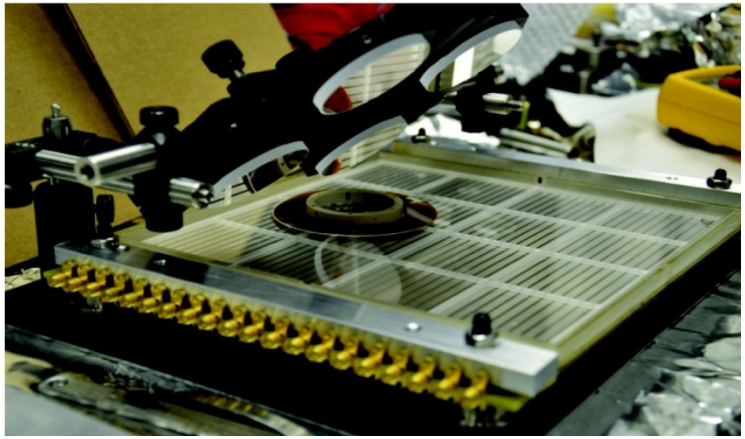
Design Drawing - September 2010



Actual Glass Parts - April 2012



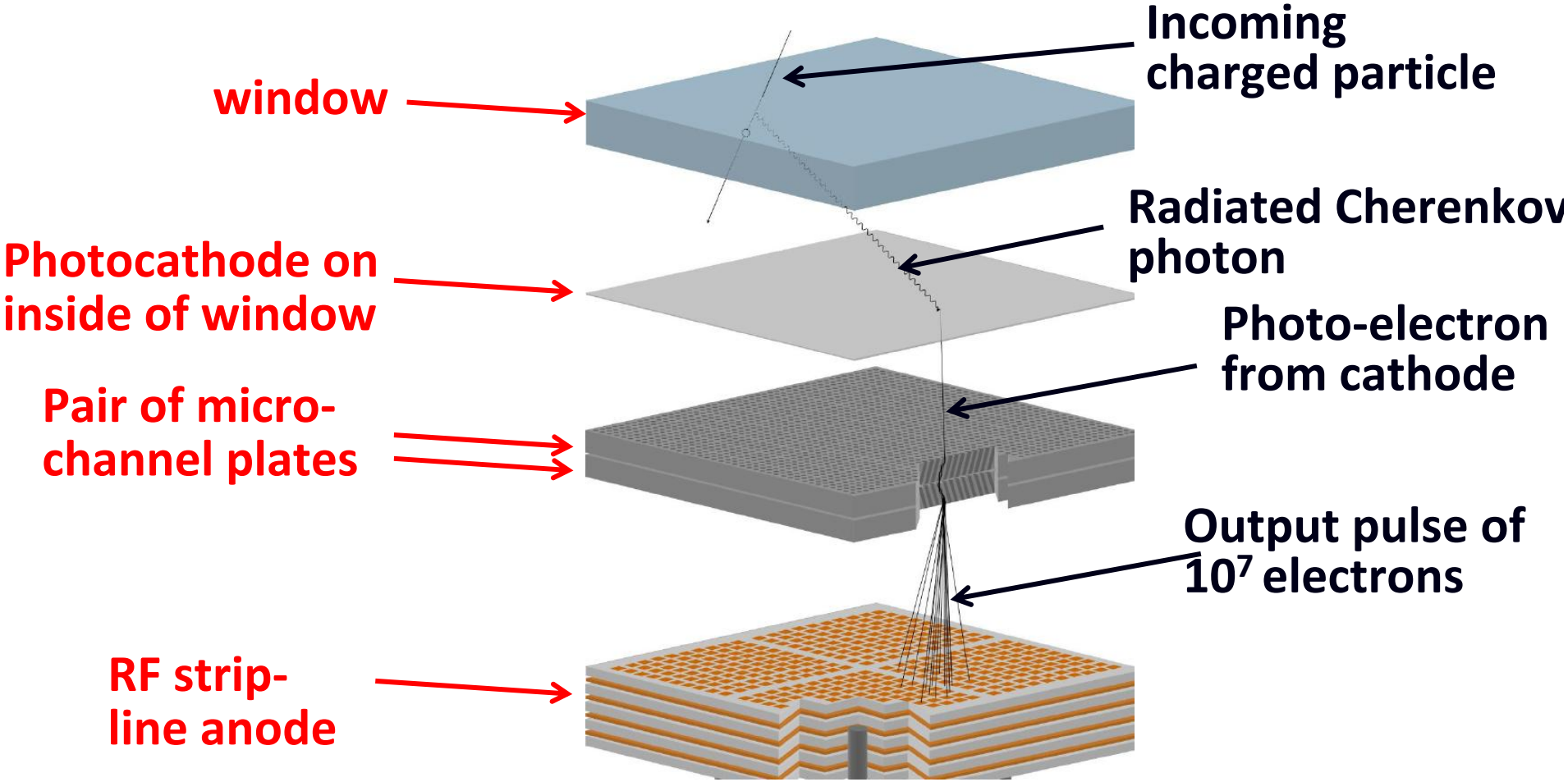




How Does it Work?

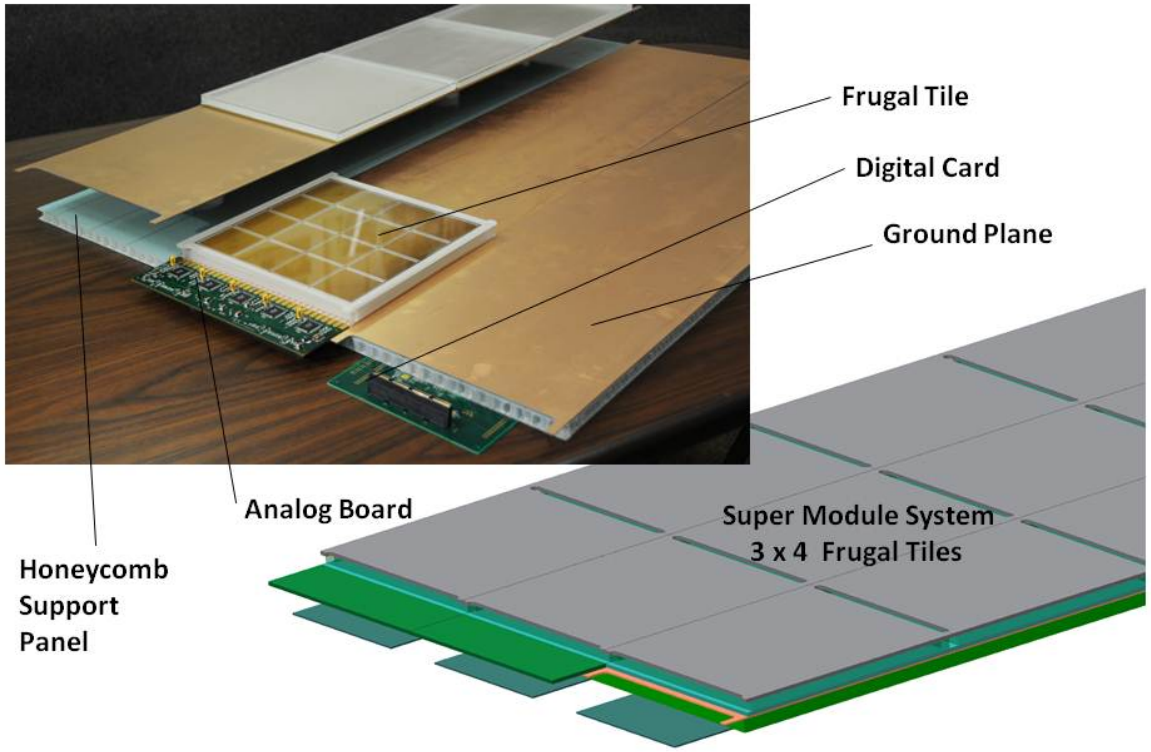
Requires large-area, gain > 10^7, low noise, low-power, long life, $\sigma(t)<10$ psec, $\sigma(x) < 1$mm, and low large-area system cost

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)



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.

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)

Parallel Efforts on Specific Applications

Explicit strategy for staying on task-
Multiple parallel cooperative efforts

LAPD Detector Development

ANL,Arradiance,Chicago,Fermilab, Hawaii,Muons,Inc,SLAC,SSL/UCB, UIUC, Wash. U

Drawing Not To Scale (!)

PET
(UC/BSD, UCB, Lyon)

Collider
(UC, ANL,Saclay.

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

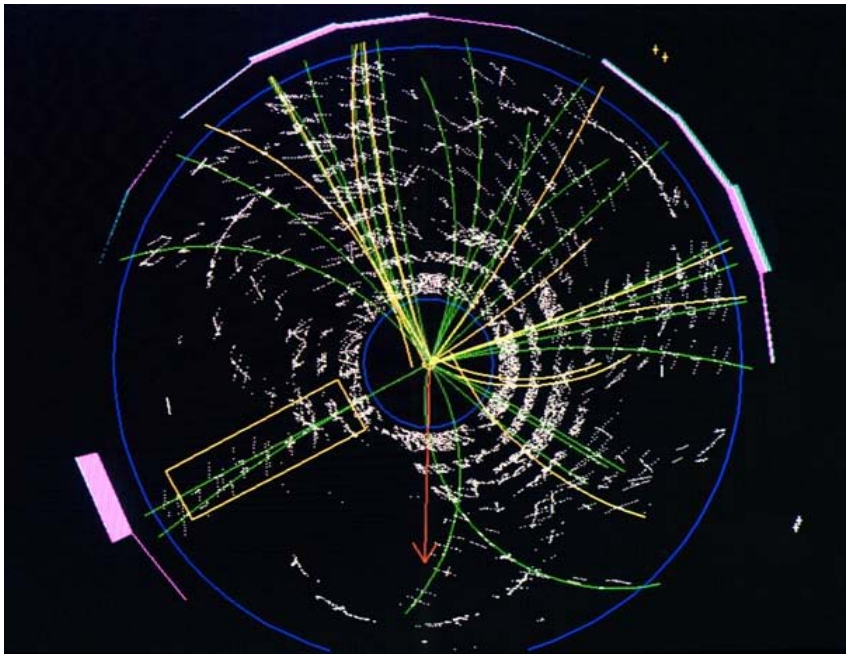
All these need work- naturally tend to lag the reality of the detector development

Motivation-Colliders:

Need: 1) identify the quark content of charged particles

2) separate vertices at the LHC; vertex photons

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



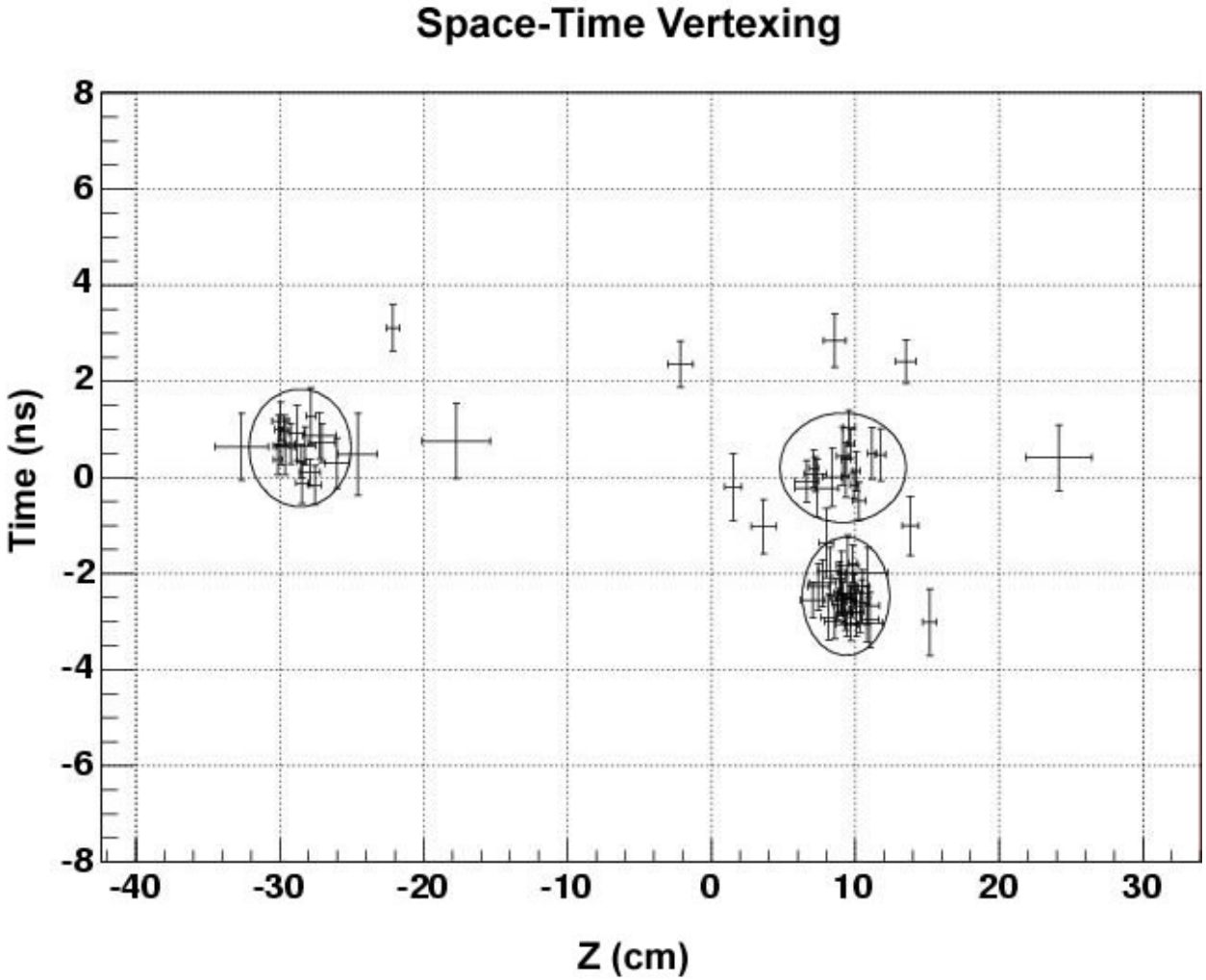
New idea-measure the difference in arrival times of photons and charged particles which arrive a few psec later.

Light source is Cherenkov light in the window/radiator.

Searches- opens window on CKM-forbidden signatures

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

Major problem coming up at LHC- vertexing at high luminosity (quote Joe Incandela)

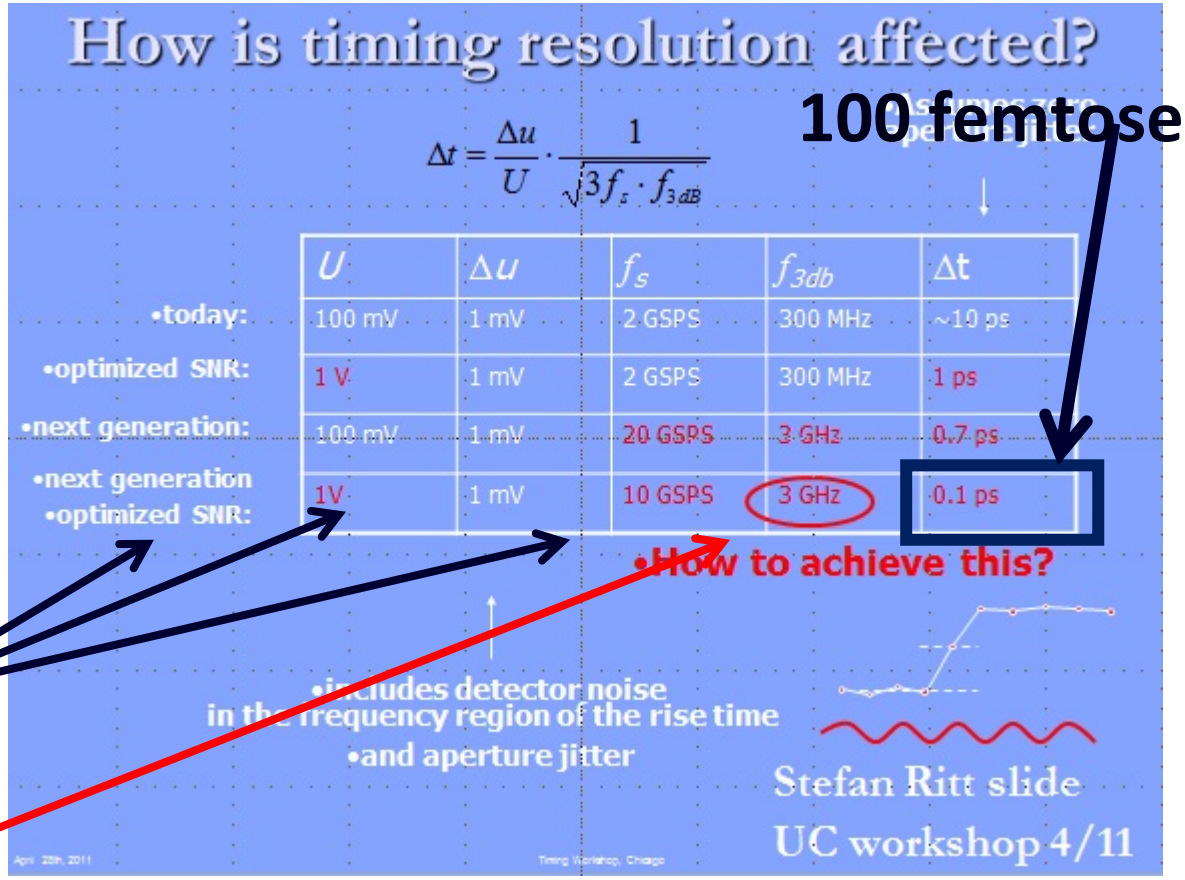


Example need- Higgs to gamma-gamma at the LHC - tie the photons to the correct vertex, and more precisely reconstruct the mass of the pair

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

(agrees with JF MC)

Stefan Ritt slide, doctored

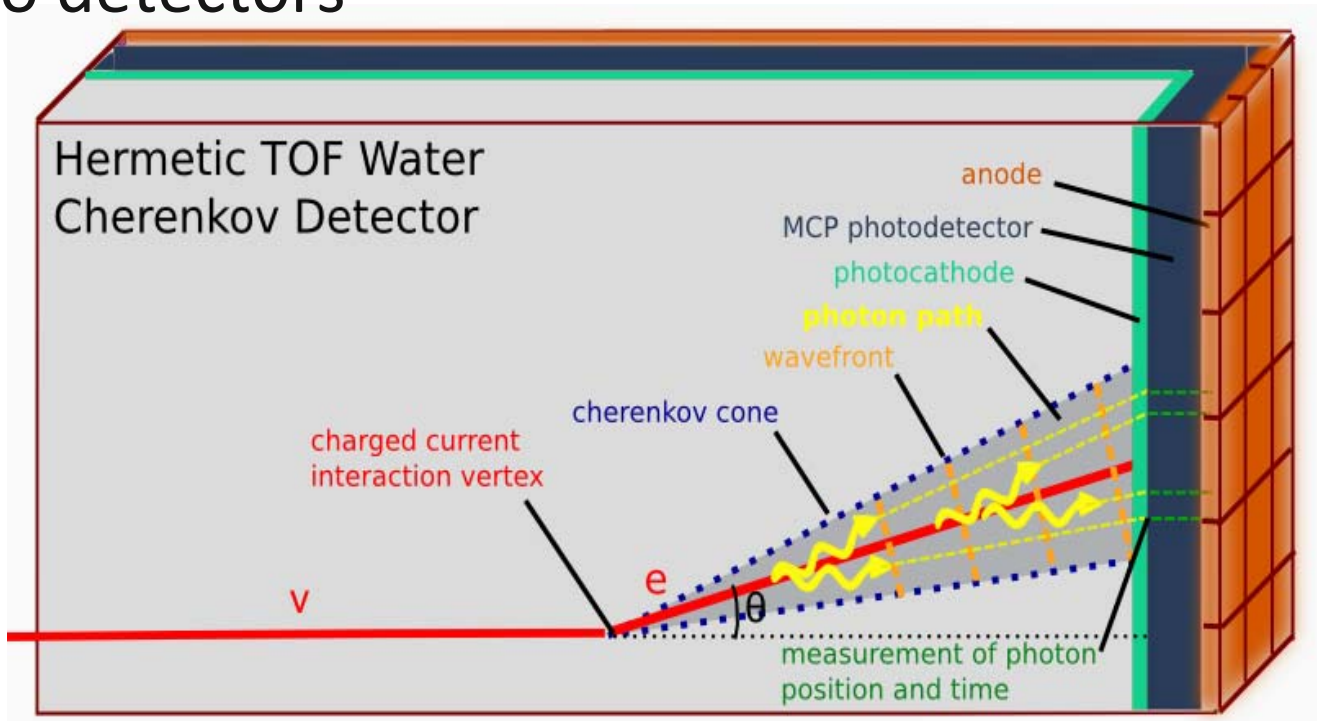


S/N, f_Z: DONE

abw: NOT YET

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.

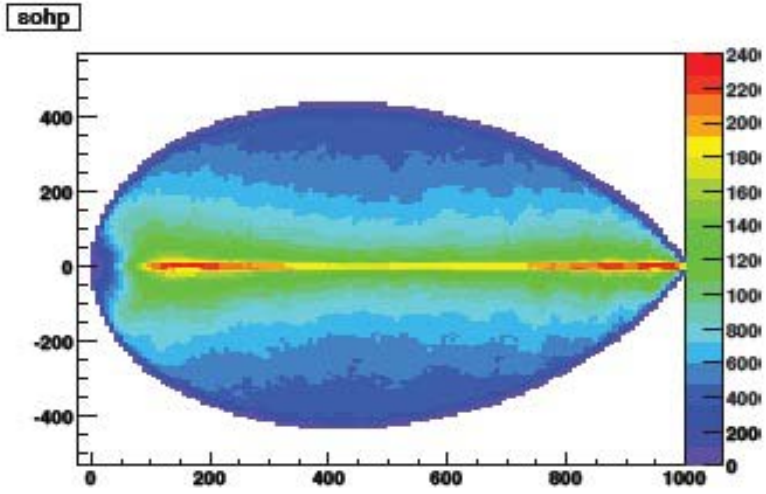
Competition- large PMT's (Hamatsu), Hybrid PMT's (China), Liquid Argon

Can we build a photon TPC?

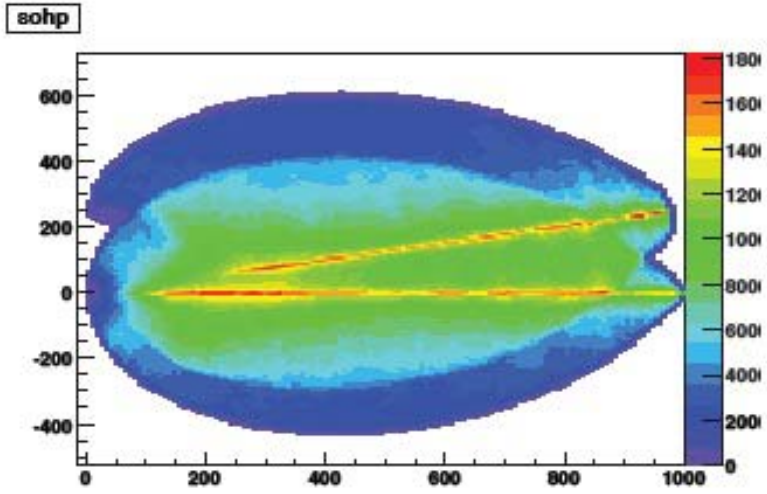
Track Reconstruction Using an "Isochron Transform"

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

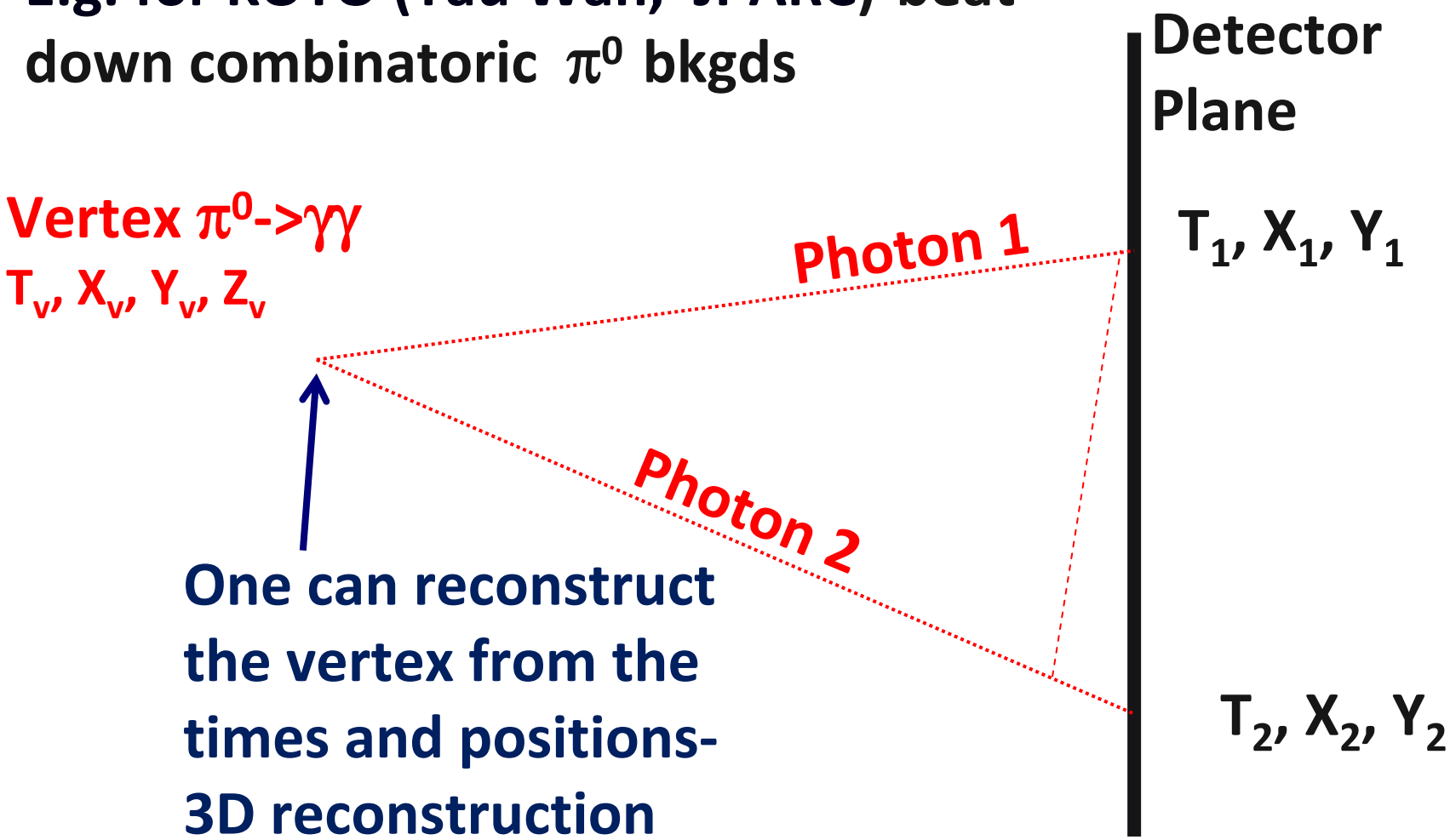


Two tracks displaced from a common vertex

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

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

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



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

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

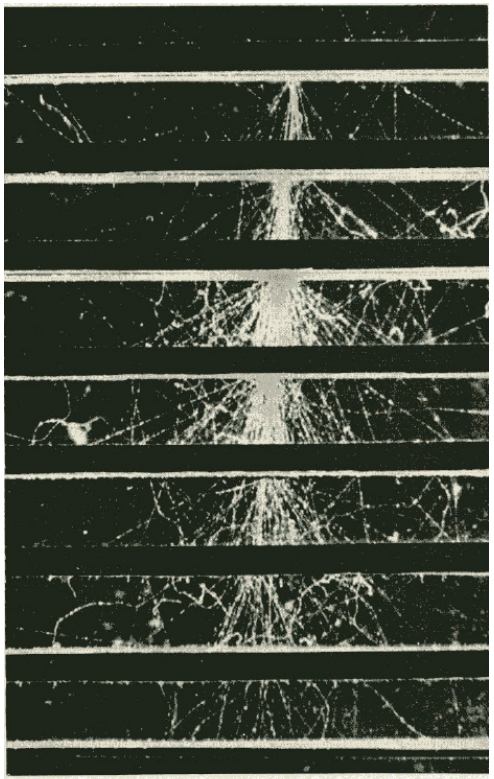
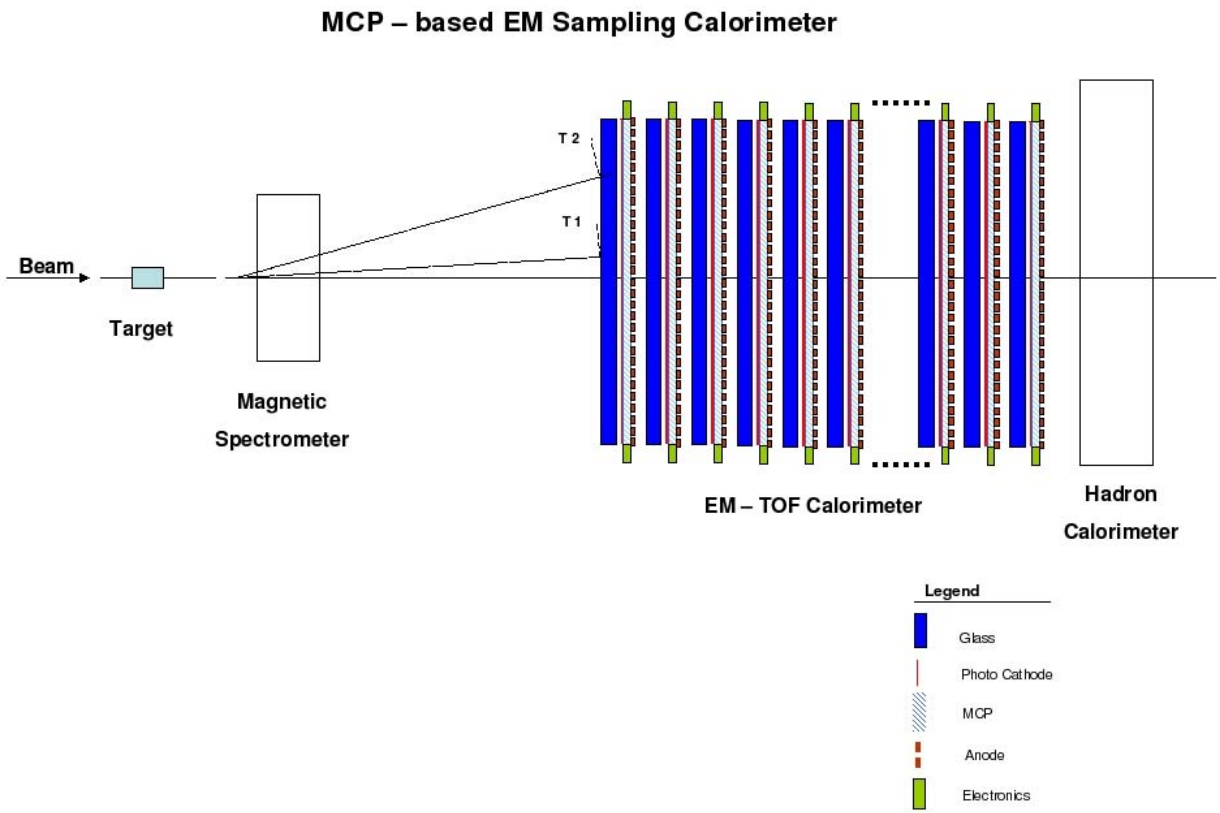


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.

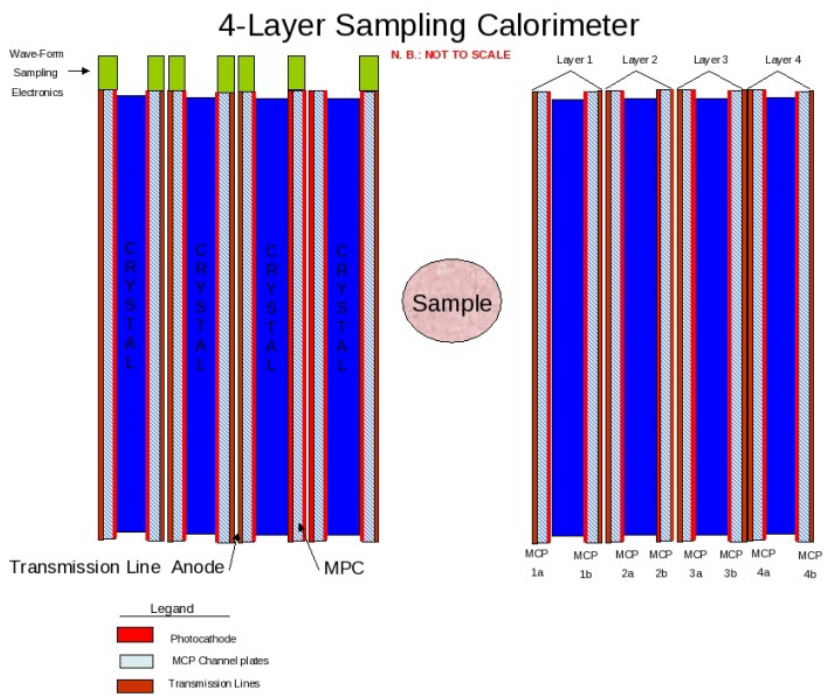


A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

Medical Imaging -PET

Collaboration with UC Radiology (Chen, Kao, Kim).



Gains due to much larger solid angle for coincidence, TOF.
Studies under way

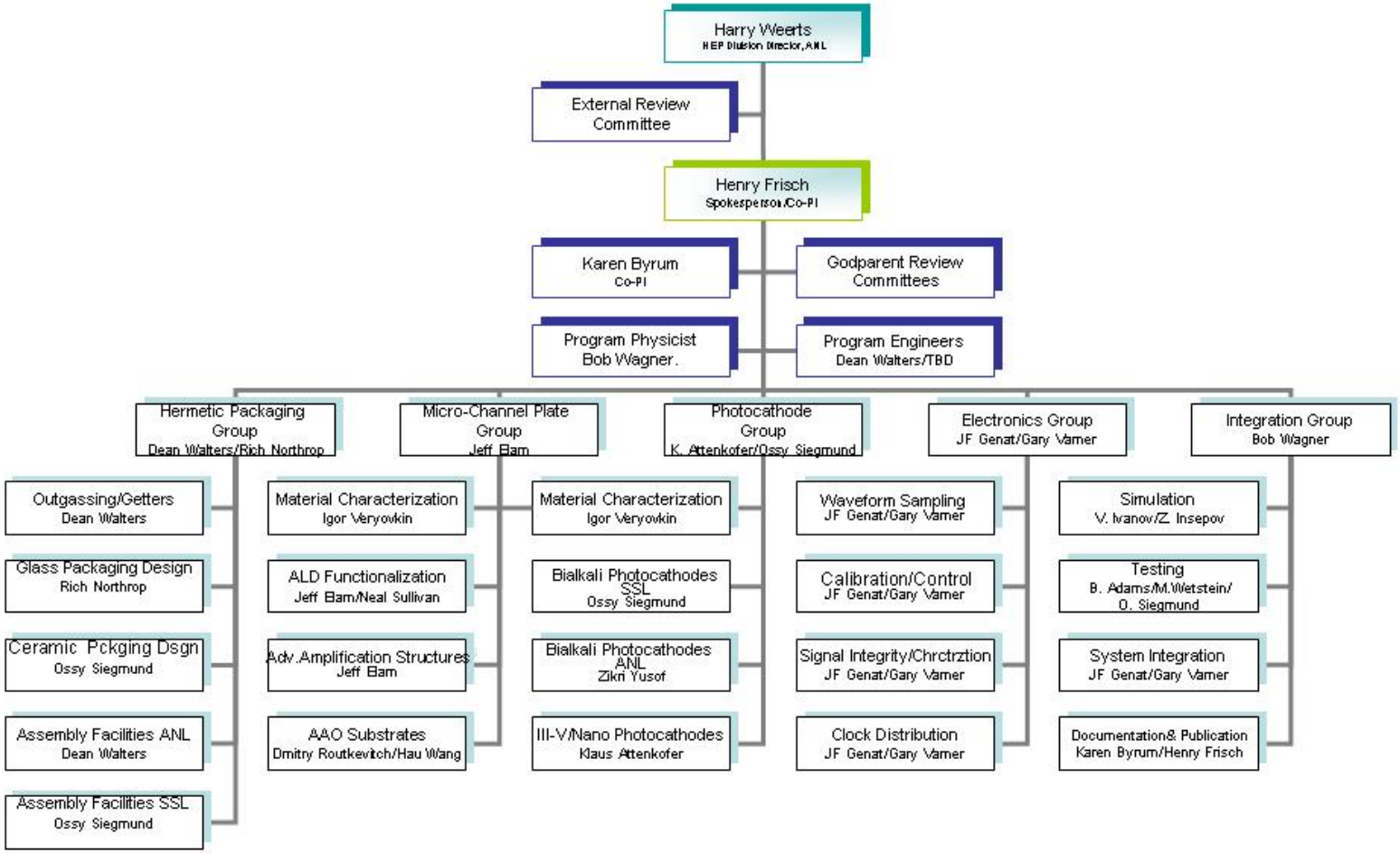
Competition is Silicon PMT's-e.g. RMD talk at SORMA2012

The Large-Area Psec Photo-Detector Collaboration (2010)

Version 2.0
Feb. 9, 2010

Organization Chart

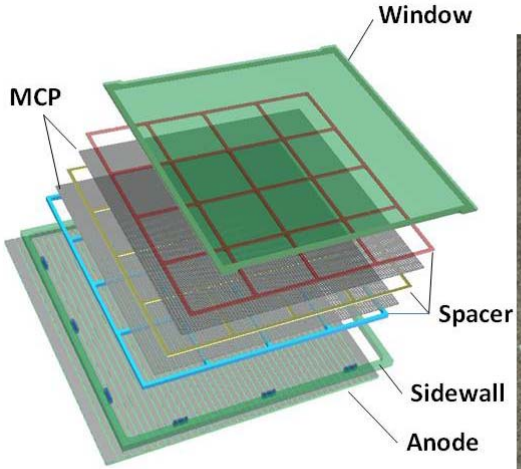
R&D Program for the Development of Large-Area Fast Photodetectors



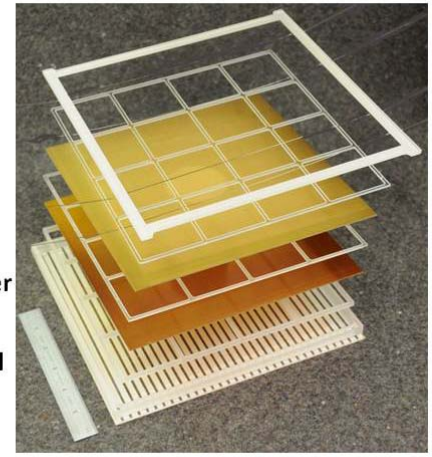
Collaboration with SSL/UCB

- **Two parallel but intertwined efforts :**
  - **SSL/Hawaii** (Siegmund)- ceramic package based on Planacon experience, NaKSb cathode, higher cost, smaller area, lower throughput;
  - **ANL/UC** (Wagner, Byrum,Frisch)- glass package, KCsSb cathode, lower cost, larger area, higher throughput;
  - **Reduce risk and enhance reward by diversification onto the 2 paths.** Has proved very beneficial to both efforts (much cross-fertilization, and shared MCP development). Not a competition, but a shared collegial effort that has worked, and is working, very well.

The Half-Meter-Squared SuperModule



Design Drawing - September 2010

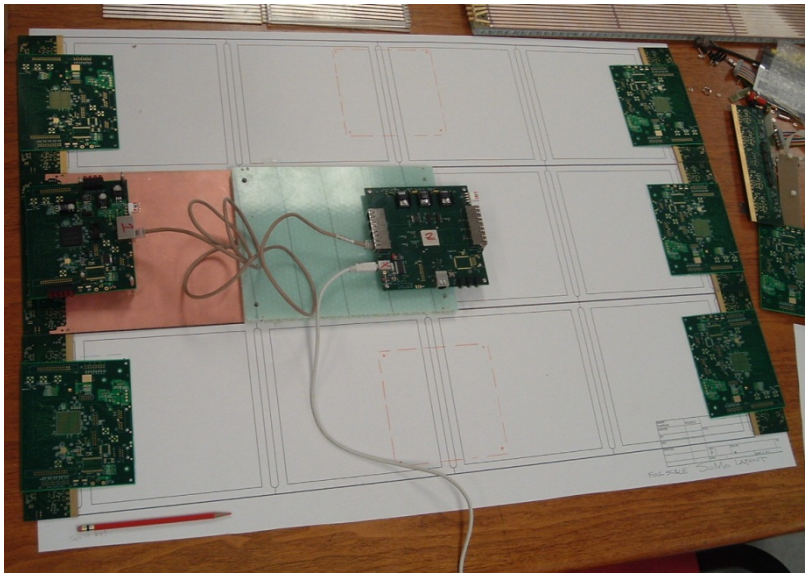


Actual Glass Parts - April 2012

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

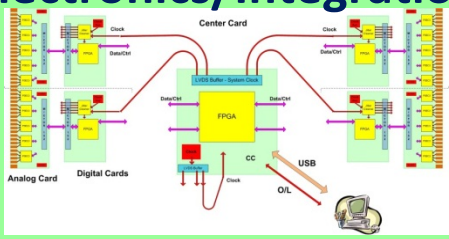


Achievements of DOE R&D

Hermetic Packaging

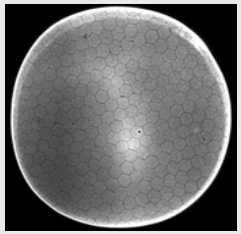
- `Frugal '(Tshirt) 1.6-GHz glass anode
- `Frugal' no-pin B33 glass package
- ALD-based internal voltage divider
- `Frugal' Frit glass bottom seal
- Large-area Multi-tile Supermodule

Electronics/Integration



- `
- 15 Gs/sec 6-channel `scope-in-a-chip'
- Full DAQ design – 2 layers of FPGA
- Test setups at Hawaii and Chicago
- Student leadership on ASICs,firmware

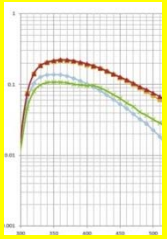
MicroChannel Plates



- High-quality 8" 20μ substrates (Incom)
- Proprietary ALD coatings with <0.1 cts/cm^2/s, gains> 10^7, `no' aging
- Multiple test stations at ANL, SSL

Photocathodes

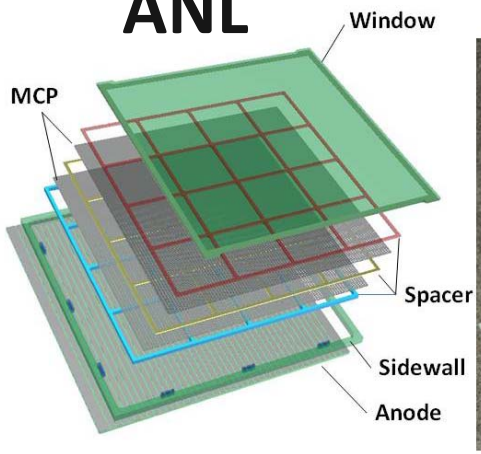
CV



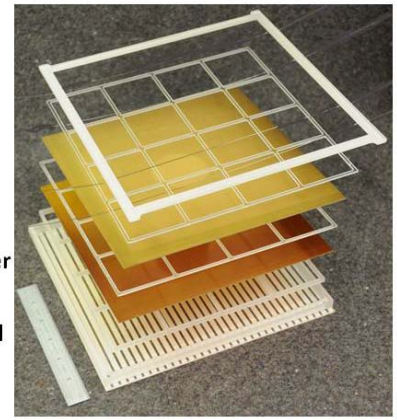
- 8" SbKNa cathode (SSL)
- Cathode facility/lab (ANL)
- SbKCs cathode with 24% QE (ANL)
- InGaN development (WashU)
- Started high-QE cathode collaboration

Hermetic Packaging

ANL



Design Drawing - September 2010

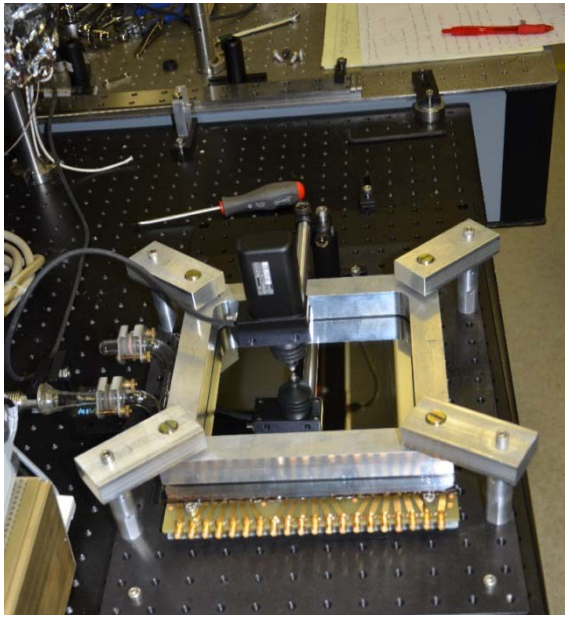


Actual Glass Parts - April 2012

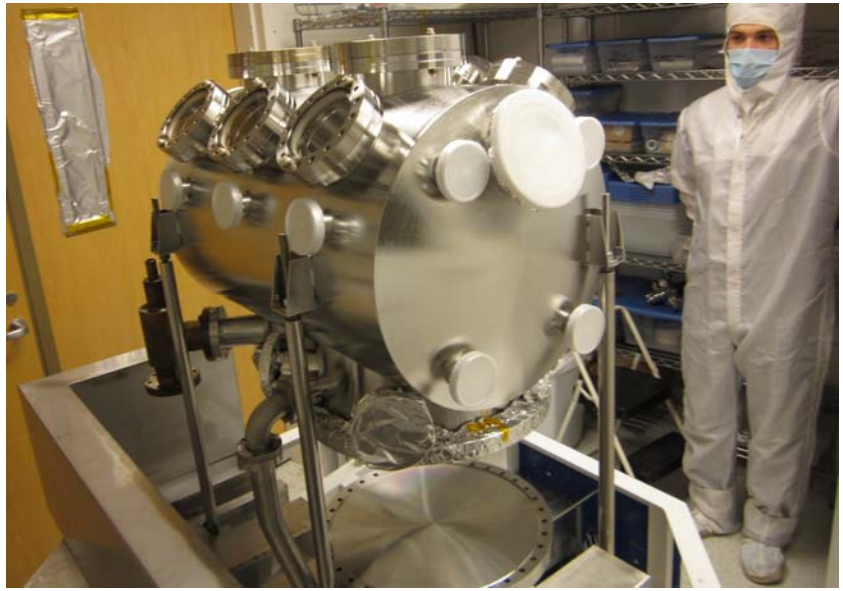
Evolution of the glass tile

SSL

The ceramic tube body, anode, and In well

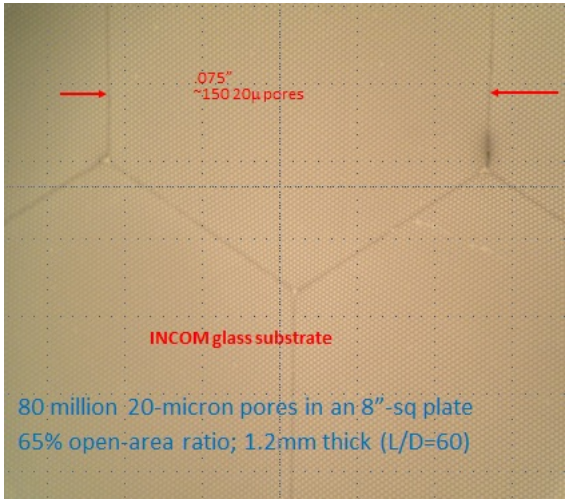


Demountable glass tile at the APS laser

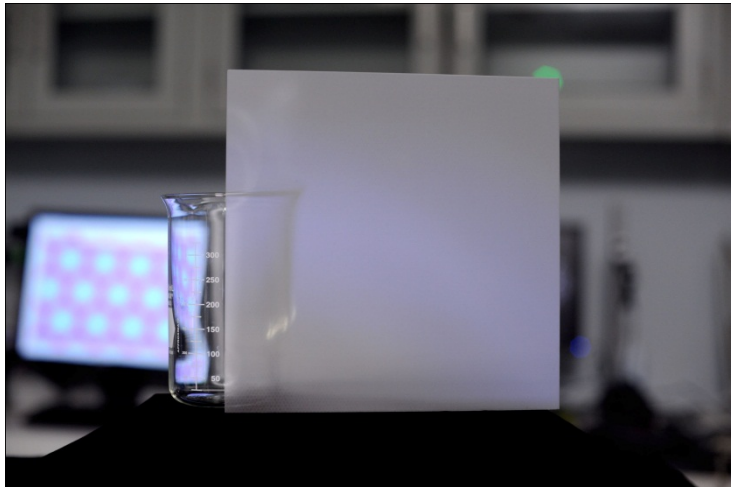


The new SSL assembly tank and …

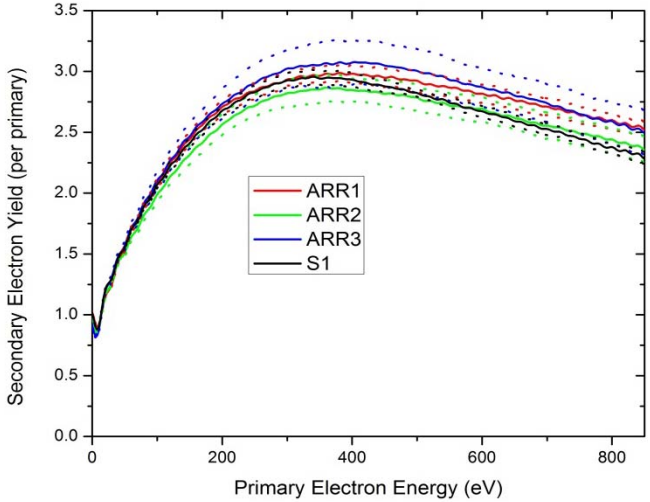
Micro-Channel Plate Development



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

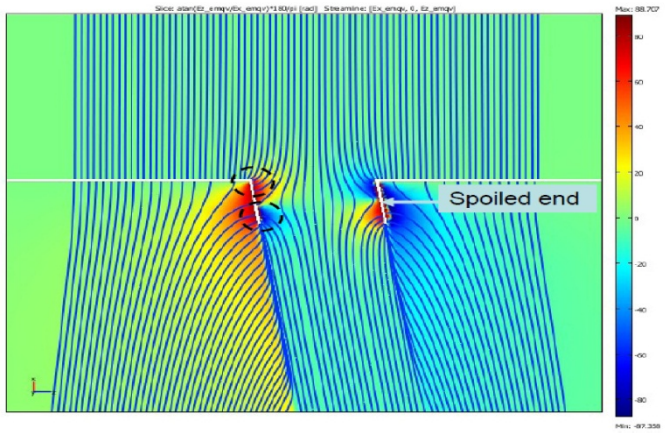


Incom 8"-sq high-quality MCP plate with > 65% OAR



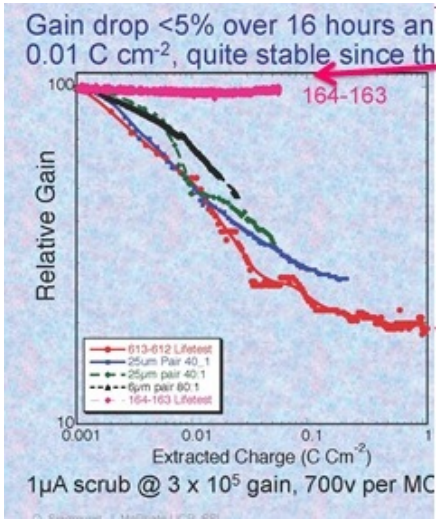
Characterization of SEY of emitting materials (ANL/MSD, here for Arradiance)

Spoiled end. Color: field angle



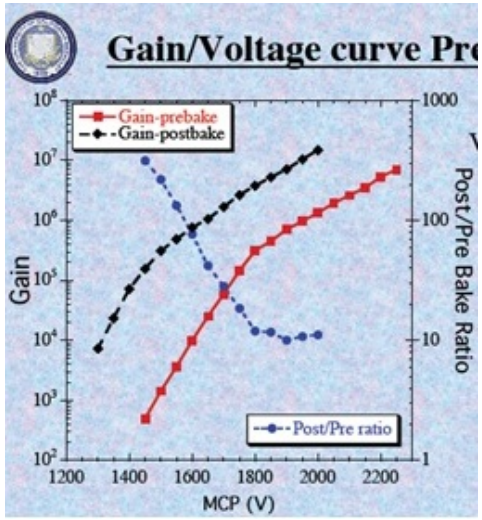
Detailed simulation of MCP's and materials; comparison with data

Micro-Channel Plate Performance



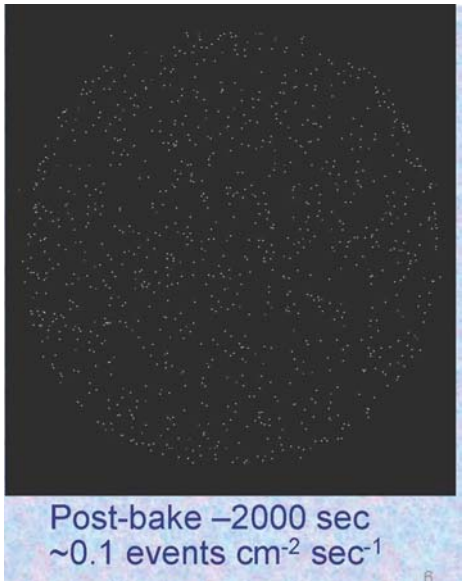
SSL

ALD plates show no aging



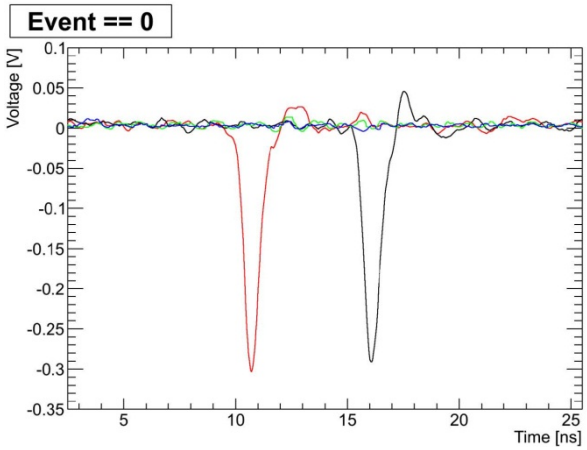
SSL

Gains are as good or better than commercial



SSL

Noise is <0.1 cts/cm²-sec (very good)



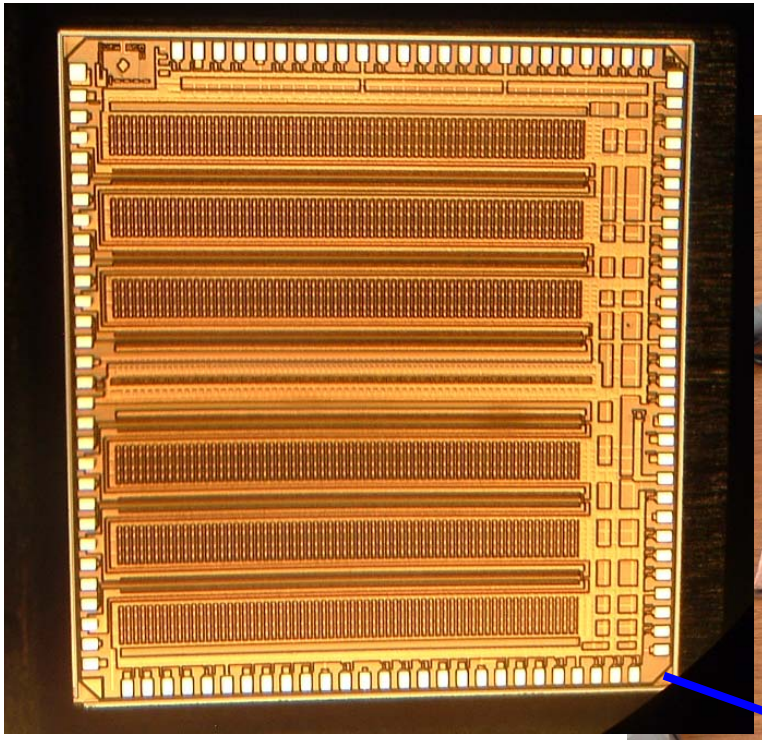
ANL

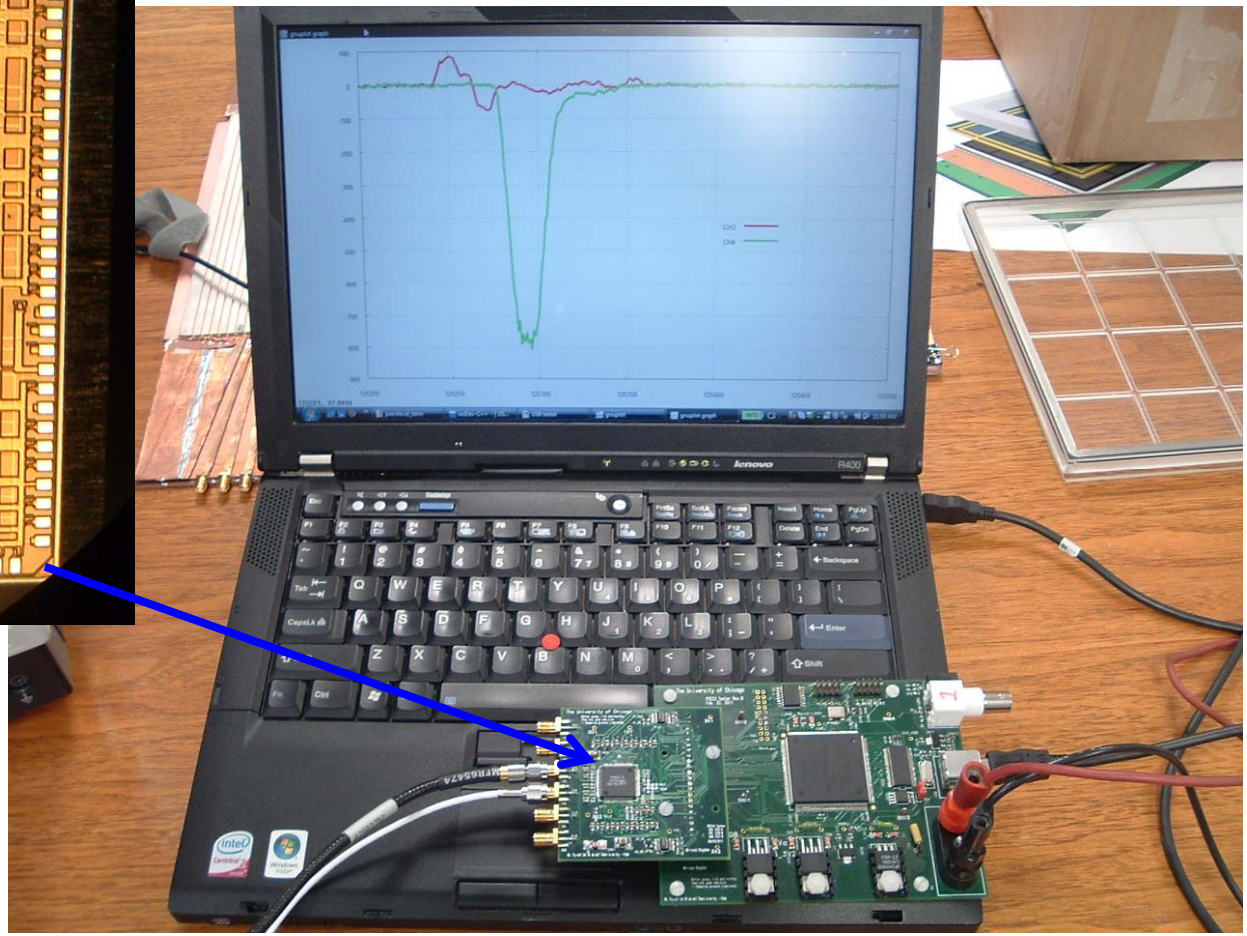
Pulses from two ALD-functionalized MCP's measured on 2 ends of an 8" anode RF strip

Electronics-ASIC Development

PSEC-4 ASIC

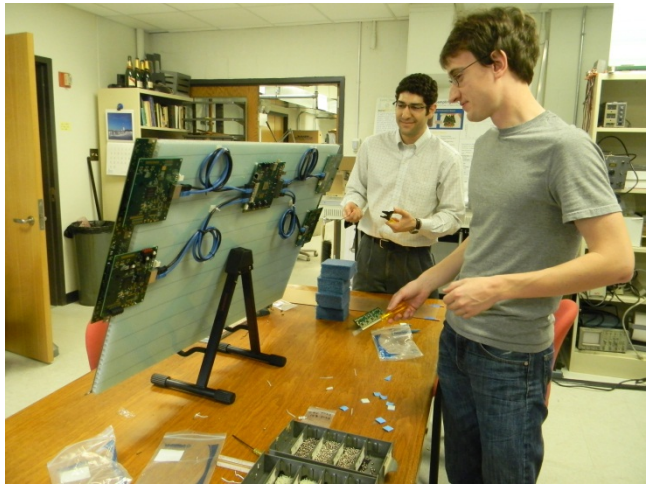
Eric Oberla, ANT11



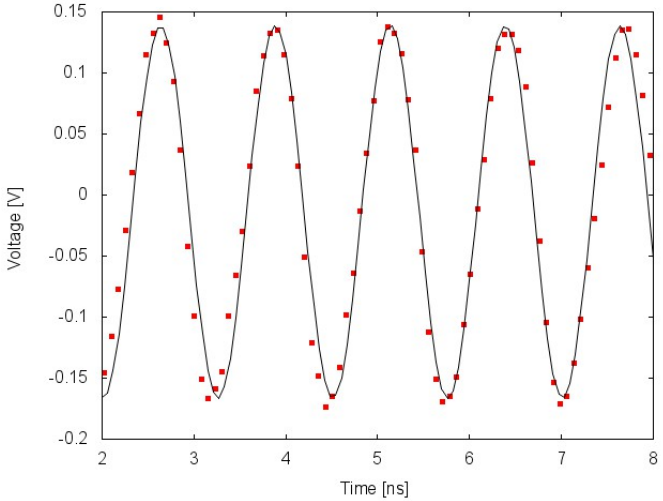


- 6-channel "**oscilloscope on a chip**" (1.6 GHz,10-15 GS/s)
- Evaluation board uses USB 2.0 interface + PC data acquisition software

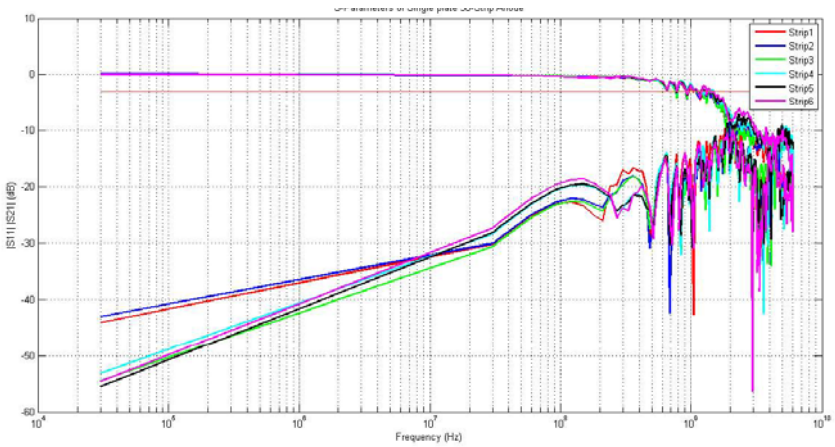
Electronics- Integration & Performance



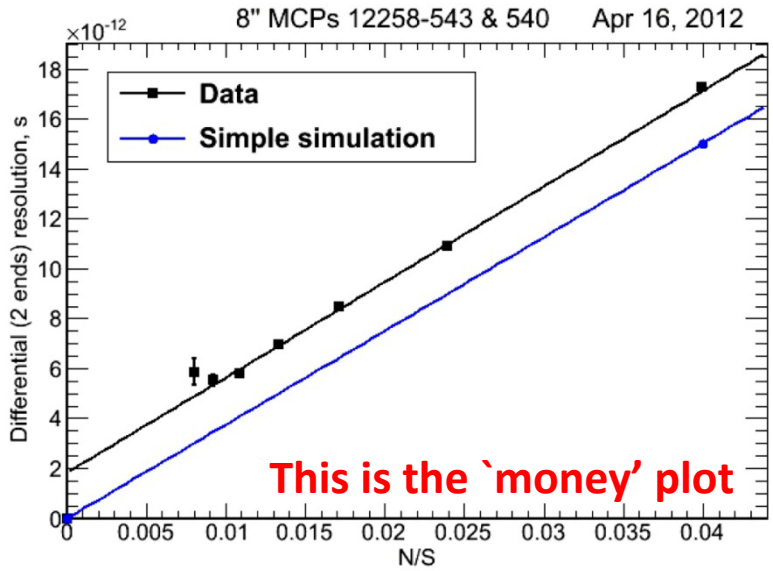
Eric Oberla and Craig Harabedian cabling SuMo digital and central FPGA cards



PSEC-4 sampling at 13.3 Gsamples/sec



Analog Bandwidth of strip-line anode

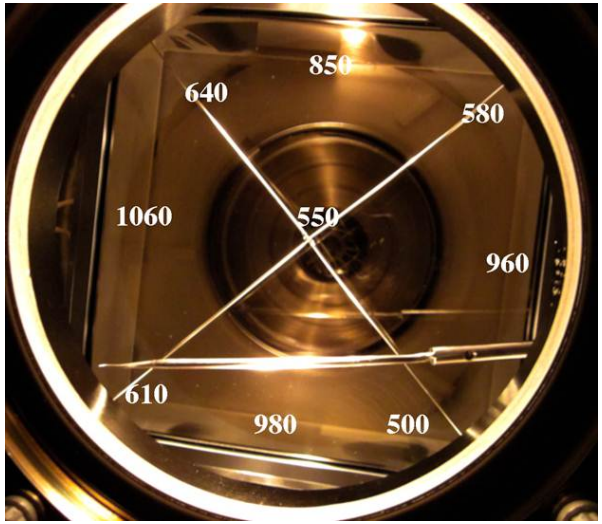


N = RMS of the noise; S = signal amplitude

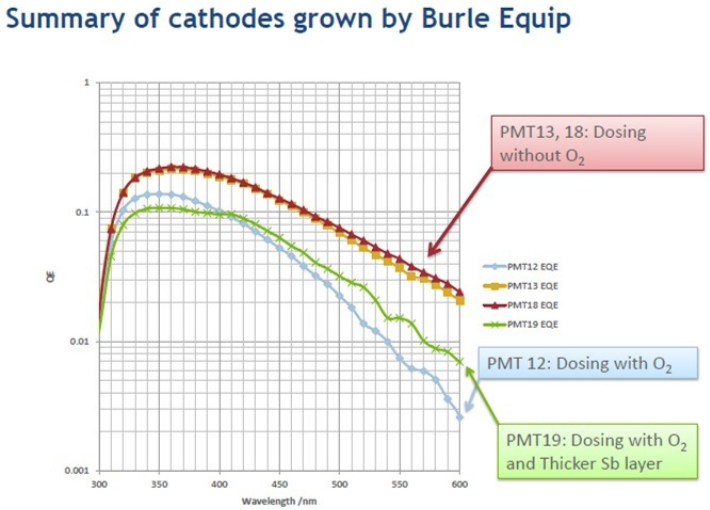
Time resolution on 2 ends of anode strip vs $(S/N)^{-1}$ in psec

Achievements: PhotoCathodes

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

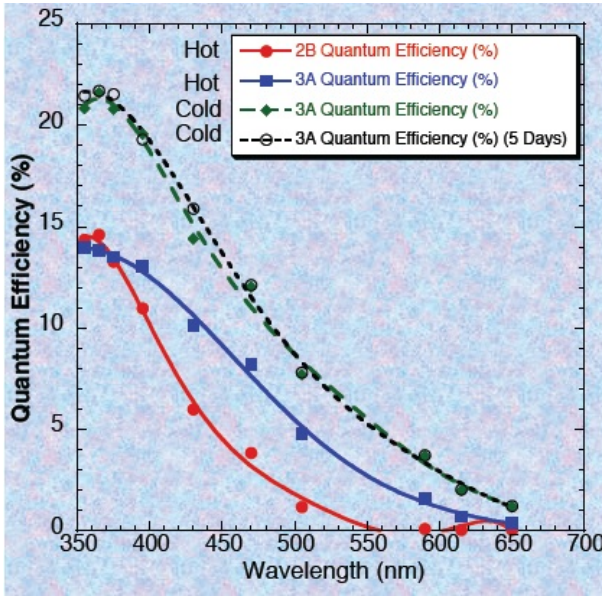


SSL 8" SbNaK cathode

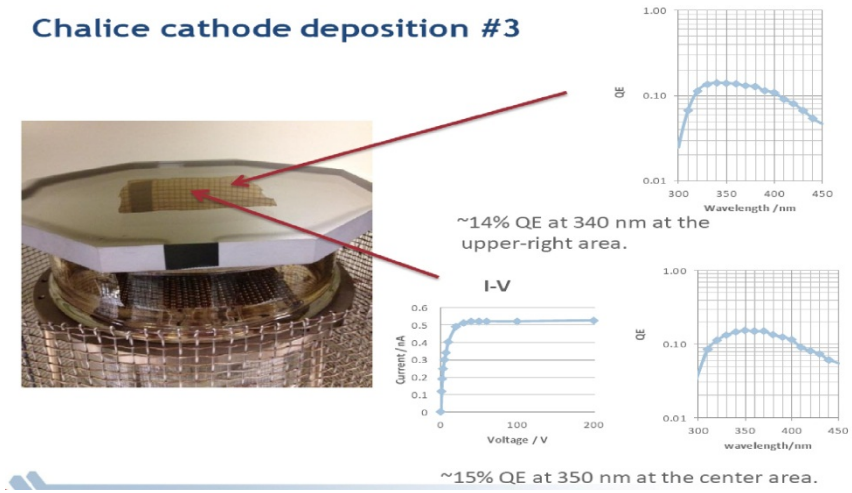


ANL

QE of ANL small SbKCs cathodes

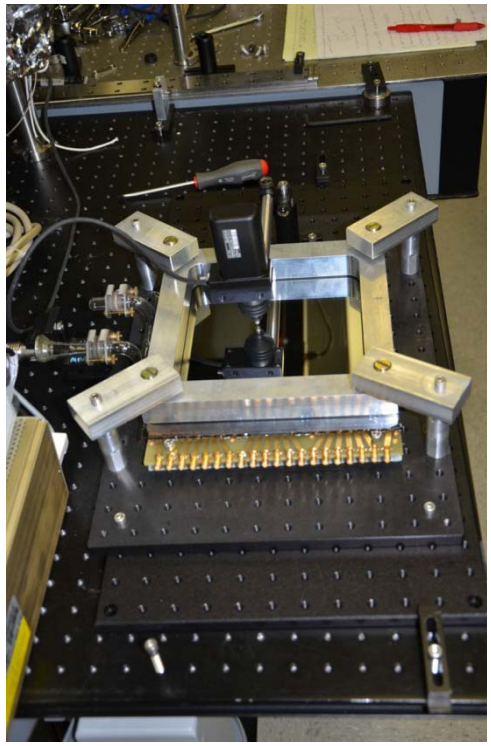


QE of SSL 8" SbNaK cathode

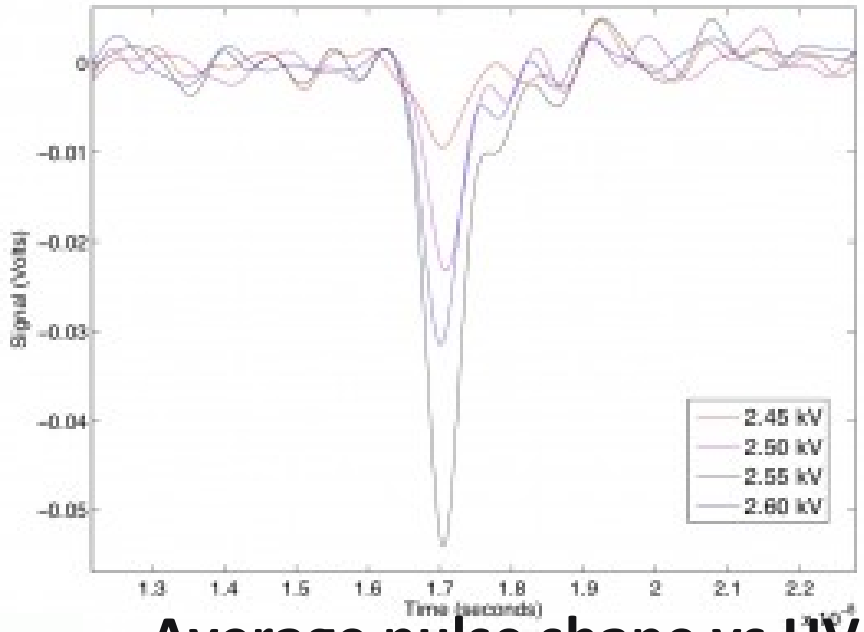


4" cathode: Chalice in Burle oven ANL

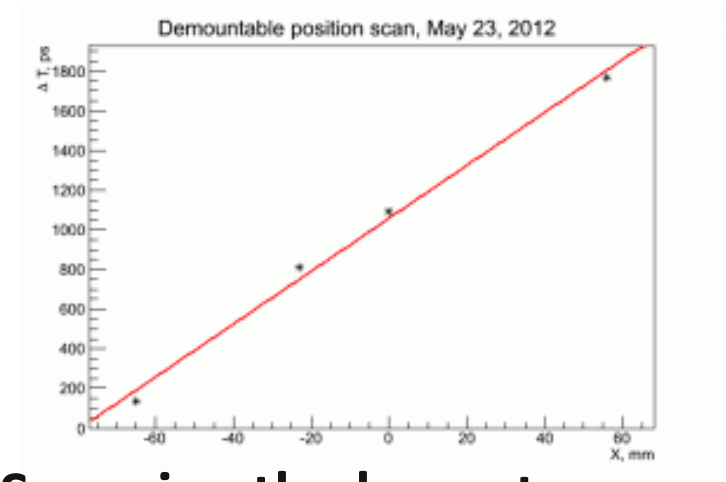
Demonstration of The Internal ALD HV Divider in the Demountable



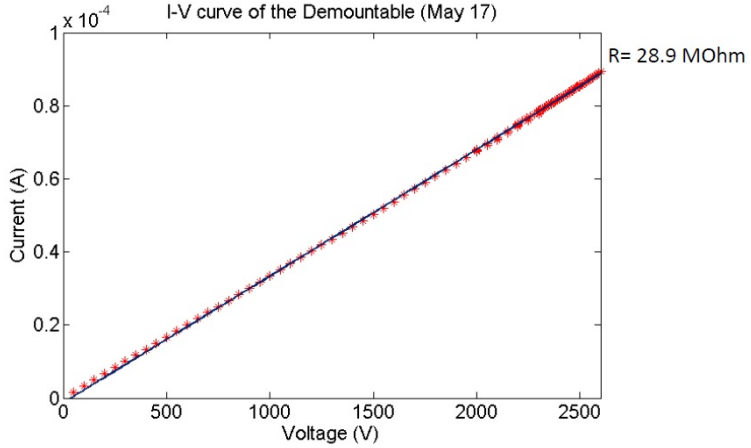
Demountable at APS



Average pulse shape vs HV



Scanning the laser: t vs x



IV Curve (expected 32 Megs)

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

The Initial LAPPD Collaboration

The Development of Large-Area Fast Photo-detectors
April 15, 2009

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

3 National Labs, 6 Divisions at Argonne, 3 US small companies (Arradiance, Muons,Inc, and Synkera); SSL/UC Berkeley and the Universities of Chicago and Hawaii

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

Have since added effort at UIUC, WashU, UIC, Minotech

Working/in-contact with Incom, CatIglass, Photonis, ElectronTubes, Perkin-Elmer (last 3 are tube manufacturers)

GodParent Review Panels

Packaging Group	MCP Group	Photocathode Group	Electronics Group
Karen Byrum	Bob Wagner	Gary Varner	Zikri Yusof
K.Arisaka	K.Attenkofer	J. Buckley	B. Adams
J. Elam	A. Bross	K. Harkay	M.Demarteau
D. Ferenc	Z. Insepov	V. Ivanov	G. Drake
J.F. Genat	A. Tremsin	A. Lyashenko	T. Liu
P. Hink	J. Va'vra	T. Prolier	I. Veryovkin
M. Minot	A. Zinovev	M. Wetstein	S. Ross
A. Ronzhin			

8” Glass Package Component Costs

Rich Northrop

Fabricated per unit cost estimates

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

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

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