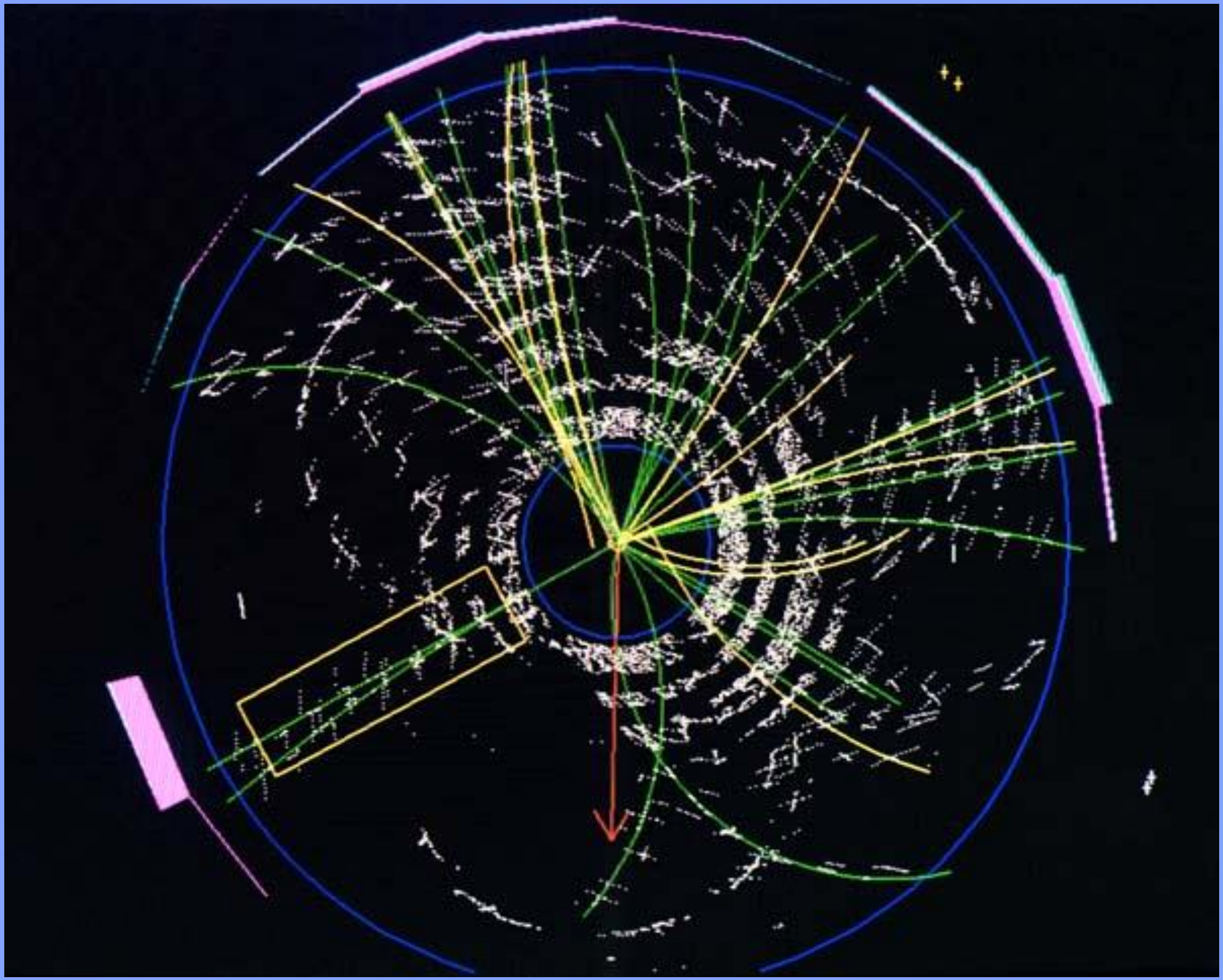
The Development of Large-Area Thin Planar Psec Photodetectors

Henry Frisch,
Enrico Fermi Institute and ANL



The Large-Area Psec Photo-detector Collaboration

The Development of Large-Area Fast Photo-detectors

April 15, 2009

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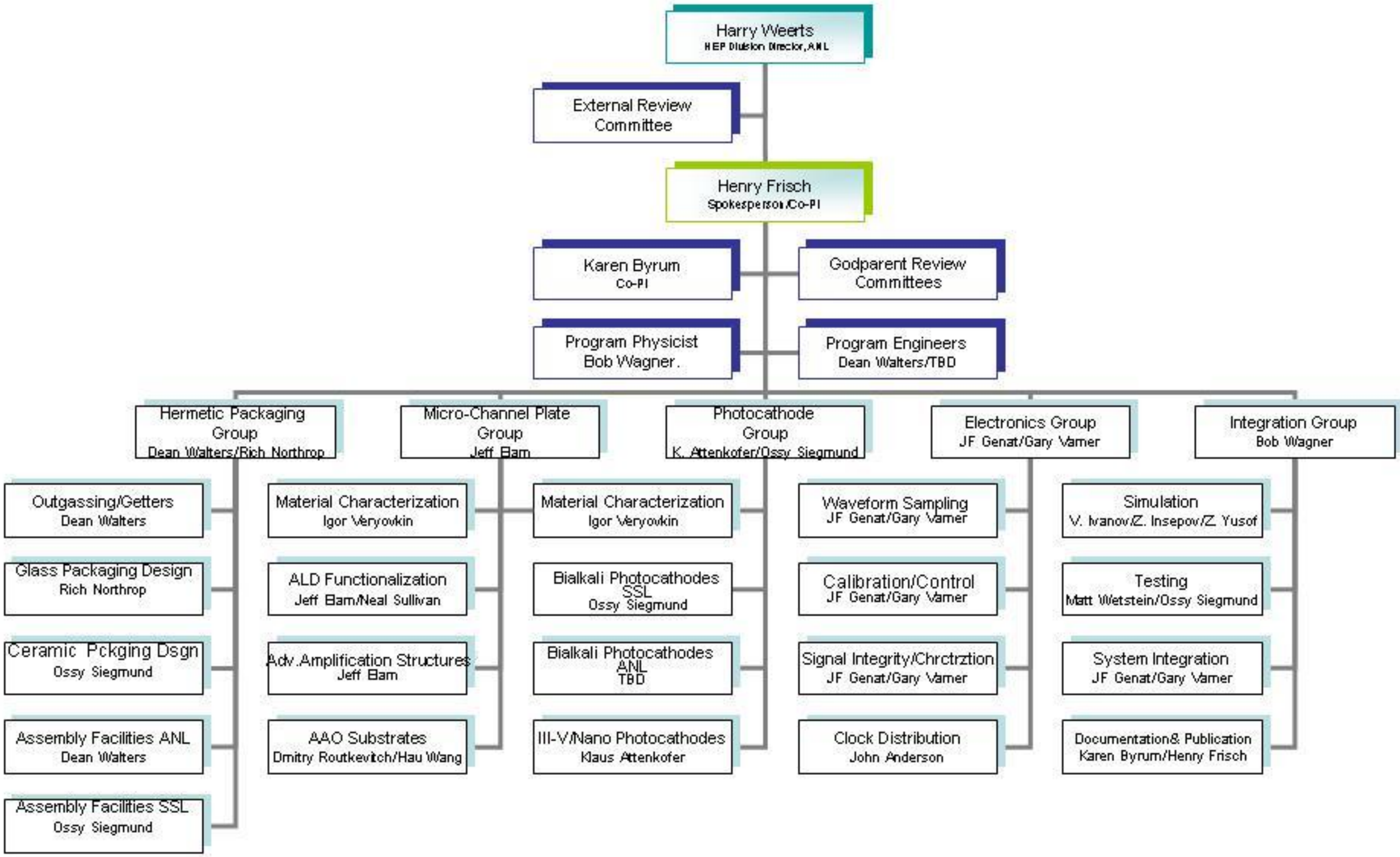
3 National Labs +SSL, 6 Divisions at Argonne, 3 US small companies; electronics expertise at Universities of Chicago and Hawaii

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

Organization Chart

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



4 Groups + Integration and Management

Parallel Efforts on Specific Applications

Explicit strategy for staying on task

PET
(UC/BSD, UCB, Lyon,Strasbourg)

Collider
(UC, ANL,Saclay.

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

Muon Cooling
Muons,Inc
(SBIR)

K->πνν
Wah?

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

Non-proliferation
LBNL,ANL,UC

Mass Spec
Andy Davis, Mike Pellin, Eric Oberla

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

Three Goals of a New (1.9 yr-old) Collaborative Effort:

1. Large-Area Low-Cost Photodetectors with good correlated time and space resolution (target 10 $/sq-in incremental areal cost)
2. Large-Area TOF particle/photon detectors with psec time resolution (< 1psec at 100 p.e.)
3. Understanding photocathodes so that we can reliably make high QE, tailor the spectral response, and develop new materials and geometries (QE > 50%?, public formula)

Detector Development- 3 Prongs

MCP development- use modern fabrication processes to control emissivities, resistivities, out-gassing

Use Atomic Layer Deposition for emissive material

Readout: Use transmission lines and modern chip technologies for high speed cheap low-power high-density readout.

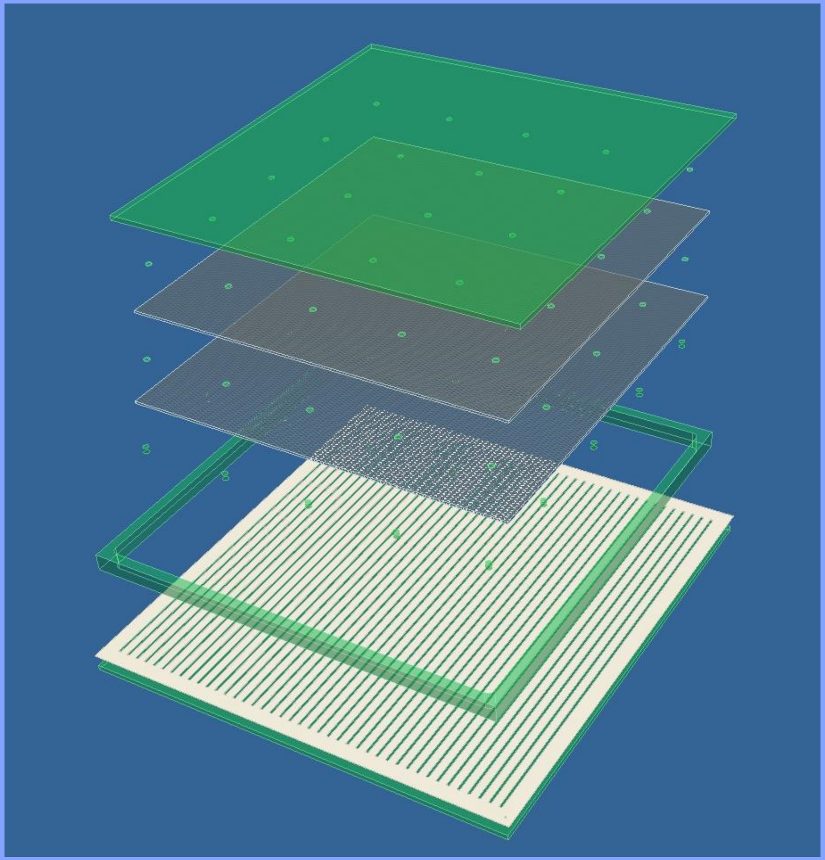
Anode is 50-ohm stripline. Scalable up to many feet in length ; readout 2 ends; CMOS wave-form sampling

Use computational advances -simulation as basis for `rational design' of materials and devices

Modern computing tools allow simulation at level of basic processes- validate with data.

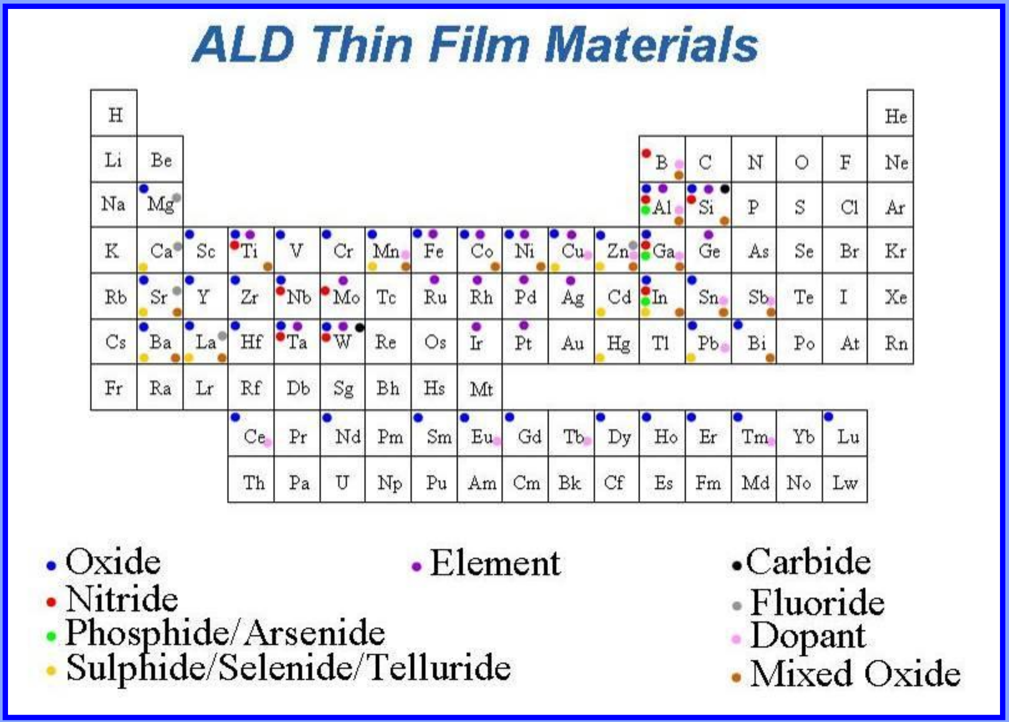
The 24”x16” `SuperModule

Sealed Tube (Tile) Construction

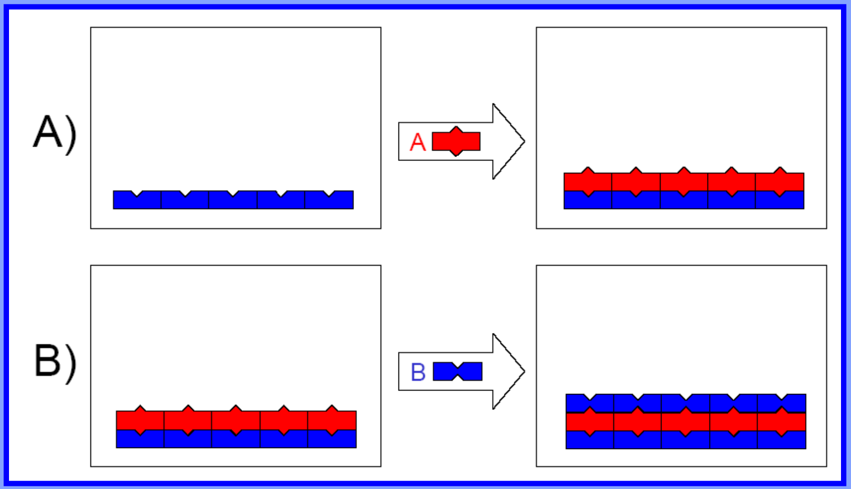


- All (cheap) glass
- Anode is silk-screened
- No pins, penetrations
- No internal connections
- Anode determines locations (i.e. no mech tolerancing for position resolution)
- Fastens with double-sticky to readout Tray: so can tile different length strings, areas
- Tile Factory in works (ANL)

Atomic Layer Deposition (ALD) Thin Film Coating Technology



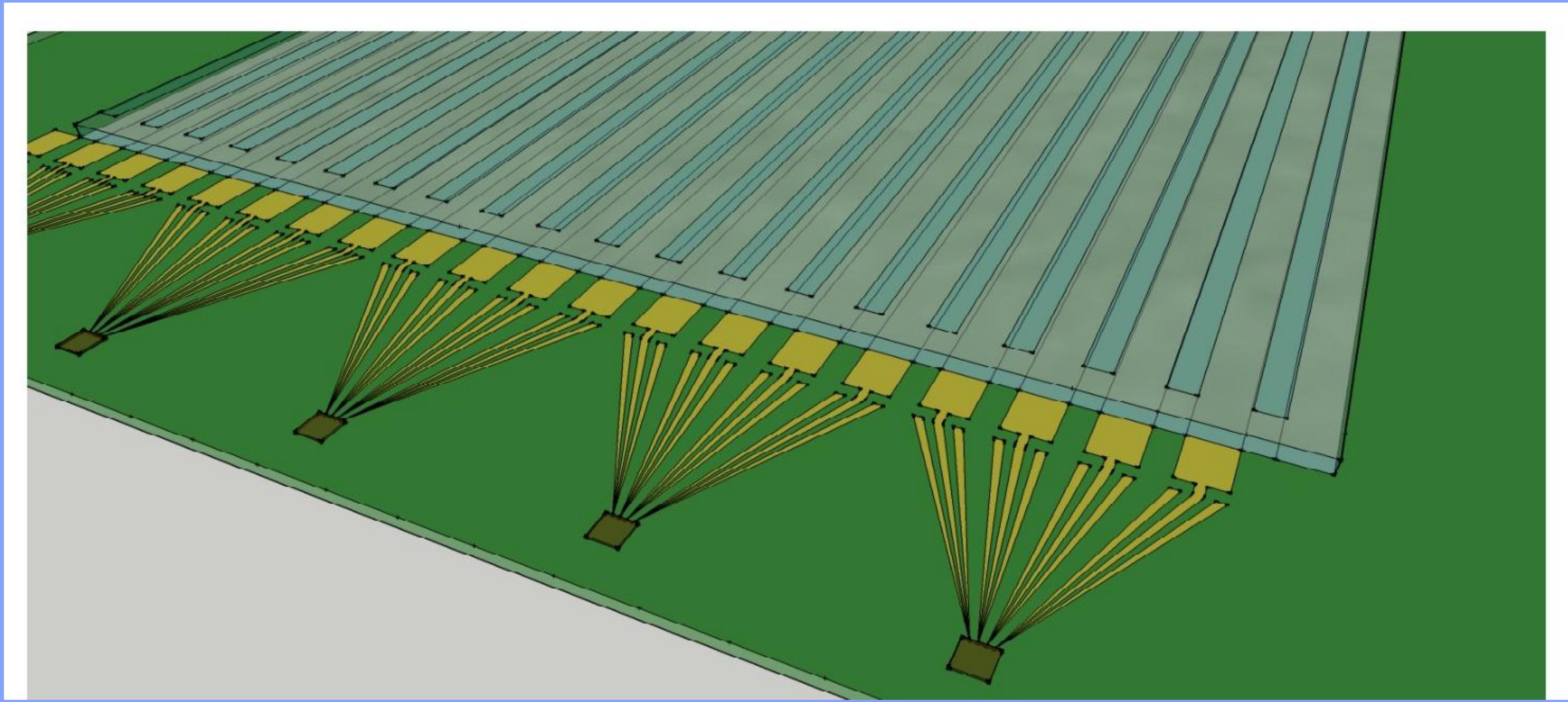
•Lots of possible materials => much room for higher performance



- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

Jeff Elam pictures

High (multi-GHz) ABW readout



Note signal is differential between ground (inside, top), and PC traces (outside)

•MCP testing setup

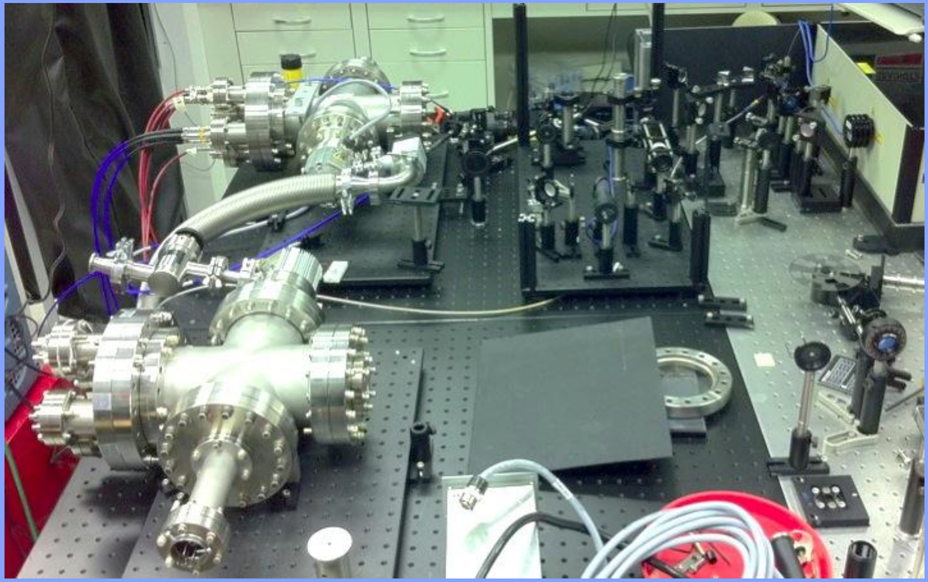
•Laser setup improvement:

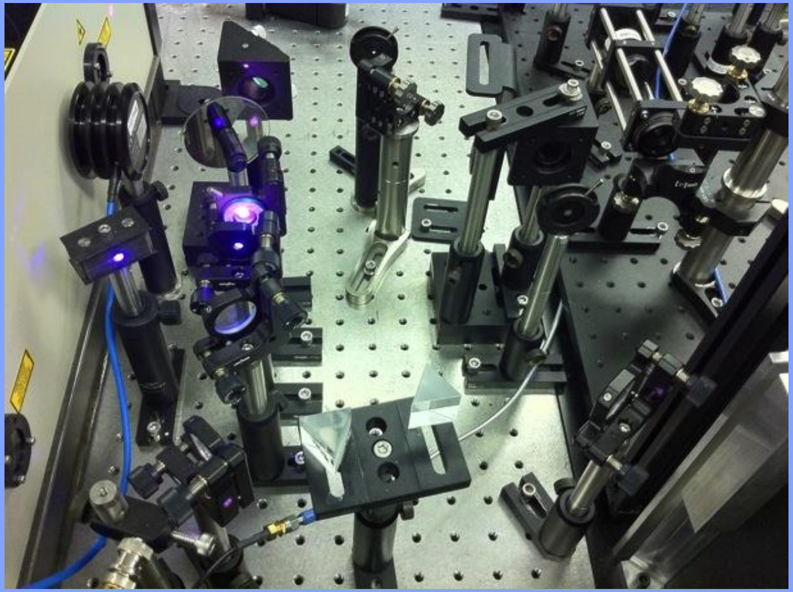
•Cleaner UV beam

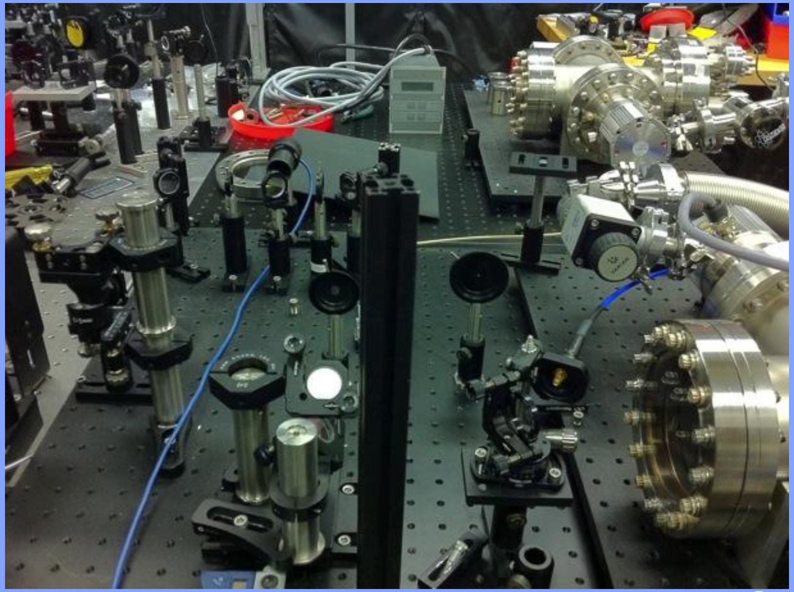
•laser power monitoring

•Position scan

Absolute laser arrival time on MCP (in progress)

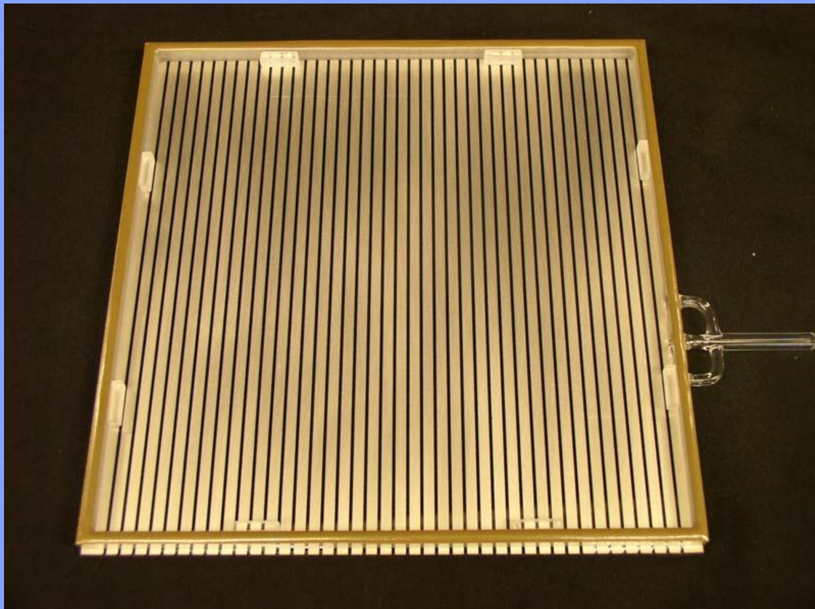






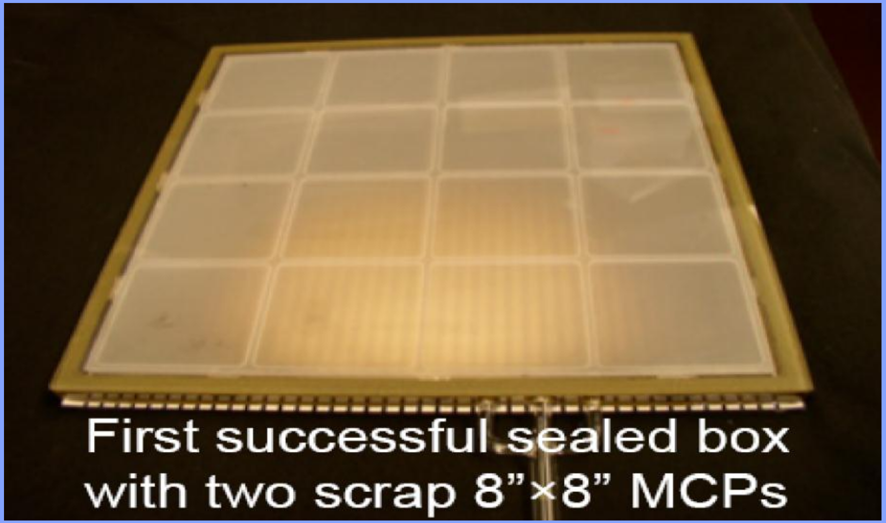
Matt Wetstein Slide(EFI/ANL)-fs laser at APS

Status of the Tiles



Completed Lower Anode Seal

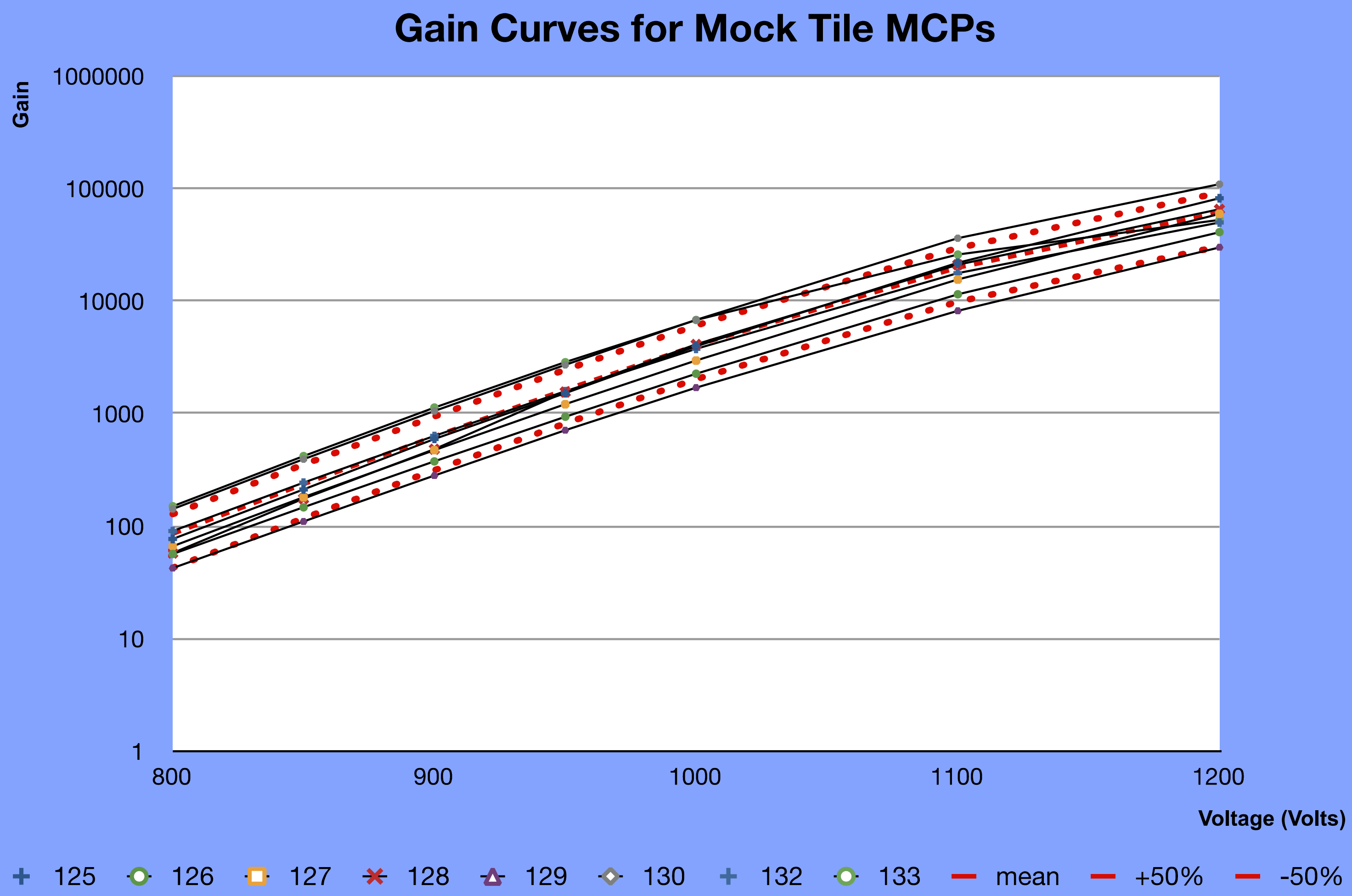
Frit work by Joe Gregar (ANL)-ALD by Anil Mane, Qing Peng, and Jeff Elam. Design by Rich Northrop (EFI)



•Argonne National Laboratory Scientific Glassblowing Facility

•Gain measurements:

- •UV lamp
- •Characterization of mock tile MCPs gain



Matt Wetstein Slide(EFI/ANL)-fs laser at APS

How is timing resolution affected?

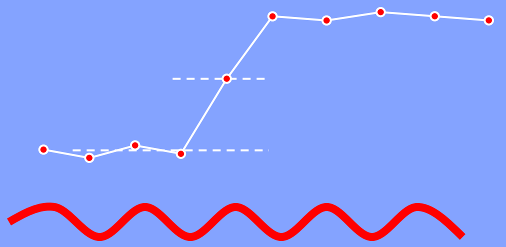
$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

- Assumes zero aperture jitter

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

- **How to achieve this?**

- includes detector noise in the frequency region of the rise time
- and aperture jitter

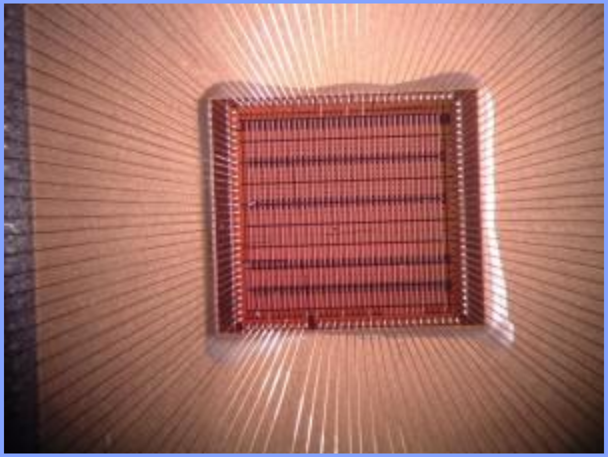


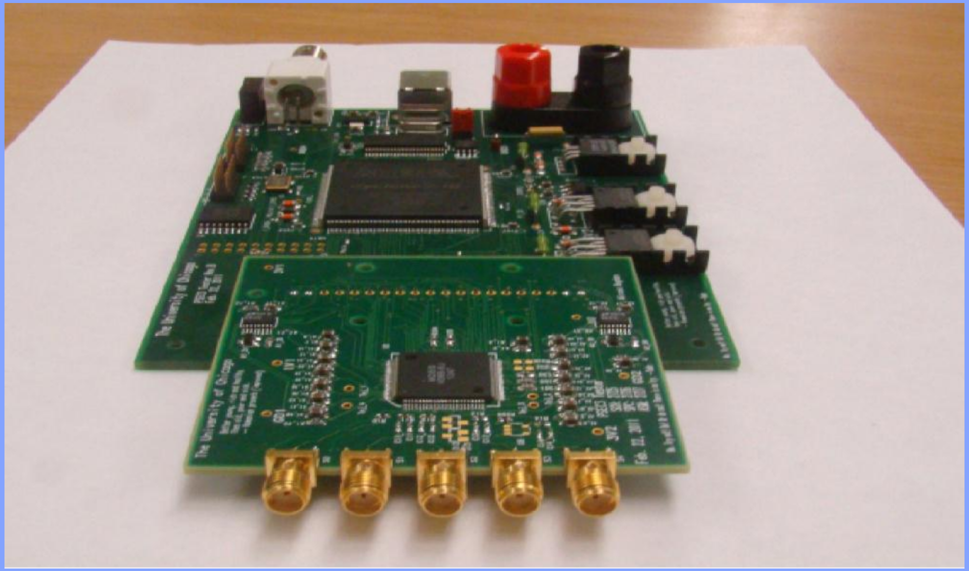
Stefan Ritt slide

UC workshop 4/11

PSEC3 ASIC

Chicago- Hawaii: Eric Oberla, Herve Grabas

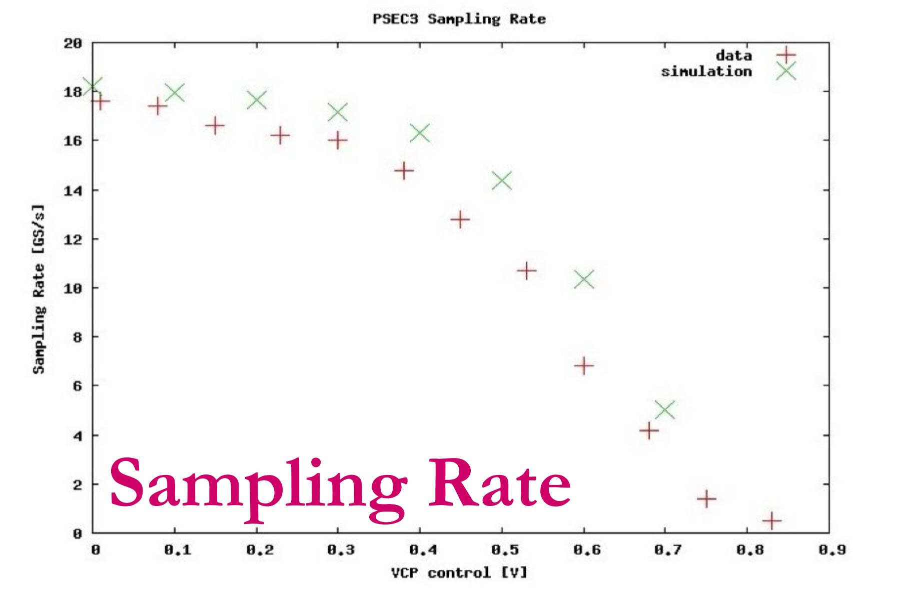


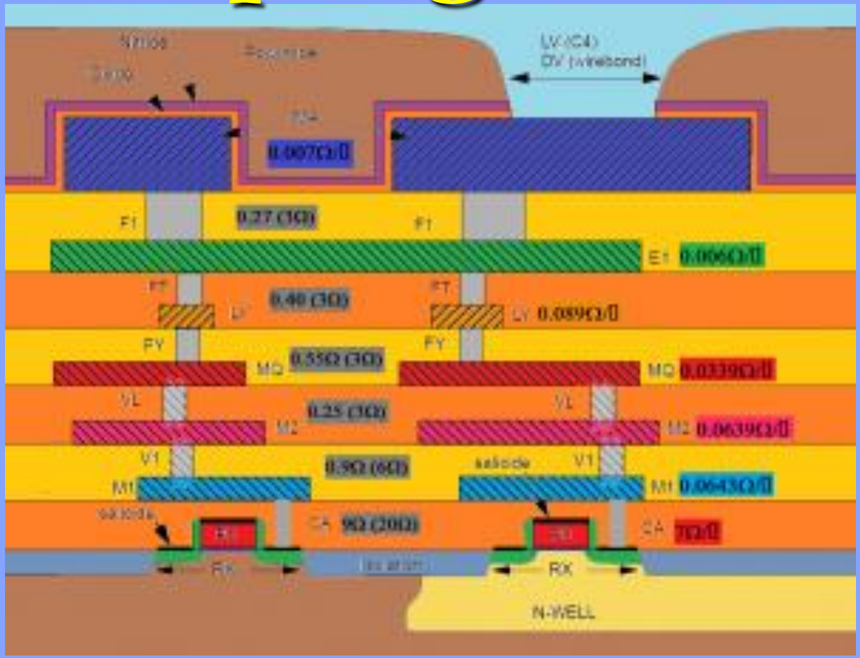


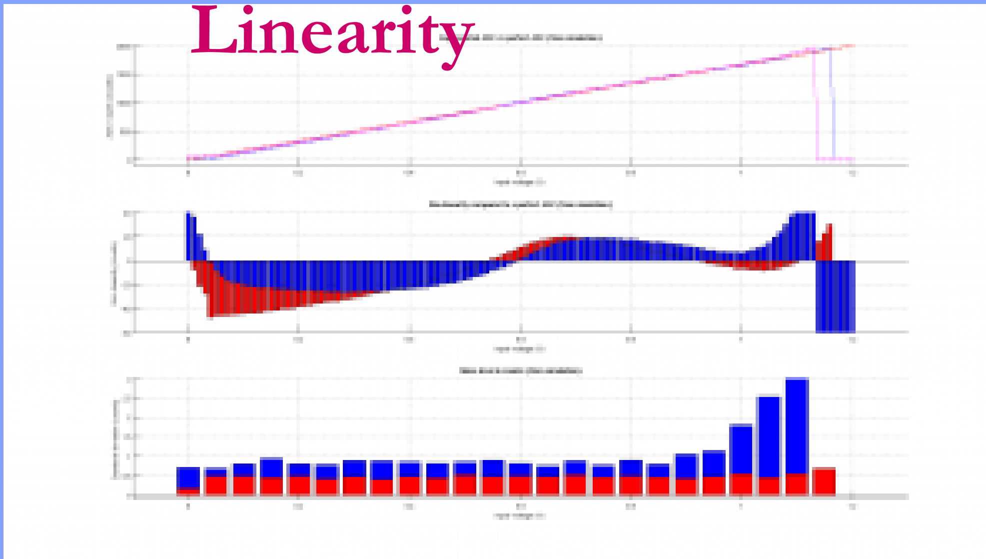
- 130nm IBM 8RF Process
- This chip 4 channels, 256 deep analog ring buffer
- Sampling tested at (almost) 18 GS/sec
- Each channel has its own ADC- 10 bits effective
- Fastest waveform sampling chip by a factor of ~3

PSEC3 Waveform Sampling ASIC

Made (sic) in our own EDG







Looks really good, frankly…already meets 3 of Stefan's 4 criteria. Some glitches, and we can up performance even more: Next submission is May 9th

8" Glass Package Component Costs

Rich Northrop

Fabricated per unit cost estimates

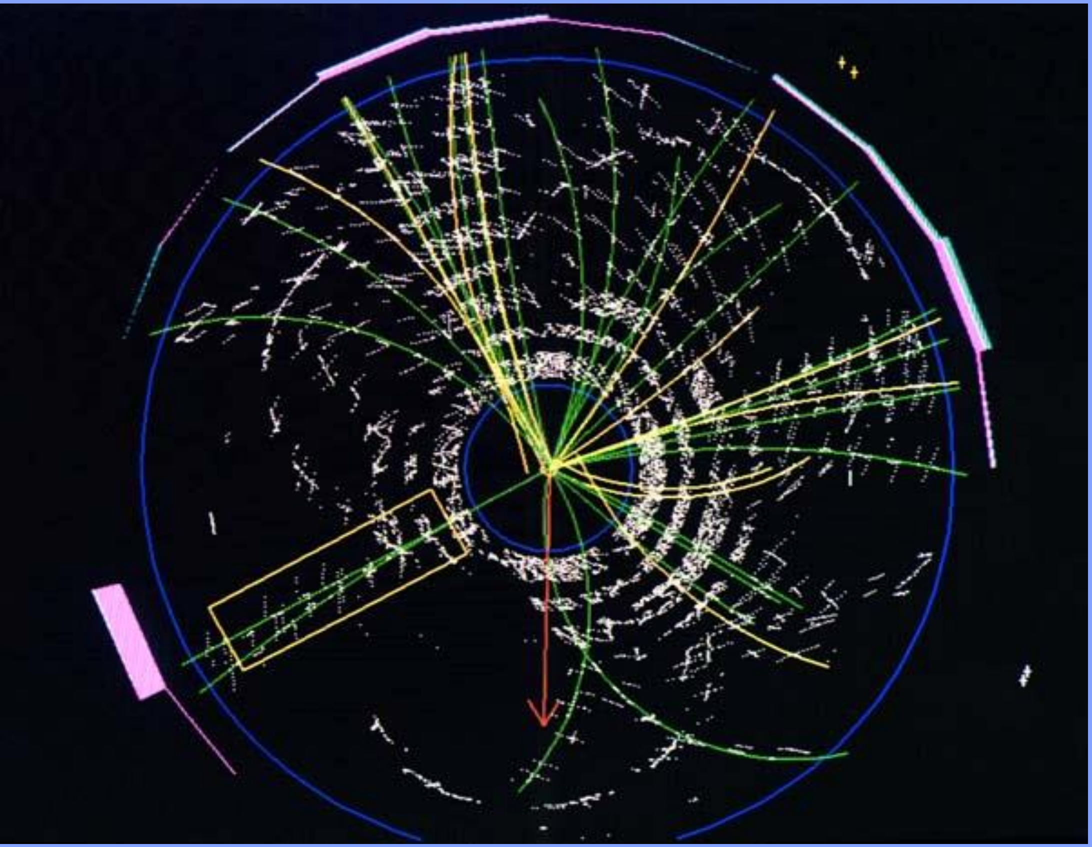
	---------Quotations---------		----------------------Cost estimates---------------------		
	30	**1000**	**3000**	**10,000**	**100,000**
Window (1@)	**$18**	**13**	**11**	**10**	**8**
Side wall (1@)	**$78**	**55**	**52**	**48**	**40**
Base plate (1@)	**$20**	**13**	**11**	**10**	**8**
Rod Spacers (75@)	**$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

Application to Colliders

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

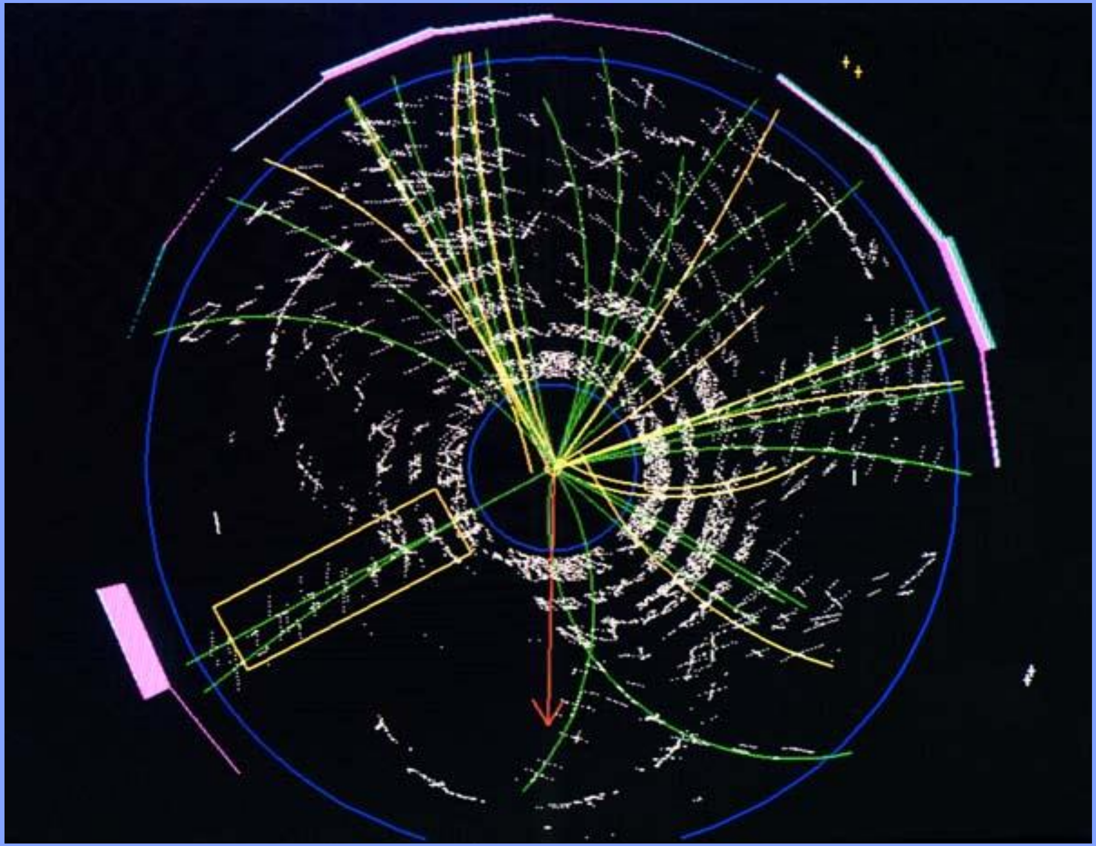


A real top candidate event from CDF- has top, antitop, each decaying into a W-boson and a b or antib. Goal- identify the quarks that make the jets. (explain why…)

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

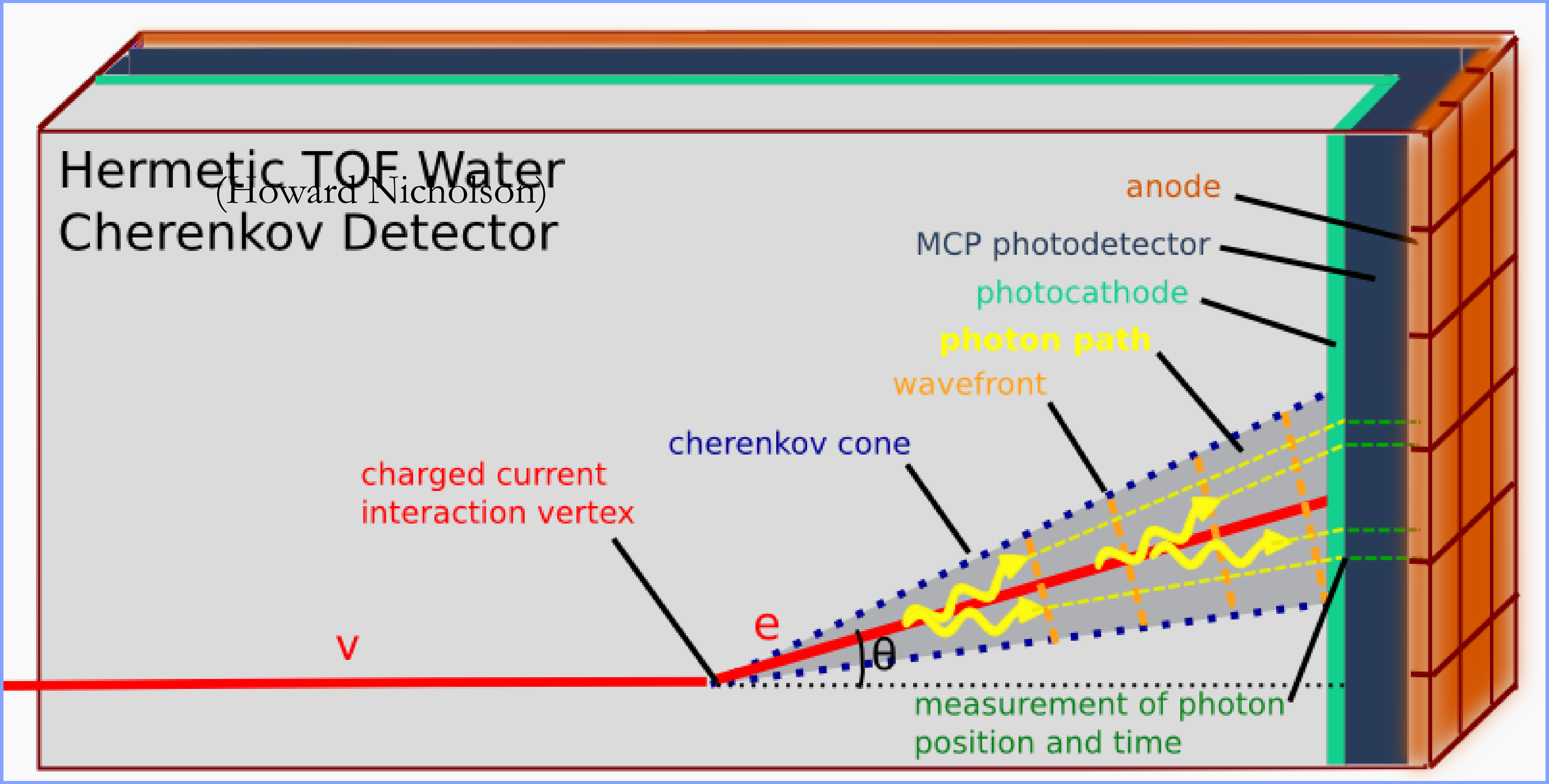
Specs:
Signal: 50-10,000 photons
Space resolution: 1 mm
Time resolution 1 psec
Cost: <100K$/m2:

New Idea (?)-Differential TOF



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

Application 2- Neutrino Physics



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

New Idea:Hi-res H_2O

- Spatial Res of <1cm plus >50% coverage would allow working close to the walls => greater Fid/Tot ratio;
- Also would make curve of Fid/Tot flatter wrt to symmetry- could make a high, long, narrow (book-on-end) detector at smaller loss of F/T;
- Cavern height cheaper than width; robust tubes can stand more pressure
- Narrow may allow magnetic field (!)

New idea: Hi-Res H_20-continued

- 100 psec time resolution is 3cm space resolution ALONG photon direction;
- Transverse resolution on each photon should be sub-cm;
- Question- can one reconstruct tracks?
- Question- can one reconstruct vertices?
- Question- can one distinguish a pizero from an electron and 2 vertices from one? (4 tracks vs 1 too)

New idea: Hi-Res $H_2$0-continued

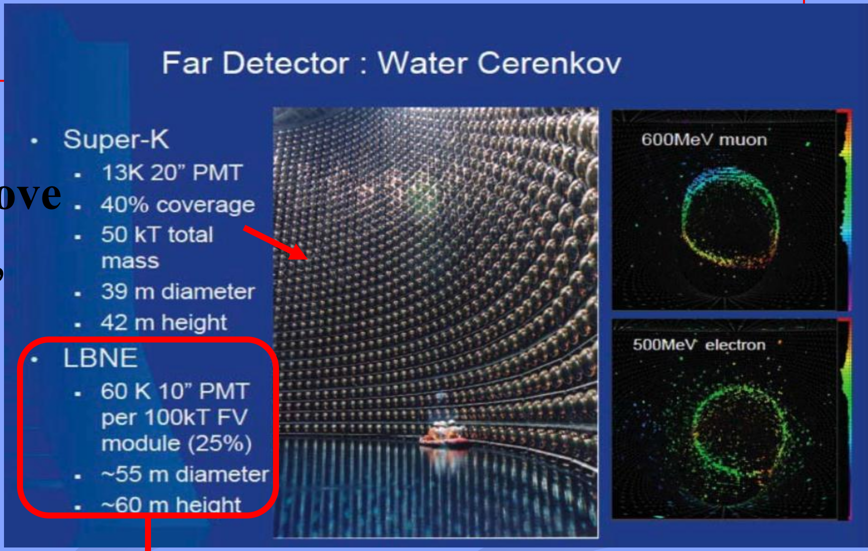
- **Question: Can we reconstruct the first 3 radiation lengths of an event with resolution ~1/10 of a radiation length?**
- **Handles on pizero-electron separation: 2 vs 1 vertices; no track vs 1 track between primary vertex and first photon conversion; 2 tracks (twice the photons) from the 2 conversion vertices;**
- **Know photon angle, lots of photons-fit to counter dispersion, scattering;**
- **Book-on-end aspect ratio helps against dispersion, scattering-have to look at whole picture.**

•LDRD Proposal Prototype of a Large-Area Picosecond Photosensor-based Detector

•Zelimir Djurcic, Marcel Demarteau, Henry Frisch, Mayly Sanchez, Matt Wetstein

Zelimir slide

•HEP



•Problem

•-with novel detector applications one has to improve
• performance by increasing the detector coverage,
• granularity, timing resolution and quantum
• efficiency and/or reduce the cost of technology.

•Approach

•-use Large Area Photo-Detectors (LAPD) currently
• under development at ANL/UC: MCP-based,
• potentially cheap, scalable, flat panel photo-detectors
• with a high precision time and spatial resolution.

•Goal

•-first application of LAPD-based detector in a liquid
• scintillator (LS), water, and water-based LS
• detector.

•-Example of basic science
• i.e. neutrino physics:
•future LBNE Experiment

Zelimir slide

•LDRD Goals

•-1st year: characterize and design LAPD-based detector: simulate and quantify the benefits of a precise position and time resolution, understand particle ID and background rejection capabilities.

•-2nd year: LAPD module available, start building a prototype of LAPD based detector: understand the LAPD module/liquid interface, design vessel containment, readout scheme (test wireless).

•-3rd year: application and operation of LAPD in LS, water, or water-based LS detector: data analysis and comparison with expectation.

•Phased Approach in Technology Development: Beyond LDRD

•-Short-term: design, build and operate ~1m^3 detector (~3 years). → **This LDRD.**

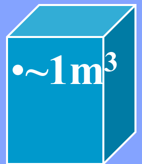
•-Intermediate-term: build a 20 ton LAPD-based detector (~4-6 years).→**Future**

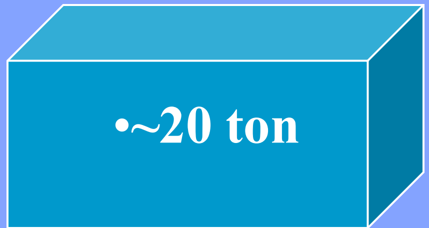
•Funding.

• Application: short-baseline neutrino physics (oscillatio tests and cross-section measurements), LBNE near detector, low-background counting facili
underground), etc.

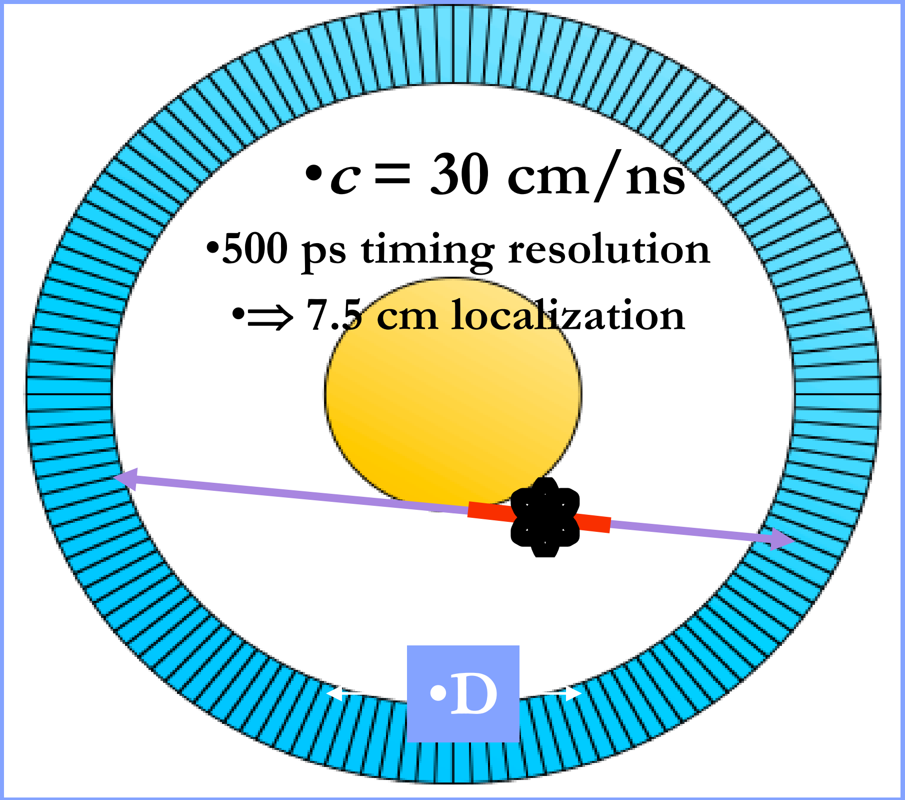
•-Long-term: large multi-kton detectors. → **Future Funding.**

•Application: long-baseline neutrino physics (LBNE far det.), proton
nova detection.





Application 3- Medical Imaging (PET)



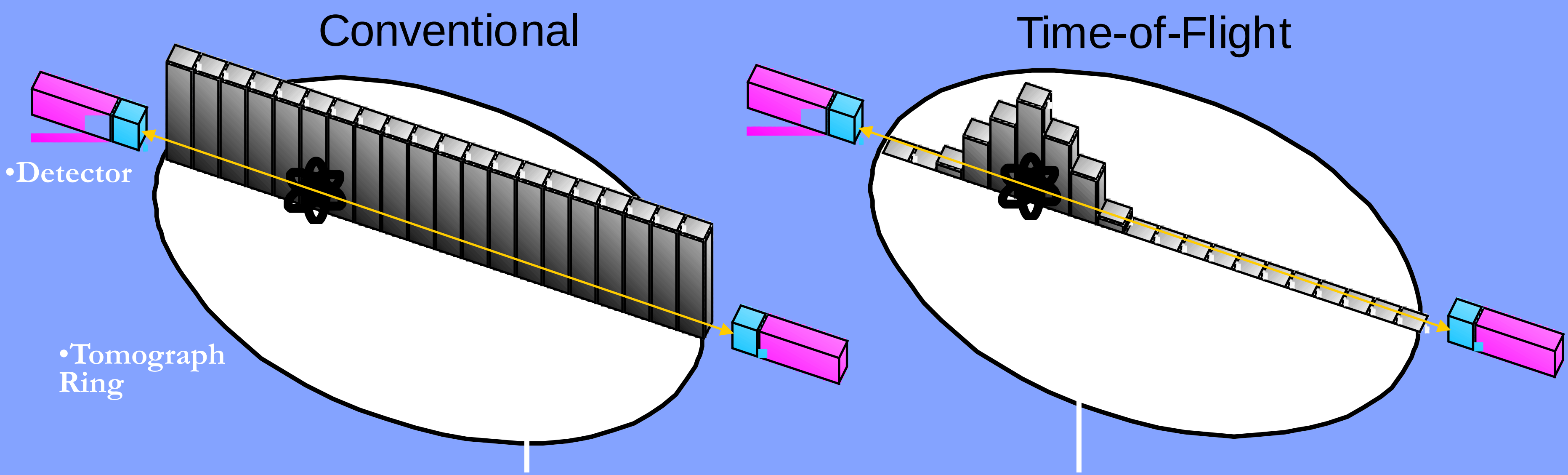
•Bill Moses Slide (Lyon)

- Can localize source along line of flight.
- Time of flight information reduces noise in images.
- Variance reduction given by 2D/$c\Delta$t.
- 500 ps timing resolution ⇒ 5x reduction in variance!

- Time of Flight Provides a *Huge* Performance Increase!
- Largest Improvement in Large Patients

Adding Time-of-Flight to Reconstruction ⇒ Faster Convergence

- Bill Moses Slide (Lyon)



•Height represents weight assigned to each voxel by reconstruction algorithm

•Conventional:

- Detected event projected to *all* voxels between detector pairs
- Lots of coupling between voxels
- ⇒ Many Iterations to Converge

•Time-of-Flight:

- Detected event projected *only* to voxels consistent w/ measured time
- Little coupling between voxels
- ⇒ Few Iterations to Converge

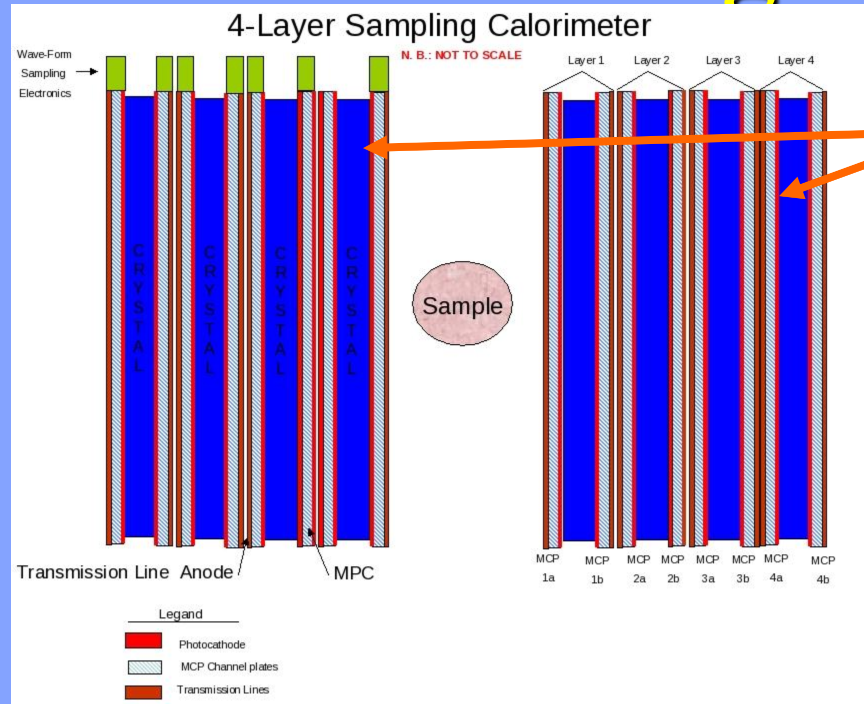
Improve Limits with New Scintillators?

Hardware	Δt (ps)	TOF Gain
BGO Block Detector	3000	0.8
LSO Block (non-TOF)	1400	1.7
LSO Block (TOF)	550	4.2
$LaBr_3$ Block	350	6.7
LSO Single Crystal	210	11.1
LuI_3 Single Crystal	125	18.7
$LaBr_3$ Single Crystal	70	33.3

Gain means lower dose rate: additional factor from whole-body coverage vs scanning camera

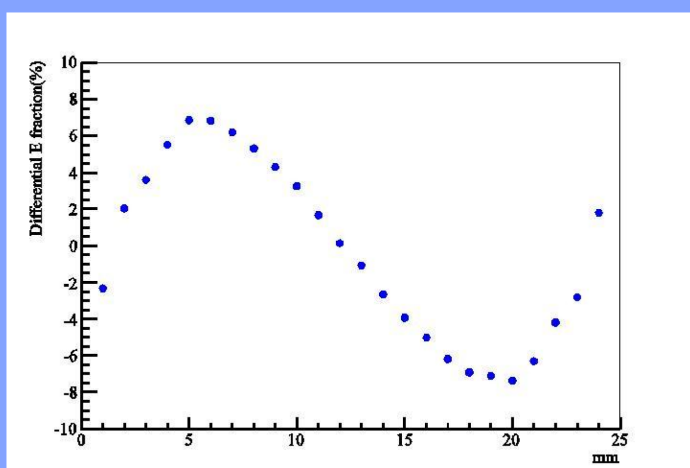
Application 3- Medical Imaging (PET)

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

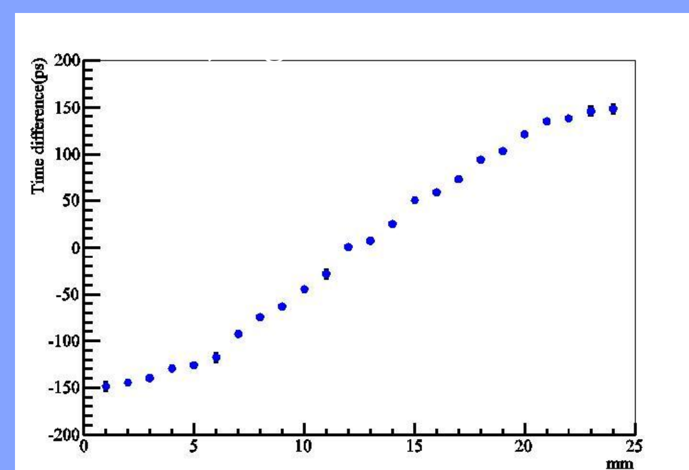


Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side

Simulations by Heejong Kim (Chicago)

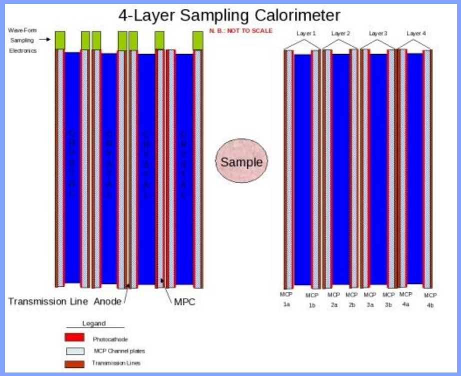


Depth in crystal by energy- asymmetry



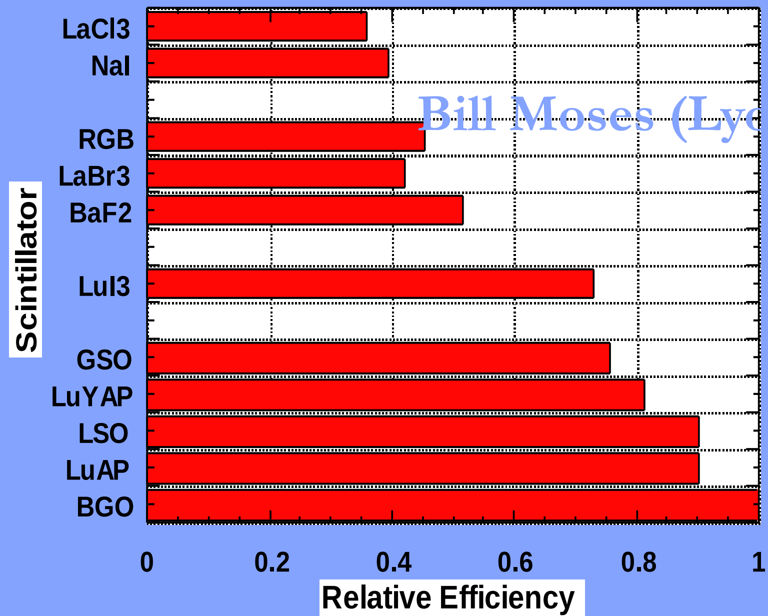
Depth in crystal by time-difference

A radical idea driven by sampling calorimeters based om thin cheap fast photodetectors with correlated time and space waveform sampling



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

- Both Photons Deposit >350 keV



Give up on the 511 KeV energy cut for bkgd rejection (!?), Give up on the Compton fracfion (!??), and instead use cheaper faster lower-density scintillator, adaptive algorithms, and large-area to beat down background.

Question for wkshp- candidate scintillators (Ren-yuan suggests BaF2- even lower density candidates?)

Application 4- Cherenkov-sensitive Sampling Quasi- Digital Calorimeters

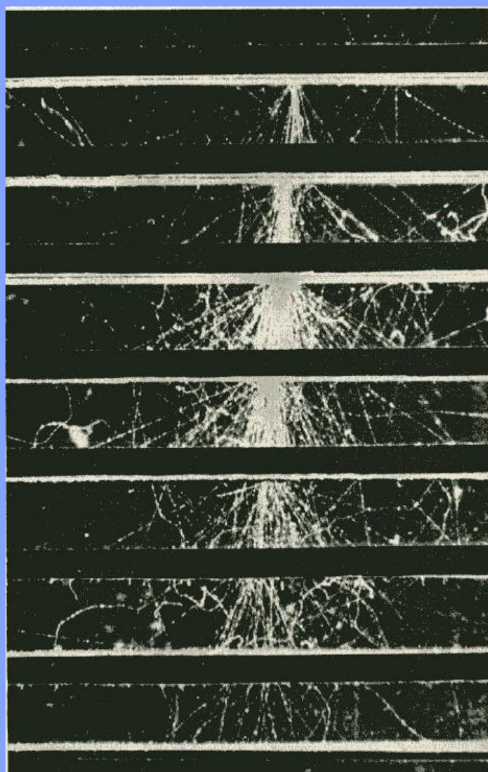
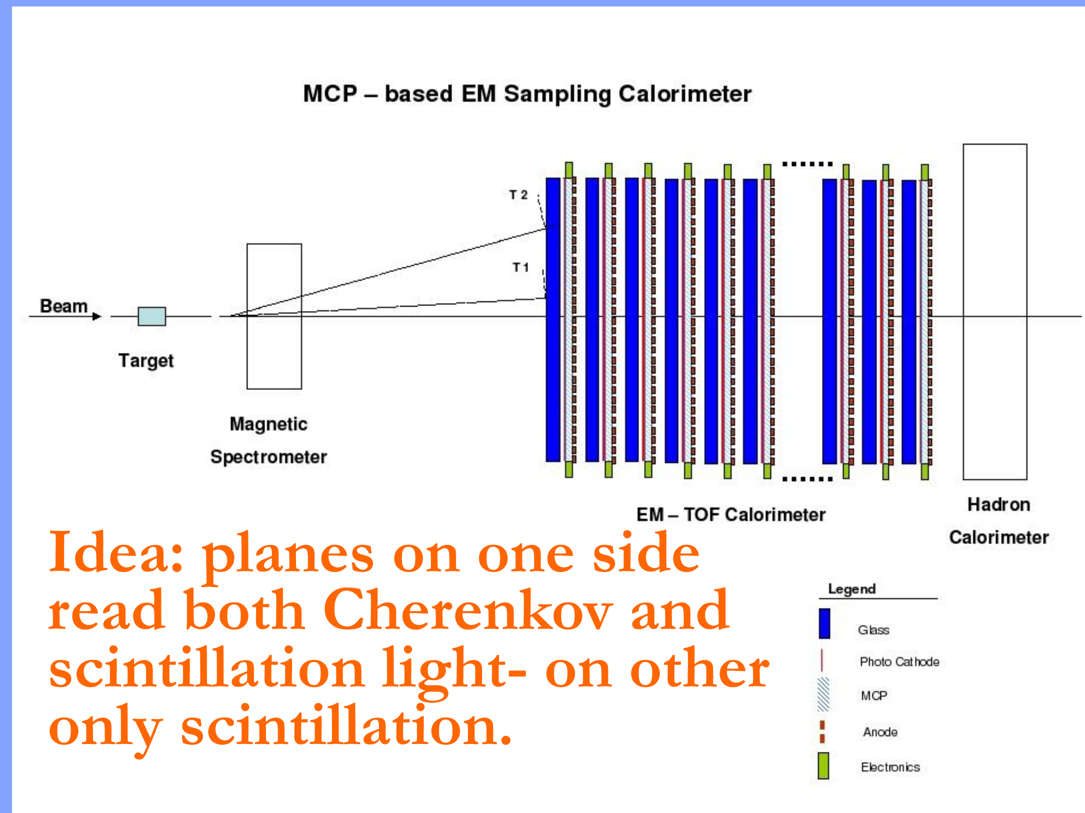


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.



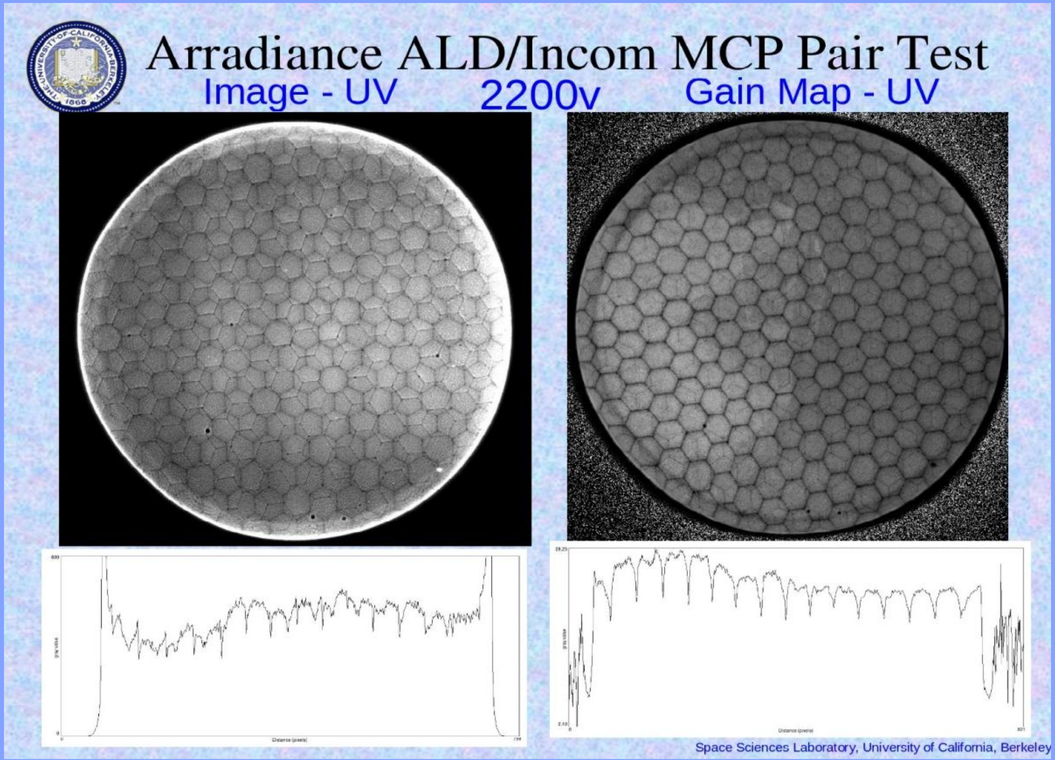
A picture of an em shower in a cloud-chamber with ½" Pb plates (Rossi, p215- from CY Chao)

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

Can one build a `Quasi-digital' MCP-based Calorimeter?

Idea: can one saturate pores in the the MCP plate s.t.output is proportional to number of pores. Transmission line readout gives a cheap way to sample the whole lane with pulse height and time- get energy flow.

Oswald Siegmund, Jason McPhate, Sharon Jelinsky, SSL (UCB)



Note- at high gain the boundaries of the multi's go away

Electron pattern (not a picture of the plate!)- SSL test, Incom substrate, Arradiance ALD. Note you can see the multi's in both plates => ~50 micron resolution

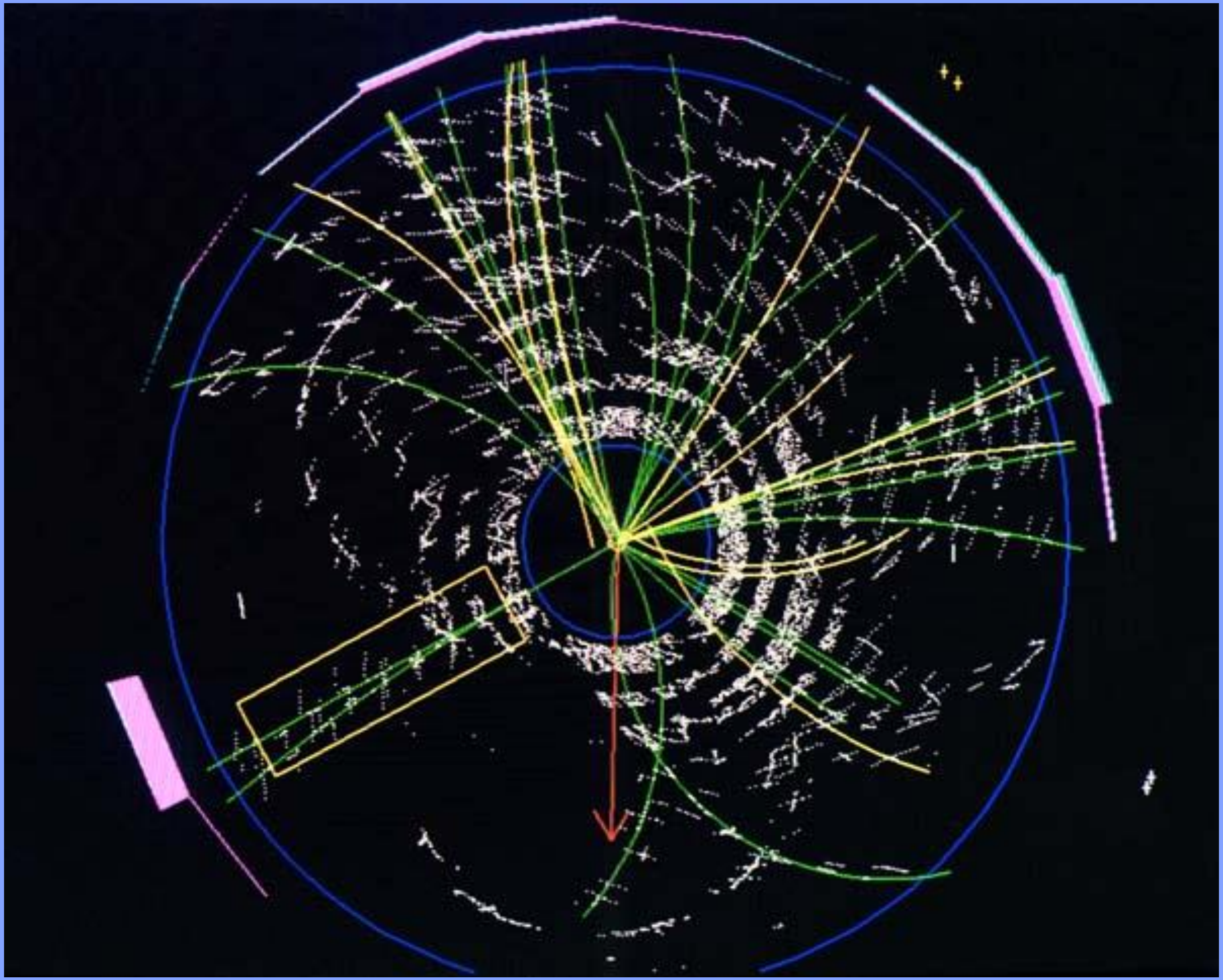
More Information:

- Main Page: http://psec.uchicago.edu
- Library: Image Library, Document Library, Year-1 Summary Report, 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);
- Wish us well- goal is in 3 years (2 from now) to have commercializable modules- too late for the 1^{st} round of LBNE, but maybe not too late for a 2^{nd} or 3^{rd}-generation detector.

Conclusions

- ANL is amazingly deep in talent and resources
- LAPPD has met 1st and 2nd year milestones
- Innovation in lots of areas- detectors, wave-form sampling, ALD, material science, photocathodes..
- Lots of interest from many areas- TOF at STAR (RHIC), PET, CT (maybe), Reactor Monitoring, HEP neutrino detectors, Mass-spec in Geophysics, …
- Lots of interest, but no money, from mass producers of tubes (tho get lots of help from our collaborating industrial partners)
- EFI plays a very big technical role- the EDG, Rich, machine shop, support staff, space, colleagues…

The End-



Backup

The Large-Area Psec Photo-detector Collaboration

The Development of Large-Area Fast Photo-detectors

April 15, 2009

John Anderson, Karen Byrum, Gary Drake, Edward May, Alexander Paramonov, Mayly Sanchez, Robert Stanek, Hendrik Weerts, Matthew Wetstein[1], Zikri Yusof
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3 National Labs, 6 Divisions at Argonne, 3 US small companies; electronics expertise at UC Berkely, and the Universities of Chicago and Hawaii

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

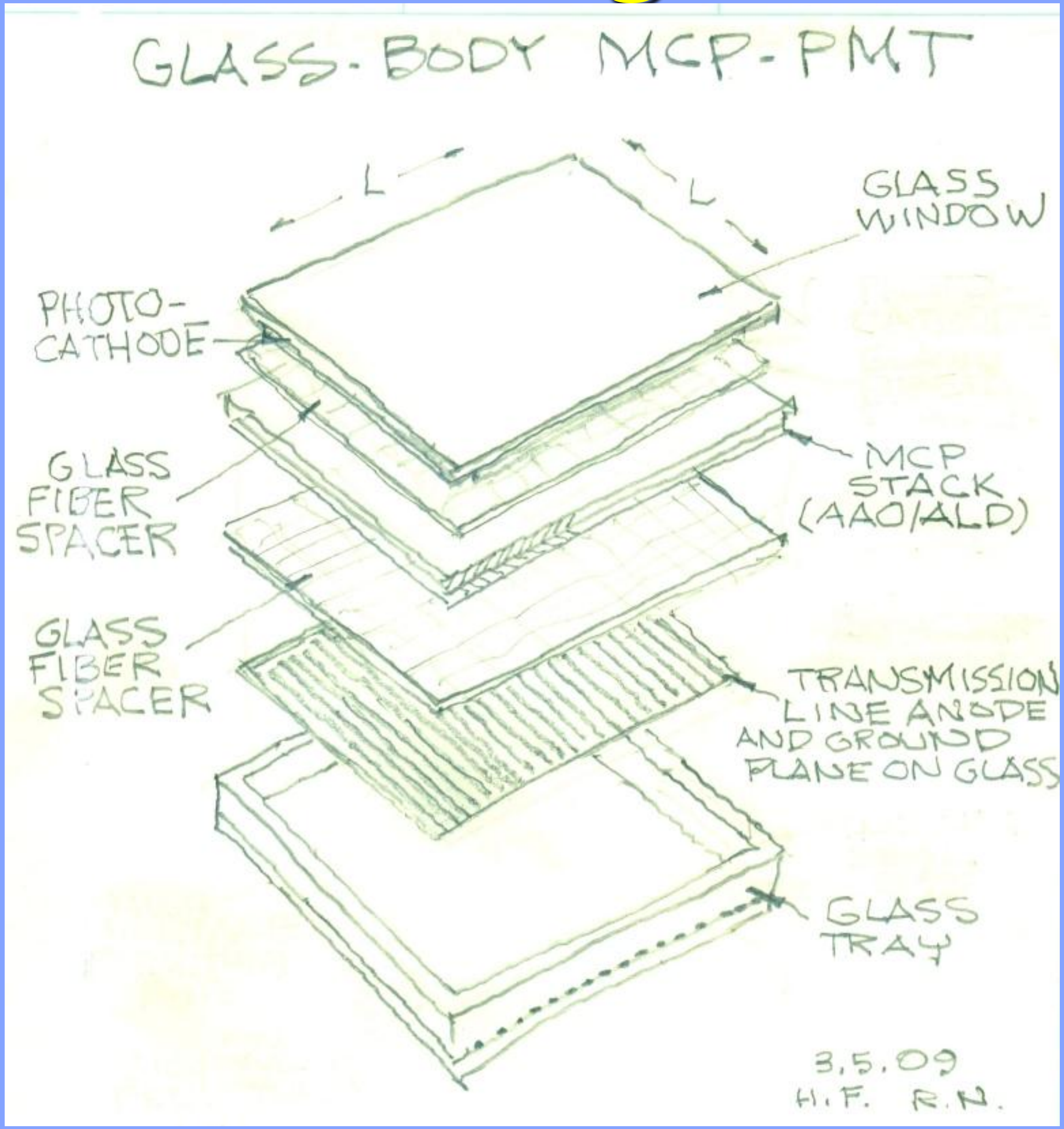
DOE Funded (a little NSF)

Parallel Efforts on Specific Applications

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

Put it all together- the `Frugal' MCP

- Put all ingredients together- flat glass case (think TV's), capillary/ALD amplification, transmission line anodes, waveform sampling
- Glass is cheap, and they make vacuum tubes out of it- why not MCP's?



GodParent Review Panels

- Packaging Group
  - Karen Byrum
  - K.Arisaka
  - J. Elam
  - D. Ferenc
  - J.F. Genat
  - P. Hink
  - A. Ronzhin

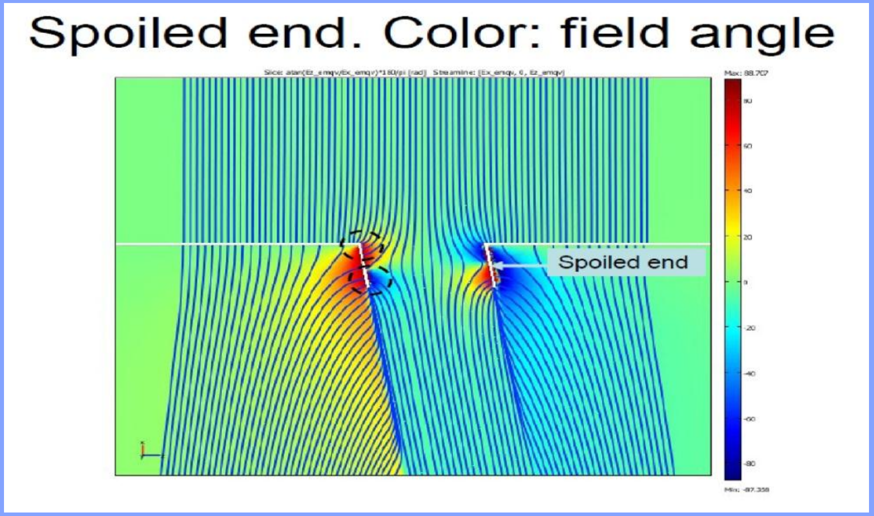
- MCP Group
  - Bob Wagner
  - K.Attenkofer
  - A. Bross
  - Z. Insepov
  - A. Tremsin
  - J. Va'vra
  - A. Zinovev

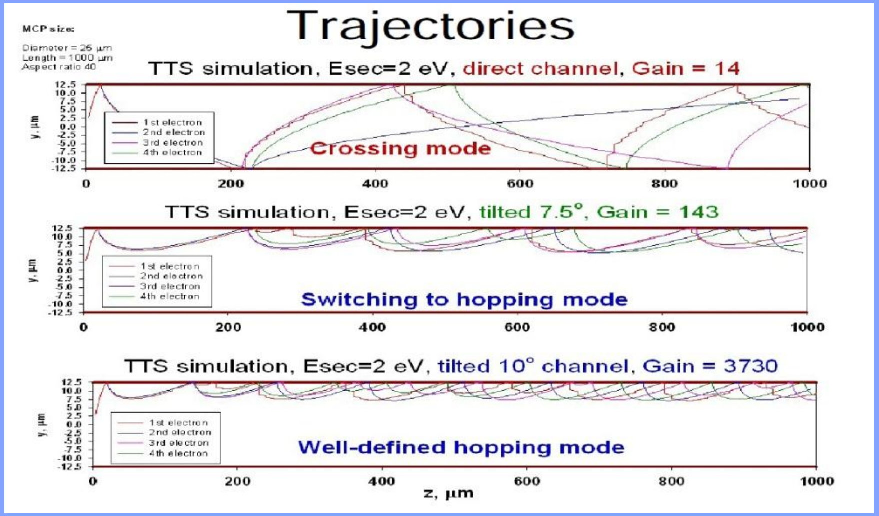
- Photocathode Group
  - Gary Varner
  - J. Buckley
  - K. Harkay
  - V. Ivanov
  - A. Lyashenko
  - T. Prolier
  - M. Wetstein

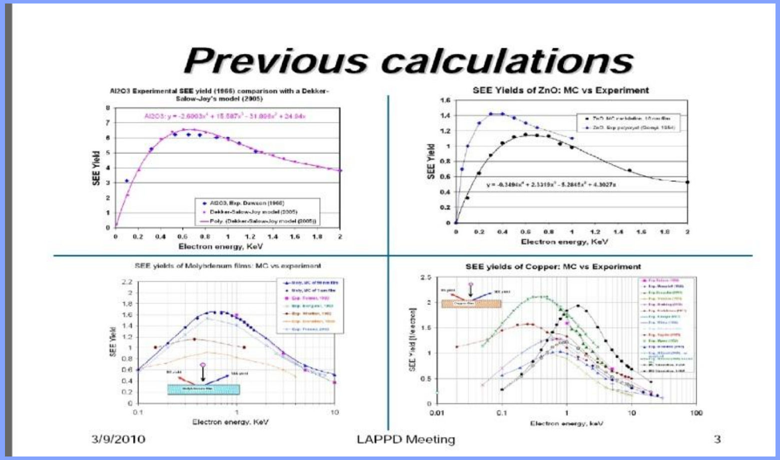
- Electronics Group
  - Zikri Yusof
  - B. Adams
  - M. Demarteau
  - G. Drake
  - T. Liu
  - I. Veryovkin
  - S. Ross

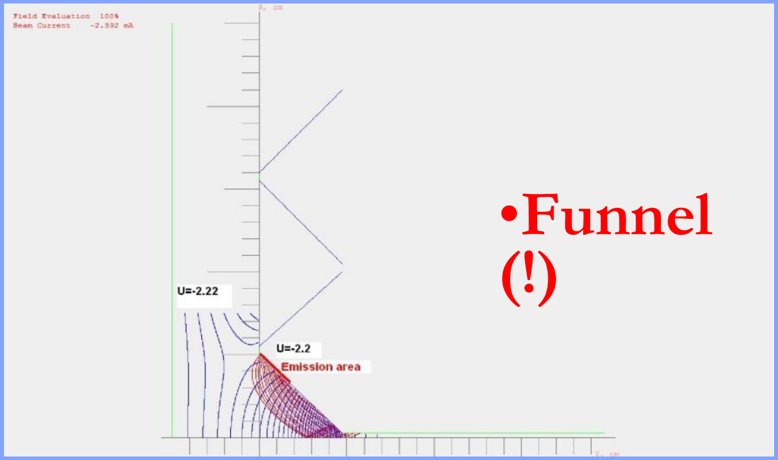
Simulation (crosses all groups)

Valentin Ivanov, Zeke Insepov, Zeke Yusof, Sergey Antipov









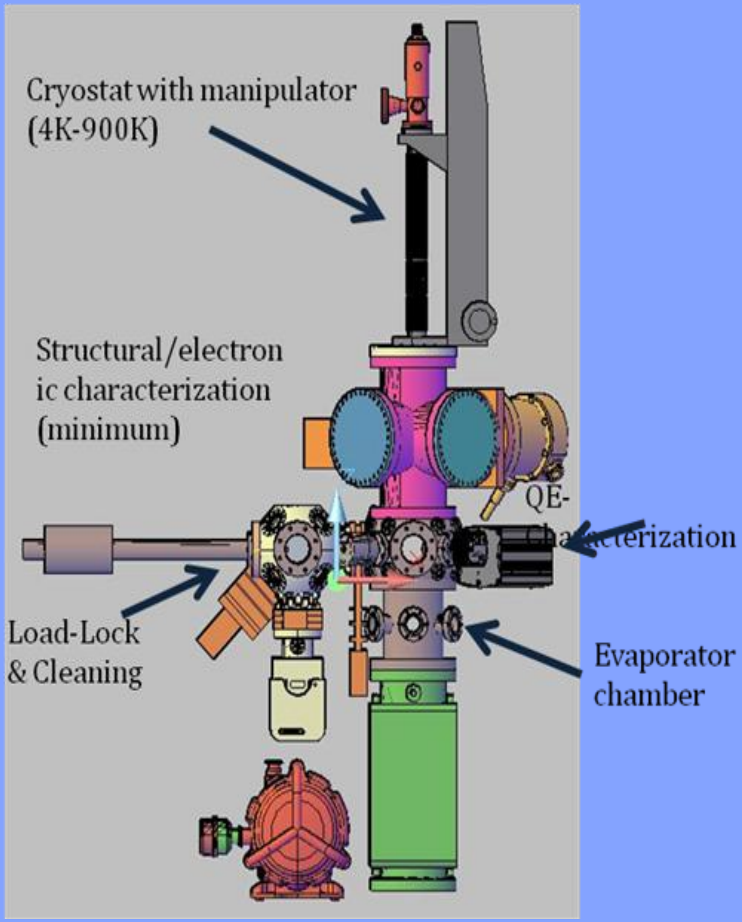
- Funnel (!)

Advanced Photocathode Group

Moving to understanding the physics

Klaus Attenkofer, Sasha Paramonov, Zikri Yusof, Junqi Xi, Seon Wu Lee, UIUC, WashU, ….

- III-V have the potential for high QE, shifting toward the blue, and robustness i.e. they age well, high-temp)
- Opaque PC's have much higher QE than transmission PC's- we have the geometry
- Many small factors to be gained in absorption, anti-reflection- see papers by Townsend and talk by Fontaine on our web site
- Quantum Effic. Of 60% have been achieved in bialkalis



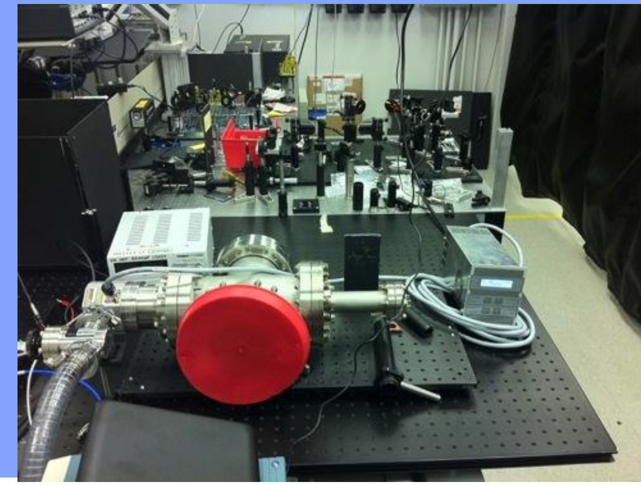
Big payoff if we can get >50% QE robust Photocathodes, and/or more robust (assembly). Also want to get away from `cooking recipes' to rational design.

Some Neutrino-specific Thoughts

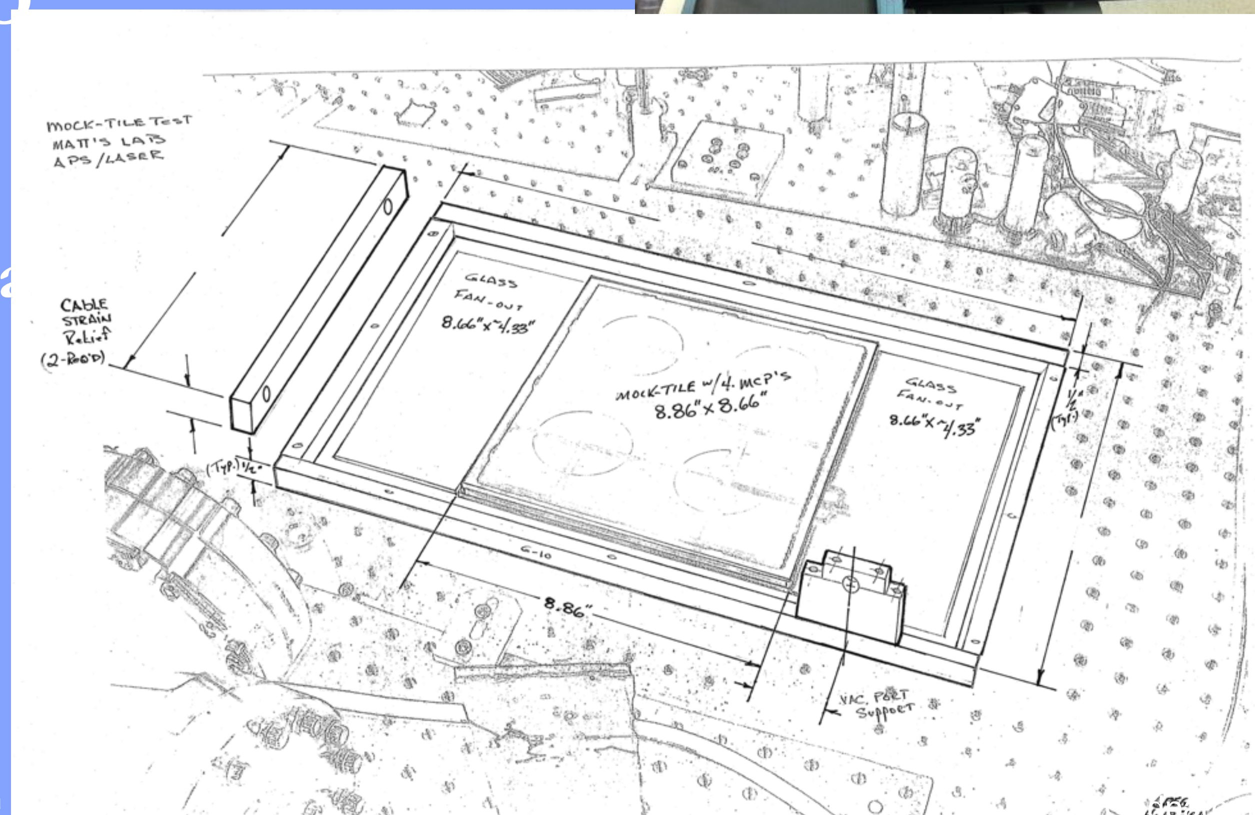
NEXT STEPS? (needs discussion…)

- Simulation
  - Pizero/electron vertex recon
  - True track reconstruction
  - Proton Decay
- Proto-type Testing in situ: Can we add someSuperModules to an existing water/scint detector (apologies for my ignorance)?
- A new small near detector proto-type/test-bed for Fermilab?
- Other?

•Mock-tile testing:



- New laser setup, shielding: Inspection by LSO
- High voltage shielding: electrica inspection
- Require ESAF before testing
- Test before DOE review



•8” chamber

•Design for the 8” plate holder is ready, just need to make them.

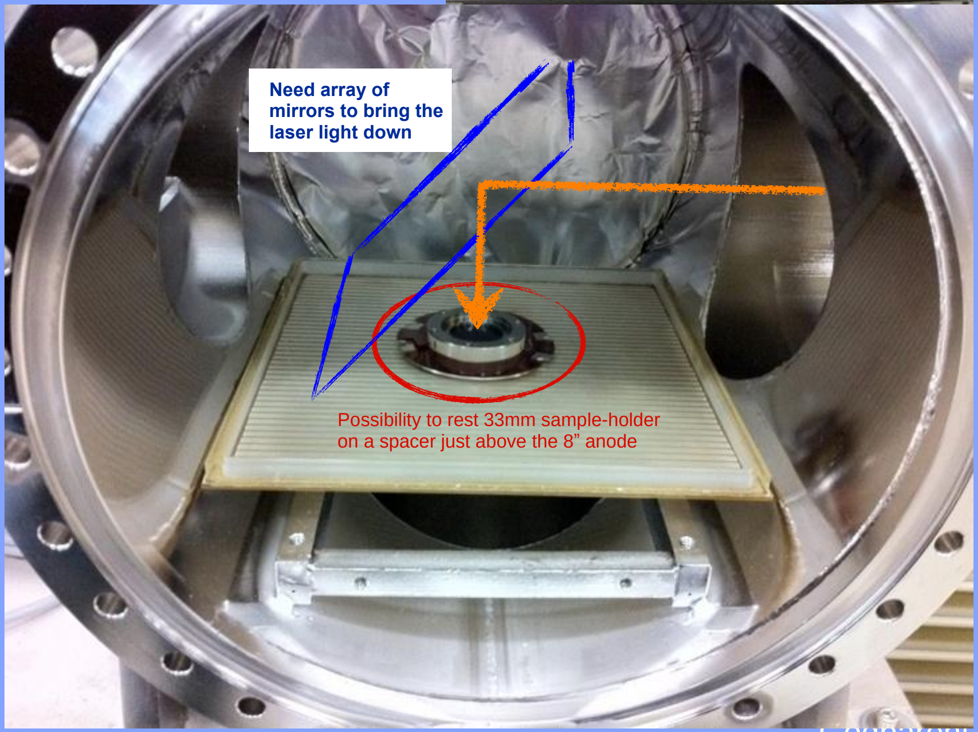
•Mirror system is coming along

Design and start making 8" holder and stack (< week)

- Electrodes designed, need to make them
- Design fanout board to fit in our chamber
- Get production of the fused silica window, sidewalls, spacers, etc, started

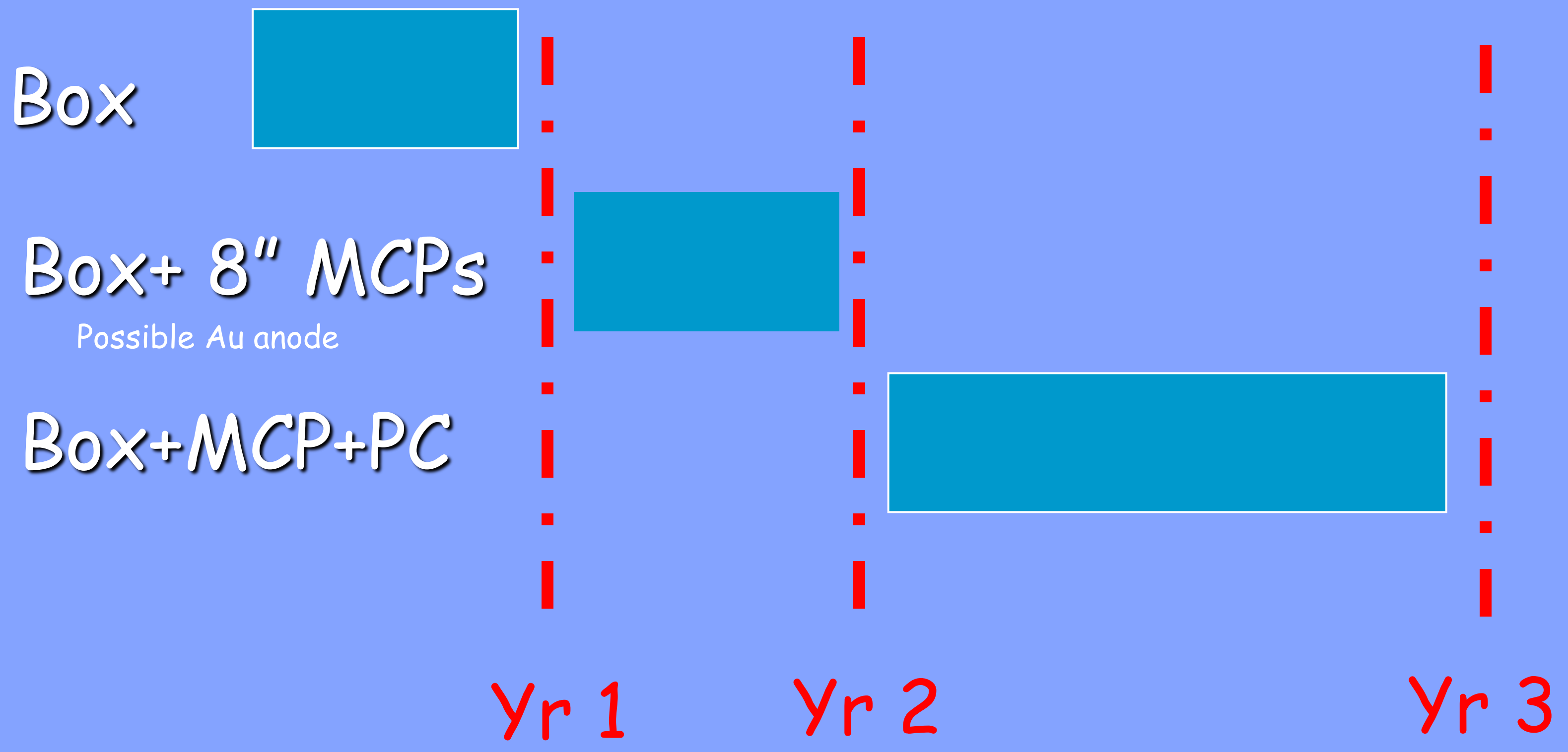
Solve mirror mount problem, possibly welding a mount directly in the chamber

Start testing (sometime next month)



ANL-UC Glass Hermetic Packaging Group

- Proceed in 3 steps: 1) hermetic box; 2) Add MCP's, readout, (Au cathode); 3) Add photocathode



Medical Imaging (PET)-cont.

Spec: signal 10,000 photons,30 ps time resolution , 1 mm space resolution, 30K$/m2, and commercializable for clinical use.

SUMMARY

However- truth in advertising- there is a long way to go (see Bill Moses's talk at Clermont.) It looks promising, as it may be possible to produce large panels with better spatial and time resolution than possible with photomultipliers, and our initial estimates are that MCP-PMT's may be as much as a factor of 10 cheaper. However, the development will take a collaborative effort on measurements and simulation (see papers by Heejong Kim et al on web and in this conference). Talks are also underway among Clermont, Strasbourg, Lyon, and Chicago.