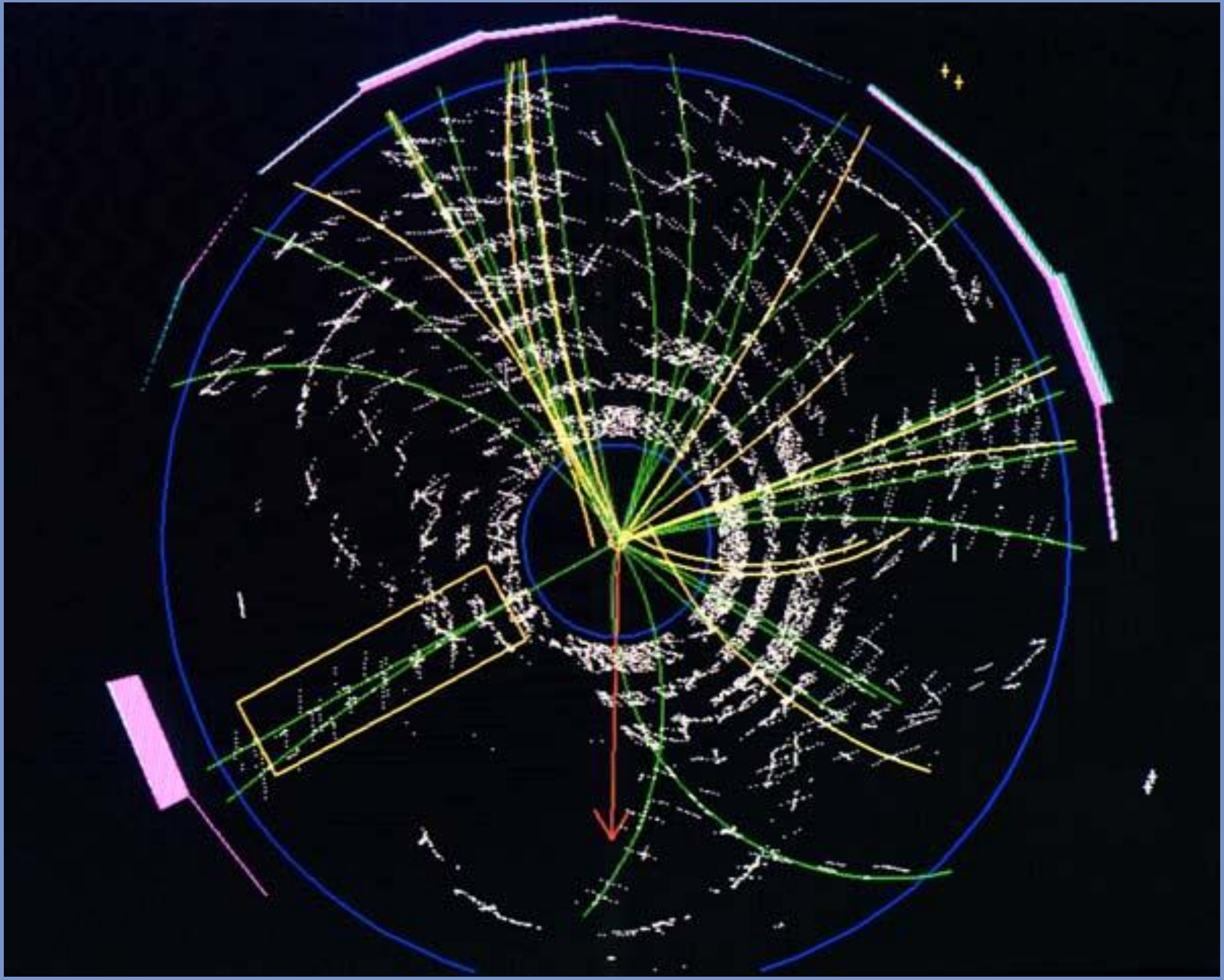
The Development of Large-Area Thin Planar Psec Photodetectors

Henry Frisch,
Enrico Fermi Institute and ANL



Three Goals of a New (1 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

(amplification) on cheap inert substrates (glass capillary arrays, AAO). Scalable to large sizes; economical; pure – i.e. chemically robust and (it seems- see below) stable

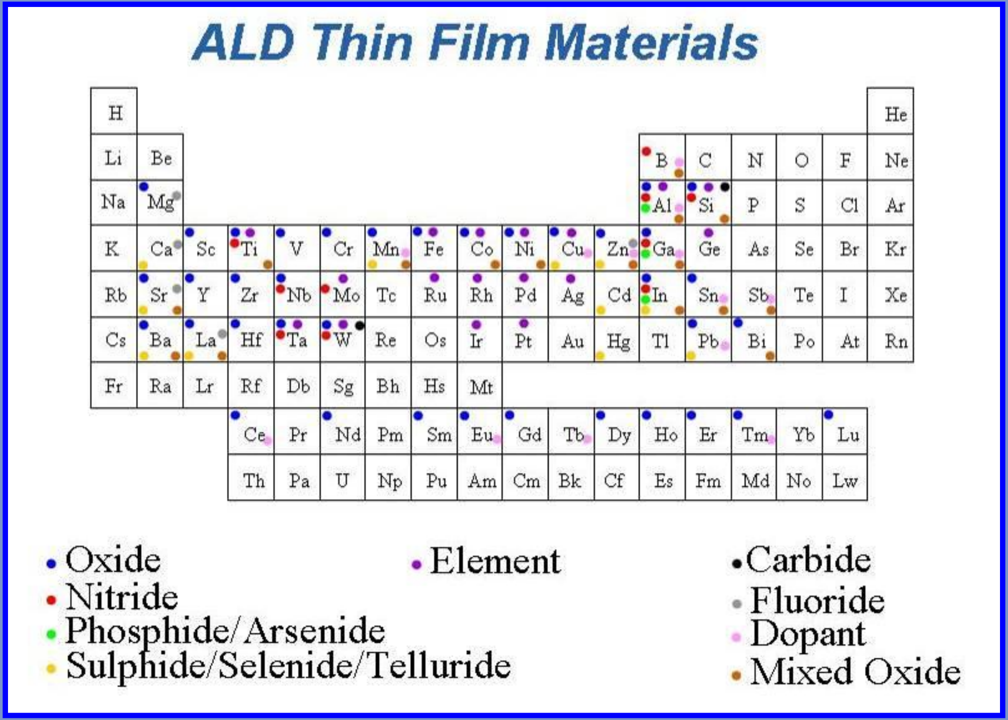
Readout: Use transmission lines and modern chip technologies for high speed cheap low-power high-density readout.

Anode is a 50-ohm stripline. Scalable up to many feet in length ; readout 2 ends; CMOS sampling onto capacitors- fast, cheap, low-power (New idea- make MCP-PMT tiles on single PC-card readout- see below)

Use computational advances -simulation as basis for design

Modern computing tools allow simulation at level of basic processes- validate with data. Use for `rational design' (Klaus Attenkofer's phrase).

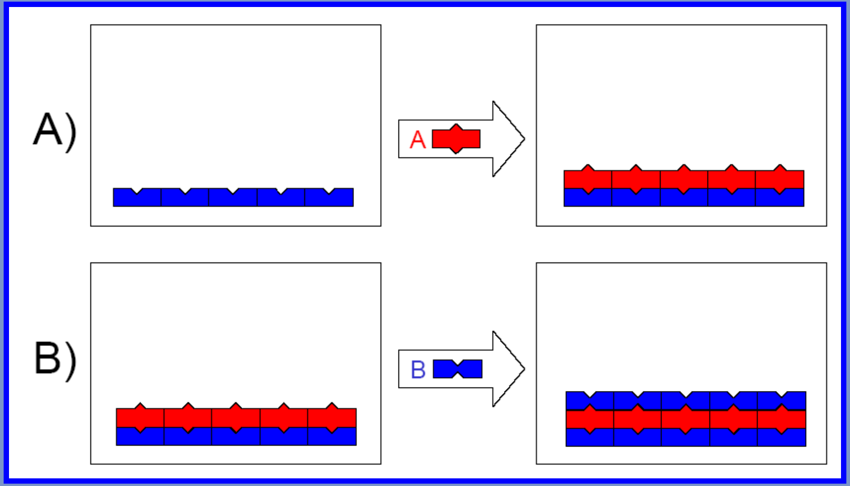
Atomic Layer Deposition (ALD) Thin Film Coating Technology



ALD Thin Film Materials

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt									
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lw	

- ● Oxide
- ● Nitride
- ● Phosphide/Arsenide
- ● Sulphide/Selenide/Telluride
- ● Element
- ● Carbide
- ● Fluoride
- ● Dopant
- ● Mixed Oxide



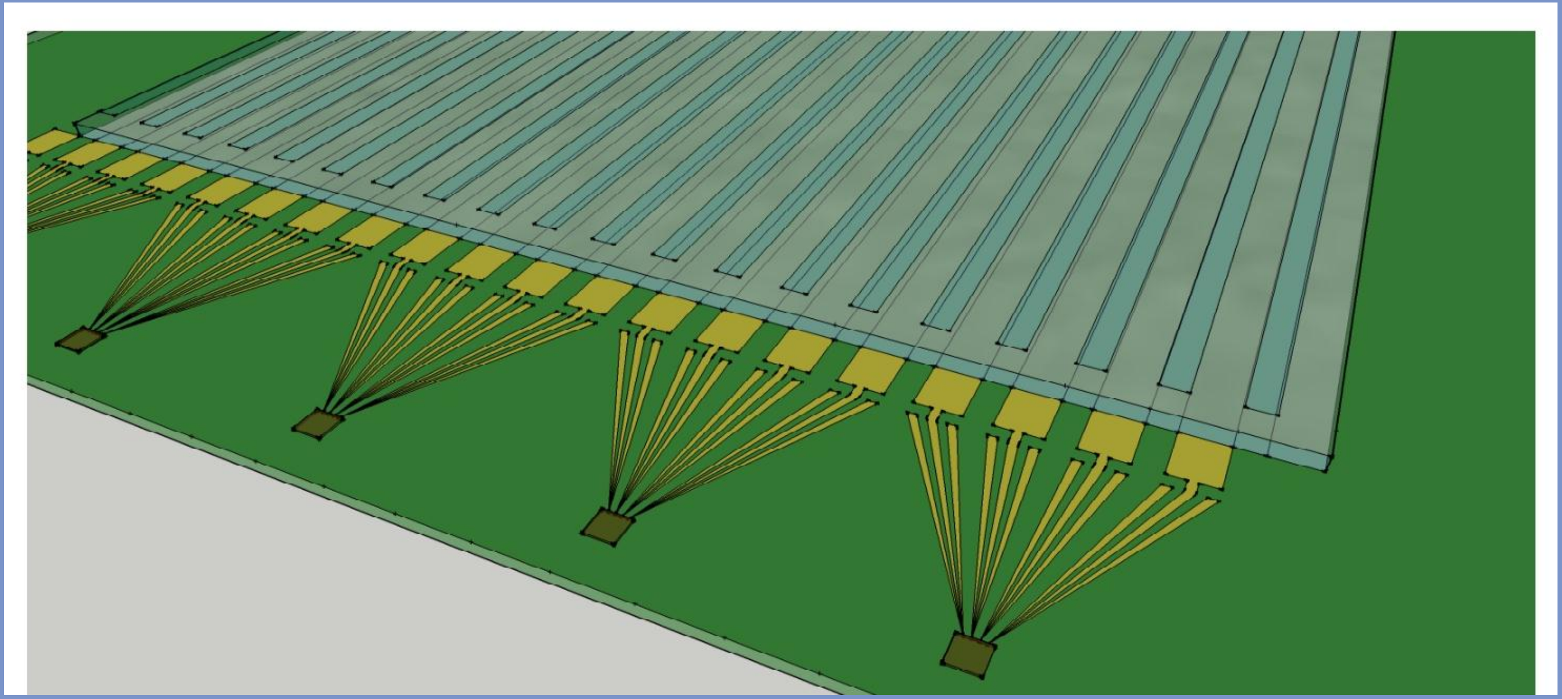
- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

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

Jeff Elam pictures

High (multi-GHz) ABW readout

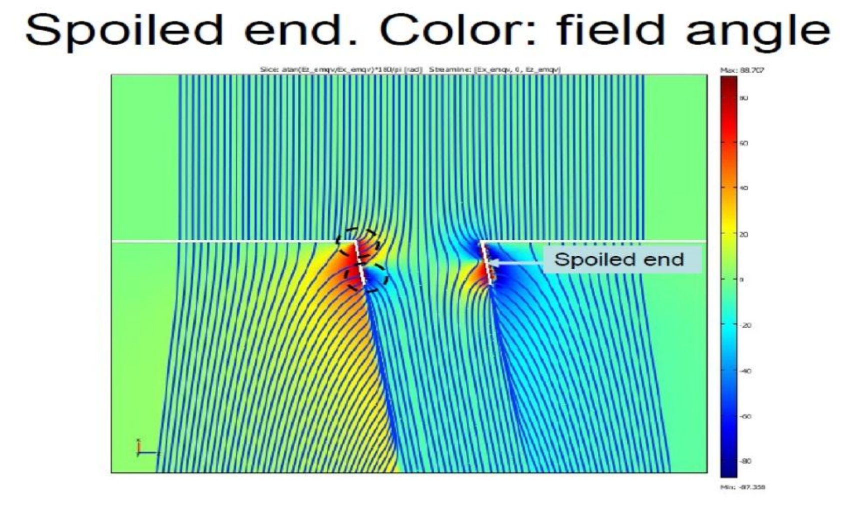
New Idea (Herve' Grabas)-Put bottom traced on PC-card (not on the glass).

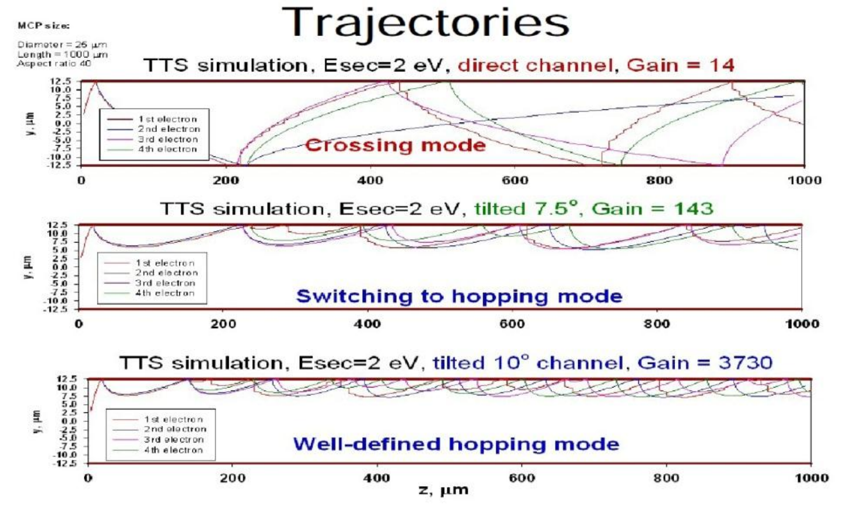


Note signal is differential between ground (inside, top), and PC traces (outside)

Simulation (crosses all groups)

Valentin Ivanov, Zeke Insepov, Zeke Yusof, Sergey Antipov


Spoiled end. Color: field angle


Trajectories

MCP size:
Diameter = 26 μm
Length = 1000 μm
Aspect ratio 40

TTS simulation, Esec=2 eV, direct channel, Gain = 14

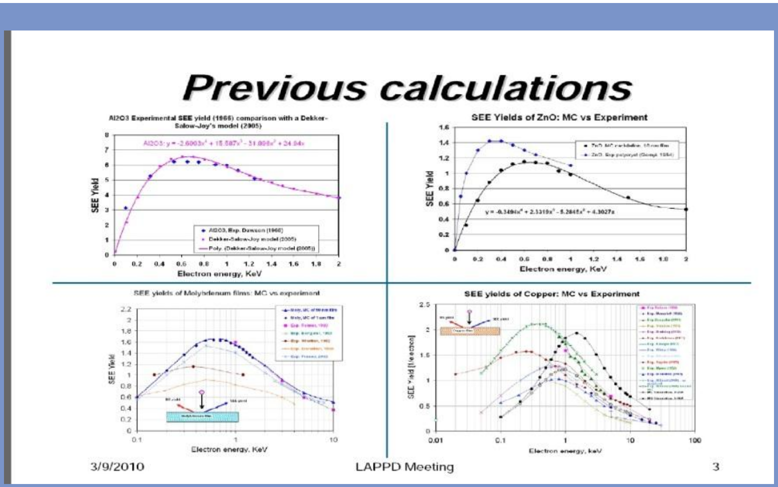
Crossing mode

TTS simulation, Esec=2 eV, tilted 7.5°, Gain = 143

Switching to hopping mode

TTS simulation, Esec=2 eV, tilted 10° channel, Gain = 3730

Well-defined hopping mode


Previous calculations

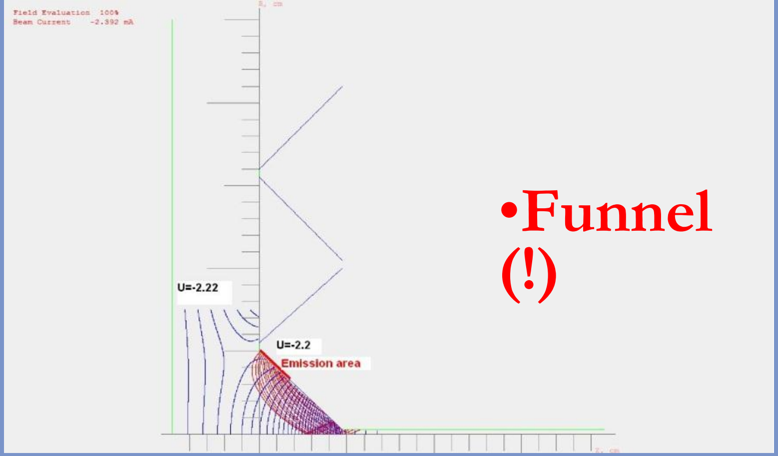
Al2O3 Experimental SEE yield (1966) comparison with a Dekker-Salow-Joy's model (2005)

SEE Yields of ZnO: MC vs Experiment

SEE yields of Molybdenum films: MC vs experiment

SEE yields of Copper: MC vs Experiment

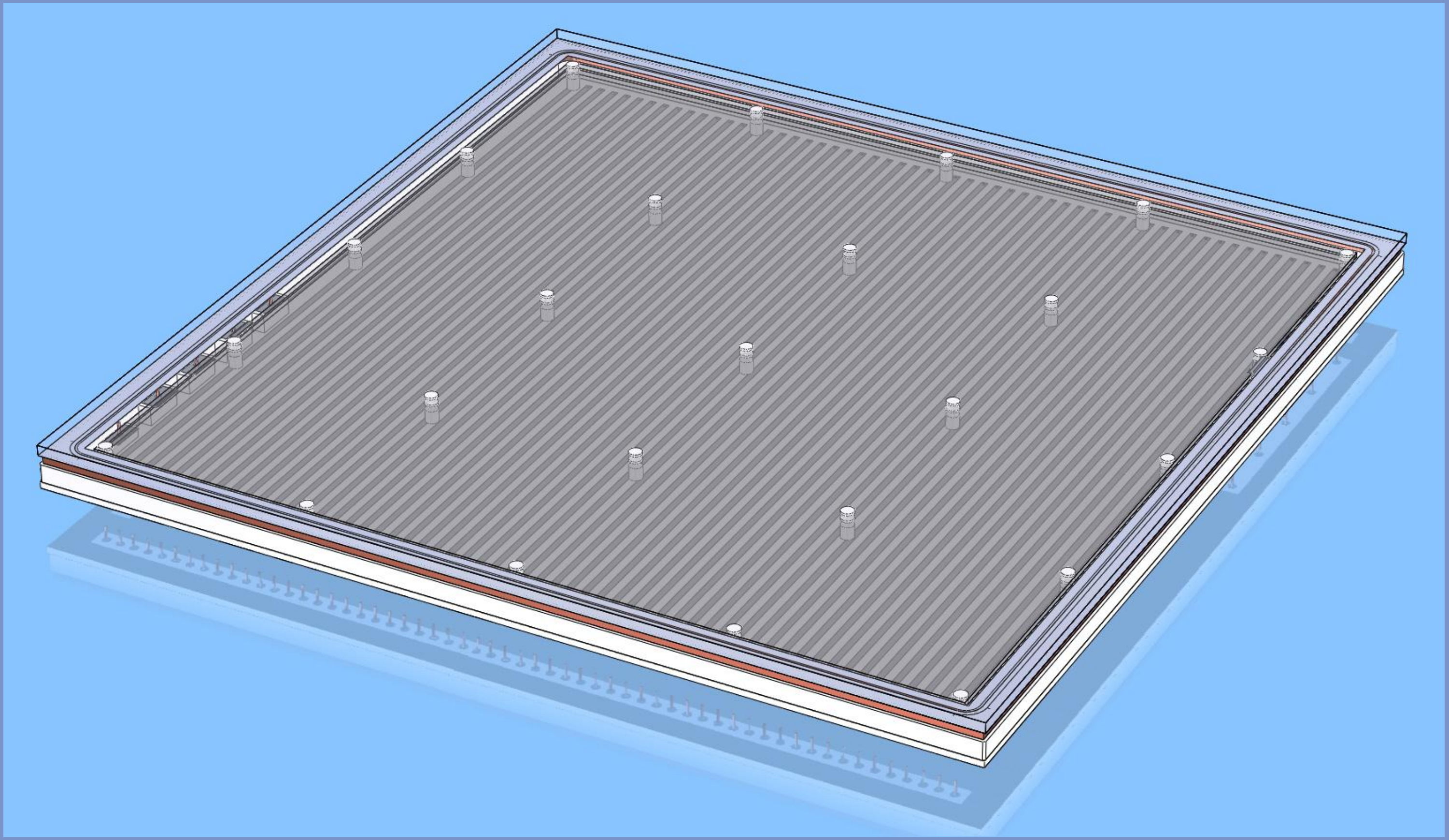
3/9/2010 LAPPD Meeting 3



- **Funnel (!)**

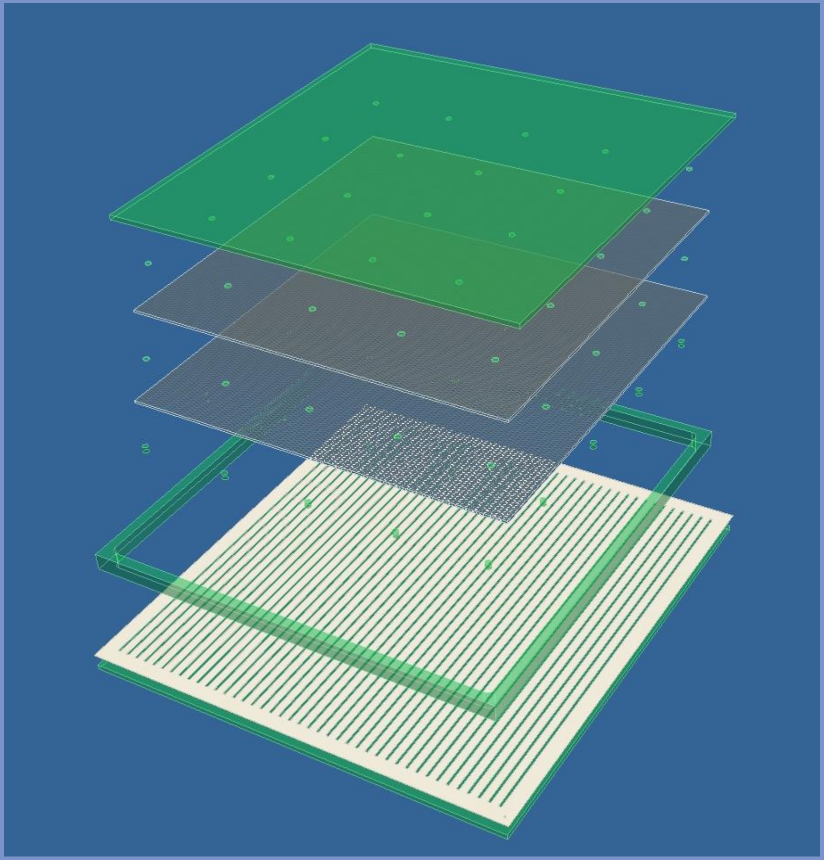
UCB Concept ‘B’ 8” Tube Design

- Jason McPhate
- Experimental Astrophysics Group
- Space Sciences Laboratory
- University of California, Berkeley



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)

8” Glass Package Component Costs

Rich Northrop

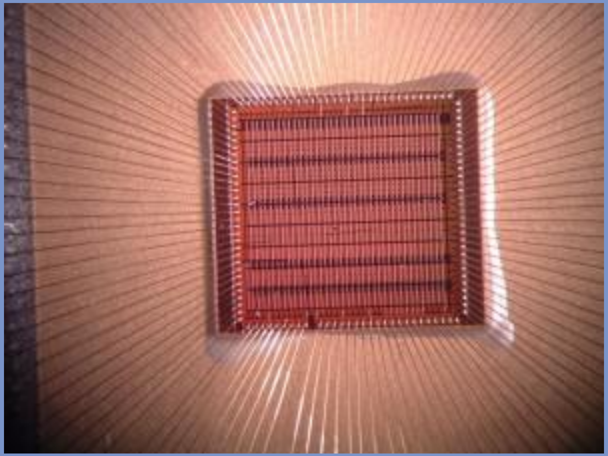
Fabricated per unit cost estimates

	---------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

PSEC-2 ASIC

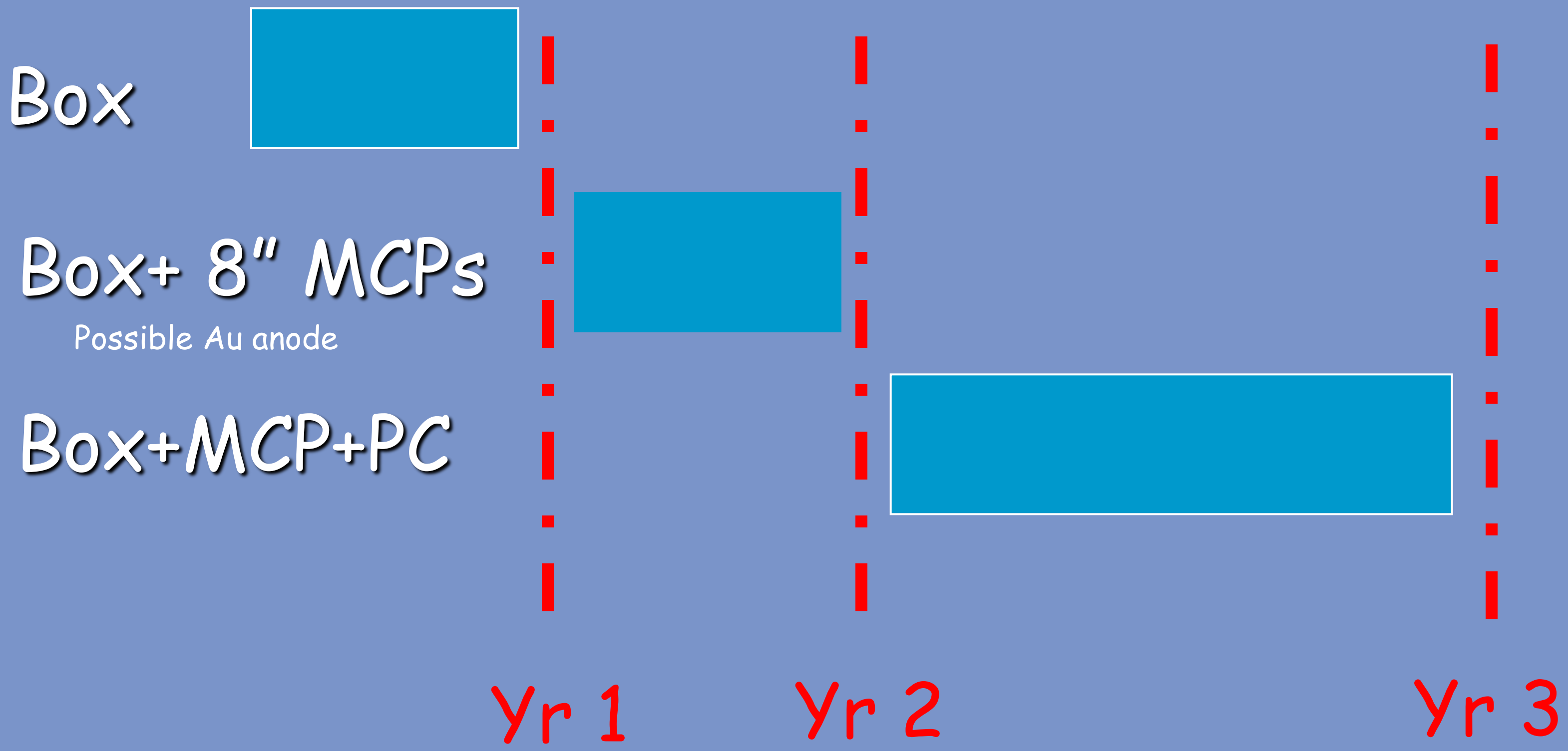


Chicago- Hawaii

- 130nm IBM 8RF Process
- This chip 4 channels, 256 deep analog ring buffer
- Sampling tested at 11 GS/sec
- Each channel has its own ADC- 9 bits eff (?)
- The ADCs on this chip didn’t work due to leakage (silly, didn’t simulate slow easy things) - resubmitted, and test card out for fab with external ADC - will use 1 of 4 chnls
- We’re learning from Breton, Delagnes, Ritt and Varner (Gary is of course a collaborator)

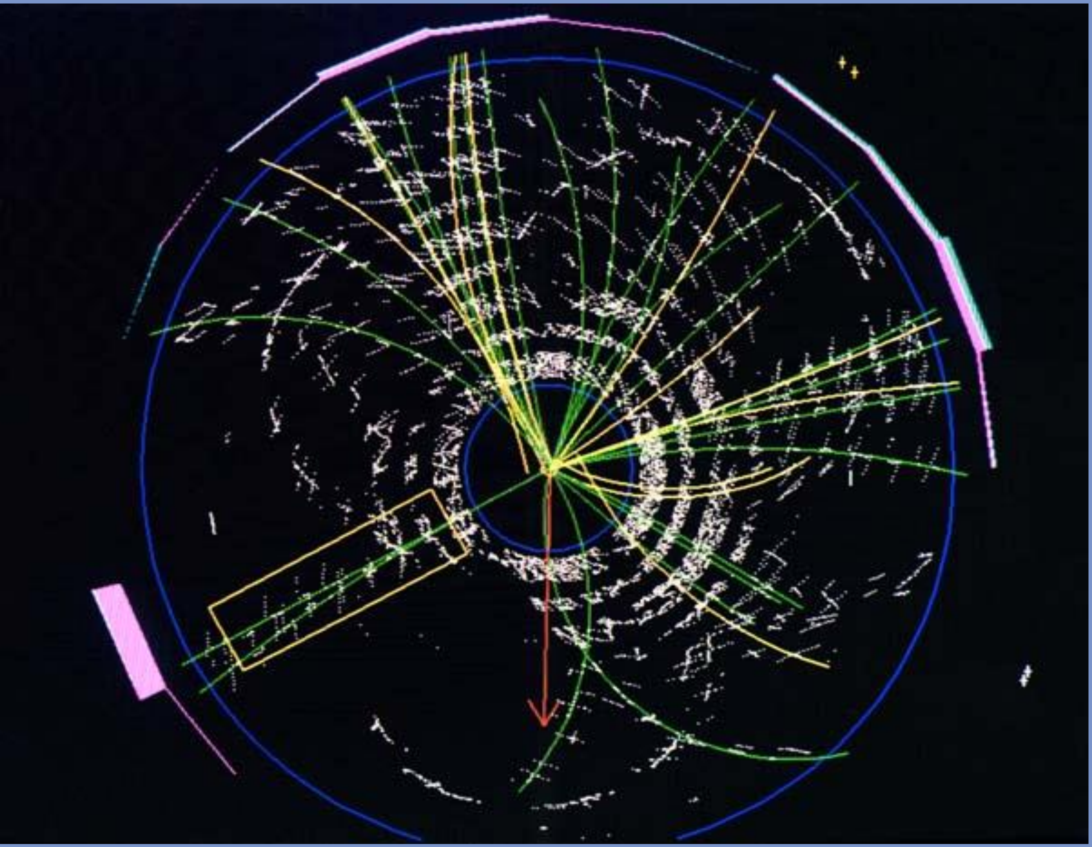
ANL-UC Glass Hermetic Packaging Group

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



Application to Colliders

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

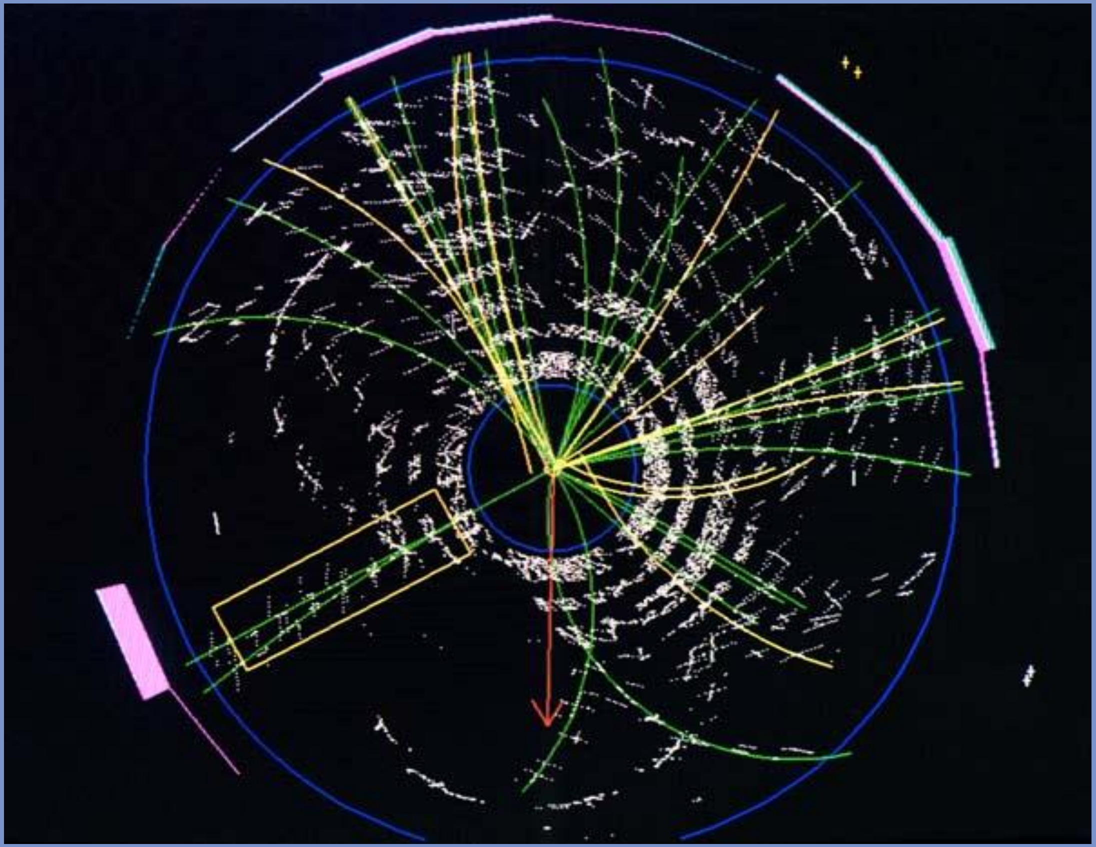


t-tbar -> W^+bW^-bbar->
e+ nu+c+sbar+b+bbar

A 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…)

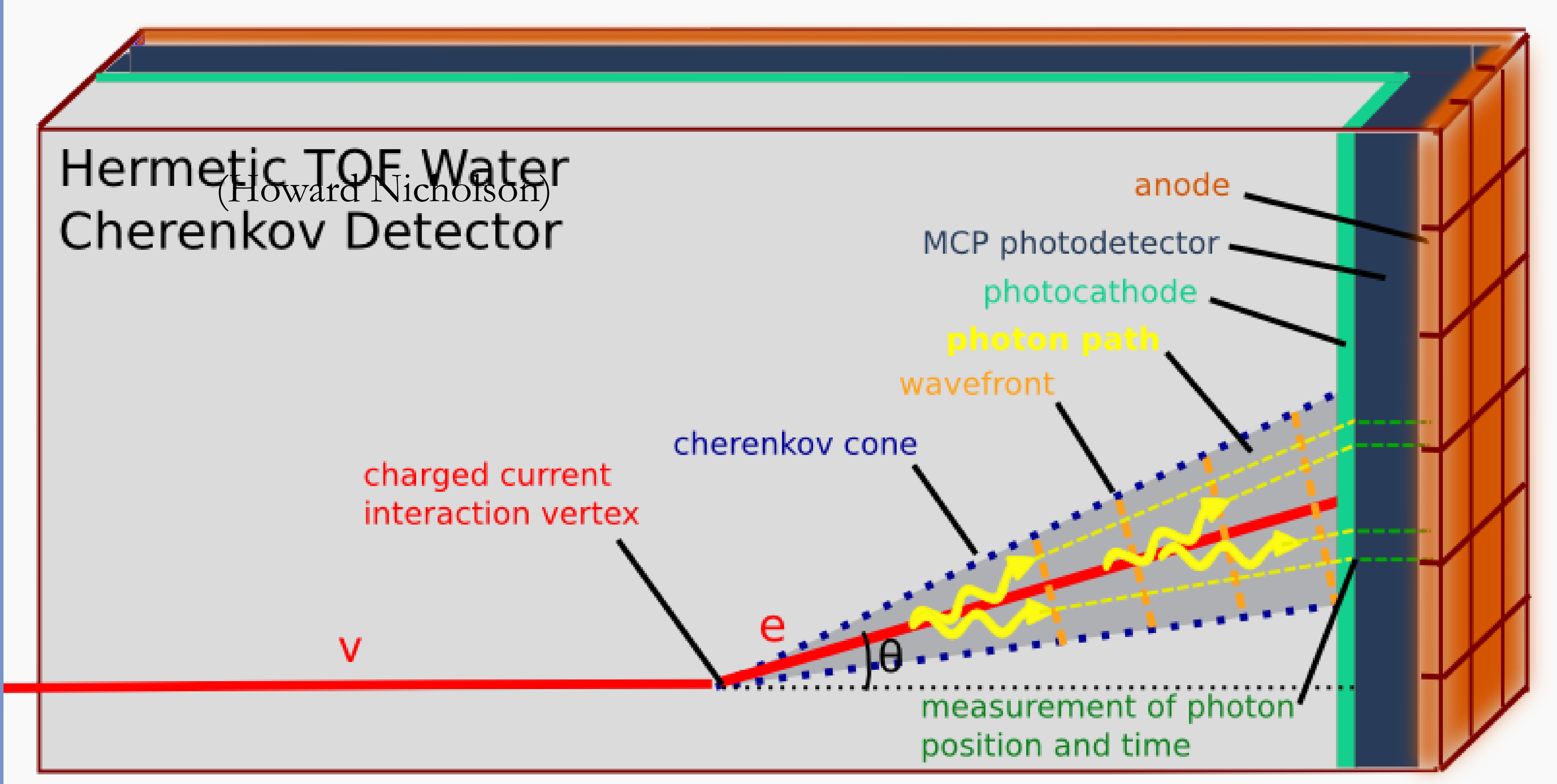
Specs:
Signal: 50-10,000 photons
Space resolution: 1 mm
Time resolution 1 psec
Cost: <100K$/m2:

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 (!)

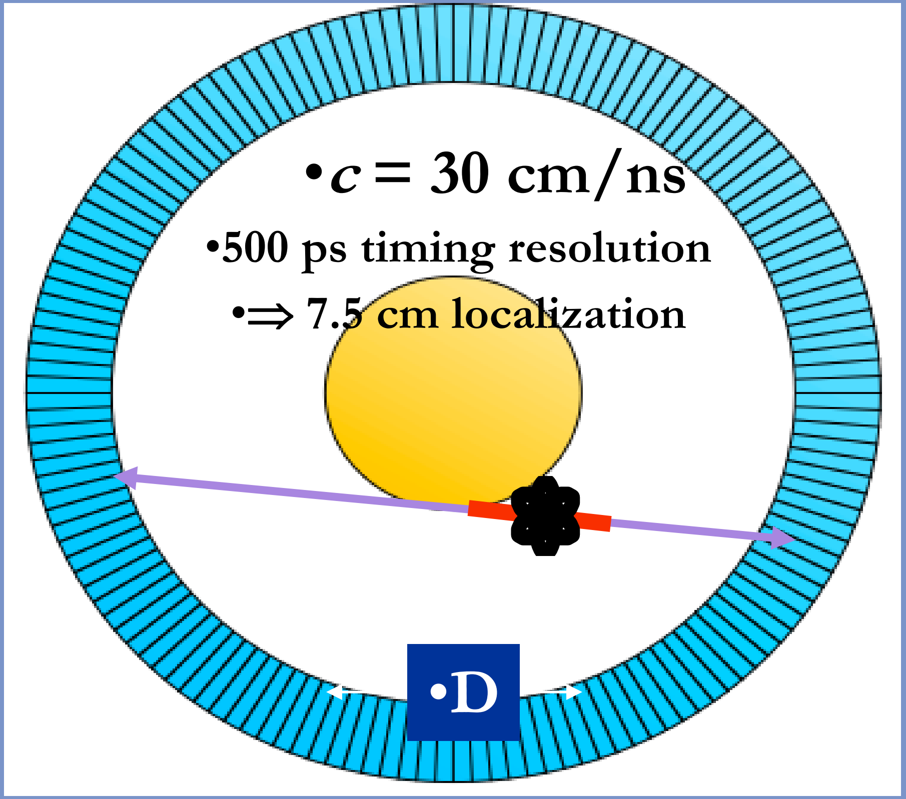
New idea: Hi-Res H_20-continued

- 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.

Application 3- Medical Imaging (PET)



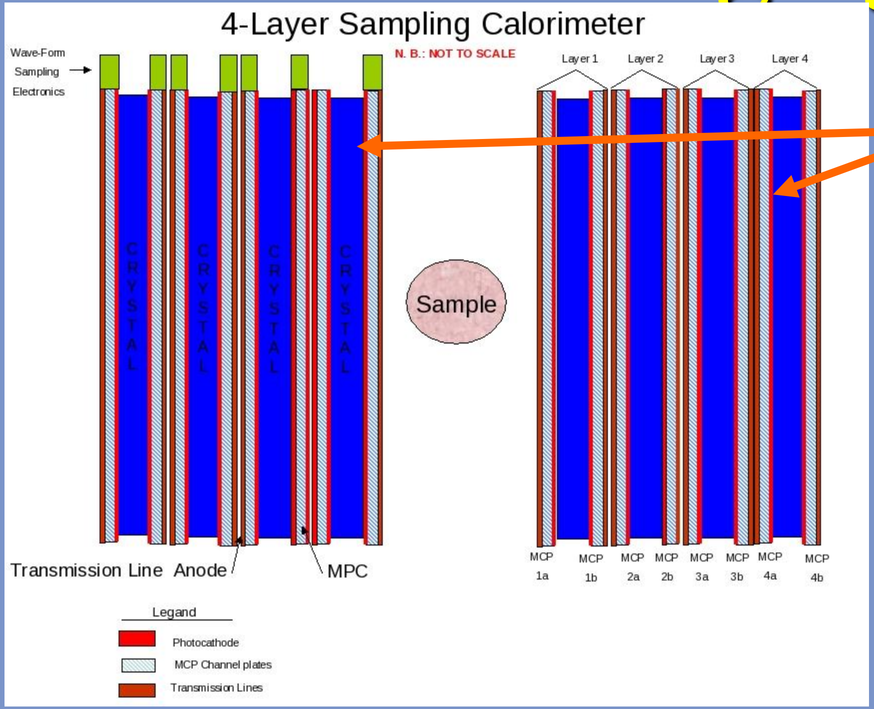
- Bill Moses Slide (Lyon)

- 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

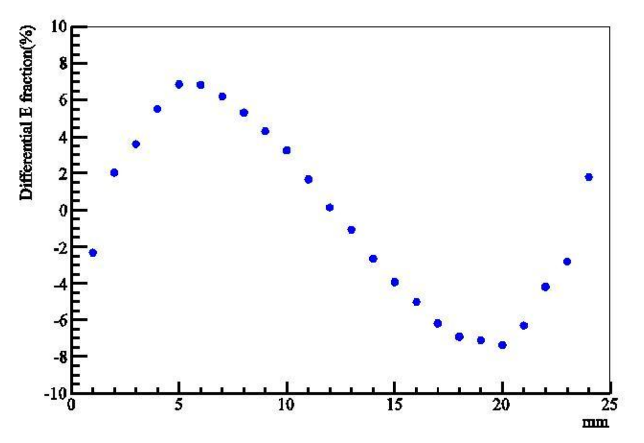
Application 3- Medical Imaging (PET)

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

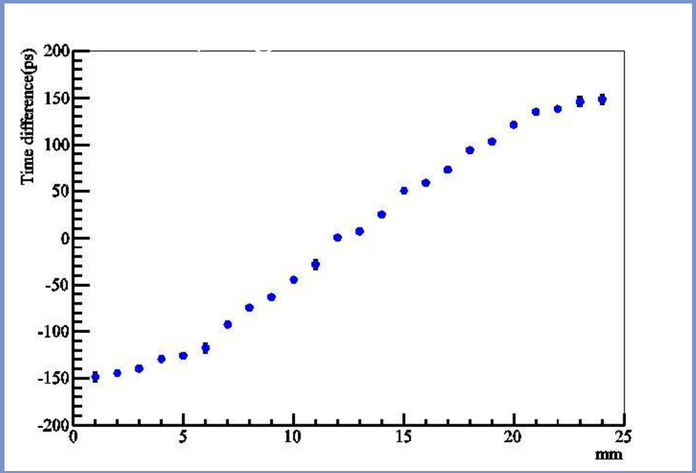


Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side

Simulations by Heejong Kim (Chicago)

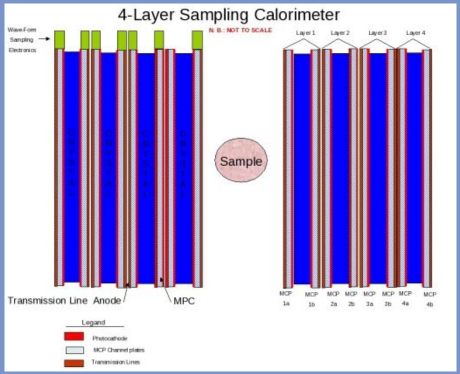


Depth in crystal by time-difference



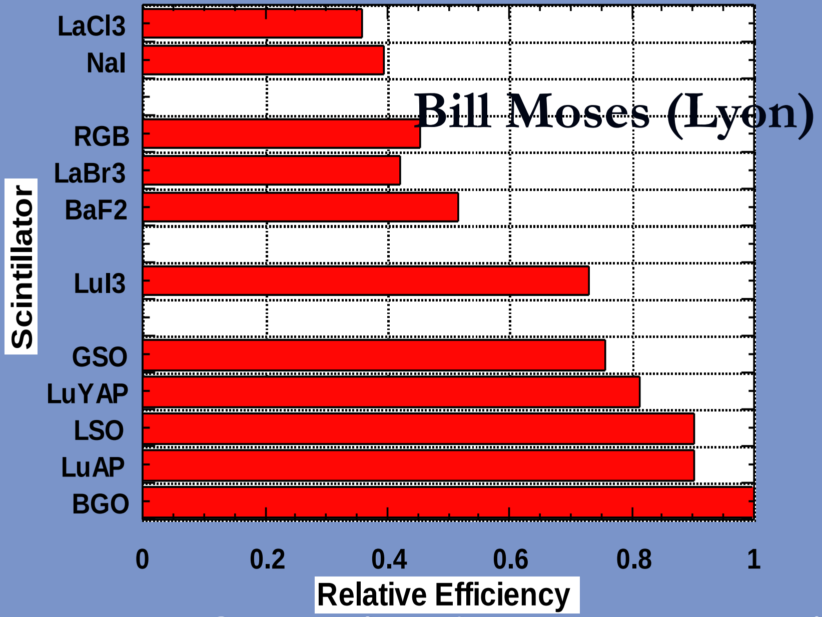
Depth in crystal by energy- asymmetry

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



Bill Moses (Lyon)

Give up on the 511 KeV energy cut for bkgd rejection (!?), Give up on the Compton fraction (!??), 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?)

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.

Application 4- Cherenkov-sensitive Sampling Quasi- Digital Calorimeters

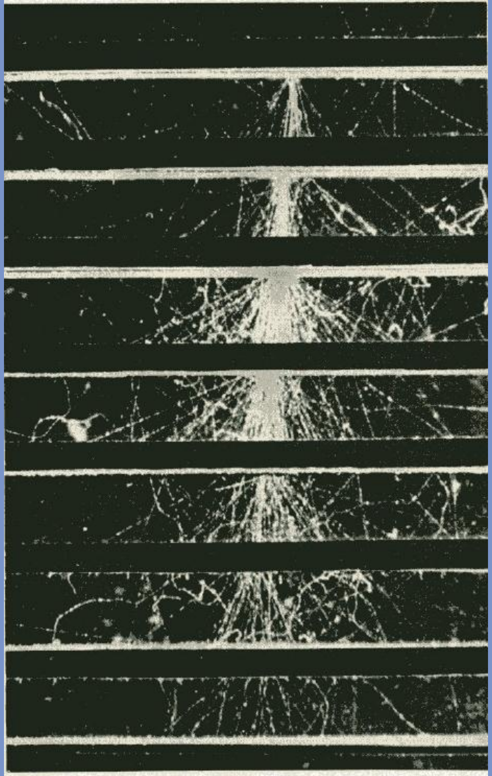
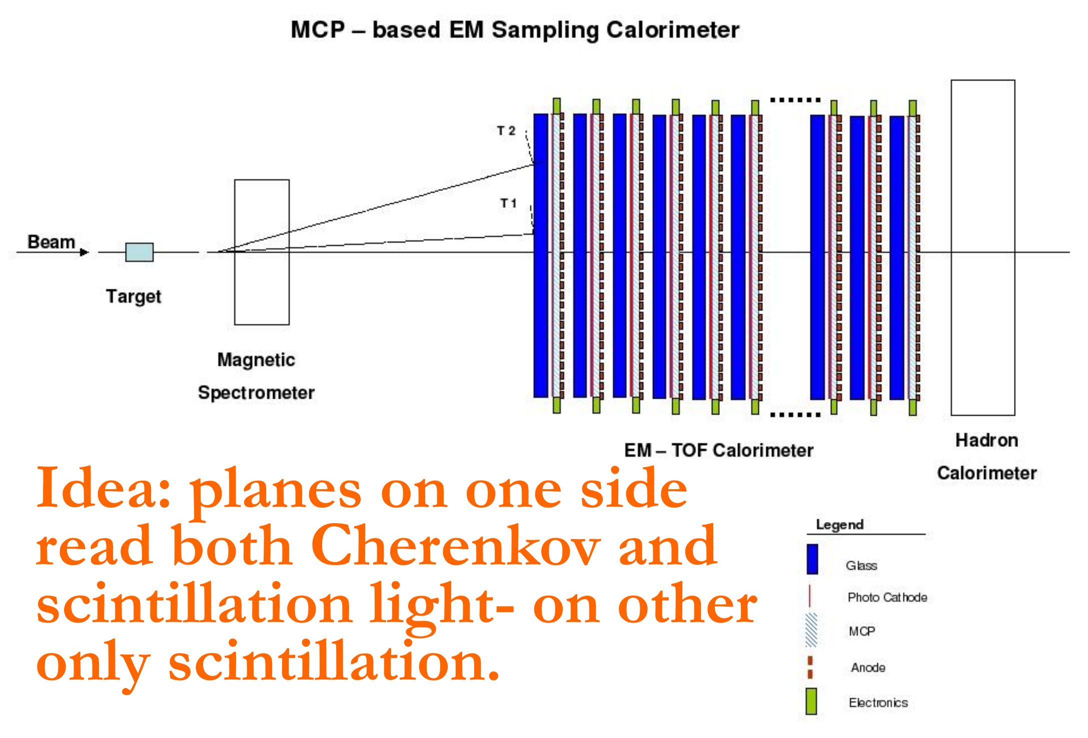


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.



Idea: planes on one side read both Cherenkov and scintillation light- on other only scintillation.

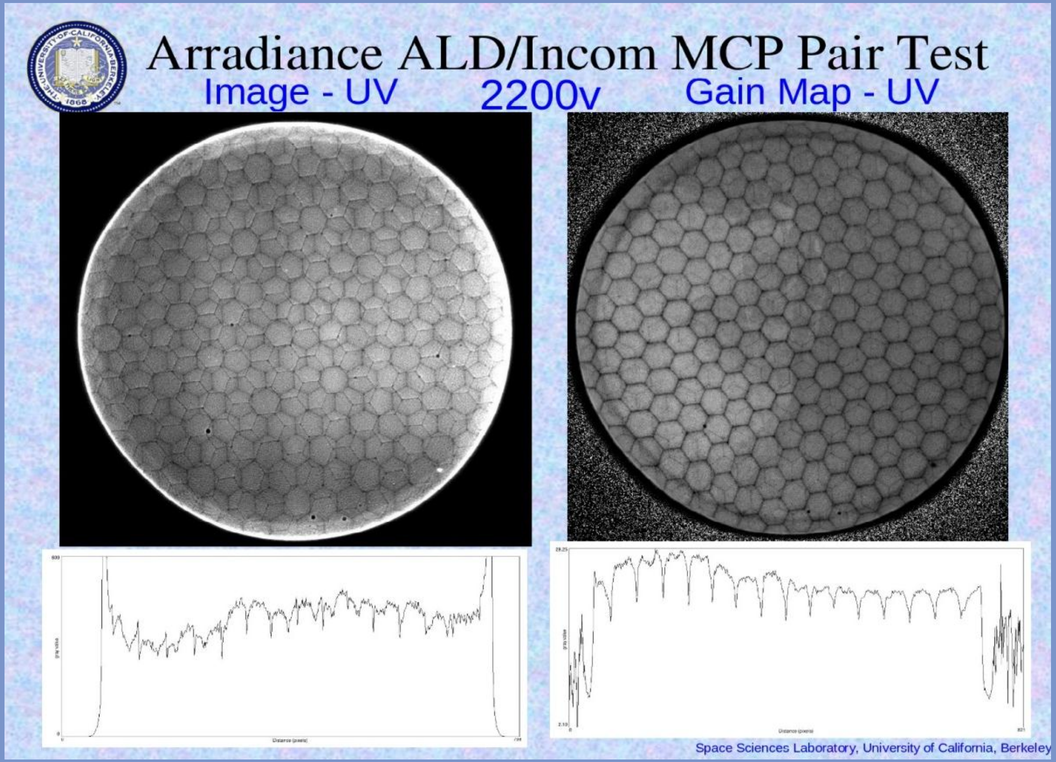
A picture of an em shower in a cloud-chamber with ½” Pb plates (Rossi, p215- from CY Chao)

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)



Arradiance ALD/Incom MCP Pair Test

Space Sciences Laboratory, University of California, Berkeley

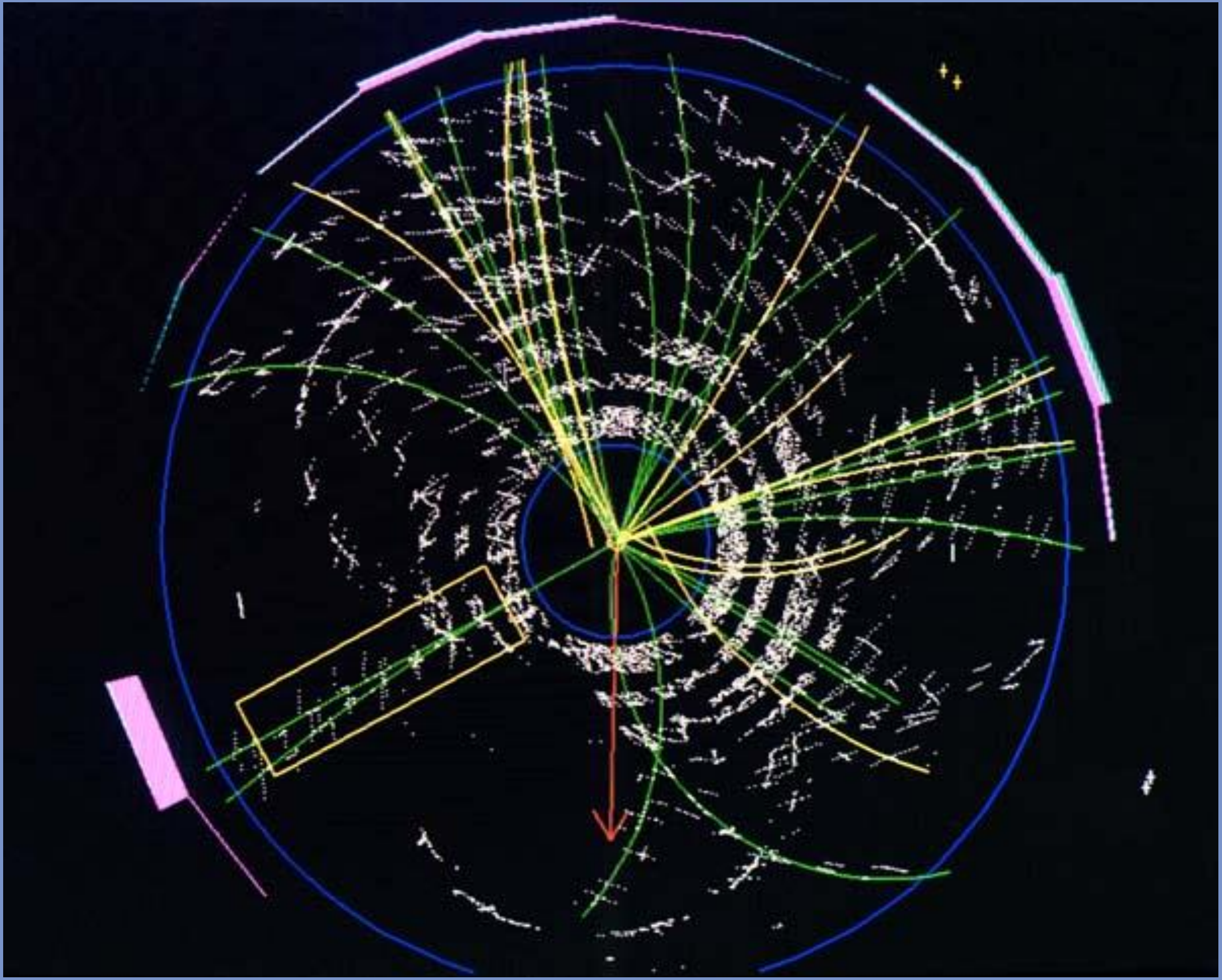
Note- at high gain the boundaries of the multi's go away

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 1st round of LBNE, but maybe not too late for a 2nd or 3rd-generation detector.

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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Michael Pellin, Igor Veryovkin, Hau Wang, Alexander Zinovev
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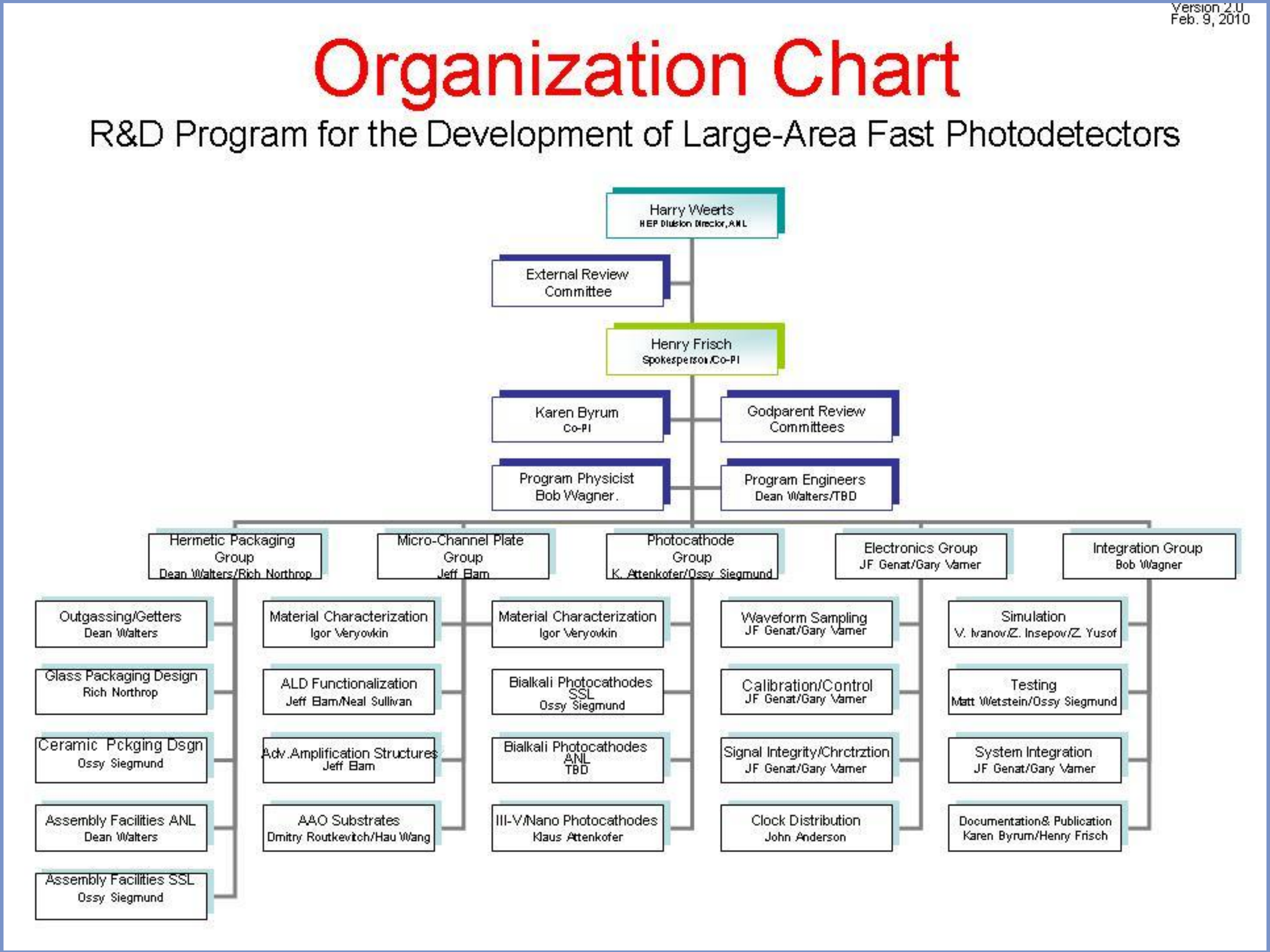
[1] Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

3 National Labs, 6 Divisions at Argonne, 3 US small companies; 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)



Version 2.0
Feb. 9, 2010

Organization Chart

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

- Harry Weerts – HEP Division Director, ANL
  - External Review Committee
  - Henry Frisch – Spokesperson/Co-PI
    - Karen Byrum – Co-PI
    - Godparent Review Committees
    - Program Physicist – Bob Wagner.
    - Program Engineers – Dean Walters/TBD
    - Hermetic Packaging Group – Dean Walters/Rich Northrop
      - Outgassing/Getters – Dean Walters
      - Glass Packaging Design – Rich Northrop
      - Ceramic Pckging Dsgn – Ossy Siegmund
      - Assembly Facilities ANL – Dean Walters
      - Assembly Facilities SSL – Ossy Siegmund
    - Micro-Channel Plate Group – Jeff Elam
      - Material Characterization – Igor Veryovkin
      - ALD Functionalization – Jeff Elam/Neal Sullivan
      - Adv.Amplification Structures – Jeff Elam
      - AAO Substrates – Dmitry Routkevitch/Hau Wang
    - Photocathode Group – K. Attenkofer/Ossy Siegmund
      - Material Characterization – Igor Veryovkin
      - Bialkali Photocathodes SSL – Ossy Siegmund
      - Bialkali Photocathodes ANL – TBD
      - III-V/Nano Photocathodes – Klaus Attenkofer
    - Electronics Group – JF Genat/Gary Varner
      - Waveform Sampling – JF Genat/Gary Varner
      - Calibration/Control – JF Genat/Gary Varner
      - Signal Integrity/Chrctrztion – JF Genat/Gary Varner
      - Clock Distribution – John Anderson
    - Integration Group – Bob Wagner
      - Simulation – V. Ivanov/Z. Insepov/Z. Yusof
      - Testing – Matt Wetstein/Ossy Siegmund
      - System Integration – JF Genat/Gary Varner
      - Documentation& Publication – Karen Byrum/Henry Frisch

4 Groups + Integration and Management

Parallel Efforts on Specific Applications

Explicit strategy for staying on task

LAPD Detector Development

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

Drawing Not To Scale (!)

PET
(UC/BSD,
UCB, Lyon)

Collider
(UC,
ANL,Saclay.

Muon Cooling
Muons,Inc
(SBIR)

K->$\pi\nu\nu$
(UC(?))

DUSEL
(Matt, Mayly,
Bob, John, ..)

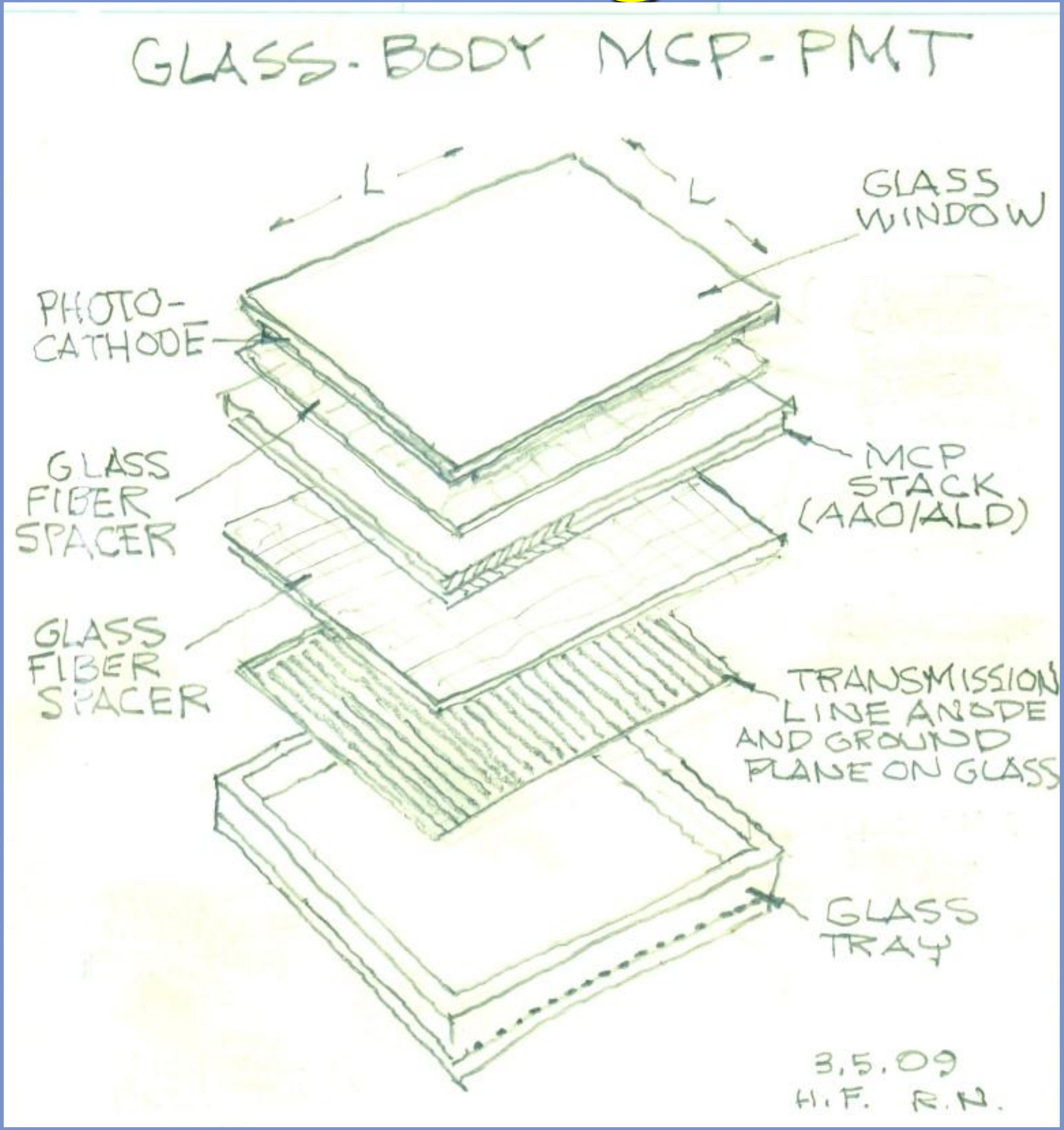
Security
(TBD)

Mass Spec

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

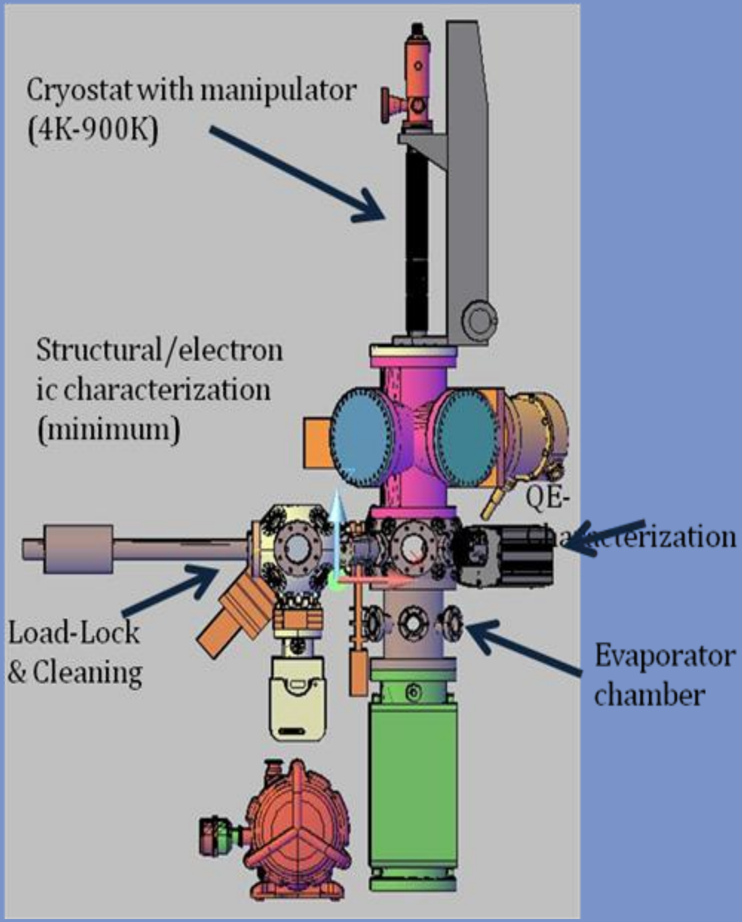
- Zikri Yusof
- B. Adams
- M. Demarteau
- G. Drake
- T. Liu
- I. Veryovkin
- S. Ross

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?