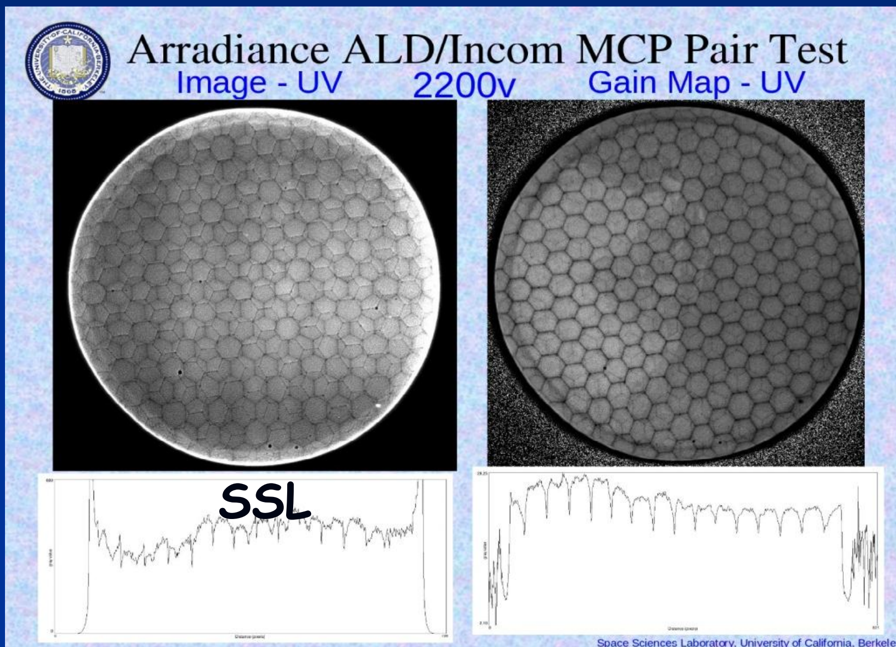
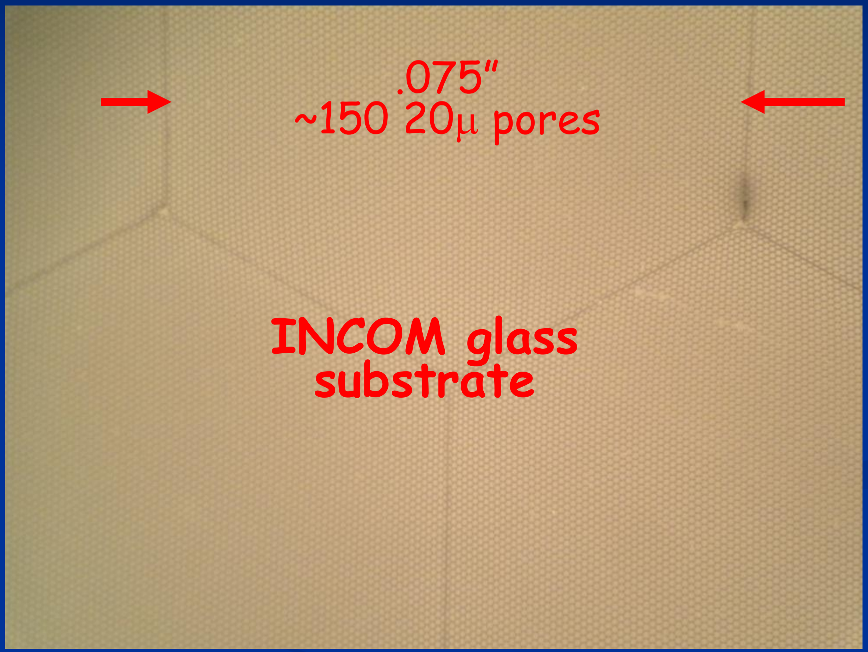
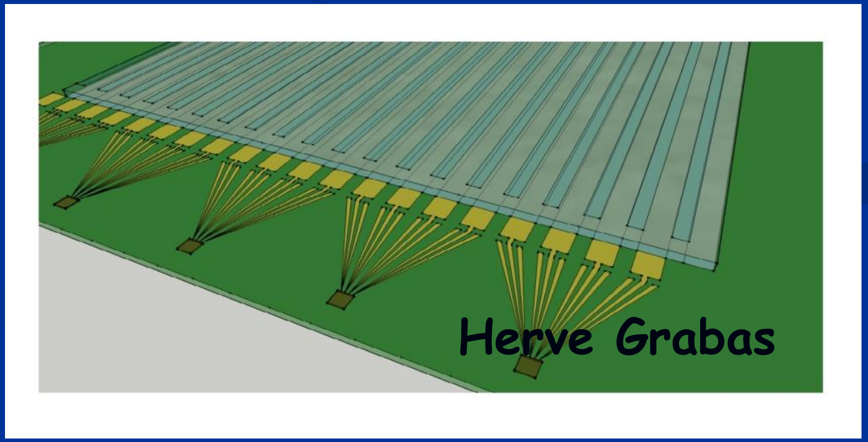
The Development of Large-Area Thin Planar Psec Photodetectors

Henry Frisch,
Enrico Fermi Institute UC and HEPD, ANL





SSL



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, 6 Divisions at Argonne, 3 US small companies, 3 universities

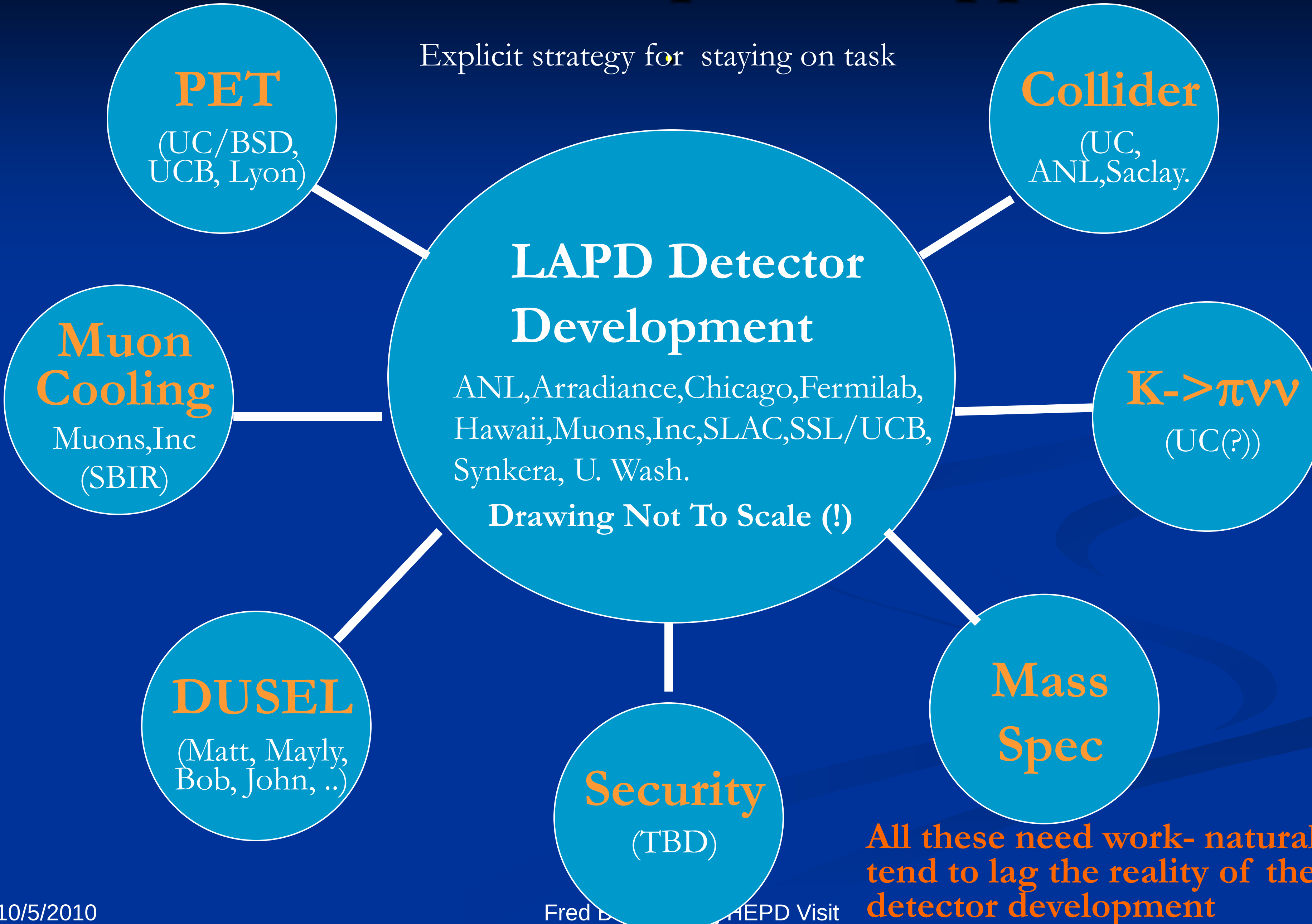
Goal of 3-year R&D- commercializable modules.

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)

Parallel Efforts on Specific Applications

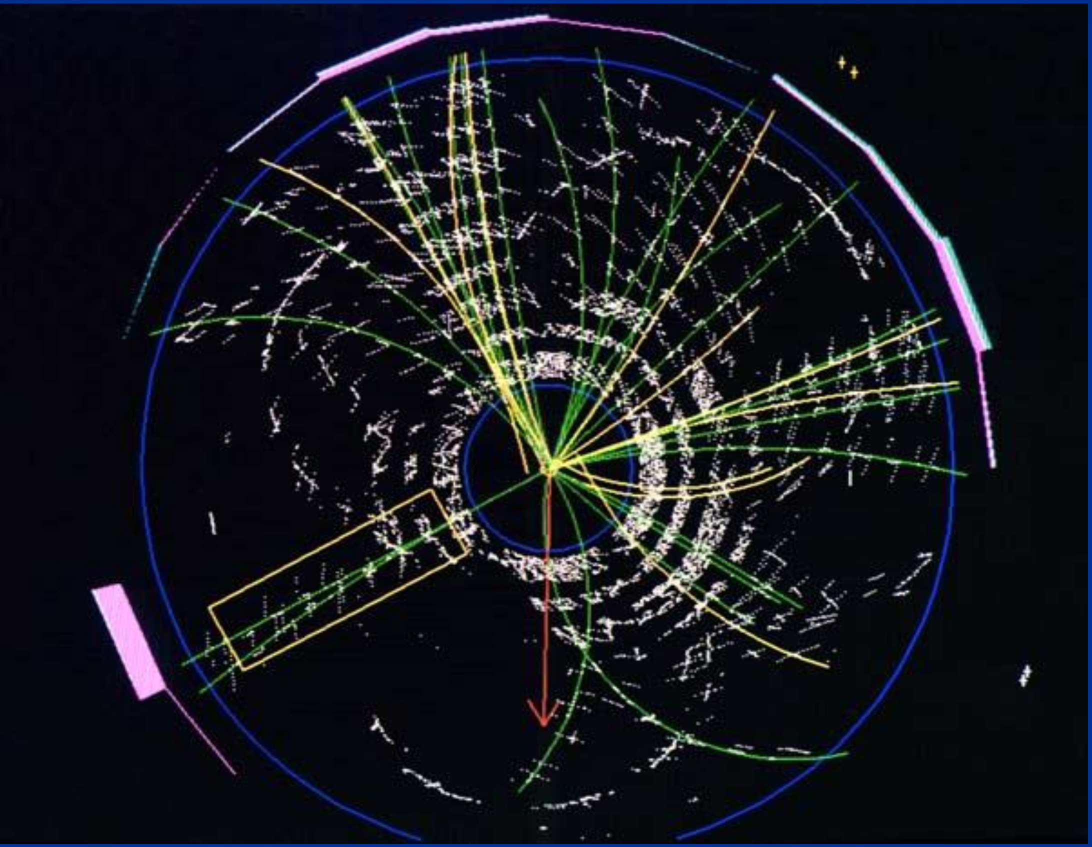
Explicit strategy for staying on task



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

Application 1-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.

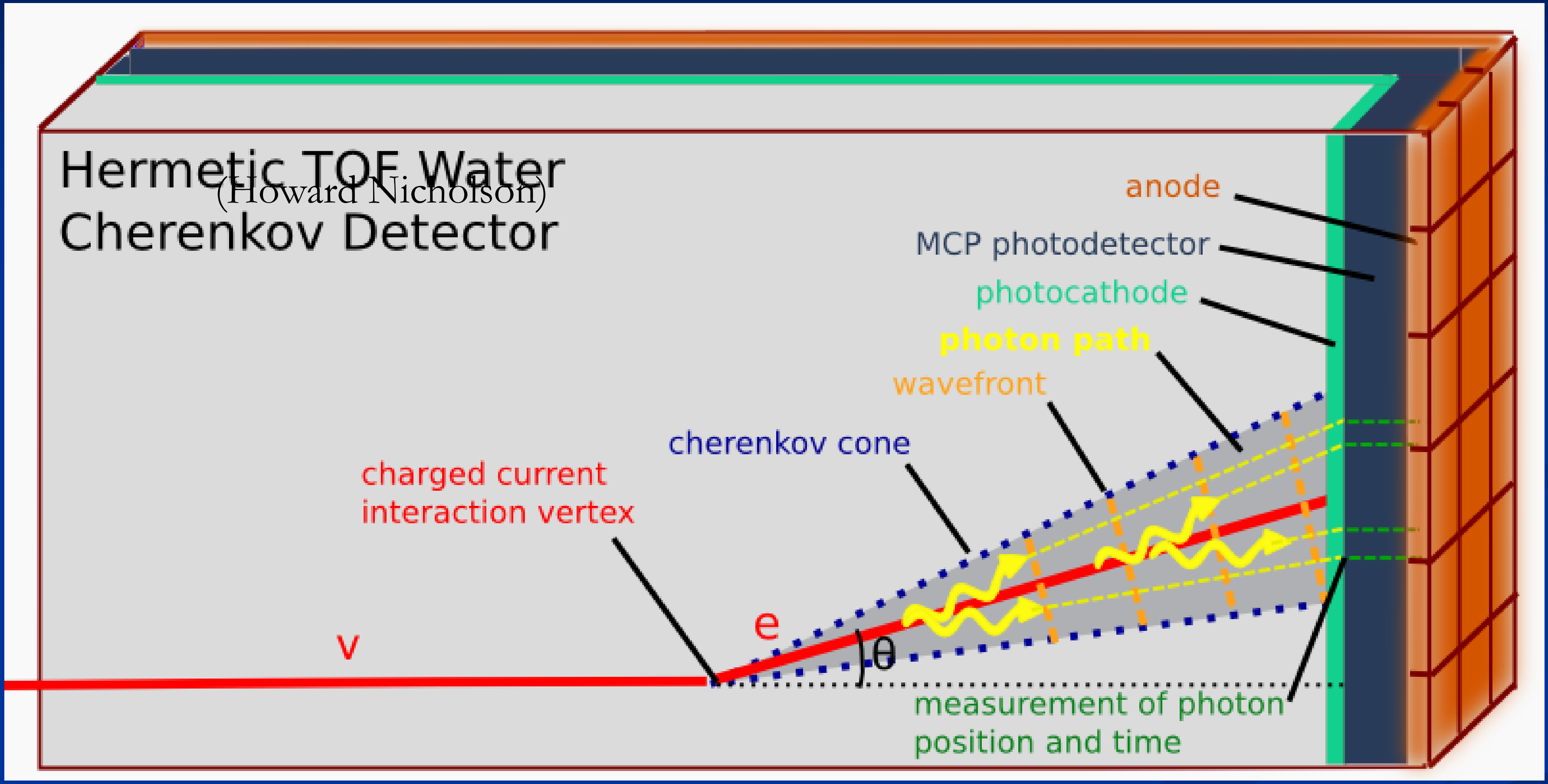


t-tbar -> W^+bW^-bbar->
e+ nu+c+sbar+b+bbar

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:

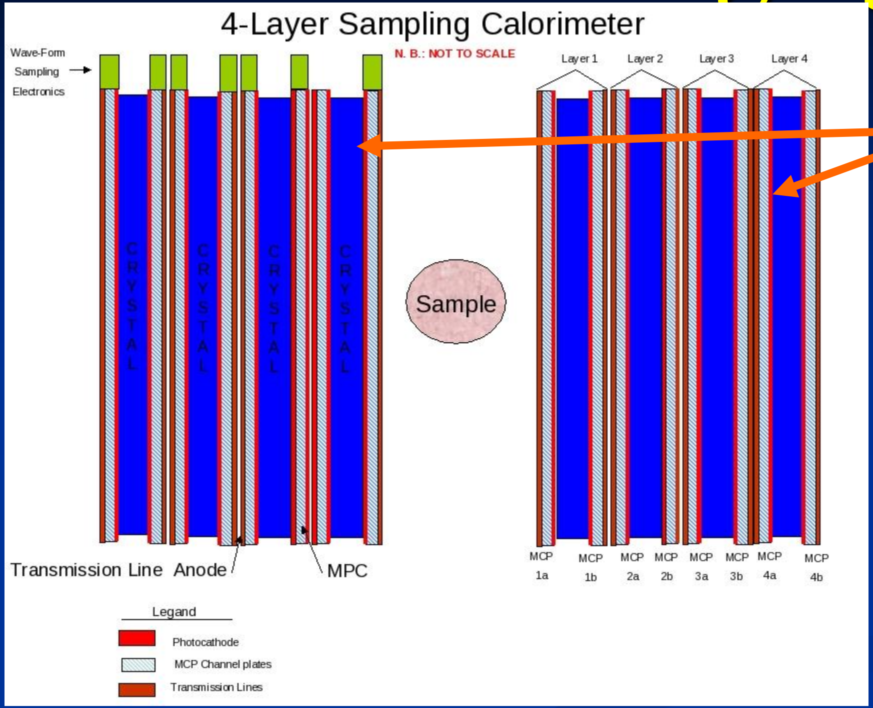
Application 2- Neutrino Physics



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

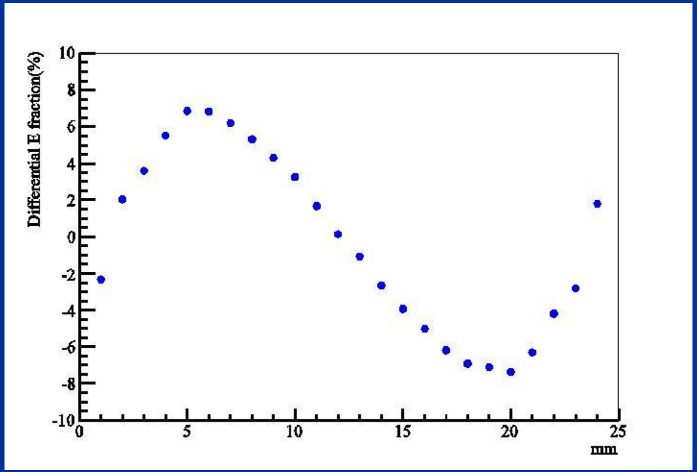
Application 3- Medical Imaging (PET)

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

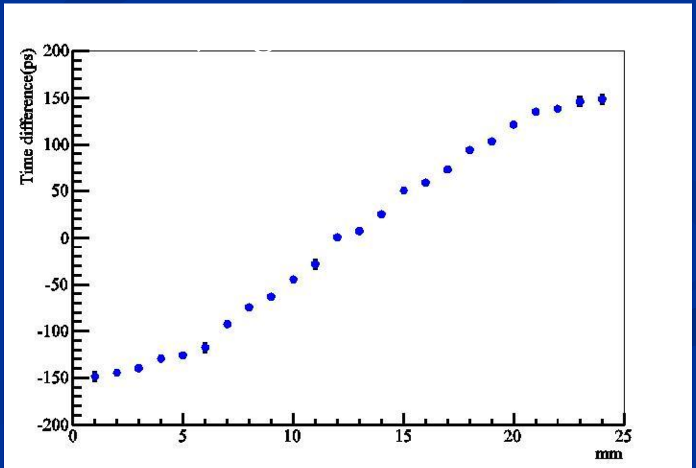


Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side

Simulations by Heejong Kim (Chicago)



Depth in crystal by time-difference



Depth in crystal by energy- asymmetry

Application 4-
Cherenkov-sensitive Sampling Calorimeters

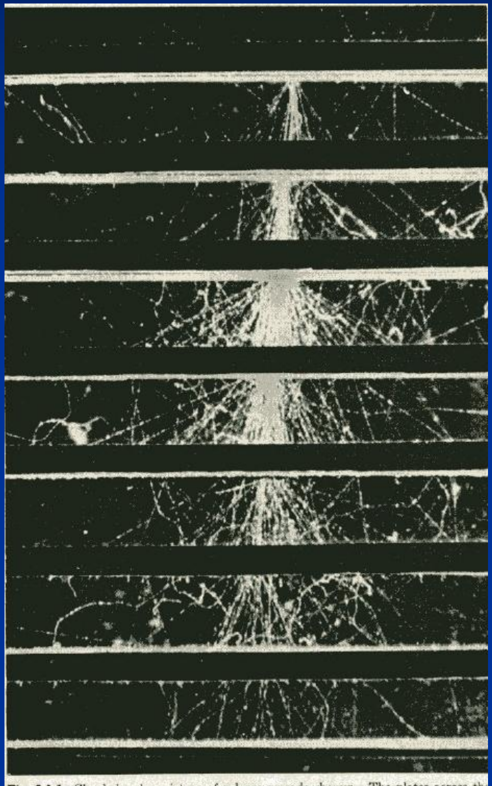
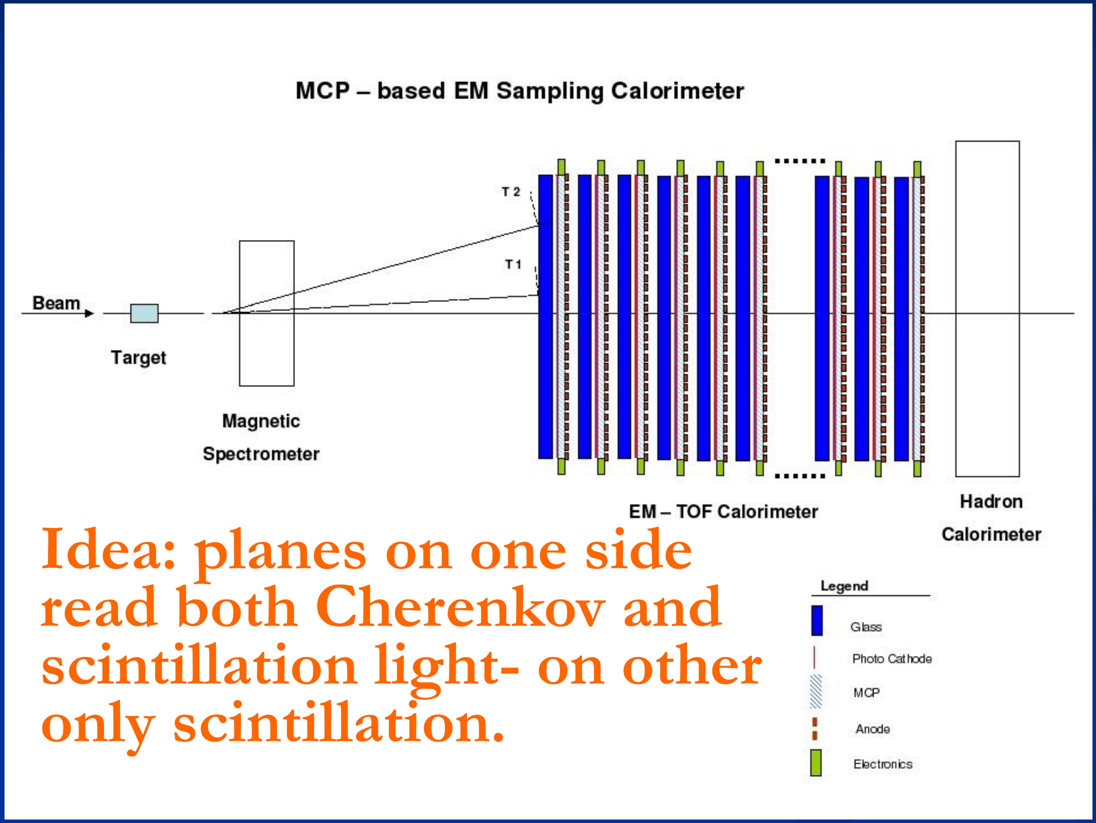


Fig. 5.1.1. Cloud-chamber picture of a large cascade shower. The plates across the chamber are lead, 1.27 cm thick. From C. Y. Chao.



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

Application 5- Nuclear Non-proliferation

1. MCP's loaded with Boron or Gadolinium are used as neutron detectors with good gamma separation (Nova Scientific).
2. Large-area means could scan trucks, containers
3. Time resolution corresponds to space resolution out of the detector plane IF one has a t_0– i.e can do 3D tomography of objects

Specs: TBD

An area for possible applications- need a counterpart to form an application group. (ANL an obvious place)

Detector Prescription (Generic)

- **Small feature size** << 300 microns (1 inch = 1 nsec, 300 microns=1 psec)
- **Homogeneity** – the ability to make uniform large-areas (think solar-panels, floor tiles, 50”-HDTV sets)
- **Intrinsic low cost**: although application specific, all need low-cost materials and robust batch fabrication. Needs to be simple.

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).

Detector Development- 3 Prongs
Progress since last DOE visit (6 mo)

MCP development-

Received first 8” plates; installed Beneq ALD Prod. Facil; measured gain > 10^6 in multiple plates with multiple chemistries, measured lifetime, uniformity, characterized prime secondary-emitting layers, established baseline 8”x8” design at SSL in ceramic and 16”x24” design in glass at ANL, constructed hermetic base seals, started a top seal program , constructed multiple test facilities at SSL and ANL and (almost) fabrication facility at SSL, made multiple photocathodes at SSL, made our first photocathode with ANL folks, acquired space for the Tile Factory and Photocathode Growth Facility, started designs.

Readout:

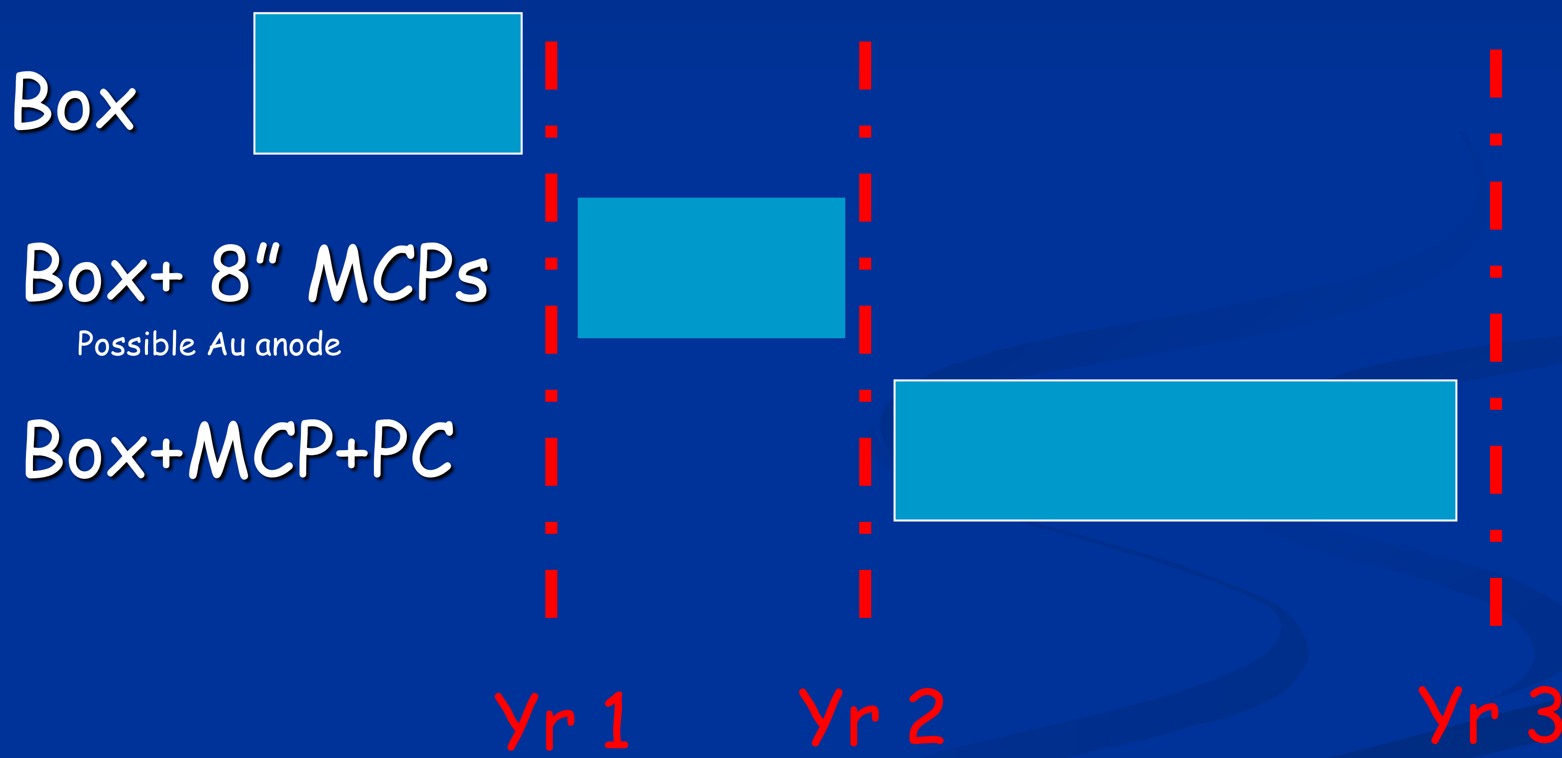
Submitted 2nd and 3rd gen sampling chips, simulated anode, baseline design of SuperModule Tray, design of analog/digital/test board, simulation of analog bandwidth and signal generation.

Simulation as basis for design

Developed modular end-to-end MCP simulation framework, defined canonical plots, first comparisons of testing and sim

ANL-UC Glass Hermetic Packaging Group

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



Year 2 Milestones

June 3, 2010

LAPPD Year 2 ARRA Funding Milestones

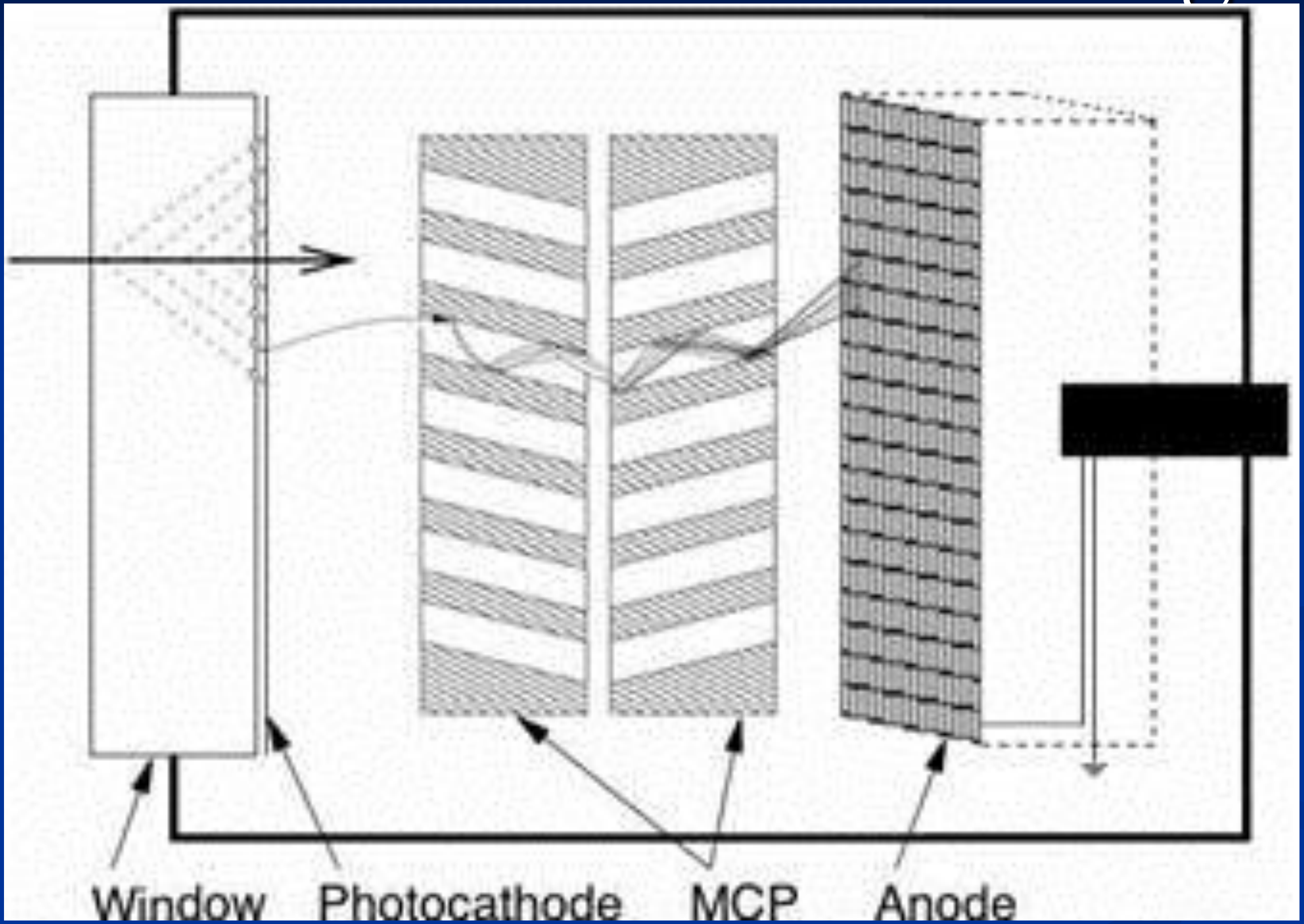
Milestones for the ARRA funding from July 1, 2010 to June 30, 2011

1. Demonstration of gain of 10^6 and aging performance comparable to or better than that of commercial plates with a pair of capillary MCP plates functionalized by ALD; **•Done**
2. Development of an MCP test facility capable of handling 8" plates in tiles; **• Almost- 2 mo.? ANL and SSL**
3. Functionalization of an 8" × 8" glass capillary substrate with ALD; **•Almost - 2 mo. ?**
4. Observation of gain from an ALD-functionalized 8" × 8" MCP plate; **•3-6 mo.?**
5. Design and costing of a photocathode characterization facility; **•Done**
6. Design and costing of an 8" glass tile assembly facility. **•3-4 mo.?**

•These are my estimates- godparent reviews in progress

Micro-channel Plates PMTs

Satisfies small feature size and homogeneity



Photon and electron paths are short- few mm to microns=>fast, uniform Planar geometry=>scalable to large areas

ANL Test-stand Measurements

Jean-Francois Genat, Ed May, Eugene Yurtsev

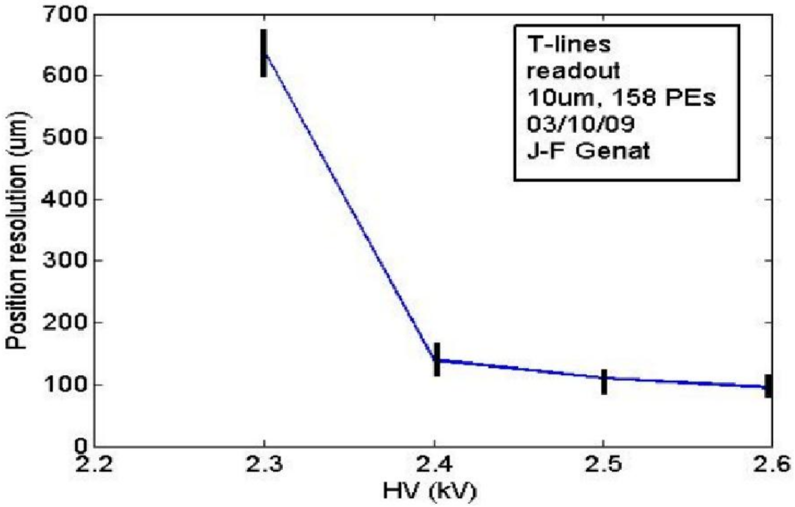
Sample both ends of transmission line with Photonis MCP (not optimum)

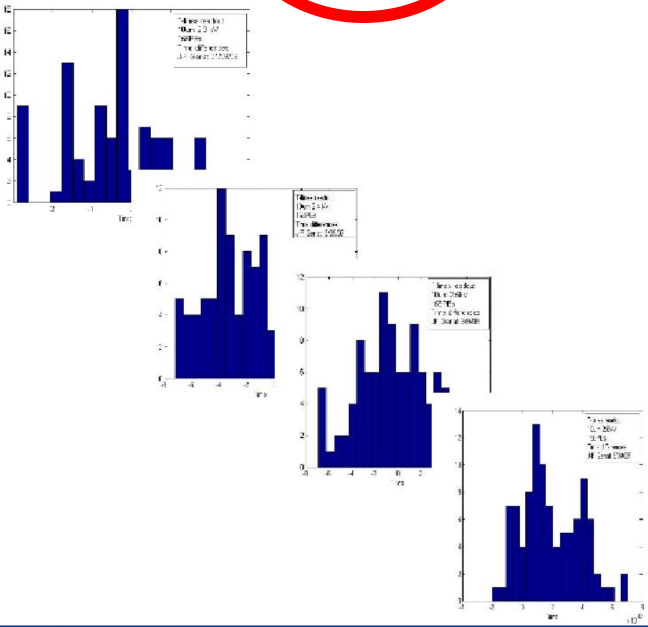
Position Resolution at 158PEs

2 picoseconds; 100 microns measured

158 PEs

HV =	2.3 kV	2.4 kV	2.5 kV	2.6 kV
Std	12.8ps	2.8ps	2.2 ps	1.95 ps
	640µm	140µm	110µm	97µm





03/10/09 Jean-Francois Genat

Simplifying MCP Construction

Chemically produced and treated Pb-glass does 3-functions:

1. Provide pores
2. Resistive layer supplies electric field in the pore
3. Pb-oxide layer provides secondary electron emission

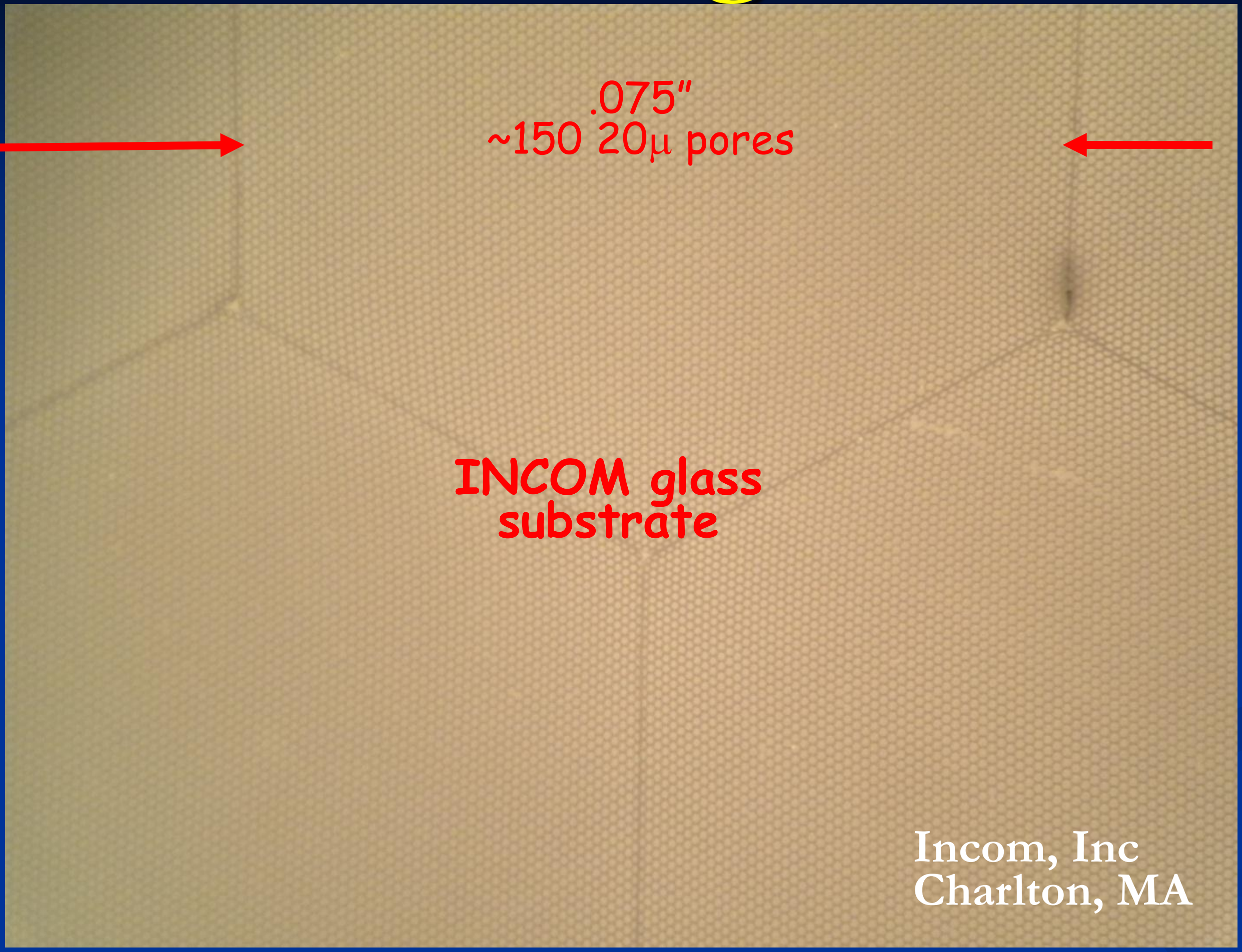
Separate the three functions:

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

Where we are with glass substrates

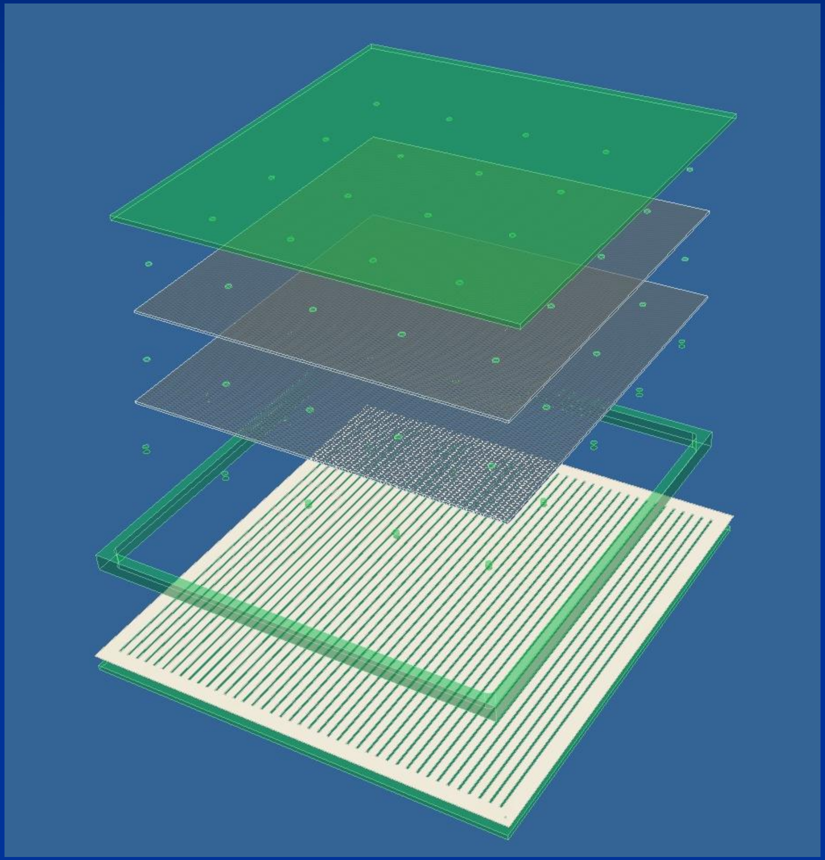
Hexagonal bundle of capillaries is called a `multi'. Each multi has ~15,000 capillaries

Many many multis in an 8"-square plate.



- Have received multiple samples of 10-micron, 20-micron, 40-micron glass substrates from Incom in 3/4"-sq and 33 mm round formats – will show results after ALD below
- Two developments at Incom (our glass folks)- 1) 8" plates are being fabricated and the process improved, and 2) replacement of some multis with solid islands (`pads') for installation of mechanical spacers. Idea is low cost amplification section - so far so good (hesitate to quote a # yet).

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)

The 24”x16” `SuperModule

Glass Package Component Costs

Rich Northrop

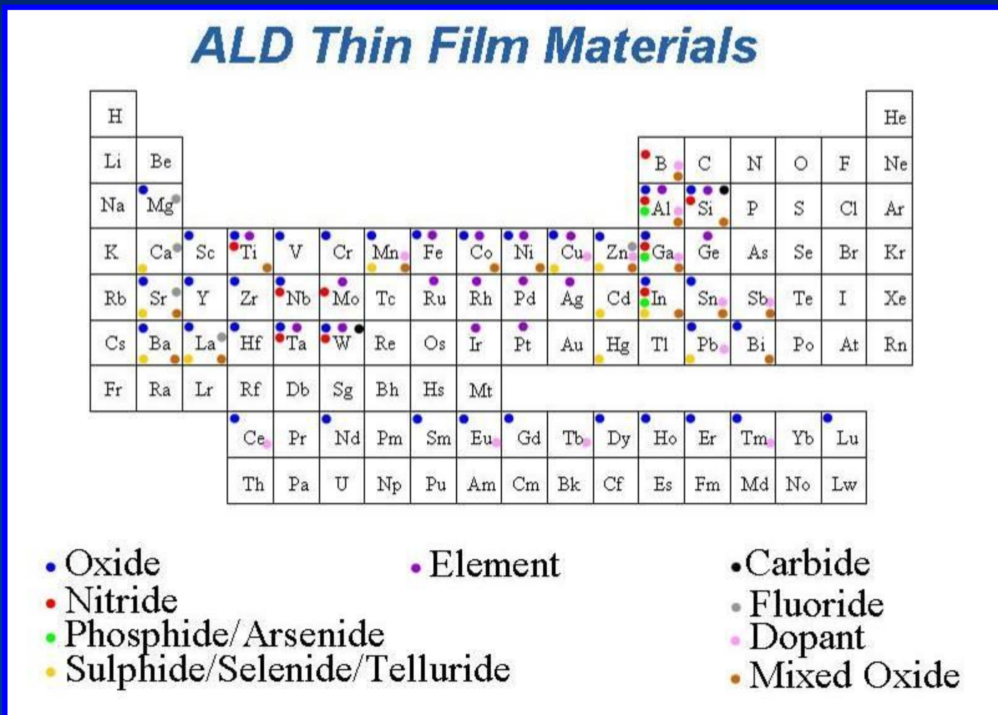
Fabricated per unit cost estimates

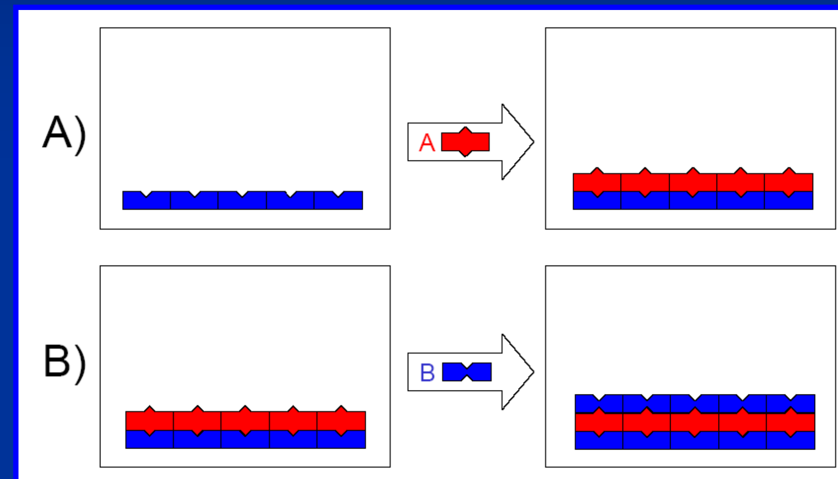
	---------Quotations---------		----------------------Cost estimates---------------------		
	30	1000	3000	10,000	100,000
Window (1@)	$18	13	11	10	8
Side wall (1@)	$78	55	52	48	40
Base plate (1@)	$20	13	11	10	8
Rod Spacers (75@)	$7	3	2	1.20	.80
Total	$641	$306	$224	$158	$116

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

Glass components are a small percentage of the proposed 8 x 8 MCP

Atomic Layer Deposition (ALD) Thin Film Coating Technology





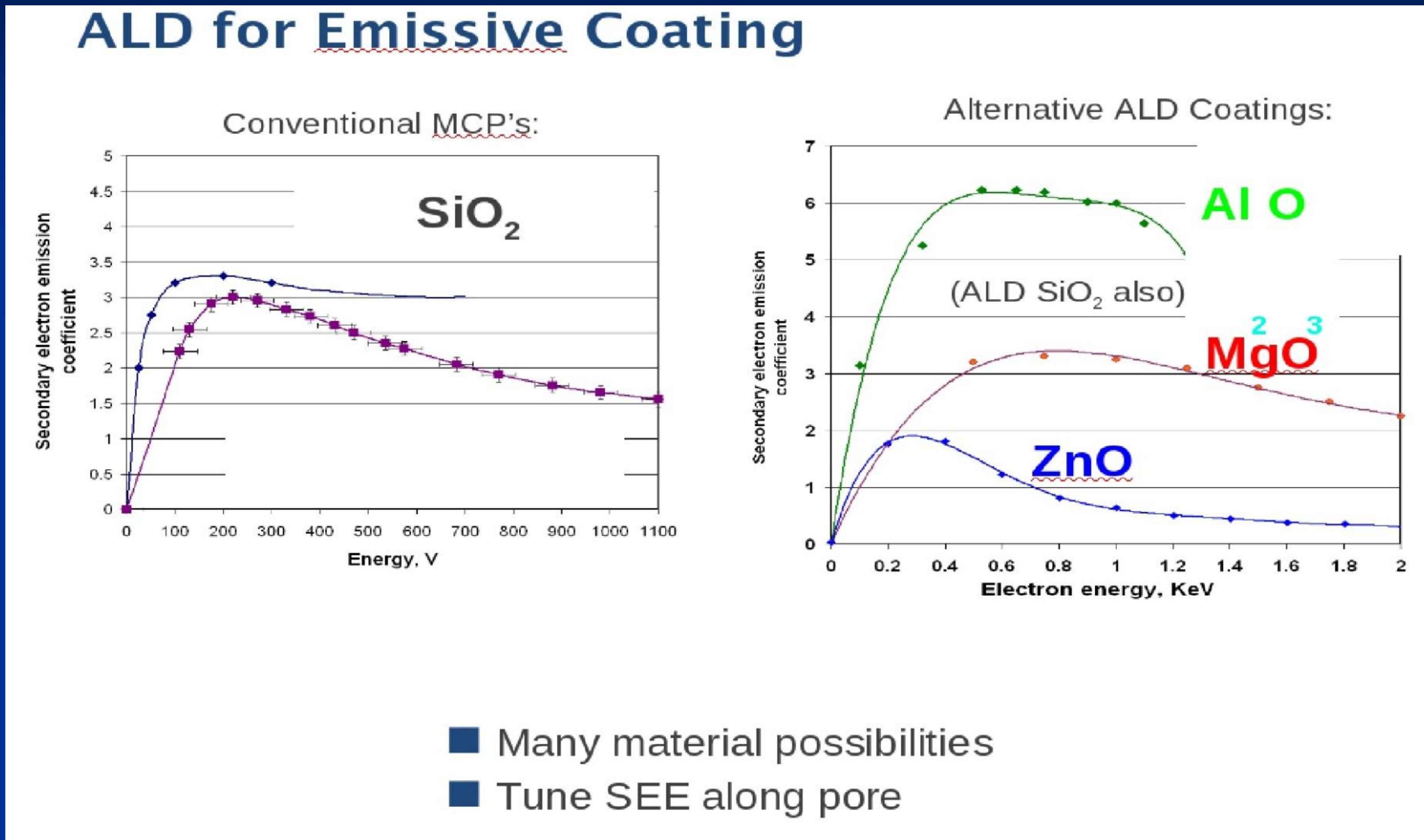
- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects (JE)

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

Jeff Elam pictures

ALD for Emissive Coating

Conventional MCP's: Alternative ALD Coatings: (ALD SiO_2 also)



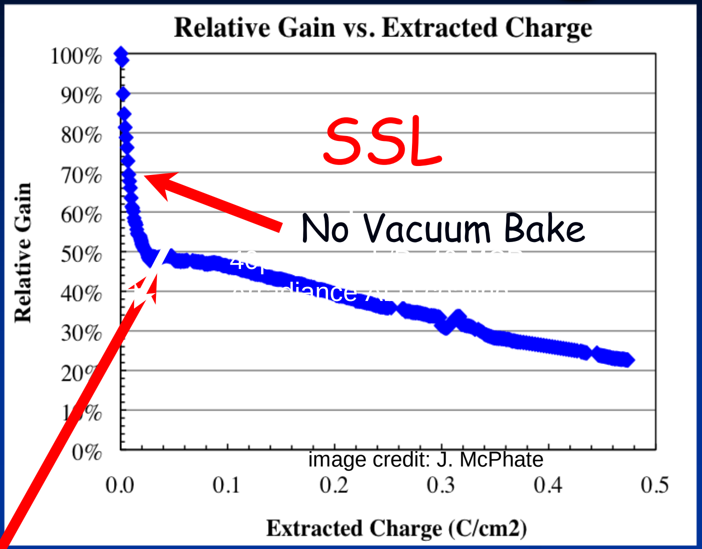
- Many material possibilities
- Tune SEE along pore (HF- possible discrete dynode structure (speed!)

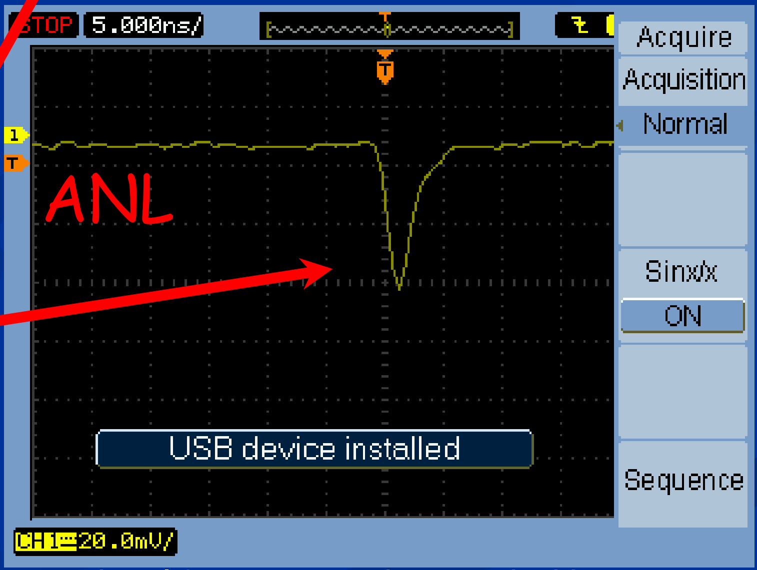
**Jeff Elam ,
Zeke Insepov,
Slade Jokela**

MCP and Photocathode Testing

Jeff Elam, Anil Mane, Qing Peng, Neal Sullivan (Arradiance), Bernhard Adams, Matt Wetstein, Slade Jokela, Igor Veryovkin, Alex Zinovev,, Ossy Siegmund

- Conventional lead-oxide MCPs have single composition for resistive/emissive material
  - Functionalized in H-furnace requiring long “scrubbing” time (removal of volatiles)
- ALD allows separate control of resistive and emissive layers
  - separately optimize each layer for best overall performance
  - Precise control over composition; tunable resistance
- **Arradiance coatings on Incom plate- Scrub time reduced by up to ×10 (!) (SSL)**
- **Have functionalized several pairs with newly developed resistive layer plus Al_2O_3 secondary emissive layer (ANL)**



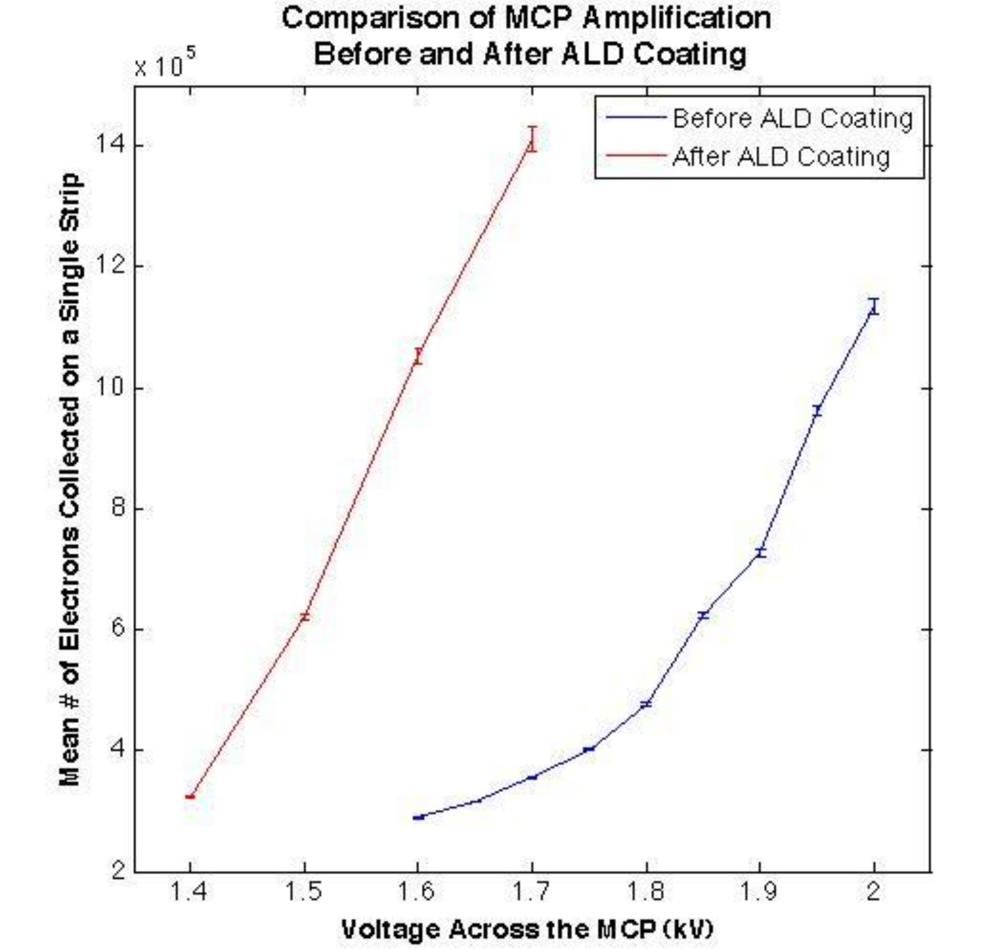


Signal from MCP pair coated with new resistive layer Al2O3 emissive layer

MCP and Photocathode Testing

Testing Group: Bernhard Adams, Matthieu Cholet, and Matt Wetstein at the APS, Ossy Siegmund's group at SSL

N. B.!

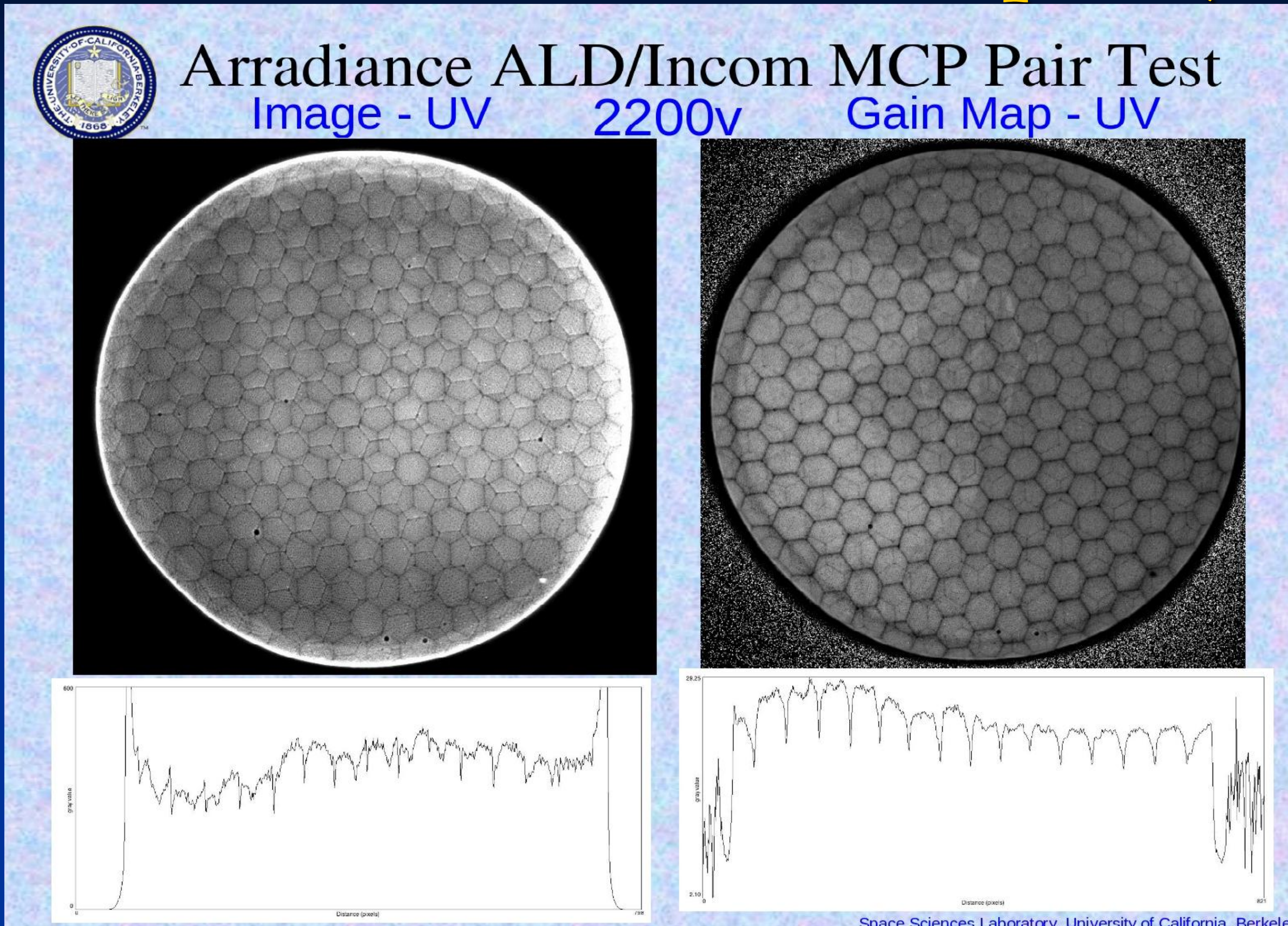


LAPPD Preliminary

(very)

First measurements of gain in an ALD SEE layer at the APS laser test setup (Bernhard Adams, Matthieu Cholet, and Matt Wetstein)

First-ever test of an ALD pair (Ossy, SSL)

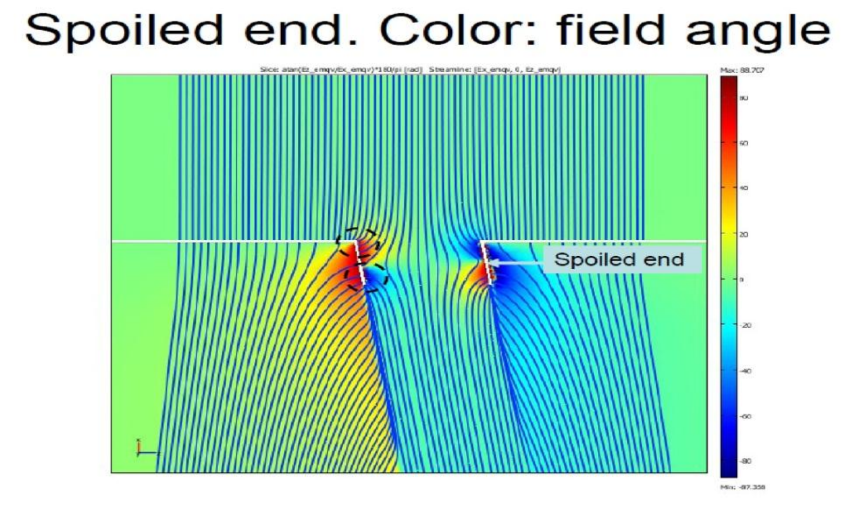


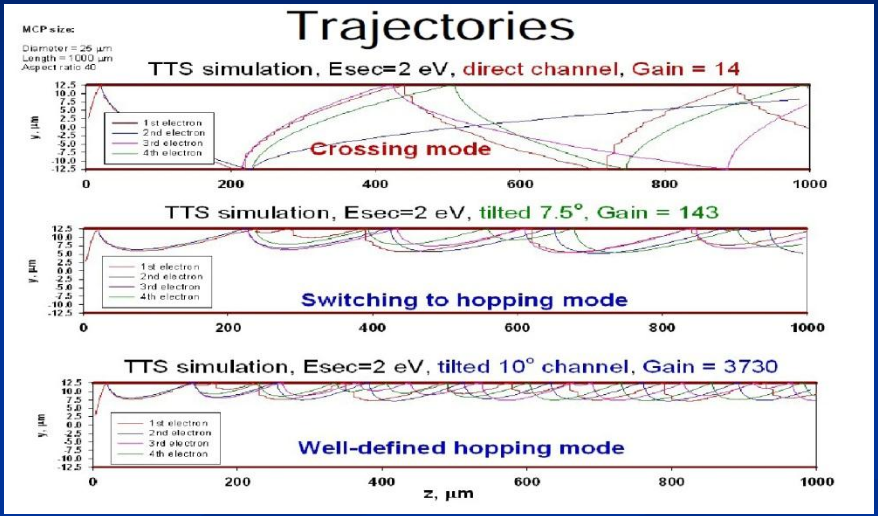
Note- at high gain the boundaries of the multi's go away

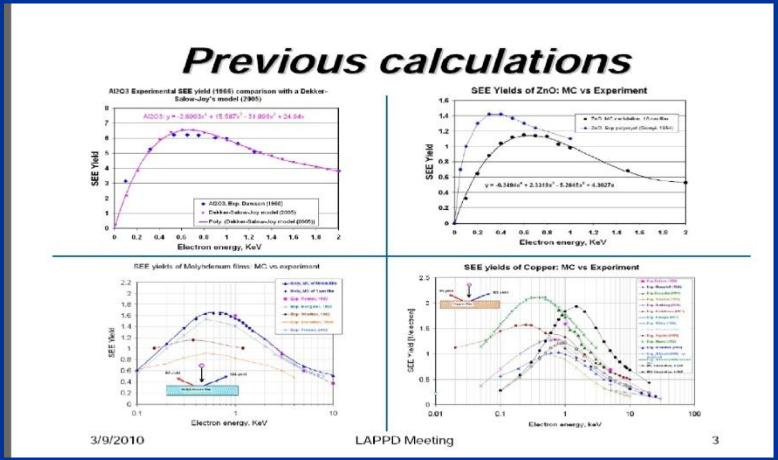
Electron pattern (not a picture of the plate!)- SSL test, Incom substrate, Arradiance ALD. Note you can see the multi's in both plates => ~50 micron resolution

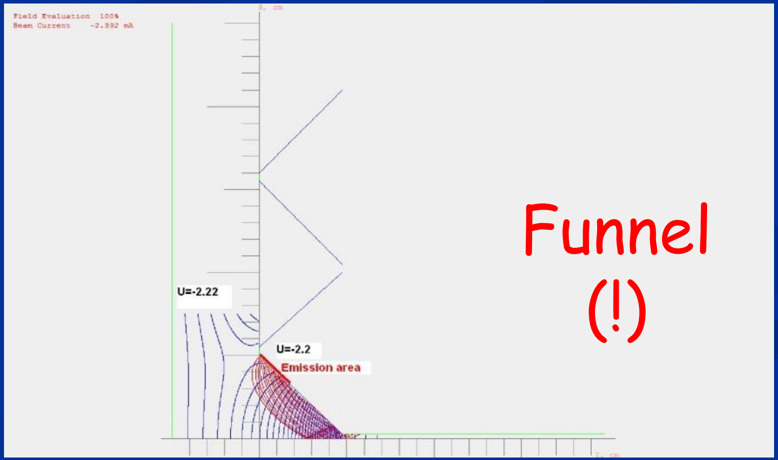
Simulation (crosses all groups)

Valentin Ivanov, Zeke Insepov, Zeke Yusof, Sergey Antipov





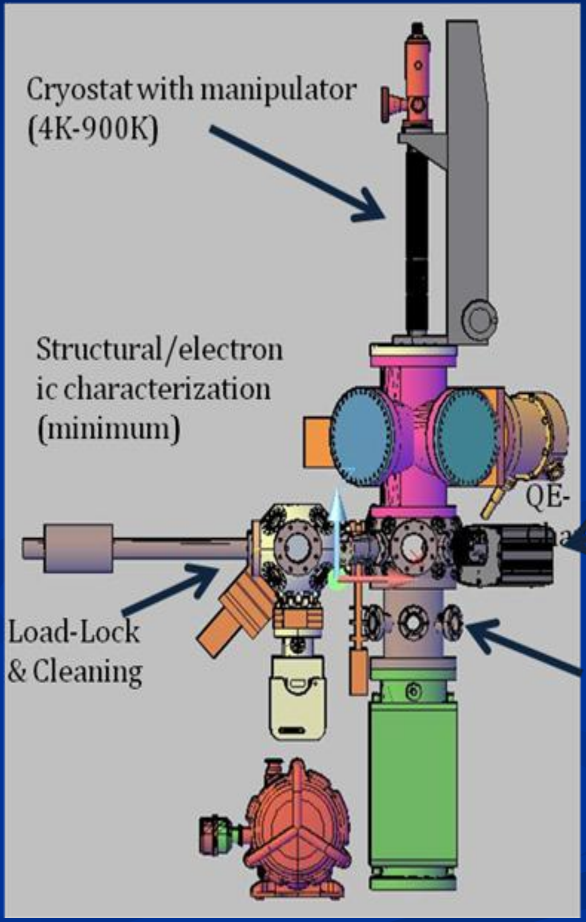




Photocathode Group

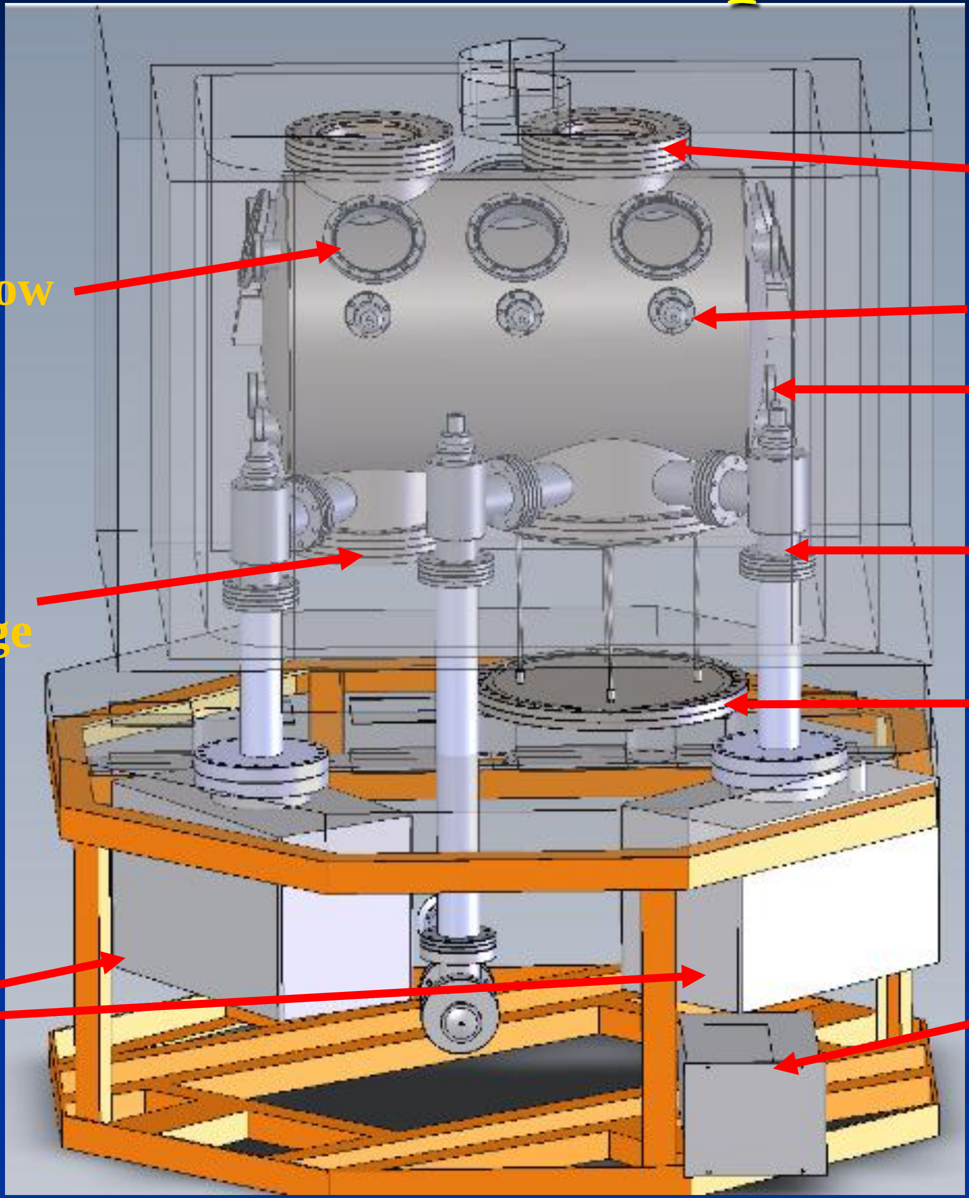
Klaus Attenkofer, Zikri Yusof, Ossy Siegmund, Junqi Xi, Sasha Paramonov, Seon Wu Li, Slade Jokela, Ryan Dowdy (UIUC), Jim Buckley (WashU, Dan Leopold (WashU)

- 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 50% have been achieved in multi-alkalis
- Basic understanding is missing- we think we can make major contributions here to applications

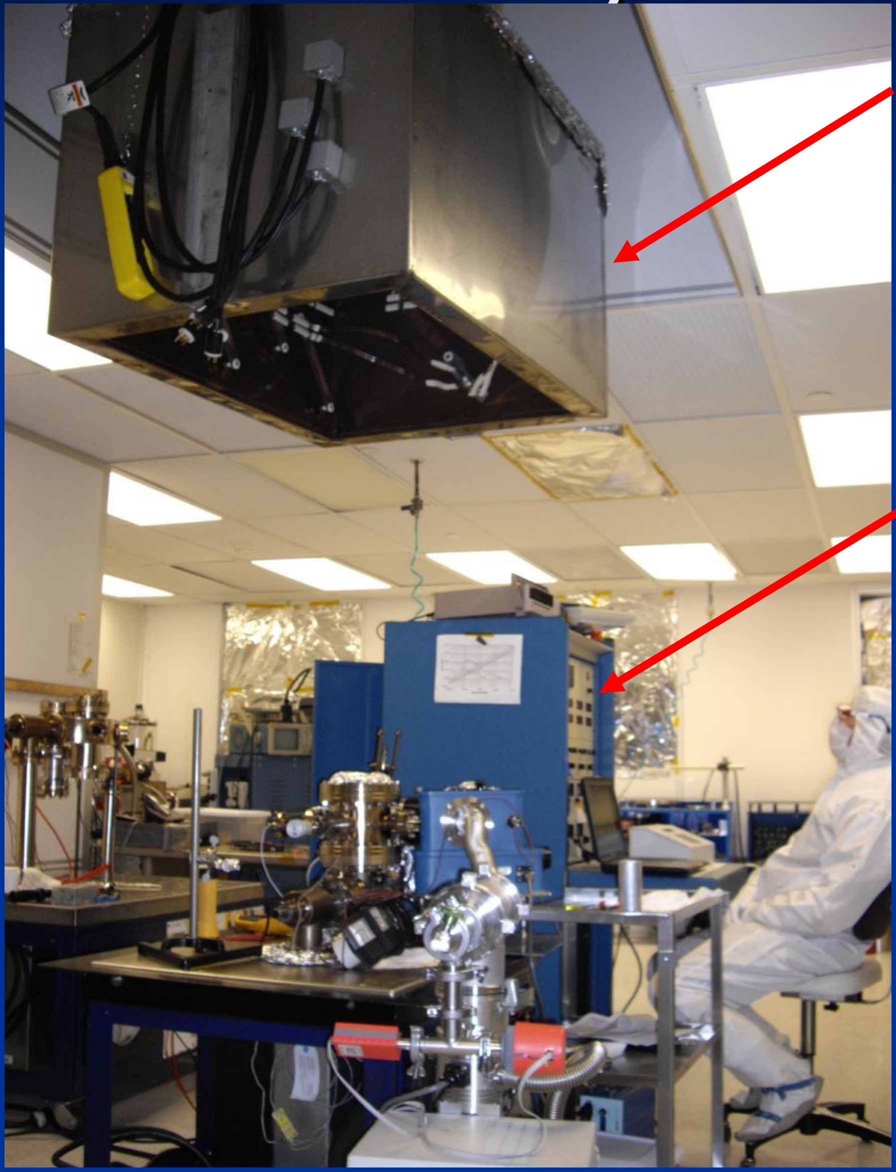


Big payoff if we can get >50% QE robust Photocathodes, and/or more robust (assembly). Also want to get away from `cooking recipes' to rational design.

SSL Photocathodes: Large Process Chamber – our backup (Ossy Siegmund)



SSL Photocathodes: Processing Oven, Cathode Deposition



- Oven accommodates Large Format Inside Envelope: 36” x 30” x 25” High
- Defines Large Chamber Limits
- Cathode station controls alkali metal deposition, and monitors cathode response

- Ossy Siegmund

•30

Purchase of Burle Photocathode Facility (LDRD money)

Our System

All wrapped up ready to ship

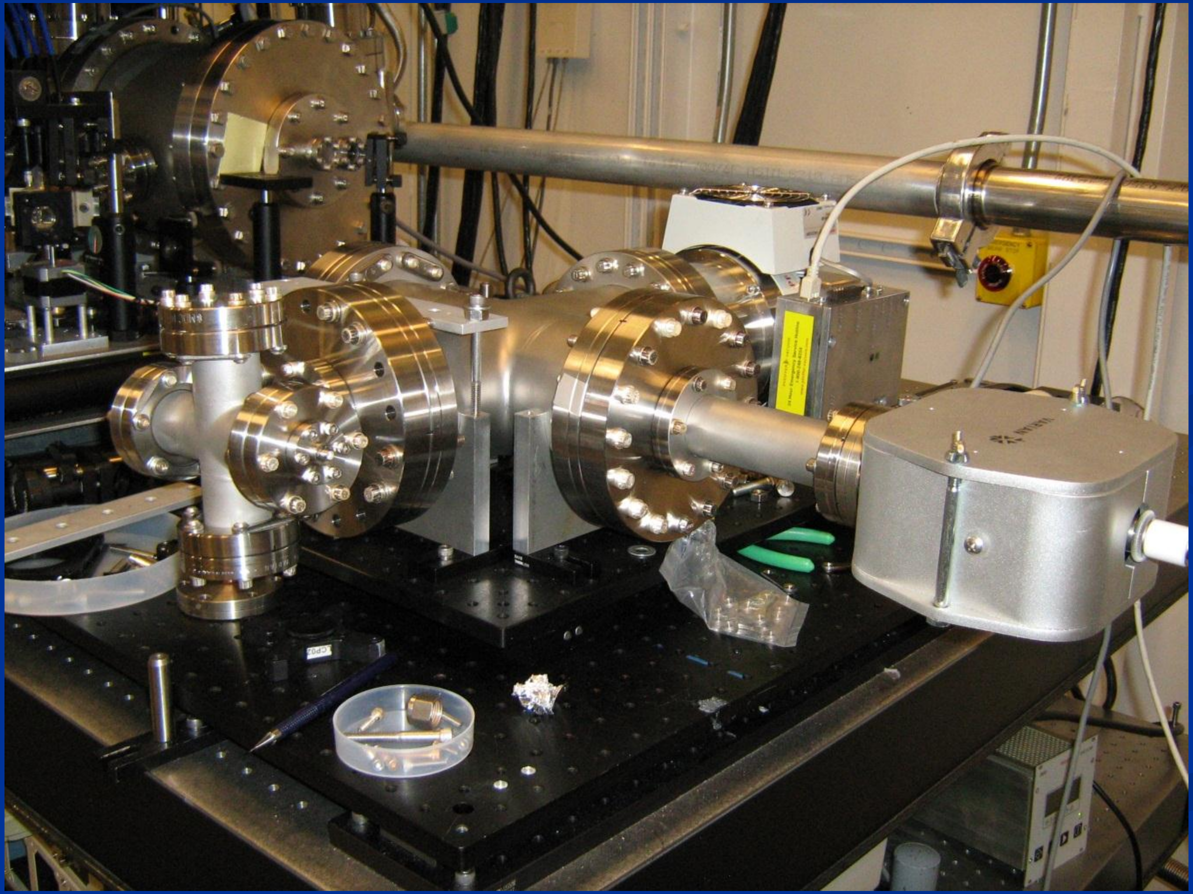
Alkali Metals (K, Cs) Deposition

Making electrical contacts to the various electrodes. A "white" light source is also installed over the tube to monitor the photocurrent during deposition

The oven cover was then lowered. The temperature was set to 150 C, which was the deposition temperature for the alkali metals.

MCP/Photocathode Development-Test setup at APS laser

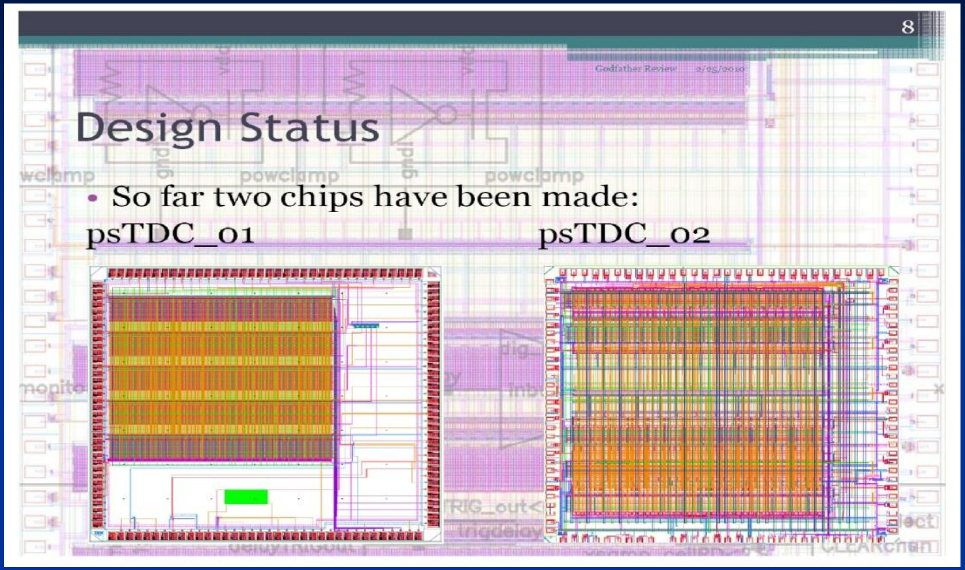
Bernhard Adams, Klaus Attenkofer, (APS), Matt Wetstein (HEP), Matthieu Chabon

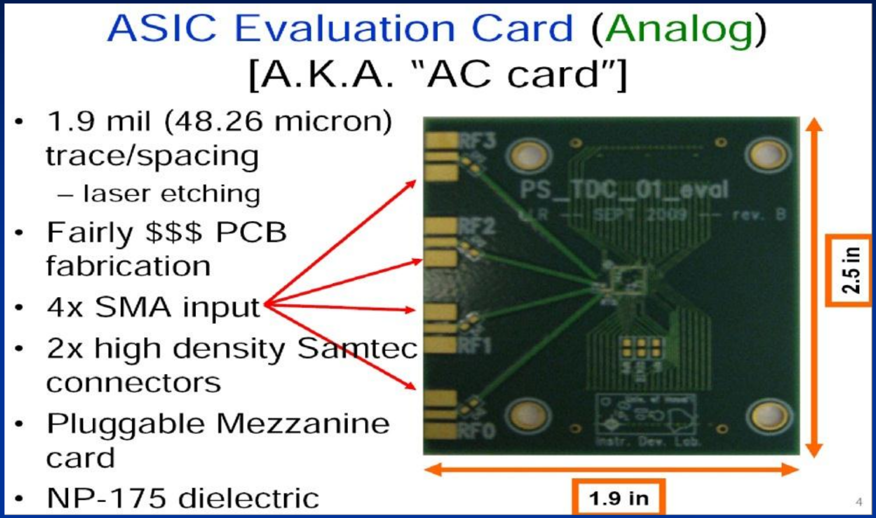


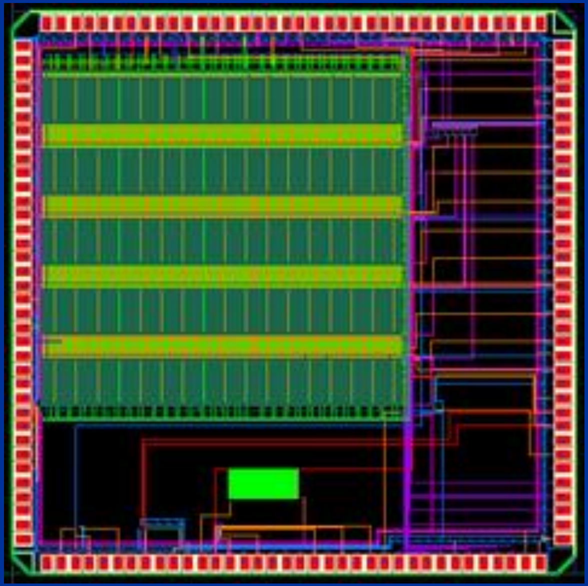
New Femtosec Laser Lab at APS

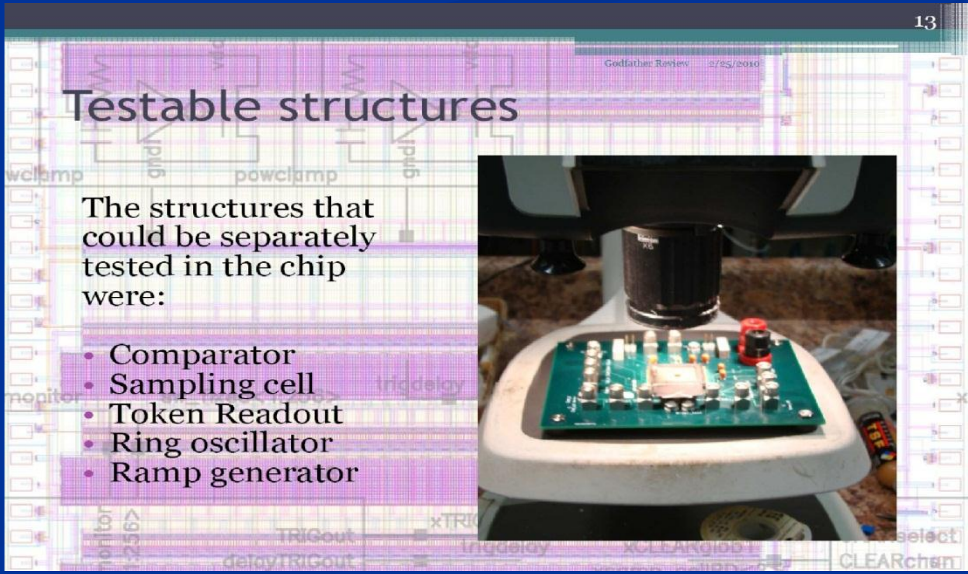
- **Bernhard Adams, Matthieu Chabon, Matt Wetstein**

Electronics Group
Chicago- Hawaii



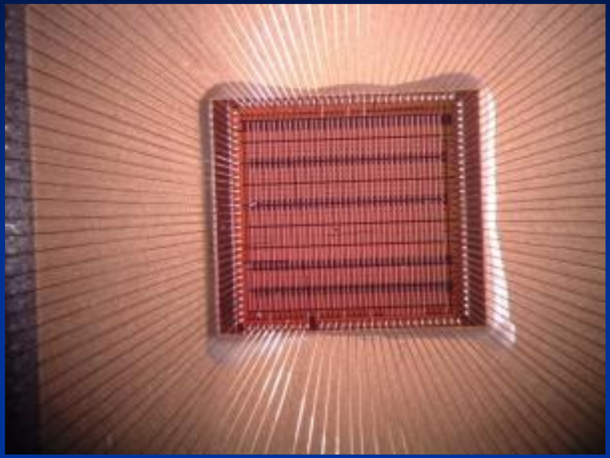






Electronics Group
Chicago- Hawaii

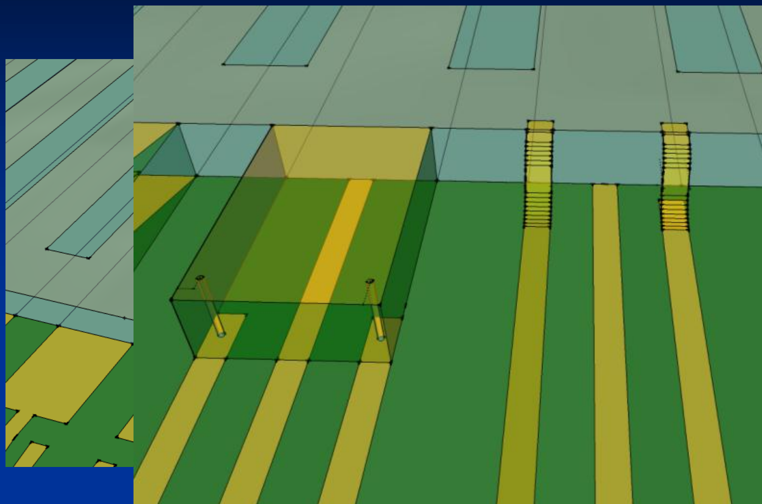
Psec2 ASIC



- 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)

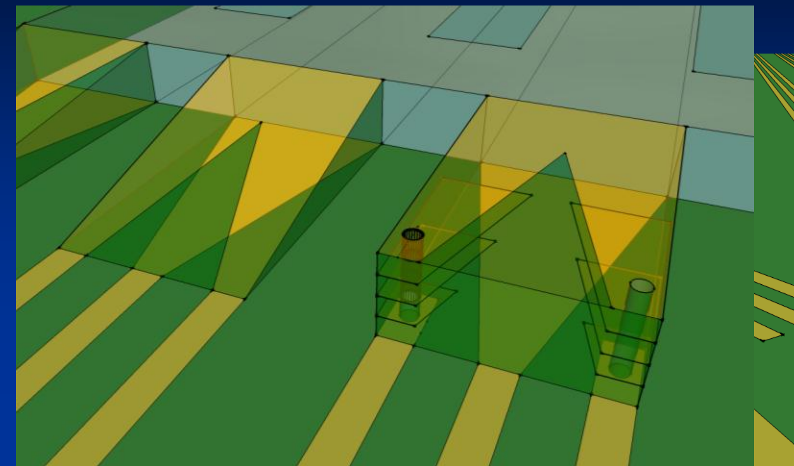
Microstrip to Coplanar E-Field transition

Herve Grabas



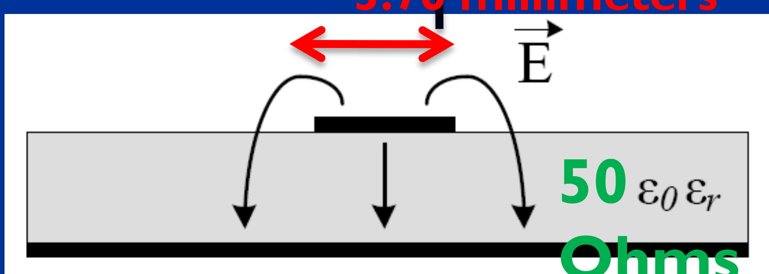
Simplest

?



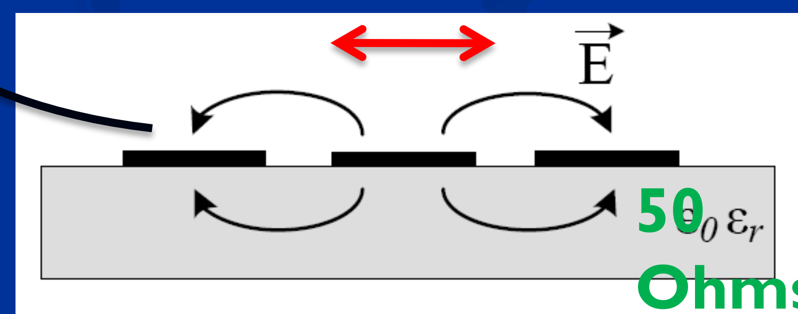
More complicated

3.76 millimeters



50 Ohms

0.15 millimeters



50 Ohms

Many configurations are possible from very simple to complicated. Simulation and test can only tell which one will be the best.

Summary

- Glass substrates with ALD looks viable- still some questions and evolution, but looks good.
- Basic questions on SSE materials are answered and are solid.
- The necessary test and development facilities have been developed at SSL and ANL.
- We have developed a `frugal' 16"x24" design at ANL and a conservative but very solid 8"by 8" design at SSL; both places are close to making full-size proto-types
- Multi-alkali photocathodes have been made at SSL and at Burle by ANL folks- we are much more confident than 6 months ago
- We have attracted excellent young talent, less-young talent, interest from industry and applications- it's a really good, highly-motivated group.

Concerns

- Funding- 4,3,1 vs 4, 2,2
- SuperModule design has led to larger area goal at 3-year end- goal now is enough SuperModules to engage industrial production (a step beyond `commercializable')- Tile Factory wasn't in the Proposal
- We had requested strategic LDRD funds for the Photocathode Growth and Characterization Facility at ANL- just turned down (not unexpected)-
- Missing an engineer/manager for the Tile Factory; photocathode effort still something of a pick-up ball game (but these can be the best, but a concern)

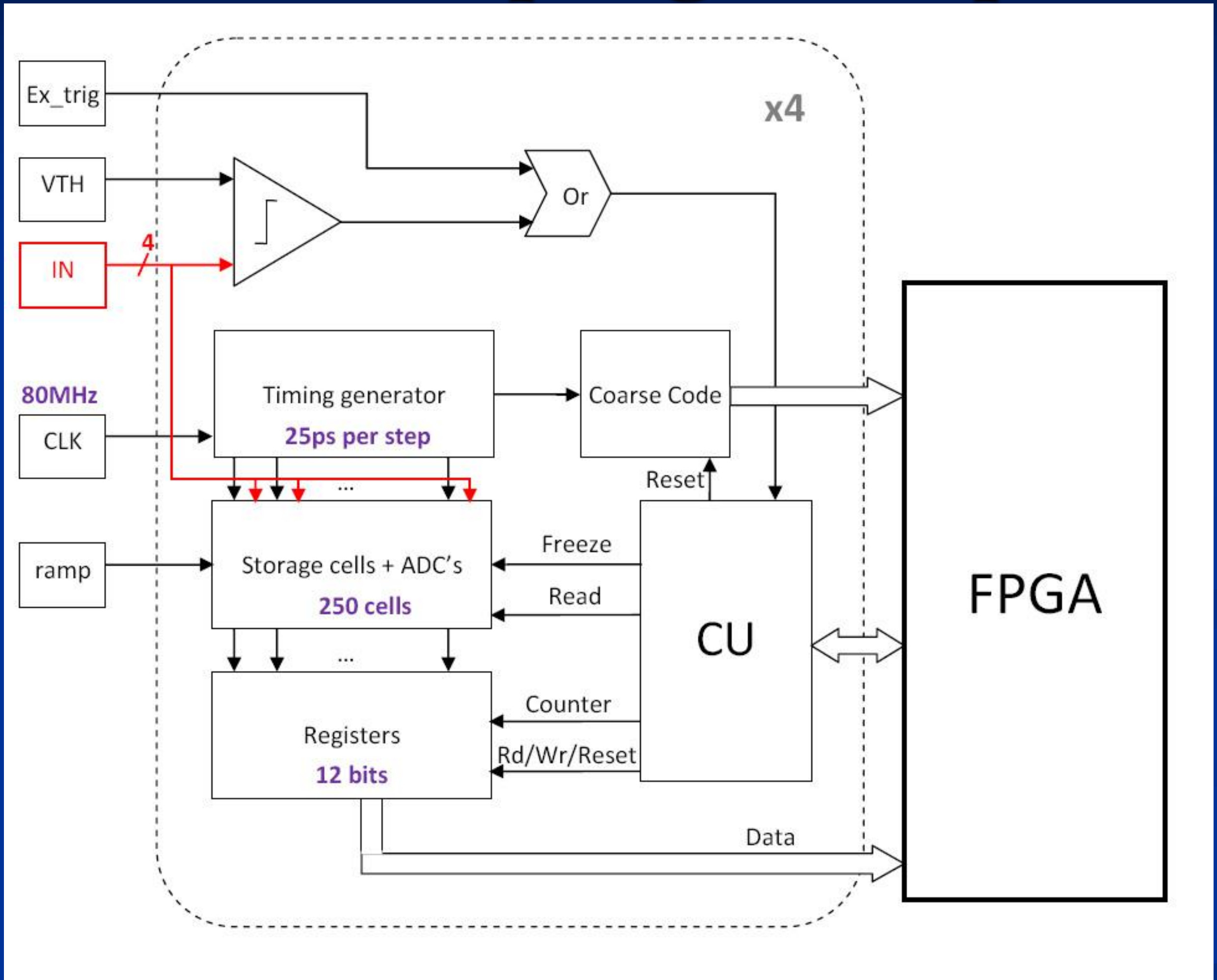
THE END

Thanks to everybody in the LAPPD collaboration, esp. the young ones.

Making electrical contacts to the various electrodes. A "white" light source is also installed over the tube to monitor the photocurrent during deposition

The oven cover was then lowered. The temperature was set to 150 C, which was the deposition temperature for the alkali metals.

Front-end Electronics/Readout
Waveform sampling ASIC prototype

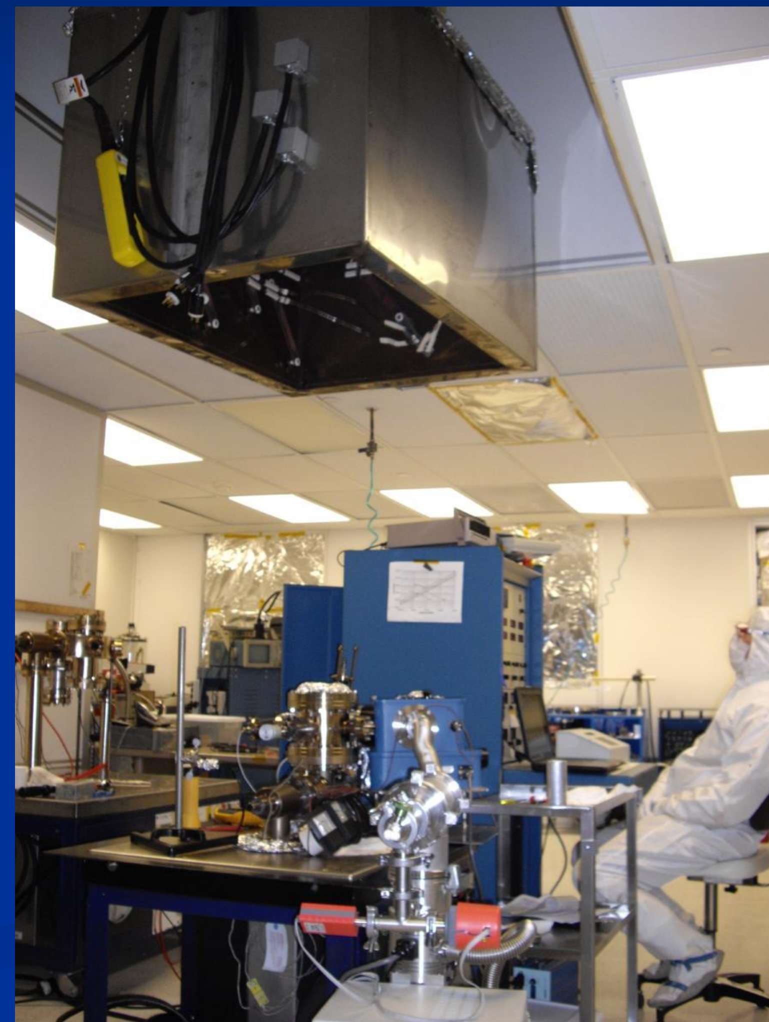


- Varner, Ritt, DeLanges, and Breton have pioneered waveform–sampling onto an array of CMOS capacitors.

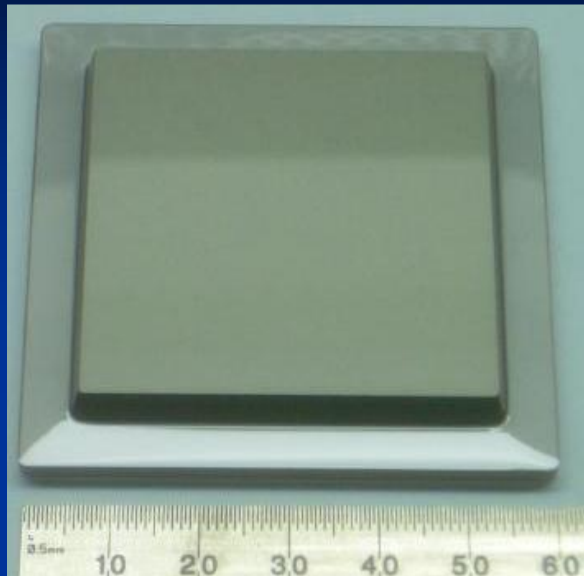
SSL Tube Processing Facilities

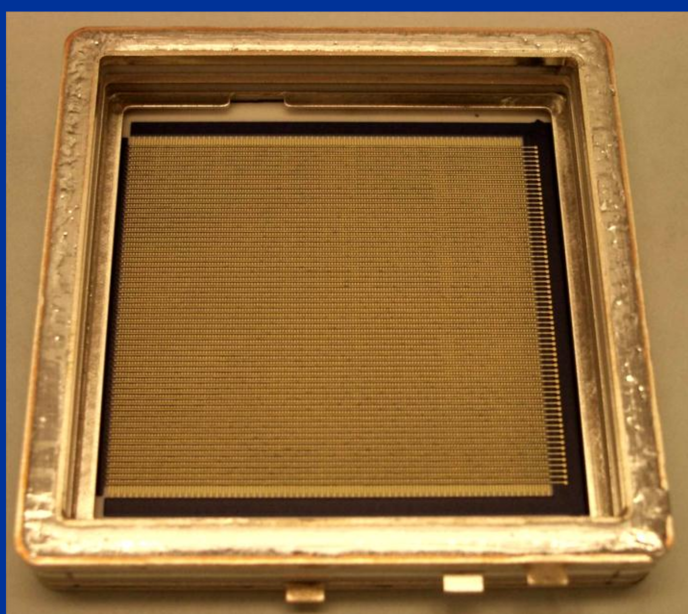
UHV detector/cathode
processing station

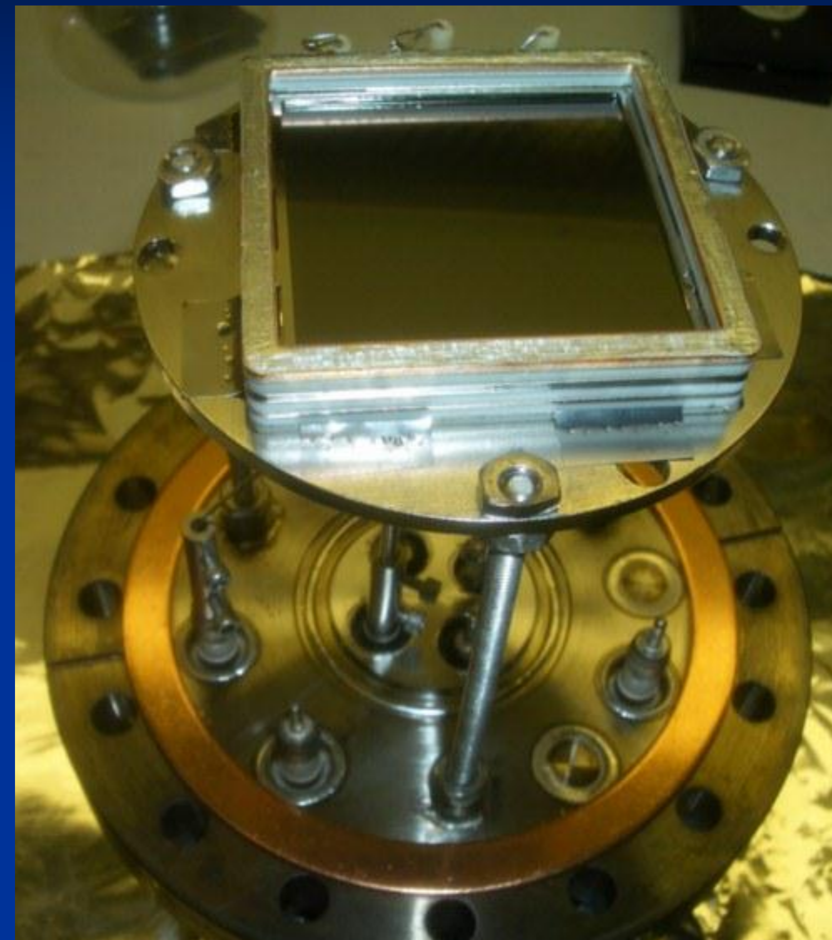
Sealed tube facilities and oven



SSL Sealed tube detectors Pre-process assembly

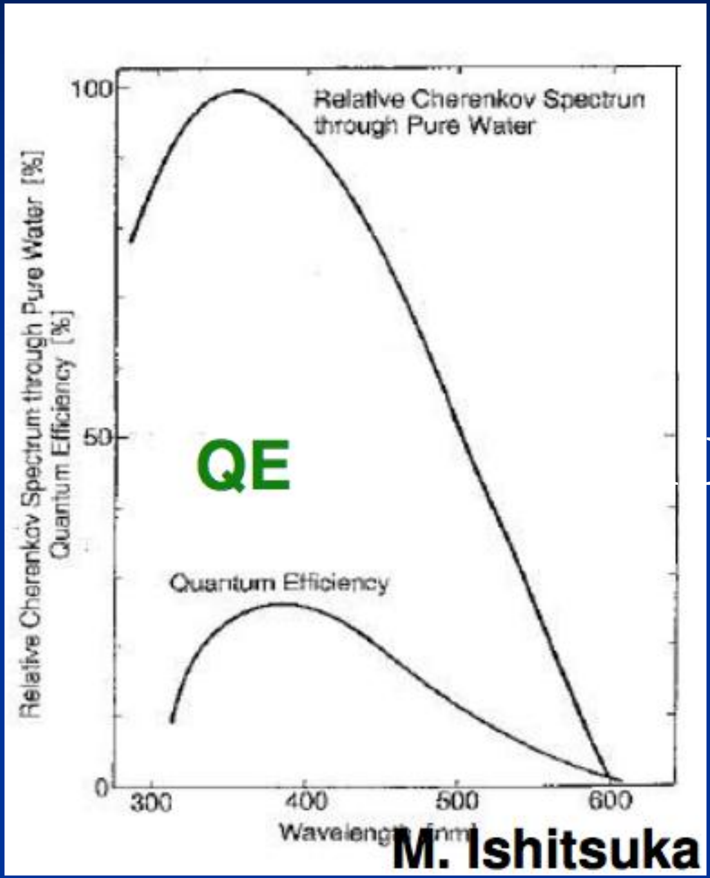




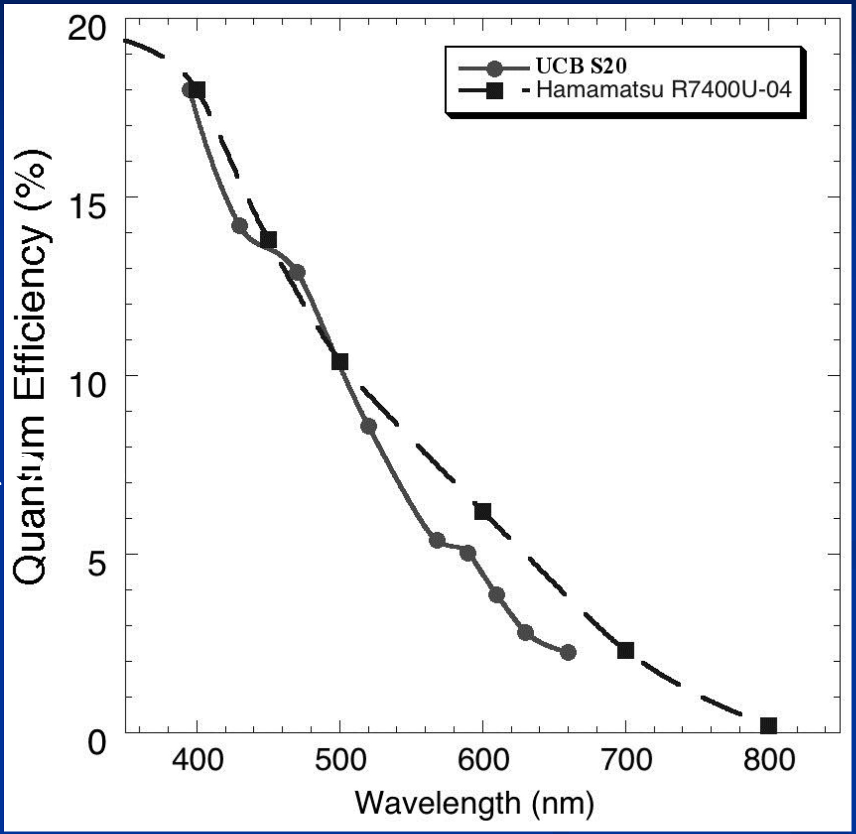


Planacon, with fiber optic window and cross strip anode (signal vias straight through substrate), in assembly with MCPs installed (above) ready to process.

SSL: Alkali Photocathodes



Fran



Emission spectrum of Cherenkov in water compared with bialkali response.

UCB SSL cathode compared with commercial product.