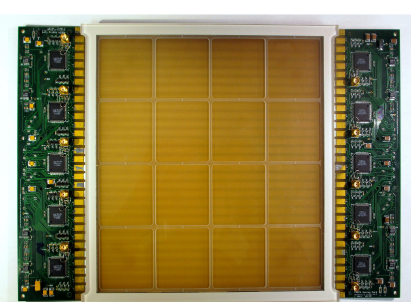
The Development of Large-Area Picosecond Photo-Detectors and Fast Timing Implications for Neutrino-less Double-Beta Decay Searches

Andrey Elagin
University of Chicago



Mitchell Institute Seminar, Texas A&M University
10/31/2013

Outline

University of Chicago

- Motivation for Large-Area Picosecond Photo-Detectors
- LAPPD design concept
- LAPPD components, system integration and testing
- Neutrino-less double-beta decay
- Separation of Cherenkov and scintillation light using fast timing detectors
- Summary

LAPPD Collaboration

SPACE SCIENCES LABORATORY
UNIVERSITY OF CALIFORNIA
Berkeley

THE UNIVERSITY OF CHICAGO

Argonne NATIONAL LABORATORY

UNIVERSITY of HAWAI'I® MĀNOA

INCOM
Bright Ideas in Fiberoptics

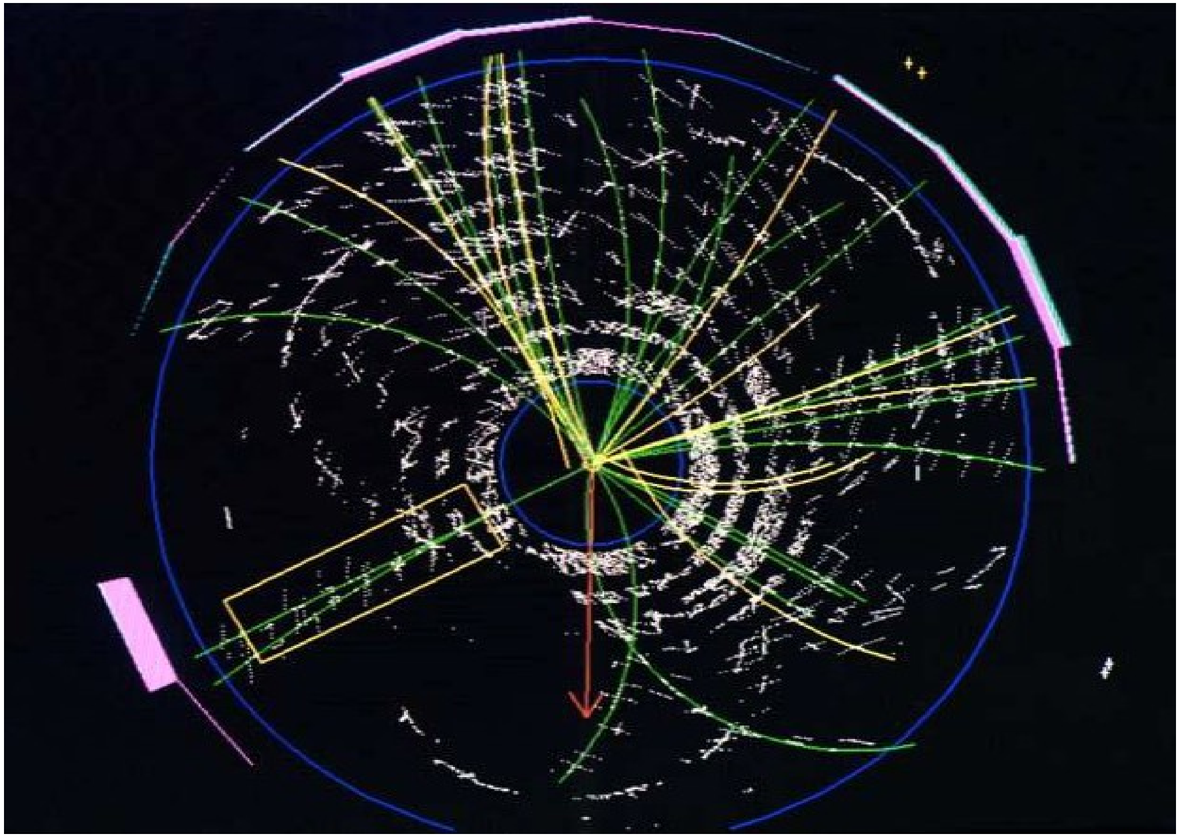
Fermilab

Colliders

University of Chicago

„A jet is a narrow cone of hadrons and other particles..."

Can we be more specific about jets?
- quark content of charged particles
- 4-vectors

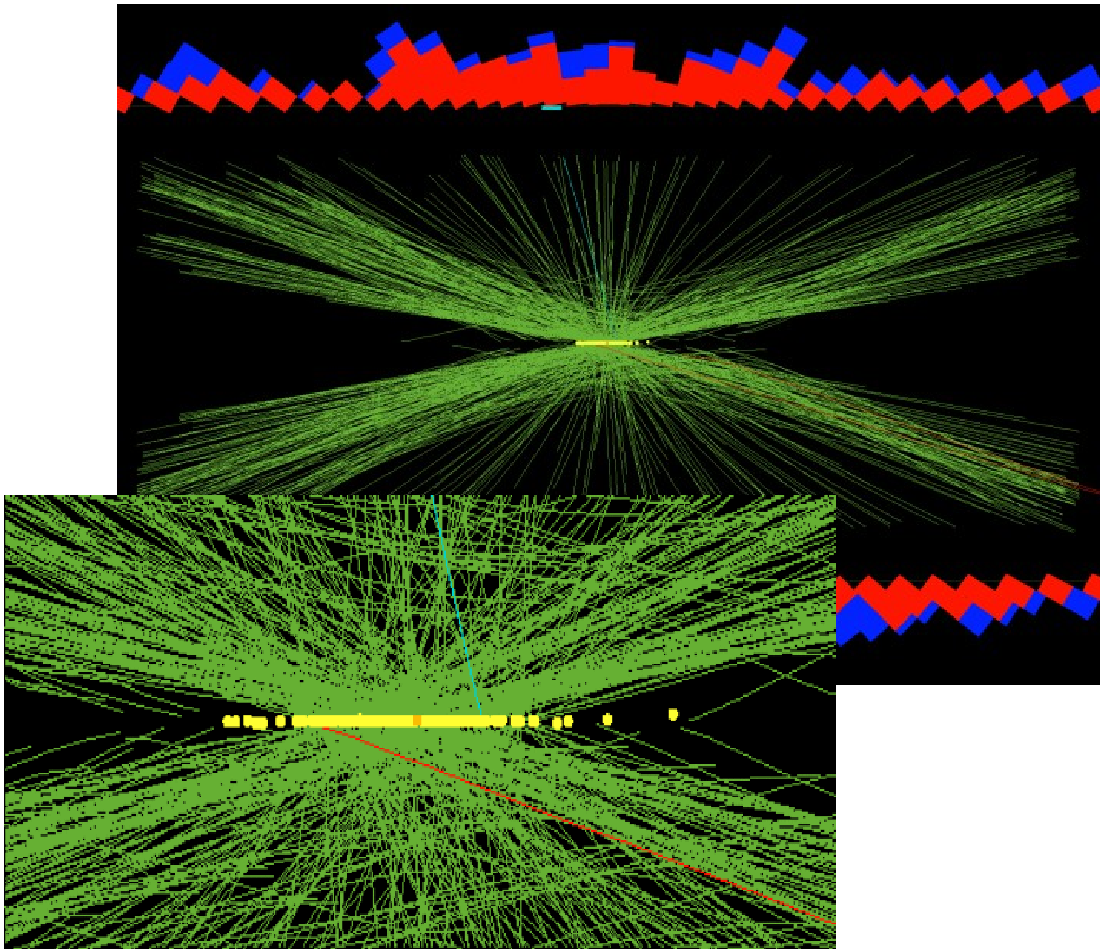


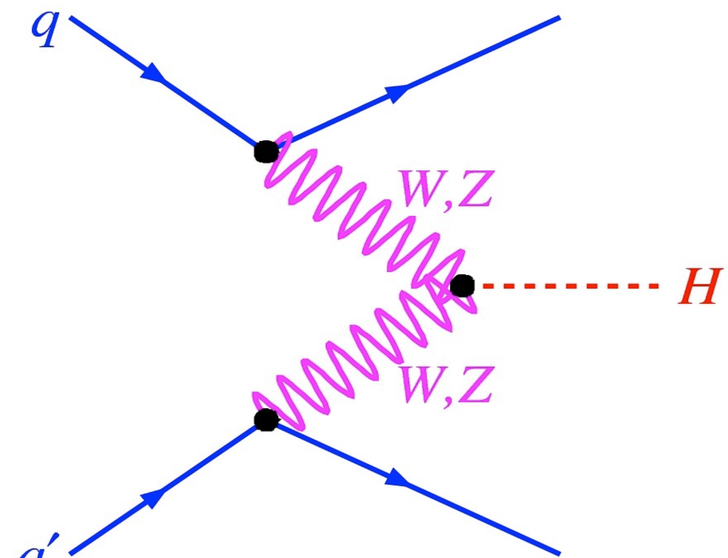
Need: ~1ps

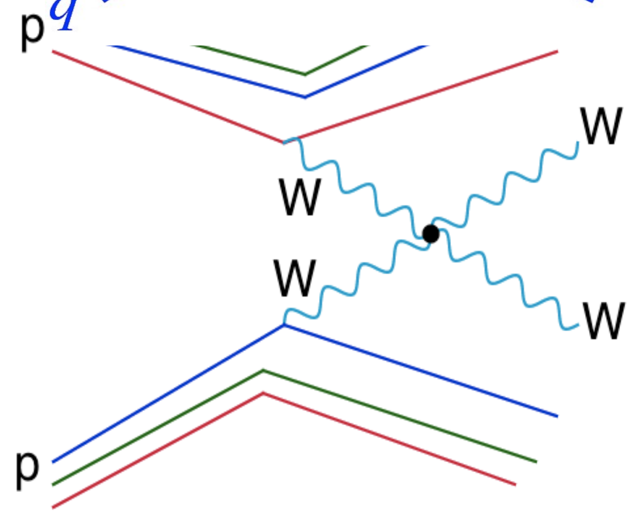
Photons arrive first, followed by pions, kaons, etc.

Colliders

Can we do better vertexing?





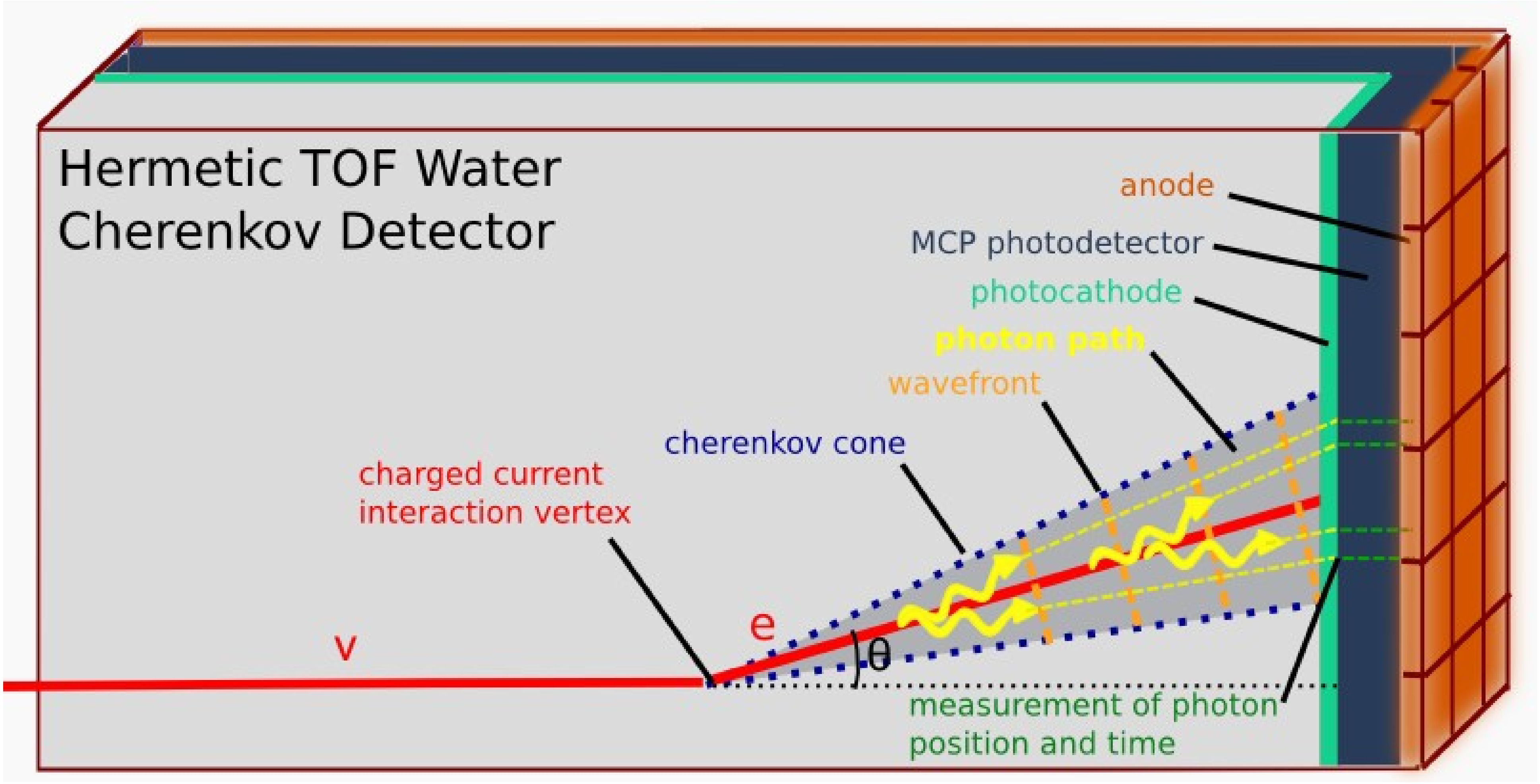


- Tie the photons to the correct vertex for precise H→γγ mass reconstruction
- Associate (often forward) jets with VBF Higgs or WW scattering

Neutrinos

Can we build an optical TPC?

H. Nicholson



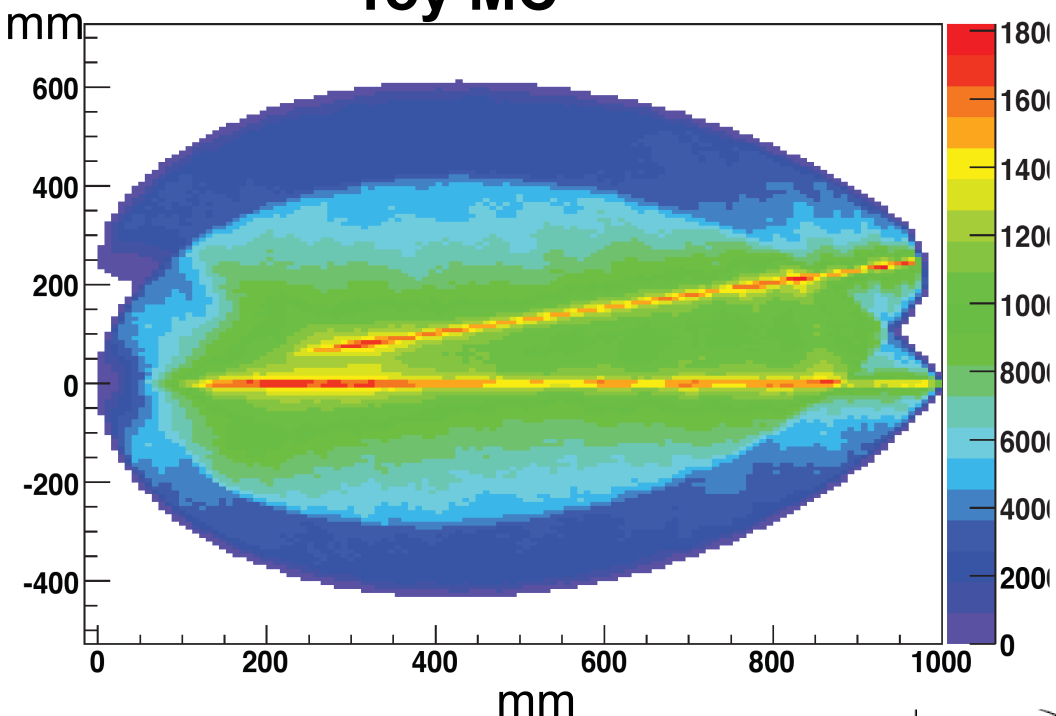
Reconstruct tracks from measurement of position and arrival time of the photons

Neutrinos

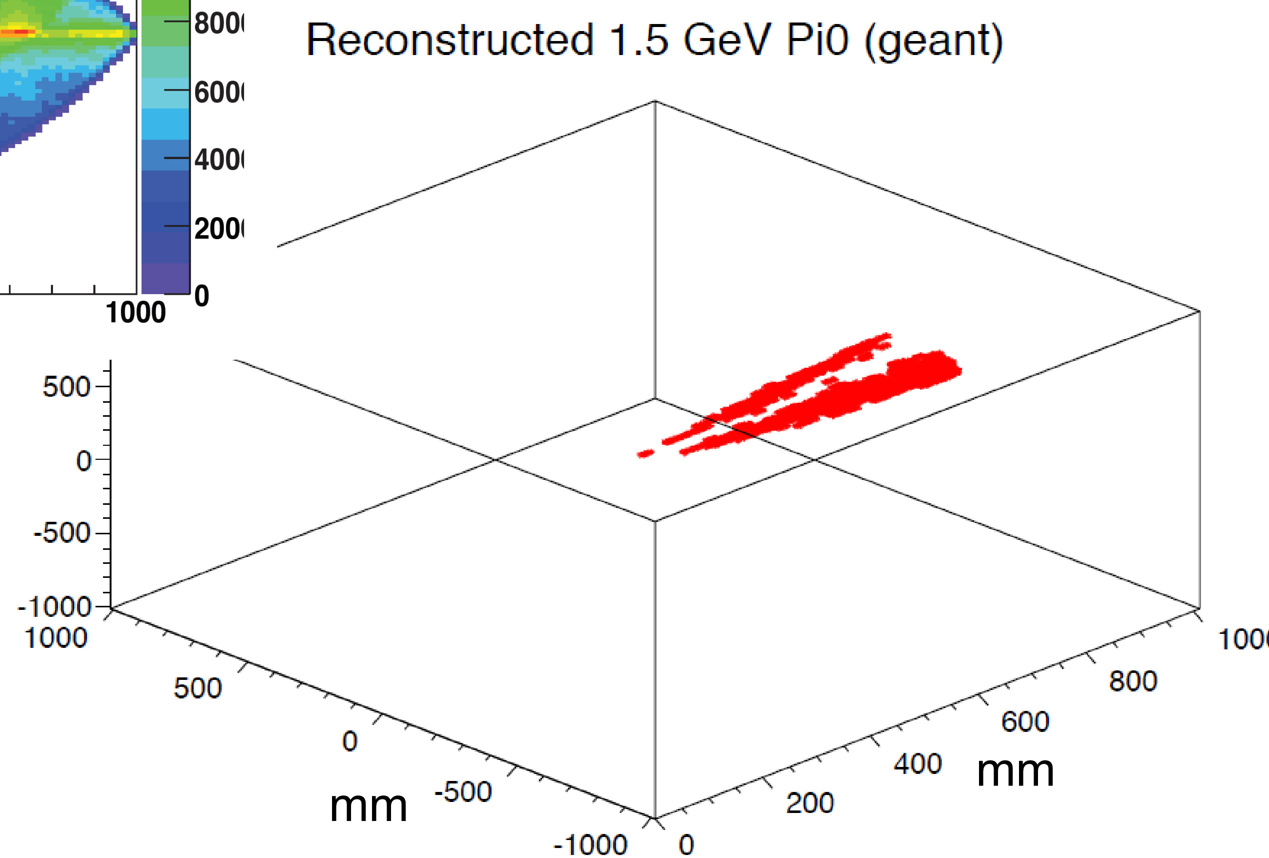
University of Chicago

M. Wetstein

Toy MC



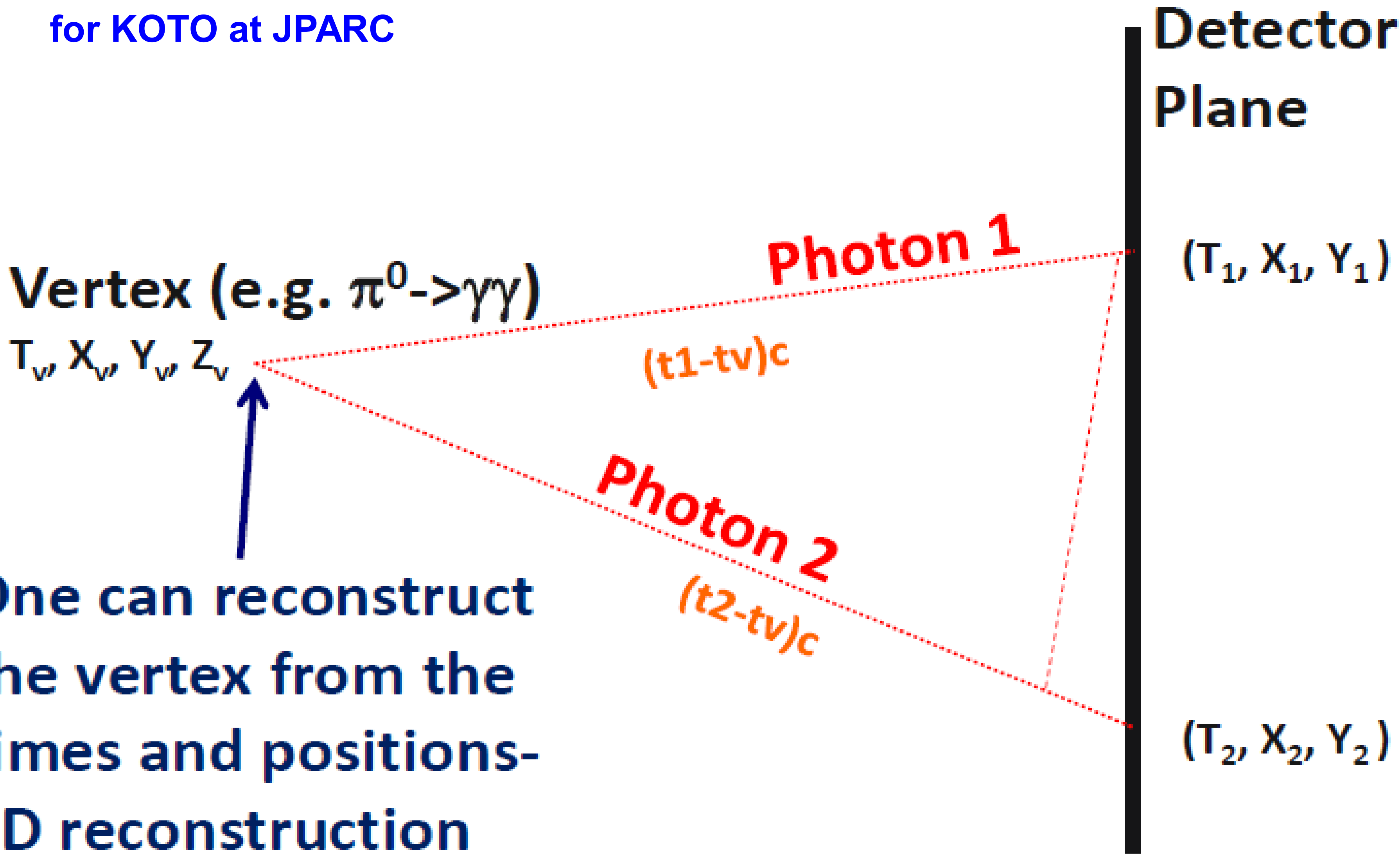
$$\pi^0 \rightarrow \gamma\gamma$$



Need: ~100ps

Rare Kaon Decays

for KOTO at JPARC



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

Need: ~1ps

Medical Imaging

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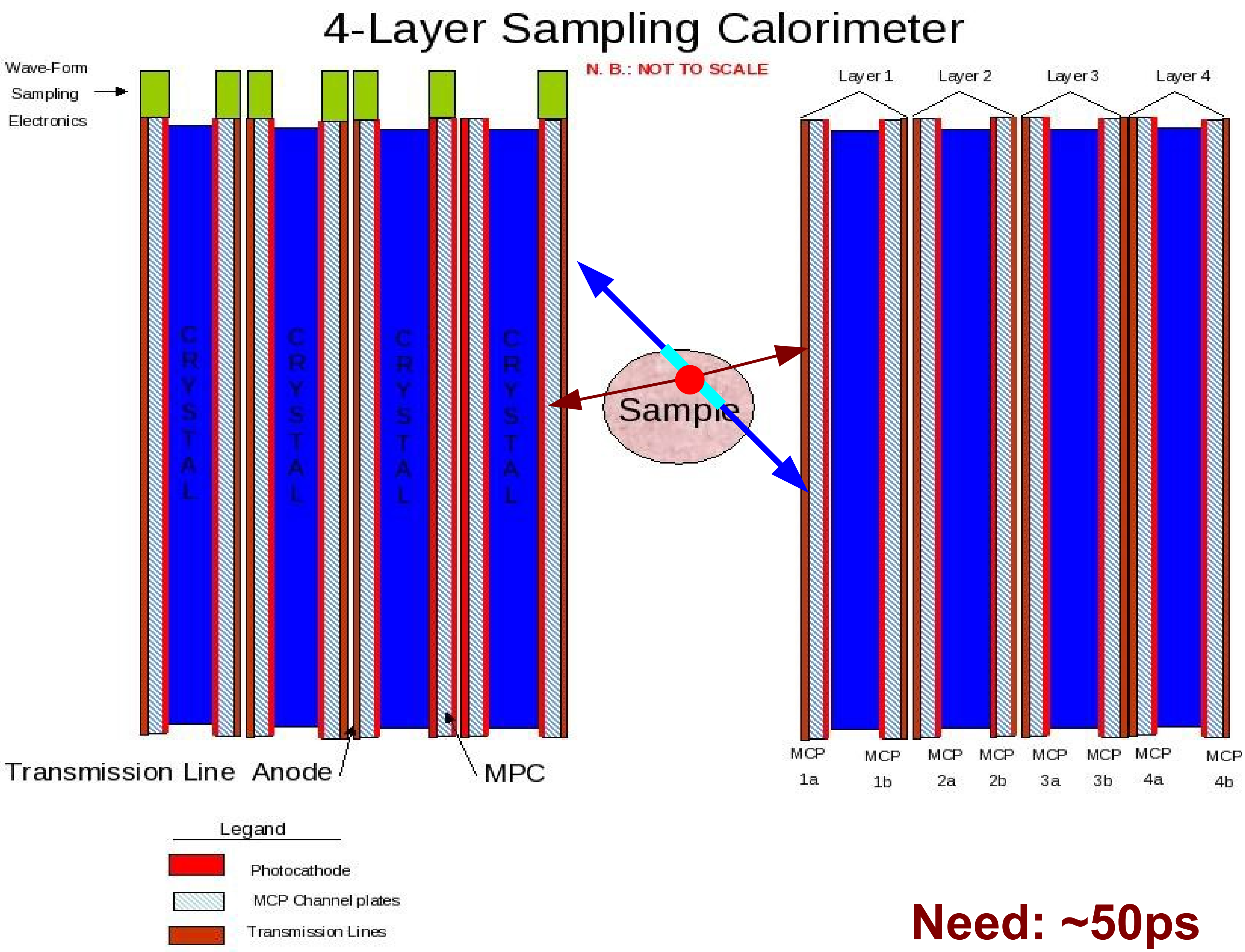

Need: ~50ps

Large Area Picosecond Photo Detectors

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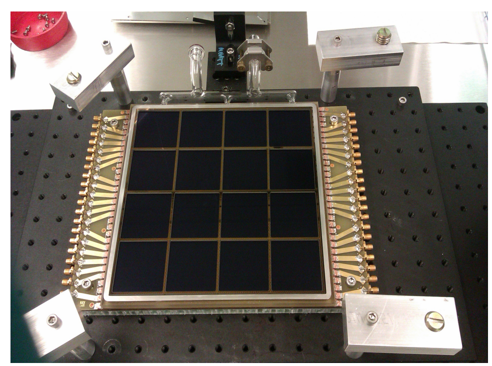
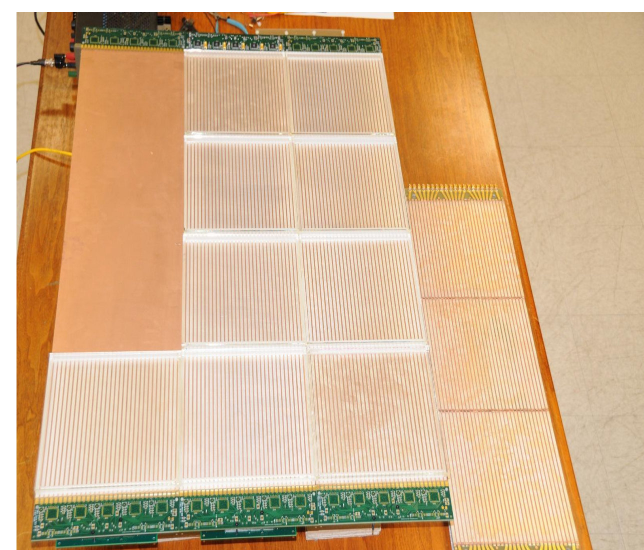
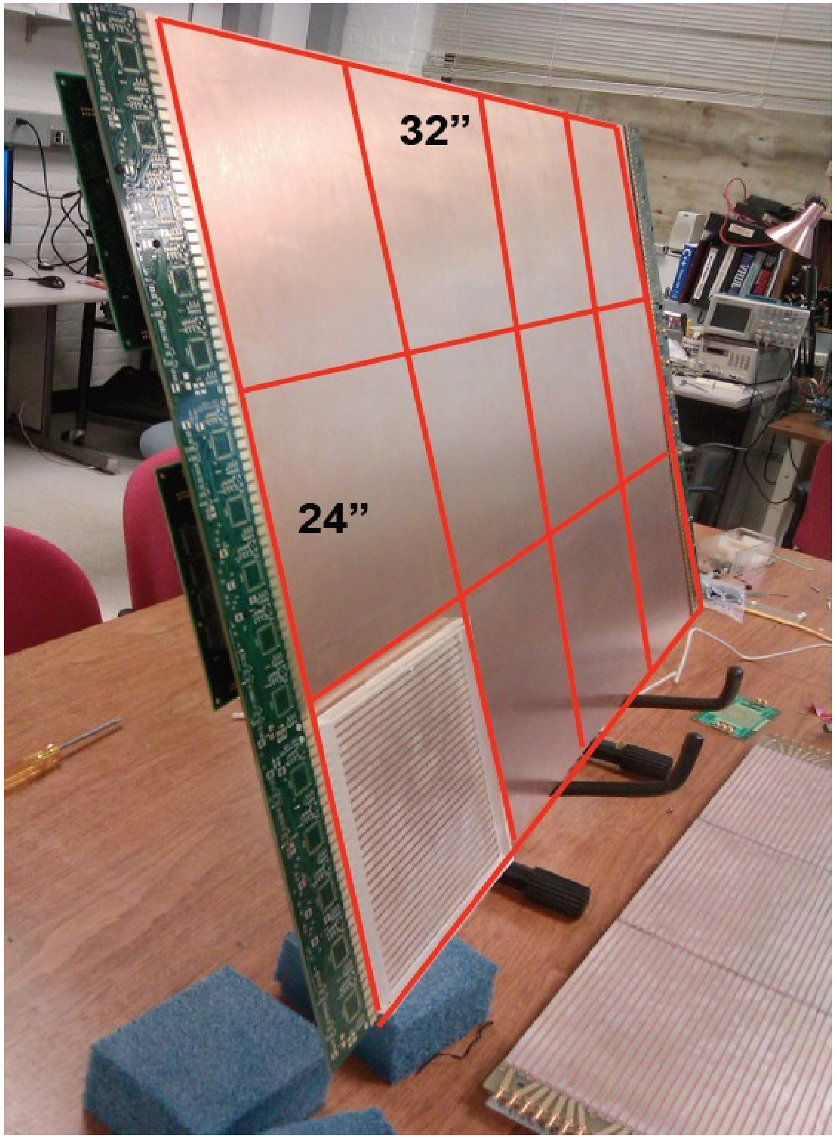
Transformational Change

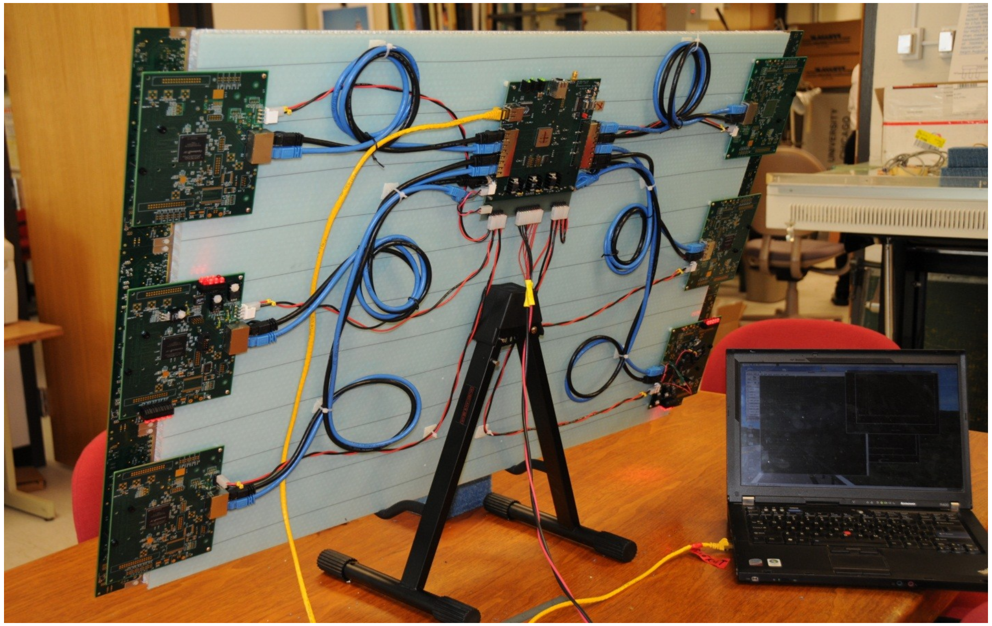

- *Large area*
- *Fast timing*
- *Inexpensive*

Super Module



- *<u>Thin</u> planar glass body detector*
- *Tiles share single delay line anode*
- *Fully integrated electronics*



Glass Package (20x20cm^2)

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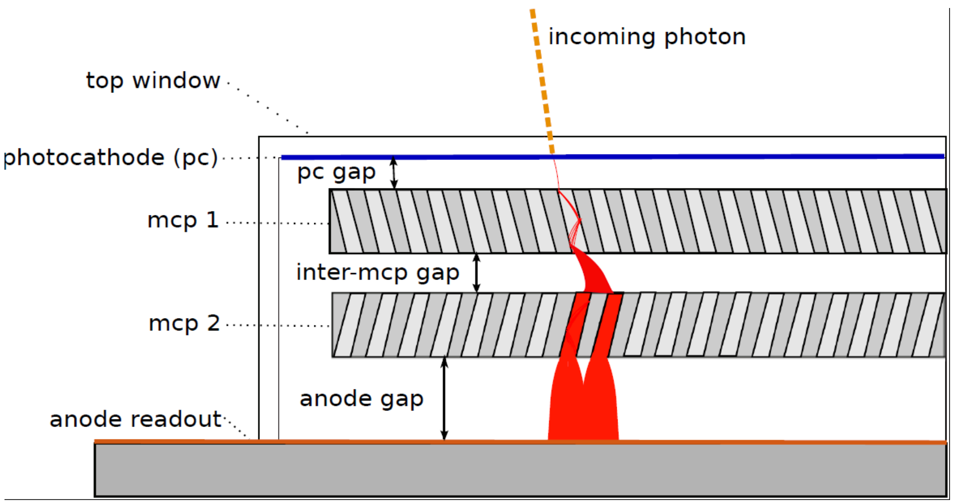
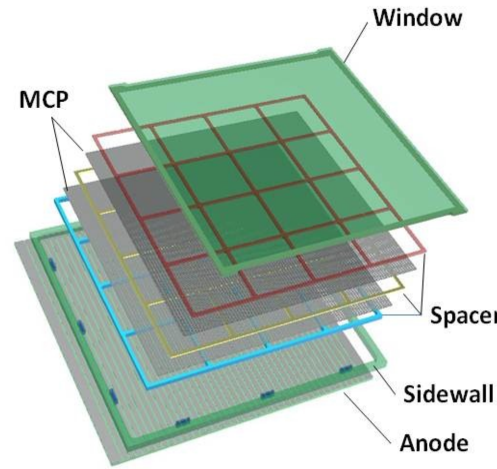
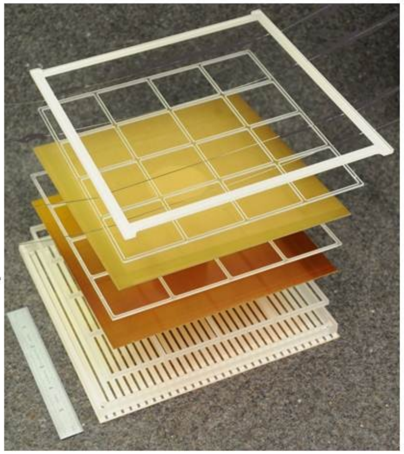




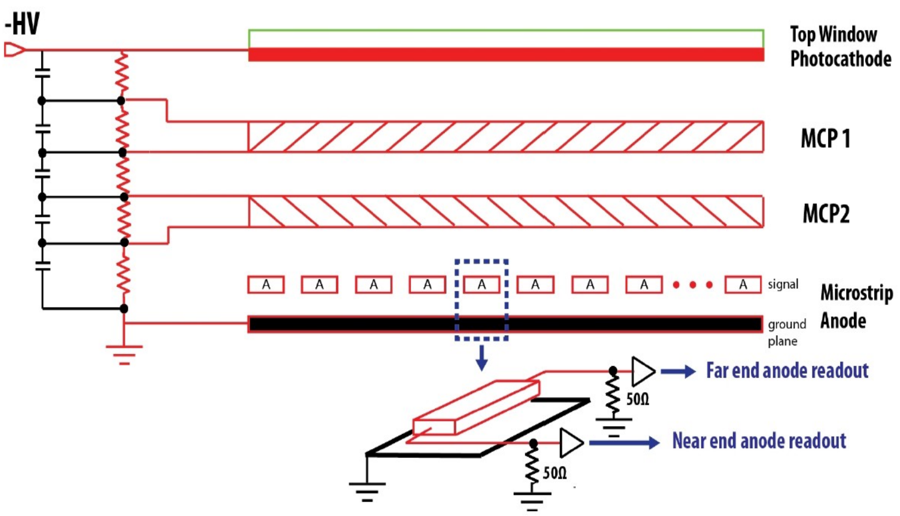
Design Drawing - September 2010



Actual Glass Parts - April 2012

The Frugal Tile

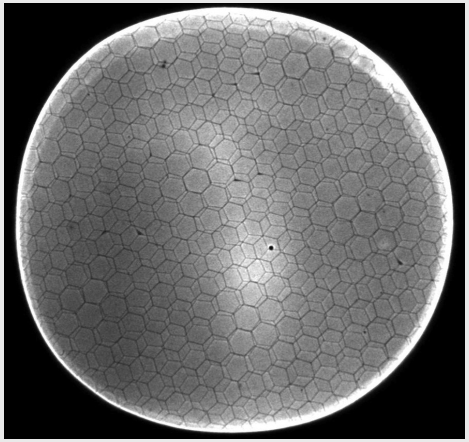
- Cheap, widely available float glass
- Anode is made by silk-screening
- Flat panel
- No pins, single HV cable
- Modular design
- High bandwidth 50 Ω object
  - designed for fast timing



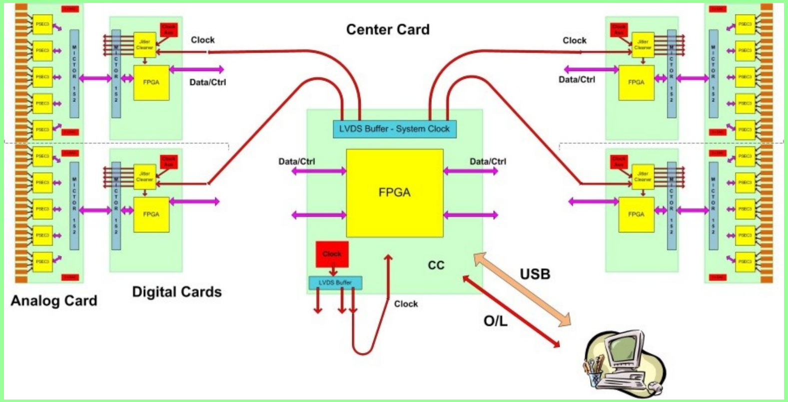
Ceramic body packaging is a parallel (and collaborative) effort at Berkeley SSL

LAPPD Components

MicroChannel Plates

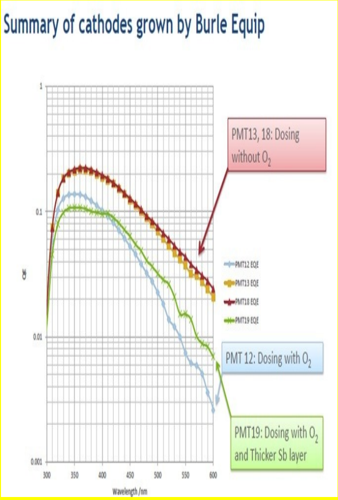


Electronics/Integration



Hermetic Packaging

Photocathodes



MCP Fundamentals

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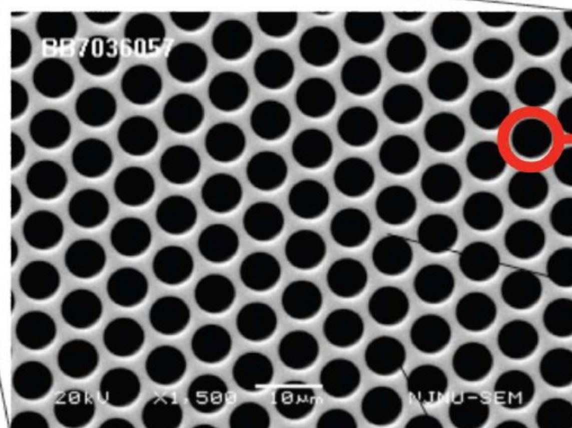
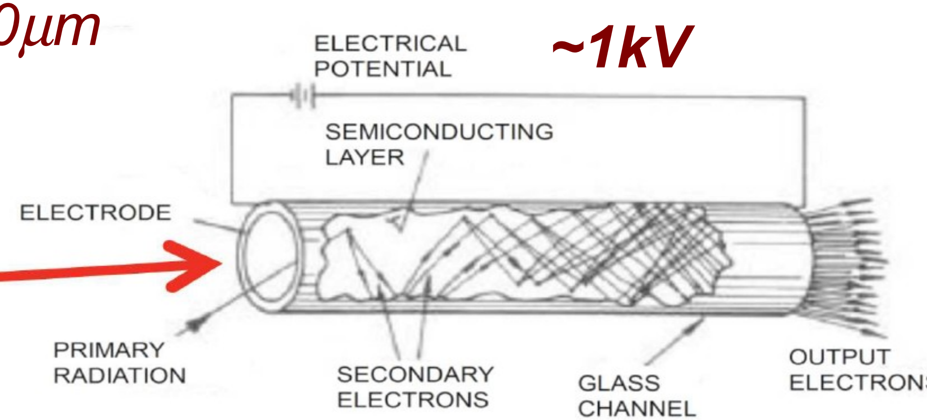
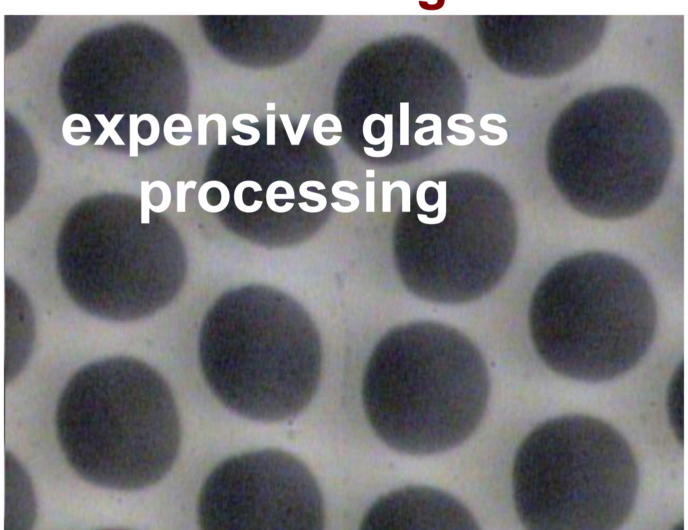
Glass thickness ~1mm
Pore size 10-40μm





Conventional Pb-glass MCP



Incom Inc. glass substrate

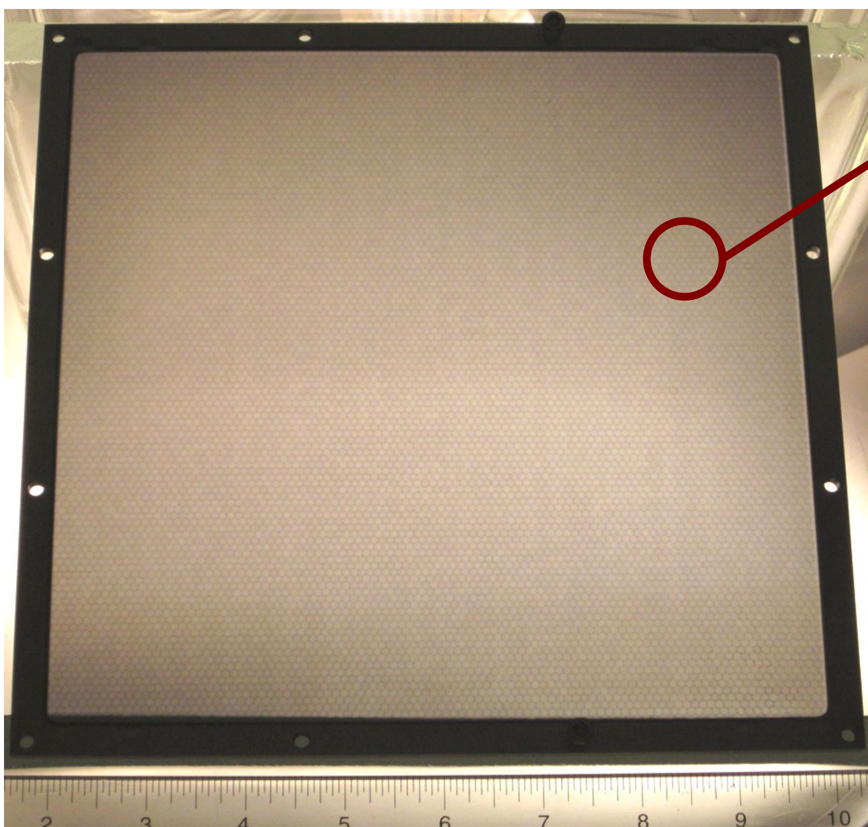
INCOM
Bright Ideas in Fiberoptics

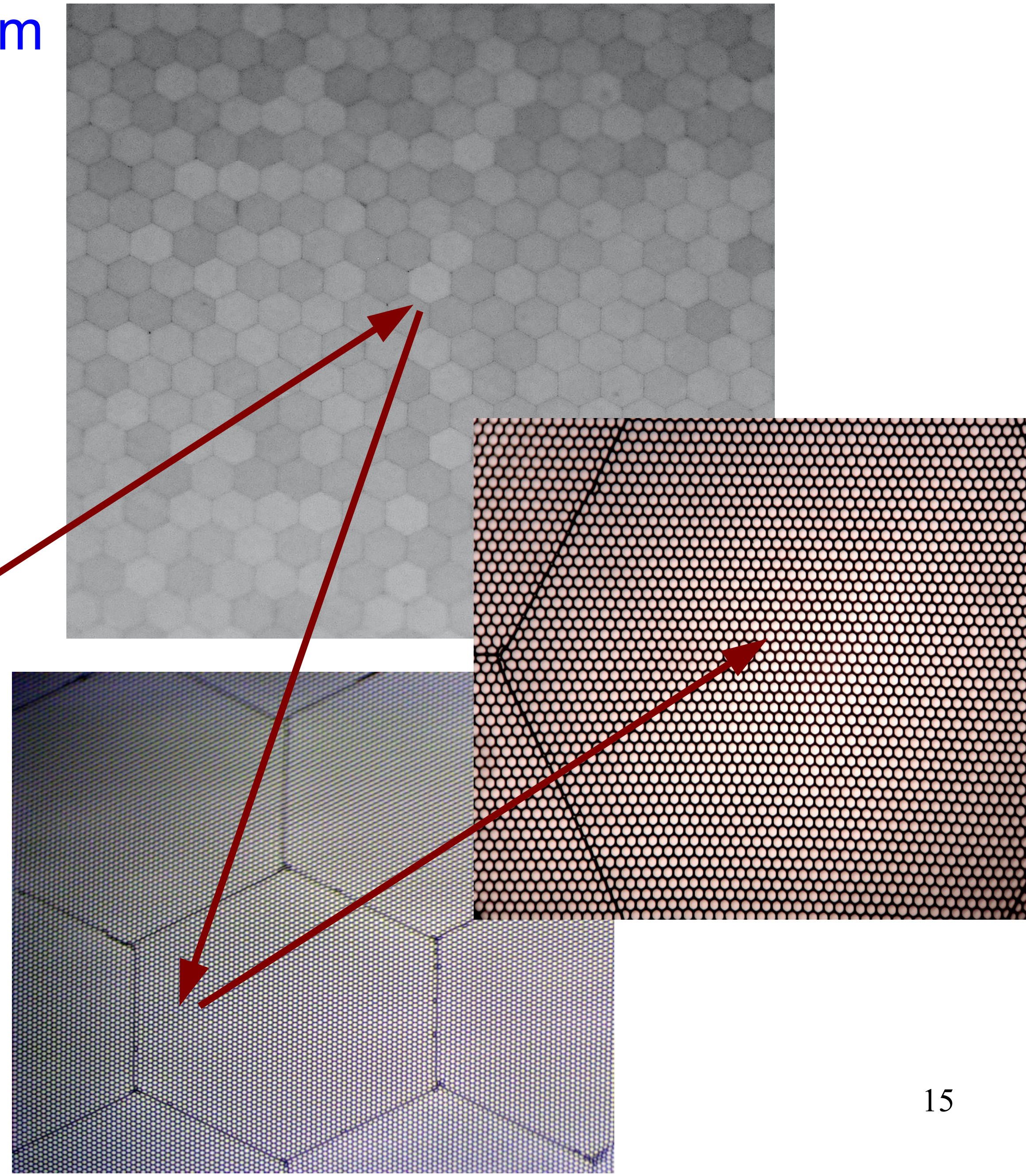
Large-Area MCPs

University of Chicago

Micro-Capillary Arrays by Incom

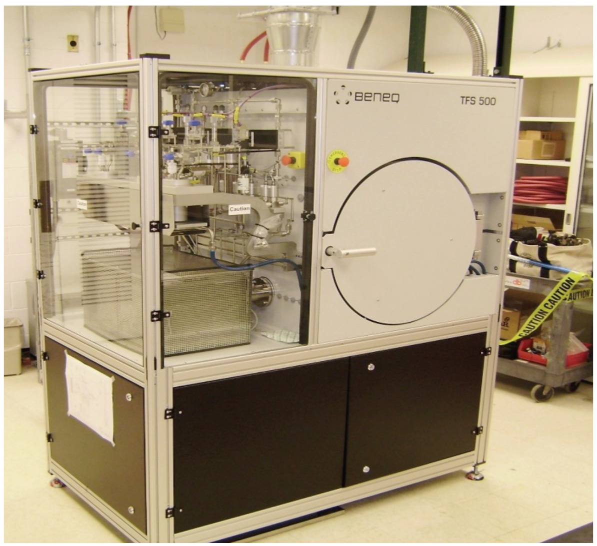
- ***Material:*** ***borosilicate glass***
- ***Area:*** ***$20x20cm^2$***
- ***Thickness:*** ***1.2mm***
- ***Pore size:*** ***20 μm***
- ***L/D ratio:*** ***60:1***
- ***Open area:*** ***65-83%***



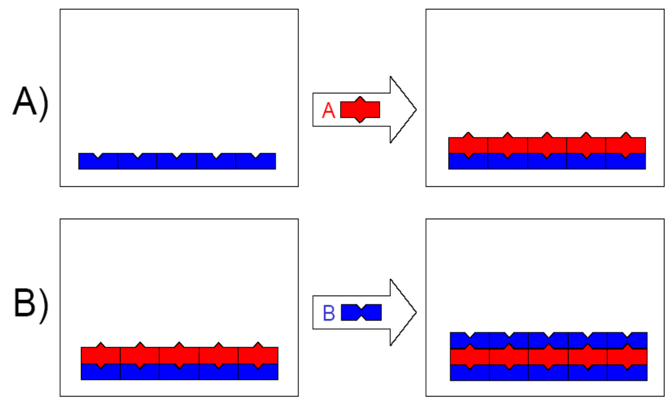


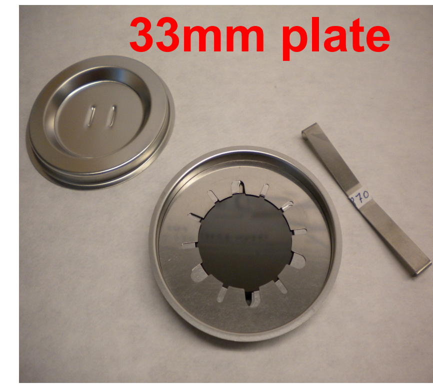
MCP by Atomic Layer Deposition (ALD)

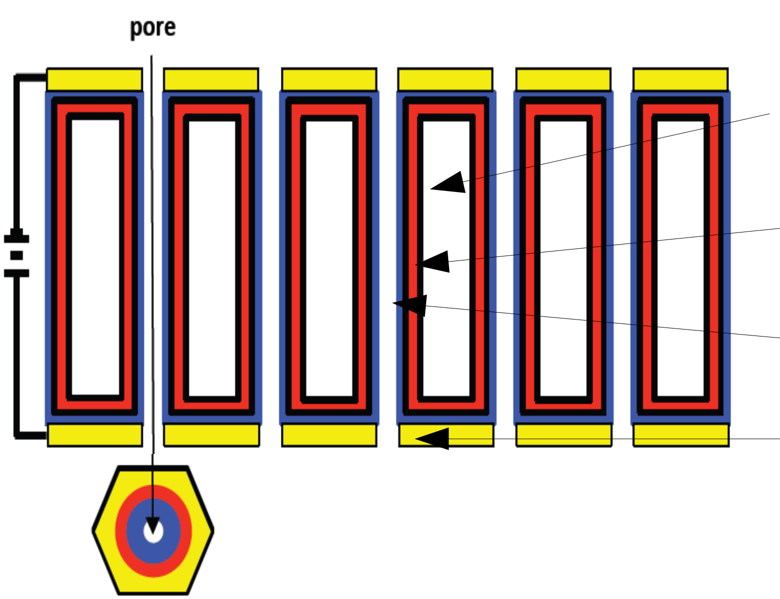
Beneq reactor for ALD @Argonne National Laboratory



ALD Process for MCP Coating Developed by A.Mane, J.Elam





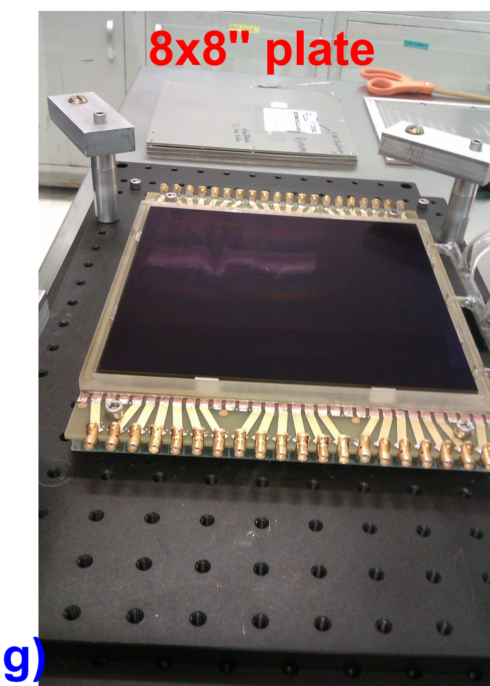


Porous glass

Resistive coating ~100nm (ALD)

Emissive coating ~ 20nm (ALD)

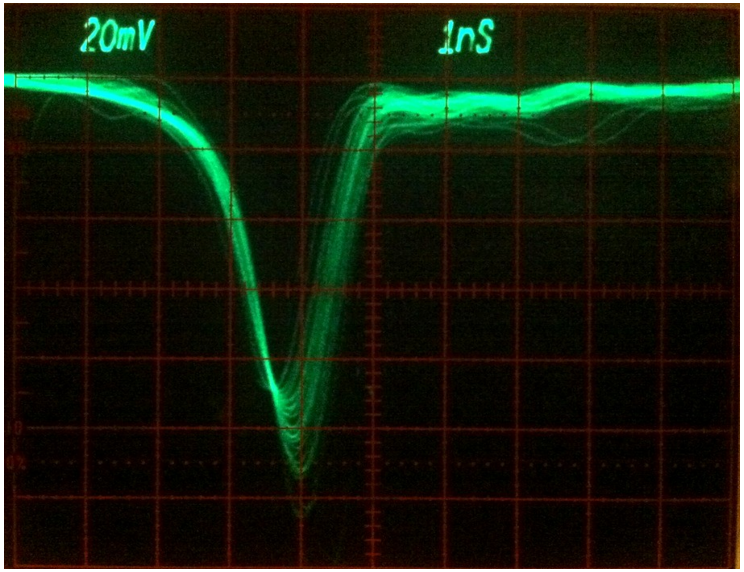
Conductive coating (thermal evaporation or sputtering)

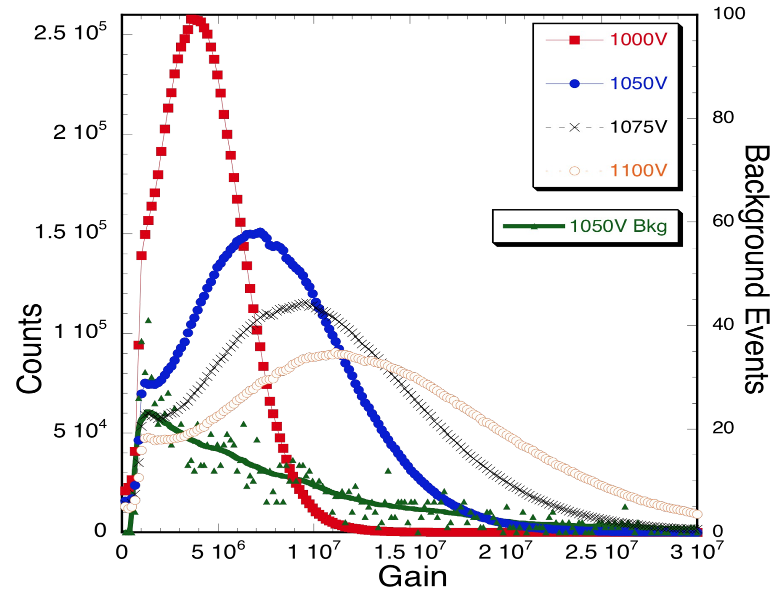


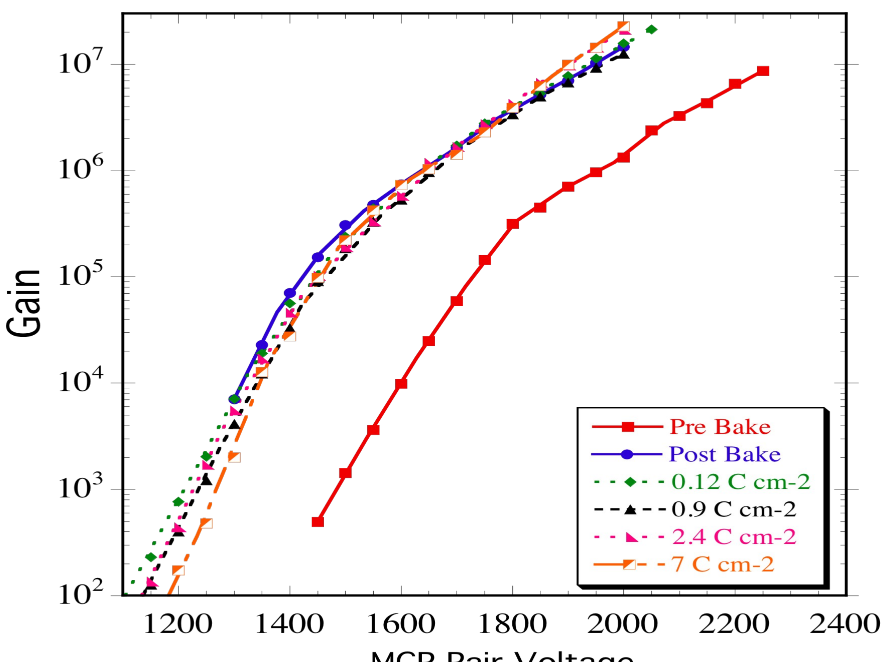
33mm ALD-MCP Performance

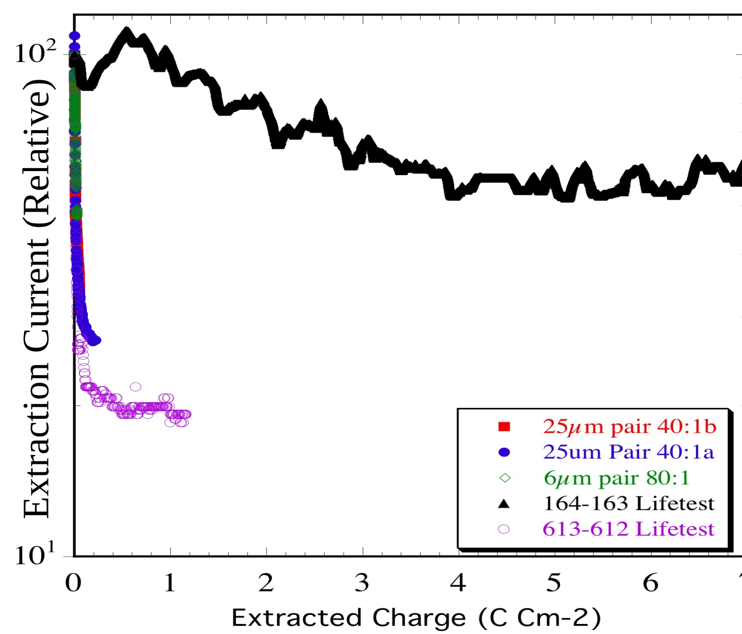
University of Chicago

Measurements by J.McPhate and O.Seigmund





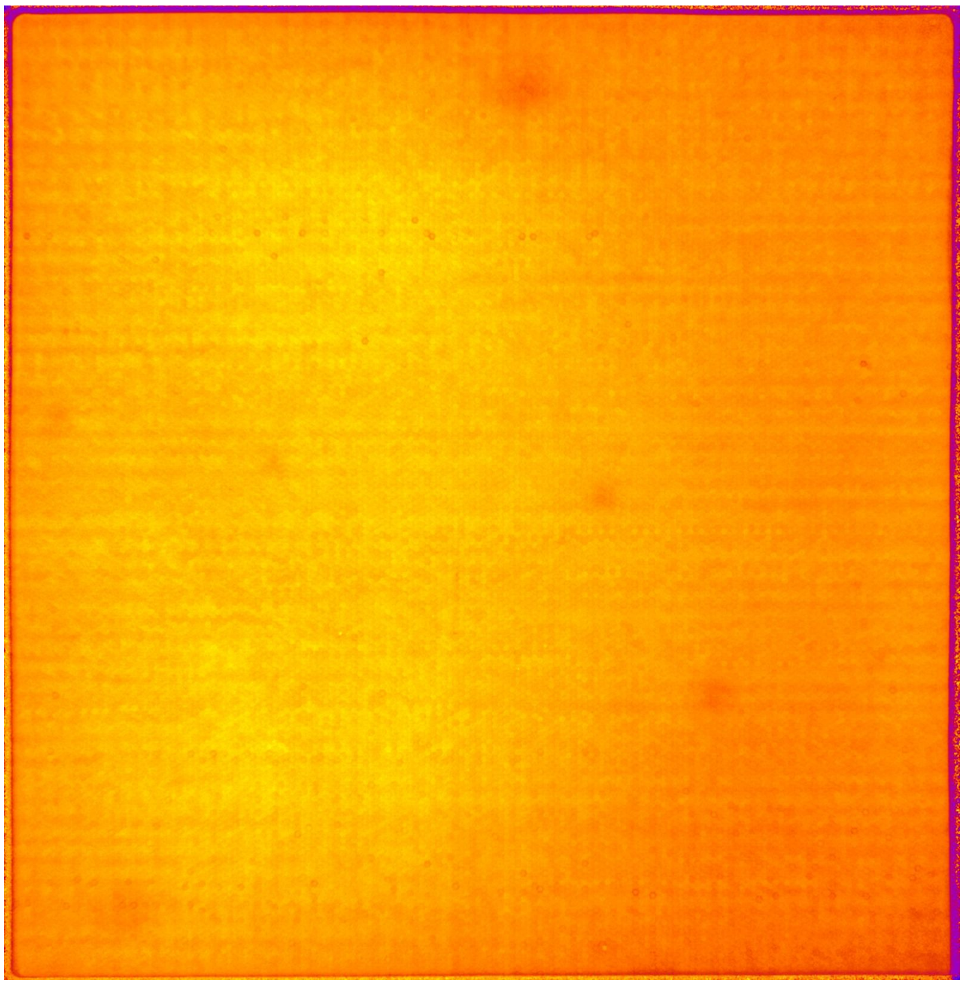


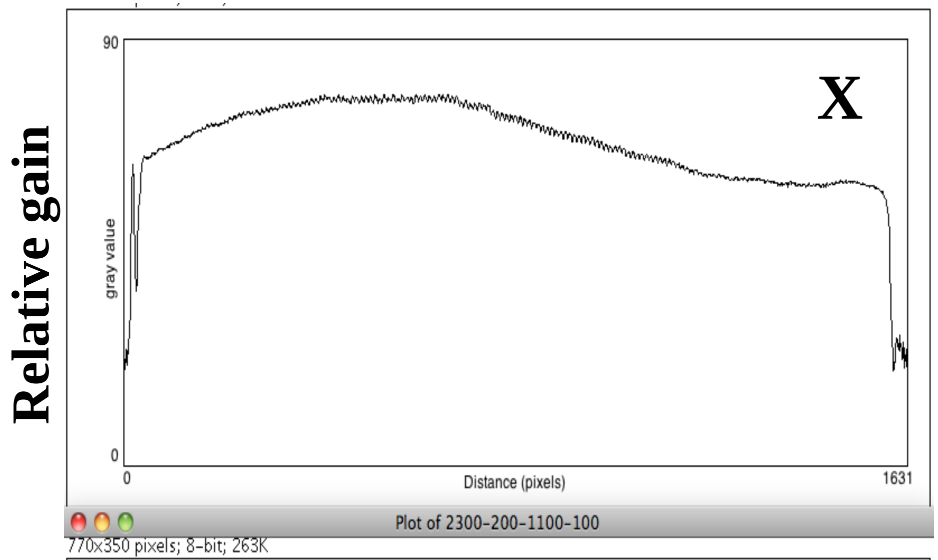


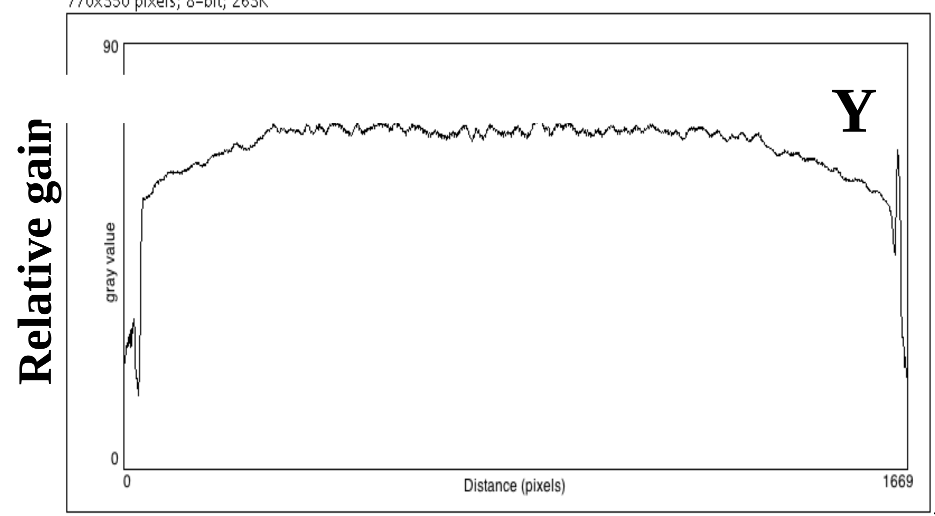
8x8" ALD-MCP Gain Uniformity

Measurements by J.McPhate and O.Seigmund

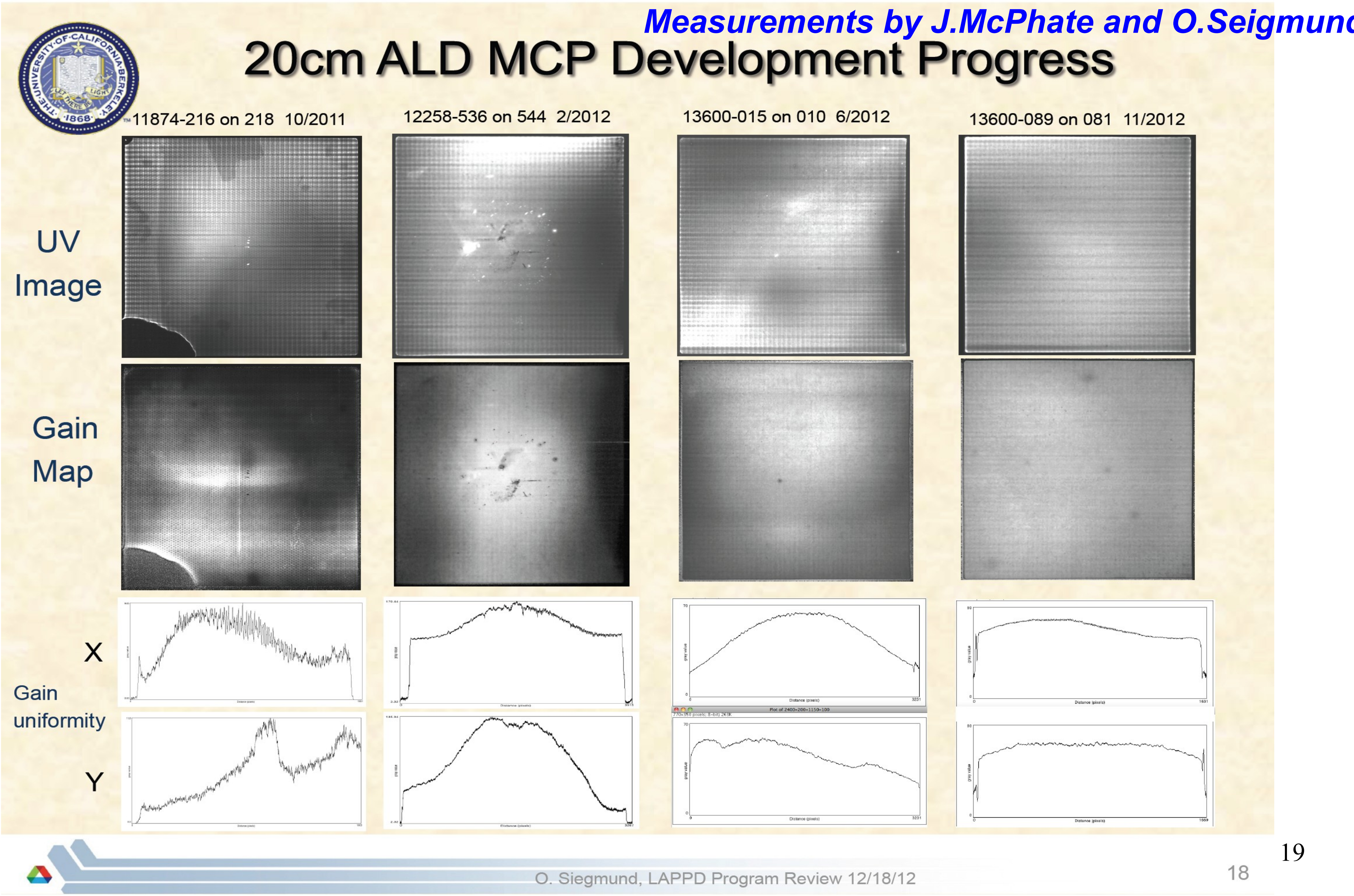
8” MCP pair average gain map image



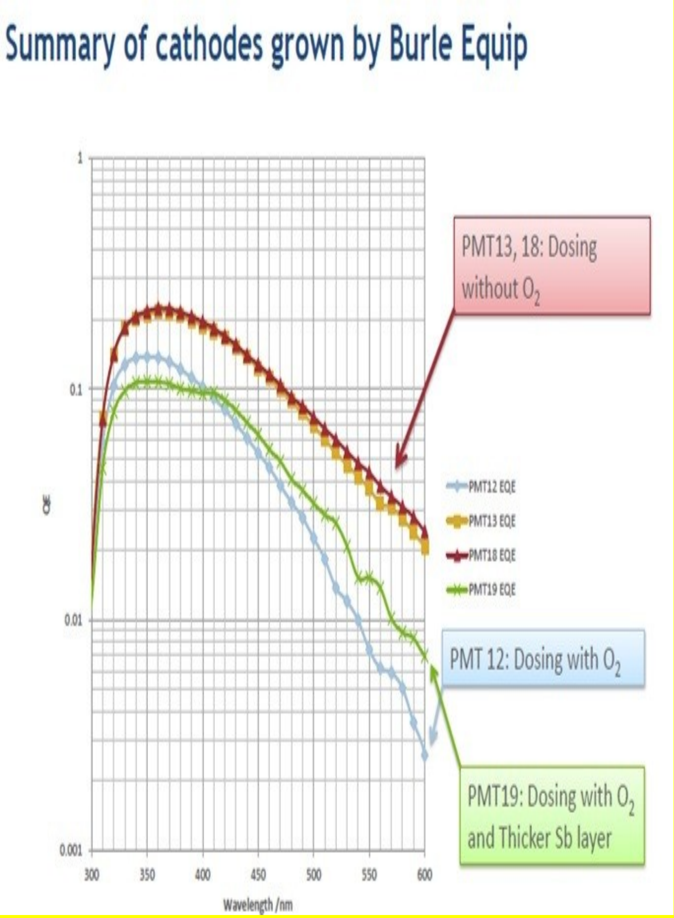




8x8" ALD-MCP Gain Uniformity



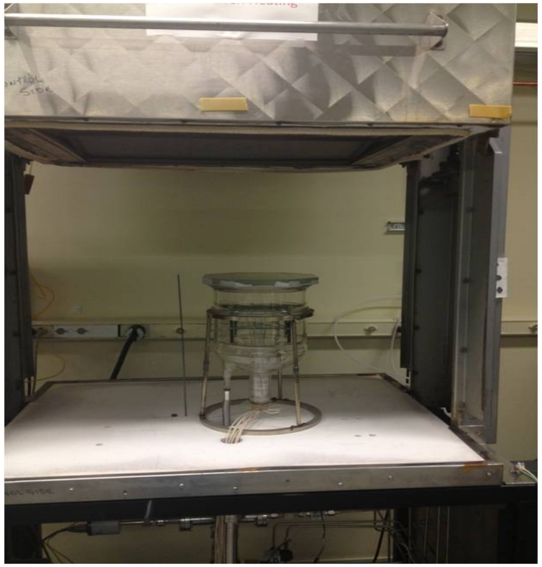
Photocathodes

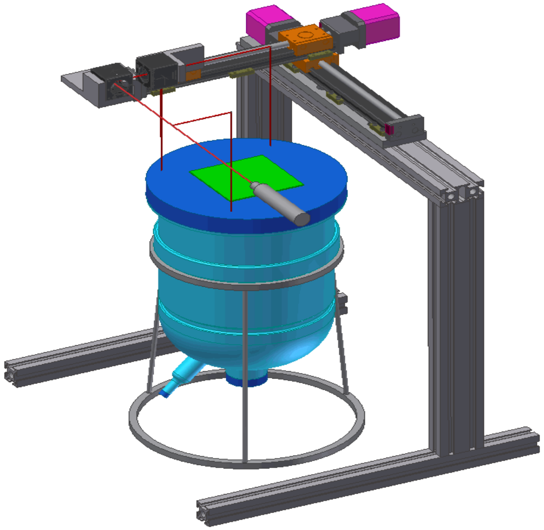


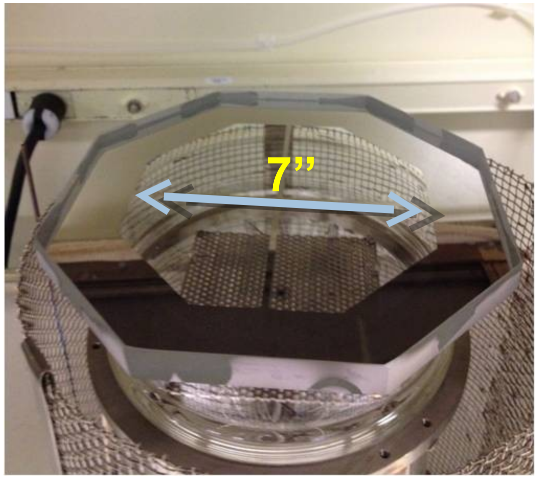
Photocathodes at ANL

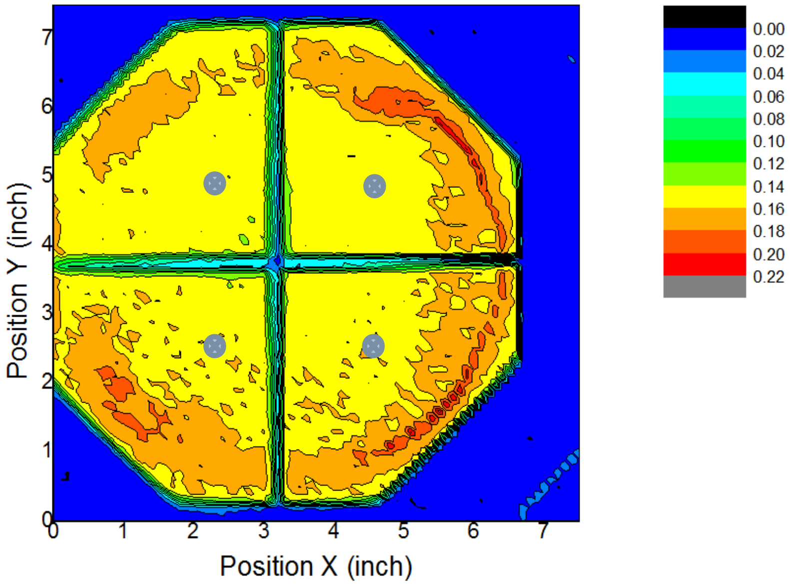
K_2CsSb

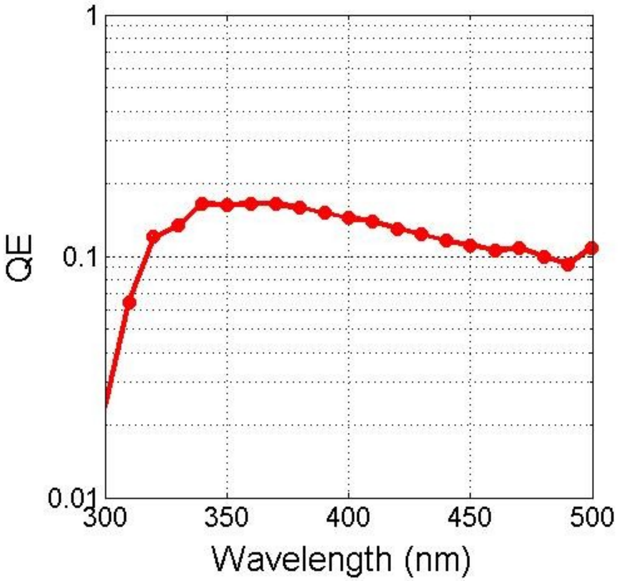
R.Wagner, J.Xie, et.al
with K.Attenkofer @BNL







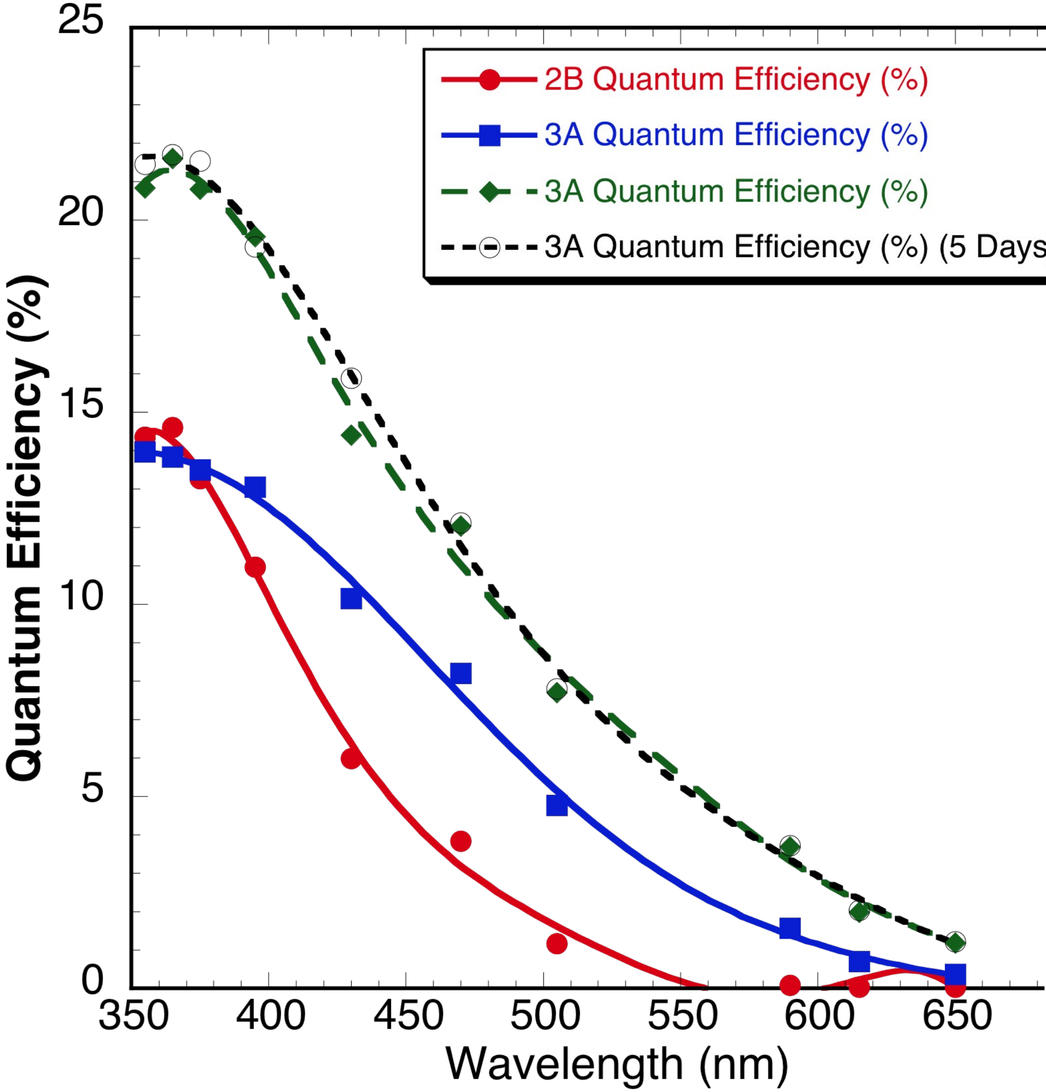


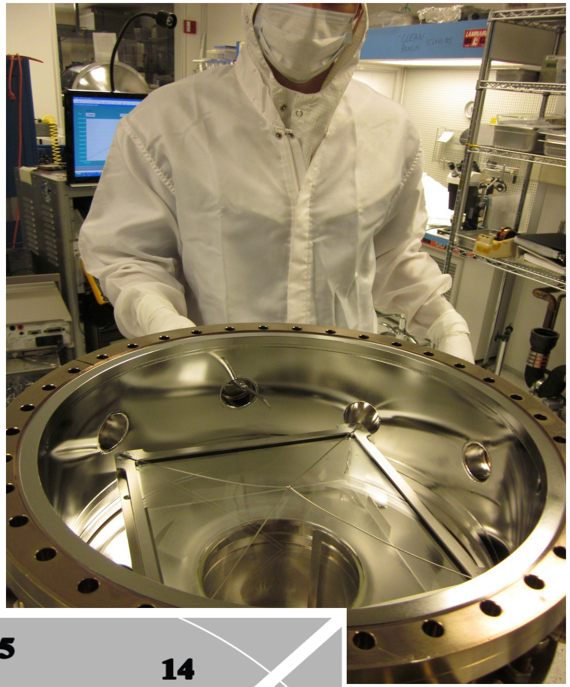


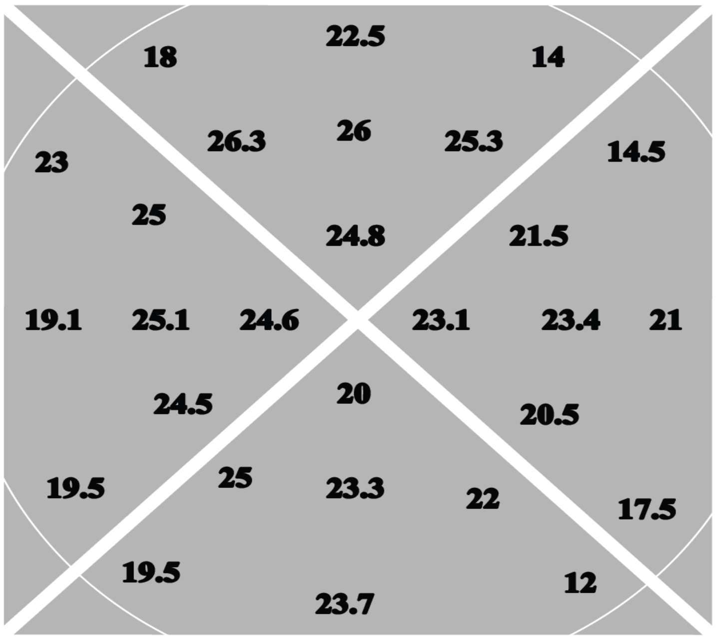
Photocathodes at SSL

Na_2KSb

J.McPhate, O.Seigmund







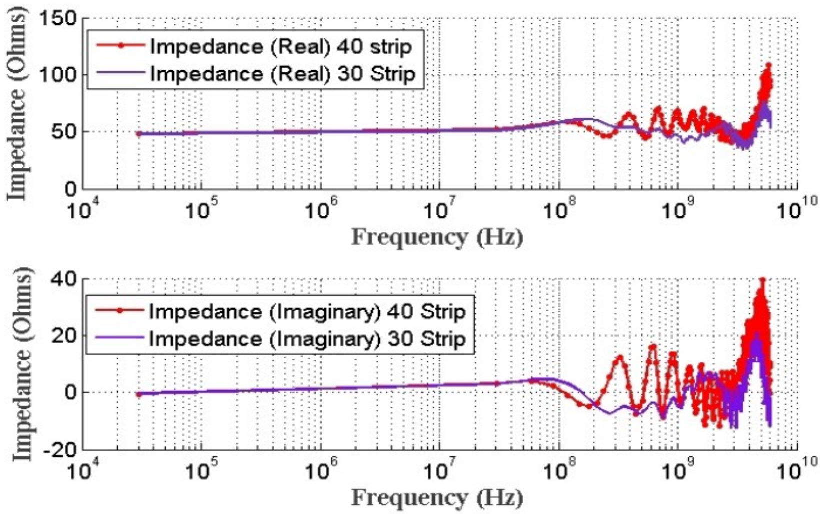
RF Strip Line Anode

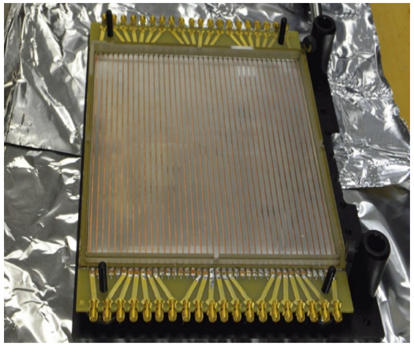
H.Grabas, R.Obaid, E.Oberla, H.Frisch J.F.Genat

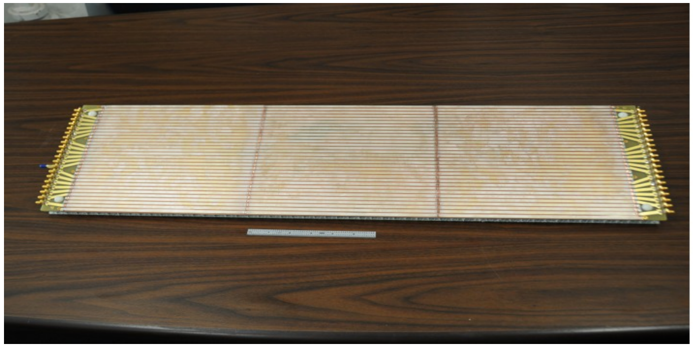
NIMA 711, (2013) 124-131

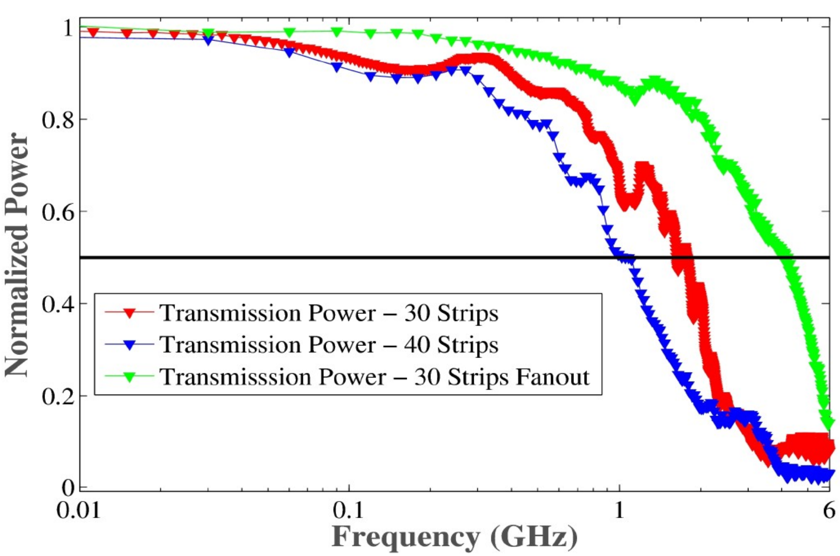
A.Axtell, P.Jaynes

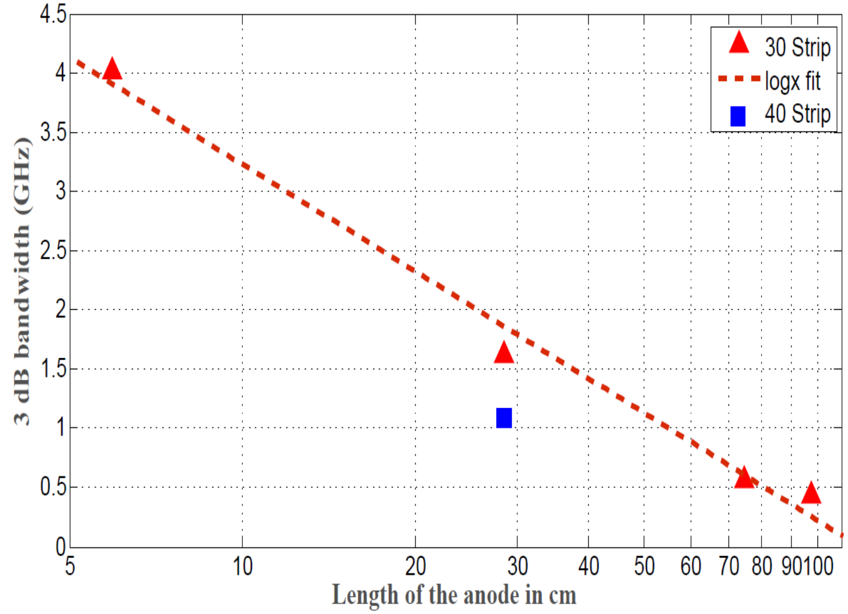
- *Silk-screened silver on inexpensive glass*
- *50 Ω impedance*
- *1.6-0.4GHz bandwidth*





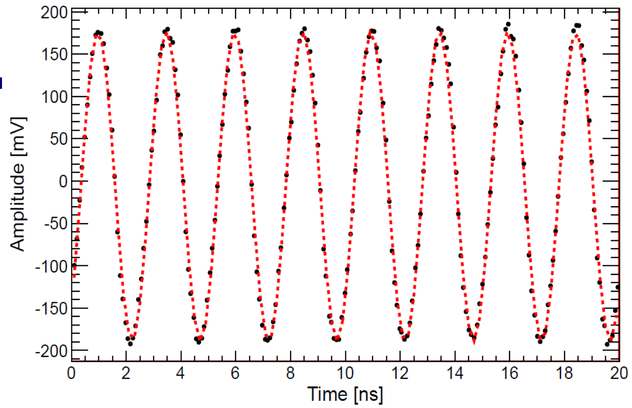






Scope-on-a-chip

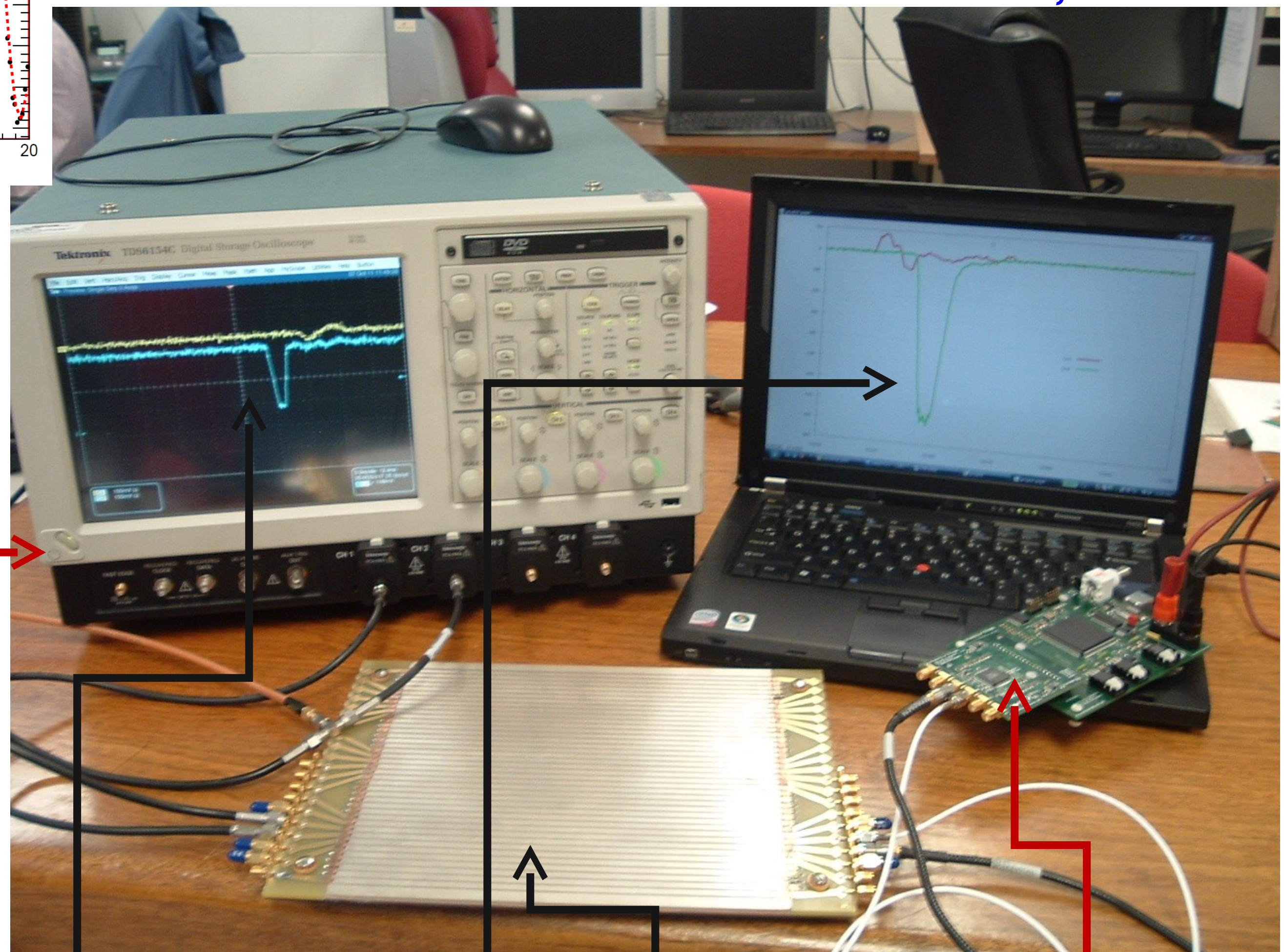
University of Chicago



NIMA 735, (2014) 452-461

E.Oberla, J.-F. Genat, H. Frisch, K.Nishimura, G.Varner

Designed by Eric Oberla (UC grad student)



Real digitized traces from anode

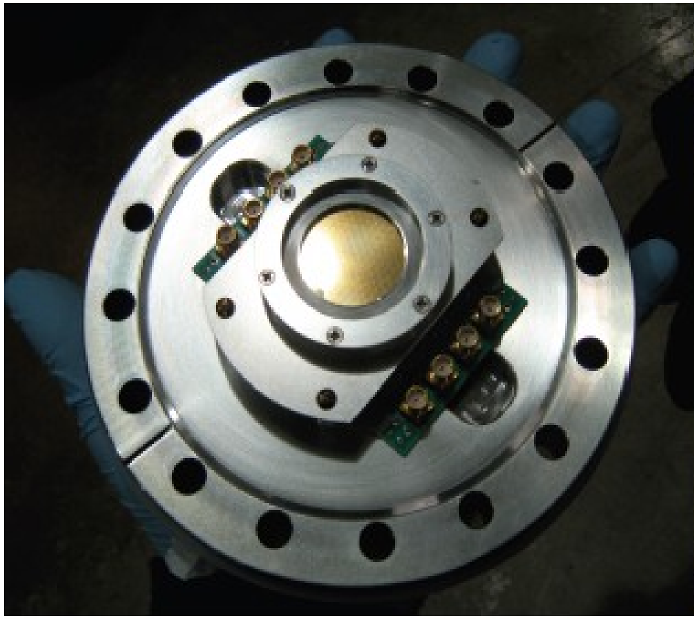
20 GS/scope
4-channels (142K$)

17 GS/PSEC-4 chip
6-channels (\$130 ?!)

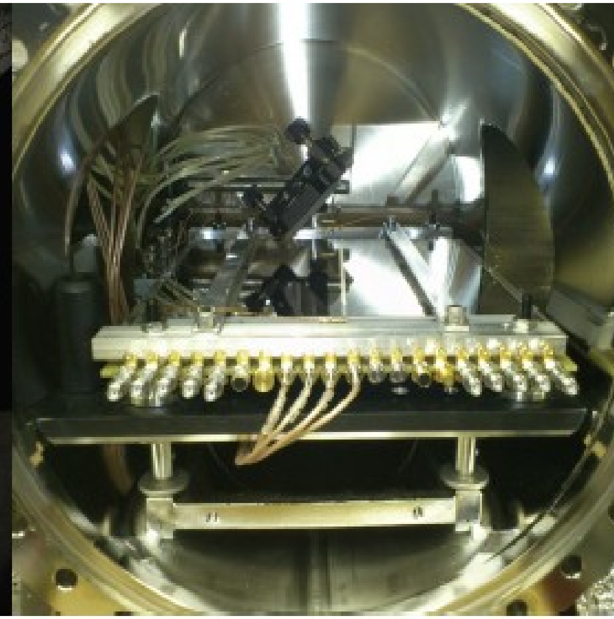
24

System Integration and Testing

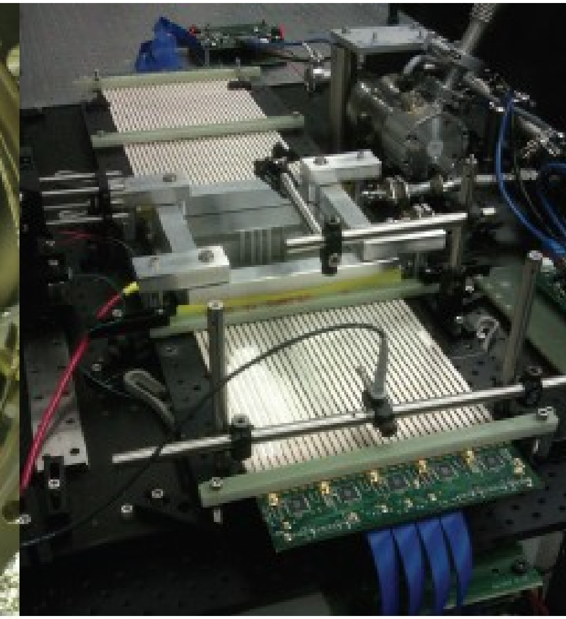
B.Adams, A.E., E.Oberla, R.Obaid, A.Vostrikov, M.Wetstein



33mm Testing



8" Testing



Complete detector systems

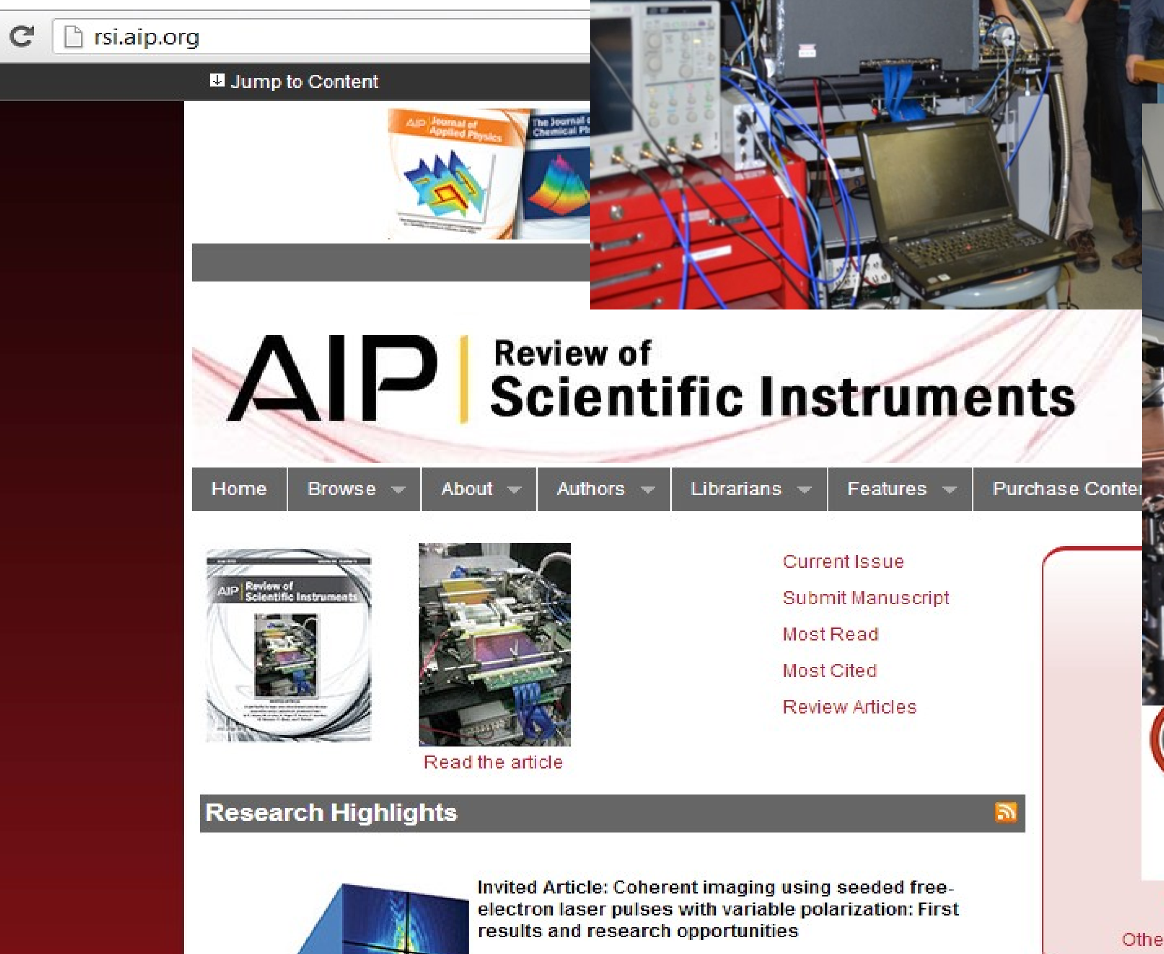
- Operational experience
- Testing fundamental properties of MCPs
- Study wide variety of sample prototypes

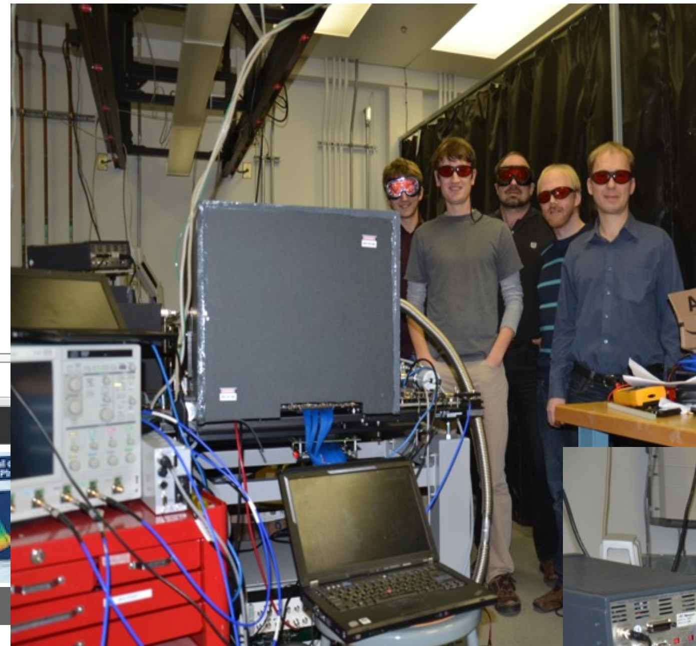
- Demonstrate working 8" MCPs
- Test near complete detector systems with realistic anode
- Optimize and measure key resolutions

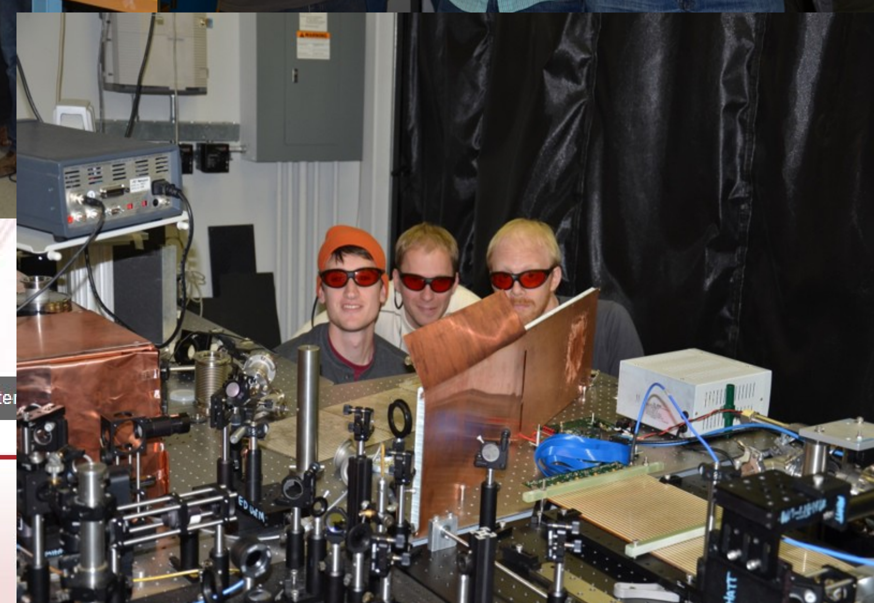
- Demonstrate complete sealed-tube detector
- Study characteristics of 80cm anode
- Test integrated front-end electronics in fully operational conditions

RSI Invited Article

Rev. Sci. Instrum. 84, 061301 (2013)

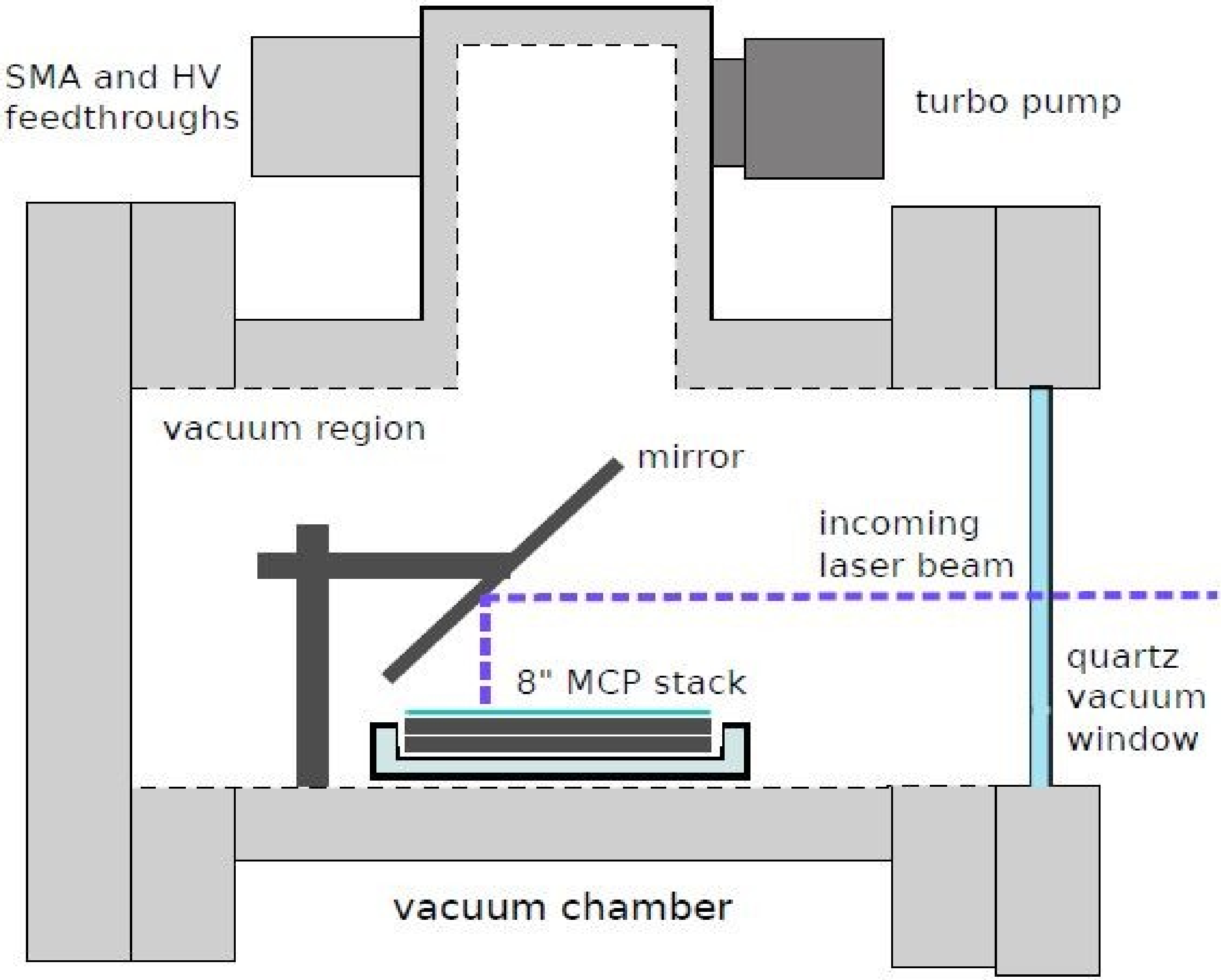




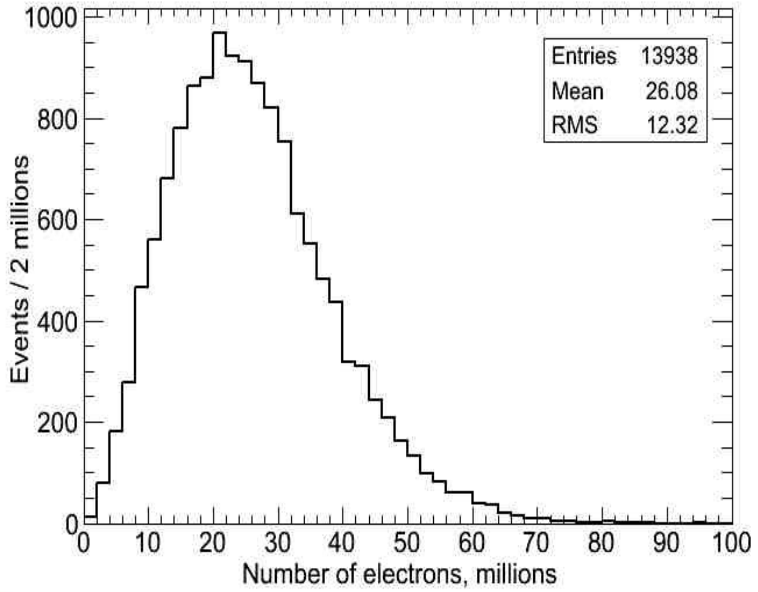


8" MCP Testing Chamber

University of Chicago



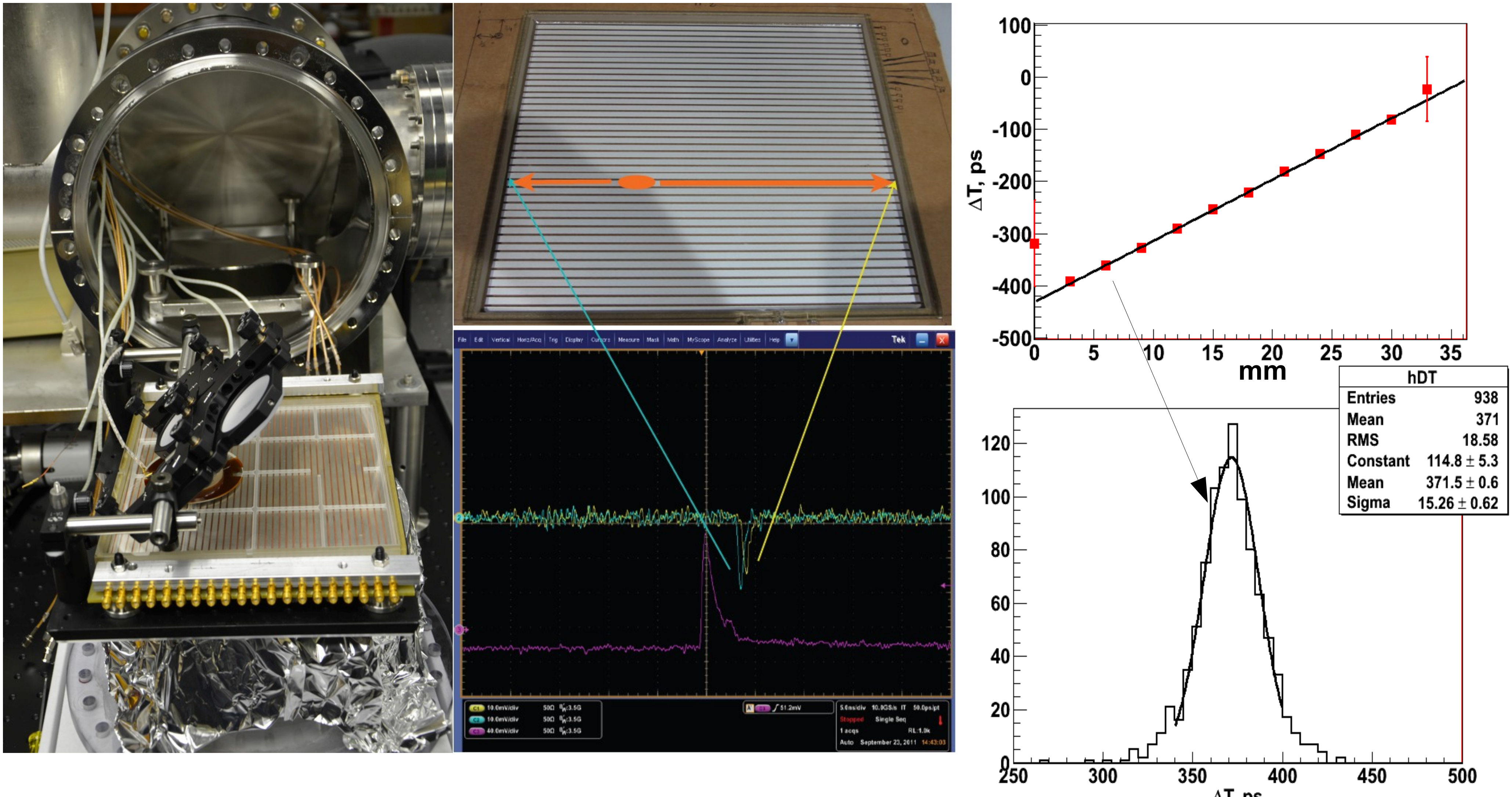
pulse height distribution



Gain $2x10^7$

8" MCP in Action

University of Chicago



Slope ~10ps/mm corresponds to ~2/3 c signal propagation speed along the anode stripline

ΔT = 15ps → ΔX = 1/2 ΔT 2/3c = 1.5mm

Differential Time Resolution

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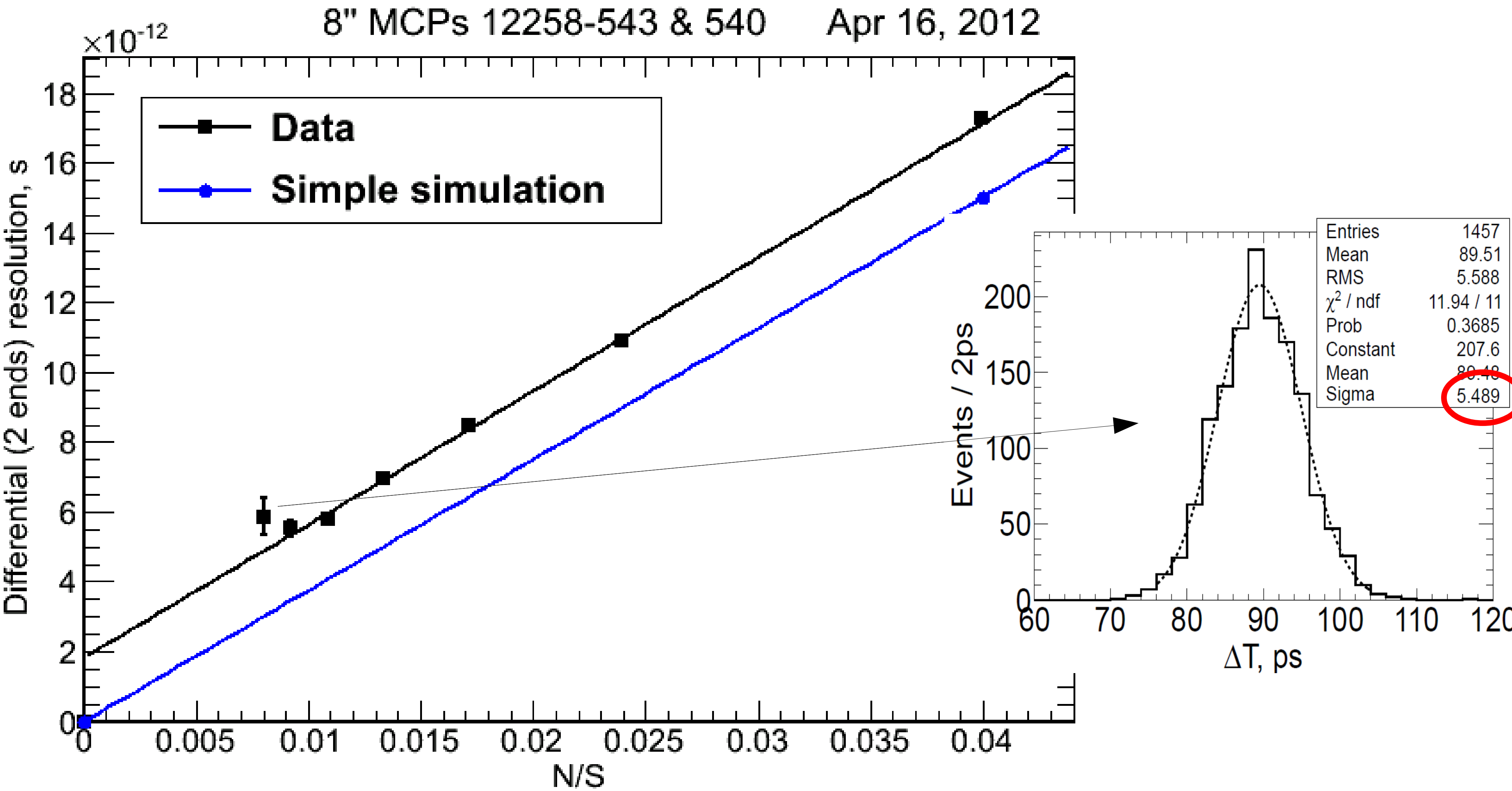
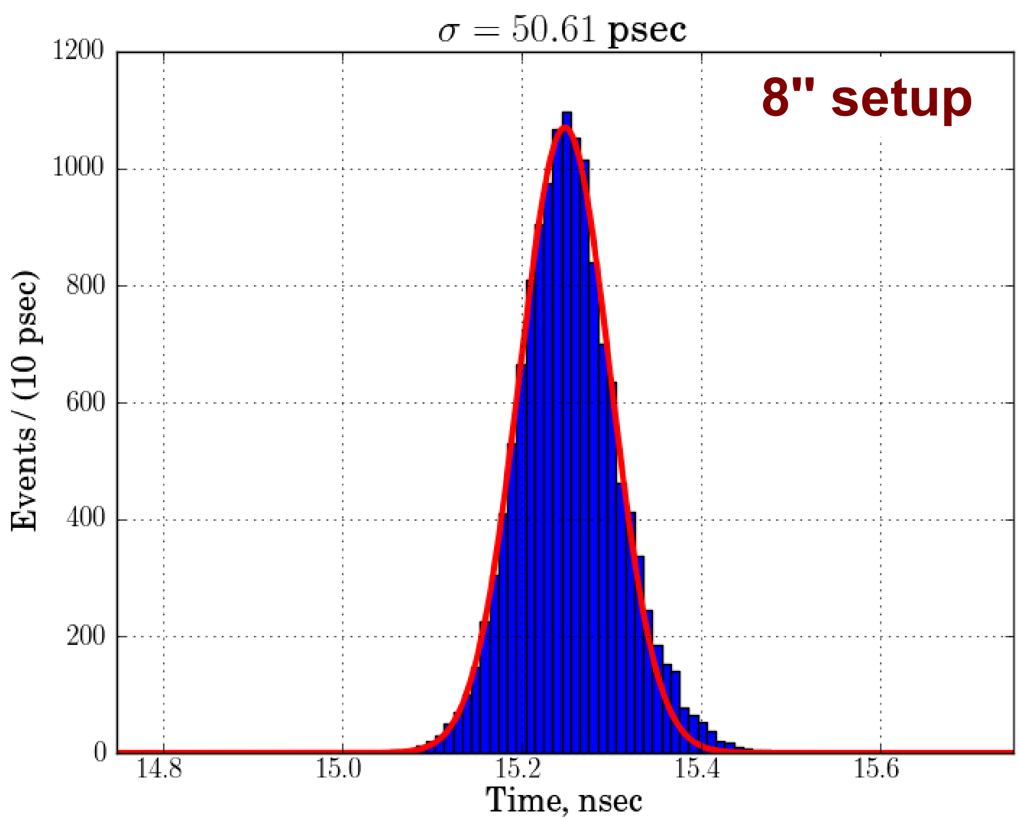
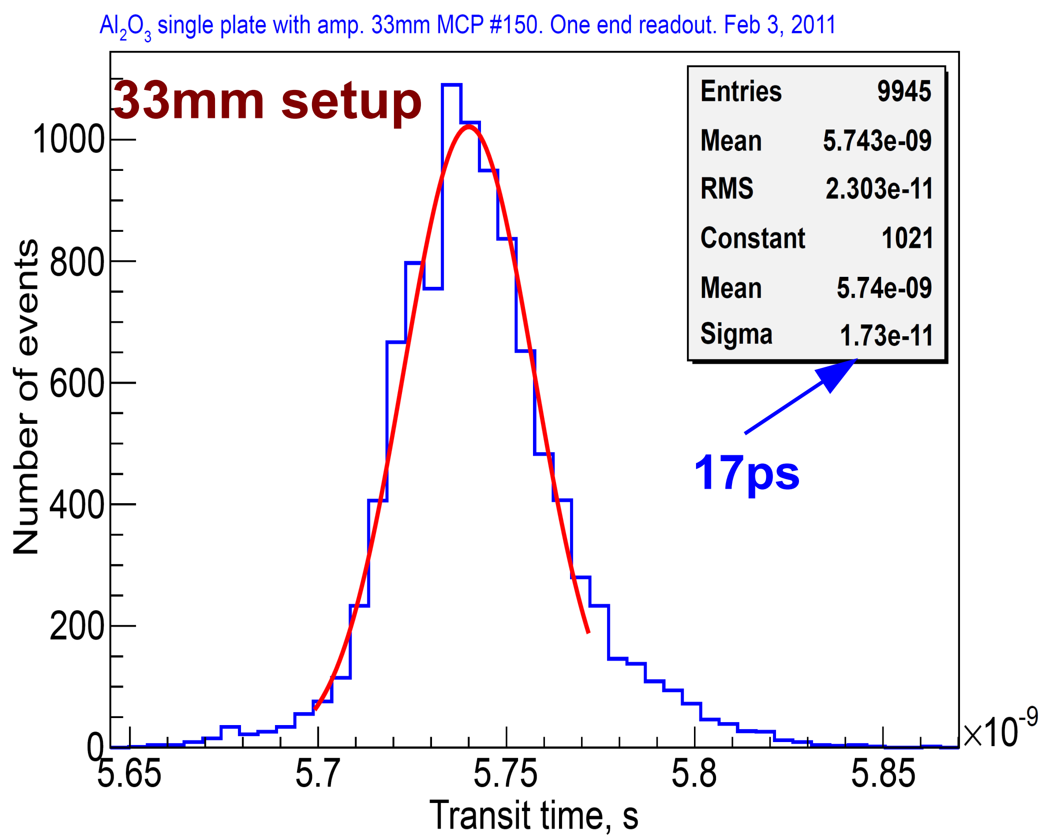


~5 ps in ΔT → ~0.5 mm in ΔX

NIMA: http://dx.doi.org/10.1016/j.nima.2013.07.091

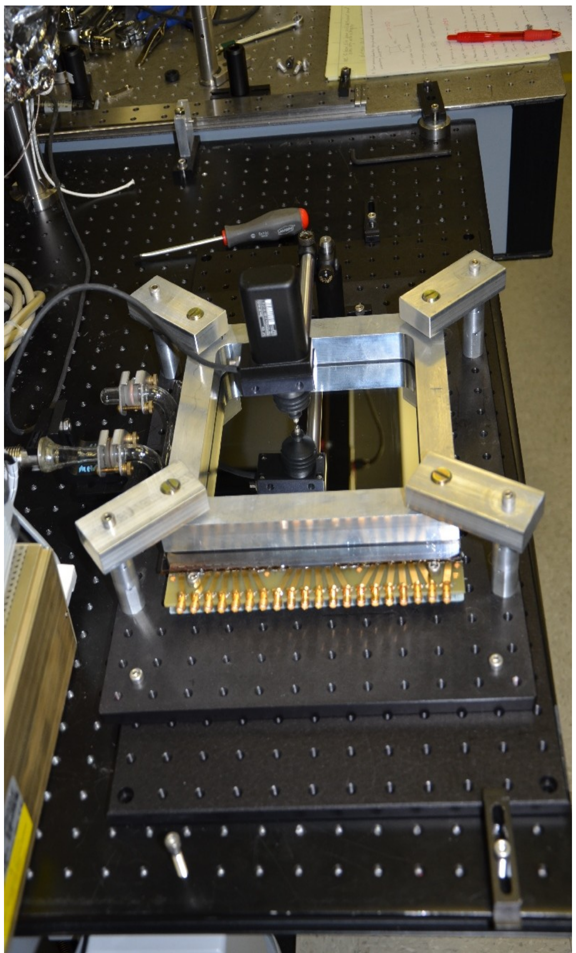
Time-of-Flight Resolution



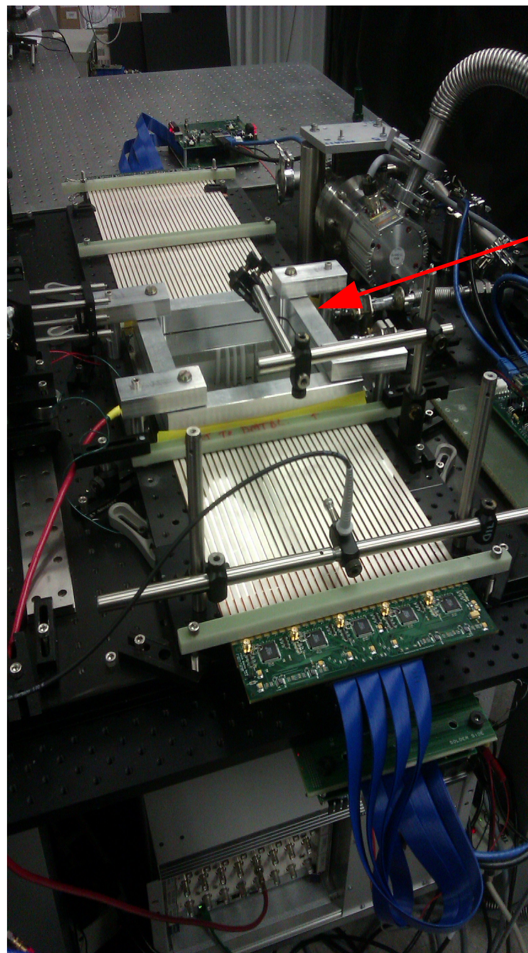


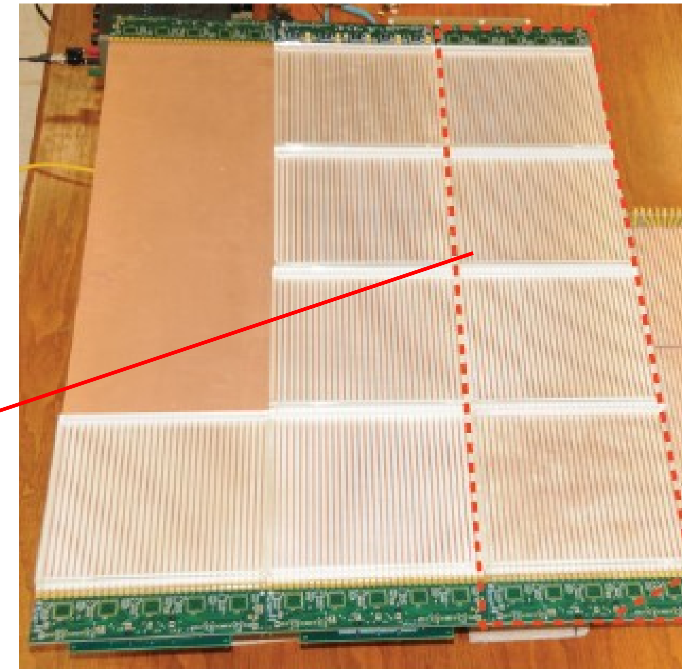
System Integration: "Demountable"

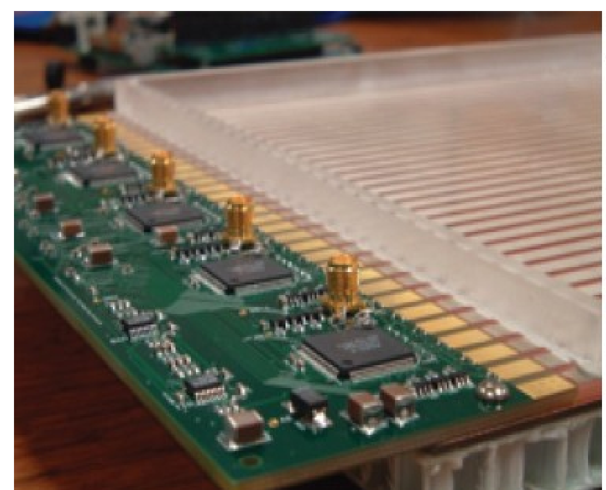
Demountable 1.0
(May 2012)

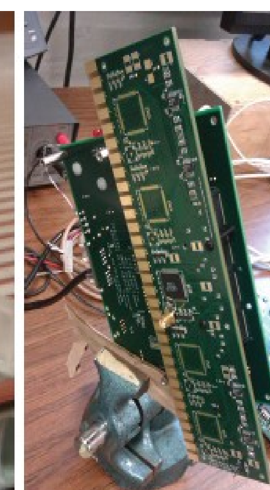


Demountable 3.0
(Sep-Dec 2012)





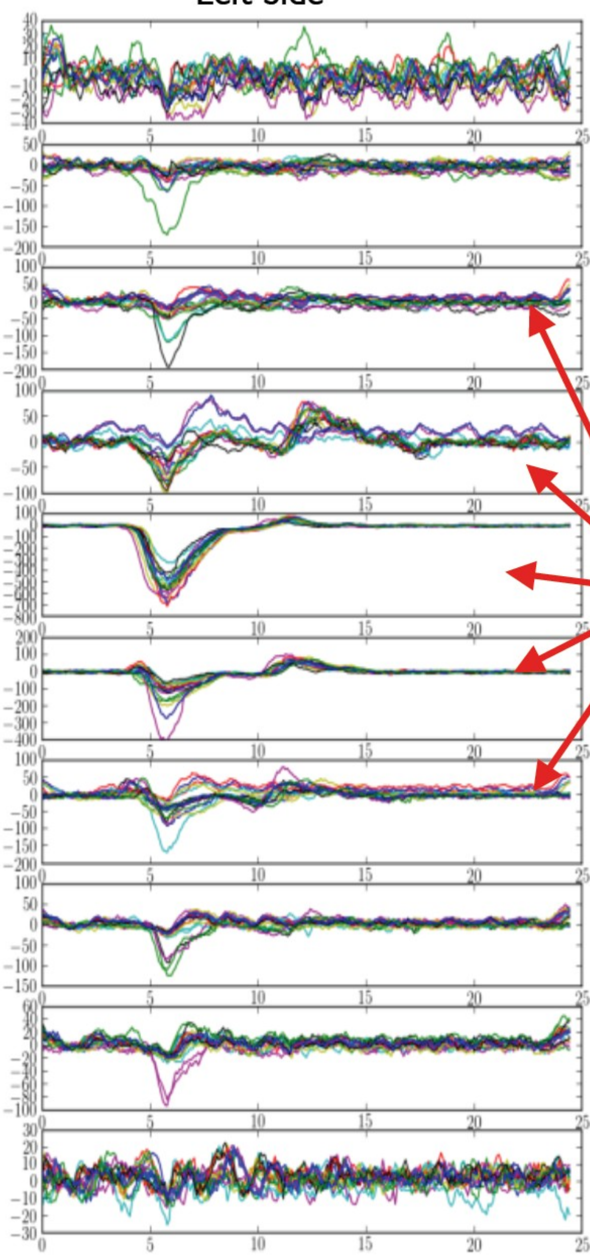




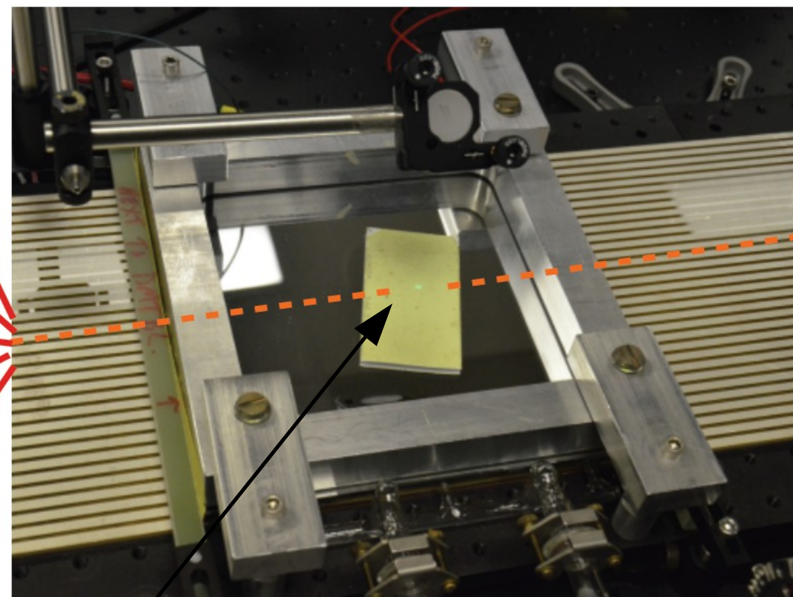
Position Reconstruction

Pulses on 10 striplines

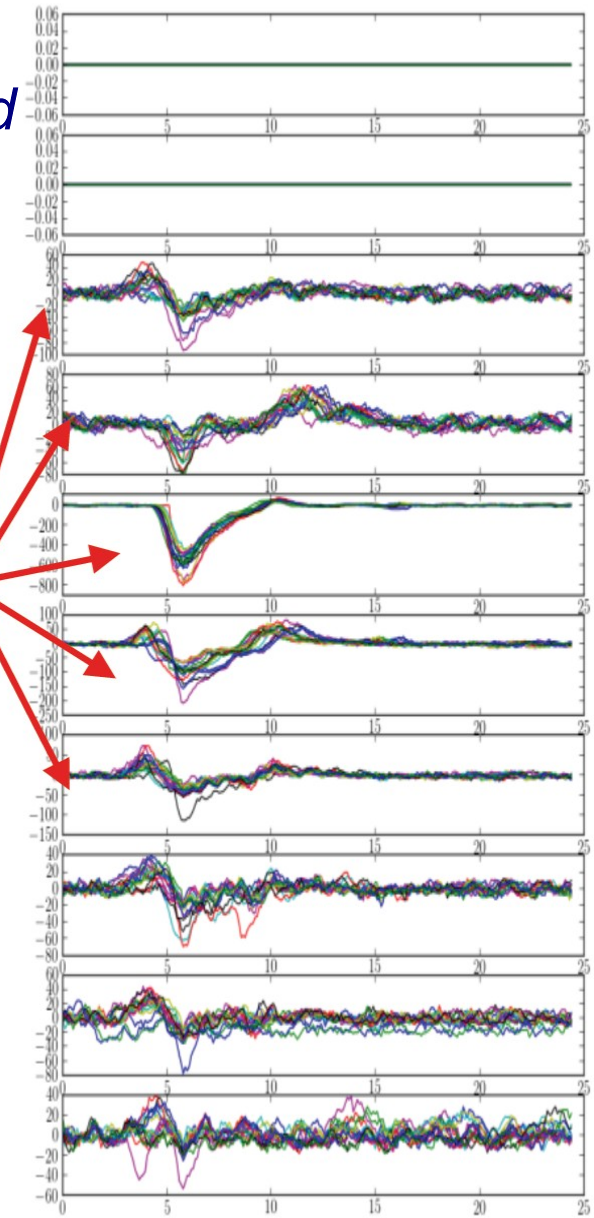
Left Side



Transverse position is determined by centroid of integrated signal on a cluster of striplines



Laser beam spot



Right Side

Pulses on 10 striplines

Spatial resolution across the striplines **~0.7mm**

Position Reconstruction

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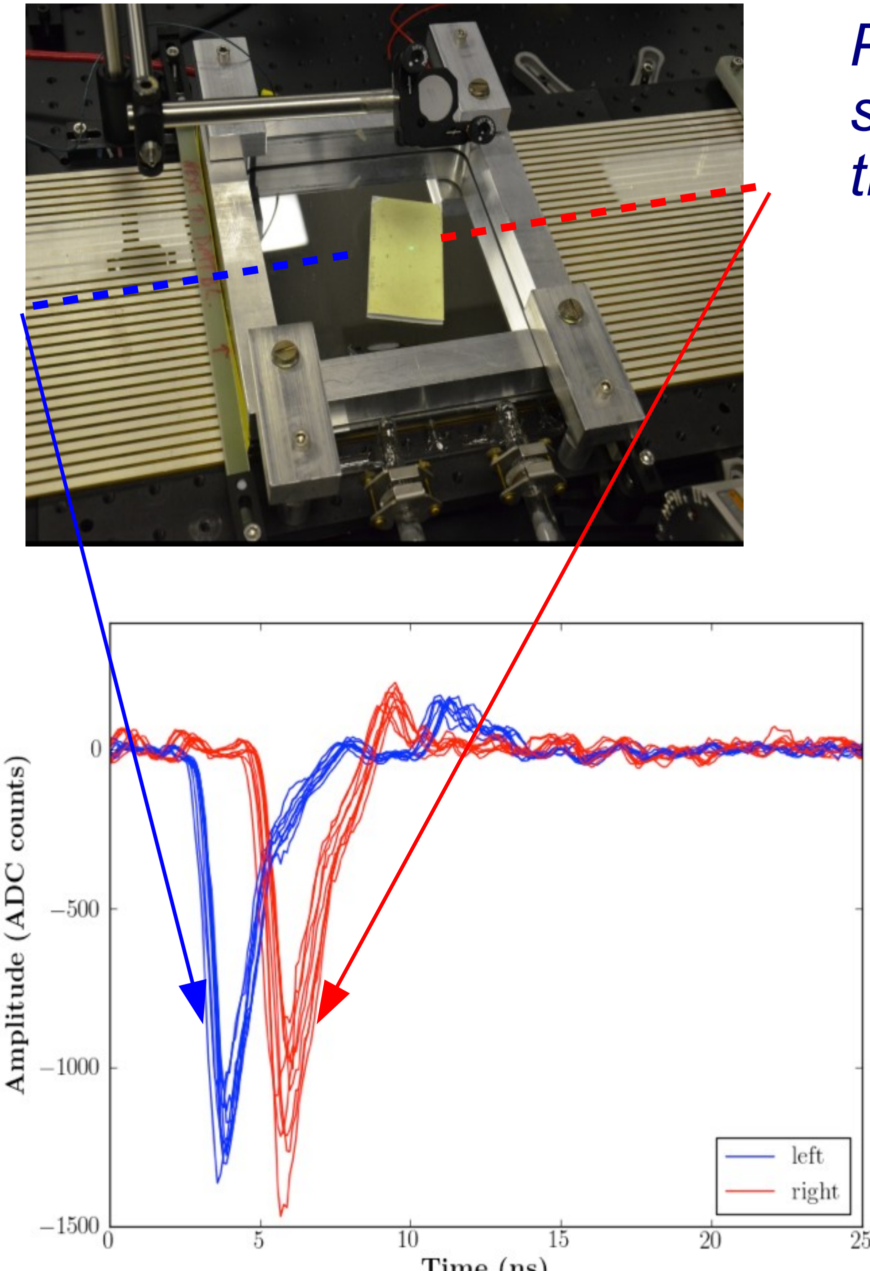
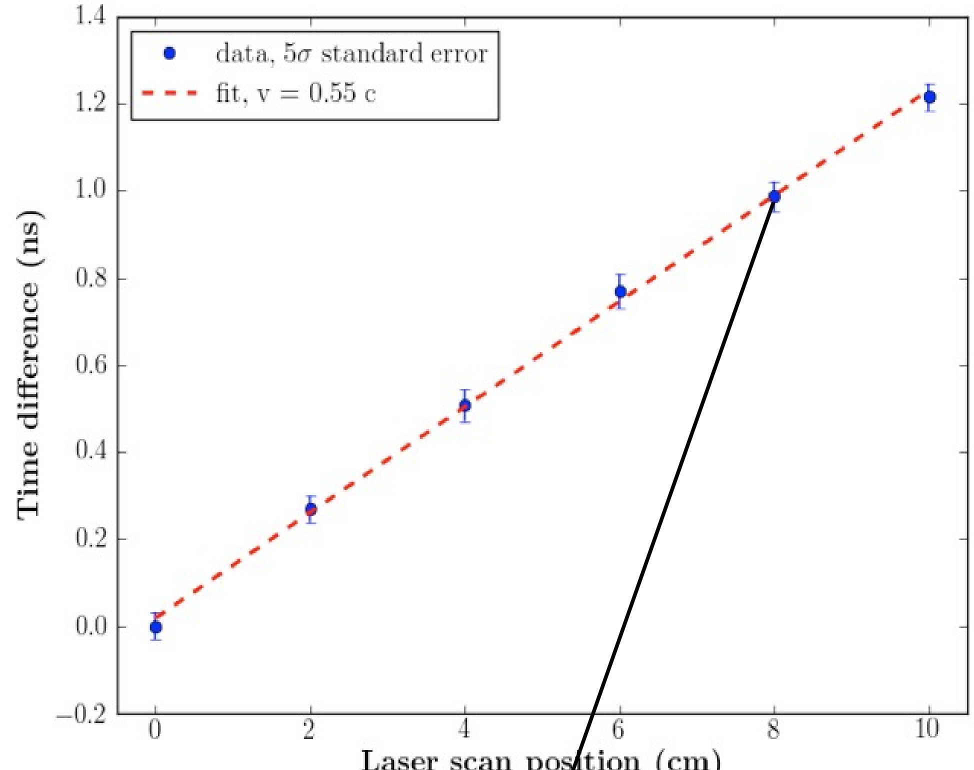
Position in the direction parallel to the striplines is determined by differential transit time to the opposite ends of the anode





4 tiles (90-cm anode): ΔT=~18ps → **ΔX=~1.8mm**

1 tile (20-cm anode): ΔT=~5ps → **ΔX=~0.5mm**

Time-of-Flight Resolution

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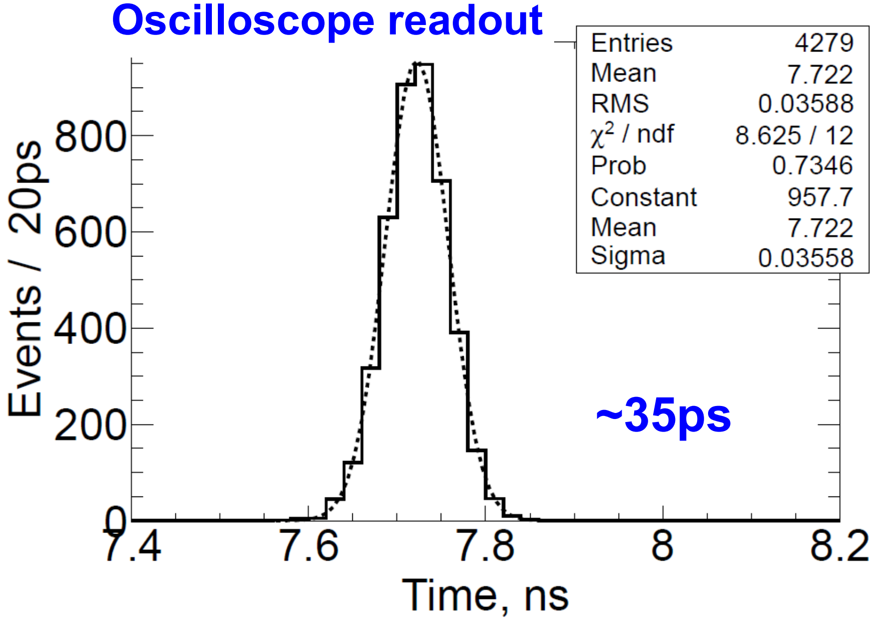
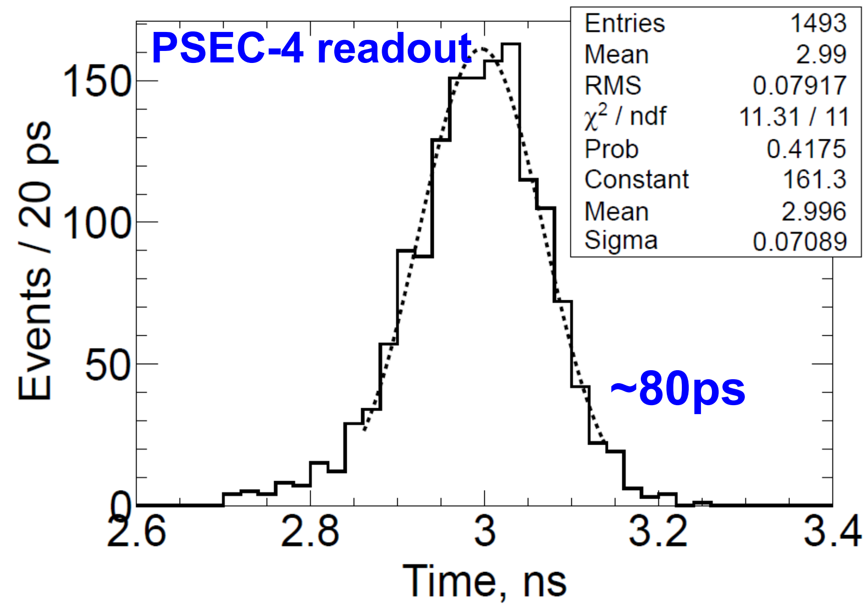
90-cm long anode!

Oscilloscope readout





NIMA: http://dx.doi.org/10.1016/j.nima.2013.07.091

Where do we go from here?

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- Commercialization through industry partners

- Universities and Labs will guide optimization of the detectors design for specific applications
  - ALD development for MCP fabrication
  - Electronics
  - Photo-cathodes

- DOE has been very supportive to the LAPPD project

- DOE awarded Phase I of STTR (Small Tech Transer) grant to Incom Inc. to start work on making LAPPD detectors

Applications

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- *We hope to bring LAPPD detectors into the field relatively soon*

- *We invite people to think what fast timing and large area coverage will do for their experiments*

- *Some examples:*
  - vertexing at CMS (A.Apresyan, M.Spiropulu, et al.)
  - optical tracking for ANNIE (M.Wetstein, et al.)
  - large water cherenkov detectors (M.Sanchez, et al.)

More Applications

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LAPPDs are digital photon counters

- *measure position and time for each individual photon*
- *photons can be tested for their*
  - vertex,
  - propagation history (e.g. scattered vs direct light), and
  - production mechanism (e.g. Cherenkov vs scintillation)

Can fast timing photo-detectors help us to search for neutrino-less double beta decay?

What is 0νββ?

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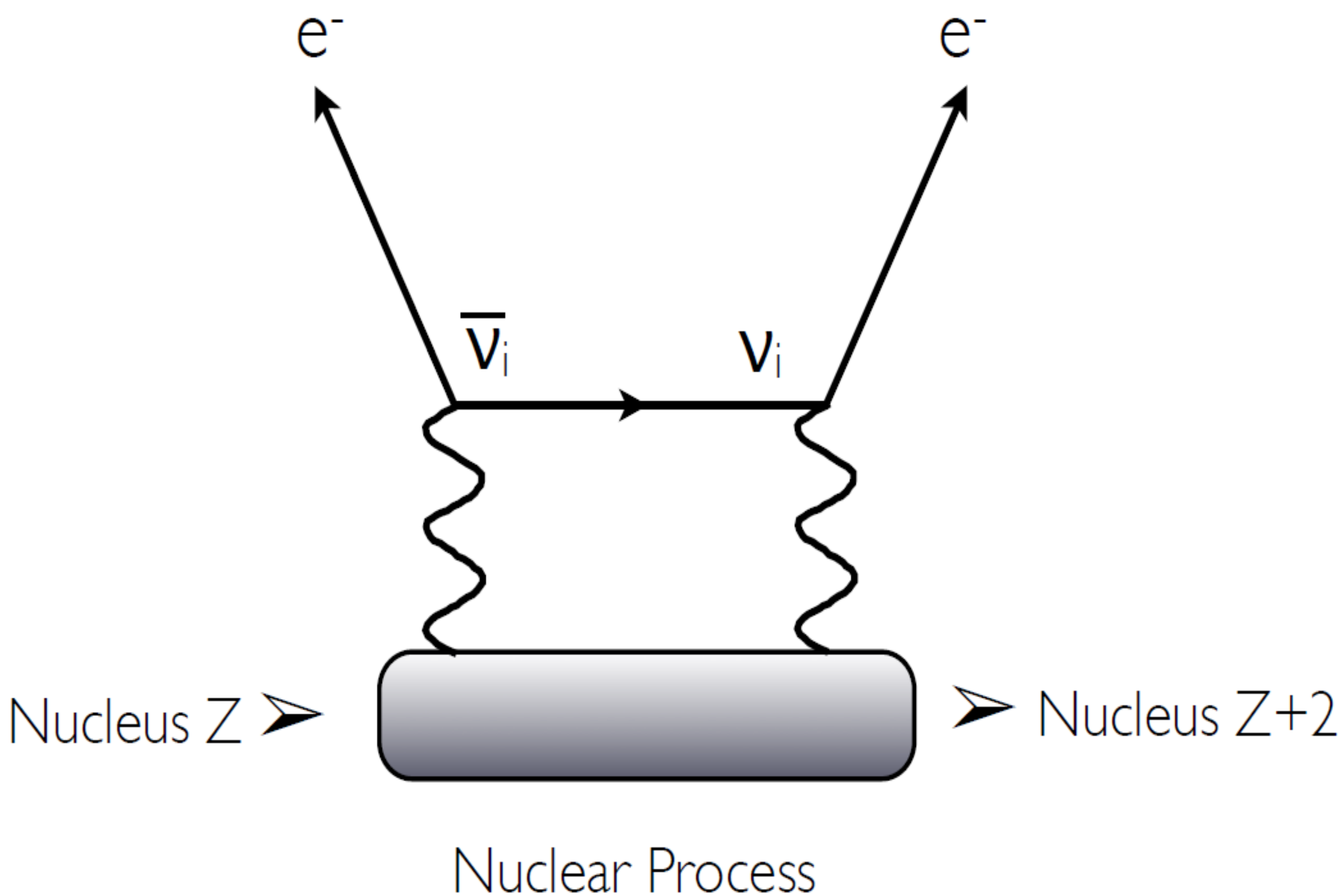
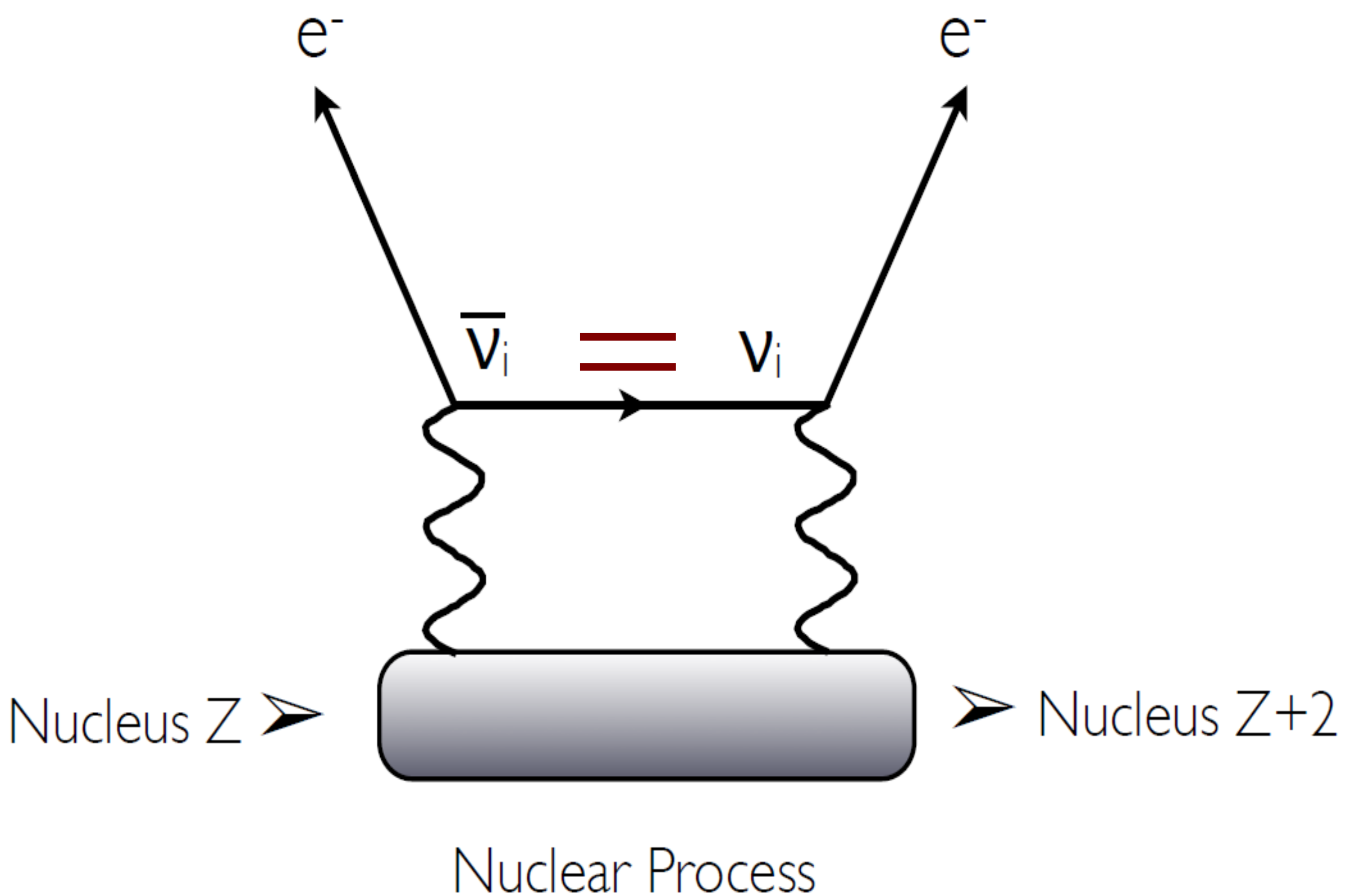


Compare to normal beta decay: $Z \rightarrow (Z+1), e^-, \bar{\nu}_e$

Why is it interesting?



If observed, neutrino is a Majorana particle, i.e. own antiparticle.

Signature: two electrons with well defined total kinetic energy (2-4 MeV)

What are the challenges?

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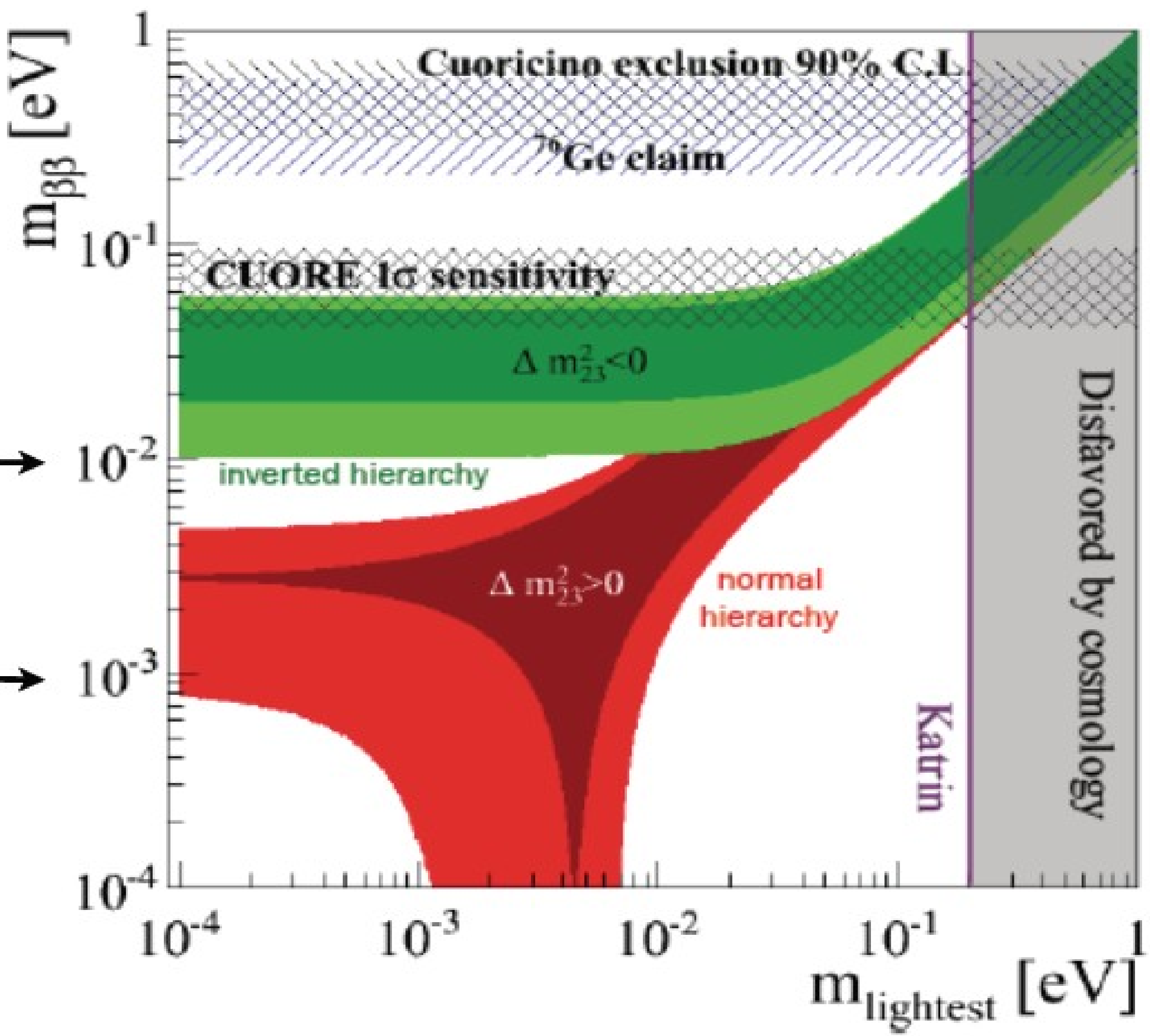
Rare process (e.g. $T_{1/2}[^{136}Xe] > 10^{25}$ years): need to get bigger

$$\Gamma = G\,|M|^2\,|m_{\beta\beta}|^2$$

EXO ~32 kg yr

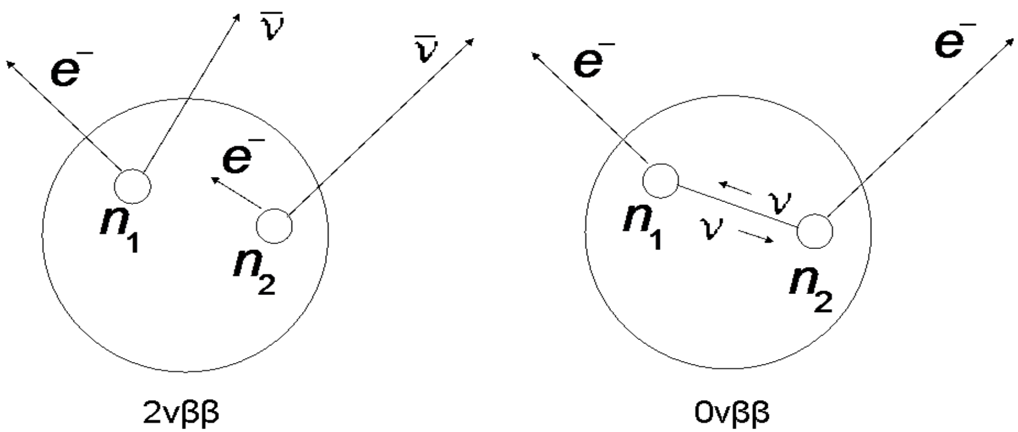
I ton

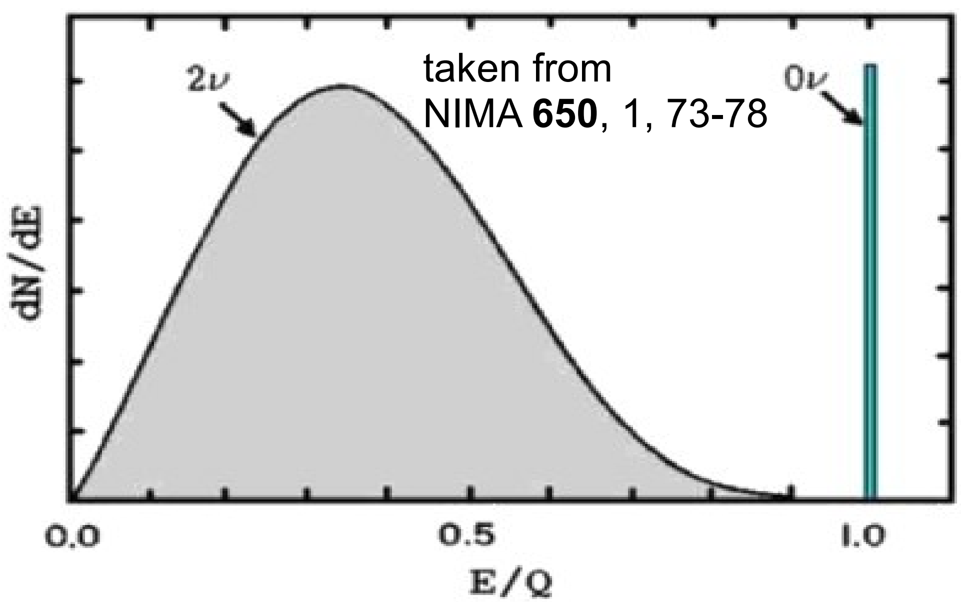
10 ton

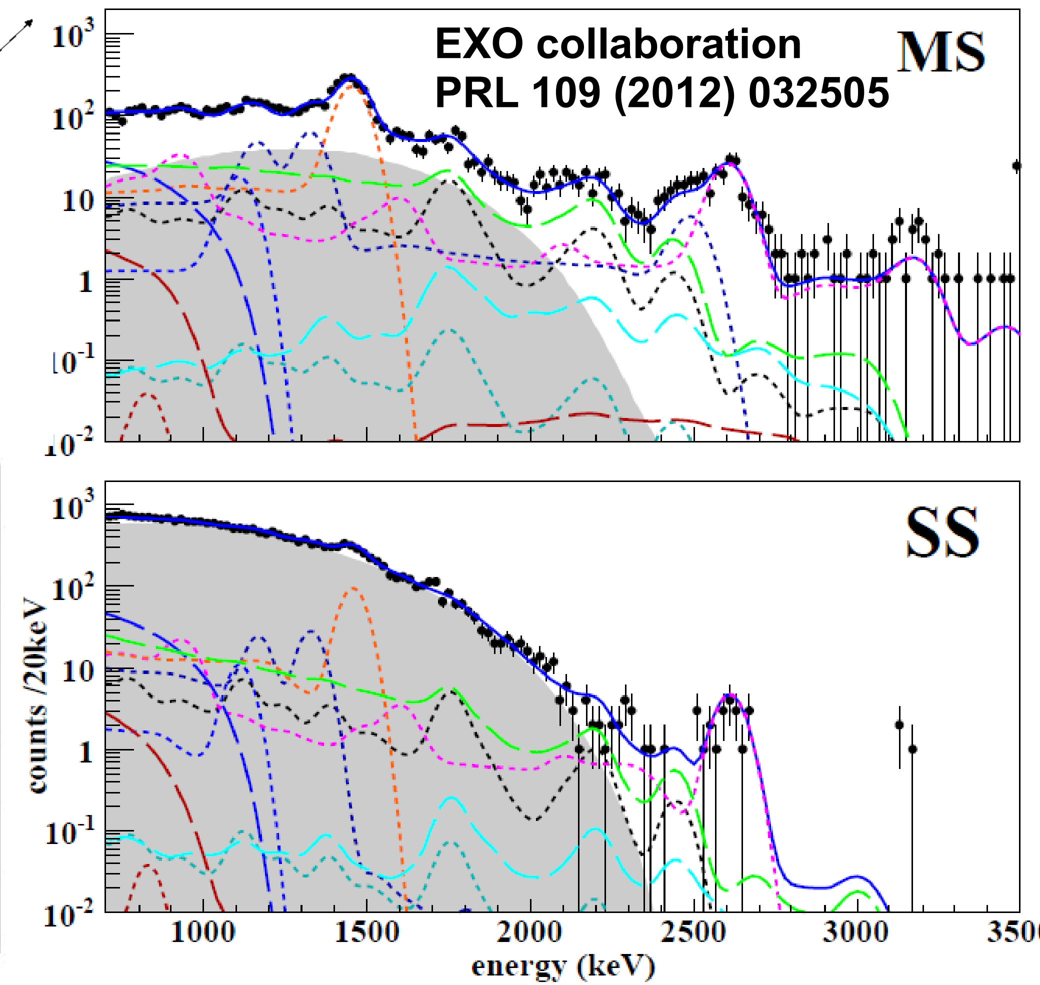


What are the challenges?

Tough backgrounds: need to get smarter



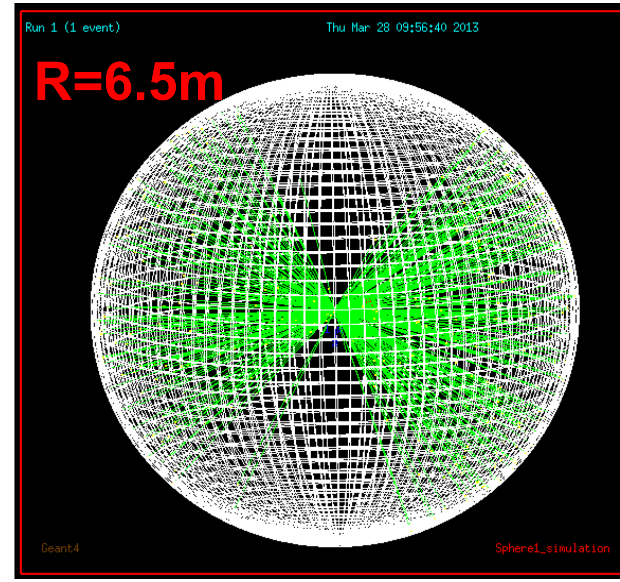




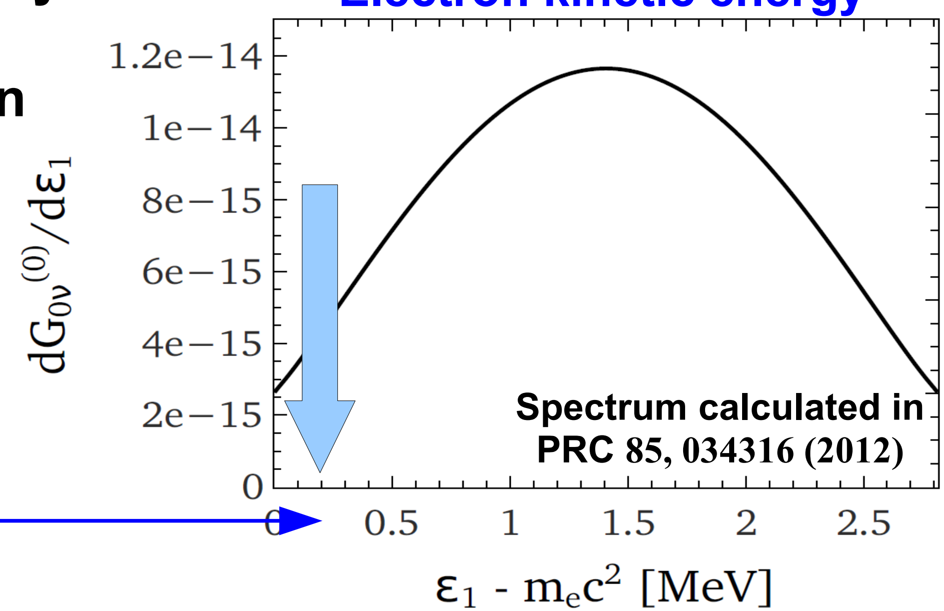
Ideas for 0νββ experiments

- **Total energy in signal events is well defined.**
- **Use scintillation light for energy measurements**
- **Use event topology to suppress backgrounds**
  - signal is two, mostly, "back-to-back" electrons
- **Electrons are ~1MeV → above Cherenkov threshold**
- **Use Cherenkov light to extract directionality of the two electrons**
  - all light can be used to constrain location of the vertex
  - Cherenkov light arrives early because of longer wavelength and delay of the scintillation process

Simulation of ^{116}Cd 0νββ event



Electron kinetic energy



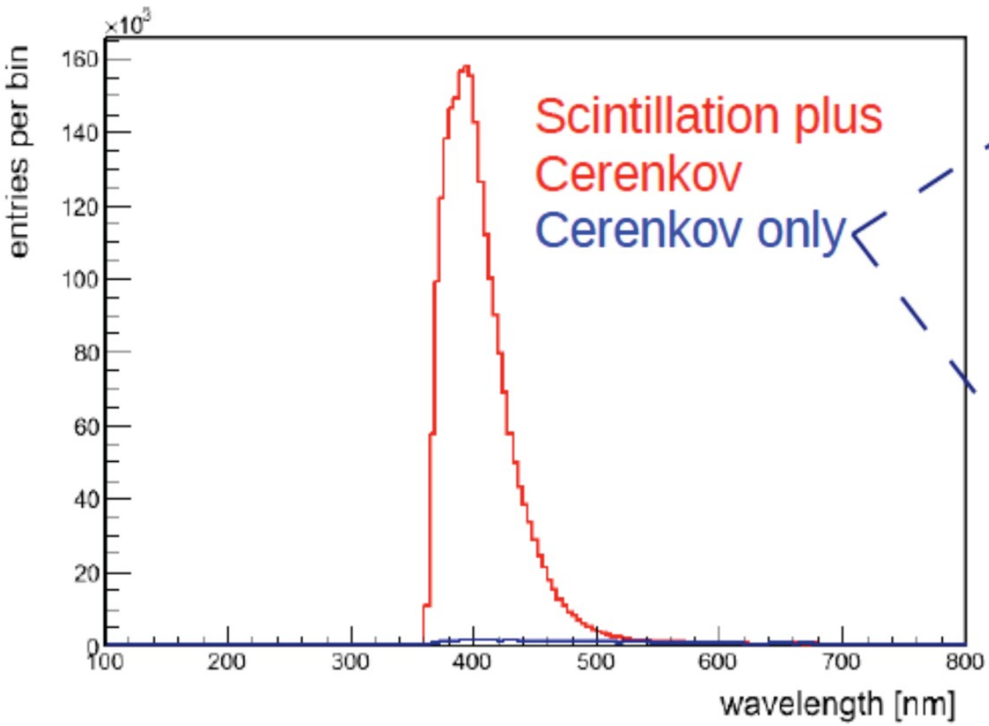
Cherenkov threshold for n=1.47 →

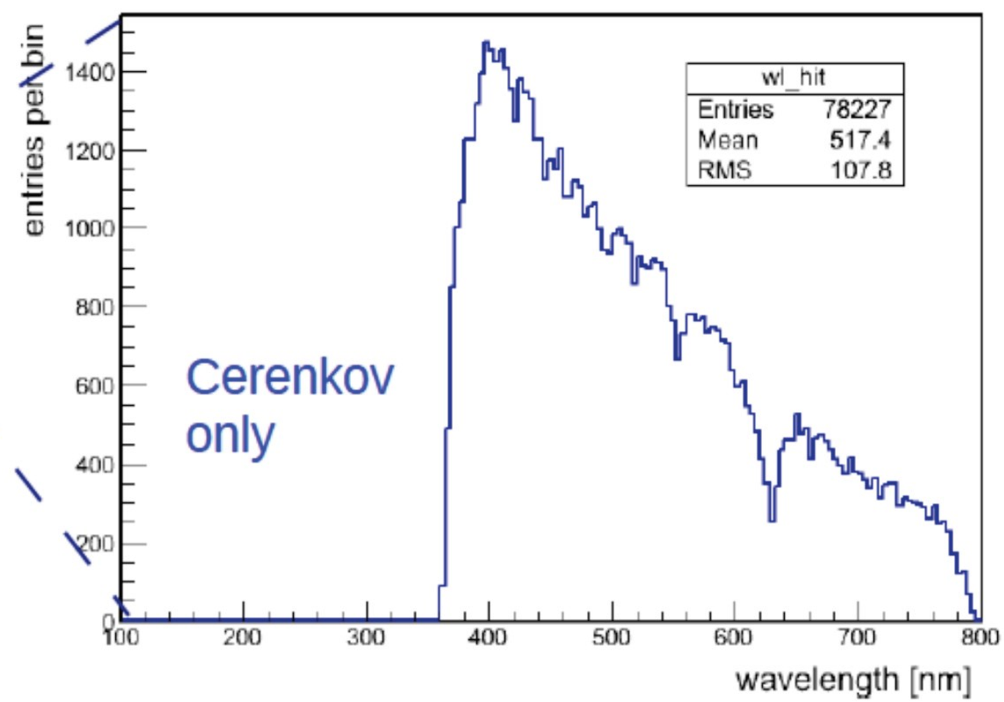
Emission Spectra

Simulation of 5 MeV electrons in KamLAND scintillator

5 MeV is a little higher for 0νββ search but much lower than typical energies where cherenkov light is being considered.

Seems to be a reasonable choice to test separation between Cherenkov and scintillation light for low energy electrons





All photons below 360nm get absorbed

Cherenkov vs Scintillation

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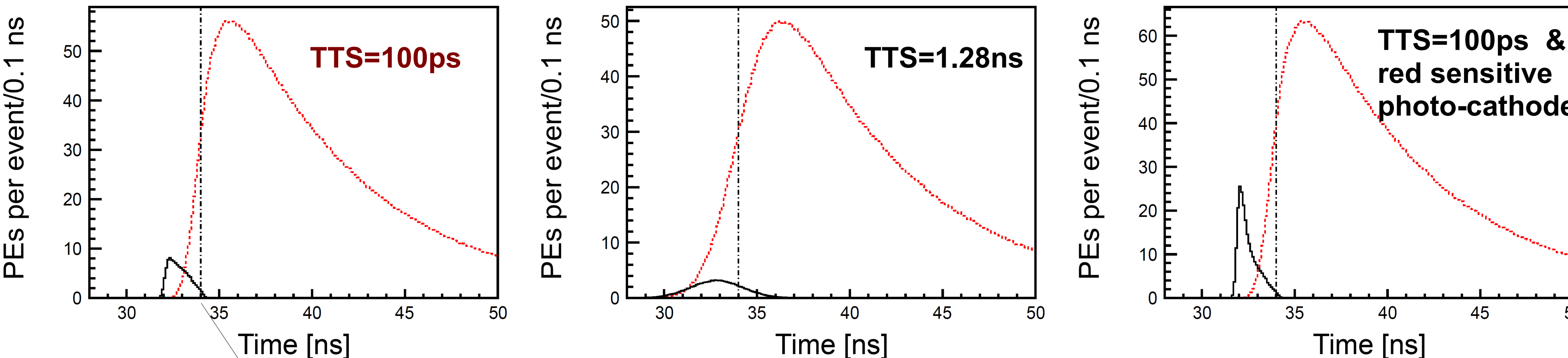
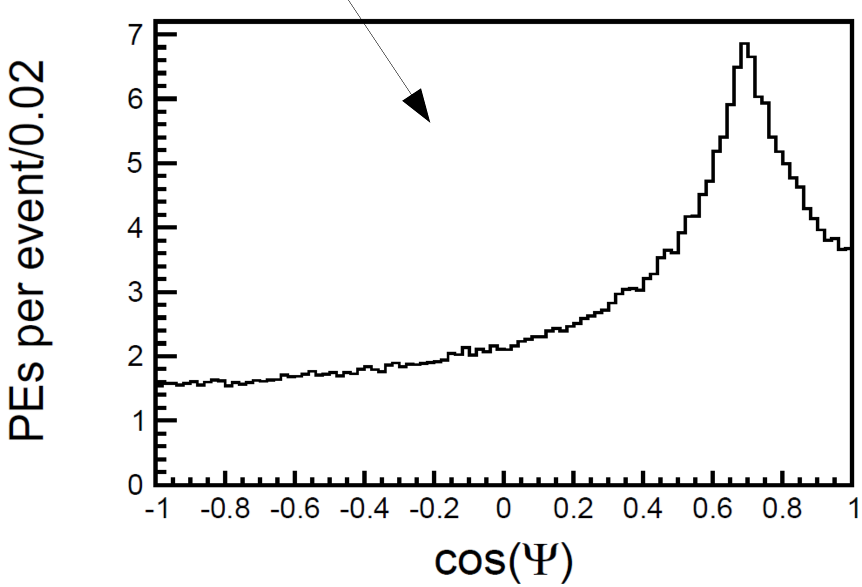
Simulation of 5 MeV electrons in KamLAND scintillator





Use early light to extract directionality

A shift between cherenkov and scintillation spectra is a plus

Reconstruction: vertex

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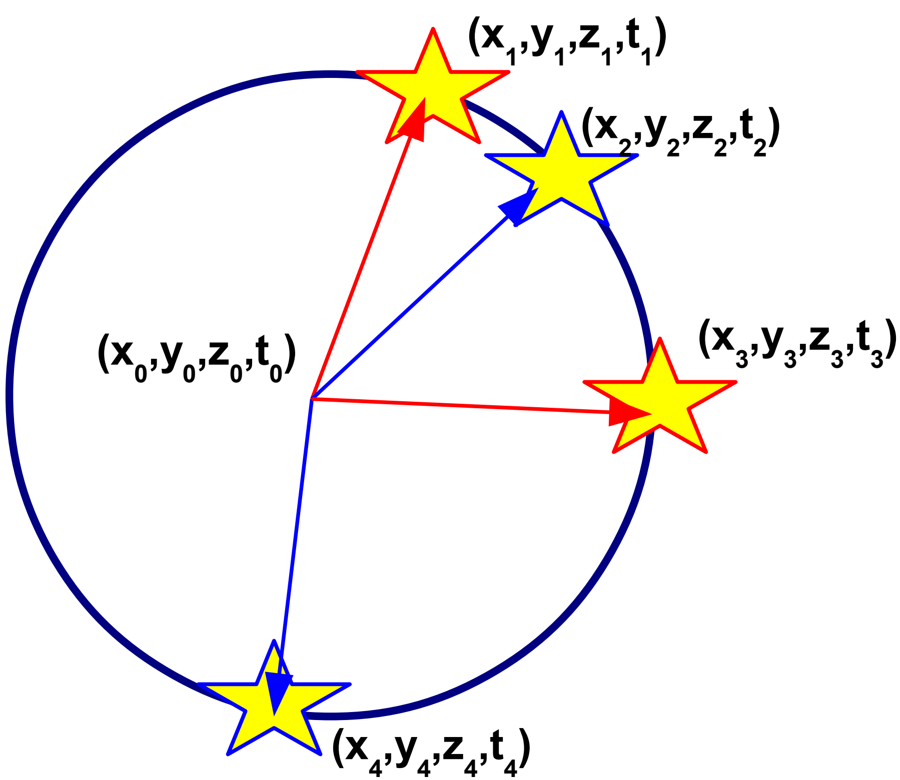
Step 1: find vertex (adapted from water-cherenkov)

- *Assume all light is emitted from a single point (~3 cm track in a ~6 m detector)*
- *For light emission from a single point any 4 photons (quadruplets) would be sufficient to solve for vertex*
- *With all „real world" effects we use 400 randomly chosen quadruplets and select the one which fits the best to the full ensemble of all photon hits*
- *Goodness of the fit is based on the distribution of „point time residuals" (the difference between actual hit time and predicted time of flight from the vertex)*



For i=1...4:

$$(x_i-x_0)^2 + (y_i-y_0)^2 + (z_i-z_0)^2 = v(t_i-t_0)^2$$

v **is the speed of light in the media**

Time residuals $\Delta T = (t_j - t_0)$, where $j=1...N_{all}$

The most narrow ΔT distribution is the closest to the true vertex

Reconstruction: direction

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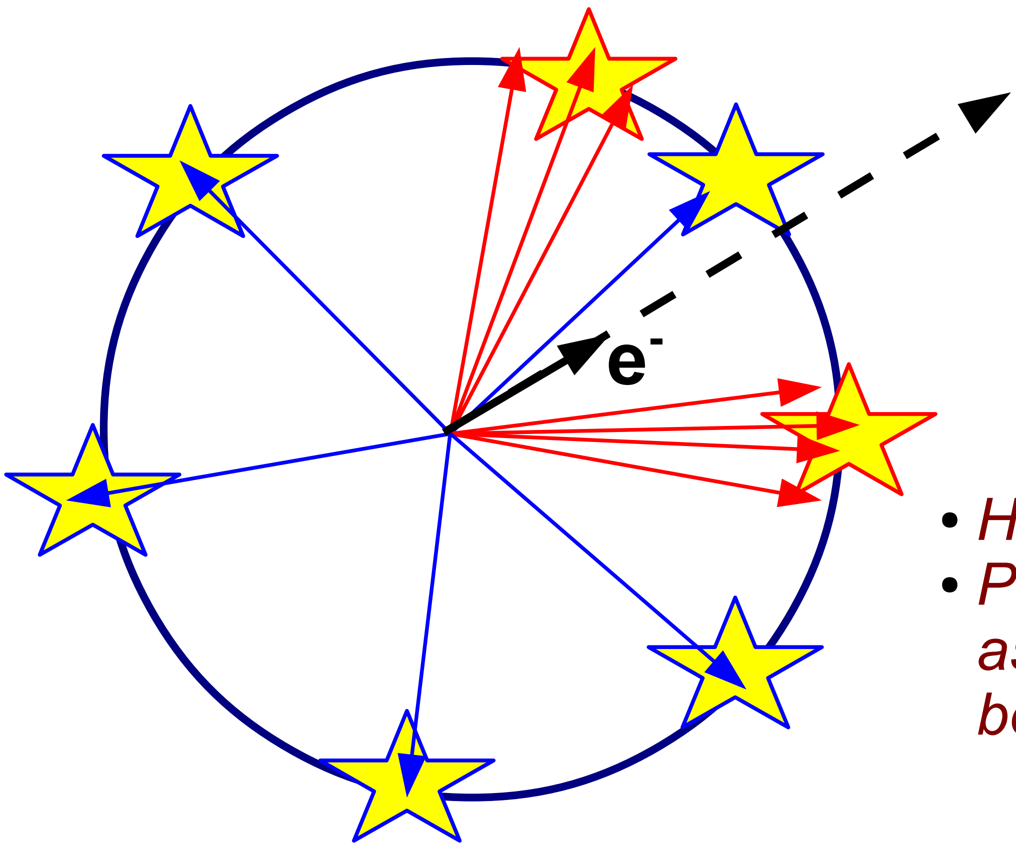
Step 2: find direction

- Cherenkov light is directional
- Timing cut enhances the purity of the Cherenkov light
- The centroid of all vectors pointing from the vertex is a good measure of the direction of the track



- *Has to be modified for 2 tracks*
- *Plenty of algorithms exist as long as Cherenkov light can be separated from scintillation*

Directionality of 5 MeV e^-

UCLA

University of Chicago

Measuring Directionality in Double-Beta Decay and Neutrino Interactions with Kiloton-Scale Scintillation Detectors

C. Aberle,[1] A. Elagin,[2] H. J. Frisch,[2] M. Wetstein,[2] and L. Winslow[1]

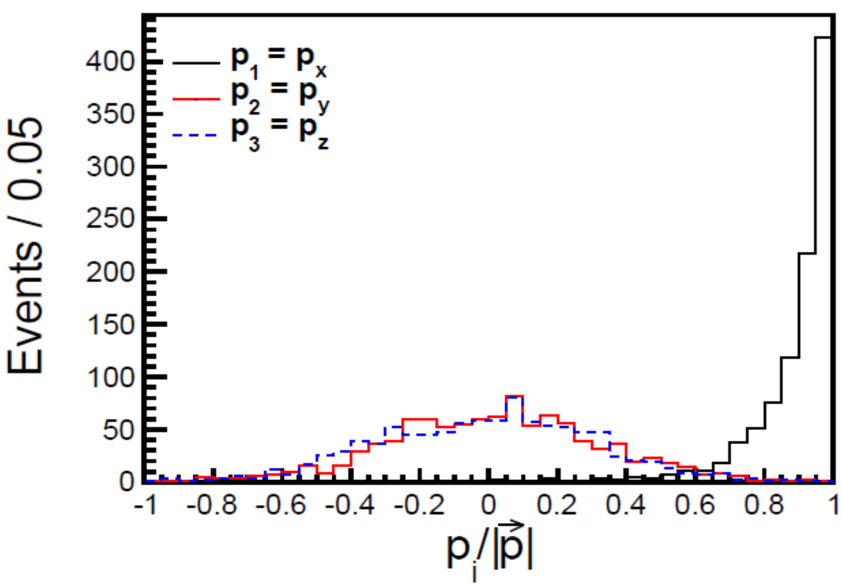
[1] *University of California Los Angeles, Los Angeles, CA 90095, USA*

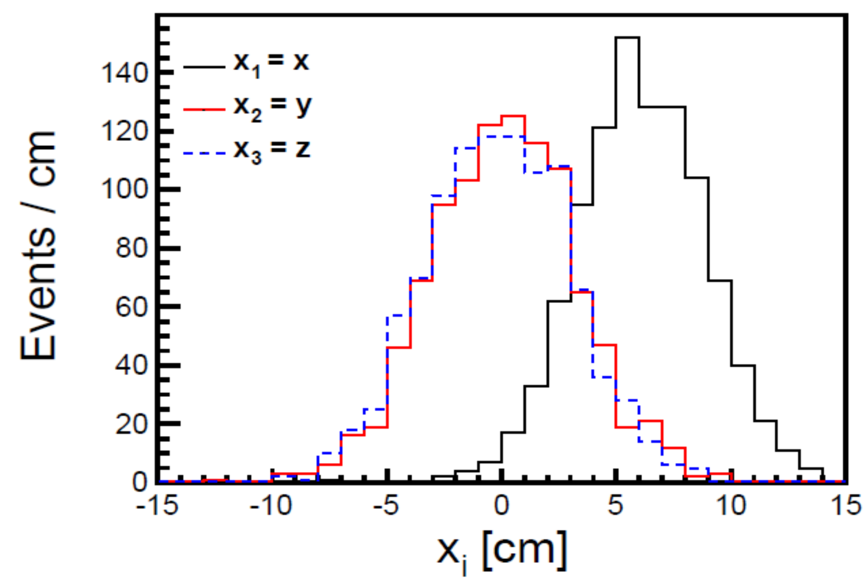
[2] *University of Chicago, Chicago, IL 60637, USA*

(Dated: July 23, 2013)

arxiv:1307.5813

Large liquid-scintillator-based detectors have proven to be exceptionally effective for low energy neutrino measurements due to their good energy resolution and scalability to large volumes. The addition of directional information using Cherenkov light and fast timing would enhance the scientific reach of these detectors, especially for searches for neutrino-less double-beta decay. In this paper, we develop a technique for extracting particle direction using the difference in arrival times for Cherenkov and scintillation light, and evaluate several detector advances in timing, photodetector spectral response, and scintillator emission spectra that could be used to make direction reconstruction a reality in a kiloton-scale detector.

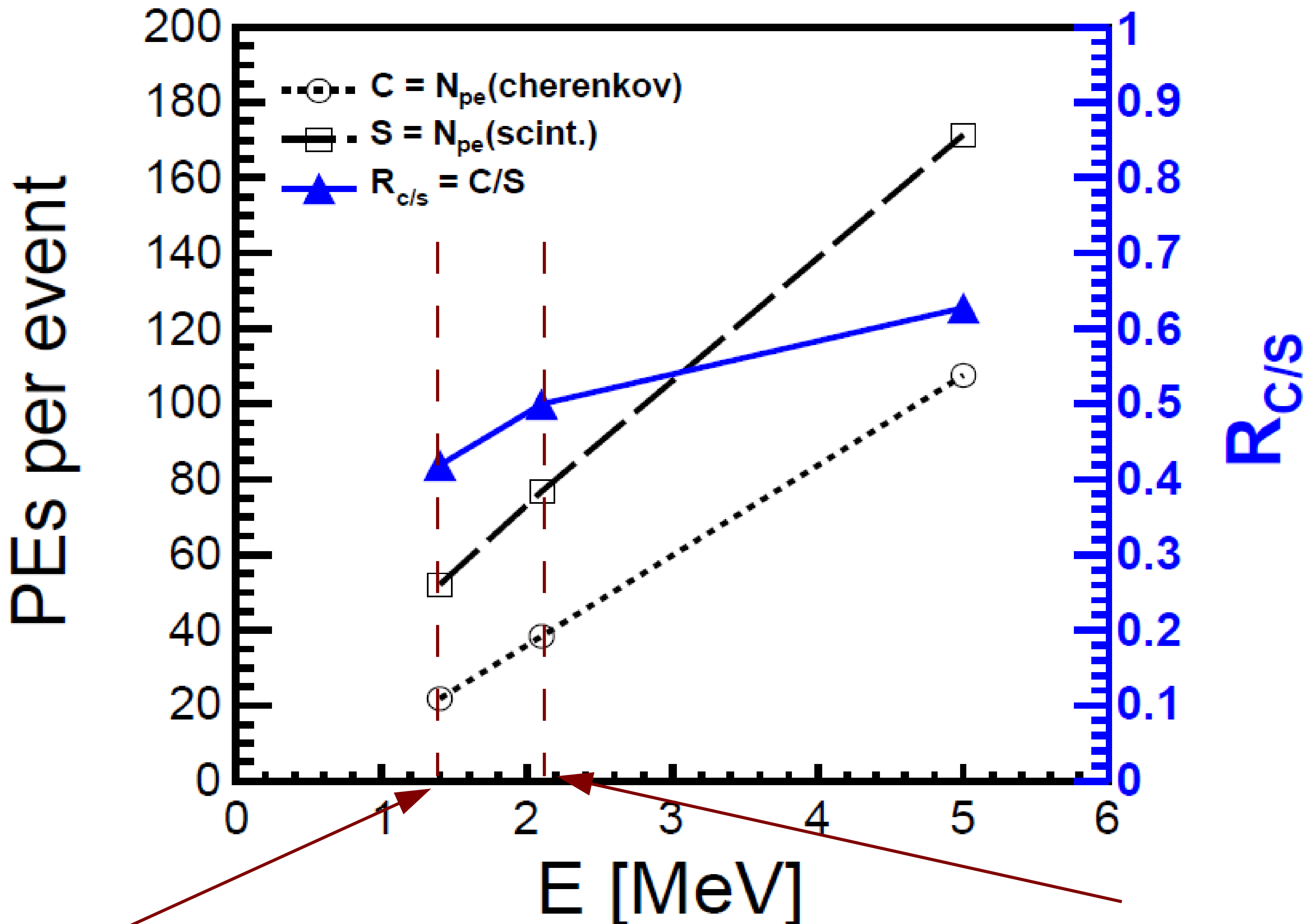




5 MeV electrons are very promising even with a very simple reconstruction

What about Lower Energies?

Light yield: Cherenkov vs scintillation



½ Q (^{116}Cd) =1.4 MeV

½ Q (^{48}Ca) =2.1 MeV

What about Lower Energies?

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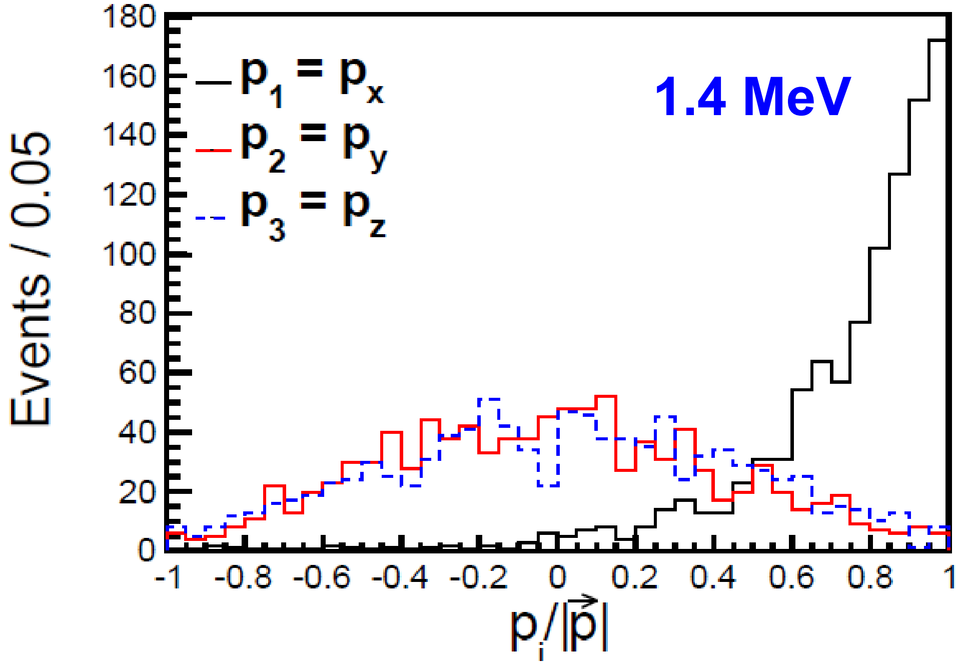

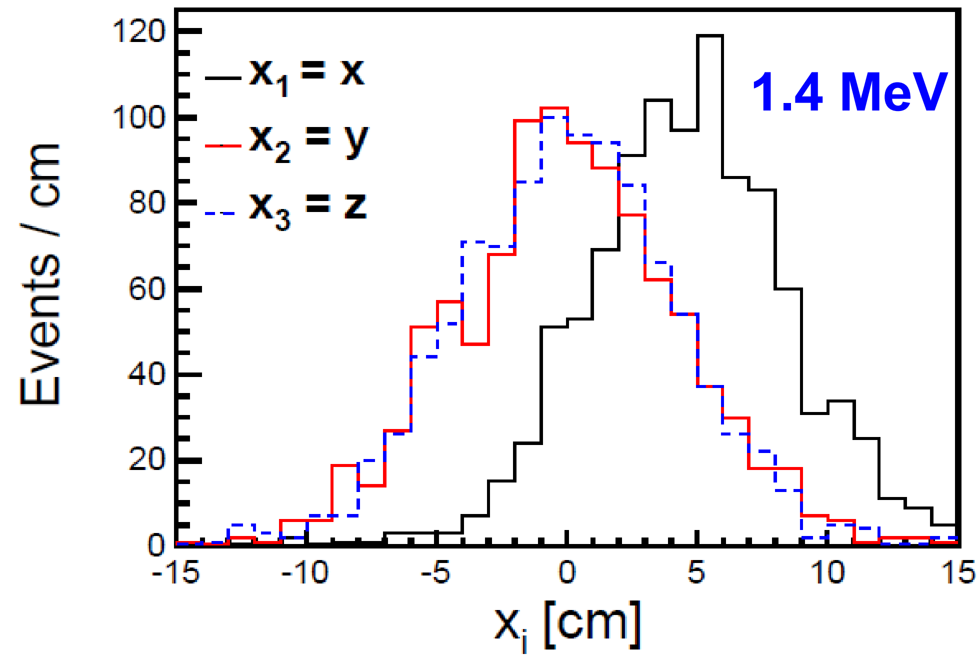

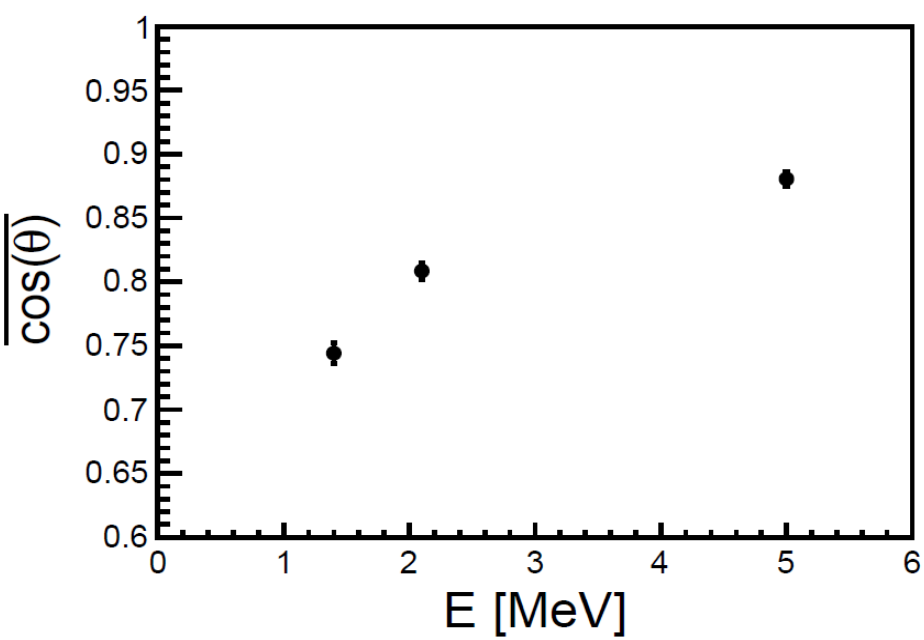

- *With 100ps timing, the vertex is constrained within 4-6 cm and the directional information can be extracted even for ~1MeV electrons*
- *The next major step is to compare „back-to-back“ $0\nu\beta\beta$ events with $2\nu\beta\beta$ background (work in progress)*

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Candidate Isotopes for 0νββ

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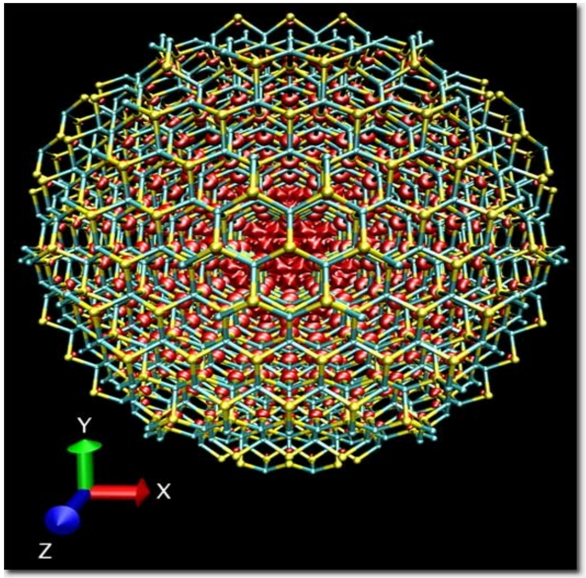
Isotope	Endpoint	Abundance
^{48}Ca	4.271 MeV	0.0035%
^{150}Nd	3.367 MeV	5.6%
^{96}Zr	3.350 MeV	2.8%
^{100}Mo	3.034 MeV	9.6%
^{82}Se	2.995 MeV	9.2%
^{116}Cd	2.802 MeV	7.5%
^{130}Te	2.533 MeV	34.5%
^{136}Xe	2.479 MeV	8.9%
^{76}Ge	2.039 MeV	7.8%
^{128}Te	0.868 MeV	31.7%

Quantum dot doped scintillators



Common materials are CdS, CdSe, CdTe

Advantage of quantum dot doping:

- Narrow the scintillation spectrum
- Shift scintillation spectrum to shorter wavelength
- Dope with metals which can undergo 0νββ

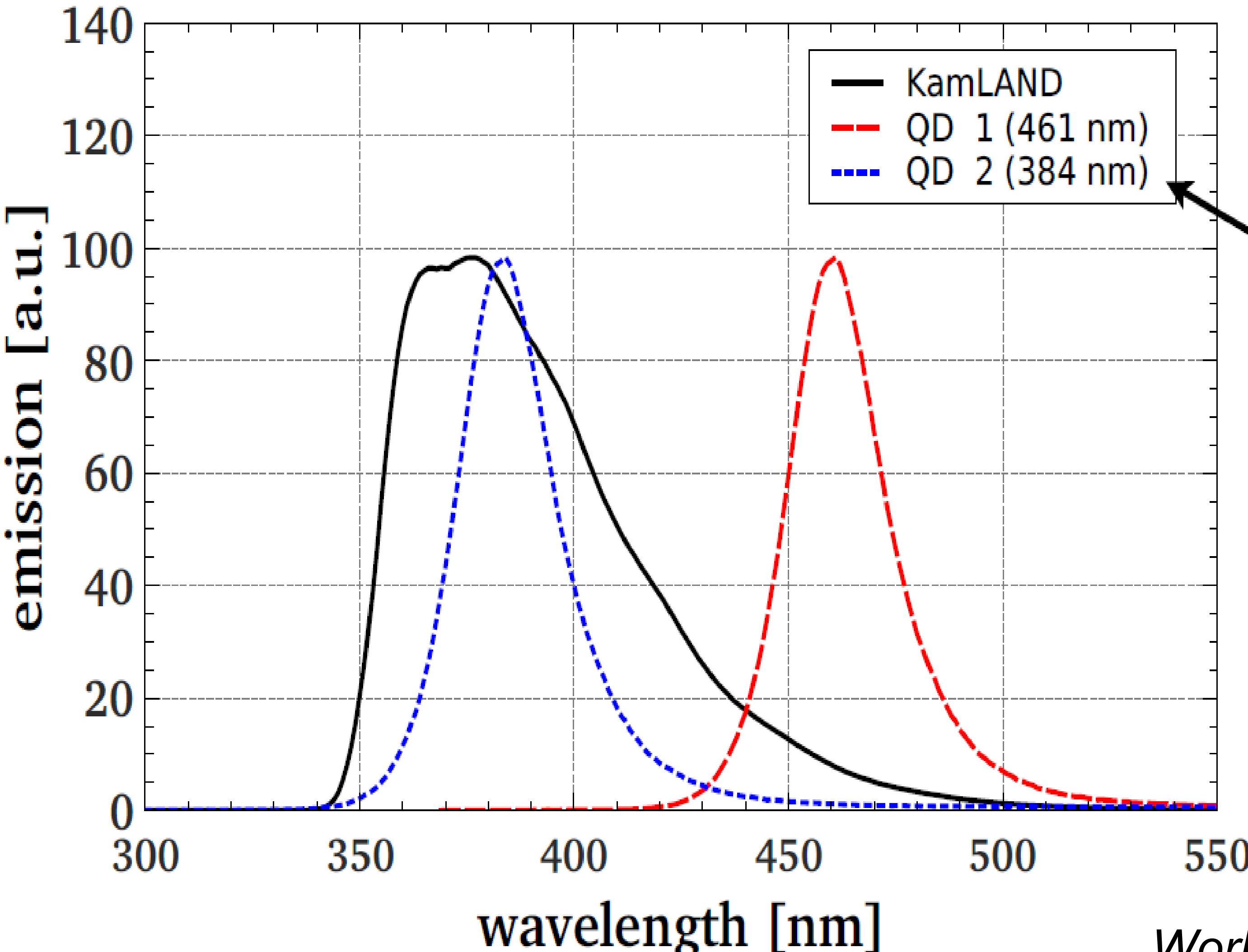
Work by UCLA group C.Aberle, J.J.Li, S.Weiss, and L.Winslow

This a whole new topic for a separate seminar!

UCLA

QDots Doped Scintillator

University of Chicago



384nm not yet available, but is the goal of future work

Work by UCLA group C.Aberle, J.J.Li, S.Weiss, and L.Winslow

Strategy for $0\nu\beta\beta$

- Pending proposal to build a ~1m radius tank filled with liquid scintillator to test low energy electron reconstruction using separation between Cherenkov and scintillation light

- Need to fully explore imaging capabilities of the LAPPDs
  - map large volume to relatively small number of photo-sensors
  - this is a key to large detector mass for a reasonable budget

- Working on a modular design for a kiloton scale detector

Summary

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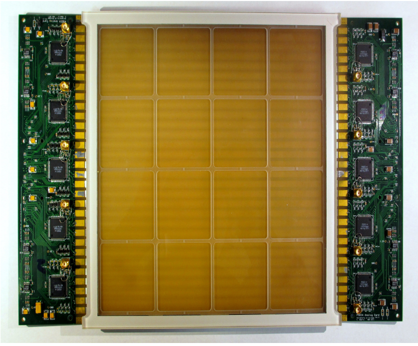
- Many applications can benefit from precise timing measurements and large area coverage
- LAPPDs are approaching picosecond domain
- Incom Inc. STTR Phase II program will produce several sealed tiles for testing in the field
- First LAPPD adopters are identified
- Experiments looking for neutrino-less double-beta decay can improve their sensitivity by reconstructing event topology using fast timing photo-detectors



Back Up

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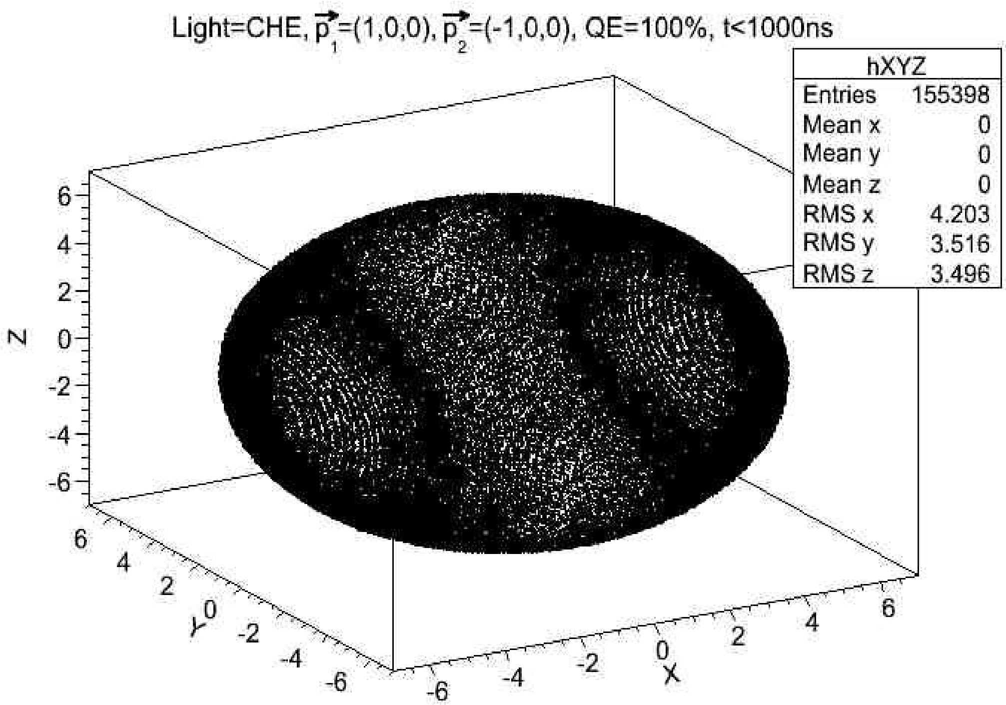
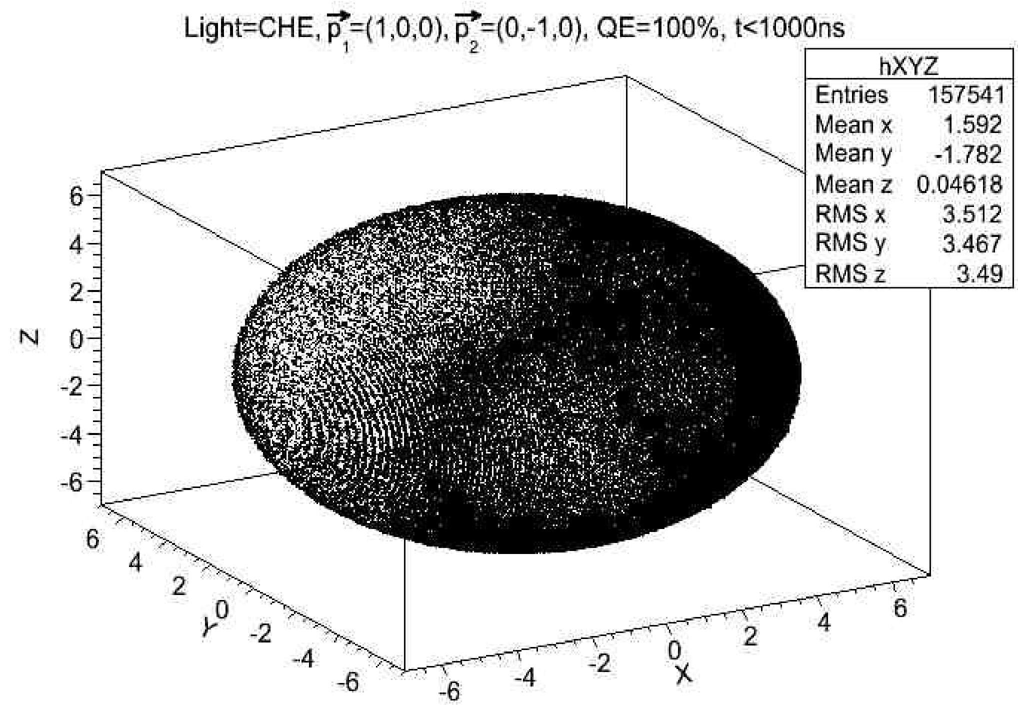
Event Topology

100 „signal-like“ events
(5MeV electrons back-to-back)



100 „bkg-like“ events
(5MeV electrons at 90 degree)



Cherenkov light only, no time cut, 100% light collection

Spherical Harmonics

Real-value basis:

$$Y_{\ell m} = \begin{cases} \frac{1}{\sqrt{2}}\left(Y_\ell^m + (-1)^m Y_\ell^{-m}\right) = \sqrt{2} N_{(\ell,m)} P_\ell^m(\cos\theta)\cos m\varphi & \text{if } m > 0 \\ Y_\ell^0 & \text{if } m = 0 \\ \frac{1}{i\sqrt{2}}\left(Y_\ell^{-m} - (-1)^m Y_\ell^m\right) = \sqrt{2} N_{(\ell,|m|)} P_\ell^{|m|}(\cos\theta)\sin|m|\varphi & \text{if } m < 0. \end{cases}$$

$$f(\theta,\varphi) = \sum_{\ell=0}^{\infty}\sum_{m=-\ell}^{\ell} f_{\ell m} Y_{\ell m}(\theta,\varphi).$$

$$N_{(\ell,m)} \equiv \sqrt{\frac{(2\ell+1)}{4\pi}\frac{(\ell-m)!}{(\ell+m)!}}.$$

$$f_\ell^m = \int_\Omega f(\theta,\varphi) Y_\ell^{m*}(\theta,\varphi)\, d\Omega = \int_0^{2\pi} d\varphi \int_0^\pi d\theta\, \sin\theta f(\theta,\varphi) Y_\ell^{m*}(\theta,\varphi).$$

L2 norm

$$\int_\Omega |f(\Omega)|^2 d\Omega = \sum_{\ell=0}^{\infty} S_{ff}(\ell)$$

„Power" (rotation invariant)

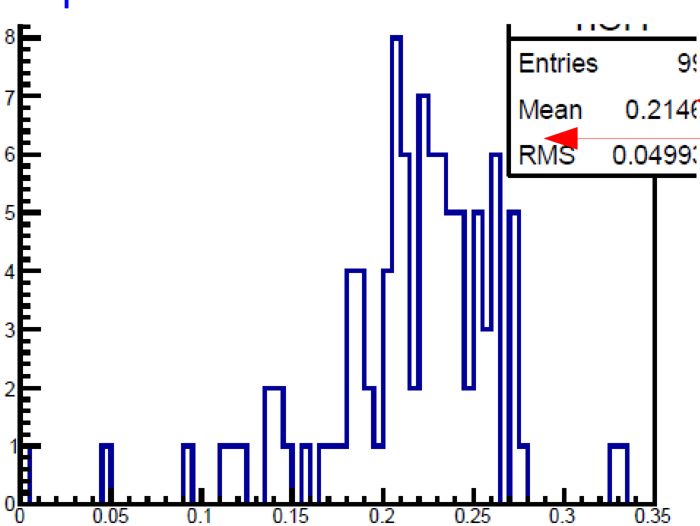
$$S_{ff}(\ell) = \sum_{m=-\ell}^{\ell} |f_{\ell m}|^2$$

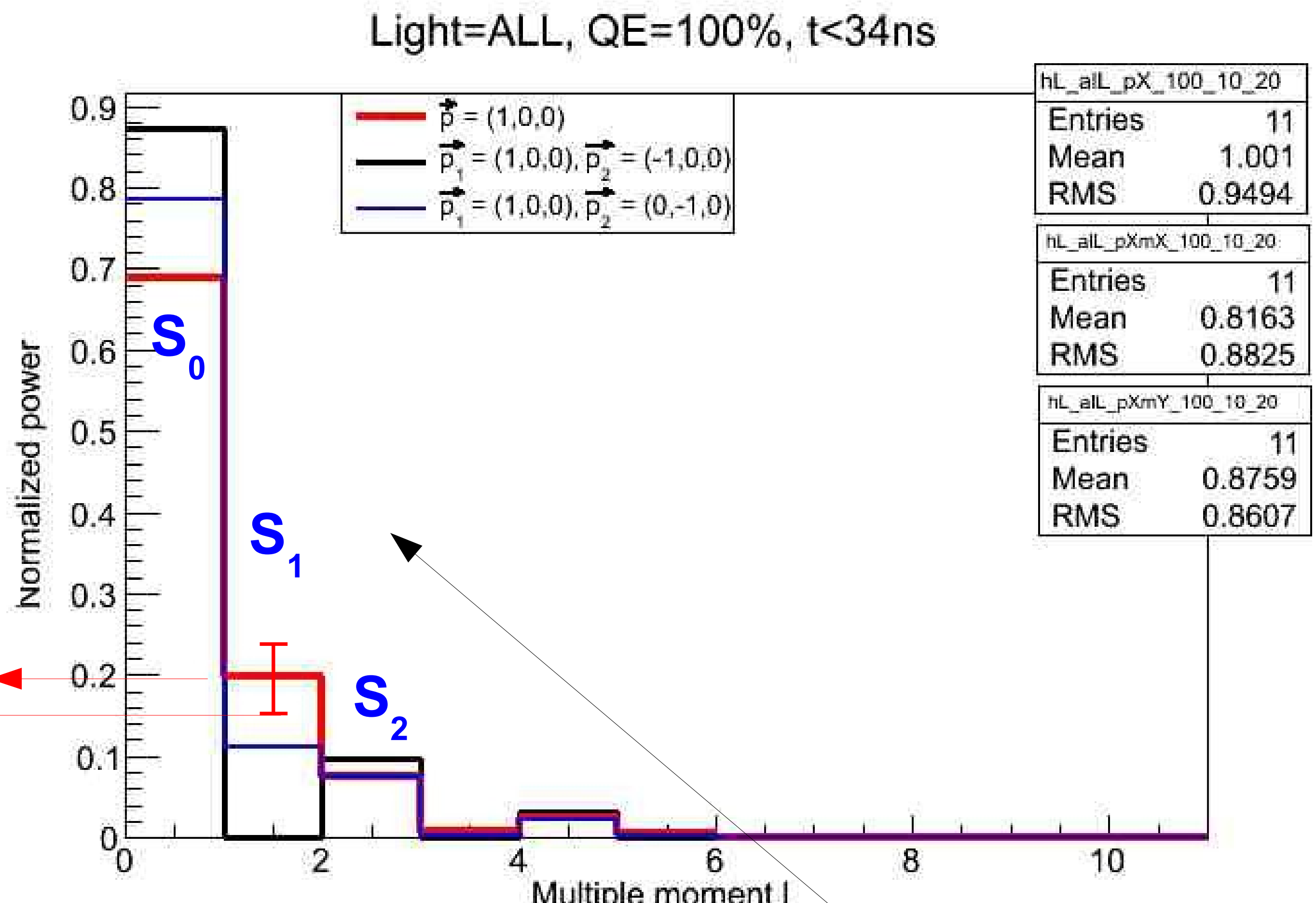
Spherical Harmonics for back-to-back vs 90 degree topologies

- *Look for the difference between* ***black (back-to-back)*** *and* ***blue (90-degree)*** *lines.*
- ***Red line*** *is for comparison with single electron events*

$$S_{ff}(\ell) = \sum_{m=-\ell}^{\ell} |f_{\ell m}|^2$$

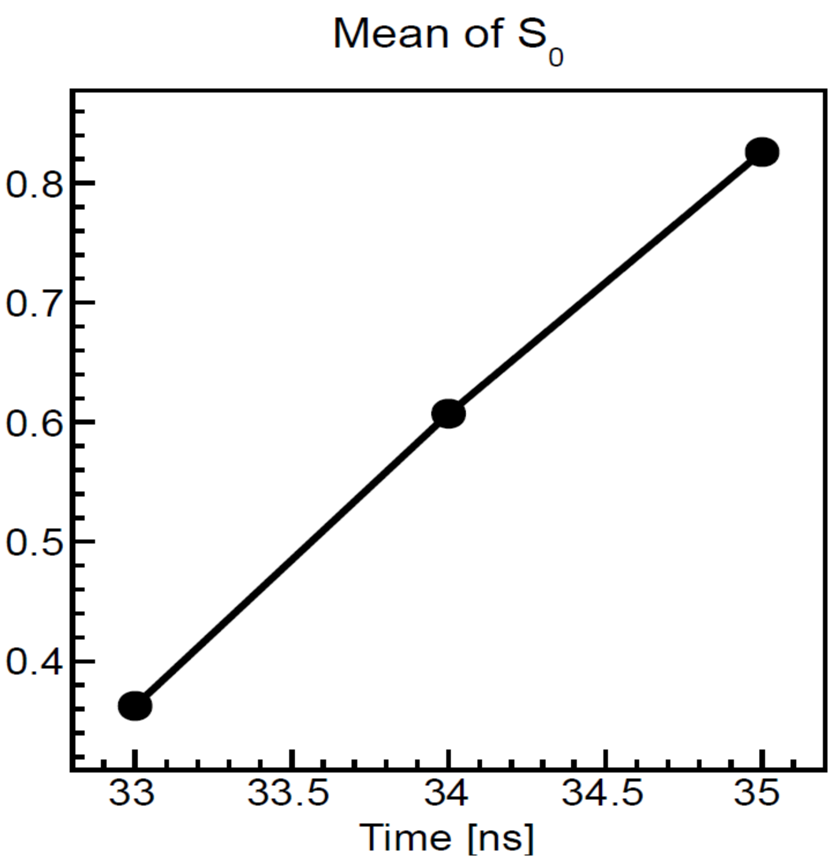
S_1 event-by-event fluctuations

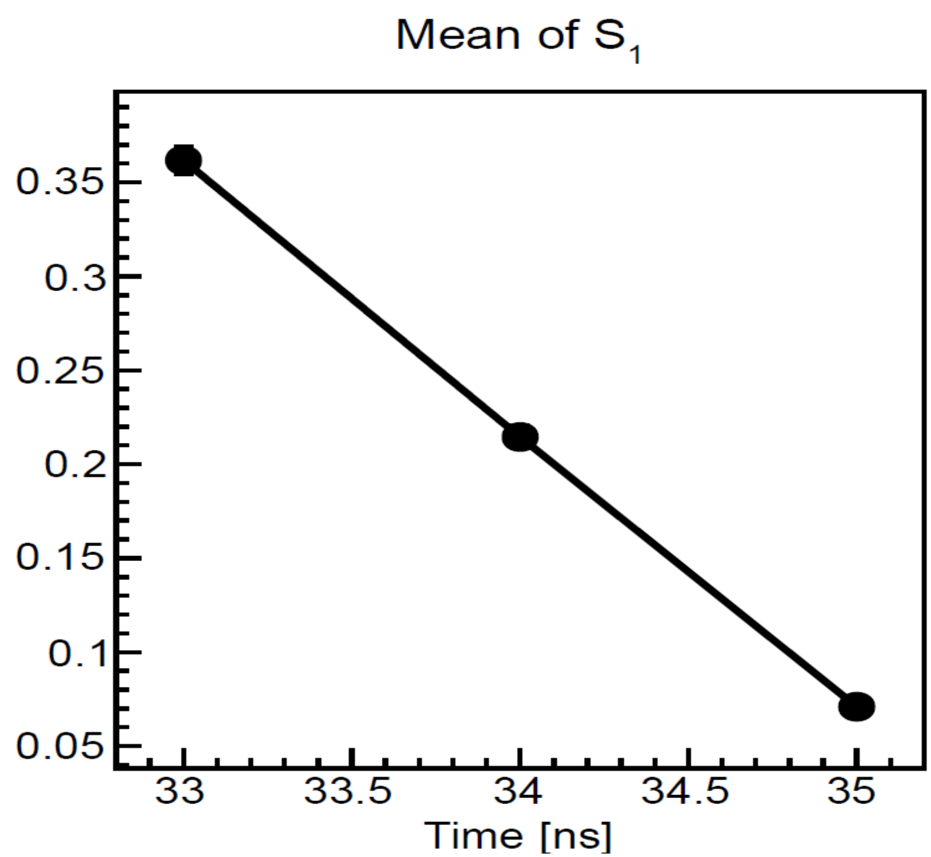




These S_l are calculated for combined hit distribution of 100 events

S_l as function of time cut





I like this strong dependence on time because

with fast photo-detectors we may be able to follow the time evolution of spherical harmonics and use this information in reconstruction

S_l as function of electron energy

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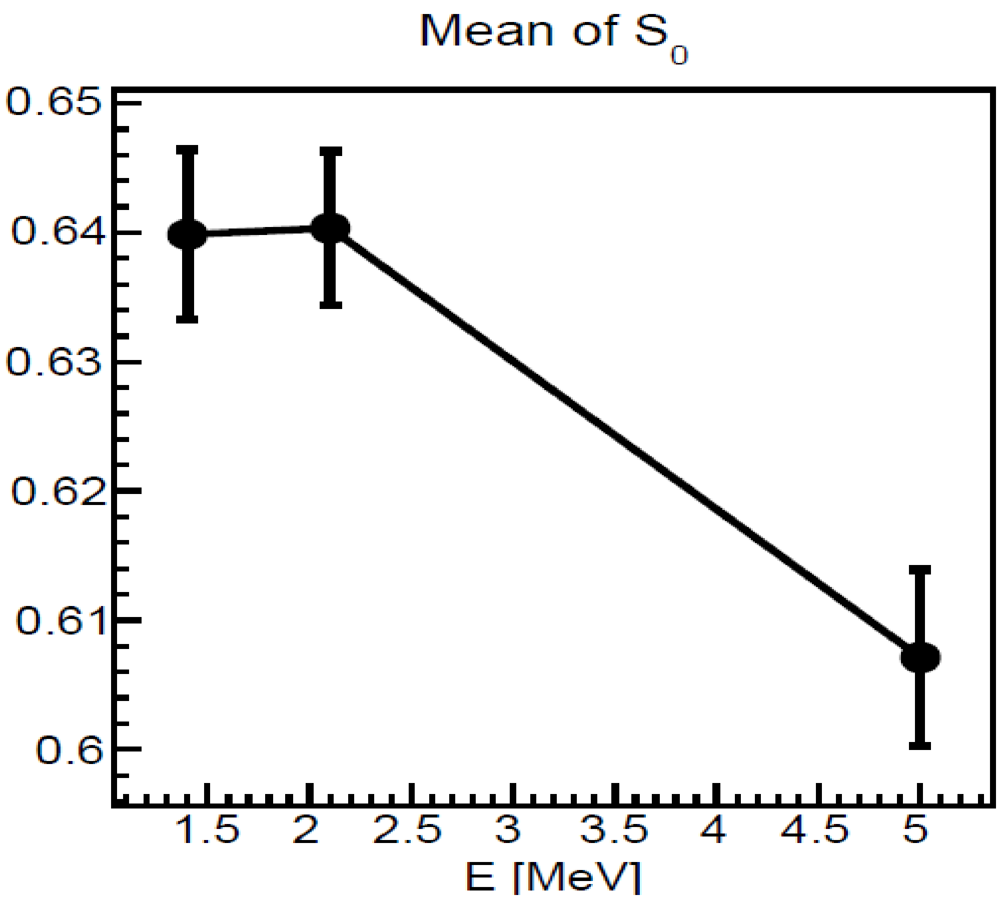

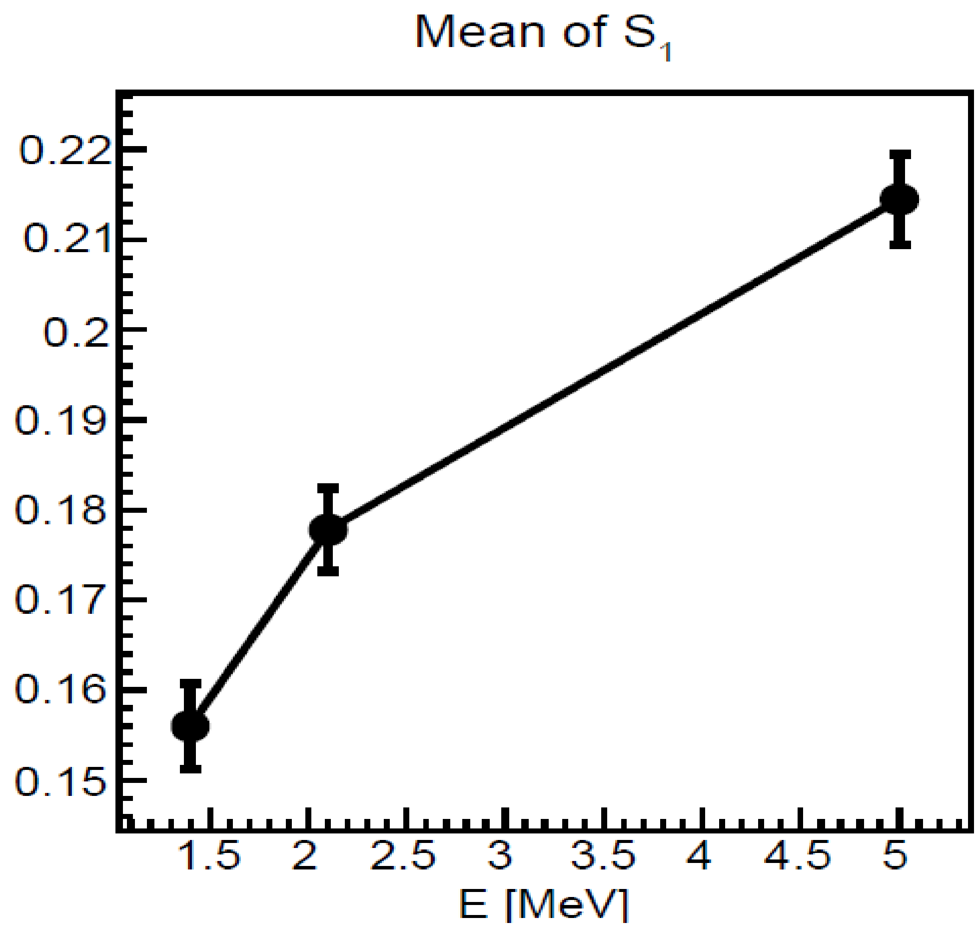

Note Y axis range, the dependence isn't too strong

Next steps:

- *Compare simulated $0\nu\beta\beta$ events with $2\nu\beta\beta$*
- *Consider events off center*

Sub-picosecond Pulsed Laser @APS ANL

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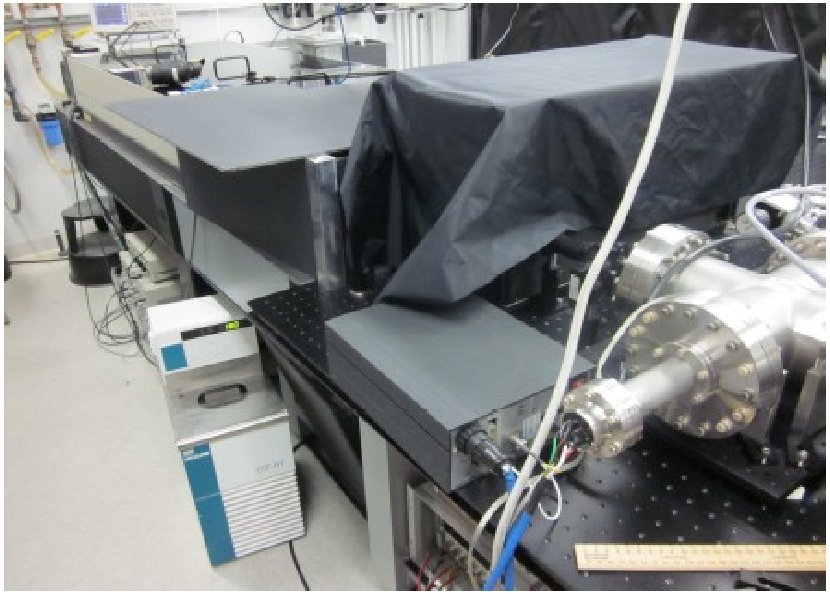
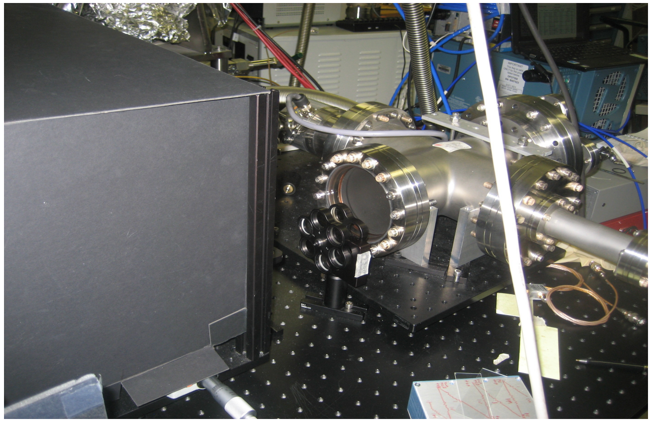
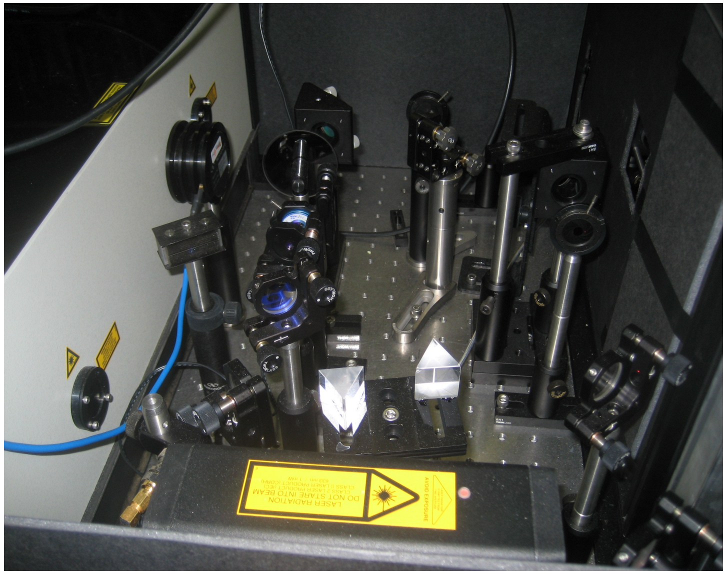
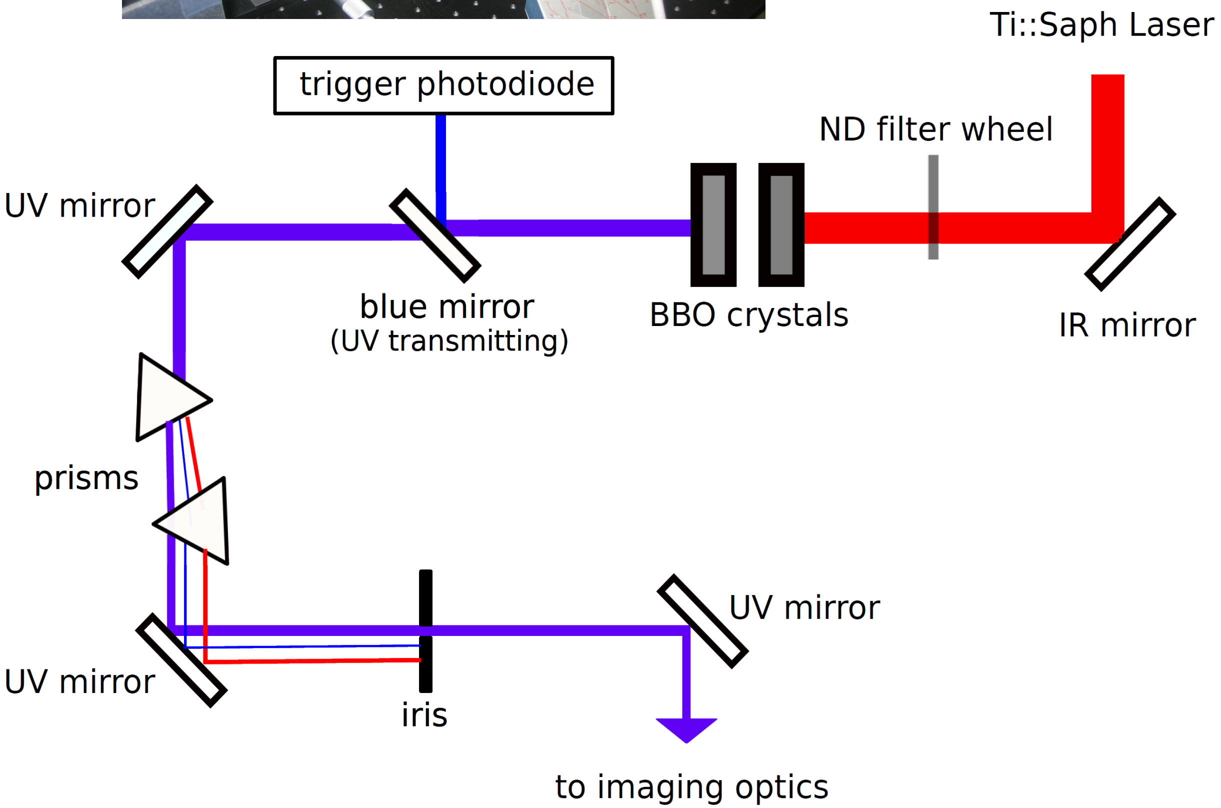


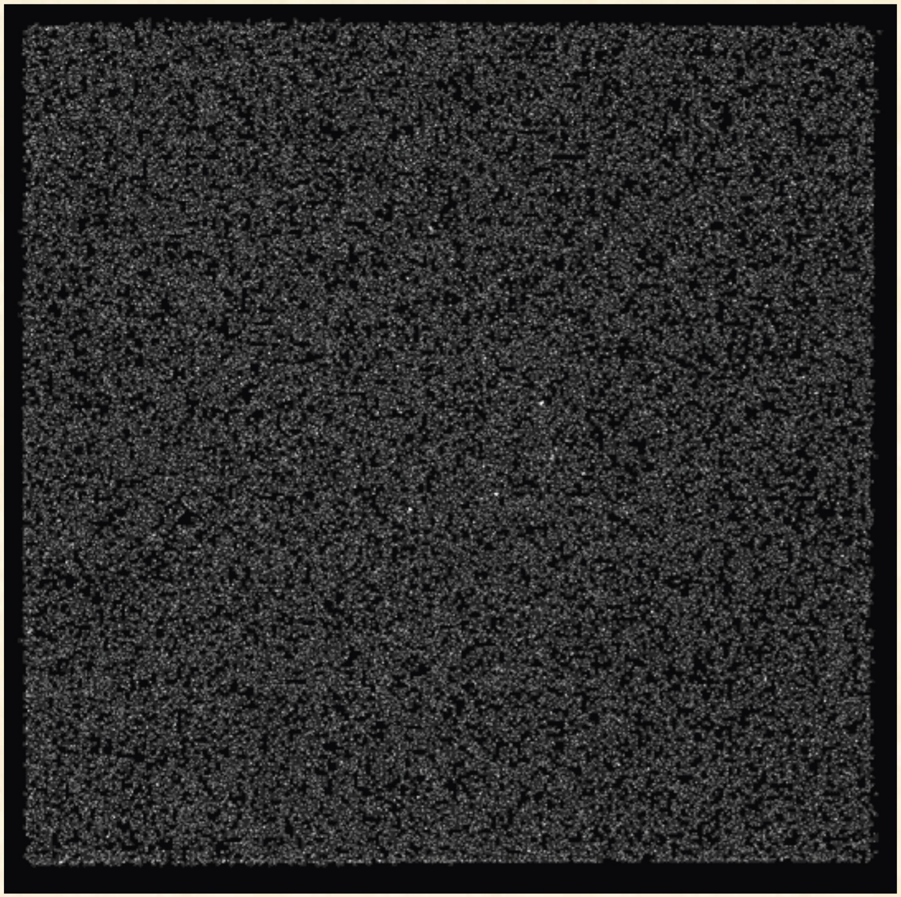






Background

Background, 20cm, 20μm pore ALD-MCP Pairs



20cm MCP pair background, 2000 sec, 0.068 cnts sec^{-1} cm^{-2}. 2k x 2k pixel imaging.

- 20µm pore, 60:1 L/d ALD-MCP pair, 0.7mm gap/200v.
- Background very low !! 0.068 cnts sec^{-1} cm^{-2} is a factor of 4 lower than normal glass MCPs.
- This is a consistent observation for all MCPs with this substrate material and relates to the low intrinsic radioactivity of the glass.
- Without lead content the cross section for high energy events is also lower than standard glasses.
- There are issues with hotspots on some substrates, however this can be addressed

Timing Limits

Can we achieve sub-picoseconds?

Stefan Ritt slide

How is timing resolution affected?

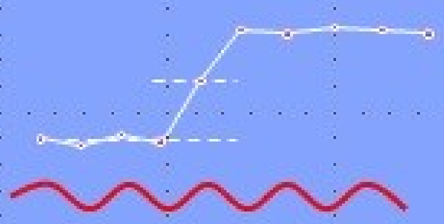
$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3 f_s \cdot f_{3dB}}}$$

•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



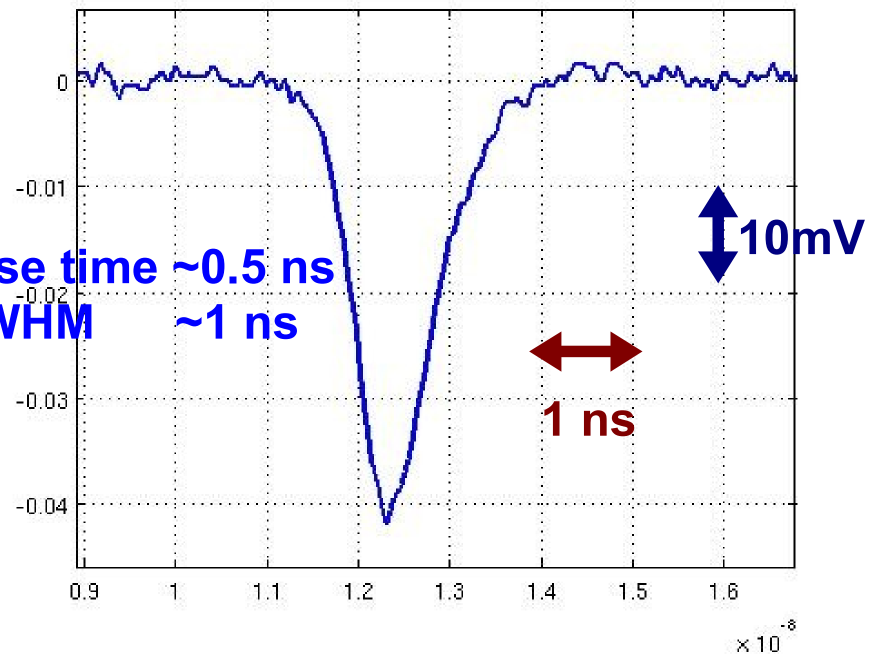
Stefan Ritt slide

UC workshop 4/11

April 28th, 2011 Timing Workshop, Chicago

MCP pulses and timing

Rise time ~0.5 ns
FWHM ~1 ns



Timing analysis approach

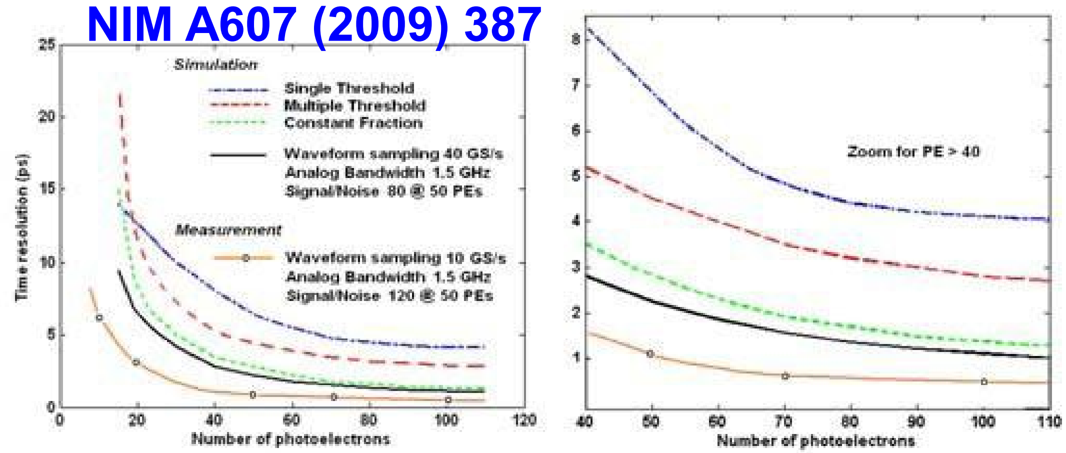
- Fit rising edge
- Use constant fraction descriminant

Questions

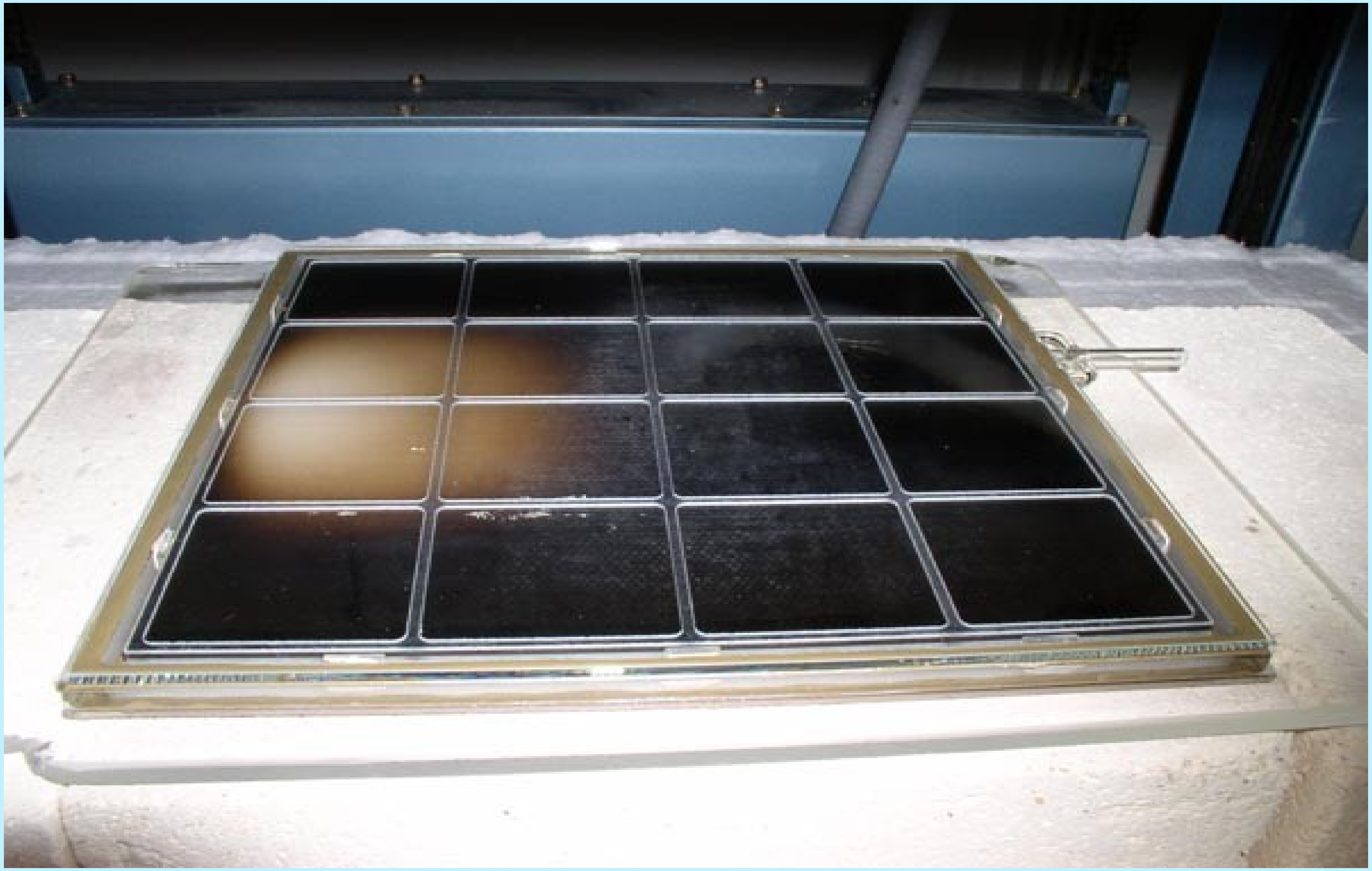
- Time resolution
- Position resolution

Time resolution determinants:
1) Signal to noise
2) Analog Bandwidth
3) Sampling rate
4) Signal statistics

NIM A607 (2009) 387



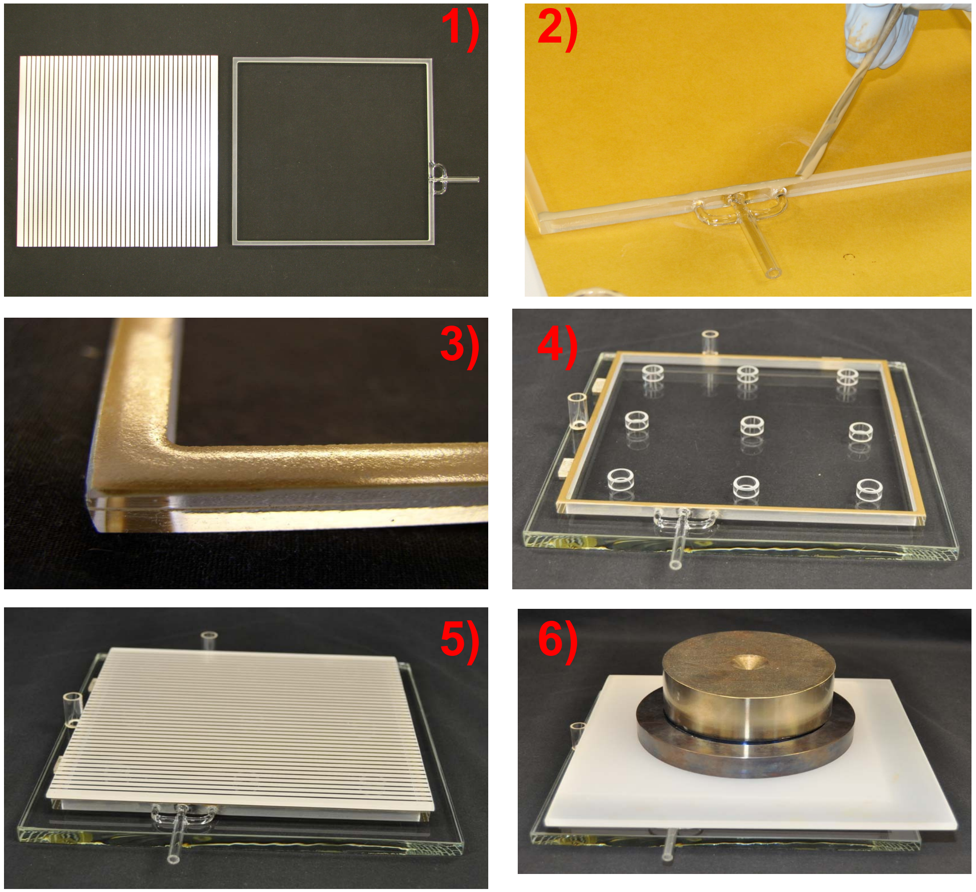
Hermetic Packaging



Frit Seal

University of Chicago

J.Gregar, M.Minot



1) Attach pump out tube to 8.66x8.66" frame

2) Apply schott #G018-223 K3 frit paste to frame

3) Fire the frit (many trials to optimize parameters)

4) Prepare for anode plate frit sealing

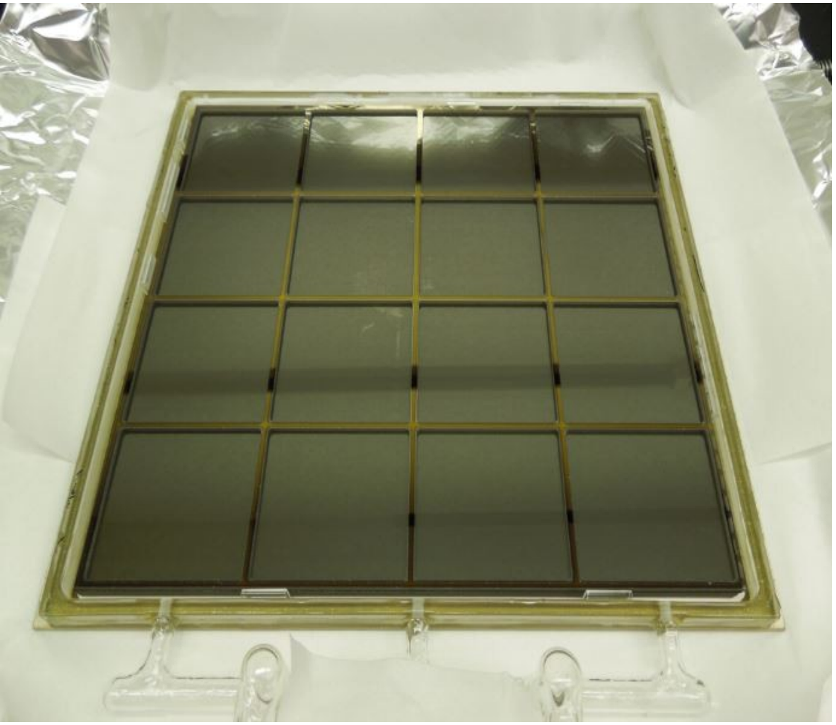
5) Position anode on top of the frame

6) Add weight

- **Tile bases are reliably reproducible**
- **Mechanical and vacuum properties have been tested**

Top Seal

How to close frit sealed tile base at the top and stay at moderate temperatures? "Top Seal" problem

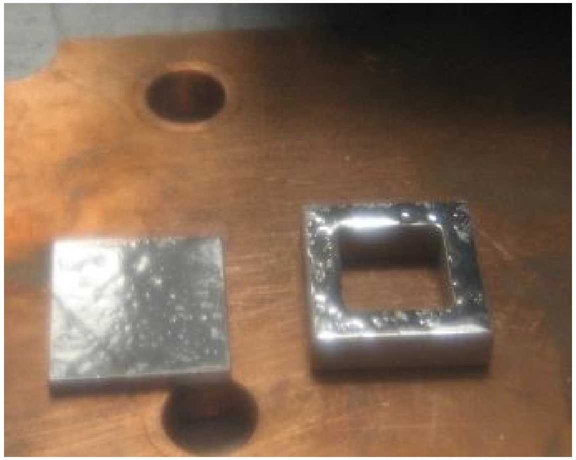


Use indium or indium alloys
- soft metal
- low melting point (157C for pure In, 72C for InBi)
- essentially zero vapor pressure
- indium-glass seals are successfully used by industry

Parallel efforts: „Hot Seal“ and „Cold Seal“ (or “Compression Seal“)

Hot Seal

Step 1:
apply melted indium onto the glass



Step 2:
bring parts into contact and press

Step 3:
pump from open side and leak check

Prerequisites for leak-tight seal

- **Strong Indium-Glass bond**
- **Strong Indium-Indium bond**

Phase I (in air)

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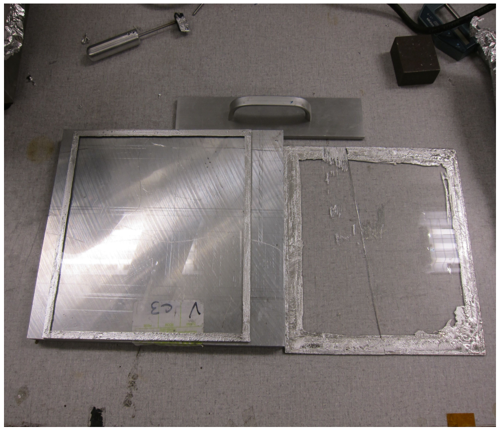
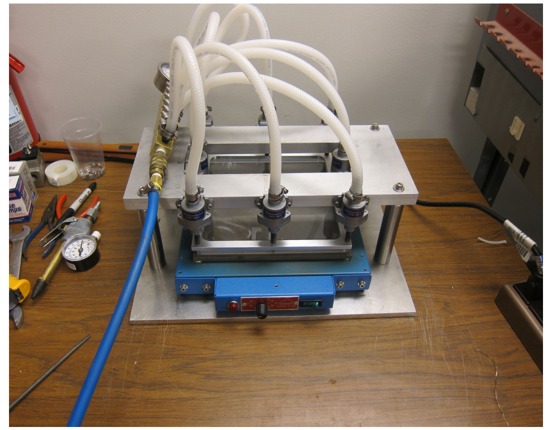




A.E., Henry Frisch, Mary Heintz, Bob Metz, Richard Northrop, Razib Obaid

- **Indium seal fundamentals**
  - interface (good adhesion of indium to the glass surface)
  - oxide formation

- **Proof of principle using 1x1" test samples**
  - little oxidation (assembly is fast)
  - many successful reproducible leak tight samples

- **Several (>10) attempts to make 8x8" seal**
  - oxide formation becomes limiting factor (slow assembly)
  - best result is a part with 10^{-6}cc/s leak at a single pinpoint

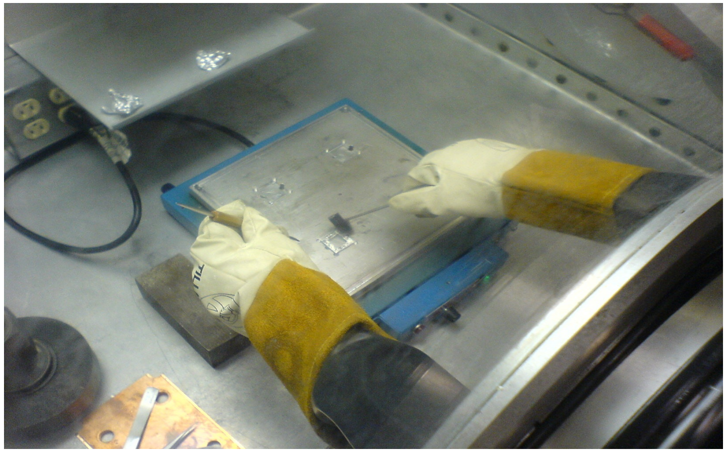
...indium oxidizes quickly...

Phase II (in inert atmosphere)

Phase IIa (in inert atmosphere)

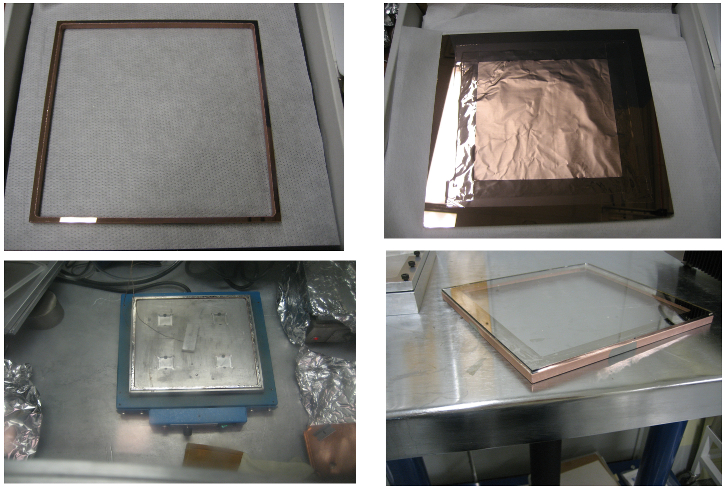
Nitrogen filled glove box:

O_2 and H_2O concentration ~5ppm



...indium doesn't stick to glass if no O_2...

Phase IIb (add NiCr-Cu layer)



Borrowed from SSL seal (200nm of NiCr+Cu)

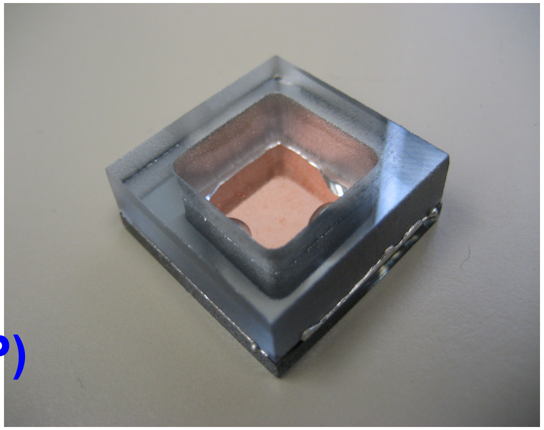
Known facts:

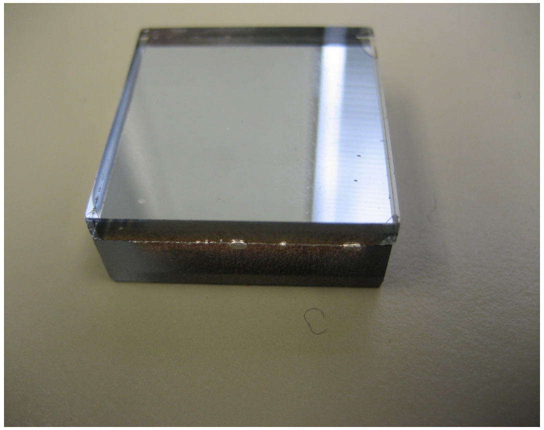
- **Indium wets copper surface**
  - *Alloy is formed at the interface over time*
- **NiCr interface to glass is essential**
  - *NiCr is a good match to glass in terms of thermal coefficient*
  - *Cu would not stick to bare glass but does so on NiCr*

Testing NiCr-Cu-In Interface

Total 8 small size seals made: 5 are leak tight
3 have leaks (oxidation of Cu surface or electroding peeling off the glass)

NiCr-Cu coating of 1" samples done by
D. Walters (ANL)
M. Kupfer (UIC)
J. Williams (ANL-HEP)
C. Liu (ANL-APS)
Q. Guo (UChicago MRSEC)





Shear tests results

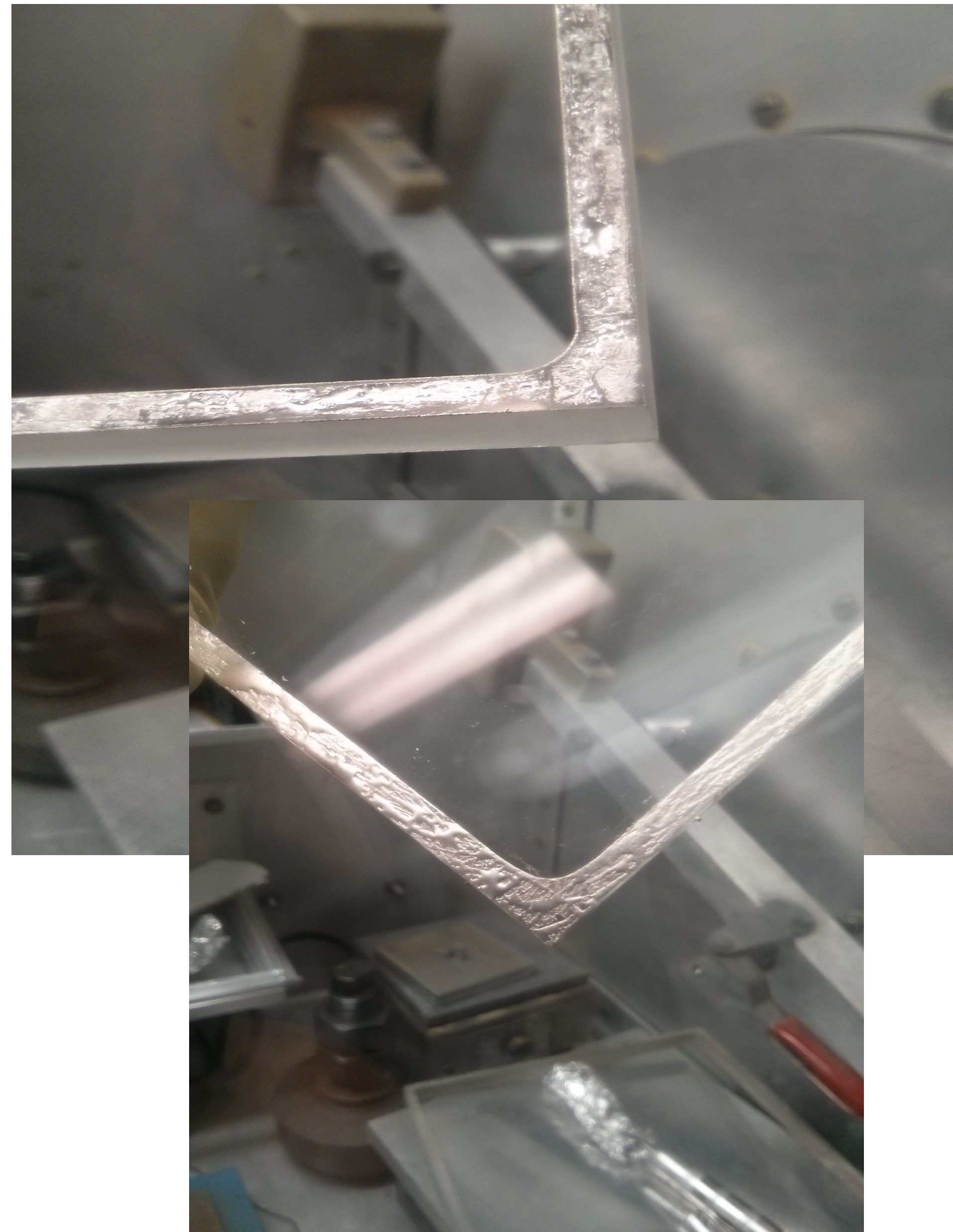
Leak tight samples:

Bare glass #1	190 lbs
Bare glass #2	278 lbs
Bare glass with groove	268 lbs
Cu coated glass #3	390 lbs
Cu coated glass #4	345 lbs

Samples with a leak:

Bare glass #4	47 lbs
Cu coated glass #1	213 lbs
Cu coated glass #2	221 lbs

Sealing 8x8" parts



Testing NiCr-Cu-In Interface

Coating goes away if re-heated to 180C

Photos from Metallurgical Microscope (by H.L.Clausing)

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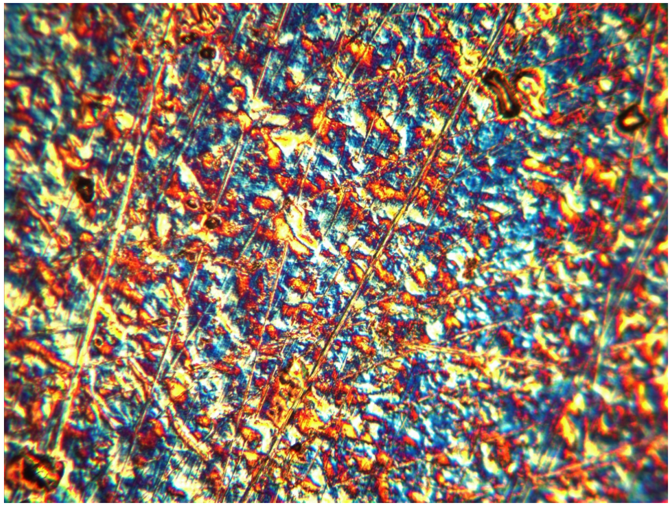
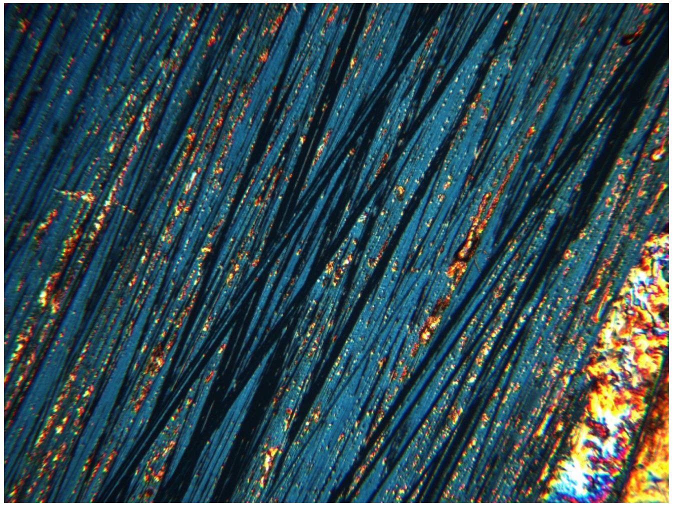
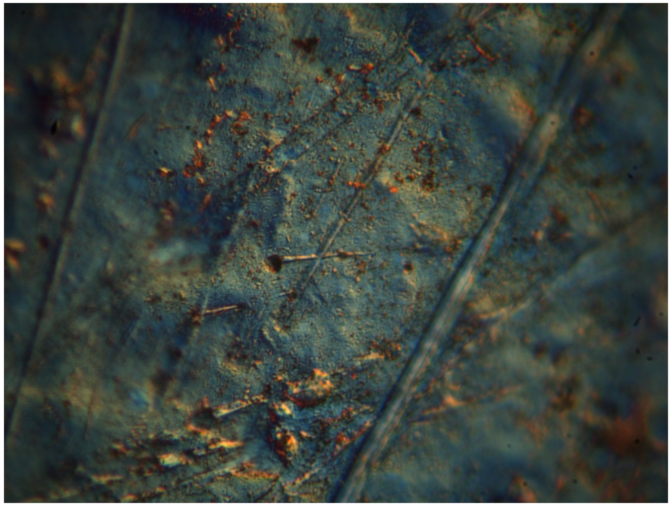
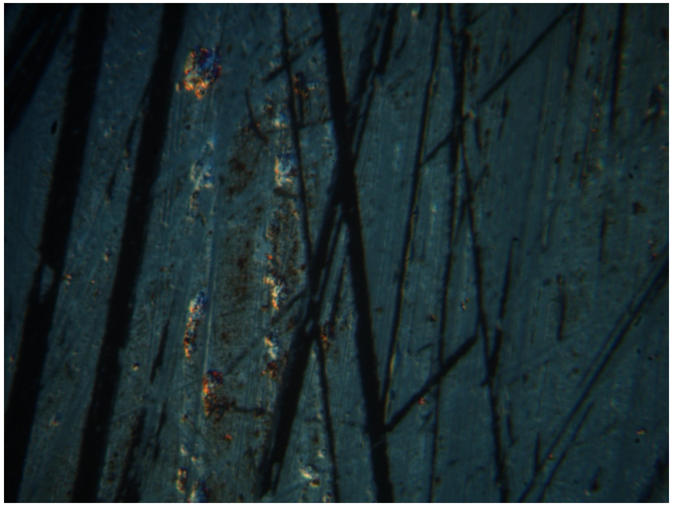
Thick side		Thin side
	x200	
	x1000	

Cu layer dissolves in indium

Solution

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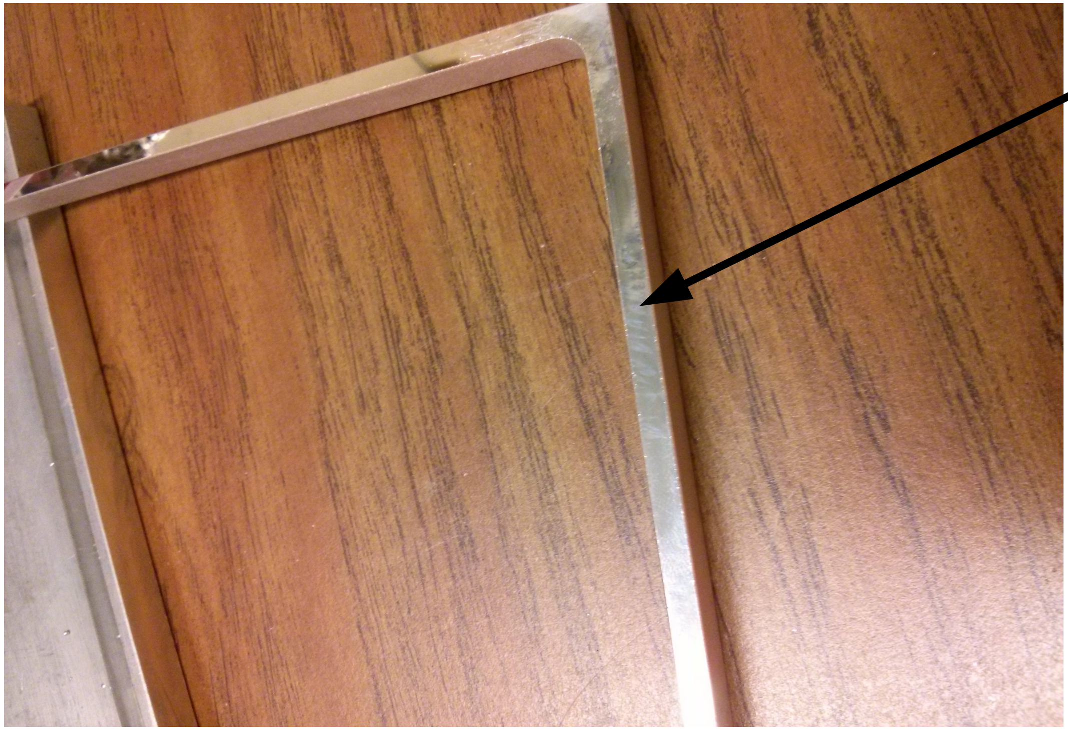
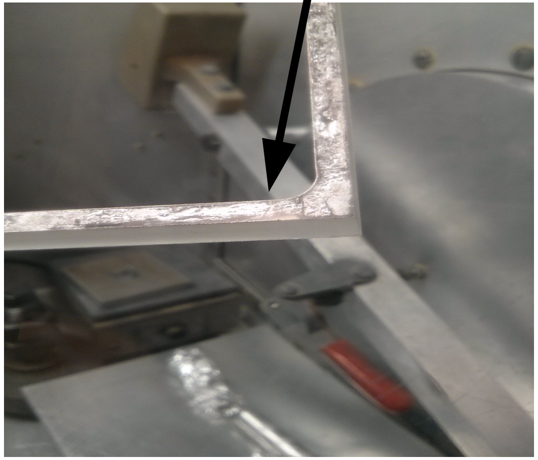
Switched to InBi alloy (melting point 72C)
No signs of Cu scavenging by InBi

Why pure In works on 1x1“ samples?
- faster assembly (less time at high temperature)
- less mechanical rubbing

InBi wetting test



Compare pure In



400cm^2 seal with 2.75 mm window

First leak tight 8x8“ seal using LAPPD glass parts

Leak Test

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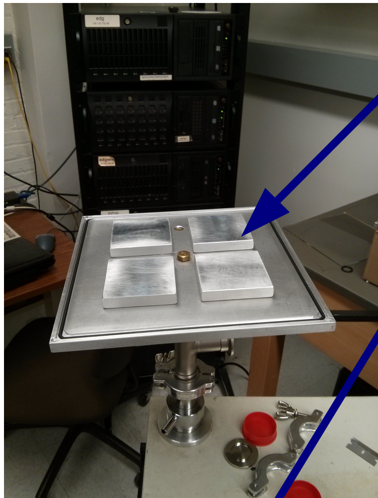
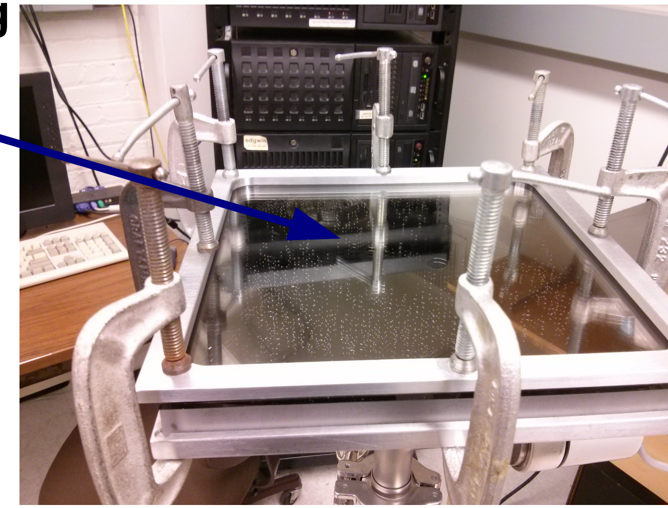
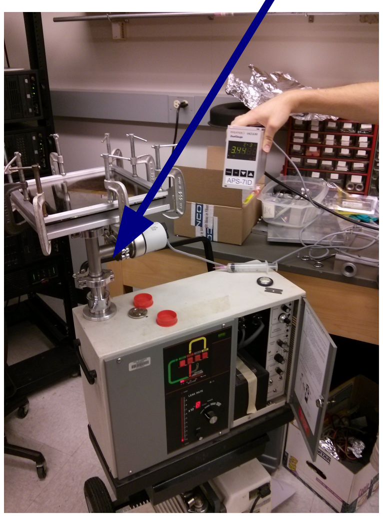
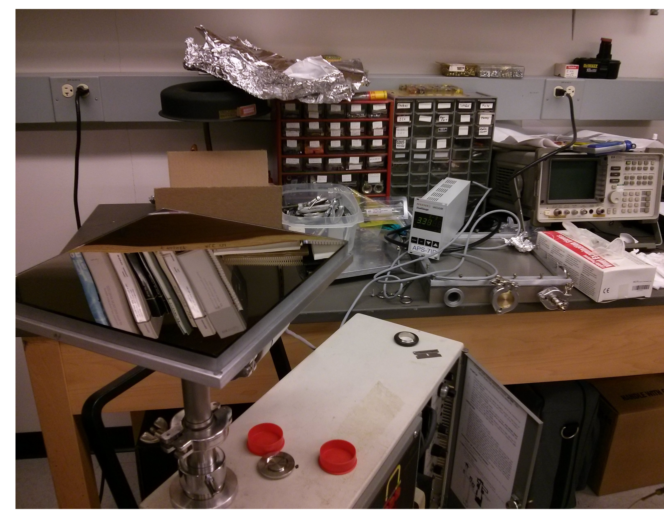


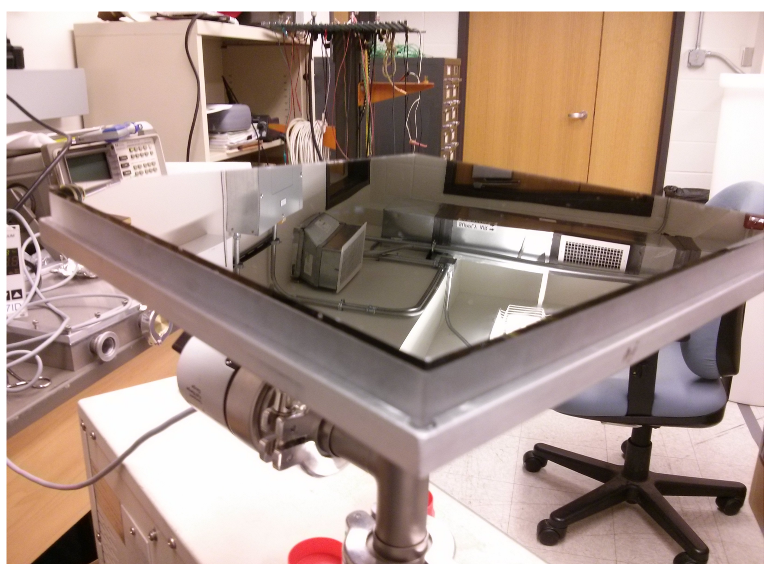
Many tricks to avoid glass cracking when the pump starts



- Leak checker sensitivity 10^-8 cc/s of He
- Leak test lasted for 1 hour
- No leaks found!







Next Steps

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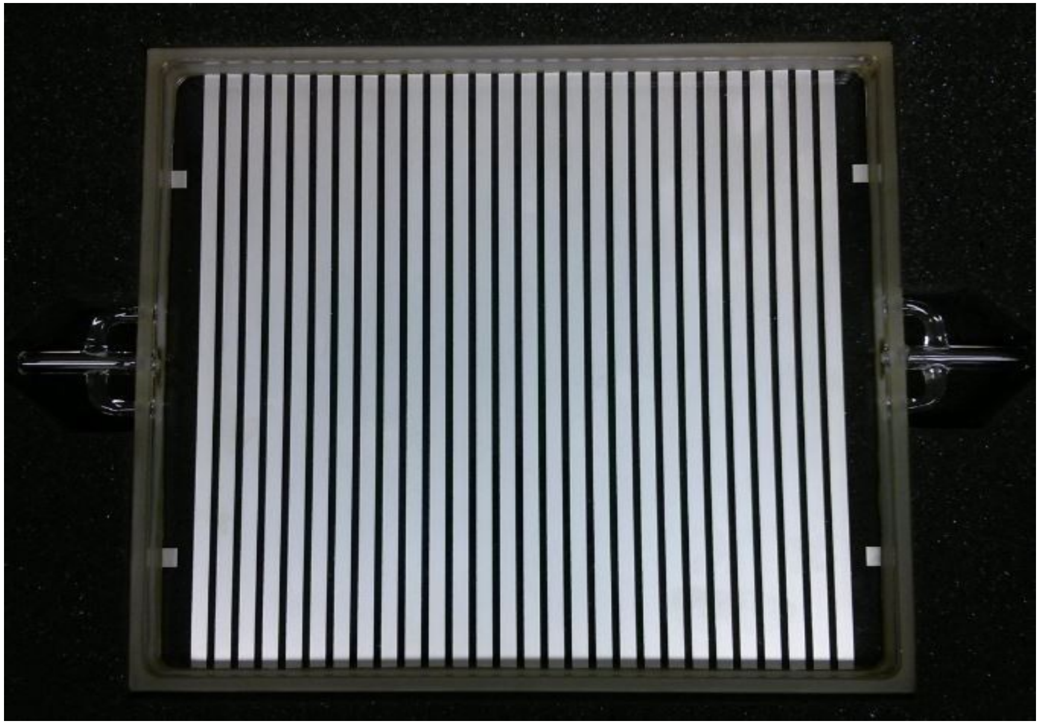
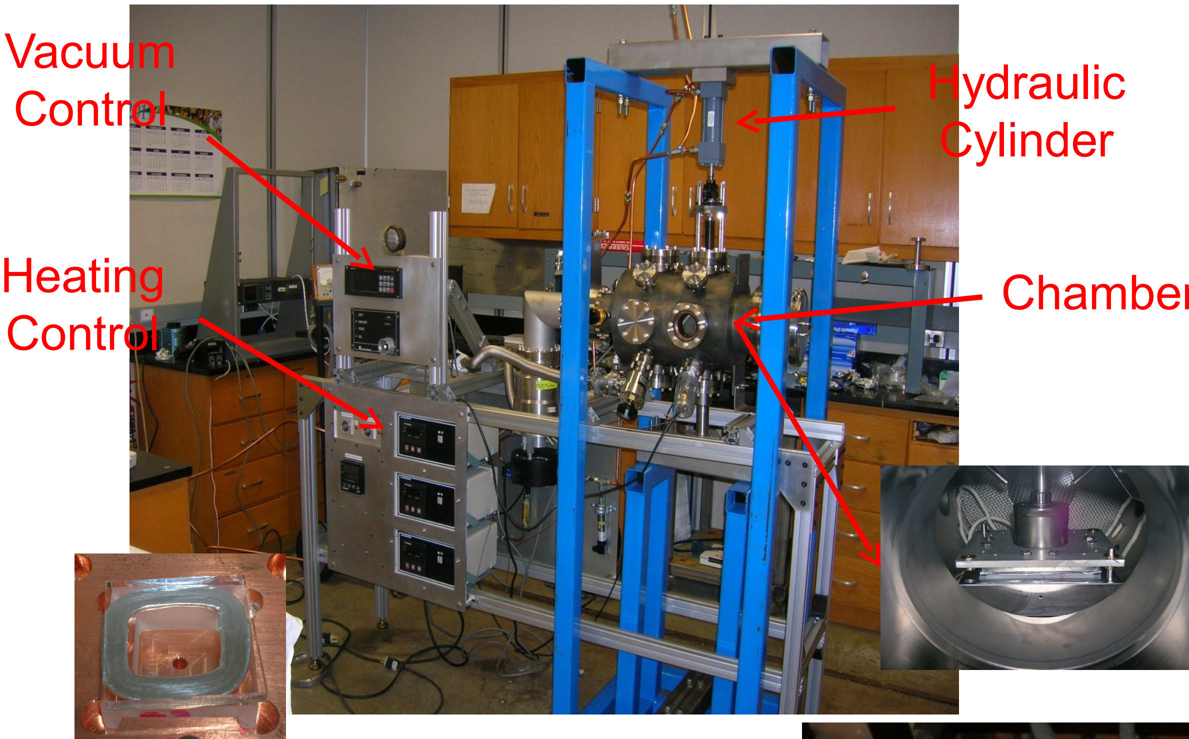
- **Test reproducibility of the"hot seal" recipe**
- **Move forward with tile assembly**
- **Try to make photo-cathode by In-Situ Photo-Cathode Synthesis** (possible lunch topic)

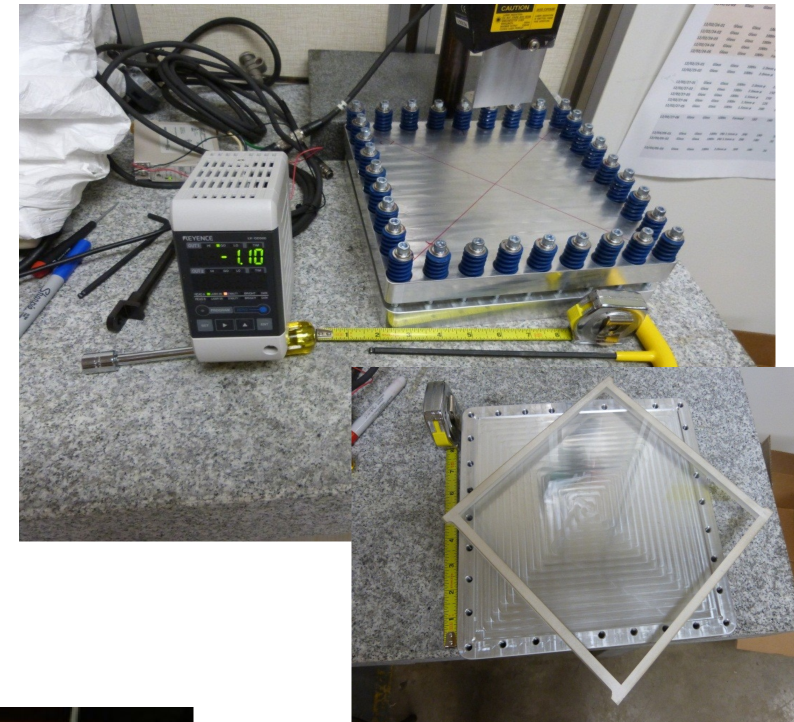


"Cold Seal"

Hydraulic system



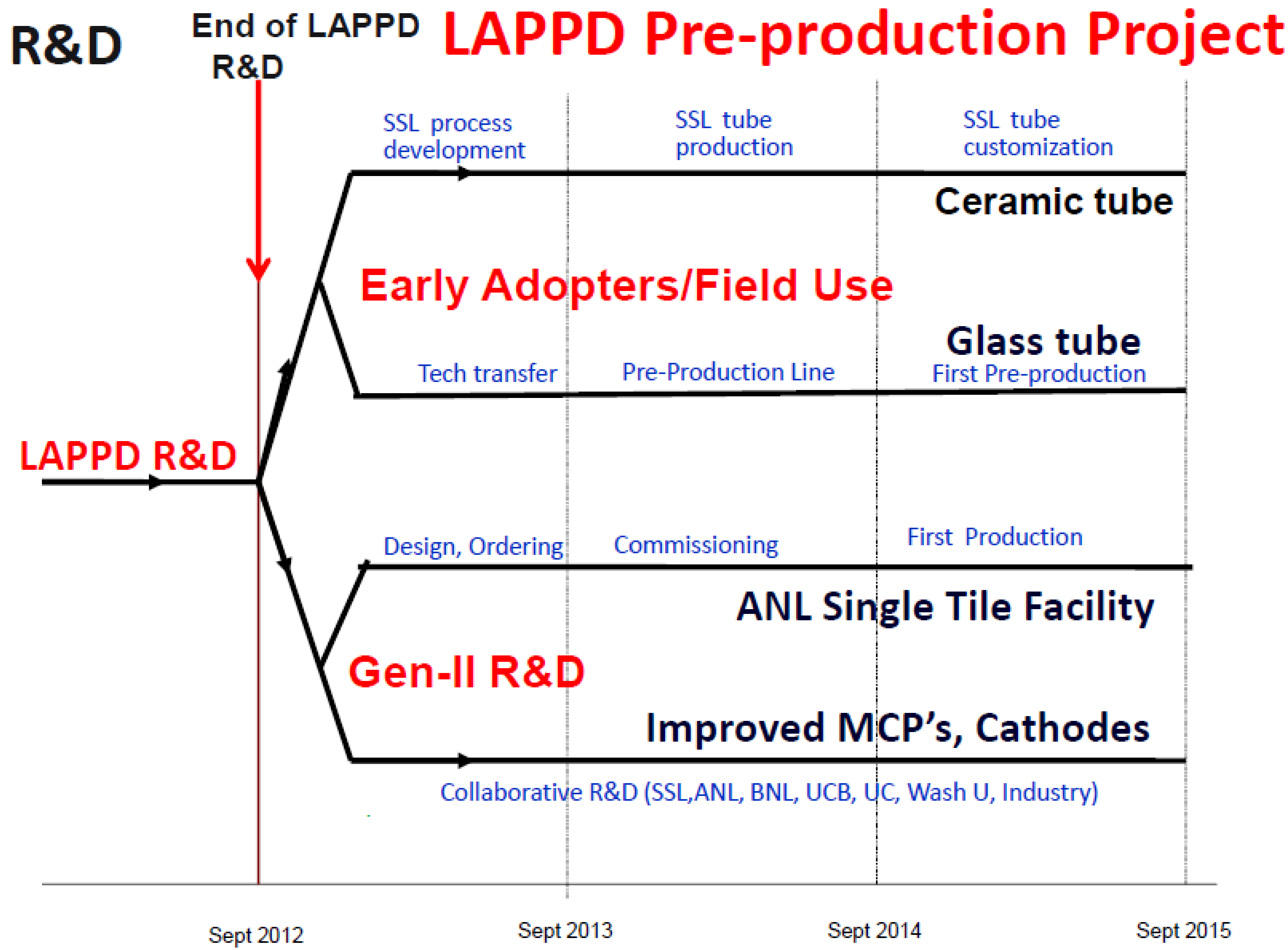
Spring compression



M.Kupfer, D.Walters,

J.E.Indacochea

Parallel Efforts on Specific Applications



12/11/2012

Organization of Pre-production Project

3

1. TOF in the LArIAT Beam
   a) Why: Simplest set-up that has a large impact on HEP programs
   b) Straight-forward interface to experiment
   c) Local, have collaborators in place;
   d) Drop in for scintillators and PMTs at higher cost and better performance
   e) Spec: 4 stand-alone single tile stations, 10 psec time resolution, 50KHz (needs checking)

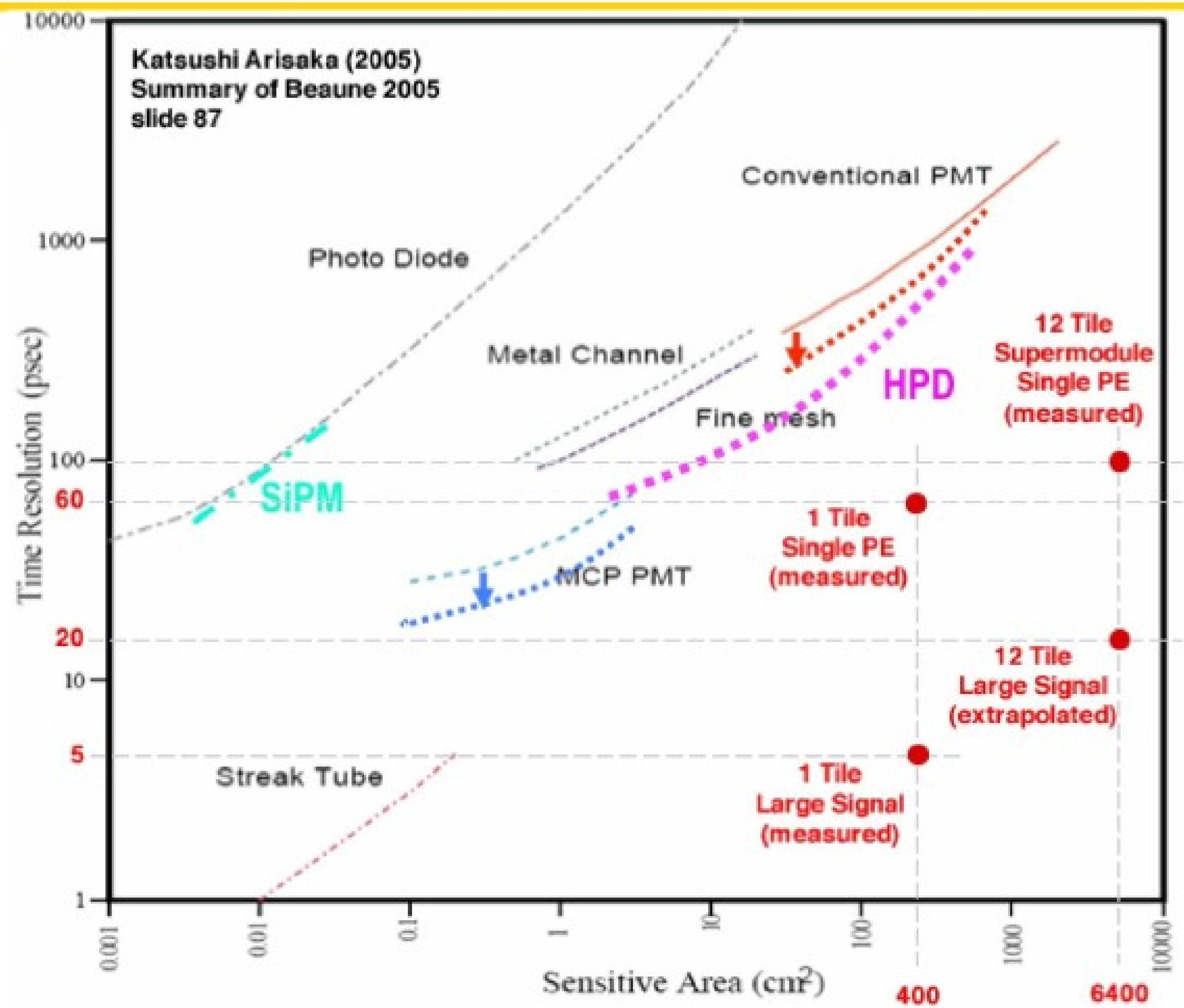
2. Small (1-4 m^3) water neutrino detector prototype
   a) Why: Comparison to simulation; test of the optical TPC concept with track reconstruction
   b) If successful, no competition
   c) From 1 to 6 SuperModules;
   d) Spec: Single pe resolution ~ 100psec, low rate

3. Pre-converter in KOTO
   a) Why: Archetype for 3D localization and precise timing of high energy photons
   b) Good access to management and technical expertise in the experiment
   c) If successful, no competition
   d) 1-4 SuperModules
   e) Spec: Timing = 1 psec; Rate = 200 kHz; Position = several mm; Trigger latency = 5 μsec
   f) HEP benefit: Increased physics reach

COST COMPARISONS DEPEND ON CAPABILITY

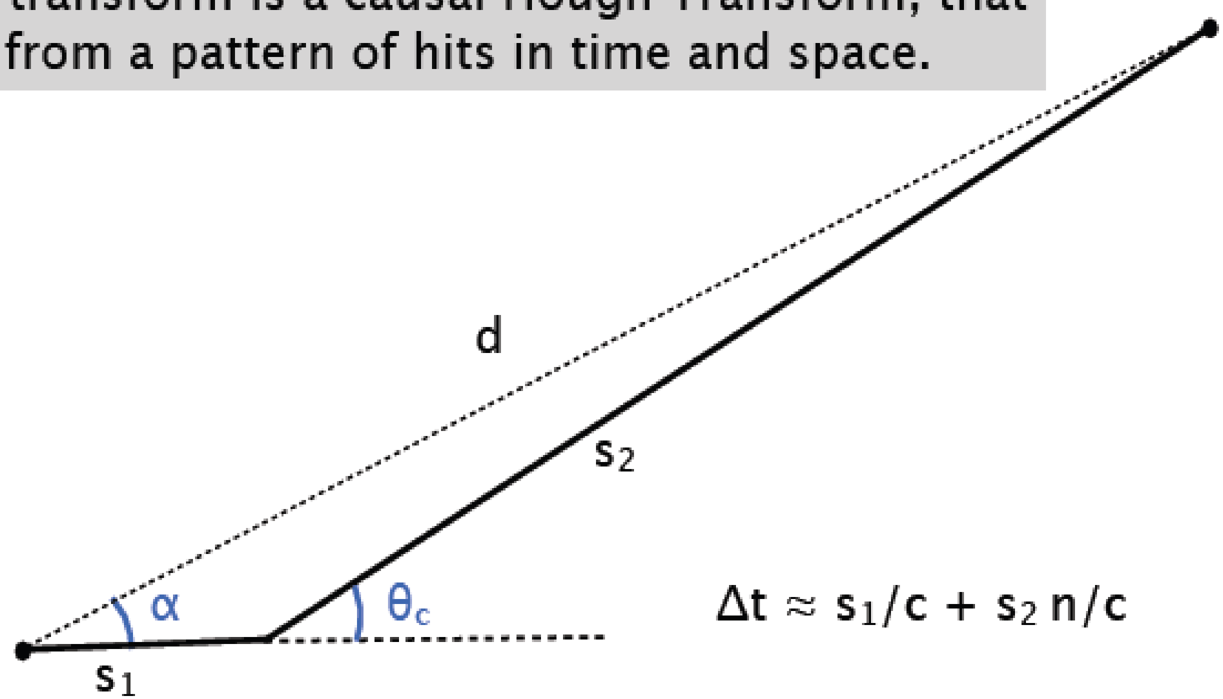
Correlated time-space points can lower overall cost- for applications that don't need time-space resolution it's very unlikely MCP-PMTs will ever be as cheap as PMT's. However:

The dt/A Arisaka plot



Track Reconstruction Using an "Isochron Transform"

The isochron transform is a causal Hough Transform, that builds tracks from a pattern of hits in time and space.



Connect each hit to the vertex, through a two segment path, one segment representing the path of the charged particle, the other path representing the emitted light. There are two unknowns:

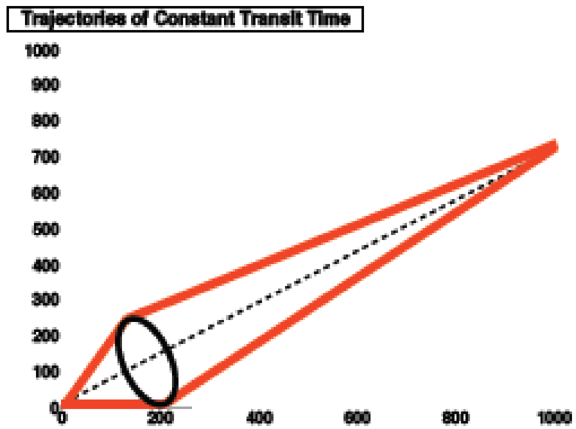
s_1 and α

but there are two constraints:

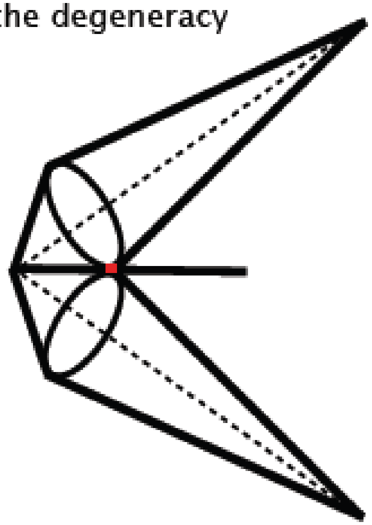
$s_1 + s_1 = d$ and $\Delta t_{measured} = s_1/c + s_2\, n/c$

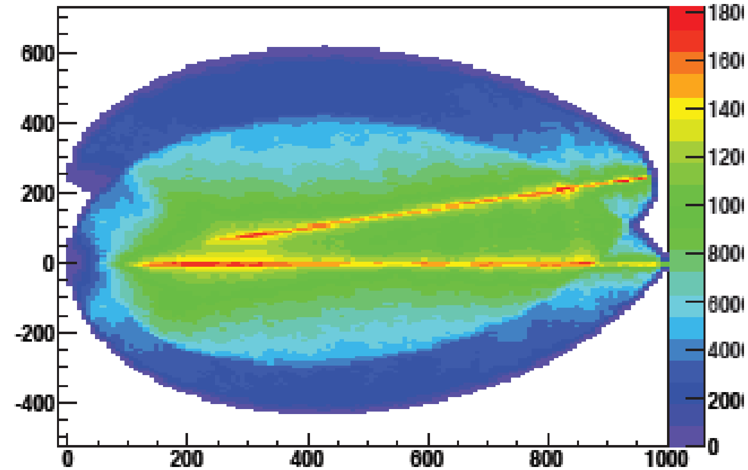
Track Reconstruction Using an "Isochron Transform"

Of course, there is a rotational ambiguity in the position of possible tracks.

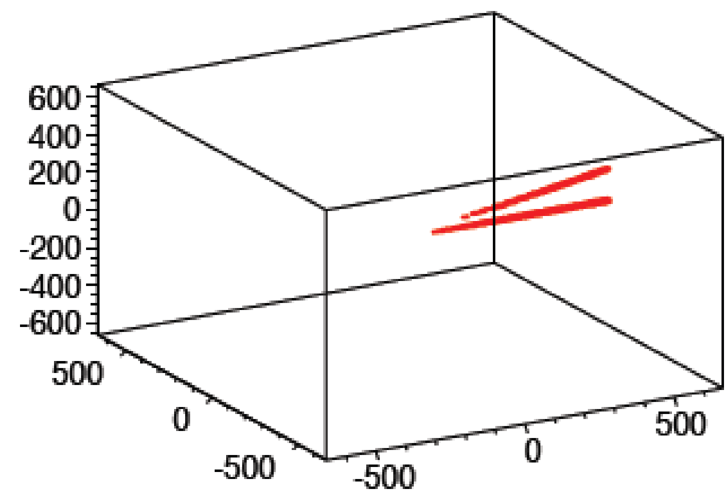


But, multiple hits from the same track will intersect maximally around their common emission point, resolving the degeneracy

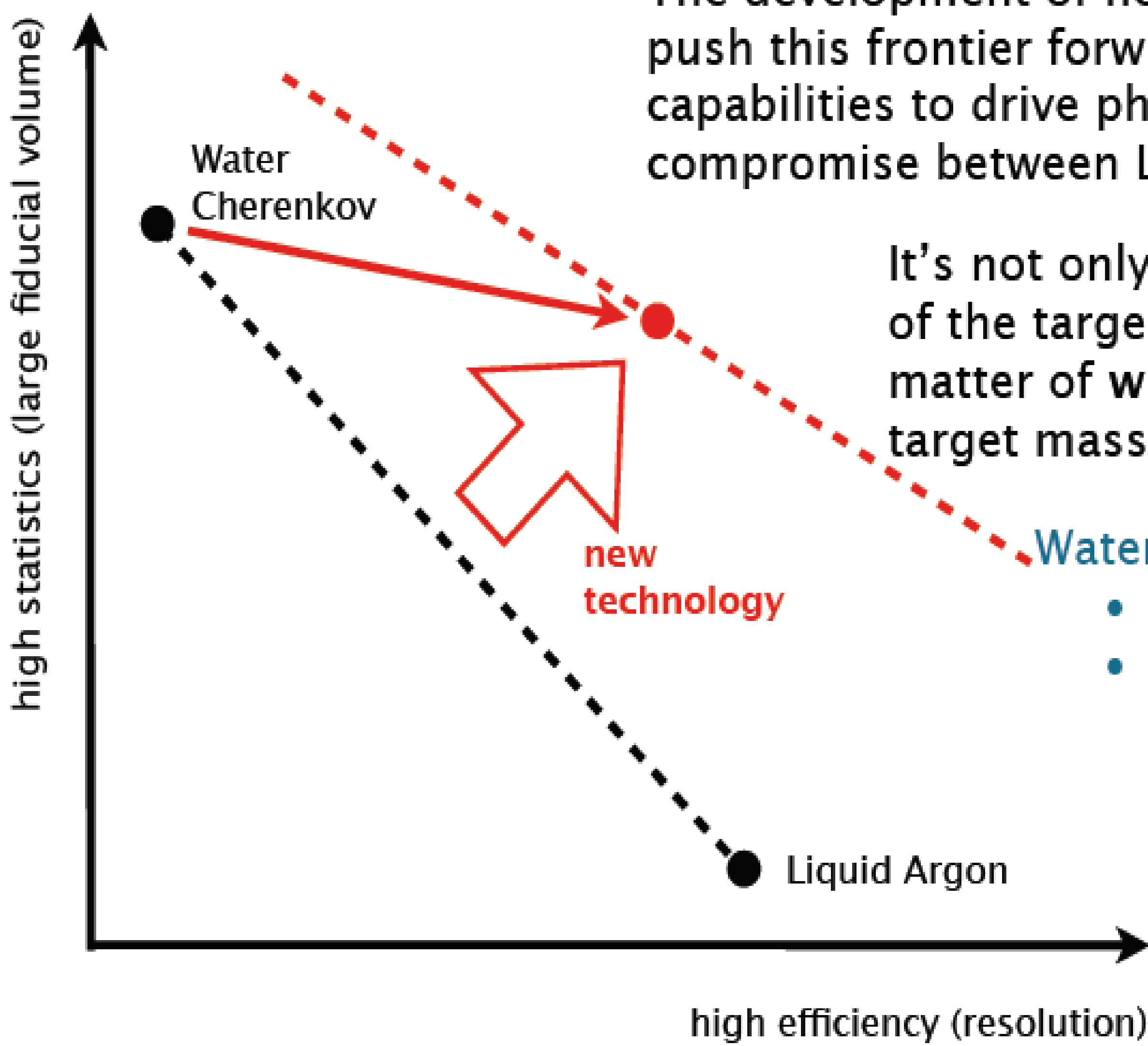




When integrated over all hits, these regions of dense intersection points form clusters around those tracks that share a common vertex. Here we demonstrate closure on a simple two-track toy with light no scattering or dispersion



The limits of thinking bigger



The development of new technology could push this frontier forward. New capabilities to drive physics. A compromise between LAr and WC?

It's not only a matter of the size of the target mass! It's also a matter of **what** you use for your target mass.

Water:

- lots of free protons
- sensitivity to low energy $\overline{\nu}_e$