Using Fast Photosensors in the Next Generation Water Cherenkov Neutrino Detectors

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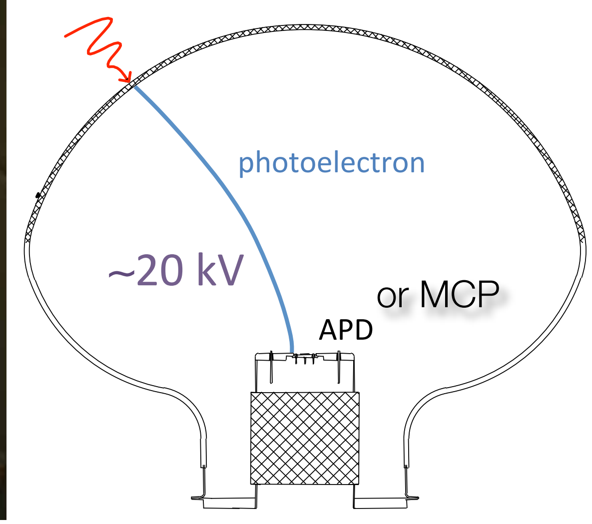
3rd International Open Working Group Meeting for the Hyper-Kamiokande Project - June 21-22, 2013

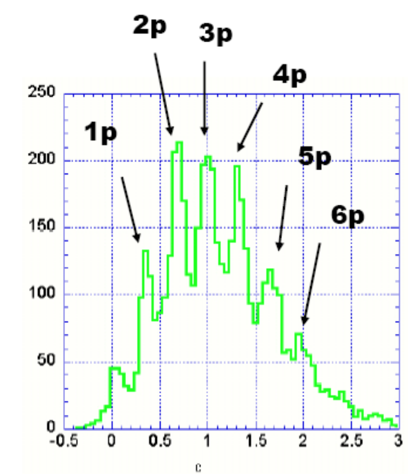
Photodetector technologies

Two promising large-area photosensor R&D

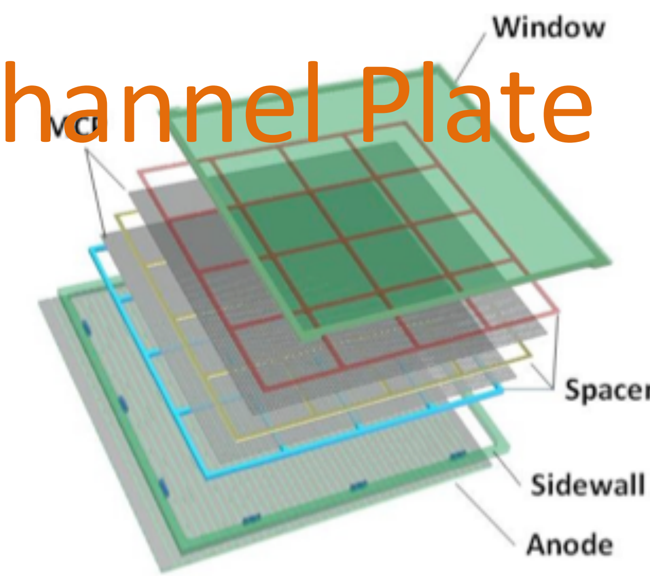
E. Kearns

Hybrid Photo-Detector





Large Area Micro Channel Plate



<100 ps timing

Both with potential improvements in timing resolution

Photodetector R&D for Hyper-K

- Hyper-K photosensor candidates:
  - 20-inch hybrid photodetector (HPD)
  - 20-inch improved or HQE PMT
- 99K required for 20% coverage
- 58K HQE for 13% coverage
- **Expected time resolution gains for HPDs:**

	8”HPD	20”HPD	20”PMT
HV	~8kV	~8kV	~2kV
Gain	10^4-10^5	10^4-10^5	~10^7
TTS(ns)	0.6	1.1(*)	2.2
C.E.	~97%	~95%(*)	~70%
AD dia.	5mm	20mm	-

(*) expectation from field calculation. preliminary value

H. Tanaka - ISOUPS

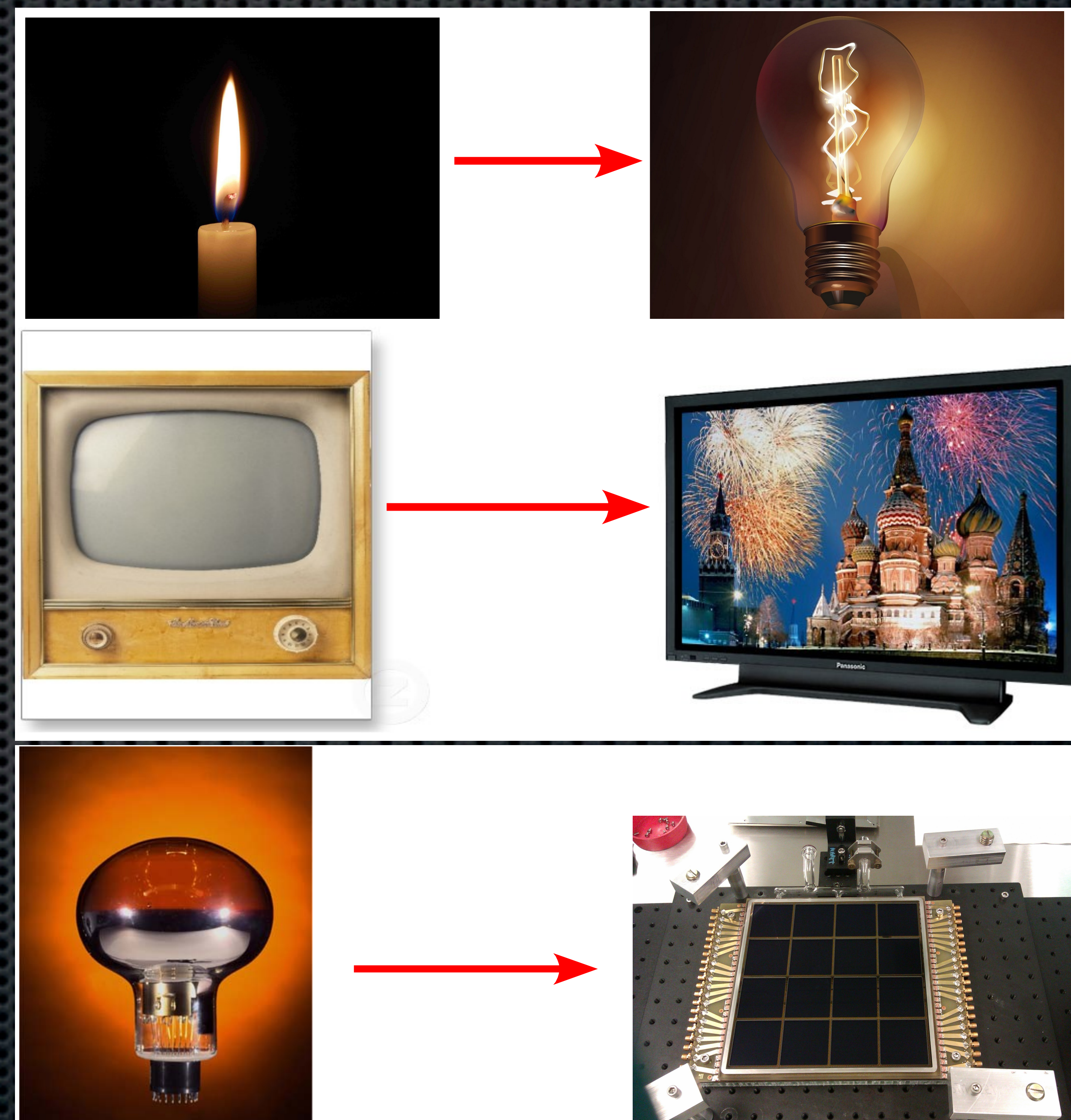
M. Shiozawa/ T. Nakaya

Photodetector

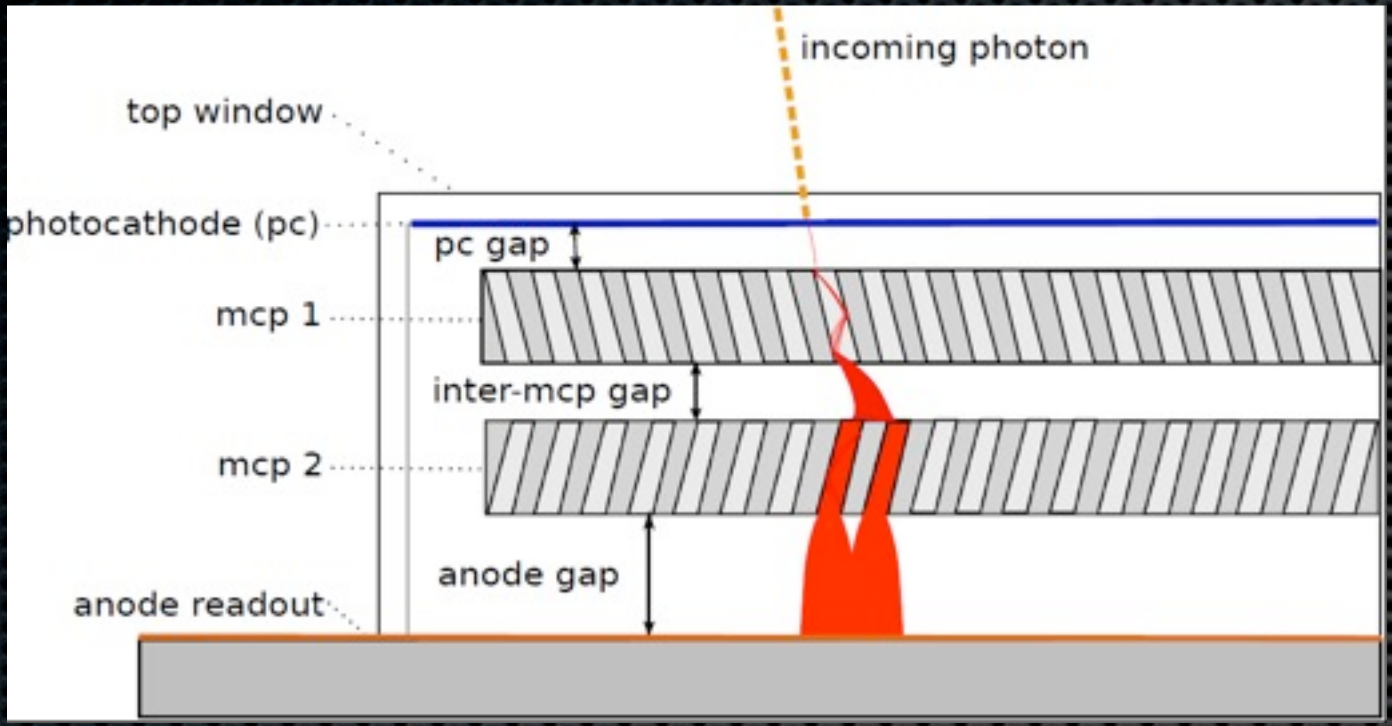
2012 R&D 100 50th ANNIVERSARY

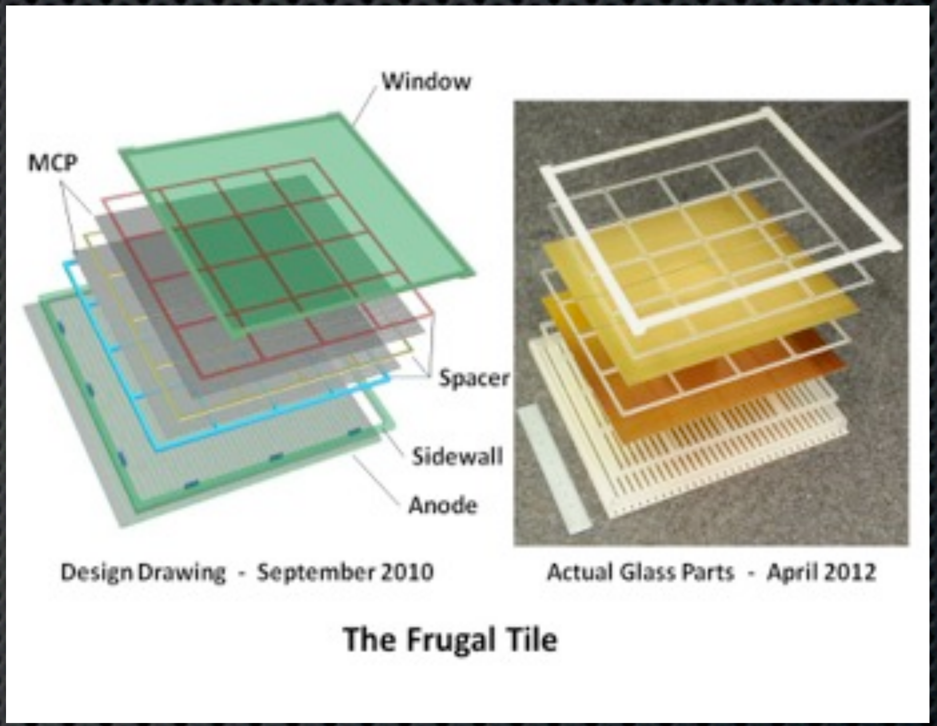
generic

- **Large-area picosecond photodetectors (LAPPD)** based on **microchannel plates** are being developed at Argonne National Laboratory in close collaboration with universities, other labs and private companies.
- For a **neutrino application**, these could be tuned to:
  - Timing resolution of **~100 psec** (order of magnitude improvement)
  - Spatial resolution of **~1cm**
- Alternatively, worse timing/less spatial resolution could lower price.

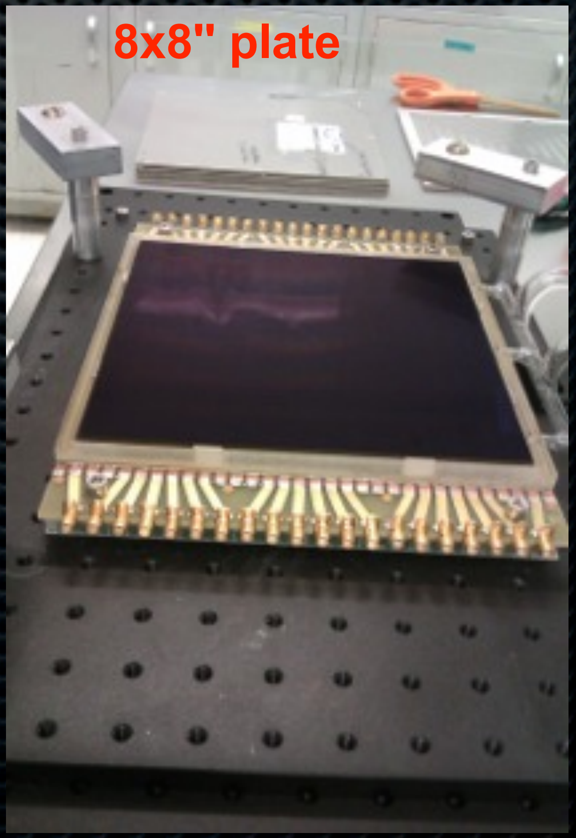


The 8-inch LAPPD glass tile



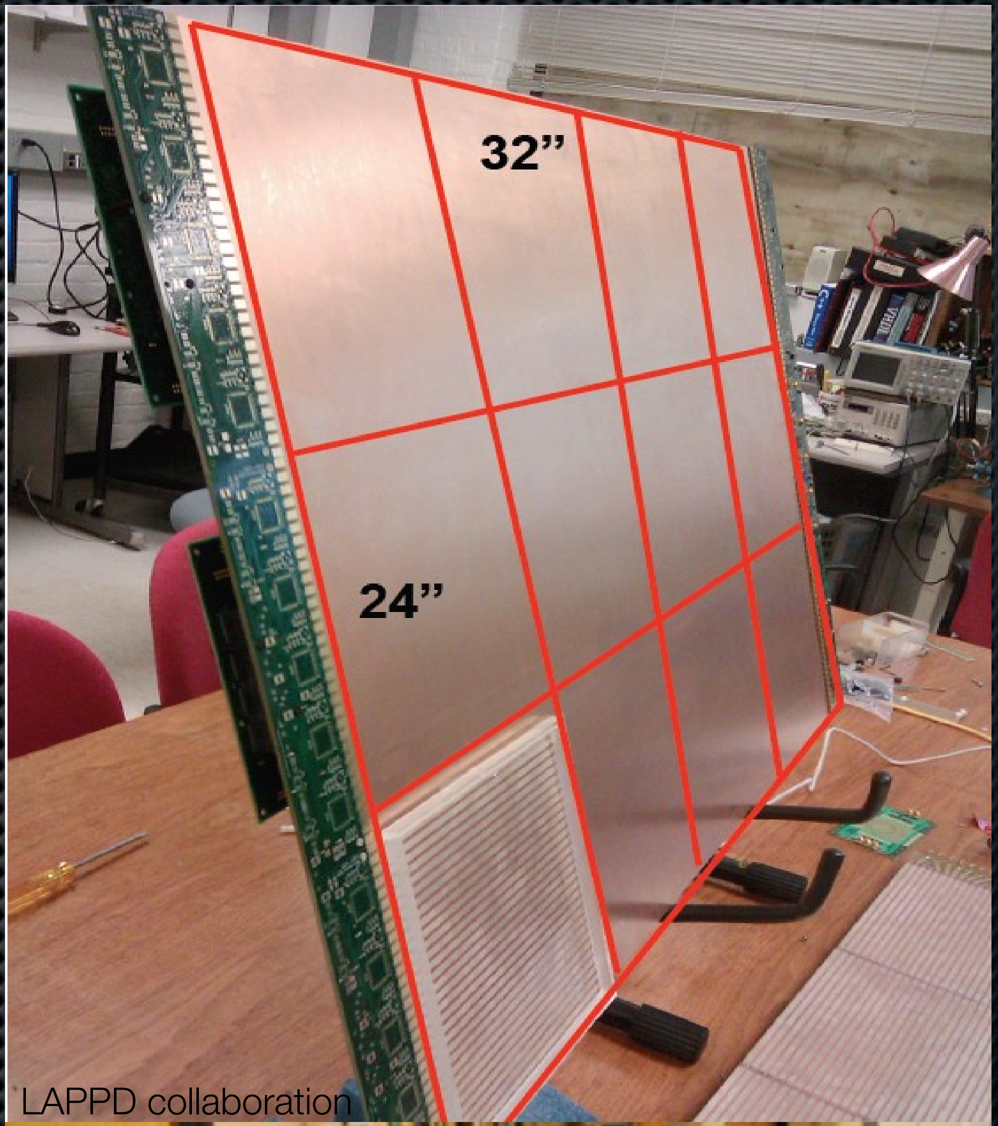


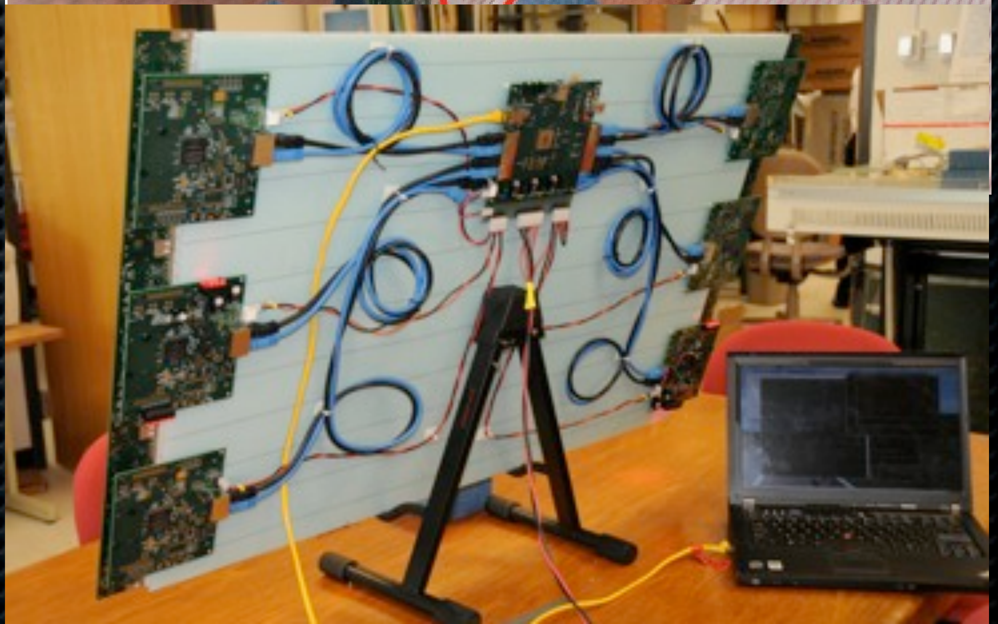
- Cheap, widely available float glass
- Anode is made by silk-screening
- Flat panel
- No pins, single HV cable
- Modular design
- High bandwidth 50 Ω object
- Designed for fast timing
- Alternative ceramic packaging also developed



The LAPPD super-module

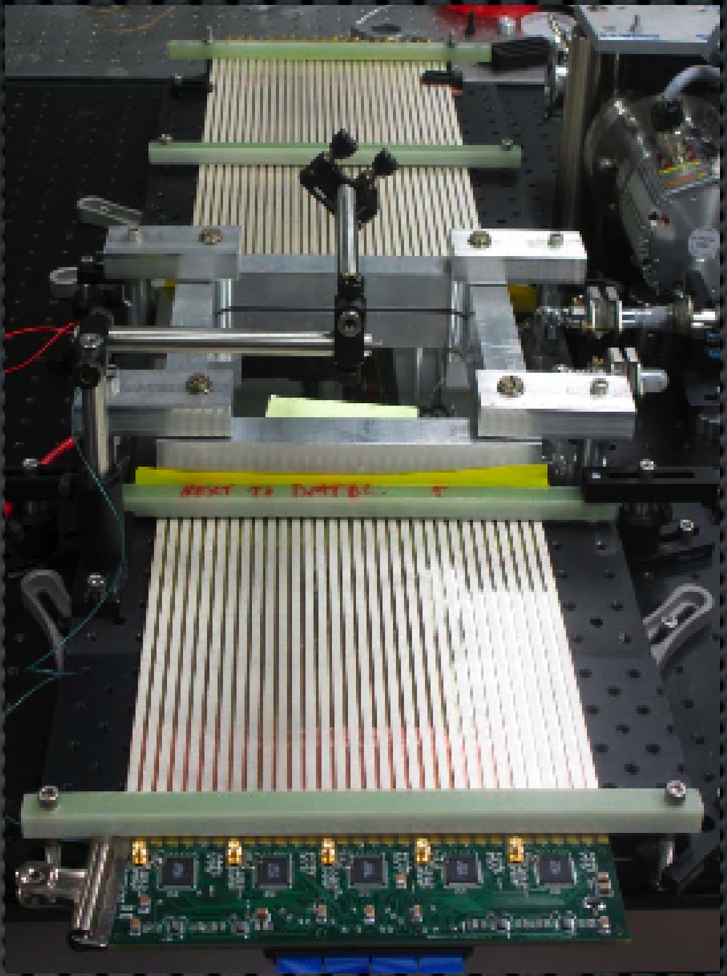
- Microchannel plate photosensor in 8x8” tiles arranged in 24x32” super-module.
- Tiles share single line anode.
- 100 psec time res/1cm spatial res
- Channel count optimized to large area/desired granularity.
- Integrated electronics/double-sided readout.
- Scaled high QE photocathode.
- Thin planar glass body detector.
- No magnetic susceptibility.



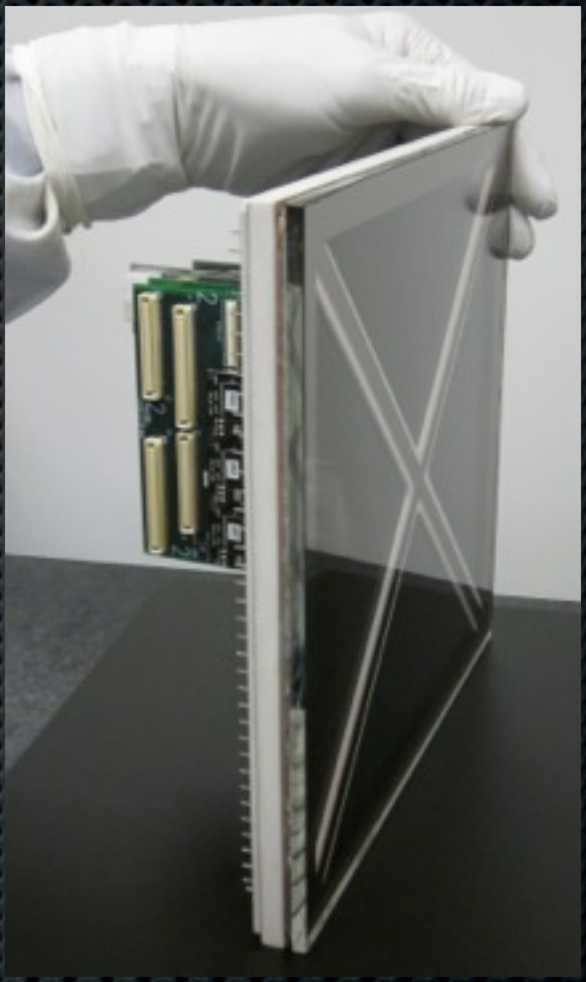


LAPPD Status

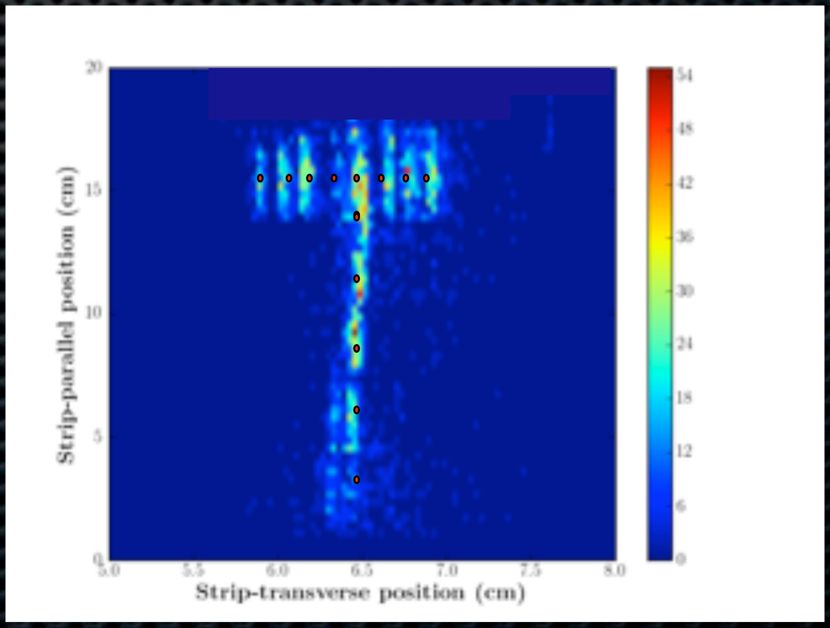
- Testing end-to-end detector system:
  - complete “demountable” glass-body 8” MCP-detector.
  - full readout and front-end electronics, 80 cm anode line.
- Producing and testing separate 8” x 8” tile, bialkalai photocathodes with QE > 20%
- There is also 8” Sealed-Tube processing tank at Berkeley SSL built and being tested.
- Psec4 chip benchmarked at:
  - 1.6 GHz analog bandwidth,17 Gsamples/second, ~ 1mV noise
- Psec electronics system is capable of shape-fitting the LAPPD pulses for time, position, and charge at the front-end.



ANL “demountable” detector system - glass body LAPPD
Reconstruct of a “T” below



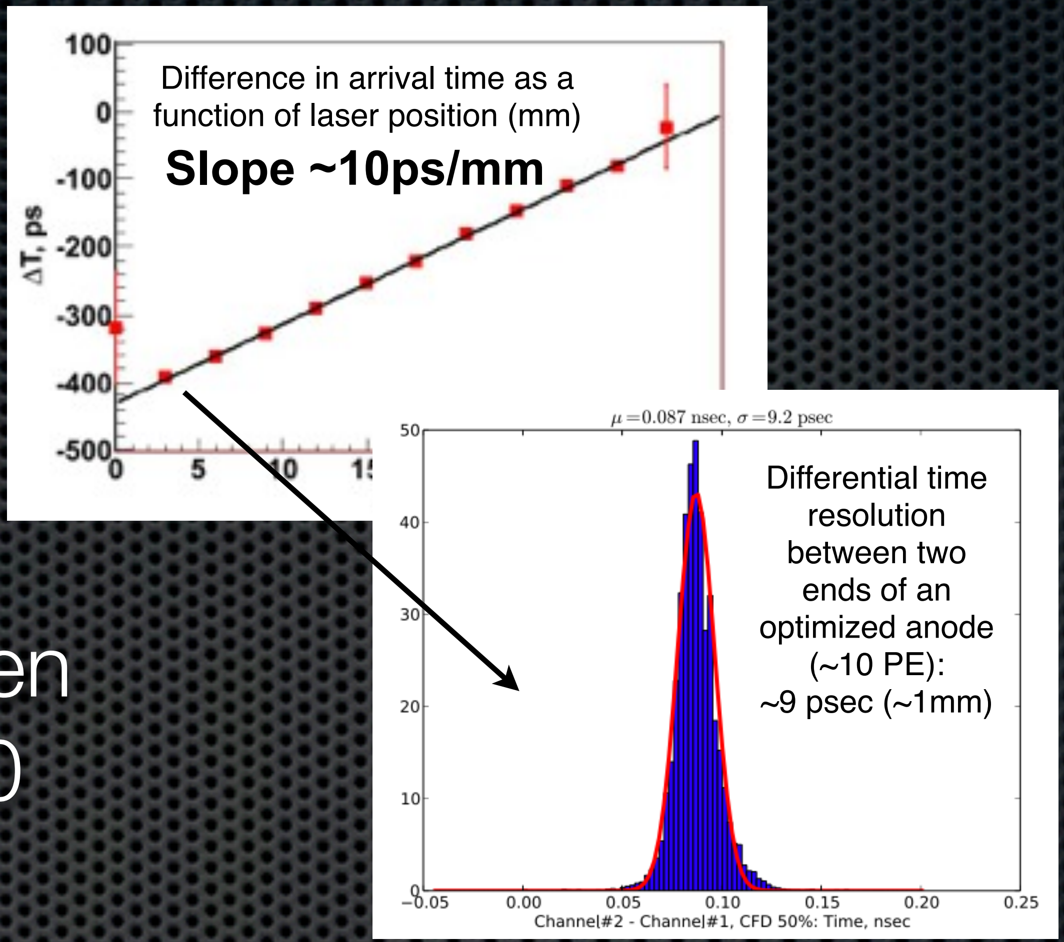
Berkeley SSL detector system- ceramic body LAPPD

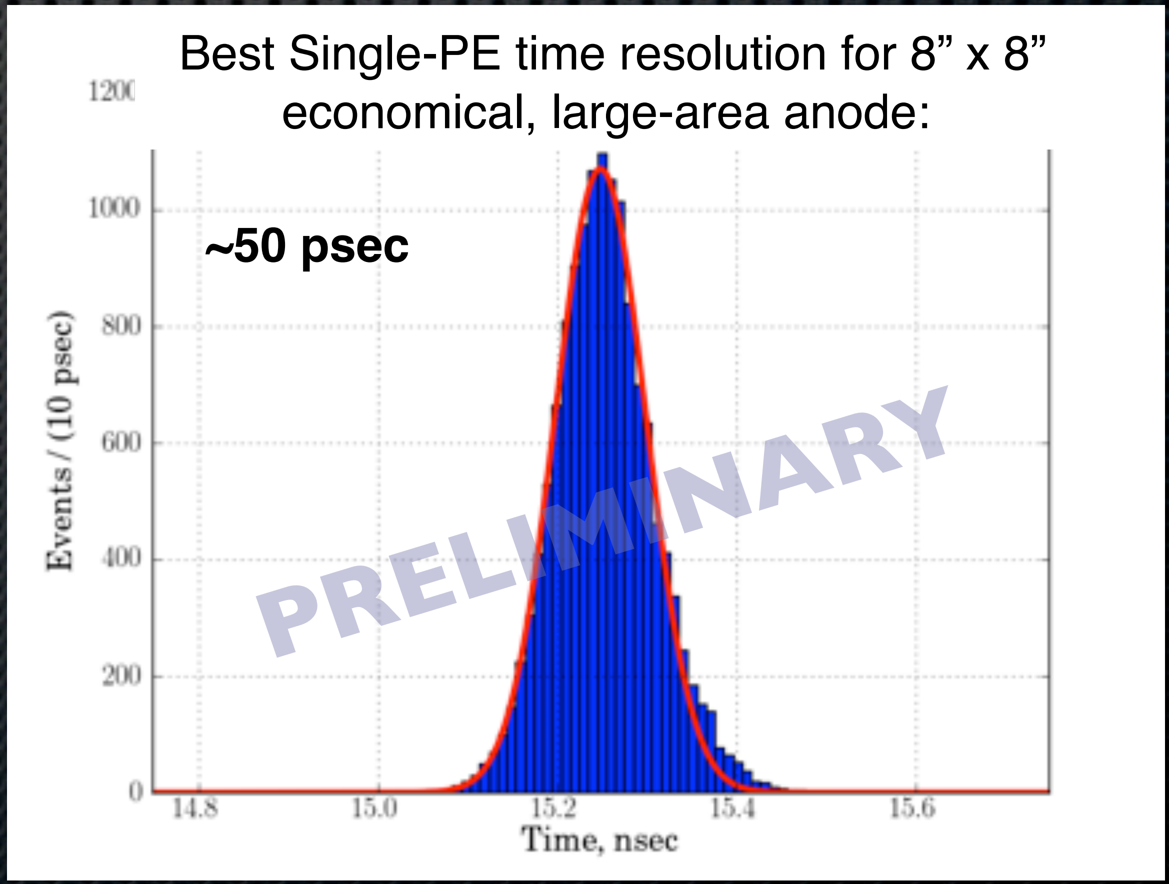


Berkeley SSL Sealed-Tube Processing Tank

LAPPD Status

- Testing 8” x 8” (Argonne-made) MCPs:
  - Pulse height peaked at **10^7 gain**.
  - Differential time resolution between two ends of delay-line anode <10 psec.
  - **2 mm spatial resolution** parallel to the strip direction, <1 mm in transverse.
  - **Time resolution of ~50 psec** using economical anode design.
- Commercialization progress: **$3 M awarded** in SBIR funding to US company to commercially develop LAPPDs.

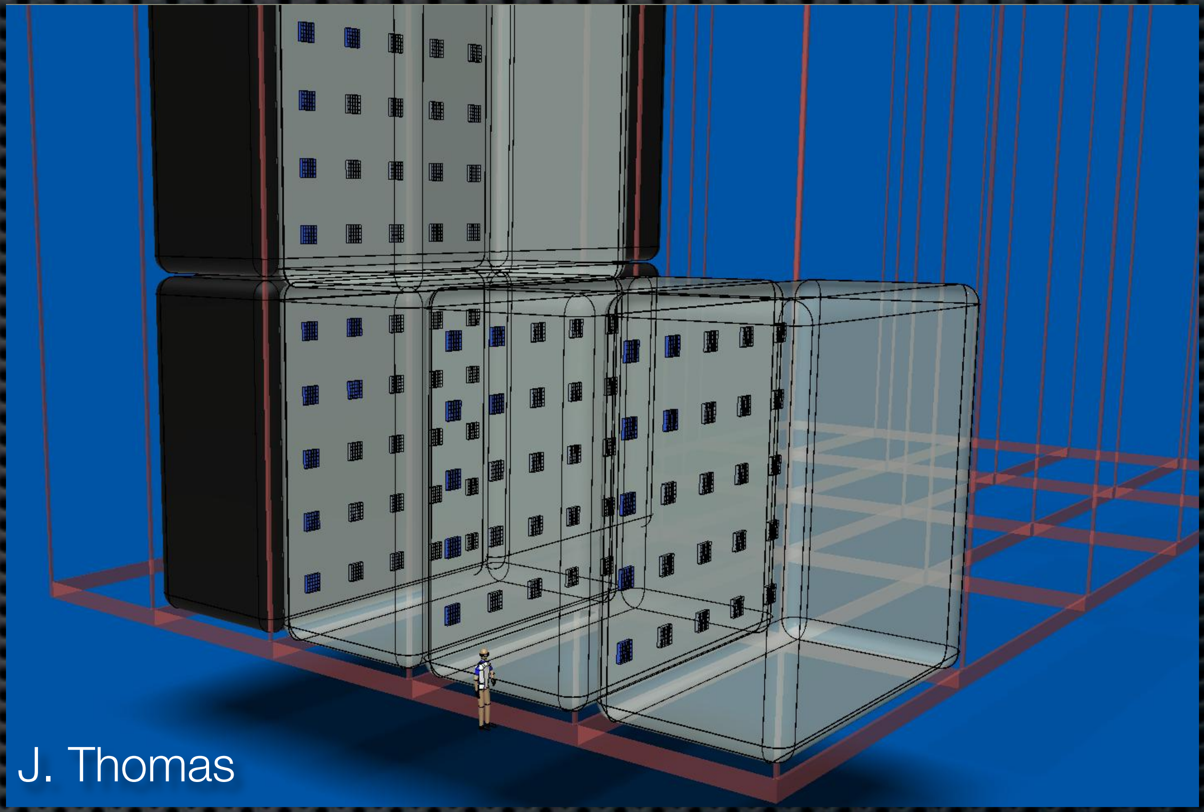




M. Wetstein/A. Elagin (UChicago/ANL)

Using fast large-area photosensors for Water Cherenkov detectors

- Motivated by these advances in photosensor technology is worth asking the following questions:
  - Does **better timing information** improve the physics capabilities of Water Cherenkov Detectors?
  - Do **photon counting** (as opposed to integrating charge) provide a significant advantage?
  - Does **improved granularity or coverage** provide additional useful information?
  - What changes to detector and photosensor design are required?



In order to answer these questions we need tools: simulation/reconstruction

Using WCSim (C. Walter - Duke U.) simulation for these studies. Modifications in digitization appropriate for LAPPDs. Reconstruction developed within WCSimAnalysis framework used in LBNE Water Cherenkov design.

Exploiting better timing/spatial information in WCh

Fast/parametric

(Timing residuals)

Useful for seed fits and helpful understanding of detector tradeoffs

Limited for complex events

Timing-residual based fits to study:

- The relationship between vertex resolution and detector parameters.
- Improvements to track reconstruction with chromatic corrections.

Using causality

(Generalized Hough Transforms)

Requires no initial assumptions about event topology

Only makes use of direct light

- Isochron Transform: Causality-based Hough transform for building track segments from photon hit parameters.
- Exploring more detailed reconstruction of EM shower structure.

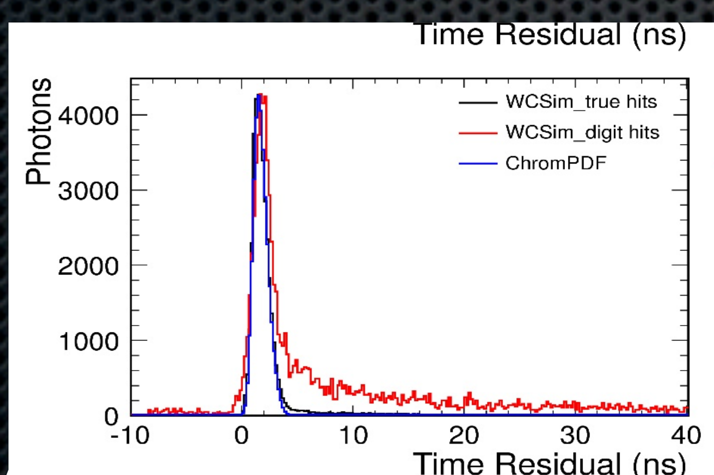
Using all light

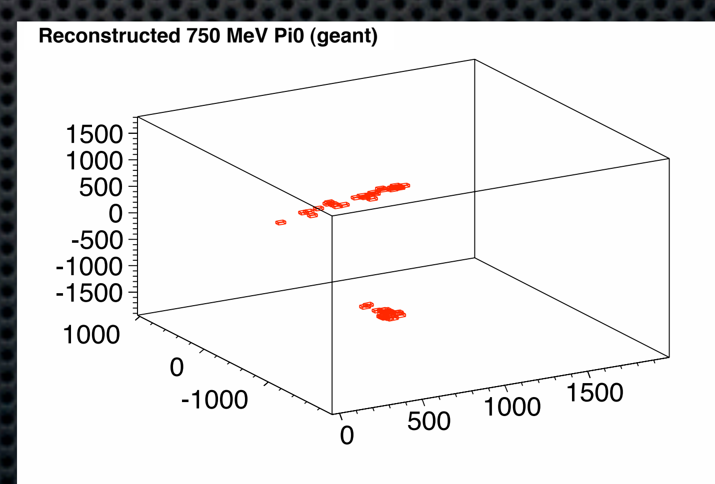
(Pattern of Light)

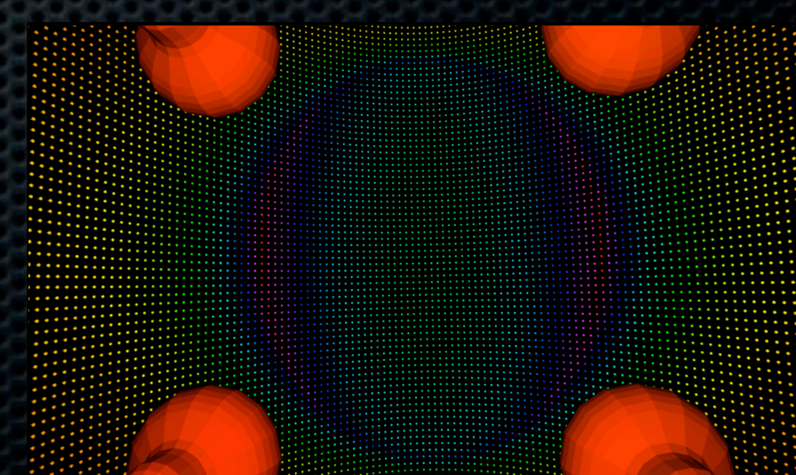
Makes fullest use of all photon information, both direct and indirect light

Becomes computationally intensive as one tries to resolve finer structure in the event topology

- Use of pattern-of-light fit, where the full light pattern for each track hypothesis is generated.
- Used in Miniboone and newer Super-K/T2K reconstruction.
- Use of large sample MC/scattering tables to address computational challenge.

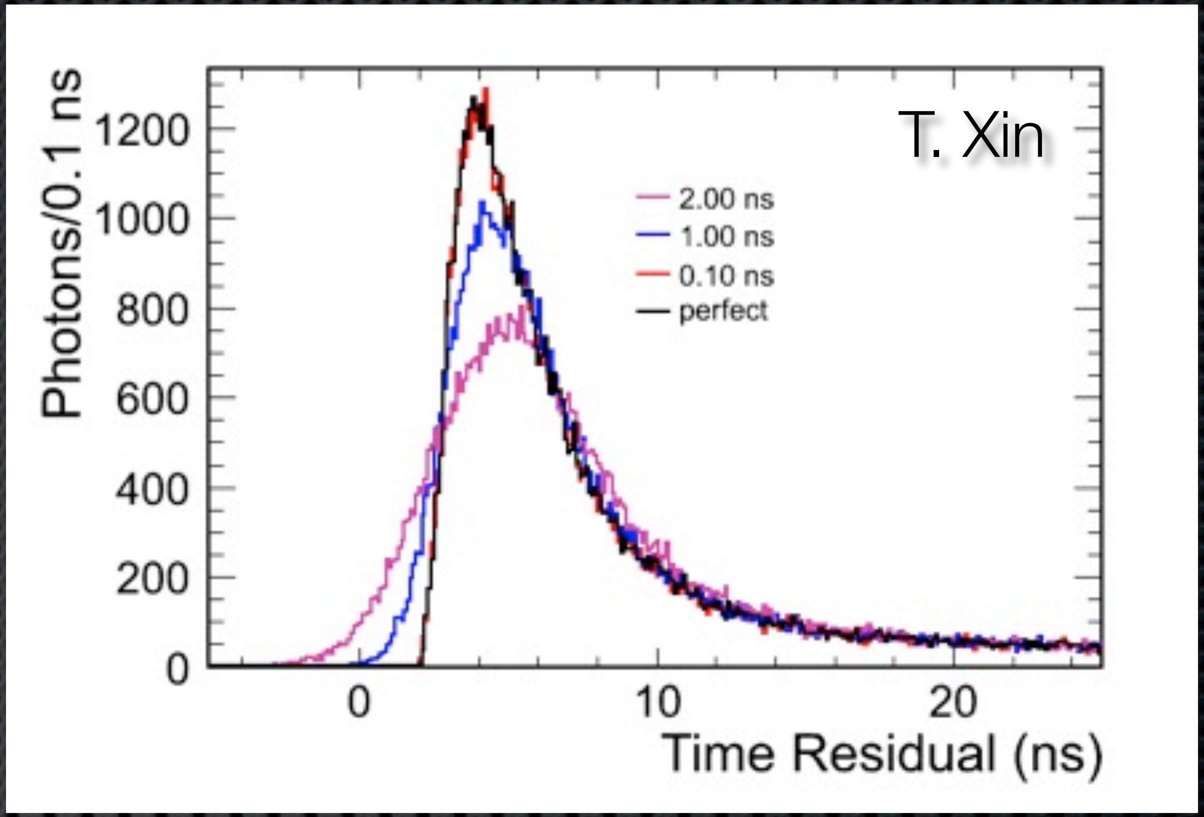


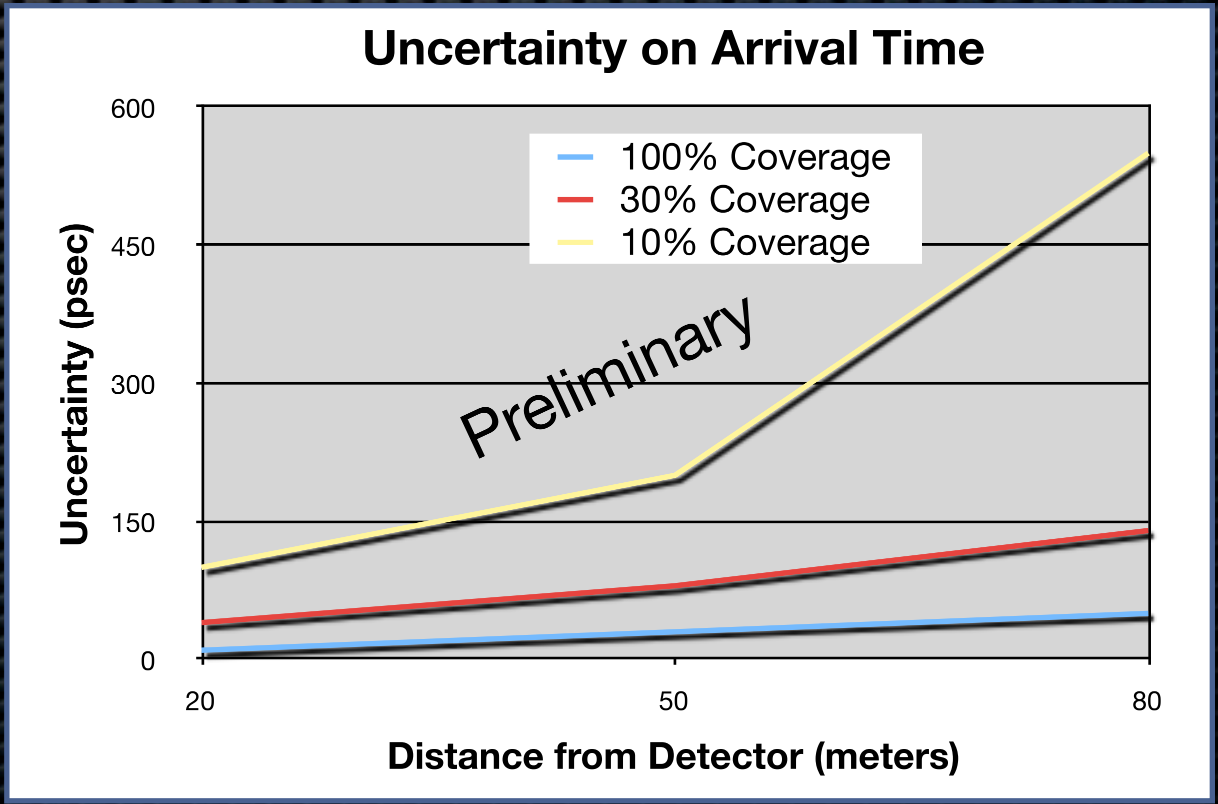




Using LAPPDs for Neutrinos

- The application of this new technology could enhance background rejection and vertex resolution by **improving spatial and timing information**.
- Our studies show that beyond 100 psec there are no further gains when using time residual distributions in a 200kton detector.
- We have also found that for a given detector size, the uncertainties in the position of the leading edge become smaller if better photodetector coverage is considered.



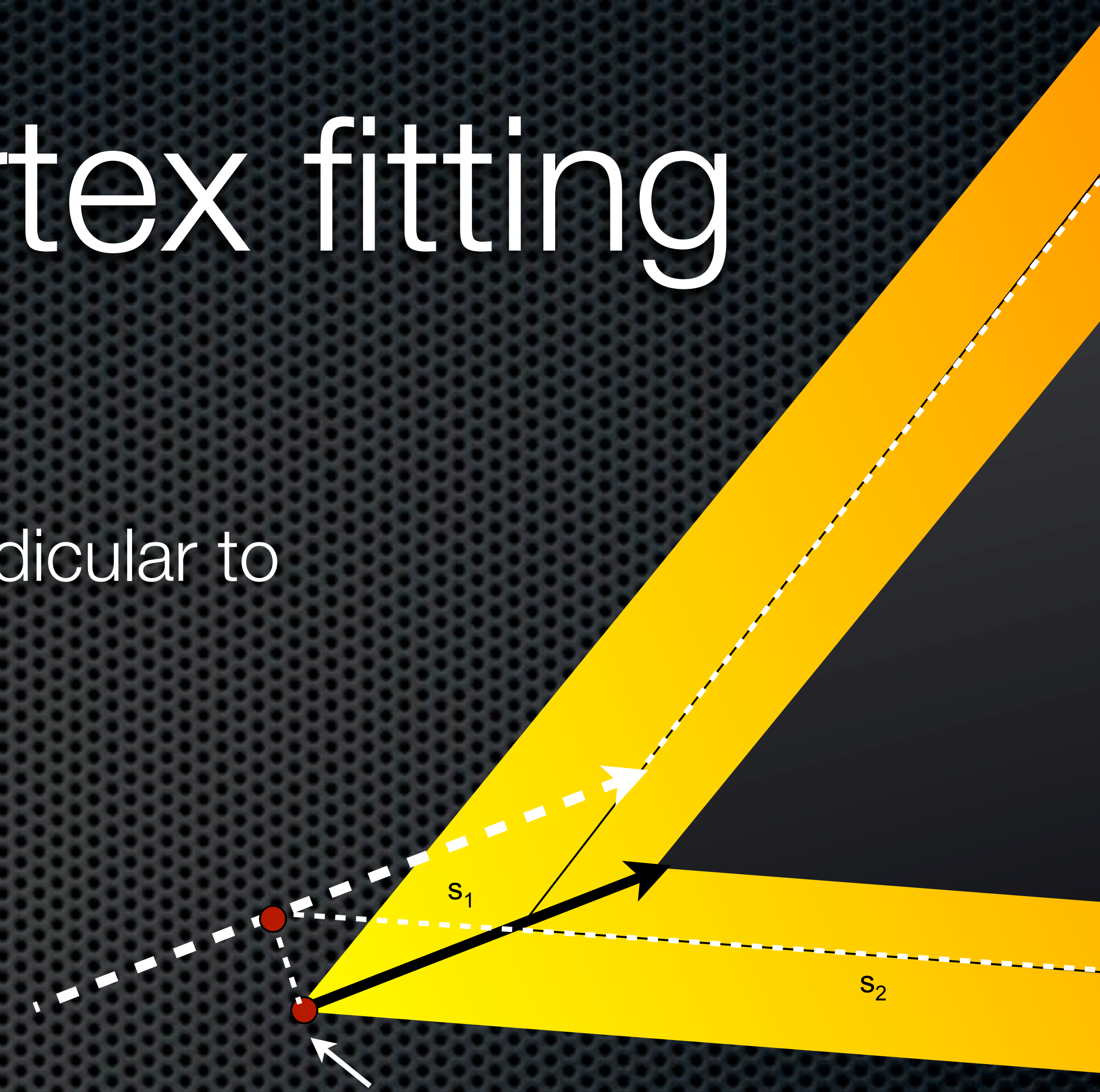


M. Sanchez (ISU/ANL), M. Wetstein (U Chicago/ANL), I. Anghel (ISU), G. Davies (ISU), T. Xin (ISU)

Project funded under NSF CAREER award

Timing-based vertex fitting

Position of the vertex in the direction perpendicular to the track *is* fully constrained by causality



casually consistent vertex hypothesis (albeit non-physical)

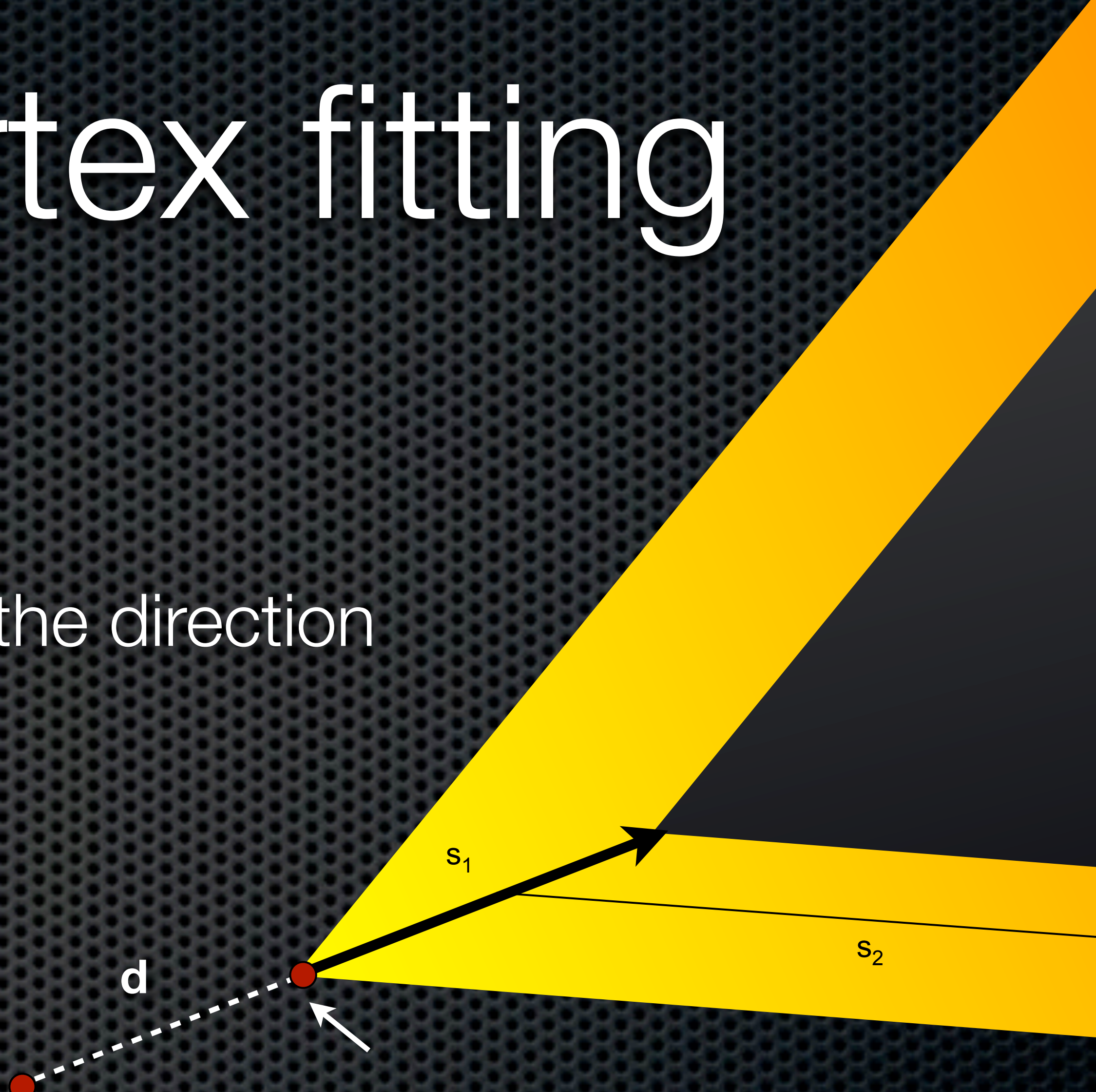
$T_0' = T_0 - dn/c$

true vertex: point of first light emission

For single vertex fitting, we expect the transverse resolution to improve significantly with photosensor time-resolution.

Timing-based vertex fitting

Based on pure timing, vertex position along the direction parallel to the track is unconstrained



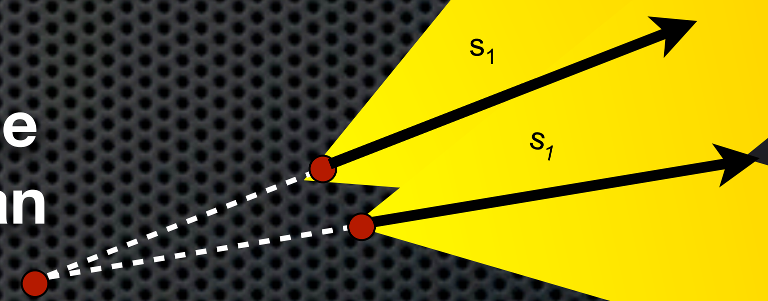
Must use additional constraint: fit the “edge of the cone” (first light)

Timing-based vertex fitting

Fortunately, multi-vertex separation is a differential measurement.

Causality arguments are sufficient to distinguish between one and two vertices.

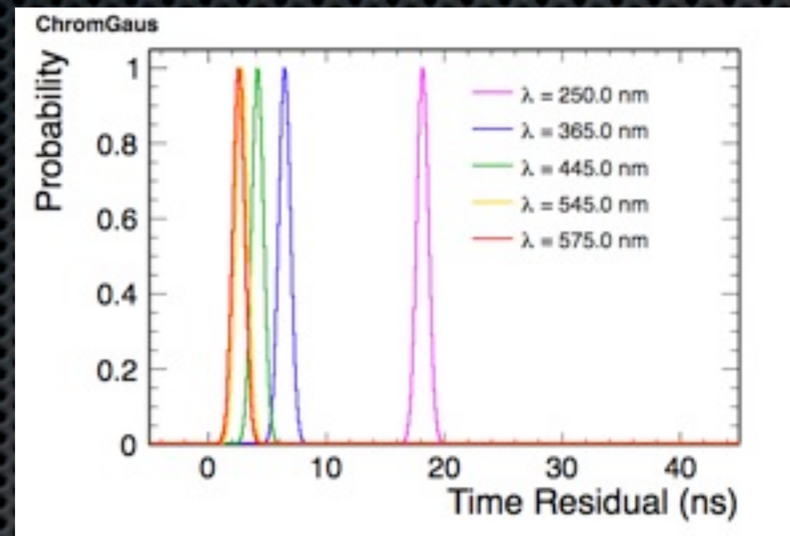
Only one unique solution that can satisfy the subsequent timing of both tracks



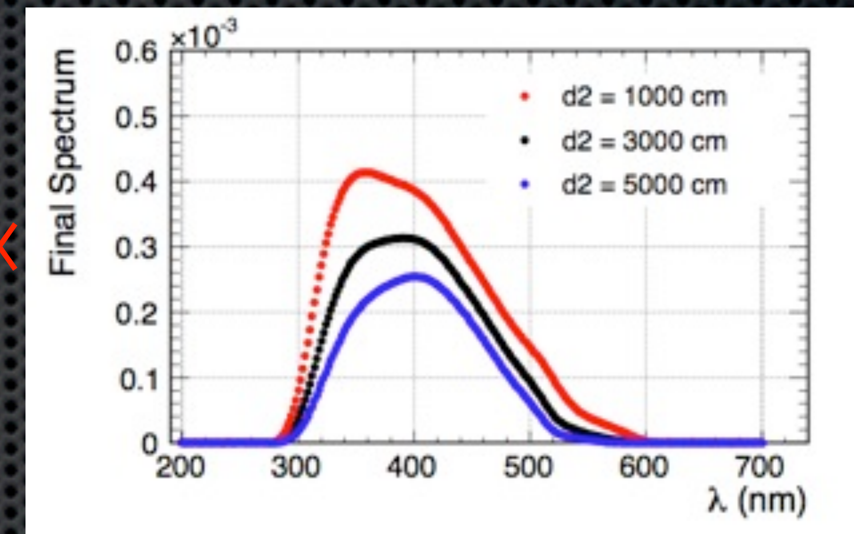
100 picoseconds ~ 2.25 centimeters

Using Time Residuals

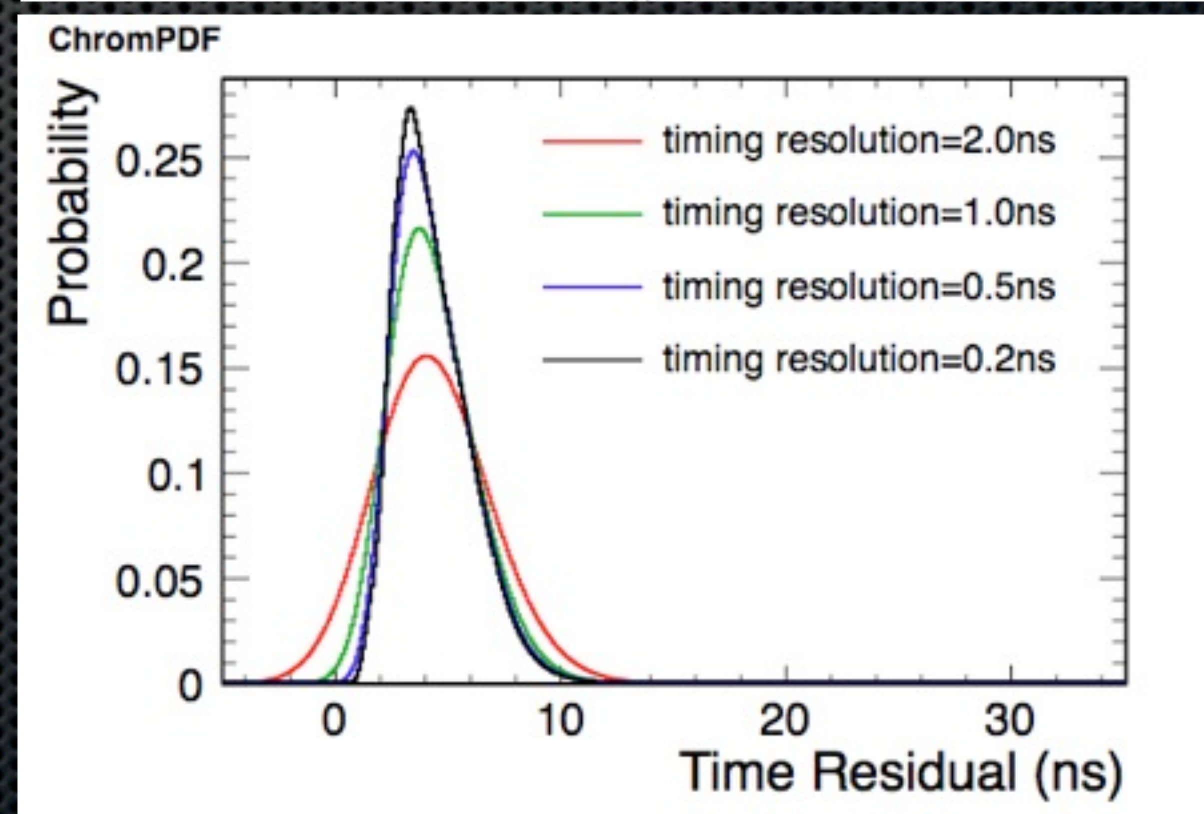
- We build a **timing residual-based fit** assuming an extended track.
- The model accounts for effects of chromatic dispersion and scattering.
  - Separately fit each photon hit with each color hypothesis, weighted by the relative probability of that color.
- For MCP-like photon detectors, **we fit each photon** rather than fitting (Q,t) for each PMT.



X



$$\mathrm{ChromPDF}(\lambda, \mathrm{d}) = \frac{\sum_\lambda \mathrm{ChromGaus}(\delta t(\lambda), \mathrm{d}) \times \mathrm{FinalSpectrum}(\lambda, \mathrm{d})}{\sum_\lambda \mathrm{FinalSpectrum}(\lambda, \mathrm{d})}$$



T. Xin, I. Anghel, M. Wetstein

Using Time Residuals

- Likelihood captures the full correlations between space and time of hits (not factorized in the likelihood).
- A simple window excludes any light that projects back to points far away from the vertex hypothesis.

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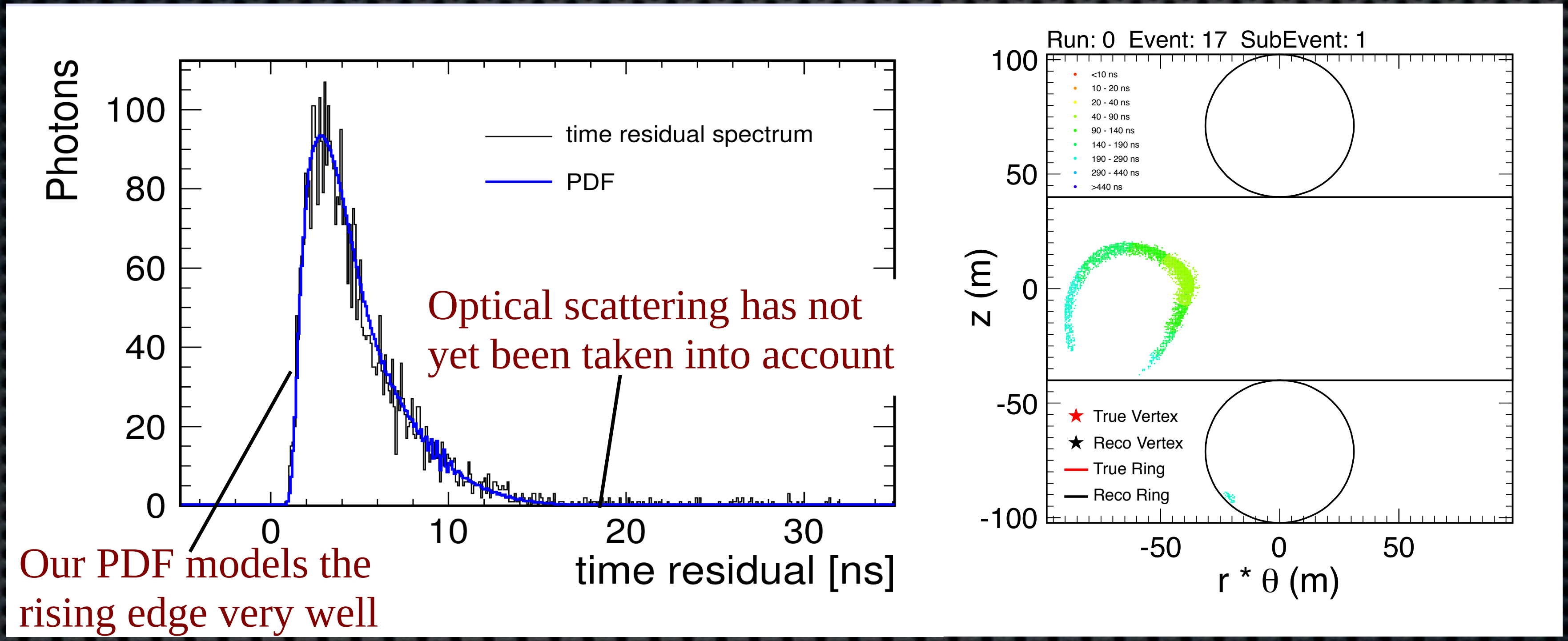
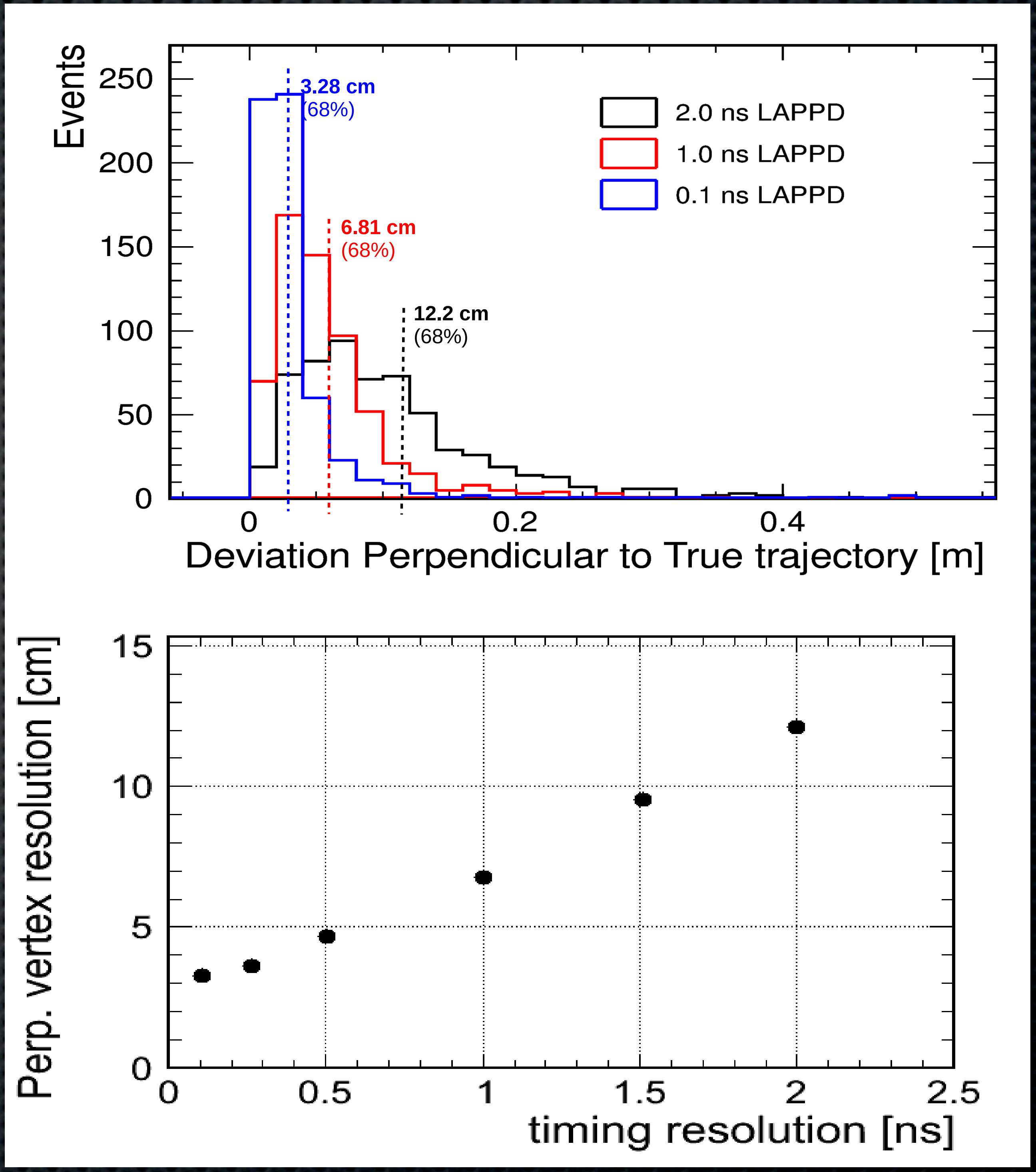


- It is not as sophisticated as full pattern-of-light fitting.
- However in local fits, all tracks and showers can be well-represented by simple line segments on a small enough scale.

Using WCSim (C. Walter - Duke U.) simulation for these studies. Modifications in digitization appropriate for LAPPDs. Reconstruction developed within WCSimAnalysis framework used in LBNE Water Cherenkov design.

Using Time Residuals

- Using a 200 kton simulated detector with 13% photodetector coverage (LBNE WCh design) using WCSim.
  - 1.2 GeV muons uniformly distributed.
- Our preliminary studies, indicate a **factor of 3 to 4 gain** in the perpendicular vertex resolution.
  - Compare this vertex resolution to ~20 cm for LBNE WCh using similar fits with no chromatic corrections and standard digitization.



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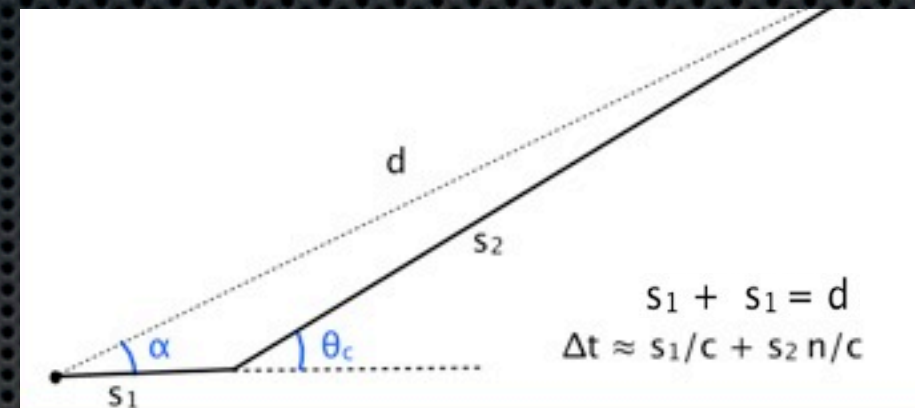
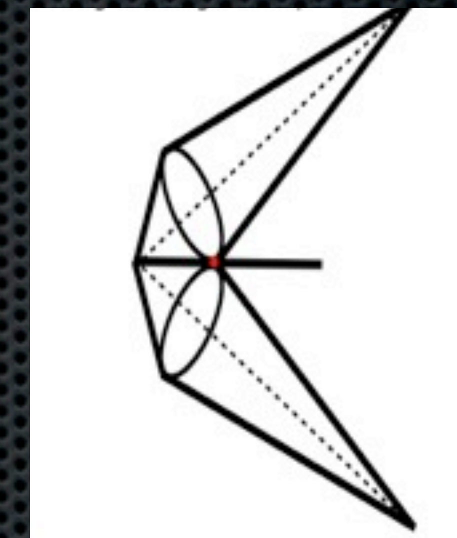
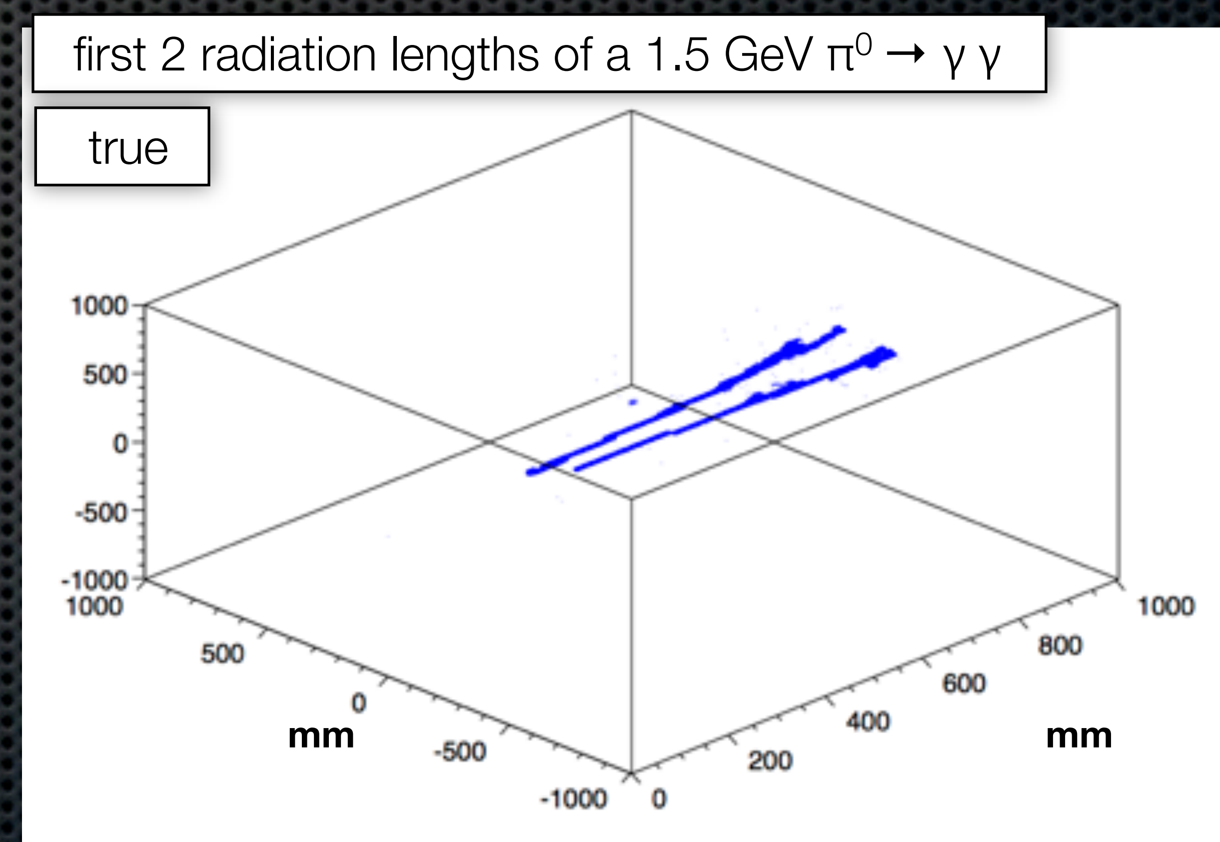
More statistics, other configurations in progress

Using the Isochron method

- The isochron transform is a **causal Hough transform**, that build tracks from a pattern of hits in time and space.
- This approach **requires a seed vertex**, but no prior assumption about number of tracks or event topology.
- It connects each hit to the vertex through a two segment path, one that of the charged particle, the other representing emitted light.
- The rotational ambiguity is easily resolved, since the same track will intersect maximally around their common emission point.



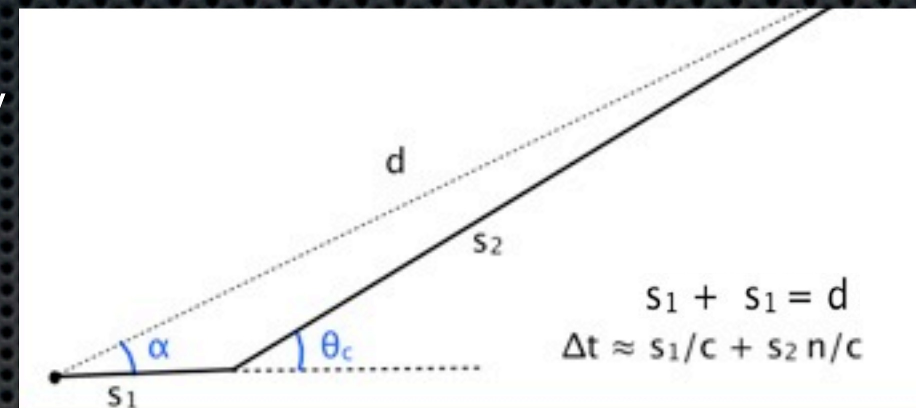


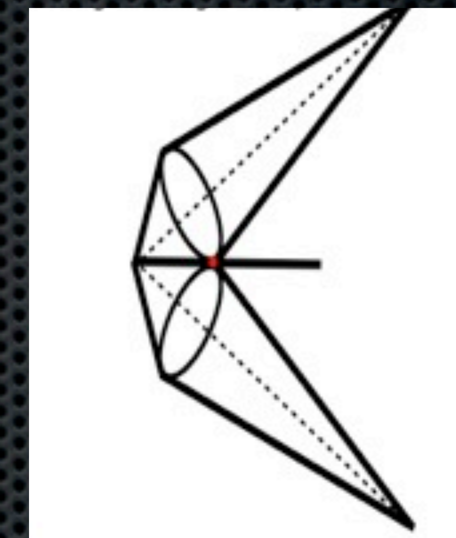


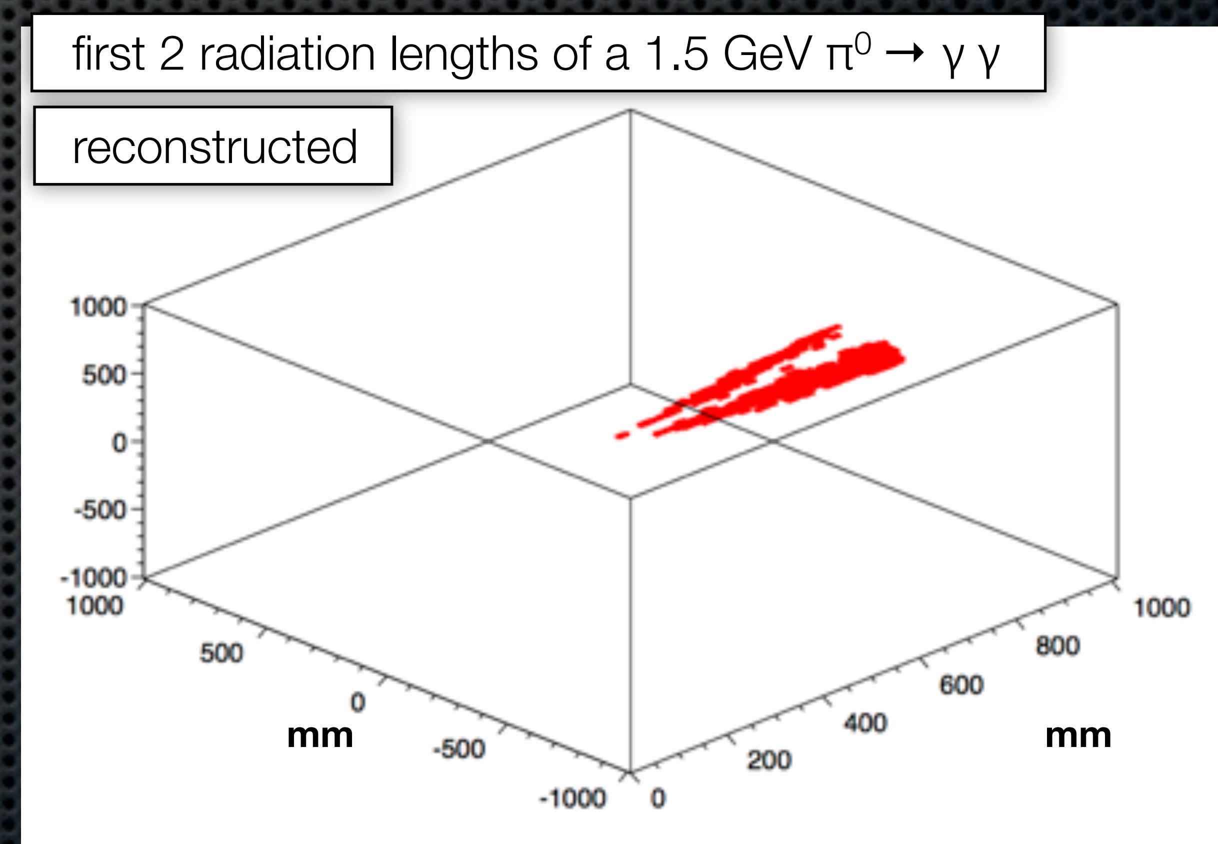
M. Wetstein

Using the Isochron method

- Track-like clusters emerge from density of intersections:
  - This density is sensitive to the position of the vertex hypothesis.
  - Image sharpness can be used as a figure of merit for fitting the vertex.
- Initial implementation tested on a 6m spherical detector with 100% coverage and perfect resolution.
- Full optical effects are applied
  - Not yet correcting for chromatic dispersion.
  - Not using any timing-based quality cuts.
- Challenges for realistic implementation: optimization for larger detectors, sparser coverage, less resolution.







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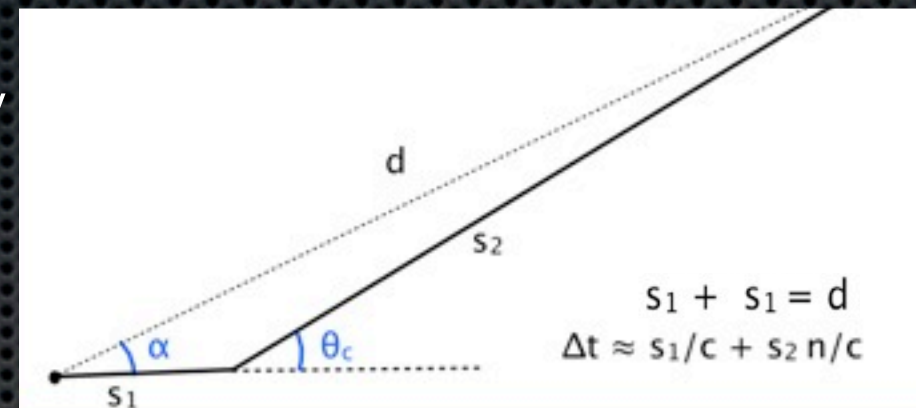

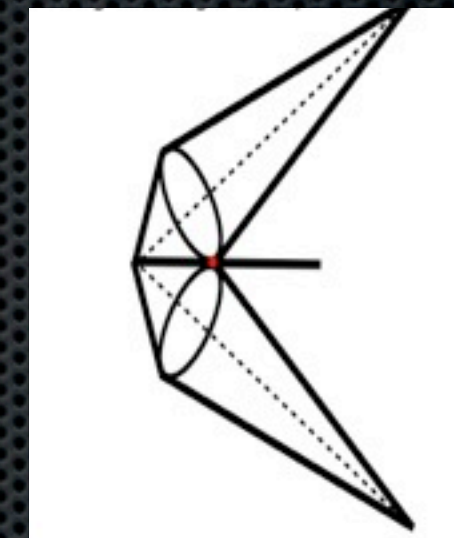

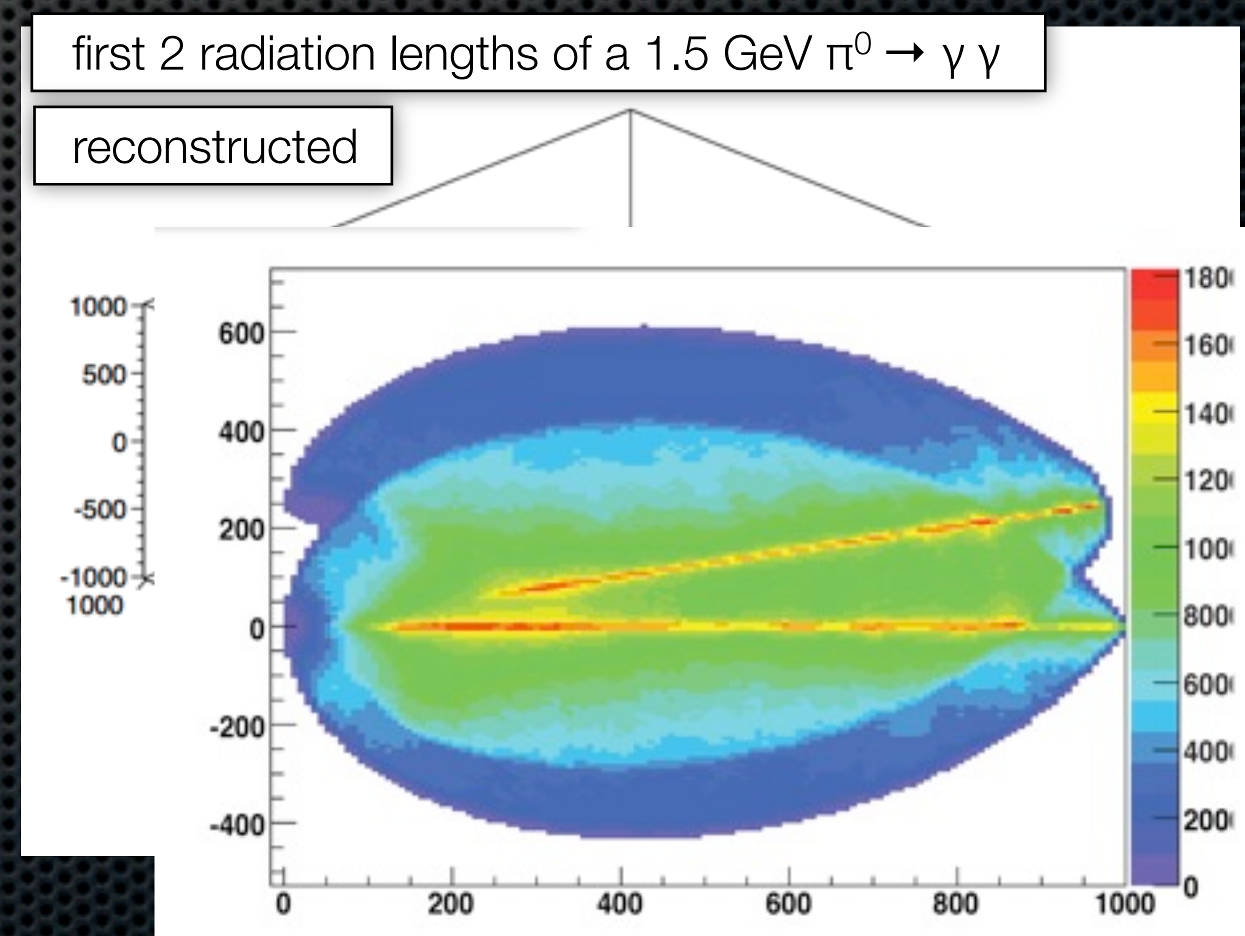

Conclusions

- A new generation of larger area photodetectors is in development.
  - Hyper-K is evaluating and developing photodetector technology such as HPDs which have improved timing resolution over PMTs.
  - The LAPPD collaboration has made progress in demonstrating key innovations in producing large-area microchannel plates.
- Studies are in progress to explore the benefits of improved time resolution and detector coverage/granularity impact in large Water Cherenkov detector design.
  - Fast timing as in LAPPD also of high interest for Near Detector (see M. Wilking talk). Isochron algorithm ideally suited for this application.

Time resolution gains could enhance background rejection and improve physics capabilities of Hyper-Kamiokande