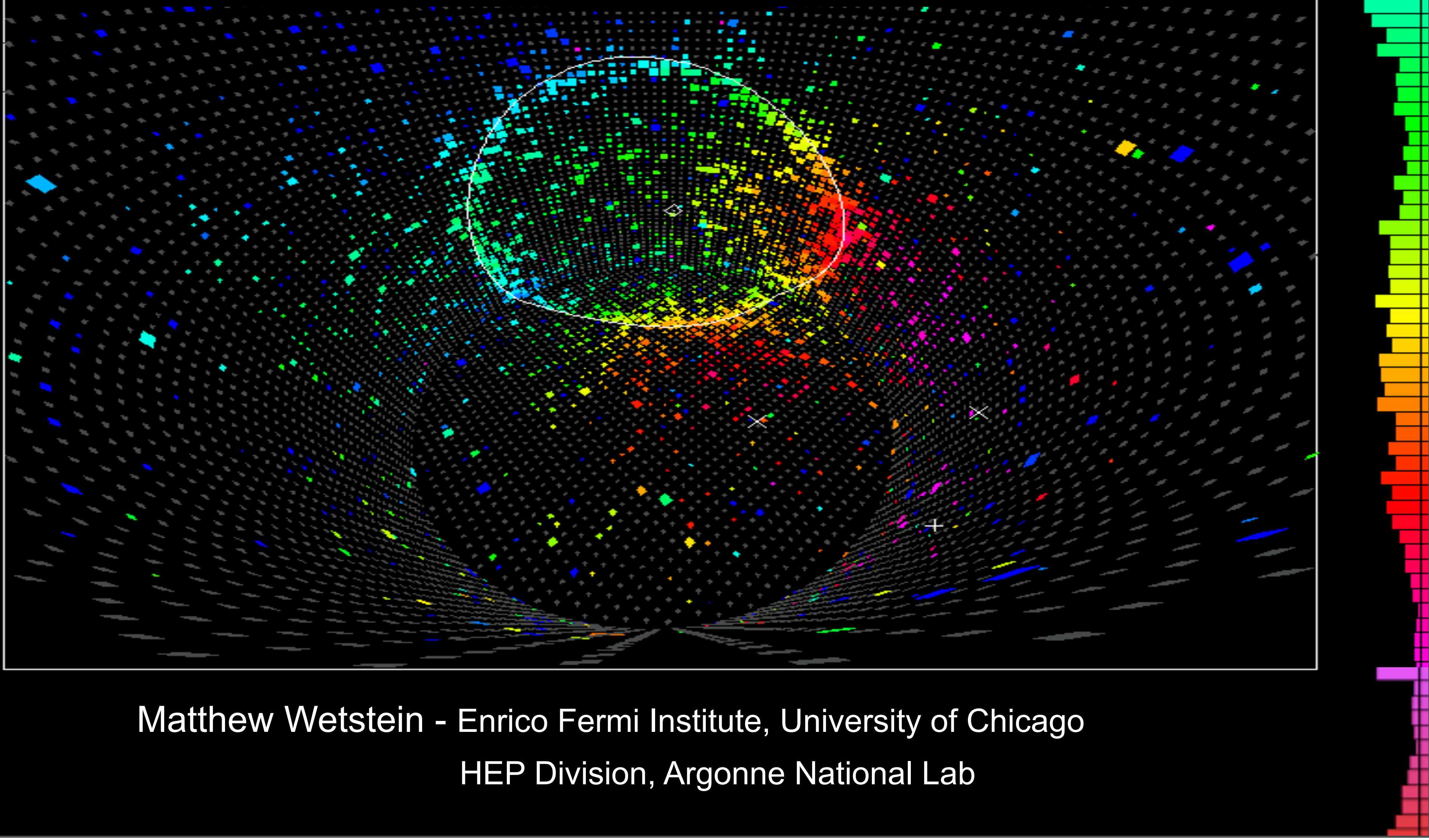
Big, Fast, and Cheap:

Precision Timing in the Next Generation of Cherenkov Detectors

LAPPD Collaboration Meeting 2010

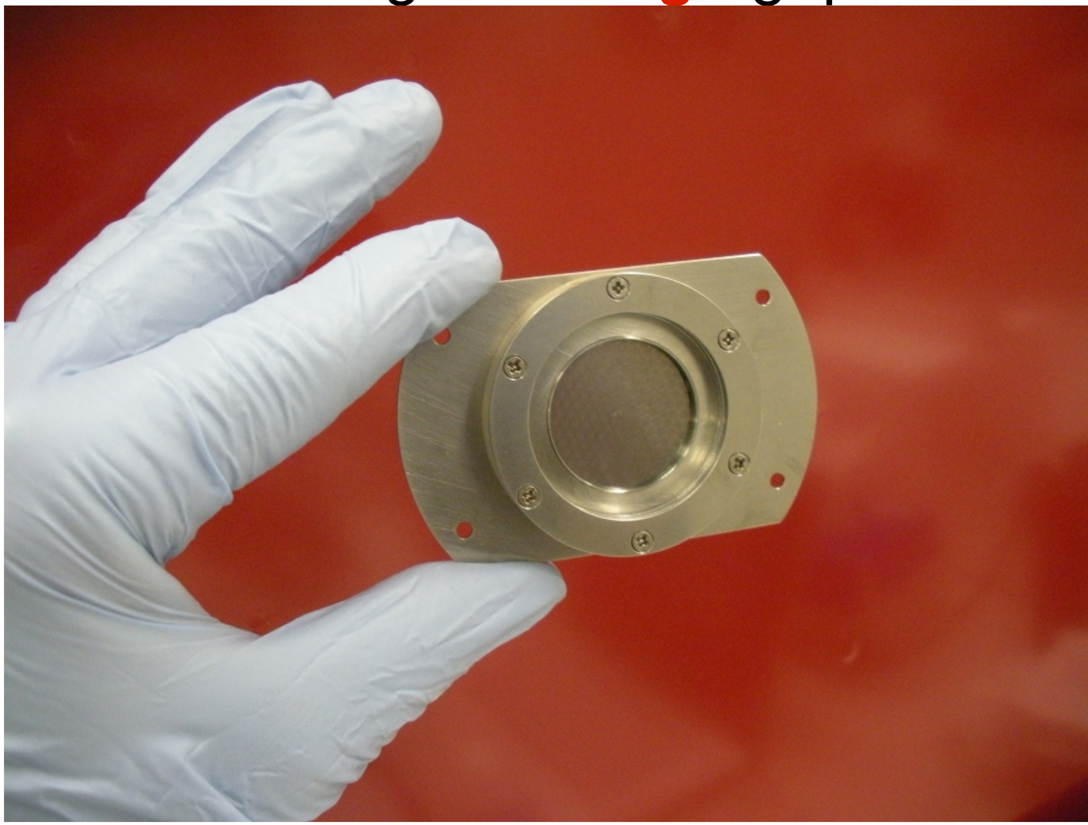


Matthew Wetstein - Enrico Fermi Institute, University of Chicago

HEP Division, Argonne National Lab

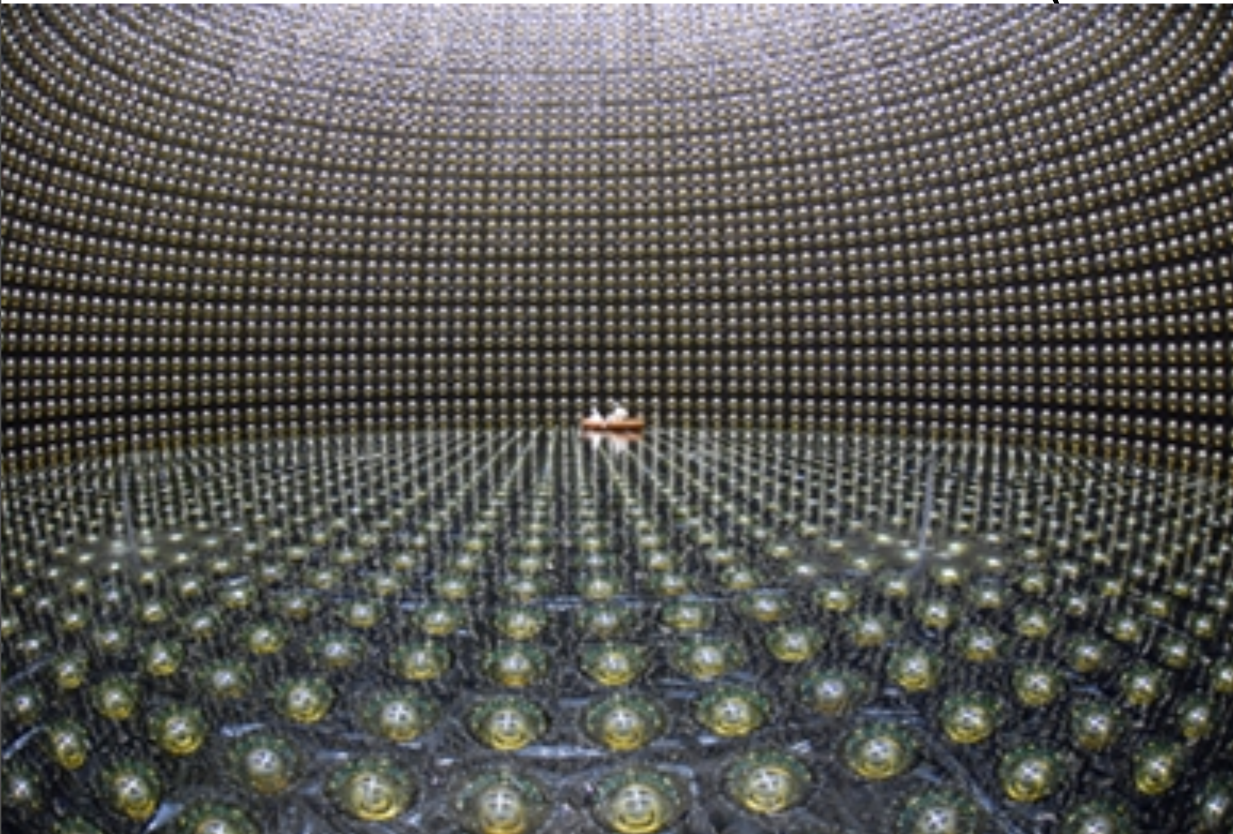
The Challenge in Designing Detectors for HEP Experiments:

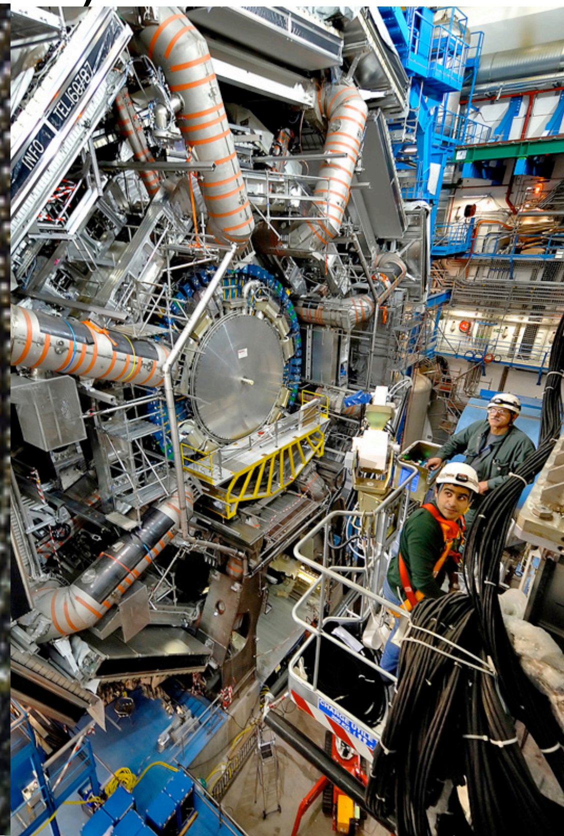
Need to bridge the ***huge*** gap between what is possible



The Challenge in Designing Detectors for HEP Experiments:

...and what is feasible (scalable)

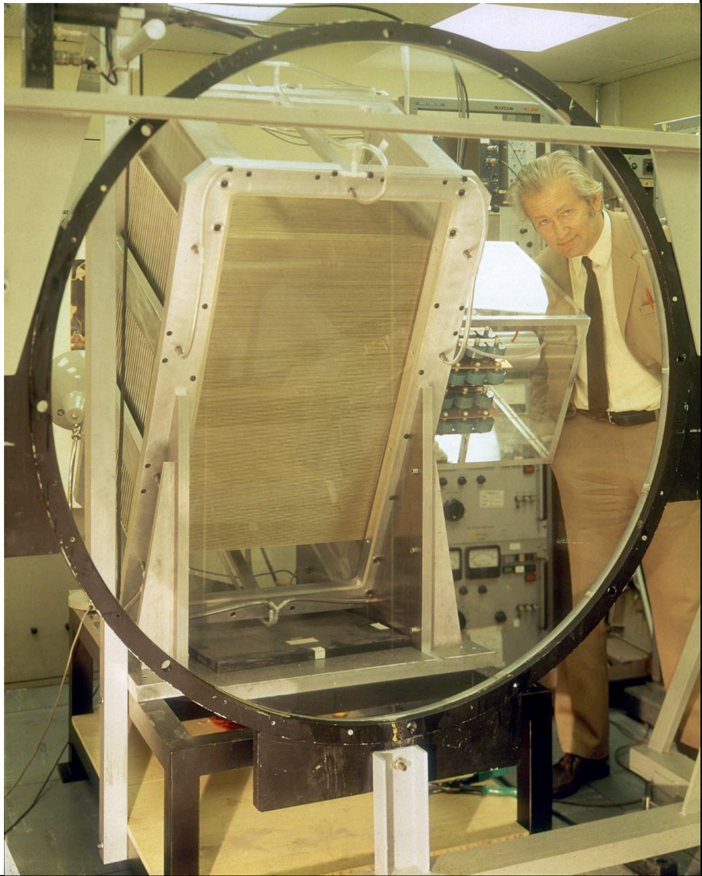




The Good News is:

Sometimes it's worth the effort…

Georges Charpak

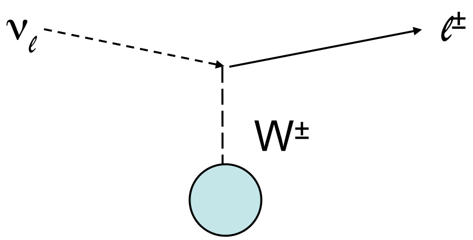


- If successful, we stand to greatly improve the quality of physics we can study in a given experiment.
- Because we are also forced to really understand that science behind the device, we end up
  - Making the device better
  - Enabling new possible spinoffs for other scientific or commercial applications
- In the R&D process, we are forced to imagine entirely new analysis techniques and new physics capabilities.

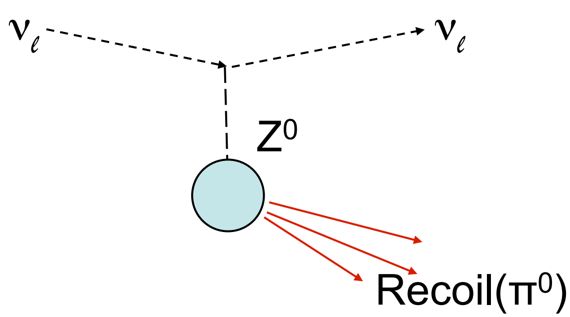
Water Cherenkov Basics

Main Neutrino Interactions:

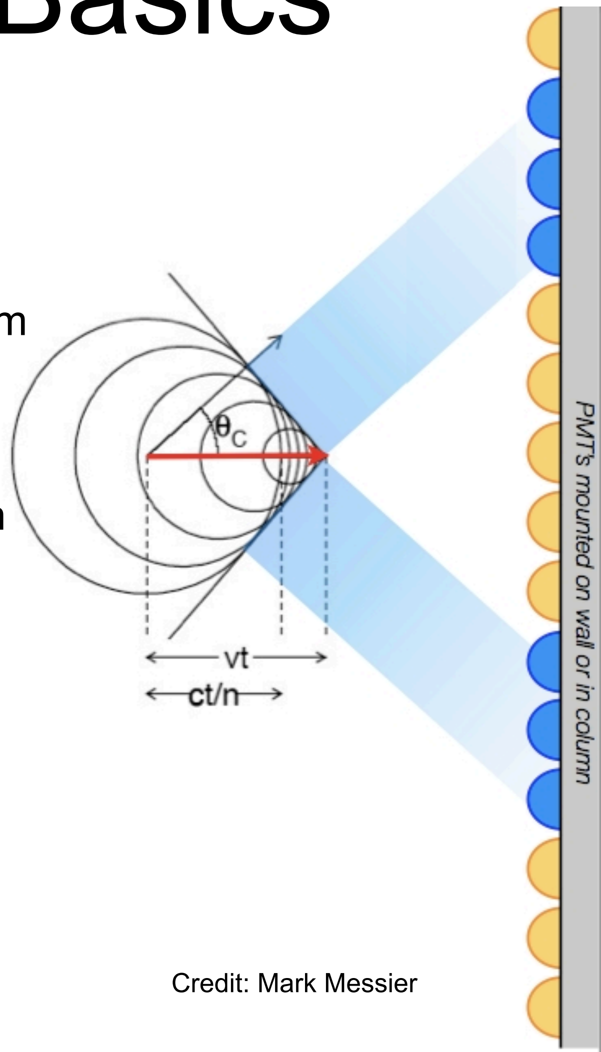
Charged Current (signal)



Neutral Current (bkgd)

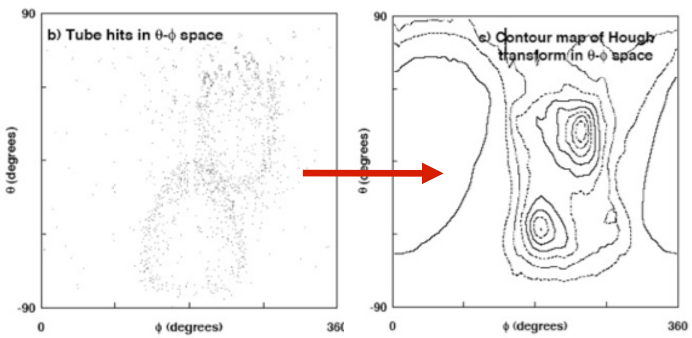


- An shockwave of optical light is produced when a charged particle travels through a dielectric medium faster than the speed of light in that medium: c/n
- This light propagates at an angle $\theta_C = 1/n\beta$ with respect to the direction of the charged particle…
- Using photodetectors, we can measure the emitted light and reconstruct the track

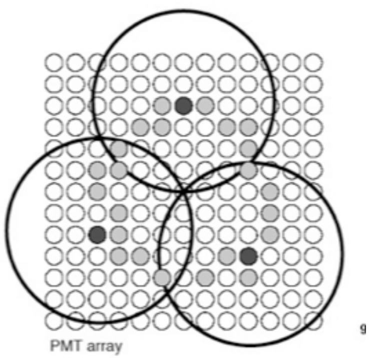


Credit: Mark Messier

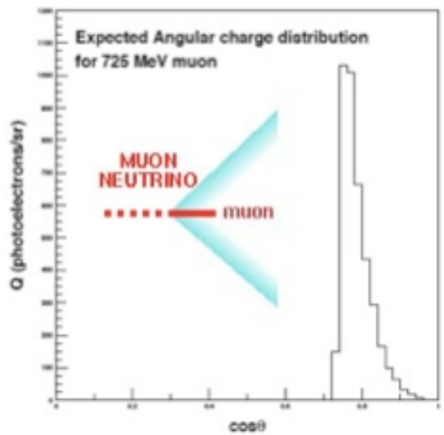
Ring Counting

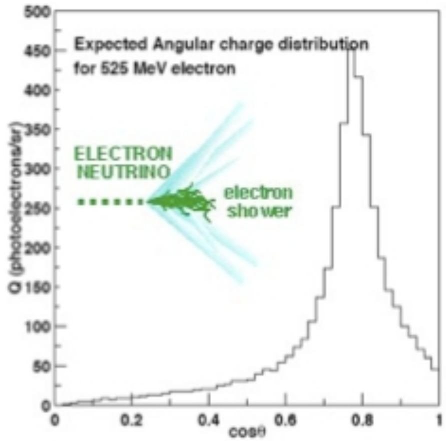


Hough transformation converts ring counting into peak counting

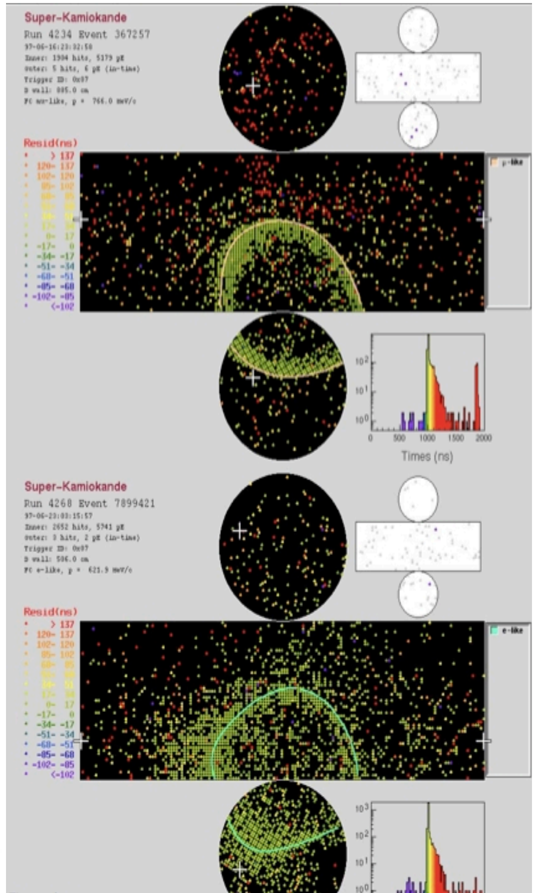


Particle ID





Figures from M. Earl's PhD Thesis



Figures from
http://hep.bu.edu/~superk/atmnu/

Tracking in Water Cherenkov

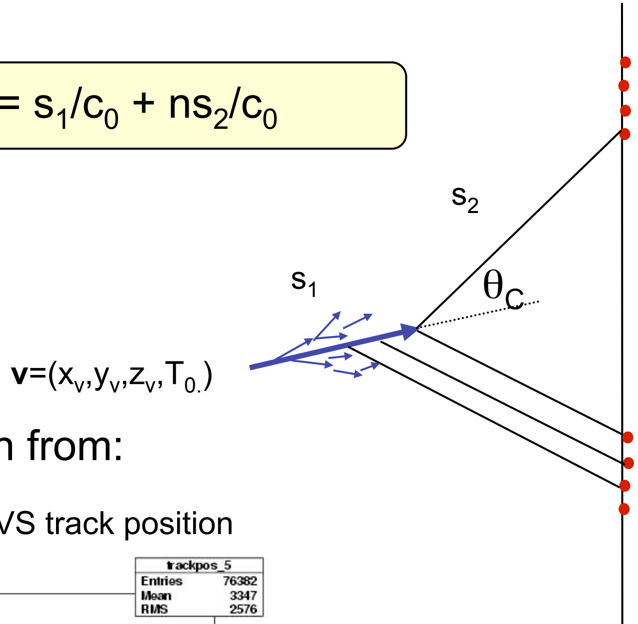
1-D Track → Multiple Tracks/ Showers

$\Delta t_{hyp} = s_1/c_0 + ns_2/c_0$

7 Fit pameters:

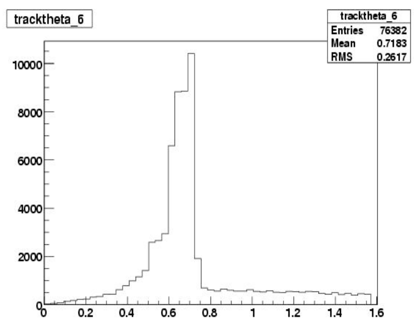
$x_v, y_v, z_v, T_0, \theta_{track}, \phi_{track}, \beta$

Also: Particle ID? How many tracks?

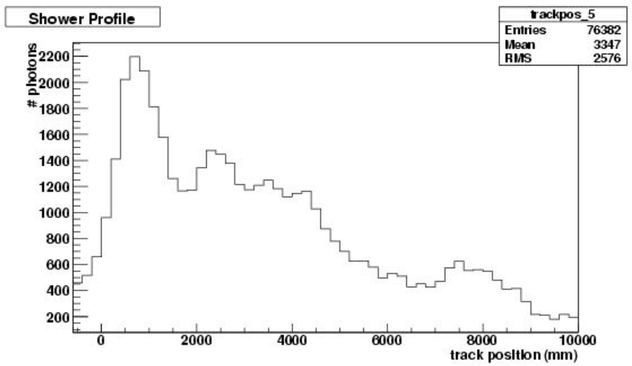


In addition to Δt_{hyp}, we can also use information from:

Light intensity VS $\Delta\theta_{track}$



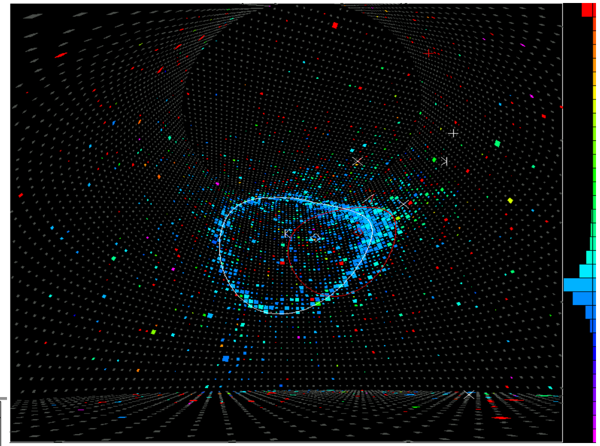
Intensity of emitted light VS track position

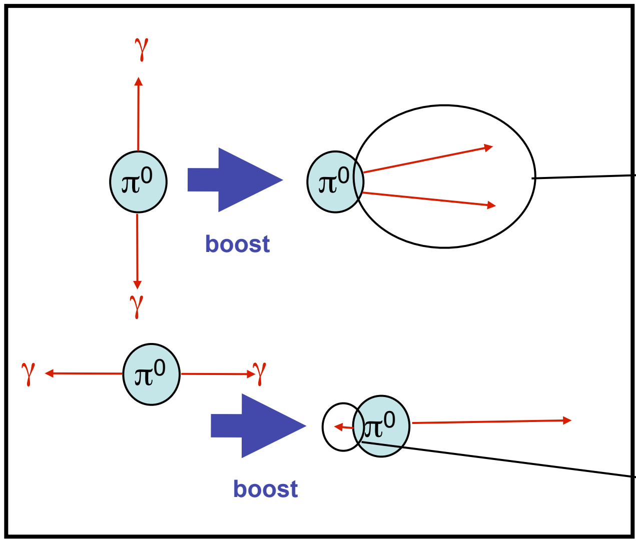


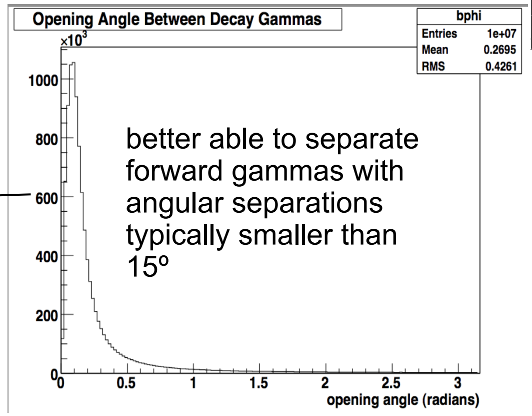
Possible Neutrino Applications

As a successor to photomultiplier tubes in water-Cherenkov based neutrino experiments

- Provide better coverage
- Use timing information to improve tracking and vertex separation
- suppress largest reducible background - neutral pion fakes an electron







improved sensitivity to low momentum gammas with better coverage

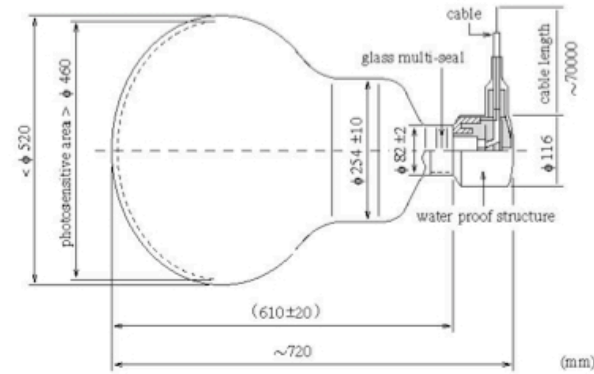
Typical vertex resolutions in Super K O(10) cm

100 psec TOF for light in water corresponds to roughly 3 cm

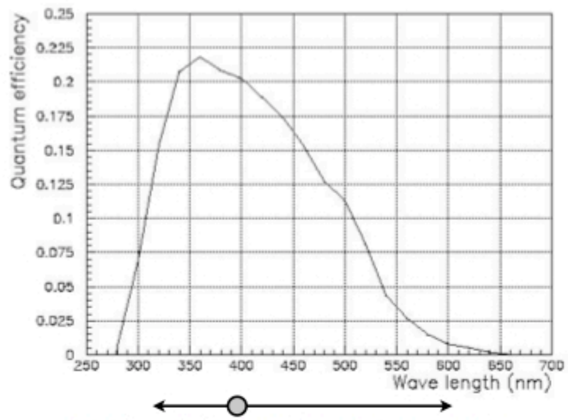
Photomultiplier Tubes

Phototubes:

- ~2-3 nsec time resolution
- Spatial resolution cannot exceed tube radius
- Total coverage offered is typically less than 40%
- Typical photocathode efficiency ~25%



100 ns transit time, 2.2 ns time resolution



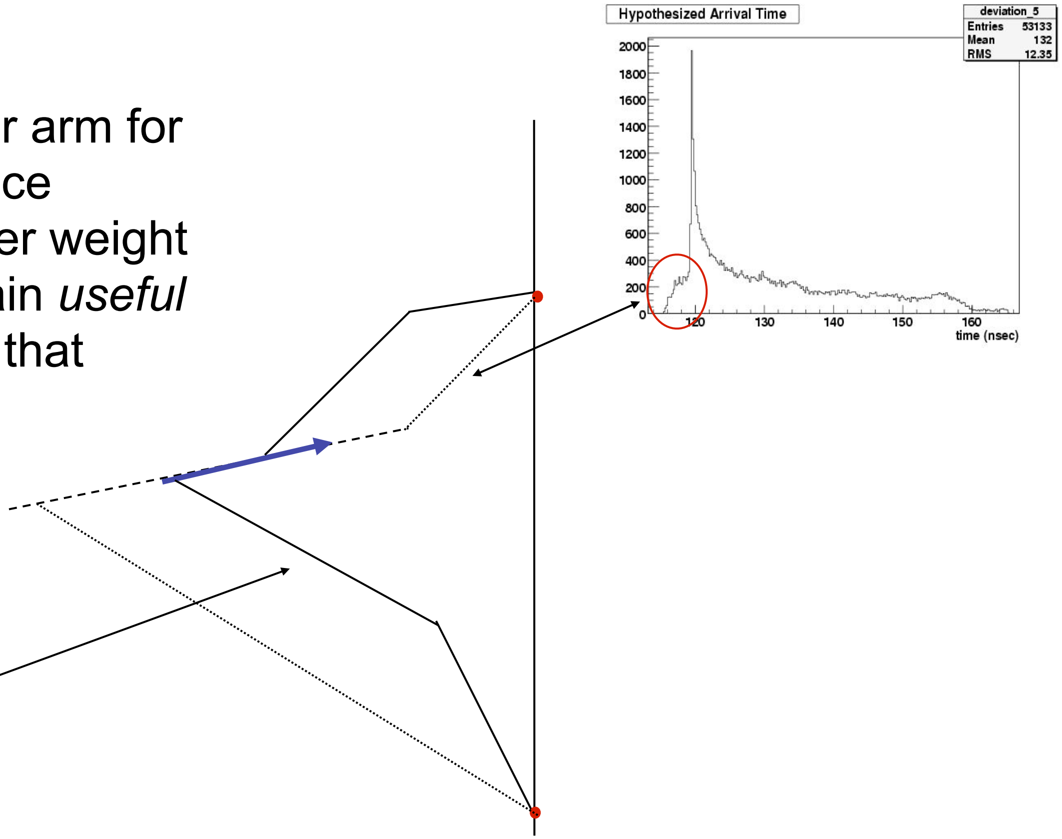
wavelength of Cherenkov photons in water

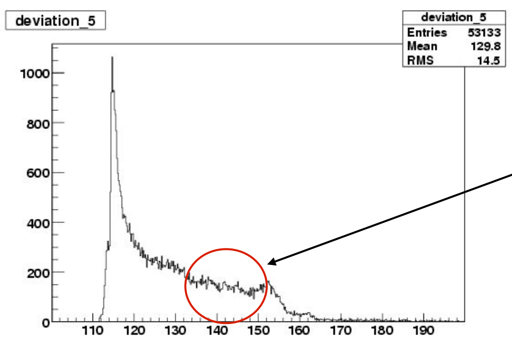
Timing in Water Cherenkov

Aren’t time and space information degenerate?

Timing Information:

Can provide an extra lever arm for constraining time and space information, placing greater weight on detector hits that contain *useful* information (ie, those hits that haven’t scattered)

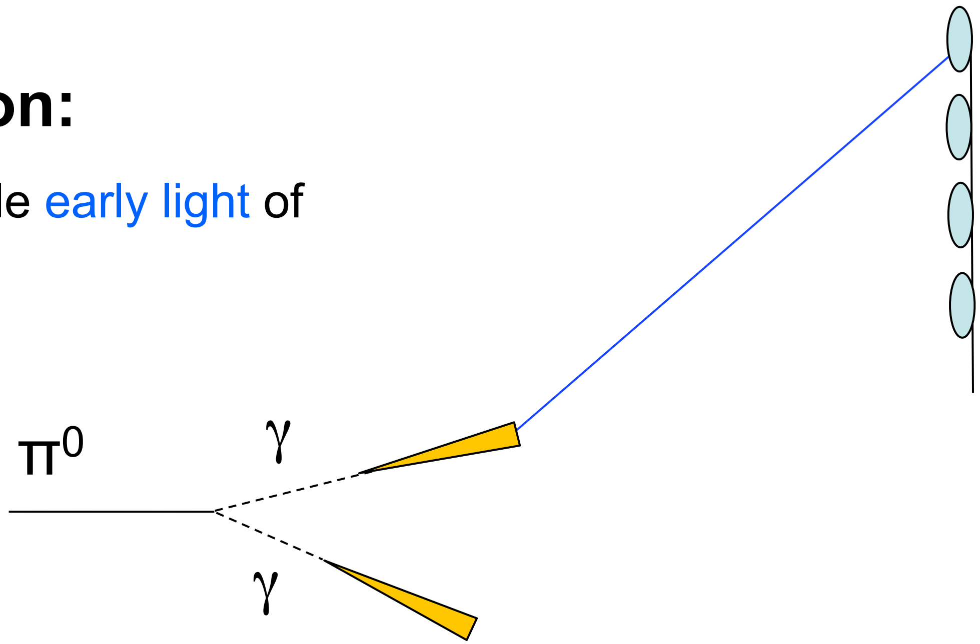




Timing in Water Cherenkov

Timing Information:

Can help to disentangle early light of one track….

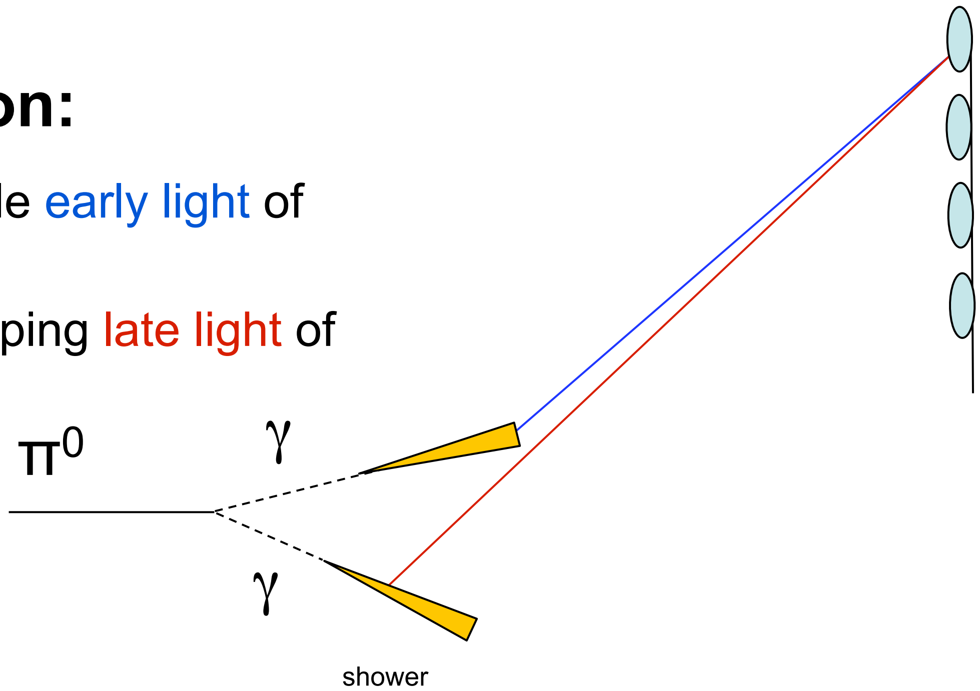


Timing in Water Cherenkov

Timing Information:

Can help to disentangle early light of one track….

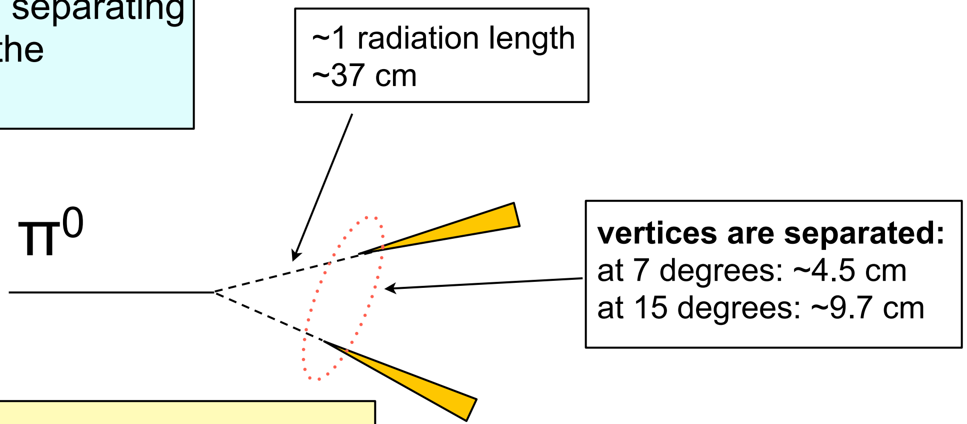
From spatially overlapping late light of another track



Timing in Water Cherenkov

Timing Information:

On average, this amounts to separating the two vertices from which the Cherenkov cones radiate...

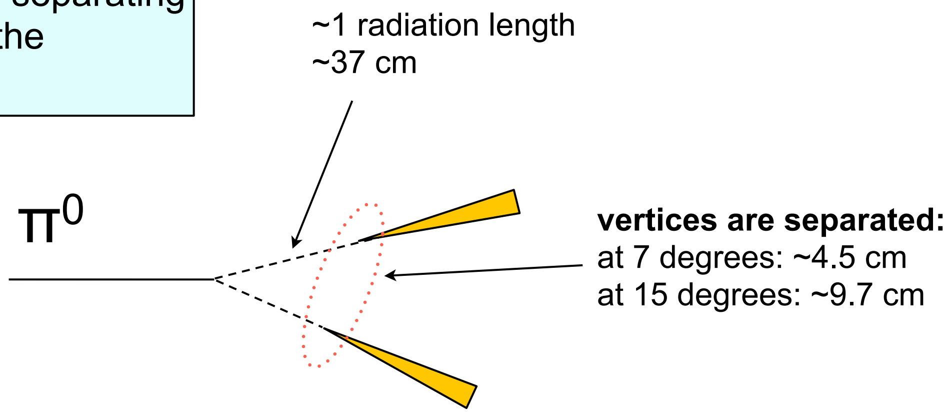


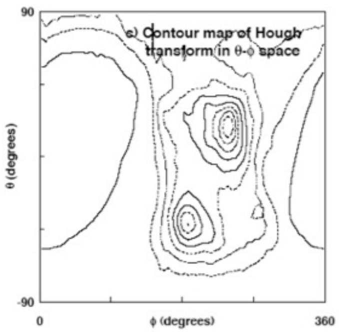
- Finding a single event vertex is limited by our ignorance of T_0.
- Vertex *separation* is not...

Timing in Water Cherenkov

Timing Information:

On average, this amounts to separating the two vertices from which the Cherenkov cones radiate...



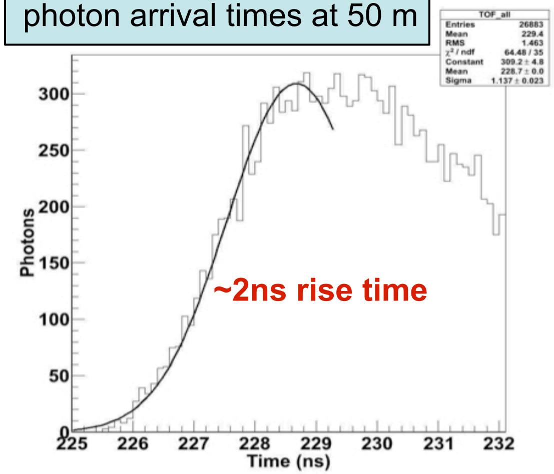


Imagine a likelihood fit for ring counting that uses both time and space information (cut the Hough transform into slices in time)…

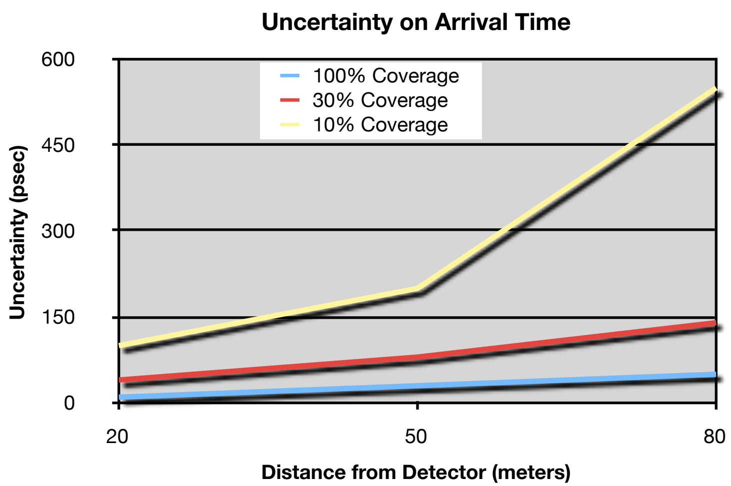
Understanding Chromatic Dispersion

- Chromatic dispersion/scattering/absorption present a problem
- We probably won't need the same time resolution as collider applications
- Still, even at 50 meters, we can expect to do much better than 2 nanosecond resolution in water
- Typical PMT timing resolutions > 1ns

photon arrival times at 50 m



J. Felde, B. Svoboda: UC-Davis

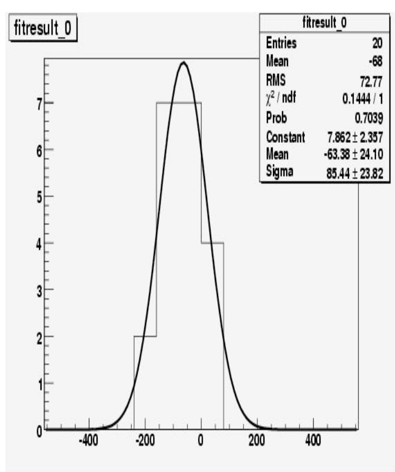


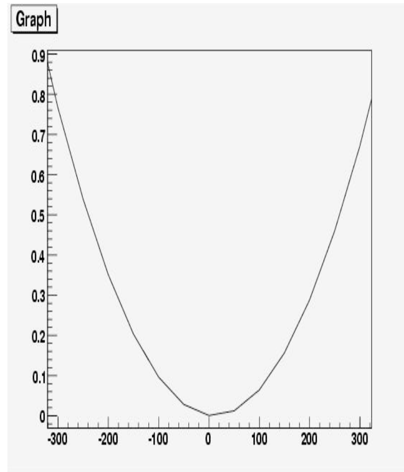
Resolution losses over large distances in water can be recovered with more coverage (photon statistics)

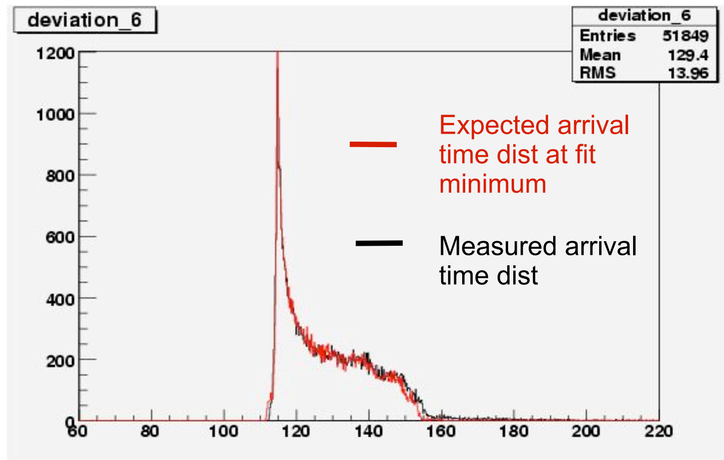
Understanding Timing in Water Cherenkov

TrackFit_x

- Package for analytic track-fitting based on Cherenkov geometry
- Currently optimizing multi-parameter fitting and smoothness of likelihood curve
- Goal:
    - to study identification of π^0 backgrounds as a function of time resolution
    - To better understand analysis using large-area, picosecond photodetectors



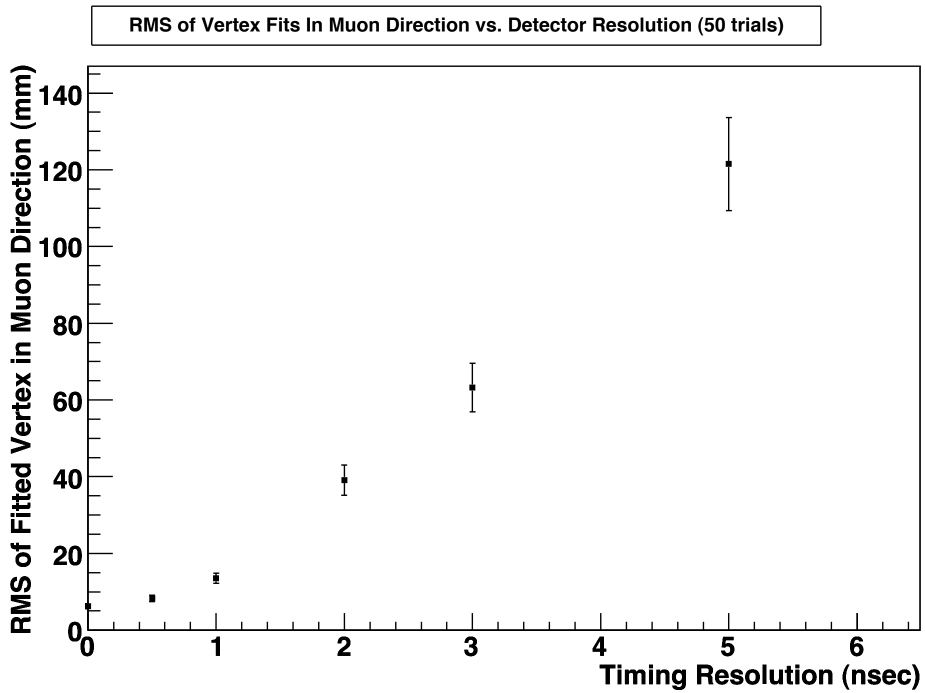




M. Wetstein(ANL/UofC), M. Sanchez (Iowa State/ANL), B. Svoboda (UC Davis)

Understanding Timing in Water Cherenkov

TrackFit_x

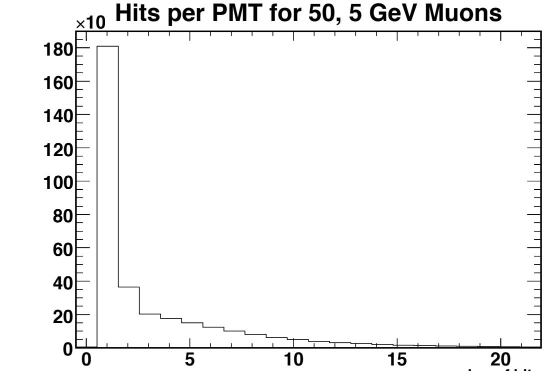


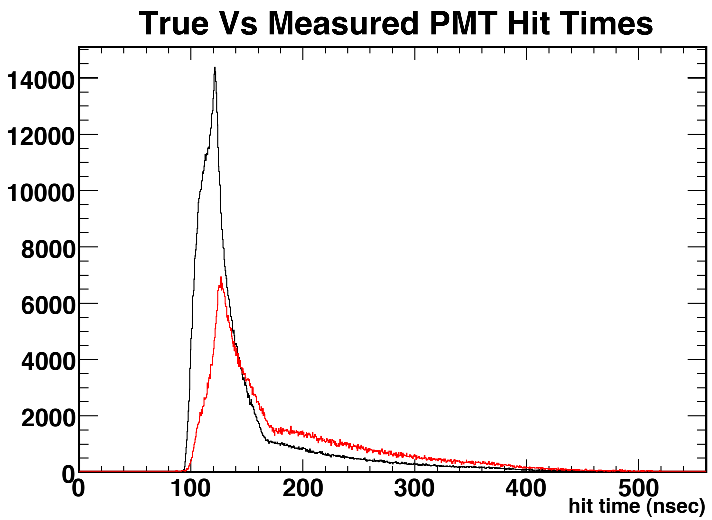
Simple test of the refined track fitting:

- No chromatic dispersion
- straight muon trajectory
- 100% covereage
- T_0 is known
- Proof of methodology

M. Wetstein(ANL/UofC), M. Sanchez (Iowa State/ANL), B. Svoboda (UC Davis)

Next Steps





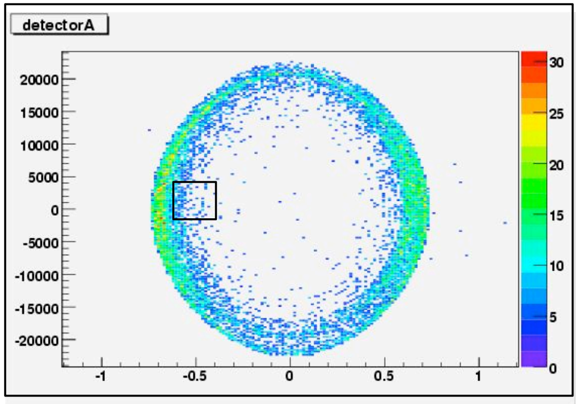
M. Wetstein(ANL/UofC), M. Sanchez (Iowa State/ANL), B. Svoboda (UC Davis)

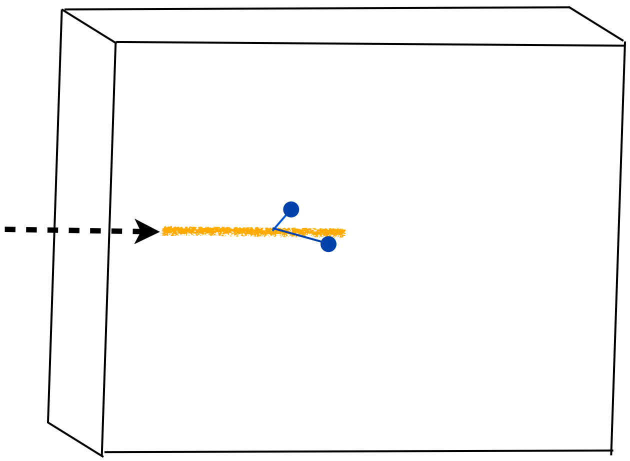
- Generate data directly on the official, LBNE Geant model.
- Apply tracking algorithms directly to PMT data.
- Test tracking algorithms in more realistic scenarios (include chromatic dispersion, etc).
- Coordinate with the LBNE algorithms group.
    - build tools to do particle ID/ring counting
    - keep the algorithms flexible over variations in detector resolution, granularity, and geometry

Possible Neutrino Applications

Finer spatial resolution =
Ability to resolve $dN_\gamma/d\Omega$ *within* a single module

- better particle ID (ability to resolve the sharpness of ring-edge)
- better able to reconstruct events close to the wall
- Could imagine new tank geometries (building walls closer together in direction orthogonal to beam?)





Other Possible Advantages:

- Better magnetic susceptibility (applied magnetic field?)
- Further cost reductions by
  - requiring less bulk mass for the same physics
  - cheaper excavation costs

Will require detailed simulation

Summary of Potential Payoffs

- Improved π^0/electron separation.
  - Better vertex resolution.
  - Additional forward ring separation.
  - Lowered threshold for lower energy gamma detection.
- Reduced magnetic field susceptibility compared to PMTs.
- Increased fiducial volume by designing flat photodetectors.
- Lessened constraints on cavern height, thanks to geometric design.

Effort is under way to study each of these possibilities.