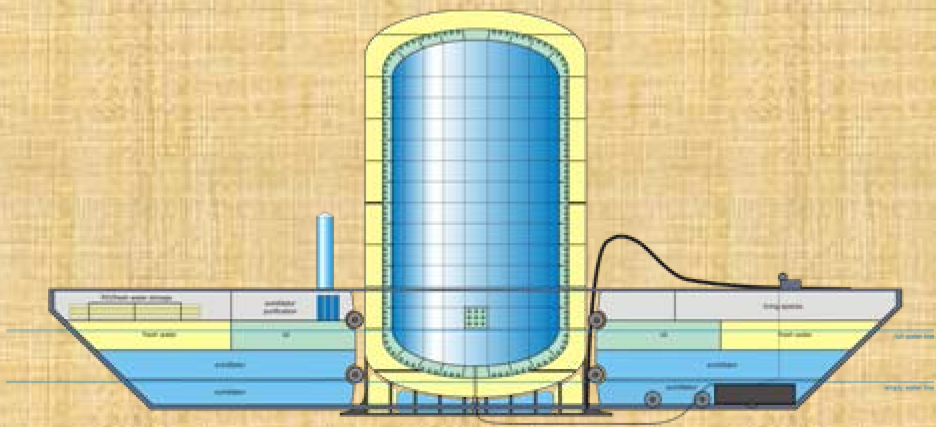
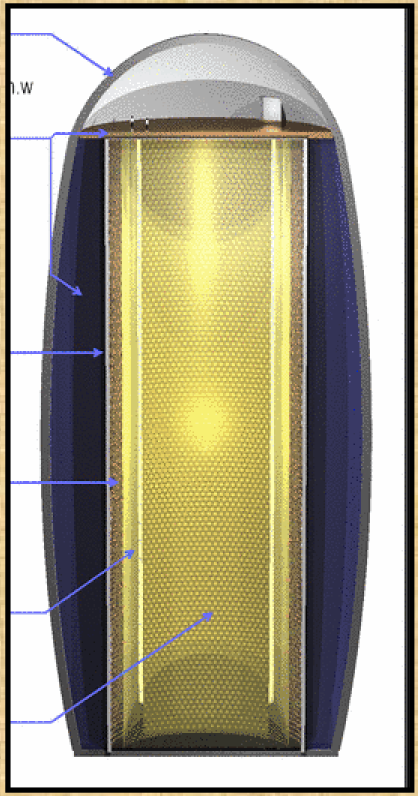
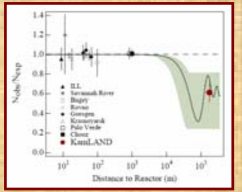
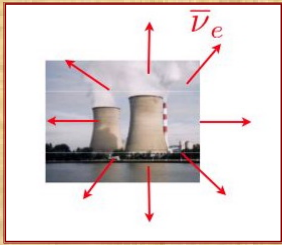
Hanohano + LENA





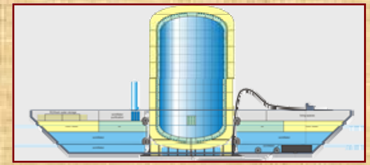
John Learned, *University of Hawaii at Manoa*
(& other colleagues at UH and elsewhere)

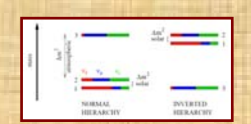


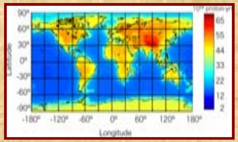


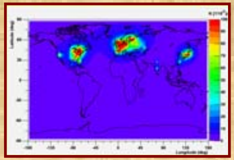
Outline

- **NEW GeV Neutrinos: Fermat Surface**
  - new recognition, '09
  - competitor for long baseline expts
- **Challenges**
  - directionality
  - better light detectors
  - giant cost-effective instruments

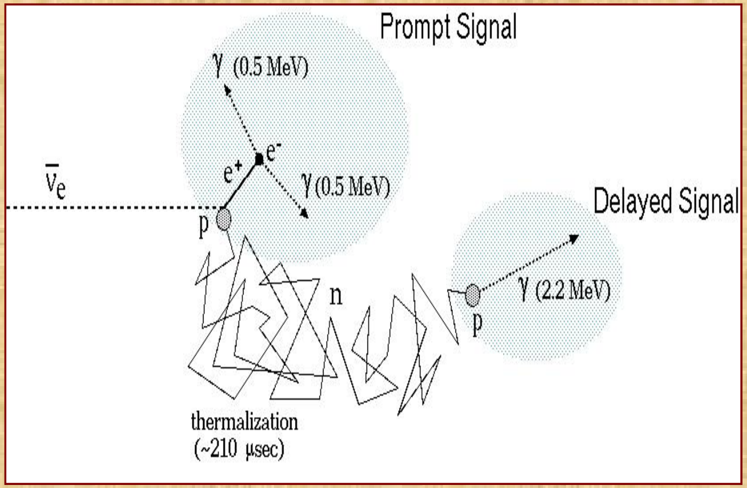


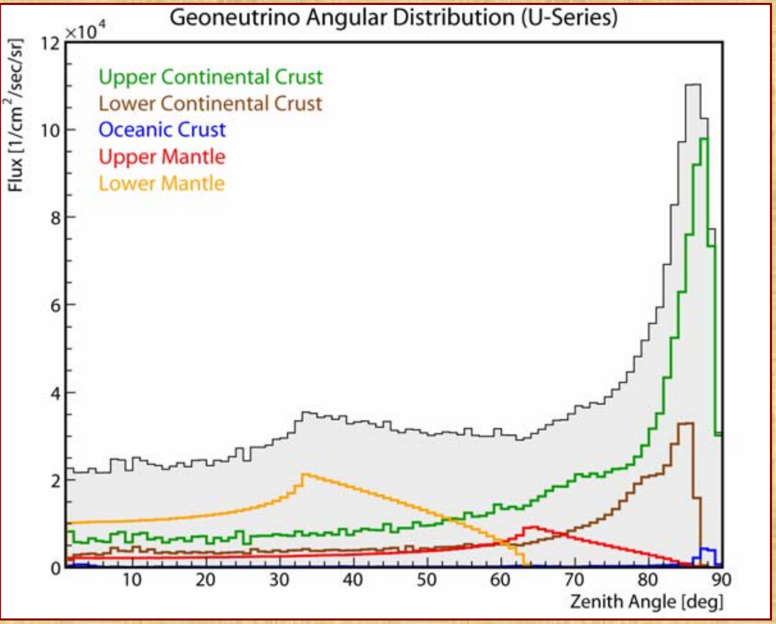






Future Dreams: Directional Sensitivity w/Scintillators





Directional information provides:
- Rejection of backgrounds
- Separation of crust and mantle
- Earth tomography by multi detectors

Directional (statistical) Resolution:
- Recoil neutron remembers direction
- Thermalization blurs the info
- Gamma diffusion spoils the info
- Present resolution is too poor
- Doable (Chooz.. need better though)

Goals:
- large neutron capture cross-section
- (heavy) charged particle emission
- excellent energy resolution (3%/$\sqrt{(E)}$?)
- high spatial resolution detector (~1cm)

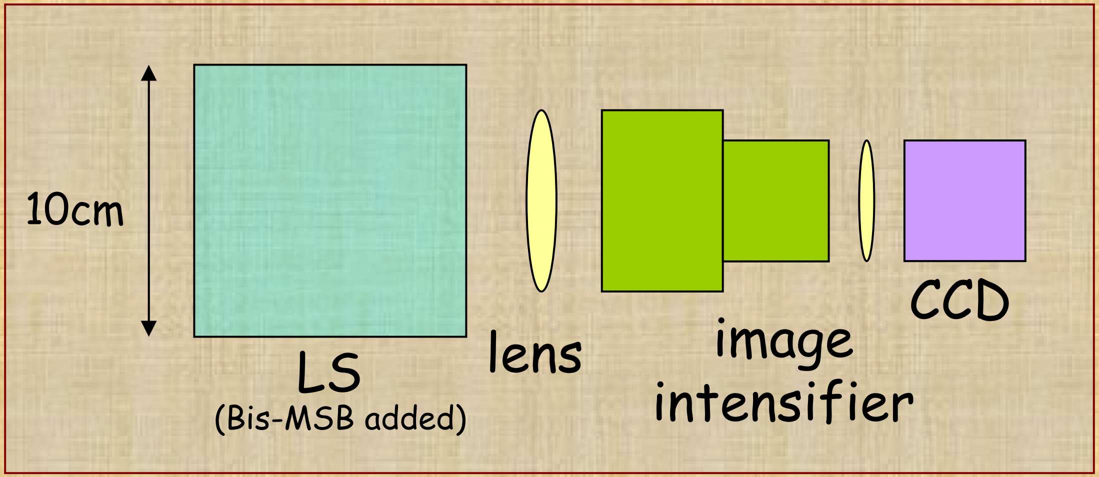
see Oberauer, Watanabe, Dye talks

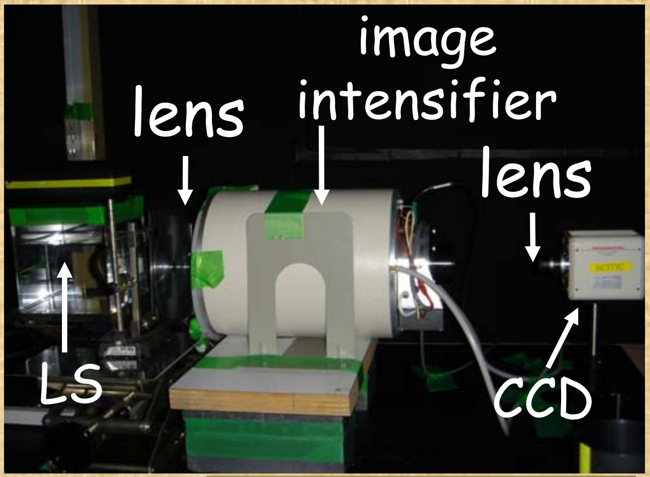
Direct Track Imagine in Scintillator

~1M pixel imaging can achieve 1 cm resolution

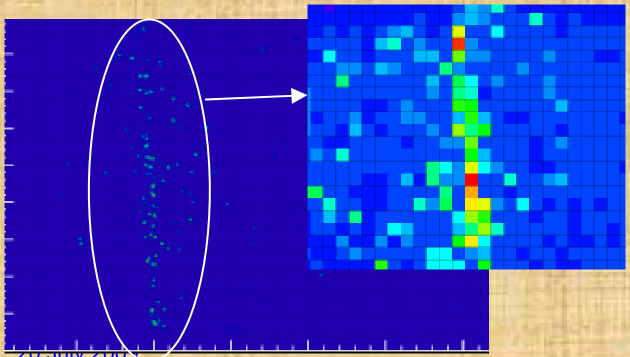
- Proper optics need to be implemented
- Sensitivity to 1 p.e. and high-speed readout required

First step for LS imaging, just started…

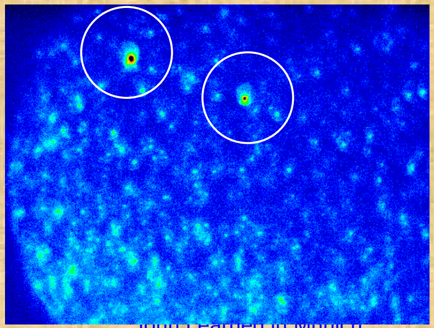




Muon Event ???



Isotope Decay Event ???



See Watanabe talk

More details on directionality with scintillators and via photography

- Show Hiroko Watanabe slides from Trieste ……….

New Topic

- Using Liquid Scintillation detectors for ~1 GeV studies .... accelerator beams and nucleon decay!
- (Formerly assumed that events in this range would be purely isotropic... a big calorimeter only).

NEW: The Fermat Surface

- Central idea:
  - Scintillation radiation is isotropic at each point along track
  - Large (many kiloton) scintillation detector PMTs would have > 100 PE/PMT @ 1 GeV
  - First hit is very close to Fermat Surface (Cherenkov and spheres)
  - Huge statistics determining surface.
  - Large difference between equi-charge and equi-time surfaces reflect topology of interaction (i.e. muon or electron).
  - There is much more information… how complex a topology can we extract?
- **High Energy ~1 GeV neutrino interactions may thus be studied (& Nucleon Decay)**
- Potential for long baseline experiments, and many others
- Does not interfere with lower energy (MeV) physics (e.g. reactors, geonus, supernovae, etc.)

Much useful work done by muon fitting using Fermat Principle by KL folks: Mitsui, Tajima, Enomoto and others. Thanks to UH colleagues (Jason, Misha, Shige, Steve, Stephanie, Sandip) for discussions that launched this investigation.

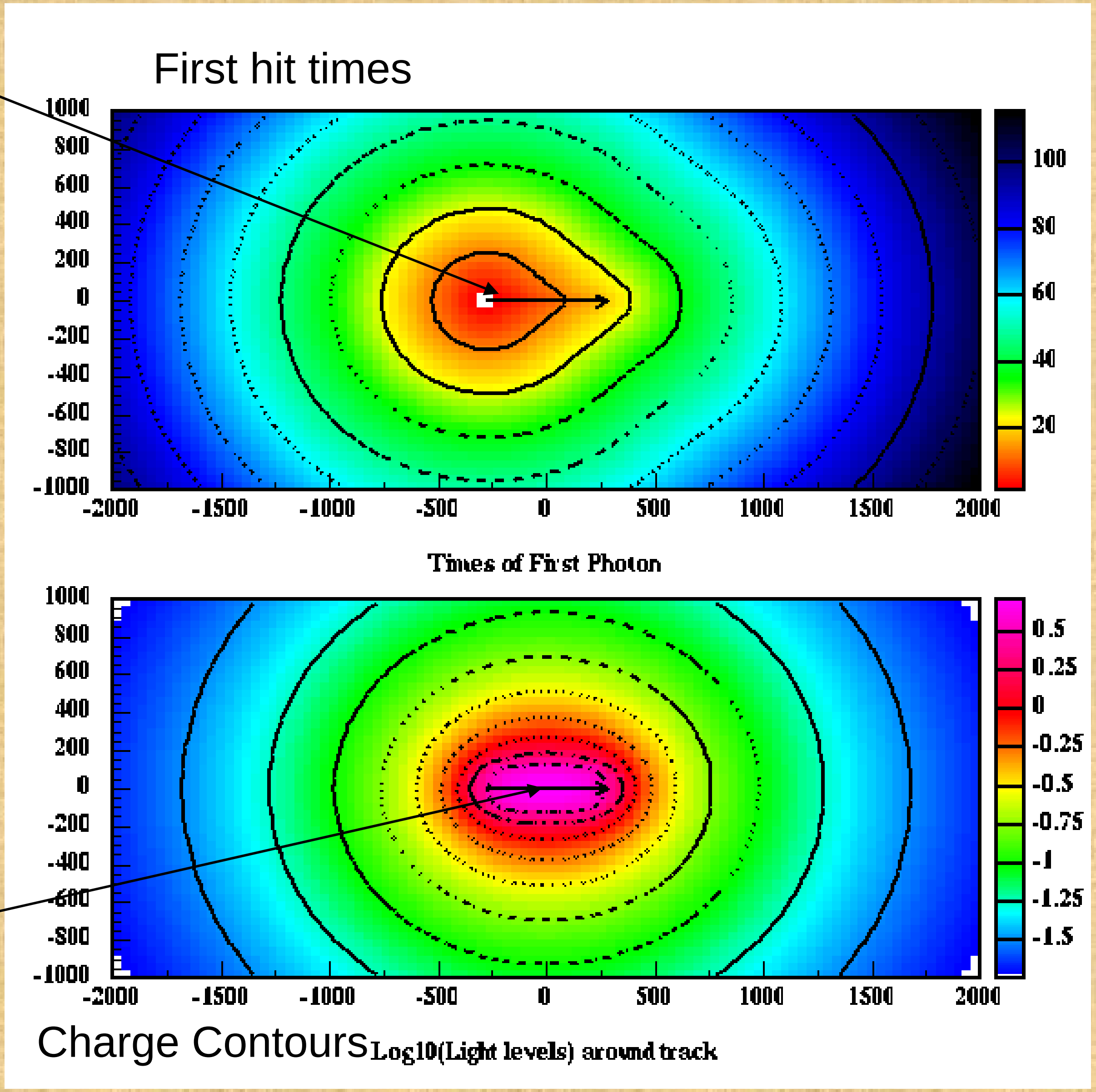
Fermat and Equi-Charge Surfaces

center of time

Strong separation between mu's and e's just on point fits to centers of time and charge

Angles to <1 degree

center of charge

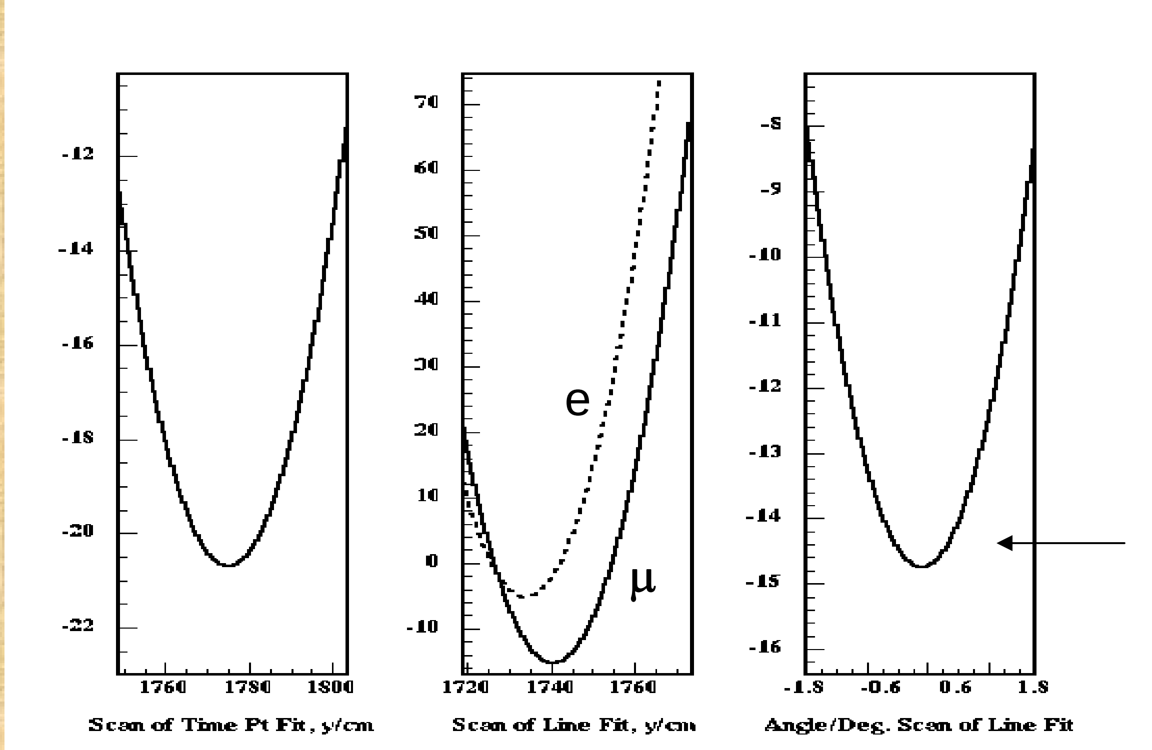


Simple Point Fits (Q and T) Give Center of Track and point Near Origin

results of line fit for muon

Chisquare/ DOF

Equivalent



Muon angular resolution to <1 Degree

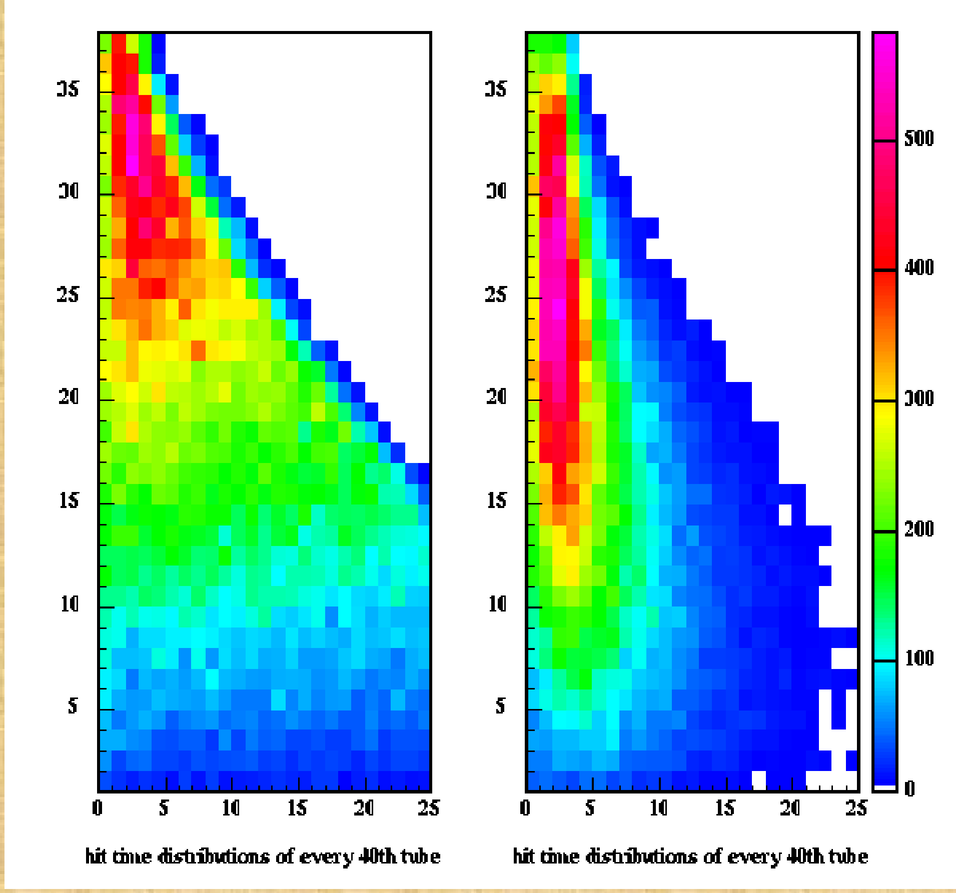
Vertex location to few cm with first point fit.

10 sigma better fit to line than shower profiles

Further: Much Information in Time Distribution of Hits (PMT Waveform)

Sample PMT hit time distributions from top of detector

1 GeV Muon



1 GeV e Shower

Given real world problems (PMTs, scint lifetime, scattering….), how much of this can we utilize? Needs detailed modeling.

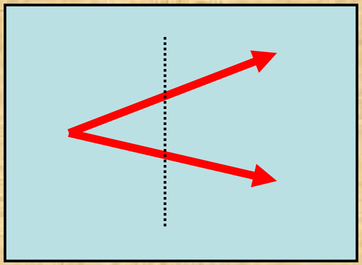
There is much more information in the Fermat Surface: Multiple particles resolvable?

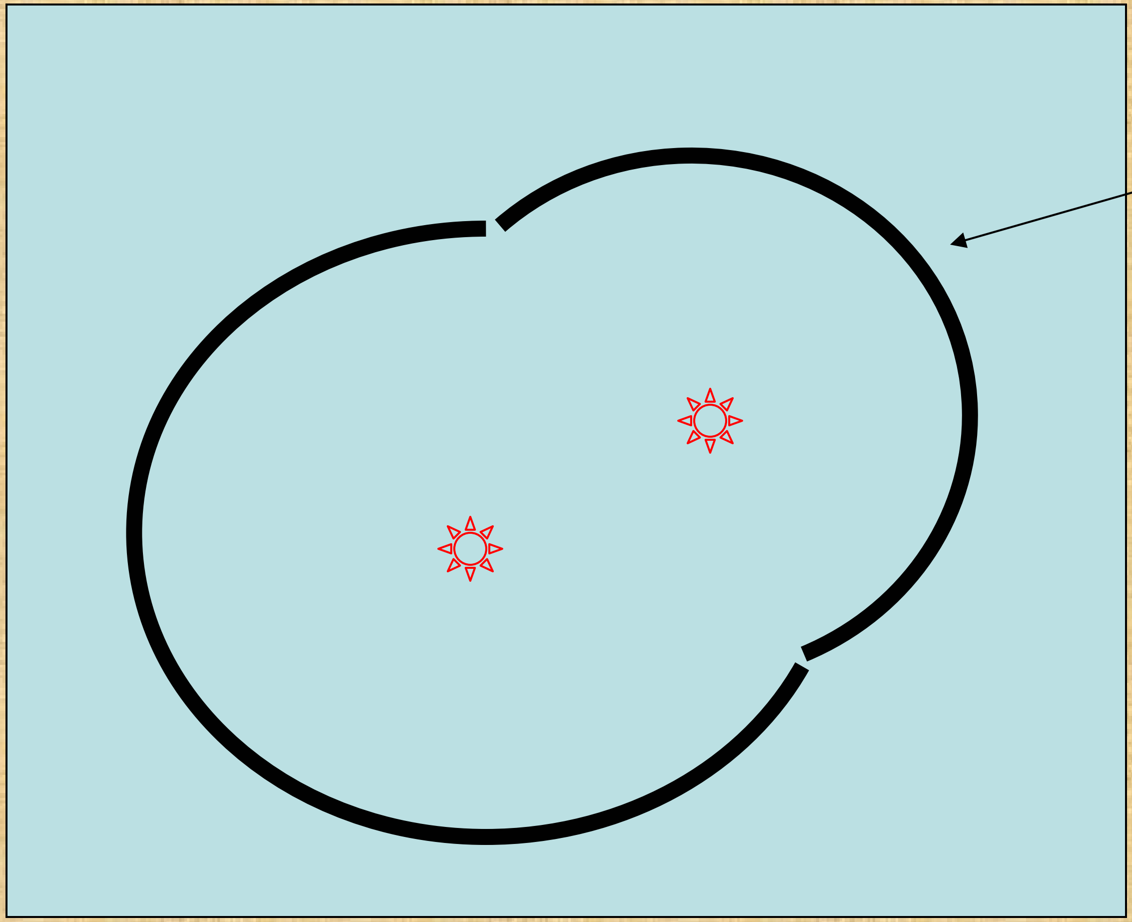
- Huge statistics on shape of surface.
- Local vectors determine shape (Q and T)
- Surface in some regions has texture.
- Key question for LB experiments: How well at resolving asymmetric pi-zeroes relative to Water Cherenkov. Needs detailed Monte Carlo study.
- Need good model of light propagation in LS, including Cherenkov.

More: Can Do Tomography to Reconstruct Event Topology

- very early and encouraging results follow

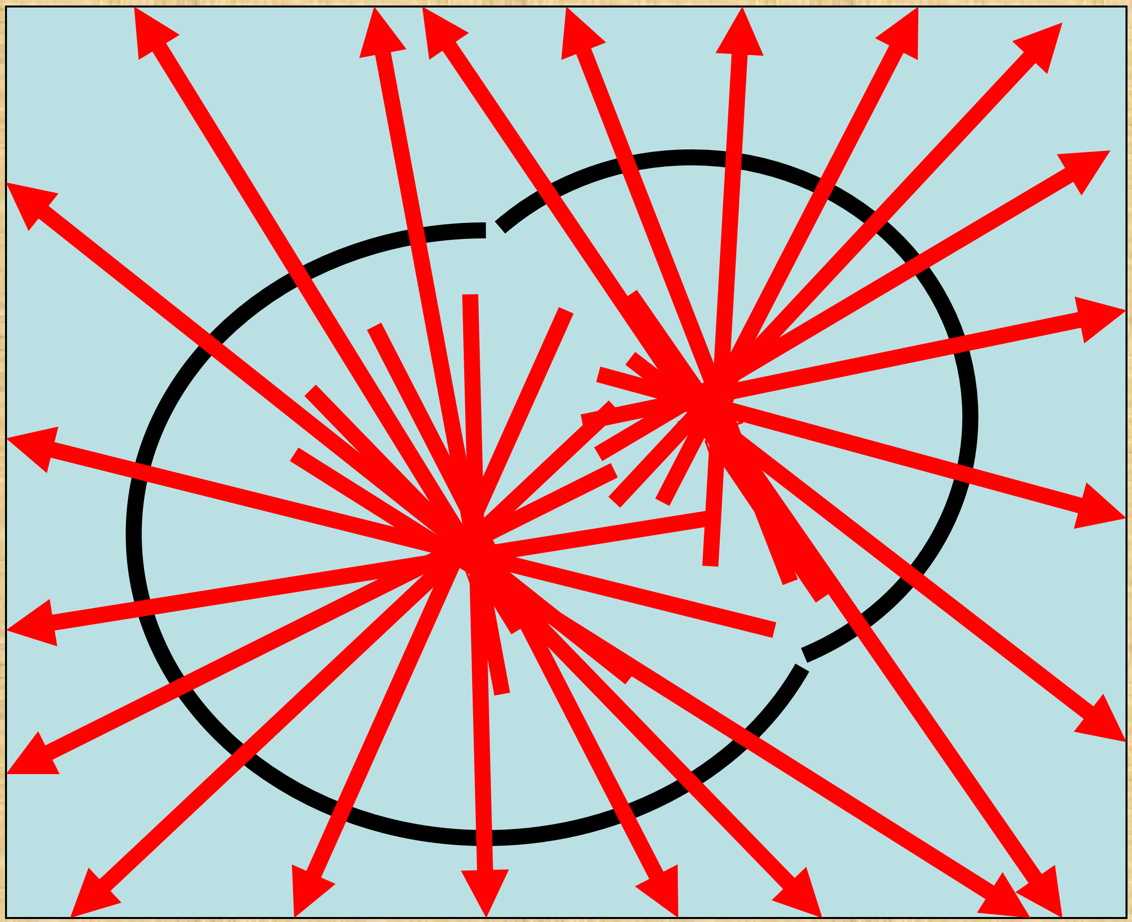
Fermat Surface Crossection for Two Tracks

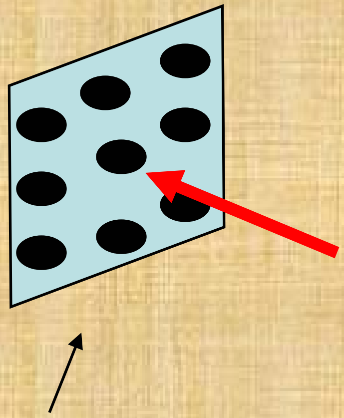




- Equi-time contours.
- How well can we resolve multi-track events via Fermat Surface fitting?

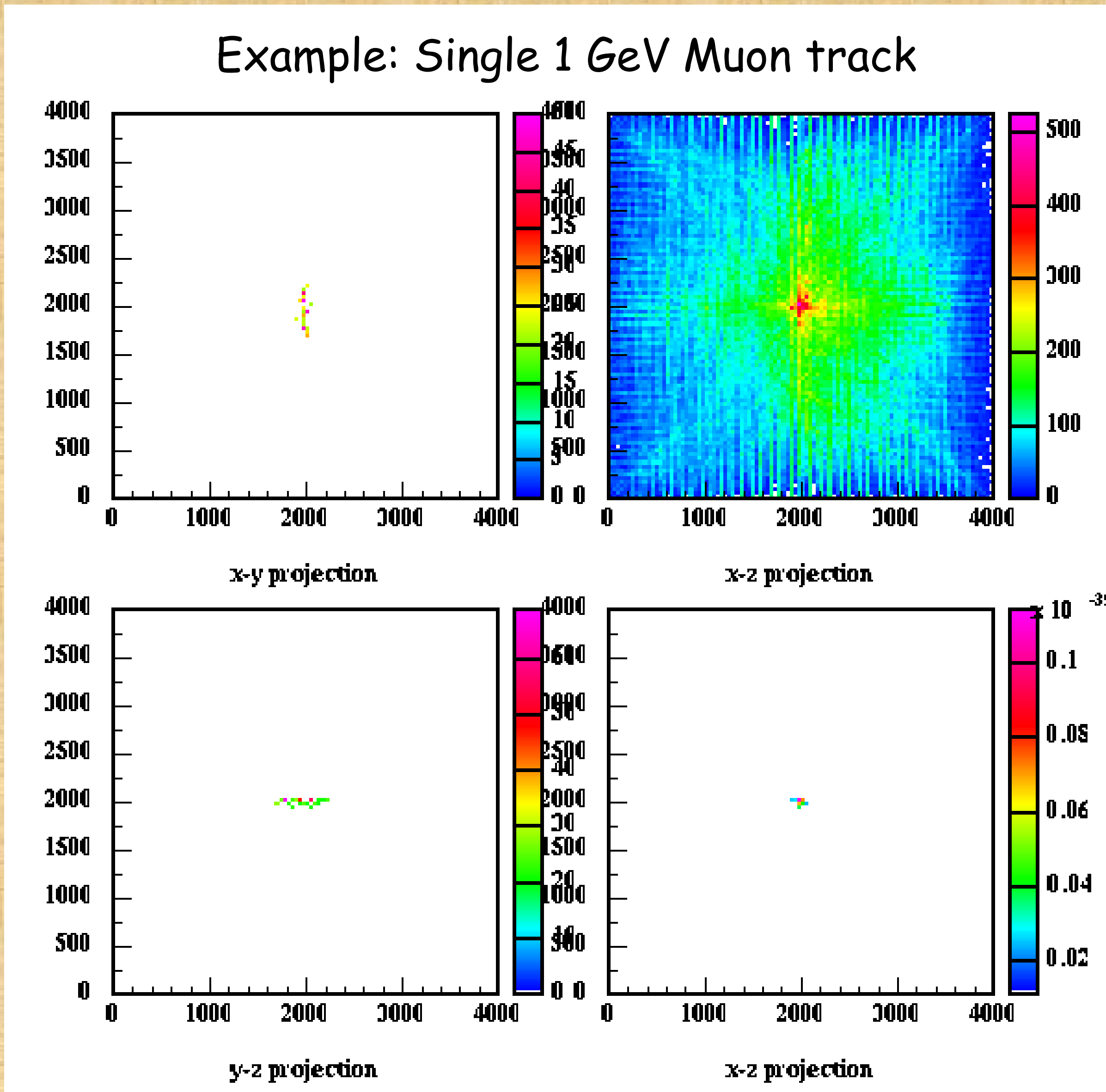
Pictorial Fermat Surface Crossection for Two Tracks





- Project back from PMT clusters by first-PE-time gradient (Plane wave fit)
- Do it in 3D, and include time (back projections crossing at same time).
- A form of tomography
- Demands high time resolution and dealing with prepulses.

First Results on Tomographic Reconstruction from Fermat Surface



before cuts

after contrast cuts

We should be able to reconstruct bubble chamber like images from multiple tracks

jgl 10 July '09

Applications

- Long Baseline with accelerators ~ 1 GeV
  - **LENA with CERN beam?**
  - **Hanohano with Tokai Beam? (Demonstration)**
  - New DUSEL Experiment with Fermilab Beam?
- Nucleon Decay (high free proton content)
  - See details of decays such as Kaon modes
- Particle Astrophysics (low mass WIMPS,…)
- All the Low Energy Physics (geonus, reactor studies, monitoring, solar neutrinos…..) unimpeded!
- Much work to be done, fancier calculations in progress.

Final comments on new photodetectors in the US....

- Chicago/ANL... new version of large area (channel plate-like detector but of ~anodized aluminum).

    very fast (10's of ps)
    as much pixelization as one can want
    large areas (m^2 panels)
    claim several years to production

-MIT ... woven fiber light detectors

    flexible, large areas
    not clear can get to low noise

US government putting resources into large photodetector development