Timing in Large Liquid Cherenkov/Scintillator Detectors

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Disclaimer

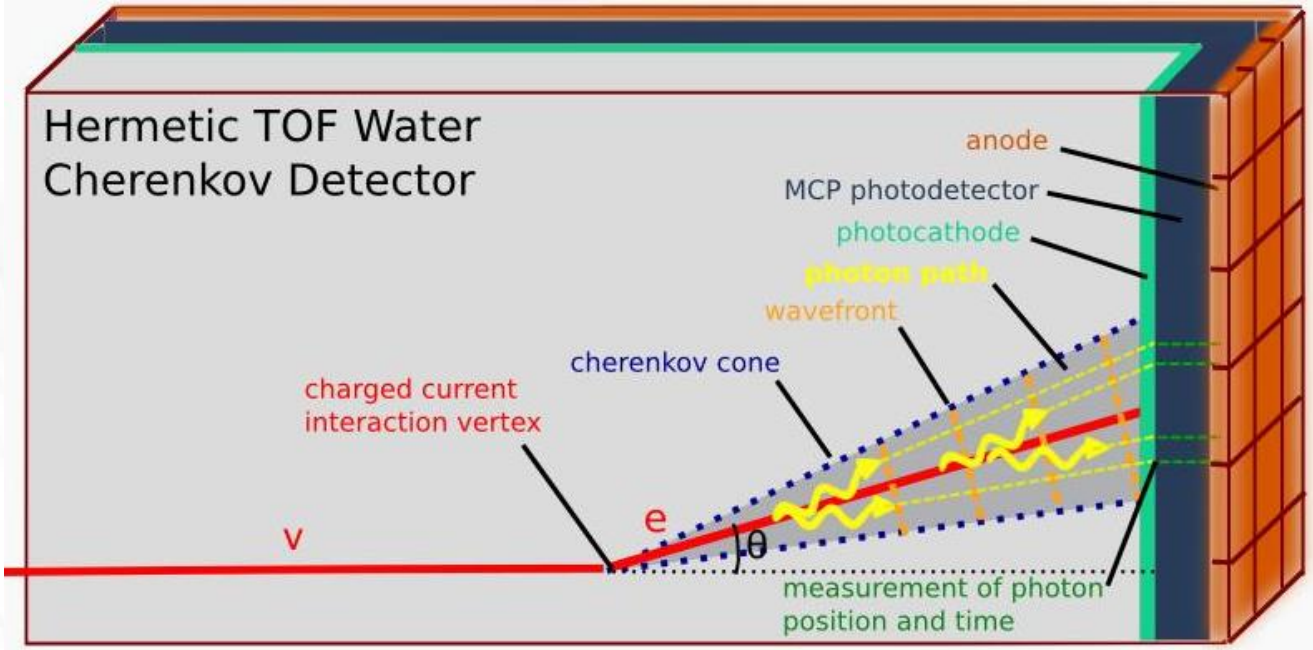
This talk is NOT an exhaustive overview of

1) Ongoing or planned experiments
2) Various reconstruction algorithms

What follows are some thoughts on photon timing in large liquid detectors where there is access to both Cherenkov and scintillation light

Optical Time Projection Chamber

- Like a TPC but drifts photons instead of electrons
- Exploits precise location and time for each detected photon
- Would allow track /vertex reconstruction in large liquid counters



Suggestion to use LAPPD's for DUSEL and the name (OTPC) due to Howard Nicholson

Eric Oberla has built a 40 kg OTPC and tested it at Fermilab TestBeam for his PhD thesis:

- 60 mrad angular resolution over a lever arm of 40 cm NIMA 814 (2016) 19
- 1.5 cm spatial resolution

- It doesn't have to be water (use prompt Cherenkov light that arrives early)
- In fact, for long tracks optical tracking also works using just scintillation (e.g. see B.Wonsak et al., JINST 13 (2018) no.07, P07005 and M. Sakai PhD thesis 2016)

Cherenkov vs Scintillation Light

Cherenkov

- Prompt emission
- Directional for each charged track segment
- Higher energy threshold
- Less abundant compared to scintillation light
- Conventionally used for particle ID, vertexing and "coarse" energy measurements

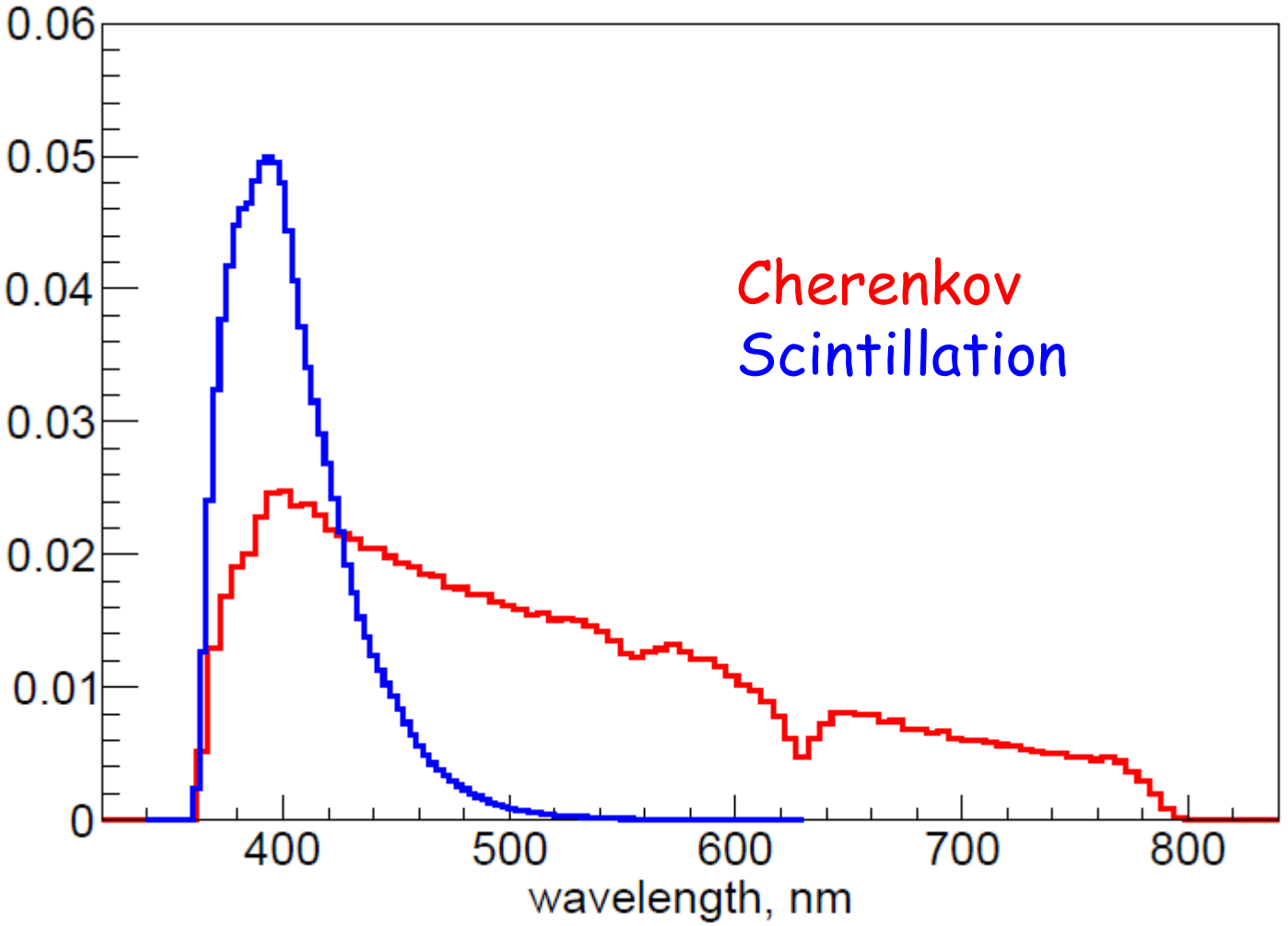
Scintillation

- Slow emission
- Isotropic for each charged track segment
- Very low energy threshold
- Abundant: often completely overshadows Cherenkov light
- Conventionally used for vertexing and "precision" energy measurements

Combining the two could make for a very powerful detector

Normalized Che/Sci Spectra

An example of a scintillator model similar to KamLAND



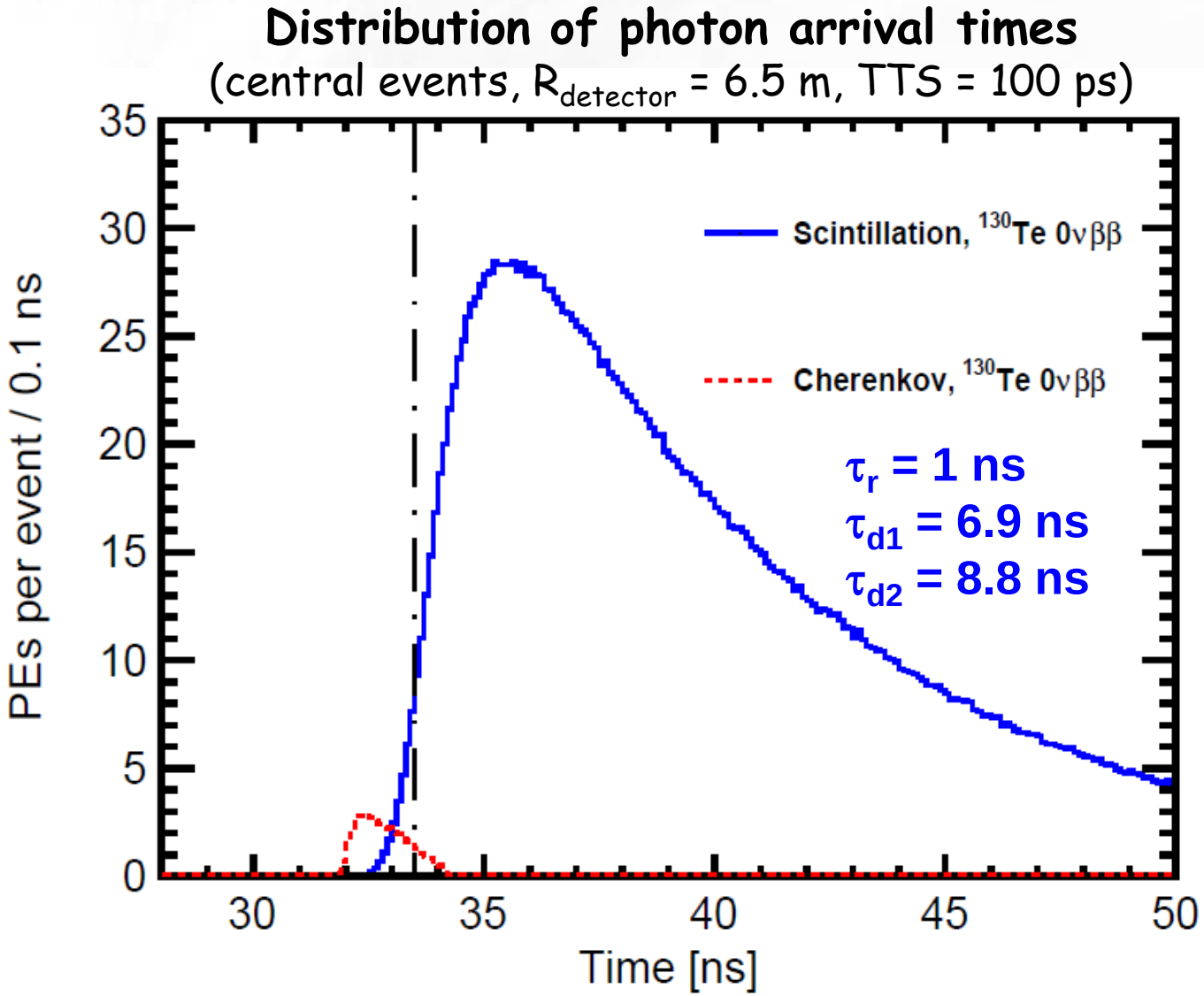
Role of chromatic dispersion

370 nm → 0.191 m/ns

600 nm → 0.203 m/ns

~2 ns difference over 6.5m distance

Cherenkov Light Comes First



- Scintillation emission is slower
- Longer wavelengths travel faster
- Cherenkov light arrives earlier

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North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Dilute scintillators for large-volume tracking detectors

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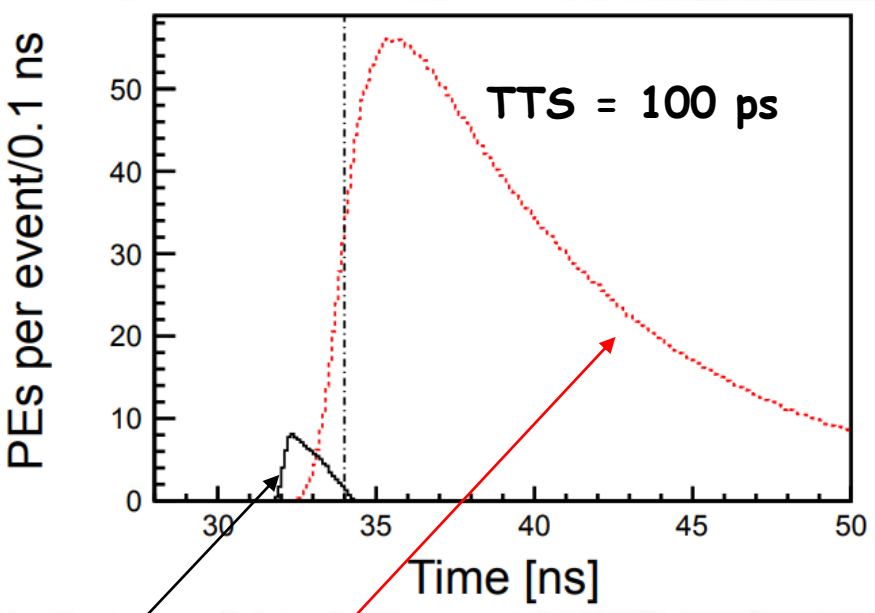
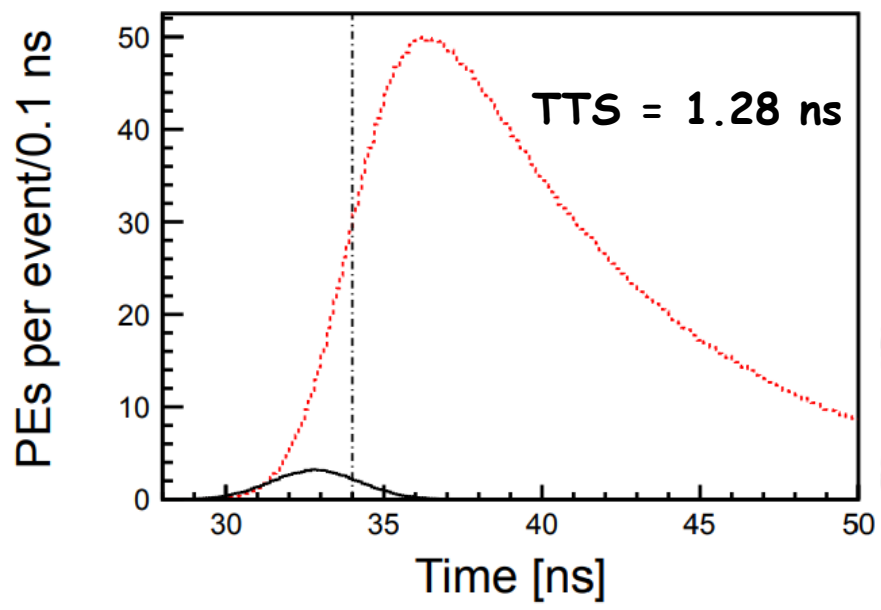
Received 2 April 1993

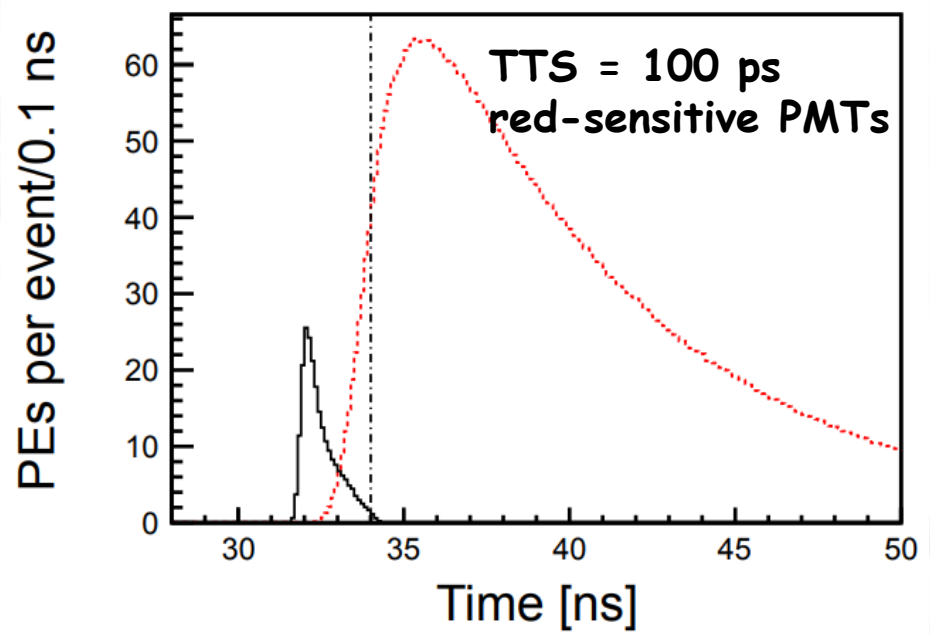
Dilute scintillation mixtures emit isotropic light for both fast and slow particles, but retain the Cherenkov light cone from fast particles. Large volume detectors using photomultipliers to reconstruct relativistic tracks will also be sensitive to slow particles if they are filled with these mixtures. Our data show that 0.03 g/l of b-PBD in mineral oil has a 2.4:1 ratio (in the first 12 ns) of isotropic light to Cherenkov light for positron tracks. The light attenuation length is greater than 15 m for wavelength above 400 nm, and the scintillation decay time is about 2 ns for the fast component. There is also a slow isotropic light component that is larger (relative to the fast component) for protons than for electrons. This effect allows particle identification by a technique similar to pulse shape discrimination. These features will be utilized in LSND, a neutrino detector at LAMPF.

Cherenkov/Scintillation Separation

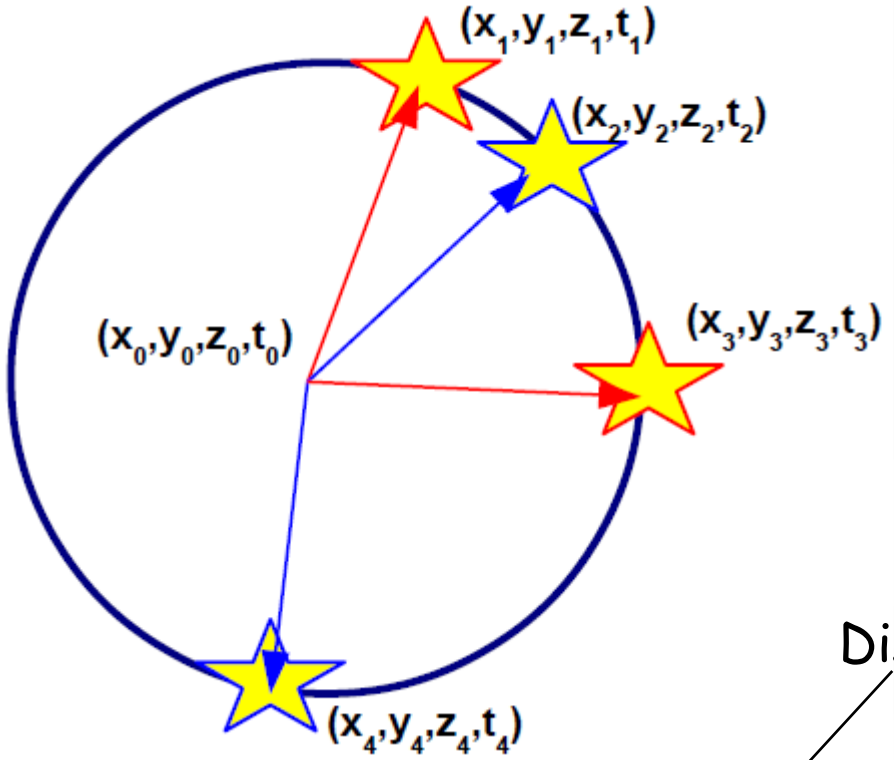
5 MeV electrons in a detector similar to KamLAND







Vertex Reconstruction



Dispersion

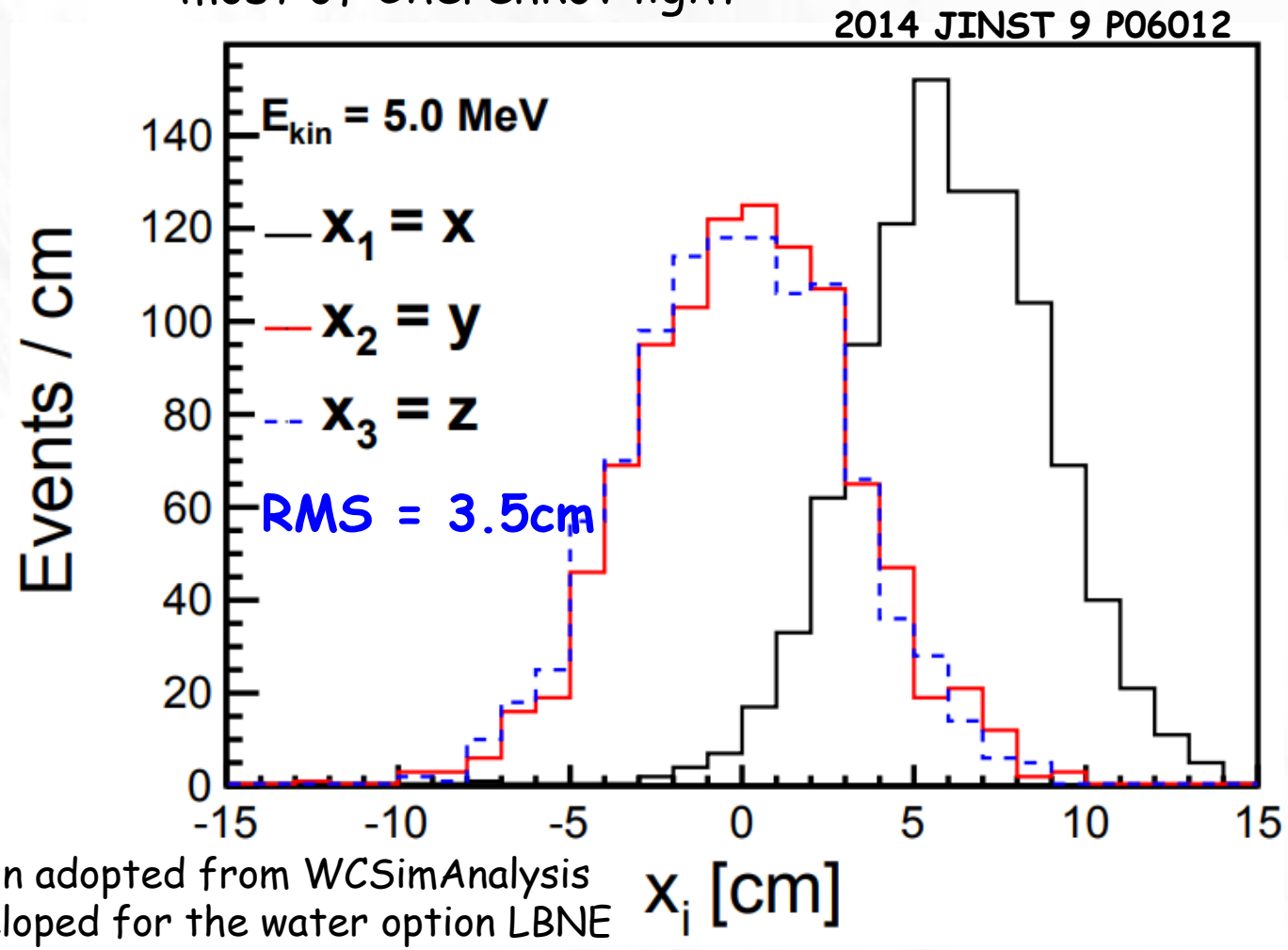
$$(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2 = V(\lambda_i) \times (t_i - t_0)^2$$

- Ideally one could do precision vertexing with just 4 photons
- The "real world" effects require an ensemble of quadruplets
- There are various strategies to get best estimate on vertex
  - M. Ishitsuka
  - M. Smy
  - M. Wetstein

Distribution of time residuals $\Delta T = (t_i - t_0)$ is used to optimize the best choice of t_0 out of all quadruplets

Vertex Reconstruction

- 5 MeV electrons in a detector similar to KamLAND
- Short tracks ~cm
- After selecting a sample of "early" photons containing most of Cherenkov light



For a media with refraction index of n=1.5
3.5cm -> 175ps

Reconstruction adopted from WCSimAnalysis package developed for the water option LBNE

Transition from O(1cm) vertexing of a "point-like" source to O(100ps) T_0 of a neutrino interaction is detector and event topology specific

Summary

Hybrid Cherenkov-Scintillator Large Liquid detectors are compatible with ~100 ps timing

… and, btw, there is a viable (potentially affordable) path to < 100 ps resolution over very large areas

The "Air-Transfer" LAPPD Tile-31
(E.Angelico, A.E, H.Frisch, E.Spieglan)