Cascade and ν_τ Reconstruction in IceCube

MANTS 2009

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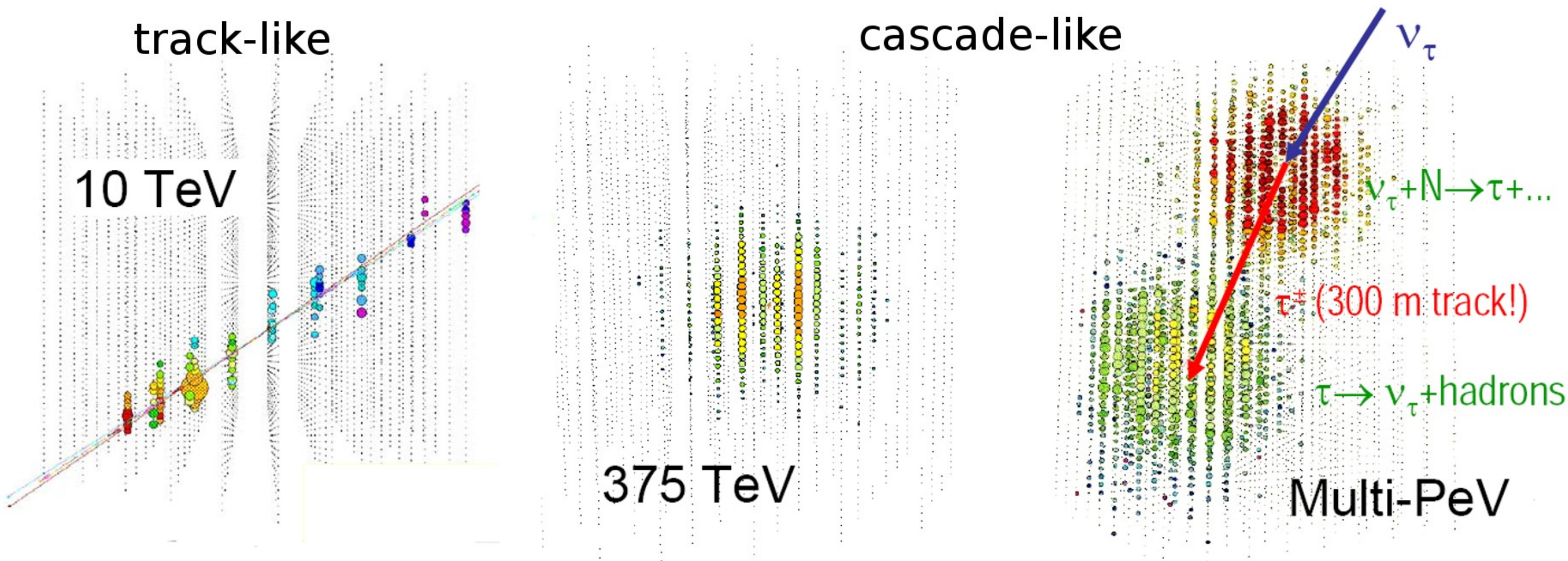
Outline:

- Event Signatures
- Light Propagation in Ice
- First Guess Algorithms
- Likelihood Reconstructions
- ν_τ Reconstructions

Event Signatures in IceCube

- distinguish between track-like and cascade-like events
- all neutrino flavours can create cascade-like event
- cascades: good energy reconstruction but in ice poor directional information

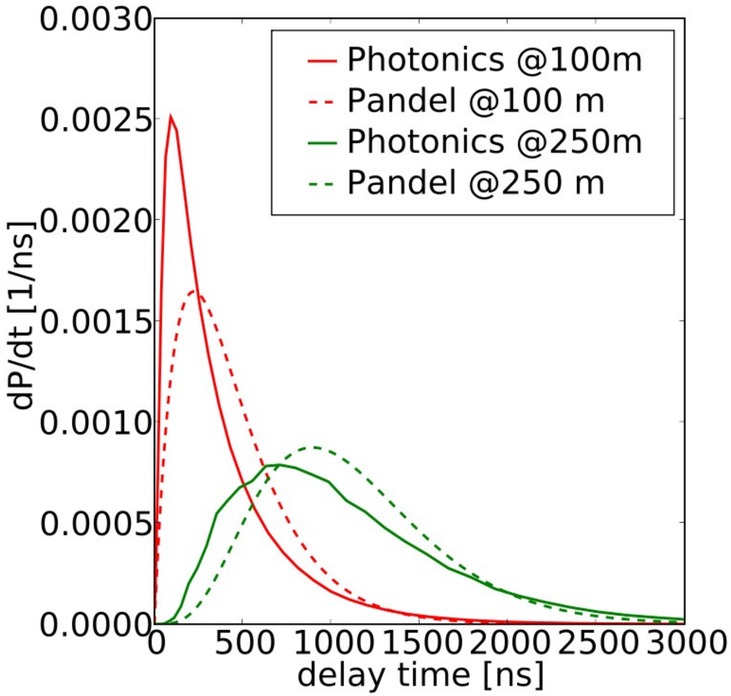


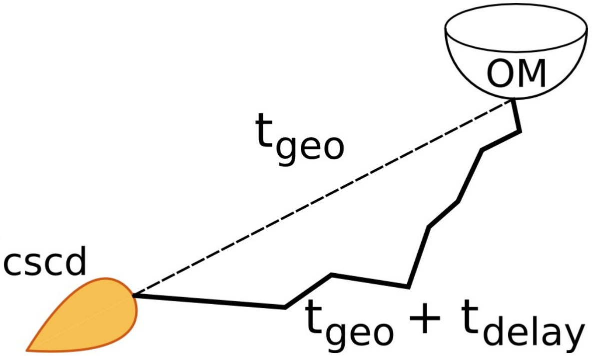
signature of ν_μ | signature of ν_e | signature of ν_τ

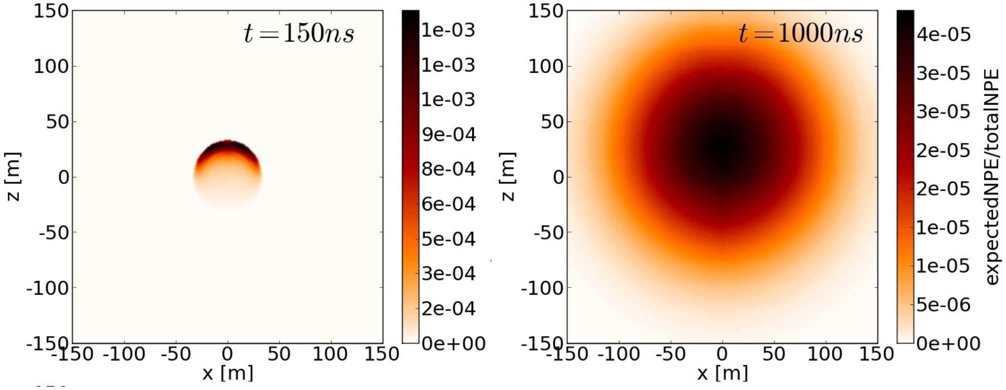
Light Propagation

- cascades are nearly point-like but anisotropic light sources
- inhomogeneous medium
- light propagation (scattering, absorption) simulated with Photonics

→ mean amplitude
→ delay time probability



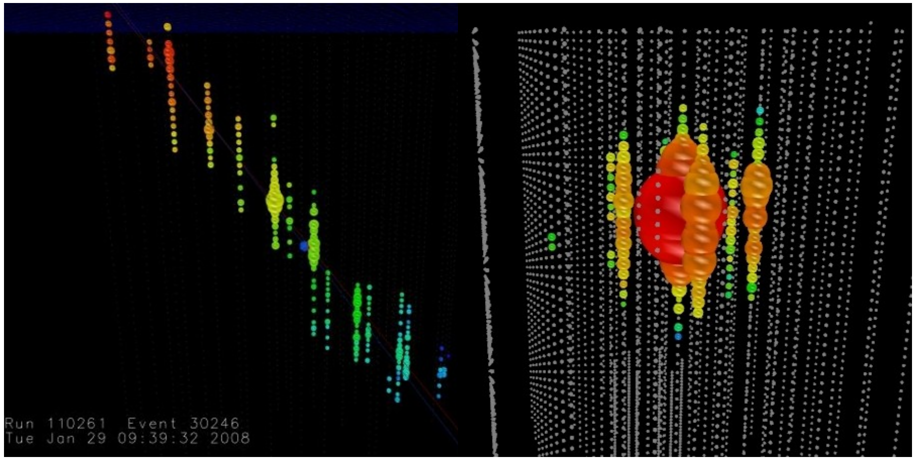




First Guess Algorithms

- LineFit - muon first guess

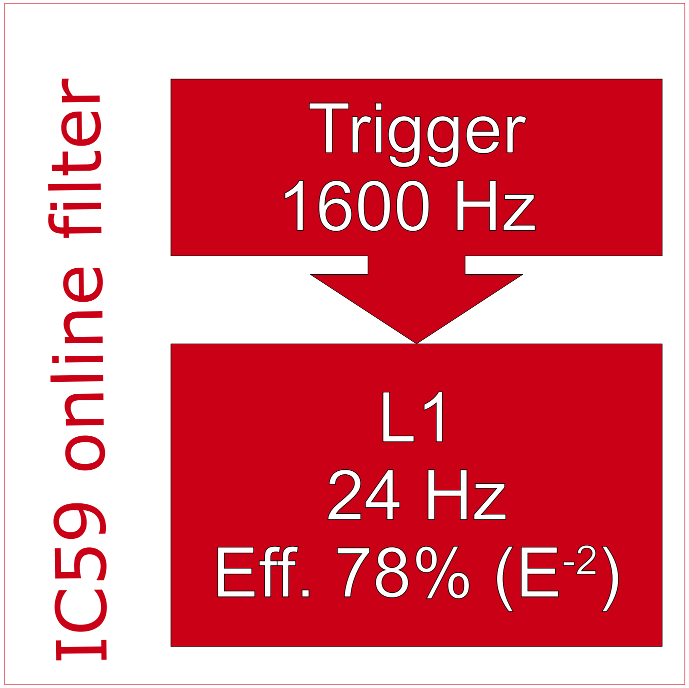
$$x = x_0 + \vec{V} \cdot t \qquad V = \frac{\langle r_i \cdot t_i \rangle - \langle r_i \rangle \cdot \langle t_i \rangle}{\langle t_i^2 \rangle - \langle t_i \rangle^2}$$



- rigid body analogy: tensor of inertia
- vertex ~ center of gravity
- eigenvalue ratio to select spherical events

$$R = \frac{E_1}{E_1 + E_2 + E_3}$$

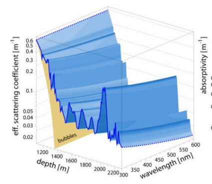
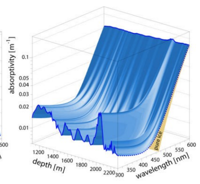
- used in cascade online filter (+muon reconstruction)
- seeds more elaborate reconstructions



LLH Reconstruction

- need a probabilistic description of the measurement

point-like anisotropic light source (t,x,y,z,E,θ,φ) → light propagation → PE at photo-cathode → PMT & digitization → waveforms → feature extraction → reconstructed pulses (time, charge, width)

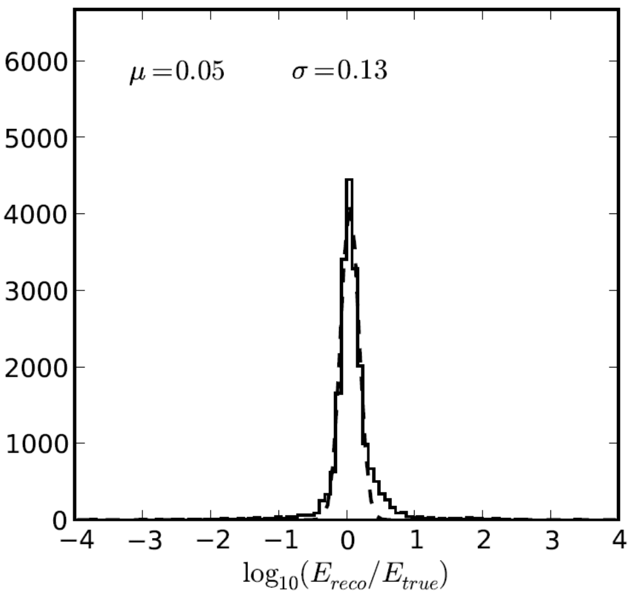
Photonics tables

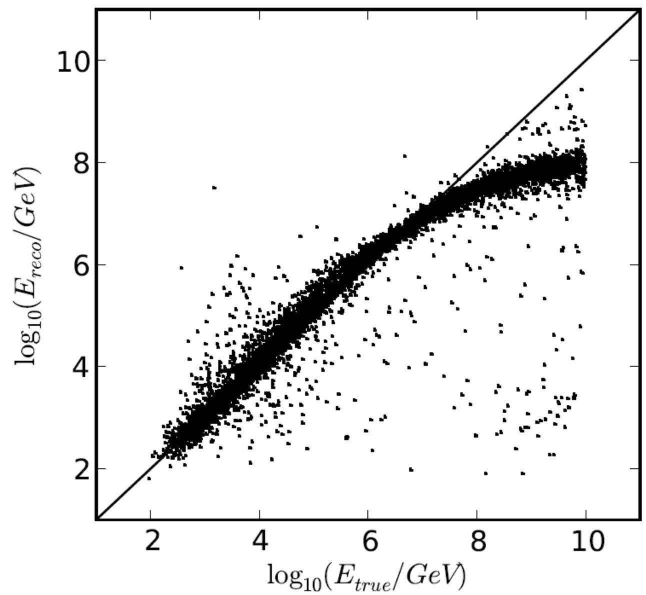
parametrization

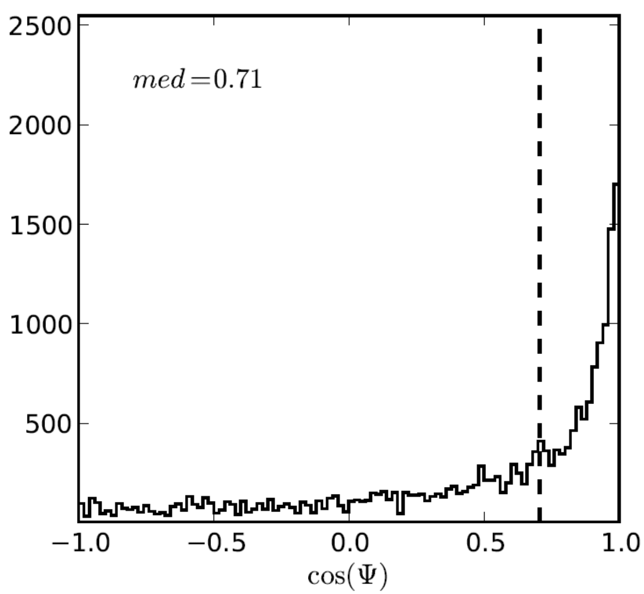
- Poisson process in each time interval (waveform bin, reconstructed pulse)
- tables allow to predict the measured charge
- in DOM o, pulse i: compare charge n_{oi} to prediction μ_{oi}

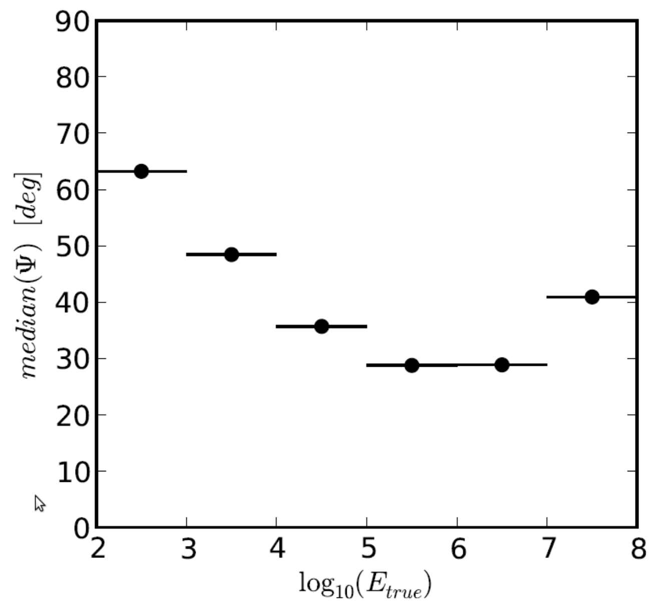
$$L = \prod_{\substack{\text{hit DOMs} \\ o}} \prod_{\substack{\text{Pulse} \\ i}} \frac{\mu_{oi}^{n_{oi}}}{n_{oi}!} \exp\left(-\mu_{oi}\right) \prod_{\substack{\text{unhit DOMs} \\ o}} \exp\left(-\mu_o\right)$$

Resolutions







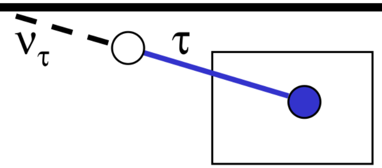
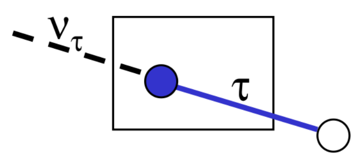
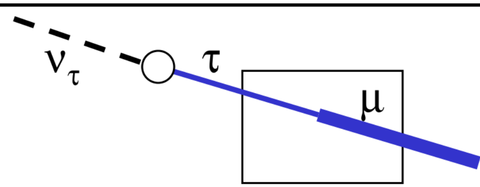
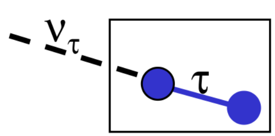
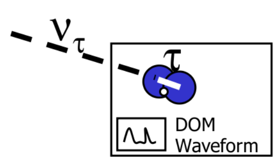
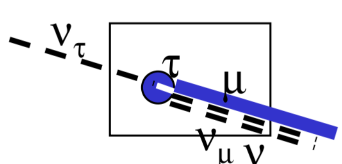


- simulated ν_e E^{-2} dataset
- contained events
- σ(log E)=0.13
- med(ψ) ~ 30° for 10 TeV – 10 PeV
- above 10PeV:
  - saturation effects
  - point-like reconstruction hypothesis not longer applicable

Further Remarks

- computational intensive
  - good energy and vertex resolution obtainable with a single minimization
  - directional reconstruction requires iterative minimization strategy
  - reconstruction results will be available at late filter levels
- other uses of this Poisson likelihood are possible:
  - use other reconstructions to fix some parameters (t,x,y,z,E,θ,φ) → fast energy reconstruction
  - change reconstruction hypothesis to more than one light source

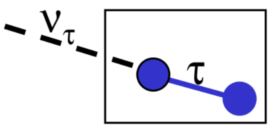
Tau Event Signatures

Signature	Cartoon	Description
Lollipop		Tau created outside (un-detected), decays→cascade
Inverted Lollipop		Tau created inside→cascade, decays outside (undetected)
Sugardaddy (see talk by T. DeYoung)		Tau created outside (un-detected), decays→muon, see Δ in light level along track
Double Bang		Tau created and decays inside, cascades well-separated
Double Pulse		Double bang, w/cascades un-resolvable, but nearby DOM(s) see double pulsed waveform
Low E_τ μ Lollipop		Inverted lollipop but low-E tau decays quickly to μ; Study ratio E_{sh}/E_{tr}

Decreasing IceCube Acceptance Energy →

Doug Cowen

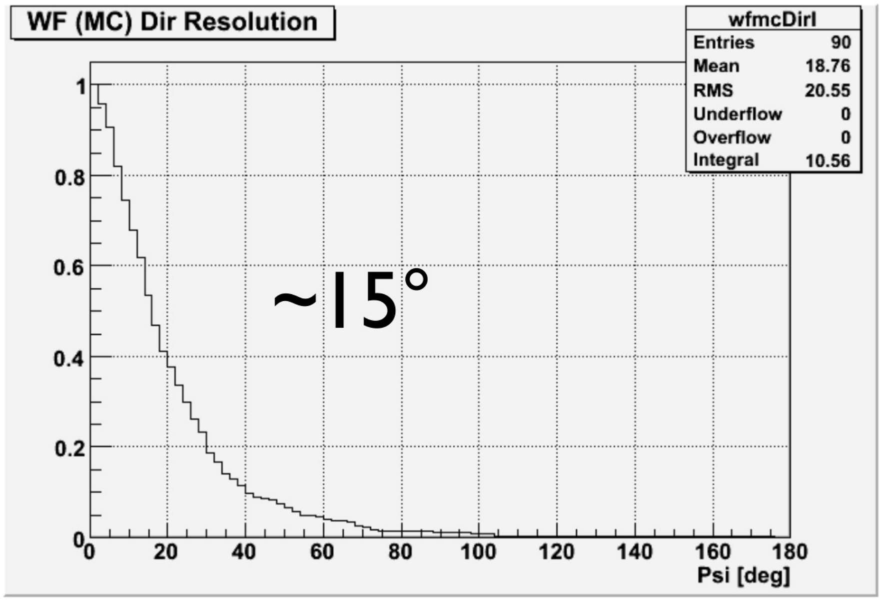
Tau Double Bang Reconstruction



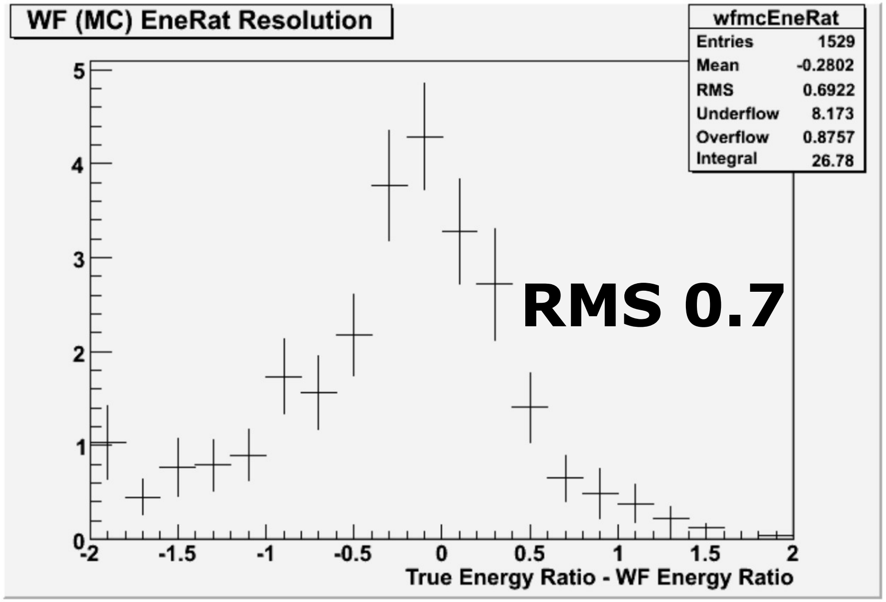
- event hypothesis of two cascades

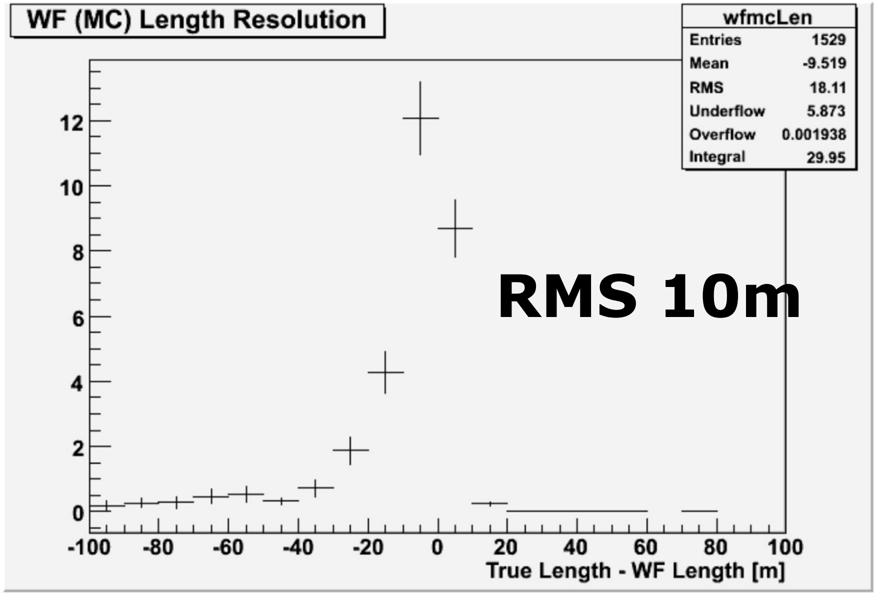
  7 → 9 parameters
- vertex and time t,x,y,z,
- tau direction Θ, φ
- track length L
- energy sum $\sigma=\log(E_1+E_2)$
- energy ratio $\rho=\log(E_1/E_2)$

Double Bang Reconstruction Performance

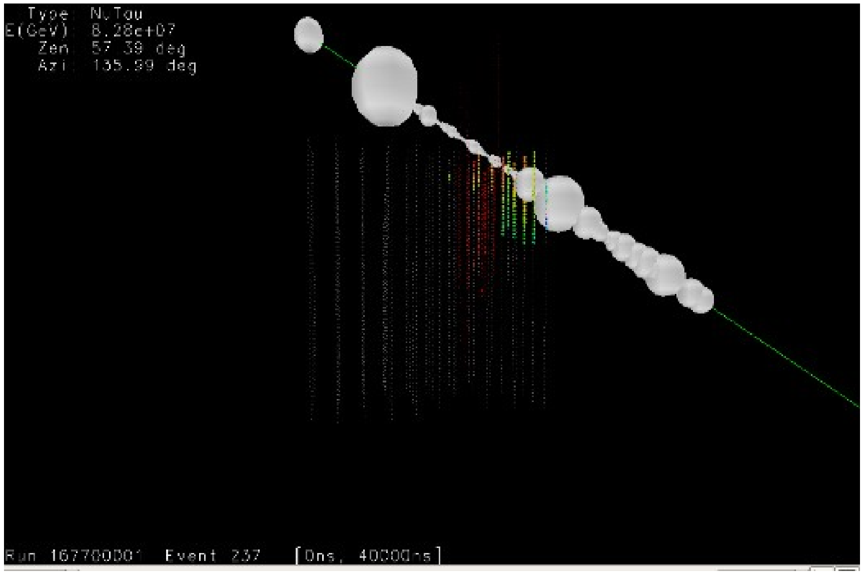


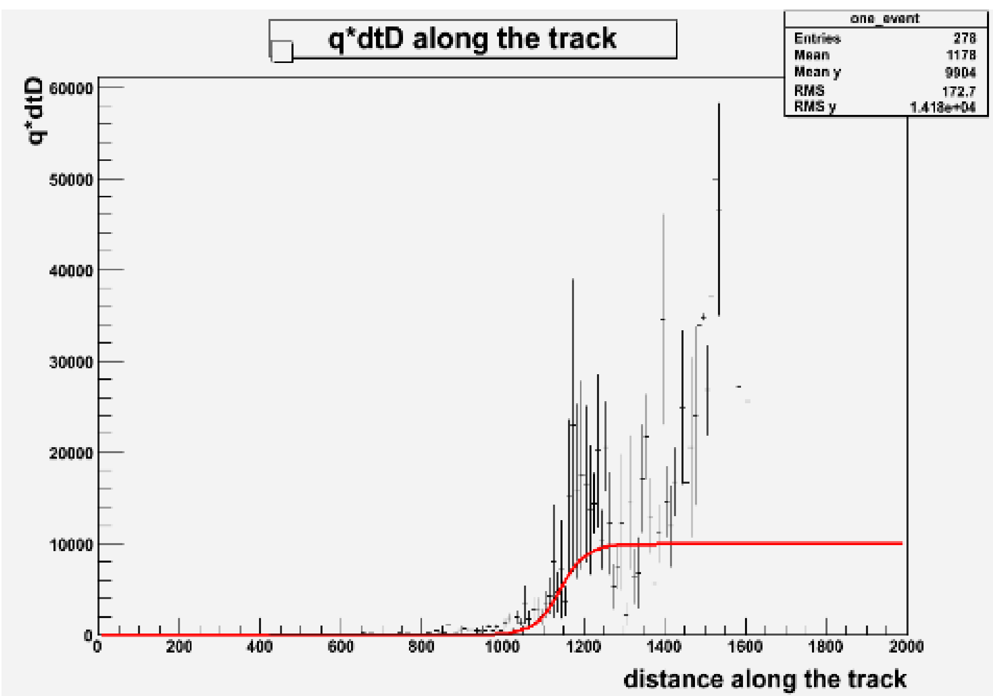
- IC40 MC study
- select bright cascade events (Nchannel ≥40, NCharge ≥ 300pe)
- start minimization with true parameters

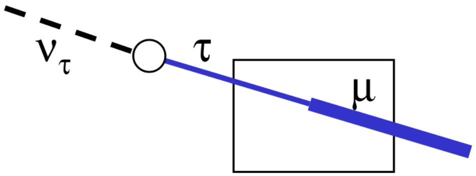




ν_τ Detection via $\tau \rightarrow \mu$ Decay







- TeV to PeV energies
- look for decay $\tau \rightarrow \mu\, \nu_\tau \nu_\mu$
- μ track 3-7 times brighter than τ track
- fit charge distribution along track with sigmoid function

Sabrina Bechet

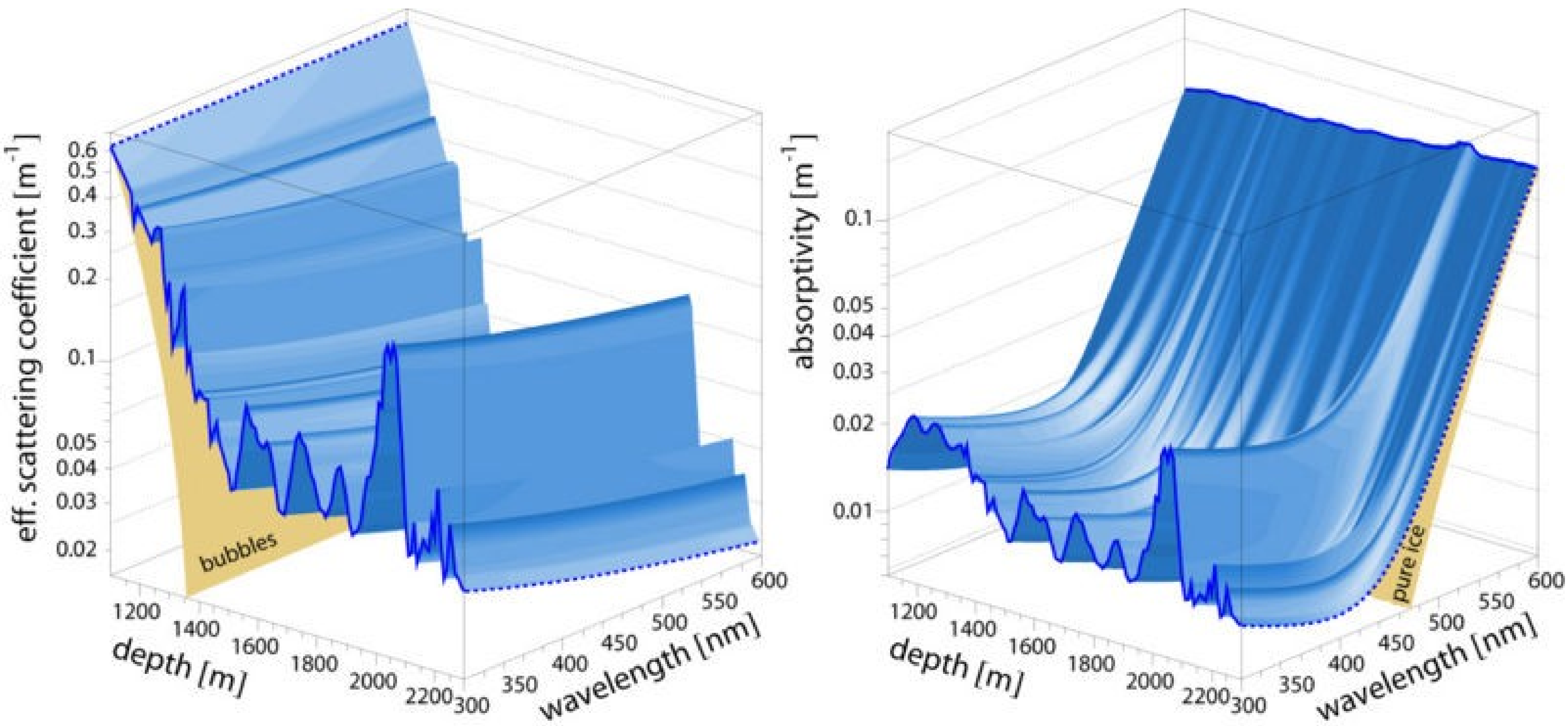
References

- http://photonics.sourceforge.net
- J. Lundberg et al., Nucl.Instrum.Meth.A581:619-631 (2007)
- E. Middell et al., in Proc. of 31th ICRC (2009)

Backup

Ice Properties

- scattering and absorption coefficients as functions of depth and wavelength



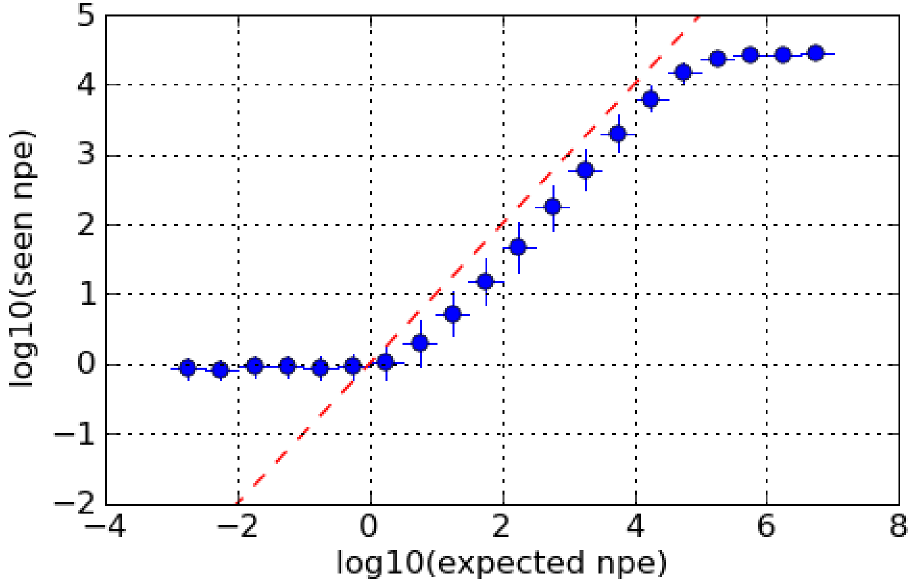
Charge Prediction

- calculate charge prediction from tabulated mean expected amplitude and delay time pdf
- simplify integration to p(t0)·pulse width
- correction factor f tunes charge prediction to observed charge in MC
- accounts for PMT effects, time window (ATWD only), feature extraction
- Credo contains correction functions for pulse maps with and without FADC pulses (see talk Madison '09)

$$\mu = f \langle \mu \rangle \int_{t_1}^{t_2} p(t)dt + R_{\text{noise}}(t_2 - t_1)$$

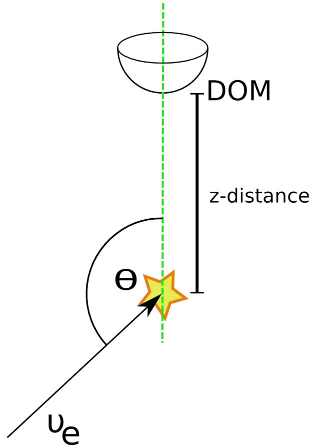
mean total npe — delay time pdf — noise

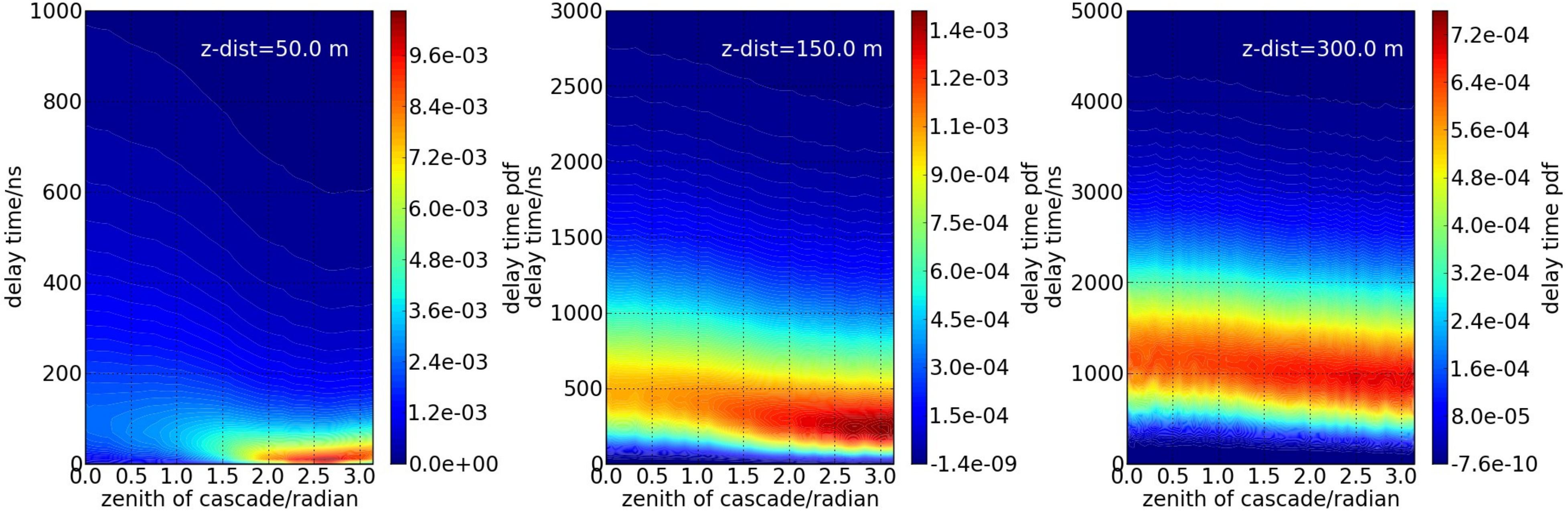
Nue2027, IC40, ATWD only



Photonics Table Scan

- test setup of one cascade and a DOM
- scan table for different orientation and delay times
- initial angular information gets nearly lost with increasing distance





Tau Channels in IceCube