Event ID and tau reconstruction in KM3NeT

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Event Identification

Method

Distinguish different event types in the detector to give analysis easy access to signal selection (and bkg suppression). Train neural network to distinguish events into target classes based on reconstruction output. Available reconstructions algorithms are **track** and **single shower**.

Target classes:

- Track:
  - starting tracks
  - through-going tracks
  - up-going tracks
  - down-going tracks
- Single Cascade
- Double Cascade (*"Double Bang"*)

Event Identification

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For the neural network the scikit-learn package for feature identification and build with the python theanets packages Training:

- Train on 57 high impact features from input reconstructions
- Homogenize samples in energy

Track and single shower identification

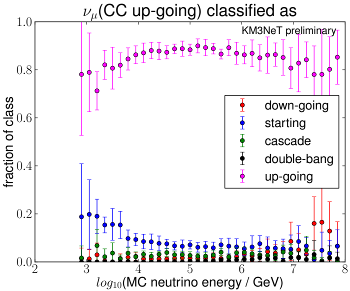

Figure : Identification of nueCC and up-going numuCC events into target classes; errors are dominated by statistics

Double shower identification

Training of neural network for two shower events for tau flight length $\geq 20\,\mathrm{m}$

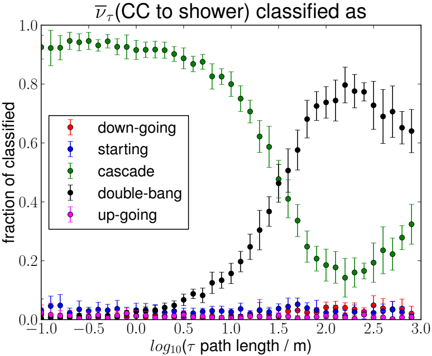

Figure : Identification of tau "Double Bang" events into target classes

Double shower identification

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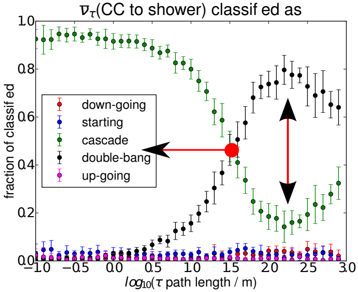


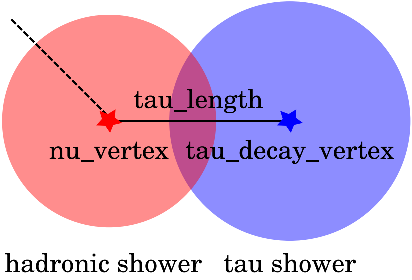
Figure : Identification of tau “Double Bang” events into target classes

Performance based on output of single shower and track reconstructions
$\hookrightarrow$ significant improvement expected if **dedicated two shower reconstruction** is available

Tau “Double Bang” event

- Tau decays 83 % into electron or hadrons causing a shower (called “Double Bang”)
- At mean life τ the tau lepton flight path for a given energy is:

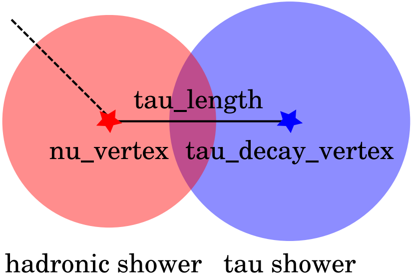
$$\text{tau.len} = 4.9\,\text{m} \times \frac{E_\tau}{100\,\text{TeV}}$$



Tau “Double Bang” event

Tau flavor reconstruction and identification is highly desirable

- Almost no atmospheric background (at least 1-2 orders lower than other flavors)
- Needed for full flavor decomposition of flux
- Tau neutrino just recently discovered (2000)



Belle Starr: a "Double Bang" Reconstruction

1. Single shower position, direction and energy fit
2. Scan two shower position likelihood $\mathcal{L}$ along prefit trajectory
3. Analyze likelihood $\mathcal{L}$ landscape using TSpectrum
4. Full phase space fit of two shower position likelihood $\mathcal{L}$

where steps 1 to 3 are used to discriminate events and provide good starting parameters for step 4

Fitted variables:

- two positions and one time

Likelihood

$$-log\mathcal{L} = \sum_{\text{hit}} -log\Big[P\,(\text{vertex}_1) + P\,(\text{vertex}_2) + P\,(\text{bkg})\Big]$$

$$P\,(\text{vertex}_1) = P\left(\text{hit}^{i}_{r1}|\text{vertex}_1\right)$$

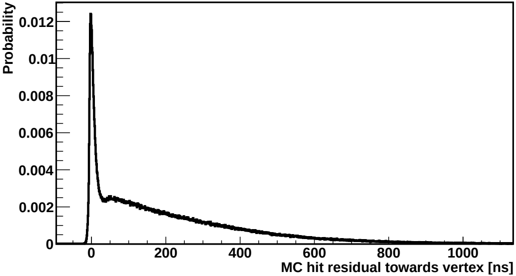
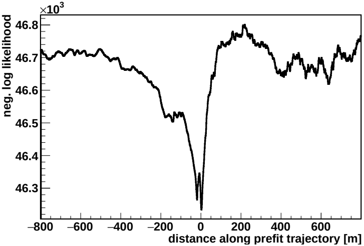


Figure : Hit time residual for e.m. shower at 100 TeV

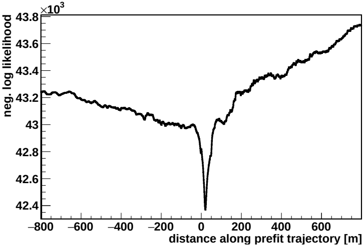
Likelihood Scan

The two shower position likelihood is evaluated in 1 m steps along the prefit trajectory. Prefit performance:

- Position resolution: $\approx 2\,\mathrm{m}$
- Direction resolution: $\approx 3^\circ$



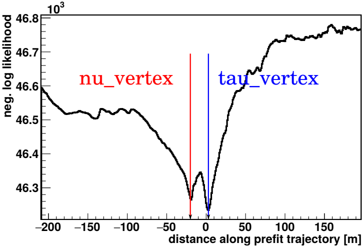
(a) Two showers of similar energies



(b) Tau decay shower much higher energy (≥ 98 percent)

Figure : Likelihood scan; 0 is prefit position

Likelihood Scan



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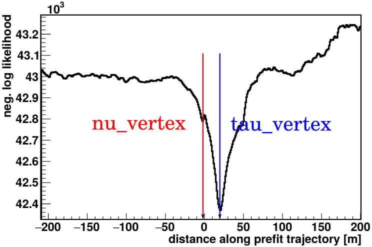


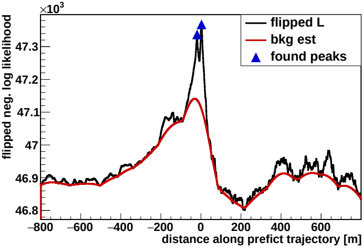
(b) Tau decay shower much higher energy (≥ 98 percent)

Figure : Likelihood scan; 0 is prefit position

Evaluating Likelihood Scan

Used class for γ spectrum peak finding implemented in TSpectrum:

1. Flip likelihood scan
2. Estimate continuous background
3. Find peaks based on derivative change



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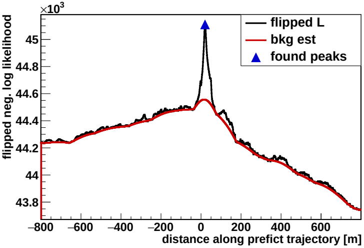


(b) Tau decay shower much higher energy ($\geq$ 98 percent)

Figure : Likelihood scan; 0 is prefit position

Full Fit of Two Shower likelihood

Method

Select interesting events based on Prefit and Scan parameters (rec Energy, rec length,. . .) and fit two shower position likelihood globally using Scan position as starting parameters

Why not fit the two shower likelihood immediately?

- Fit needs good starting parameters
- Fit is computationally demanding

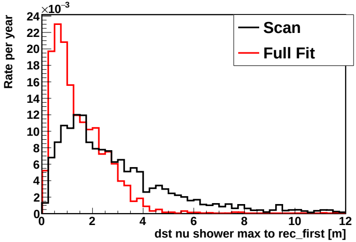
Tau MC

Current MC production:

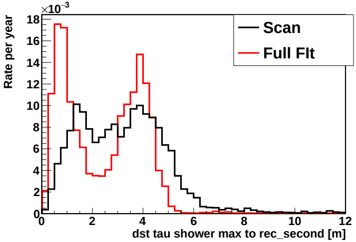
- Events generated with GENHEN v7
- Tau lepton decay handled with TAUOLA package

Currently, earth propagation is **not yet implemented** causing all tau neutrinos to be absorbed by earth at high energies (although tau neutrinos can regenerate)

Position Reconstruction



(a) Neutrino shower



(b) Tau decay shower

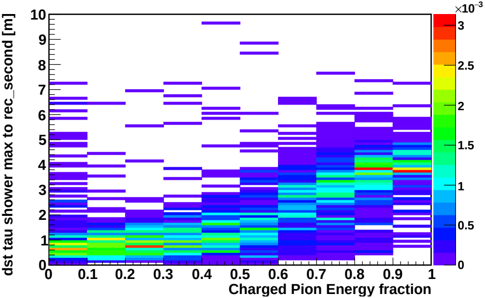
Figure : Vertex maximum resolution after scanning and full fit, position resolution shower mean 1.5 m RMS 1.1 m

*What causes the **difference** in vertex resolution?*

Tau decay shower

π shower length

at **100 TeV** $\pi^{\pm}$ showers are simulated to be **3.5 m longer** than π^0 showers
$\hookrightarrow$ tau decay of 2 or 3 Pions makes extreme energy distributions likely ("Enhance" tau flight length)



Direction resolution

Replace prefit direction with direction from two shower position fit:

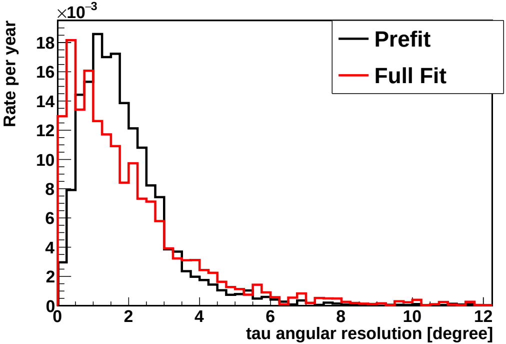


Figure : Direction resolution shower mean 2.5° RMS 2.4°

Event selection

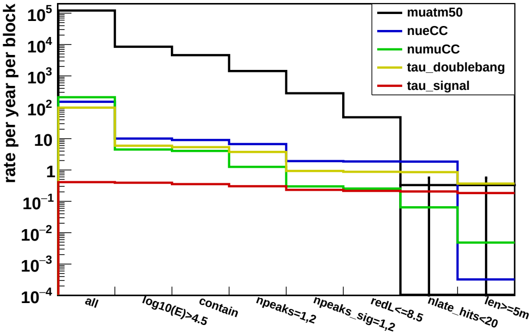
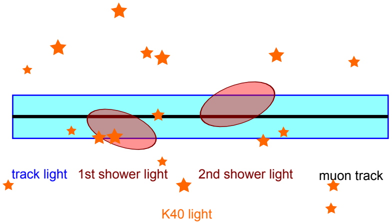


Figure : Selection cuts; Resulting rates for diffuse flux $\Gamma = 2.46$; tau_signal are all "Double Bang" events with tau.len $\geq 10\,\mathrm{m}$ and double contained vertices

Atmospheric Muon suppression

Method

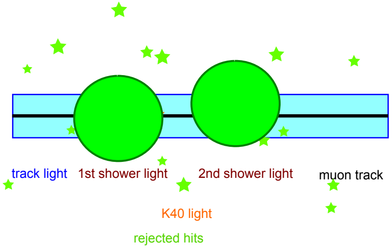
Use the fact that the muon track produces light before and after the two reconstructed showers!



Atmospheric Muon suppression

Hit Selection

- hit.residual(shower|vertex12)≤−20 ns
- Four hit coincidence on DOM within 20 ns time window



Atmospheric Muon suppression

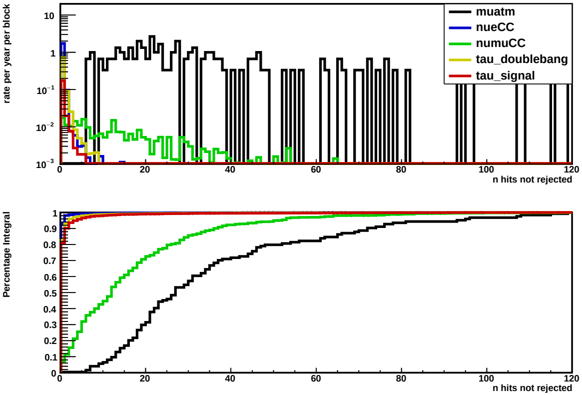


Figure : top: distribution of left over hits; bottom: cummulative of top (in percent)

Selected tau events

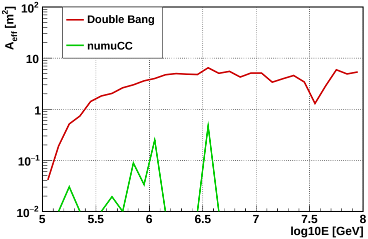
Tau rates after selection per block:

3 PeV cut-off:

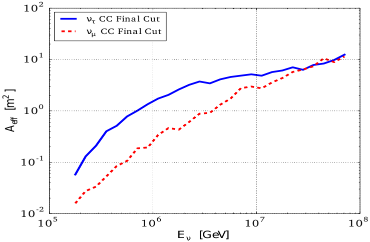
- $\Gamma = 2.46$: 0.37 per year
- $\Gamma = 2$: 0.44 per year

No cut-off:

- $\Gamma = 2$: 0.61 per year
- **IC:** 0.51 per 914.1 days



(a) KM3NeT



(b) IceCube

Figure : Effective areas for tau Double Bang and numuCC

Summary and Conclusion

Belle Starr:

- Robust reconstruction of Double Bang events down to 5 m tau flight length
- Excellent atmospheric muon rejection based on excellent hit time
- Good discriminating tool for all neutrino event types

Event ID:

- Already at working stage
- Further improvements expected by incorporating Belle Starr

Event ID parameters

- linear fits to ranges of cumulative time residual distributions with respect to shower or track hypothesis
  - y-intersect
  - slope
- characterizing values of time residual distributions (width, mean, ...)
- tensor of inertia of light pattern in detector
- fraction of hits associated with vertex or track hypothesis
- reconstruction values (Vertex, Energy, quality parameters)

Further muon suppression cut variable

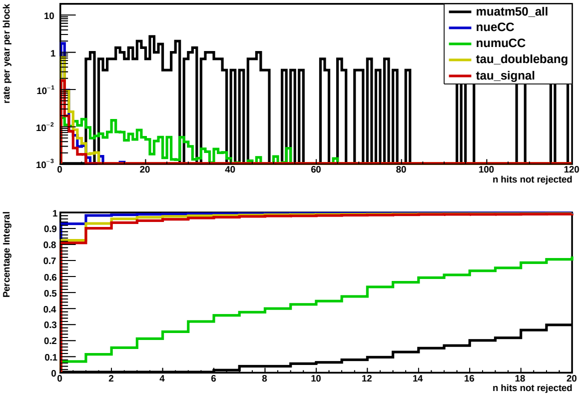


Figure : top: distribution of left over hits; bottom: cummulative of top (in percent)

Backup - MC production details

Production stage:

- Program: genhen v7r6
- No propagation through the Earth (no regeneration)
- Cross-sections and primary interaction: LEPTO on isoscalar target using CTEQ 6D PDF tables (f77 cern lib table #58 4)
- Tau decays: TAUOLA v2.6, 22 possible decay modes [S.Jadach et al., Comput.Phys.Commun. 64, 275 (1991)]
- Generation spec: $E^{-1.0}$ if you're using v7

Backup - MC production details

Light production stage:

- Program: km3mc v5r3
- Histogrammed photon distributions based on GEANT 3.21
- Tau track treated as minimum ionising particle (short, so reasonable)
- Use 'multi-particle' approximation: each non-electron/muon replaced with equivalent electron with scaled energy and distance to shower maximum
- No scaled shape about maximum OR fluctuations from one shower to another
- Work in progress: direct simulations with GEANT 4.10