Double Bang Reconstruction and Flavor Analysis

MANTs

October 2, 2016

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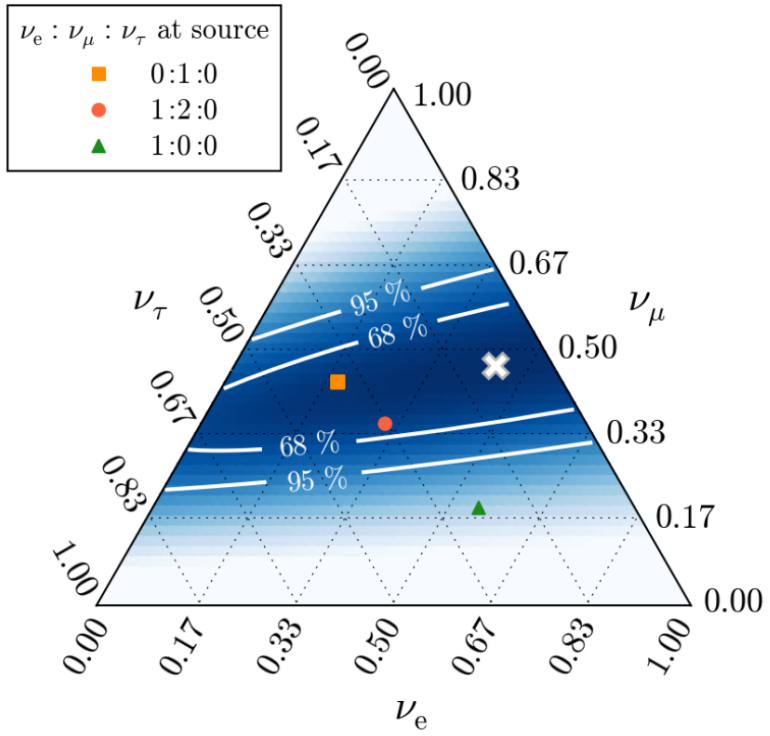
Outline

1. Introduction
2. Double Bang Reconstruction
3. Analyses Overview
4. Summary and Outlook

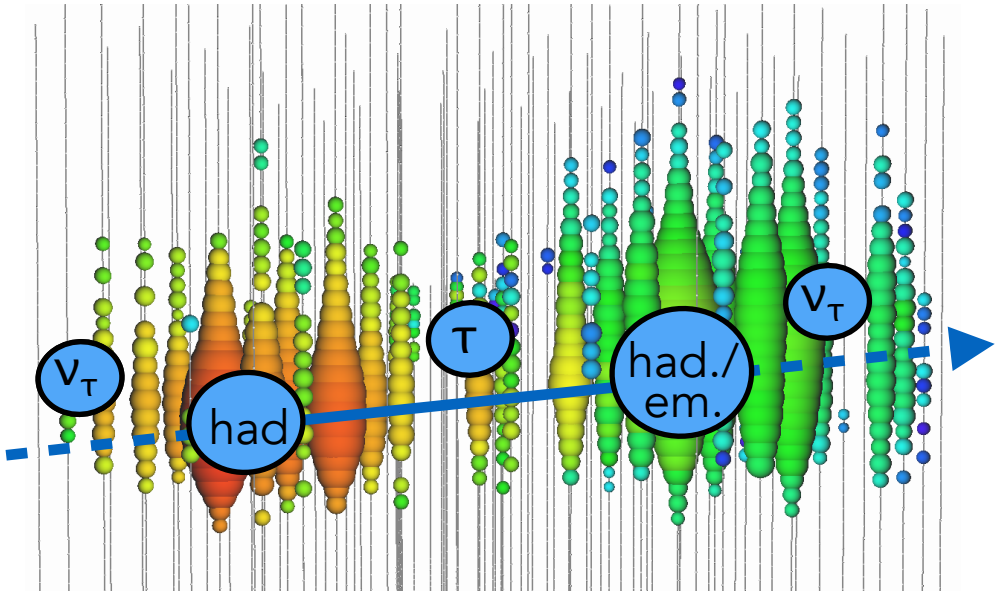
Motivation

- only few tau neutrinos have ever been observed
- vanishing atmospheric component → tau neutrinos = astrophysical neutrinos!
- tau neutrinos needed for flavor ratio analysis → can constrain sources & production mechanisms
- current flavor analyses not directly sensitive to ν_τ content (ν_e-ν_τ degeneracy)



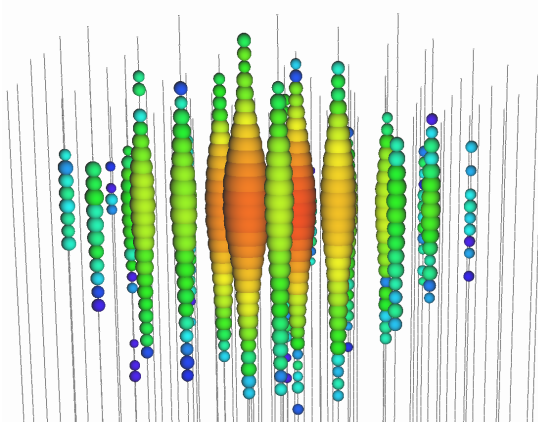
Double Bang Signal

- ν_τ interaction (1:1:1 ratio for astrophysical neutrinos expected)
- charged current (71%)
- tau decays into hadrons / electrons (83%)
- mean length: 50m x energy/1PeV

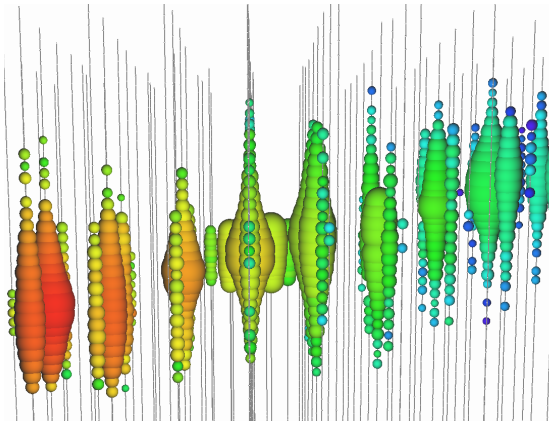


simulated 10PeV Double Bang event

Background



Cascades:
all nc interactions
ν_e cc interactions
ν_τ cc interactions with unresolvable lengths



Tracks:
ν_μ cc interactions
atmospheric muons

Taupede algorithm

- maximum likelihood fit
- assumption: two cascades connected by τ lepton

input (seed): 1 cascade with vertex, direction, energy, time, estimate for tau length

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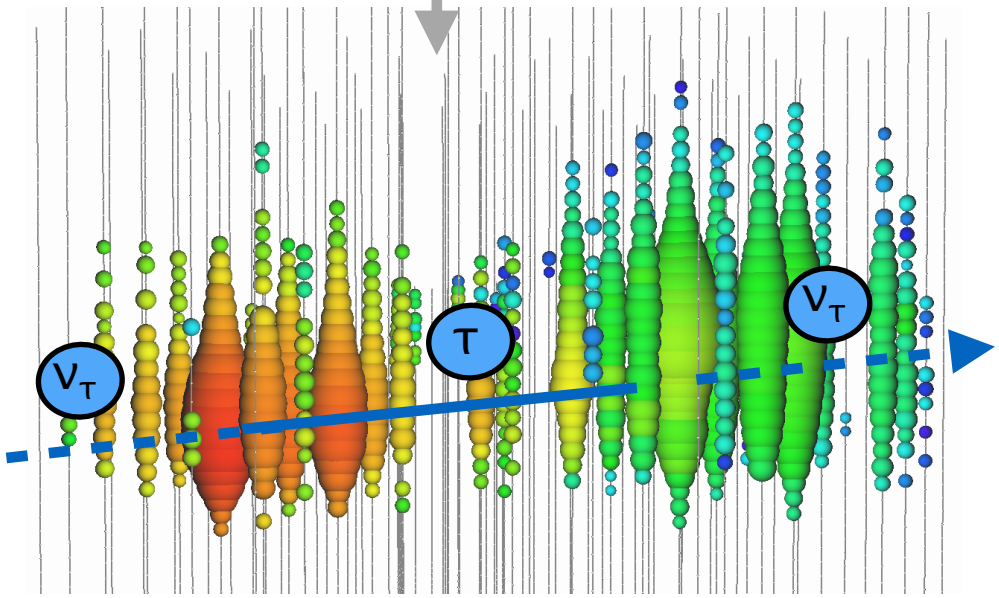

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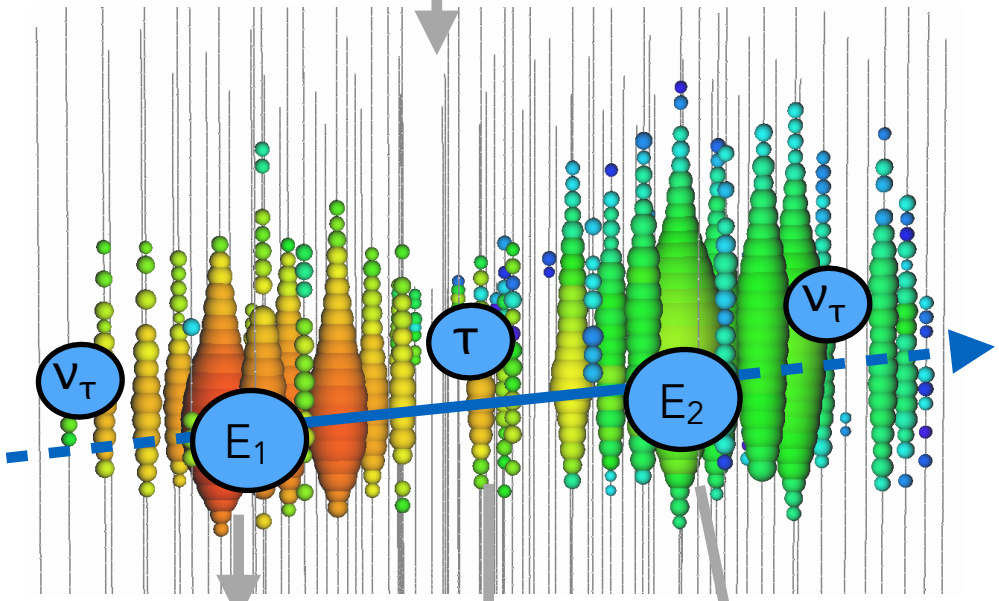
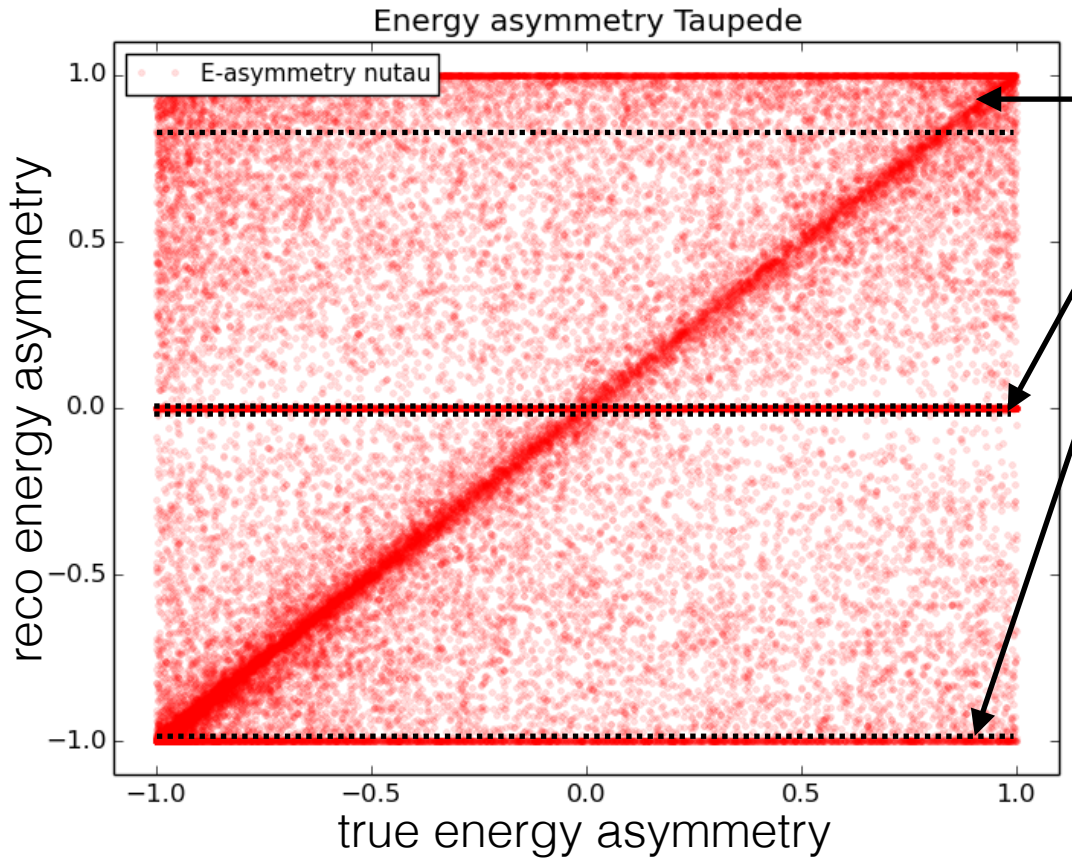


fitting parameters:

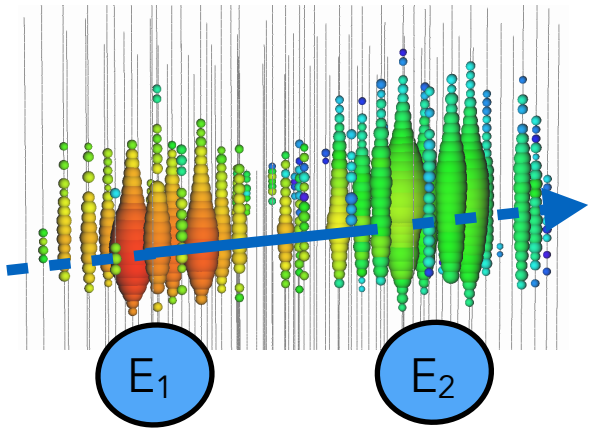
- energy, direction, vertex, time
- tau length
- energy

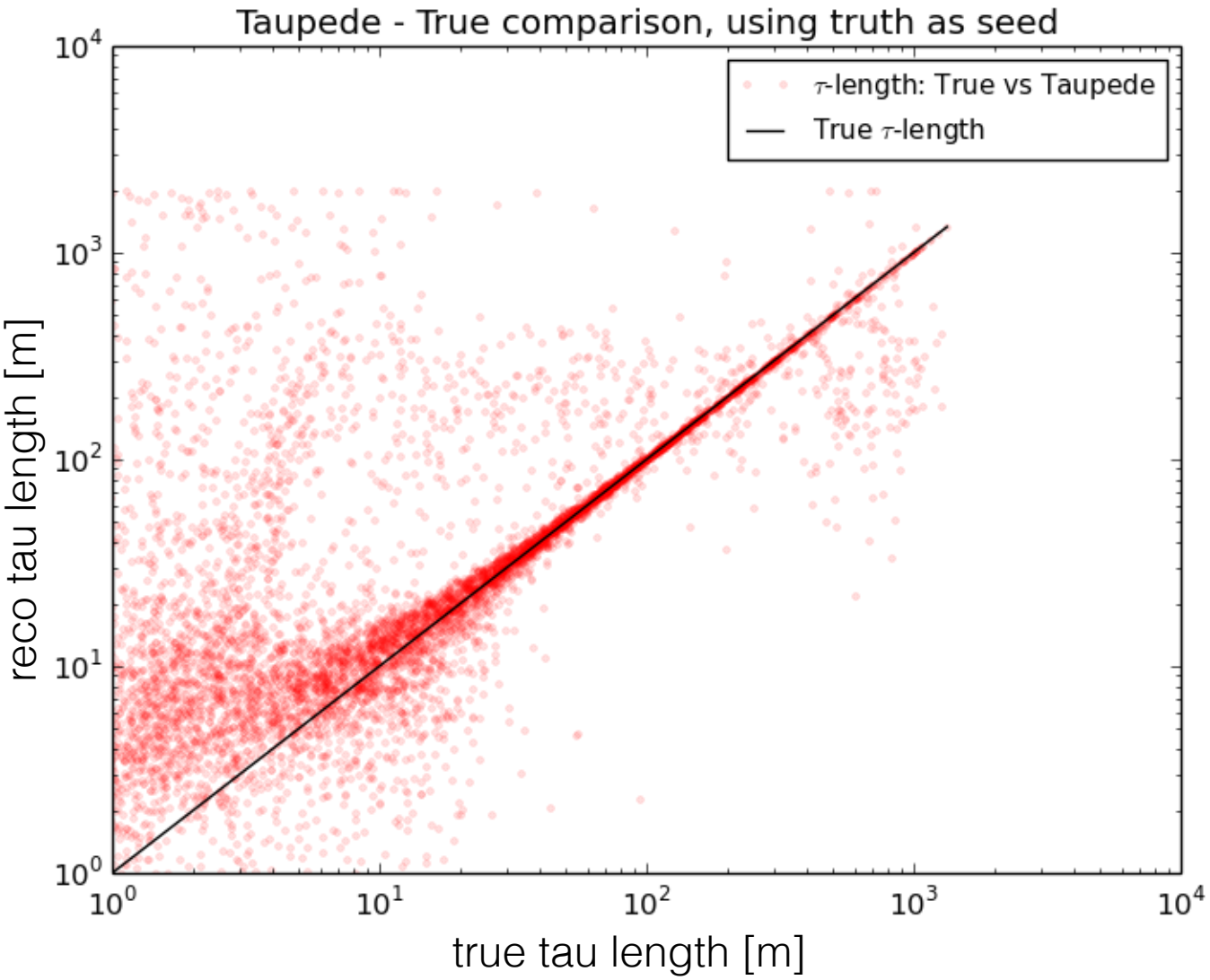
Taupede — observables



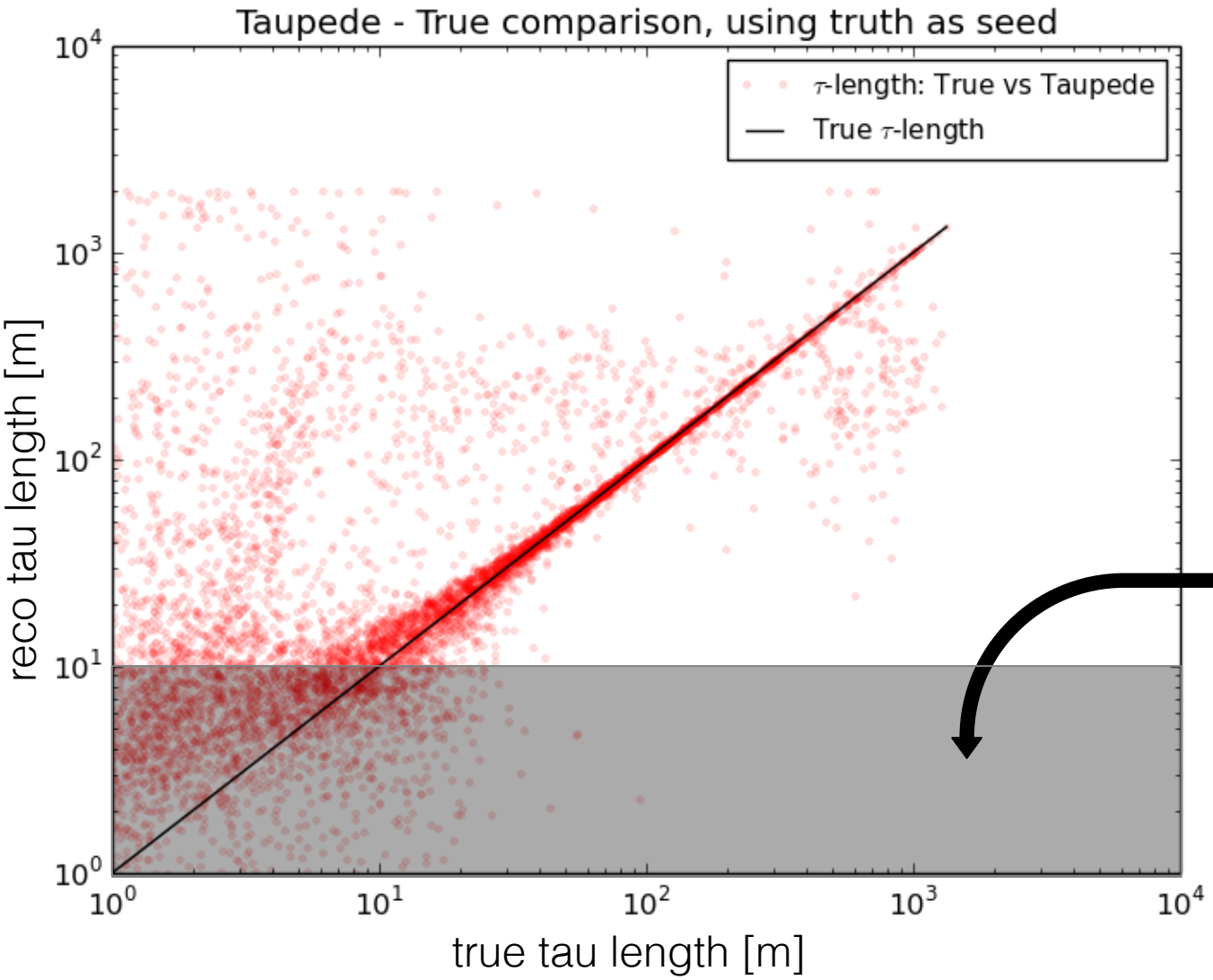
single cascades (low lengths)
events cluster at $A_E \approx +1,0,-1$

Energy asymmetry:
$A_E = (E_1-E_2)/(E_1+E_2)$





region with $L_{\tau,reco} > 10$, 20m looks good, mostly well-reconstructed
problem: some events get misreconstructed to higher lengths



not a problem

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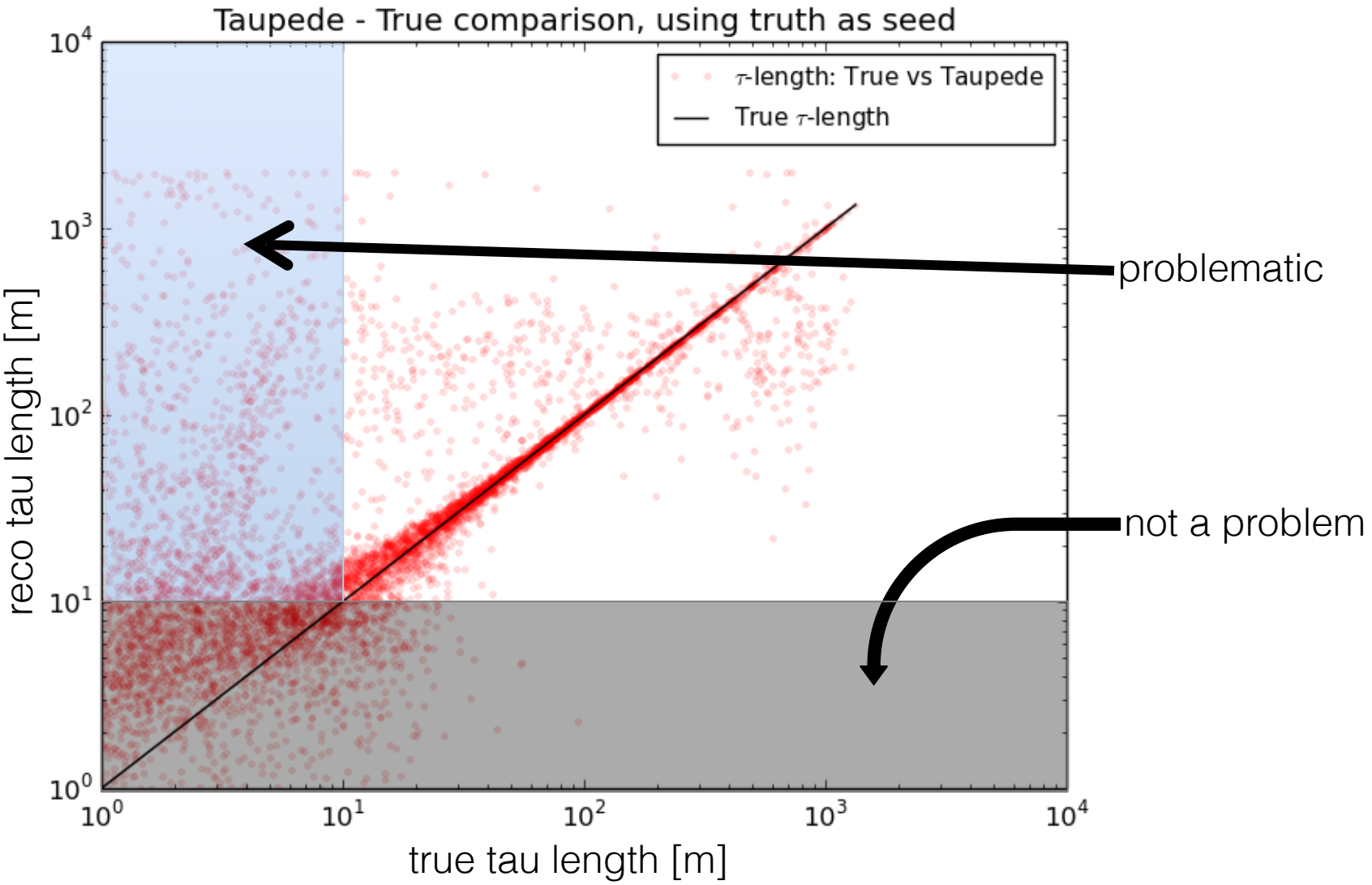

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Analyses Overview

- currently 3 analyses with direct Double Bang reconstruction
- common: use same reconstruction algorithm
- differences: starting point, event selection, algorithm use, sensitivity range, goals

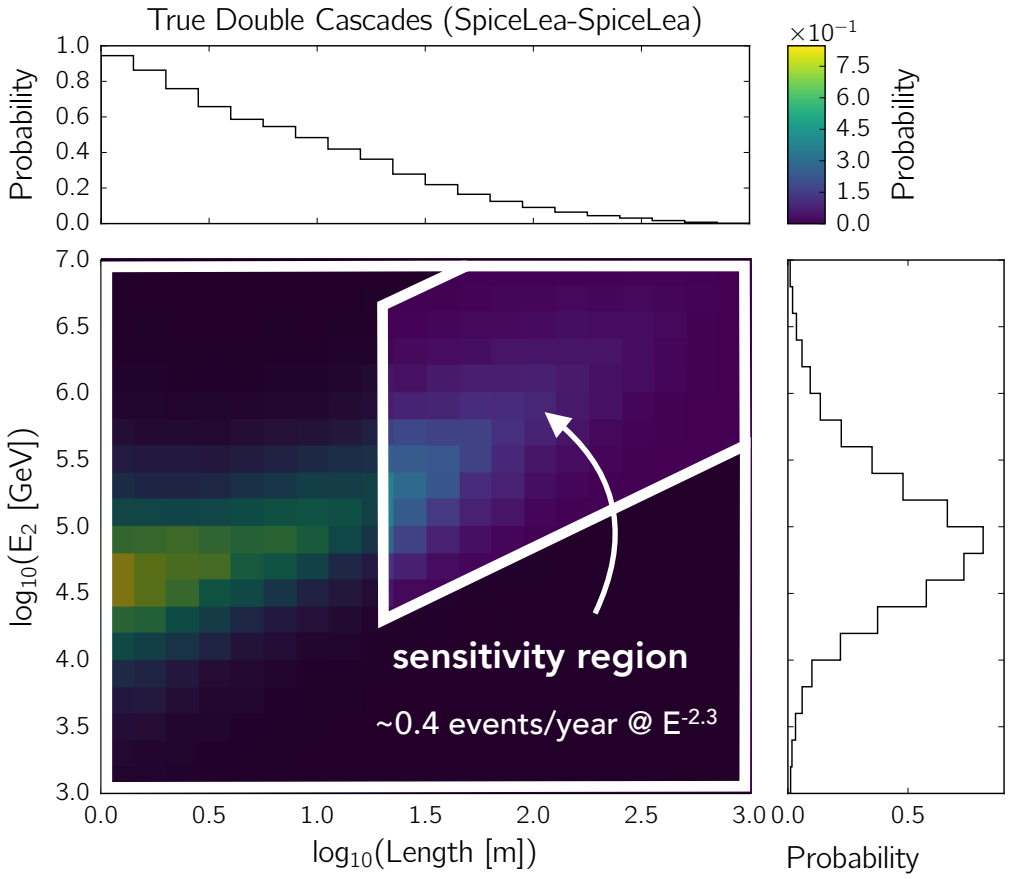
  → complementary!

Analysis I

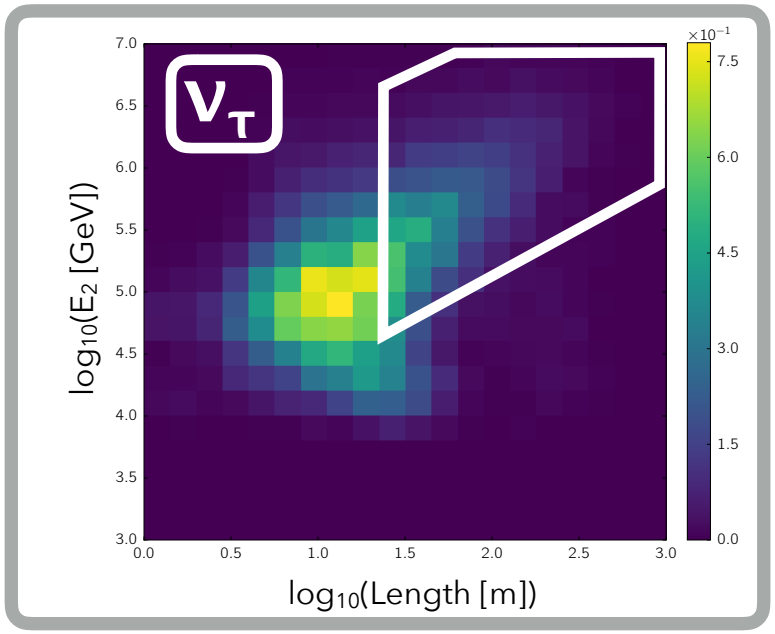
- Marcel Usner, DESY
- sample: 6 year HESE sample
- goal: measure all-flavor ratio with evidence for ν_τ at > 90% C.L. in energy range 60TeV < E < 3PeV
- expectation: ~2 identifiable events with L>20m

Analysis I — method

- preselection: energy asymmetry
- particle ID based on length vs E_2
- define sensitivity region



Analysis I — example



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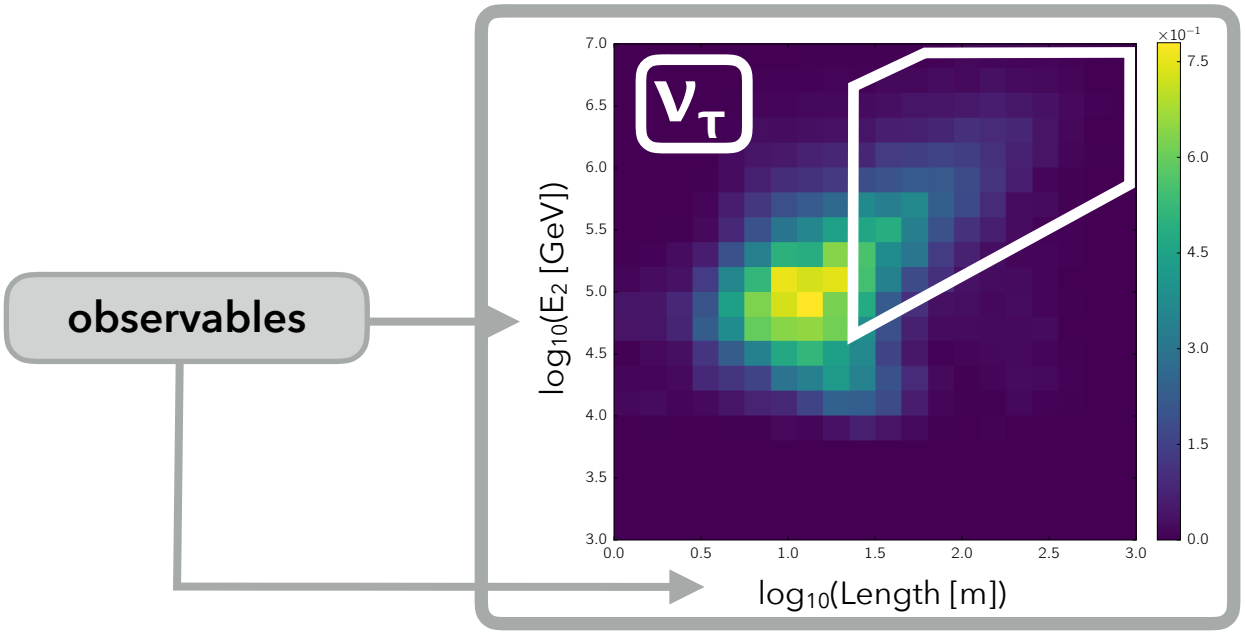

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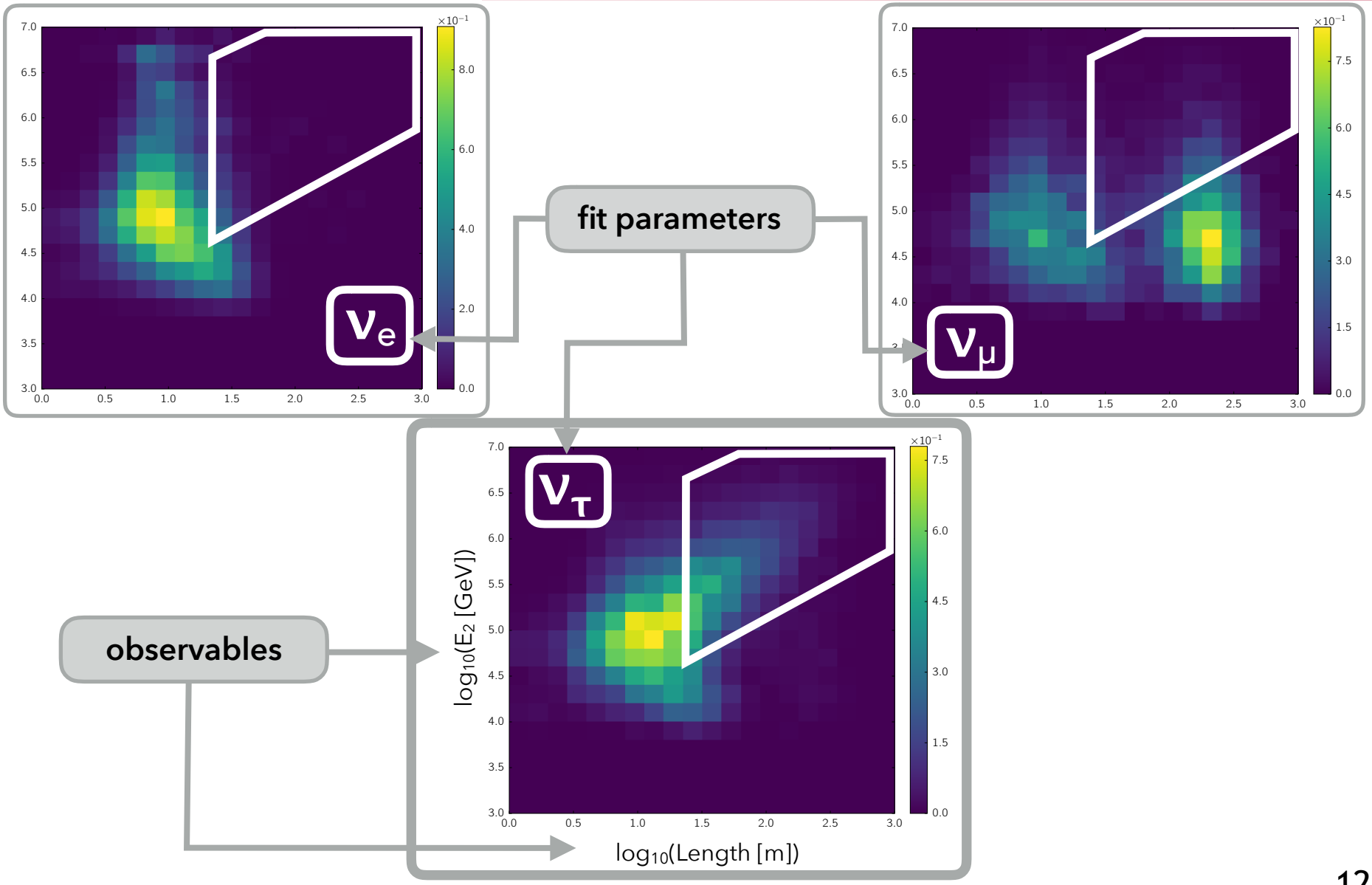

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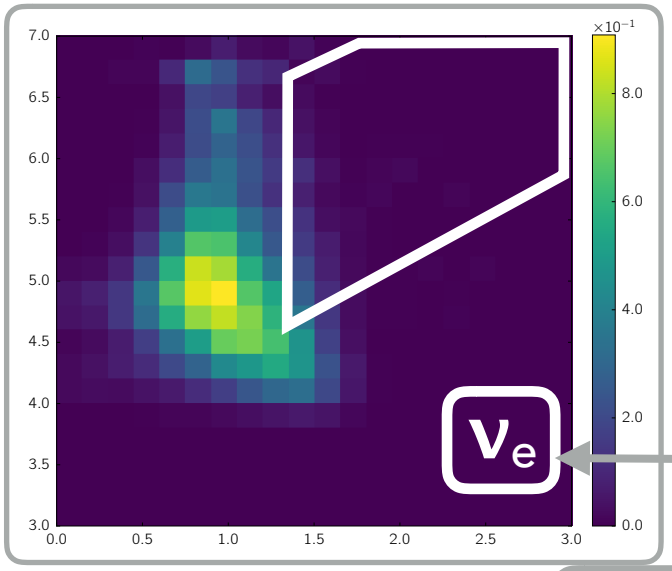
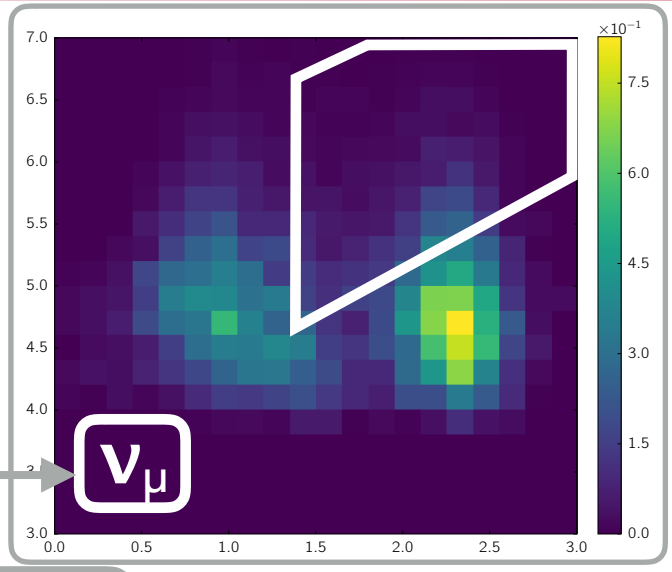
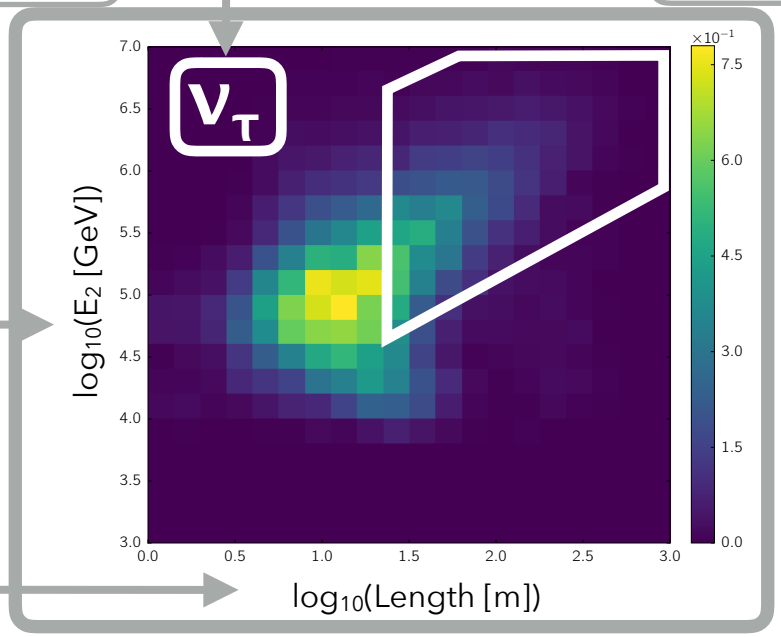


0.17 background events/year



fit parameters

observables



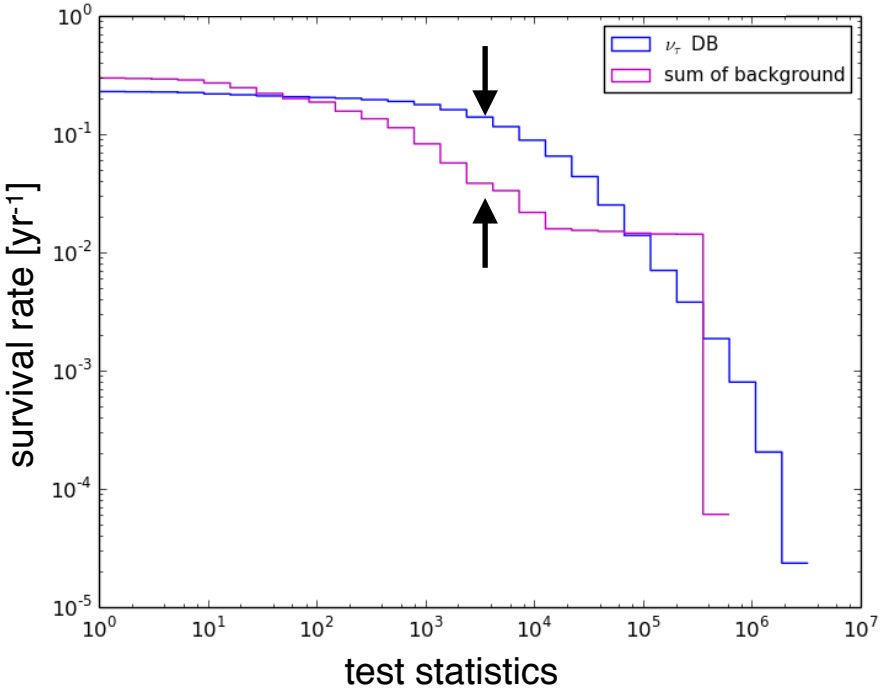
0.34 signal events/year

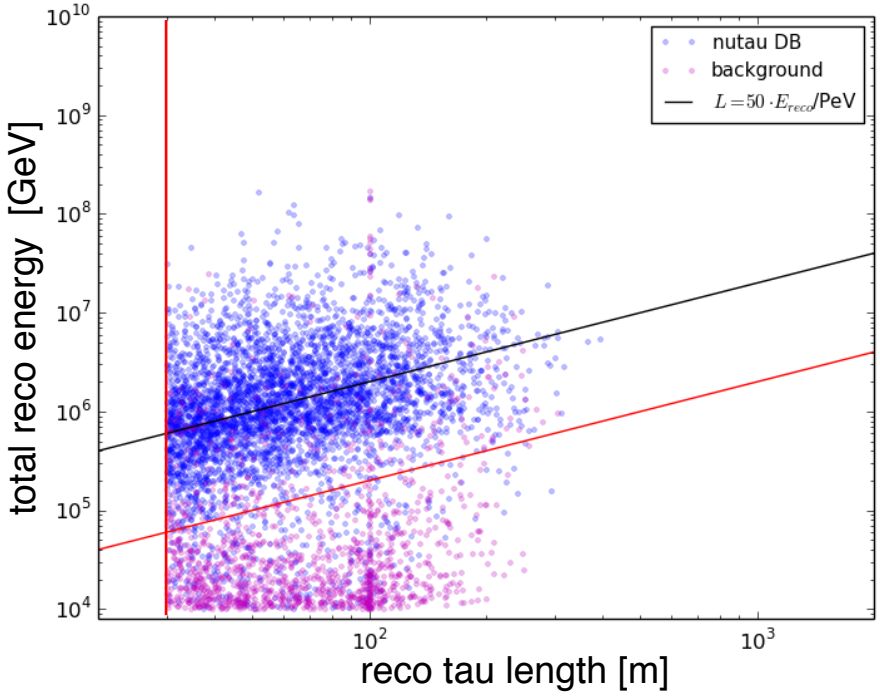
Analysis II

- Juliana Stachurska, Stony Brook ➔ DESY
- sample: High Energy Cascades (2 years now, 4 more years in preparation)
- goal: separate cascade sample into ν_τ-Double Bang and "single cascades" subsamples, lifting ν_e-ν_τ degeneracy in flavor ratio
- optimized for short tau lengths

Analysis II — method

- pre-selection: length, energy asymmetry
- remove misreconstructed events using likelihood space of reconstruction algorithm & removing unphysical regions





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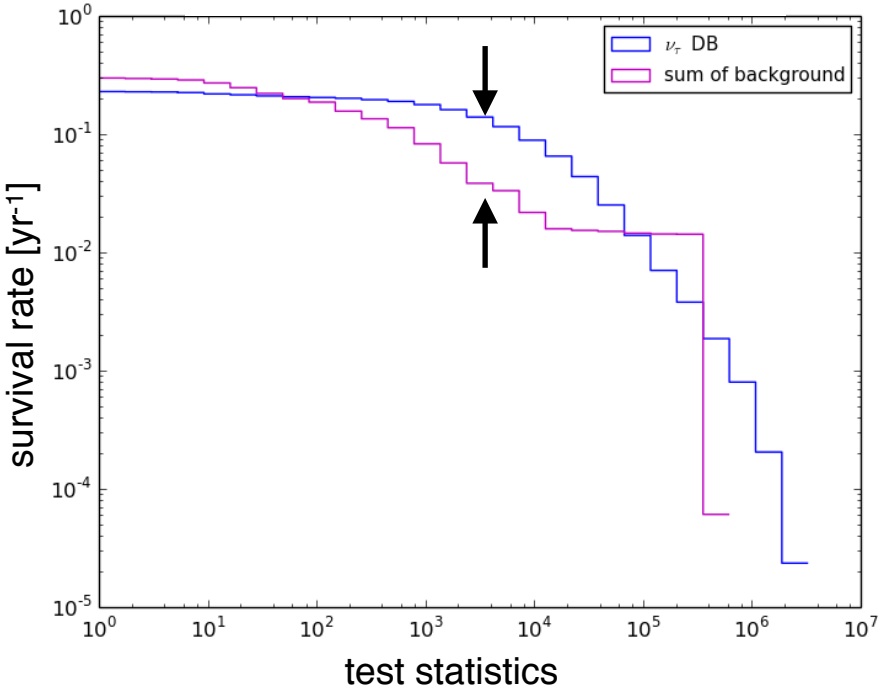
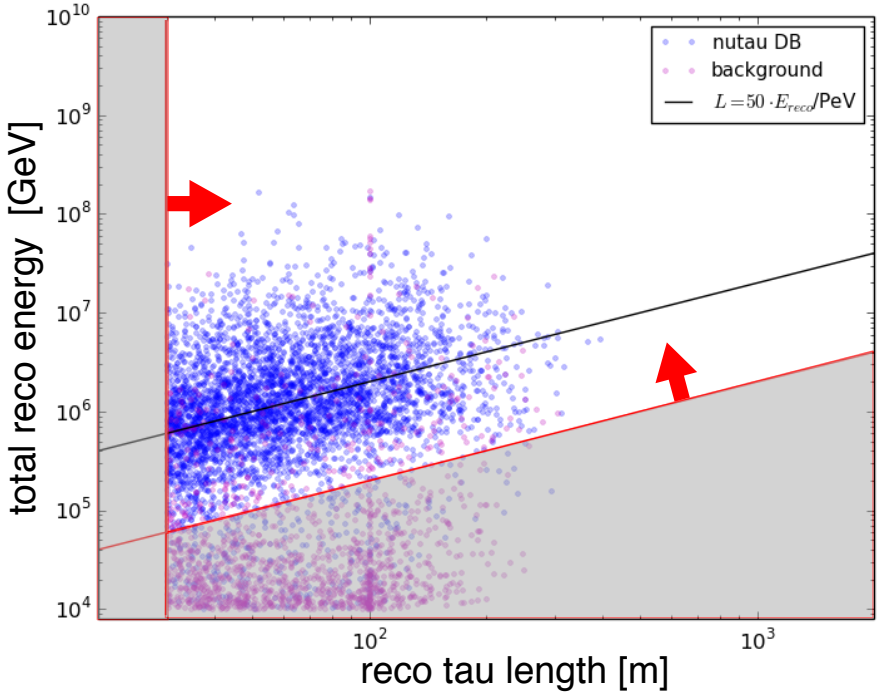
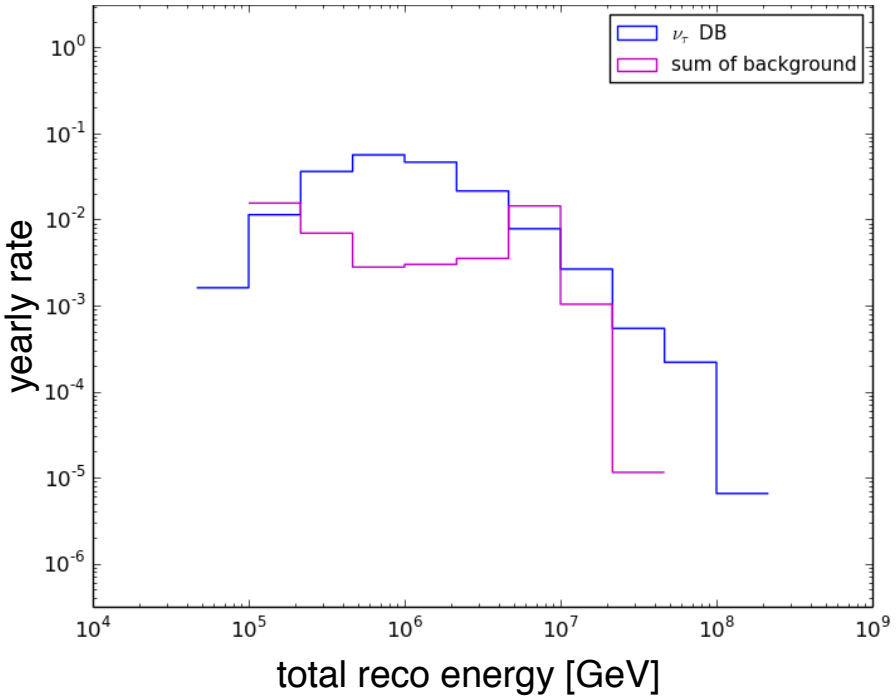


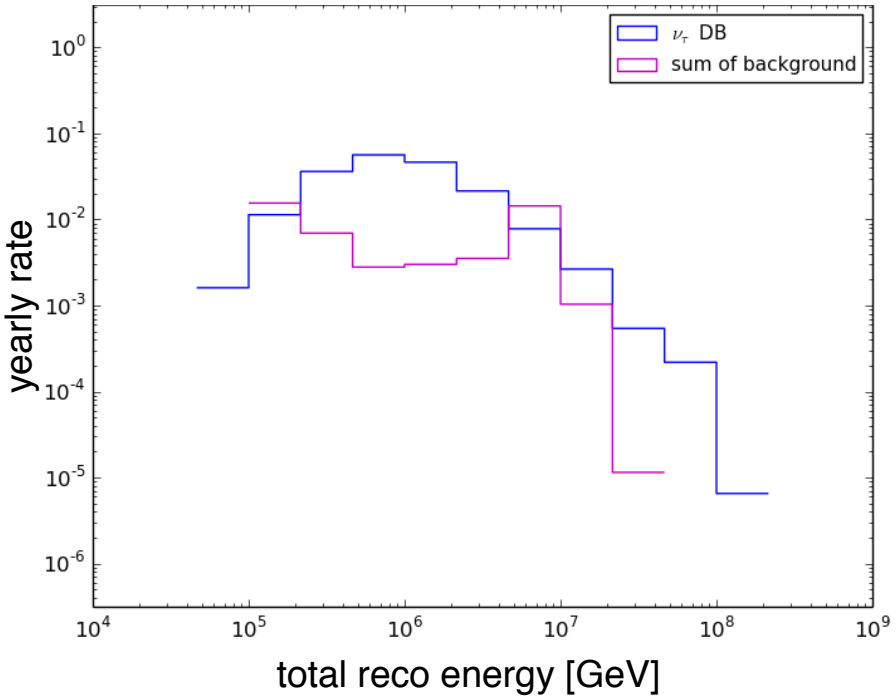


Analysis II — outlook



highest sensitivity in E≈100TeV - 10PeV region

Analysis II — outlook



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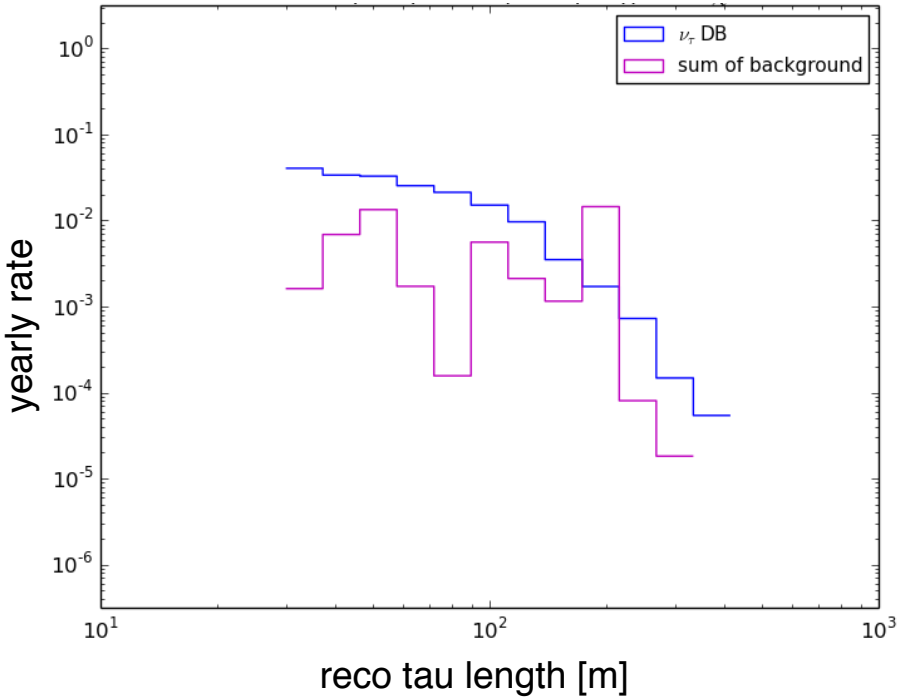
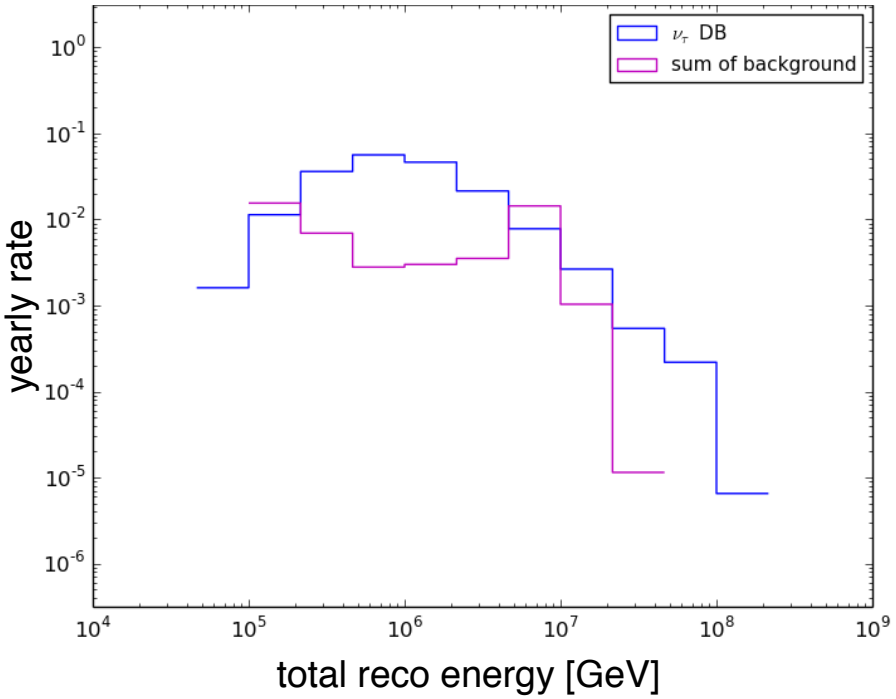
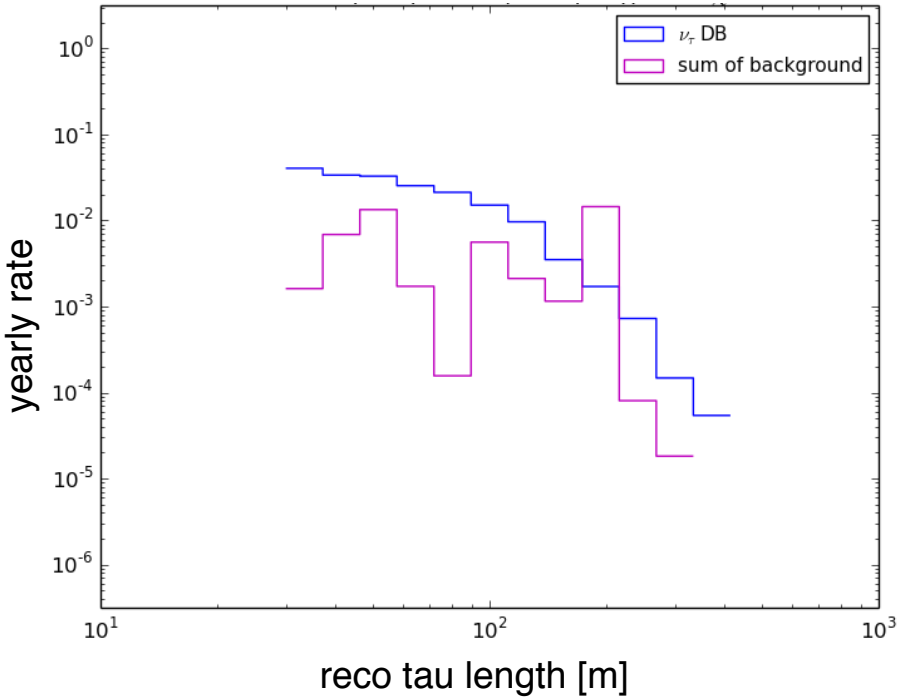


highest sensitivity at lower lengths (L_τ ≈ 30-50m)

Analysis II — outlook





highest sensitivity in E≈100TeV - 10PeV region

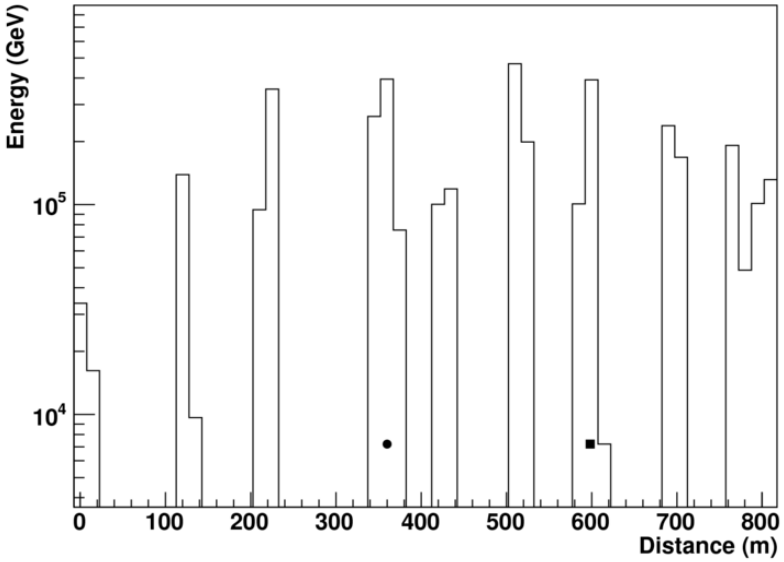
highest sensitivity at lower lengths (L_τ ≈ 30-50m)

➔ need to add background simulation, try to lower length threshold

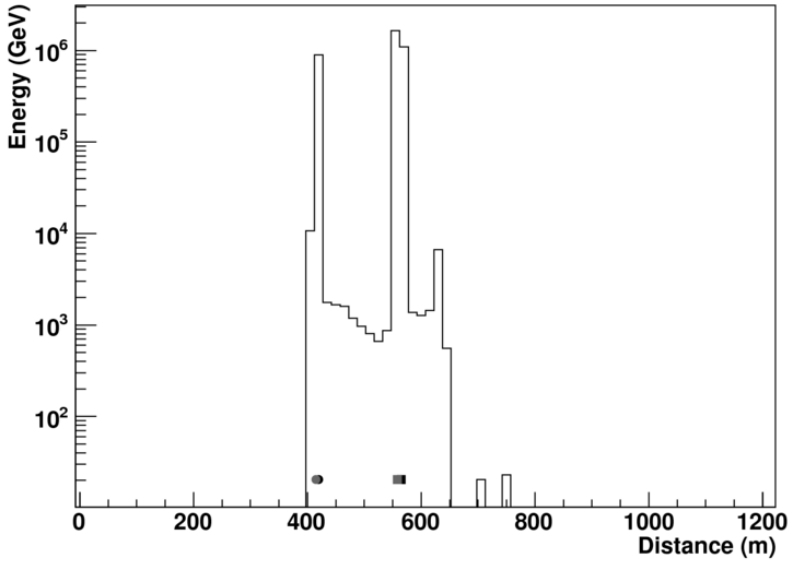
Analysis III

- Matthias Vraeghe, Ghent
- own event selection optimized for Double Bang
- select:
  - high energy,
  - high charge,
  - well reconstructed,
  - (almost) contained events
- BDT based on 6 variables
- select L > 50m, $-0.998 < A_E < 0.8$, energy loss profile
- goal: find and clearly identify high energy tau neutrino Double Bang interactions

Analysis III — example

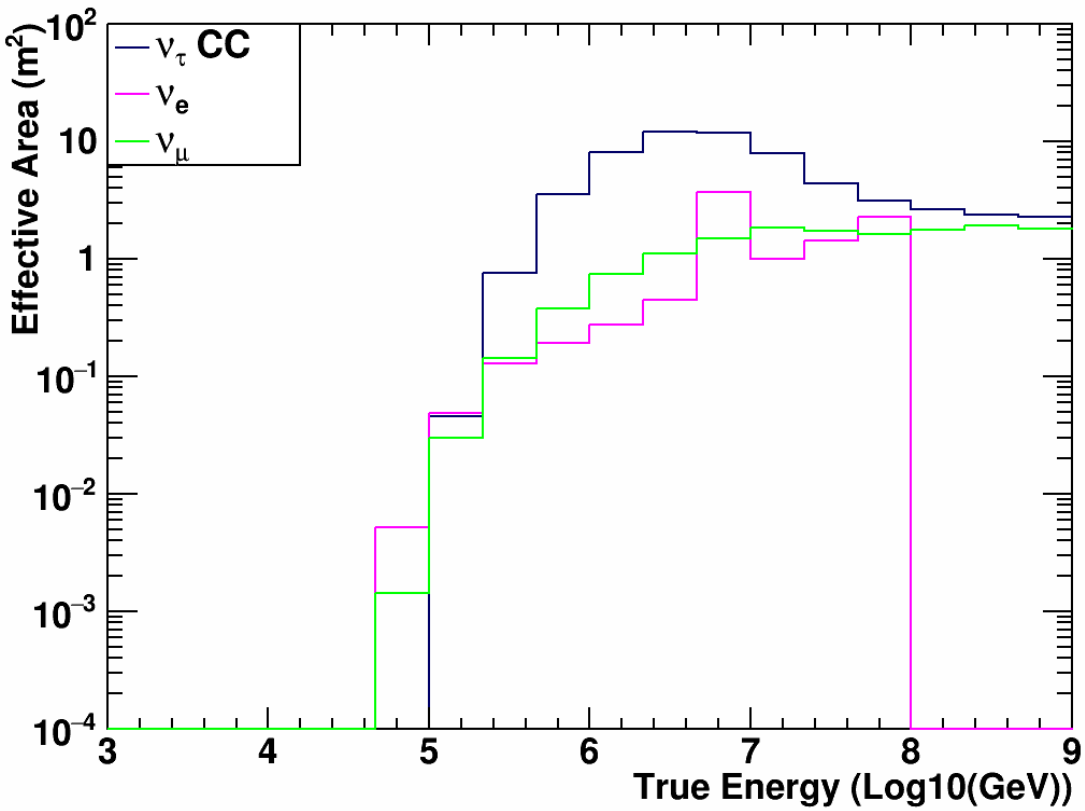


energy-loss profile of track-like background event: multiple energy depositions



energy-loss profile of signal event: 2 major energy depositions

Analysis III — expectations



0.34 signal events/year

~0.24 background events/year

background has low statistics / high uncertainty

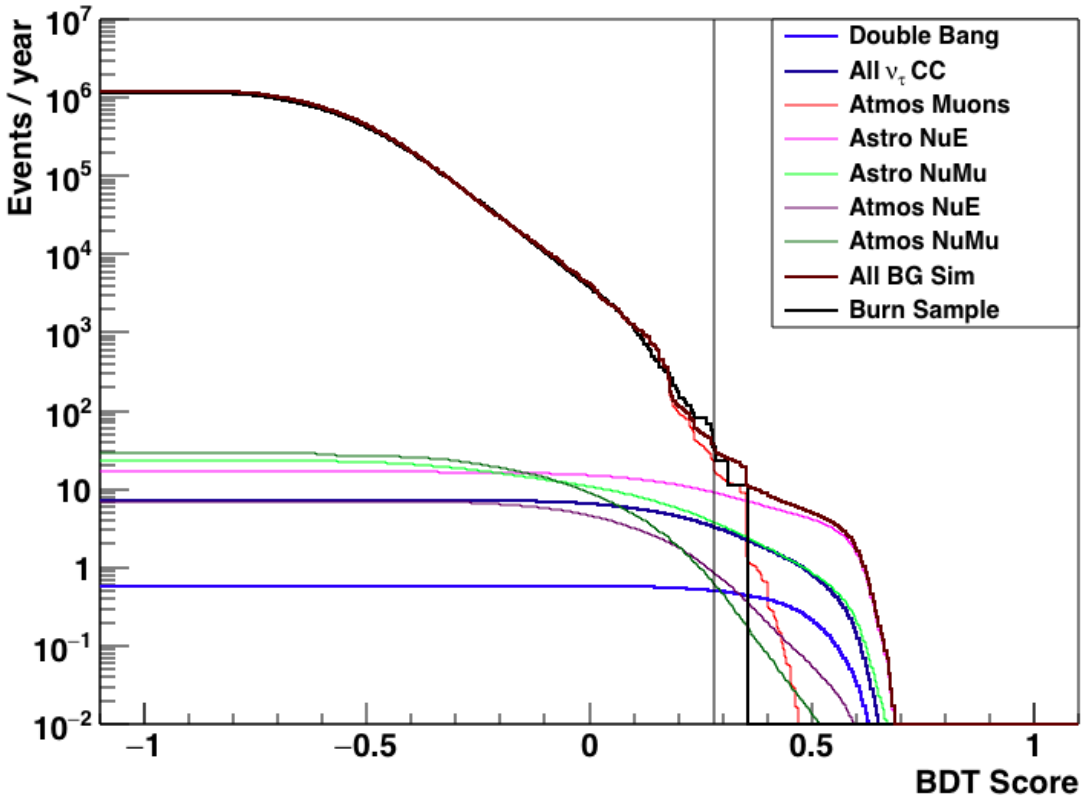
Summary and Outlook

- only ~0.3 identifiable tau neutrino interactions per year
- need tau neutrino fluxes / limits to constrain flavor ratio and neutrino production models
- with currently 6 years of data, tau neutrino detection with IceCube is around the corner
- 3 different analyses currently underway

Stay tuned for upcoming results!

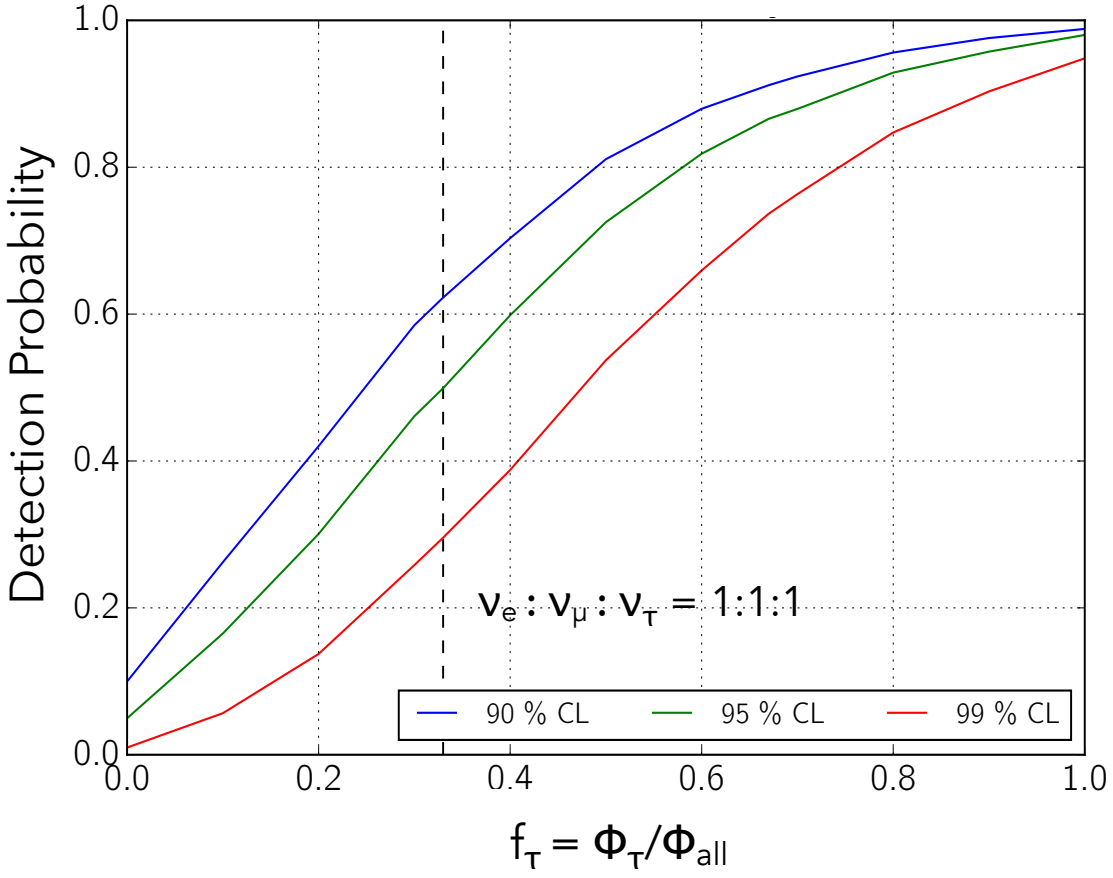
Backup

Analysis III — BDT



Variables:
total charge, # charge peaks, duration, jumpiness (movement of COG), early charge ratio (first 100ns), starting Z position

Analysis I — expectation



@ HESE flux: $\Phi(E)=1.5 \times 10^{-8}\ (E/100\text{TeV})^{-2.3}$ GeV cm^{-2} s^{-1} sr^{-1} ,
$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$ ratio:
~50% ν_τ detection probability at 95% CL

Muon vs. Tau Neutrinos