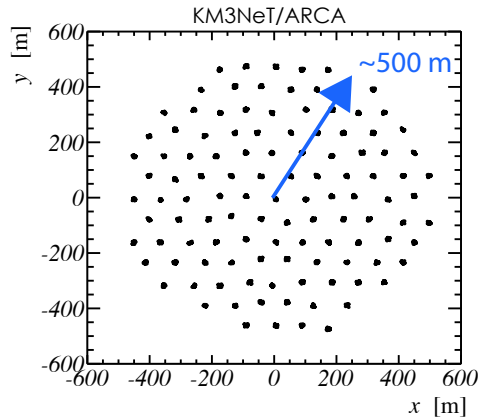# KM3NeT/ARCA Reconstruction Algorithms

Karel Melis on Behalf of the KM3NeT Collaboration

35th ICRC (2017) – Busan - South Korea

The KM3NeT Detectors
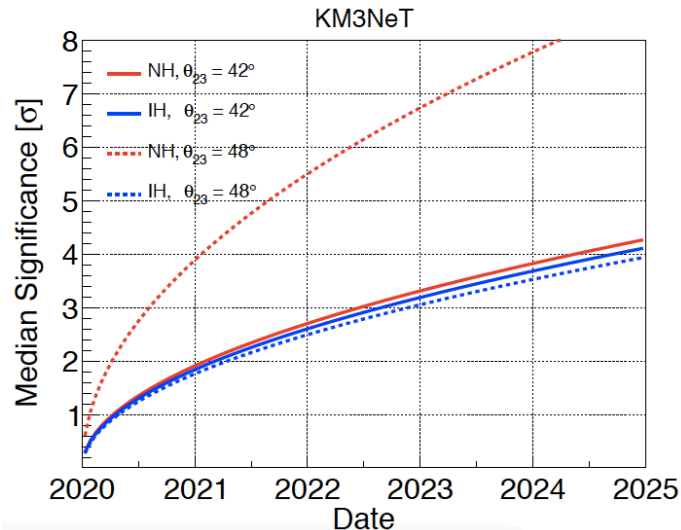
KM3NeT/ARCA

- **Digital Optical Module (DOM)**
  - 31 x 3-inch PMTs
  - DAQ + Calibration devices

- **Detection Unit (DU)**
  - 18 DOMs
  - ARCA: DOMs ~36m apart
  - ORCA: DOMs ~9m apart

- **Building Block**
  - 115 DUs
  - ARCA: DUs ~95m apart
  - ORCA: DUs ~ 23m apart
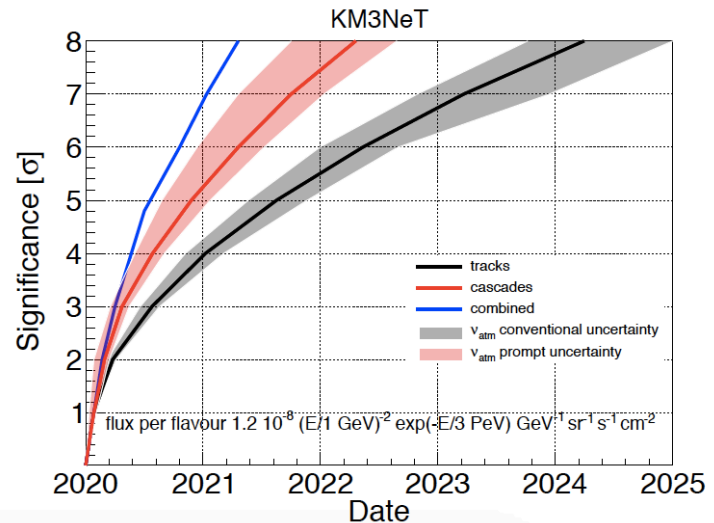
KM3NeT Science Objectives

KM3NeT/ORCA

- Neutrino mass hierarchy
- Low-energy atmospheric neutrinos
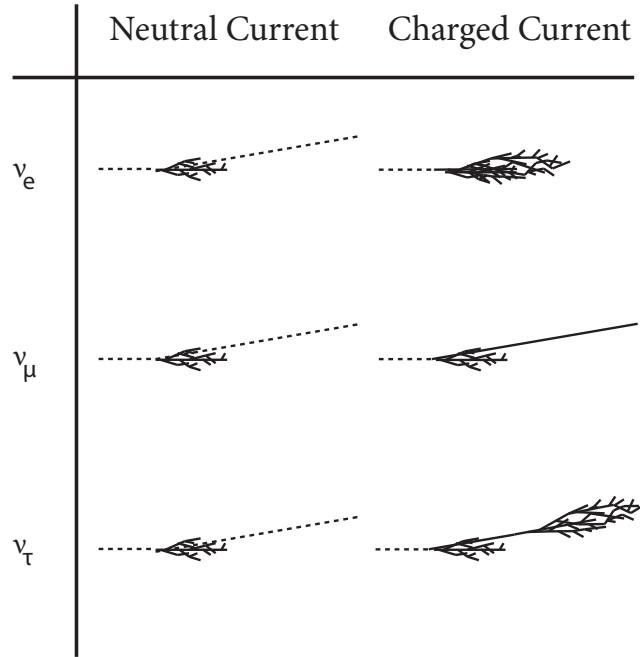- Sensitivity: **3 sigma in 3 years**

KM3NeT/ARCA

- Cosmic high-energy neutrino sources
- Diffuse flux
- Sensitivity: **5 sigma in 0.5 year**
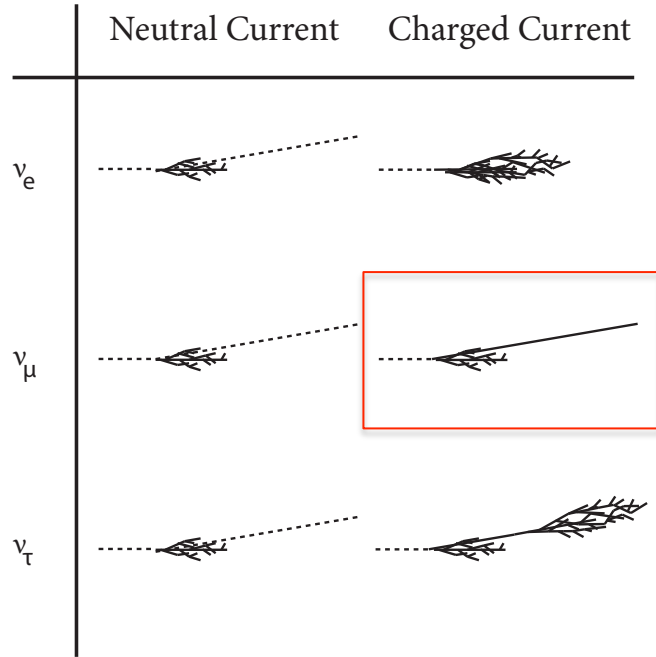
Event Reconstruction

- Three event topologies:
  - Shower-like
  - Track-like
  - Tau double-bang

- Reconstruction of:
  - Position and time
  - Direction and energy

Event Reconstruction

	Neutral Current	Charged Current
ν_e		
ν_μ		
ν_τ		

- Three event topologies:
  - Shower-like
  - Track-like
  - Tau double-bang

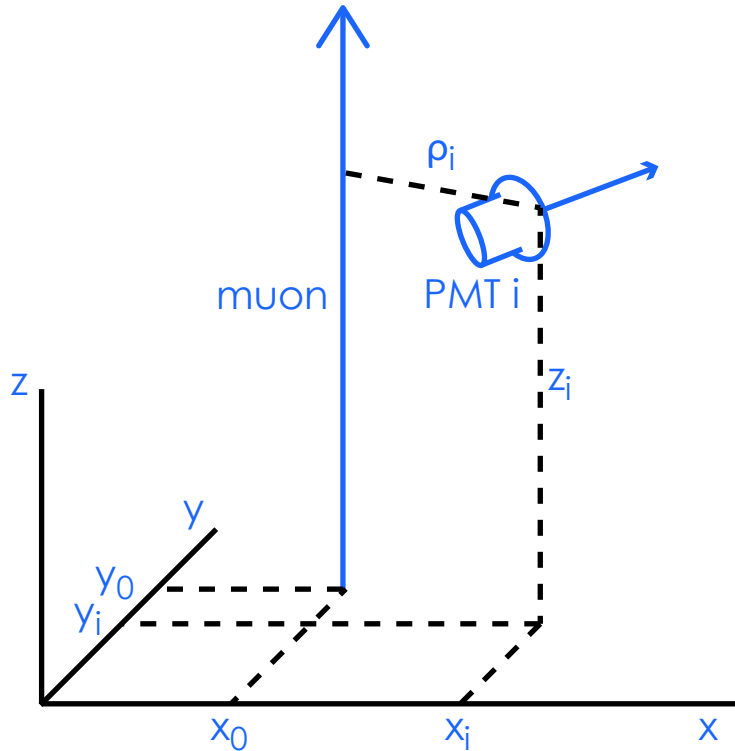- Reconstruction of:
  - Position and time
  - Direction and energy

Track Direction and Energy

$$\mathscr{L} = \prod_{hit\,PMTs} \left[\frac{\partial P}{\partial t}(\rho_i, \theta_i, \phi_i, \Delta t) \right]$$

PMT response to 1 TeV muons at ρ=50m
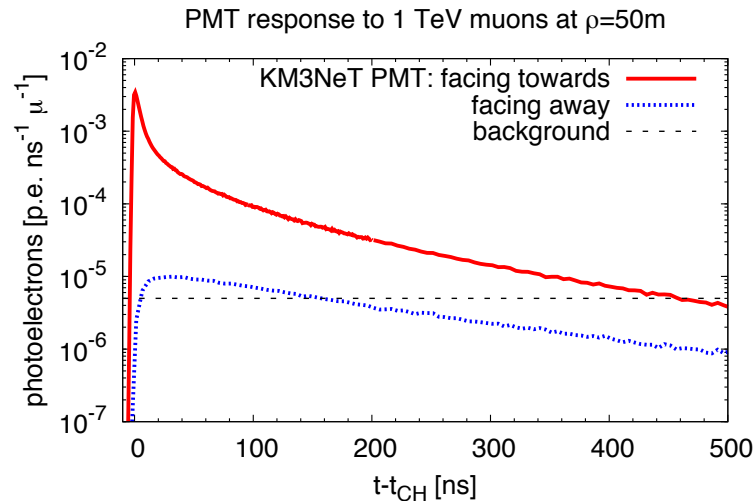
- Data: time of 1st hit on PMT

- PDF:
  - Interpolated tables in 4D
  - Includes ionization losses, light propagation, detector response (TTS), optical backgrounds etc.

- **Water ideal medium**
  - Very sharply peaked PDF
  - Very narrow maximum

Track Prefit

- Provide set of (12) best start values
  - Many sharp local maxima in likelihood landscape
- Scan over assumed track directions
  - Linear chi^2 fit of track trajectory
- Outlier removal
  - Clustering algorithm
  - One less hit must lead to >3 sigma chi^2 improvement
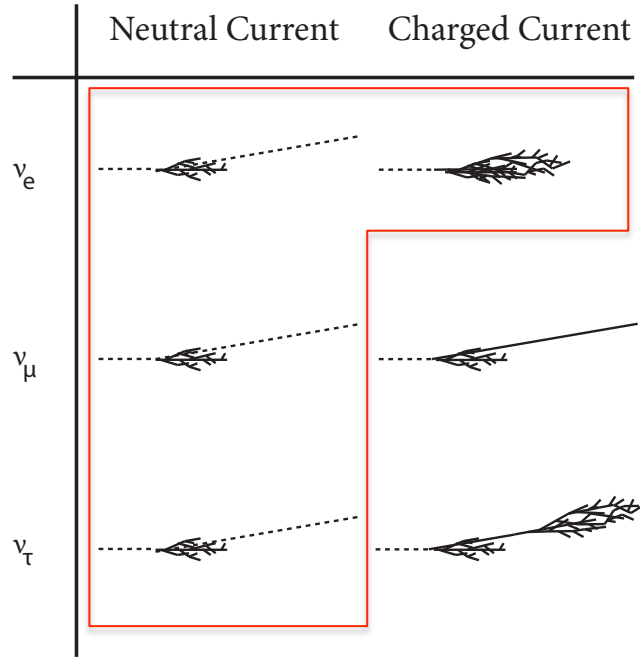- Good start value in 90% of events

Track Resolutions

KM3NeT

Red: Angle neutrino-muon (MC truth)

ν_μ CC

KM3NeT preliminary

ν_μ CC
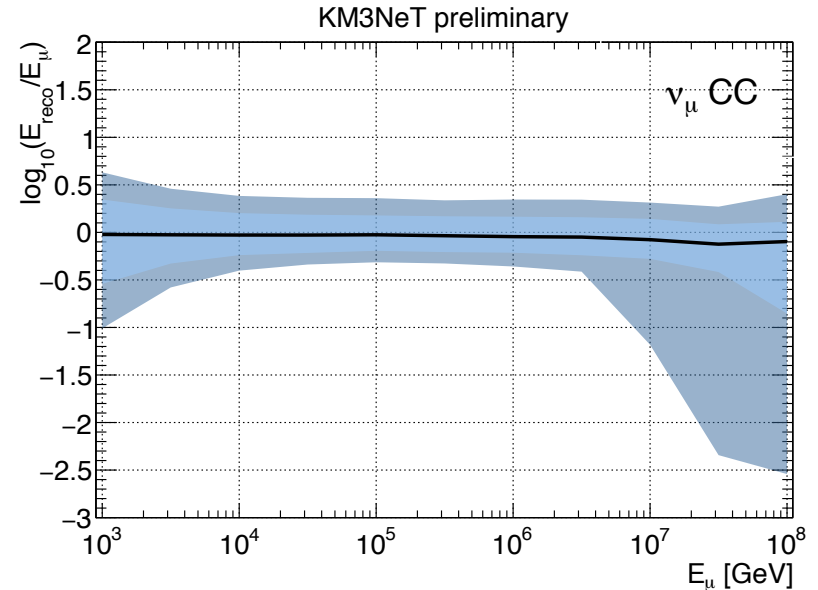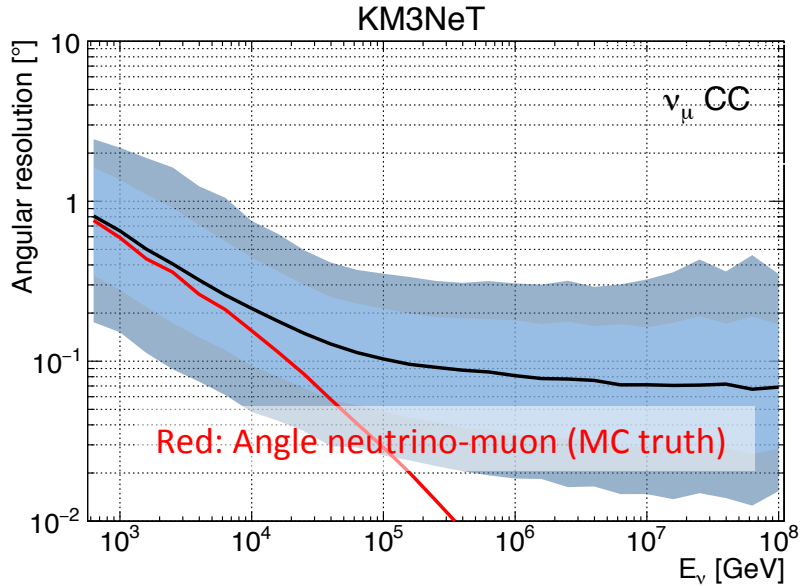
Direction resolution: < 0.1 degree

Energy resolution: $\sigma < 0.3$ in $\log_{10}(E_{reco}/E_{mu})$

Event Reconstruction

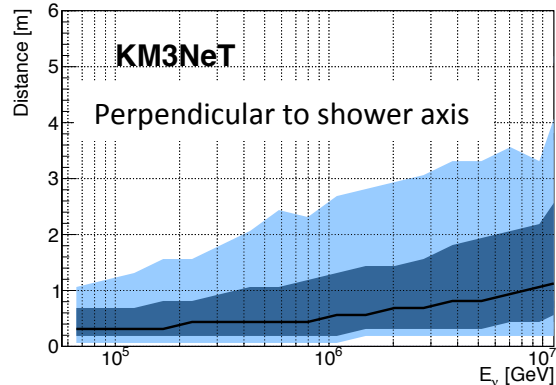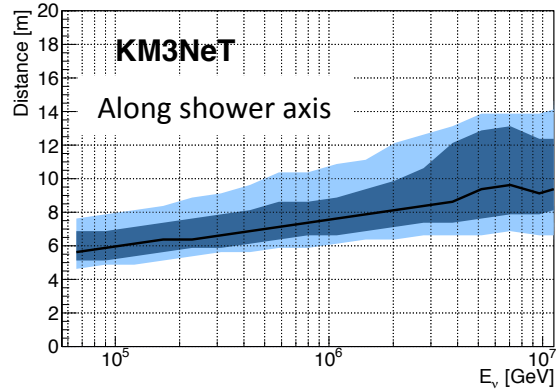|	Neutral Current	Charged Current
ν_e		
ν_μ		
ν_τ		

- Three event topologies:
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- Reconstruction of:
  - Position and time
  - Direction and energy

Shower Position

KM3NeT

Along shower axis

KM3NeT

Perpendicular to shower axis

- Data: Hit times of local coincidences in DOM
  - High-purity sample
- Model: Expanding sphere from shower position
- M-estimator score function
  - Background hits further suppressed

- **Vertex Fit Resolution: <1 meter**
  - Shower maximum fitted rather than interaction vertex
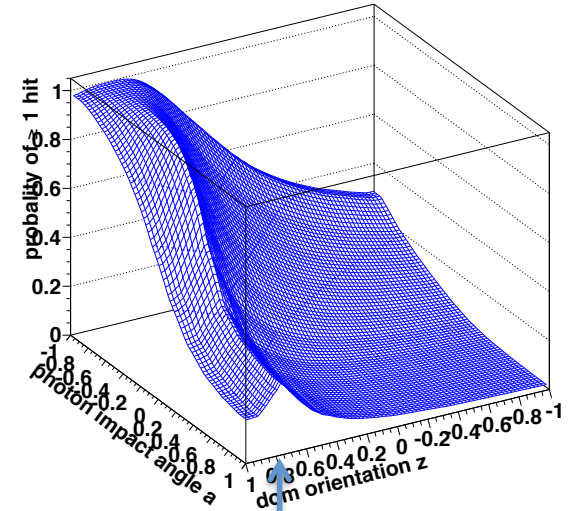
Shower Direction and Energy Fit

- Fitted vertex as pivot point
- Spatial distribution of hit/not hit PMTs
- Number of photons proportional to shower energy

r=100 m, E_S=1 PeV
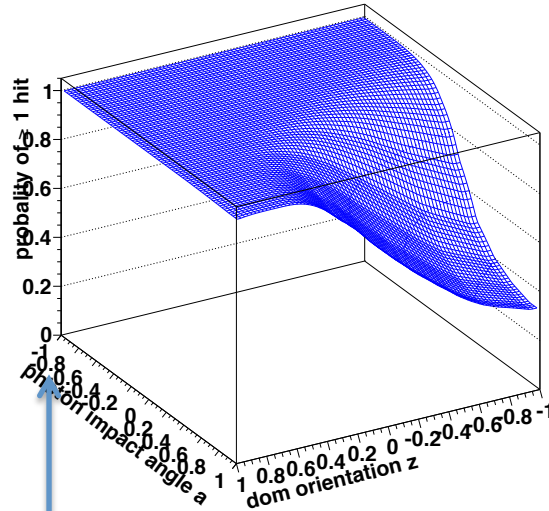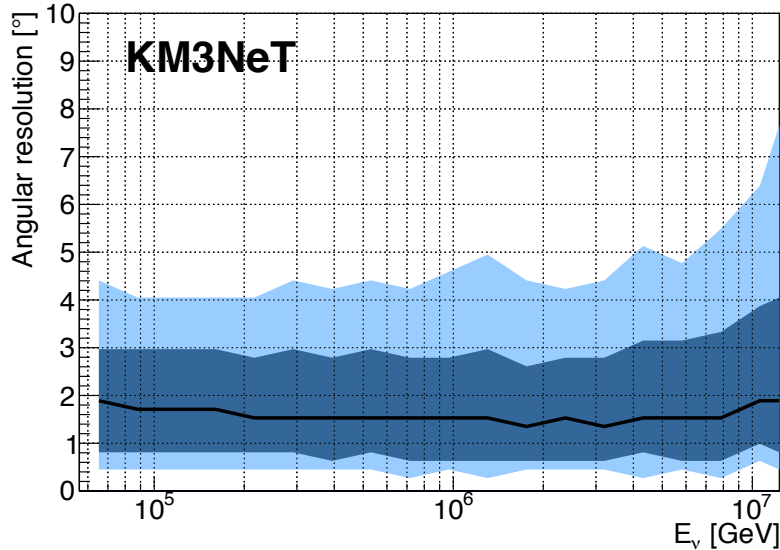

r=200 m, E_S=1 PeV

PMT facing shower

PMT at Cherenkov angle

Shower Resolutions

Ang. resolution vs E_ν

KM3NeT

Angular resolution [°]

E_ν [GeV]

Direction resolution: ~1.5 degree

E_{reco}/E_ν vs E_ν

KM3NeT

E_{reco}/E_ν

E_ν [GeV]
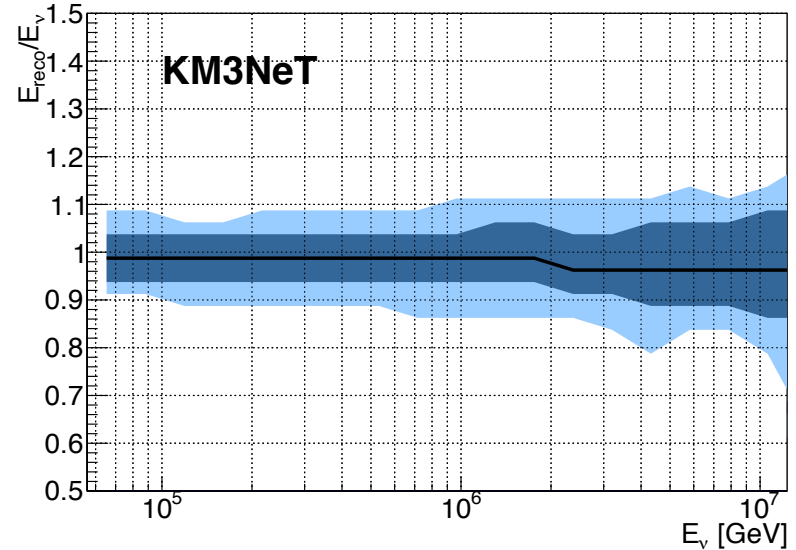
**Energy resolution: ~5%**

Showers in Antares

ANTARES Preliminary
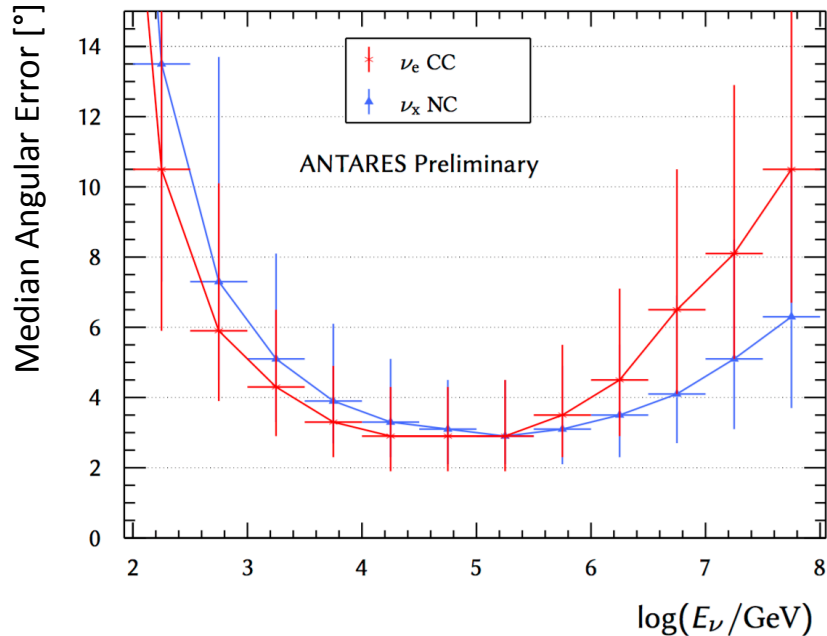
- **More or less same algorithm used in Antares**
  - Direction resolution: ~4 degrees

- **Antares**
  - Smaller detector
  - Fewer PMTs

Neutrino point source search including cascade events with the ANTARES neutrino telescope , T. Michael, ICRC (2015)

Showers in Antares

ANTARES Preliminary

Data
atm. Muons
atm. Muons, small Error
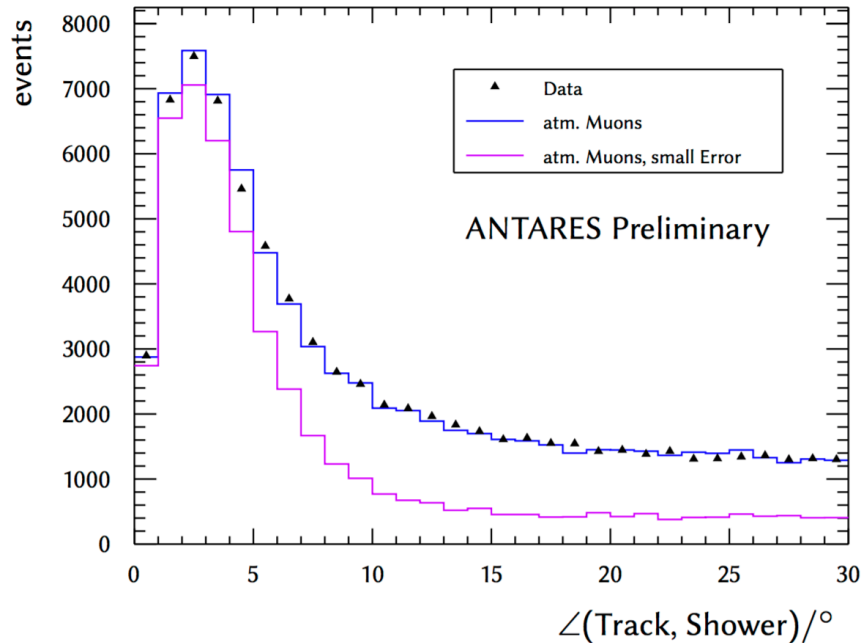
∠(Track, Shower)/°

- More or less same algorithm in Antares
  - Direction resolution: ~4 degrees

- Reconstructed muon tracks with luminous (Bremsstrahlung) shower along axis
  - Both approximately same direction

- Confirmation of angular resolution

Neutrino point source search including cascade events with the ANTARES neutrino telescope , T. Michael, ICRC (2015)
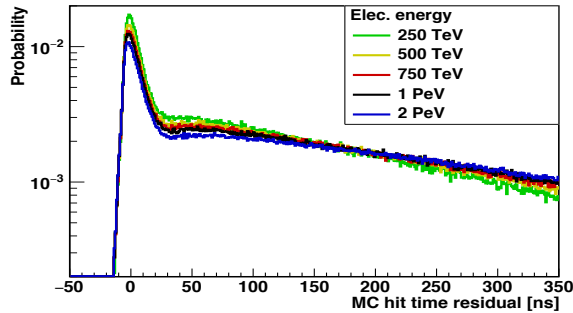
Event Reconstruction
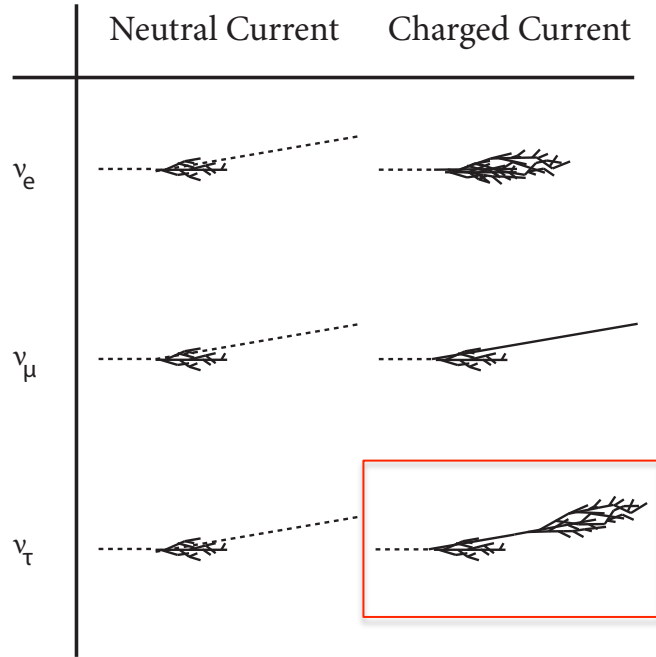
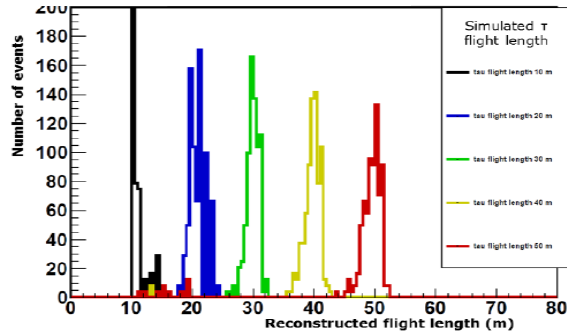|	Neutral Current	Charged Current
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Tau Double Bang Events

PDF:

Tau flight length resolution:

- Study by R. Bormuth with preliminary results

- Clustering hit selection algorithm
  - High purity sample related to single shower
- Single shower fit
  - Vertex + Direction
- Full likelihood fit
  - Data: Hit times of first hits on all PMTs
  - Model: Very simple PDF based on hit times

- Good resolving power of shower positions
  - Expected angular resolution: ~1 degree

Conclusions

- All-flavour reconstruction algorithms tested on Monte Carlo & Antares data
- 5σ confirmation of IC high-energy diffuse flux in 0.5 year
- Pinpoint cosmic neutrino sources with unprecedented resolutions:
- Muon tracks:
  - Direction: < 0.1 degree,
  - Energy: <0.3 in $\log_{10}(E_{reco}/E_{mu})$
- Showers:
  - Direction: ~ 1.5 degree
  - Energy: ~5%
- Tau double bang:
  - Preliminary results very promising