Characterising Details in ORCA ν-events

Dalfsen

Jordan Seneca

May 31, 2018

Projected outcomes

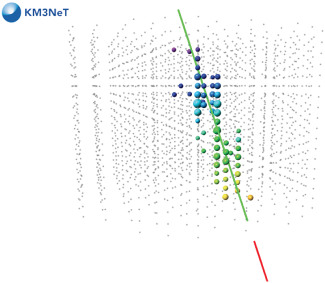
- Model of charged particles in ORCA
- ν-interaction model independent ORCA event analysis tool
- Sensitivity to interaction flavour
- Sensitivity to Bjorken-Y
- Fast Monte-Carlo

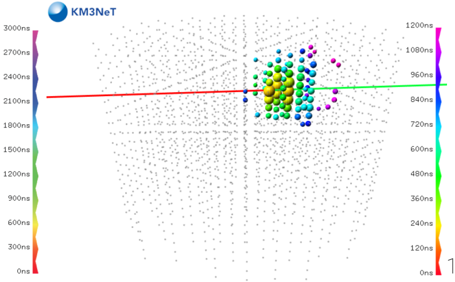
Motivation:

Global topology models could be better

Motivation

- track-like: μ (ν_μ-CC, muonic ν_τ-CC)
- shower-like: no μ (ν-NC, ν_e-CC, other ν_τ-CC)

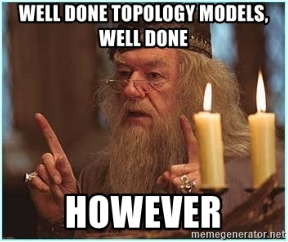




[1]

[1] from the KM3NeT Phase II LOI

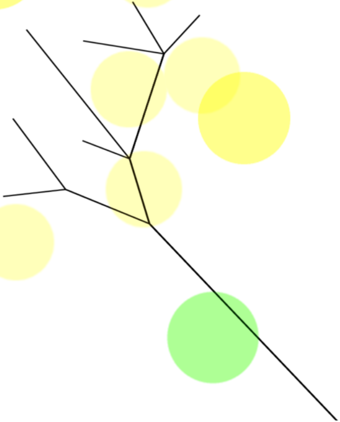
Motivation



- Interaction model **dependent**.
- Minimal interaction flavour and current information
- Minimal Bjorken-Y information

There is more stuff going on inside!

Can we exploit **details**?



Procedure

Why we are optimistic:

1. **ORCA is dense**
   (Detect finer features)

Procedure

Why we are optimistic:

1. **ORCA is dense**
   (Detect finer features)
2. **KM3NeT has multidirectional DOMs**
   (Additional dimensions in phase space)

Procedure

Why we are optimistic:

1. **ORCA is dense**
   (Detect finer features)
2. **KM3NeT has multidirectional DOMs**
   (Additional dimensions in phase space)
3. **Events propagate in water**
   (Straighter light path)

Procedure

Why we are optimistic:

1. **ORCA is dense**
   (Detect finer features)
2. **KM3NeT has multidirectional DOMs**
   (Additional dimensions in phase space)
3. **Events propagate in water**
   (Straighter light path)
4. **(Our detection modules look super cool)**

Procedure

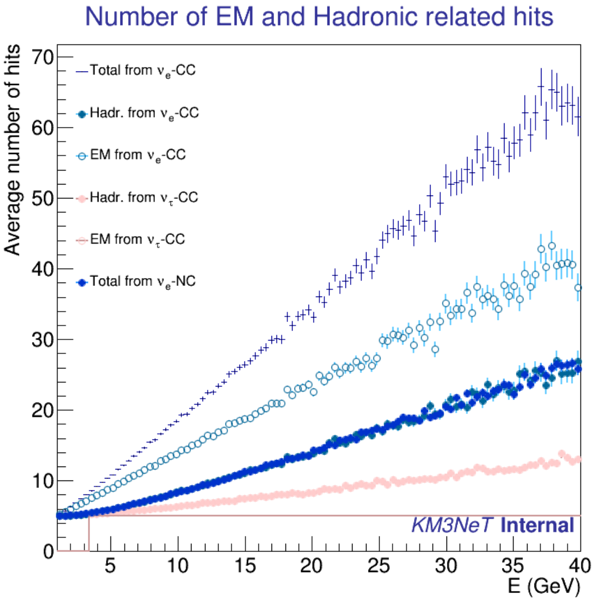
Used ORCA 1-100GeV all flavours ν-interaction samples

Procedure

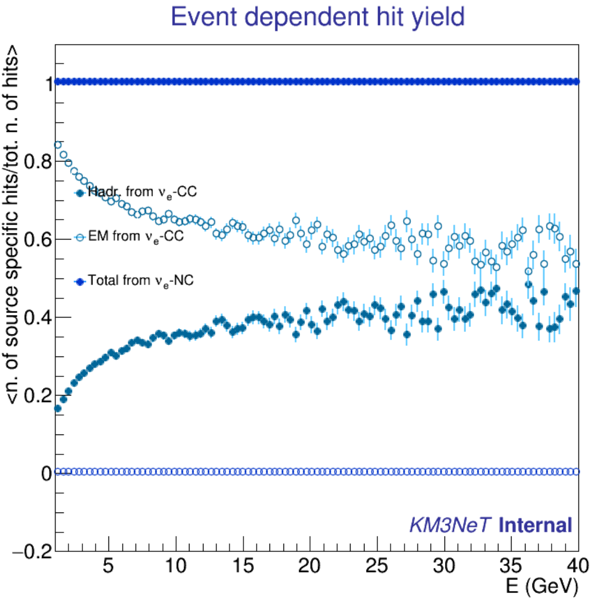
Chain of simulation:

$\downarrow$ - Input ν
$\downarrow$ GENIE - - - - - - - - - - - - Interaction
$\downarrow$ Km3Sim - - - Propagation + Re-interactions
JTE - - - - - - - - - - -PMT response + Trigger

Secondaries



Secondaries



Procedure

Chain of simulation:

↓ - - - - - - - - - - - - - - - - - - - Input ν
↓ GENIE - - - - - - - - - - - - Interaction
↓ Km3Sim - - - Propagation + Re-interactions
JTE - - - - - - - - - - - -PMT response + Trigger

We wanted to:

- be independent from GENIE

- remove assumptions on E-scaling of showers

Procedure

Model whole event	E-scaling
↓	↓
Model secondary particles	E free

Procedure

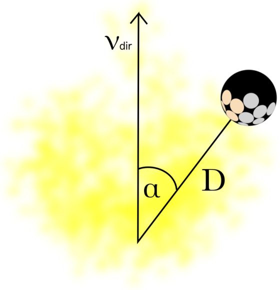
Model whole event	E-scaling
↓	↓
Model secondary particles	E free

In technical terms:

Expand JPhysics PDF tables and transformers, JSirene CDF tables, JApplication HDG, CDG and PDG structures to include energy as parameter and feed secondary light yield

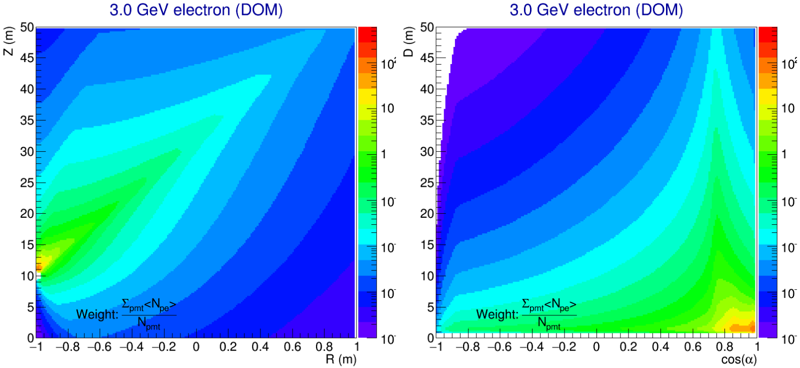
Description

1. Pick secondary particle
2. $E_{particle}$, D_{vertex}, α, θ_{pmt}, ϕ_{pmt}, $t_{arrival}$ of photo-electrons from particle gets filled in 6d histogram
3. Make PDF from histogram for each particle

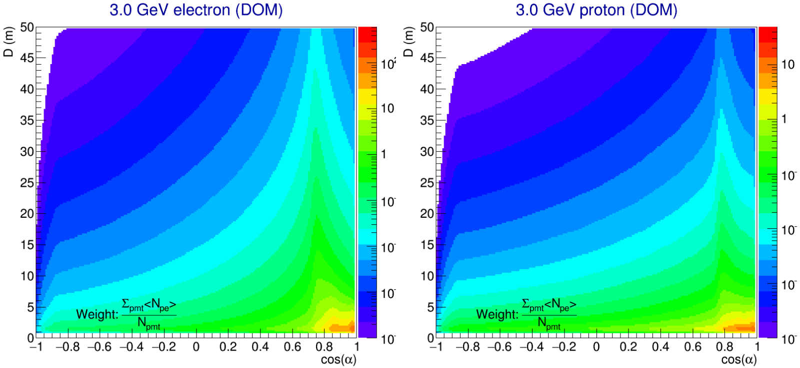


The PDF tells you **the expected number of PE** given **particle type** and **position in phase space**

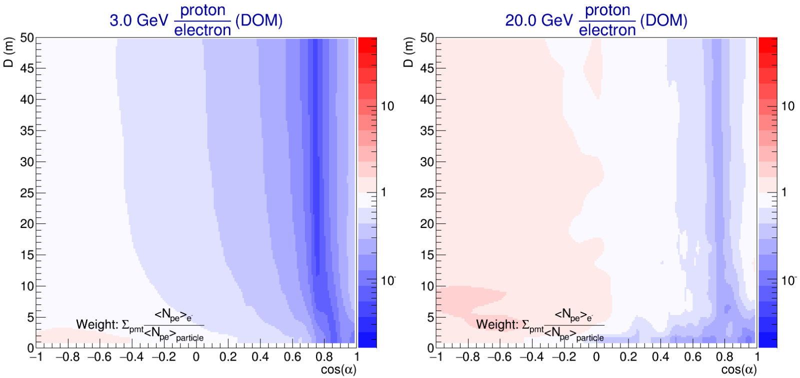
PDFs Geometry



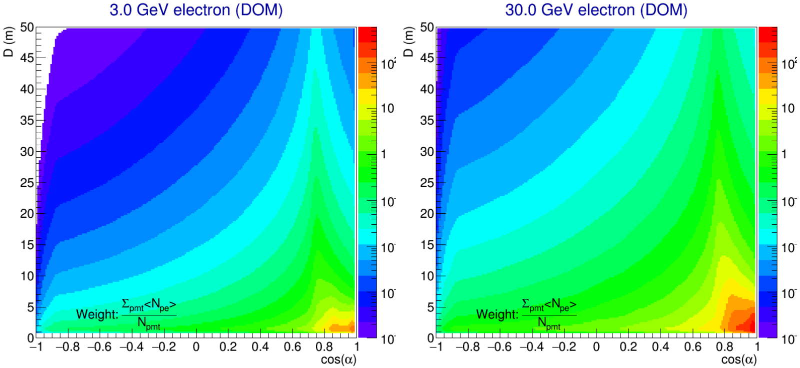
PDFs Geometry



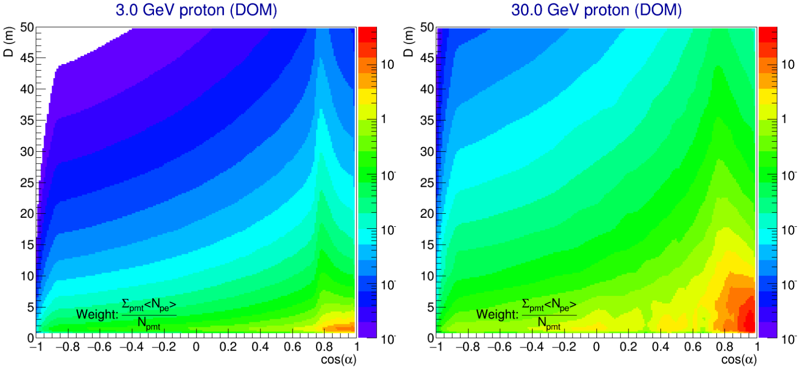
PDFs Geometry



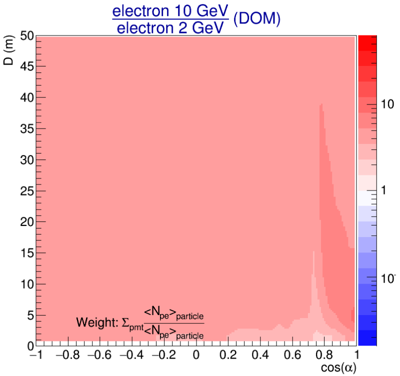
PDFs Geometry

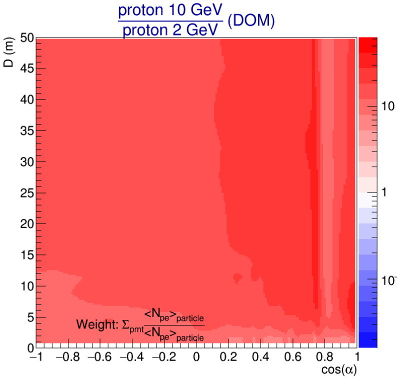


PDFs Geometry



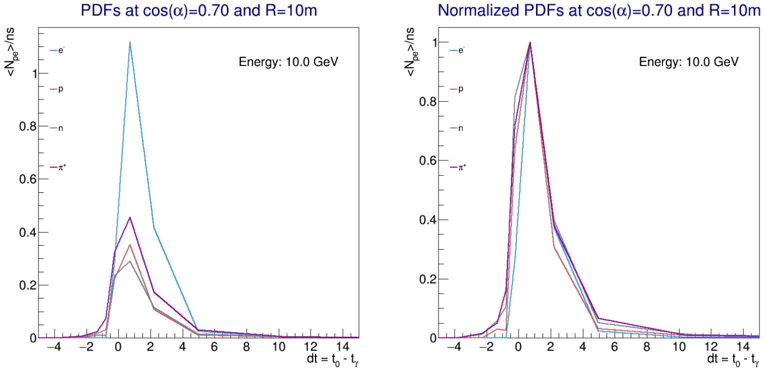
PDFs Geometry





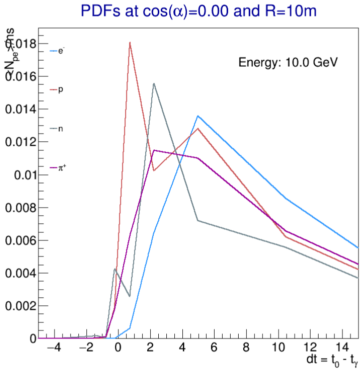
PDFs Time Arrival

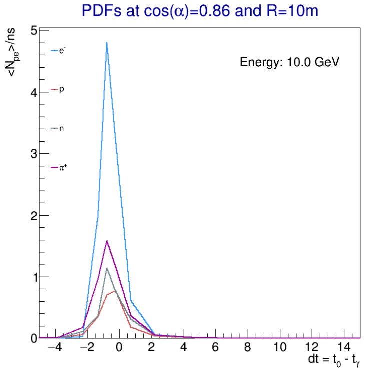
Normalised view



PDFs Time Arrival

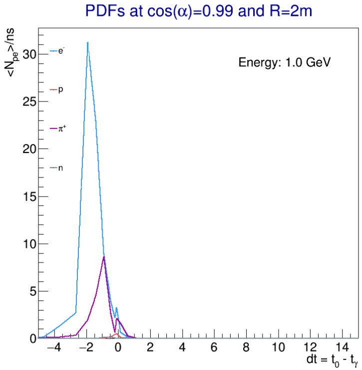
Angle dependence

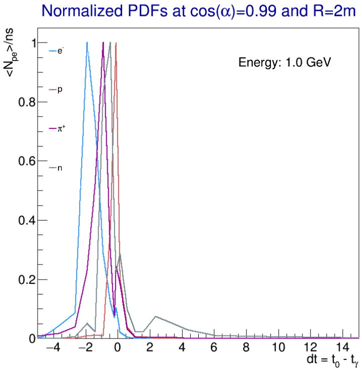




PDFs Time Arrival

Discerning power in time dependence

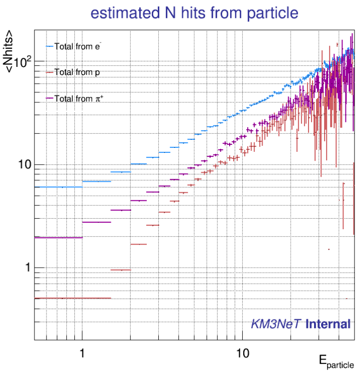


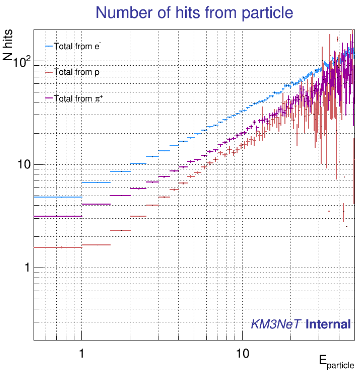


Applications

Accuracy of PDFs

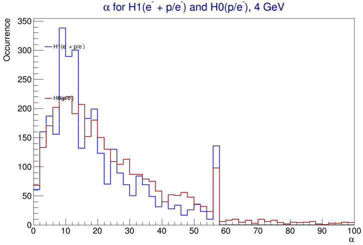
Potential for fast MC!

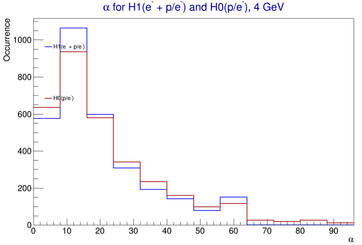




Reconstruction attempts

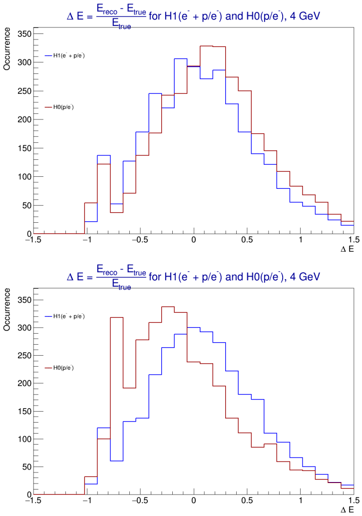
α 6d (7d) hypothesis above (below) for e-CC





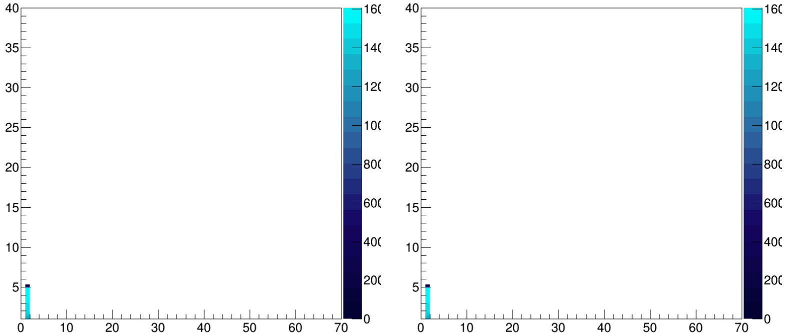
Reconstruction attempts

E reco 6d (7d) hypothesis above (below) for e-CC



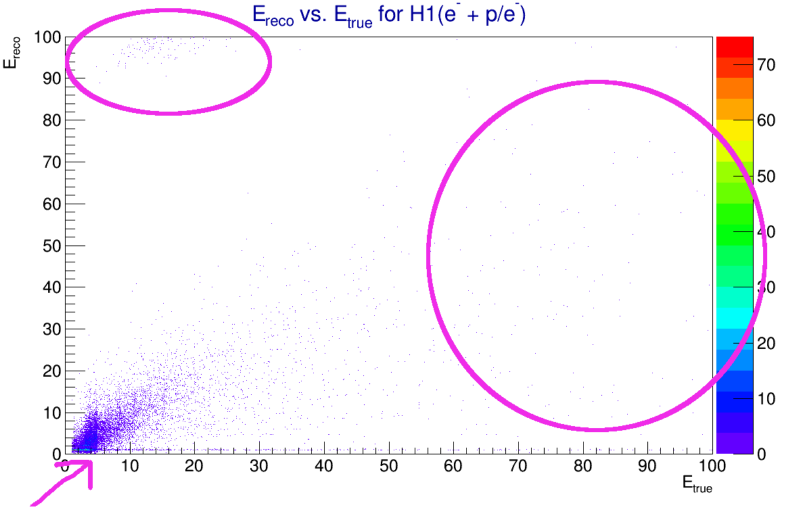
Reconstruction attempts

3d hypothesis Single electron and proton: ???



Reconstruction attempts

(BIG) room for improvement



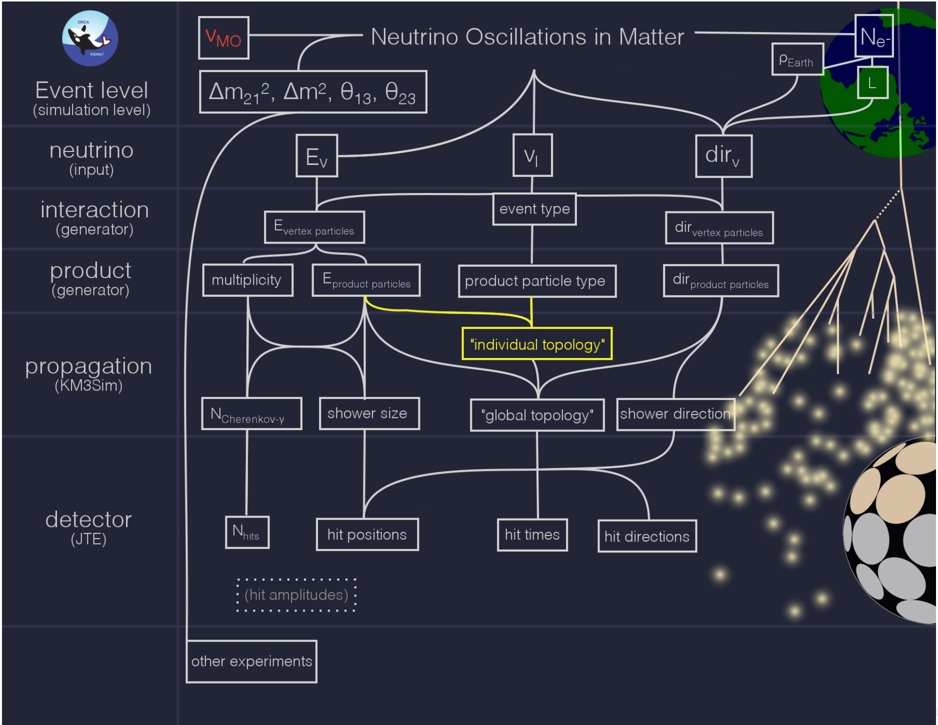
Next step

- 7d Likelihood analysis (free electron + coupled electron/proton) improvements...
- Probe bjorken-Y reco
- Finer time resolution for PDFs?
- Include K-40 background + PMT response

Thank you for listening!

Question time

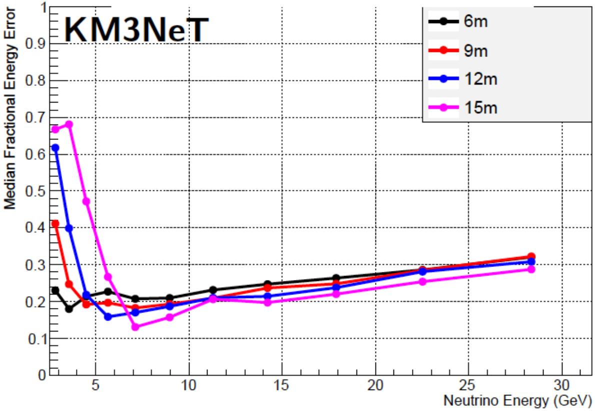
Leftovers..



Event level
(simulation level)
neutrino
(input)
interaction
(generator)
product
(generator)
propagation
(KM3Sim)
detector
(JTE)
ν_{MO}
Neutrino Oscillations in Matter
Δm_{21}^2, Δm^2, θ_{13}, θ_{23}
N_{e^-}
ρ_{Earth}
L
E_ν
ν_l
dir_ν
event type
$E_{vertex\ particles}$
$dir_{vertex\ particles}$
multiplicity
$E_{product\ particles}$
product particle type
$dir_{product\ particles}$
"individual topology"
$N_{Cherenkov\text{-}\gamma}$
shower size
"global topology"
shower direction
N_{hits}
hit positions
hit times
hit directions
(hit amplitudes)
other experiments

Motivation

Orca Energy resolution



2

[2] KM3NeT Phase II LOI

Motivation

Here are the parameters necessary to accurately predict the oscillation probability of a neutrino through matter.

- Oscillation parameters
- The number of electrons in the neutrino's path
- Energy of the neutrino
- Flavor of the neutrino
- Neutrino Mass Ordering (NMO)

$$P_{3\nu}m(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - sin^2 2\theta_{23} cos^2\theta_{13}^m sin^2\left(\frac{AL}{4} + \frac{\Delta m_{31}^2 + \Delta^m m^2)L}{8E_\nu}\right) - some\,other\,terms \quad (1)$$

Motivation

Here are the parameters necessary to accurately predict the oscillation probability of a neutrino through matter.

- Oscillation parameters
- The number of electrons in the neutrino's path
- Energy of the neutrino
- Flavor of the neutrino
- Neutrino Mass Ordering (NMO)

$$P_{3\nu}m(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - sin^2 2\theta_{23} cos^2\theta_{13}^m sin^2\left(\frac{AL}{4} + \frac{\Delta m_{31}^2 + \Delta^m m^2)L}{8E_\nu}\right) - some\,other\,terms \quad (1)$$

Motivation

Here are the parameters necessary to accurately predict the oscillation probability of a neutrino through matter.

- Oscillation parameters
- The number of electrons in the neutrino's path
- Energy of the neutrino
- Flavor of the neutrino
- Neutrino Mass Ordering (NMO)

$$P_{3\nu}m(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - sin^2 2\theta_{23} cos^2\theta_{13}^m sin^2\left(\frac{AL}{4} + \frac{\Delta m_{31}^2 + \Delta^m m^2)L}{8E_\nu}\right) - some\,other\,terms \quad (1)$$

Motivation

Here are the parameters necessary to accurately predict the oscillation probability of a neutrino through matter.

- Oscillation parameters
- The number of electrons in the neutrino's path
- Energy of the neutrino
- Flavor of the neutrino
- Neutrino Mass Ordering (NMO)

$$P_{3\nu}m(\nu_\mu \rightarrow \nu_\mu) \simeq 1 - sin^2 2\theta_{23} cos^2\theta_{13}^m sin^2\Big(\frac{AL}{4} + \frac{\Delta m_{31}^2 + \Delta^m m^2)L}{8E_\nu}\Big) - some\,other\,terms \quad (1)$$

Motivation

Here are the parameters necessary to accurately predict the oscillation probability of a neutrino through matter.

- Oscillation parameters
- The number of electrons in the neutrino's path
- Energy of the neutrino
- Flavor of the neutrino
- Neutrino Mass Ordering (NMO)

$$P_{3\nu}m(\nu_\mu \to \nu_\mu) \simeq 1 - sin^2 2\theta_{23} cos^2\theta_{13}^m sin^2\Big(\frac{AL}{4} + \frac{\Delta m_{31}^2 + \Delta^m m^2)L}{8E_\nu}\Big) - some\,other\,terms \quad (1)$$

Motivation: number of electrons in path

Requires knowledge of the following:

- The matter density of the Earth
- The distance travelled through the Earth

Motivation: number of electrons in path

Requires knowledge of the following:

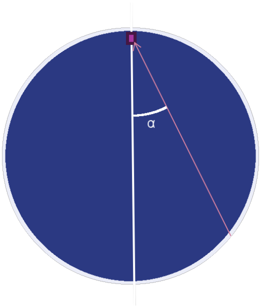
- The matter density of the Earth
- The distance travelled through the Earth

Motivation: number of electrons in path

Requires knowledge of the following:

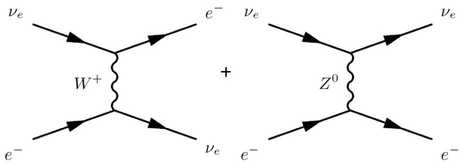
- The matter density of the Earth
- The distance travelled through the Earth
  - $\rightarrow$ known by neutrino direction

Figure: Parametrization of electrons in path using the Earth



Motivation: neutrino flavor

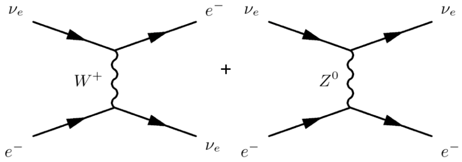
The flavor of a neutrino is defined by the interaction it induces.



- Type of product particles
- Energies and directions of product particles

Motivation: neutrino flavor

The flavor of a neutrino is defined by the interaction it induces.



- Type of product particles
- Energies and directions of product particles

Motivation: neutrino energy

The neutrino energy affects the following outcomes:

- The size of the event in the detector (PMT positions)
- The number of $\gamma_{cherenkov}$

Procedure

Signatures are visible in the detector *hit pattern*.

What affects the hit pattern?

Procedure

Global topology, size, brightness, and direction *directly* couple to hit pattern.

Procedure

Global topology, size, brightness, and direction *directly* couple to hit pattern.

"Global Topology": The shape of an <u>entire event</u>

vs.

"Individual topology": The shape of a <u>single particle</u>

Procedure

Global topology, size, brightness, and direction *directly* couple to hit pattern.

"Global Topology": The shape of an entire event

vs.

"Individual topology": The shape of a single particle

Disclaimer: not *really* individual since particle themselves decay/re-interact into other particles.

Procedure

What affects global topology?

Product particle types

Product particle energies

Product particle directions