Sub-topologies in ORCA ν-events

Overview

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Projected outcomes

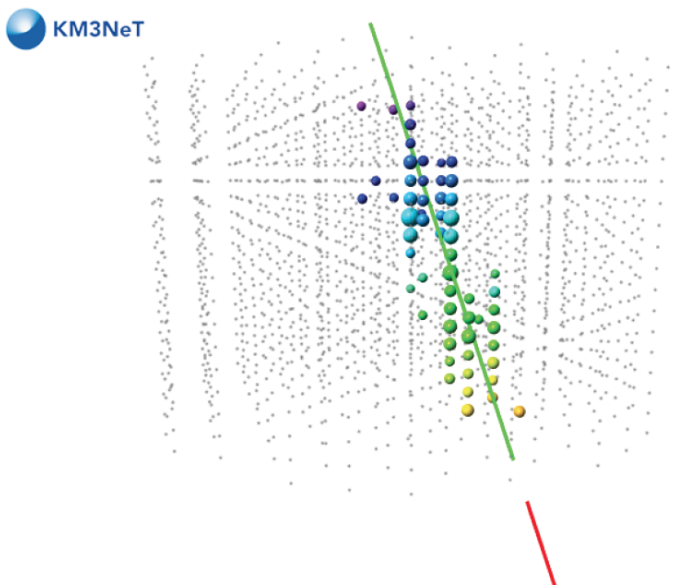
- Tool to analyse ORCA events without ν-interaction priors
- Probe for ν_e-CC and ν_τ-CC events
- Improved reconstruction in energy and direction

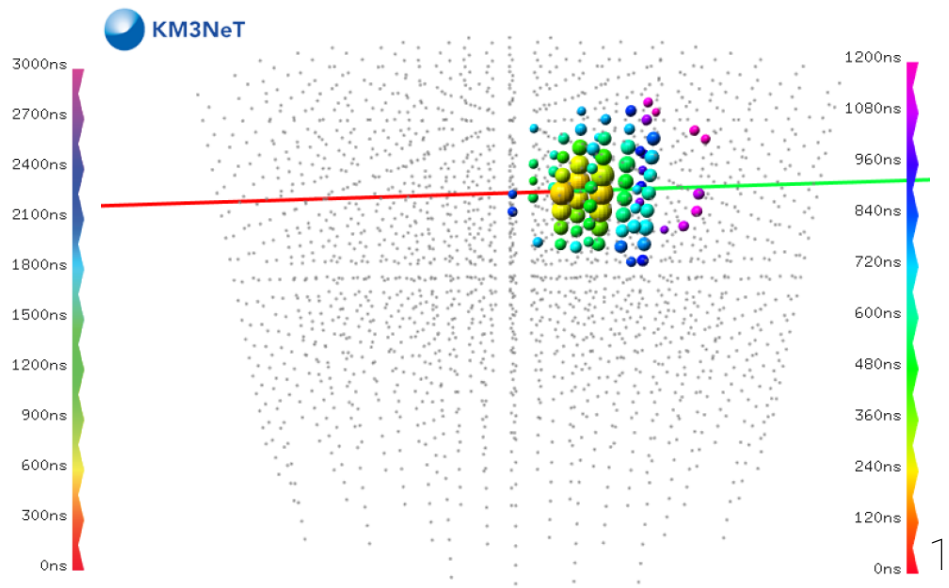
Motivation

The Global Topology Models

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

The Global Topology Models

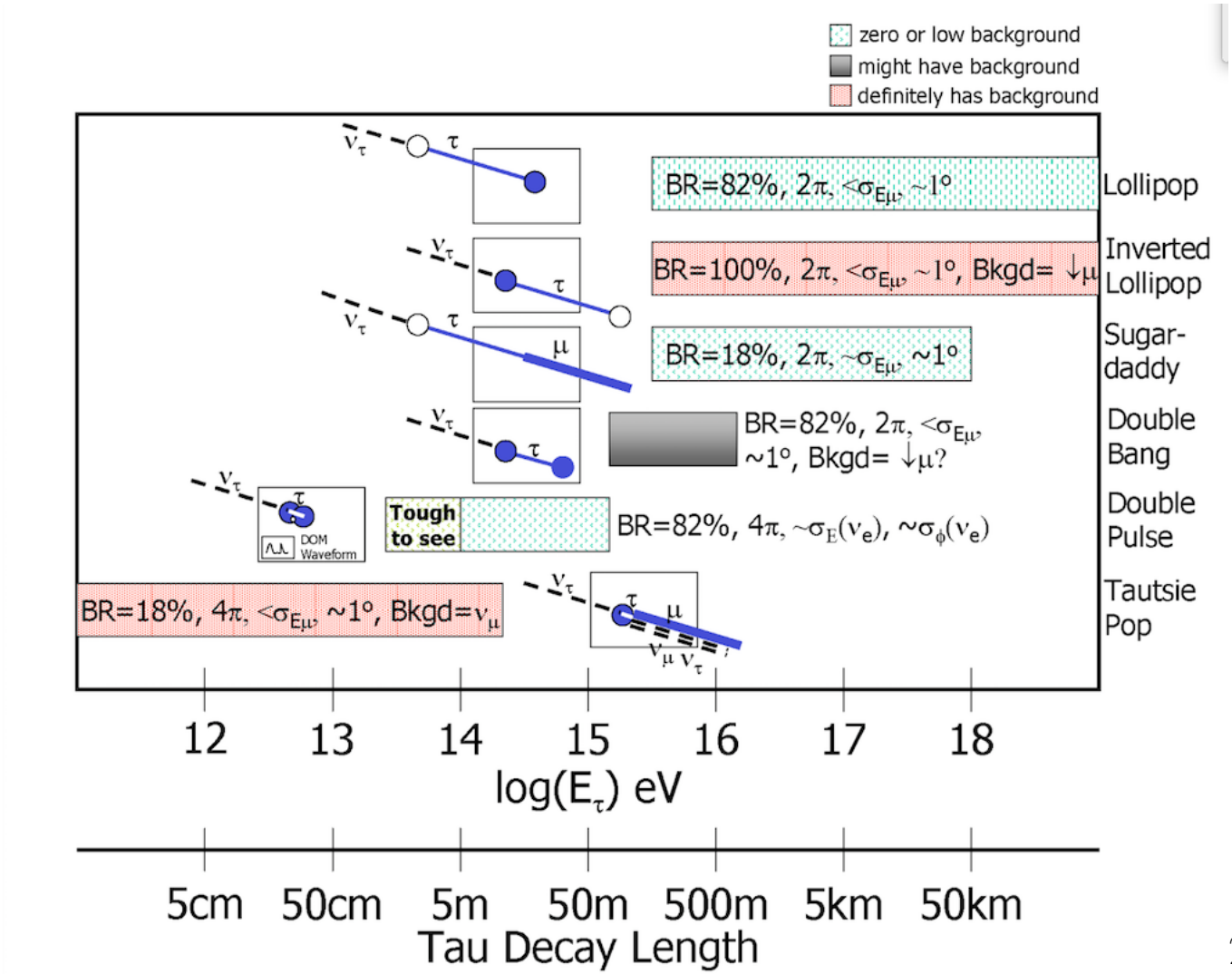
Motivation

Complaints:

- NC, elec-CC, low E μ-CC, most τ-CC **all look similar**.
- Fluctuations from interaction dominate.
- Tenuous information about the Bjorken-Y.
- Interaction model **dependent**.

Motivation

Other event topologies at high energies



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[2] D. Cowen. Tau Neutrinos in IceCube. Internal IceCube Report, June

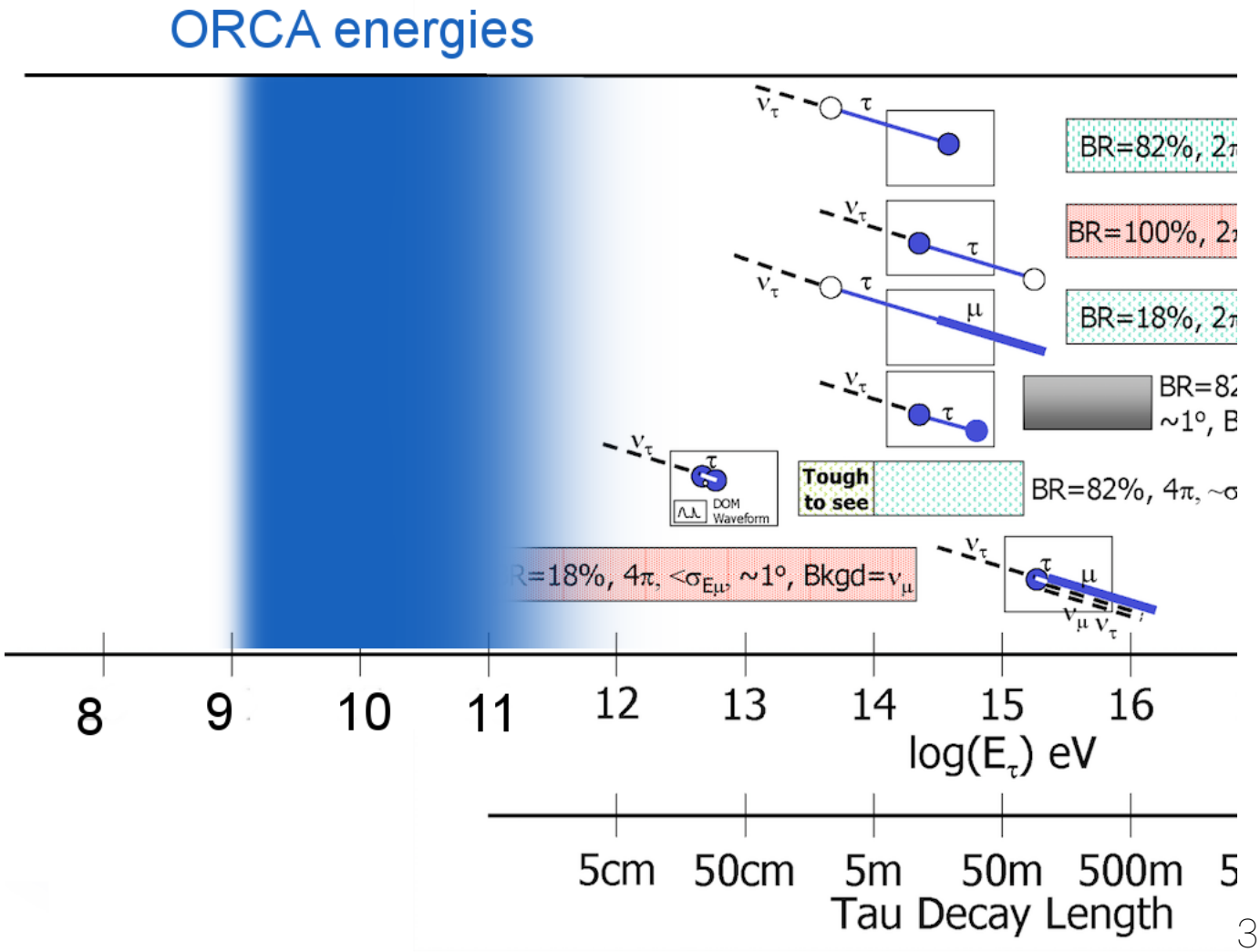
Motivation

Established work

- Study of high energy Double Bang events, Double Pulse, Sugar Daddy, etc. (IceCube and ARCA)
- Topological features used to train neural networks. (KM3NeT)
- Other... ? (I don't know about all of the literature)

Motivation

What can we find at lower energies?

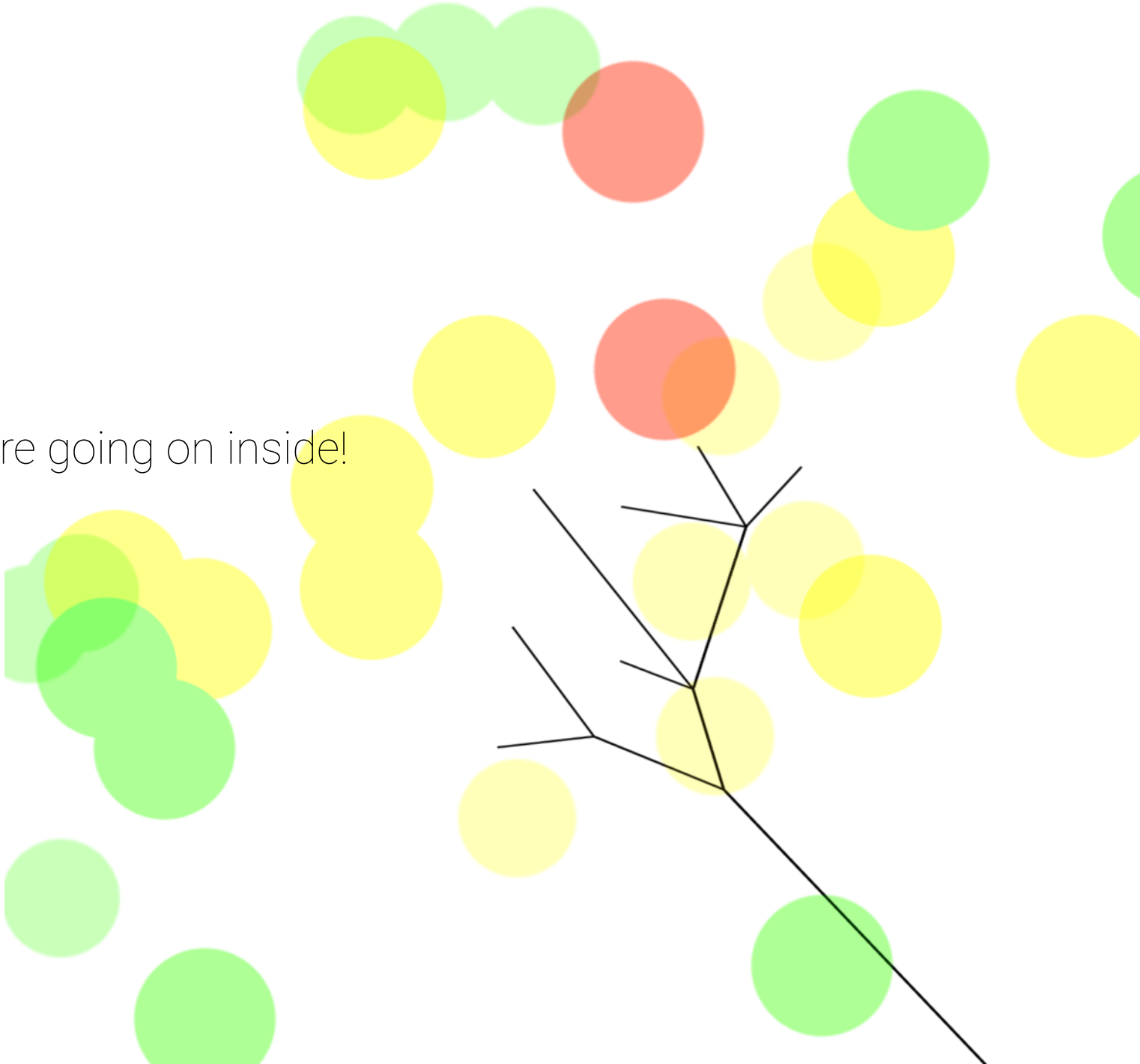


[3]

[3] D. Cowen. Tau Neutrinos in IceCube. Internal IceCube Report, June

Motivation

There is more going on inside!



Can we find more signatures?

New signatures

Why we think there are new signatures: particles look more **distinct** at lower energies!

- Particles re-interact less
- Particles re-interact into more common (and different) channels
- Decays become more visible

New signatures

Why we think **we** can do this:

New signatures

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

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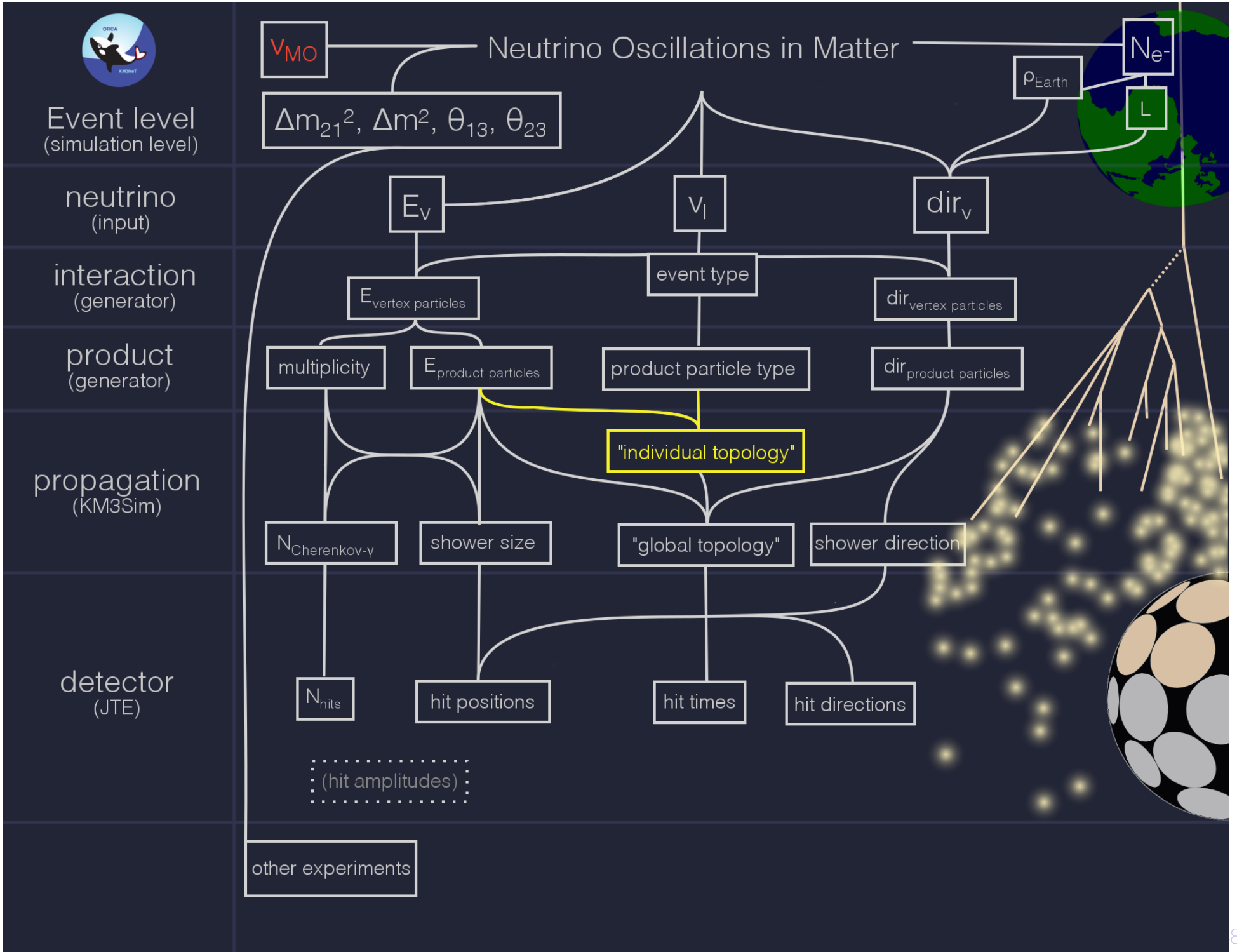
   (Detect finer features)
2. **KM3NeT has multidirectional DOMs**
   (Additional dimensions in phase space)
3. **Events propagate in water**
   (Straighter light path)
4. **Our detection modules look super cool**

Finding new signatures

Use ORCA 1-100GeV ν-interaction samples

Finding new signatures

Chain of simulation:
Input $\nu \rightarrow$ GENIE interaction $\rightarrow$ Km3Sim propagation $\rightarrow$ JTE PMT response + trigger


Neutrino Oscillations in Matter
Event level
(simulation level)
neutrino
(input)
interaction
(generator)
product
(generator)
propagation
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detector
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ν_{MO}
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product particle type
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$N_{Cherenkov\text{-}\gamma}$
shower size
"global topology"
shower direction
N_{hits}
hit positions
hit times
hit directions
(hit amplitudes)
other experiments

Finding new signatures

Chain of simulation:
Input $\nu \rightarrow$ GENIE interaction $\rightarrow$ Km3Sim propagation $\rightarrow$ JTE PMT response + trigger

We wanted to be independent from GENIE to test it.

Finding new signatures

Global Topology $\rightarrow$ Sub-Topology

Start with $\nu \rightarrow$ Start with Product

E scaling $\rightarrow$ E as free parameter

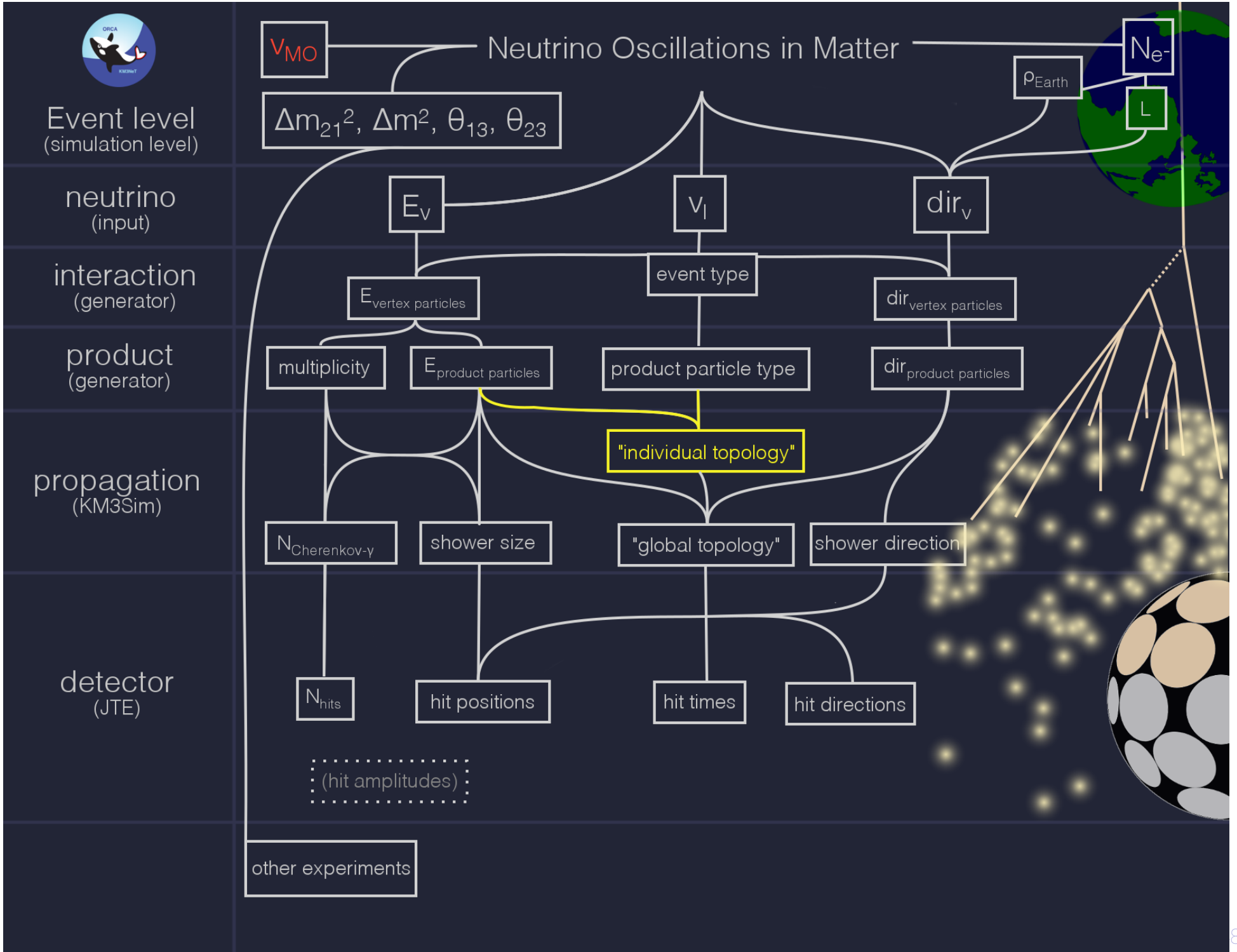
Description

	Previous work	**This work**
Starting point	Primary neutrino Global topology	Proton, neutron, electron, etc. Individual topology
Simulators	GENIE, KM3Sim, JTE	KM3Sim, JTE
Parameters	R, $\cos(\alpha)$, θ, ϕ, dt (E $\propto$ shower size)	E, R, $\cos(\alpha)$, θ, ϕ, dt E free

Description

Novelty in this work in the context of ORCA:

- Topology of individual product particles
- Energy as free parameter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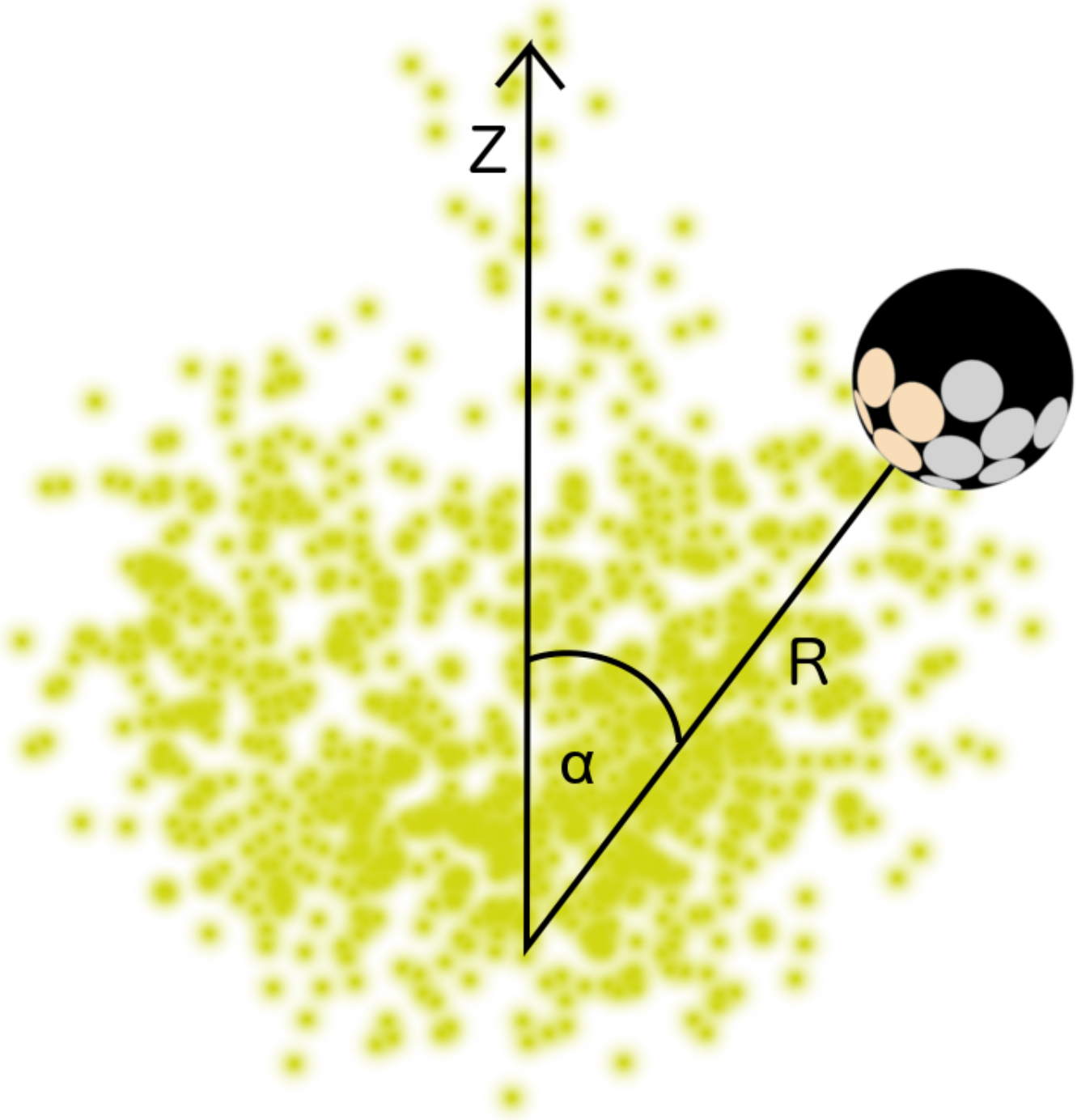
Description

1. Inject one particle into ORCA
2. KM3Sim propagates particle in the detector volume, creates Cherenkov photons, absorbs and propagates photons
3. JTE simulates PMT response
4. JTE triggers signal (this step could be skipped)
5. Make PDF of number of photo-electrons at arrival time
6. Sort PDFs according to $E_{particle}$, r_{vertex}, $\cos(\alpha_{vertex})$, θ_{pmt}, ϕ_{pmt}.


Z
R
α

Arrival time PDFs

Arrival time PDFs

Arrival time PDFs

Arrival time PDFs

NPE yield

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No bias from simulation of primary interaction

We can describe an event without knowing anything about ν-interactions

So what?

Description

Prescriptive reconstruction

Bulk reconstruction

Reliant on ν interaction model

Partially descriptive reconstruction

Segmented reconstruction

Additional reconstruction

Probes ν interaction model

Primary bias independent

- Segmented reconstruction
  Example: we could probe only a leptonic cascade, or only a hadronic cascade say something about the Bjorken-y

Description

Prescriptive reconstruction

Bulk reconstruction

Reliant on ν interaction model

Partially descriptive reconstruction

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Additional reconstruction

Probes ν interaction model

Primary bias independent

- Segmented reconstruction
- (partially) Independent reconstruction
  Example: reconstructing from global topology vs. reconstructing from individual topology will give two different results that can be compared

Description

Prescriptive reconstruction

Bulk reconstruction

Reliant on ν interaction model

Partially descriptive reconstruction

Segmented reconstruction

Additional reconstruction

Probes ν interaction model

Primary bias independent

- Segmented reconstruction
- (partially) Independent reconstruction
- Probe quality of neutrino-interaction models
  Example: relation between EM shower and Hadronic shower consistently different in direction/energy from what interaction model predicts

Looking forward next couple of months

Next step

PDFs and CDFs are in hand for all common particles.
Caveats: only one PMT direction, hi-E muon not to be trusted.

Consider using events before triggering

Next step

- Likelihood analyses
- EM vs. Hadr shower
- EM + Hadr vs. Hadr shower
- Lepton + Hadr vs. Hadr shower
- Reconstruction of Hadr in track-events
- Reconstruction of Hadr and EM in shower
- Ideas... ?

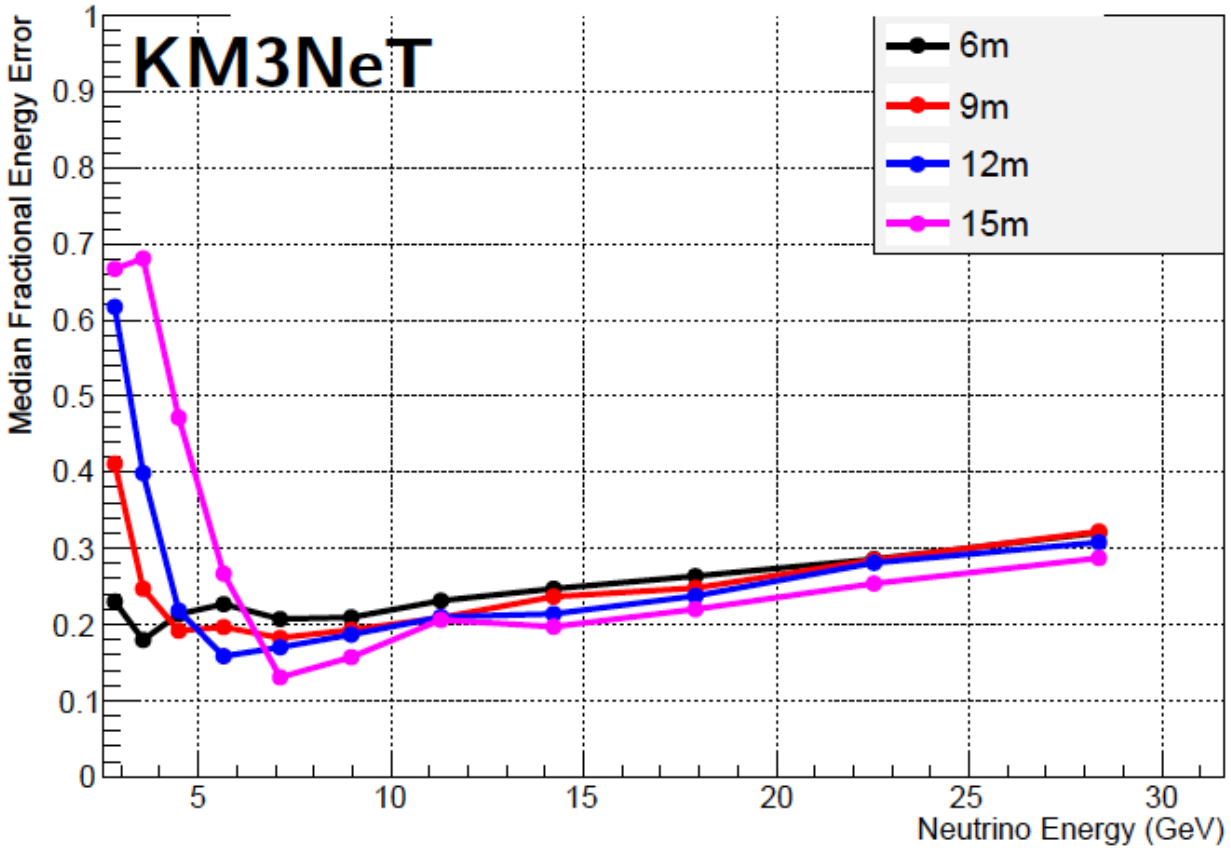
Thank you for listening and for hosting me!

Inputs, suggestions, questions?

Leftovers..

Motivation

Orca Energy resolution



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[4] 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)

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

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Motivation: number of electrons in path

Requires knowledge of the following:

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

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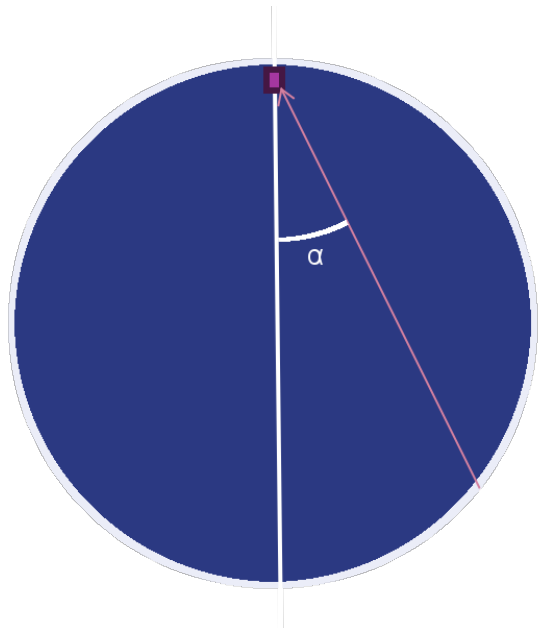
Motivation: number of electrons in path

Requires knowledge of the following:

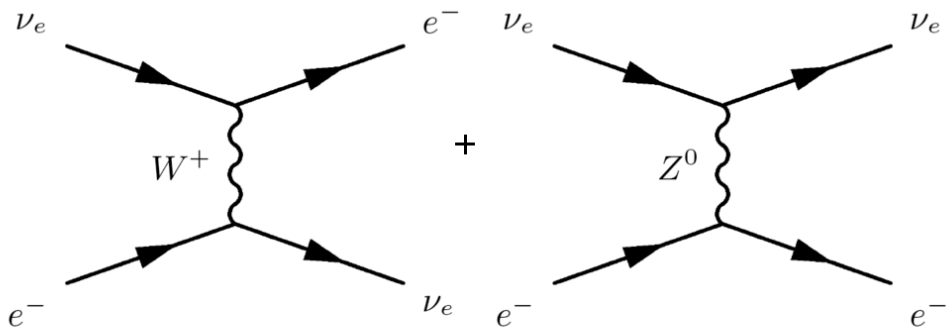
- The matter density of the Earth
- The distance travelled through the Earth
  - $\rightarrow$ known by neutrino direction

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

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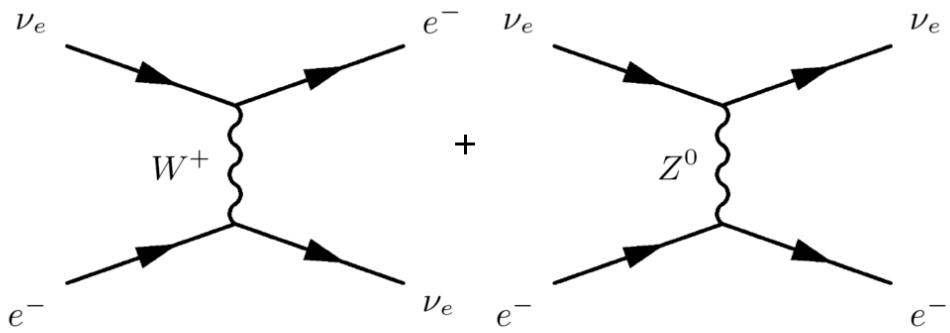

- Type of product particles
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Motivation: neutrino energy

The neutrino energy affects the following outcomes:

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

Finding new signatures

Chain of simulation:
Input $\nu \rightarrow$ GENIE interaction $\rightarrow$ Km3Sim propagation $\rightarrow$ JTE PMT response + trigger

We wanted to be independent from GENIE.

Finding new signatures

Signatures are visible in the detector *hit pattern*.

What affects the hit pattern?

Finding new signatures

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

Finding new signatures

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

Finding new signatures

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

What affects global topology?

Product particle types

Product particle energies

Product particle directions