

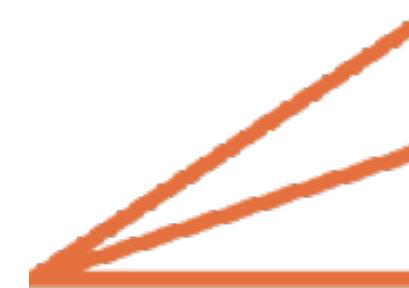
Your first DUNE neutrino-interaction analysis

Cheryl Patrick

University College London

June 21, 2021

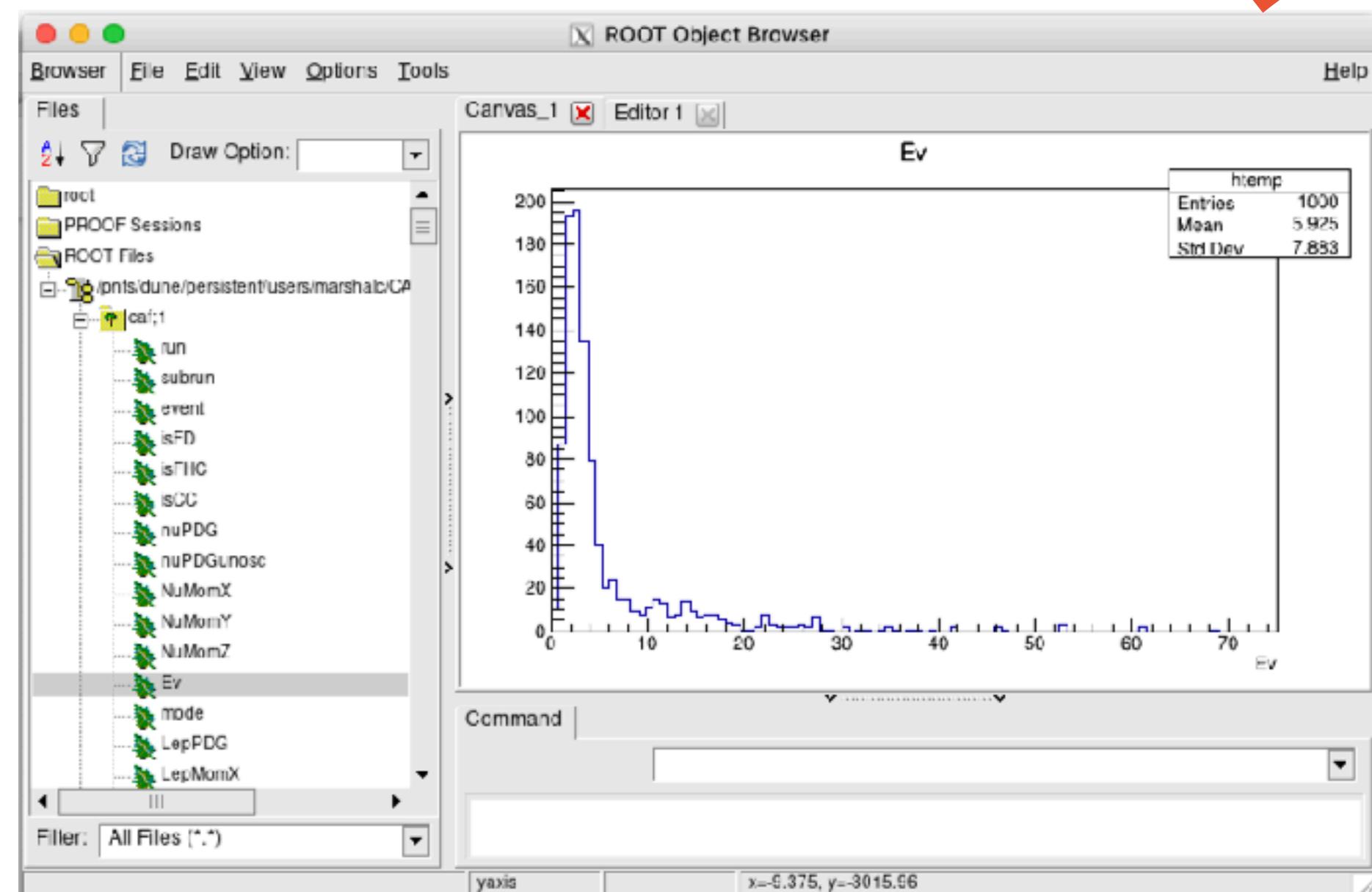
With thanks to Chris Backhouse, UCL



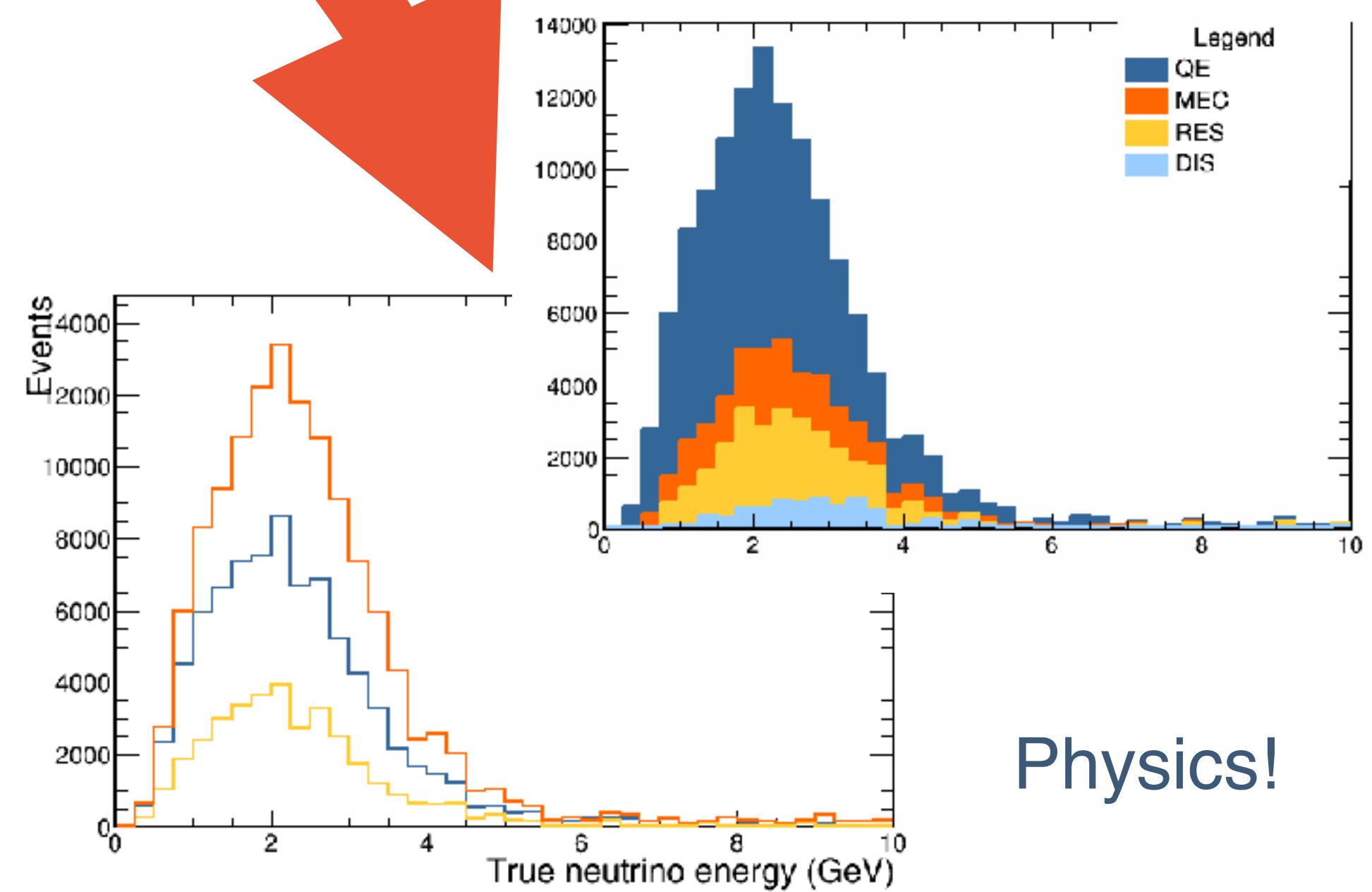
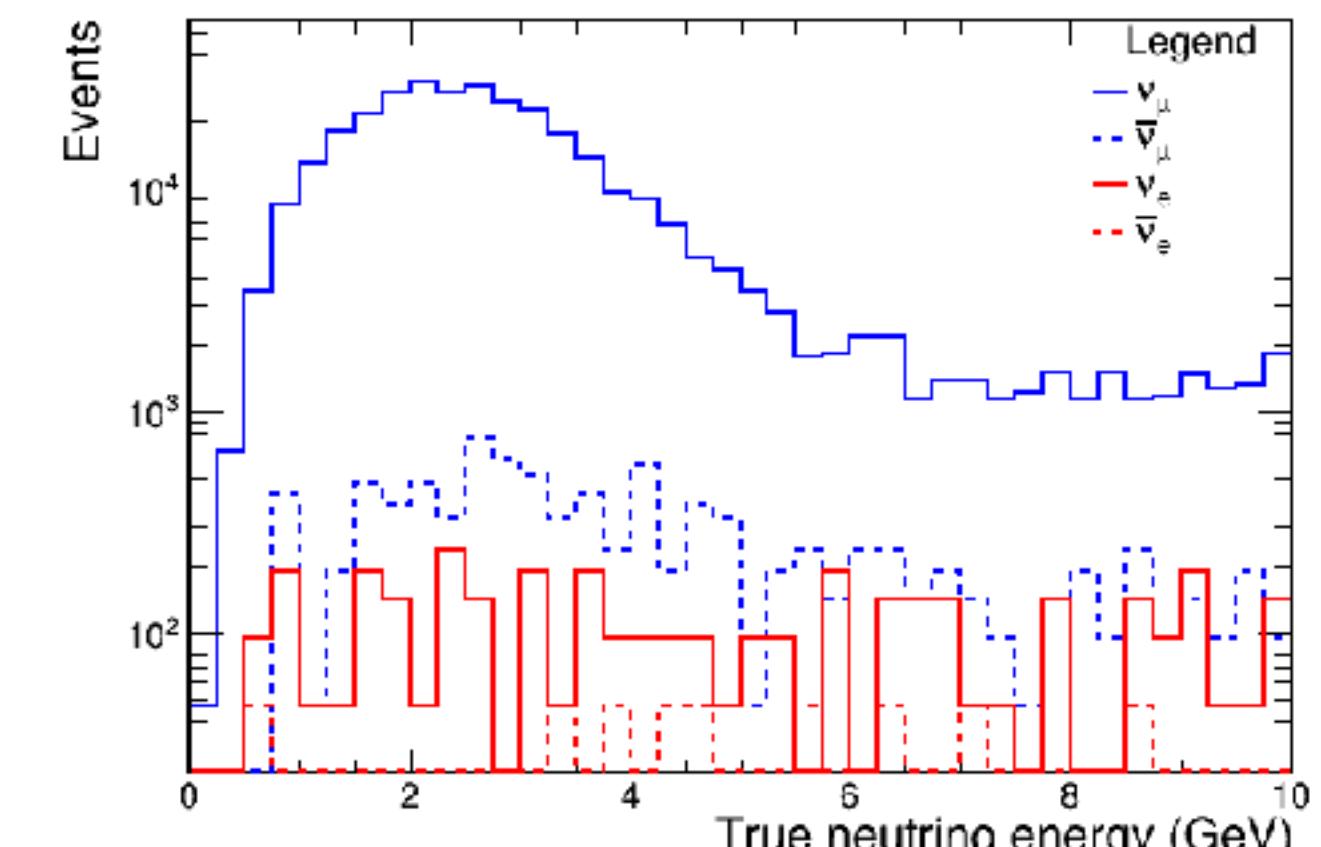
Neutrino
Interaction
School 2021



DUNE simulation



CAFAna Analysis Tool



CAFs: Common Analysis Files

Physics!



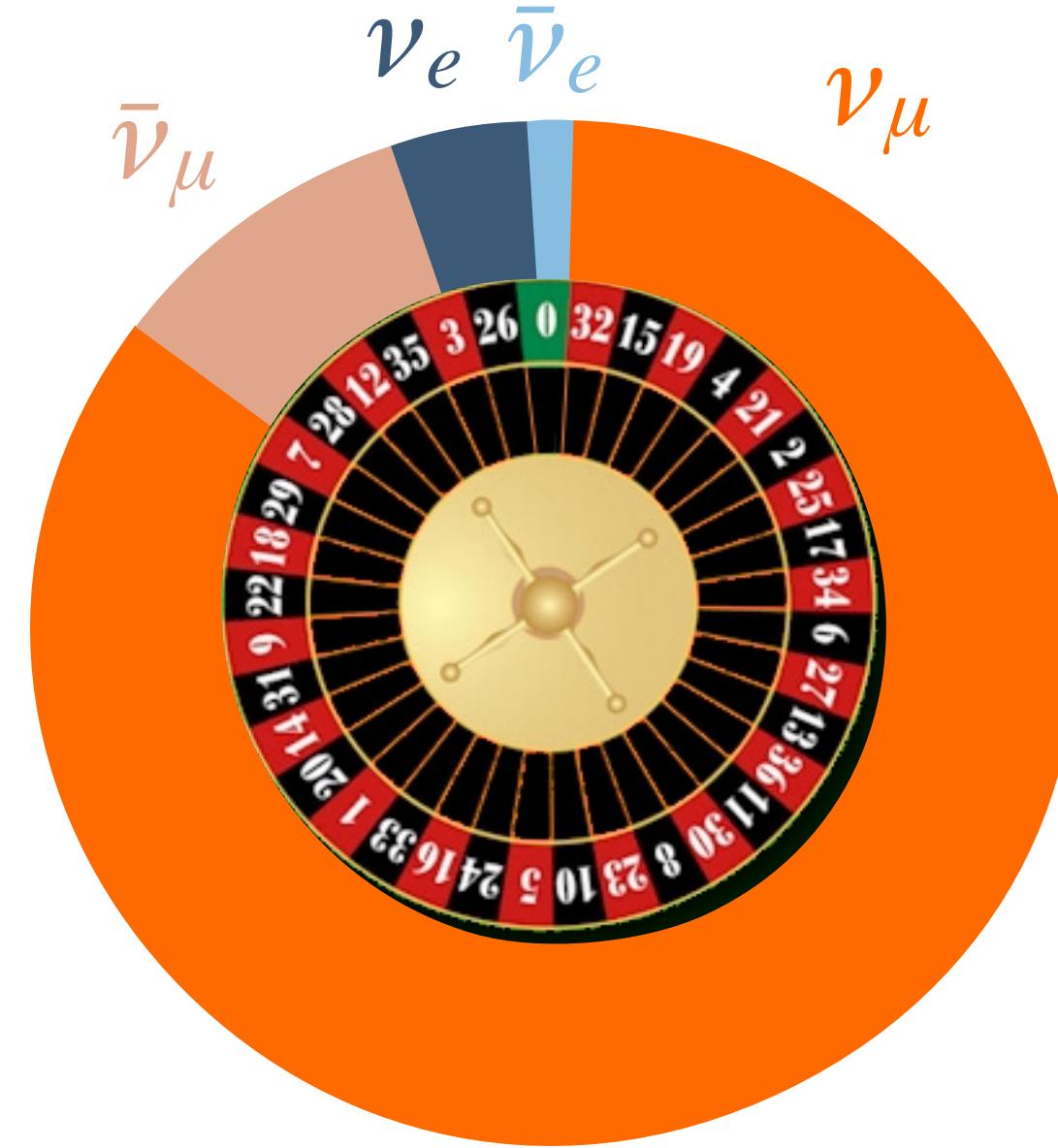
Simulating a neutrino-interaction event

1. Generate a neutrino from the DUNE beam

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Roll a **flavor** based on fractions in the beam



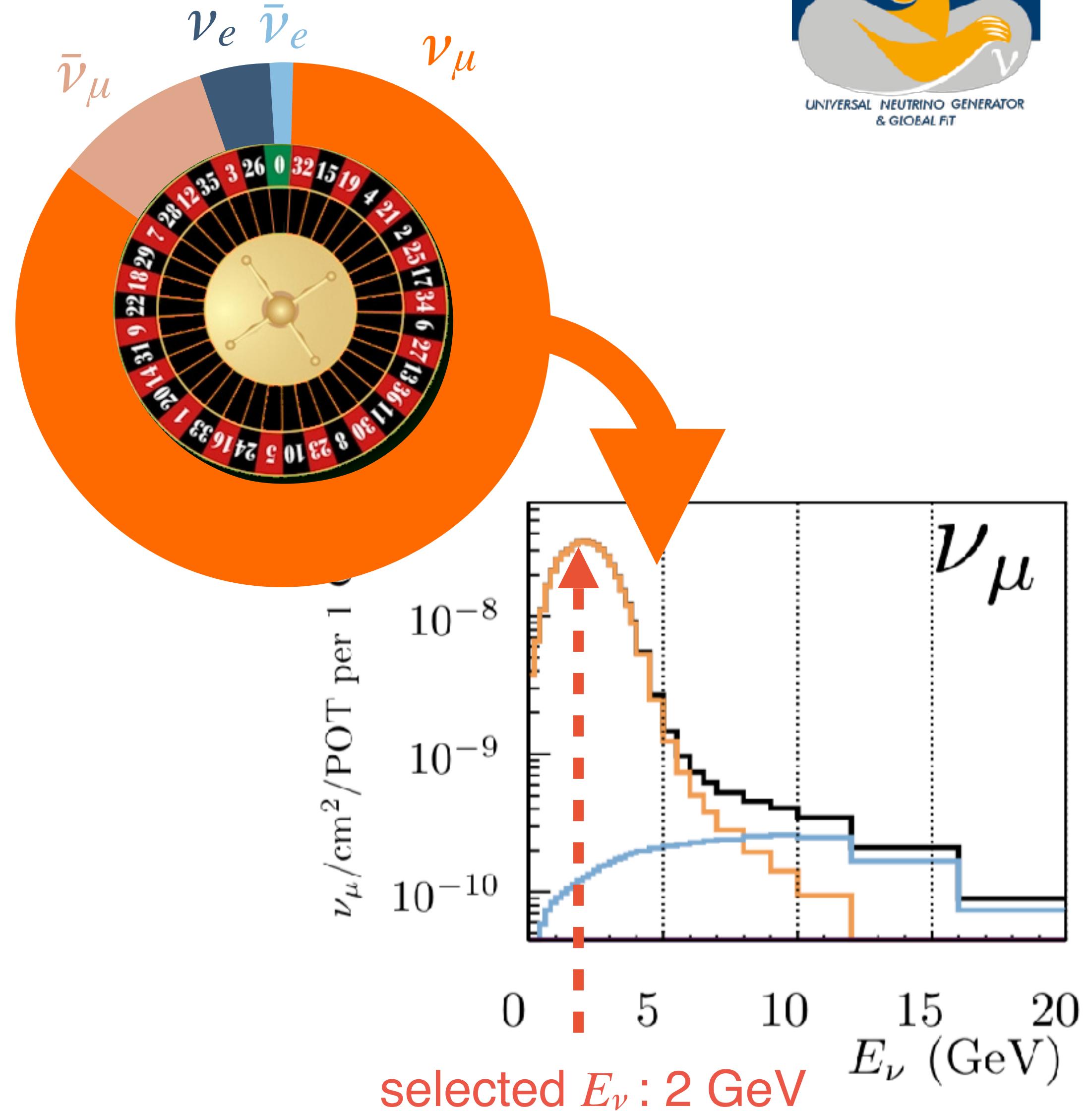
Monte Carlo technique

Simulating a neutrino-interaction event

1. Generate a neutrino from the DUNE beam

Roll a **flavor** based on fractions in the beam

Roll its **energy** from the beam flux spectrum



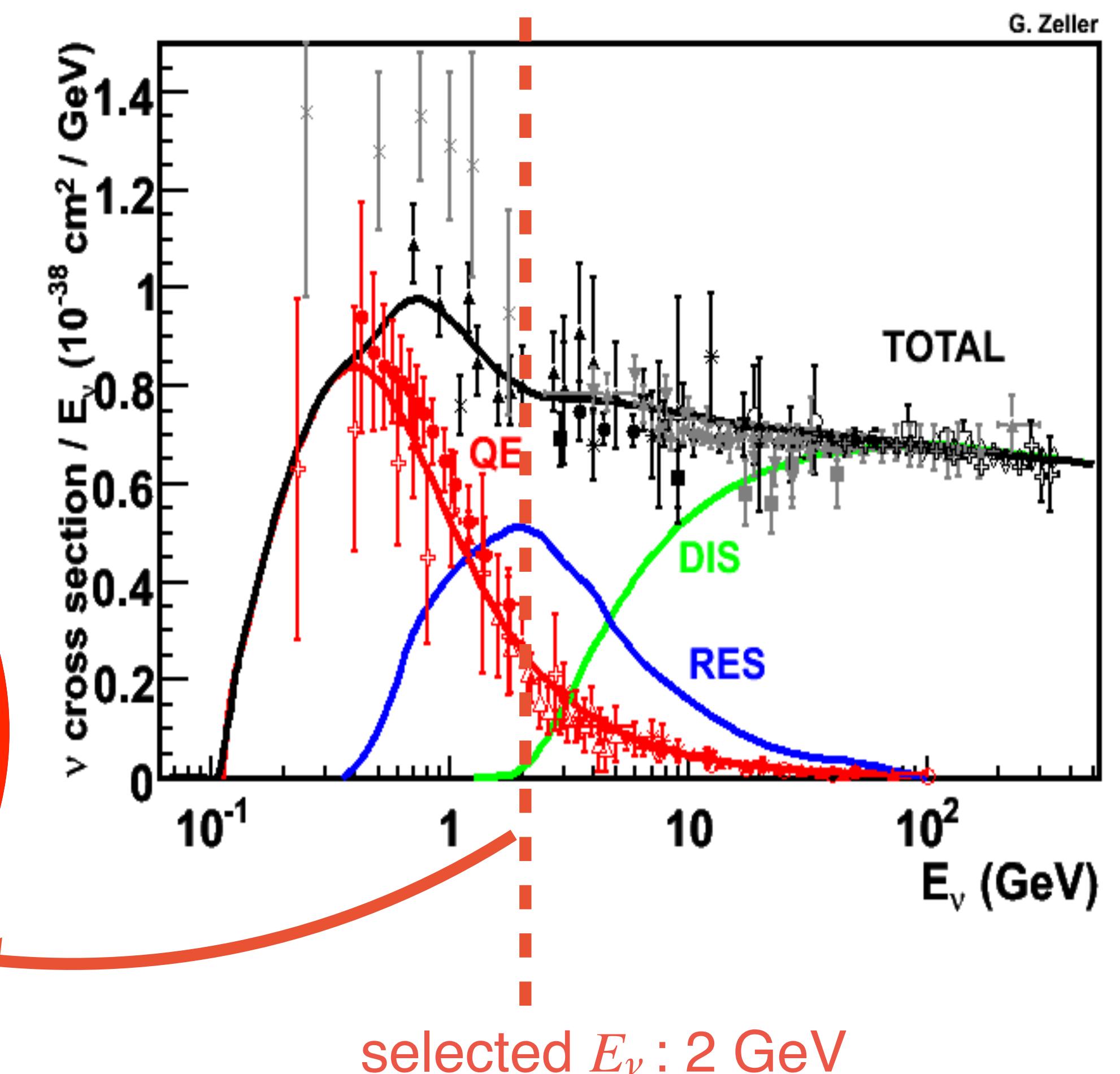
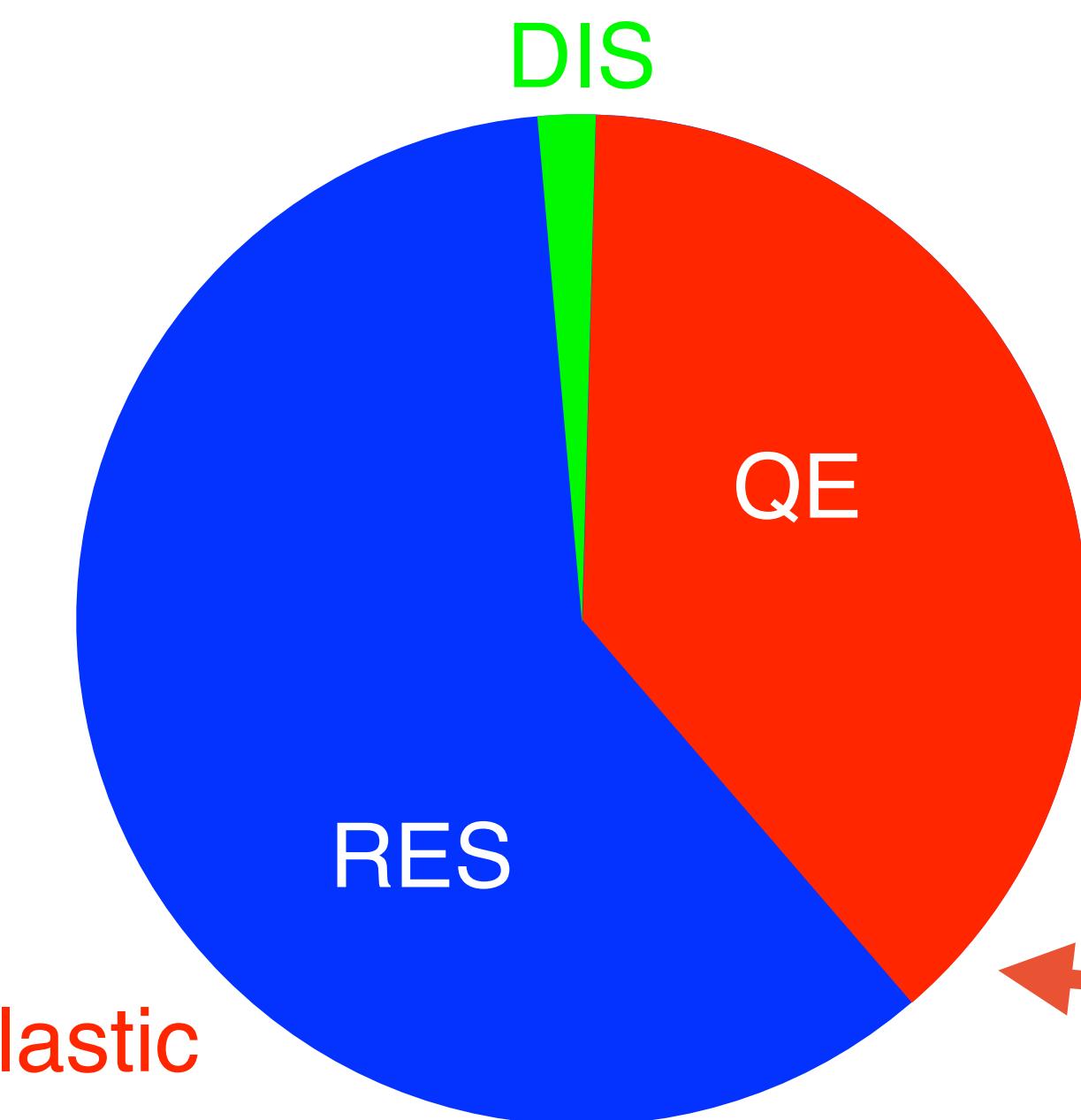
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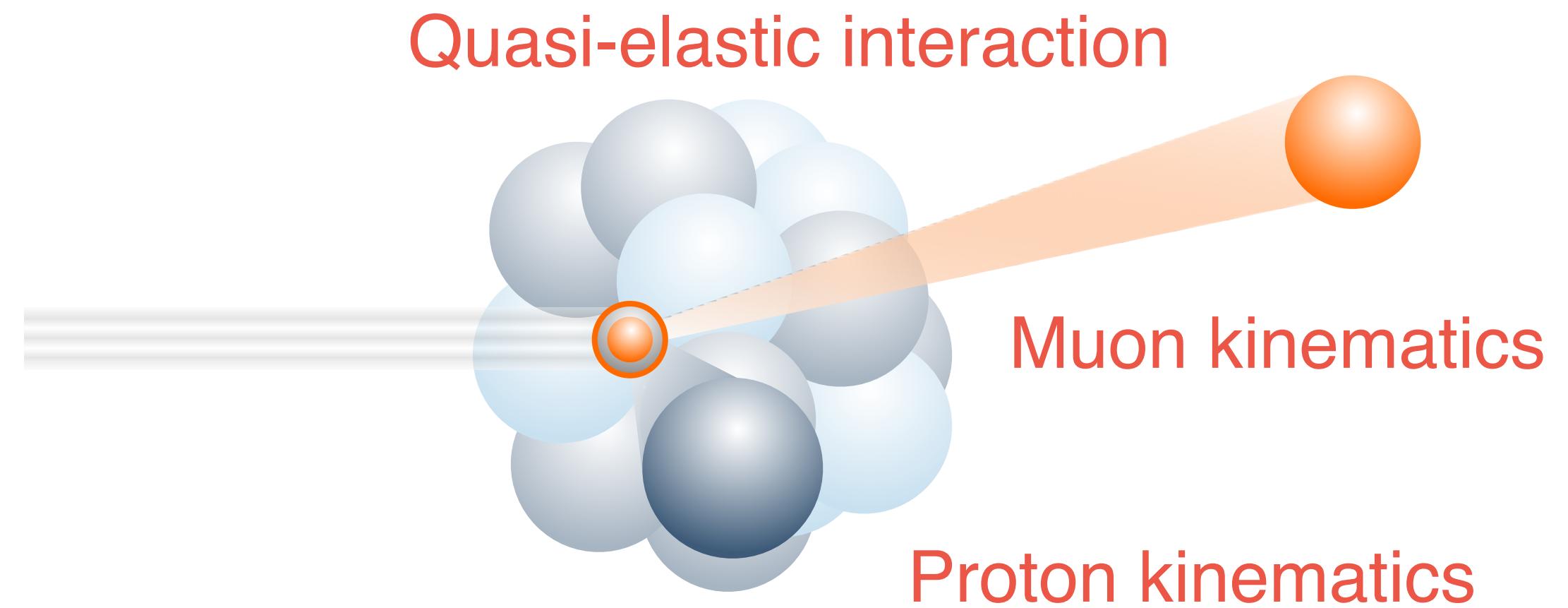
Roll a **flavor** based on fractions in the beam

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Initial scattering



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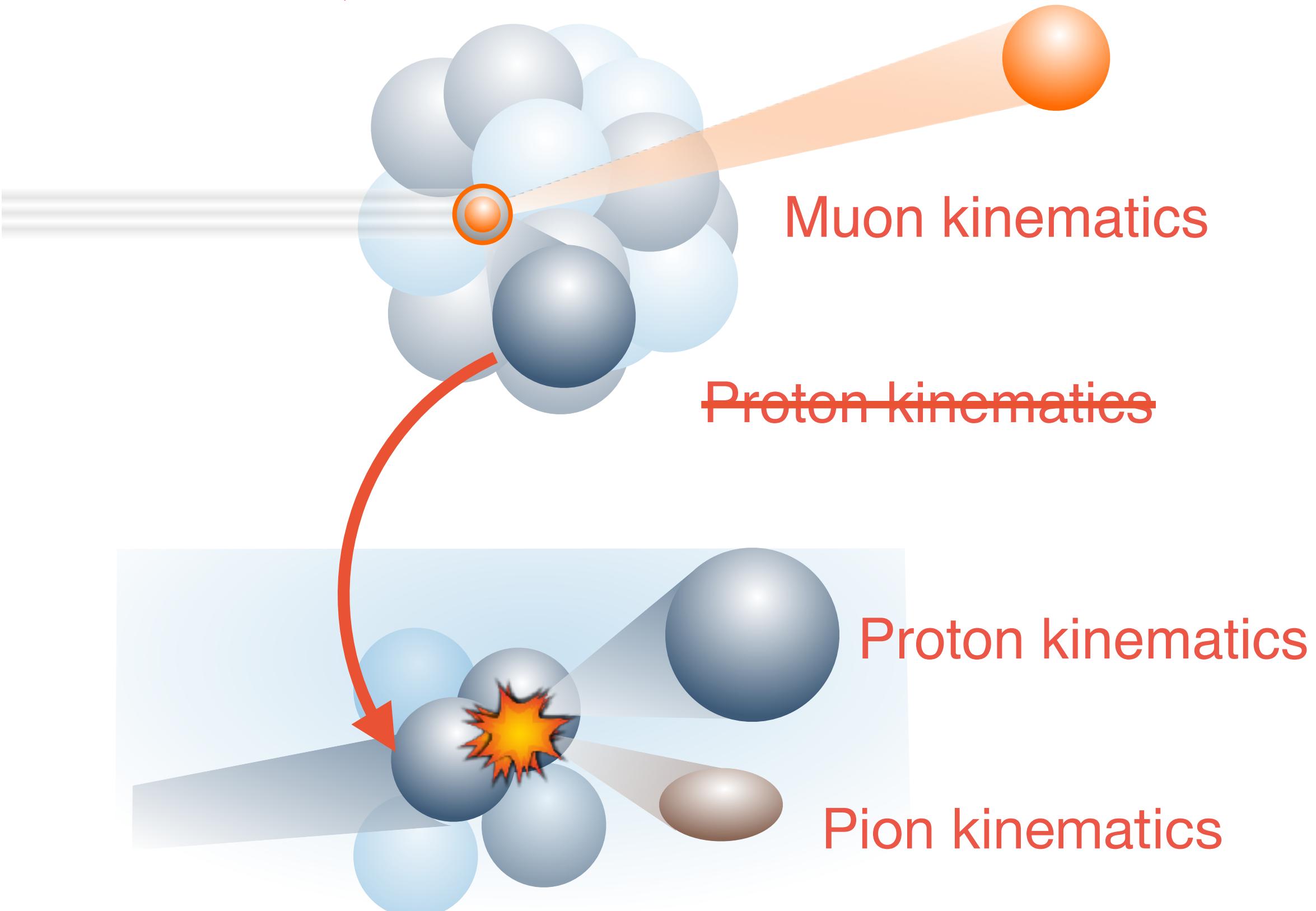
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Initial scattering

Final-state interaction

Quasi-elastic interaction





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Initial scattering

Final-state interaction

“Truth” information - what our event generator simulated.

Truth information

1. Generate a neutrino from the DUNE beam

Neutrino flavor
Momentum (GeV)

ν_μ
(0, 0, 2.0)

2. Roll an interaction mode

Charged-current?
Interaction mode

Yes
CCQE

3. Simulate the interaction

Initial scattering

Muon energy
Muon angle
 Q^2
 W
...

1.4 GeV
30°
0.75 GeV^2
1.1 GeV
...

Final-state interaction

Particle
Momentum (GeV)

Proton
(0.04,0.2,0.1)

π^0
(0.08,0,0.06)

Truth info in CAFs: Common Analysis Files

Our CAFs are a DUNE-specific ROOT ntuple

[https://root.cern.ch/root/html/doc/guides/primer\(ROOTPrimer.html](https://root.cern.ch/root/html/doc/guides/primer(ROOTPrimer.html)

(But you can think of it as a big table...)

Event	ν flavor	ν energy (GeV)	Charged current?	Interaction mode	etc...
1	ν_μ	2.0	Yes	CCQE	...
2	$\bar{\nu}_\mu$	2.7	Yes	RES	...
3	ν_μ	5.4	No	DIS	...
4	ν_e	1.8	Yes	CCQE	...

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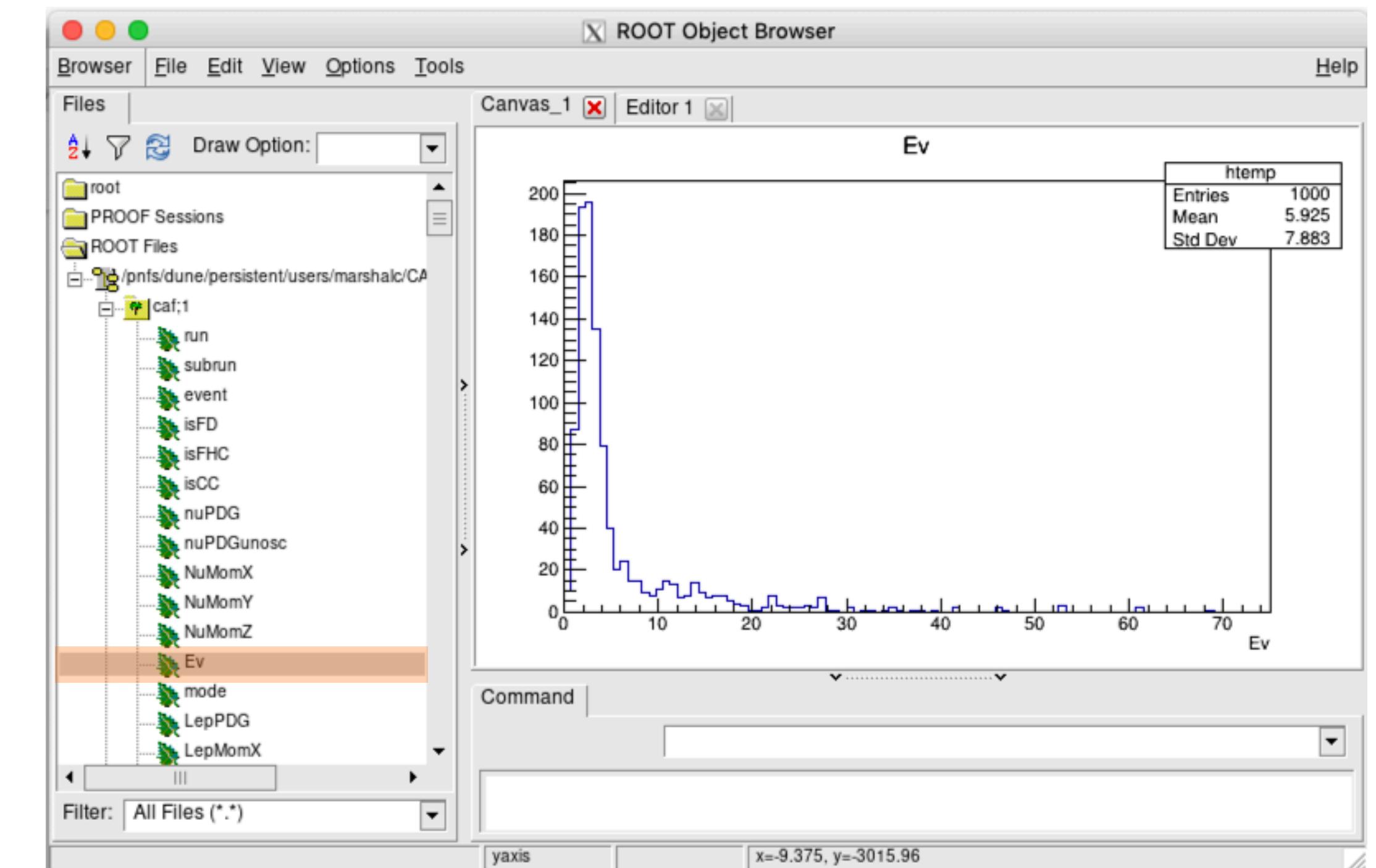
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↑
Ev



`root -l CAF_FHC_9.root`
`TBrowser b`

Truth info in CAFs: Common Analysis Files

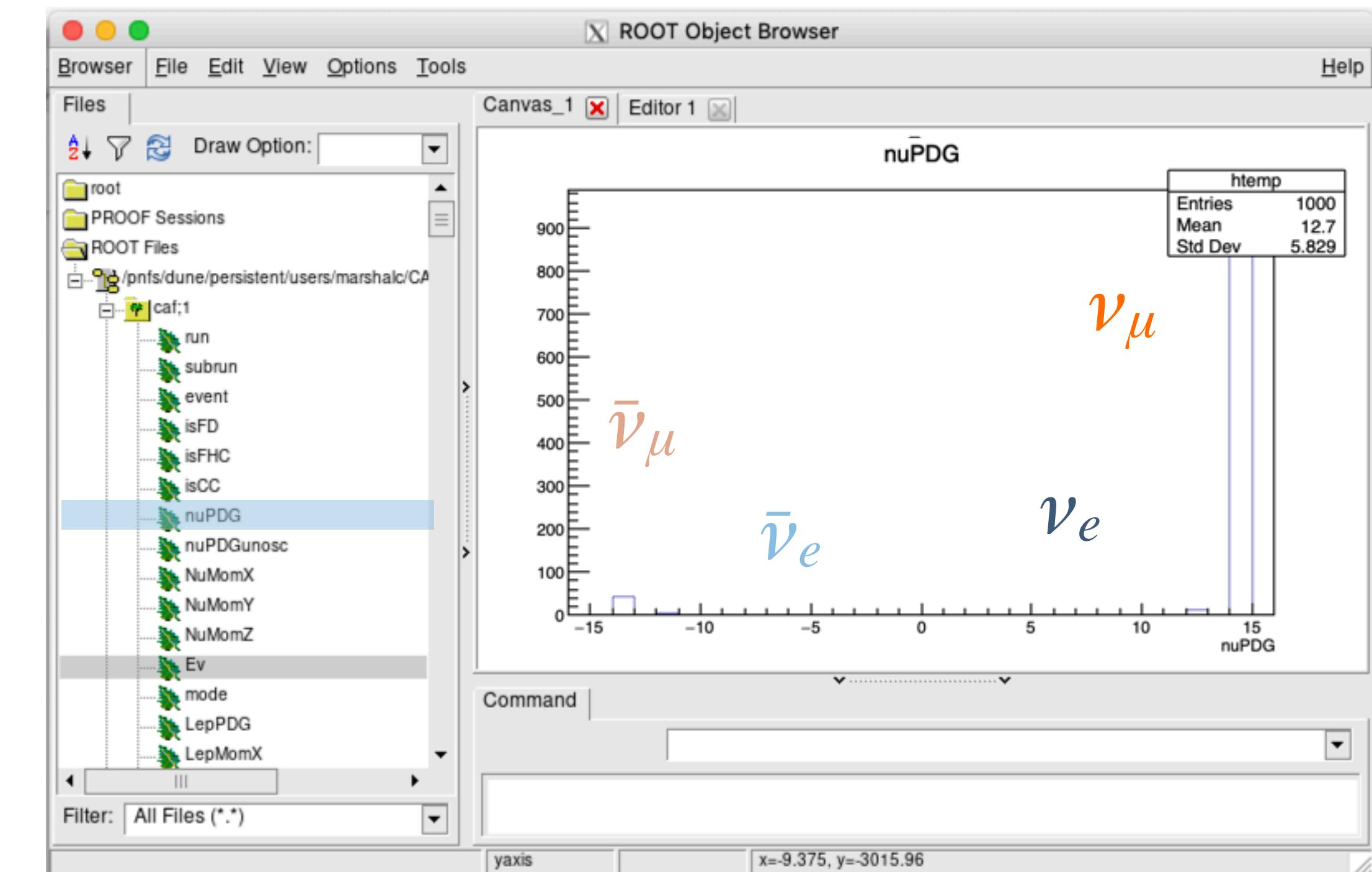
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↑
nuPDG



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The diagram shows two arrows pointing upwards from the bottom of the slide towards the table. An orange arrow points from the word "isCC" to the fourth column of the table, which contains the text "Charged current?". A dark blue arrow points from the word "mode" to the fifth column of the table, which contains the text "Interaction mode".

isCC

mode

What else is in the CAFs?

https://wiki.dunescience.org/wiki/CAF_ntuple_format

Event configuration information
(e.g. run number, near vs far detector,
beam mode...)

Truth information
(the generated interaction)

What else is in the CAFs?

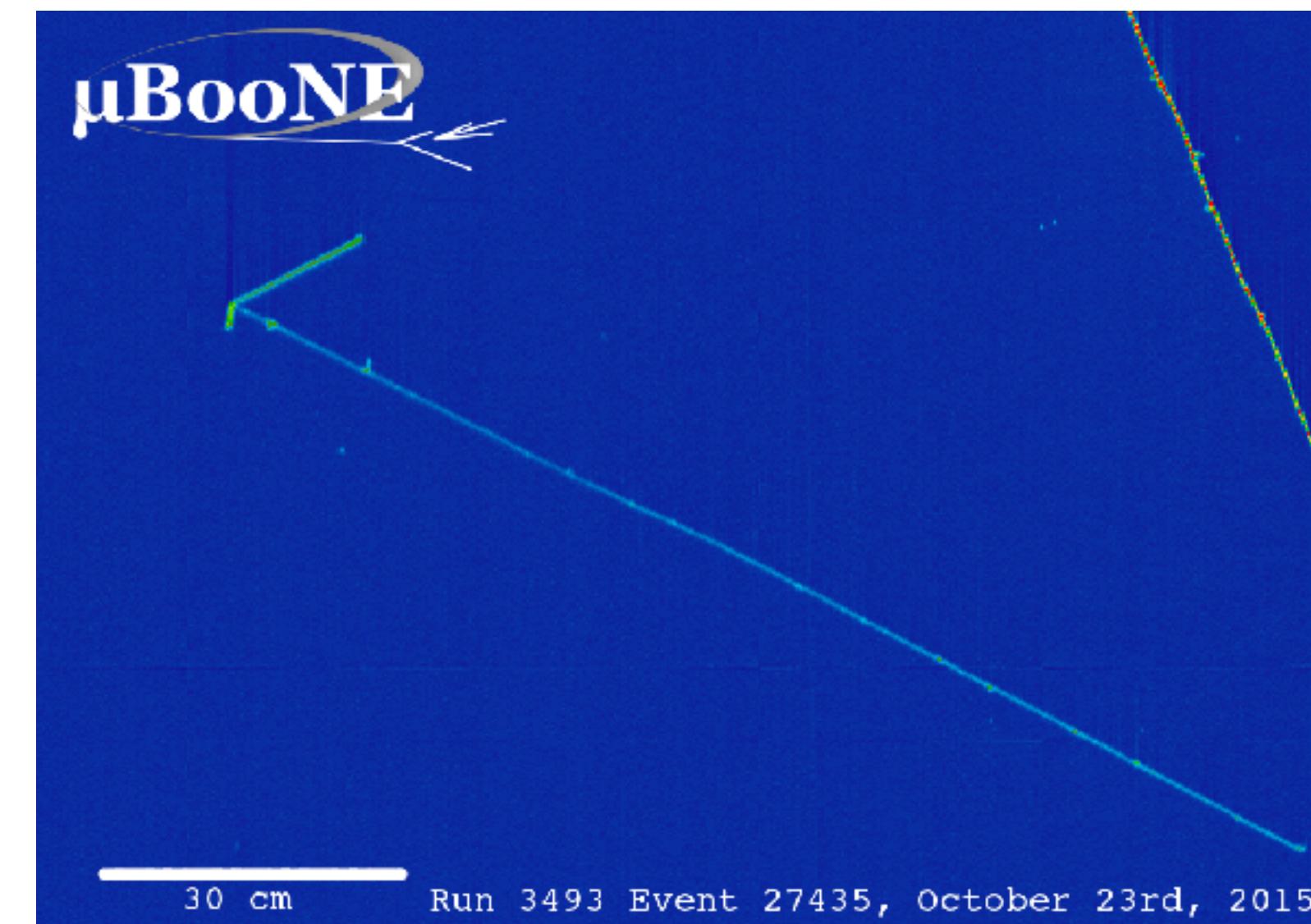
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Reconstructed information
(what we saw in the detector)

For a real (or simulated) detector



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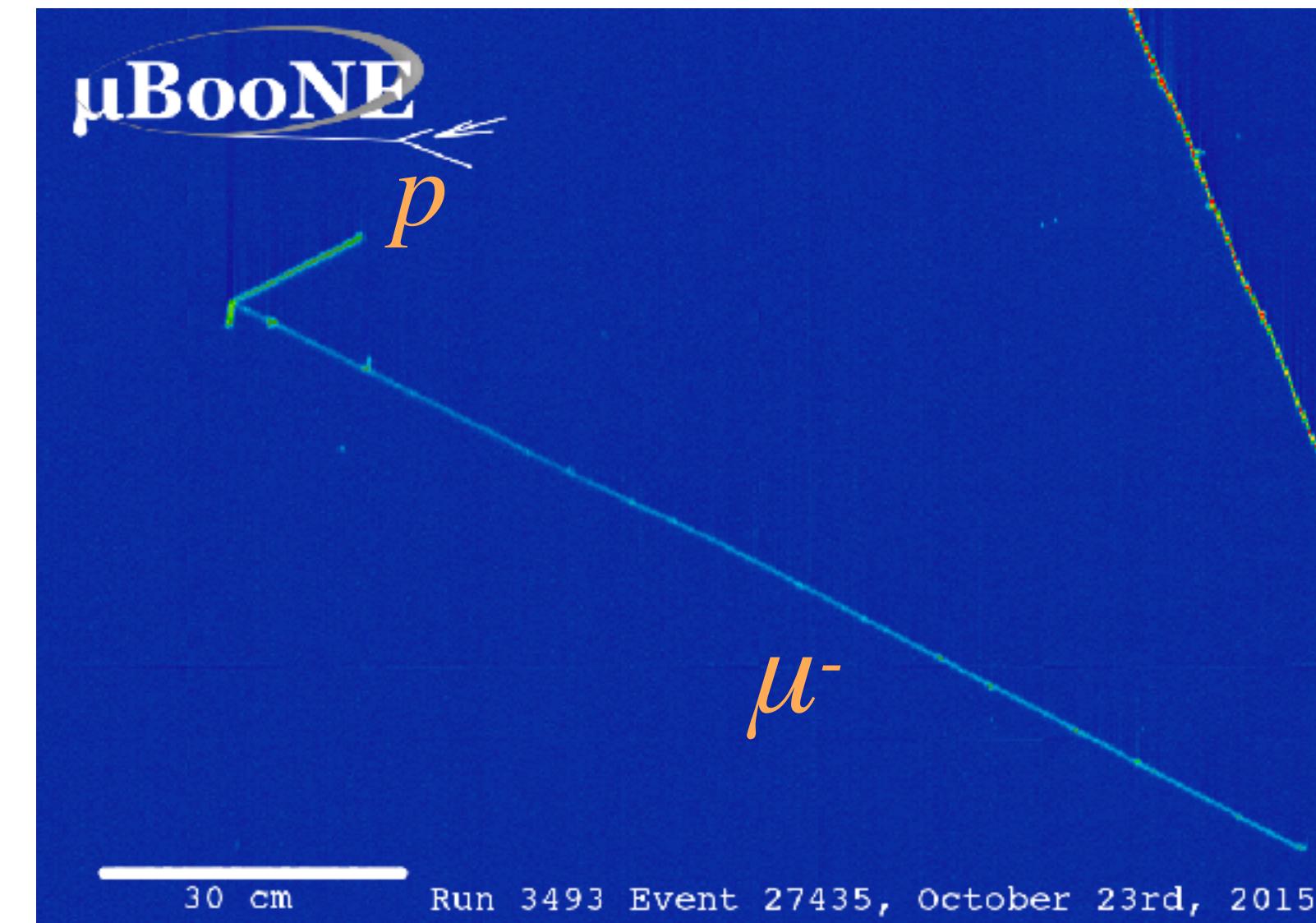
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Attempt to identify
particle tracks:

Is there a muon?

`reco_numu = TRUE`

What else is in the CAFs?

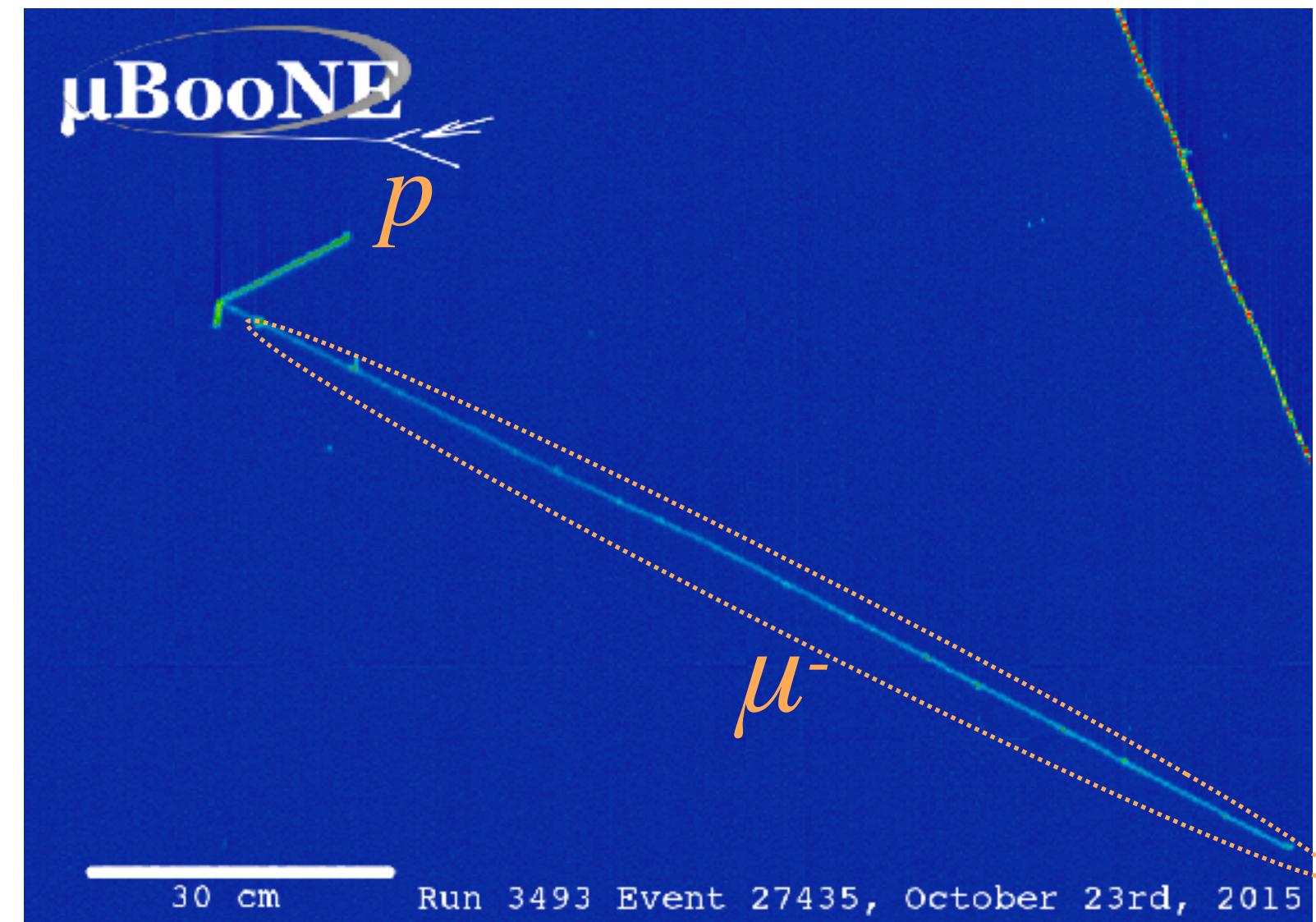
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Sum energy in muon
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`Elep_reco = 1.5`

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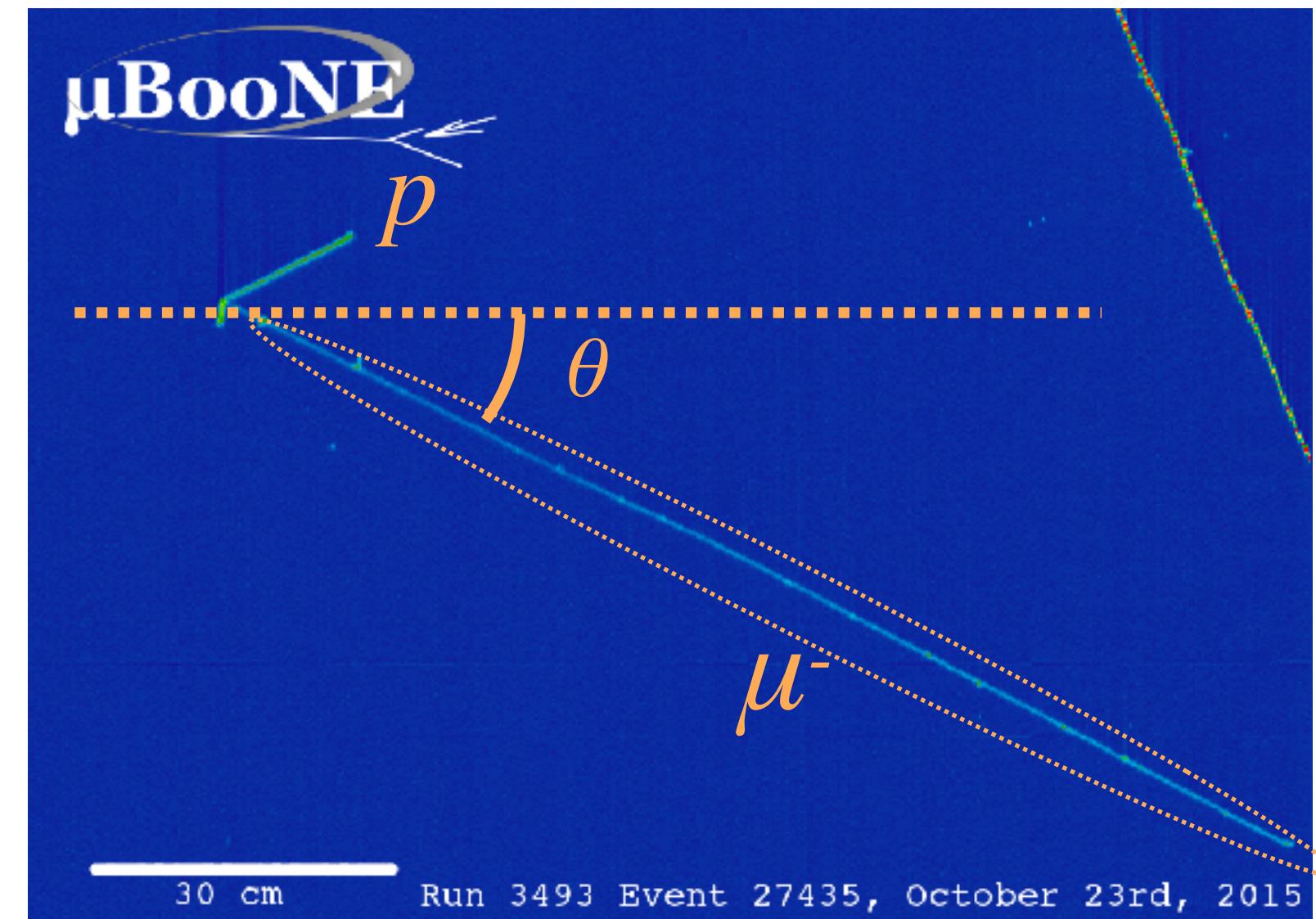
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Attempt to identify
particle tracks:

Is there a muon?

`reco_numu = TRUE`

Sum energy in muon
track (in GeV)

`Elep_reco = 1.5`

Estimate muon track's angle in radians

`theta_reco = 0.52`

etc...

What else is in the CAFs?

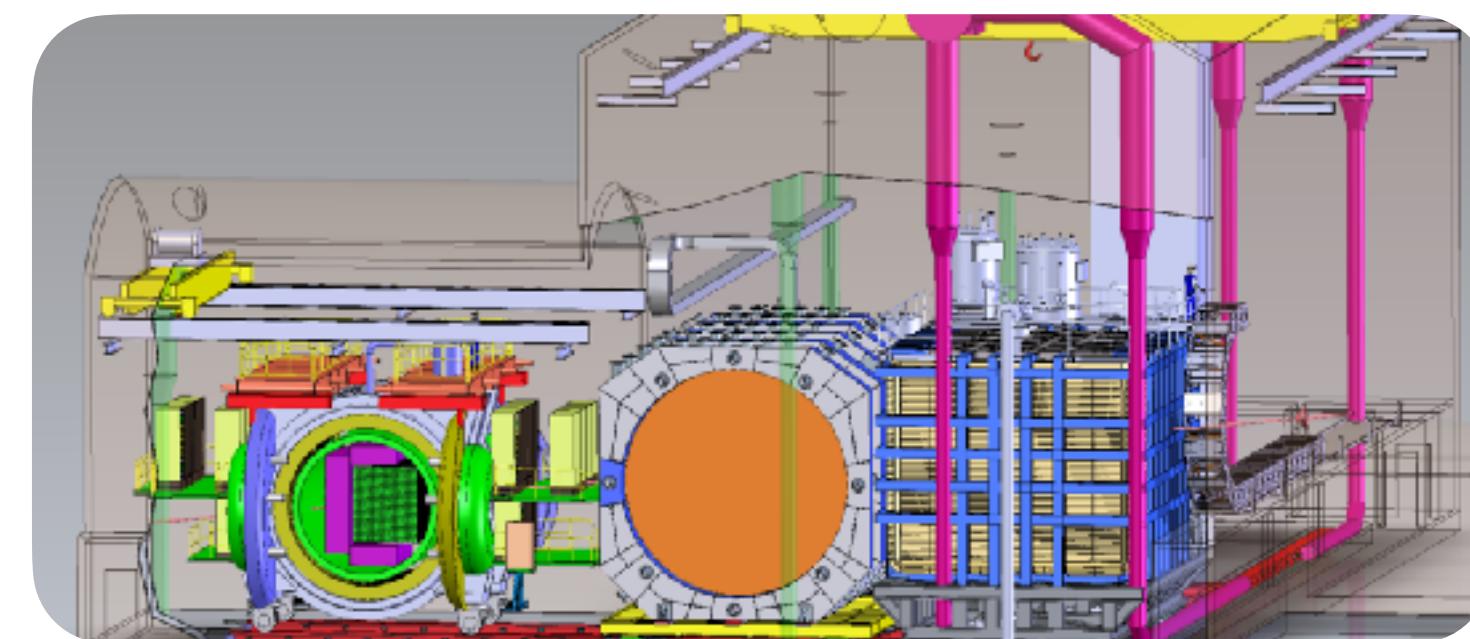
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Event configuration information
(e.g. run number, near vs far detector,
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In our current CAFs



But we do have an idea of
their capabilities...

We don't yet have full
simulations of the DUNE
detectors...

Michel detection efficiency

Proton energy threshold

Energy resolution

Vertex resolution

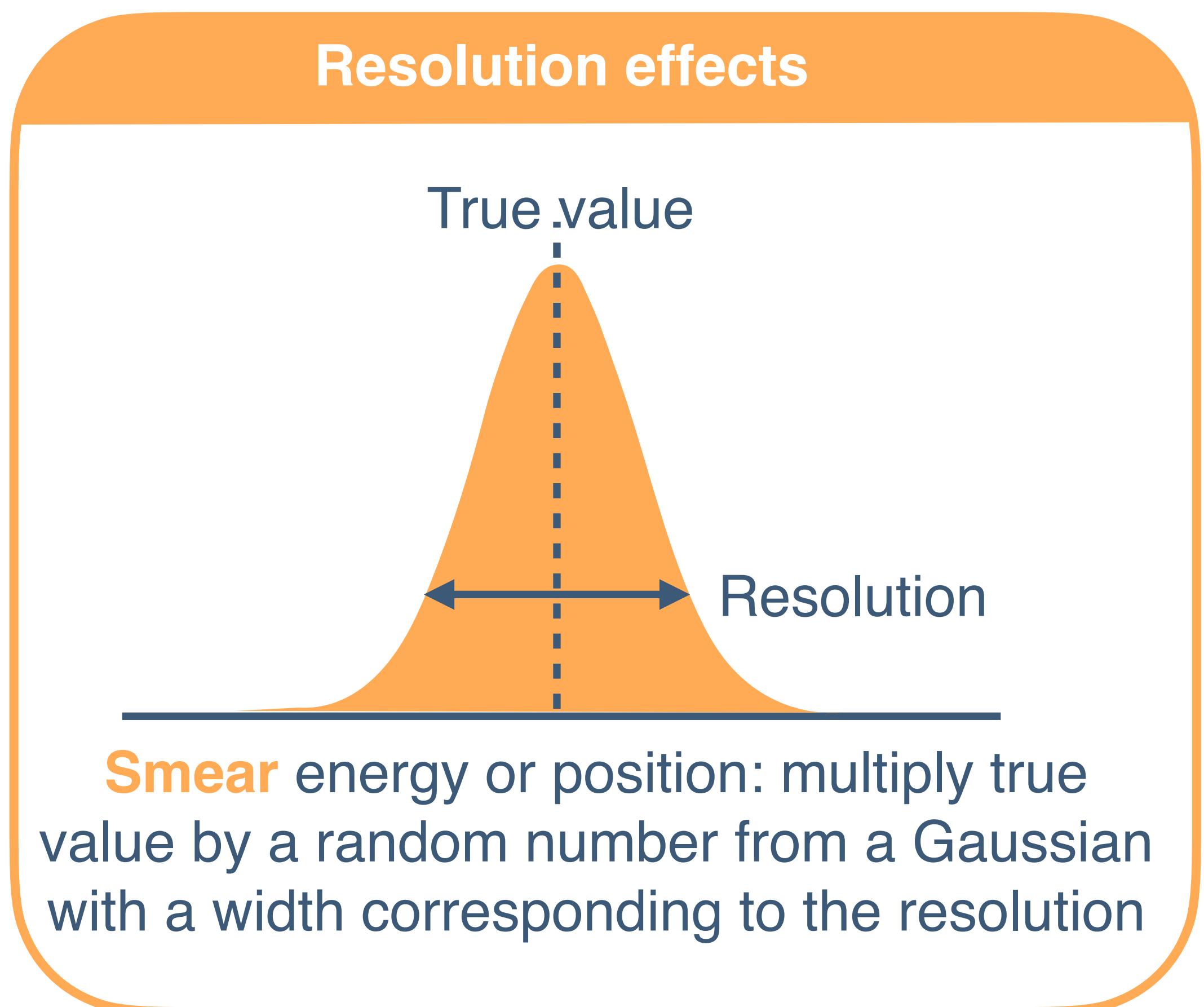
...which we can use to make a
“parametrized” mock reconstruction

Parametrized reconstruction

Use what we know about the detector's capabilities to **mimic** detector effects

Parametrized reconstruction

Use what we know about the detector's capabilities to **mimic** detector effects



Parametrized reconstruction

Use what we know about the detector's capabilities to **mimic** detector effects

Resolution effects

True value

Resolution

Smear energy or position: multiply true value by a random number from a Gaussian with a width corresponding to the resolution

Energy thresholds

Ignore any particles with energy below a threshold



Resonant scattering event

Parametrized reconstruction

Use what we know about the detector's capabilities to **mimic** detector effects

Resolution effects

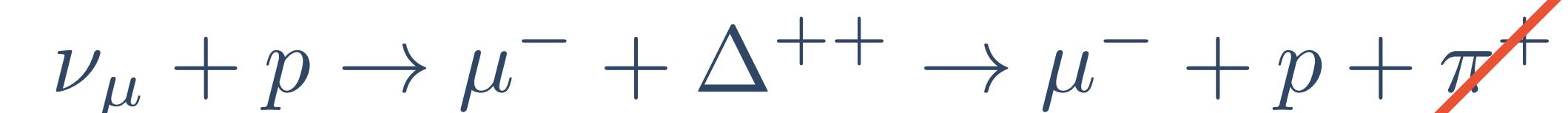
True value

Resolution

Smear energy or position: multiply true value by a random number from a Gaussian with a width corresponding to the resolution

Energy thresholds

Ignore any particles with energy below a threshold



Fakes quasi-elastic event

Low-energy:
ignore

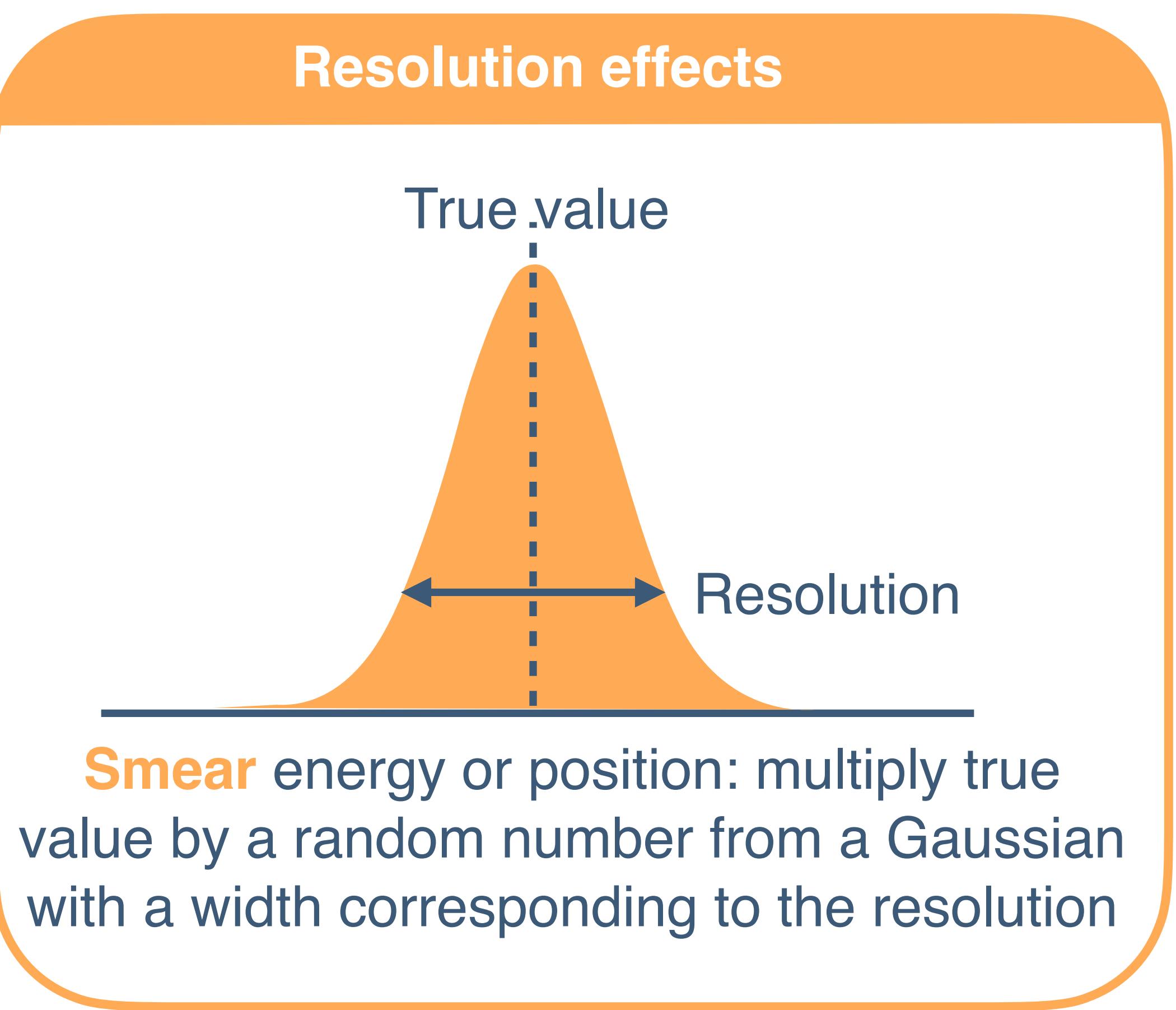
Parametrized reconstruction

Use what we know about the detector's capabilities to **mimic** detector effects

Resolution effects

True value

Resolution



Energy thresholds

Ignore any particles with energy below a threshold



Fakes quasi-elastic event

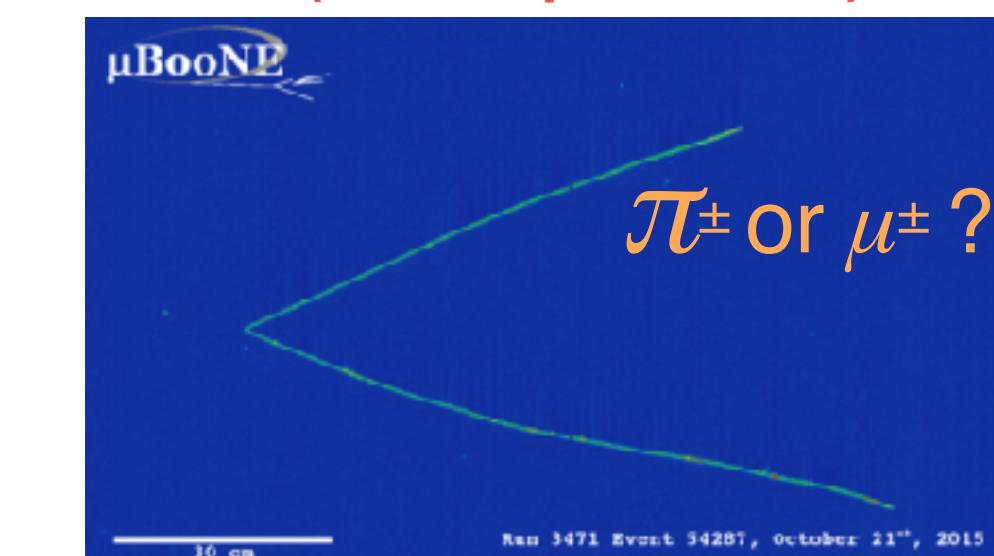
Low-energy:
ignore

Efficiency, acceptance, misconstruction

Reject some tracks to account for:

- tracks that can't be identified (efficiency)
- tracks outside the active detector (acceptance)

Simulate some particles being mis-identified

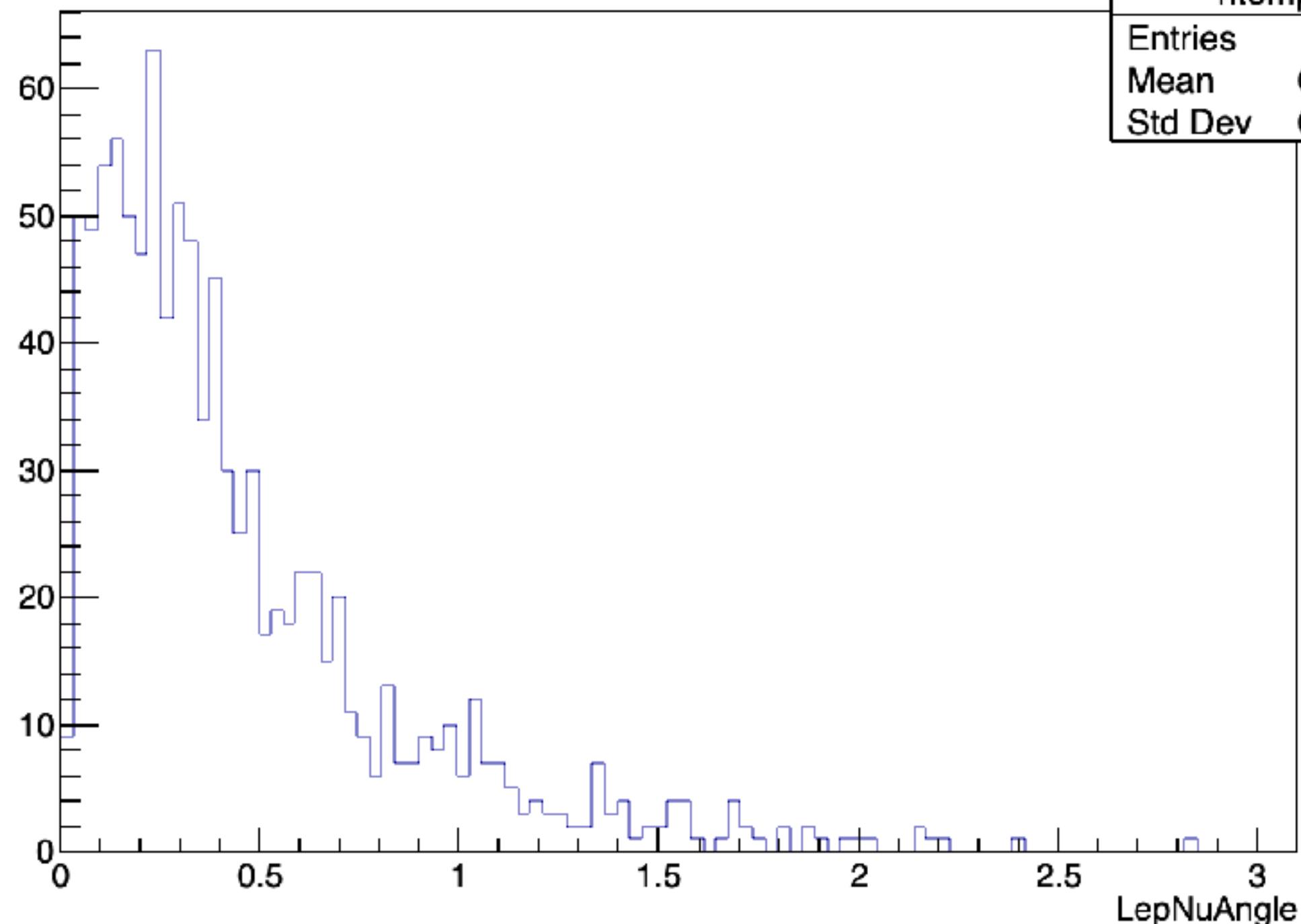


“True” vs. reconstructed values

True muon angle

LepNuAngle

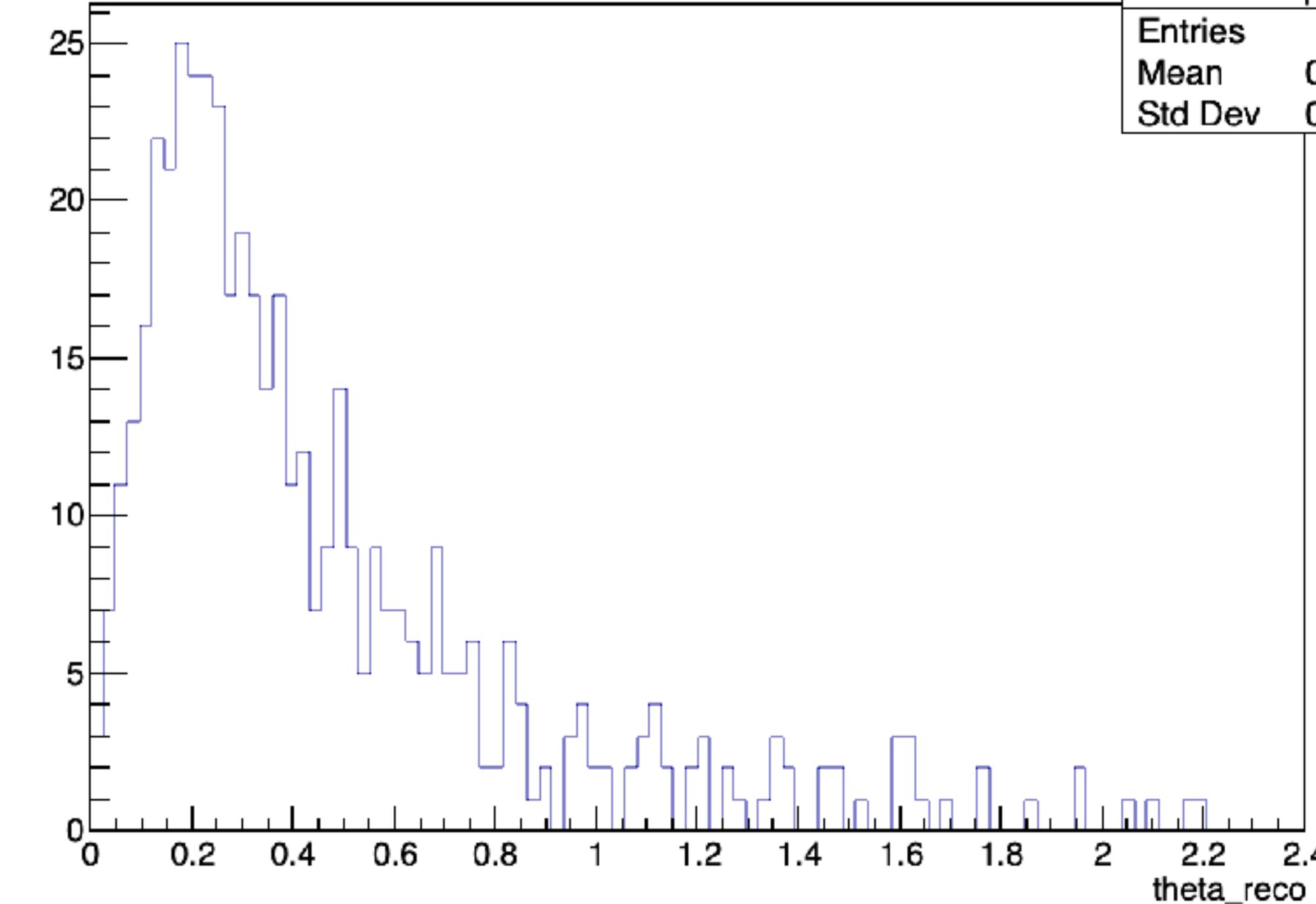
htemp
Entries 1000
Mean 0.4539
Std Dev 0.4032



Reconstructed muon angle

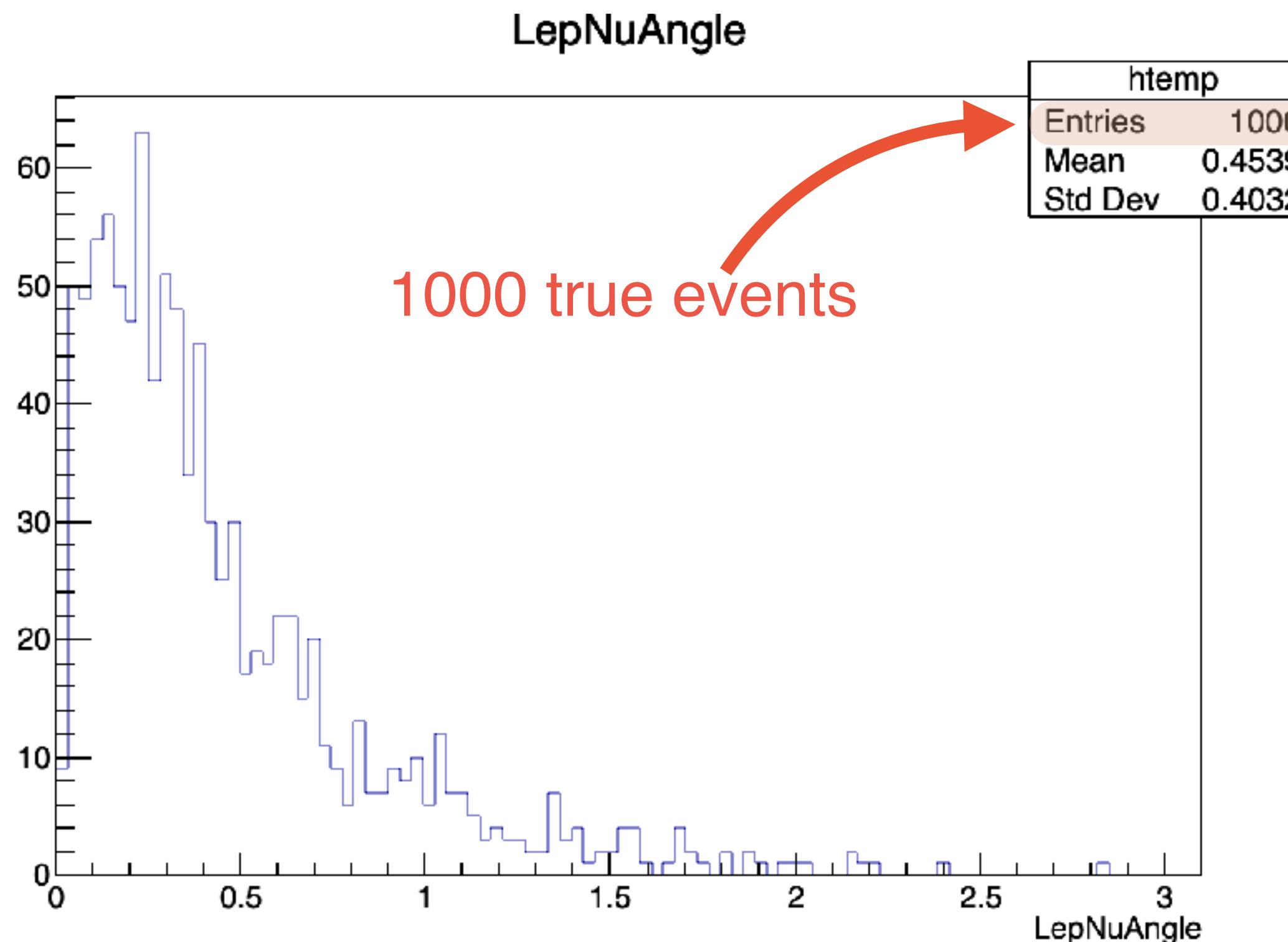
theta_reco {theta_reco>0.99}

htemp
Entries 474
Mean 0.4654
Std Dev 0.4072

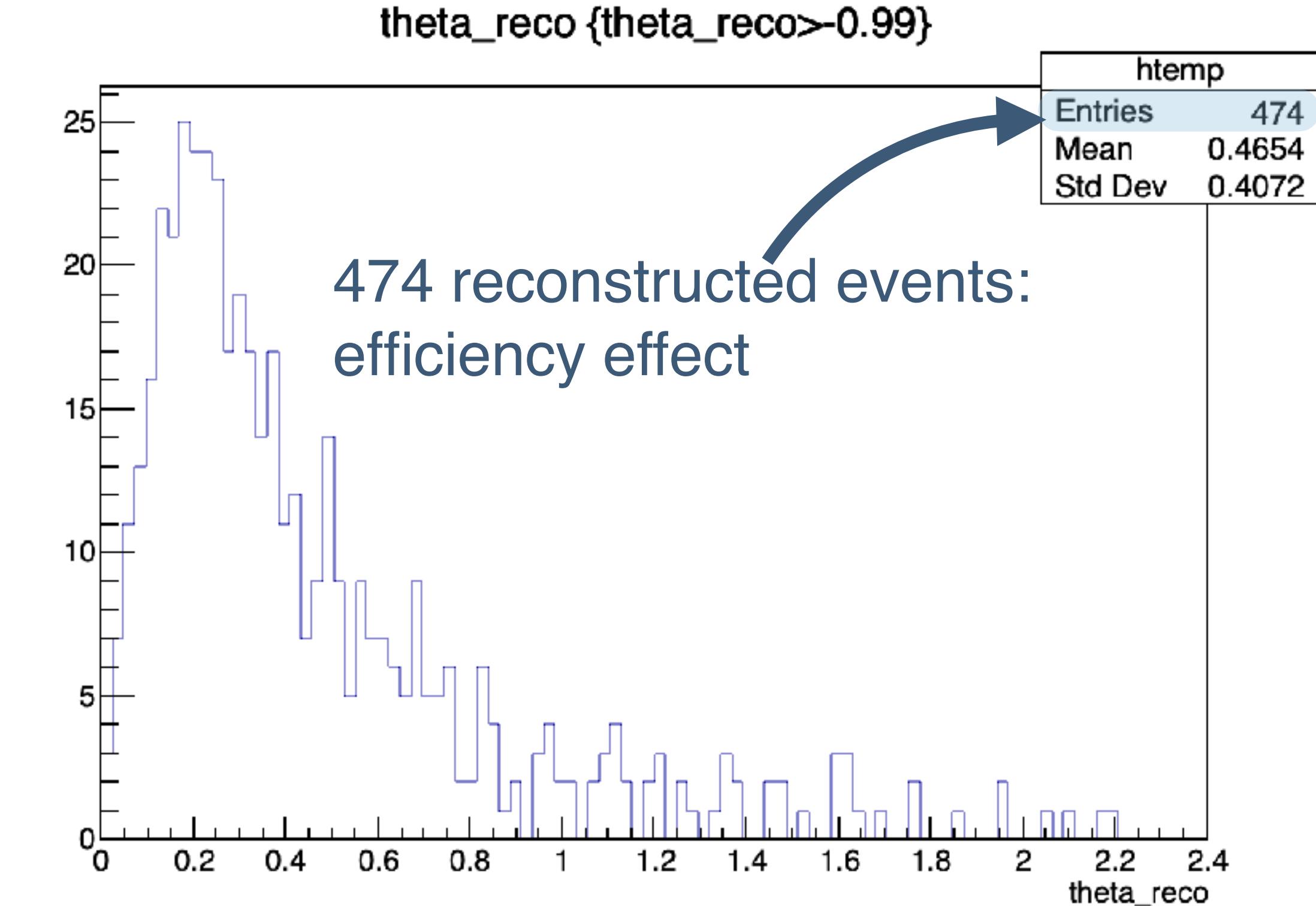


“True” vs. reconstructed values

True muon angle

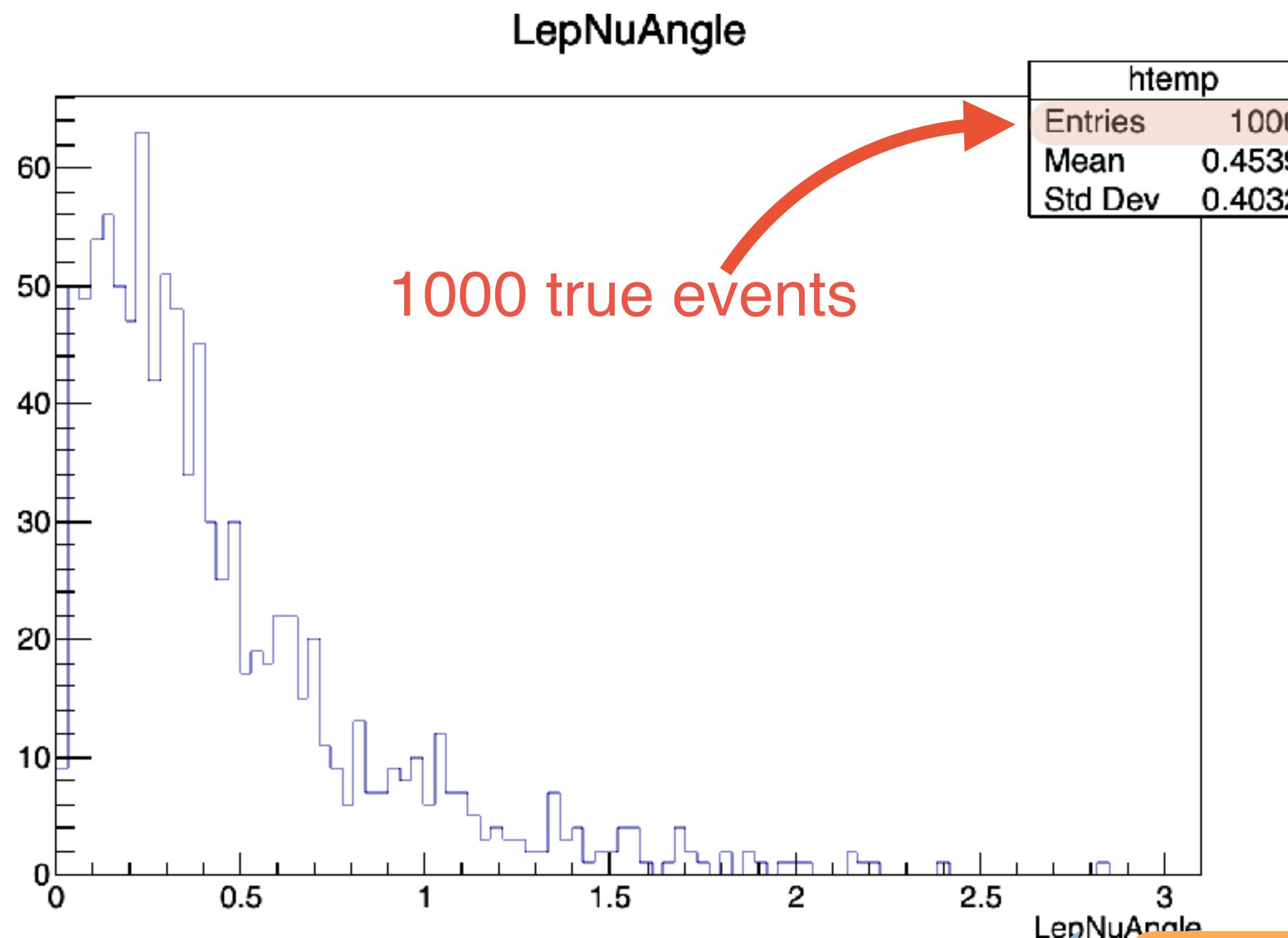


Reconstructed muon angle

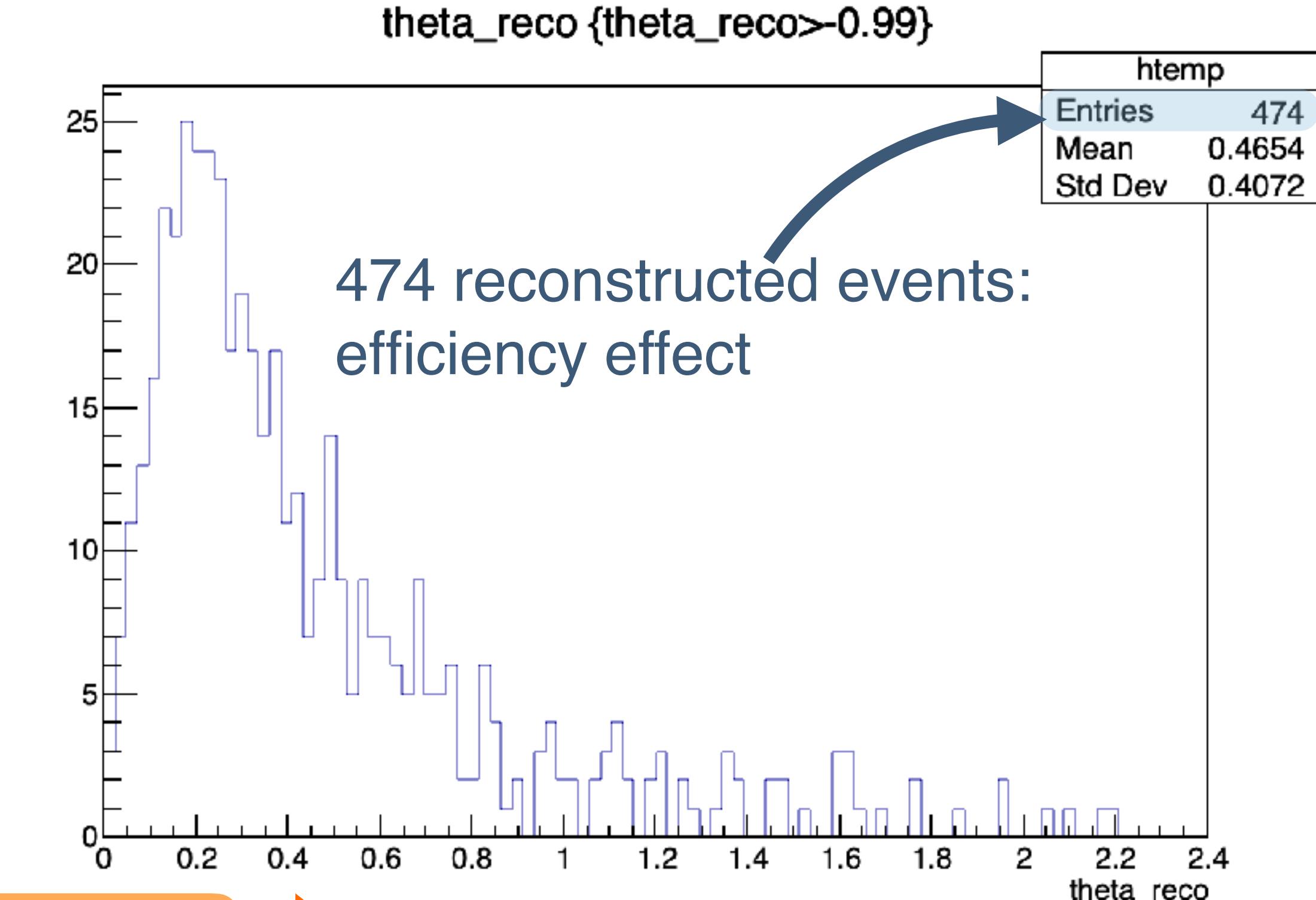


“True” vs. reconstructed values

True muon angle



Reconstructed muon angle

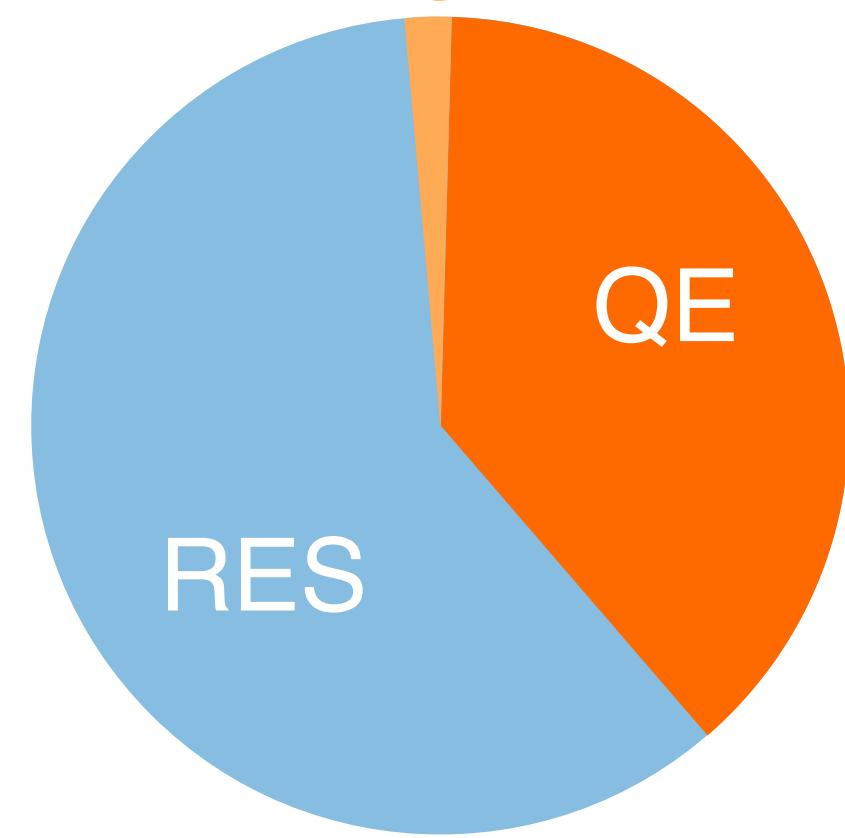


Shape change:
resolution effect

Analyzing CAFs

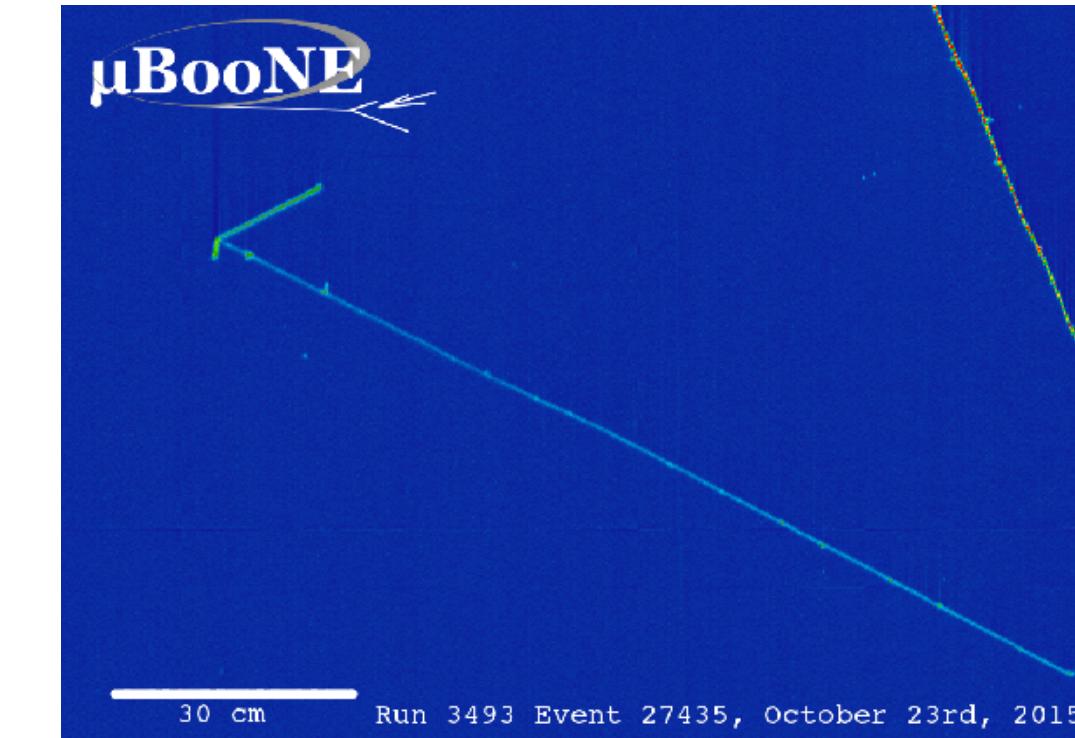
Select some events

based on true...



“True QE events”

... or reconstructed quantities

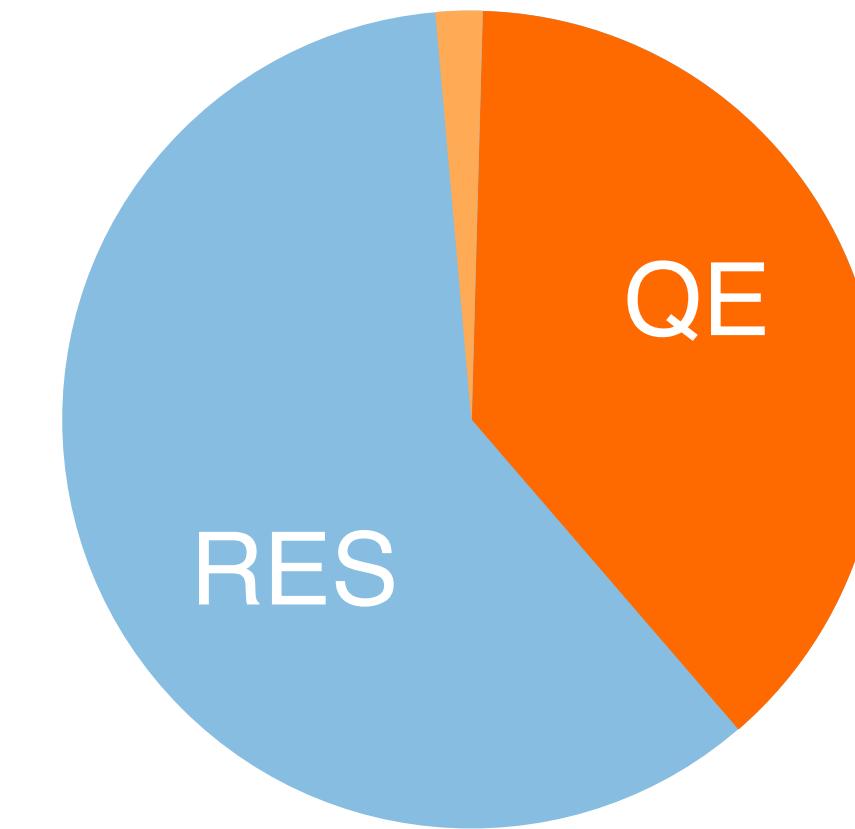


“Events with a muon-like
and a proton-like track”

Analyzing CAFs

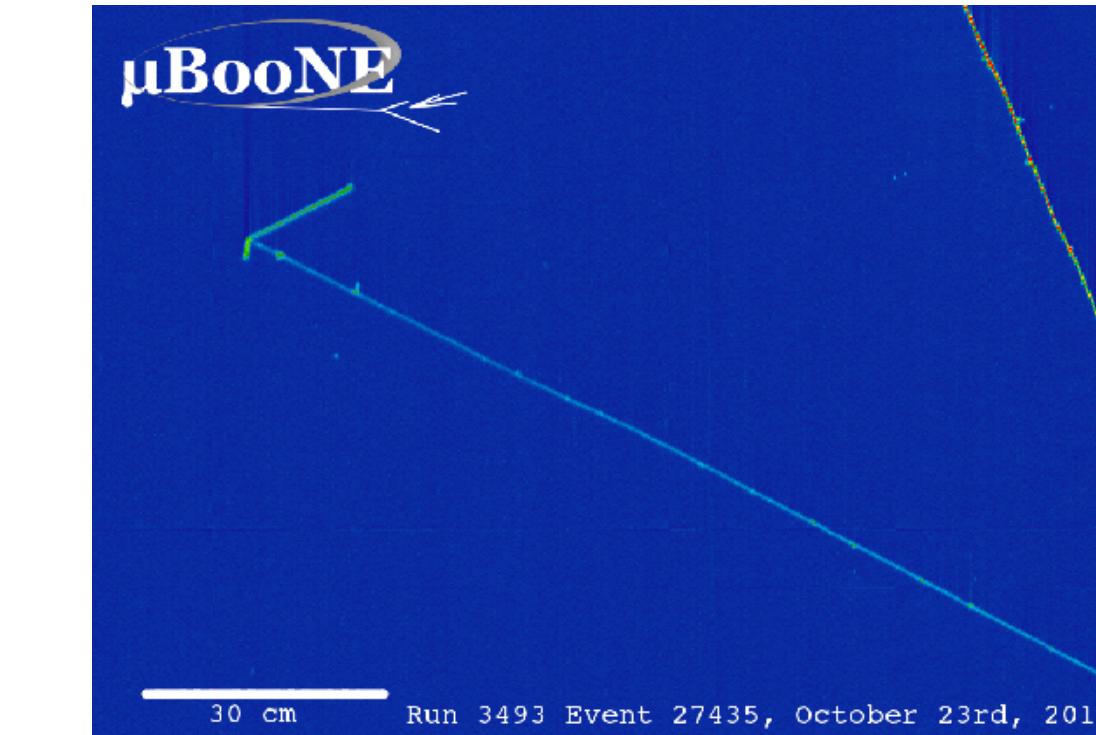
Select some events

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DIS



“True QE events”

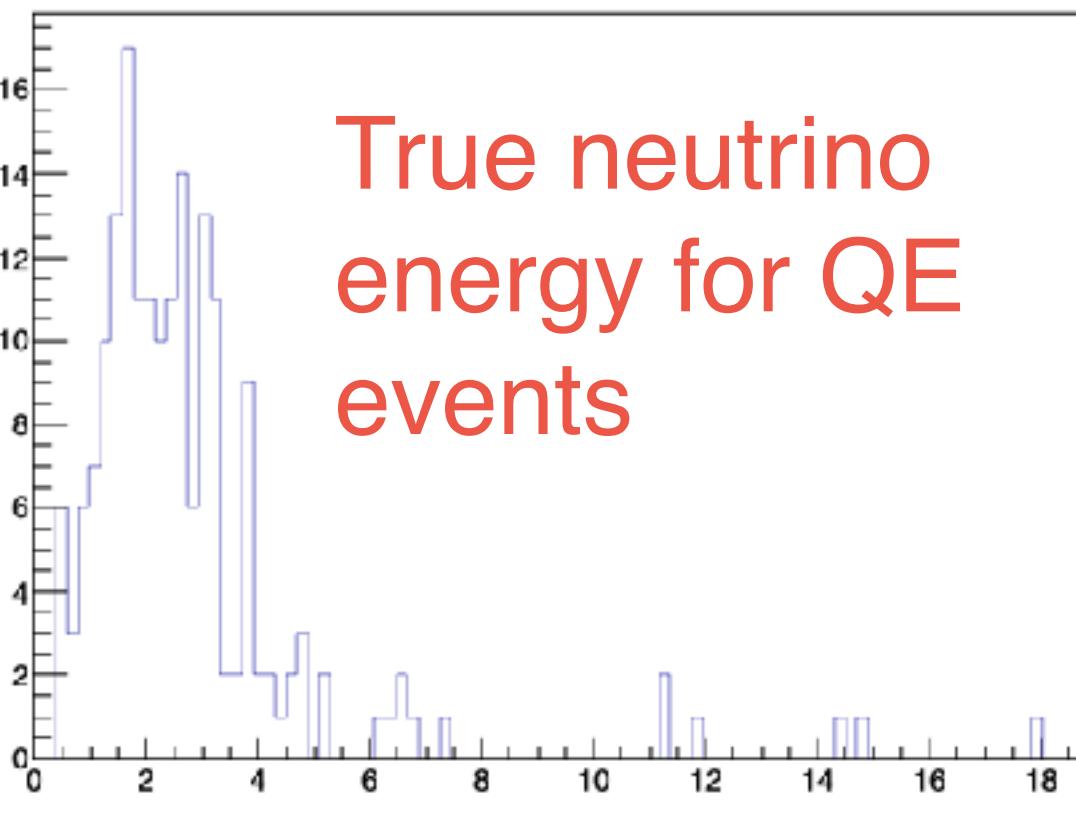
... or reconstructed quantities



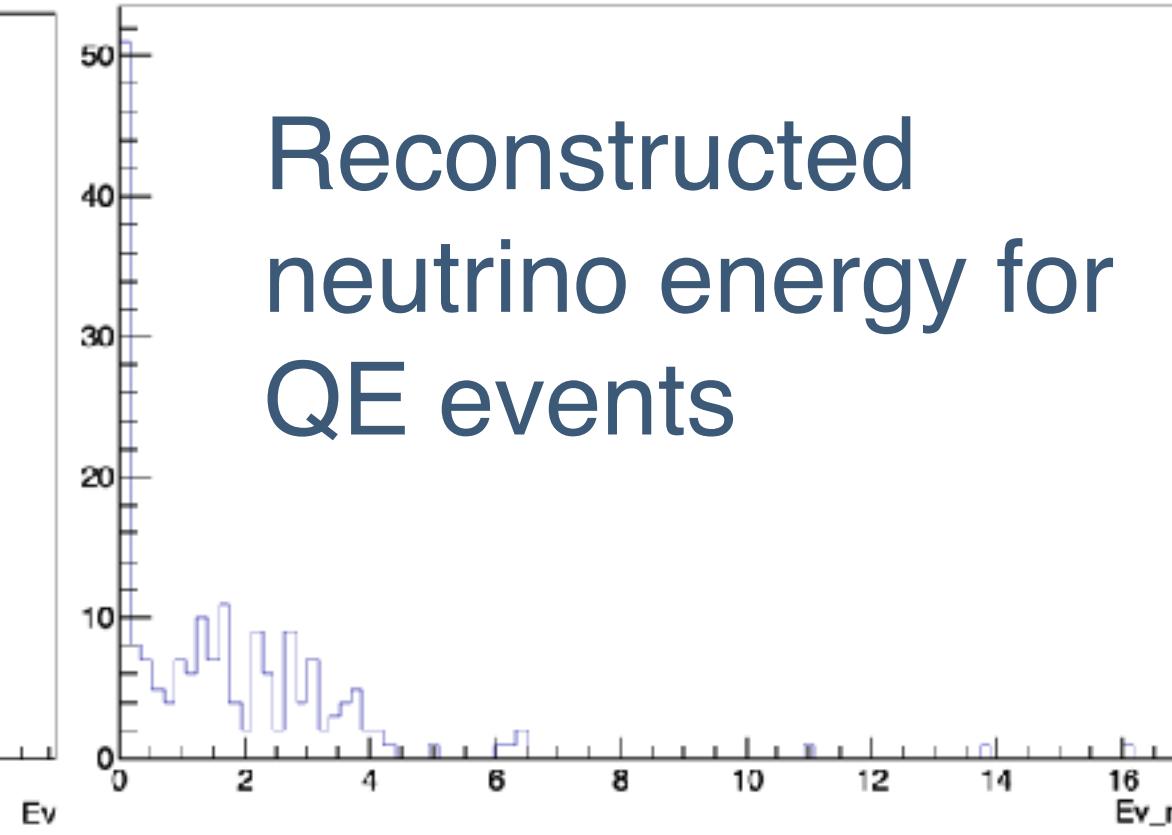
“Events with a muon-like
and a proton-like track”

Plot some quantity

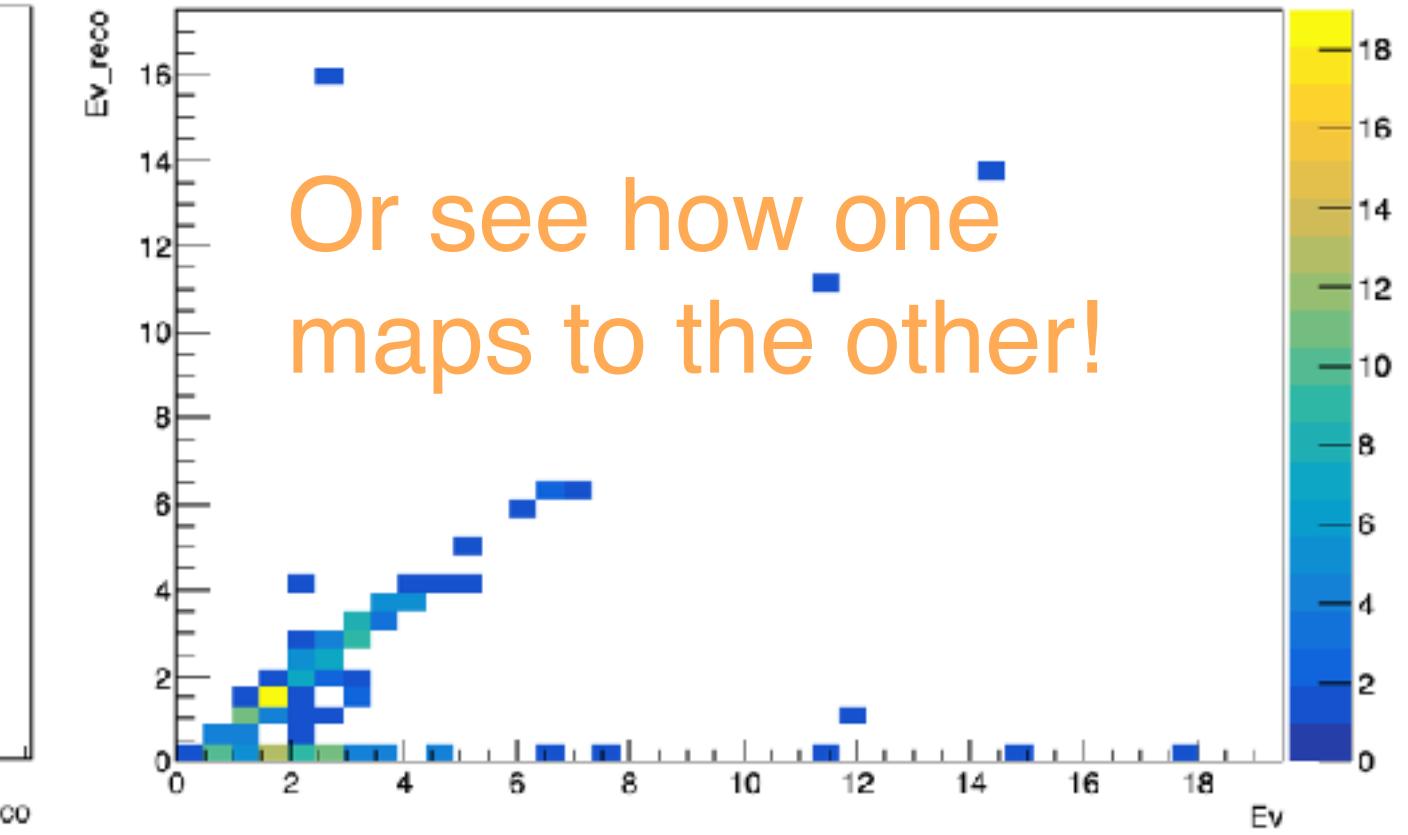
True neutrino
energy for QE
events



Reconstructed
neutrino energy for
QE events



Or see how one
maps to the other!



Analyzing CAFs with CAFAna

https://wiki.dunescience.org/wiki/CAFAna_Cuts
https://wiki.dunescience.org/wiki/CAFAna_Variables
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With the CAFAna framework, we study **Spectrum** objects of (simulated) data.

A data source (SpectrumLoader)

- A single CAF file: /source_directory/CAF_FHC_9.root
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- Predefined
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HistAxis

Add axis title

How to group it (Binning)

- Min and max values
- How many bins to divide into

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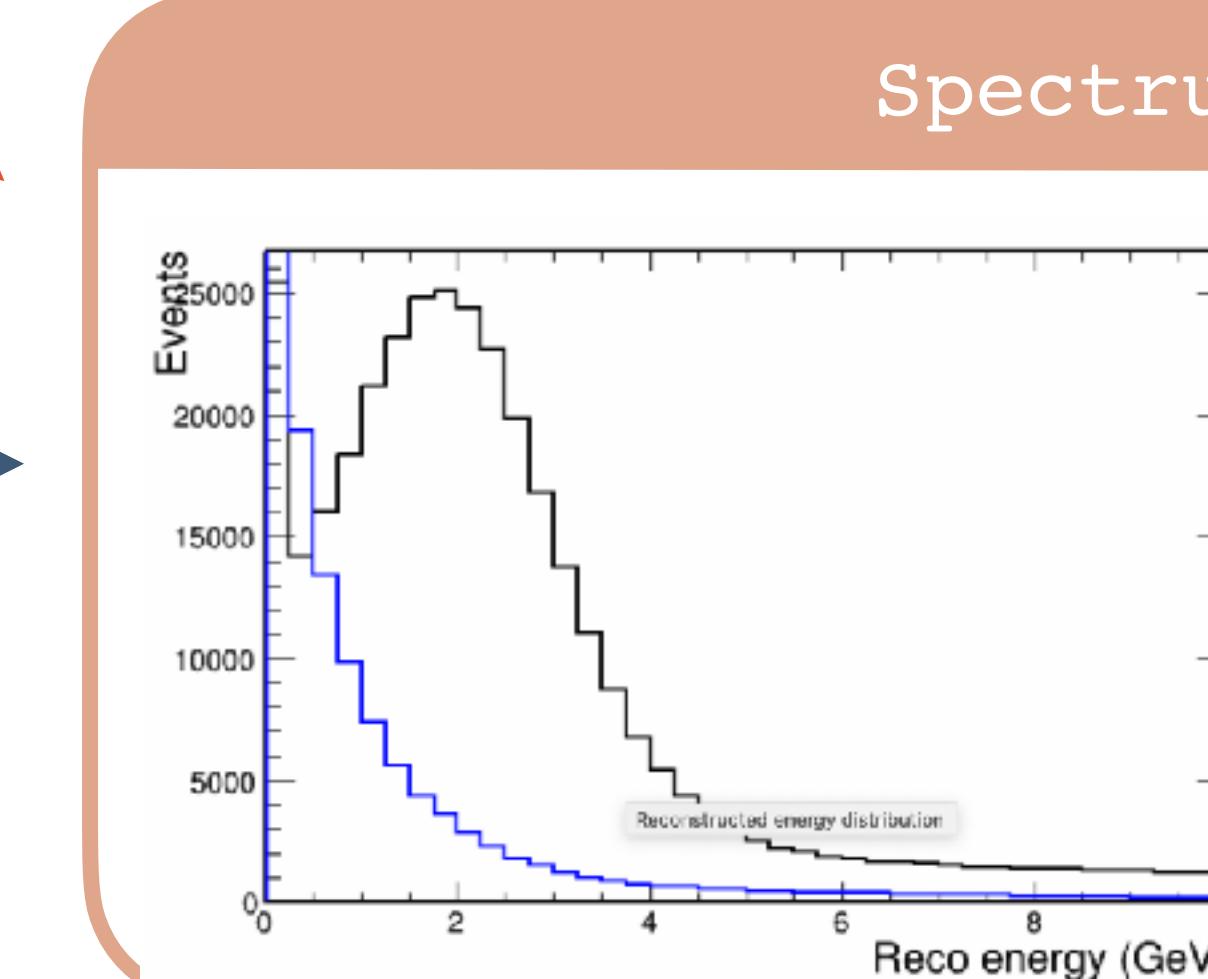
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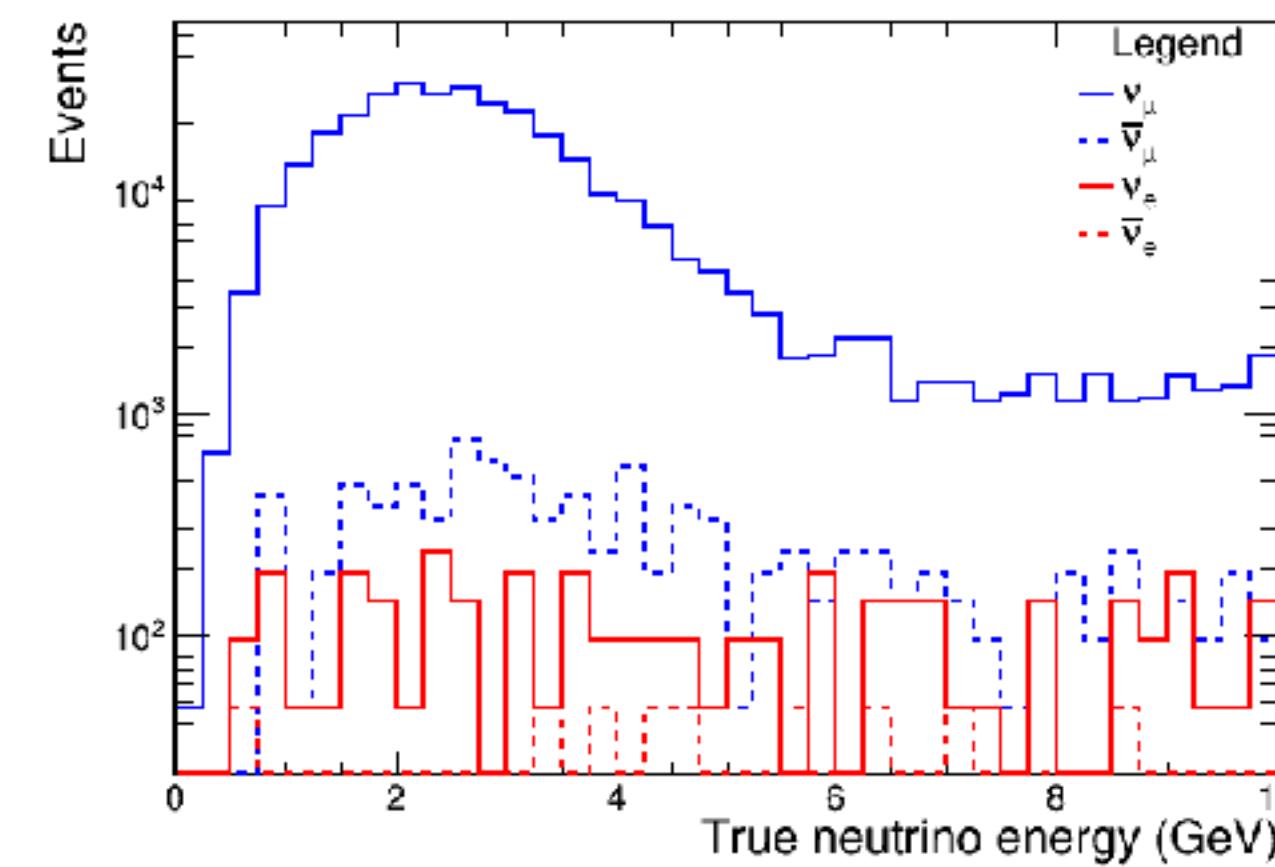


Spectrum

Convert to
ROOT
histogram to
format and
display

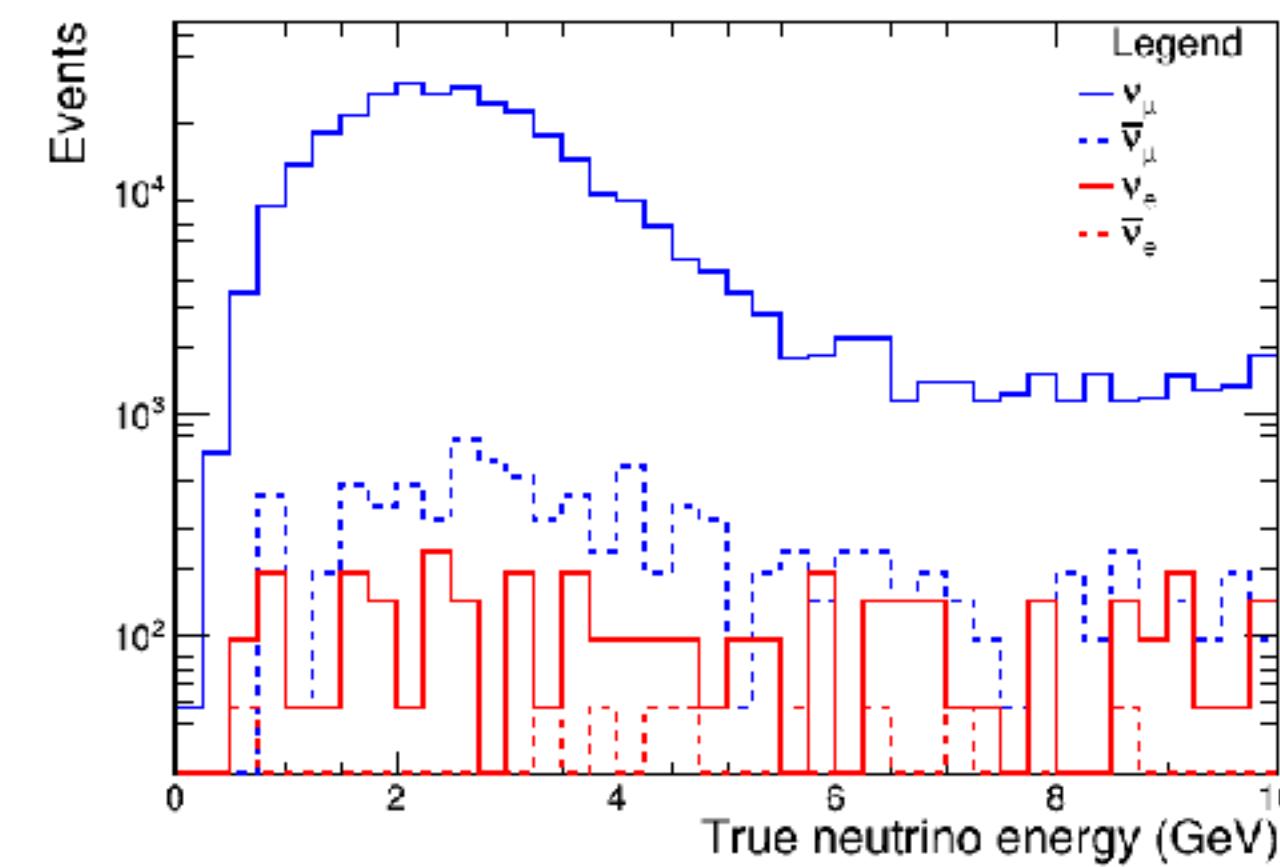
What you'll analyze with CAFAna

1: DUNE's
neutrino
beam flux

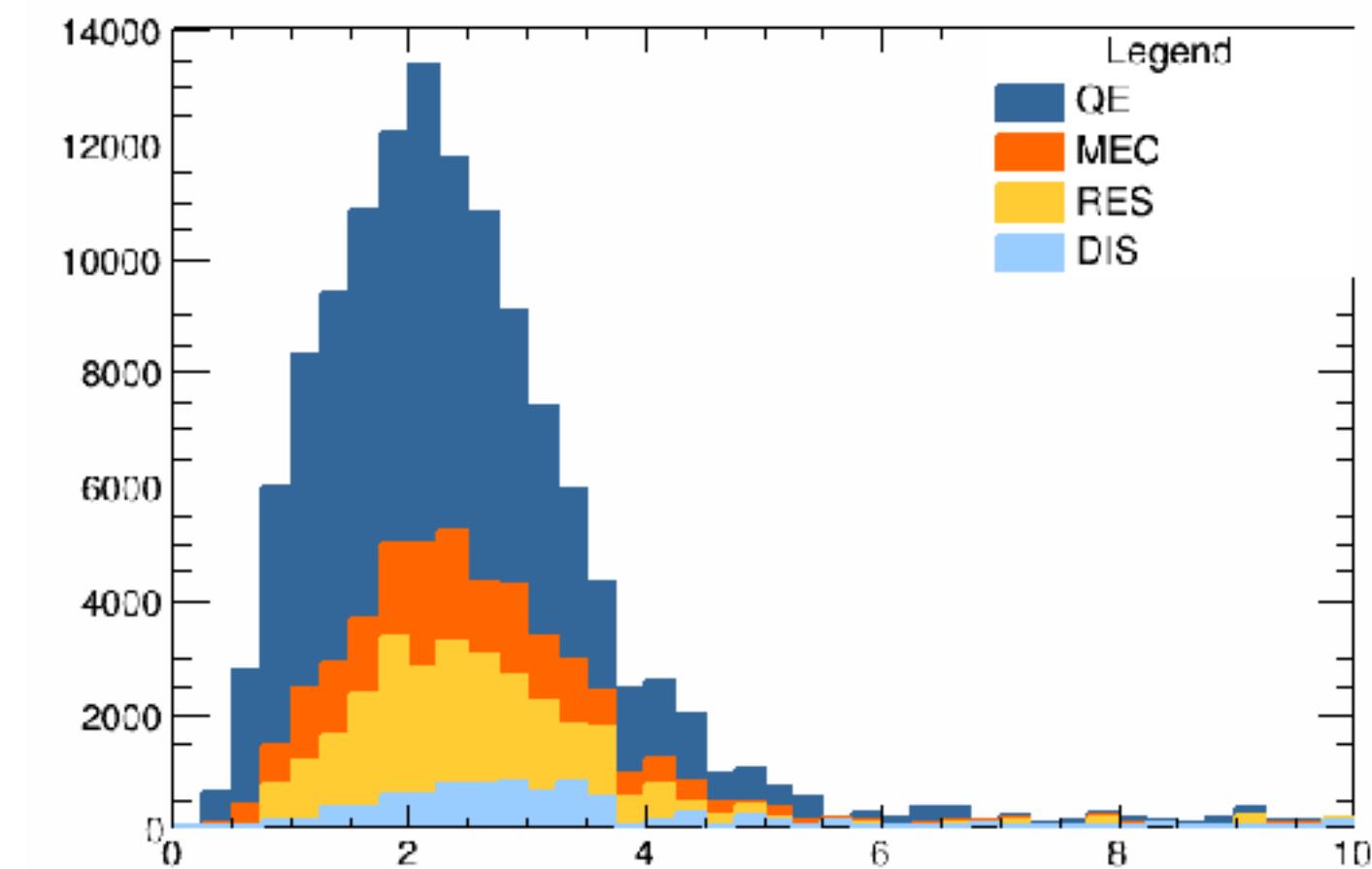
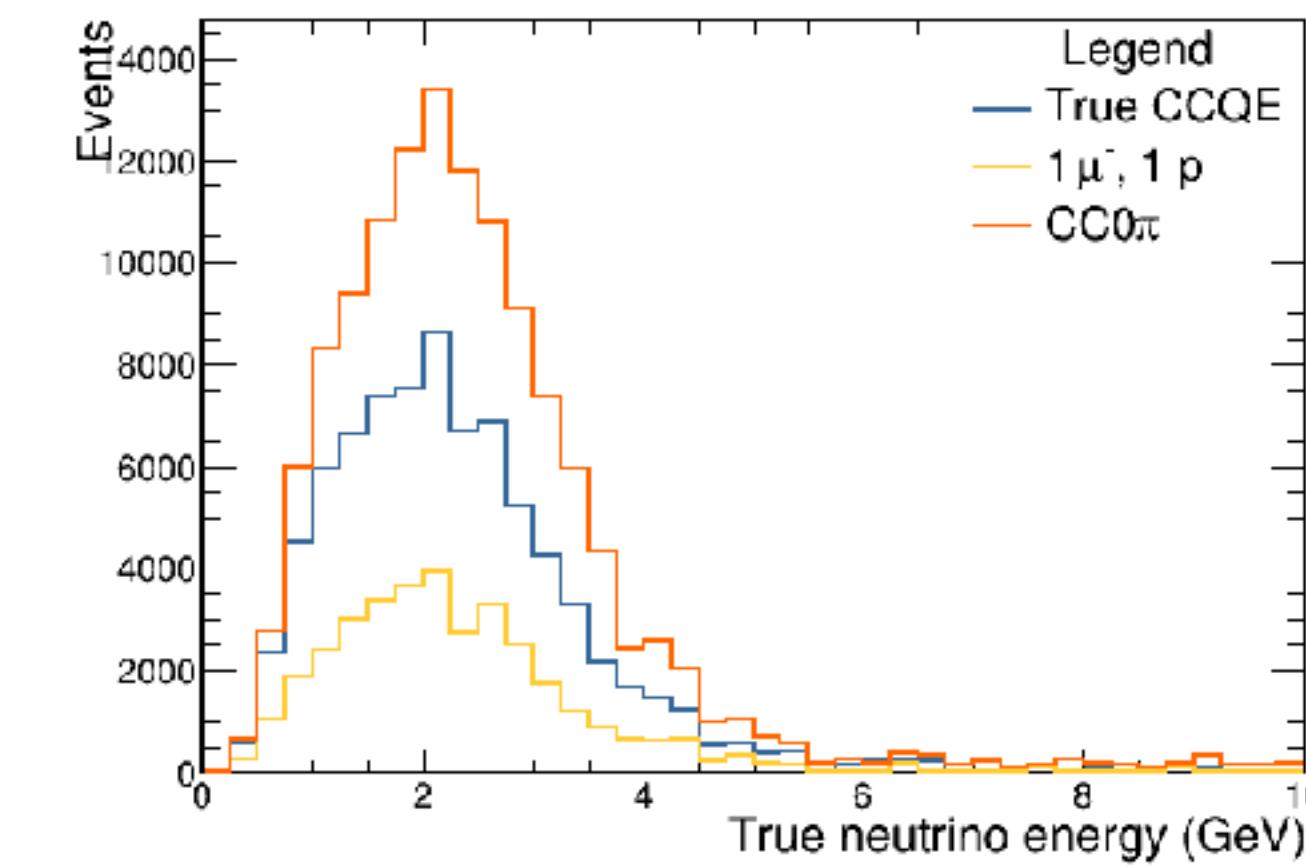


What you'll analyze with CAFAna

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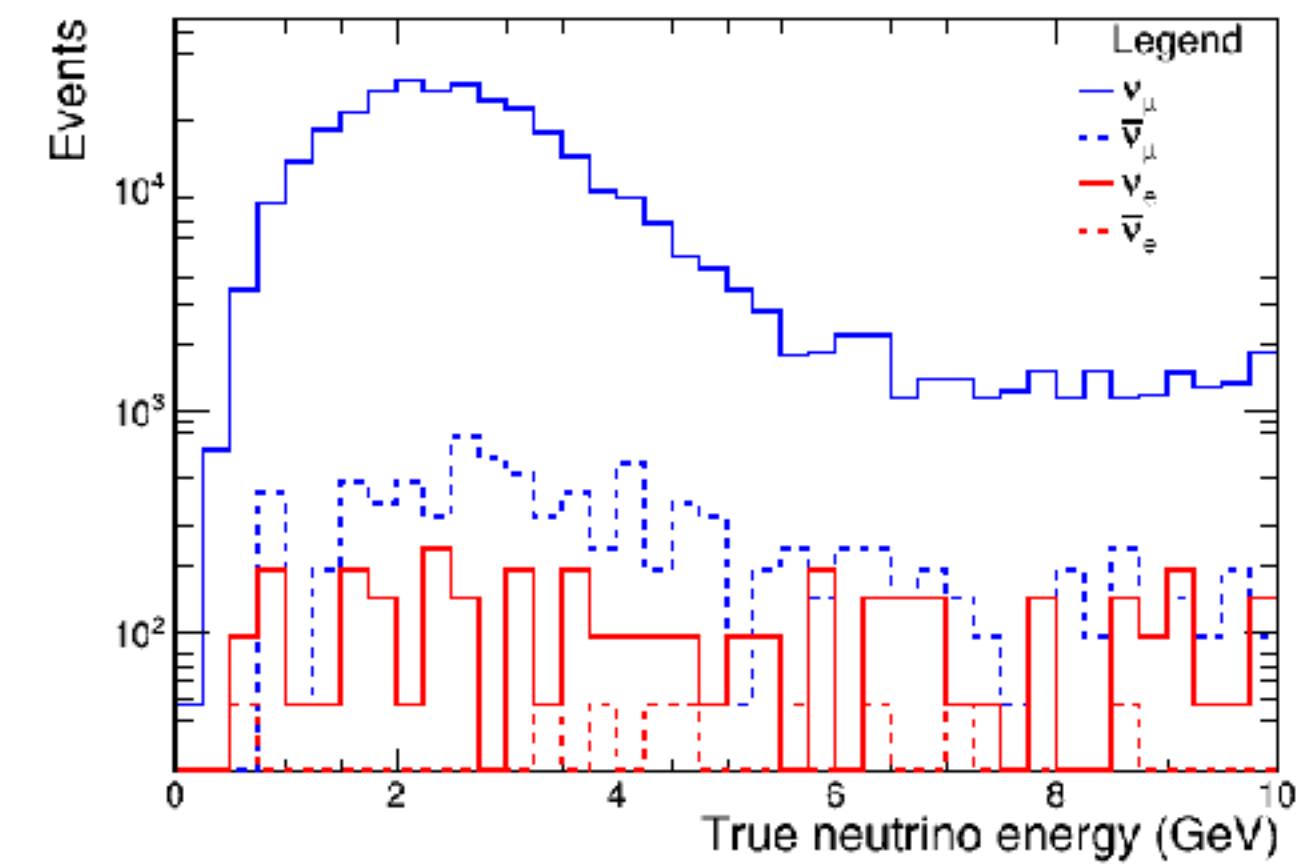


2: Quasi-elastic-like scattering

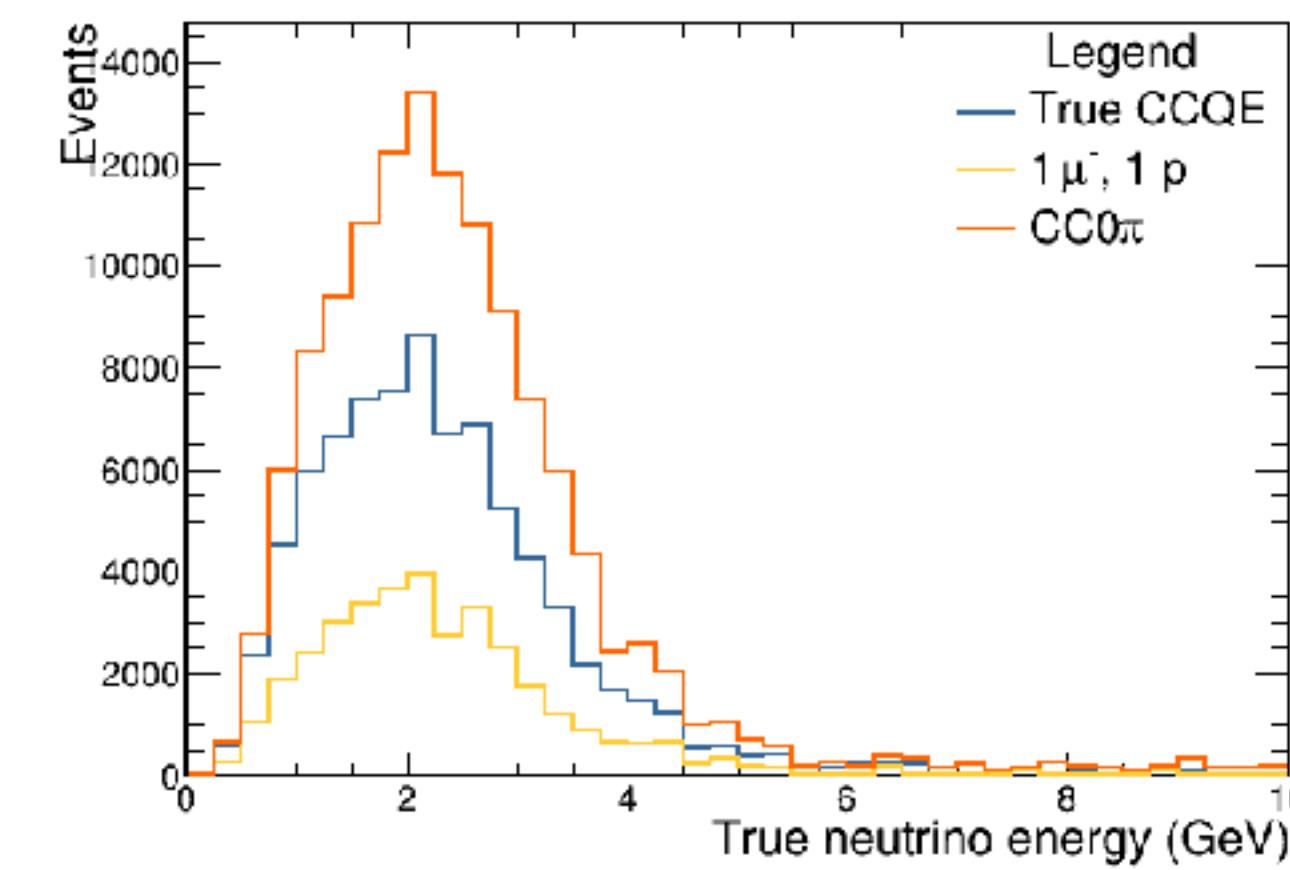


What you'll analyze with CAFAna

1: DUNE's neutrino beam flux



2: Quasi-elastic-like scattering



3: Energy reconstruction techniques

