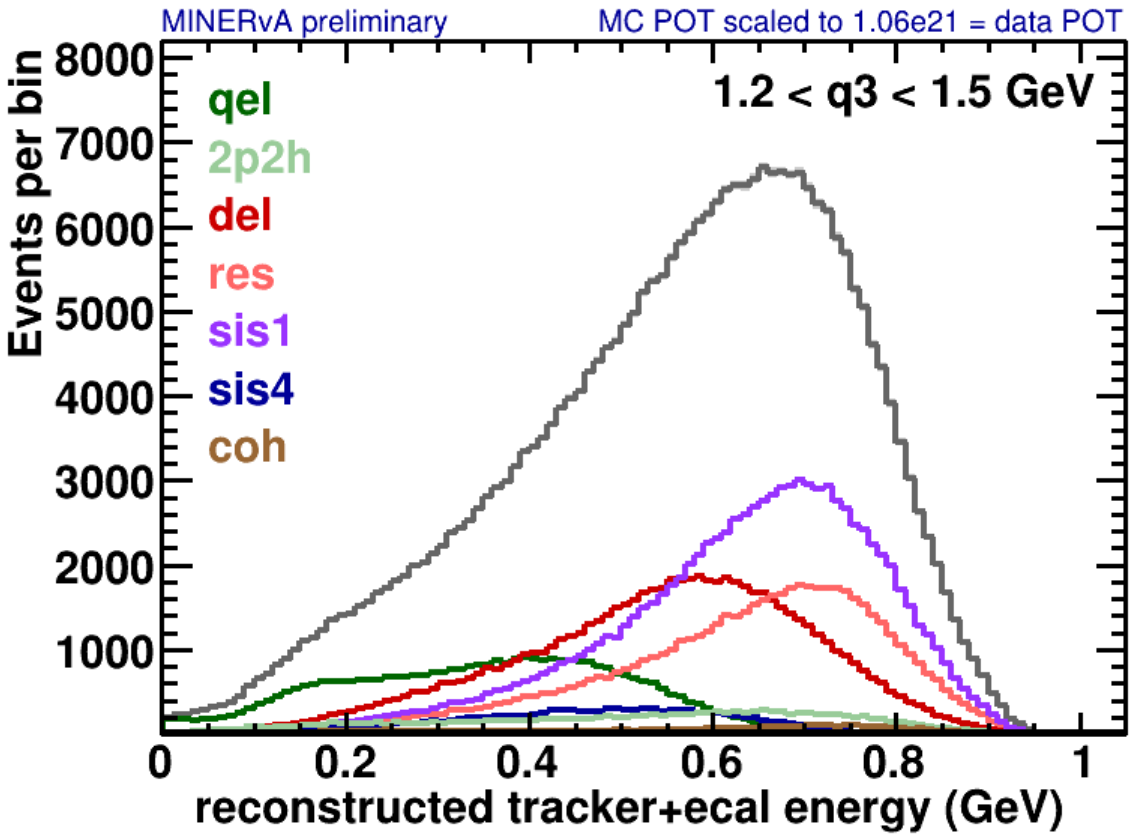
Guided tour through a reco distribution ready for fitting

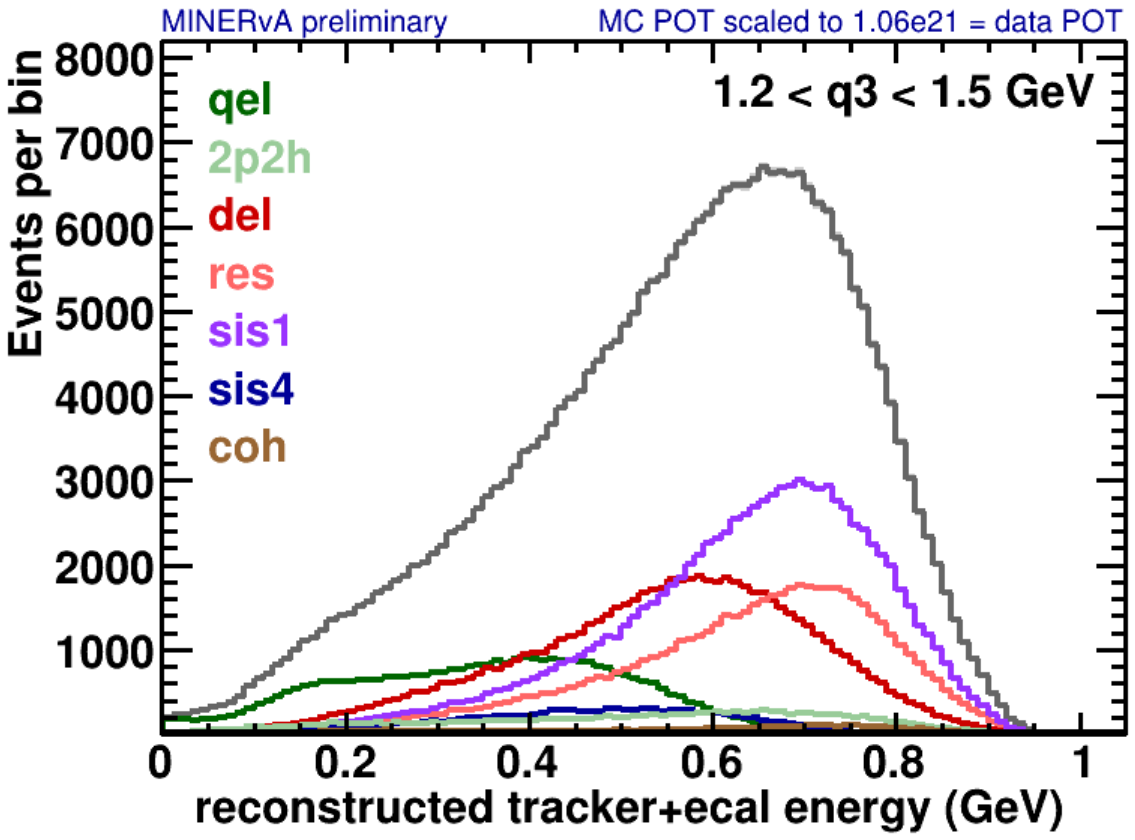


For DUNE NIUWG

Rik Gran
Minnesota Duluth

10 February 2025

Guided tour through a reco distribution ready for fitting

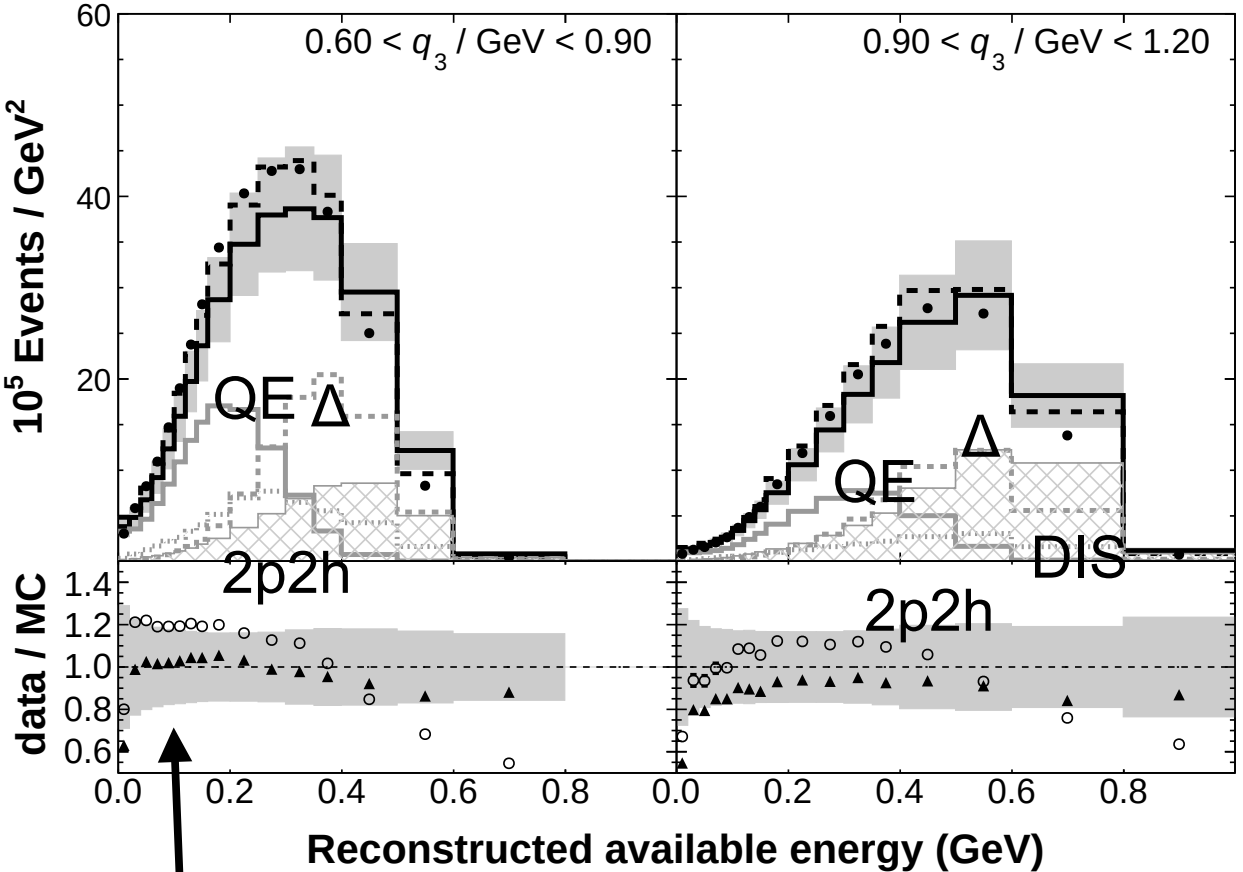


Going to introduce features
One or two per slide

This is MINERvA MC
NuMI beam peak at 6 GeV
"medium energy"
fully simulated
calorimetric reconstruction
MC scaled to data not shown

GENIE2 breakdown by
interaction type

Reference and history unfolded q3 < 1.2



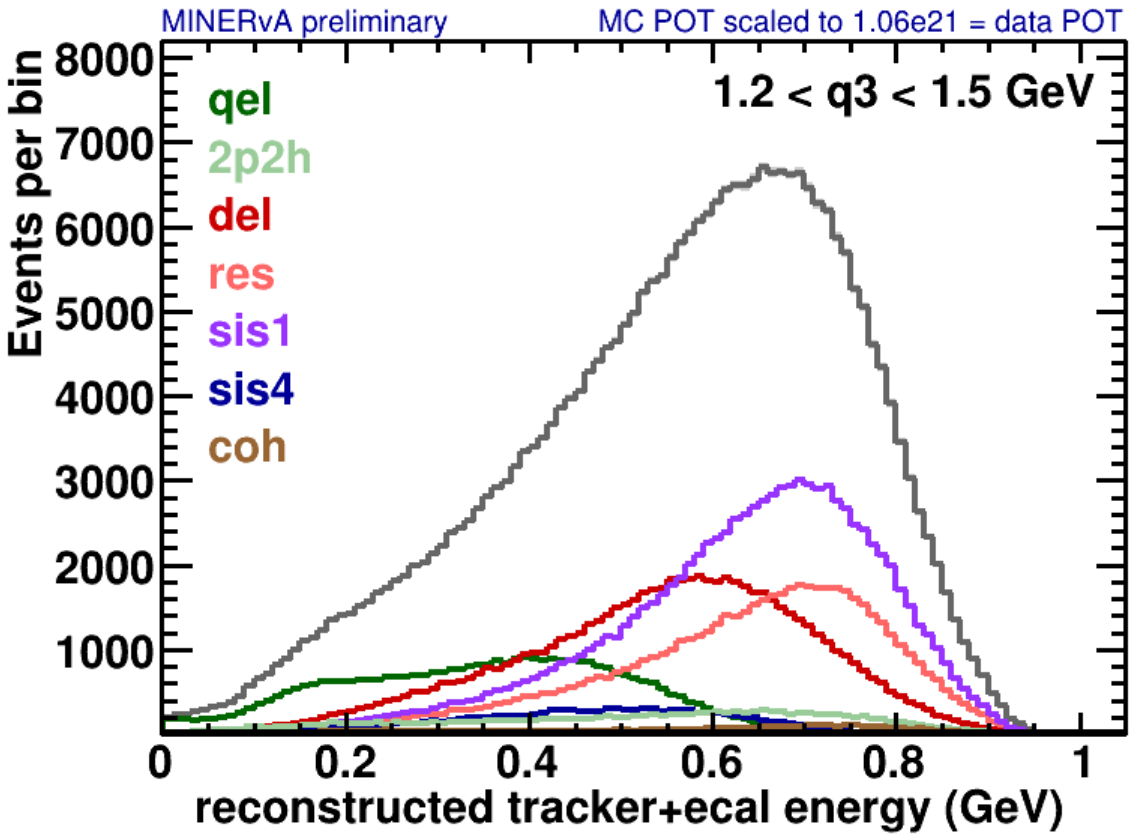
Ascencio et al. [MINERvA] PRD 106 032001 (2022) Low momentum transfer inclusive distribution.

these are the input reconstructed samples

If we were a LBL OA we would fit these

Open circles MINERvA Tune v1.2 pre Ascencio paper
Filled triangles candidate tune (used to unfold) in Ascencio

q3 bin chosen to match Naseem's region of interest

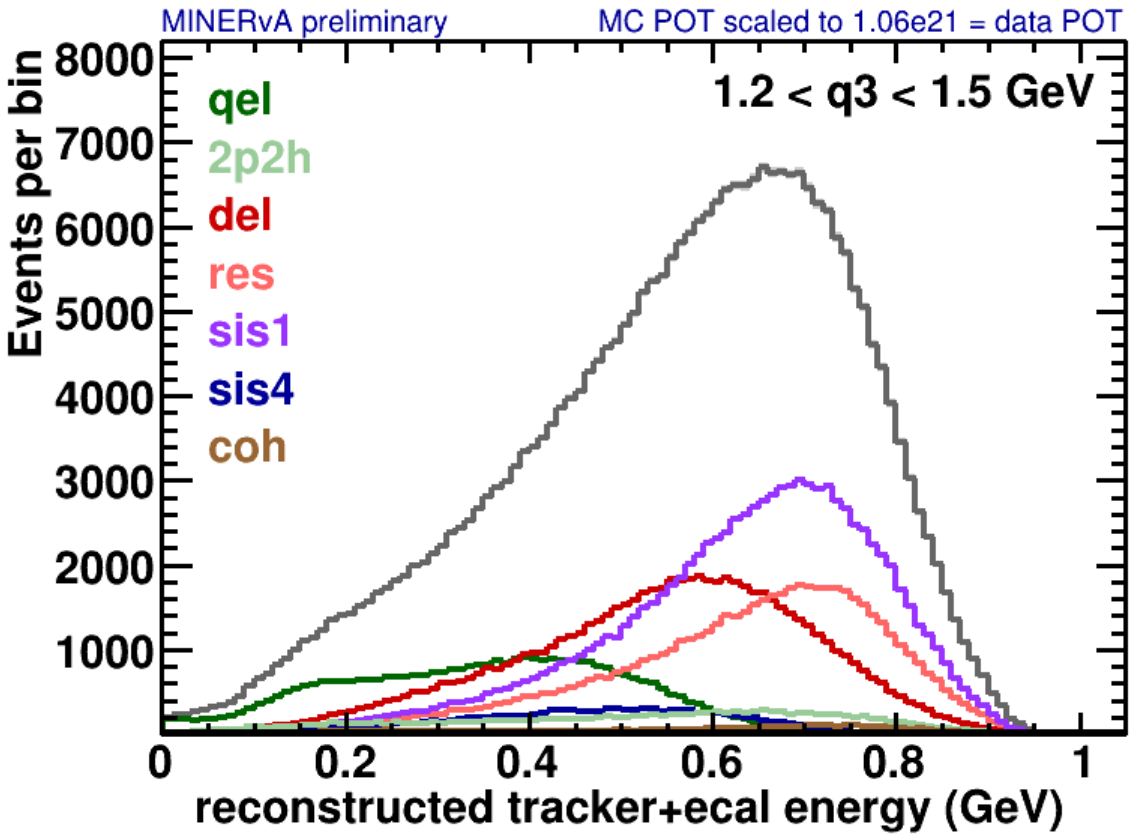


Next higher q3 bin chosen to match Naseem's check
NDLAr has a blind spot
NDGAr has good acceptance

But anyway, its a core panel of the inclusive distribution that we will fit.

not unfolding, so binned to give 1k to 10k events/bin (3% to 1% stat fluctuation)

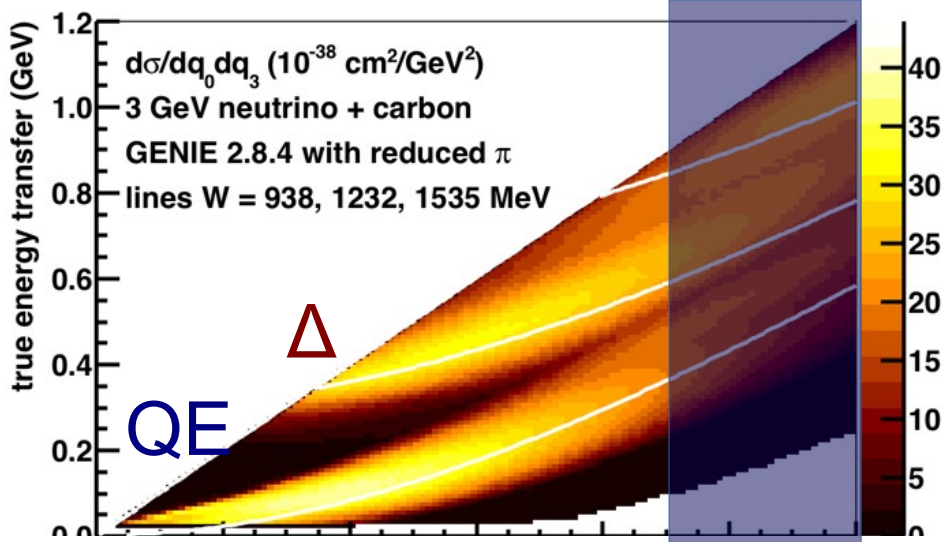
Calorimetric reconstructed energy with leakage

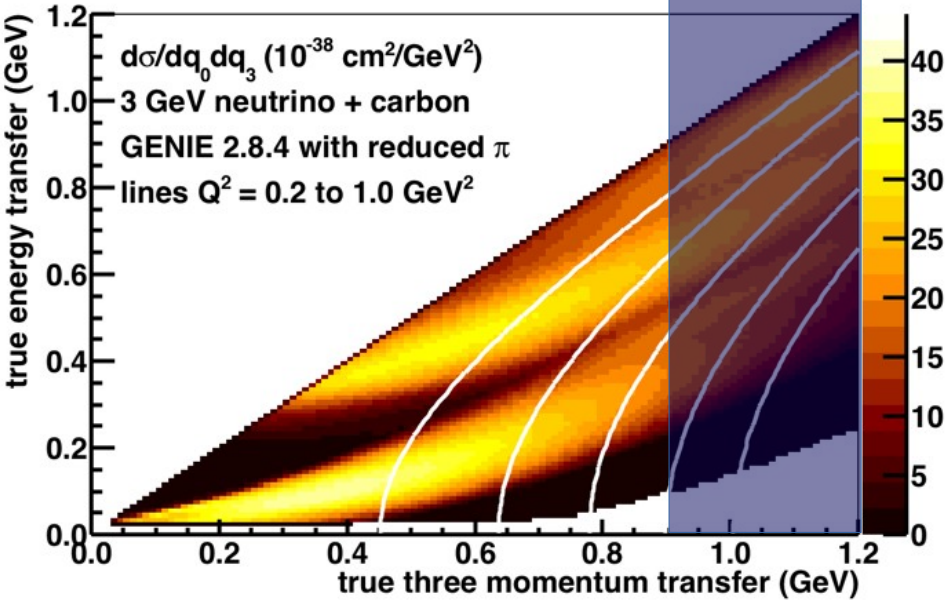


The horizontal axis is Ascencio / 1.17 but scale won't affect interpretation

Ascencio q3 < 1.2 GeV
Has good hadron containment with tracker + ecal only and applies a 1.17 factor for simple calorimetry (on top of passive material)

Leakage into HCAL is not negligible for q3 > 1.2, but ignored here.





Intuitions about variables

pZ correlates with Enu

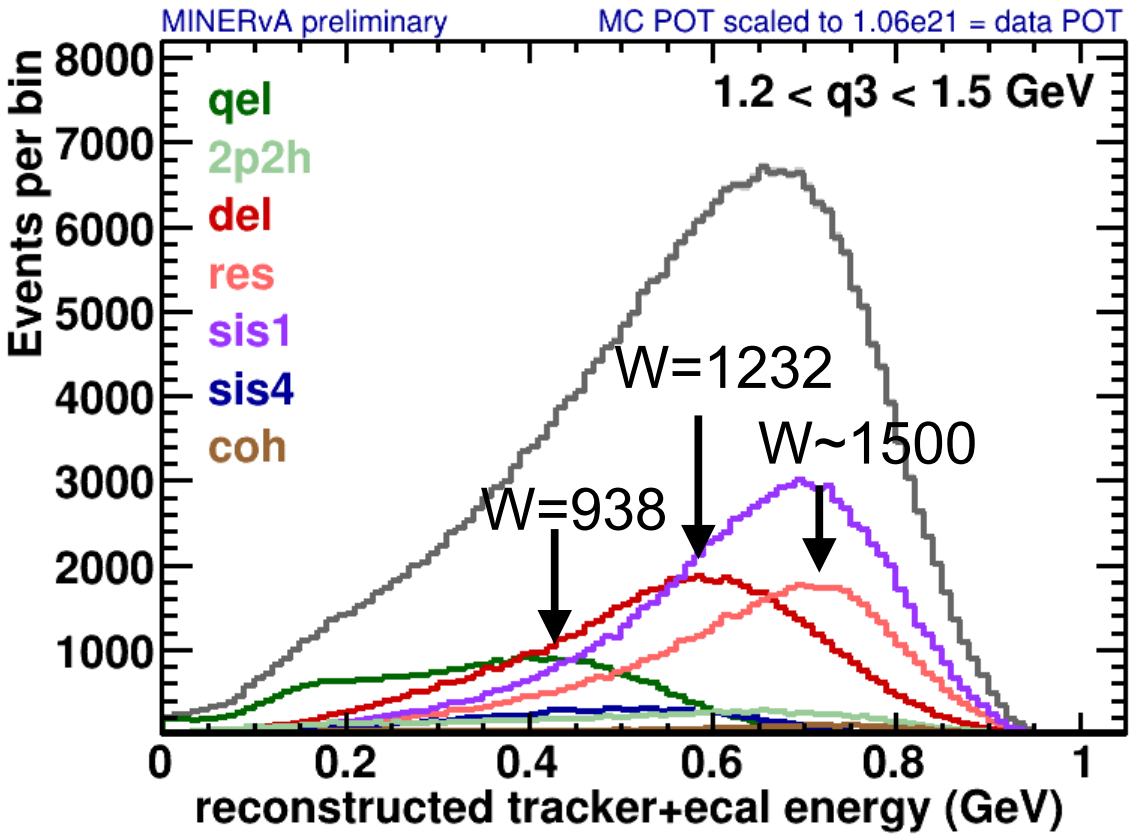
pT correlates with q3, sorta Q2

Ehad, Eavail correlates q0, W

Around Enu ~ 1 GeV correlation is less strong and also significant energy dependence

Q2 = 0 is the diagonal here
Q2 = q3^2 - q0^2
is far right in energy transfer

Kinematics orientation part one



QE and Delta peaks move up in had energy ~ q0 (and Q2) with every q3

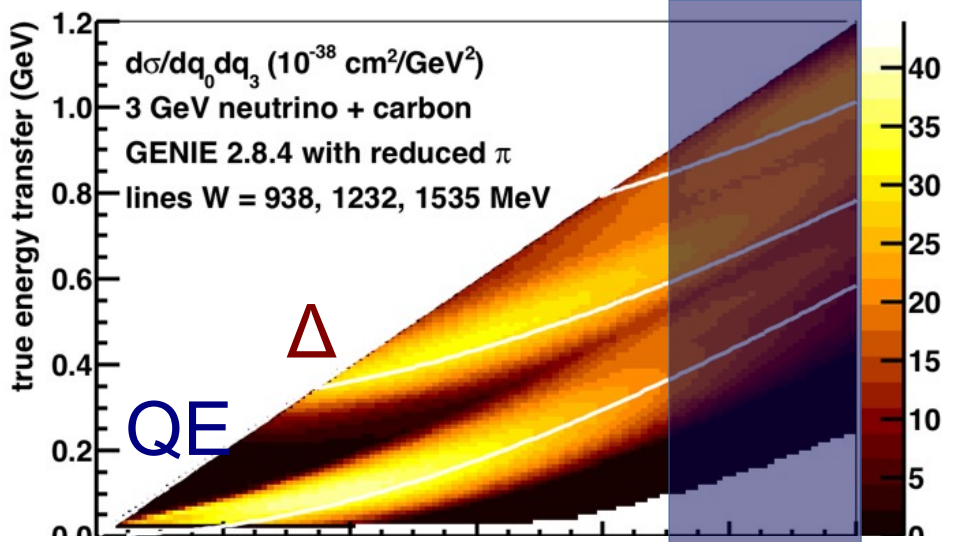
Light Red is all GENIE higher resonances

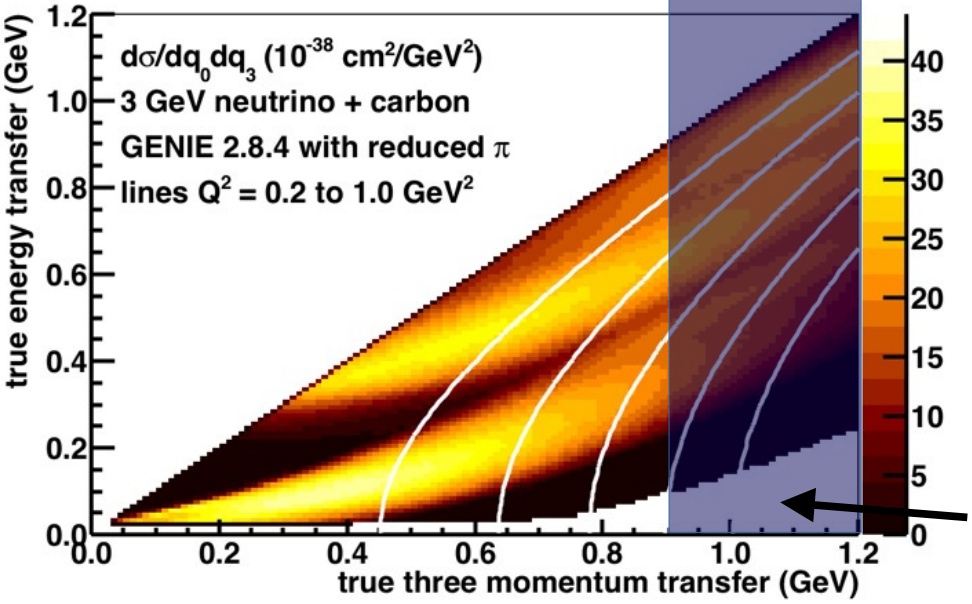
Similar idea to (e,e') data
ω = q0 at fixed θ & incident E

Q2 ~ 1.35

Q2 ~ 0

Q2 = 0 to right in q0=ω plot





Step back to GENIE truth

the last Ascencio slice = blue

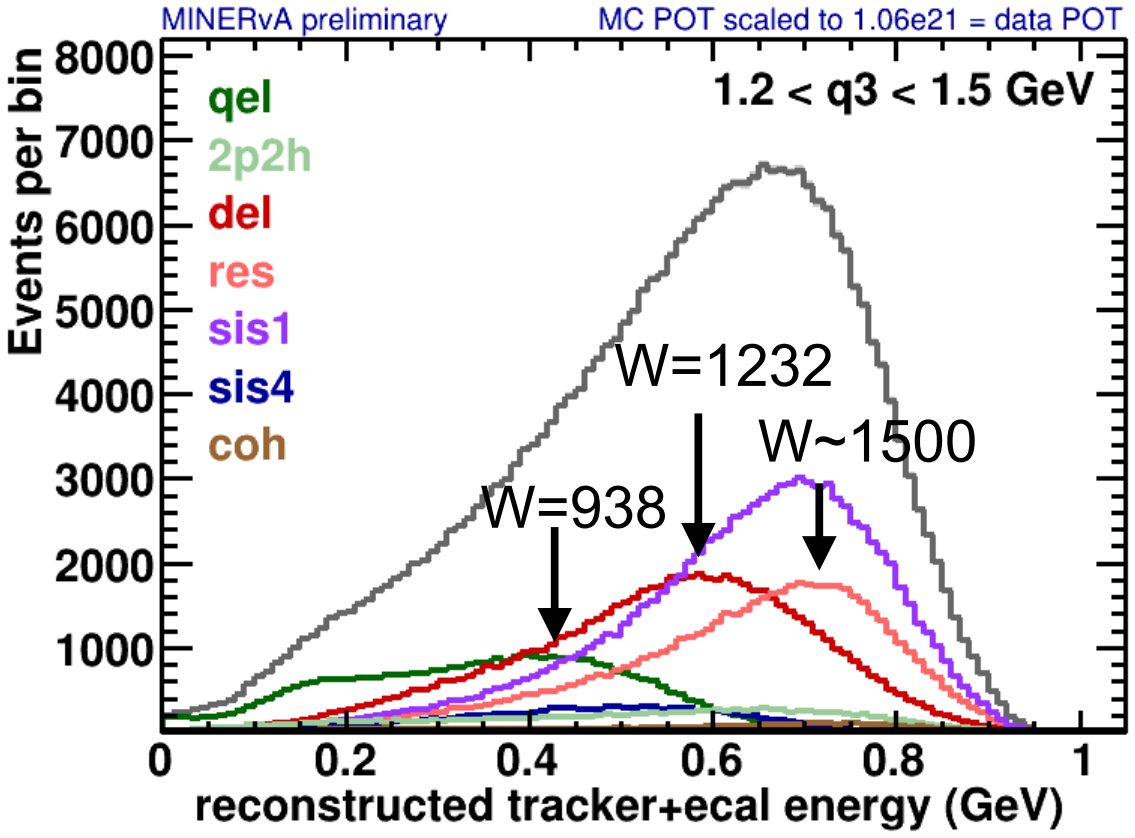
Distribution on previous slide
is the next slice higher in q3

Previous slide horizontal axis
Is an estimator for this

Q2 = 0 is the diagonal here
Q2 = q3^2 - q0^2
is far right in energy transfer

Notice lower corner is empty

Kinematics orientation slide repeated



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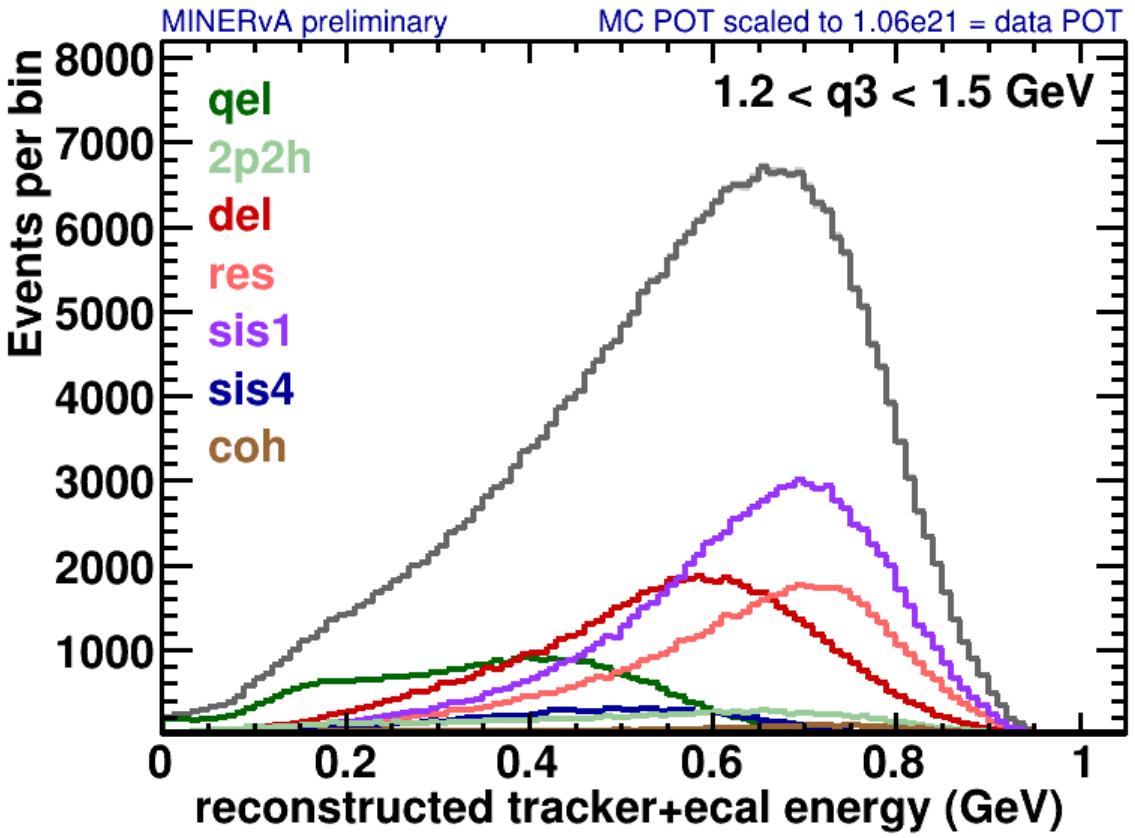
Map to proposed pT, pz, Eavail binning



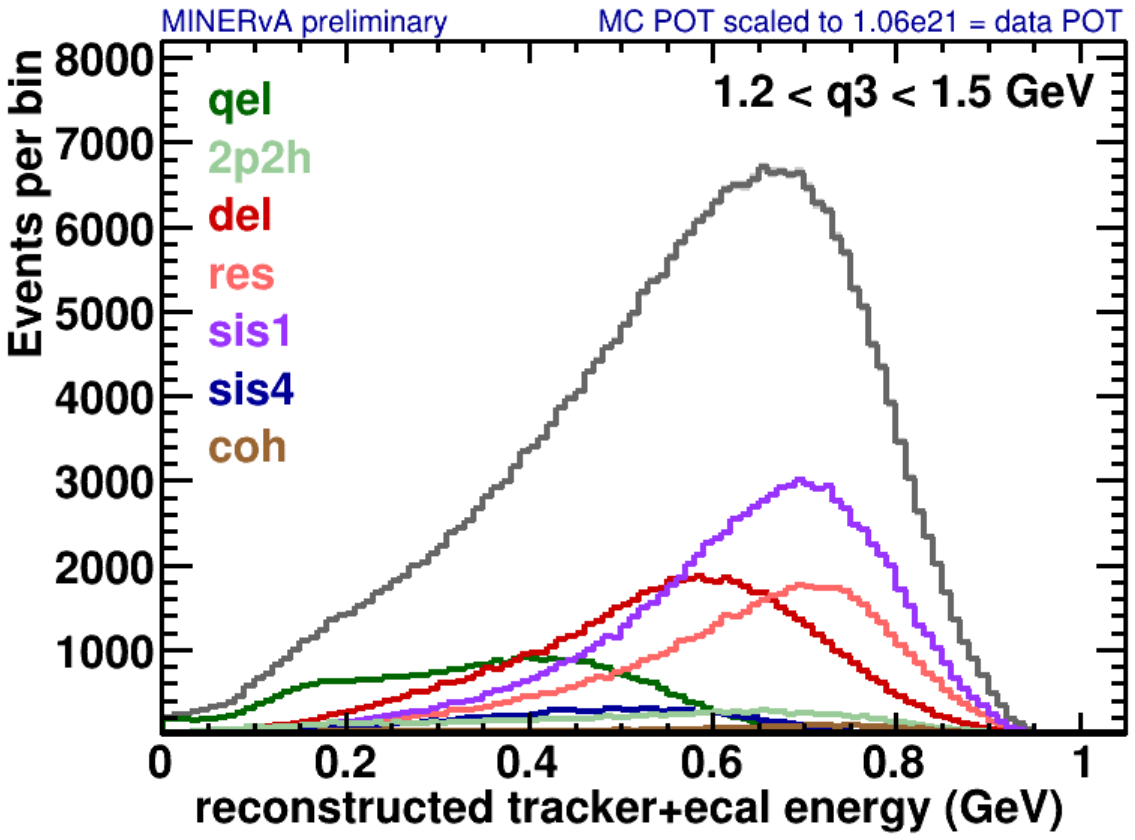
Starting around 2 GeV
Strong correlation between q3 bin and pT bin

Hadron energy + leakage (and missing neutrons) correlates with q0

Flux integrated so its like pZ ~ 5 GeV

So equivalent to one panel of our proposed 3D binning! Yay!

Wait, does it look like this with the DUNE flux?



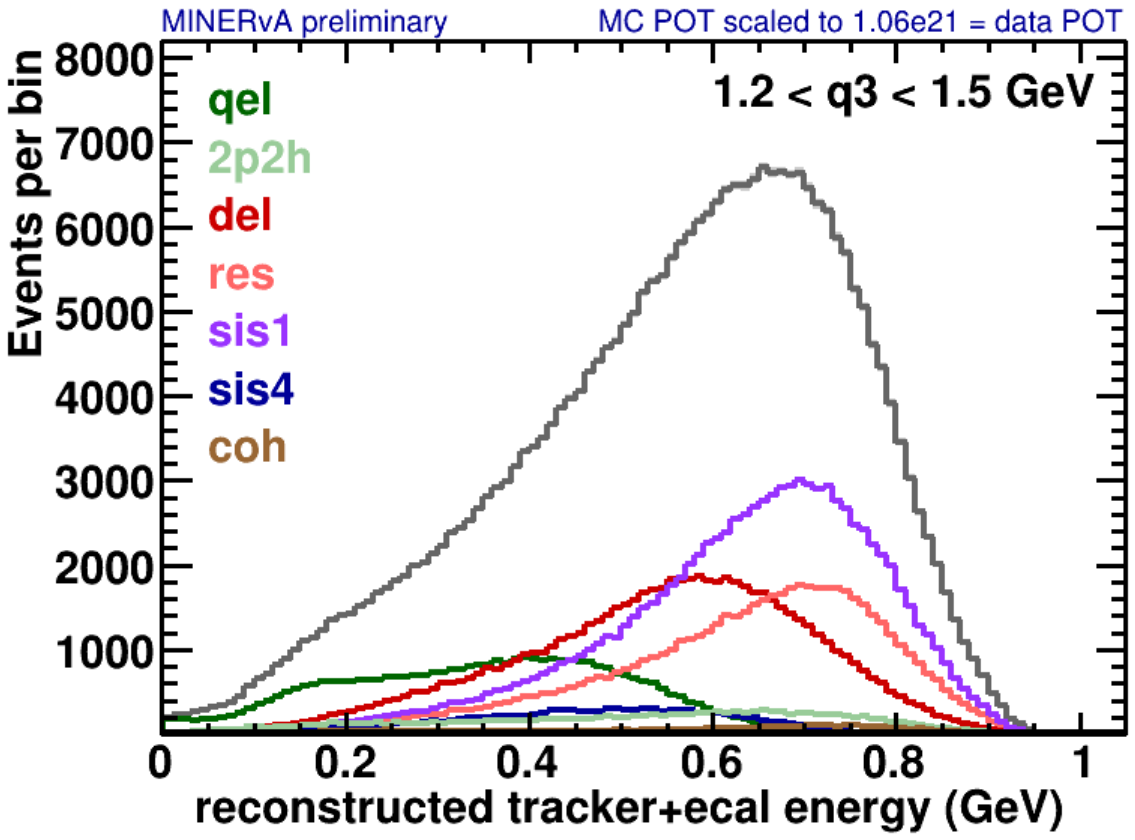
Good question but !
We propose slices of pZ rather than flux integrated

Slices in pZ this is ~ 5 GeV

pZ ~ 4 GeV looks same

At MINERvA energies all pZ slices > 5 GeV look same

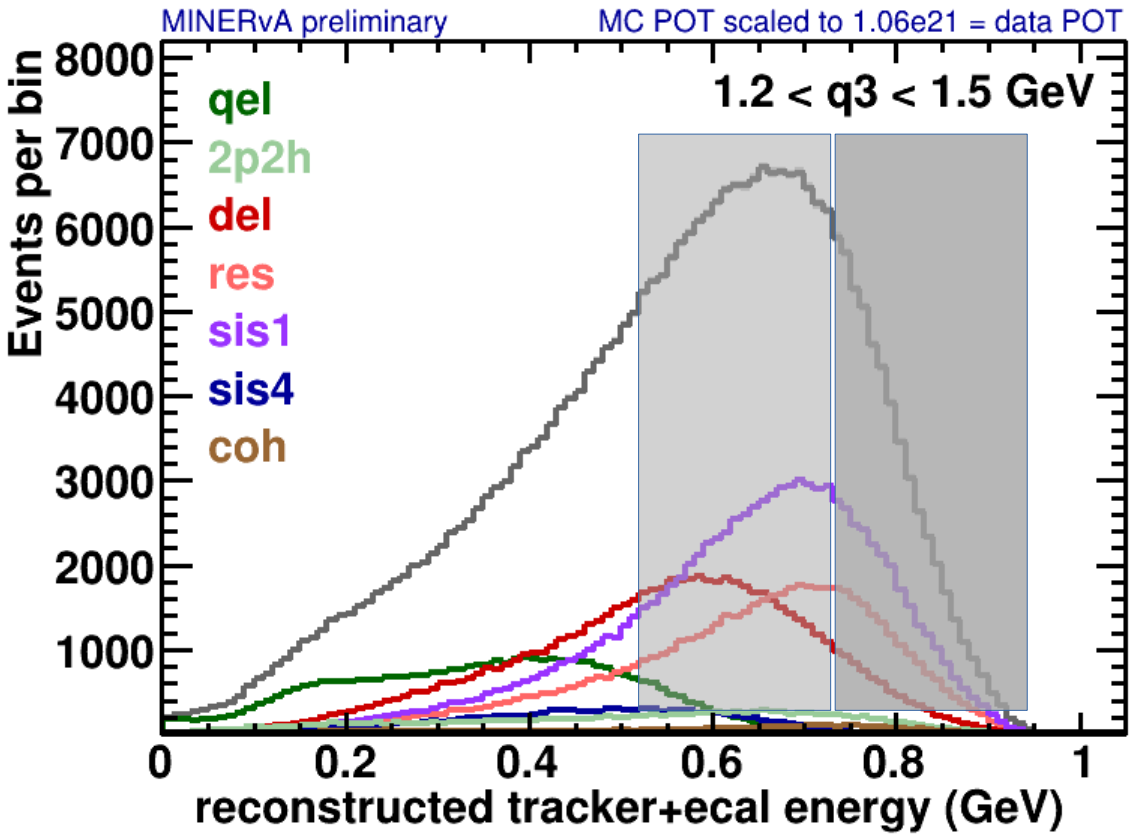
But 2nd oscillation minimum is 2.5ish GeV?



Sure, the energy dependence comes from the contraction of the lepton hadron tensors

1/E terms are Q2 dependent W3 increases, so shape suppresses low Q2 (right) enhances high Q2 (left) (and opposite, sign flip, for anti-neutrino)

What about 2nd oscillation maximum ~ 1 GeV?



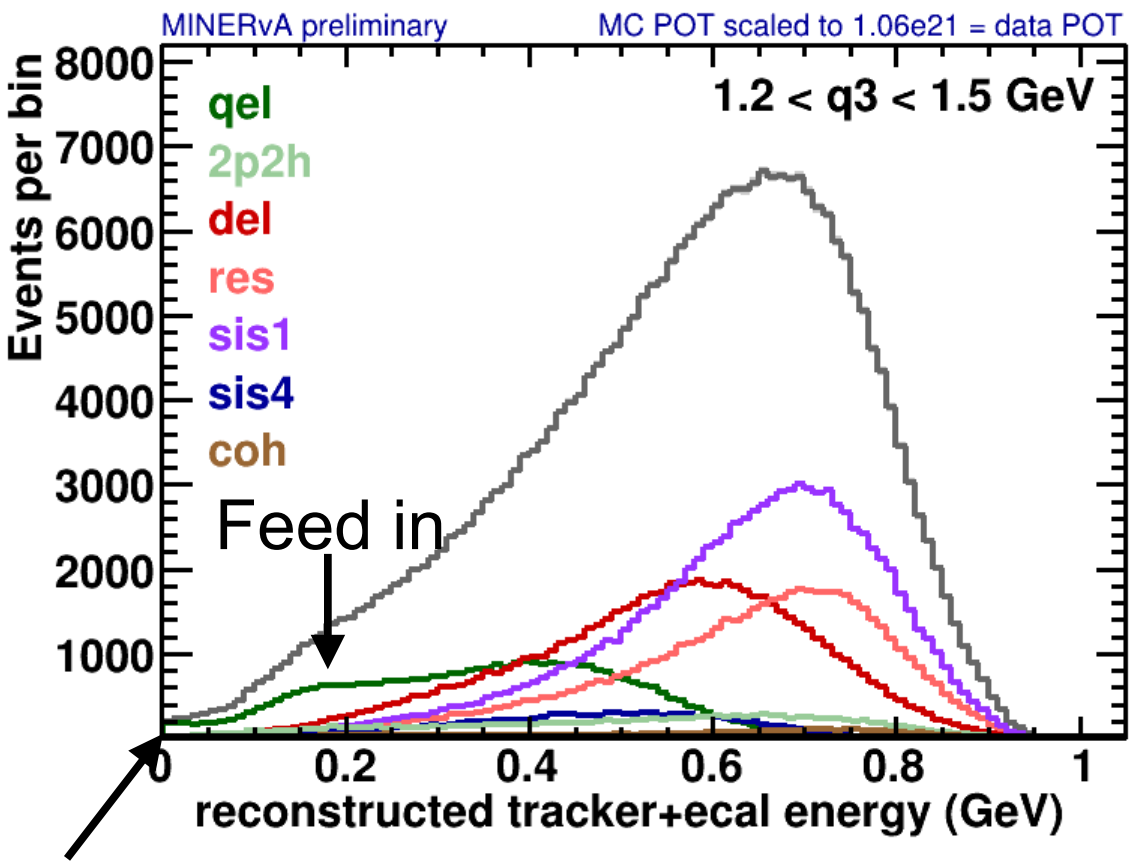
These kinematics are NOT accessible at Enu = 1 GeV

If we bin in pZ and step DOWN in energy around Enu ~ 1.5 GeV and pZ ~ 1.0 GeV

This content disappears not enough Enu to transfer 1.2 GeV momentum

Events are removed from right to left as you go down in Enu, pZ

GENIE doesn't produce events below QE peak



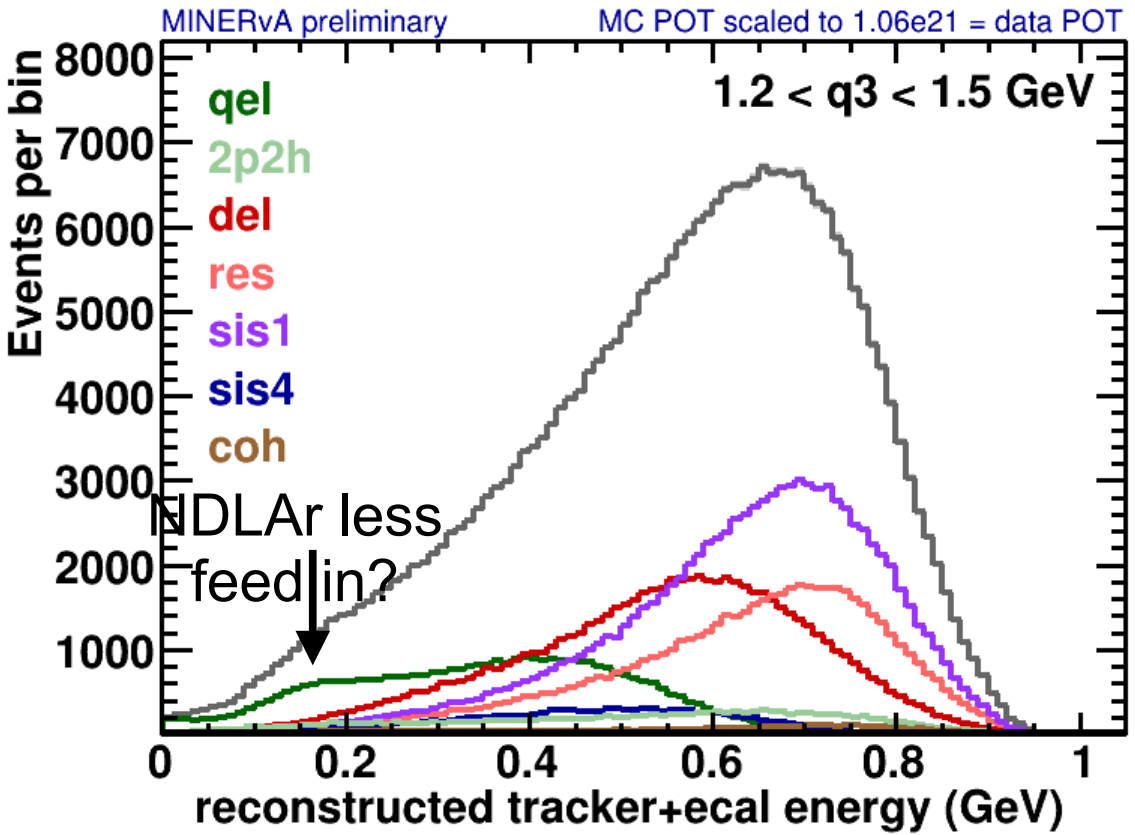
Right, its a reco distribution
Everything has a left side tail
partly from neutrons
a little from leakage
and lower q3 feed-in

The lower bump in QE is
feed in from lower q3
via resolution smearing

Fitter needs to know these

GENIE2 MC has QE events down to 0 MeV from FSI here

Can we guess how DUNE resolution different?

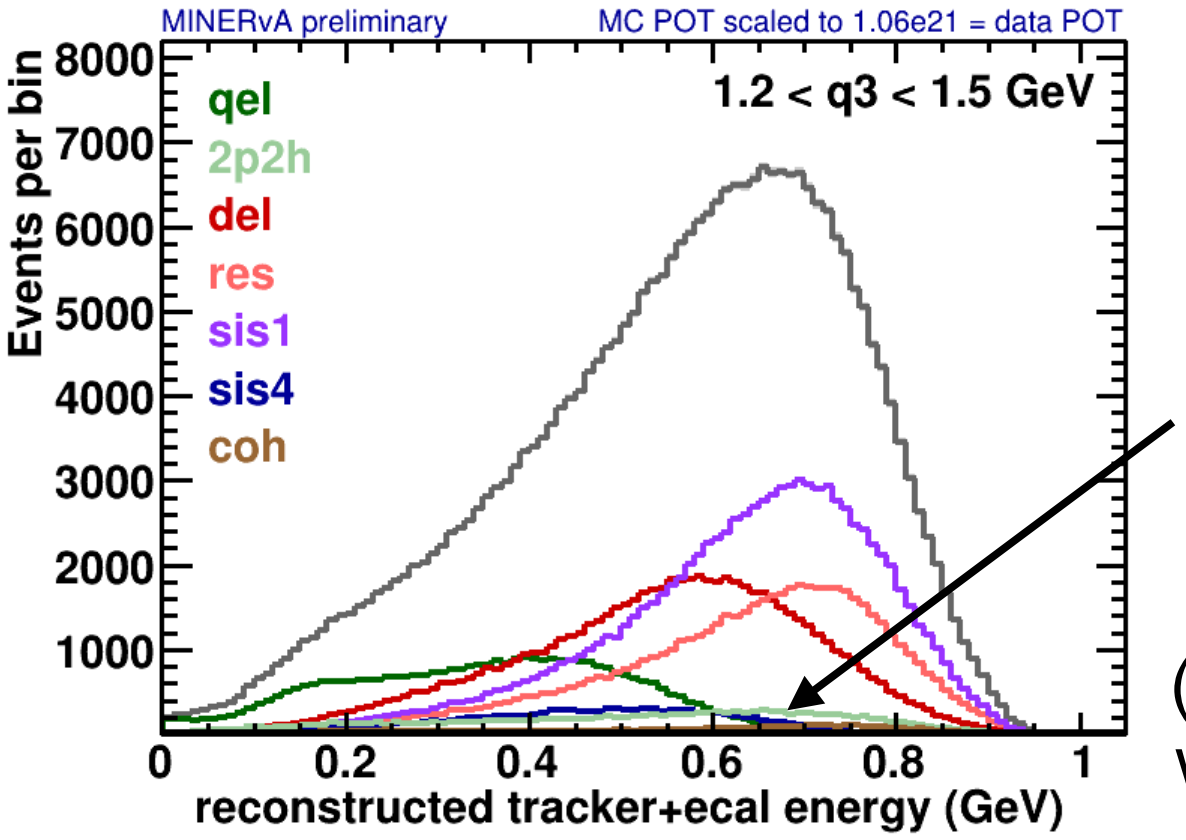


This is inclusive calorimetry
NDLAr is probably similar even using reco tracks
q3 resolution might be better
Neutron effects are same

Notice the sum is smooth components overlap
first thing a fitter will do is adjust the rate of the components.

Tracking protons and pions in NDGAr is probably higher resolution

Why is 2p2h so small?

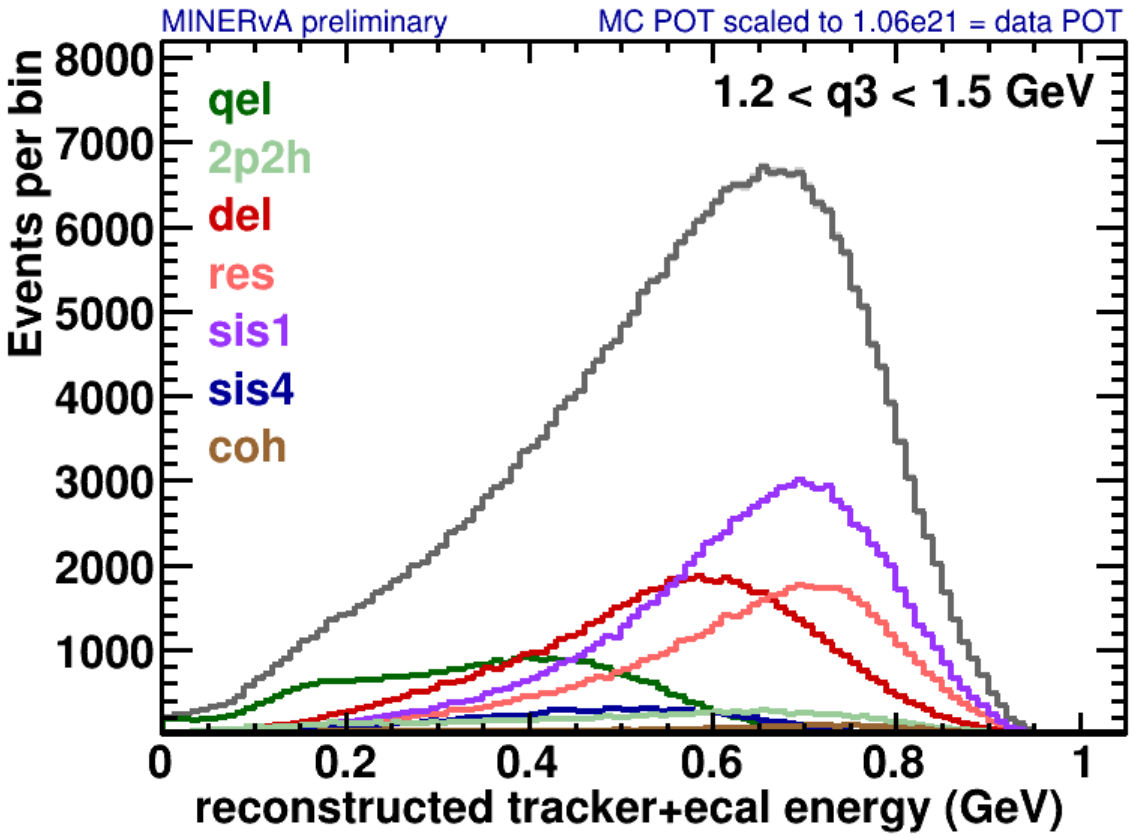


Using Valencia prediction that only goes to q3 < 1.2 plus resolution smearing

its all resolution leakage into higher q3

An expanded model (SuSA, extended Valencia) would have more up to 2.0 then what?

Whats sis1 and sis4 an acronym for?

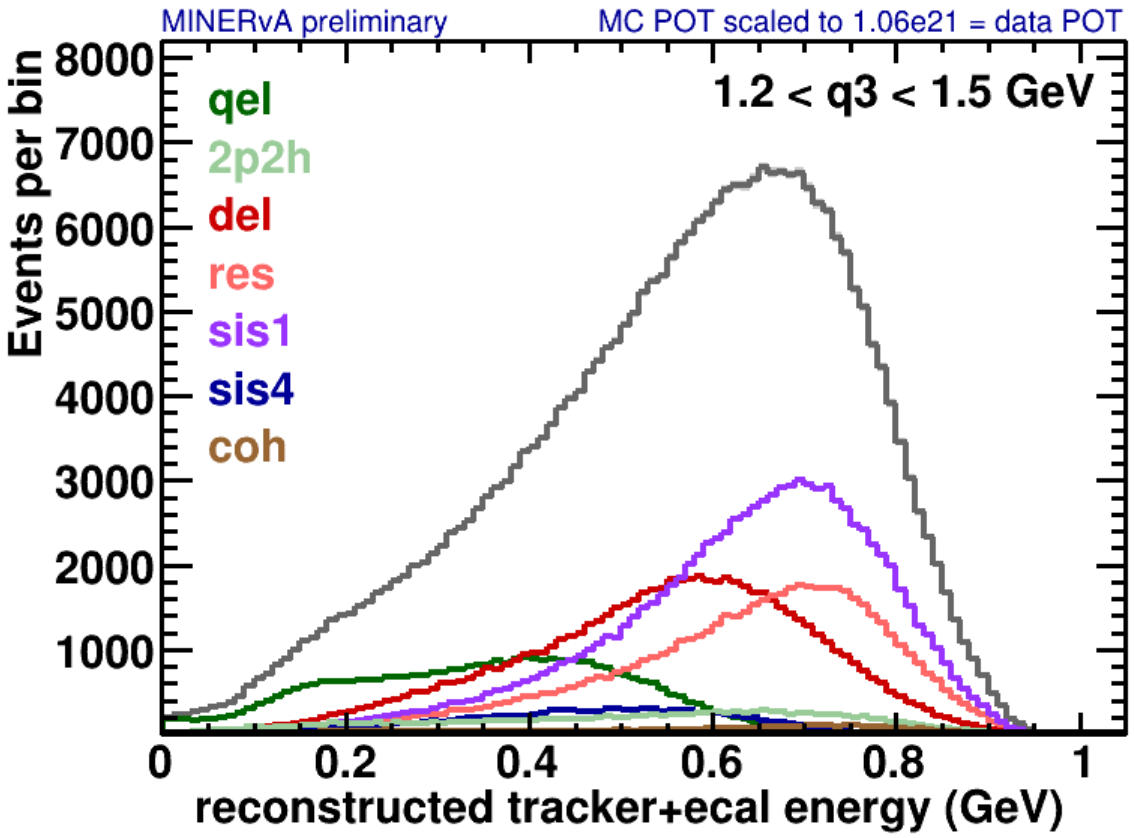


SIS1 is GENIE DIS Q2 < 1
(at any W, but ~ 1.5 here)

SIS4 is DIS 1 < Q2 < 4 GeV2
(again, at any W)

Jorge's definitions.
Historically neutrino says
Safe DIS is Q2 > 1 GeV2
CTEQ says safe is Q2 > 4

Whats unsafe about Q2 < 1 GeV2 ?

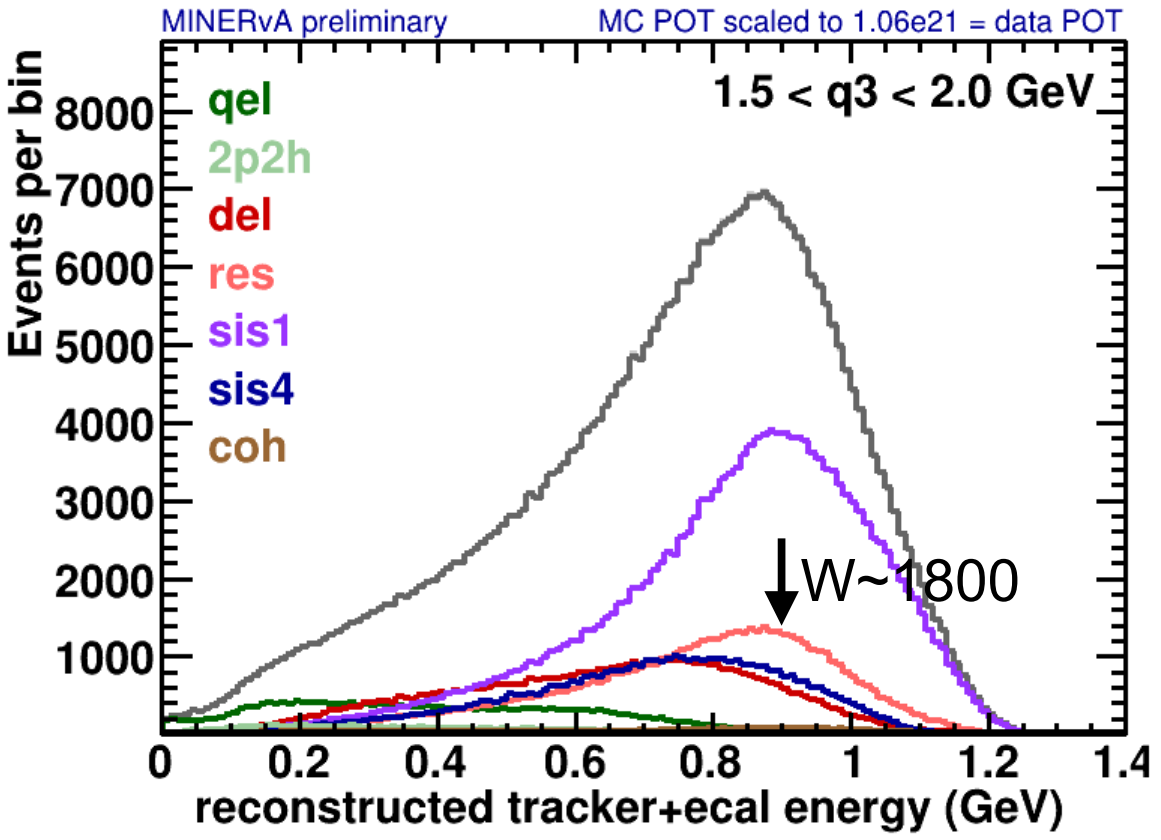


GENIE's Bodek Yang model
is a quark model
with target mass corrections
and higher twist
maybe nuclear effects

Q2 < 1 is nucleon stuff
(all W but not resonant)
multi-quark processes.

If purple describes data, its probably a quark-hadron duality thing?

sis4 is easier to see at higher q3

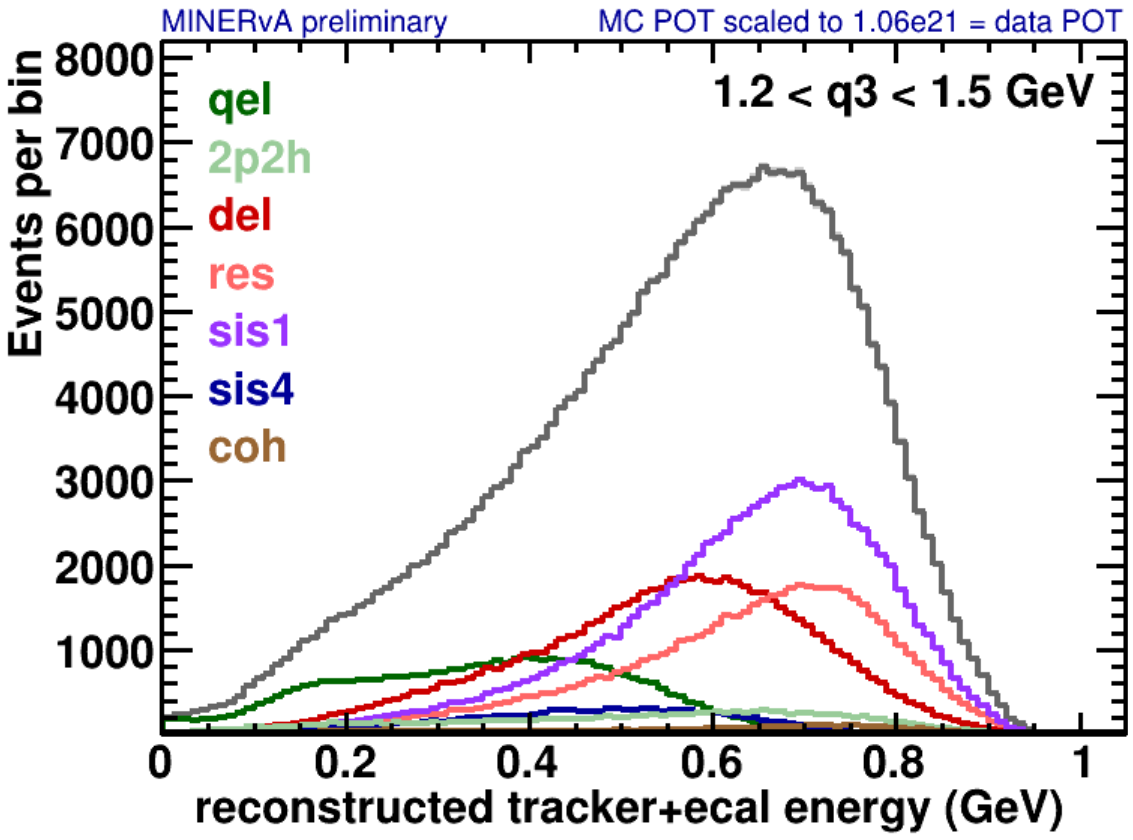


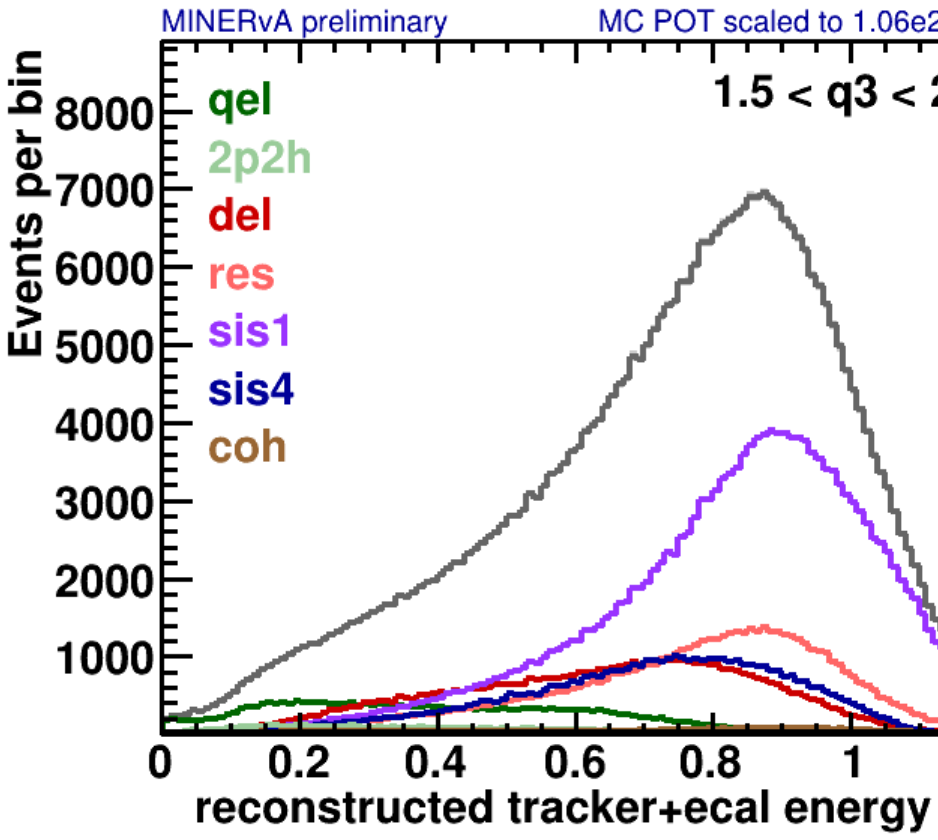
I went up one more step
SIS Q2 < 1 is half the rate
its W ~ 1.8 GeV and is
near Q2 ~ 0 (to the right!)

dark blue can be seen rising
at higher Q2 (to the left!)

We are designing
uncertainty priors for these
based on the AMU model

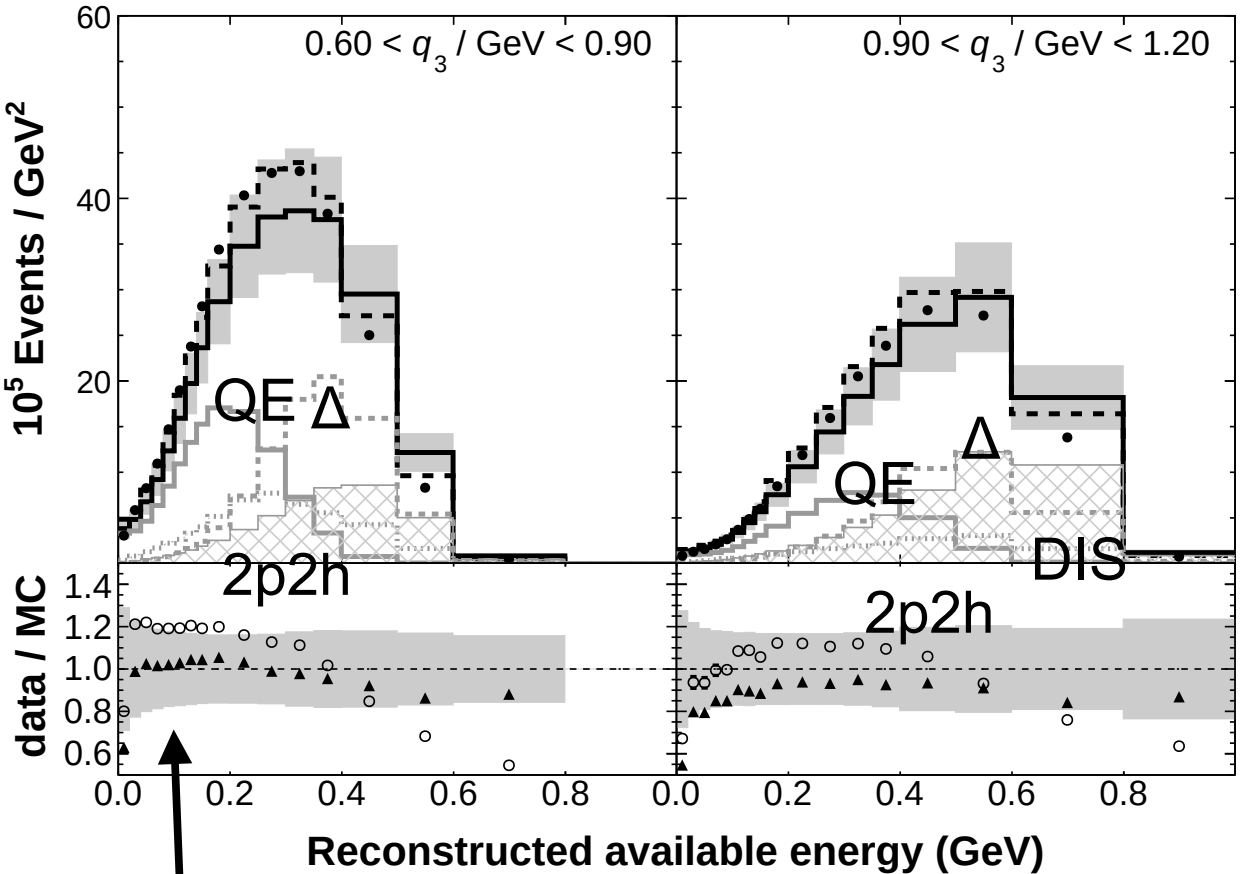
This is what a fitter gets. What will it do? Don't know.





Parameters change rate and (multi-dimension) shape

GENIE error bands c. 2020 in the reco distribution



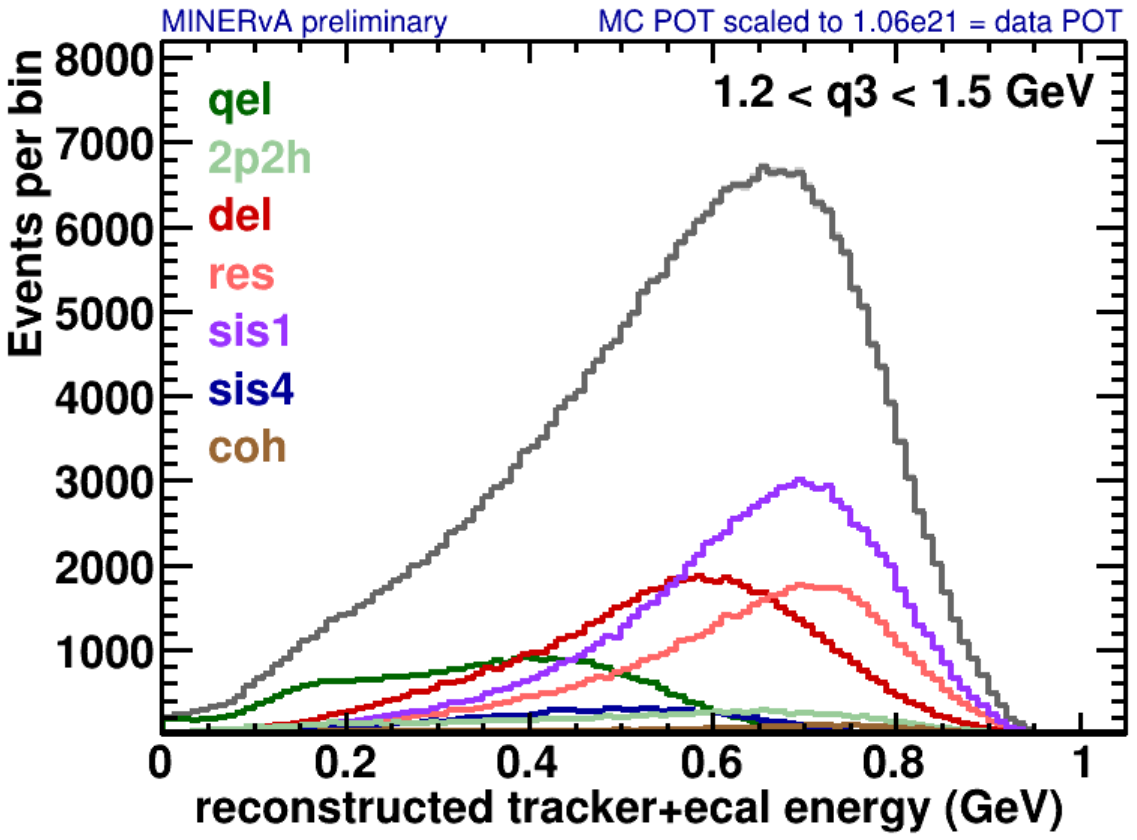
Largely MA and MV
And original GENIE priors

MINERvA flux ~ 4%
hadron energy scale
is about the same on right

A hand tuning with three
theory-motivated knobs
gets within 10%

Open circles MINERvA Tune v1.2 pre Ascencio paper
Filled triangles candidate tune (used to unfold) in Ascencio

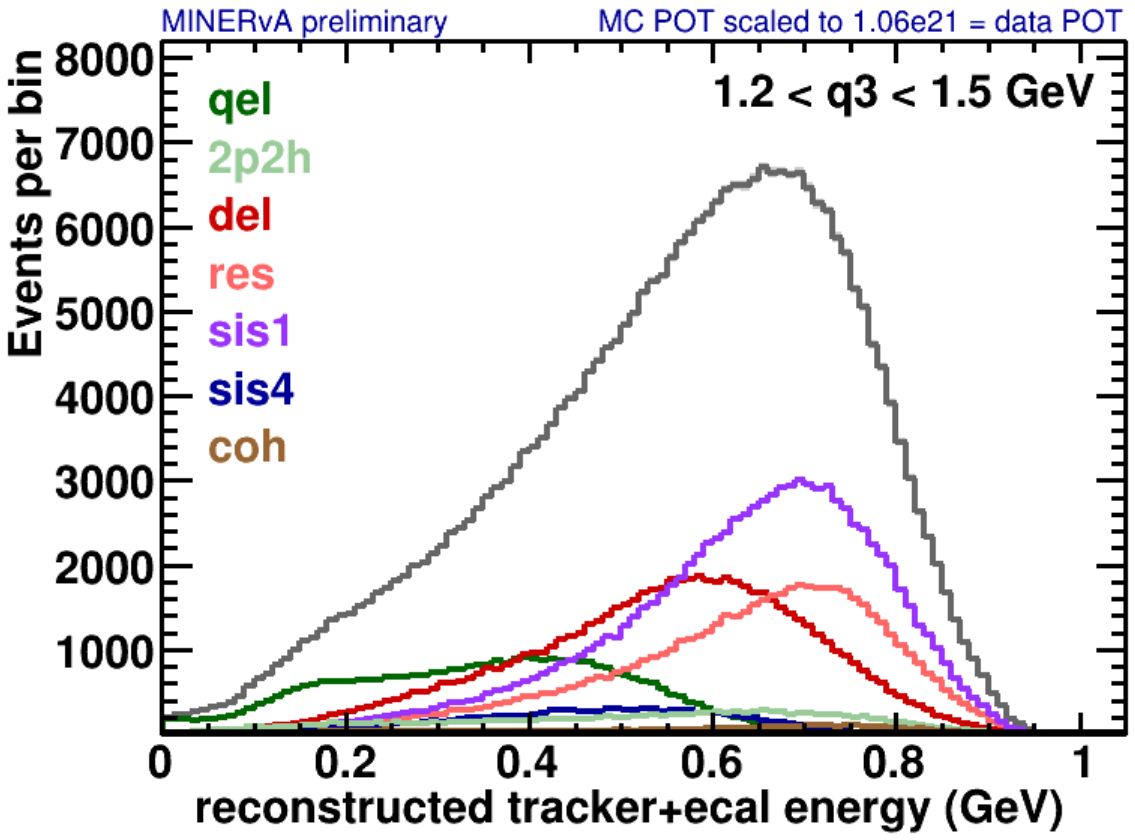
The inputs have improved since Ascencio



Improved uncertainty priors
most around 10%
but are more numerous

Net error band priors
will still be about 20%
but better at describing
model shifts and smears
rather than normalizations

So what would a new hand tuning give?



Based on MnvTune efforts
(never to get best fit)

Across most of the space
The best fit will wiggle
around the data ~5%
(stat unc ~3%)
So chi2 ~ 2 per dof

Haven't done this yet.
Cant show you the data

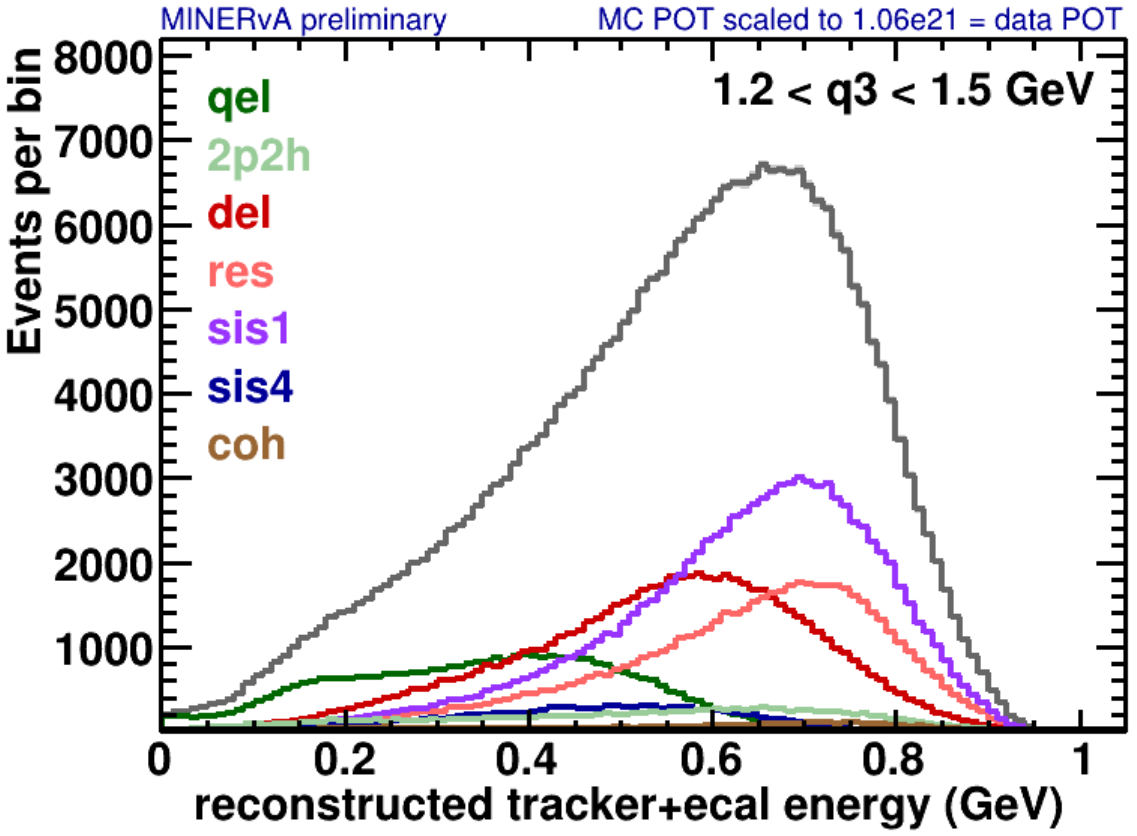
Conclusions

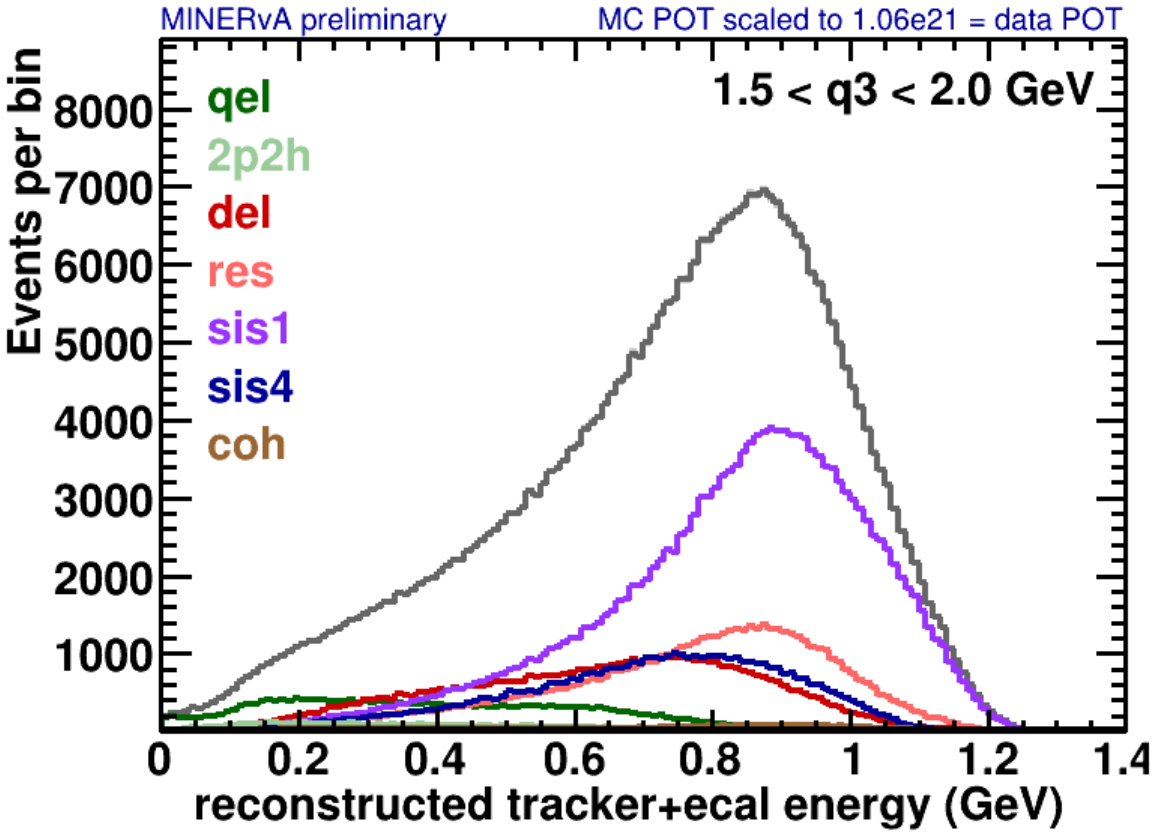
Have shown a little-before seen slice of MINERvA MC
the next q3 bins up from the MINERvA Ascencio paper
especially one that touches the SIS region

demonstration is equivalent to proposed 3D binning
many features of interest to models and the fitter stand out

not ready to show data yet (but see q3<1.2 in Ascencio paper)
Undergraduate projects looking at it and up to q3 < 3.0 GeV

will be in MINERvA's upcoming data preservation product


MINERvA preliminary
MC POT scaled to 1.06e21 = data POT
1.2 < q3 < 1.5 GeV
qel
2p2h
del
res
sis1
sis4
coh
Events per bin
8000
7000
6000
5000
4000
3000
2000
1000
0
0.2
0.4
0.6
0.8
1
reconstructed tracker+ecal energy (GeV)


MINERvA preliminary
MC POT scaled to 1.06e21 = data POT
1.5 < q3 < 2.0 GeV
qel
2p2h
del
res
sis1
sis4
coh
Events per bin
8000
7000
6000
5000
4000
3000
2000
1000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
reconstructed tracker+ecal energy (GeV)