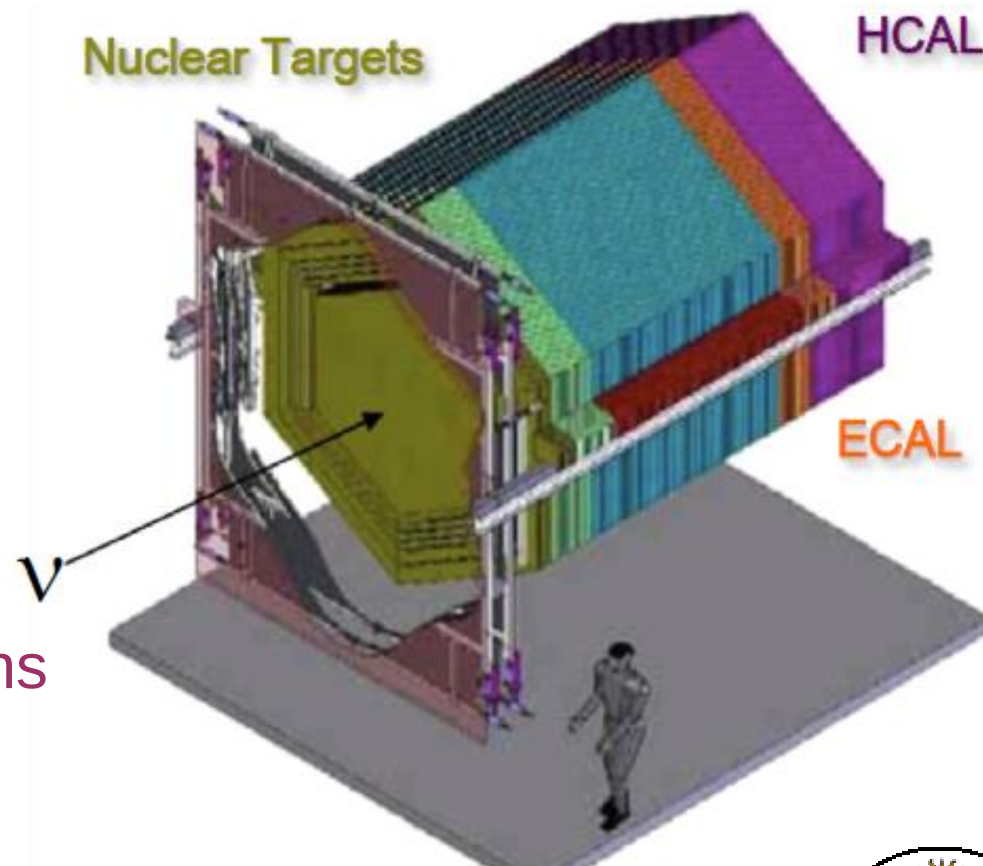
Recent Results from MINERνA



what is Minerνa ?

ν beam and ν flux

ν / $\bar{\nu}$ inclusive x-sections

double differential x-sections

NuTel2017
Venice
15 Mars 2017

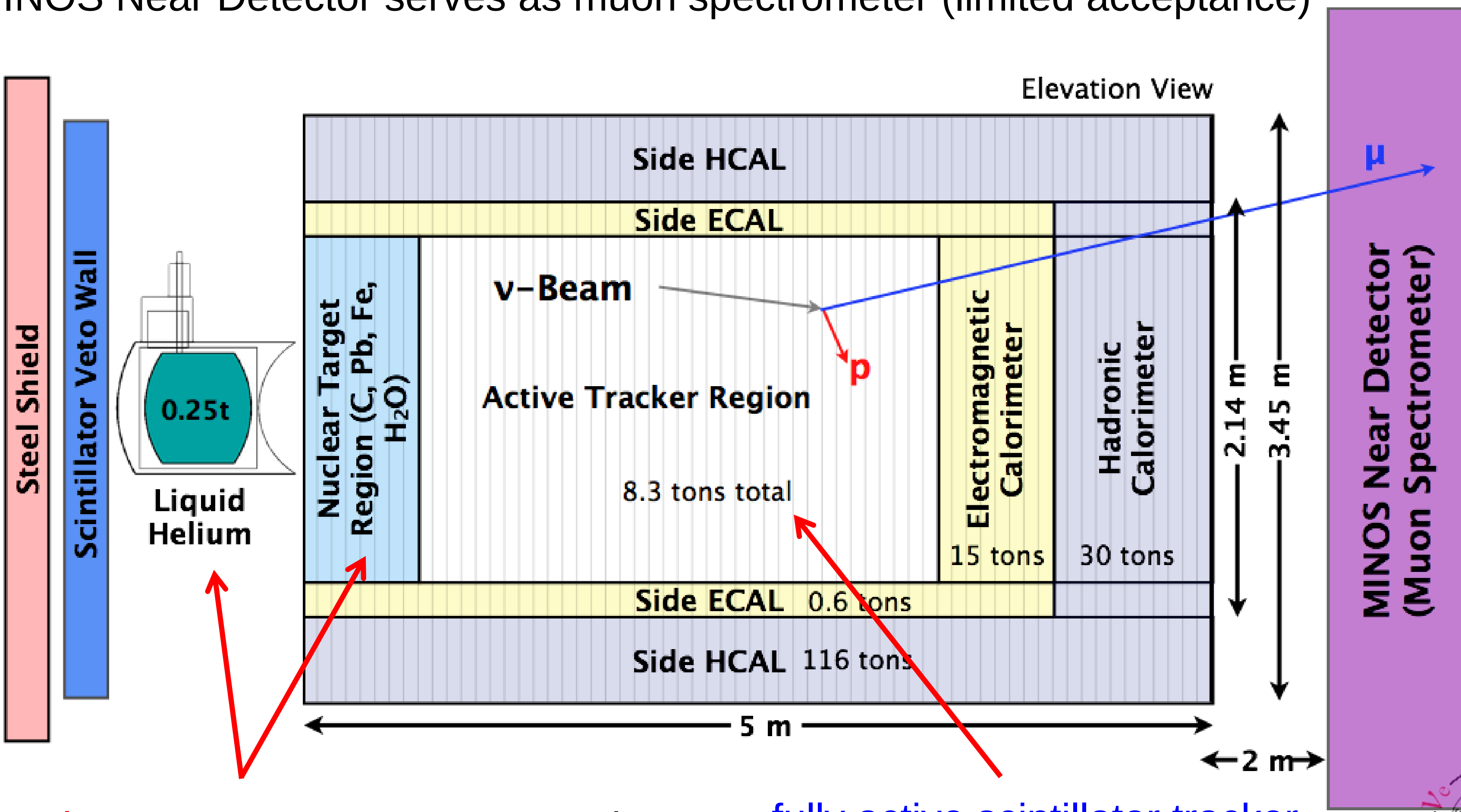
Alessandro Bravar
Université de Genève
for the Minerνa Collaboration

MINERνA Detector

MINERνA, NIM A743 (2014) 130

120 plastic fine-grained scintillator modules stacked along the beam direction for tracking and calorimetry (~32k readout channels with MAPMTs)

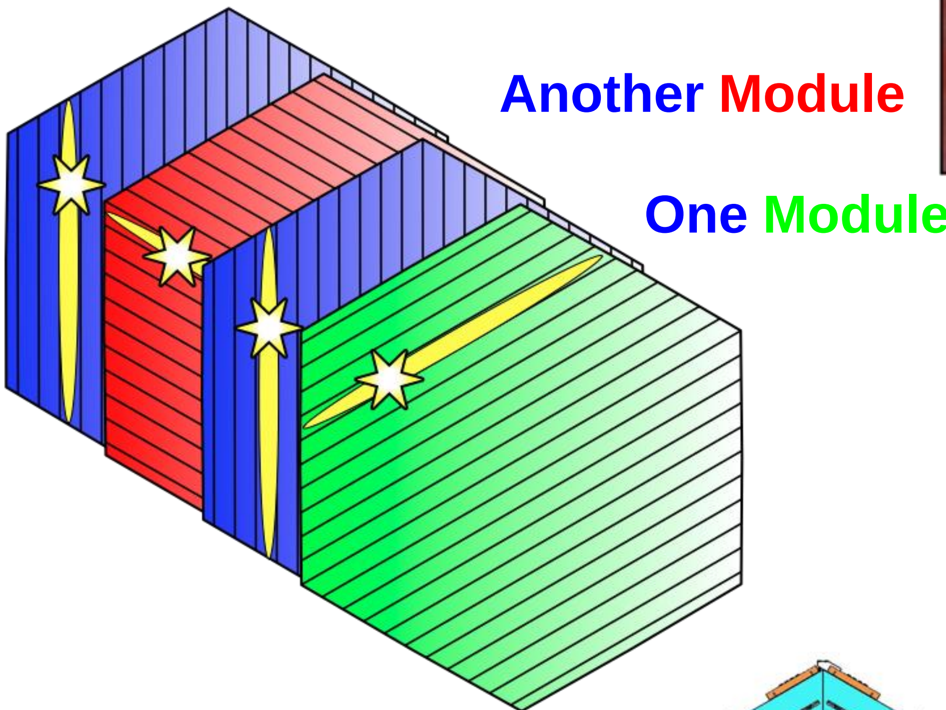
MINOS Near Detector serves as muon spectrometer (limited acceptance)

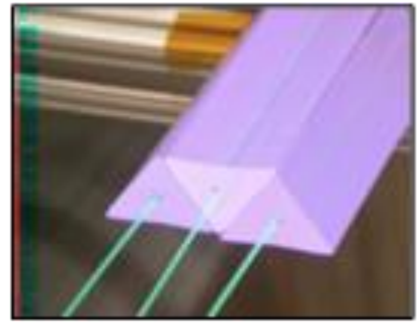


nuclear targets: He, C, $H_2$0, Fe, Pb in the same neutrino beam

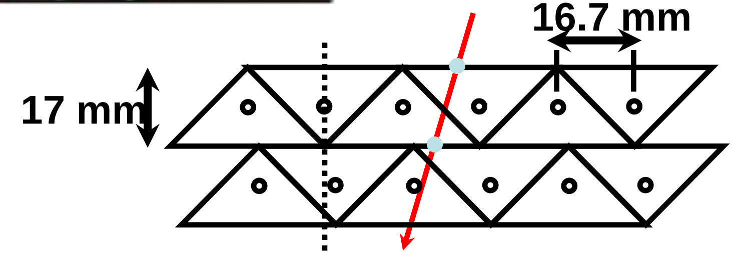
fully active scintillator tracker (x/v and x/u modules)

Detector Technology

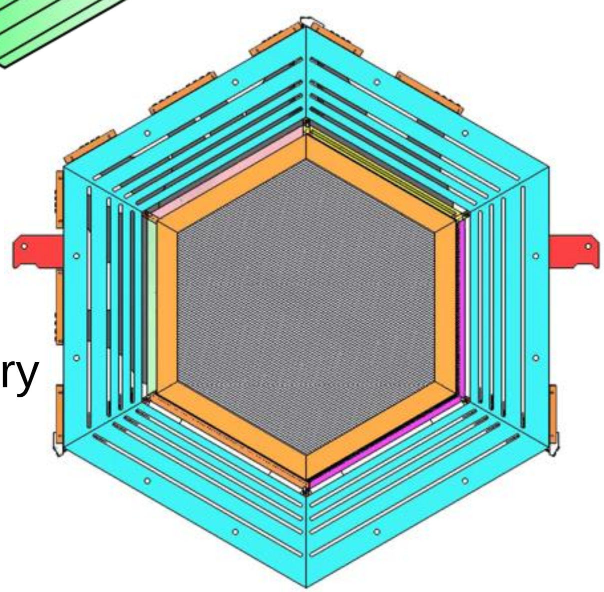




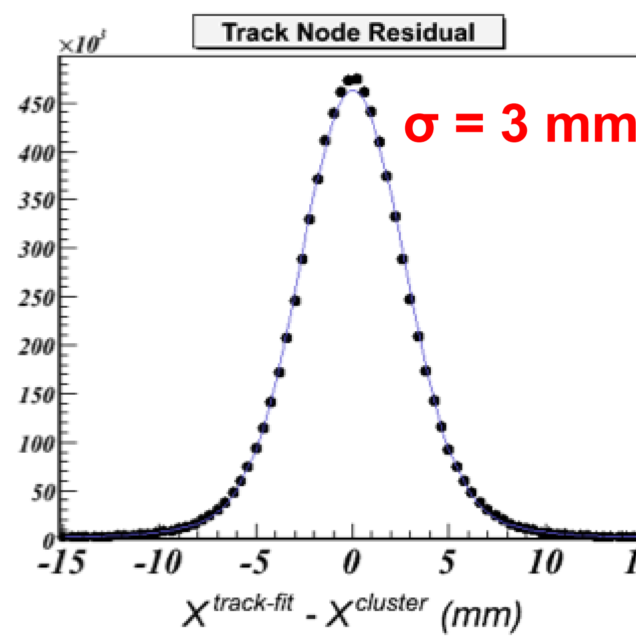
triangular scint. bars
with WLS fiber
and MAPMT readout



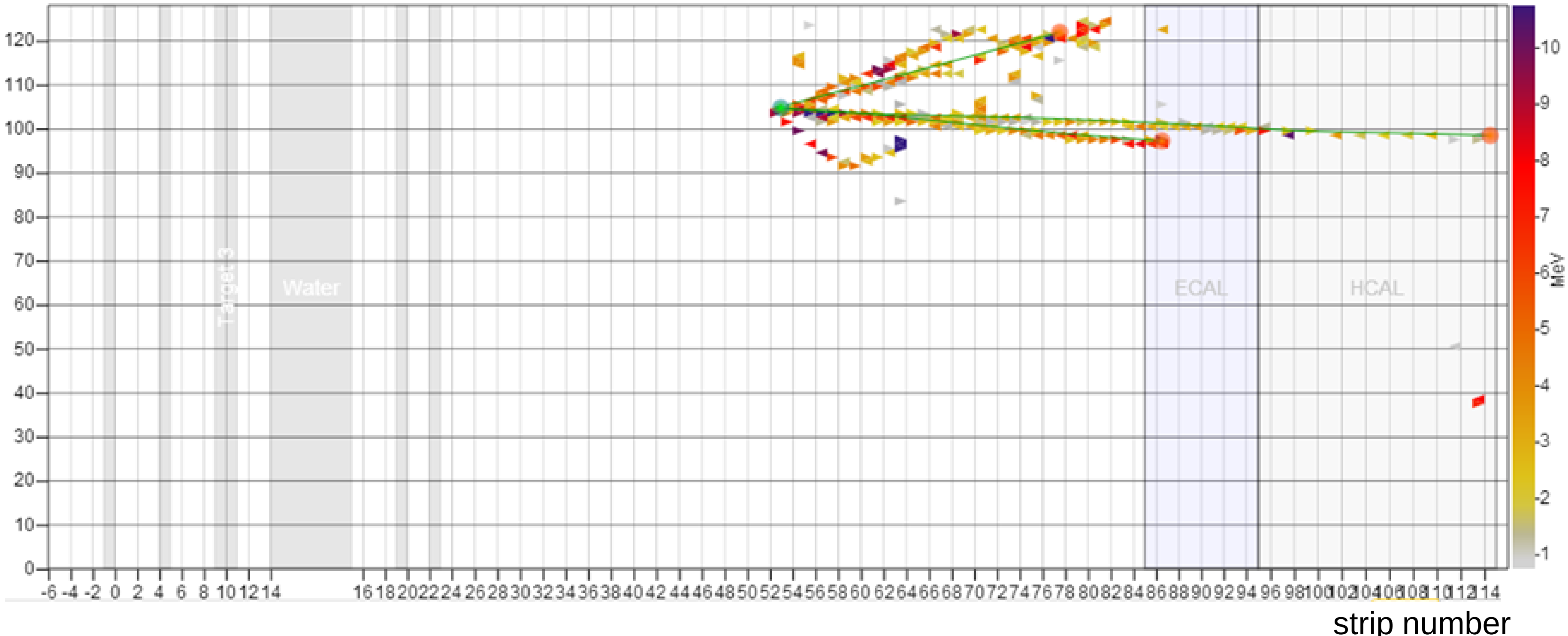
Charge sharing for improved position resolution (~3 mm) and alignment



Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry



MINERνA Event Display



Identification of outgoing muon track

Vertex activity

Identification of charged particles (p, π, K, e) and γ

Calorimetric reconstruction of recoil energy

$$\text{calorimetric } E_{\text{recoil}} = \alpha \times \sum_i c_i E_i$$

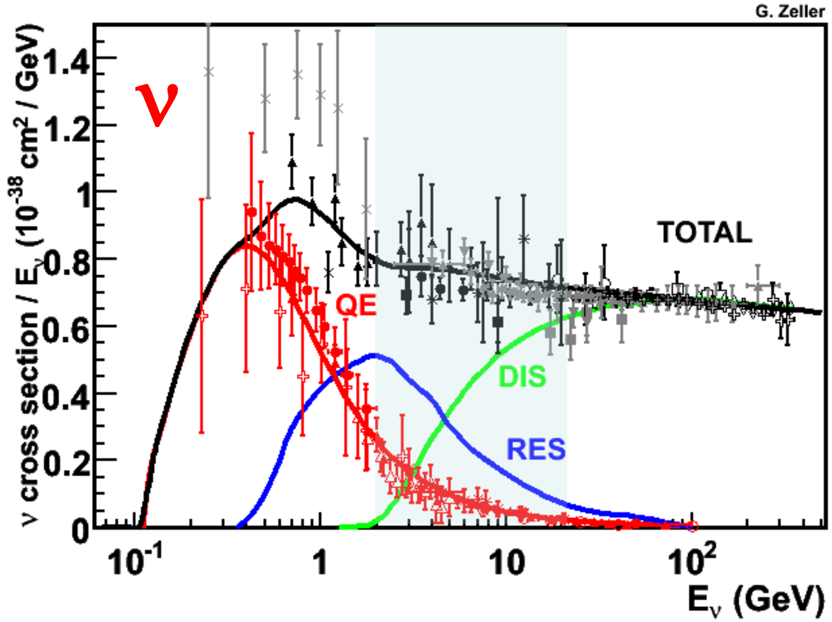
$$E_\nu = E_\mu + E_{\text{hadronic}}$$

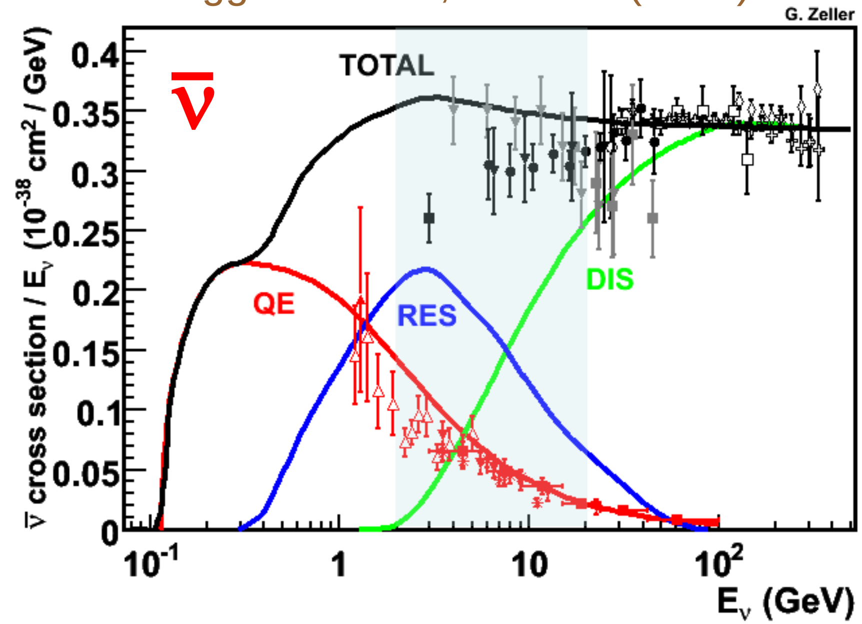
More selective identification of events

ν ×-sections

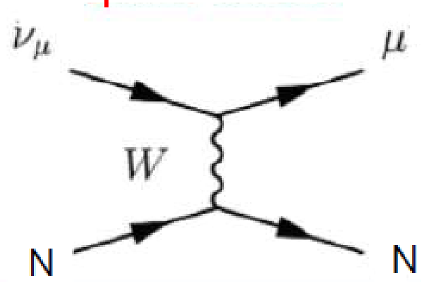
MINERνA measures ν – N interactions in the transition region from exclusive states to DIS

Formaggio & Zeller, RMP 84 (2012) 1307

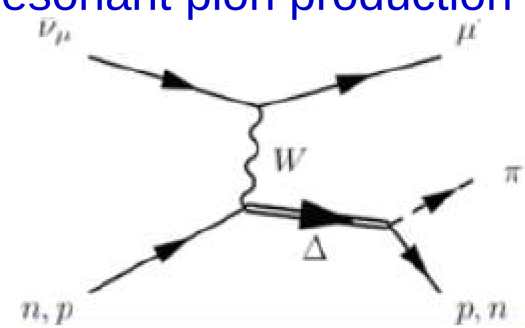




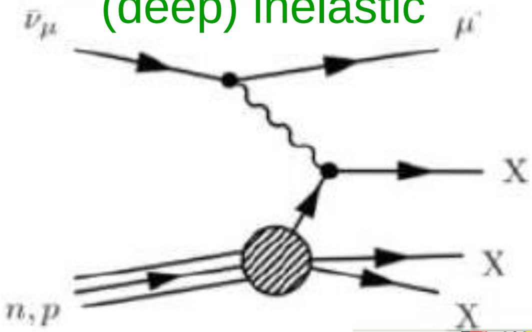
quasi-elastic



resonant pion production



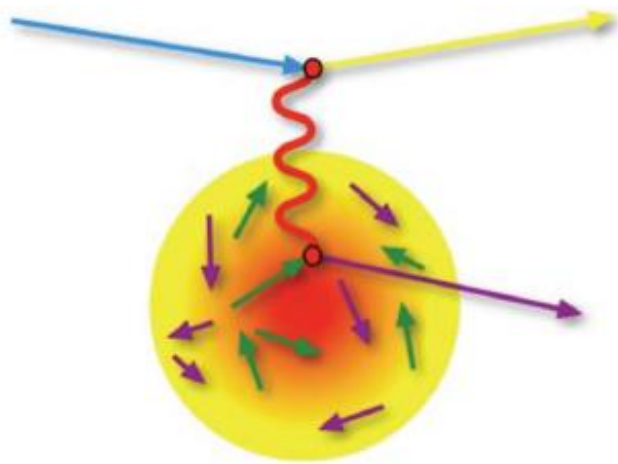
(deep) inelastic



elastic → inelastic

increasing E_ν, Q^2

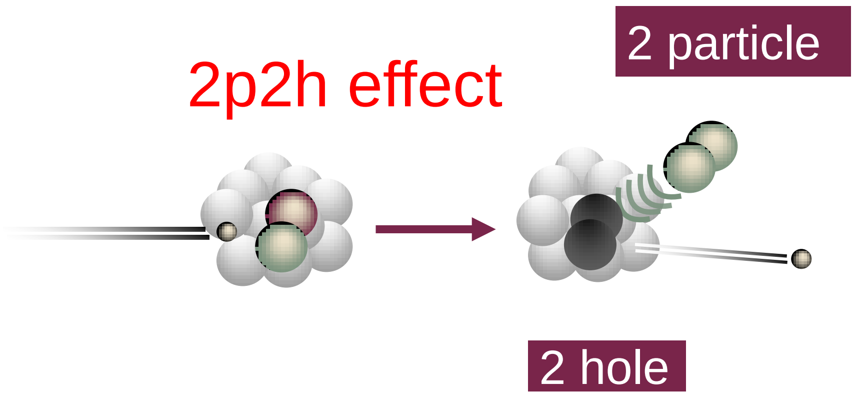
Don’t Forget the Nucleus!

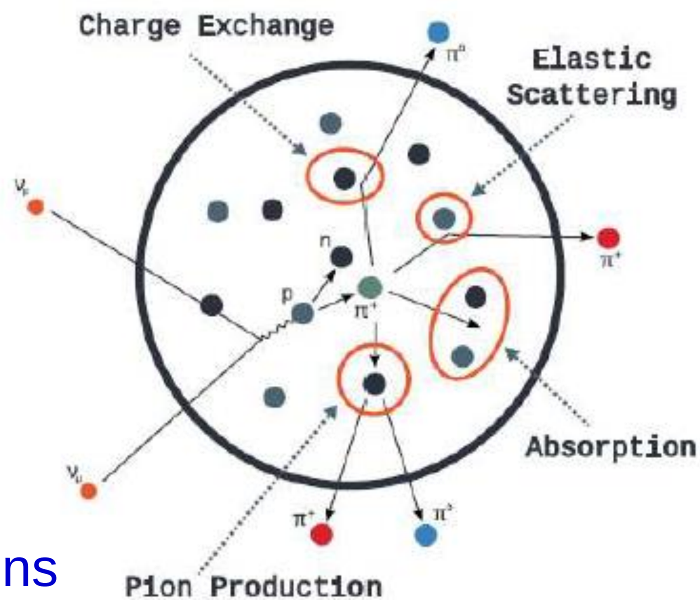


short range correlations and
medium range correlations
scatters off a pair of correlated nucleons – 2p2h effect

long range correlations – RPA effect

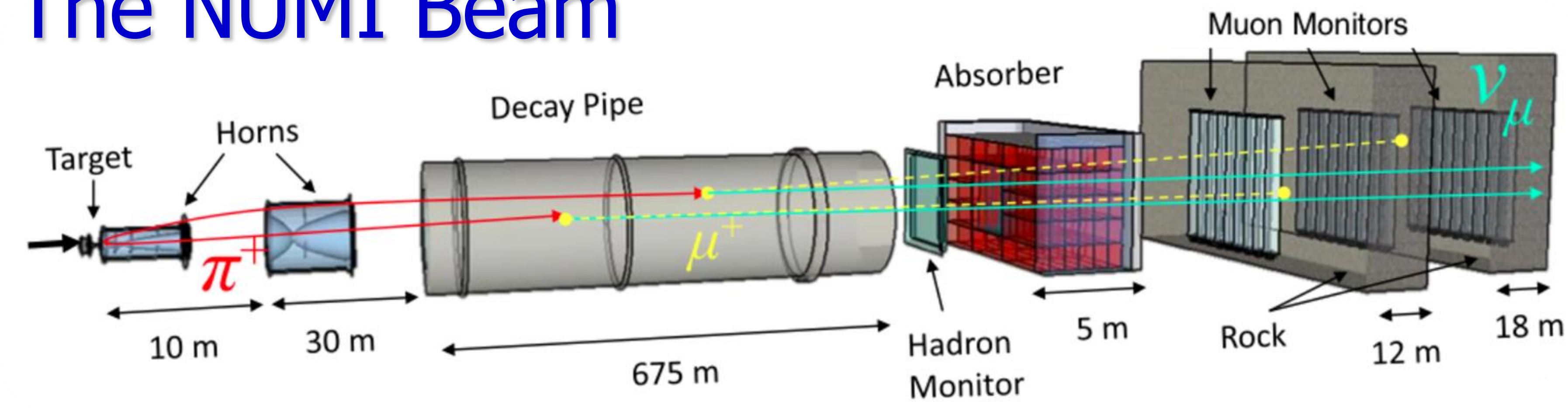
final state interactions
created particles have to work their way out of the nucleus





big source of uncertainties in neutrino interactions
Minerνa tries to provide information on all these effects

The NUMI Beam

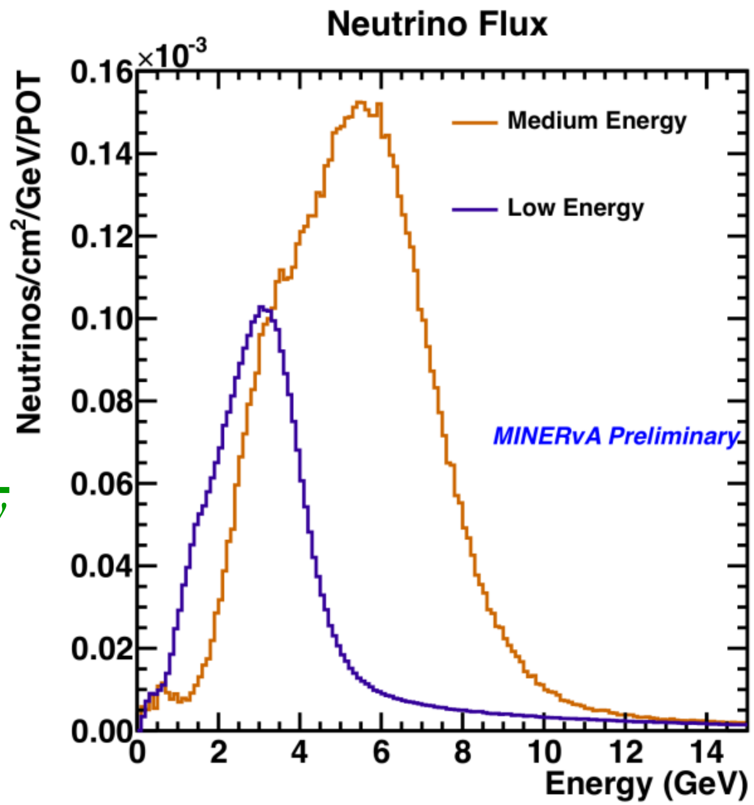


NuMI (Neutrinos at the Main Injector)
120 GeV protons from Main Injector, ~650 kW

By moving the production target w.r.t. 1st horn and changing the distance between the horns one can modify the ν spectrum:
LE (peak ~3 GeV) → ME (peak ~6 GeV)

LE data taking completed in 2012 (ν and $\bar{\nu}$)
Since 2013 running in ME mode, 20/02/17 started $\bar{\nu}$

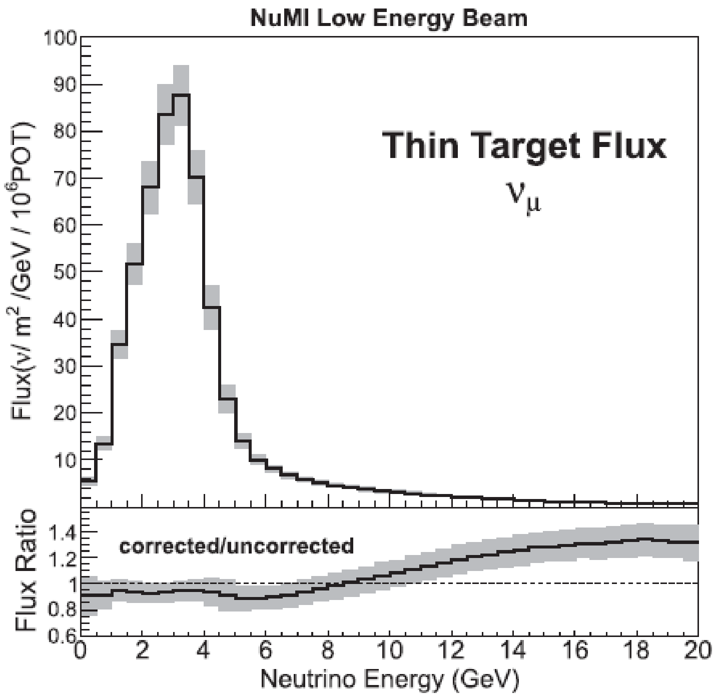
Flux determination
external hadron production data
ν – e elastic scattering
low–ν extrapolation
special runs (vary beam configuration)

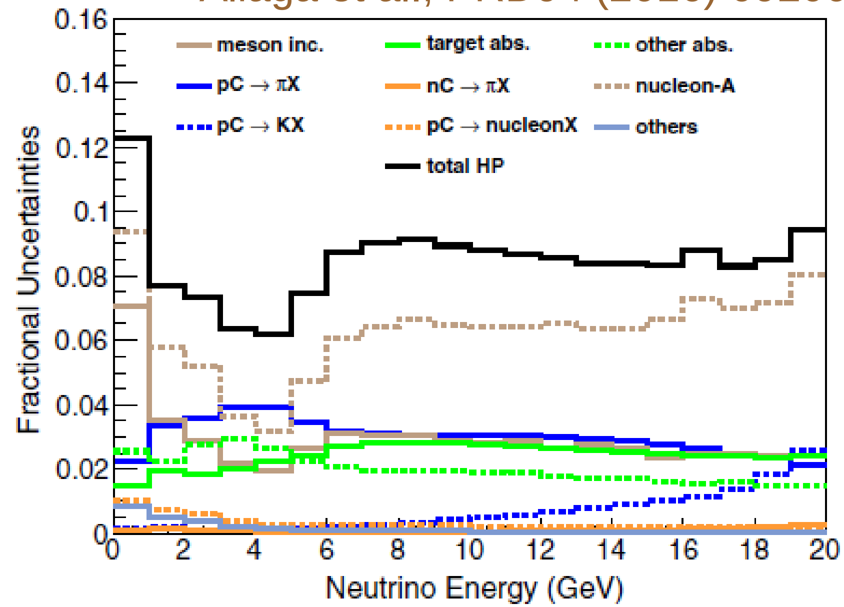


ν Flux and Uncertainties

Extensive revision of the NuMI beamline simulation

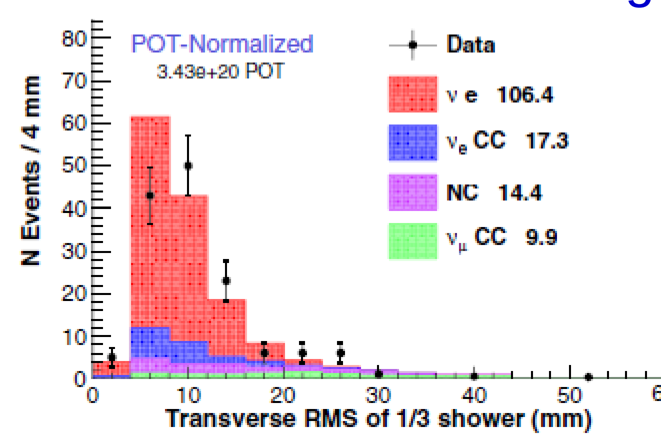
Aliaga et al., PRD94 (2016) 092005





Park et al., PRD93 (2016) 112007

in situ νe elastic scattering



Focusing uncertainties
Hadronic interactions
Absorption in the beamline
Constraining the simulation
Thin target pion production (NA49)
NuMI target pion production (MIPP)

Low-ν Method

Charged-current scattering with low hadronic recoil energy ν (sub-set of all events) is flat as a function of E_ν

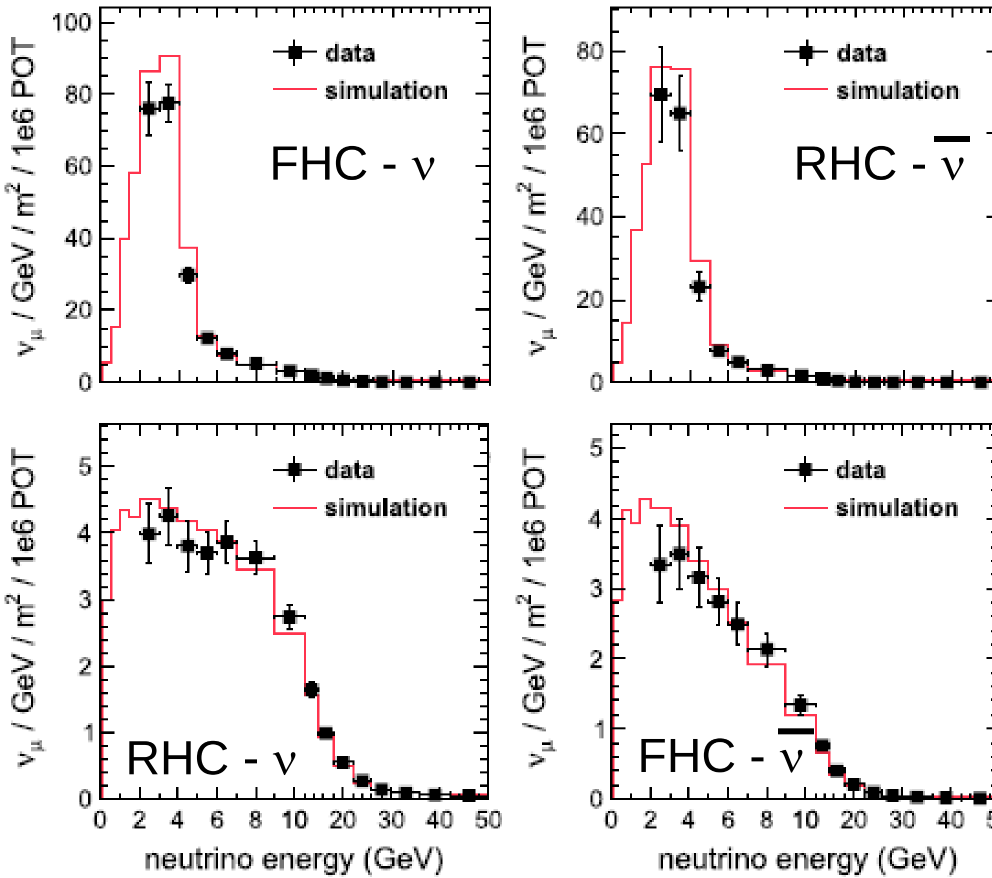
$$\frac{d\sigma}{d\nu} = A\left(1 + \frac{B}{A}\frac{\nu}{E_\nu} - \frac{C}{A}\frac{\nu^2}{2E_\nu^2}\right)$$

where A, B, and C depends on Integrals overs structure functions

Gives a measurement of the flux shape

Flux is normalized so that the extracted inclusive cross section matches an external measurement at high neutrino energy

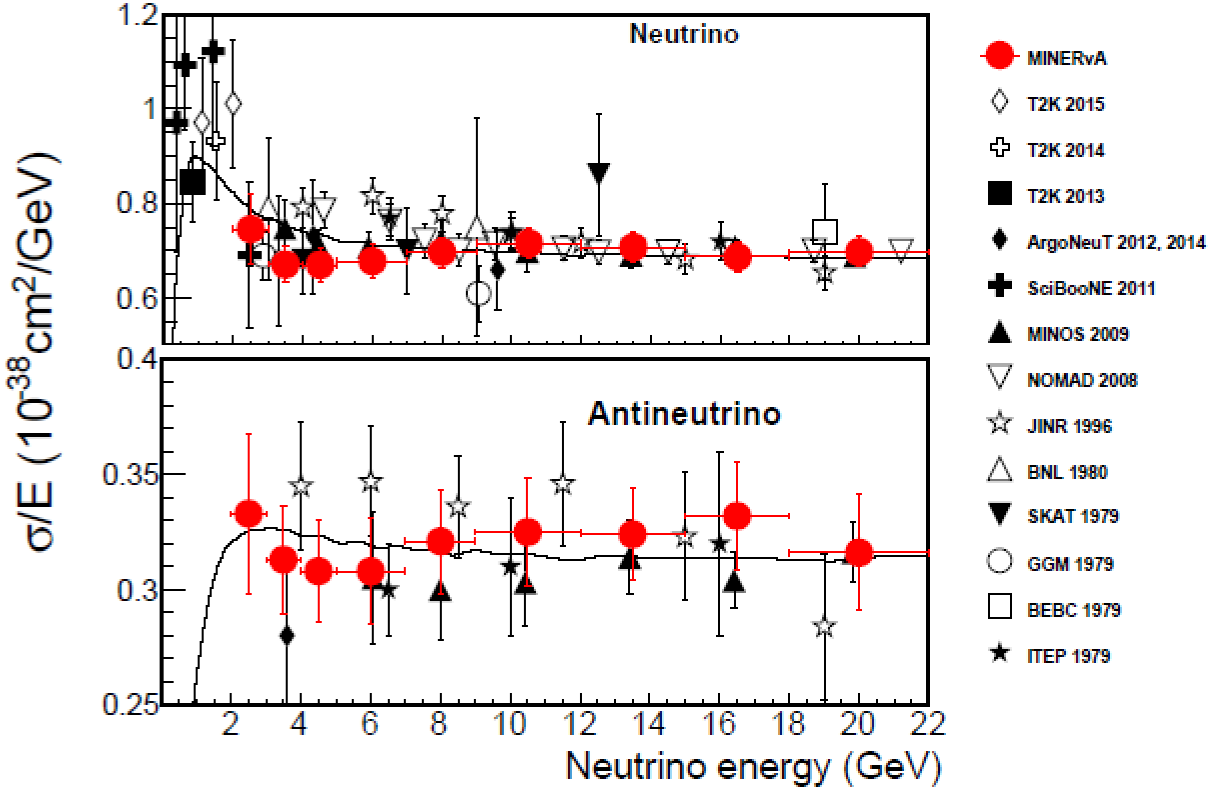
Devan et al., PRD94 (2016) 112007



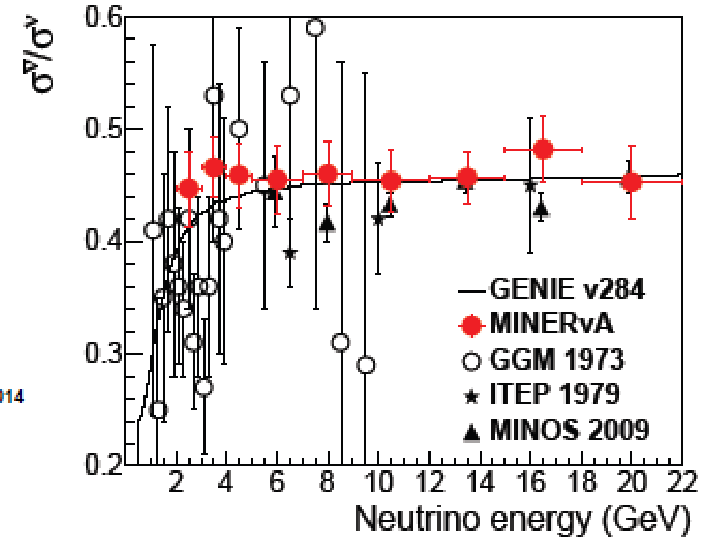
low ν-flux compared to flux simulations

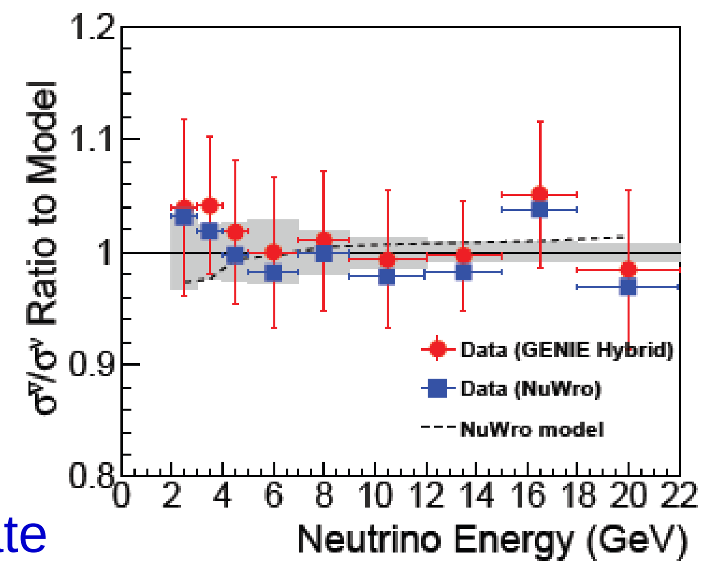
$\bar{\nu}$ and ν CC Interaction ×-sections

Ren et al., arXiv:1701.04857



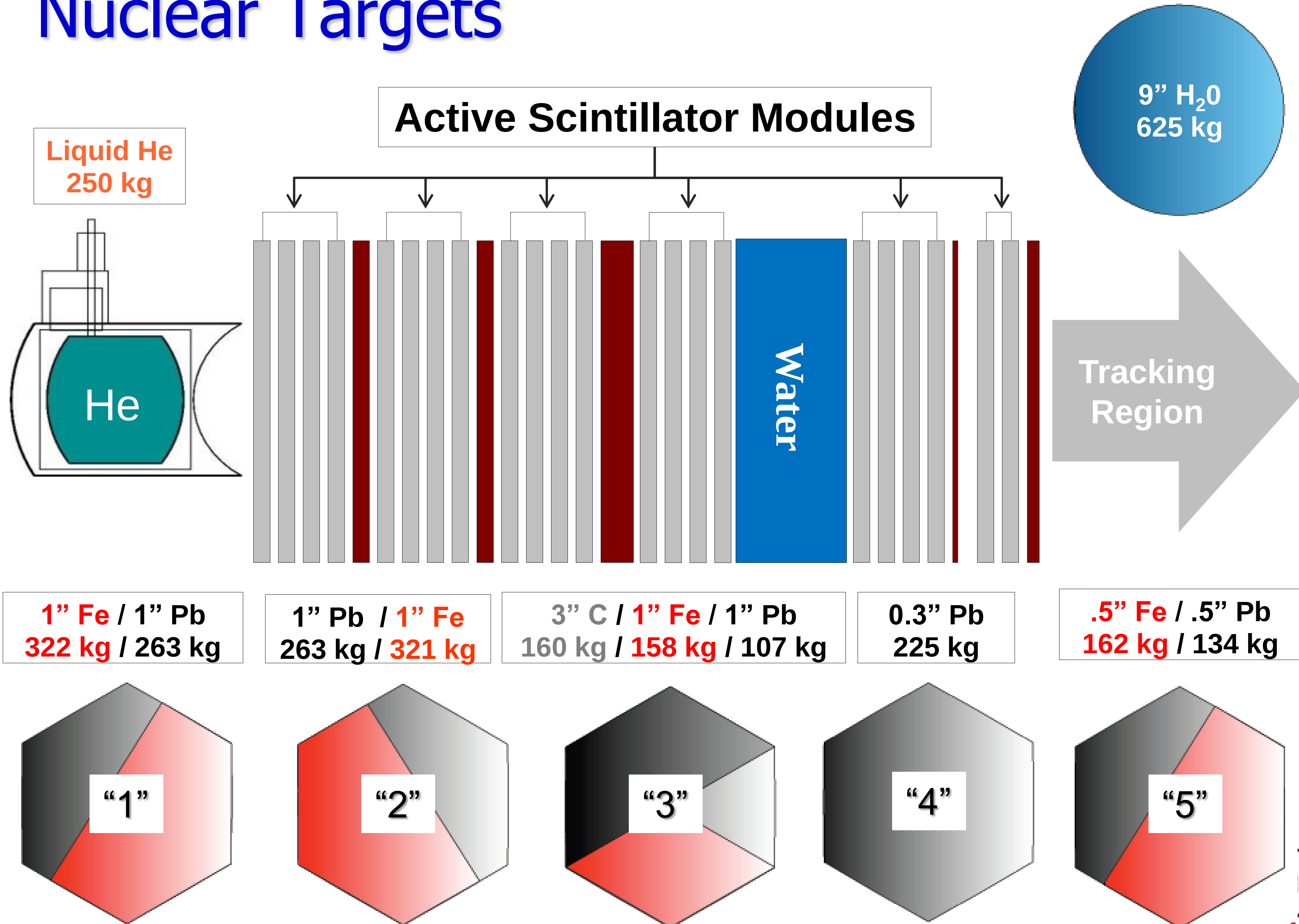
reference curve shows the prediction of GENIE 2.8.4





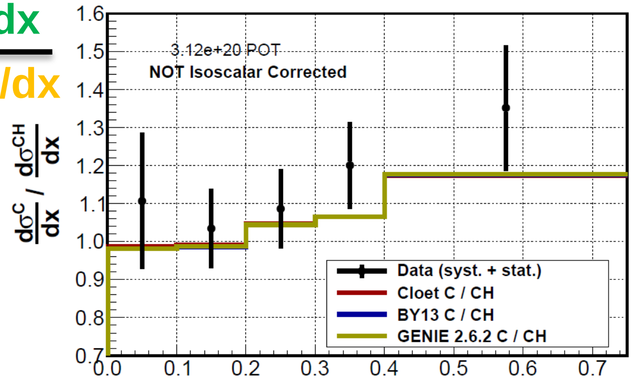
GENIE and NuWro generators slightly overestimate the measured CC cross sections at low E_ν

Nuclear Targets

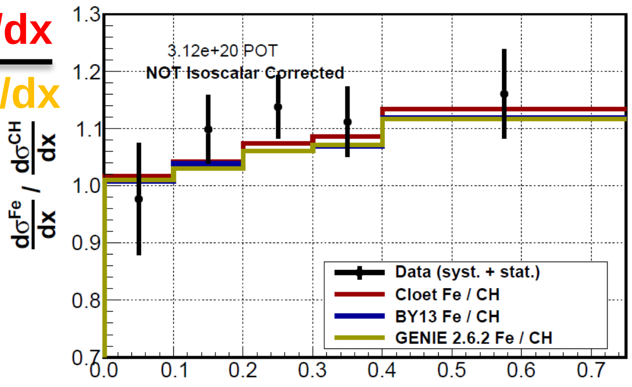


DIS Cross Section Ratios – $d\sigma / dx_{Bj}$

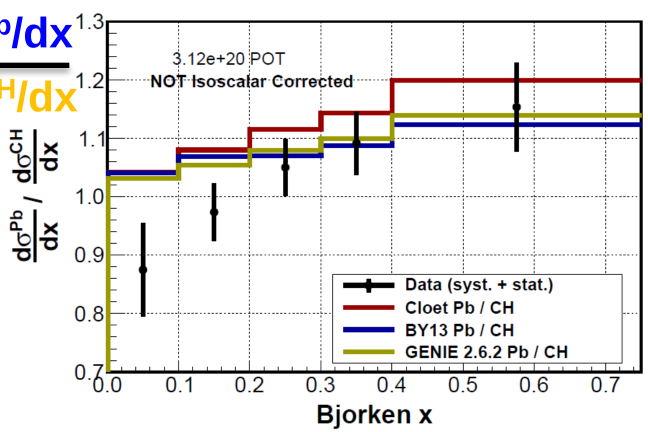
$\frac{d\sigma^{C}/dx}{d\sigma^{CH}/dx}$



$\frac{d\sigma^{Fe}/dx}{d\sigma^{CH}/dx}$



$\frac{d\sigma^{Pb}/dx}{d\sigma^{CH}/dx}$



Mousseau et al., PRD93 (2016) 071101

DIS selections
- $Q^2 > 1$ GeV^2
- $W > 2.0$ GeV
- 5 GeV < E_ν < 50 GeV (HE tail of LE beam)

Unfolded x (detector smearing)
Not corrected for n excess (isosclar correction)

“Simulation” based on nuclear effects observed with electromagnetic probes

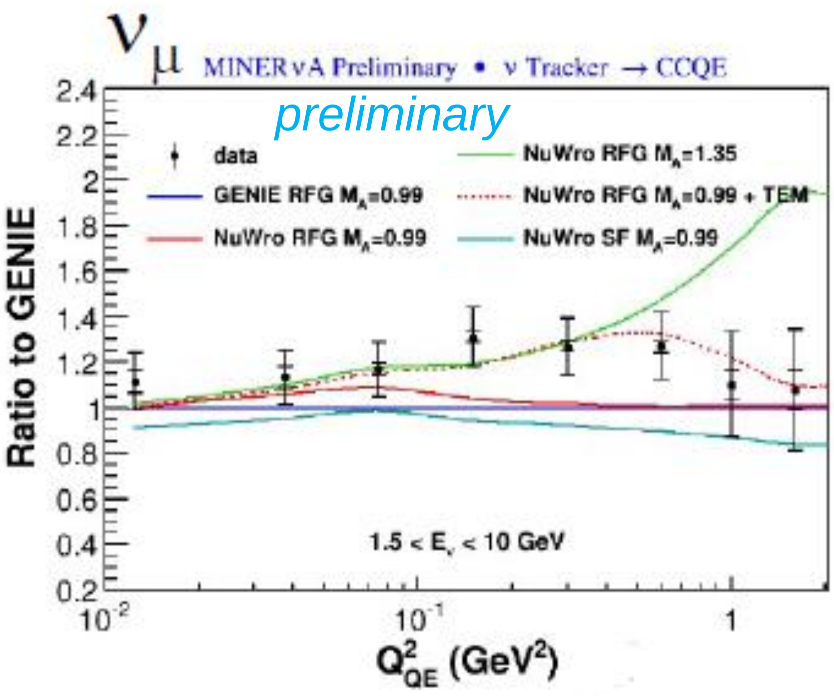
Observe no neutrino energy dependent nuclear effect

In EMC region (0.3 < x < 0.7) agreement between data and models

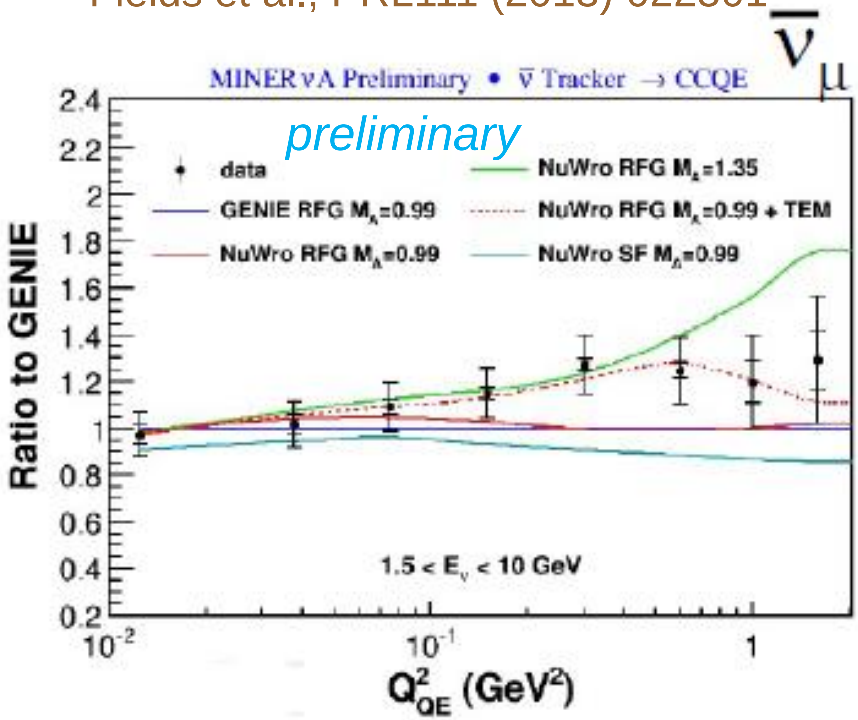
Data suggests additional nuclear shadowing in the lowest x bin ($\langle x \rangle = 0.07$, $\langle Q^2 \rangle = 2$ GeV^2)

Flux Updated CCQE-like ν and $\bar{\nu}$ Results

Fiorentini et al., PRL111 (2013) 022502



Fields et al., PRL111 (2013) 022501

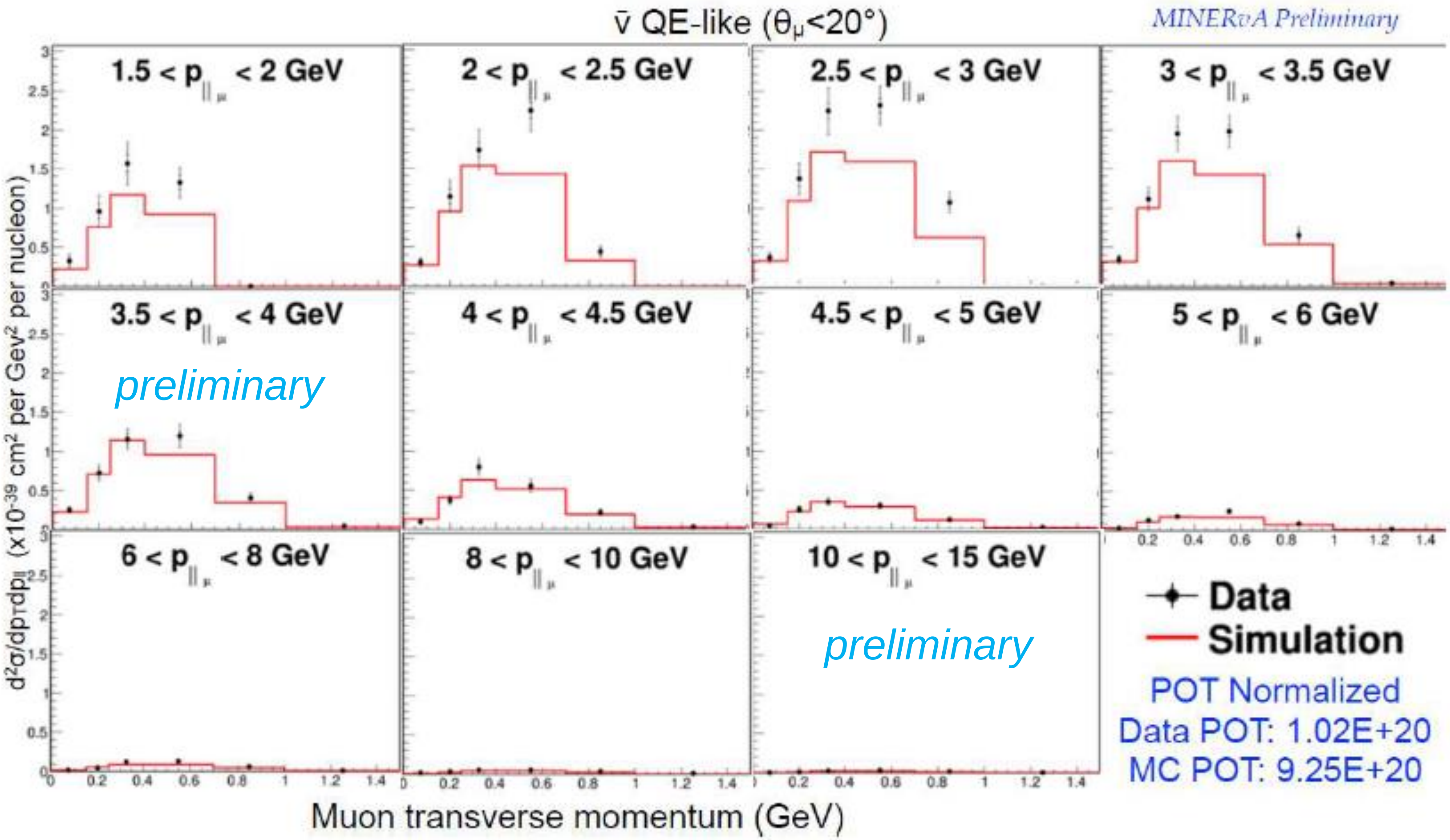


Both results prefer a model with 2p2h enhancement

fills in low Q^2 RPA suppression
increases cross section in the $0.1 < Q^2 < 1$ GeV^2 region
does not increase like the modified M_A prediction does at high Q^2

Double Differential $\overline{\nu}$ CCQE-like Analysis

double differential in muon transverse and longitudinal momentum



Improved reconstruction and systematics WRT prior publications

Data indicates extra strength at moderate transverse momenta

A New Way to Study QE

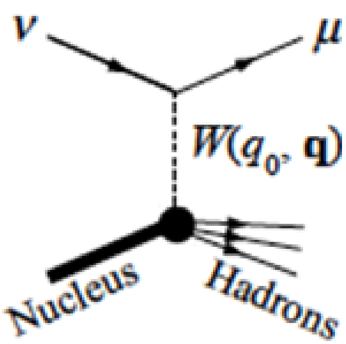
Look at inclusive scattering in 2 kinematic dimensions

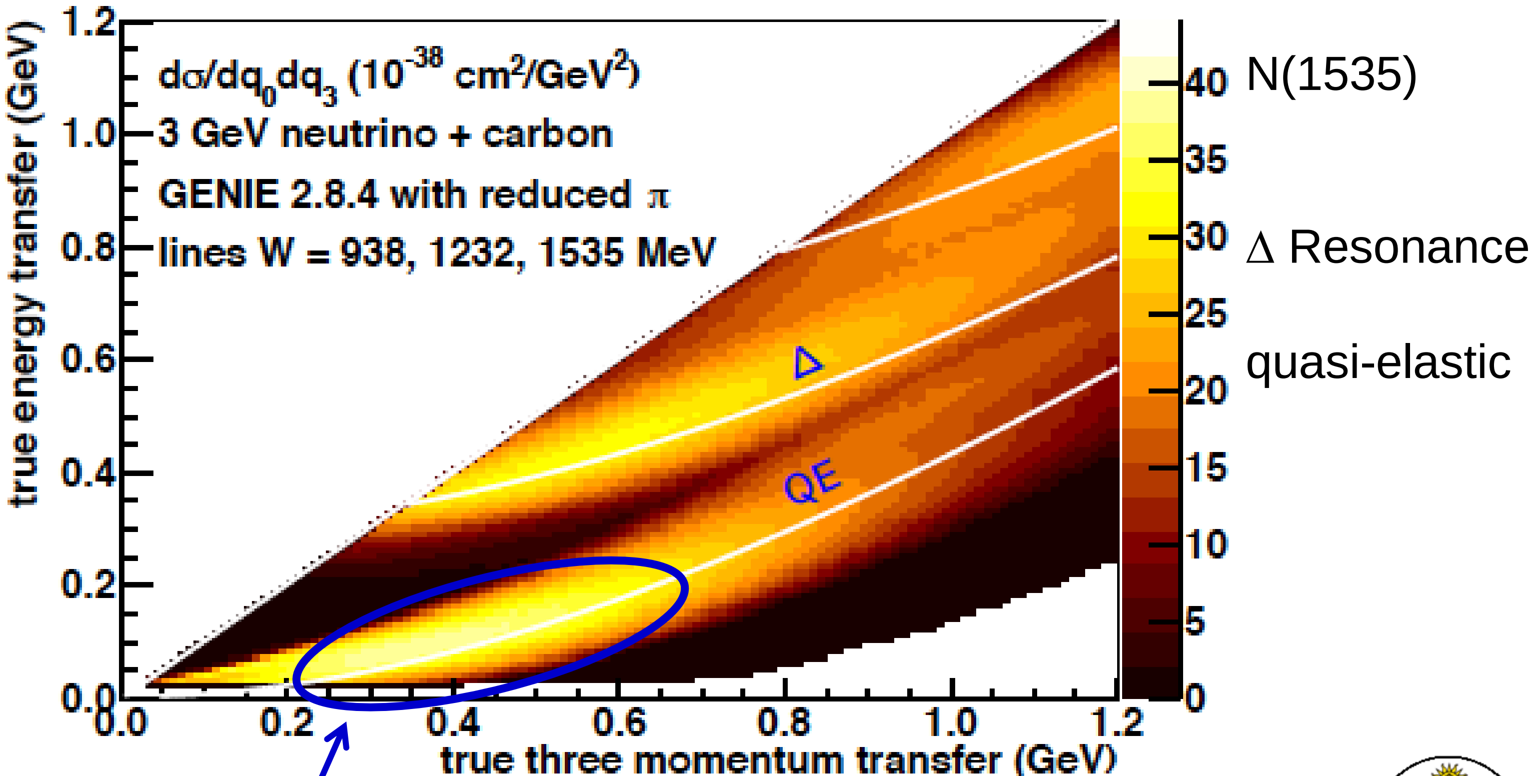
(do not cut on the recoil but look at the low recoil in an inclusive sample)

Separate Q^2 into energy transfer q_0 and 3-momentum transfer $\mathbf{q}_3$

Just looking at $d\sigma / dQ^2$ integrates across the "bands" hiding details

bands in the q_0 – $\mathbf{q}_3$ plot show different scattering channels

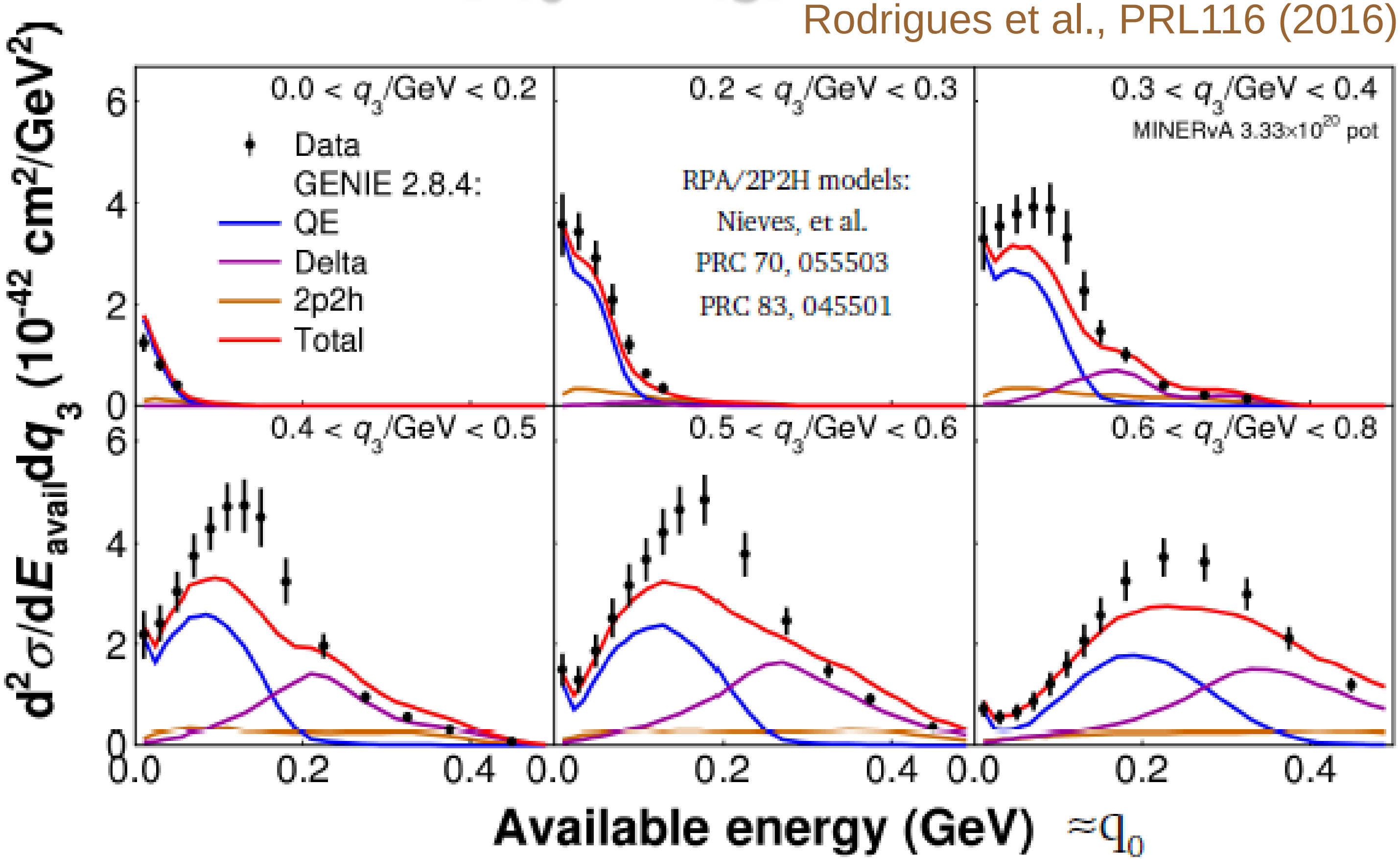




models of scattering off two nucleons
tend to increase the cross-section in this area

ν_μ Data in the $(q_0 - q_3)$ Plane

Rodrigues et al., PRL116 (2016) 071802



$$E_{\text{avail}} = \sum \text{p and } \pi^{\pm} \text{ K.E.} + \text{total energy of all other particles except n}$$

Adding in models RPA (a charge screening nuclear effect) and 2p2h processes improves agreement in some regions, but not in others (not strong enough to cover the observed rates).

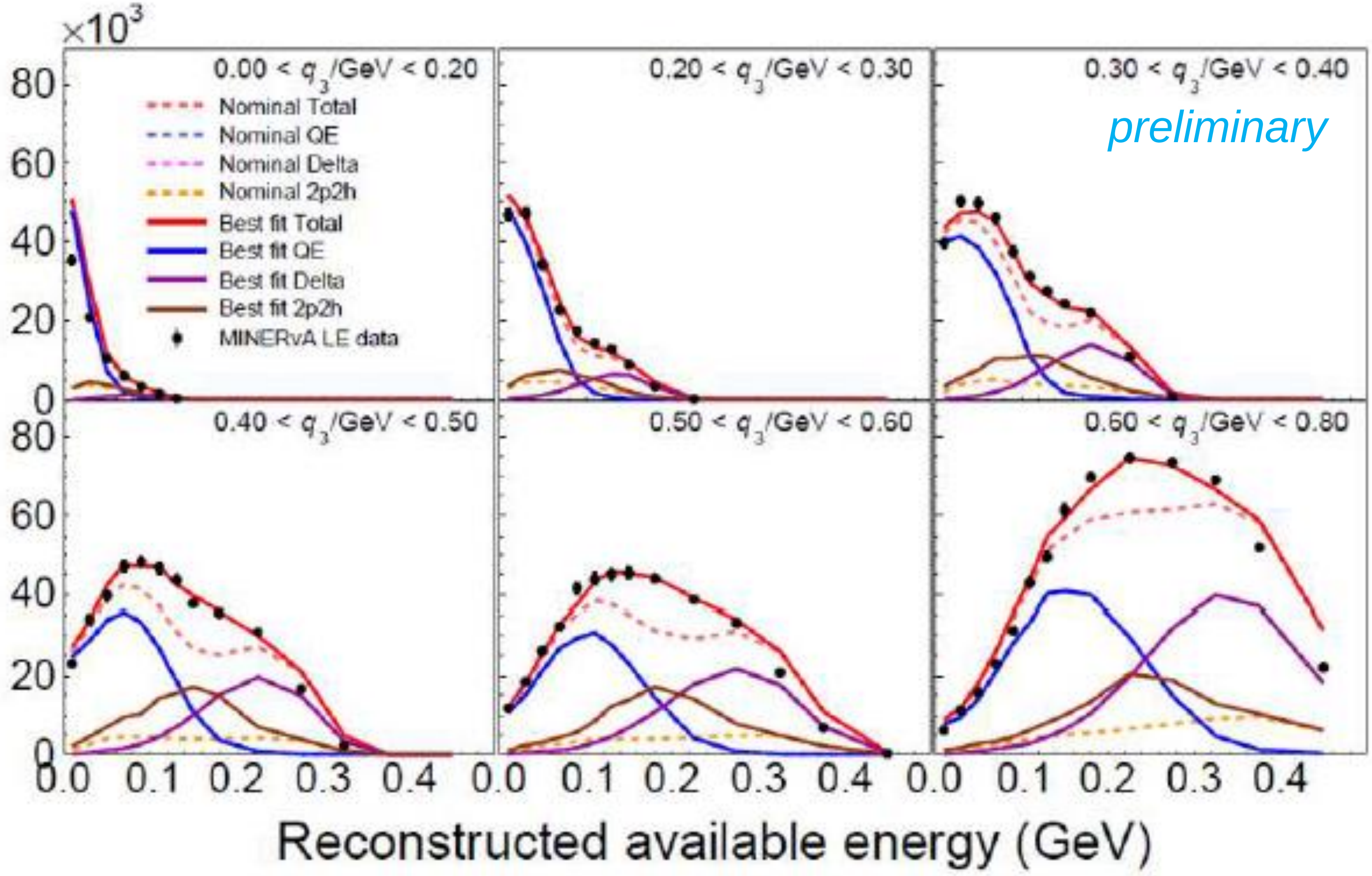
Excess in similar kinematic region to excess in antineutrino CCQE

The Low Energy Recoil Fit

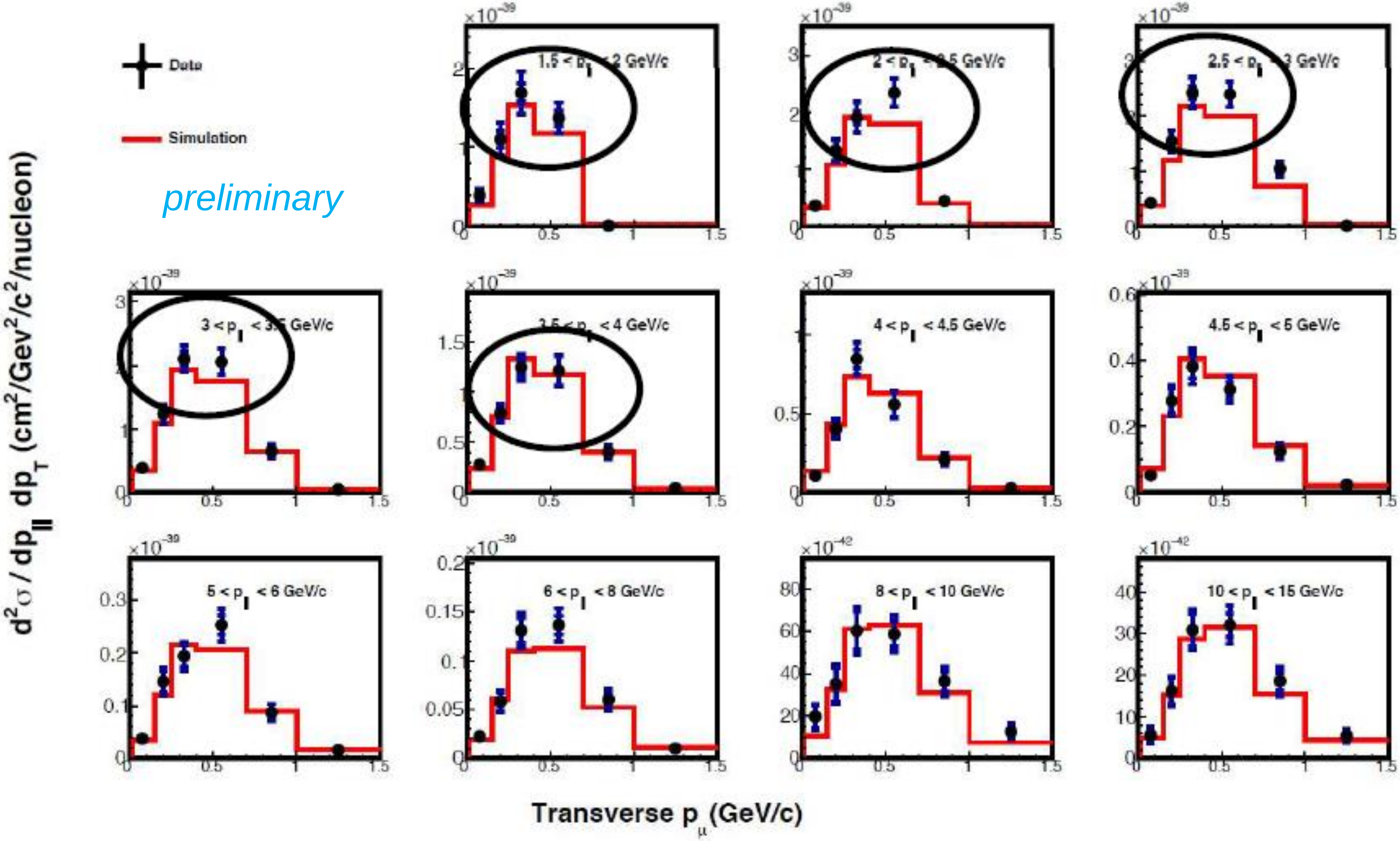
fit a 2D Gaussian in true (q_0, q_3) as a reweighting function to the 2p2h contribution to get the best agreement

does not scale true QE or resonant production

⇒ modified simulation which represents inclusive data quite well

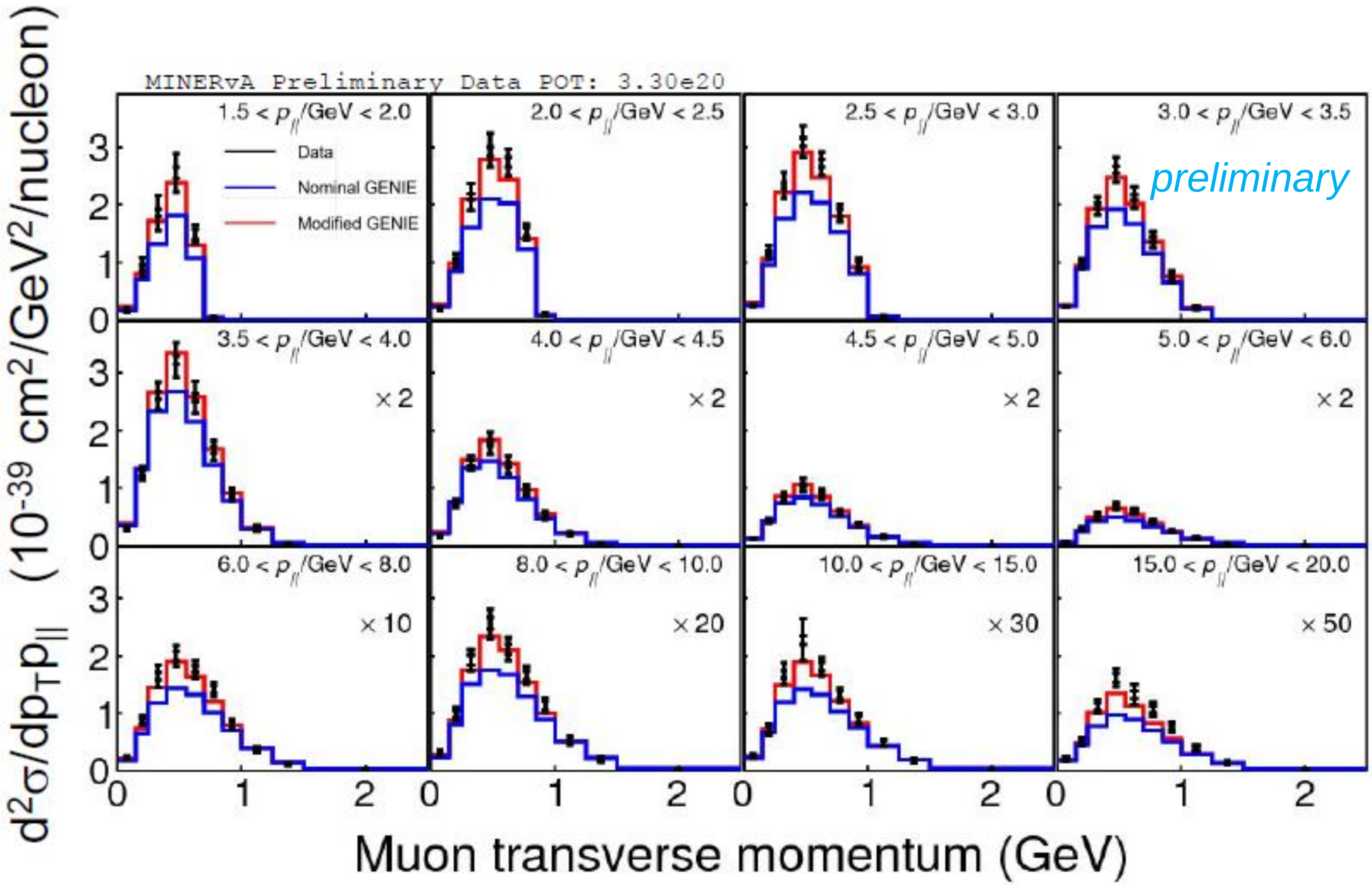


Back to Exclusives – CCQE-like $\overline{\nu}$



The reweight from the inclusive neutrino fit gives improved agreement with the antineutrino QE-like result!

Back to Exclusives – CCQE-like ν



The reweight from the inclusive neutrino fit gives improved agreement with the neutrino QE-like result!

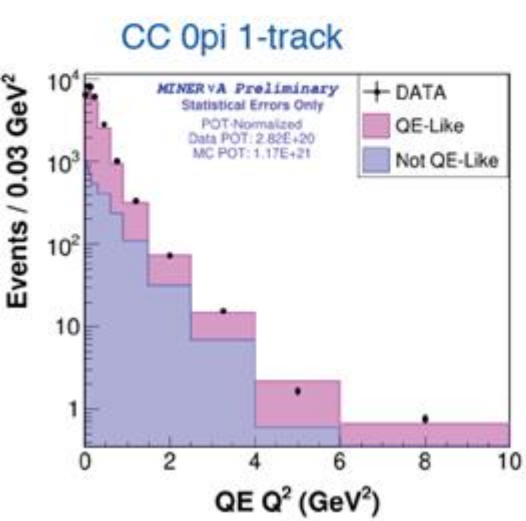
Outlook

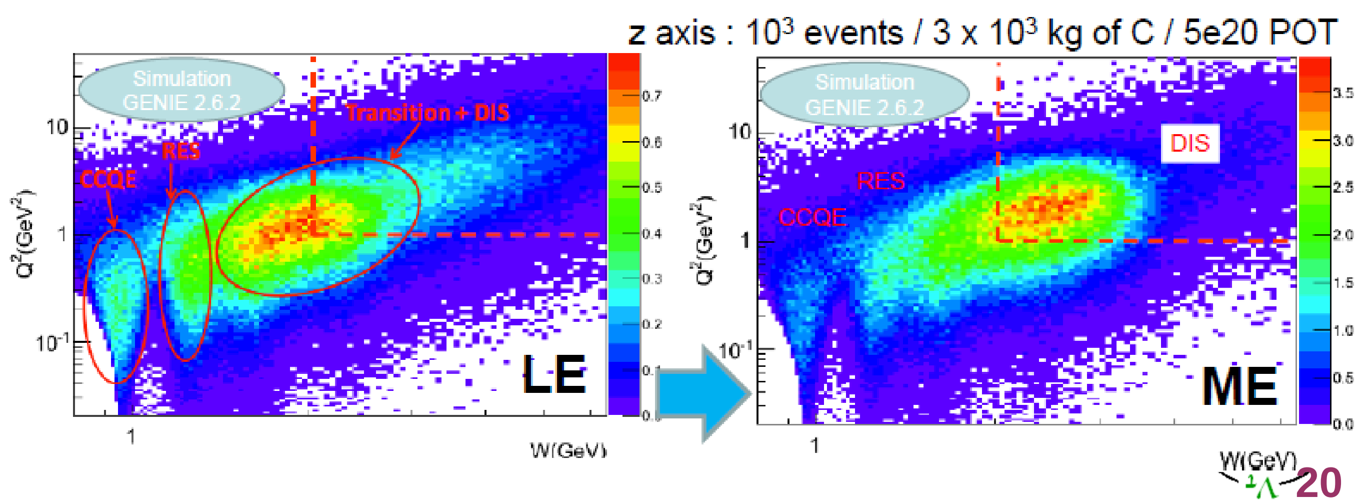
MINERνA provides measurements for a variety of neutrino induced processes.
Today we saw only inclusive and CCQE-like channels.
New first time measurements also on π and K production.

MINERνA data helps improve model descriptions.
Current models do not fully describe MINERνA data yet.
Able to differentiate between nuclear models – they favor a 2p2h component

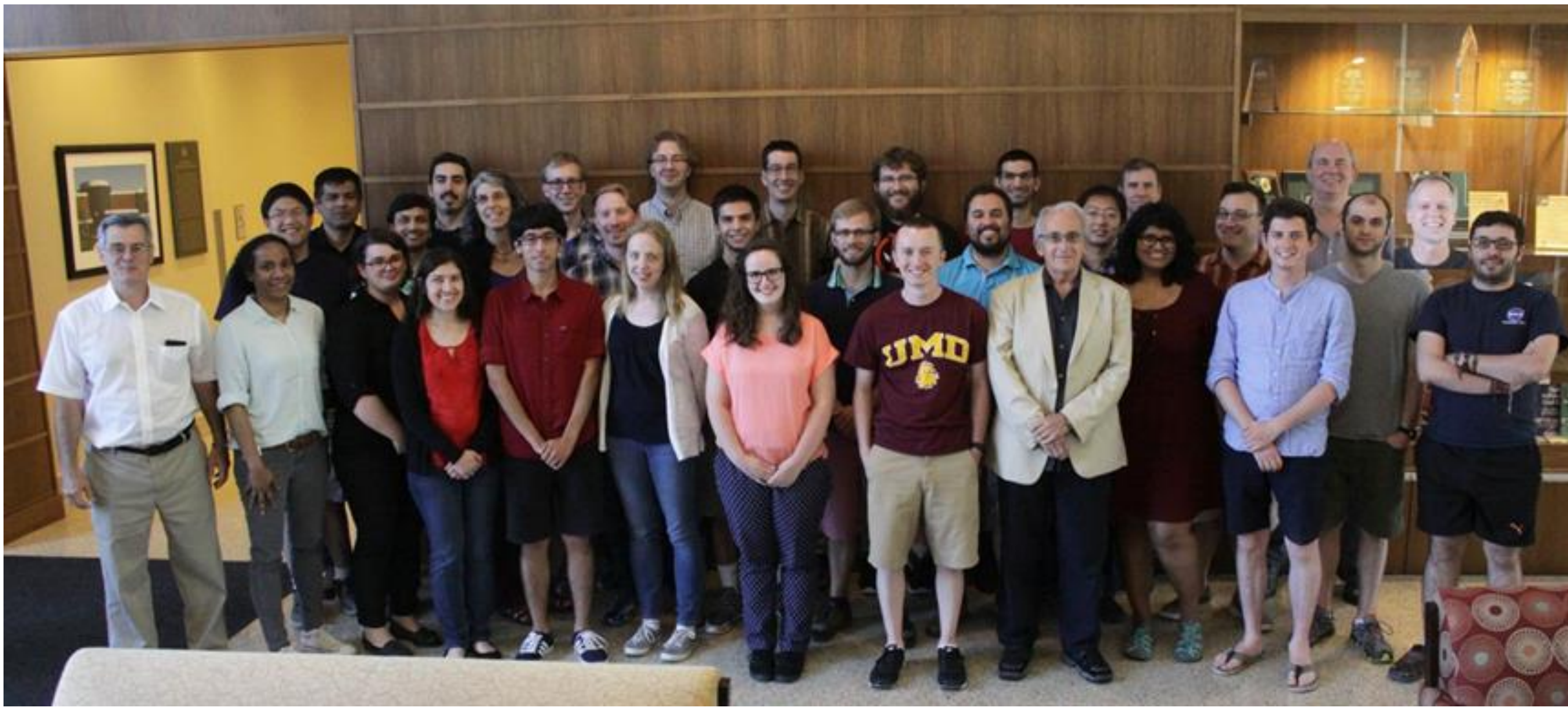
Data taking with a "Medium Energy" ν beam started in fall 2013,
switched to anti-neutrino mode on Feb. 20.

Increased kinematic coverage, LE data able to reach $Q^2 \sim 2\ GeV^2$

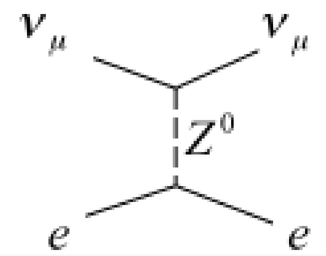




The MINERνA Collaboration

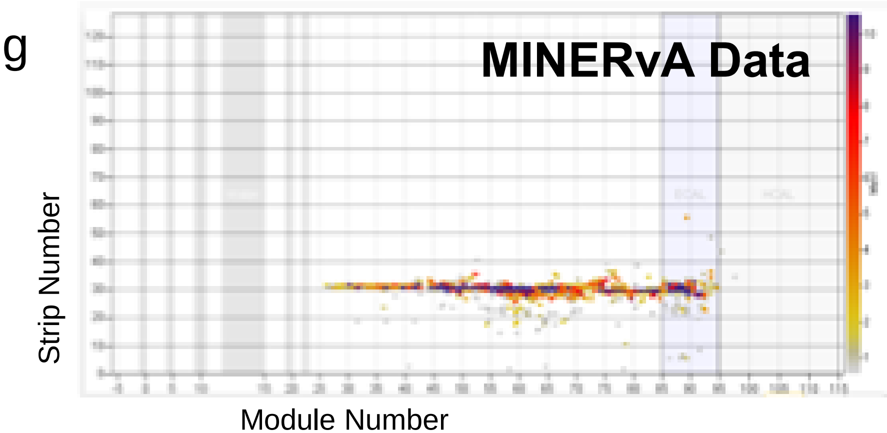


Flux from ν on e scattering



Signal is a single electron moving in beam direction

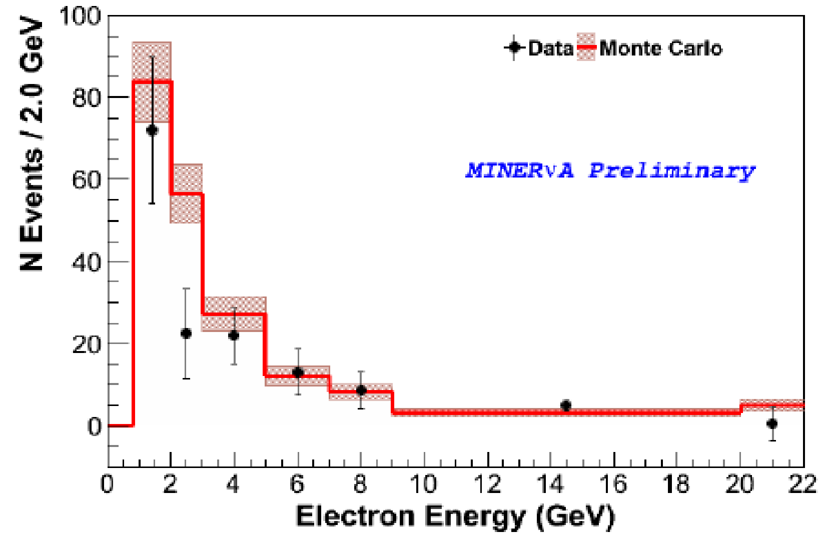
- Purely electro-weak process
- x-section is smaller than nucleus scattering
  - by ~2000
- 123 ±17(stat) ±9(syst) events



Park et al., PRD 93 (2016) 112007

Independent *in situ* flux constraint

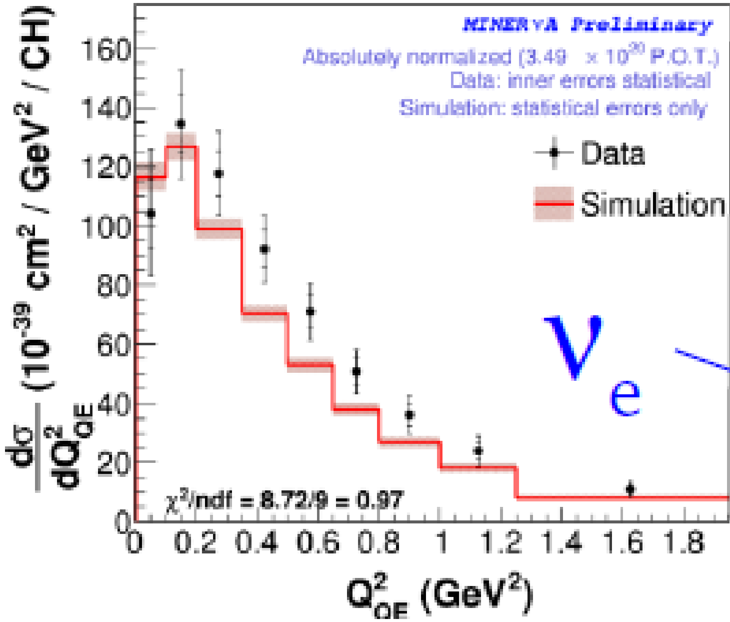
- Important proof of principle for future experiments
- Statistically limited in the MINERvA LE sample (~8% error)
- Results are consistent with new flux calculations
- Results are consistent with the *a priori* flux (~2%) and with the low *ν* flux



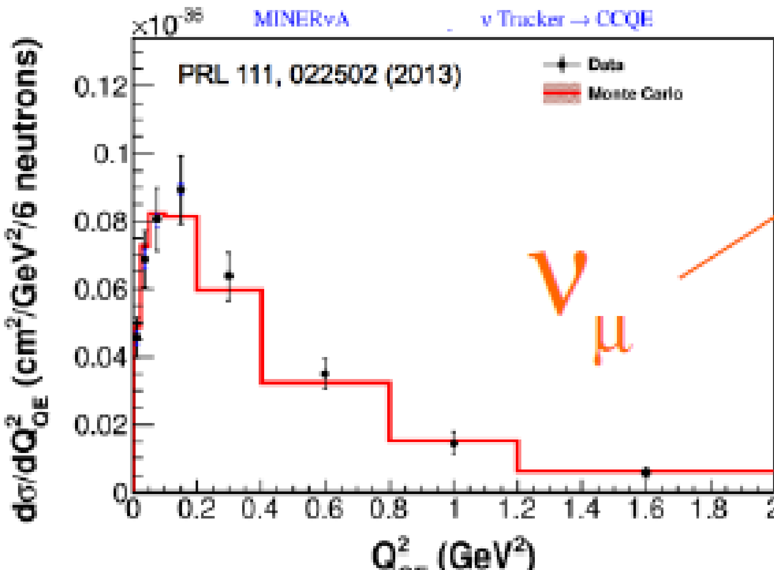
Further confidence in flux!

3 independent methods yield consistent results

ν_e vs. ν_μ



ν_e



ν_μ

Walcott et al., PRL116 (2016) 081802