Quasi-elastic scattering results at a few GeV

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Results from NOMAD

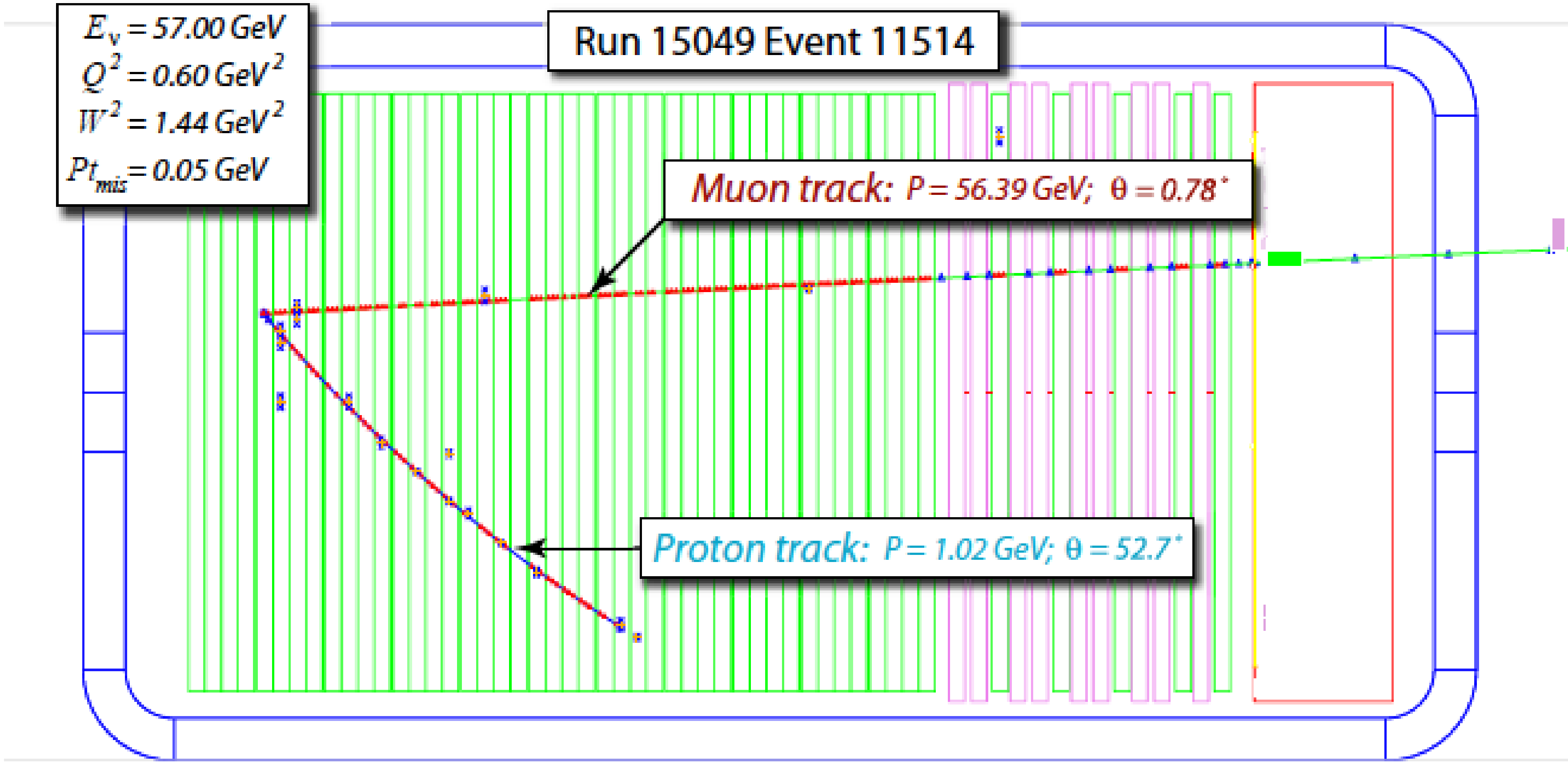
Preliminary result from MINOS

Discussion and looking forward

NuFact09, Illinois Institute of Technology, July 2009

NOMAD quasi-elastic measurement

From V. Lyubushkin, et. al arXiv:0812.4543v3 and NuInt09 talk



Excellent resolution from plastic drift tube detector
In magnetic field. CH (plastic) target.
But reconstruct protons only in the lower hemisphere.
~10k QE candidates each 1-track and 2-track sample

NOMAD analysis techniques

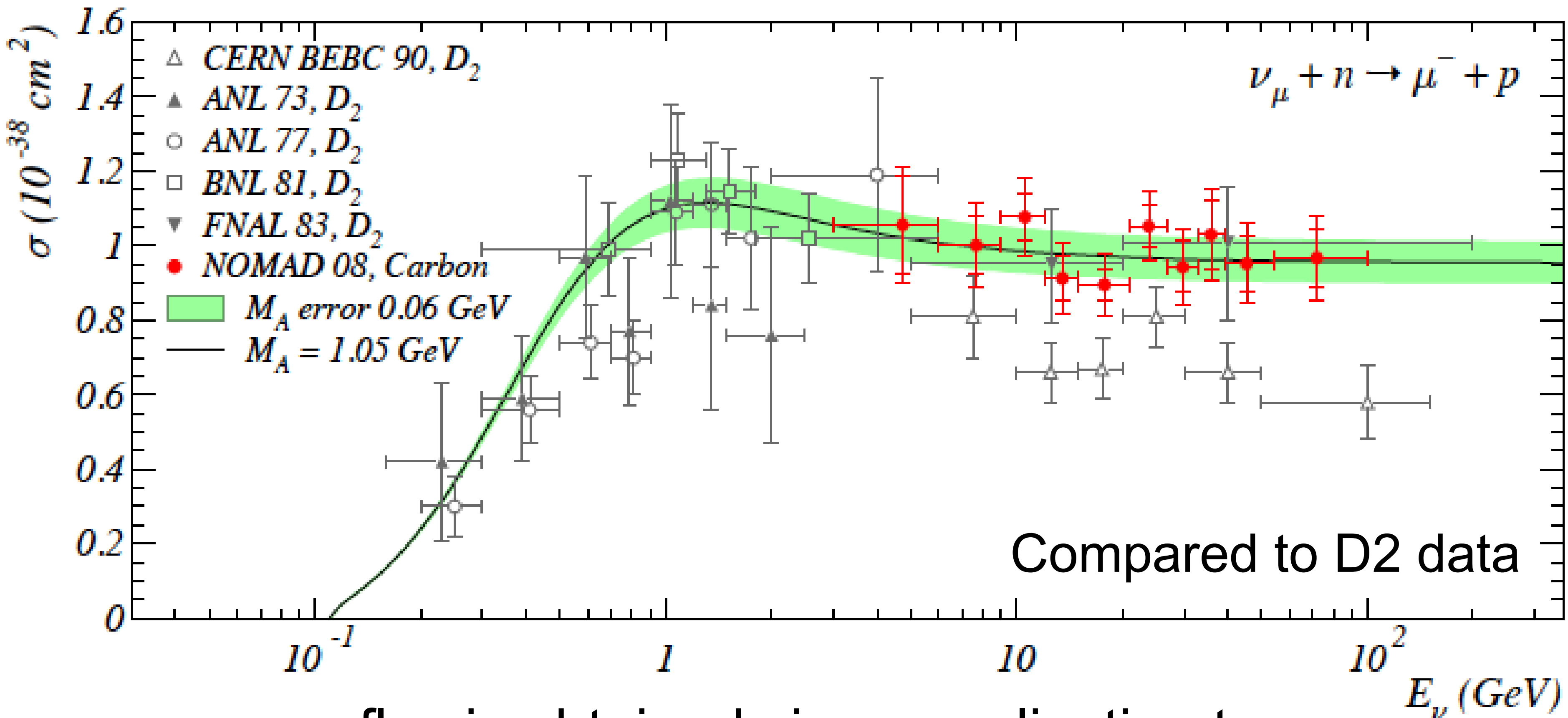
Form total cross section measurement from
Rate(1tk+2tk) / Flux
with efficiency & background corrections

Fit for M_A from this cross-section result.

nb: intranuclear rescattering effects
cause migrations between these two samples
can't use just one or the other, need both.

Separately, reconstruct the two-track sample,
including the reconstructed proton kinematics
and form the Q^2 distribution.
Fit for M_A from shape of this distribution
but not presented as $d\sigma/dq^2$

NOMAD neutrino QE cross section result

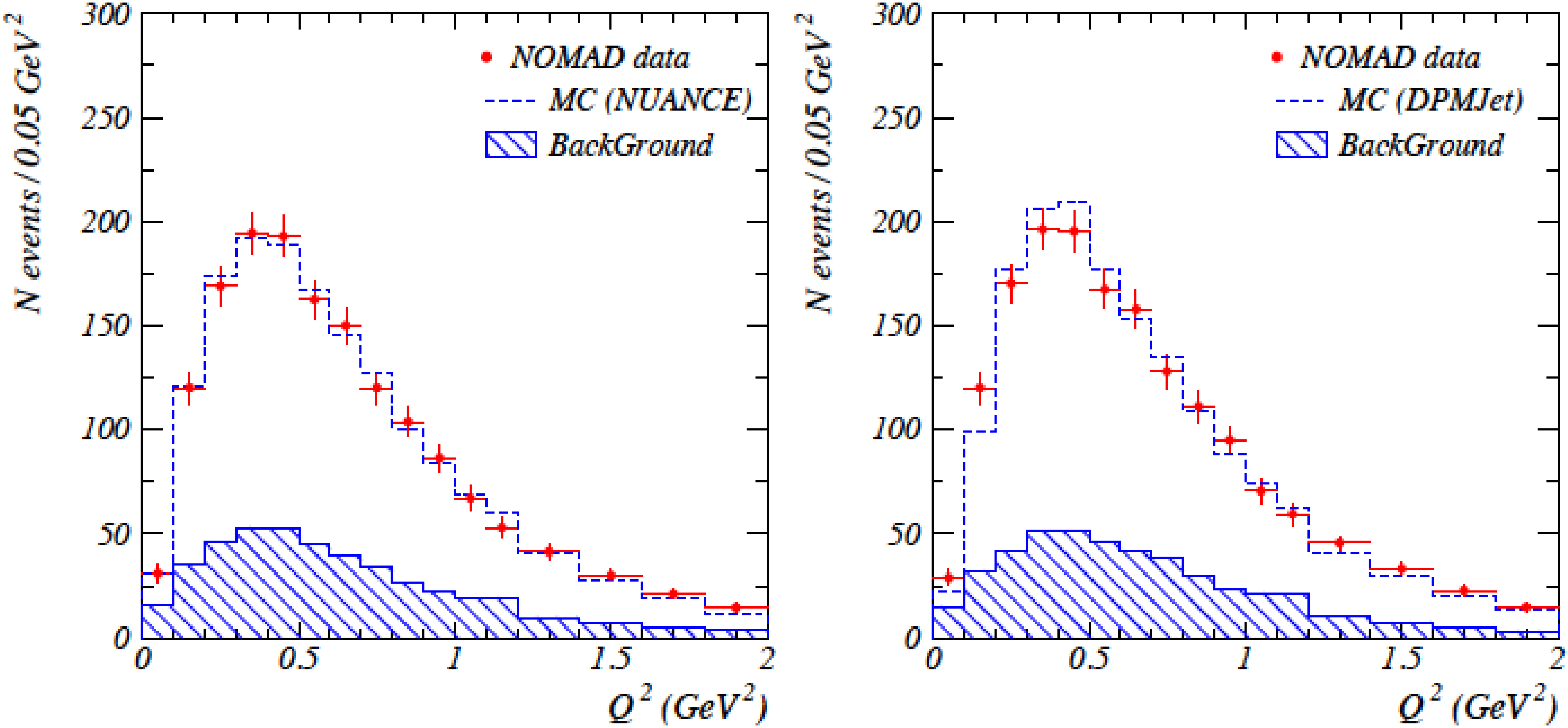


flux is obtained via normalization to
deep inelastic scattering and inverse muon decay

major systematics: 3.5% QE selection,
2.9% DIS background, 4.0% RES background, ~4% flux

Fit for M_A = 1.05 GeV ± 0.02 stat ± 0.06 syst

NOMAD neutrino QE shape fit of Q2 distribution

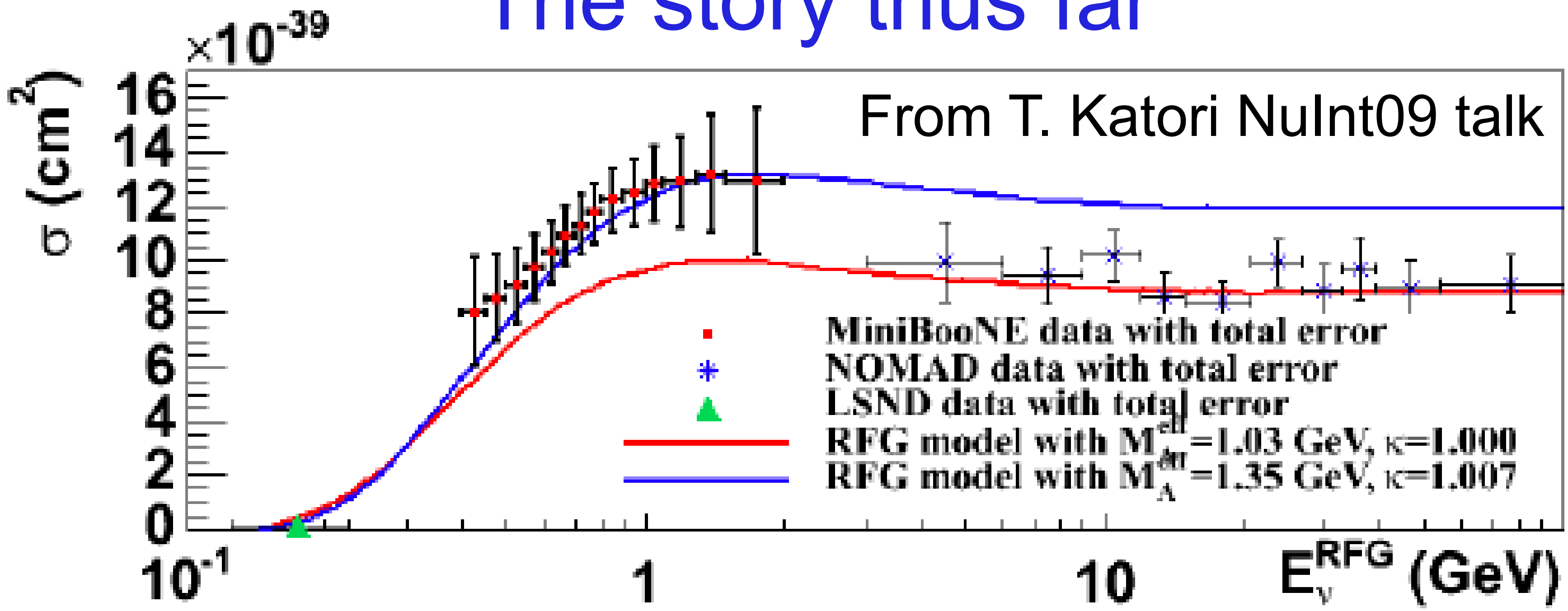


This is the High Q^2, two track sample only (before fitting) compared to two neutrino event generators

purity of this sample is 74%
main systematics: QE selection 2.4% nuke reinteractions 6%

Fit for M_A = 1.07 GeV ± 0.06 stat ± 0.07 syst

The story thus far

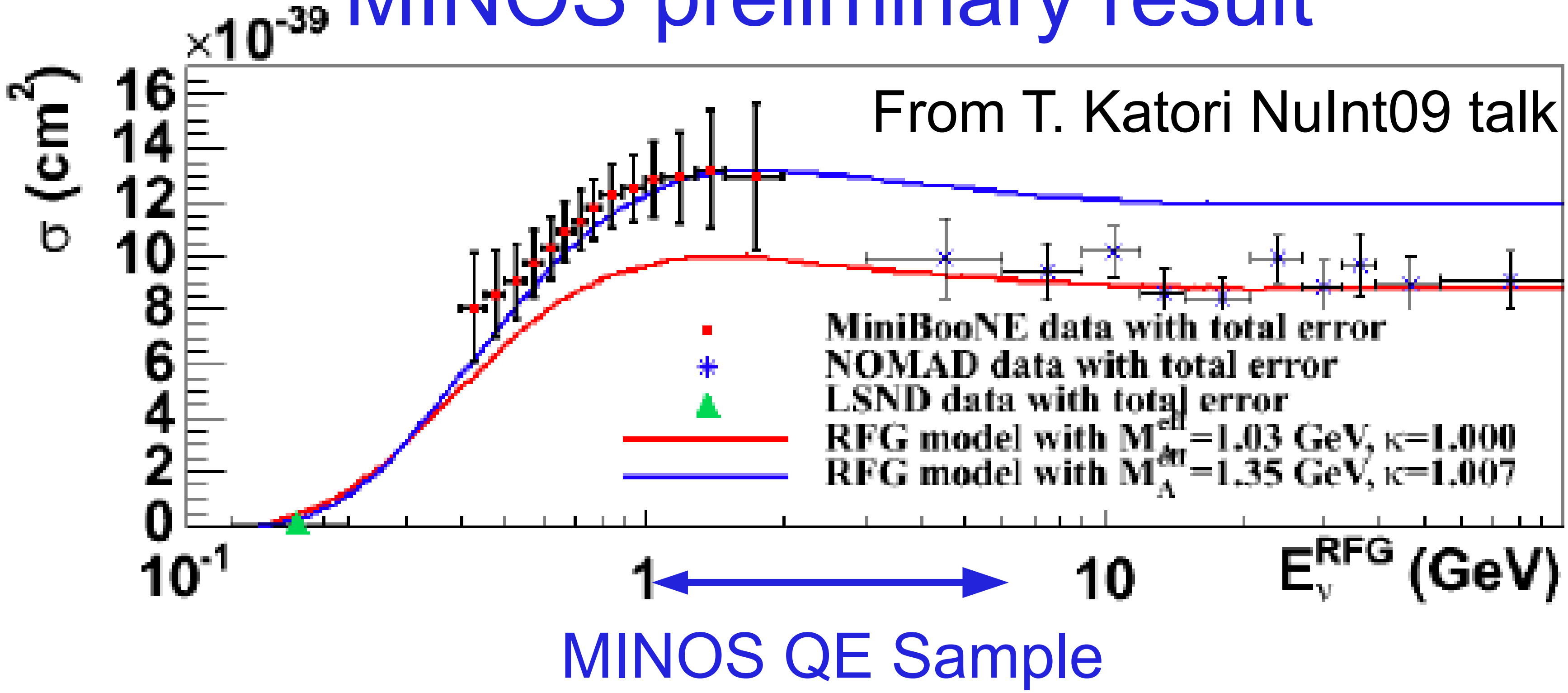


MiniBooNE data is described by a high M_A (~1.35) based both on a rate measurement and Q^2 shape.

NOMAD data is described by a moderate M_A (~1.05) based both on a rate measurement and Q^2 shape of a high-Q^2 two-track sample.

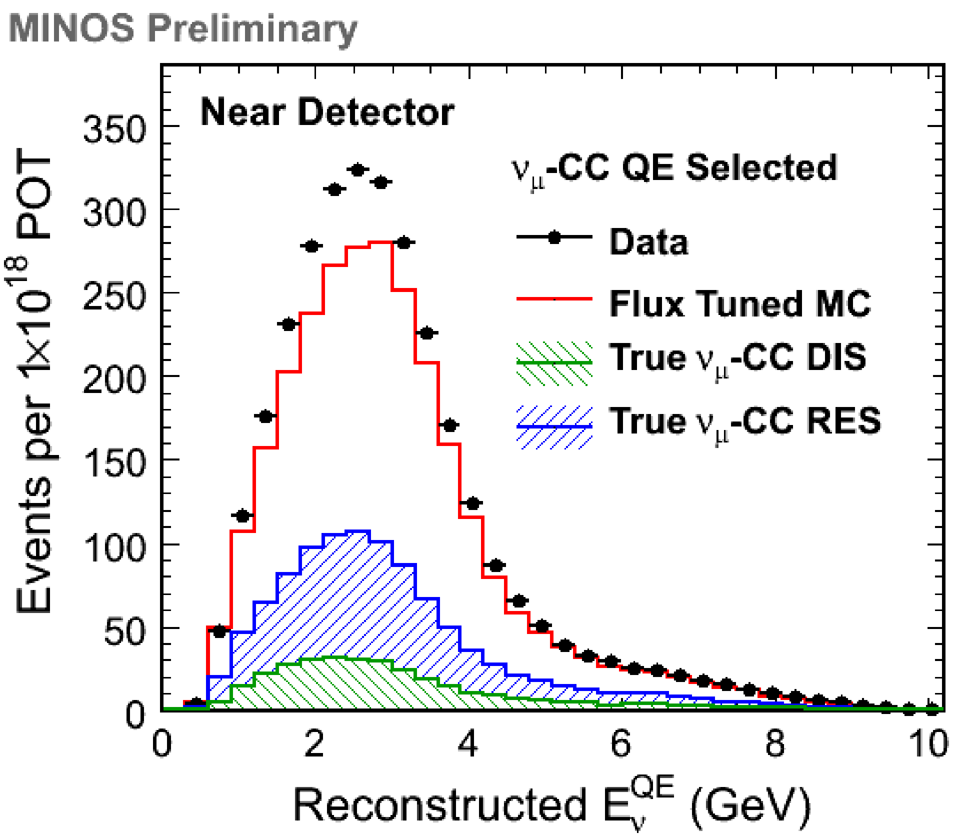
Consistent with each other? Sure.
Consistent with older experiments? Uncomfortable.

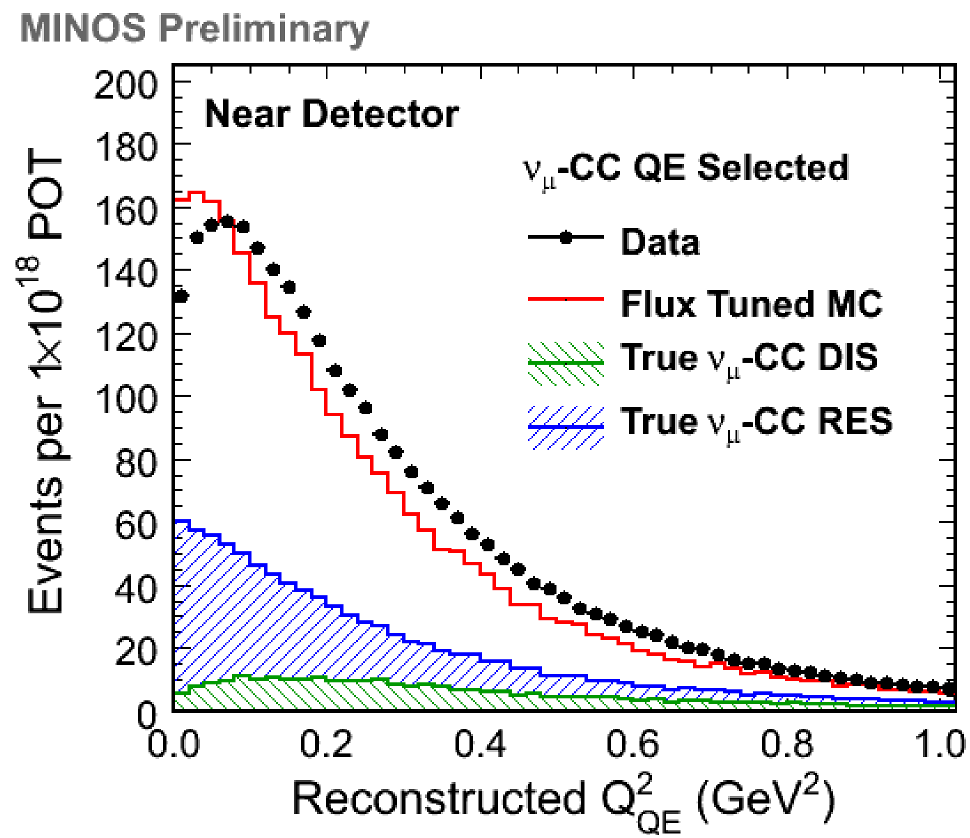
MINOS preliminary result



Shape fit to the Q^2 distribution of a
Low Q^2, one-track QE sample, 61% pure
Reconstruction from muon kinematics
Limited to the stopping muon sample: p_μ from range
Includes most of the NuMI beam peak at 2.5 GeV
Most data is in the range 1 GeV < Ev < 6 GeV

MINOS QE sample and MC before fitting

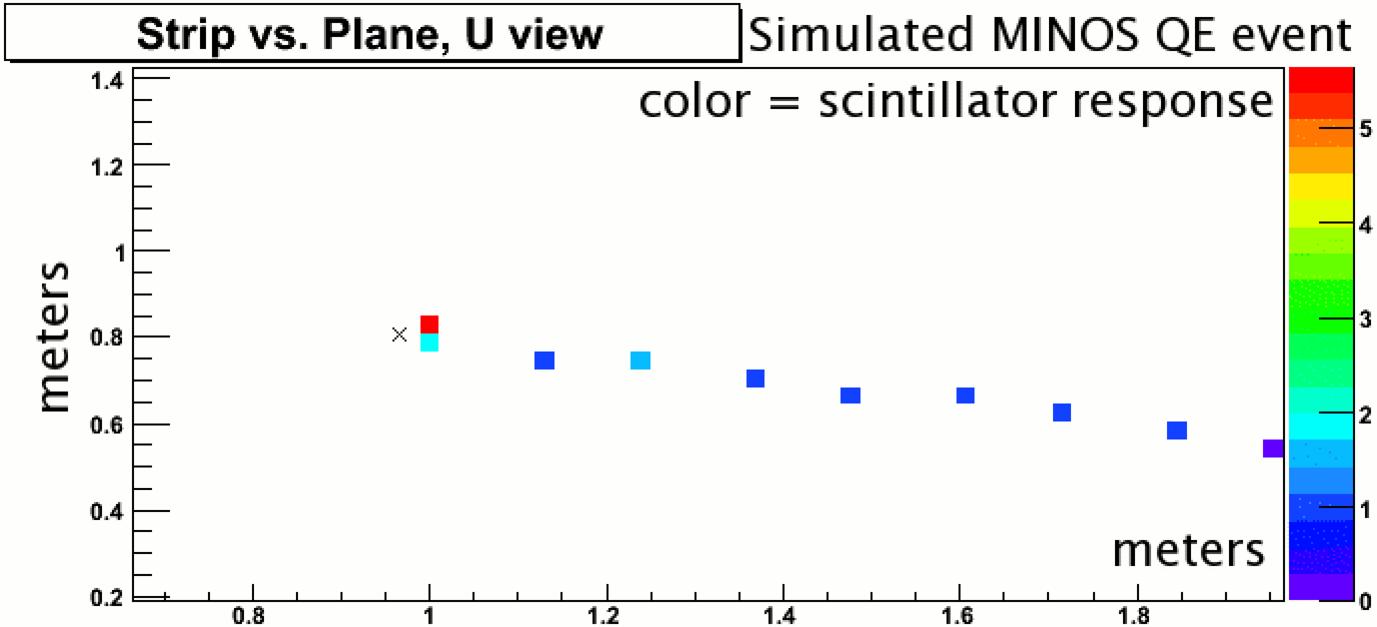


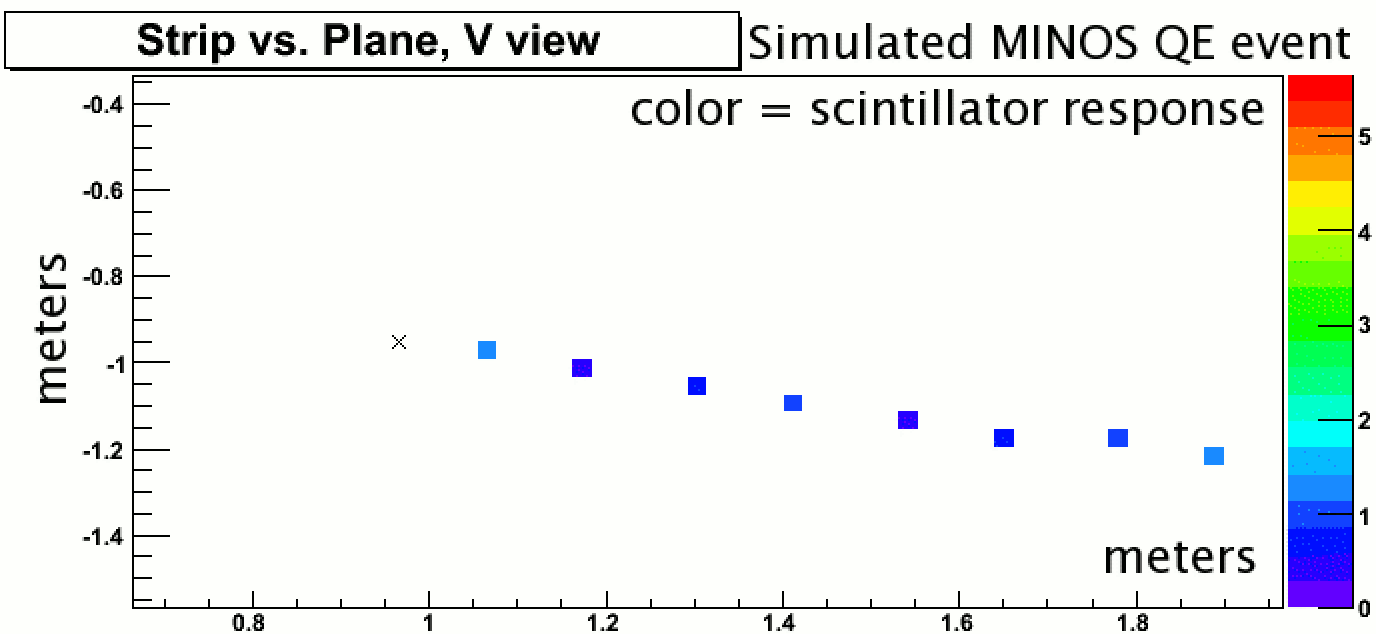


POT normalized samples with an all-CC tuned flux but not (yet) a measured flux with its uncertainties

Needs less low-Q^2 in the MC, and a bit higher M_A. (and compared to this flux, needs more QE in MC)

More details on the one-track selection

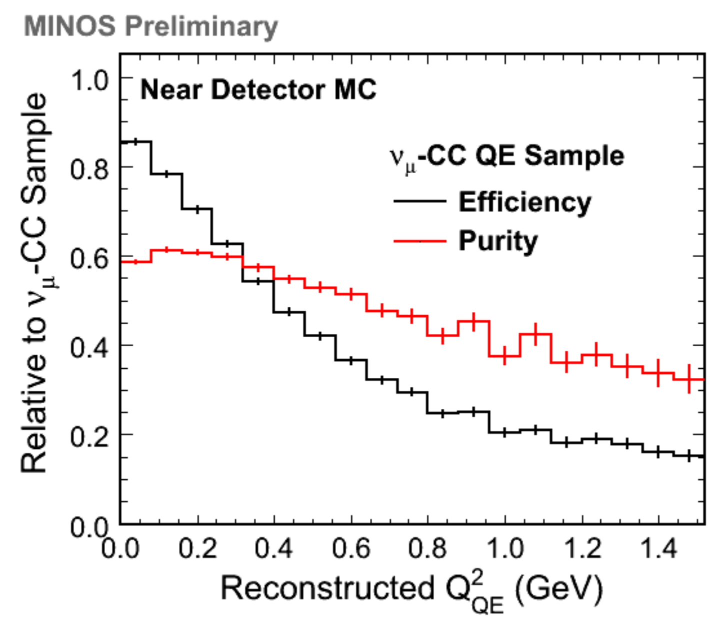




Require one reconstructed track.

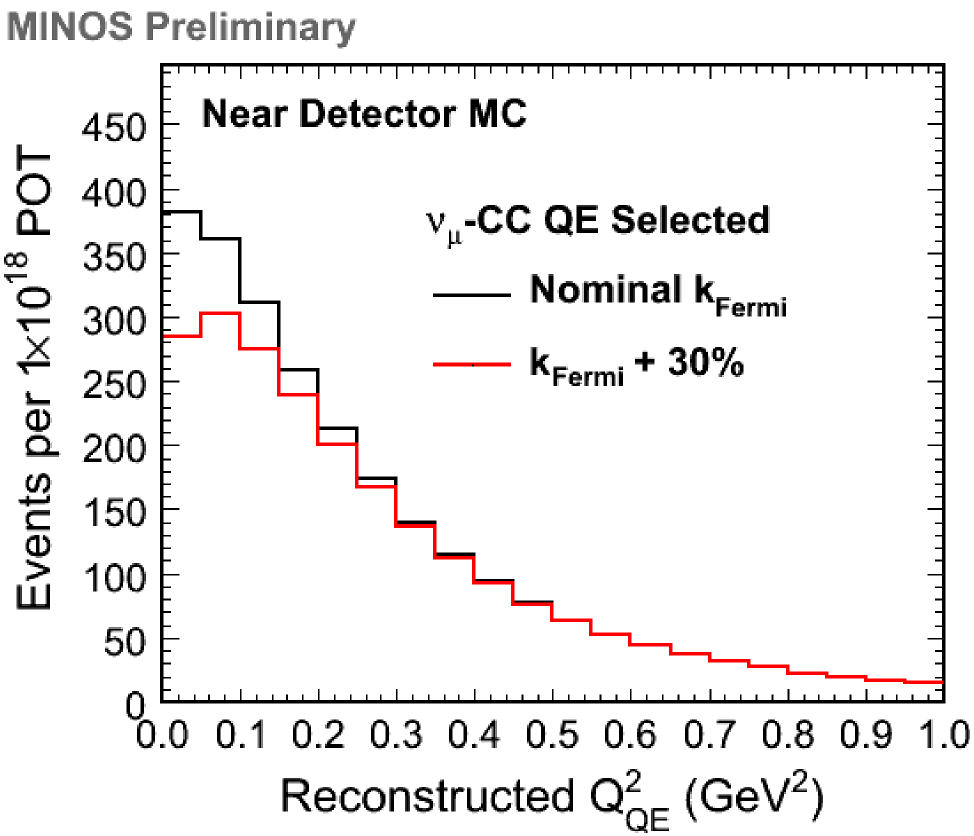
Visible shower energy < 250 MeV

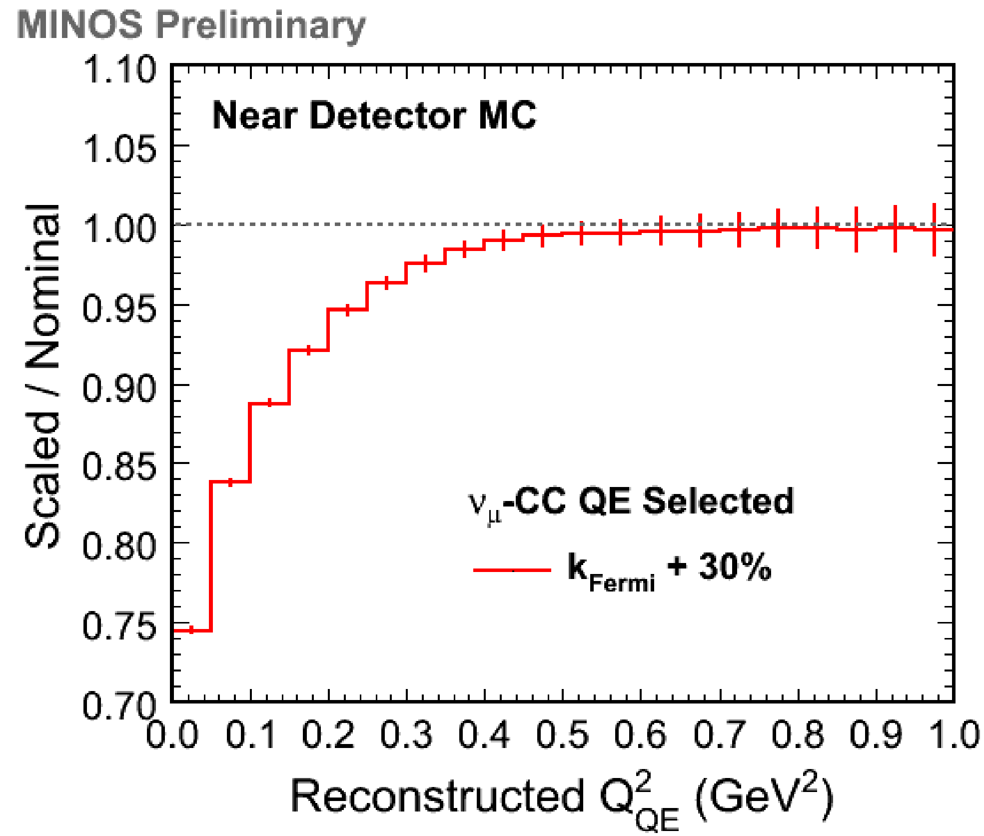
Event stops in near detector.



Efficiency 53%
Purity 61%

How to deal with that very-low Q2 region



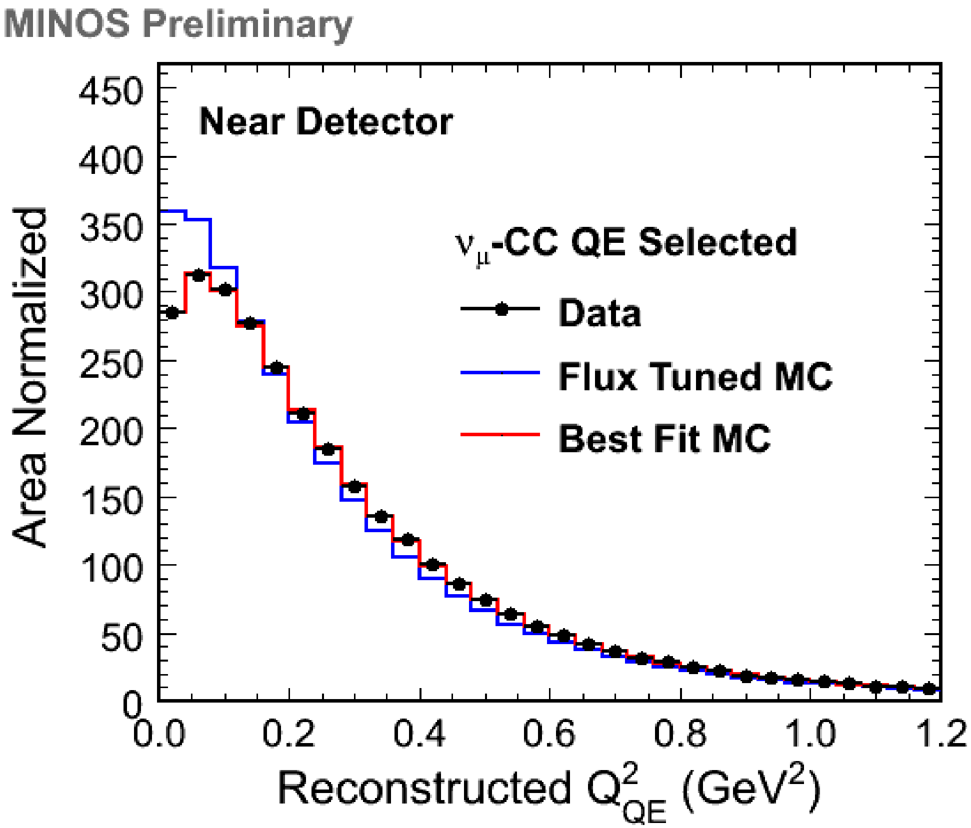


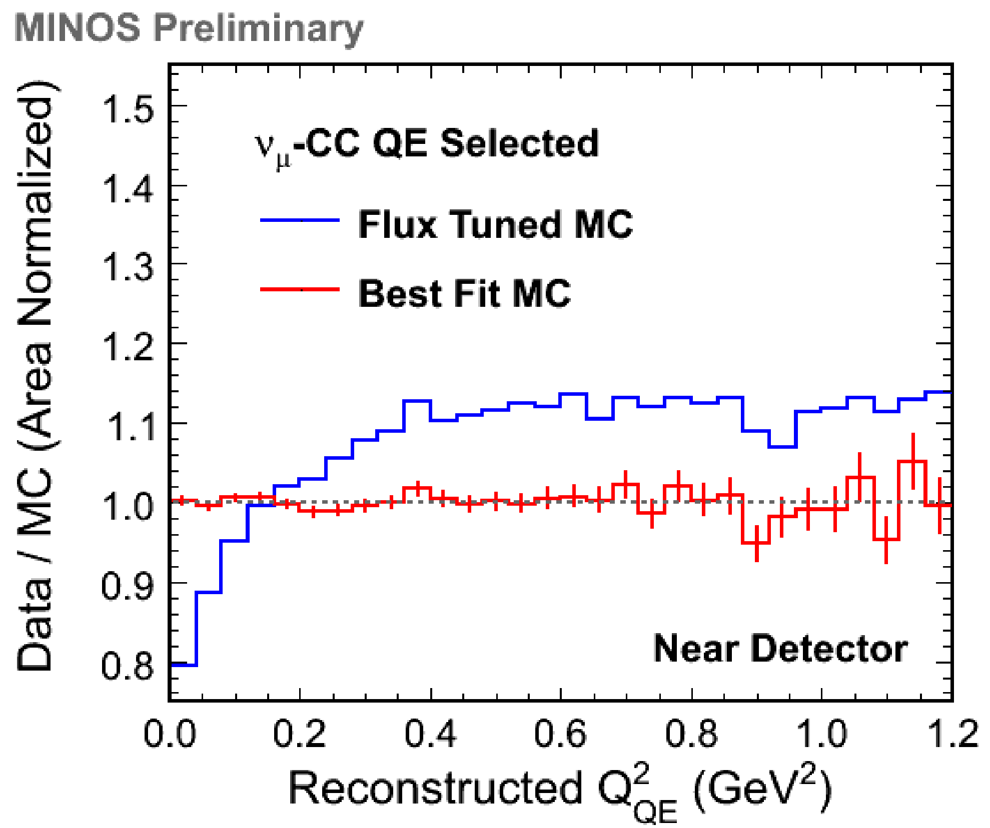
All nuclear models beyond-the-Fermi-gas produce MORE lowest-Q^2 suppression.

As a substitute, we use a simple prescription within the Fermi-gas to Pauli-block more events.

AND/OR we evaluate the shape above 0.3 GeV^2 only.

Best Q2 shape fit, including the lowest Q2 region

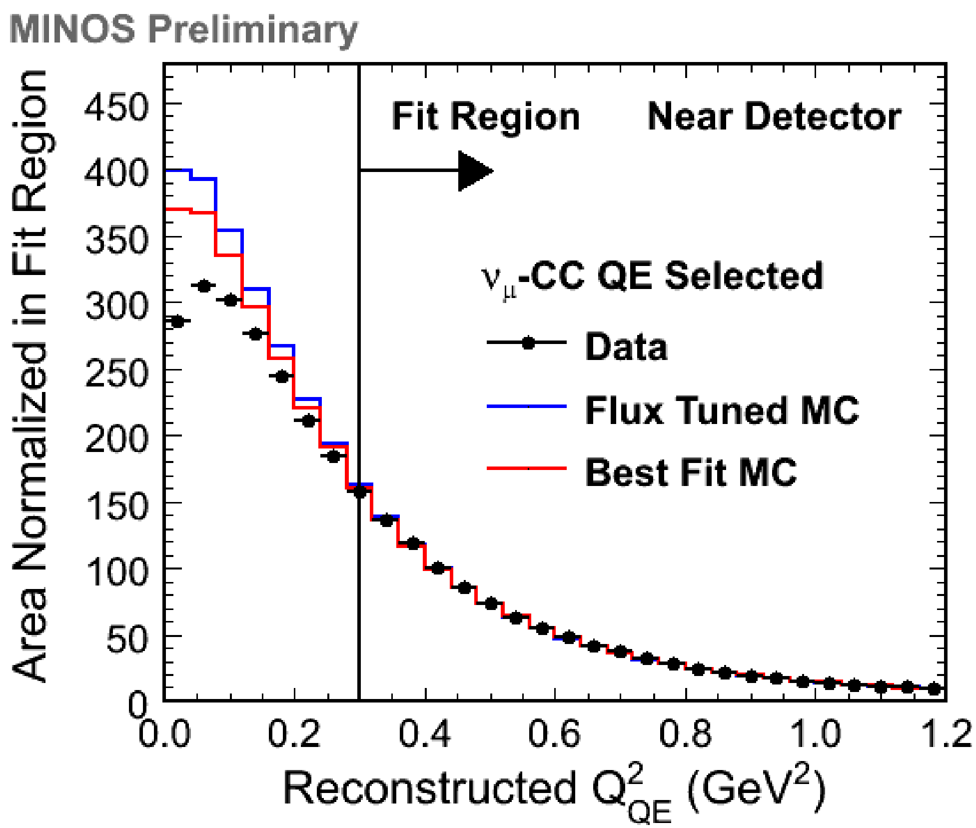


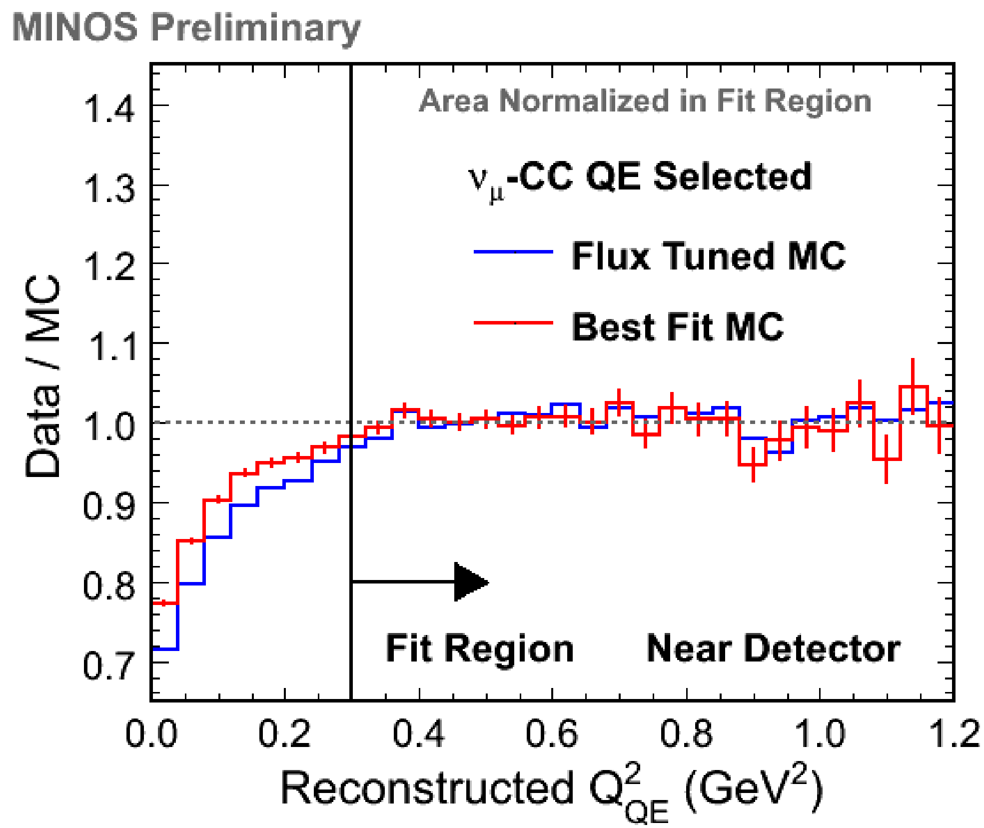


Best fit k_{Fermi} scale =1.28, E_μ scale 0.988, M_A Res=1.112
Largest additional systematics in this result are from
Hadronic energy scale errors and Intranuclear rescattering

$$\text{Effective } M_A = 1.19 \text{ GeV } {}^{+0.09}_{-0.10} \text{ (fit) } {}^{+0.12}_{-0.14} \text{ (syst)}$$

Best Q2 shape fit, avoiding the lowest Q2 region





Best fit E_μ scale 0.988, M_A Res=1.065

Largest additional systematics in this result are from Low Q^2 suppression in QE & RES interactions

$$\text{Effective } M_A = 1.26 \text{ GeV } {}^{+0.12}_{-0.10} \text{ (fit) } {}^{+0.08}_{-0.12} \text{ (syst)}$$

Initial conclusions

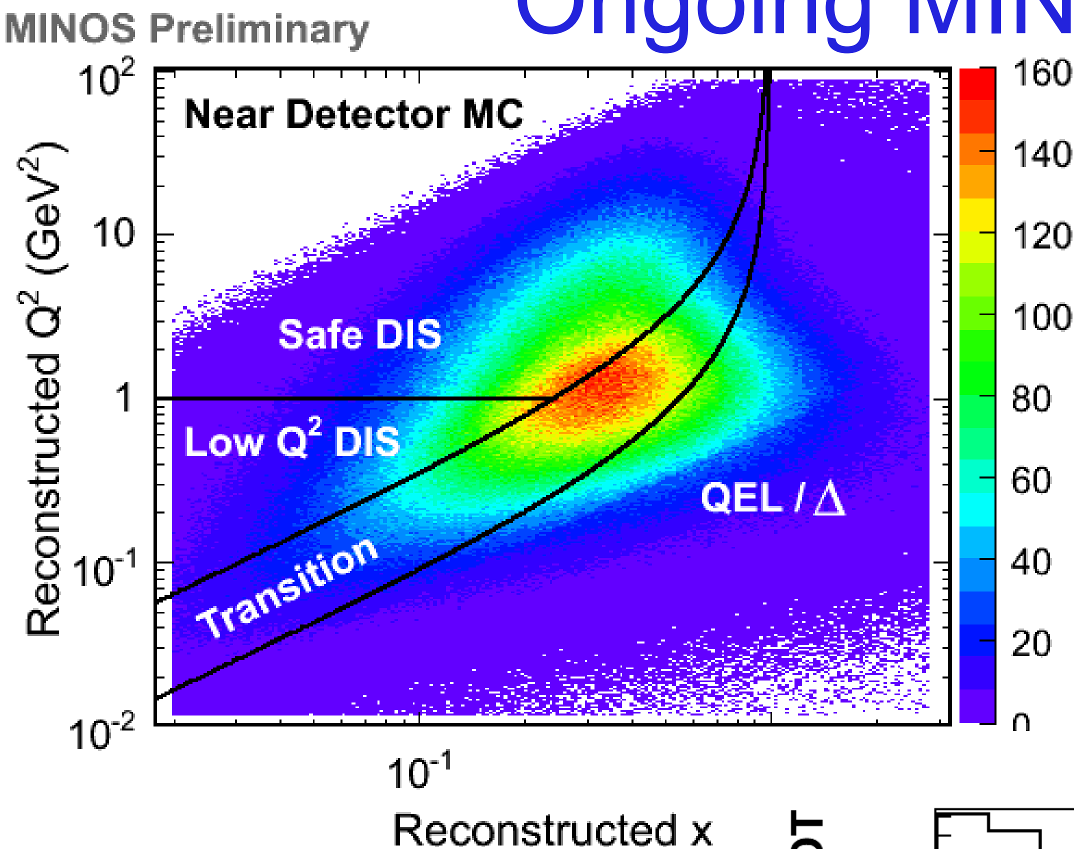
We present the preliminary MINOS Q^2 shape fit of a low Q^2 one-track sample of ν-Fe interactions

it prefers a higher effective M_A
similar to K2K, but not as much as MiniBooNE

At one-sigma it is consistent with NOMAD, and barely consistent with the D2 results.

also requires additional Q^2 suppression
(but consistent with better nuclear models)

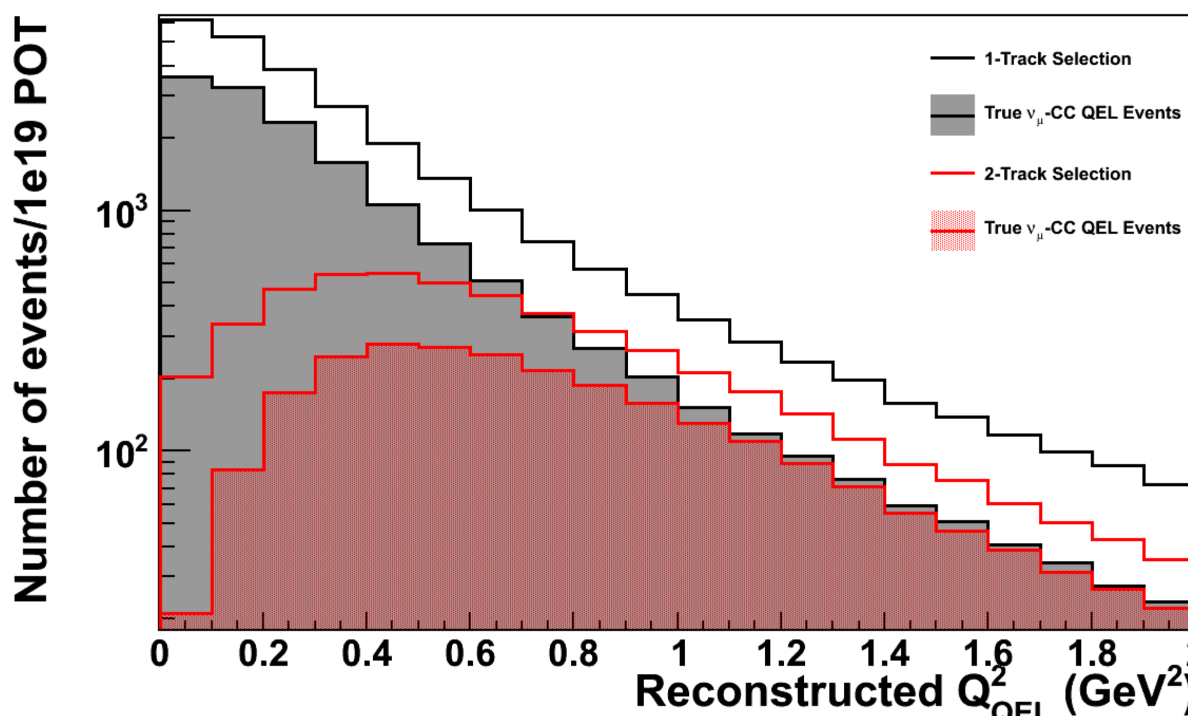
Ongoing MINOS efforts



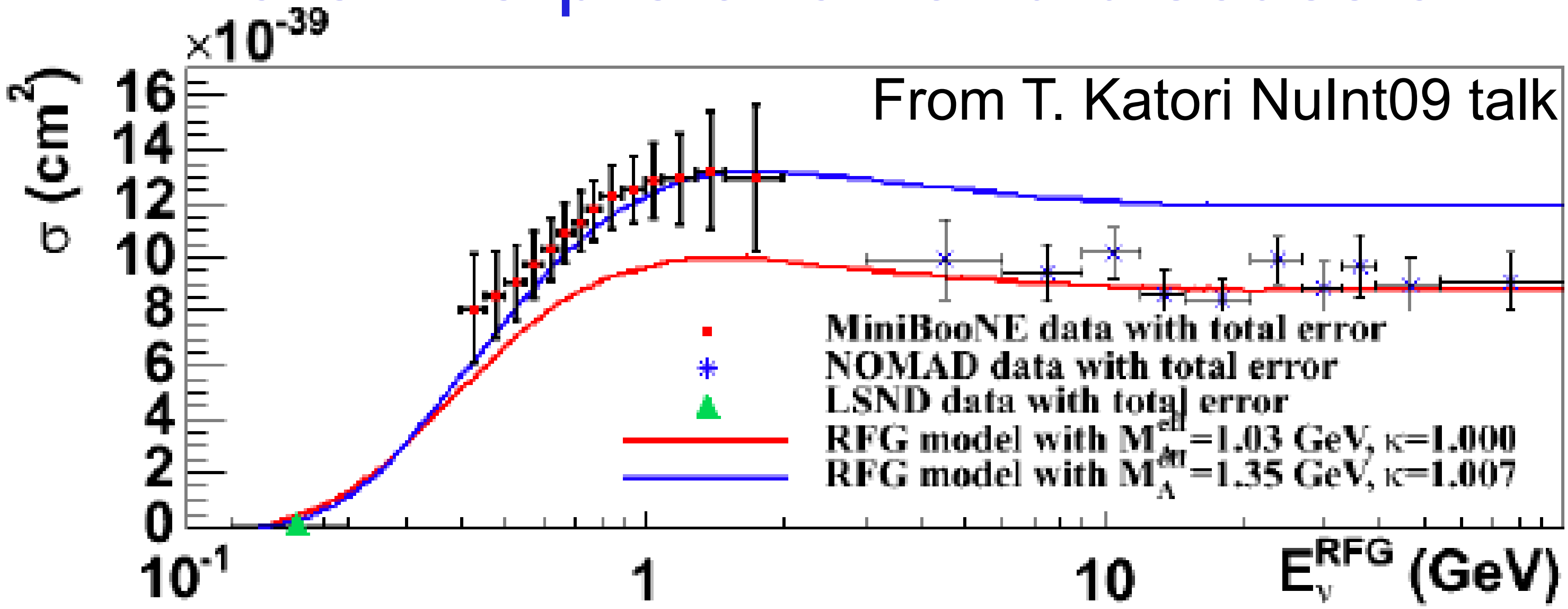
Finalize low energy flux measurements

Treat QE, Δ, and RES to DIS transition together

Include complementary two-track sample with higher Q^2 reach.



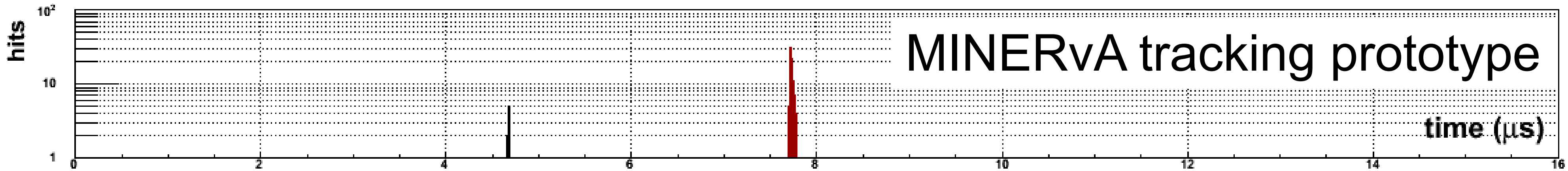
More interpretation and discussion

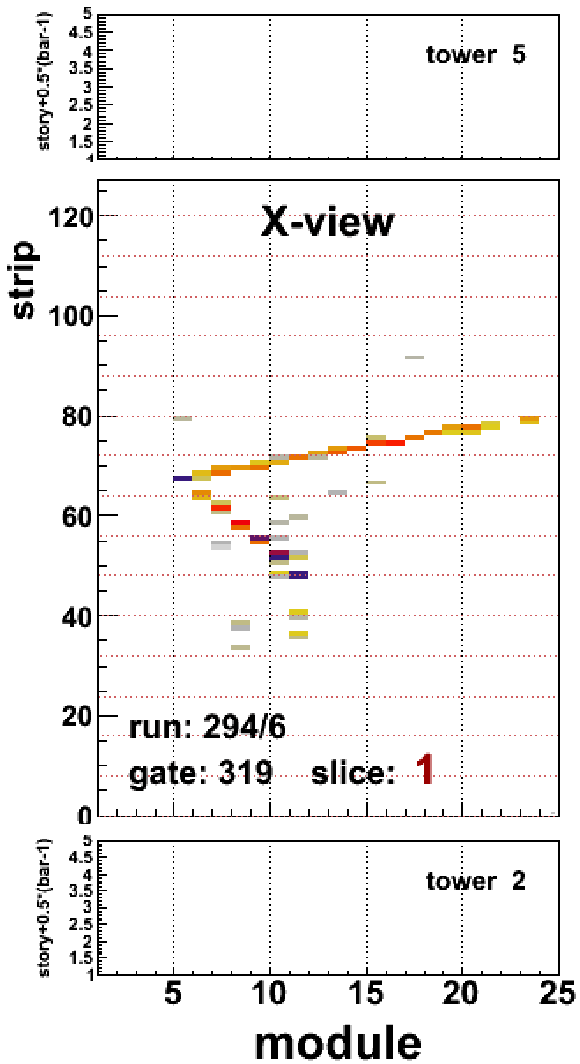


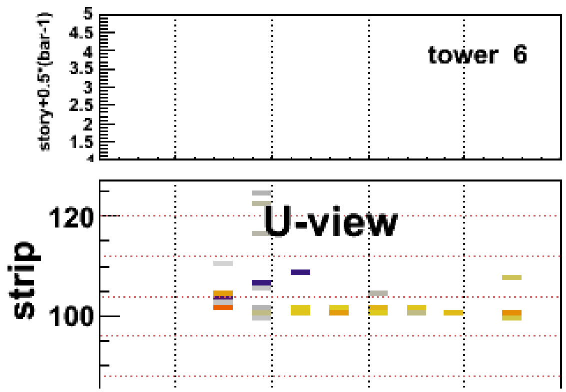
With the flux estimate and 2-track sample MINOS puts Fe data on this plot connecting (or not) these two data sets.

A nuclear effect that melts away with energy?
A systematic that affects the low Q^2 region beyond our current error estimates?
Real form factor effect? Resonance Background?

Preview of MINERvA

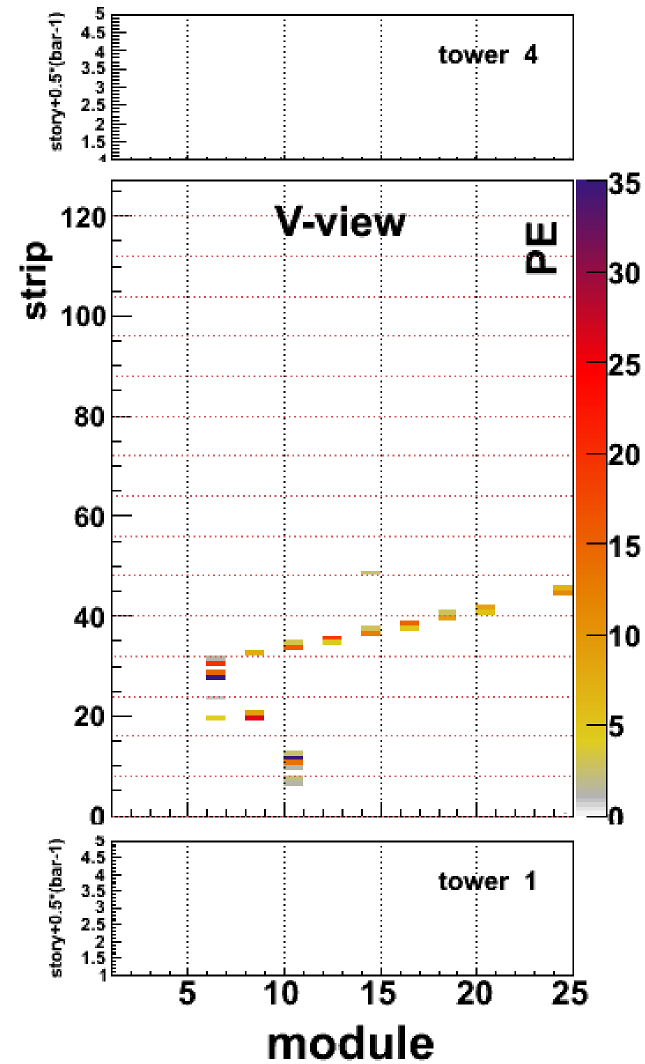






High resolution
fully active
scintillator
tracking region

comparison of
He, CH, C, Fe, Pb



B. Eberly talk on Friday

Conclusions

At and above a few GeV
The NOMAD and MINOS data seem to disagree,
but physics reach is complementary, not overlapping.

Possibly telling us about the nature of the QE puzzle,
something at low Q^2 is different than high Q^2?

ongoing MINOS effort,
and then MINERvA show promise
to fill in all the details at energies of few GeV
and connect with the other results presented here.