Experimental activities on neutrino cross-section

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IFAE

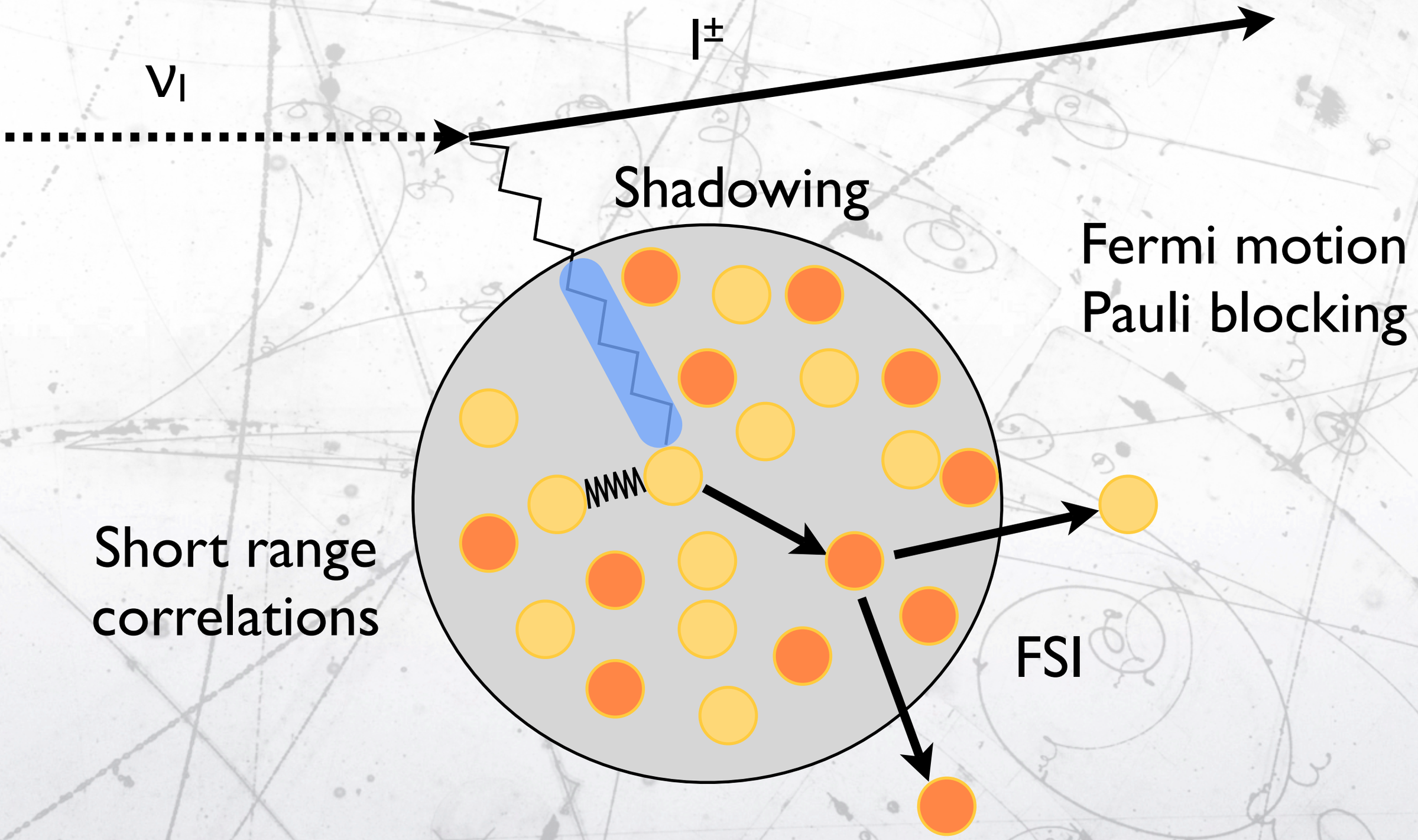
Outline

- What do we need to measure ?
- Running activities:
  - Oscillation related: ND280/T2K, MINOS, SciBoone, MiniBoone, Nova, MicroBoone
  - Dedicated experiments: Minerva, ArgoNeut
  - Reanalysis: Nomad.
- Electron scattering.
- Coverage of topics.
- Personal view.

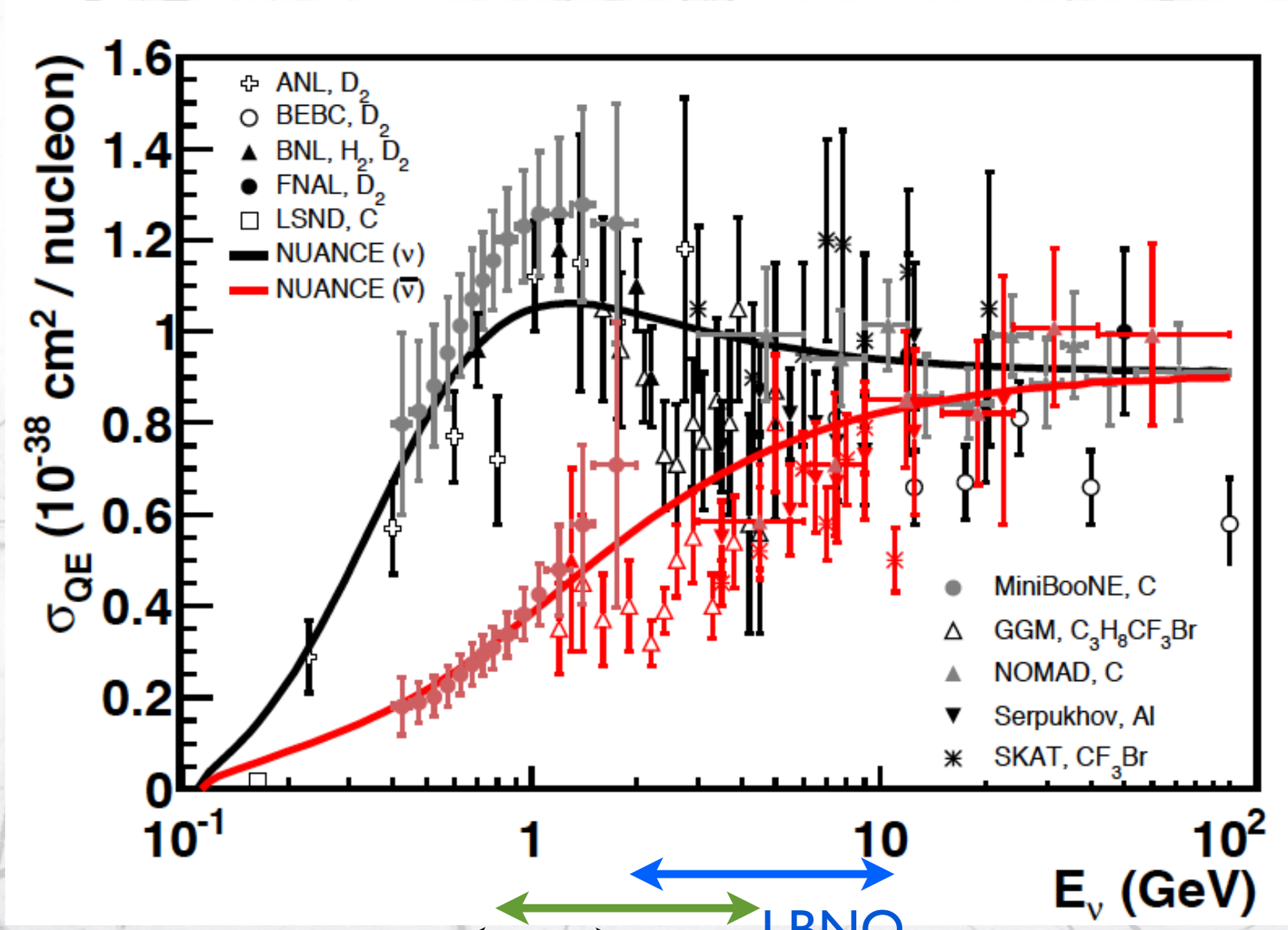
Measurements

- Future CP violation measurements with LBL neutrino beams require the measurement of ν_μ, anti-ν_μ, ν_e and anti-ν_e
  - between 500 MeV and 10 GeV,
  - for (at least) 4 nuclei: C, O, Fe and Ar.
- All exclusive channels:
  - QE, $1\pi^{0\pm}$, $N\pi^{0\pm}$, DIS both CC and NC.
- Require a precise determination of the energy of the neutrino for the dominant(s) channel(s) at each energy.

The problem


$l^{\pm}$
ν_l
Shadowing
Fermi motion
Pauli blocking
Short range correlations
FSI

The problem



T2K
T2HK

LBNE

LBNO

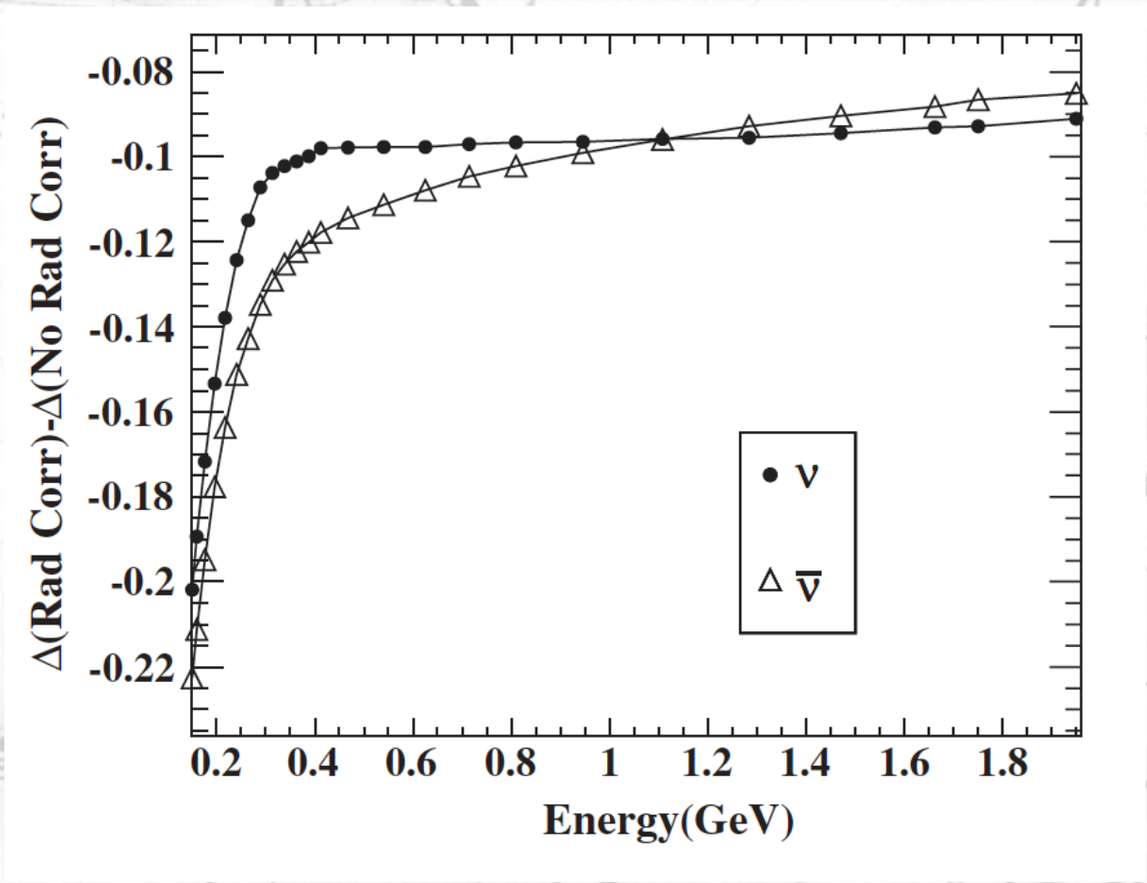
The problem

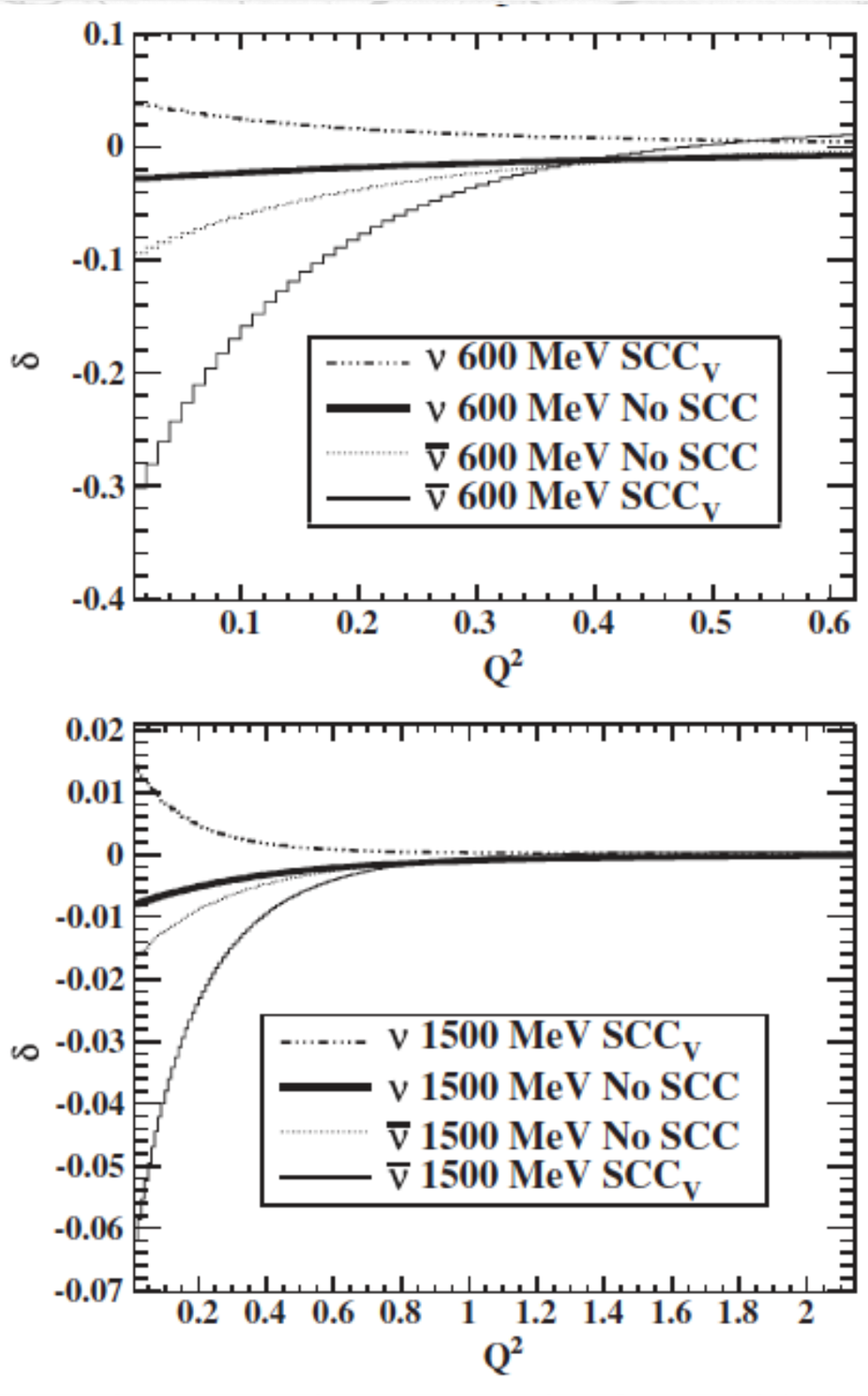
- The nucleus affects the neutrino energy reconstruction:
  - Changing the channel identification when the reconstruction is based on the lepton kinematics.
  - Adding Fermi motion, Pauli blocking and bound energy.
  - Altering via nuclear re-scattering the hadronic energy.

- These problems are less severe at higher energies where ($E_l >> E_{had}$):
  - $E_\nu = E_l + E_{had}$
  - and where DIS is dominant.

LBNO, LBNE and T2HK has a low energy contribution for the first or second oscillation maximum.

The problem: ν_e





- Calculations show significant differences in electron to muon cross-sections due to:
  - form factors.
  - radiative corrections.
  - lepton mass.

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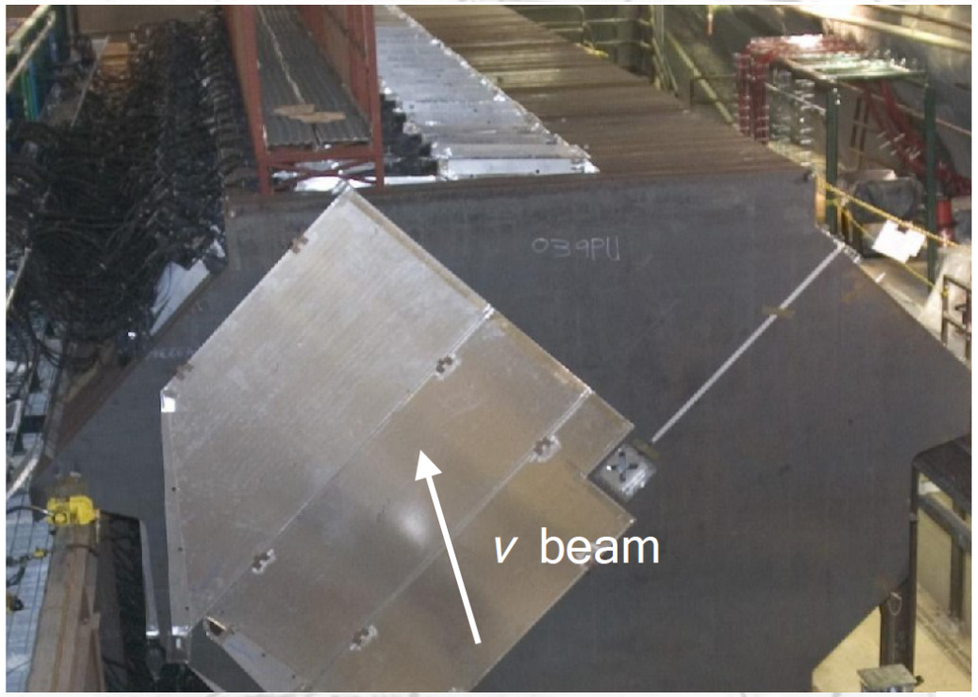
Oscillation related experiments

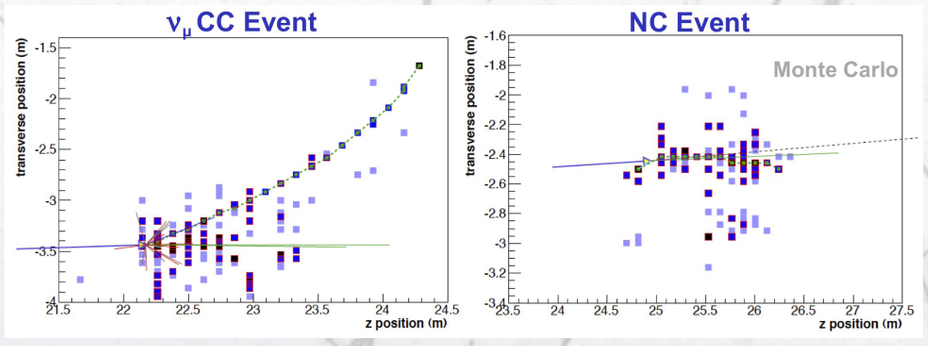
Near Minos

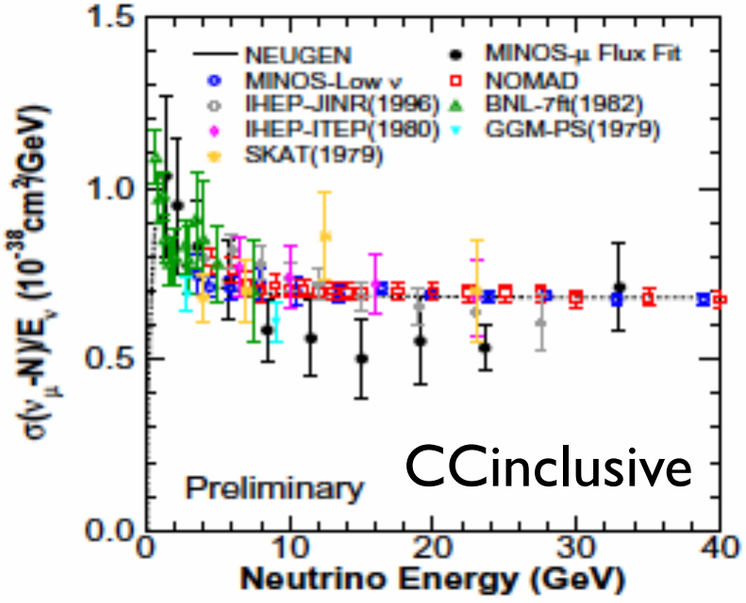


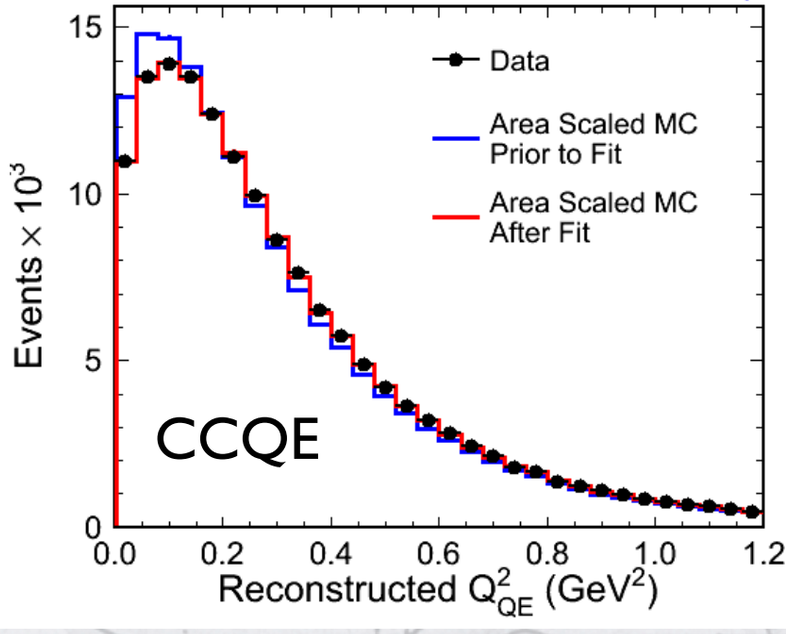
- Iron target.
- Magnetised.
- Large statistics.

	M_A^{QE} (GeV)	E_μ Scale	M_A^{RES} (GeV)	k^{QE}_{Fermi}
Principal: $0 < Q^2 < 1.2$	1.21 +0.18 -0.10	0.996 +0.007 -0.015	1.10 +0.15 -0.16	1.10 +0.02 -0.03
Alternative: $0.3 < Q^2 < 1.2$	1.19 +0.19 -0.17	0.995 +0.008 -0.016	1.13 +0.17 -0.18	Not fit

MINOS Preliminary

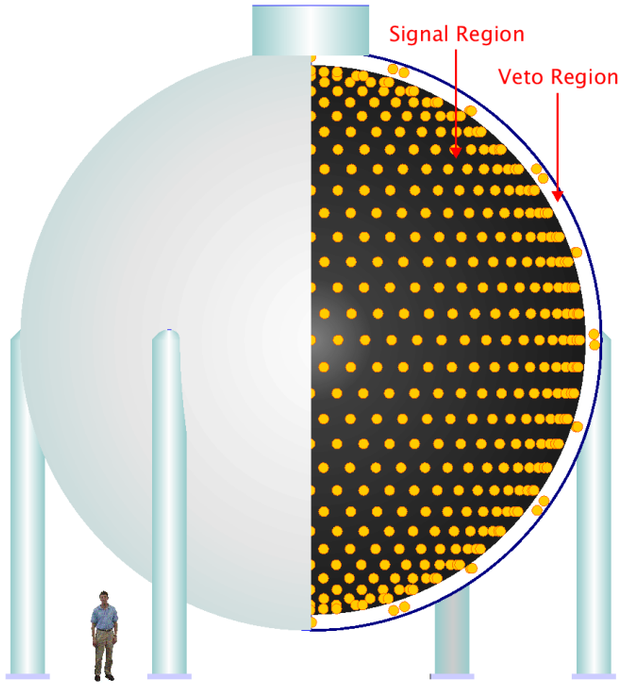




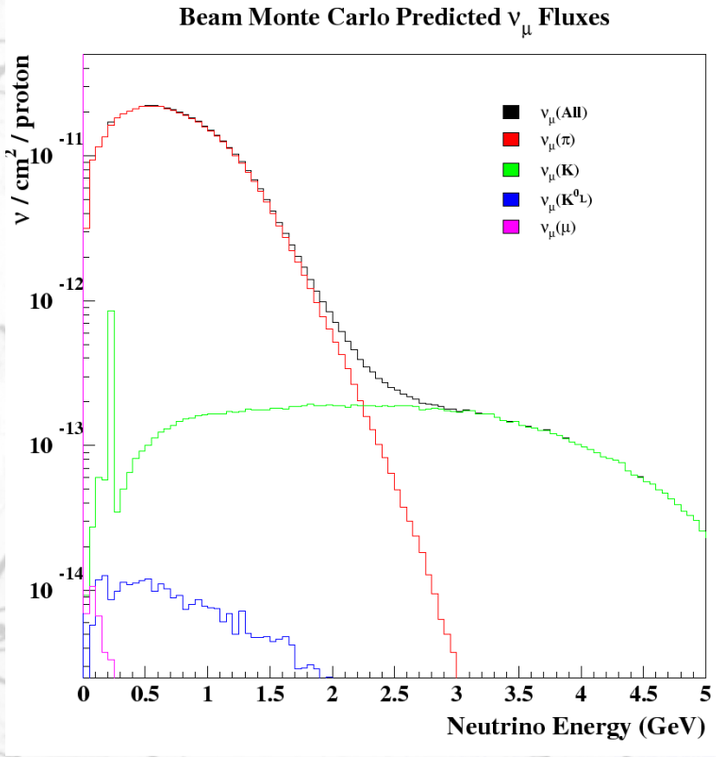


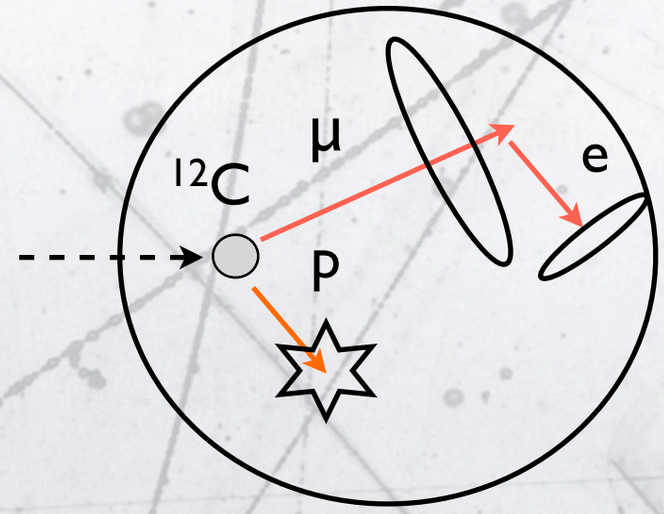
MiniBoone

MiniBooNE Detector

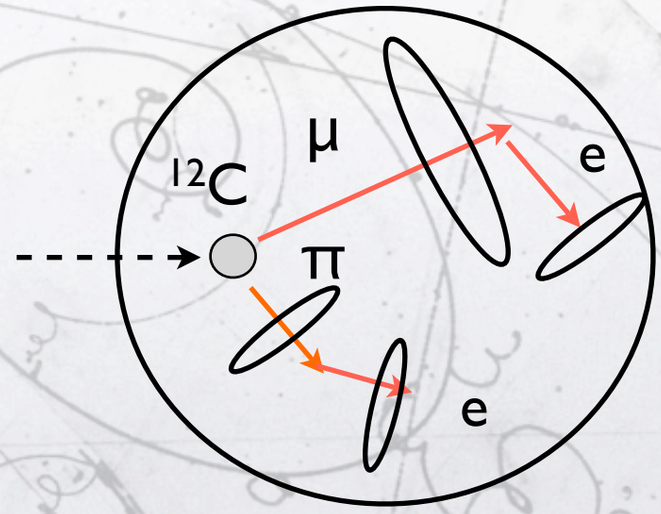


- 800 tons mineral oil Cherenkov detector.
- Boone neutrino line with sharp edge at 3 GeV.
- Flux constrained from HARP hadro-production experiment.

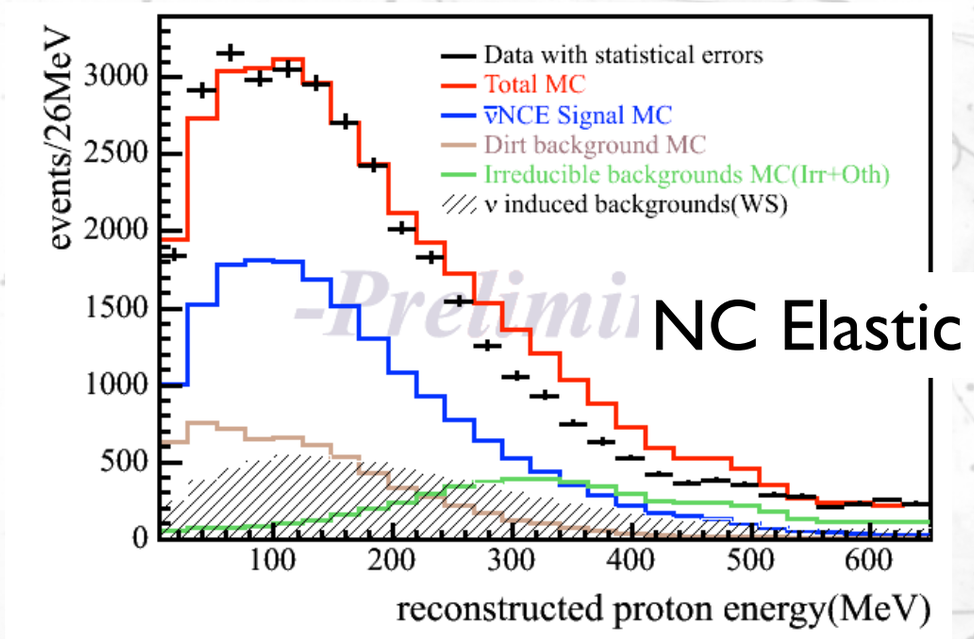


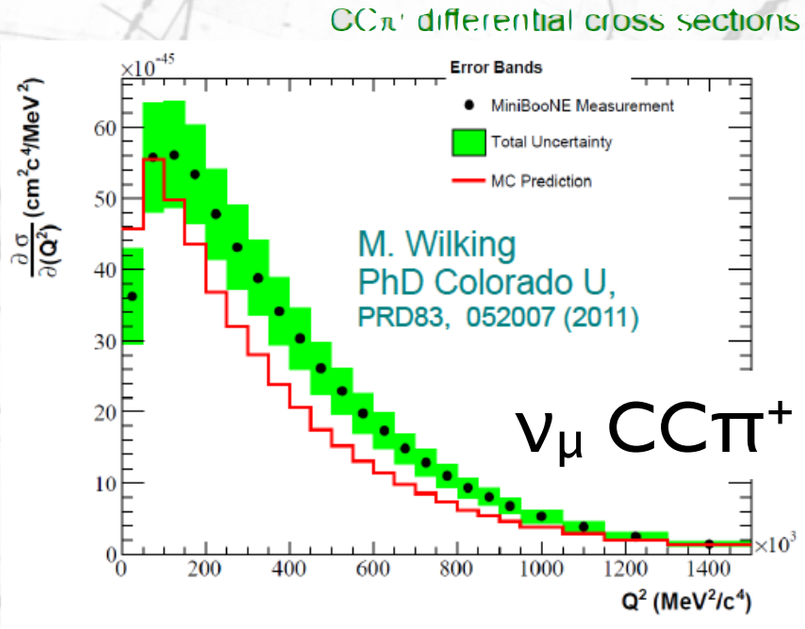


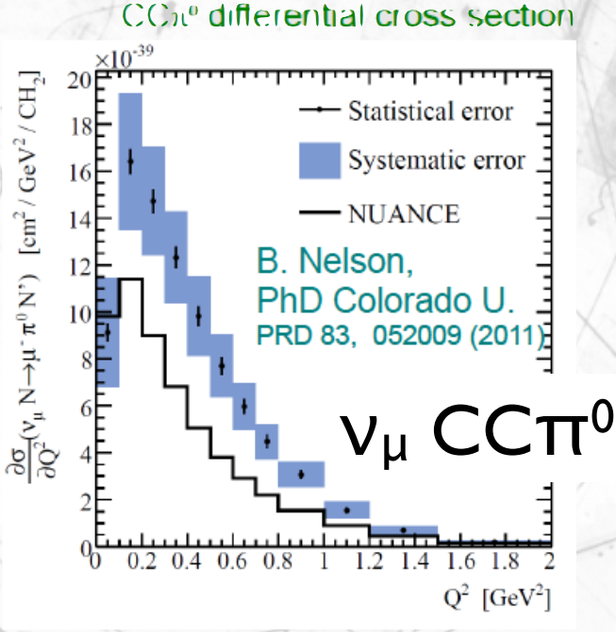
- ~450 Mev/c proton threshold.
- Excellent pion detection and tagging.
- Very large statistics.

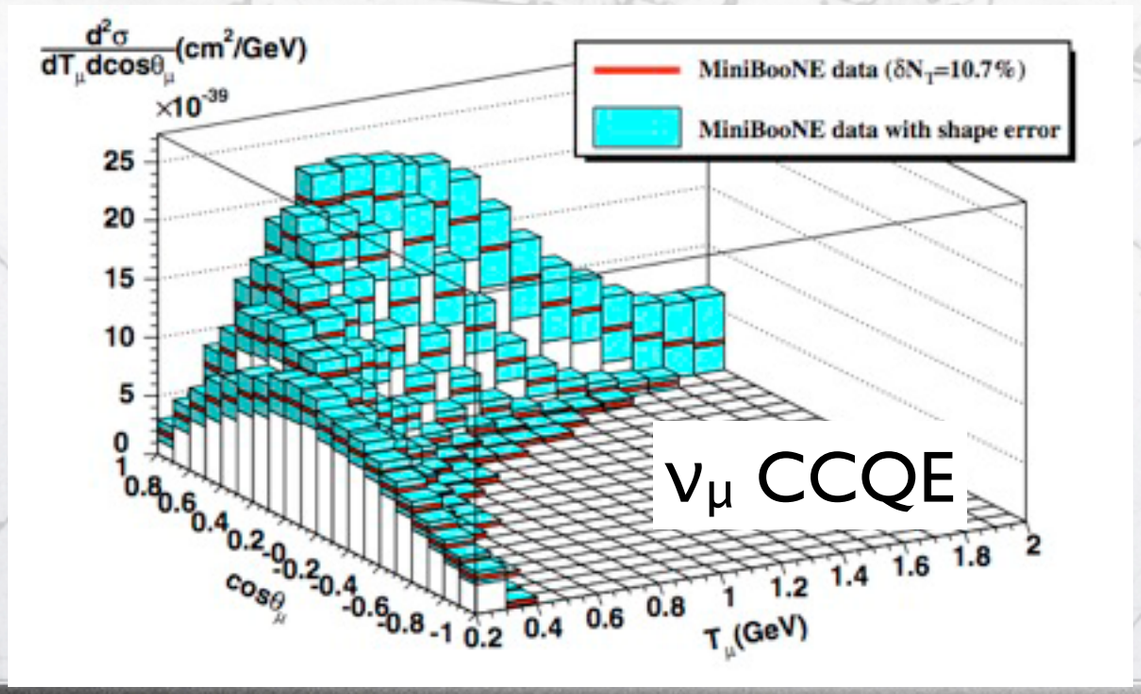


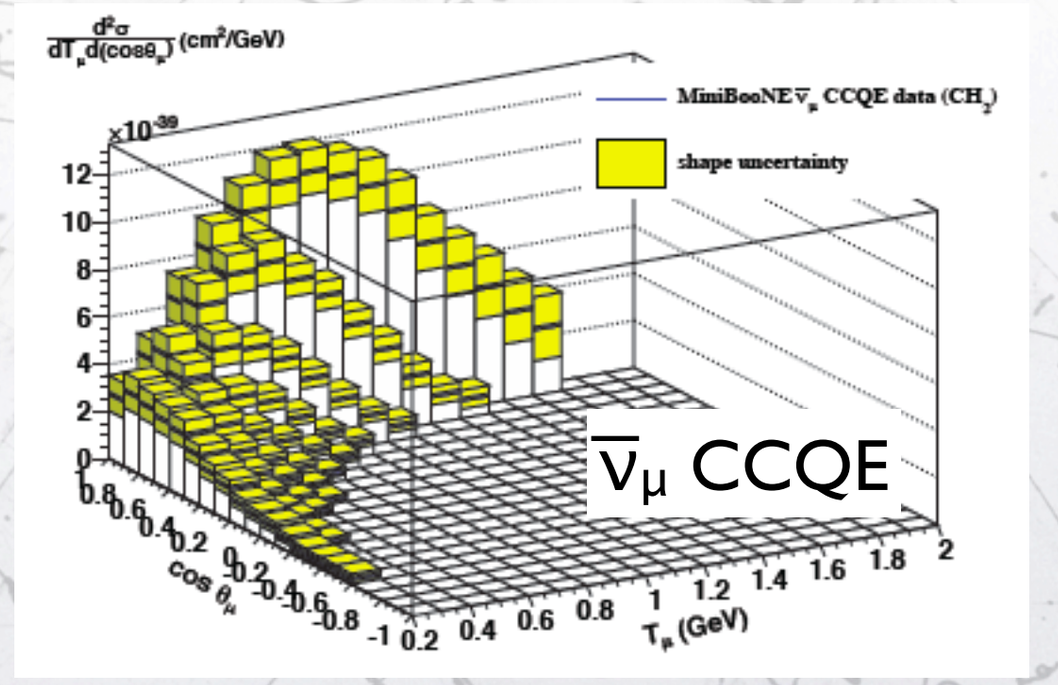
MiniBoone


Data with statistical errors
Total MC
ν̄NCE Signal MC
Dirt background MC
Irreducible backgrounds MC(Irr+Oth)
ν induced backgrounds(WS)
events/26MeV
reconstructed proton energy(MeV)
NC Elastic


CCπ+ differential cross sections
Error Bands
MiniBooNE Measurement
Total Uncertainty
MC Prediction
M. Wilking
PhD Colorado U,
PRD83, 052007 (2011)
νμ CCπ+
Q² (MeV²/c⁴)

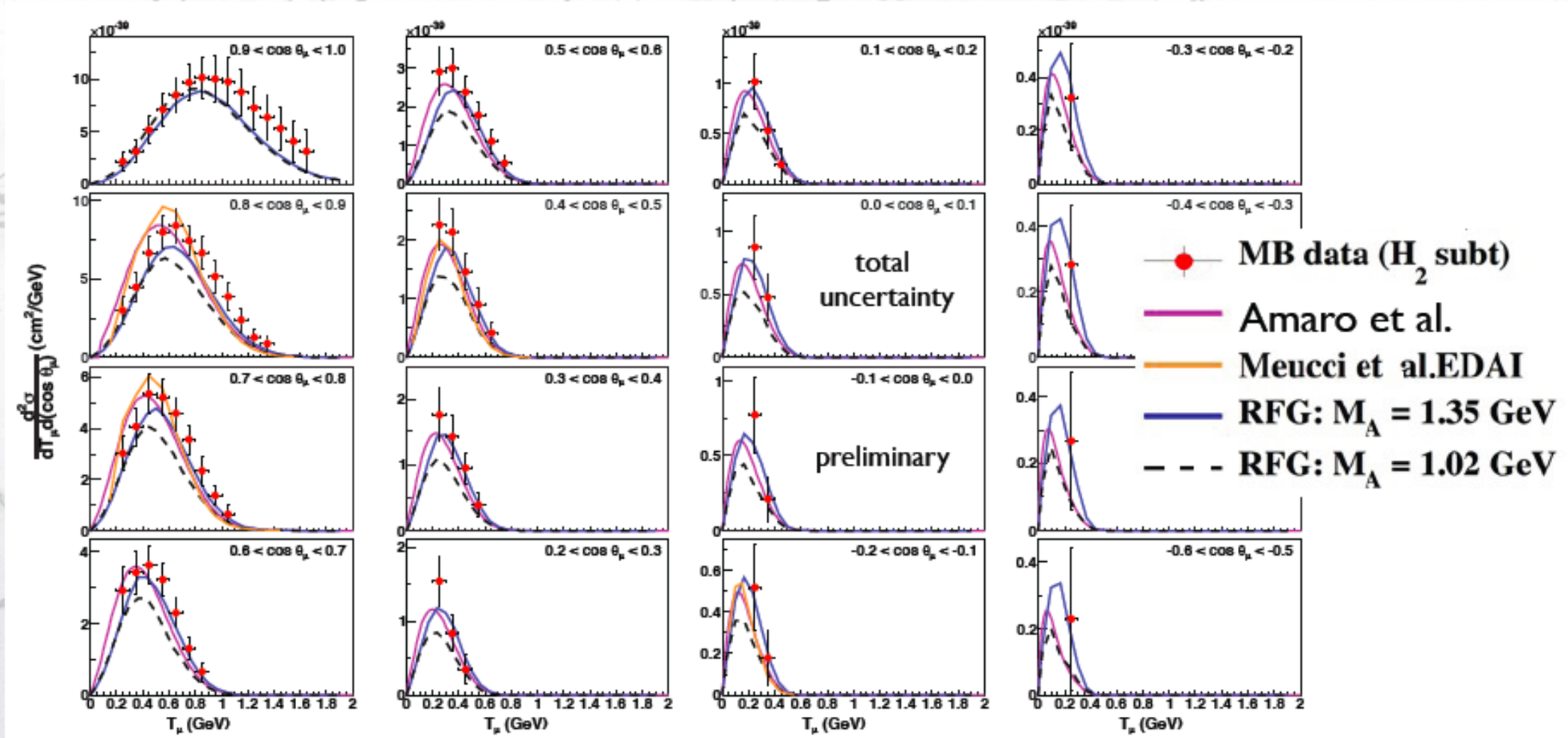

CCπ0 differential cross section
Statistical error
Systematic error
NUANCE
B. Nelson,
PhD Colorado U.
PRD 83, 052009 (2011)
νμ CCπ0
Q² [GeV²]


MiniBooNE data (δN=10.7%)
MiniBooNE data with shape error
νμ CCQE
cosθμ
Tμ(GeV)


MiniBooNE ν̄μ CCQE data (CH2)
shape uncertainty
ν̄μ CCQE
cos θμ
Tμ (GeV)

MiniBoone

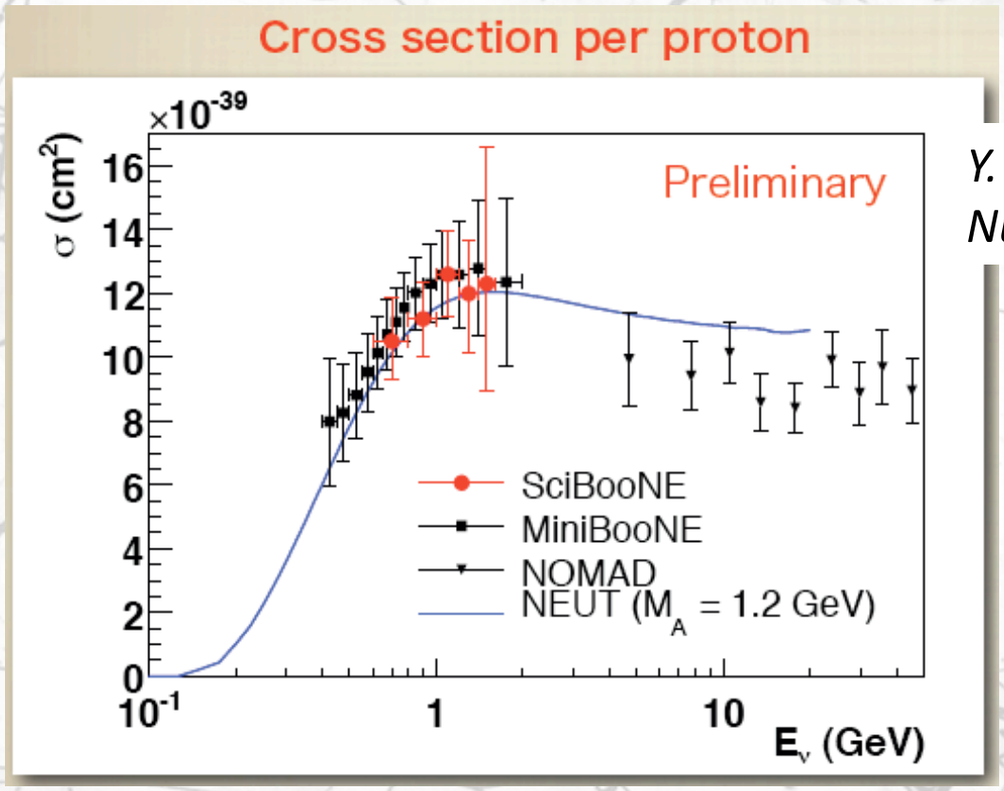
- Minimal model dependency and full lepton kinematics.
- These results has boosted the theoretical understanding of the neutrino cross-sections around 1 GeV.
  - first indirect evidence of 2p2h cross-section contributions.



It is not only the quality of the data, also the way to presented!

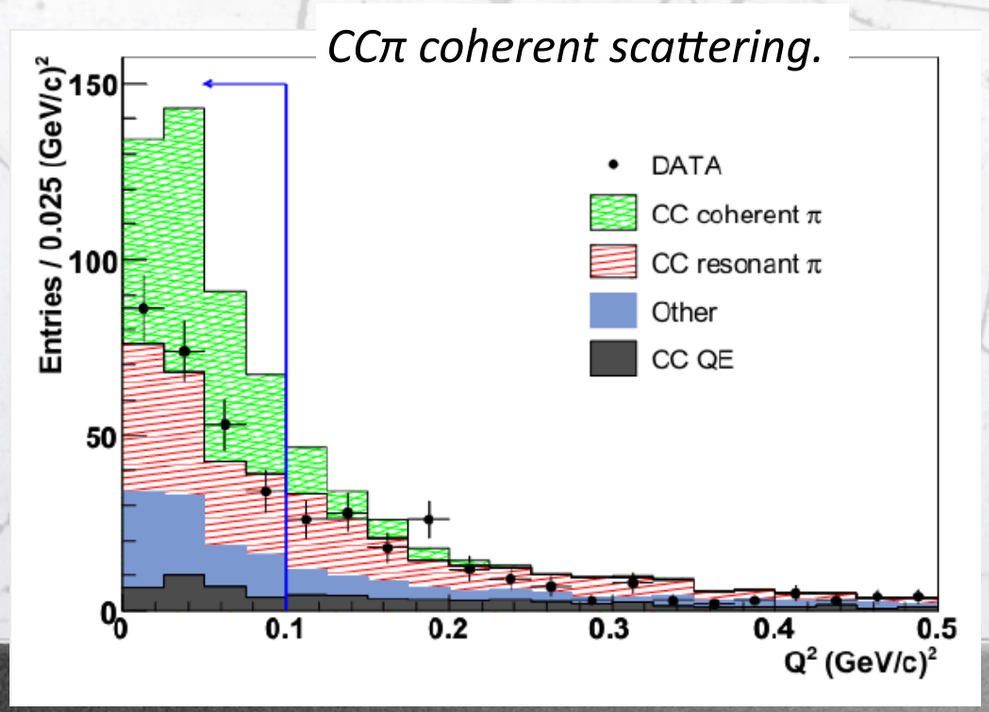
SciBoone

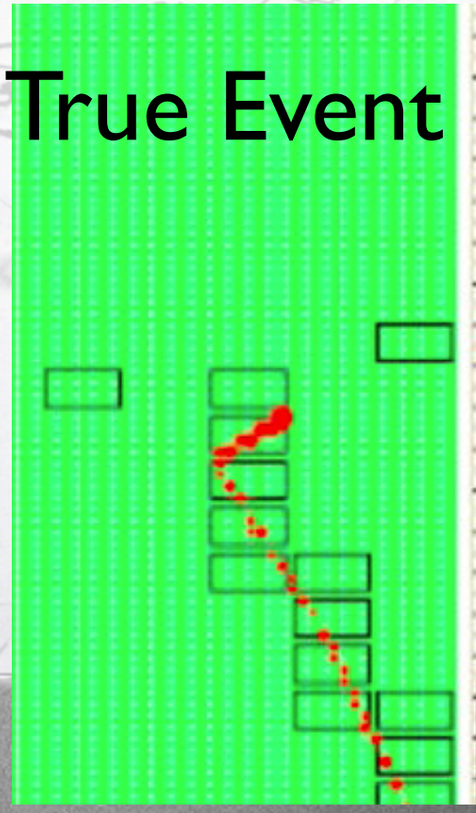
- Boone beam (< 3 GeV)
- Carbon target.
- Low proton tagging threshold (p > 450 MeV/c)
- Low statistics.
- Forward acceptance (> 60º)

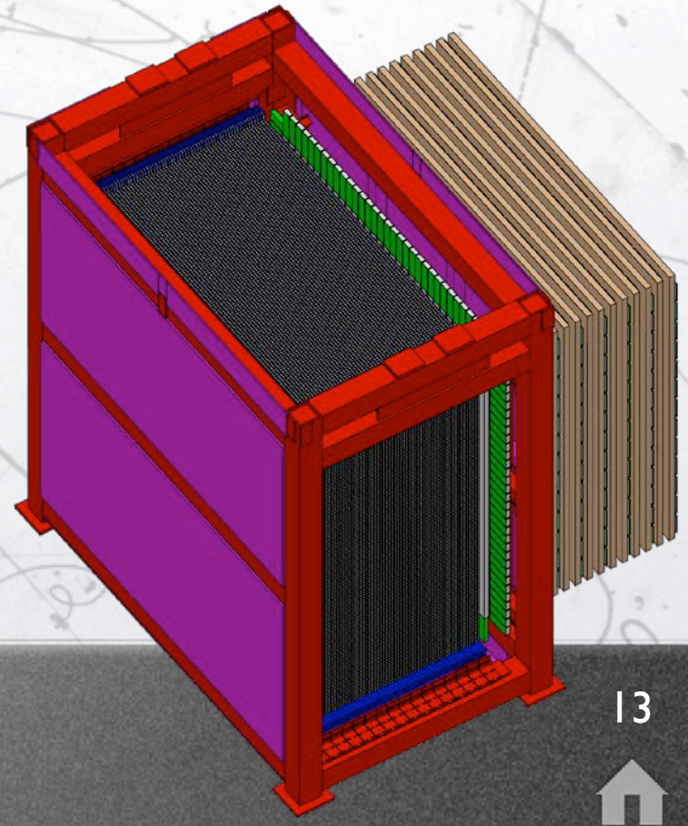


Y. Nakajima, NuInt11

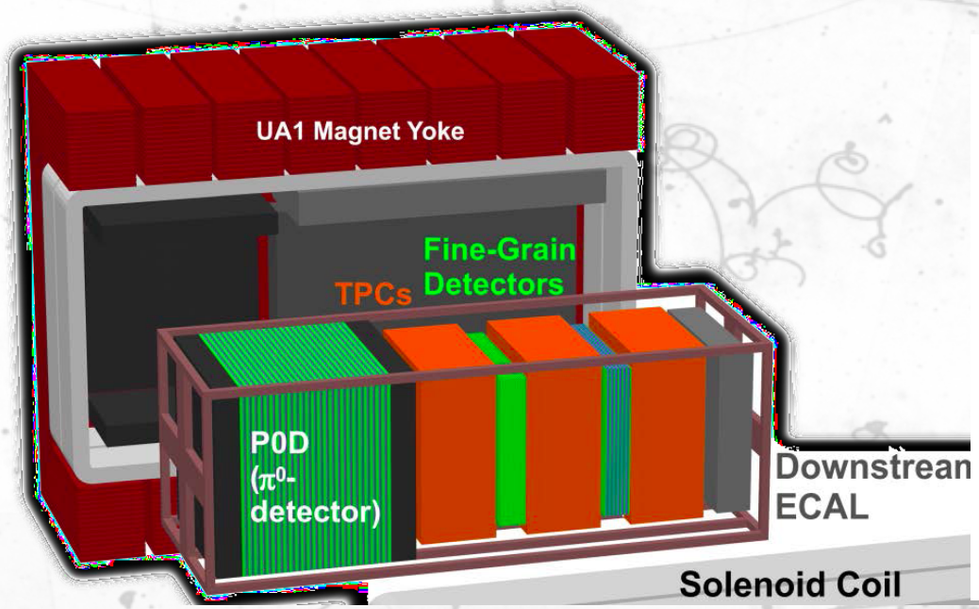
CCπ coherent scattering.

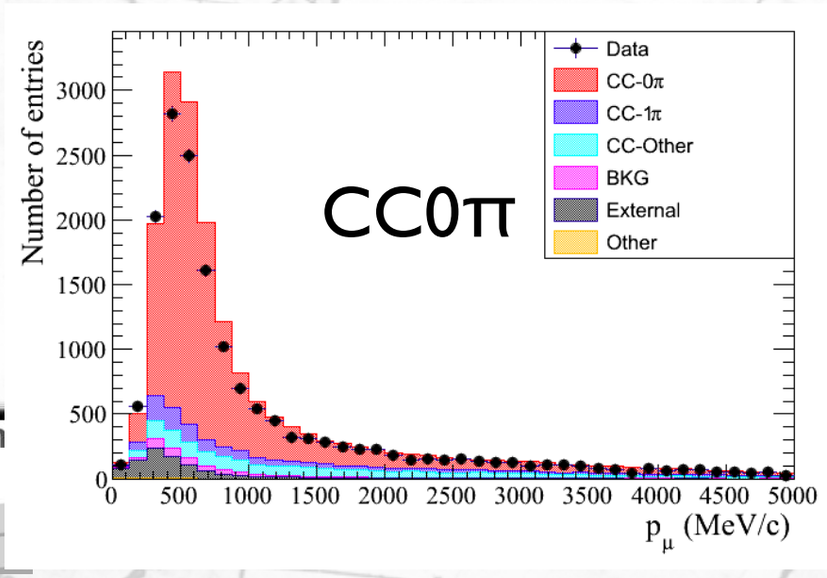


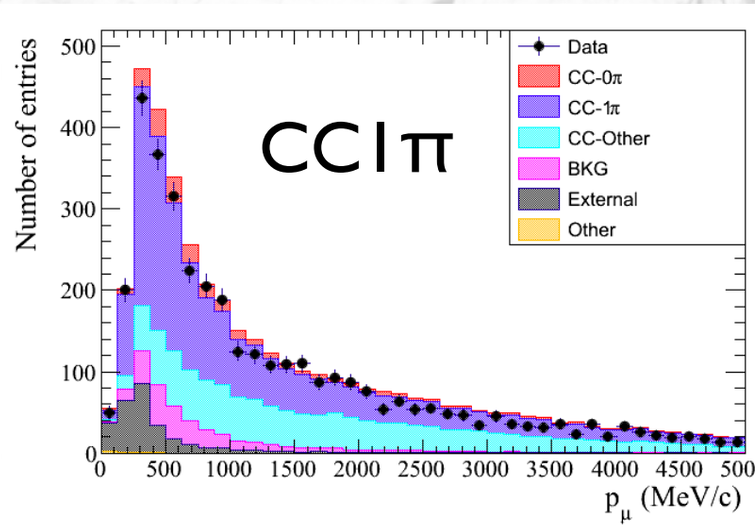




T2K/ND280

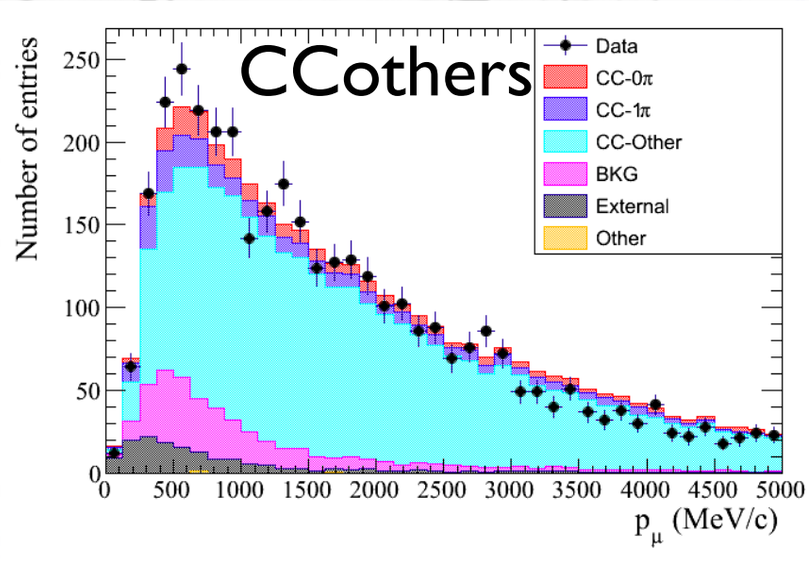






All detectors located within 0.2T UA1 magnet (charge sign determination):

- 2 scintillator based tracking detectors (FGD) Nucl. Instrum. Meth. A 696, 1 (2012)
- 3 Ar - time projection chambers (TPC) NIM A 637, 25 (2011)
- P0D (triangular scintillator bars) Nucl. Instrum. Meth. A 686, 48 (2012))
- Electromagnetic calorimeters (ECALs JINST 8 P10019 (2013))
- Muon range detectors (scintillator in magnet, sMRD Nucl. Instrum. Meth. A 698, 135 (2013))



T2K/ND280

CCinclusive double differential cross-section

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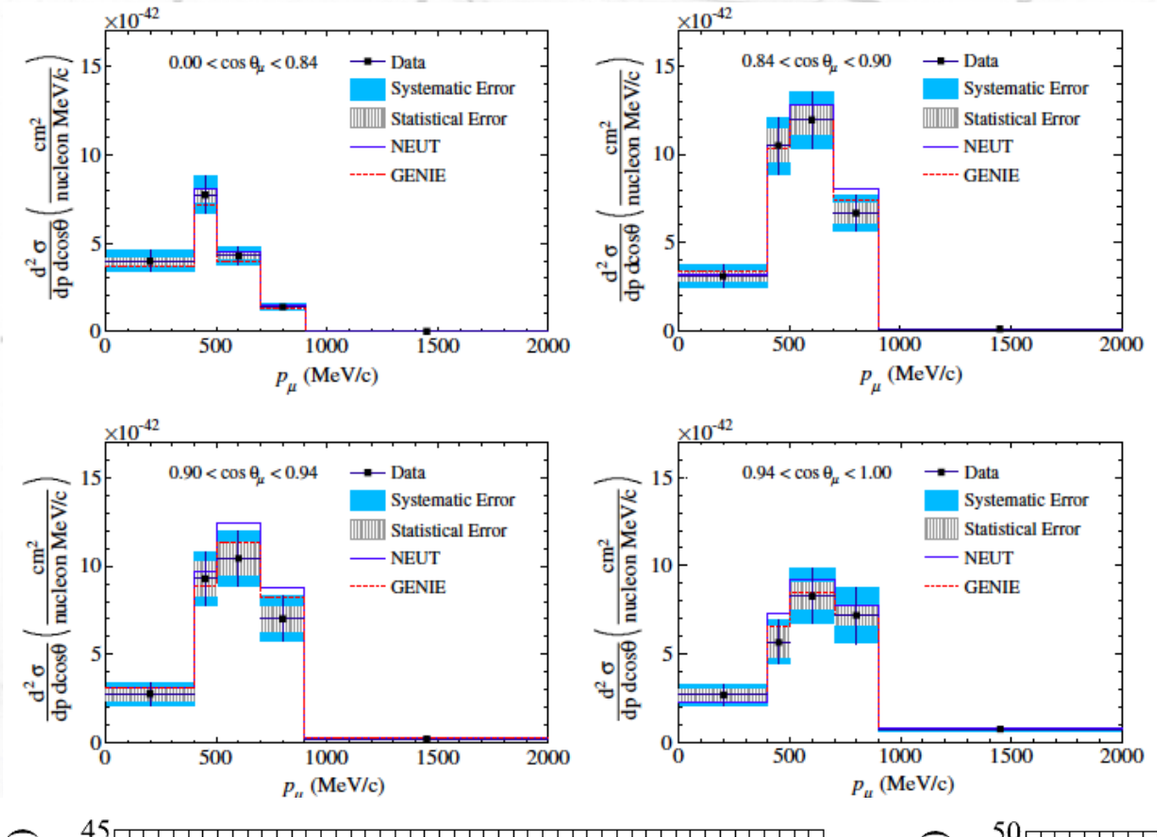
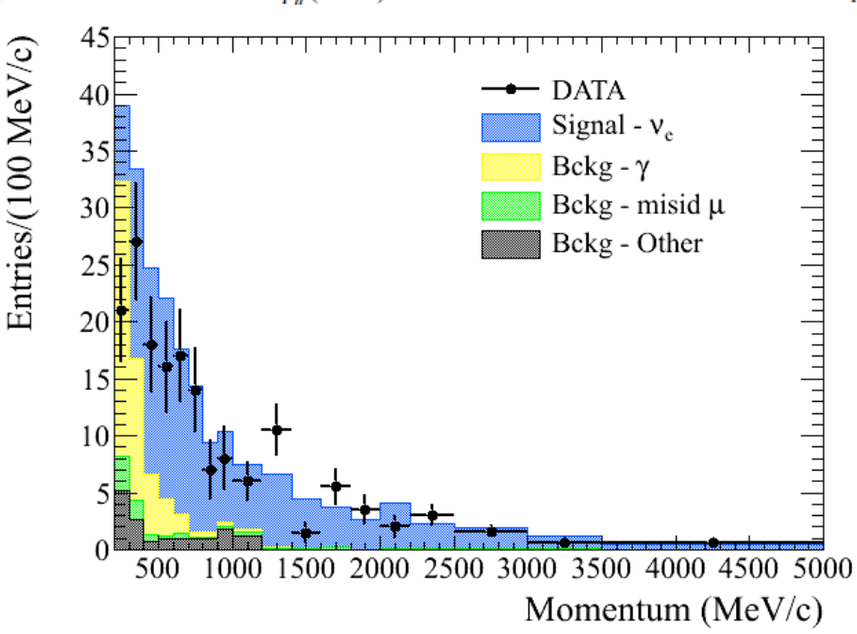
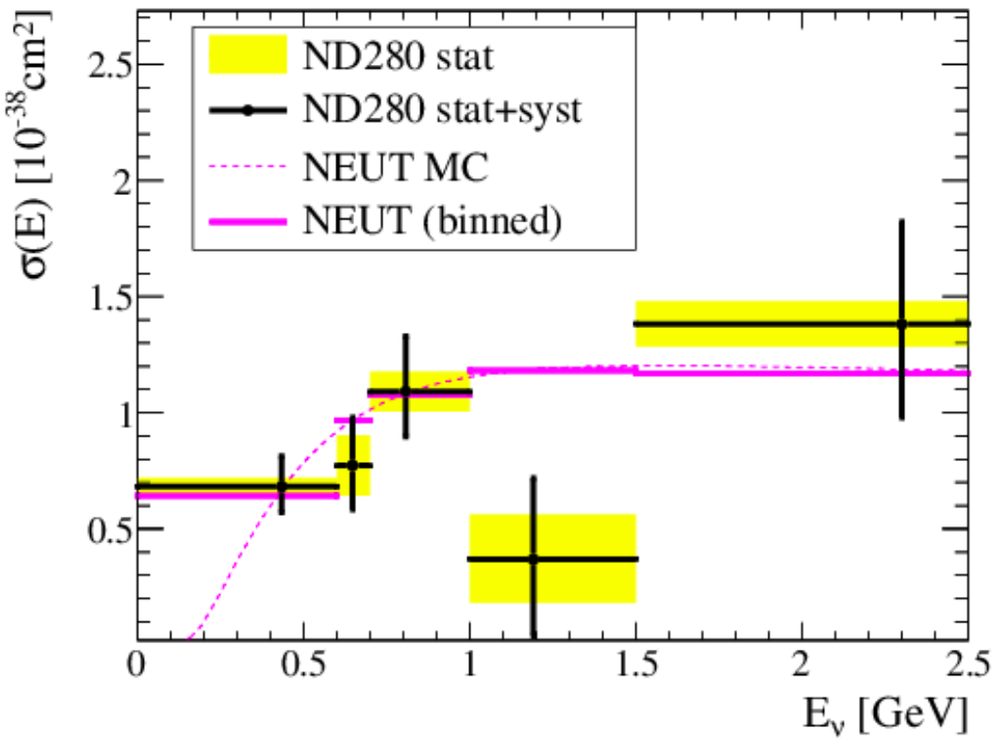
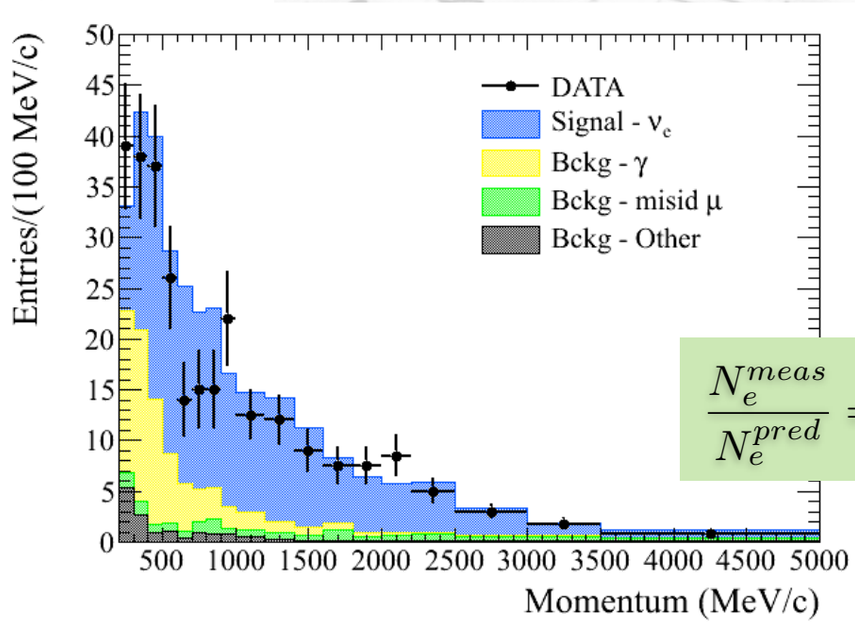




CCQE cross-section



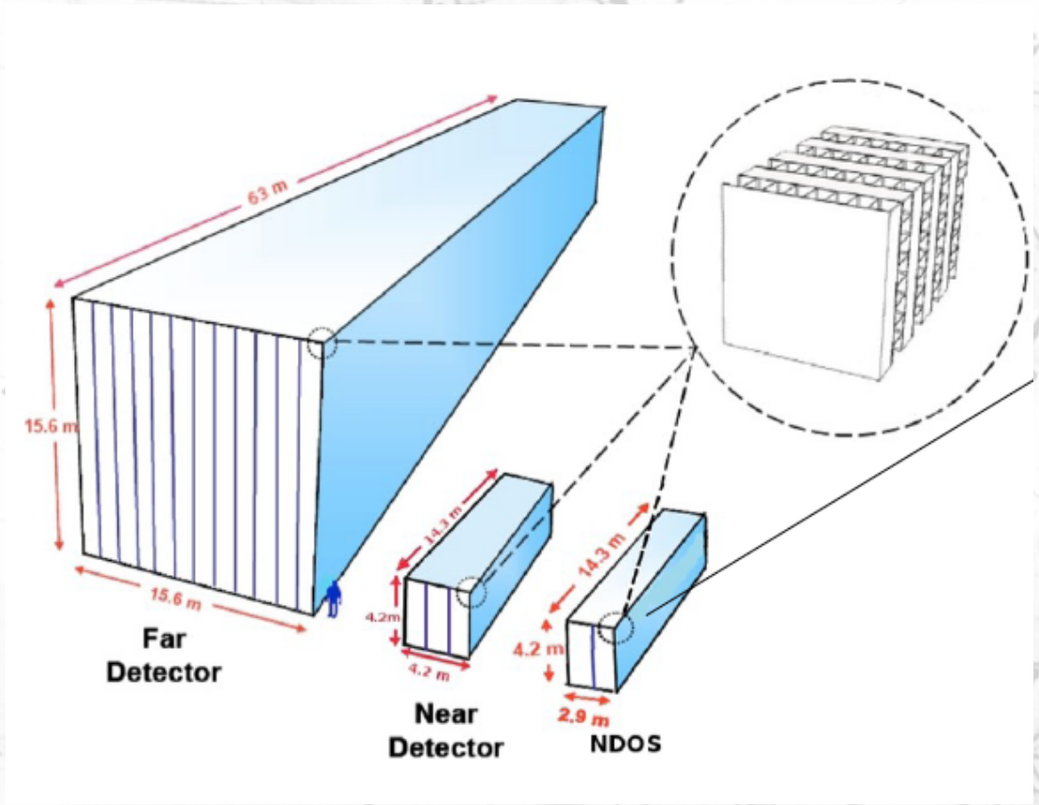
νe flux x cross-section



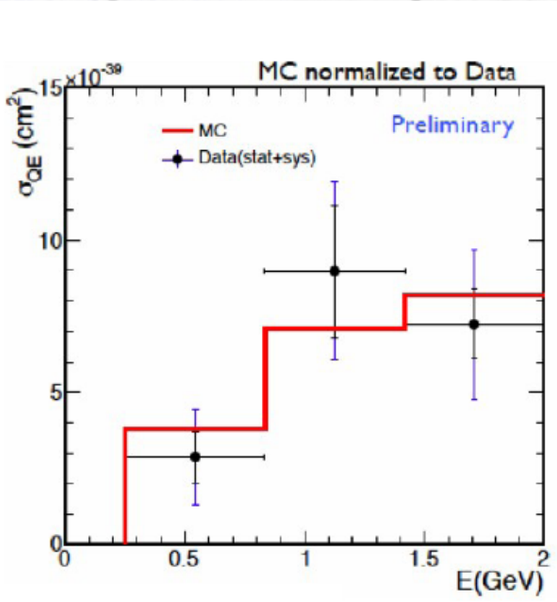
$$\frac{N_e^{meas}}{N_e^{pred}} = 1.06 \pm 0.06(stat) \pm 0.08(syst)$$

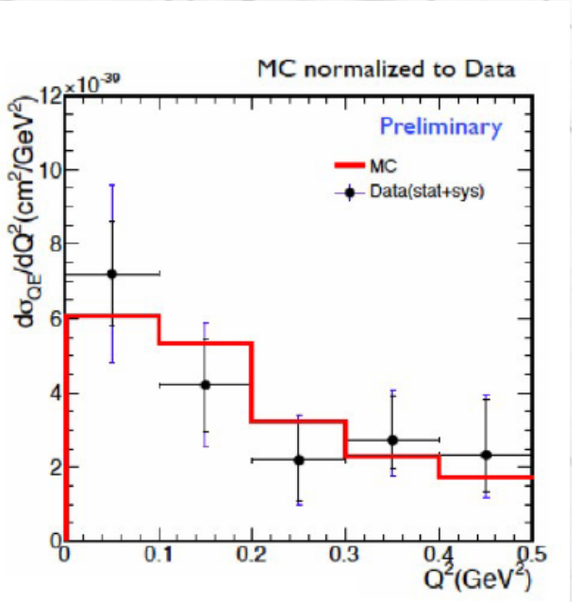
New results expected in the future

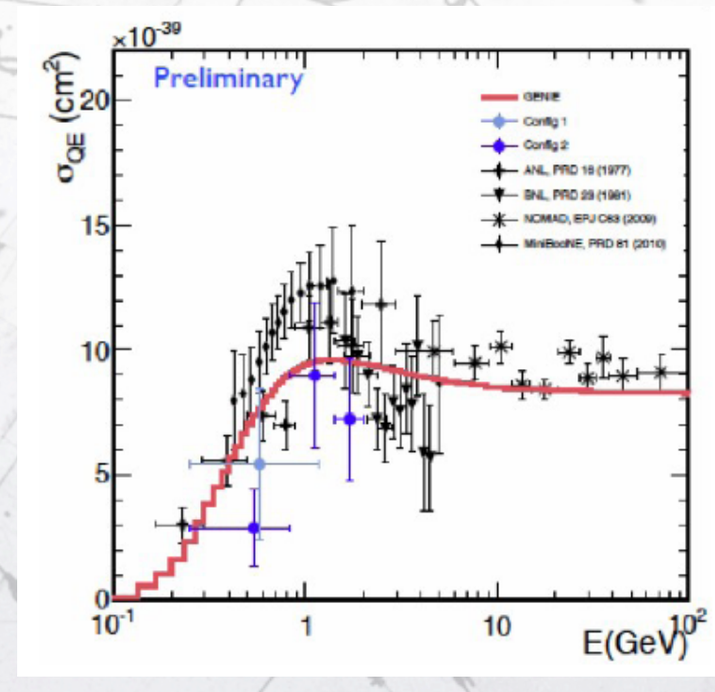
Nova ND



- Fully active target.
- Carbon target.
- Momentum by range.
- ND under construction.
- NDOS preliminary results.

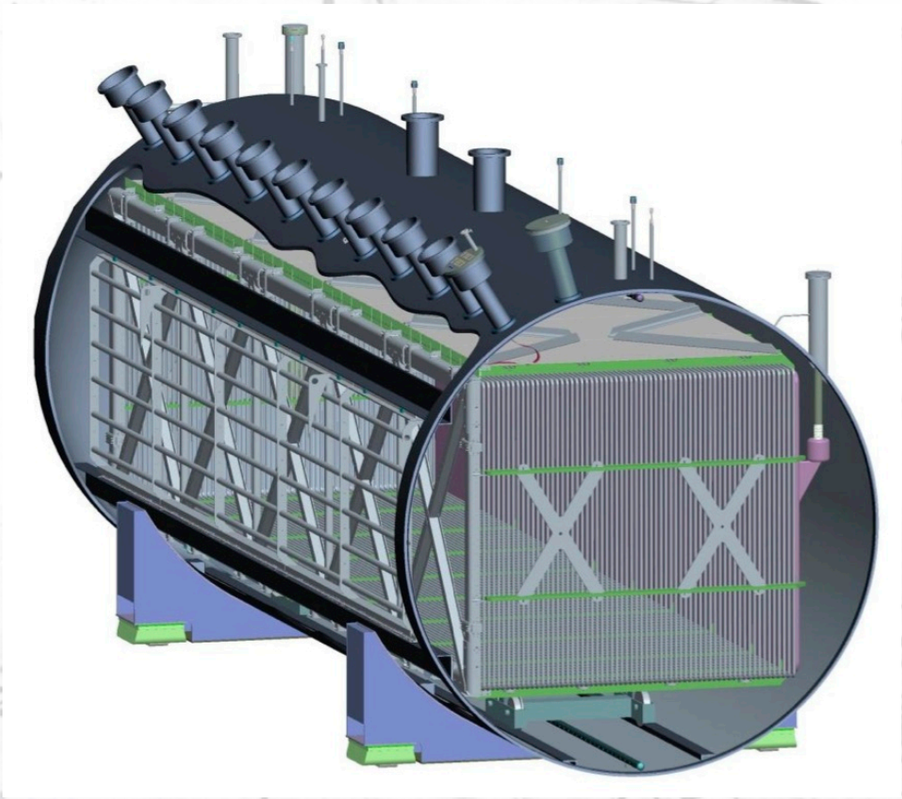




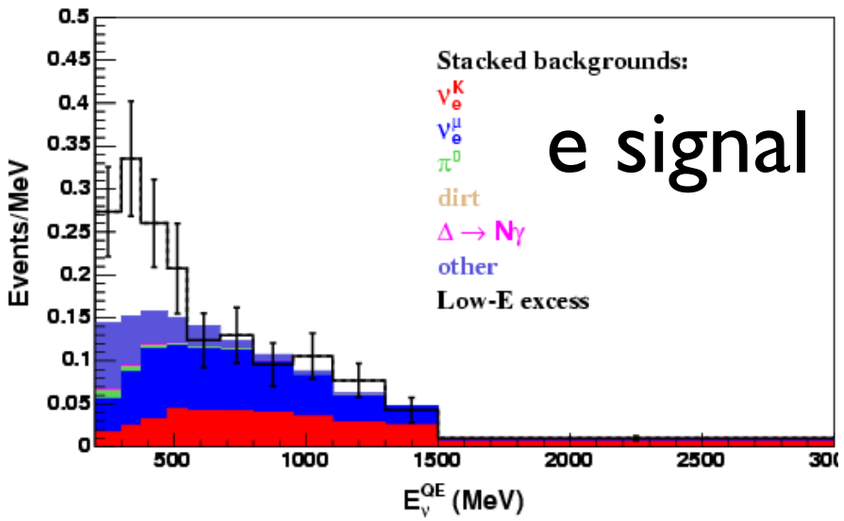


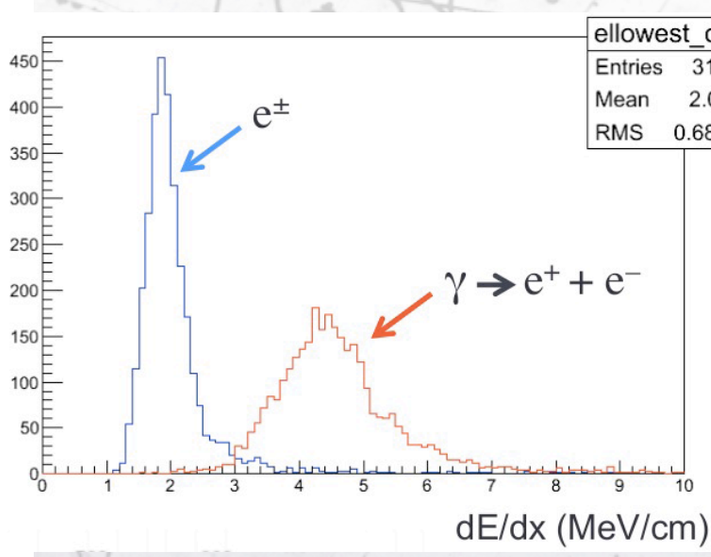
New results expected in the future

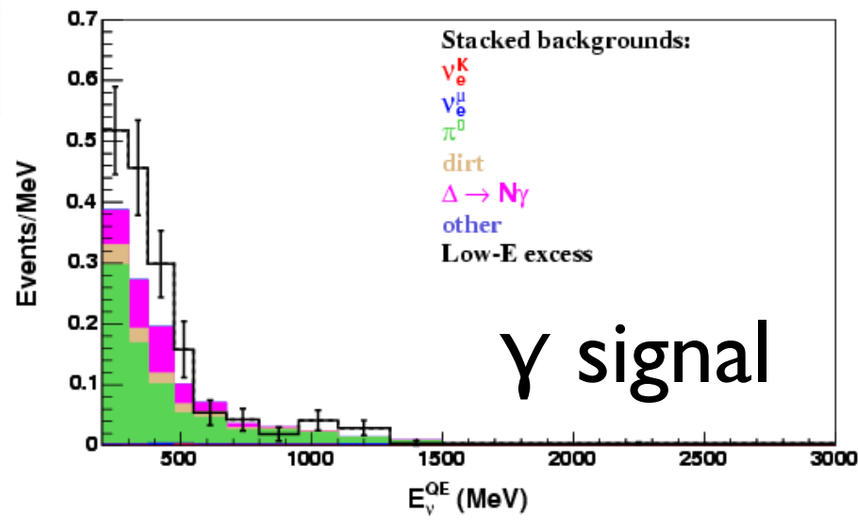
MicroBoone



- 60 ton fiducial volume LiqAr.
- Boone neutrino beam.
- Search for sterile neutrinos and study the low energy MiniBoone excess.
- Low momentum threshold for protons.
- Large mass!.
- no muon catcher!



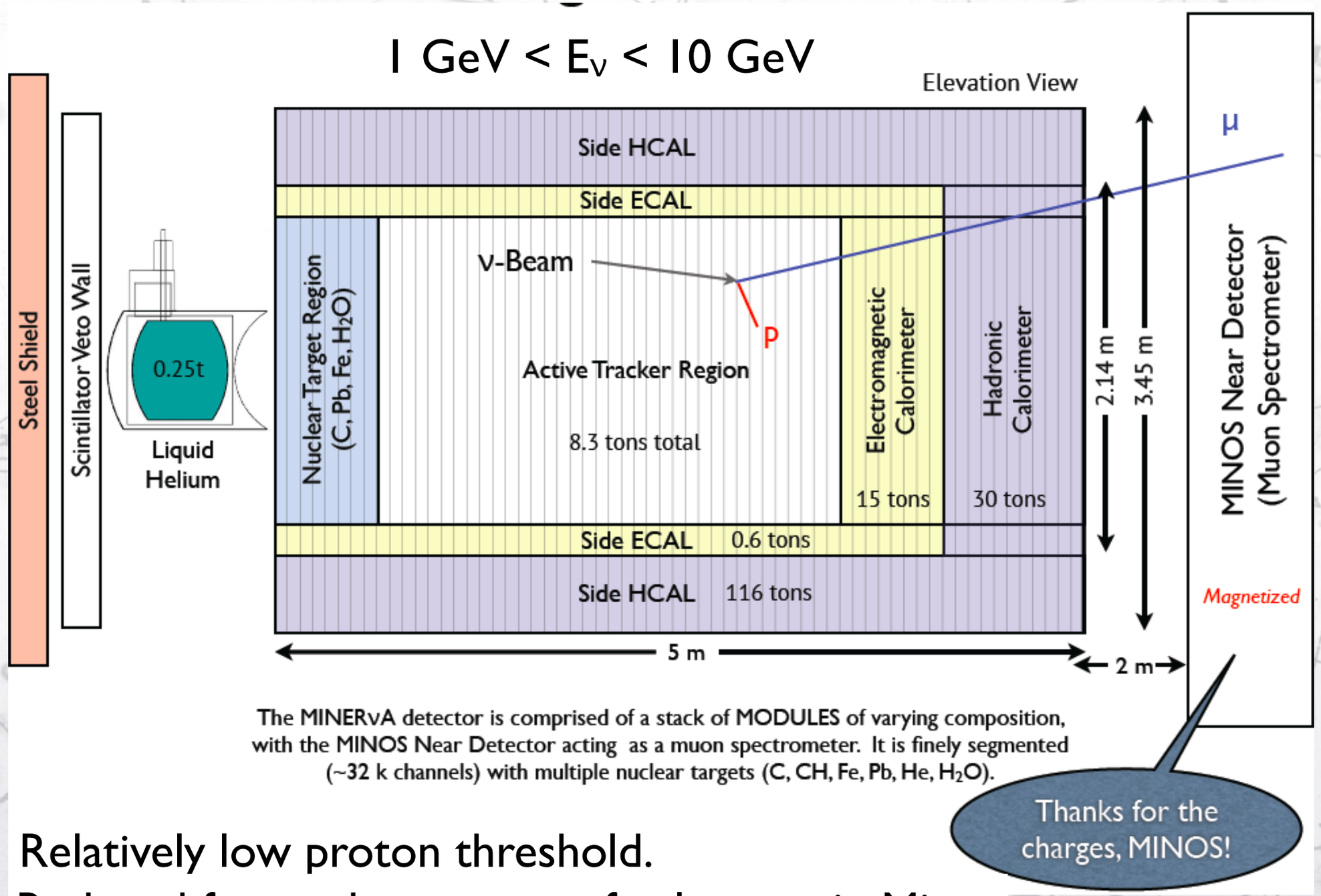




New results expected in the future

Specific experiments

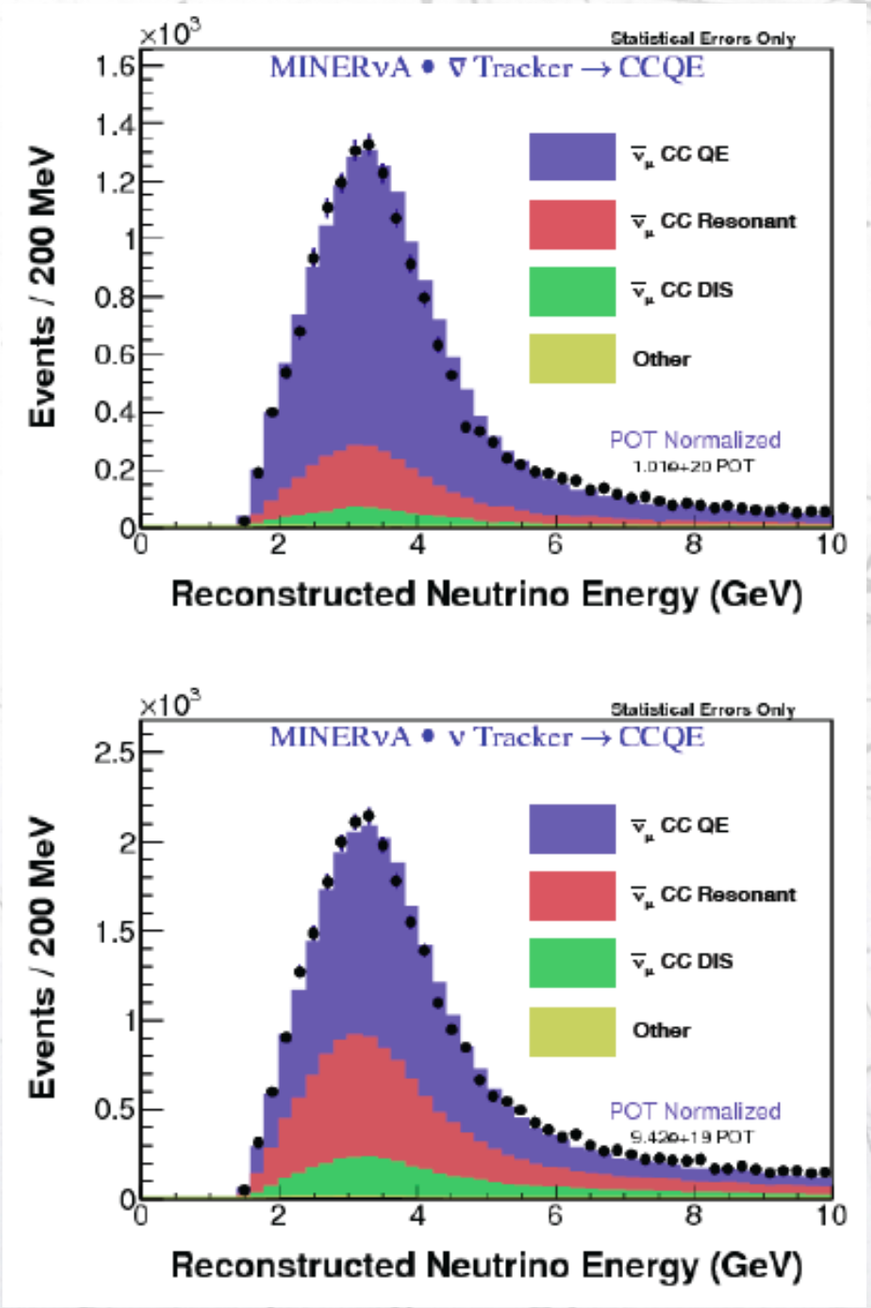
Minerva

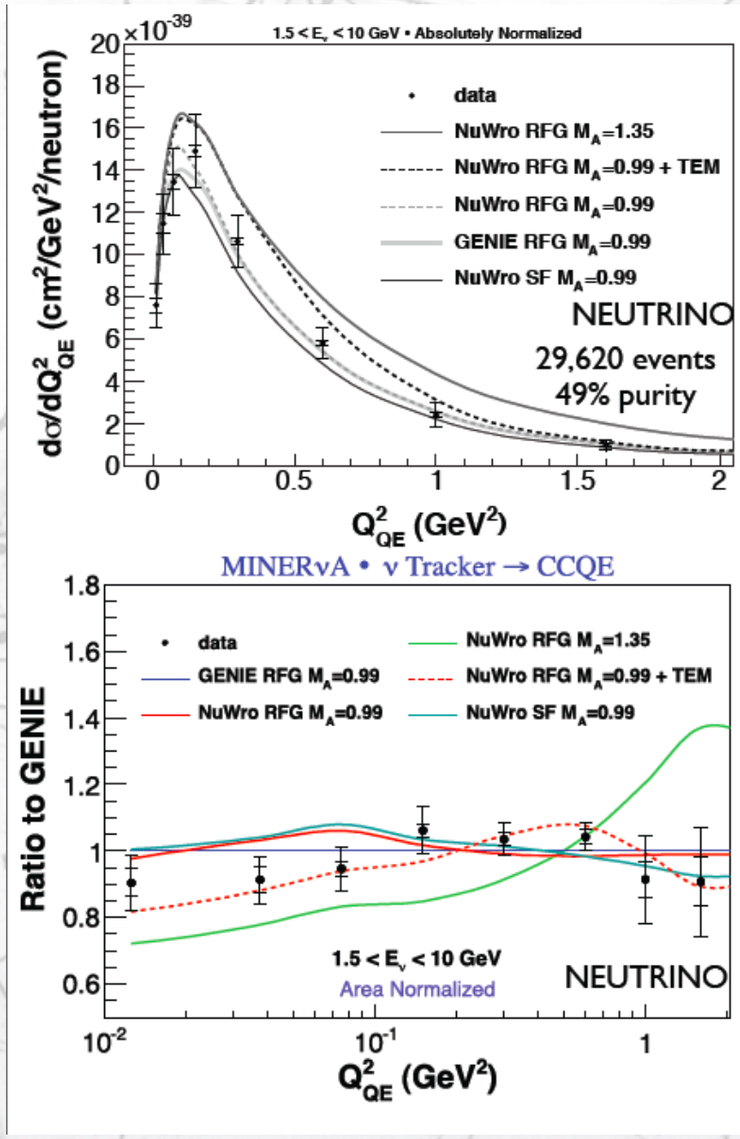


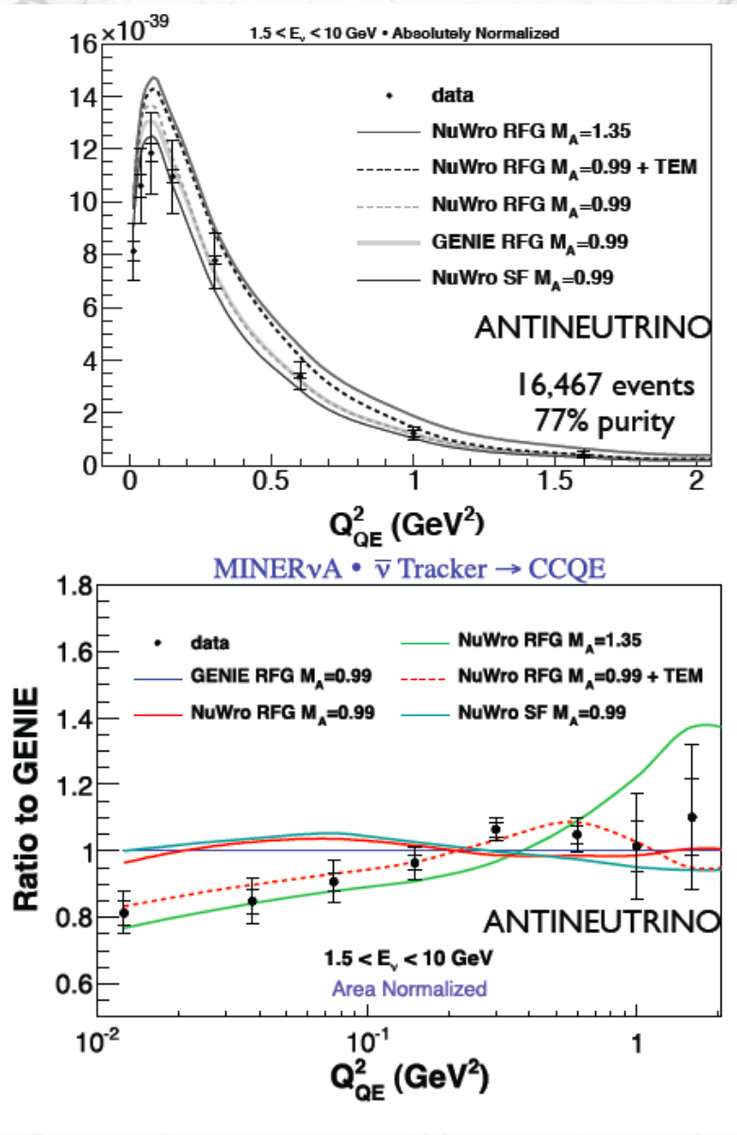
Relatively low proton threshold.

Reduced forward acceptance for leptons in Minos

Minerva

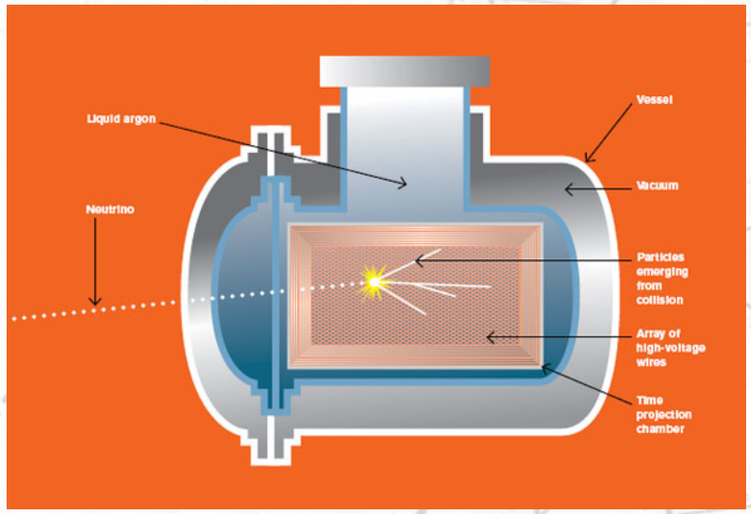




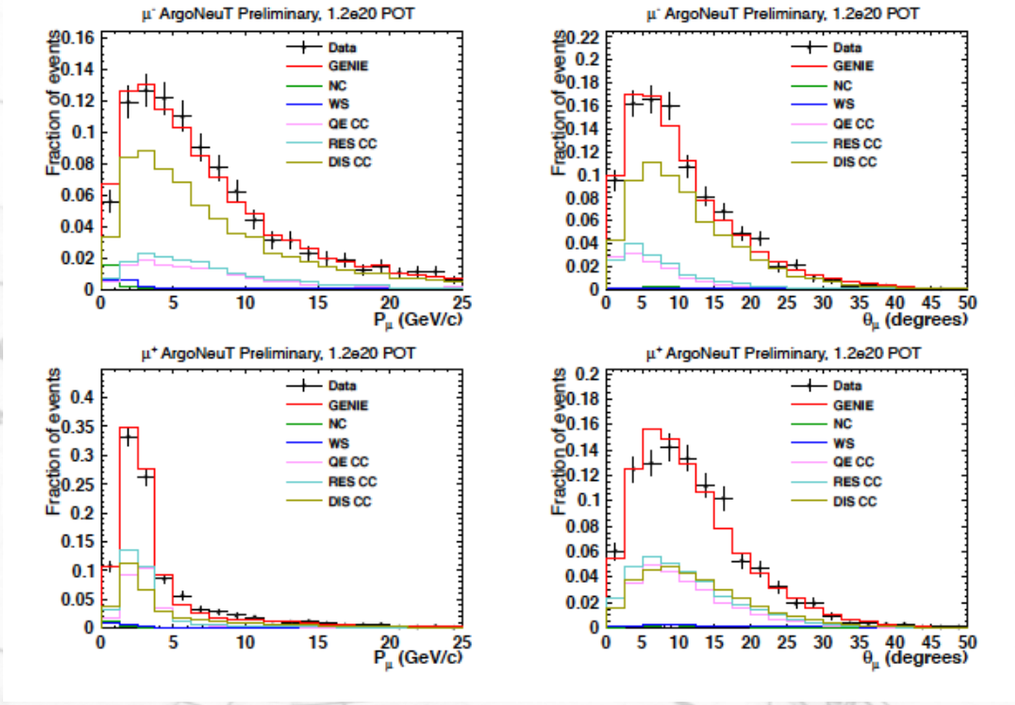


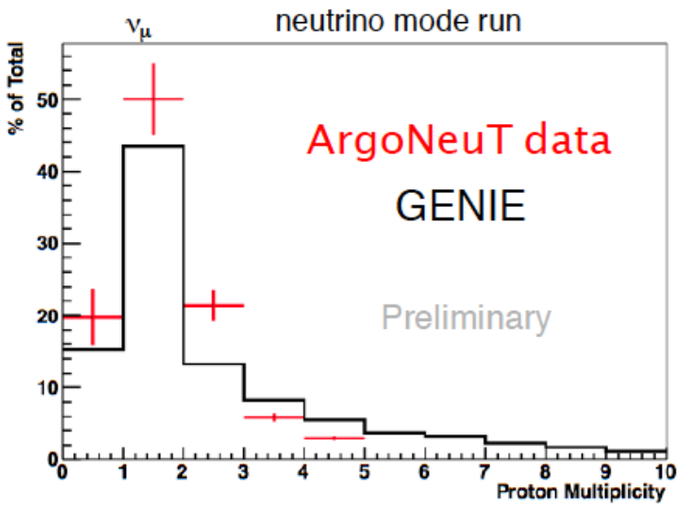
New results expected in the future

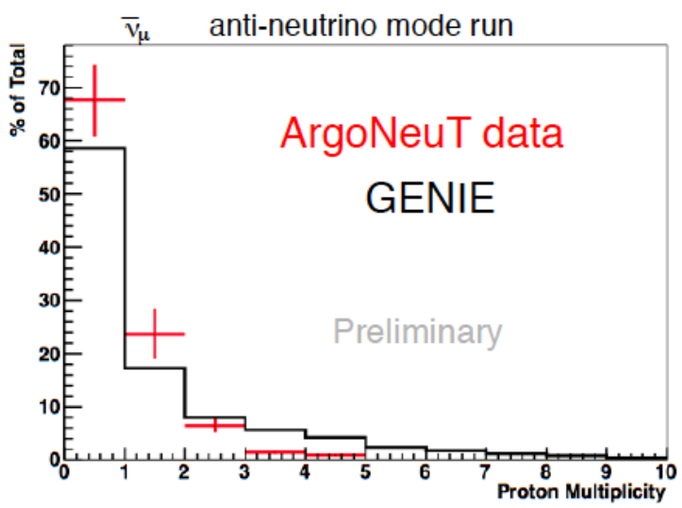
ArgoNeut



- LiqAr detector demonstrator: 240 kg.
- Boone neutrino beam.
- Low proton threshold.
- Operation: ~5 months.

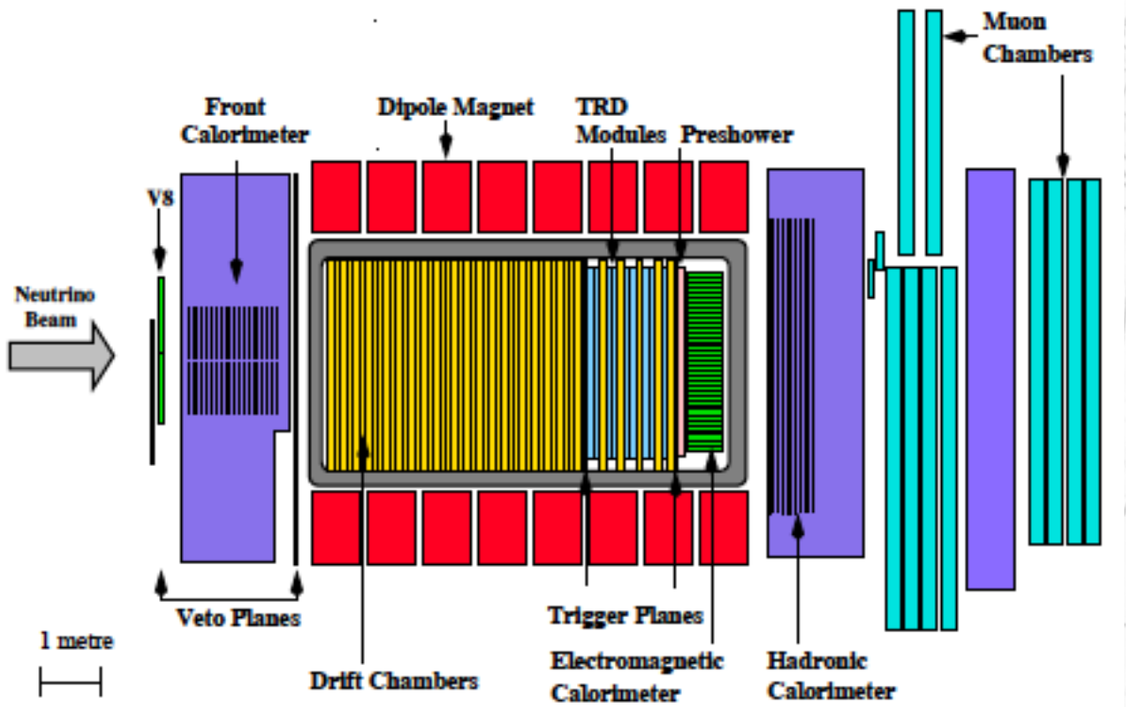




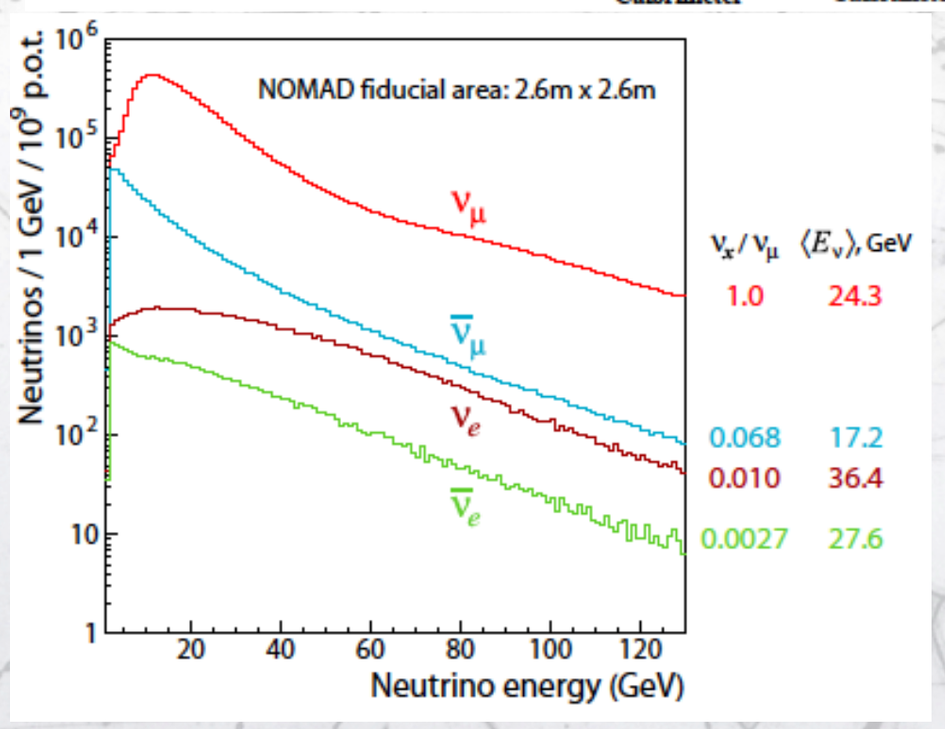


Reanalysis

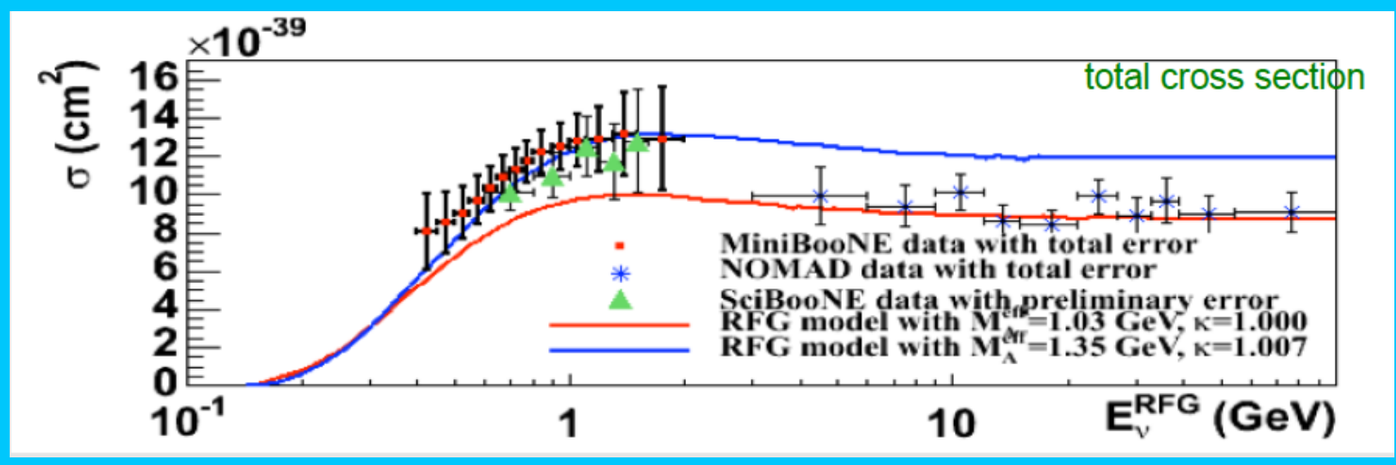
NOMAD



- Tracking detector with magnet.
- Low threshold.
- High energy neutrinos.
- Charge sign identification capabilities.
- Old data, reanalysis in progress.



Nomad-MiniBoone CCQE incompatibility



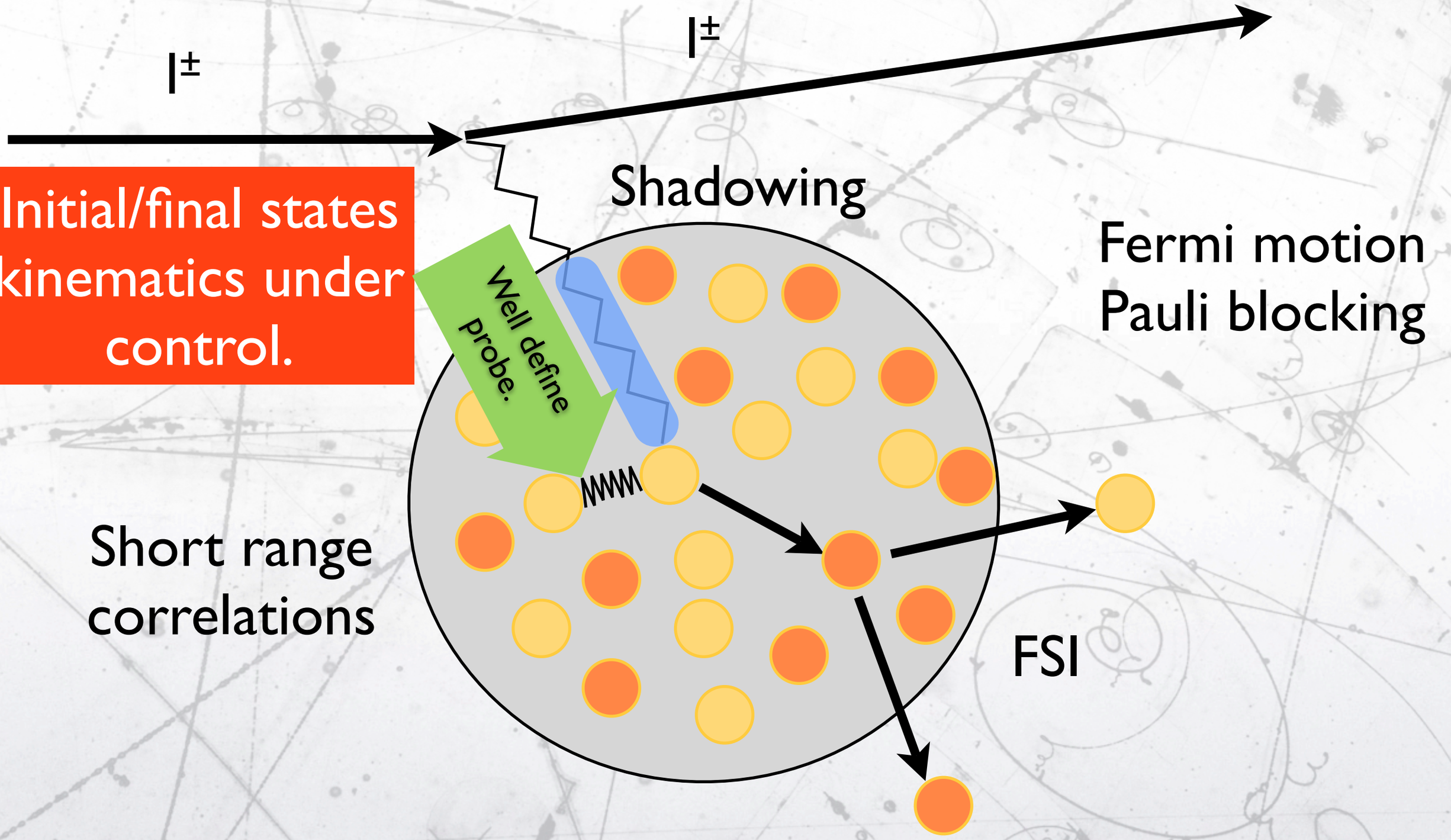
New results expected in the future ?

Electron scattering

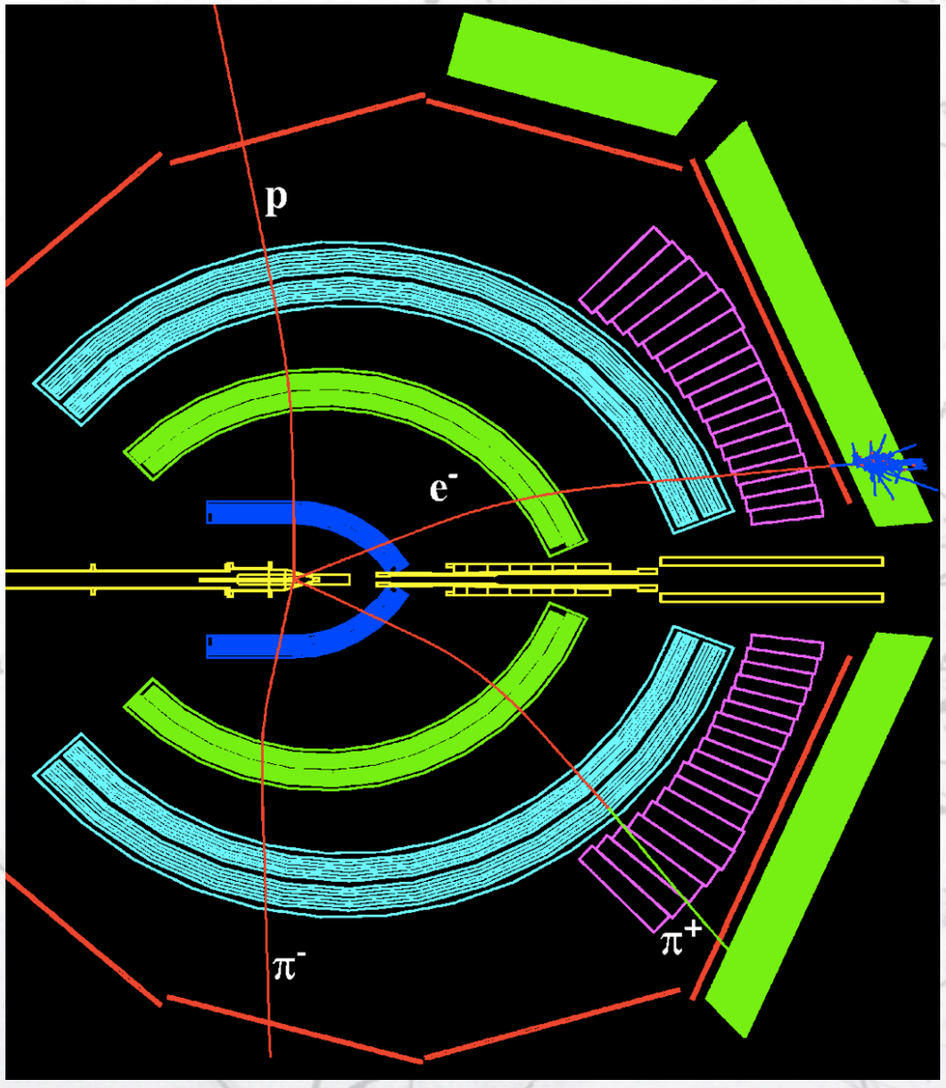
Electron scattering

Initial/final states kinematics under control.

Short range correlations



Electron scattering



- Control on incident beam kinematics allow to:
  - Identify the channel: Elastic, resonant, etc…
  - Calculate the kinematics of hadronic final state (smeared by fermi-motion).
- This allows to understand the:
  - vector component of interaction.
  - effects of FSI and final state multiplicities.
- It is relevant to analyze electron and neutrino scattering based on the same MC to increase synergies between the two worlds.

CLAS experiment at Jefferson Lab.
Data exists, analysis on going, limited man-power.

New results expected in the future ?

Topic coverage

- ν_μ cross-sections are covered by several experiments:
  - Missing low energy and better understanding of nuclear effects: FSI, short and long range nuclear correlations (first indirect indications from MiniBoone).
- $\sigma_{\nu e}$ adressed by T2K/ND280 but with very little statistics, high energy ν´s and large backgrounds.
  - Most probably it will require new beam concept !!!!
- Absolute beam flux knowledge is poor (~10%).
  - This might be irrelevant in future oscillation experiments.
  - Bin to bin uncertainty is the critical issue for oscillation and cross-sections.

Personal view

- I believe the most critical problem is the difficulty to measure the ν_e and anti-ν_e cross-sections
  - we do not have a proper beam to perform this measurement except for the NuStorm proposal.
- We need to reduce the threshold of proton detection to access the 2p2h section of the cross-section (critical for ν energy reconstruction):
  - this is possible with LiqAr but this is a very heavy nuclei. Extrapolation to light nuclei (Oxygen) is complex, new ideas are welcome (HPTPC with several target nuclei!) .
- We need to produce results that are easy to interpret by theorist (avoid the infamous axial mass and model dependent results). NOT TRIVIAL!
- We need to work on an universal language (MC) to be able to compare all experimental results in the same basis.

Personal view

- There are two components of the cross-section:
  - free-nucleon cross-section.
  - effects of nucleon inside high density nuclear matter.
- The free-nucleon is very poorly known (sparse ANL and BNL data):
  - Axial, scalar and pseudoscalar form factors based on models.
  - Resonance and non-resonance interference based on e^- scattering.
  - Better modelling of underlying theory: mainly for resonance production.
- Theorist are requesting this measurements.
  - We need to repeat measurements in deuterium.

Personal view

- Conventional beams suffer from large uncertainties, hadro-production experiments are critical for these studies:
  - MiniBoone, SciBoone, and T2K are following this path.
- Producing your own flux contrains based on data might be acceptable for oscillation analysis but not for the cross-section measurements (Minerva has a different opinion!).

Several experiments on-going.

Many experiments related to oscillations → no optimization for cross-section measurements.

Large progress during last decade, but not enough!

My own conclusions

- I believe (and I am not the only one!) the community needs, parallel to the LBL oscillation, a consistent program of neutrino interaction cross-sections involving:

1. Experiments with several targets nuclei and low proton thresholds: ~100 MeV/c.
    - Monochromatic or changeable neutrino beam (off-axis?) & hadro-production experiments.
2. Clean electron neutrino beam : NuStorm ?
3. Common MC tools and consistent models developed in close interaction with theorists.
4. Electron and photon scattering experiments needs to be integrated in the process.
5. Need of a deuterium target measurement.