S. BORDONI, P. SALA

THOUGHTS ABOUT ND

NEUTRINO OSCILLATIONS

- Neutrino oscillations experiments are based on the comparison of neutrino interactions at the near and far sites

$$\frac{N^{far}_{events}(E_\nu)}{N_{events}(E_\nu)} = P_{osc}(E_\nu)$$

- For a given neutrino energy, the number of events can be determined knowing flux and cross-section

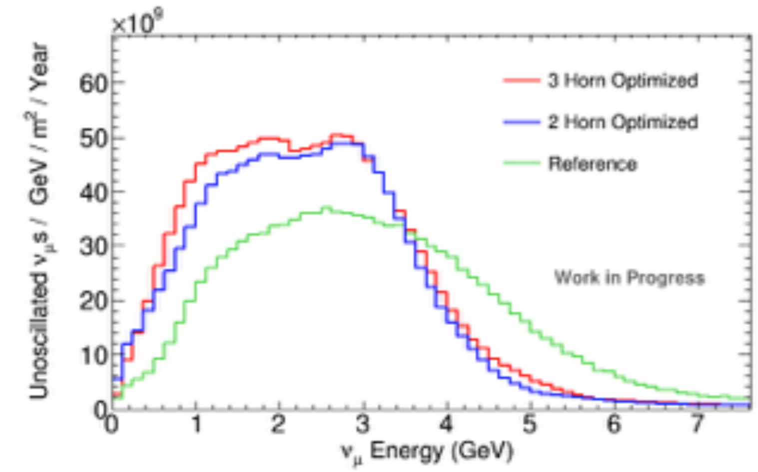
Near Detector

$$N_{events}(E_\nu) = \sigma_\nu(E_\nu)\Phi(E_\nu)$$

Far Detector

$$N^{far}_{events}(E_\nu) = \sigma_\nu(E_\nu)\Phi(E_\nu)P_{osc}(E_\nu)$$

easy !?



NEUTRINO OSCILLATIONS

- But we don't know the neutrino energy because beams are not monochromatic : has to be determined event by event
- The energy estimation is not trivial and might not be perfect
- Furthermore, the oscillations introduce differences in the flux spectrum
- as a consequence: not perfect cancelation of the cross-section and flux dependencies in the ratio

$$\frac{N^{far}_{events}(E_\nu)}{N_{events}(E_\nu)} = \frac{\int \sigma(E'_\nu)\Phi(E'_\nu)P(E_\nu|E'_\nu)P_{osc}(E'_\nu)dE'_\nu}{\int \sigma(E'_\nu)\Phi(E'_\nu)P(E_\nu|E'_\nu)dE'_\nu}$$

Oscillation experiments needs to know : $\Phi(E_\nu)$, $\sigma(E_\nu)$, $P(E_\nu | E'_\nu)$

FROM LATEST OA MEASUREMENTS

T2K

Source of uncertainty (number of parameters)	$\delta n_{SK}^{exp} / n_{SK}^{exp}$ neutrino mode	antineutrino mode
Flux+ ND280 constrained cross section (without ND280 fit result) (61)	10.81%	11.92%
Flux+ ND280 constrained cross section (using ND280 fit result) (61)	2.79%	3.26%
Flux+ all cross section (65)	2.90%	3.35%
Super-Kamiokande detector systematics (12)	3.86%	3.31%
Pion FSI and re-interactions (12)	1.48%	2.06%
Total (77)	5.06%	5.19%

NOvA

Systematic	Effect on $\sin^2(\theta_{23})$	Effect on Δm^2_{32}
Normalisation	± 1.0%	± 0.2 %
Muon E scale	± 2.2%	± 0.8 %
Calibration	± 2.0 %	± 0.2 %
Relative E scale	± 2.0 %	± 0.9 %
Cross sections + FSI	± 0.6 %	± 0.5 %
Osc. parameters	± 0.7 %	± 1.5 %
Beam backgrounds	± 0.9 %	± 0.5 %
Scintillation model	± 0.7 %	± 0.1 %
All systematics	**± 3.4 %**	**± 2.4 %**
Stat. Uncertainty	**± 4.1 %**	**± 3.5 %**

Near Detector tasks

- Measure the incoming flux
- Measure neutrino cross-section
- Determine the energy of the incoming neutrinos
  - need low threshold
  - need excellent e/γ separation
  - …

ND EFFORT IN DUNE

- Dune is strengthening the effort towards a final design of the near detector. The time scale is ~1 year
- From the latest March Workshop, DUNE is moving towards an hybrid design.
  - Composite detector (like general purpose HEP detector)?
  - More than one detectors to address different questions?
- Design is still 100% open. Needs to carefully think to purposes and measurements we need/want to perform at the ND to determine the most suitable design.
- Many interesting talks at the workshop, here some links (arbitrary choice)
  - Flux measurements
  - requirements for a ND
  - Method to evaluate ND optimisation options

Dune ND working group : taking over from Task Force
Conveners: Kam-Biu Luk and Alfons Weber

MAIN TOPICS BEING QUESTIONED

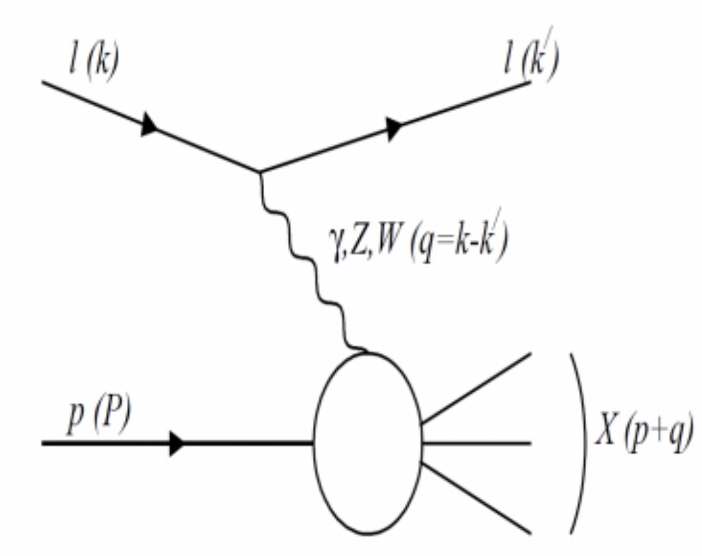
- Flux measurements usually imply Flux $\otimes$ cross-section measurements. Is it possible to achieve independent flux measurements ?
  - low-ν, ν-e elastic scattering
- The neutrino-nucleus cross-section is not well known. Which measurements can help to improve the current modelling?
  - Electron scattering data, pion cross-section in Ar for FSI, Reduce the $\sigma_{\nu_\mu}/\sigma_{\nu_e}$ error

Meeting 9th May

- Which is the best (= updated/ complete) event generator in the market ?
  - GENIE, NEUT, NuWRO, NUISANCE , FLUKA (need some developments)
- What is the most robust analysis strategy ?
  - Fits (à la T2K) , matrices (à la MINOS and/or NOvA)
- Do we need a magnetised ND?

LOW-ν FLUX DETERMINATION

reference talk



- ν is the energy of the final state hadron in the laboratory framework $\nu = E_{had} = E_{\nu} - E_{\mu}$
- The differential cross section can be written as

$$\frac{d\sigma}{d\nu} = A + B\frac{\nu}{E} - C\frac{\nu^2}{2E^2}$$

A, B, C are integrals of structure functions

- In the limit ν/E –> 0 $\lim_{\frac{\nu}{E}\to 0} \frac{d\sigma}{d\nu} = A$

$$\lim_{\frac{\nu}{E}\to 0} \frac{dN}{d\nu} \simeq \Phi A$$

independent from the neutrino energy

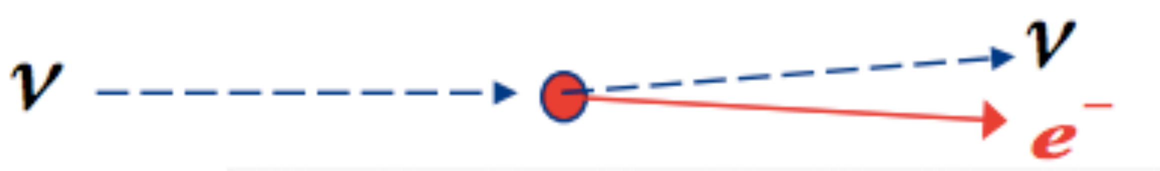
- Measure the shape of the neutrino spectrum. Need normalisation to external measurement to extract the absolute flux

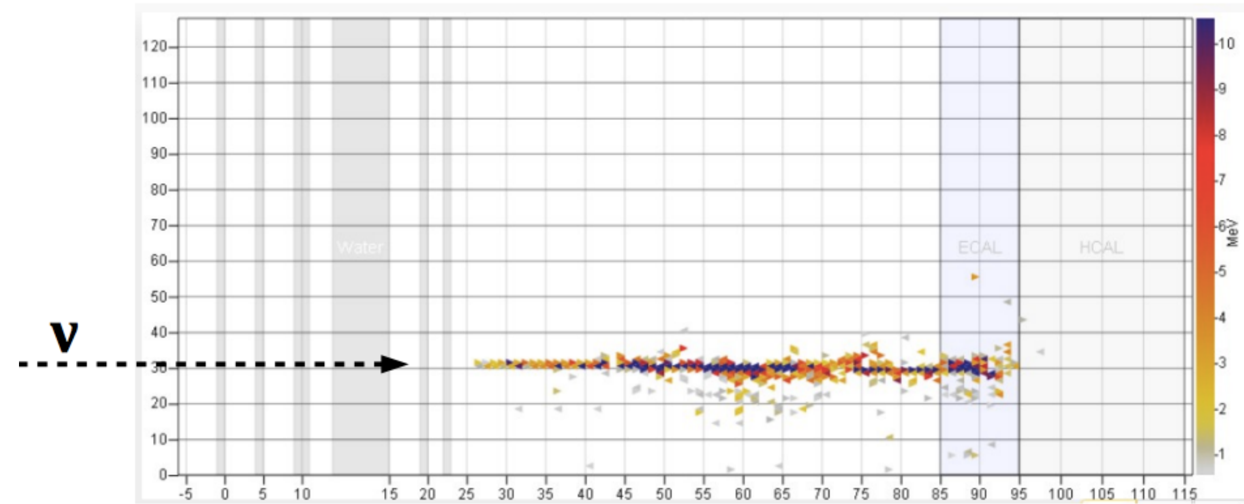
Comments: Needs good reconstruction of lepton and hadronic energy

→ Containment, detection of neutrons.

→ LAr not so good (maybe if dopants) , plastic scintillator could work

NEUTRINO ELECTRON SCATTERING





- Cross section well known : purely electroweak
- No nuclear effects
- Very forward single electron final state. Need very good angular resolution (<10 mrad)
- Can measure total flux, shape is more difficult

Possible requirements

Low density detector to suppress multiple scattering

High granularity tracking

Non negligible mass needed (1 – 3 tons) , nearby position preferred

Gas TPC? Straw tube Tracker? (ex-baseline ND)

CROSS SECTIONS – DETECTOR EFFECTS

- Nuclear effects have proven to be important and TRICKY (never know if we describe everything correctly…)
- Reconstruction efficiency/cuts/biases enter in oscillation analysis

To control those aspects, it recommanded to have:

- same target nucleus as in Far Detector
- similar detection technique or at least similar density
- same/larger acceptance than in Far Detector

Possible options:

Ar gas TPC ? (+ calorimeter)

LAr TPC ? (small (order few tons) + calorimeter)

LAr with different readout?

Ar target in other detector (bad, needs subtractions..)

DETECTORS OPTIONS ON THE TABLE

- Ex-baseline: straw trackers in magnetic field, calorimeter around, might interleave Ar layers
- LAr gas TPC, following developments for T2K, + surroundings
- Scintillator à la MINERvA , maybe preceded by LAr box
- LrA modular small drift detector: Argoncube , could be magnetized
- CALICE: high granularity scintillator prototypes
- Reuse KLOE (high granularity scintillator fibre calorimeter in B field, central cavity to be filled with tracker/Lar/gAr…)
- More?

Consensus on : we need a complex system..or maybe two

NEUTRINO GENERATORS

- In the past few years remarkable achievements.
- Several generators available with different approaches
- Some comparison with electron scattering data on-going

from J. Nowak talk at IPPP/NuSTEC Workshop

Model/generator	GENIE (2.14 defaul)	NuWro	NEUT	Fluka
QE	Lwlyn-Smith Nieves, Eff MA	Lwlyn-Smith RPA	Lwlyn-Smith Eff RPA	Lwlyn-Smith
Nuclear model	RFG, LFG, Effective spectral function	RFG, LFG, spectral function	RFG, LFG, spectral function	LFG
MEC	Valencia Empirical	Valencia Marteau	Valencia	-
Delta model	Rein-Sehgal (updated)	Home-grown, great	Rein-Sehgal (update)	Rein-Sehgal (delta only)
Coherent	Rein-Sehgal(corrected) Berger-Sehgal	Rein-Sehgal Berger-Sehgal	Rein-Sehgal Berger-Sehgal	-
FSI	Schematic Cascade (med corr)	Cascade(med corr)	Cascade(med corr)	Cascade+pion abs+pre-eq+evap

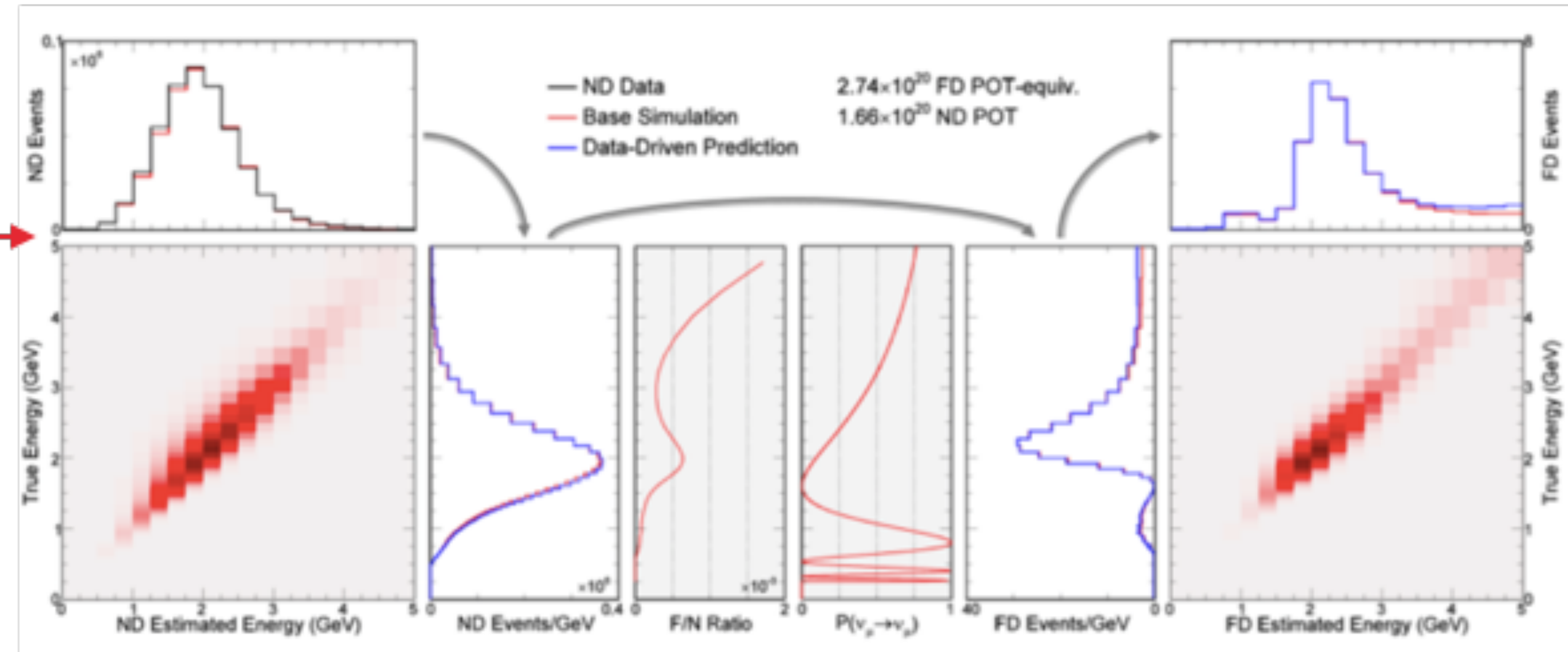
S. Dytman

σ(ν_μ) / **σ**(ν_e) differences due to lepton mass:
→ Nuclear effects (again!)
→ Radiative corrections (easier)

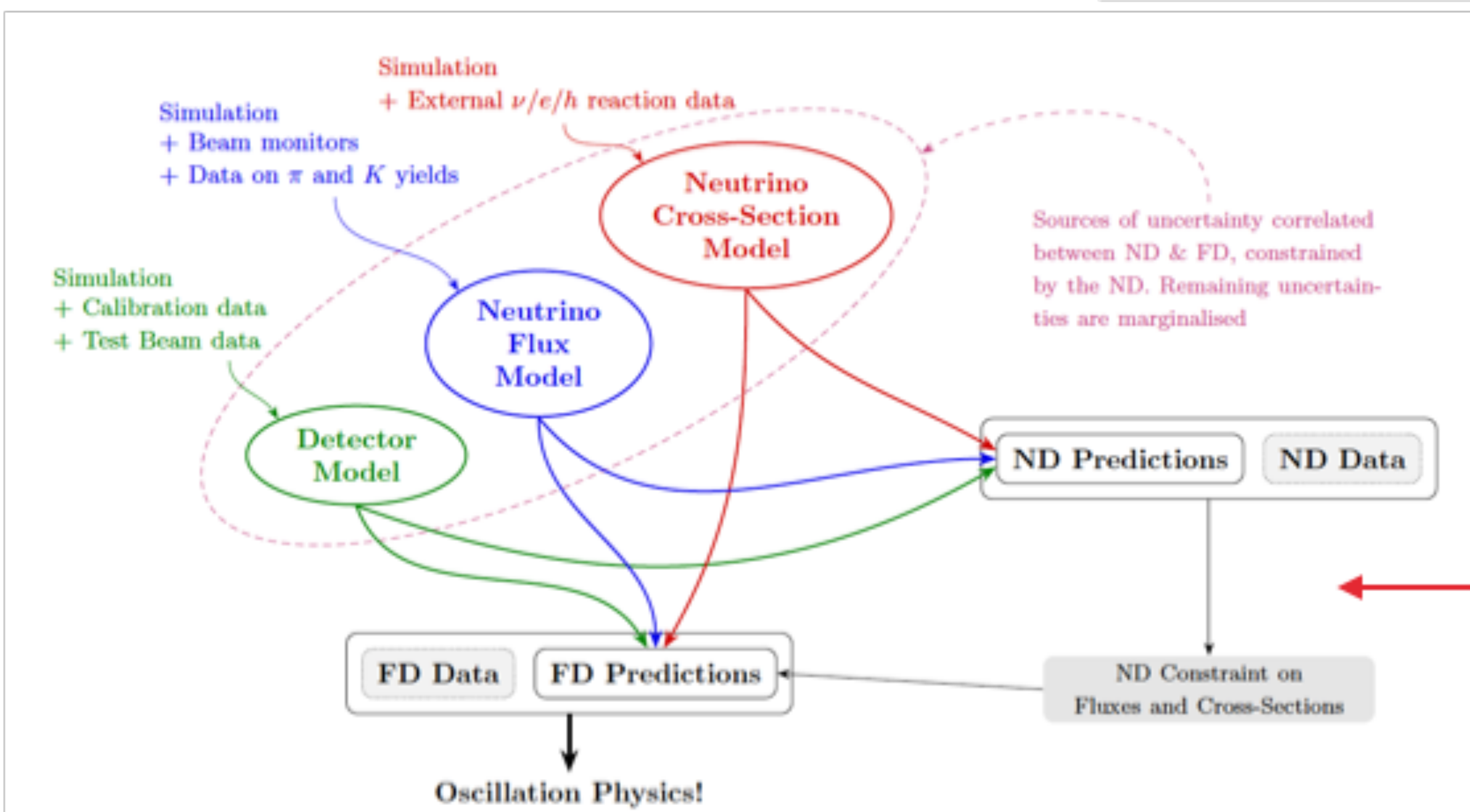
ANALYSIS STRATEGY

à la MINOS and NOvA

Uses of matrices to to unfold the reconstructed E + F/N ratio (NOvA) or beam matrix matrix (MINOS)



VALOR (à la T2K)

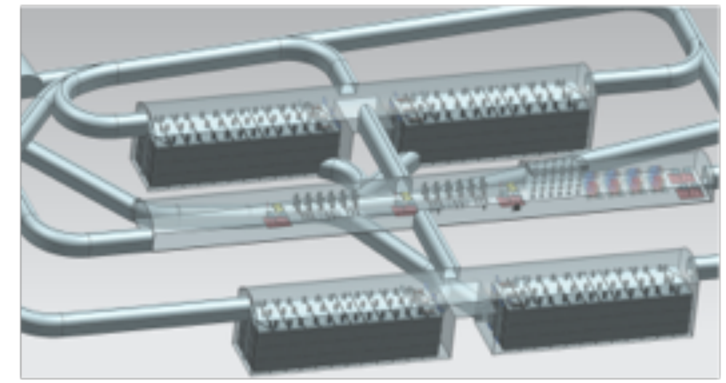


Fit ND data to extract flux and cross section constrains and tune the FD MC

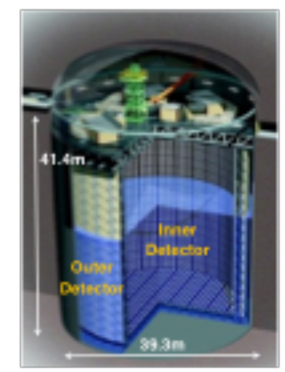
MAGNETISED DETECTOR ?

- Far detector are usually huge and not magnetised: **need to know the wrong sign contamination** (e.g. neutrino in antineutrino beams) by the ND! → *magnetised!*

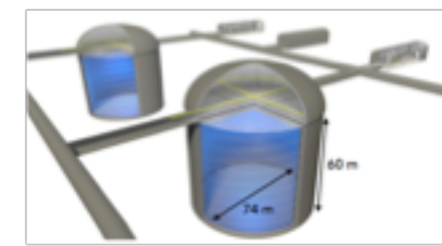
DUNE



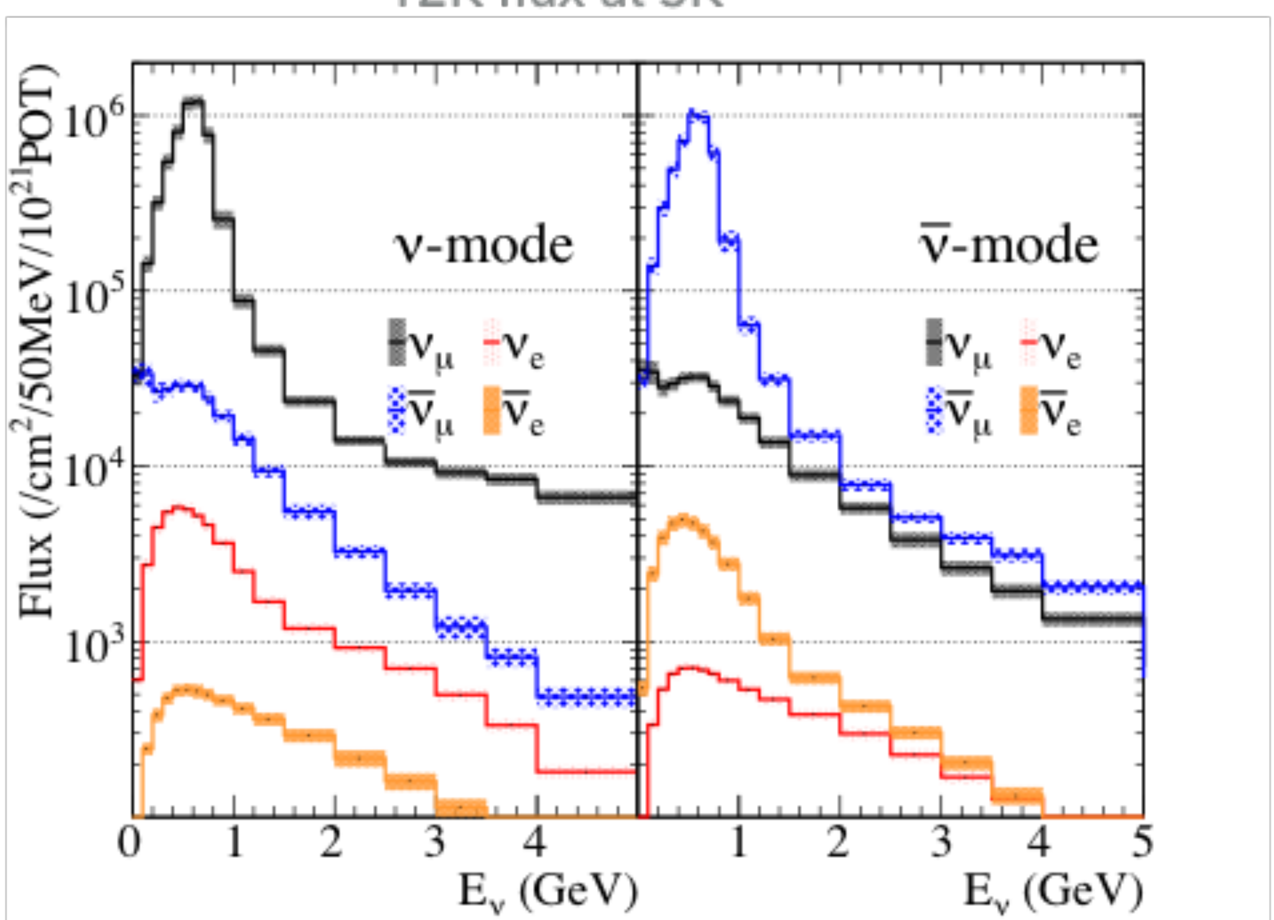
SK



HK



T2K flux at SK



- Having a magnetised detector will also allow to measure muons

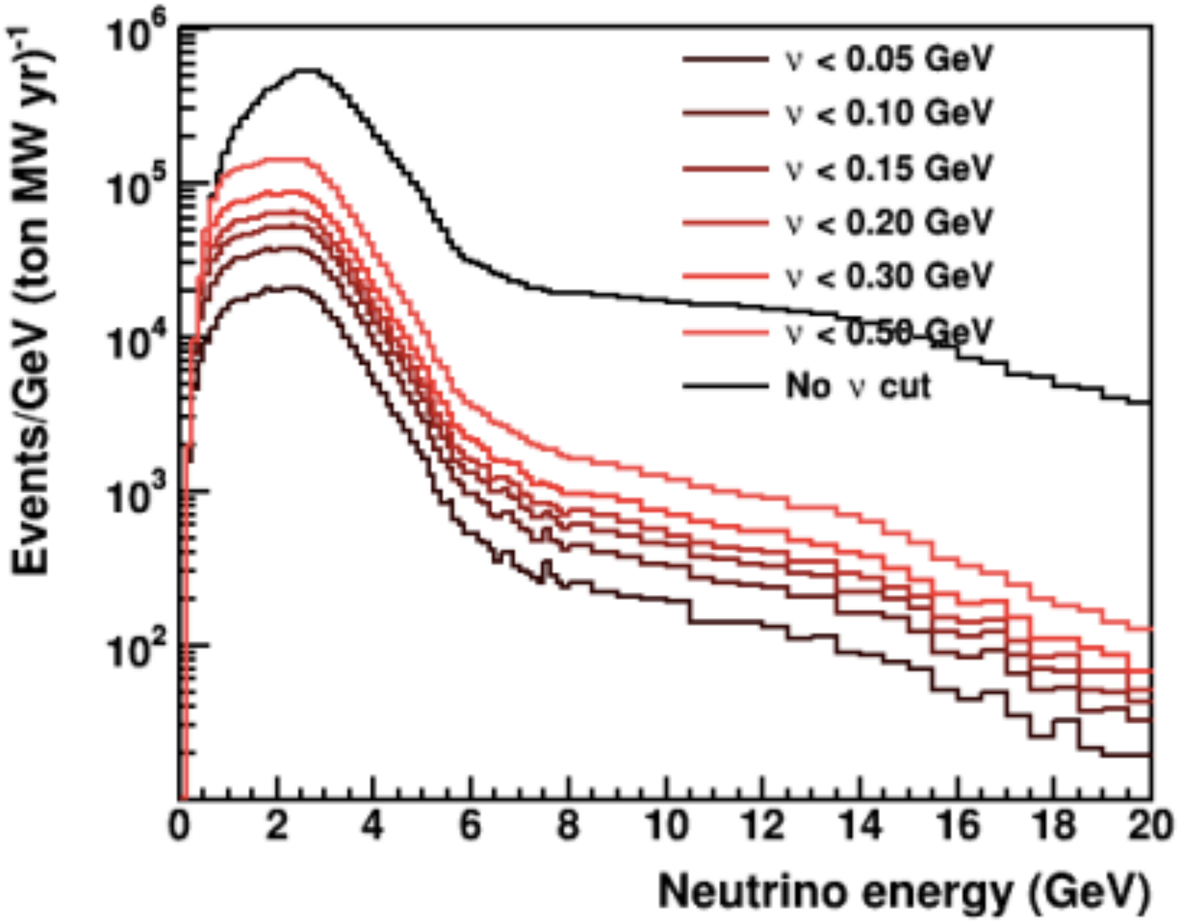
ND EFFORT AT CERN ?

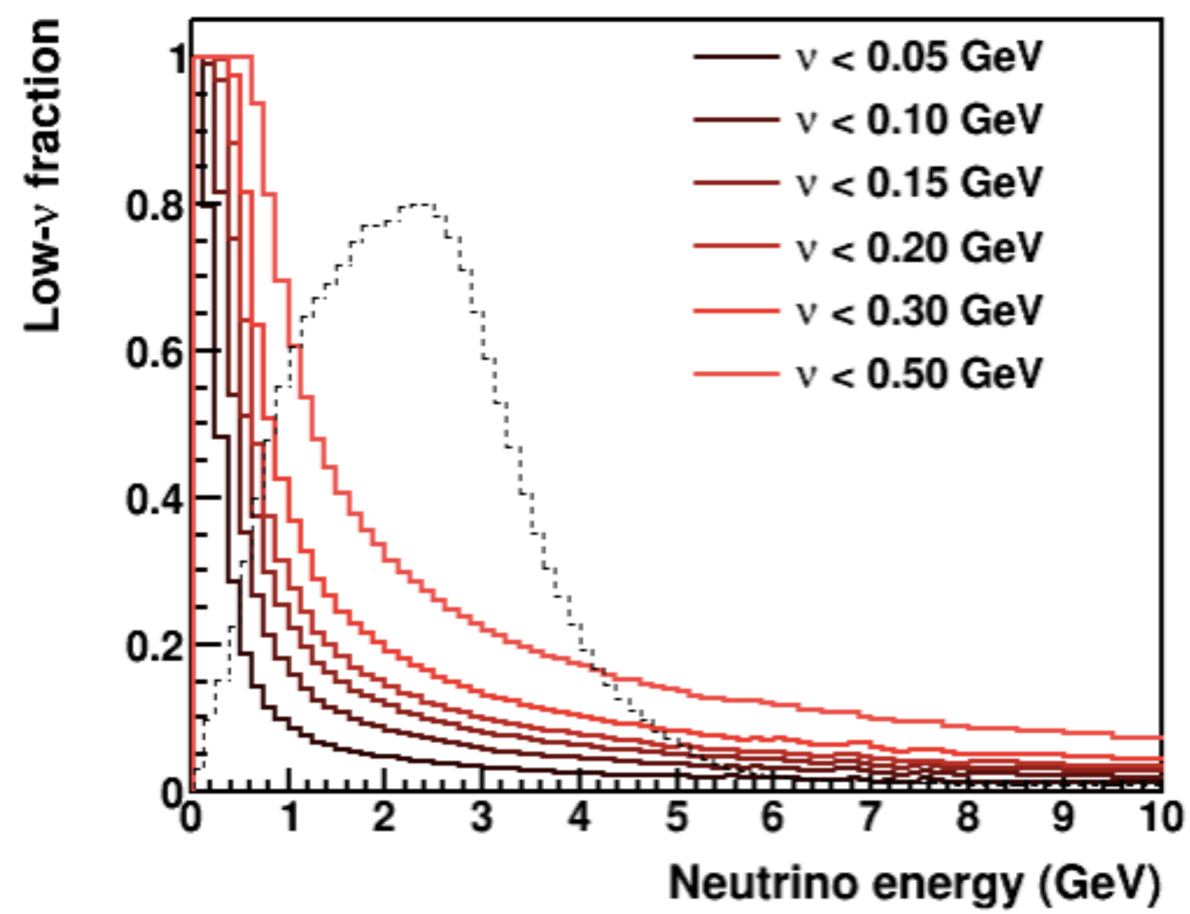
- Determine interests and expertise from our group and start to contribute to the DUNE effort
- Considering invitation of experts/collaborators for some visiting at CERN to work together *e.g.*
    - Milind (BNL) → e-nu scattering
    - Xin → figures of merits with matrices
- Join the study of some topics and contribute to list-down requirements for a ND

In the backup slides some other material…

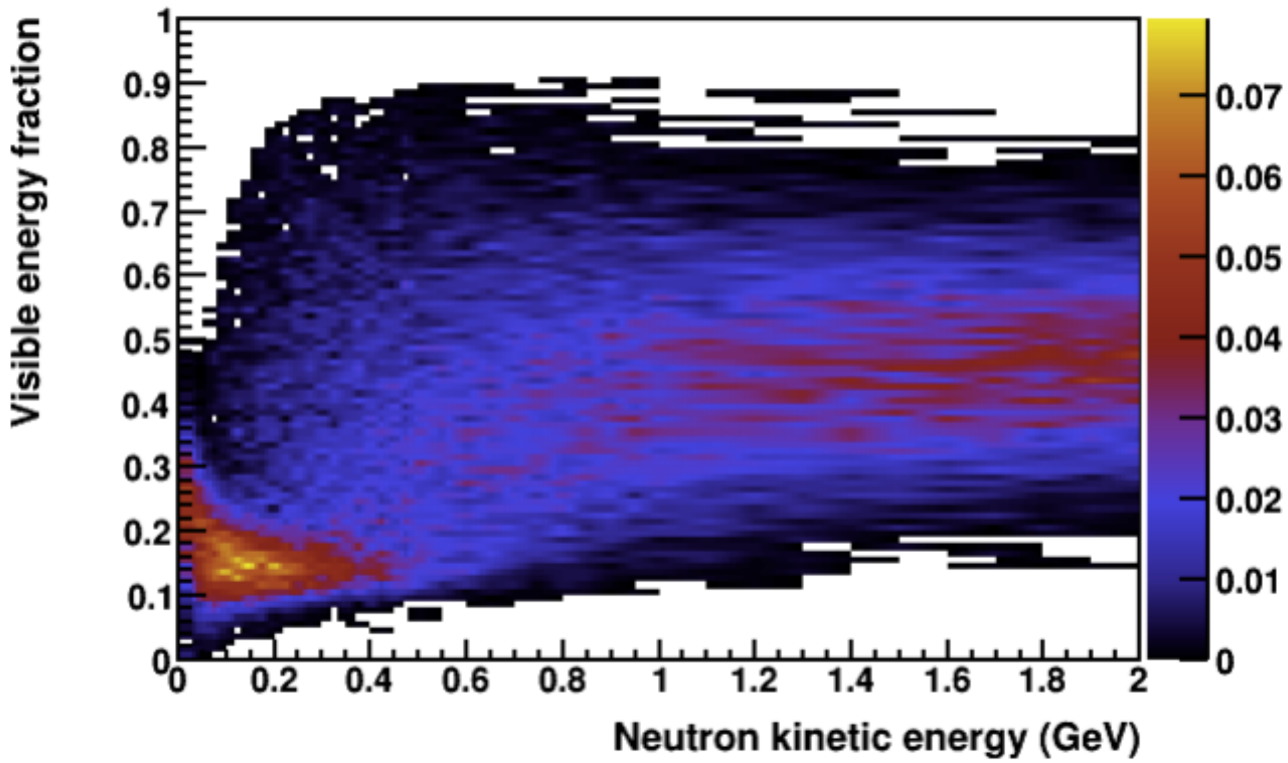
BACKUP

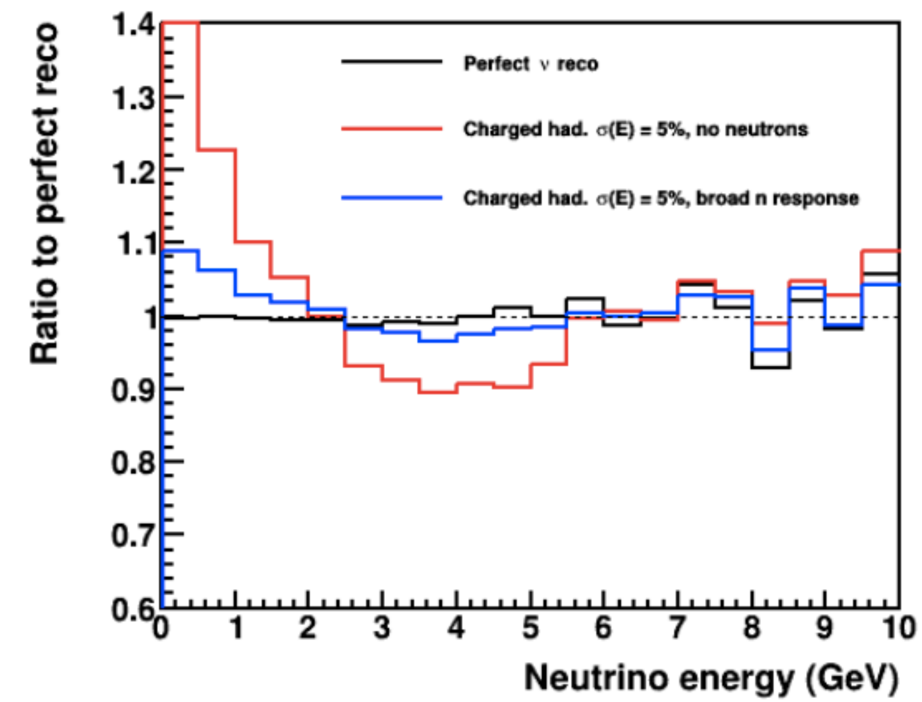
LOW-ν FLUX DETERMINATION

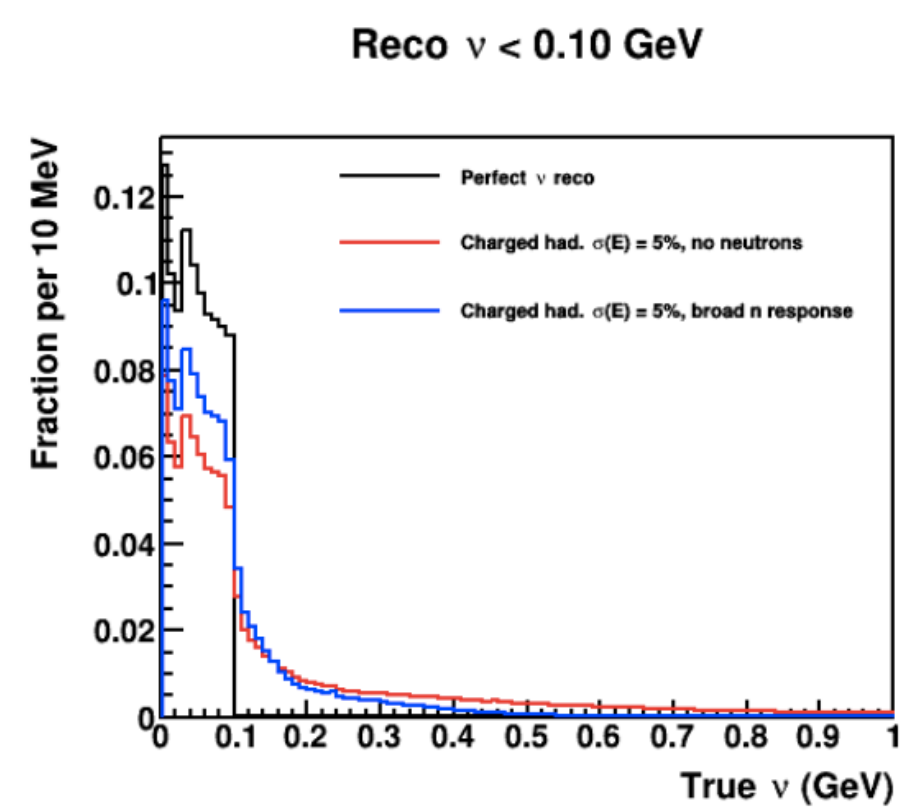




LOW-ν METHOD FOR FLUX DETERMINATION



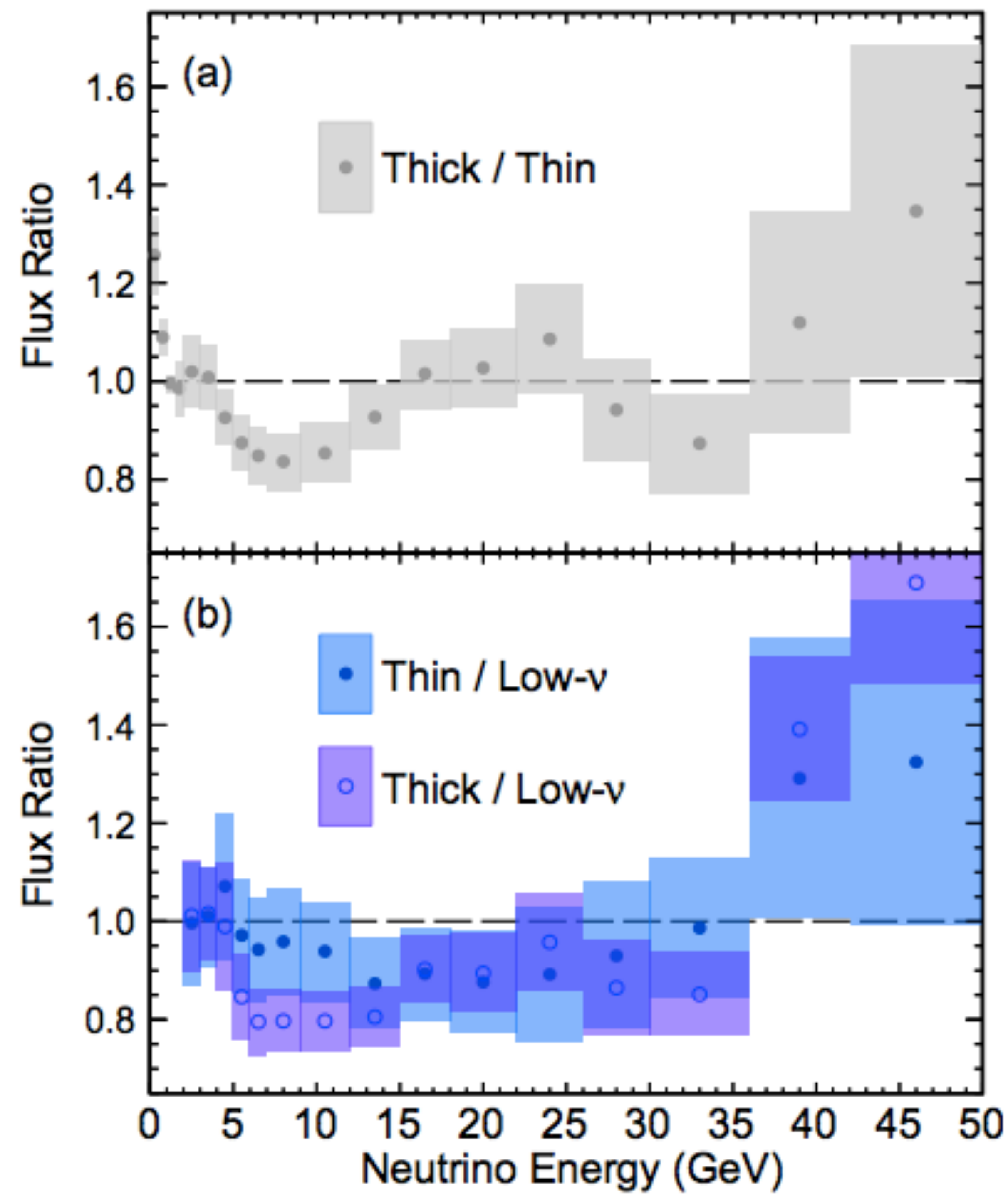




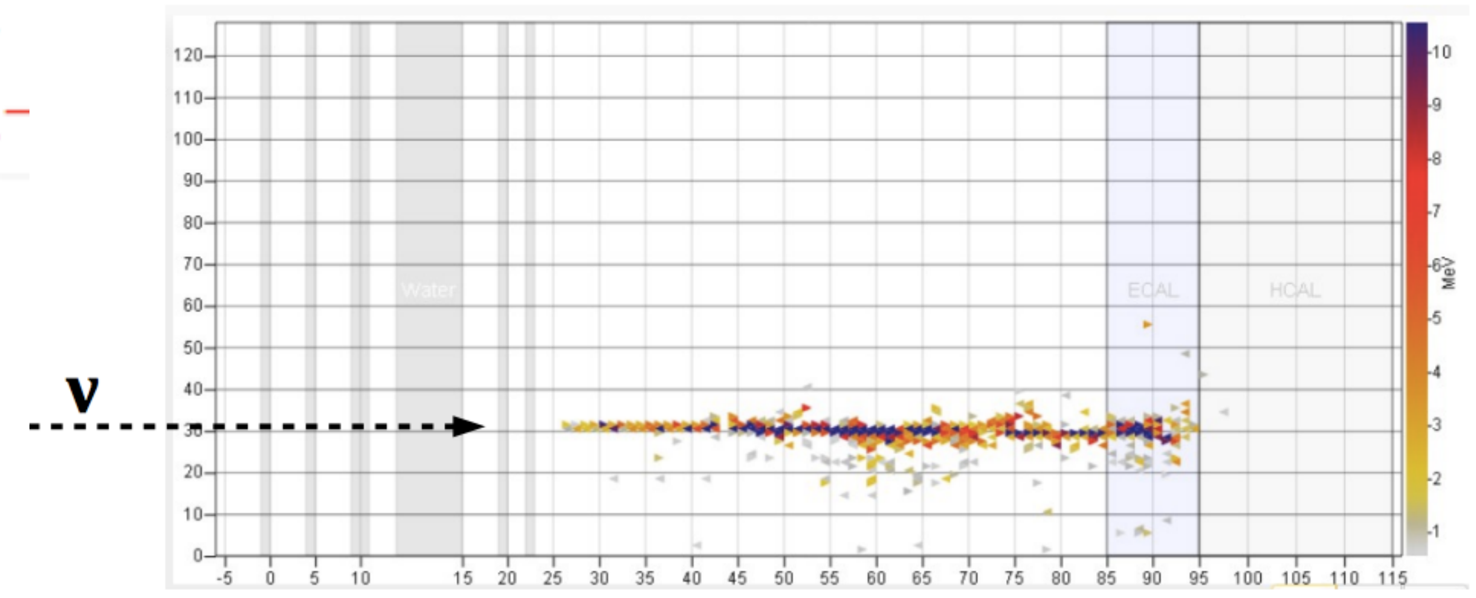
LOW-ν FLUX DETERMINATION

arXiv:1607.00704

- MINERvA estimation of the NUMI beam and comparison of different approaches
- low-nu relative flux normalised requiring the cc inclusive ν_μ + A → μ +X matches NOMAD measurements at 10 GeV



NEUTRINO ELECTRON SCATTERING



$\sigma(\nu_\mu)$ / $\sigma(\nu_e)$

- Uncertainties between these cross sections contributes to the current experimental uncertainties of OA
- **Differences arises from the final state lepton mass**
- Differences are studied for CCQE cross-sections:
  - **not-calculable differences:** interaction quarks inside a nucleon, nucleon inside a nucleus
  - **calculable differences:** radiative corrections in CC interactions with fundamental fermion

models included in the generators: e.g. RFG (GENIE, NEUT, NUANCE) , spectral functions (NuWRO) or FLUKA

Approximative calculation giving ~10% errors

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