JENNIFER - WP3 – Task 3.1 : **neutrino interactions and cross-sections**

S.Bolognesi (CEA, Saclay) for the JENNIFER collaborators

JENNIFER Consortium General Meeting

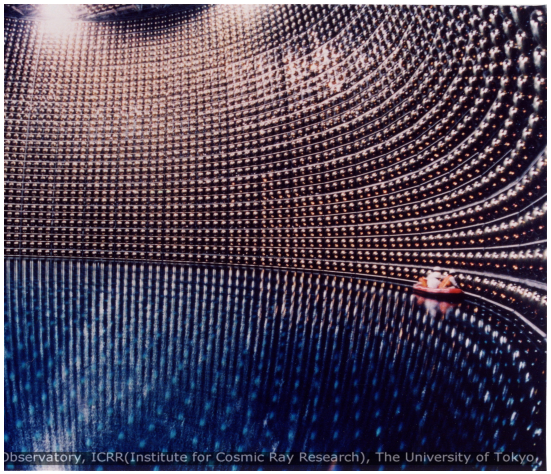
- Rome, June 2015 -

Oscillations at T2K

Neutrino mixing : $\nu_\alpha = \sum_1^3 U_{\alpha i}\,\nu_i$

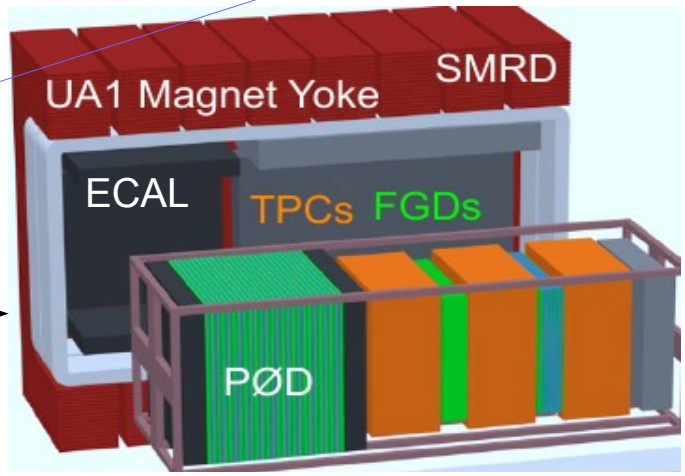
$U_{\alpha i}$ PMNS matrix :
3 angles + 1 phase

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - f(\theta_{13}, \theta_{23}) \sin^2(k\,\Delta m^2\, L/E)$$

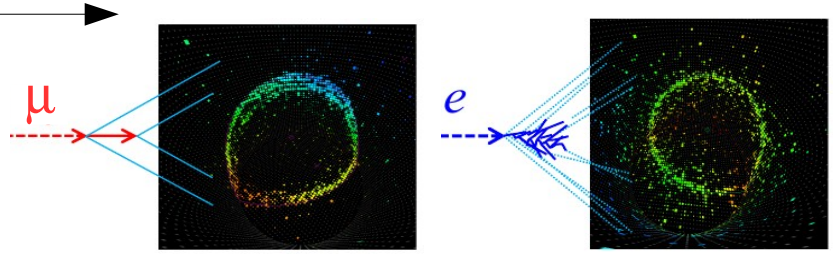


Beam of ν_μ
(+ background of anti-ν, ν_e)

280m



295km



Near detector (ND280) :
measurement of ν_μ flux
(off-axis, E~600MeV)

SuperKamiokande far detector :
measurement of oscillated neutrinos : ν_μ, ν_e

dependance on neutrino interactions :
need to disentangle flux and nu xsec

measurement of e/μ kinematics →
need neutrino interaction modeling
to translate into neutrino energy

Near detector constraints

Extrapolation of number of neutrinos (xsec x flux) from Near Detector to Far Detector :

- **different acceptance** (SK is ~4π while ND280 has fwd-bwd geometry)

→ need measurements as a function of e/μ kinematics and extrapolation based on models

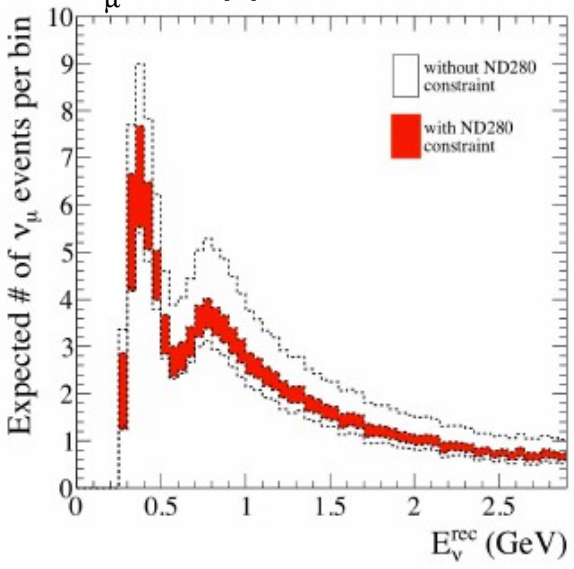
- **different targets** : SK is water while ND contains water and carbon

→ need measurements of xsec on different targets and scaling of ν interactions with number of nucleons (importance to understand nuclear effects)

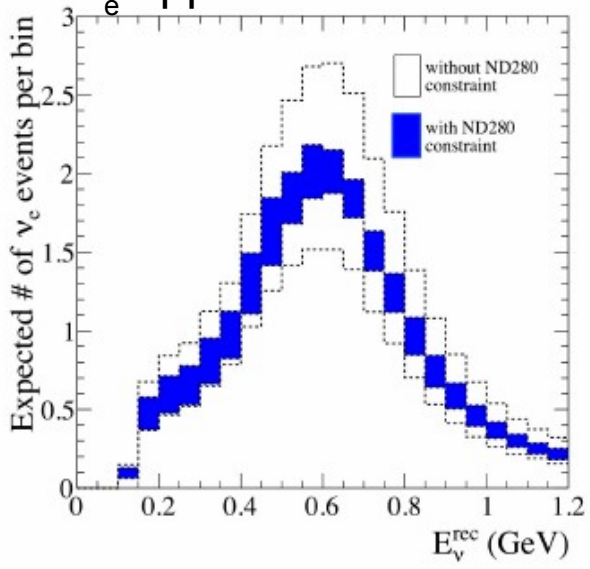
- even if ND and FD were identical they would still see different fluxes (due to oscillation)
  → need to go from lepton kinematics to neutrino energy to measure oscillations

Systematics on oscillation analysis :

ν_μ disappearance



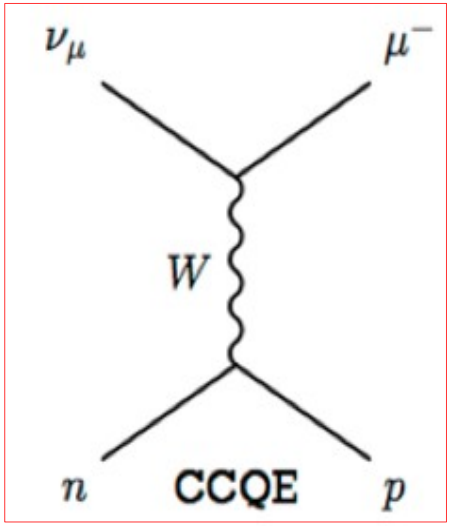
ν_e appearance



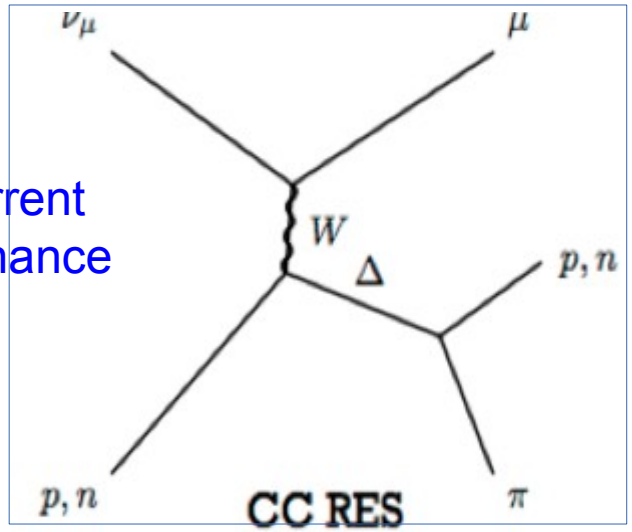
Source of uncertainty	ν_μ CC	ν_e CC
Flux and common cross sections		
(w/o ND280 constraint)	21.7%	26.0%
(w ND280 constraint)	2.7%	3.2%
Independent cross sections	5.0%	4.7%
SK	4.0%	2.7%
FSI+SI(+PN)	3.0%	2.5%
Total		
(w/o ND280 constraint)	23.5%	26.8%
(w ND280 constraint)	7.7%	6.8%

Neutrino interactions

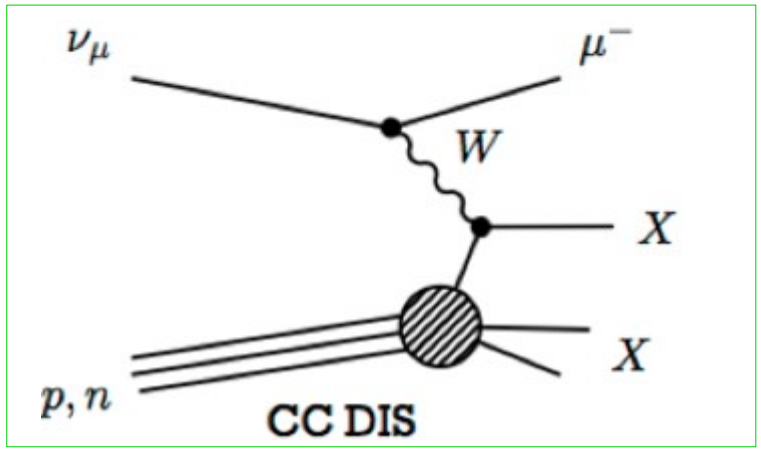
Charged Current Quasi-Elastic



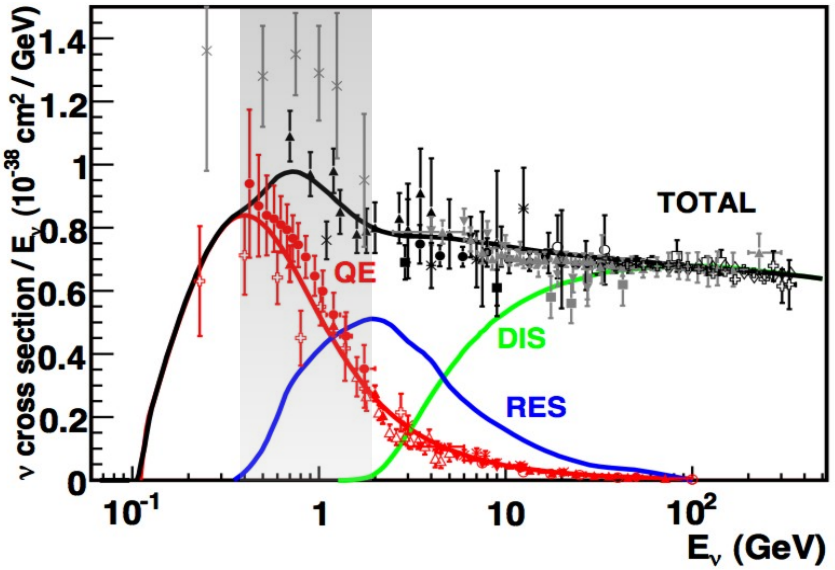
Charged Current with Δ Resonance



Deep Inelastic Scattering



T2K flux



Final State Interaction : **interaction of outgoing nucleons and pions with nucleus** may change the actual final state

(pion and proton absorption, production or charge exchange)

CCQE → CC0π, CCRes → CC1π,
DIS → CCOther (multipions)

From bubble chamber to T2K

- Parametrization of cross-section as a function of **nucleon 'form factors' (analogue to EM electron-proton scattering)** → effective cut-off parameters : vector and axial mass

  Vector term from EM e-p , axial mass from **measurements in bubble-chambers** (deuterium)

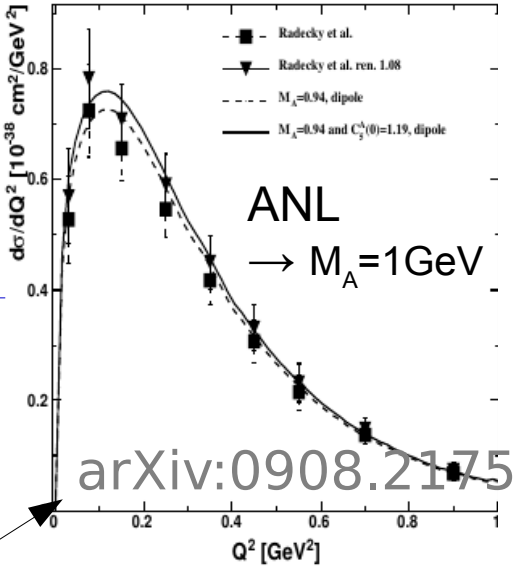
- 2007 measurement from **MiniBoone shows large discrepancy** with this model !

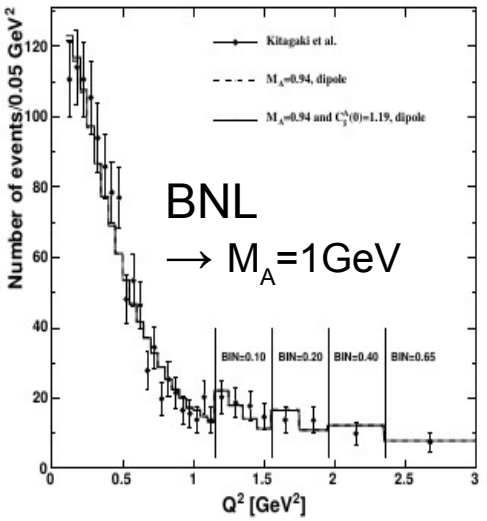
  → in modern experiments interaction of neutrino with heavier nuclei (C, O) and not with free nucleon : **nuclear effects !**

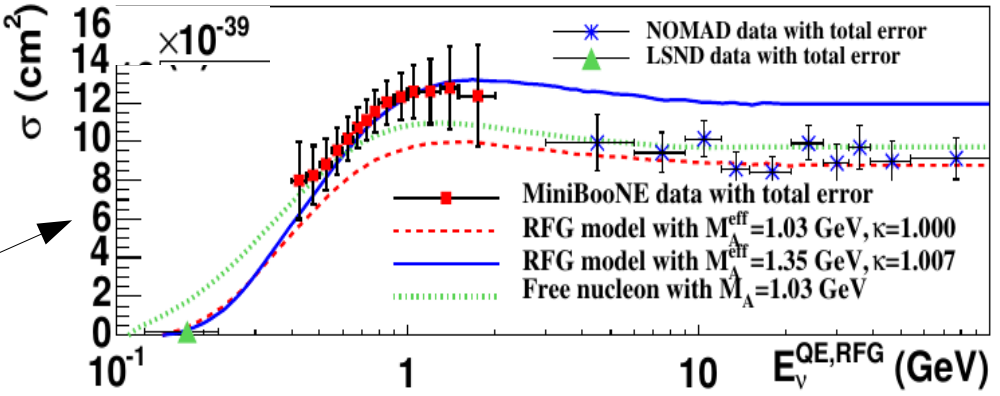
- Rich recent theoretical development :

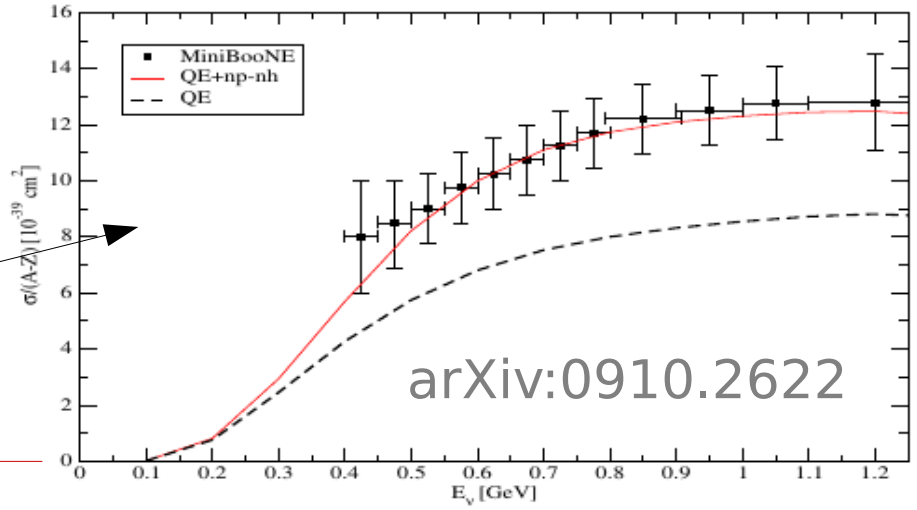
  long range **correlation between nucleons** (aka RPA)

  possibility of **interactions with n-p pairs** (aka 2p2h or MEC effects)



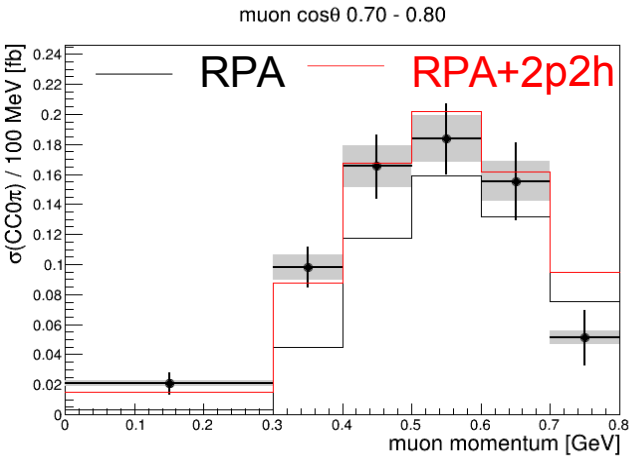


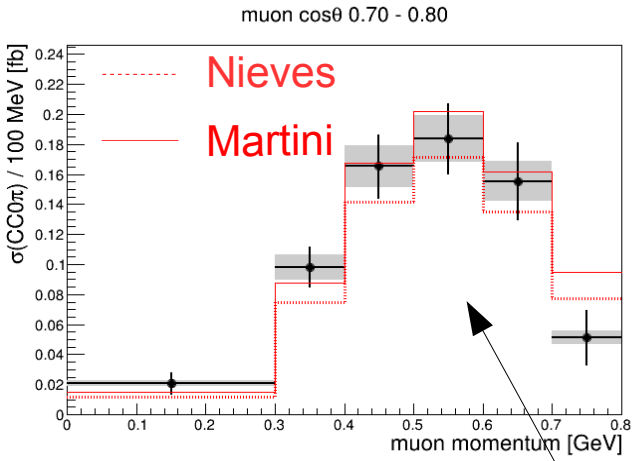


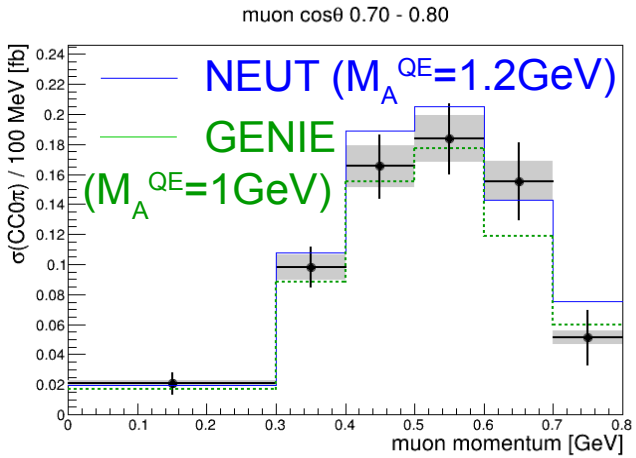


CC0π activities in JENNIFER

- Measurement of cross-section on Carbon (same measurement on water on-going)



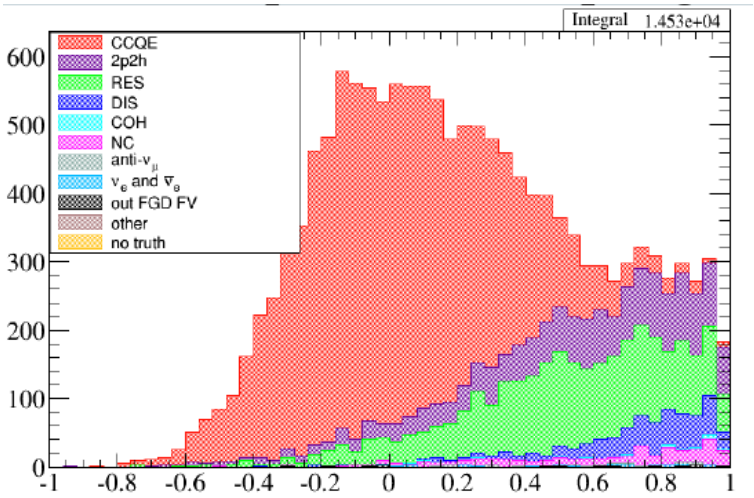




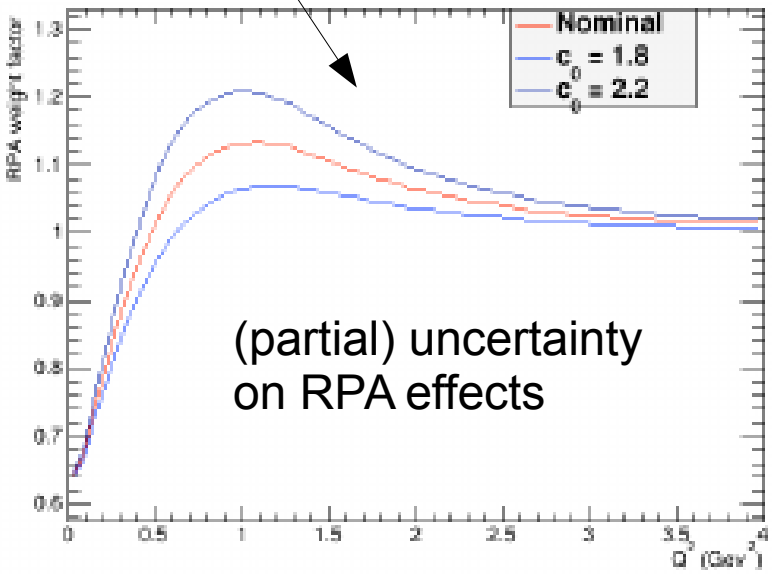
CEA Saclay

- Identification of variables sensitive to 2p2h effects: eg p-μ angle

NCBJ Polland



- Study of the recent models and reconsider uncertainty on xsec



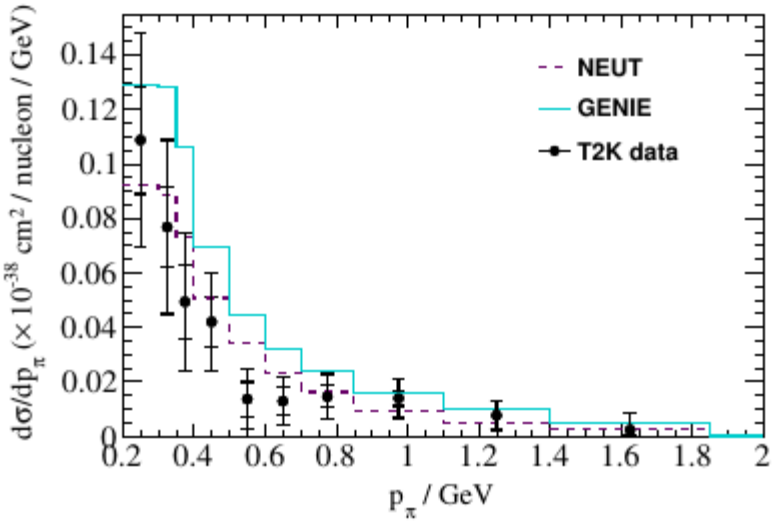
IFAE Barcelona

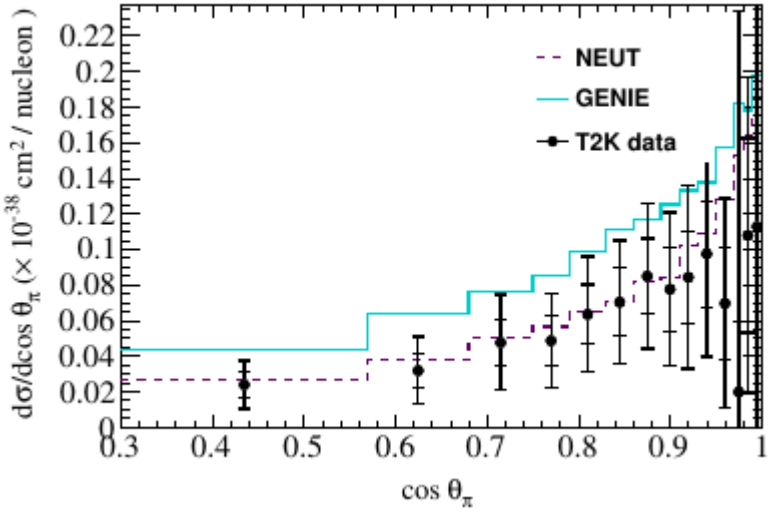
problem : dependence on 2p2h models and FSI

CC1π measurements in JENNIFER

Process most affected by FSI uncertainty : big background from DIS with pion reabsorption

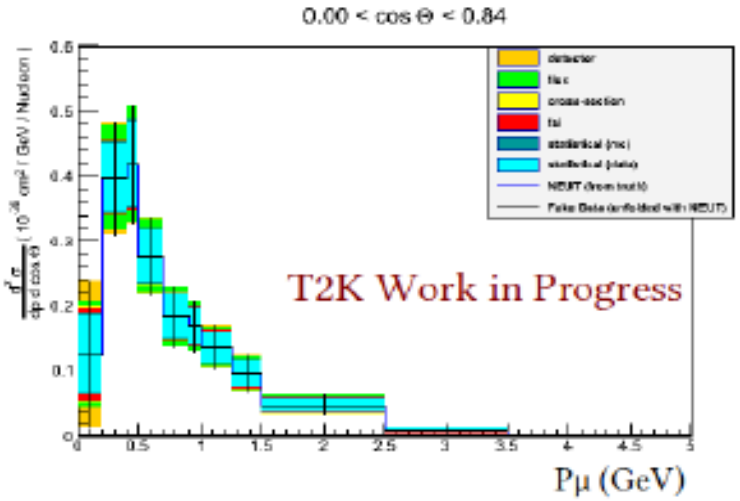
- First measurement on water !

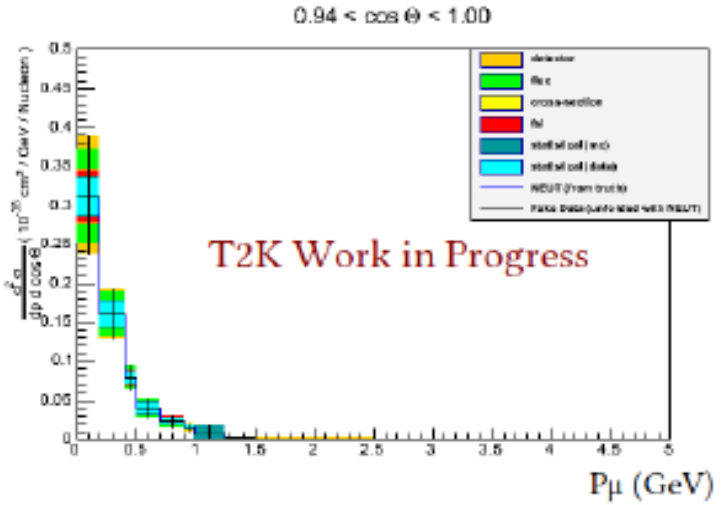




QMUL, London

- Measurement on Carbon is ongoing





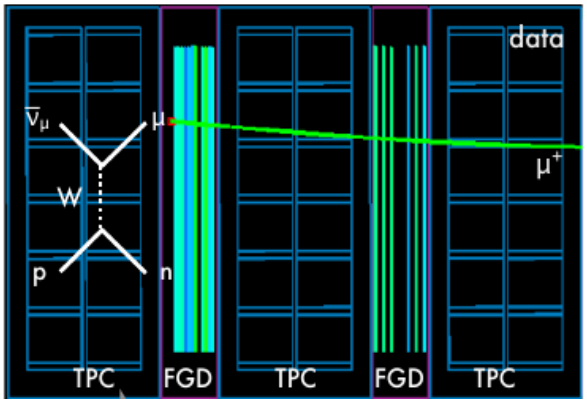
IFAE Barcelona

Importance of antineutrino analysis

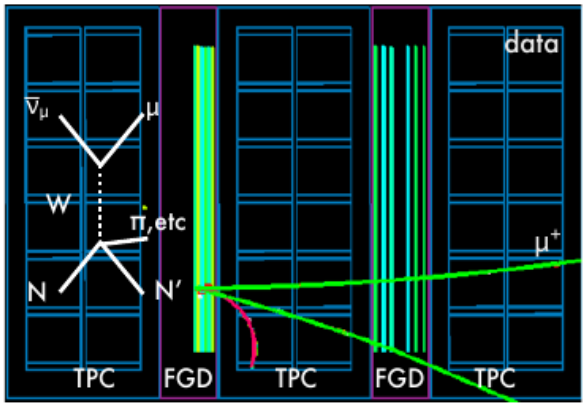
If CP phase in PMNS matrix not 0 → difference between ν and anti-ν oscillations

CP-violation in leptonic sector may be the key to understand matter-antimatter asymmetry in the universe

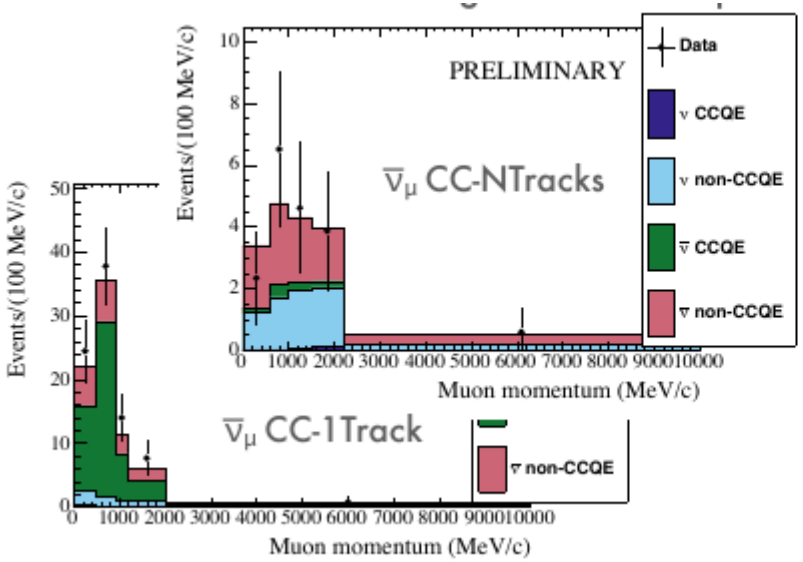
$\bar{\nu}_\mu$ CC-1Track

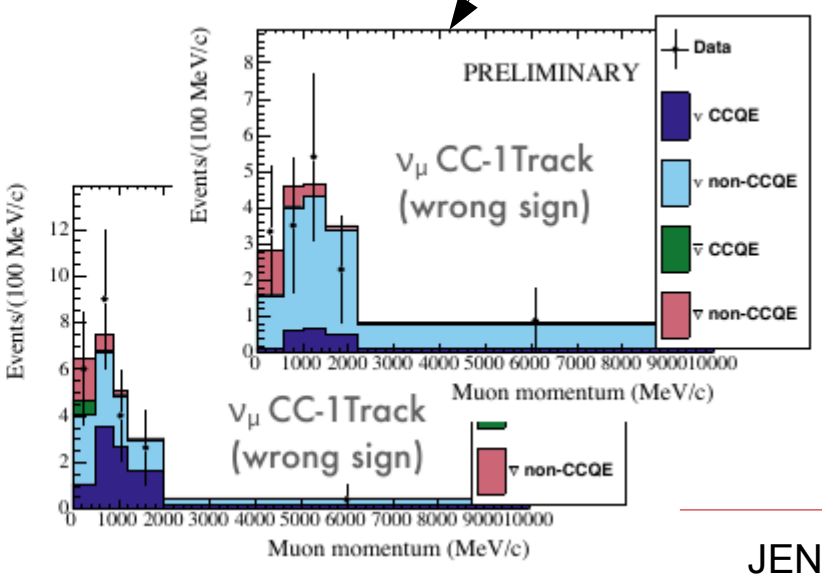


$\bar{\nu}_\mu$ CC-NTrack



- Specific selection based on tracks counting
- Large pollution from ν in anti-ν beam → similar ν dedicated topologies



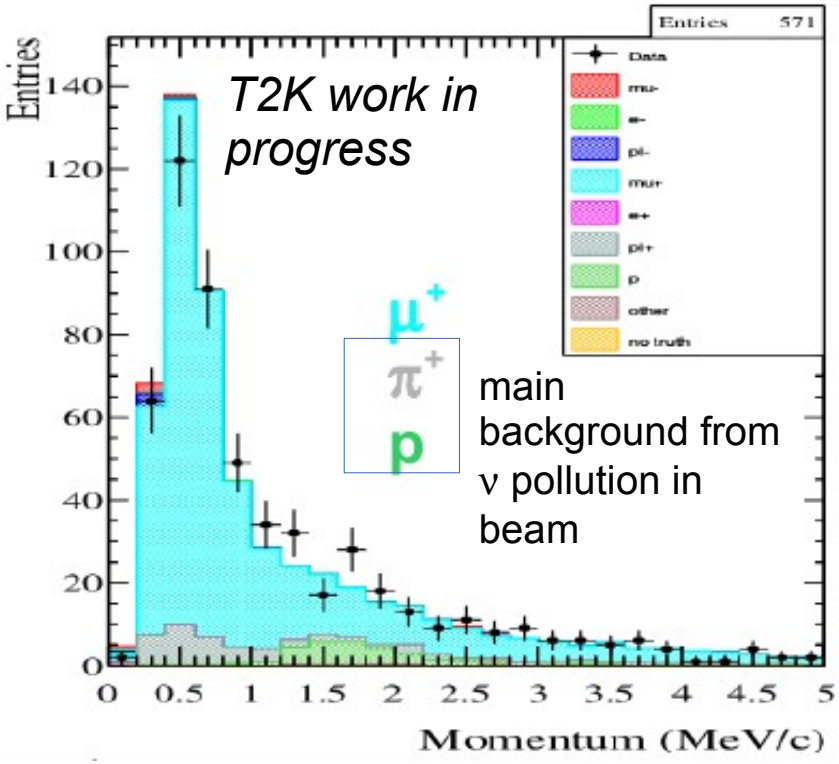


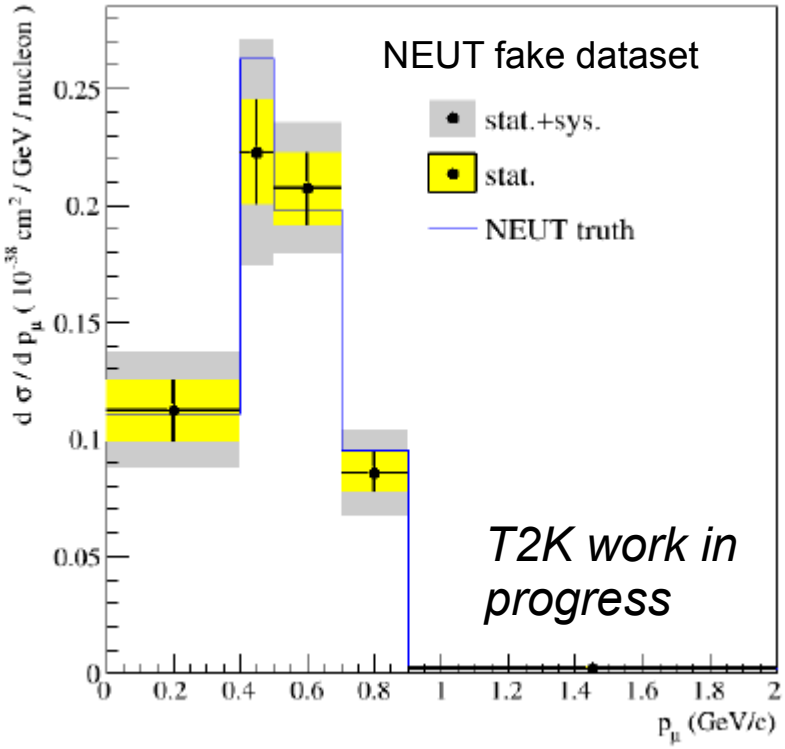
INFN, Bari

Anti-ν cross-section in JENNIFER

For CP phase measurement from comparison of ν VS anti-ν oscillation the **knowledge of the ν VS anti-ν cross-section is a crucial systematics :**

- Anti-ν Inclusive Charged Current cross-section ongoing





- MEC effects in CC0π are very different between ν and anti-ν : joined measurement may univoquely identify the existance of MEC

xsec term most affected by MEC

$$\frac{d\sigma^{\nu n}_{CC}}{dQ^2} - \frac{d\sigma^{\bar{\nu} p}_{CC}}{dQ^2} = \frac{G_F^2 |V_{ud}|^2 (s-u) Q^2}{4\pi (p_\nu \cdot p_{N_i})^2} G_A (F_1 + F_2)$$

Cross-fertilization from JENNIFER

- First set of meetings between JENNIFER groups (+ other T2K collaborators) just ended : very fruitful discussions !

  Presented here the measurements where JENNIFER groups are main drivers
  → 2 papers (CC0π, CC1π) being written ! More to come !

- Discussions about comparison of tools and strategies between different JENNIFER groups to design future analyses:

  - **CC0π xsec vs MEC** measurement
  - uncertainties on the theoretical modeling → **how to design a model-independent MEC search**
  - **scaling C → O** : systematics studied in CC1π analysis to be re-used in CC0π water analysis
  - first discussions through a **joined CC0π ν VS anti-ν cross-section measurement**

Conclusions

- **Neutrino cross-section measurements are very interesting for (nuclear) physics and a crucial systematics for measurement of ν oscillation (eg. CP phase)**

- Future experiments (DUNE, HK) claim 1 % uncertainty on signal normalization : current knowledge from models ~10 %

Only T2K can make the jump 10 % → 1 % possible !!!

- **JENNIFER groups are the most active** in this field and are producing world leading measurements. **JENNIFER funding is allowing to setup common projects/strategy through future analyses**

Expected delivrables :

report on antinu analysis (EDM:24)

report on MEC searches (EDM:48)