Asimov and fake data studies

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2nd Workshop on Neutrino Near Detectors based on gas TPCs

Ideas

➤ If it can be easy to track down current detector limits, it's harder to assess how much an upgrade of the near detector, with a different phase space, would impact the oscillation analysis.

➤ In order to have quantitative informations on this impact the idea is to use the analysis tools currently used in T2K oscillation analysis with predicted efficiencies.

➤ We use MC true tracks, selected relatively to those predicted efficiencies and use this as a selection of events.

What do we do with this tool ?

With the Asimov/fake data studies we want to get quantitative informations on :

1. How is the constraints on the model's parameters improved by the upgrade ?
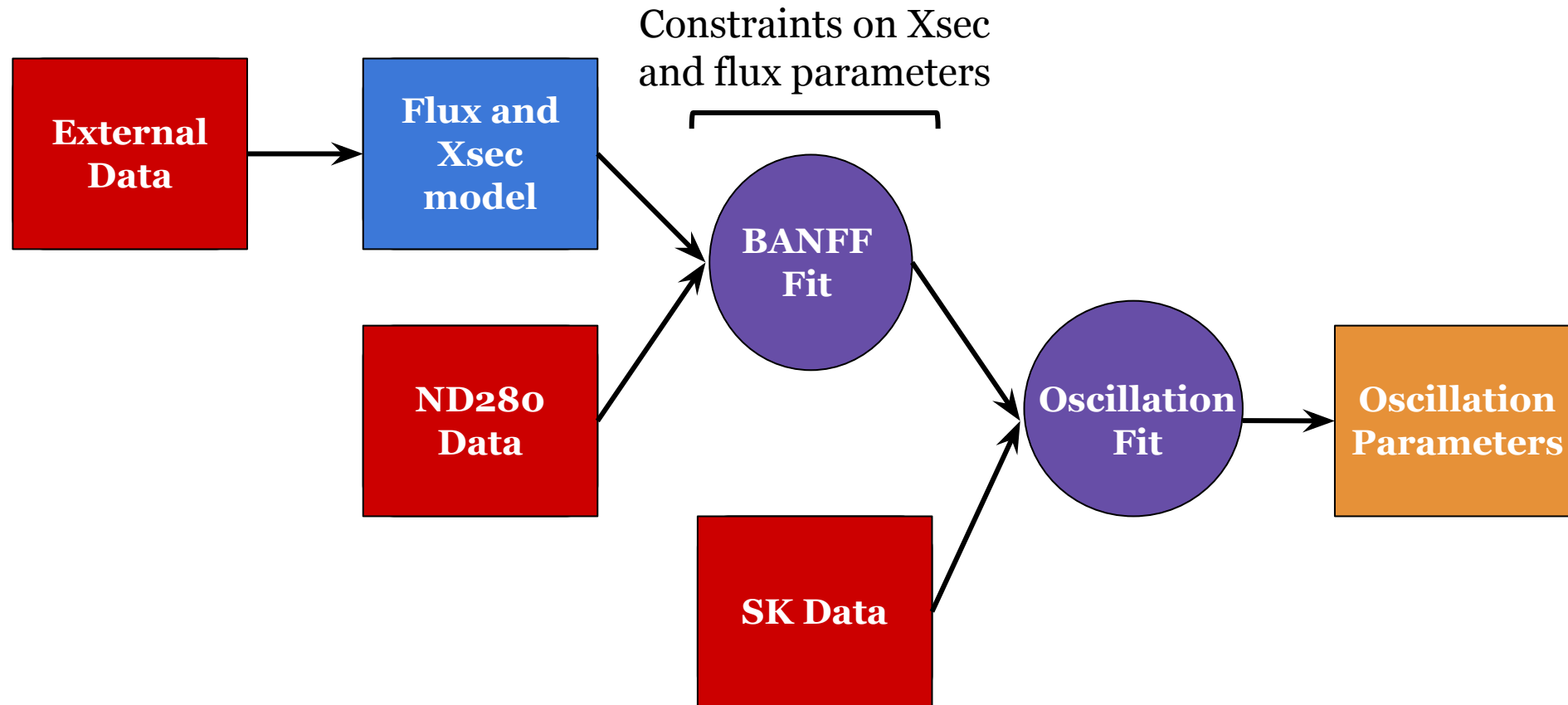
    ➡ Asimov studies

2. What is the sensitivity to the cross section model separation ? And in particular can we reduce the bias introduced by cross-section modelling ?

    ➡ Fake data studies

Use this selection of MC tracks as input in a fit and perform several Asimov and fake data studies for answer those questions

T2K analysis chain

Constraints on Xsec
and flux parameters

External Data → **Flux and Xsec model** → **BANFF Fit**

ND280 Data → **BANFF Fit**

BANFF Fit → **Oscillation Fit**

SK Data → **Oscillation Fit**

Oscillation Fit → **Oscillation Parameters**

➤ We do a first fit (BANFF) with the near detector data in order to constrain our flux and cross-section models, to have a precise prediction of the number of events we expect at the far detector
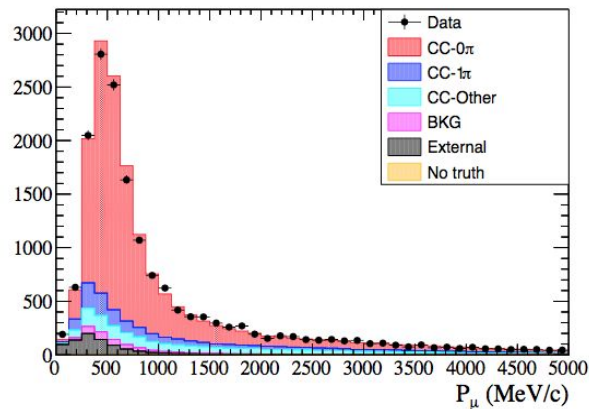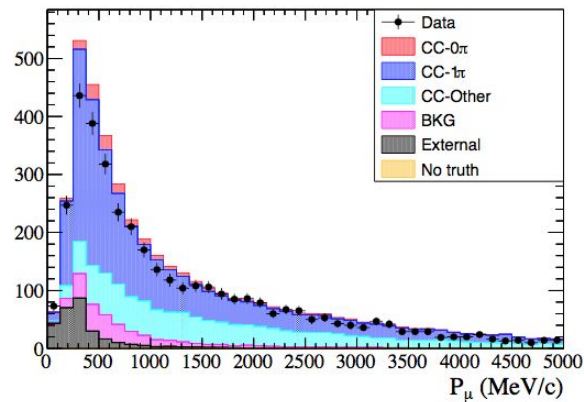
Systematics reduction with ND280
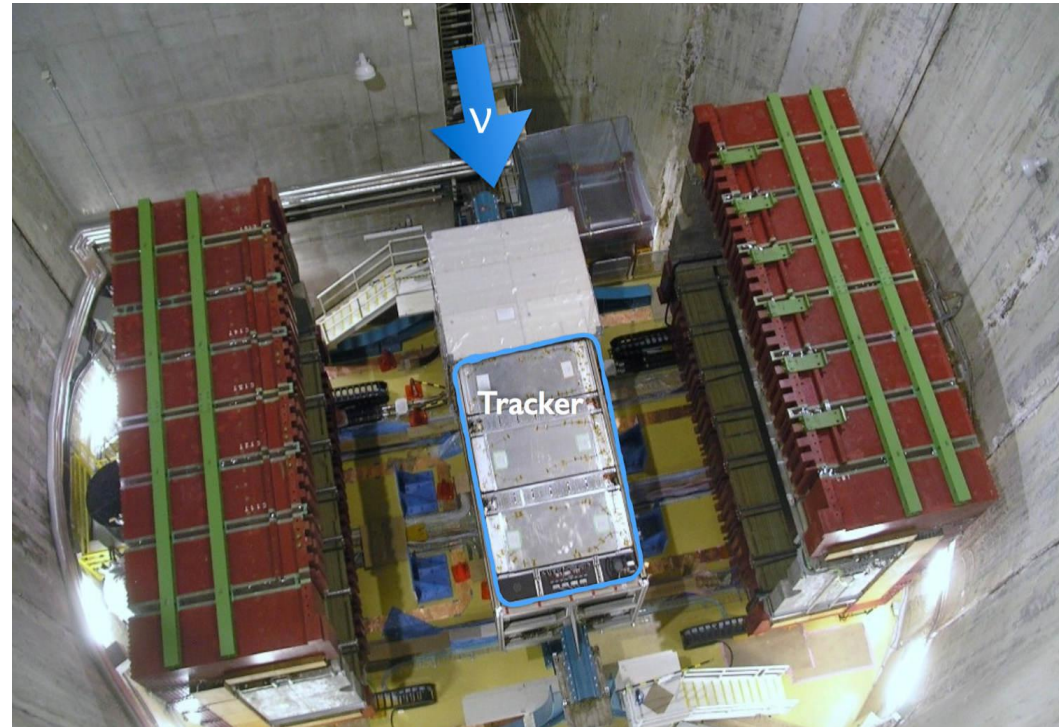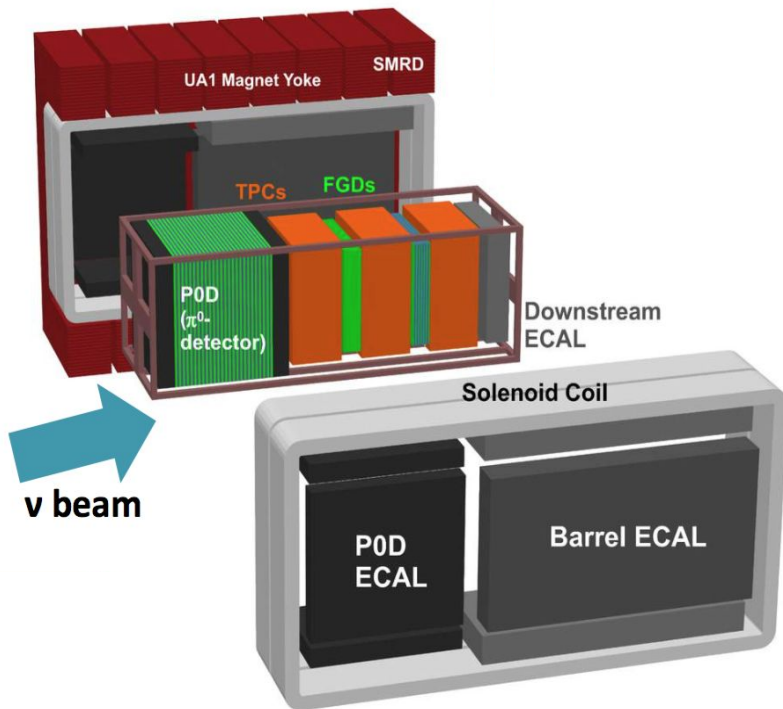
➤ The main systematics in the experiment are coming from neutrino flux and neutrino interaction cross-section. We use the near detector to constrain them.
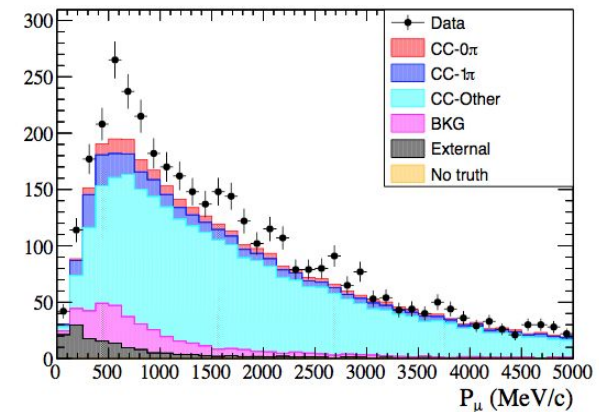
ND280 event selection

CCopi   CC1pi   CCOther

➤ We currently use a selection of ν_μ CC events in the tracker, using the FGD as target and the TPC to reconstruct charge and momentum.

➤ We separate the CC inclusive events in three topologies depending on the number of pions reconstructed (0, 1 and ≥2)
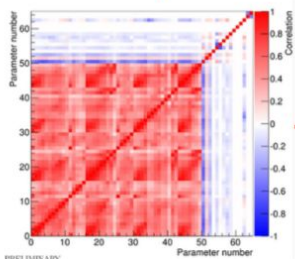
This selection is used as input in the fit

T2K Oscillation Analysis

Flux model constrained by NA61/SHINE

Cross section model constrained by other experiment (Minerva, Miniboone...)

Systematic error source	$\Delta N_{SK}/N_{SK}$ before ND fit	$\Delta N_{SK}/N_{SK}$ after ND fit
Flux	8.8%	3.2%
Cross section	7.1%	4.7%
Flux and cross section	11.4%	2.7%
Final state/secondary interactions at SK	2.5%	
SK detector	2.5%	
Total	11.9%	5.2%

BANFF   lepton p-θ

SK Fit

Oscillation Parameters

Constrained covariance matrix

The constraints
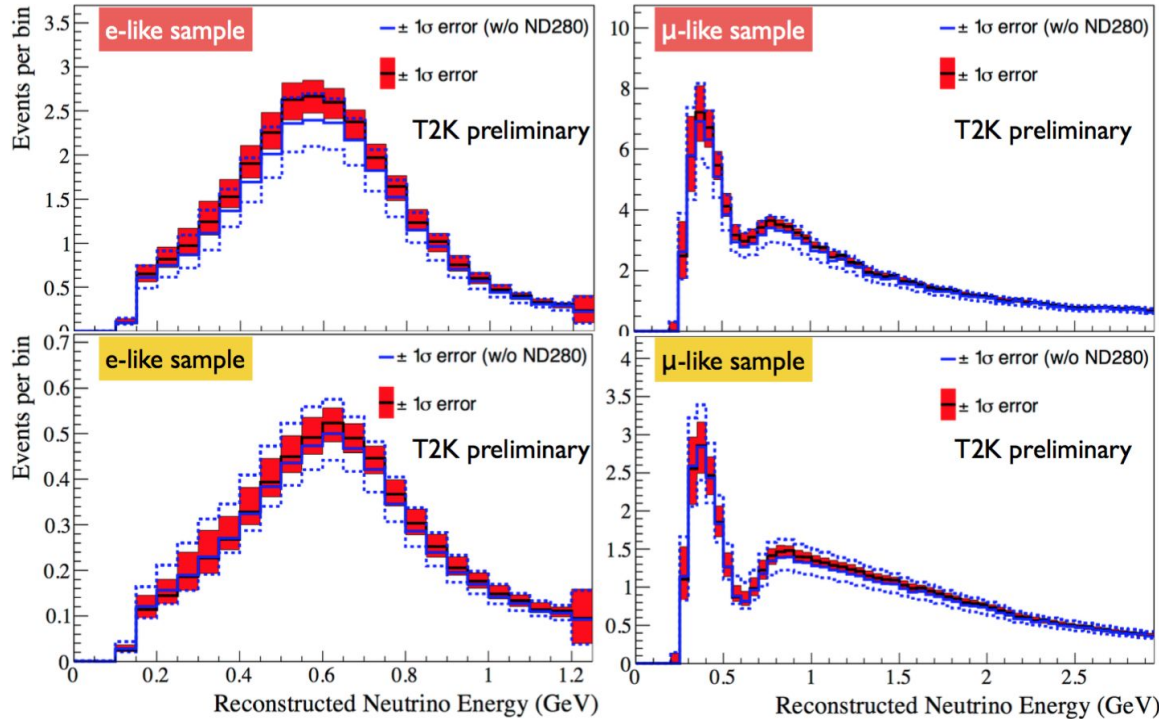
➡ With the help of the near detector fit, we can reduce the uncertainties on the number of events expected at the far detector to ~5% !

|	ν_μ sample 1R$_\mu$ FHC	ν_e sample 1R$_e$ FHC	$\bar{\nu}_\mu$ sample 1R$_\mu$ RHC	$\bar{\nu}_e$ sample 1R$_e$ RHC
Total w/o ND280	12,0%	11,9%	12,5%	13,7%
Total with ND280	**5,0%**	**5,4%**	**5,2%**	**6,2%**

An upgrade of the near detector

➤ As T2K data taking is ongoing, a large number of oscillated events will be collected.

➤ Systematics will become dominant, and need to be lowered to 2-3%

 ➡ Hard with the current near detector currently at ~5%
 ➡ Indeed this detector is limited by low efficiency at high angles, backward and for low momentum hadrons

➤ Need to understand how an upgrade of the near detector can lower down those systematics, which phase space is important for the oscillation analysis

Trying to use current oscillation analysis tool ("BANFF-like") to evaluate the impact of an upgrade

Upgrade configuration

➤ All the studies presented after are done with the configuration with two targets (one empty and one filled with water) surrounded by TPCs.
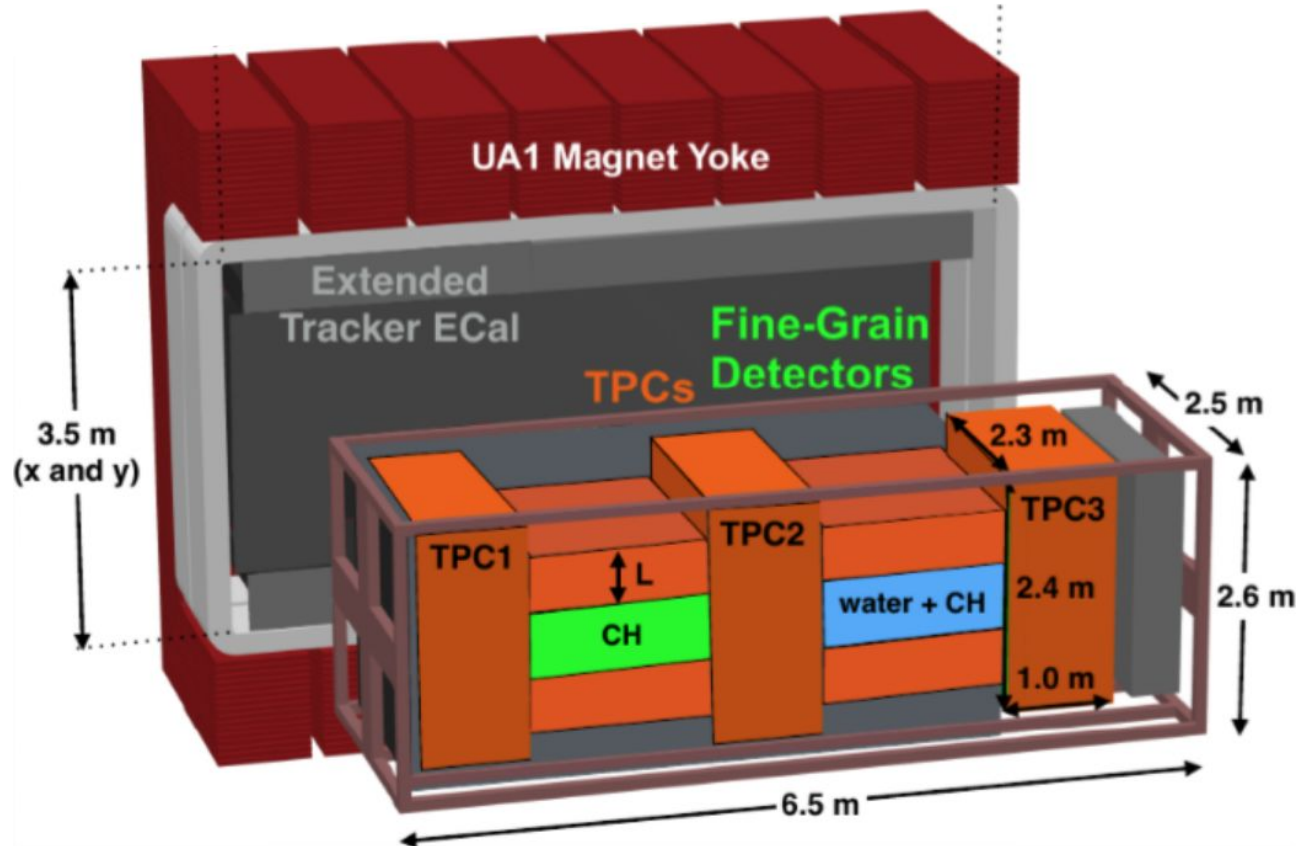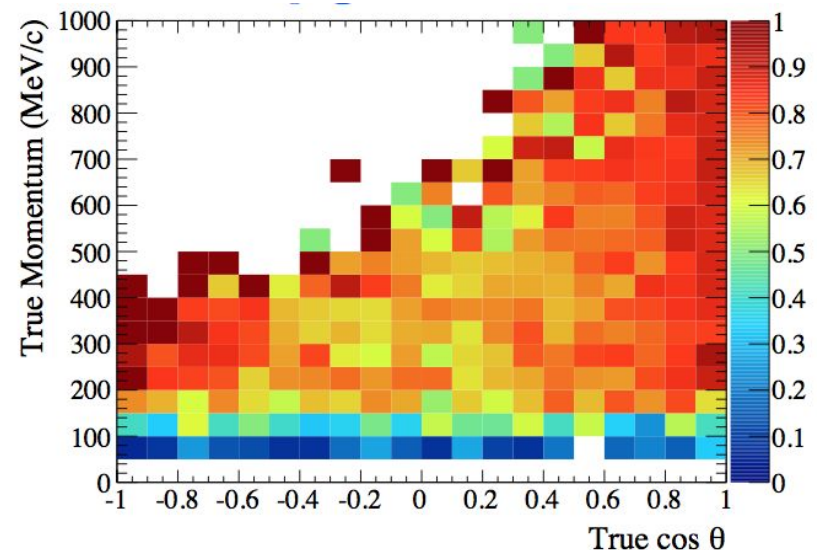
ND280 upgrade study tool

➤ A first study is made, using GEANT4 and current ND280 software, to get predicted efficiencies for different configurations of an upgrade.

➤ We can then compare those efficiencies to the one we currently have.
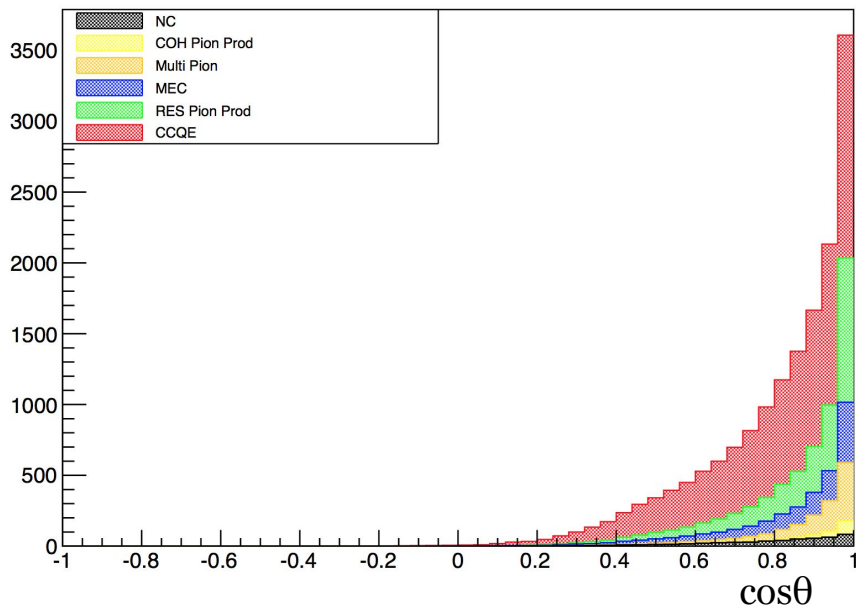
4π selection efficiency in current ND280
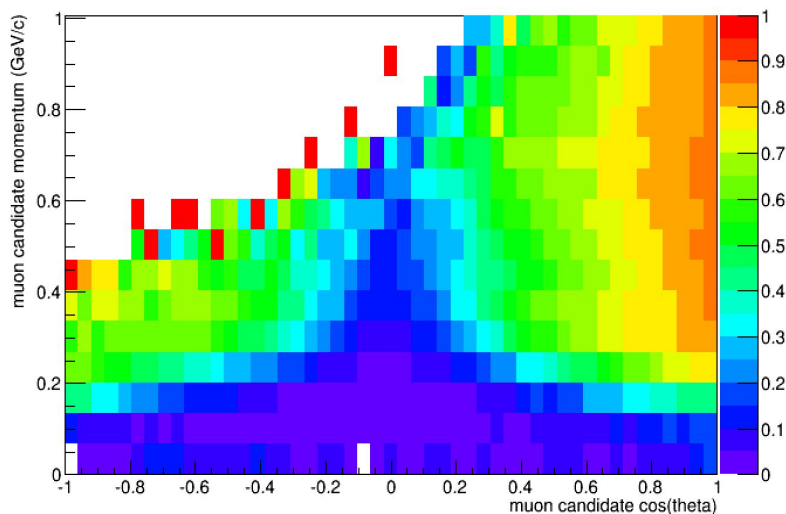
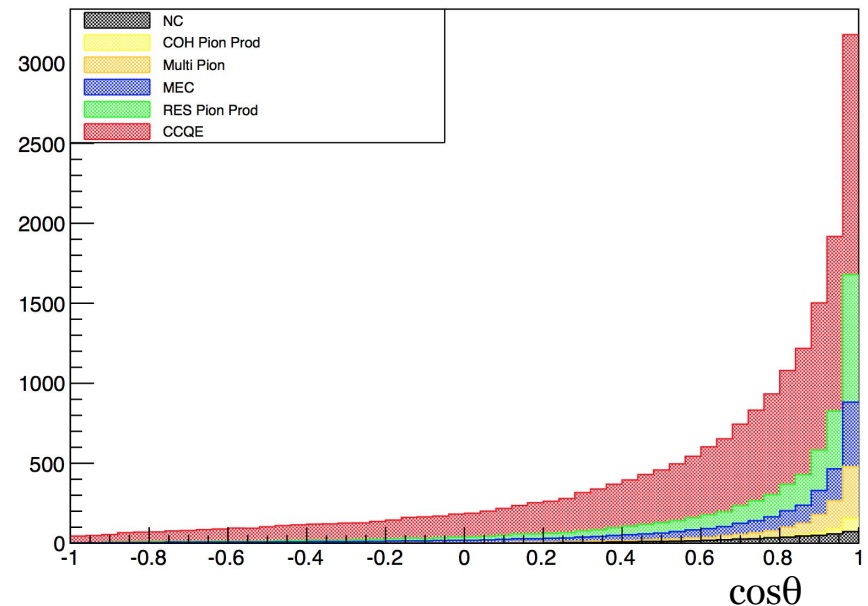GEANT4 predicted efficiency of an upgrade

Distributions : enhanced phase space

➤ We use those efficiencies to select true MC tracks.

➤ This selection can be considered as a simulation of a selection done in the upgrade

➤ This selection is used as input in the tool, as we do in the oscillation analysis.

Currently

Upgrade

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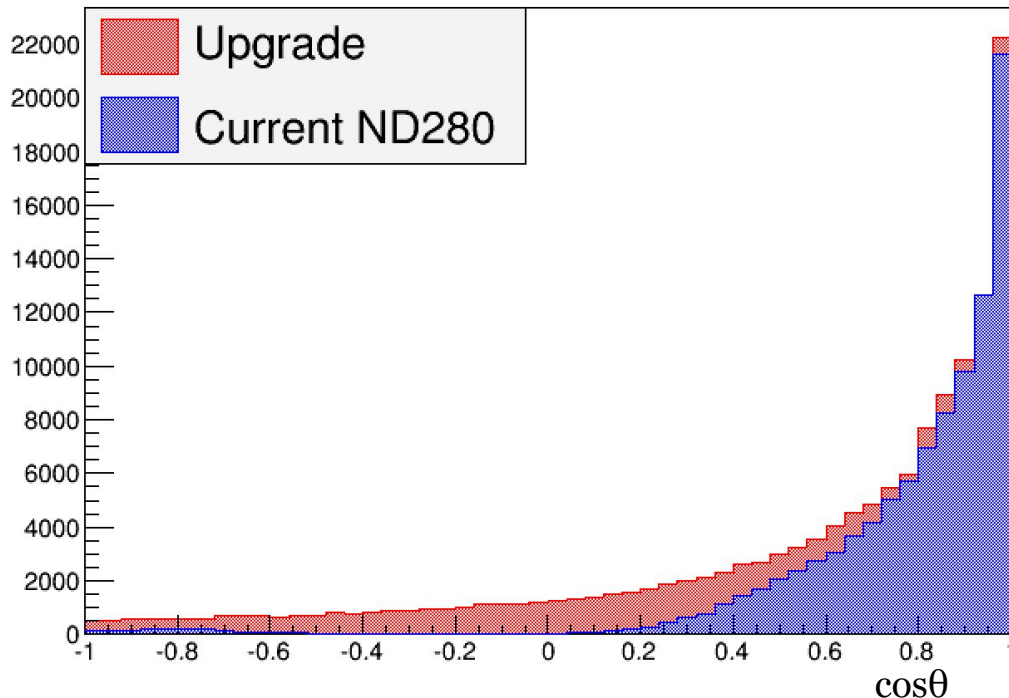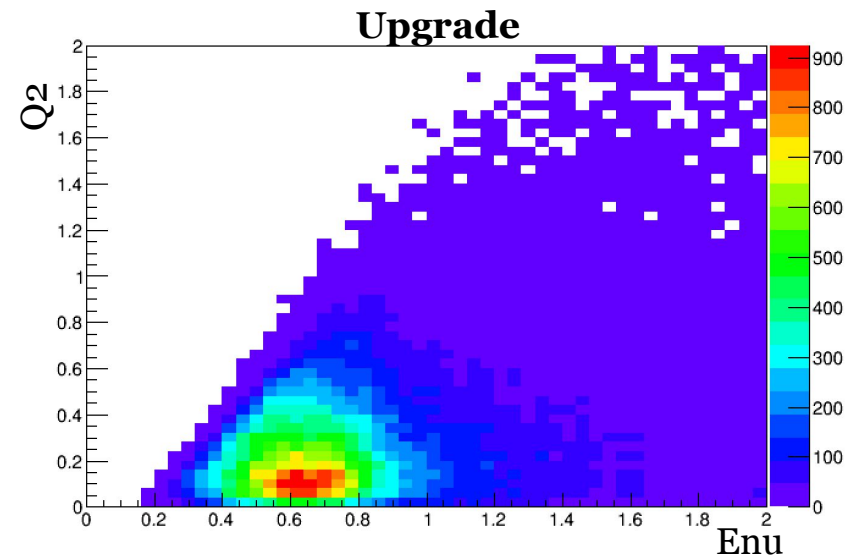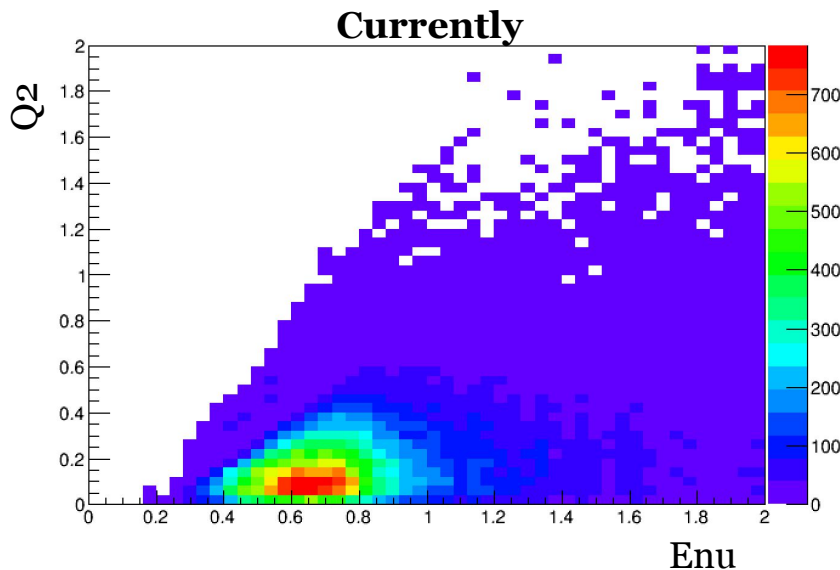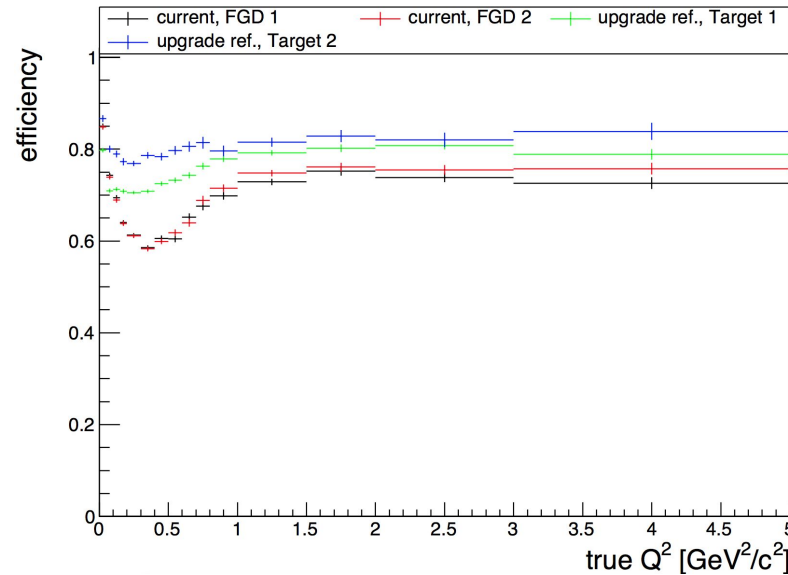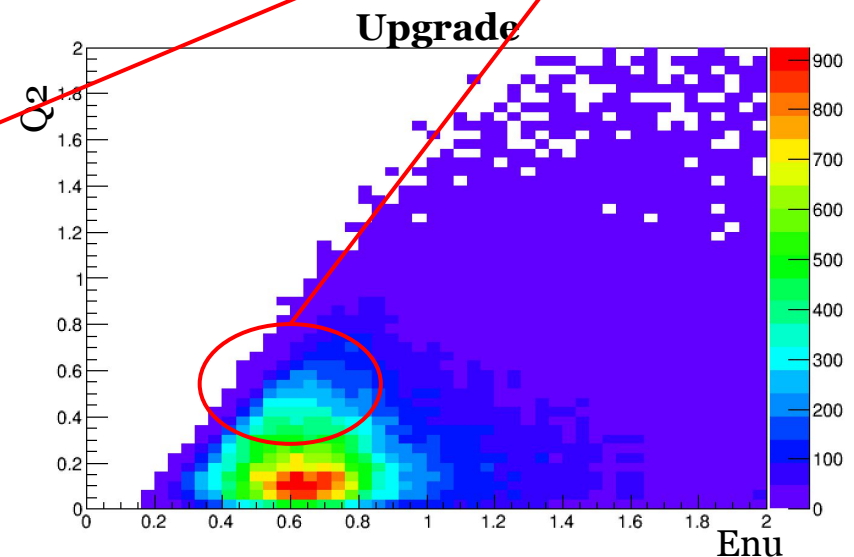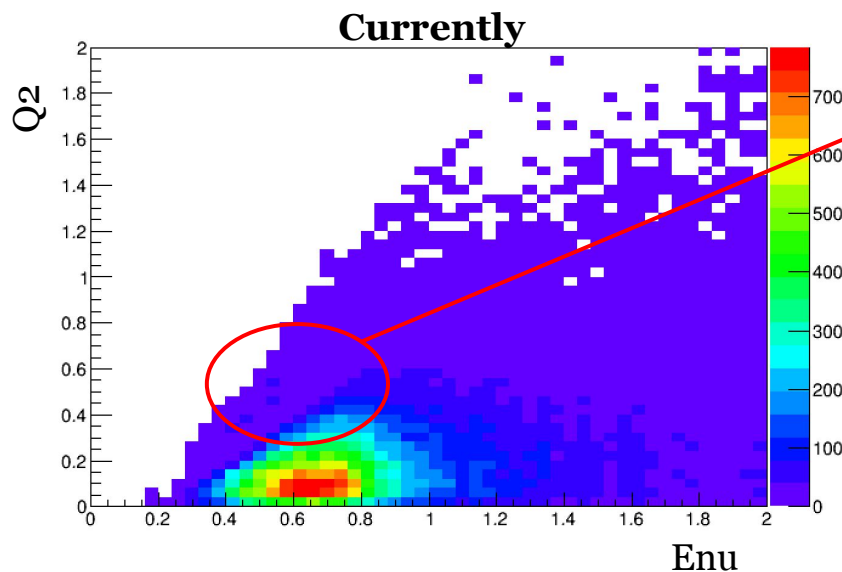➤ This selection is used as input in the tool, as we do in the oscillation analysis.

Distributions : a better Q2 sensitivity

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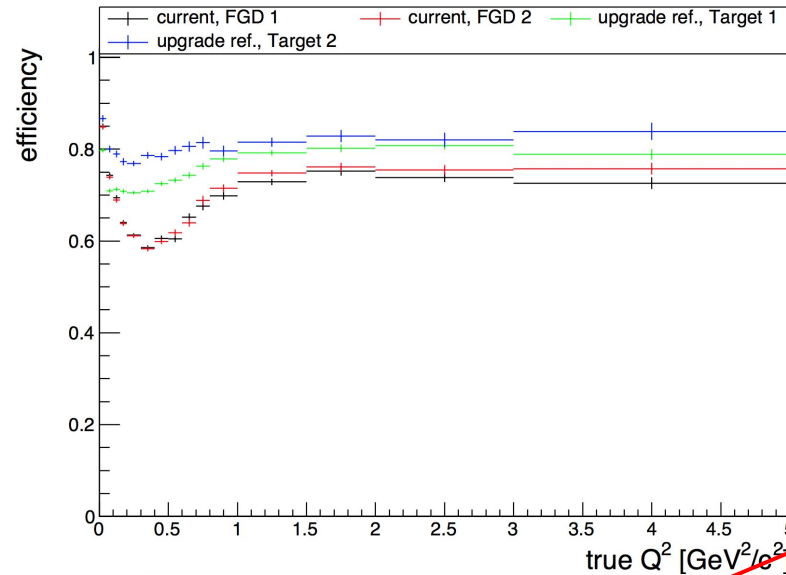
Region of interest in T2K

Currently

Upgrade

Asimov Study

➤ The first point is to do Asimov fit (fitting the nominal MC) with both the current ND280 efficiency and the predicted upgrade efficiency.

➤ We do this fit without considering detector systematics, and with full T2K statistics (7.8e21POT).

➤ This gives information on how the constraint on model's parameters evolve. And in particular how the constraint on the spectrum of neutrino events at SK evolve.

Asimov Study

Parameter	Current efficiency	Upgrade Efficiency
FSI_INEL_LO_E	-1.6806e-11 ± 0.068441	4.3306e-10 ± 0.056263
FSI_INEL_HI_E	3.4781e-11 ± 0.093177	2.7874e-11 ± 0.076476
FSI_PI_PROD	-1.0704e-10 ± 0.1368	1.3121e-10 ± 0.1132
FSI_PI_ABS	6.7712e-10 ± 0.089278	3.3278e-10 ± 0.087147
FSI_CEX_LO_E	8.6049e-10 ± 0.15523	6.9044e-10 ± 0.13869
FSI_CEX_HI_E	-5.9467e-11 ± 0.076	7.2894e-11 ± 0.062891
MAQE(GeV/c^2)	1.2 ± 0.014726	1.2 ± 0.011088
pF_C(MeV/c)	217.0 ± 6.5003	217.0 ± 5.5199
MEC_C(%)	100.0 ± 9.6821	100.0 ± 9.2904
EB_C(MeV)	25.0 ± 5.1669	25.0 ± 1.6219
pF_O(MeV/c)	225.0 ± 13.376	225.0 ± 10.01
MEC_O(%)	100.0 ± 14.45	100.0 ± 12.579
EB_O(MeV)	27.0 ± 6.3862	27.0 ± 2.5793
CA5	1.01 ± 0.022391	1.01 ± 0.023206
MANFFRES(GeV/c^2)	0.95 ± 0.018097	0.95 ± 0.017318
BgRES	1.3 ± 0.10444	1.3 ± 0.090715
CCNUE_0	1.0 ± 0.029679	1.0 ± 0.029663
DISMPISHP	8.3674e-11 ± 0.070812	9.8225e-11 ± 0.064188
CCCOH_O_0	1.0 ± 0.13357	1.0 ± 0.12536
NCCOH_0	1.0 ± 0.27462	1.0 ± 0.27288
NCOTHER_NEAR_0	1.0 ± 0.079392	1.0 ± 0.071508
MEC_NUBAR	1.0 ± 0.10813	1.0 ± 0.11119

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Interesting to notice that one of the only parameter depending on Q^2 in the current parametrization which is the axial mass MAQE, gets a better constraint with the upgrade (~25% better constrained)

Asimov Study

➤ We can compare the error on the expected number of events at SK in both configuration

	$\Delta N_{SK}/N_{SK}$
Current efficiency	1.23%
Upgrade efficiency	1.11%

➤ The difference is not impressive but we can expect that for several reasons :

➡ The forward statistic is a bit lower with the upgrade which probably compensate the added backward sensitivity

➡ The model currently used in the fit is almost not Q² dependant which is where the upgrade gets better.

➡ Currently working on using a more Q² dependant model for the study !

Fake data chain of study in T2K oscillation analysis

➤ We produce some fake data set (example here alternative 2p2h model) that we fit to ND280 data.

➤ This fit results is used to adjust SK predicted spectra.

➤ We produce and fit SK fake data set, with the fit to ND280 data as input, to obtain the bias on the oscillation parameters.
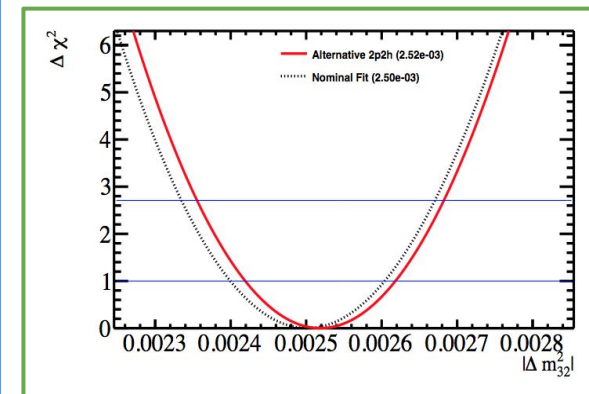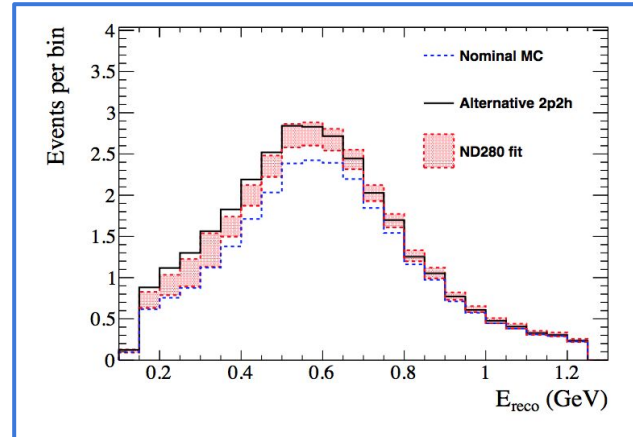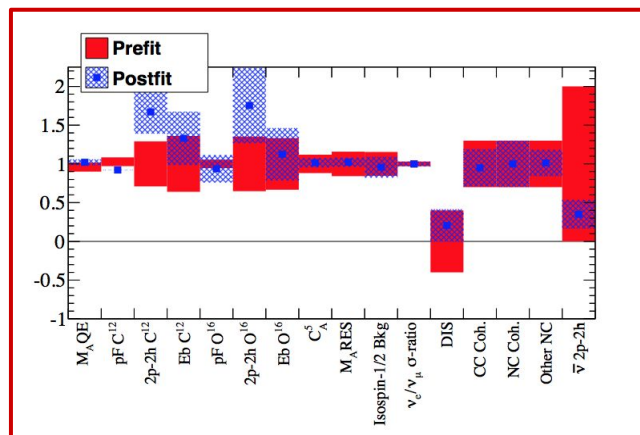
Alternative model	Maximum bias on parameter (σ)		
	Δm_{23}^2	$sin^2\theta_{23}$	$sin^2\theta_{13}$
Alternative 2p−2h	0.20	0.21	0.18

Fake data studies

➤ The bias observed is, for now, small when compared to the overall error.

➤ As the statistic is growing we can expect this bias to become significant.

➡ We need to evaluate how an upgrade of the near detector can reduce this bias.

➤ The same chain of study is used for the upgrade fake data studies.

➤ We are now testing several fake data sets, in particular in the new framework with more Q^2 dependence, that will soon be ready.

Fake datasets planned

➤ **BANFF/OA fake datasets (ordered by priority) :**

➡ BeRPA +1σ

➡ alternative Form Factor (3 component model +1σ)

➡ 2p2h :

  ➥ Martini fake datasets ➡ most important change on nu/nubar

  ➥ Delta and NotDelta fake datasets ➡ change p_μ $\cos\theta_\mu$ shape at ND and the reconstructed energy at SK

➡ Other important fake datasets : SF, Nieves

➡ In the future ? : Eb-only, pion kinematics

Fake data studies

➤ Still working on several fake data sets, but here is an example for alternative 2p2h.

➤ Hard to see discrepancies between the fitted values for current ND280 and upgrade but interesting to notice that the fit χ^2 is worse for the upgrade (75 against 45).
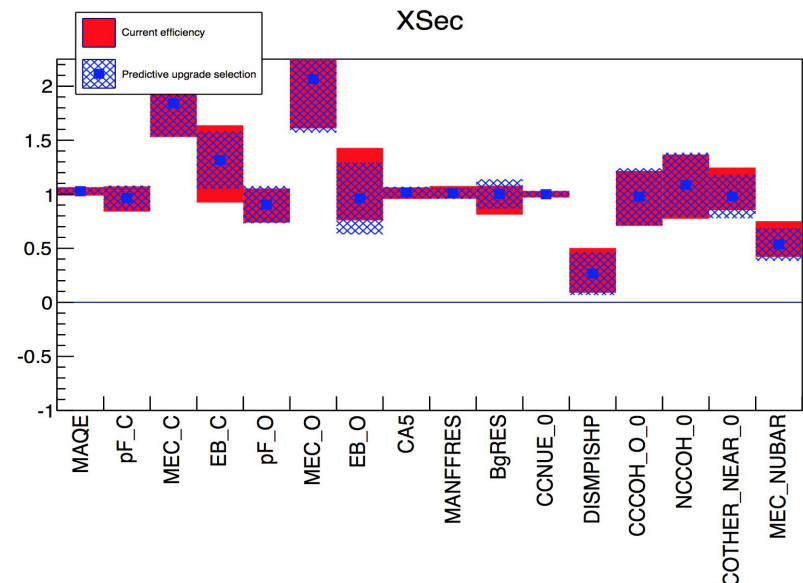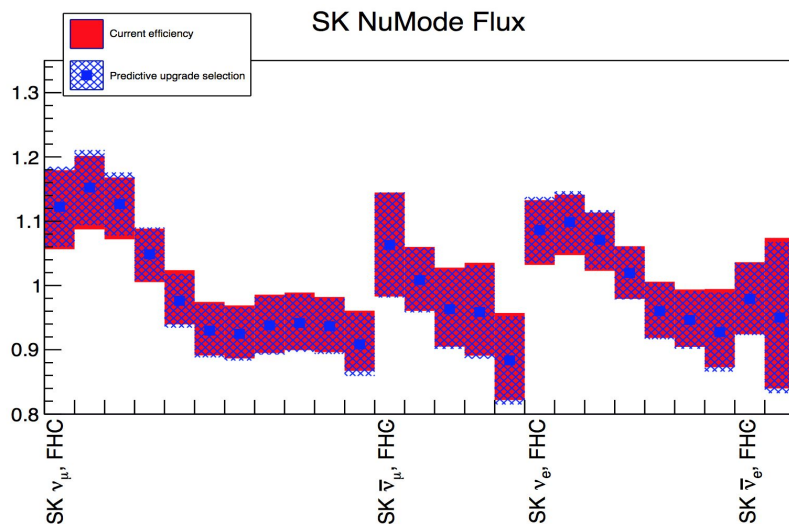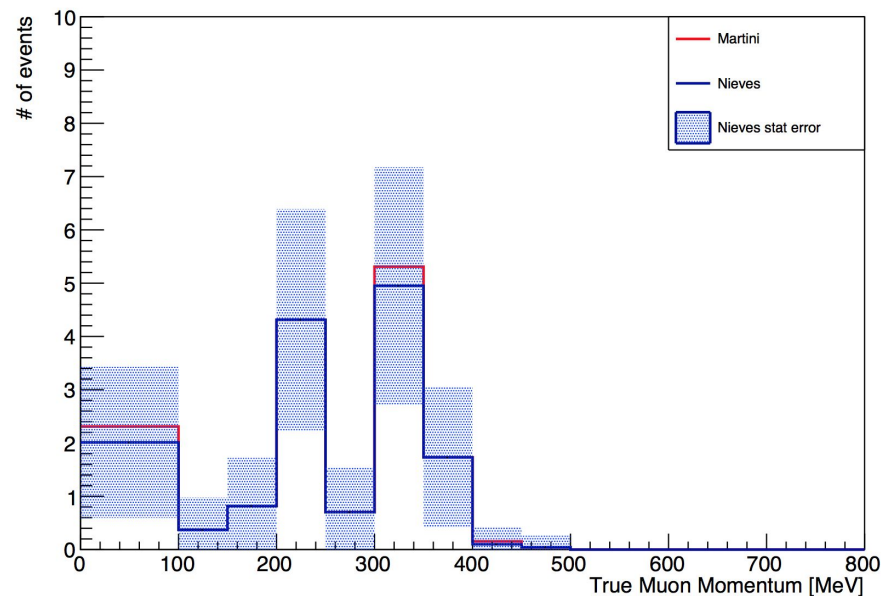
Example of model separation study

➤ We're also studying how an upgrade can help to separate two cross-section models apart.

➤ Here is an example for high angle tracks, with the nominal model used in the analysis and an alternative 2p2h model.
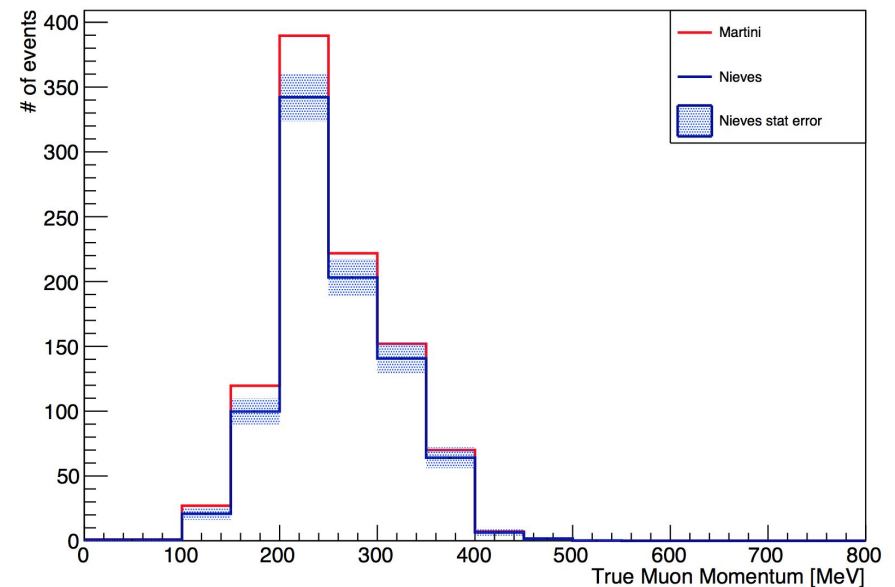
Current efficiencies

True cosθ [-1,-0.4]

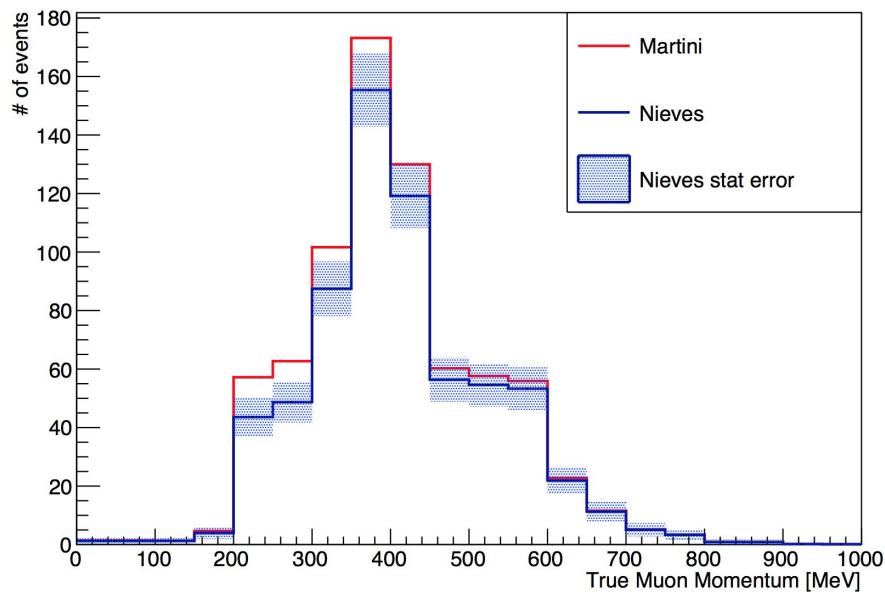Upgrade efficiencies

True cosθ [-1,-0.4]

Example of model separation study

➤ We're also studying how an upgrade can help to separate two cross-section models apart.

➤ Here is an example for backward tracks, with the nominal model used in the analysis and an alternative 2p2h model.
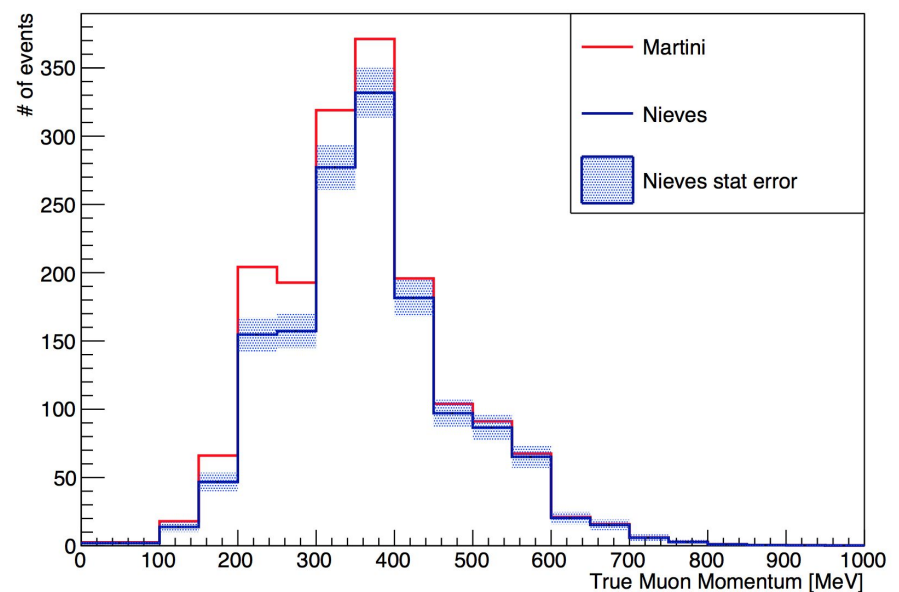
Current efficiencies

True cosθ [0.0,0.4]

Upgrade efficiencies

True cosθ [0.0,0.4]

Summary

➤ The chain of analysis for the upgrade is fully working, and every step has been tested.

➤ Working now on moving to an other cross-section model with more Q^2 dependence to get more precise idea on what exactly the upgrade would add to the oscillation analysis.

➤ A lot of studies ongoing, soon to come !

BACKUP

Cross-section model update
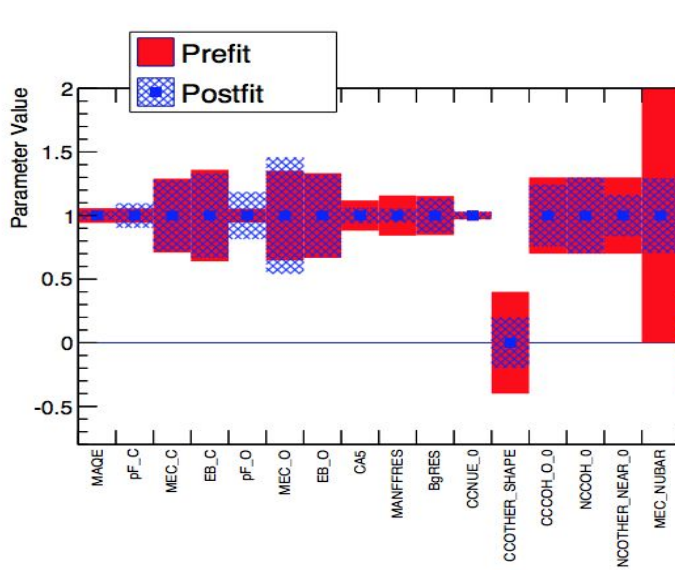

2015 cross-section parametrization
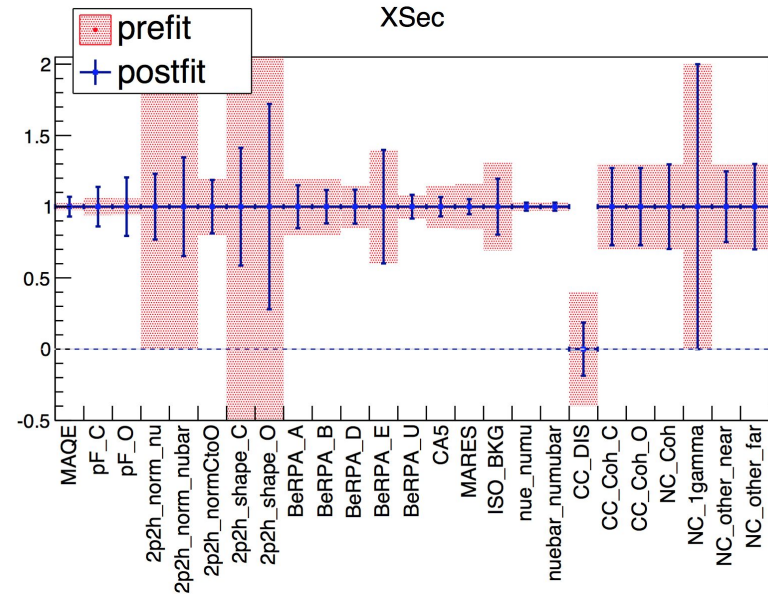
New cross-section parameterization

The new cross section parametrization has more freedom for the 2p2h interactions, and new BeRPA parameters, depending on Q^2.

2p2h

If you develop the total CC cross-section, the first order expansion gives the CCQE process, the second order gives additional nucleon or Δ resonances. This process is often called a multi-nucleon interaction or 2-Particle-2-Holes (2p2h).
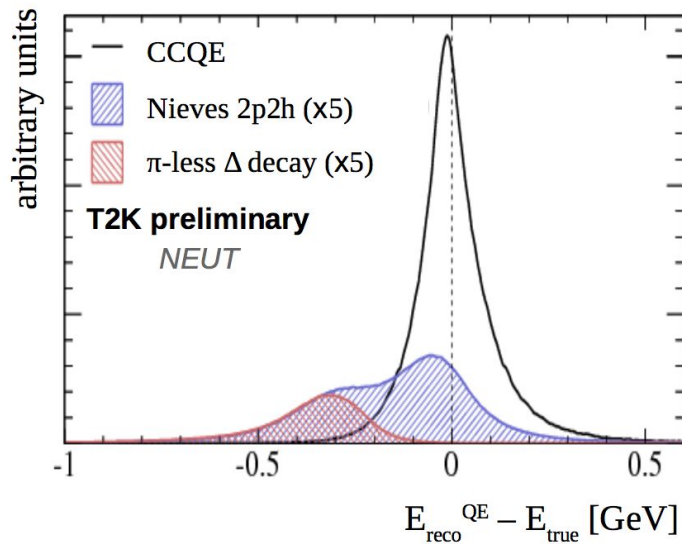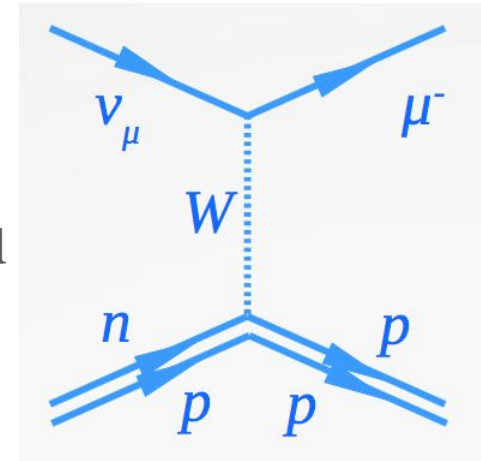
Effect on oscillations
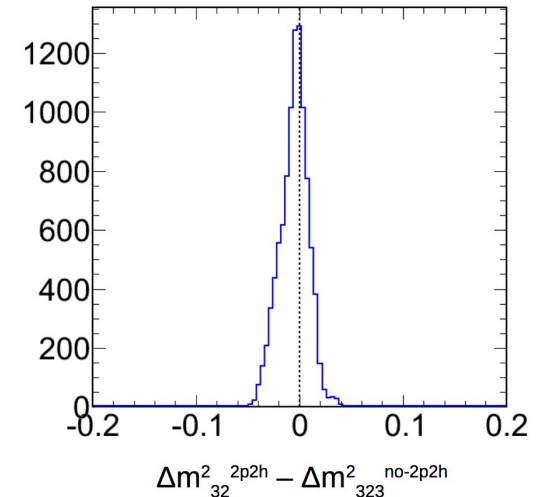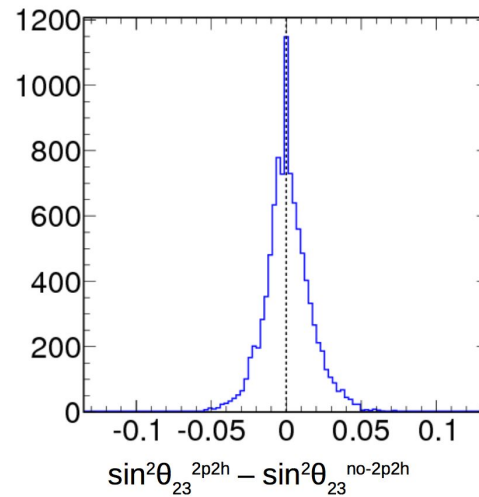
1) The parameter's constraints

➤ Make BANFF Asimov fit with the nominal (current) efficiency, and with improved efficiency

➤ Propagate the results to the far detector

Just an asimov fit, does not require toys, therefore easy to get.

2) Bias study : a) bias on oscillation parameters

➤ Do BANFF fake data fits for nominal and improved efficiencies for different fake data sets :

➡ Martini/Nieves

➡ 1p1h NEUT/Nieves

➡ Try if possible some other fake data sets to be as much model independant as possible (extreme cases)

➤ Propagate to the far detector and check the bias on the parameters

2) Bias study : b) bias on ND280 syst params

ASIMOV STUDY

Perform a pull study for all the systematic parameters.

Make BANFF fake data fit for nominal and improved efficiencies and look at the parameter's pull mean.

➤ If you increase high angle efficiency you expect larger discrepancies if models depend on that phase space.

➤ If the fitted xsec parameters are pulled in the right direction when increasing the efficiency, it probably means the update is going in the right direction.

$\Rightarrow$ **Difficult to quantify as a sensitivity**

Maybe we could also have informations on the possibility to reduce flux, xsec and detector systematics degeneracy.

3) Model sensitivity : a) Goodness of fit

➤ Goodness of fit test for different fake data sets (i.e. different models).

➤ Assume one model, make many toys, fit with nominal model (current BANFF) and get best fit χ^2 distributions.

➤ Then calculate the g.o.f. as p-value using nominal Asimov fit.

➤ Same procedure used for the run 1-6 data set BANFF fit.

➤ Do it for different models and get two χ^2 distributions and g.o.f.

➤ Follow the procedure above for the nominal and improved efficiencies : expect larger distance between χ^2 distributions and worse g.o.f. for improved efficiency if the additional phase space improve model separation.

$\Rightarrow$ **Difficult to quantify as a sensitivity**

3) Model sensitivity : b) Likelihood ratio

TOY STUDY

➤ Make one BANFF fake data fit for one fake data set (e.g. Martini) and fit it with two hypotheses :

No need for new parameters in the framework

➡ nominal MC = Nieves   => χ^2_{Nieves}

➡ nominal MC = Martini   => $\chi^2_{Martini}$

➤ Analogue to the beta parameter in nue bar appearance analysis

➤ Get $\Delta\chi^2 = \chi^2_{Nieves} - \chi^2_{Martini}$ and obtain a significance from it.
(See mass hierarchy paper, also discrete and non-nested
https://arxiv.org/pdf/1305.5150v4.pdf)

➤ Do it fot the two sets of efficiencies, nominal ($\Delta\chi^2_{NOM}$) and improved ($\Delta\chi^2_{UP}$), and compare them.

➤ If efficiency improvement is good we expect : $\Delta\chi^2_{UP} > \Delta\chi^2_{NOM}$

➤ Do first asimov fit (approximation, but still useful to get an idea), and eventually with many toys.