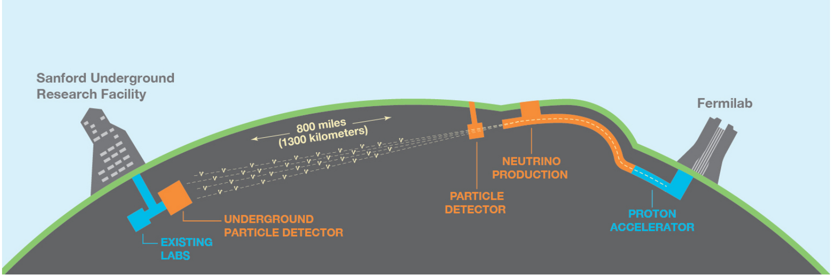
GENIE parameters tuning

Matteo Mazzanti

Universita degli studi di Ferrara & Fermilab

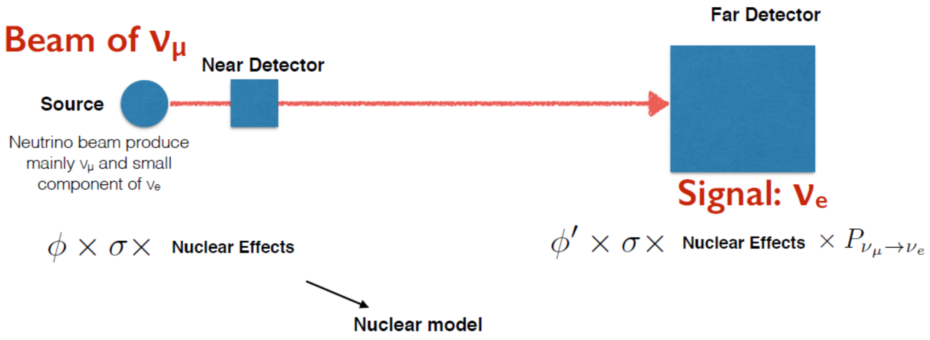
The DUNE experiment



- CP violation for leptons using neutrino oscillations
  $P[\nu_\mu \to \nu_e] \neq P[\bar{\nu}_\mu \to \bar{\nu}_e]$
- Hierarchy of neutrino masses
- Search of new kind of neutrinos

The far detector will be using a LArTPC for neutrino detection

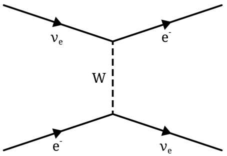
The DUNE experiment



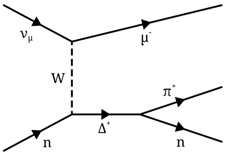
- Using simulation to extrapolate $\sigma_{\nu\mu} \to \sigma_{\nu e}$
- Need a good nuclear model that can reproduce the detected energy spectra and topologies for the near and far detector
- Propagation of uncertainties from the nuclear model to the oscillation parameters

CC interaction types

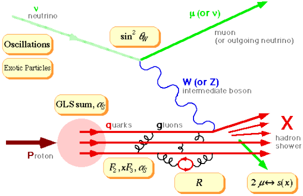
Quasi Elastic

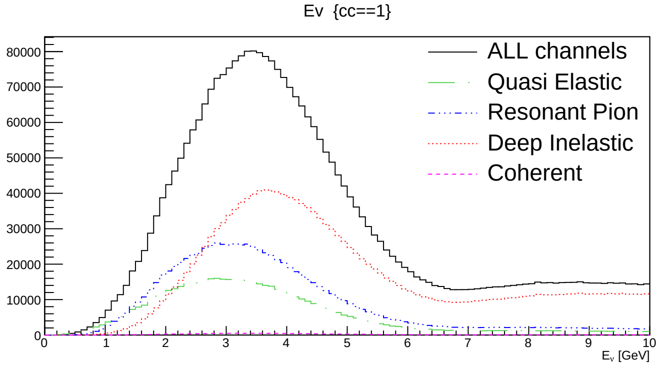


Resonant Pion



Deep inelastic





Contribution of each channel using the default model and HA.

Different models for neutrino interactions

GENIE, a Monte Carlo generator provides wide energy range for modelling neutrino interaction (from 100 MeV to some hundred GeV).

Nuclear Models

- Bodek Richie Fermi Gas model (DEFAULT)
- Effective spectral function
- Local Fermi Gas Model

Hadron Transport

- HA : An effective model in GENIE which just approximates whether a hadron should leave the nucleus or not given its initial momentum.
- HN : A Monte-Carlo model where step each particle forwards in tiny steps until it re-interacts with another part of the nucleus, or leaves the nucleus.

Generator configuration

The comparison between various models has been done as following:

Hadron Transport

- Default nuclear model and HA hadronic transport
- Default nuclear model and HN hadronic transport

Nuclear model (CCQE only)

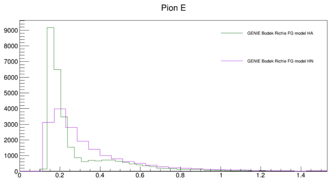
- Effective spectral function and HA hadronic transport
- Local fermi gas and HA hadronic transport
- Default model and HA hadronic transport

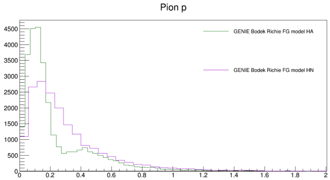
All simulations have been done for muonic neutrinos on liquid Argon using a neutrino energy range between 0 and 10 GeV.

Hadron Transport

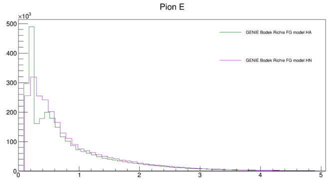
- Default nuclear model and HA hadronic transport
- Default nuclear model and HN hadronic transport

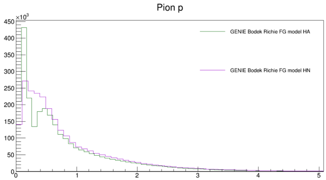
CCQE





DEEP INELASTIC

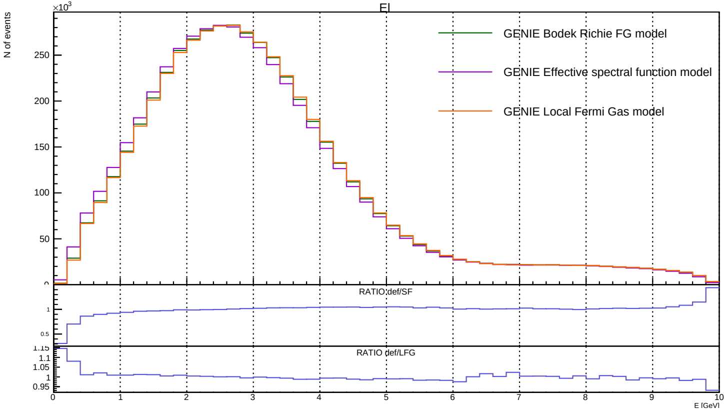




E_l, $E_\nu - E_l$

Nuclear model (CCQE only)

- Effective spectral function and HA hadronic transport
- Local fermi gas and HA hadronic transport
- Default model and HA hadronic transport



E_l, $E_\nu - E_l$

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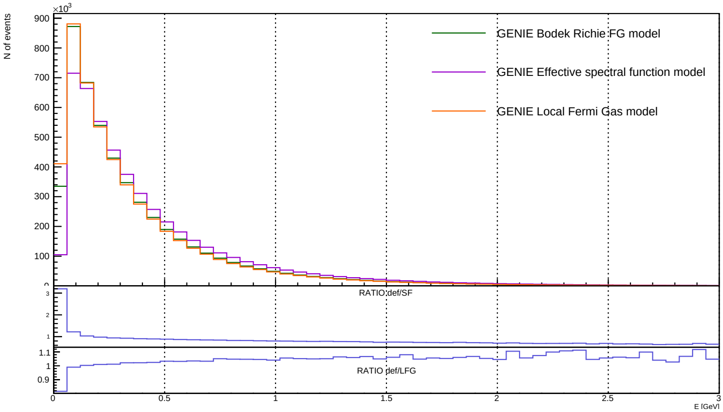
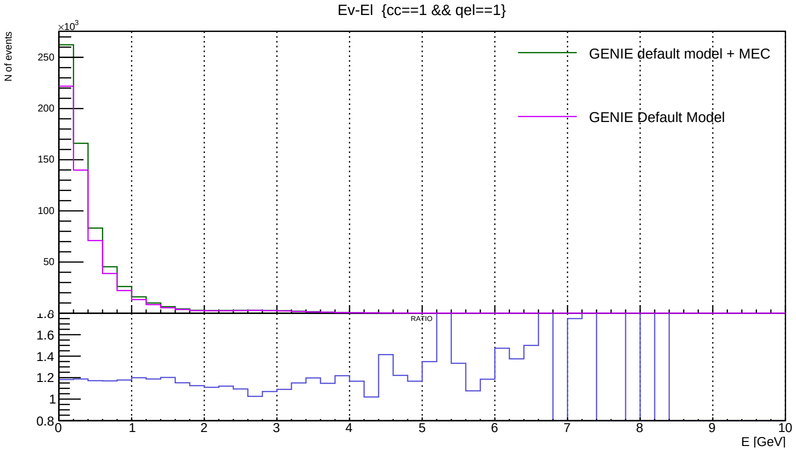


2P2H process (MEC) for only CCQE

- Default model
- Default model with MEC

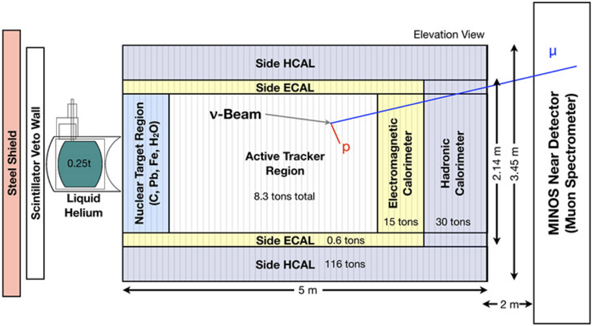


The MINERvA experiment

MINERvA main scope is to investigate the neutrino interaction on various nuclei using the Neutrinos produced at the Main Injector beam-line (NuMI) at Fermilab.

MINERvA is located 100 meters underground in front of MINOS near detector

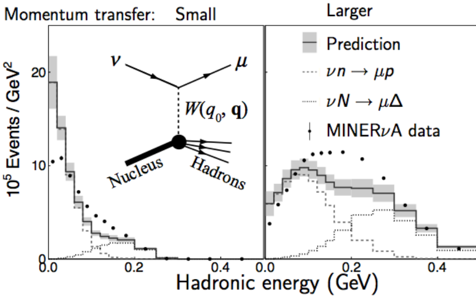
In the front part of the detector is possible to insert different targets (C, Pb, Fe, H_2O)



NUISANCE

Nuisance offers a framework for comparing neutrino generators to external data.
The software can also be used to tune the cross-section parameters.
The first step using Nuisance has been checking the change of distribution varying the value of different dials.

There are some discrepancies between experiment and Monte Carlo simulations ⟶ need Monte Carlo tuning



Bayesian method

NUISANCE can use the Migrad algorithm to search for the best values of GENIE parameters. However:

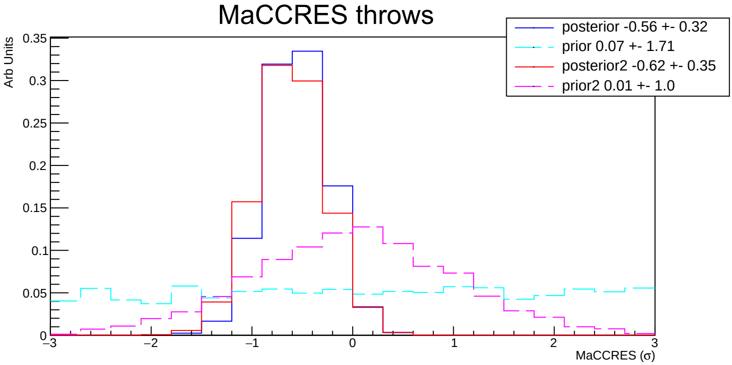
- Can fall in local minima
- Need to re-do the fit when adding new samples

Using bayesian method :

- Throw each parameter according to an arbitrary prior distribution (flat,Gaussian)
- Calculate the χ^2 for each of them
- For each throw assign the weight $w = e^{-\chi^2}$

The final weighted distribution should show a peak for the throws that maximize the likelihood, avoiding any constraint on the values of the dial, local and global minimums can be determined

FLATTHROW & GAUSTHROW



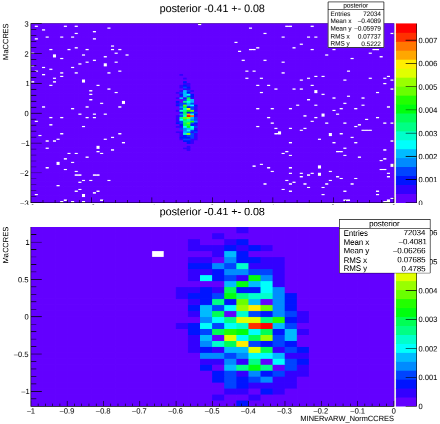
- Dashed : throws without weights
- Solid : throws with weights properly normalized

The value for the same dial obtained using minuit is : -0.50 ± 0.50
The two methods seem in agreement

Correlation between parameters

- MaCCRES
- MinervaRW
- NonRESBGvnCC1pi (non-res background for νn CC1pi), NonRESBGvpCC1pi(non-res background for νp CC1pi), NonRESBGvbarnCC1pi, NonRESBGvbarpCC1pi
- FrCEX_pi (π charge exchange)
- FrInel_pi (*pi* inelastic reaction)
- FrAbs_pi (*pi* absorption)
- FrPiProd_pi (π $\pi-$production)

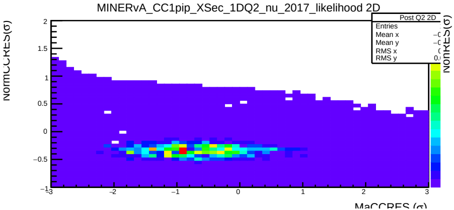
Correlation between MaCCRES and MinervaRW ?

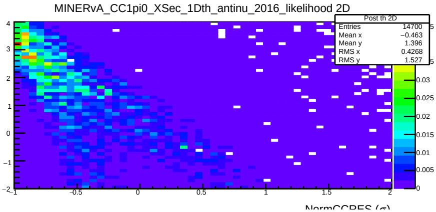


Analysis of the dial's space

Adding more dials will increase the dimensions of the dial's space. Using the projection on a plane it's possible to analyse :

- The correlation between two dials
- The presence of some "hidden" minima that minuit can't see

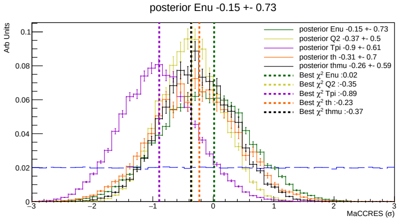


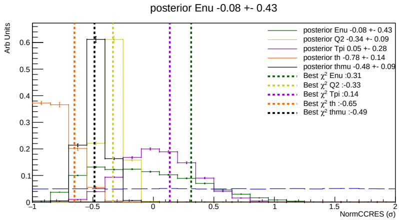


Best value from throws

Despite of where the peak for the posterior is, the minimum is sometimes found far from it.

- Statistical fluctuations
- Not enough resolution, low number of throws



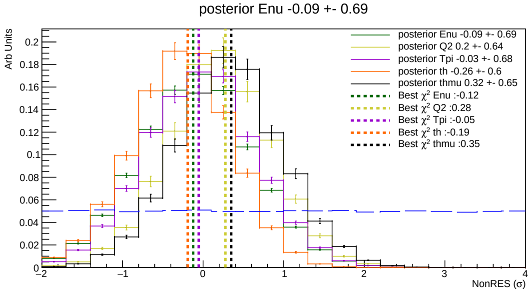


MaCCRES :

- All values compatible
- Only Tpi distribution fairly away from others

FrAbs_pi :

- Q2, th and thmu compatible
- Tpi and Enu compatible



From Patrick fits :

Dataset	MaCCRES	NormCCRES	NonRES
Q2	-0.43 +- 0.18	0.22 +- 0.05	-1.10 +- 0.08
Tpi	-0.86 +- 0.22	0.15 +- 0.07	-1.07 +- 0.08
th	-0.94 +- 0.07	0.10 +- 0.03	-1.06 +- 0.07
thmu	-0.29 +- 0.19	-0.02 +- 0.06	-1.11 +- 0.07

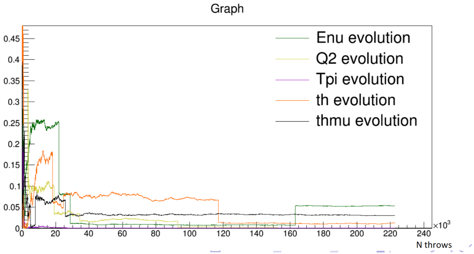
Problems and conclusions

From Bayesian method :

Dataset	MaCCRES	NormCCRES	NonRES
Q2	-0.37 +- 0.5	0.2 +- 0.64	-0.34 +- 0.09
Tpi	-0.9 +- 0.61	-0.03 +- 0.68	0.05 +- 0.28
th	-0.31 +- 0.7	-0.26 +- 0.6	-0.78 +- 0.14
thmu	-0.26 +- 0.59	0.32 +- 0.65	-0.48 +- 0.09

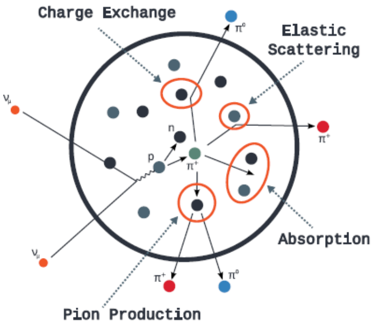
- Going up with number of dials the dimension of the dial's space increases. To have a small resolution for d dimensions one need $\sim 20^d$ throws

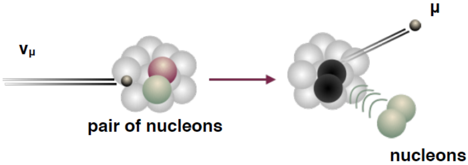
- The space can be splitted in :
  - 1: MaCCRES, NormCCRES and NonRES
  - 2: FrInel_pi, FrAbs_pi, FrPiProd_pi and FrCEx_pi



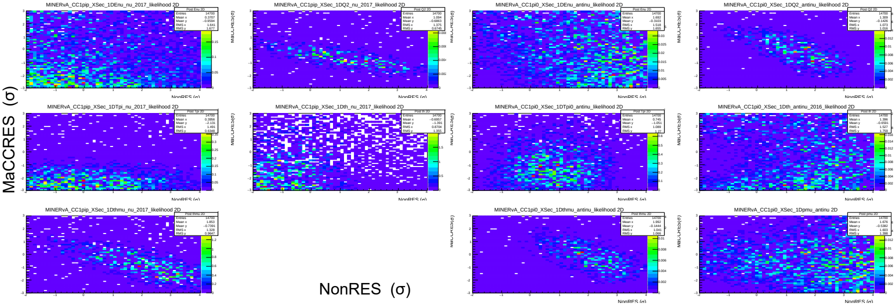
Conclusions

- Biggest effect seen on nuclear model are coming from 2P2H process
- The Hadronic transportation algorithm are changing the final state interaction energy distributions
- Validation of the dials seems working, values are in agreement with Minuit

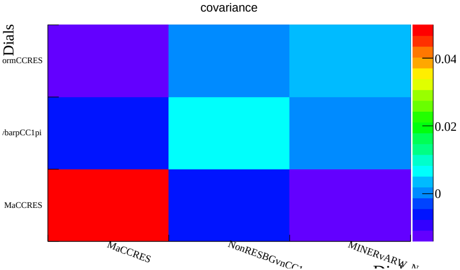

Charge Exchange
Elastic Scattering
Absorption
Pion Production
ν_μ
ν_μ
n
p
π^0
π^+
π^+
π^+
π^0


ν_μ
pair of nucleons
μ
nucleons

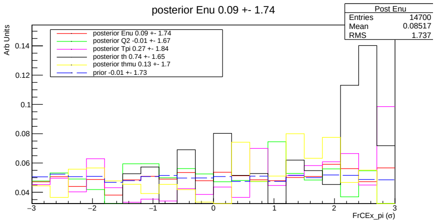
Neutrino Antineutrino

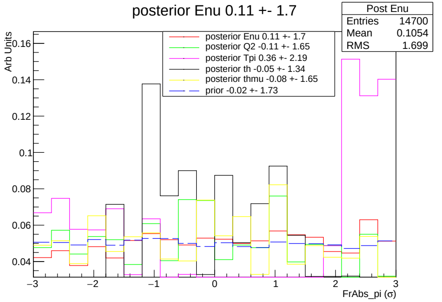


Covariance matrix



FSI Dials


posterior Enu 0.09 +- 1.74
Post Enu
Entries 14700
Mean 0.08517
RMS 1.737
posterior Enu 0.09 +- 1.74
posterior Q2 -0.01 +- 1.67
posterior Tpi 0.27 +- 1.84
posterior th 0.74 +- 1.65
posterior thmu 0.13 +- 1.7
prior -0.01 +- 1.73
Arb Units
FrCEx_pi (σ)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Post Enu
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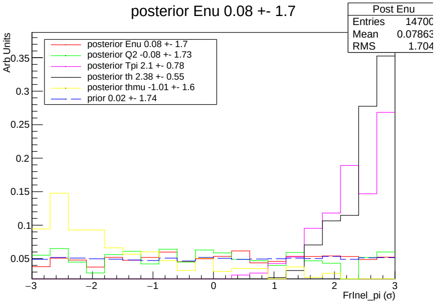
posterior Enu 0.11 +- 1.7
posterior Q2 -0.11 +- 1.65
posterior Tpi 0.36 +- 2.19
posterior th -0.05 +- 1.34
posterior thmu -0.08 +- 1.65
prior -0.02 +- 1.73
Arb Units
FrAbs_pi (σ)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Post Enu
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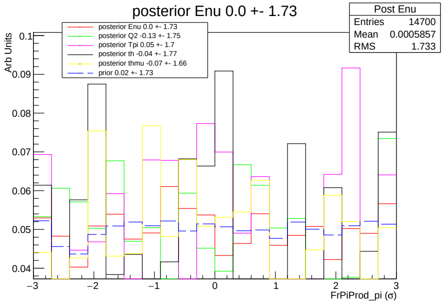
posterior Q2 -0.08 +- 1.73
posterior Tpi 2.1 +- 0.78
posterior th 2.38 +- 0.55
posterior thmu -1.01 +- 1.6
prior 0.02 +- 1.74
Arb Units
FrInel_pi (σ)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Post Enu
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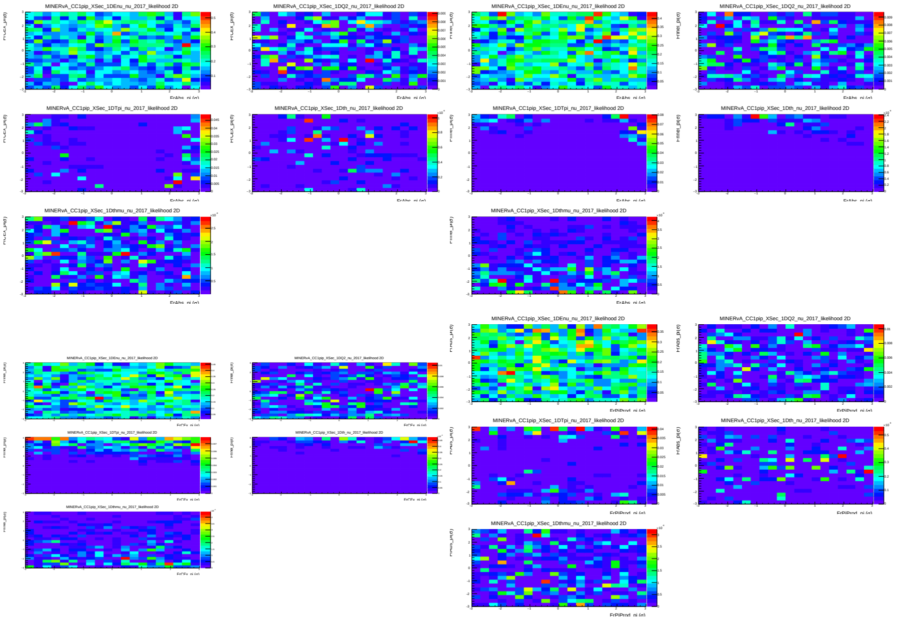
prior 0.02 +- 1.73
Arb Units
FrPiProd_pi (σ)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MINERvA_CC1pip_XSec_1DTpi_nu_2017_likelihood 2D
MINERvA_CC1pip_XSec_1Dth_nu_2017_likelihood 2D
MINERvA_CC1pip_XSec_1Dthmu_nu_2017_likelihood 2D
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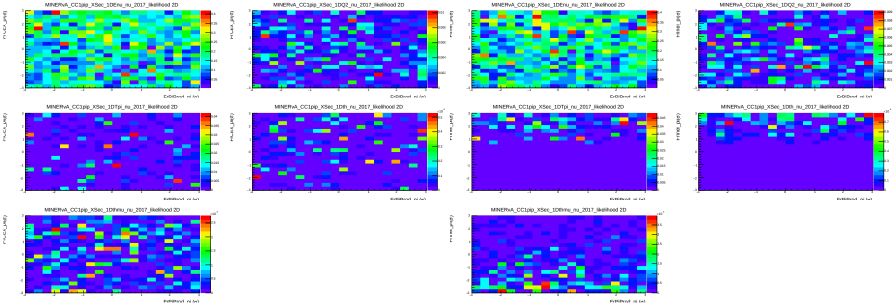
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MINERvA_CC1pip_XSec_1DQ2_nu_2017_likelihood 2D
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MINERvA_CC1pip_XSec_1Dth_nu_2017_likelihood 2D
MINERvA_CC1pip_XSec_1Dthmu_nu_2017_likelihood 2D
MINERvA_CC1pip_XSec_1Dthmu_nu_2017_likelihood 2D

Next steps

- Use the information about the correlation between the three parameters to create a penalty term.
  $\chi^2_{pen} = \sum_{ij} (cv_i - Fv_i) \left(M^{-1}\right)_{ij} (cv_j - Fv_j)$
  where:
  - cv_i = value of the throw on the i-th dial
  - Fv_i = value of the prior (from BC) for the i-th dial
  - M^{-1} = inverse of the correlation matrix (from BC)
- Include one by one the FSI dials inside of the card file and obtain the same distributions with them