Atmospherics analysis

First implementation in MaCh3

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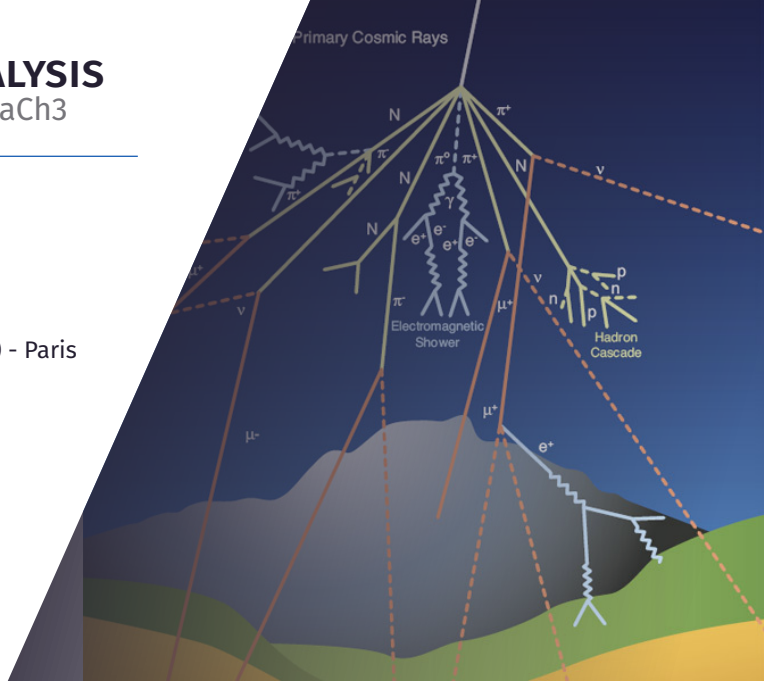
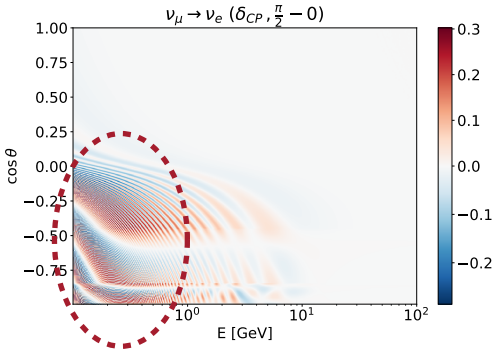
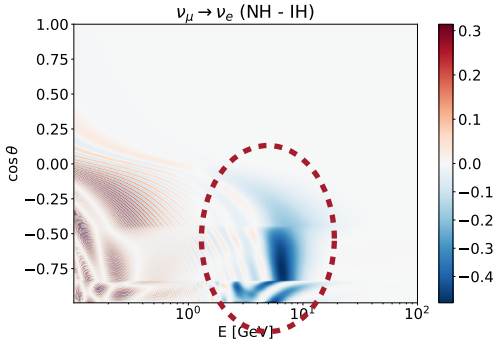
APC (Astroparticule et cosmologie) - Paris

November 16, 2023



What are we trying to see?



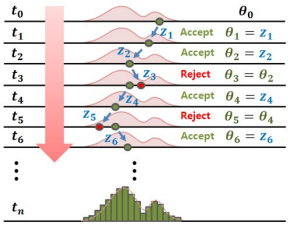


- Sensitivity to δ_{CP} coming from sub-GeV upgoing ν
- Sensitivity to MH coming from few-GeV upgoing ν

MACH3

MCMC principle

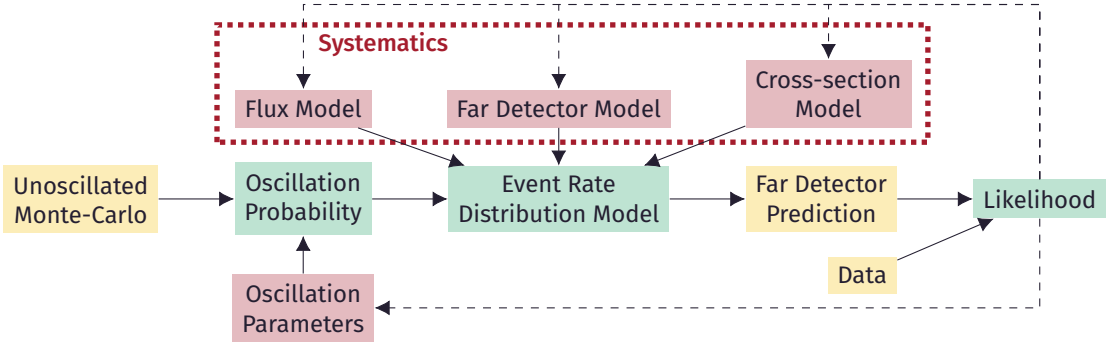
- Sampling likelihood space using Markov Chains
- Stepping in parameter space targeting high-likelihood regions
- Output is a series of steps. Their distribution in parameter space represents the posterior probability



Interpreting the output

- All the variables are sampled simulteanously by Markov Chains
- Full posterior in parameter space available in the end. Allows for any projection through marginalization.

Oscillation analysis flowchart

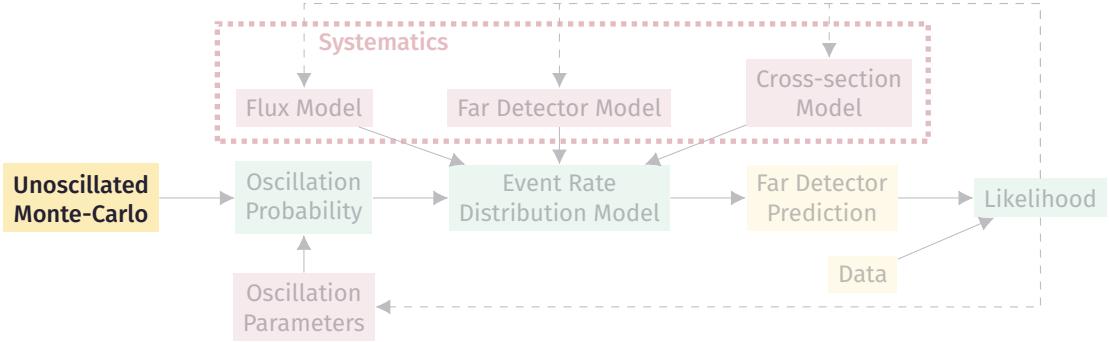


Legend:

Input/Output data | **MaCh3** internal machinery | Fit parameters

Oscillation analysis flowchart

Input sample



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Input sample

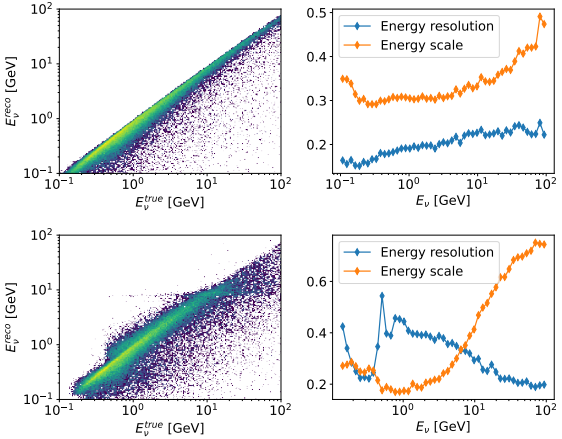
Sample characteristics

- 300k events in the HD 1x2x6 AV
- Production identical to the large sample request
- Correct fluxes and normalizations applied after the CAF stage $\rightarrow 400$ kt yr
- Sample split in 24 sub-samples with $\nu_{e,\mu}$ flux, $\nu_{e,\mu,\tau}$ detected and $\nu_{e,\mu}$ reconstructed.

Assumptions

- Perfect flavour determination assumed (as current CVN cannot be used for atmospherics)
- Using the true lepton direction as reco direction
- Using only the ν events (no $\bar{\nu}$)

Energy resolution

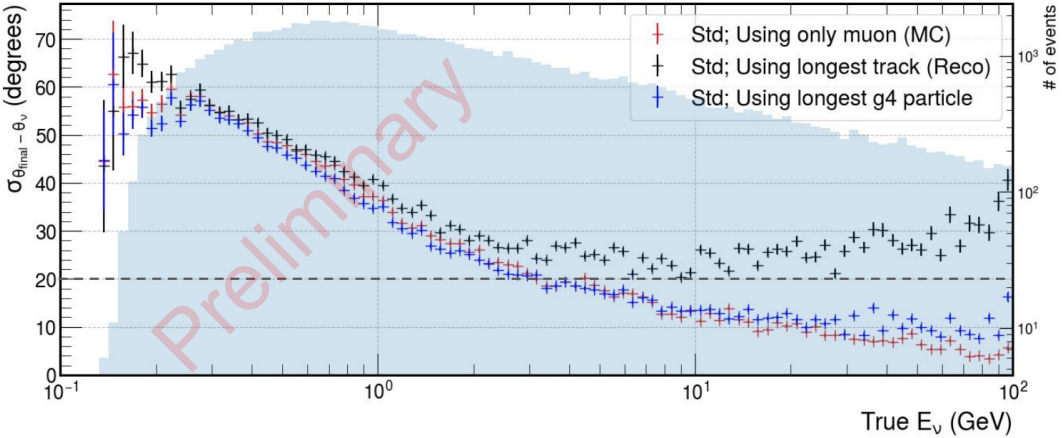


ν_e

ν_μ

- Reconstructed energy taken as is.
- No correction for energy-scale (center of $1 - E_\nu^{\text{rec}}/E_\nu^{\text{truth}}$ distribution).
- More details in Henrique's talk.

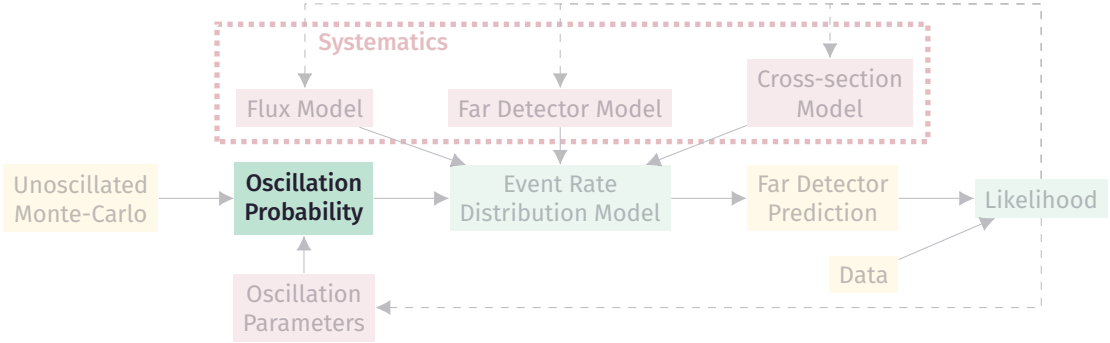
Angular resolution



- Using the true lepton direction $\rightarrow$ not too far from reconstructed performances

Oscillation analysis flowchart

Oscillations calculation



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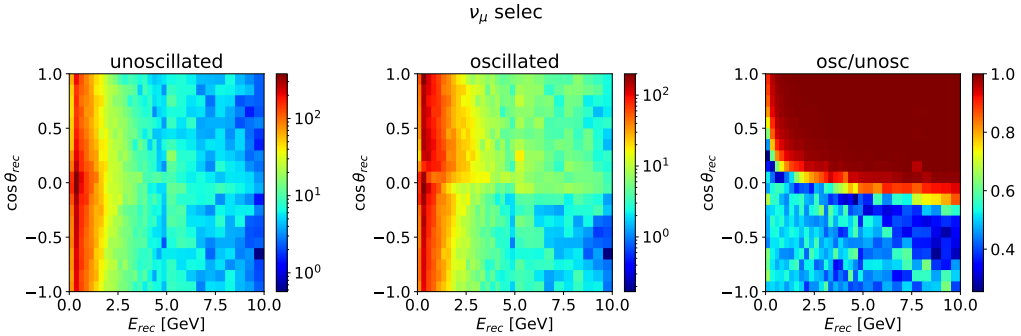
Oscillations calculation

ν_μ

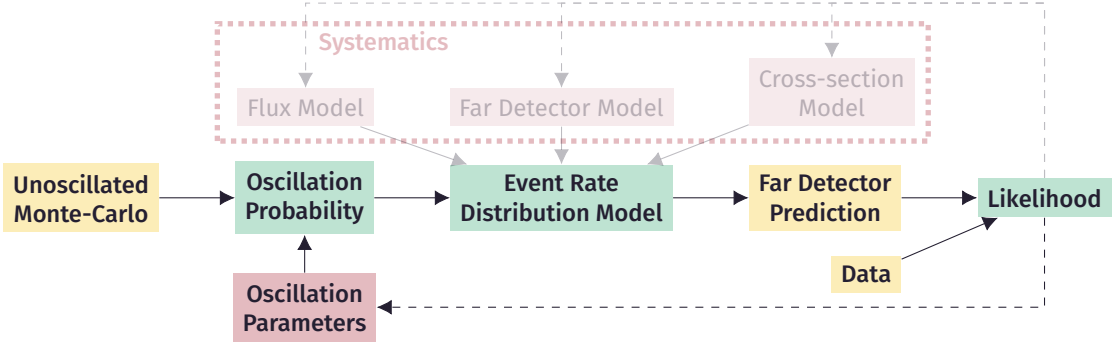
Atmospherics oscillations now implemented in MaCh3 for DUNE.



Oscillations calculated on true variables. Likelihood computed on reco quantities.

Oscillation analysis flowchart

Stats-only fit



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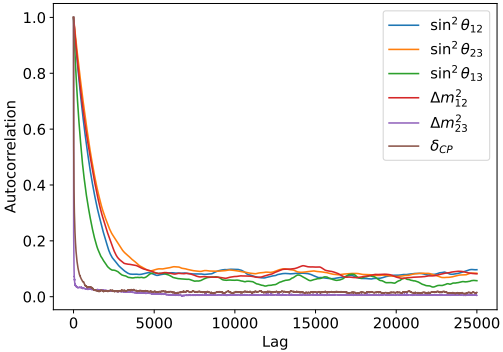
Statistics

Generated 40 chains with 100k steps per chain.

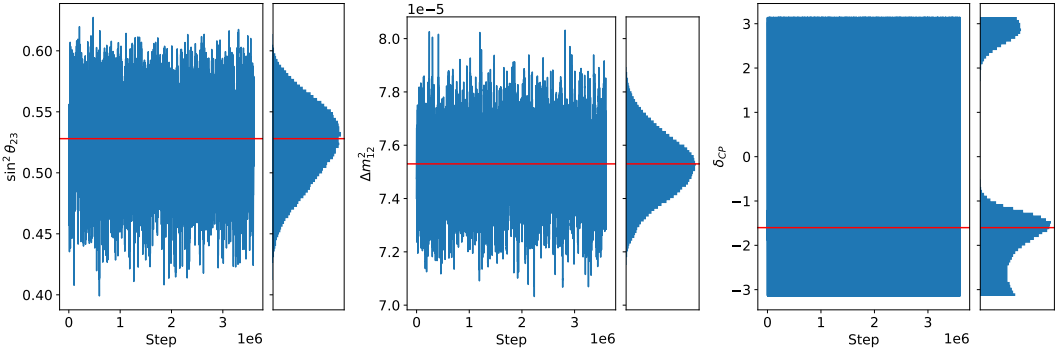
Burn-in

- First steps are biased by the initial values → removing first steps of each chain.
- Decide on the burn-in number looking at the steps autocorrelation
- 10k burn-in chosed here.



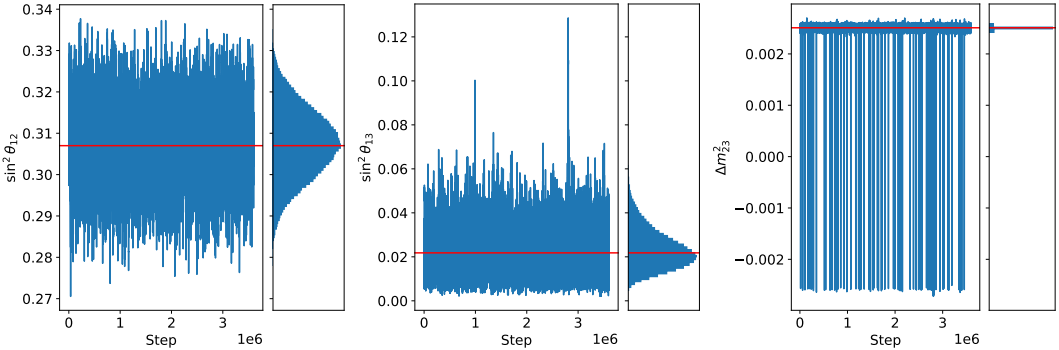
NB: Not trying to draw big conclusions looking at the following results. Proof of concept of doing an atmospherics oscillation analysis with MaCh3 for DUNE.

Looking at the chains



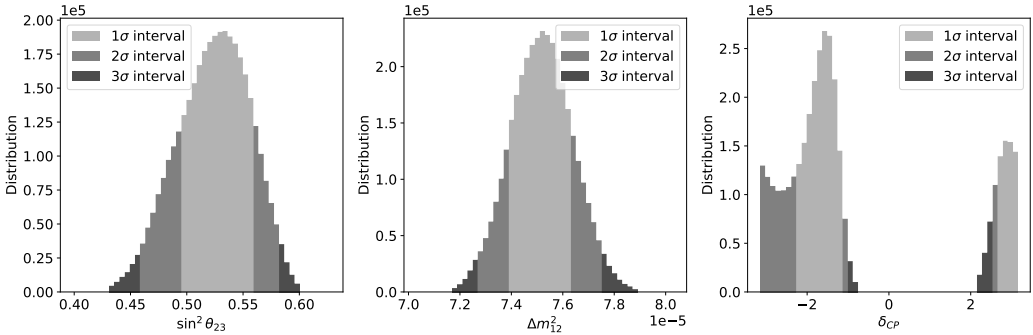
- Likelihood in both negative and positive δ_{CP} ($\sin\delta_{CP}$ vs $\cos\delta_{CP}$ degeneracy)

Looking at the chains



- Likelihood in both negative and positive δ_{CP} ($\sin\delta_{CP}$ vs $\cos\delta_{CP}$ degeneracy)
- A few steps exploring the IH, not staying there.

1D POSTERIOR PROBABILITY



- Credibility intervals obtained by taking bins with the highest probability until having 68/99/99.73% of probability inside.

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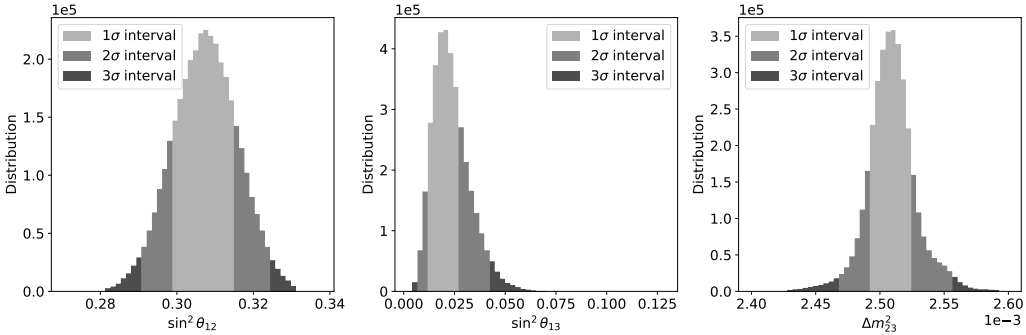
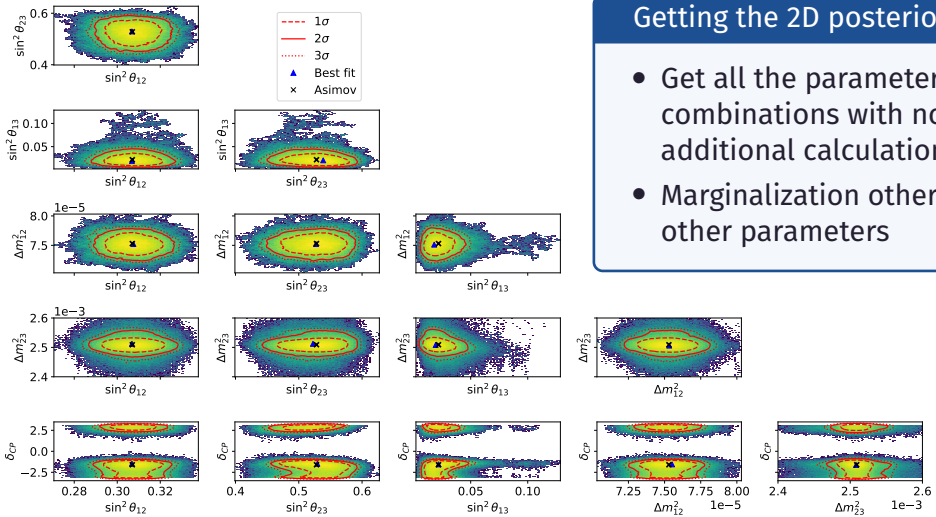


- Credibility intervals obtained by taking bins with the highest probability until having 68/99/99.73% of probability inside.

2D POSTERIOR PROBABILITY

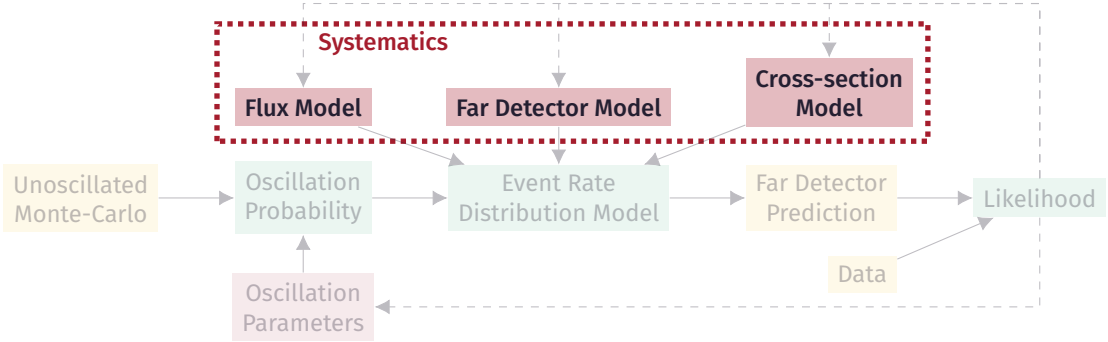


Getting the 2D posterior

- Get all the parameters combinations with no additional calculations.
- Marginalization other all the other parameters

Oscillation analysis flowchart

Adding systematics



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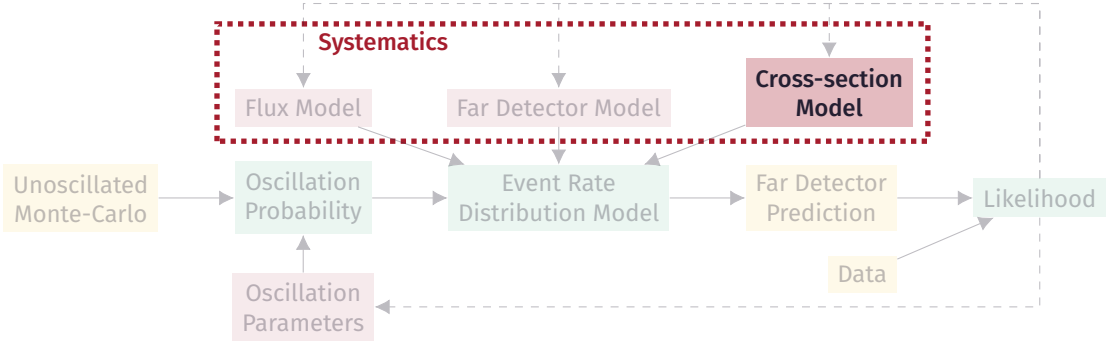
Oscillation analysis flowchart

Adding systematics



Legend:

Input/Output data

MaCh3 internal machinery

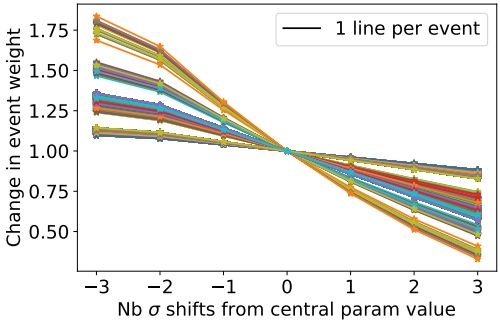
Fit parameters

Splined systematics

Spline-response functions

- Pre-compute the impact of different values of the parameter on ”knots” (evaluation points)
- Evaluate looping over the MC sample, for each event.
- Evaluate variations in-between knots by interpolating with piecewise cubic splines.

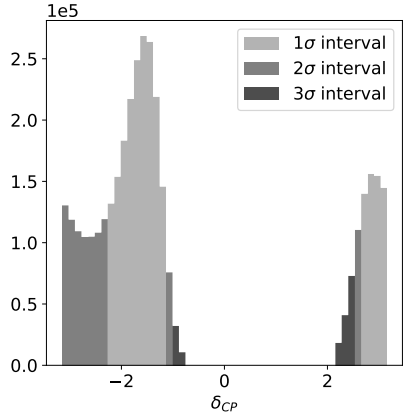
Nucleon inelastic reaction probability

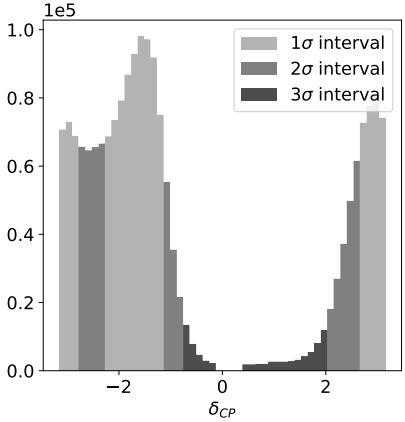


→ Computed using *nusystematics*

Splines are then averaged in E_ν^{true}, E_ν^{reco} and mode, bins with all the events.

Effect of the xsec systematics (preliminary)





There is an effect of the xsec systematics in degrading the sensitivity → good sign

Summary

Summary

- First implementation of DUNE atmospherics analysis within MaCh3 (common framework with LBL analysis).
- Managed to have the first stats-only fits with a limited sample and some assumptions
- First implementation of the LBL xsec systematics

Future work

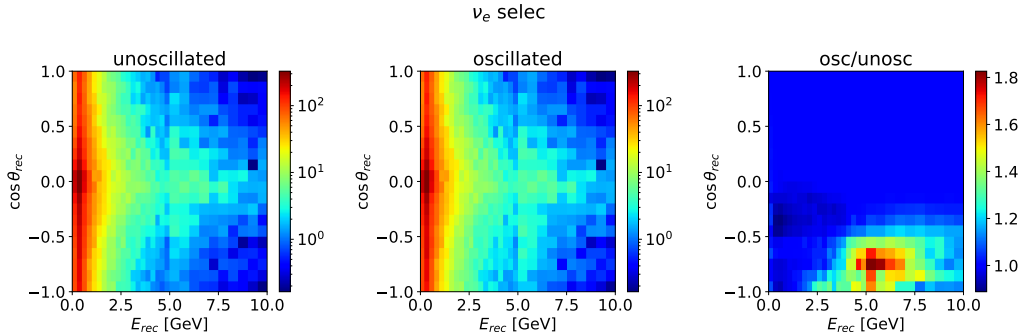
- Lot of work ongoing to improve the reconstruction for atmospherics (see Henrique's presentation).
- Plan on implementing soon several flux systematics.
- Starting considering non-inclusive xsec systematics for atmospherics (angular dependency).
- Should be able to make use of the future new atmospheric sample.

Backup slides

Oscillations calculation

ν_e

Atmospherics oscillations now implemented in MaCh3 for DUNE.



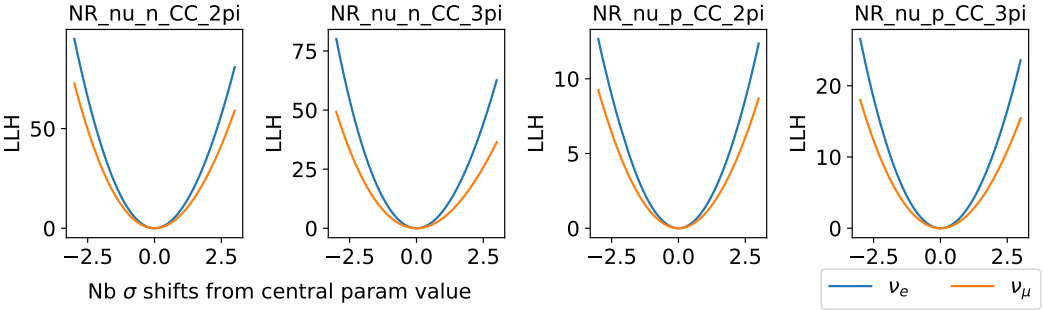
Oscillations calculated on true variables. Likelihood computed on reco quantities.

Implementing splined systematics

LBL xsec systematics

Spline binning

Splines are averaged in E_ν^{true}, E_ν^{reco} bins with all the events.



Using the xsec systematics

Change of GENIE tune

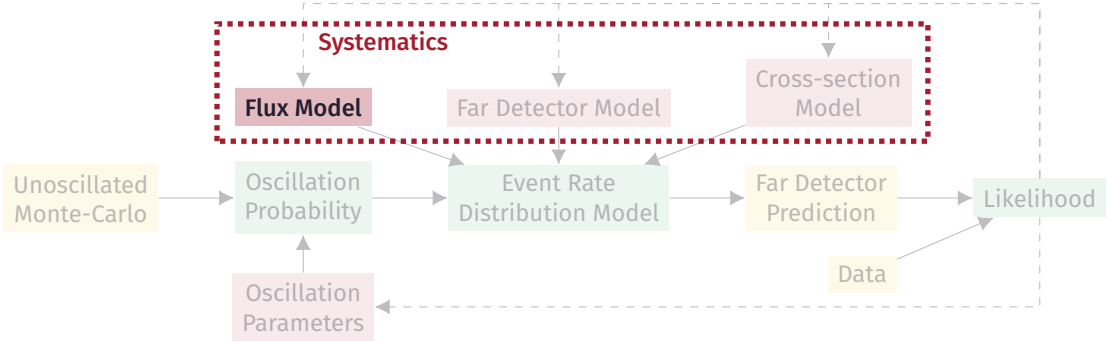
- A new GENIE tune is used for all the new DUNE productions.
- The reference systematics are from the TDR with a different GENIE tune.
- Some changes have to be made to adapt the dials to new tune.
- This developpment is still ongoing for LBL xsec systematics $\rightarrow$ I was pointed to the already available list that I'll test soon.

Thinking about atmospherics-specific xsec systematics

- The current LBL xsec systs have no angular dependency. List here
- Need to see with DIRT people what could/should be implemented.
- Significant amount of work to implement.

Oscillation analysis flowchart

Adding systematics



Legend:

Input/Output data

MaCh3 internal machinery

Fit parameters

Flux systematics

Implementation in MaCh3

- A new method to set systematics using yaml files was implemented in MaCh3
- Plan to use it very soon to implement first basic flux systematics

Proposed list of flux systematics

- Absolute flux normalization
- Relative normalization of $(\nu_\mu + \bar{\nu}_\mu)/(\nu_e + \bar{\nu}_e)$ ratio
- $\nu/\bar{\nu}$ normalization (flux models differences)
- Zenith angle normalization
- K/π ratio
- Solar activity (impacts geomagnetic field)
- Atmosphere density (impacts production height)

Using physical simulations

Looked at MCEq. They don't implement geomagnetic field which is very important at low E.
Is anyone aware of an alternative?

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November 16, 2023

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