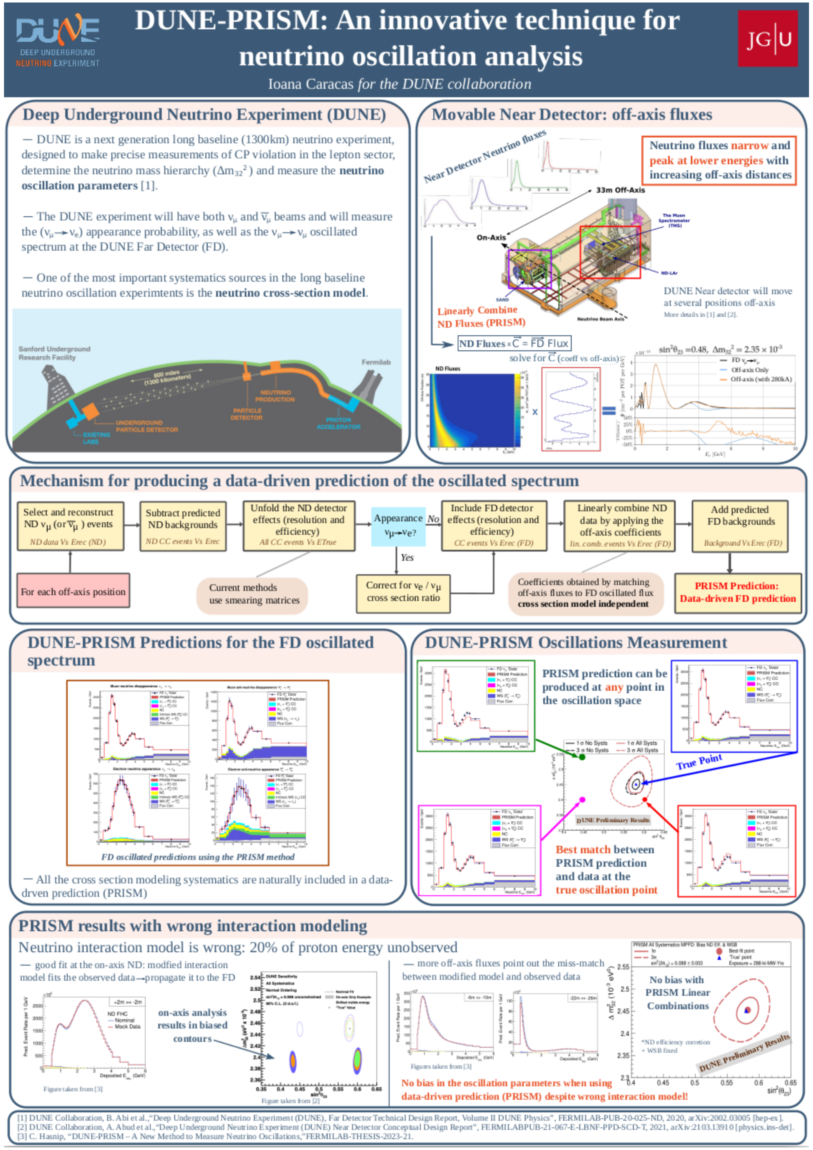
PRISM Plots for Neutrino Approval

Title: DUNE-PRISM: An innovative technique for neutrino oscillation analysis

Abstract:

The Deep Underground Neutrino Experiment (DUNE) is a next generation experiment designed to measure the neutrino and anti-neutrino oscillation probabilities, using a high-intensity neutrino beam (1.2-2.4 MW) produced at Fermilab. With a baseline of 1300 km and large (kton-scale) LArTPC detectors, DUNE will provide an unprecedented precision in measuring the oscillation parameters. Neutrinos interaction cross sections represent the main source of systematics which enters the analysis and limits the sensitivity of measuring the CP violating phase and other oscillation parameters . The Precision Reaction Independent Spectrum Measurement (PRISM) represents an innovative technique for neutrino oscillation analysis, which has the potential to significantly reduce the interaction model dependency. The DUNE Near Detector (ND) complex is designed to move to different positions along the neutrino beam axis, sampling thus several neutrino fluxes with different peak energies as a function of the off-axis position. The PRISM concept linearly combines these off-axis neutrino measurements to produce data-driven predictions of the oscillated neutrino spectrum at the Far Detector (FD). An oscillated FD prediction obtained directly from data has a minimum modeling dependency, any cross section effects being naturally incorporated in the analysis. This poster will give an overview of the PRISM concept and how it is used within DUNE. A case-study showing how PRISM can avoid potential biases resulting from the wrong interaction modeling will also be presented.

Ioana Caracas *on behalf of DUNE-PRISM WG*



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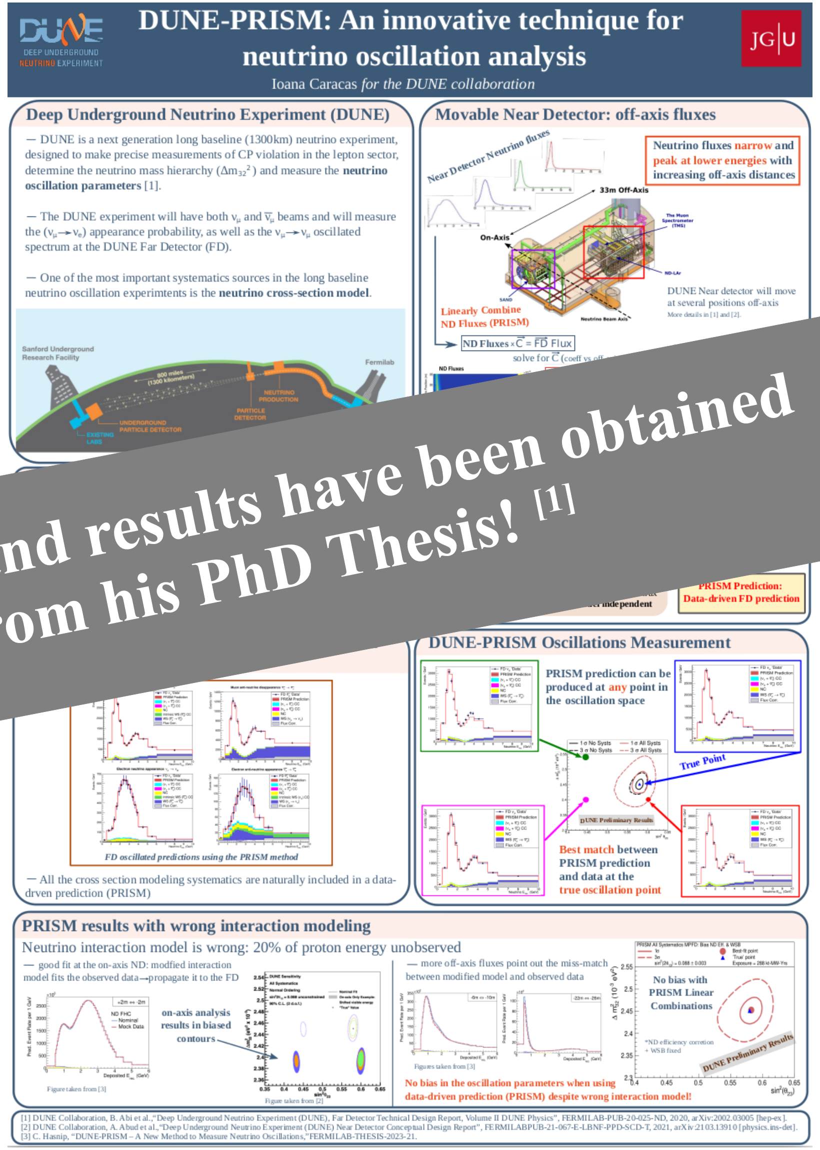
Disclaimer: Most of the presented plots and results have been obtained by C. Hasnip and taken from his PhD Thesis! [1]

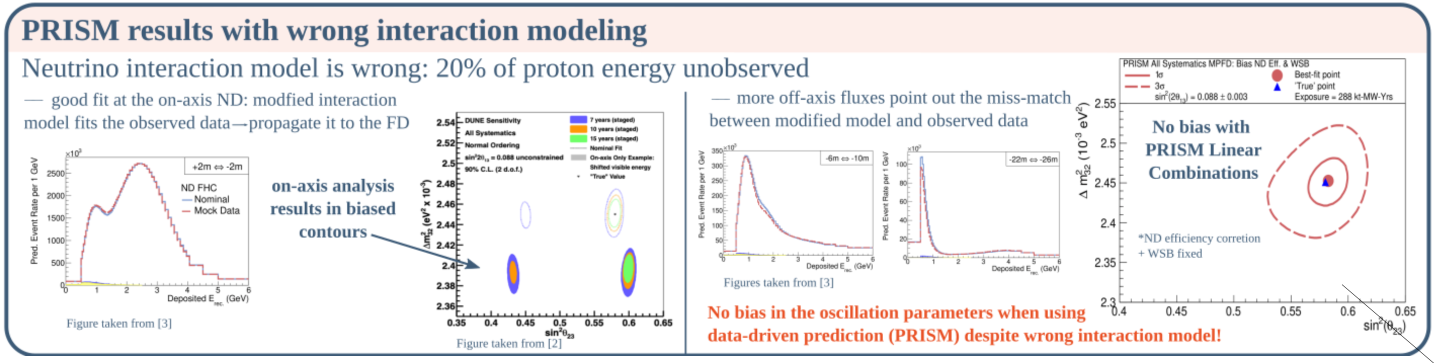
Ioana Caracas *on behalf of DUNE-PRISM WG*



[1] C. Hasnip, "DUNE-PRISM – A New Method to Measure Neutrino Oscillations,"FERMILAB-THESIS-2023-21.

PRISM Contours

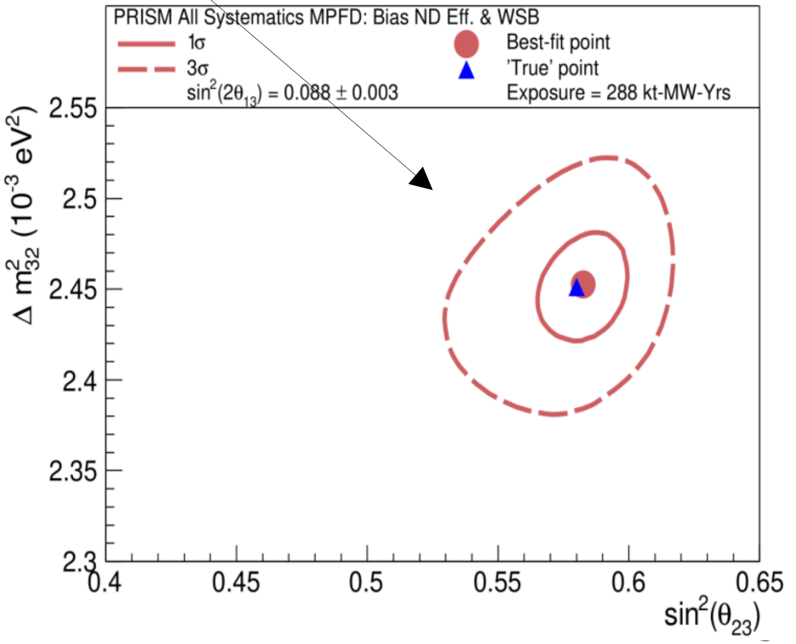
deadline poster upload: 14.06.2024



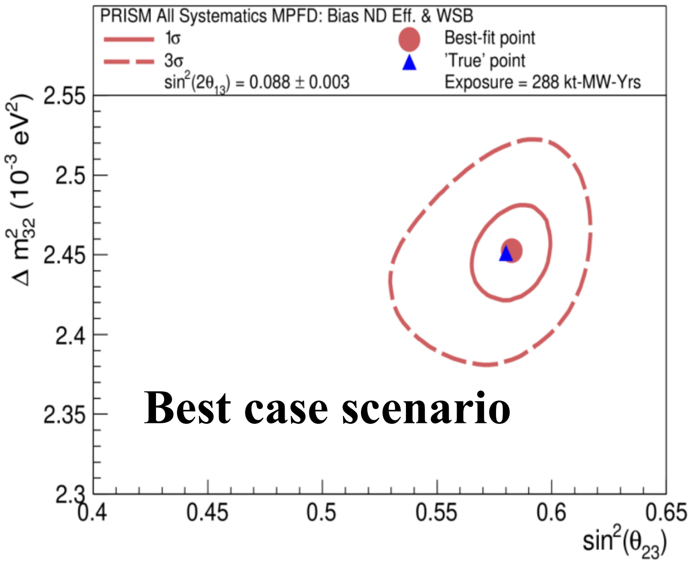
Main concerns:

- How much do we expect the contours to change with analysis improvement?
  → main assumptions for the presented contours
  → main on-going analysis improvements that could result in better contours
  → if we present this result as “best case scenario SO FAR” will the contours shrink significantly / will we end up having lots of / very different such “best case scenario” plots as the analysis evolves?

- Contours much wider than for the on-axis case: we do know PRISM sensitivity is lower than the on-axis one → is this how much lower we expect it?

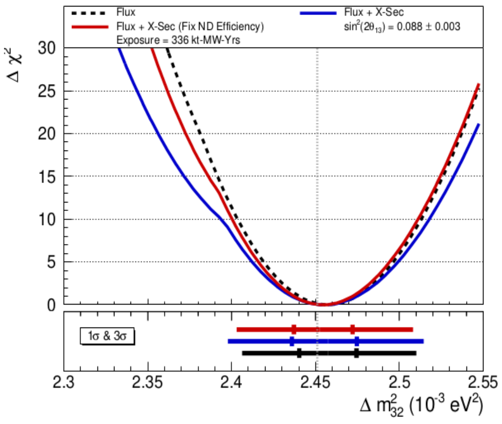


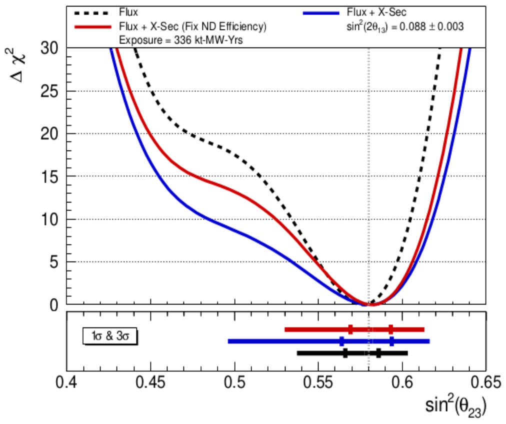
PRISM Contours – Wrong interaction model



Underlying assumptions:

- **ND Efficiency correction mimics a data-driven approach:**
  – knows about the wrong interaction model and is not prone to systematics
  – we DO know that the efficiency correction is the main source of sensitivity reduction (xsec systs) within the PRISM Analysis

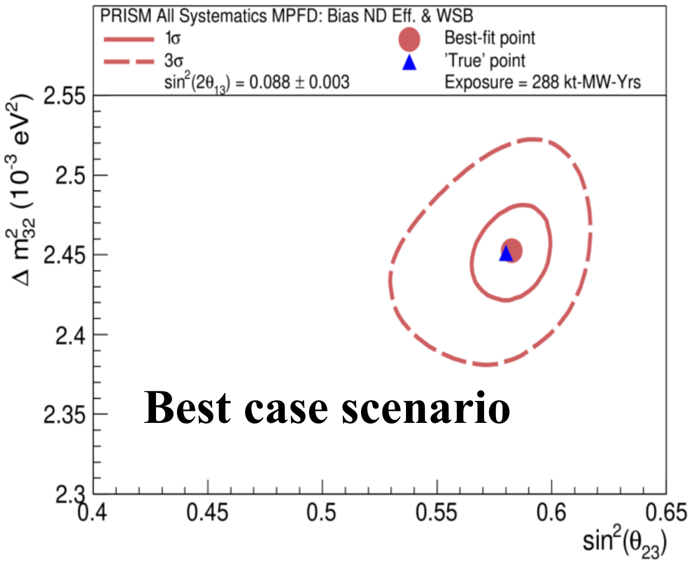




Work in progress: geometric efficiency correction → data-driven ND Efficiency correction

– will probably still have some MC dependency → **contours would be a bit wider** (depending on the MC amount)

PRISM Contours – Wrong interaction model



<u>Underlying assumptions:</u>

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  – knows about the wrong interaction model and is not prone to systematics

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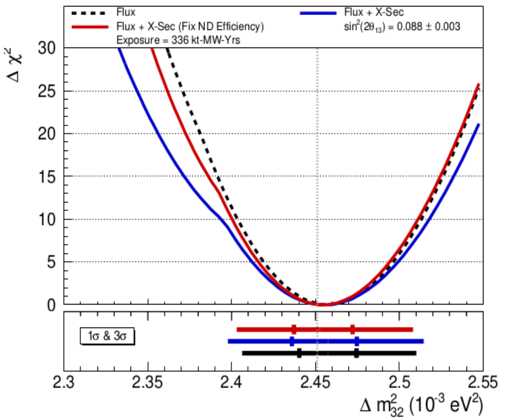
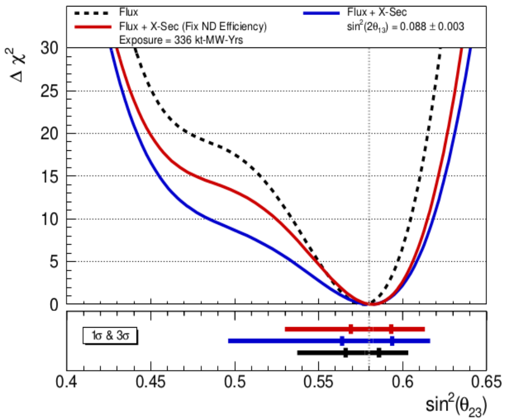




<u>Work in progress:</u> geometric efficiency correction → data-driven ND Efficiency correction

– will probably still have some MC dependency → **contours would be a bit wider** (depending on the MC amount)

- **FD – WSB mimics a data-driven approach**

  – knows about the wrong interaction model and is not prone to systematics

  – we already have a FD-WSB prediction on a data driven approach

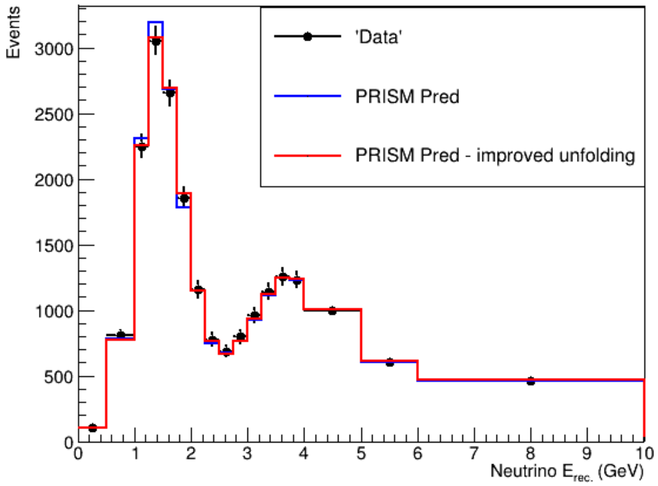
<u>Work in progress:</u> repeat analysis using the FD-WSB prediction

– we DO know the FD-WSB prediction will still have a MC component: flux correction→ **contours would be a bit wider**

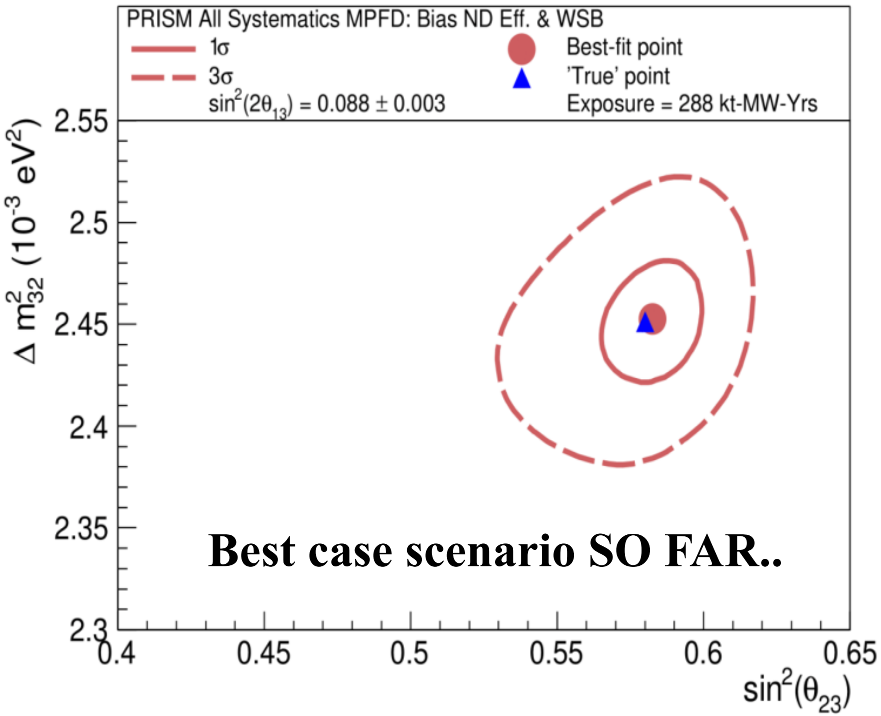
PRISM Contours

On-going analysis → **could result in narrower contours**

- Near to Far extrapolation (NDErec → Etrue → FDErec)
  - improved regularization + different binning
    - → better match between data and PRISM prediction
    - → reduces bias in one of the flux parameters

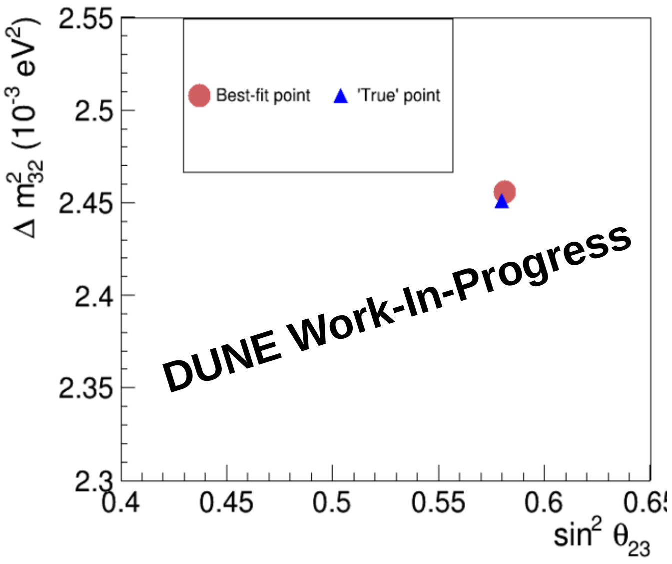


  - NDErec→ FDErec translation from NN
    - → first results already available
    - → soon to be implemented within PRISM framework



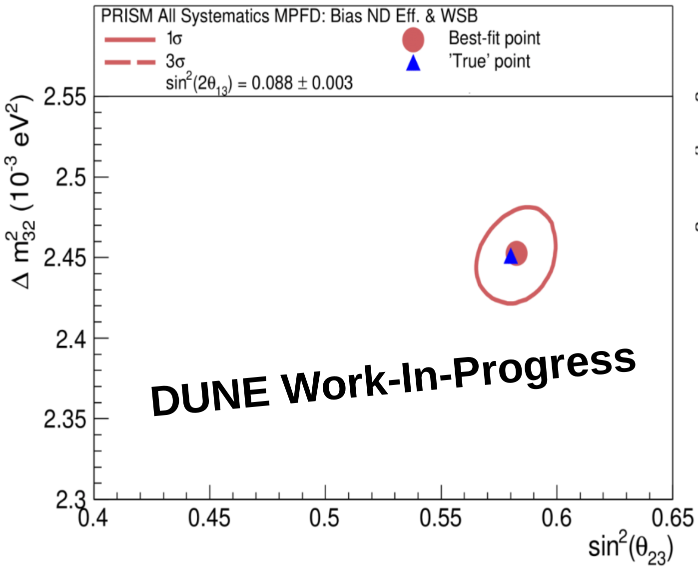
PRISM Contours – Options / Suggestions

Safest option – no contours



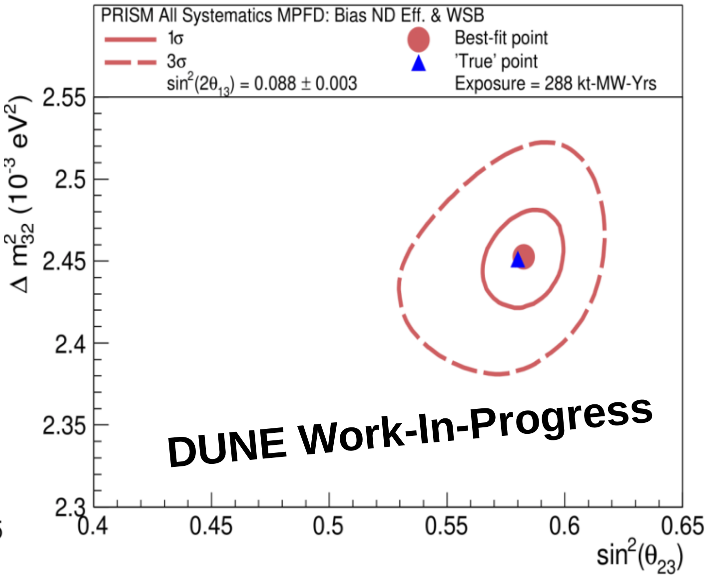
+ shows the bias removal
+ will not have the problem of presenting several version of the contours
– not much physics meaning

1 σ contours + no exposure



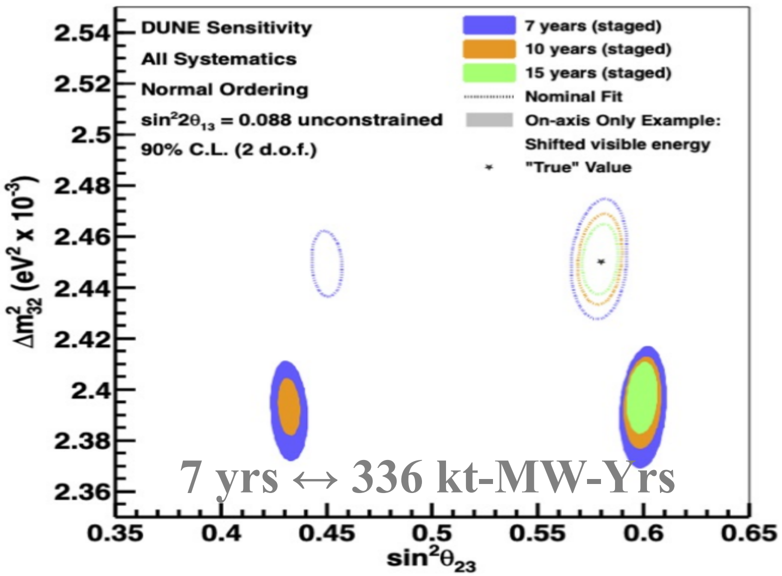
+ shows the best fit point is well within the 1σ contour
+ no exposure → not giving sensitivity
– presenting a contour which could be changed in the future

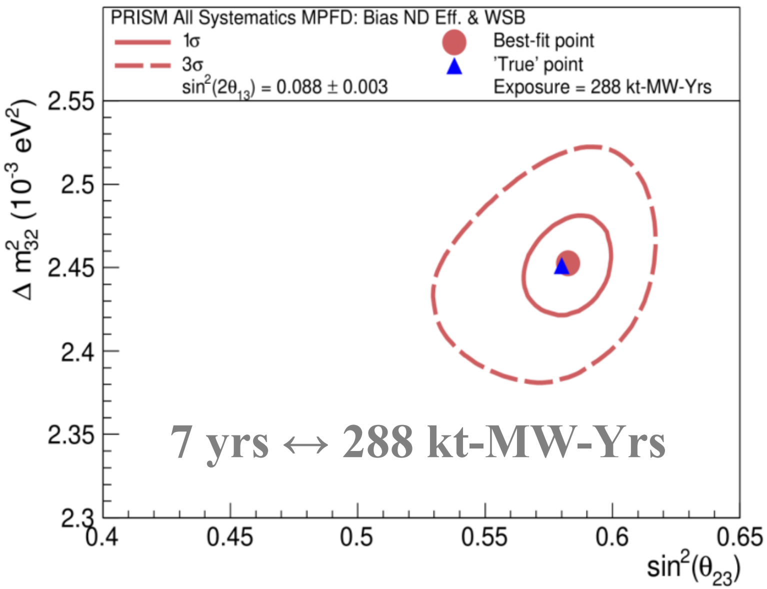
Best case scenario SO FAR..



+ shows the most complete results we got so far
– direct comparison with the on-axis cases → much lower sensitivity
– still trying to understand PRISM sensitivity ..

PRISM Contours vs On-axis Contours





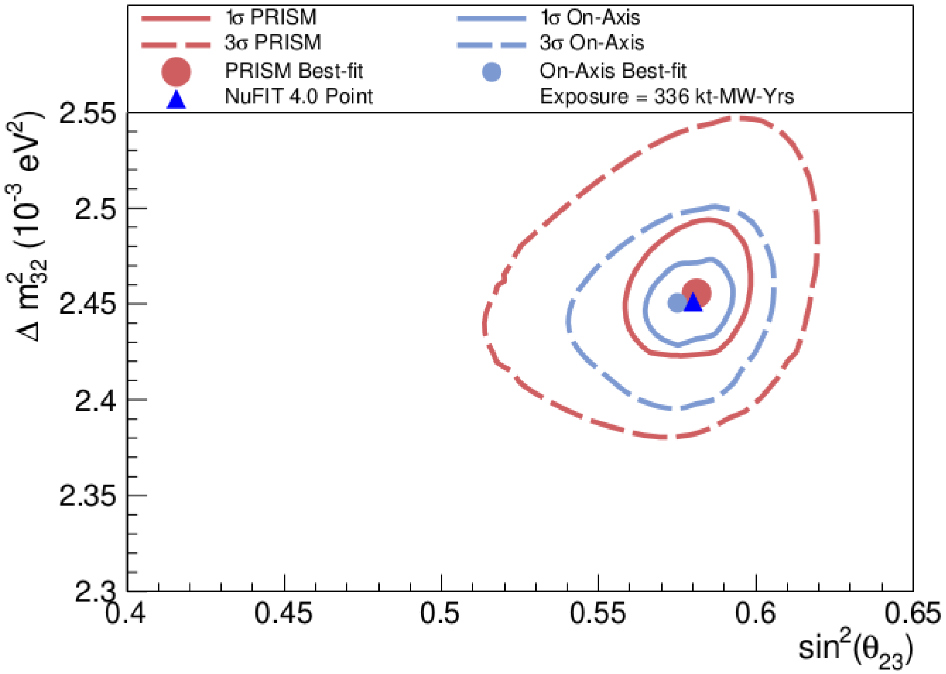
- big difference between on-axis TDR contours (7 yrs) and the presented PRISM sensitivity
  – the presented PRISM sensitivity is for a lower exposure (288 kt-MW-Yrs), which corresponds to the exposure obtained from the current staging plan (3^{rd} FD installed after 3 yrs instead of 1 yr as in TDR)

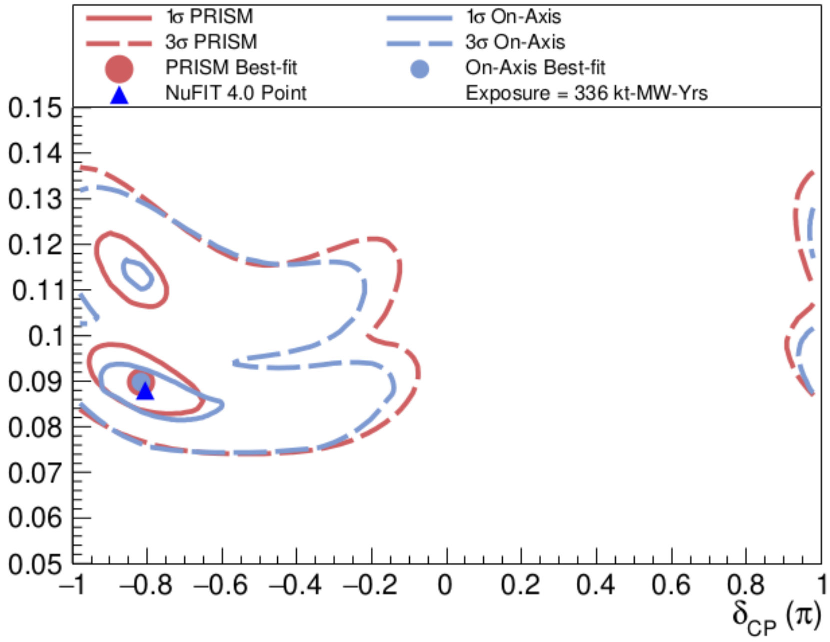
- still PRISM sensitivity is lower (we did expect that..) than the on-axis only but maybe not as drastically as it seems when comparing these 2 plots

→ **not listing the exposure in the poster should be the way to go no matter what we decide plots wise**

PRISM Contours vs On-axis Contours

- All systematics (flux + xsec + detector) applied





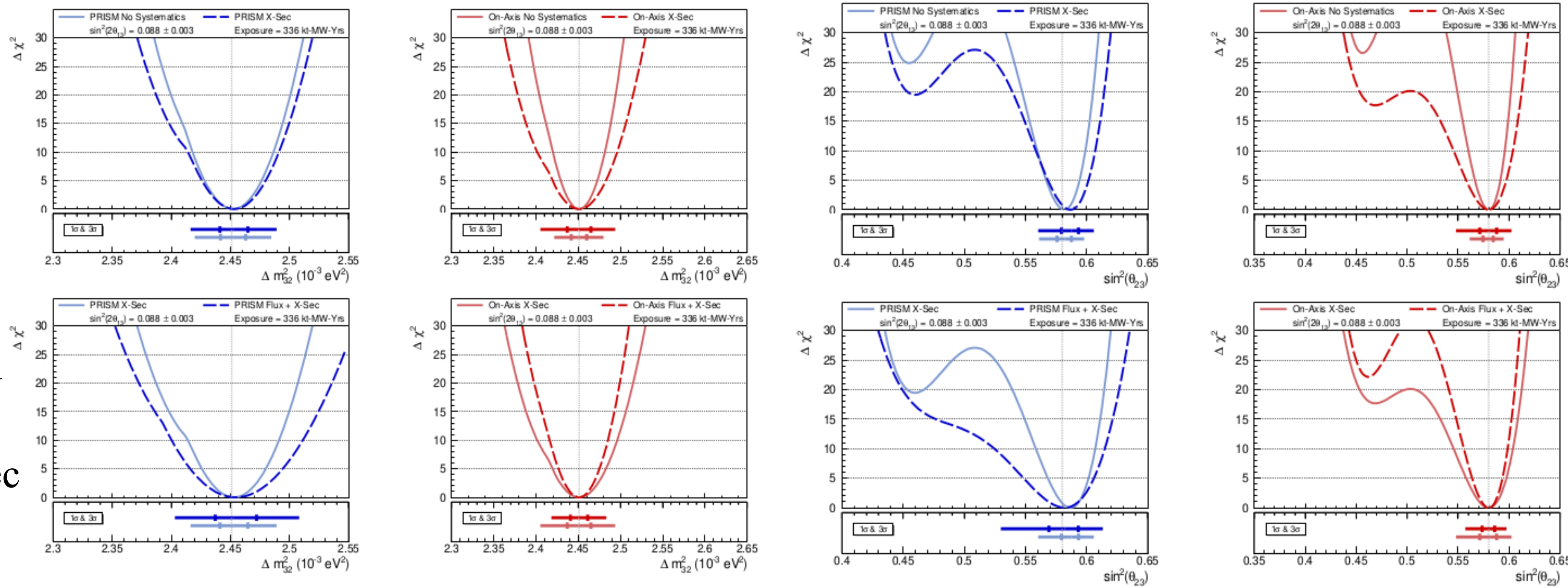
– PRISM Plots obtained with fixed exposure

– PRISM sensitivity lower for $\Delta m_{32}{}^2 - \sin^2\theta_{23}$

PRISM Contours vs On-axis Contours

nominal
vs
xsec only

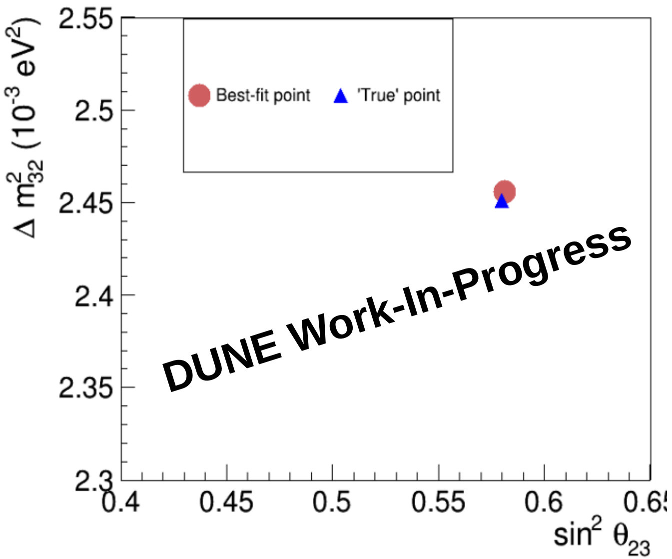
xsec only
vs
flux + xsec



- **xsec systematics** alone have a **smaller impact on** the **PRISM** than on the on-axis only sensitivity
- when both xsec and flux (xsec+flux) systematics are applied, the on-axis only sensitivity improves → PRISM must accept the impact the flux systs which don't cancel between ND/FD will have on the analysis..

PRISM Contours – what do we decide?

Safest option – no contours



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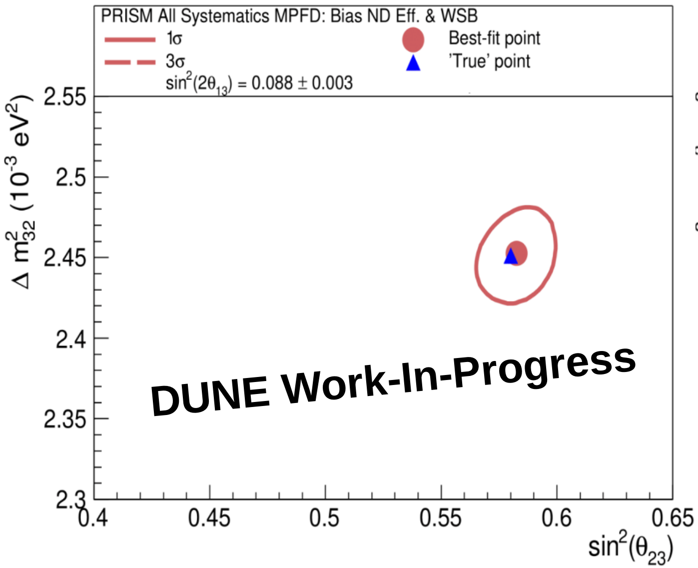

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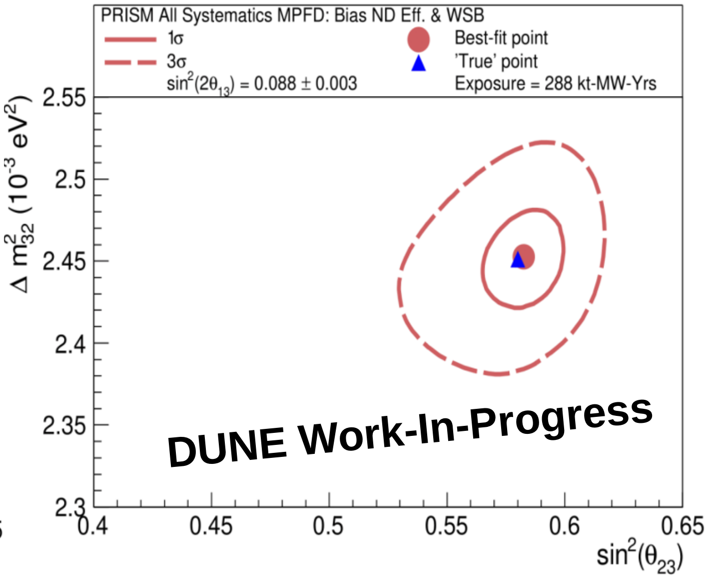
Best case scenario SO FAR..



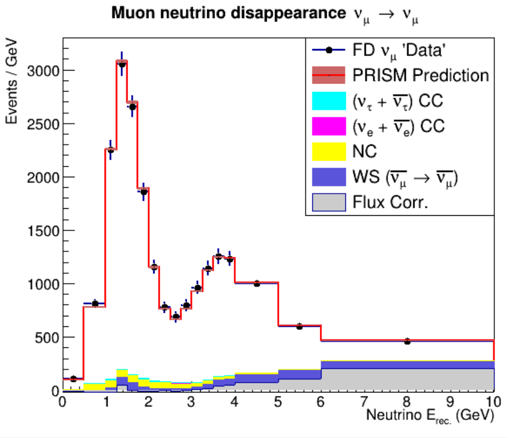
+ shows the most complete results we got so far
– direct comparison with the on-axis cases → much lower sensitivity
– still trying to understand PRISM sensitivity ..

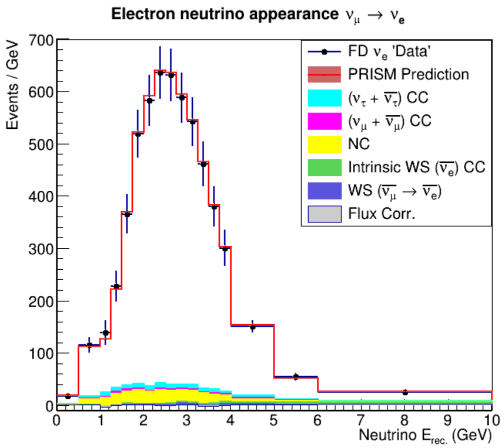
PRISM Plots to be approved

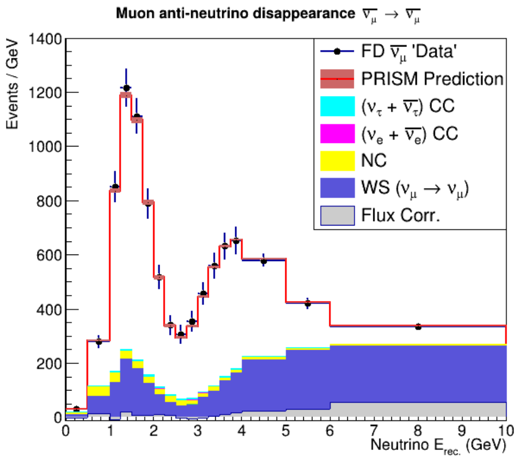
1. Best obtained PRISM prediction (PRISM prediction vs FD oscillated data)

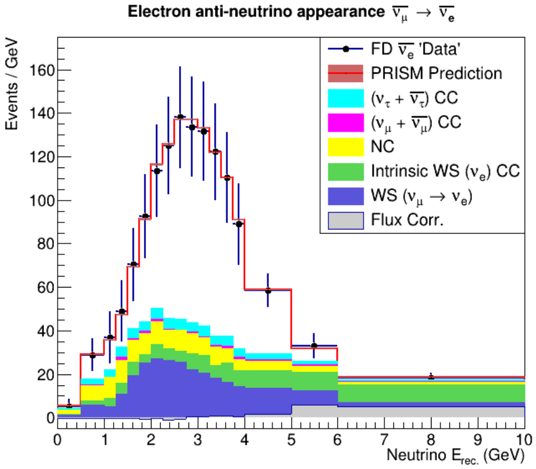
– this is the current state of the PRISM prediction match to the FD oscillated data for the nominal (no systs) scenario → nice to show **our prediction matches the data** quite good

– some changes are expected to improve the analysis (as discussed on slide 6) but I don't think the corresponding improvements would impact/modify this plot in any significant way





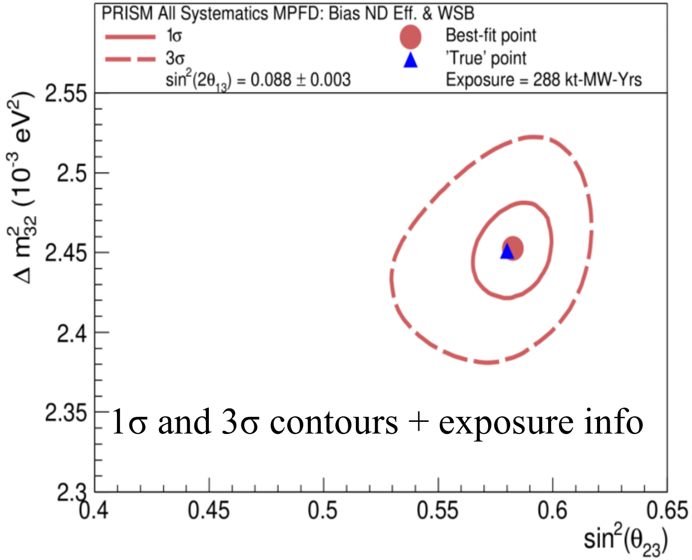




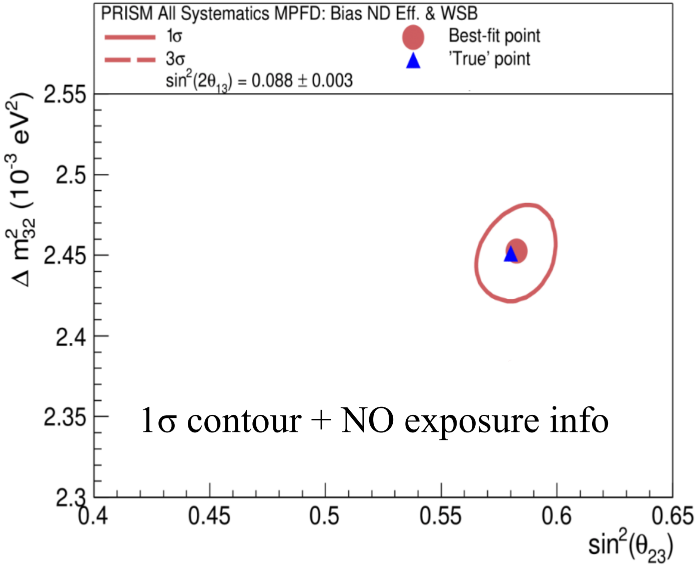
PRISM Plots to be approved

2. PRISM Contours for the fake-data study

– plots obtained with ND efficiency fixed (knows about the fake-data and is not shifted when systs are applied) + WSB correction fixed
– in a real scenario these 2 components would have some MC contribution even if/when data-driven (see slide 5 for more discussions)
– it is however the main results for the PRISM analysis – even if not in a final form: **no bias obtained when using PRISM despite wrong interaction model**



1σ and 3σ contours + exposure info



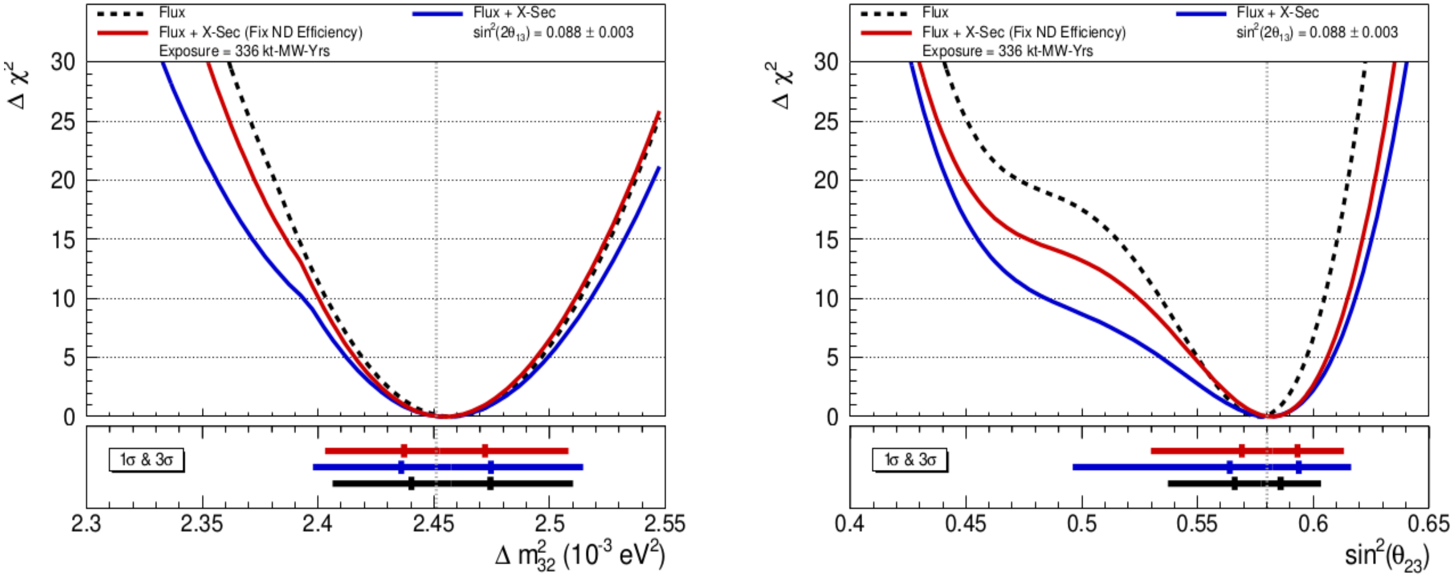
1σ contour + NO exposure info

– in case anything else is decided this plot would be updated correspondingly

PRISM Plots to be approved

2.1 PRISM sensitivity when xsec systs are applied to the analysis: standard vs fixed ND Efficieny

– if we approve any of the PRISM plots obtained with a fixed ND Efficiency it would be nice to have such plots in the backup in order to motivate the choice



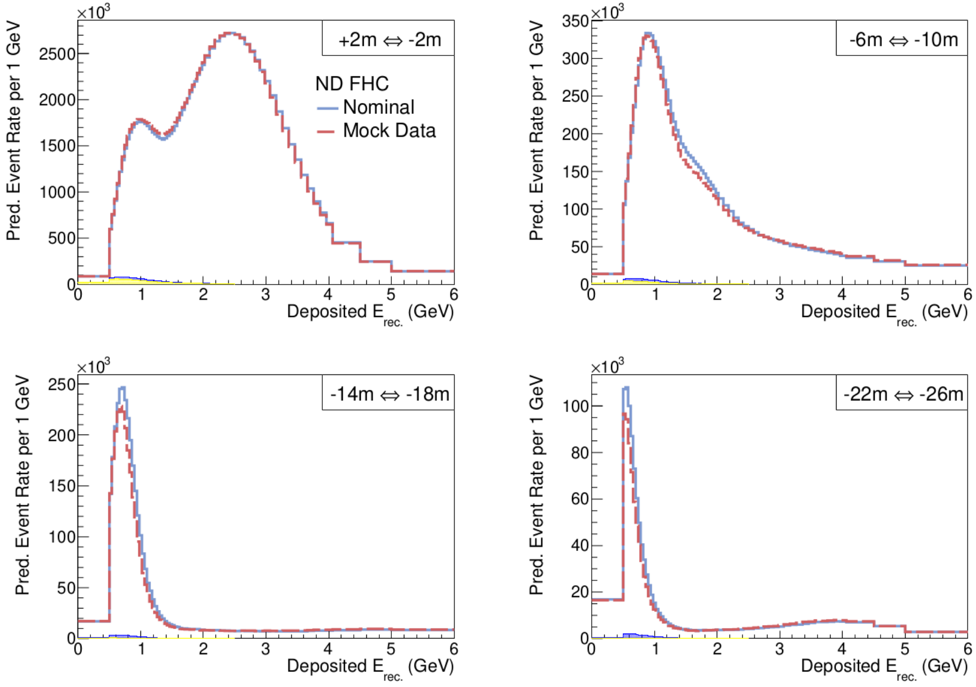
PRISM Plots to be approved

2.2 Neutrino Fluxes on-axis and off-axis when dealing with a fake-data set

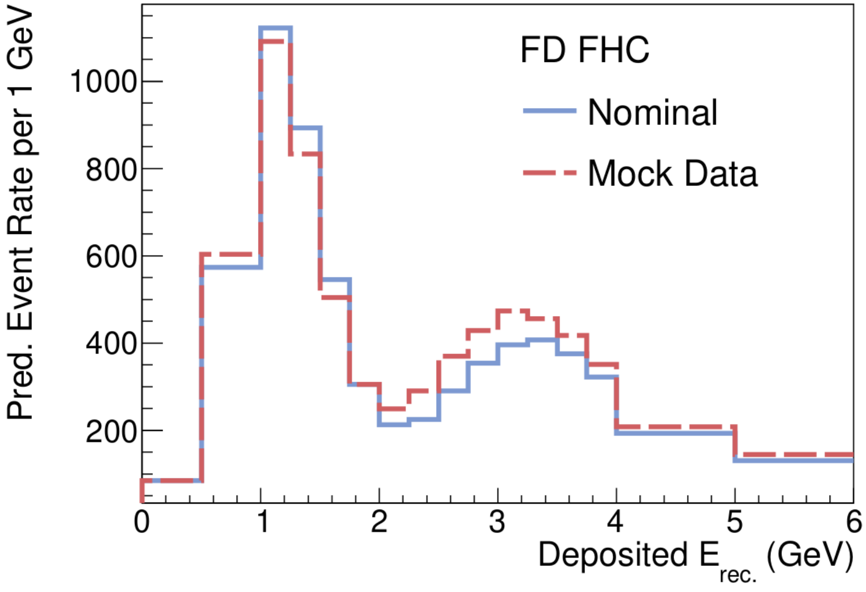
– exemplary plots showing how off-axis data can help spot the miss-match between the modified model and observed data

– plots based on the TDR fake-data study

ND Events



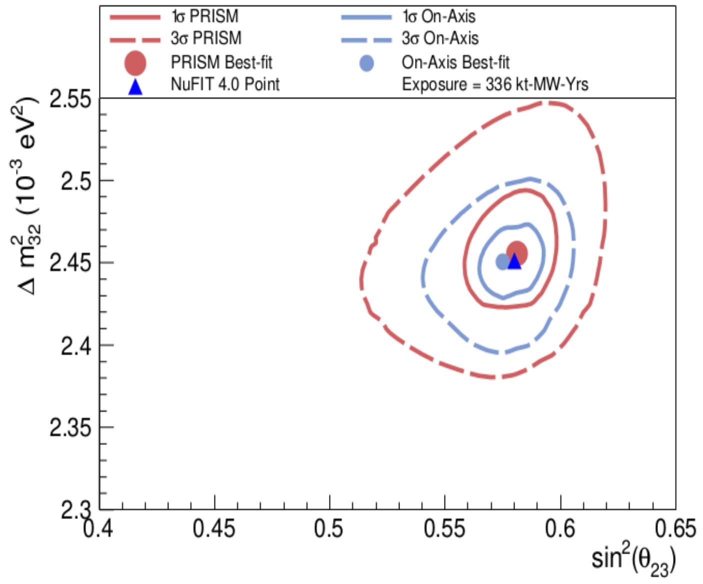
FD Events

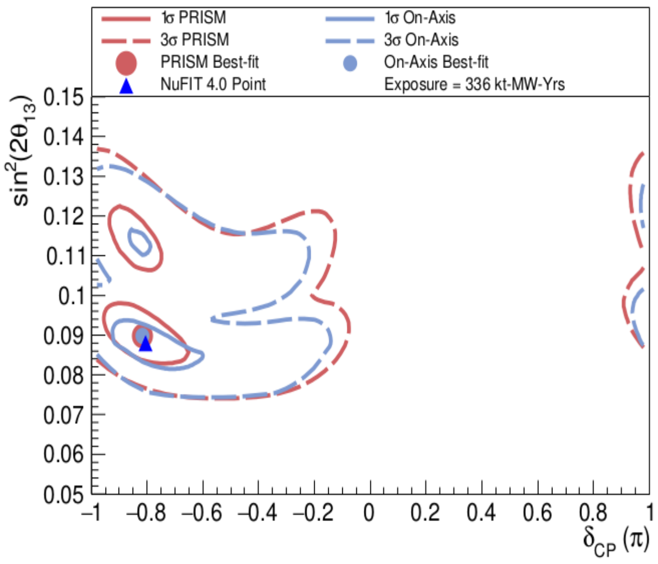


PRISM Plots to be approved

3. PRISM Contours vs On-Axis only contours with all systematics included

- – ND efficiency fixed + "older" stage of the analysis (see slide 6 – left plot – for difference in PRISM prediction with new unfolding)
- – this plot is not the final contour of PRISM analysis but it could be a nice first version for comparing the two sensitivities…
- – all systematics from TDR



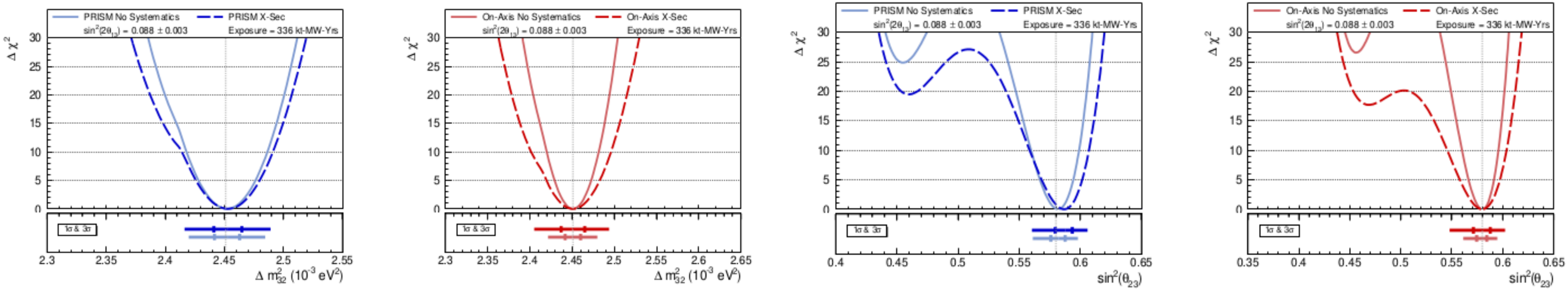


PRISM Plots to be approved

3.1. PRISM Contours vs On-Axis only: xsec vs xsec + flux systematics

– would help understand why PRISM sensitivity is lower (slide 10)

nominal
vs
xsec only



xsec only
vs
flux + xsec