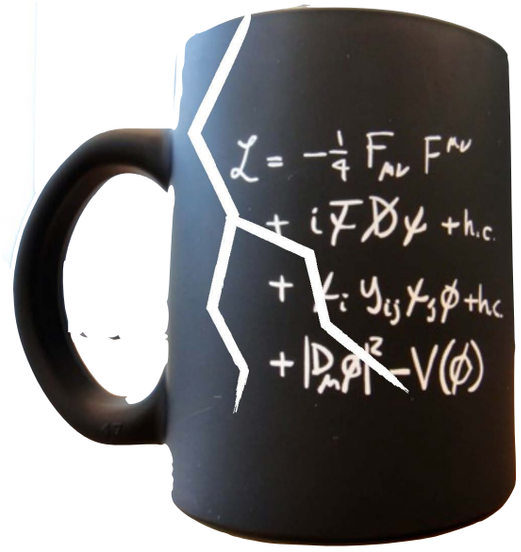


DUNE BSM Physics Goals for DUNE Physics Week

Alex Sousa, Jaehoon Yu

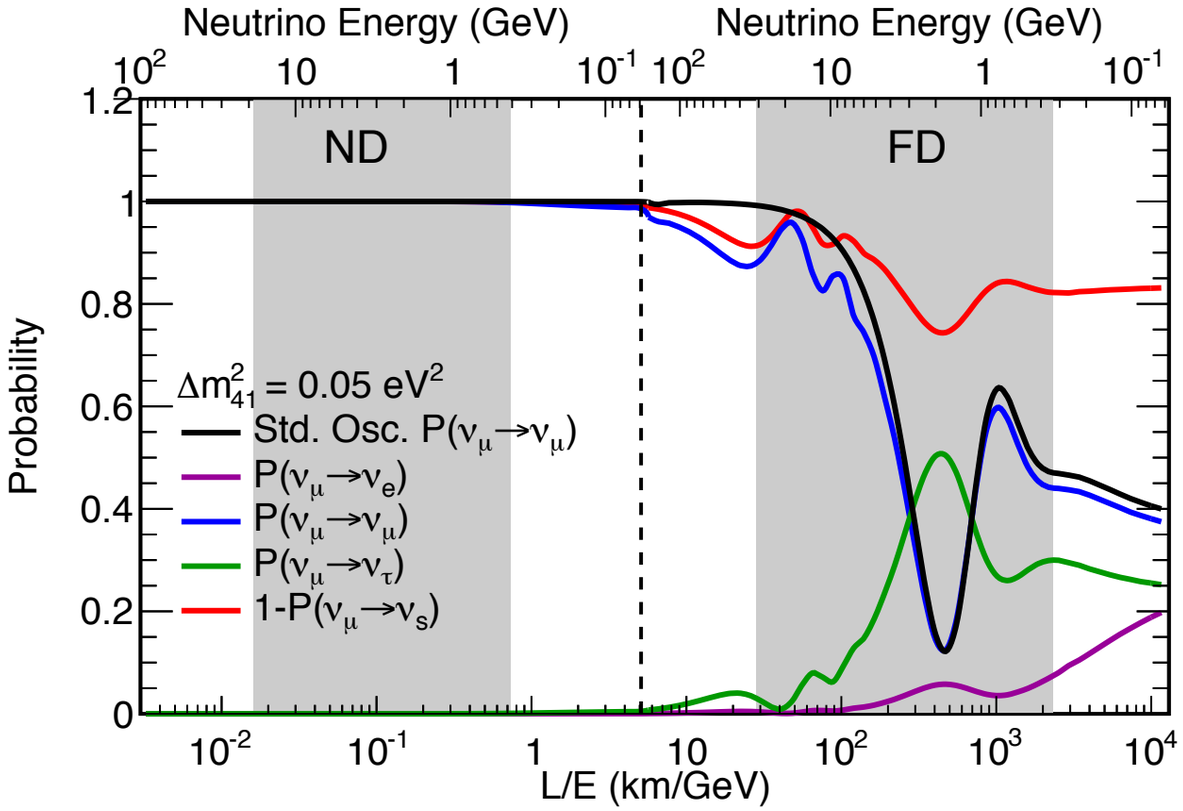
DUNE Physics Week @ Fermilab
November 15, 2017

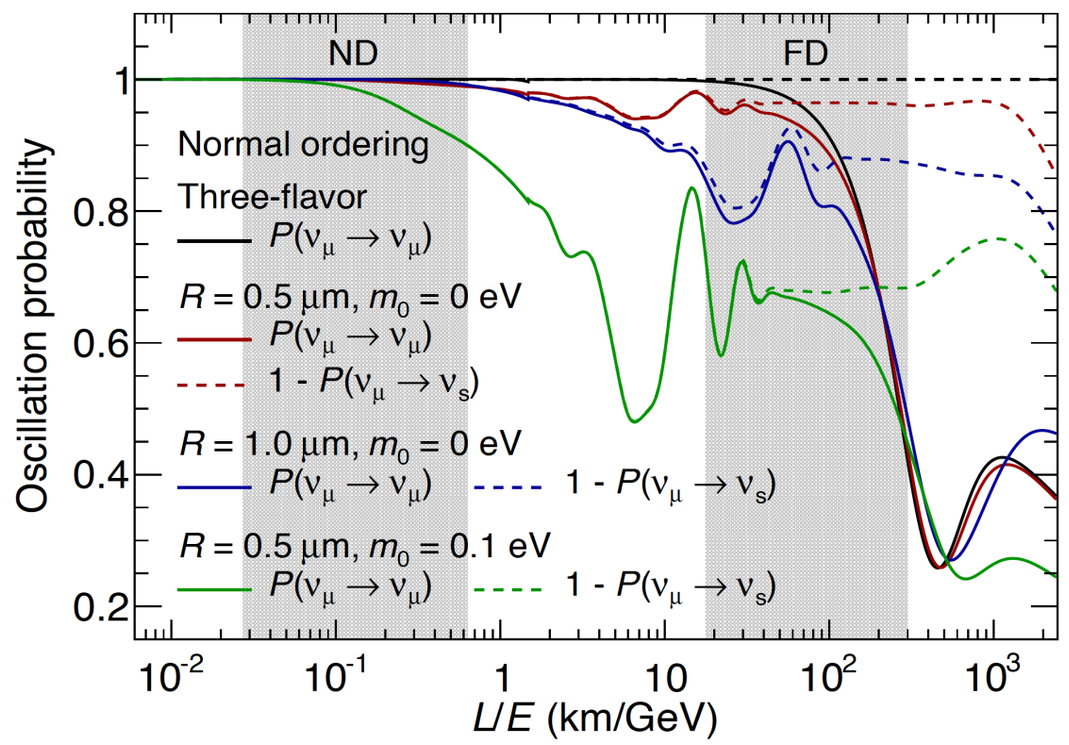
Who is Working on What?

- Sterile Neutrinos - **Enrique Fernandez-Martinez, Mattias Blennow, AS**
- Large Extra-Dimensions - **Animesh Chatterjee (Simon DeRijck, AS)**
- Neutrino Tridents - **Stefania Gori, Wolfgang Altmannshofer, Justo Martín-Albo, AS, (Chris Ontko - graduated)**

Preliminary List of Plots/Tables

- Partly guided by LBL Standard Oscillation Physics section in TDR repository, applicable to both Sterile Neutrinos and LED. Not all plots might be part of TDR, but those not shown would still be important to support/backup the ones shown in the TDR
- Table with GLoBES ND and FD detector parameters
- Table with oscillation parameters used for 3-flavor and 3+1-flavor models (and gaussian uncertainties if applicable)
- L/E plots for one or several Δm^2_{41} regimes (or R, m_0 for LED)



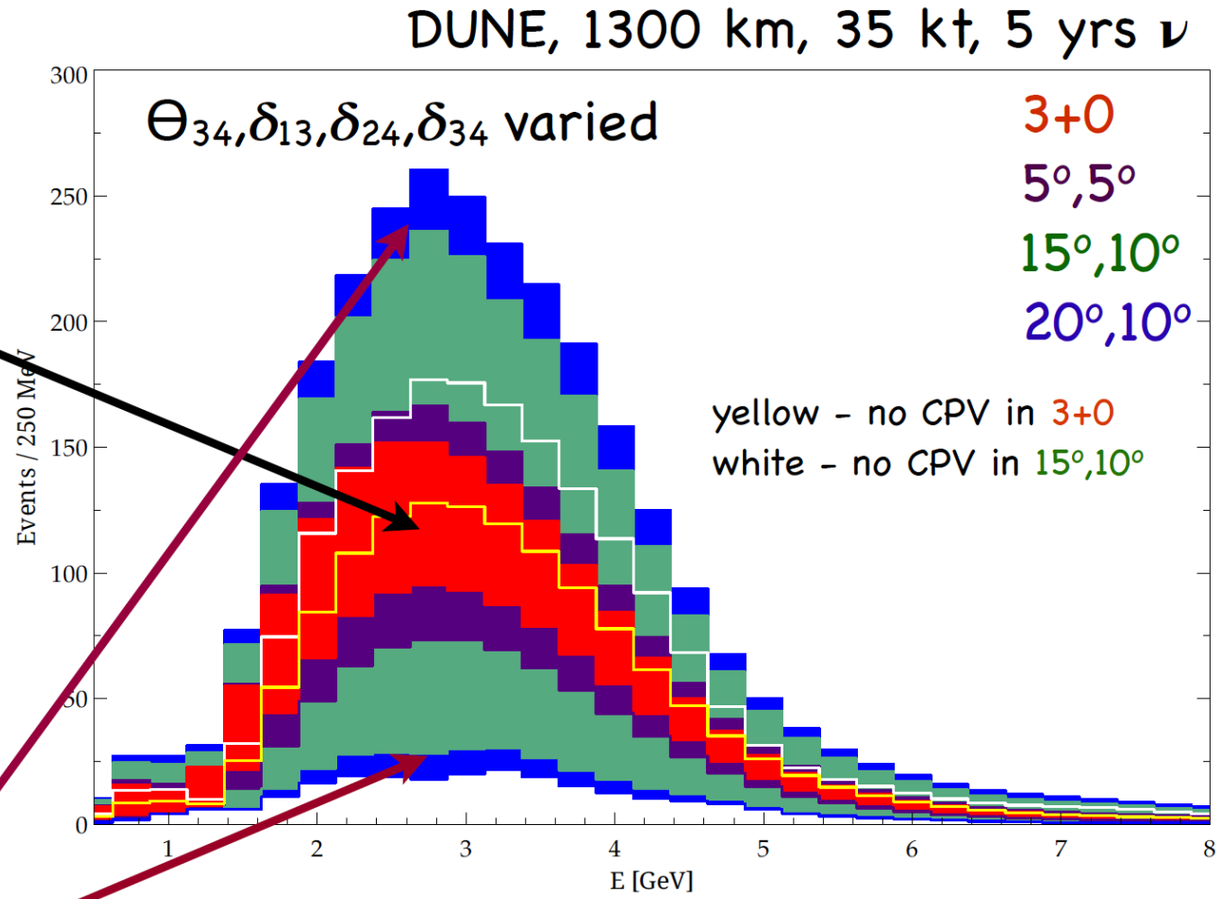


Preliminary List of Plots/Tables

- ND and FD Energy Spectra comparing 3-flavor with 4-flavor cases for ν_μ-CC and NC channels (and ν_e-CC?) and equivalent LED plot

- Table with selection efficiencies used for each sample (if applicable) or just reference Reco section

The 3+1 band can potentially encompass the 3+0 band, leading to substantial degeneracy.



For large active-sterile mixings, an excess or shortage of events, esp. at osc. max. will be pointers to the existence of new physics.

$\Theta_{12} = 33.48°$, $\Theta_{13} = 8.5°$, $\Theta_{23} = 45°$

$\Delta m^2_{31} = +2.457e\text{-}3\ eV^2$, $\Delta m^2_{21} = 7.5e\text{-}5\ eV^2$

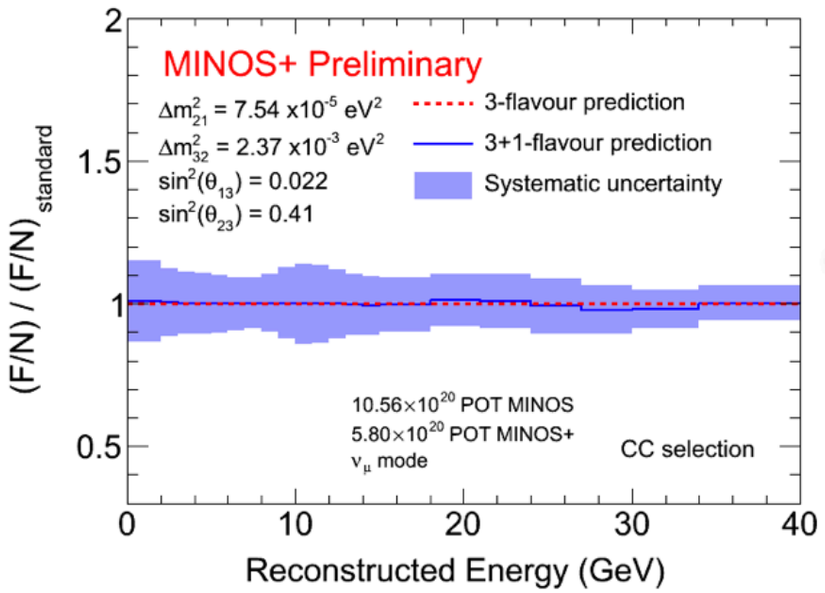
R. Gandhi, B. Kayser, M. Masud, S. Pakrash, arXiv:1508.06275

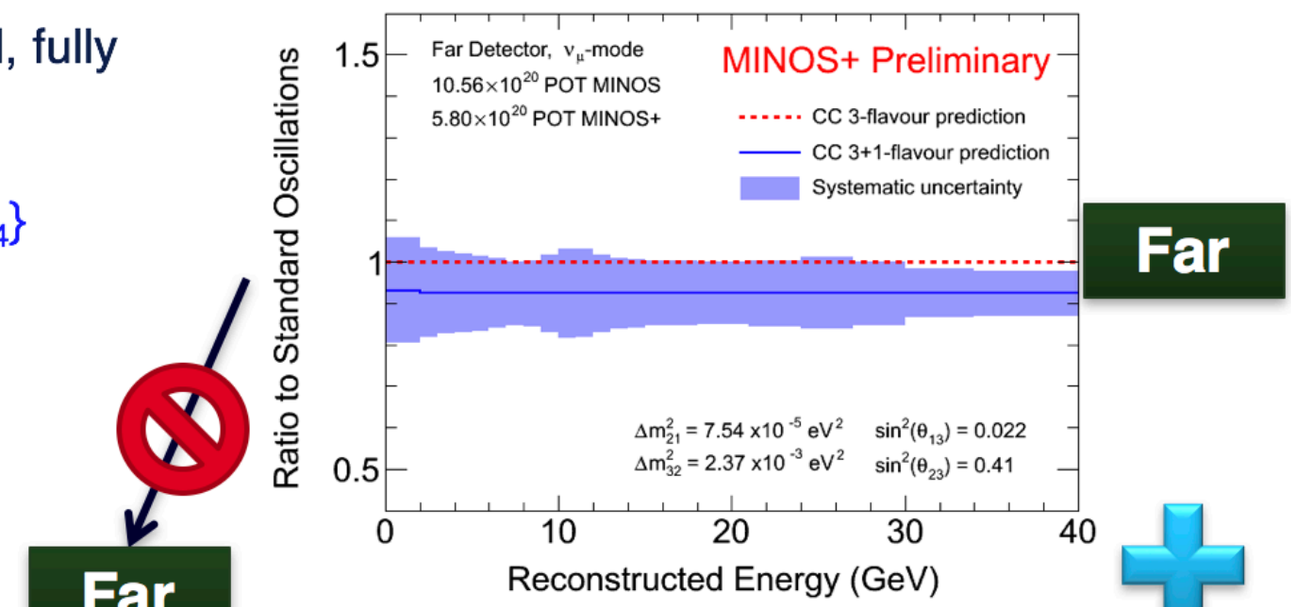
Preliminary List of Plots/Tables

- Table of systematic uncertainties used for ND-only and FD-only, and for F/N ratio

- Show systematic error bands for all three cases (spectra or ratio)

- Here we present results using a simultaneous two-detector fit method, fully utilizing both detectors
  - Fit parameters:
    $\{\Delta m^2_{41}, \Delta m^2_{32}, \theta_{23}, \theta_{24}, \theta_{34}\}$
  - Parameters set to zero:
    $\{\theta_{14}, \delta_{13}, \delta_{14}, \delta_{24}\}$





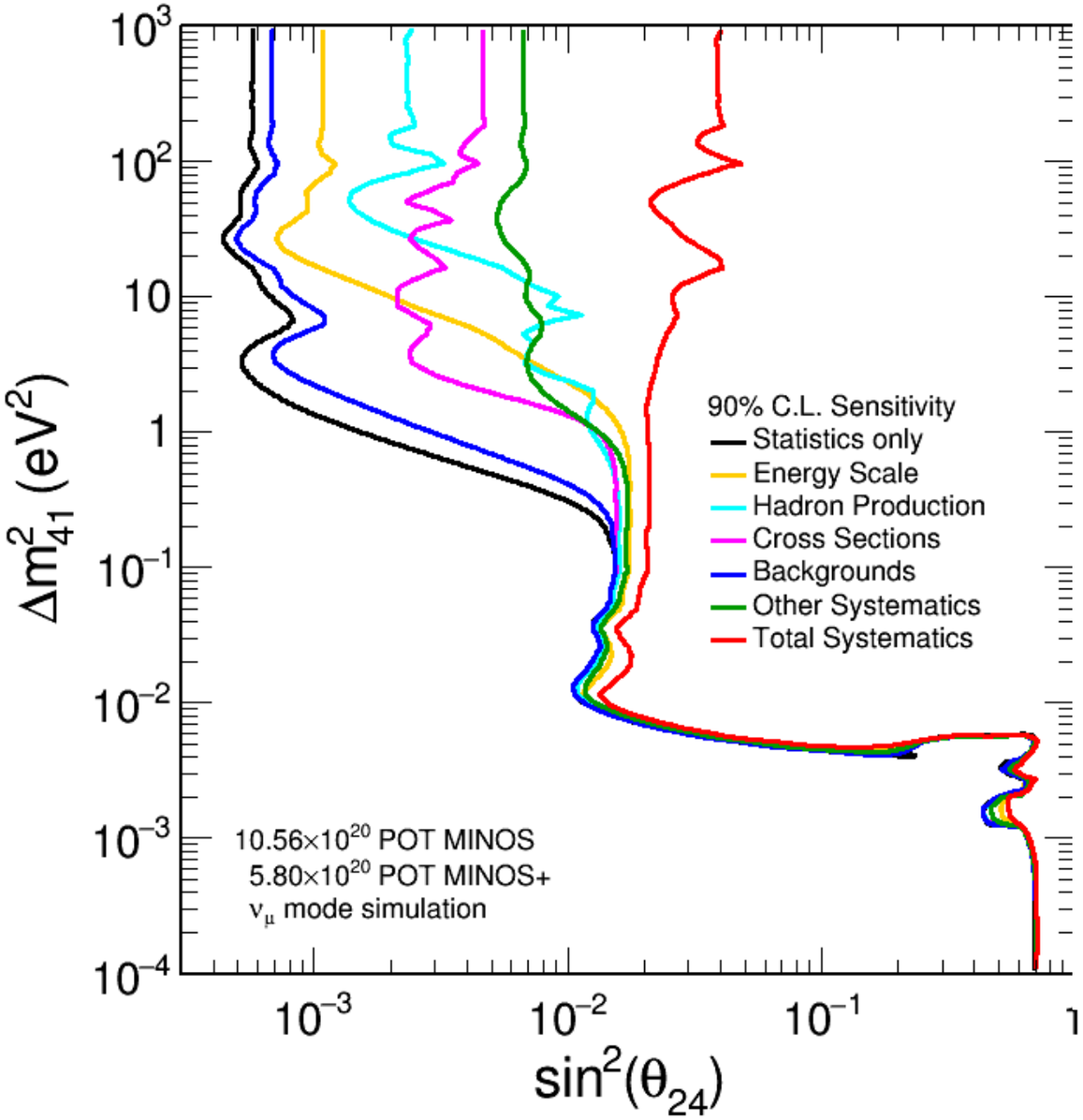
Sample Parameters:
$\theta_{24} = 0.2$;
$\Delta m^2_{41} = 80.0$ eV^2;

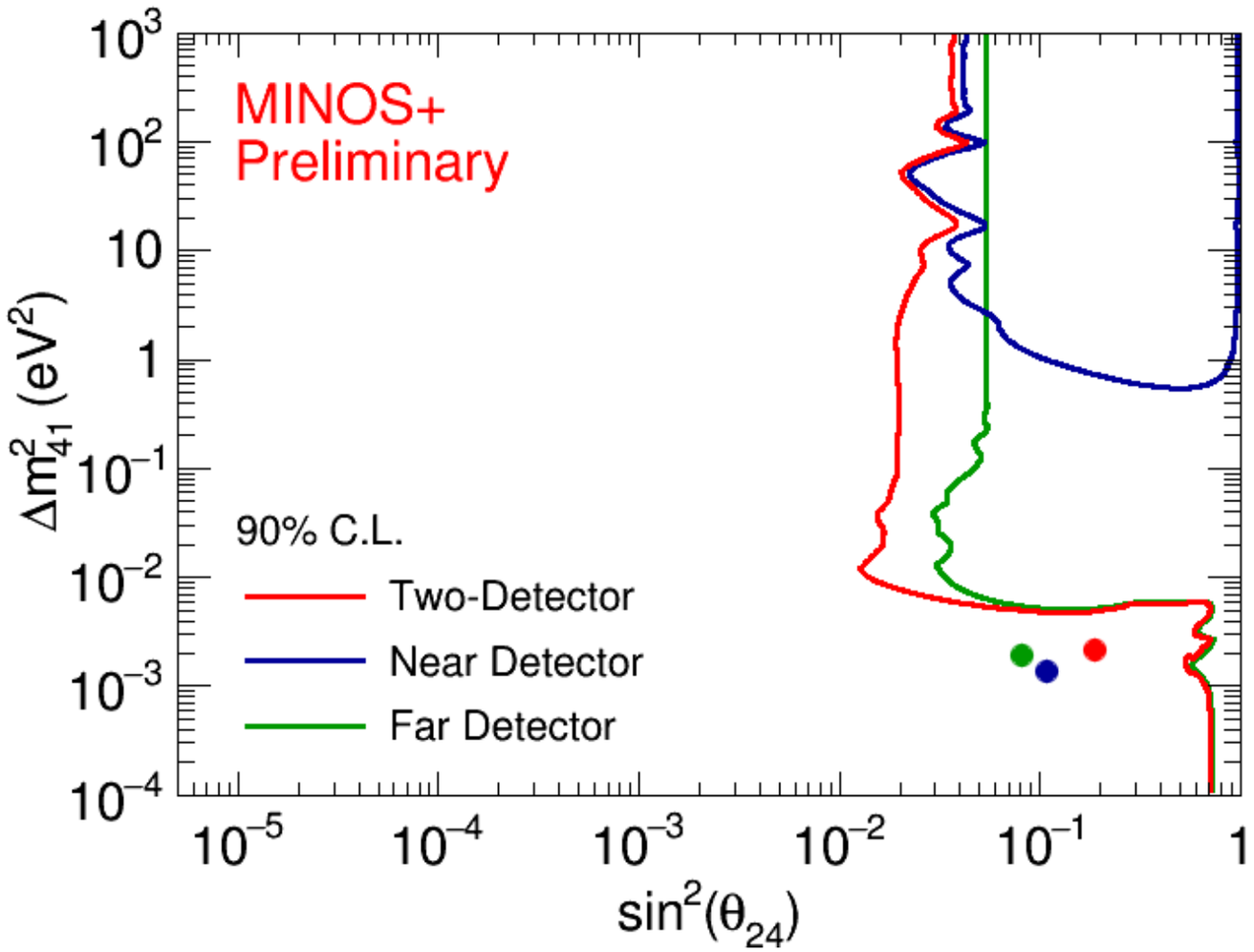
J. Todd, MINOS+ Wine & Cheese (2017)

Preliminary List of Plots/Tables

- Plot showing evolution of sensitivity with different systematics (might show this after main sensitivity plots)

- Would be very nice to also show relative contributions of ND and FD to sensitivity

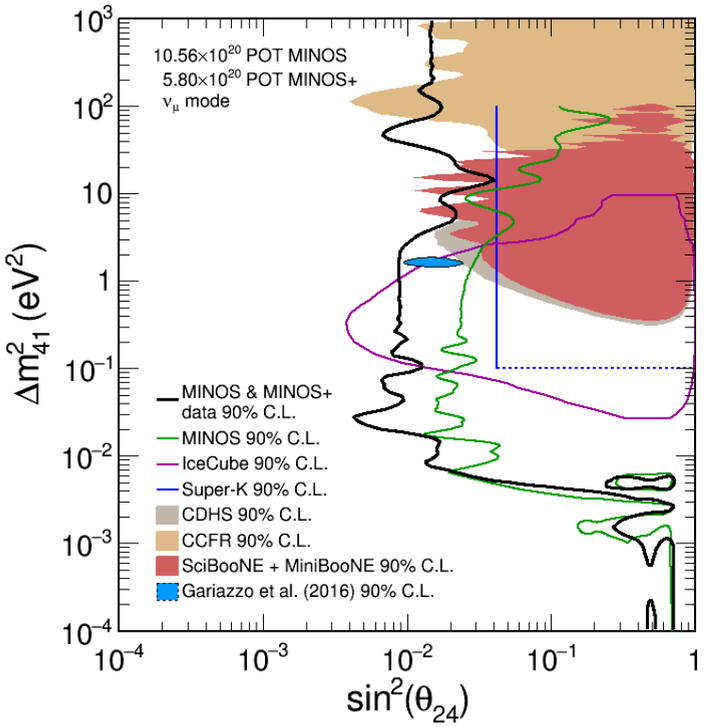


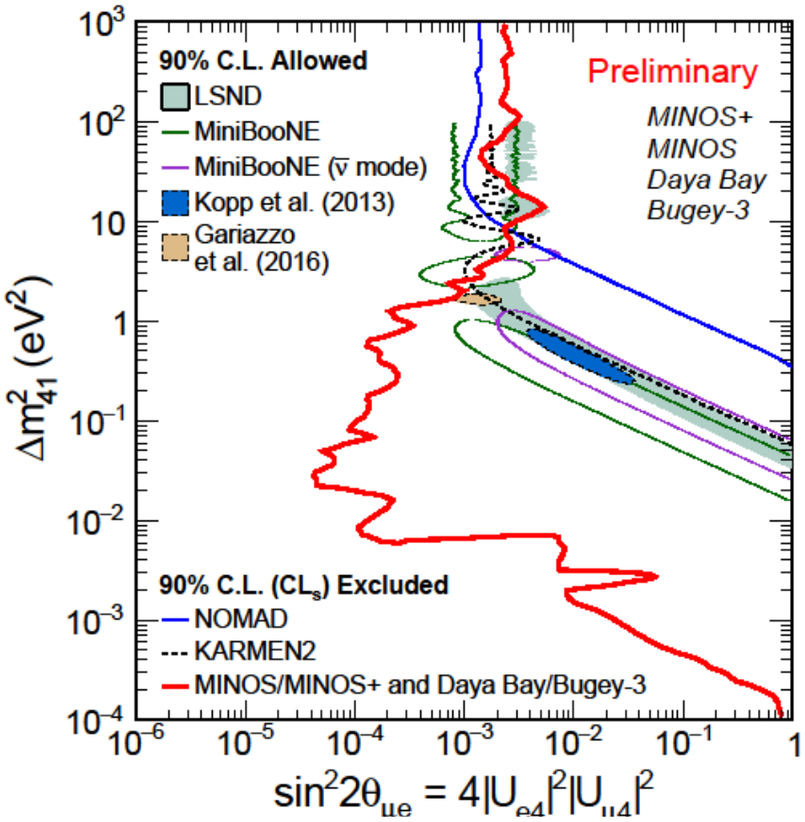


J. Todd, MINOS+ Wine & Cheese (2017)

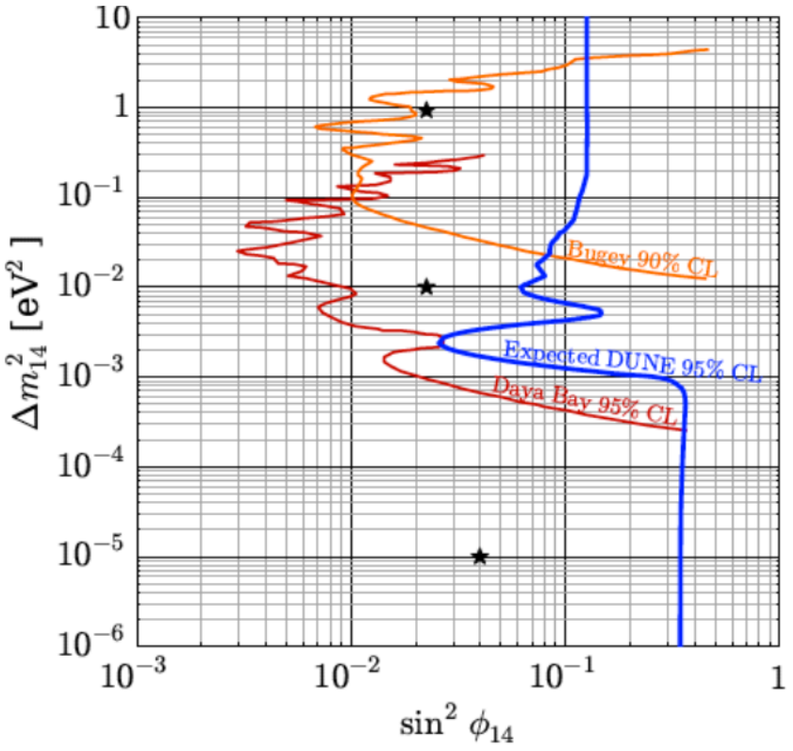
Preliminary List of Plots/Tables

- Sensitivities to different regions of parameter space, table of limits on sterile params.
- Comparison of sensitivities with different beam optimizations, different NDs?

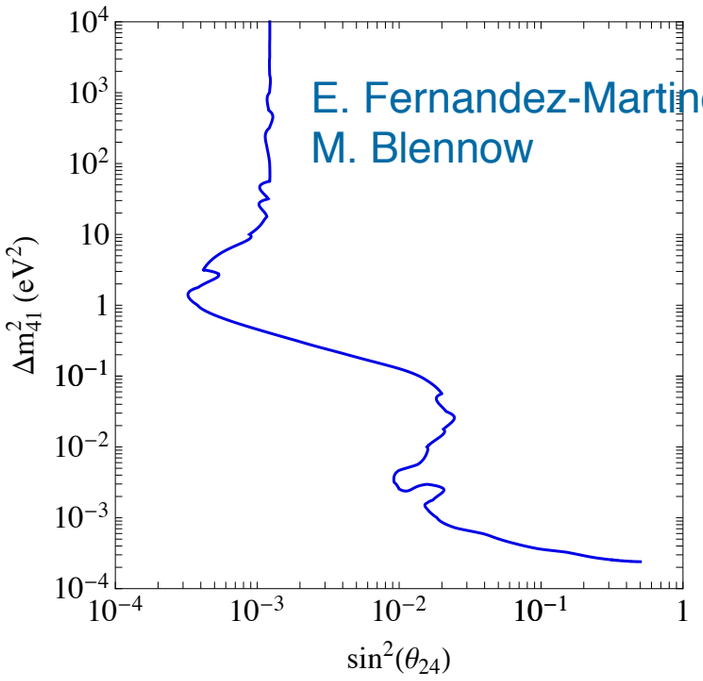




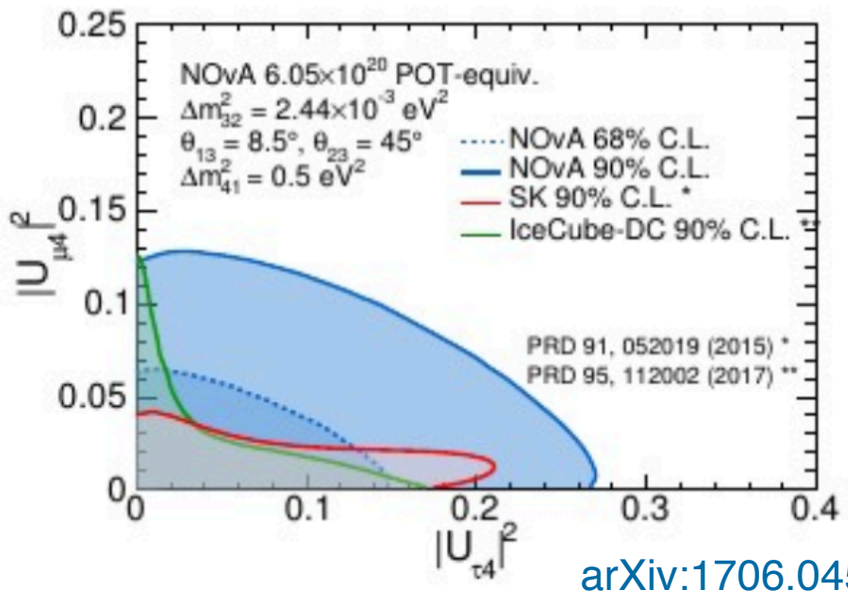
J. Todd, MINOS+ Wine & Cheese (2017)



[AdG and Kelly, arXiv:1511.05562]

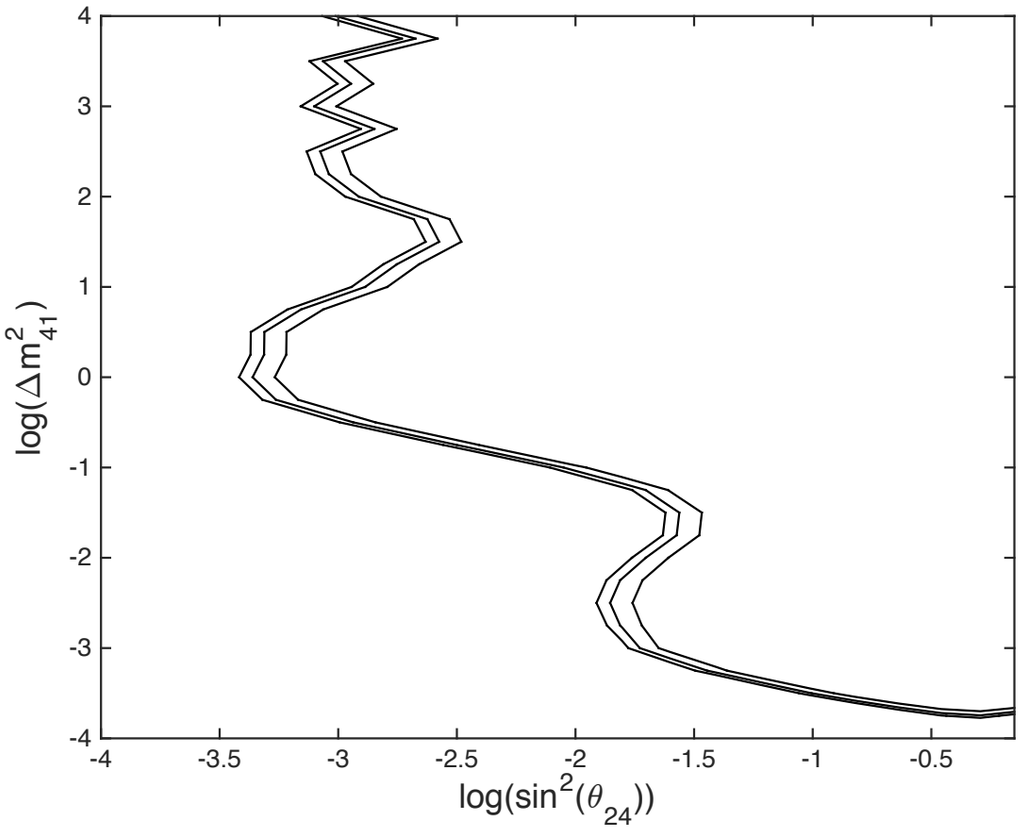


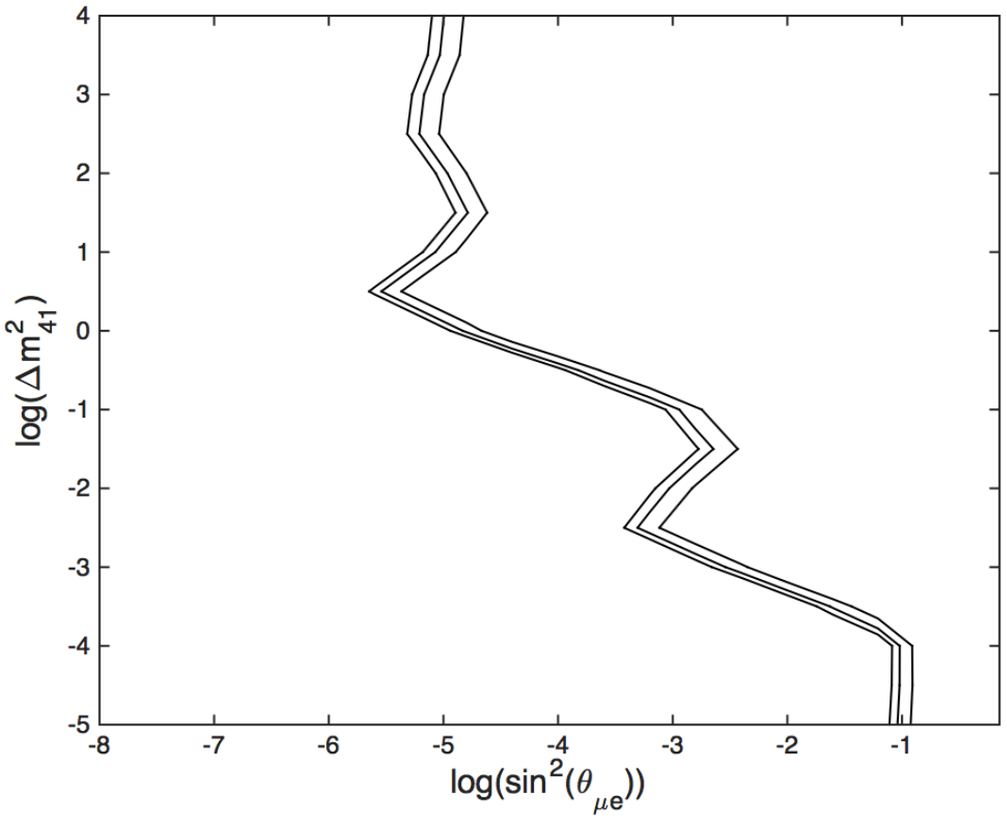
E. Fernandez-Martinez
M. Blennow

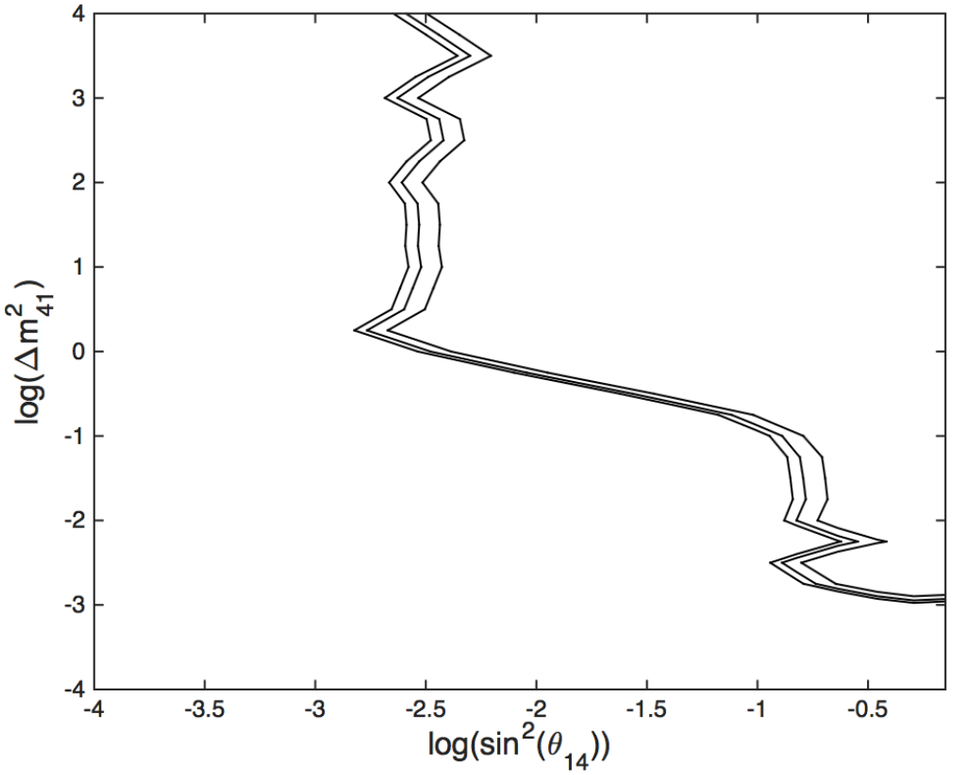


arXiv:1706.04592 (NOvA), accepted in PRD

New Plots!



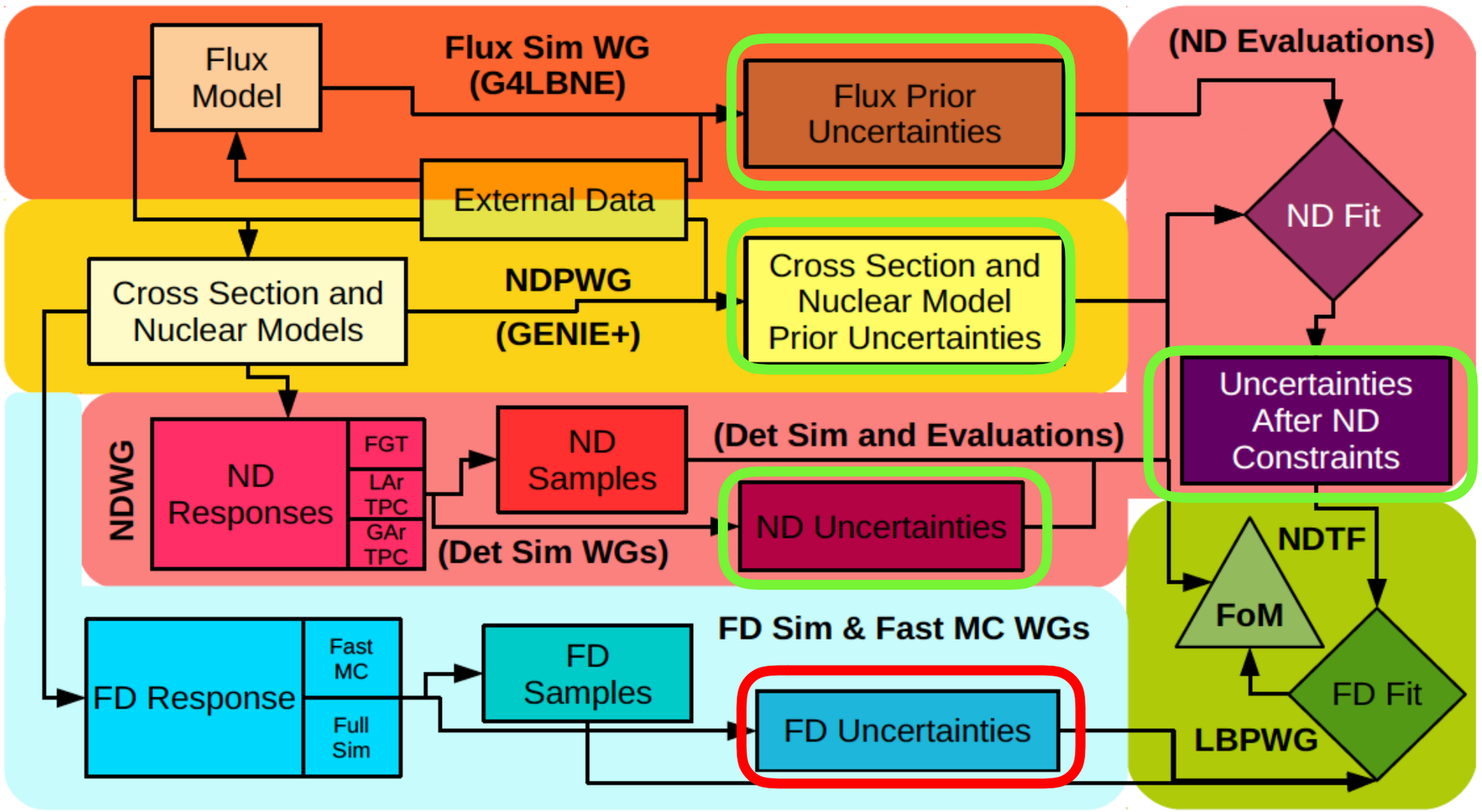




E. Fernandez-Martinez
M. Blennow

Systematics (see Sept. 26 talk)

- What we have:
  - Information on neutrino flux uncertainties
  - Information on cross section uncertainties
  - Information on NDs detector uncertainties
  - A description of uncertainties after ND constraints



Source of Uncertainty	MINOS ν_e	T2K ν_e	DUNE ν_e
Beam Flux after N/F extrapolation	0.3%	3.2%	2%
Interaction Model	2.7%	5.3%	$\sim 2\%$
Energy scale (ν_μ)	3.5%	included above	(2%)
Energy scale (ν_e)	2.7%	2.5% includes all FD effects	2%
Fiducial volume	2.4%	1%	1%
Total	5.7%	6.8%	3.6 %
Used in DUNE Sensitivity Calculations			$5\% \oplus 2\%$

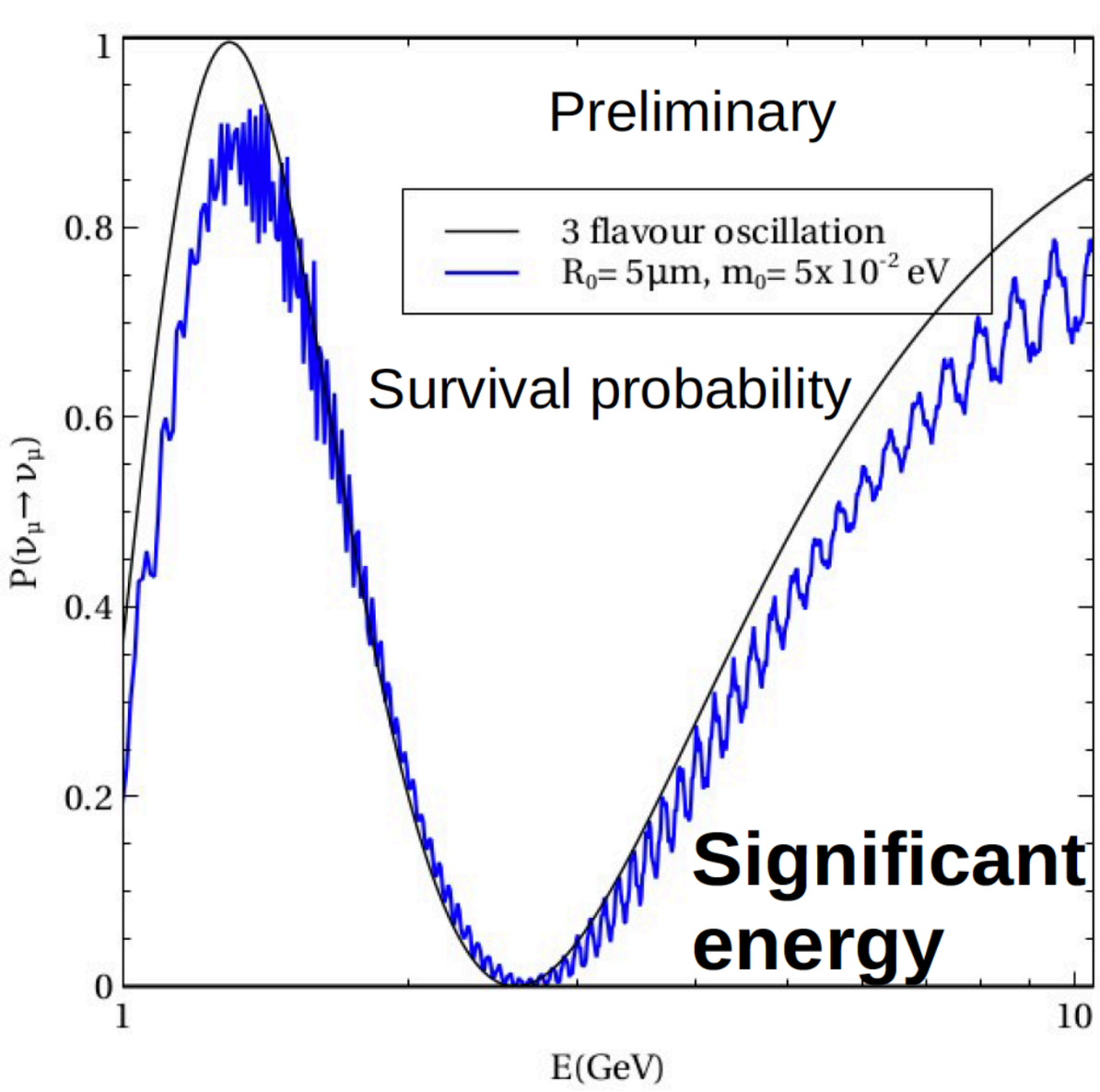
CDR - Table 3.8

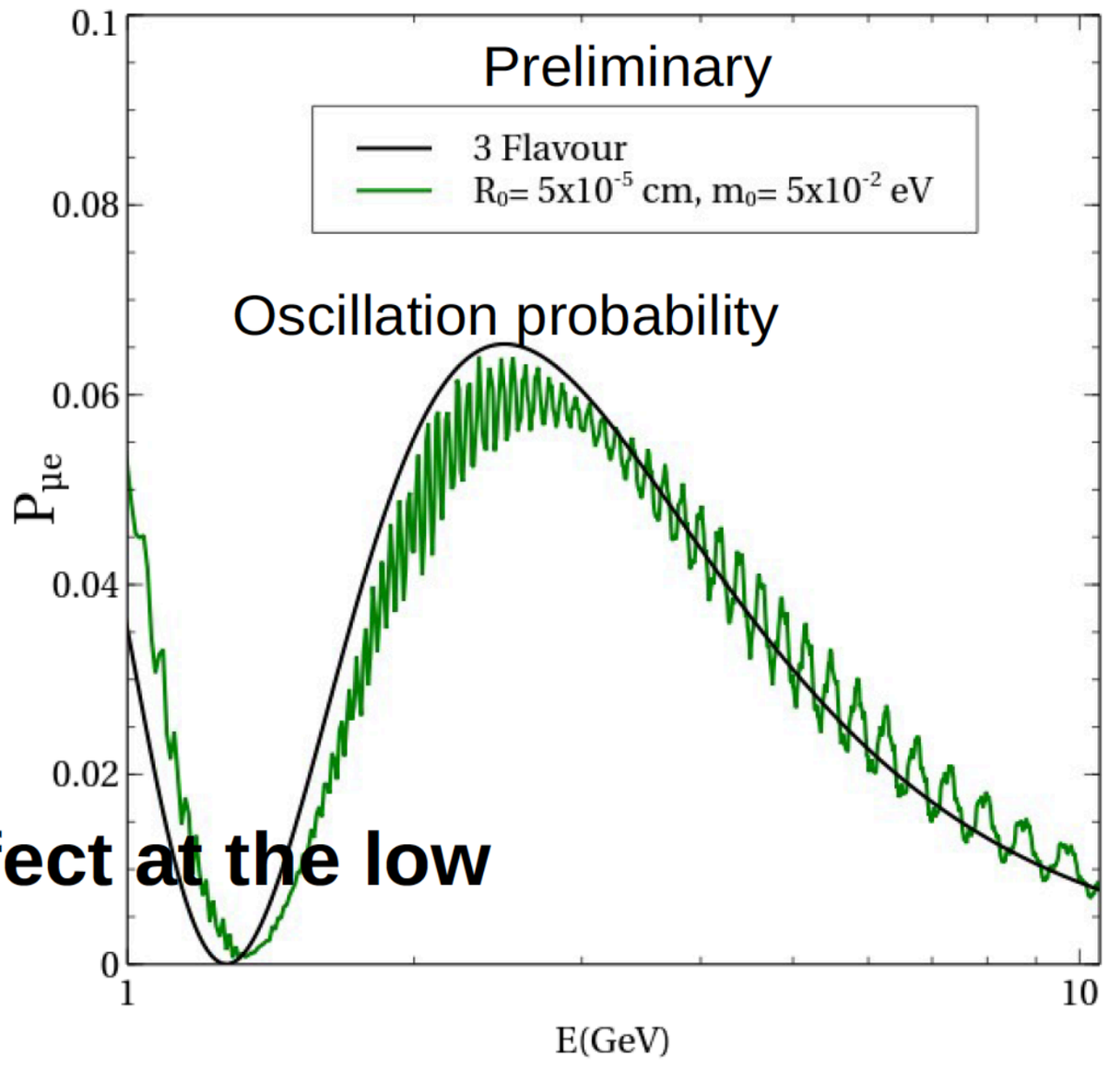
- What we do not have:
  - First 3 bullets above encoded in a GLoBES file
  - Information on FD-only detector uncertainties

Large Extra-Dimensions

A. Chatterjee

Probability plot for DUNE with LED





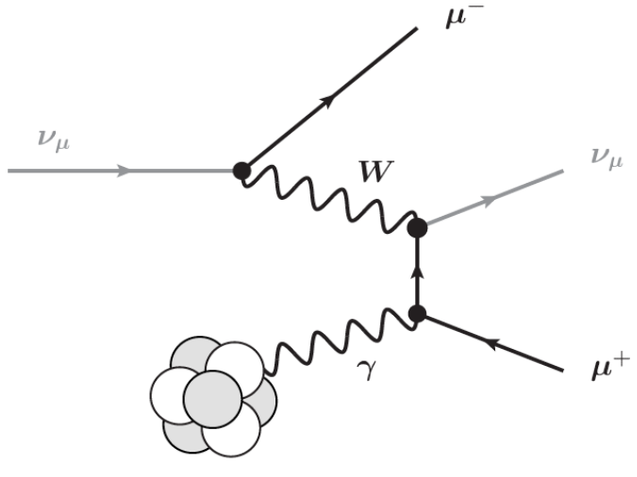
Significant effect at the low energy

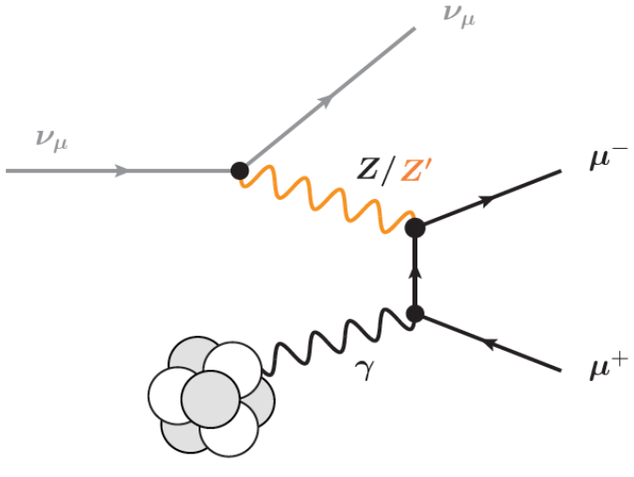
- LED probabilities in place and validated. Same needs as sterile analysis

Neutrino Tridents

W. Altmannshofer,
S. Gori, J. Martín-Albo, AS

- Rare SM process. Has been observed with measured cross section in good agreement with SM





first signal claimed at CHARM II:
neutrinos with average energy
$\sim$ 20 GeV on glass
Phys.Lett. B245, 271 (1990)

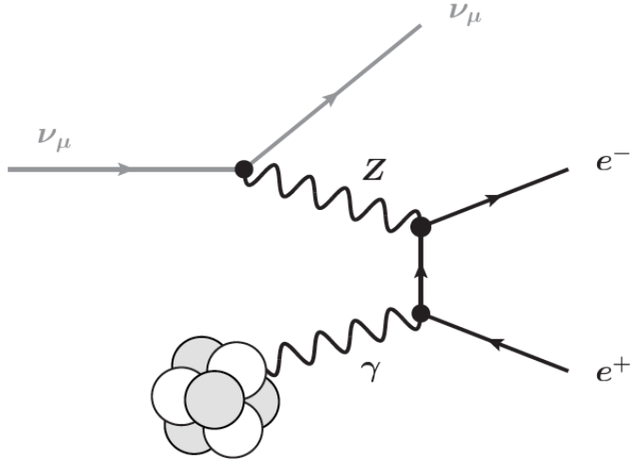
$\sigma_{\text{CHARM II}}/\sigma_{\text{SM}} = 1.58 \pm 0.57$

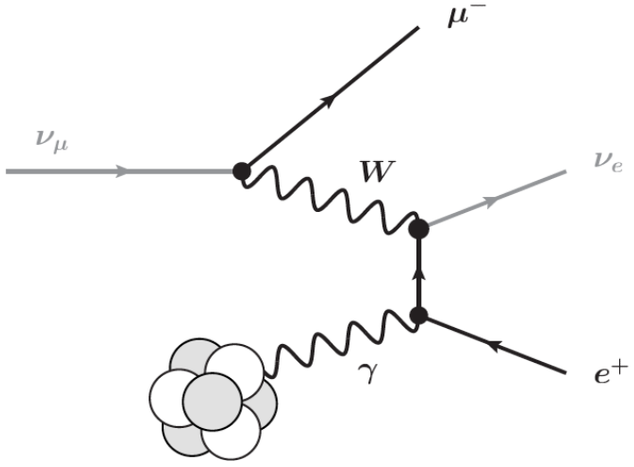
demonstration of the destructive W interference at CCFR:
neutrinos with average energy
$\sim$ 160 GeV on iron
Phys.Rev.Lett. 66, 3117 (1991)

$\sigma_{\text{CCFR}}/\sigma_{\text{SM}} = 0.82 \pm 0.28$

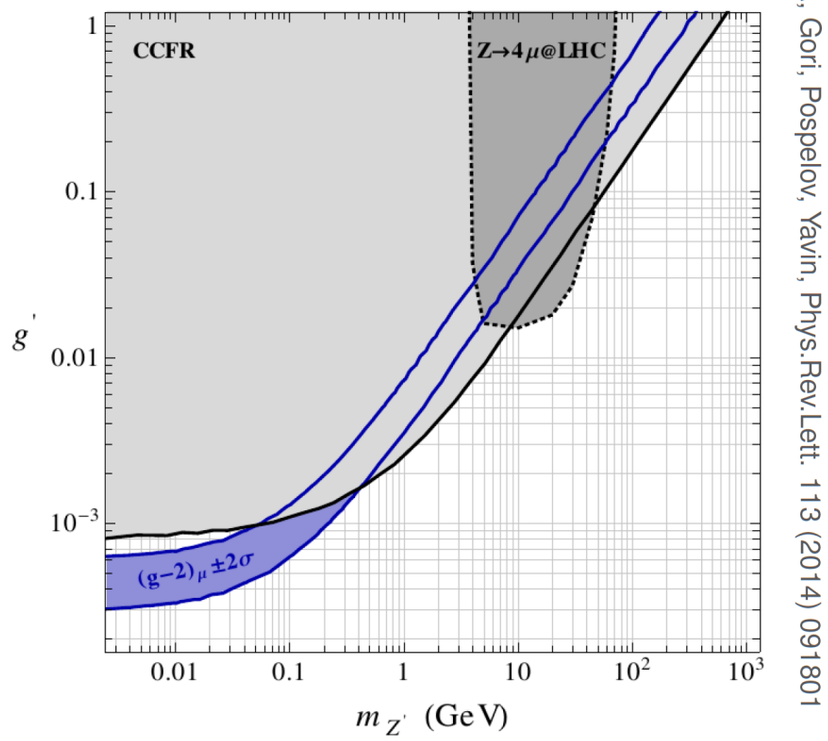
no conclusive signal at NuTeV:
neutrinos with average energy
$\sim$ 160 GeV on iron
Phys.Rev.D 61, 092001 (2000)

$\sigma_{\text{NuTeV}}/\sigma_{\text{SM}} = 0.72^{+1.73}_{-0.72}$





- Strong probe of potential new Z' boson advanced as explanation for (g-2) anomaly
  - Z' couples to muons, but also to muon neutrinos
    - Enhances trident production w.r.t. SM
  - DUNE can probe still-allowed $m_{Z'} < 0.4$ GeV region



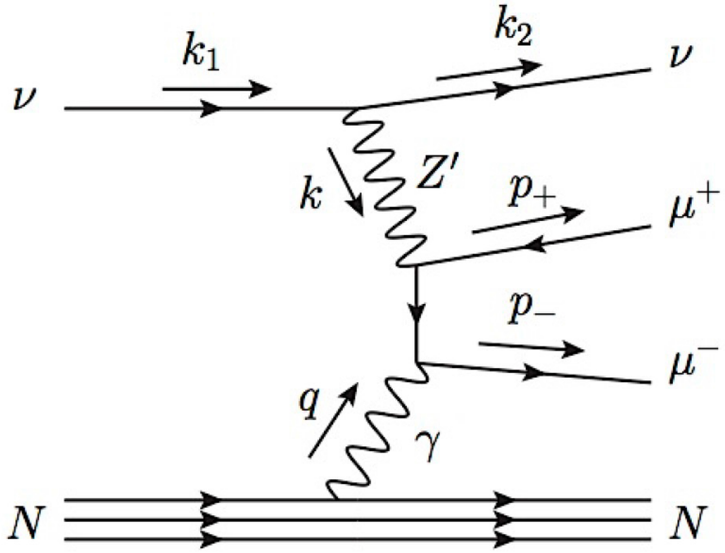
WA, Gori, Pospelov, Yavin, Phys.Rev.Lett. 113 (2014) 091801

Neutrino Trident Status

W. Altmannshofer,
S. Gori, J. Martín-Albo, AS

- Using simulation developed at UC, generated two files with 1 million ν trident events each, one for a carbon target, the other for a LAr target

- Provided files to Justo Martín-Albo, who ran them over the Ar ND simulations (output is a ROOT file)
  - Can use files to understand detector inefficiencies, energy containment, comparisons with backgrounds, etc.



- In the meantime, Justo provided regular DUNE beam files so we can start working with the format and investigating backgrounds such a ν_μ CC with single charged pion production

- Looked at files with UC summer undergraduate, but was unable to loop over events in the file
  - Justo will regenerate new files we can analyze (need help with analysis)

DUNE Physics Week Plans

- Work with Enrique and Mattias on sterile sensitivities
- Sit down with Elizabeth Worcester and/or Dan Cherdack to converge on GLoBES description of ND-only systememmatics
- Work with Justo on Neutrino Tridents
- Work with Animesh in defining plots needed for LED (where different from sterile plots)
- Add a text skeleton for the above to the TDR repository
- Understand which ND to use in producing sensitivities

Preliminary List of Tasks

- Sterile Neutrinos
  - Incorporate more realistic systematic uncertainties into sensitivities
  - Add impact of PID performance and reconstruction efficiencies to sensitivities

- Large Extra-Dimensions
  - Same as the above
  - Produce comparison of sensitivities with MINOS/MINOS+

- Neutrino Trident Studies
  - Final state (true) energy containment in detector
    - as a function of interaction vertex position
  - Track Length Fraction containment in detector for each muon track
  - Two-track reconstruction efficiency
    - as a function of energy containment
    - as a function of interaction vertex position