NOvA Experiment Overview and Run Plan

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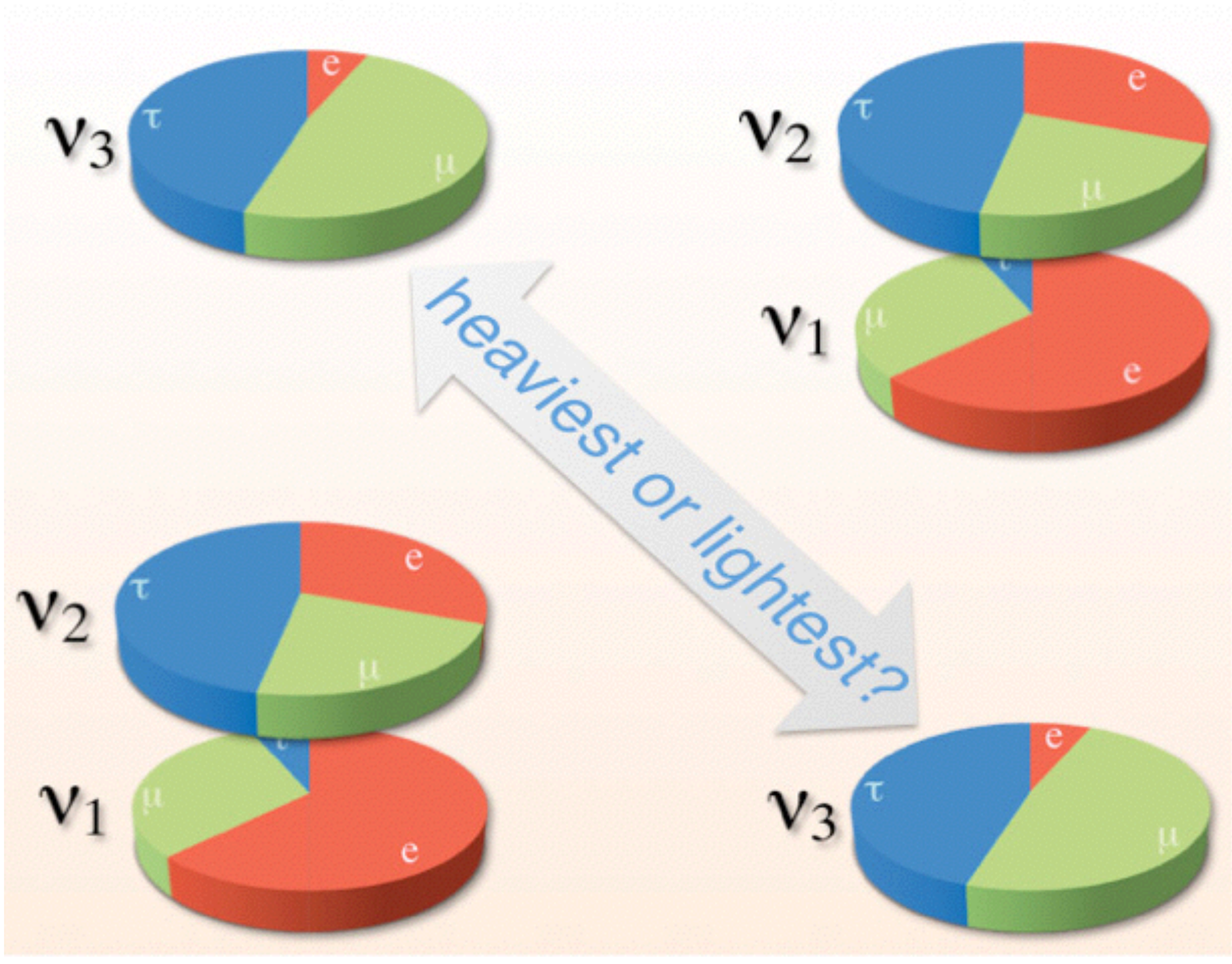
Experiment Readiness Review
Fermilab
October 28, 2014

PRINCIPLES OF THE NOVA EXPERIMENT

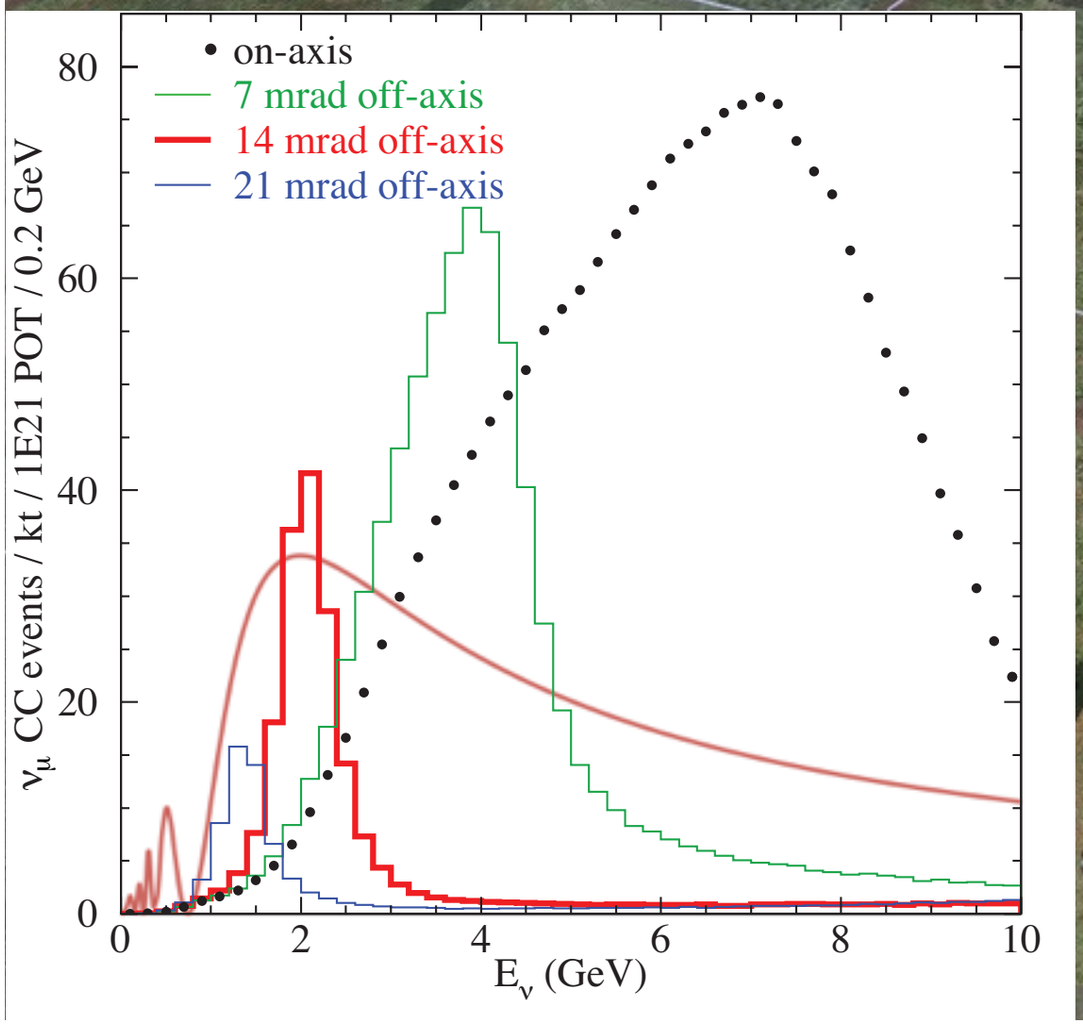
Next Questions In Neutrino Physics

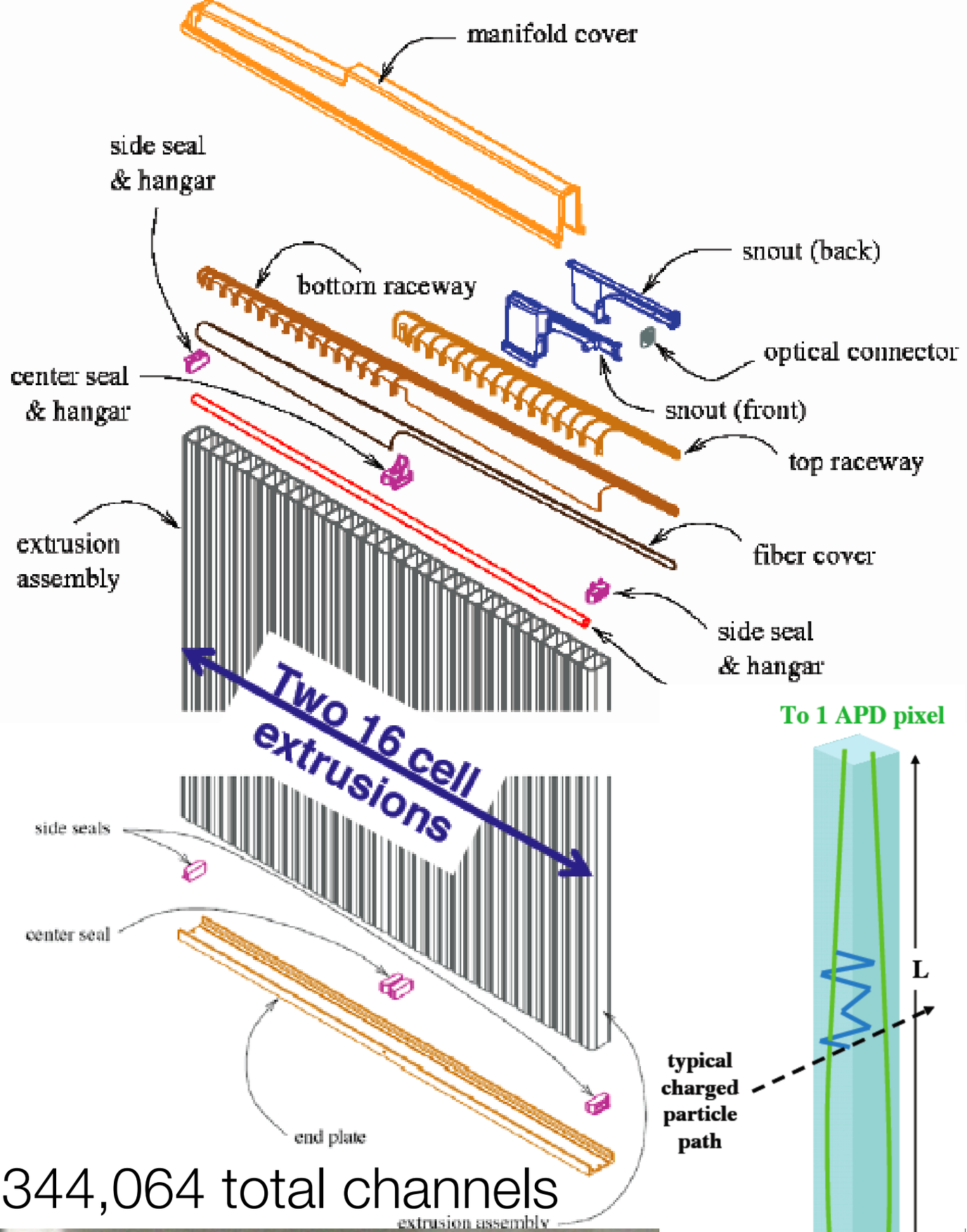
- Mass hierarchy
- Nature of ν_3 - θ_{23} octant
- Is CP violated?
- Is there more to this picture?



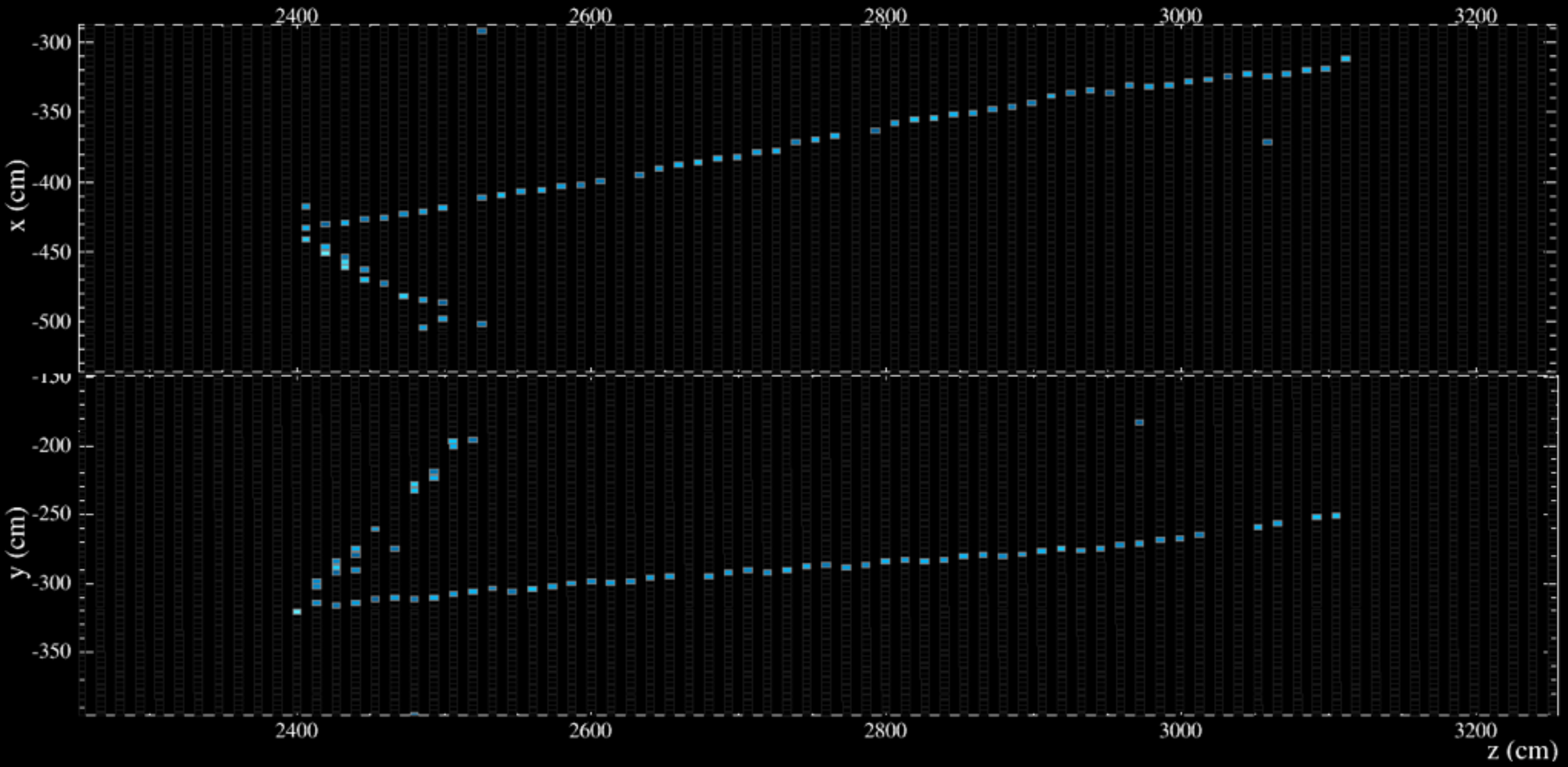
NOvA Experiment

Ash River, MN
810 km from Fermilab





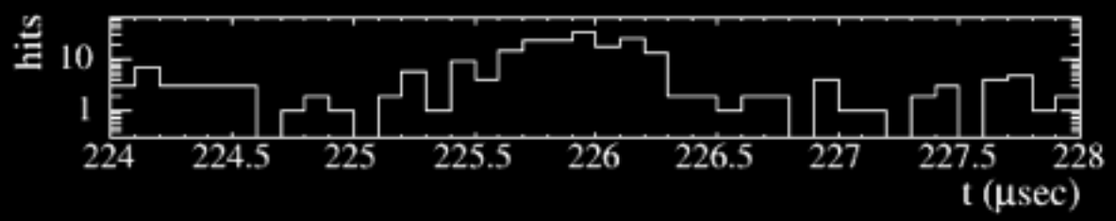
344,064 total channels

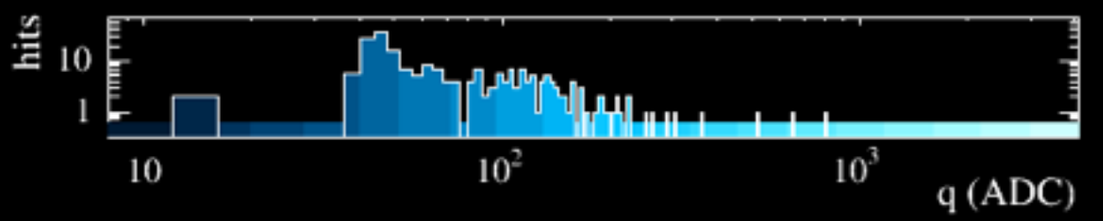


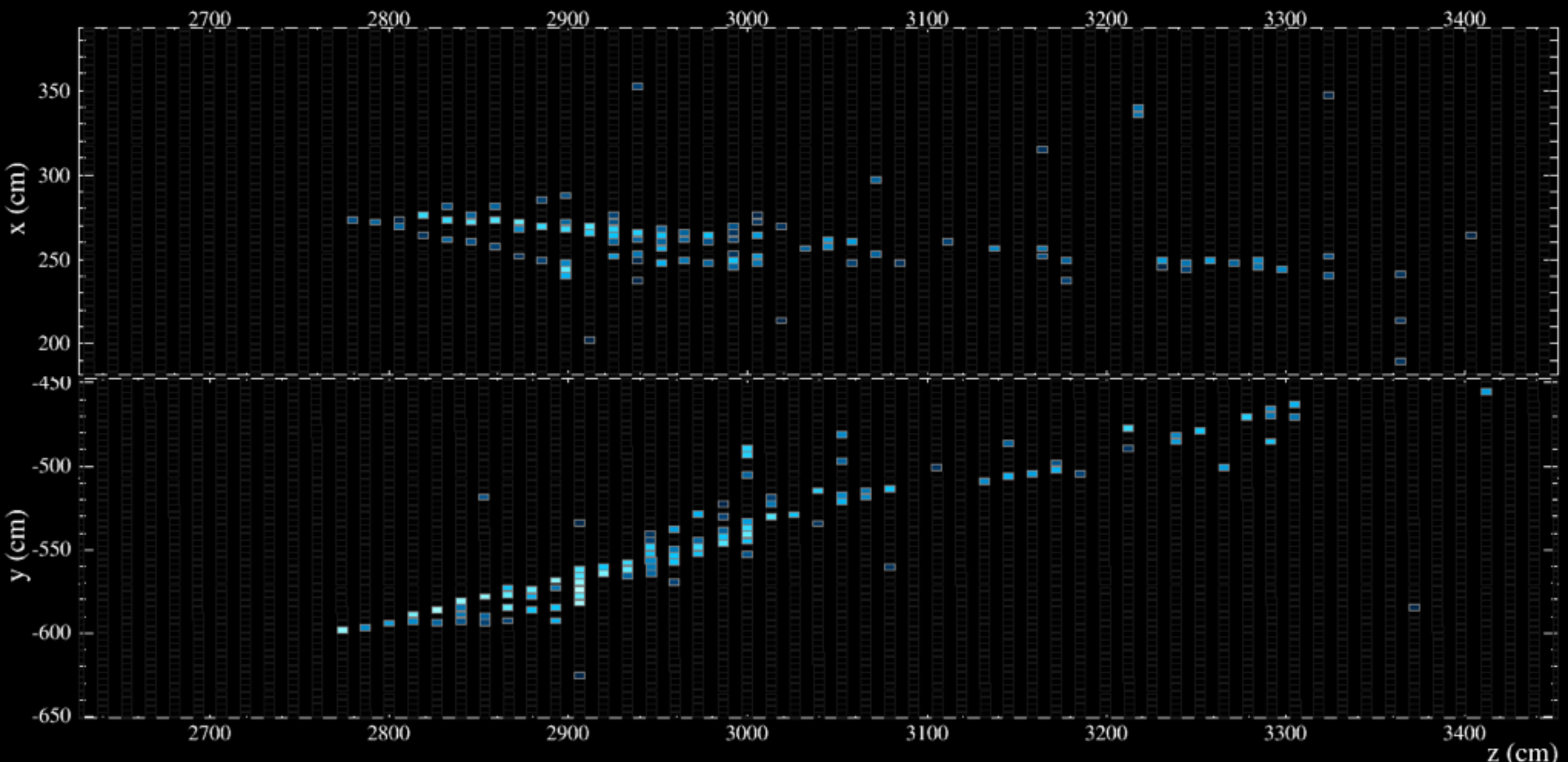
NOvA - FNAL E929

Run: 14828 / 38
Event: 192569 / NuMI

UTC Tue Apr 22, 2014
21:41:51.422846016



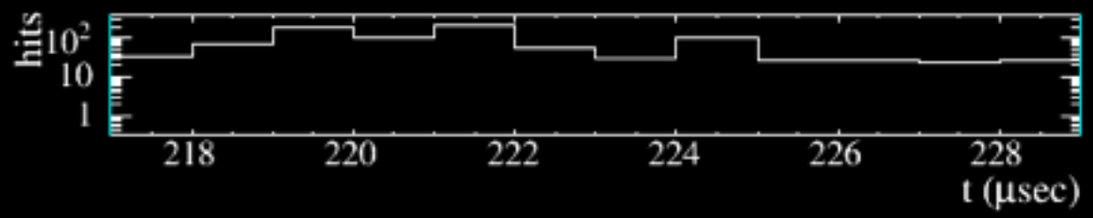


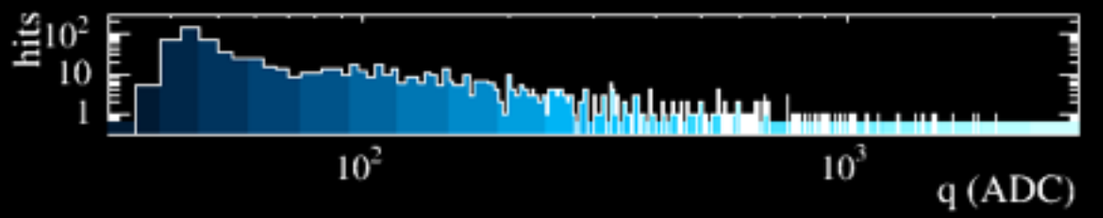


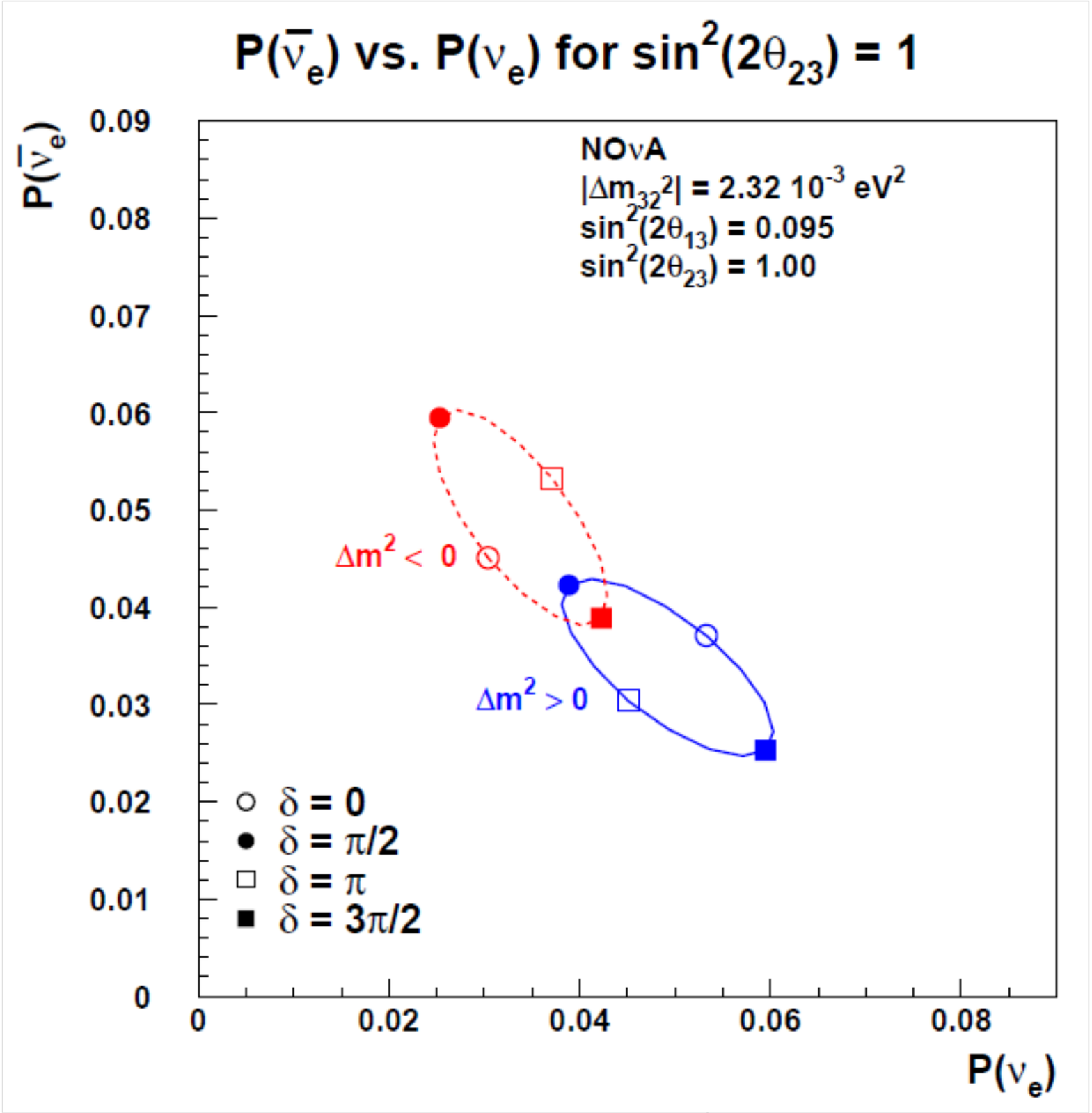
NOvA - FNAL E929

Run: 15392 / 55
Event: 125664 / NuMI

UTC Wed May 28, 2014
04:55:46.939251776





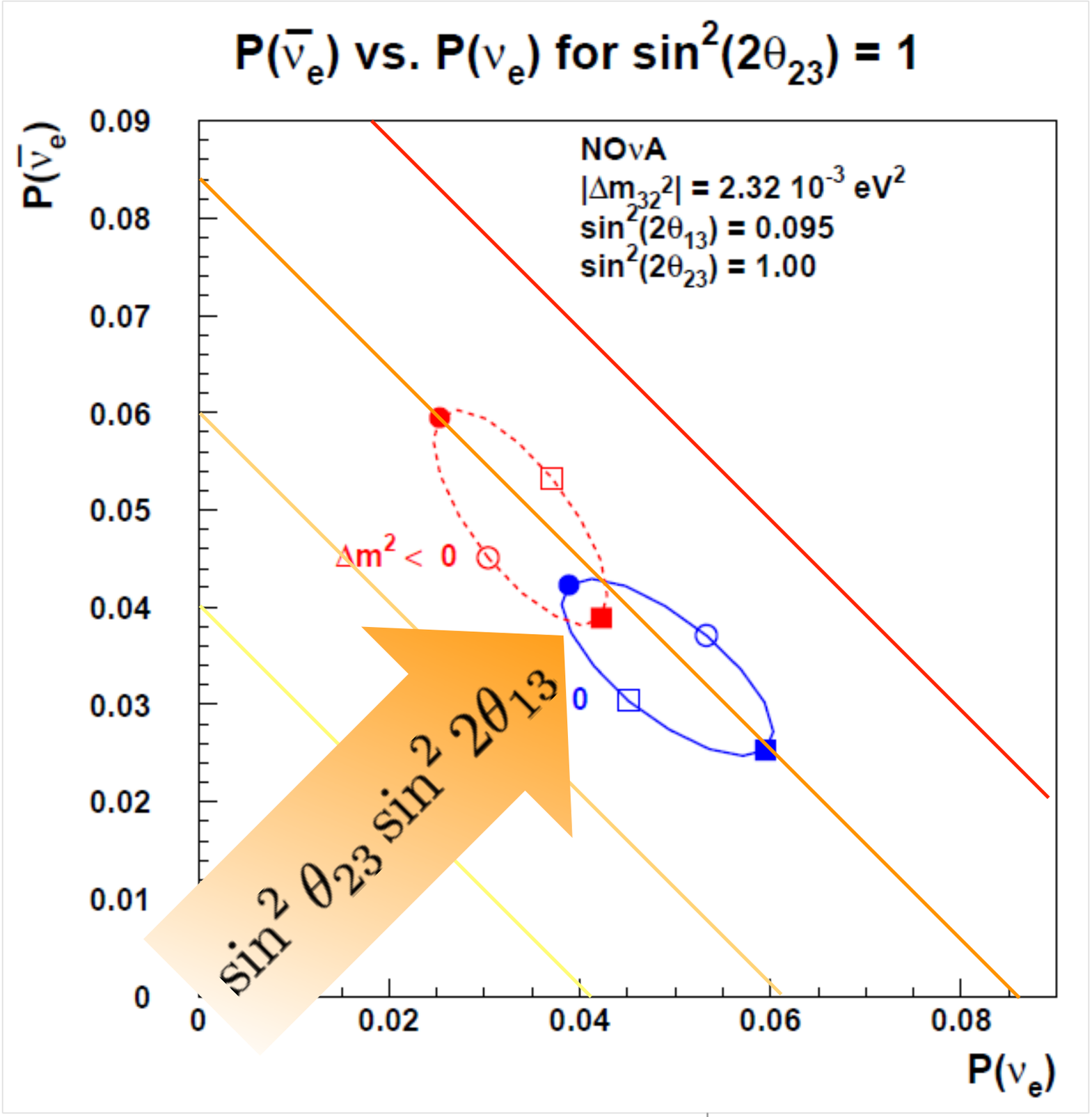


Principle of NOvA measurements

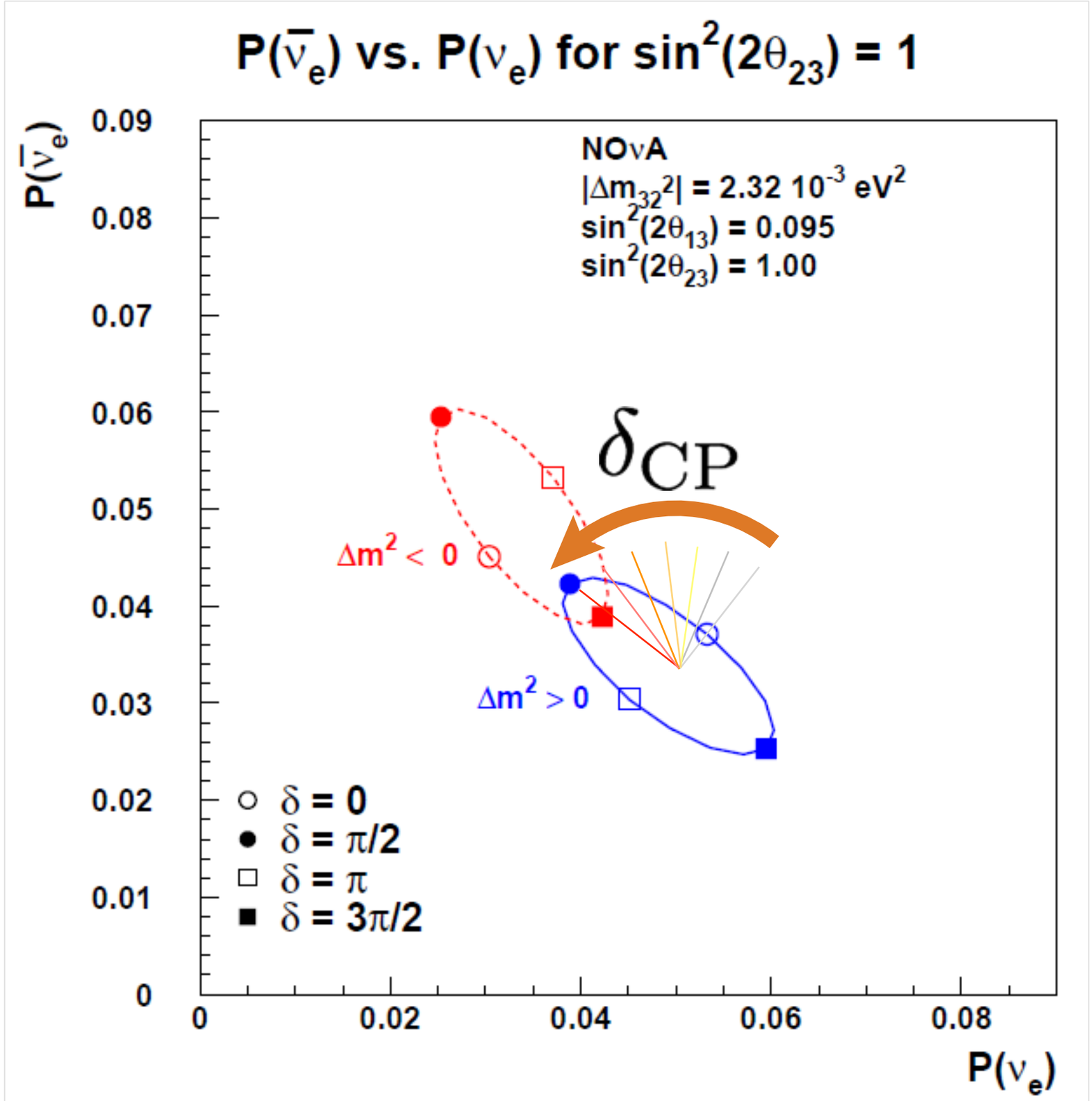
NOvA measures oscillations in four channels

$$\nu_\mu \to \nu_e \quad \& \quad \bar{\nu}_\mu \to \bar{\nu}_e$$

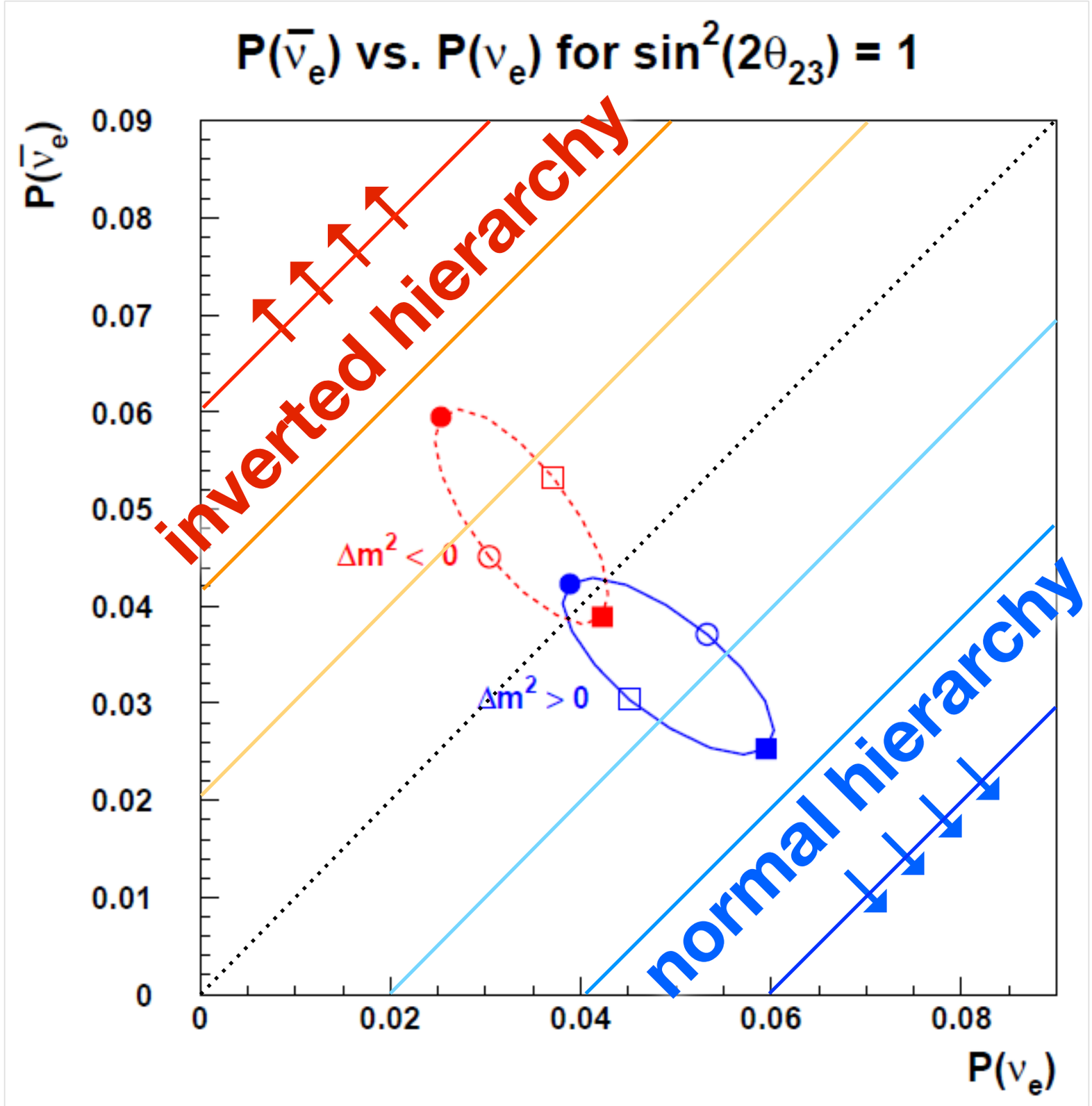
$$\nu_\mu \to \nu_\mu \quad \& \quad \bar{\nu}_\mu \to \bar{\nu}_\mu$$



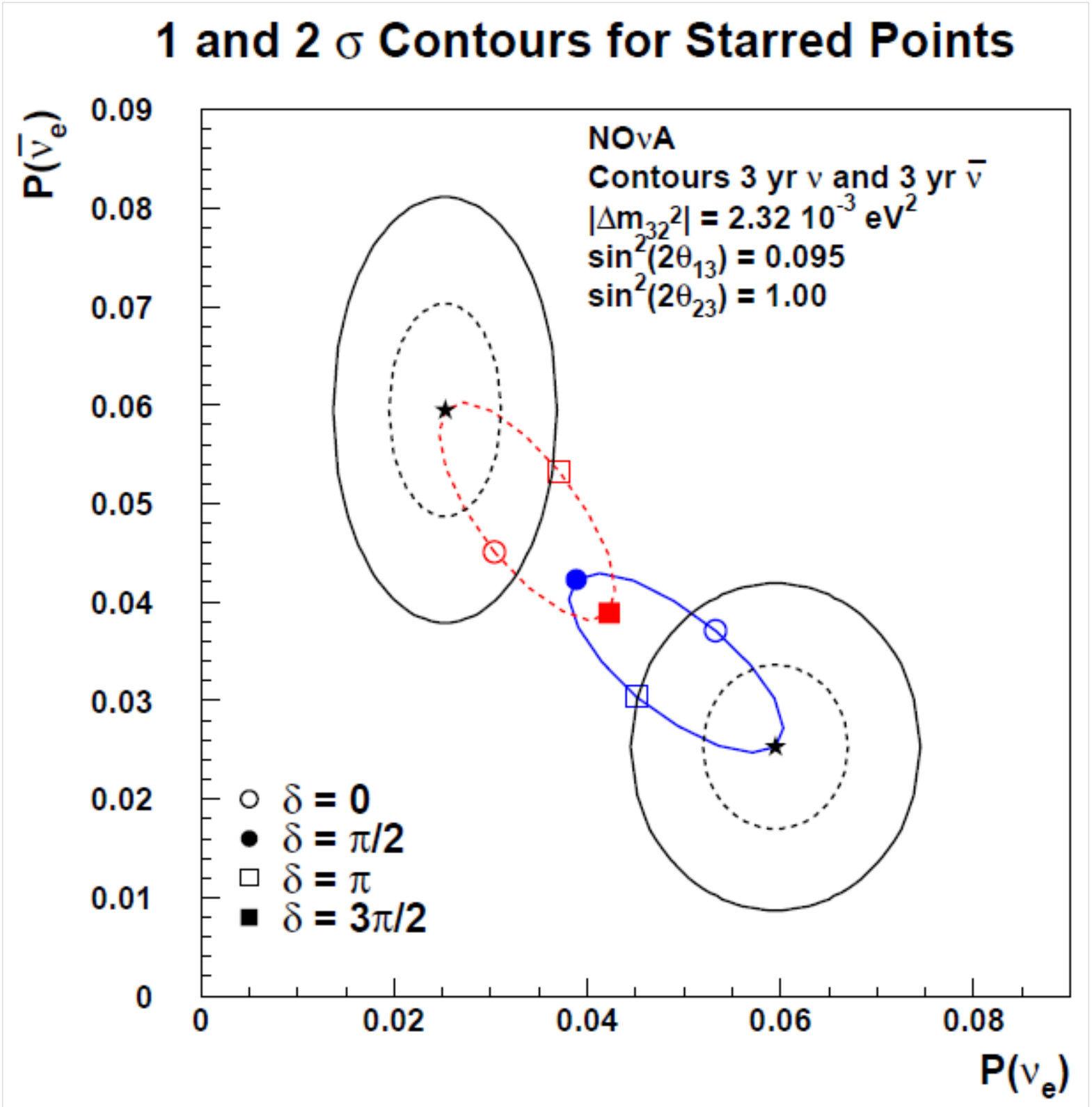
Principle of NOvA measurements



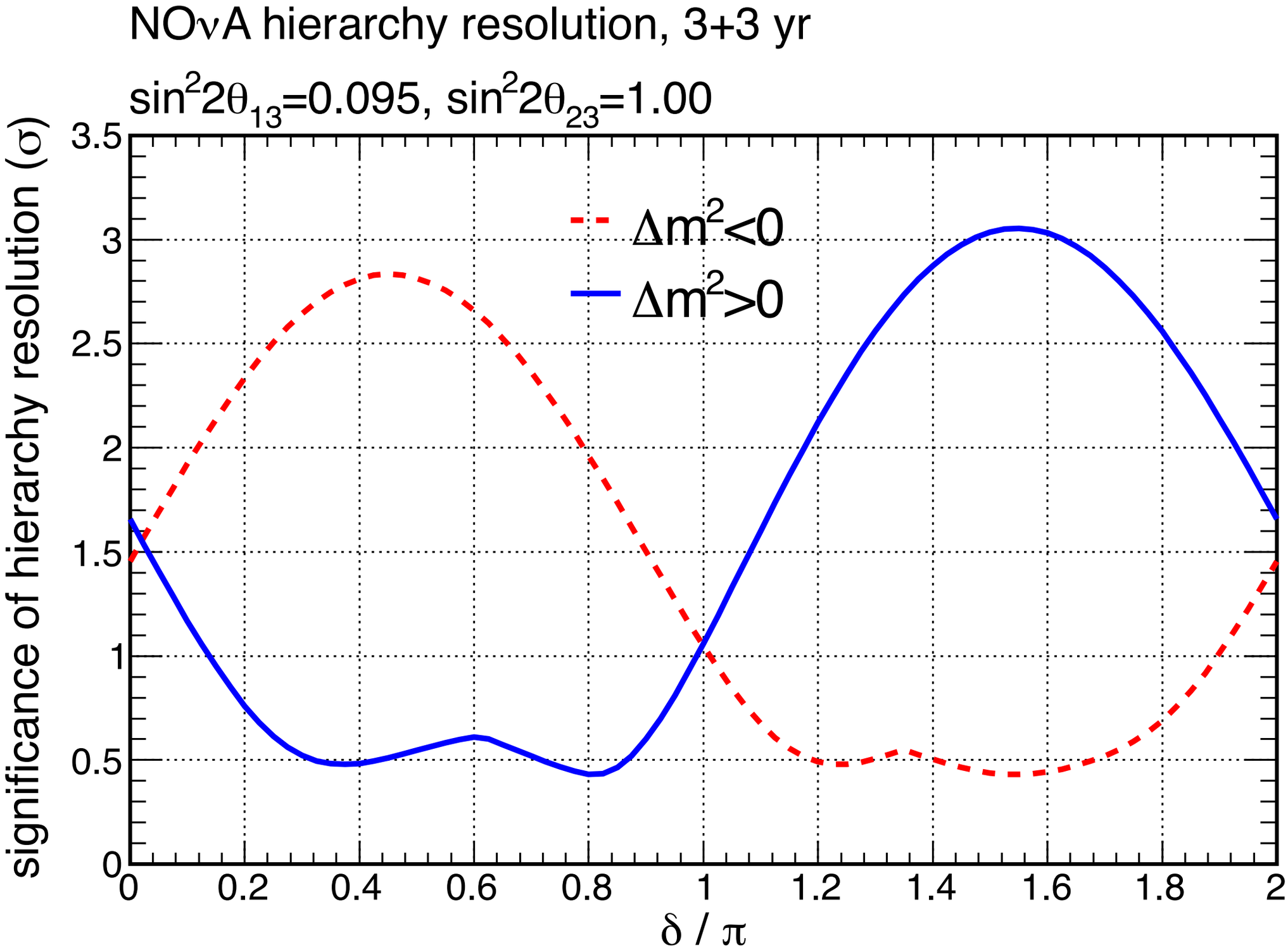
Principle of NOvA measurements



Principle of NOvA measurements | Hierarchy resolution



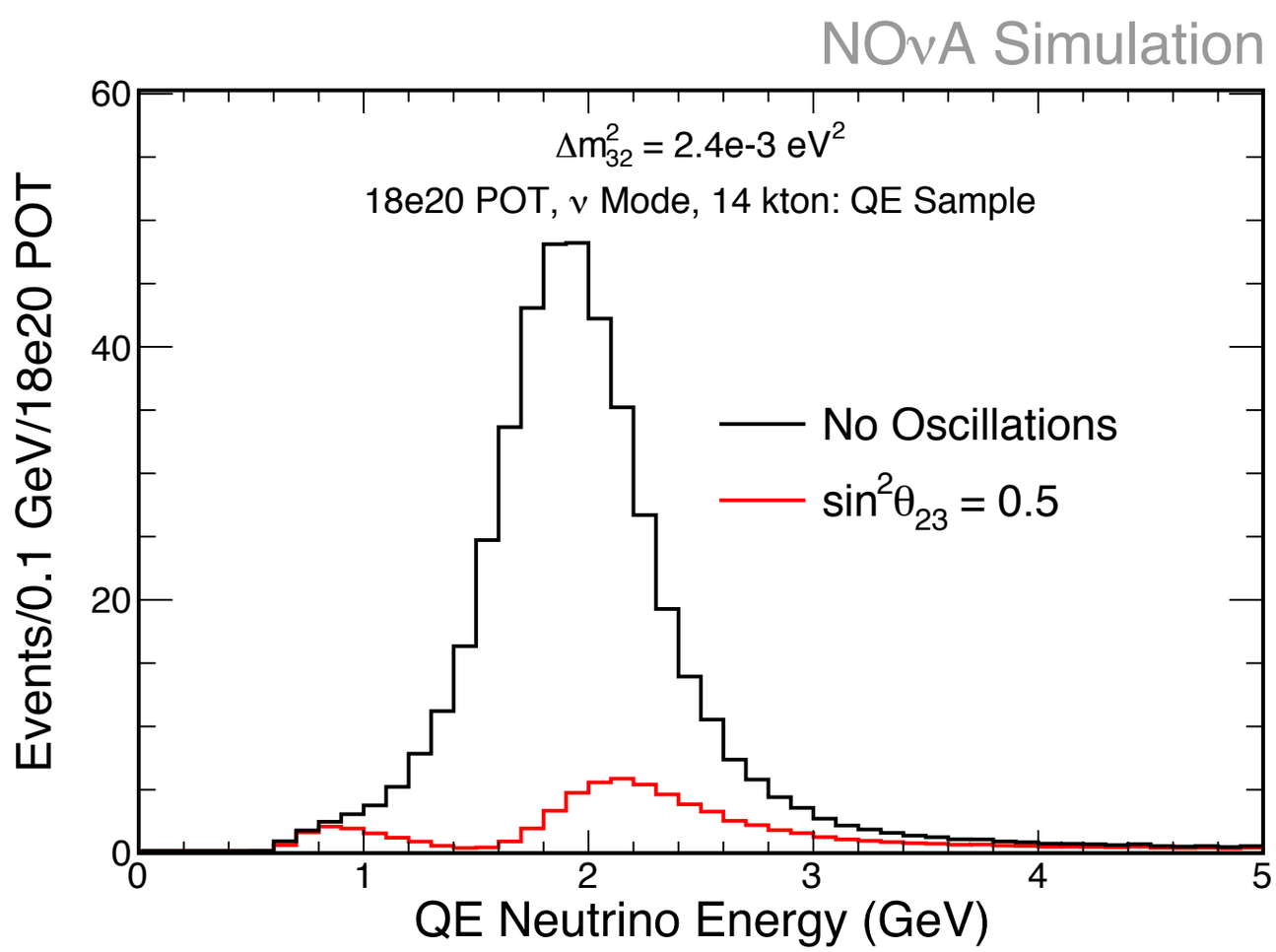
Principle of NOvA measurements

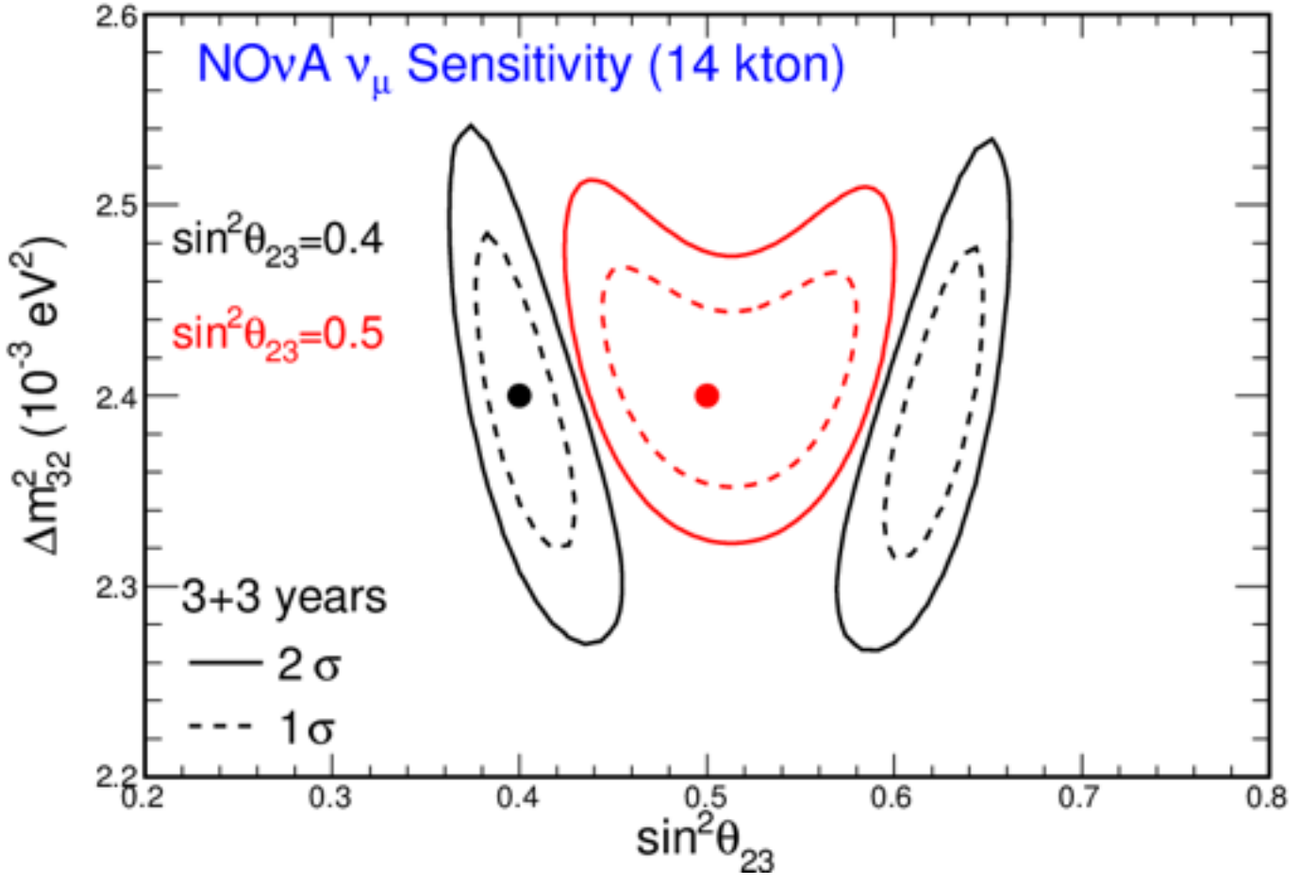


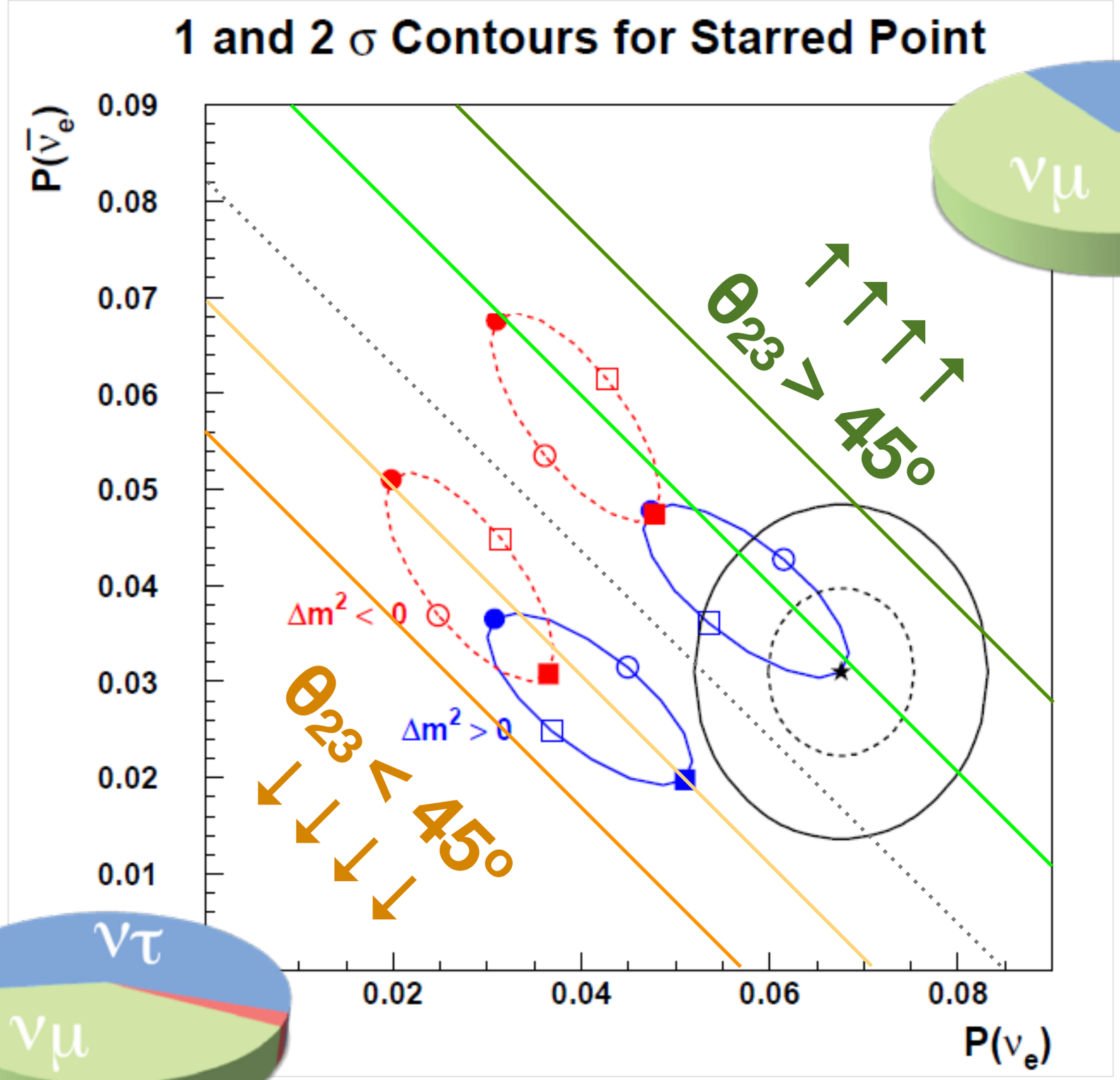
NOvA Sensitivity to mass hierarchy

$$\nu_\mu \rightarrow \nu_\mu$$

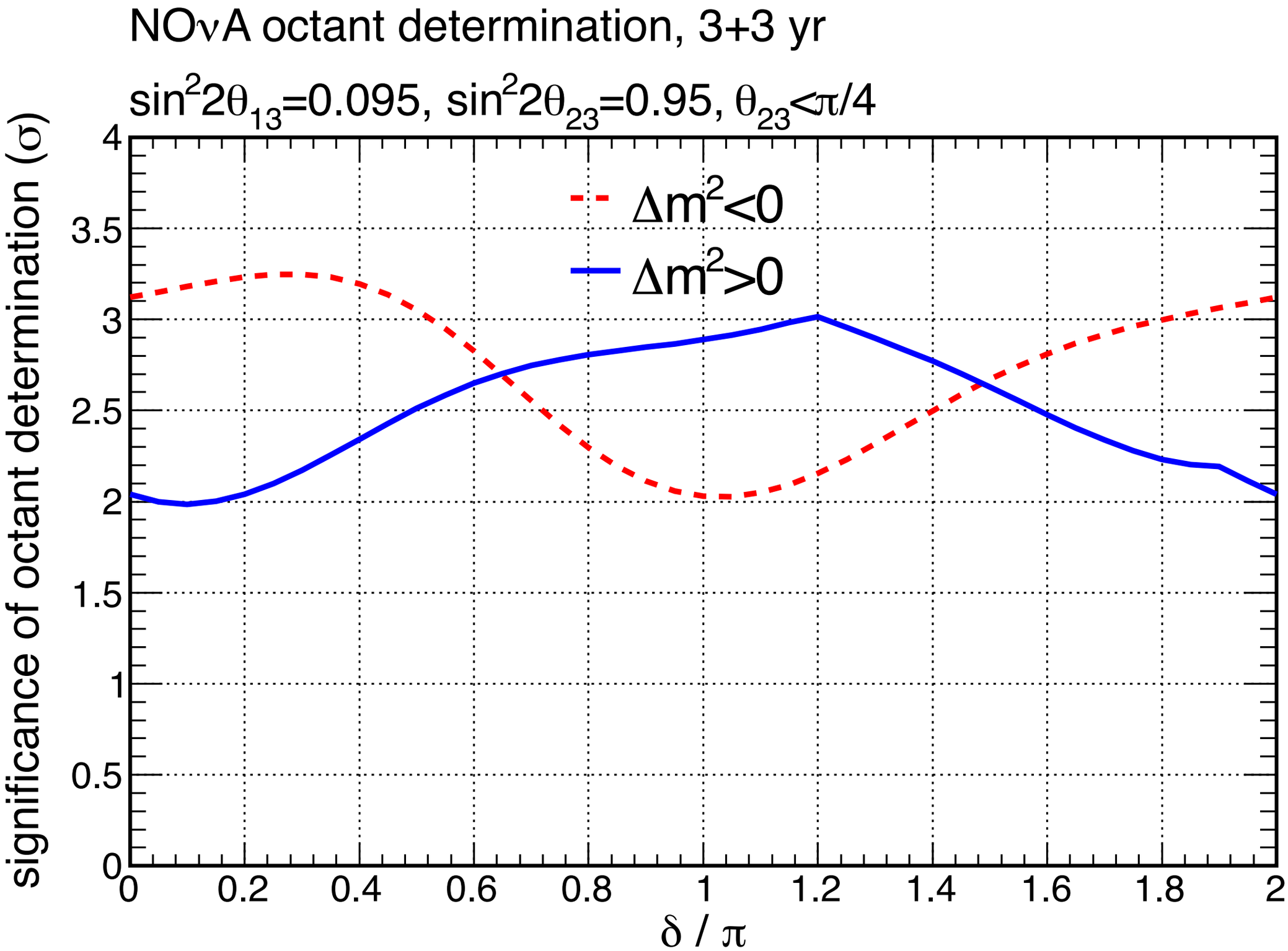
- 4.5% energy resolution for quasi-elastic events
- 6% energy resolution for non-quasi-elastic events







Principle of NOvA measurements | Octant resolution



NOvA Octant resolution

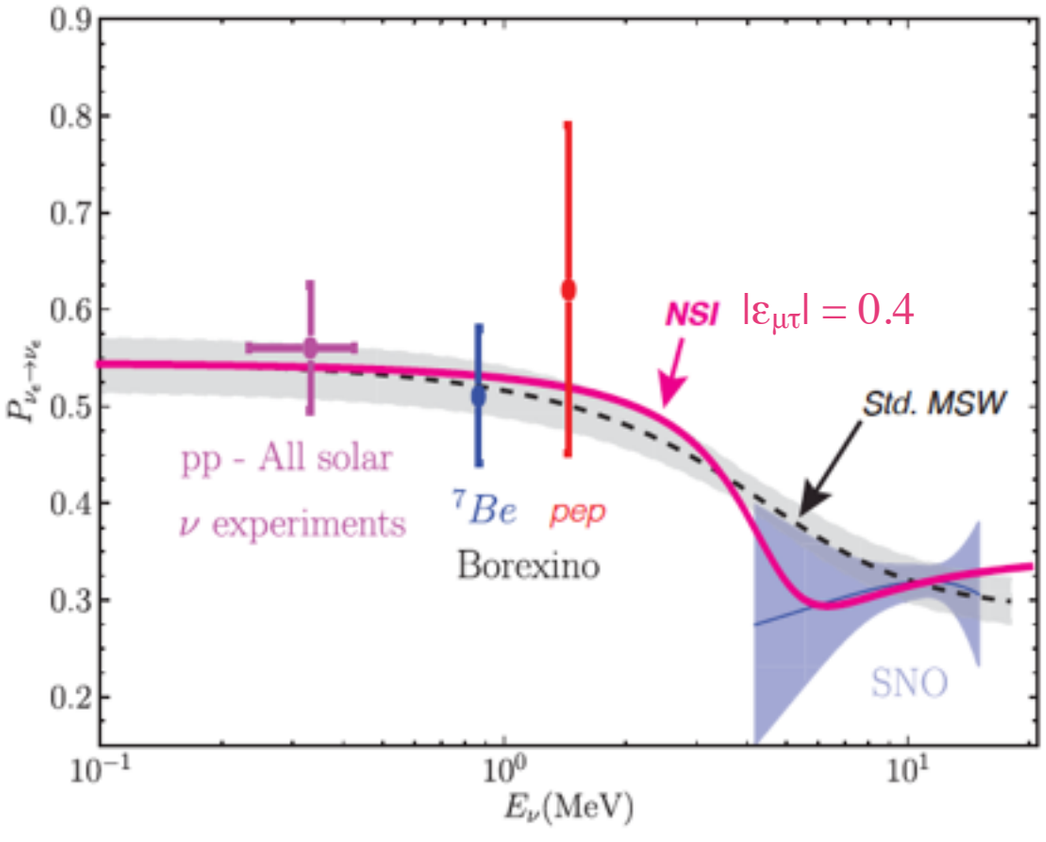
NOvA sensitivity to “non-standard interactions”

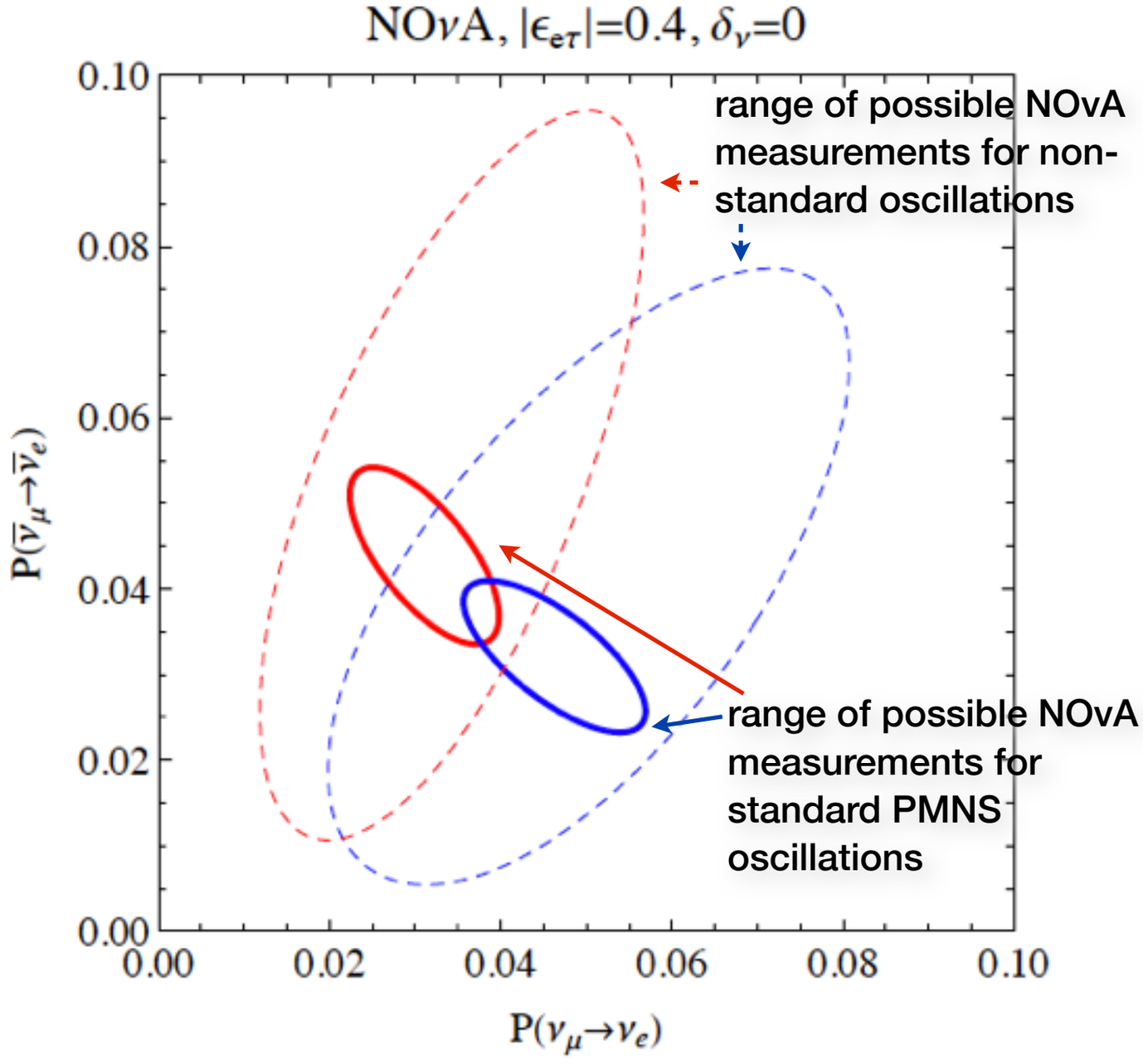
Friendland and Shoemaker, arXiv:1207.6642v1

standard matter effect

$$H_{mat}^{flav} = \sqrt{2} G_F n_e \begin{pmatrix} 1 & 0 & |\varepsilon_{e\tau}|\, e^{-i\delta_\nu} \\ 0 & 0 & 0 \\ |\varepsilon_{e\tau}|\, e^{i\delta_\nu} & 0 & 0 \end{pmatrix}$$

new interactions



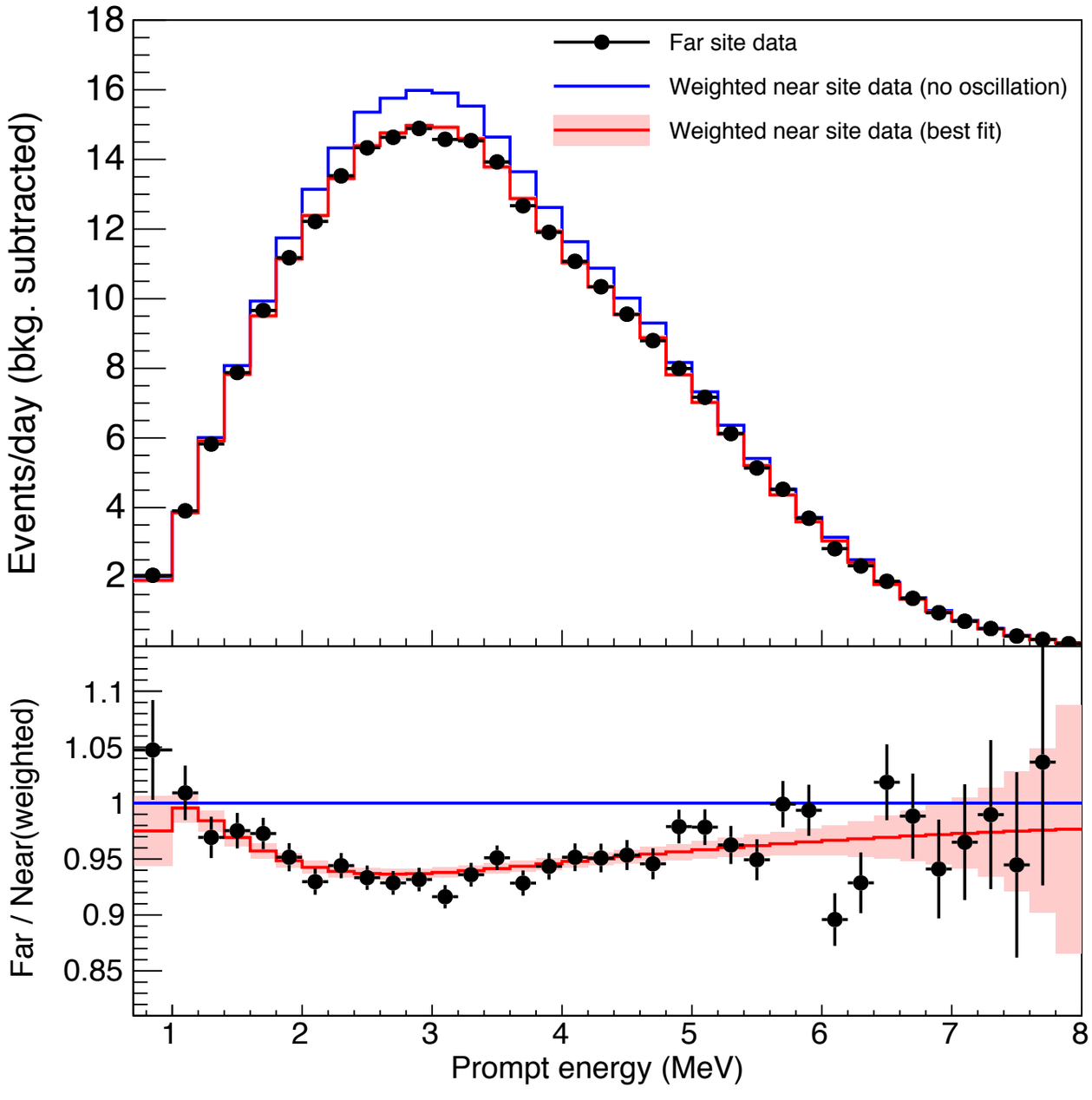


- Non-PMNS oscillations could place NOvA measurements outside the regions expected from standard oscillations
- Crucial to this is combining results from all four of NOvA’s channels

NOvA Run Plan

Current experimental situation: Daya Bay Reactor Neutrino Results

$$\bar{\nu}_e \rightarrow \bar{\nu}_e$$



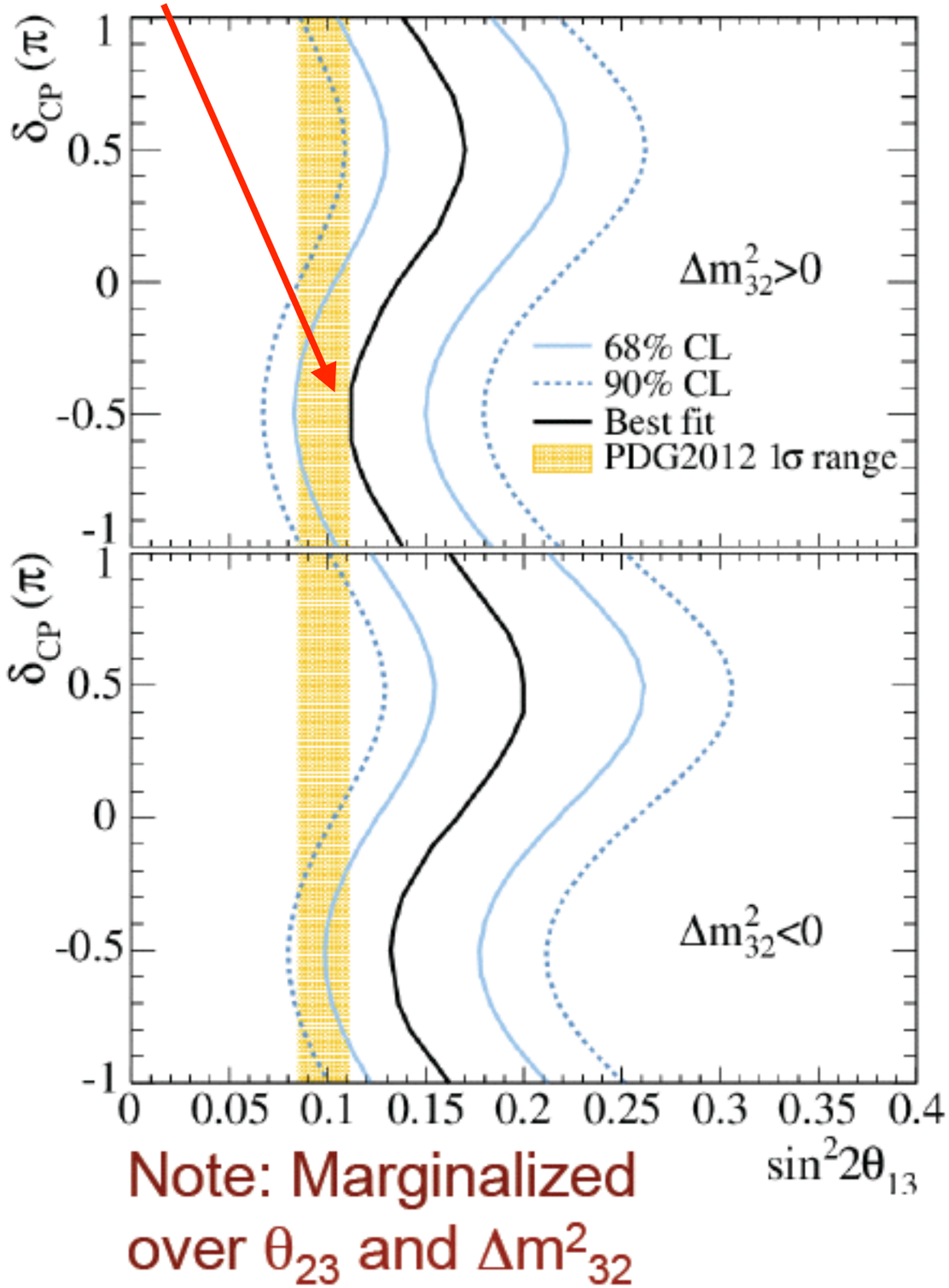
Reactor neutrino results are already very precise and not likely to change very much in coming years.

$$\sin^2 2\theta_{13} = 0.084 \pm 0.005$$

Current experimental situation: T2K $\nu_\mu \rightarrow \nu_e$ Results

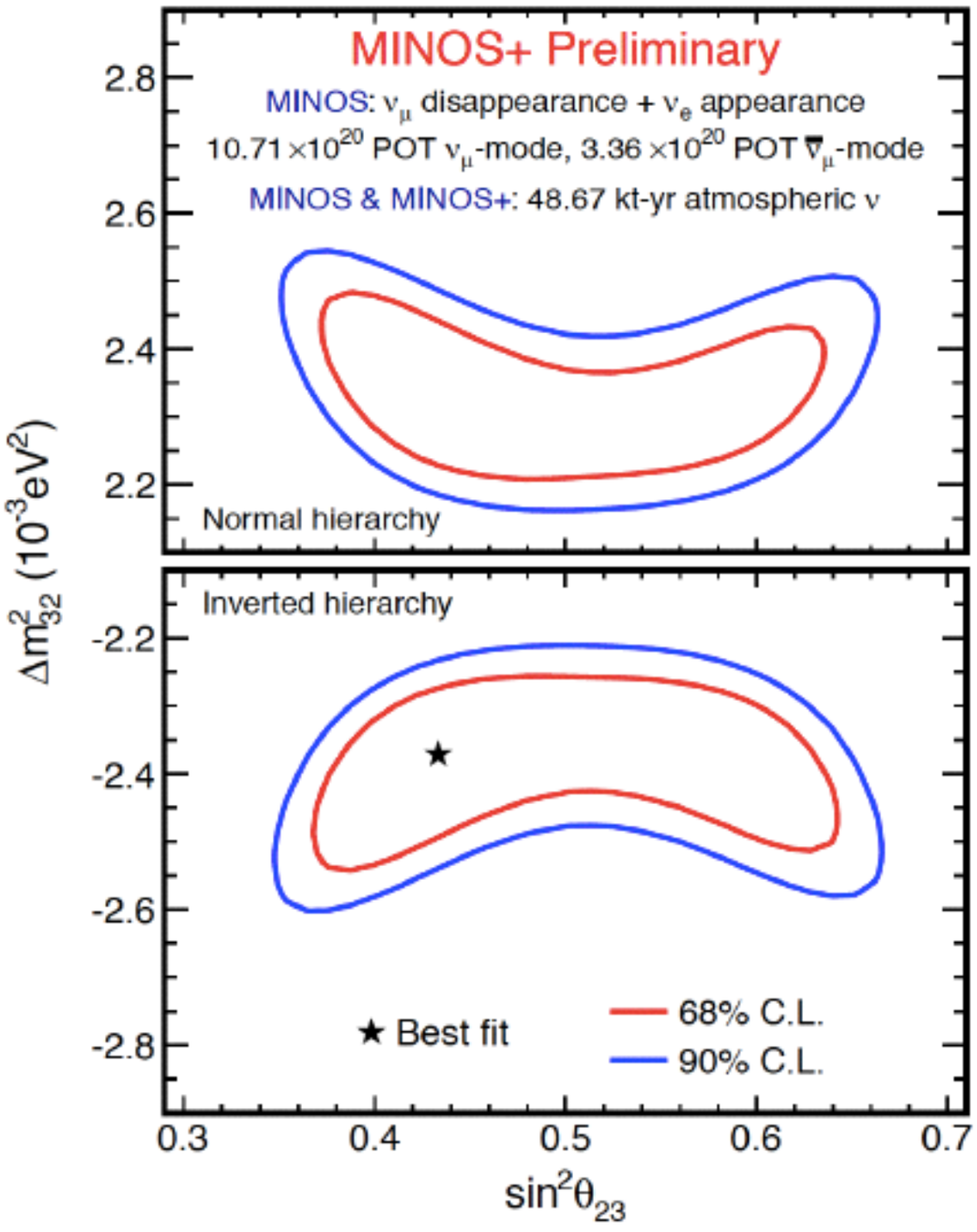
- T2K has run at 235 kW and integrated 6.6E20 POT to date.
- Plans are to ramp intensity to 750 kW by 2017.
- Seen 28 signal events on background of 5.
- 22 signal events expected based on reactor measurements.
- Plan to run antineutrinos this year. Expect ~6 events.

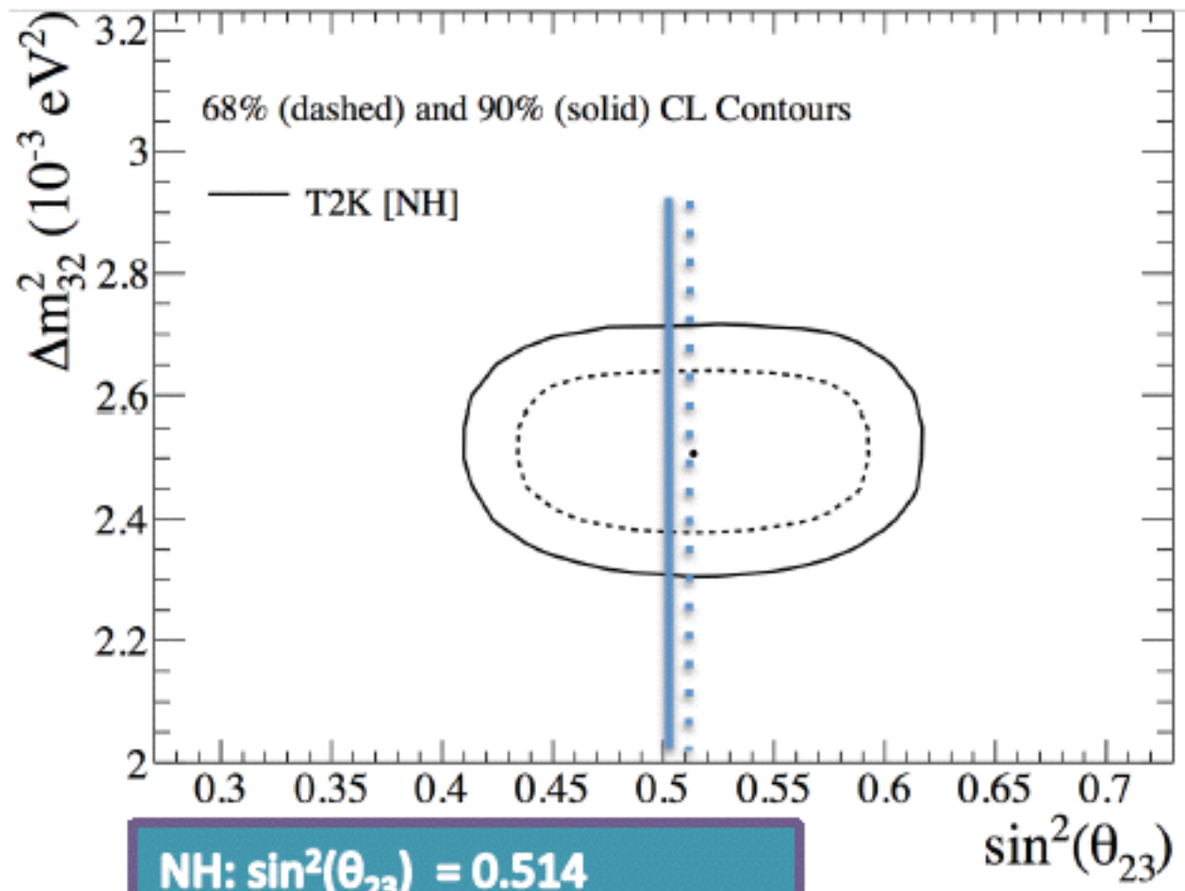
Most consistent point is a "NOvA sweet spot" where we would see maximum enhancement of neutrino oscillations and maximum suppression of antineutrino oscillations.



Note: Marginalized over θ_{23} and Δm^2_{32}

Current experimental situation: MINOS and T2K $\nu_\mu \rightarrow \nu_\mu$ Results





NH: $\sin^2(\theta_{23})$ = 0.514
NH: Δm^2_{32} = 2.51x10^{-3} eV^2

Approach to run plan

- Reactor experiments are already so precise there is not likely to be new information coming from them in coming years.

- If T2K runs antineutrinos, there is not likely to be actionable new information from them in coming years

- Assuming good beam performance, NOvA will be providing most of the new information in coming years.

- Rather than work through a large number of scenarios, I have defined some milestones for the NOvA physics reach

- Note that NOvA is not over-designed; our headline measurements (hierarchy, θ_{23} octant) require full 36E20 POT and are even then statistics limited. The milestones are a few points along the way where I think the sensitivity of the experiment crosses an interesting threshold and informs the run plan for the experiment.

Electron Appearance Numbers

POT	Neutrino Running Signal	Neutrino Running Background	Antineutrino Running Signal	Antineutrino Running Background
1E+20	2.8	1.4	1.3	0.7
2E+20	5.5	2.9	2.5	1.3
3E+20	8.3	4.3	3.8	2.0
4E+20	11.1	5.7	5.0	2.6
6E+20	16.6	8.6	7.5	3.9

We have this much neutrino data "in the can"

Given FY15 POT estimates we would have this much by summer 2015 conferences

Minimum POT for 5-sigma appearance signal. Enough to make neutrino vs. antineutrino decision.

Minimum reportable antineutrino data set (95% CL)

Electron Appearance Milestones

- 5 sigma observation of electron neutrino appearance; enough data to make informed neutrino vs. antineutrino running decision: **6E20 (1 TDR year)**

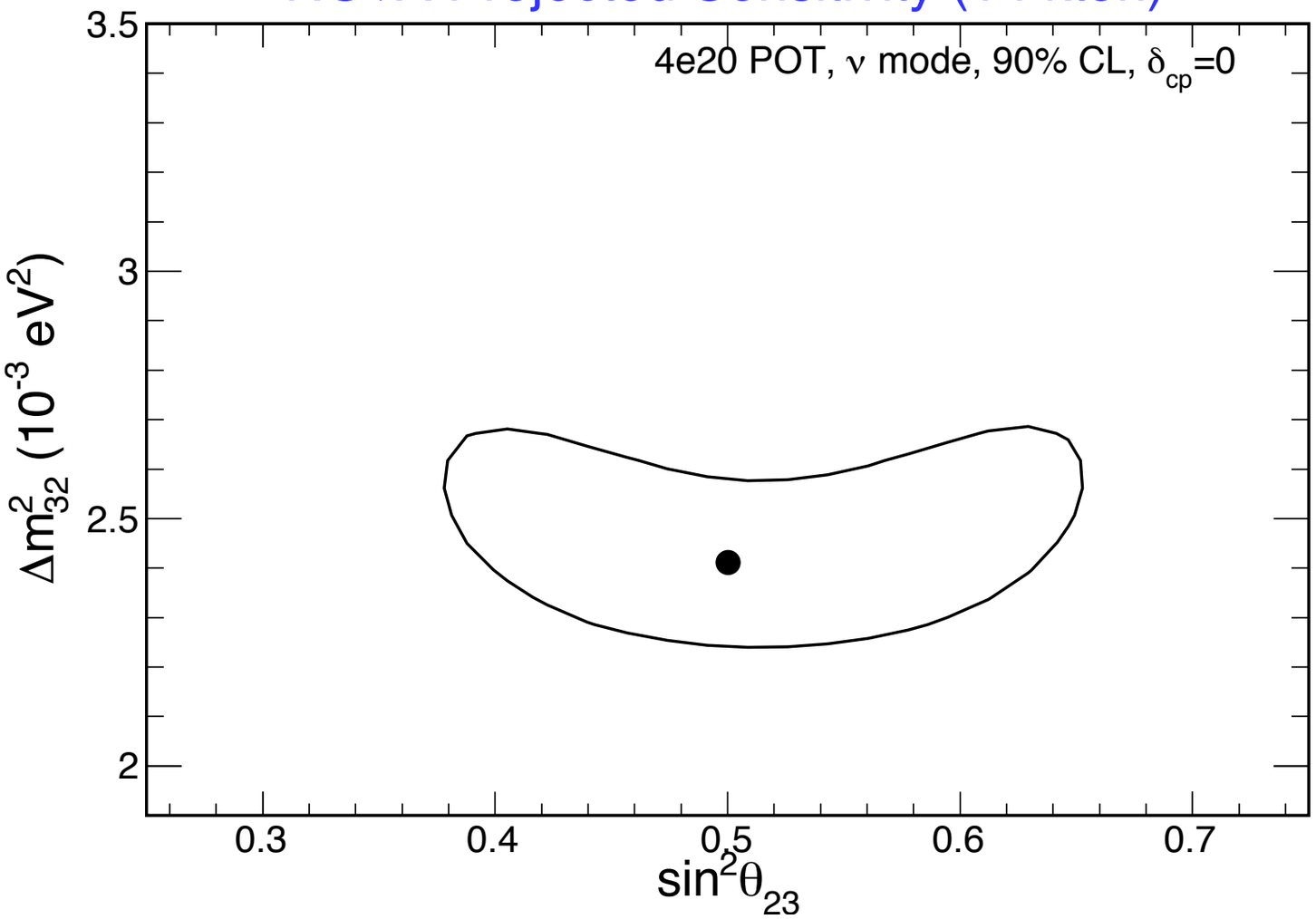
- Reach 28 signal events (equal to T2K's current number) in (28/16)*6E20 POT = **10E20 POT (1.67 TDR years)**

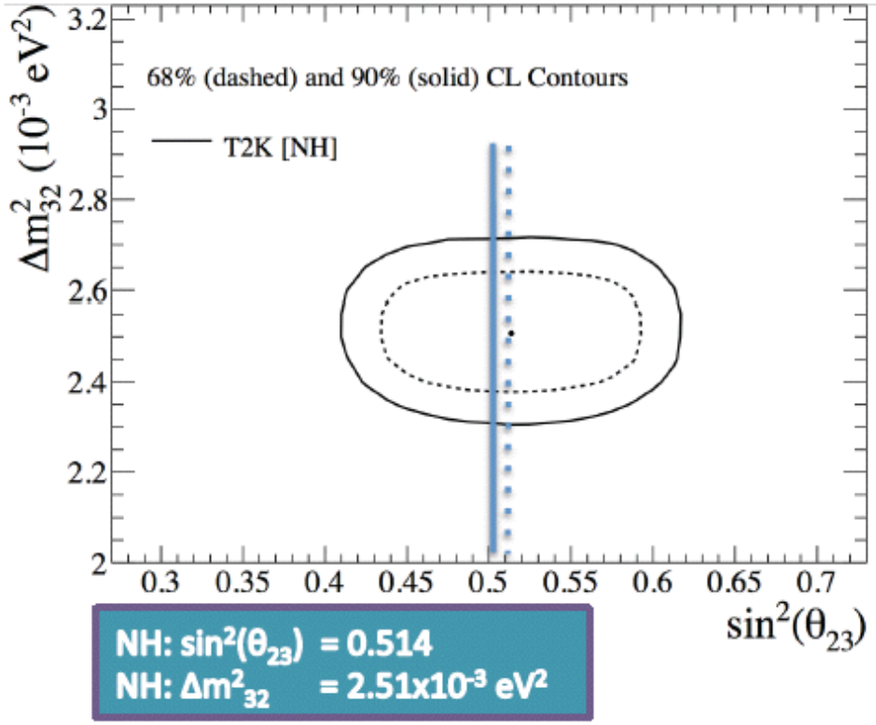
- Earliest reportable antineutrino results: **12E20 (2 TDR years)**

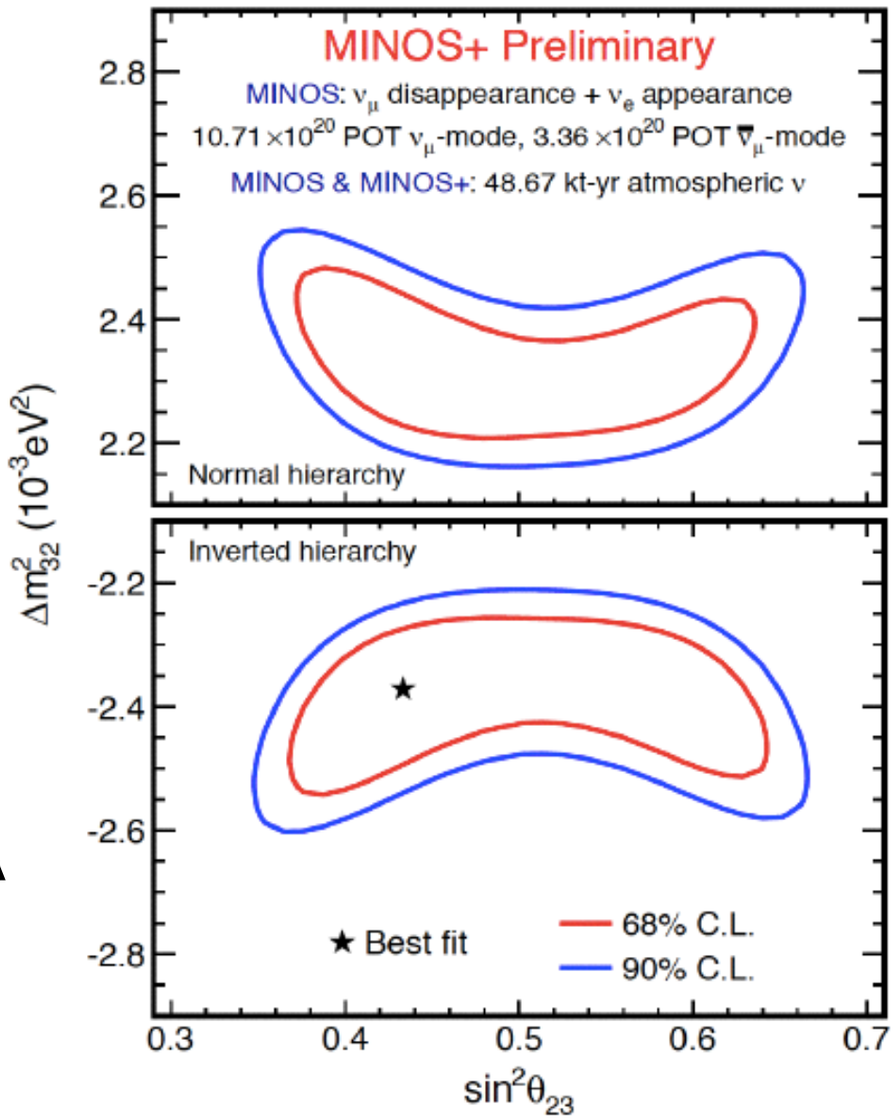
- 2 sigma sensitivity to mass hierarchy at T2K + Reactors best match point: **18e20 POT = 3 TDR years**.

Muon neutrino disappearance milestones

NOνA Projected Sensitivity (14 kton)

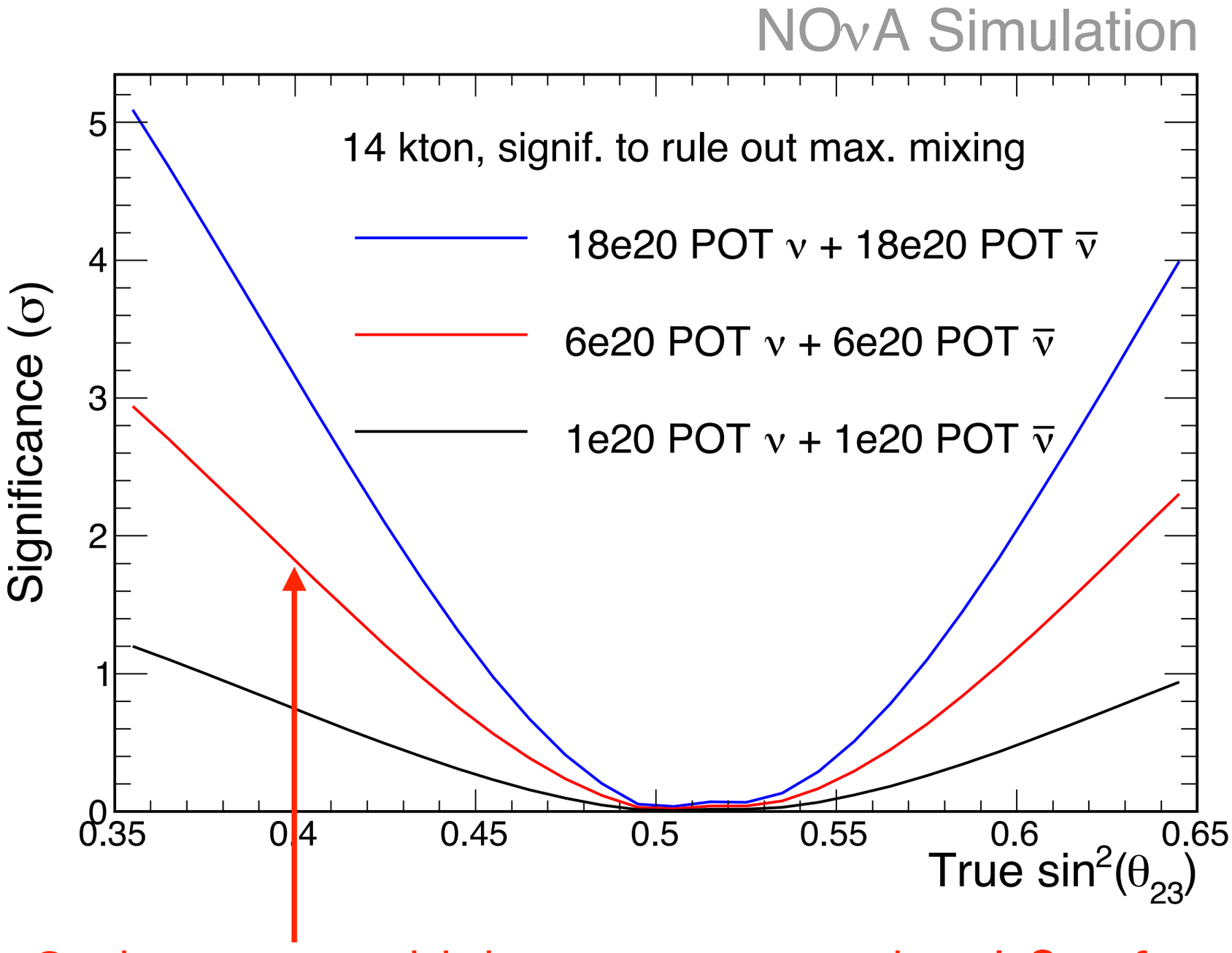






With 4E20 POT (2/3 TDR year) NOvA catches up to current experiments

Muon neutrino disappearance milestones



2 sigma sensitivity to non-maximal θ_{23} for ~9e20POT

NOvA Proton Assumptions for FY15

From Paul Derwent Proton PMG, August 21, 2014

- **Average power to NuMI in FY15 is projected to be 390 kW:**
  - Booster at 7.5 Hz / 4.3E12 ppp. Will not reach 15 Hz in FY15.
  - RR 2+6 Slip Stacking (8 total batches, TDR: 12)
    - These combine to give ~433 kW maximum power
  - SY120 Uptime = 90% / SY120 fraction of cycle time 10%
    - SY120 “tax” lowers average power to 390 kW
- Accelerator x NuMI uptime = 80%x80% = 64%
- Start up Oct. 31, 12 week shutdown starting in July = 36 weeks of operations
  - 36 weeks is 80% of TDR 44-week year

Put these together: **(433 kW/700 kW) * 90% * (64%/64%) * 80% = 44% TDR POT/ year** which corresponds to the “design” number below. The numbers in the denominator indicate assumptions we made in the TDR, numerators are current assumptions.

Base POT for FY15: 2.0E20 (1/3 of a NOvA TDR-year)

Design POT for FY15: 2.9E20 (~1/2 of a NOvA TDR-year)

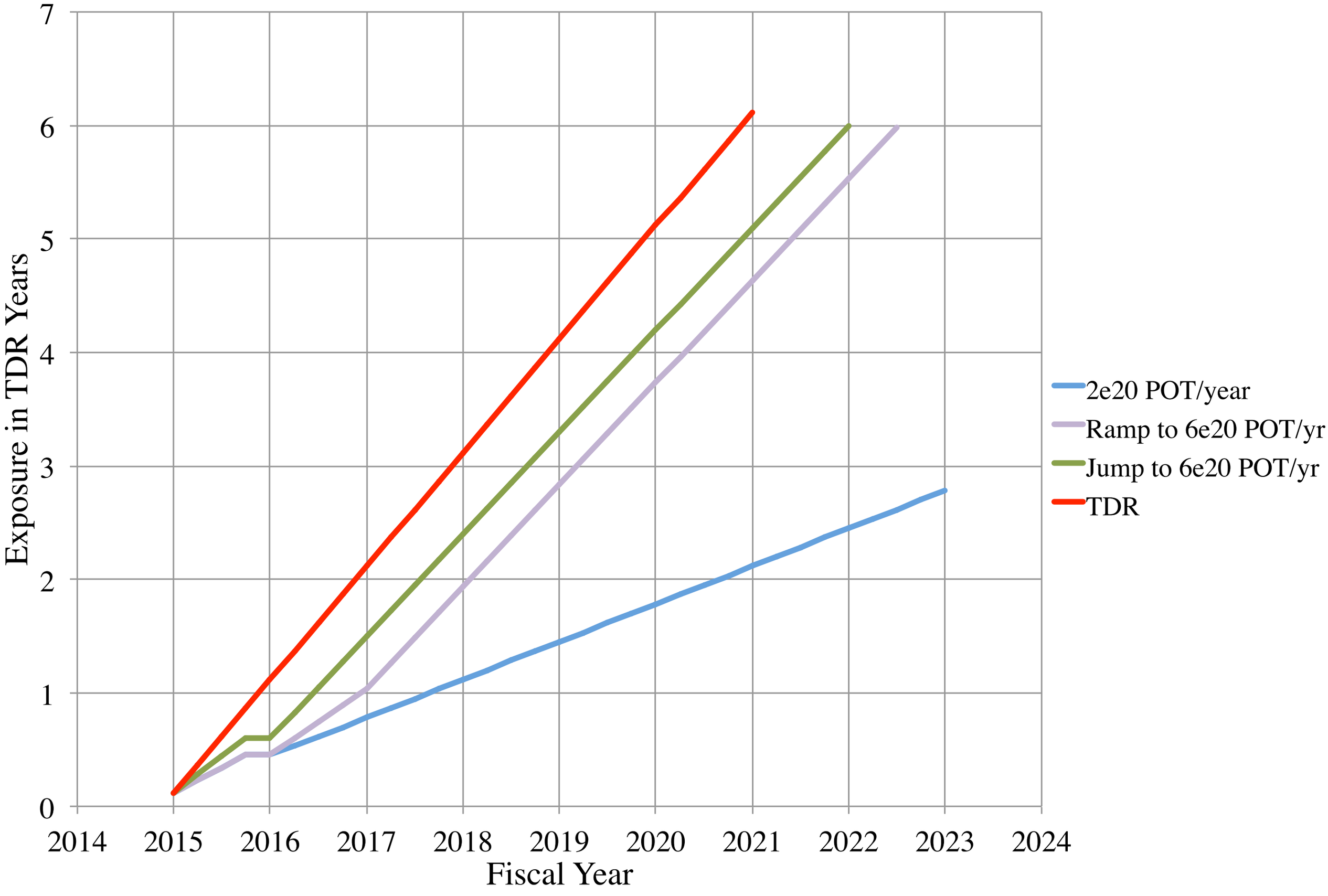
NOvA Proton Assumptions Beyond FY15

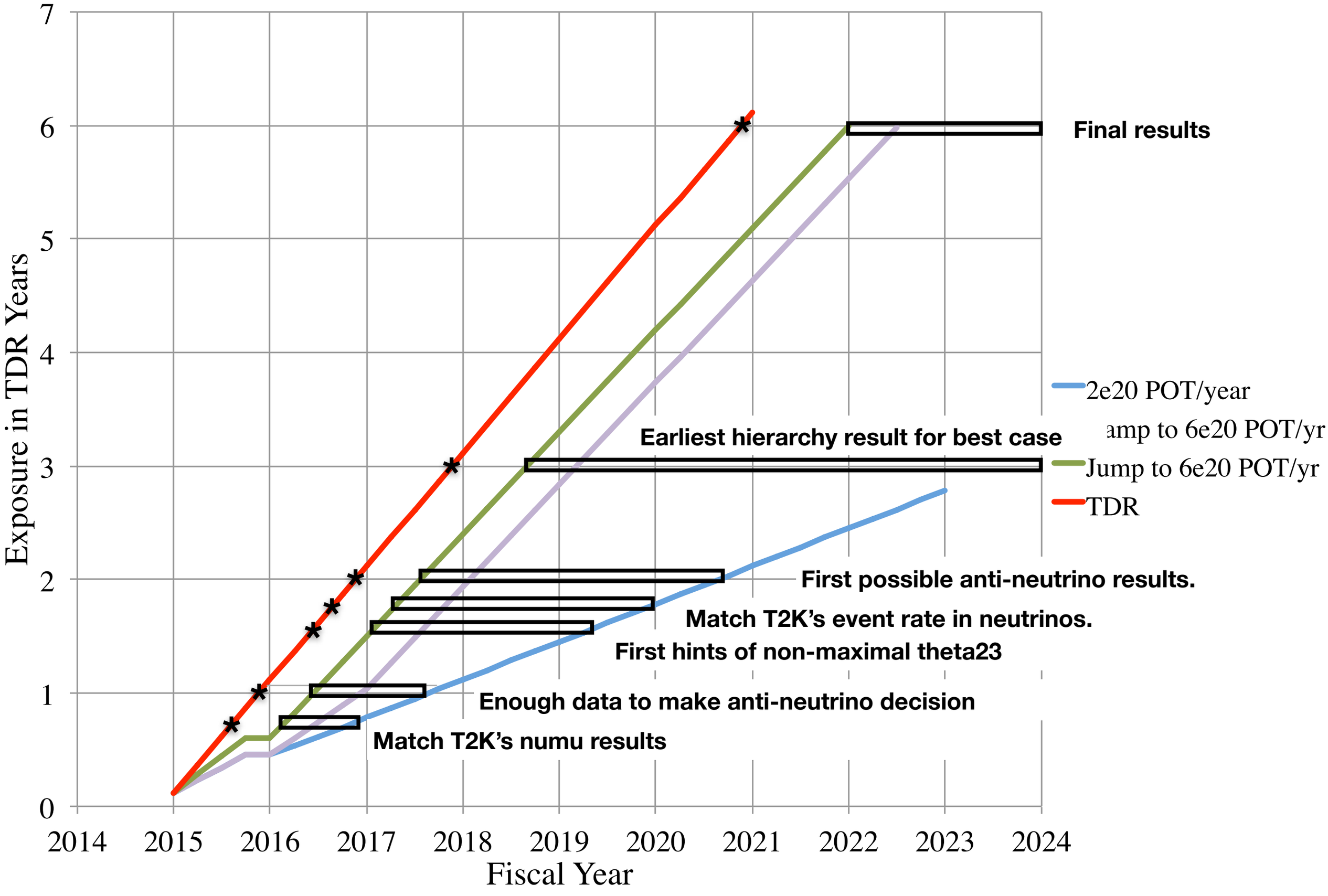
- I have made my own unofficial guesses for proton performance beyond FY15

- What if 2e20 POT/yr continues?

- What if we get 2e20 this year and have a 2-year ramp to 5.4E20 POT/year in out years (TDR 6E20 * 90% SY tax)

- What if we get 3e20 this year (“design” number) and jump to 5.4E20 POT/year in out years in FY16.


Exposure in TDR Years
0
1
2
3
4
5
6
7
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
Fiscal Year
2e20 POT/year
Ramp to 6e20 POT/yr
Jump to 6e20 POT/yr
TDR


Exposure in TDR Years
Fiscal Year
0
1
2
3
4
5
6
7
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
Final results
Earliest hierarchy result for best case
First possible anti-neutrino results.
Match T2K's event rate in neutrinos.
First hints of non-maximal theta23
Enough data to make anti-neutrino decision
Match T2K's numu results
2e20 POT/year
amp to 6e20 POT/yr
Jump to 6e20 POT/yr
TDR

Run plan for FY15

- **Physics running:**
  - None of our analysis milestones are met with <4e20 POT and hence no change of running configuration can be justified in FY15.
  - We will run neutrinos during all of FY15
- **Special runs**
  - We have no need for runs with special NuMI configurations but rather do have a need to maximize POT.

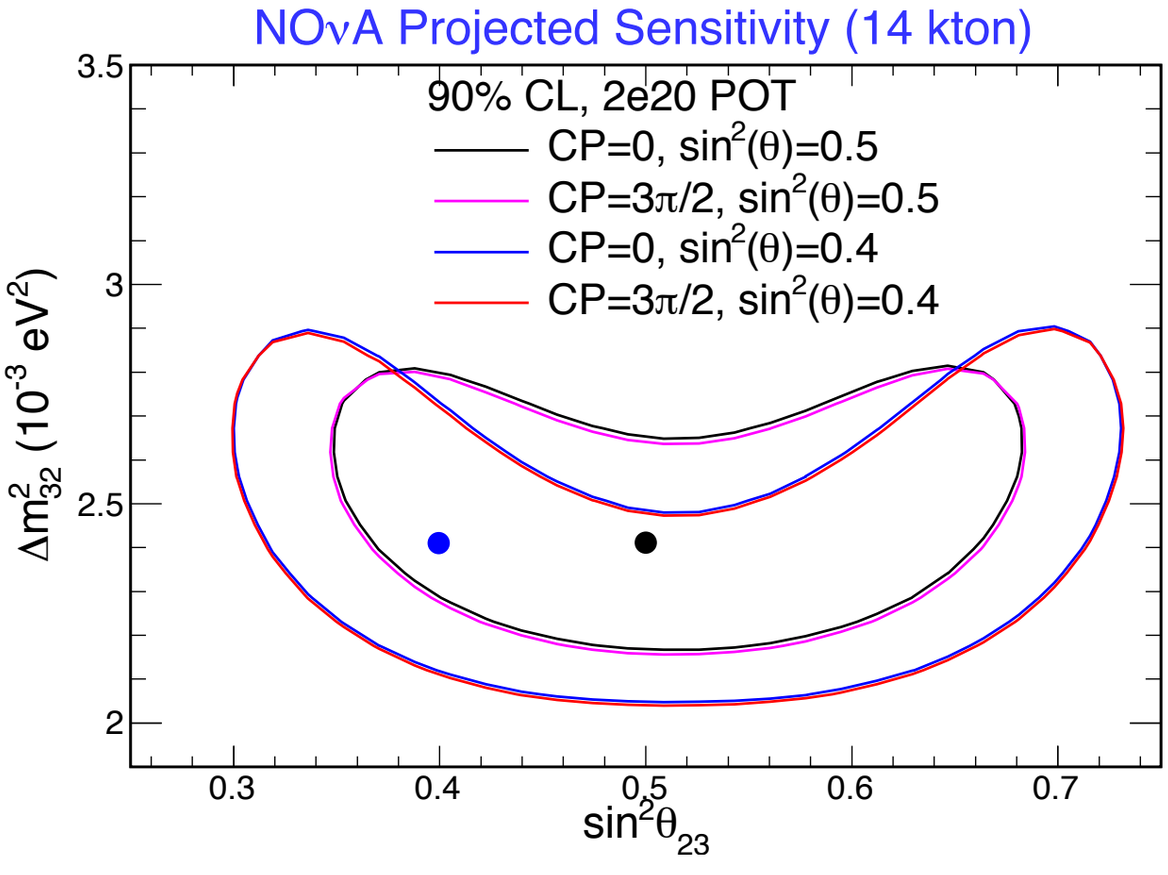
Summer 2015 conference results

- We are on track to release current data (~1E20 POT) this winter. These will be interesting to the community as they will be NOvA's first results
- Next results should be interesting to the community because of physics impact. As you've seen from the milestones, that requires at least 4 - 6E20 POT.
- With 2E20 POT expected in FY15 we would have a total of about 2E20 POT analyzed by summer 2015. This does not meet any new milestones beyond "first results"

$$\nu_\mu \rightarrow \nu_e$$

5.5 events signal on background of 2.9

$$\nu_\mu \rightarrow \nu_\mu$$



Summary

- The proposed 36E20 POT NOvA run addresses all the remaining questions in neutrino oscillations
  - Neutrino mass ordering
  - CP violation
  - Is θ_{23} maximal? What octant is it in?
- Experiment will release first results in FY15
- 2E20 POT in FY15 does not enable any additional physics milestones