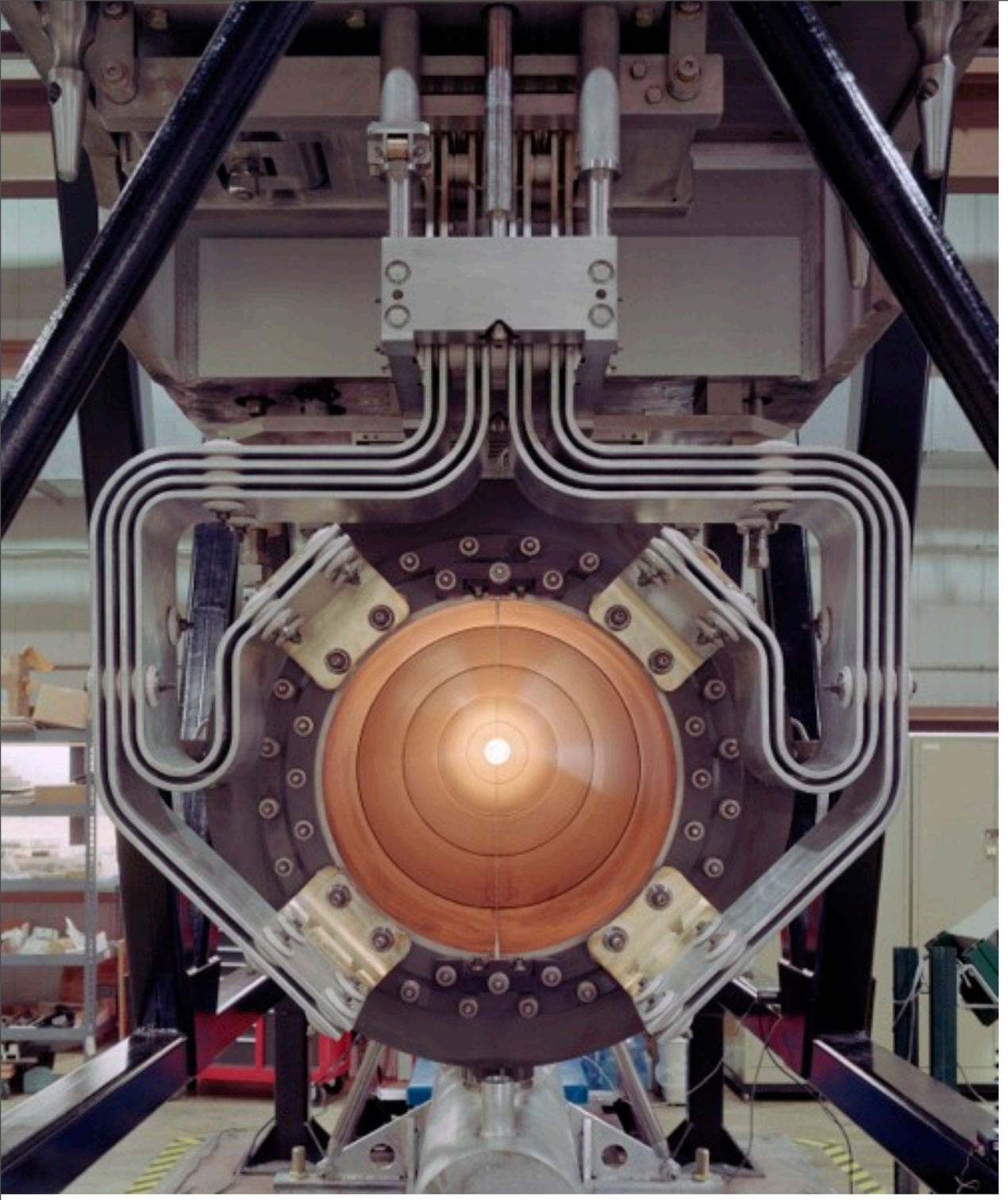
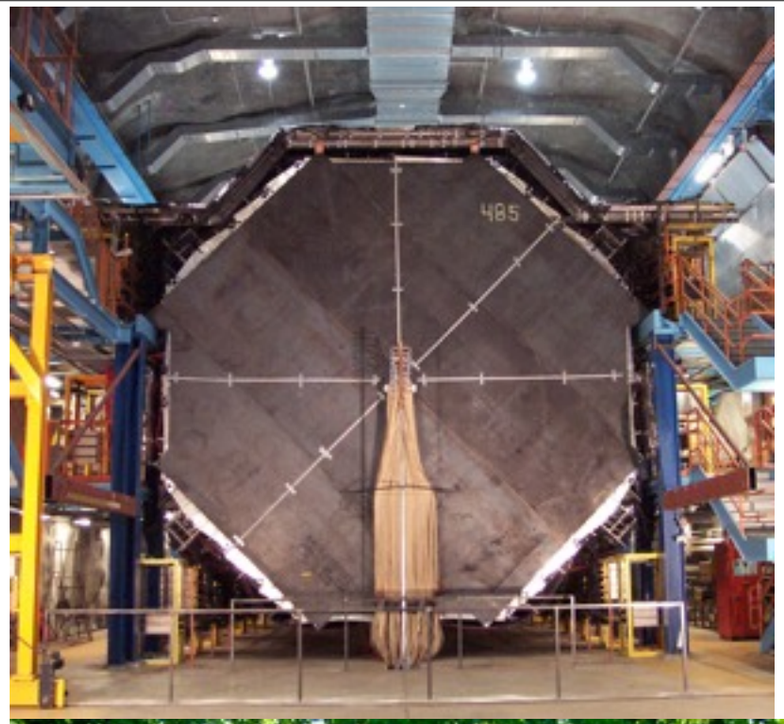
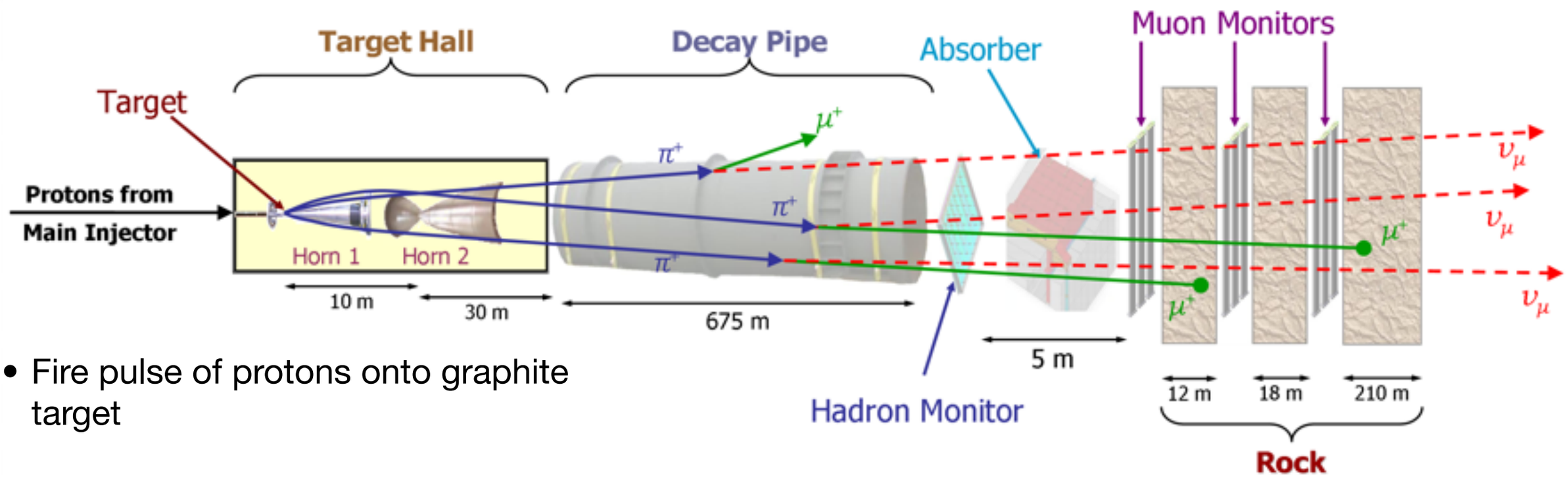




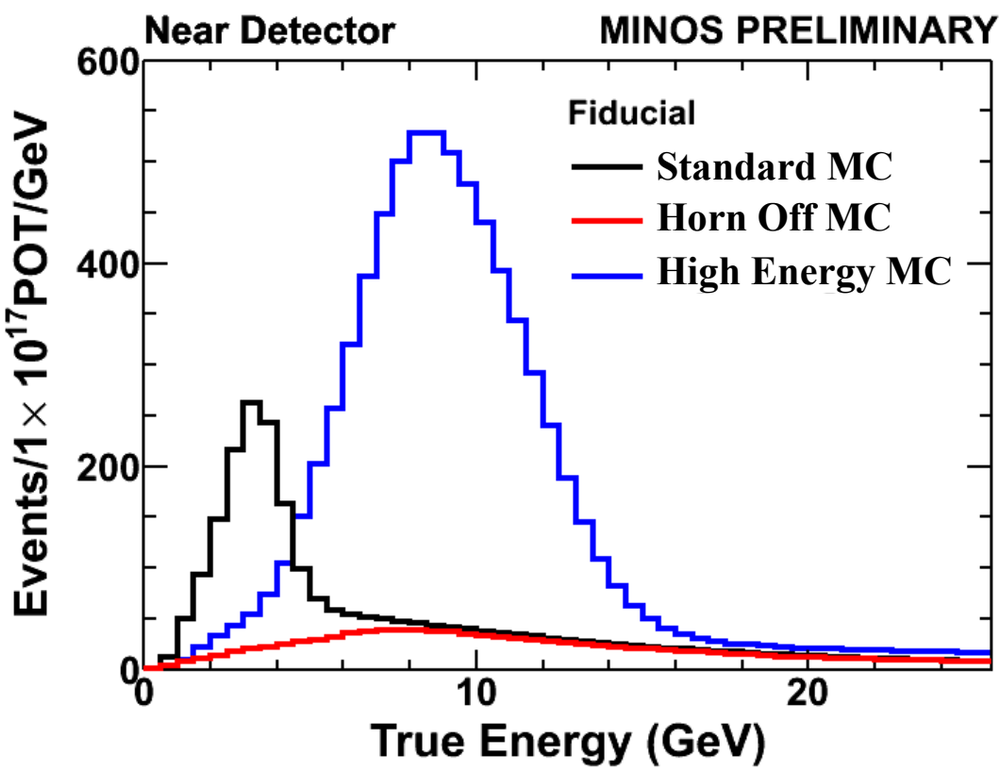
MINOS+ and GLADE: Maximising the Physics from the NuMI Beam

Ryan Nichol

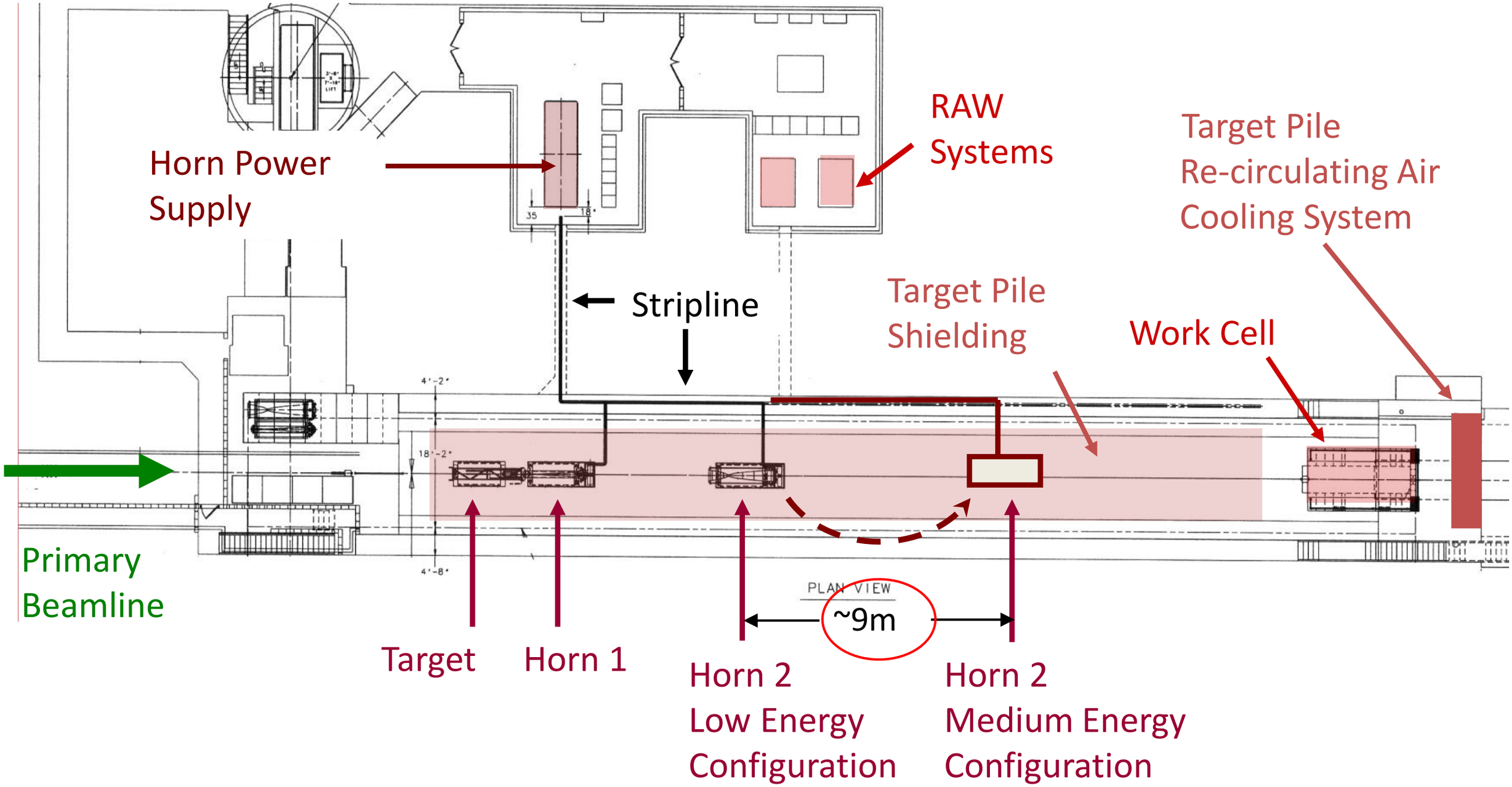
NuMI-MINOS Beam



- Fire pulse of protons onto graphite target
  - Focus secondary hadrons (pions and kaons) into decay pipe
  - Neutrino beam arises from subsequent decay in flight
- 3.0 x 10^{13} protons (120GeV) every 2.2s
- 350kW typical beam power



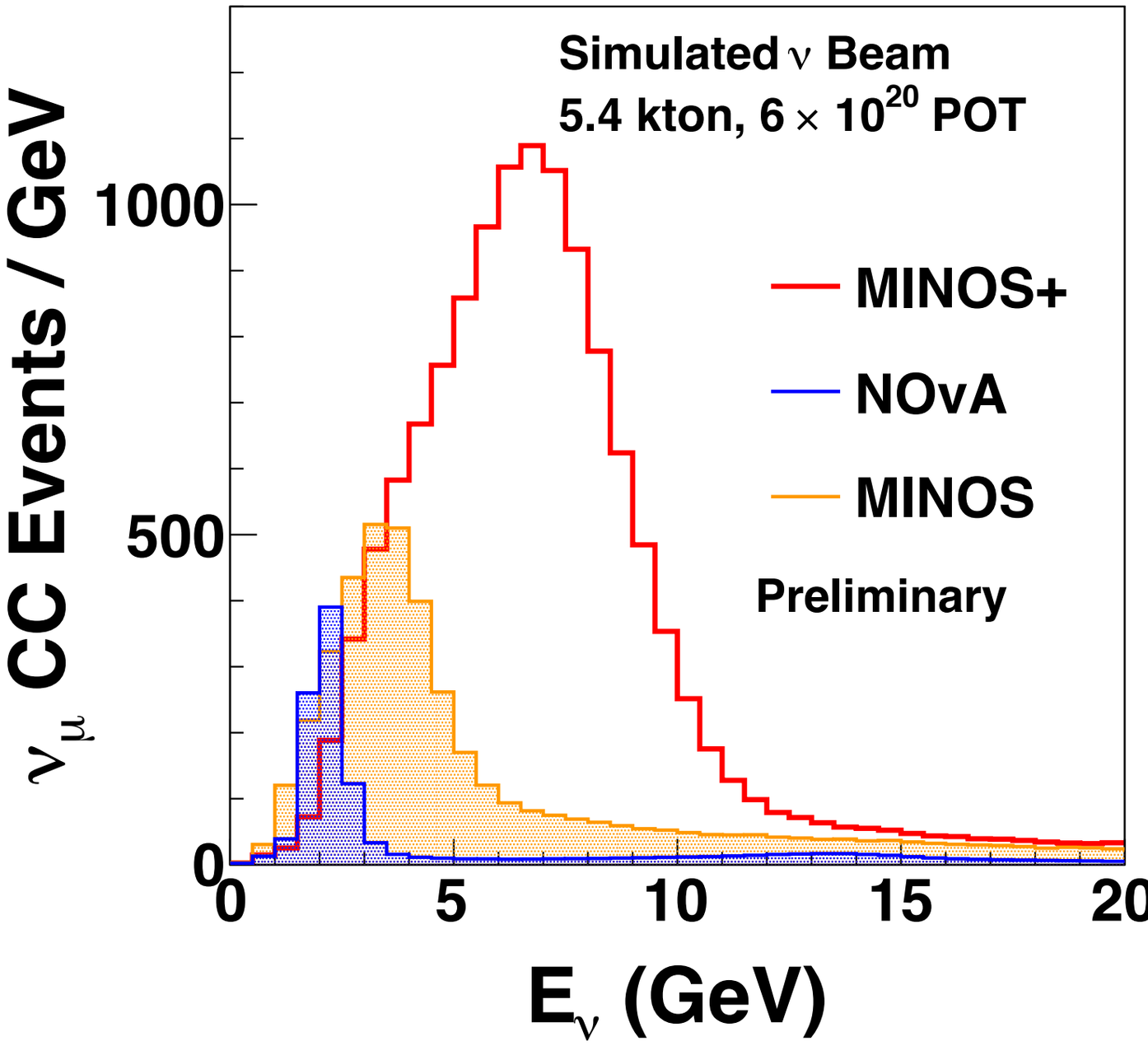
NuMI-NOvA Beam

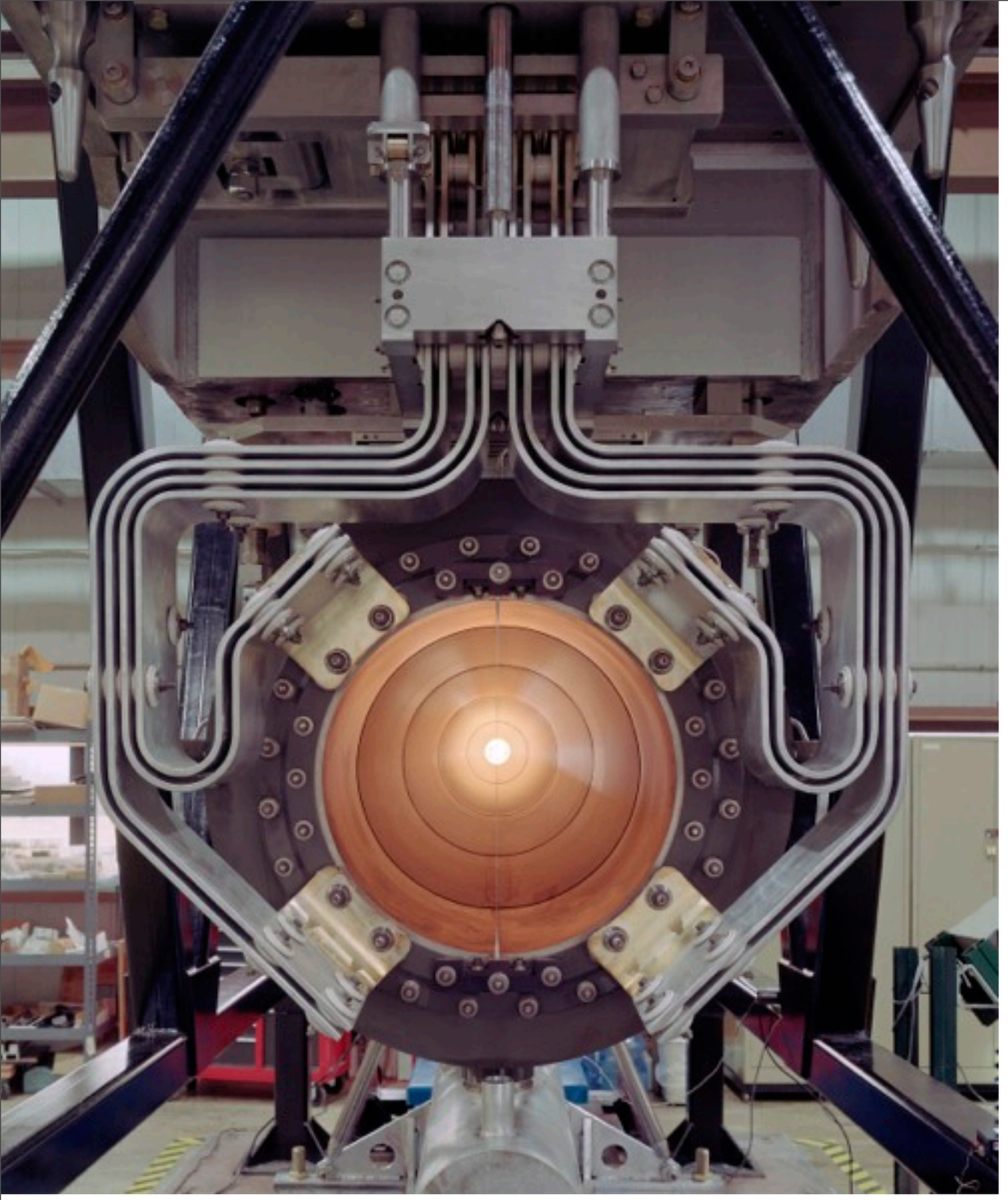


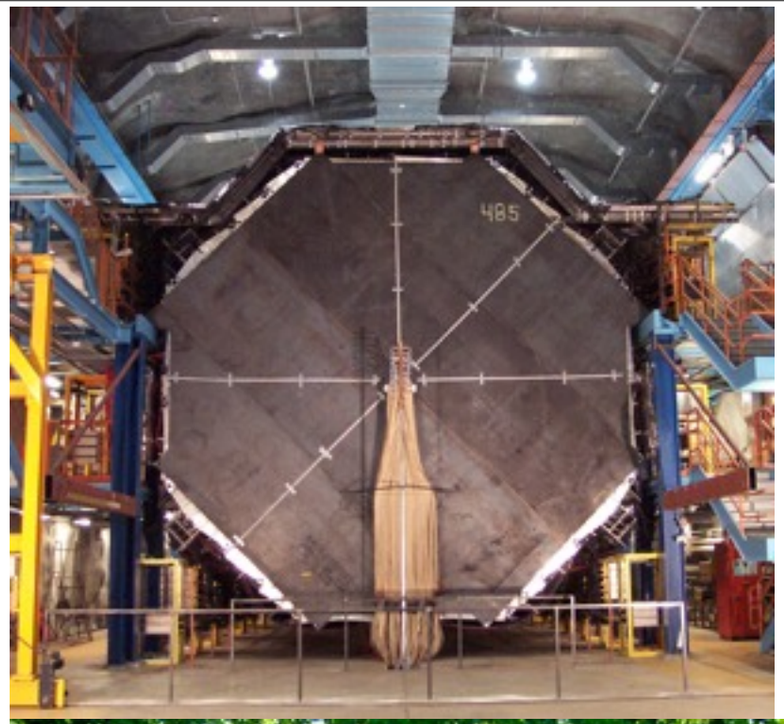
Details from Jim Hylen

NuMI-NOvA Beam

- After upgrade (and commissioning, etc.)
  - Power 375kW --> 750kW
    - <E> ~3GeV --> ~8GeV
- Primary purpose is off-axis beam to NOvA
- Bonus is high-intensity, high-energy beam aimed at the MINOS Far Detector





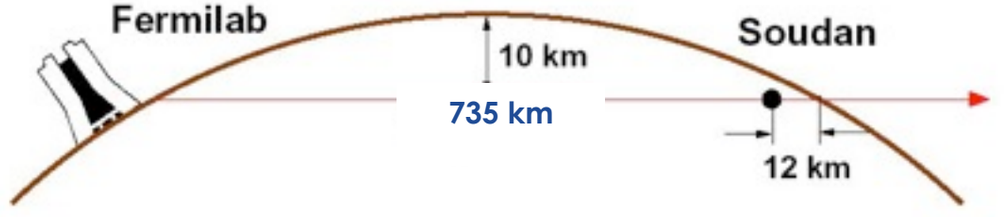


MINOS+: Old Detector New Physics

Ryan Nichol

The MINOS(+) Concept

- Basic Concept
  - Fire beam of neutrinos through the Earth
  - Measure energy and flavour content of beam at Near Detector
  - Measure energy and flavour content of beam at Far Detector
  - Interpret differences in terms of neutrino mixing

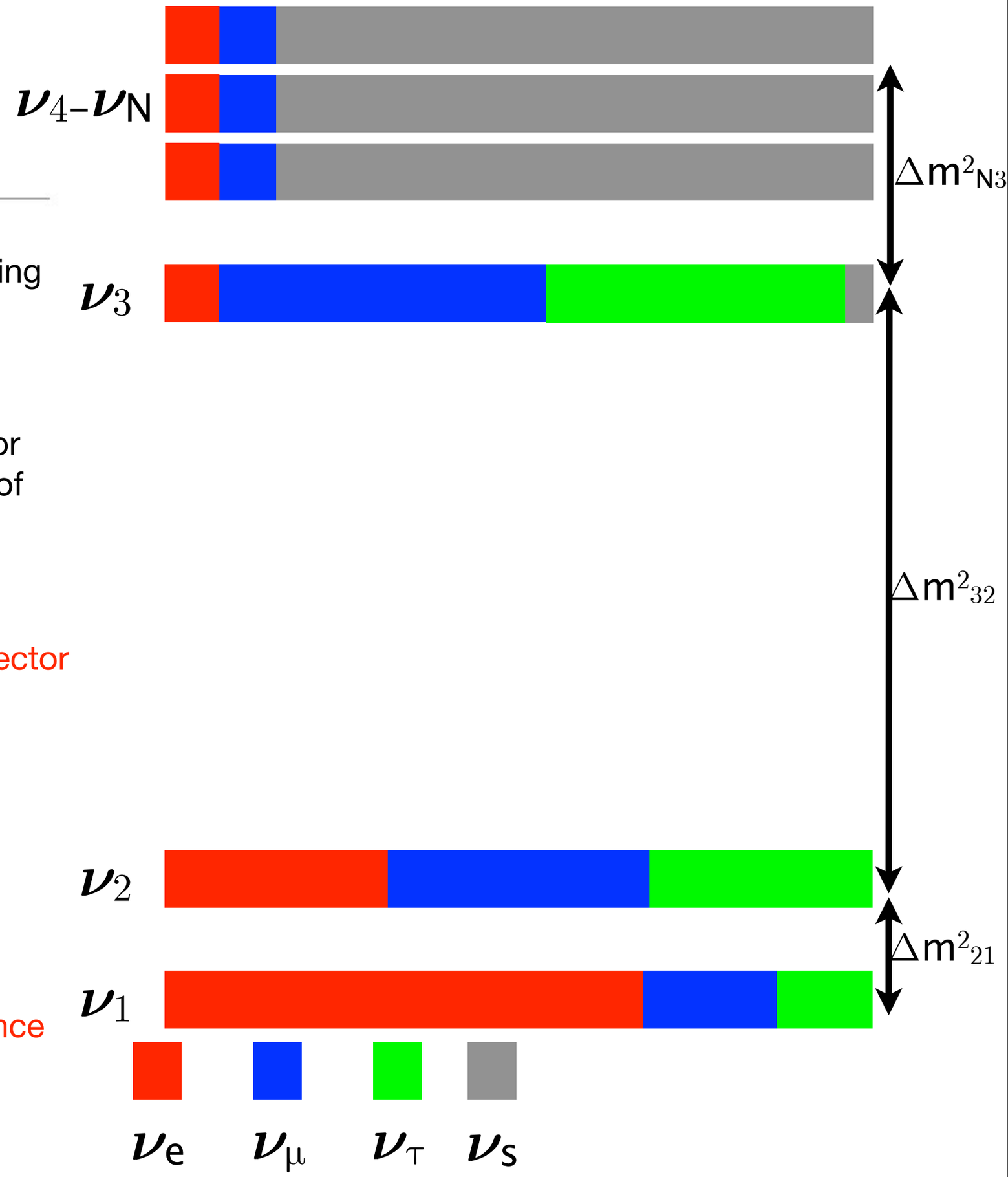


MINOS(+) Physics Goals

- Measurements of “atmospheric” mixing parameters through muon neutrino disappearance (and tau appearance)

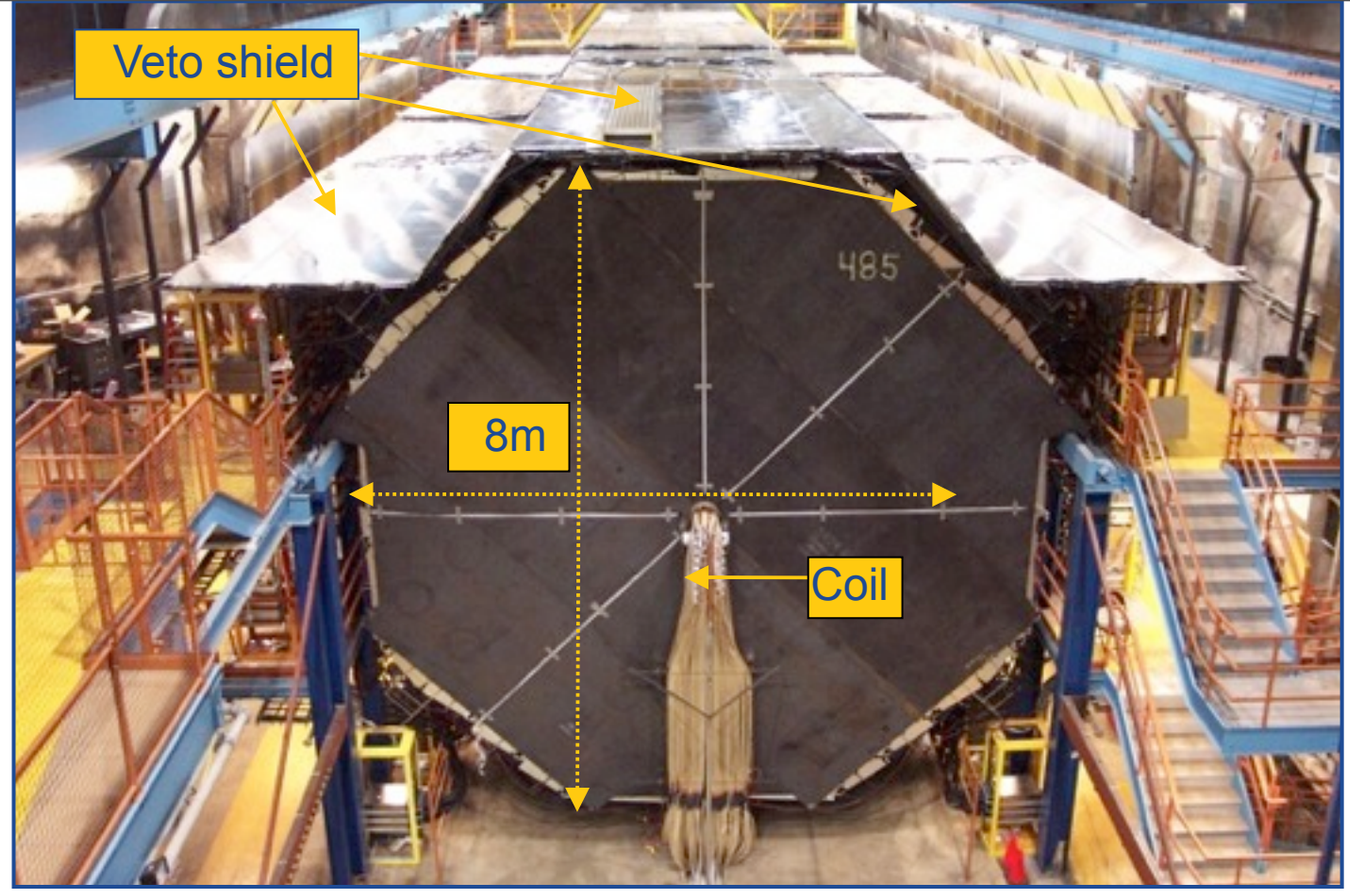
- Identify mass hierarchy and search for CP violation through measurements of subdominant oscillations of muon neutrinos to electron neutrinos

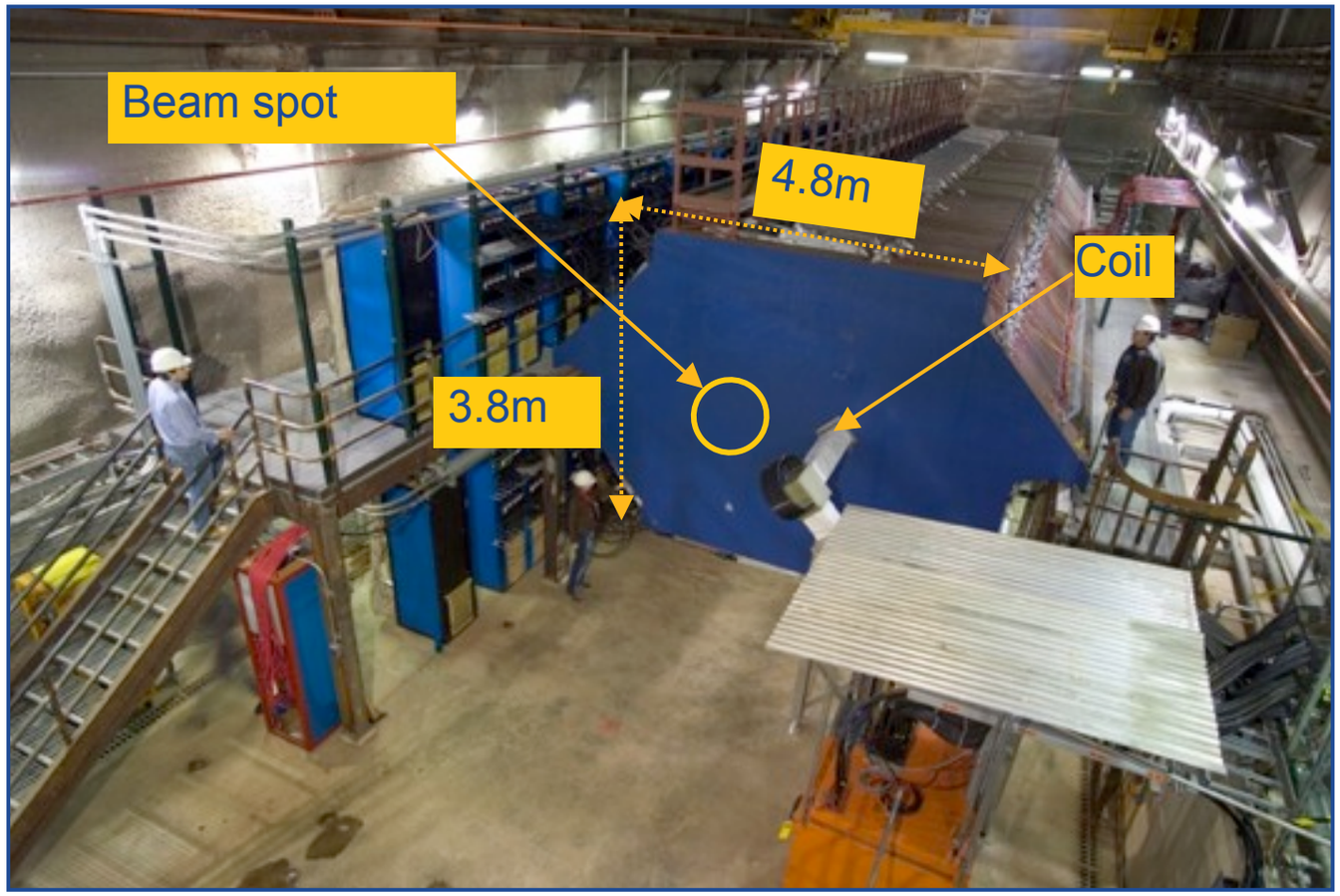
- Search for new physics in neutrino sector
  - Sterile neutrinos
  - Non-standard interactions
  - The unexpected
- Statistical evidence of tau appearance



MINOS Detectors

- 980 ton Near Detector
- 5.4 kiloton Far Detector
- Magnetised steel-scintillator tracking calorimeter
- Magnetised to 1.3T
- 1 inch thick steel, 1cm thick scintillator
- Similar design mitigates many systematic uncertainties
- Event-by-event charge discrimination of muons

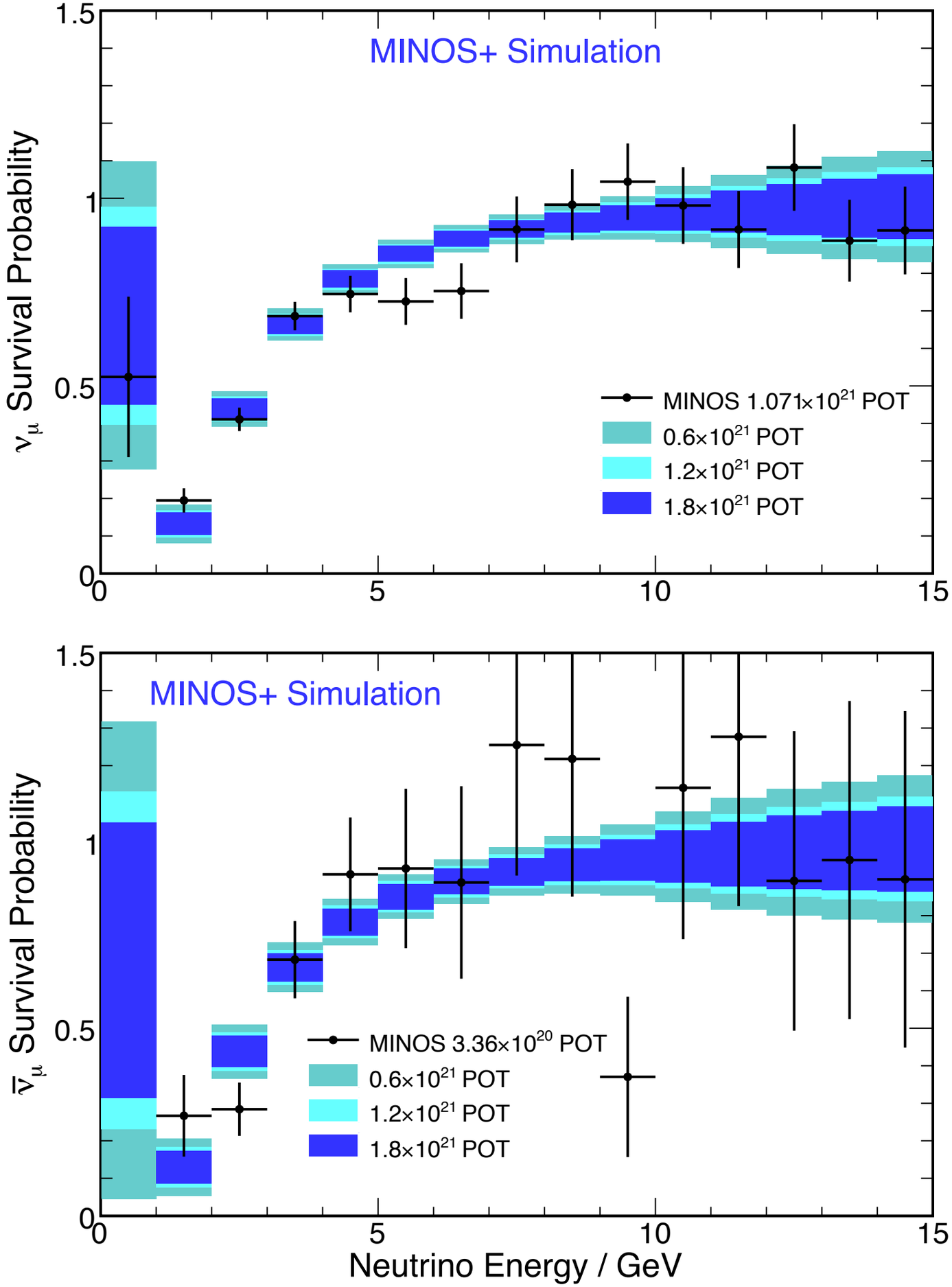




MINOS+ Muon Disappearance

- MINOS+ will measure muon neutrino disappearance with unprecedented precision in 4-10 GeV region

- Subdominant effects may become apparent in the data
  - Sterile neutrinos
  - Non-standard interactions
  - Sterile+large extra dimensions
  - Crazy stuff



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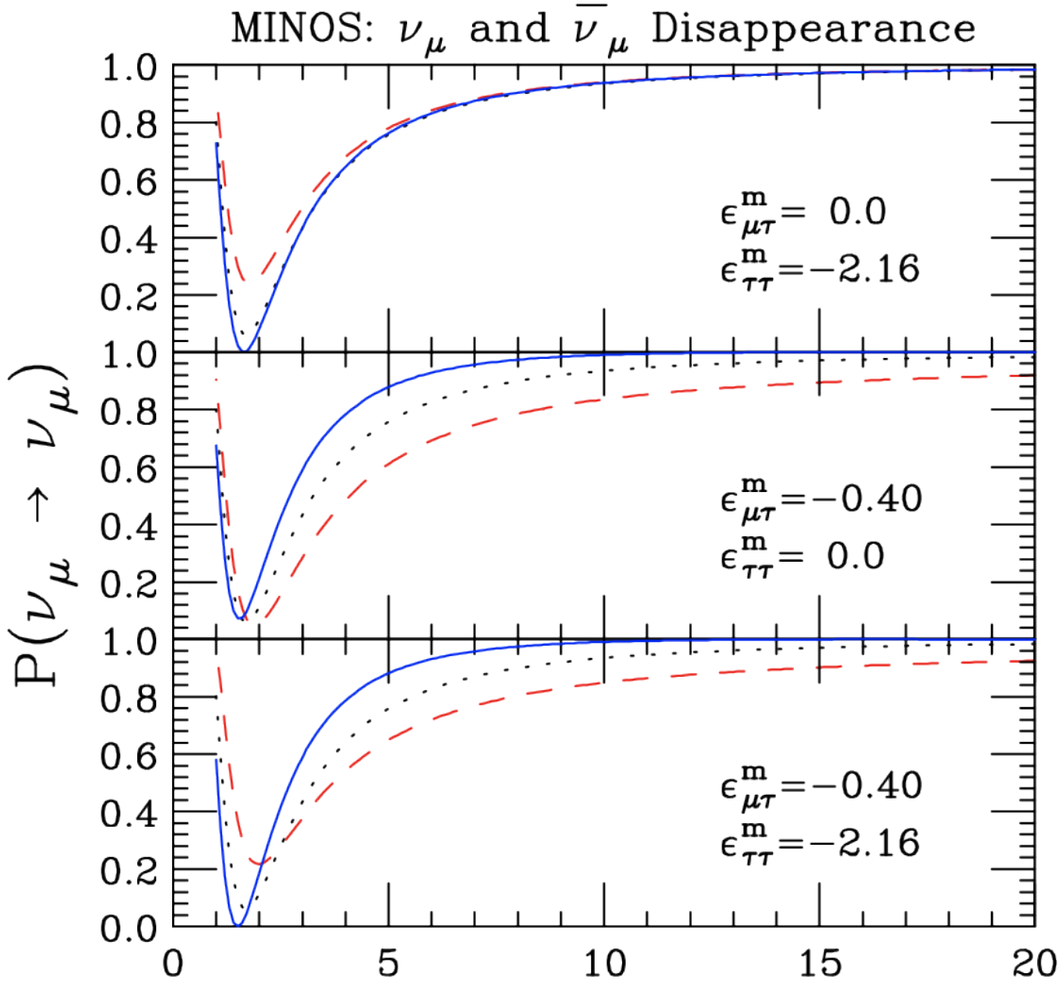
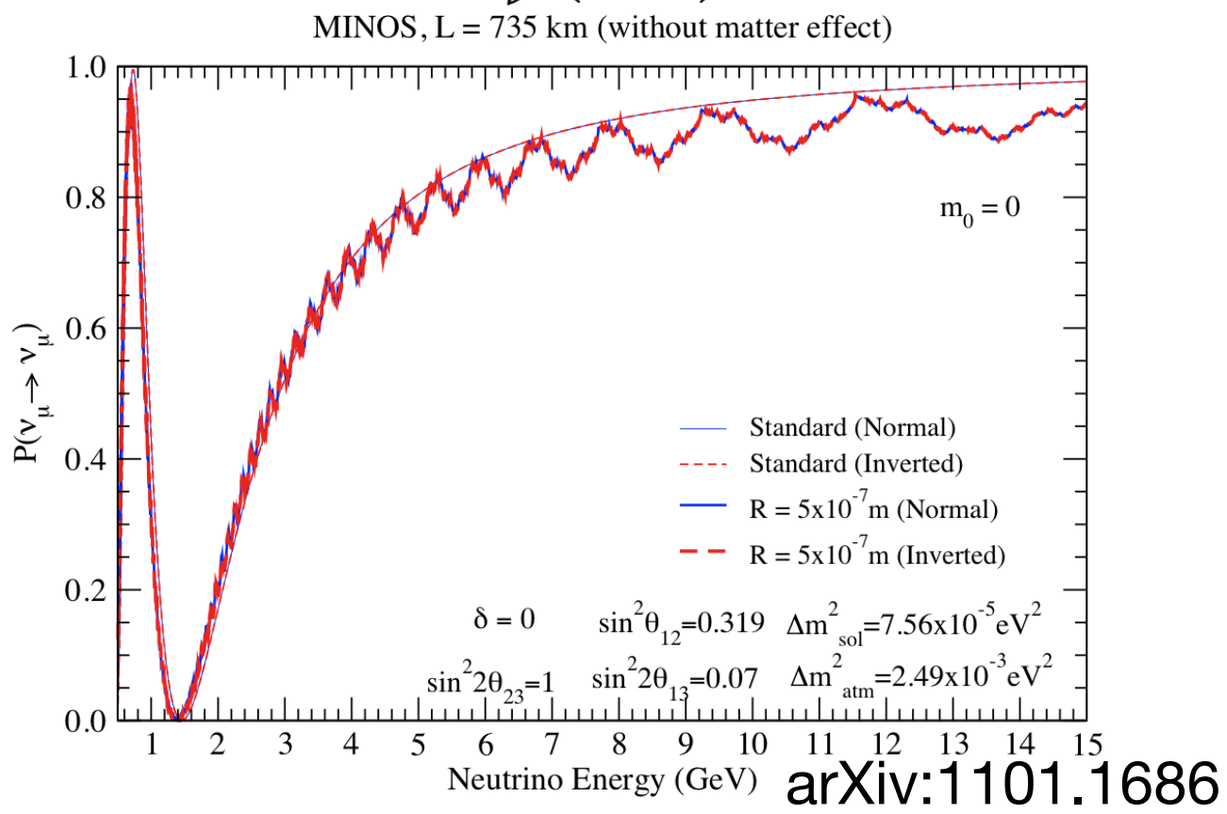




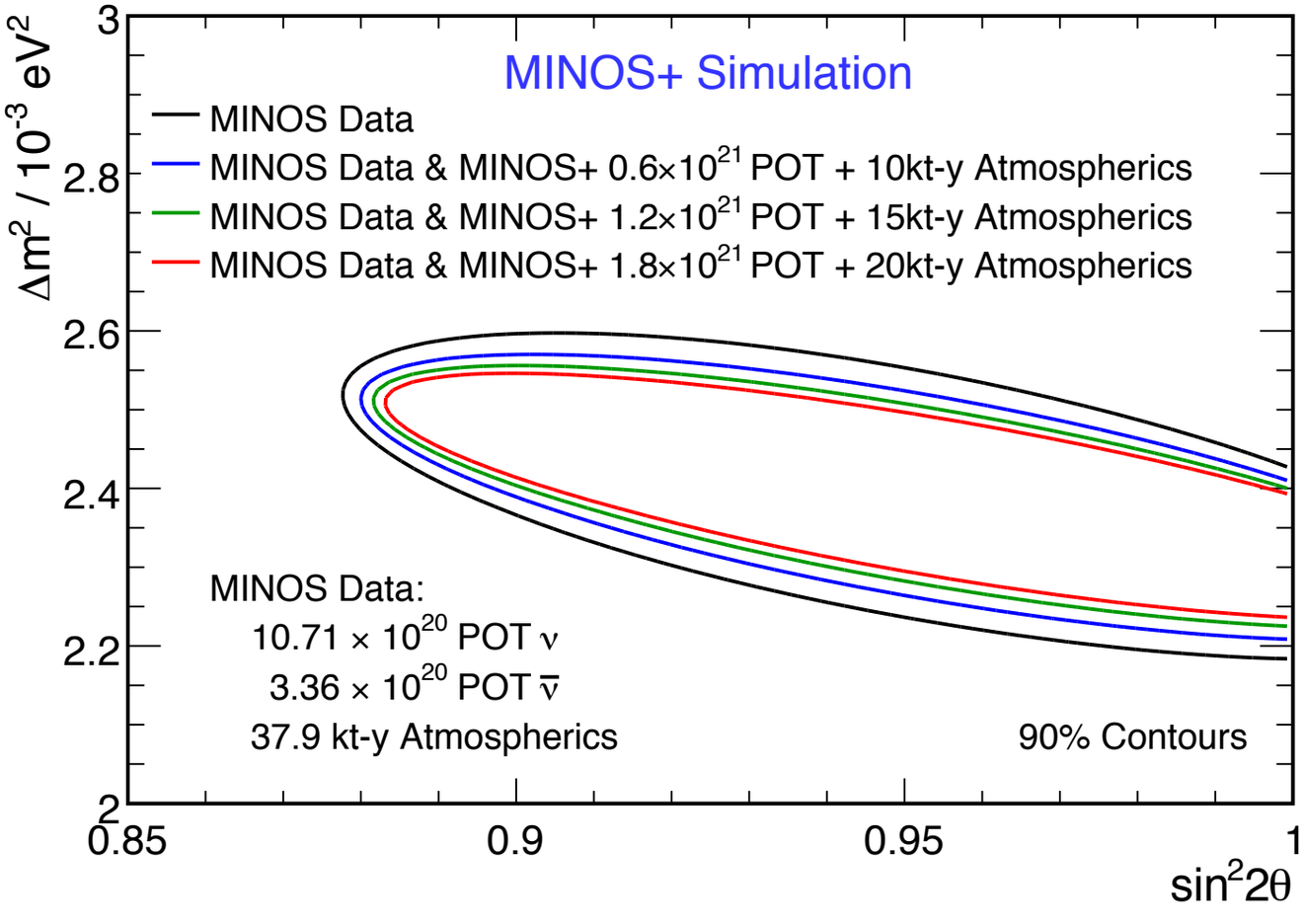
arXiv:1101.1686

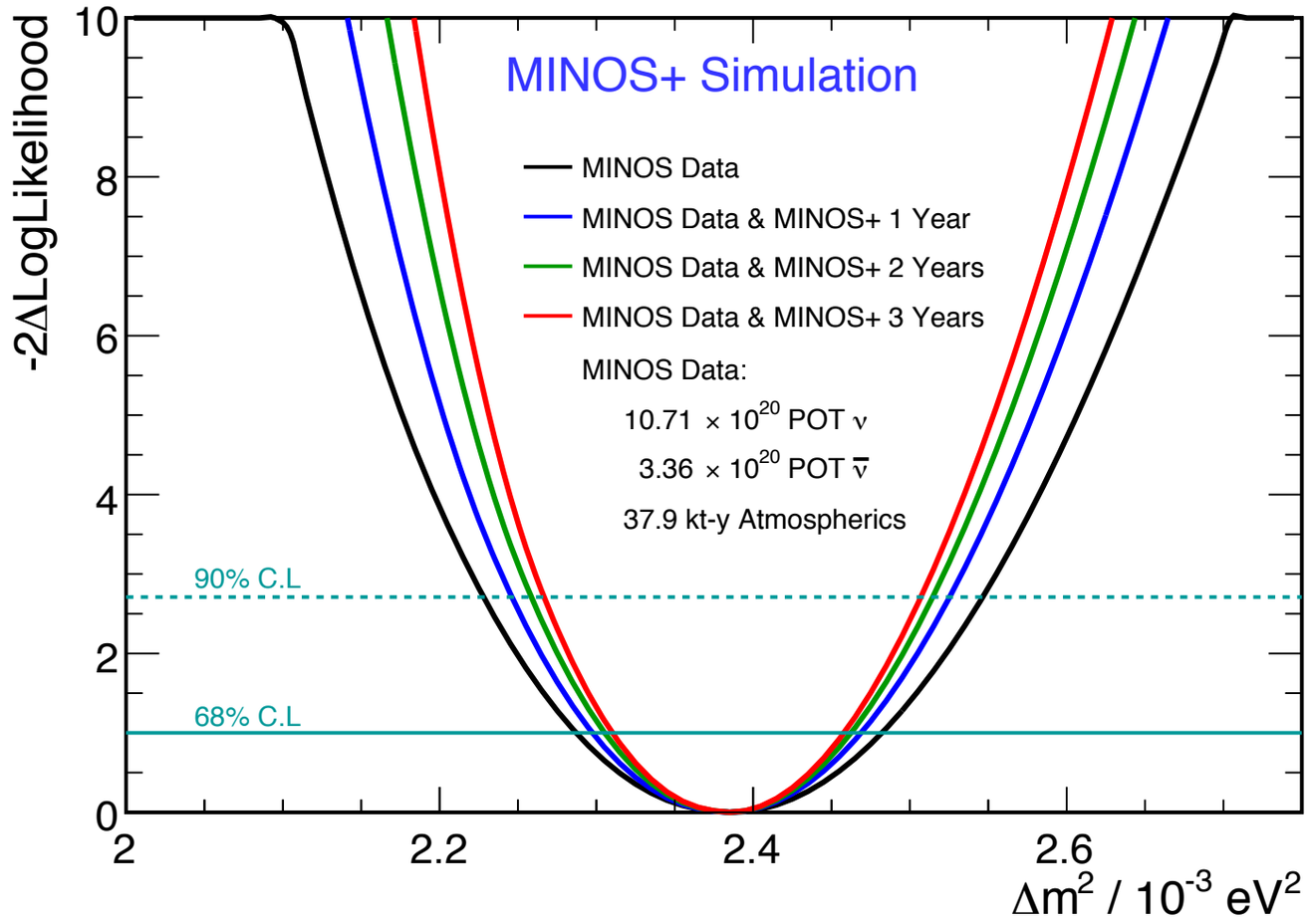
Atmospheric Sector

- MINOS+ will incrementally improve on the precision of the “atmospheric” oscillation parameters

- Not the main motivation for MINOS+

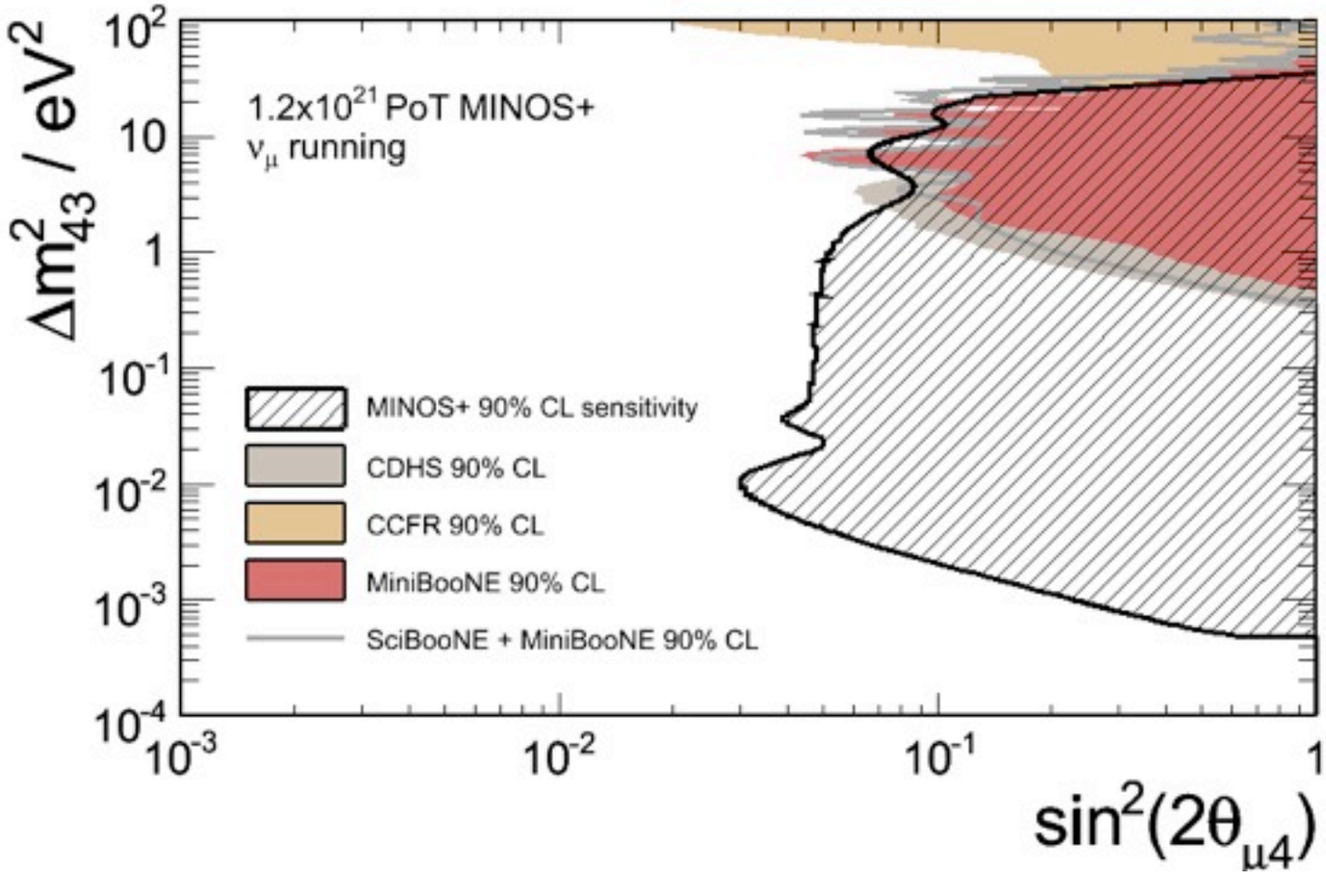
  - But will continue to be a competitive measurement of the mass-splitting in the short term

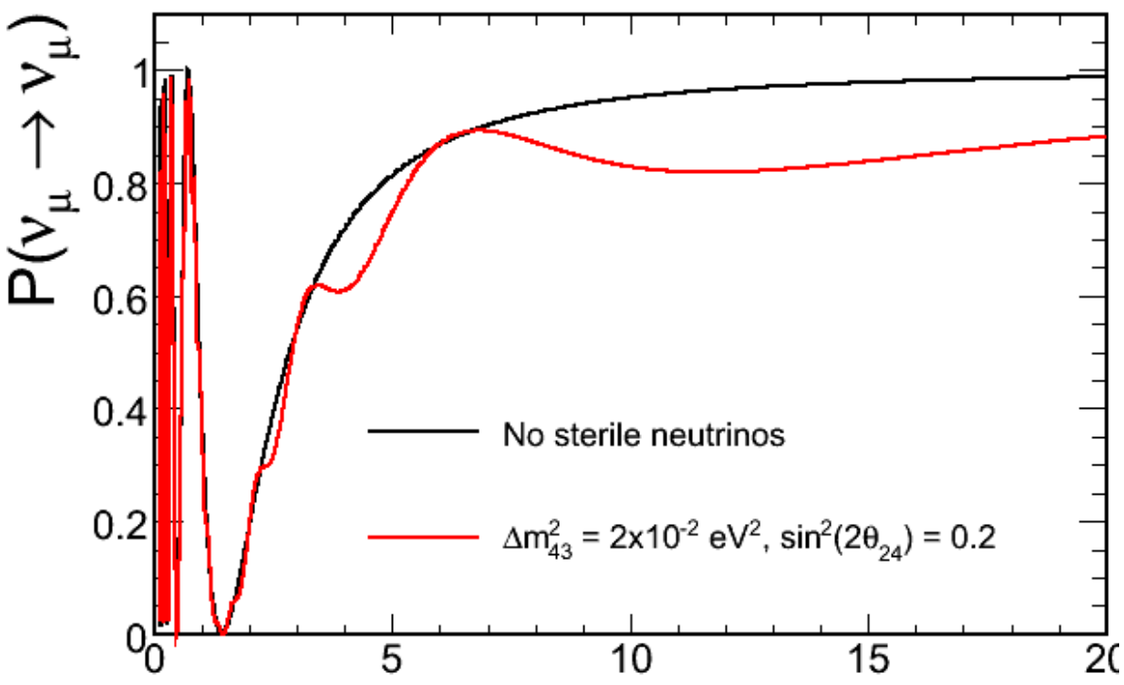


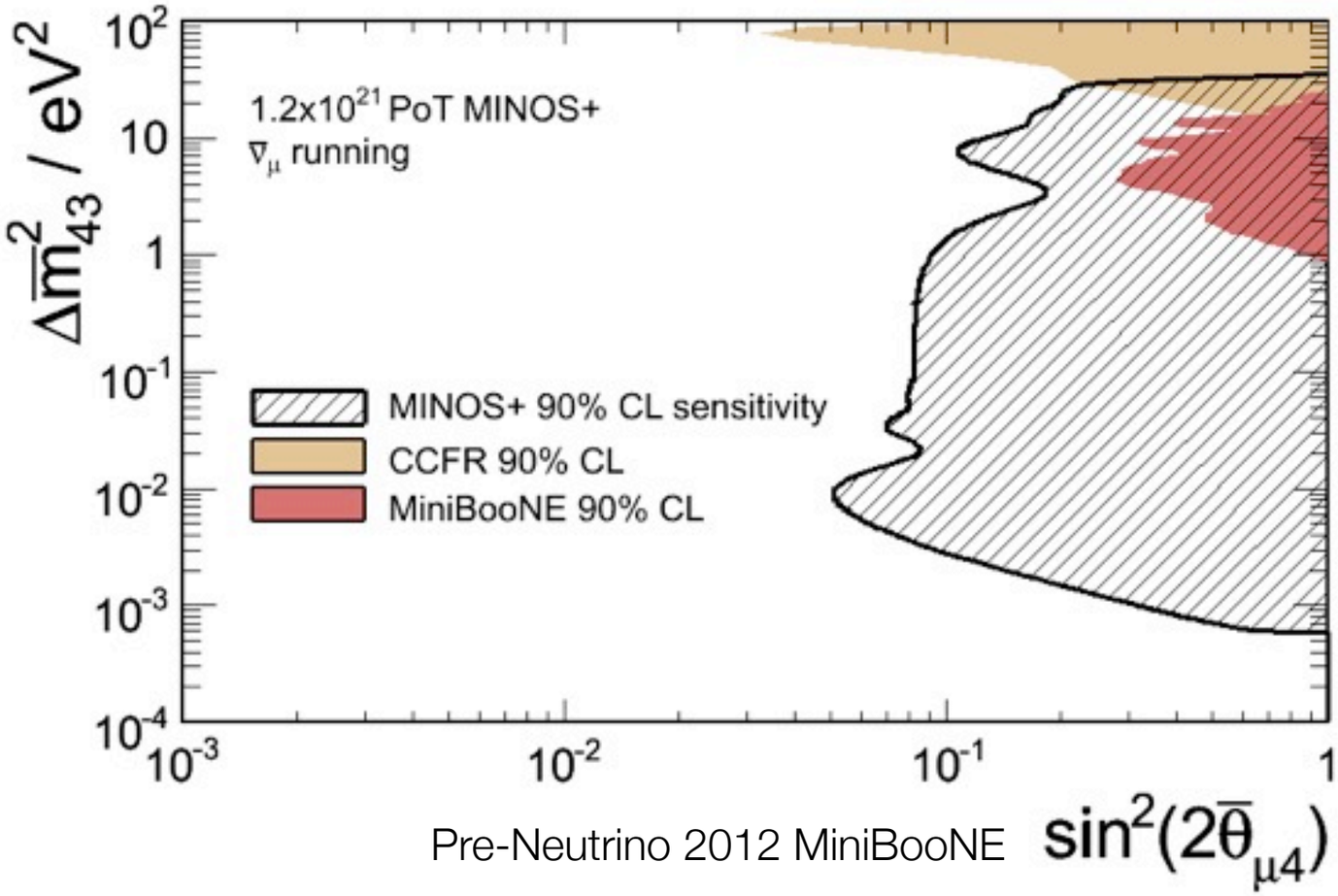


Sterile Neutrino Search

- Sterile mixing is a proxy for any new physics
- Shows up as a distortion to the (oscillated) CC and NC Far Detector spectra







Pre-Neutrino 2012 MiniBooNE

The MINOS+ vs LSND vs MiniBooNE Plot

- Can not have appearance without disappearance
- MINOS+ will (most likely) place limits on:

$$\sin^2 2\theta_{24} \text{ (vs } \Delta m^2_{41})$$

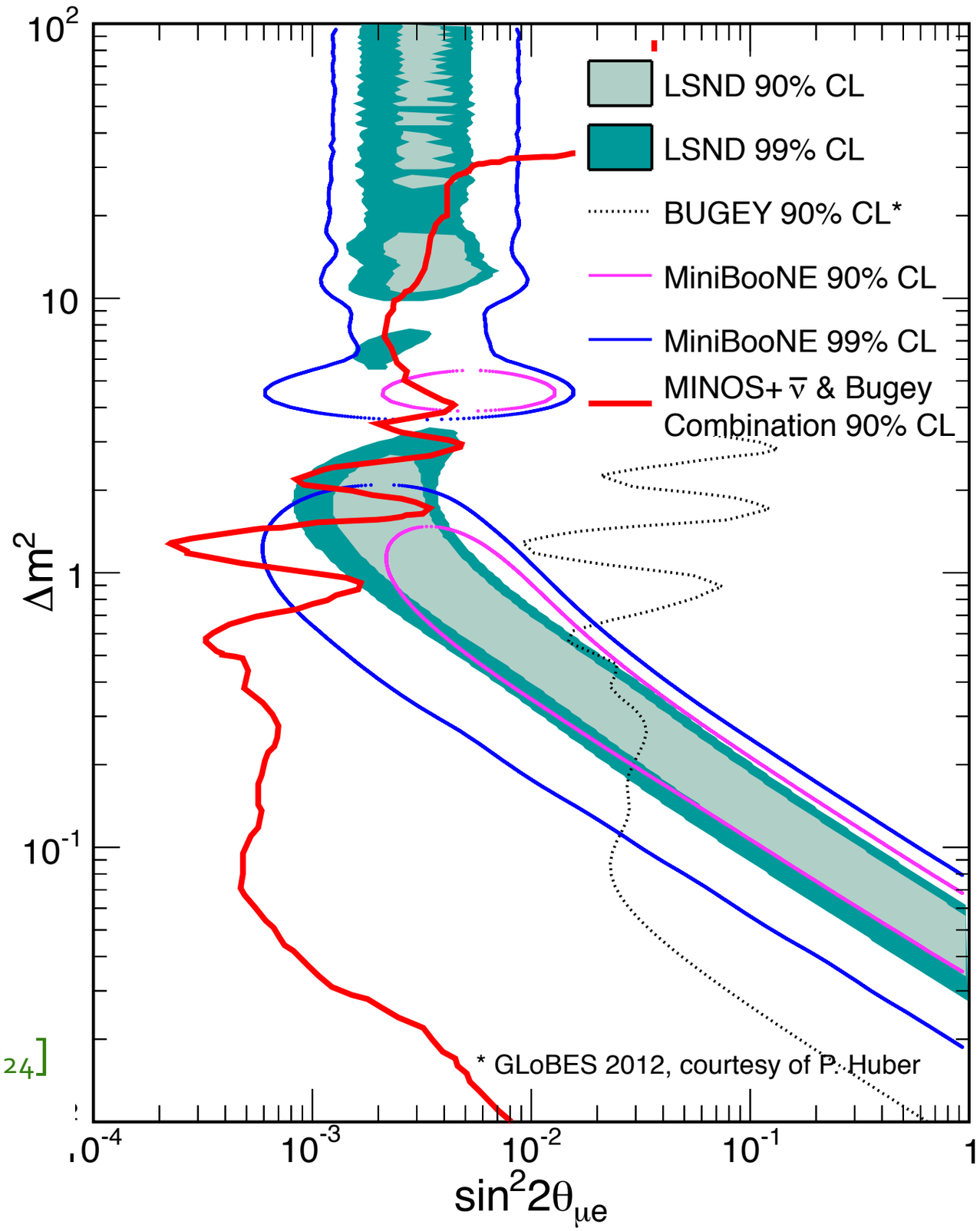
- Bugey (and other reactor experiments) placed limits on:

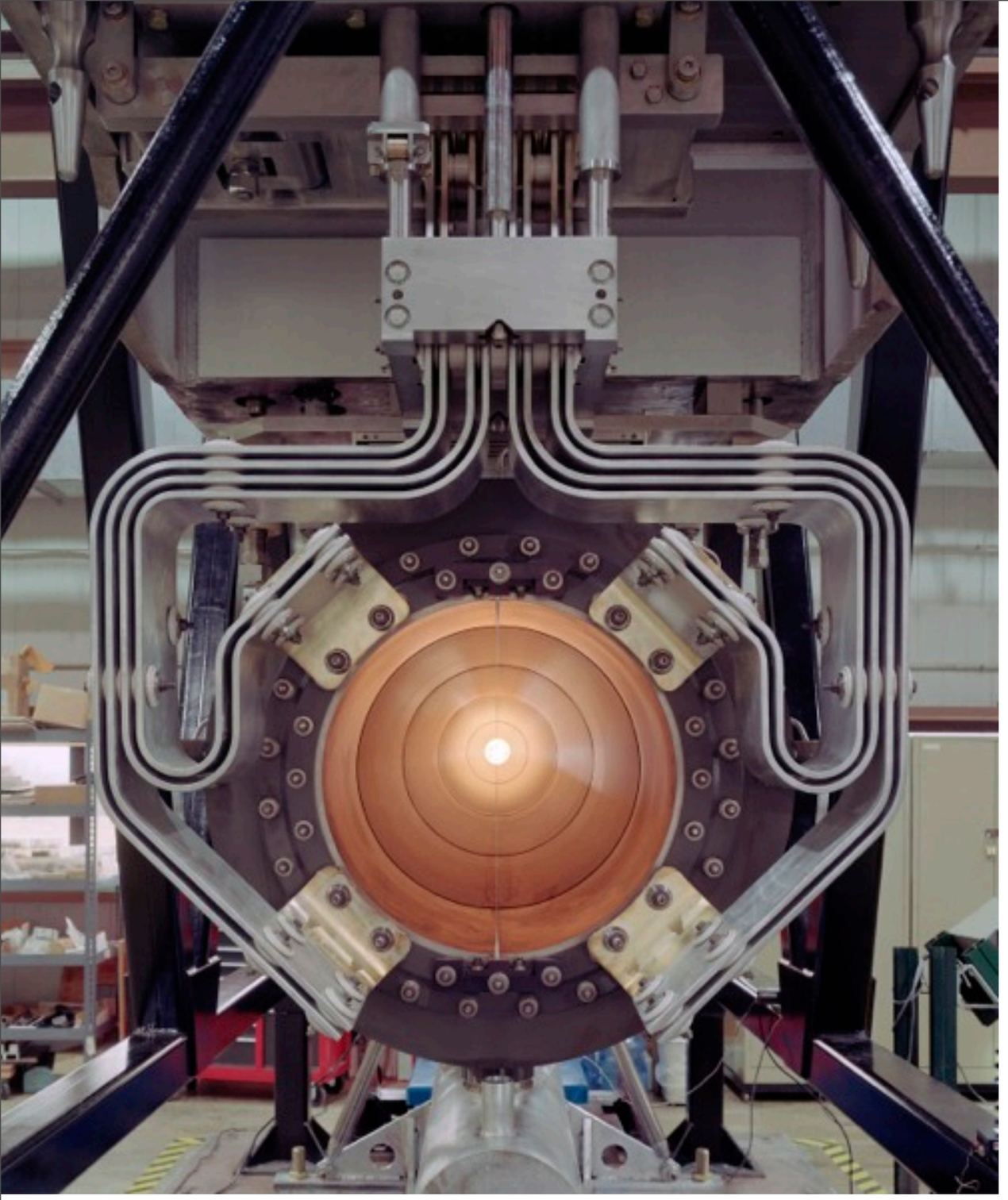
$$\sin^2 2\theta_{14} \text{ (vs } \Delta m^2_{41})$$

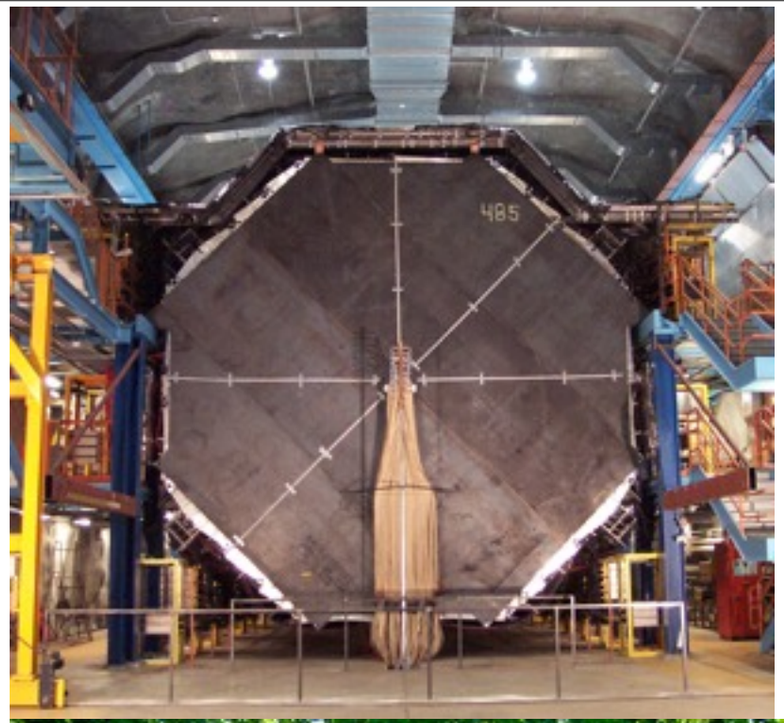
- LSND/MiniBoone measure:

$$\sin^2 2\theta_{\mu e} = 4|U_{e4}|^2 \times |U_{\mu 4}|^2 = 4\,[\sin^2\theta_{14}] \times [\cos^2\theta_{14} \sin^2\theta_{24}]$$
$$= \sin^2 2\theta_{14} \times \sin^2\theta_{24}$$

- Combine Bugey&MINOS+





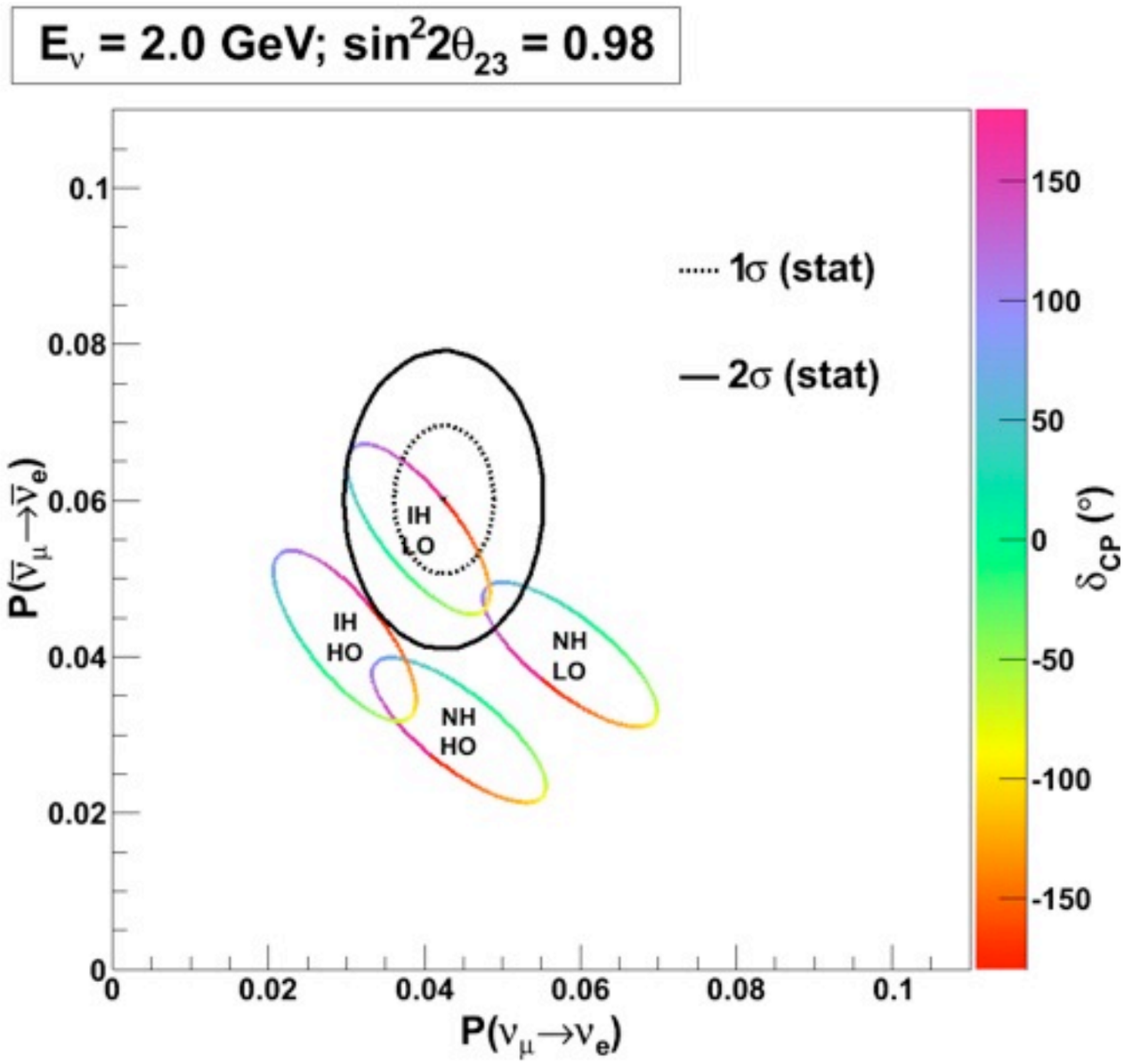


GLADE:
New Detector Old Physics

Ryan Nichol

Global Liquid Argon Detector Experiment

- The last mixing angle has been measured and is large
- Mass hierarchy and delta are the new targets
- A liquid argon detector in the NuMI beam would increase the sensitivity of NOvA and provide an engineering testing platform for future (100kT) detectors
- Relatively cheap (50-100M$) and quick (2017+) experiment
- Following SOI have been asked to submit a proposal to Fermilab



Example:
3+3 years of running of NOvA

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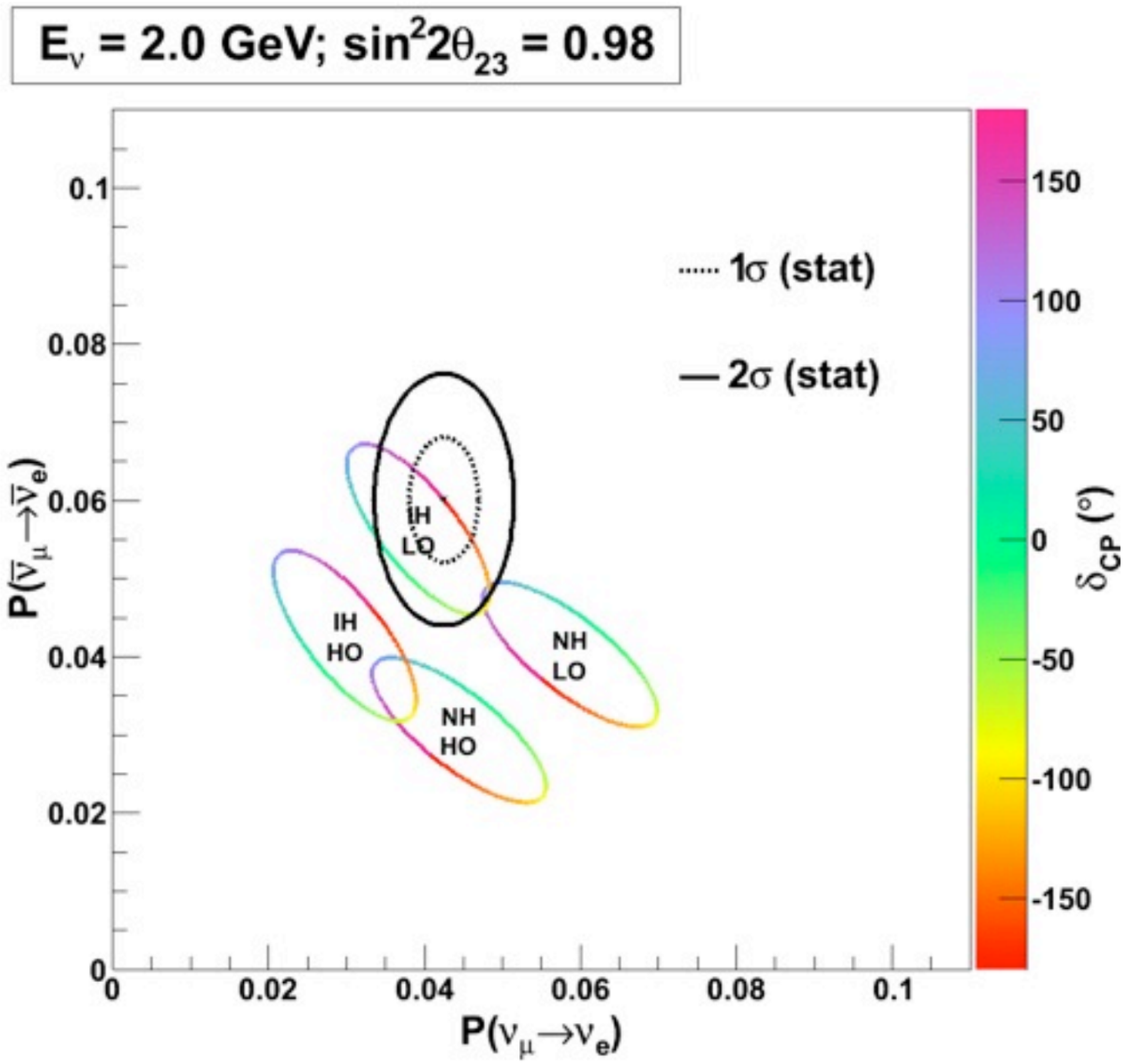

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3+3 years of GLADE

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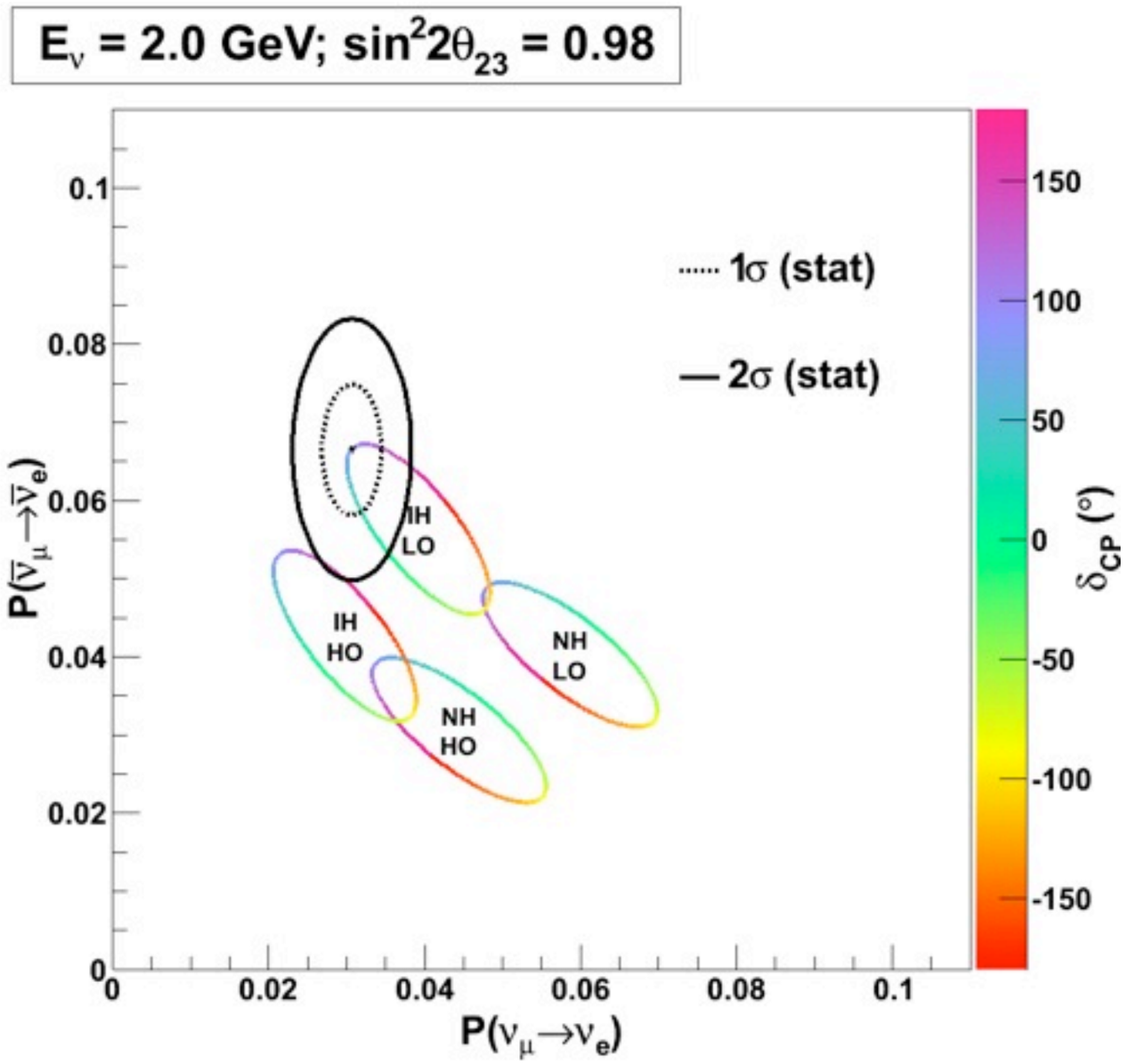
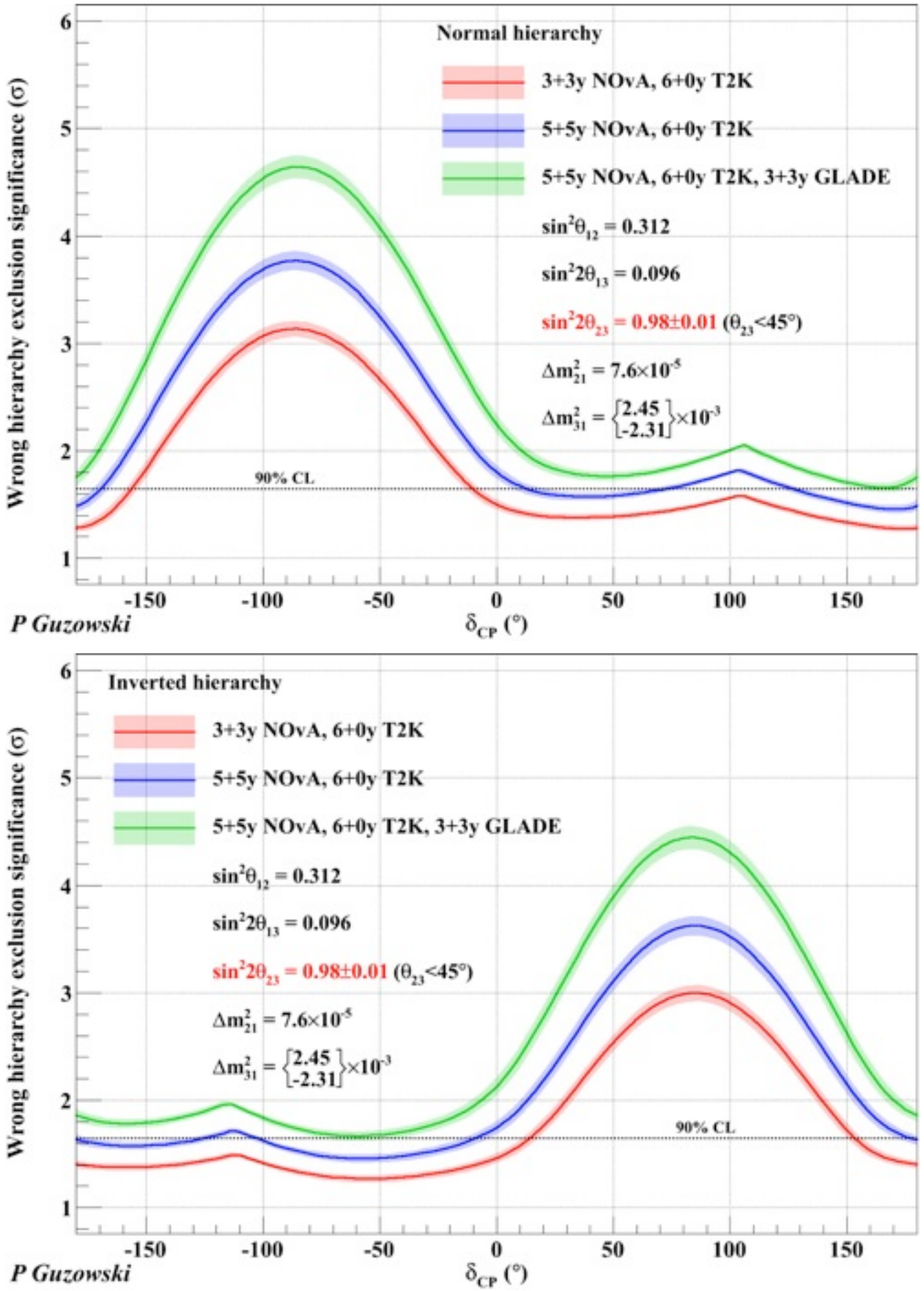


Example:
3+3 years of running of NOvA
3+3 years of GLADE

Mass Hierarchy

- Physics reach of GLADE is similar to NOvA
  - NOvA+GLADE = 2 NOvA
- Sensitivities assume we know $\sin^2 2\theta_{23}$ to 0.01 by 2020
- The (less sensitive) lower octant is assumed
- Extends the three sigma reach of NOvA+T2K, but need to get lucky



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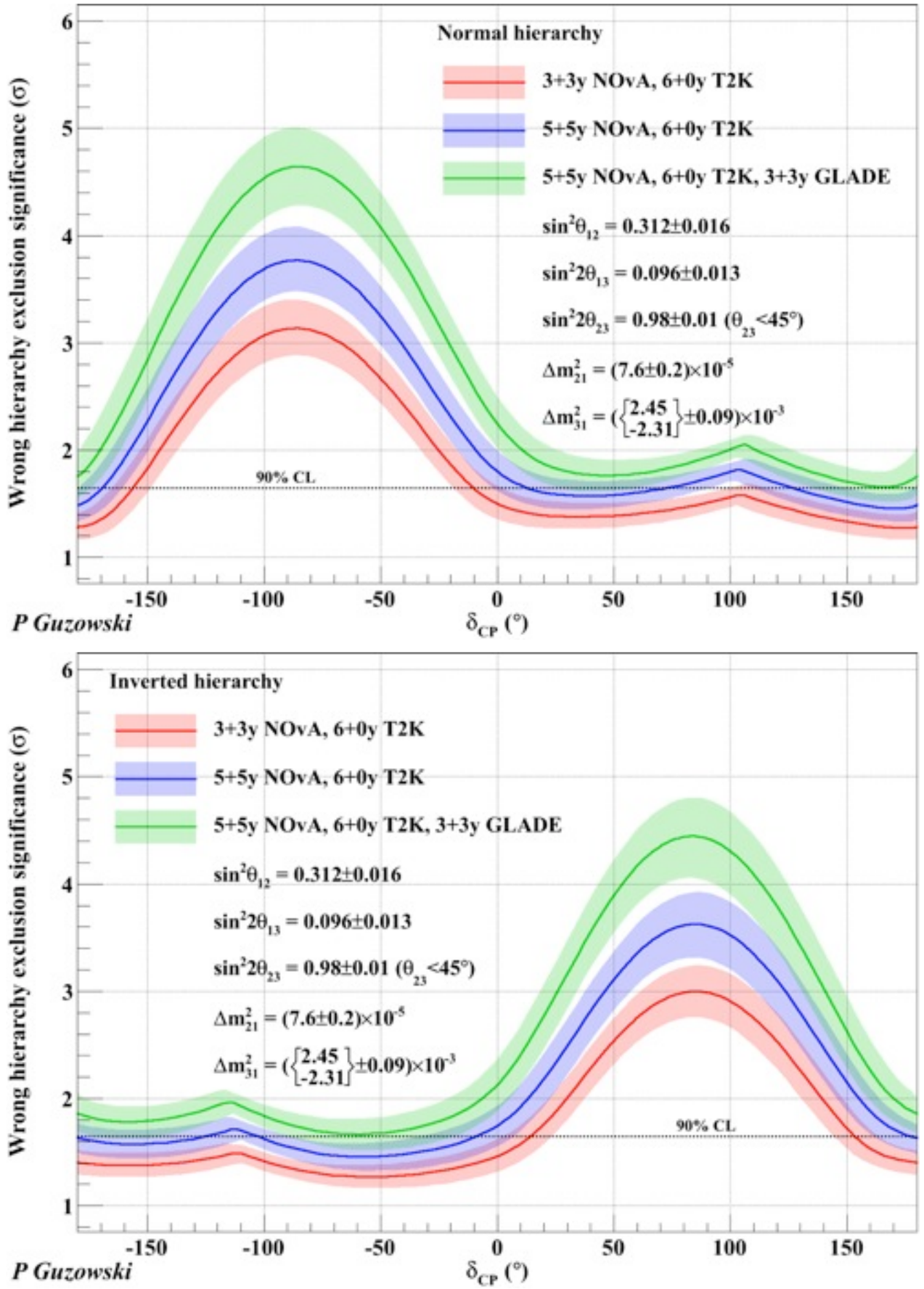
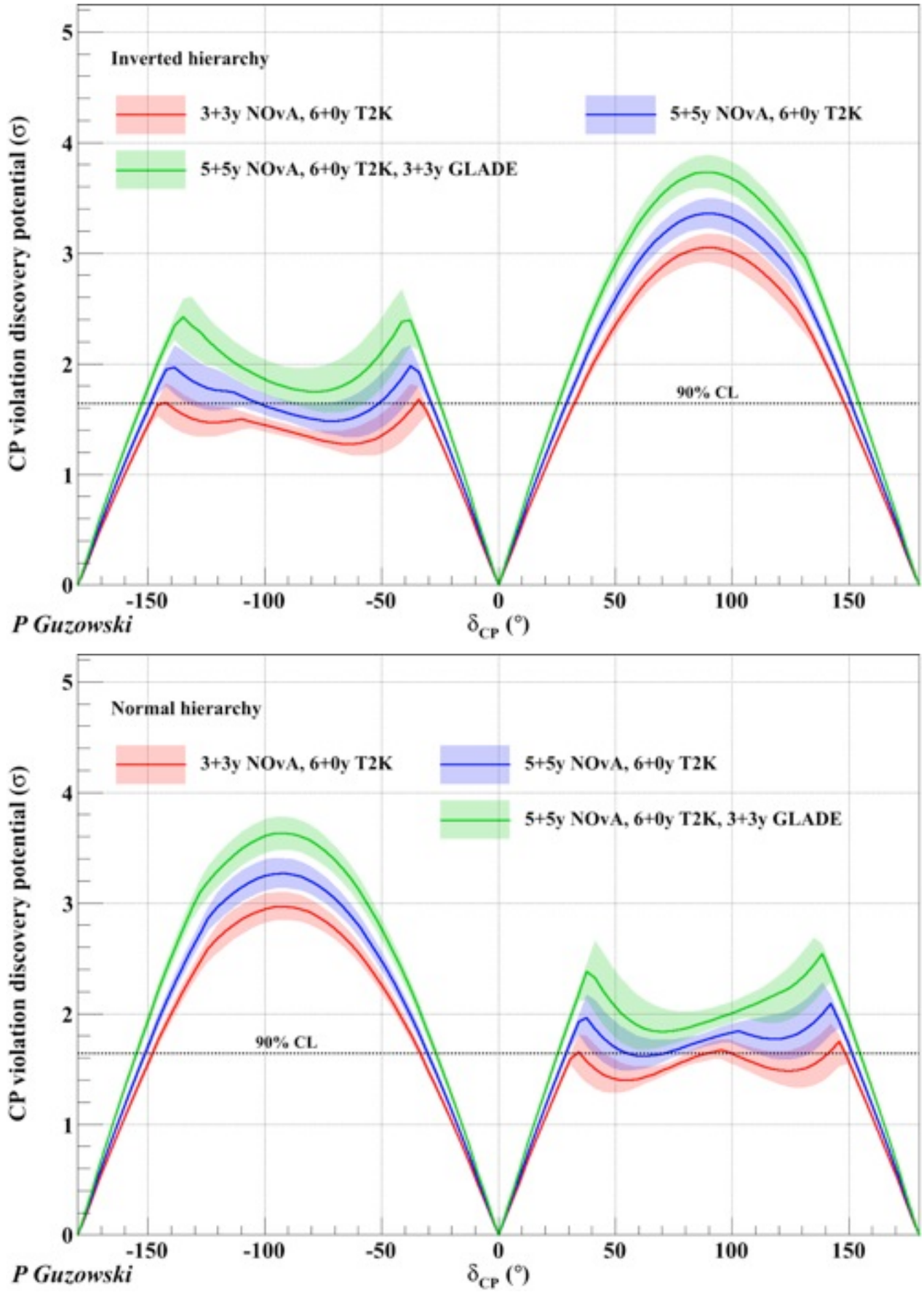


CP Violation

- Physics reach of GLADE is similar to NOvA
    - NOvA+GLADE = 2 NOvA
- Sensitivities assume we know $\sin^2 2\theta_{23}$ to 0.01 by 2020
- The (less sensitive) lower octant is assumed
- Addition of GLADE provides some 90% sensitivity in the less favourable sectors



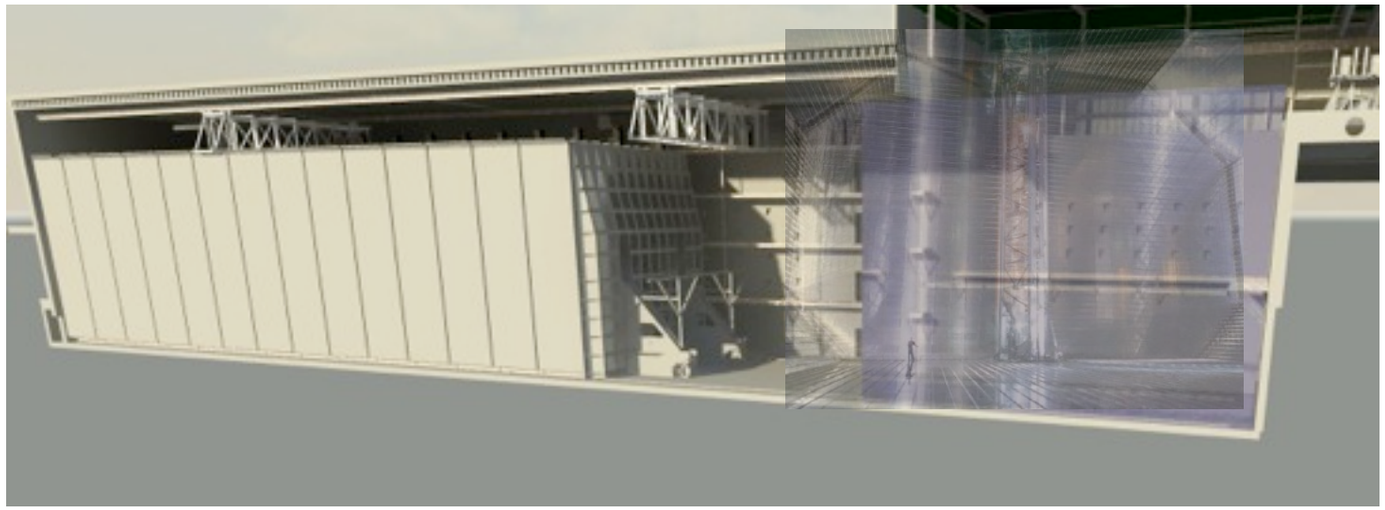
Experimental Considerations

- Detector located inside the NOvA surface building at Ash River, 18mx18mx24m available

- Purity required for 5-10m drift lengths has been demonstrated in US and Europe

- Need total field of 1-2MV to achieve 1kV/cm drift, promising studies (arXiv:1009.4908)

- Dual phase or wire readout possible



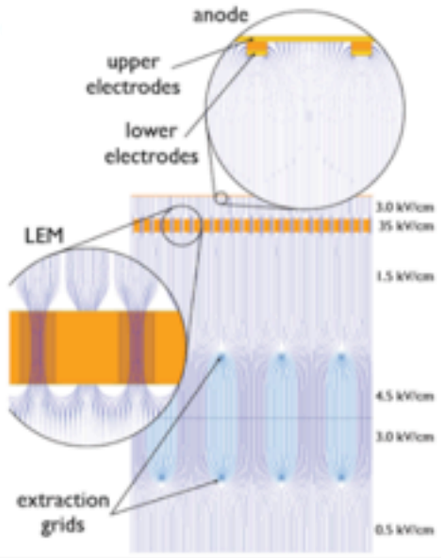
Double phase charge readout principle: LEM and projective 2D anode

A. Badertscher, et al., NIM A 641 (2011) 48-57

Readout principle

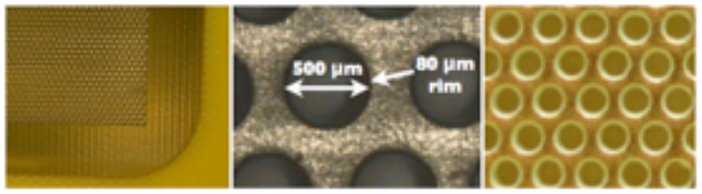
1. ionization electrons are **drifted** to the liquid-gas interphase
2. if the E-field is high enough (≈ 3 kV/cm) they can efficiently be **extracted** to the gas phase
3. in the holes of the LEM the E-field is high enough to trigger an electron avalanche
4. the **multiplied** charge is collected on a 2D readout

Electric fields



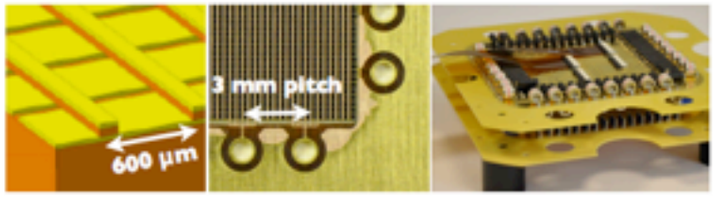
LEM (THGEM): Large electron multiplier

- Macroscopic Gas hole multiplier
- more robust than GEMS (cryogenics, discharges)
- manufactured with std. PCB techniques
- Large area coverable (1 m² size modules)



Projective 2D anode readout

- Charge is equally collected on two sets of strips (views)
- induced signals have the same shape for both views
- readout independent of multiplication



LEM and 2D anode produced by CERN TS/DEM group

A. Rubbia

inar at Osaka University – April 2012

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Other Considerations

- The next generation of long-baseline experiments (LBNE,LBNO/ Laguna,T2HK) are 10-20 years away and expensive

- A smaller, cheaper, faster experiment would provide a fantastic engineering platform for future very large LAr TPC

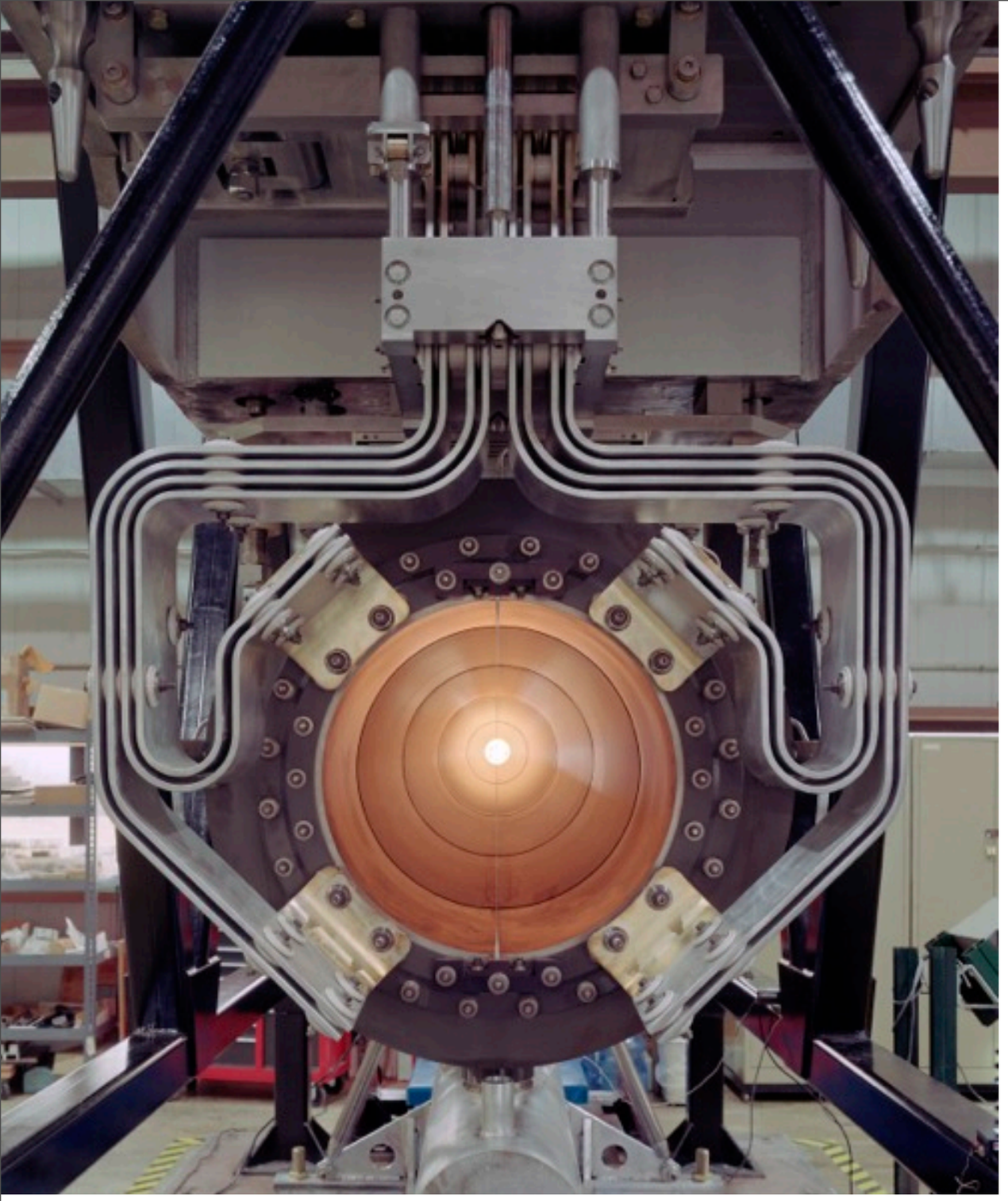
- GLADE only makes sense if it is run concurrently with NOvA:

  - Would need, say University X to build the cryostat during the approval process

  - Maximising the use of existing worldwide expertise in LAr technology is essential to operate on a short timescale

Summary

- The NuMI beam is currently the Rolls Royce of long-baseline neutrino beams
    - Need detectors to maximise scientific exploitation
- MINOS+ will provide a precision test of the 3x3 mixing hypothesis, with an impressive sensitivity to sterile neutrinos
- GLADE is an opportunistic experiment, similar physics reach to doubling the NuMI beam power and invaluable engineering experience for the future.



Backup Slides

Ryan Nichol

T2K Beam Projections

Period	Integ. No. of Proton on Target	Beam Power (kW)	
-Jun.2012	3.1E+20	170	
-Jun.2013	7.8E+20	200	
-Jun.2014	1.2E+21	250	*2
-Jun.2015	1.8E+21	250	
-Jun.2016	2.5E+21	300	
-Jun.2017	3.2E+21	300	
-Jun.2018	3.9E+21	300	
-Jun.2019	5.5E+21	700	*1
-Jun.2020	7.1E+21	700	
-Jun.2021	8.8E+21	700	

*1 Completion time of MR upgrade (assumed to be 2018) is suject to change, depending on economical situation, readiness and so on.

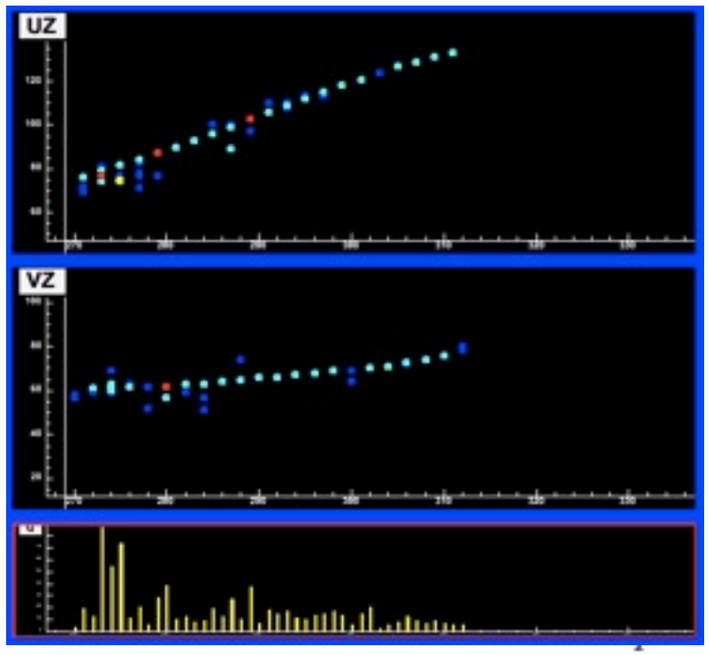
*2 LINAC upgrade completed

* Beam Energy 30GeV

MINOS Event Topologies

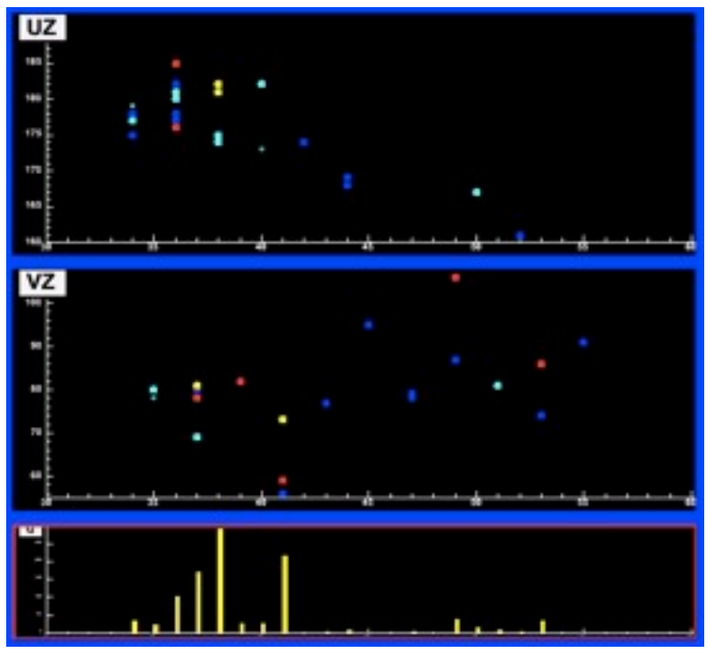
Monte Carlo

ν_μ CC Event



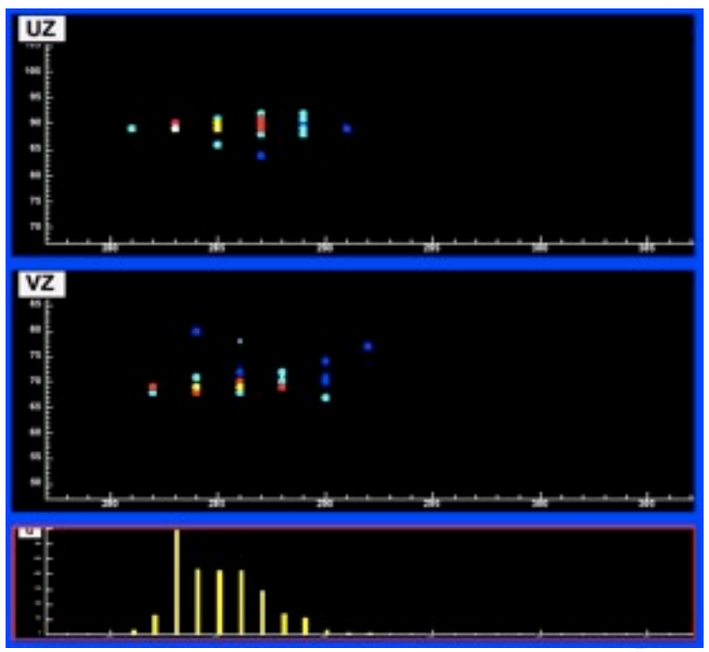
long μ track & hadronic activity at vertex

NC Event



short event, often diffuse

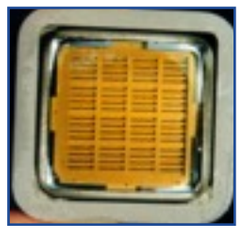
ν_e CC Event



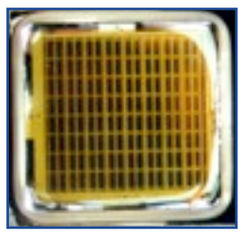
short, with typical EM shower profile

MINOS Detector Technology

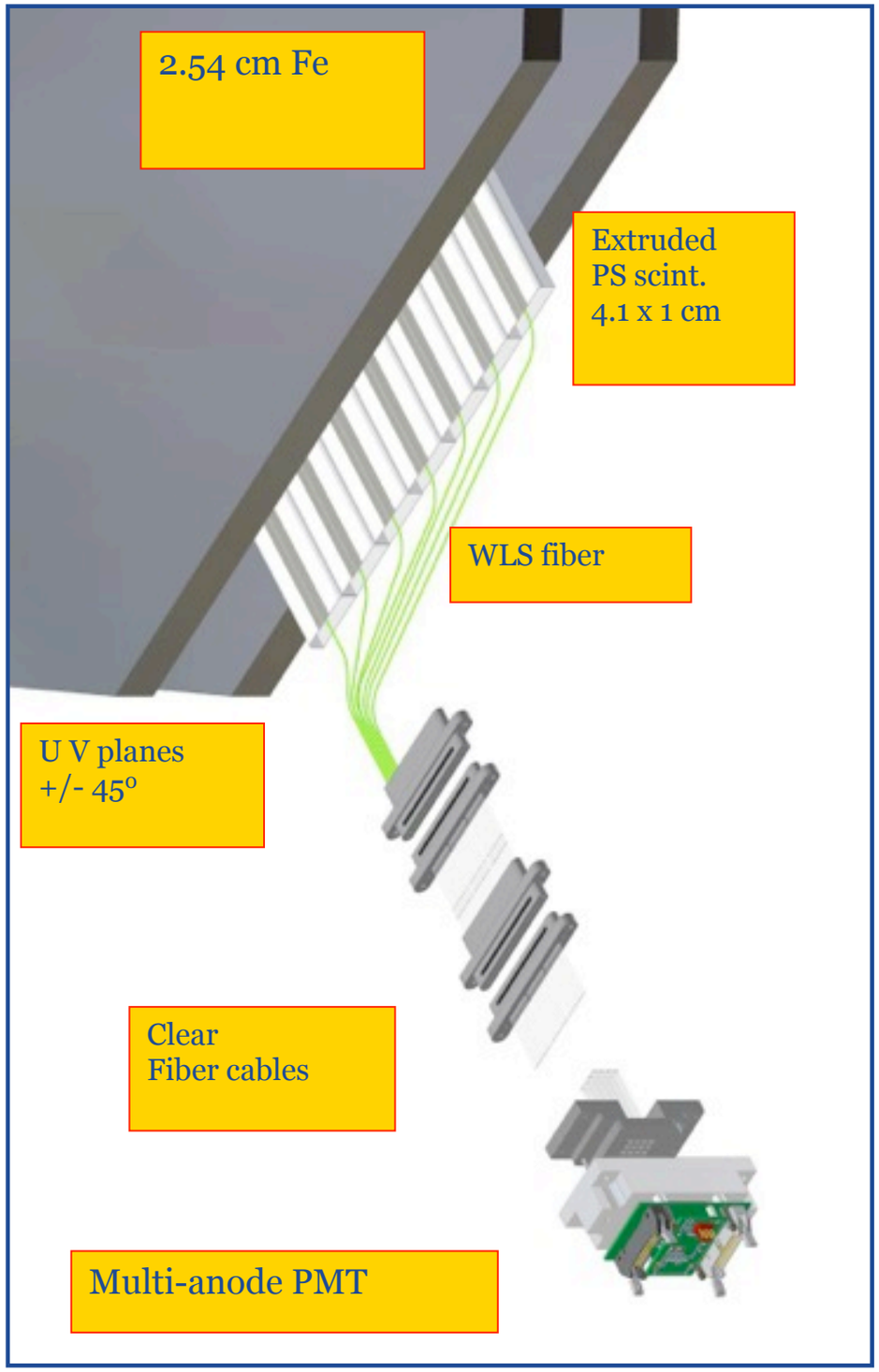
- Magnetised steel-scintillator tracking calorimeters
  - 2.54cm steel planes
  - 1cm x 4.1cm scintillator strips
  - Hamamatsu multi-anode PMTs



M16

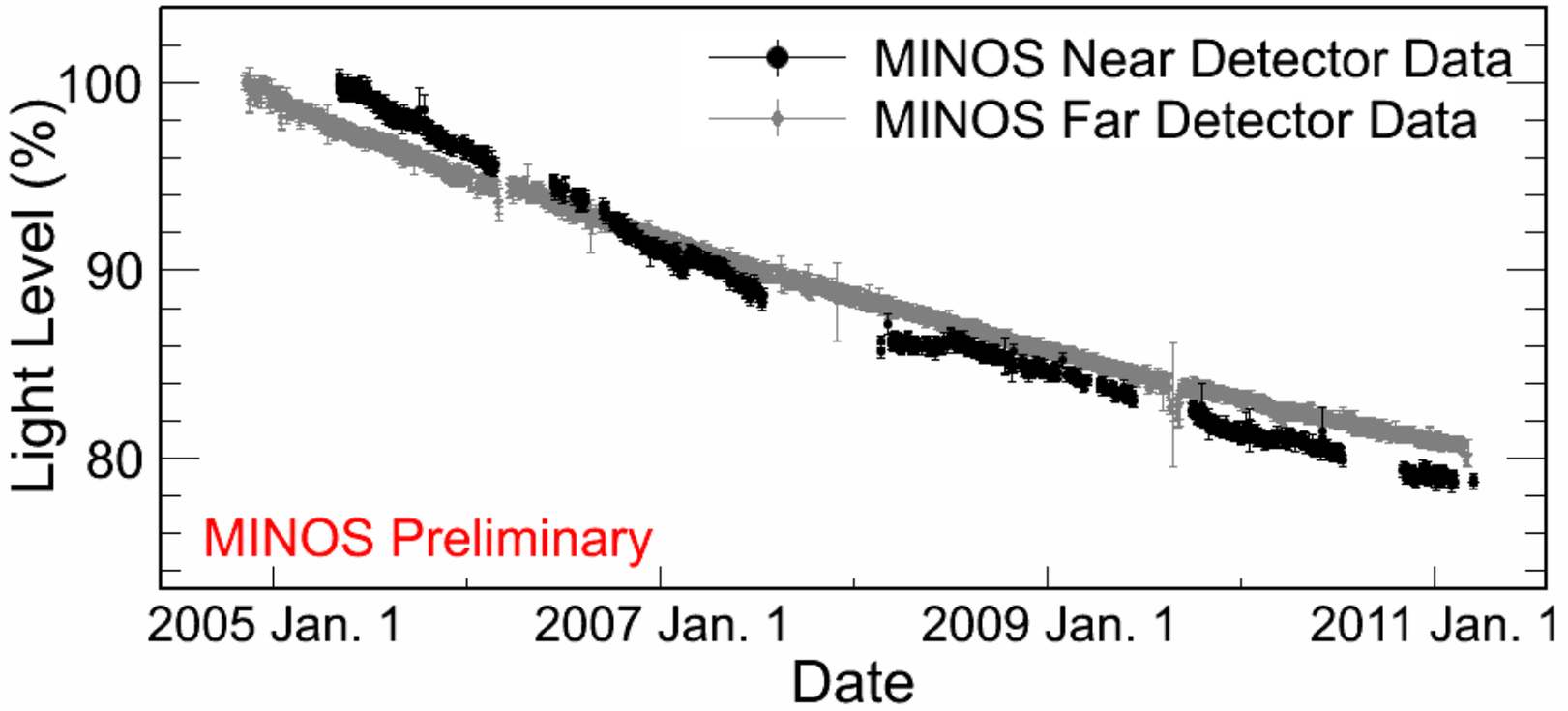


M64



Detector Performance

- Careful monitor the stability of the detector using light injection and cosmic ray muons



See Poster