The NOvA Experiment

Professor Mark Messier
Indiana University
for the NOvA collaboration
180 scientists and engineers
26 Institutions

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Nucl B: The Chemistry and Physics of Neutrino Experiments
Washington DC
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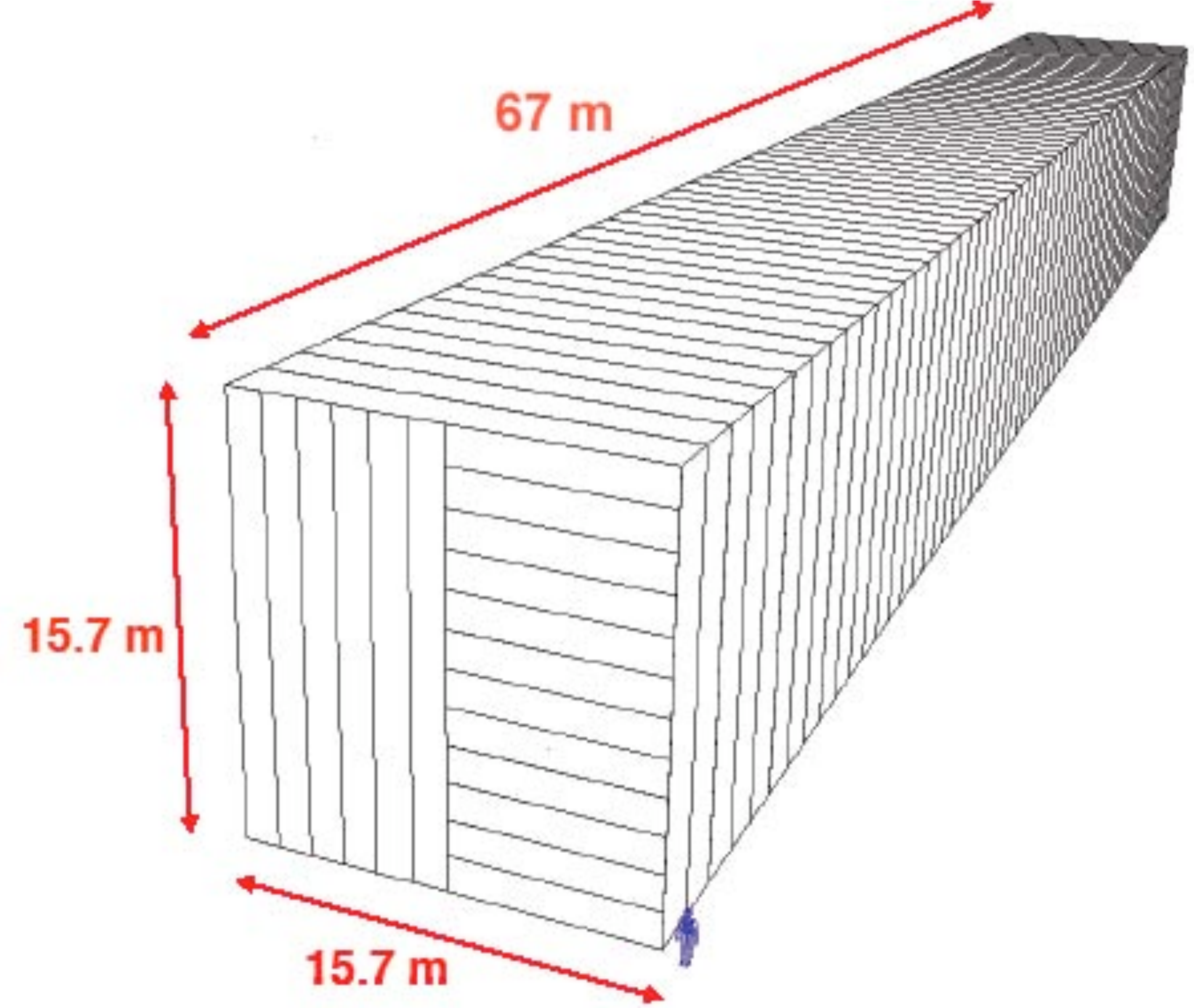
The NOvA Collaboration

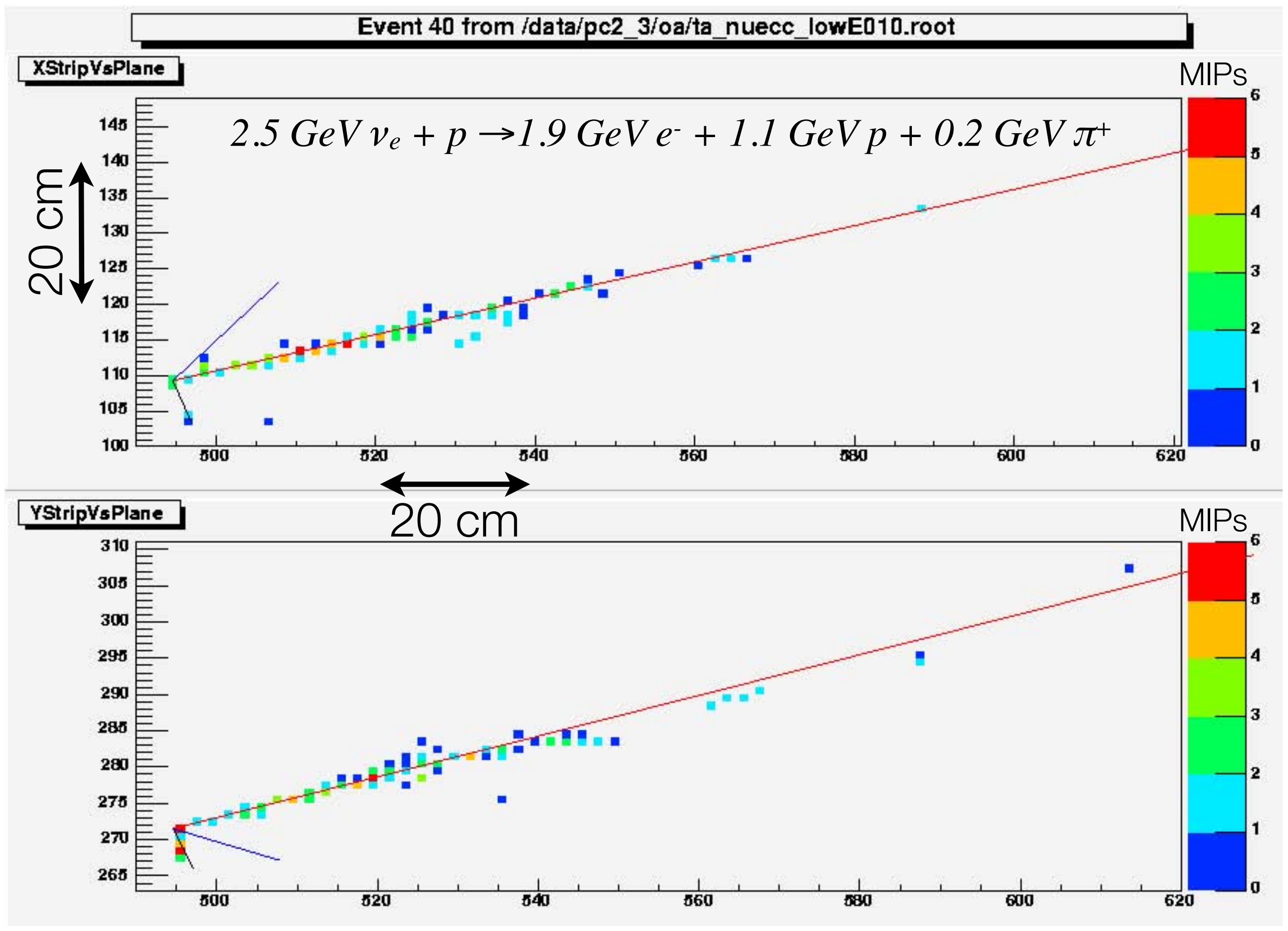
at Argonne National Lab, 25 April 2009

Argonne National Laboratory - University of Athens - California Institute of Technology - University of California, Los Angeles - Fermi National Accelerator Laboratory - College de France - Harvard University - Indiana University - Lebedev Physical Institute - Michigan State University - University of Minnesota, Duluth - University of Minnesota, Minneapolis - The Institute for Nuclear Research, Moscow - Technische Universität München, Munich - State University of New York, Stony Brook - Northern Illinois University, DeKalb - Northwestern University - Ohio State University, Columbus - Pontifícia Universidade Católica do Rio de Janeiro - University of South Carolina, Columbia - Southern Methodist University - Stanford University - University of Tennessee - Texas A&M University - University of Texas, Austin - University of Texas, Dallas - Tufts University - University of Virginia, Charlottesville - The College of William and Mary - Wichita State University

The NOvA Experiment

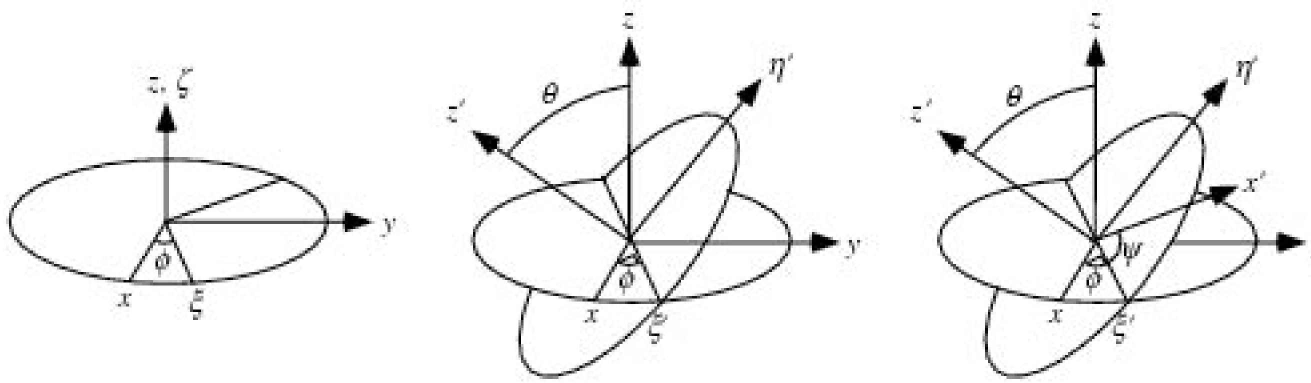
- NOvA is a second generation experiment on the NuMI beamline which is optimized for the detection of $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations
- NOvA is:
  - An upgrade of the NuMI beam intensity from 400 kW to 700 kW
  - A 15 kt "totally active" tracking liquid scintillator calorimeter sited 14 mrad off the NuMI beam axis at a distance of 810 km
  - A 220 ton near detector identical to the far detector sited 14 mrad off the NuMI beam axis at a distance of 1 km



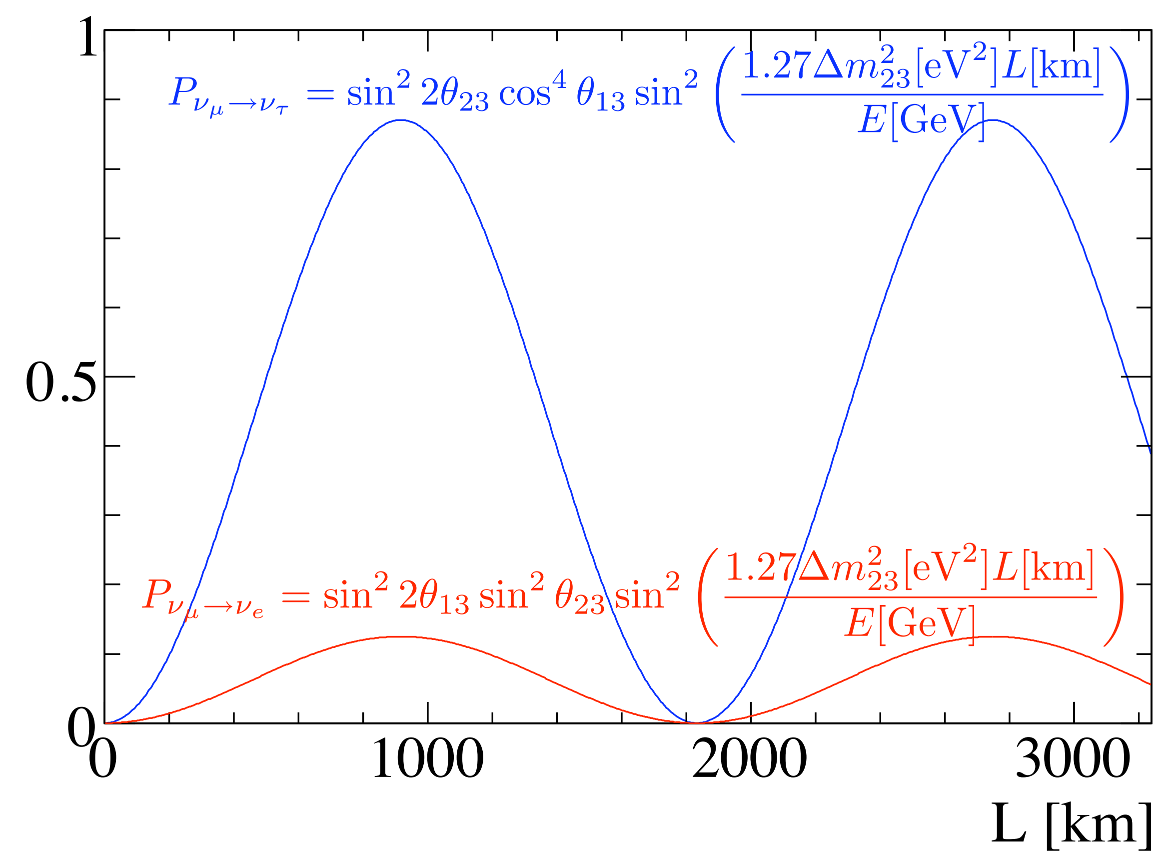


Neutrinos and neutrino oscillations

- Neutrinos feel neither the electric force nor the strong nuclear force
- They are described by their electro-weak charge (e,μ,τ) and their mass (m_1,m_2,m_3) but these properties are not simultaneously observable
- Neutrinos are produced and detected in electro-weak eigenstates, but propagate as mass eigenstates. Interference among the m_1, m_2, and m_3 mass eigenstates results in an oscillation of the electro-weak composition of the neutrino beam as it propagates from source to detector



$$\left| \begin{matrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{matrix} \right\rangle = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \left| \begin{matrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{matrix} \right\rangle$$



Where to go from here?

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

SK, K2K, and MINOS

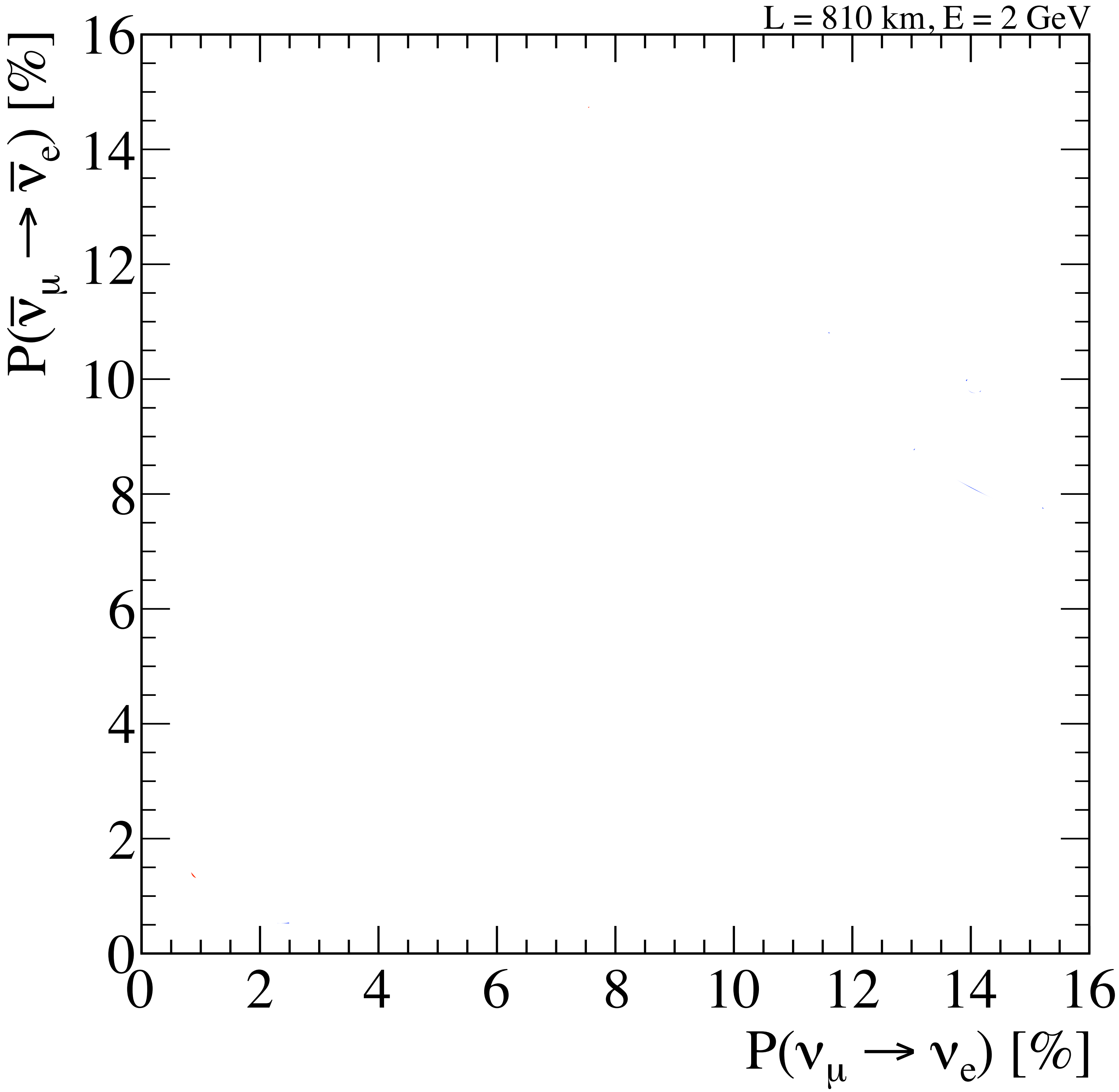
$\nu_e \rightarrow \nu_\mu + \nu_\tau$

Solar neutrinos + KamLAND

$\nu_\mu \rightarrow \nu_e$

Not observed. If this occurs opens possibility of CP violation in neutrino sector

- What is θ_{13}?
- What is the pattern of masses? Is m_3 the heaviest or lightest state?
- Is the neutrino a Dirac or Majorana particle?
- Is CP violated?
- Is θ_{23} really maximal? μ-τ symmetry?
- Does the PMNS framework hold together or is there more going on?

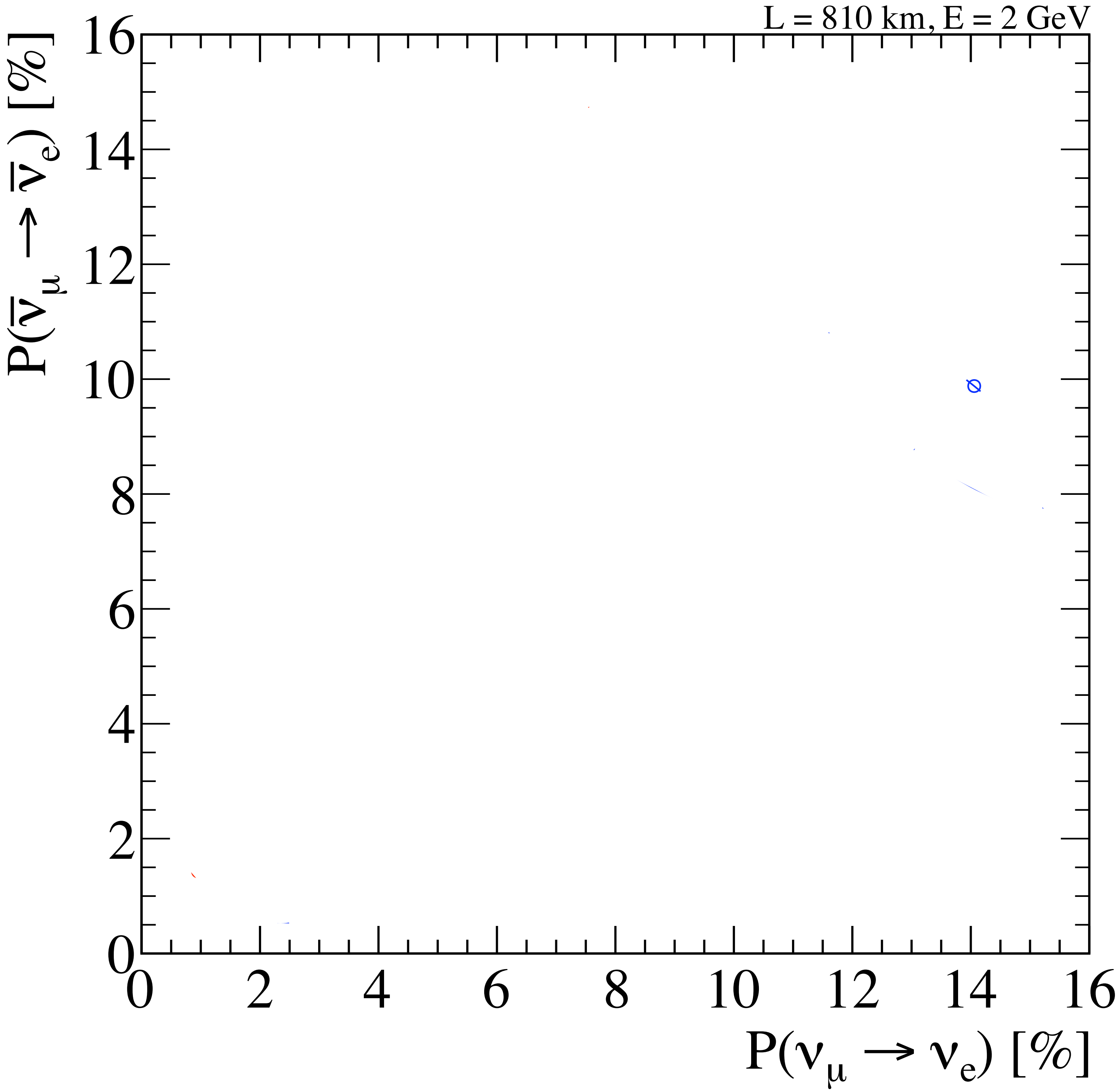


Using a muon neutrino beam, we have two basic observables

1. $P(\nu_\mu \rightarrow \nu_e)$ for neutrinos
2. $P(\nu_\mu \rightarrow \nu_e)$ for anti-neutrinos

We can plot these two observables as a function of the remaining unknowns θ_{13}, δ_{CP} , and mass hierarchy.

Principle of the NOvA Experiment



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$\theta_{13} = 15^o$

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$\delta_{CP} = 0$

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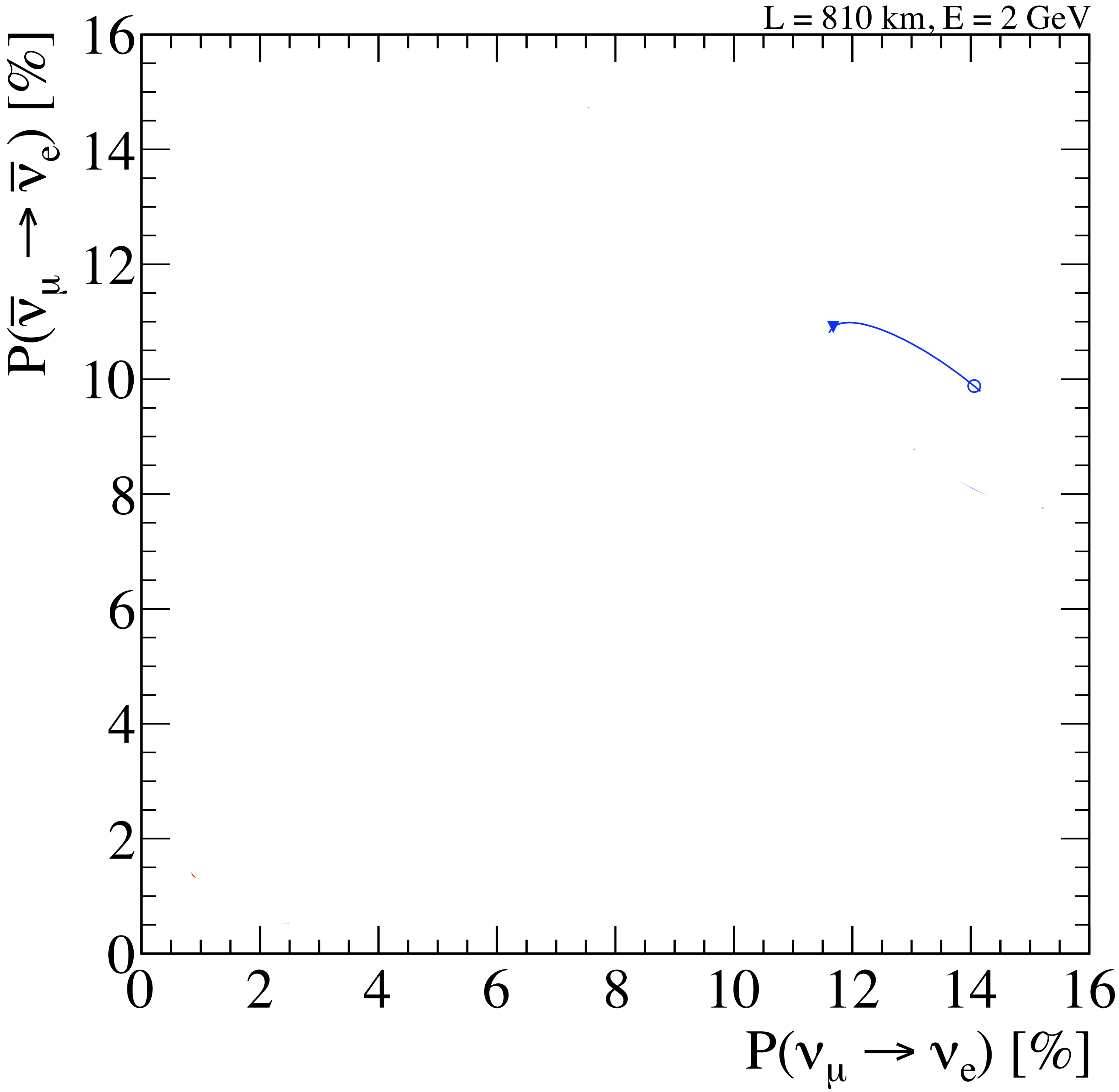

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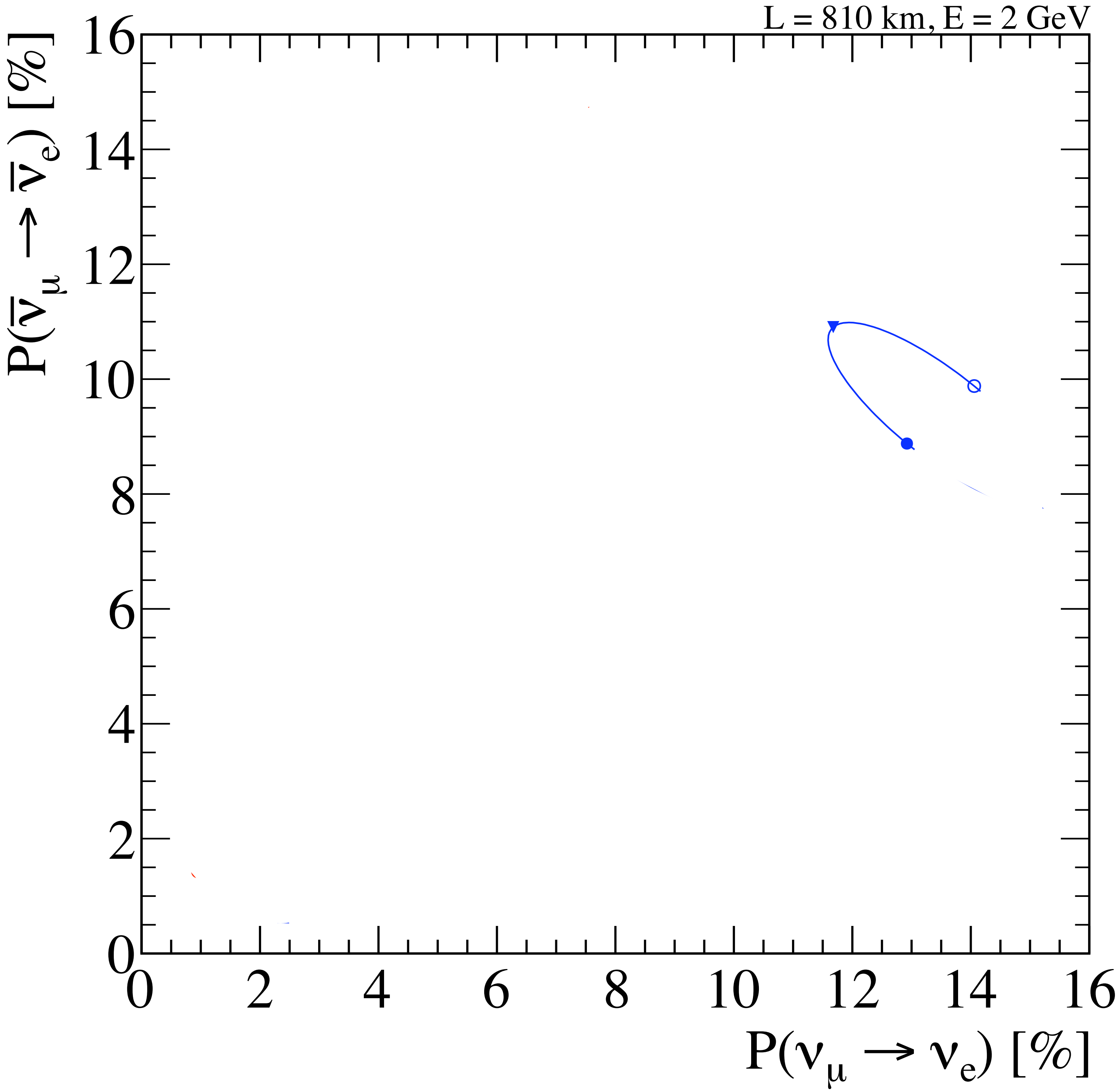

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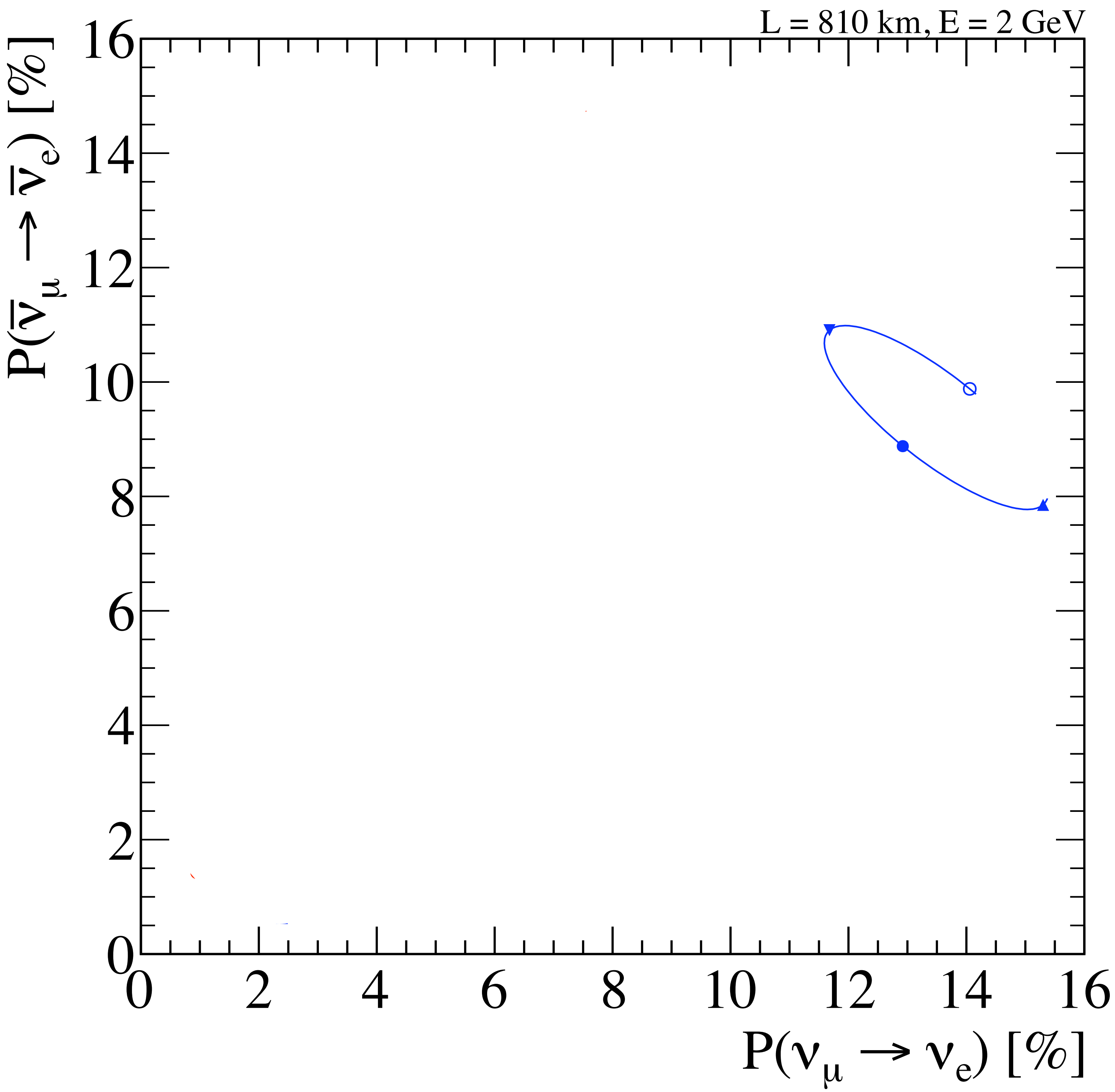

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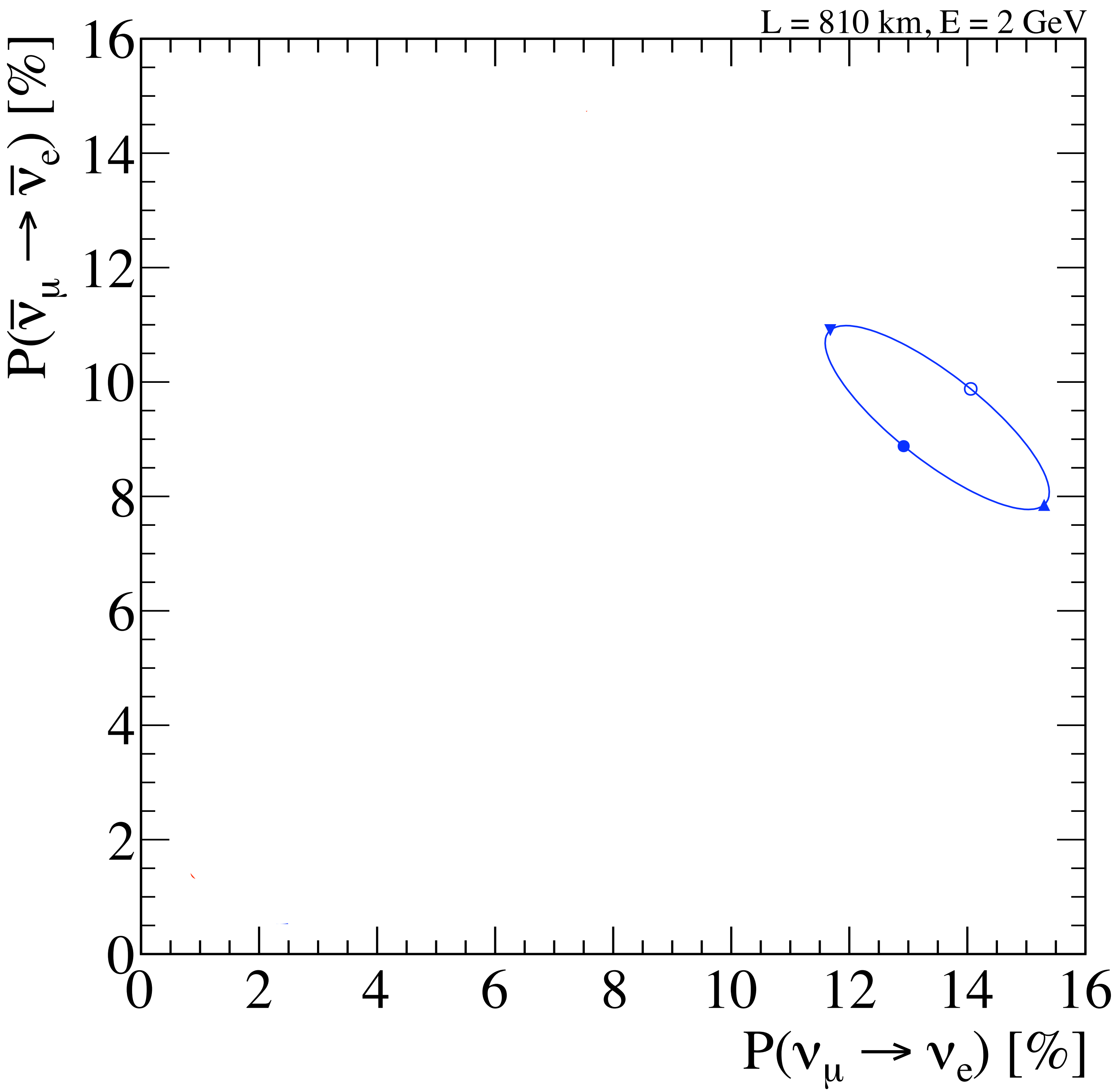

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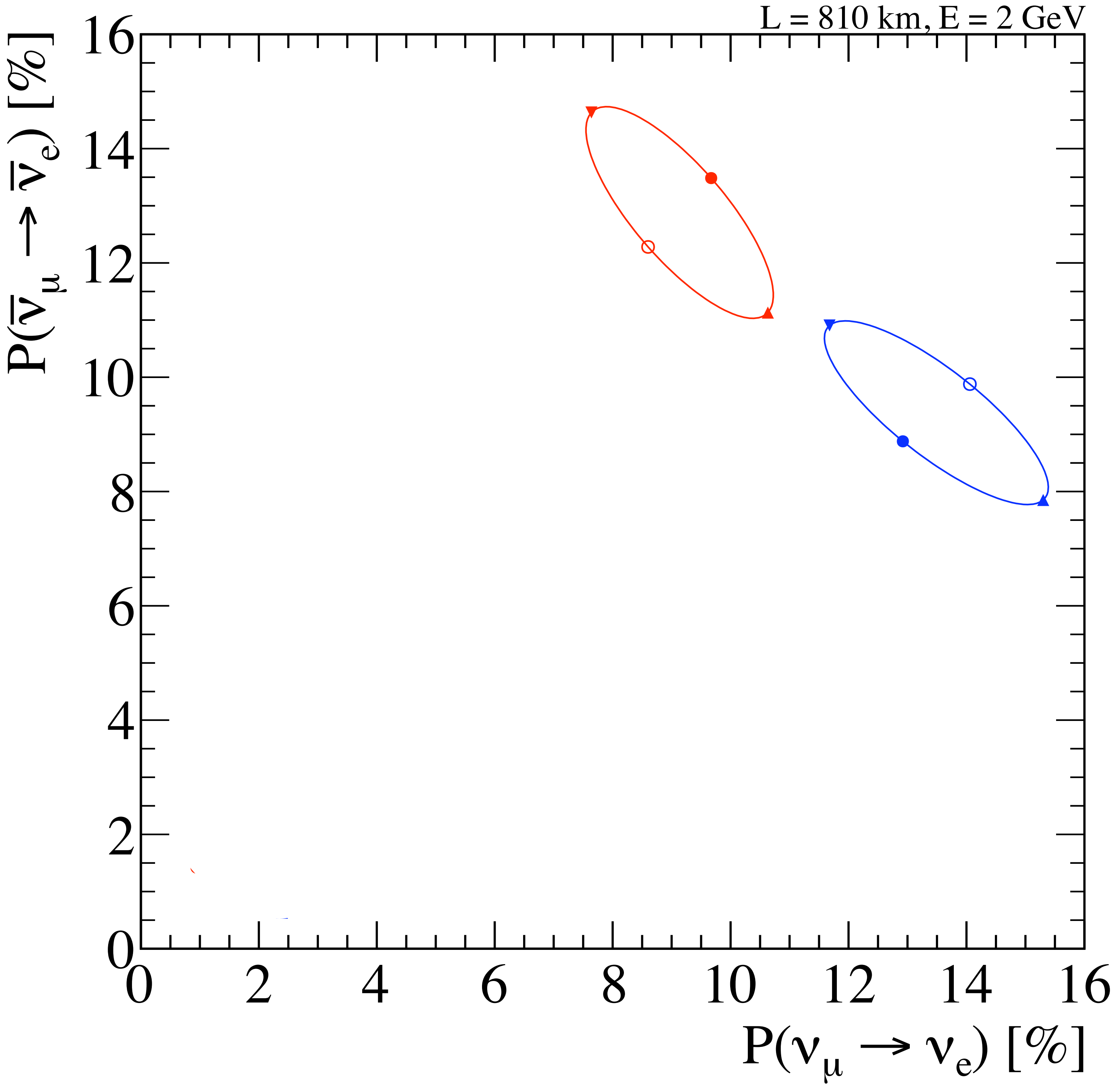

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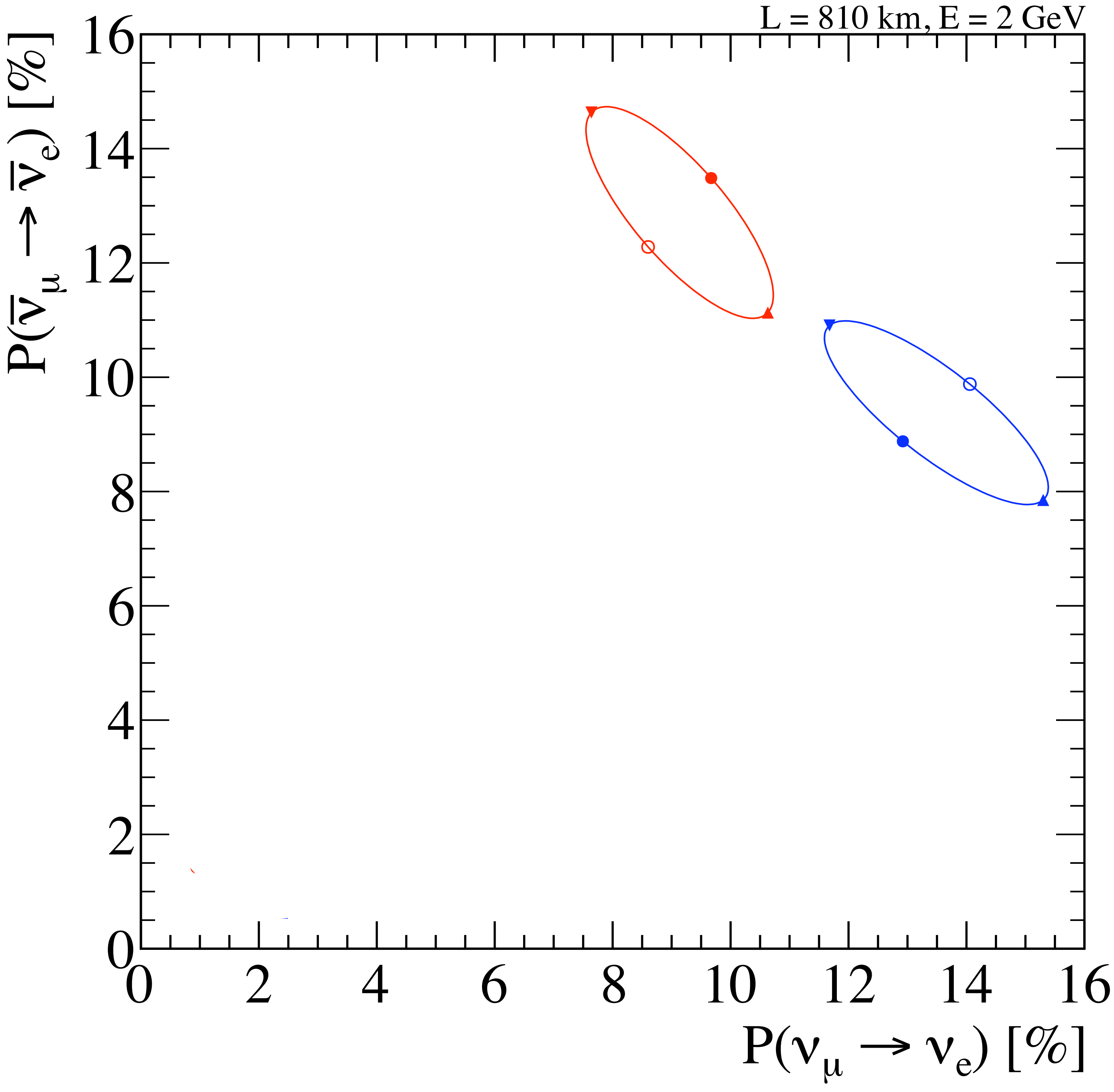

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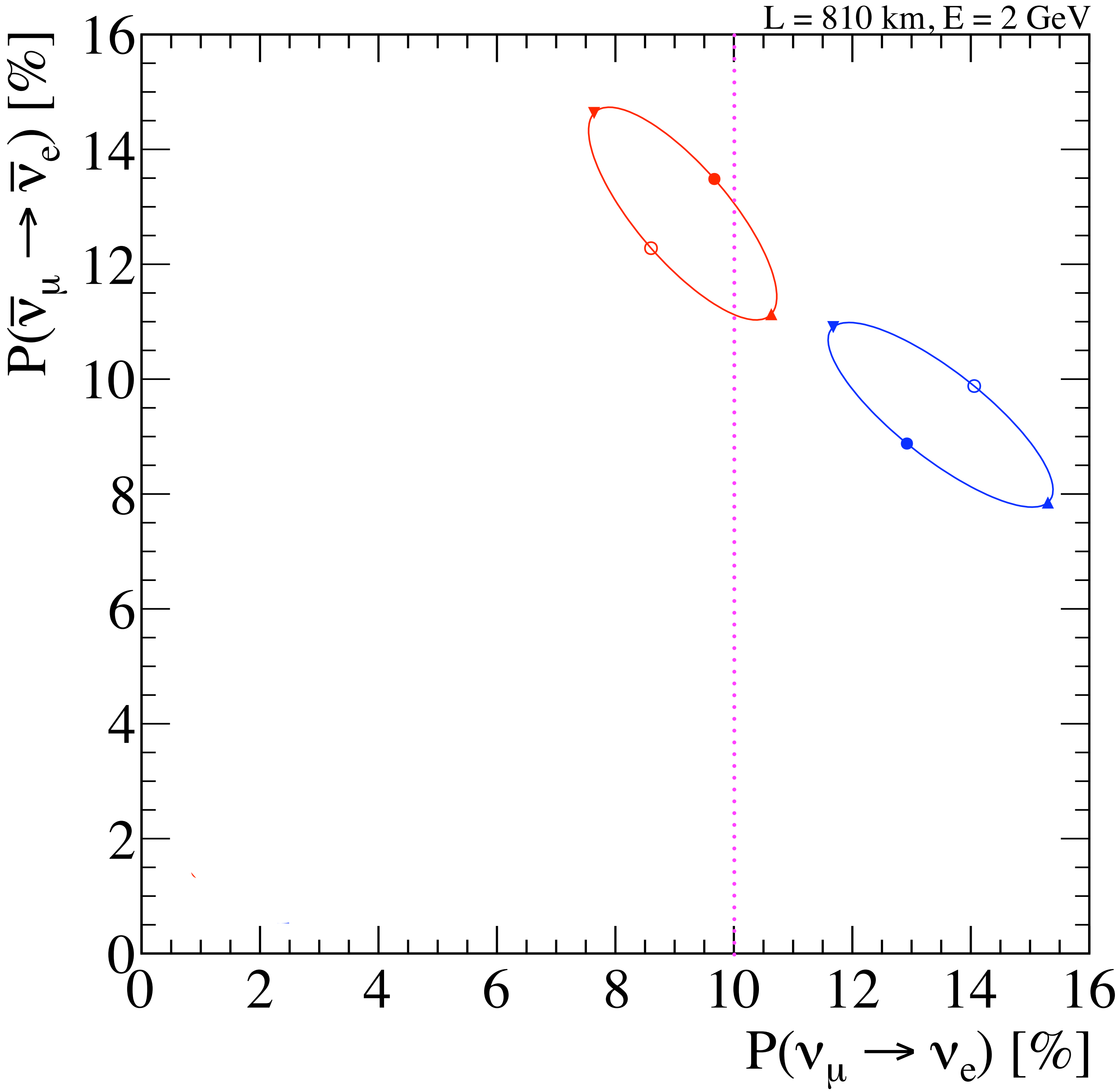
Principle of the NOvA Experiment



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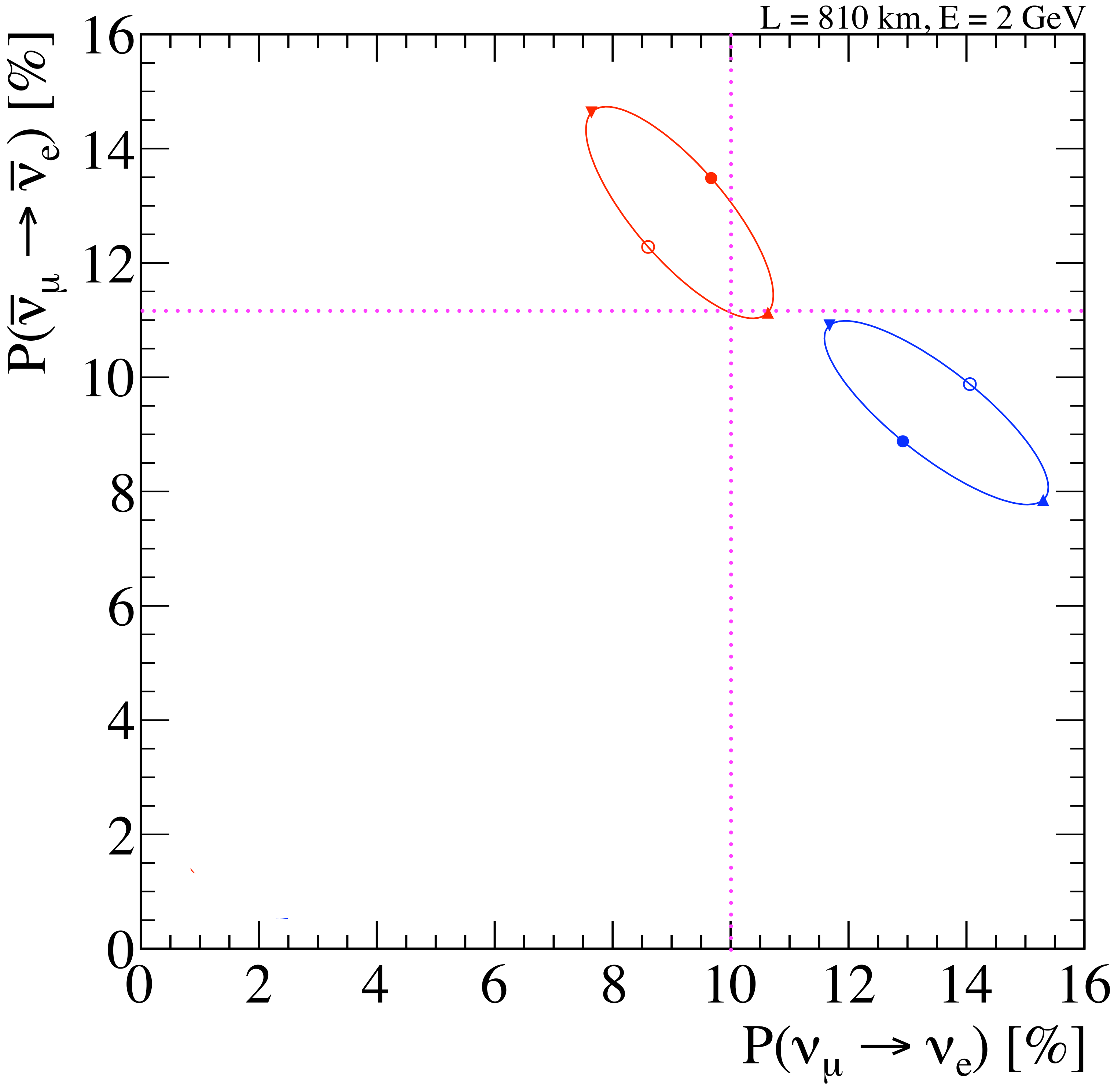

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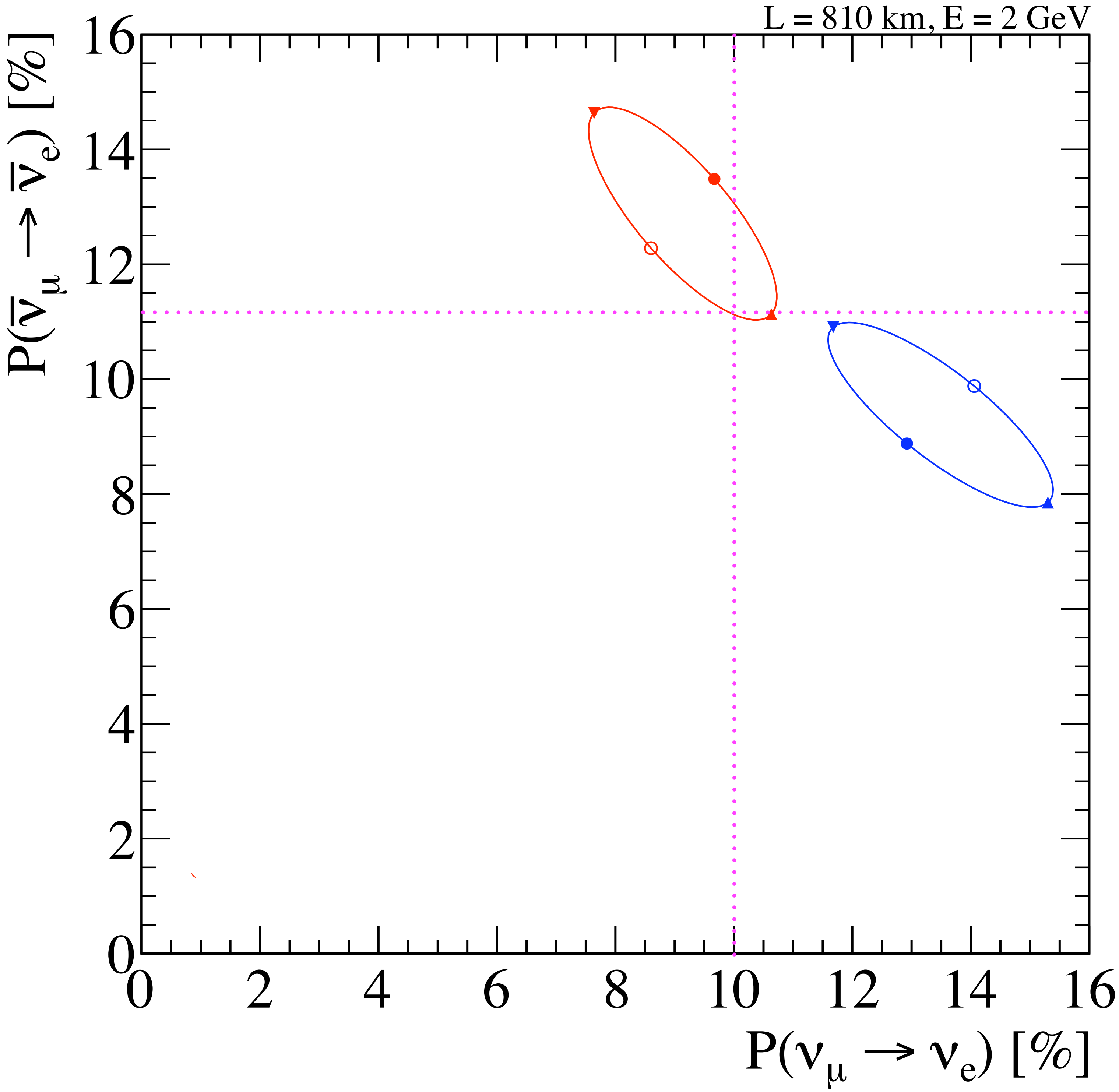

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For small θ_{13} there are inherent ambiguities between hierarchy choice and δ_{CP}. However, even in these cases we learn something about δ_{CP}.

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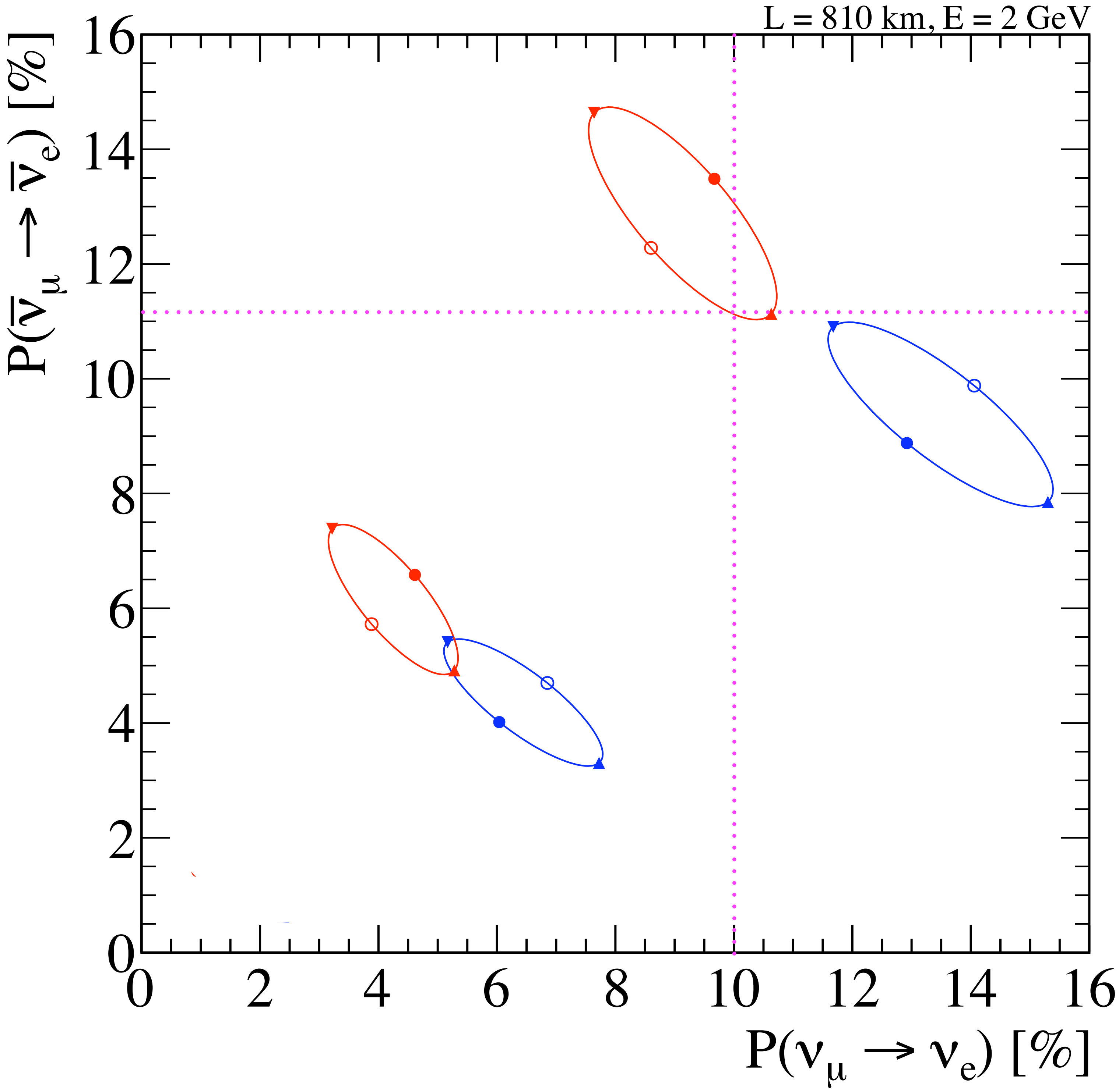

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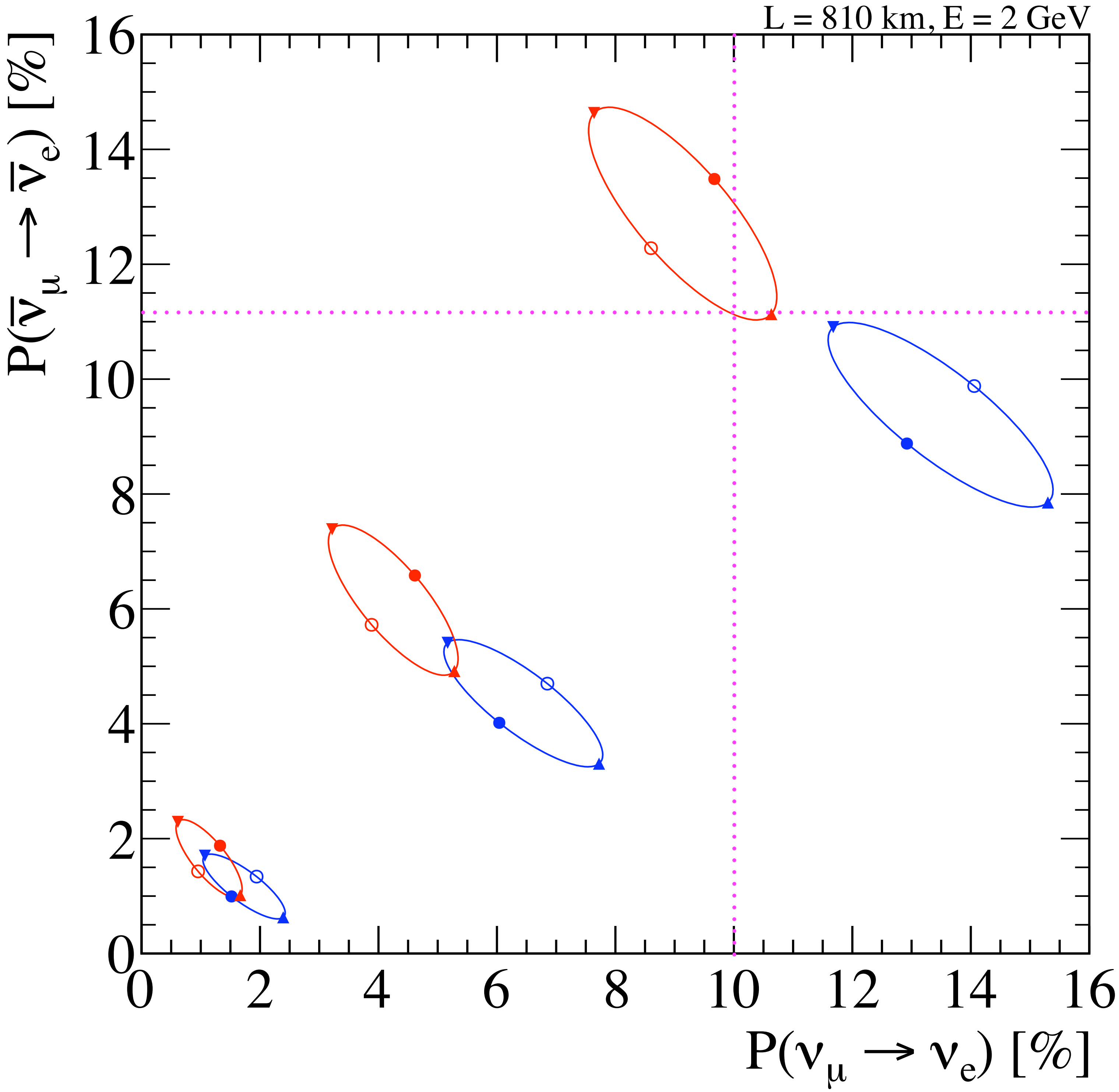

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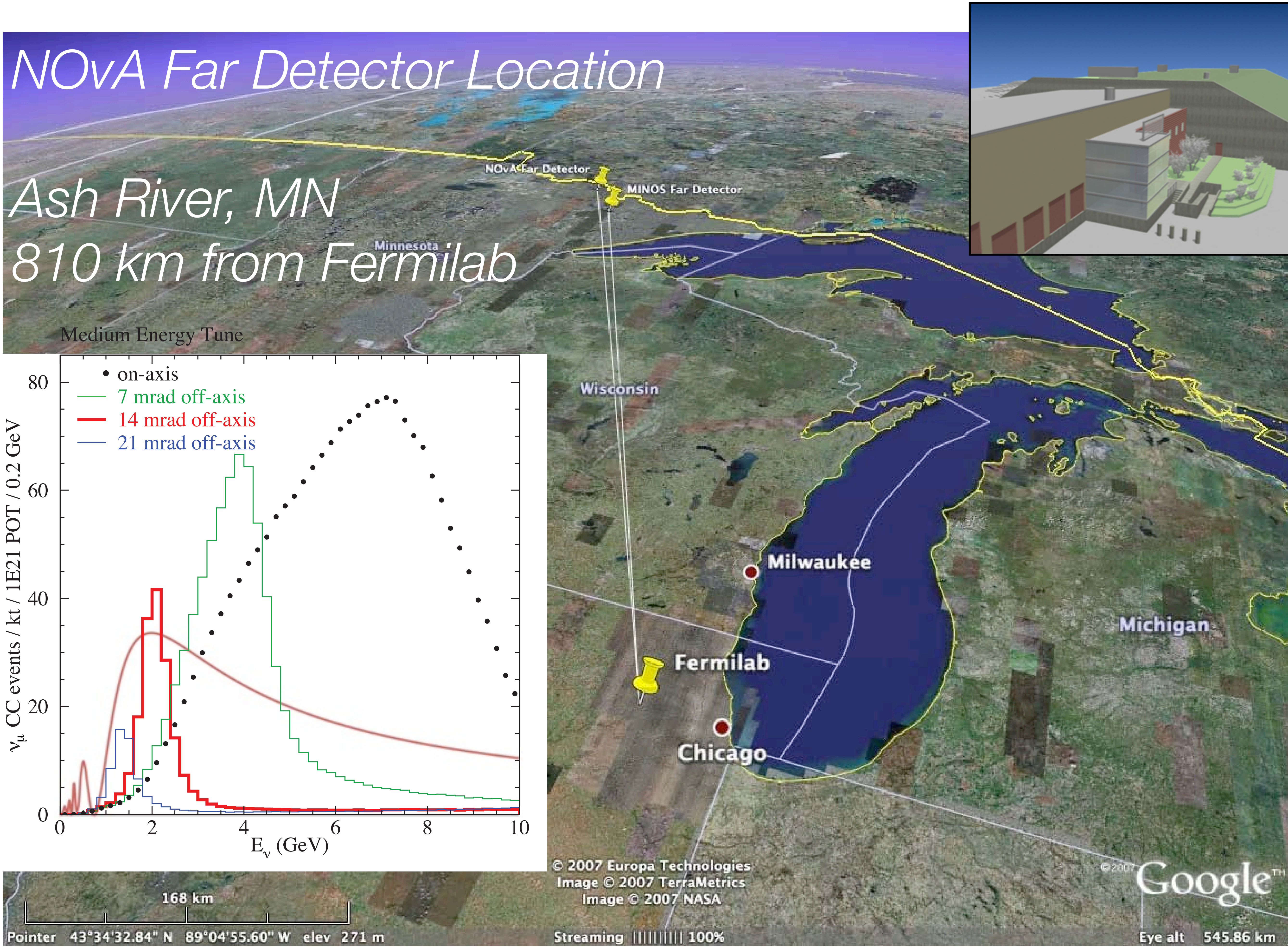
NOvA Far Detector Location

Ash River, MN
810 km from Fermilab



Event quality

Topologies of basic interaction channels shown at right. Each “pixel” is a single 4 cm x 6 cm cell of liquid scintillator

Top: ν_μ *charged-current*

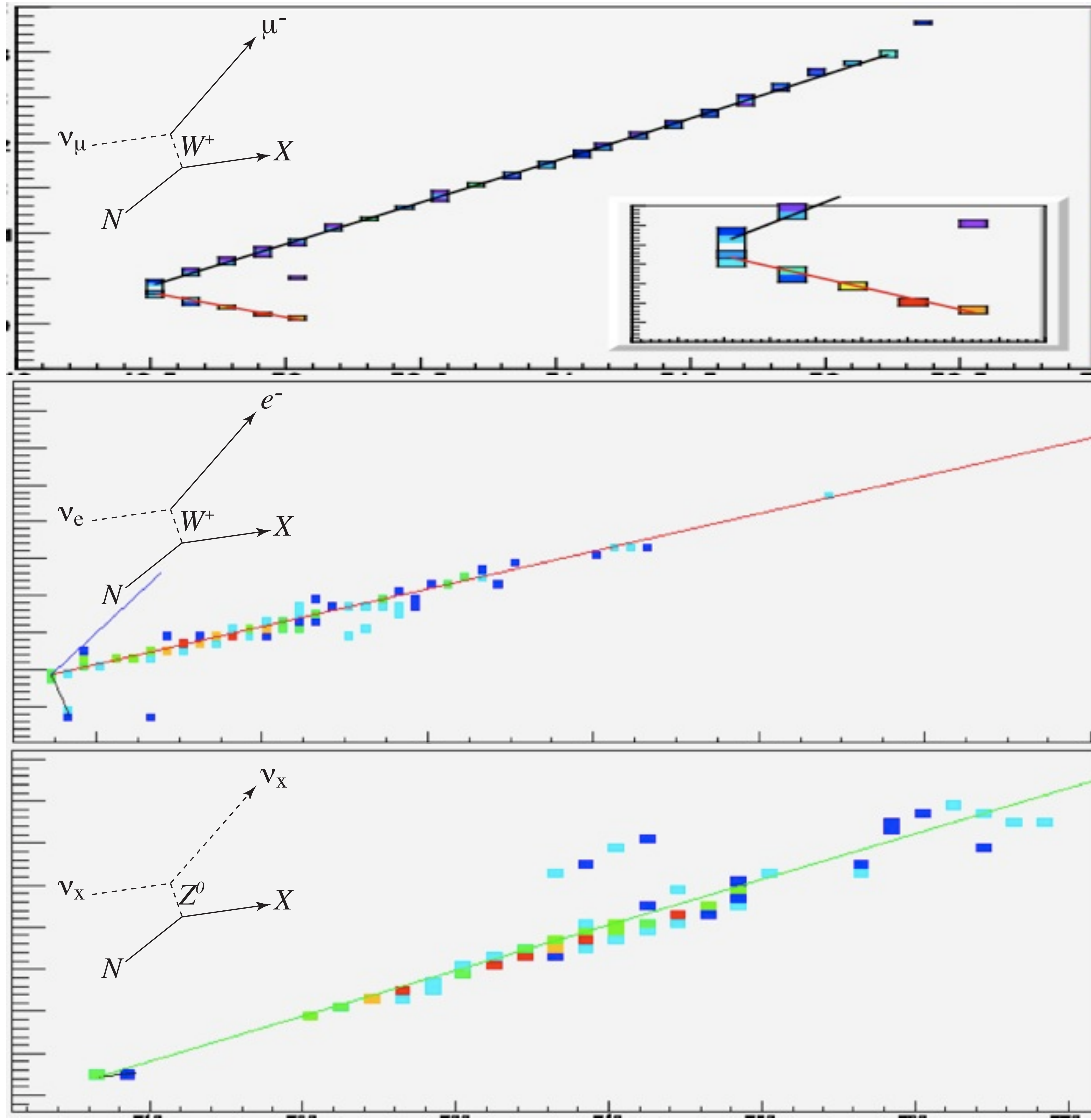
Center: ν_e *charged-current*

Bottom: neutral-current

Need >100:1 rejection against background

Detector challenge: Achieve large target mass (10’s+ kilotons) while maintaining high granularity to avoid confusing the detection channels

NOvA achieves 35% efficiency for ν_e CC while limiting NC→ν_e CC fake rate to 0.1%



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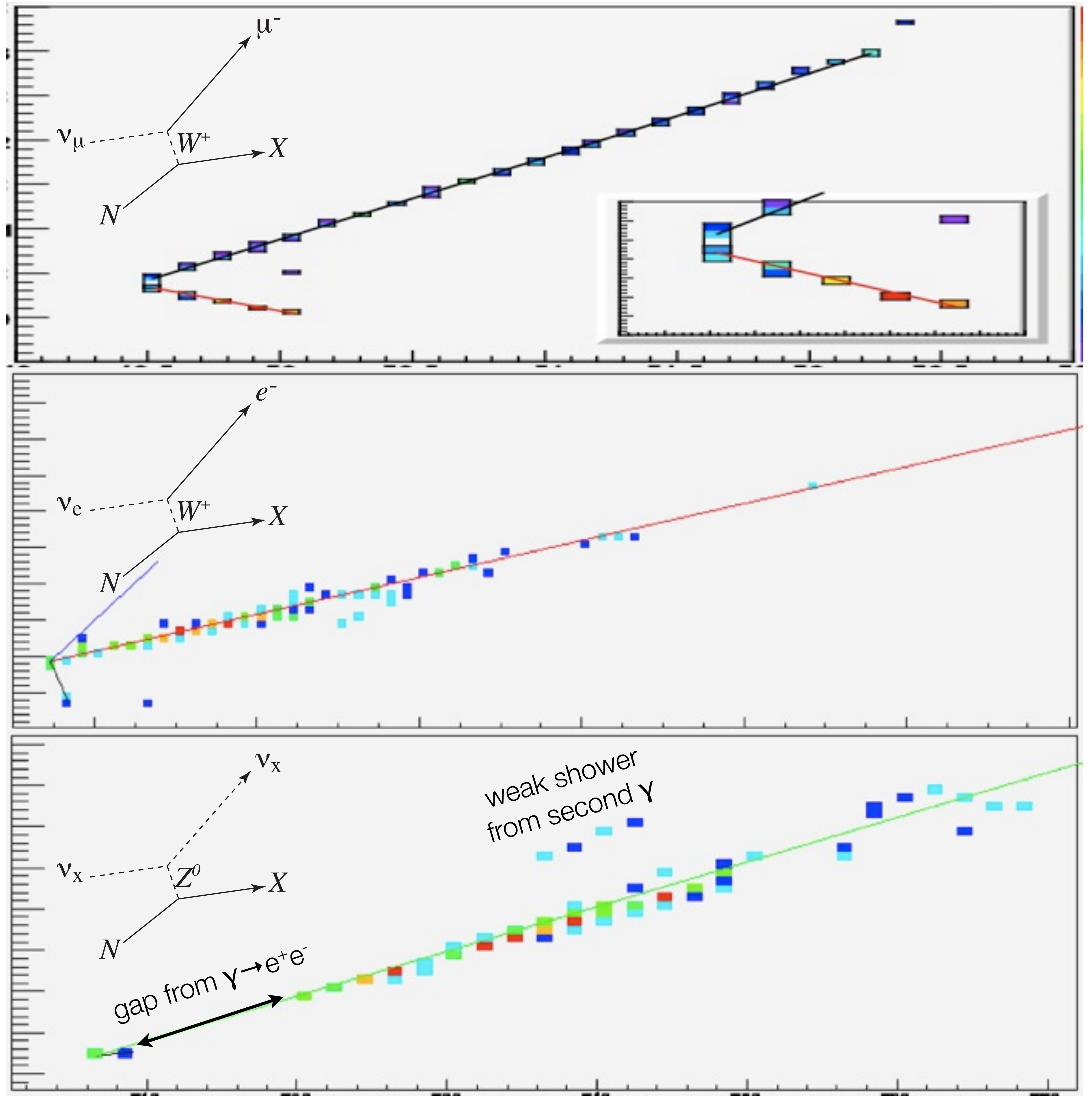
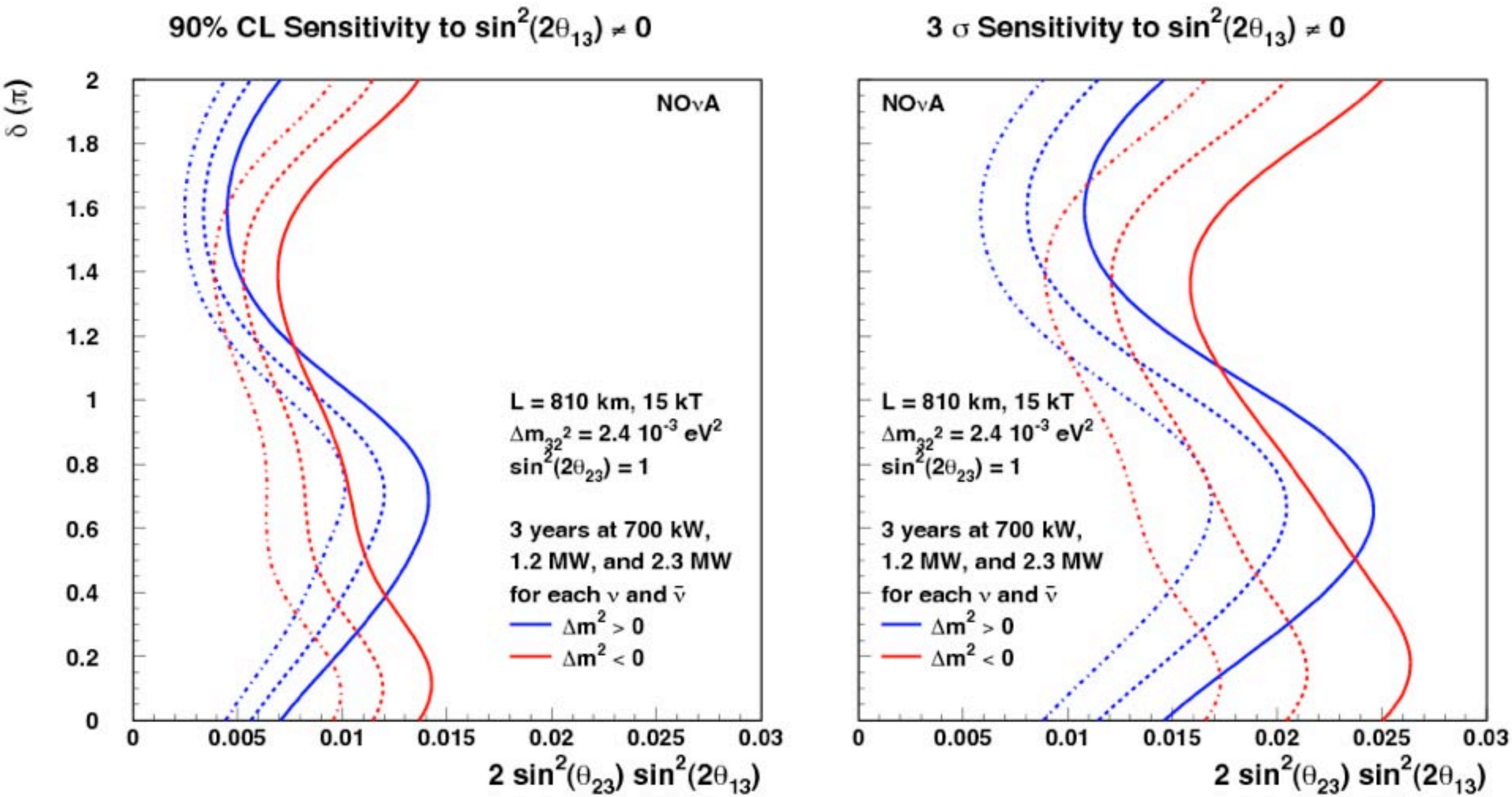
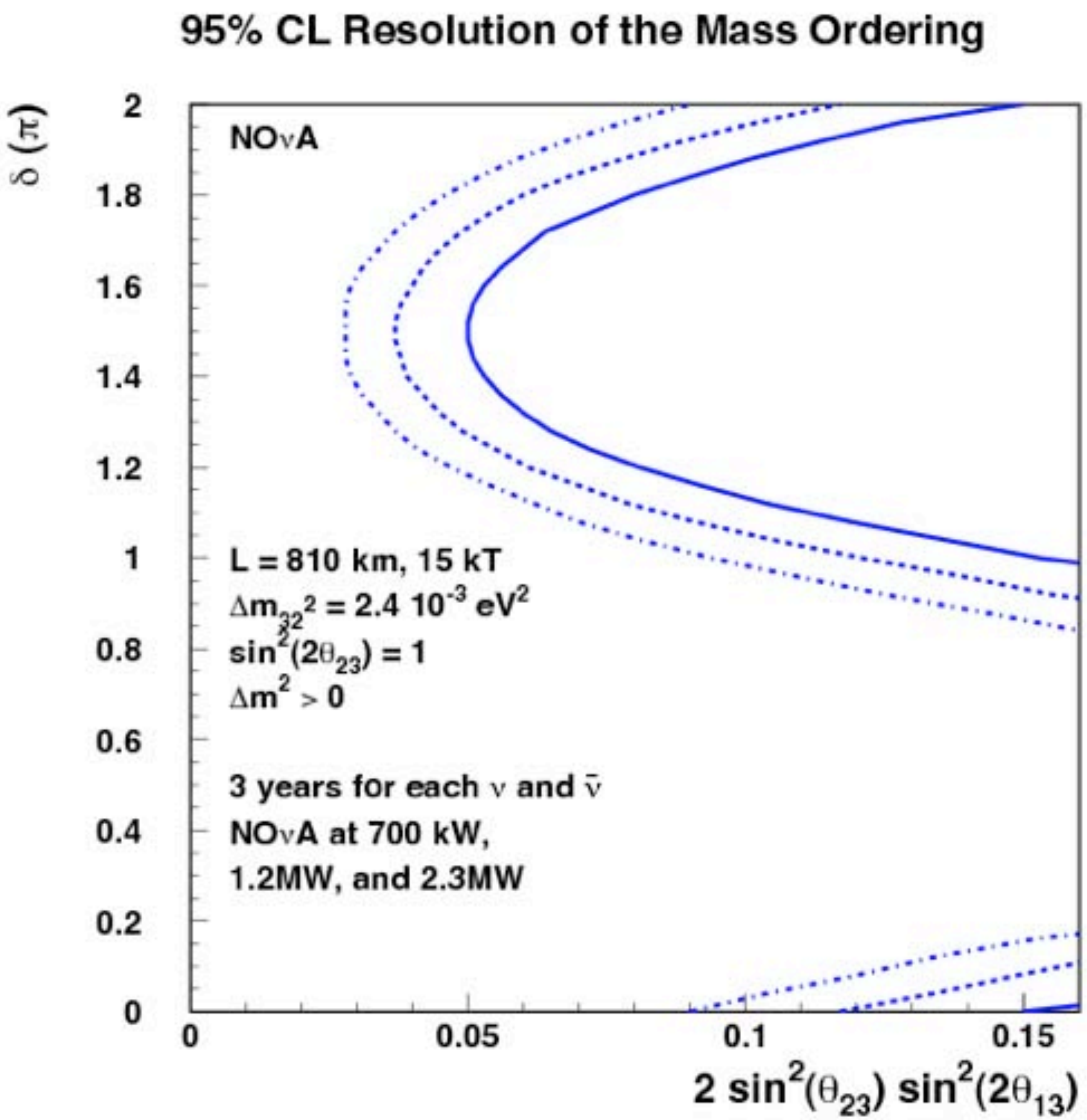


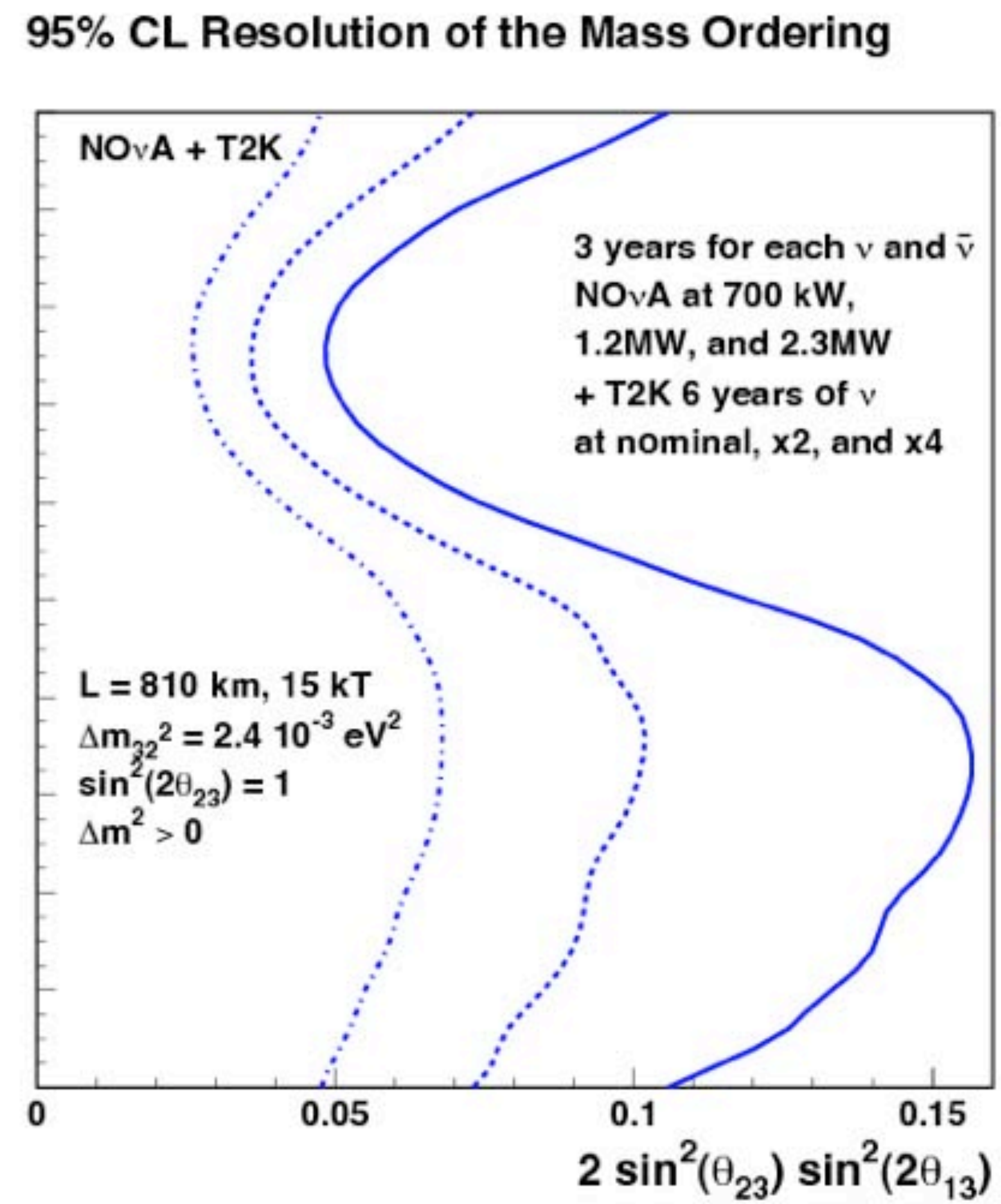
Sensitivity to $\nu_\mu \rightarrow \nu_e$ Oscillations



Resolution of the mass hierarchy



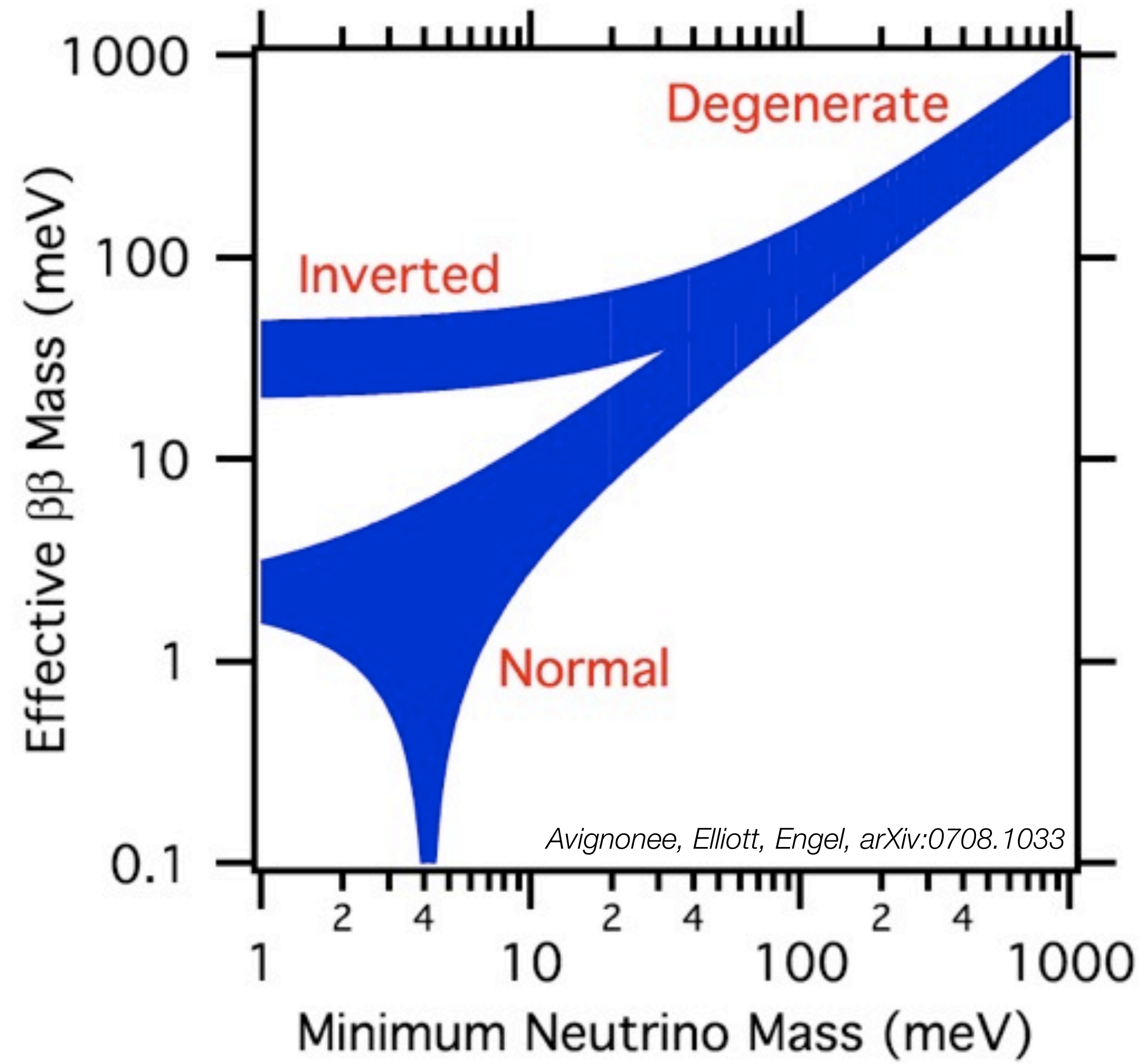
Compare NOvA's neutrinos to NOvA's anti-neutrinos



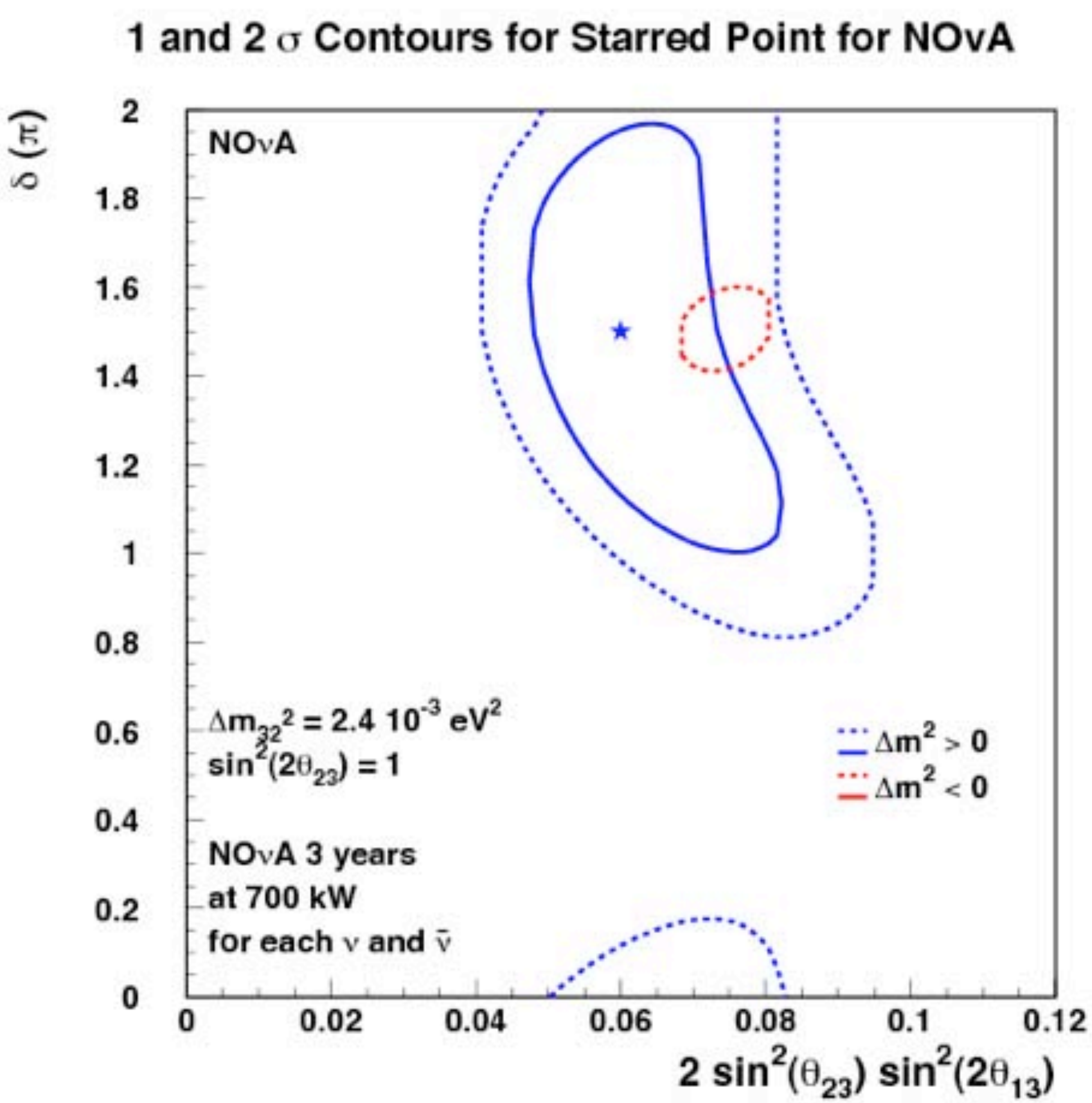
Compare NOvA's neutrinos w/ matter effect to T2K's neutrinos ~w/o matter effect

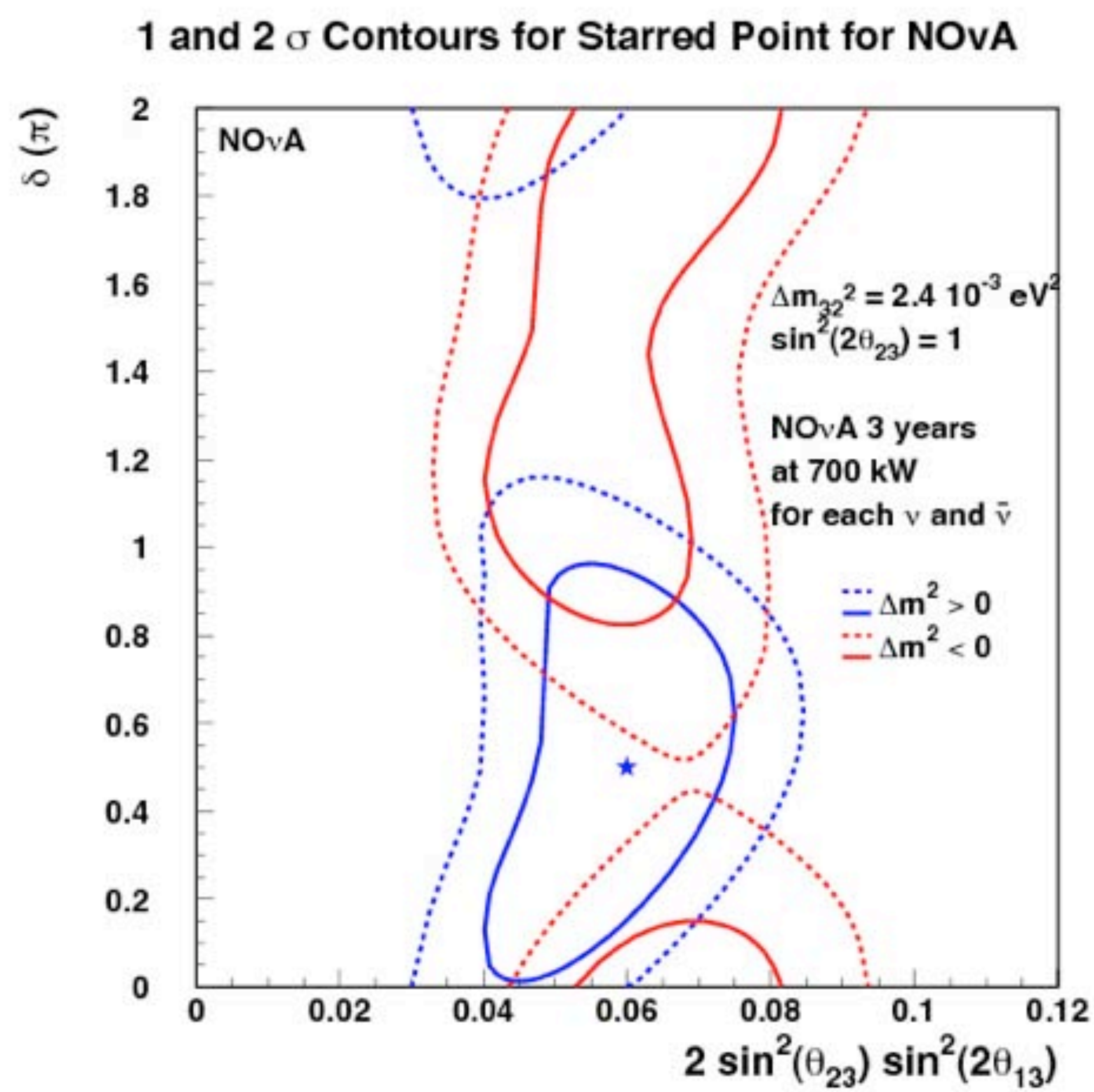
Resolution of the mass hierarchy

- The mass hierarchy provides a window on very high energy scales. Most GUTs naturally produce normal mass hierarchy. Other approaches produce inverted hierarchy.
- Establishing inverted hierarchy makes next generation of $0\nu\beta\beta$ searches even more interesting. Either they will see $0\nu\beta\beta$ or its absence indicates neutrinos are Dirac particles



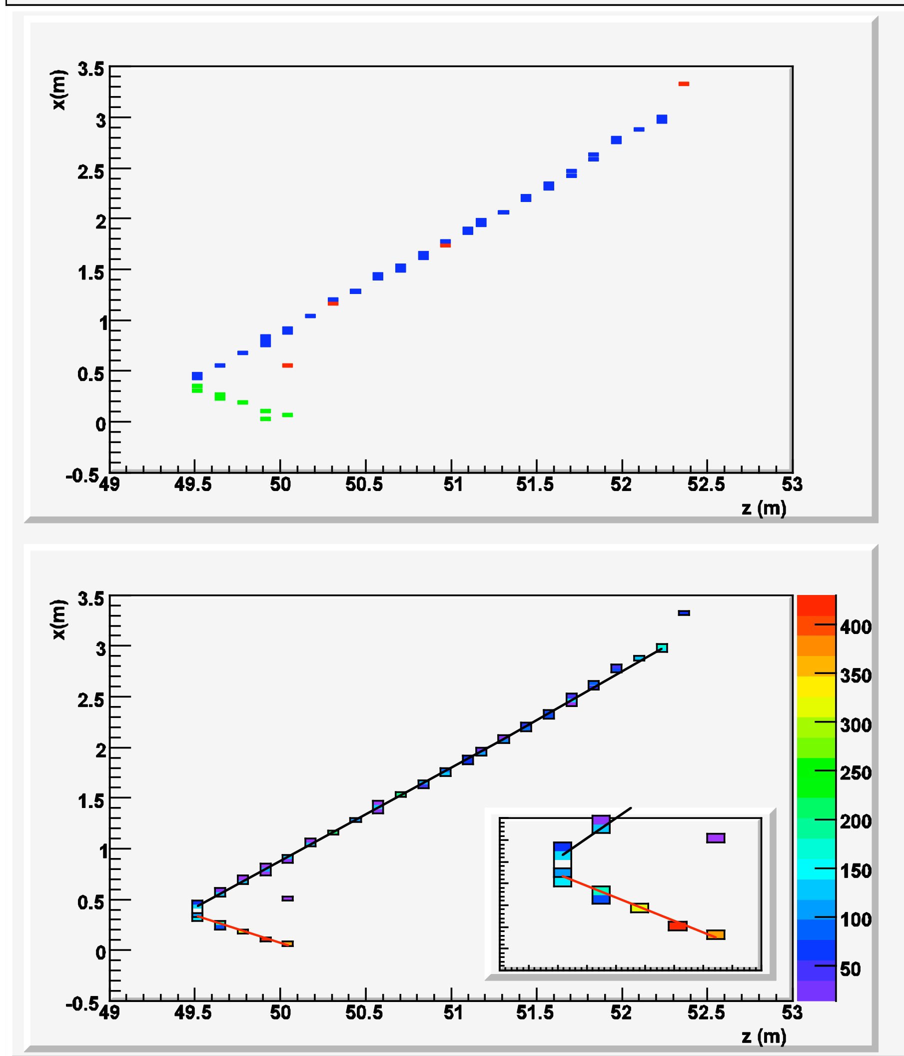
Begin study of δ_{CP}

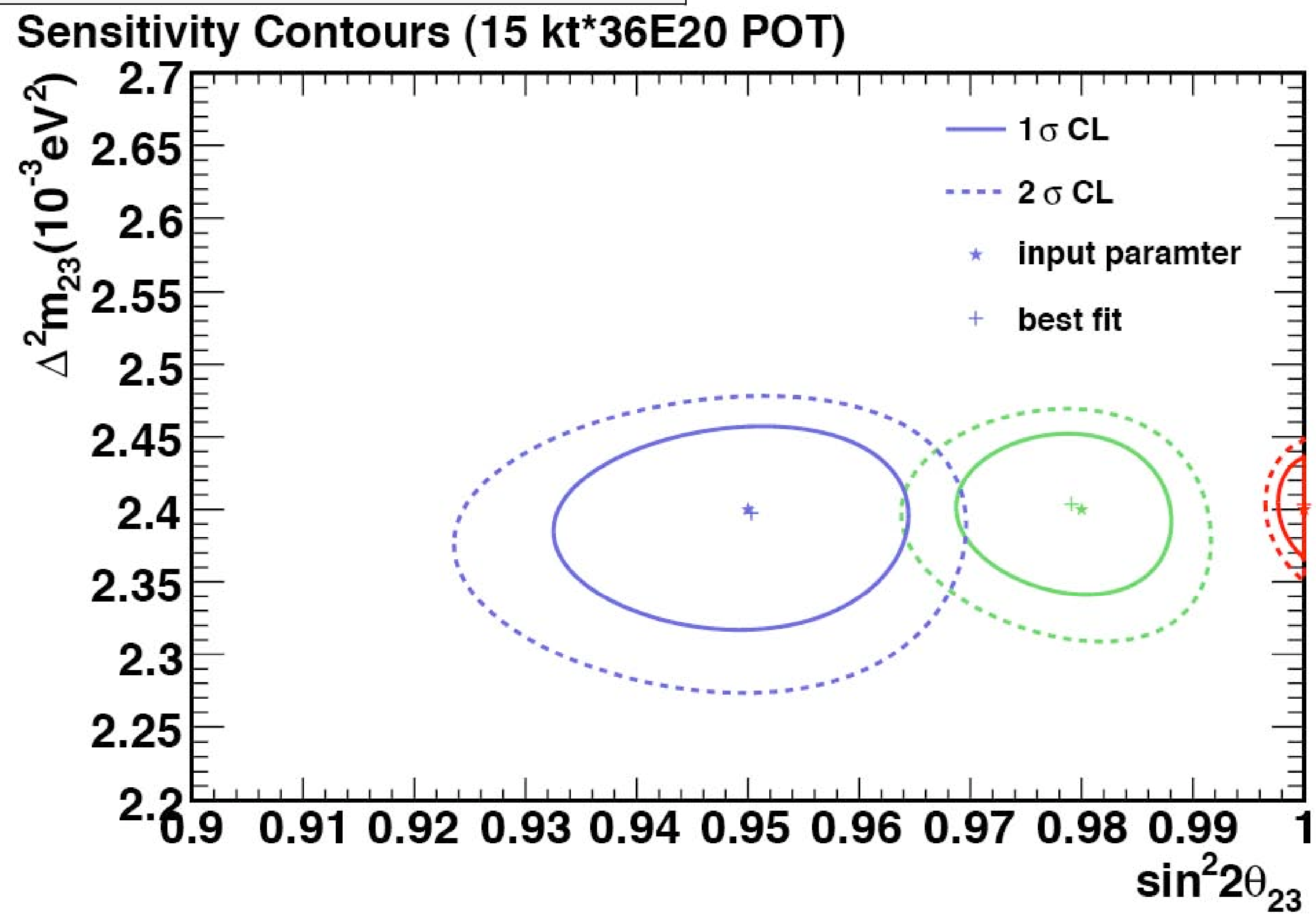




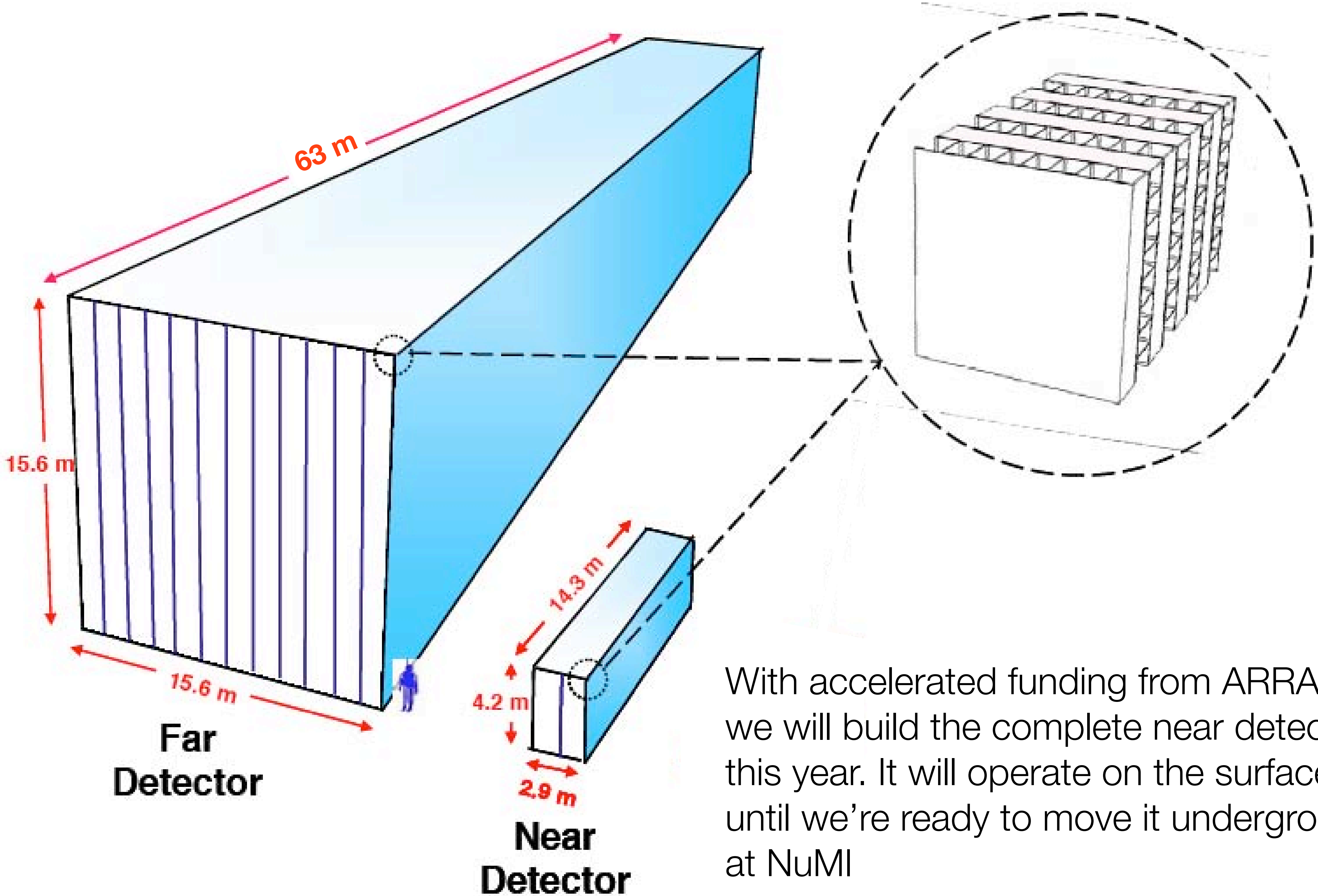
Is θ_{23} Maximal?

ν_μ (1.4 GeV) + N$\rightarrow\mu^-$ (1.0 GeV) + X (QEL)





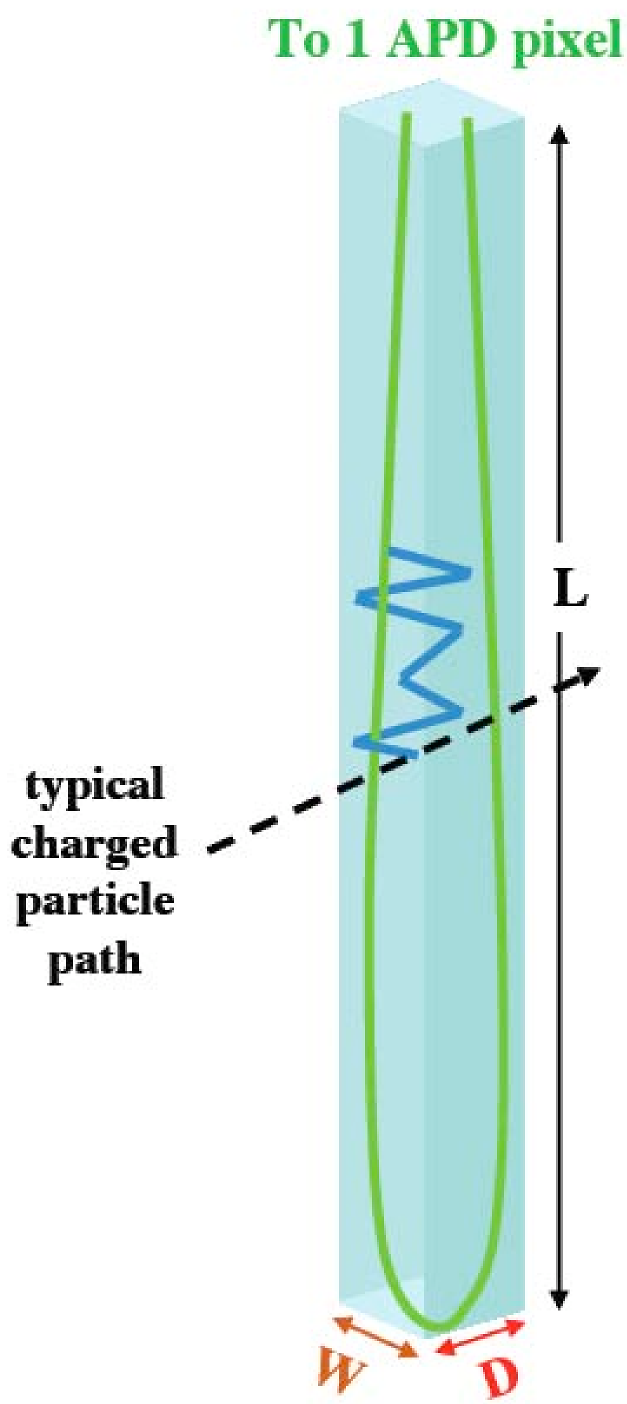
Since NOvA's spectrum peaks at the oscillation maximum and the detector has excellent QE resolution, any ν_μ CC events in the dip energy region indicate a non-maximal θ_{23}. NOvA will make this measurement for both neutrinos and anti-neutrinos.

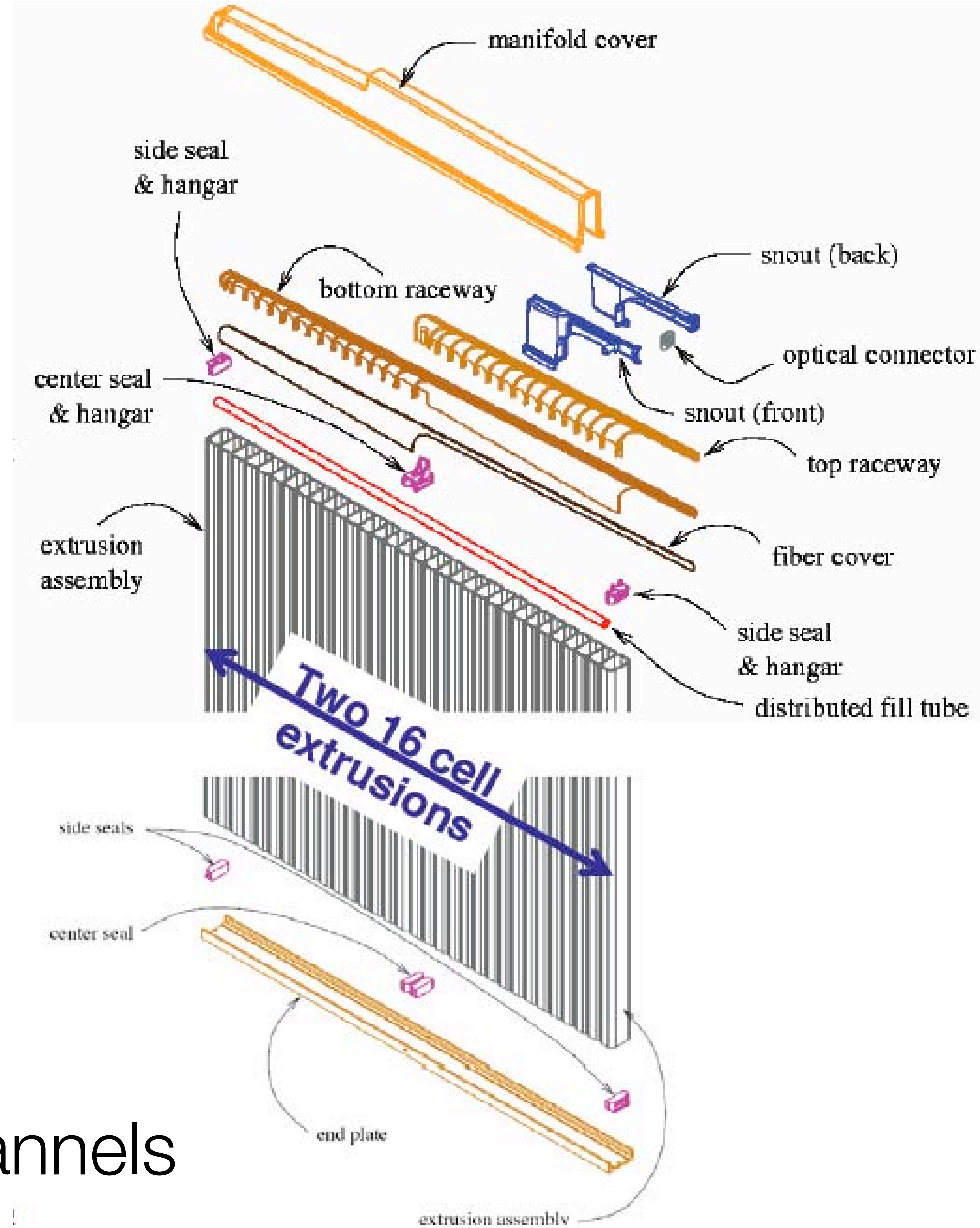


With accelerated funding from ARRA, we will build the complete near detector this year. It will operate on the surface until we're ready to move it underground at NuMI

The NOvA Detectors

- 14-18 kton far detector
- 220 ton near detector





357,120 total channels

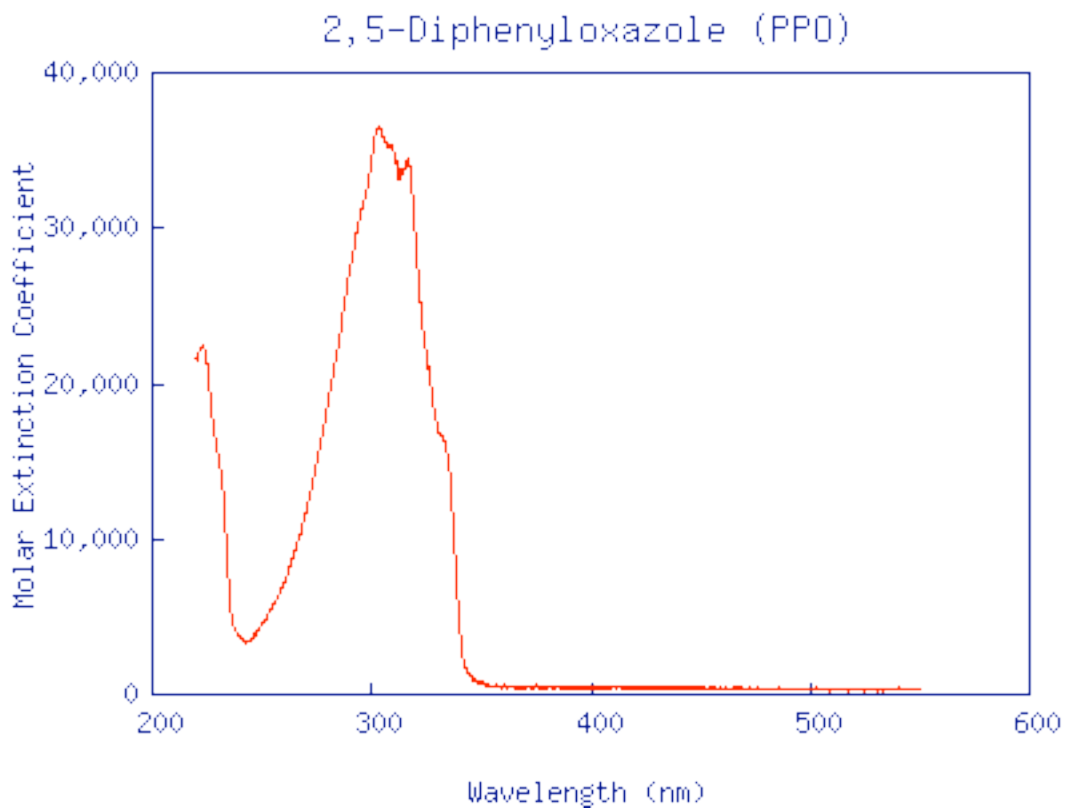
Liquid Scintillator Composition

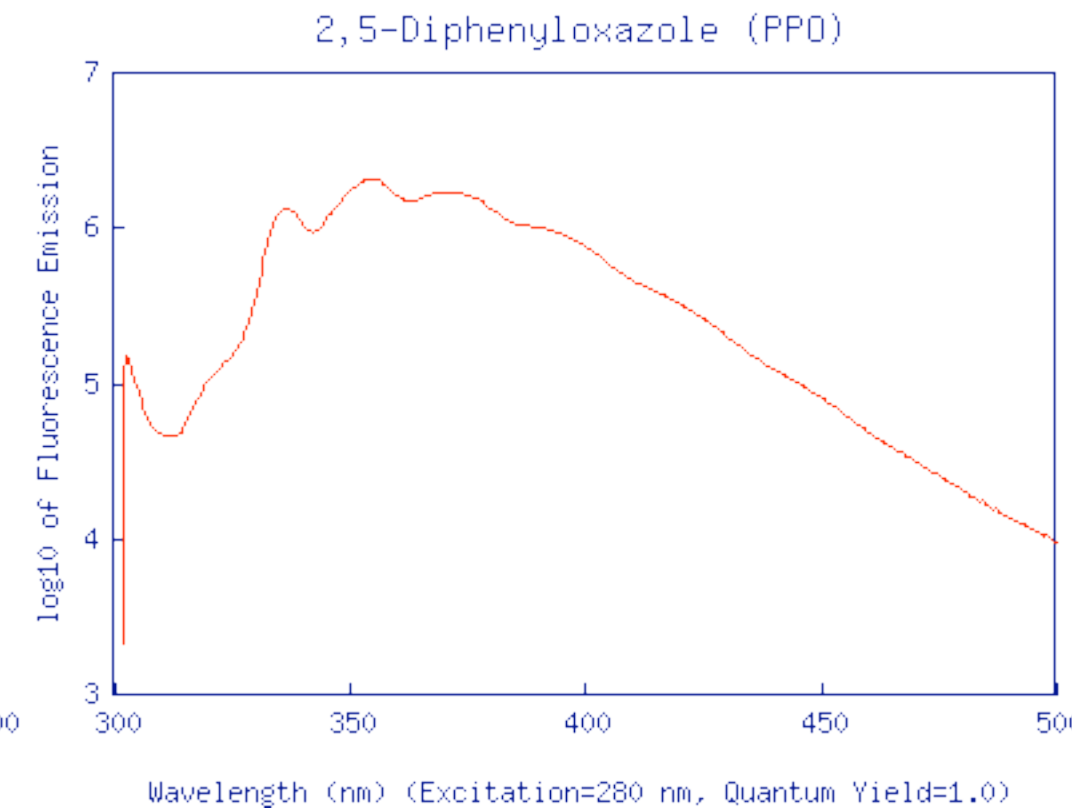
component	purpose	mass fraction	volume [gal]	mass [kg]
mineral oil	solvent	95.79%	2,810,674	9,074,478
pseudocumene	scintillant	4.11%	117,528	389,720
PPO	primary waveshifter	0.091%		8,576
bis-MSB	secondary waveshifter	0.0013%		120
Stadis-425	antistatic agent	0.0003%		28.4
tocopherol (Vit E)	antioxidant	0.0010%		95
Total		100.00	2,928,200	9,473,017

- Scintillator mixture optimized to deliver required light at low cost. For our application technical grade mineral oil is sufficient.
- Relatively low pseudocumene fraction reduces interactions with WLS/PVC/adhesives to below what we can measure

Waveshifter absorption and emission spectra

Primary wave shifter (PPO)





http://omlc.ogi.edu/spectra/PhotochemCAD/html/PPO.html

Secondary wave shifter (bisMSB)

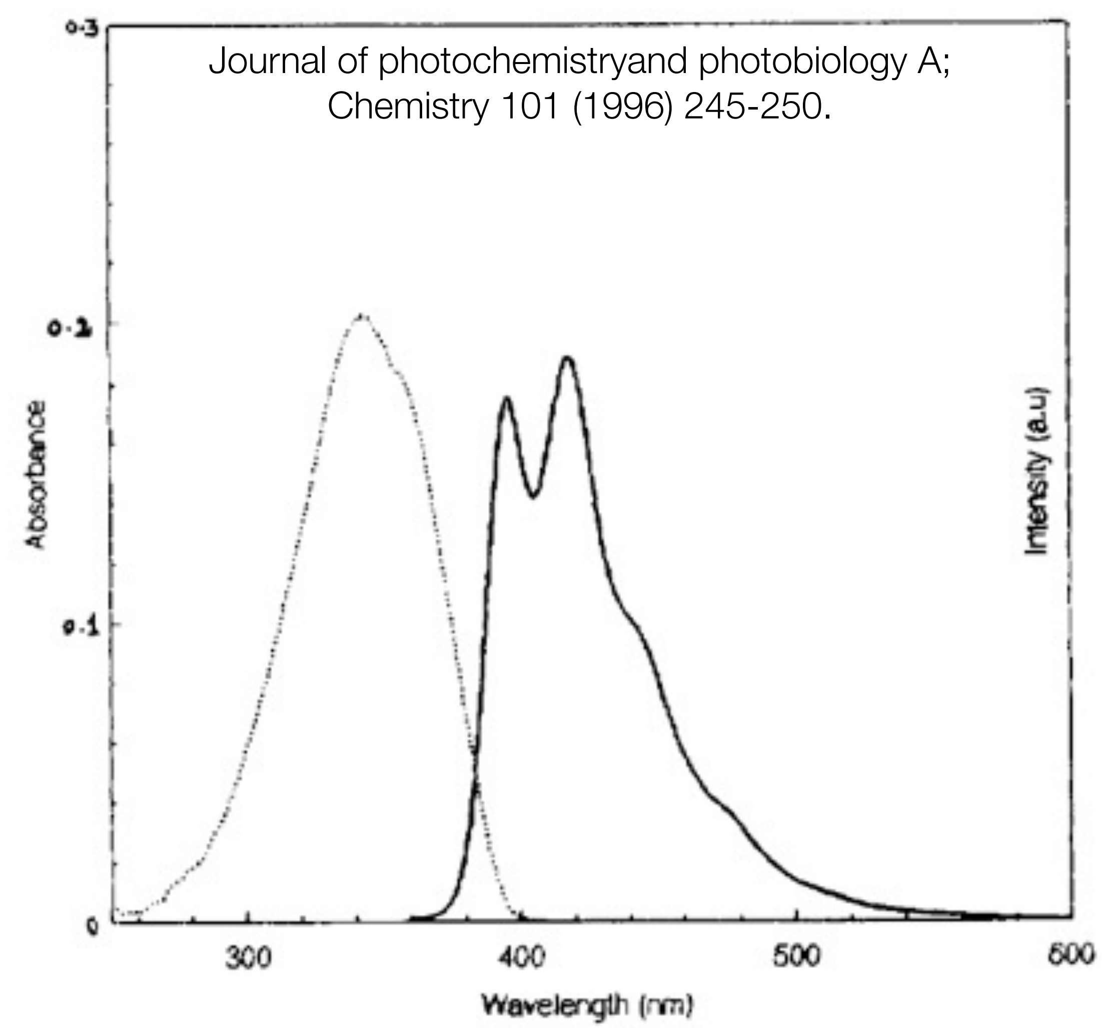
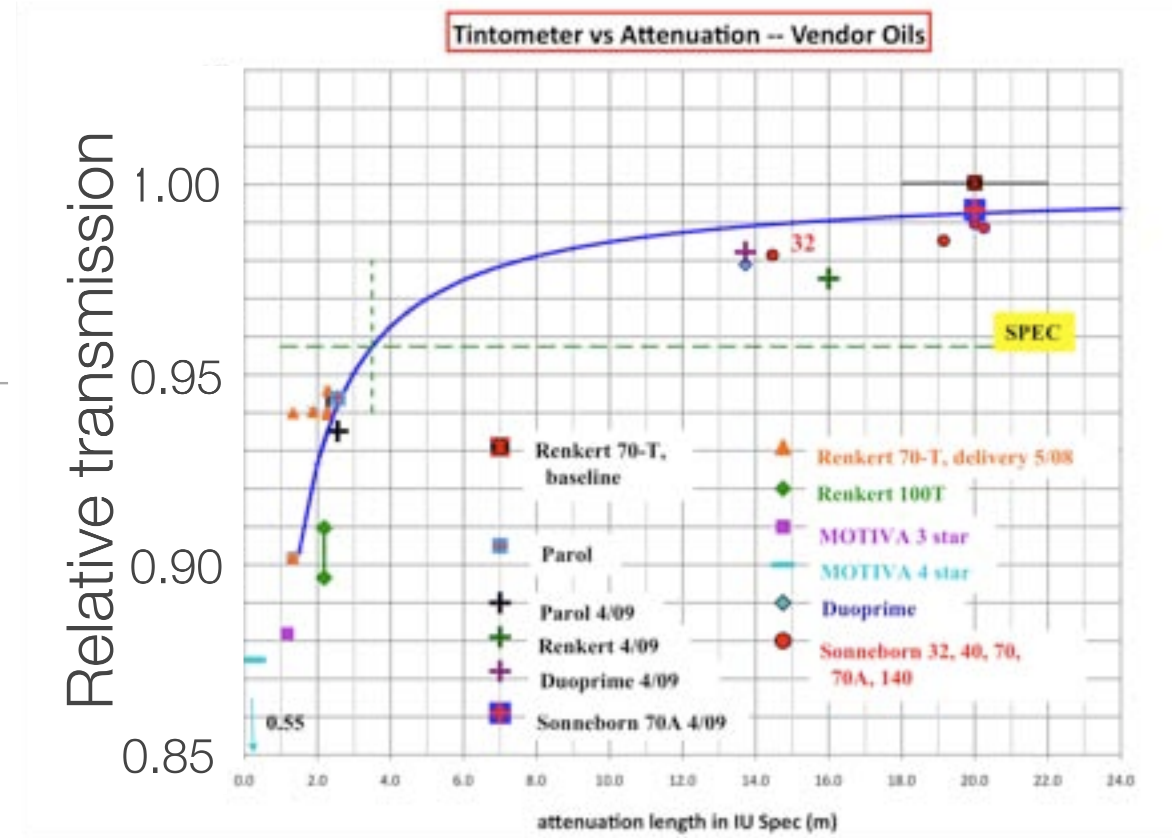
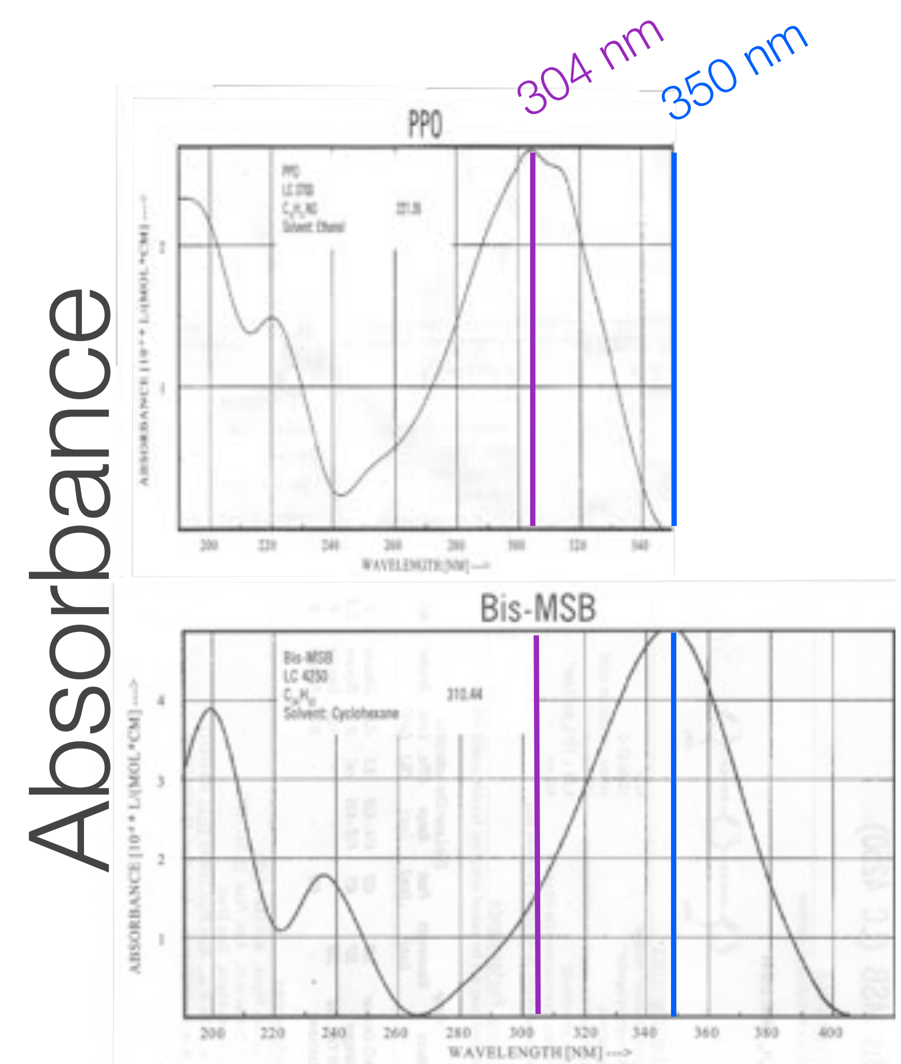


Fig. 1. Absorption (· · ·) and emission (— — —) spectrum of Bis-MSB in cyclohexane at 25 °C.

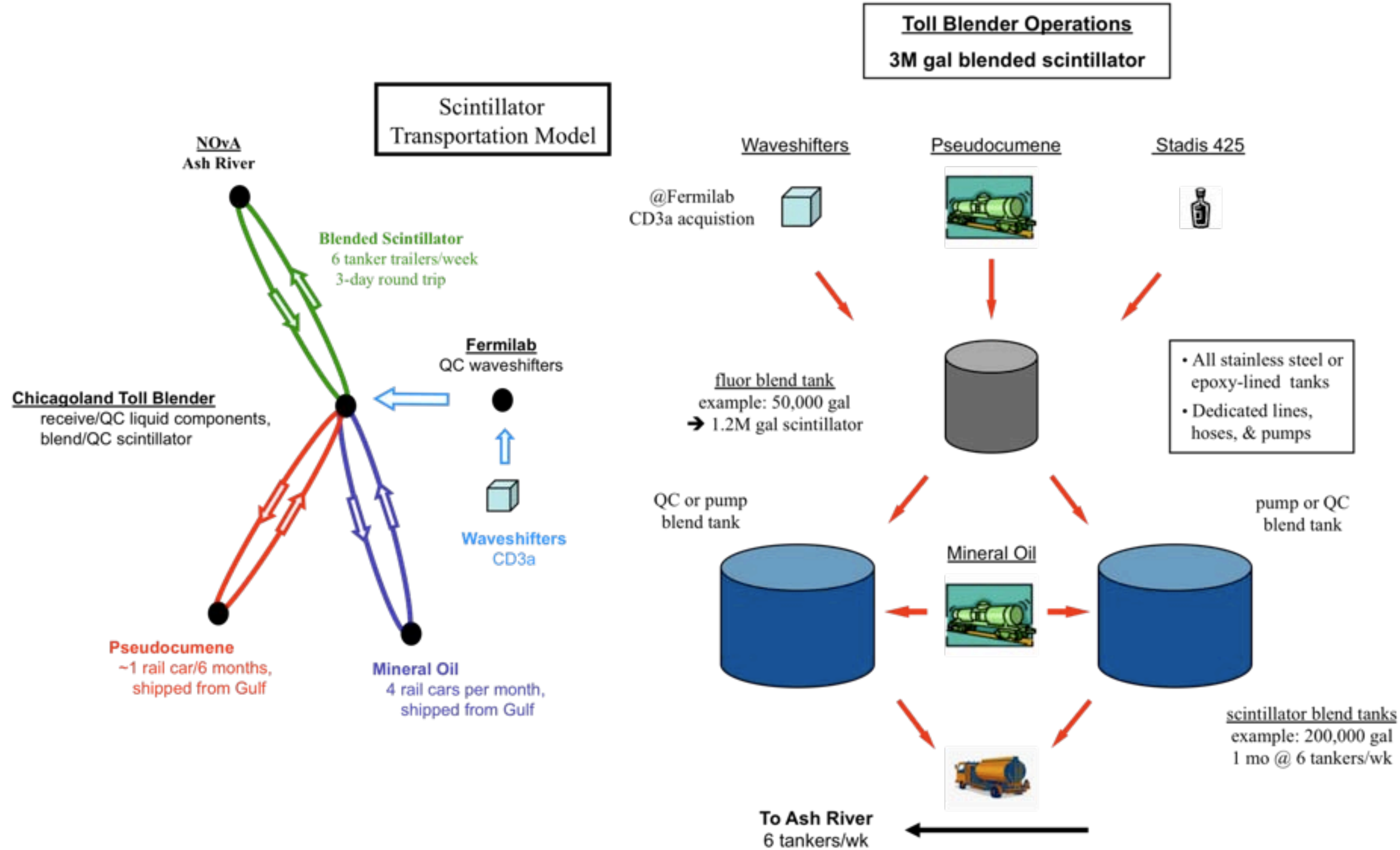
Scintillator Quality Control

- Mineral oil: Require > 3.5 m attenuation length at 420 nm. Measure transmission across 6” cell relative to a glass standard using a Tintometer [Figure top, right]
- Pseudocumene fraction determined by separating it from oil using gas chromatography and electron impact mass spectrometry
- Fractions of wave shifters determined by UV absorbance at 304 (PPO) and 350 nm (PPO) [Figures bottom, right]
- Analysis takes 1-2 days measures pseudocumene concentration to 5% RSD and waveshifter concentrations to 2% RSD.



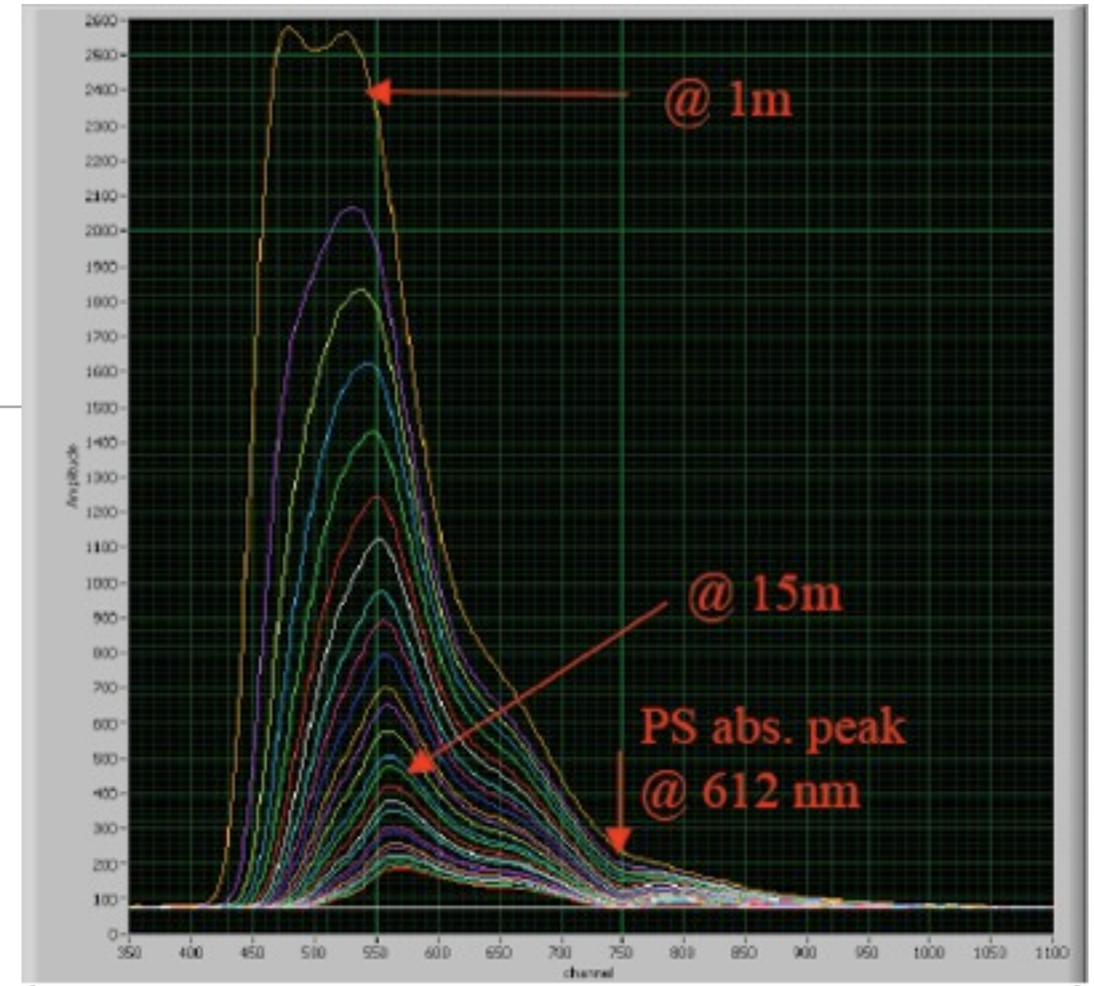


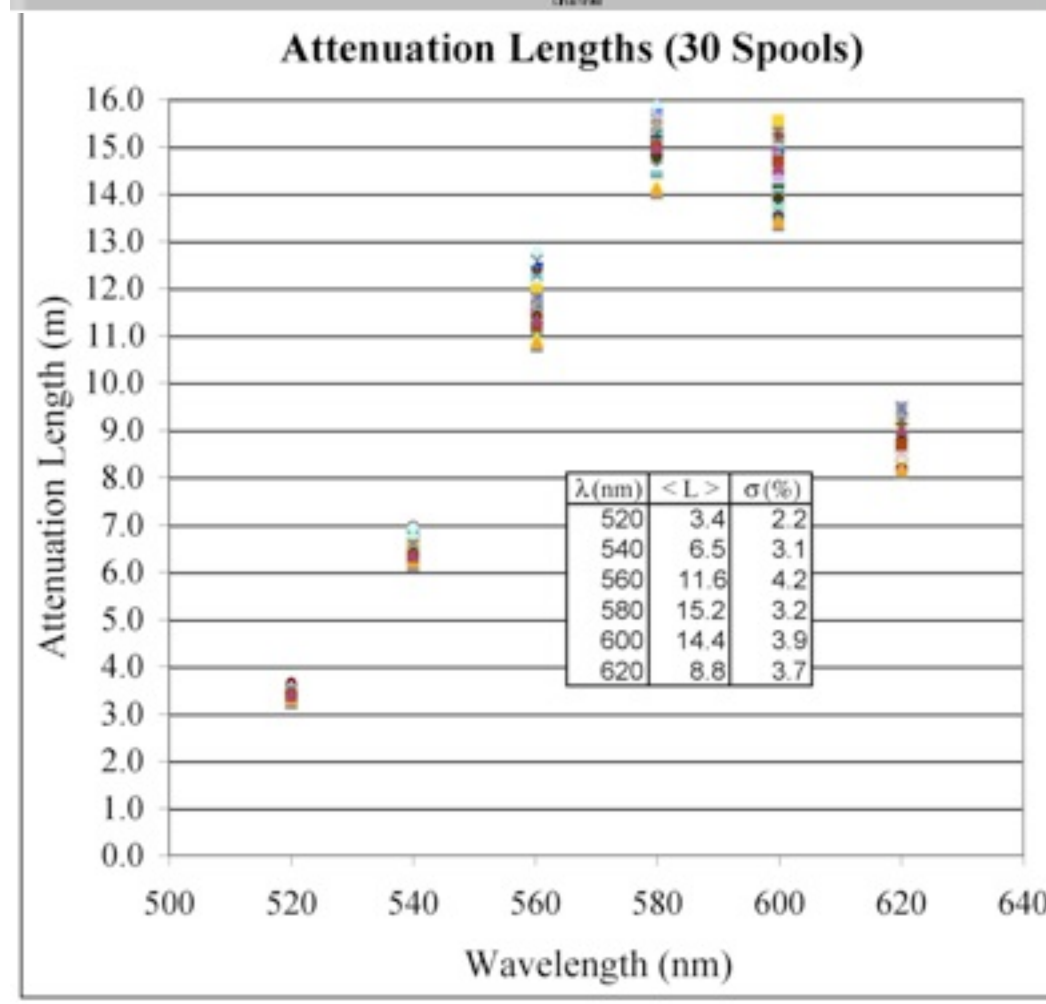
Scintillator production



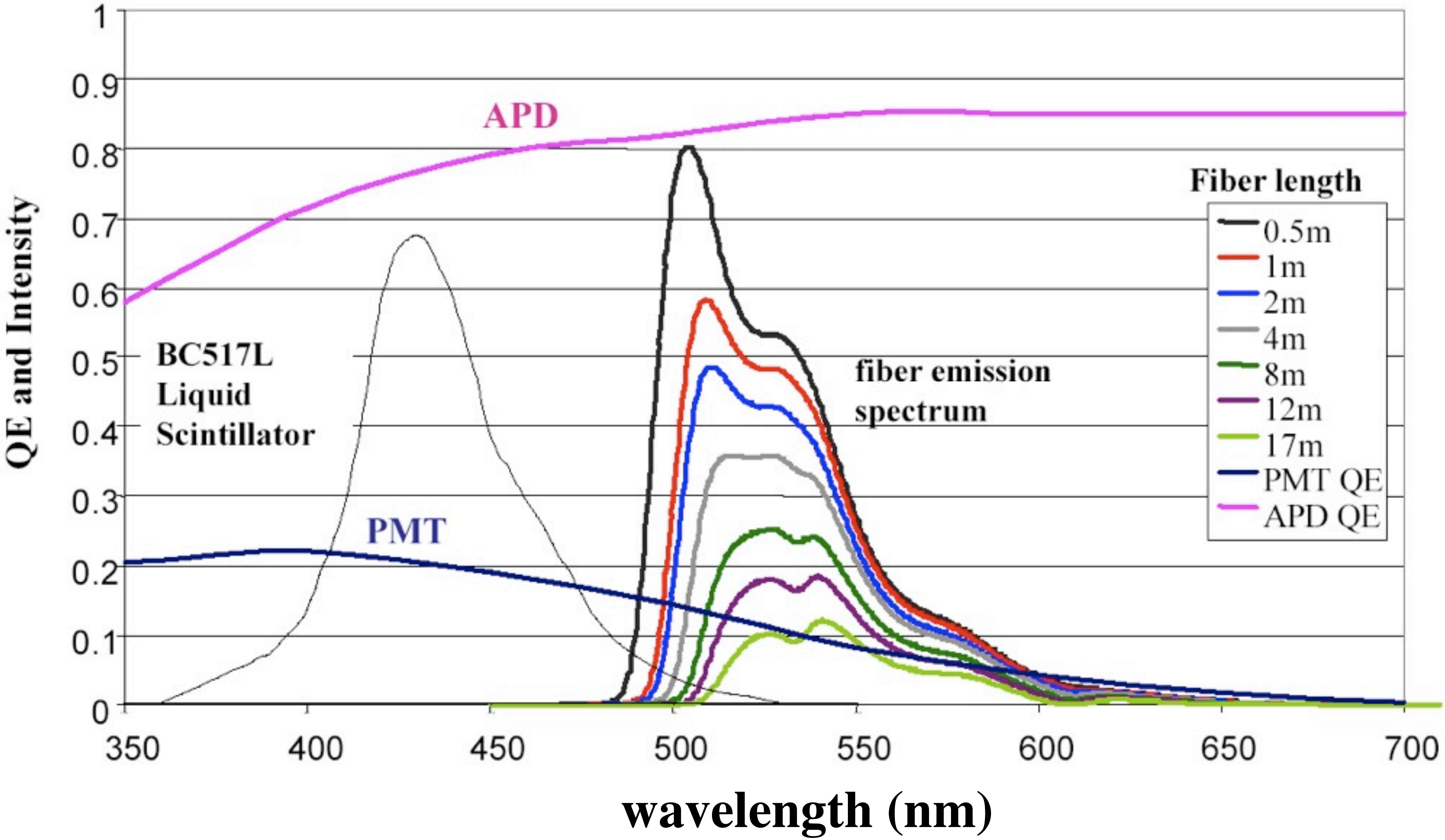
WLS Fiber

- NOvA will use 13,000 km WLS fiber from Kurrary. No other producer produces fibers with long enough attenuation length
- Delivered at 360 km/mo over three years
- 0.7 mm “S” type (most flexible), 300 ppm of fluorescent dye
- Double clad with PMMA and flourinated plastic
- Tested >200 m of fiber in scintillator with high PC fraction at elevated temperatures wrapped in tight coils. We’ve seen no degradation in performance.
- A copy of our QC device will be send to Kurrary so they can test the fiber as it comes off production line





Matching photodetector to scintillator performance



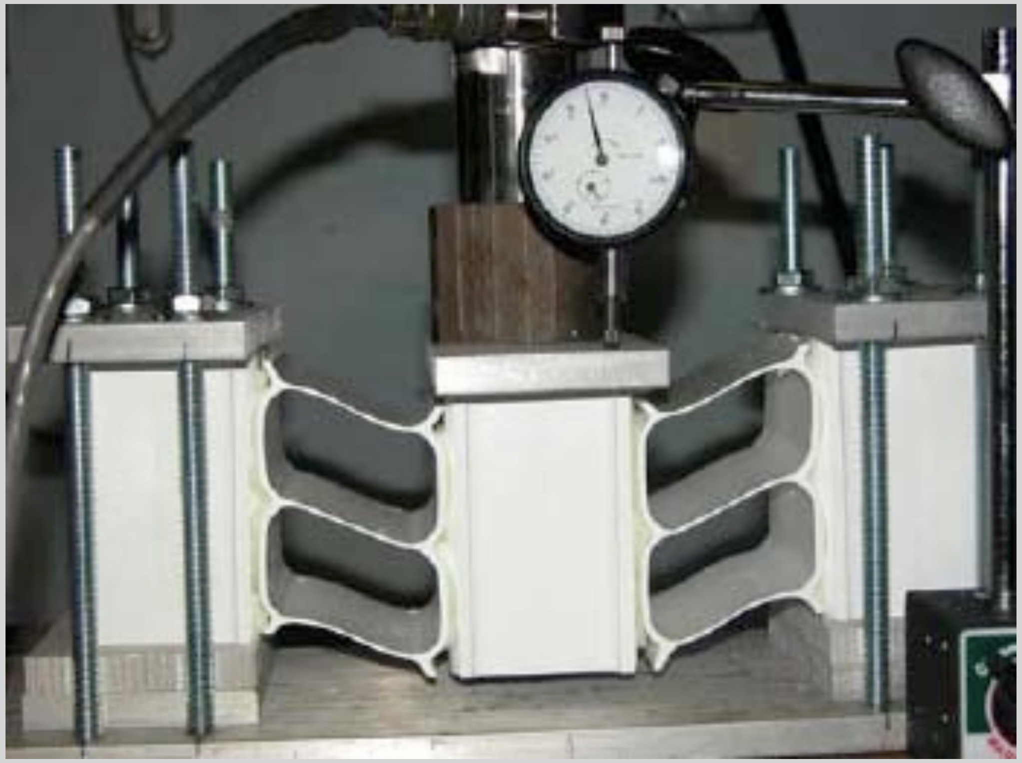
Development of PVC Resin

The PVC that the extrusions are made from must satisfy multiple requirements

1. ***High reflectivity***: Light bounces ~10 times off the walls before being captured in the WLS fiber so we need high reflectivity to achieve required light levels
2. ***Mechanical***: The PVC must be strong enough to contain the liquid scintillator at pressures of >19 psi and support the horizontal modules. It must maintain its strength throughout the lifetime of the experiment. We must be able to glue to the surface.
3. ***Extrudability***: The resin must reliably pass through the extruder and produce parts with good shape and structure

phr - per hundred parts of resin	NOVA-24	NOVA-27	
Shintech SE950EG (high reflectivity)	100	100	PVC
Rohm & Haas Advastab TM-181 20% monomethyl tin	2.5	2.5	heat stabilizer
DuPont R-102 rutile titanium dioxide	19	0	
Kronos 1000 anatase titanium dioxide	0	19	
Ferro 15F calcium stearate	0.8	0.8	lubricants
Honeywell Rheochem 165-010 paraffin wax	1.1	1.1	lubricants
Ferro Petrac 215 oxidized polyethylene	0.2	0.2	lubricants
Rohm & Haas F1005 glycerol monostearate	0.3	0.3	lubricants
Arkema Durastrength 200 Acrylic impact modifier	4.0	4.0	
Rohm & Haas Paraloid K120N processing aid	1.0	1.0	
wt % titanium dioxide	15	15	

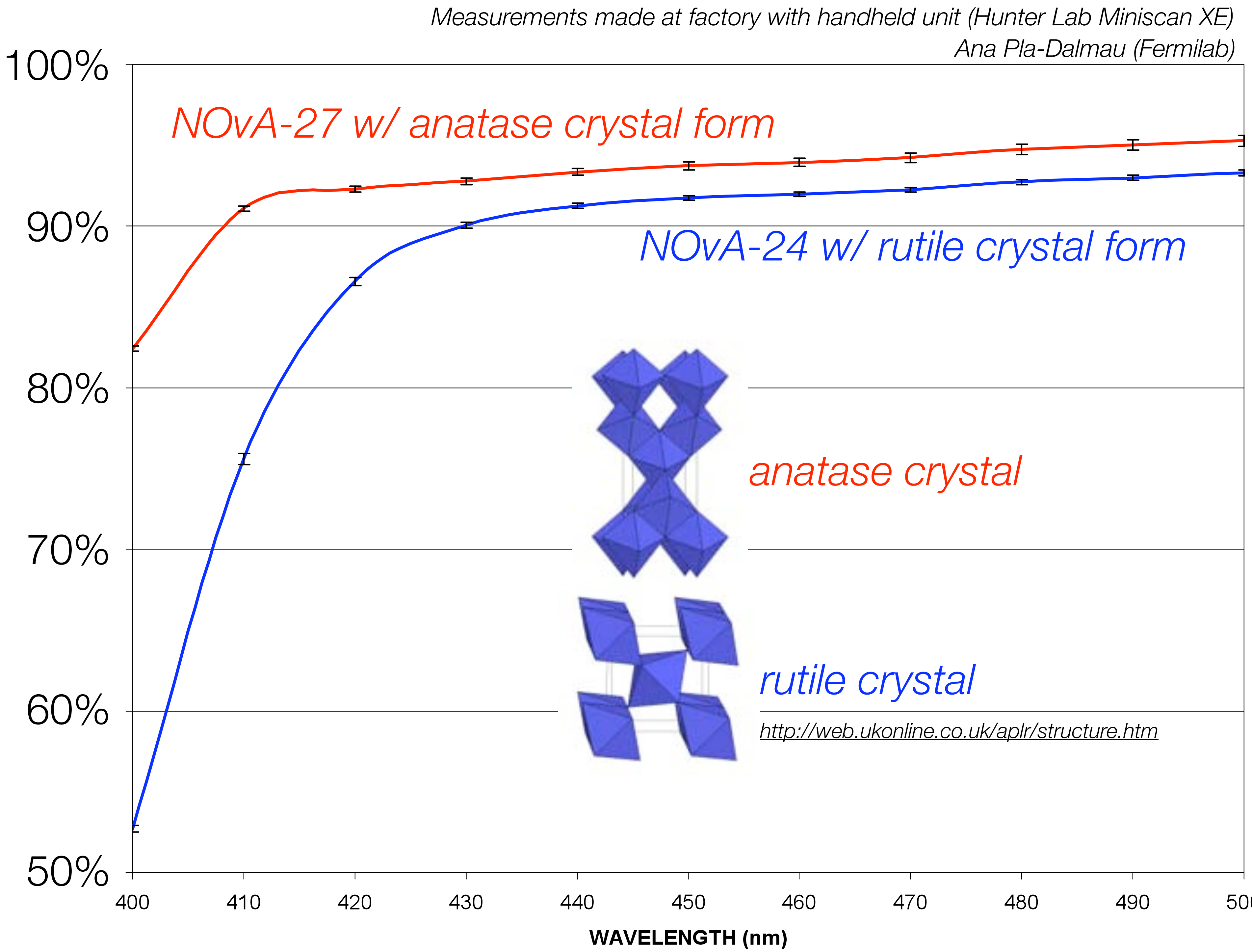
Our two best formulations: Only difference is crystal structure of TiO_2. Numbers indicate iteration number on formula.



Top left: extrusions coming off the line
Bottom left: testing compressive strength
Above: Horizontal pieces for IPND

PVC Extrusions

PVC Reflectivity Measurements

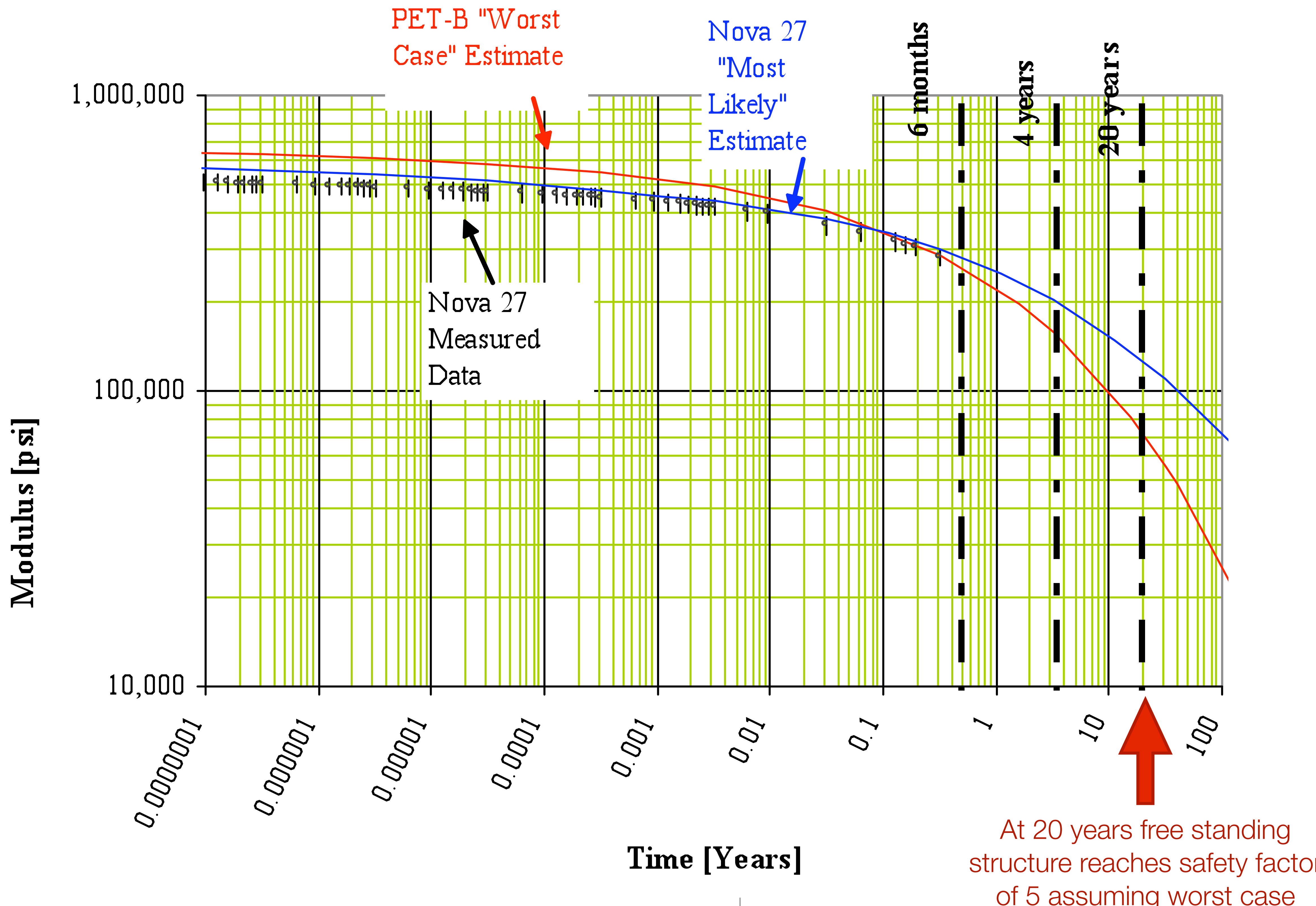


Compare 90% reflectivity to 92% after 10 bounces:

$0.90^{10} = 0.35$
$0.92^{10} = 0.43$

2% change in reflectivity = 25% change in light yield

In a NOvA test cell anatase yields ~14% more detected photons than rutile



Long term plastic strength

Plastic is "glassy" and creeps if held under tension long term

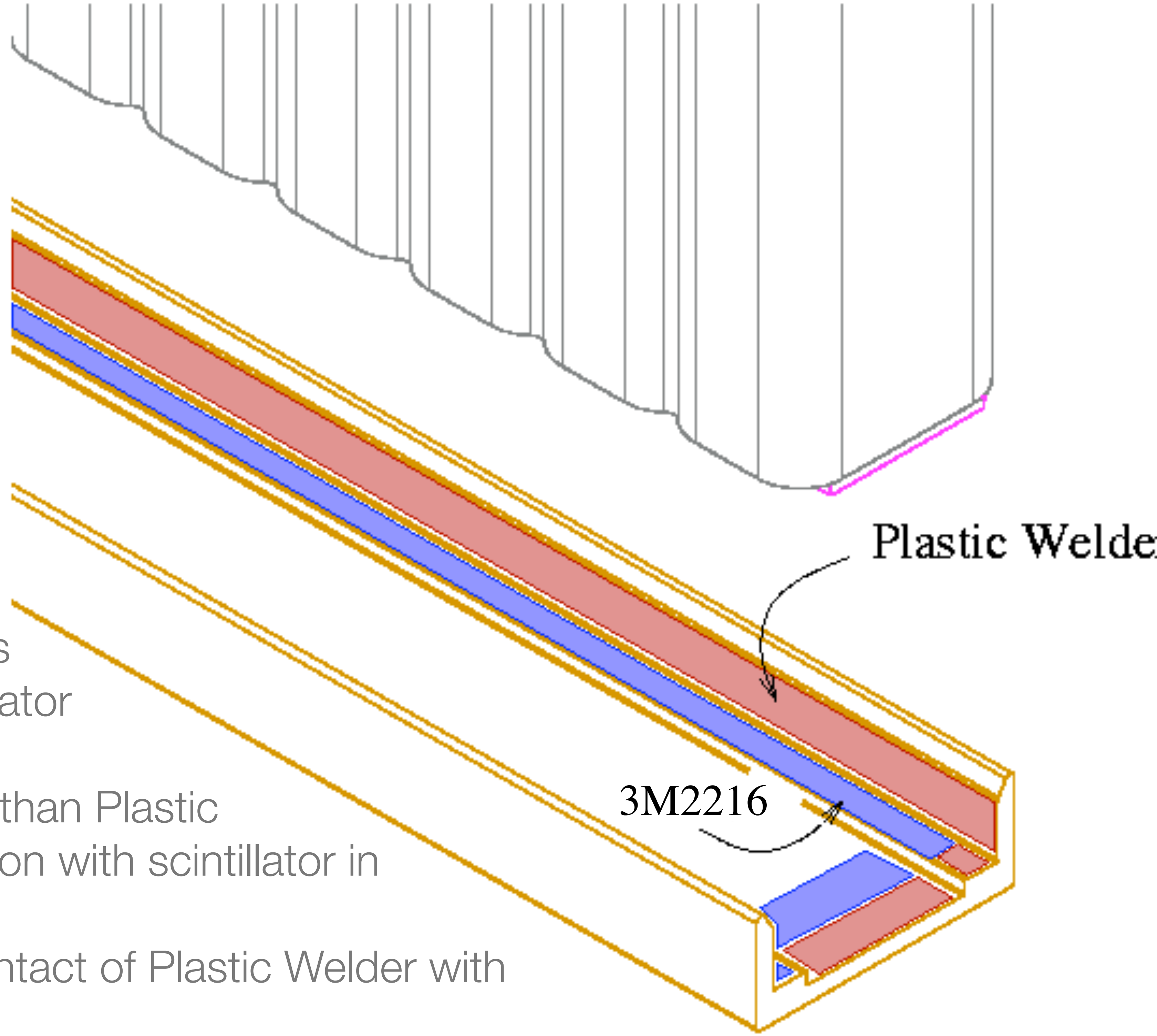
Adhesives

The detector is assembled with adhesives. They are used to:

- Join two 16-cell wide extrusions together to make a 32-cell wide module
- Connect the top and bottom end caps on a module
- Join adjacent 15 m x 15 m planes together to form blocks

Requirements for the adhesives vary according to above function, but in general we need

- High strength (shear and peel)
- ~20+ minute setup times
- Where adhesive is in contact with scintillator, low reactivity with scintillator
- Safe working conditions



- *Plastic welder* is very strong in over-pressure tests, but shows signs of interaction with scintillator in high exposure tests.
- *3M2216* is somewhat weaker than Plastic Welder, but shows no interaction with scintillator in high exposure tests.
- Two-glue solution prevents contact of Plastic Welder with scintillator

Glue seals

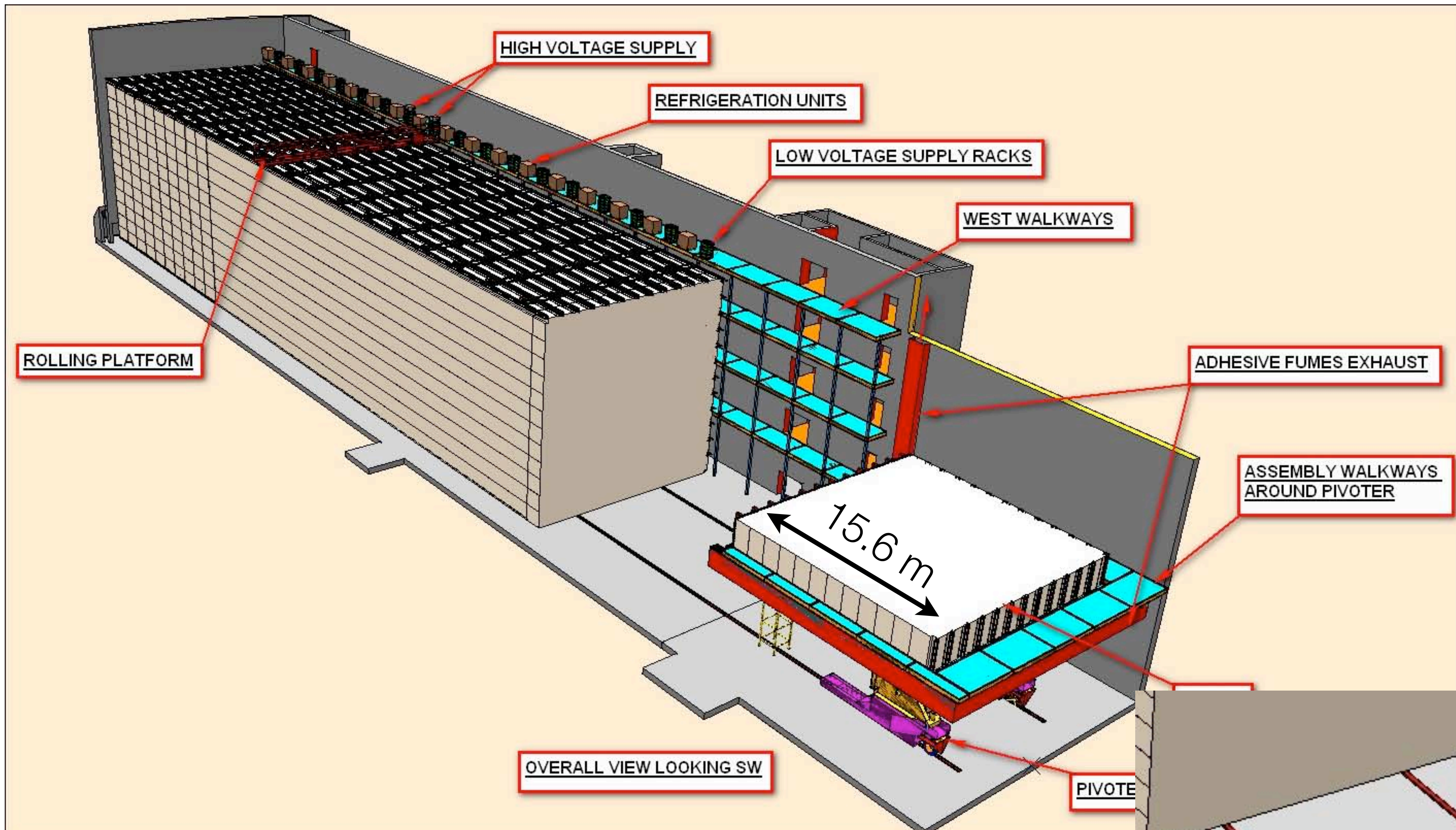
Two-glue solution for bottom module plate

Adhesive dispenser

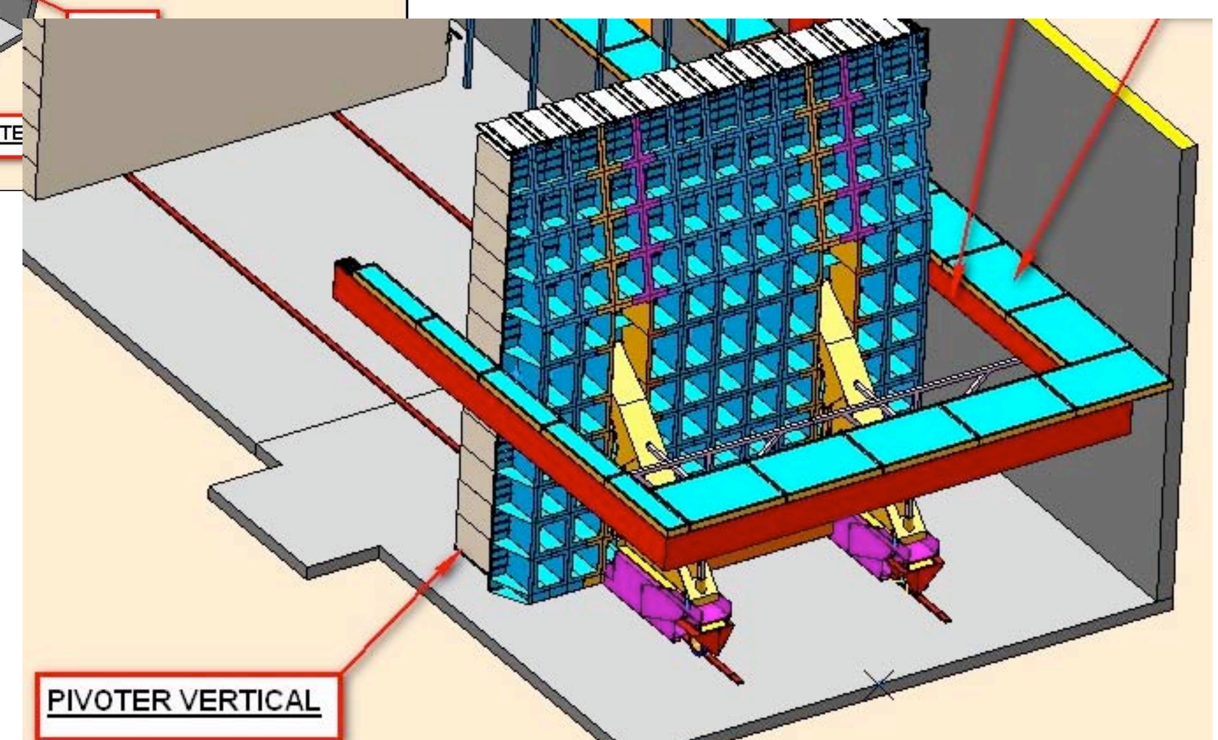
Prototype working at half capacity
Clear plastic for testing purposes

Moving module from glue machine to plane assembly

Block Pivoter



work platform



Schedule

- Construction has started on far detector building. Should have occupancy next summer allowing installation for construction of far detector to begin. Building complete in November 2010.
- We will construct the near detector over the next year and begin running it on the surface at Fermilab next summer
- Recommended for CD3b in July. Last approval before we're completely authorized for all procurements
- Plan to run experiment while its being constructed. First data in 2012 and a completed detector in 2013.