Off Axis

Progress Report on the NuMI Off-Axis Experiment (P929)

Fermilab PAC

12 December 2003

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PAC Questions

- We submitted an LOI last year and the PAC asked us to address 8 questions in any future submission.
- We will address those questions as best we can today. We are preparing better answers in the proposal to be submitted in March.
- Major areas needing more work are simulations and costing.

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Question 2: What is the optimum detector technology, for a fixed cost, to measure θ_{13}?

- **Dismissed water Cerenkov -- insufficient discrimination against π^0 misidentification.**
- **Dismissed liquid argon TPC -- too much R&D needed for our time scale.**
- **Considered medium-Z sandwich detectors:**
  - **Scintillators**
    - **Liquid**
    - **Plastic**
  - **Glass RPCs**
    - **2-d readout**
    - **1-d readout**

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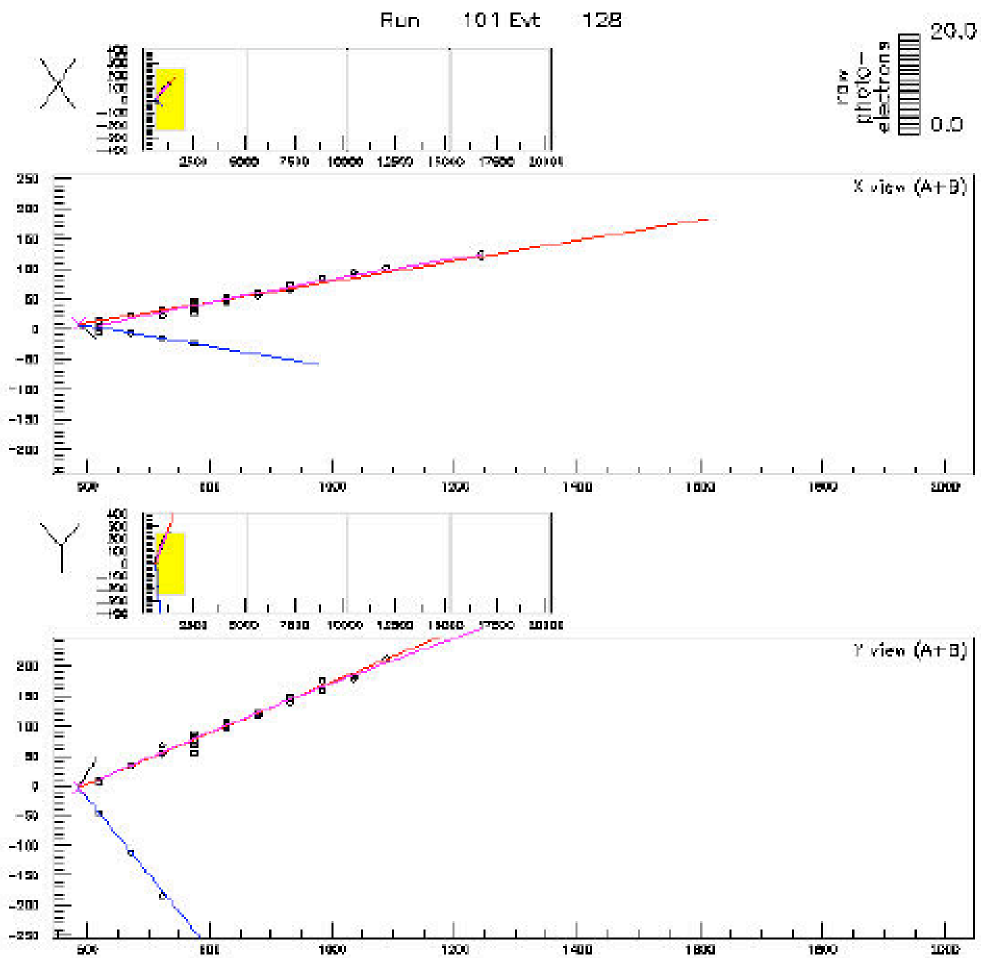
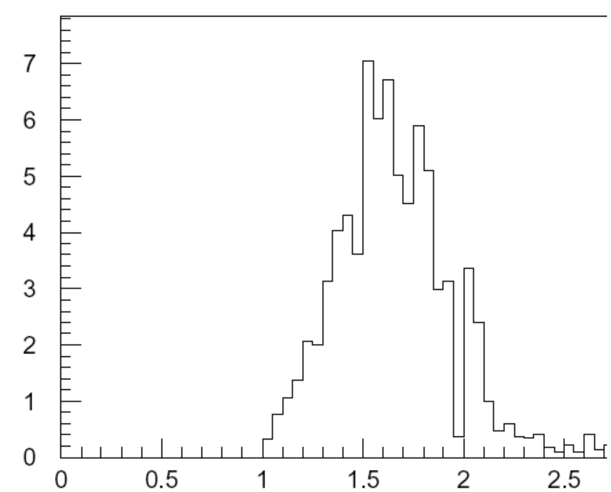
Medium-Z Sandwich Detector Electron Track



Hits per plane > 1



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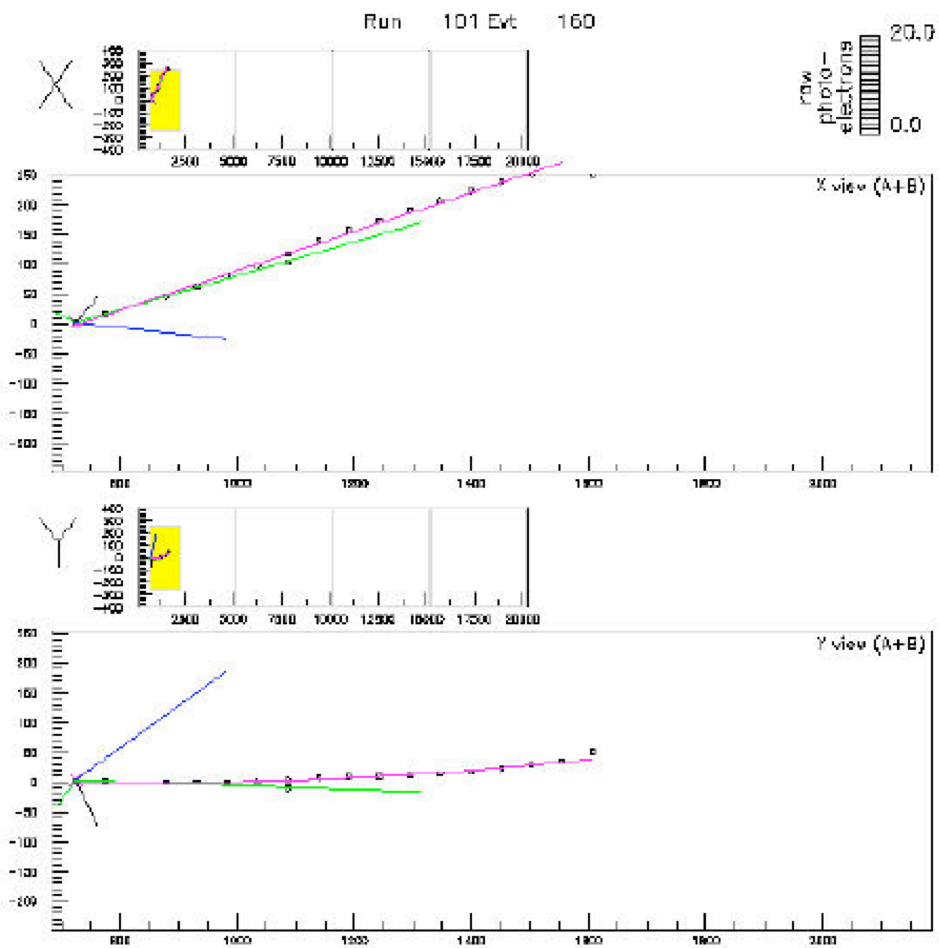
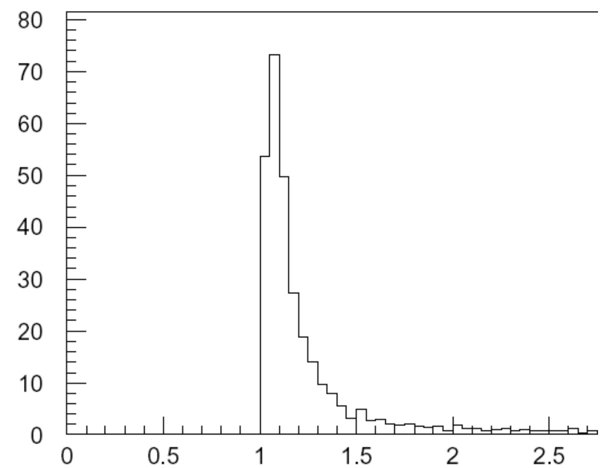
Medium-Z Sandwich Detector Muon track



Hits per plane ~1



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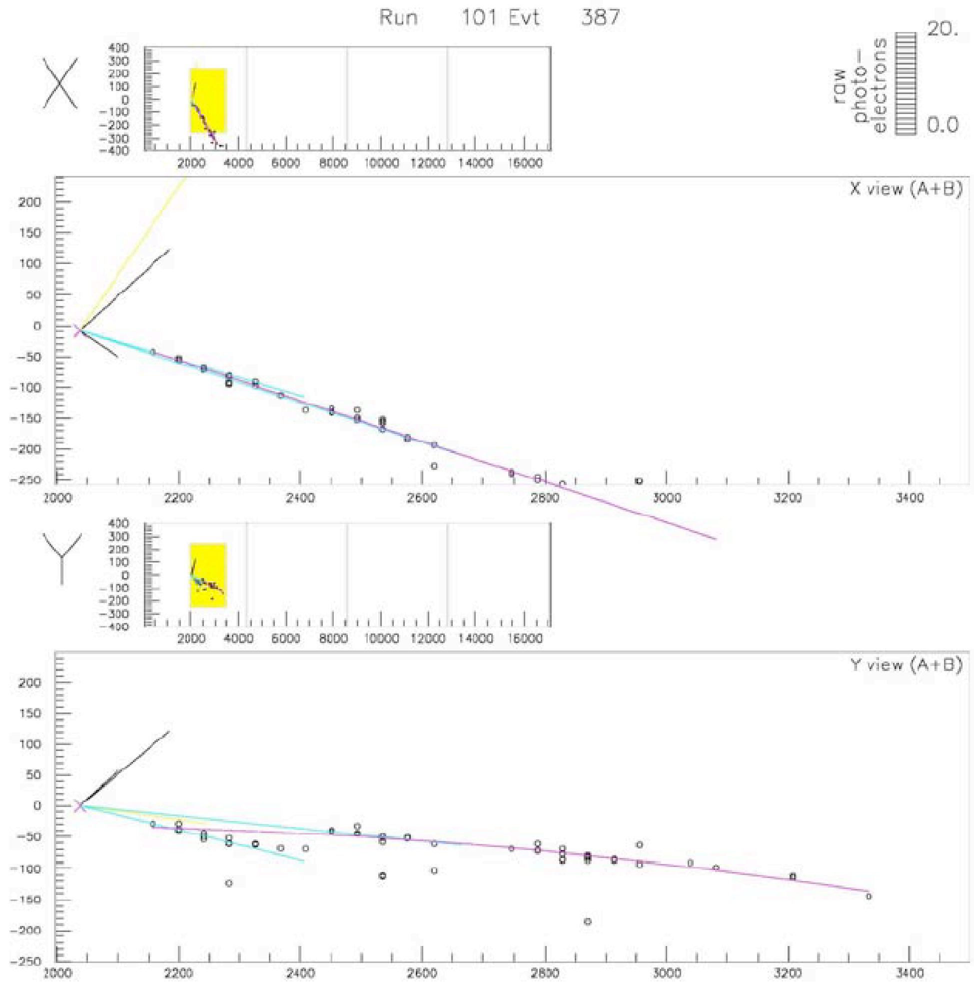
Medium-Z Sandwich Detector NC with leading π^0



Two tracks with different starting points leading to a "gap"

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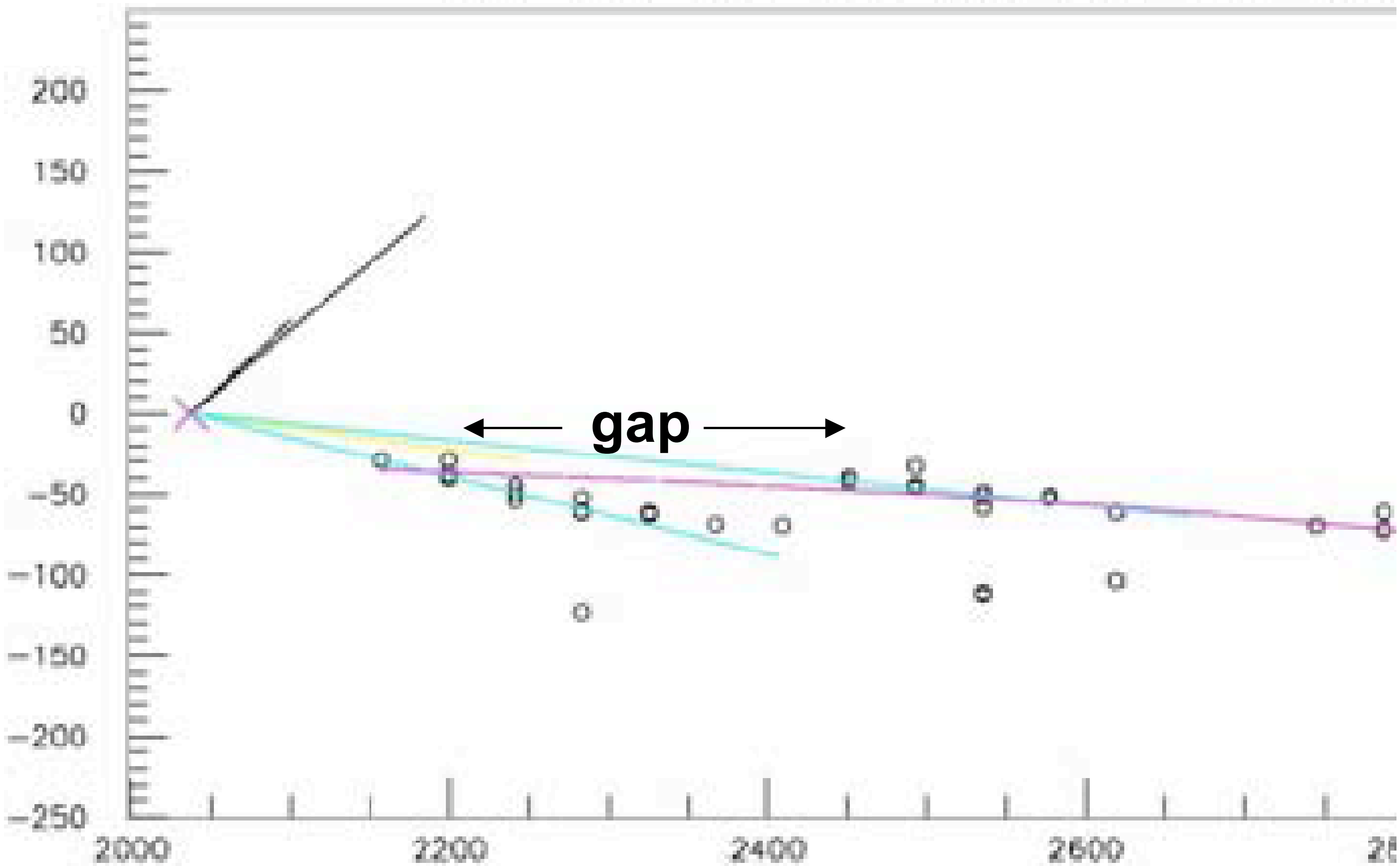
Detail of NC with leading □⁰



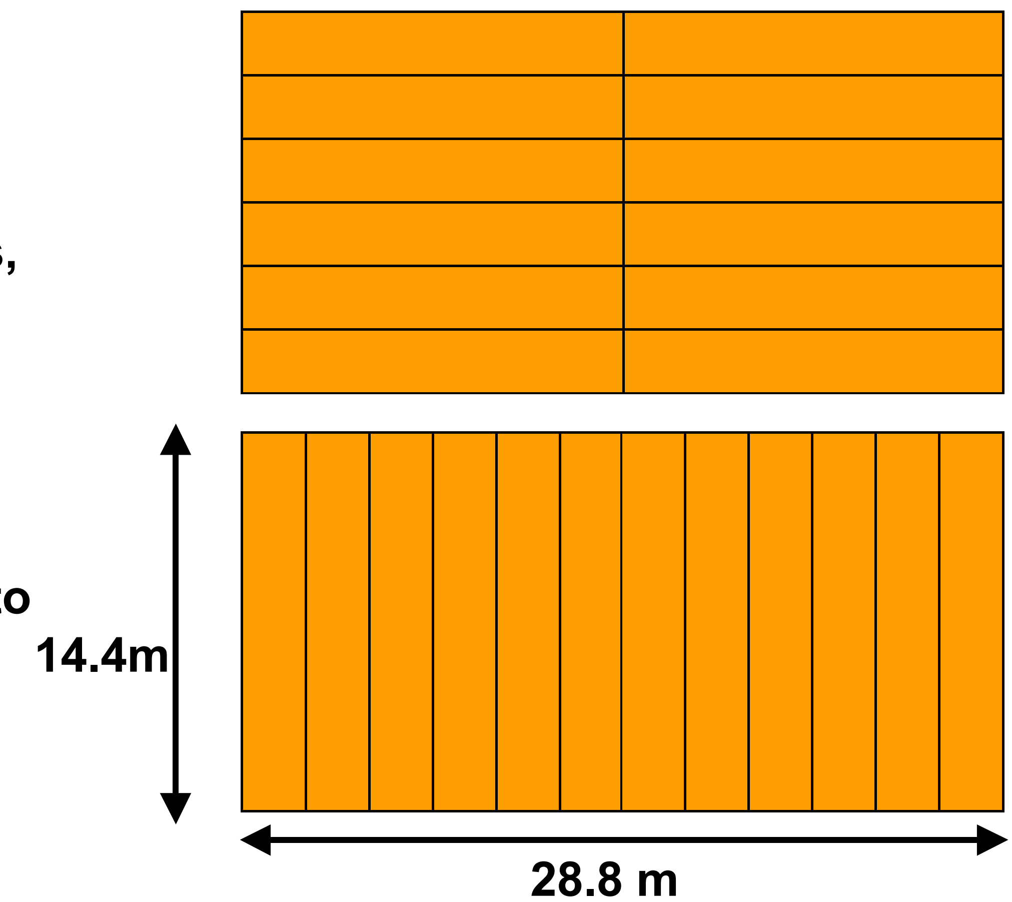
Scintillator Layout

Monolithic structure

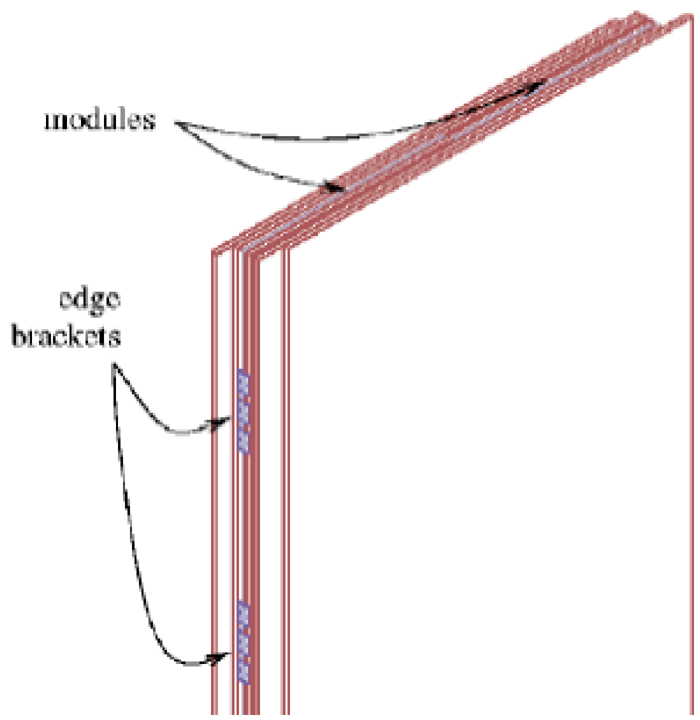
Liquid Scintillator:
1.2 m x 3 cm x 14.4 m
30-cell PCV extrusions,
24 extrusions/plane,
750 planes
= 18 000 extrusions
= 540 000 channels

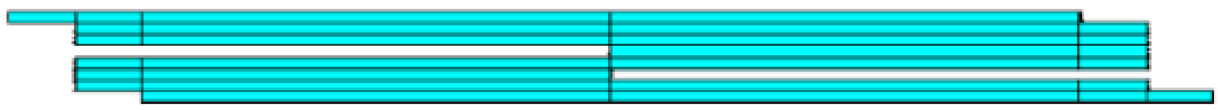
U-shaped WLS fiber into
a APD photodetector

Absorber:
20 cm particleboard/
plane (~1/3 X_o)



Absorber Structure Details



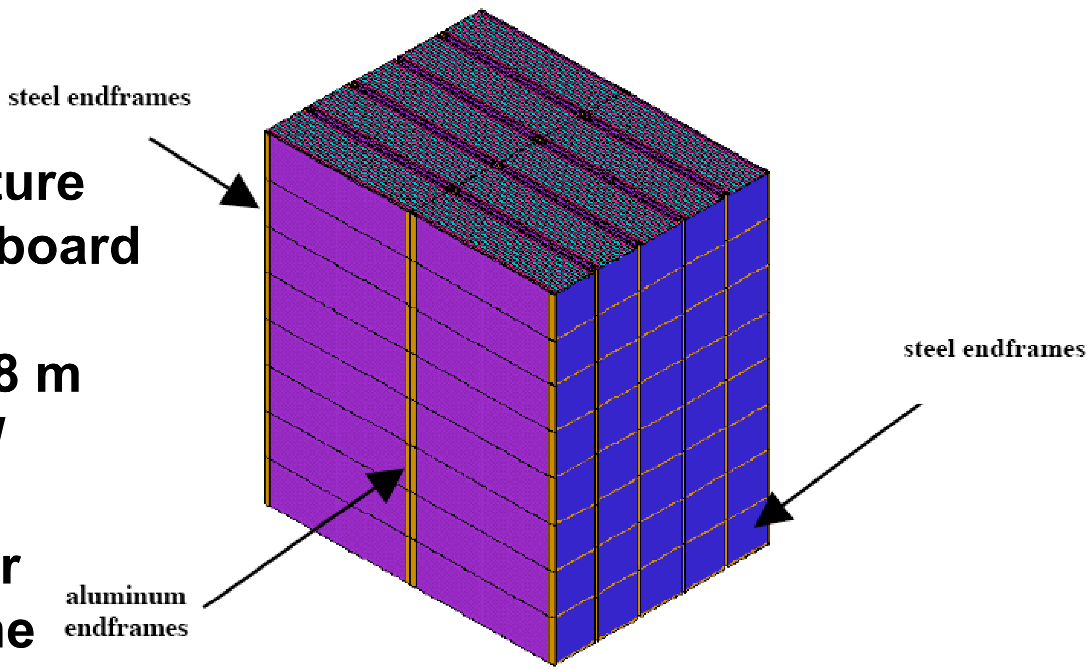


End View of Defining Volumes

Glass RPC Layout

"Container" structure
Built from particleboard

Chambers 2.4 x 2.8 m
3 2-gap chambers/
  container layer
12 layers/container
16 containers/plane
75 planes of containers
86,400 chambers
3,686,400 strips



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Physics Comparison

- Scintillator has analog readout with minimum of 28 photoelectrons; RPCs have a binary readout.
  - Calculated advantage for scintillator: 5.4 ± 2.4% in FOM
- RPCs can have 2-d readout at each layer; scintillators are inherently 1-d devices.
  - Calculated advantage for scintillator: 13 ± 3% in FOM
- Warning: simulations are quite preliminary and need to be improved and repeated.

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Cost Comparison

- Detailed costing exercise for a 50 kT detector, fully loaded, but does not include near detector or active shield:
  - Liquid scintillator 174 M
  - 1-d readout RPC 188 M
  - 2-d readout RPC 208 M
  - Plastic Scintillator 259 M
- Liquid scintillator is less expensive because of lower amount of labor to fabricate -- needs verification

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Tentative Conclusion

- Liquid scintillator is our current baseline
  - Have the least experience here -- need a “vertical slice” test to verify performance.
  - Will review decision in ~ 1 year.

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Question 1: Can one confidently pick a location of the off-axis experiment today? What is the flexibility in optimizing the location of the detector once Δm_{23}^2 is known better?

- **No need to pick a location today. We can permit several locations and decide at the last moment.**
- **Sensitivity is broad. A site optimized for $\Delta m^2 = 2.5\text{x}10^{-3}$ eV^2 is only 2.4% off maximum in the FOM for $\Delta m^2 = 2.0\text{x}10^{-3}$ eV^2. At fixed Δm^2, only a 2% variation in a 3 km transverse interval.**

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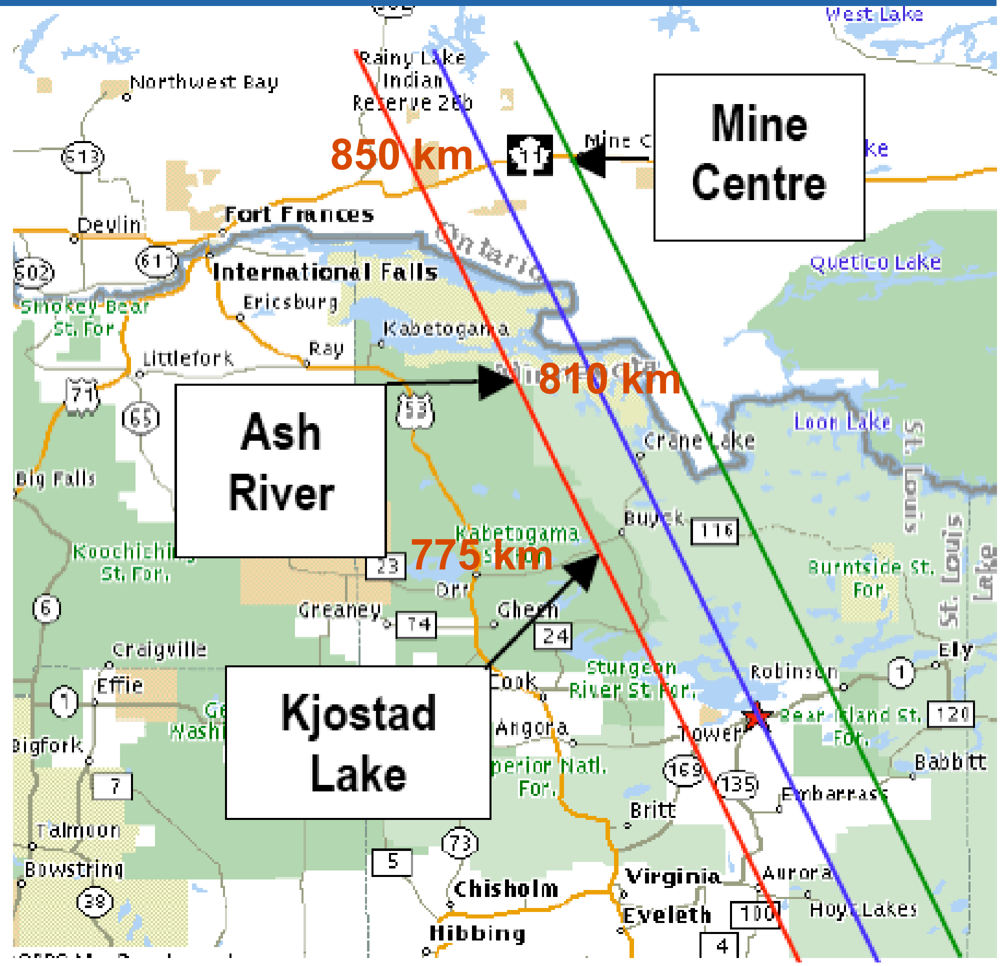
Possible Sites

We are now focusing on the Ash River site.



6 Locations at Ash River

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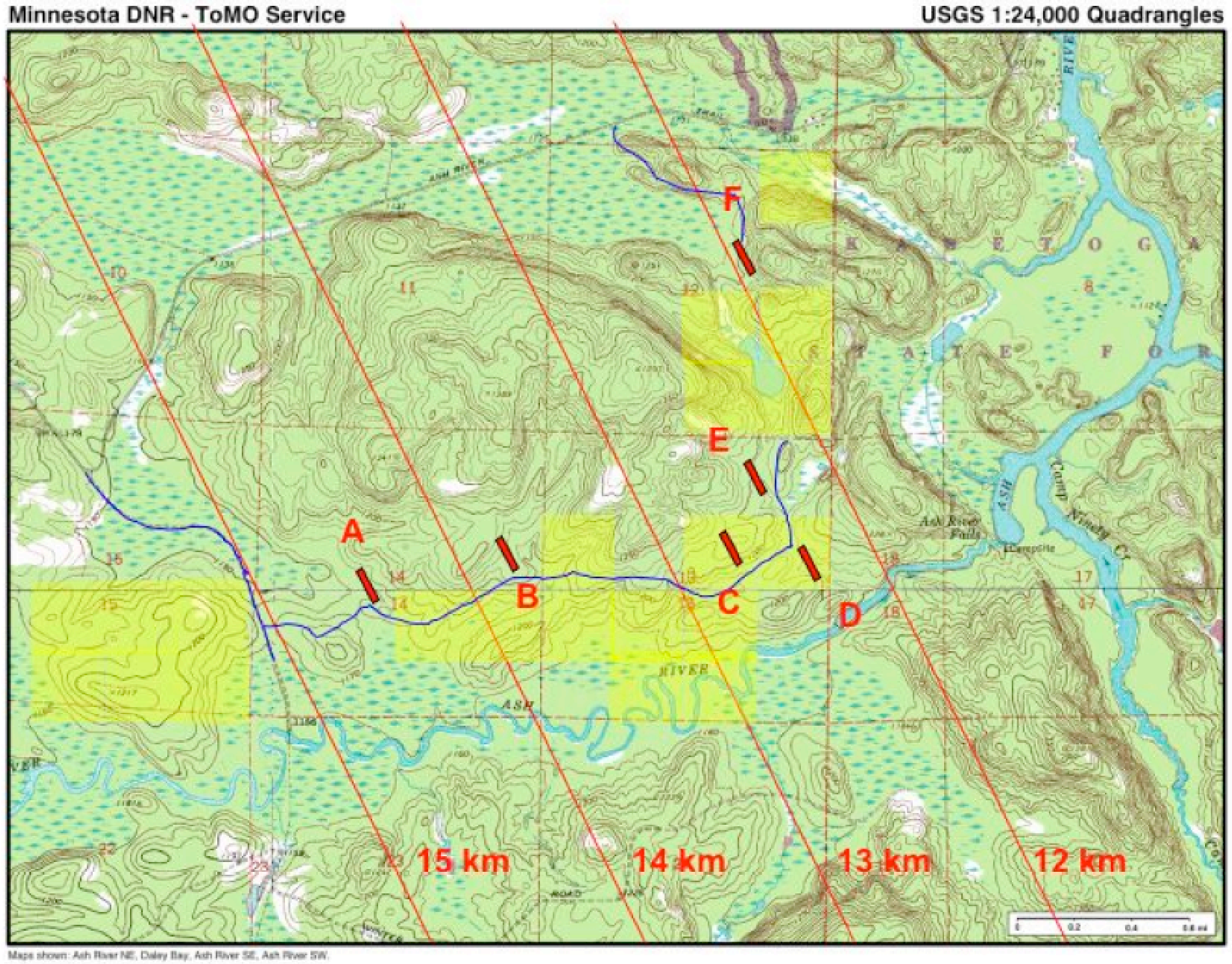

Question 4: …can the nature and magnitude of all important backgrounds be determined experimentally?

- **Almost**
- **Non-beam backgrounds are determined by off-spill data.**
- **Beam backgrounds are determined by an off-axis near detector located in the tunnel upstream of the MINOS near detector hall.**
  - **Beam ν_es and NC scale as $1/L^2$**
  - **CC do not scale due to oscillations. 5 to 14% of the background. Needs some modeling to extrapolate.**
- **Little work on the near detector design so far.**

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Question 5: If the MINOS on-axis near detector is the only one available to characterize the beam, how well can the flux at the off-axis far detector be understood?

- **With the off-axis near detector, we estimate that we can determine the background with a 5% systematic uncertainty.**
- **An on-axis near detector would involve a longer chain of modeling and might increase the uncertainty to the 10-15% range. However, more important, it would not provide a convincing case that backgrounds are controlled for a small positive signal.**

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Question 7a: …how significant are the cosmic-ray backgrounds, and is it convincing that the detector can be on …the surface?

- We are only live for 100 s/yr.
- We expect 1000 muons/yr to produce a pion with *E* > 2 GeV. Probability that such an event would be misidentified as a beam electron is quite low. However, we plan to have an active shield. Only 3% increase in the scintillator modules.
- We expect 10^5 neutrons/yr with E > 2 GeV. The probability that a neutron induced event could be misidentified as a beam electron is about 1/yr.
- However, we need to test this with a small surface detector.
- If neutron backgrounds are significant, we can remove them with a few meter earth overburden at significant additional cost.

Question 7b: Is there other compelling physics that an underground version of the same detector could do?

- I can't think of any.

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Question 3: What is the discovery reach … in θ_{13} and the achievable precision in such a measurement?

- **Short answer: The 3-σ discovery reach is about an order of magnitude better than that of MINOS, a factor of about 20 better than the 90% CL CHOOZ limit.**
- **Longer answer: discovery and precision are quite different because $\sin^2(2\theta_{13})$, sign(Δm_{13}^2), and δ all significantly affect the oscillation probability.**
- **Discovery is the first goal.**

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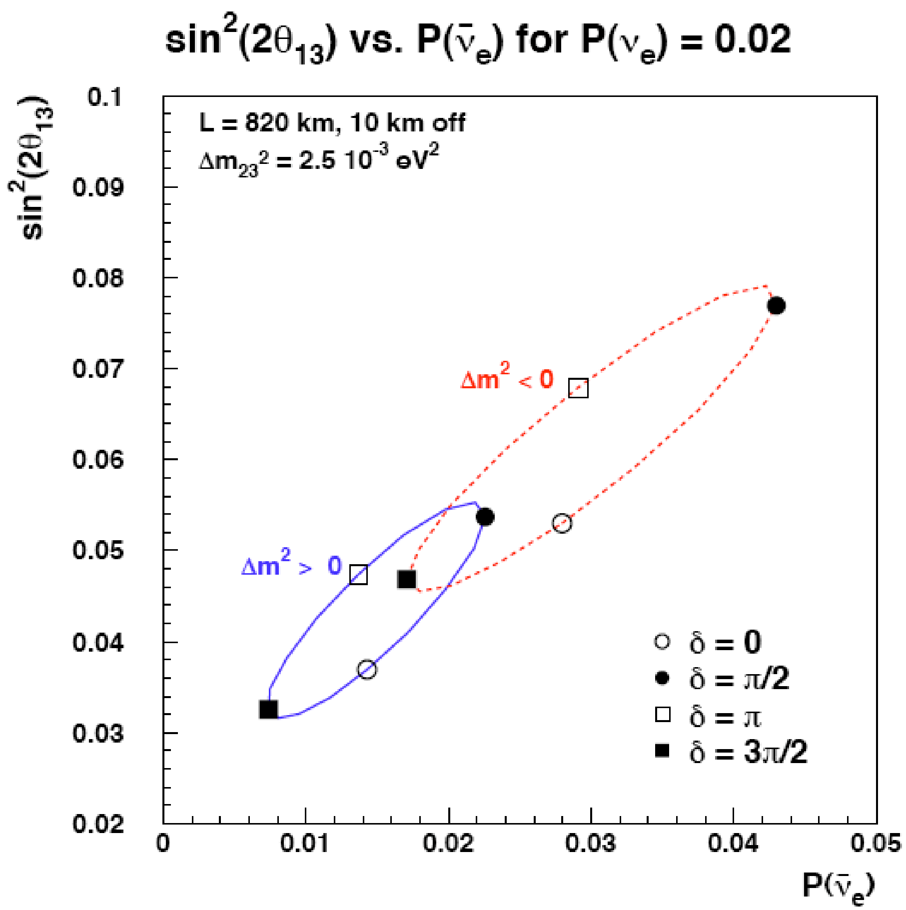
$P(\nu_\mu \rightarrow \nu_e) = 0.02$ at 820 km



Assumes $\sin^2(2\theta_{23}) = 1.0$.
Direct production μ $\sin^2(\theta_{23})$.
If $\sin^2(2\theta_{23}) = 0.95$
$\sin^2(\theta_{23}) = 0.39$ or 0.61.

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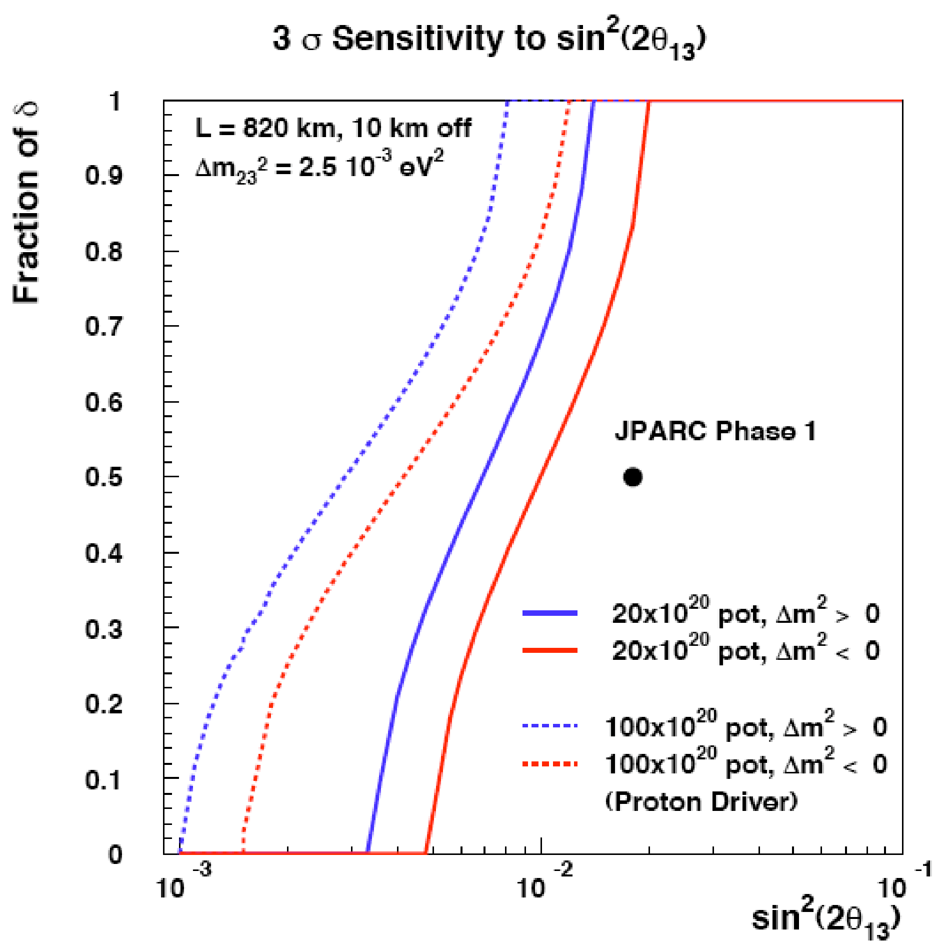
3 □ Discovery Potential for □□□ □e



Probably slightly optimistic since coherent pion production not included (~12% effect in the FOM).

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Question 6: How does the detector proposed fit into a longer term program to measure CP violation?

- The second goal is to resolve the mass hierarchy. This can only be done with a long-baseline experiment.
- In general, three measurements are required; in some cases, two suffice.

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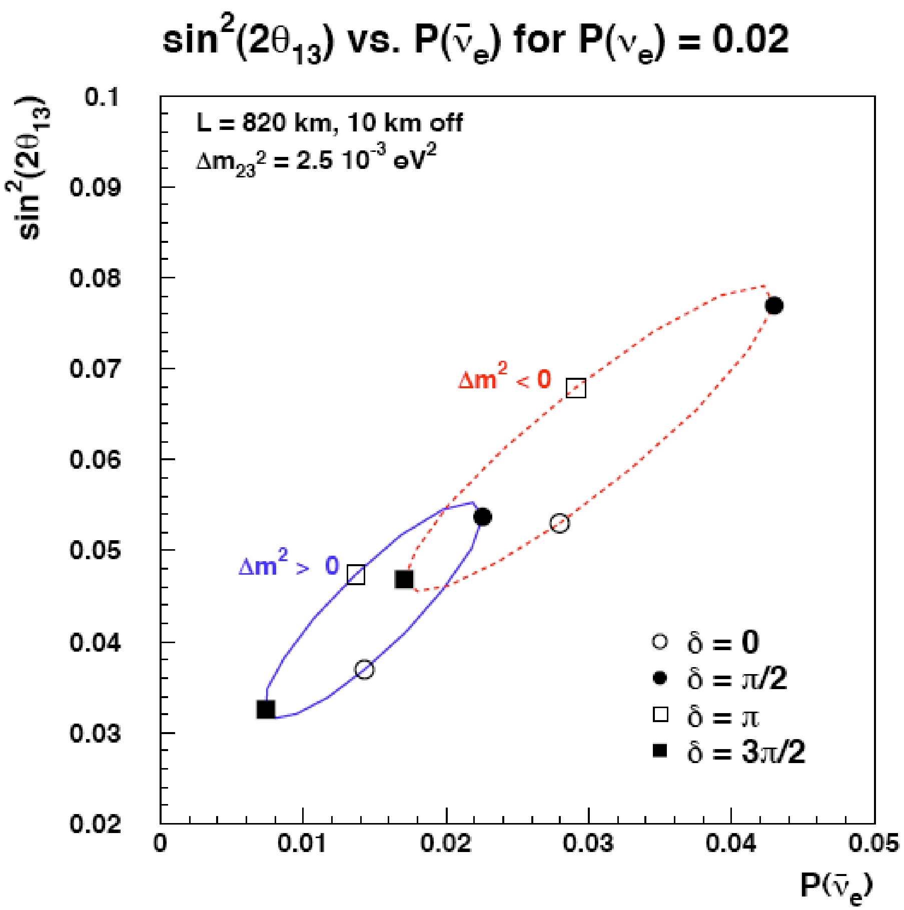
$P(\nu_\mu \rightarrow \nu_e) = 0.02$ at 820 km



Reactor experiments measure $\sin^2(2\theta_{13})$ directly. Hence, note rough equivalence of reactor and antineutrino measurements

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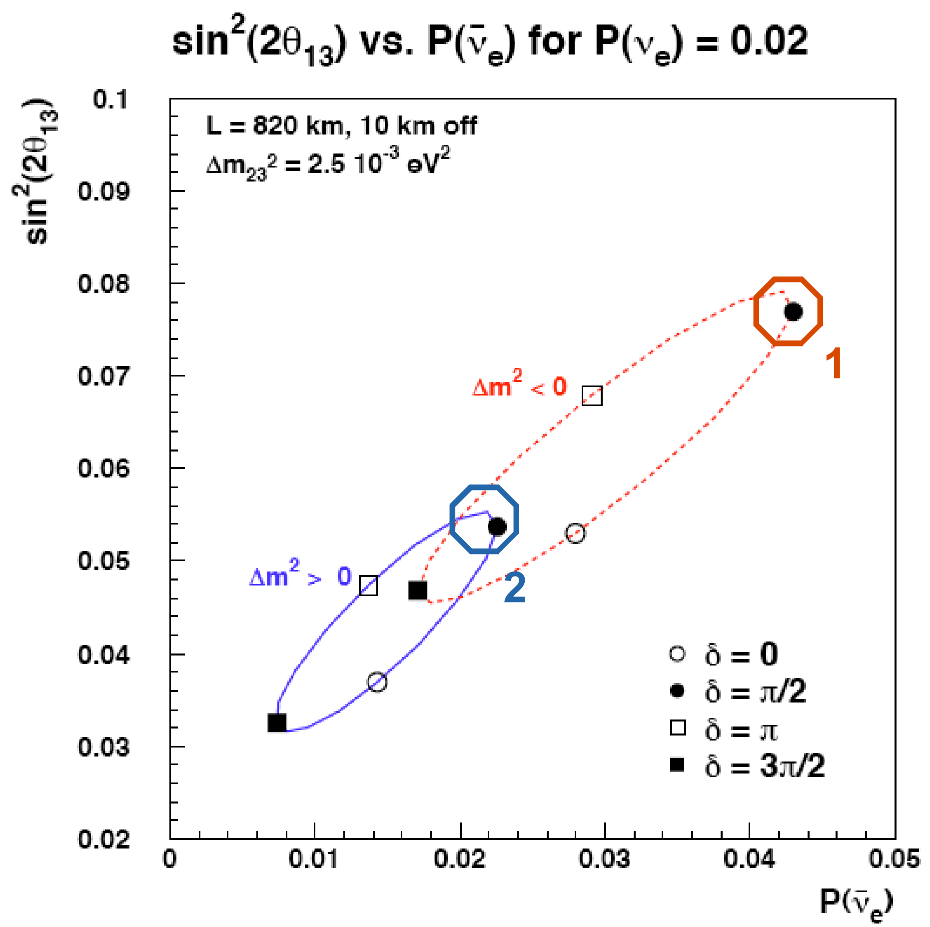
Study Points



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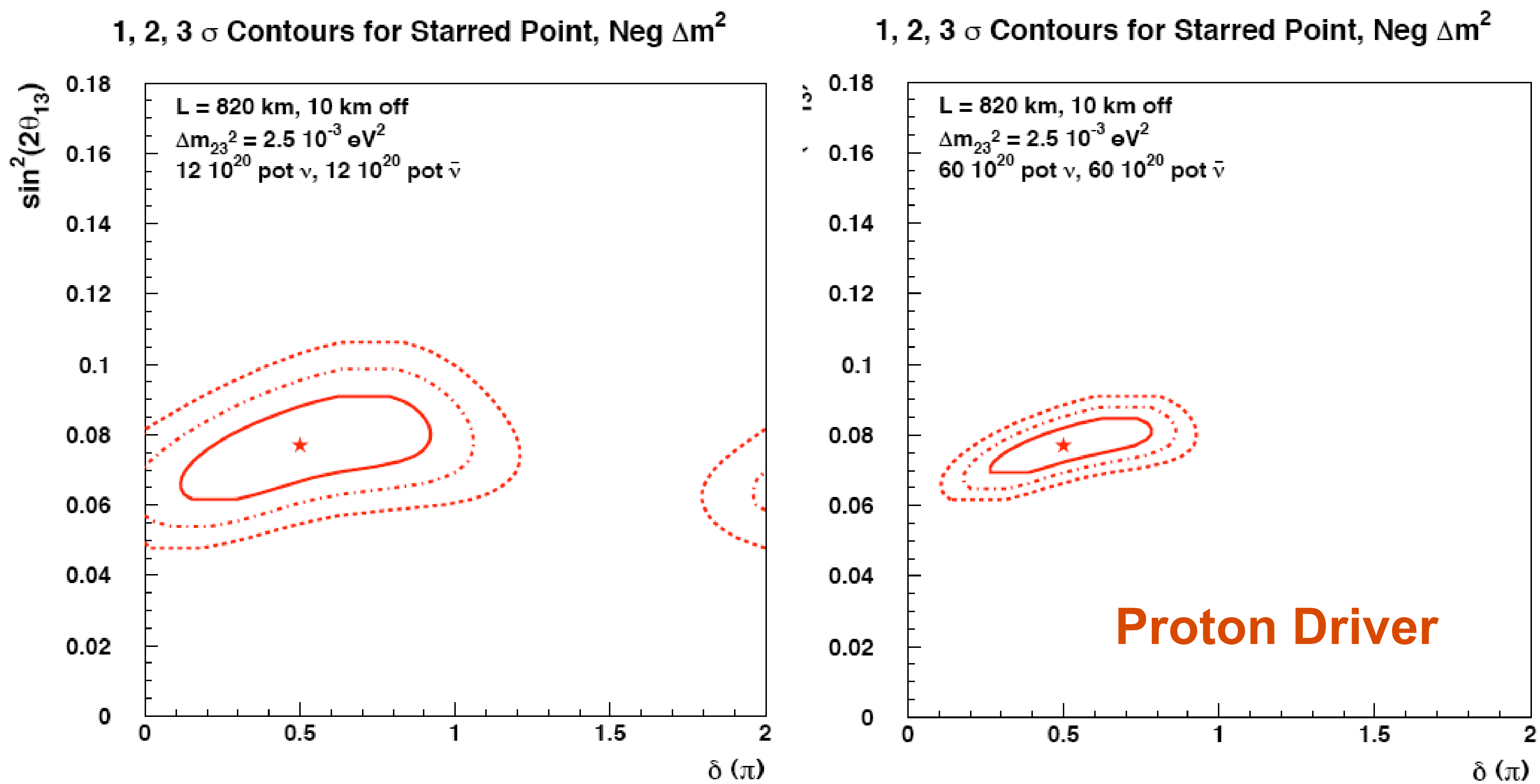
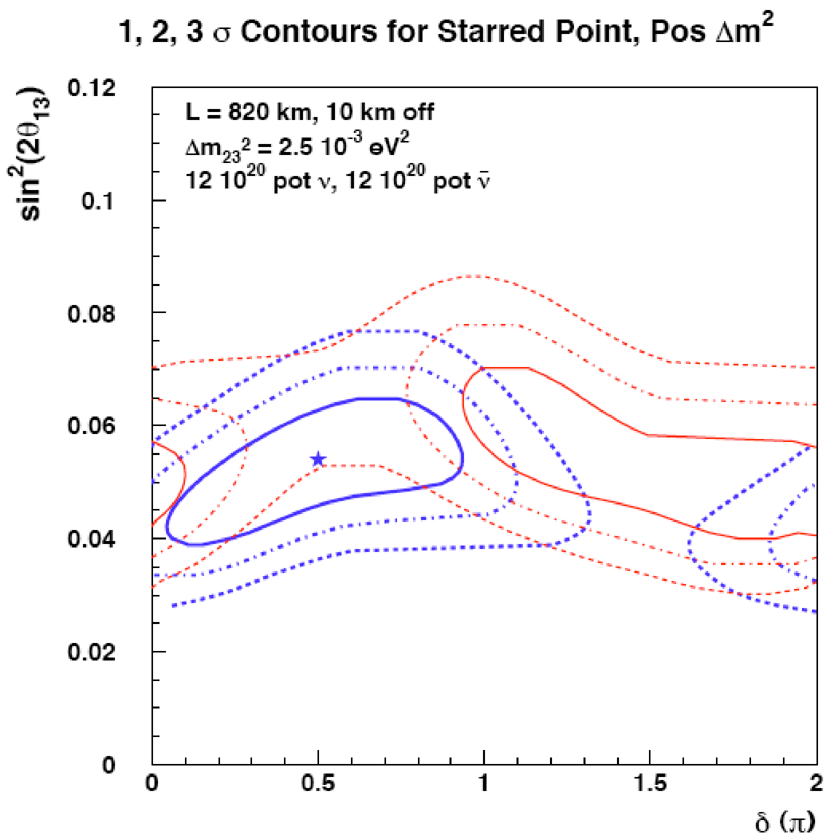
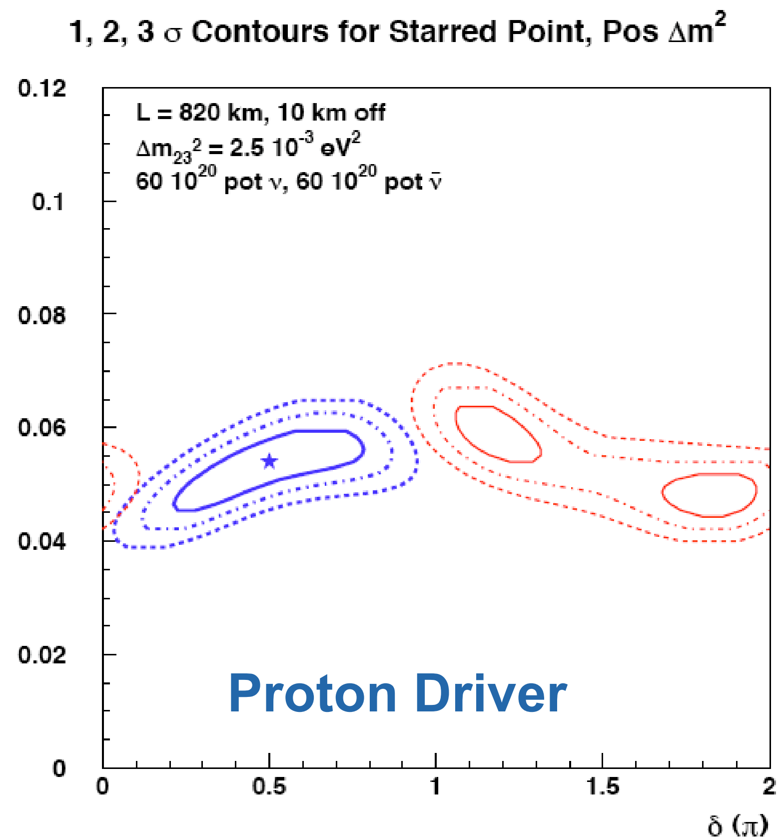
Point 1: NuMI 3 yr □, 3 yr □□
4 10^{20} and 20 10^{20} pot/yr



Point 2: NuMI 3 yr □, 3 yr□□ 4 10^{20} and 20 10^{20} pot/yr





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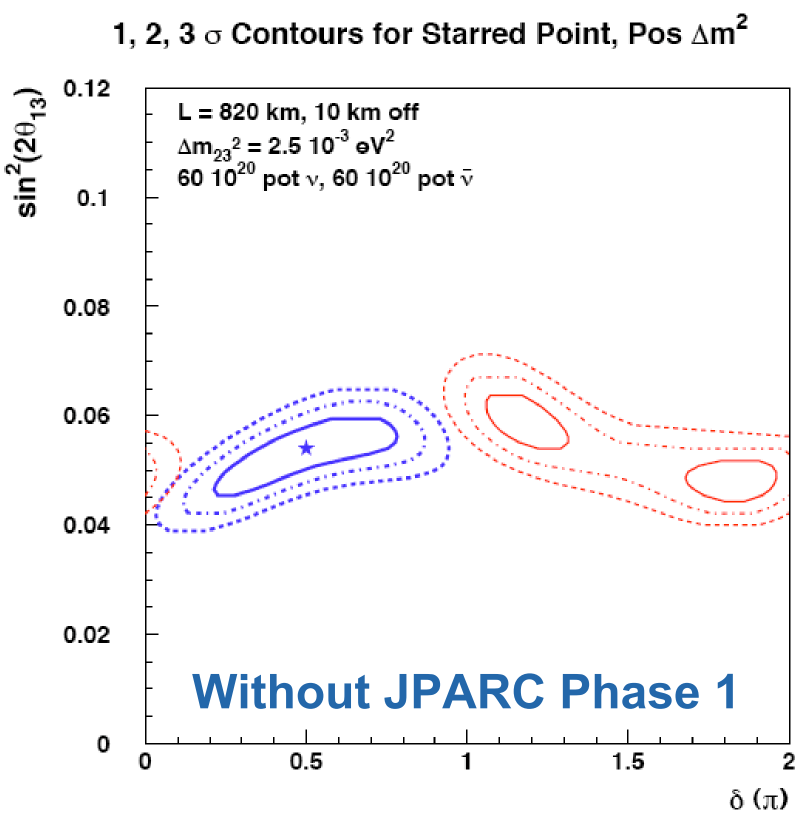
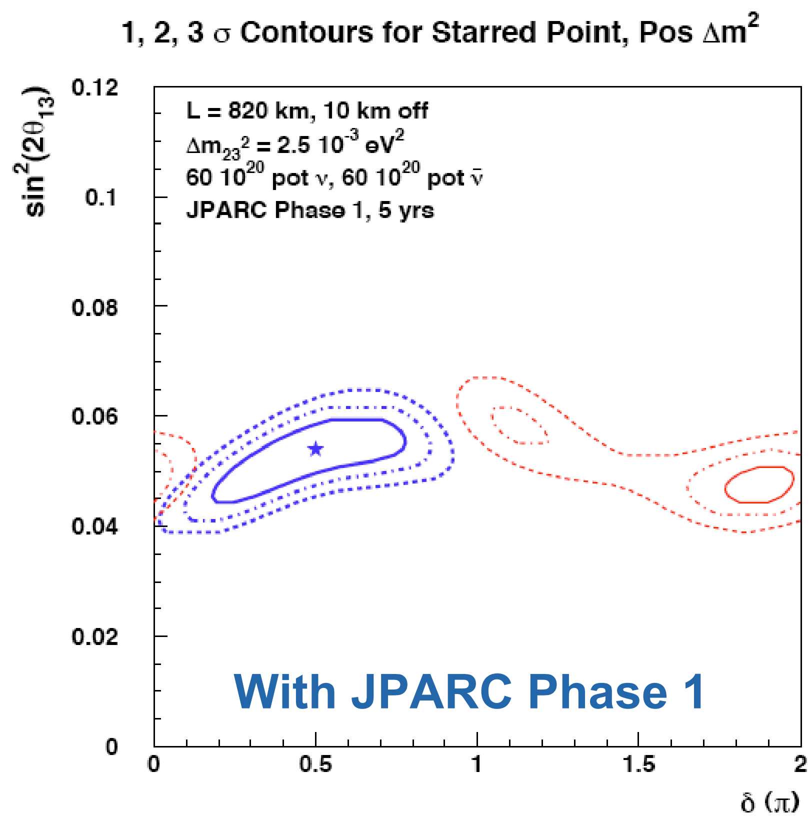
NuMI 3 yr □, 3 yr□□, 20 10^{20} pot/yr and JPARC, Phase 1





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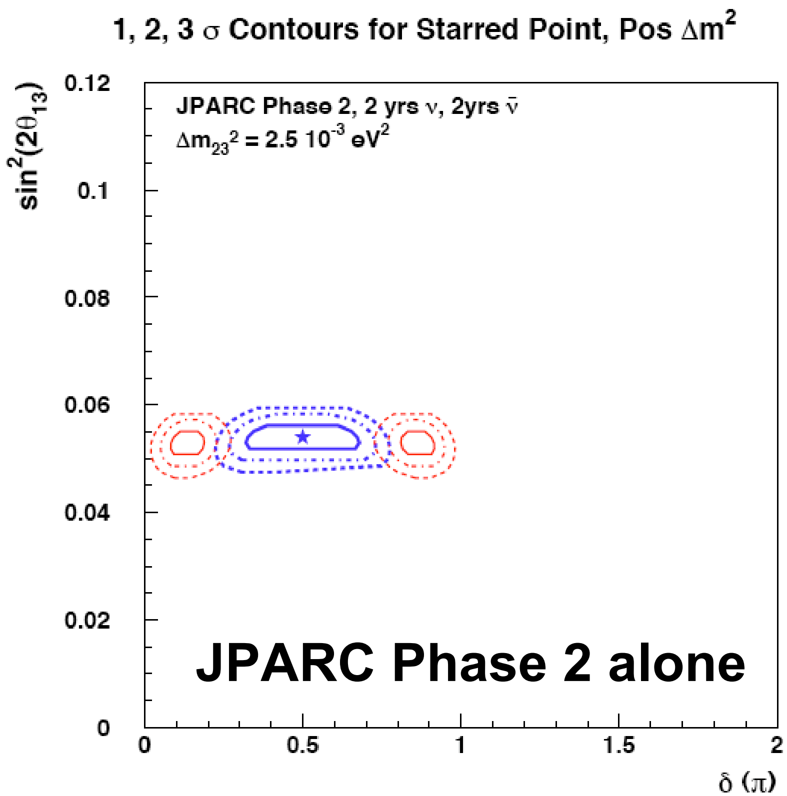
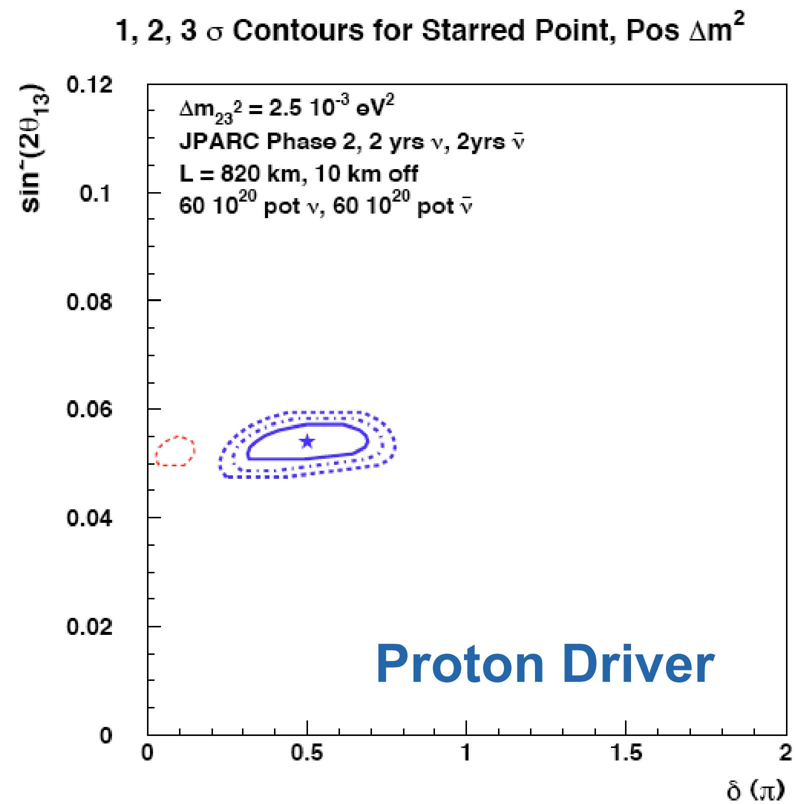
NuMI 3 yr □, 3 yr□□, 20 10^{20} pot/yr and JPARC Phase 2, 2 yr □, 2 yr□□





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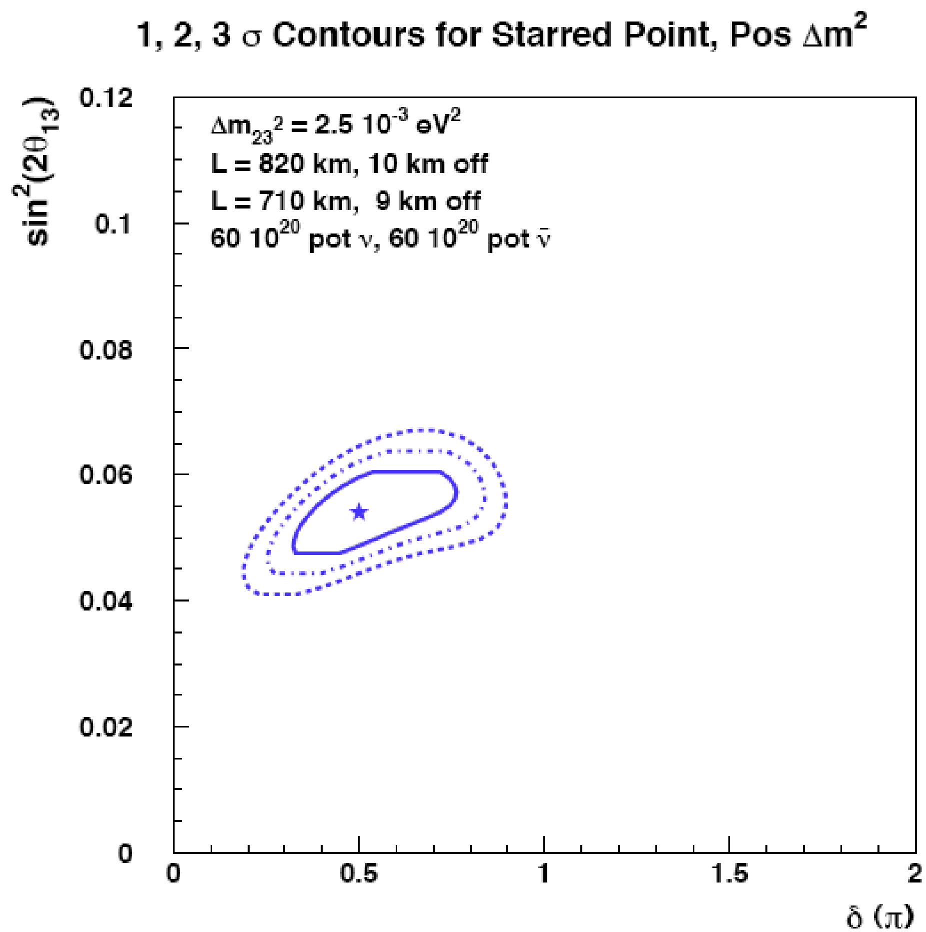
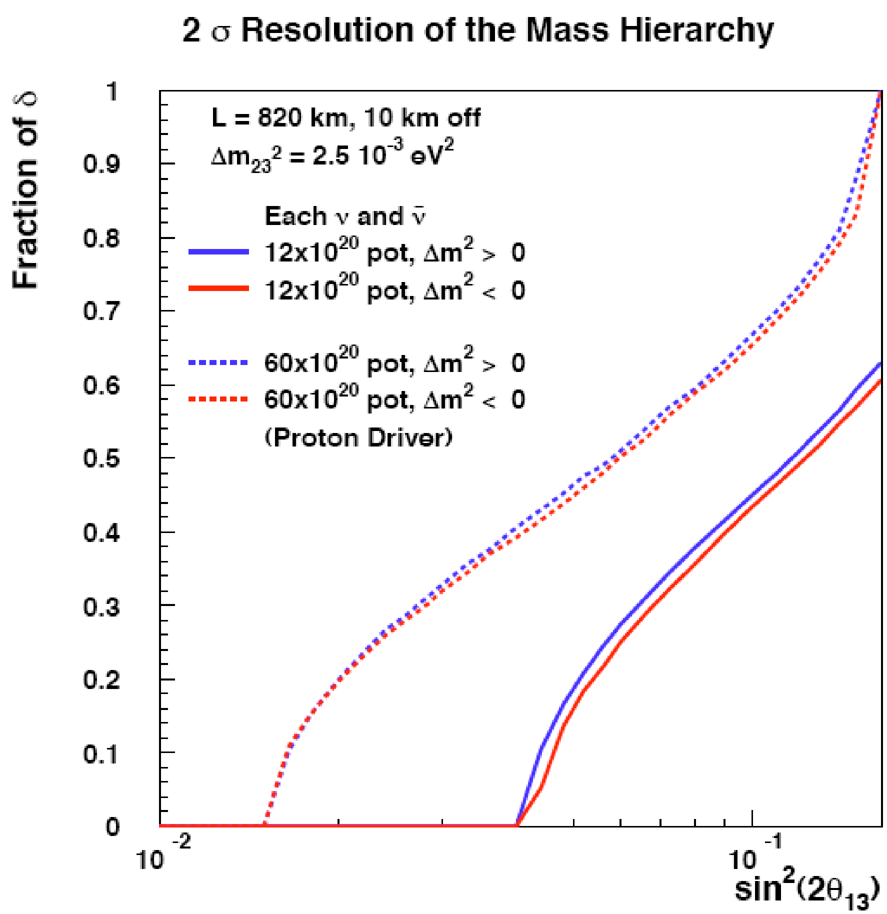
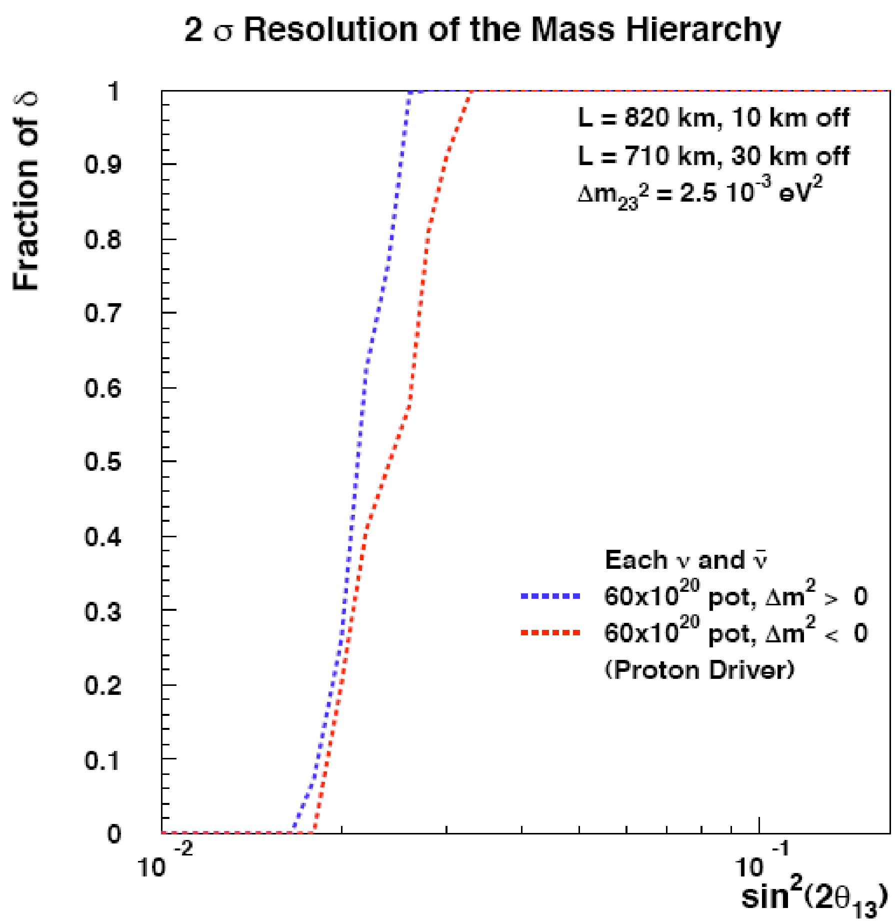
NuMI 3 yr ν, 3 yr $\bar{\nu}$, 2 Detectors and Proton Driver



95% CL Resolution of the Mass Hierarchy



95% CL Resolution of the Mass Hierarchy with 2 Detectors



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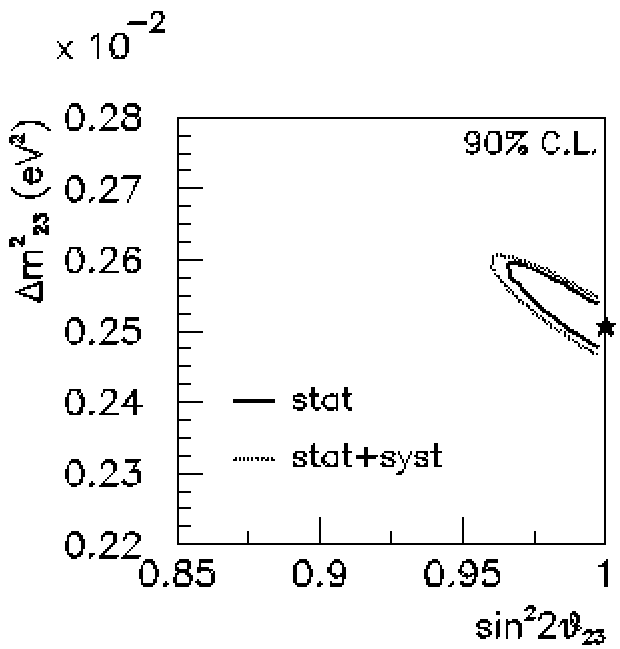
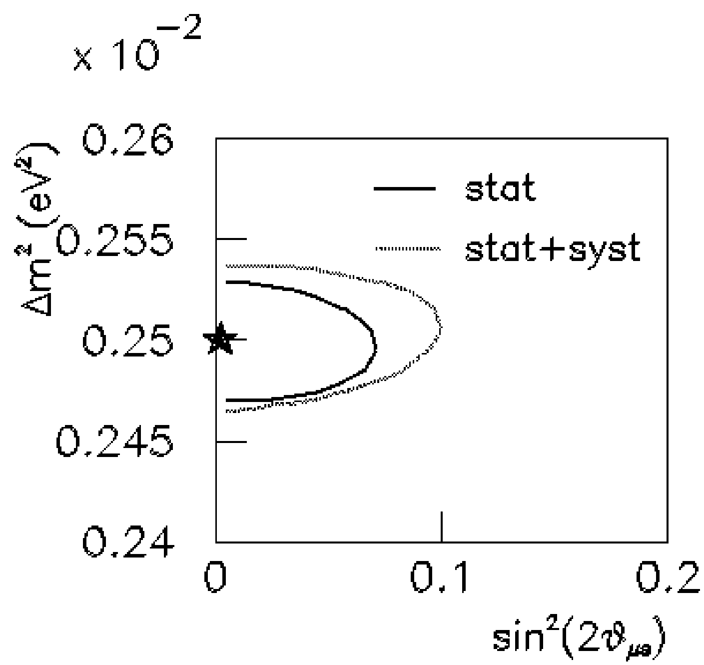
Question 8: Are there other important measurements that a …detector optimized for electron ID could perform?

- **Approximately factor of two improvement over MINOS in the precision on $\sin^2(2\theta_{23})$, Δm_{23}^2, and fraction of sterile neutrinos.**





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Hypothetical Question 9: How can we help you?

- **We would like to have official R&D status.**
- **The collaboration universities have applied for a 3-yr NSF grant for R&D: about 600 k$ in the first year, more in the later years.**
- **Requests for FY 04:**
  - **Fermilab 659 k$ for engineering and technician effort**
  - **Argonne and supplemental university support 300 k$ largely for mechanical and electronics engineering at Argonne**
  - **Minnesota 100 k$ for site permitting at Ash River**
  - **Itemizations available**