Off Axis

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

Fermilab PAC

12 December 2003

Gary Feldman

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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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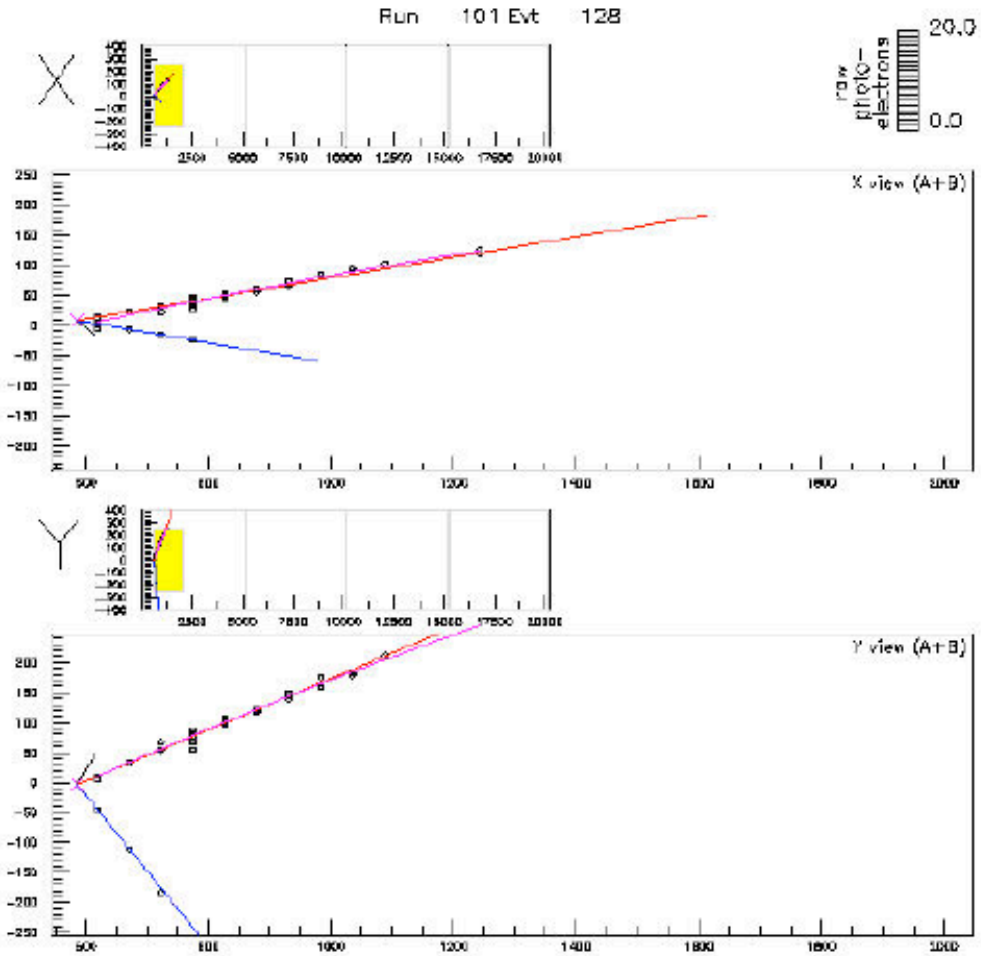
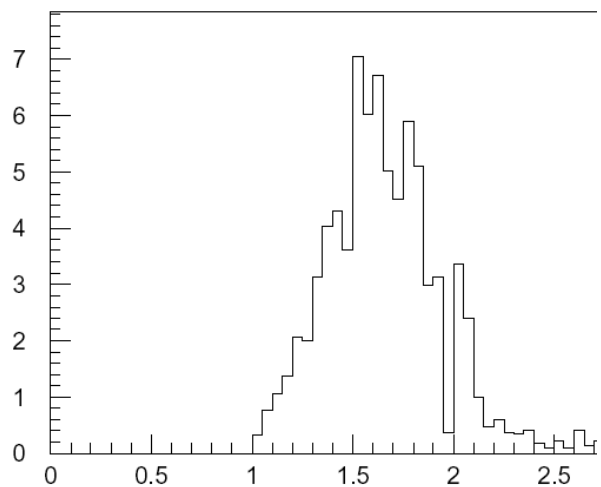
Medium-Z Sandwich Detector Electron Track



Hits per plane > 1



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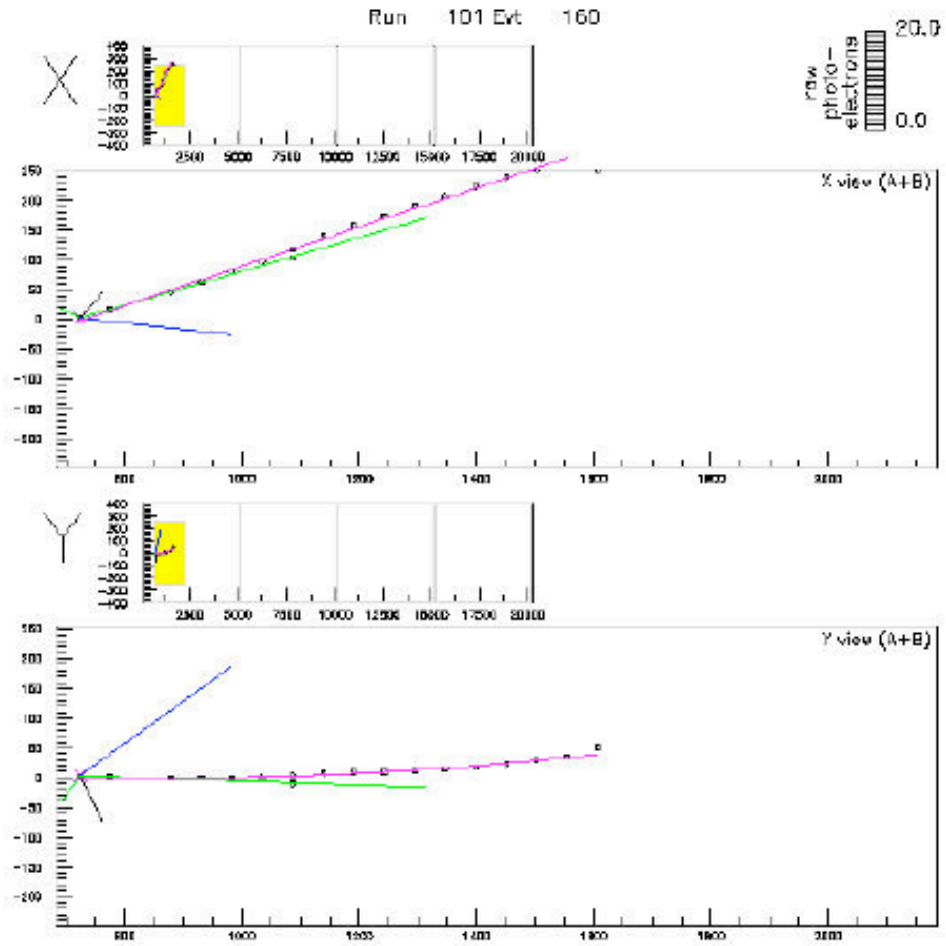
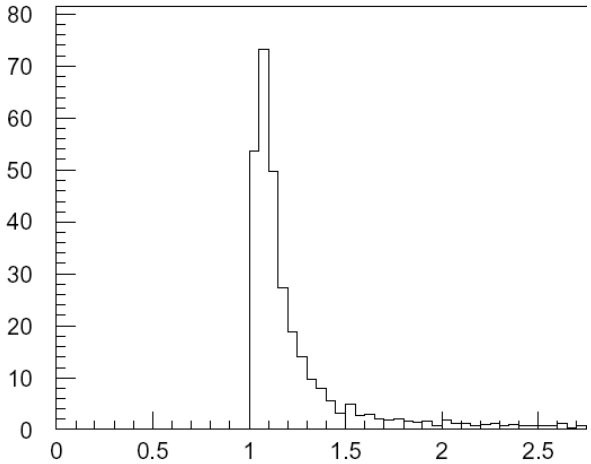
Medium-Z Sandwich Detector Muon track



Hits per plane ~1



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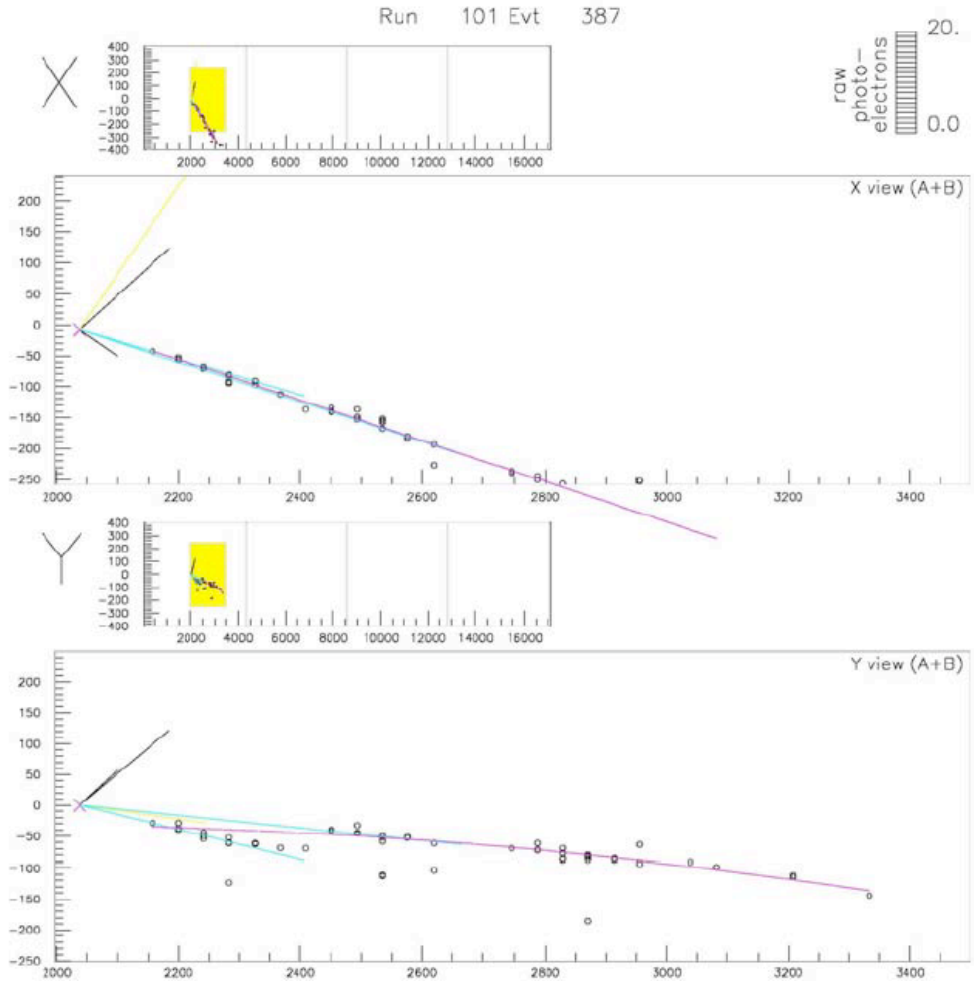
Medium-Z Sandwich Detector NC with leading π^0



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

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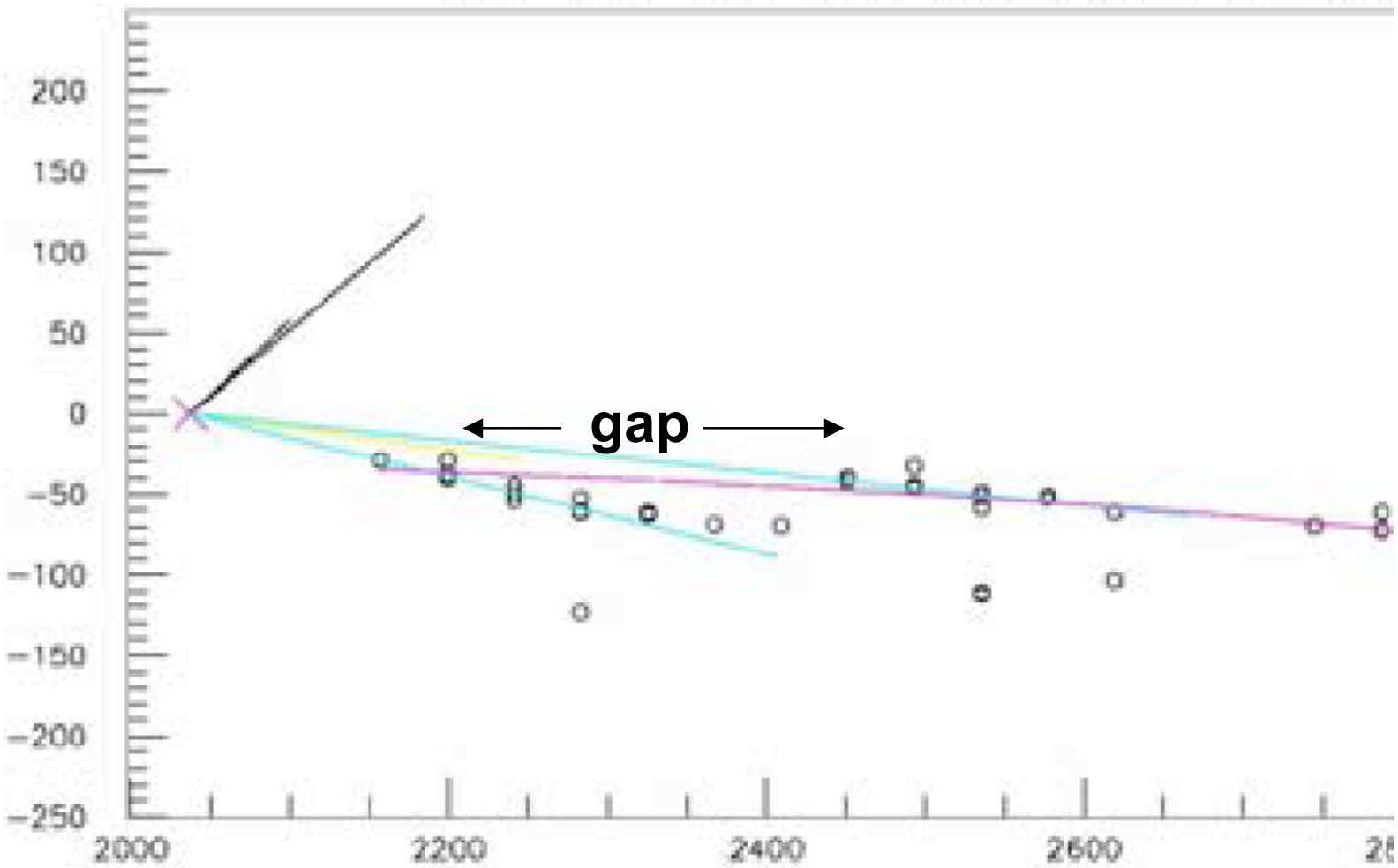
Detail of NC with leading π^0



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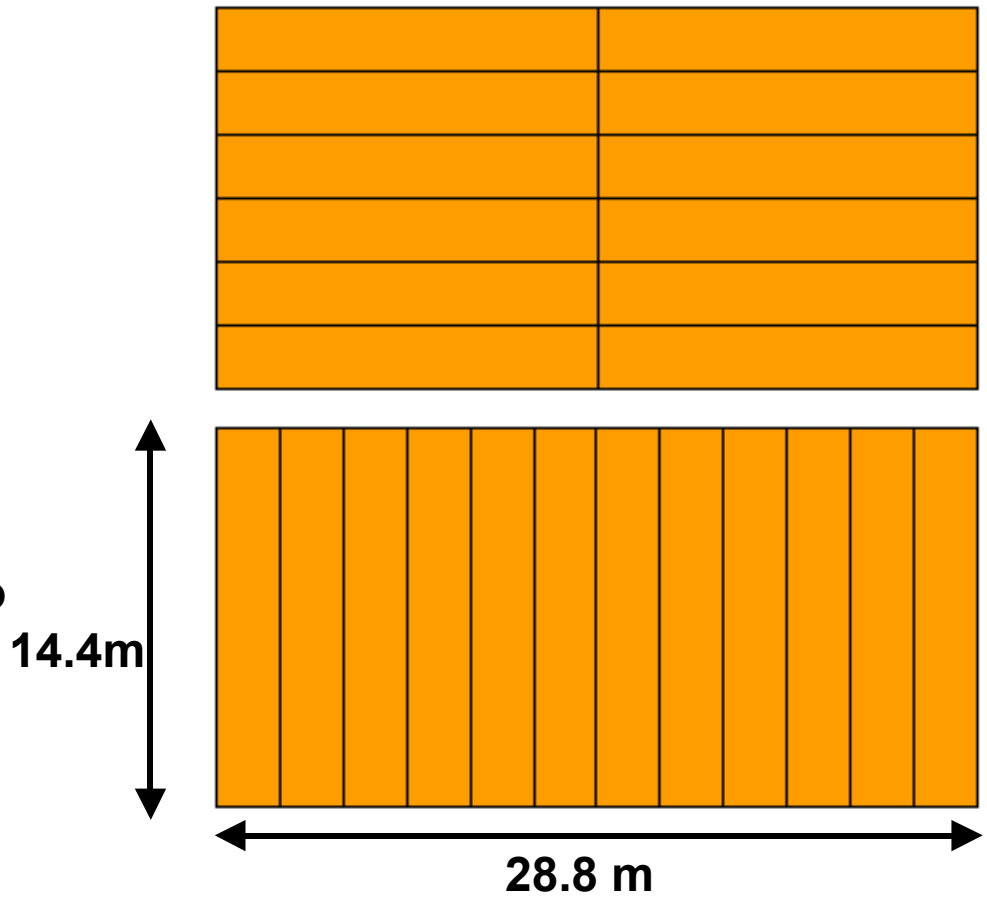
Scintillator Layout

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)



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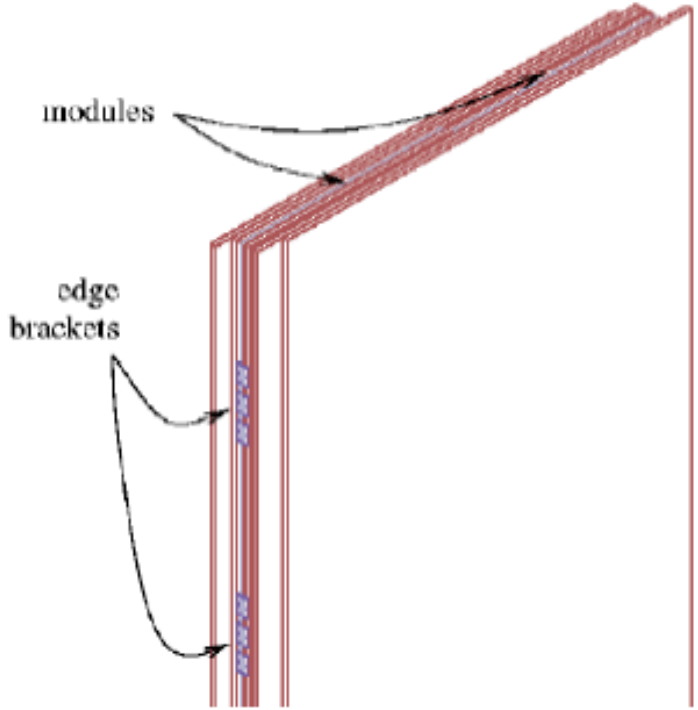
Absorber Structure Details

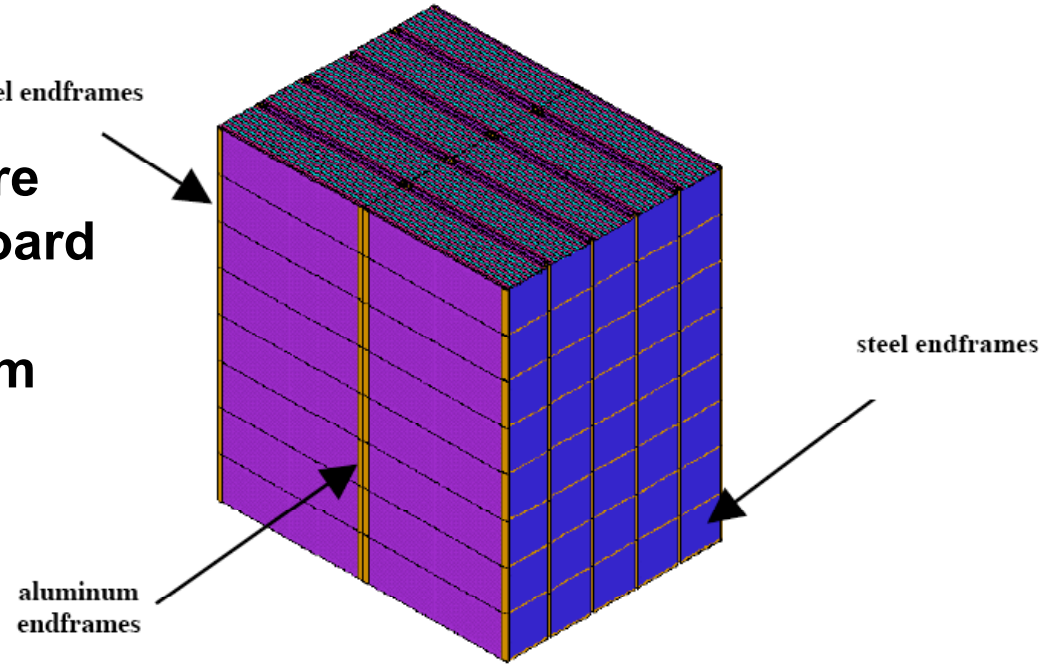


End View of Defining Volumes

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 RPCs: 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 $\Delta m^2 = 2.5\times10^{-3}$ eV^2 is only 2.4% off maximum in the FOM for $\Delta m^2 = 2.0\times10^{-3}$ eV^2. At fixed Δm^2, only a 2% variation in a 3 km transverse interval.**

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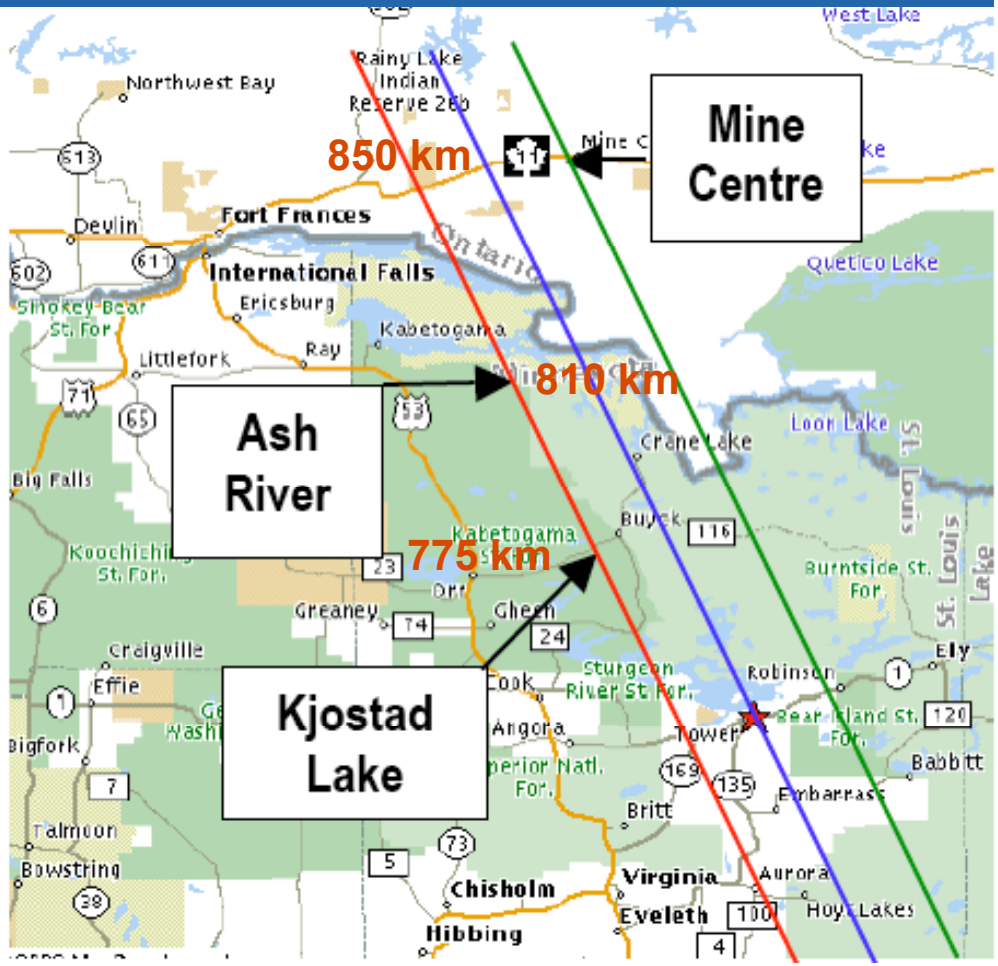
Possible Sites

We are now focusing on the Ash River site.



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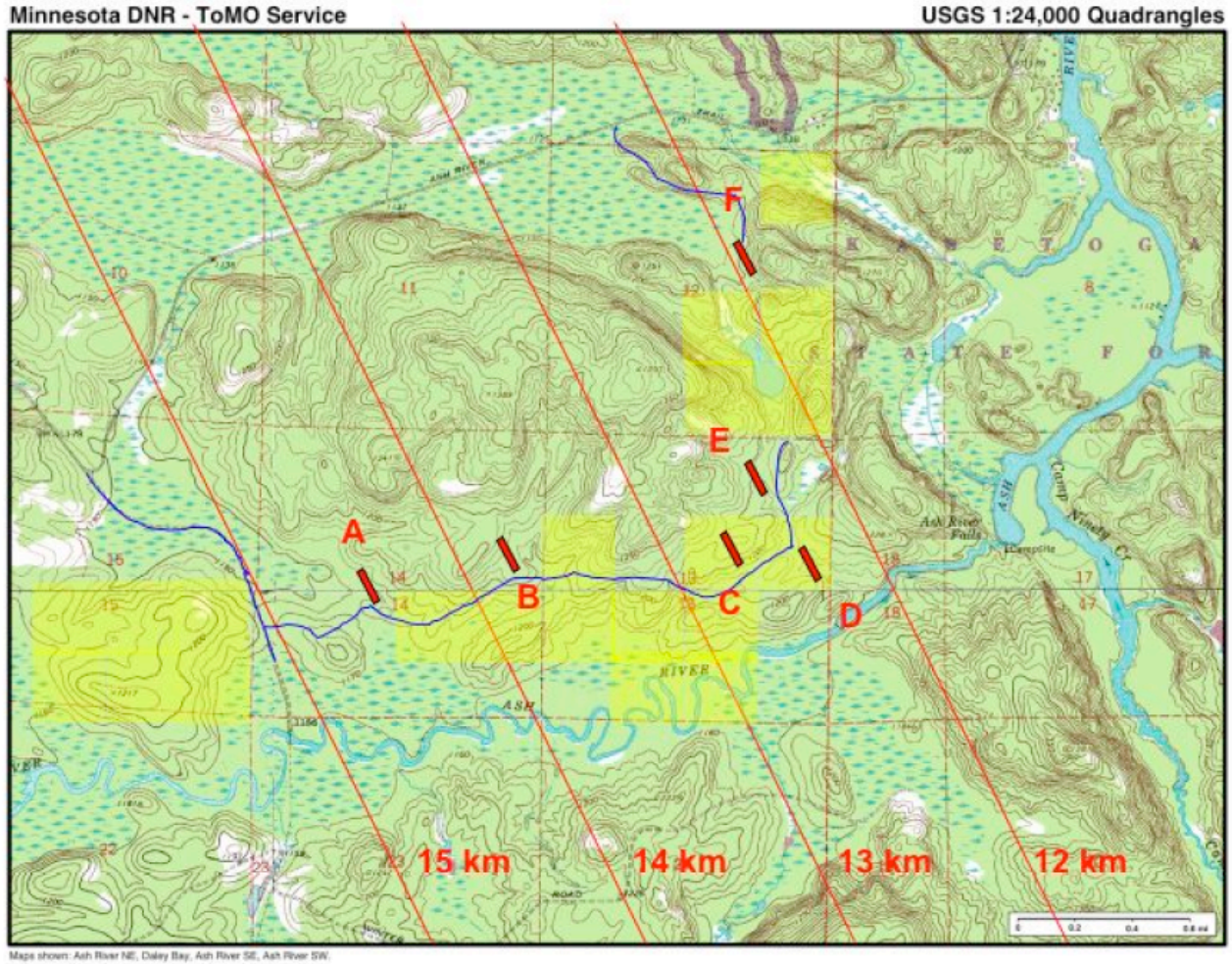
6 Locations at Ash River



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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.**

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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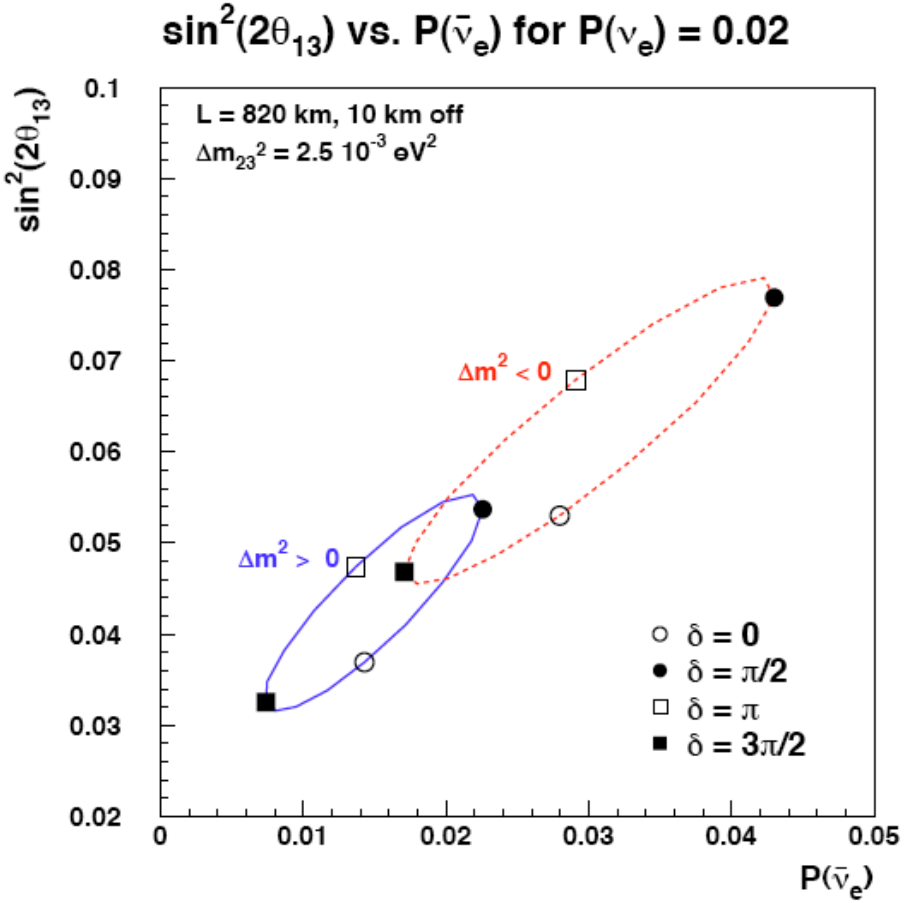
$P(\square_{\square}\square\ \square_e)$ = 0.02 at 820 km



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

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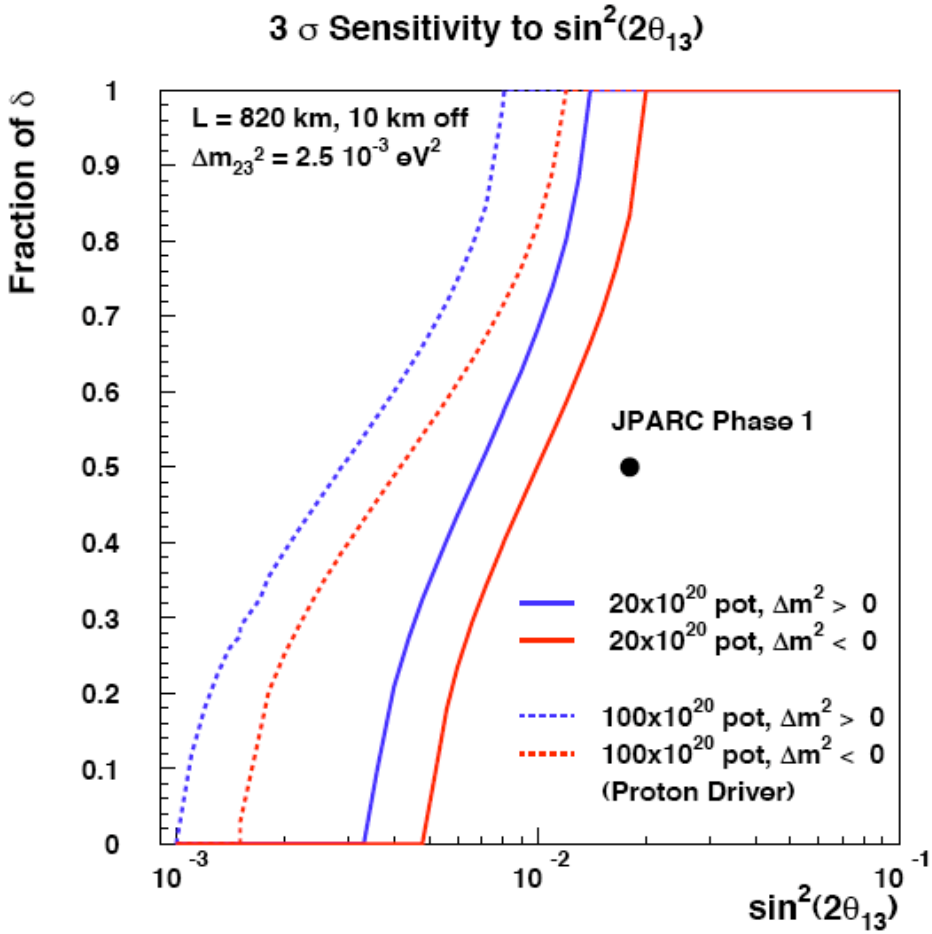
3 □ Discovery Potential for □□ □e



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

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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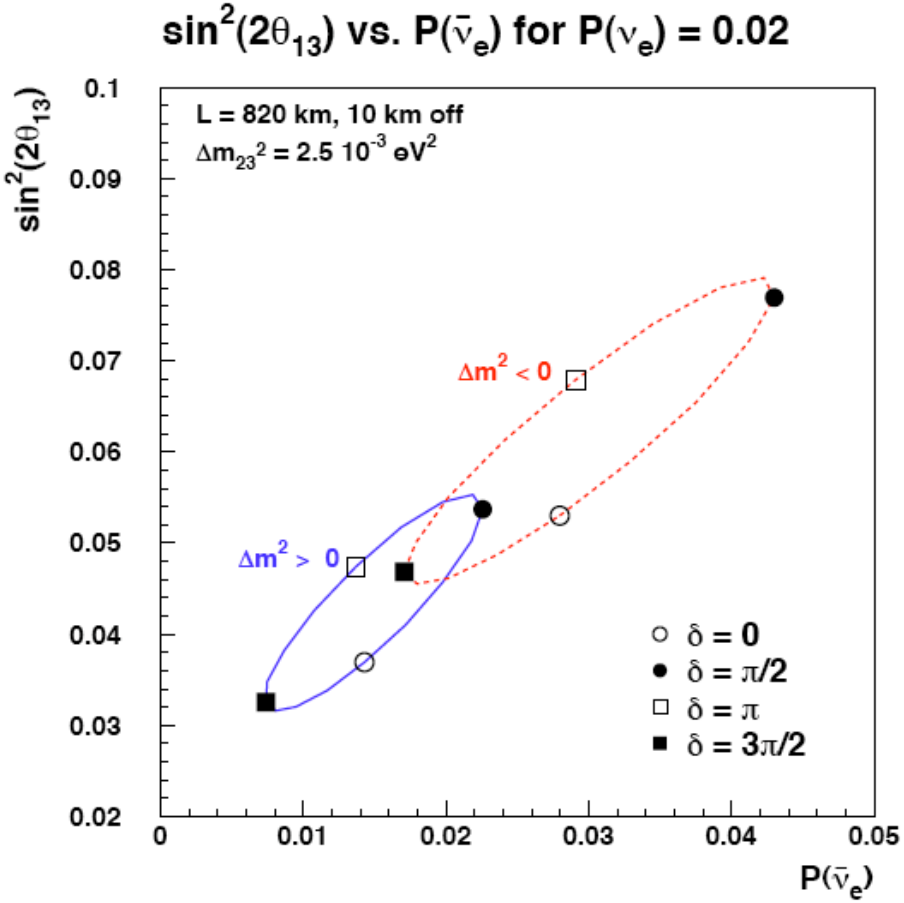
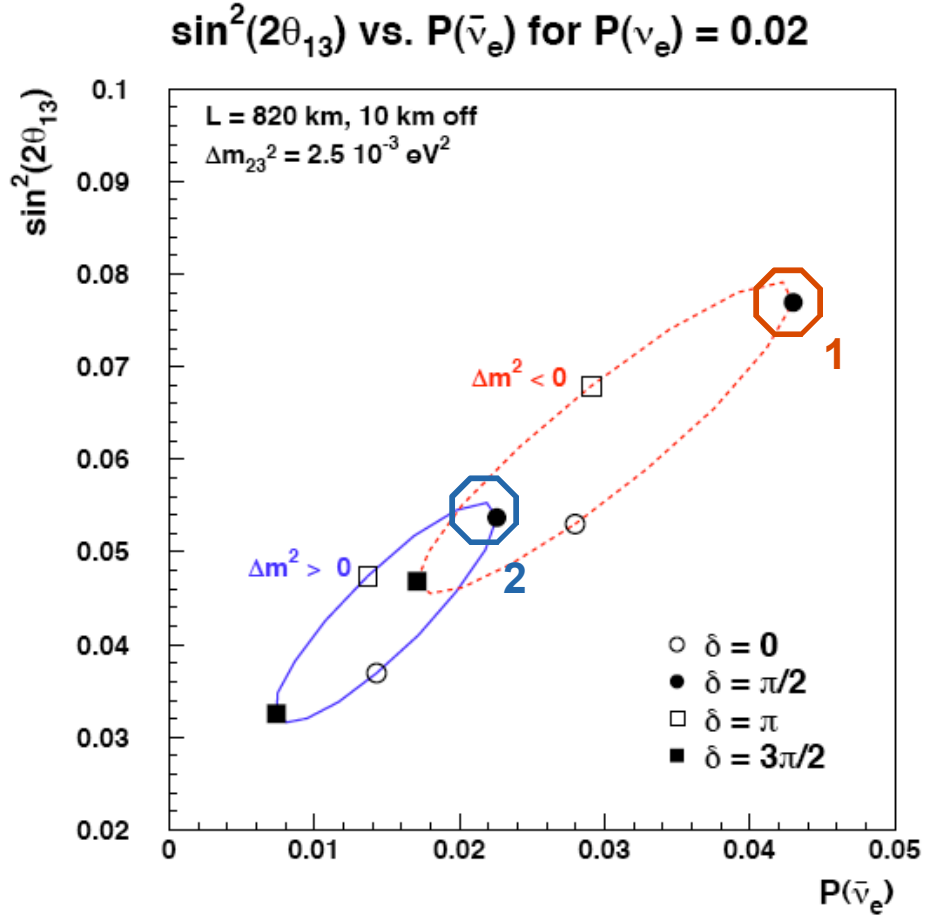
P(□□ □e) = 0.02 at 820 km



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

Study Points



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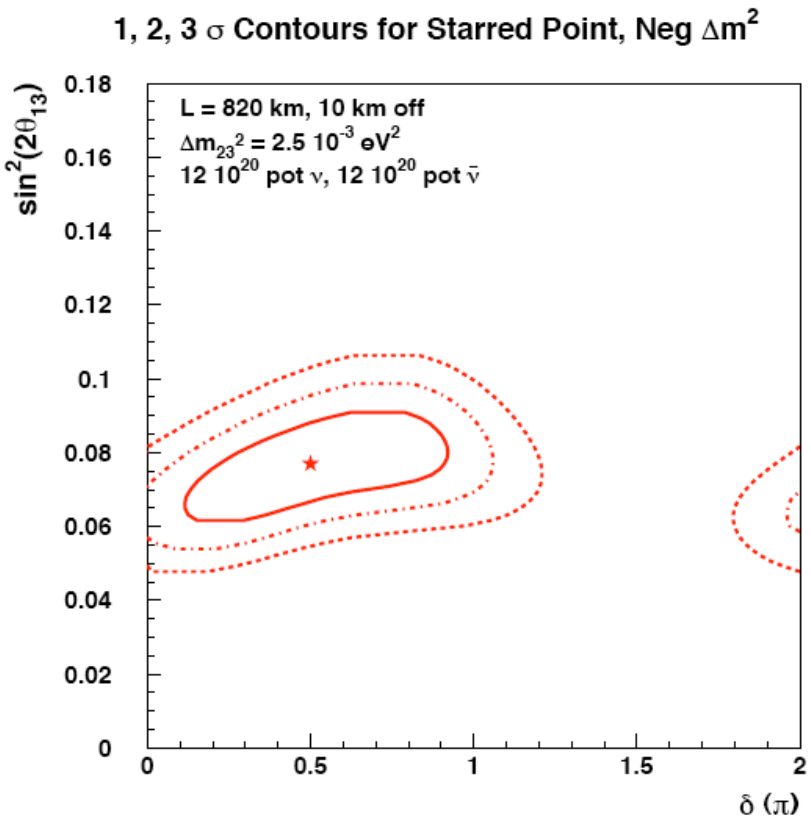
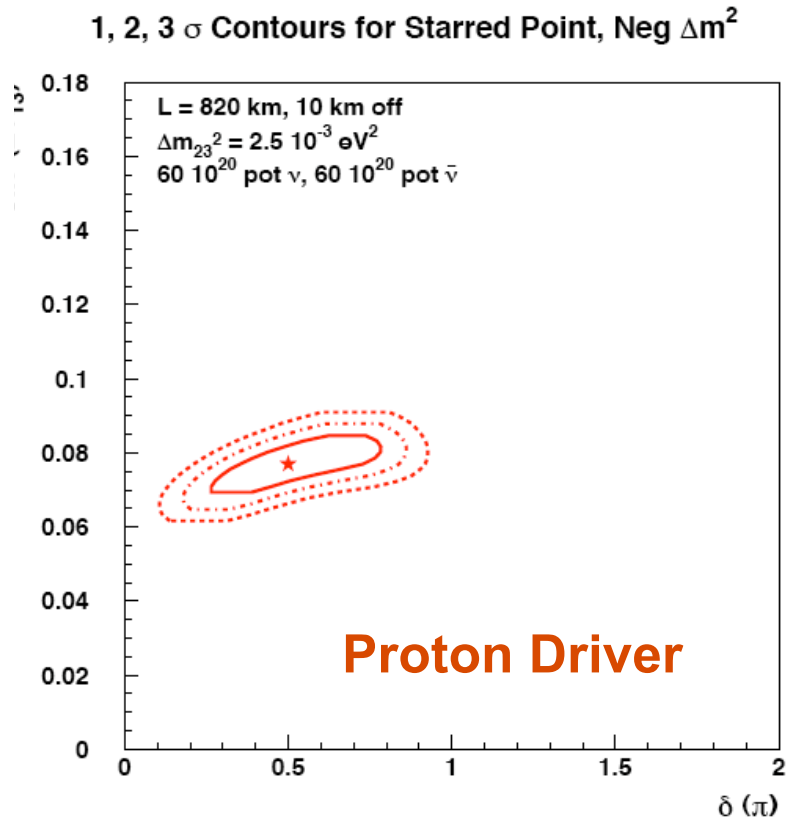
Point 1: NuMI 3 yr □, 3 yr□□ 4 10^{20} and 20 10^{20} pot/yr





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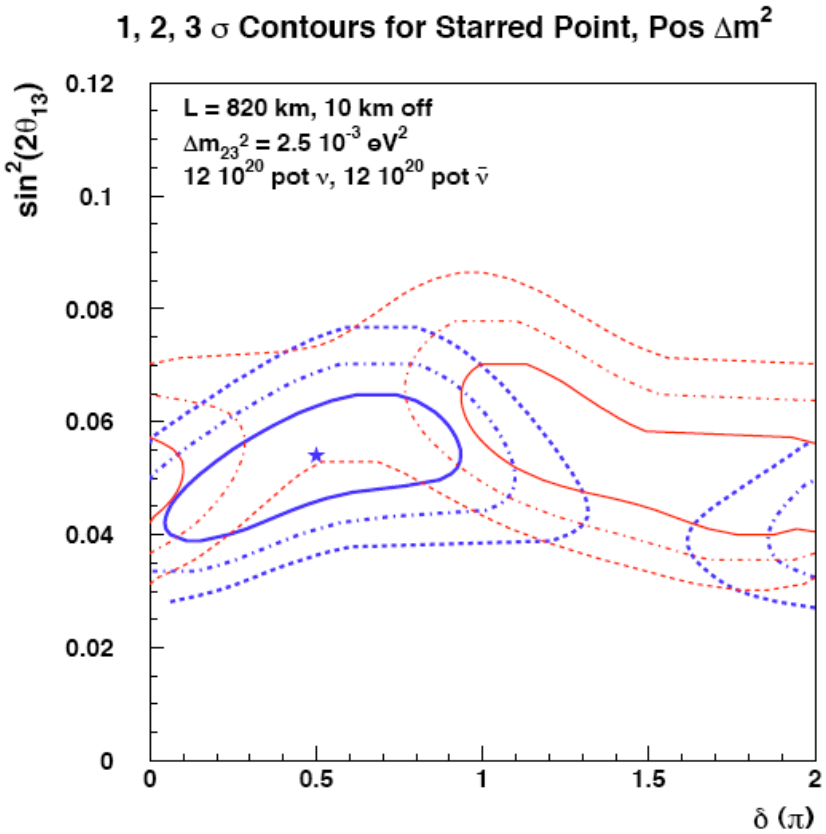
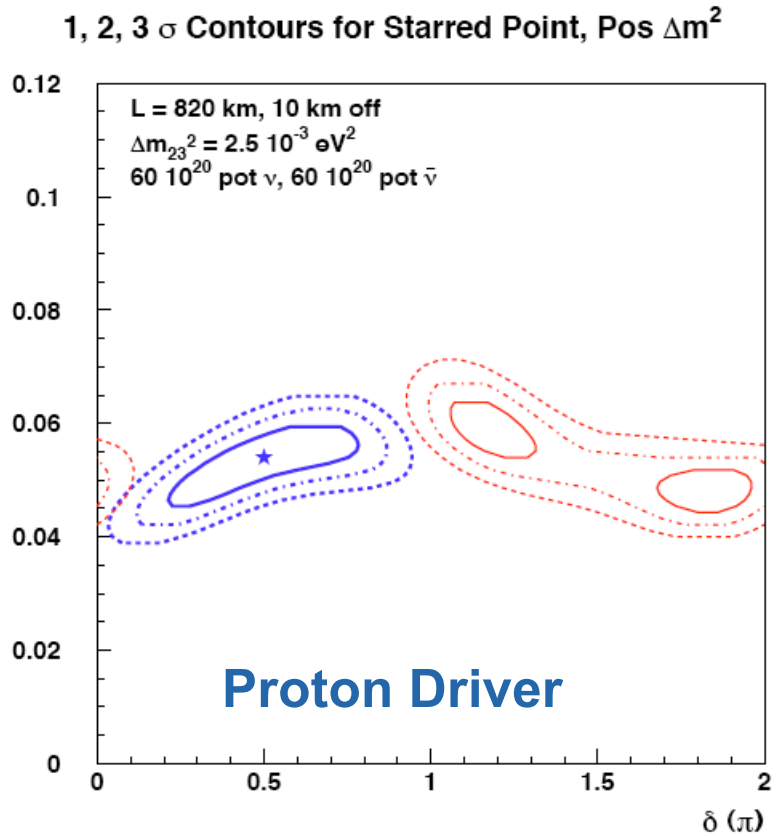
Point 2: NuMI 3 yr ν, 3 yr ν̄ 4 10^{20} and 20 10^{20} pot/yr





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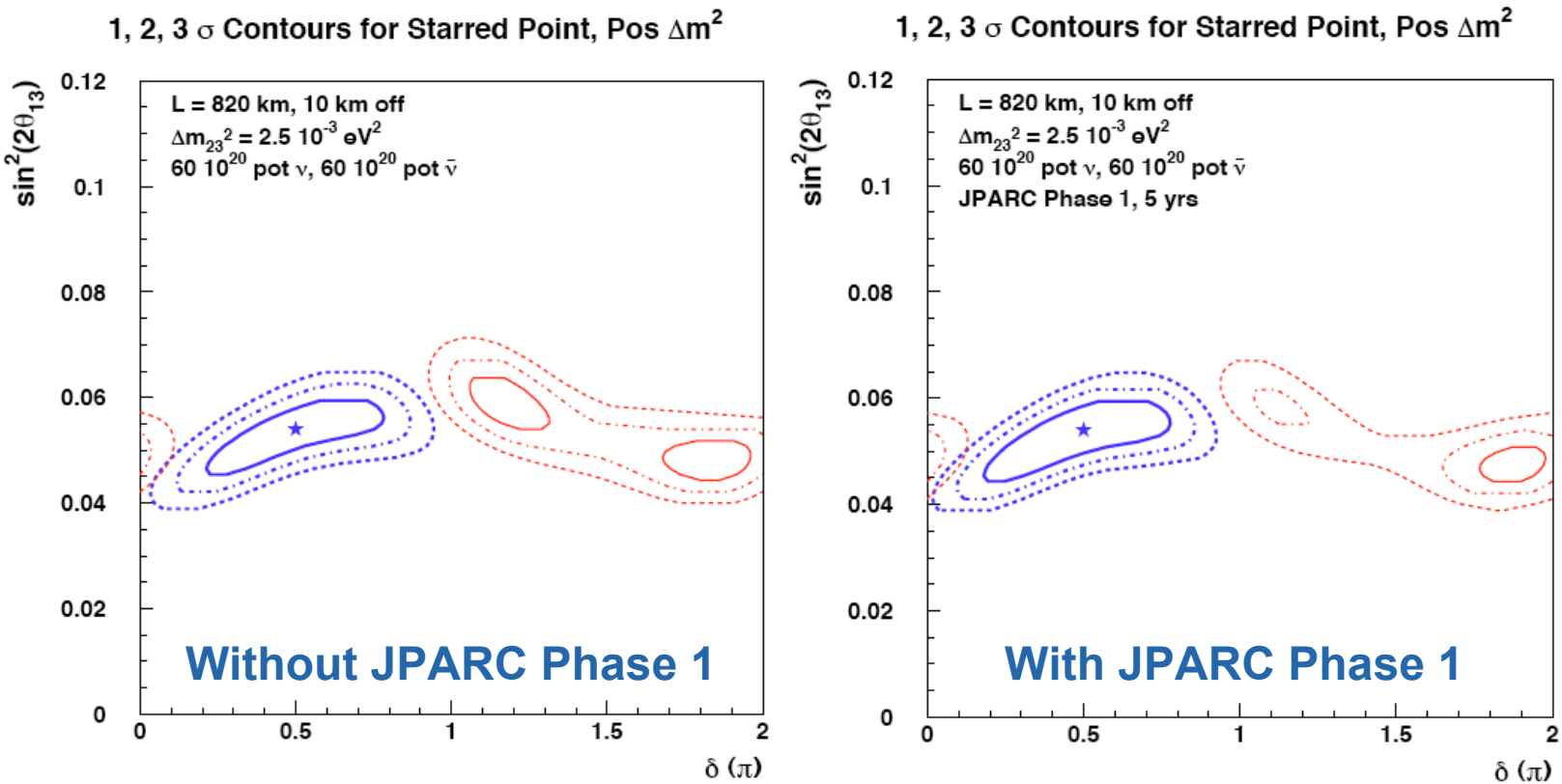
NuMI 3 yr □, 3 yr□□, 20 10^{20} pot/yr and JPARC, Phase 1



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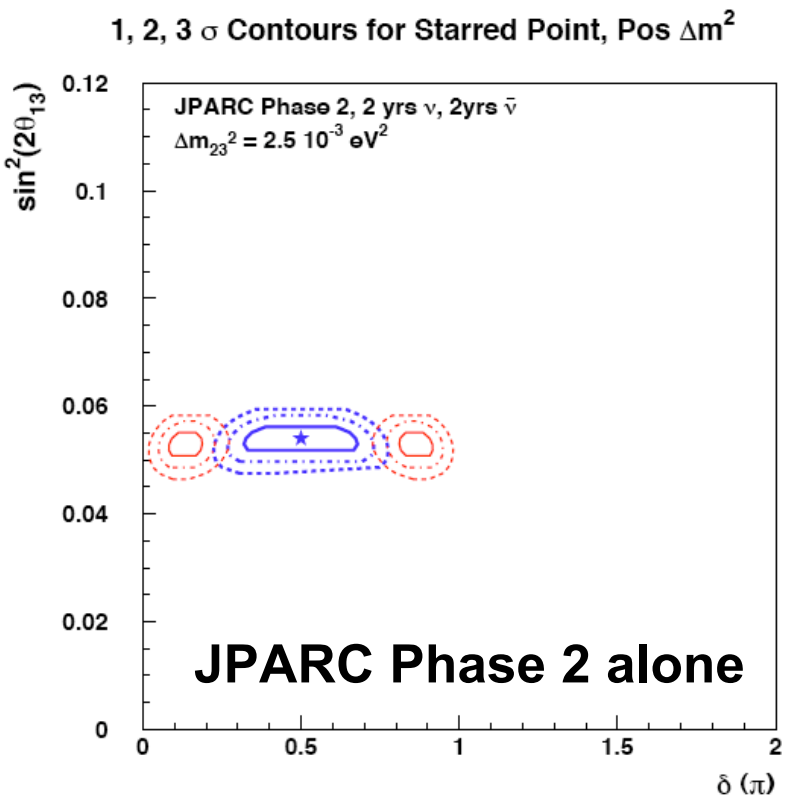
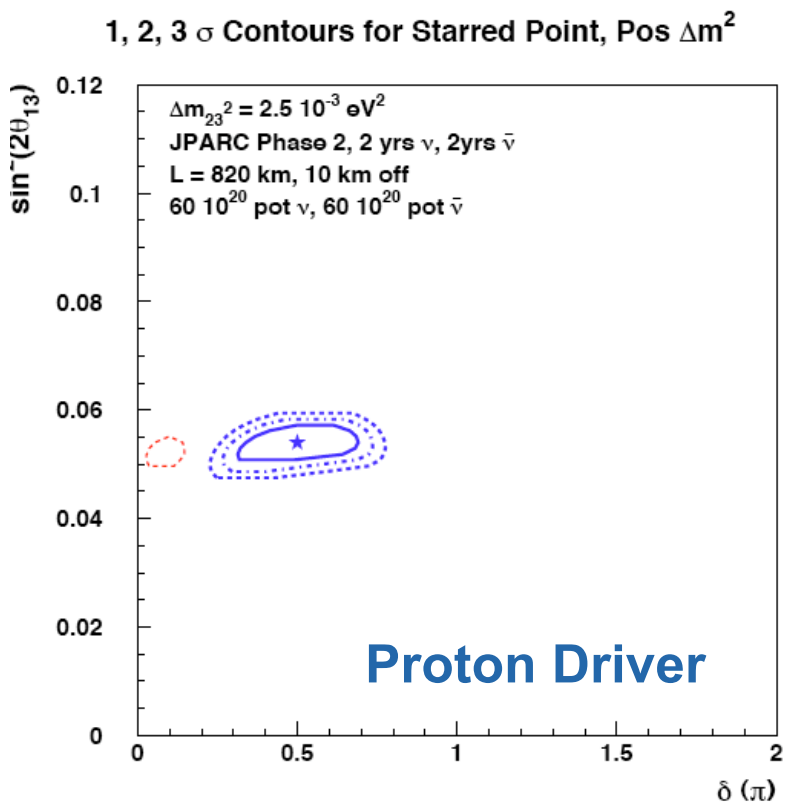
NuMI 3 yr □, 3 yr□□, 20 10^{20} pot/yr and JPARC Phase 2, 2 yr □, 2 yr□□





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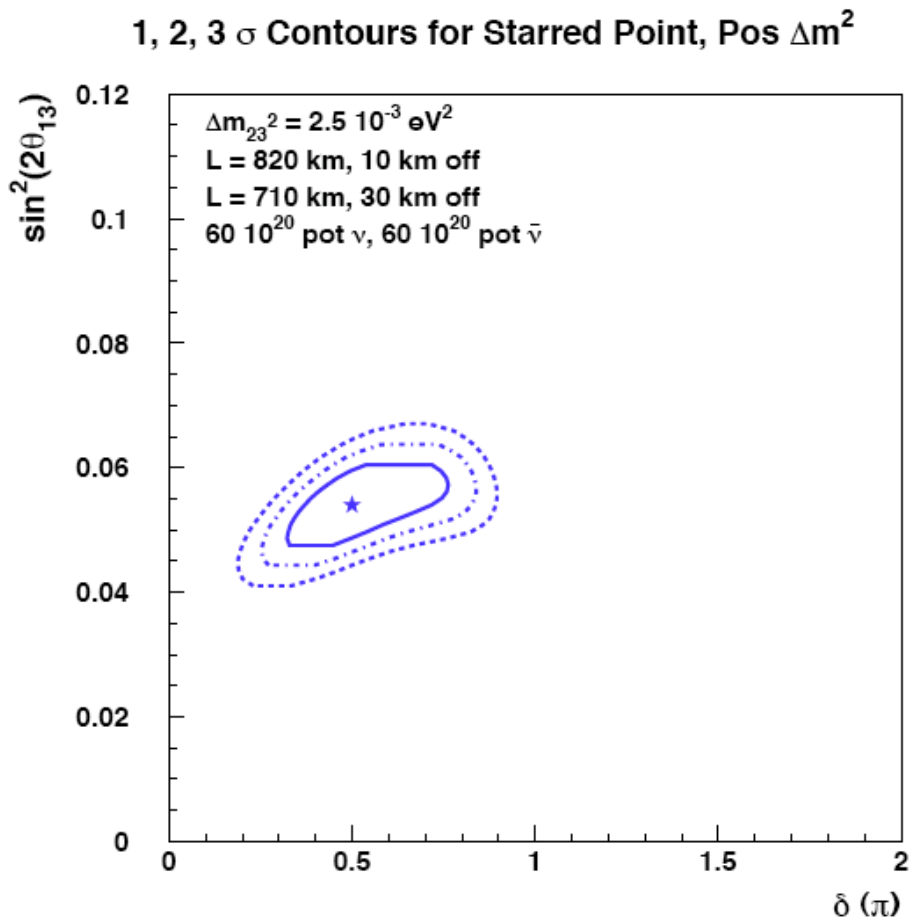
NuMI 3 yr □, 3 yr□□, 2 Detectors and Proton Driver



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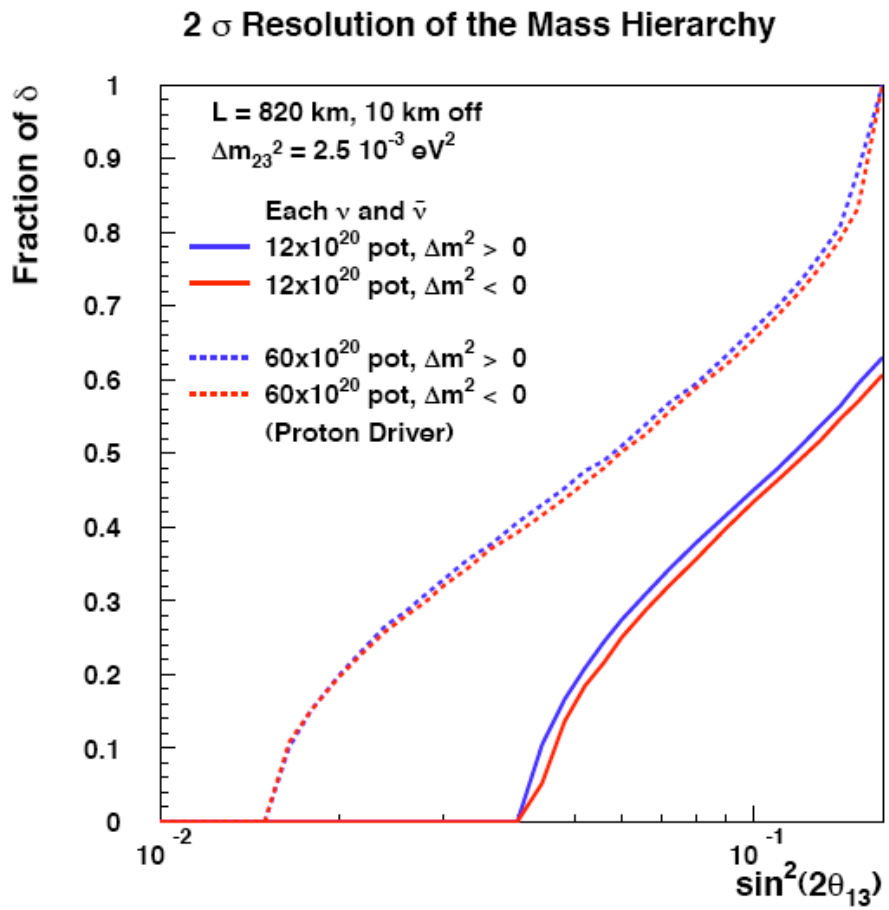
95% CL Resolution of the Mass Hierarchy



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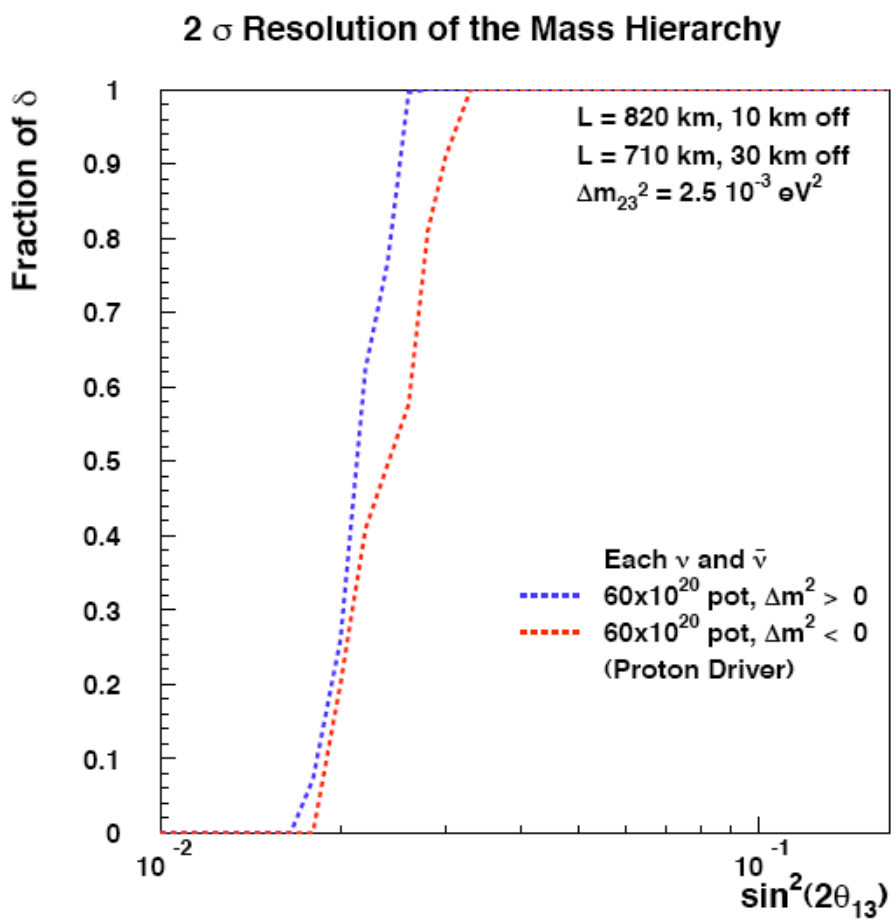
95% CL Resolution of the Mass Hierarchy with 2 Detectors



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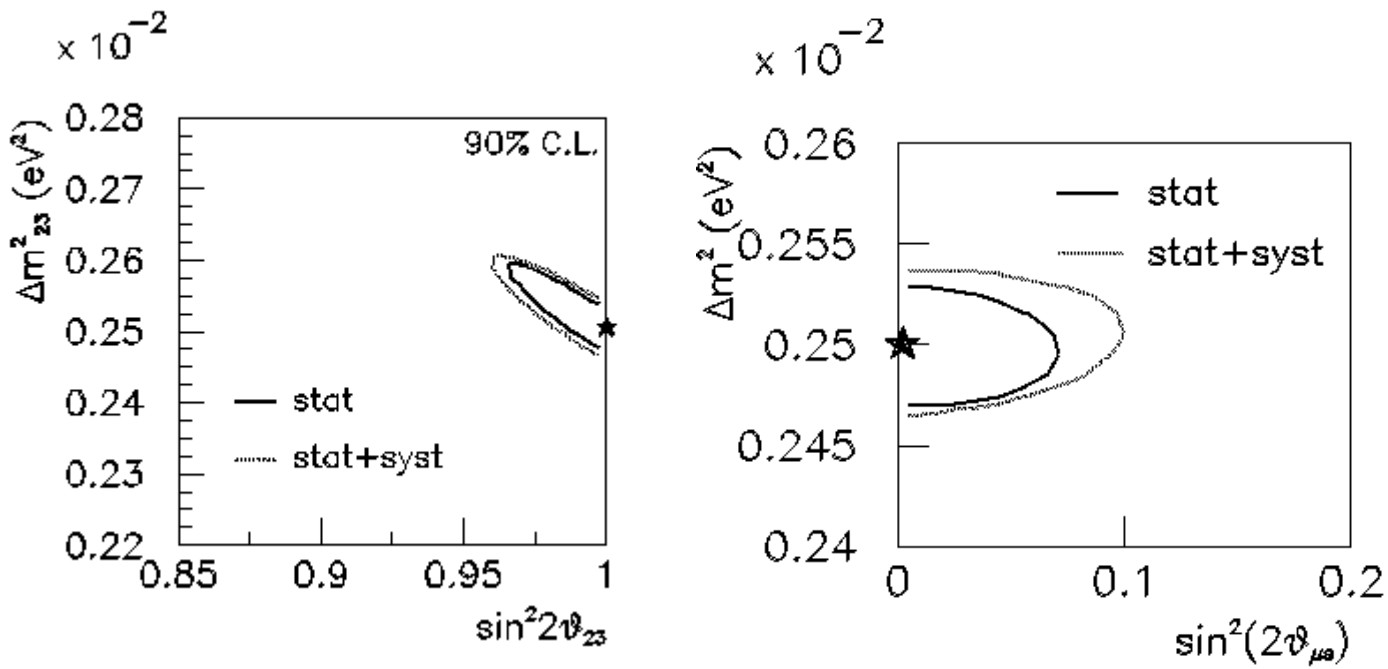
Question 8: Are there other important measurements that a …detector optimized for electron ID could perform?

- **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

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PAC Question: Would it make more sense to wait for reactor experiments to establish or limit the value of $\sin^2(2\theta_{13})$?

- **Reactor measurement of θ_{13}: Have two or more detectors at different distances and compare the rates and spectra.**
- **Measurement requires a subtraction of two large numbers. Thus, need both high statistics and excellent control of systematics.**
- **The latter is possible only if the far detector can be moved next to the near detector for calibration.**
- **Both detectors need to be underground to reduce backgrounds (minimum 300 mwe). Thus a 1-2 km tunnel is required.**

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Time scale and sensitivity

- "An international proto-collaboration has been formed to work towards a proposal by 2005" – J. Link, NuFact03
- Adding 2 years for approval and technical design and 2 years for construction ⇒ run start in 2009.
- Three-year run ⇒ result in 2012.

- "With a 3 year run, the sensitivity in $\sin^2 2\theta_{13}$ could reach 0.01 (90% CL) at $\Delta m^2 = 2.5\times10^{-3}$." – J. Link, NuFact03
- Consistent with "$\sin^2 2\theta_{13} < 0.01$-$0.02$ at 90% CL within reach of reactor θ_{13} experiments" – K. Heeger, TAUP03
- Take 0.01 at 90% CL ⇒ 0.018 at 3 σ or 0.014 at 3 σ for a five-year run.

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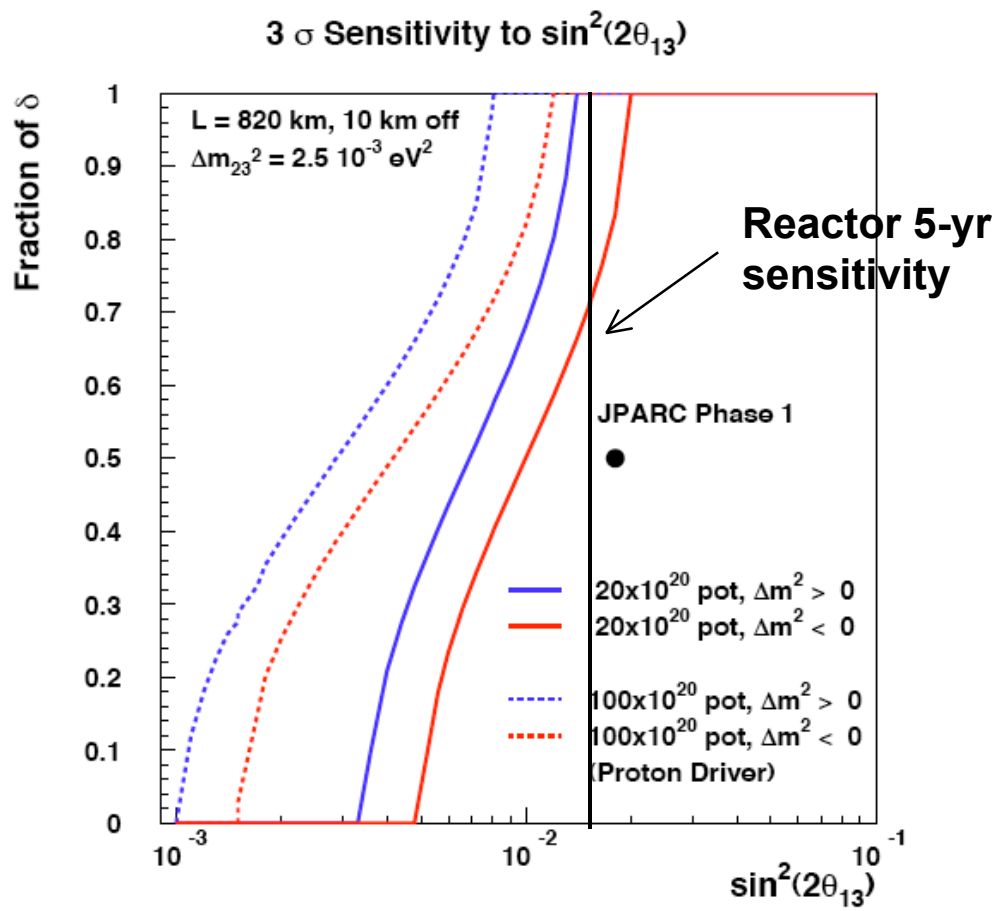
Sensitivity Comparison



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Scenarios if we wait for reactor results

- Reactor experiments see a signal or have an ambiguous result: Lost time confirming the signal and the continuation of the program to resolve the mass hierarchy and measure θ.
- Reactor experiments have not seen a signal by 2014:
  - Want to continue the search for θ_{13}
  - This is the time scale of "Phase 3", JPARC Phase 2, CERN SPL, Fermilab Proton Driver (?)
  - Probably want to push superbeams to their limit before investing in beta beams or neutrino factories
  - Having a 50 kT detector optimized for electron detection puts us in a more favorable position