

LBNE Staging and Alternatives

Gina Rameika

April 25-26, 2012

LBNE Reconfiguration Workshop

Outline

- LBNE Scientific Goals
- θ_{13} – a new way to look at things
- LBNE reach with smaller detectors
- Options with the NuMI Beam
- Summary ~~and Conclusions~~

Physics Research Goals of LBNE

This
talk

The primary science objectives of the LBNE Project are:

1. A search for, and precision measurements of, the parameters that govern $\nu_\mu \rightarrow \nu_e$ oscillations. This includes measurement of the third mixing angle θ_{13} , for whose value only an upper bound is currently known, and if θ_{13} is large enough, measurement of the CP-violating phase δ and determining of the mass ordering (sign of Δm^2_{32}).
2. Precision measurements of θ_{23} and $|\Delta m^2_{32}|$ in the ν_μ disappearance channel.
3. Search for proton decay, yielding a significant improvement in current limits on the partial lifetime of the proton (τ/BR) in one or more important candidate decay modes, e.g. $p \rightarrow e + \pi^0$ or $p \rightarrow K^+ \nu$.
4. Detection and measurement of the neutrino flux from a core collapse supernova within our galaxy, should one occur during the lifetime of LBNE.

Though outside of the primary objectives, the far detector placed at the proposed depth could enable studies of atmospheric ν physics, and with additional upgrades, studies of day/night ${}^8\text{B}$ solar ν physics and relic supernova neutrinos.

In addition to the physics goals of the Far Detector, the Near Detector Complex will enable precision measurements of neutrino cross sections which are needed for the long-baseline physics.

Physics Research Goals of LBNE

Talks tomorrow by Mary Bishai and Kate Scholberg

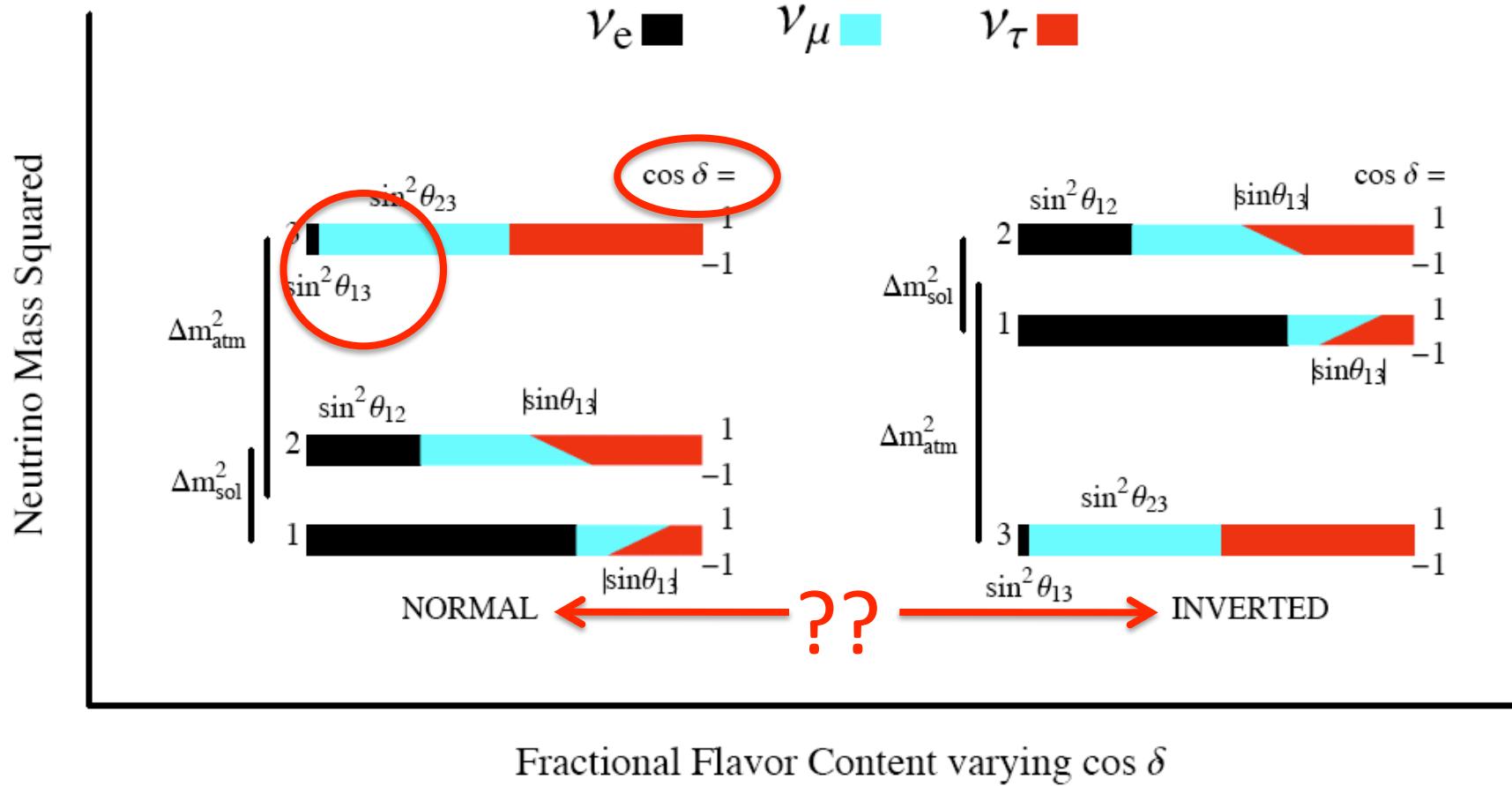
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In addition to the physics goals of the Far Detector, the Near Detector Complex will enable precision measurements of neutrino cross sections which are needed for the long-baseline physics.

$$P(\nu_a \rightarrow \nu_b) = f(\Delta m^2 s, \theta^s, E_\nu, L)$$



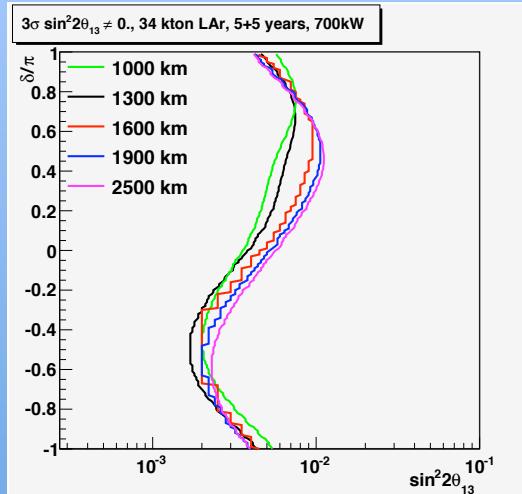
The Old Days, i.e. pre-fall 2011

- We didn't know θ_{13}
- We wanted to measure δ_{CP}
- You want to know the mass hierarchy to eliminate degenerate solutions for δ
- Baseline matters for the mass hierarchy

How do sensitivities depend on baseline?

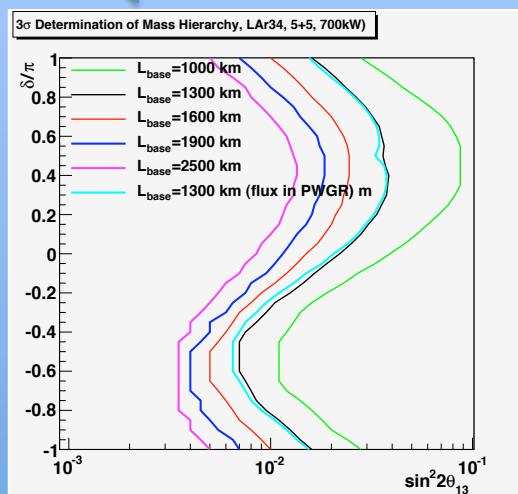
Study done with a Wide Band Beam that is “tuned” to increase with energy as the baseline increases

Curves moving in this direction is good

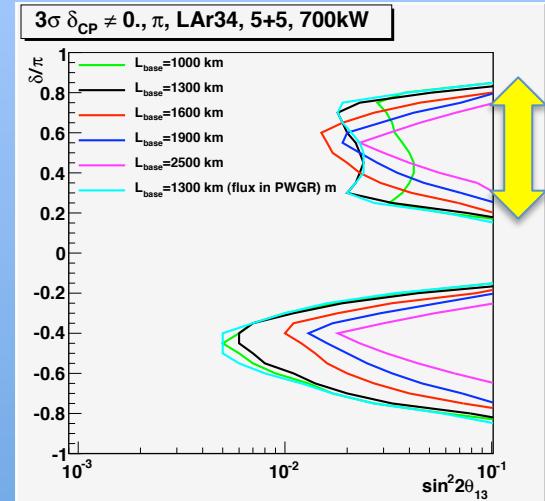


θ_{13} is relatively
independent of L

1300 km appears to be nearly optimum
if the Mass Hierarchy is unknown and
 $\sin^2 2\theta_{13} \geq 0.02$

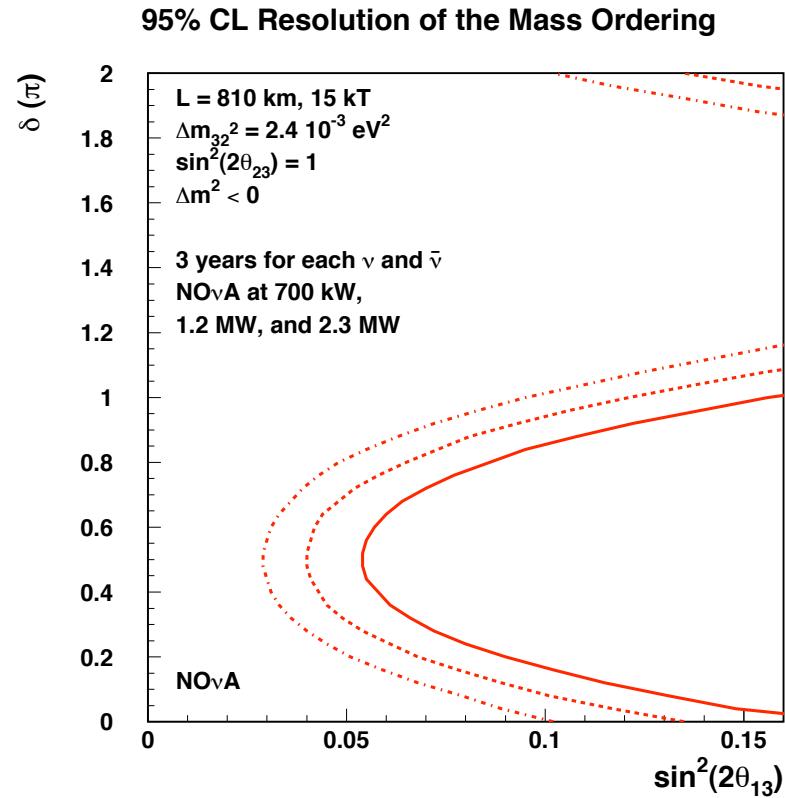
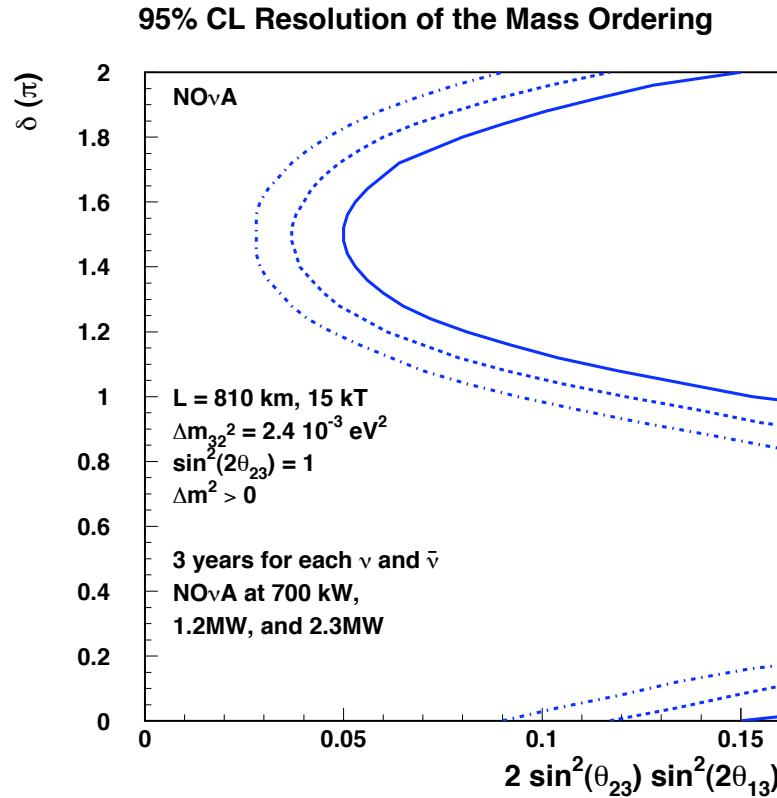


MH improves with L

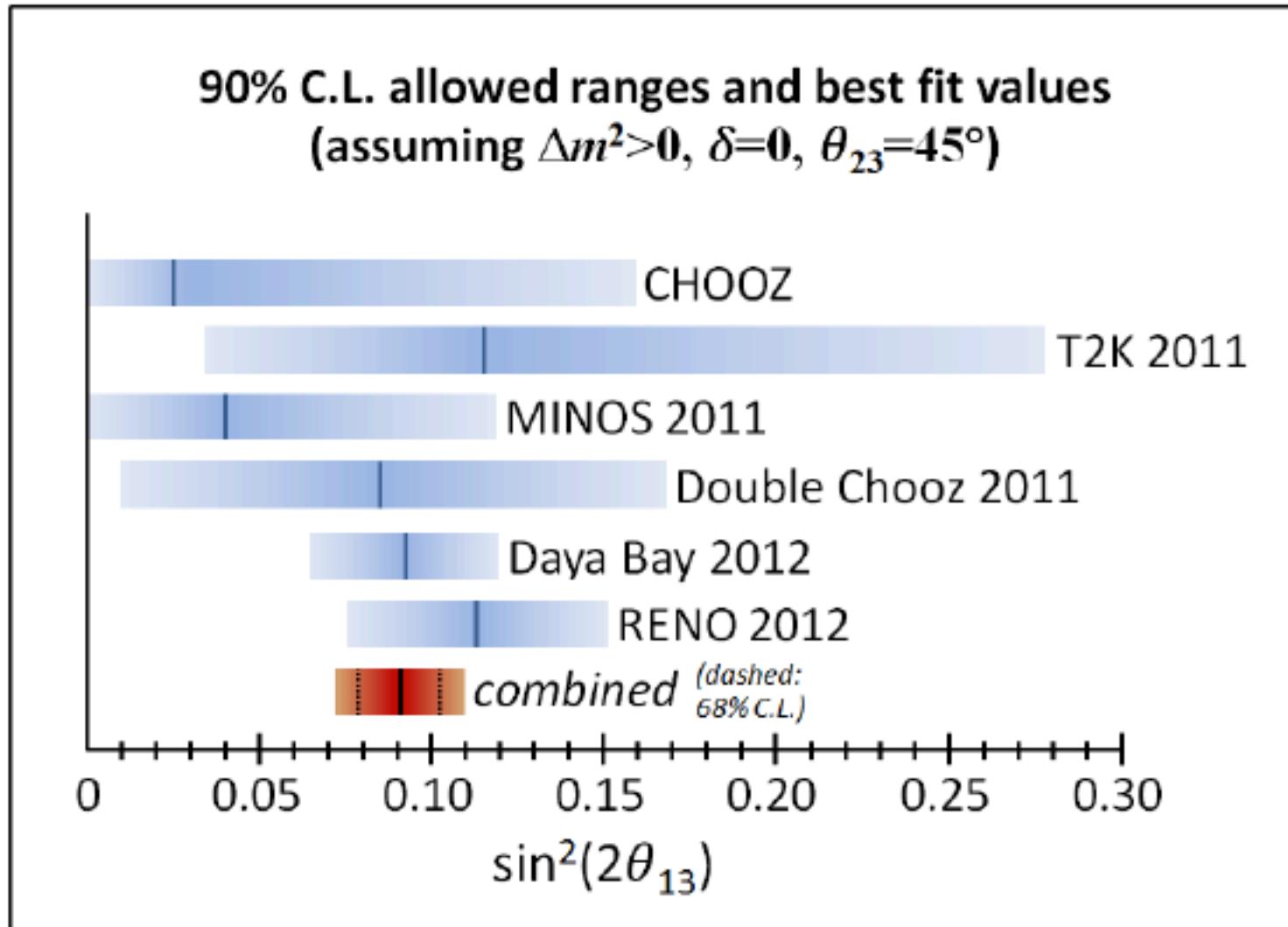


matter and CP
asymmetries are
coupled
 CP asymmetry is a
function of θ_{13}

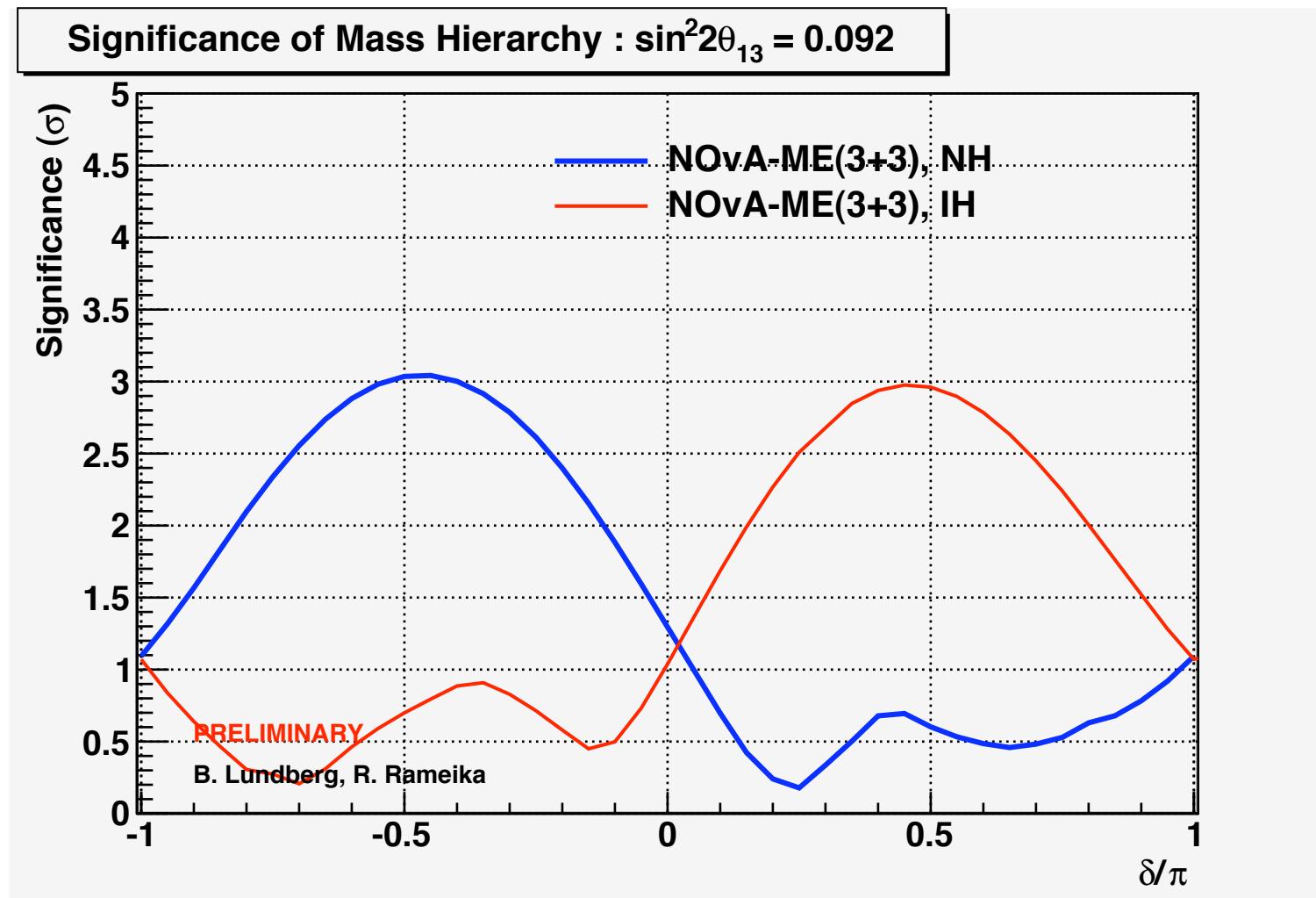
NOvA – in the unknown θ_{13} world



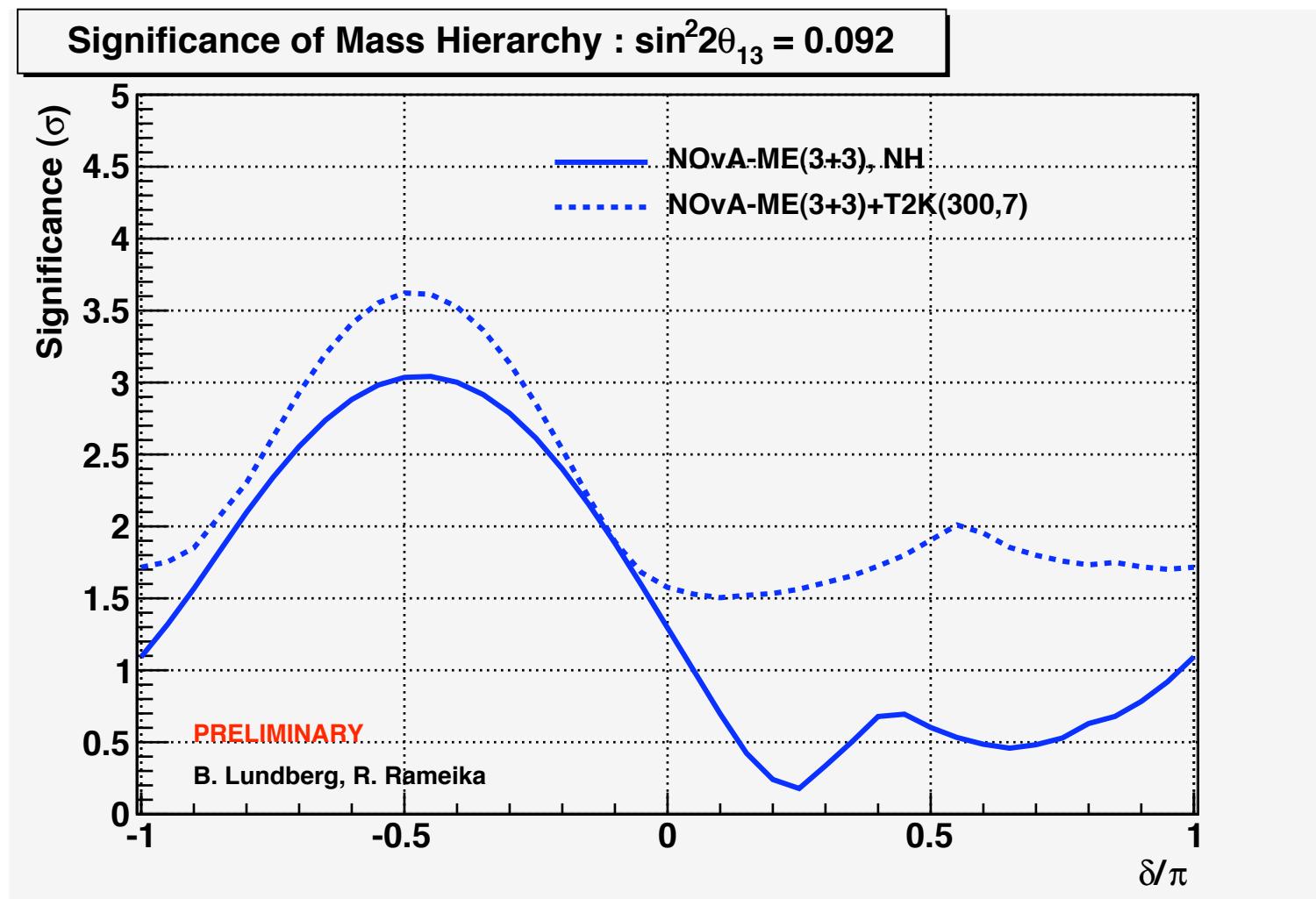
Winter 2012



We can plot things differently now

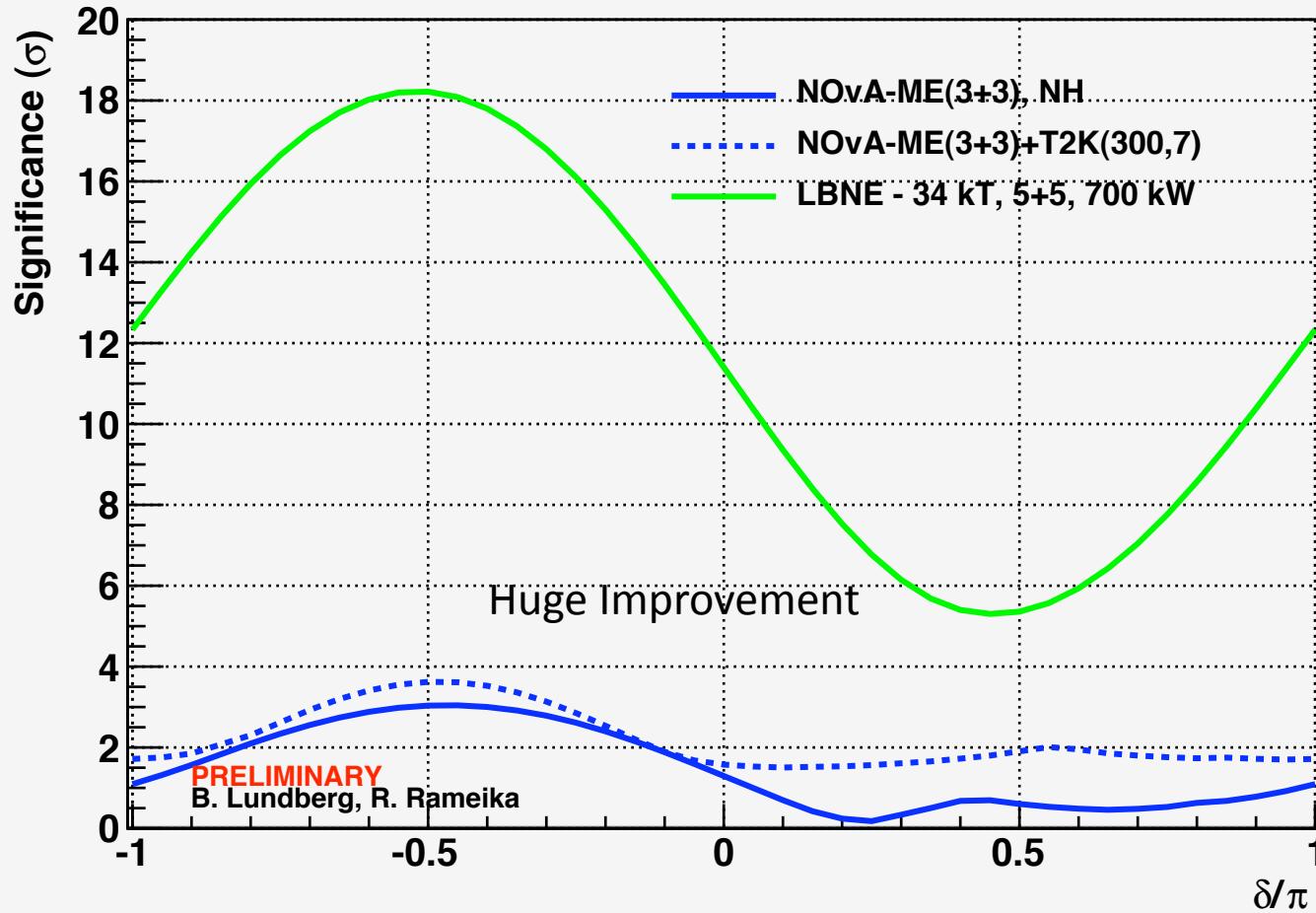


NOvA + T2K



Beyond NOvA : LBNE

Significance of Mass Hierarchy : $\sin^2 2\theta_{13} = 0.092$



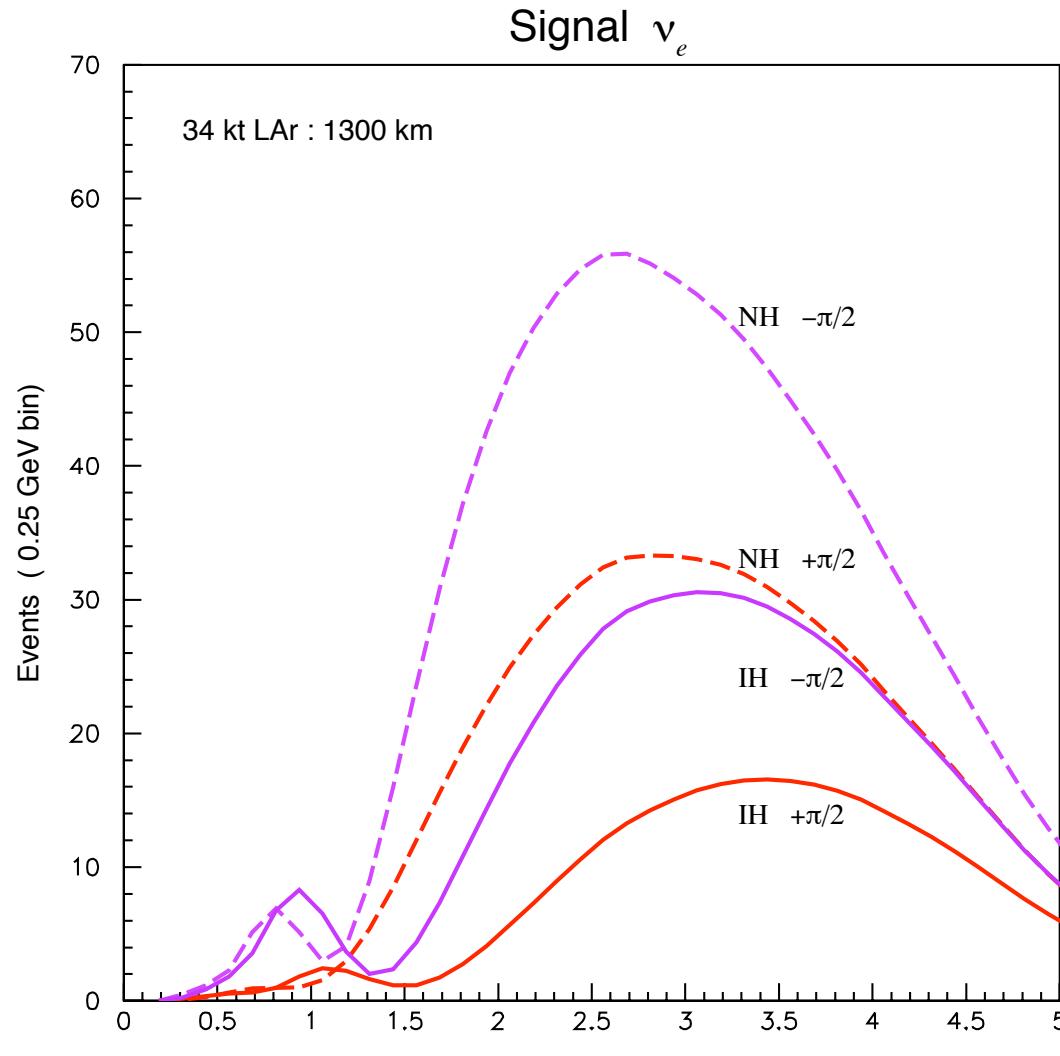
Mass hierarchy is easily determined; goal is to measure δ

4/25/12

R. Rameika - LBNE Reconfiguration
Workshop

12

Why we like long-baseline



March 19, 2012

Dr. Pier Oddone
Director
Fermilab
Wilson and Kirks Road
Batavia, IL 60510-5011

Dear Pier,

Thank you for your recent presentation on the status and plans for the Long Baseline Neutrino Experiment (LBNE). The project team and the scientific collaboration have done an excellent job responding to our requests to assess the technology choices and refine the cost estimates for LBNE. We believe that the conceptual design is well advanced and the remaining technical issues are understood.

Based on our considerations, we cannot support the LBNE project as it is currently configured. This decision is not a negative judgment about the importance of the science, but rather it is a recognition that the peak cost of the project cannot be accommodated in the current budget climate or that projected for the next decade.

Options we have

- We consider three baselines :
 - 1300 km : SURF @ Homestake
 - 735 km : MINOS @ Soudan
 - 810 km : NOvA @ Ash River
- Other baselines?
 - 1000 km?
 - 2500 km?
 - Some discussion tomorrow in Mary's talk

Introduction to Input to PWG for the Reconfiguration

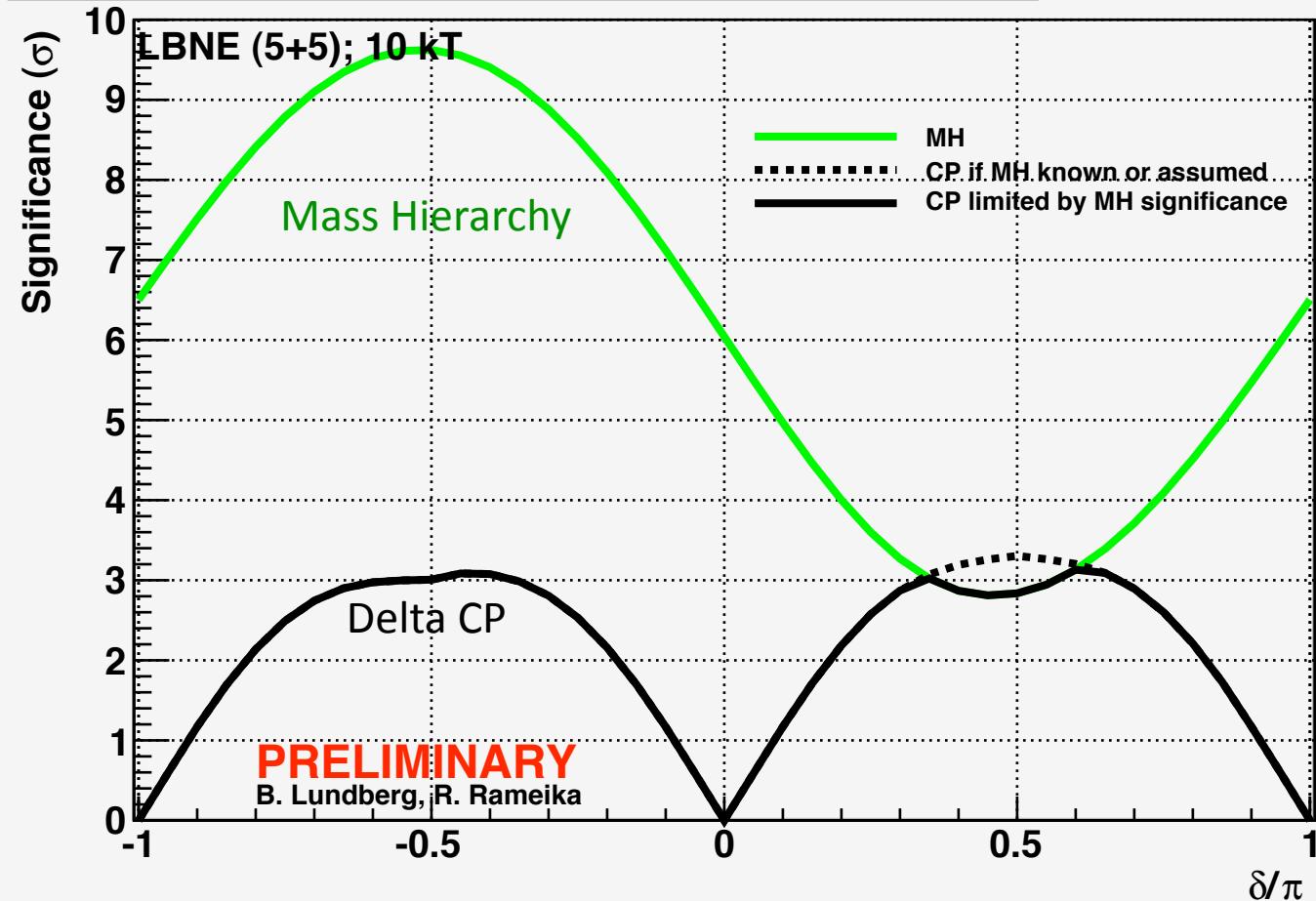
- Studies are done using GLoBEs
- This is a great tool for making comparisons of different options
 - It is not a substitute for real Monte Carlo, reconstructions, etc.
 - We have used conservative efficiency inputs for LAr
 - Event scanning indicates higher efficiency; but needs further confirmation
 - Beam configurations will be somewhat different in reality
- Absolute significances may be higher or lower than what is seen here, but these analyses are internally consistent
 - Definition of CP “significance” (p.49) slightly different than plots in Mary’s talk, but both are internally consistent

Plot formats

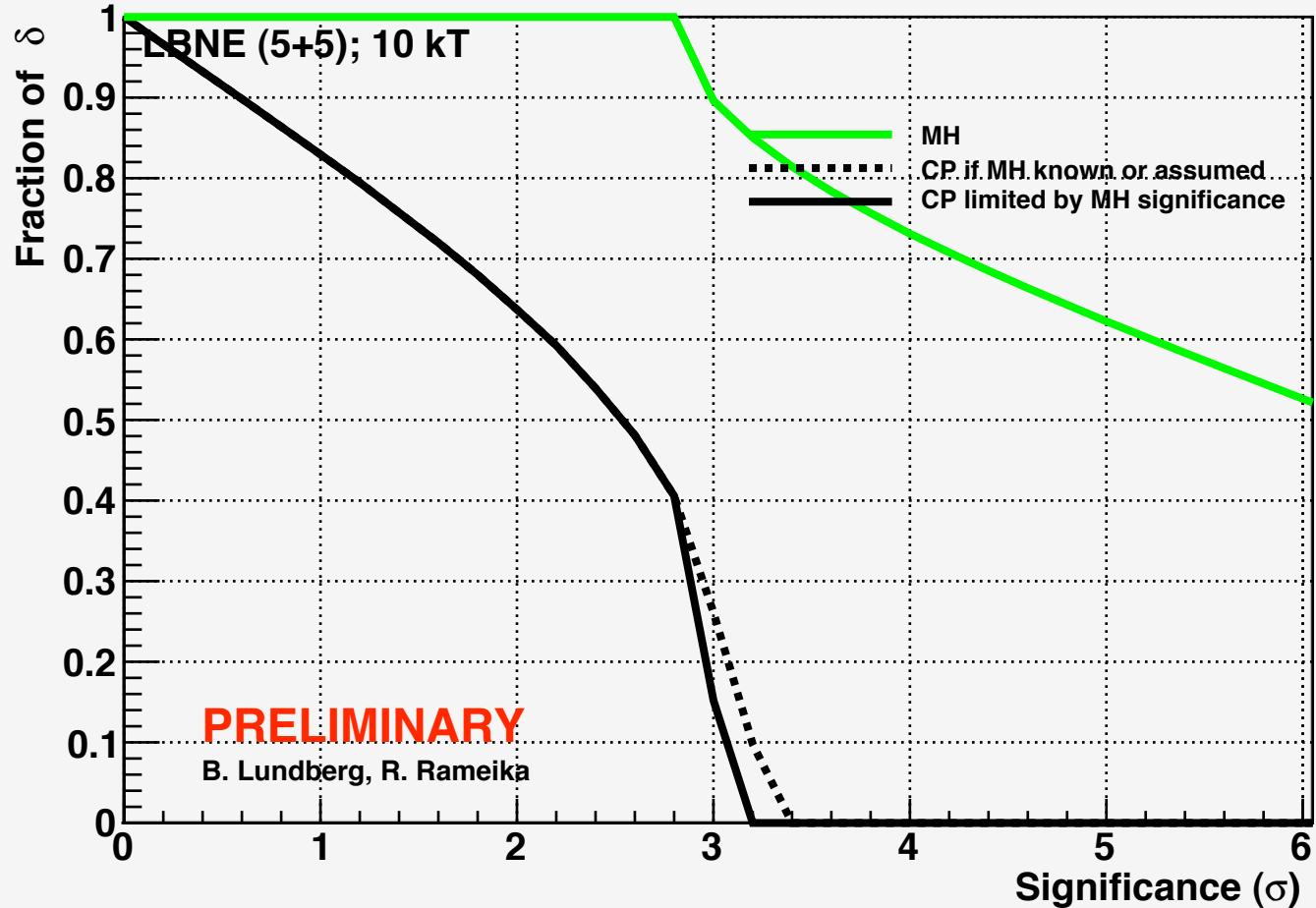
Three Formats :

- Significance of measuring Mass Hierarchy vs. δ and significance of determining $\delta \neq 0, \pi$ vs. δ
- Fraction of δ vs. significance for MH and CP
- 1 sigma error in δ vs. δ
- The three examples follow

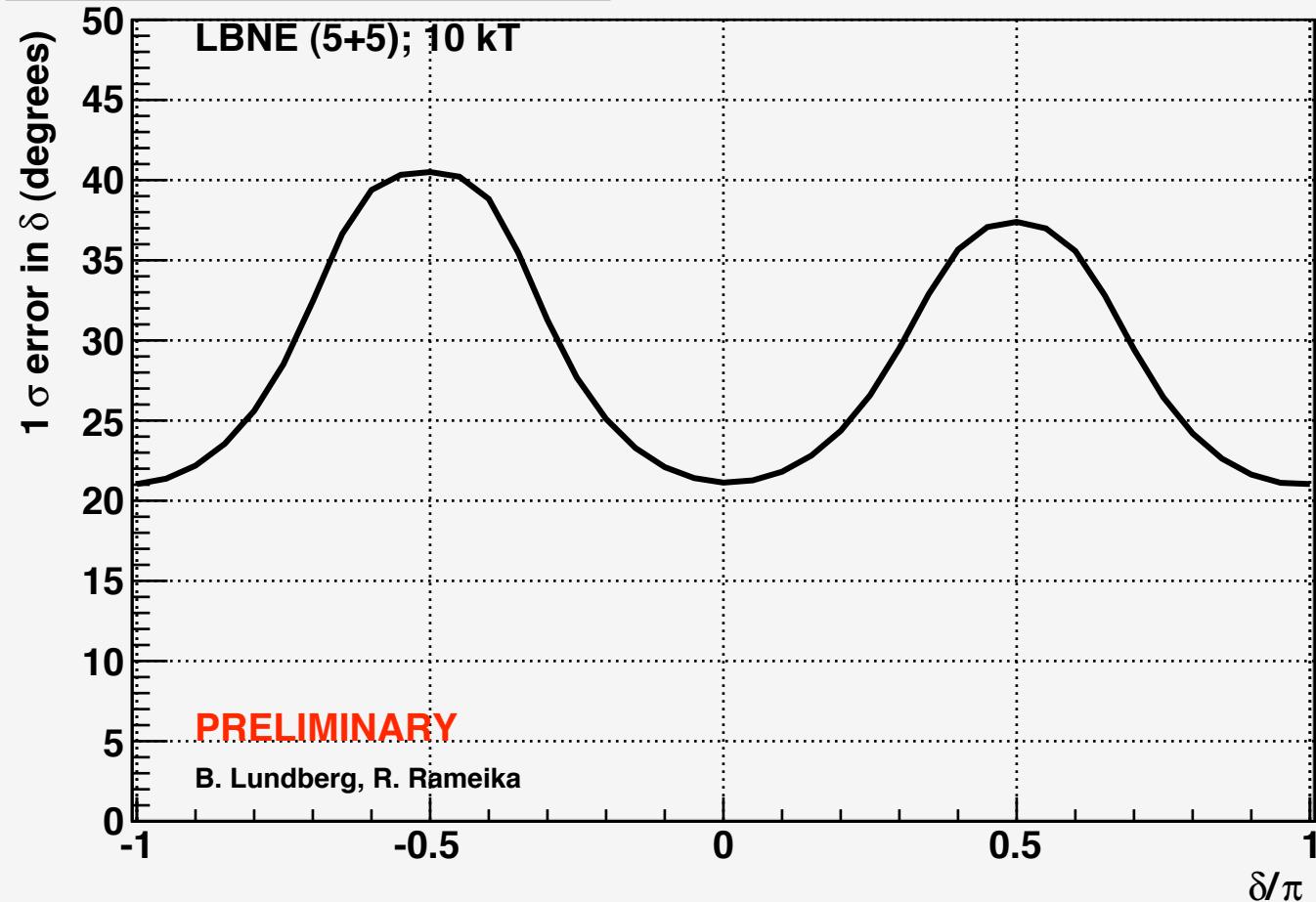
Significance of Mass Hierarchy and $\delta_{CP} \neq 0, \pi$: $\sin^2 2\theta_{13} = 0.092$



Fraction of δ vs. Significance of measuring $\delta_{CP} \neq 0, \pi$: $\sin^2 2\theta_{13} = 0.092$



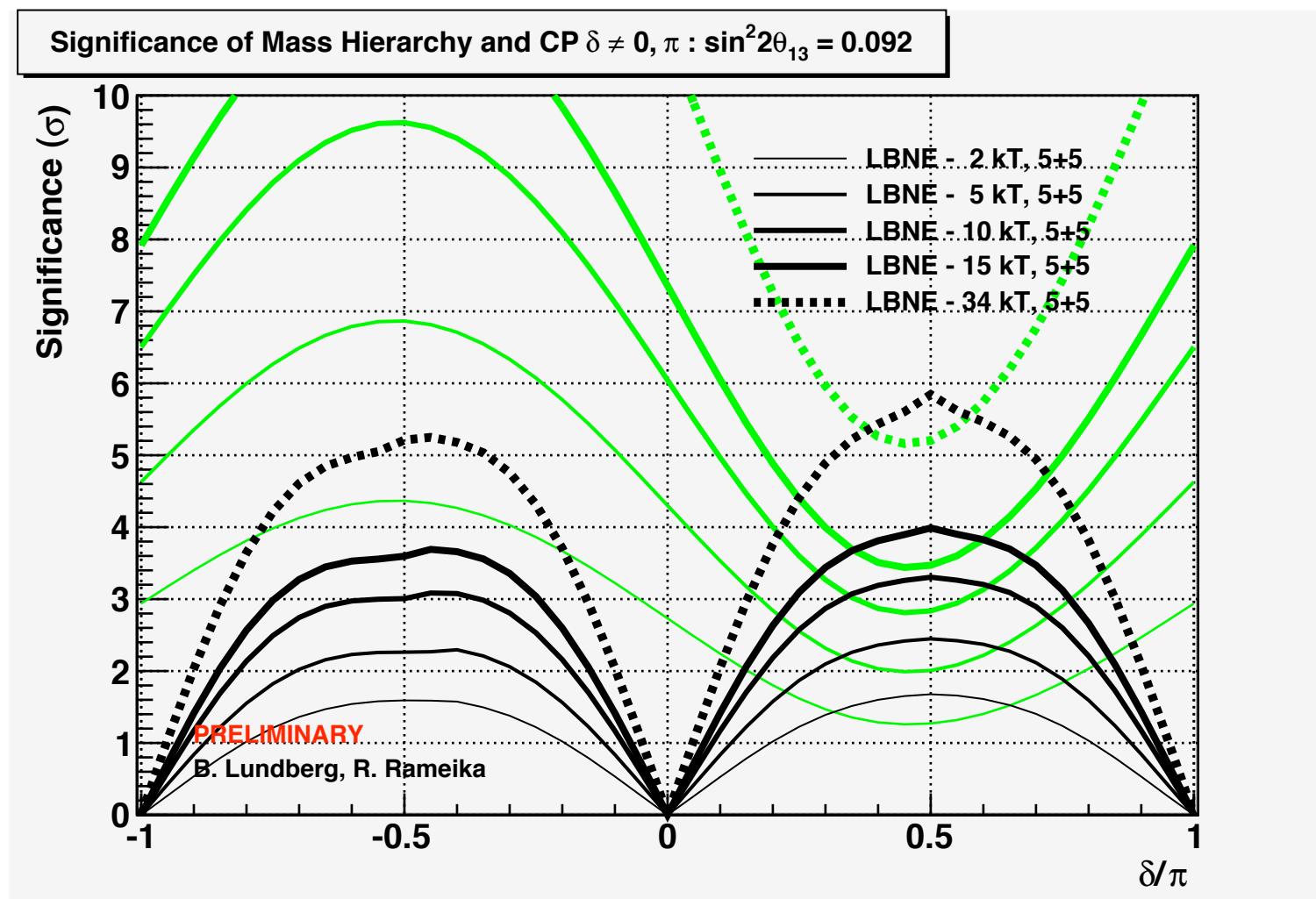
Error in δ : $\sin^2 2\theta_{13} = 0.092$



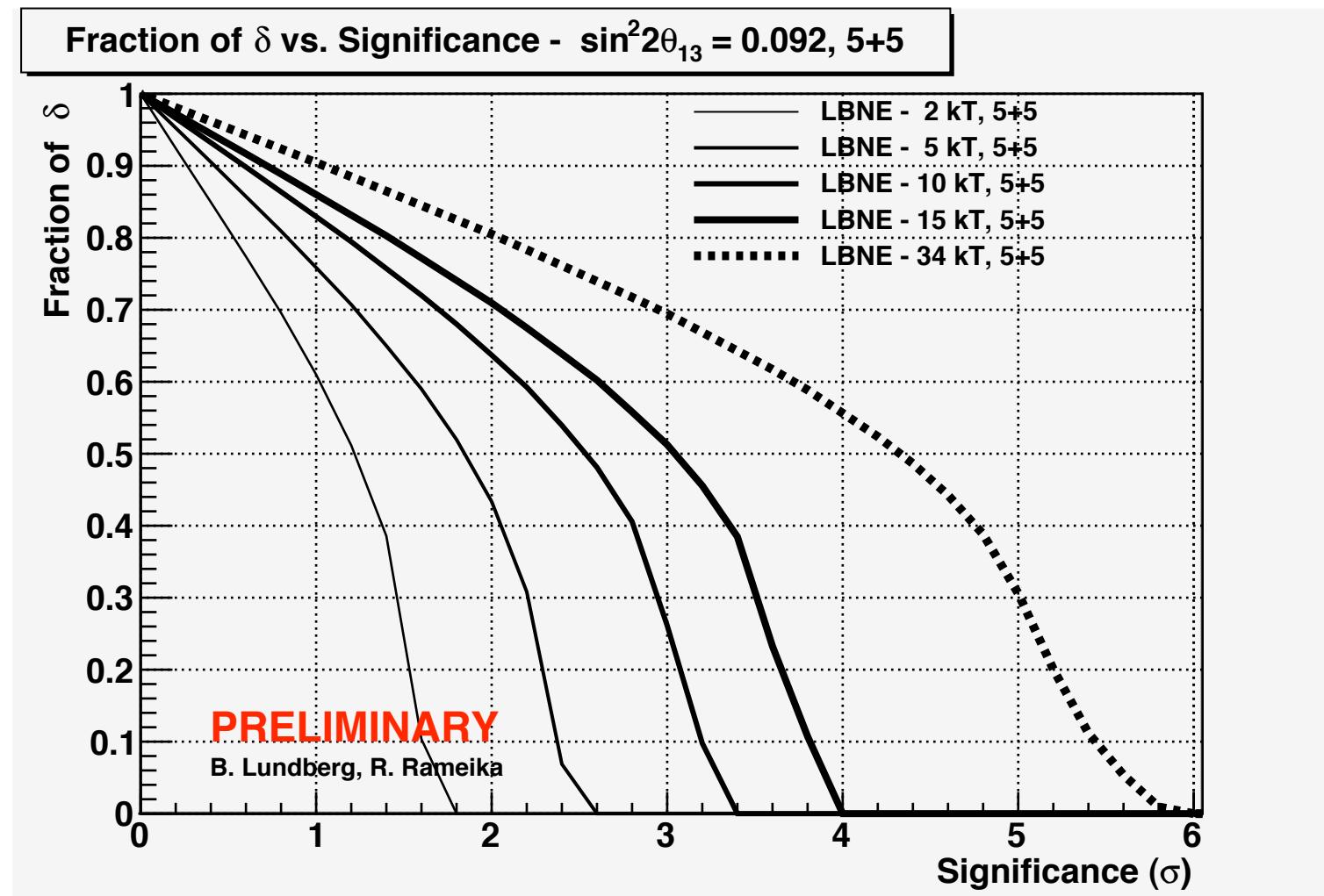
Reminder of the options

- Detectors at SURF (LBNE-Homestake)
 - 2, 5, 10, 15 (34 kT for comparison)
- Detectors in NuMI
 - 5, 10, 15 kT (34 kT only for comparison)
 - Placement at Soudan, Ash River
- For the NuMI option there will be an assumption about NOvA operations
 - Phase I : 3+ 3 years with the NuMI ME beam
 - Phase II : 5 + 5 years with the NuMI LE beam
- For the NuMI option we need input from T2K to help resolve the Mass Hierarchy

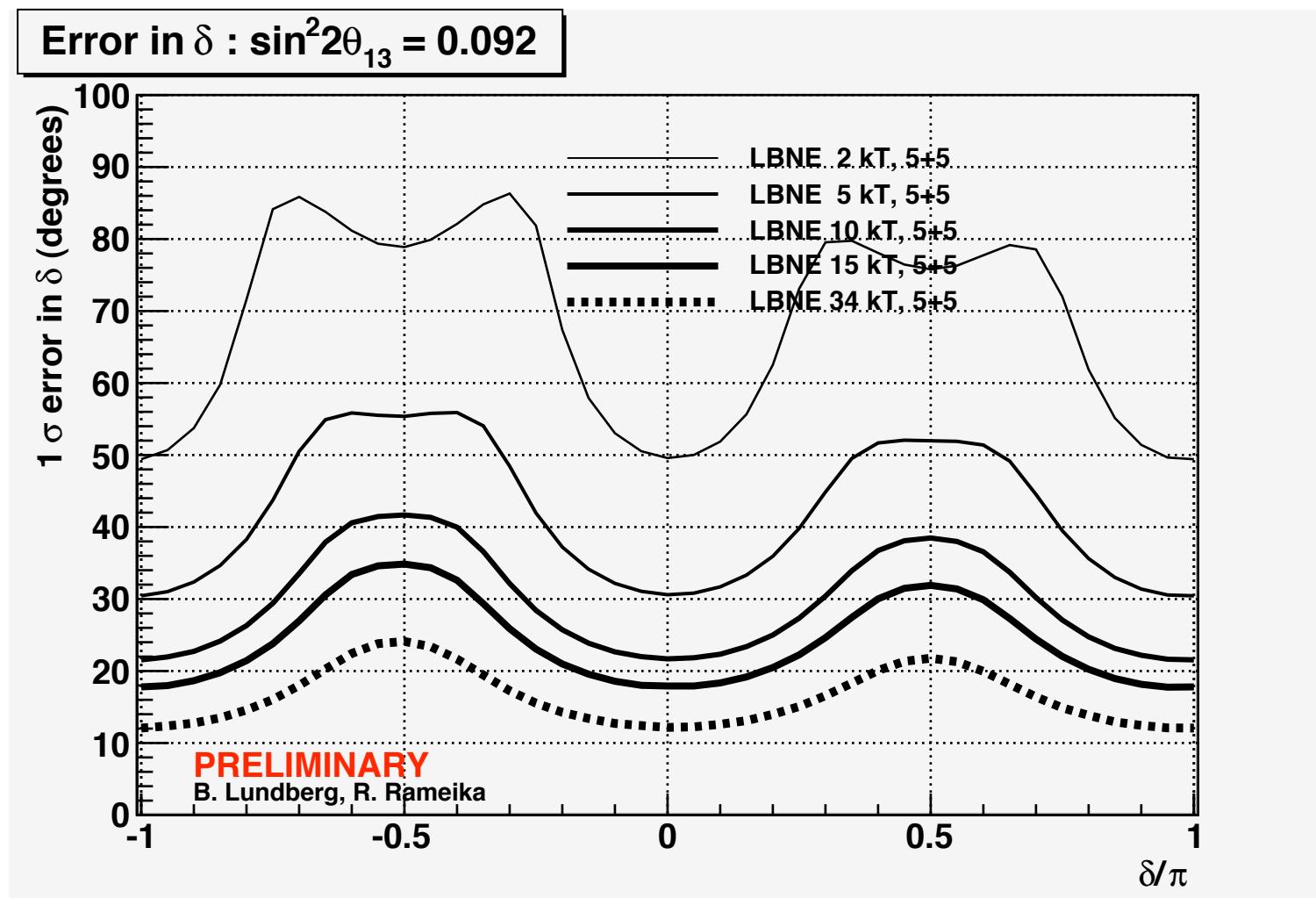
Smaller detectors at LBNE-Homestake



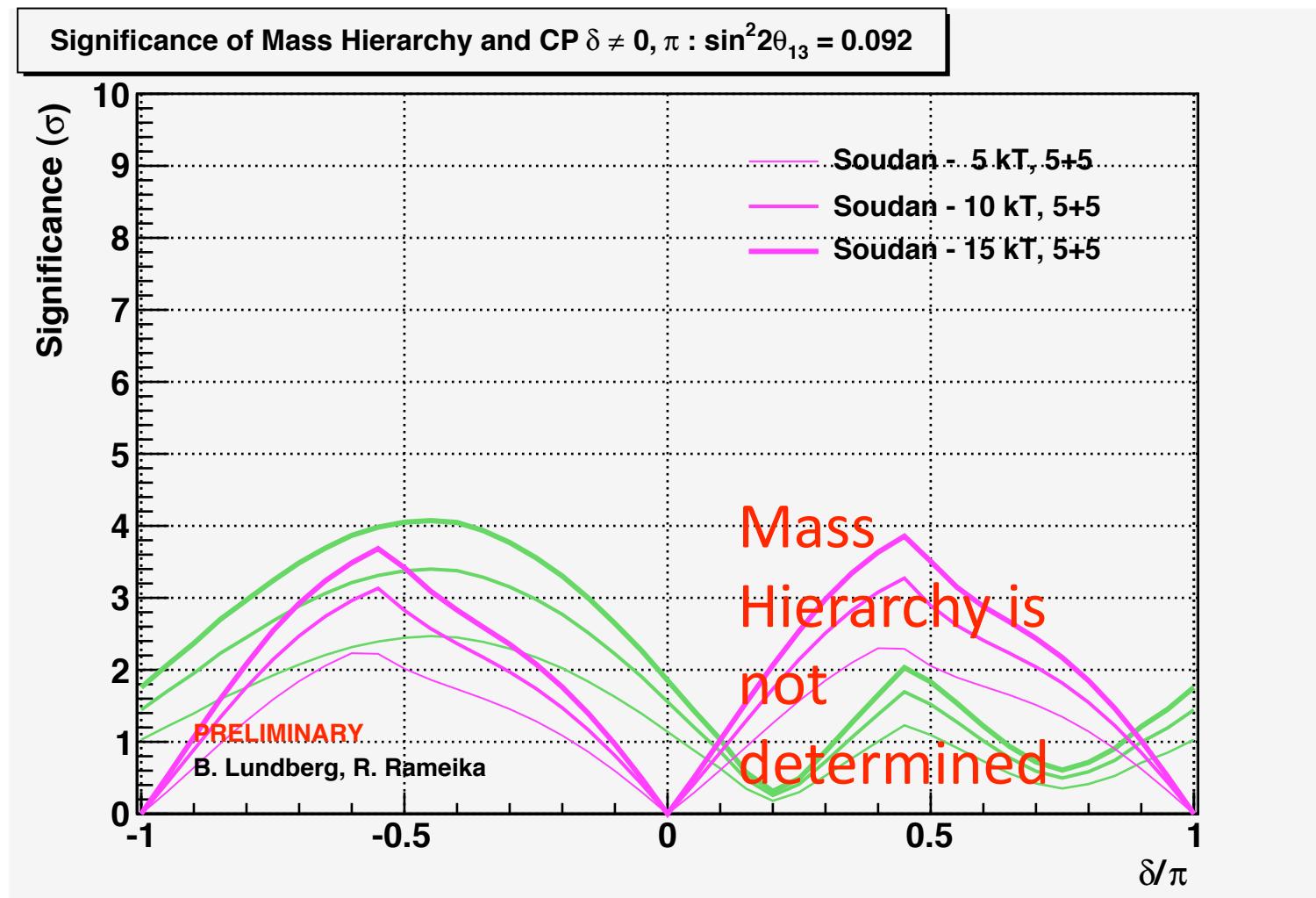
CP reach at LBNE



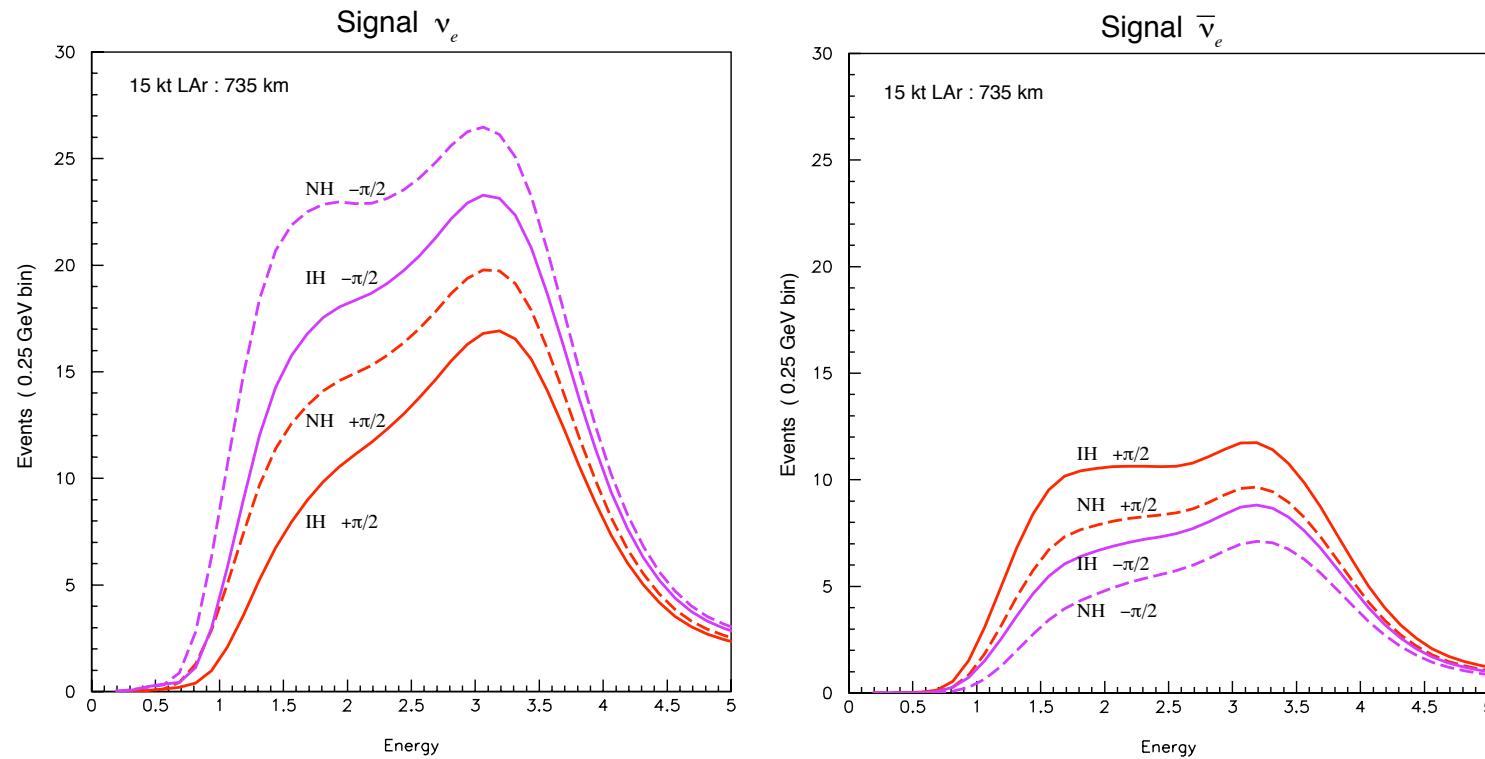
Error in delta

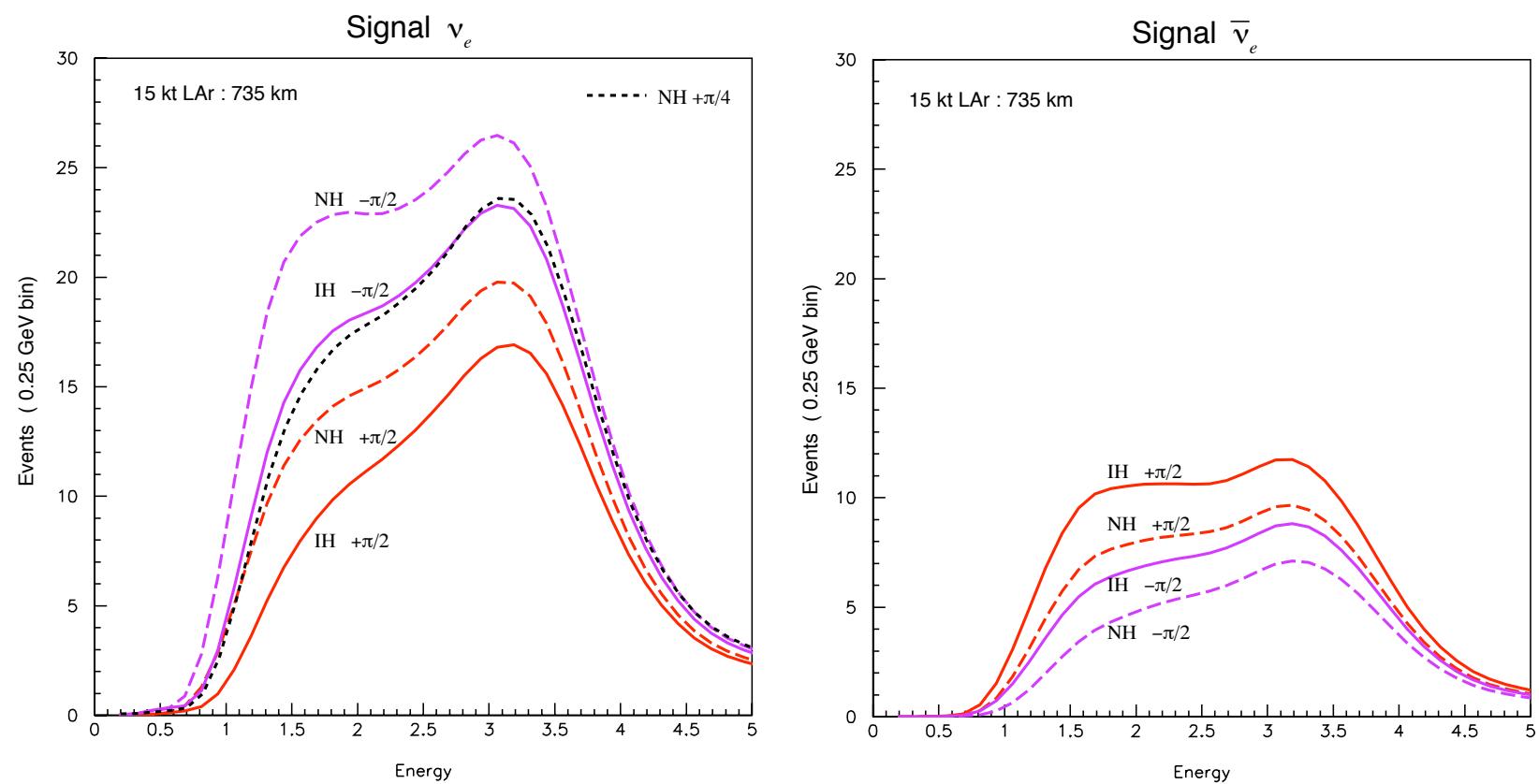


LAr Detectors at Soudan



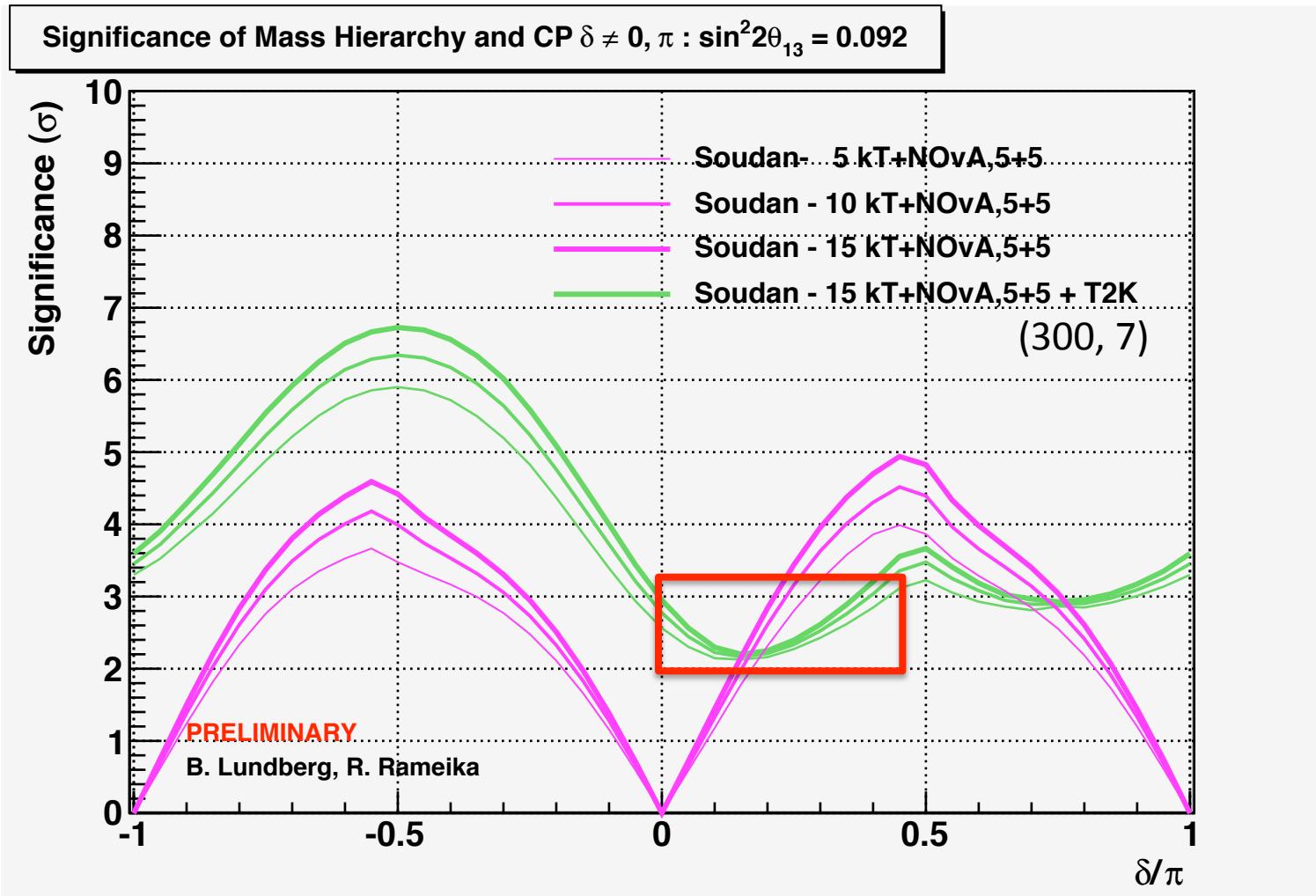
What is happening on the positive delta side?





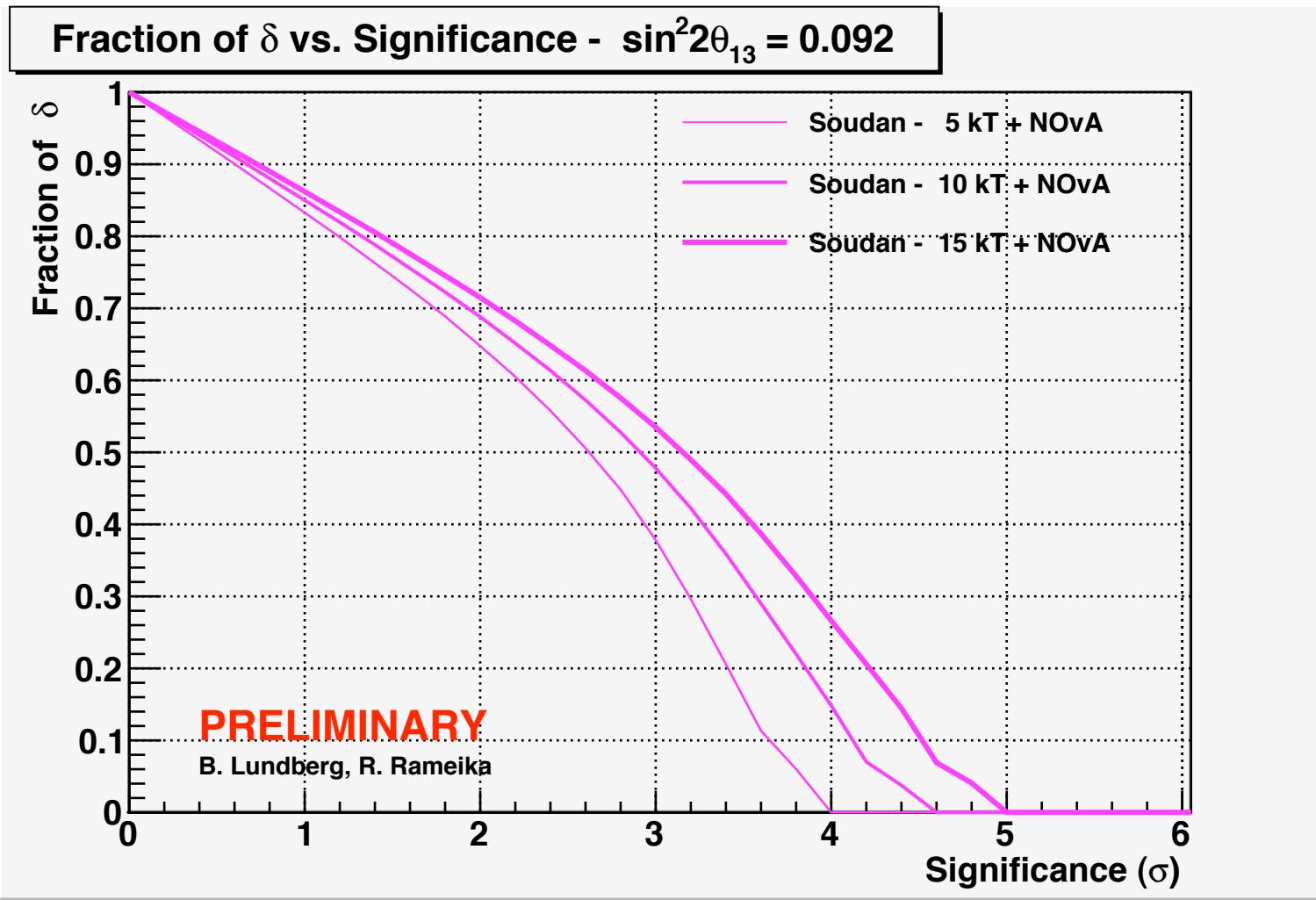
We have ambiguous solutions in the inverted hierarchy

Combine Soudan + NOvA (& T2K)

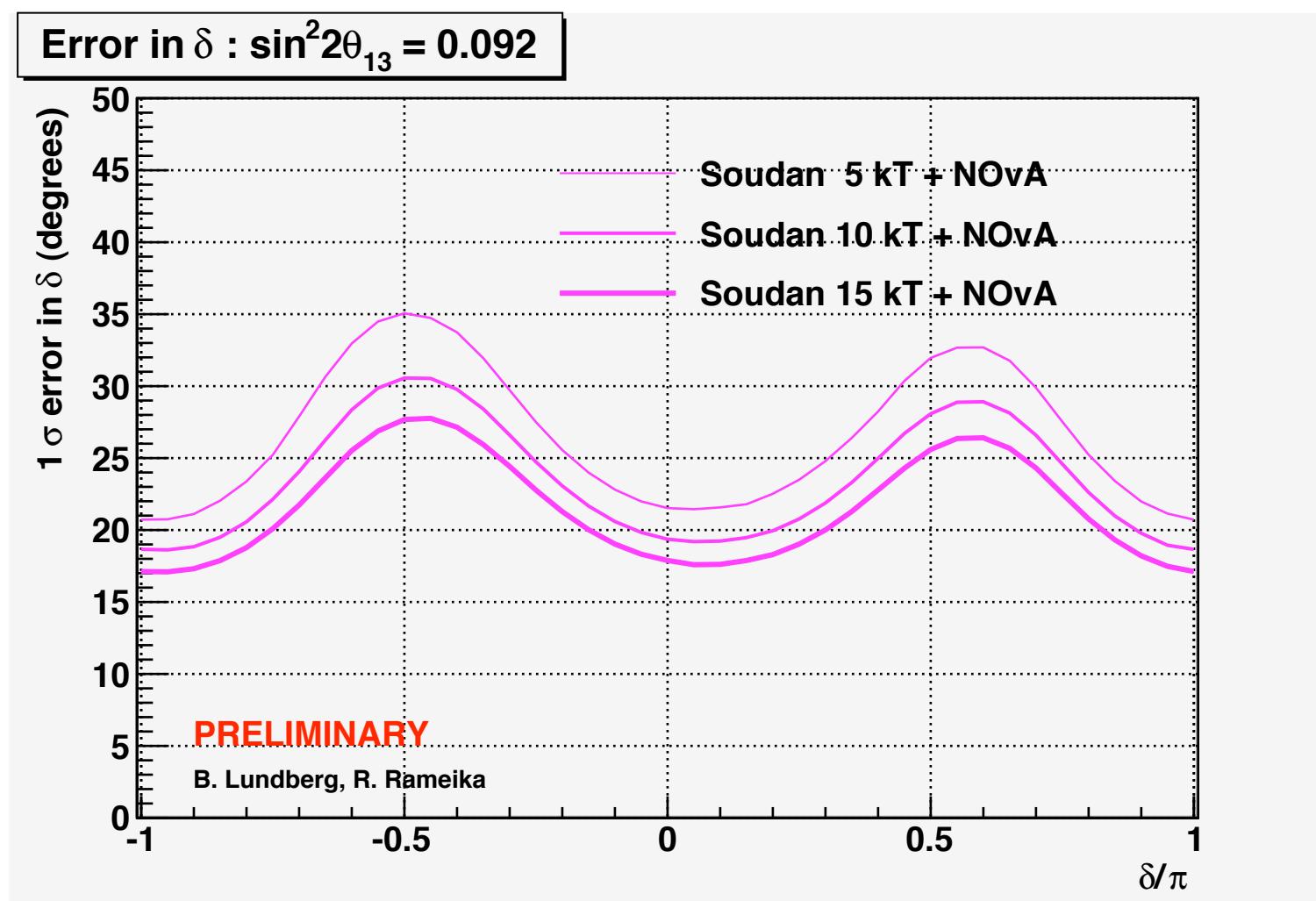


We have a small region of δ where the MH is only resolved at the 2σ (95% CL)

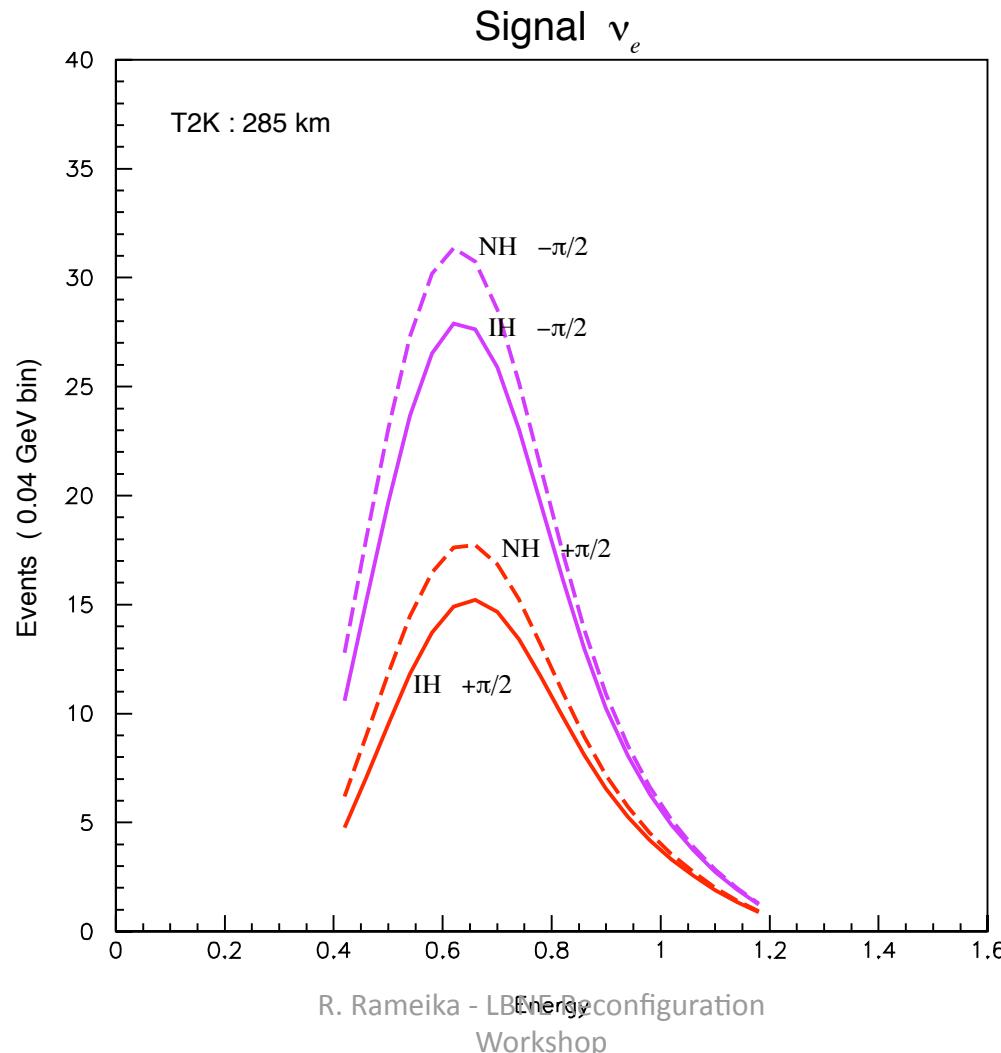
CP Reach in a NuMI “Program” with “help” from T2K

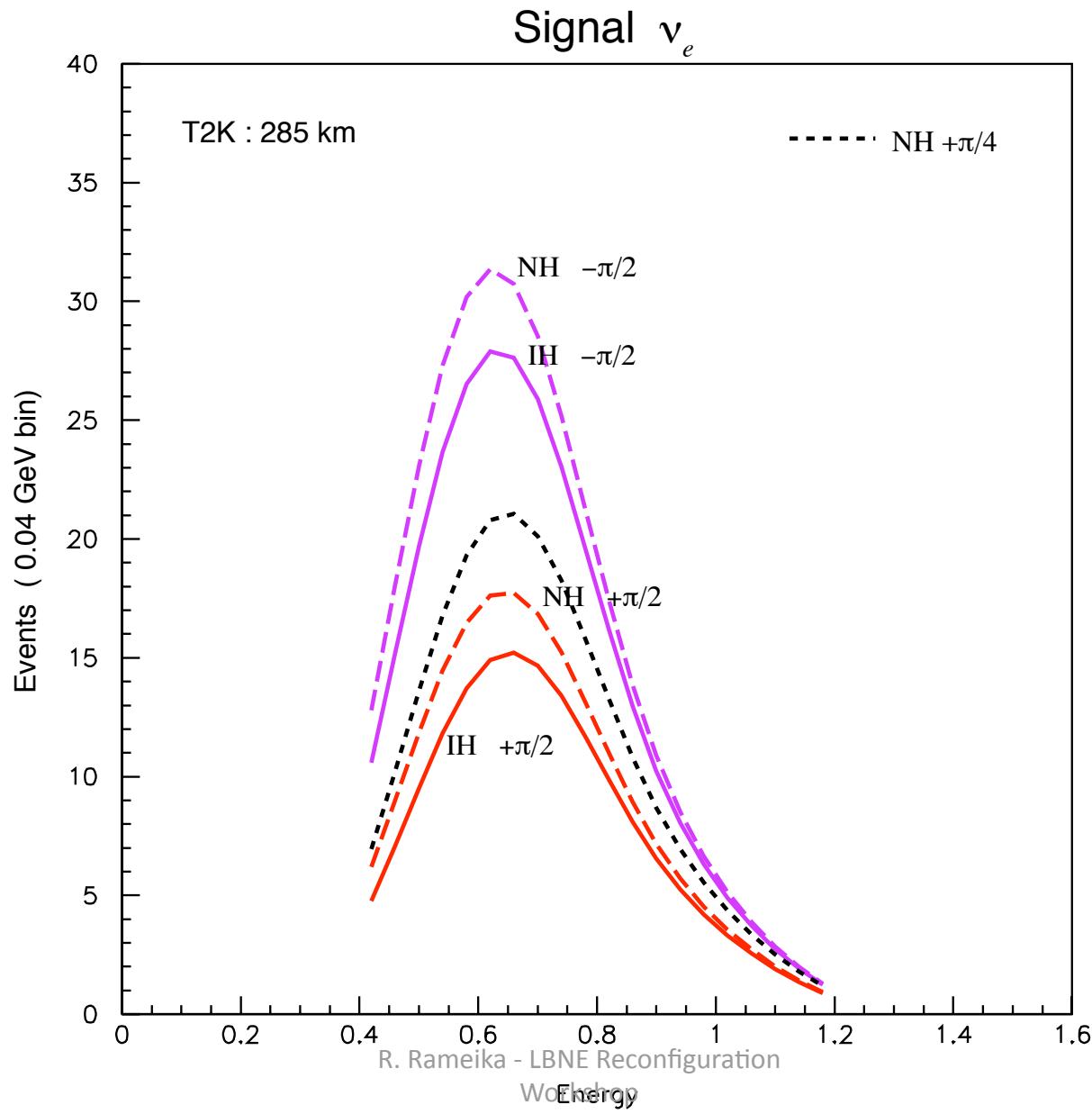


Error in Delta in the NuMI Program

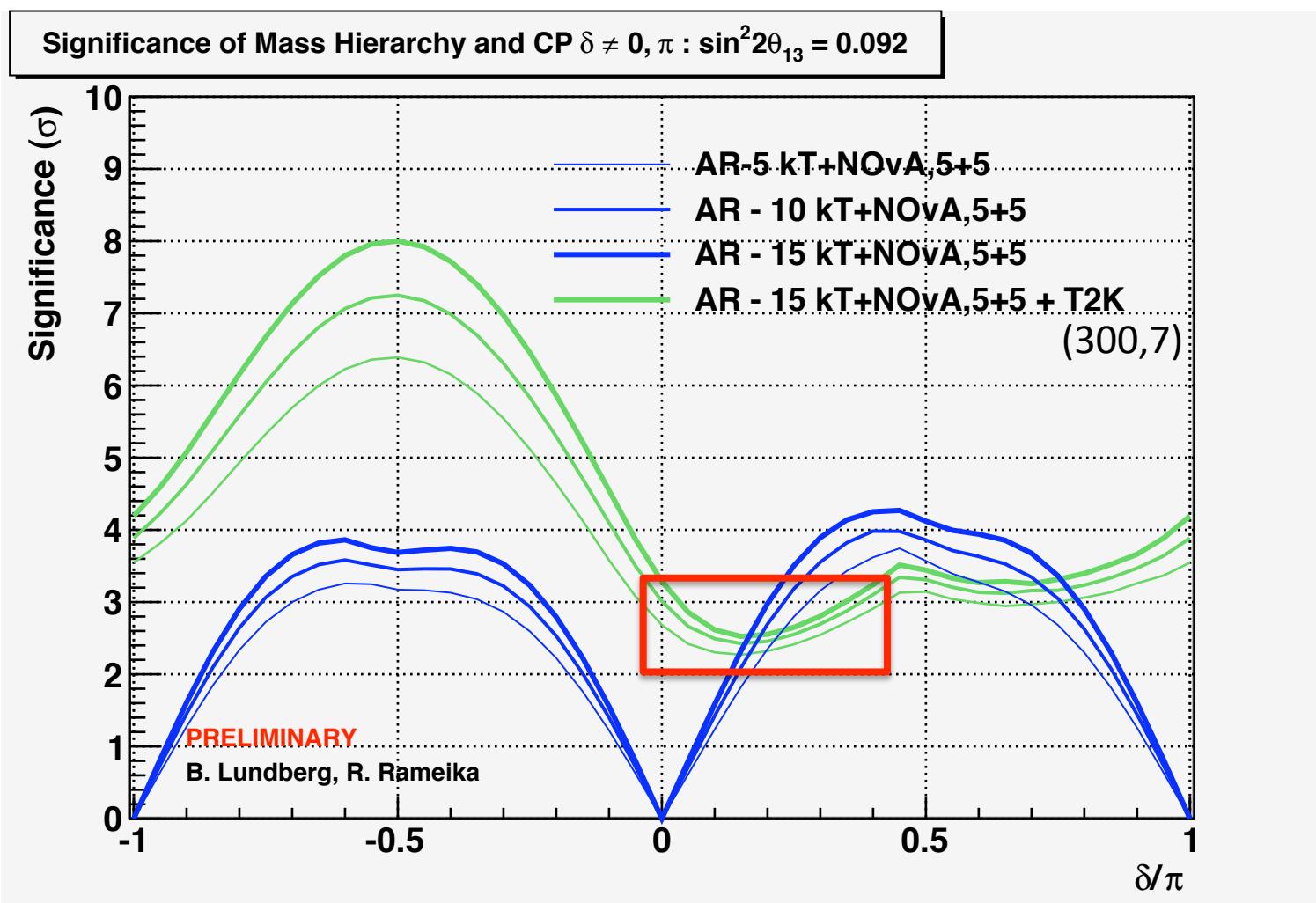


How does T2K help?

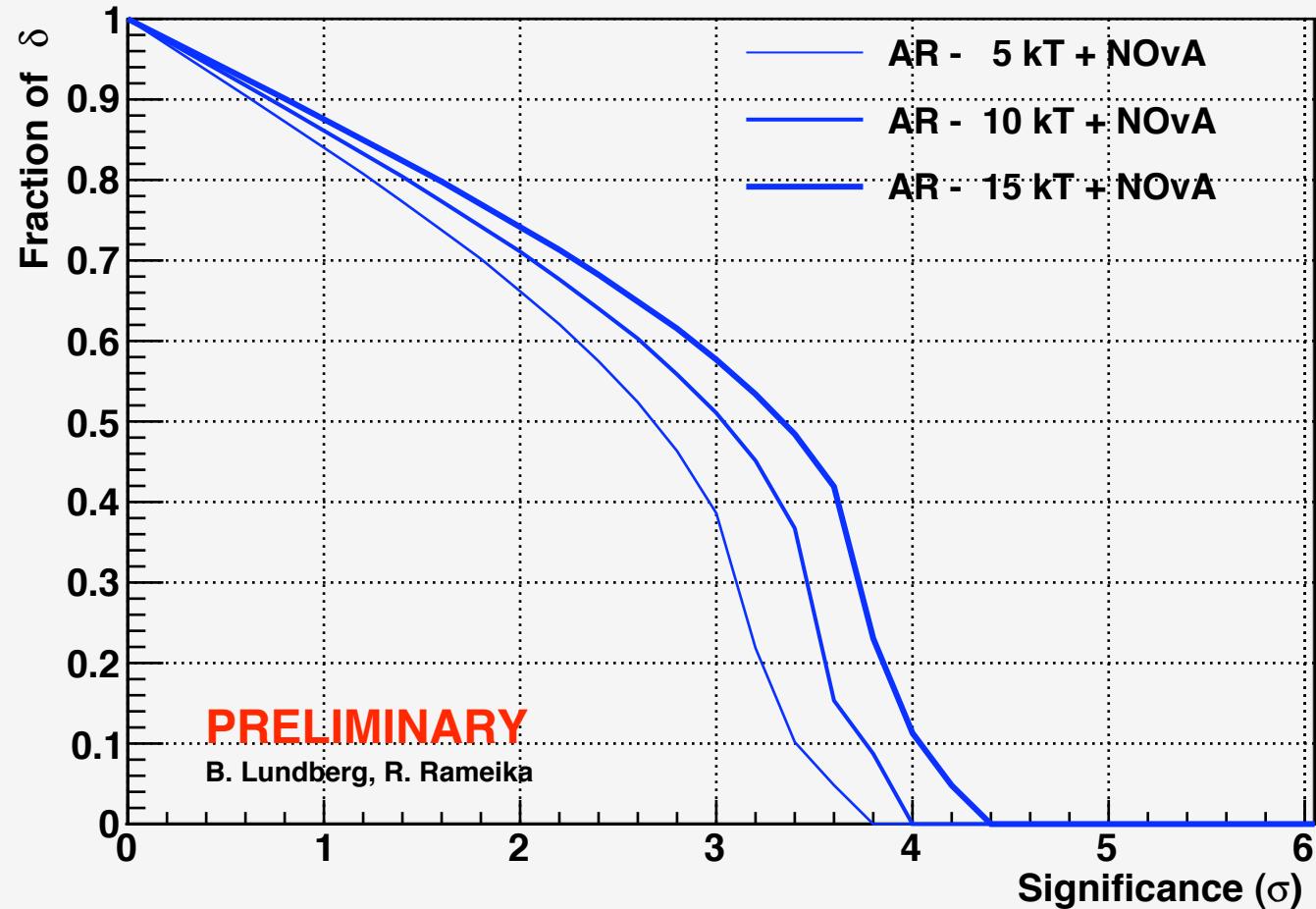




Detectors at Ash River



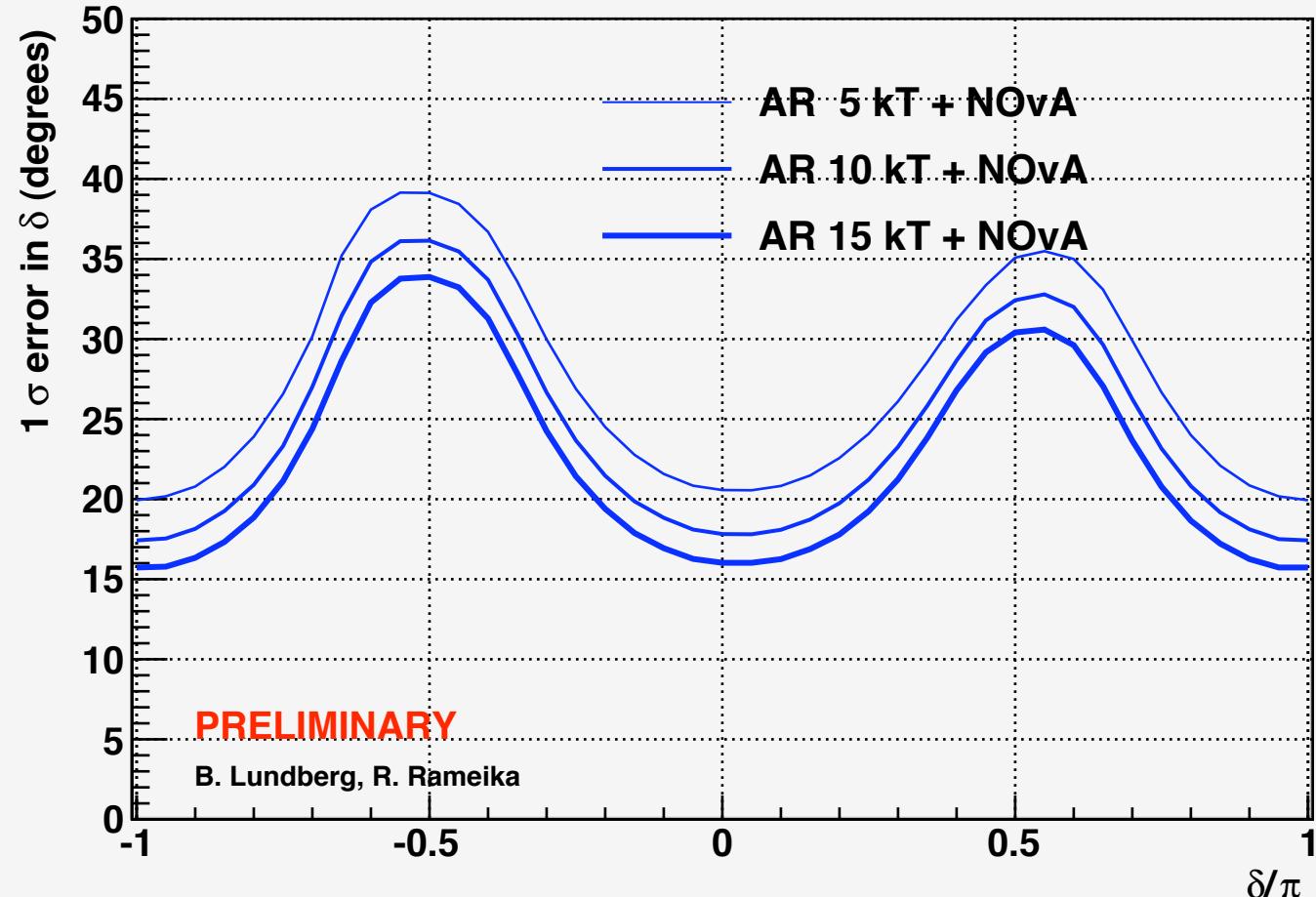
Fraction of δ vs. Significance - $\sin^2 2\theta_{13} = 0.092$



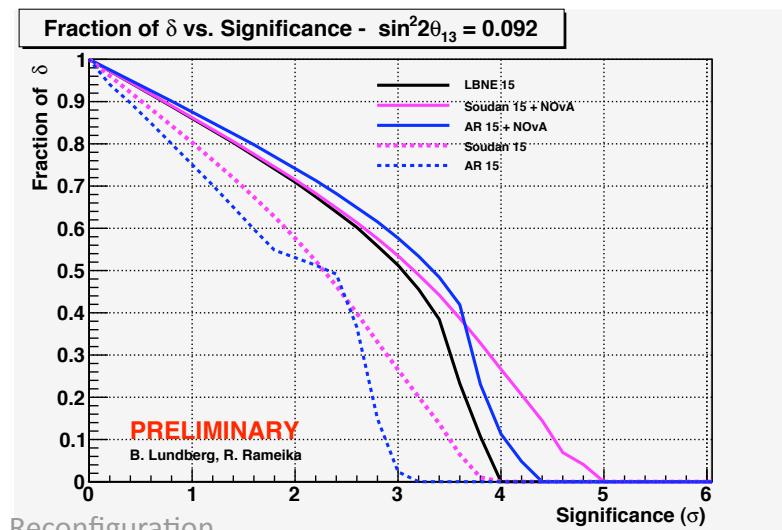
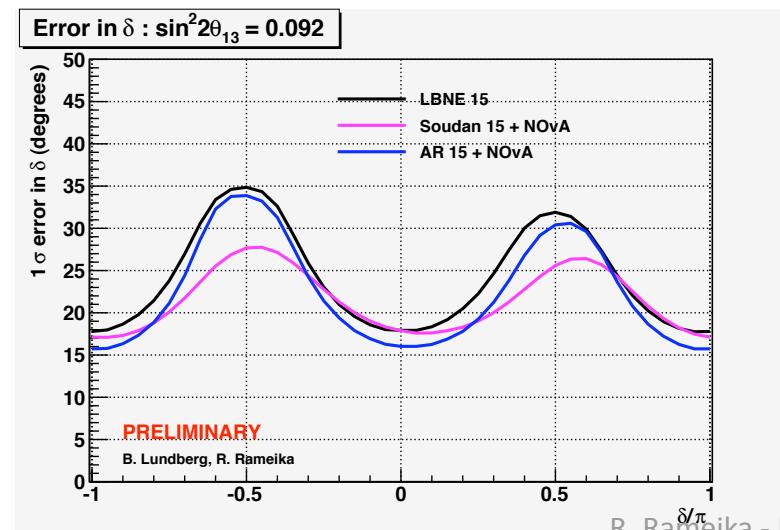
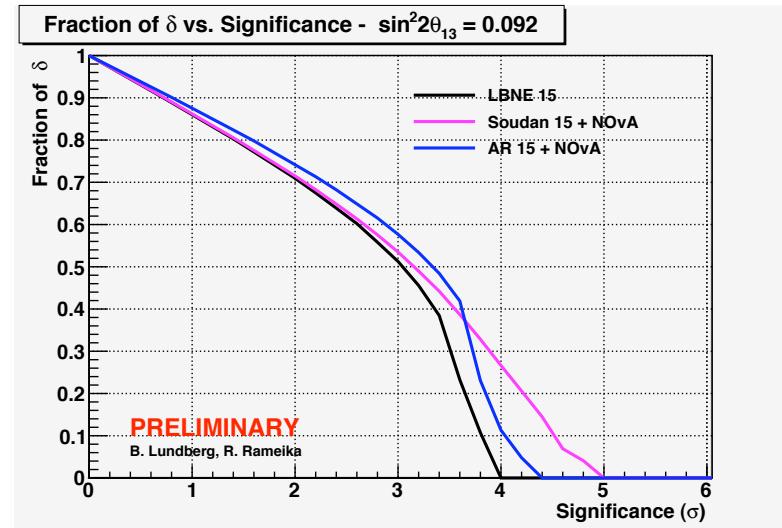
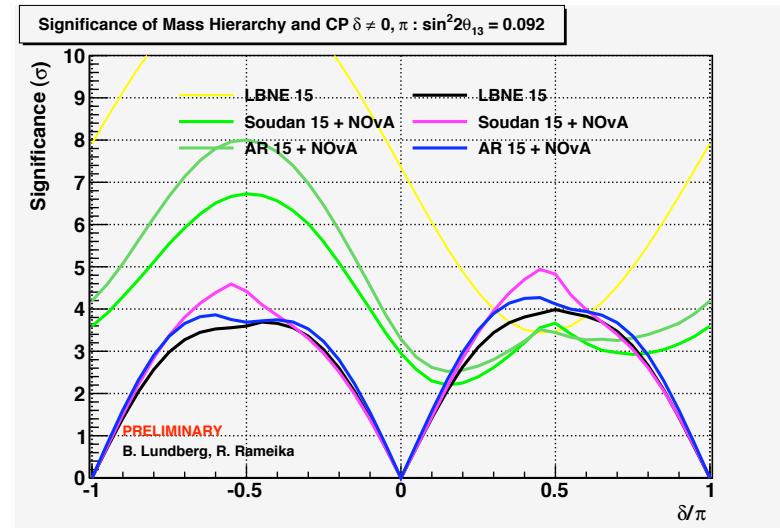
PRELIMINARY

B. Lundberg, R. Rameika

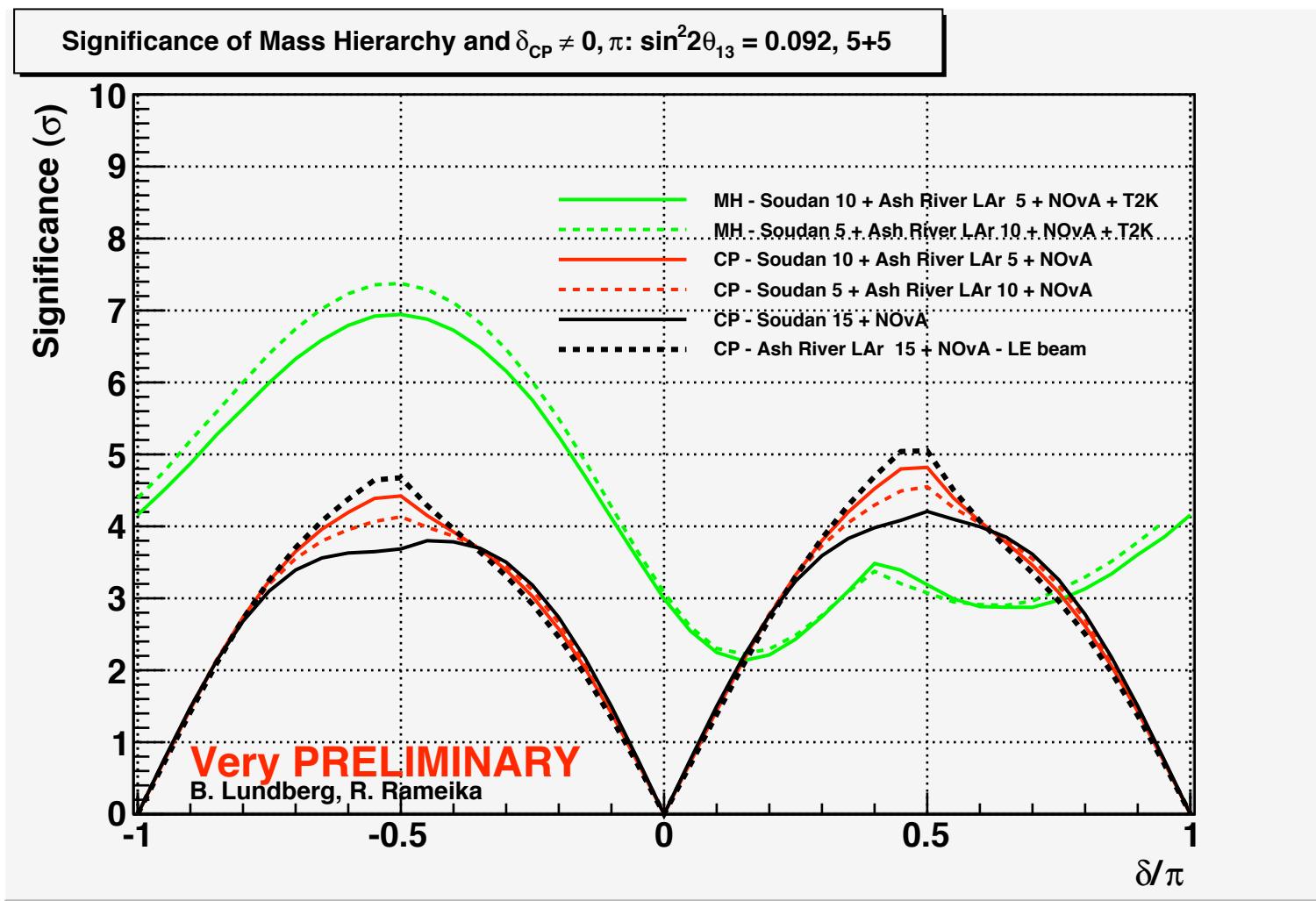
Error in δ : $\sin^2 2\theta_{13} = 0.092$



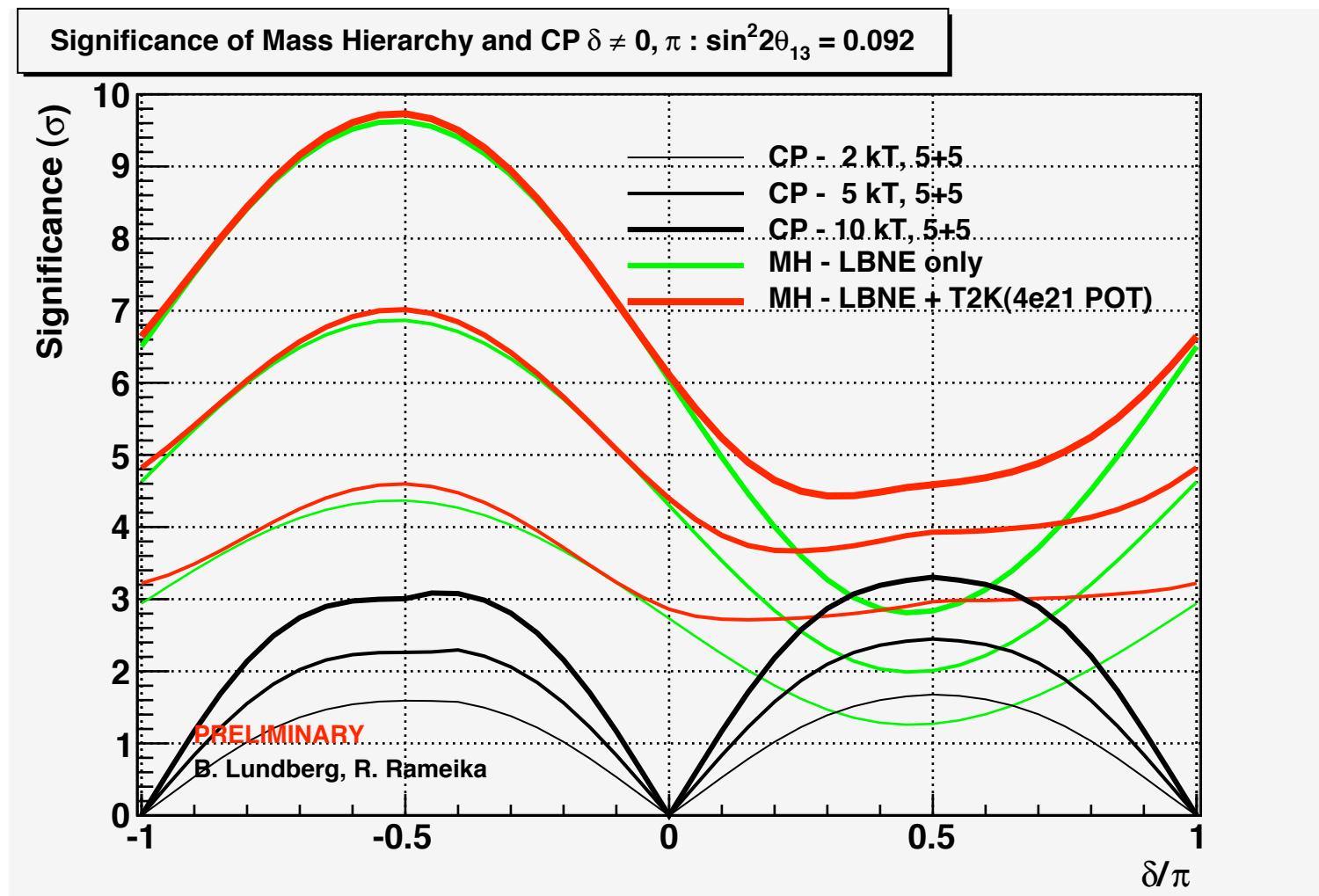
Compare LBNE and NuMI Options



Is there reason/justification for a hybrid NuMI solution?



How would T2K help small LBNE detectors?



Summary

- We have studied the reach in Mass Hierarchy and dcp for :
 - LBNE detectors of 2, 5, 10, and 15 kT
 - Detectors of 5, 10, and 15 kT at 2 sites in the NuMI beam, Soudan and Ash River
 - Exposure for the studies was 10 years, 5+5, nu-nubar, beam power – 700kW (6e20 POT/yr)
- A 10 kT LBNE detector has a minimum significance of 2.8σ for determining the mass hierarchy
- Detectors in the NuMI beam have a limitation of distinguishing the MH in the region $0 < \delta < \pi/2$
- This degeneracy can be mitigated to $\sim 2\sigma$ (95% CL) by including the expected results from T2K
- A NuMI “program” of a new detector plus continued running of the NOvA detector can achieve comparable reach in δ to the smaller LBNE detectors
- Both an LBNE experiment and a NuMI program can measure CP significance of $\sim 3\sigma$ for 50% of δ_{CP} with 15kT (5+5, 700kW)
- 1σ errors in δ are $\sim 15^\circ$ and 35° for $\delta = 0$ and $-\pi/2$, respectively

Summary of Mass Hierarchy Significance

Configuration	σ_{max}	σ_{min}	fod(2σ)	fod(3σ)
NOvA-I (3+3)	3.0	0.3	0.35	0.05
NOvA-I + T2K	3.6	1.5	0.4	0.2
LBNE-2	4.2	1.2	0.68	0.46
LBNE-5	6.8	2.0	0.96	0.7
LBNE-10	9.6	2.8	1.0	0.9
LBNE-15	12.0	3.4	1.0	1.0
LBNE-34	17.7	5.2	1.0	1.0
Soudan-5	5.4	0.6	0.6	0.46
Soudan-10	6.0	0.7	0.68	0.5
Soudan-15	6.4	0.8	0.72	0.52
AR-5	6.0	0.6	0.61	0.49
AR-10	7.0	0.6	0.64	0.53
AR-15	7.8	0.6	0.66	0.55
Soudan-5 + NOVA+T2K	5.9	2.1	1.0	0.6
Soudan-10+NOvA+T2K	6.3	2.2	1.0	0.68
Soudan-15+NOvA+T2K	6.8	2.3	1.0	0.74
AR-5+NOvA+T2K	6.3	2.2	1.0	0.7
AR-10+NOvA+T2K	7.3	2.4	1.0	0.8
AR-15+NOvA+T2K	8.0	2.5	1.0	0.84

Summary of δ_{CP} Significance

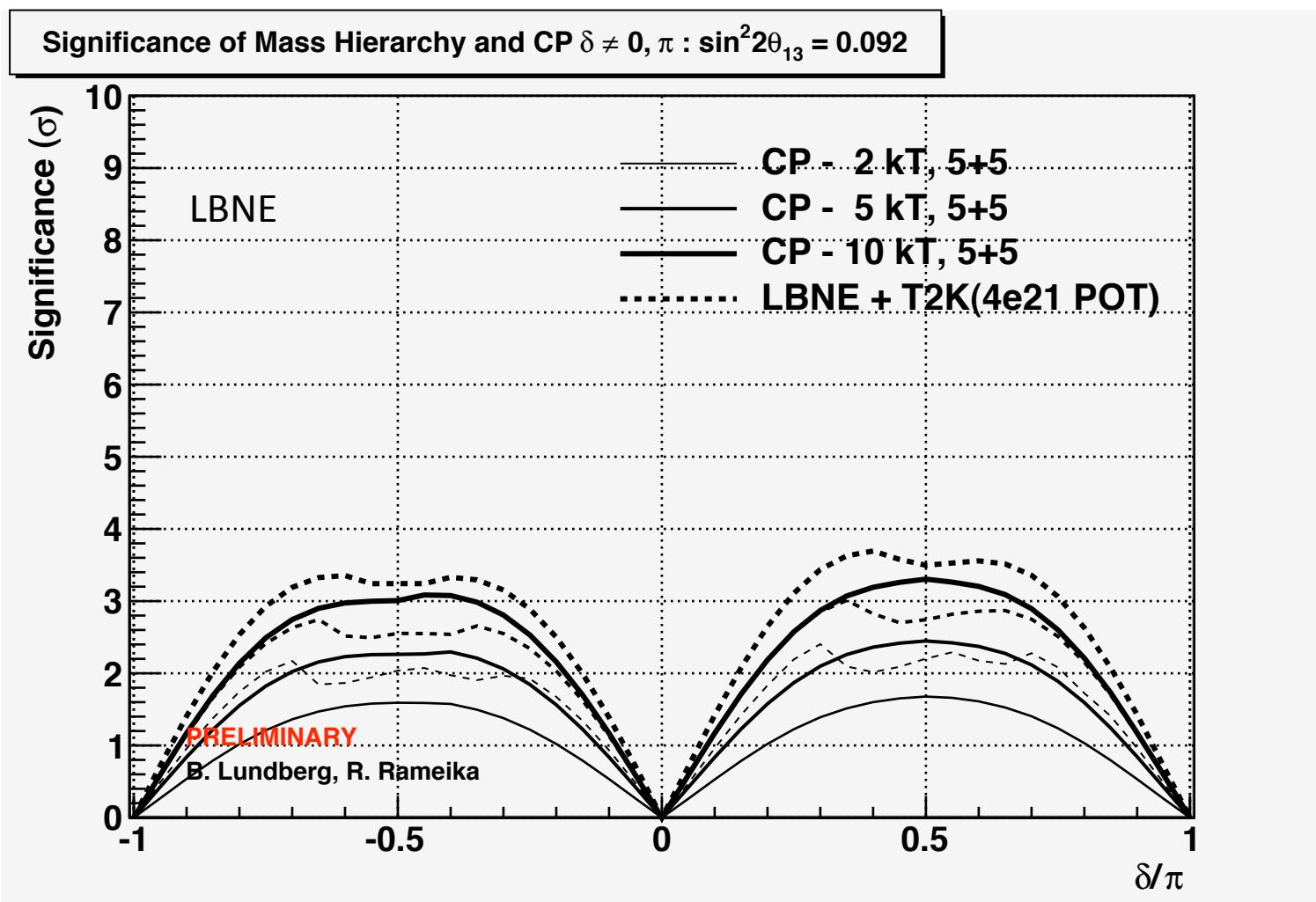
Configuration	fod(2σ)	fod(3σ)	$\Delta\delta_{max}(\text{deg})$	$\Delta\delta(\delta=0)$
NOvA-I (3+3)	N/A	N/A	75	40
NOvA-I + T2K	N/A	N/A	55	20
LBNE-2	0	0	85	50
LBNE-5	0.42	0	56	30
LBNE-10	0.63	0.25	42	22
LBNE-15	0.7	0.5	34	18
LBNE-34	0.8	0.7	22	12
Soudan-5	0.19	0	58	41
Soudan-10	0.47	0.09	43	30
Soudan-15	0.58	0.26	36	25
AR-5	0	0	84	36
AR-10	0.52	0	60	26
AR-15	0.52	0	50	20
Soudan-5 + NOVA	0.65	0.38	35	21
Soudan-10+NOvA	0.69	0.48	31	19
Soudan-15+NOvA	0.72	0.53	27	17
AR-5+NOvA	0.66	0.39	39	21
AR-10+NOvA	0.7	0.5	36	17
AR-15+NOvA	R. Rameika 0.74	0.58	34	16

Summary of Mass Hierarchy Significance

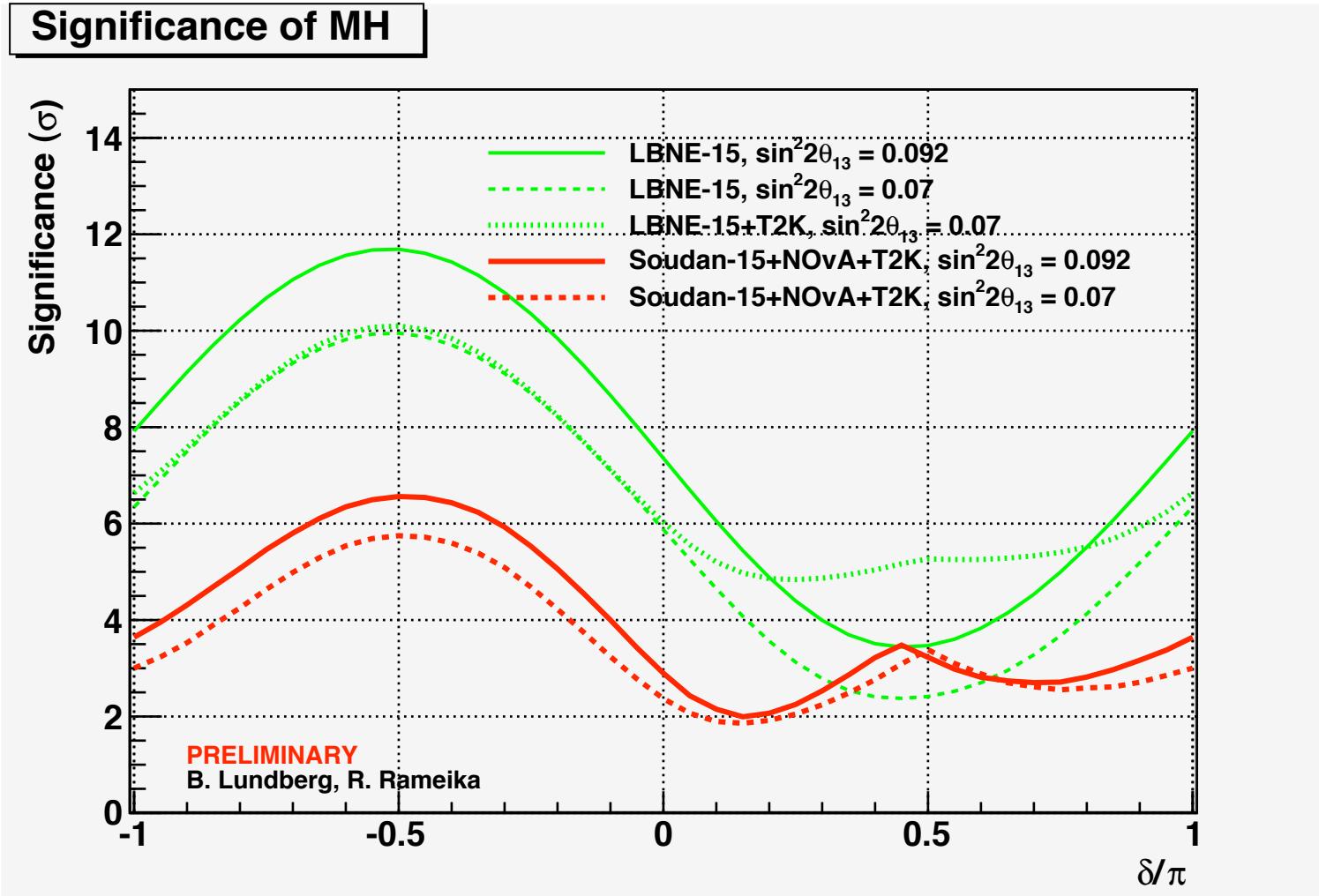
Configuration	σ_{\max}	σ_{\min}	fod(2σ)	fod(3σ)
NOvA-I (3+3)	3.0	0.3	0.35	0.05
NOvA-I + T2K	3.6	1.5	0.4	0.2
LBNE-2 + T2K (4e21)	4.4	2.4	1.0	0.75
LBNE-5 + T2K (4e21)	7.0	3.8	1.0	1.0
LBNE-10 + T2K (4e21)	9.9	4.8	1.0	1.0
LBNE-15 + T2K (4e21)	12.0	5.0	1.0	1.0
LBNE-34 + T2K (4e21)	17.0	6.5	1.0	1.0
Soudan-5	5.4	0.6	0.6	0.46
Soudan-10	6.0	0.7	0.68	0.5
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AR-15+NOvA+T2k	8.0	2.5	1.0	0.84

Back-up

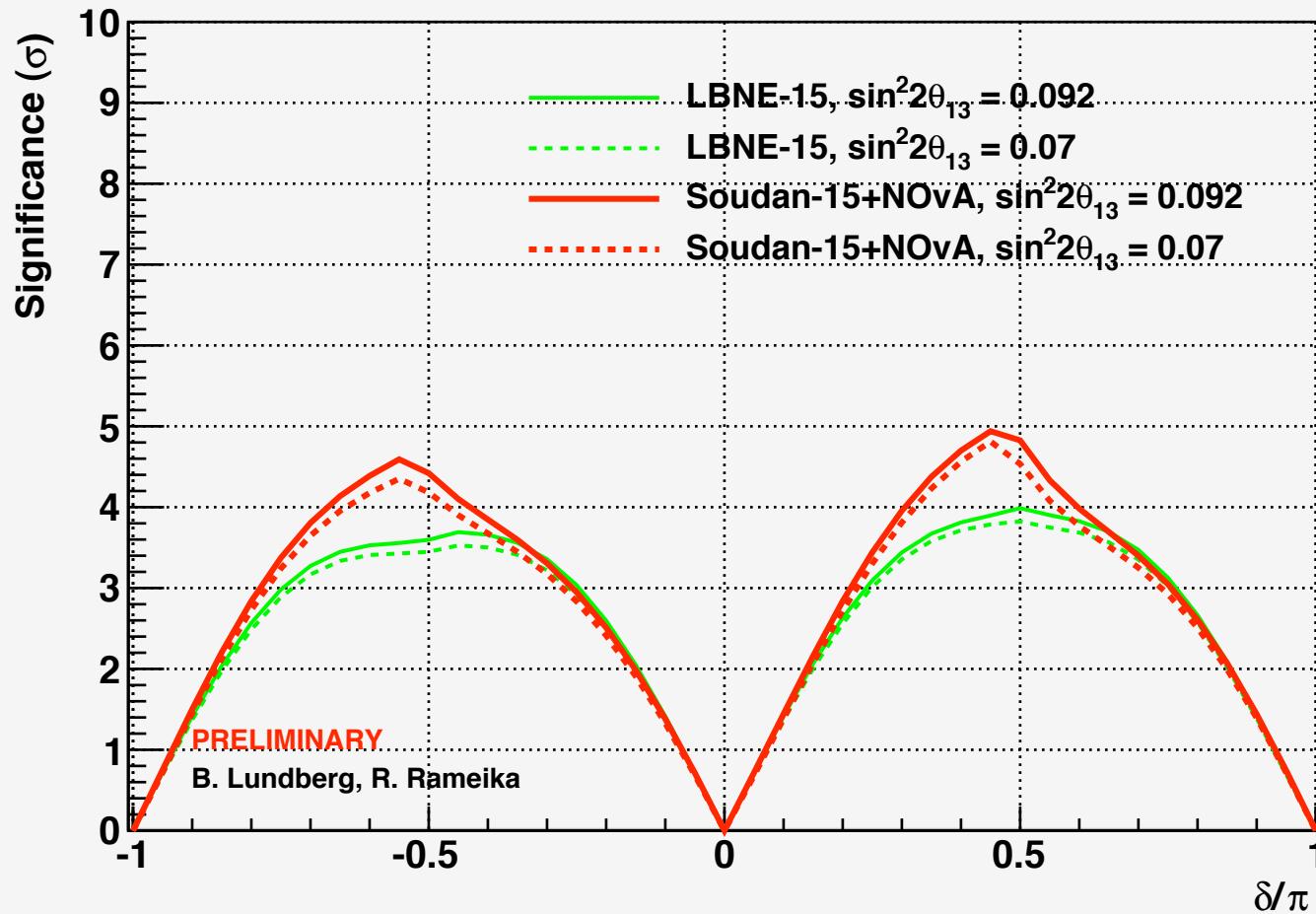
How does T2K help in CP reach?



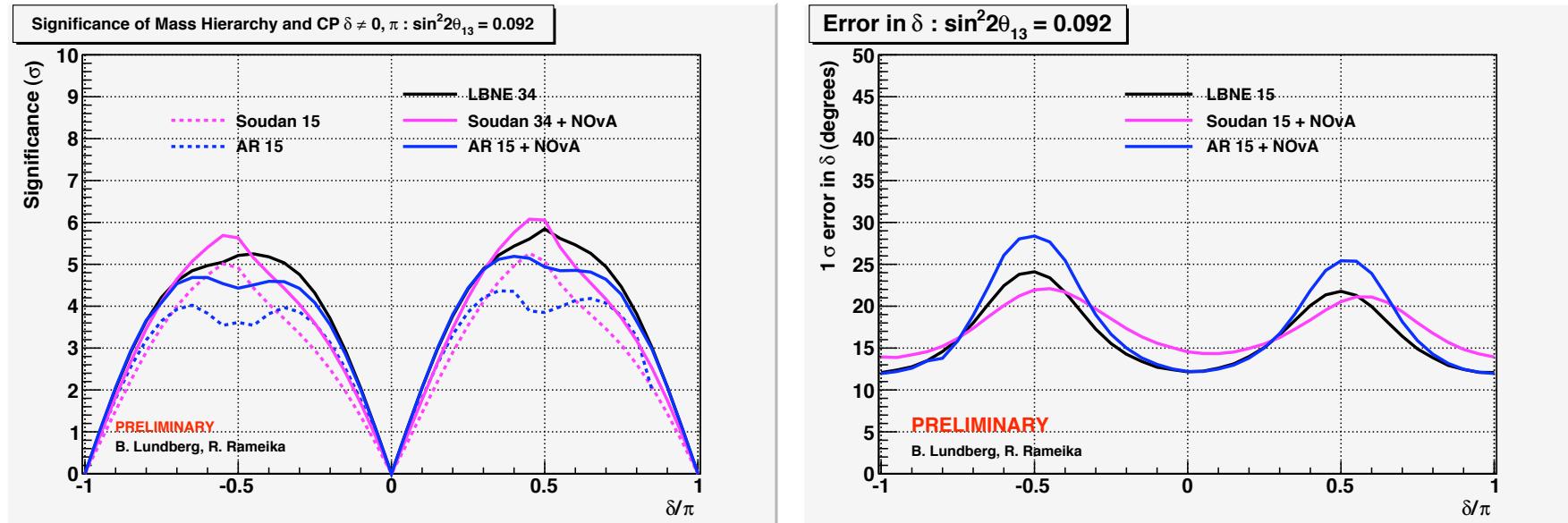
What if $\sin^2 2\theta_{13}$ fluctuates down 2σ



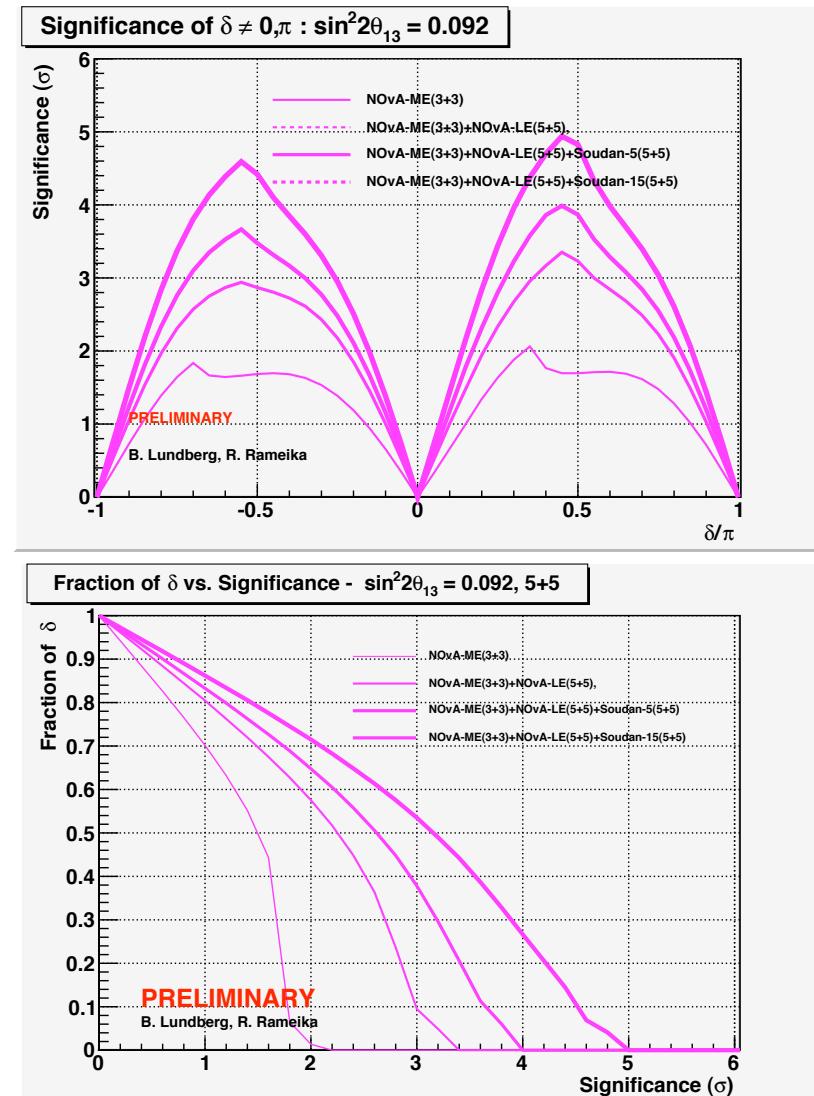
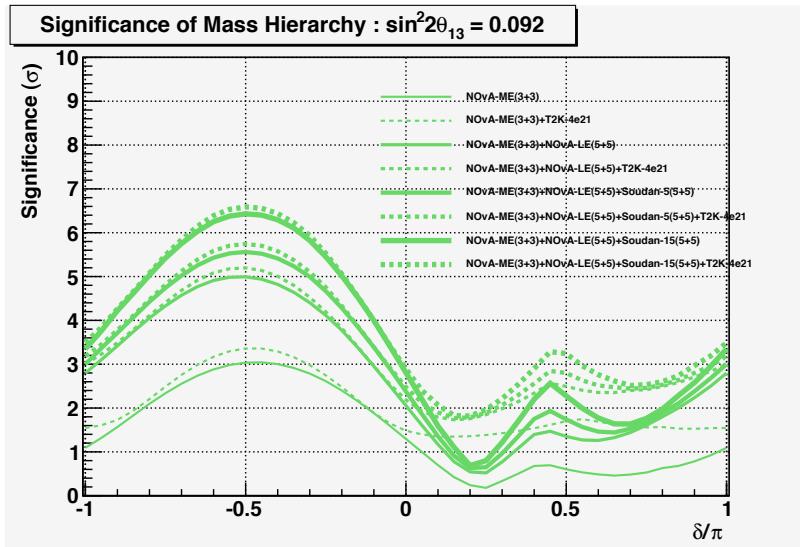
Significance of CP $\delta \neq 0, \pi$



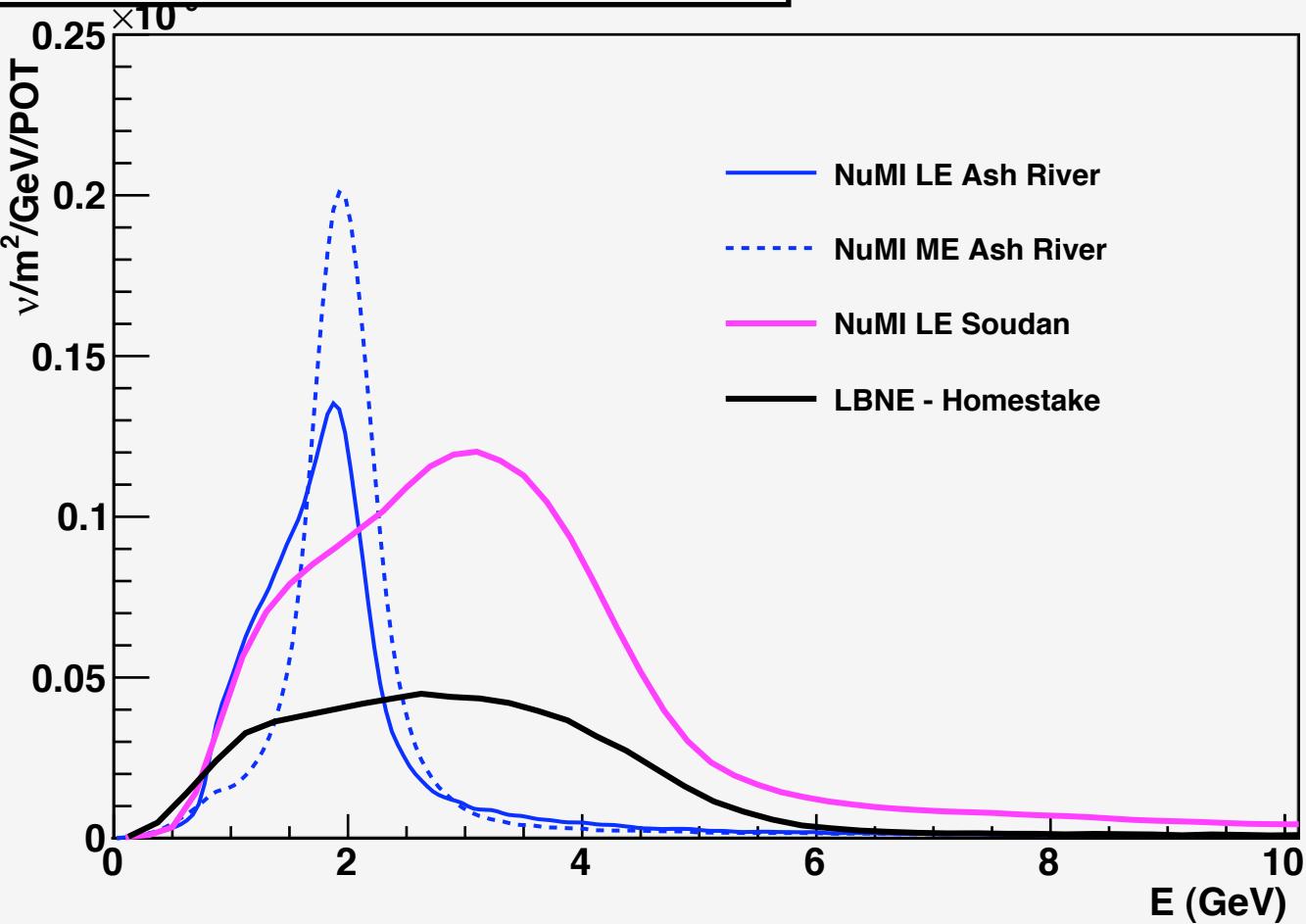
Large Detectors



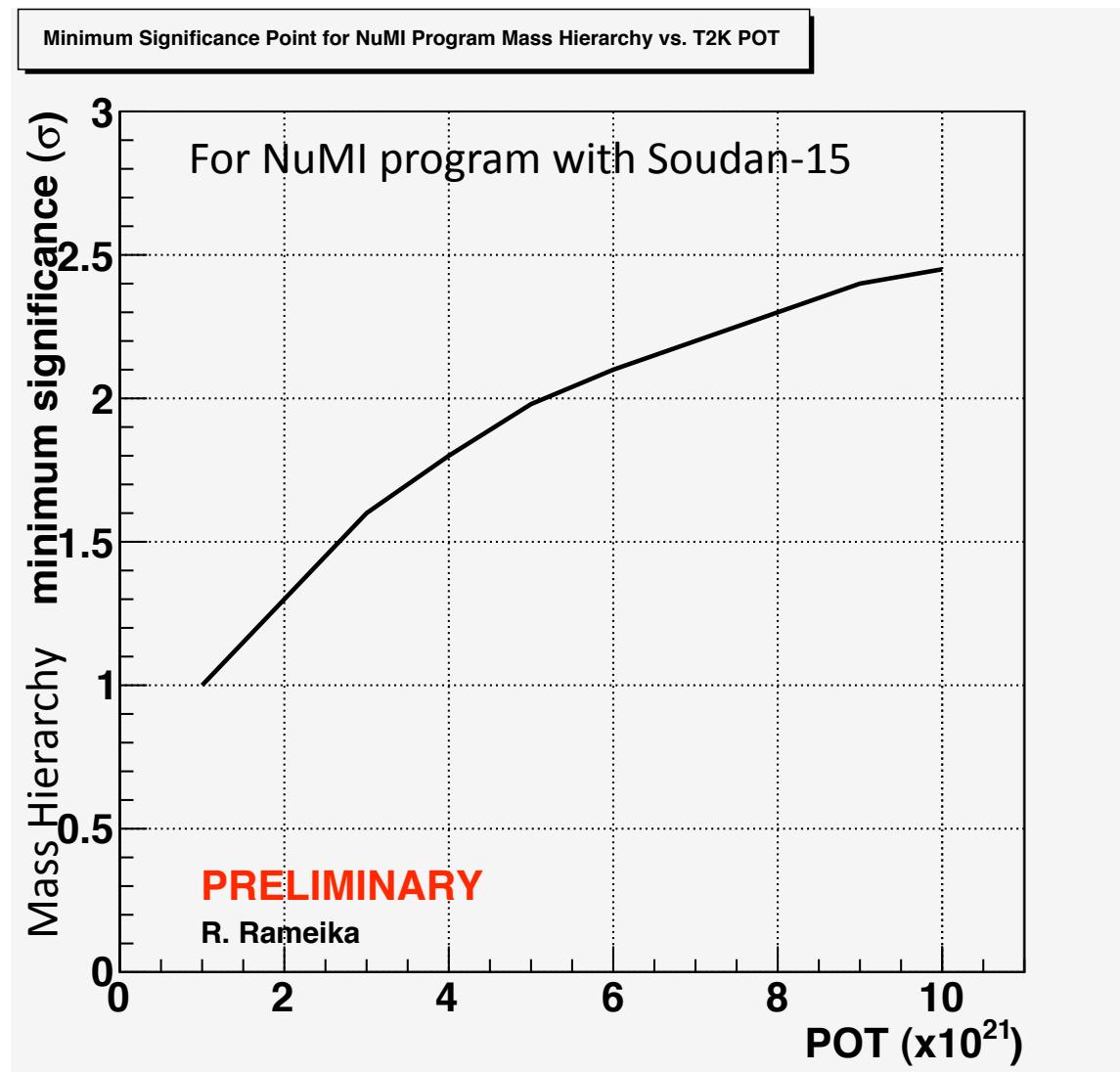
Evolution of a NuMI Program



uninteracted non-oscillated ν_μ flux



Input from T2K



Definition of CP Significance

At a given value of δ Significance is defined as the number of standard deviations, d, from $\delta = 0$ or π (whichever is smaller)

Standard deviation (d) is defined as finding d with :

$$\Delta\chi^2 = \chi^2(\delta) - \chi^2(\delta + \sigma) = 1.0$$

MH Ambiguity at 735km

Animation – will not work in .pdf

— IH
..... NH $\pi/4$

