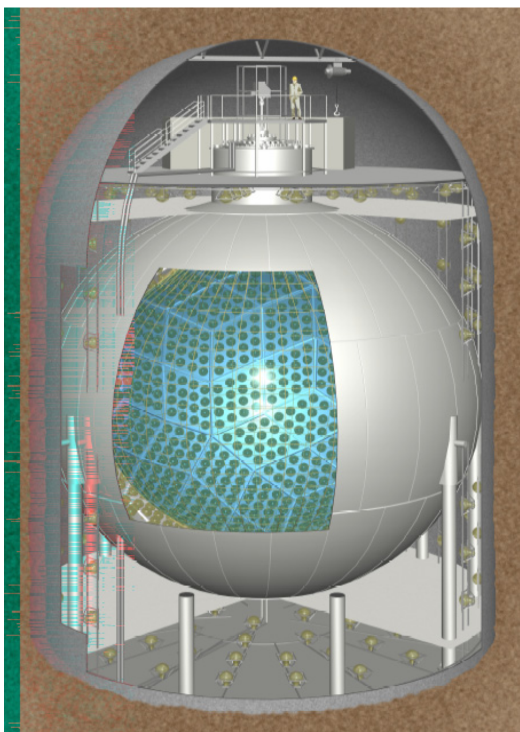
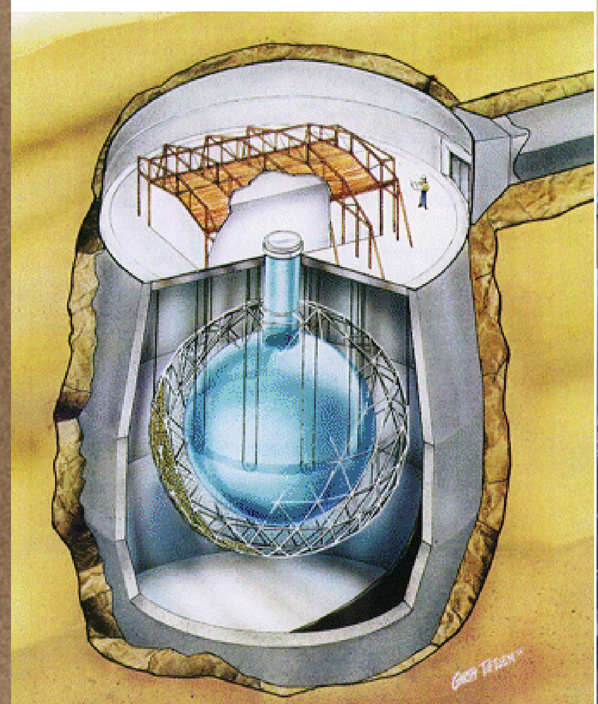
Long baseline experiments (JJ) + strategy of future neutrino experiments

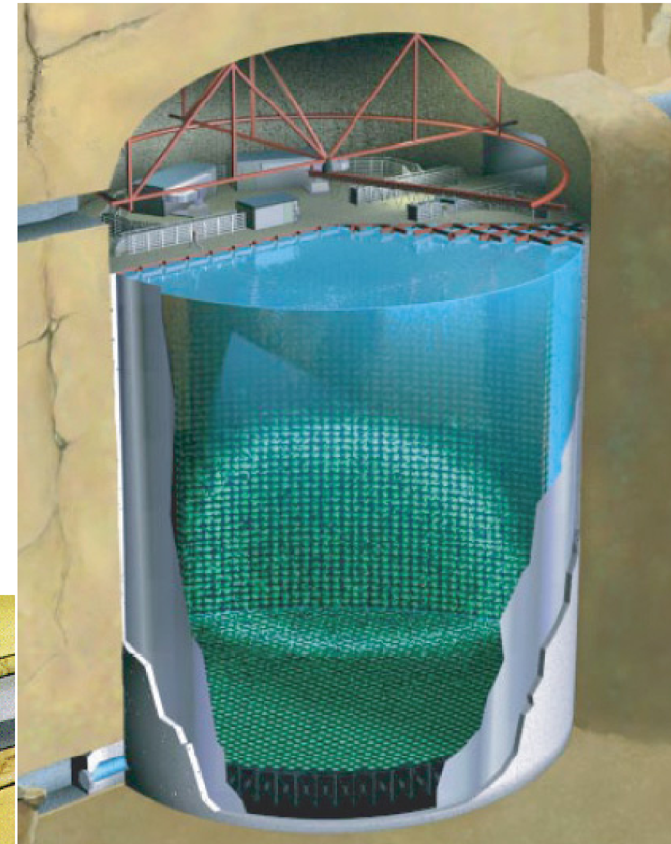
Hisakazu Minakata

Tokyo Metropolitan University

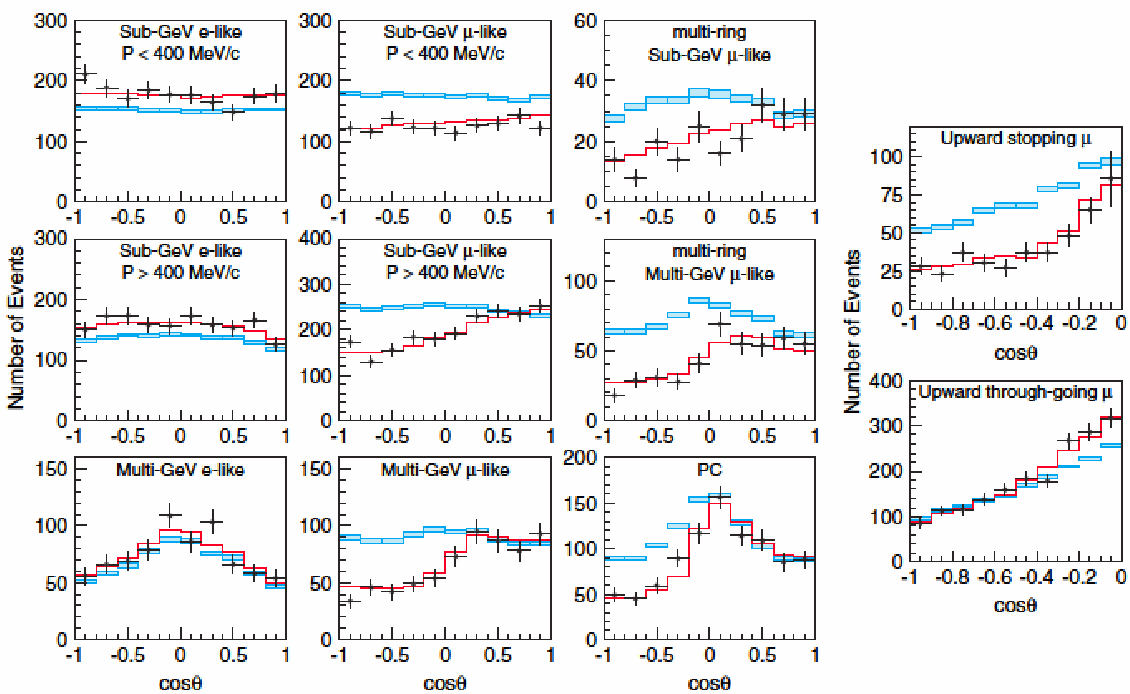
In the last several years we have experienced the most exciting era in physics

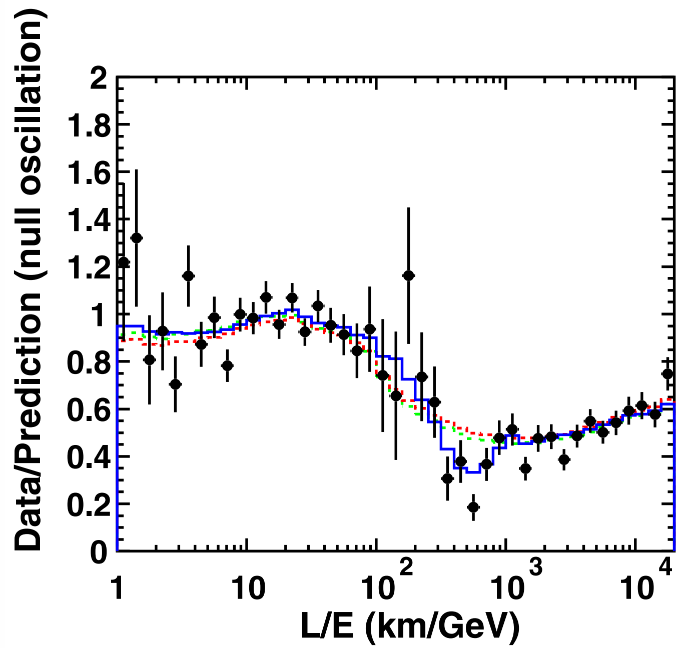


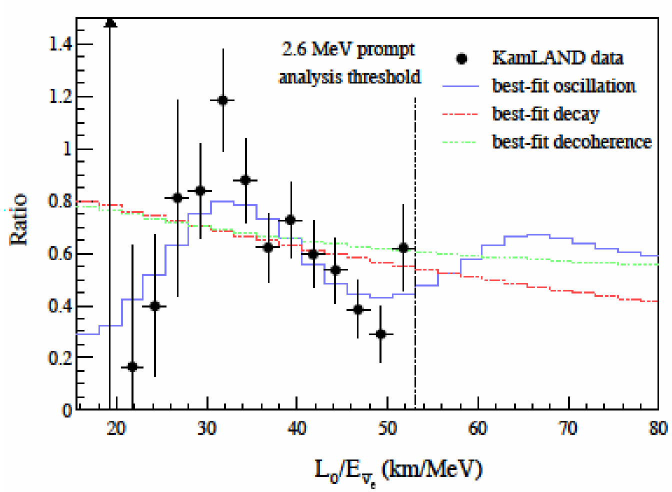


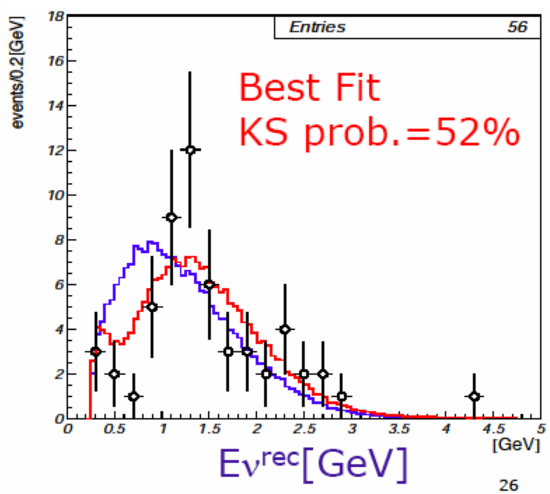


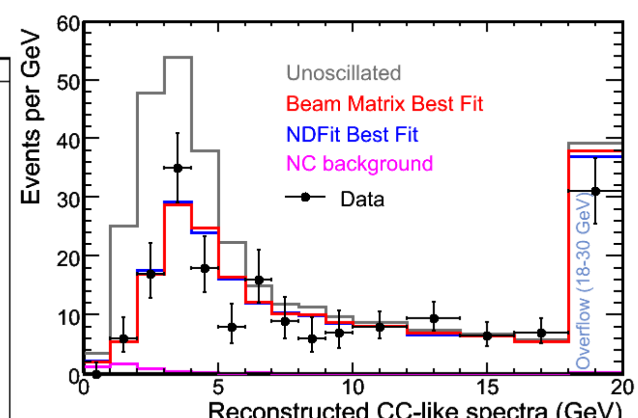
oscillation has been seen!





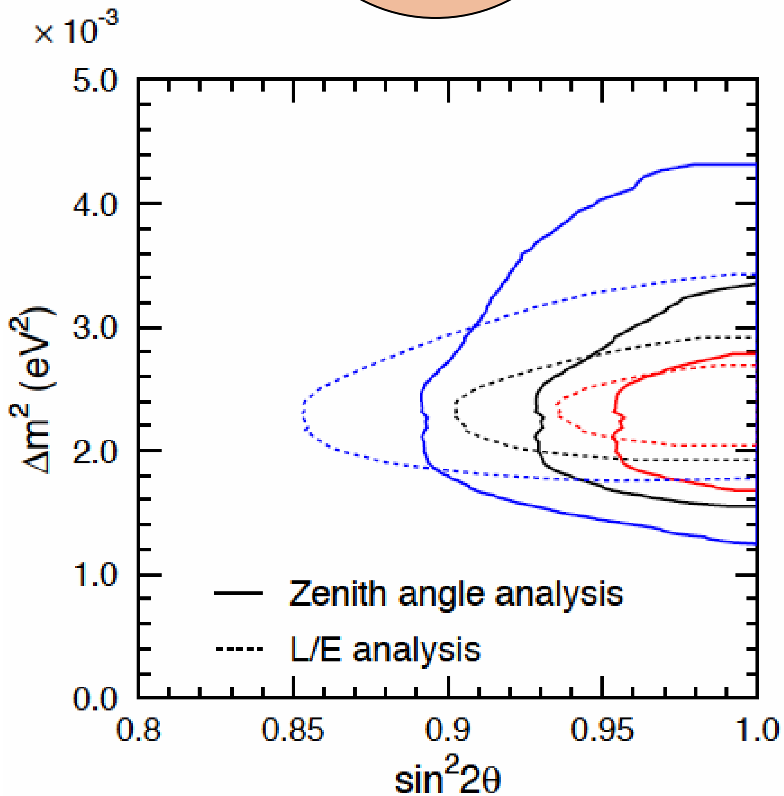


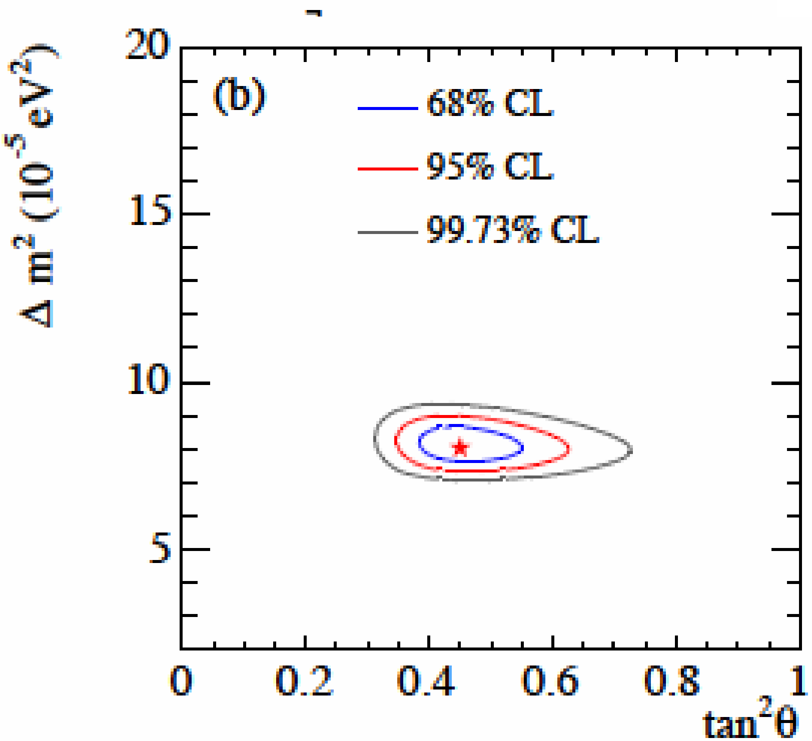




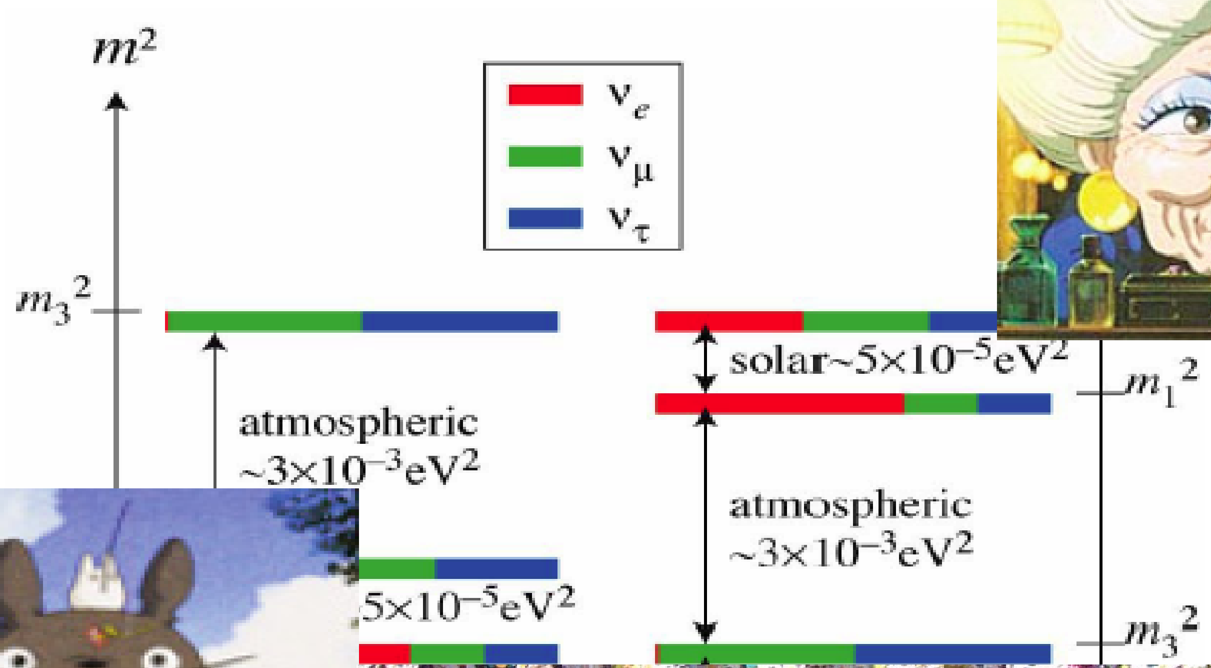
MNS matrix and mass pattern

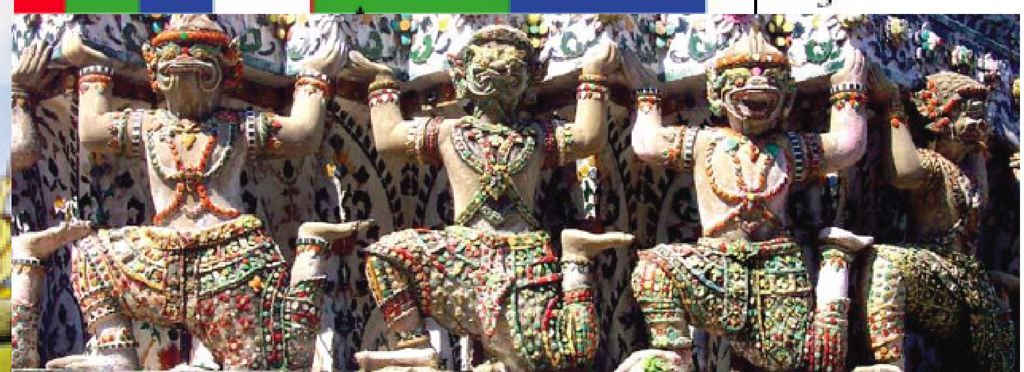
$$U \equiv U_{\rm MNS}\cdot\Gamma = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \times {\rm diag}(1, e^{i\beta}, e^{i\gamma})$$





mass hierarchy & absolute mass scale





Pressing questions

- Origin of masses and mixing
- Large lepton mixing vs. small quark mixing
- Quark lepton symmetry/relationship incl. flavor symmetry
- How to determine remaining parameters?…

Need for some strategic thoughts?

1. How to detect nonzero $_{13}$
2. How to measure CP violation phase
3. A coupled problem; CPV-mass hierarchy

13 first

To measure $_{13}$ one needs $_{e}$

- P($_{e}$ -> $_{e}$) is the interference between

e->1 -------> 1->e and e->2 -------> 2->e

e->3 -------> 3->e

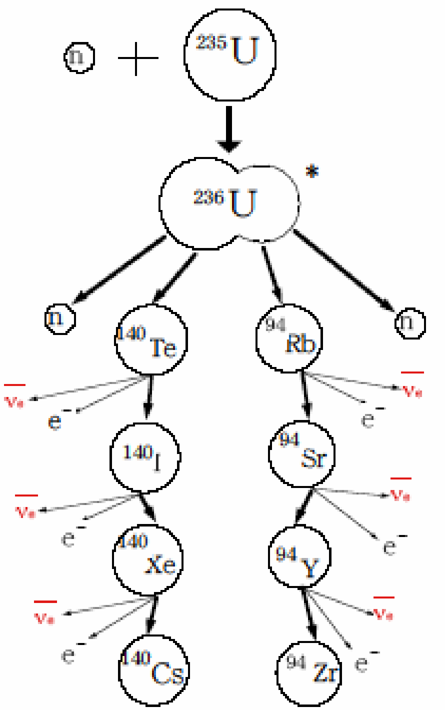
- P(-> $_{e}$) is the interference between

->1 -------> 1->e and ->2 -------> 2->e

->3 -------> 3->e

Reactor neutrino experiments

Reactor $\bar{\nu}_e$



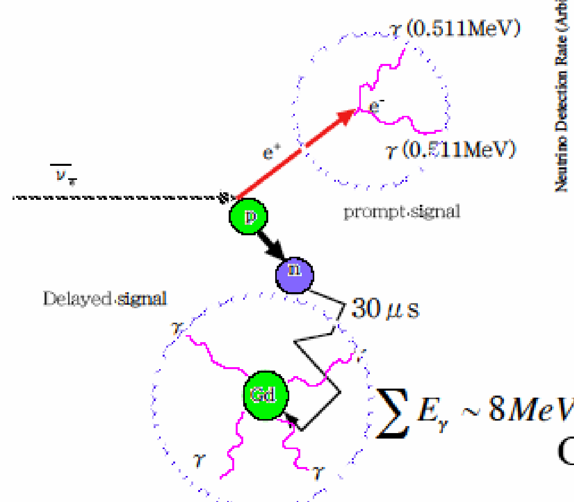
~6ν/fission & ~200MeV/fission

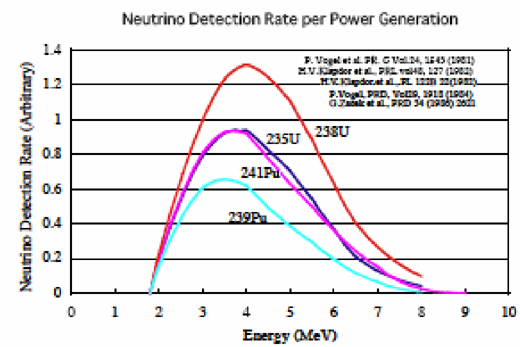
⇓

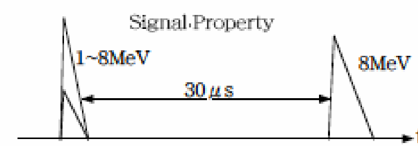
$\sim 6\times10^{20}\,\bar{\nu}_e\,/\,s\,/\,reactor$ (1GWe)

$\bar{\nu}_e$ Detection

(Most of the proposed project uses Gd-LS)







Gd => largest n absorption σ & emits high energy γs.

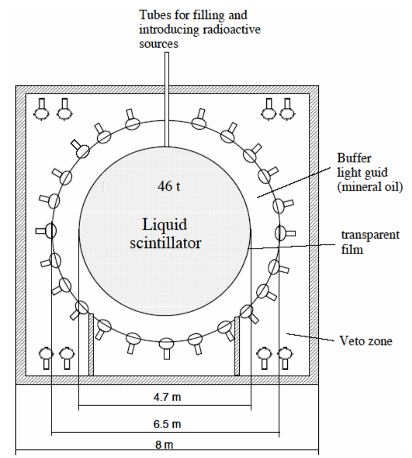
Delayed Coincidence

=> Background is severely suppressed

Reactor measurement of 13

$$1 - P(\bar{\nu}_e \to \bar{\nu}_e) = \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + O(\epsilon s^2_{13}) + O(\epsilon^2)$$

$$\epsilon \equiv \Delta m^2_{21}/\Delta m^2_{31} \simeq 0.03$$



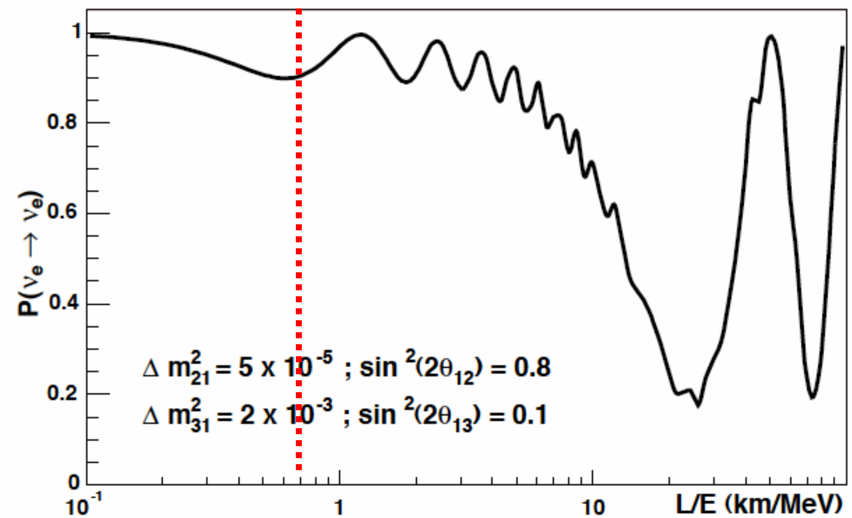


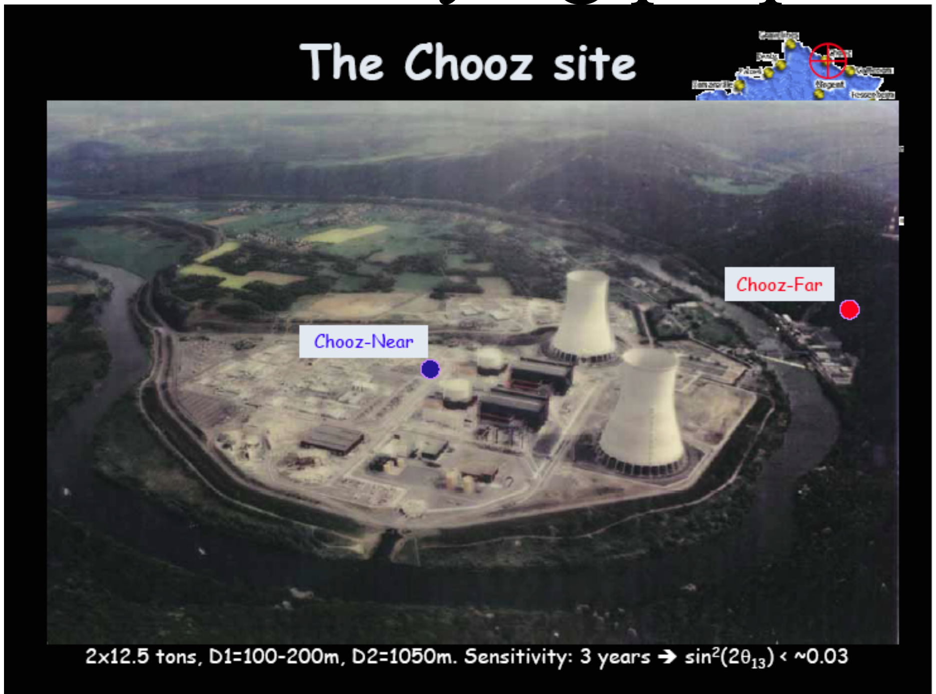
Figure 3: Probability of ν_e disappearance versus L/E for θ_{13} at its current upper limit

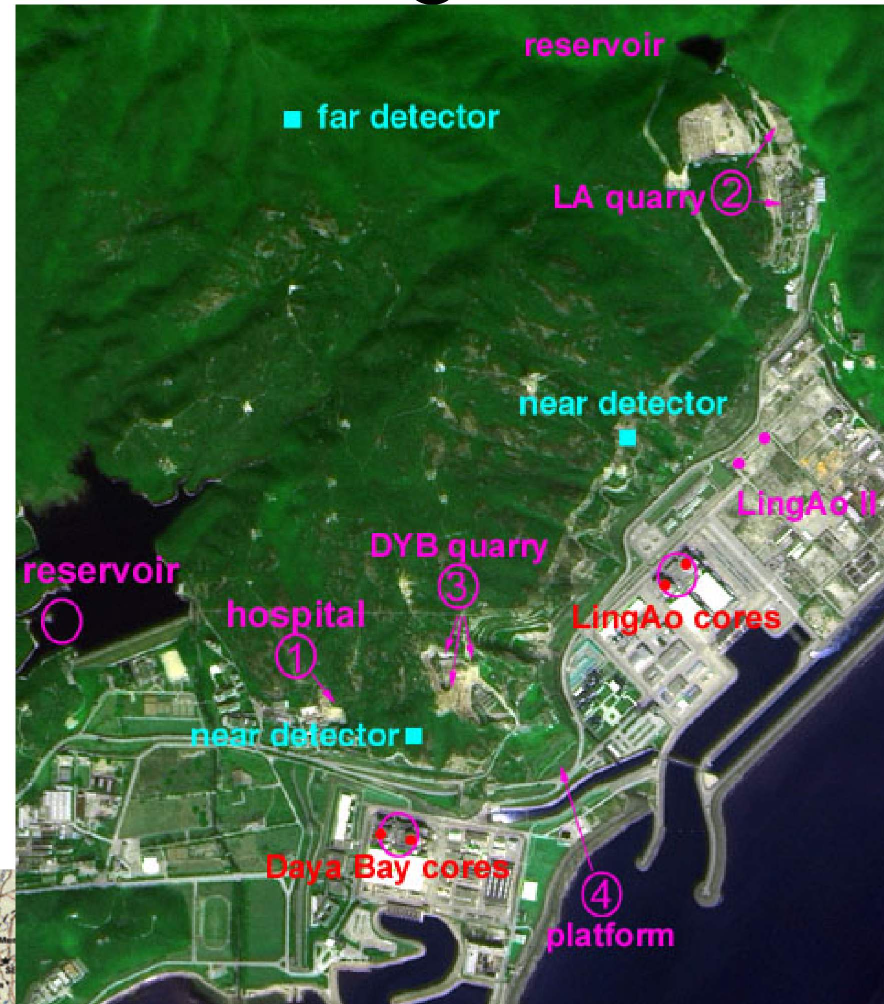
- Independent of ,
  matter effect, 23, 12,
  solar m^2

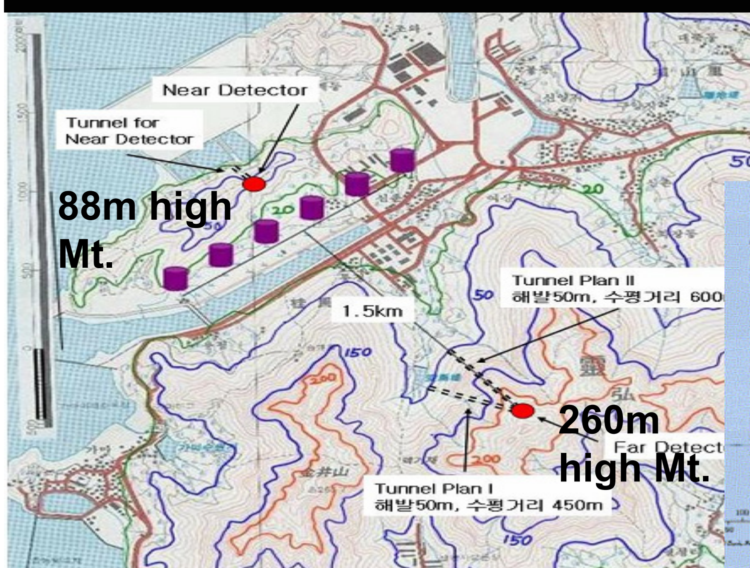
=> Pure measurement of

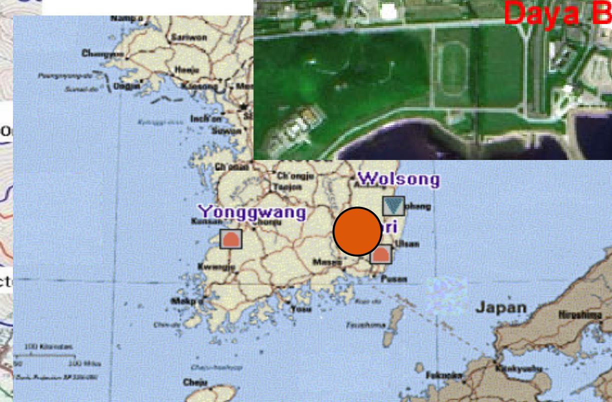
13

Varying proposals over the globe









LBL measurement of $_{13}$ (<= JJ)

$$P(\nu_\mu \to \nu_e) = |\sqrt{P_{atm}} + e^{i\left(\delta \pm \frac{\Delta_{31}}{2}\right)}\sqrt{P_{solar}}|^2$$

$$P_{atm} = \left(s_{13} s_{23} \Delta_{31} \frac{\sin\left(\frac{\Delta_{31} \mp aL}{2}\right)}{\left(\frac{\Delta_{31} \mp aL}{2}\right)} \right)^2$$

$$P_{solar} = \left(c_{12} s_{12} c_{23} \Delta_{21} \frac{\sin\left(\frac{aL}{2}\right)}{\left(\frac{aL}{2}\right)} \right)^2$$

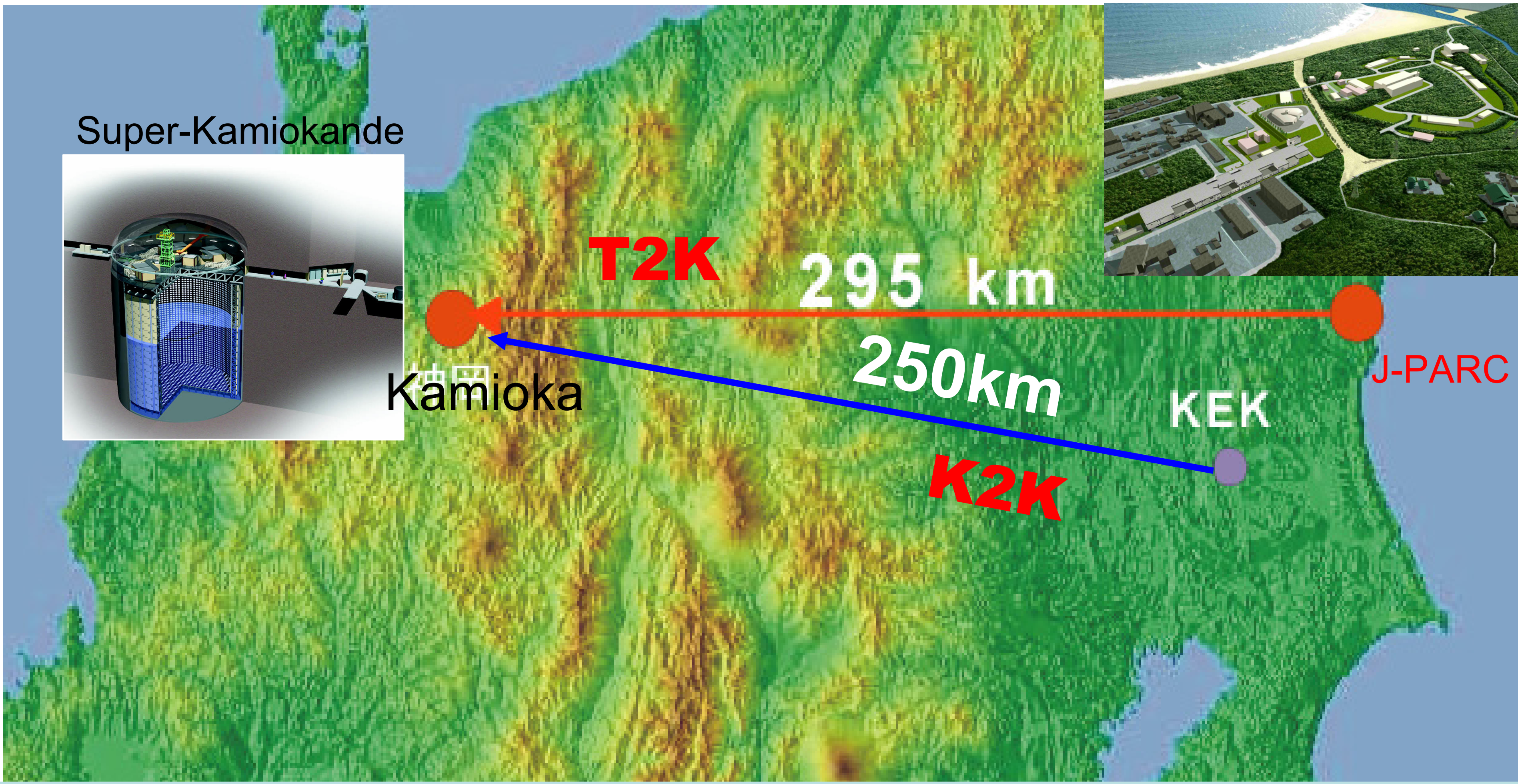
$$\Delta_{31} \equiv \frac{|\Delta m^2_{31}| L}{2E}, \quad a = \sqrt{2} G_F N_e(x),$$

$$\pm = \text{sign of } \Delta m^2_{31}$$

Slides come from:

- Takaaki Kajita @NOW2006 (Otoranto, Italy) for T2K and
- Mark Messier @2nd Korean Detector Workshop (Seoul, Korea)

T2K Phase-I

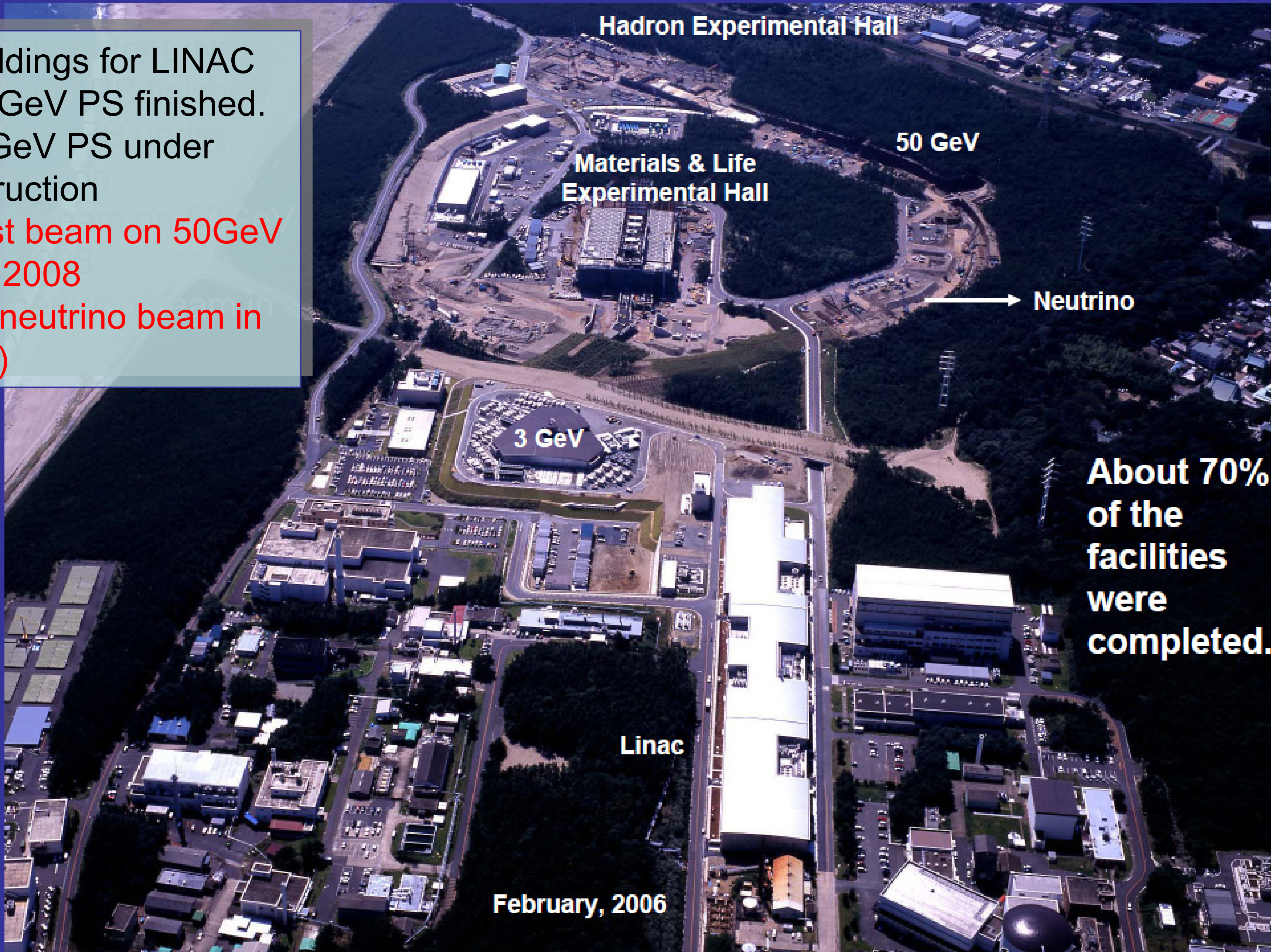


Collaboration (at present): Canada, France, Germany, Italy, Japan, Korea, Poland, Russia, Spain, Switzerland, UK, USA

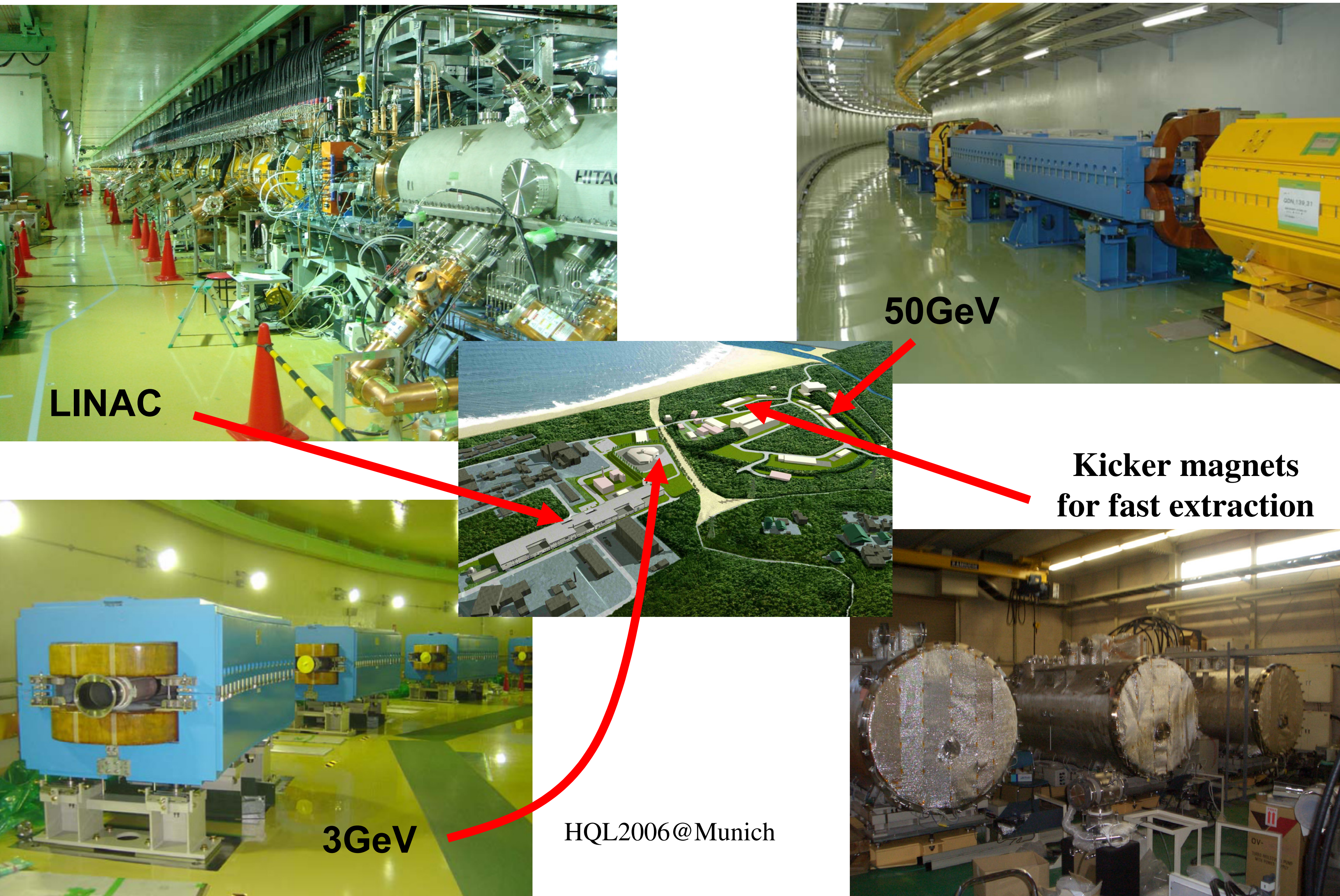
For details: I. Kato' talk

Status of J-PARC construction

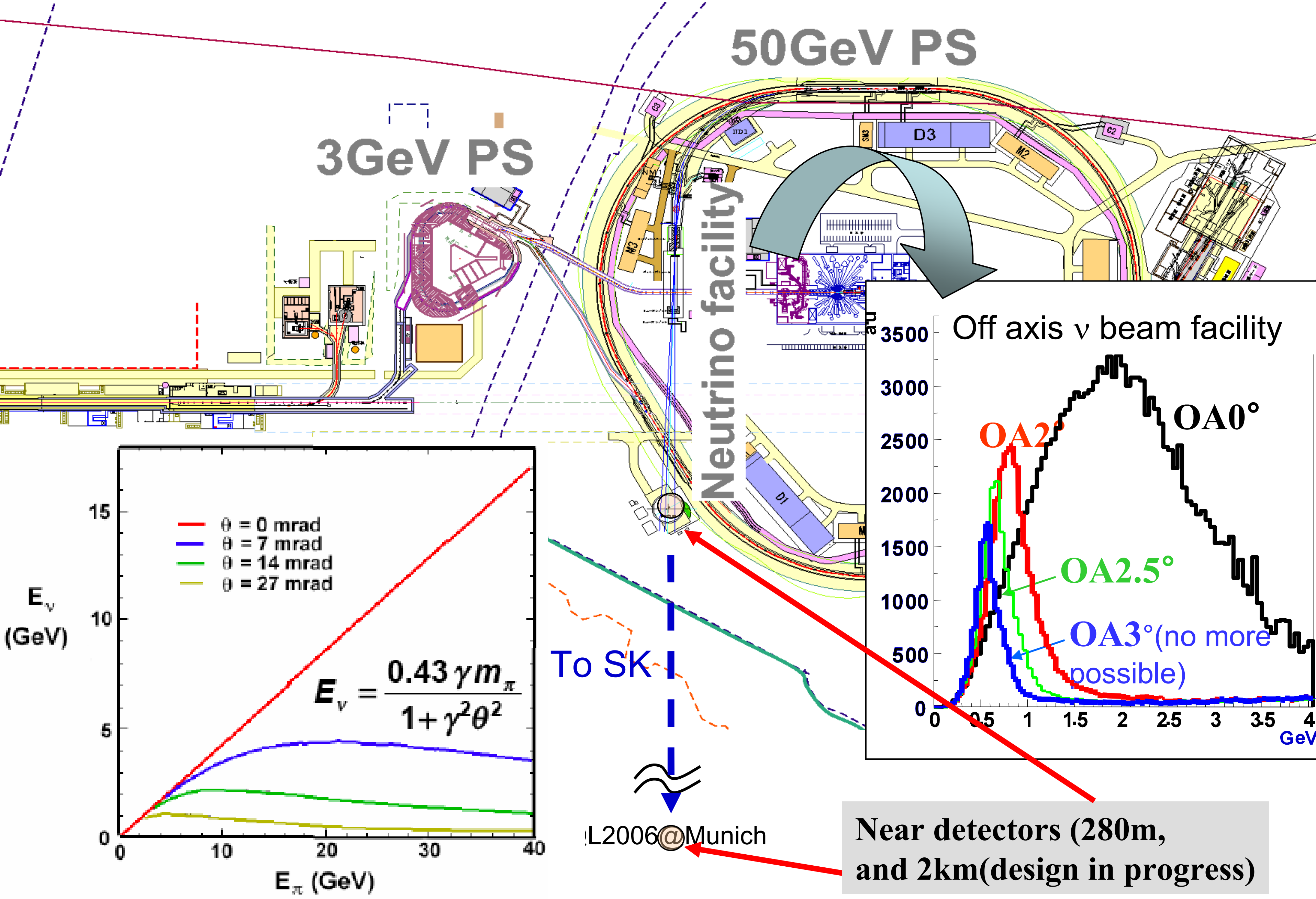
- ➔Buildings for LINAC and 3GeV PS finished.
- ➔50GeV PS under construction
- ➔First beam on 50GeV PS in 2008 (First neutrino beam in 2009.)



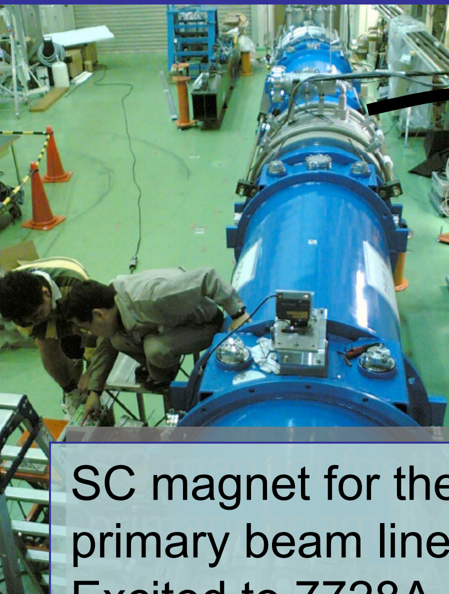
Installation of Accelerator components



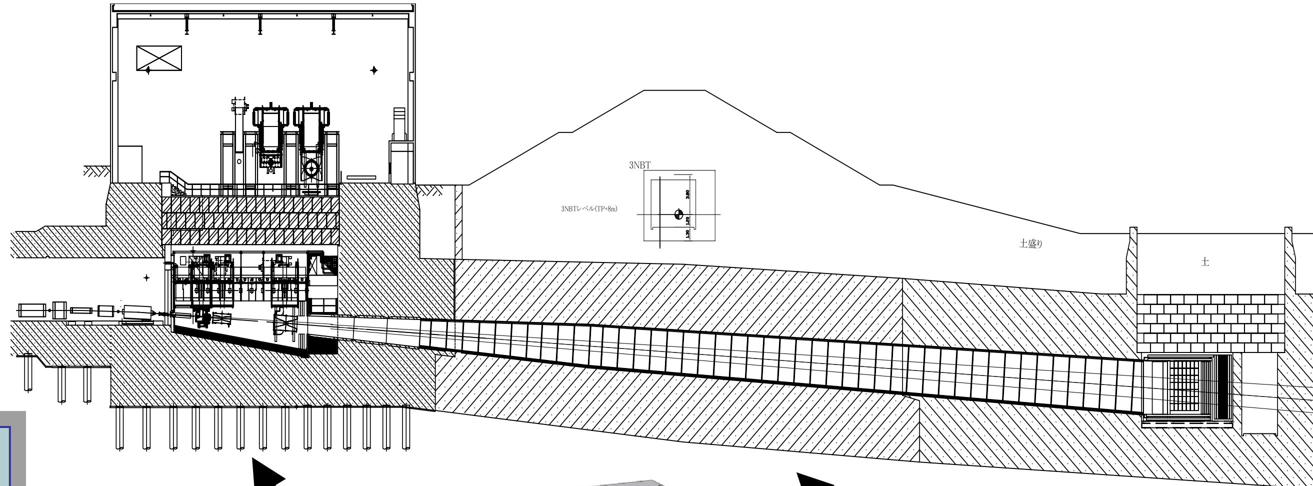
T2K neutrino facility

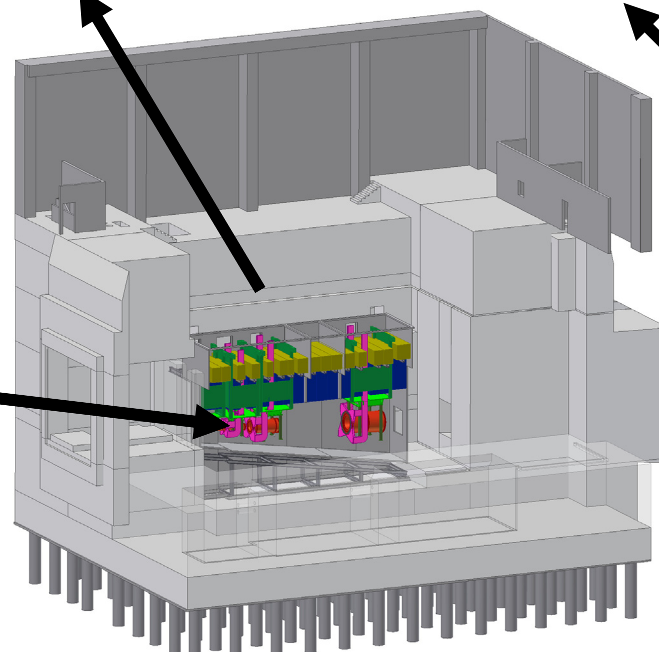


Neutrino beam line construction

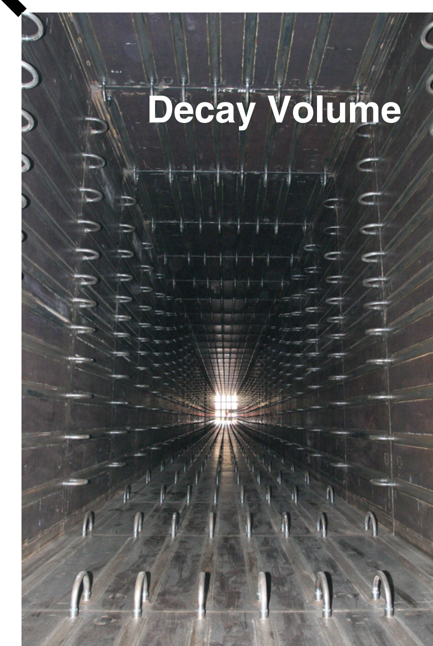


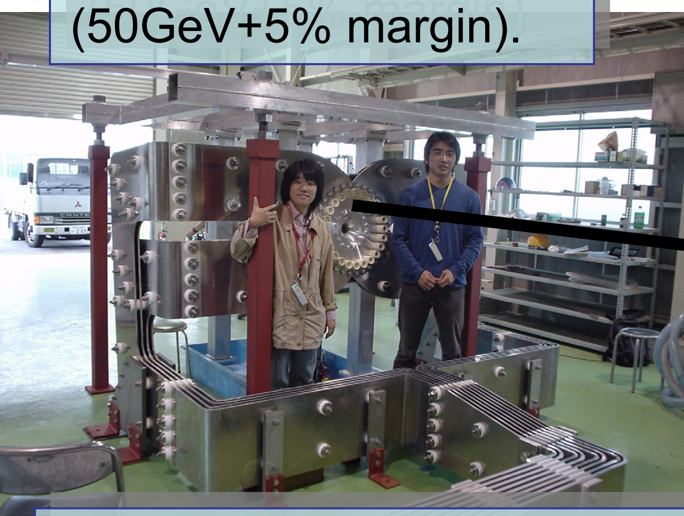
SC magnet for the primary beam line.
Excited to 7728A
(50GeV+5% margin).





Designing the target station

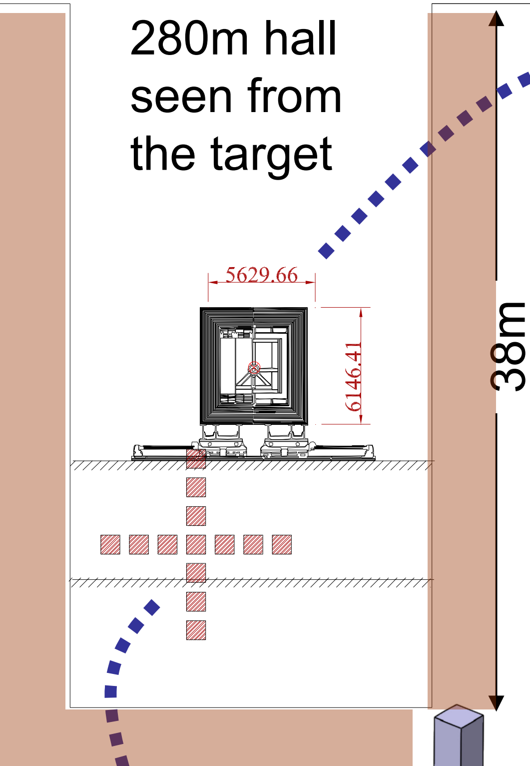




1st horn plot type.
Test with 320KA successful.

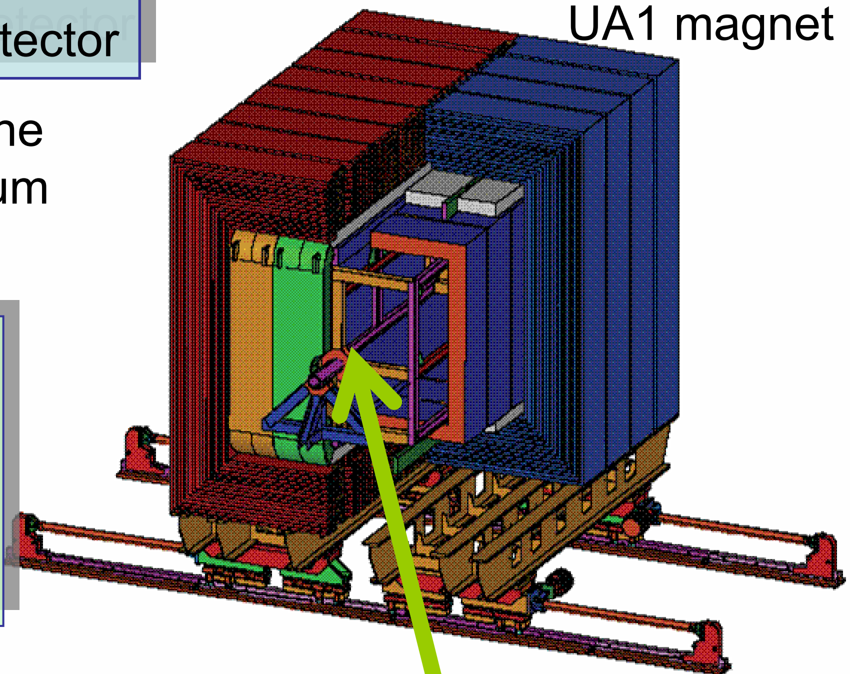
Near Detectors @ 280m

280m hall seen from the target

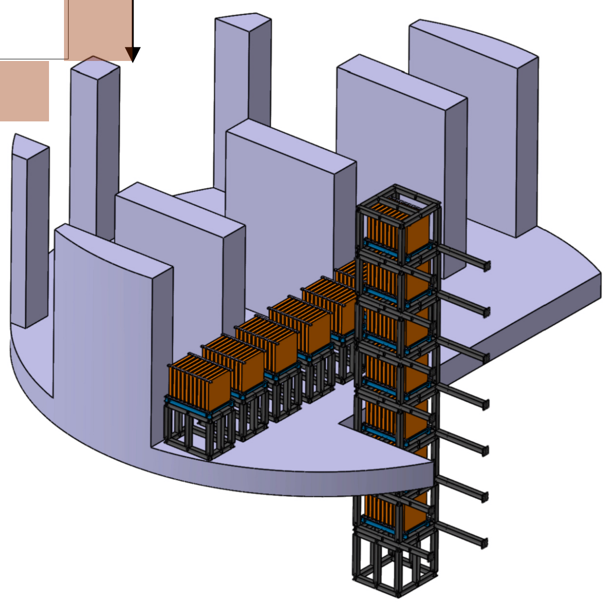


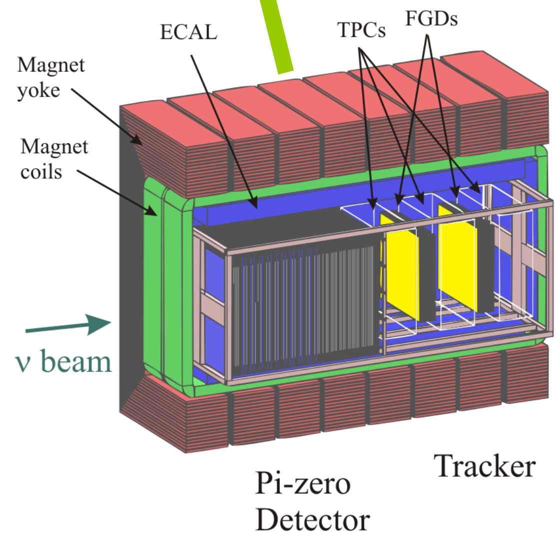
Off-axis detector

To predict the flux, spectrum and flavor.



Construction of the 280m hall will start in 2007, the detector must be ready in 2009.



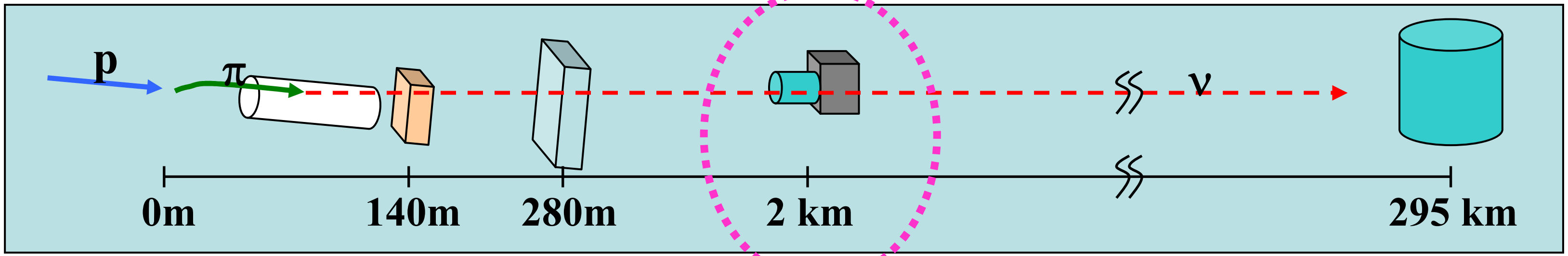


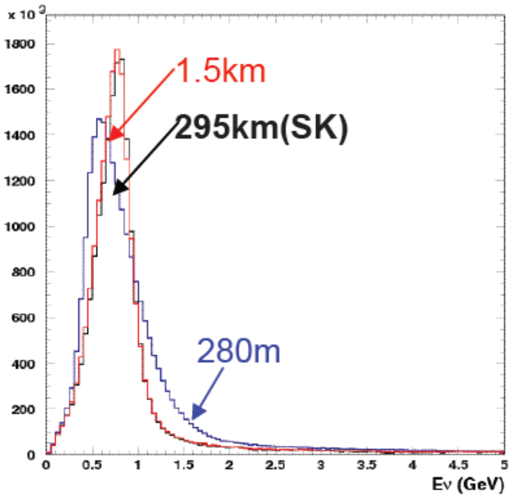
On-axis detector

beam center and profile

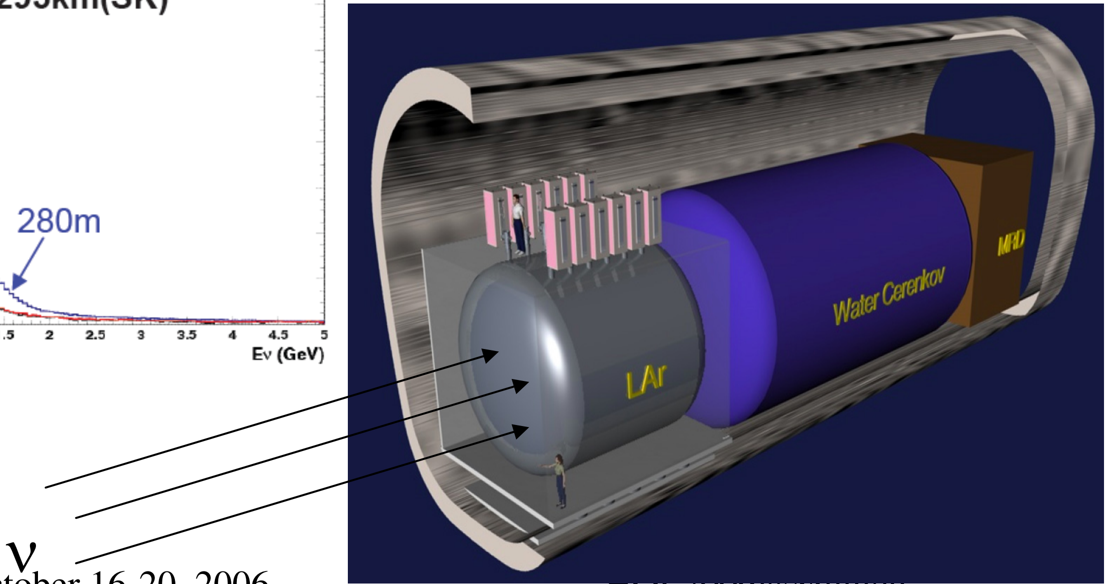
Getting the most from T2K

In order to get the best sensitivity from T2K, one has to know the neutrino spectrum (both ν_μ and ν_e) precisely before the oscillation.

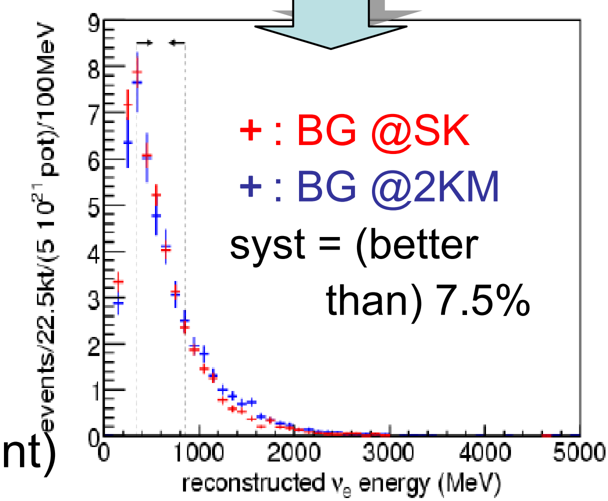




Near detector complex at 1.84km from the target



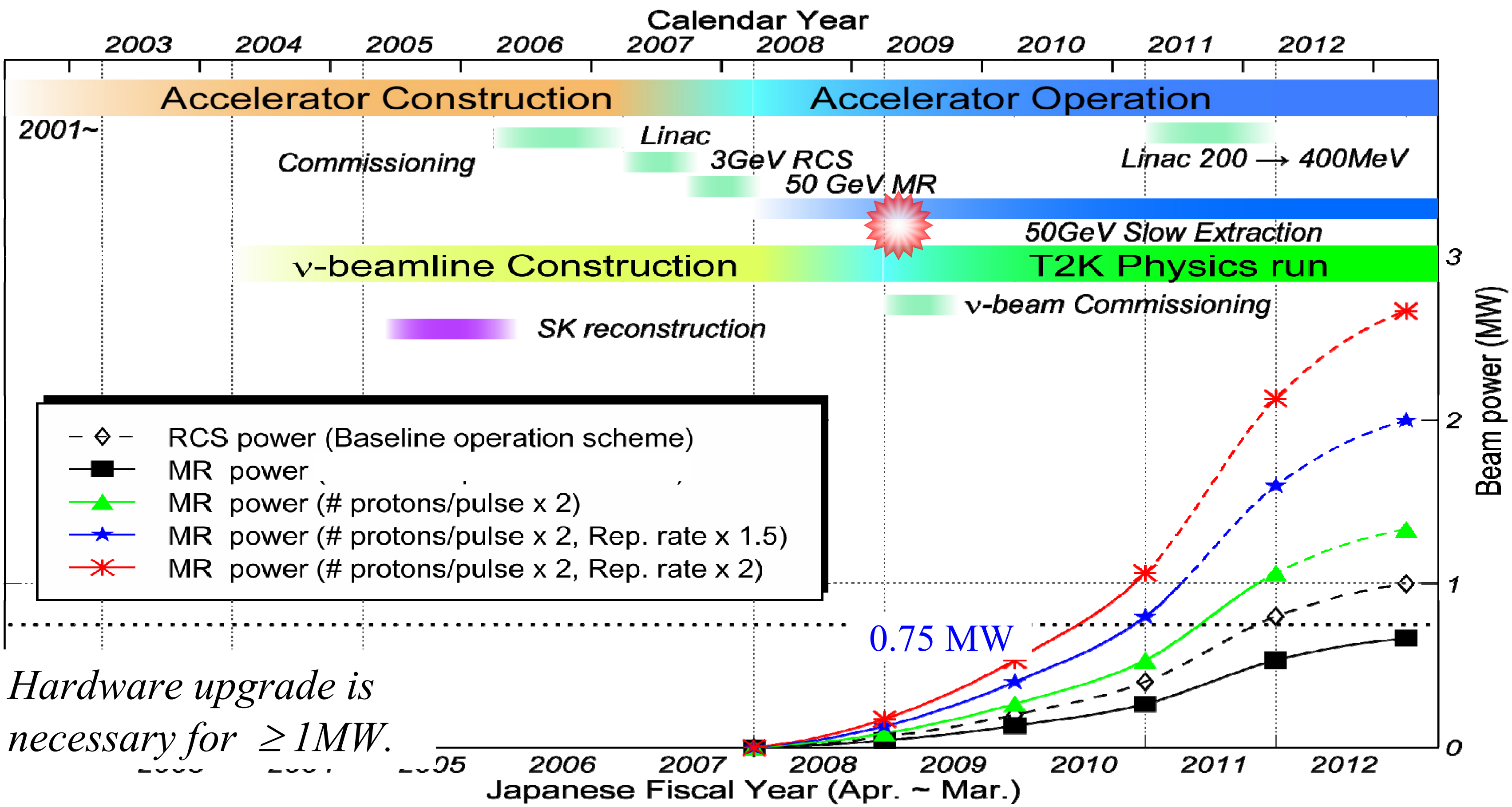
- ➔Same spectrum
- ➔Same target
- ➔Same detector technology
- ➔Same reconstruction program



(Budget request (in Japan) after starting experiment)

J-PARC schedule & Beam Power estimation

Nakadaira neutrino2006

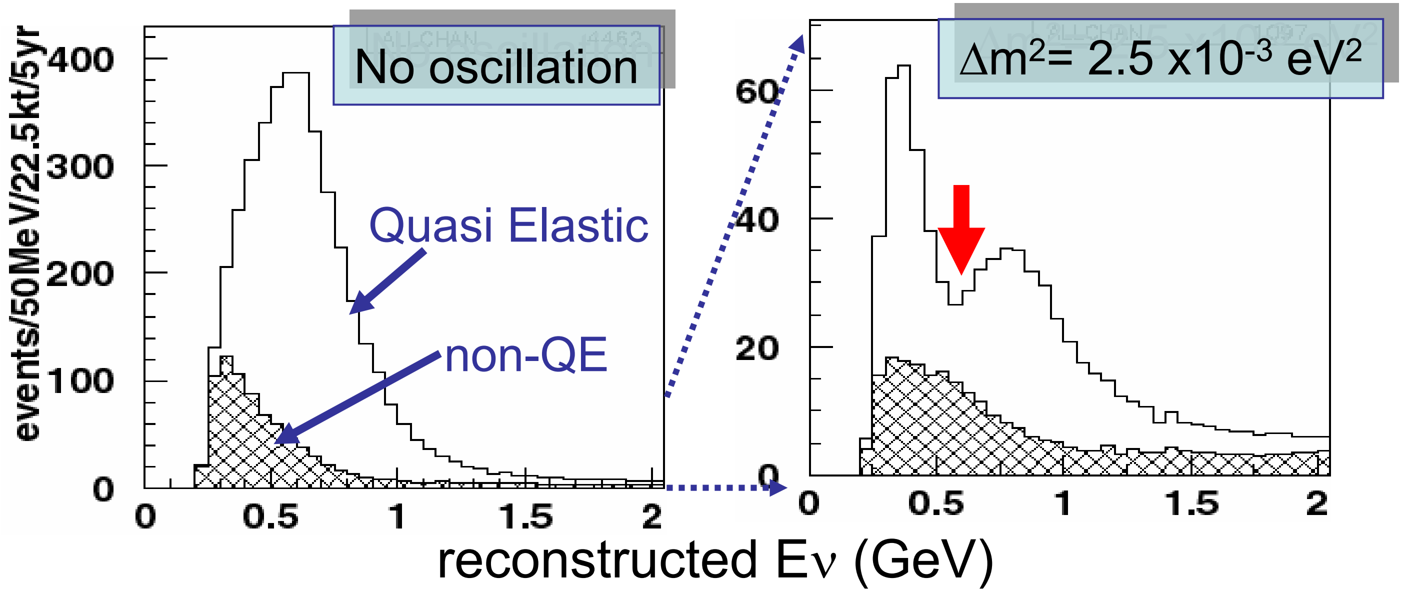


Hardware upgrade is necessary for ≥ 1MW.

Target date for new RF system installation.

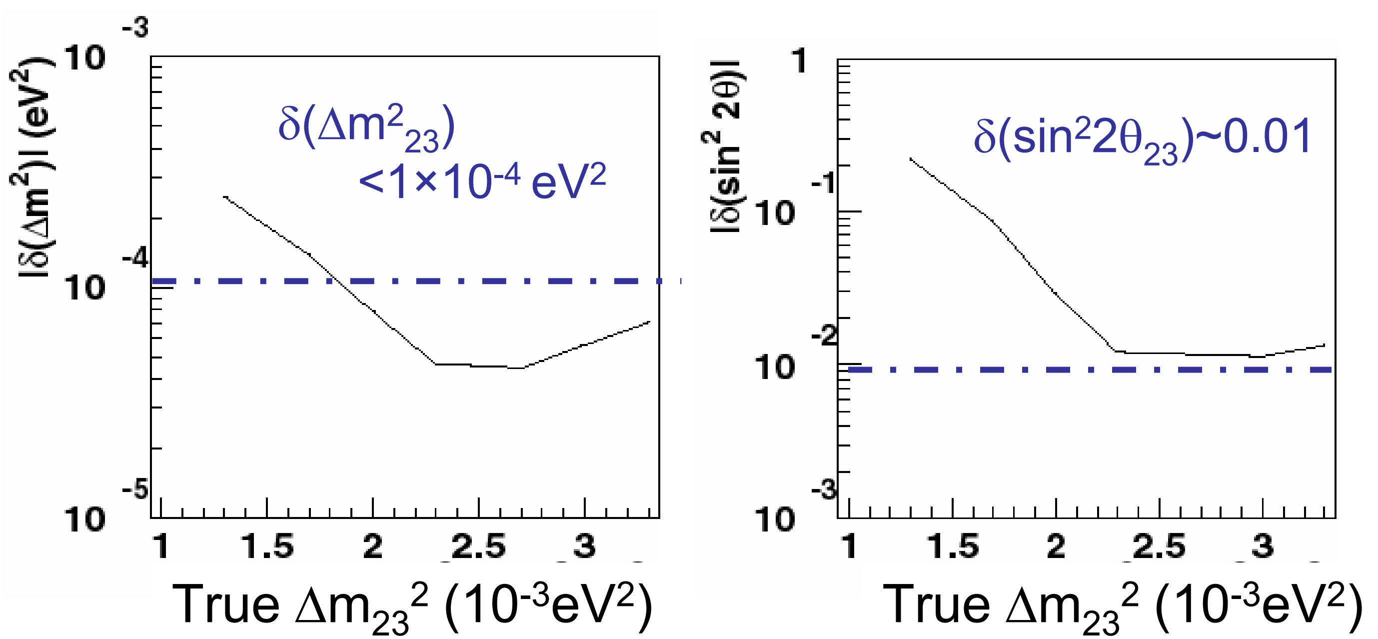
Measurement of Δm^2 and $\sin^2 2\theta_{23}$

Reconstructed ν energy distribution for single ring μ-events.



Sensitivity with 0.75MW・ 5years and

- normalization (5%)
- non-qe/qe ratio (20%)
- E scale (1%)
- Spectrum shape(5%)
- Spectrum width (5%)

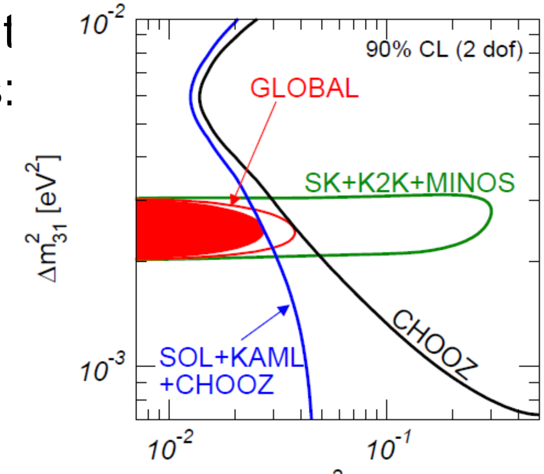


θ_{13}

$$P(\nu_\mu \to \nu_e) = \sin^2\theta_{23} \cdot \sin^2 2\theta_{13} \cdot \sin^2\left(\frac{1.27\Delta m_{23}{}^2 L}{E}\right)$$

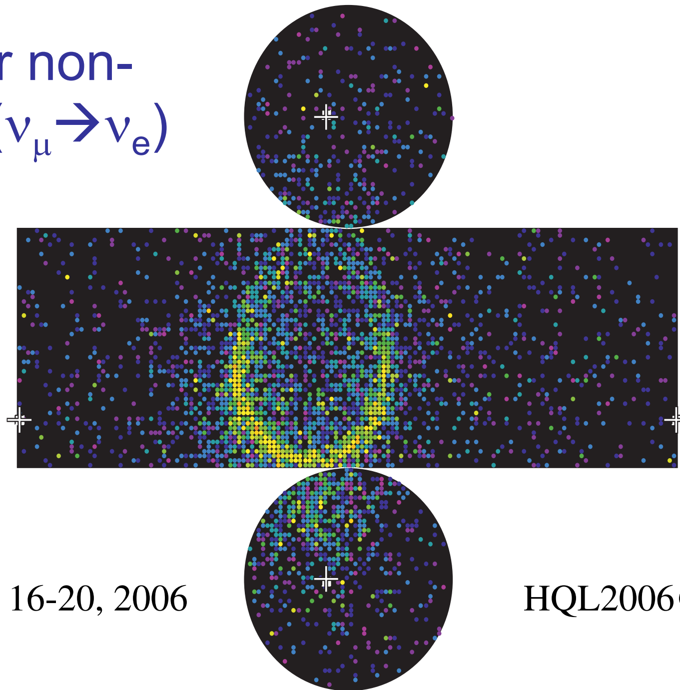
($\Delta m_{12}{}^2=0$ assumed, matter effect not included)

Present status:

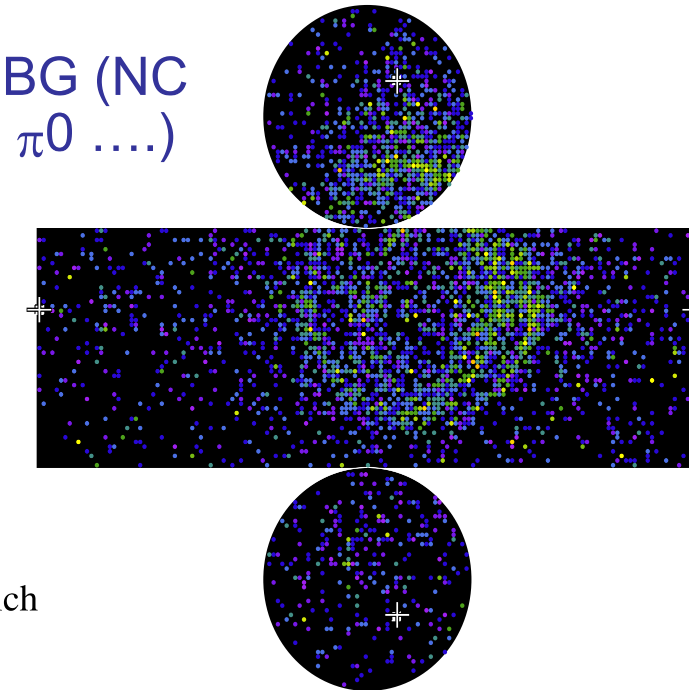


$\sin^2\theta_{13}$ T.Schwetz hep-ph/0606060

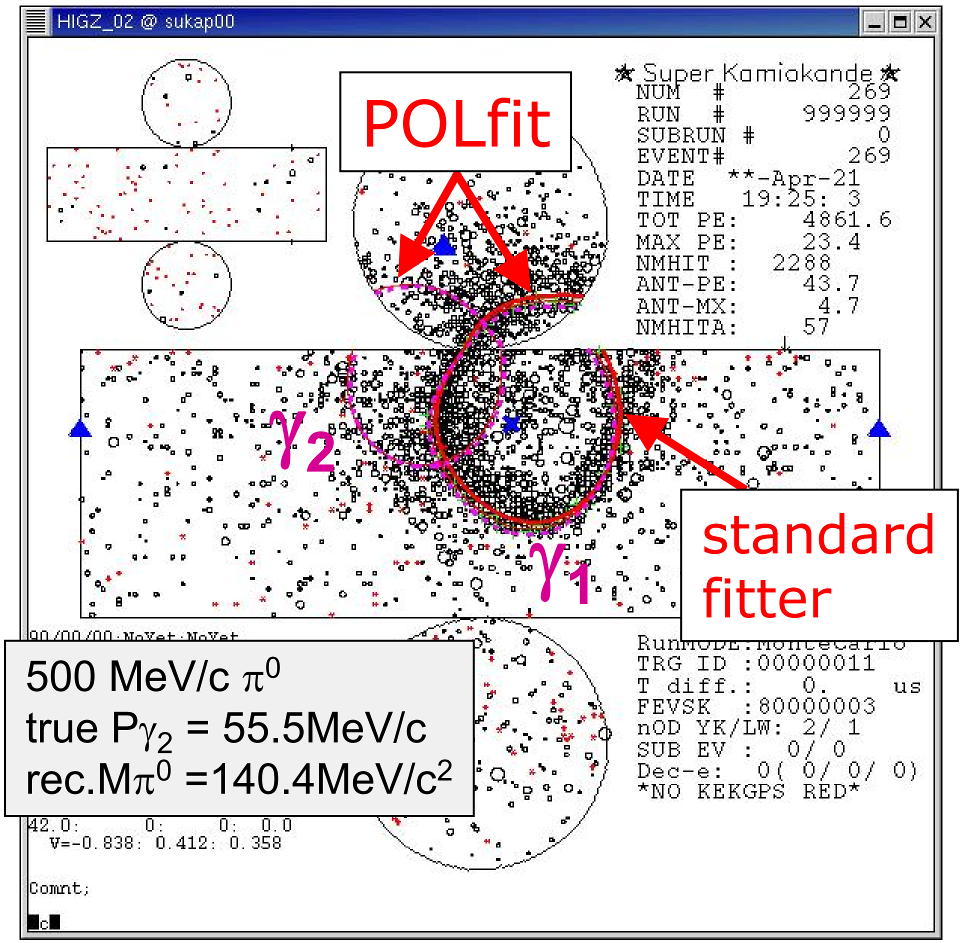
Signal for non-zero θ_{13} ($\nu_\mu \rightarrow \nu_e$)



BG (NC π0 ….)



POL(Pattern of Light)fit – π^0 fitter –



- Target: FCFV 1R-elike events
- $\Delta L \equiv$ Likelihood(2γ assump.) – Likelihood(electron assump.)

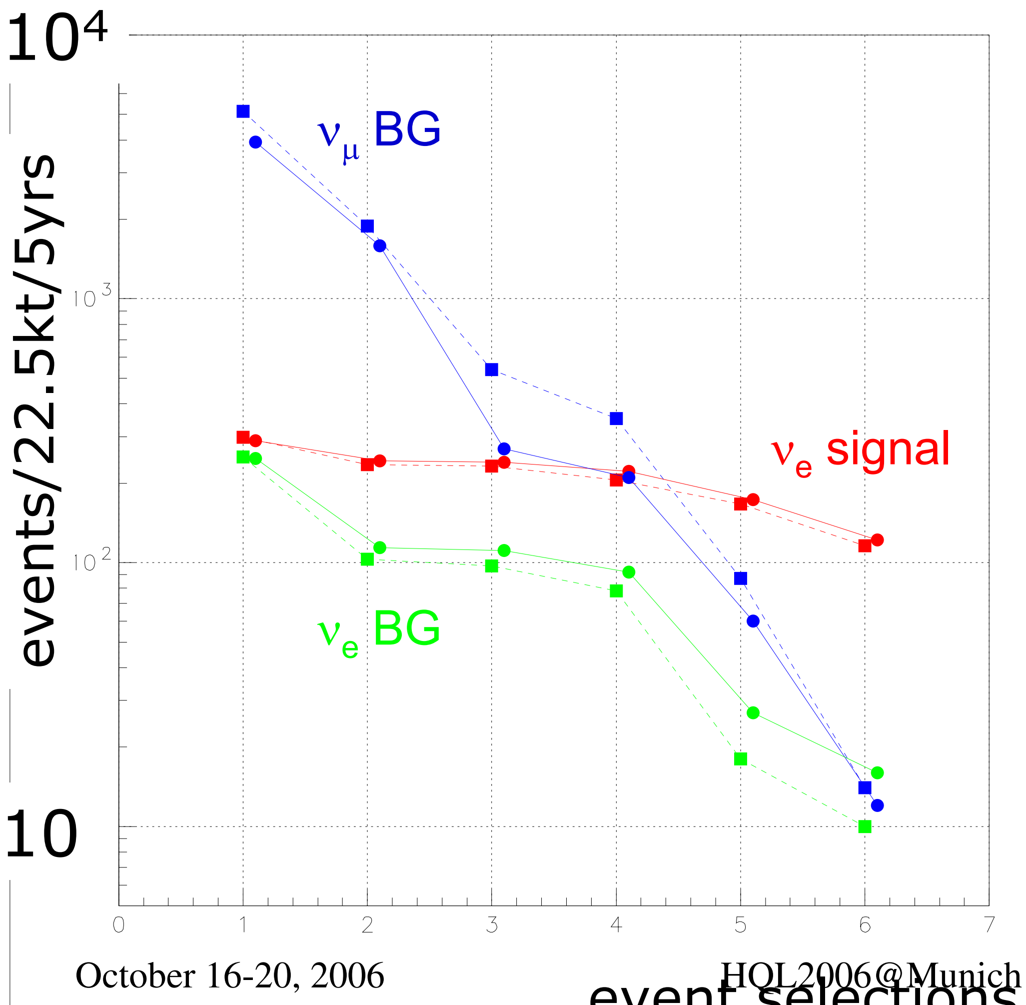
- Try to reconstruct two γ rings
- Input: vertex, visible energy, and the 1st γ direction by the standard fitter
- Compare observed & expected (direct+scatter) charge
- Vary the 2nd γ direction and the energy fraction until the best match found

→ $M\pi^0$ etc.

S. Mine (UCI) @ NP04

Events vs. Selections

$\Delta m^2 = 2.5\text{x}10^{-3}\ eV^2$
$\sin^2 2\theta_{13} = 0.1$



Event selections:

1. FCFV, $E_{vis} > 100$
2. 1 ring
3. e-like
4. no decay-e
5. $0.35 < E_\nu^{rec} < 0.85$
6. π^0 cuts:
   - cos < 0.90
   - $\Delta L < 80$, $M\pi^0 < 100$

Events vs. selections

$\Delta m^2 = 2.5\times10^{-3} eV^2, \sin^2 2\theta_{13} = 0.1$

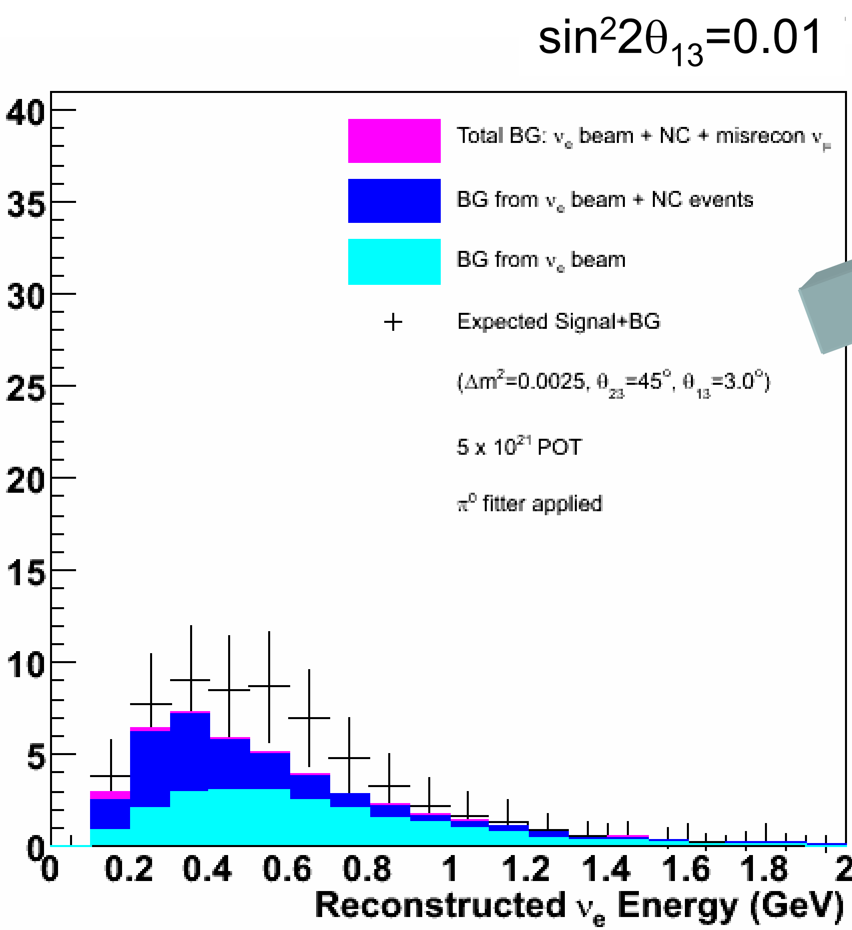
(events / 22.5kt / 5yrs)

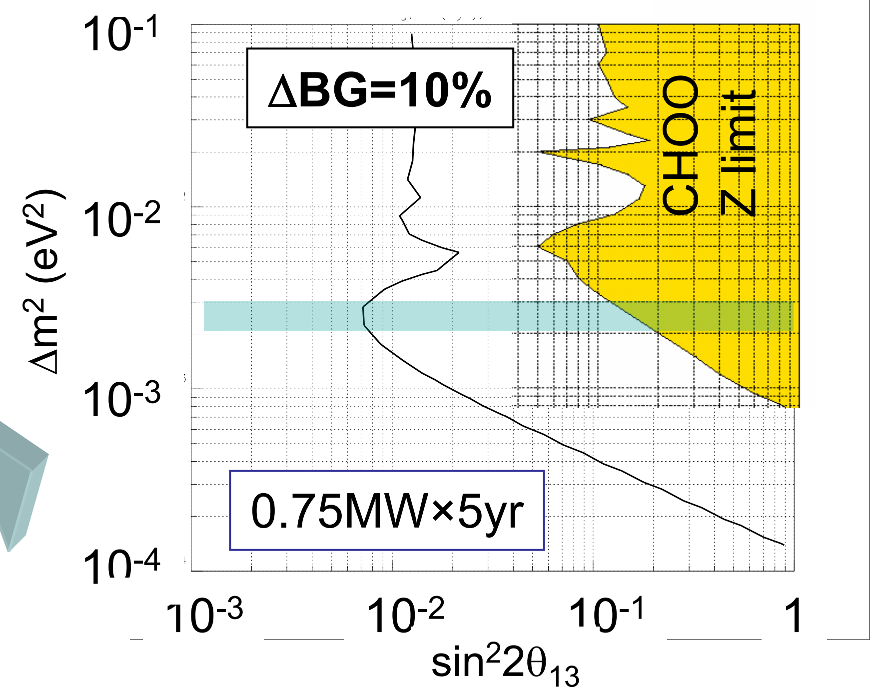
	ν_μCC BG	ν_μNC BG	beam ν_e BG	ν_e(CC) Signal
FCFV, E_{vis}>100	**2849**	**1082**	**248**	**290**
1R	**1313(46%)**	**277(26%)**	**114(46%)**	**243(84%)**
e-like	**51(1.8%)**	**219(20%)**	**111(45%)**	**240(83%)**
no decay-e	**15(0.5%)**	**195(18%)**	**92(37%)**	**222(77%)**
$0.35<E_\nu^{rec}<0.85$	**2.2(0.1%)**	**58(5%)**	**27(11%)**	**173(60%)**
ΔL<80,M<100,cos<0.9	**12±0.8(0.3%)** (stat.)		**16±0.4(6%)** (stat.)	**122±3(42%)** (stat.)

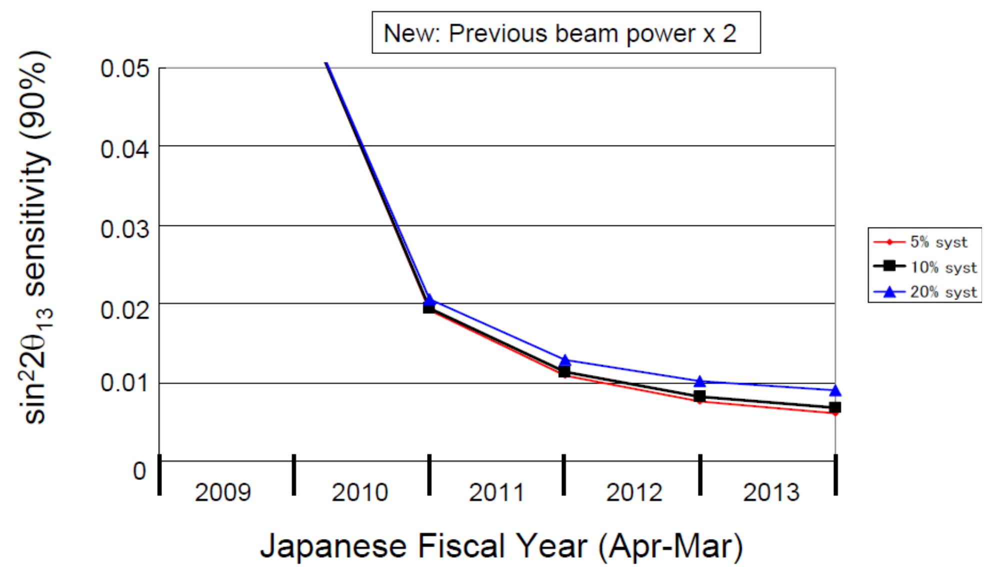
(old π^0 fitter: 12 15 109)

ν_e appearance and θ_{13} sensitivity

ν_e appearance signal and BG at SK.

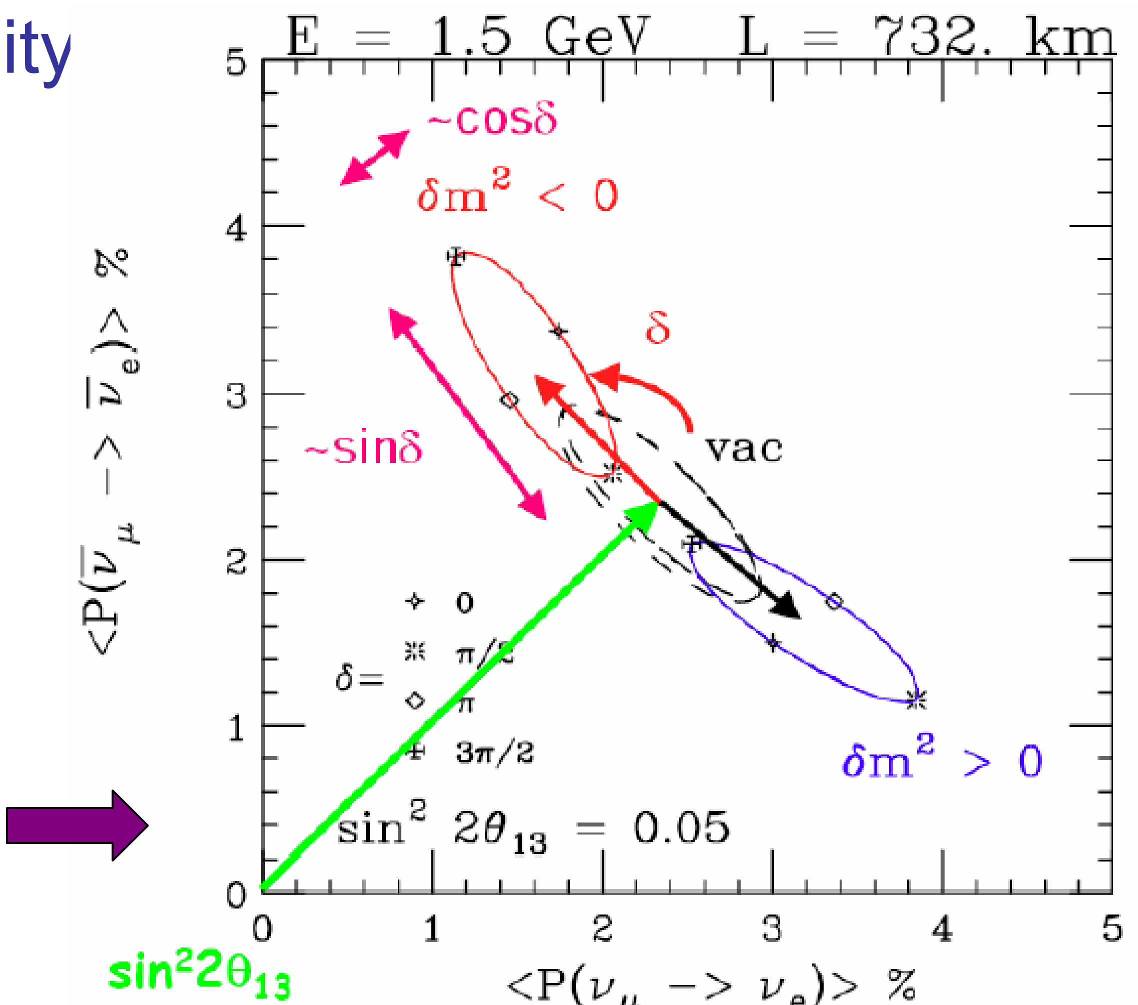






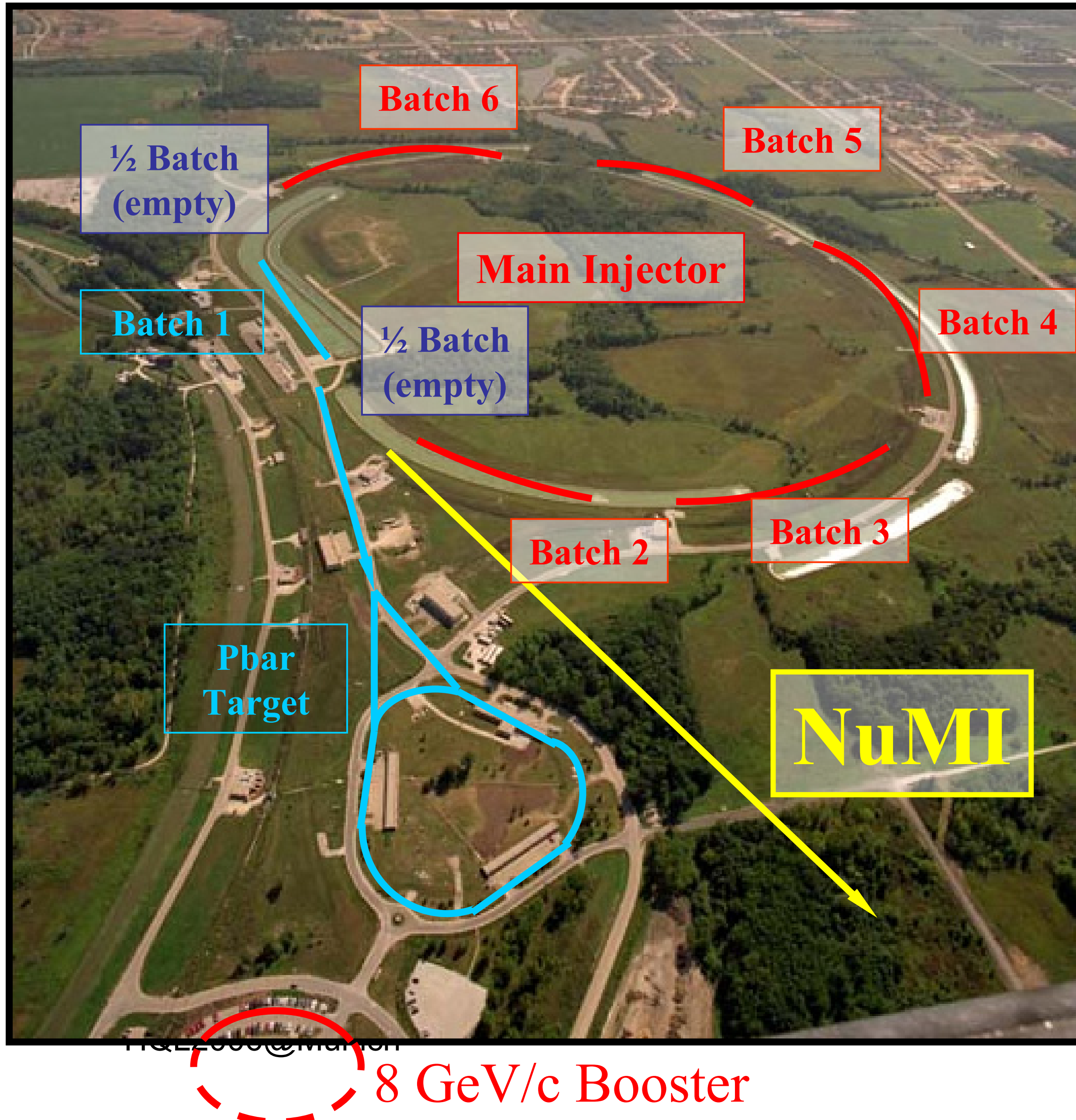
A machinery in my talk

- Oscillation probability draw ellipse if plotted in bi-P plane
- Role played by CP phase δ and the matter clearly distinguished

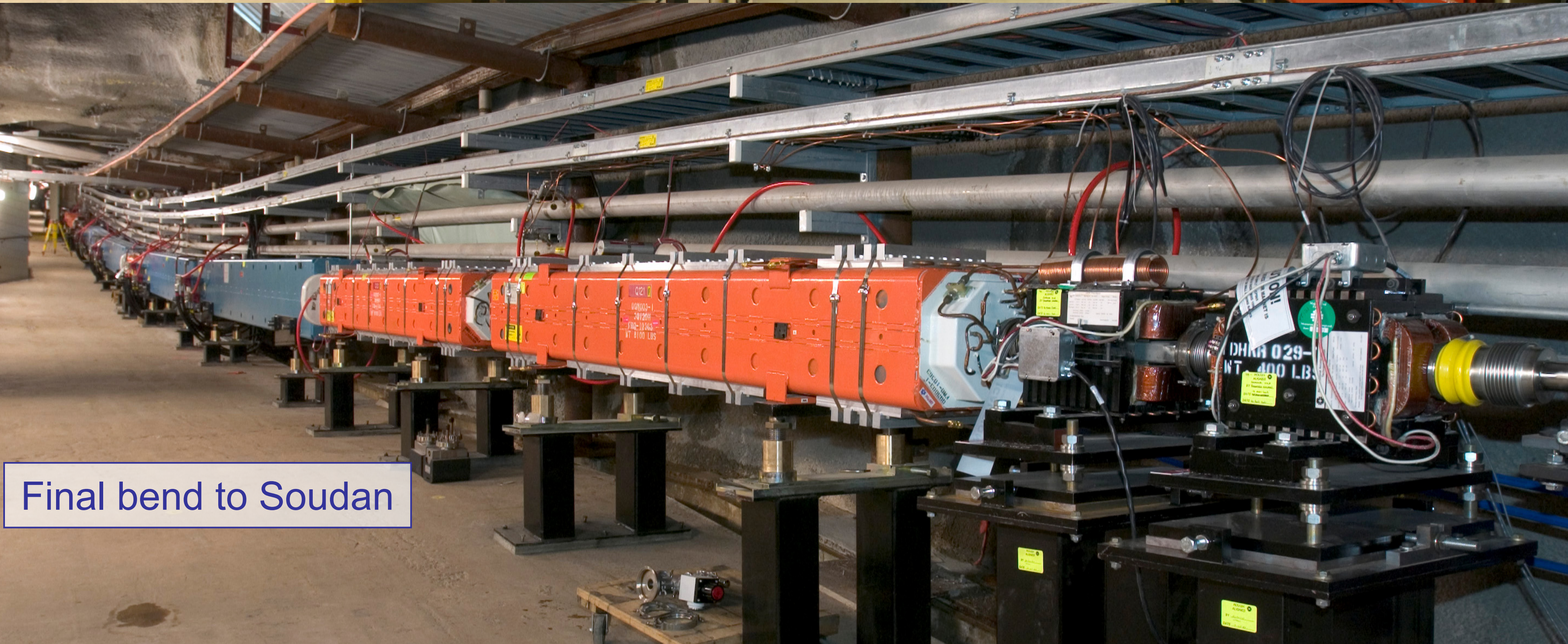


NuMI in the Collider Era

- MI ramp time ~1.5sec
- MI is fed 1.56μs batches from 8 GeV Booster
- Simultaneous acceleration & dual extraction of protons for
  - Production of *p* (Tevatron collider)
  - Production of neutrinos (NuMI)
- NuMI designed for
  - 8.67 μs single turn extraction
  - 2-3×10^{13}ppp @ 120 GeV
- Current limitations:
  - Booster can deliver at most 5×10^{12}p/batch
  - Gymnastics associated with mixed Pbar/NuMI operations

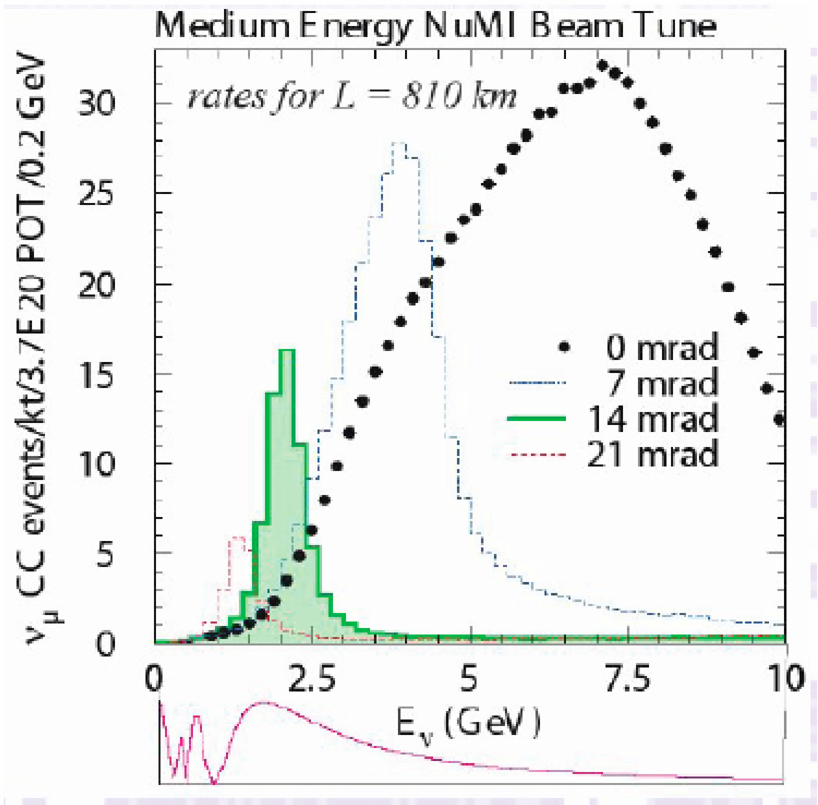



Lambertsons

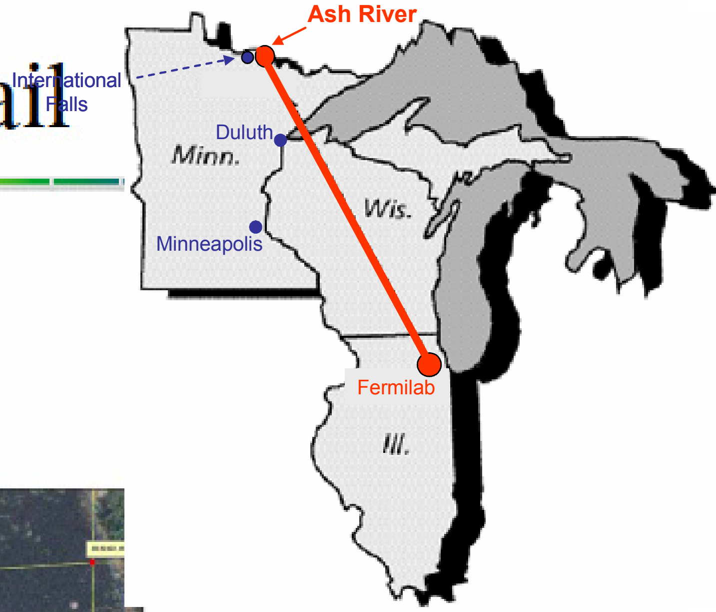
Bend out of MI

Final bend to Soudan

Off-Axis Spectra

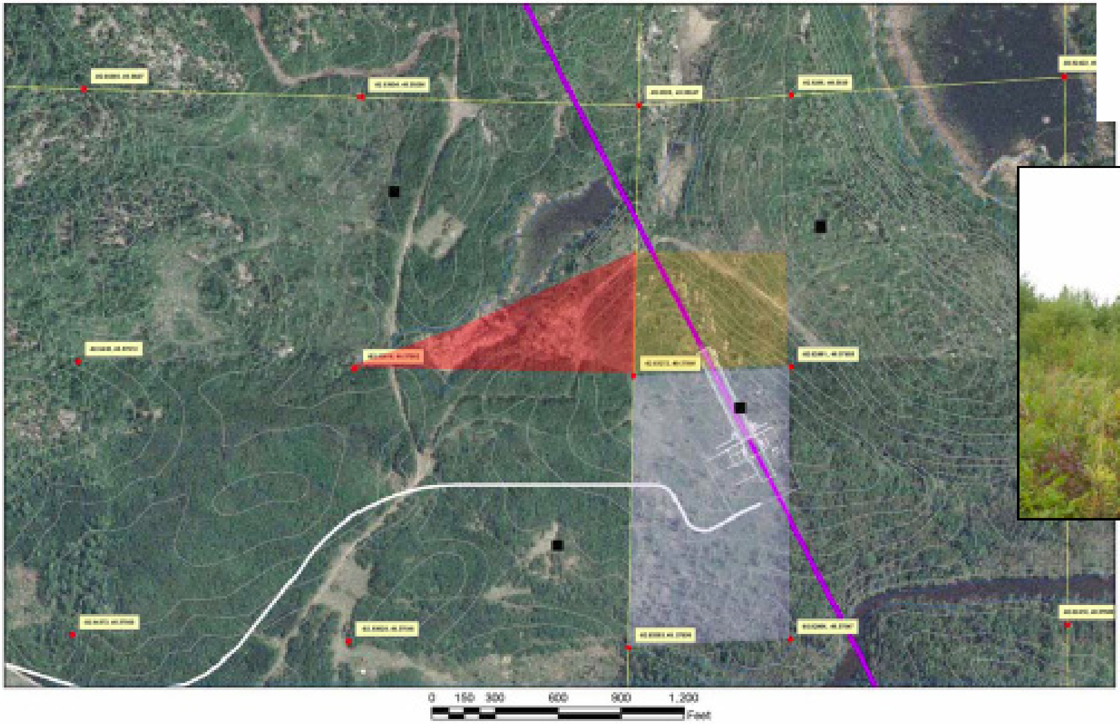
- Benefits of off-axis spectrum:
  - More flux near oscillation maximum
  - Reduction of High Energy Tail reduces NC Feed-down
  - Concentration of ν_e from oscillation relative to intrinsic beam ν_e (from 3-body K and μ decay)



Site – Ash River Trail

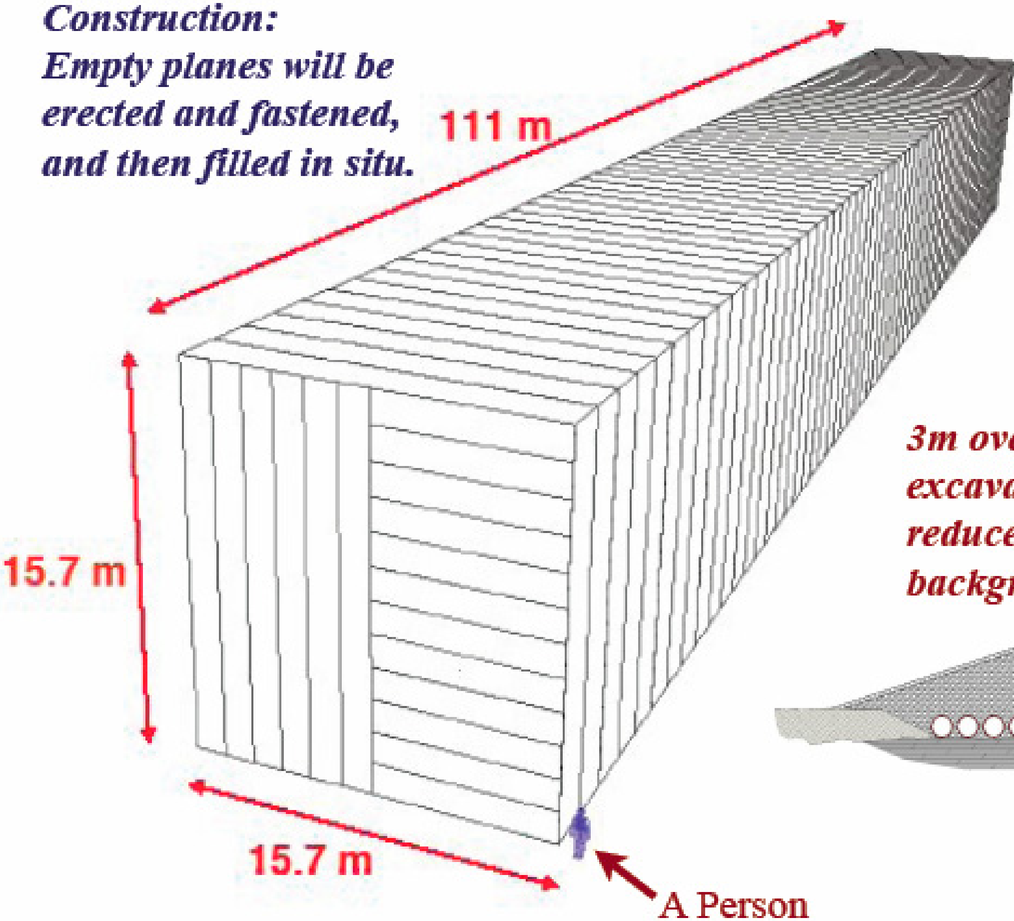


- 503 miles (810 km) from Fermilab
- 3.6 Mile Access Road
- Electrical Upgrade



Far Detector

Construction:
Empty planes will be erected and fastened, and then filled in situ.



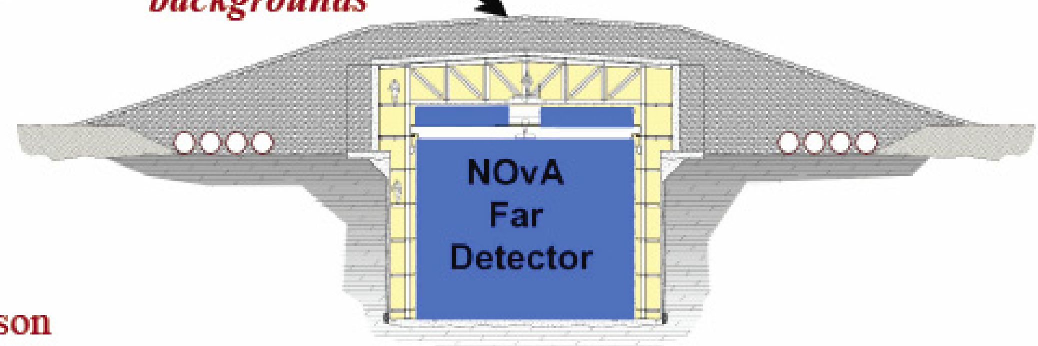
25kT Total Mass
(18.25 kT Scintillator)

Detector supported in blocks of 31 planes

54 blocks = 1654 planes total

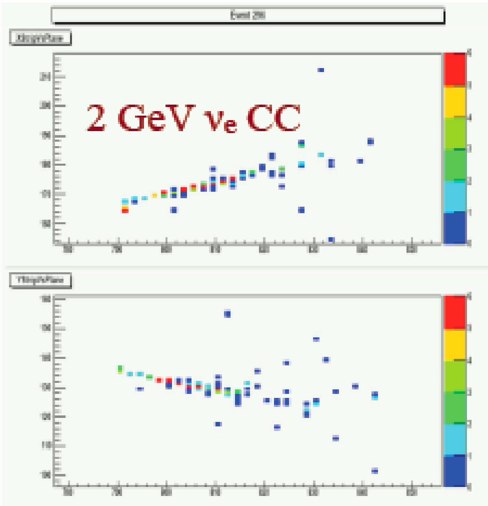
635136 cells

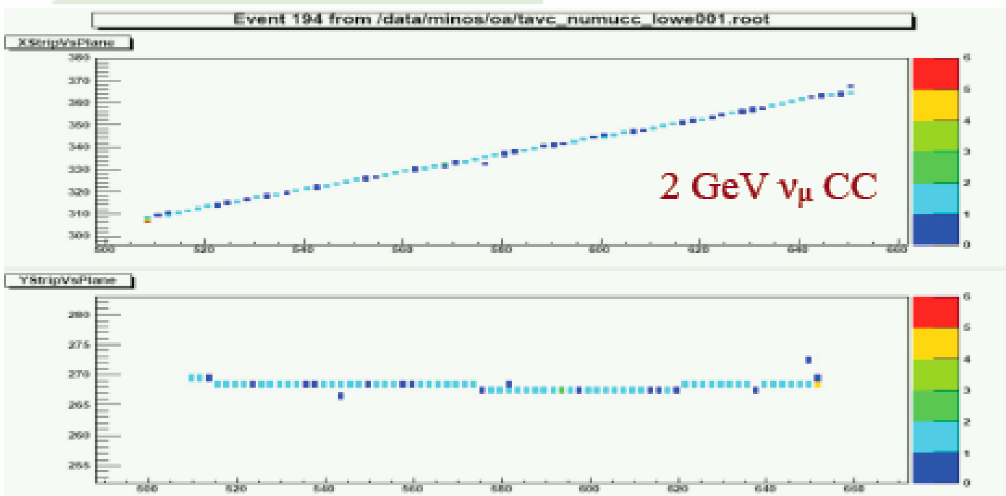
3m overburden of excavated rock - reduce cosmic backgrounds



Beam's view

Performance

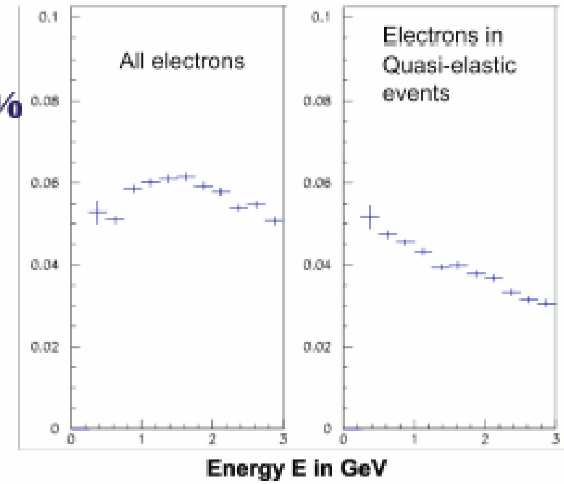




e/μ separation is easy

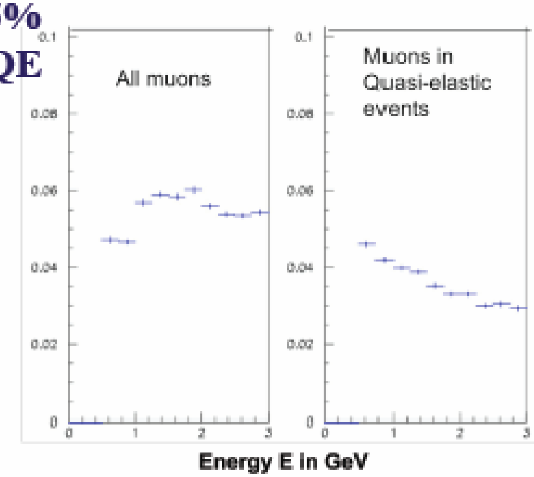
electron
σ(E)/E<6%

σ(E)/E

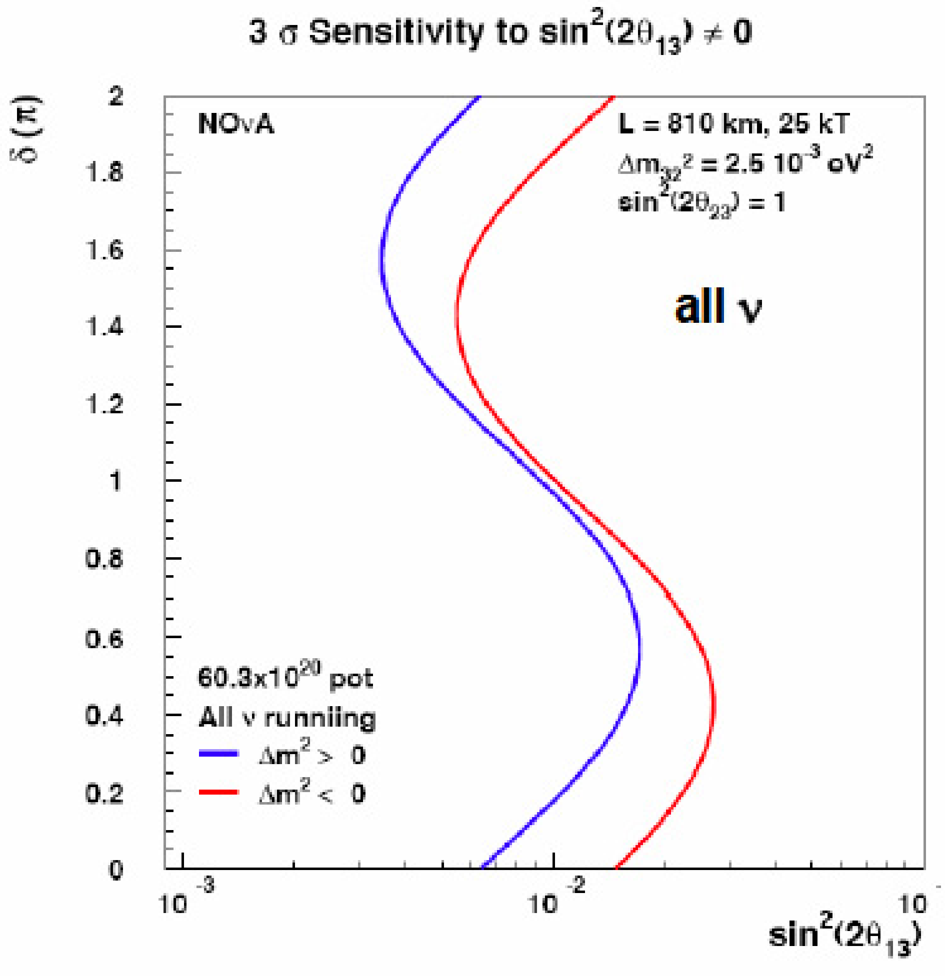


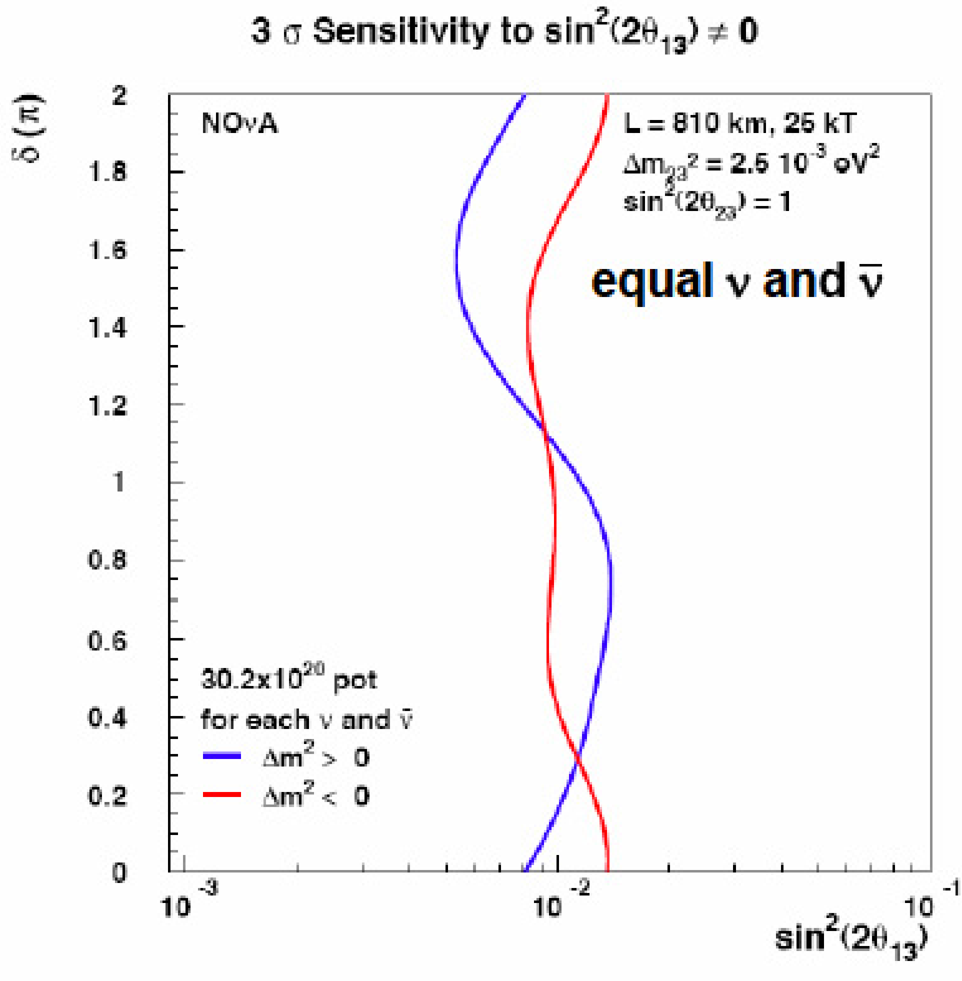
muon
σ(E)/E<3.5%
for 2GeV QE

σ(E)/E

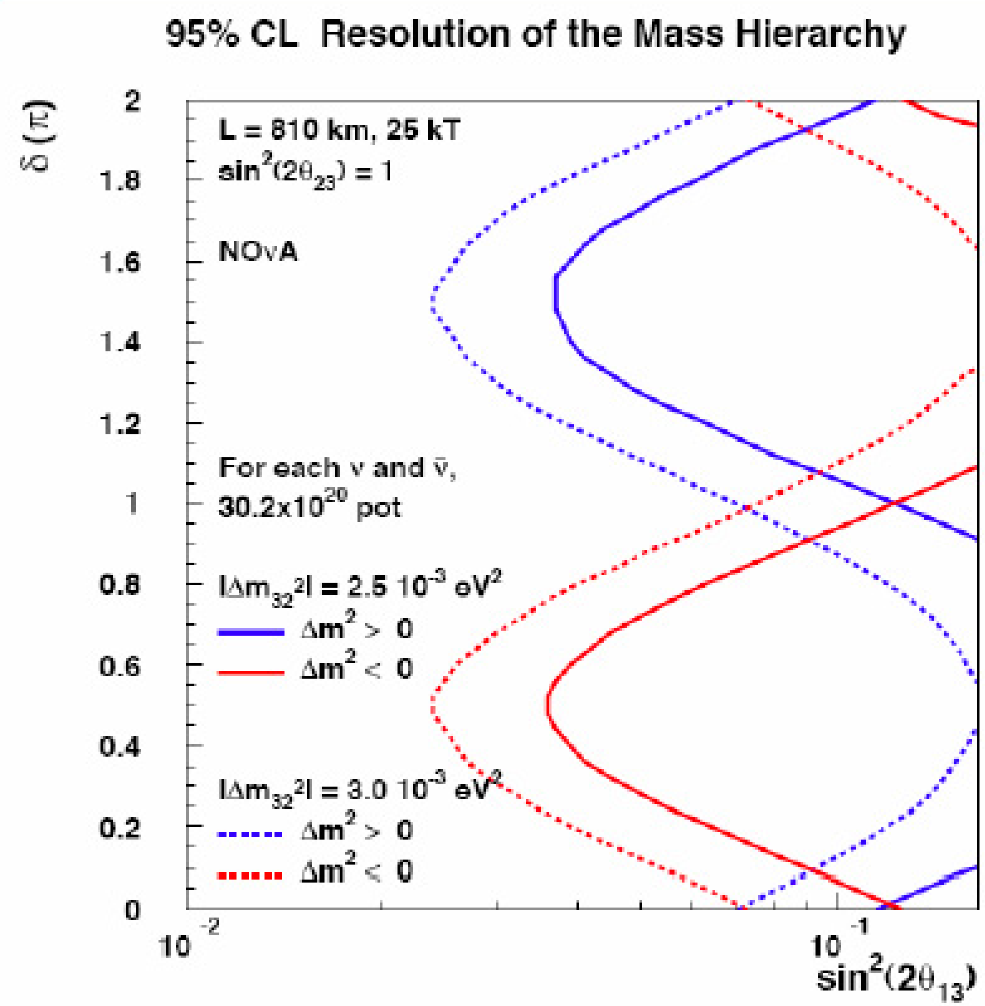


3 σ Sensitivity to $\theta_{13} \neq 0$



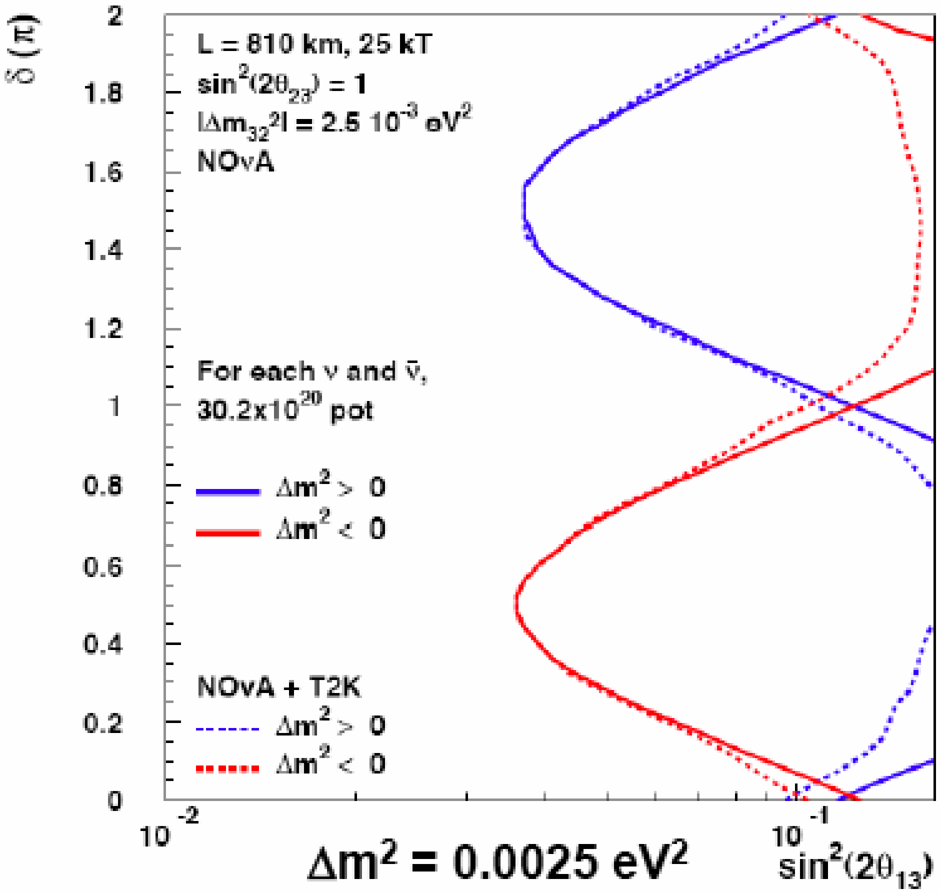


95% CL Resolution of the Mass Ordering

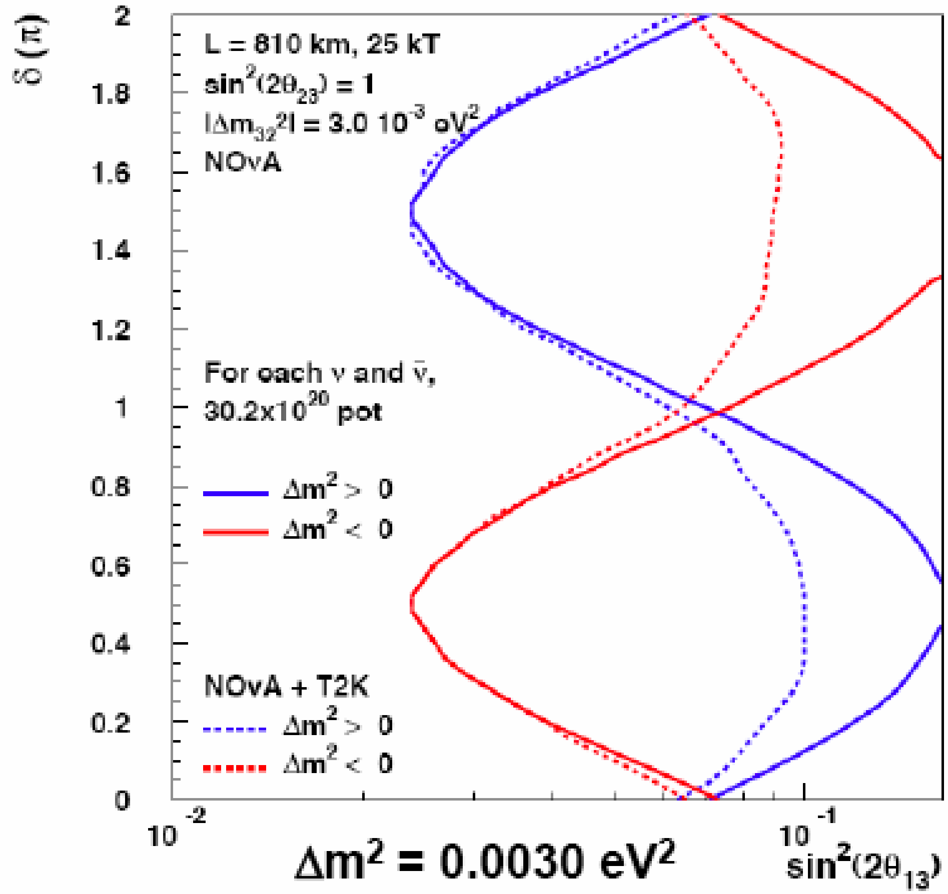


Combining NOνA and T2K

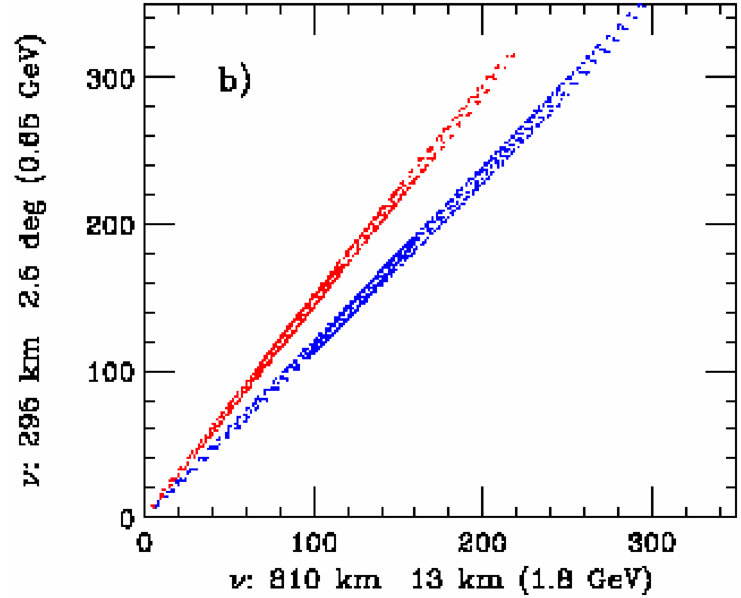
95% CL Resolution of the Mass Hierarchy

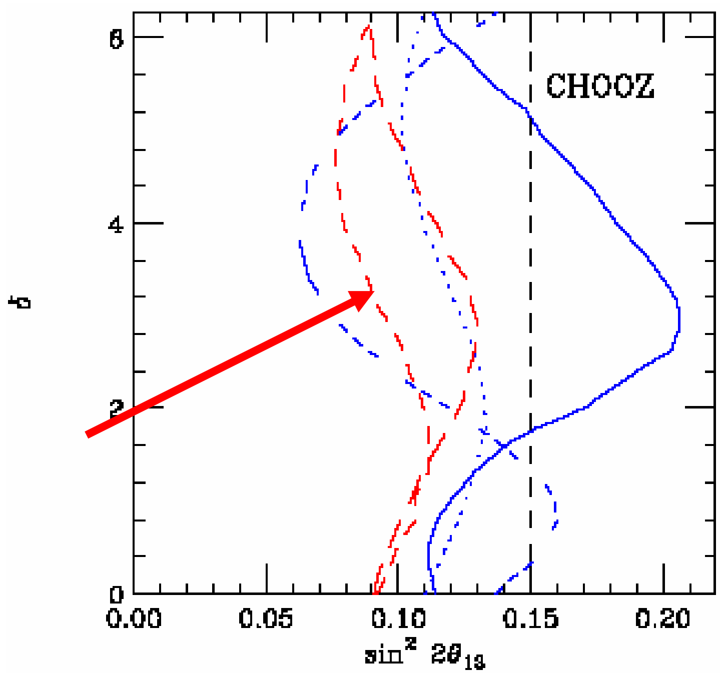


95% CL Resolution of the Mass Hierarchy

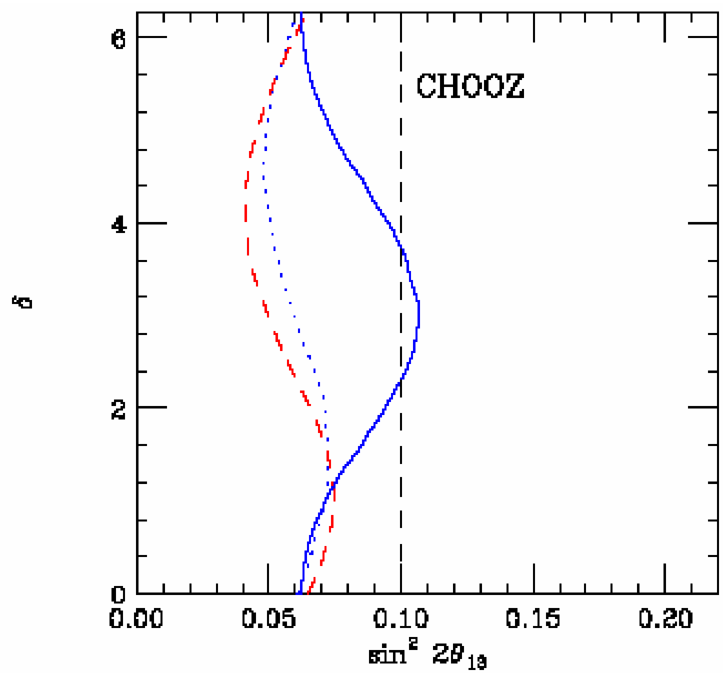


Alternative way; ν_{T2K}-$\nu_{NO\nu A}$ comparison





(a) $\Delta m^2_{31} = +2.4 \times 10^{-3}$ eV^2



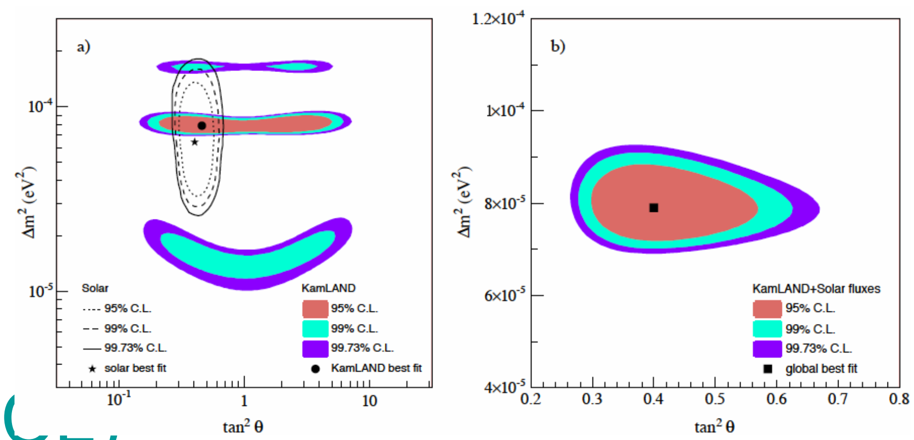
(b) $\Delta m^2_{31} = +3.0 \times 10^{-3}$ eV^2

Need for beyond the next generation (NG) experiments

- NG exp. will not determine (unless very lucky) the mass hierarchy
- NG exp. does not have sensitivity to CP violation
- NG exp. may not be able to see nonzero θ_{13} (what happens then?)
- Question: how accurately should we need to know Δm^2 and θ's?

Quark-lepton complementarity ?

$\theta_C + \theta_{solar} = 45.1^o$ +/- 2.4^o (1σ)



$36.8^o < \theta_{atm} < 53.2^o$ (90% CL)

$2.3^o < \theta_{23}^q < 2.5^o$ (90% CL)

$\theta_{23}^q + \theta_{atm} = 47.4^o$ +/- 8.3^o (90% CL)

Foreseeing the future

Things changes at $\sin^2 2\theta_{13}$~0.01

- Conventional super ν_μ beam + Mton water detector work
- Known beam technology
- Background highly nontrivial
- ν_e beam contamination not negligible but tolerable

- beta beam / neutrino factory required
- Requires long-term R&D efforts
- Low background
- pure ν_e beam (β) / well understood combination of ν_e and ν_μ beam (

Various beam options

ν-factory → proton $\xrightarrow{\text{target}}$ π^+ + ...

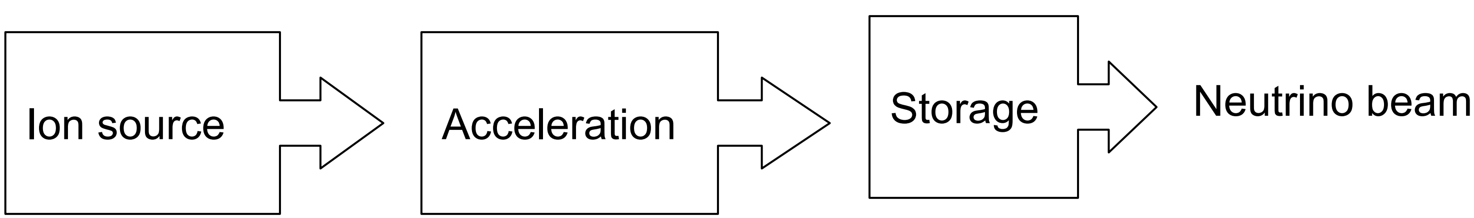
↳ $\mu^+ + \nu_\mu$ (super-beam)

↳ $e^+ + \nu_\mu + \bar{\nu}_e$ and charge conjugated

beta-beam → proton $\xrightarrow{\text{target}}$ isotope

↳ isotope* + $e^+ + \nu_e$

- ν-factory uses beam of 4th generation.
- Beta-beam uses 3rd generation beam.
- Beta-beam is technically closer to existing/used accelerator technology.



Degeneracy; a notorious obstacle

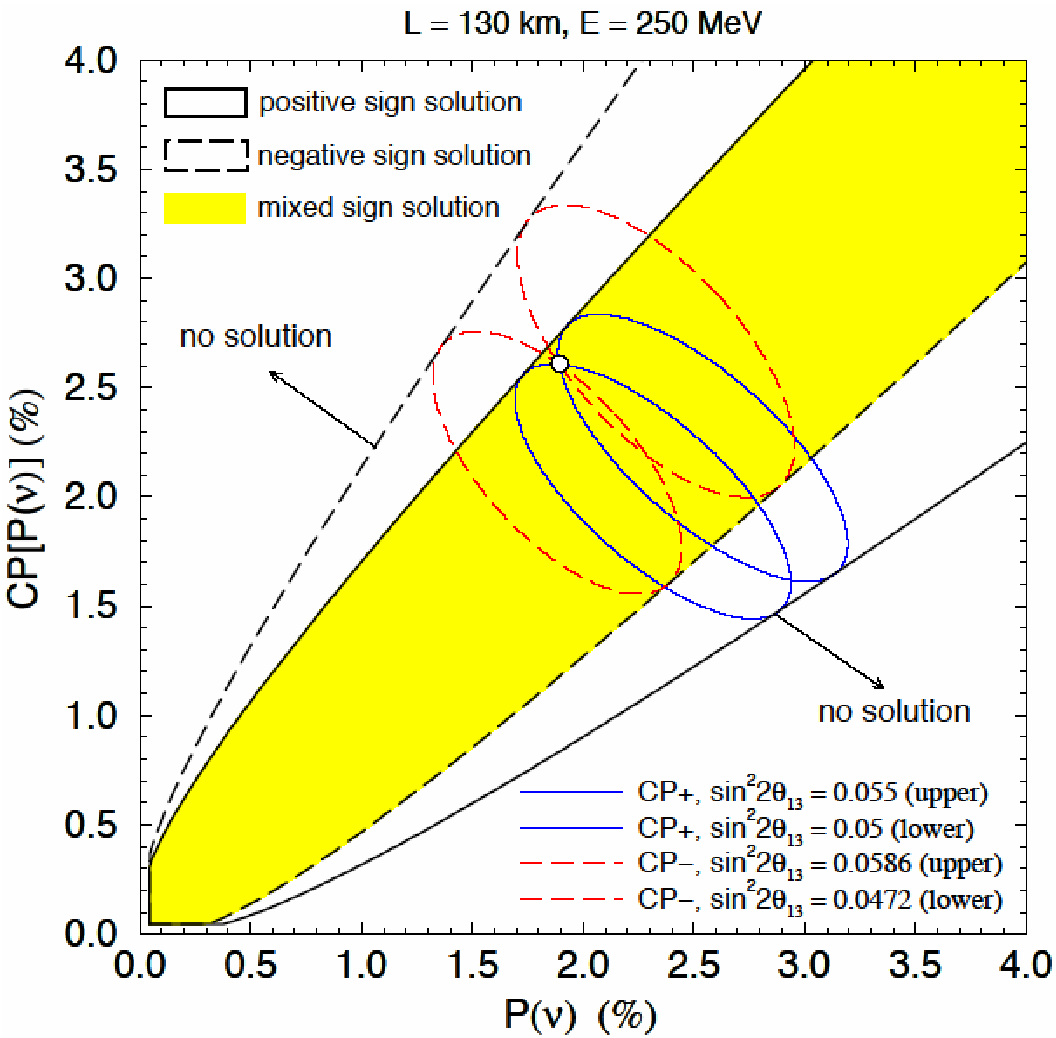
Cause of the degeneracy; easy to understand

- You can draw two ellipses from a point in P-Pbar space

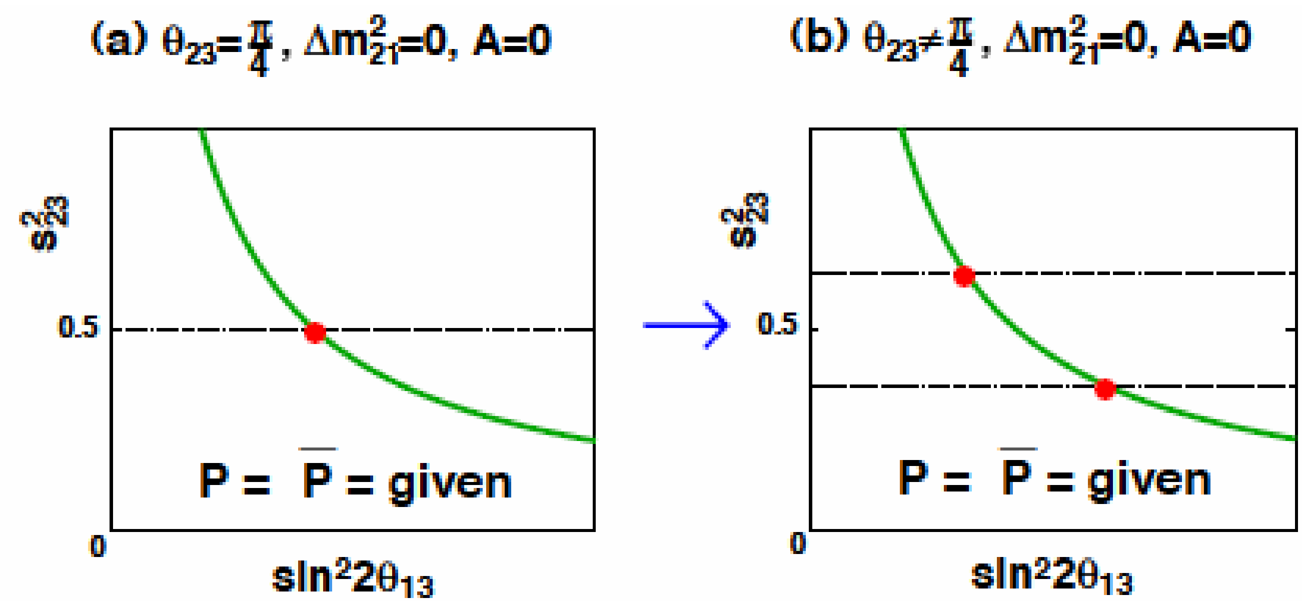
→ Intrinsic degeneracy

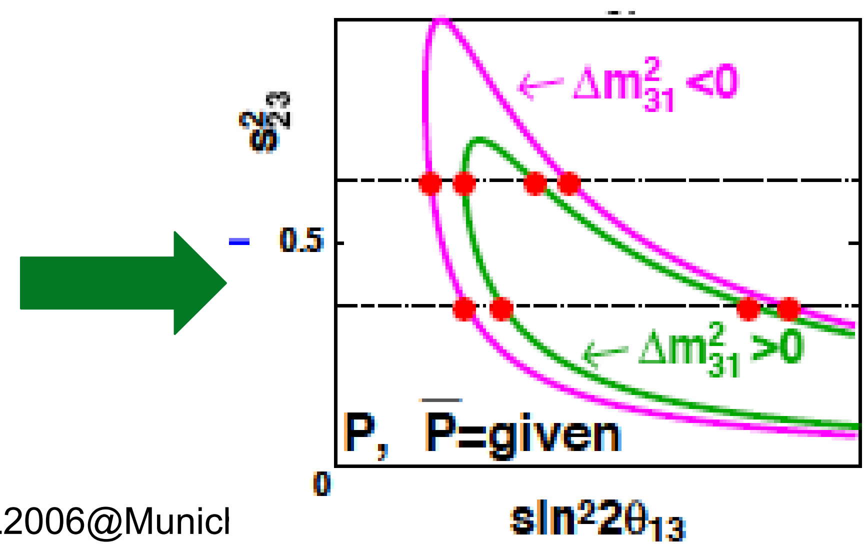
- Doubled by the unknown sign of Δm^2

→ 4-fold degeneracy

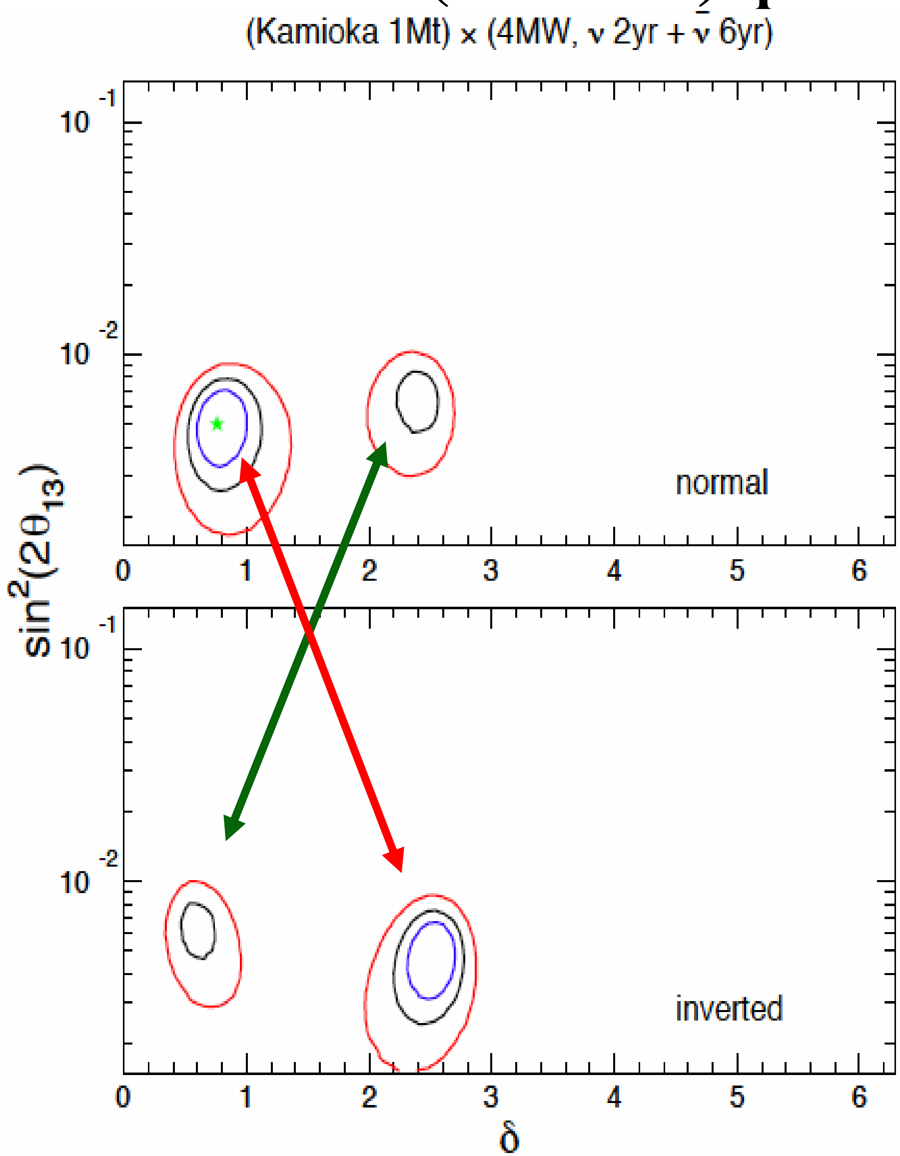


θ_{23} octant degeneracy





Structure of intrinsic & sign-Δm^2 degeneracy in (matter) perturbative regime

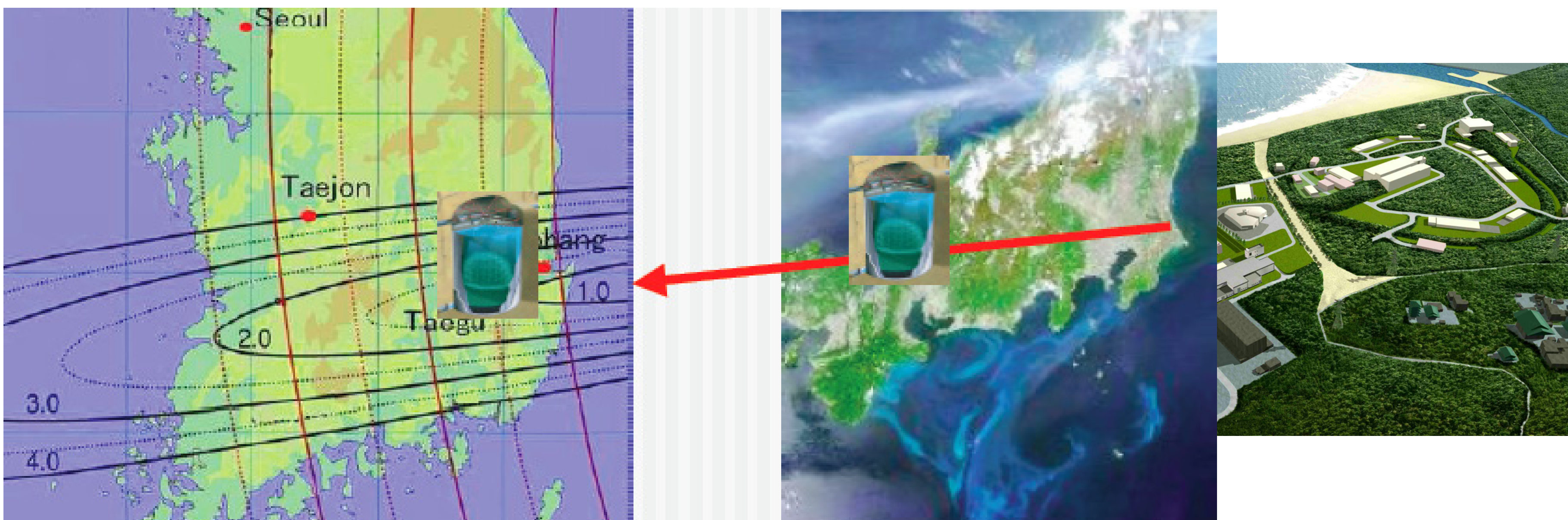


- Intrinsic degeneracy; $\delta_2 = \pi - \delta_1$
- sign(Δm^2)-δ degeneracy arises because P is approx. invariant under:
- $\Delta m^2 \longrightarrow -\Delta m^2$
- $\delta \longrightarrow \pi - \delta$

Conven
tional
super-
beam +

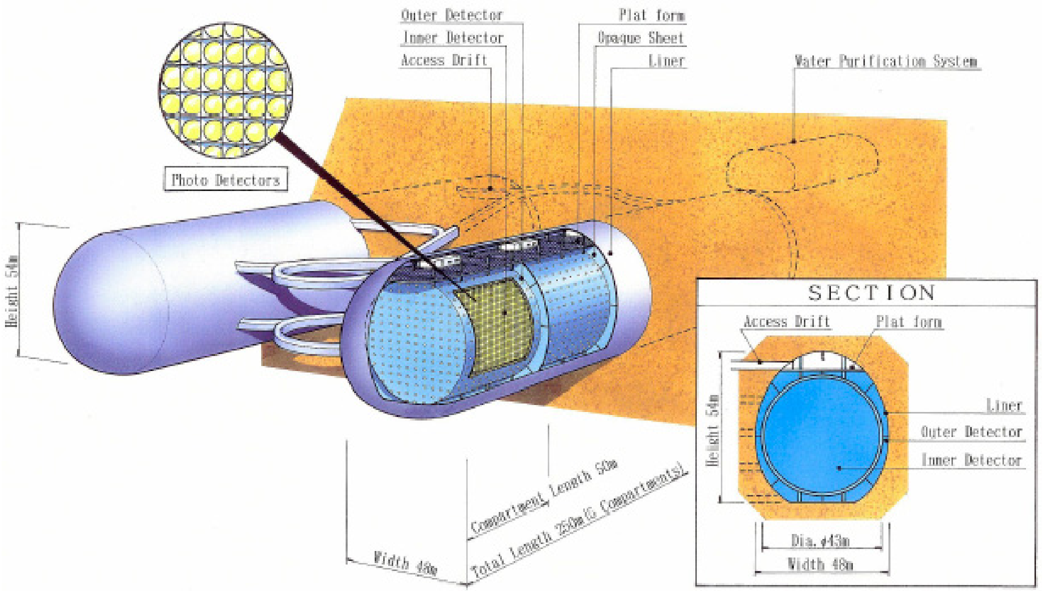
T2KK; Tokai-to-Kamioka-Korea identical two-detector complex

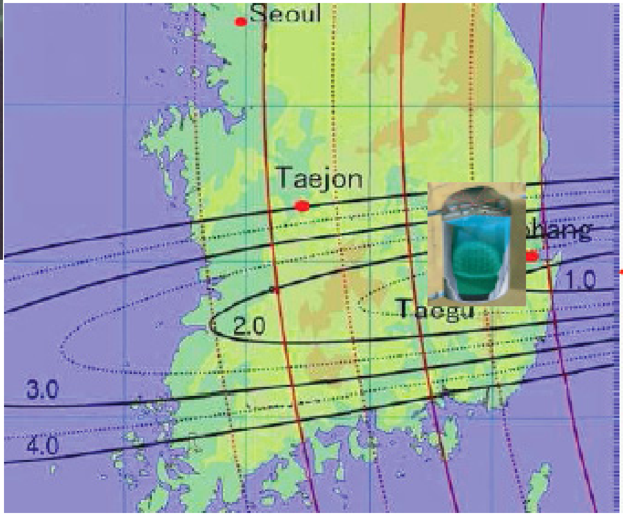
- An improvement over T2K II design with Hyper-K @ Kamioka with 1 megaton water



What's good in T2KK? (what about NOVA?)

#1. Current design of Hyper-Kamiokande contains 2 tanks !





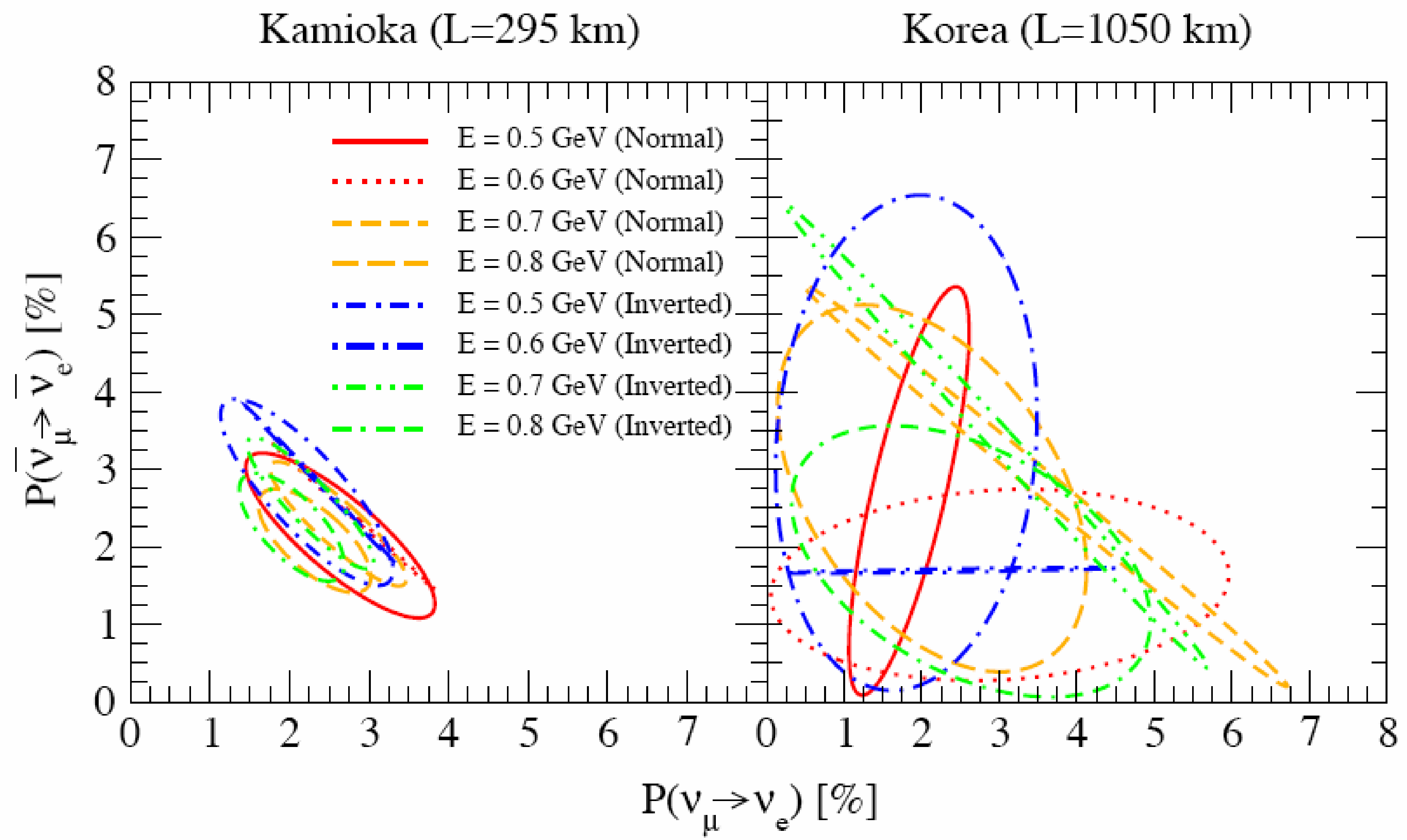
October 16-20, 2006

T2KK vs. NOVA with 2nd detector (LOI)

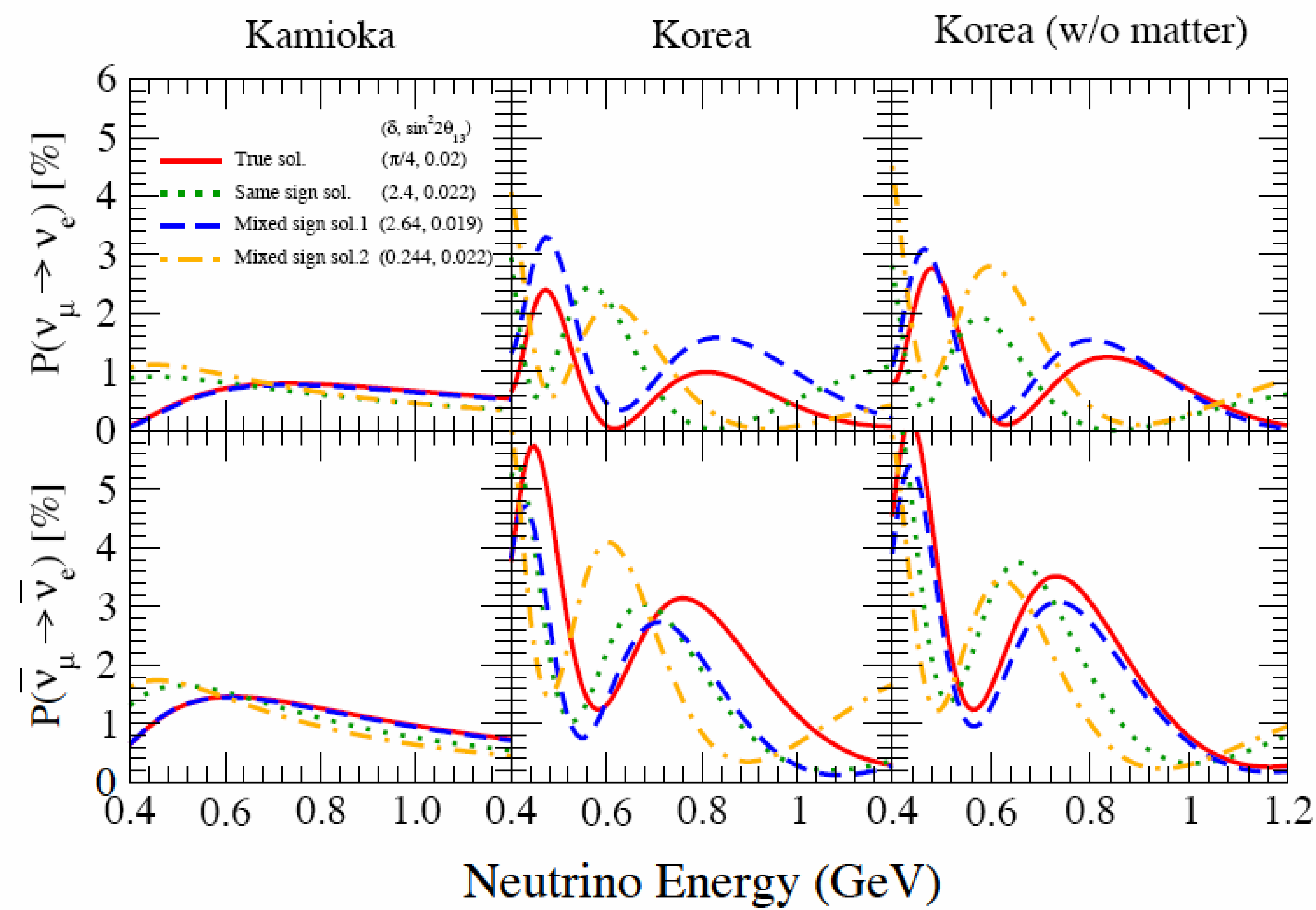
- $\Delta_{1st} = 0.8\ \pi$
- $\Delta_{2nd} \sim 2.7\ \pi$
- $(aL/\Delta)_{1st} = 0.17$
- $(aL/\Delta)_{2nd} = 0.07$

- $\Delta_{1st} = \pi$
- $\Delta_{2nd} \sim 3\ \pi$
- $(aL/\Delta)_{1st} = 0.05$
- $(aL/\Delta)_{2nd} = 0.05$

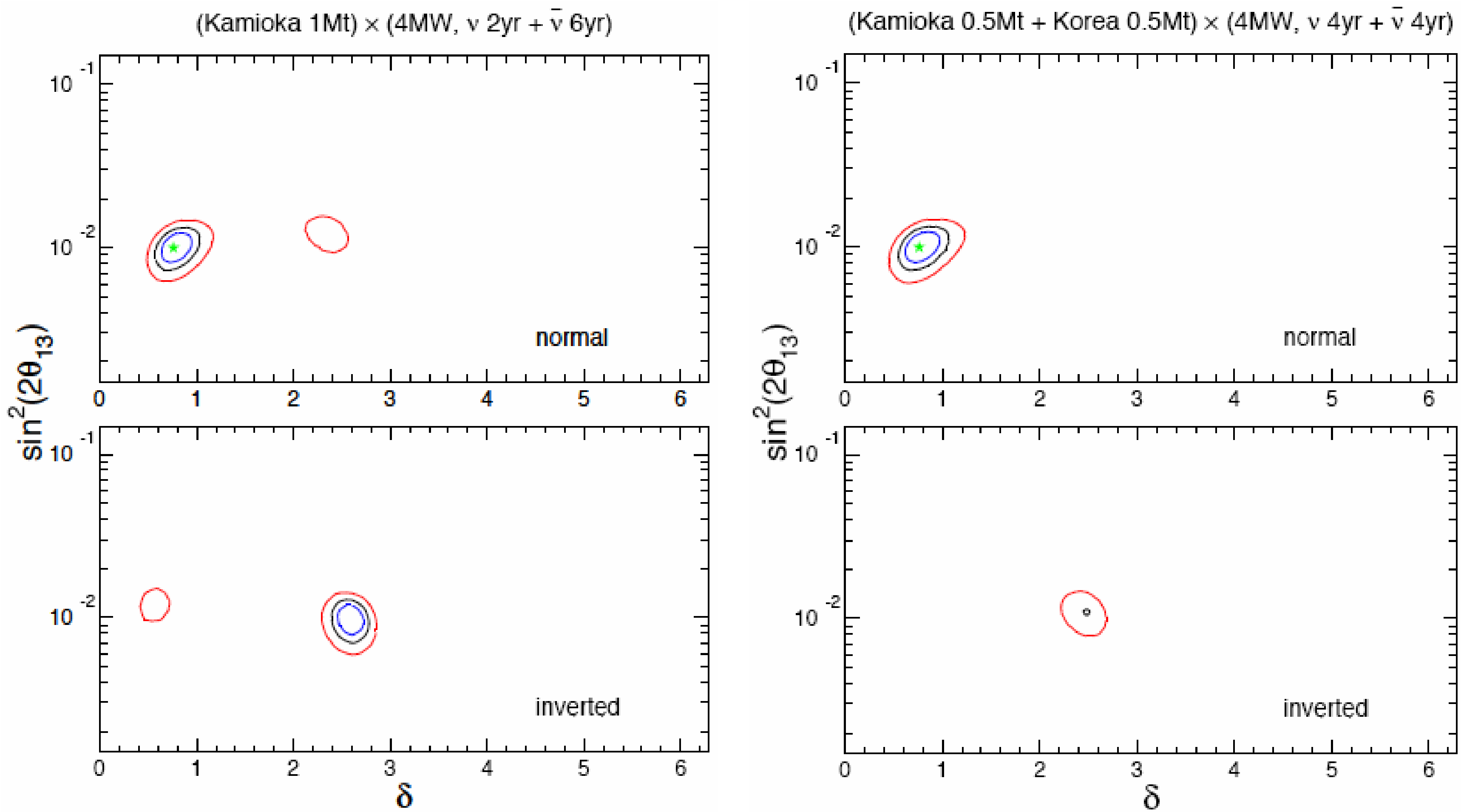
Sensitive to δ because energy dependence is far more dynamic in 2nd oscillation maximum



Spectral information solves degeneracy



Spectral information solves intrinsic degeneracy



χ^2 definition

detector x beam combination

e-like bins

μ-like bins

systematic error term

$$\chi^2 = \sum_{k=1}^{4}\left(\sum_{i=1}^{5}\frac{\left(N(e)_i^{\mathrm{obs}} - N(e)_i^{\mathrm{exp}}\right)^2}{\sigma(e)_i^2} + \sum_{i=1}^{20}\frac{\left(N(\mu)_i^{\mathrm{obs}} - N(\mu)_i^{\mathrm{exp}}\right)^2}{\sigma(\mu)_i^2}\right) + \sum_{j=1}^{7}\left(\frac{\epsilon_j}{\tilde{\sigma}_j}\right)^2$$

$$N(e)_i^{\mathrm{exp}} = N(e)_i^{\mathrm{BG}}\cdot(1+\sum_{j=1,2,7} f(e)_j^i\cdot\epsilon_j) + N(e)_i^{\mathrm{signal}}\cdot(1+\sum_{j=3,7} f(e)_j^i\cdot\epsilon_j)$$

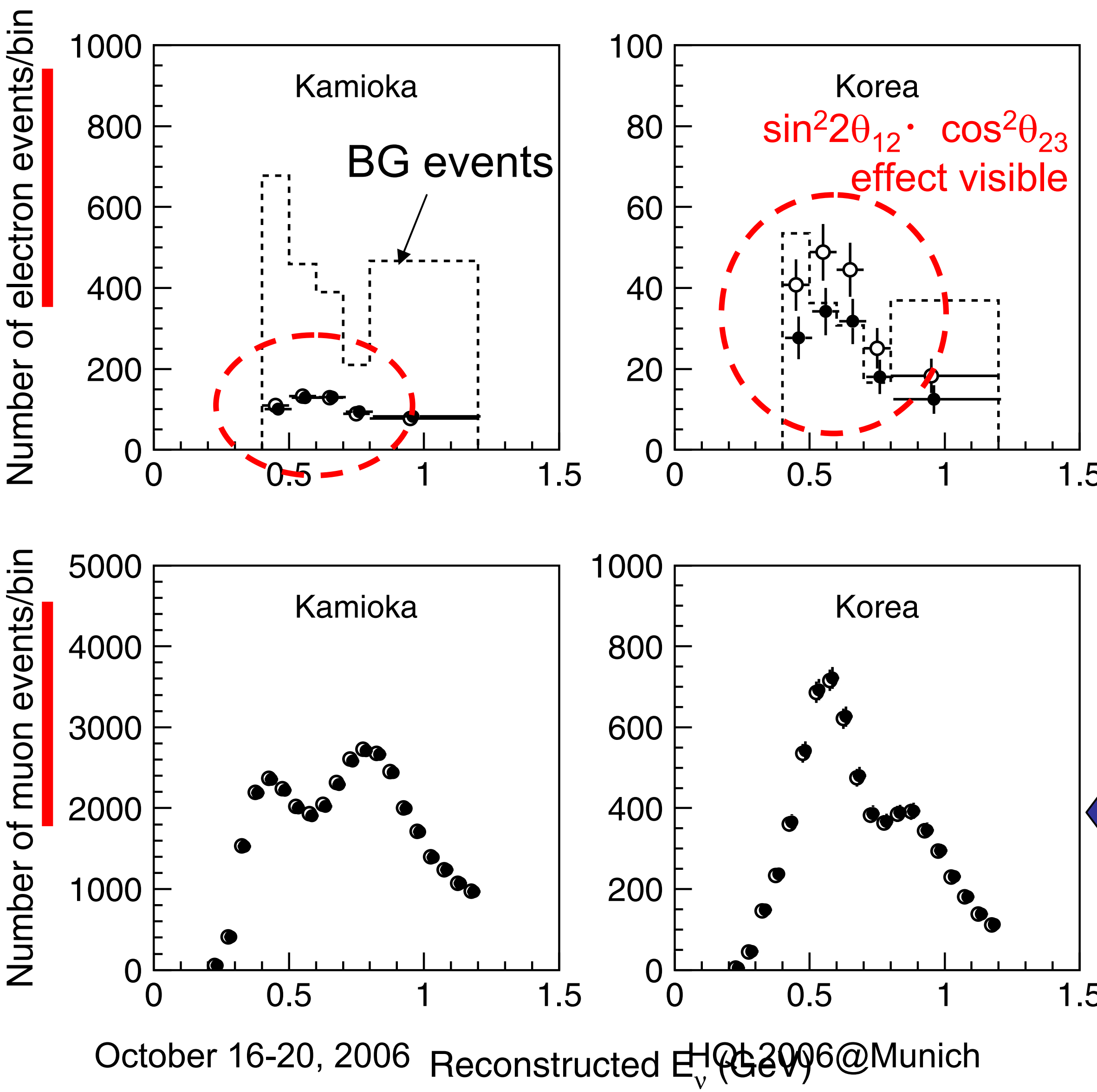
$$N(\mu)_i^{\mathrm{exp}} = N(\mu)_i^{\mathrm{BG}}\cdot(1+\sum_{j=4,5,7} f(\mu)_j^i\cdot\epsilon_j) + N(\mu)_i^{\mathrm{signal}}\cdot(1+\sum_{j=5,6,7} f(\mu)_j^i\cdot\epsilon_j)$$

f^i_j : fractional change in the predicted event rate in the i^{th} bin due to a variation of the parameter ε_j

ε_j : systematic error parameters, which are varied to minimize χ^2 for each chioce of the oscillation parameters

"Pull Approach" G.L.Fogli et al. PRD66 (2002) 053010

Effect of the solar term



○$\sin^2\theta_{23} = 0.4$,
$\sin^2 2\theta_{13} = 0.01$
●$\sin^2\theta_{23} = 0.6$,
$\sin^2 2\theta_{13} = 0.0067$
(These parameters are chosen to so that $\sin^2\theta_{23} \cdot \sin^2 2\theta_{13}$ is equal.)

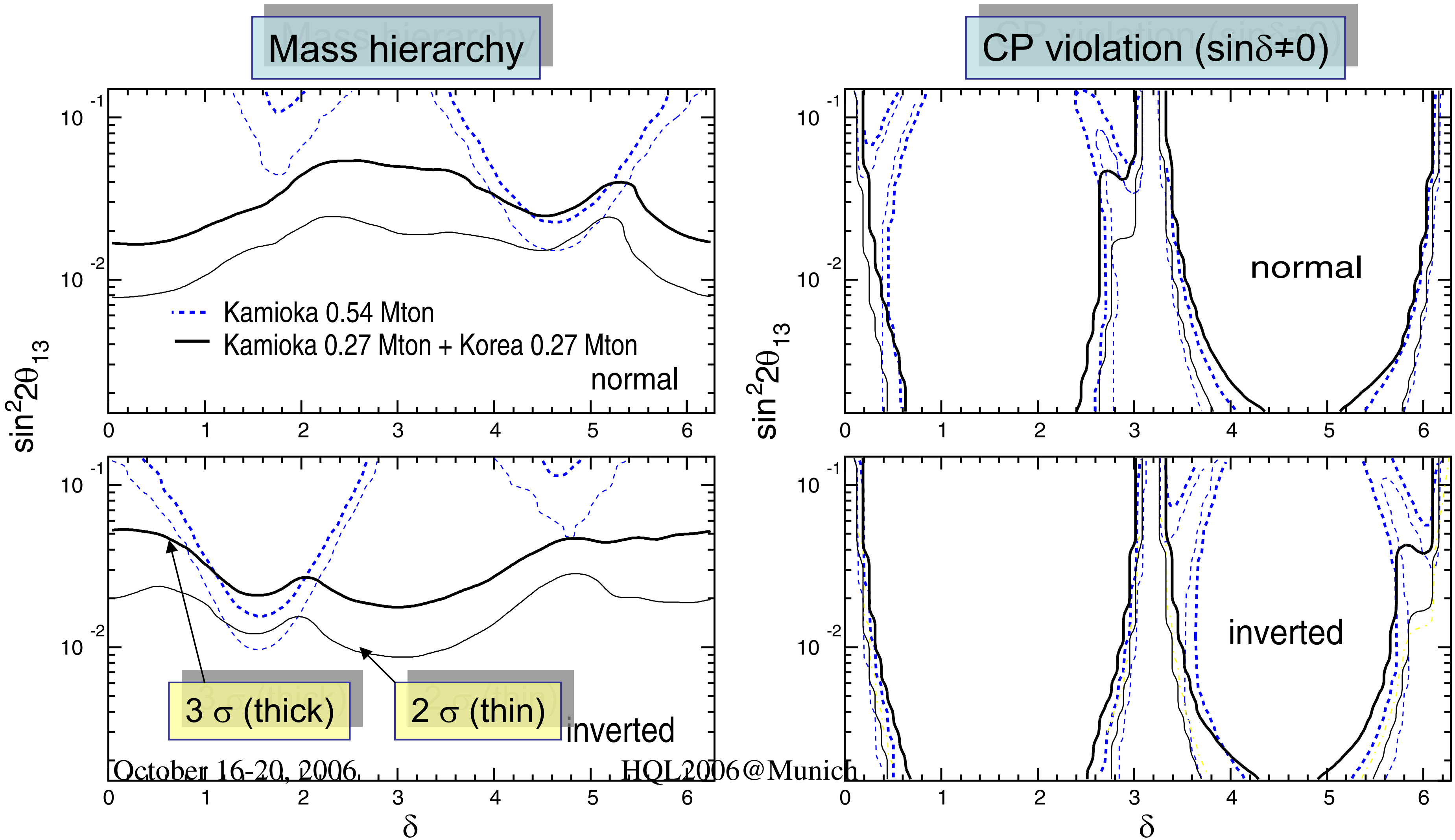
Δm^2: positive
$\delta = \pi 3/4$

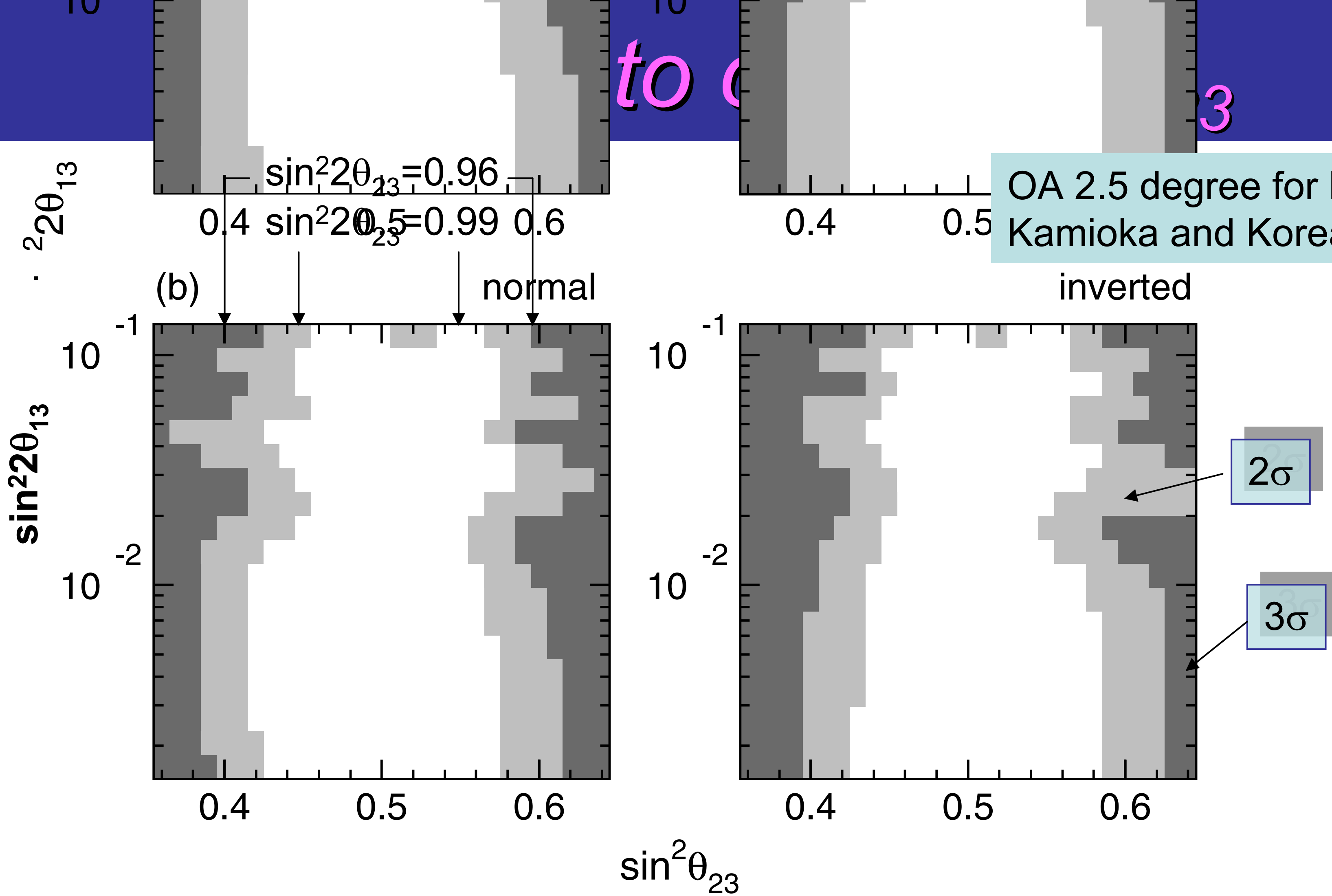
Included in this analysis, since θ_{23} is relevant.

T2KK vs. T2K II Comparison

hep-ph/0504026

Total mass of the detectors = 0.54 Mton fid. mass
4 years neutrino beam + 4 years anti-neutrino beam





OA 2.5 degree for both Kamioka and Korea

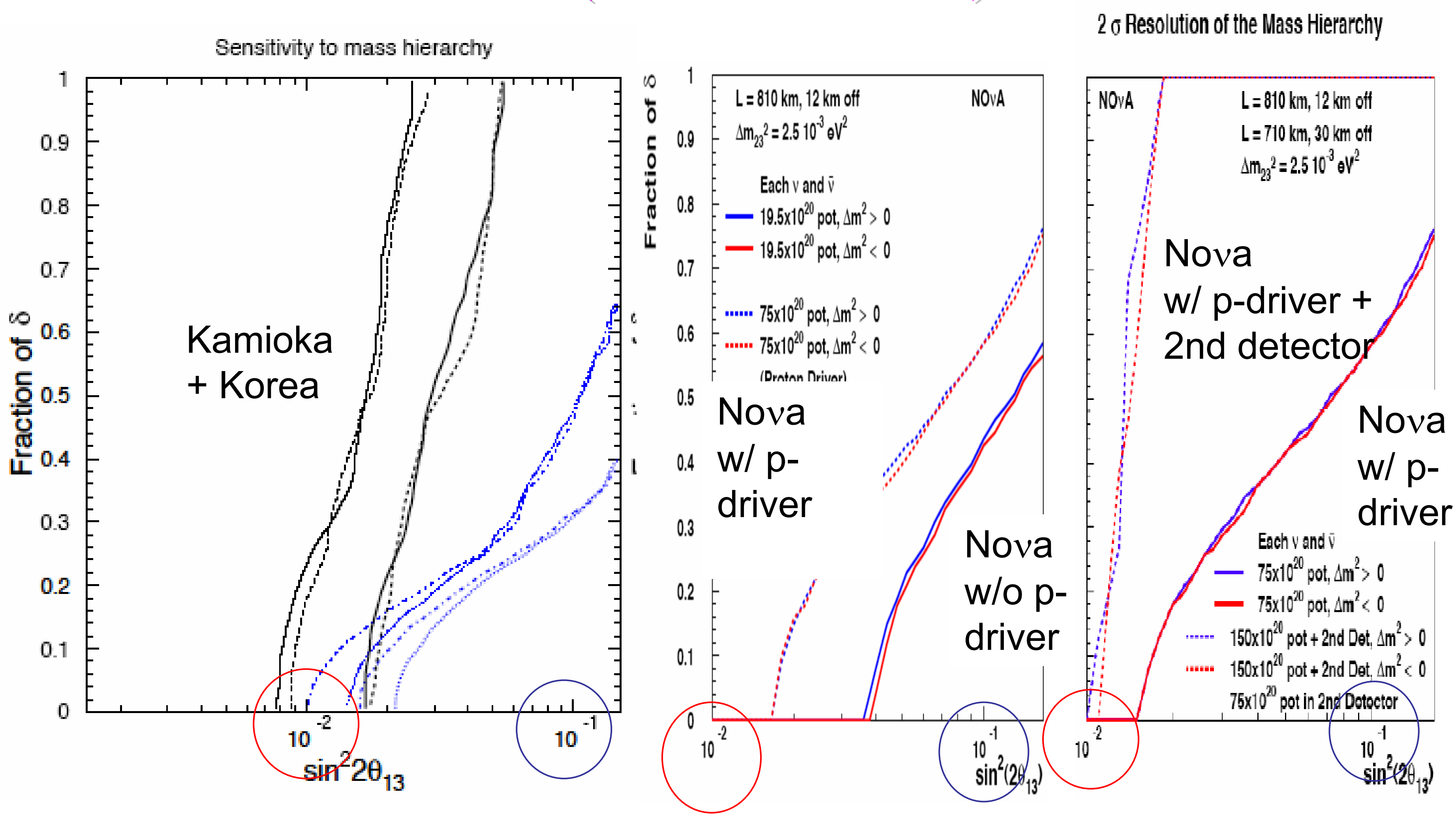
Octant ambiguity of θ_{23} can be resolved if $\sin^2 2\theta_{23} < \sim 0.97$ at 2σ (almost independent of the value of $\sin^2 2\theta_{13}$ and mass hierarchy).

Can resolve the 8 fold degeneracy of the oscillation parameters.

In a nutshell, 8 fold degeneracy can be resolved by T2KK because ..

- intrinsic degeneracy is resolved by spectrum information
- sign-Δm^2 degeneracy is solved with matter effect + 2 identical detector comparison
- θ_{23} octant degeneracy is solved by identifying the solar oscillation effect in T2KK

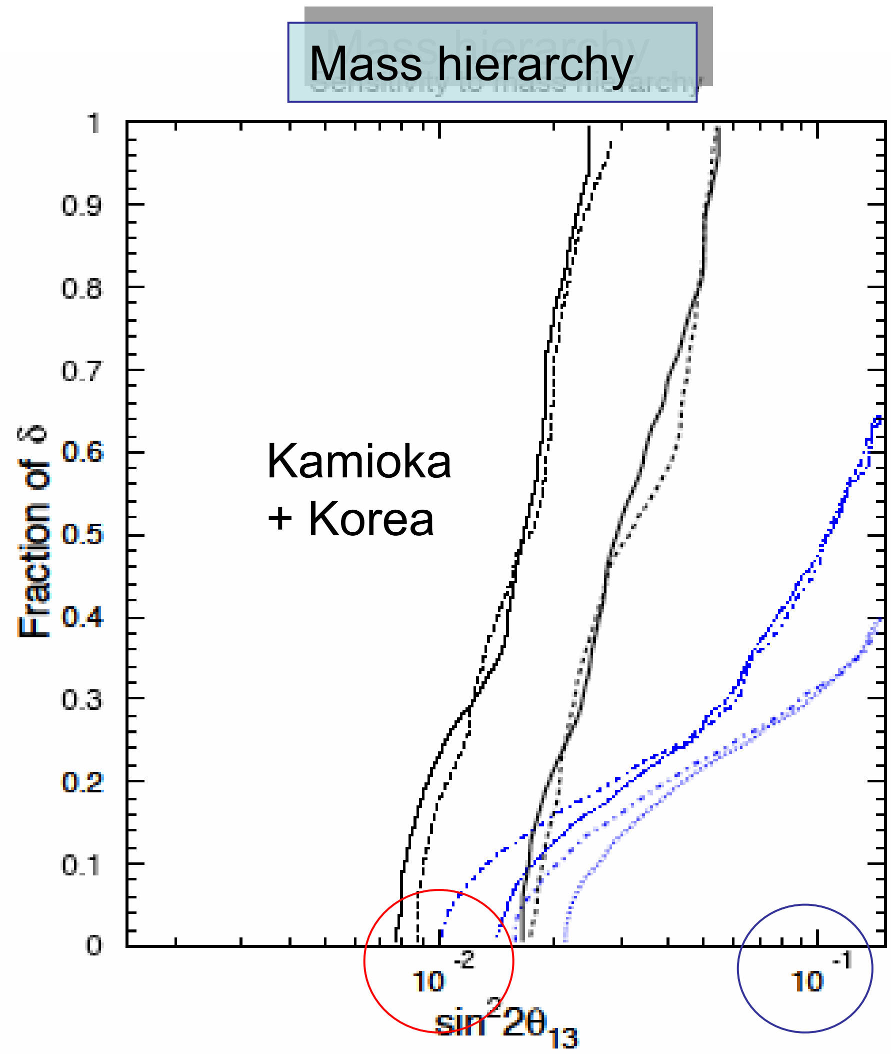
Sensitivity to mass hierarchy: T2K-II vs. (Kam+Korea) vs. Nova

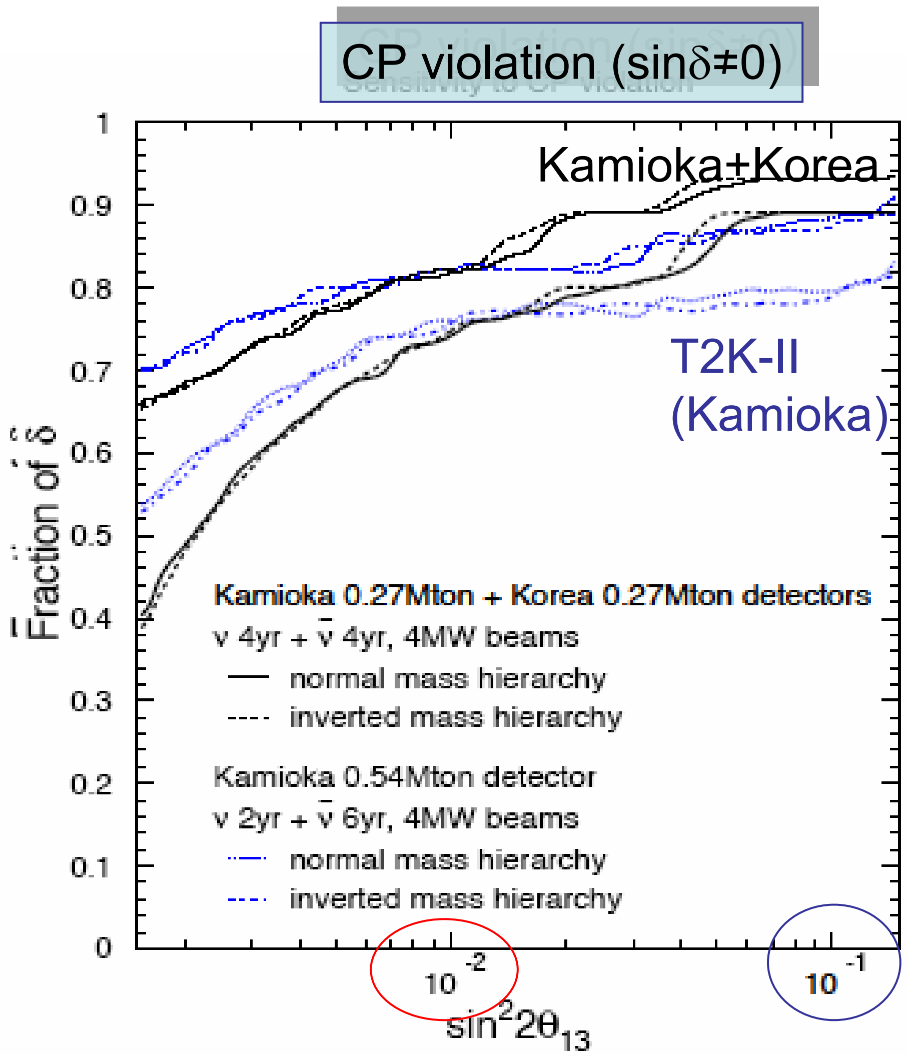


Expected sensitivity (2)

hep-ph/0504026

Total mass of the detectors = 0.54 Mton fid. mass
4 years neutrino beam + 4 years anti-neutrino beam





Beta beam

Beta beam in a word

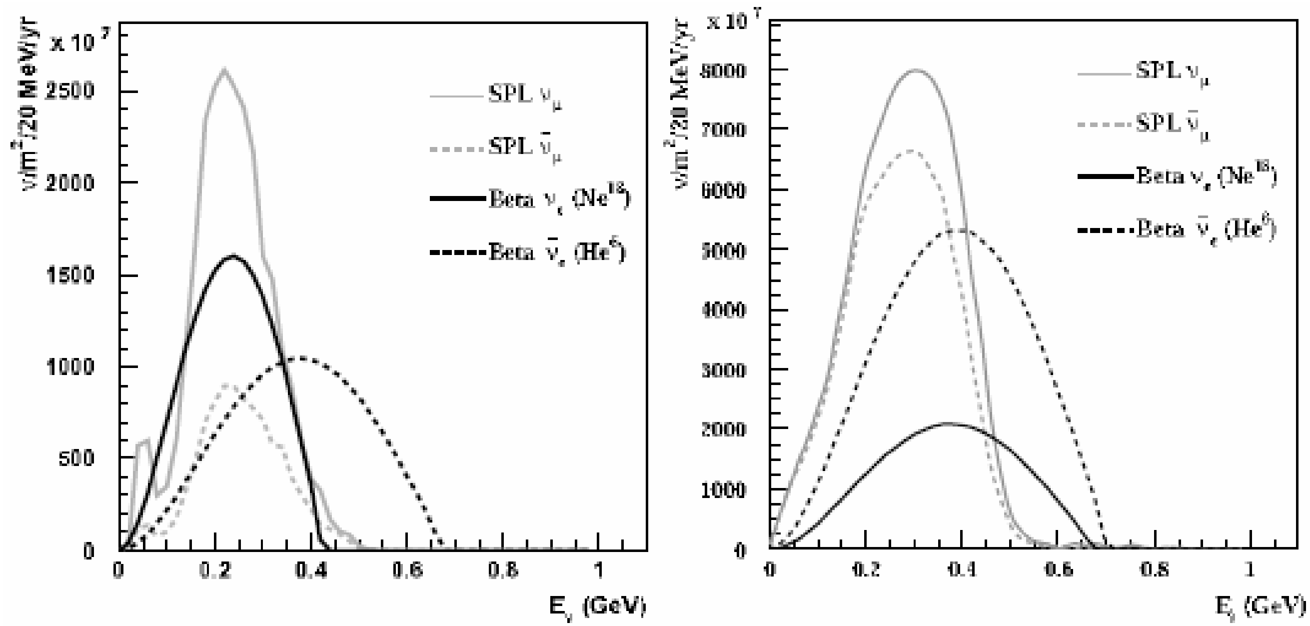


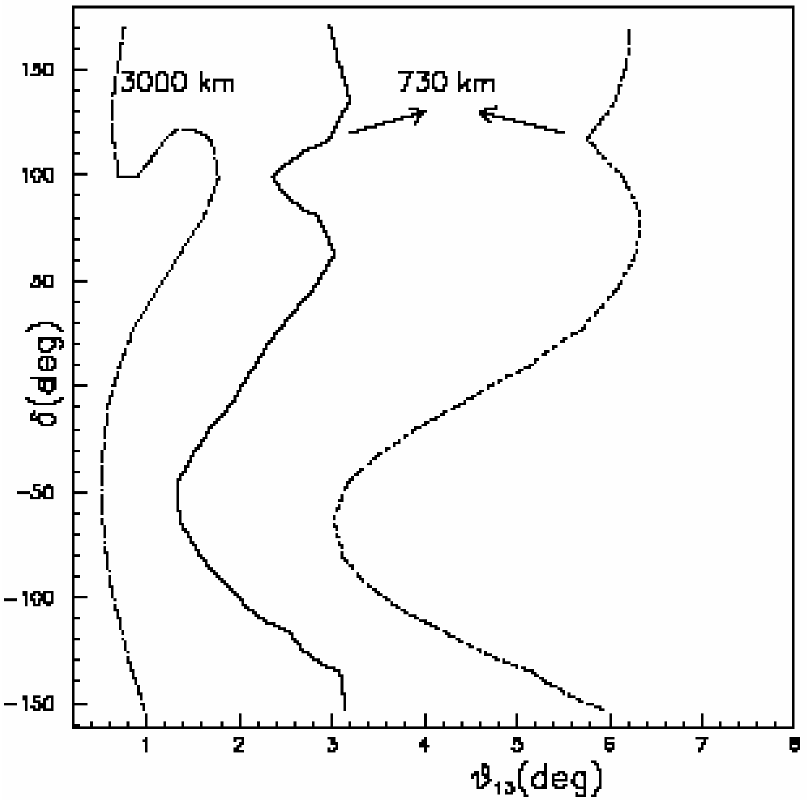
Figure 6. Comparison of neutrino fluxes from a super-beam (SPL) and a beta-beam. The neutrino beams are produced at CERN and sent to the Fréjus Underground Laboratory, 130 km from CERN. Two options for the beta-beam are shown here. Left: The ions circulate together in the storage ring, with $\gamma = 60$ (100) for ^{6}He (^{18}Ne) (Mezzetto 2005). Right: The ions circulate at the same $\gamma = 100$, independently, in the storage ring. Note that the average neutrino energies are related to the ion boost through $E_\nu \approx 2\gamma Q_\beta$ (Guglielmi *et al* 2005).

What is good in Beta beam?

- pure ν_e (^{18}Ne) or ν_e-bar (^{6}He) beam
- charged pion background seems tolerable
- e-μ separation required but no charge ID required
- multi-MW proton beam NOT required

Low vs. high γ beta beam

- Setup I, low energy: $\gamma = 60$ for ^{6}He and $\gamma = 100$ for ^{18}Ne, with $L = 130$ km (CERN–Fréjus) as in [12, 22]. [7]
- Setup II, medium energy: $\gamma = 350$ for ^{6}He and $\gamma = 580$ for ^{18}Ne, with $L = 732$ km (e.g. CERN–Gran Sasso with a refurbished SPS or with the LHC, FNAL–Soudan).
- Setup III, high energy: $\gamma = 1500$ for ^{6}He and $\gamma = 2500$ for ^{18}Ne, with $L = 3000$ km (e.g. CERN–Canary islands with the LHC).



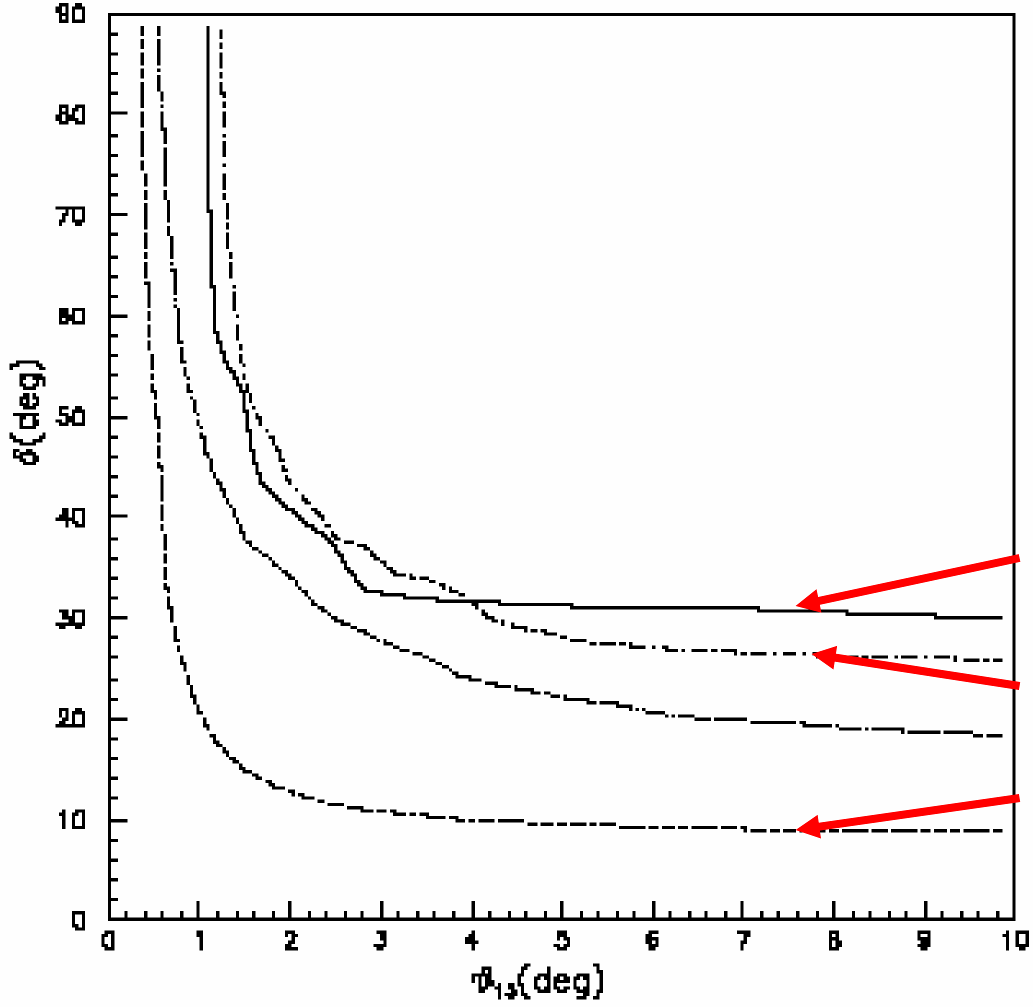
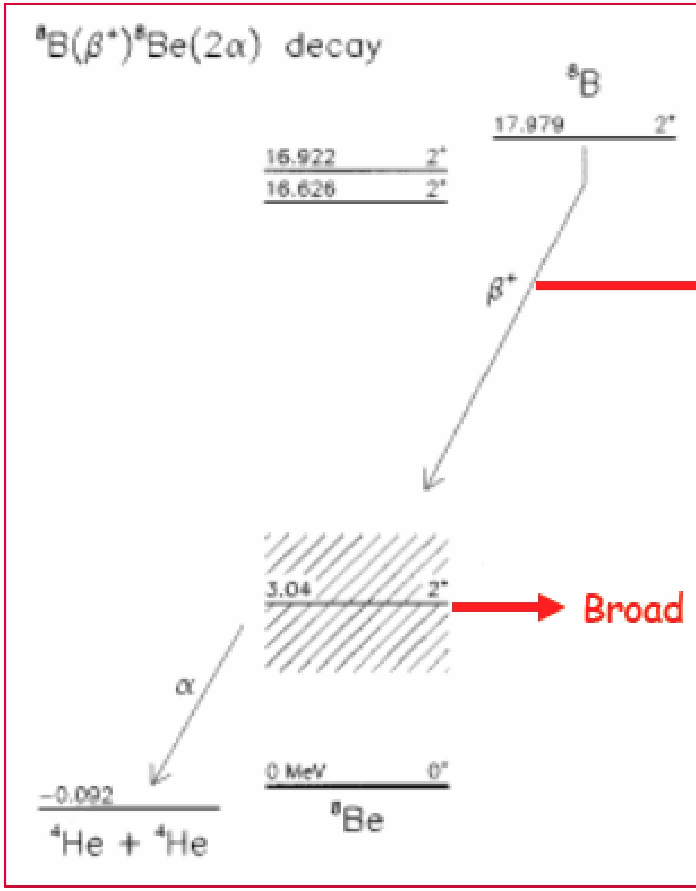
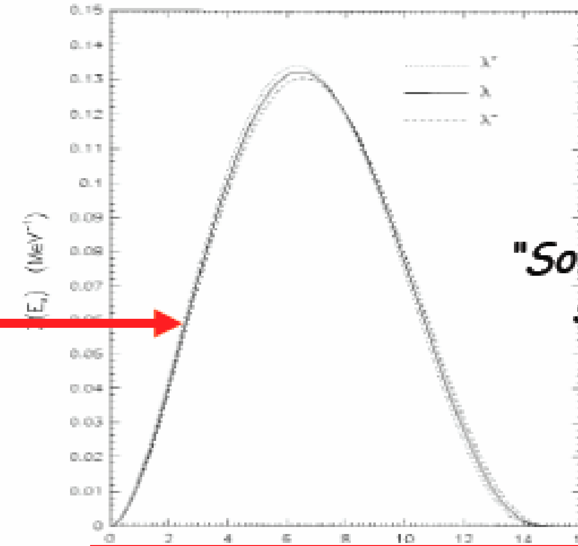


Figure 13: Region where δ can be distinguished from $\delta = 0$ or $\delta = 180^\circ$ with a 99% CL for setup I (solid), setup II with the UNO-type detector of 400 kton described in section 3.1 (dashed) and with the same detector with a factor 10 smaller mass (dashed-dotted) and setup III (dotted) with a 40 kton tracking calorimeter described in section 3.4.

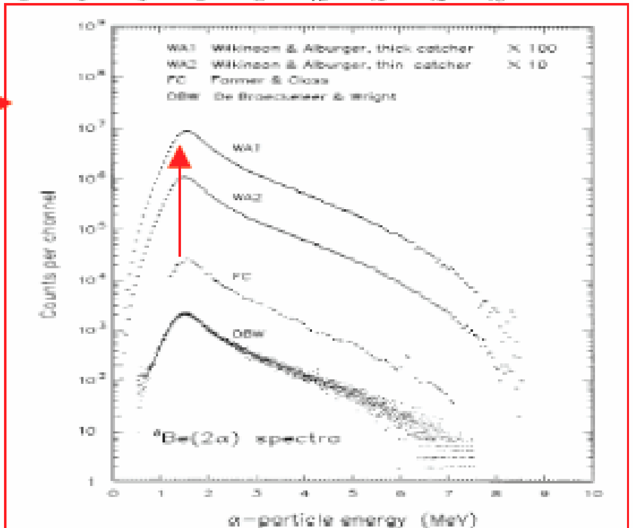
Neutrino spectrum from B-8 decay





"Solar neutrino" spectrum

Broad 2-a peak



J.N. Bahcall *et al.*
Phys Rev. C
54, 411 (1996)

Production with re-circulating ions

Production of unstable isotopes:

- Primary ions circulate in the beam until they undergo nuclear processes in the thin target foil.

Injection

- Permanent accumulation of primary ions: Single ionized ions are fully stripped by a thin foil.

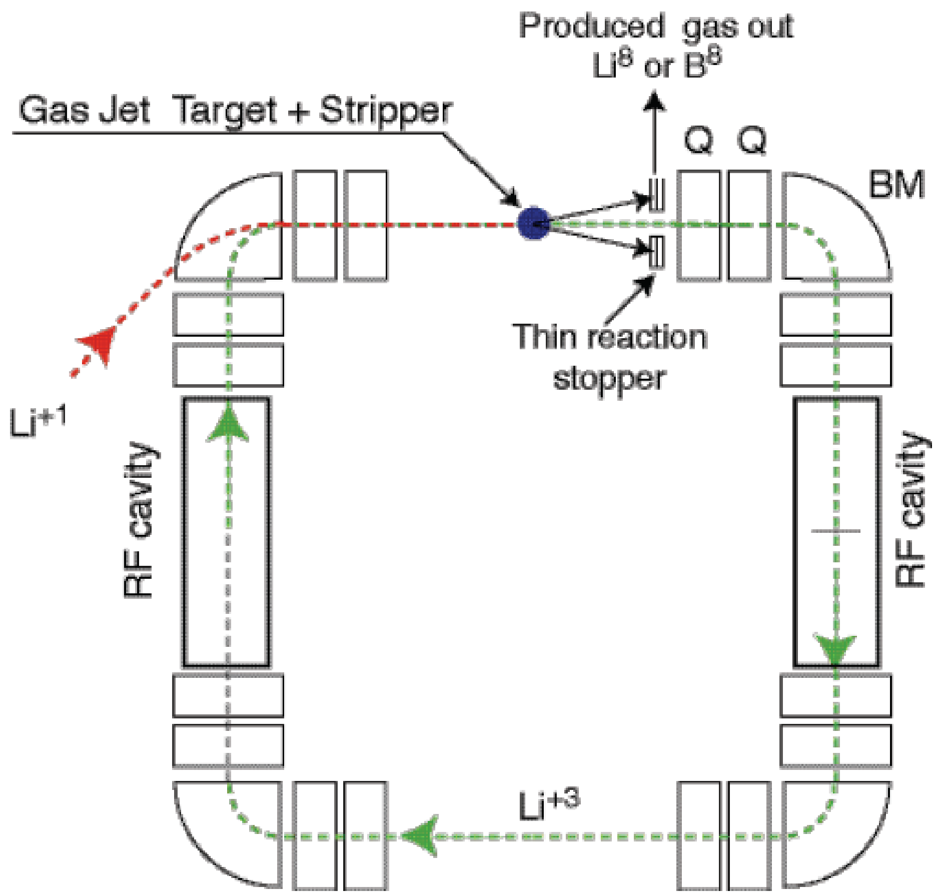
Compensating ionization losses:

- Acceleration at each turn by an adequate RF-cavity

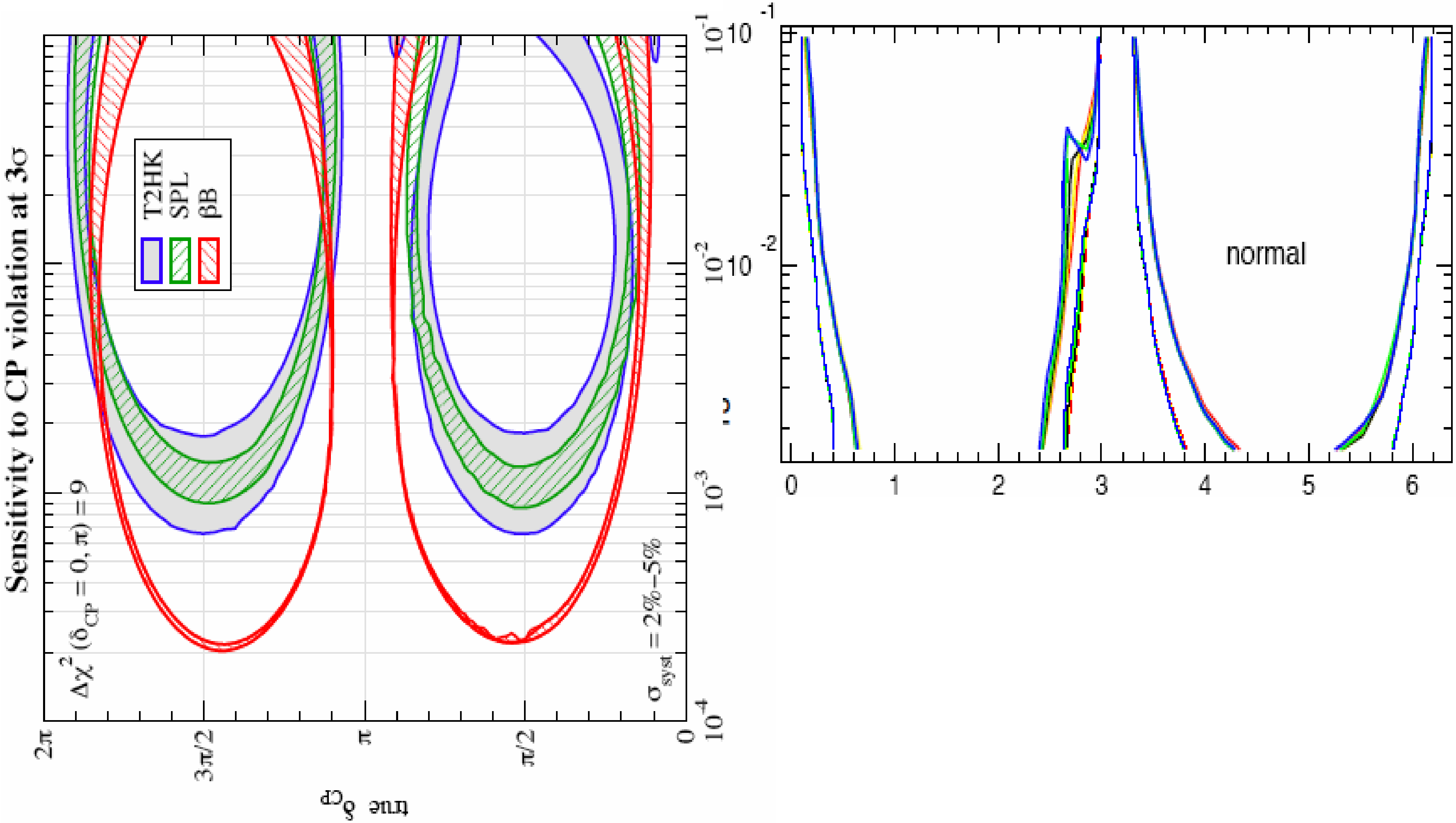
Ion channel:

- E.g.: $^{7}Li + D \rightarrow {}^{8}Li + p$
  - ^{8}Li: $t_{1/2}$~0.8 s, $<E_\nu>$~6.7MeV
- Rate: > 10^{14} ions/s

C. Rubbia et al. (see talk this week)



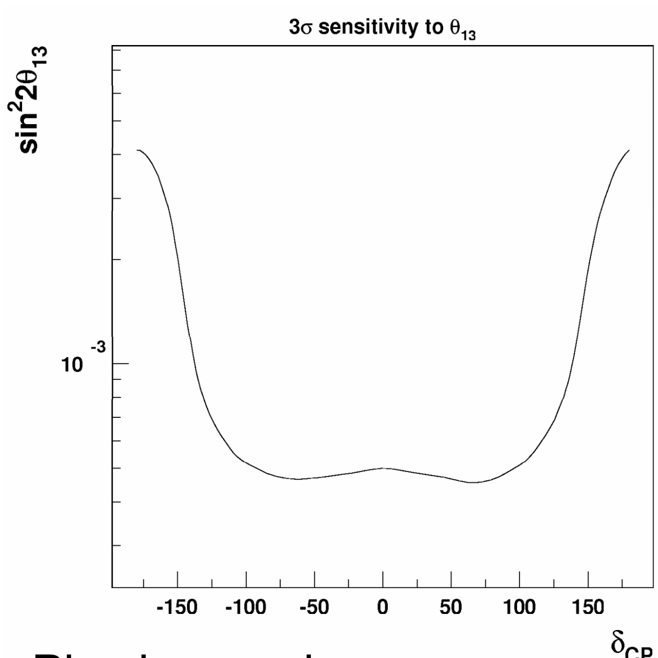
Beta vs. T2KK

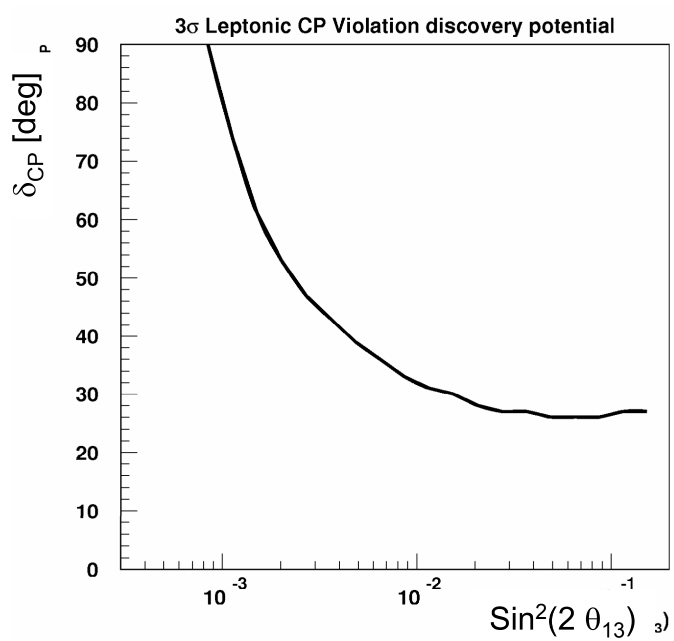


Sensitivity to CP violation at 3σ
T2HK
SPL
βB
$\Delta\chi^2(\delta_{CP} = 0, \pi) = 9$
$\sigma_{syst} = 2\%-5\%$
true δ_{CP}
normal

Physics reach; low γ

- EURISOL scenario
  - γ=100
  - each ^{6}He and ^{18}Ne with a 5-year run
  - 2.9*10^{18} ^{6}He decays/year or 1.1*10^{18} ^{6}Ne decays/year



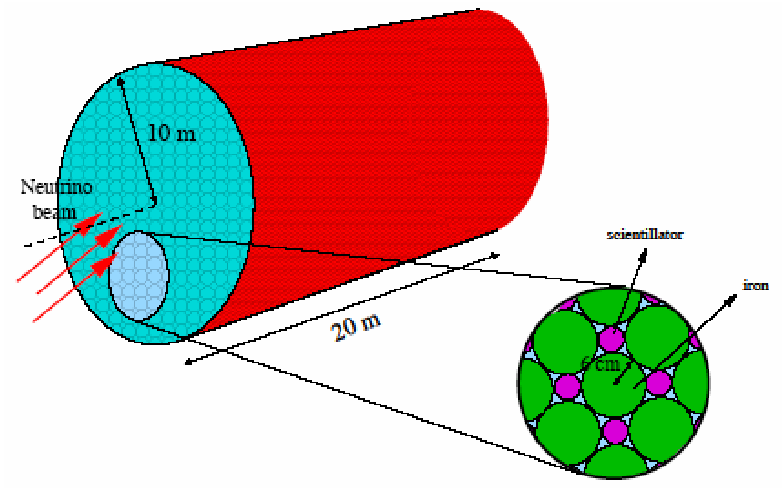


- Physics reach
  - Sensitivity on Θ_{13} down to ~1^{o}

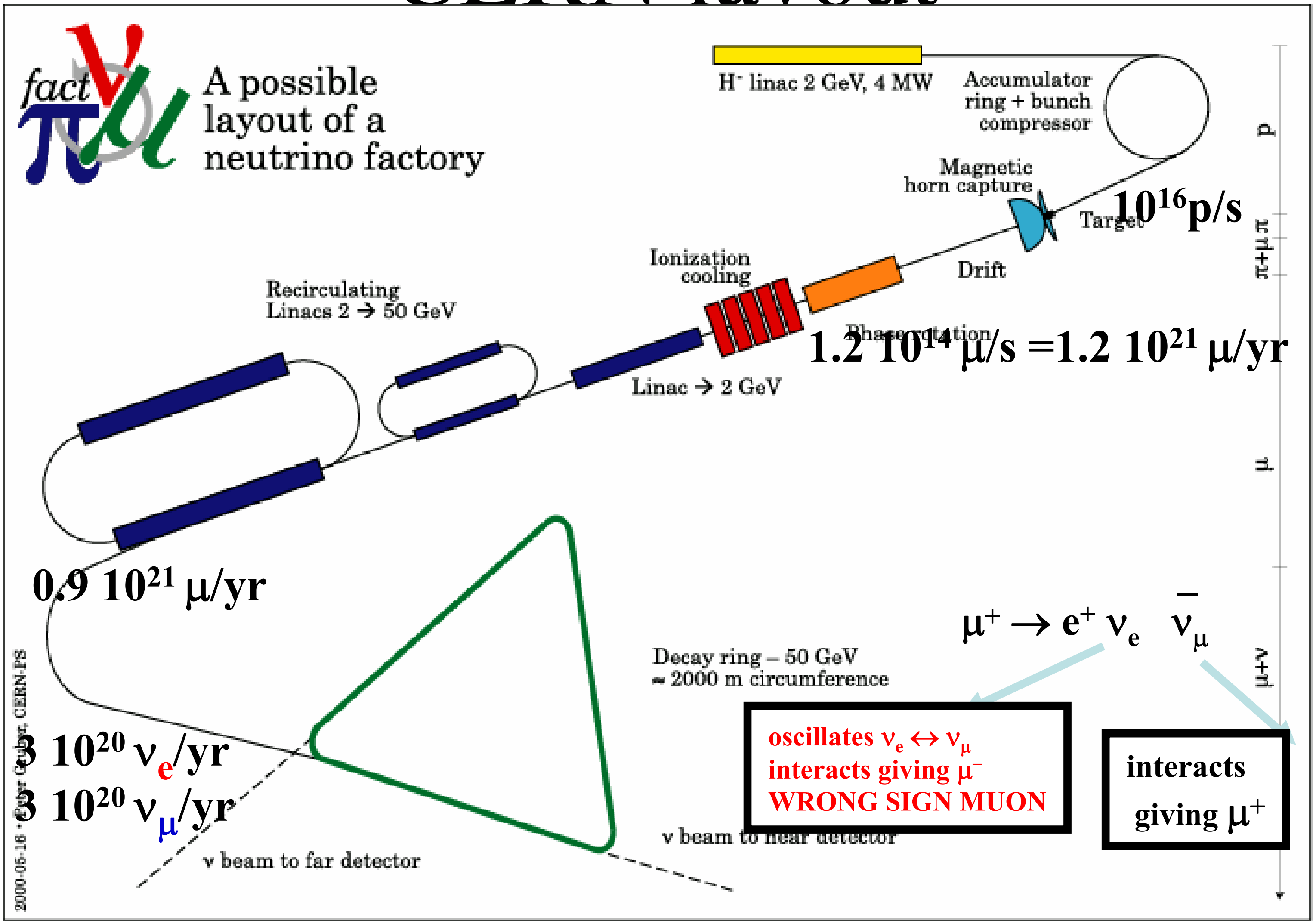
Neutrino factory

What is good in Neutrino factory ?

- well understood combination of ν_e and ν_μ beam with precisely ($\sim 10^{-5}$) known muon energy
- small background (how small, $10^{-4} - 10^{-5}$?)
- muon charge ID required
- multi-MW proton beam required



-- Neutrino Factory -- CERN layout



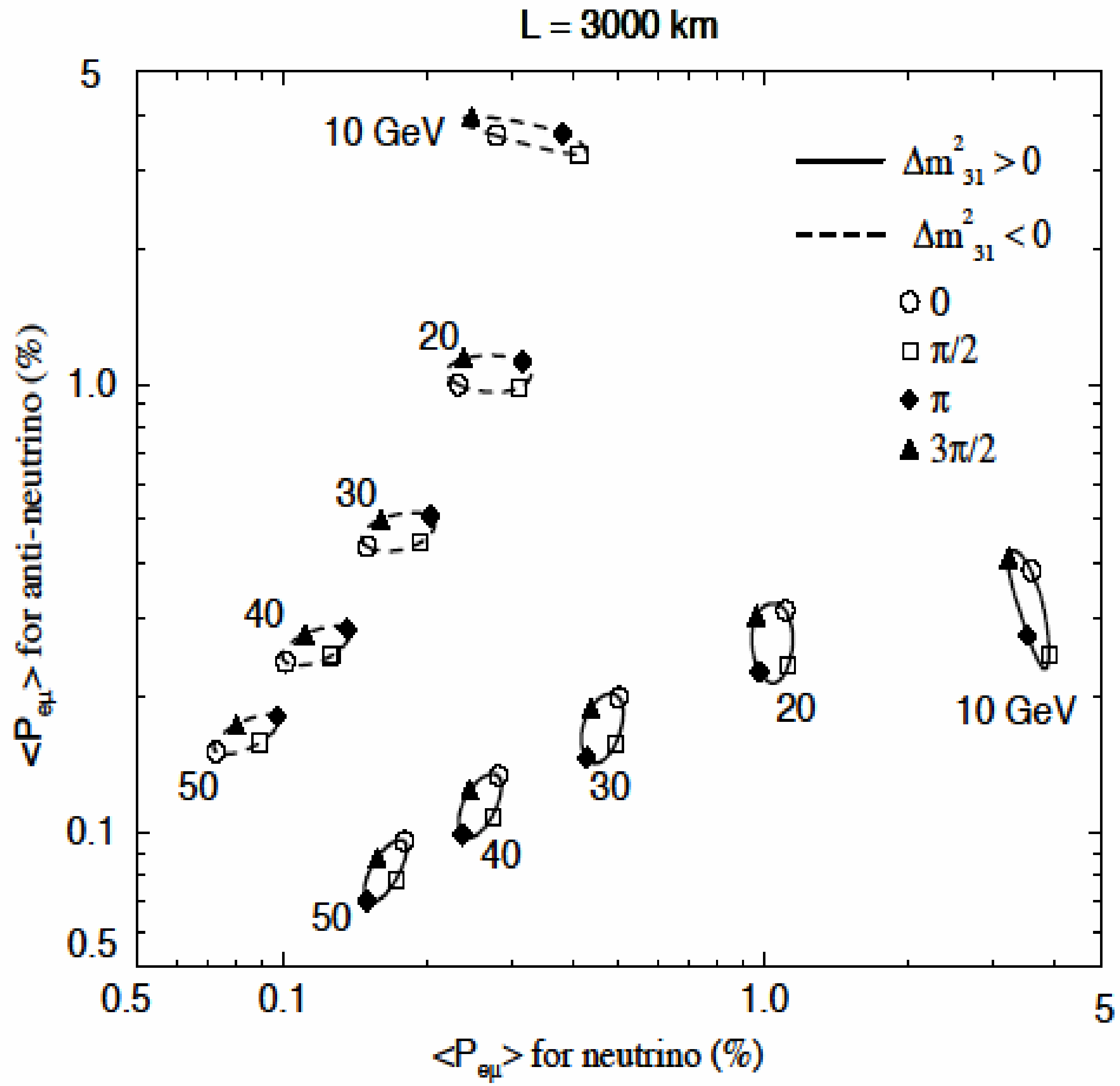
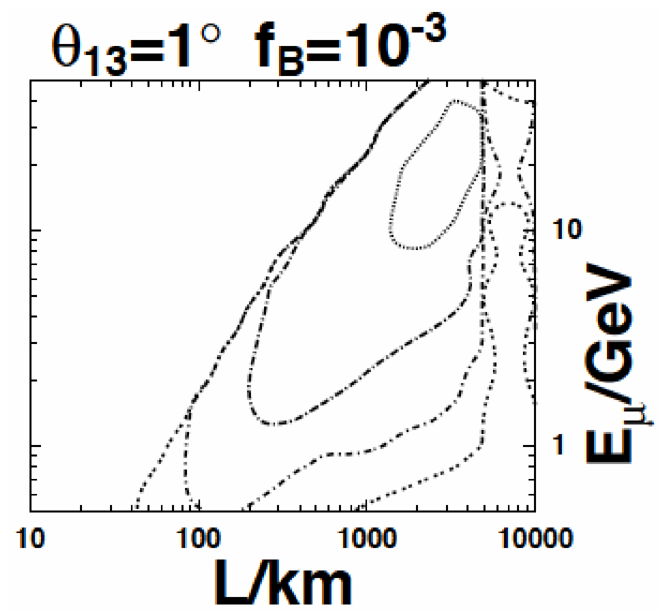


Figure 8: The CP trajectory diagram in bi-probability plane for $L = 3000$ km and much higher neutrino energies $E = 10-50$ GeV which correspond to so called "Neutrino Factory" situation. The mixing parameters are fixed to be the same as in figure 1 except that we take $\rho Y_e = 2.0$ g/cm^3.

Optimal energy E & baseline L

- $E = 30 \sim 50$ GeV
- $L \sim 3000$ km
- # of events = $(E^2 / L^2) \times E \times (L/E)$

$= (E^2 / L^2) \times L = (E / L) \times E$



Magic baseline or refraction length

$$P(\nu_\mu \to \nu_e) = \left|\sqrt{P_{atm}} + e^{i\left(\delta \pm \frac{\Delta_{31}}{2}\right)}\sqrt{P_{solar}}\right|^2$$

$$P_{atm} = \left(s_{13} s_{23} \Delta_{31} \frac{\sin\left(\frac{\Delta_{31} \mp aL}{2}\right)}{\left(\frac{\Delta_{31} \mp aL}{2}\right)} \right)^2$$

$$P_{solar} = \left(c_{12} s_{12} c_{23} \Delta_{21} \frac{\sin\left(\frac{aL}{2}\right)}{\left(\frac{aL}{2}\right)} \right)^2$$

$$\Delta_{31} \equiv \frac{|\Delta m^2_{31}|L}{2E}, \quad a = \sqrt{2} G_F N_e(x),$$

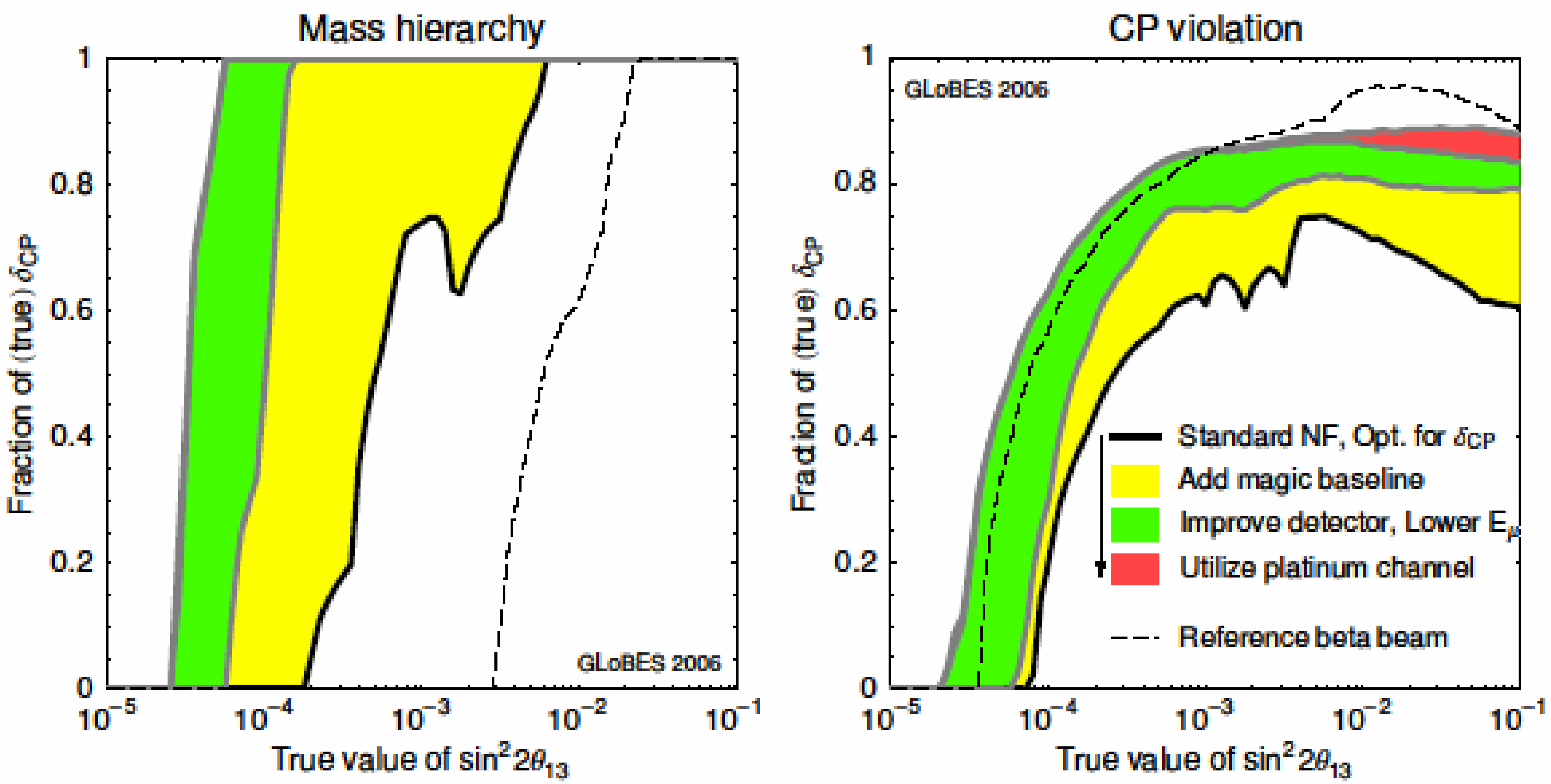
$$\pm = \text{sign of } \Delta m^2_{31}$$

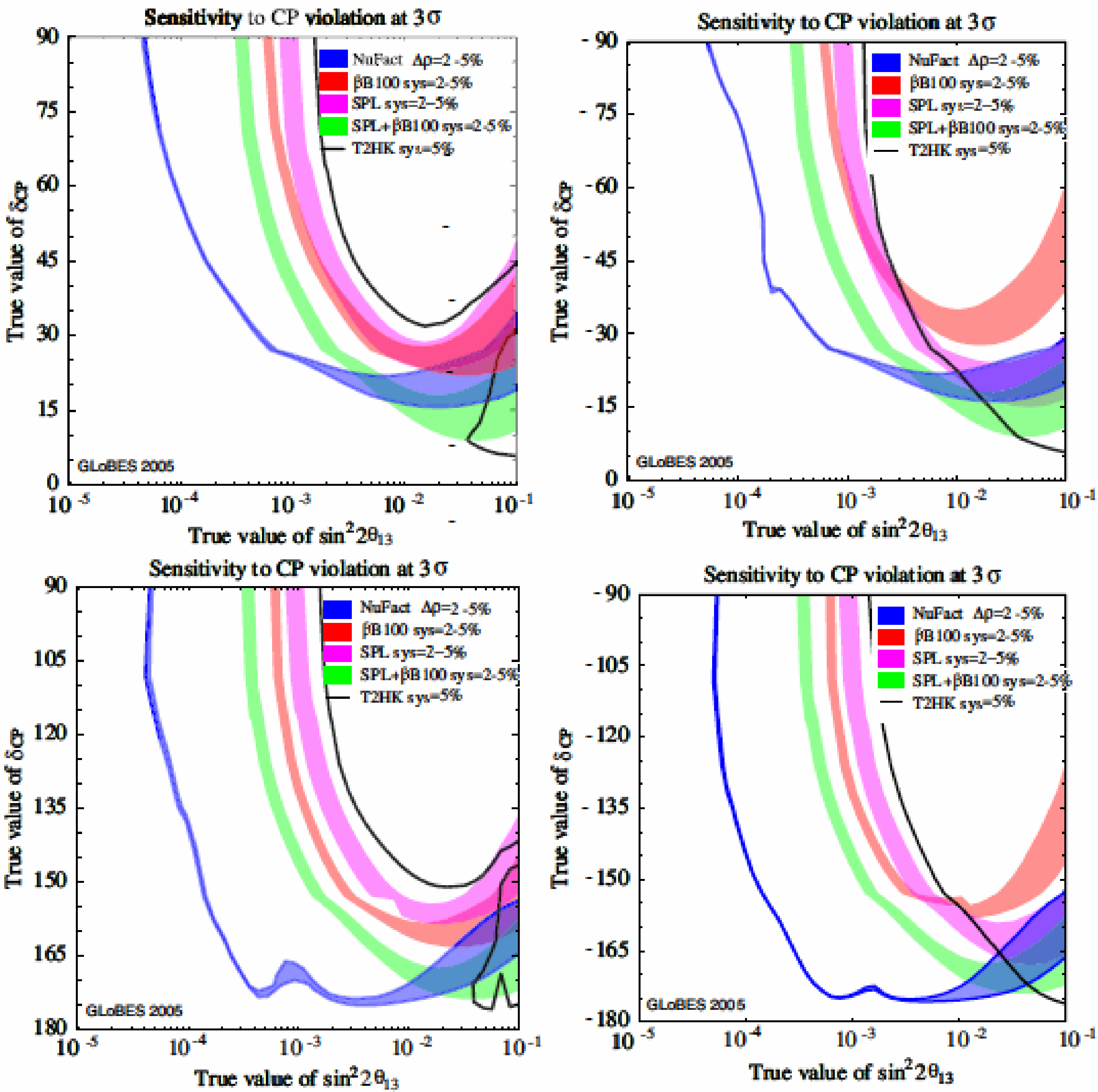
At $aL=2\pi$, P_{solar} vanishes --> No CP phase dependence

"magic baseline"

Help resolve degeneracy

Nufact sensitivity





Sensitivity to CP violation at 3σ
NuFact Δρ=2 -5%
βB100 sys=2-5%
SPL sys=2−5%
SPL+βB100 sys=2-5%
T2HK sys=5%
GLoBES 2005
True value of δCP
True value of sin²2θ13
Sensitivity to CP violation at 3σ
NuFact Δρ=2 -5%
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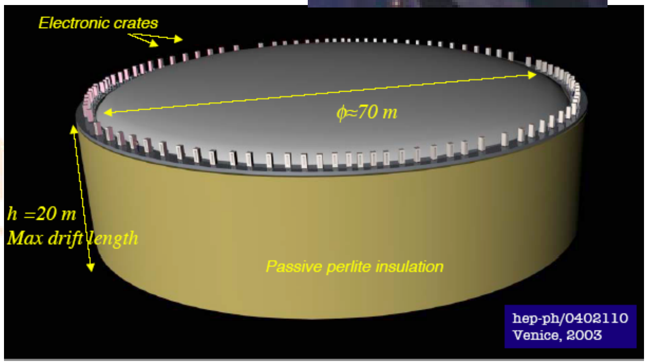
GLoBES 2005
True value of δCP
True value of sin²2θ13


SUNTORY
天然水
Natural
Mineral Water


KAPUZINER


KAPUZINER


Electronic crates
ϕ≈70 m
h =20 m
Max drift length
Passive perlite insulation
hep-ph/0402110
Venice, 2003

Conclusion

- The next-generation and some future options for LBL experiments are reviewed
- still long way to complete the MNS matrix; θ_{13} first, and then δ and mass hierarchy
- T2KK is powerful enough to solve 8-fold parameter degeneracy in situ
- if $\theta_{13} < 3^o$, we need β beam and/or neutrino factory; the choice is highly debatable -> exciting possibilities because the small θ_{13} may imply "symmetry"