Extracting the parameters of the PMNS matrix from future neutrino oscillation experiments III

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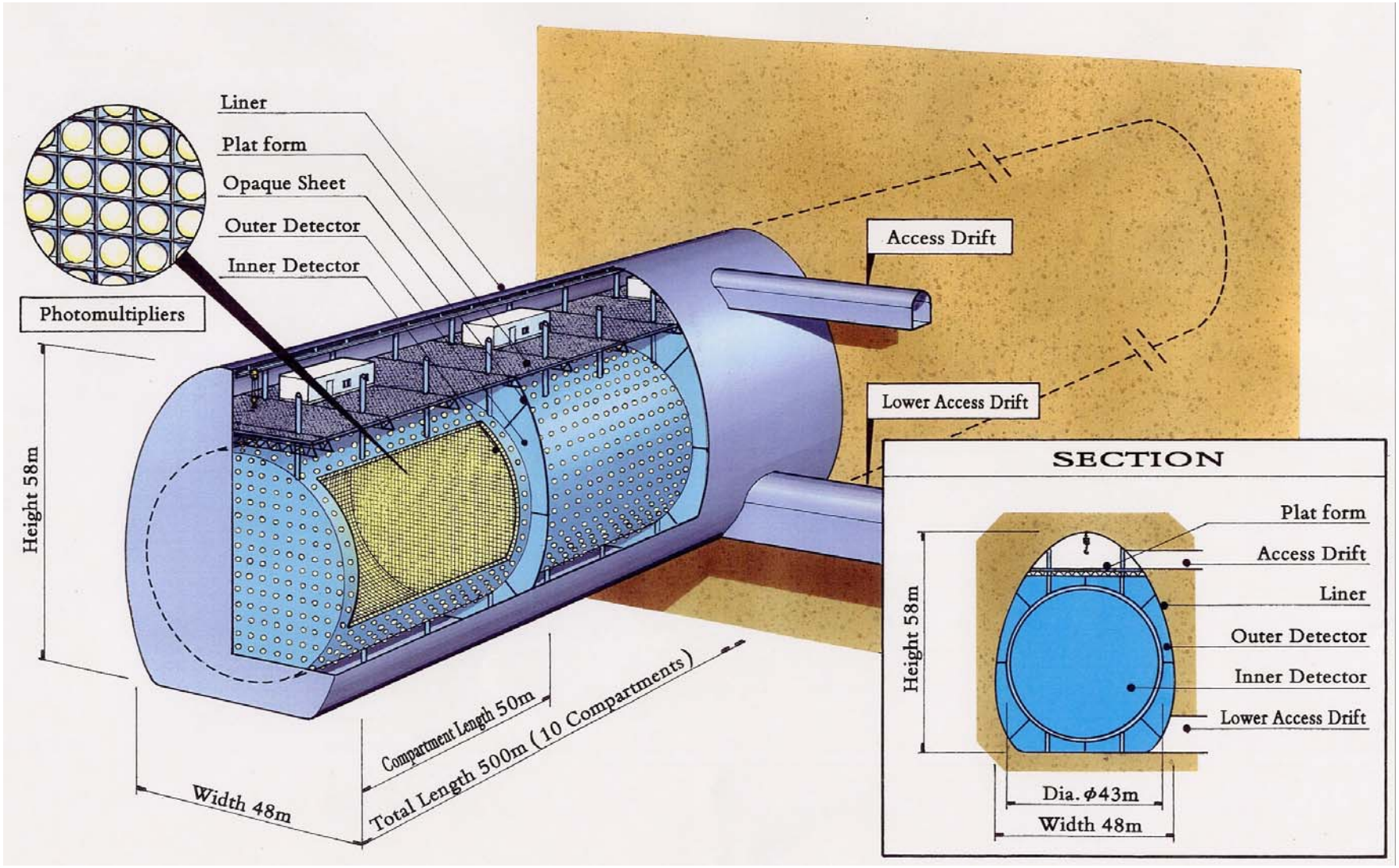
Original results presented in this talk based on work done in collaboration with P. Hernández, J. Burguet-Castell & D. Casper

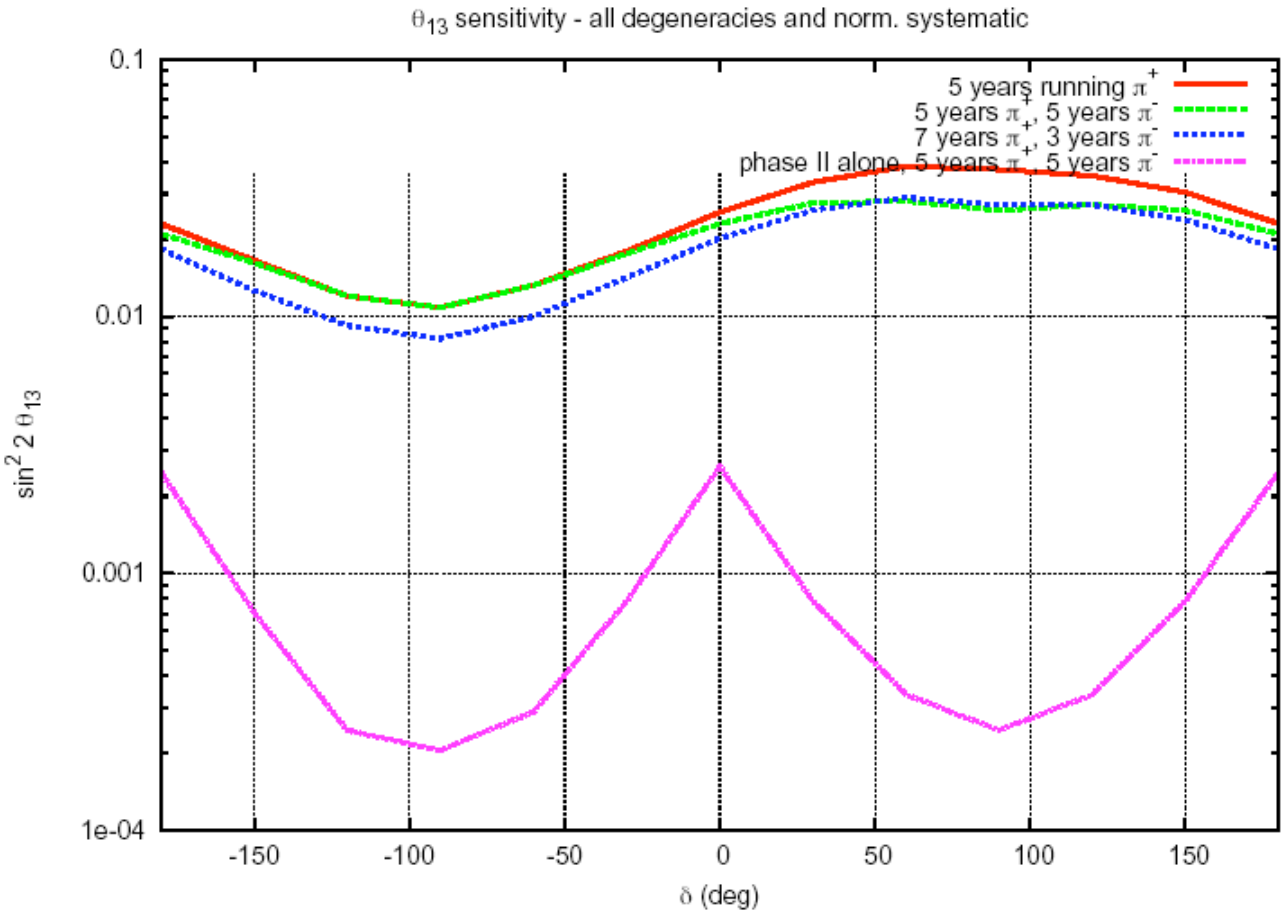
T2K Phase II

Phase-I (0.75MW + Fully reconstructed Super-K)~K2K x 100
Phase-II (4MW+Hyper-K) ~ Phase-I×100

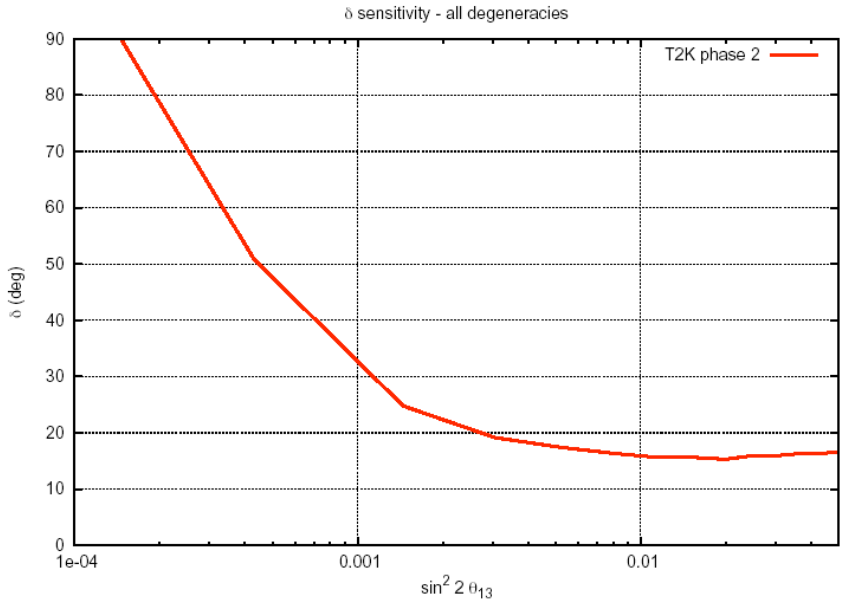
MTON water detector

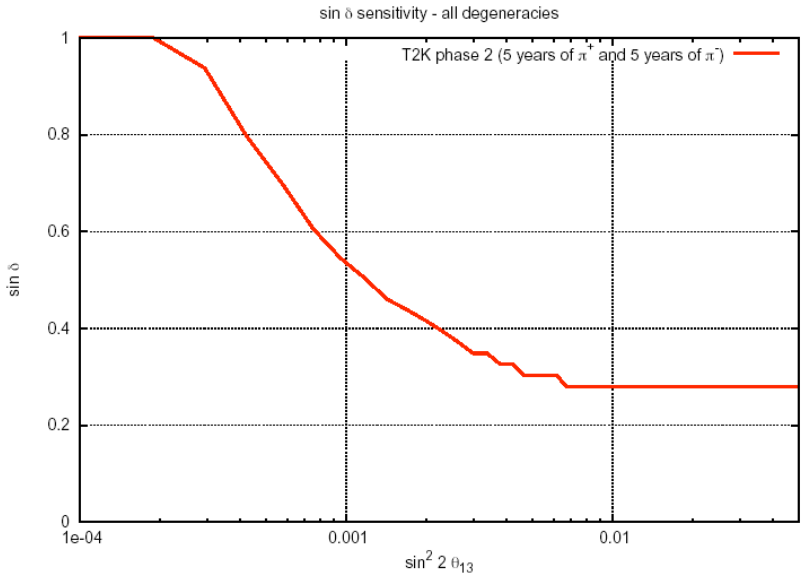


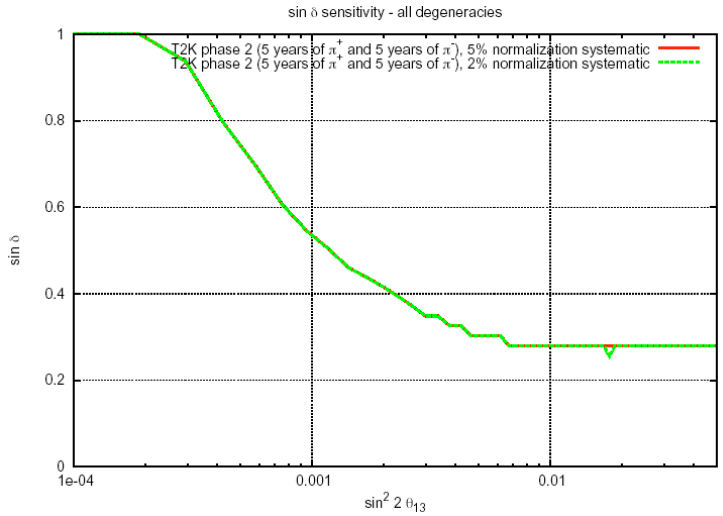
Sensitivity to θ_{13}



Sensitivity to δ

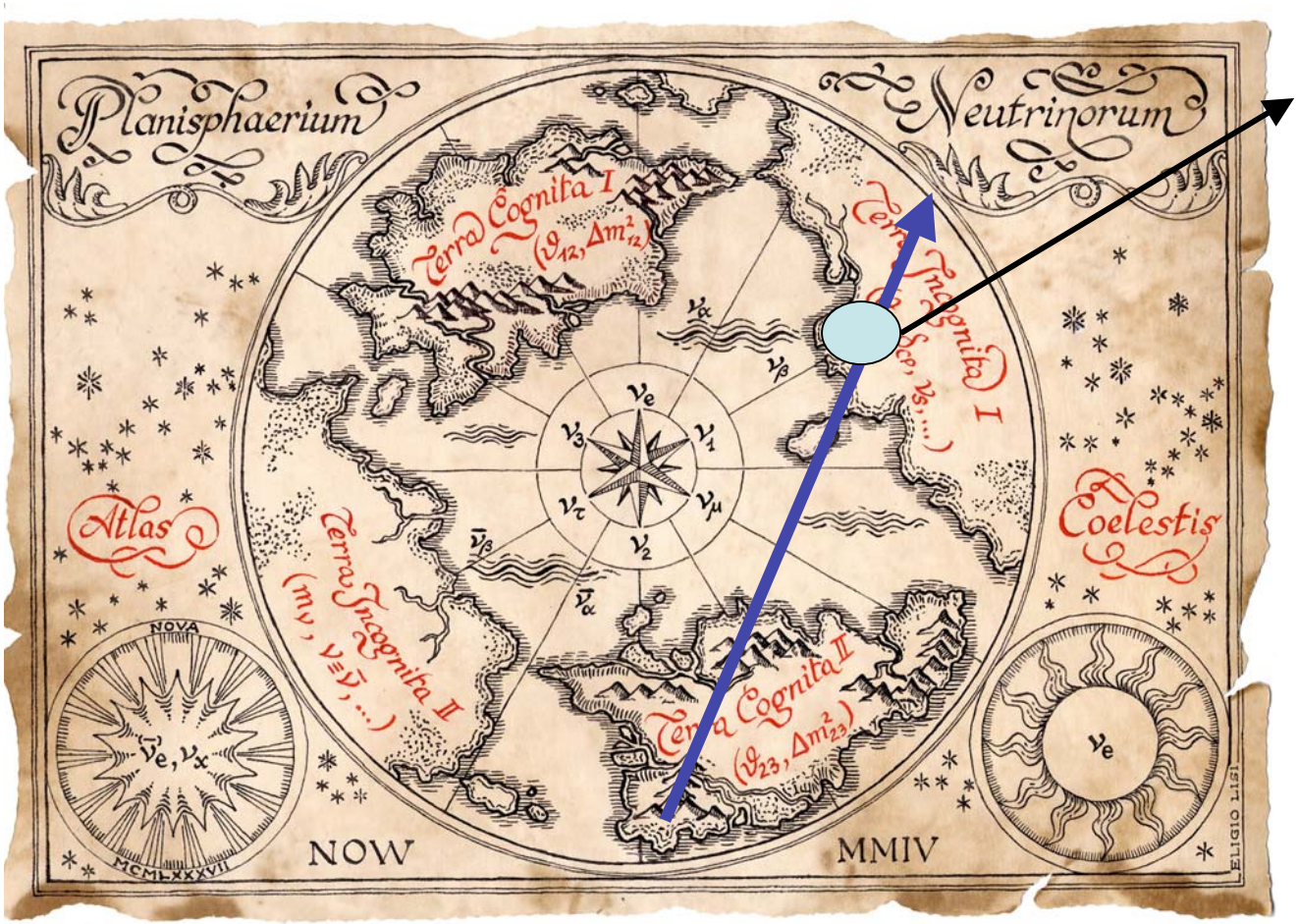






Neutrino Factories and Beta Beams

(2020--)



Measure (θ_{13},δ)

Neutrino mass hierarchy

CP violation phenomena

Fluxes from muon and radioactive β ions decay

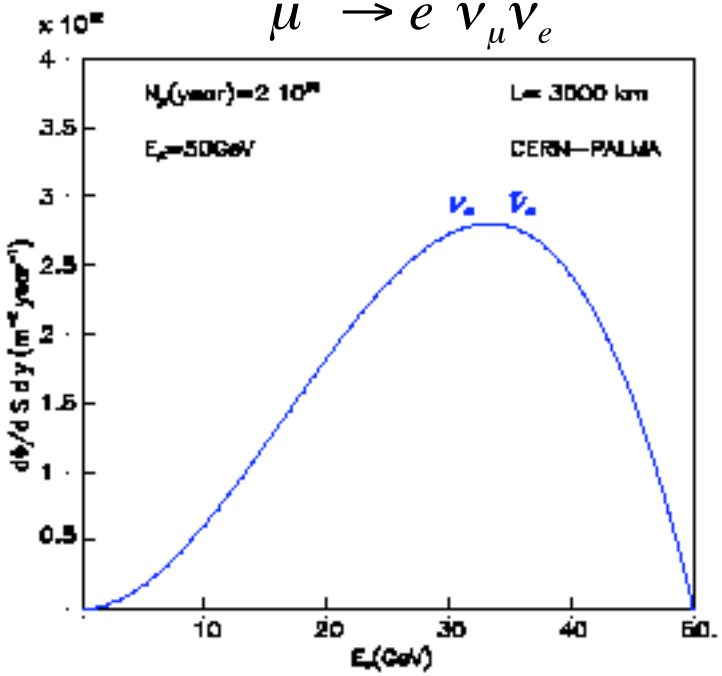
$$\left.\frac{d\Phi}{dSdy}\right|_{\theta\approx 0} \approx \frac{N_\mu}{\pi L^2} 12\gamma^2 y^2 (1-y),$$

$$y = \frac{E_\nu}{E_\mu}$$

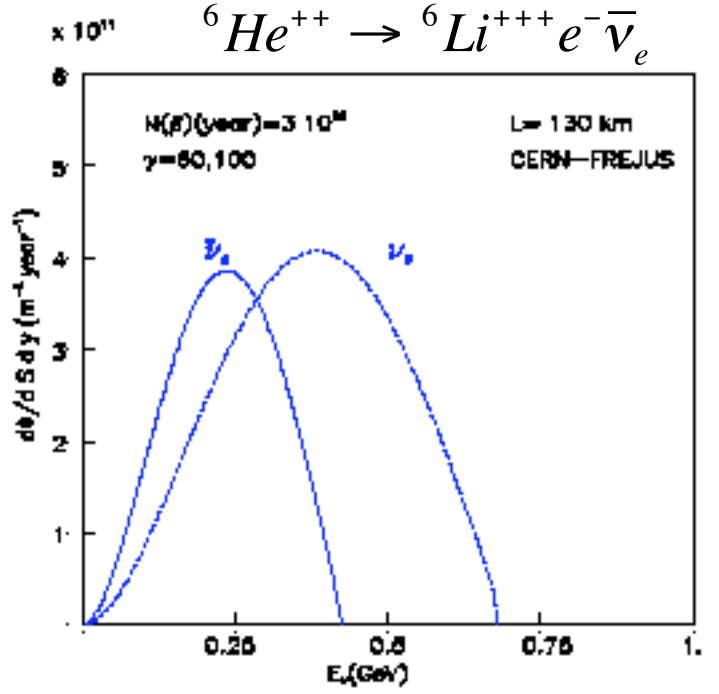
$$\left.\frac{d\Phi}{dSdy}\right|_{\theta\approx 0} \approx \frac{N_\beta}{\pi L^2} \frac{\gamma^2}{g(y_e)} y^2 (1-y)\sqrt{(1-y)^2 - y_e^2}$$

$$y = \frac{E_\nu}{2\gamma E_0},\ y_e = \frac{m_e}{E_0}$$

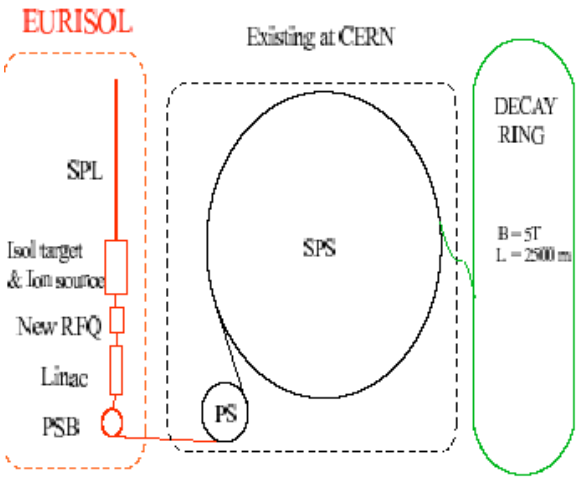
$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$

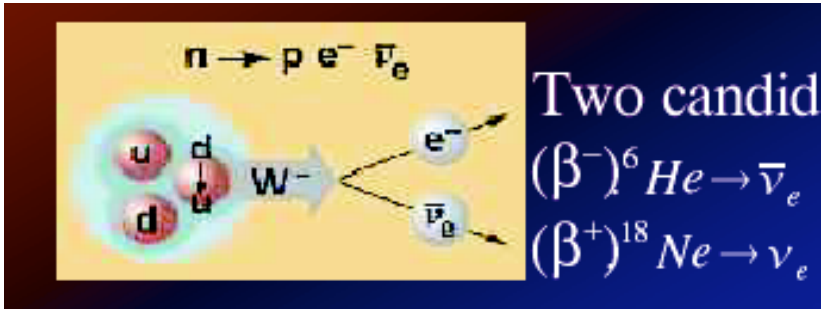


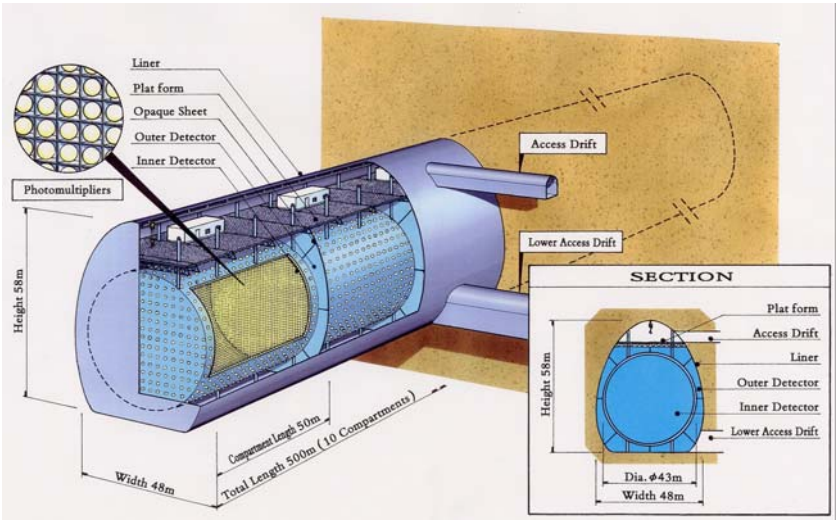
$^6He^{++} \rightarrow {}^6Li^{+++} e^- \bar{\nu}_e$



Beta Beam







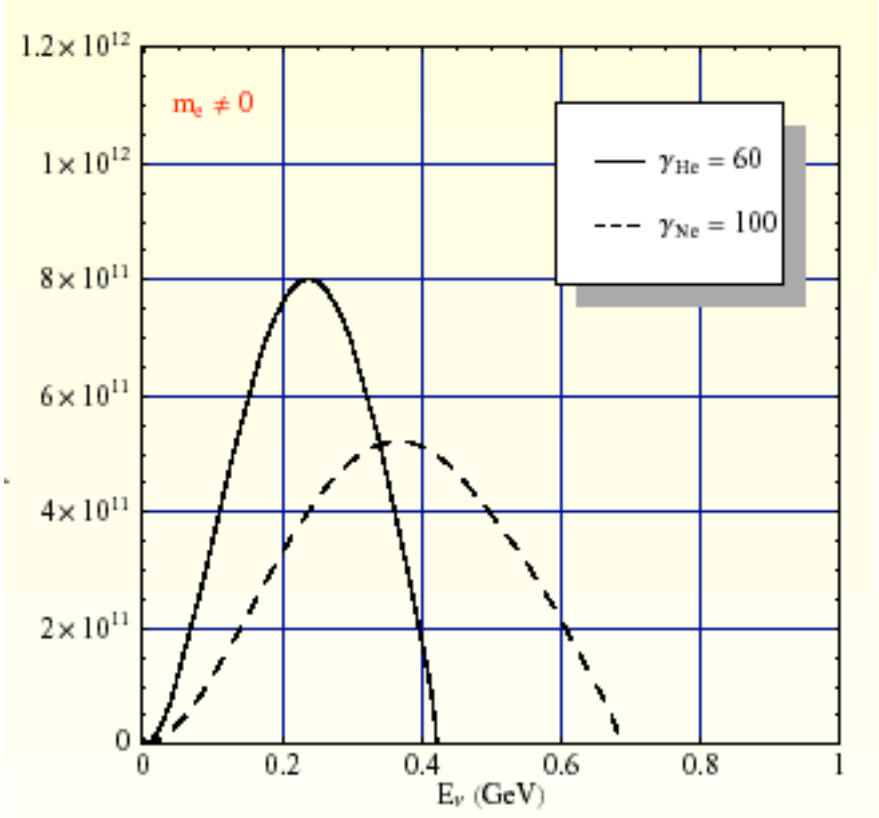
Accelerate beta-unstable ions, let them decay in storage ring pointed at far detector.

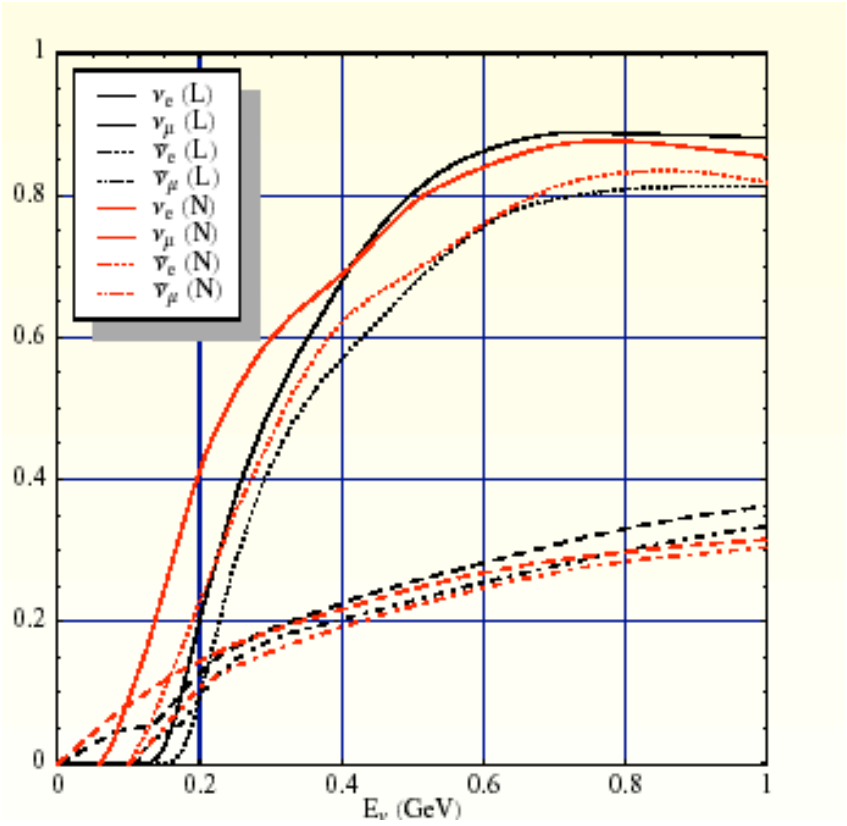
Produce a beam with

- **Single flavor**
- **Spectrum exactly known**
- Known intensity
- Focused

P. Zucchelli, Phy. Lett. B 532

BB: The low gamma scenario





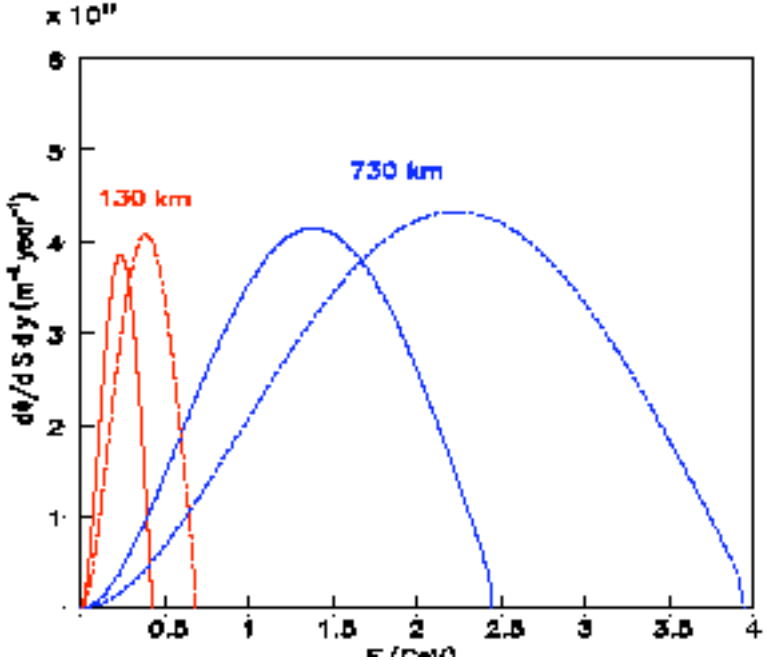
Mezzetto

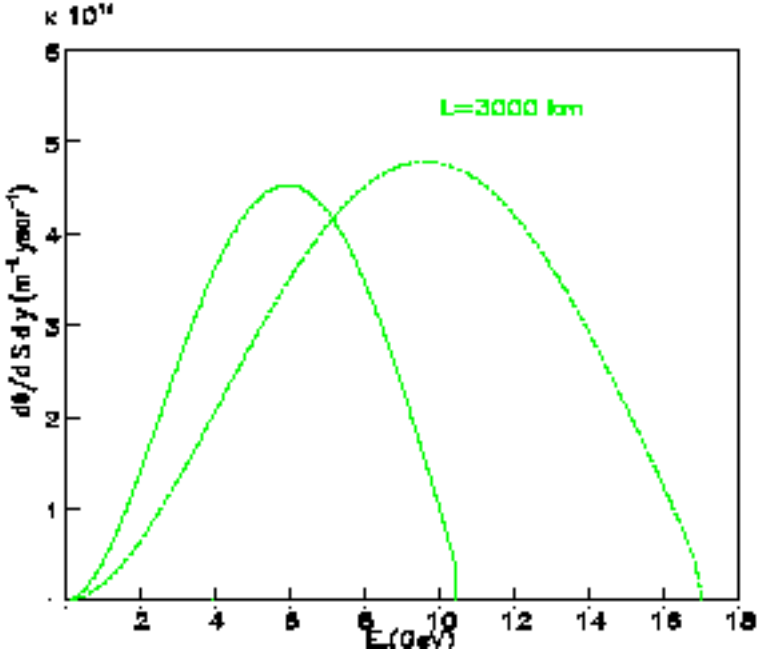
Lindroos

β Beam	N_{ν_e}	$N_{\bar{\nu}_e}$
$\langle E_\nu \rangle$	0.37 GeV	0.23 GeV

Higher-gamma Beta Beam example

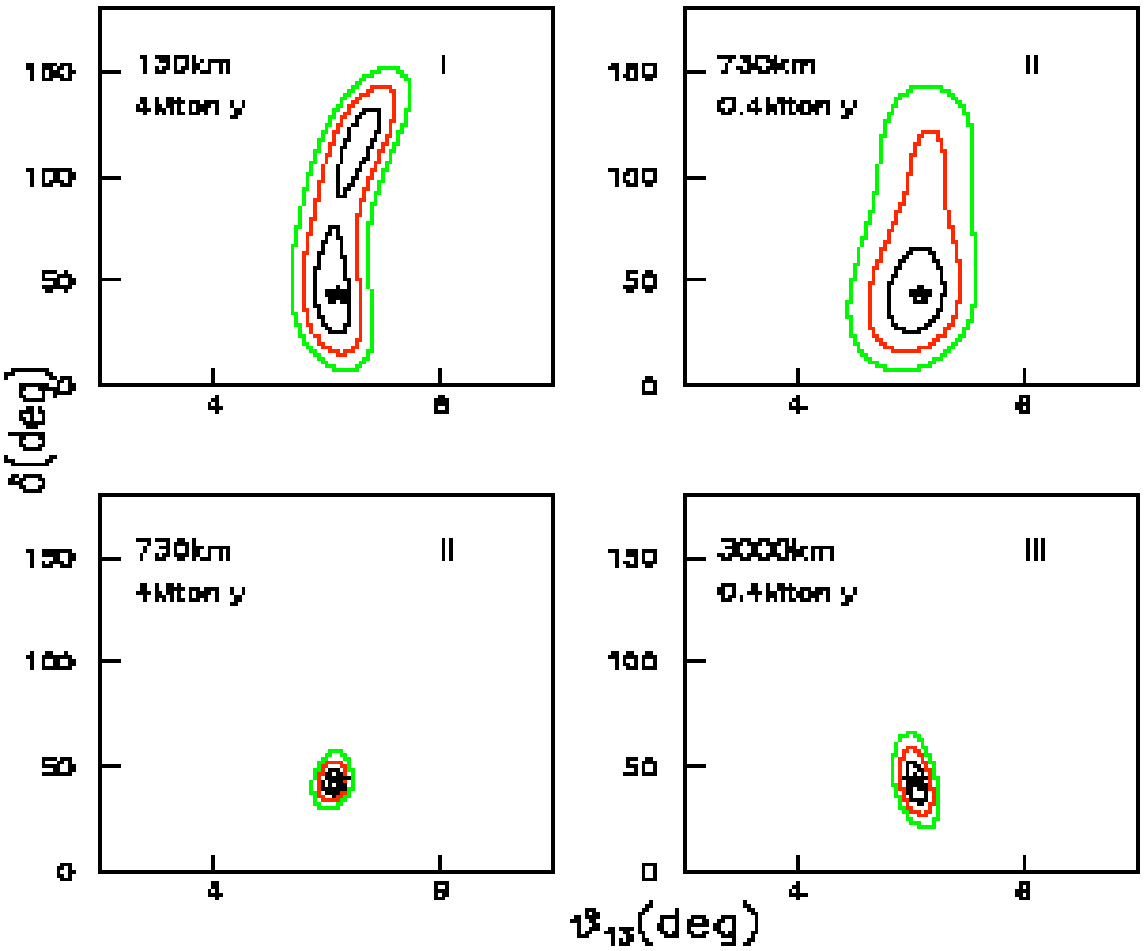
γ	$L(km)$	$\bar{\nu}_e$ CC (KTon y)	ν_e CC (KTon y)	$\langle E_\nu \rangle (GeV)$
60/100	130	4.7	32.8	0.23/0.37
350/580	730	57.5	224.7	1.35/2.18
1500/2500	3000	282.7	993.1	5.80/9.39



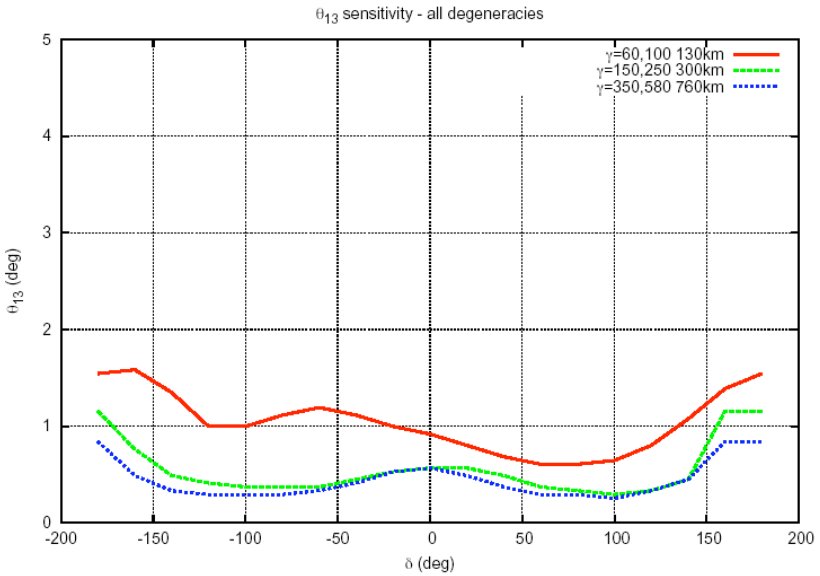


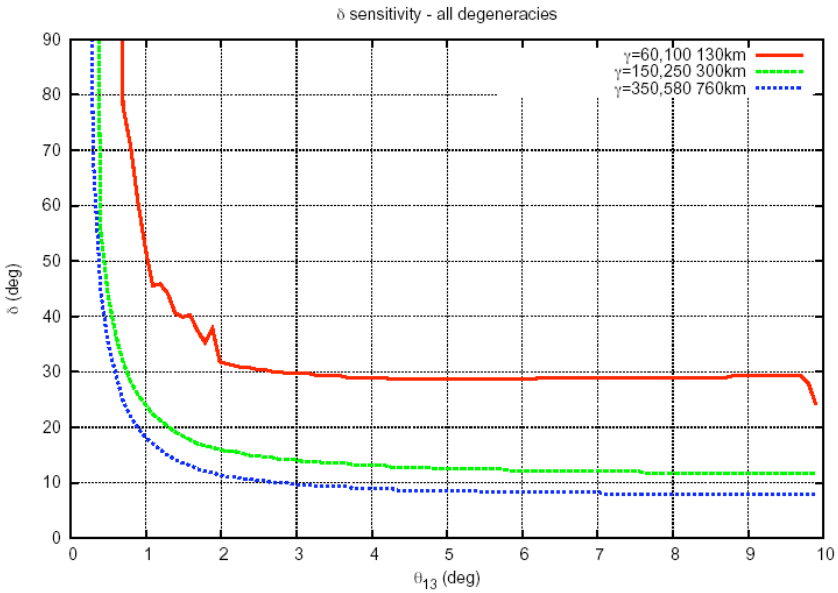
P. Hernández

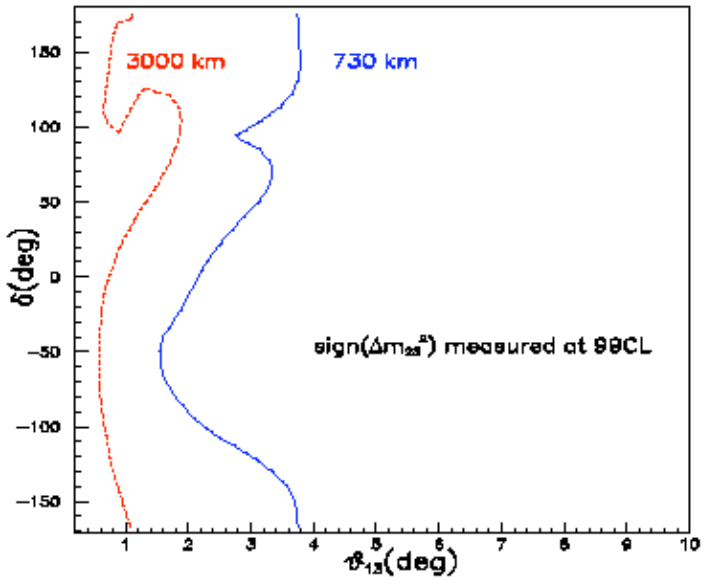
Major Physics improvement



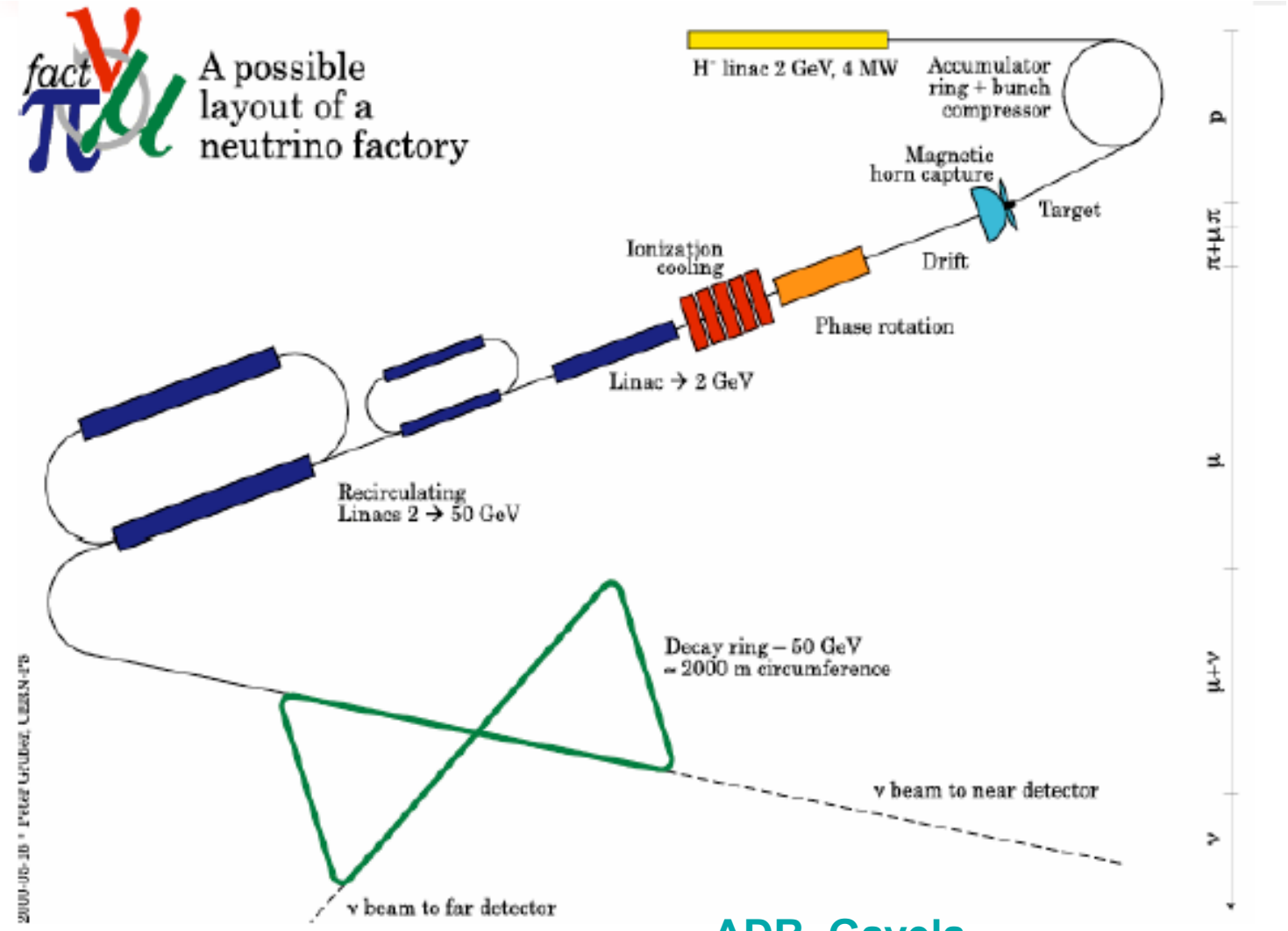
Major Physics improvement





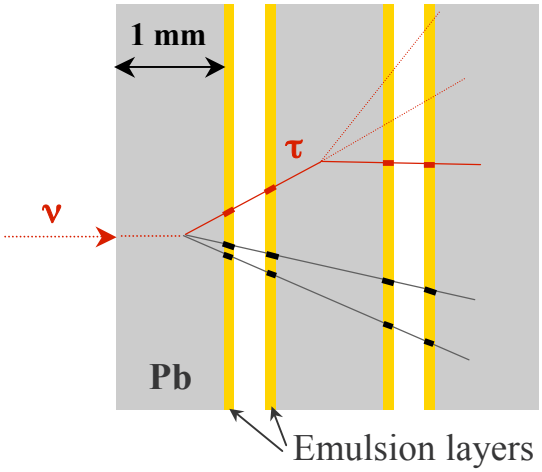


Neutrino Factory



S. Geer

ADR, Gavela, Hernández



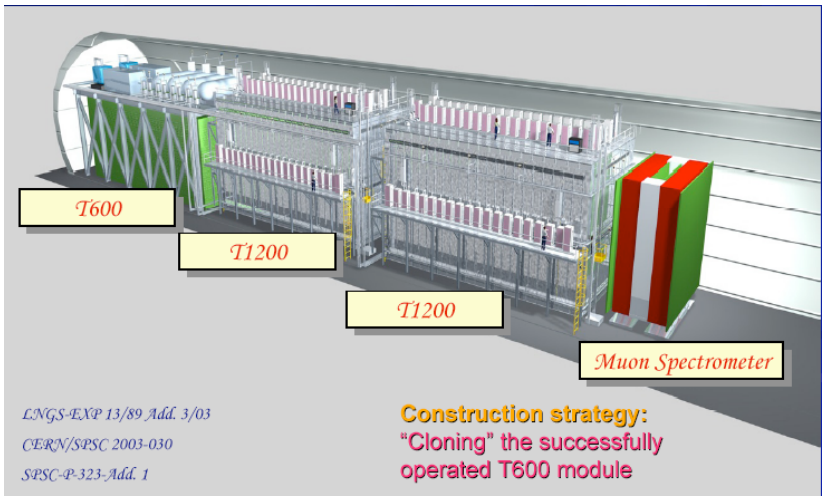
Migliozzi

Detectors for NUFACT

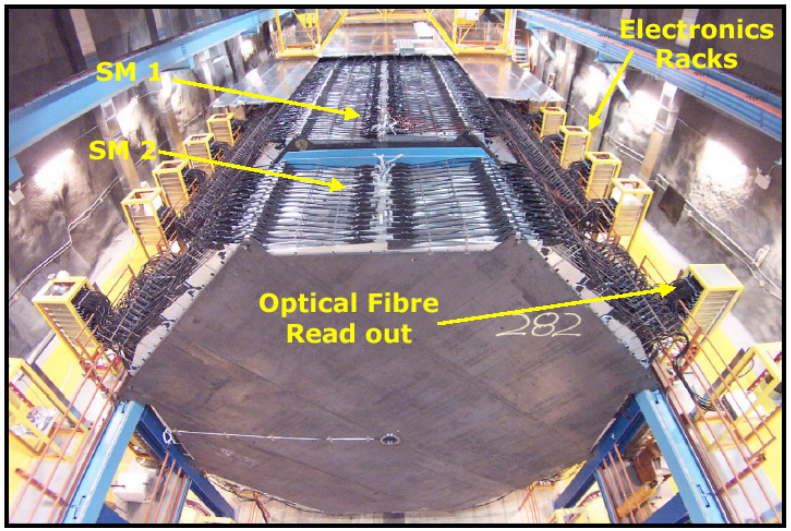
10 x Minos

5 x Opera

10 x Icarus

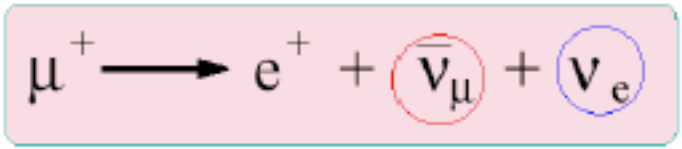


Rubbia, Bueno, Campanelli



Cervera, Didak, JJGC

Golden & Silver channels at NUFACT



The Golden Channel at the Neutrino Factory

$$\mu^+ \to \begin{cases} e^+ \\ \bar{\nu}_\mu \\ \nu_e \to \nu_\mu \to \mu^- \end{cases}$$

The oscillation probability is

$$P^{\pm}_{e\mu} = X_{\pm}\sin^2(2\,\theta_{13}) + Y_{\pm}\cos\left(\delta \mp \frac{\Delta_{atm}L}{2}\right)\cos\theta_{13}\sin(2\,\theta_{13}) + Z + \ldots$$

ADR, Gavela, Hernández

The Silver Channel at the Neutrino Factory

$$\mu^+ \to \begin{cases} e^+ \\ \bar{\nu}_\mu \\ \nu_e \to \nu_\tau \to \tau^- \to \mu^- \end{cases}$$

The oscillation probability is

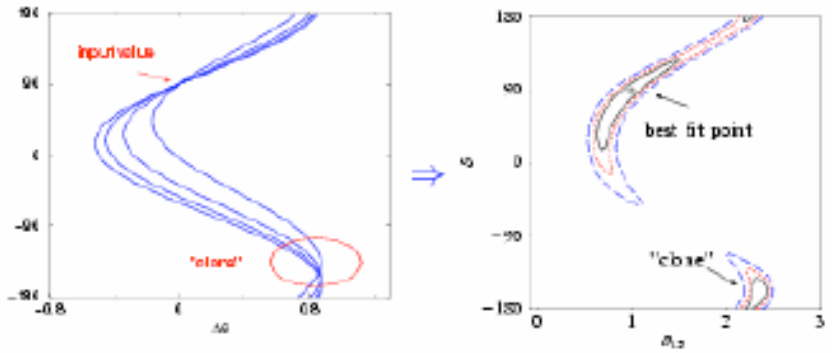
$$P^{\pm}_{e\tau} = X^{\tau}_{\pm}\sin^2(2\,\theta_{13}) - Y_{\pm}\cos\left(\delta \mp \frac{\Delta_{atm}L}{2}\right)\cos\theta_{13}\sin(2\,\theta_{13}) + Z^{\tau} + \ldots$$

Donini, Migliozzi, Meloni

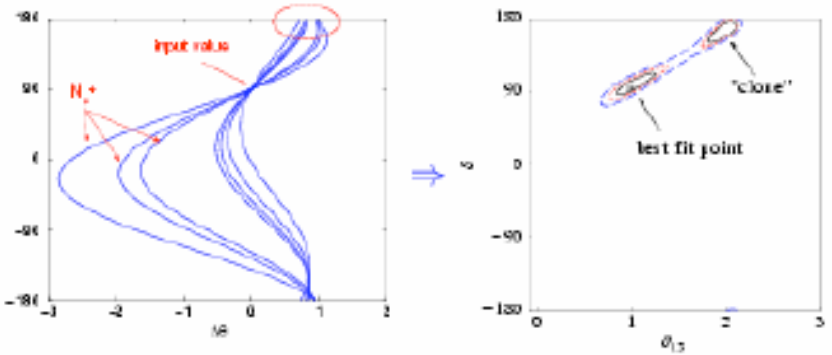
Solving degeneracies at NUFACT

Results for golden muons at $L = 3000$ Km

Five years of data taking: one polarity only
(μ^+ in the storage ring)



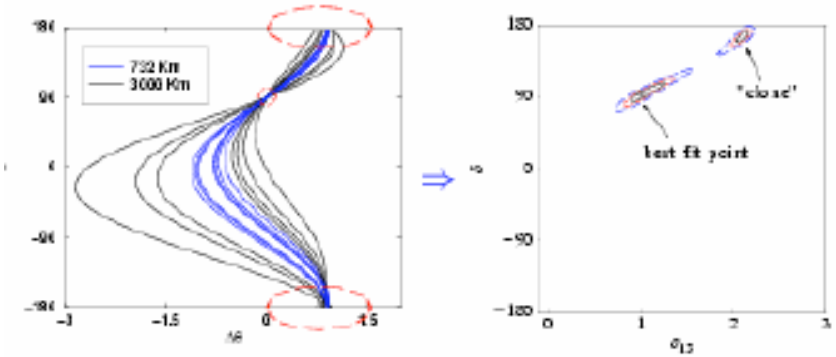
Ten years of data taking: two polarities
(μ^+ and μ^- in the storage ring)



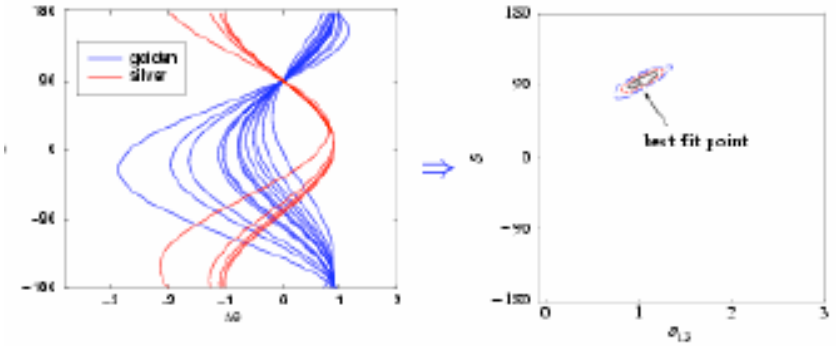
Input parameters: $\bar{\theta}_{13} = 1°, \bar{\delta} = 90°$

Using golden and silver muons

Setup A: two iron detectors and two baselines
(golden muons only)



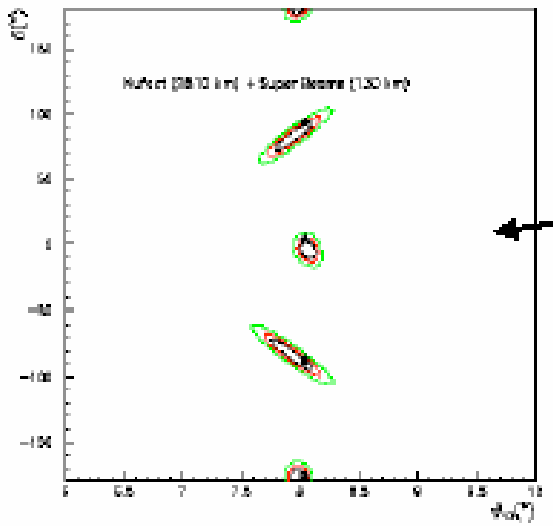
Setup B: one iron and one emulsion detectors
(golden and silver muons; IDEAL emulsion detector)



Input parameters: $\bar{\theta}_{13} = 1°, \bar{\delta} = 90°$

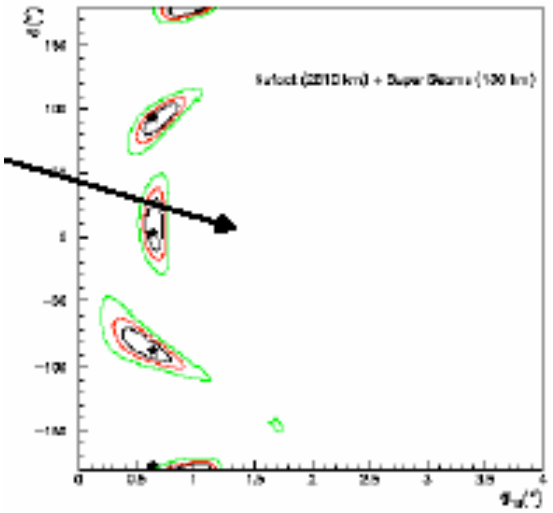
donini

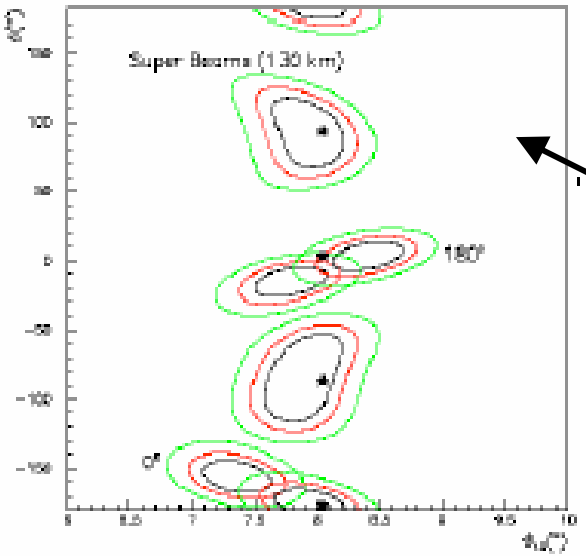
NUFACT sensitivity



NF

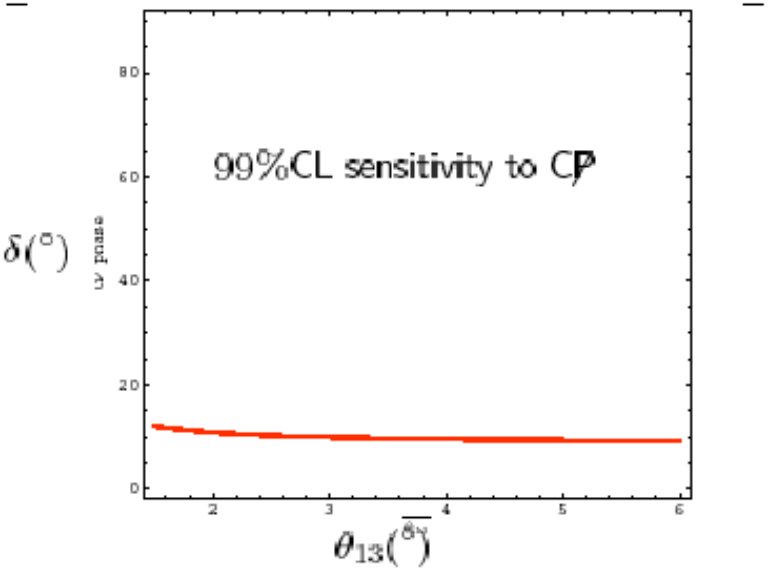
SPLSB
+NF





SPL

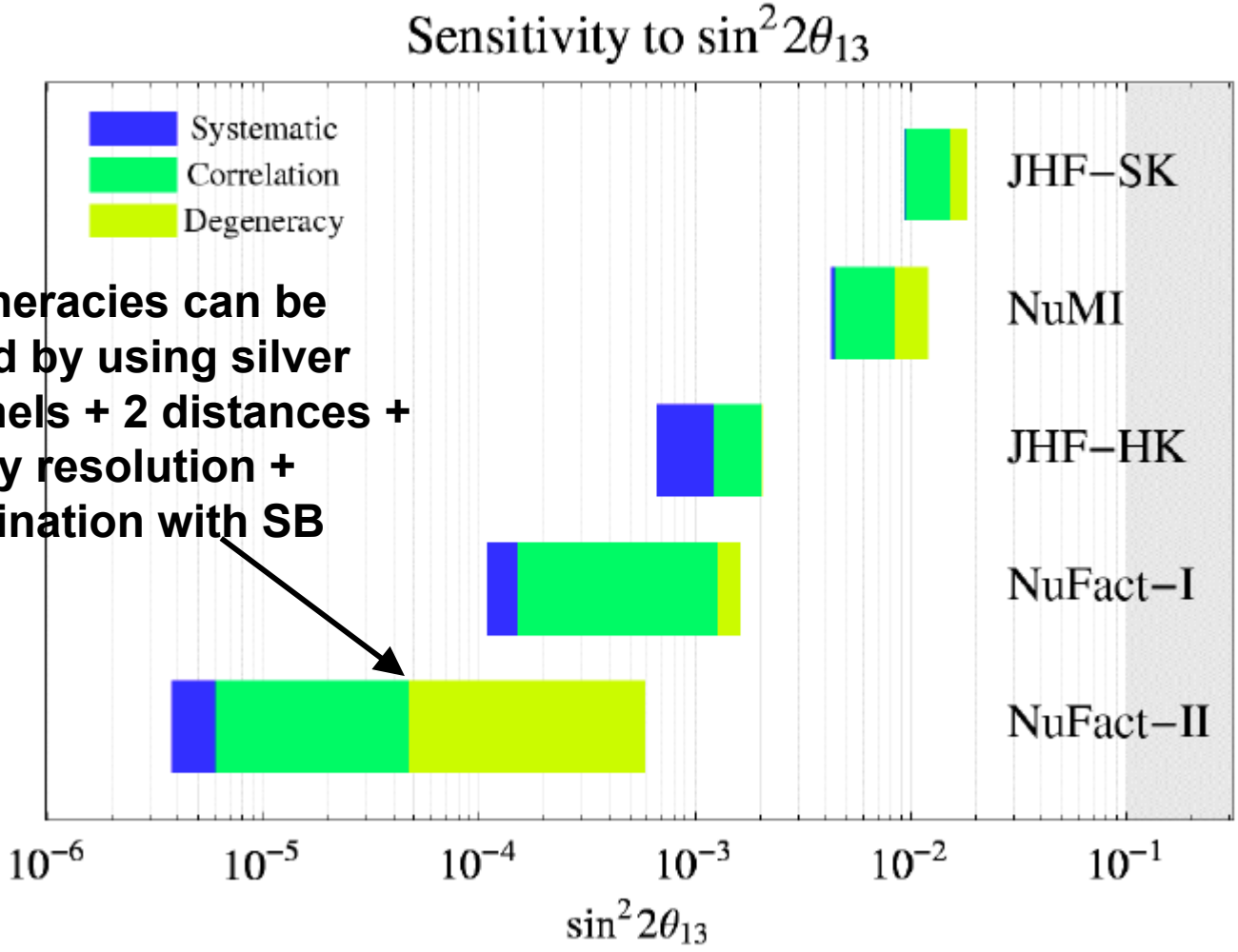
SB



Mena

Sensitivity of NUFACT

Huber, ML, Winter, hep-ph/0204352



Degeneracies can be solved by using silver channels + 2 distances + energy resolution + combination with SB

Conclusions

First generation Super-Beams (T2K-I) will hopefully observe the subleading transition, measuring or setting a lower bound to θ_{13}.

To measure CP violation very intense beams and massive detectors are needed. A careful assessment of the relative merits of a T2K-II super-beam, a Beta-Beam and muon beams is necessary.

Conclussion II

The Super Beam/Beta-Beam offers and alternative/complement to the Neutrino Factory. Different technology, different systematic errors and different E/L. Combination of both facilities is ideal to solve degeneracies.

T2K-II/beta-beam will need for ultimate sensitivity 1Mton class detector. Such a detector has a great physics potential (proton decay, supernova observatory) of their own, but it is extraordinarily challenging to build (10-20 times the size of Super-Kamiokande). However, the beat seems a necessary one. Hyper-K will be our vehicle to explore the land of Terra Incognita!