Mauro Mezzetto

Istituto Nazionale di Fisica Nucleare,

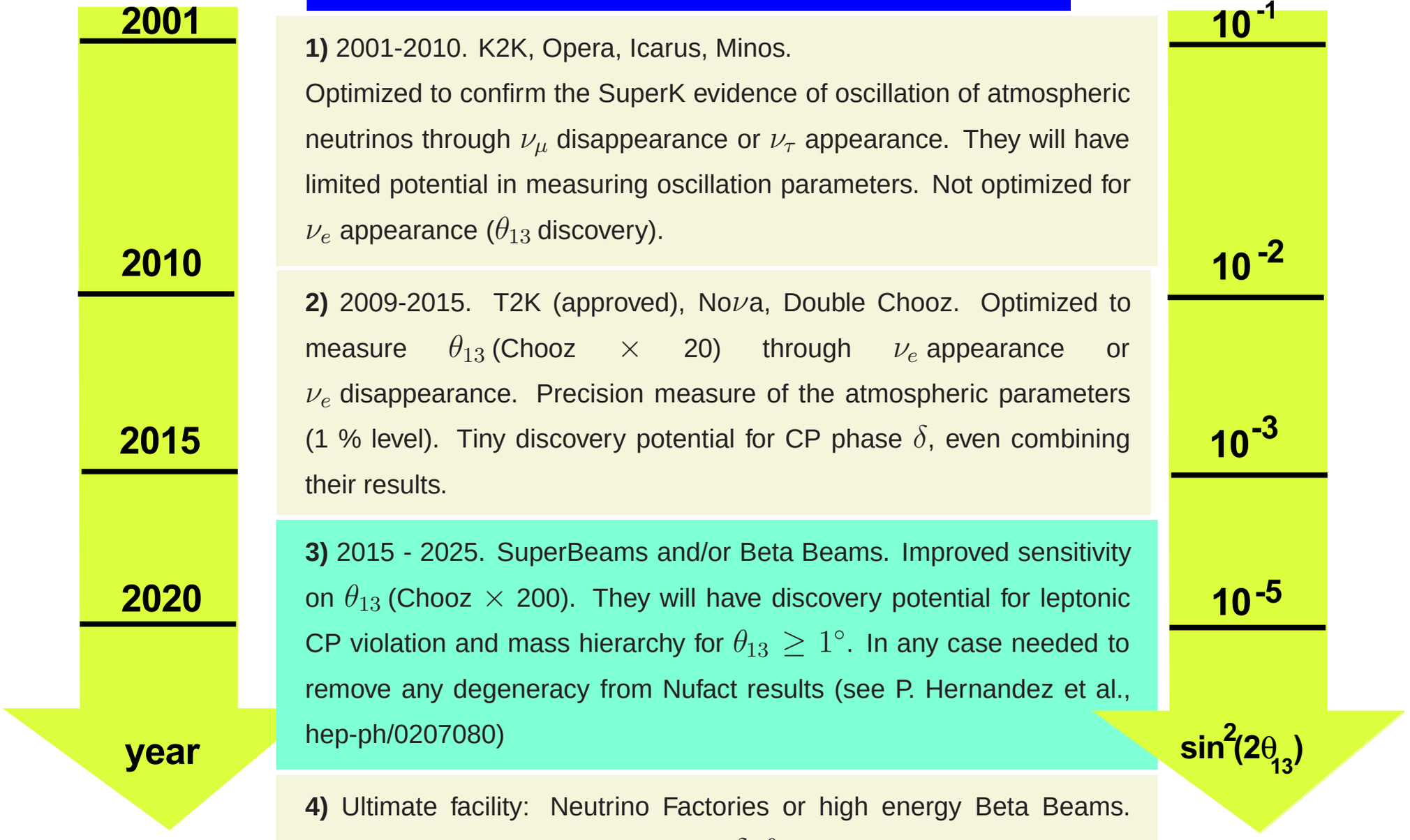
Sezione di Padova

“ Beta Beams ”

Thanks to: P. Zucchelli, M. Lindroos, J. Bouchez, P. Hernandez, JJ Gomez-Cadenas, J. Burguet-Castell, O. Mena, D. Casper, A. Blondel, S. Gilardoni, C. Volpe, S. Rigolin, A. Donini, P. Migliozzi, F. Terranova, P. Lipari.

Villars, September 24^{th}, 2004

At least 4 phases of Long Baseline experiments



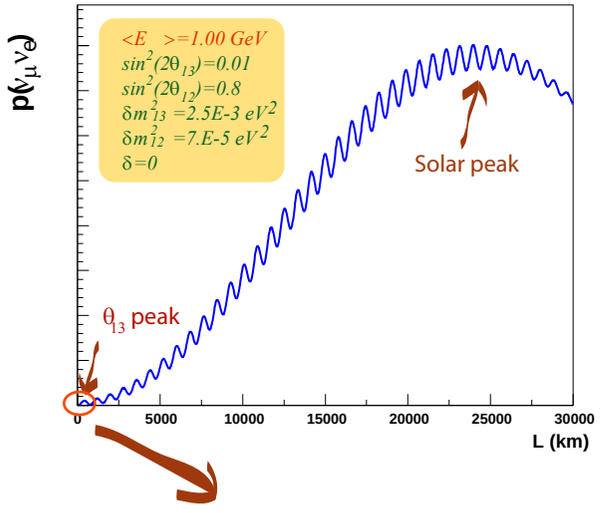
1) 2001-2010. K2K, Opera, Icarus, Minos.
Optimized to confirm the SuperK evidence of oscillation of atmospheric neutrinos through ν_μ disappearance or ν_τ appearance. They will have limited potential in measuring oscillation parameters. Not optimized for ν_e appearance (θ_{13} discovery).

2) 2009-2015. T2K (approved), Noνa, Double Chooz. Optimized to measure θ_{13} (Chooz $\times$ 20) through ν_e appearance or ν_e disappearance. Precision measure of the atmospheric parameters (1 % level). Tiny discovery potential for CP phase δ, even combining their results.

3) 2015 - 2025. SuperBeams and/or Beta Beams. Improved sensitivity on θ_{13} (Chooz $\times$ 200). They will have discovery potential for leptonic CP violation and mass hierarchy for $\theta_{13} \geq 1^\circ$. In any case needed to remove any degeneracy from Nufact results (see P. Hernandez et al., hep-ph/0207080)

4) Ultimate facility: Neutrino Factories or high energy Beta Beams. Ultimate sensitivity on the CP phase δ, θ_{13} , mass hierarchy.

Sub leading $\nu_\mu - \nu_e$ oscillations



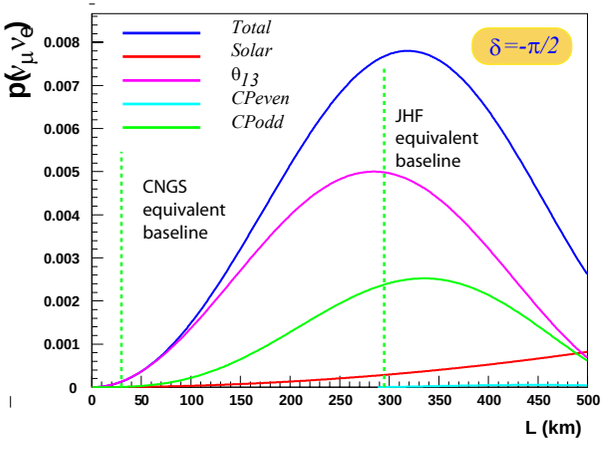
$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \qquad \theta_{13} \text{ driven}$$

$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

$$- 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driven}$$

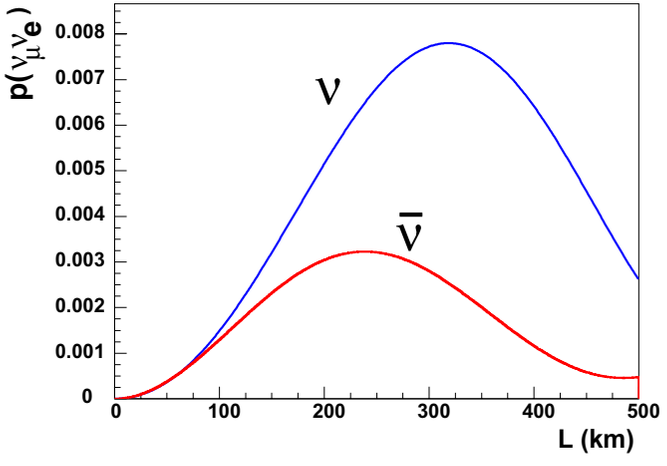
$$- 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) \qquad \text{matter effect (CP odd)}$$



θ_{13} discovery requires total probability greater than Solar probability

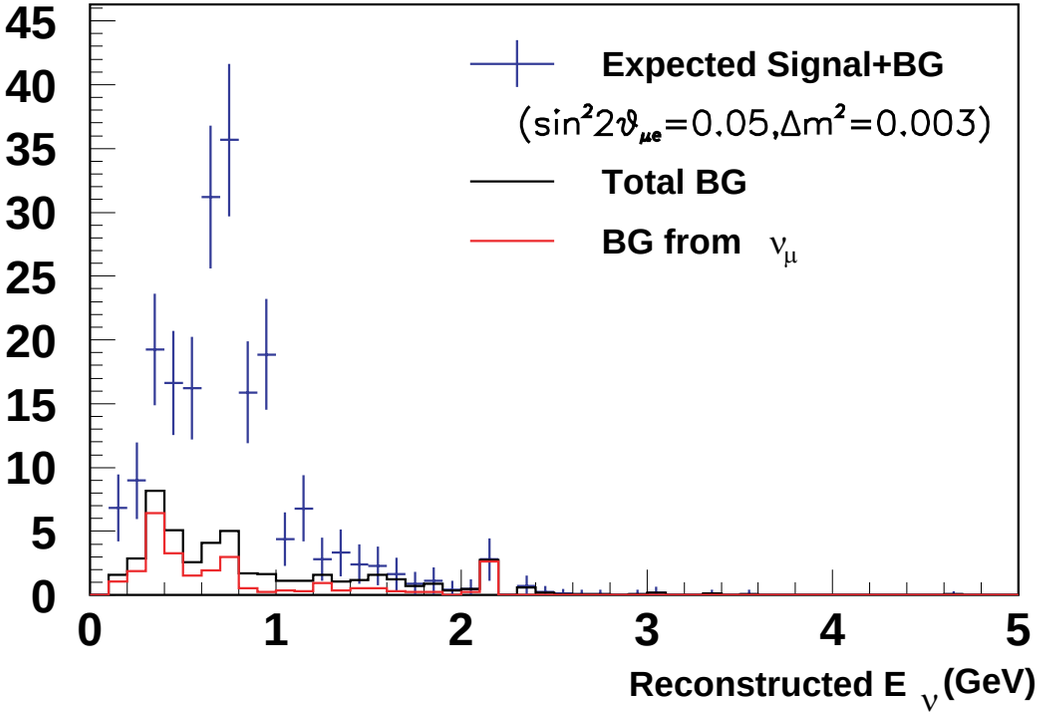
Leptonic CP discovery requires

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \neq 0$$

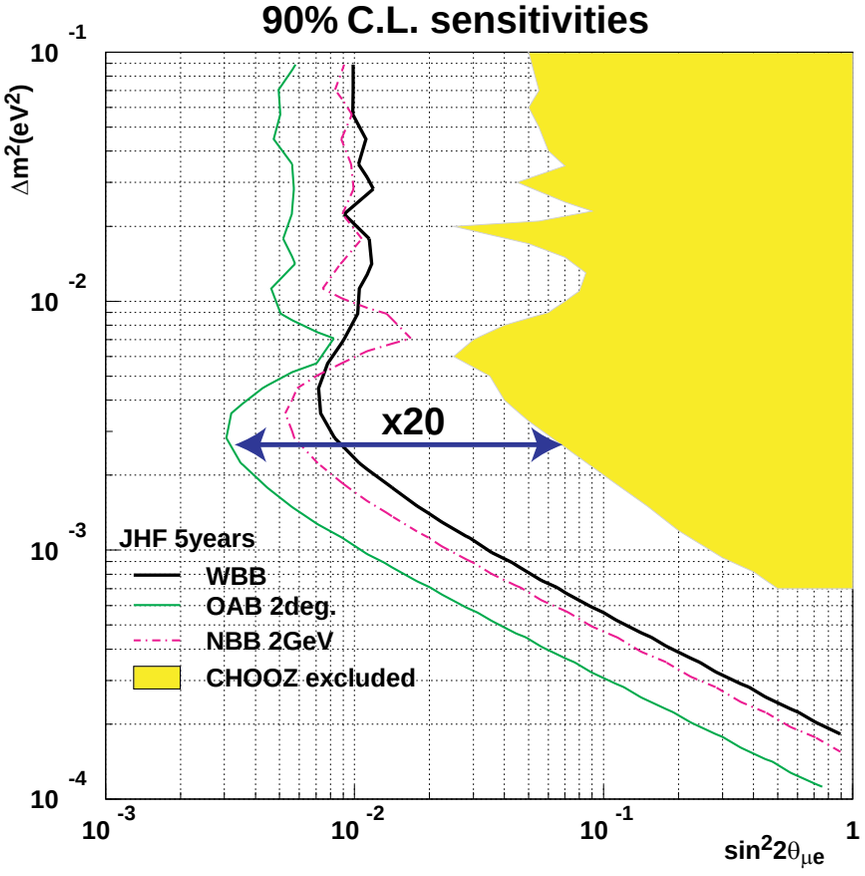


T2K ν_e appearance

OAB 2°	ν_μ CC	ν_μ NC	ν_e CC	Osc. ν_e
Generated in F.V.	10713.6	4080.3	292.1	301.6
1R e-like	14.3	247.1	68.4	203.7
e/π^0 separation	3.5	23.0	21.9	152.2
0.4 GeV$< E_{rec} <$ 1.2 GeV	1.8	9.3	11.1	123.2



Sensitivity to θ_{13}

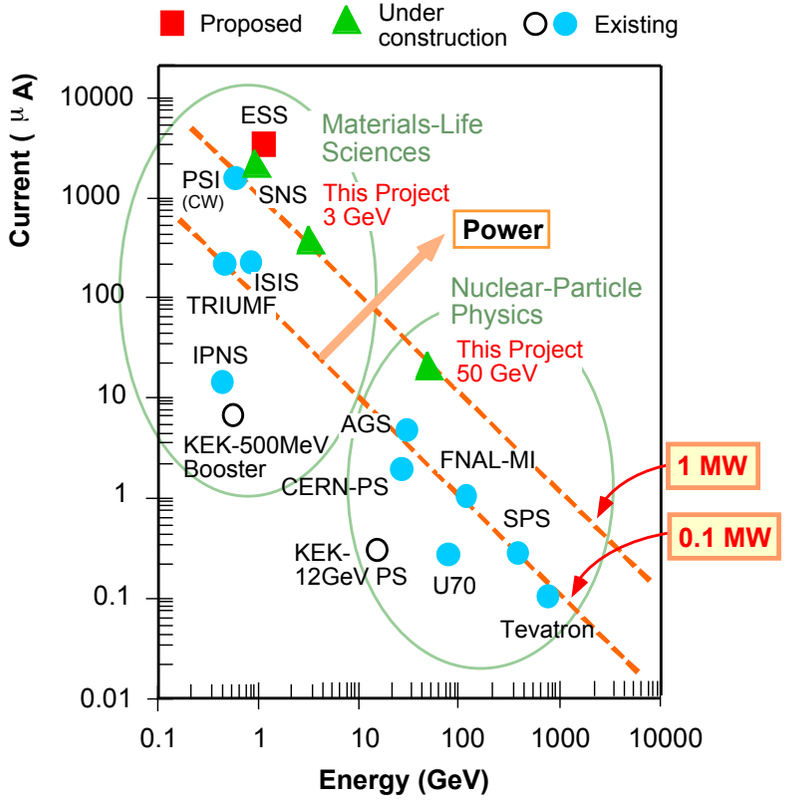


After JPARC, in the standard scenario

- θ_{13}, discovery or precision measure
- Mass hierarchy
- **Leptonic CP violation**

Any major improvement of JPARC will be extremely expensive:

- The proton driver is a next generation machine
- The detector is 10 times bigger of the second biggest: Minos.
- The design of close detectors system is challenging, but T2K will provide a very valuable first setup.

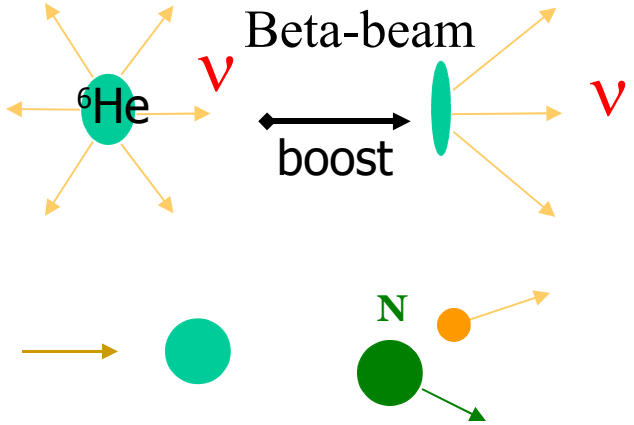


The knowledge of θ_{13} is necessary to guarantee the conditions to measure δ and to optimize the facility.

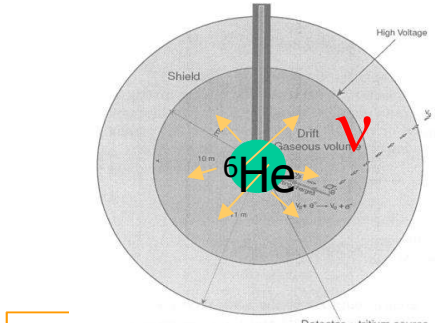
Any future initiative should have enough physics potential besides neutrino oscillations to justify the risk of starting the Leptonic CP violation searches without any guarantee.

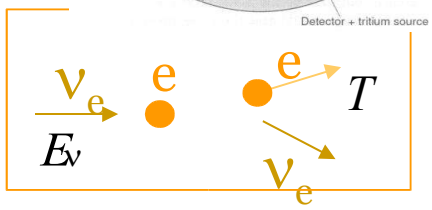
Low energy beta-beam

- The proposal
  - To exploit the beta-beam concept to produce intense and pure low-energy neutrino beams (C. Volpe, Journ. Phys. G. 30(2004)L1, J. Serreau, C.Volpe, hep-ph/0403293, C. Volpe, talk at this conference)
- Physics potential
  - Neutrino-nucleus interaction studies for particle, nuclear physics, astrophysics (nucleosynthesis)
  - Neutrino properties, like n magnetic moment



$^6He \rightarrow {}^6Li + e + \bar{\nu}_e \quad Q_\beta = 4.\ MeV$





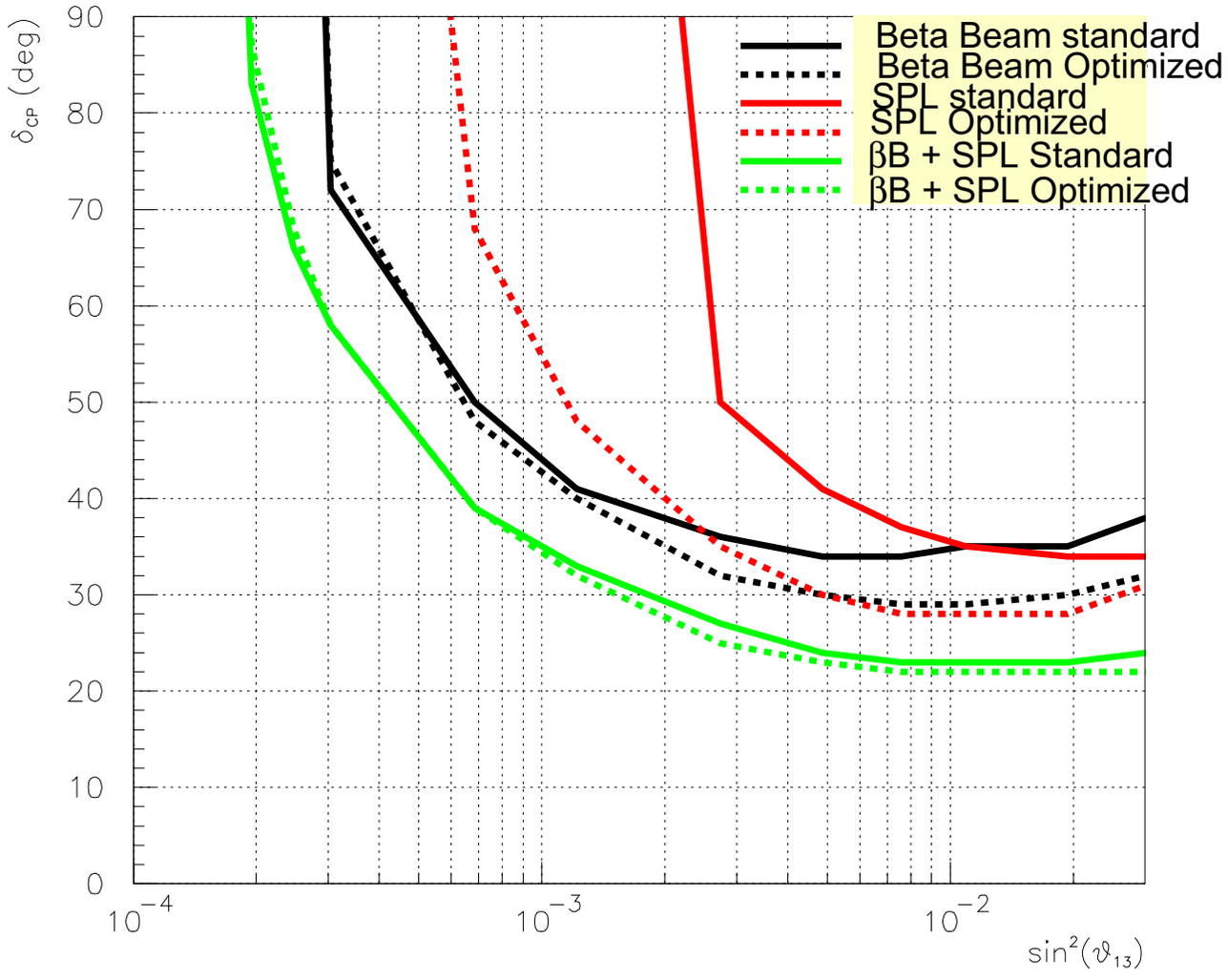
A preliminary Beta Beam optimization

- Ion fluxes already saturate PS and SPS in terms of induced radioactivity in the magnets and machine power
- What is not optimal is the comprimize of the $^6\mathrm{He}$ and $^{18}\mathrm{Ne}$ γs (60 and 100 respectively), needed to run the two ions together.
- The flux of the ions at the source can be doubled by doubling the Isol targets. In the baseline scenario 1 target is devoted to $^6\mathrm{He}$ and 3 targets (is serie) are devoted to $^{18}\mathrm{Ne}$. One could run with 2 $^6\mathrm{He}$ targets (in parallel) and with 6 $^{18}\mathrm{Ne}$ targets (2 sets of 3 targets). In this case the two ions should circulate in separate runs.
- This allows to run each ion at its optimal γ, here $\gamma = 75$ is taken for each ion.

Results of the optimizations (preliminary)

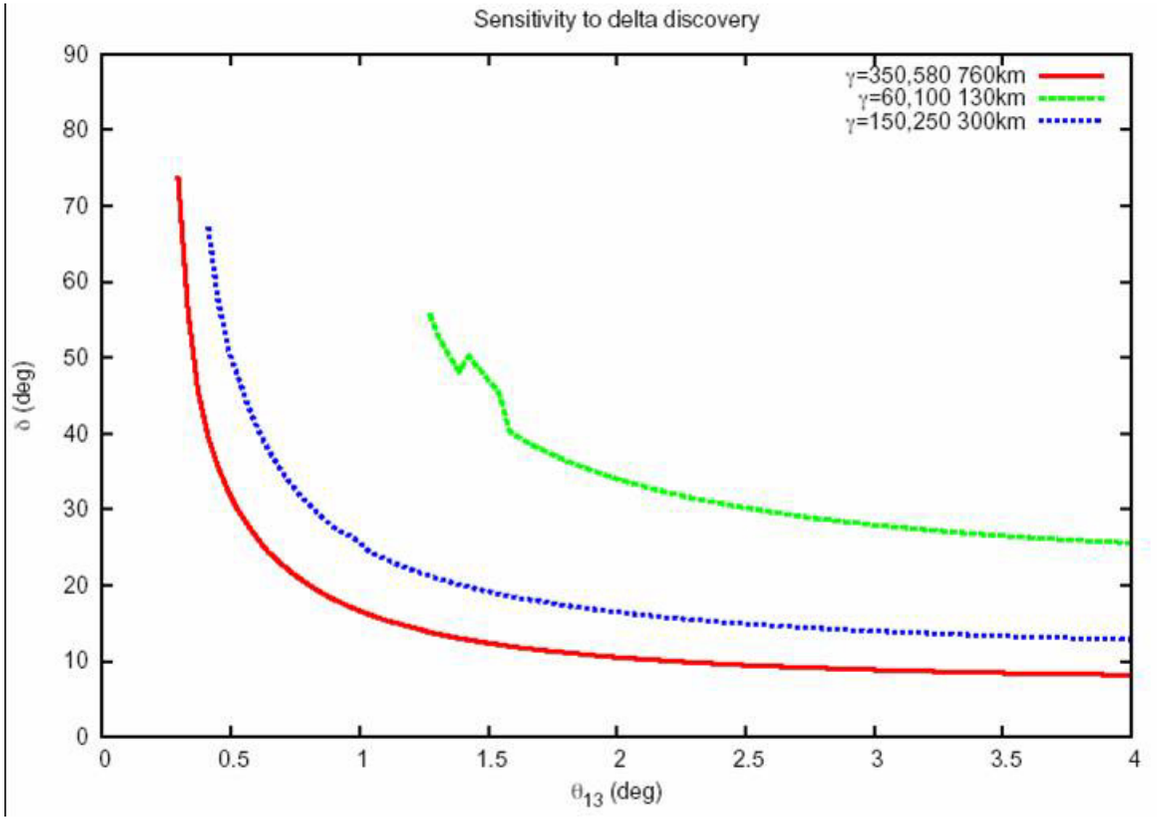
SPL SB optimization as computed by J.E. Campagne and A. Cazes, LAL, paper in preparation.

3 σ discovery potential curves



Another possible otpimization (J.J Gomez-Cadenas, talk at NOW2004, past week)

- Apply the methods developed for the medium energy βB to $\gamma(^6\mathrm{He}) = 150$, the maximum value with the SPS.
- Optimal baseline: 300 km.
- Systematic errors to be included
- 99% CL discovery potential curves



Conclusions

- Beta-Beams are a novel, innovative concept that could produce neutrino beams virtually free from intrinsic backgrounds and systematics.
- They could profit of very deep synergies with:
  - Nuclear physicists aiming at a very intense source of radioactive ions.
  - A gigantic water Cerenkov detector with great physics potential in its own.
- The baseline scenario has not technological show stoppers and could offer excellent physics in a timescale of $\mathcal{O}(10)$ years.
- The Super-Beta Beams combination can address δ_{CP} discovery having the distinctive possibility of:
  - Combine CP, T and CPT searches
  - Use ν_e disappearance to solve all the ambiguities for reasonable large values of θ_{13} .
- Additional ideas are growing around this concept attracting the interest of more and more physicists.