Mauro Mezzetto

Istituto Nazionale di Fisica Nucleare,

Sezione di Padova

" Physics with BetaBeams and SuperBeams from CERN to a Frejus based Megaton Detector "

Consolidation of the $\gamma = 100, 100$ option:

- Atmospheric neutrino backgrounds
- Energy binning
- Pion bacgkgrounds
- Use of GLoBES

Feedback to the Eurisol design study:

- Comparison of the different scenarios
- Duty factor constraints
- Overall optimization

Machine aspects in M. Lindroos talk, for the SPL see the J.E. Campagne talk, for the degeneracies see the T. Schwetz talk

This talk is powered by two GREAT public domain softwares:

- **NUANCE** for the neutrino interactions simulation: D. Casper Nucl. Phys. Proc. Suppl. **112** (2002) 161.
- **GLoBES** for the physics potential studies. P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. **167** (2005) 195

Nufact 05, Laboratori Nazionali di Frascati, 21-26 giugno 2005

Improve by 1 order of magnitude next generation θ_{13} sensitivity

Computed with:

MINOS: Start in 2005, 5 years integrating $14 \cdot 10^{21}$ pot

OPERA: Full detector since 2007

ICARUS: Full detector (3 kton) since 2008

Double Chooz: start in 2008

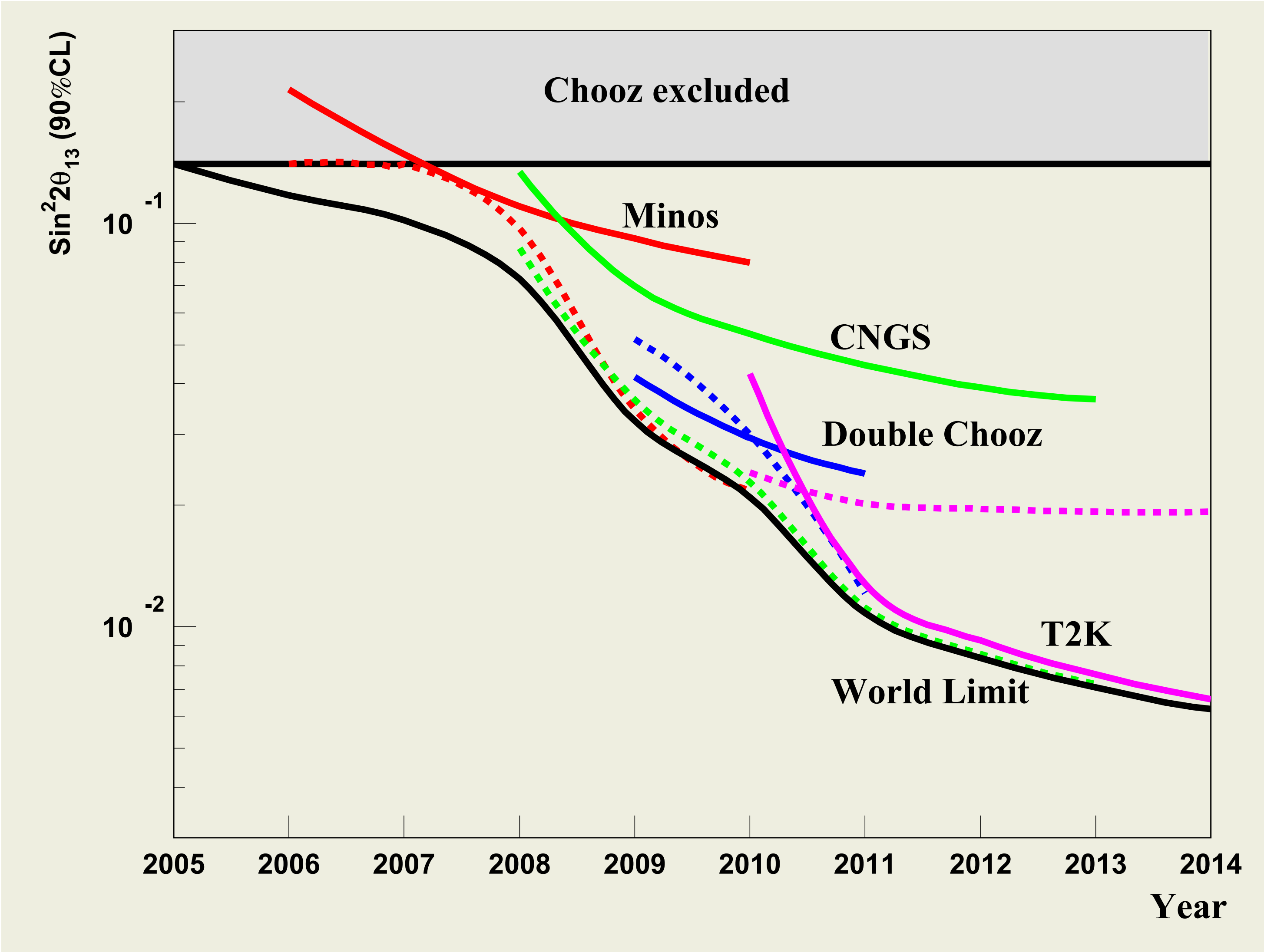
T2K: start in 2009, first year at 10% of nominal luminosity.

Solid lines:

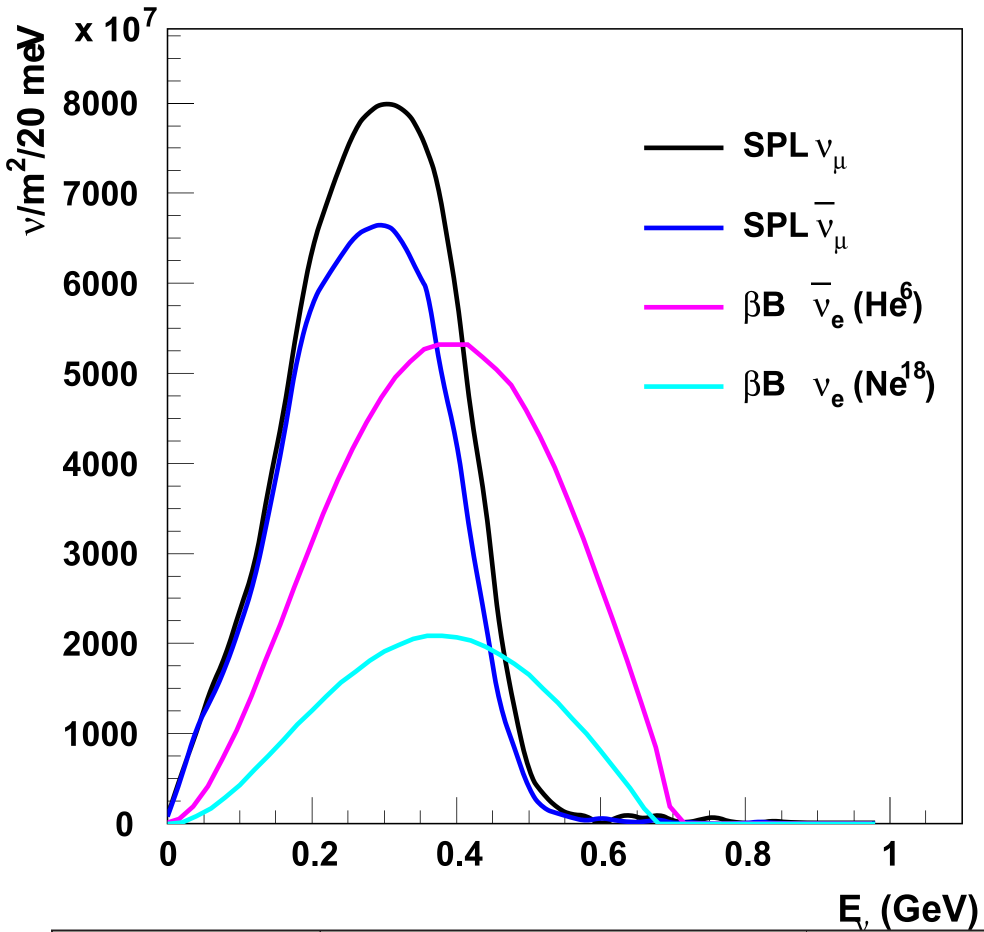
Experimental sensitivity of the single experiment

Dotted lines:

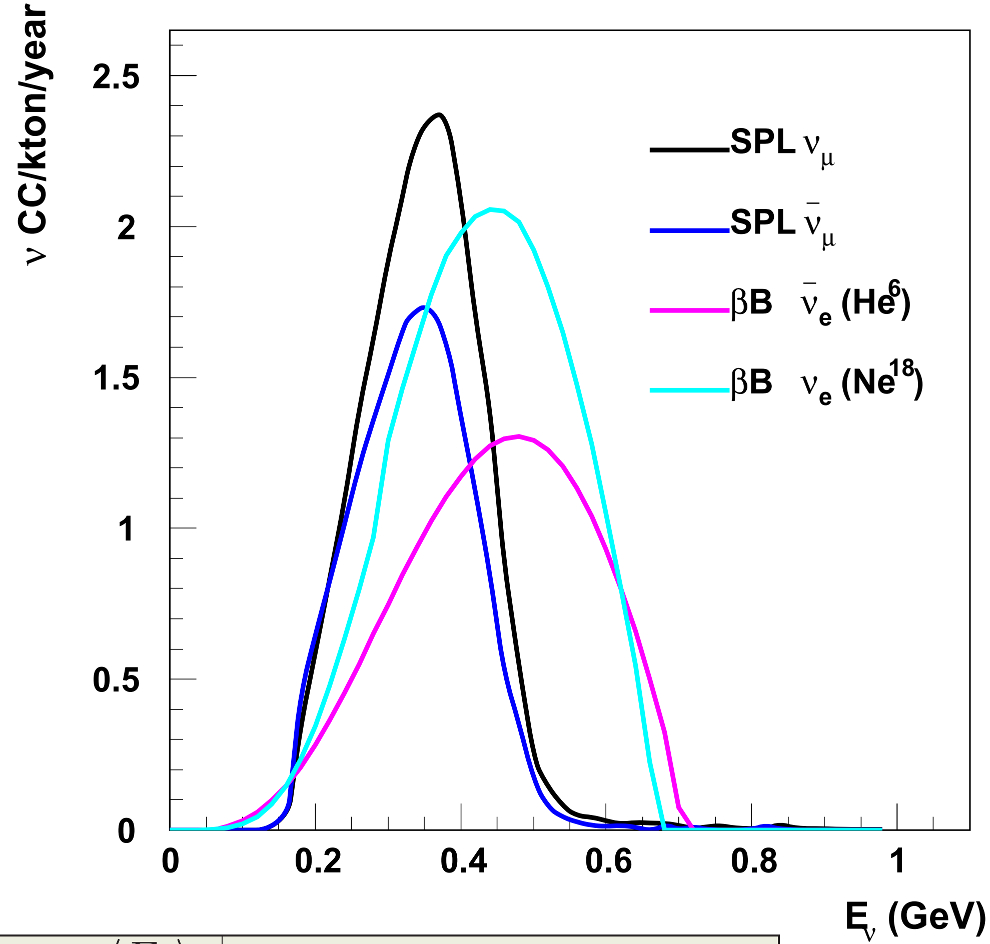
World limit without the single experiment



Yearly Fluxes



Averaged yearly CC rates in a 10 years run for CP

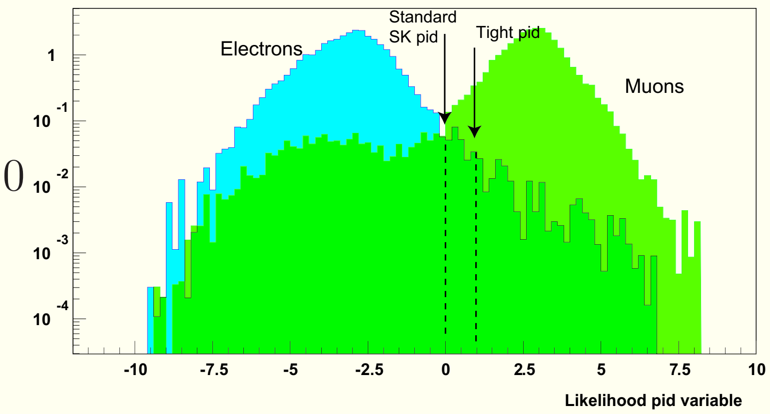


	Fluxes @ 130 km $\nu/m^2/yr$	$\langle E_\nu \rangle$ (GeV)	CC rate (no osc) events/kton/yr	$\langle E_\nu \rangle$ (GeV)	Years	Integrated events (440 kton $\times$ 10 years)
SPL Super Beam						
ν_μ	$11.80 \cdot 10^{11}$	0.29	121.7	0.36	2	107127
$\overline{\nu}_\mu$	$9.66 \cdot 10^{11}$	0.28	23.1	0.35	8	81164
Beta Beam						
$\overline{\nu}_e(\gamma = 100)$	$10.92 \cdot 10^{11}$	0.40	46.0	0.46	5	101262
$\nu_e(\gamma = 100)$	$4.06 \cdot 10^{11}$	0.38	65.4	0.44	5	143887

Particle identification and signal efficiency

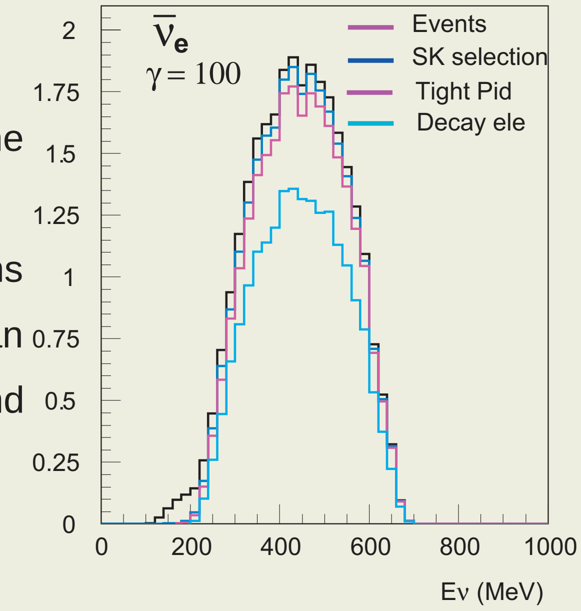
Electron/muon misidentification must be suppressed much more than in standard SK analysis to guarantee a negligible background level.

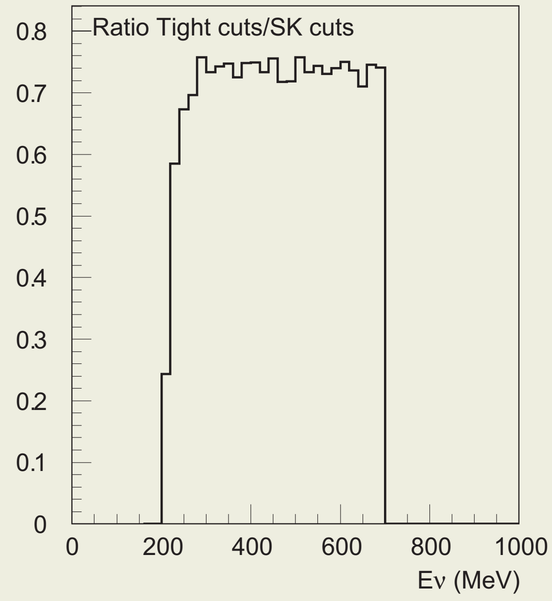
Pid in SK is performed through a Likelihood, $Pid > 0$ identifies muons. Use $Pid > 1$



To further suppress electron background ask for the signal of the Michel electron from μ decay.

Final efficiency for positive muons. Negative muons have an efficiency smaller by $\sim 22\%$ because can be absorbed before decaying. Electron background suppressed to $\sim 10^{-5}$.



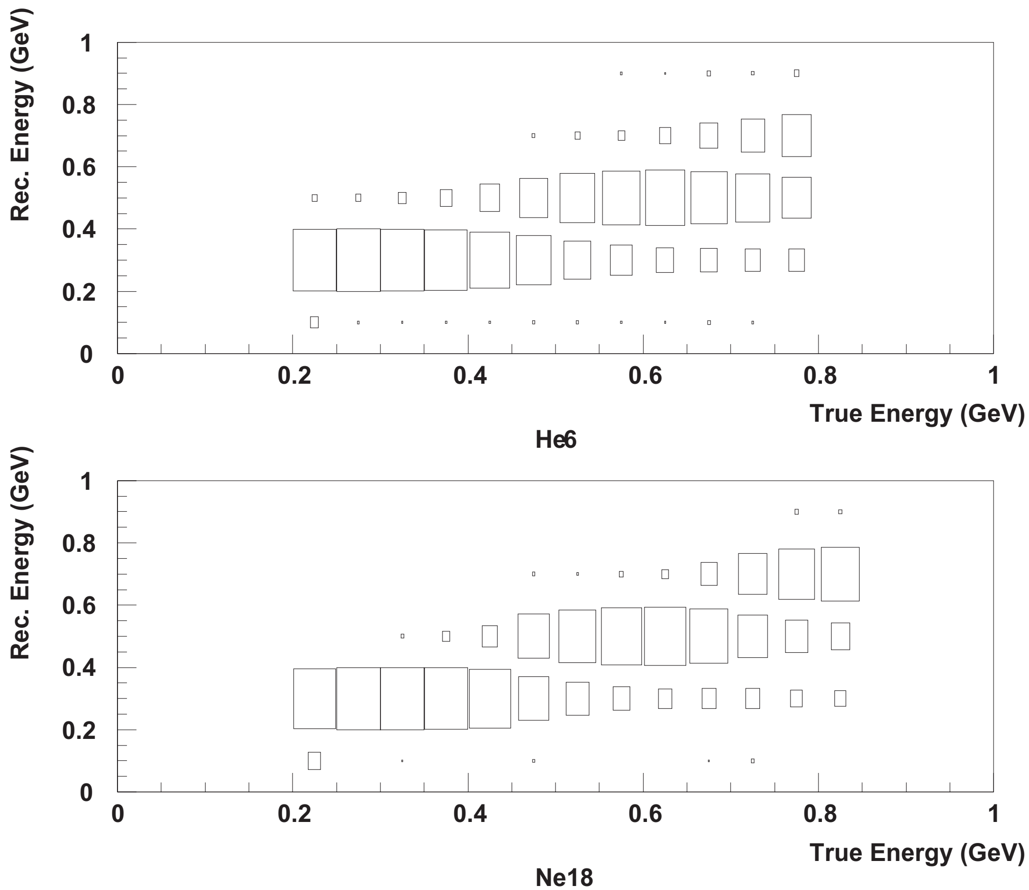


Energy reconstruction

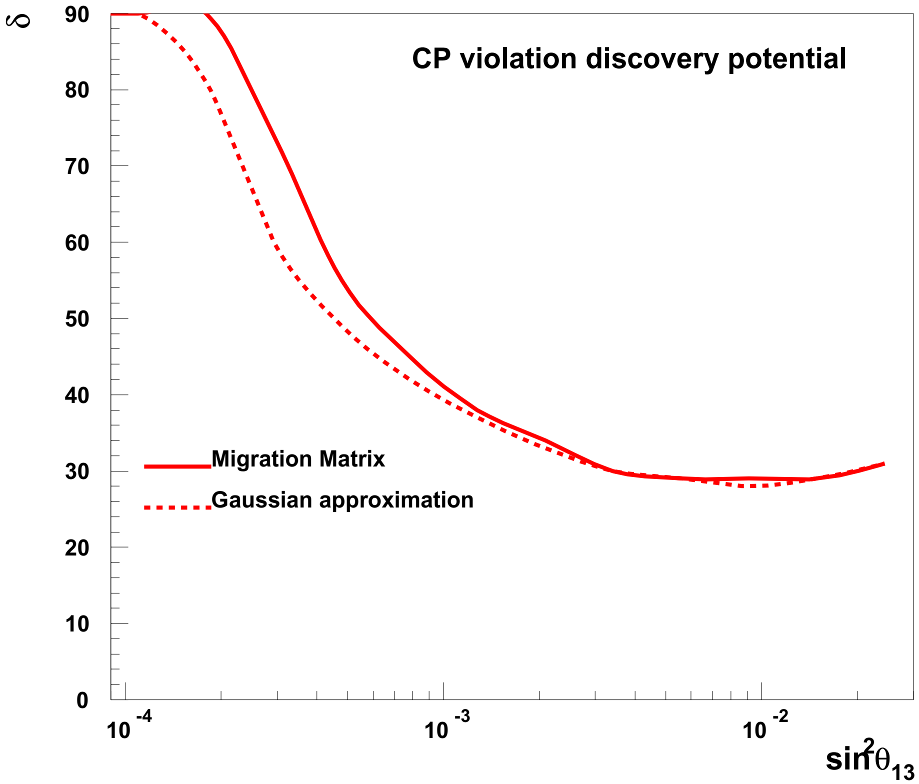
Fermi motion dominates over detector performances. It can be simulated as a flat distribution with a width of 210 MeV, approximated with a gaussian with a width of $210/\sqrt{12} \simeq 90$ MeV.

More precise: use Nuance to compute a migration matrix that relates true neutrino energy to reconstructed neutrino energy.

For $^{18}\mathrm{Ne}$ and $^{6}\mathrm{He}$ events at $\gamma = 100$ this matrix has a 200 MeV binning in reconstructed energy and a 20 MeV binning in true neutrino energy.



This affects performances at small θ_{13} values.



Beta Beam Backgrounds

Computed with a full simulation and reconstruction program. (Nuance + Dave Casper).

π from NC interactions

The main source of background comes from pions generated by resonant processes (Δ^+ production) in NC interactions.

Pions cannot be separated from muons.

However the threshold for this process is $\simeq 450$ MeV, and the pion must be produced above the Cerenkov threshold.

Angular cuts have not be considered yet.

e/μ mis-identification

The full simulation shows that they can be kept well below 10^{-3} applying the following criteria:

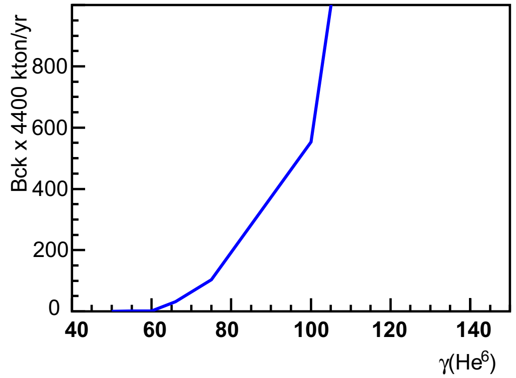
- One ring event.
- Standard SuperK particle identification with likelihood functions.
- A delayed decay electron.

Atmospheric neutrinos

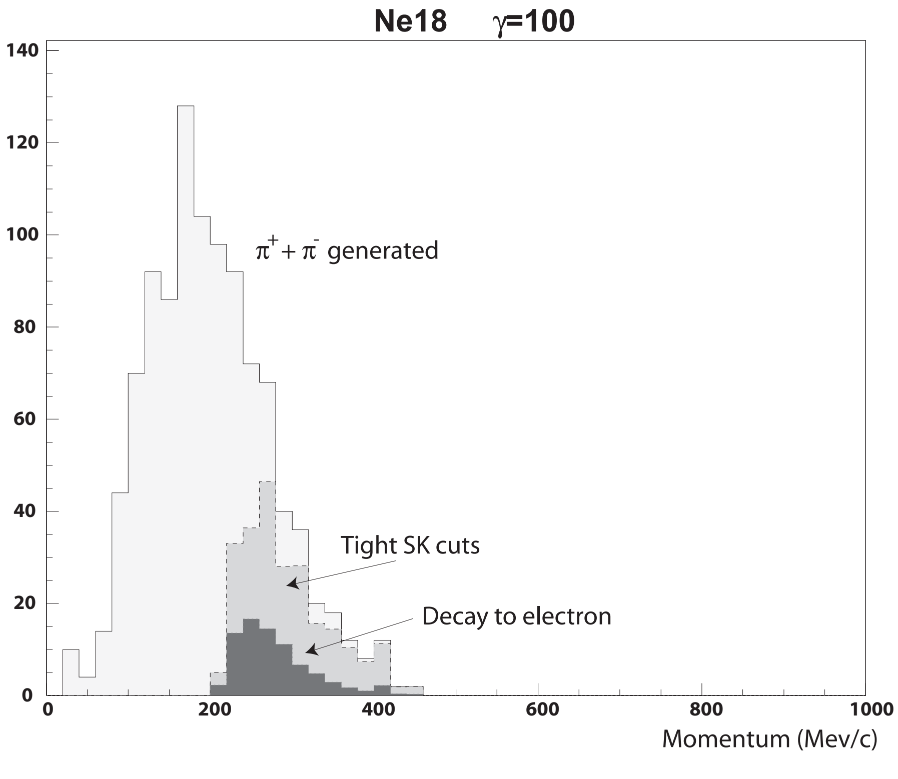
Atmospheric neutrino background can be kept low only by a very short duty cycle of the Beta Beam. A reduction factor bigger than 10^3 is needed.

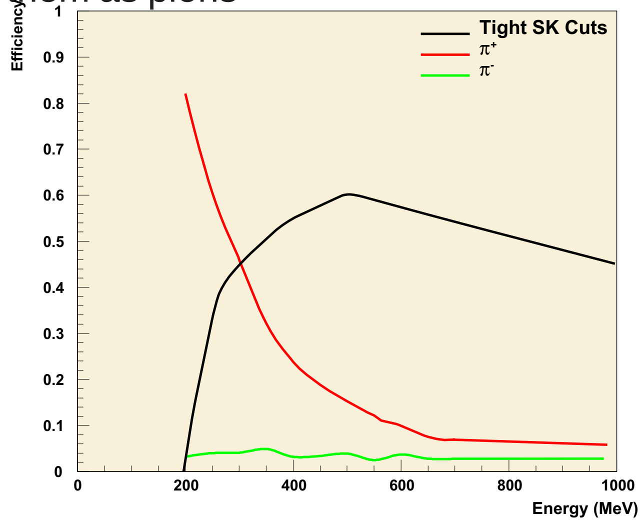
This is achieved by building 10 ns long Ion bunches.

The pion background (the main concern at the higher gammas)

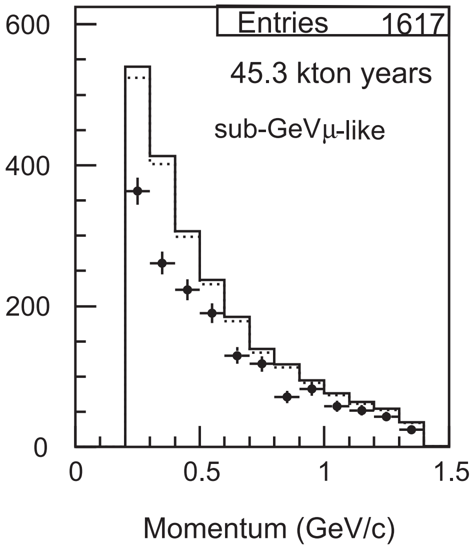


- Generate CC and NC events with Nuance
- Count events with a pion and no other tracks over the Cerenkov threshold
- Apply the tight SK cuts
- Follow pions in water (Geant 3.21) to compute the probability for $\pi \longrightarrow \mu \longrightarrow e$.
- Reconstruct the neutrino energy from the survived pions treating them as pions





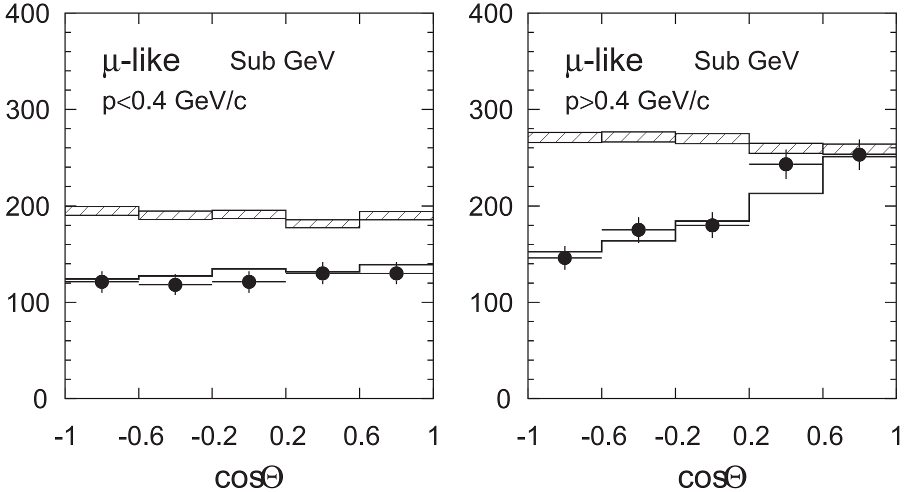
	ν_eCC	π^+	π^-	ν_eCC	π^+	π^-
	Ne18			He6		
Generated	97710	626	406	83880	860	740
Tight cuts	40616	152	89	35985	219	153
Decay	25897	75	4	28531	106	6



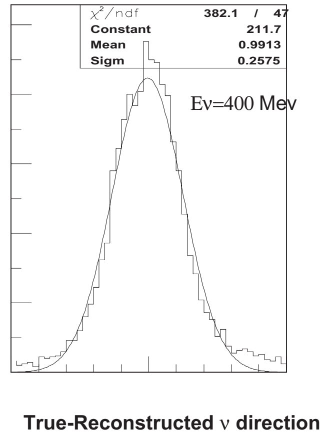
Atmospheric neutrino background

Sub-GeV μ-like events in SK integrated over the solid angle. 45.3 kton year exposure

Sub-GeV μ-like events zenithal distribution



Event direction resolution at 400 MeV. Take $\pm 2\sigma$ as acceptance, equivalent to $\pm 40°$. Solid angle reduced to 1/8



Kamioka to Frejus flux correction: + 20%

Signal efficiency with respect to standard SK algorithms: 54% (flat in energy)

Duty cycle: 8 packets 6.25 ns long in the 7 km long decay ring: $2.2 \cdot 10^{-3}$

13 events per ion specie in 4400 kton year exposure

Computed for 10 years running time (5 $^{6}\mathrm{He}$ + 5 $^{18}\mathrm{Ne}$)

Input values: $\theta_{23} = \pi/4$, $\delta m^2_{23} = 2.5 \cdot 10^{-3}$ eV^2, $\sin^2\theta_{12} = 0.315$, $\delta m^2_{12} = 7.9 \cdot 10^{-5}$ eV^2, $\mathrm{sign}(\delta m^2_{23})$ =+1

Errors: $\theta_{23} = 5\%$ (T2K), $\delta m^2_{23} = 4\%$ (T2K), $\theta_{12} = 10\%$ (today), $\delta m^2_{12} = 4\%$ (today)

2% systematic error on signal and backgrounds.

90 % CL means $\Delta\chi^2 = 4.61$, 2 dof.

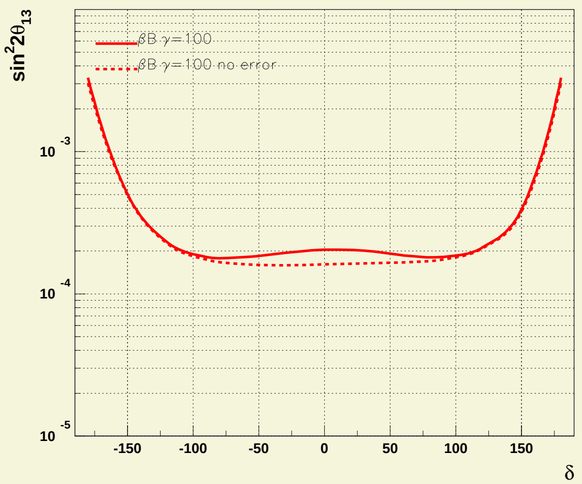
6 parameters fit minimized over the solar and the atmospherics and projected over θ_{13} (function `glbGlbChiTheta`).

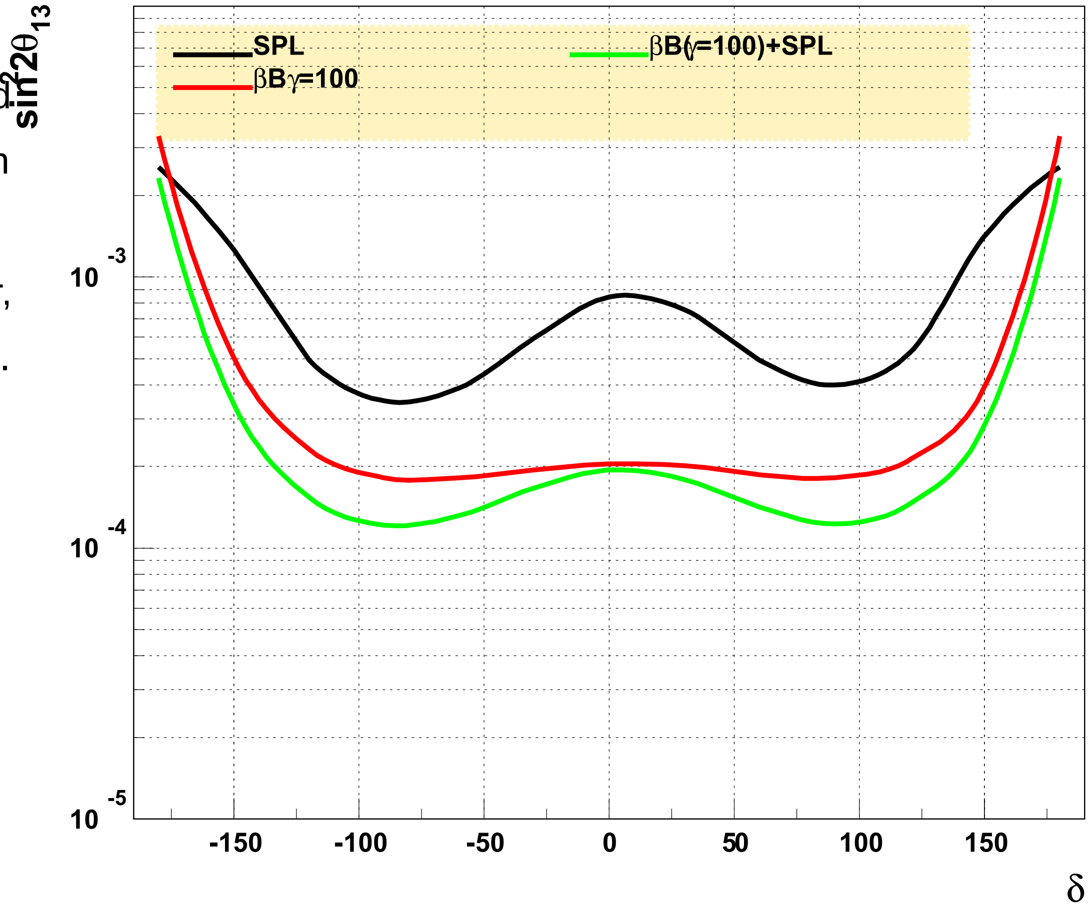
Sign and octant degeneracies not (yet) accounted for, but have a look to T. Schwetz talk.

Beta Beam ($\gamma = 100, 100$) performances

90% CL θ_{13} sensitivity

Effect of other parameters' error





Some comments on θ_{13} sensitivity plots

- 90% CL makes no sense. It's used for comparison with other proposals.
- Sensitivity plots are not representative of the performances for all the θ_{13} values. They are computed for no signal when the experiment deals with backgrounds only.
- It makes no sense to loose information projecting these plots in monodimensional or “fraction of delta” plots.
- These plots are more interesting when comparison with other facilities is shown.

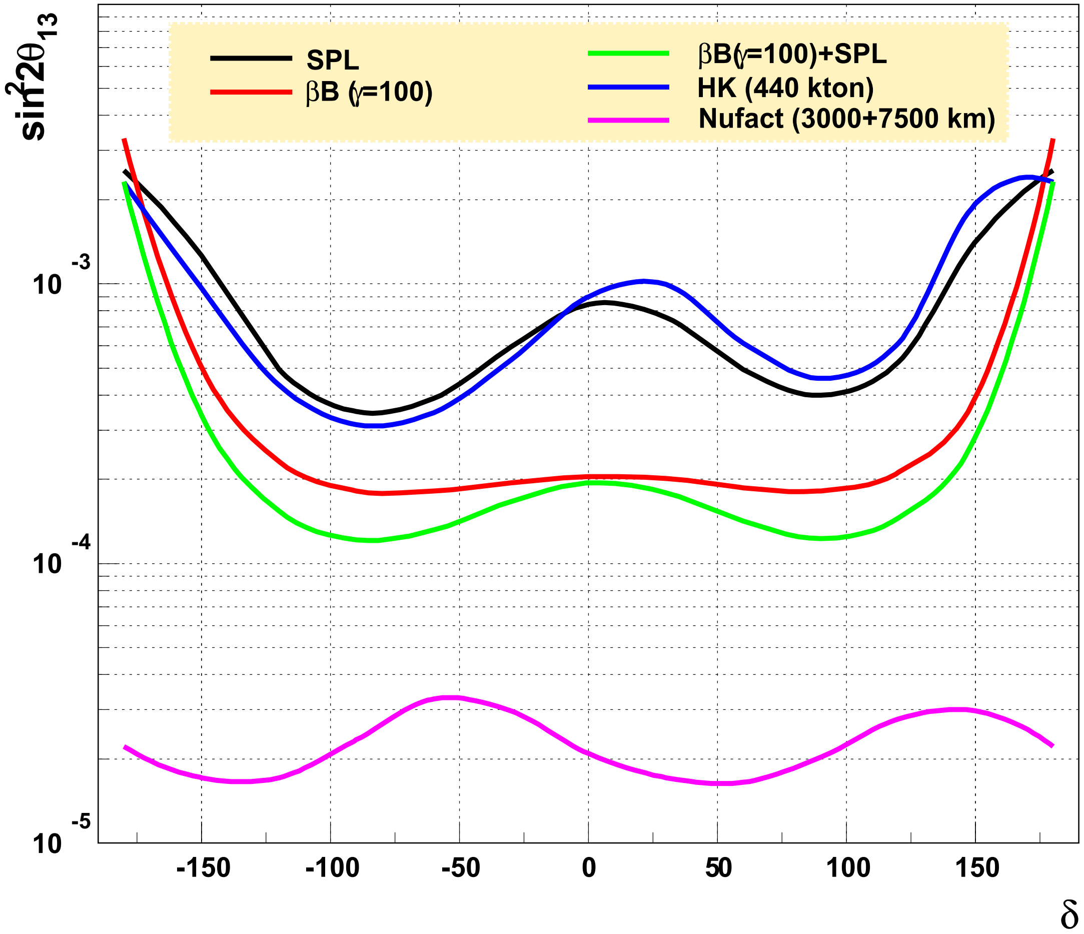
The same compared with some other facility.

Everything computed with the identical program. Thanks to the GLoBES experiment library.

HK taken from Huber, Lindner and Winter, hep-ph/0204352, with a fiducial of 440 kton (it was 1 Mton), 2% systematics on QE signal and backgrounds (it was 5%) and 2+8 years running (it was 2+6).

NUFACT taken from Huber, Lindner and Winter, hep-ph/0204352, changing the systematics from 0.1% to 2% and the running time to 5+5 years (it was 4+4). Other parameters: two iron magnetized detectors, 50 kton, at 3000 and 7500 km, 50 GeV muons, 1E21 useful decays/year, 5% systematics on matter profile, threshold at 4 GeV, 20 bins from 4 to 50 GeV.

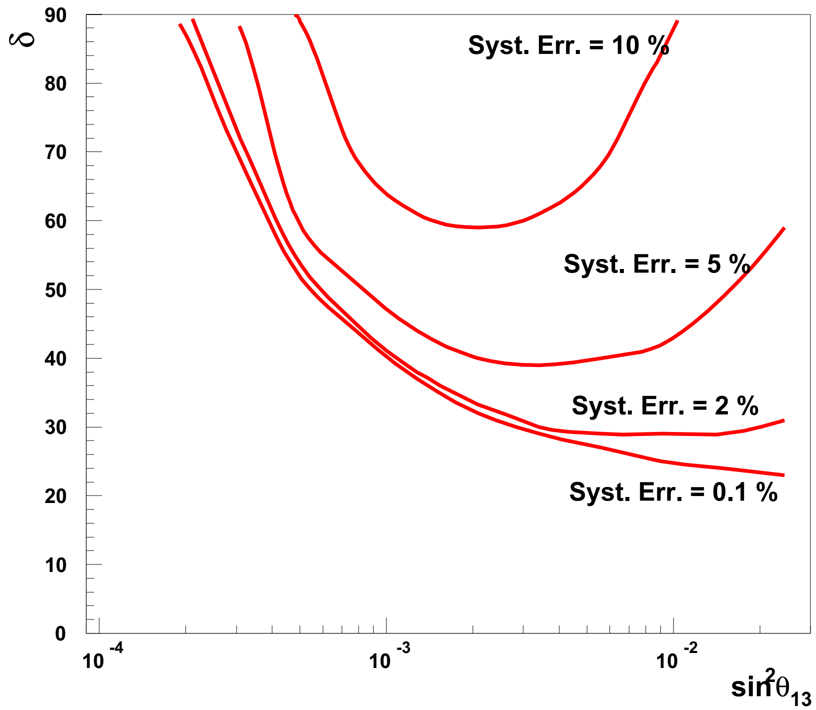
SPL 3.5 GeV (see J.E. Campagne talk) with 2 ν + 8 $\overline{\nu}$ years, 2% systematic error, 200 MeV binning, 440 kton fiducial.

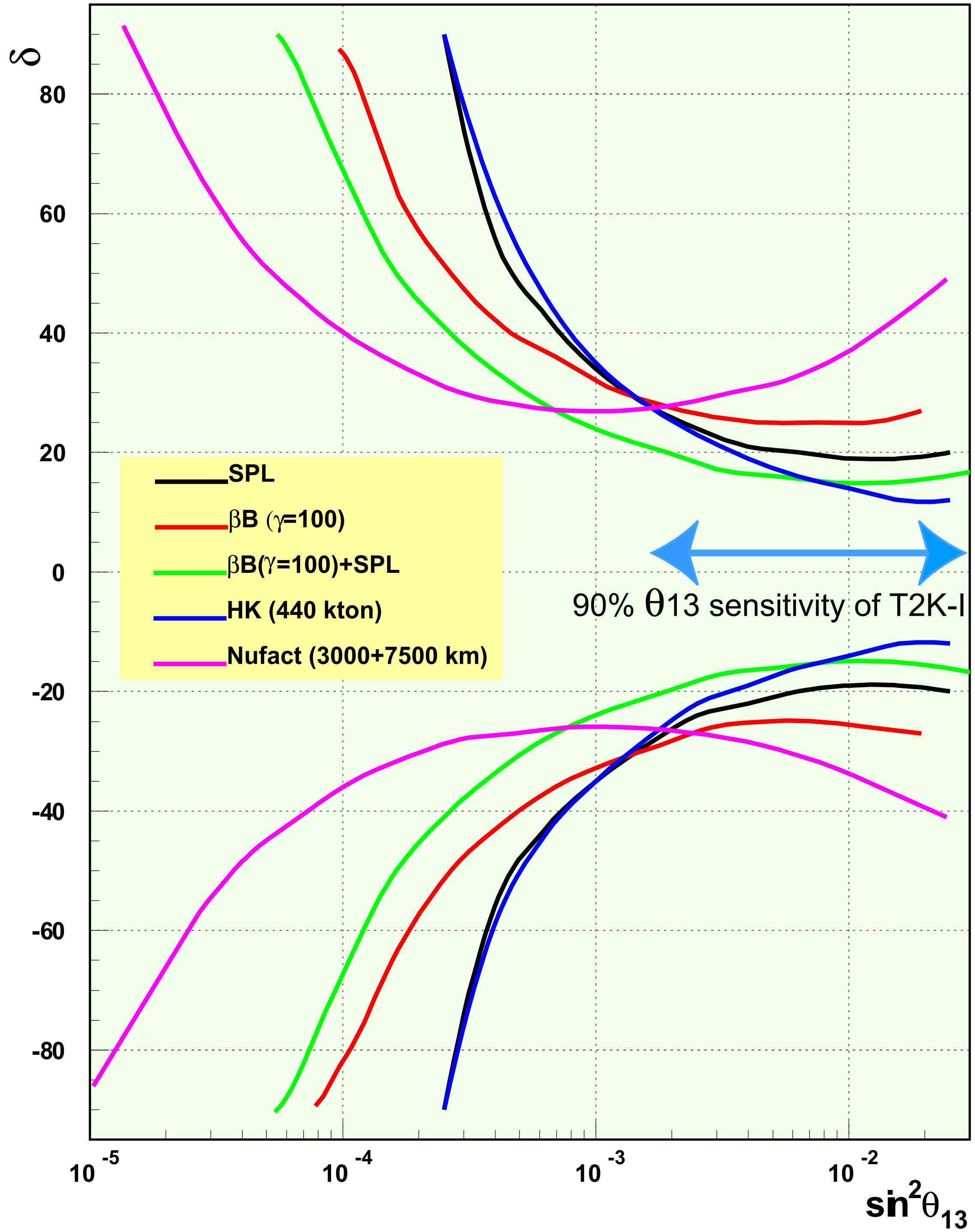


3 σ δ_{CP} discovery potential

Same parameters and references as before.

Systematic errors have a big impact on discovery potential.





Beta Beam fluxes

From J. Bouchez, M. Lindroos and M.M., proceedings of Nufact03, hep-ex/0310059: "*In the following study, it was supposed that the neutrino flux from Neon could be improved by a factor 3 over the present conservative estimate, while only a 40 % improvement was put on antineutrino fluxes.* "

Baseline fluxes: 5.8E18 $^6\mathrm{He}$ useful decays/year and 2.2E18 useful $^{18}\mathrm{Ne}$ decays/year were taken from the original P.Zucchelli paper.

The Eurisol design study (very) recently produced two intermediate papers about possible Beta Beam fluxes:

- M. Benedikt, S. Hancock, M.Lindroos: "Parameter and Intensity Values, Version 1", 17 May 2005, keeping fixed the present PS and SPS parameters
- M. Lindroos, "Possible ways of increasing the number of (anti-) neutrinos from the EURISOL beta-beam facility", (Version L), 7 June 2005, where some extensions of PS are considered, to increase the overall fluxes

Useful decays/year in the three different scenarios ($\gamma = 100$)

	Baseline	Version 1	Version L
$^6\mathrm{He}$ 6	5.8E18	1.76E17	3.45E18
$^{18}\mathrm{Ne}$	2.2E18	1.89E16	3.47E17

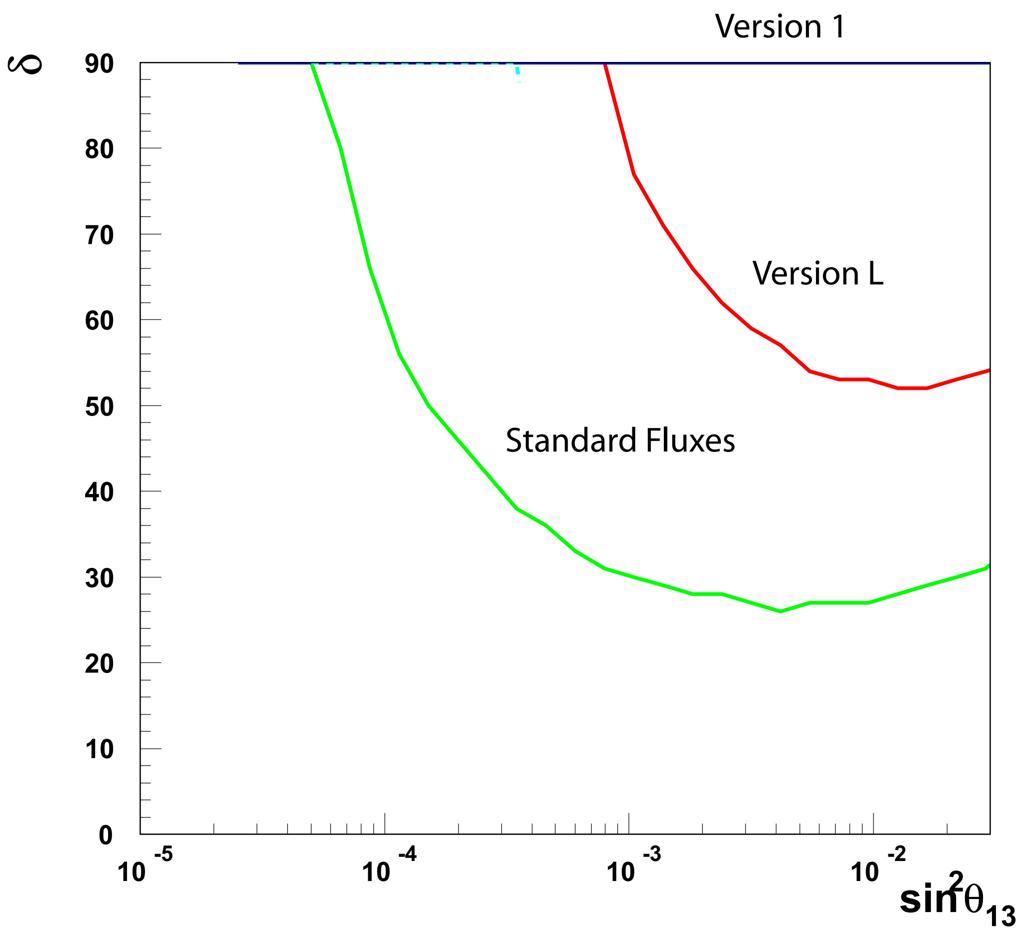
Physics Potential with the different fluxes

Computed with a fast program that keep fixed all the parameters except θ_{13} and $\delta_{\rm CP}$

Version 1 : 1 year of $^{6}\mathrm{He}$ and 9 years of $^{18}\mathrm{Ne}$

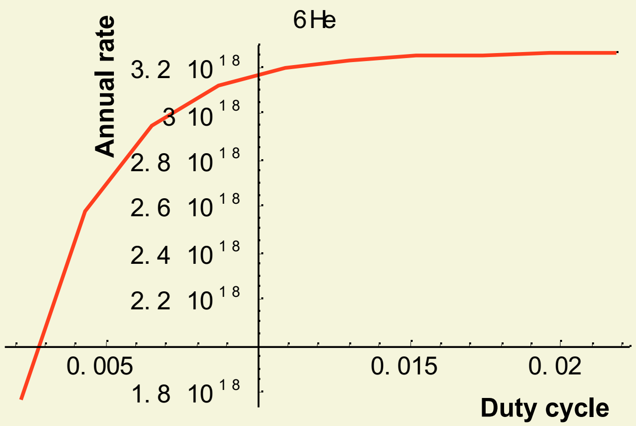
Version L: 6 + 4 years

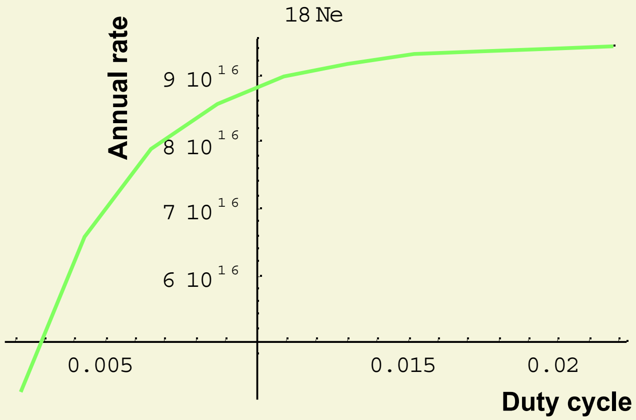
Baseline : 5 + 5 years



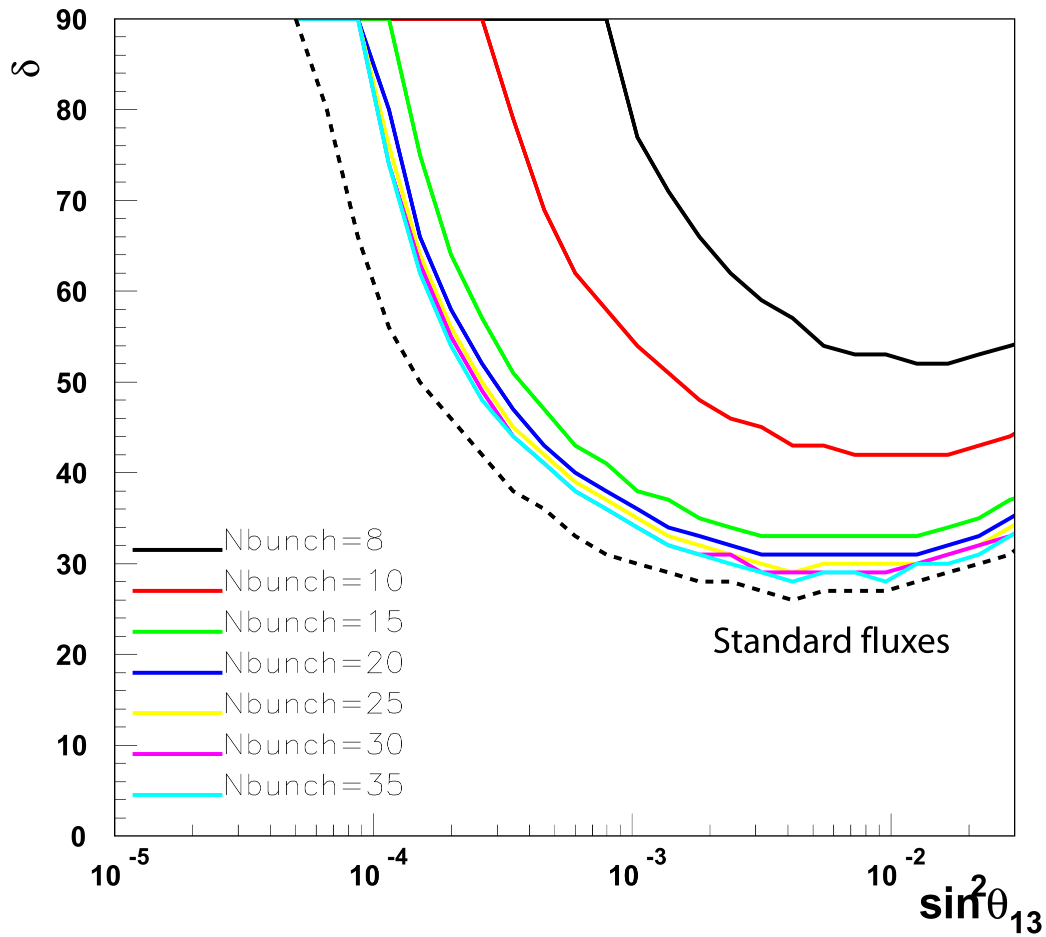
Duty factor - flux interplay

Version L computes flux increase as function of the number of bunches circulating in the decay ring (baseline is 8). Number of bunches worsens the duty factor increasing the atmospheric neutrino background.



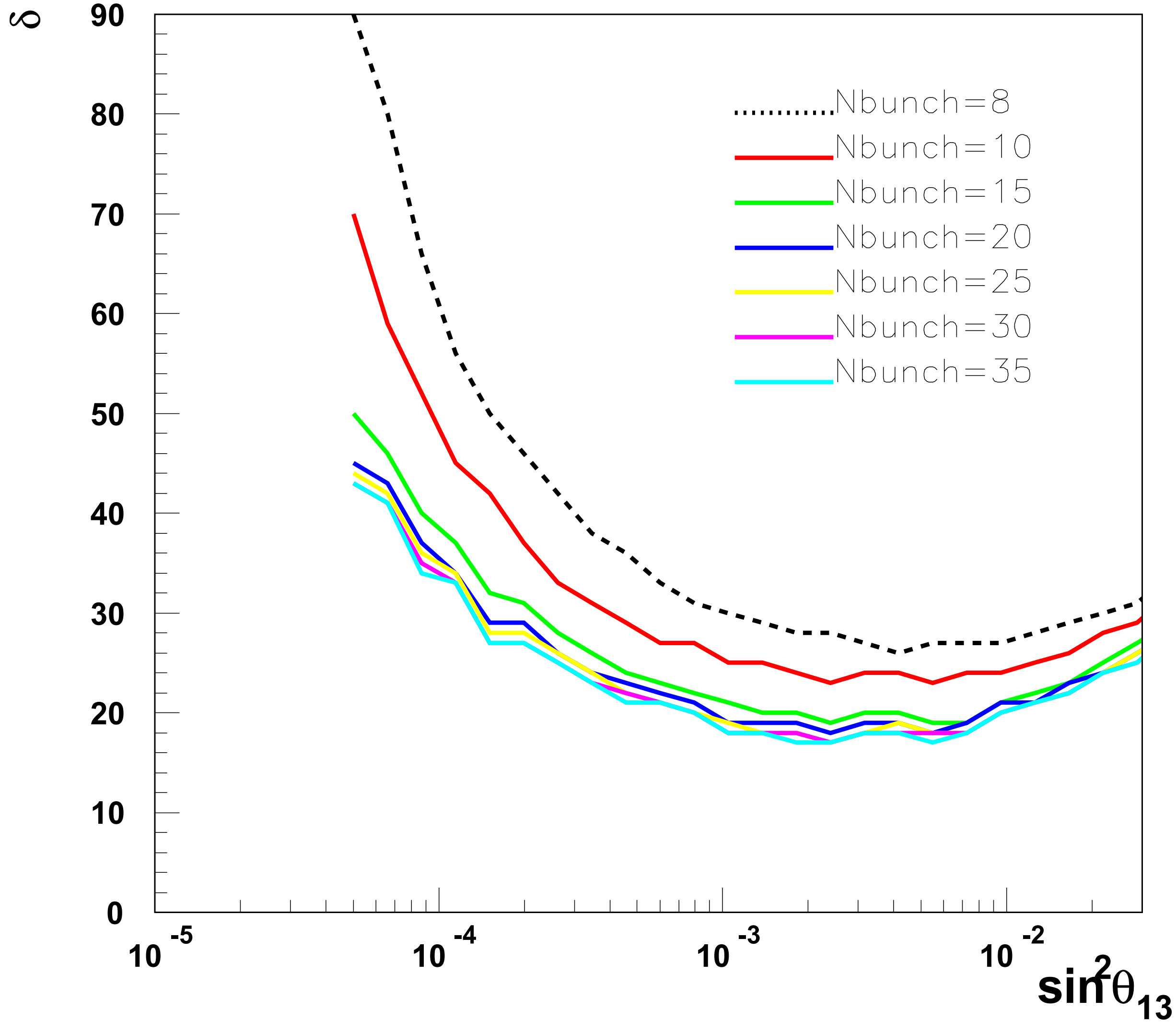


Performances can be evaluated varying fluxes and atmospheric neutrino backgrounds following the duty cycle curves:



Duty factor - flux interplay (II)

The dreamer's scenario: repeat the previous exercise by starting from the baseline fluxes

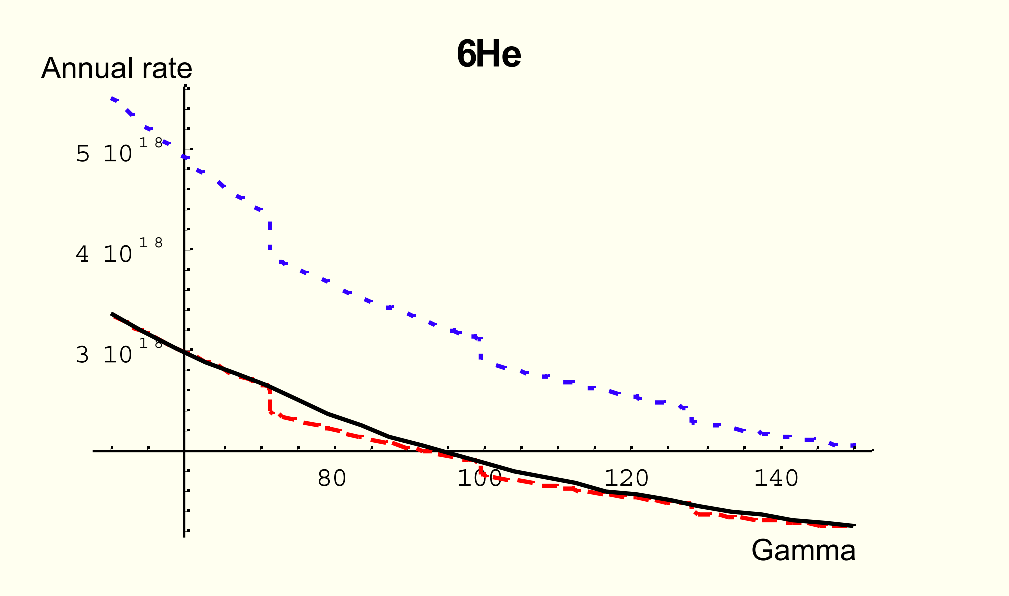


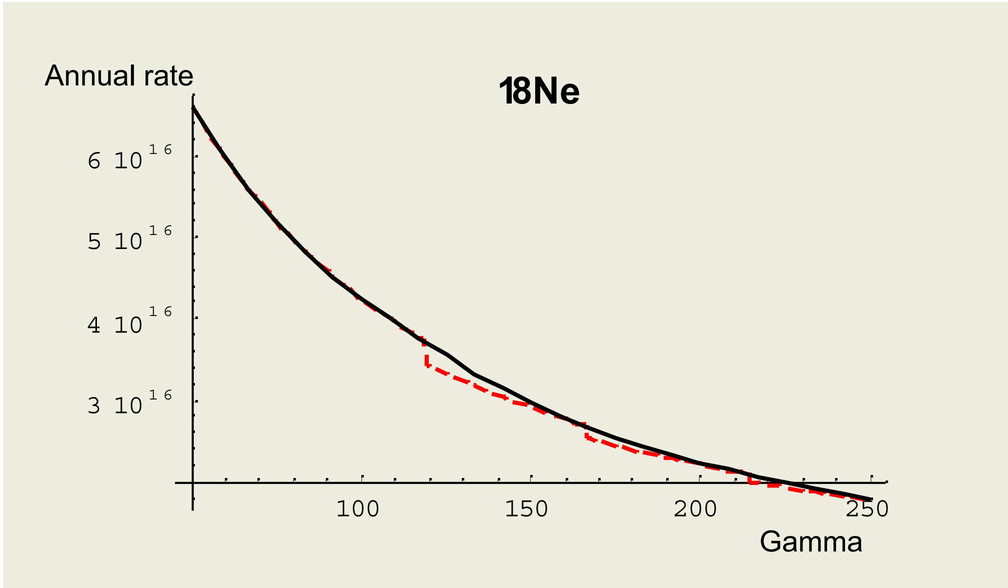
The $\gamma = 100, 100$ scenario improves performances up to the saturation of fluxes as function of the number of bunches.

Gamma - Flux interplay

Beta Beam fluxes were computed for $\gamma = 100$. Varying the ion γ, fluxes change. The higher the γ the longer the lifetime, but the number of asymmetric bunches in the decay ring is limited to 15 for $^6\mathrm{He}$ 6 and 40 for $^{18}\mathrm{Ne}$ 18.

The following curves are taken from M. Lindroos note





It is now possible to realistically study ion gammas different from 100.

Conclusions

- The Beta Beam studies are entering the maturity stage.
- First preliminary results are already encouraging, showing several different directions for developments.
- First priority now is to collaborate with the EURISOL DS to give feedback and guidelines for optimization.
- Also SPL did very important developments in the past months.
- A facility based on SPL + Beta Beam would be extremely powerful.
- The full physics potential of a megaton detector exposed to the SPL and/or Beta Beams, as $\mathrm{sign}(\delta m^2_{23})$ and degeneracy solving, is fully exploited combining them with the high statistics atmospheric neutrino studies.
- New developments as Ne^{19}, higher gammas, electron capture beams make these studies even more funny.