Improving Beta Beam physics reach

- You can run one ion at the time maintaining the same overall fluxes. In this way each of the two ions can be run at its optimal value.
- A counting experiment is too limited in the leptonic CP violation discovery game.

Restart an optimization process of the SPS based Beta Beam for the Frejus baseline (130 km) and for a free baseline

A recent SPL SuperBeam optimization . . .

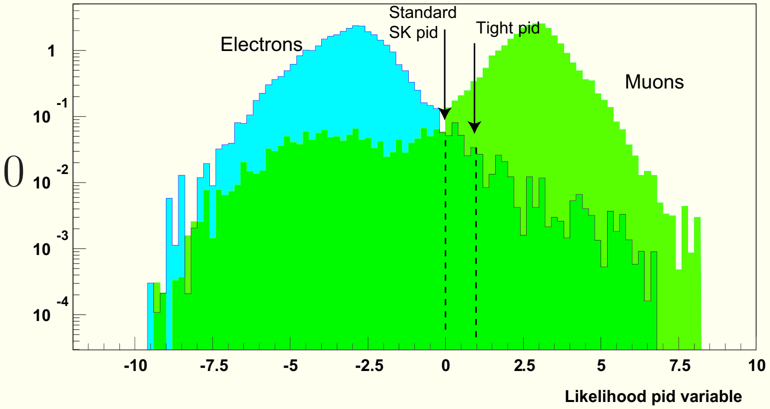
SPL SB optimization as computed by J.E. Campagne and A. Cazes, LAL, hep-ex/0411062

- Scan the proton driver energies from 2.2 to 8 GeV (4MW fixed).
- Keep the baseline fixed to 130 km
- From 3.5 GeV to above explore the possibility to focus higher momentum pions.
- The 3.5 GeV energy, with a neutrino beam with $\langle E_\nu \rangle \simeq 300 MeV$, decay length of 40 m and decay tunnel diameter of 2 m greatly improves the 2.2 GeV performances: ν_μ CC rate at 130 km from 42 to 122 events/kton/year

Particle identification and signal efficiency

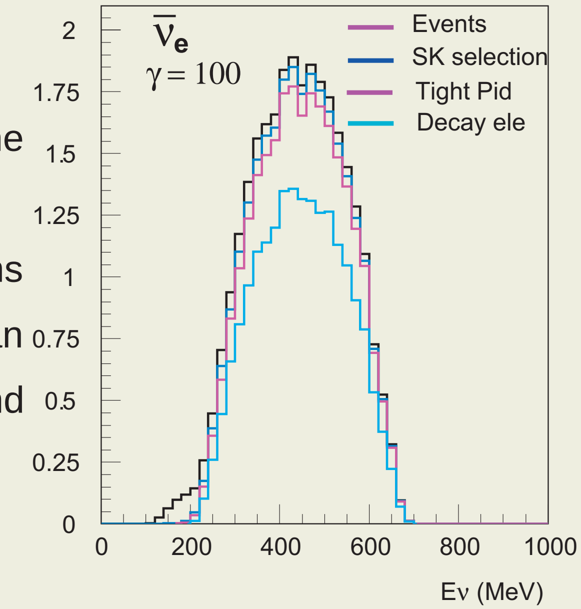
Electron/muon misidentification must be suppressed much more than in standard SK analysis to guarantee a negligible background level.

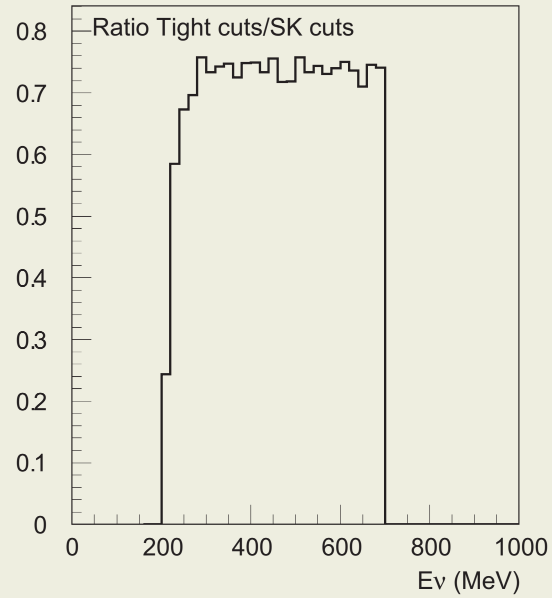
Pid in SK is performed through a Likelihood, $Pid > 0$ identifies muons. Use $Pid > 1$



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

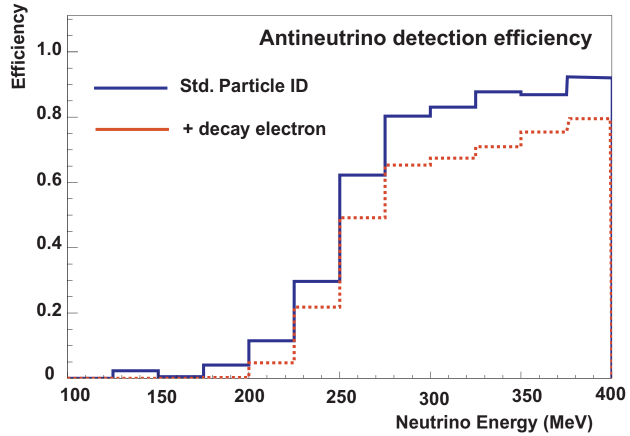
Final efficiency for positive muons. Negative muons have an efficiency smaller by $\sim 22\%$ because can be absorbed before decaying. Electron background suppressed to $\sim 10^{-5}$.



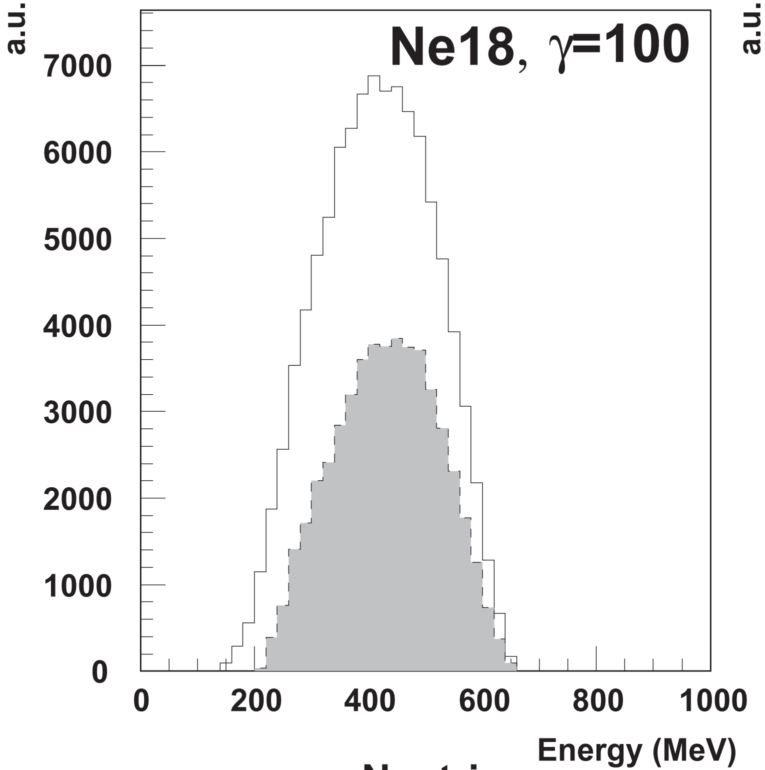


The pion background (the main concern at the higher gammas)

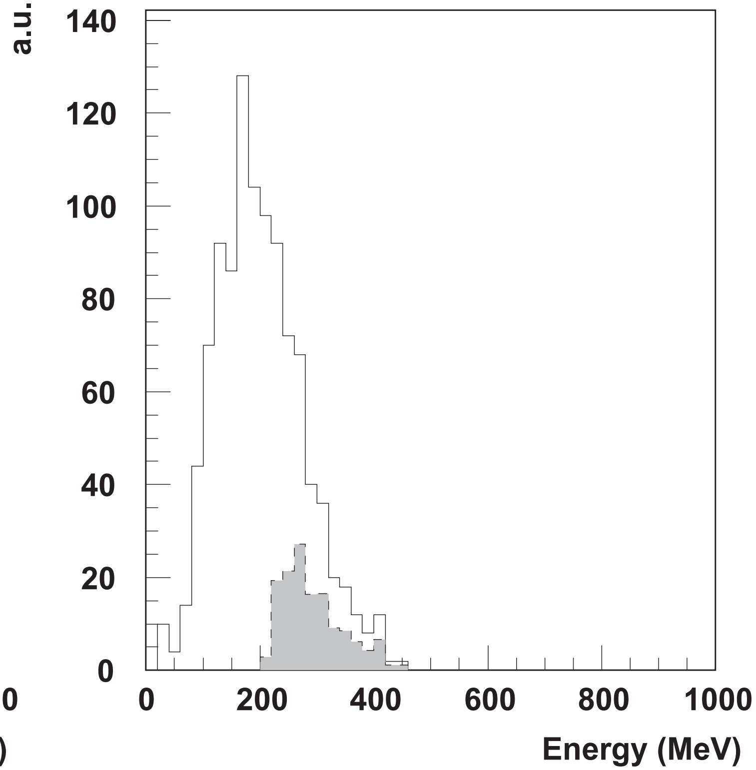
The efficiency function is computed by Nuance by asking a single ring event, one track above the Cerenkov threshold and the signature of the muon through the detection of the Michel electron. For $^{18}\mathrm{Ne}$ events the efficiency is smaller because of the muon absorption in water.



Effect on signal and background events:



Neutrinos



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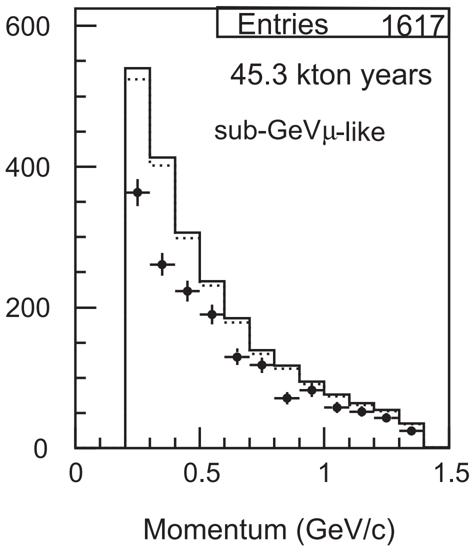
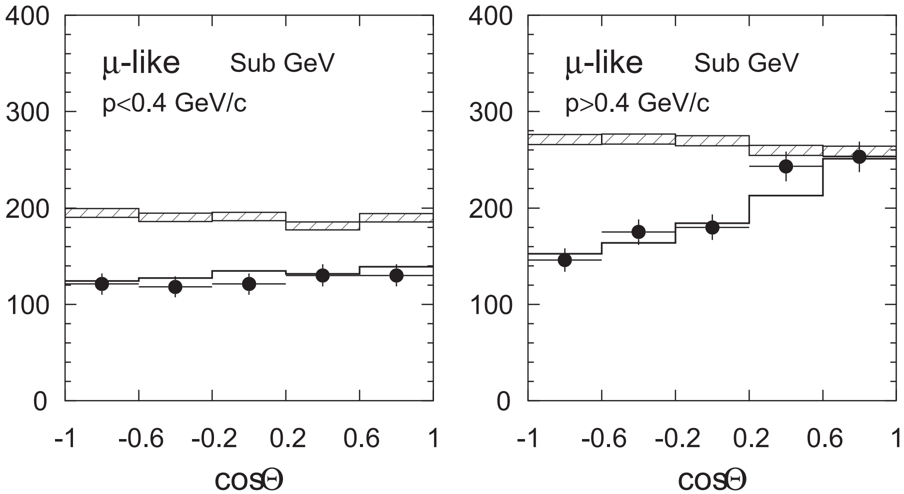
Pions could interact before decaying, missing the Michel electron signature. This requires a dedicated MC and it's not taken into account at the present. So pion background is overestimated in the following.



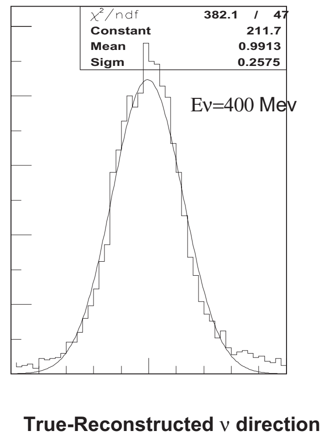
Atmospheric neutrino background

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 $\pm 40^{\circ}$. Solid angle reduced to 1/8



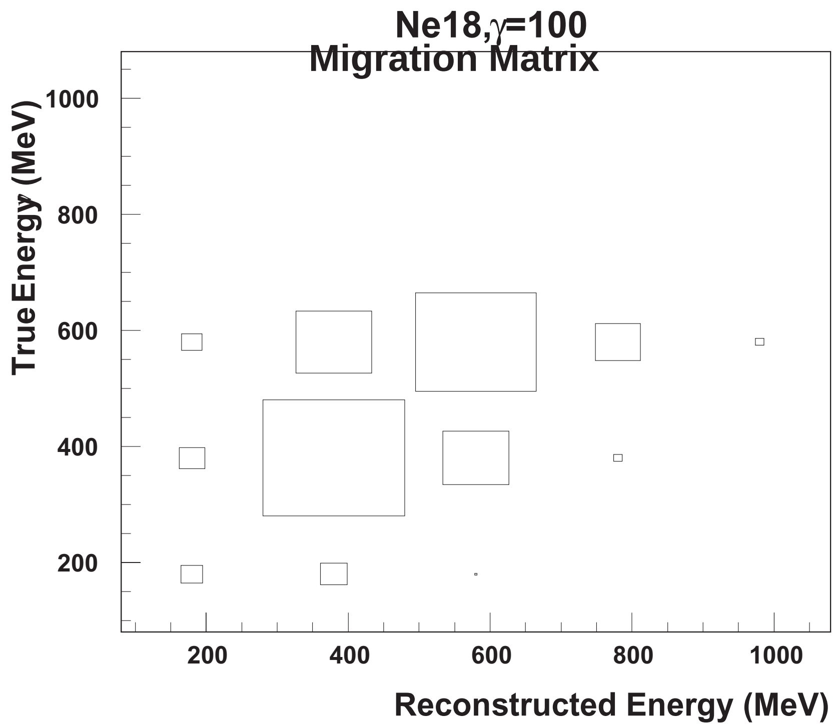
Kamioka to Frejus flux correction: + 20%

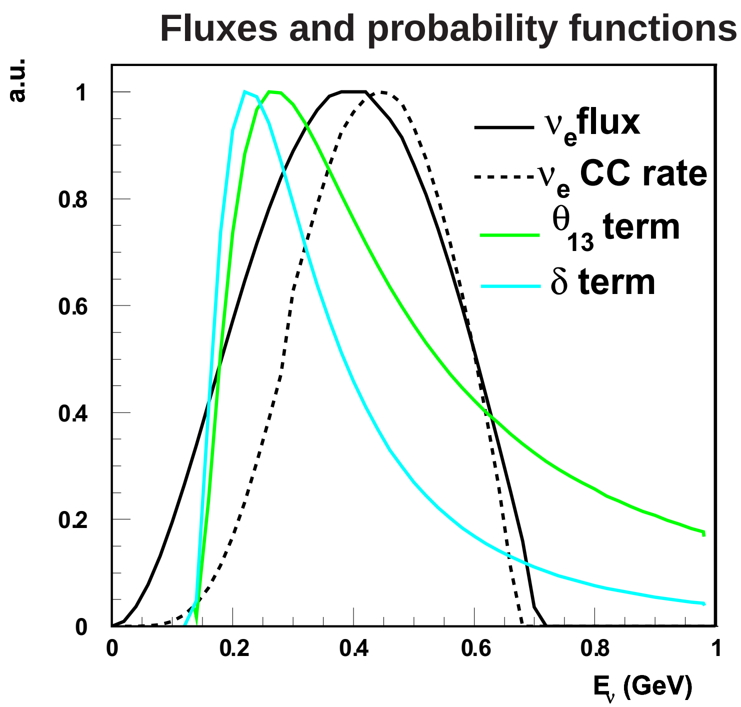
Signal efficiency with respect to standard SK algorithms: 54% (flat in energy)

Duty cycle: 4 packets 10 ns long in the 7 km long decay ring: $1.7 \cdot 10^{-3} \times \text{bunch length}[10\text{ns}]$

10 events per ion specie in 4400 kton year exposure for 10 nsec long packets

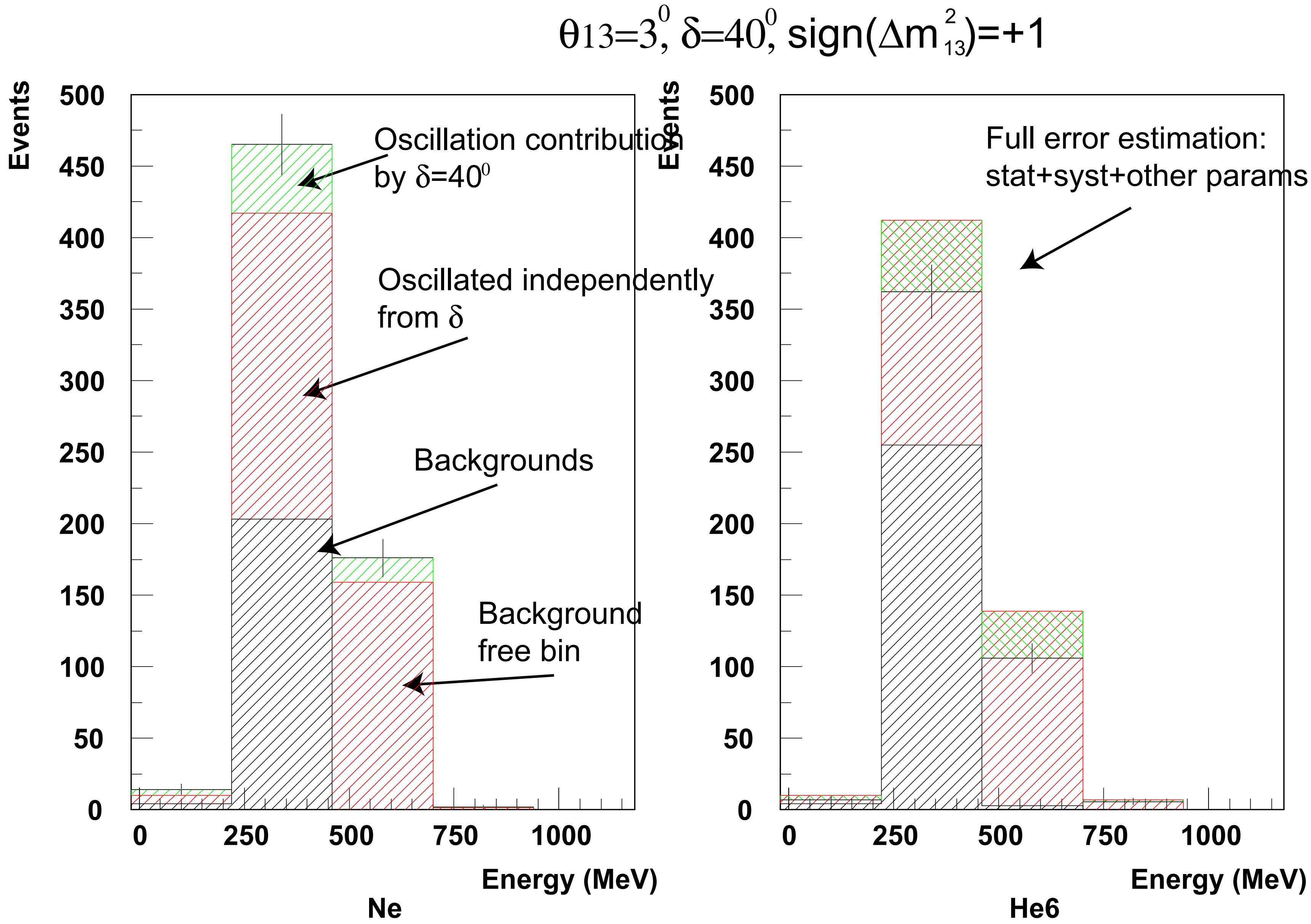
The $\gamma = 100, 100$ option



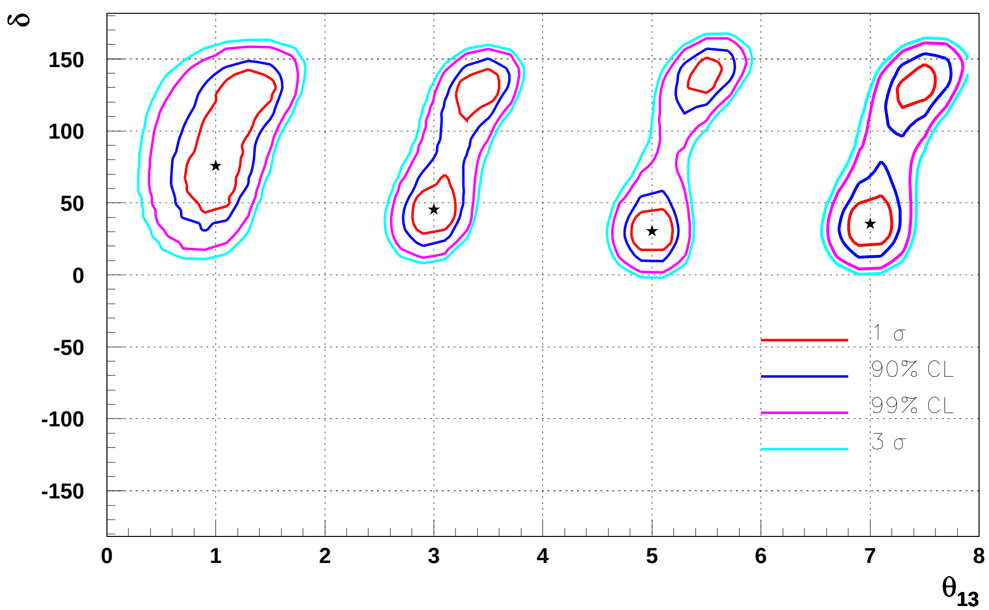


- $^6\mathrm{He}$ and $^{18}\mathrm{Ne}$ have similar end point energy, for the moment keep their gammas equal.
- Energy information can be exploited by raising the ion gammas, too small energies are severely affected by Fermi motion. At higher gamma the atmospheric neutrino background rate decreases, the neutrino flux increases.
- Events are binned with 200 MeV bins. A. Blondel et al. paper: NIM A535 (2004)665 paper suggests a MC based method to further improve energy resolution at those energies.
- After a scan the $\gamma = 100, 100$ option results to be the best one for L=130 km.

As an example: events for $\theta_{13} = 3^\circ, \delta = 40^0$



$\gamma = 60, 100$

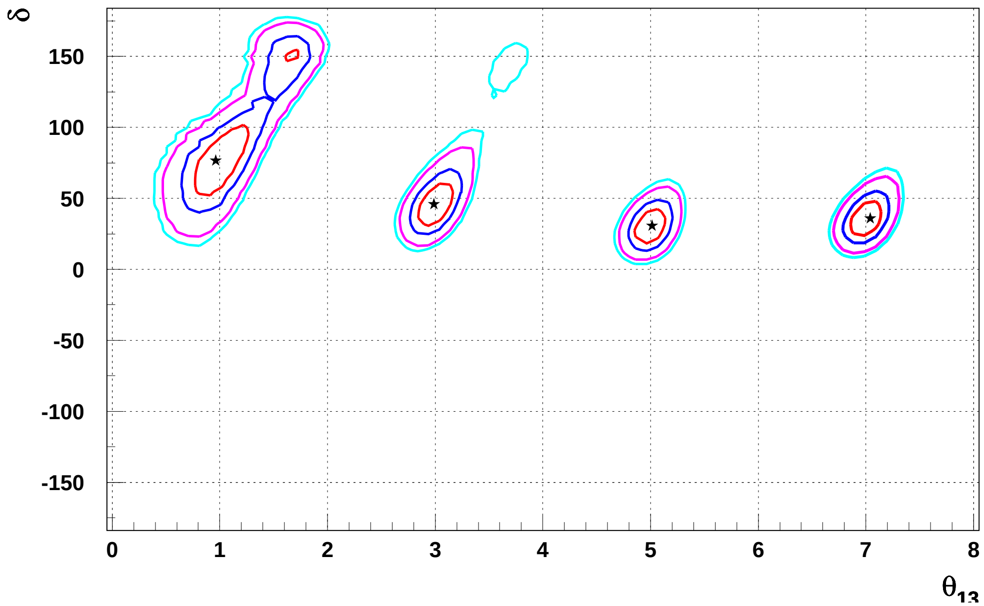


The improvement

$\delta m^2_{12} = 7 \cdot 10^{-5}\ eV^2, \theta_{13} = 1°, \delta = \pi/2$, sign$(\Delta m^2) = +1$		
	^6He ($\gamma = 60$)	^{18}Ne ($\gamma = 100$)
CC events (no osc, no cut)	19710	144784
Oscillated	1	118
δ oscillated	-12	54
Beam background	0	0
Detector backgrounds	1	397

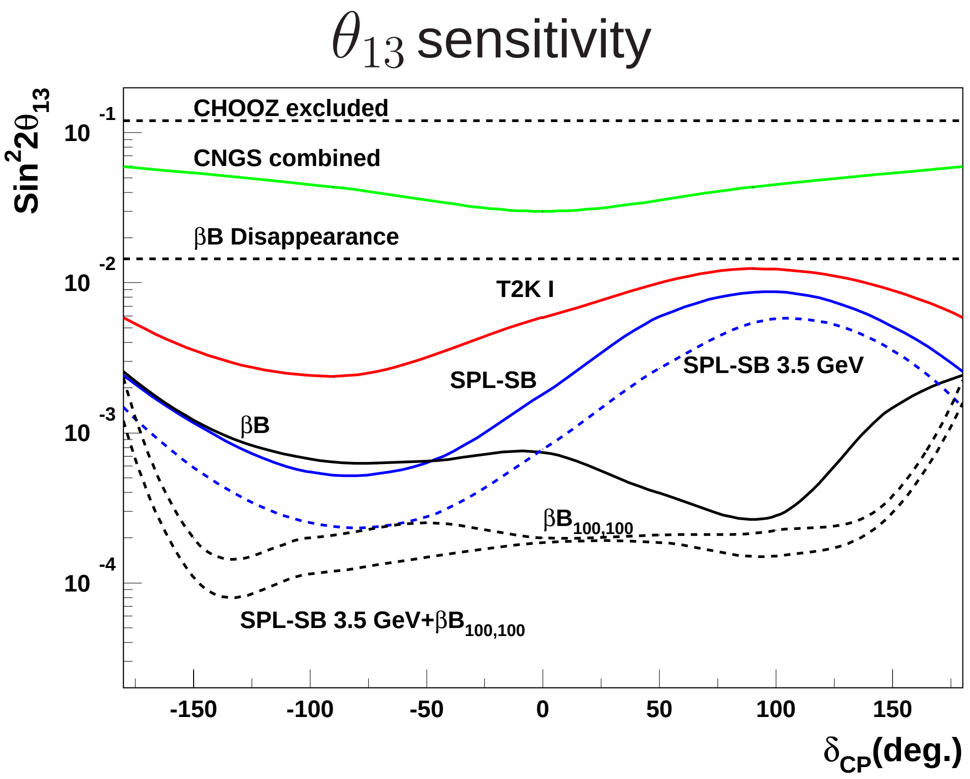
δ-oscillated events indicates the difference between the oscillated events computed with $\delta = 90°$ and with $\delta = 0$.

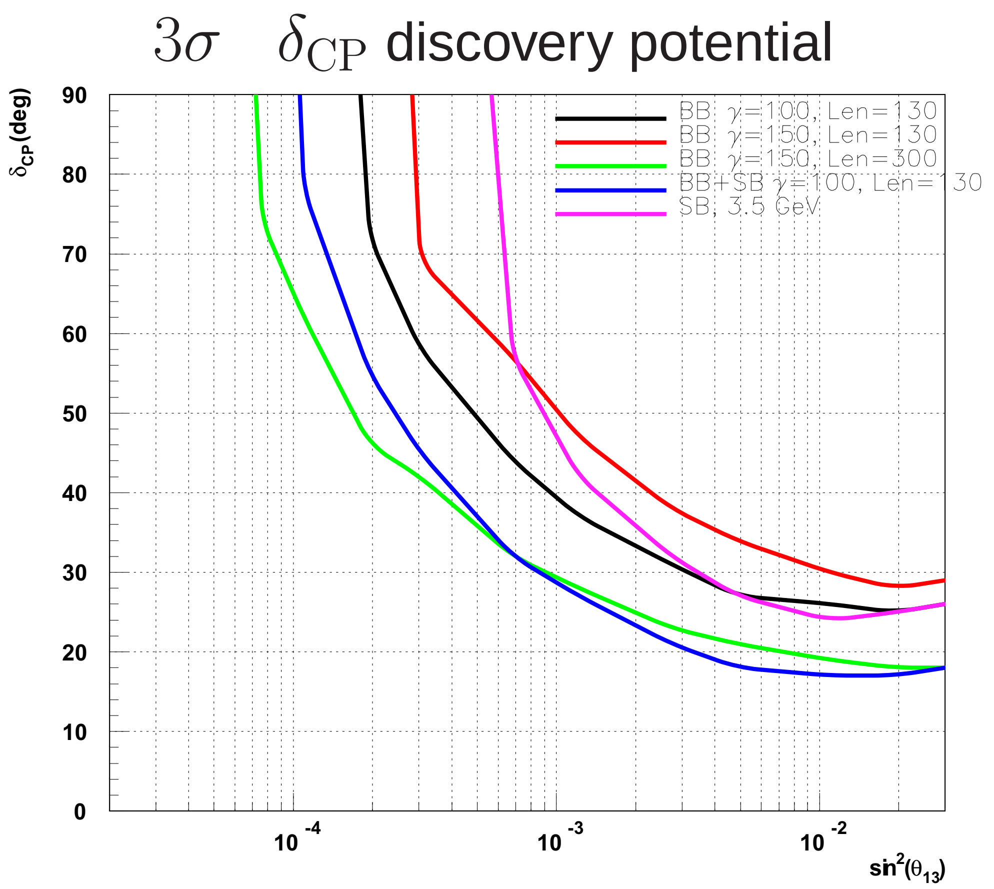
$\gamma = 100, 100$ with the new bck evaluation

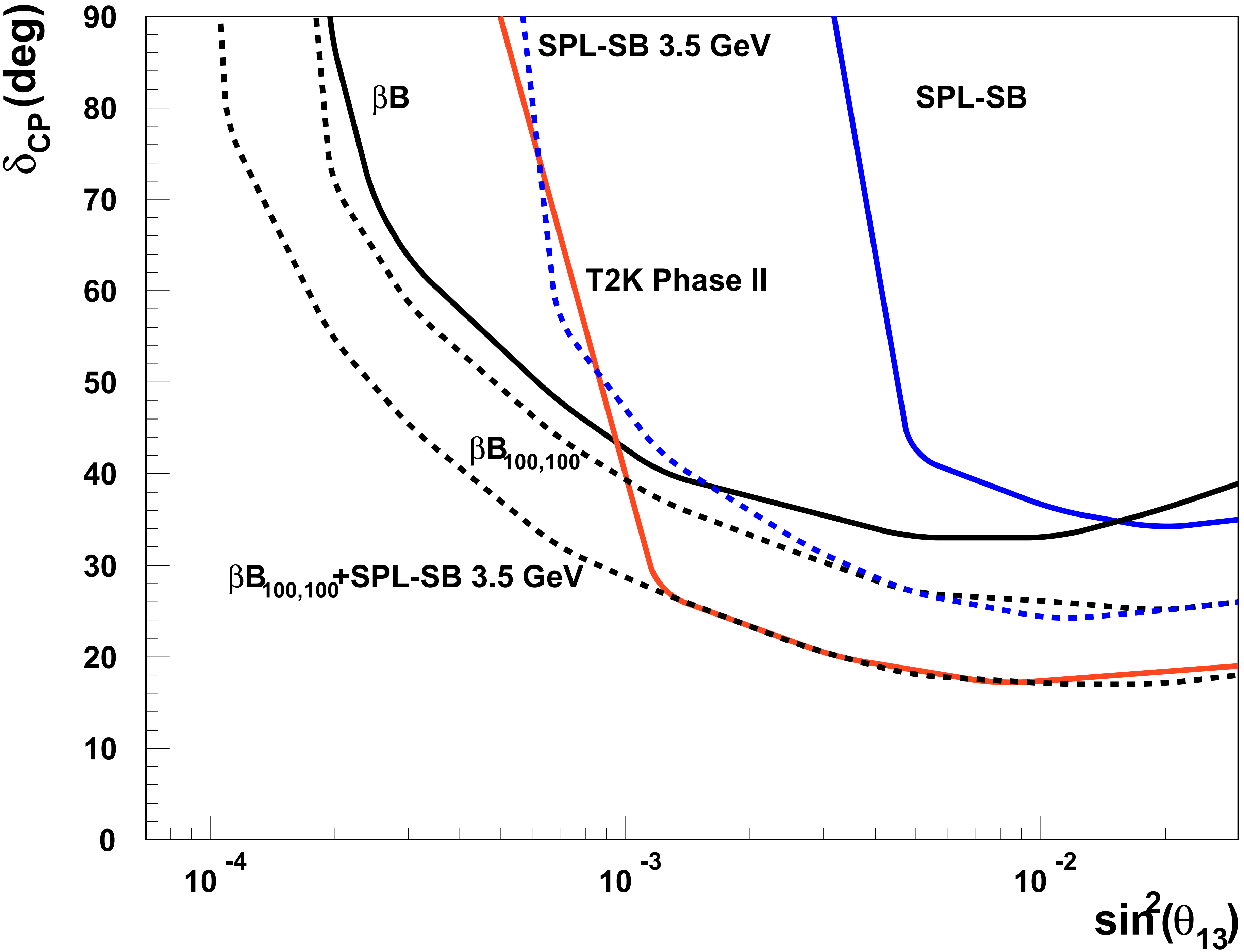


	^6He ($\gamma = 100$)	^{18}Ne ($\gamma = 100$)
CC events (no osc, no cut)	101263	144784
Oscillated	7	118
δ oscillated	-38	54
Beam background	0	0
Detector backgrounds	262	206

Performances







90
80
70
60
50
40
30
20
10
0
δ_{CP}(deg)
10^{-4}
10^{-3}
10^{-2}
$\sin^2(\theta_{13})$
SPL-SB 3.5 GeV
βB
SPL-SB
T2K Phase II
$\beta B_{100,100}$
$\beta B_{100,100}$+SPL-SB 3.5 GeV

A technical detail: how long can be the ion batches in the decay tunnel?

The 10 ns bunch length in the decay ring is very demanding from the accelerator physicists point of view. Relaxing this bound the ion fluxes could be enhanced.

How long the ion bunches can be (keeping the ion fluxes constant)? Look how the δ_{CP} sensitivity degrades.