The Low Energy Neutrino Factory

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Introduction

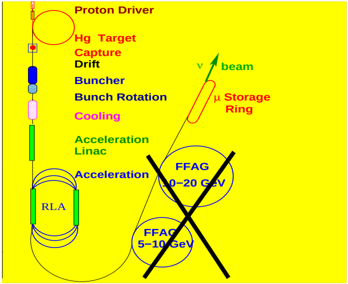
- The low energy neutrino factory is one candidate for a future neutrino oscillation experiment.

- These experiments are primarily designed to measure:
  - δ (CP violating phase)
  - θ_{13} (third mixing angle)
  - Sign of Δm^2_{31} (mass hierarchy)

- We are aiming at optimizing the LENF set-up.

The low energy neutrino factory

- Create an intense source of $\mu^{\pm}$.
- Accelerate them to energies of $E_{\mu} \sim 5$ GeV.
- Inject into a storage ring where the muons decay: $\mu^{\pm} \longrightarrow e^{\pm}\nu_e(\bar{\nu}_e)\bar{\nu}_{\mu}(\nu_{\mu})$
- Detect with a totally active scintillating detector (TASD).
- A TASD can detect $e^{\pm}$ and $\mu^{\pm}$ $\Rightarrow$ access to the $\overset{(-)}{\nu}_{\mu} \rightarrow \overset{(-)}{\nu}_{e}$ channel as well as $\overset{(-)}{\nu}_{e} \rightarrow \overset{(-)}{\nu}_{\mu}$ and $\overset{(-)}{\nu}_{\mu} \rightarrow \overset{(-)}{\nu}_{\mu}$.



www.cap.bnl.gov

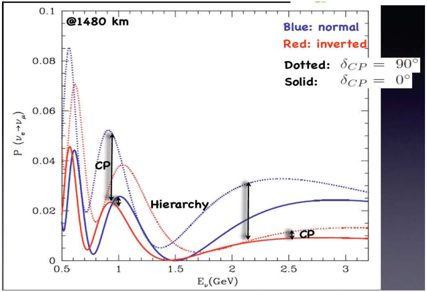
The set-up

For the LENF we assume:

- $\mu^{\pm}$ detection efficiency of 73% <1 GeV and 94% ≥ 1 GeV
- $e^{\pm}$ detection efficiency of 37% <1 GeV and 47% ≥ 1 GeV
- Background of 10^{-3} on the $\overset{(-)}{\nu}_{\mu}$ appearance and disappearance channels
- Background of 10^{-2} on the $\overset{(-)}{\nu}_{e}$ appearance channel
- Detector fiducial mass of 20 kton
- Energy resolution, dE/E, of 10%
- 1.4×10^{21} μ^{+} and μ^{-} decays per year
- 10 years running
- L $=$ 1300 km e.g. FNAL to DUSEL.

- The 'golden channel' is the $\nu_e \to \nu_\mu$ channel:
  [A. Cervera et al, 'Golden measurements at a neutrino factory']

$$
\begin{aligned}
P(\nu_e \to \nu_\mu) &= s_{213}^2 s_{23}^2((1+\frac{4EA}{\Delta m_{31}^2})\sin^2(\frac{\Delta m_{31}^2 L}{4E}) - AL\sin(\frac{\Delta m_{31}^2 L}{4E})\cos(\frac{\Delta m_{31}^2 L}{4E})) \\
&+ \alpha s_{213} s_{212} s_{223}\frac{\Delta m_{31}^2 L}{4E}((1+\frac{2EA}{\Delta m_{31}^2})\sin(\frac{\Delta m_{31}^2 L}{4E}) - \frac{AL}{2}\cos(\frac{\Delta m_{31}^2 L}{4E}))\cos(\frac{\Delta m_{31}^2 L}{4E} - \delta) \\
&+ \alpha^2 c_{23}^2 s_{212}^2(\frac{\Delta m_{31}^2 L}{4E})^2
\end{aligned}
$$

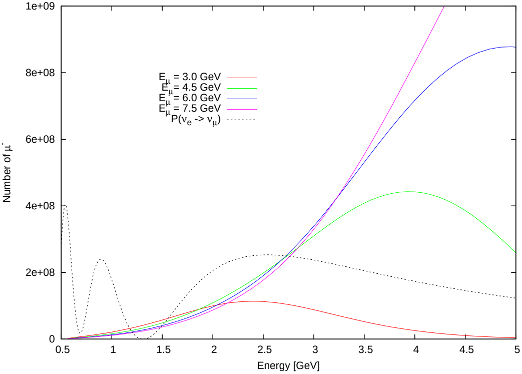


[O. Mena]

- δ affects the position and amplitude of the oscillation peaks.
- θ_{13} controls the amplitude of the oscillation peaks.
- Matter effects amplify the difference between NH and IH.

Optimizing the muon energy

- Need to maximize the oscillation signal (events $\lesssim$ 3 GeV), and minimize the non-oscillating (higher energy) background.
- Muon energy spectrum:

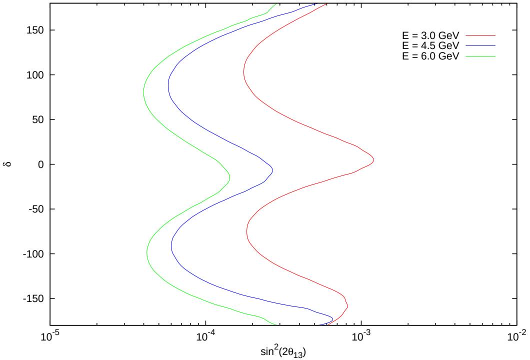


GLoBES 3.0

- The optimal muon energy is $E_\mu \sim 4.5$ GeV.

Effect of E_μ on θ_{13} sensitivity

- θ_{13} sensitivity (3σ contours), for $E_\mu = 3$, 4.5 and 6 GeV:



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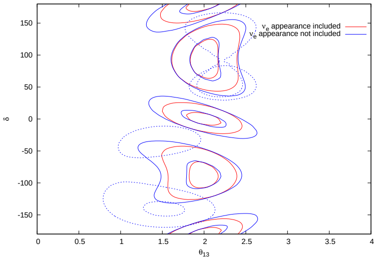
- Significant improvement in increasing E_μ from 3 to 4.5 GeV.
- Smaller improvement if E_μ is increased further.

The $\overset{(-)}{\nu}_e$ appearance channel

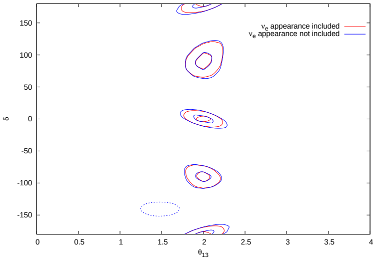
- If the set-up is not optimized, the $\overset{(-)}{\nu}_e$ appearance channel increases sensitivity to θ_{13}, δ and the mass hierarchy (left).
- With optimized E_μ, statistics and energy resolution, the additional channel helps only with the hierarchy determination (right).

4 GeV, 5.0×10^{20} decays, $dE/E = 30\%$



GLoBES 3.0

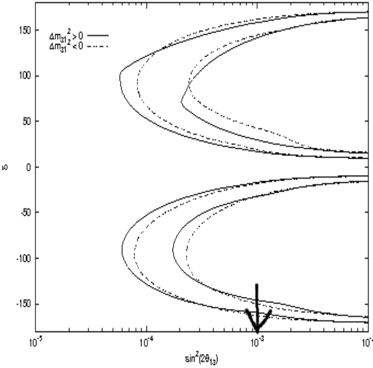
4.5 GeV, 1.4×10^{21} decays, $dE/E = 10\%$



[A. Bross et al, in preparation]

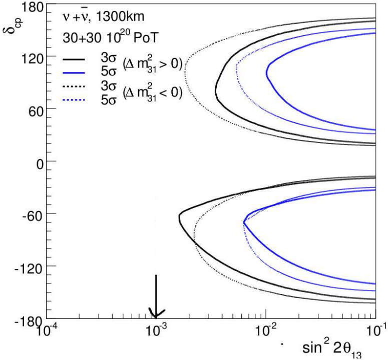
Using $E_\mu = 4.5$ GeV, $dE/E = 10\%$ and 1.4×10^{21} $\mu^\pm$ decays per year, the LENF is competitive with e.g. a wide-band super-beam:

LENF:



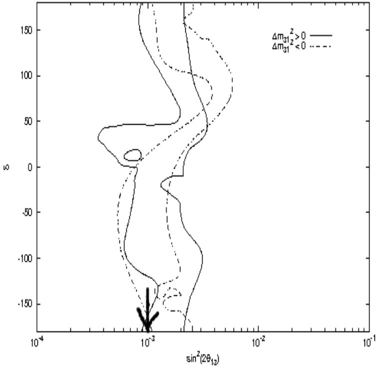
GLoBES 3.0

WBB [arxiv 0705.4396]:



Comparison with WBB: hierarchy sensitivity

LENF:



GLoBES 3.0

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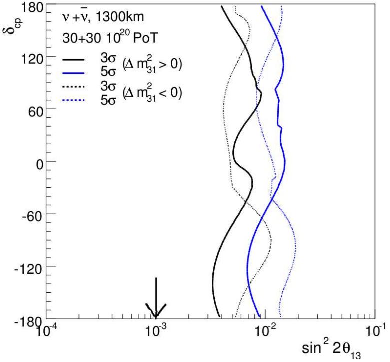

Summary

- We are optimizing a low energy neutrino factory set-up, to maximise its sensitivity to θ_{13}, δ and the mass hierarchy.

- The following set-up has been simulated:
  L = 1300 km, $E_\mu = 4.5$ GeV, 1.4×10^{21} $\mu^\pm$ decays per year for 10 years, 20 kton (fiducial) TASD with 10% energy resolution.

- The LENF has excellent sensitivity to θ_{13} (down to $\sin^2(2\theta_{13}) \backsimeq 10^{-4}$), CP violation (for $\sin^2(2\theta_{13}) \gtrsim 10^{-4}$) and the mass hierarchy(for $\sin^2(2\theta_{13}) \gtrsim 10^{-3}$).