Optimisation of the Low-Energy Neutrino Factory

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Outline of Talk

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Aims of the Next Generation

Is θ_{13} non-zero?

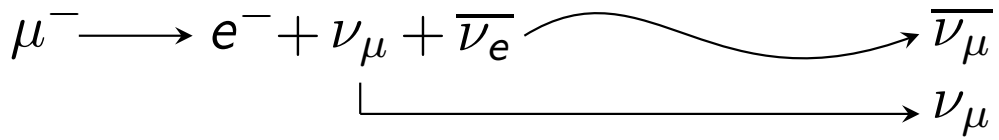
Does the neutrino sector exhibit CP violation?

What is the true hierarchy of the neutrino masses?

Does nature deviate from the standard 3-neutrino scenario?

The Neutrino Factory

- Neutrino Factories are long-baseline oscillation experiments which produce neutrinos from the decay of stored muons.
- The neutrino factory primarily studies wrong-sign muon events (the *golden channel*).



- Standard NF design[1] has a stored muon energy of $E_\mu = 25\,\text{GeV}$ and two baselines at $L_1 \approx 4000\,\text{km}$ and $L_2 \approx 8000\,\text{km}$.

[1] IDS-NF: *Interim Design Report* (IDS-NF-020)

Low-Energy Neutrino Factory

- If θ_{13} is large, a Low-Energy Neutrino Factory (LENF)[1] may be able to provide a good alternative.
- Typical configuration[2]: $E_\mu = 4.5\,\text{GeV}$ and $L = 1300\,\text{km}$.
- Strong sensitivity for key measurements thanks to the rich oscillation spectrum at low energies. This helps to avoid degeneracies.
- Preliminary studies have confirmed the potential of the LENF design but how can we make the most of it?

[1] Geer *et al.* Phys. Rev. D **75** (2007)

[2] Fernández Martínez *et al.* Phys. Rev. D **81** (2009)

Outline of Talk

Simulation Details

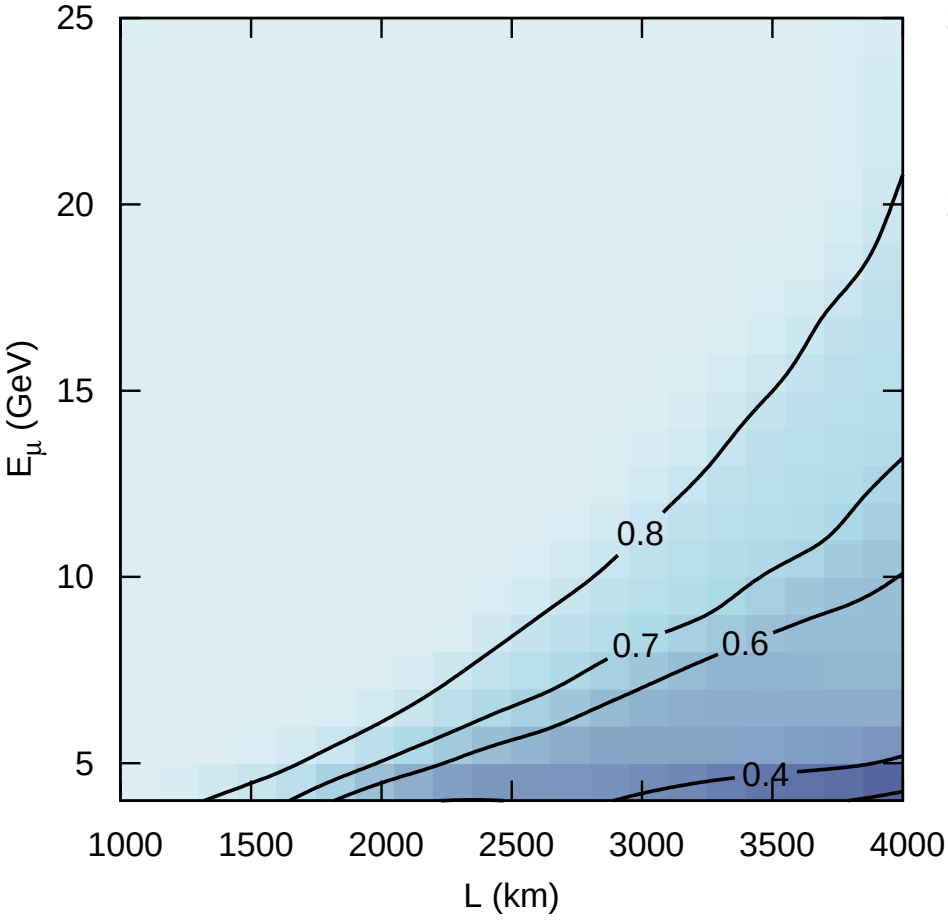
- Using GLoBES[1], we studied the performance of the LENF over the range $1000 \leq L \leq 4000\,\text{km}$ and $4 \leq E_\mu \leq 25\,\text{GeV}$.
- Our detector was a 20 kt Totally-Active Scintillator Detector (TASD)[2] with a detection efficiency of 72% below 1 GeV and 94% above with a resolution of 10%. Backgrounds of 0.1% of charge misidentification and neutral current events.
- Simulation oscillation parameters were set to recent best-fit values with corresponding uncertainities. We assumed normal mass hierarchy and 10^{21} useful muon decays per year over a runtime of $5 + 5$ years.
- Discovery fraction is the fraction of simulation values of δ for which *discovery* is possible for a given simulation value of θ_{13}.

[1] Huber *et al.* Comp. Phys. Comm. **167** (2005)
[2] IDS-NF: *Interim Design Report* (IDS-NF-020)

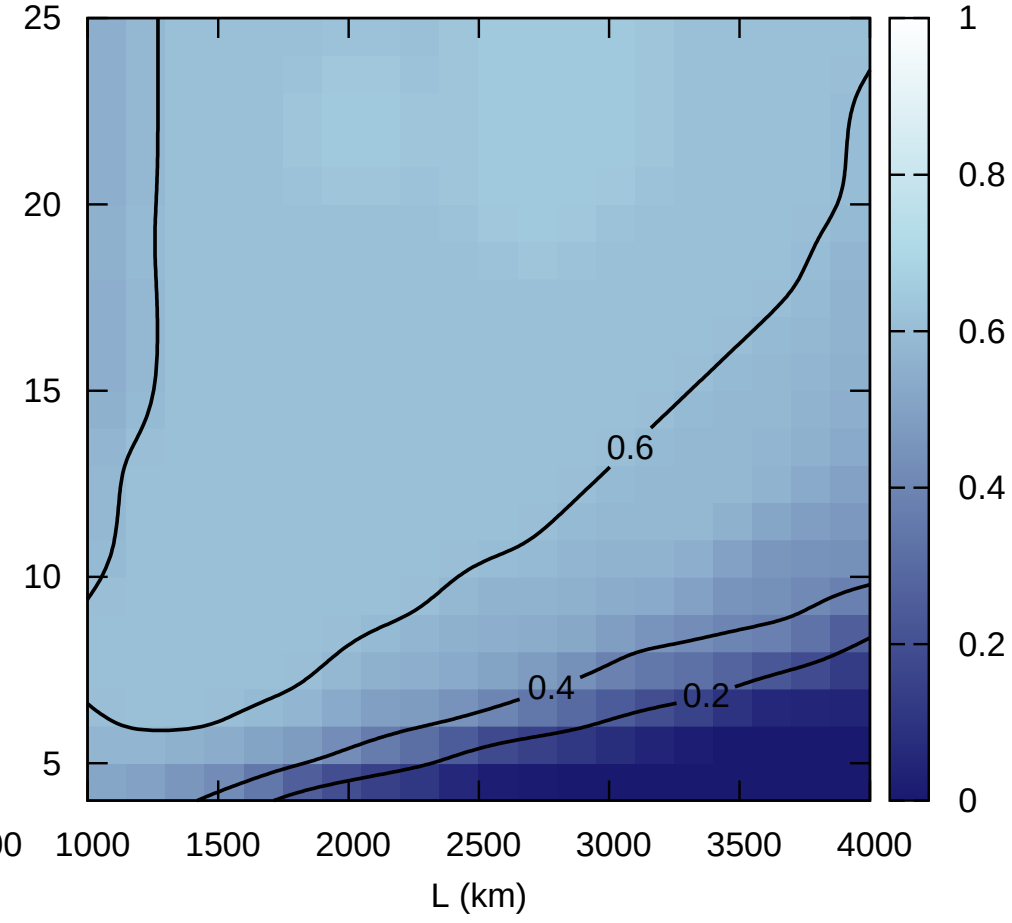
Outline of Talk

CP-Violation Discovery Fraction TASD

Discovery: when all parameter sets with $\delta \in \{0, \pi\}$ are ruled out at the 3σ CL.



(a) $\sin^2 2\theta_{13} = 10^{-2}$



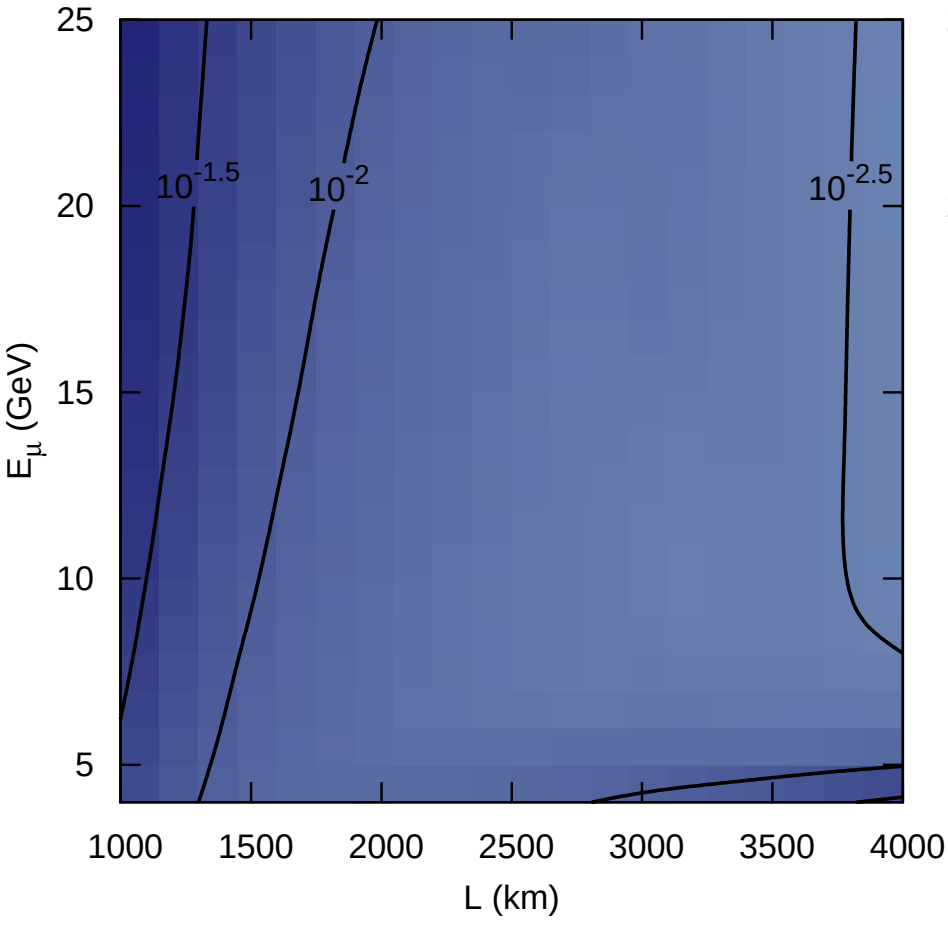
(b) $\sin^2 2\theta_{13} = 10^{-3}$

PB, Huber and Pascoli: *in preparation*.

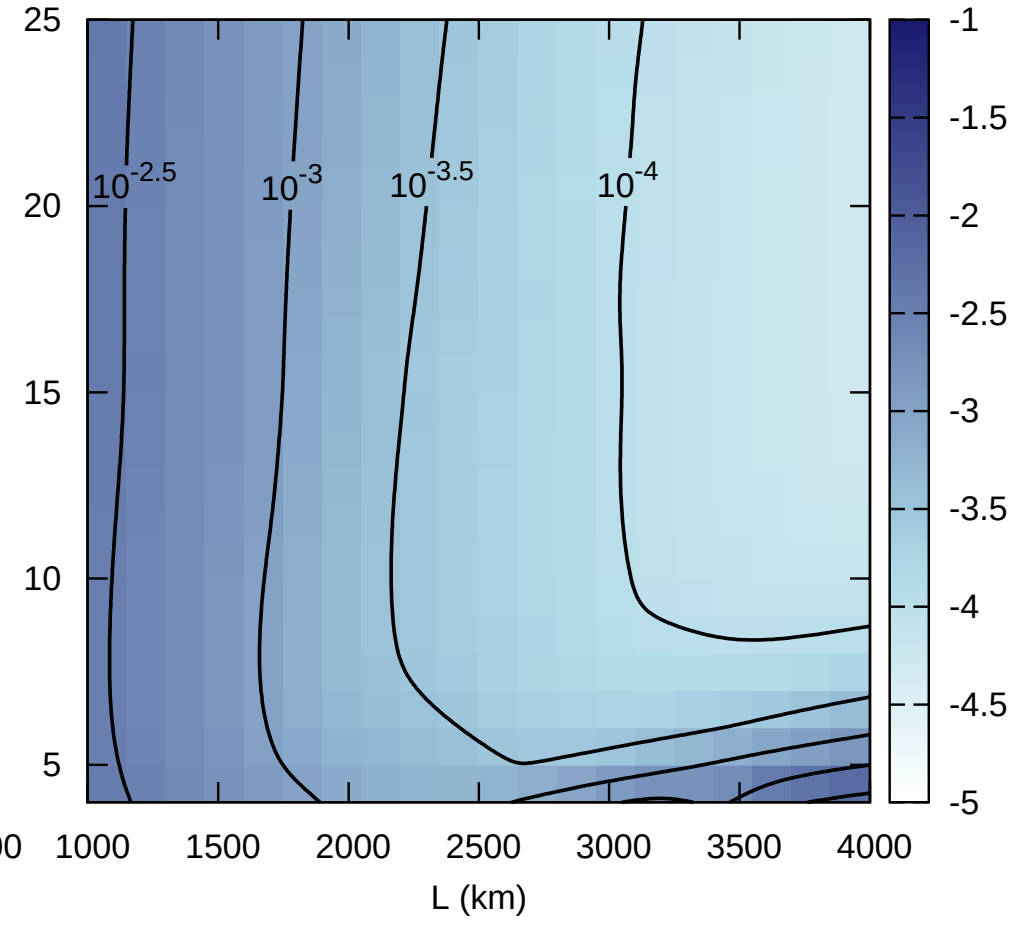
Outline of Talk

Hierarchy Determination TASD

Discovery: when all parameter sets with the wrong hierarchy are ruled out at 3σ CL.



(c) 100% discovery fraction

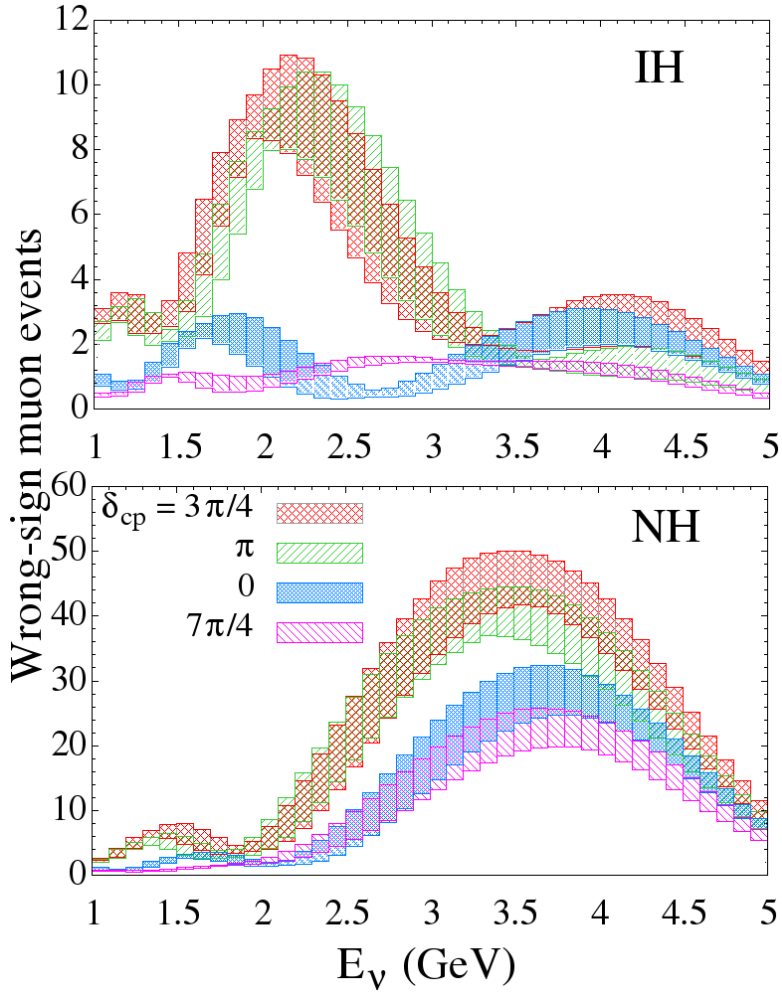


(d) 0% discovery fraction

PB, Huber and Pascoli: *in preparation*.

Hierarchy Determination with a *Bimagic* Baseline?

- It has been claimed that there is particular sensitivity to the hierarchy at $L = 2540\,\text{km}$ and $E_\mu = 5\,\text{GeV}$.
- At two distinct points in the spectrum, the oscillation probability is large for one hierarchy and small for the other. This produces a significant contrast in expected distributions.
- Can this be exploited at the NF?

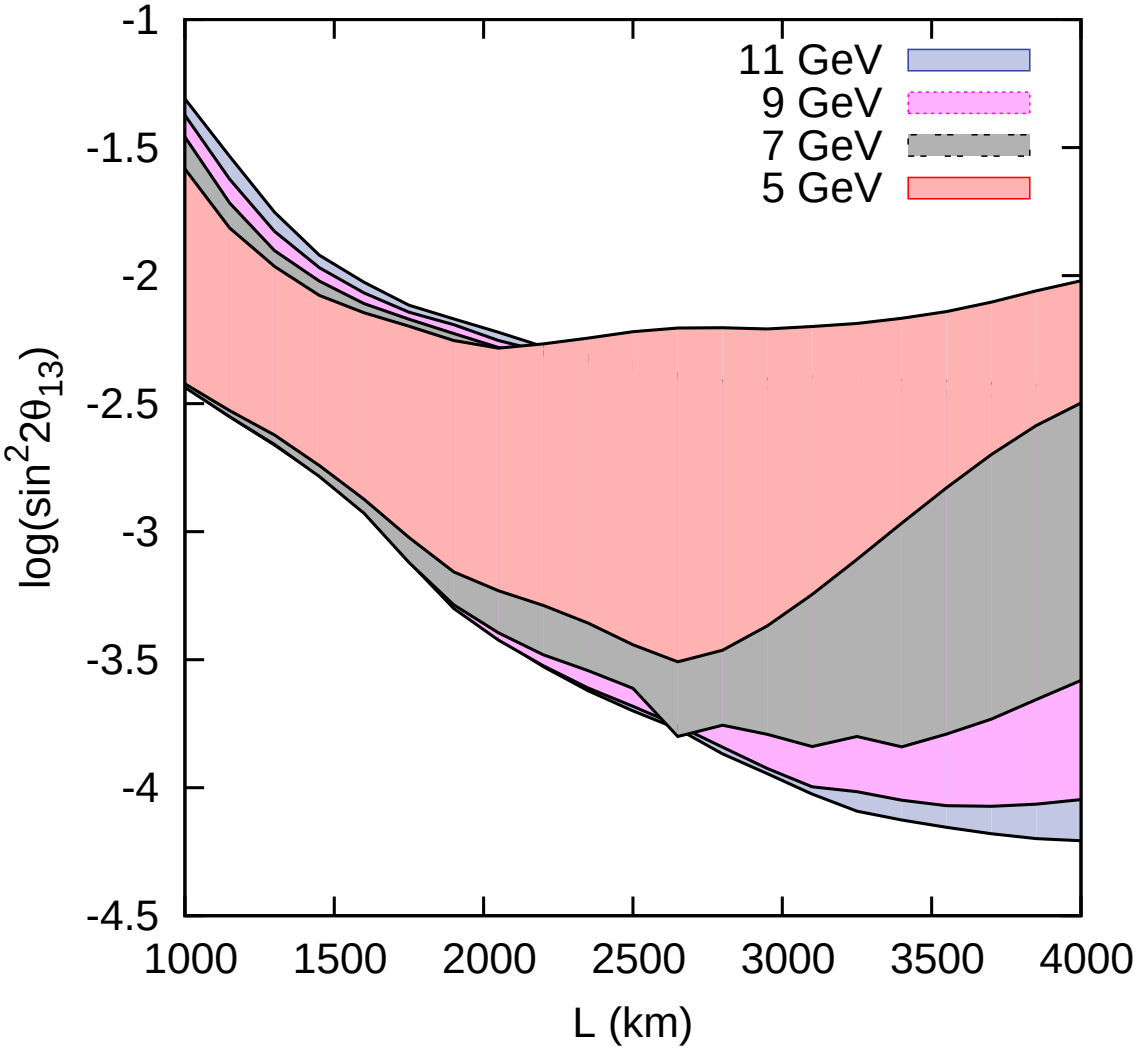


Dighe *et al.* (2010)

Dighe *et al.* Phys. Rev. Lett **105** (2010);

See also: Raut *et al.* Phys. Lett. B **696** (2011)

Performance of the *Bimagic* Baseline



- Low-energy peak in 0% discovery fraction at $L \approx 2600\,\text{km}$.
- 100% discovery reach shows little variation.
- Higher energies and baselines offer further improvements.

PB, Huber and Pascoli: *in preparation*.

Outline of Talk

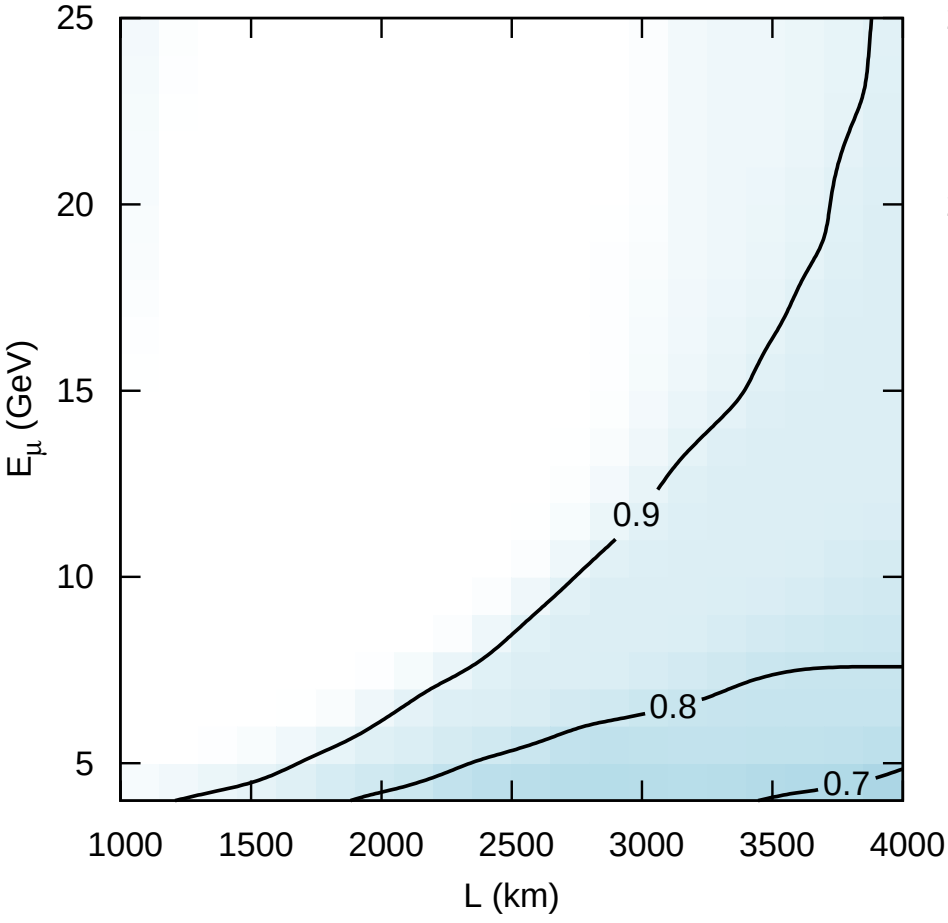
Summary

- The Low-Energy Neutrino Factory can offer competitive discovery reach for key measurements compared to traditional NF designs for large θ_{13}.
- Generically, we expect CP discovery fractions of 60 to 90% for $\sin^2 2\theta_{13} \gtrsim 10^{-3}$. This holds for all configurations provided *extremal* regions are avoided.
- Hierarchy determination is predicted for $\sin^2 2\theta_{13} \gtrsim 10^{-2}$ and potentially for as low as $\sin^2 2\theta_{13} \gtrsim 4 \times 10^{-4}$. There is a clear bias towards longer baselines.
- We see some evidence for a local *bimagic* maximum in the 0% hierarchy discovery reach amongst low-energy configurations. However, increases in the muon storage energy are favoured.

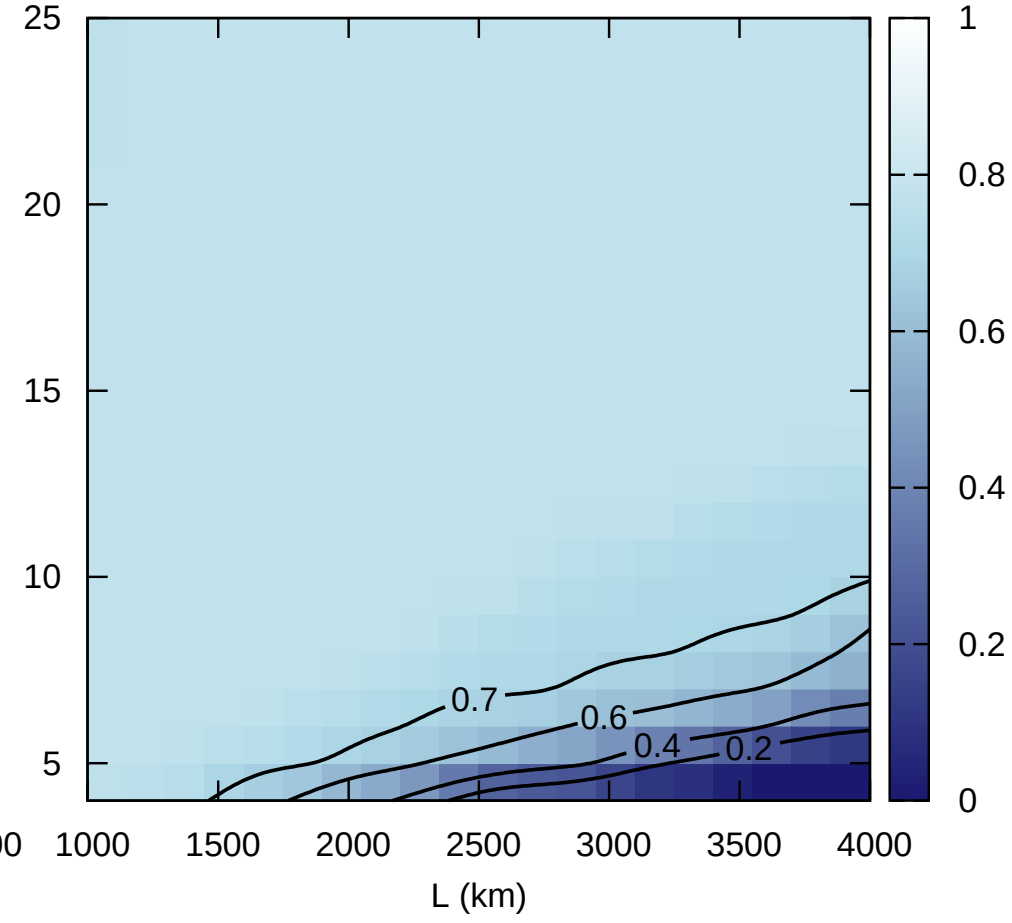
End of Talk

CP-Violation Discovery Fraction — LAr (opt)

Discovery: when all parameter sets with $\delta \in \{0, \pi\}$ are ruled out at the 3σ CL.



(e) $\sin^2 2\theta_{13} = 10^{-2}$

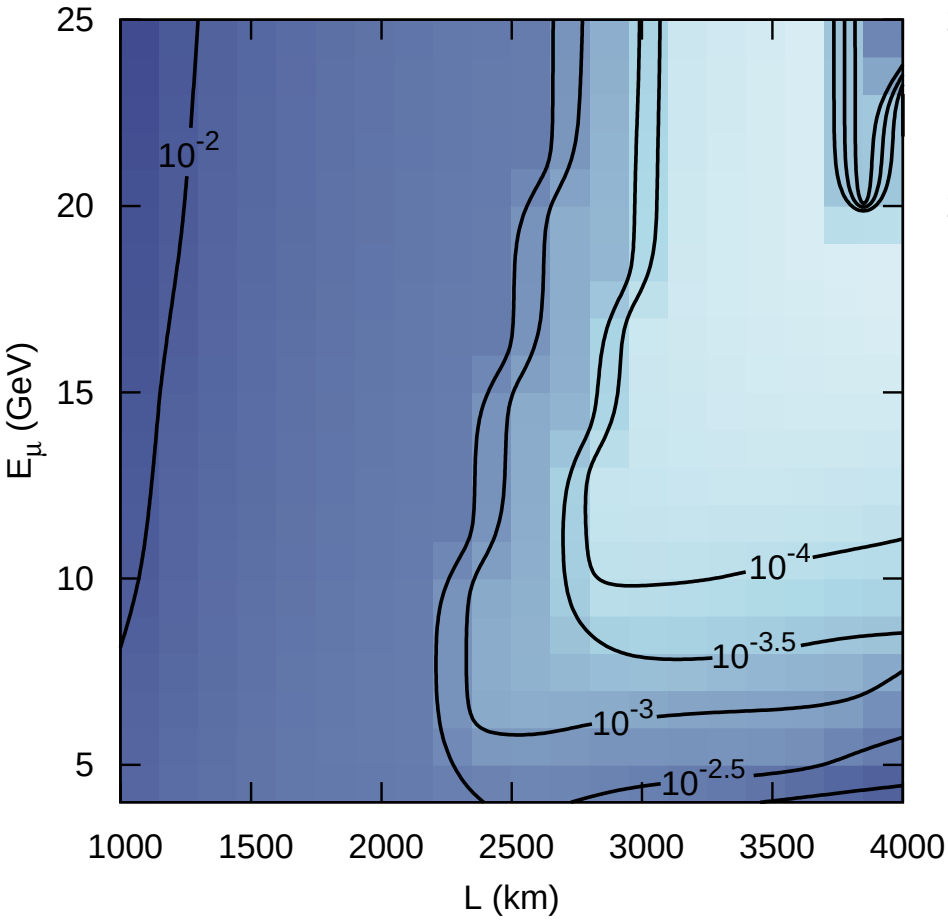


(f) $\sin^2 2\theta_{13} = 10^{-3}$

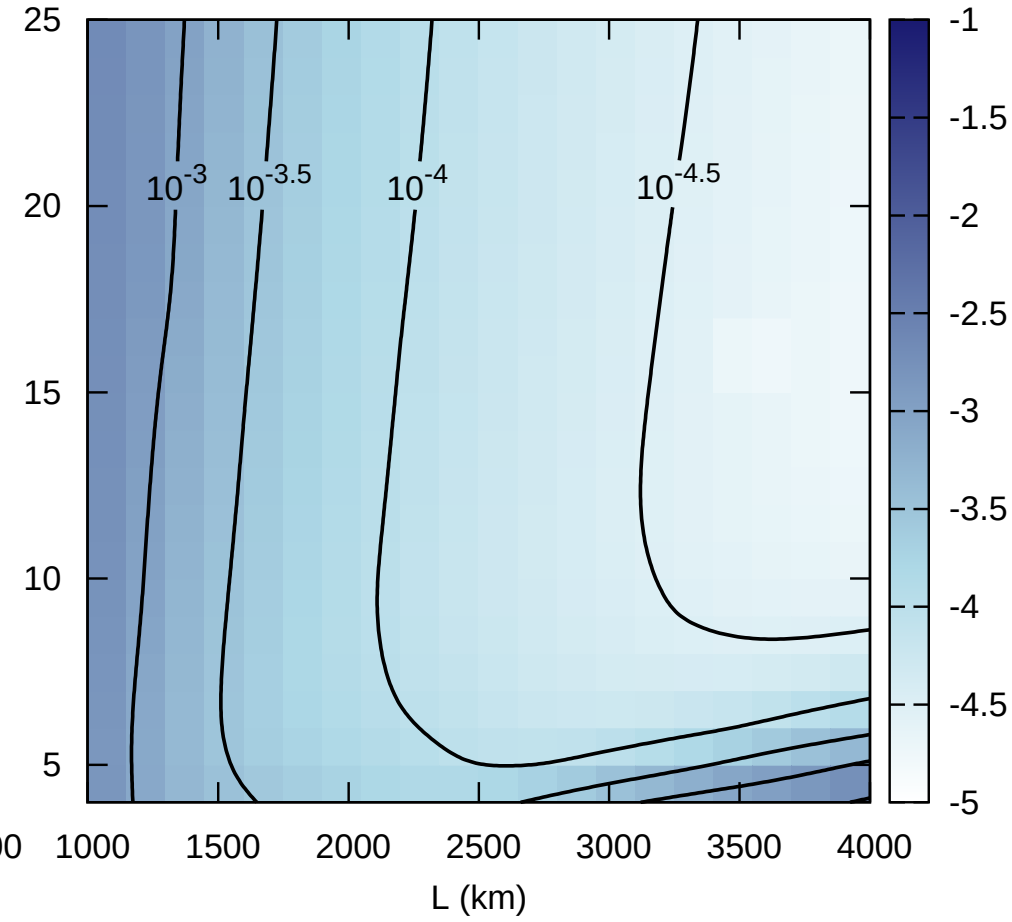
PB, Huber and Pascoli: *in preparation*.

Hierarchy Determination LAr (opt)

Discovery: when all parameter sets with wrong hierarchy are ruled out at the 3σ CL.



(g) 100% discovery fraction



(h) 0% discovery fraction

PB, Huber and Pascoli: *in preparation*.