Optimization of neutrino fluxes for future long baseline neutrino oscillation experiments

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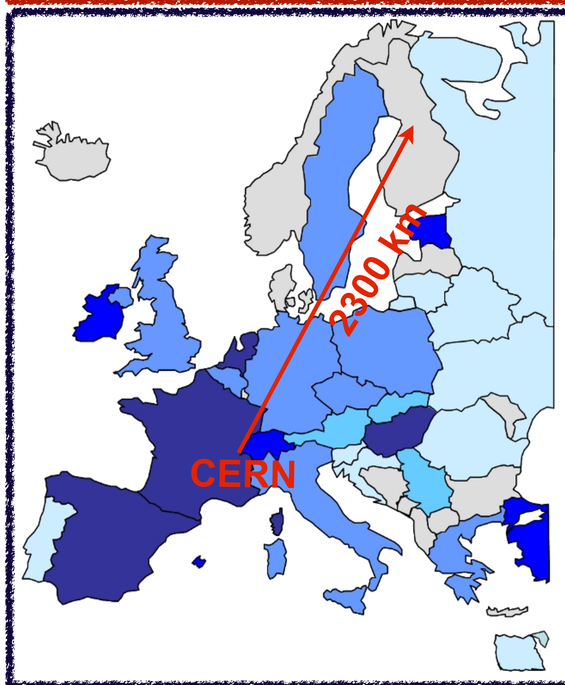


LBNO: Long Baseline Neutrino Oscillation experiment

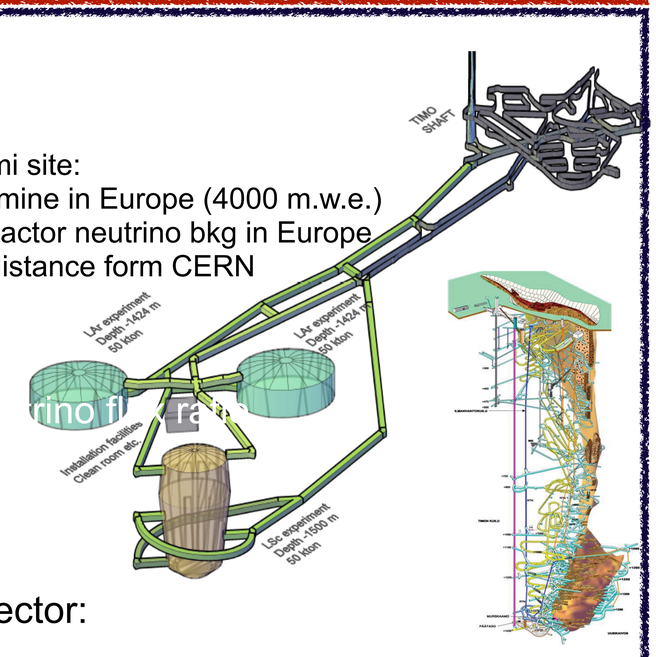
The proposed experiment will address fundamental questions in particle and astroparticle physics.

➡Determination of the neutrino ***Mass Hierarchy***
➡Measurement of δ_{cp} → ***CP-Violation*** in the leptonic sector

Experimental setup:
- New conventional neutrino beam facility @ CERN
- Next generation neutrino underground laboratory (*Far Detector*):
  - -Double phase liquid Argon TPC: 20→100 kt fiducial volume
  - -Magnetized Iron Calorimeter
- *Near Detector*: high pressure Argon gas TPC

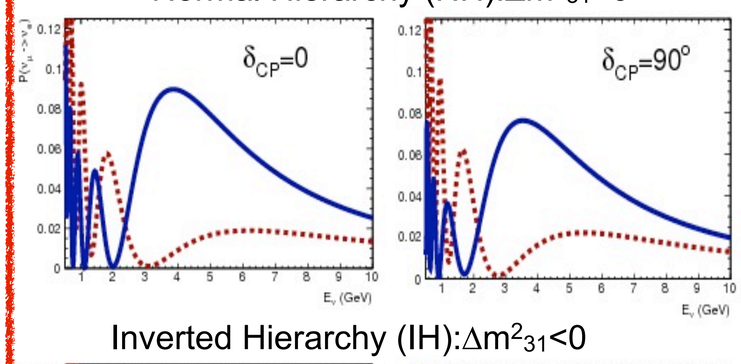
Other physics goals achievable with a deep underground massive neutrino detector: search for proton decay (GUT test), neutrino astrophysics

Pyhäsalmi site:
deepest mine in Europe (4000 m.w.e.)
lowest reactor neutrino bkg in Europe
optimal distance form CERN

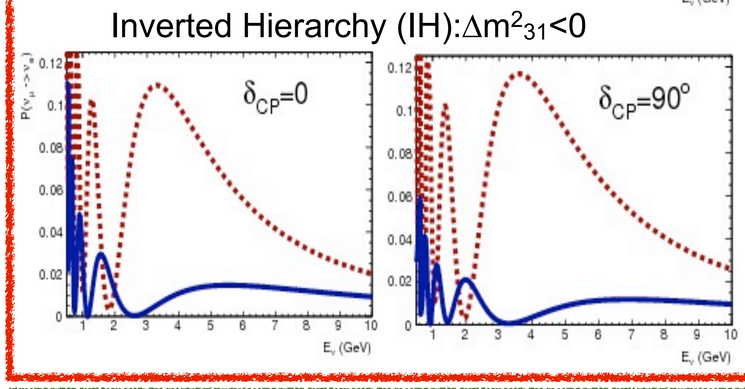


Neutrino Oscillations @ 2300 km

Normal Hierarchy (NH): $\Delta m^2_{31}>0$



Inverted Hierarchy (IH): $\Delta m^2_{31}<0$



Energy dependence of the oscillation probabilities $P(\nu_\mu \to \nu_e)$ & $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

Very Long Baseline:

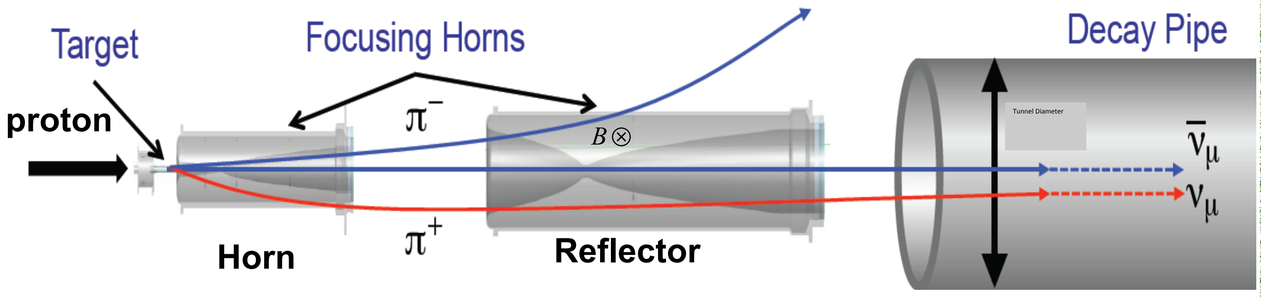
strong matter effect: clean Mass Hierarchy effect

2nd maximum at ~1.5 GeV: experimentally accessible

δ_{cp} can be measured from the spectrum analysis

A **Wide Band neutrino Beam** is needed to cover several oscillation maxima

Neutrino Beam Production



Primary proton beam: protons from CERN-SPS

Focusing: at each beam spill horns are pulsed with a current of ~ 200 kA → toroidal magnetic field in the horns volume

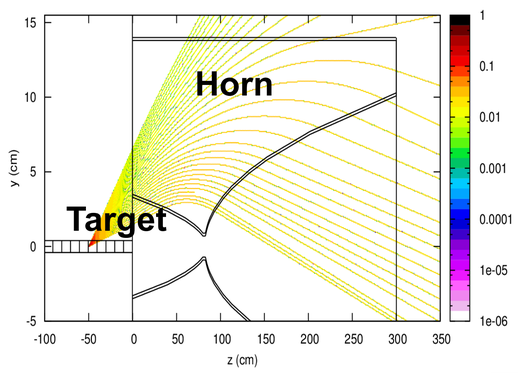
A ν_μ (anti-ν_μ) is obtained by focusing positive (negative) hadrons produced by proton interactions in the target

Energy range: π's (K's) of energy between 3 and 10 GeV need to be focused to produce ν's in the range 1.5-4.5 GeV

$\pi^+ \to \mu^+\nu_\mu$
$K^+ \to \mu^+\nu_\mu$

Background: ν_e contamination
$\mu^+ \to e^+\nu_e\bar{\nu}_\mu$
$K_L \to \pi^+e^-\bar{\nu}_e$
$K_L \to \pi^-e^+\nu_e$

Neutrino Beam Simulation



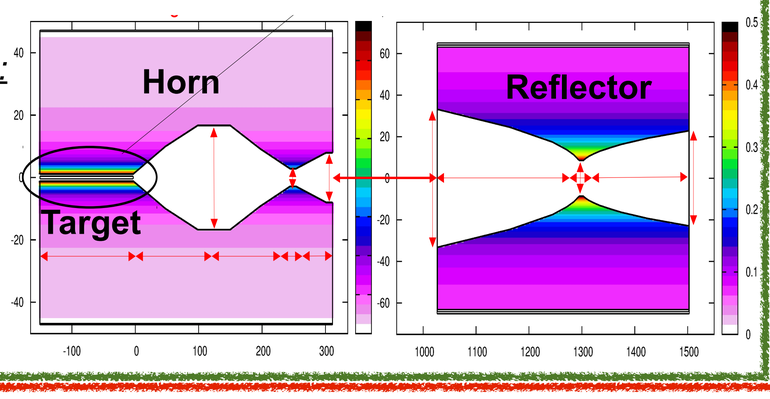
Beamline fully described in **FLUKA**

From hadron's to ν's spectrum (flux at the Far Detector):
For each decay in flight the ν energy in the direction of the far detector it calculated and then weighted for the probability for the ν to be emitted within the detector acceptance

Beam Optics Parameterization:

- Target shape and position
- Horn and Reflector shapes
- Distance between horns
- Circulating currents

18 params in total



Neutrino Beam Optimization

Genetic Algorithm approach is used to search for the best beamline configuration in the multi-dim space of the beam optics design parameters

Best set of parameters must maximize the ***Fitness function***

Starting from a random set of O(100) configurations

Select the best ones and breed them (mixing and mutation) iteratively to obtain new generations to converge towards the best performing configurations

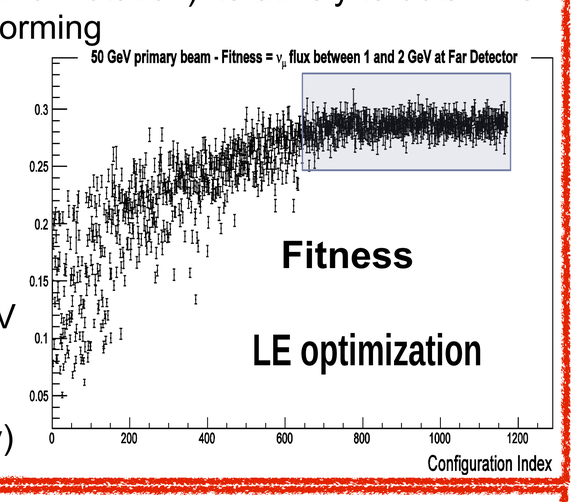
Algorithm is stopped when no more fitness enhancement is observed

Different fitness definitions

High energy (HE): total ν_μ flux for $0<E_\nu<10$ GeV

Low energy (LE): total ν_μ flux for $1<E_\nu<2$ GeV

Global (GLB): total δ_{cp} sensitivity (stat. err. only)

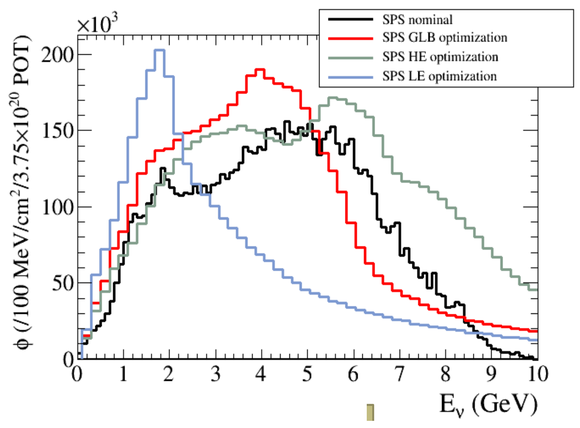


Optimized neutrino fluxes

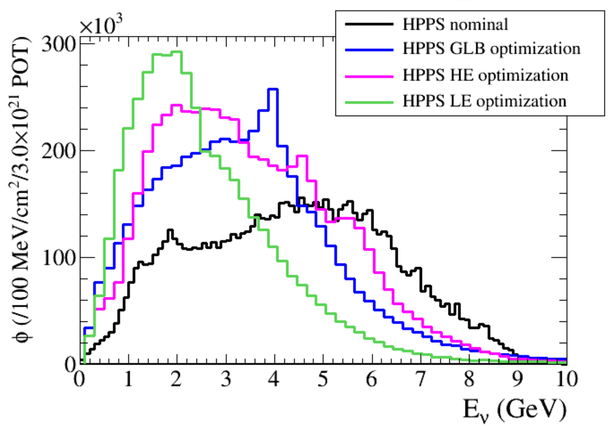
Preferred configurations have target enclosed in the horn: better focusing of high angle/ low energy hadrons → higher second oscillation maximum resolution

Two beam scenarios investigated:

SPS: 400 GeV protons @ 750 kW



HPPS: 50 GeV protons @ 2 MW

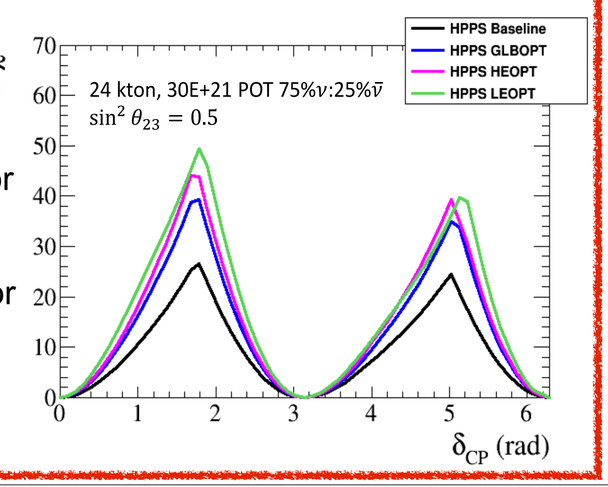


Sensitivity to CP-Violation

Simultaneous fit of appearance and disappearance channels
Systematics included as nuisance parameters

HPPS scenario, exposure: 30×10^{20} Protons On Target (~10 y)

Significant improvement in the sensitivity wrt the non optimized beam

68% 3σ coverage with 24 kton Far Detector

80% 3σ coverage with 70 kton Far Detector