Optimization of neutrino fluxes for european Super-Beams

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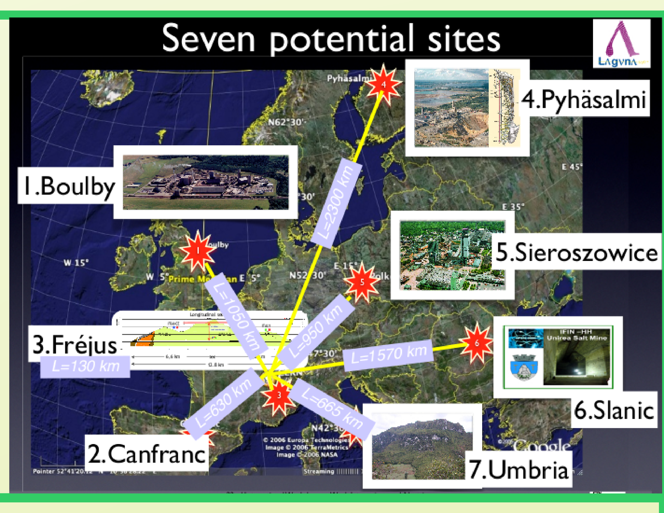
1) Introduction

- LAGUNA: feasibility of a European next-generation giant underground detectors for p-decay, astrophysics and ν-physics.
- EUROν: cost and physics performance comparison among three possible future facilities in EU

CERN-Fréjus Super Beam ⇔ Neutrino Factory ⇔ β-beam with high-Q isotopes.

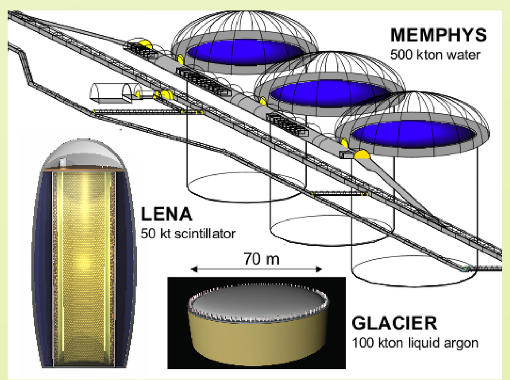


2) Goals

- Optimization of Super-Beams from CERN to the LAGUNA sites.
- Neutrino oscillation physics input for site prioritization.

3) Considered options

- **High Energy Super Beam L>130 Km**
  - "High-Power PS2" E_p = 50 GeV, $3{\cdot}10^{21}$ pot/y. [1]
  - 100 kton Liquid Argon TPC (GLACIER).
- **Low Energy Super Beam L=130 km**
  - "High-Power SPL" E_p = 4.5 GeV, $5.6{\cdot}10^{22}$ pot/y. [2]
  - 440 kton Water Cherenkov (MEMPHYS).



LENA option not covered here

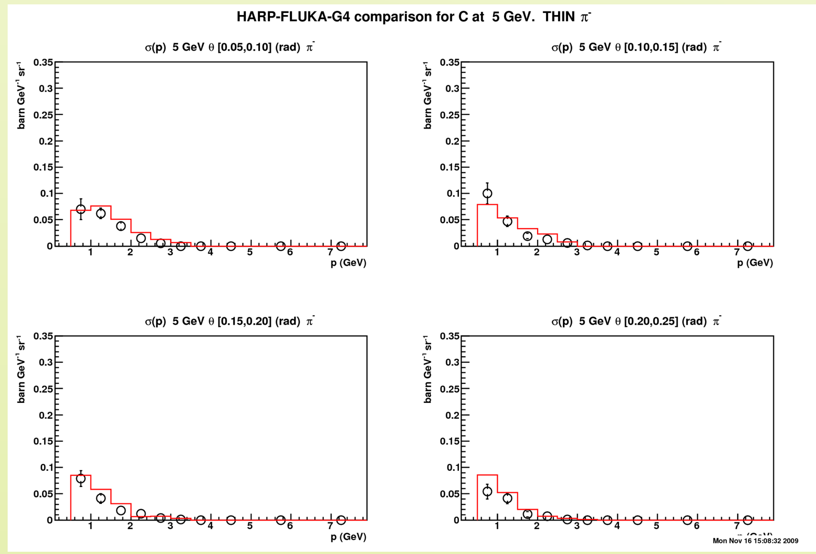
4) GEANT4 neutrino fluxes simulation

- New. GEANT4 framework from a GEANT3 code by A.Cazes-J.E.Campagne.
- Probability weighting techniques applied to GEANT4 generated decays.
- Flexible, easy interface for horn geometry. On/off axis beams.
- p-target interactions: GEANT4 or supplying input from external generators (i.e. FLUKA).

5) Fluxes simulation with GEANT4: benchmarking

Comparison with HARP data

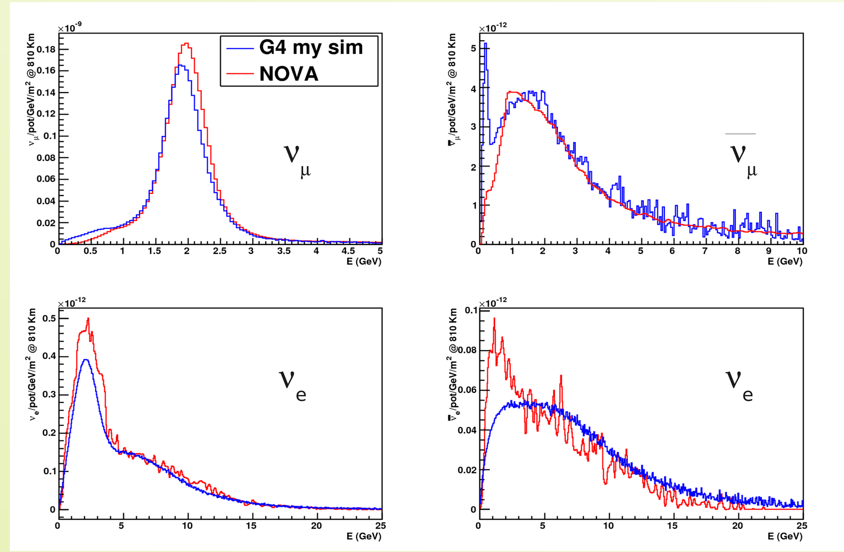
GEANT4 QGSP model can reproduce reasonably well the cross sections on carbon targets at 5 GeV in the forward region. Reweighting to the data does not alter significantly the neutrino fluxes.



Comparison with other simulations

NOvA setup: E_p = 120 GeV, L=810 Km, 10.8 Km off axis. GEANT4 used for the primary proton interactions. Completely independent simulation. Some approximations in reproducing the original geometry. Fair Agreement.

Comparison in normalization and shape



Reference fluxes from NoVA public pages http://enrico1.physics.indiana.edu/messier/off-axis/spectra/

6) Beamline optimization strategy

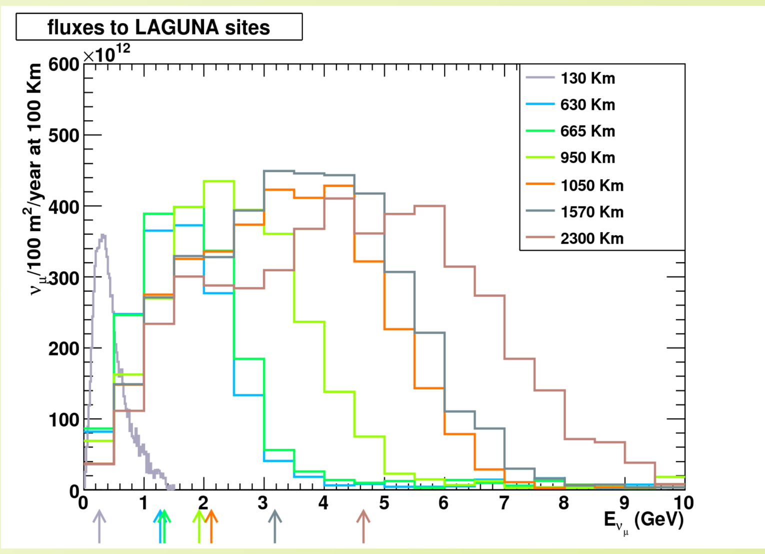
- Parametric model of horns
- Random sampling of parameters
- Ranking of configurations based on achievable θ_{13} limits

$$\lambda = \frac{10^3}{2\pi}\int_0^{2\pi} \lambda_{99}(\delta)\,d\delta$$

Figure of merit λ ≡ θ_{13} sensitivity limit at 99% C.L. averaged over the δ_{CP} phase

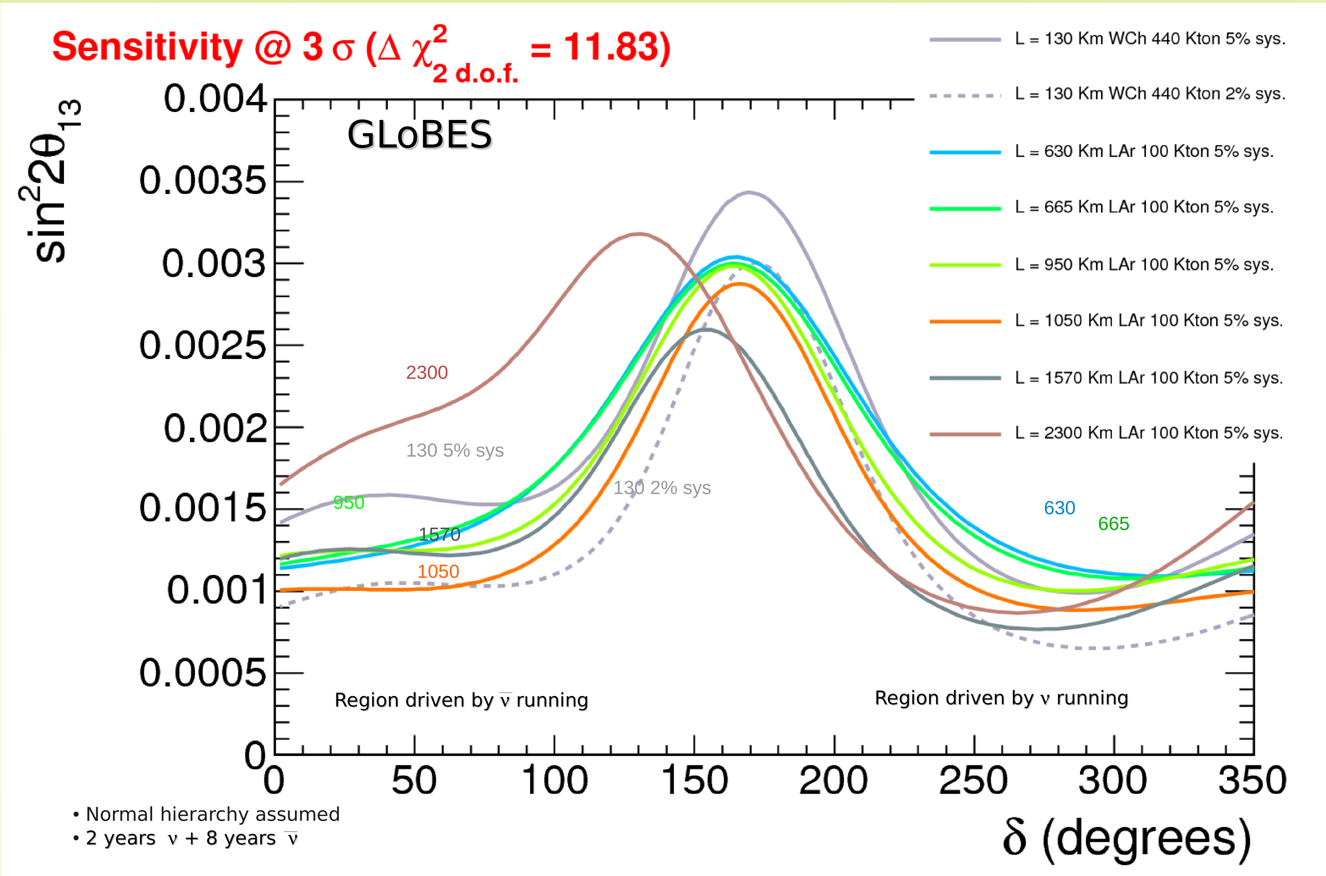
7) Optimized beams performance

ν_μ fluxes at 100 Km



Sensitivity: detailed description of backgrounds and efficiencies for Water Cherenkov based on SuperKamiokande algorithms, more simplified parametrization for LAr TPC.

Optimized fluxes tend to "sit" on the respective 1st oscillation maximum E (arrows) as expected.



Results

- Reliable simulation of neutrino beams based on modern software.
- Powerful optimization procedure based on the sensitivity to θ_{13} averaged over all possible values for the δ_{CP} phase.
- Physics performance of future scenarios compared with an homogeneous set of tools.

Outlook

- Refine optimization of H.E-Super Beam
- Consider mass hierarchy and CP violation potential
- Possibly include 50 kton L-scintillator option (LENA)

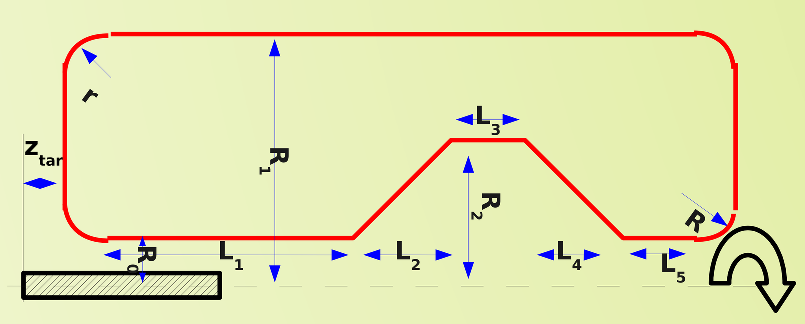
References

[1] hep-ph/1003.1921v1
[2] hep-ex/0411062v1, hep-ph/0603172

8) Procedure for Low-E Super Beam optimization (E_p = 4.5 GeV, L= 130 Km)

8.1) Horn parametric model

à la MiniBoone



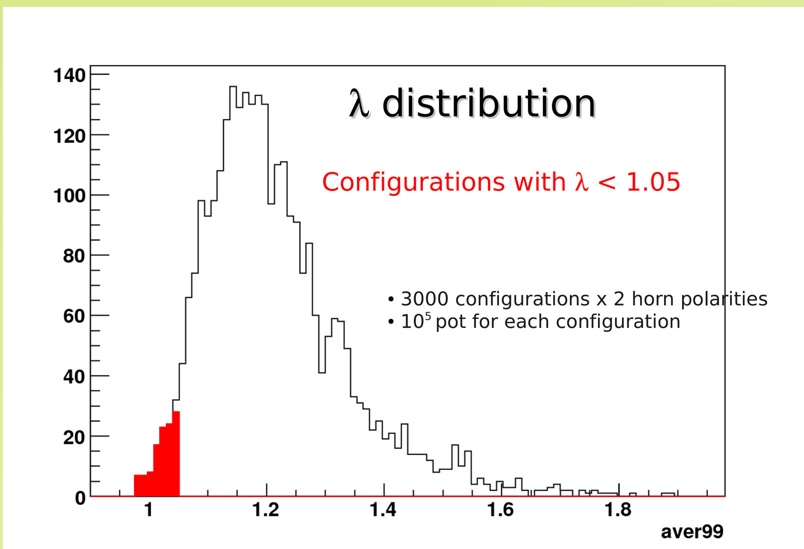
Graphite target: L = 78 cm, r = 1.5 cm.

Well suited for long targets
Good suppression of wrong charge pion
dangerous in "-" focusing mode due to ν_e from $\pi^+ \to \mu^+ \to e^+ \nu_e \bar{\nu}_\mu$.

Limit	value
L_{max}	250 cm
R_{max}	80 cm
R_{min}	1.2 cm
Parameter	Interval
L_1	[50, L_{max}] cm
L_2, L_3, L_4	[1, L_{max}] cm
L_5	[1, 15] cm
R, R_1, R_2	[R_{min}, R_{max}] cm
R_0	[R_{min}, 4] cm
z_{tar}	[-30, 0] cm
L_{tun}	[35, 45] m
r_{tun}	[1.8, 2.2] m
Parameter	Value
L_{tar}	0.78 m
r_{tar}	1.5 cm
i	300 kA
Al thickness	3 mm
r	5.08 cm

8.2) Parameters' broad scan

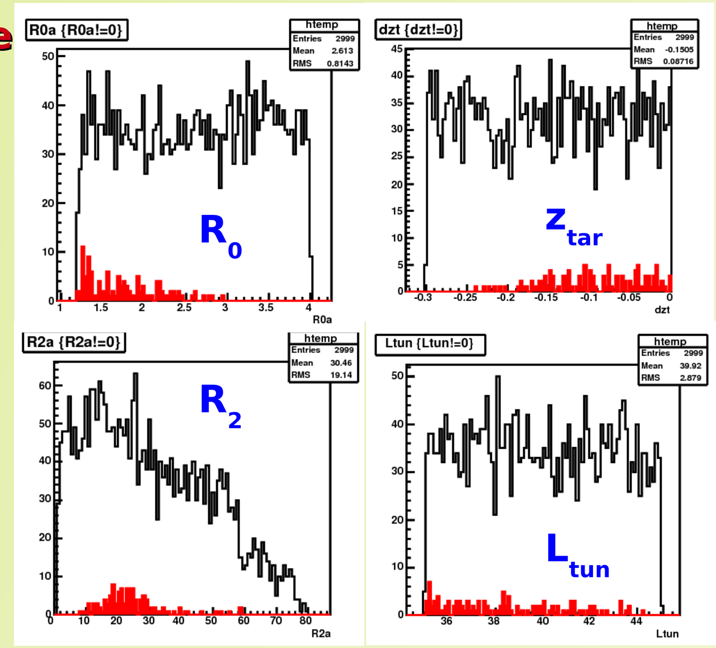
General search allowing free parameters to vary independently



8.3) "Learning" phase

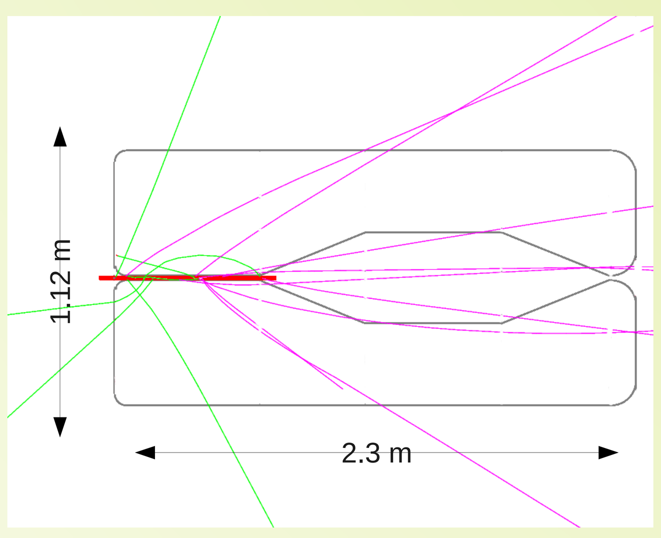
In red: configurations with λ < 1.05

A comparison of the distributions of horn parameters for configurations providing good limits gives hints to narrow down the parameters' space before re-iterating the procedure



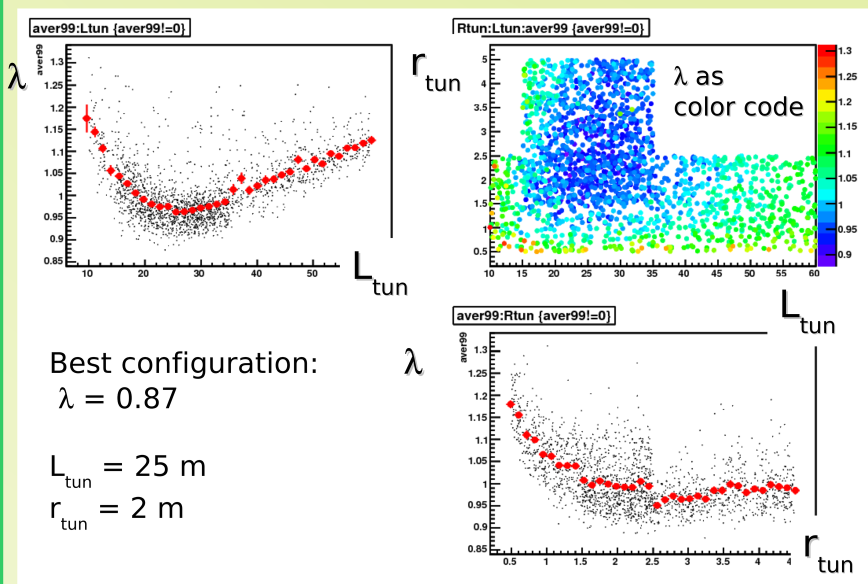
8.4) New iteration in a restricted space of parameters after which the best horn shape was frozen

best configuration (i.e. giving the minimum λ)



8.5) Decay tunnel tuning

Scan on tunnel length (L_{tun}) and radius (r_{tun})

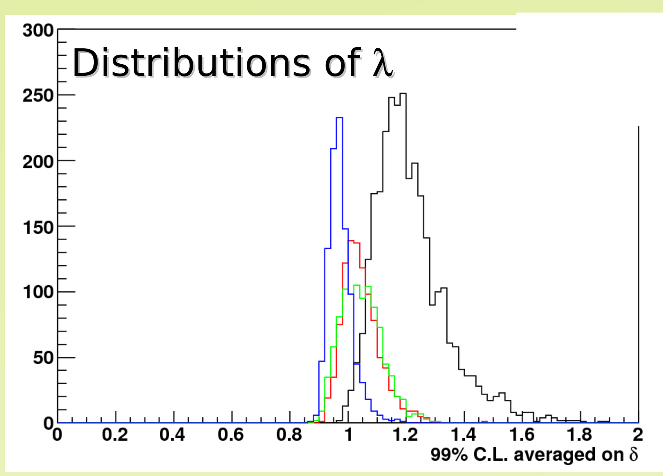


Best configuration:
λ = 0.87

L_{tun} = 25 m
r_{tun} = 2 m

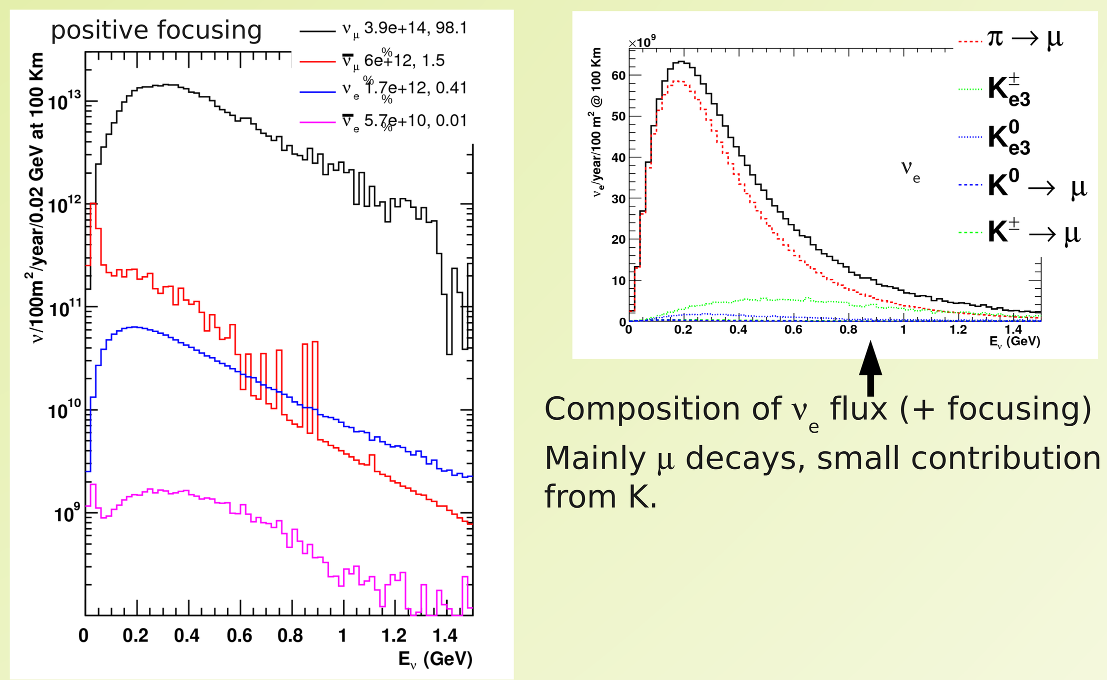
8.6) Converging to better limits

~30 % improvement w.r.t. a generic initial configuration



- broad parameters' scan
- restricted intervals for effective parameters → horn with min λ
- vary tunnel parameters in L [10-60] m r [0.5-2.5] m
- L [15-35] m r [1.5-4.5] m

8.7) ν fluxes for the optimized setup



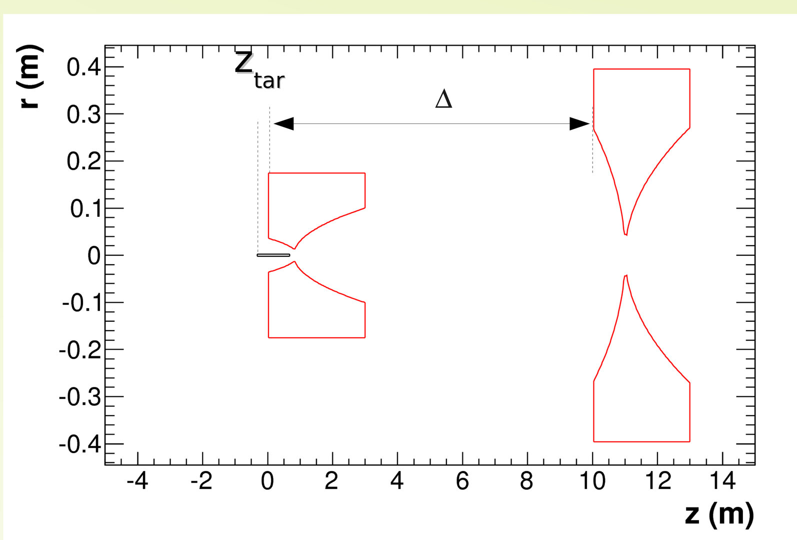
Composition of ν_e flux (+ focusing)
Mainly μ decays, small contribution from K.

9) Procedure for High Energy Super Beam optimization (E_p = 50 GeV, L: 630 ÷ 2300 Km)

9.1) Focusing scheme

Parabolic horn + reflector.
Parametrized analytically.
7 shape parameters a,b,c,d,a',b',c'.

$$- \ z \in [0, z_1] : f(z) = \sqrt{\frac{a-z}{b}} - c$$
$$- \ z \in [z_1, z_2] : f(z) = d$$
$$- \ z \in [z_2, z_3] : f(z) = \sqrt{\frac{z-a'}{b'}} - c'$$



Starting point: take horn shape used in the NuMI beam.
i = 200 kA Tunnel with L = 300 m, r = 1.5 m.
Graphite target: L = 1 m, r = 2 mm.

9.2) Play with the horn-reflector-target separation

Varied the:

- target longitud. position (z_{tar})
- the horn-refl. distance (Δ)

For each baseline i=630÷2300, evaluated:
λ_i as a function of (Δ , z_{tar}) →

Strong dependence on z_{tar} , mild on Δ.

Having fixed the best choice for (Δ , z_{tar}) for each baseline, the same procedure was repeated for the decay tunnel length and radius.

Example for L = 630 km

λ_{630} as color code