Updates on flux simulation and sensitivities

EURONU

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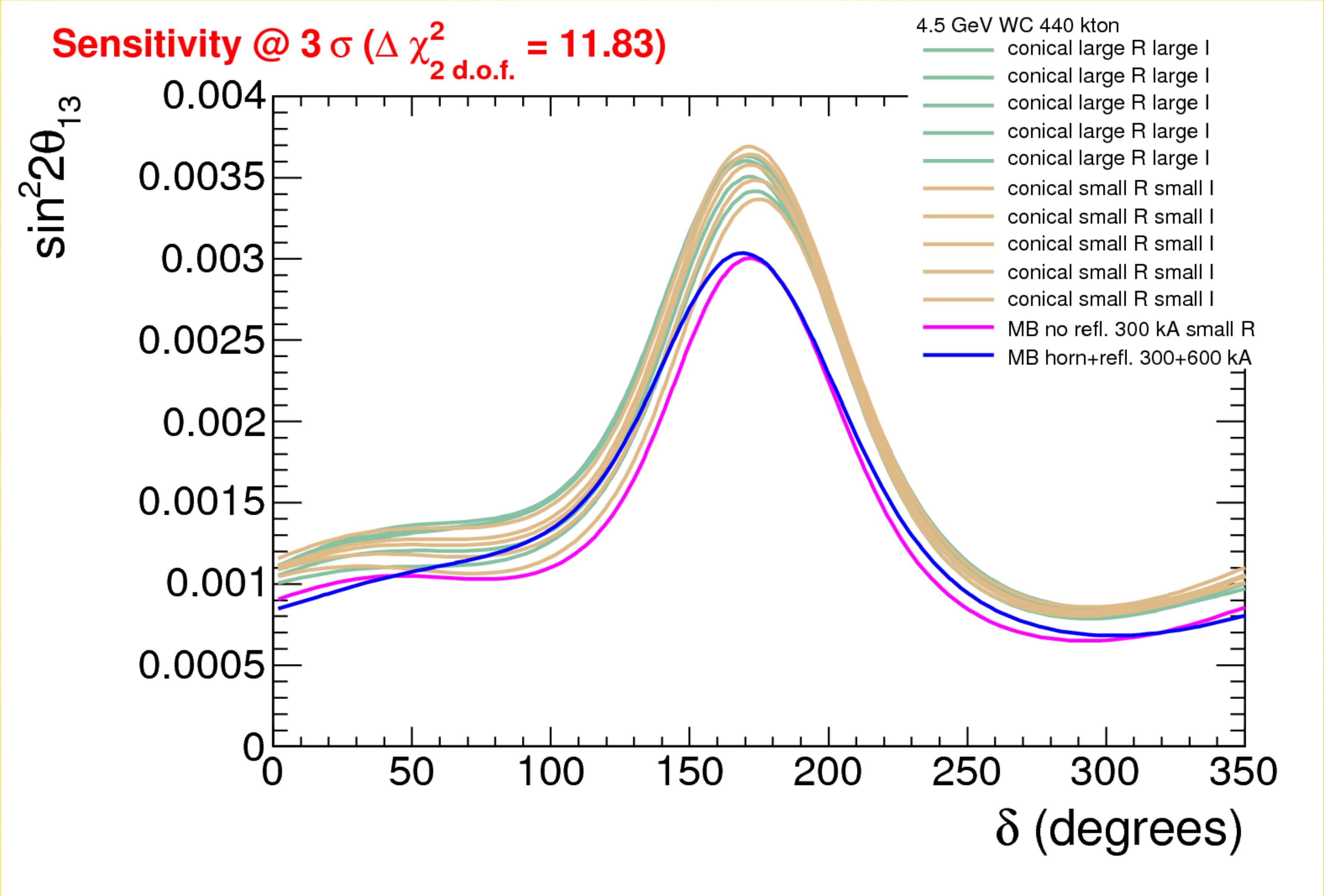
Activity since last meeting

- EUROnu note on focusing optimization with Christoph submitted.
  - comparison between our optimizations based on “conical” / “forward-closed” horns

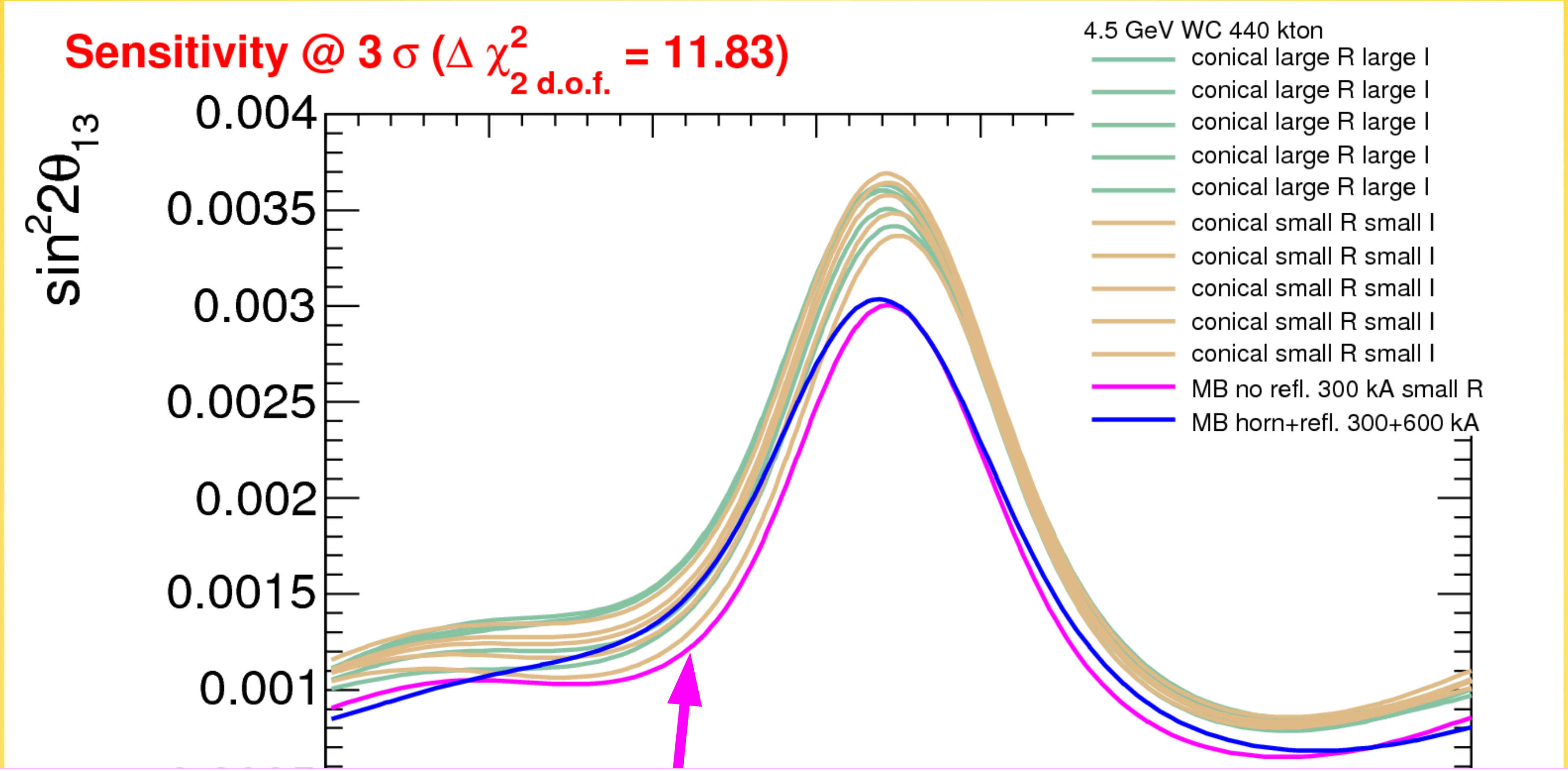
- Reorganization/finalization of the work done in view of the document for the “milestone” on the neutrino beamline
  - focus on the “forward-close” model

Conical – forward closed



Best conical horns are not far.
Forward closed horns do better.

Conical – forward closed



I focused in the following on this design i.e.

- Forward closed shape
- no reflector
- I = 300 kA
- inner radius = 1.2 cm ~ "integrated target" idea

Interplay of inner radius and current studied systematically (see later)

Structure for the milestone

Decription of the setup:

proton driver / far detector,
target / horn
calculation of fluxes and sensitivities

Optimization procedure based on θ_{13} sensitivity

Results with an optimized setup
fluxes, sensitivities

Hadroproduction uncertainties impact on sensitivities

Conclusions

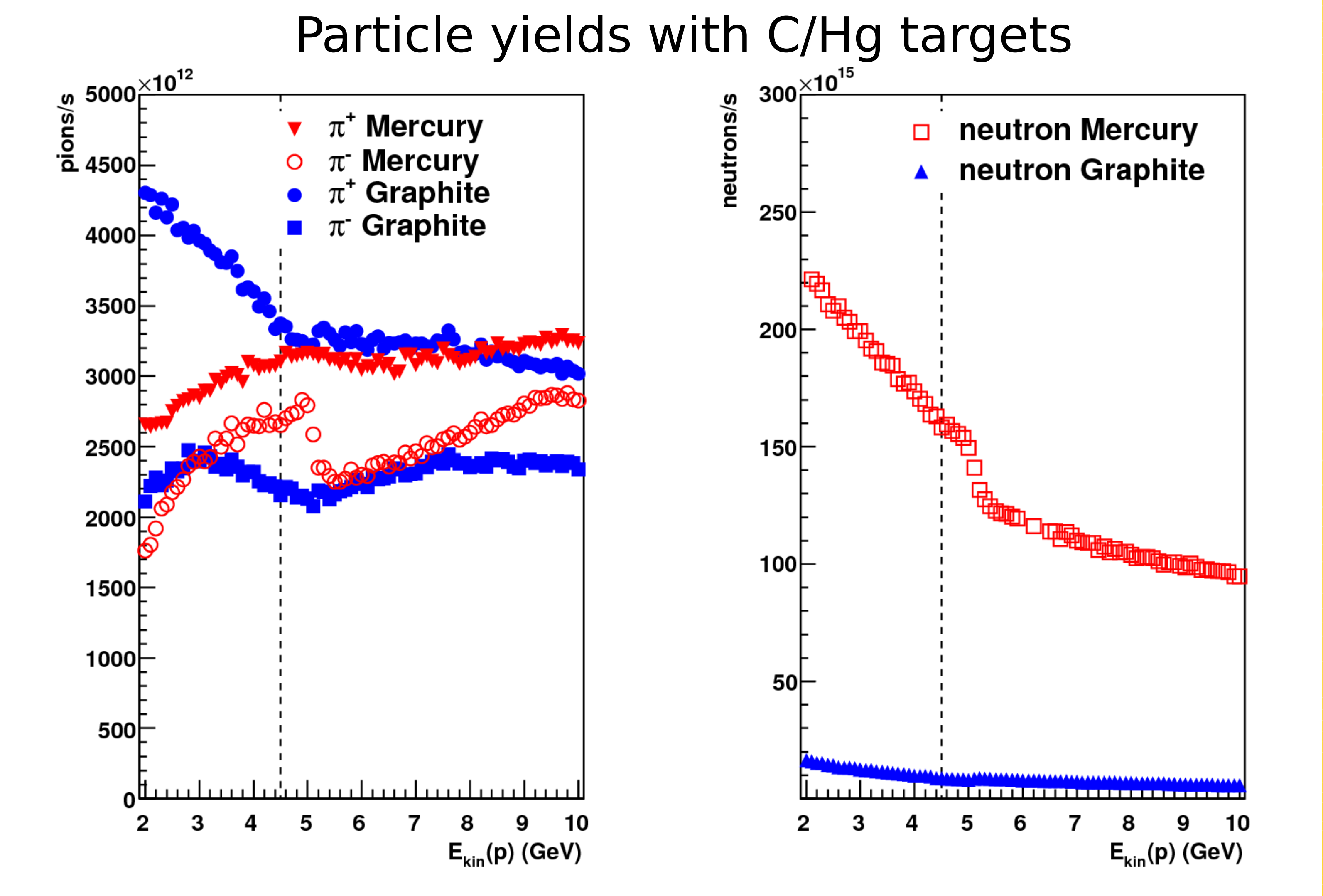
Target

Solid L = 78 cm, r = 1.5 cm

graphite (Be, Al, AlBeMet are similar)

similar yields
for pions

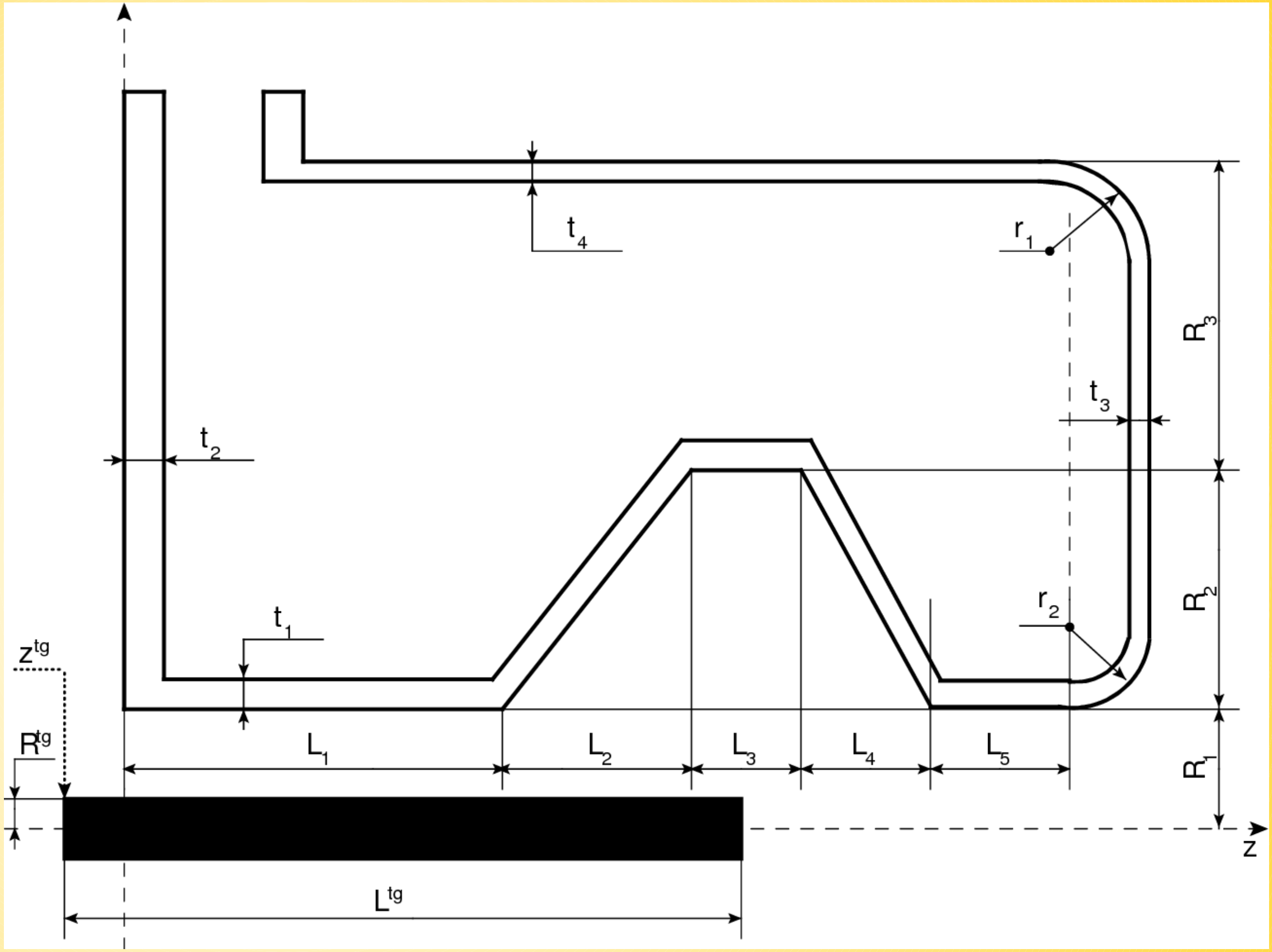
X 15 less
neutrons



Horn

à la MiniBoone
("forward closed")

large acceptance for
forward produced particles



This shape is well suited
for long targets

Good suppression of wrong charge pion
dangerous in "-" focusing mode due to
ν_e from $\pi^+ \rightarrow \mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$ and $K^+ \rightarrow \pi^0 e^+ \nu_e$ ← EUROnu-WP2 note 09-01

Optimization strategy

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

Figure of merit: $\lambda \equiv$
θ_{13} sensitivity limit at 99% C.L. averaged over the δ_{CP} phase

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

We want as low as possible λ

- Broad sampling of the (many) parameters to identify the most relevant variables. Then restrict the ranges of variation and iterate.

→

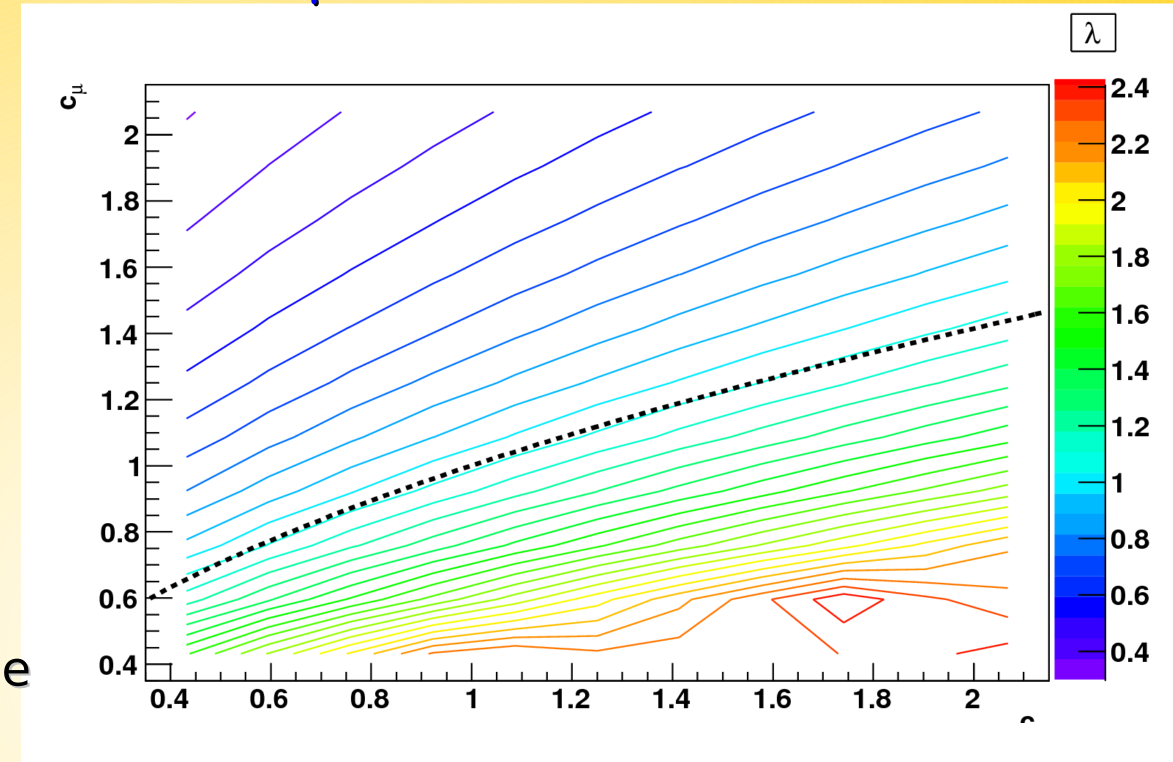
Relation between λ and ν_μ / ν_e fluxes

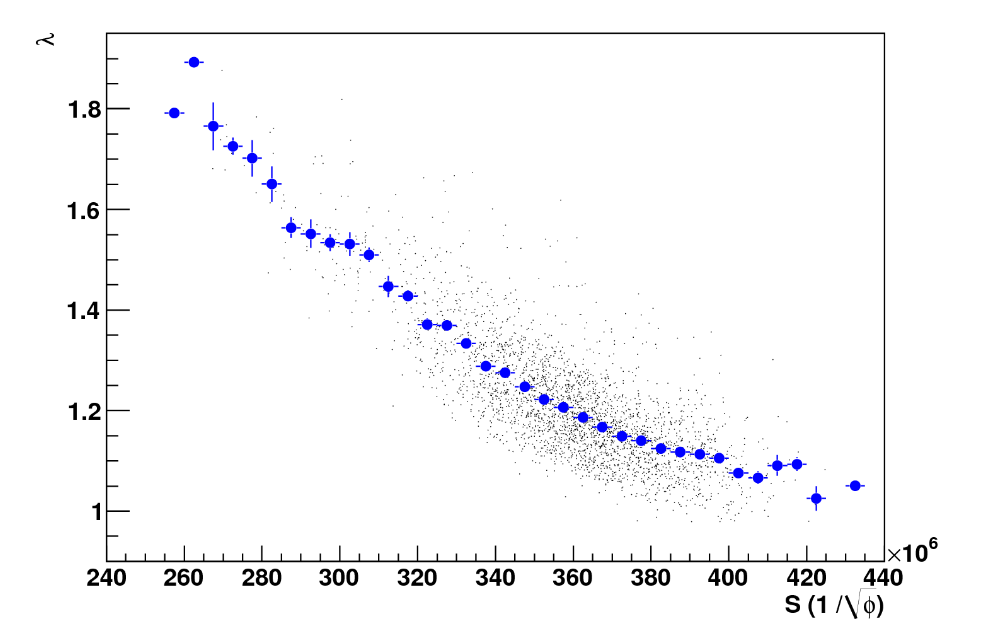
Vary the normalization of numu and nue freely with two independent multiplicative coefficients (c_e, c_μ) in [0.5, 2]

Study the variation of λ
Iso-sensitivity levels ~ $c_e = \sqrt{c_\mu}$

The experiment significance : $S/\sqrt{B}$ is invariant by scaling of the fluxes with $c_e = \sqrt{c_\mu}$
because $S \propto \nu_\mu$ and $B \propto \nu_e$
(roughly, via cross sections, efficiency, spectral shape etc)

Correlation between λ and a "pseudo-significance" build with the fluxes

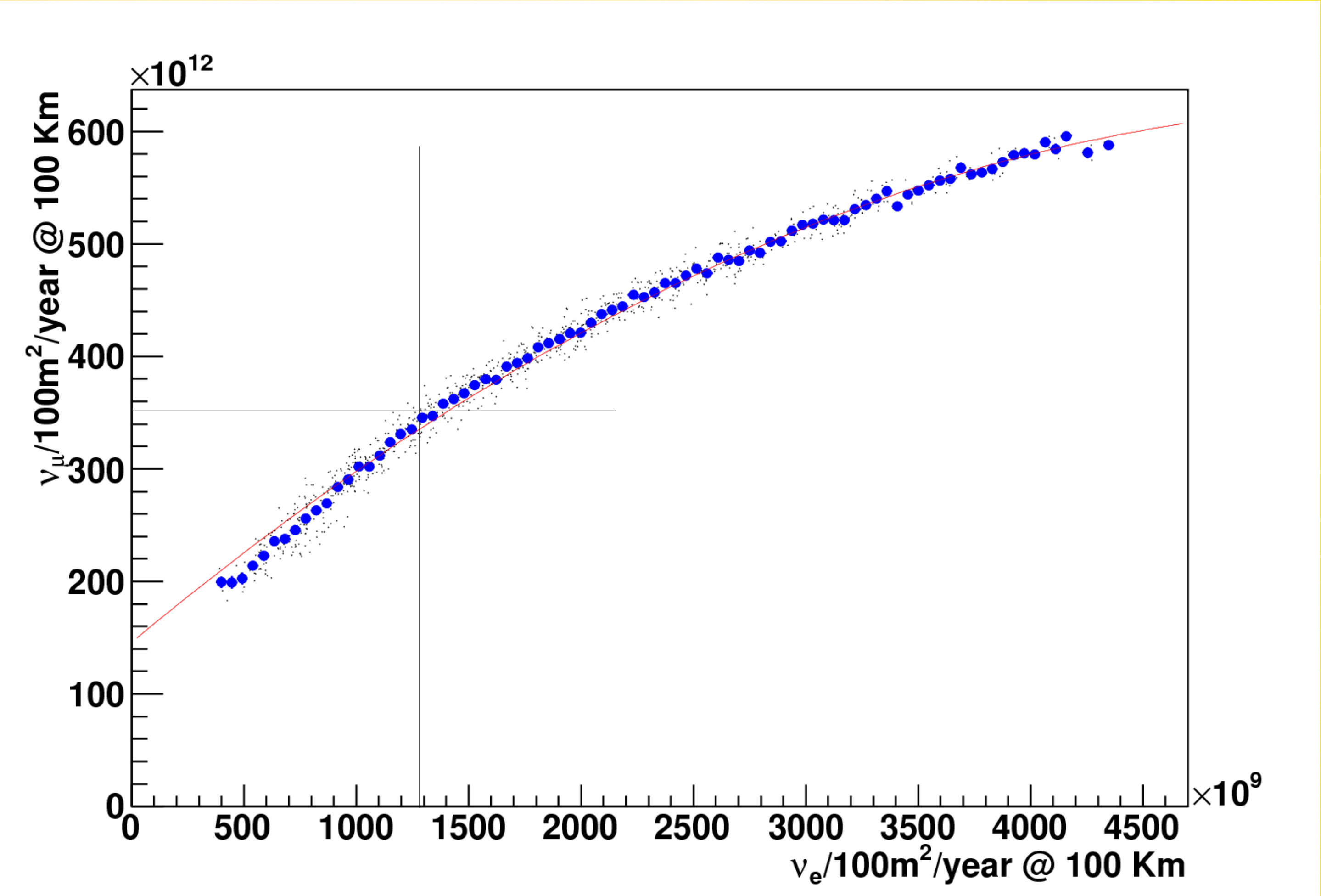




Correlation between ν_μ / ν_e under variation of the tunnel only

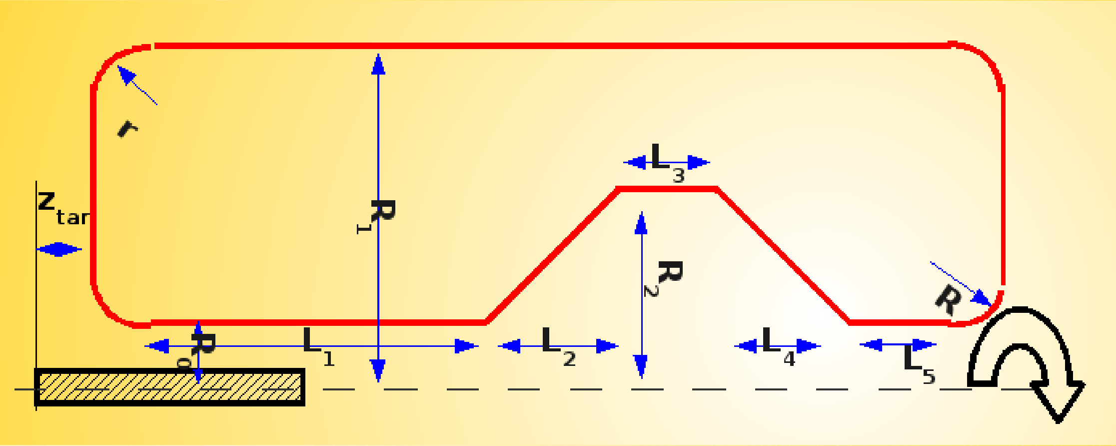
Tends to follow a quadratic dependence!

It is not possible to gain much

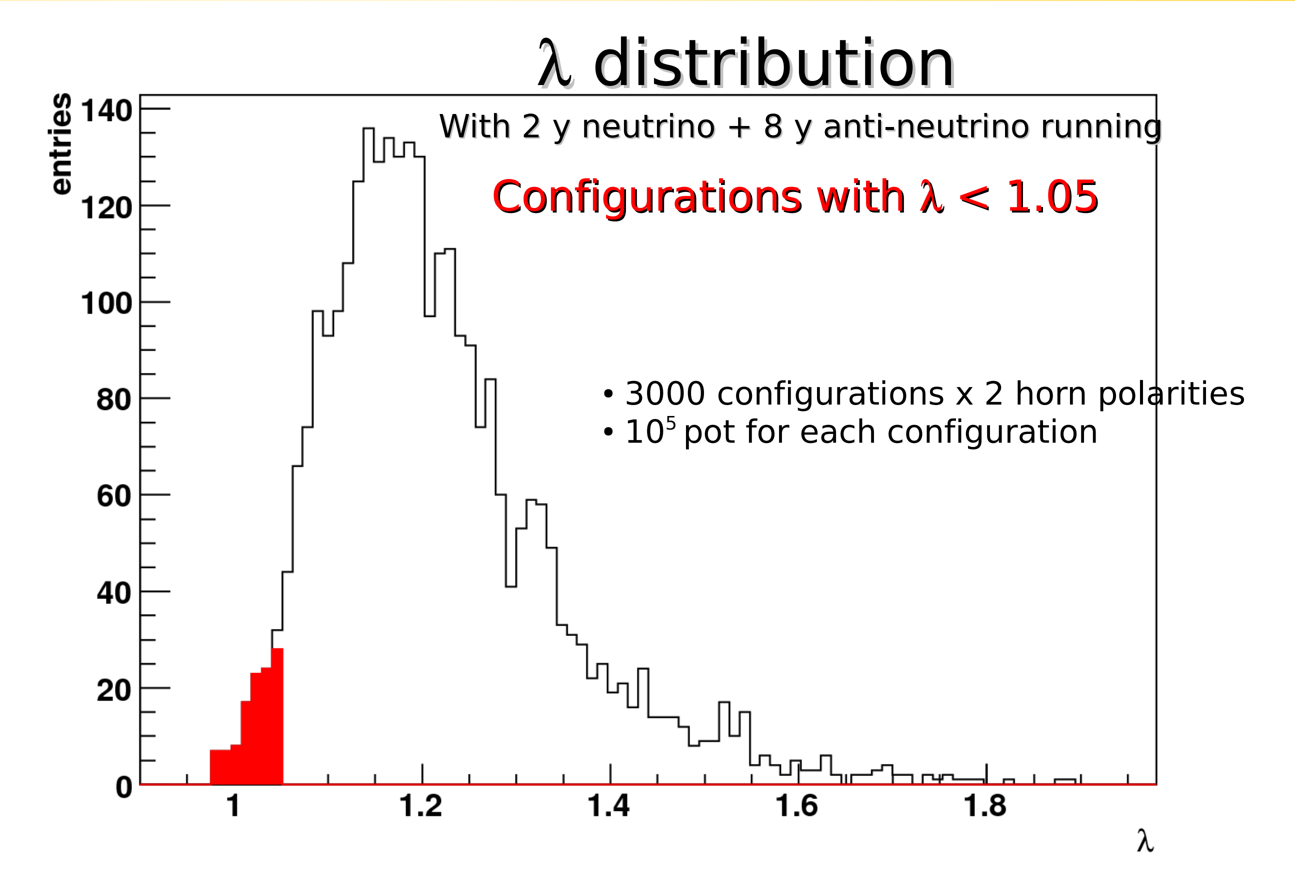


Broad scan

Allow parameters
to vary independently



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
$R,\ R_1,\ R_2$	$[R_{min}, R_{max}]$
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
s	3 mm
r	5.08 cm

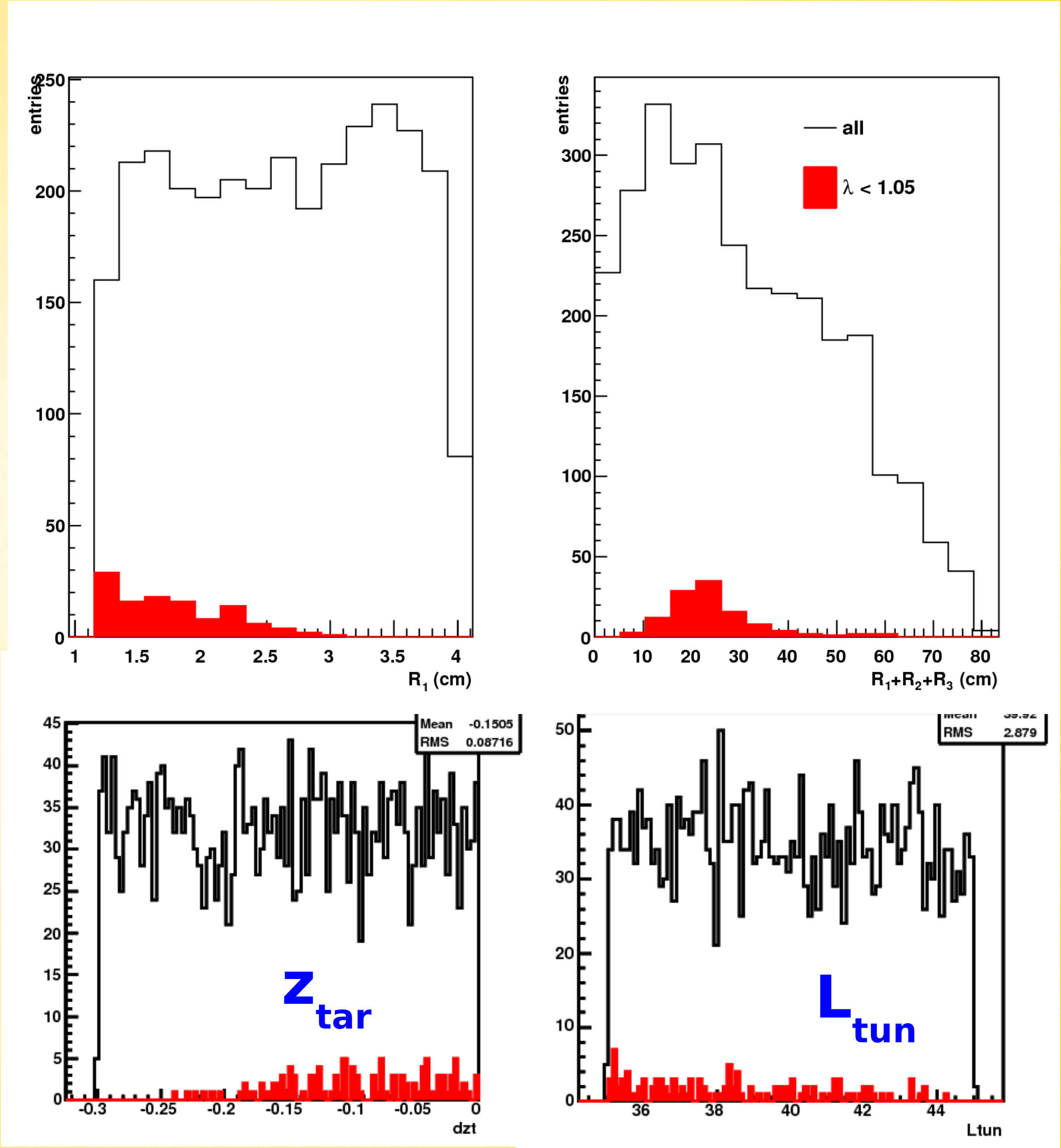


The minimal allowed inner radius corresponds to the “integrated target” solution
L_{max} and R_{max}: keep the horns small to allow for the 4-horns in parallel to fit

“Learning” phase (iteration-1)

In red: configurations with $\lambda < 1.05$

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

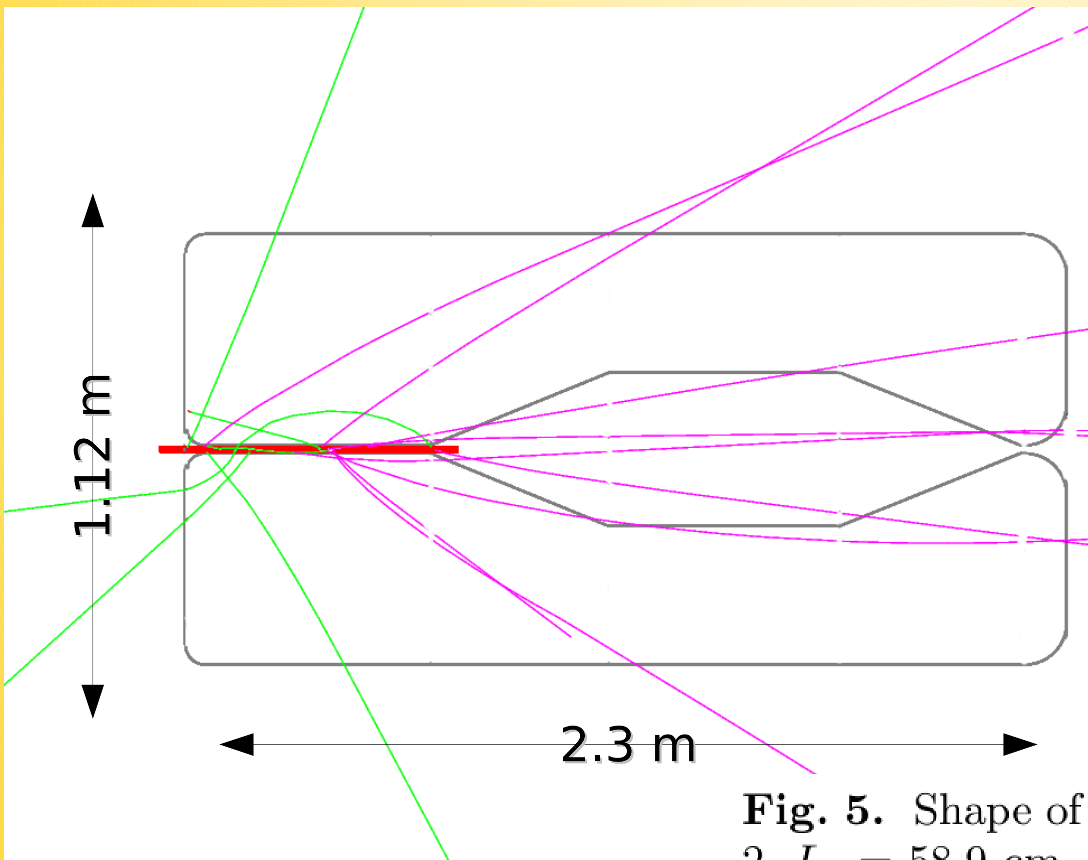


Re-iterate and fix (iteration-2)

- Restrict space of parameters
- New iteration
- Best* horn shape frozen

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

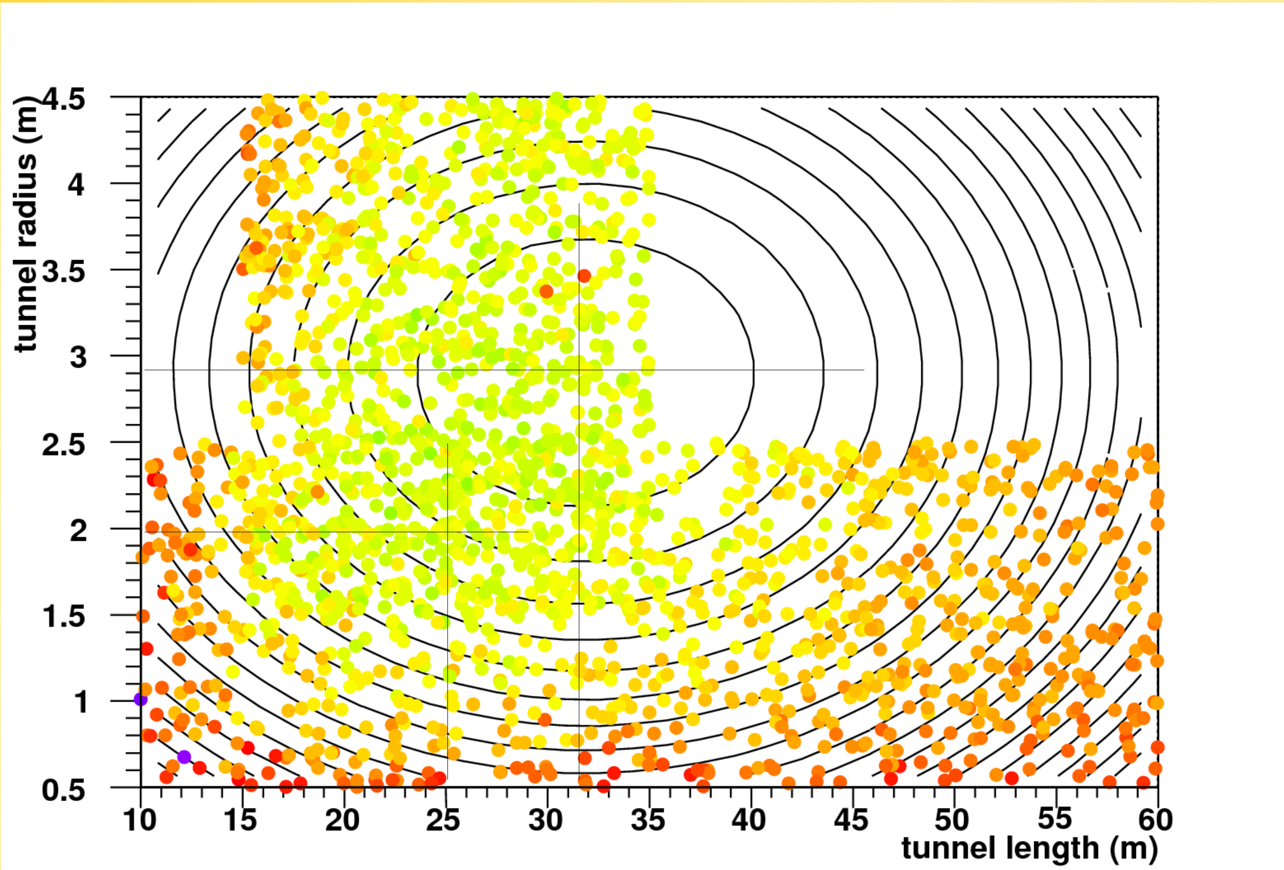
R_1 = 1.2 cm
R_1+R_2 in [20,22] cm
L_{tun} [30,40]
z_0^{tg} in [-15,0] cm

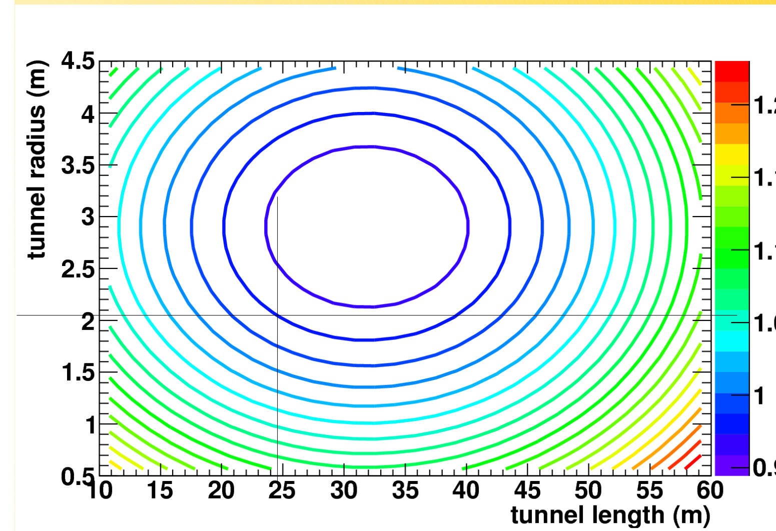


L_{tun} = 32.4 m r_{tun} = 2.06 m

Fig. 5. Shape of the optimal configuration found in iteration-2. $L_1 = 58.9$ cm, $L_2 = 46.8$ cm, $L_3 = 60.3$ cm, $L_4 = 47.5$ cm, $L_5 = 1.08$ cm $r_1 = 10.8$ cm, $R_1 = 1.2$, $\sum_{i=1}^{3} R_i = 56.2$ cm, $\sum_{i=1}^{2} R_i = 20.3$ cm, $z_0^{\rm tg}$=-6.8 cm.

Decay tunnel tuning ("iteration-3")





Quadratic fit

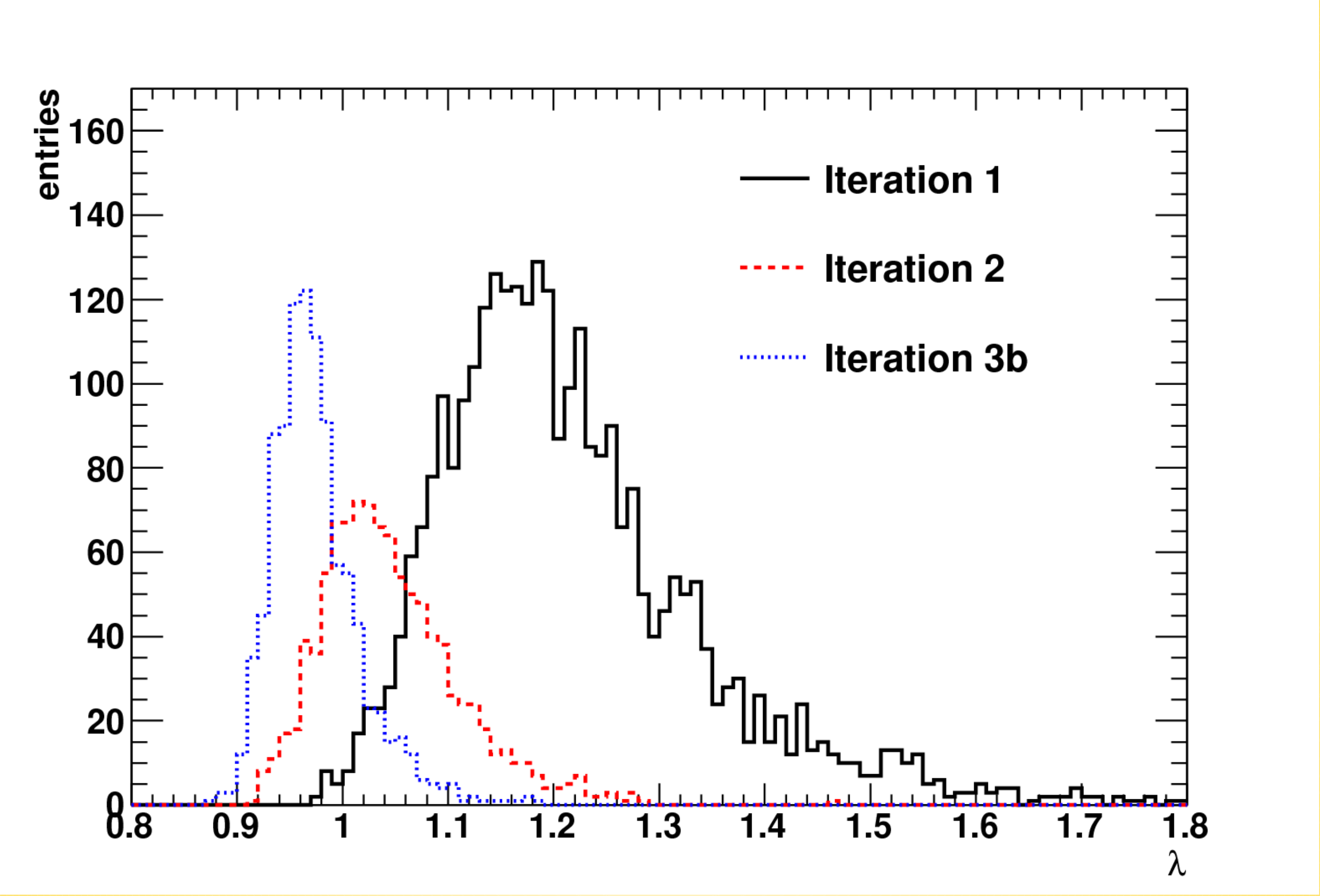
$\lambda = 0.94 + 2.1\cdot10^{-4}\,(L^{tun}\,[m]-31.8)^2 + 2.4\cdot10^{-2}\,(R^{tun}\,[m]-2.9)^2$

Broad minimum

[2.9,31.8] ~ optimal

[2, 25] reasonable choice ~> assumed as central value

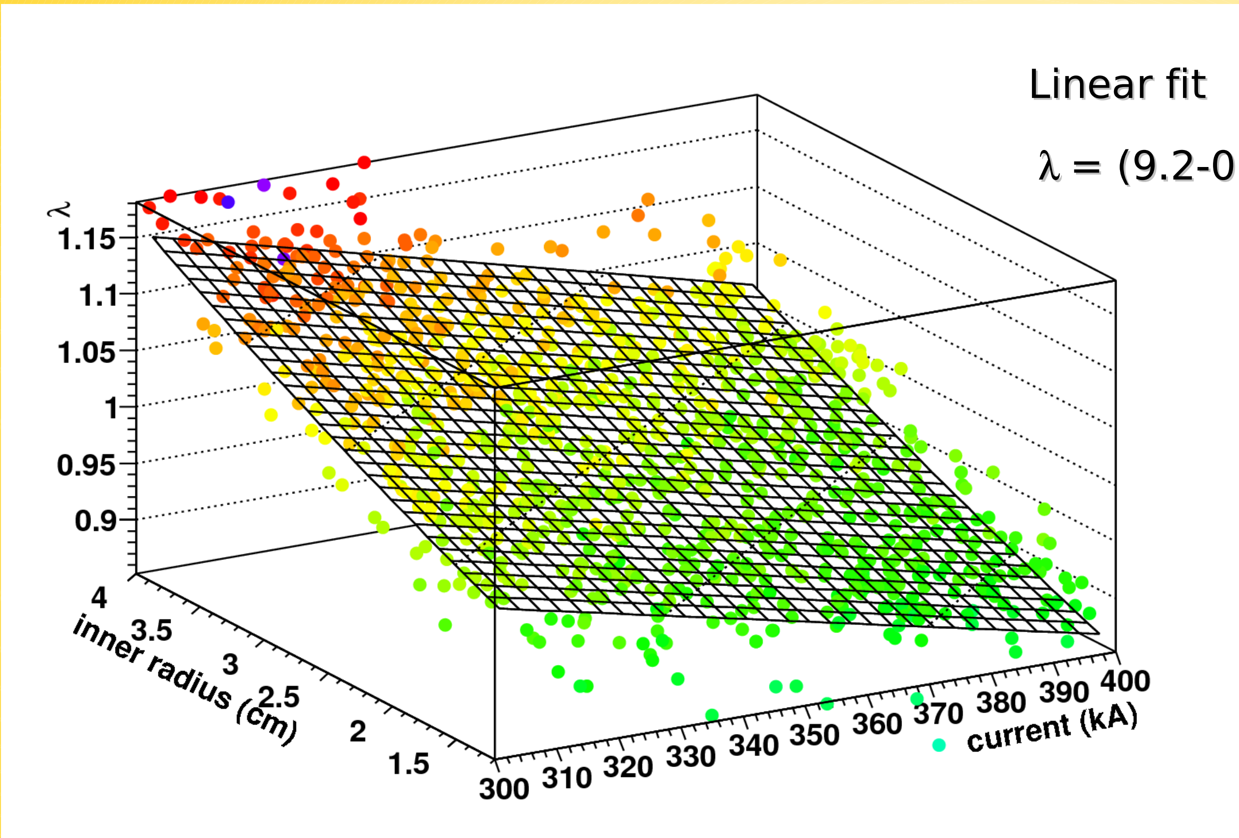
Converging to better limits

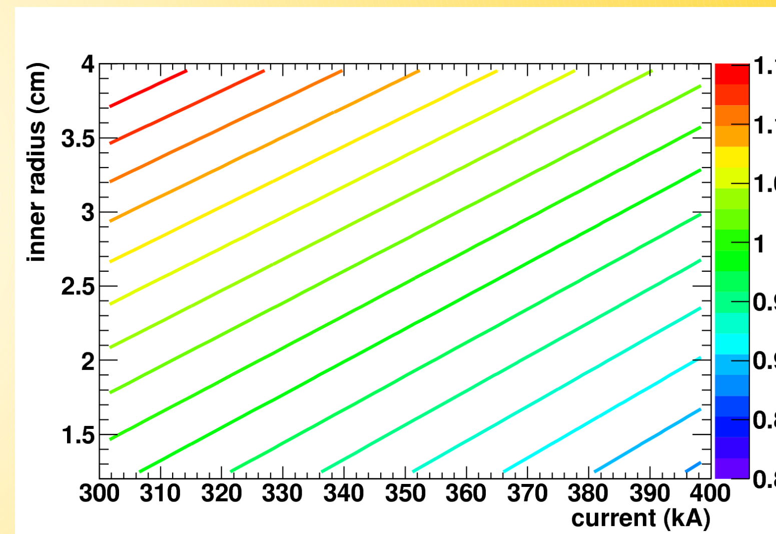


- broad parameters' scan
- restricted intervals for effective parameters → horn with min λ
- vary tunnel parameters in L [15-35] m r [1.5-4.5] m

Interplay inner-radius and current

Keep the best configuration + scan in (current, inner radius) plane





Sensitivity stays approximately constant if, when increasing the conductor's inner radius, the current is increased accordingly (B~i/r)

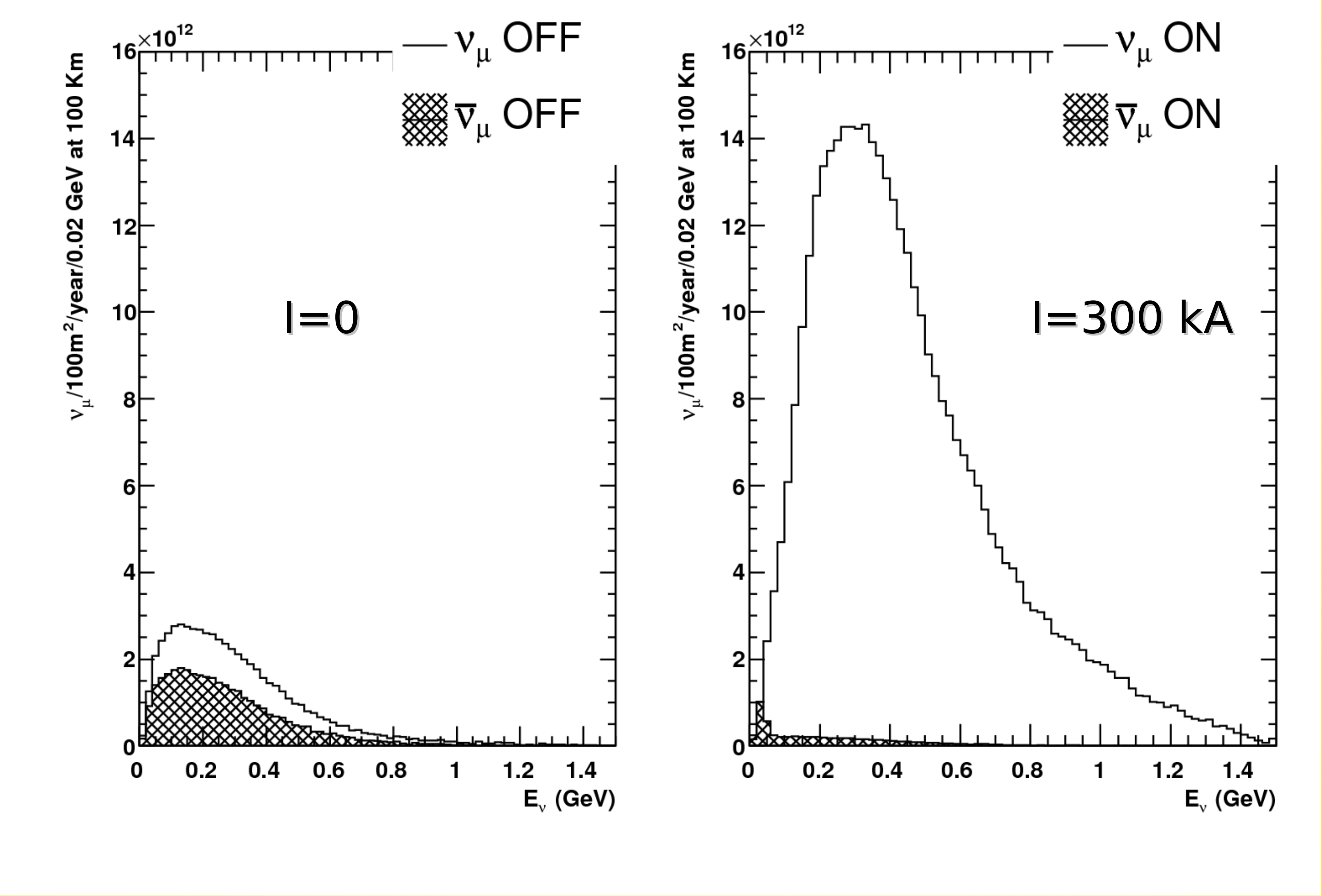
300 kA – 1.2 cm chosen as baseline

Results with the optimized setup

Focusing power (I)

ν_μ enhancement: x 6.5

anti-ν_μ suppression: x 5.4

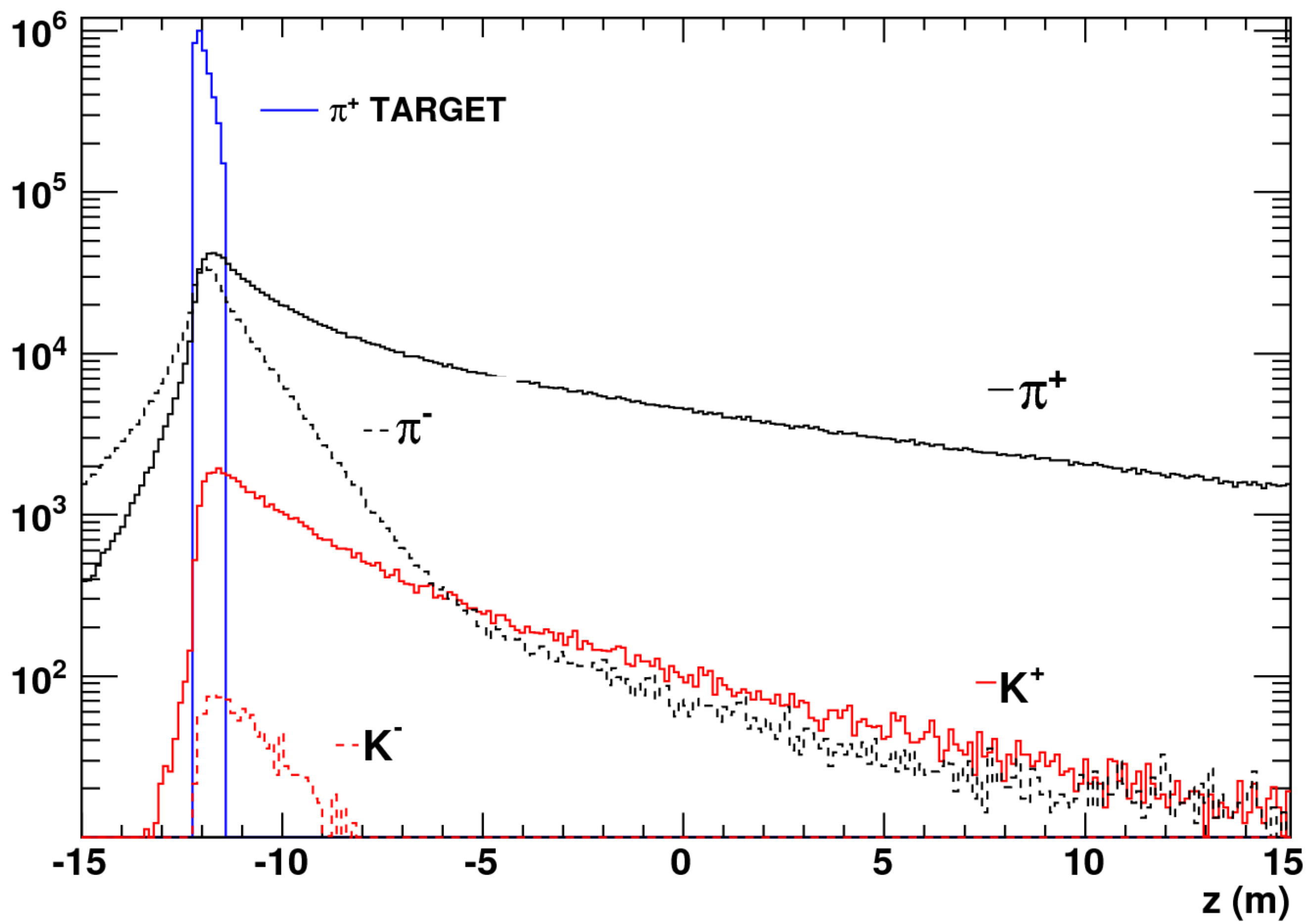


Focusing power (II)

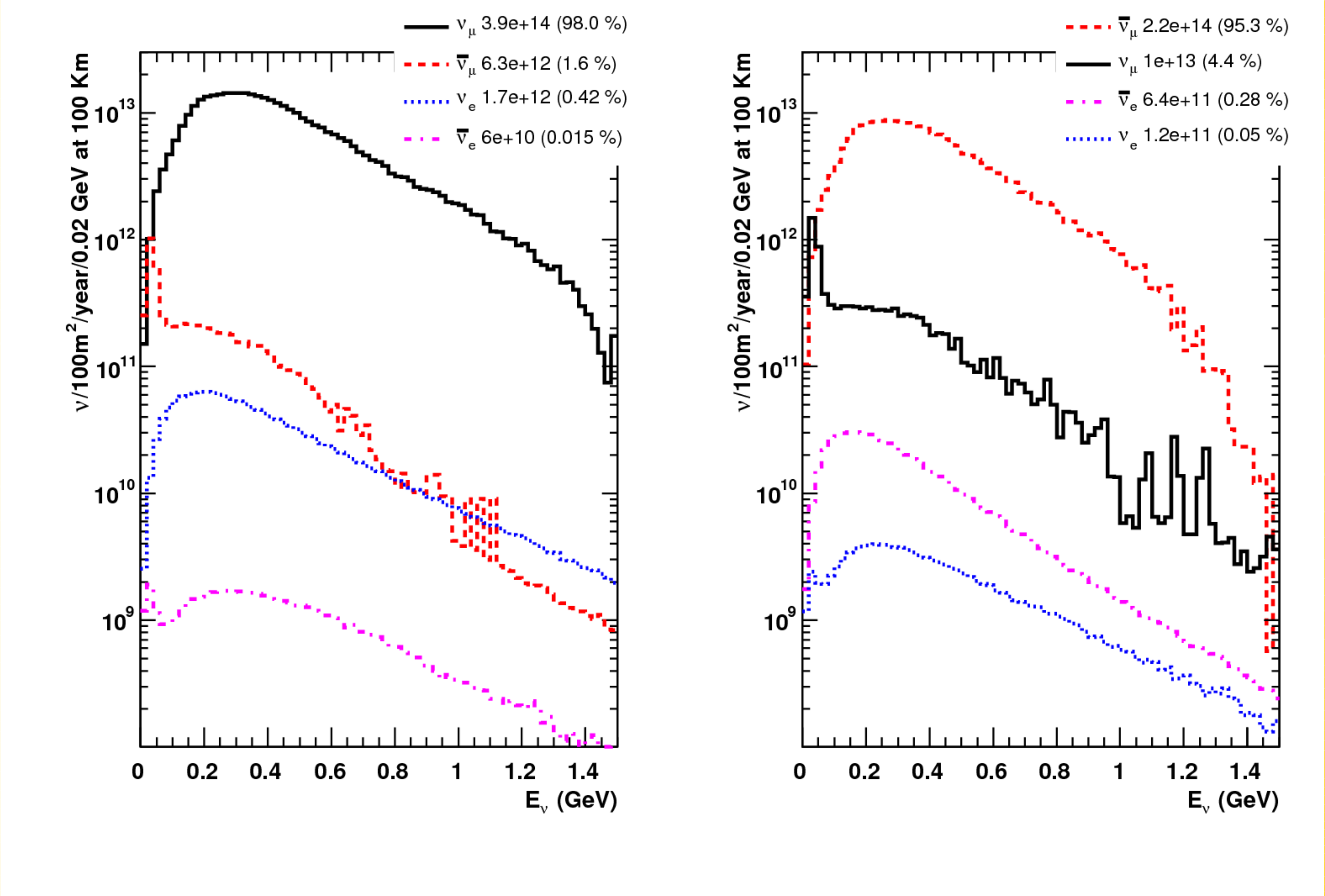
z-coordinate of $\pi^{\pm}/K^{\pm}$ decays in flight in positive focusing mode

Visible differences:

* +/- (focusing)
* lifetime of π and K
* relative π/K yield



Fluxes


ν_μ 3.9e+14 (98.0 %)
$\bar{\nu}_\mu$ 6.3e+12 (1.6 %)
ν_e 1.7e+12 (0.42 %)
$\bar{\nu}_e$ 6e+10 (0.015 %)
ν/100m^2/year/0.02 GeV at 100 Km
E_ν (GeV)
$\bar{\nu}_\mu$ 2.2e+14 (95.3 %)
ν_μ 1e+13 (4.4 %)
$\bar{\nu}_e$ 6.4e+11 (0.28 %)
ν_e 1.2e+11 (0.05 %)
ν/100m^2/year/0.02 GeV at 100 Km
E_ν (GeV)

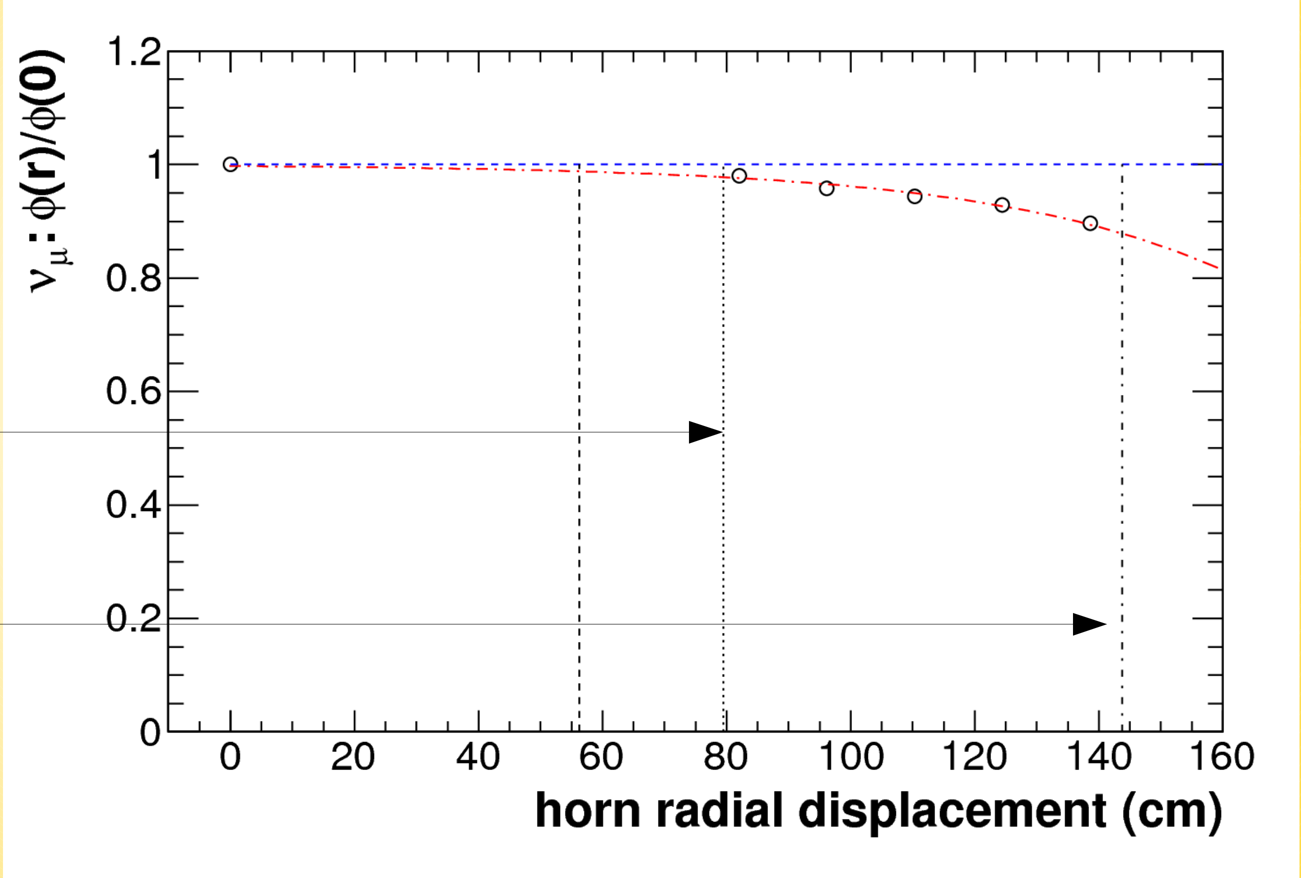
4-horn setup: effect on flux

Plot updated for the new configuration

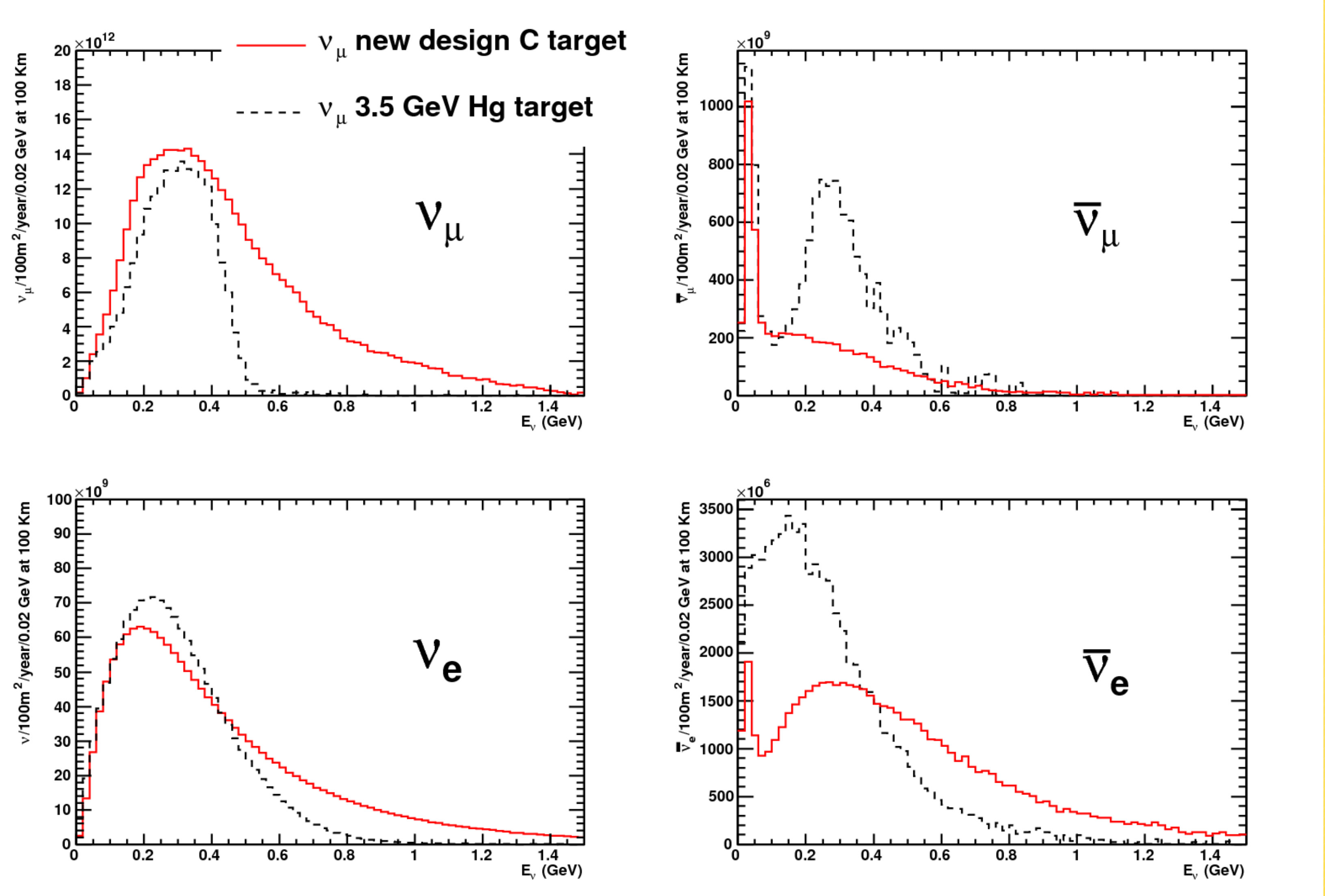
Horn radius : 56 cm
Tunnel radius: 200 cm

• horns touching the tunnel (most pessimistic assumption): 10 % loss

• 4 horns in contact (minimum possible displacement): 1-2 % loss

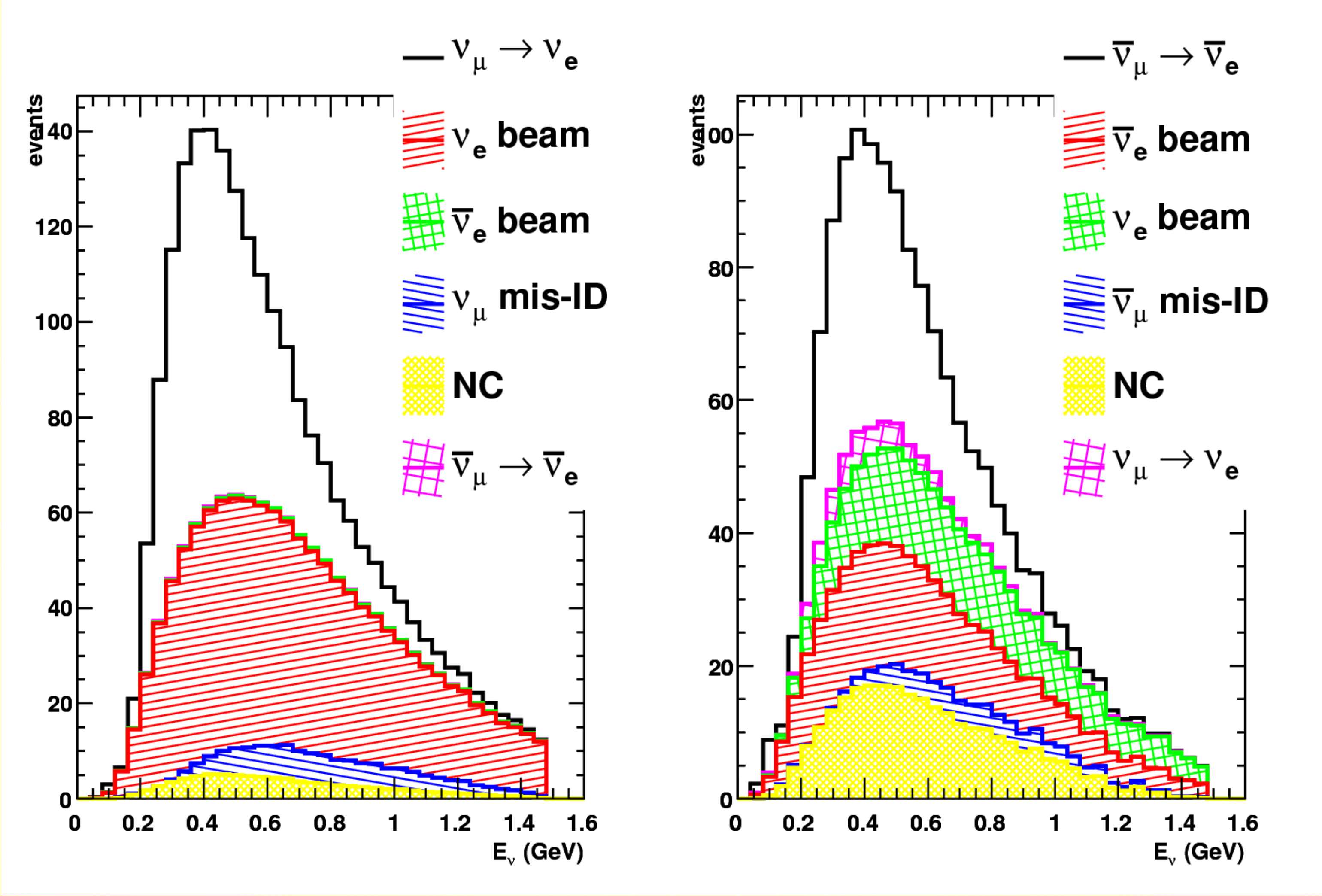


Comparison with the previous fluxes



Event rates in MEMPHYS

$\sin^2 2\theta_{13} = 0.01$, $\delta_{CP} = 0$



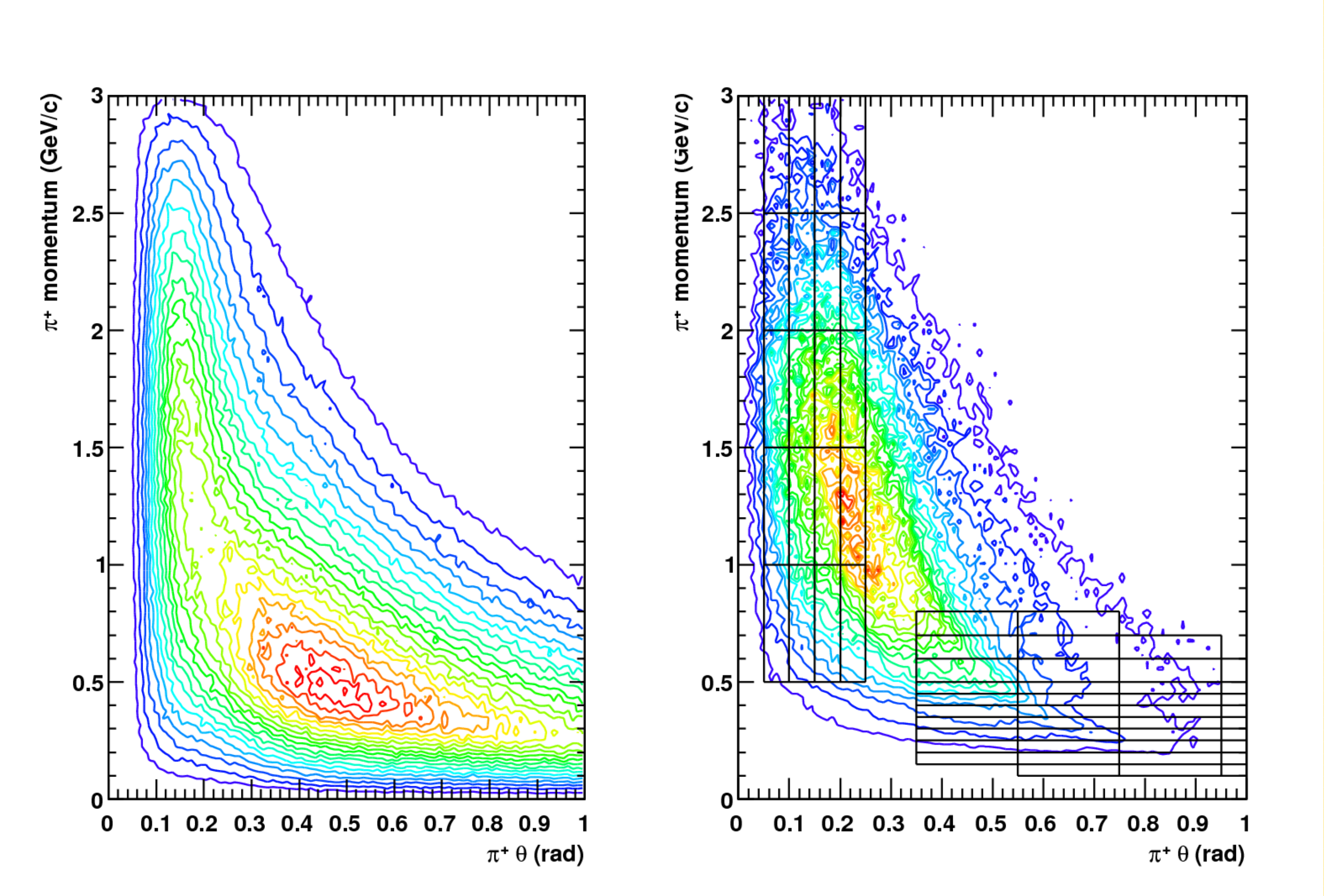
The bulk of the background comes from the intrinsic beam electron component
NC π^0 relevant for the anti-ν run (28%).

Uncertainties related to hadro-production

Pion phase space

At target exit

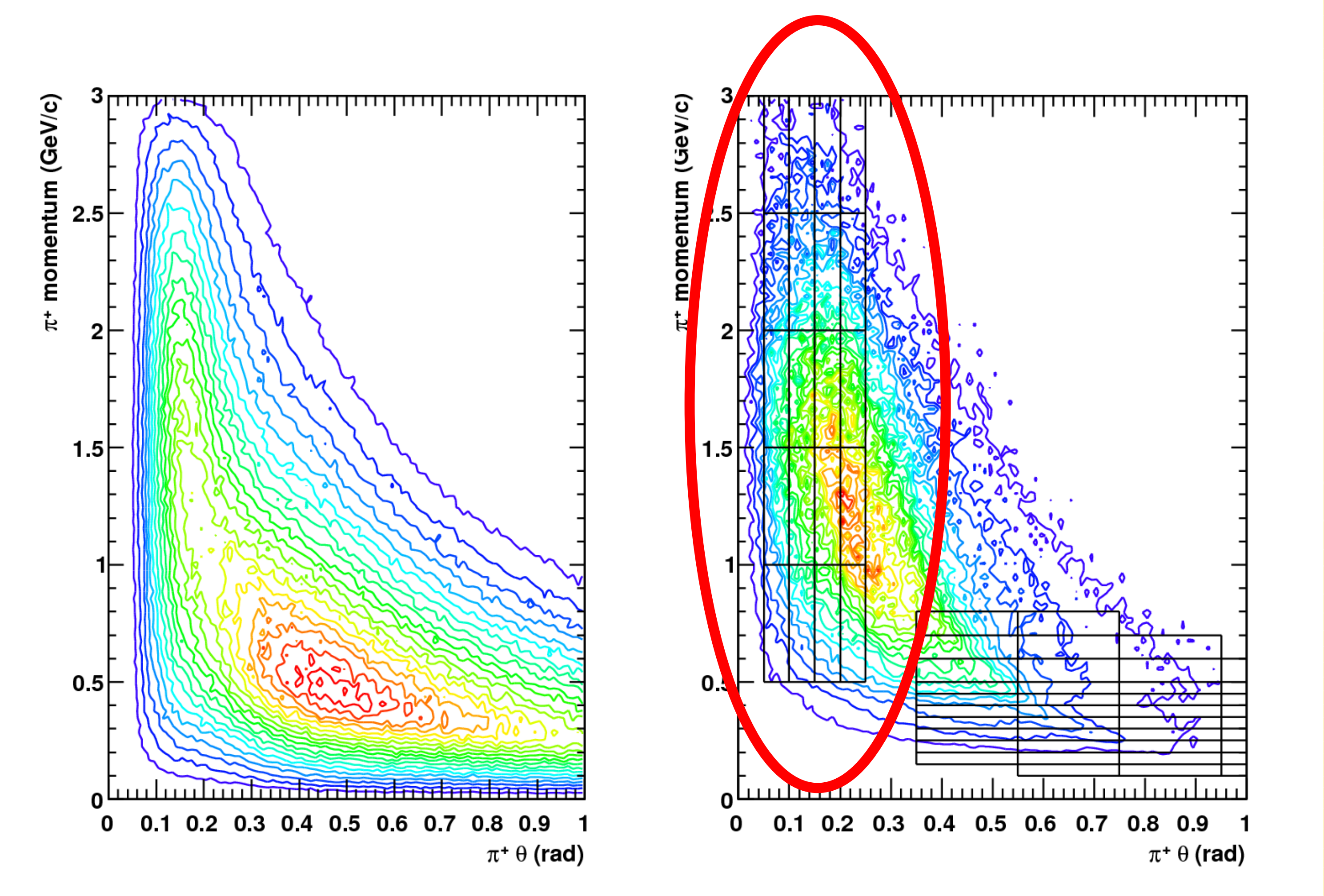
P VS θ in bins of E_ν
weighted average, $w_i = E_{\nu i}$



Weights according to the contribution to the neutrino flux

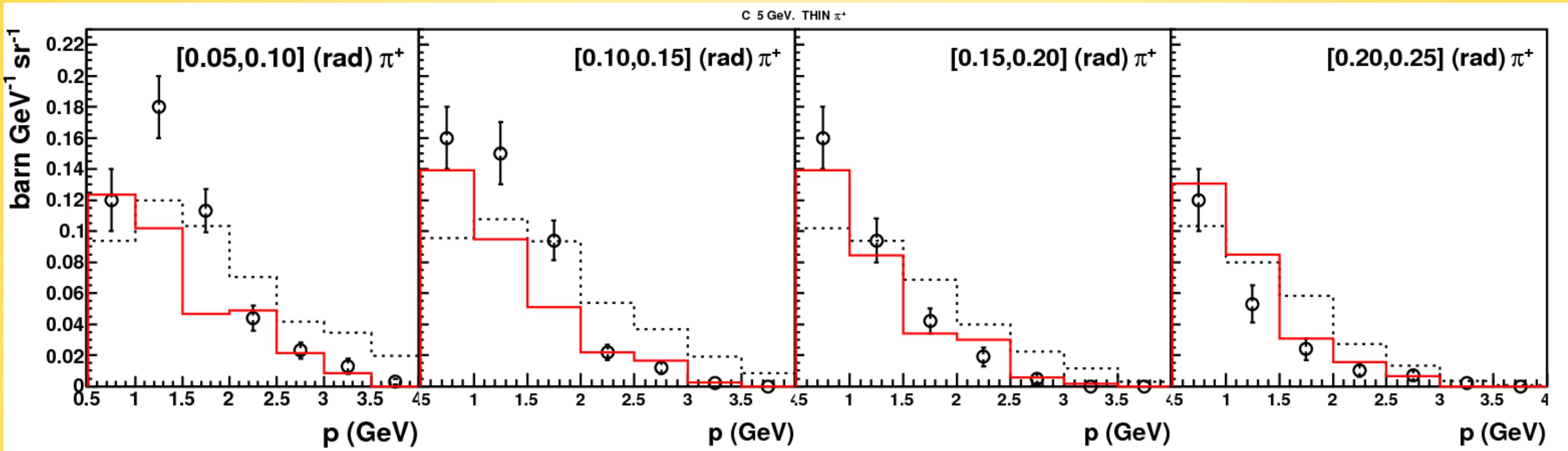
Pion phase space

HARP "Small angle" data available for a "thin target" (1.95 cm, 3 cm diameter)

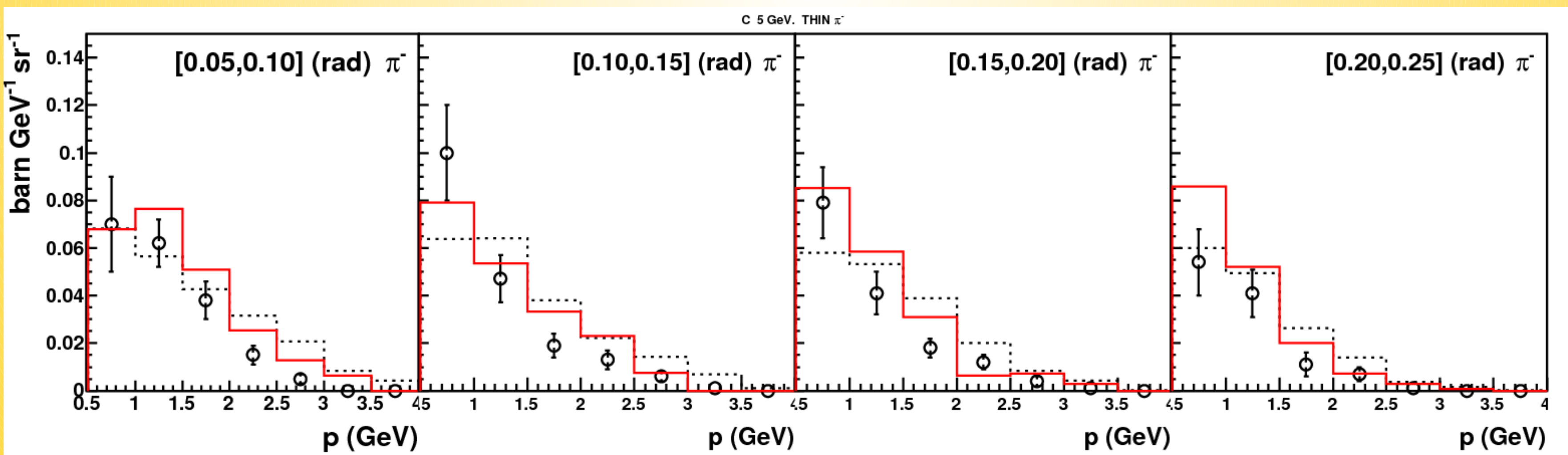


HARP data vs FLUKA-GEANT4

pi+



pi-

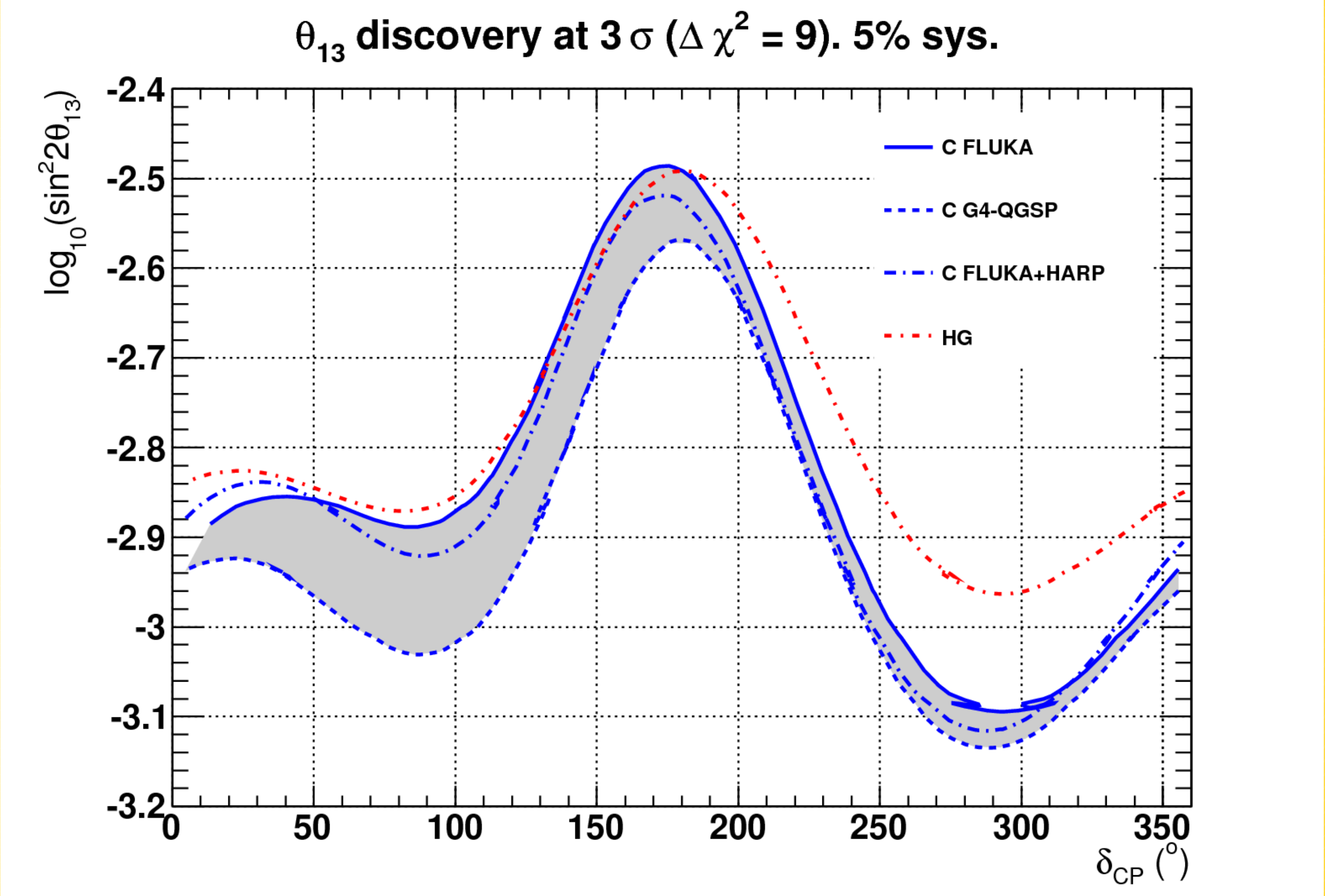


Discovery of $\theta_{13} \neq 0$

I assume 5% sys. Errors

low-energy neutrino interactions are a difficult terrain !

Red curves reproduce the published ones.

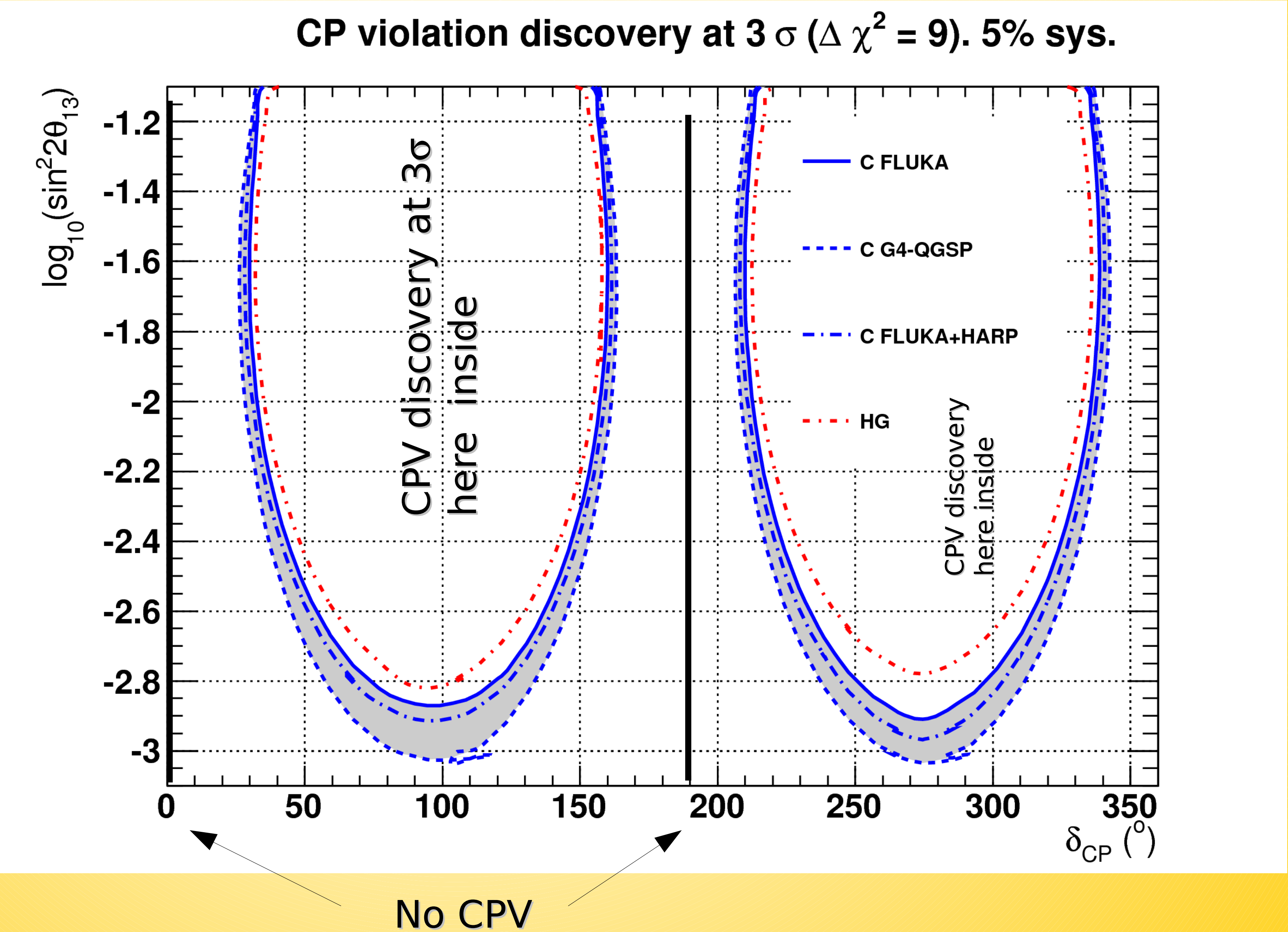


Discovery of CPV

I assume 5% sys. Errors

low-energy neutrino interactions are a difficult terrain !

Red curves reproduce the published ones.



Conclusions

Improved limits (θ_{13} and CP)

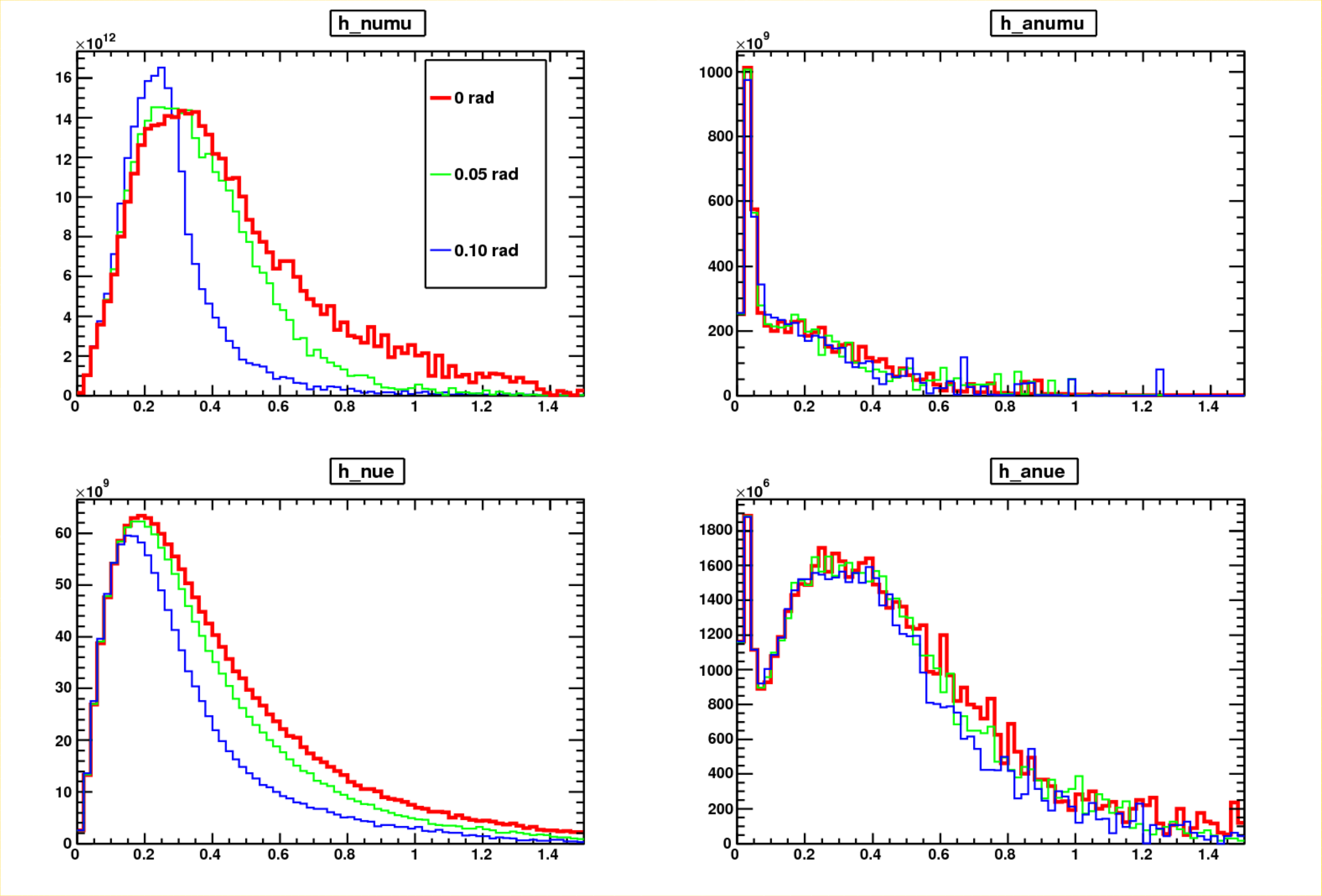
liquid mercury, horn+reflector (300+600 kA), 40 m tunnel
->
solid (integrated) target, single horn (300 kA), 25 m tunnel, 4 in systems parallel

new studies:

- Interplay of current & inner-radius studied
- Uncertainty in the hadroproduction issue addressed at the level of sensitivities

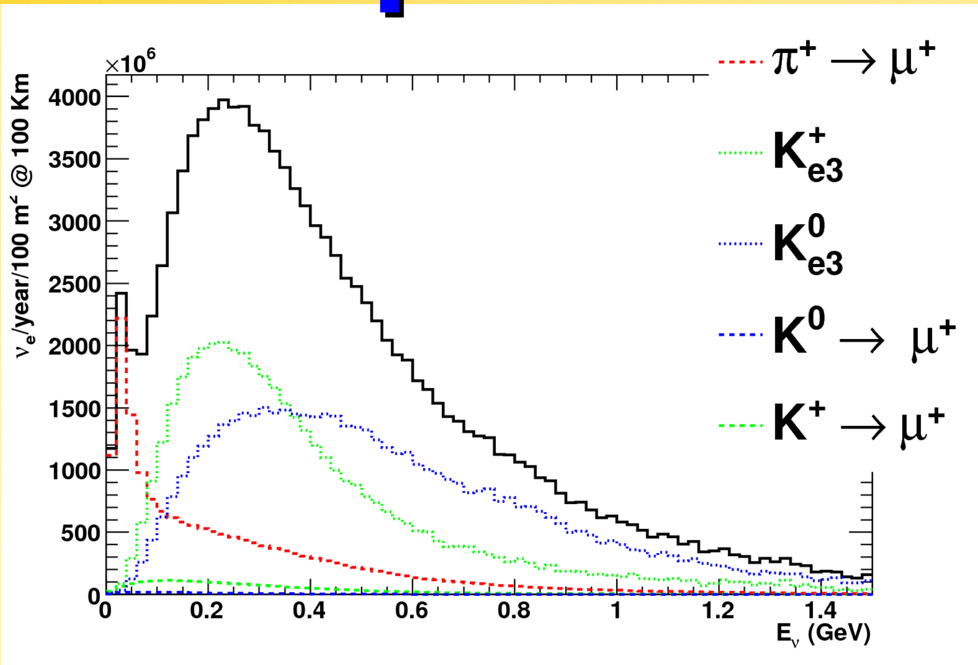
Milestone (~10 pg), in form of article, being finalized

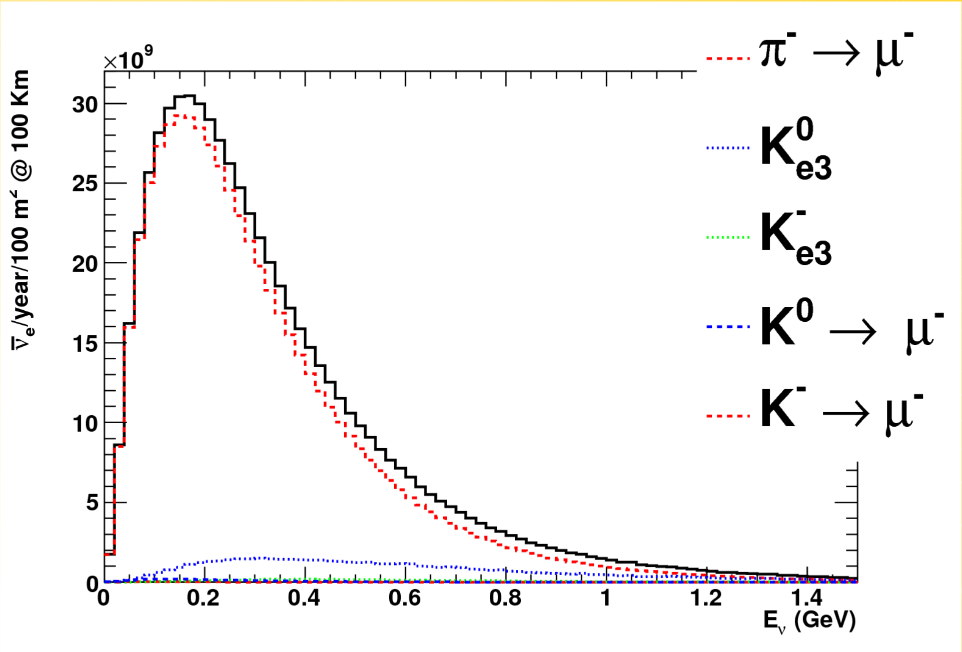
An idea

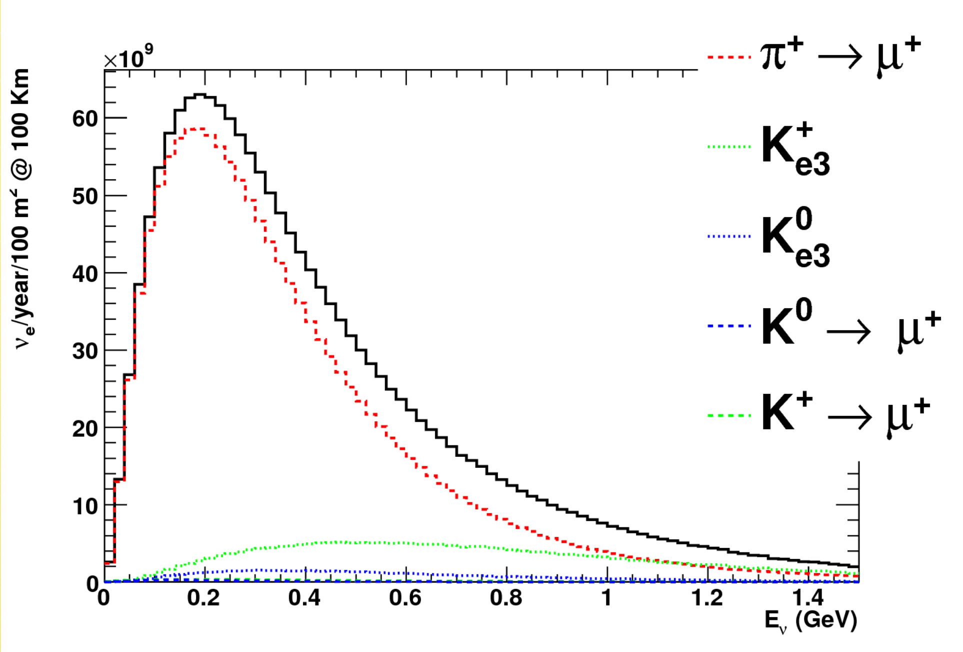


Going off-axis ? Looks promising but not a big gain when sensitivities are compared

Components


×10^6
ν_e/year/100 m² @ 100 Km
E_ν (GeV)
π⁺ → μ⁺
K⁺e3
K⁰e3
K⁰ → μ⁺
K⁺ → μ⁺


×10^9
$\bar{\nu}_e$/year/100 m² @ 100 Km
E_ν (GeV)
π⁻ → μ⁻
K⁰e3
K⁻e3
K⁰ → μ⁻
K⁻ → μ⁻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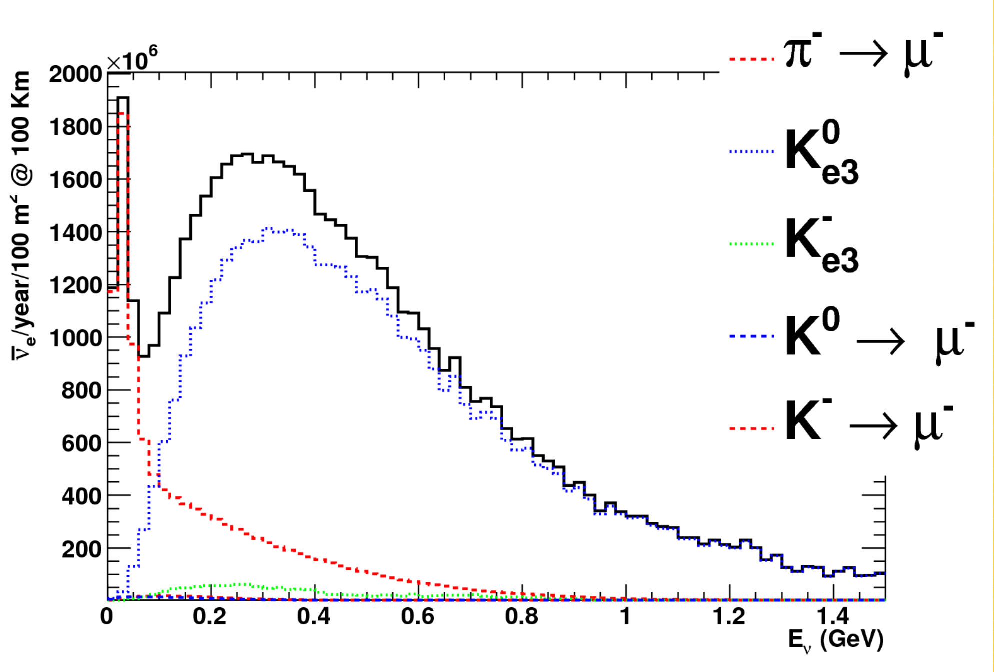
×10^6
$\bar{\nu}_e$/year/100 m² @ 100 Km
E_ν (GeV)
π⁻ → μ⁻
K⁰e3
K⁻e3
K⁰ → μ⁻
K⁻ → μ⁻

Decay tunnel tuning (iteration-3)

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