Super Beam focusing system: fluxes and physics reach

EURONU

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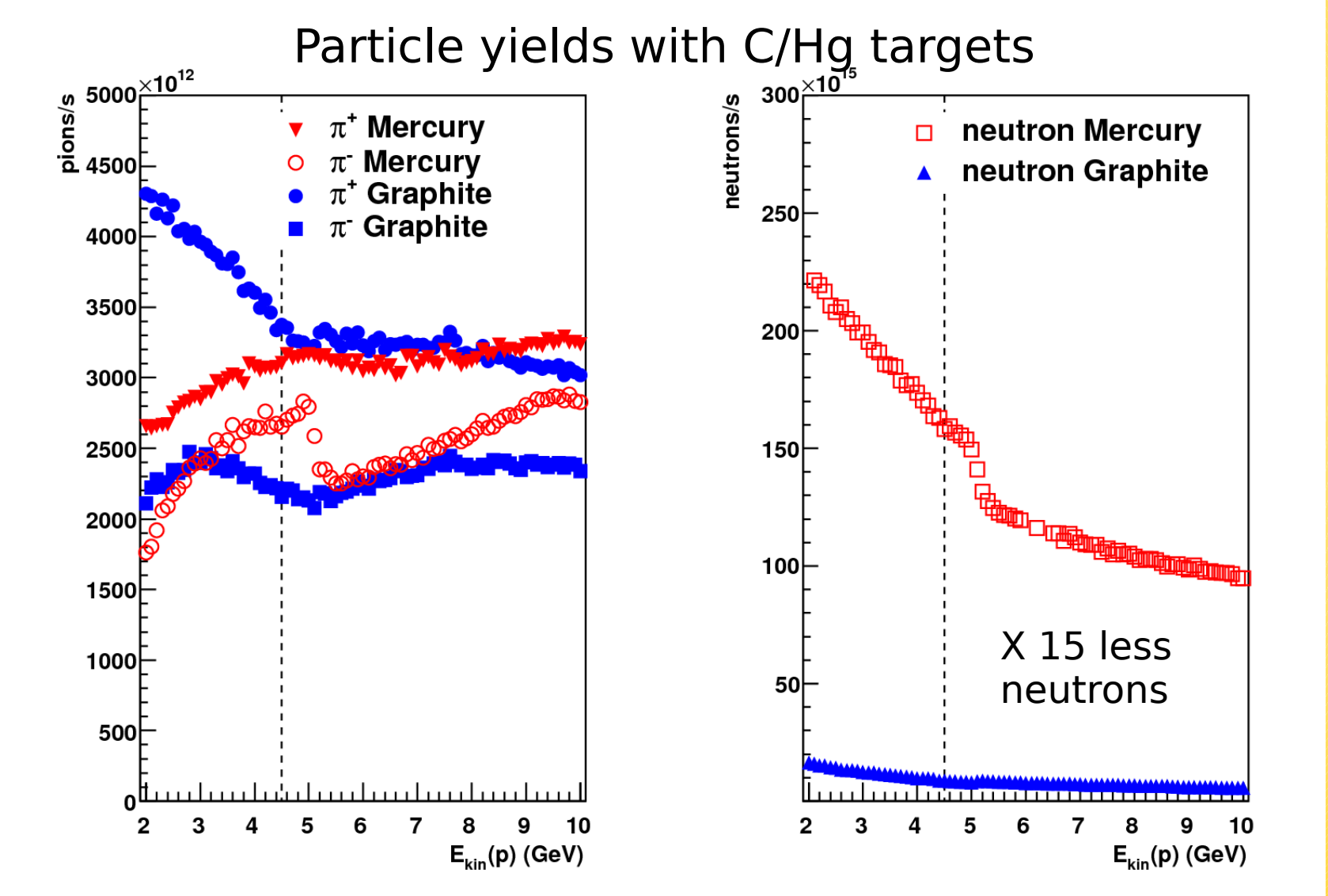
Outline

- Re-design of the focusing for a (long) solid target
- θ_{13} sensitivity-driven optimization
- Fluxes, sensitivities for an optimized setup
- Hadro-production uncertainties
- Feed-backs from engineering → a set of different solutions
  - Integrated / separated target
  - solid / granular target
- Conclusions

Solid target

- A graphite target with L = 78 cm, r = 1.5 cm
- Similar pion yields wrt to 30 cm long liquid mercury jet
- Neutron yield strongly suppressed

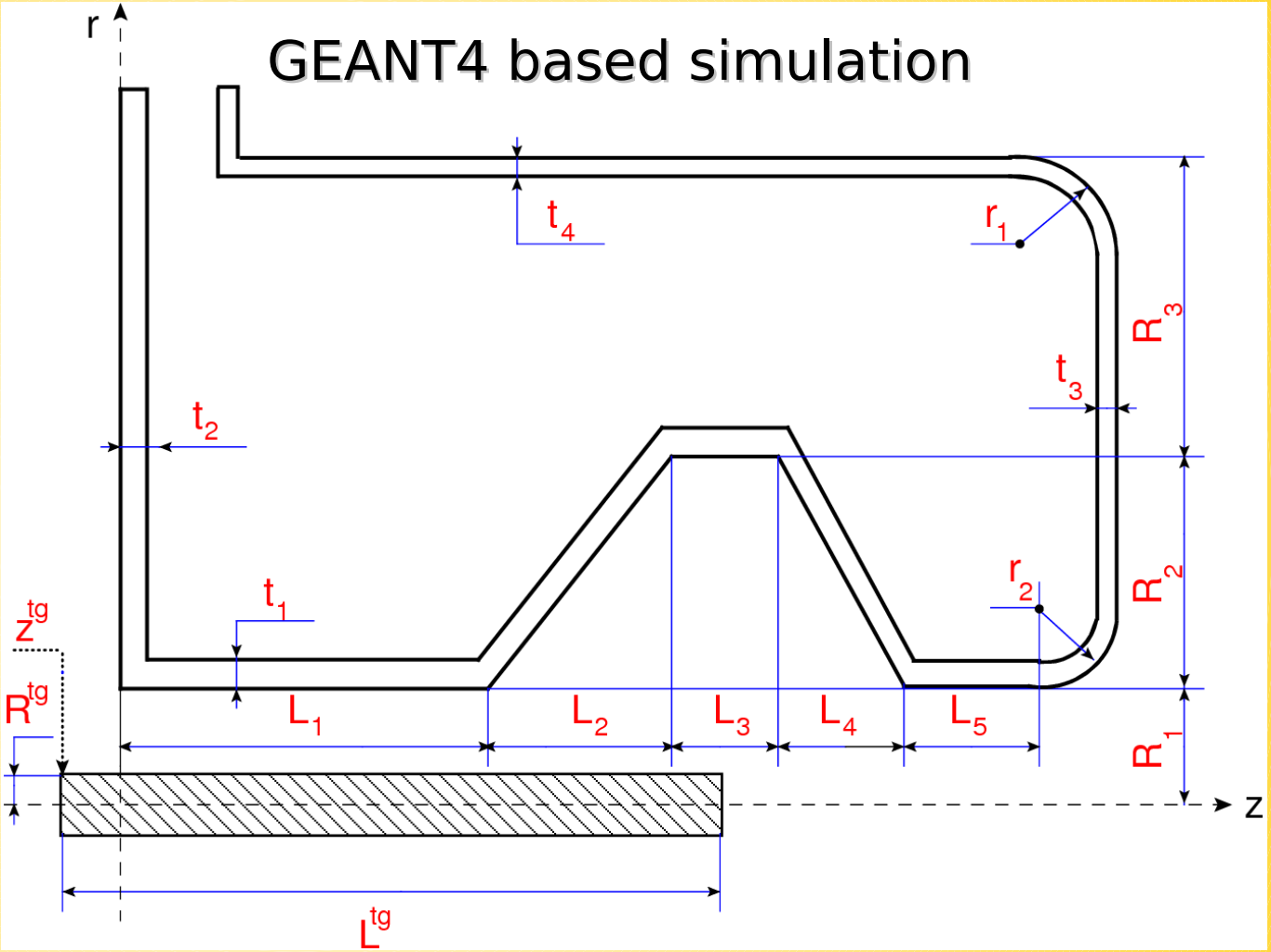


Horn geometrical model

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 $\pi^+ \to \mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ and $K^+ \to \pi^0 e^+ \nu_e$

← 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

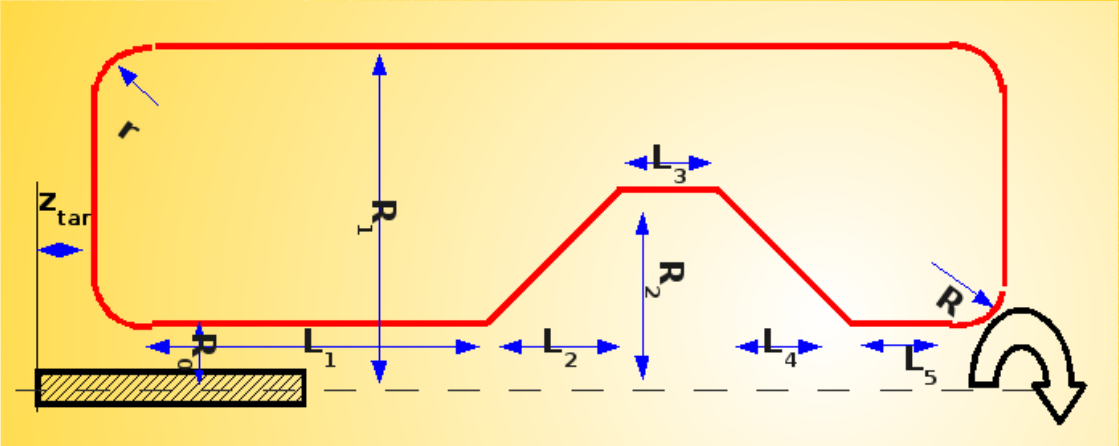
- Broad sampling of the (many) parameters to identify the most relevant variables. Then restrict the ranges of variation and iterate.

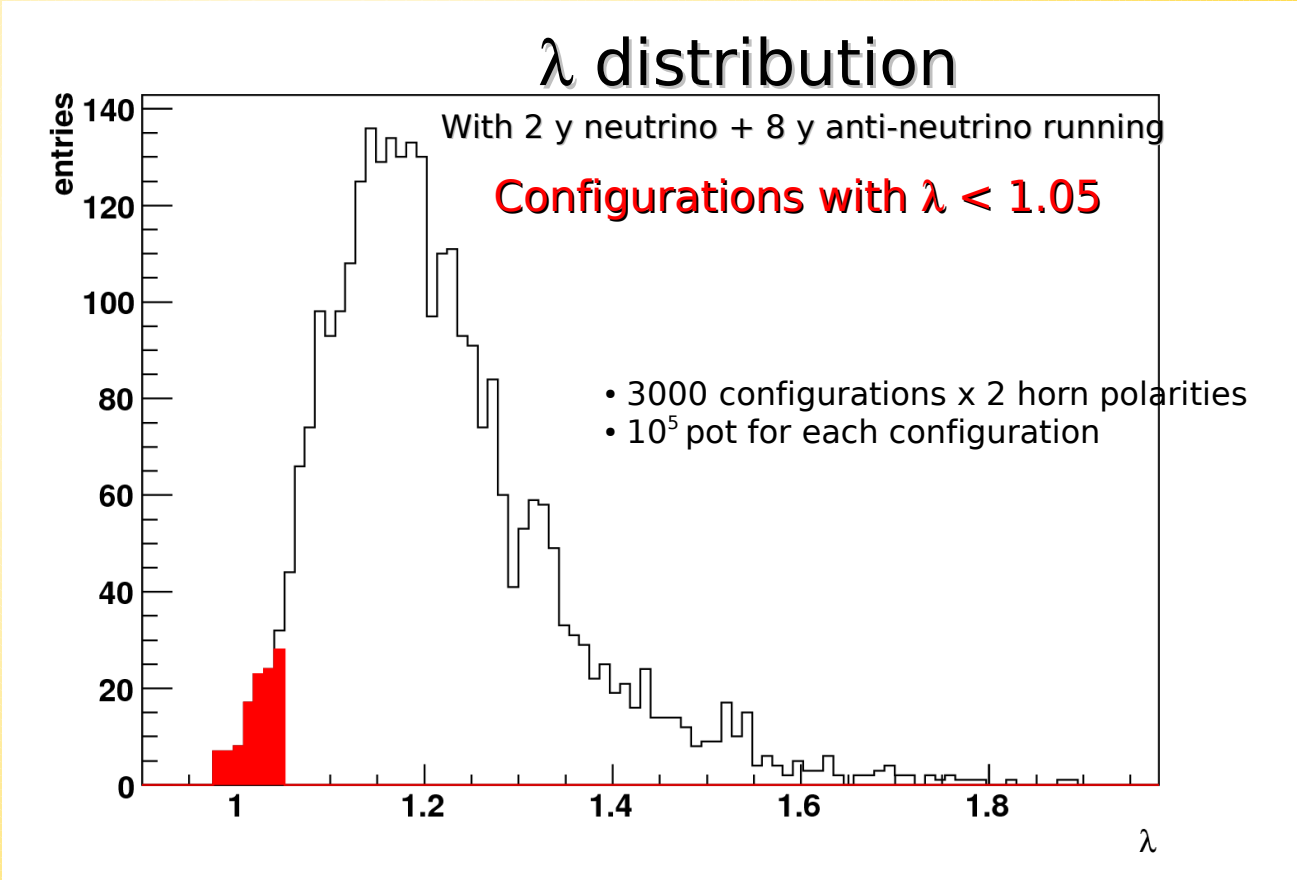
$\rightarrow$

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





L_{max} and R_{max}: keep the horns small to allow for the 4-horns in parallel to fit

"Learning" phase (iteration-1)

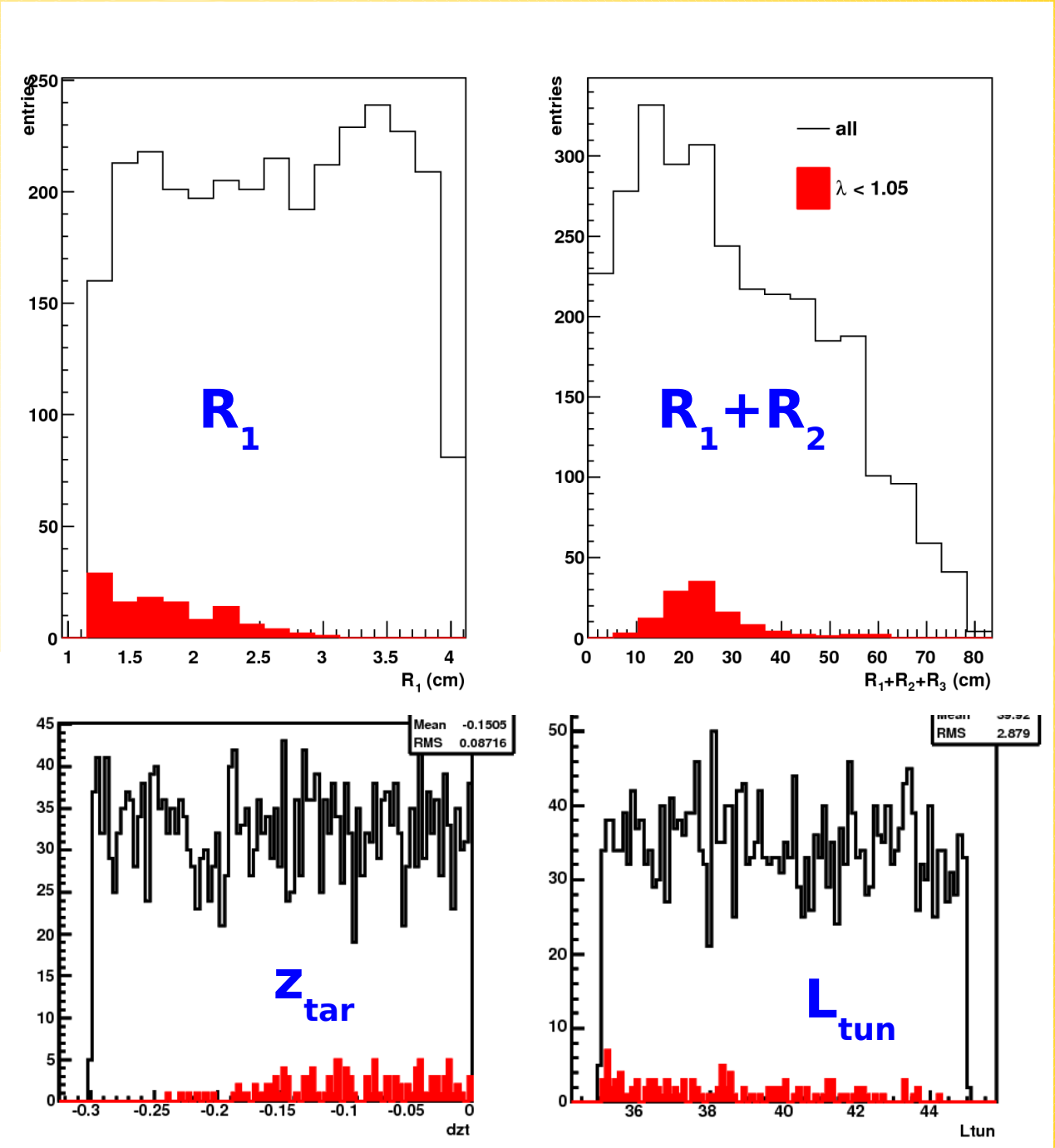
In red: configurations with $\lambda < 1.05$

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

New limits:

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

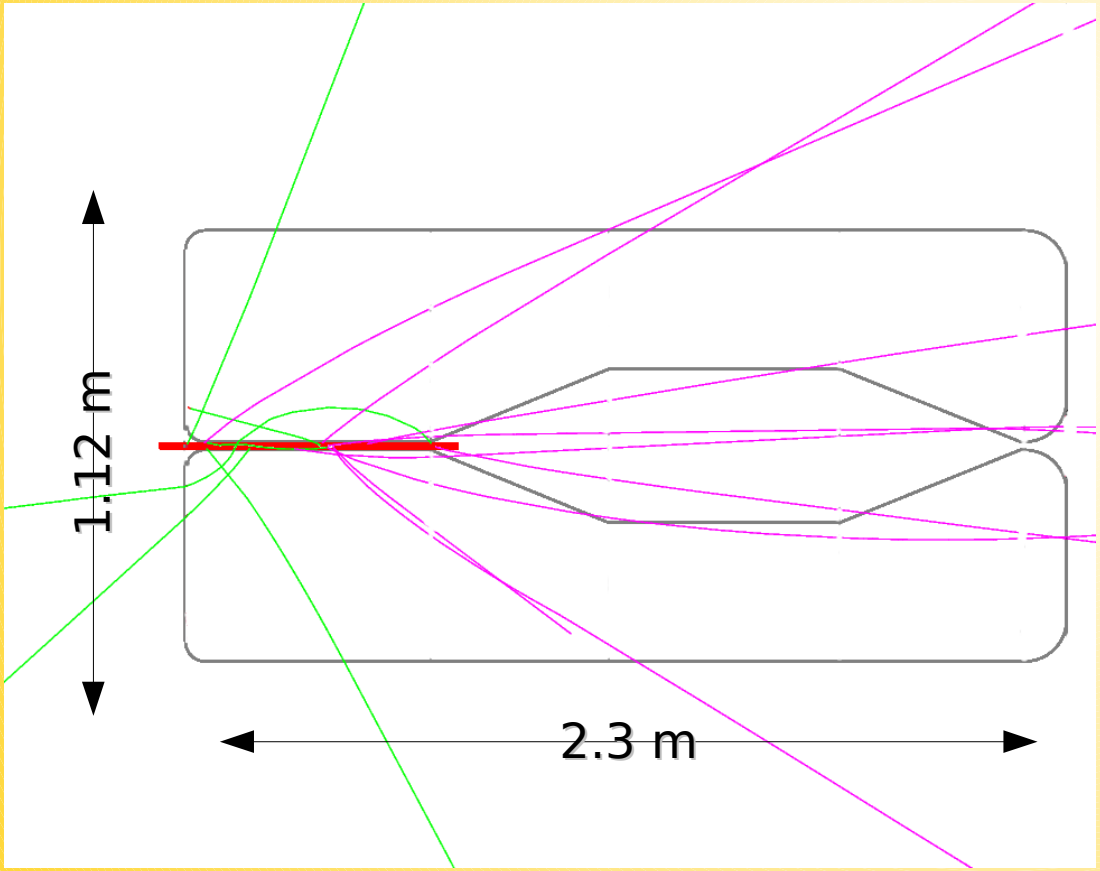
R_1=1.2 cm ~"integrated target" solution



Re-iterate and fix (iteration-2)

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

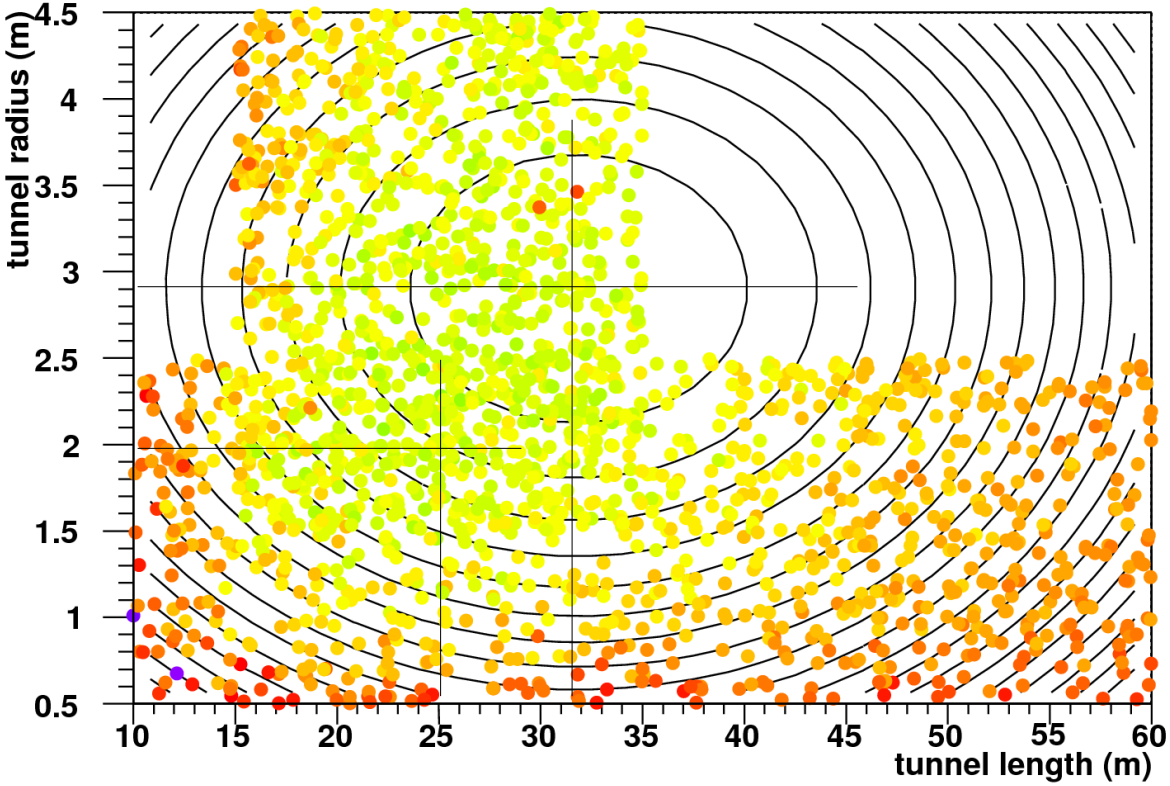
best configuration (i.e. giving the minimum λ)

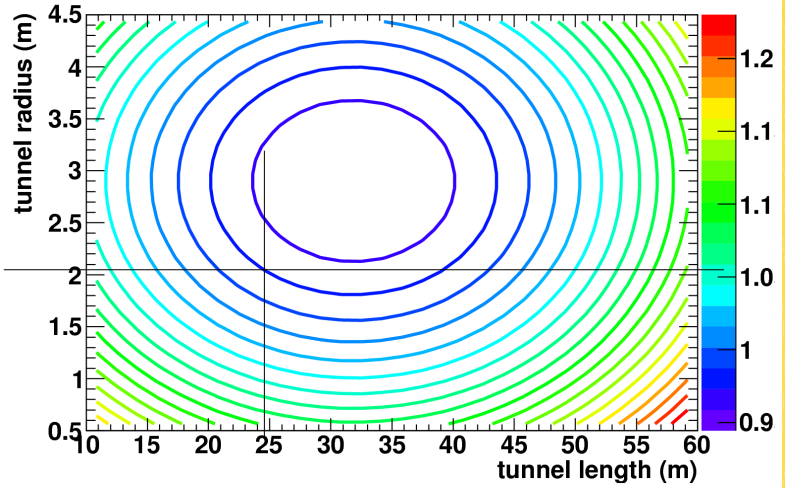


L_1	58.9	$r_1 = r_2$	10.8
L_2	46.8	R_1	1.2
L_3	60.3	$R_1 + R_2 + R_3$	56.2
L_4	47.5	$R_1 + R_2$	20.3
L_5	1.08	z_0^{tg}	-6.8

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

Decay tunnel tuning ("iteration-3")





Quadratic fit

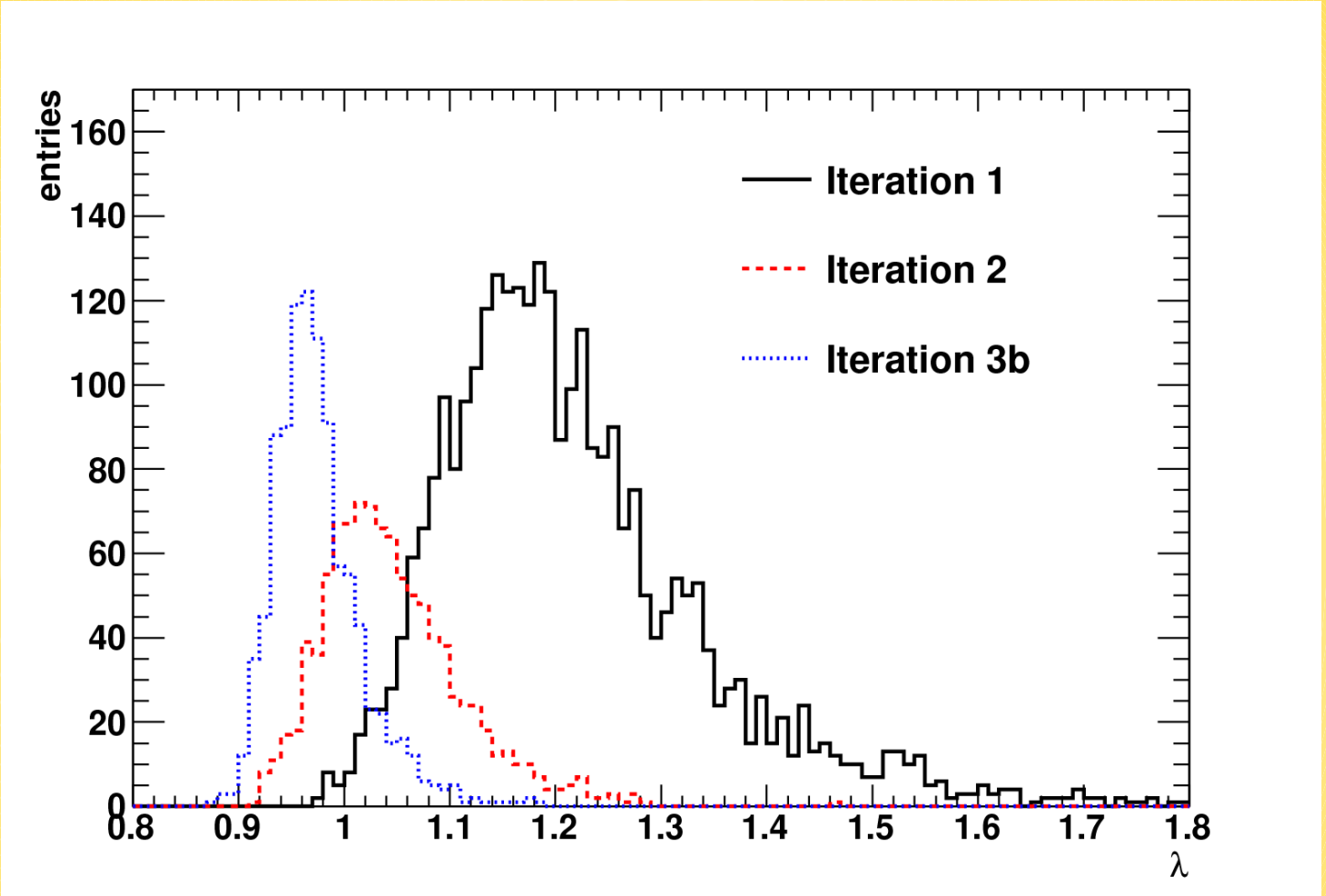
$\lambda = 0.94 + 2.1 \cdot 10^{-4} (L^{tun}\,[m] - 31.8)^2 + 2.4 \cdot 10^{-2} (R^{tun}\,[m] - 2.9)^2$

Broad minimum:

[r = 2.9, L=31.8] m ~ optimal

[r=2, L=25] m reasonable → taken as central value

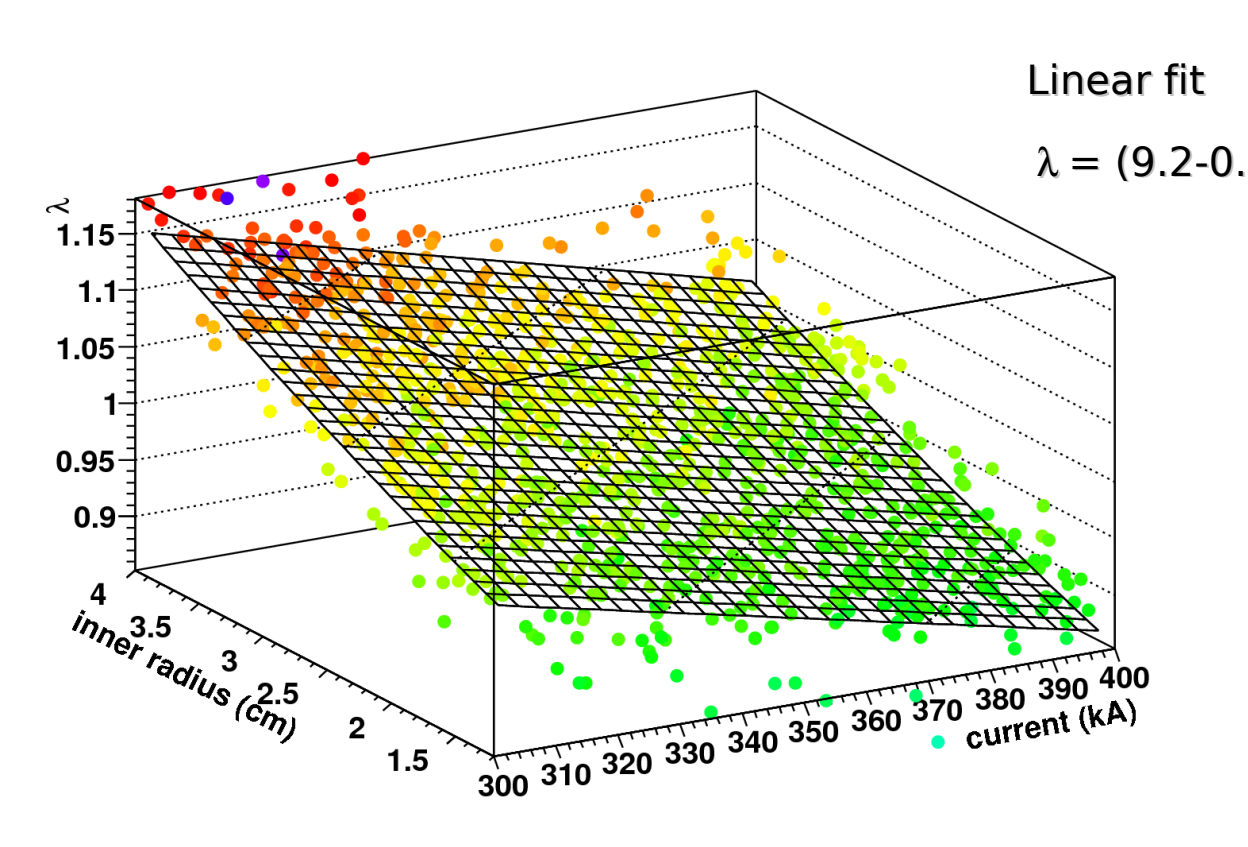
Converging to better limits

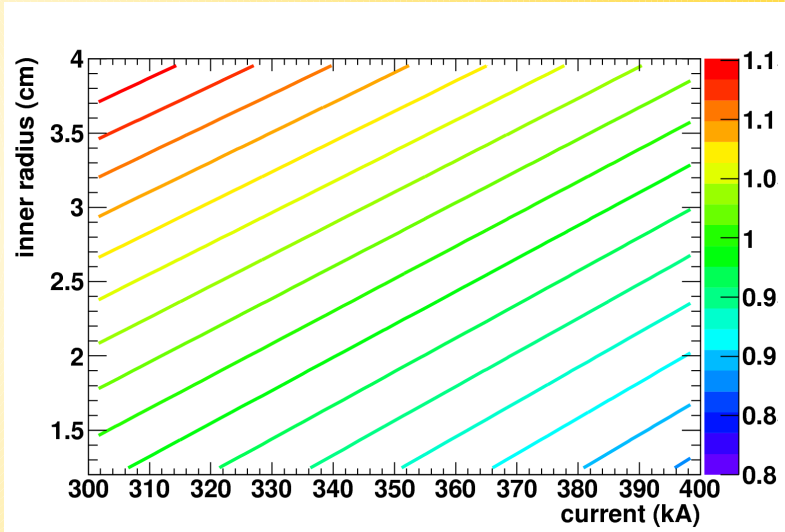


- broad parameters' scan
- restricted intervals for effective parameters → horn with min λ
- vary tunnel parameters in L [15-35] m r [1.5-4.5] m

Interplay inner-radius and current

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





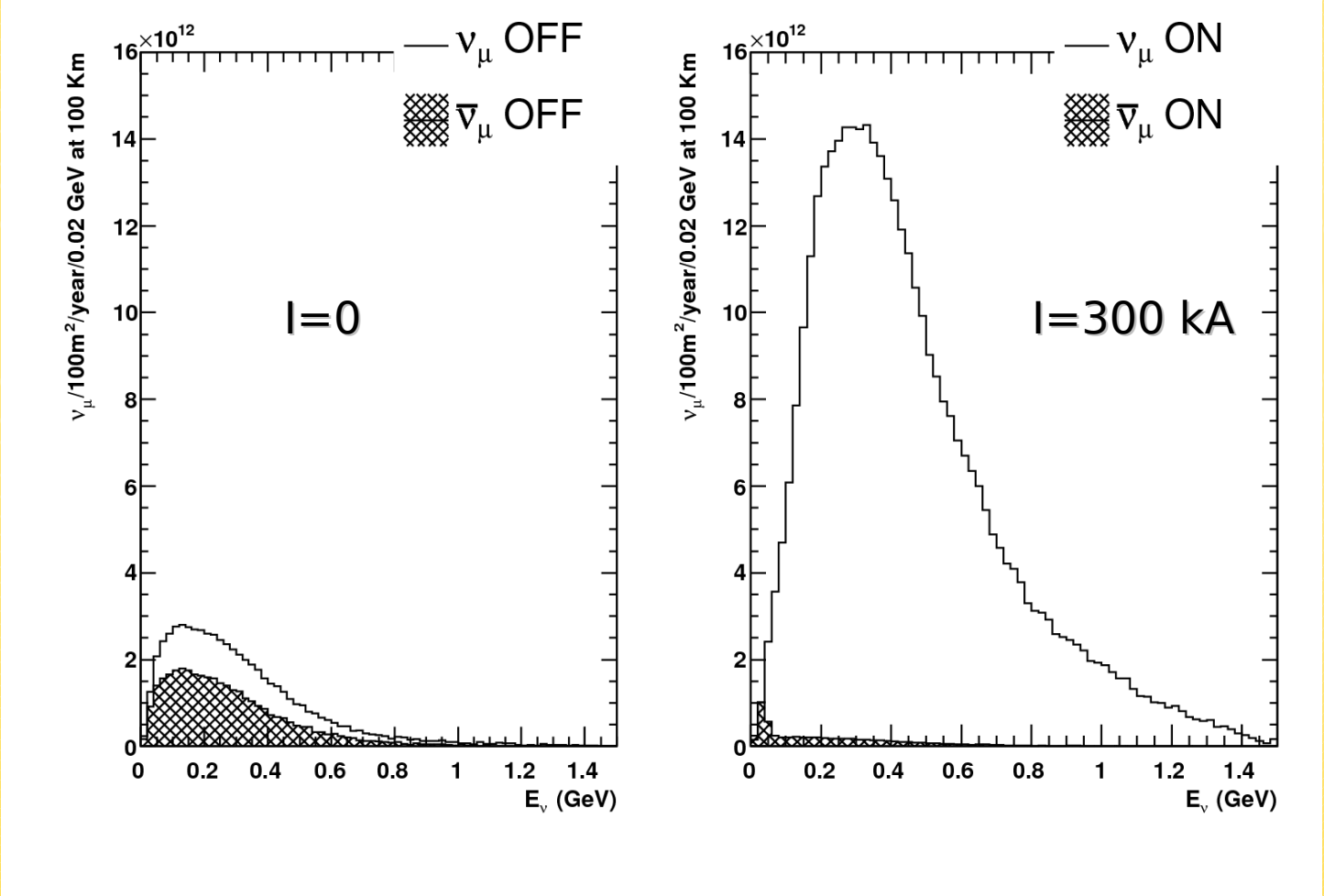
Sensitivity stays approximately constant if, when increasing the conductor's inner radius, the current is increased accordingly (B~i/r)

300 kA – 1.2 cm (~ integrated target) chosen as baseline

Optimised horn: focusing power (I)

ν_μ enhancement: x 6.5

$\bar{\nu}_\mu$ suppression: x 5.4

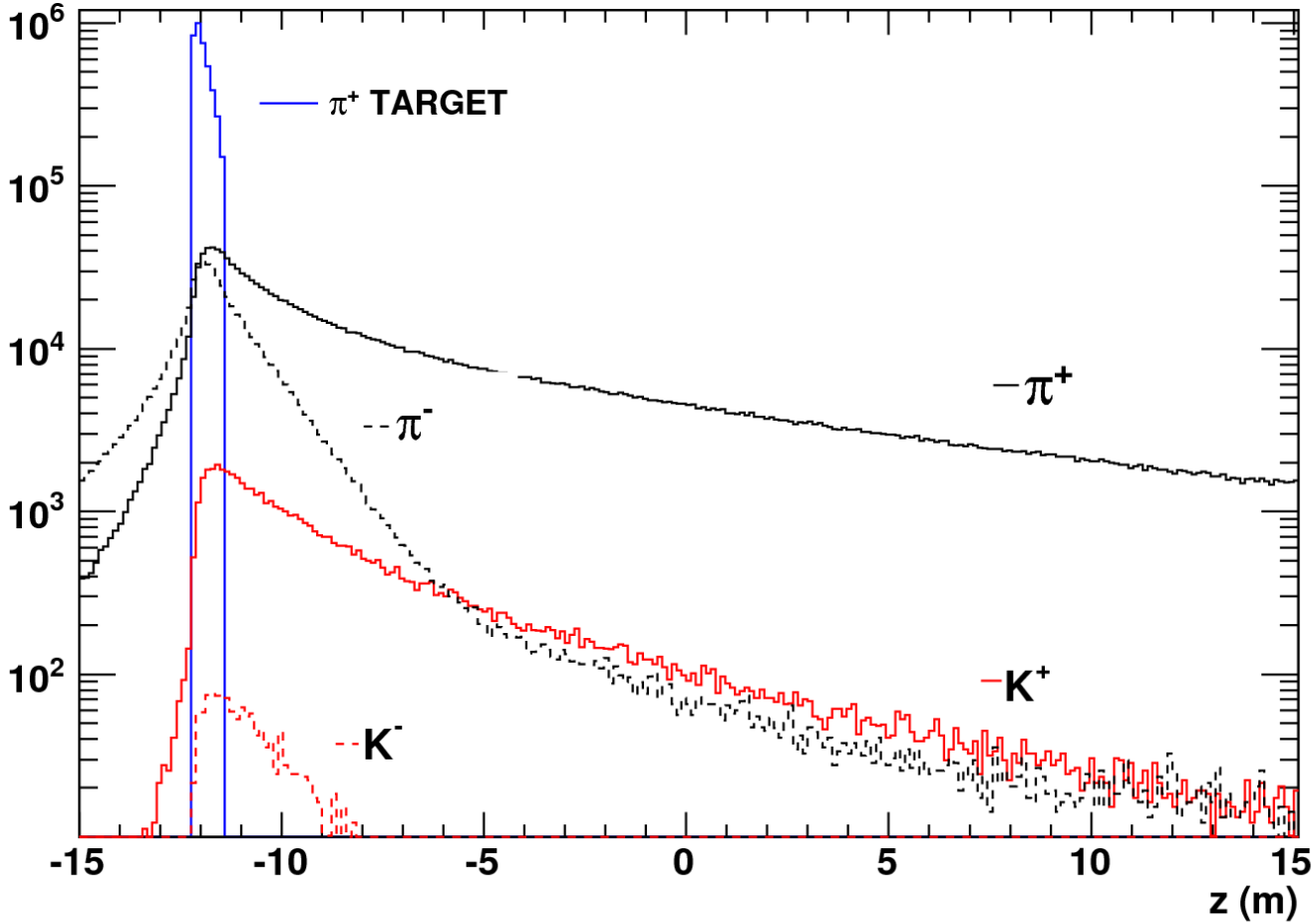


Optimised horn: focusing power (II)

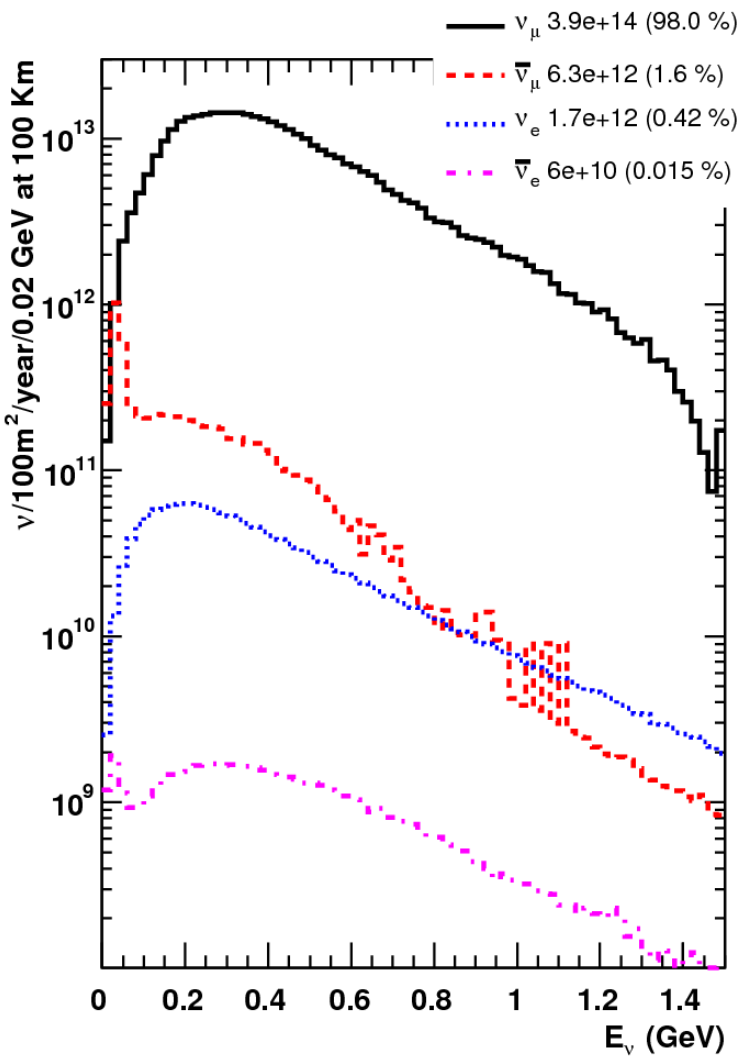
z-coordinate of $\pi^{\pm}/K^{\pm}$ decays in flight
positive focusing mode

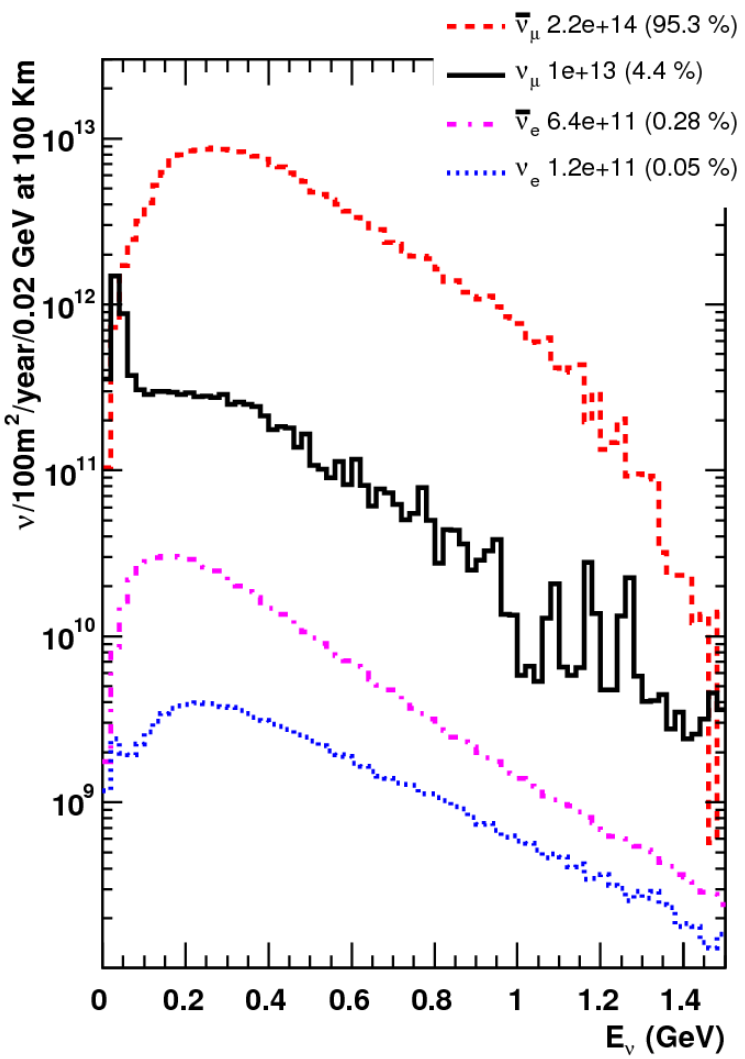
Visible differences:

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



Optimised horn: fluxes

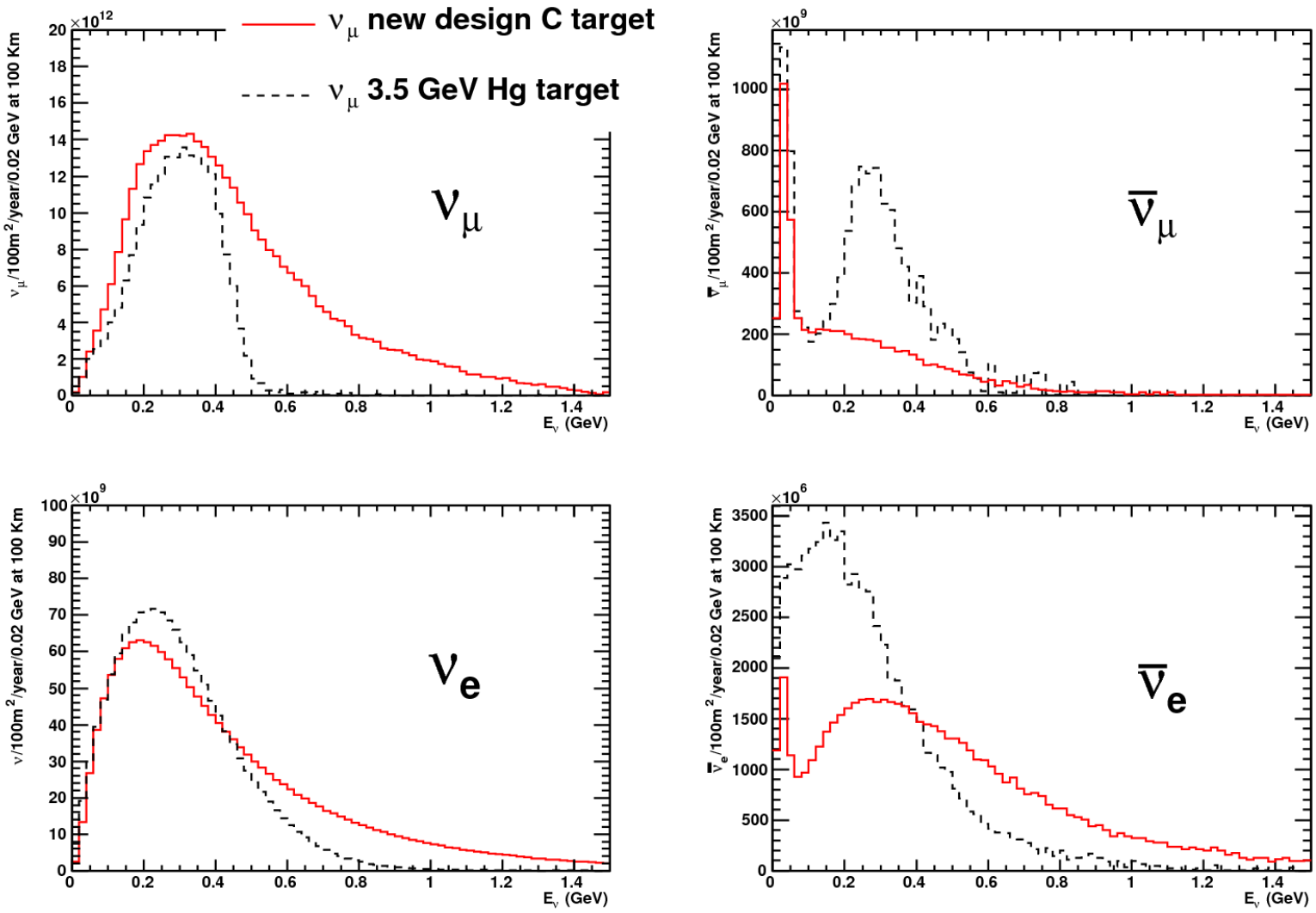




Fluxes in GloBES format are available online here:

http://irfu.cea.fr/en/Phocea/Pisp/index.php?id=54

Comparison with the previous fluxes



+ focusing

Higher ν_μ flux, higher mean energy:

baselines of 200 km do better than 130 Km

Improve for 130 Km going off-axis ? Tried, not a significant gain.

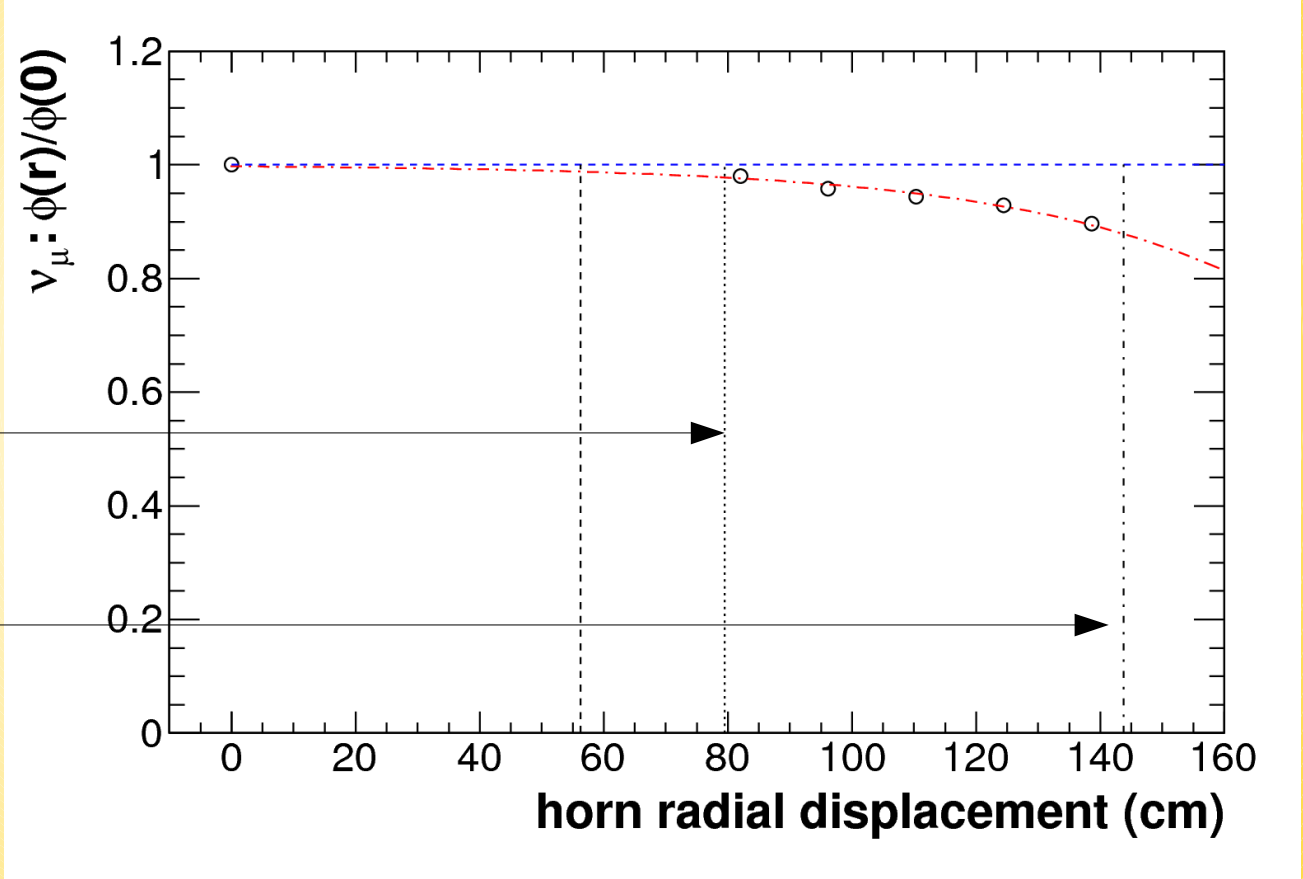
Component from wrong CP suppressed.

4-horn setup: effect on flux

Horn radius : 56 cm
Tunnel radius: 200 cm

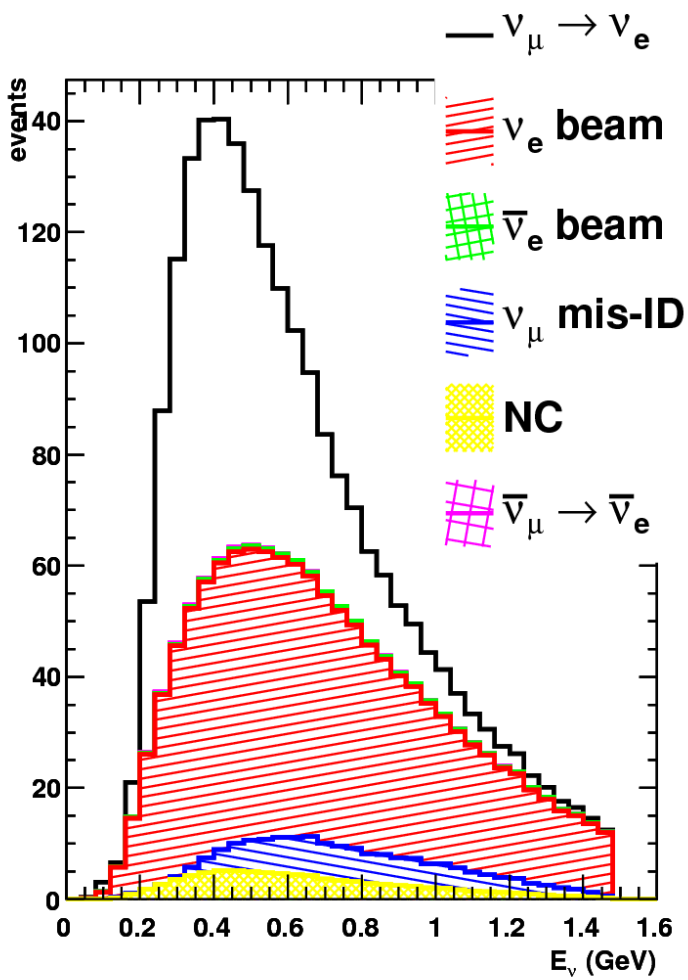
- 4 horns in contact (minimum possible displacement): 1-2 % loss

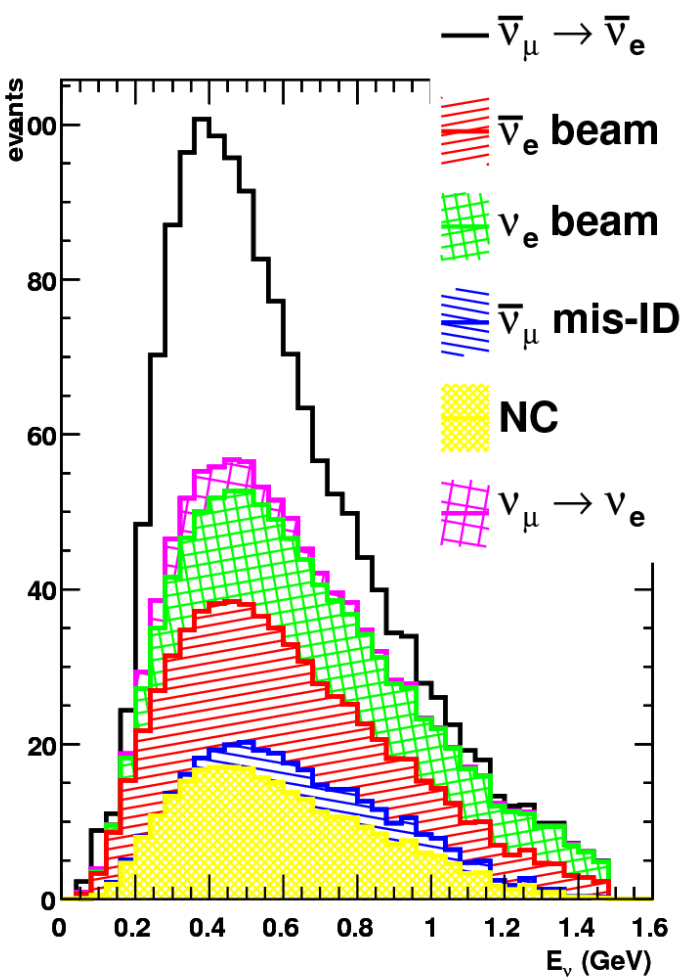
- horns touching the tunnel (most pessimistic assumption): 10 % loss



Event rates in MEMPHYS

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





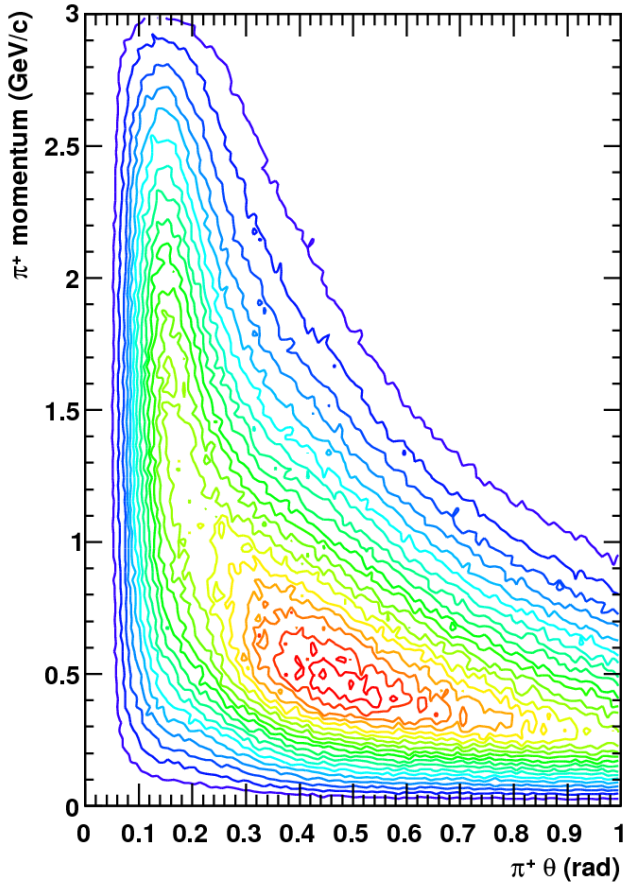
Based on the public MEMPHYS parametrization (AEDL) distributed with GLoBES
Bulk of the background from intrinsic beam electron component

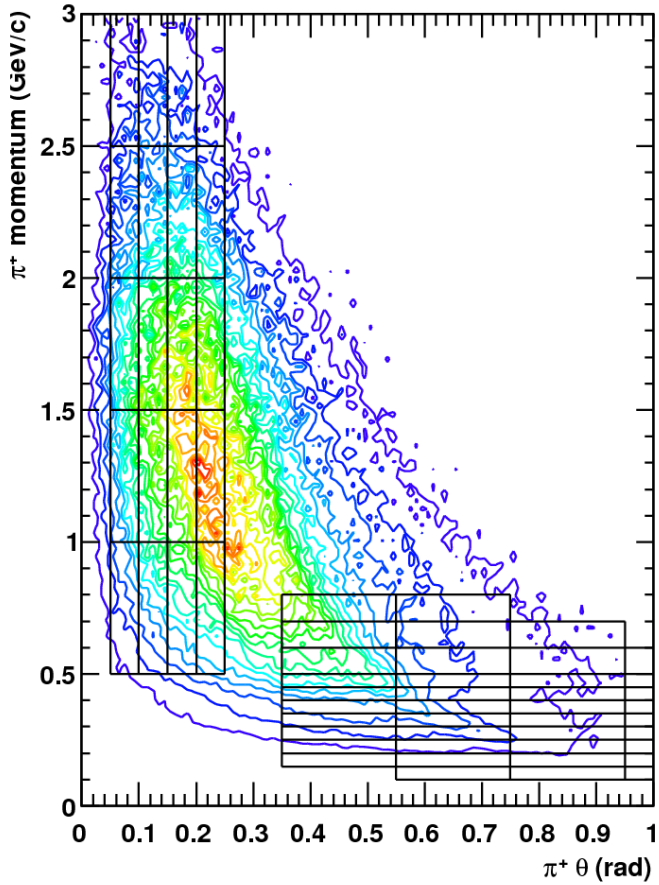
Hadro-production uncertainty: π phase space

At target exit

P VS θ in bins of E_ν

weighted average, $w_i = E_{\nu i}$



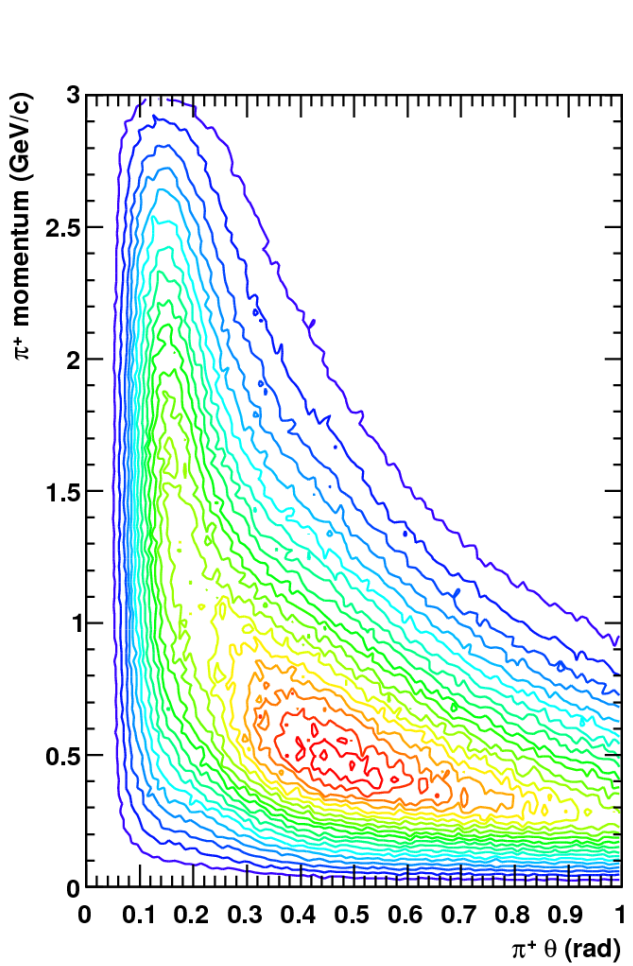


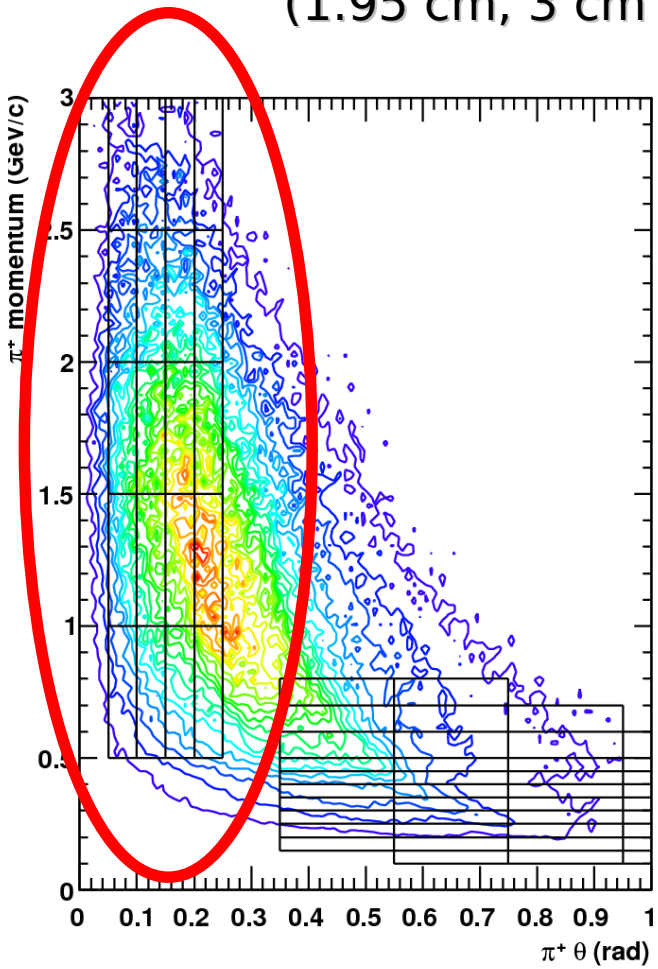
Weights according to the contribution to the neutrino flux

Hadro-production uncertainty: π phase space

At target exit

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

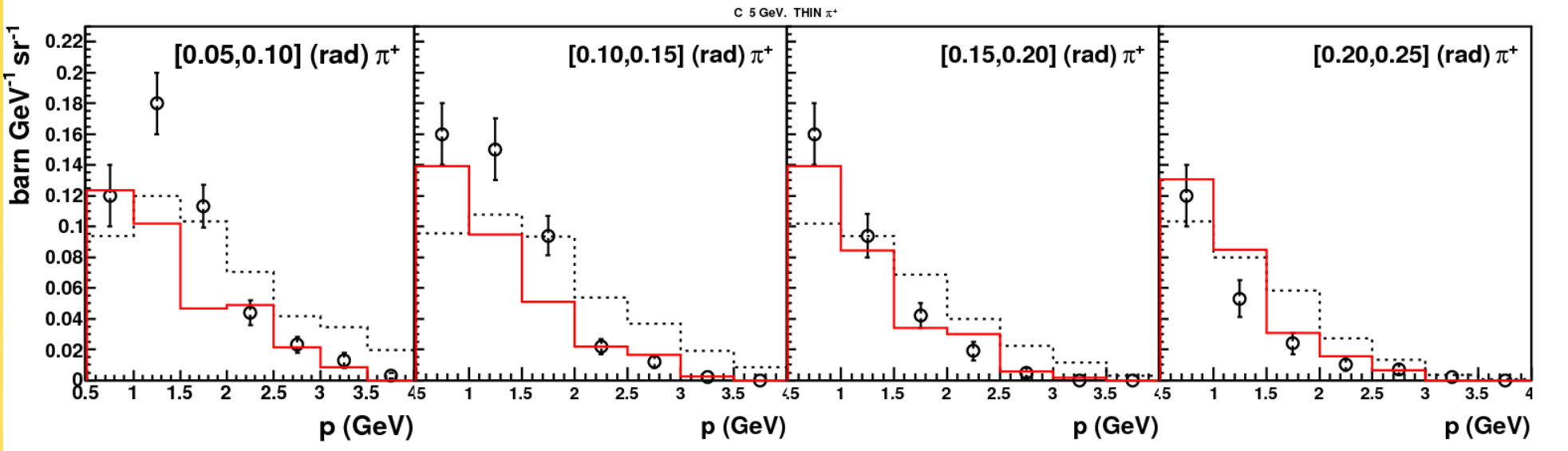




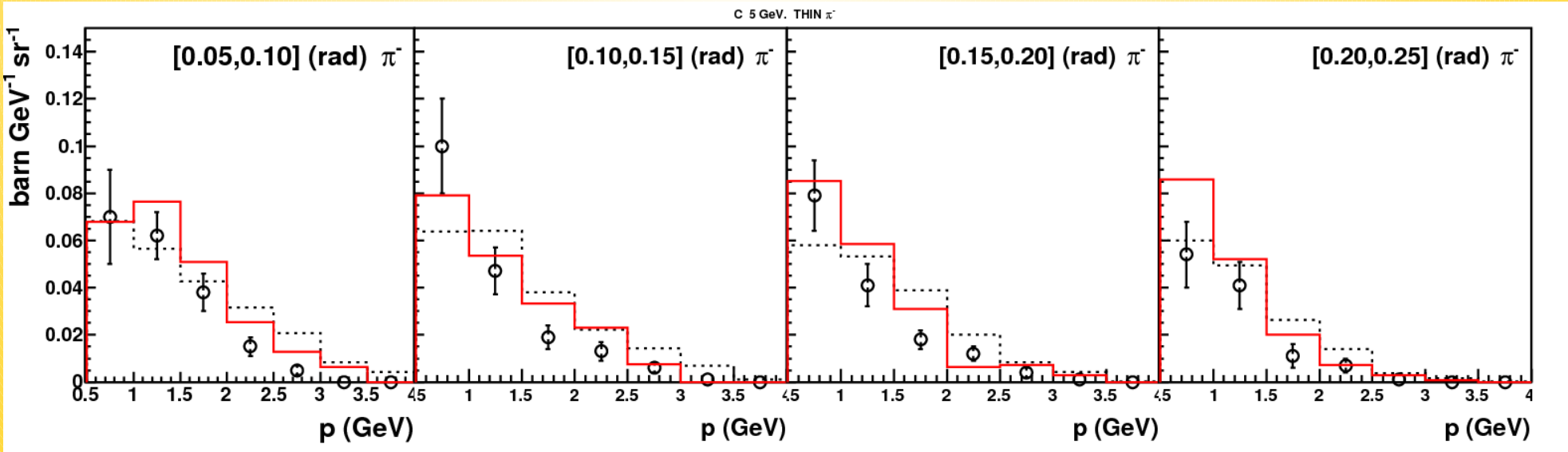
Weights according to the contribution to the neutrino flux

HARP data vs models

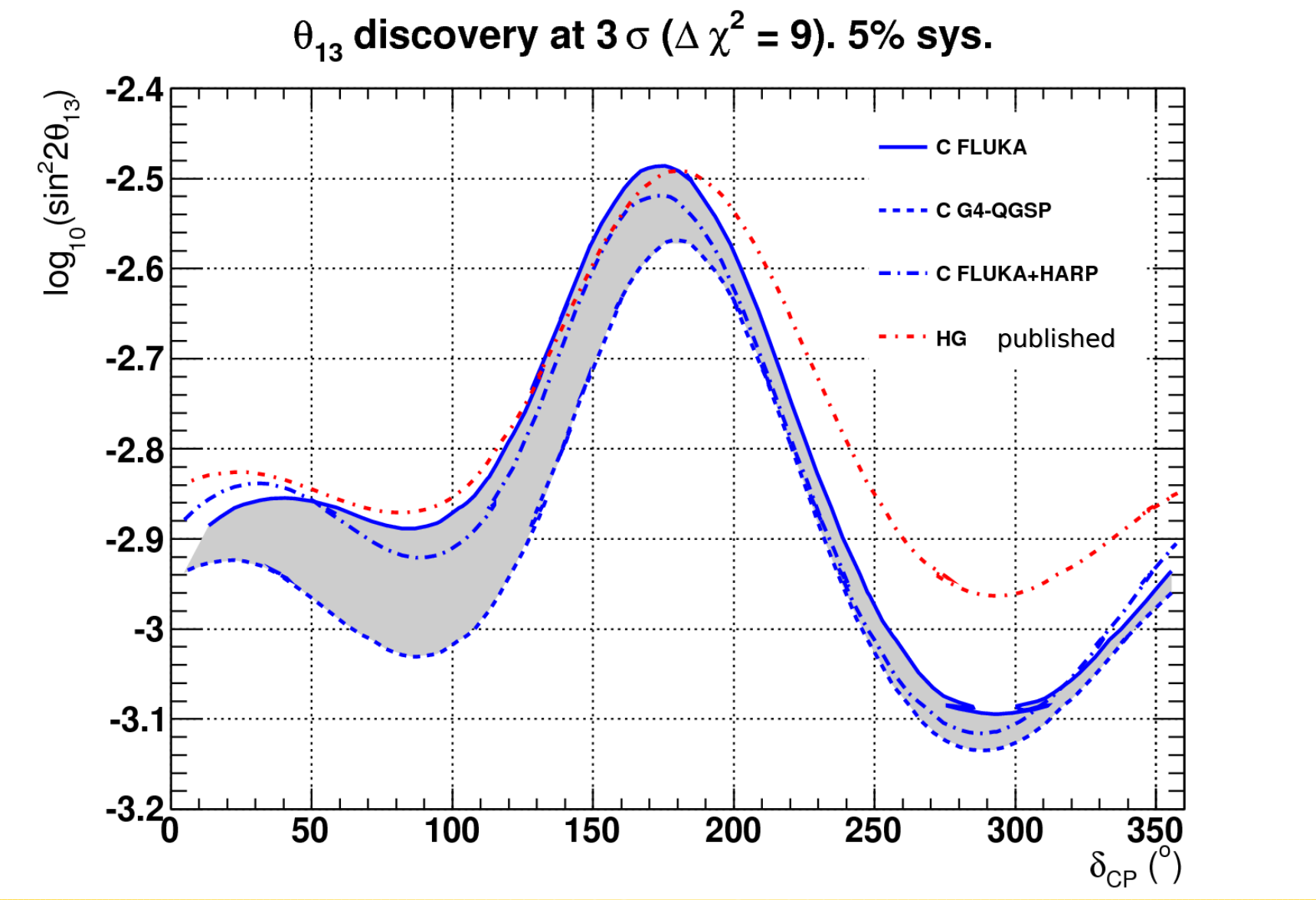
π^+



π^-

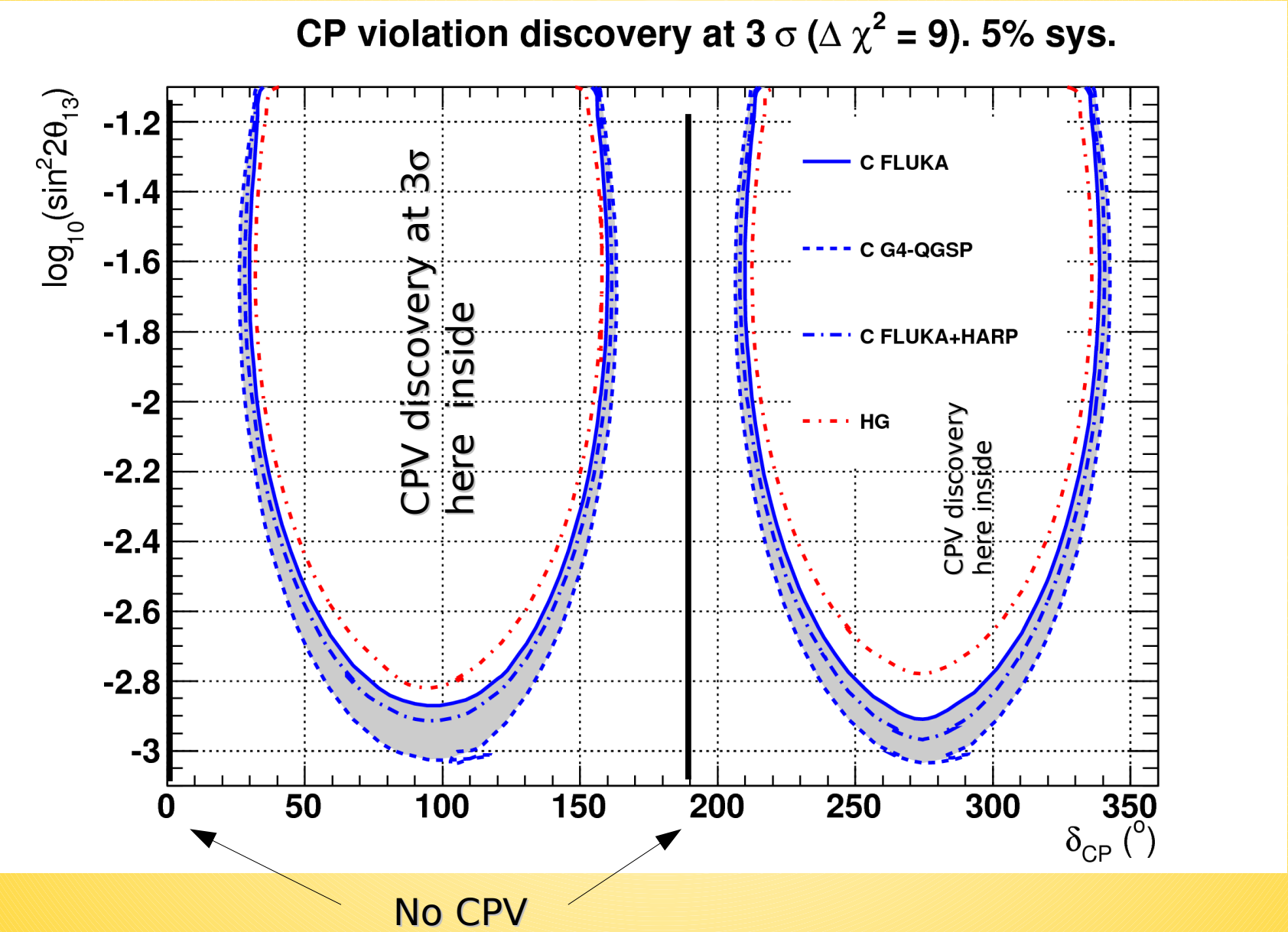


Discovery of $\theta_{13} \neq 0$



Using GEANT4 for p-target interactions or reweighting FLUKA to HARP data yields better limits

Discovery of CP violation



Physics performance with alternative designs

Mechanical/cooling analyses done in WP2 evidenced several weak points for

a) an integrated target horn system (a.k.a. “hornet”)
b) a monolithic (long) cylindrical target

Two alternatives recently tested under the point of view of physics reach:

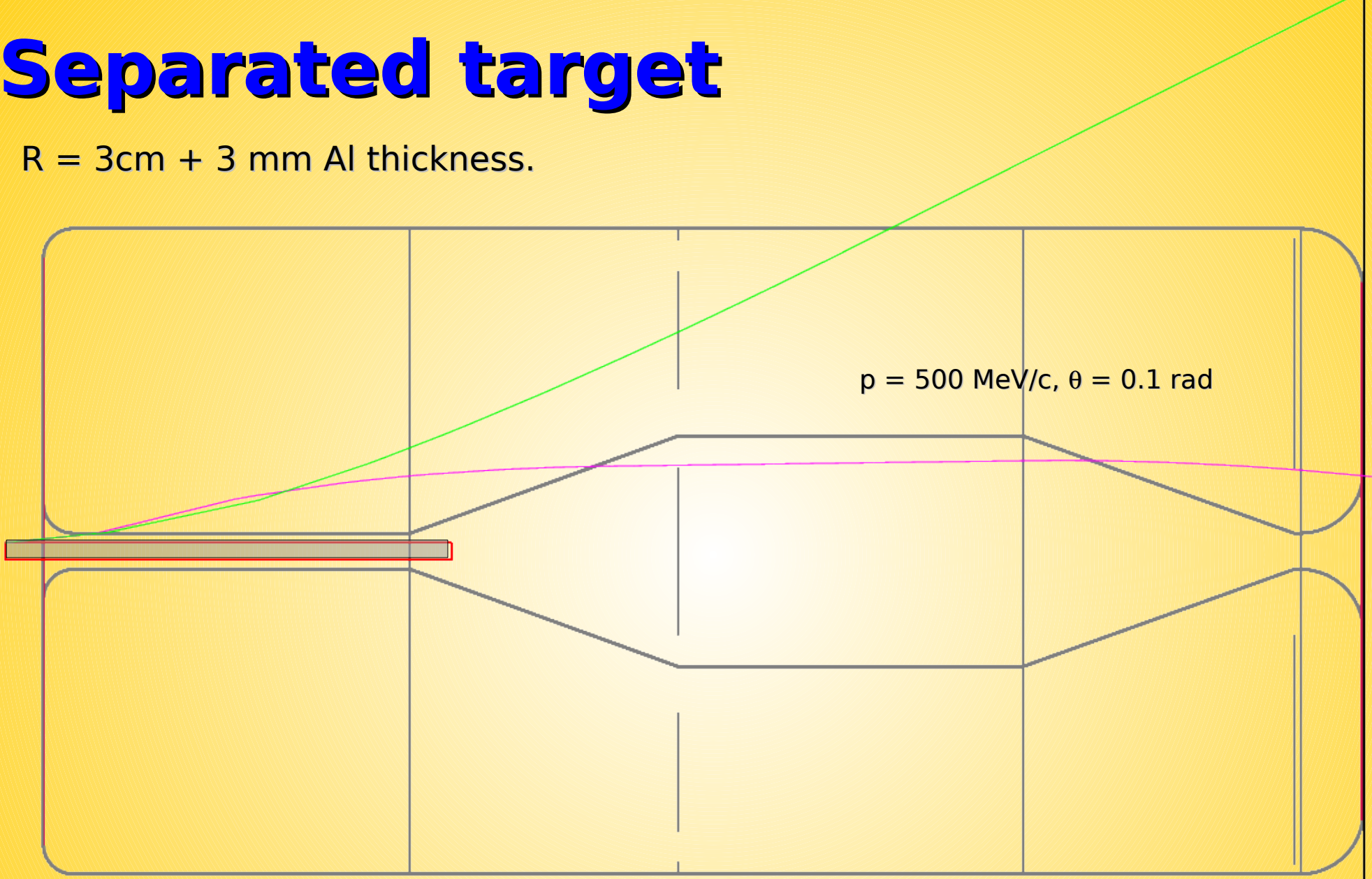
1) a separated horn-target system
2) a packed pebble bed Titanium target

Handle to keep good performances: increase in the horn current
Compensation of larger inner radius and/or reduced density

--- more details in my presentation of yesterday at WP2 // meet. ---

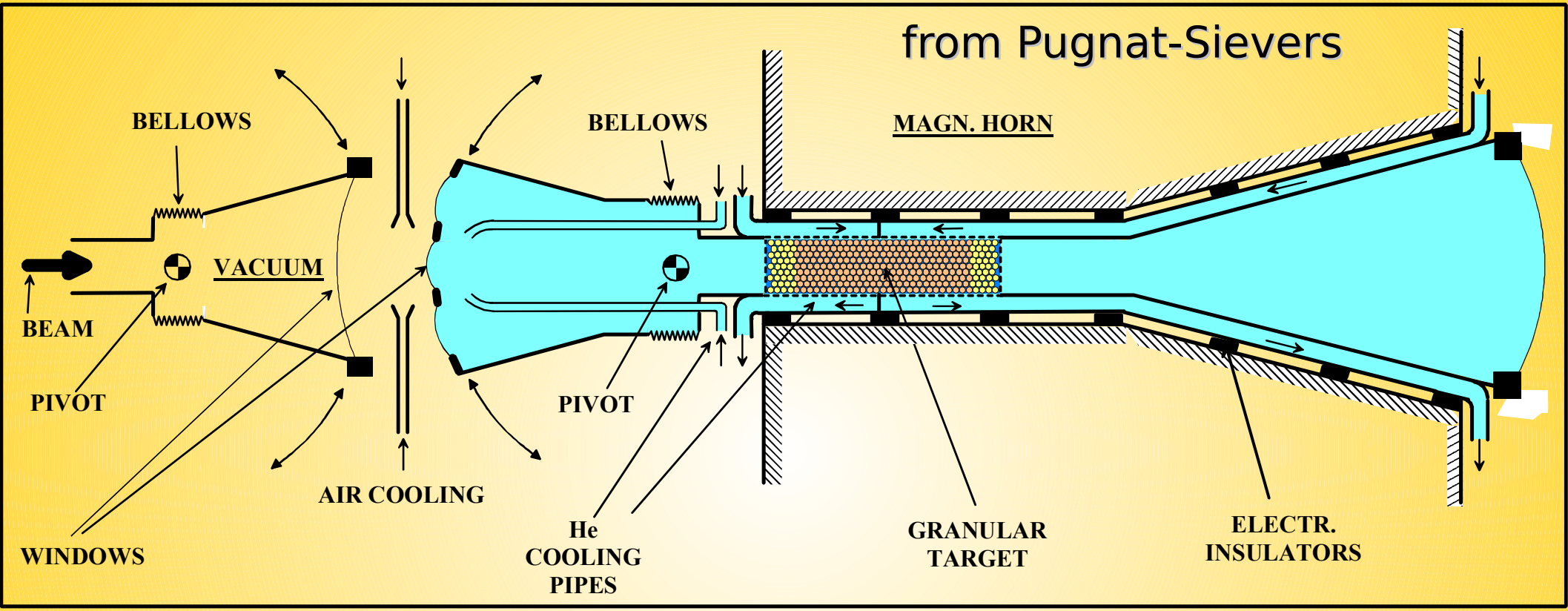
Separated target

R = 3cm + 3 mm Al thickness.



R = 3 cm: room for the target cooling system

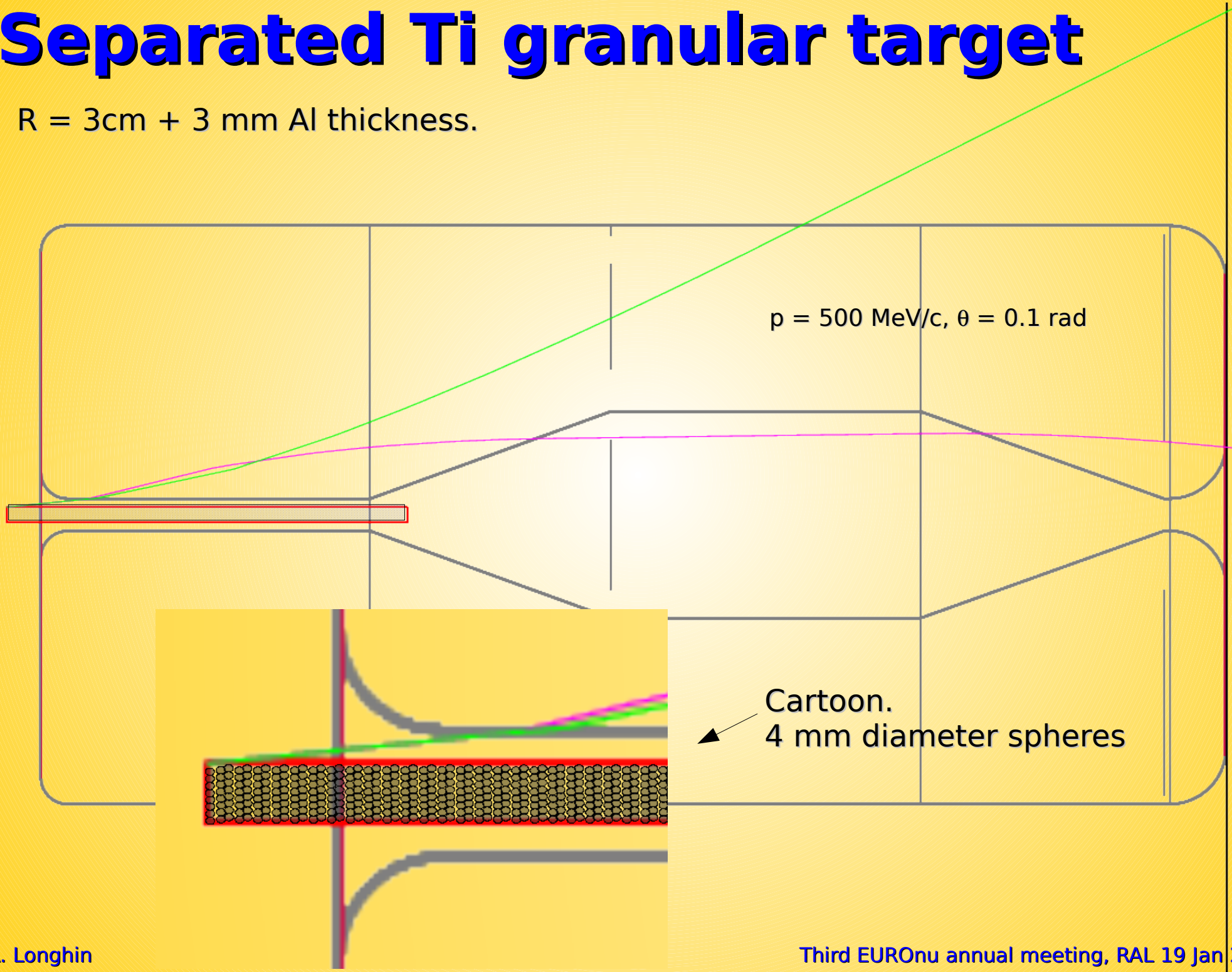
He-cooled stationary granular target



- For simplicity homogeneous Ti target with reduced density (74 %) in FLUKA
- Density reduction assumes “central packing” of the spheres (optimal one).
- Possibly optimistic and problematic (holes!)
- From the early results correcting for a more realistic values (random packing ~ 67 %) will not substantially change the conclusions

Separated Ti granular target

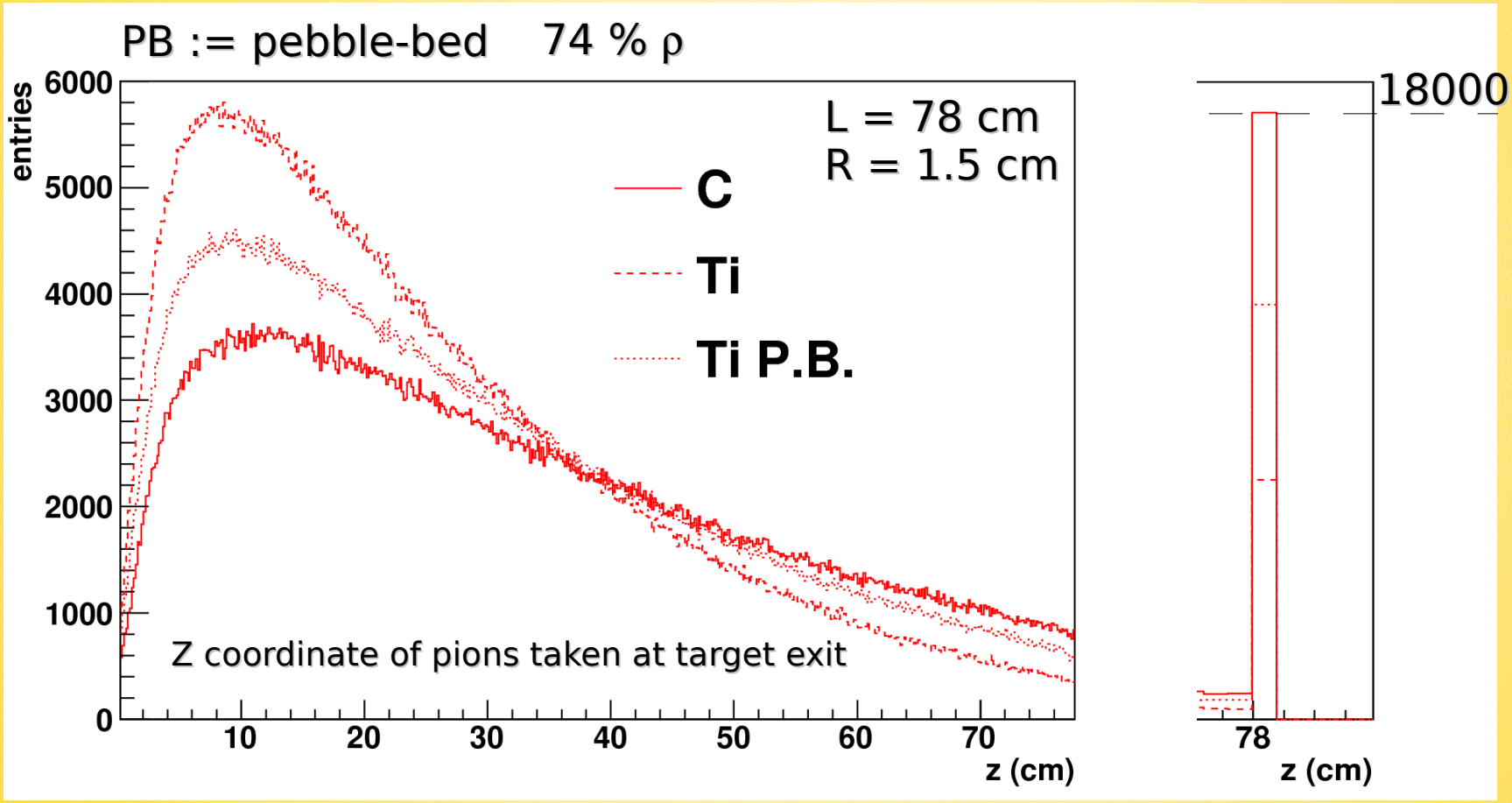
R = 3cm + 3 mm Al thickness.



Pion production comparison (FLUKA)

$\rho(Ti) = 4.506\ g/cm^3$
$0.74\ \rho(Ti) = 3.336\ g/cm^3$
$\rho(graphite) = 1.85\ g/cm^3$

	Multiplicity		downstr. face
C	1.11 $\pi^{\pm}$/p	+16%	1.6 %
Ti	1.29 $\pi^{\pm}$/p	-8%	1.0 %
Ti P.B.	1.20 $\pi^{\pm}$/p		0.6 %

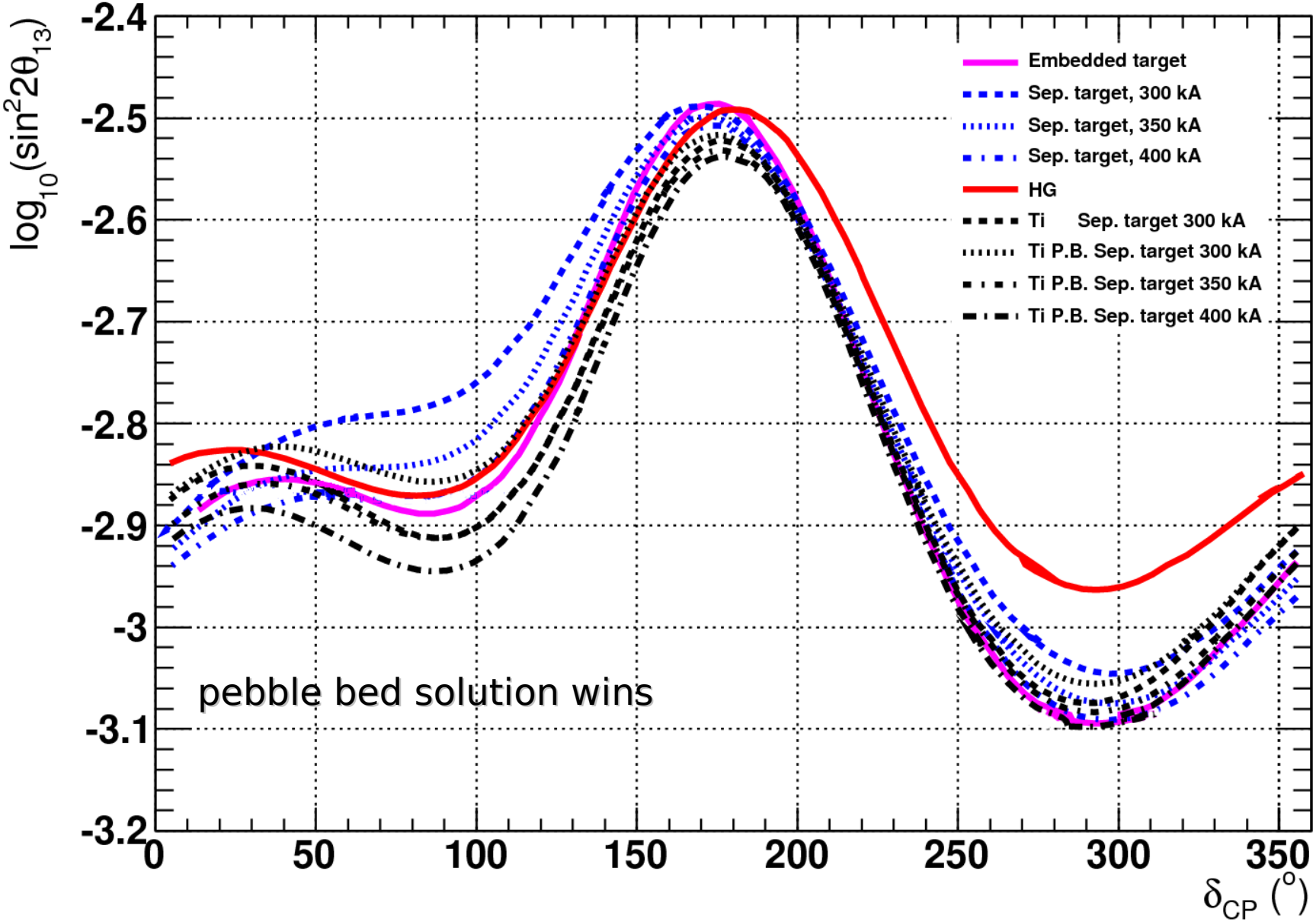


Longitudinal profile with PB "similar" to the graphite one (and more π!)

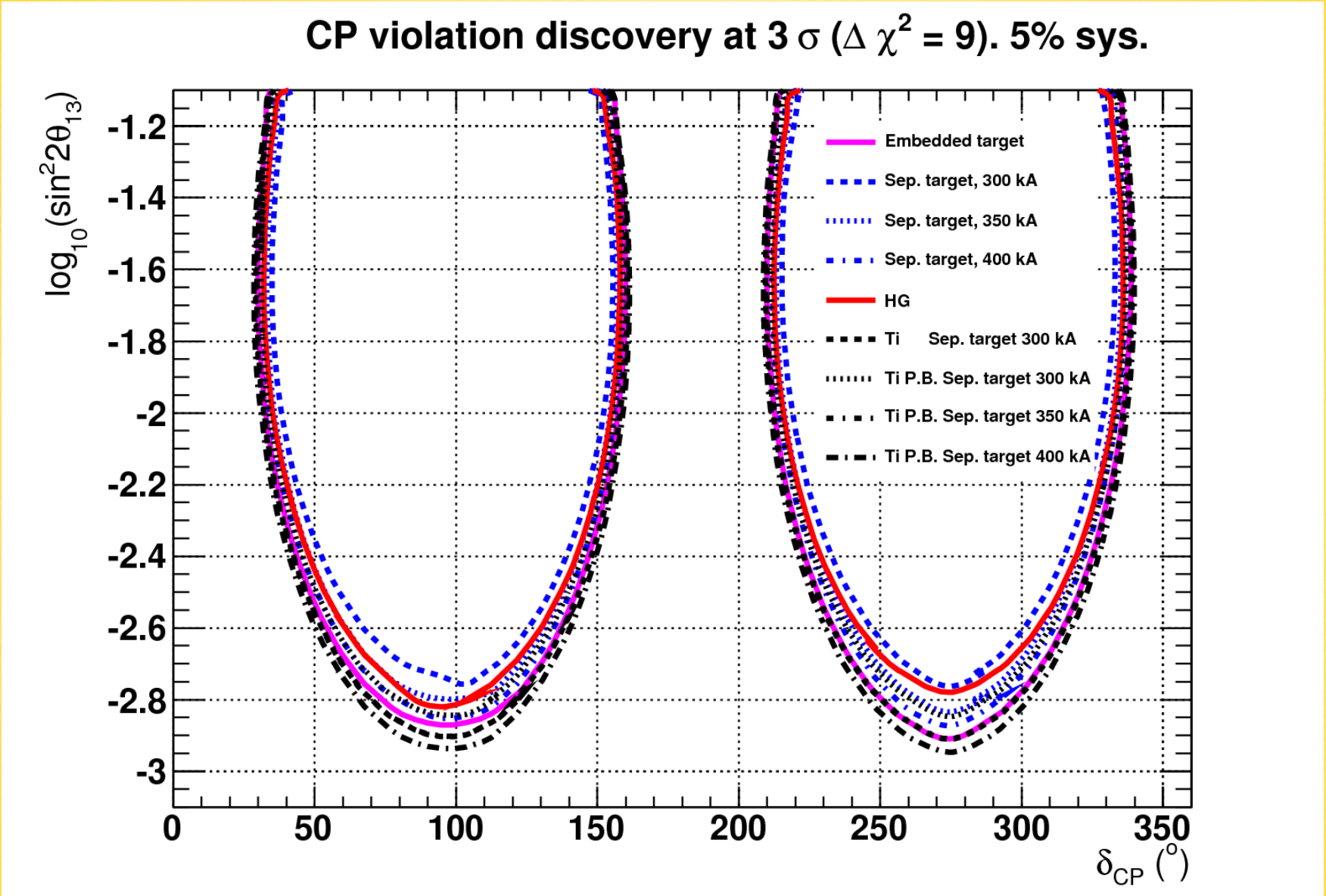
→

The horn should work well

Θ_{13} discovery potential



CP violation discovery potential



Starting from 350 kA the pebble bed solution beats the integrated target design

Conclusions

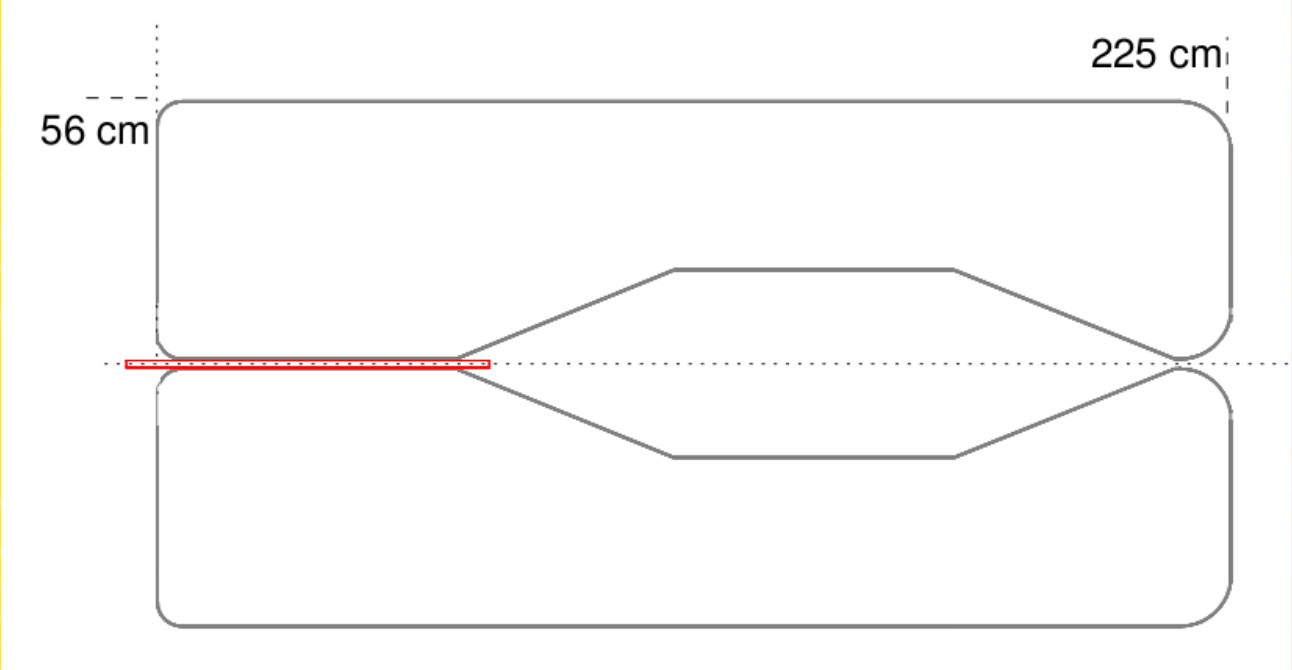
Powerful optimization procedure driven by physics reach based on GEANT4 flux simulation

Liquid mercury target,
horn+reflector (300+600 kA), (r=2 m, L=40 m) tunnel
→
solid Ti pebble bed target
horn only (350 kA), (r=2 m, L=25 m) tunnel
4 in systems parallel

Interplay of physics requirements and feasibility arguments.

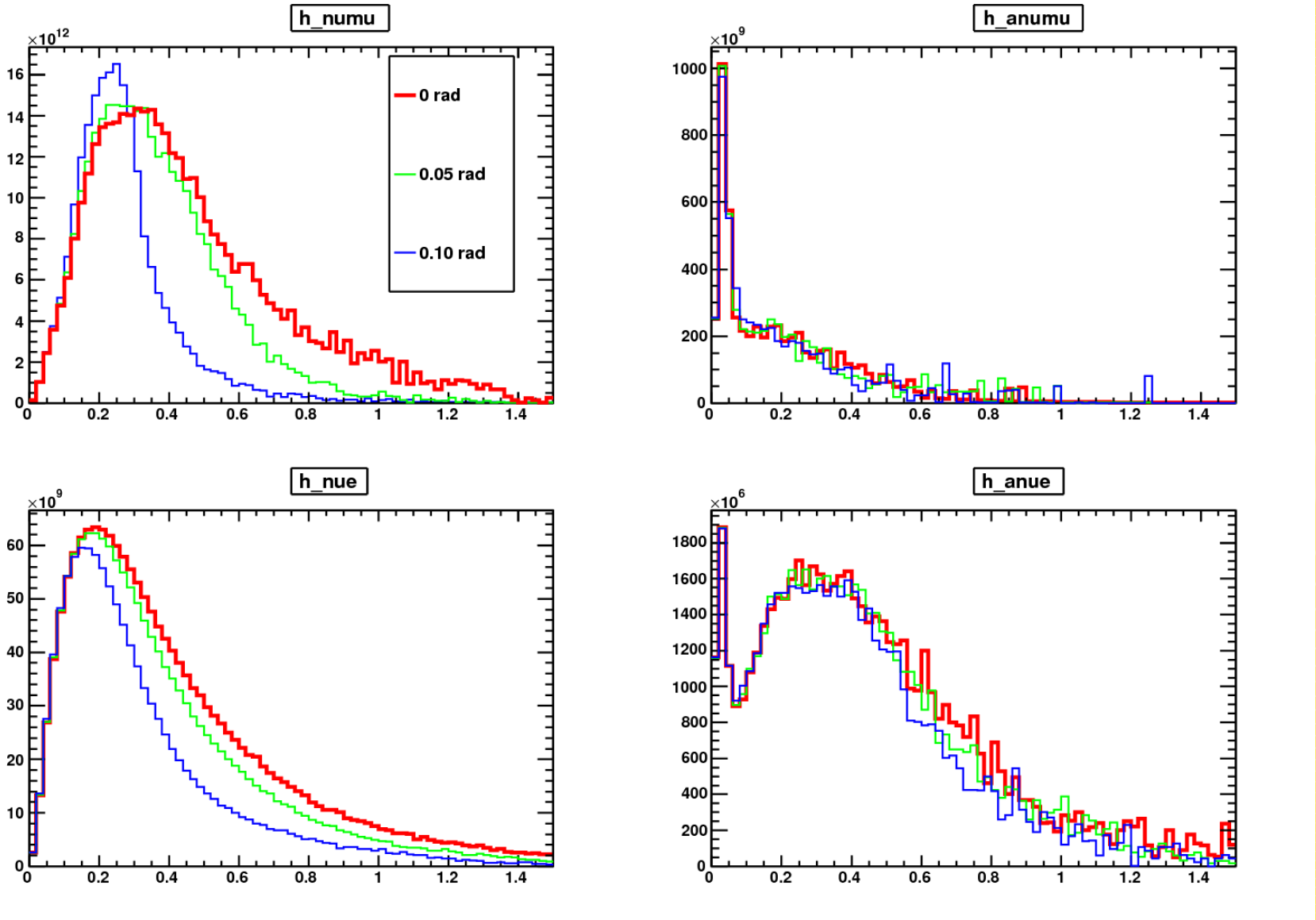
Some simplification in the technical aspects with improved limits on θ_{13} and CP.

Results with an optimized setup



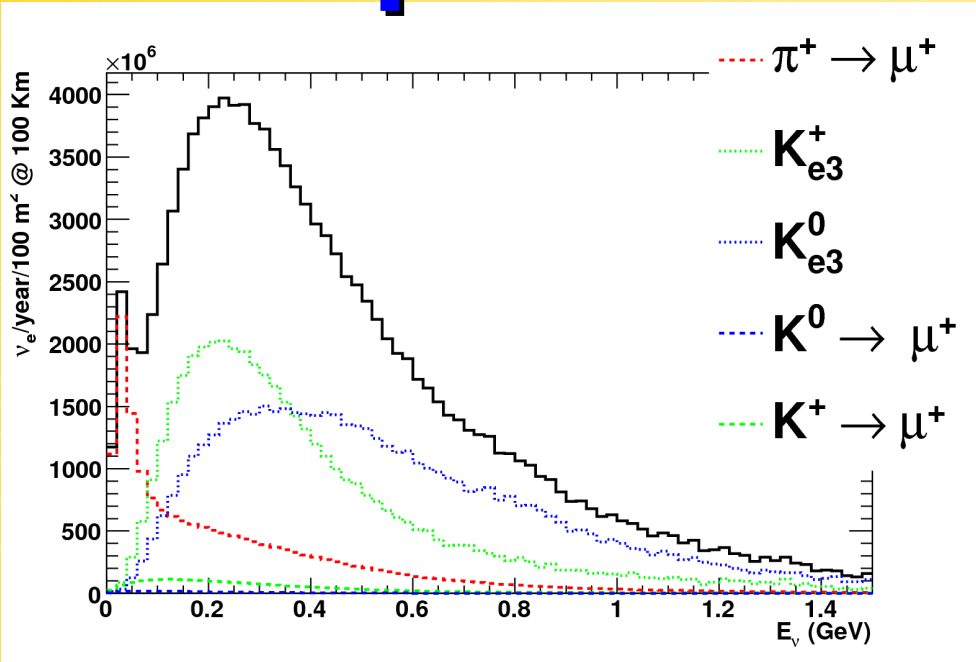
I = 300 kA
integrated target design
tunnel length 25 m
tunnel radius 2 m

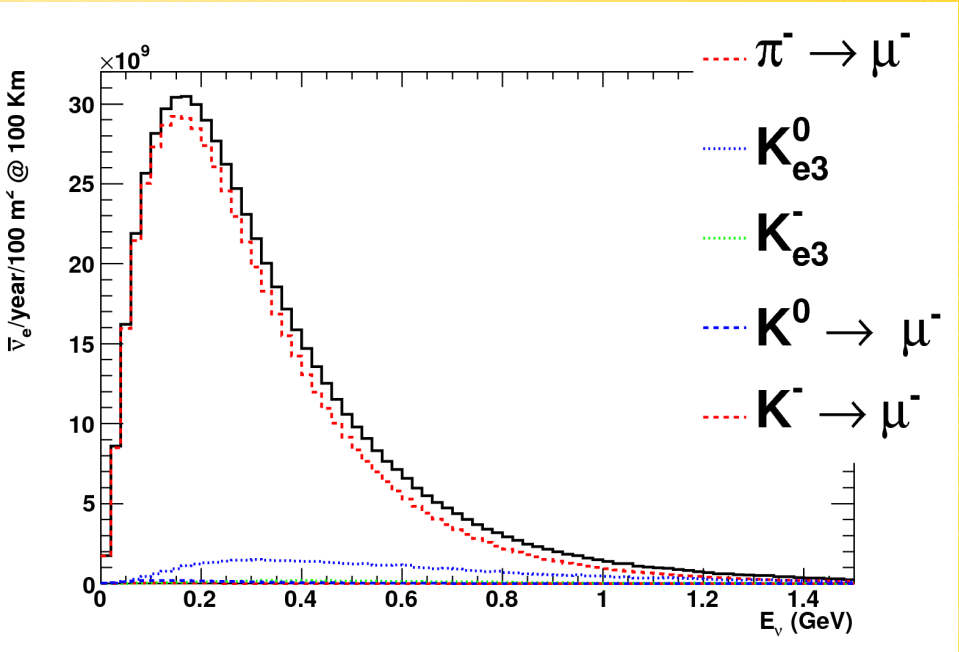
An idea

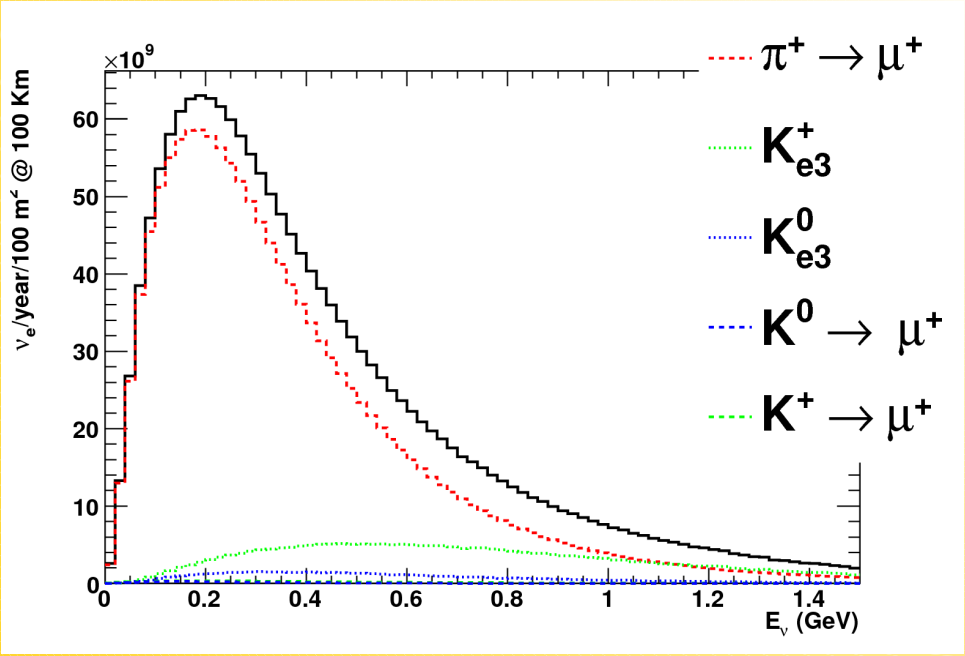


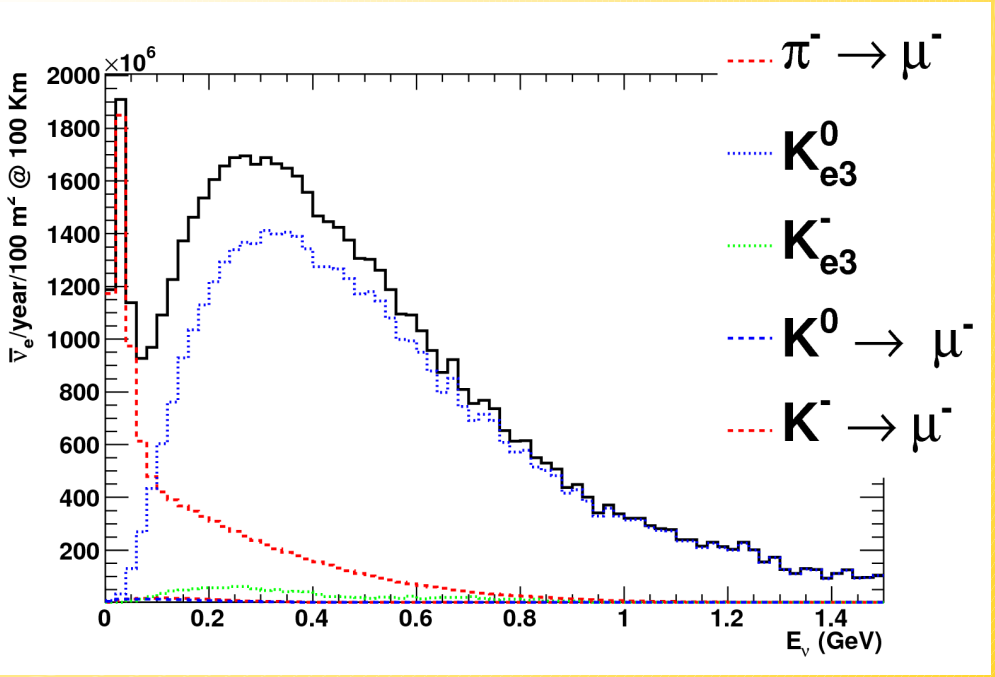
Going off-axis ? Looks promising but not a big gain when sensitivities are compared

Components


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

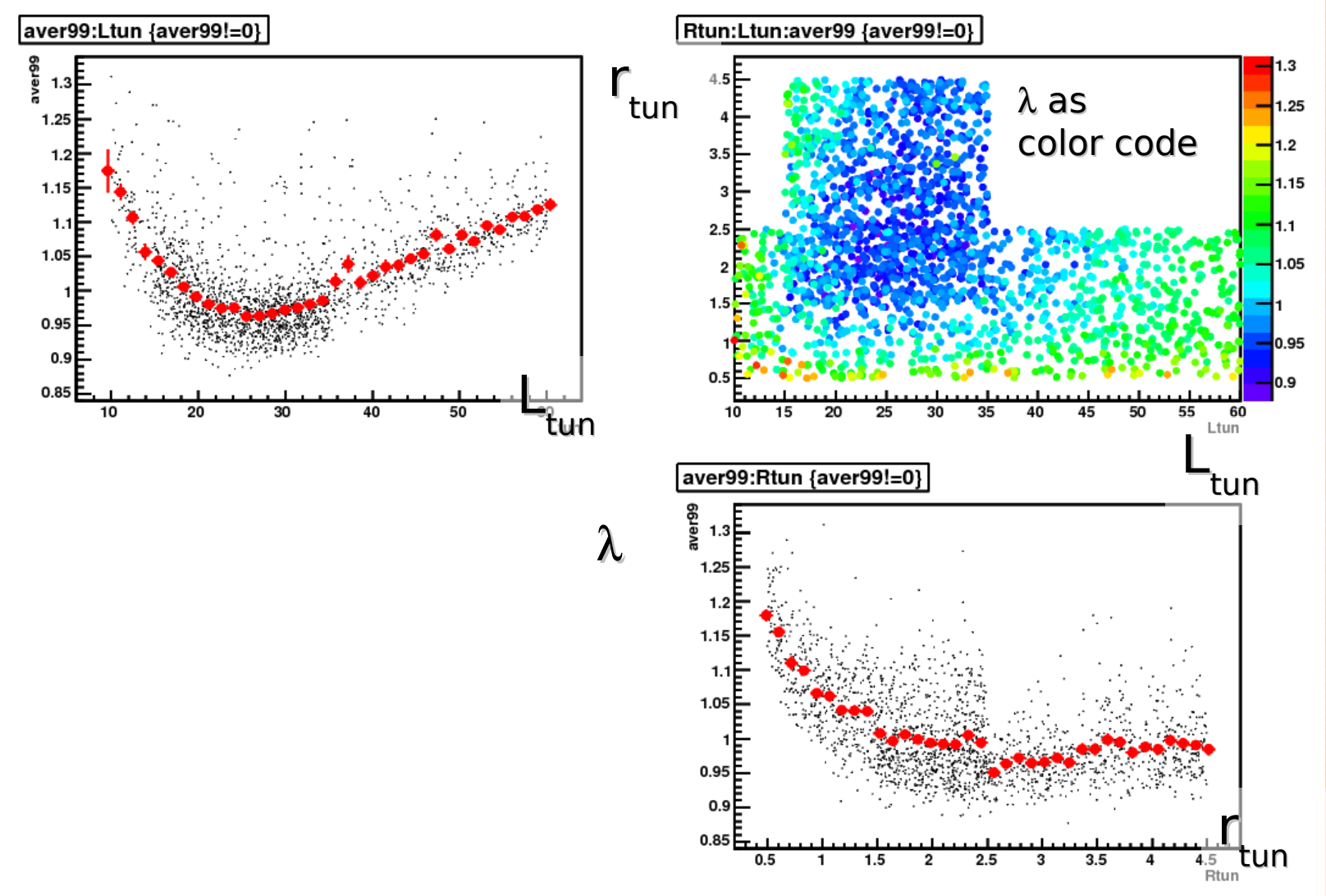

×10^9
ν̄_e/year/100 m^ϵ @ 100 Km
E_ν (GeV)
π- → μ-
K0e3
K-e3
K0 → μ-
K- → μ-

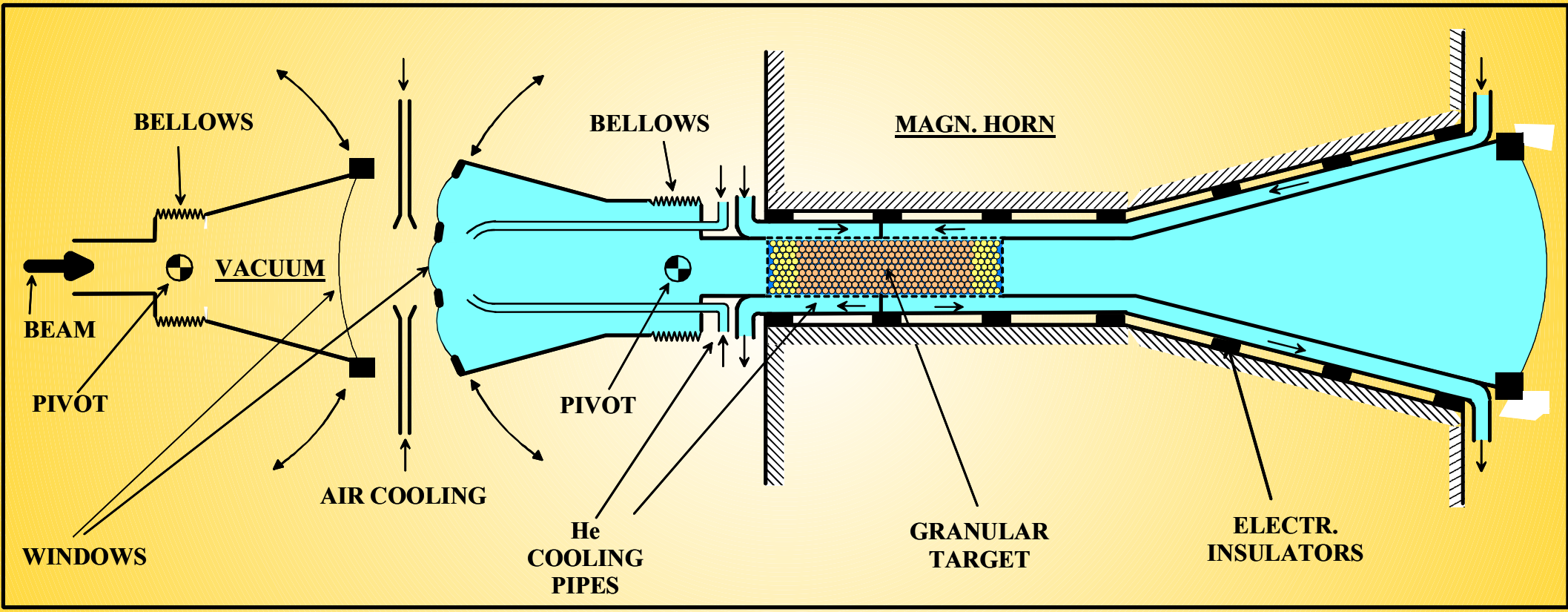

×10^9
ν_e/year/100 m^ϵ @ 100 Km
E_ν (GeV)
π+ → μ+
K+e3
K0e3
K0 → μ+
K+ → μ+


×10^6
ν̄_e/year/100 m^ϵ @ 100 Km
E_ν (GeV)
π- → μ-
K0e3
K-e3
K0 → μ-
K- → μ-

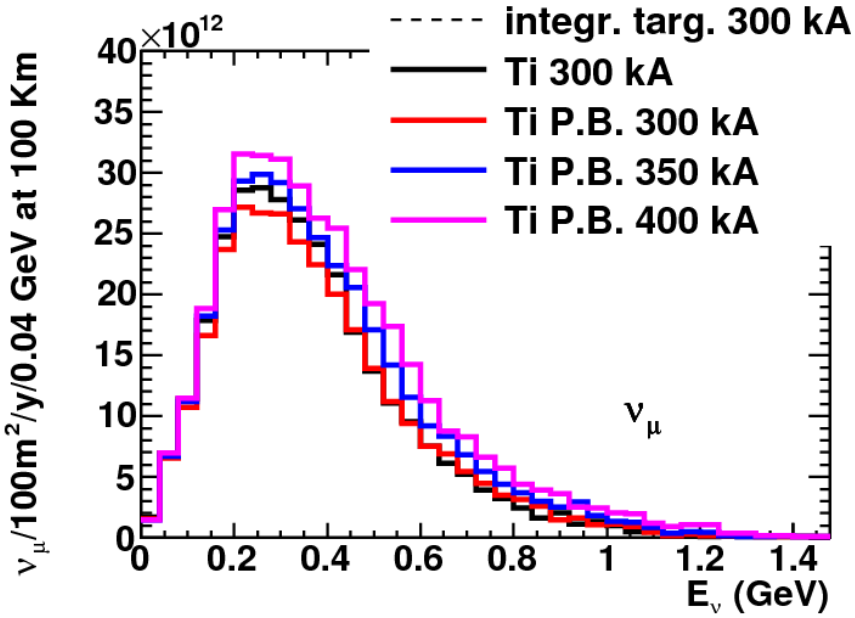
Decay tunnel tuning (iteration-3)

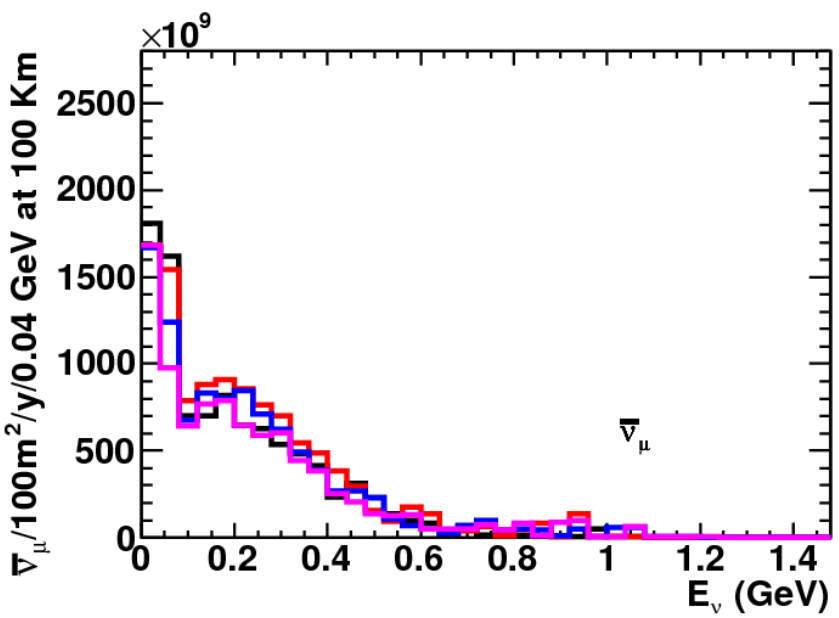
Scan on tunnel length (L_{tun}) and radius (r_{tun})

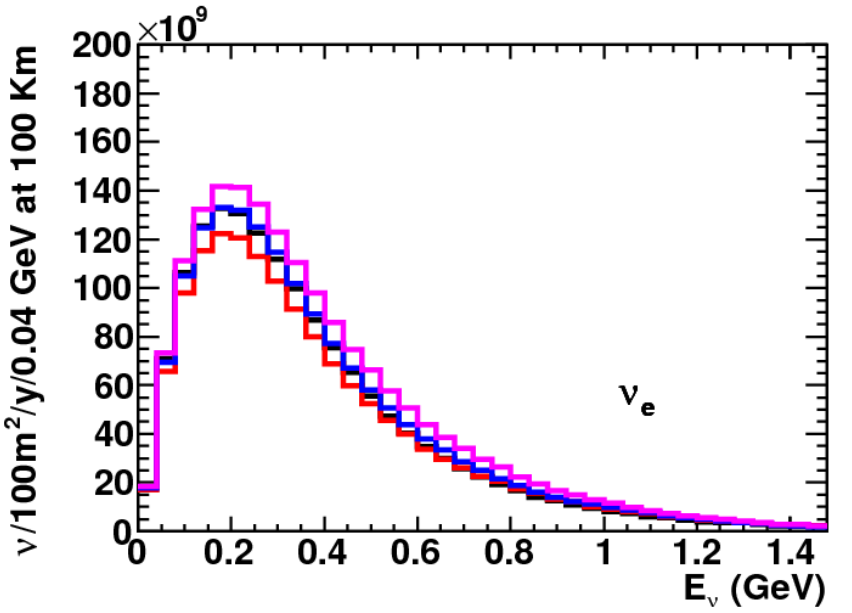


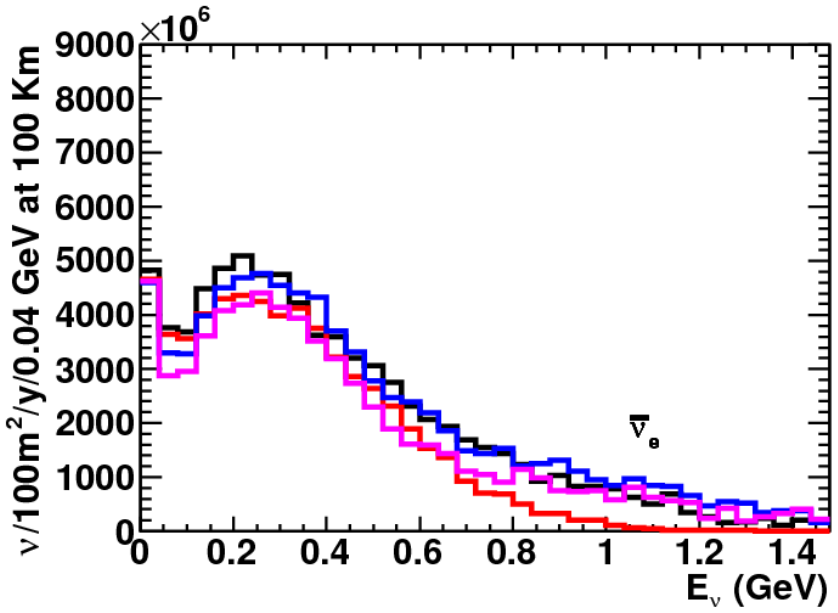

BELLOWS
BELLOWS
MAGN. HORN
VACUUM
BEAM
PIVOT
PIVOT
AIR COOLING
WINDOWS
He
COOLING
PIPES
GRANULAR
TARGET
ELECTR.
INSULATORS

Fluxes summary





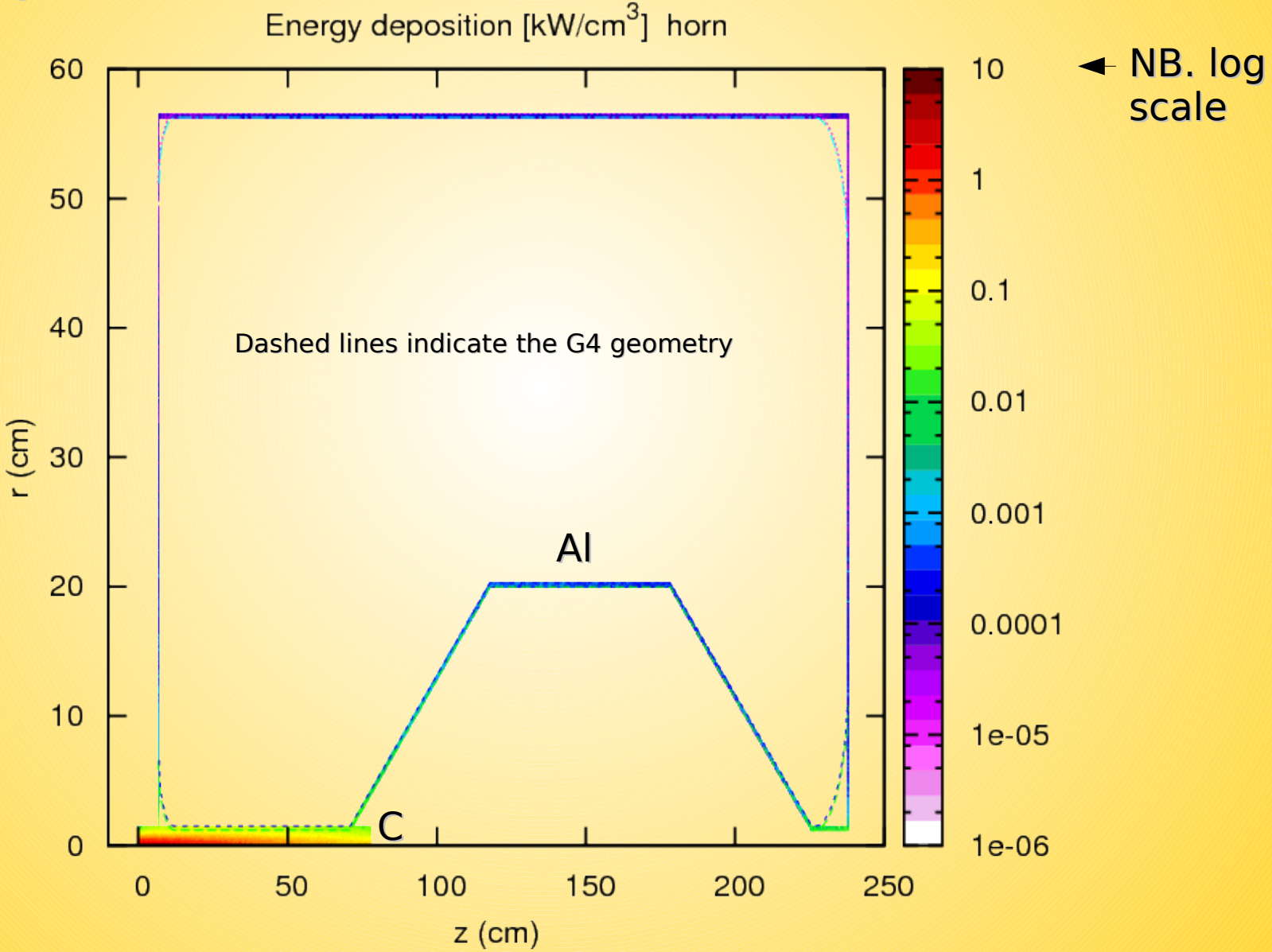




Integrated target

R_1 = 1.2 cm
R^{tg} = 1.2 cm
t_1 = 3 mm Al skin

1.3 MW at 4.5 GeV proton energy. Gaussian beam with σ = 4 mm
Same as in my last presentation.



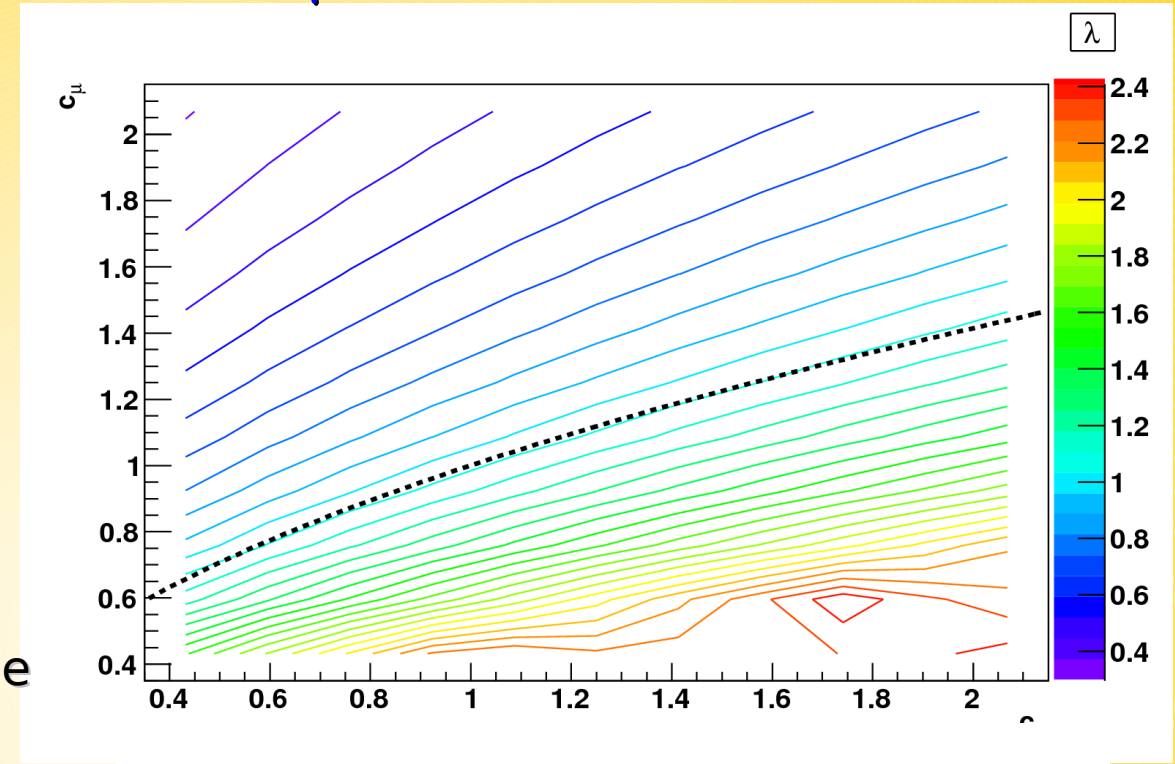
Relation between λ and ν_μ / ν_e fluxes

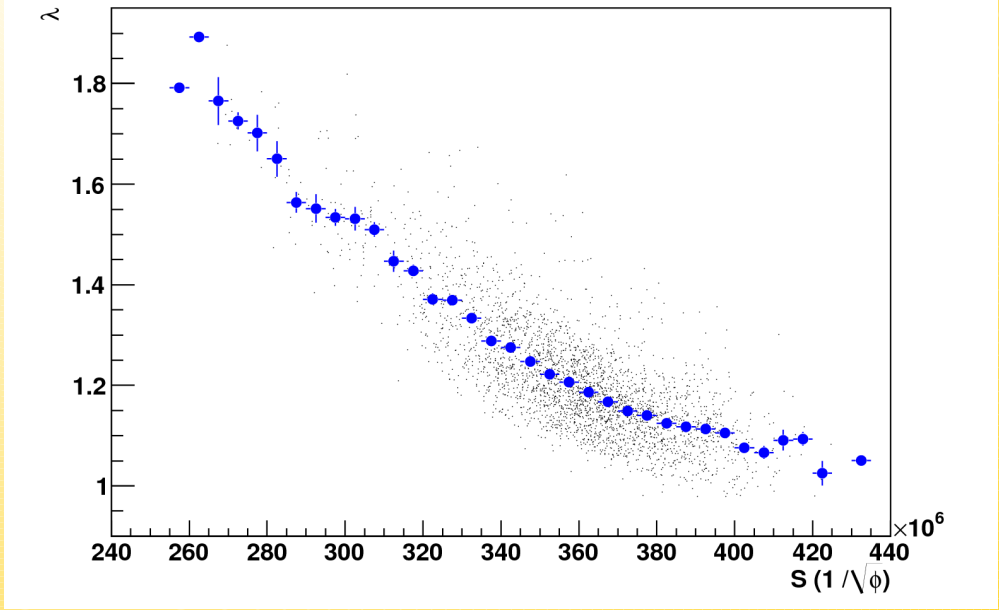
Vary the normalization of numu and nue freely with two independent multiplicative coefficients (c_e, c_μ) in [0.5, 2]

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

The experiment significance : S/√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

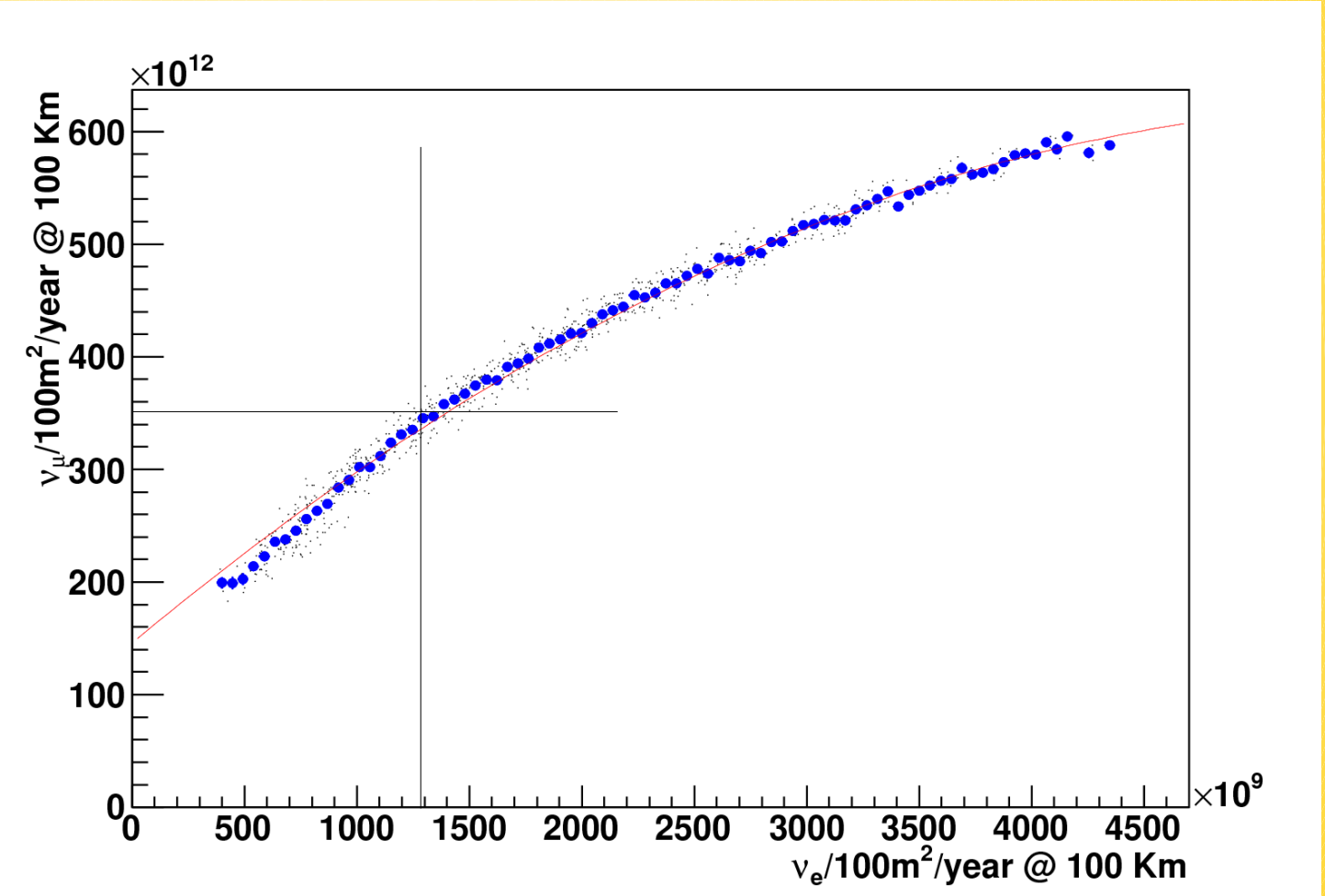




Correlation between ν_μ / ν_e under variation of the tunnel only

Tends to follow a quadratic dependence!

It is not possible to gain much

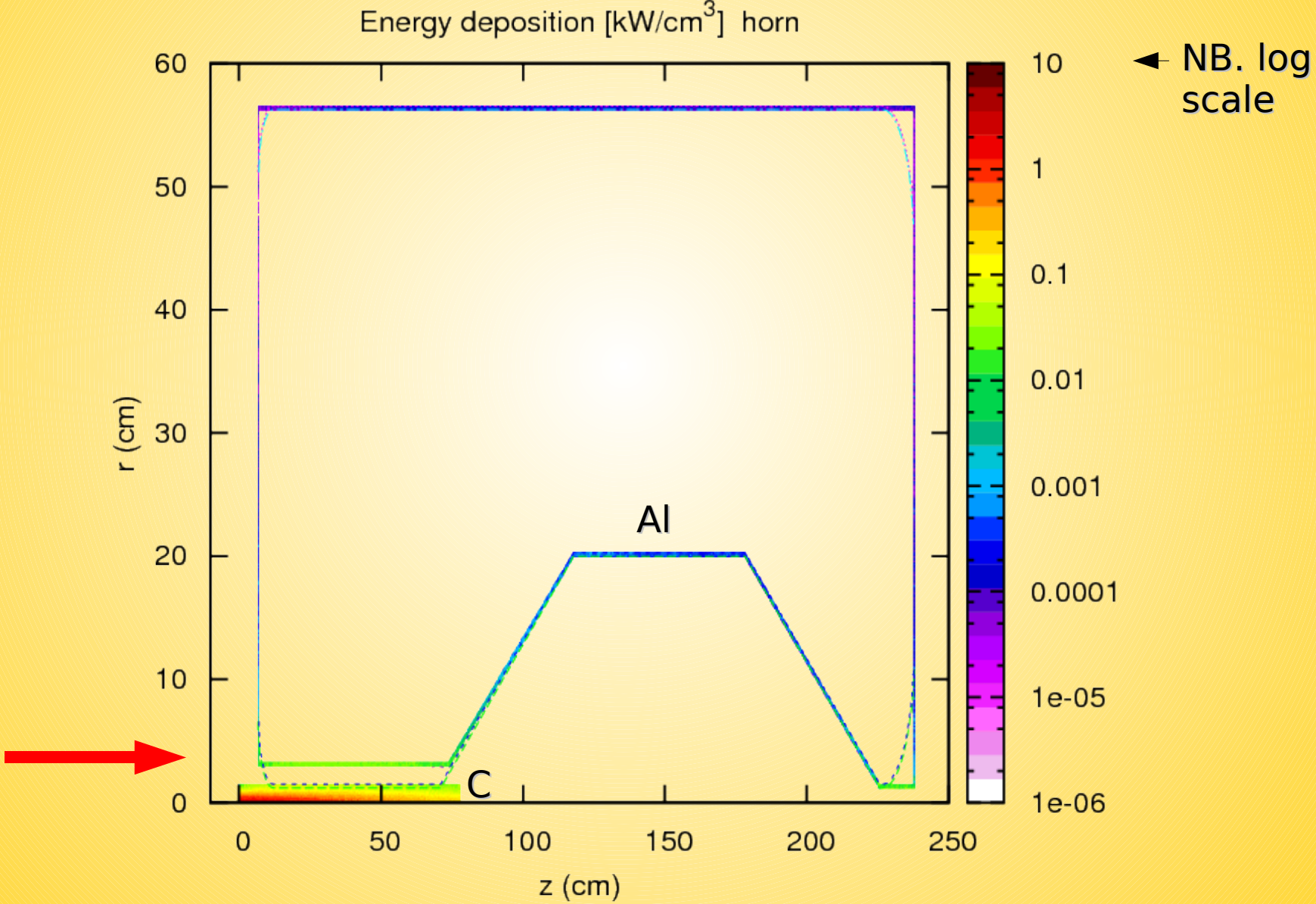


Separated target

R_1 = 3 cm as agreed during the last phone meeting in december

R^{tg} = 1.5 cm

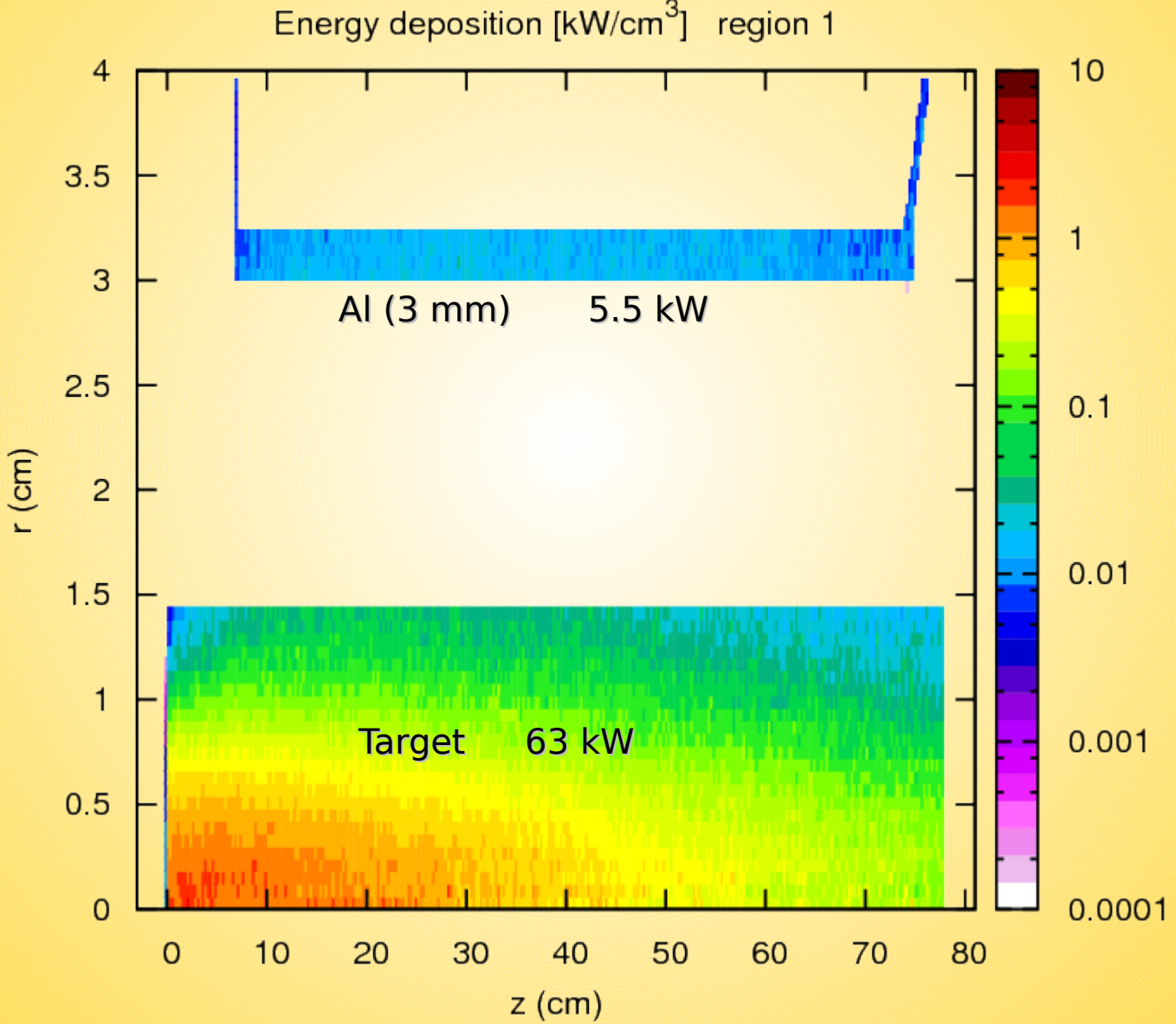
t_1 = 3 mm Al skin



◄ NB. log scale

Separated target: zoom

Inner radius 3 cm
(magnetic field starts at 3.3 cm)

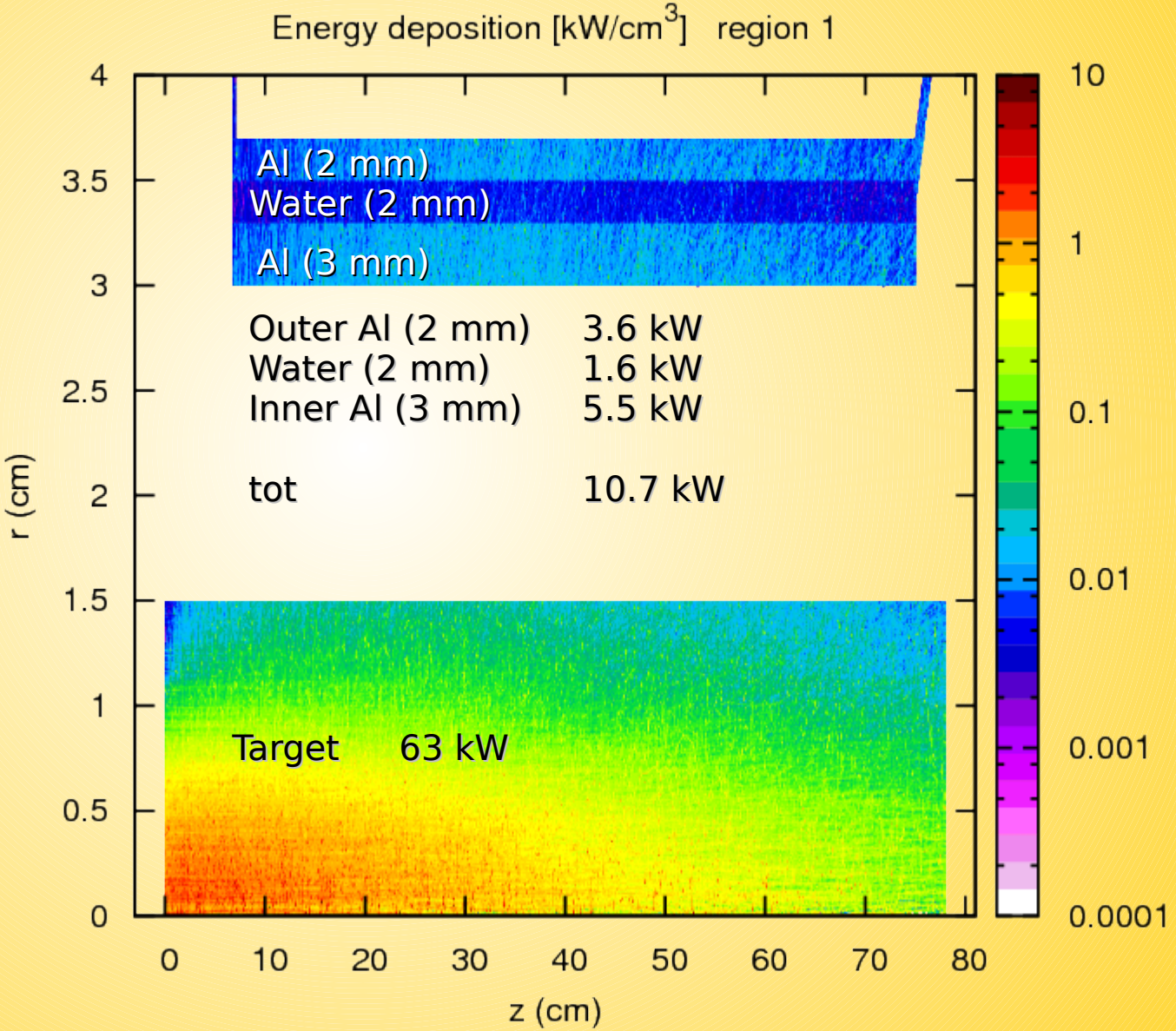


Separated target with water skin inner conductor

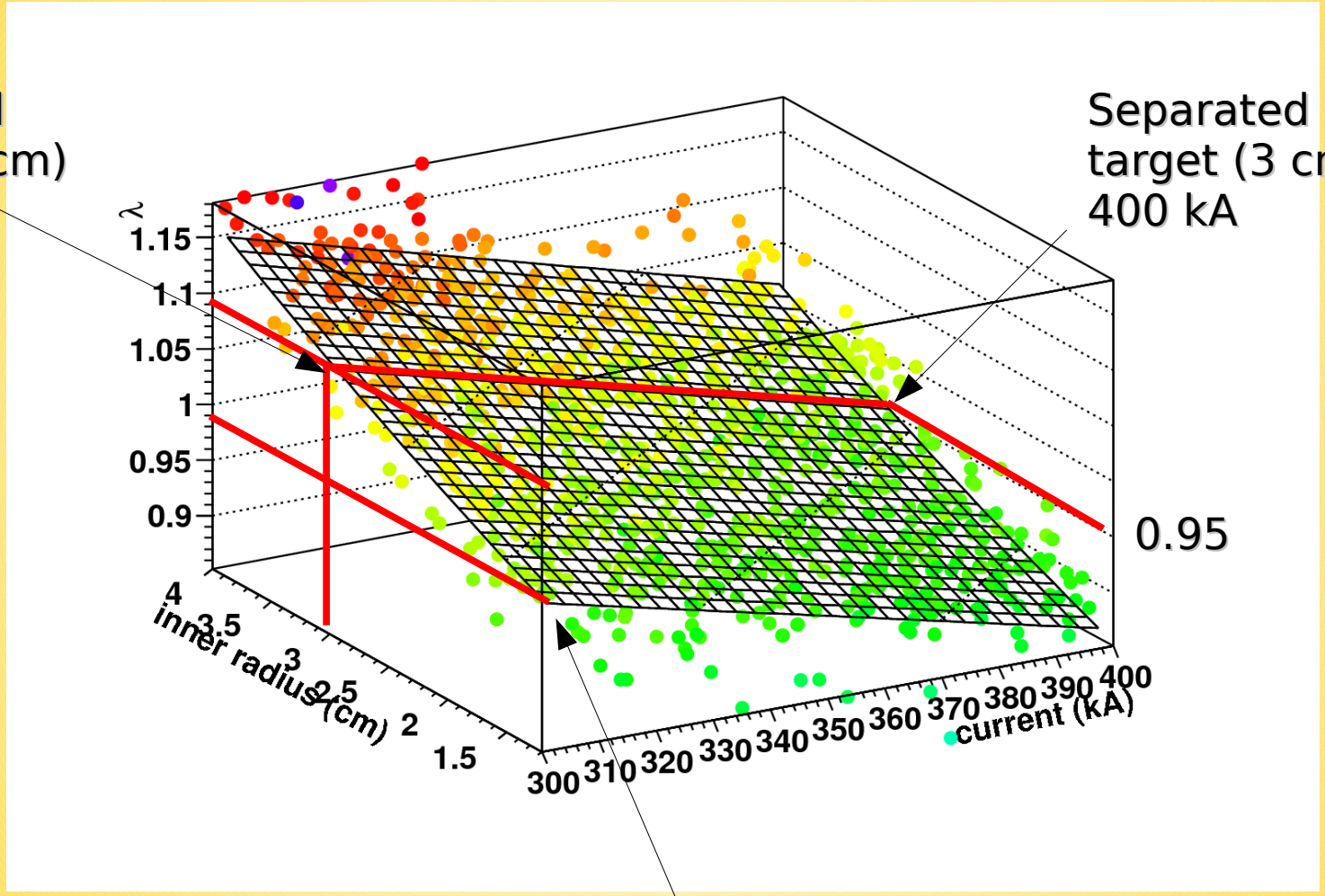
Request and dimensions by Piotr/Adam

Cross check: results are in agreement with the previous study by Christoph after rescaling for the differences in the considered volumes and the different radiuses

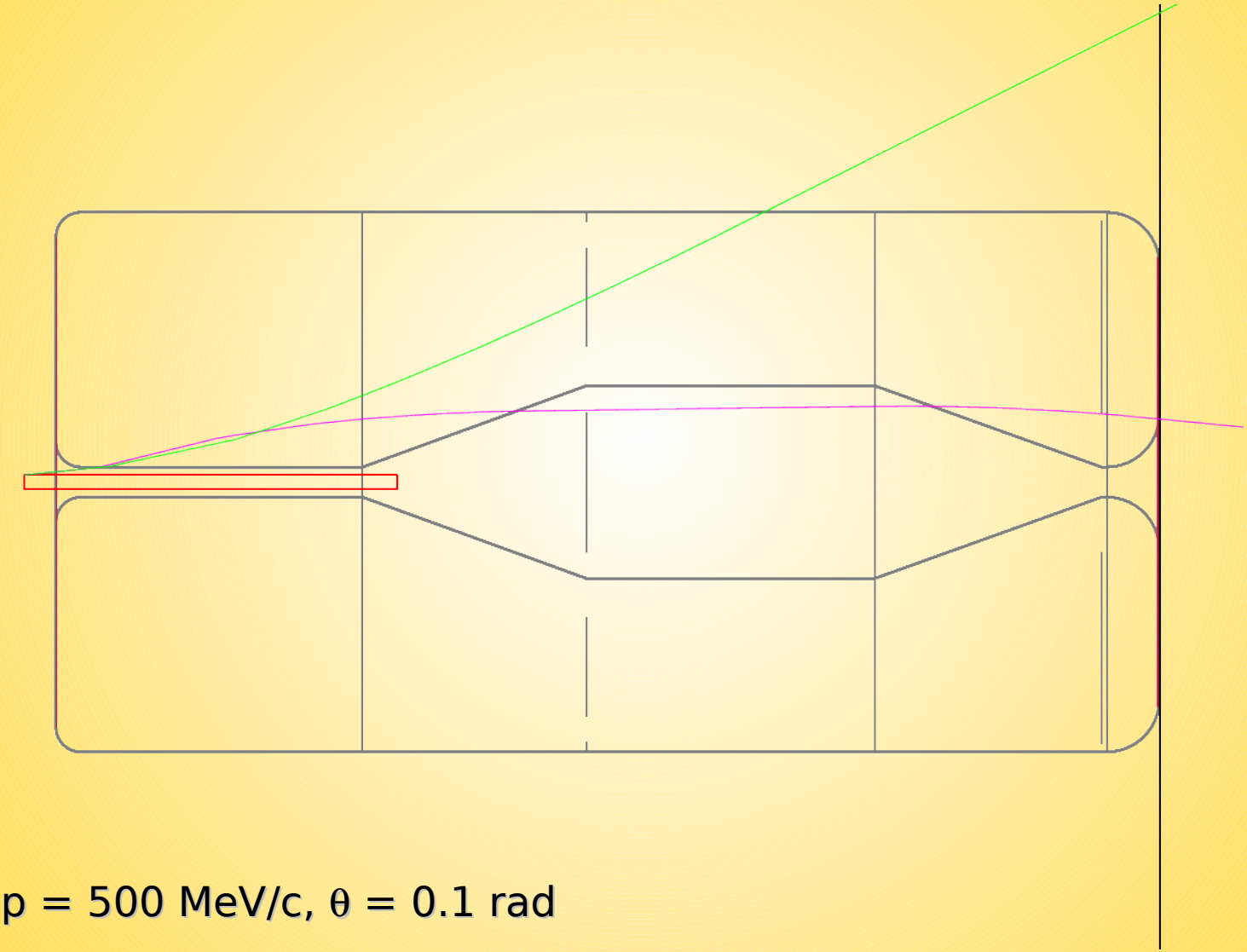
Full FLUKA simulation with water skin not done for the other horn conductors. Nevertheless numbers can be easily derived “by hand” scaling available data with single Al skin



Recovering performance by increasing the current



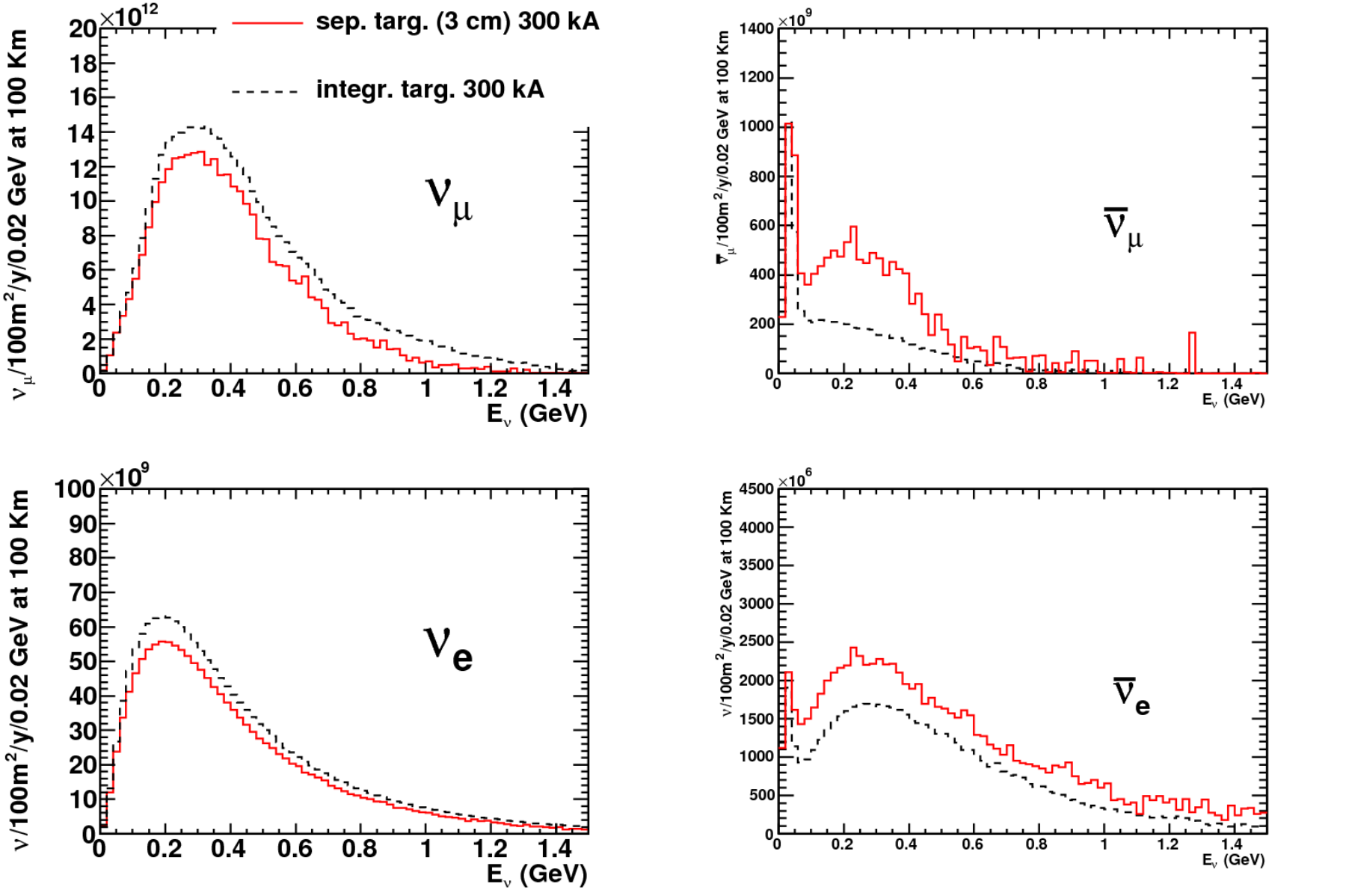
Separated target focusing



p = 500 MeV/c, θ = 0.1 rad

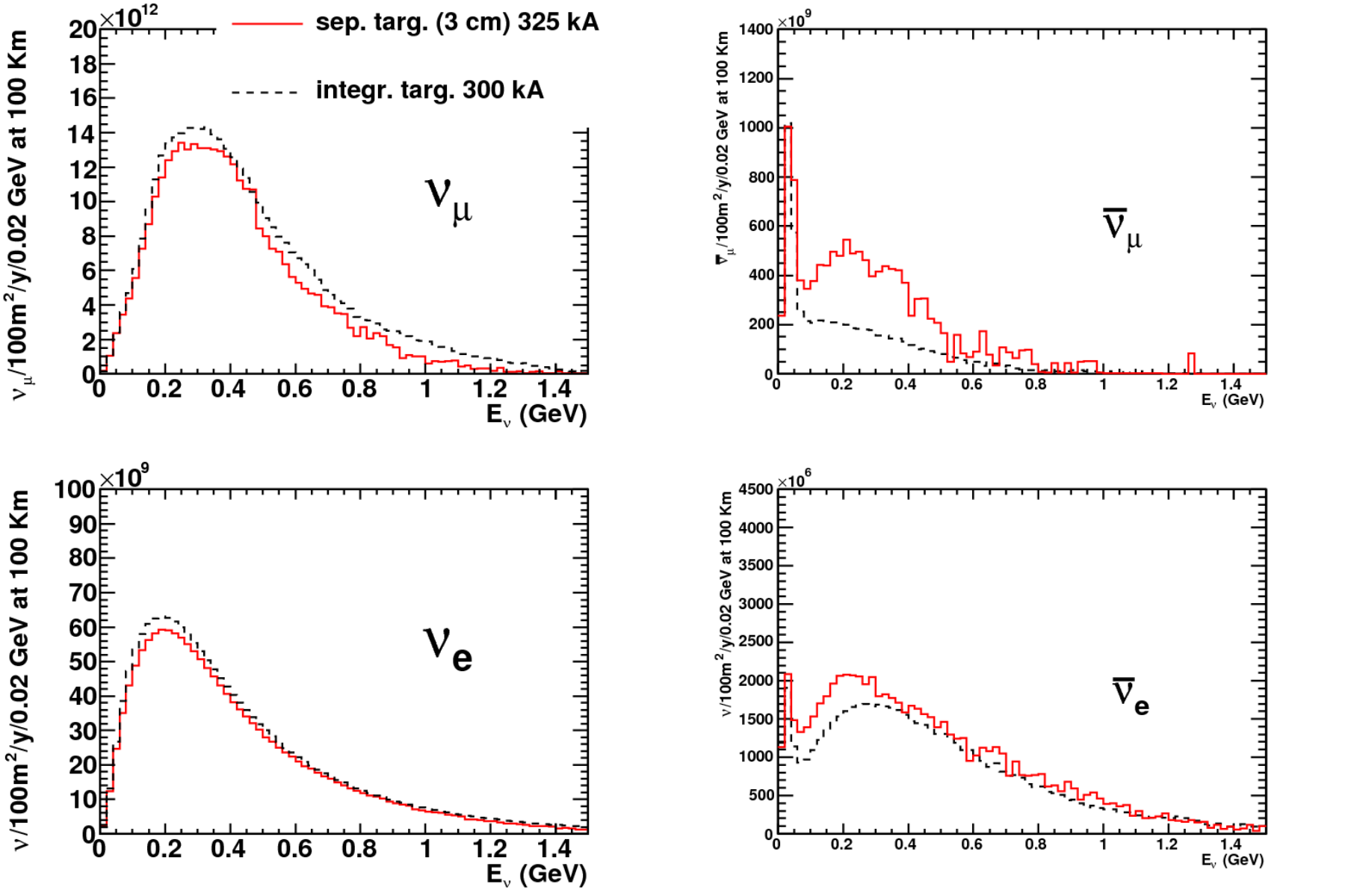
Separated target: fluxes comparison

I = 300 kA



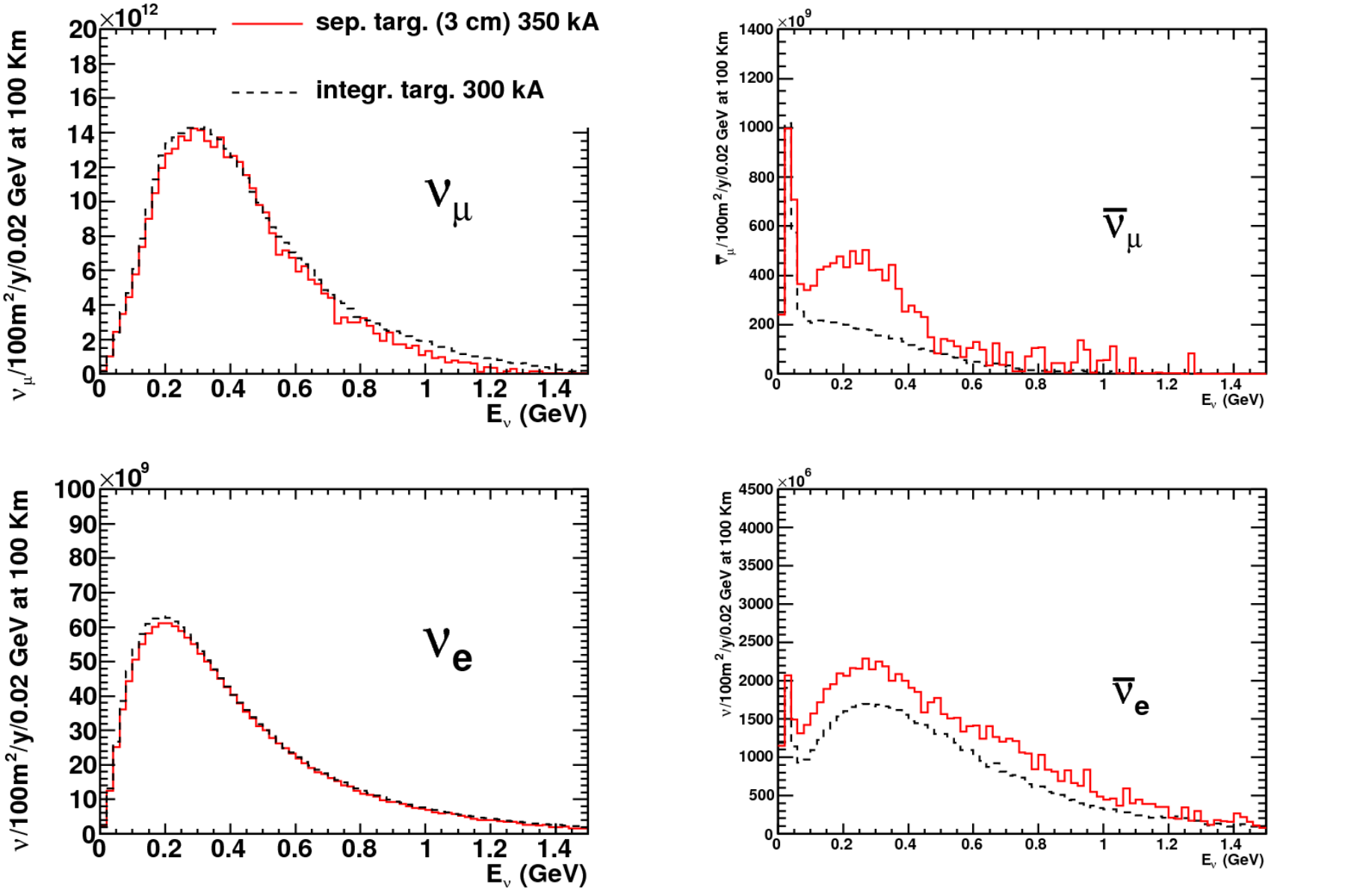
Separated target: fluxes comparison

I = 325 kA



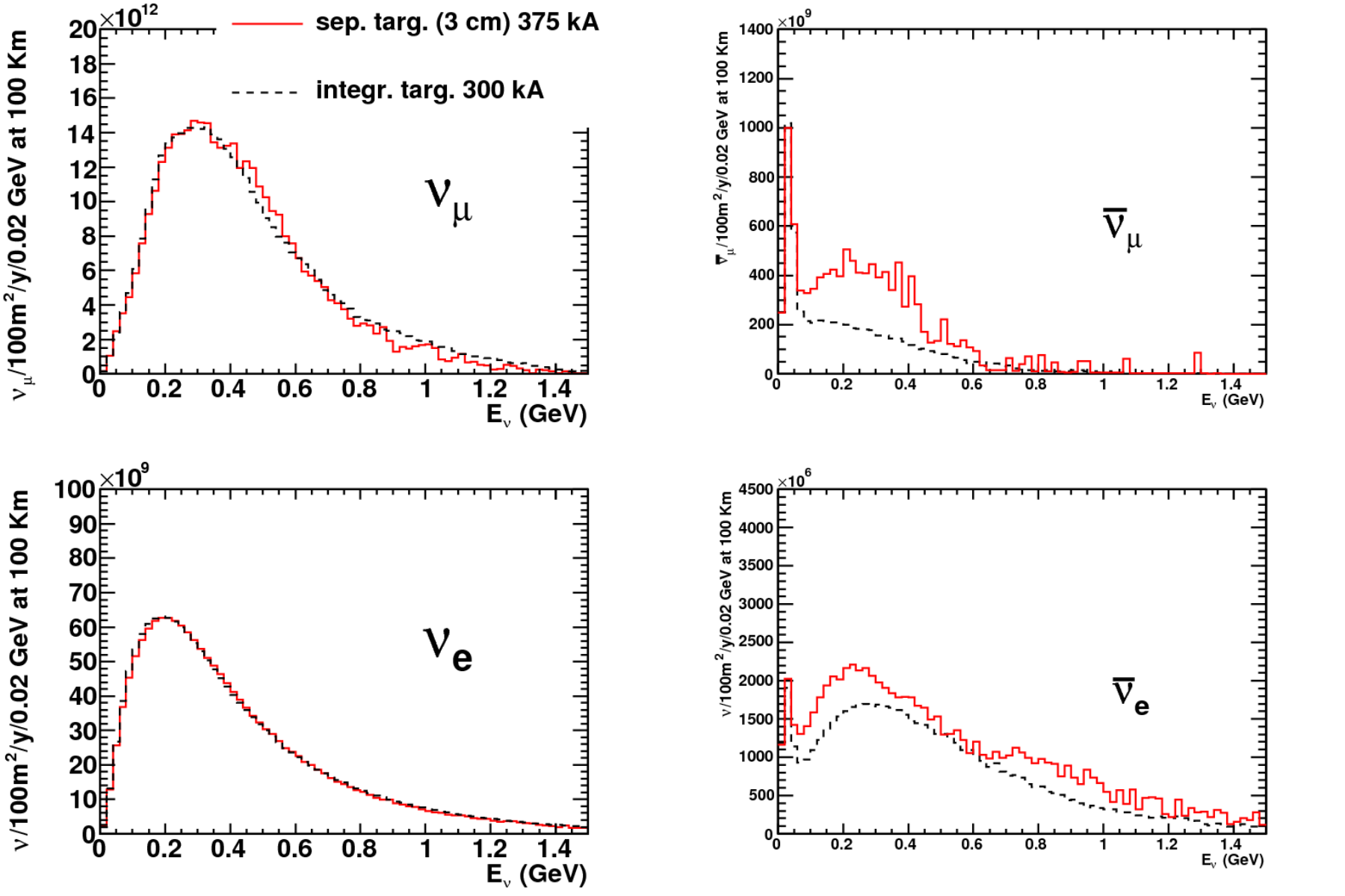
Separated target: fluxes comparison

I = 350 kA



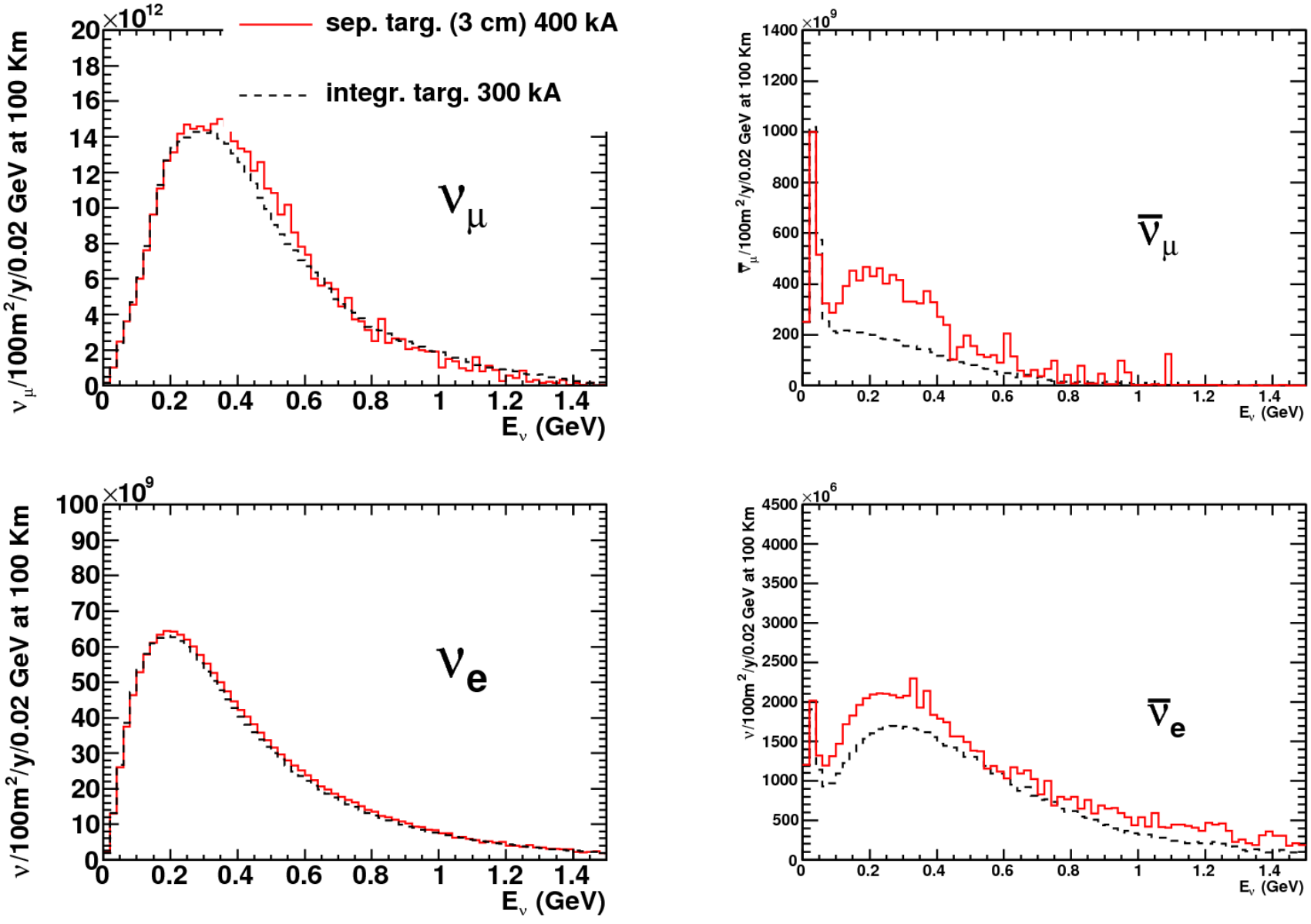
Separated target: fluxes comparison

I = 375 kA



Separated target: fluxes comparison

I = 400 kA



Next steps

1) compare sensitivity curves

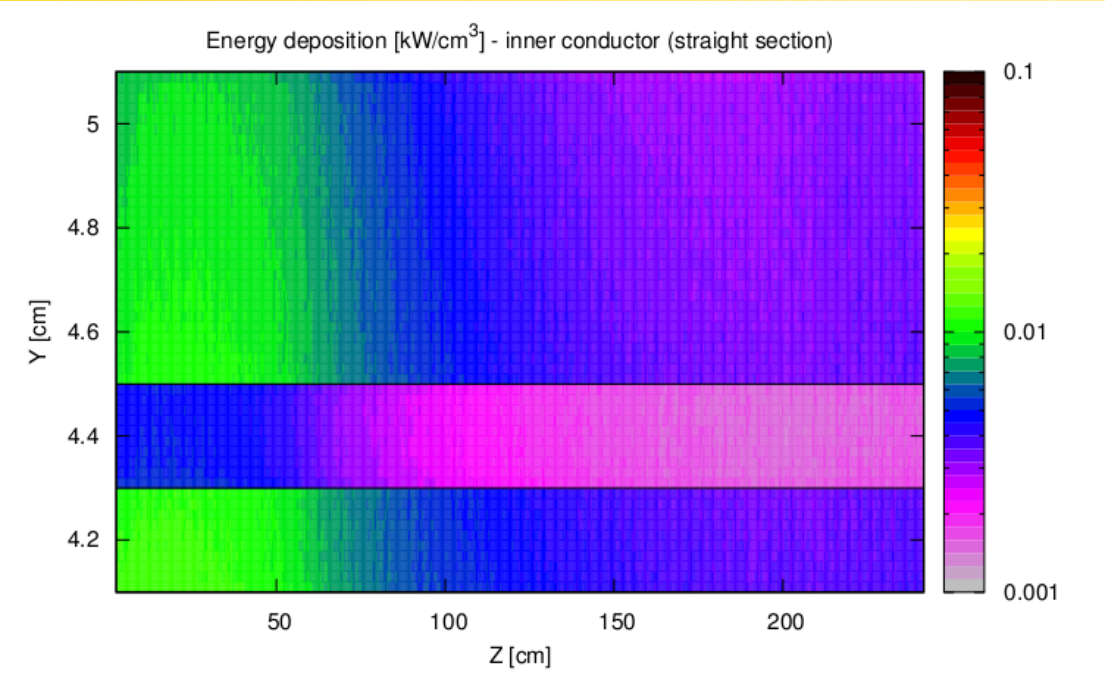
2) test the idea of Chris concerning a target with cavities to “spread” the power deposition.

3) produce a set of fluxes with increased aluminum thickness (3->4,5,6 mm)

4) write down documentation on the simulation code (ongoing)

Back-up

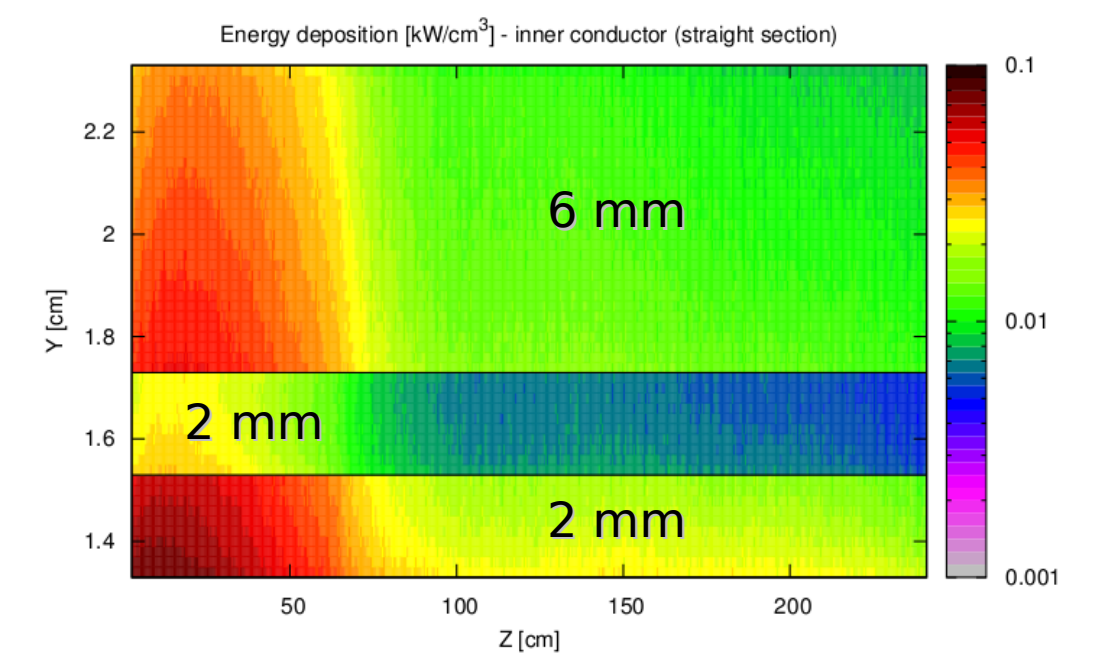
Christoph's computation



35.4 kW X 60/250 x 2/6 = 2.8
6.1 kW X 60/250 x 2/2 = 1.4
15.1 kW X 60/250 x 3/2 = 5.4

9.6

Note the different radius

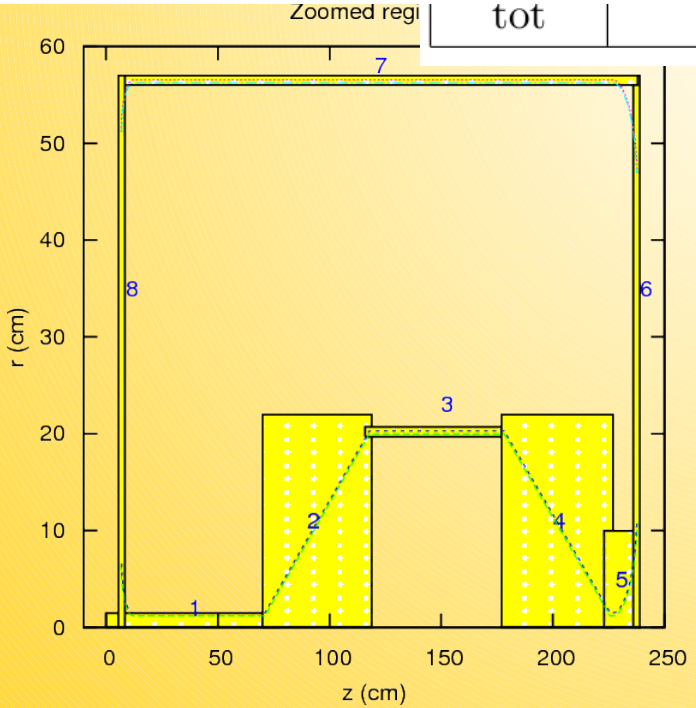
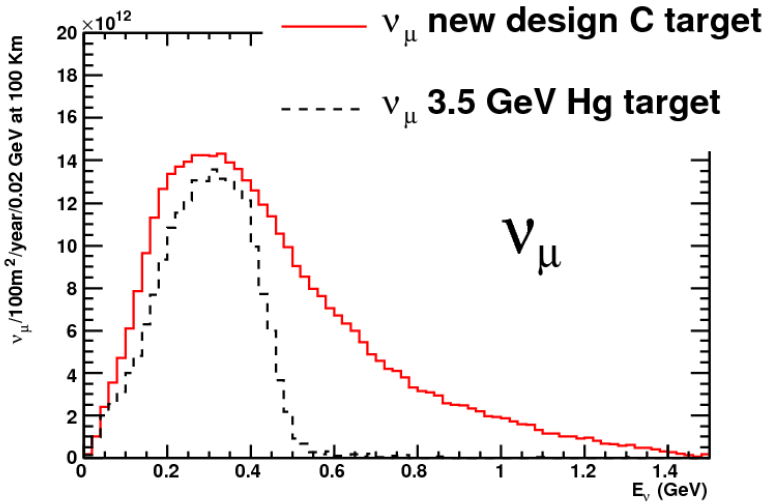
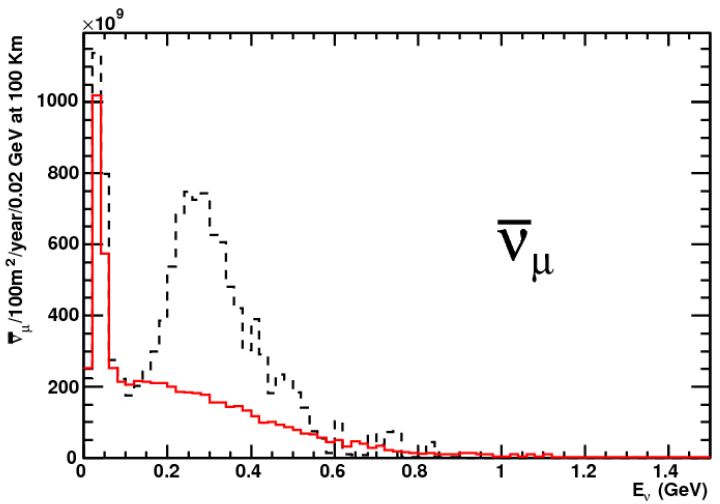
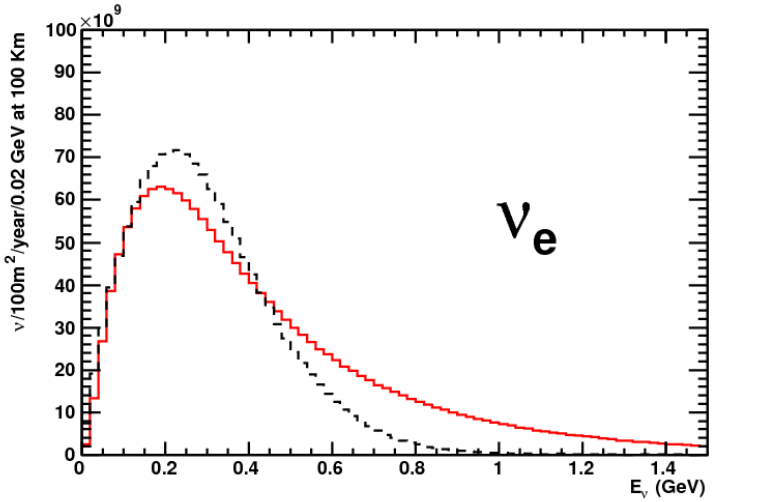
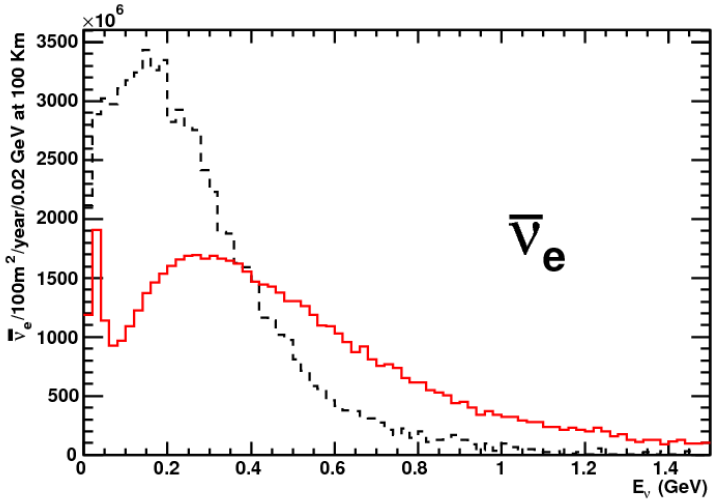


AlBeMet

46.1 kW
7.8 kW
19.2 kW

Integrated power deposition by region

Region	z range	r range	Deposited power (kW)	(%)	Deposited power (kW)	(%)
1	[0, 78]	[0, 1.5]	63.343	88.5	62.98	82.2
2	[70, 119]	[1.5, 22]	1.756	2.4	1.93	2.5
3	[116, 179]	[19.7, 20.7]	1.117	1.6	1.13	1.5
4	[177, 227]	[0, 22]	0.584	0.8	0.62	0.8
5	[225, 239]	[0, 10]	0.357	0.5	0.45	0.6
6	[236, 239]	[10, 57]	0.480	0.7	0.48	0.6
7	[6.8, 238.1]	[56, 57]	3.344	4.7	3.32	4.3
8	[5.5, 8.5]	[1.5, 57]	0.757	1.1	0.69	0.9
tot			71.580	100	5.5	7.1
					76.6	100



Comparison with the previous fluxes