HORN STUDIES FOR SPL-SUPERBEAM

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OUTLINE

- Modification of energy deposition in target due to magnetic field
  $\Rightarrow$ Study of integrated target as inner horn conductor
  (work in progress with Gérard Gaudiot and Benjamin Lepers)

- Shape optimisation NuFact-horn
  $\Rightarrow$ Material effects
  $\Rightarrow$ Pion distribution
  $\Rightarrow$ ν_μ spectrum (2-body decays)

Integrated target

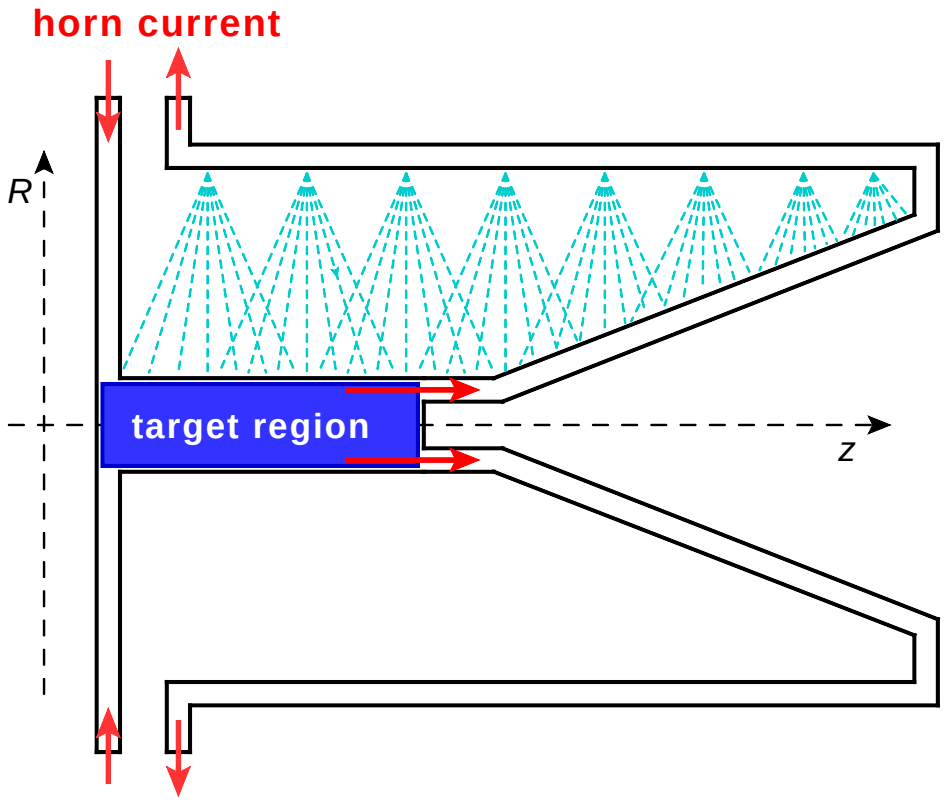
energy deposition

Effects due to magnetic field

INTEGRATED TARGET

Idea:

Target as inner conductor of horn



Requirement

- conducting target material

Advantages

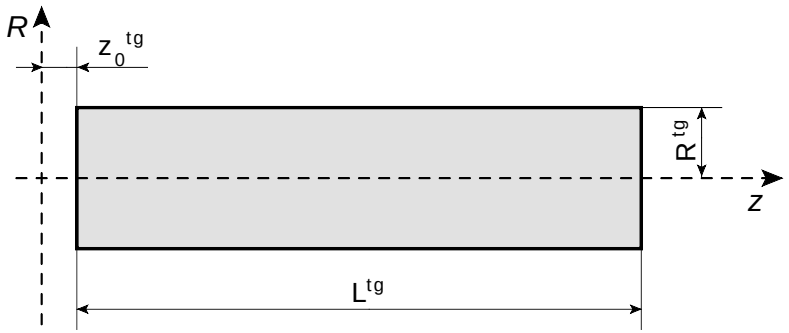
- can use water cooling of inner horn conductor also for target cooling
- lower inner radius $\rightarrow$ higher magnetic field or lower horn current

Disadvantages

- lower inner radius $\rightarrow$ higher Joule effect due to horn current

TARGET & BEAM - PARAMETERS

GEOMETRY target length $L^{tg} = 78$ cm and radius $R^{tg} = 15$ mm



MATERIAL target: low-Z materials: Beryllium, Aluminium, AlBeMet, comparing to Carbon – high-Z materials perhaps interesting too, but give more neutrons

BEAM

proton beam	
kinetic energy	$E^{bm}_{\text{kin}} = 4.5$ GeV,
beam power	4 MW,
frequency	50 Hz,
pulse duration	$\lesssim 5\ \mu$s
gaussian beam profile	$\sigma^{bm} = \{2, 4, 6\}$ mm

ENERGY DEPOSITION WITH MAGNETIC FIELD

Assuming continious energy deposition of proton beam @ 4 MW and $E_{\text{kin}}^{bm} = 4.5$ GeV.

Magnetic field due to horn current $I = \pm 300$ kA $\rightarrow B = 4$ Tesla @ $R = 1.5$ cm

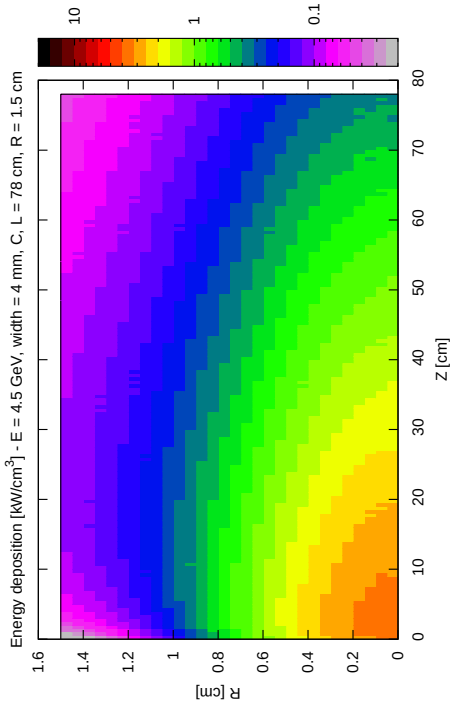
material	density [g/cm^3]	σ^{bm} [mm]	max value power density [kW/cm^3]	total power [kW] (+ I, - I)
Be	1.85	2	11.65	168.7 (+6 %, +4%)
		4	3.25	165.3 (+6 %, +4%)
		6	1.53	153.2 (+12 %, +4%)
C	1.85	2	13.22	200.0 (+6 %, +5%)
		4	3.57	196.5 (+7 %, +4%)
		6	1.72	182.2 (+12 %, +4%)
Al	2.70	2	19.26	285.6 (+8 %, +6%)
		4	5.36	279.1 (+8 %, +6%)
		6	2.73	257.4 (+14 %, +6%)
AlBeMet (Be 61%, Al 38%, O 1%)	2.1	2	14.11	204.4 (+7 %, +5%)
		4	3.92	200.1 (+7 %, +5%)
		6	1.86	185.2 (+13 %, +5%)

For "+" focusing $(6 - 14)$ % and for "-" focusing $(4 - 6)$ % increased total power due to focusing of charged particles, BUT maximal value of power density stays the same!

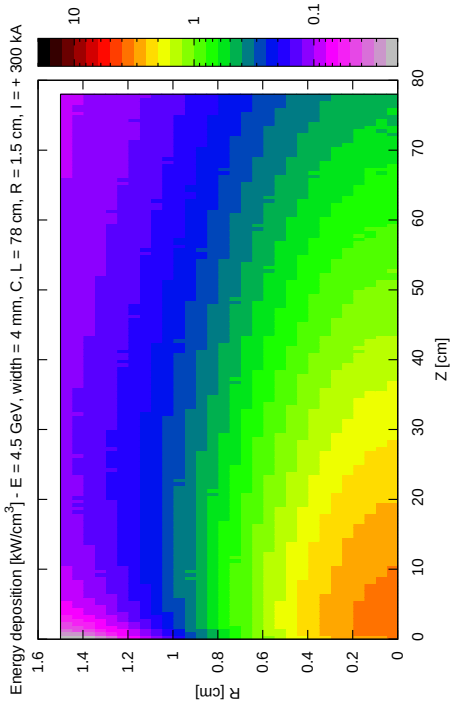
Already pointed out by Tristan Davenne (RAL) in connection with his studies.

Energy deposition - Carbon for $\sigma^{bm} = 4$ mm

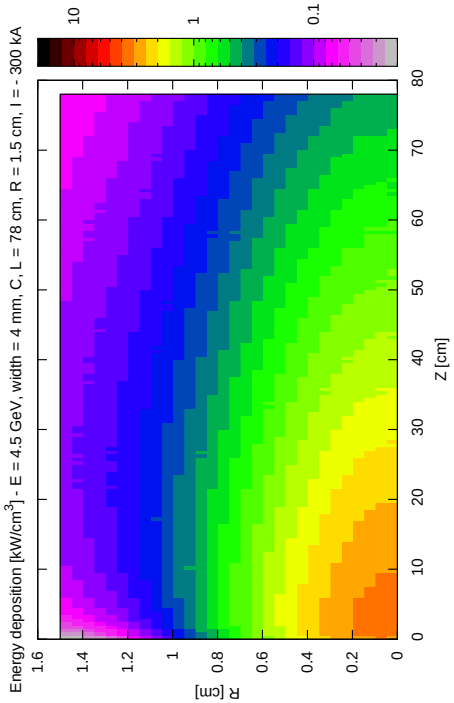
. . . in $z - R$ plane – $R^{tg} = 3.75 \times \sigma^{bm}$



$I = 0$ kA



$I = +300$ kA

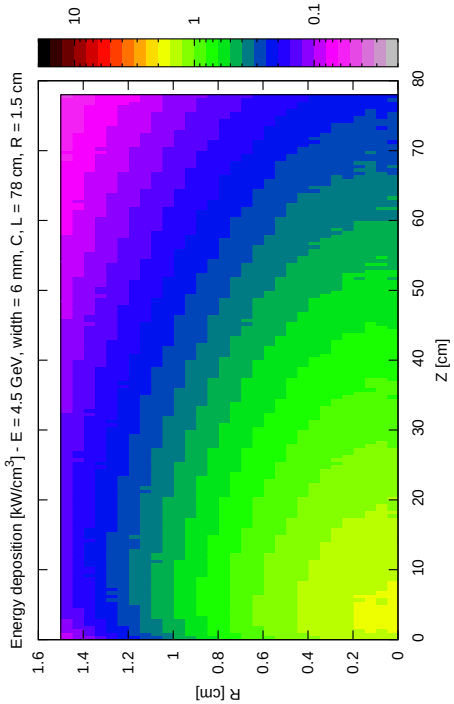


$I = -300$ kA

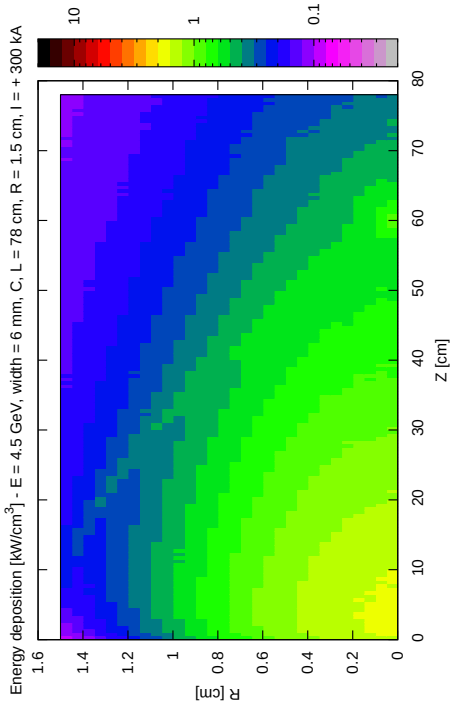
Slightly higher energy deposition close to surface (compare left upper corner)

ENERGY DEPOSITION - CARBON FOR $\sigma^{bm} = 6$ MM

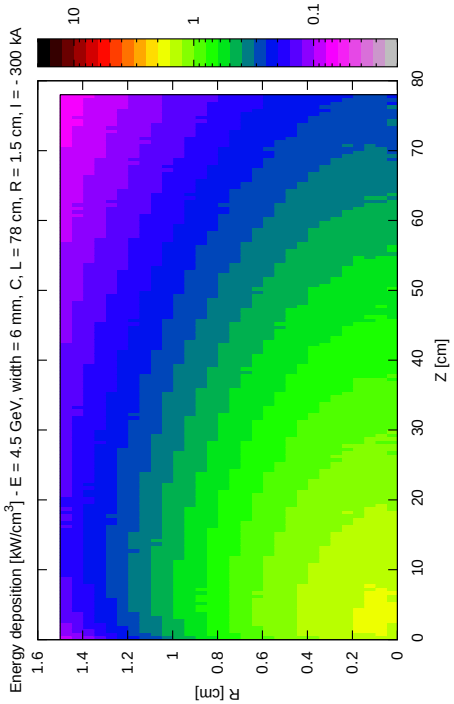
. . . in $z - R$ plane – $R^{tg} = 2.5 \times \sigma^{bm}$



$I = 0$ kA



$I = +300$ kA



$I = -300$ kA

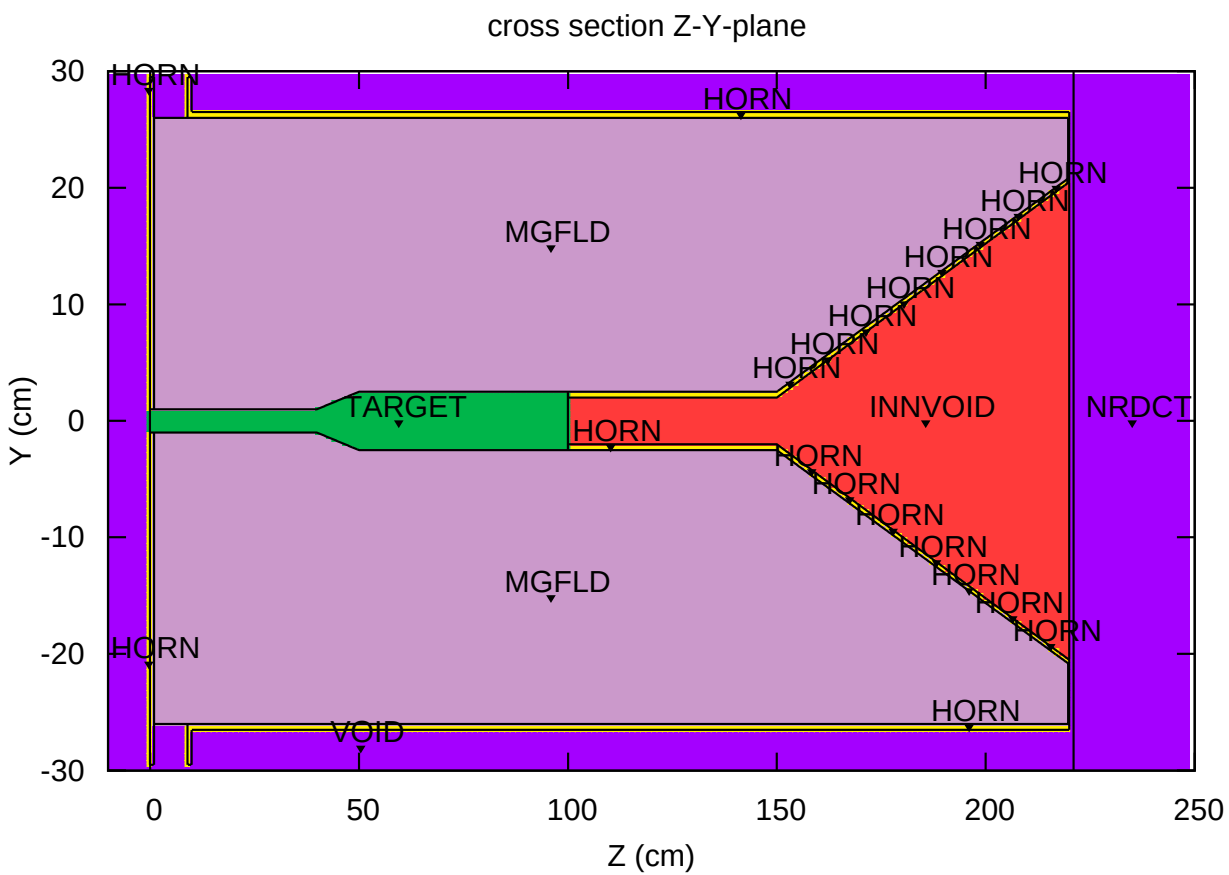
Slightly higher energy deposition close to surface

... and for $I = +300$ kA a focusing effect with spot around $z = 60$ cm from protons which enter magn. field at $r > R^{\mathrm{tg}}$ and are bended into the target

TARGET WITH TWO RADII

Cooling problems of target at point close to proton beam impact $\rightarrow$ reduce radius to get closer with cooling

Idea: target with two radii and conic section to get closer with cooling



beam width

$\sigma^{bm} = 6$ mm

target

$R_1^{tg} = 1$ cm

$R_2^{tg} = 2.5$ cm

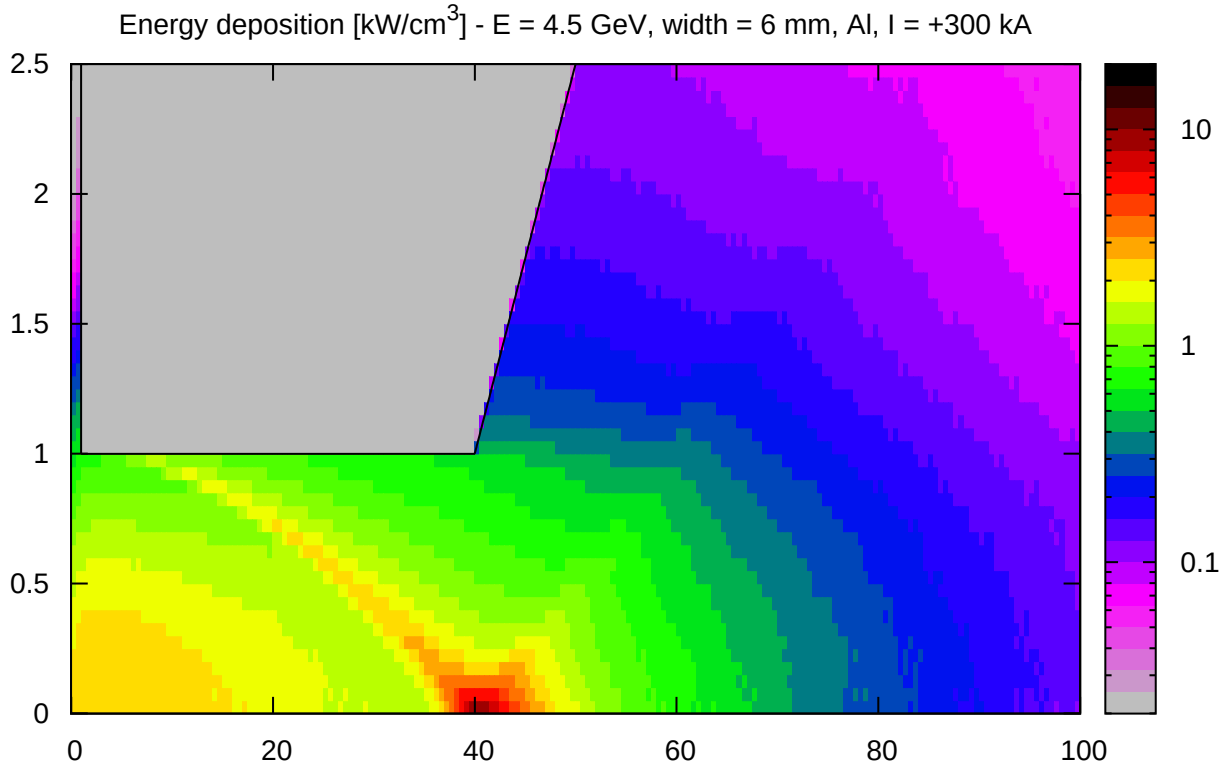
$L_1^{tg} = 40$ cm

$L_2^{tg} = 10$ cm

$L_3^{tg} = 50$ cm

material = Al

ENERGY DEPOSITION - "HOT SPOT"



$R^{tg} = 1.67 \times \sigma^{bm}$

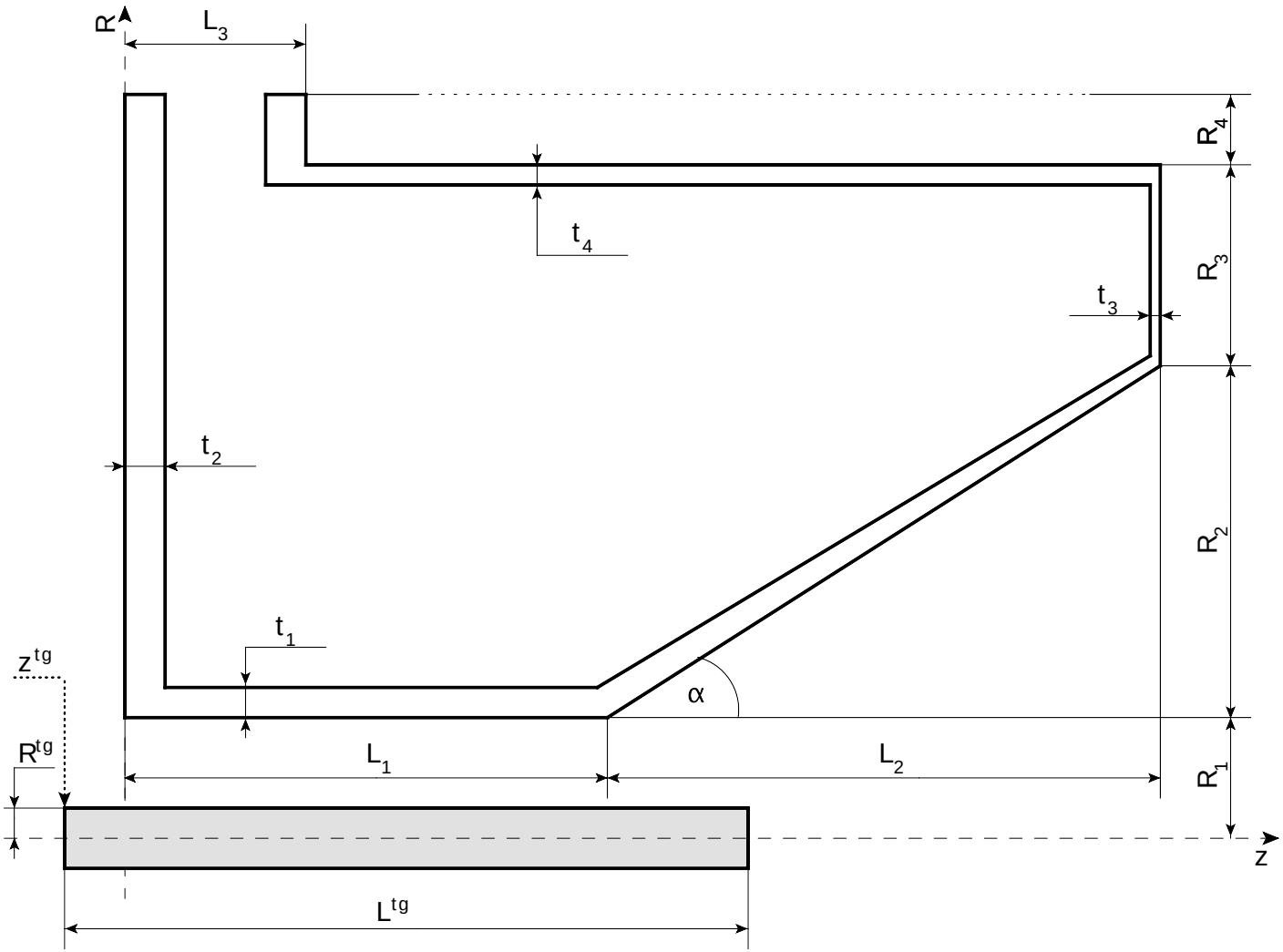
Formation of hot spot around $z = 40$ cm

Conclusion: beam width σ^{bm} should be well within target radius R^{tg} to avoid hot spot in "+" focusing operation due to protons

Shape optimisation NuFact-horn

REOPTIMISING NUFACT HORN - PARAMETERS

- optimizing for longer Carbon target $L^{tg} = 78$ cm (previous Hg $L^{tg} = 30$ cm)
- removing reflector with current $I = 600$ kA introduced by Campagne/Cazes



keeping fixed:

$E^{kin} = 4.5$ GeV

$L^{tg} = 78$ cm
$R^{tg} = 1.5$ cm
$z^{tg} = 0$ cm

$L_3 = 3$ cm
$R_4 = 4$ cm
$t_{1,2,3,4} = 3$ mm

varying:

$z_0^{hn} \in [-20, 20]$ cm,
$L_1 \in [50, 150]$ cm,
$L_2 \in [50, 150]$ cm,
$R_1 \in [1.2, 6.0]$ cm,
$\alpha \in [2, 30]^\circ$,
$R_3 \in [4, 10]$ cm,
$I \in [100, 300]$ kA

Campagne/Cazes:

$L_1 = 40$ cm,
$L_2 = 100$ cm,
$R_1 = 3.7$ cm,
$R_2 = 12.6$ cm,
$R_3 = 4$ cm

REOPTIMISING NUFACT HORN - SCAN

- use π sample generated with FLUKA for C-target 10^6 pot
  yielding 759914 π^+ and 498397 π^- at target exit (position, momentum)
- optimise horn for π^- focusing, since background suppression
  more important for $\bar{\nu}_\mu$-run
- look for optimal ratio

  $$R(\pi^-/\pi^+) = (\#\text{ of “good” } \pi^- \text{ with } p \in [0.5, 0.7] \text{ GeV})/(\#\text{ of “background” } \pi^+)$$

  π’s are counted when exiting the horn within a circular plane of $R = 1$ m
- sample contains 116689 π^+ and 77392 π^- with $p \in [0.5, 0.7]$ GeV

"BEST" 13 HORNS - MATERIAL EFFECT

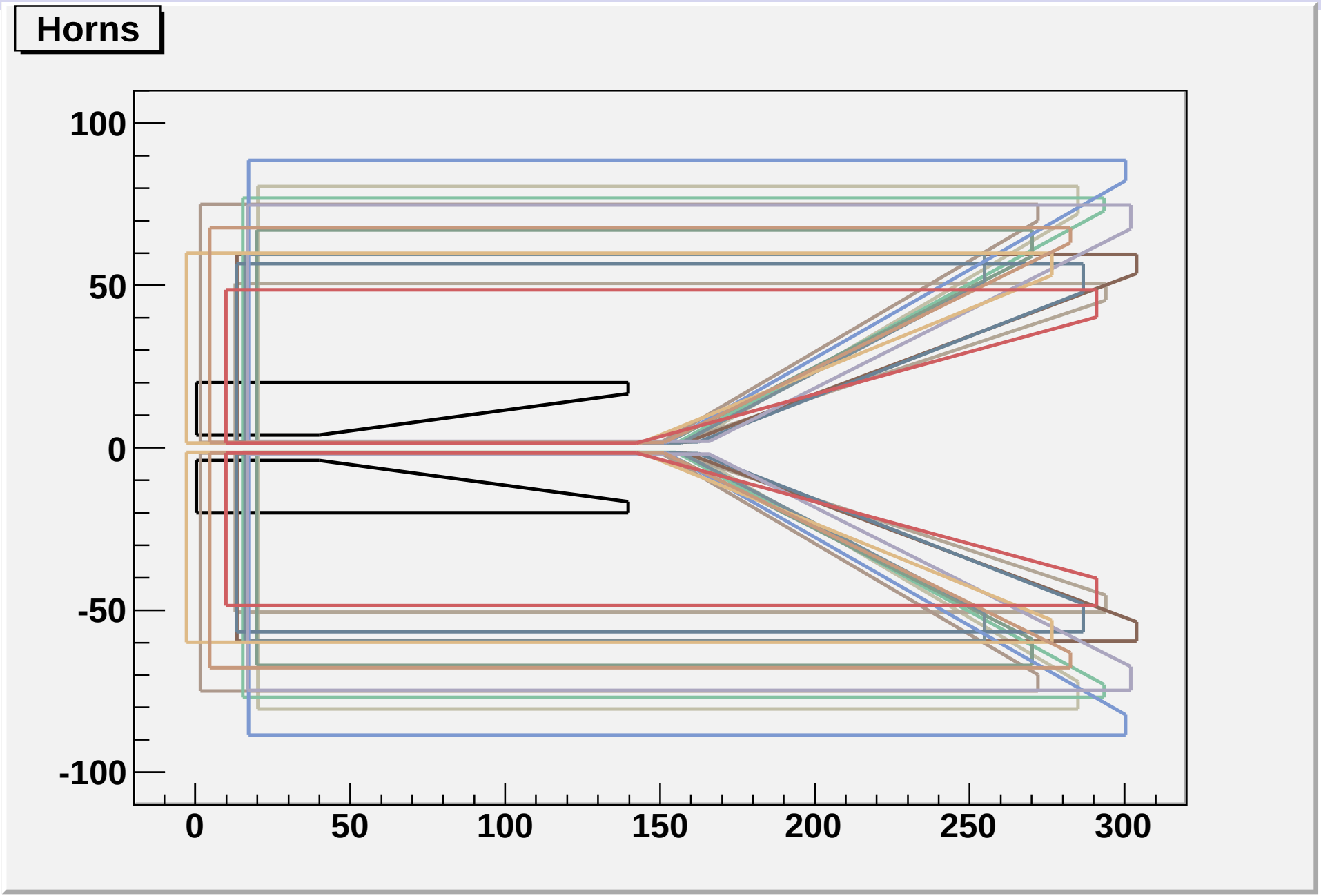
z_0^{hn} [cm]	L_1 [cm]	L_2 [cm]	R_1 [cm]	R_2 [cm]	R_3 [cm]	I [kA]	$R(\pi^-/\pi^+)$	# of π^-	# of π^+
9.5	132.9	148.9	1.22	38.8	8.9	-290	48.1 (12.3)	20832	433
16.6	149.5	136.2	1.60	65.6	7.8	-260	48.5 (14.2)	20849	430
19.8	140.4	125.0	1.45	70.4	8.8	-285	49.3 (16.4)	20359	413
-3.17	147.0	133.0	1.20	51.8	7.3	-252	49.7 (13.6)	21316	429
16.8	135.6	148.2	1.37	80.7	6.7	-298	51.1 (——)	21277	416
19.5	132.5	118.4	1.23	57.6	8.5	-265	51.9 (13.7)	20147	388
13.0	149.5	124.4	1.46	46.4	9.2	-285	52.2 (13.6)	21002	402
13.1	145.7	145.3	1.43	52.0	6.4	-296	52.3 (14.6)	21667	414
1.31	148.9	122.2	1.24	68.5	5.5	-270	54.0 (16.5)	21269	394
4.21	147.2	131.4	1.31	61.7	5.1	-294	55.0 (15.2)	22608	411
12.6	142.4	139.2	1.22	43.9	5.8	-298	57.8 (12.6)	20984	363
15.0	140.4	138.3	1.20	71.6	4.4	-278	58.9 (16.3)	21142	359
15.8	141.0	98.34	1.22	49.3	9.3	-297	60.2 (16.1)	21369	355
0.0	40.0	100.0	3.70	12.6	4.0	-300	—— (2.63)	—	—
0.0	40.0	100.0	3.70	12.6	4.0	0	—— (0.09)	—	—

last lines: Campagne/Cazes (no reflector), opt. for $p = 600$ MeV and with Hg target $L = 30$ cm

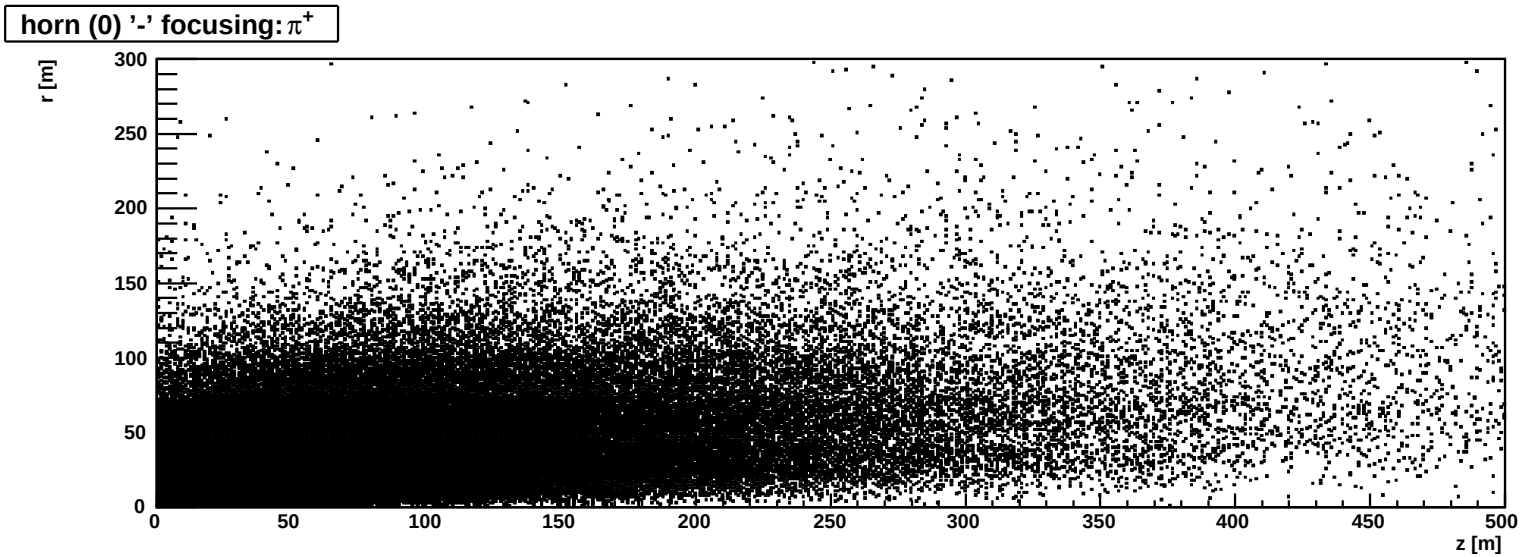
Material effect with FLUKA:

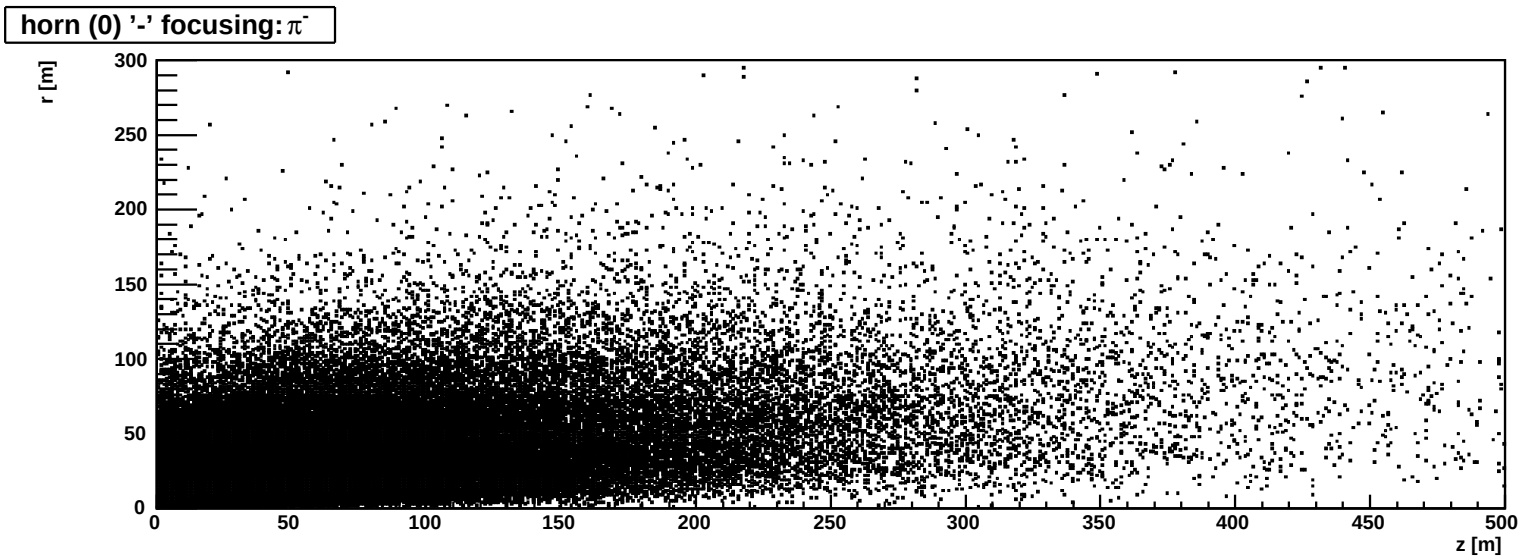
3 mm Aluminium horn skin decreases $R(\pi^-/\pi^+)$ by about factor 4 due to more π^+

"BEST" 13 HORNS

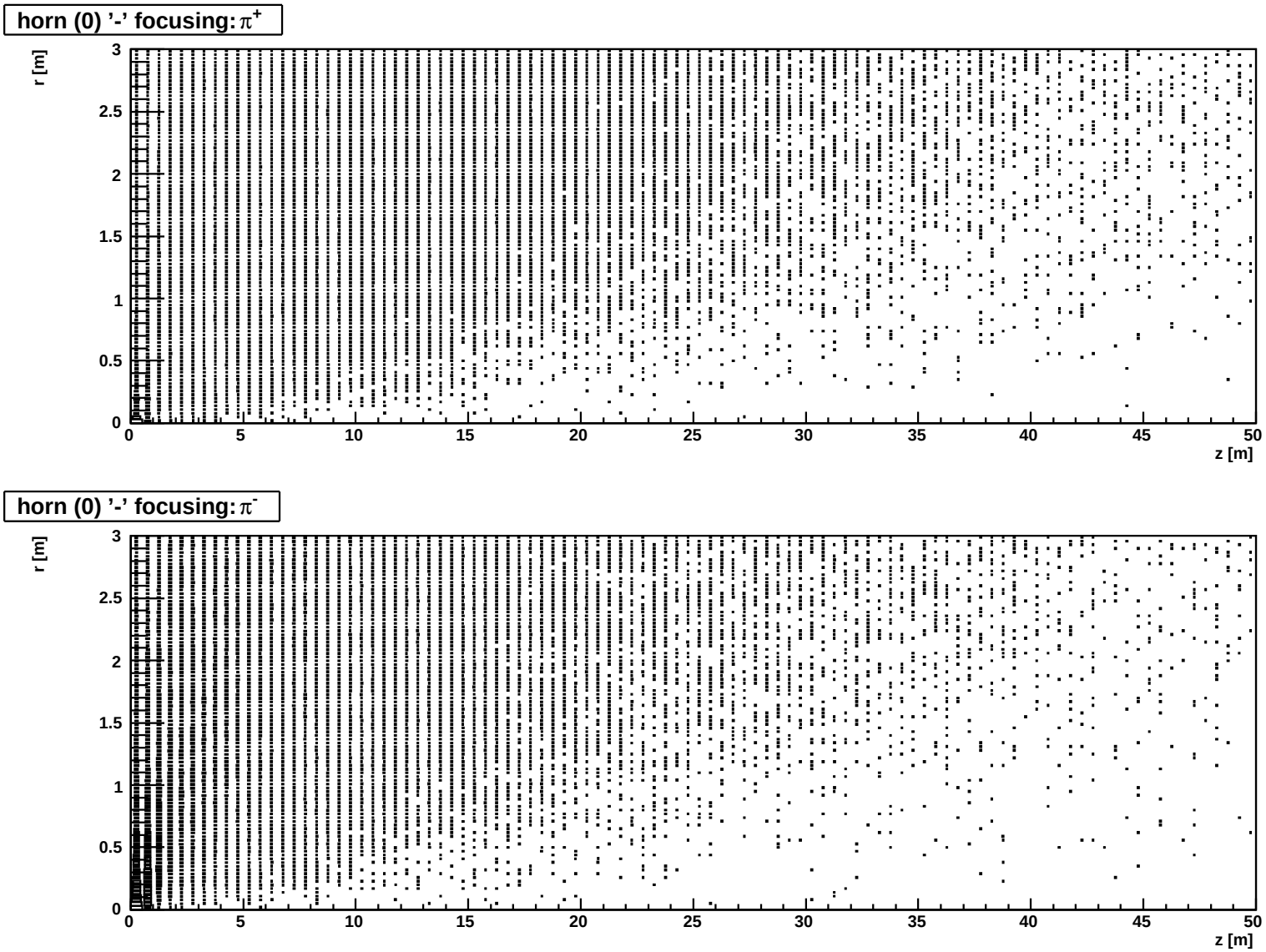


π DECAY POSITIONS - NO MAGNETIC FIELD



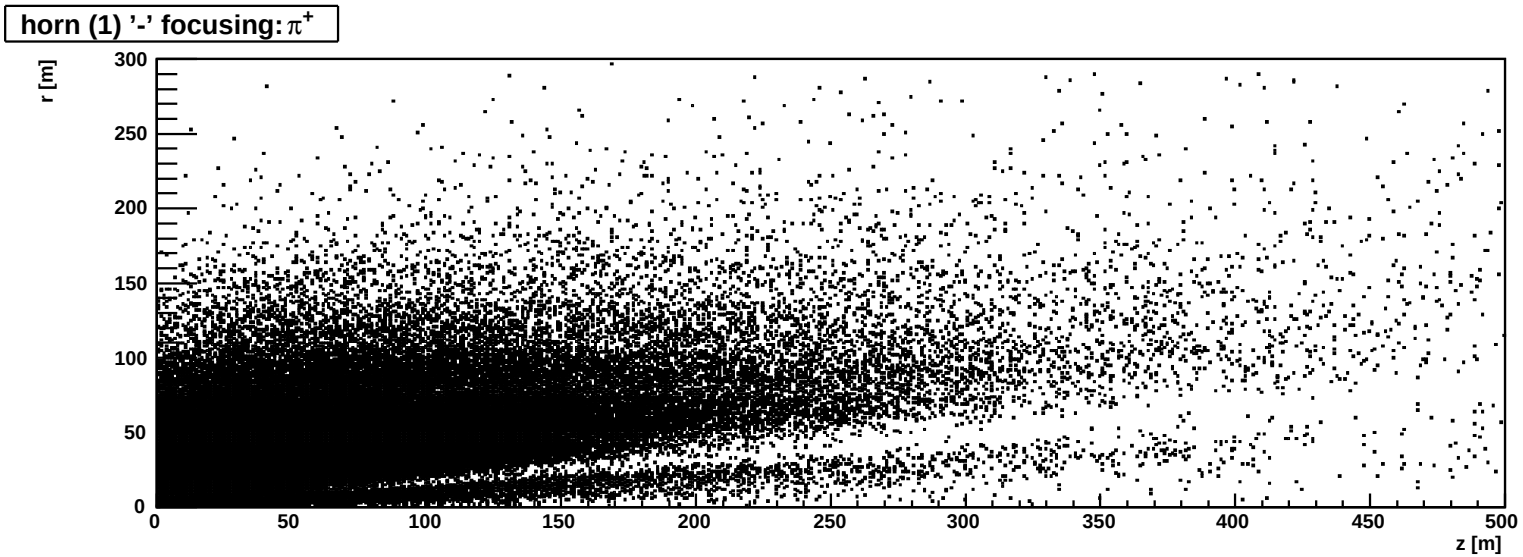


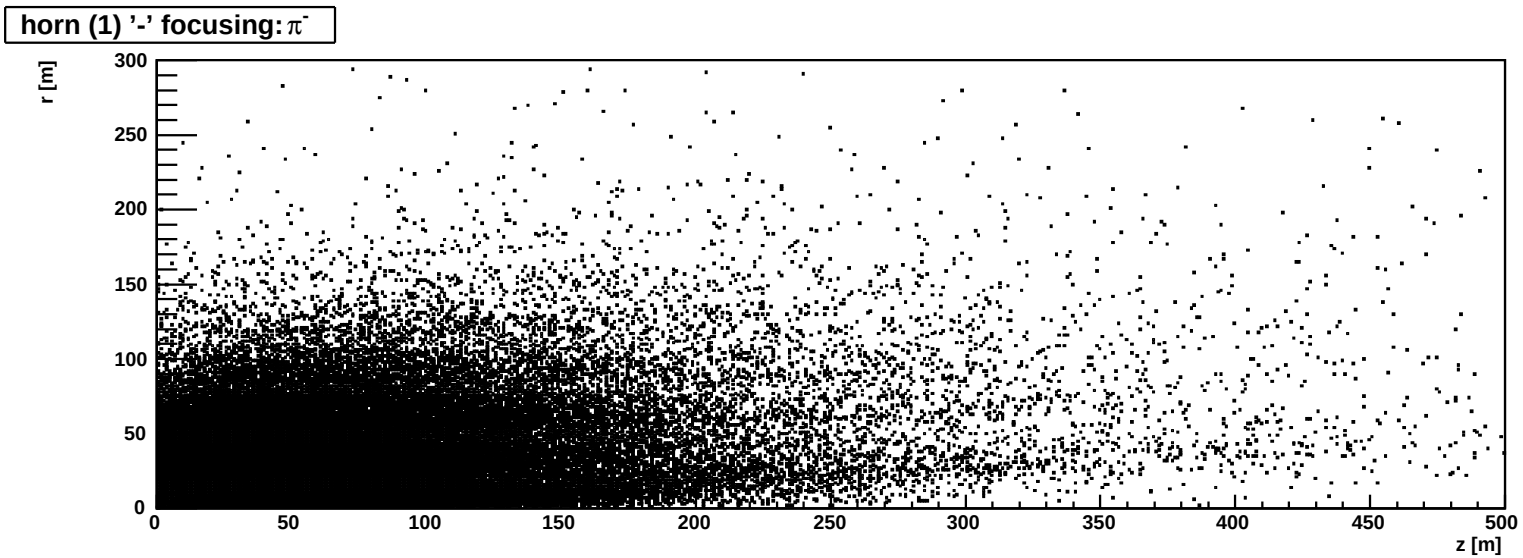
π DECAY POSITIONS (ZOOM) - NO MAGNETIC FIELD



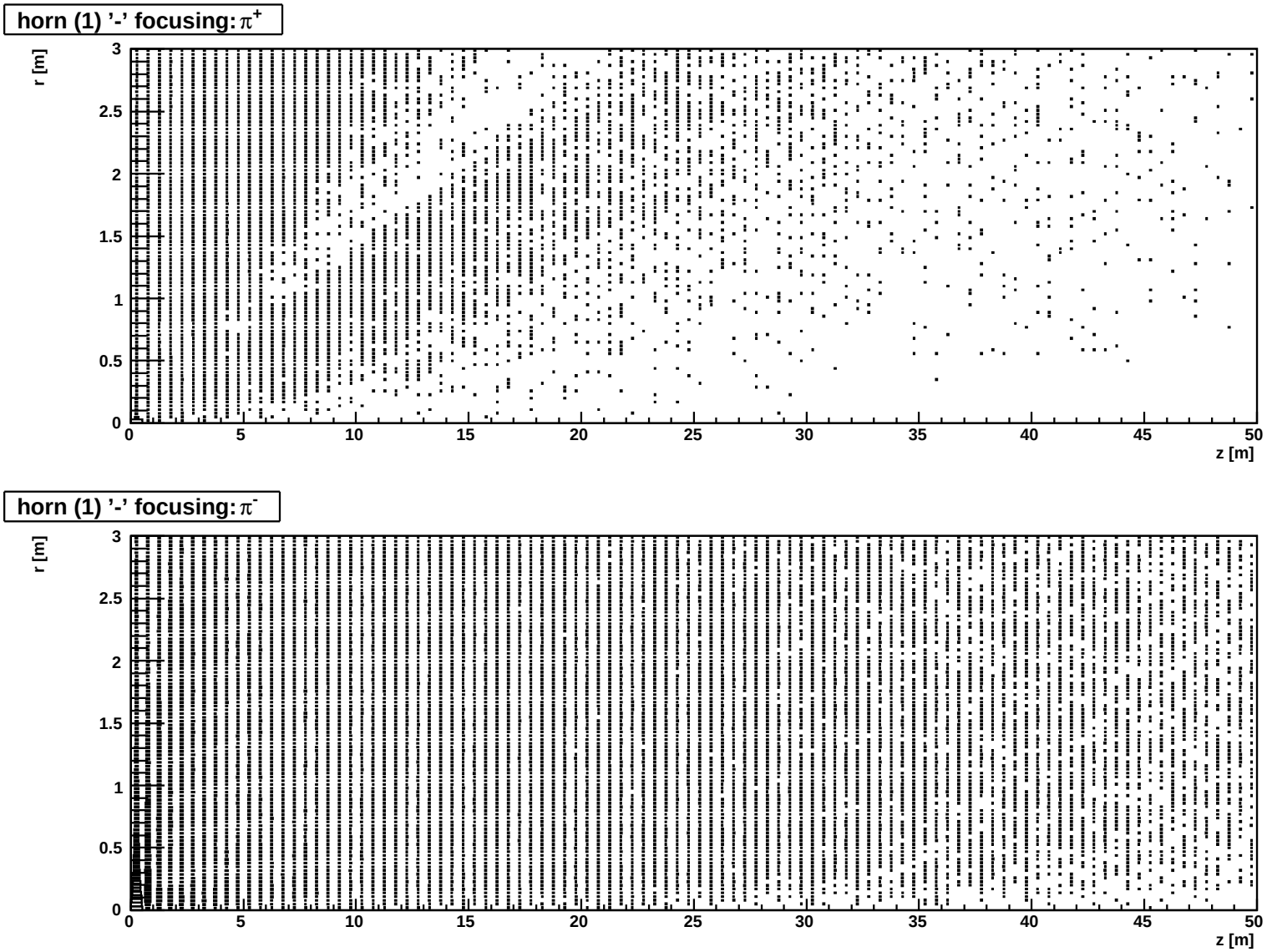
current decay tunnel: $L^{dt} = 40$ m, $R^{dt} = 2$ m

π DECAY POSITIONS - CAMPAGNE/CAZES



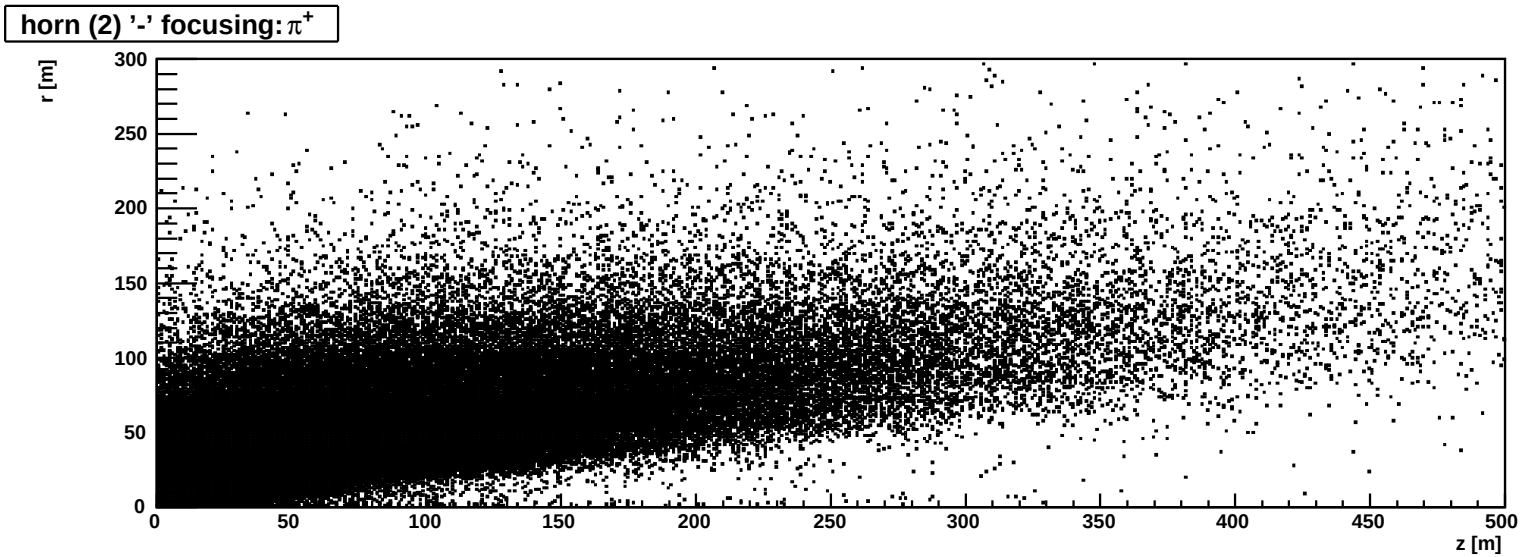


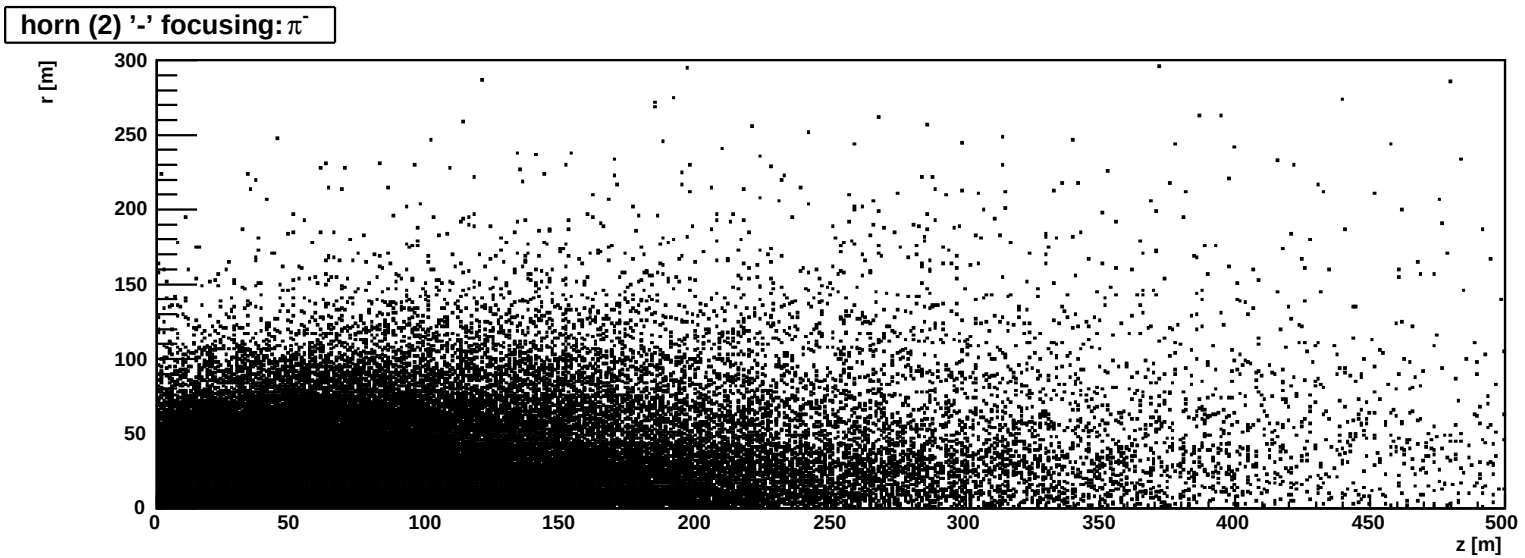
π DECAY POSITIONS (ZOOM) - CAMPAGNE/CAZES



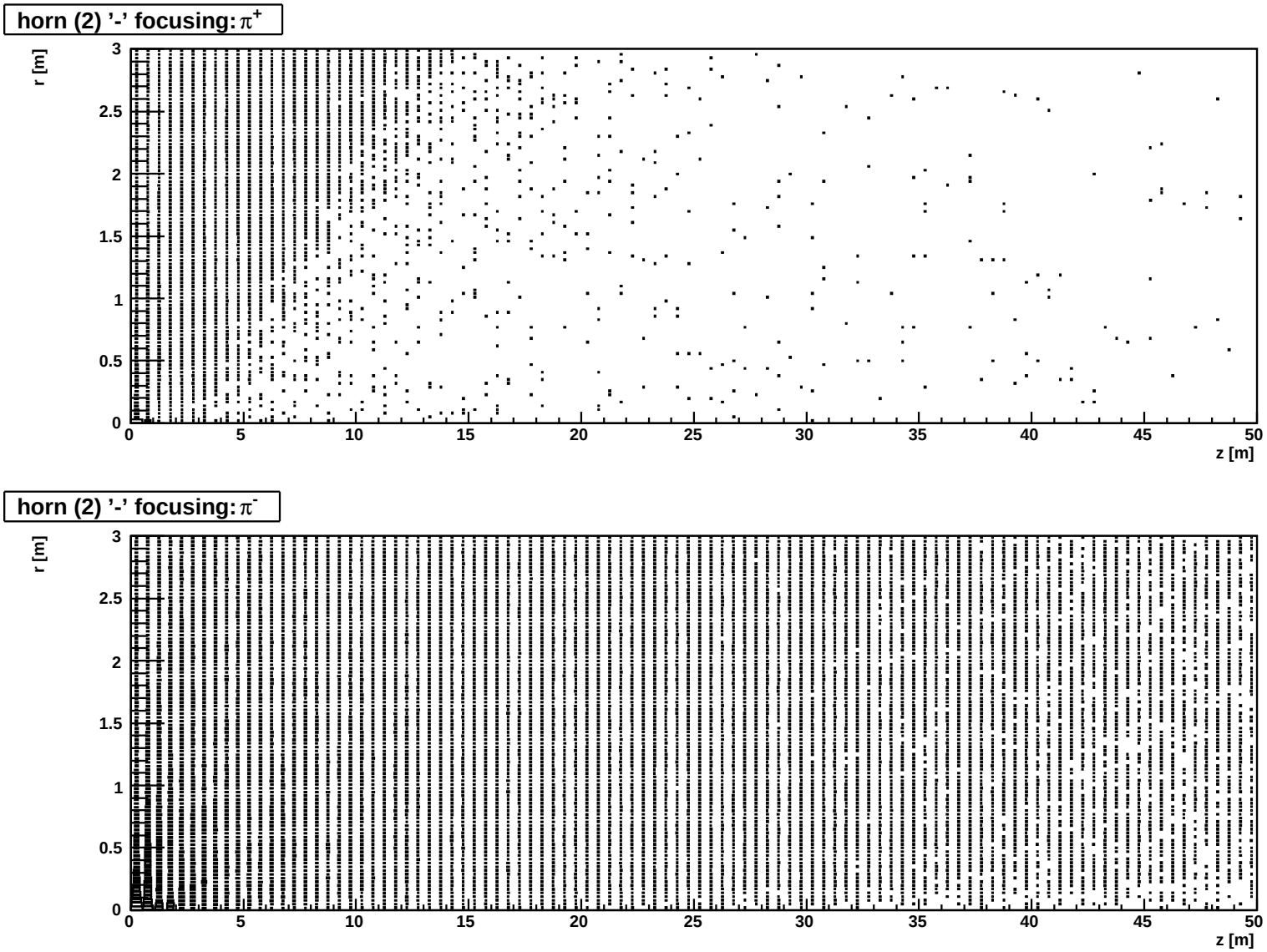
current decay tunnel: $L^{dt} = 40$ m, $R^{dt} = 2$ m

π DECAY POSITIONS - 13 BEST OF



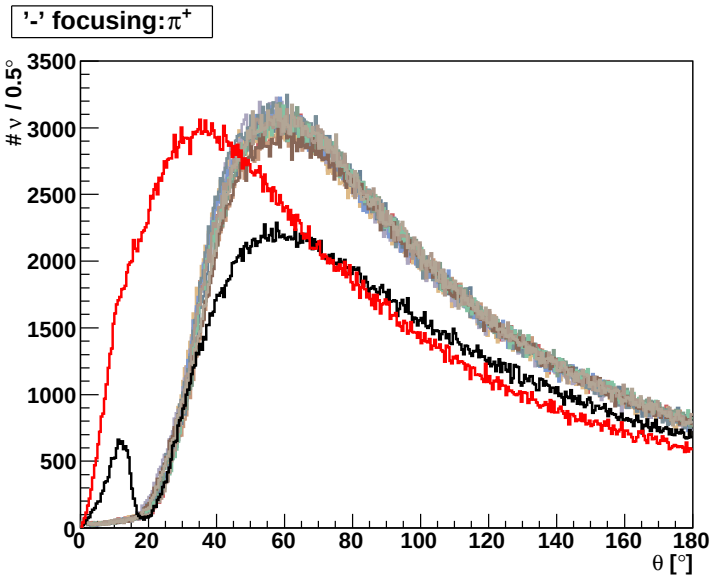


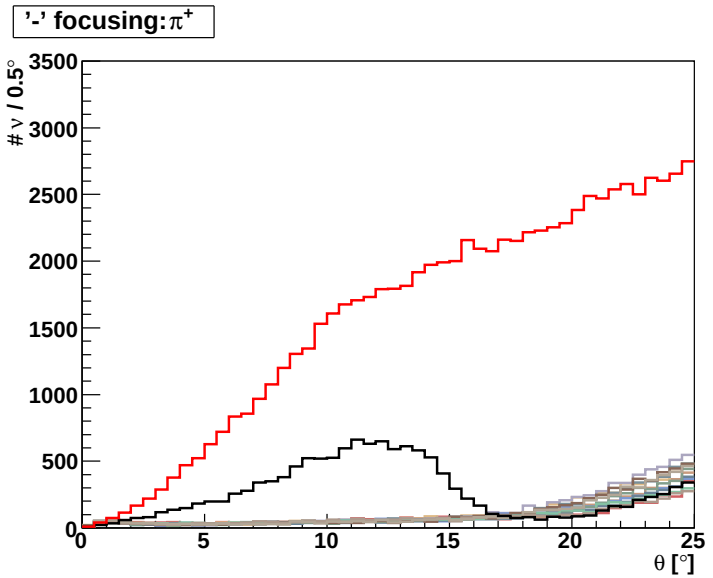
π DECAY POSITIONS (ZOOM) - 13 BEST OF



current decay tunnel: $L^{dt} = 40$ m, $R^{dt} = 2$ m

π POLAR ANGLE AT DECAY POSITIONS

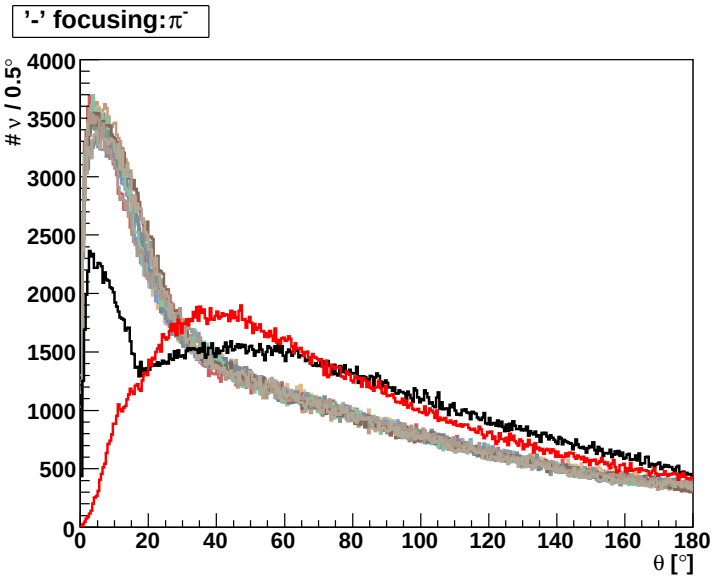


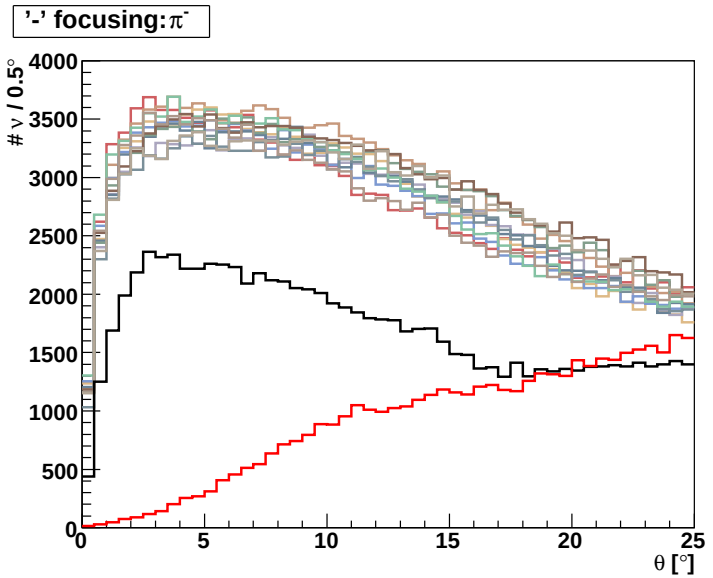


no magn. field

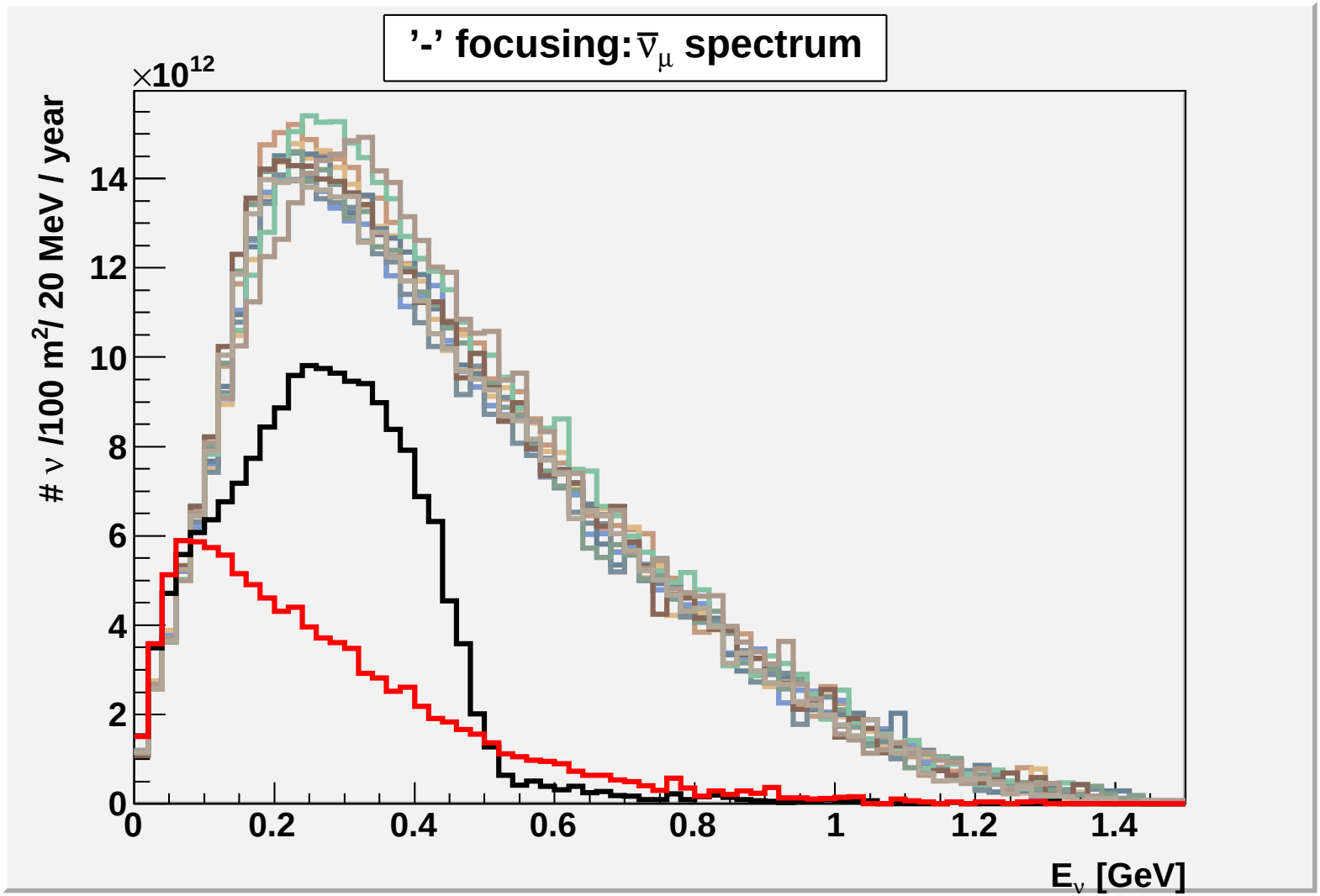
Campagne/Cazes

13 best of





$\bar{\nu}_\mu$ SPECTRUM FROM $\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu$



$\bar{\nu}_\mu$ spectrum in detector (100 m^2) from $\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu$ 2-body decays

need to add decay tunnel, beam dump and 3-body decays