Target simulations for SPL-Superbeam

Comparative studies with FLUKA

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SETUP – MATERIALS

A comparative study of low- and high-Z target materials

Z	ρ $[g/cm^3]$	λ_I $[g/cm^2]$	λ_I/ρ $[cm]$
Be	1.85	77.8	42.1
C	1.85	85.8	46.4
Al	2.7	107.2	39.7
AlBeMet$^{*)}$	2.1		
Ta	16.69	191.0	11.4
W	19.25	191.9	10.0
Hg	13.546	197.5	14.6

$^{*)}$ AlBeMet $=$ 61% Be, 38% Al, 1% O (mass fraction)

Setup – FLUKA + Target

Simulations with FLUKA

- using latest FLUKA (Oct. 2009) - default parameter set
- scoring # of secondary particles when exiting target surface

Target and parameters

Target geometry ⇒ cylinder centered around beam axis ($= +z$-axis)

- Z . . . target material
- $L[cm]$ . . . target length
- $R[cm]$ . . . target radius
- $E_k[GeV]$ . . . p^+-beam kinetic energy
- $\sigma[cm]$ . . . width of gaussian beam profile

Reference target (used by Andrea Longhin)

$$Z = \text{C}, \quad L = 78\,cm, \quad R = 1.5\,cm, \quad E_k = 4.5\,GeV, \quad \sigma = 0.0\,cm$$

2NDY PARTICLE IDS AND MULTIPLICITIES

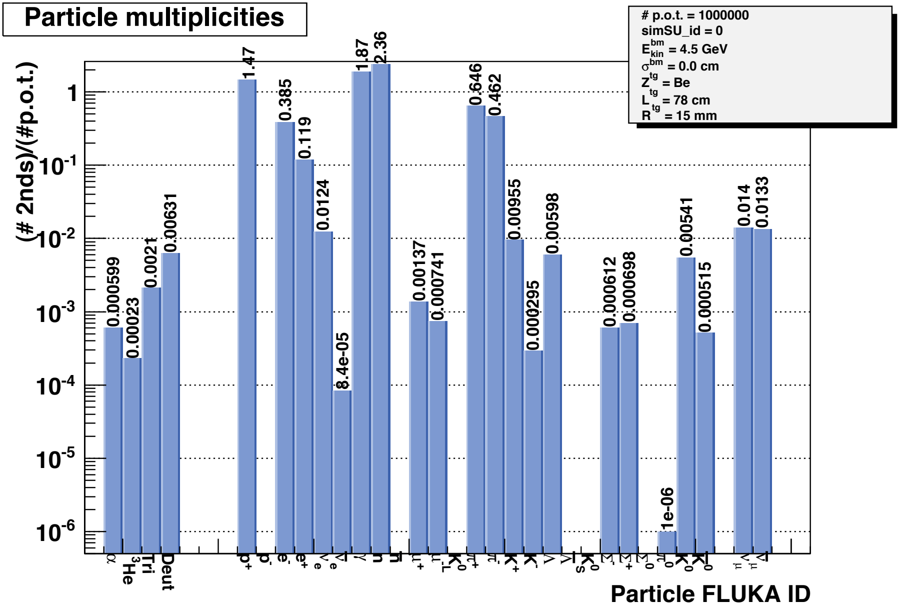
MULTIPLICITY

$$\text{particle multiplicity of type } j = \frac{\#\text{ of 2ndy particles type } j}{\#\text{ of p.o.t}}$$

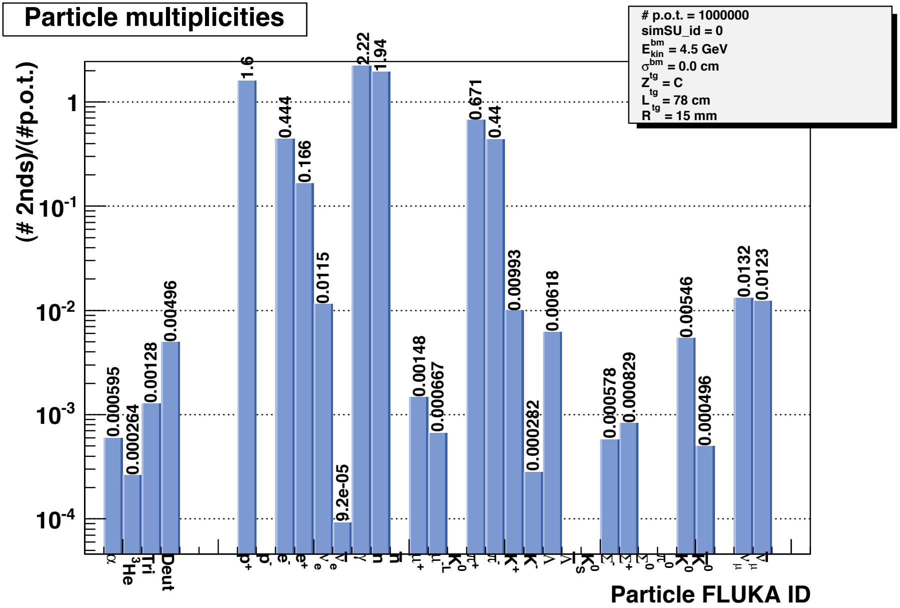
IDS OF 2NDY PARTICLES EXITING TARGET

- light nuclear boundstates: α, ^{3}He, Tritium and Deuterium
- light baryons: p, n, Λ, Σ
- light mesons: π, K
- leptons, neutrinos and photons: e, μ, ν_e, ν_μ, γ

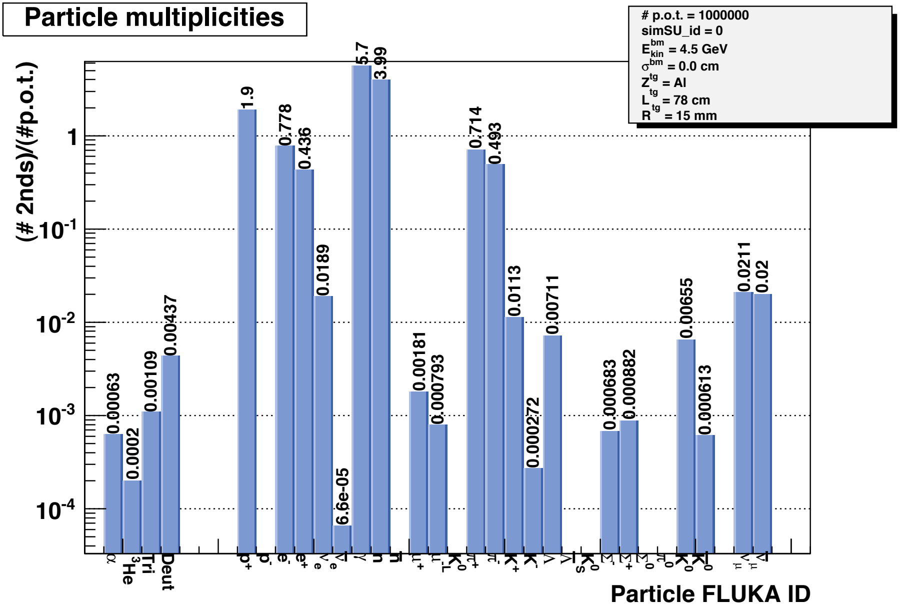
2NDY PARTICLE IDS AND MULTIPLICITIES – BE



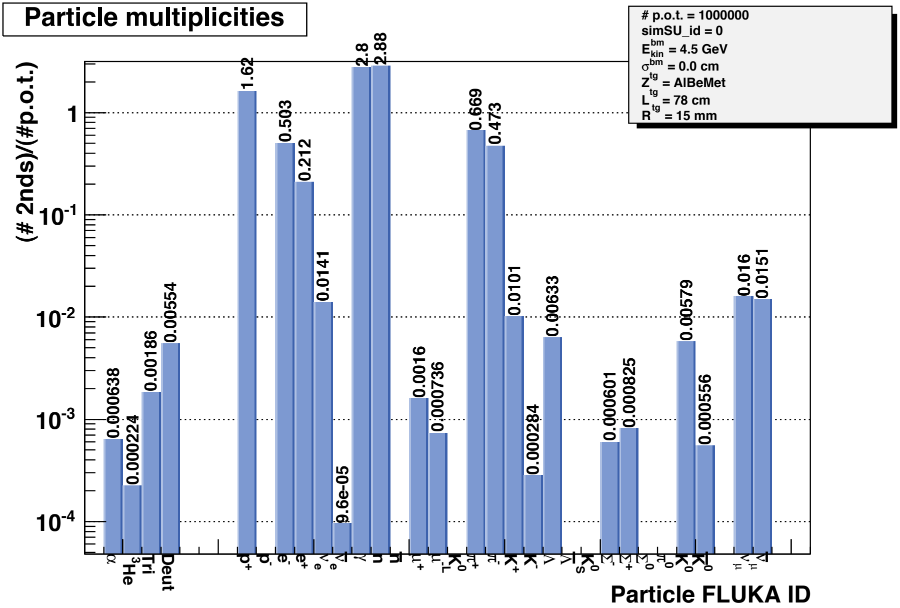
2NDY PARTICLE IDs AND MULTIPLICITIES – C



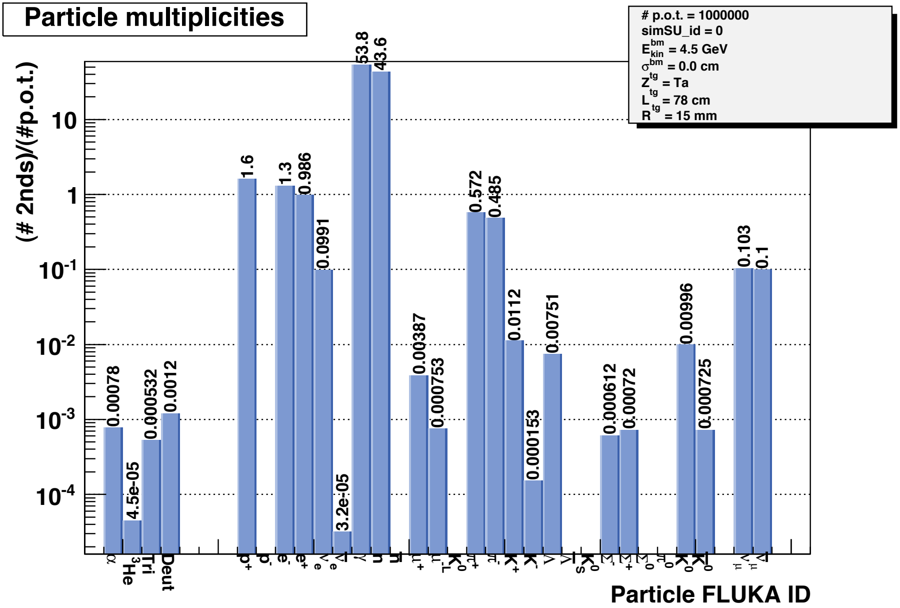
2NDY PARTICLE IDS AND MULTIPLICITIES – AL



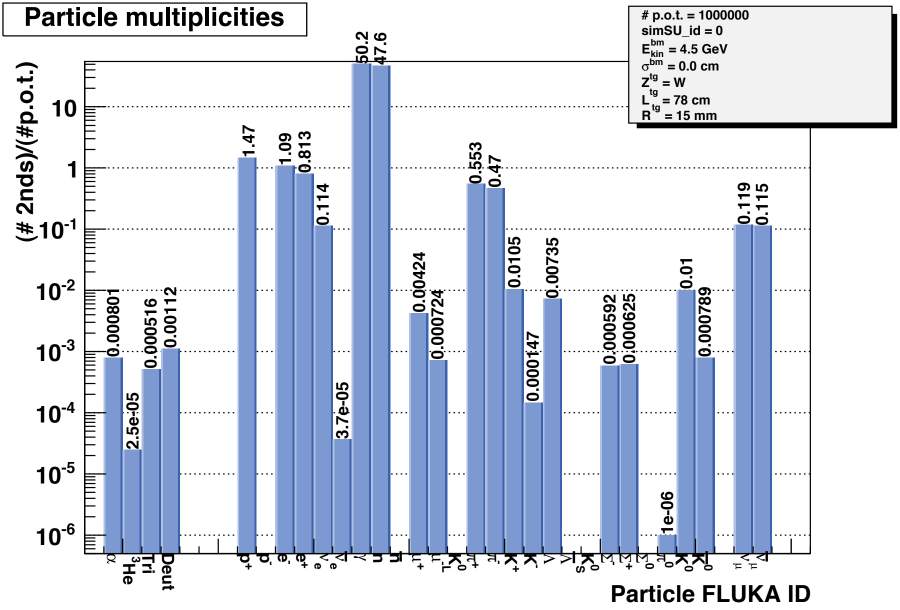
2NDY PARTICLE IDS AND MULTIPLICITIES – ALBEMET



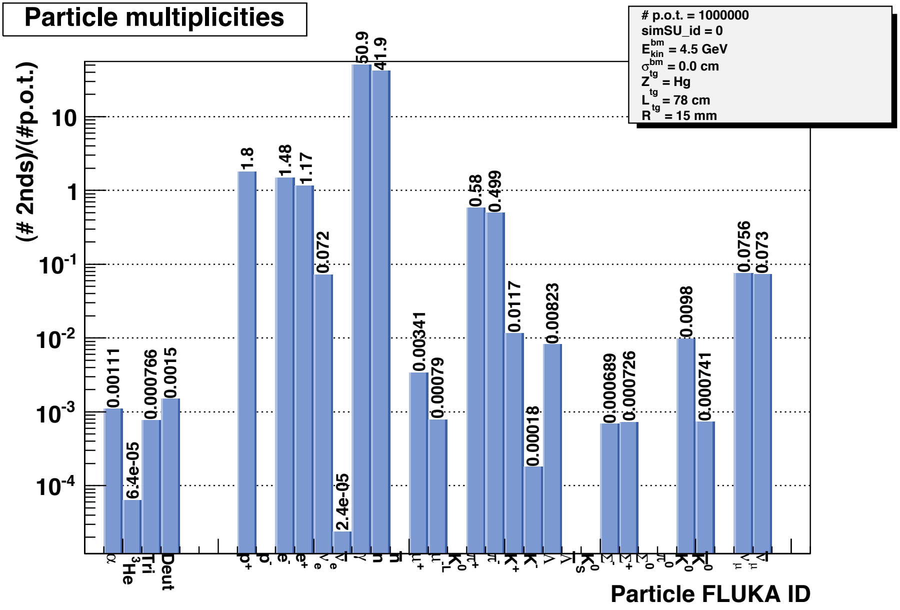
2NDY PARTICLE IDS AND MULTIPLICITIES – TA



2NDY PARTICLE IDS AND MULTIPLICITIES – W



2NDY PARTICLE IDS AND MULTIPLICITIES – HG



MULTIPLICITIES

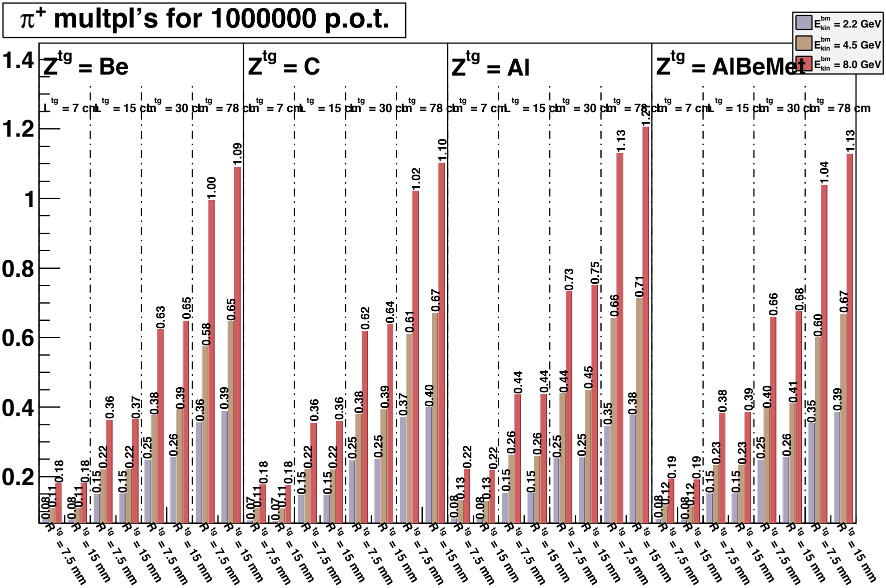
Comparing total multiplicities for $\{\pi^+, \pi^-, p^+, n, \gamma\}$ varying

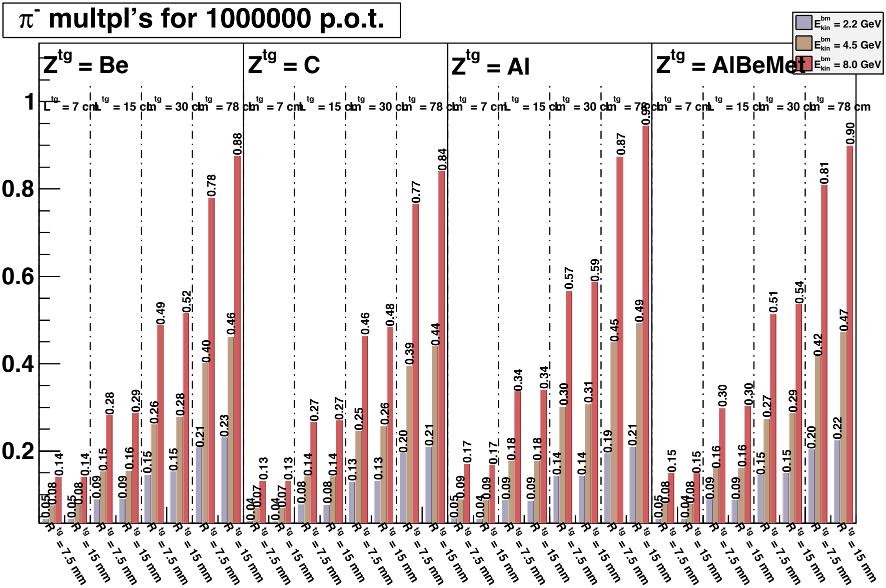
- $Z \in \{\text{Be, C, Al, AlBeMet, Ta, W, Hg}\}$
- $L \in \{7,\ 15,\ 30,\ 78\}$ *cm*
- $R \in \{0.75,\ 1.5\}$ *cm*
- $E_k \in \{2.2,\ 4.5,\ 8.0\}$ *GeV*

FIXED BEAM POWER 4 *MW* YIELDS

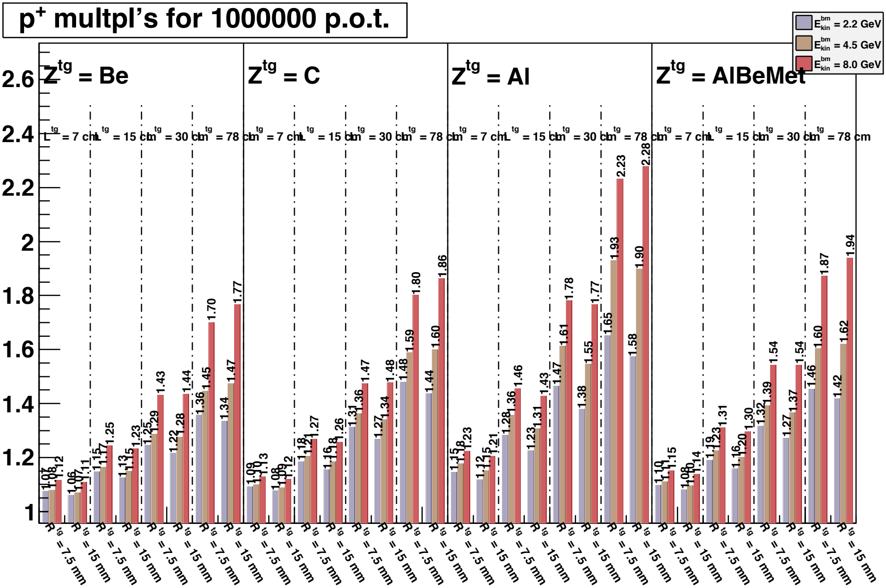
E_k [*GeV*]	p.o.t/s $\times 10^{16}$	p.o.t/pulse $\times 10^{14}$ at 50 *Hz*	factor
2.2	1.14	2.27	2.04
4.5	0.56	1.11	1.00
8.0	0.31	0.63	0.55

LOW-Z – π^+


π+ multpl's for 1000000 p.o.t.
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV
Z^{tg} = Be
Z^{tg} = C
Z^{tg} = Al
Z^{tg} = AlBeMet
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
1.4
1.2
1
0.8
0.6
0.4
0.2
0.08 0.11 0.18 0.08 0.11 0.18 0.15 0.22 0.36 0.15 0.22 0.37 0.25 0.38 0.63 0.26 0.39 0.65 0.36 0.58 1.00 0.39 0.65 1.09
0.07 0.11 0.18 0.07 0.11 0.18 0.15 0.22 0.36 0.15 0.22 0.36 0.25 0.38 0.62 0.25 0.39 0.64 0.37 0.61 1.02 0.40 0.67 1.10
0.08 0.13 0.22 0.08 0.13 0.22 0.15 0.26 0.44 0.15 0.26 0.44 0.25 0.44 0.73 0.25 0.45 0.75 0.35 0.66 1.13 0.38 0.71
0.08 0.12 0.19 0.08 0.12 0.19 0.15 0.23 0.38 0.15 0.23 0.39 0.25 0.40 0.66 0.26 0.41 0.68 0.35 0.60 1.04 0.39 0.67 1.13

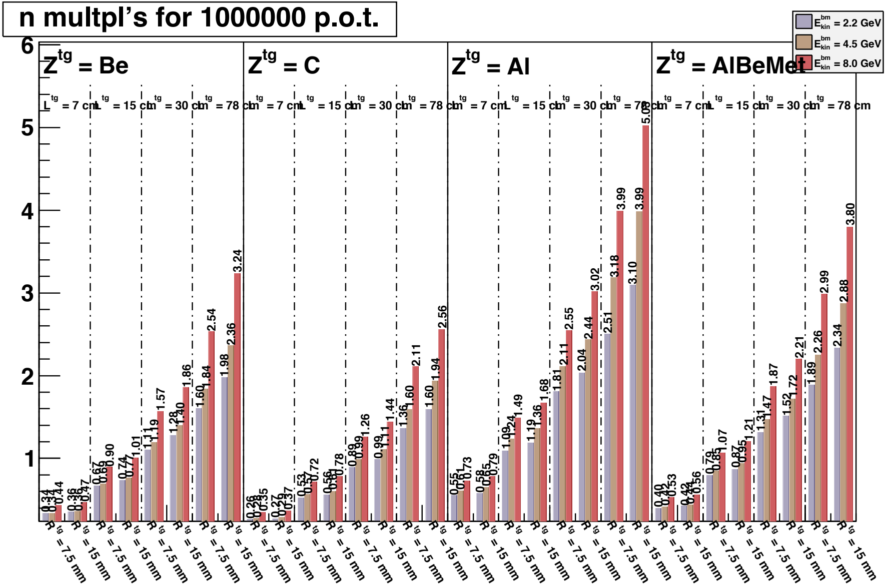

π- multpl's for 1000000 p.o.t.
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV
Z^{tg} = Be
Z^{tg} = C
Z^{tg} = Al
Z^{tg} = AlBeMet
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
0.2
0.4
0.6
0.8
1
0.05 0.08 0.14 0.05 0.08 0.14 0.09 0.15 0.28 0.09 0.16 0.29 0.15 0.26 0.49 0.15 0.28 0.52 0.21 0.40 0.78 0.23 0.46 0.88
0.04 0.07 0.13 0.04 0.07 0.13 0.08 0.14 0.27 0.08 0.14 0.27 0.13 0.25 0.46 0.13 0.26 0.48 0.20 0.39 0.77 0.21 0.44 0.84
0.05 0.09 0.17 0.04 0.09 0.17 0.09 0.18 0.34 0.09 0.18 0.34 0.14 0.30 0.57 0.14 0.31 0.59 0.19 0.45 0.87 0.21 0.49 0.9
0.05 0.08 0.15 0.04 0.08 0.15 0.09 0.16 0.30 0.09 0.16 0.30 0.15 0.27 0.51 0.15 0.29 0.54 0.20 0.42 0.81 0.22 0.47 0.90

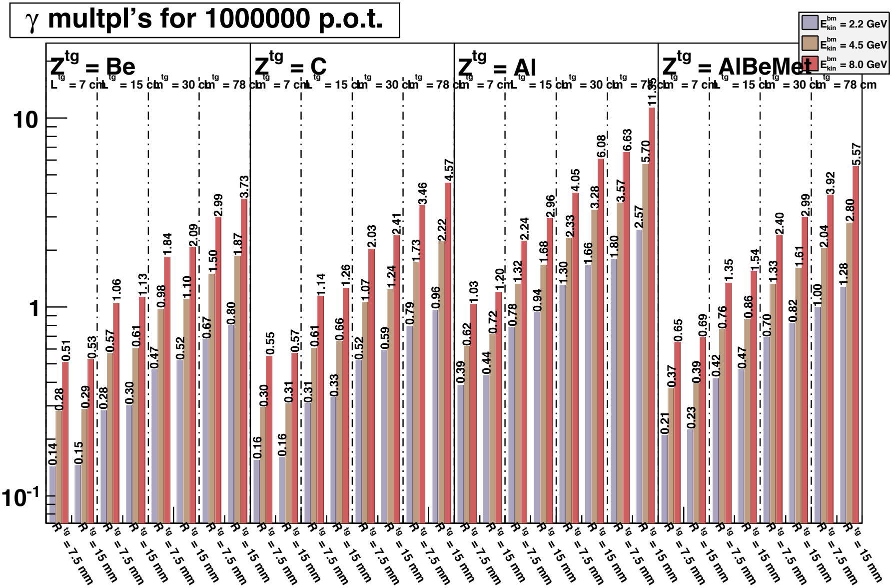
LOW-Z – p^+



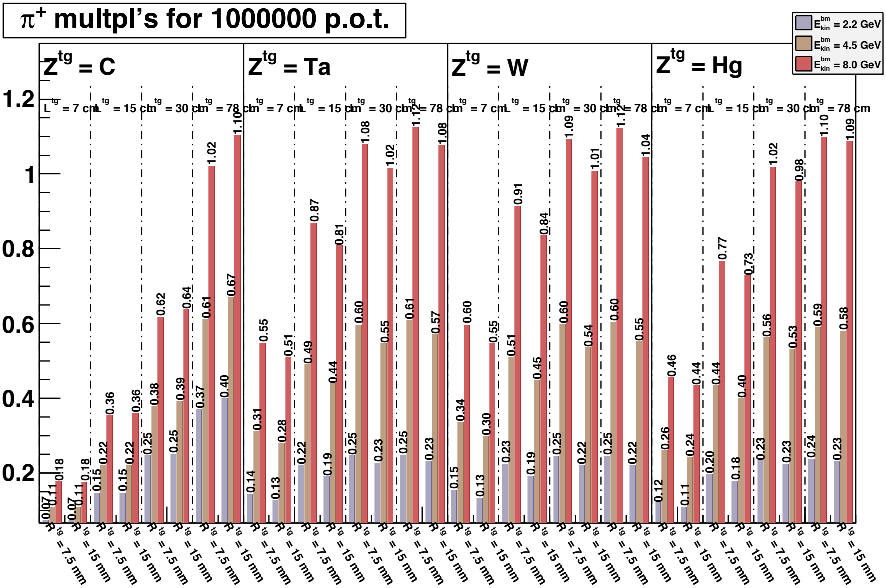
p⁺ multpl's for 1000000 p.o.t.
Z^tg = Be
Z^tg = C
Z^tg = Al
Z^tg = AlBeMet
E_kin^bm = 2.2 GeV
E_kin^bm = 4.5 GeV
E_kin^bm = 8.0 GeV
L^tg = 7 cm
L^tg = 15 cm
L^tg = 30 cm
L^tg = 78 cm
R^tg = 7.5 mm
R^tg = 15 mm

LOW-Z – n

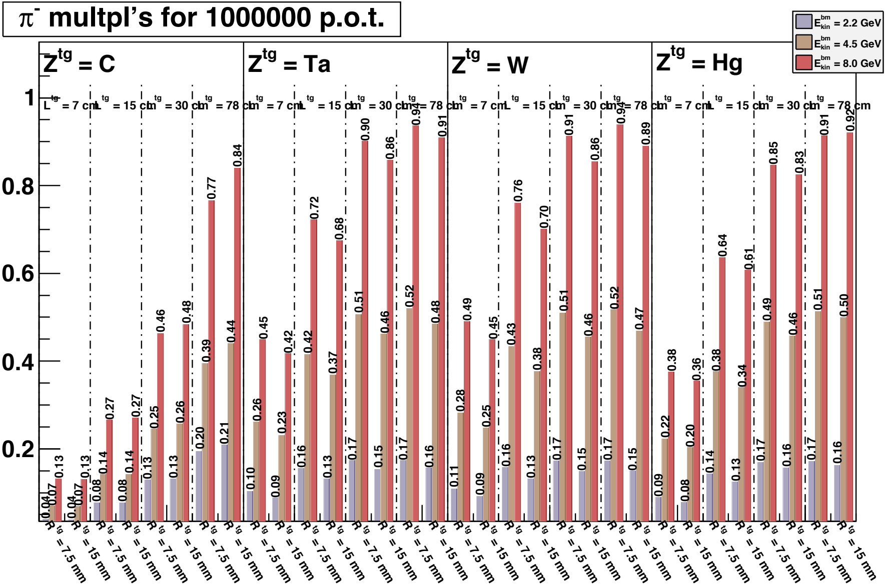

n multpl's for 1000000 p.o.t.
Z^{tg} = Be
Z^{tg} = C
Z^{tg} = Al
Z^{tg} = AlBeMet
E^{bm}_{kin} = 2.2 GeV
E^{bm}_{kin} = 4.5 GeV
E^{bm}_{kin} = 8.0 GeV
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
1
2
3
4
5
6


γ multpl's for 1000000 p.o.t.
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV
Z^{tg} = Be
Z^{tg} = C
Z^{tg} = Al
Z^{tg} = AlBeMet
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
10
1
10^{-1}
0.14 0.28 0.51 0.15 0.29 0.53 0.28 0.57 1.06 0.30 0.61 1.13 0.47 0.98 1.84 0.52 1.10 2.09 0.67 1.50 2.99 0.80 1.87 3.73
0.16 0.30 0.55 0.16 0.31 0.57 0.31 0.61 1.14 0.33 0.66 1.26 0.52 1.07 2.03 0.59 1.24 2.41 0.79 1.73 3.46 0.96 2.22 4.57
0.39 0.62 1.03 0.44 0.72 1.20 0.78 1.32 2.24 0.94 1.68 2.96 1.30 2.33 4.05 1.66 3.28 6.08 1.80 3.57 6.63 2.57 5.70 11.3
0.21 0.37 0.65 0.23 0.39 0.69 0.42 0.76 1.35 0.47 0.86 1.54 0.70 1.33 2.40 0.82 1.61 2.99 1.00 2.04 3.92 1.28 2.80 5.57

HIGH-$Z - \pi^+$

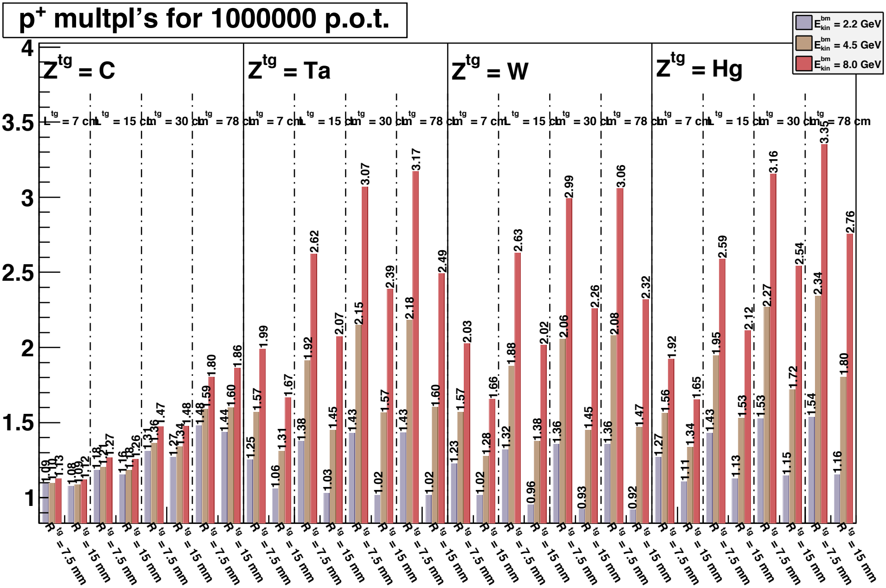

π^+ multpl's for 1000000 p.o.t.
Z^{tg} = C
Z^{tg} = Ta
Z^{tg} = W
Z^{tg} = Hg
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV

HIGH-$Z - \pi^-$



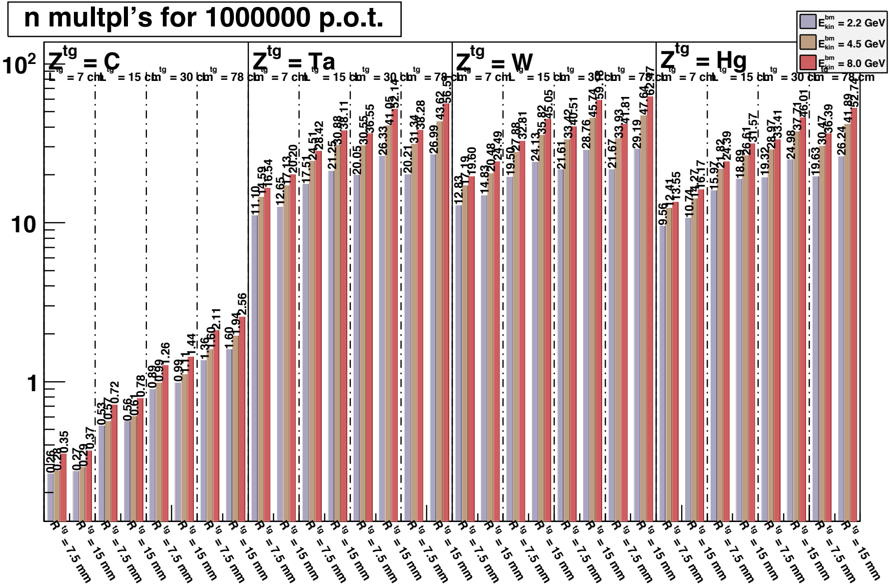
π⁻ multpl's for 1000000 p.o.t.
E_kin^bm = 2.2 GeV
E_kin^bm = 4.5 GeV
E_kin^bm = 8.0 GeV
Z^tg = C
Z^tg = Ta
Z^tg = W
Z^tg = Hg
L^tg = 7 cm
L^tg = 15 cm
L^tg = 30 cm
L^tg = 78 cm
R^tg = 7.5 mm
R^tg = 15 mm
0.2
0.4
0.6
0.8
1
0.04 0.07 0.13
0.04 0.07 0.13
0.08 0.14 0.27
0.08 0.14 0.27
0.13 0.25 0.46
0.13 0.26 0.48
0.20 0.39 0.77
0.21 0.44 0.84
0.10 0.26 0.45
0.09 0.23 0.42
0.16 0.42 0.72
0.13 0.37 0.68
0.17 0.51 0.90
0.15 0.46 0.86
0.17 0.52 0.94
0.16 0.48 0.91
0.11 0.28 0.49
0.09 0.25 0.45
0.16 0.43 0.76
0.13 0.38 0.70
0.17 0.51 0.91
0.15 0.46 0.86
0.17 0.52 0.94
0.15 0.47 0.89
0.09 0.22 0.38
0.08 0.20 0.36
0.14 0.38 0.64
0.13 0.34 0.61
0.17 0.49 0.85
0.16 0.46 0.83
0.17 0.51 0.91
0.16 0.50 0.92

HIGH-$Z - p^+$

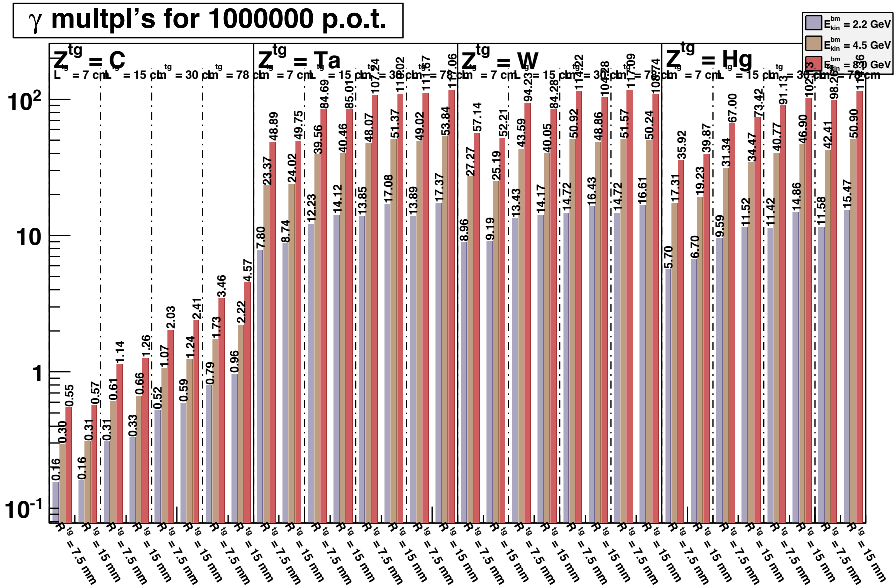


p^+ multpl's for 1000000 p.o.t.
E^{bm}_{kin} = 2.2 GeV
E^{bm}_{kin} = 4.5 GeV
E^{bm}_{kin} = 8.0 GeV
Z^{tg} = C
Z^{tg} = Ta
Z^{tg} = W
Z^{tg} = Hg
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm

HIGH-Z – n



n multpl's for 1000000 p.o.t.
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV
Z^{tg} = C
Z^{tg} = Ta
Z^{tg} = W
Z^{tg} = Hg
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
10^2
10
1


γ multpl's for 1000000 p.o.t.
E_{kin}^{bm} = 2.2 GeV
E_{kin}^{bm} = 4.5 GeV
E_{kin}^{bm} = 8.0 GeV
Z^{tg} = C
Z^{tg} = Ta
Z^{tg} = W
Z^{tg} = Hg
L^{tg} = 7 cm
L^{tg} = 15 cm
L^{tg} = 30 cm
L^{tg} = 78 cm
R^{tg} = 7.5 mm
R^{tg} = 15 mm
10^2
10
1
10^{-1}

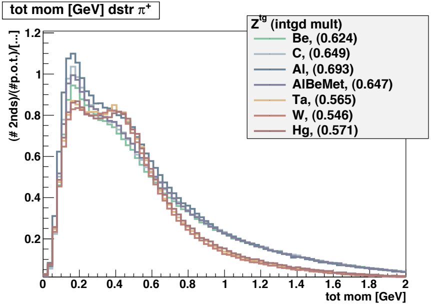
DIFFERENTIAL MULTIPLICITIES

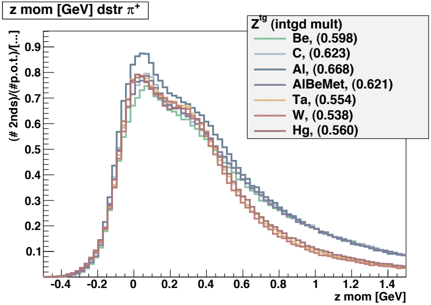
Differential multiplicities w.r.t

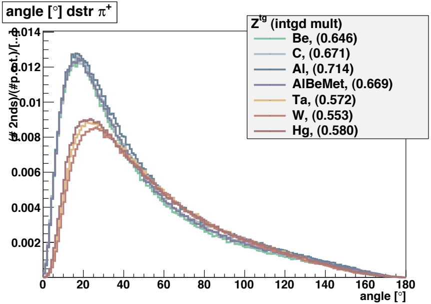
- momentum of 2ndy particle
- angle of momentum of 2ndy particle w.r.t. beam-axis
- *z*-position when exiting the target

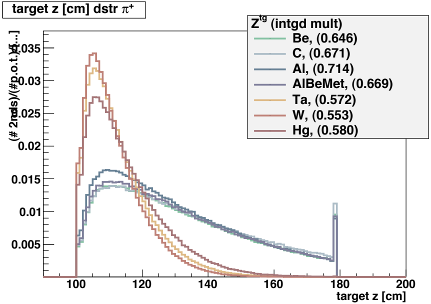
for reference target and $\{\pi^+, \pi^-, p^+, n, \gamma\}$

DIFFERENTIAL MULTIPLICITIES – π^+

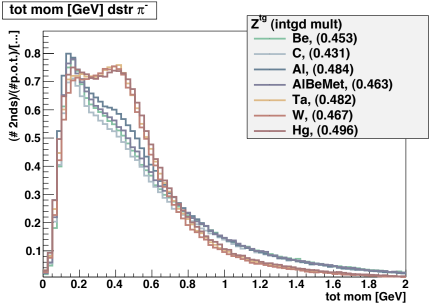


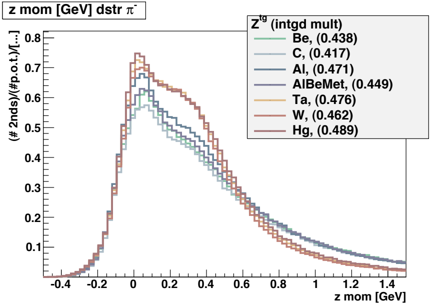


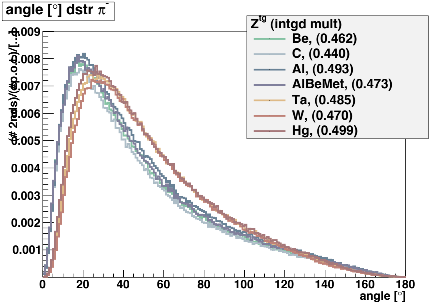


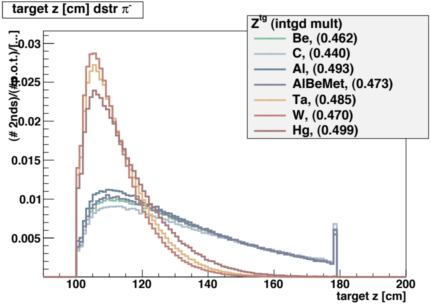


DIFFERENTIAL MULTIPLICITIES – π^-

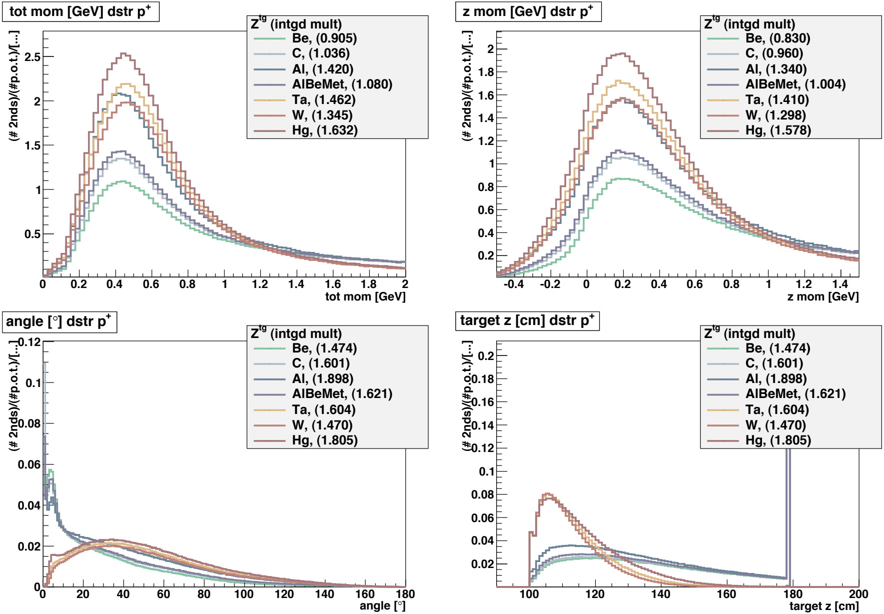




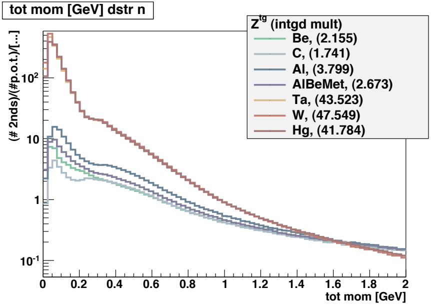


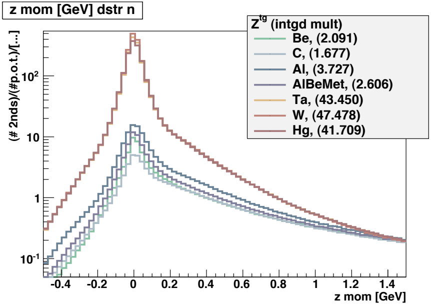


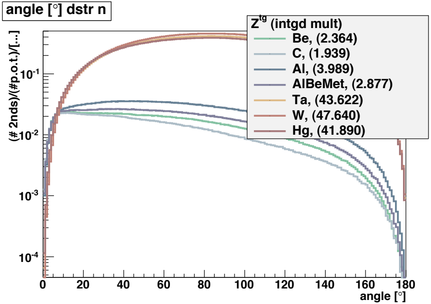
Differential multiplicities – p^+

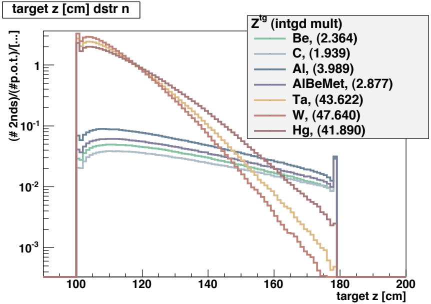


DIFFERENTIAL MULTIPLICITIES – *n*

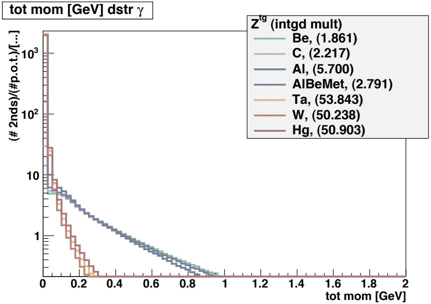


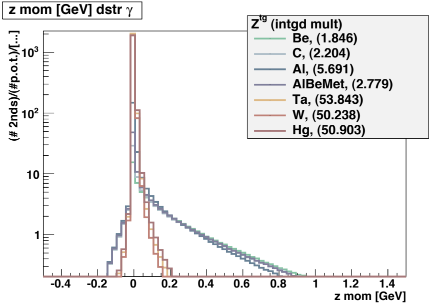


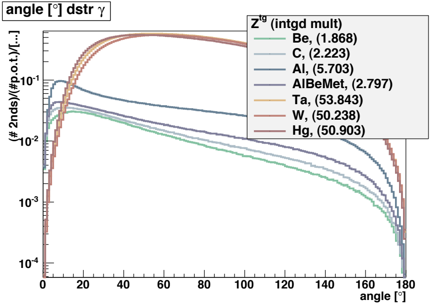


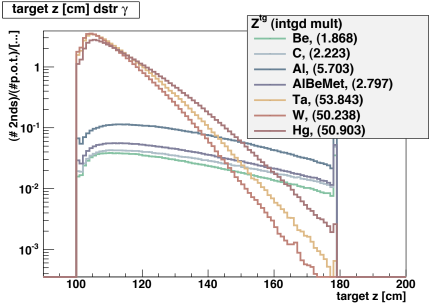


DIFFERENTIAL MULTIPLICITIES – γ







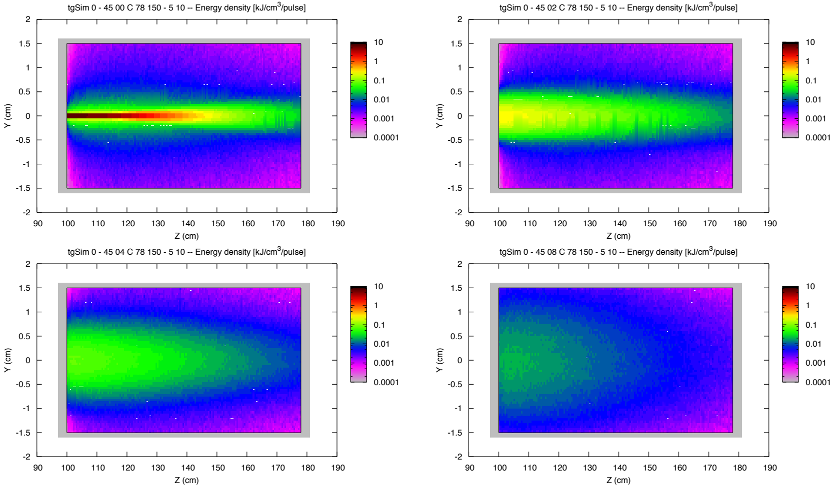


ENERGY DEPOSITION

Remember, that at 4 *MW* and 50 *Hz* for $E = 4.5\,GeV$ ...

... 0.56×10^{16} p.o.t/s and 1.11×10^{14} p.o.t/pulse

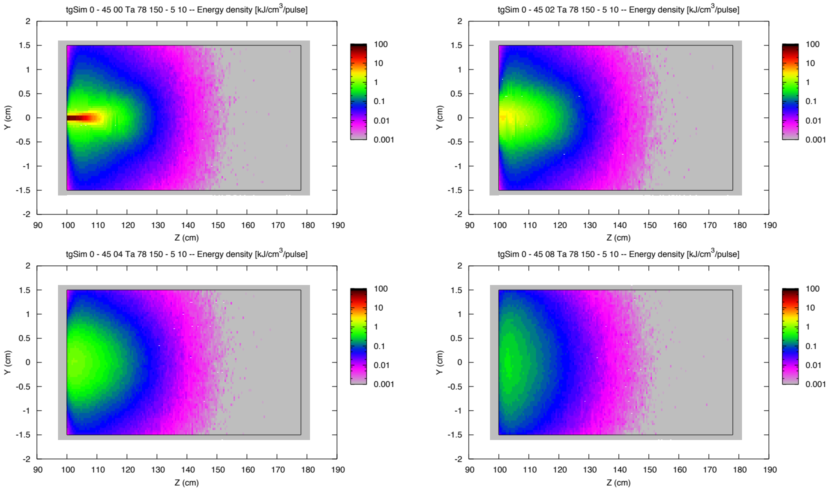
ENERGY DENSITY – C



for beam width $\sigma \in \{0.0,\ 0.2,\ 0.4,\ 0.8\}\mathit{cm}$

similar for {Be, Al, AlBeMet}

ENERGY DENSITY – TA



for beam width $\sigma \in \{0.0,\ 0.2,\ 0.4,\ 0.8\} cm$

One order higher then for C!

Deposited energy/pulse and power for beam width $\sigma = 0.0$ *cm*

Z	$E/pulse$ [$kJ/pulse$]	P [kW]
Be	3.39	169.5
C	4.03	201.5
Al	5.73	286.6
AlBeMet	4.09	204.8
Ta	23.6	1180
W	25.4	1272
Hg	20.7	1036

For beam width $\sigma = 0.4$ *cm* (0.8 *cm*) deposited power drops to 97 % (72-75 %) compared to $\sigma = 0.0$ *cm*

SUMMARY

	low-Z	high-Z
$L \sim 2\lambda_I$	(80 - 90) cm	(20 - 30) cm
pi^+	0.65 - 0.71	0.55 - 0.58
pi^-	0.44 - 0.49	0.47 - 0.50
pi^- / pi^+	0.66 - 0.72	0.85
$pi^+ \in [0.5, 0.8]$ GeV	0.13 - 0.15	0.13 - 0.14
$pi^- \in [0.5, 0.8]$ GeV	0.09 - 0.11	0.11 - 0.12
pi^- / pi^+	0.66 - 0.72	0.86 - 0.88
n	1.9 - 4.0	42 - 48
γ	1.9 - 5.7	50 - 54
deposited power$^{*)}$	$(170 - 290)\,kW$	$(1000 - 1300)\,kW$

$^{*)}$ for reference target at 4 MW beam power