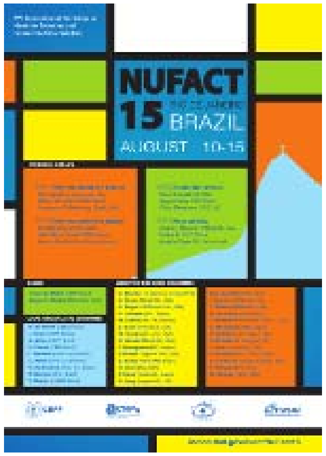
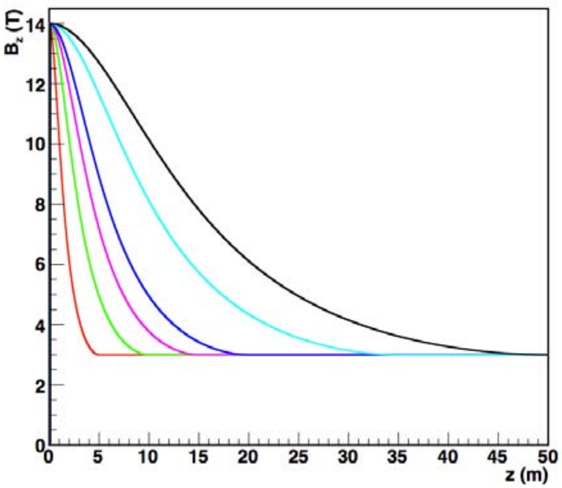
Institute of High Energy Physics
Chinese Academy of Sciences

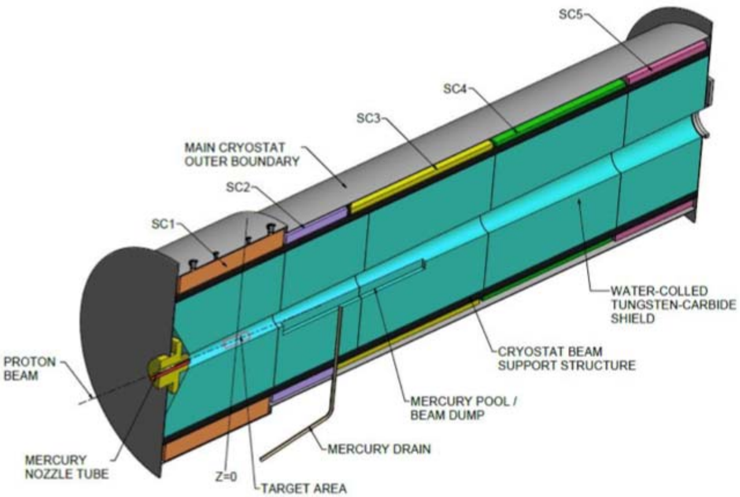


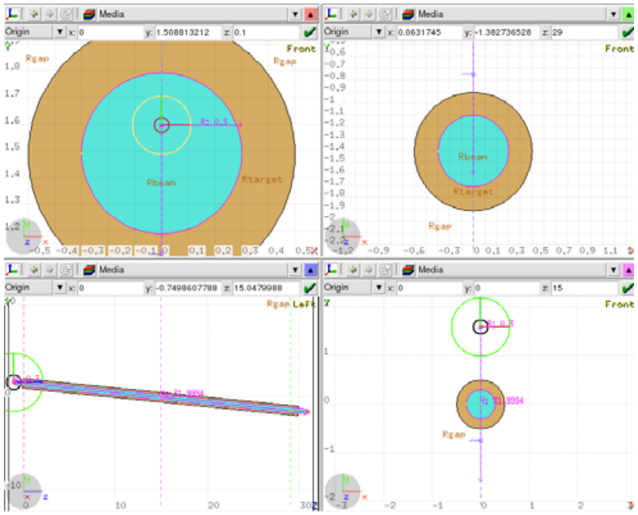
Studies on pion/muon capture at MOMENT

Nikos Vassilopoulos
IHEP, CAS

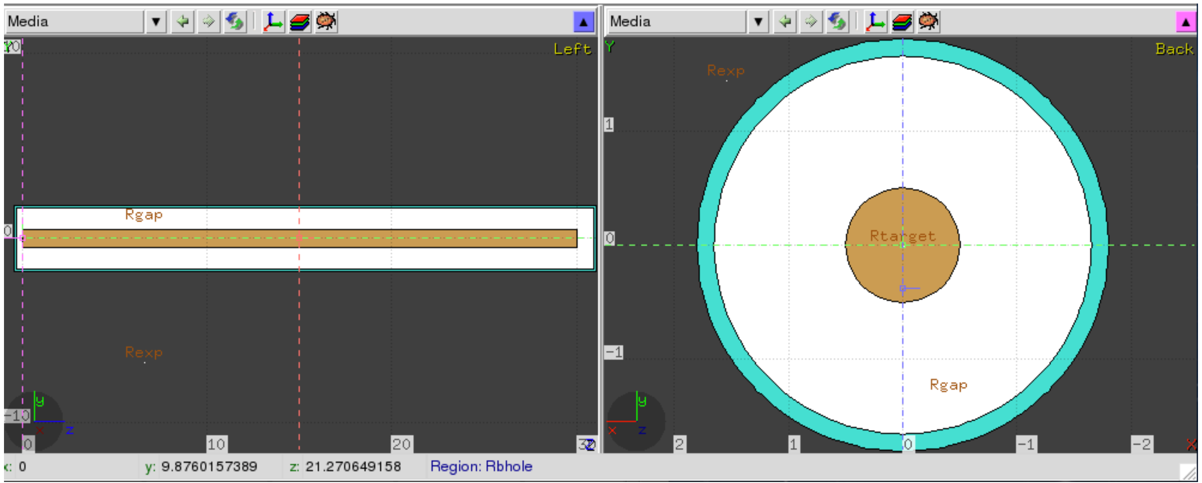
August 11, 2015

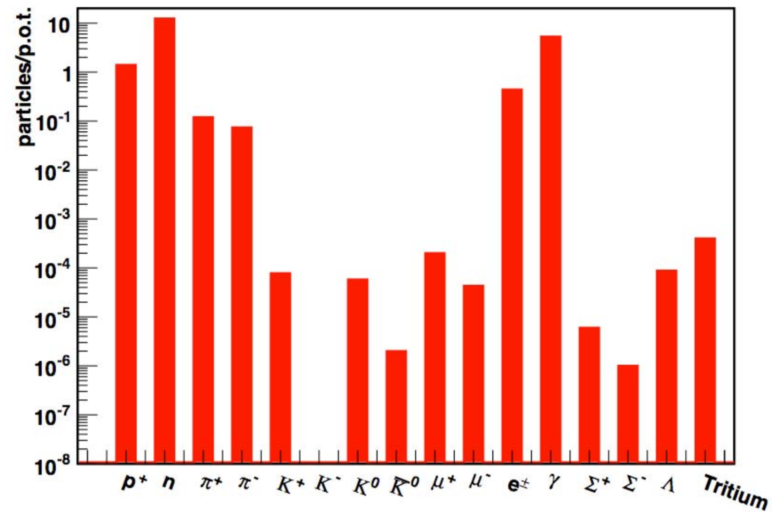






particle production for Hg





MOMENT – Hg, L =30 cm, R = 0.5 cm: current parameters						
σ_b (mm)	π^+	π	μ^+	μ^-	n	p^+
1	0.124	0.075	1.8×10^{-4}	5.3×10^{-5}	12.4	1.38

- E_k = 1.5 GeV
- no field, tilt
- 10^6 p.o.t. -> stat. error <1% for π, n, p and 6, 15% for μ^+, μ^-
- FLUKA 2015

π^+ production and P_T acceptance for adiabatic solenoids

for adiabatic taper solenoid
- B_1=14 T, r_1 = 20 cm
- P_{T1} = 420 MeV/c

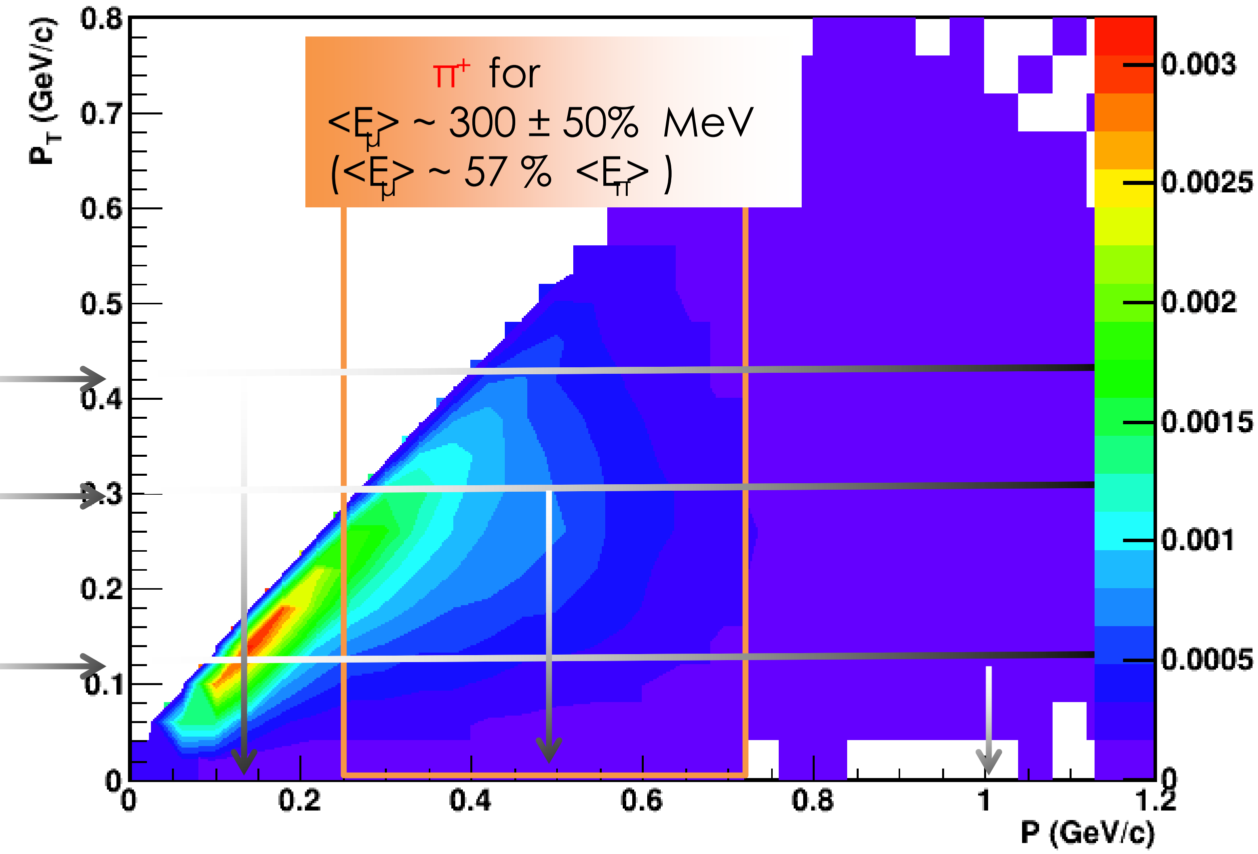
→

- B_2 = 3 T, r_2 = 43 cm
- P_{T2} = 193 MeV/c

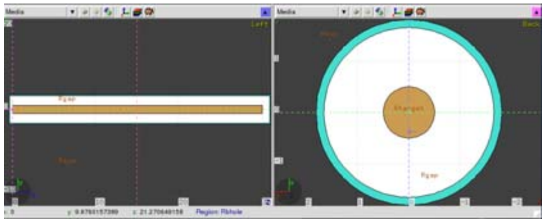
P_T accepted
r_1 = 20 cm, r_2 = 43 cm

P_T accepted
r_1 = 14 cm, r_2 = 30 cm

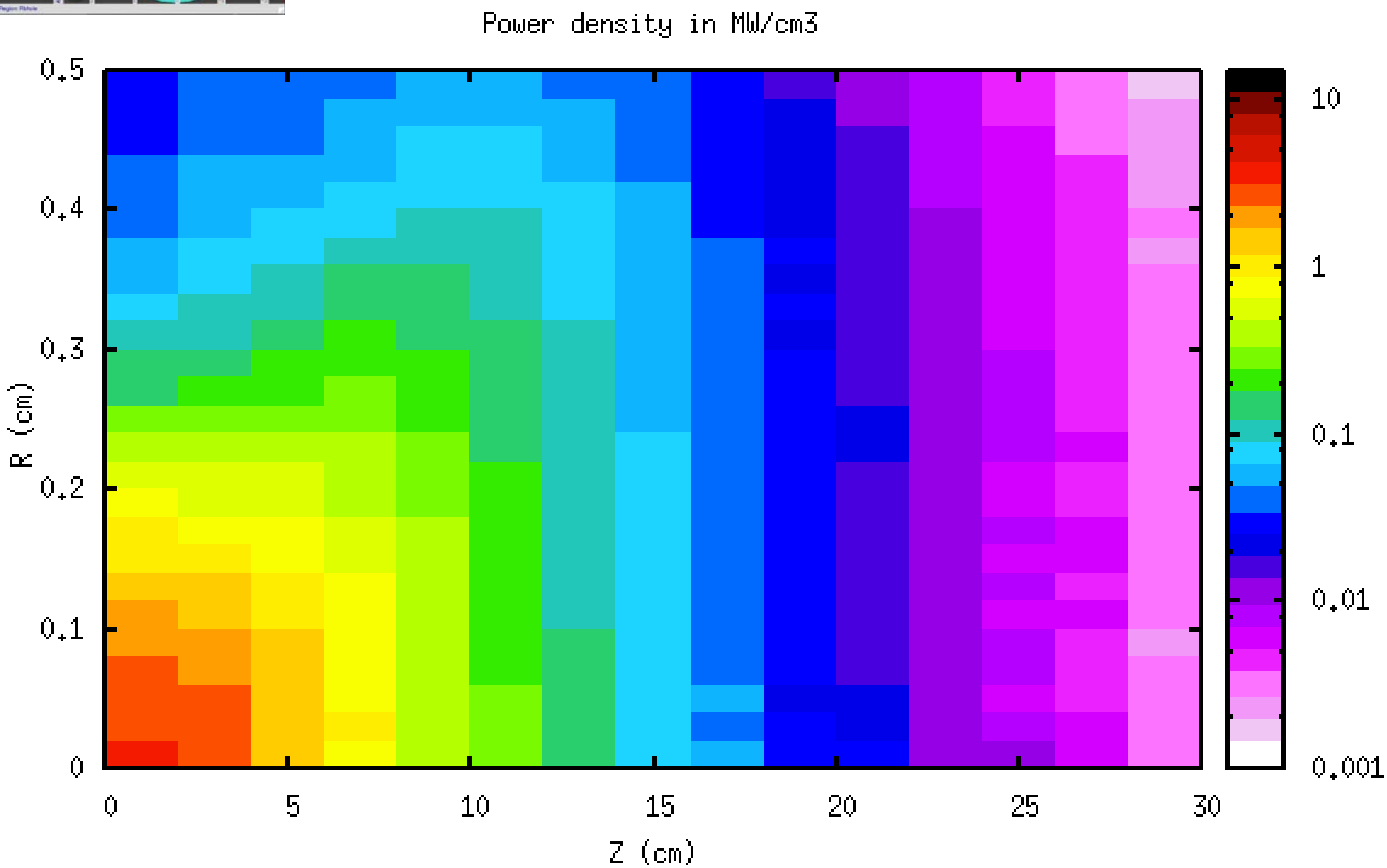
P_T accepted
r_1 = 7 cm, r_2 = 15 cm



FLUKA 2015 (1e6 p.o.t.)



Power on target



$P_{trg} = 2.5$ MW

optimization studies

figure of merit:
π, μ, *p* yields, distributions downstream of:

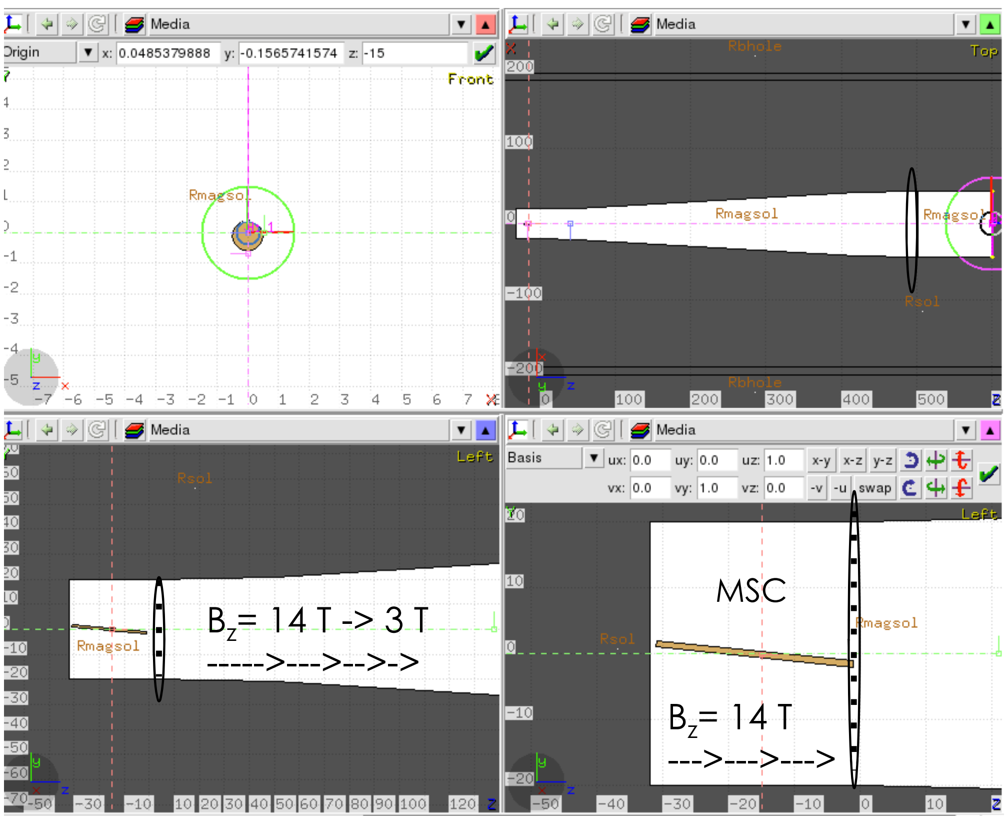
- the Main Capture Solenoid (MSC)
- Adiabatic Transport Solenoid

Main Capture Solenoid
"idealized" field
B = 14 T, L_{MCS}= 32 cm, r_{MCS}= 20 cm

study tilts, lengths, radii, beam-sizes

Gaussian field approximation at MCS

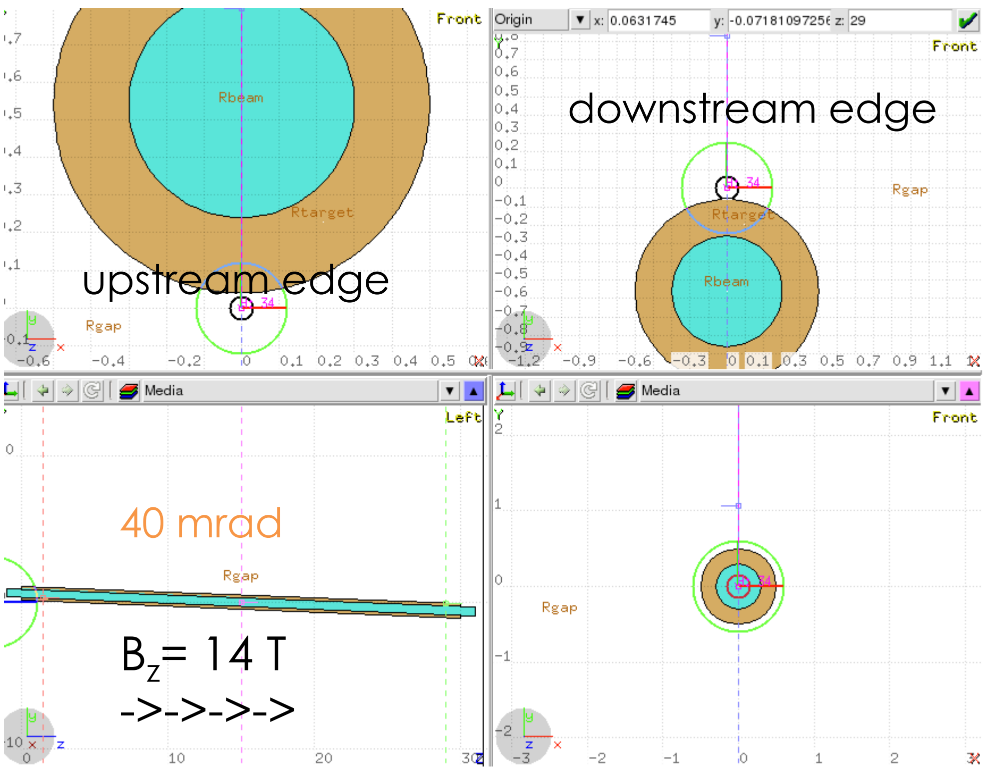
Adiabatic Transport Solenoid
L = 5, 10, 15, 20, 35, 50 m
r = 20 cm - > 43.2 cm
B = 14 T -> 3 T

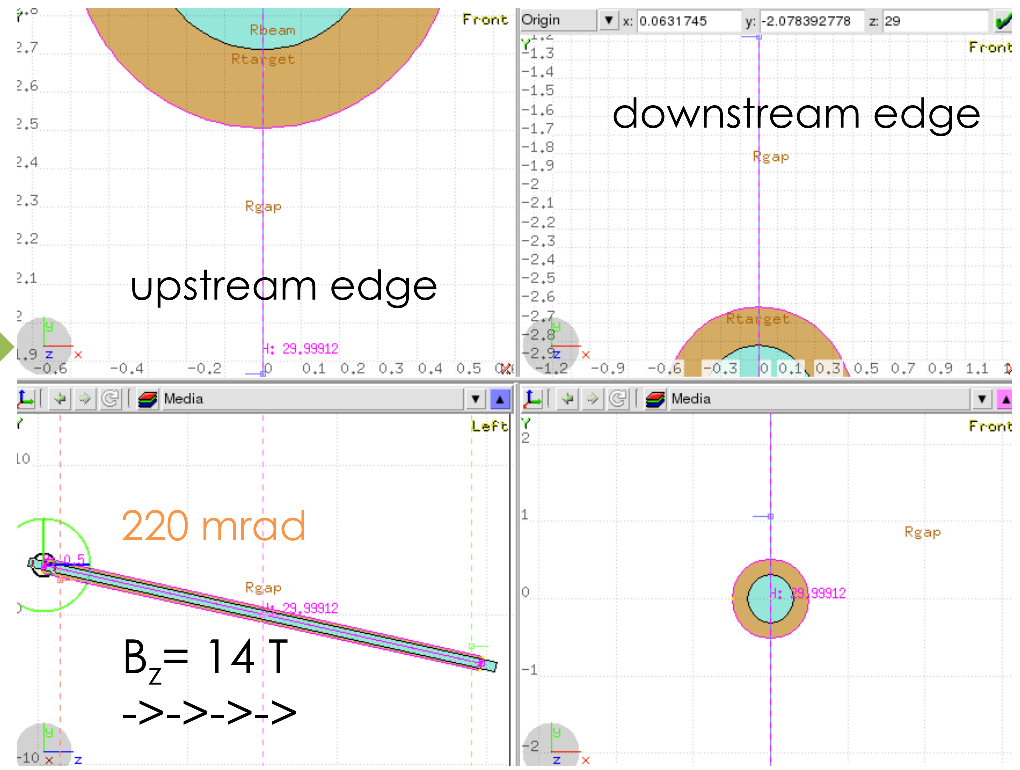


target tilt studies

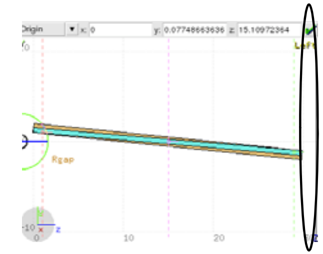
L_{trg}= 30 cm, r_{trg}= 5 mm, σ_b= 1 mm

- π after one helix might hit the target, target tilt needed
- $\lambda_{helix} = \frac{2.1 * P_L(MeV/c)}{B_z(T)} cm$, $r_{helix} = \frac{P_T(MeV/c)}{3 * B_z(T)} cm$





particle yields at the edge of MCS for different tilts



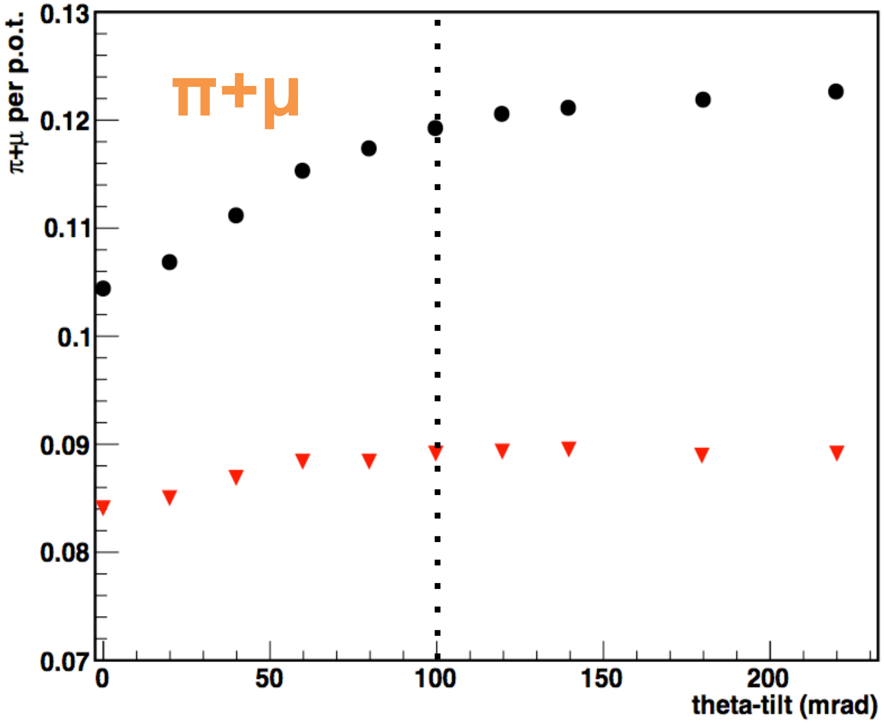
all momenta in black

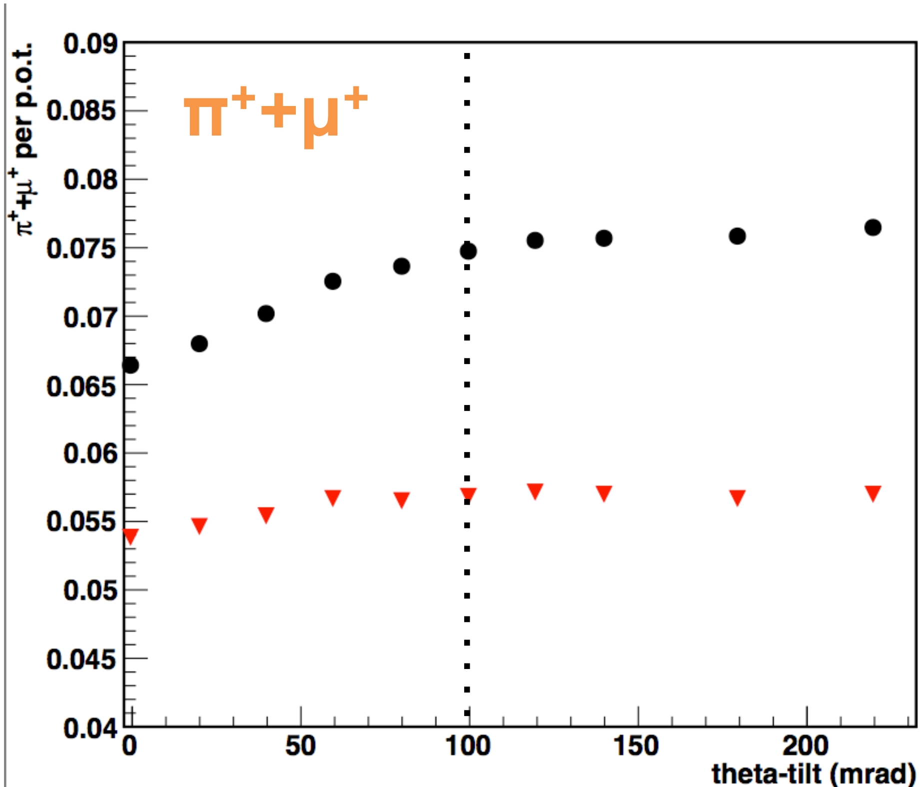
selection in red

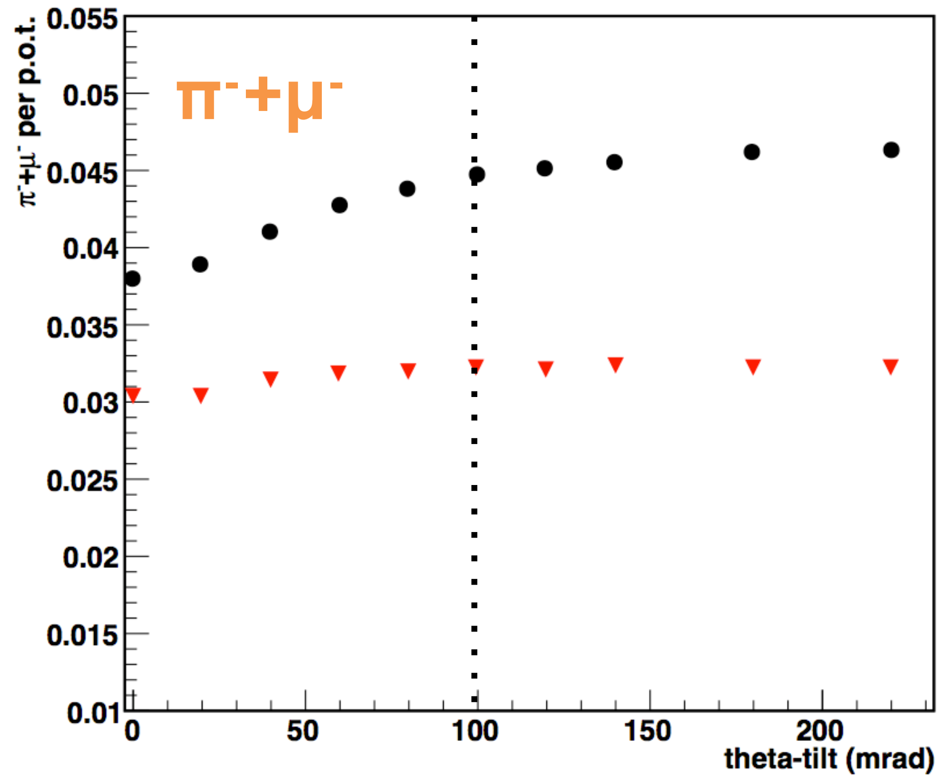
- pions 0.222 < P (GeV/c) < 0.776
- muons 0.111 < P (GeV/c) < 0.438

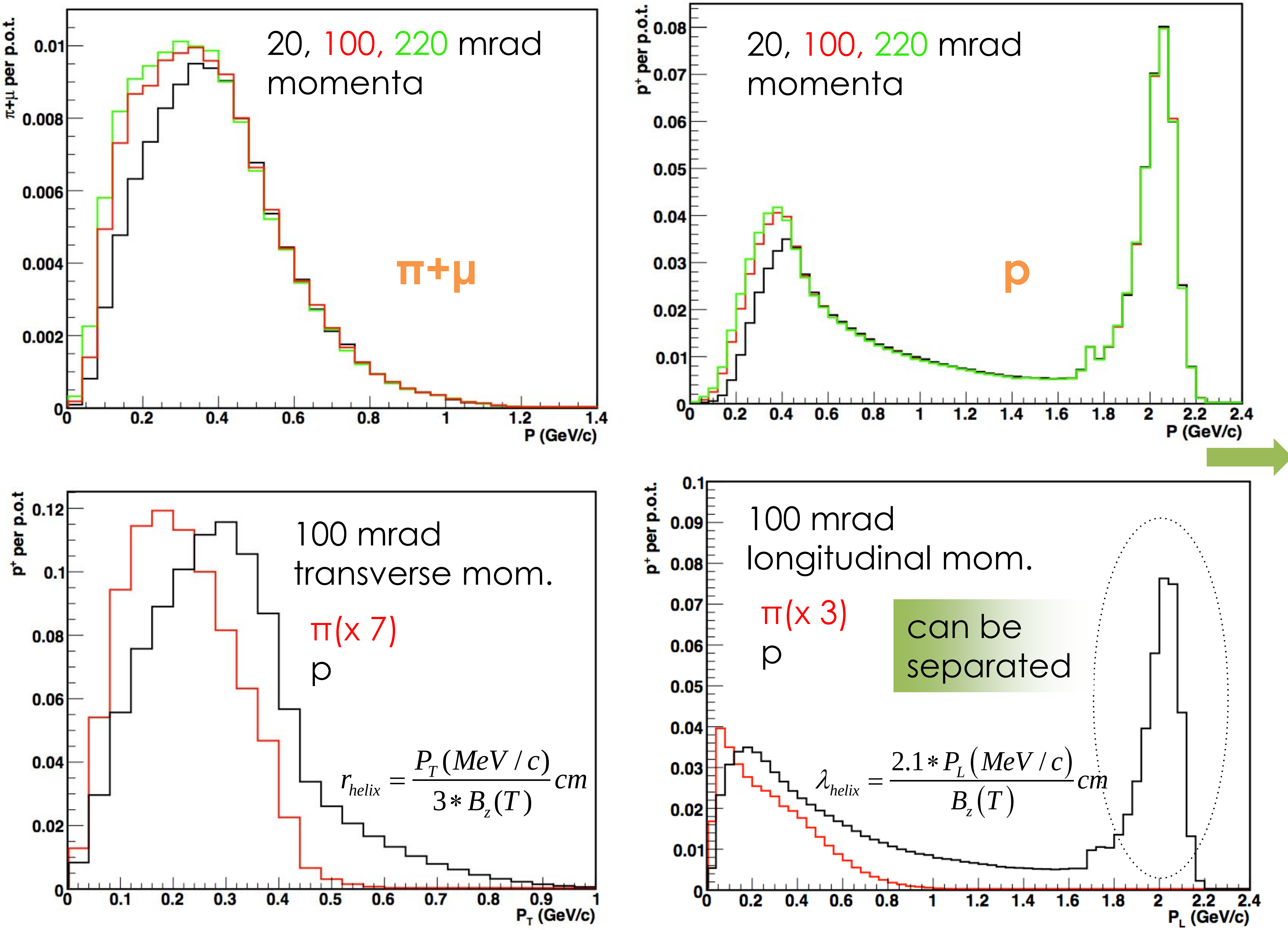
statistical error < 1 %

write the % of pi & mu



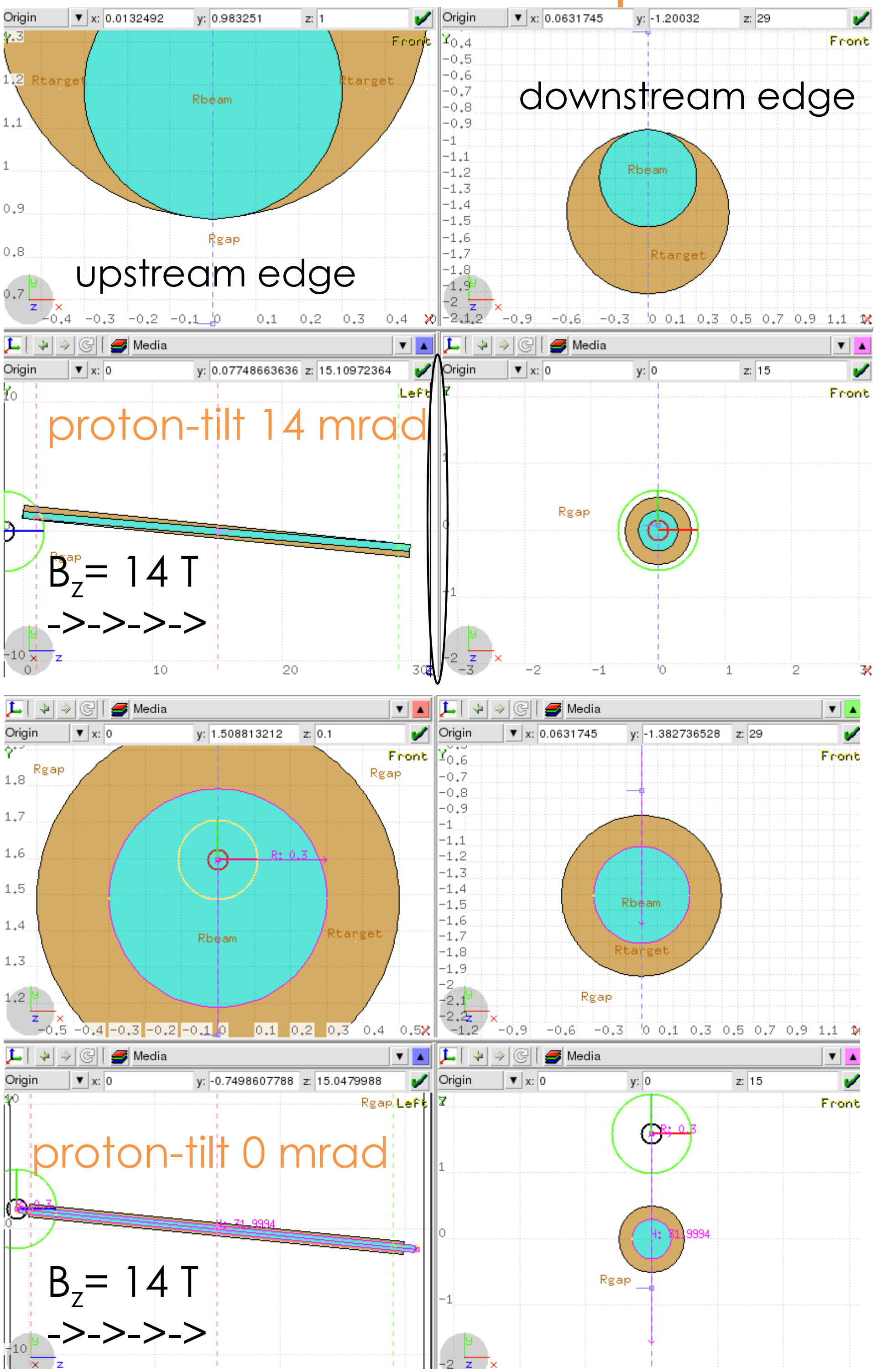


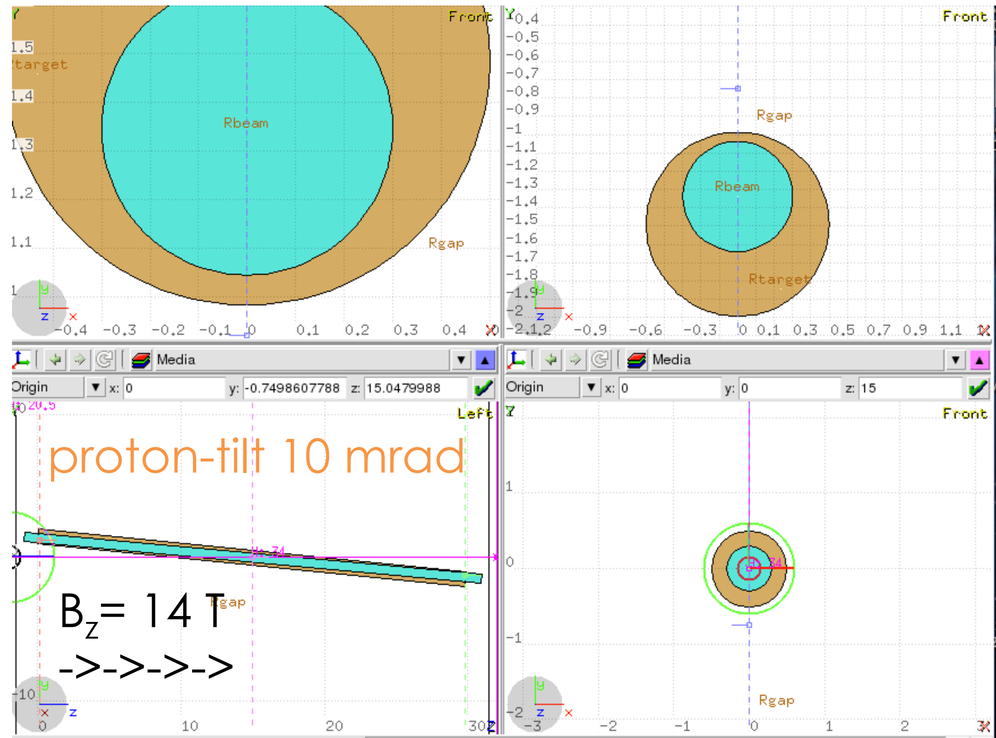


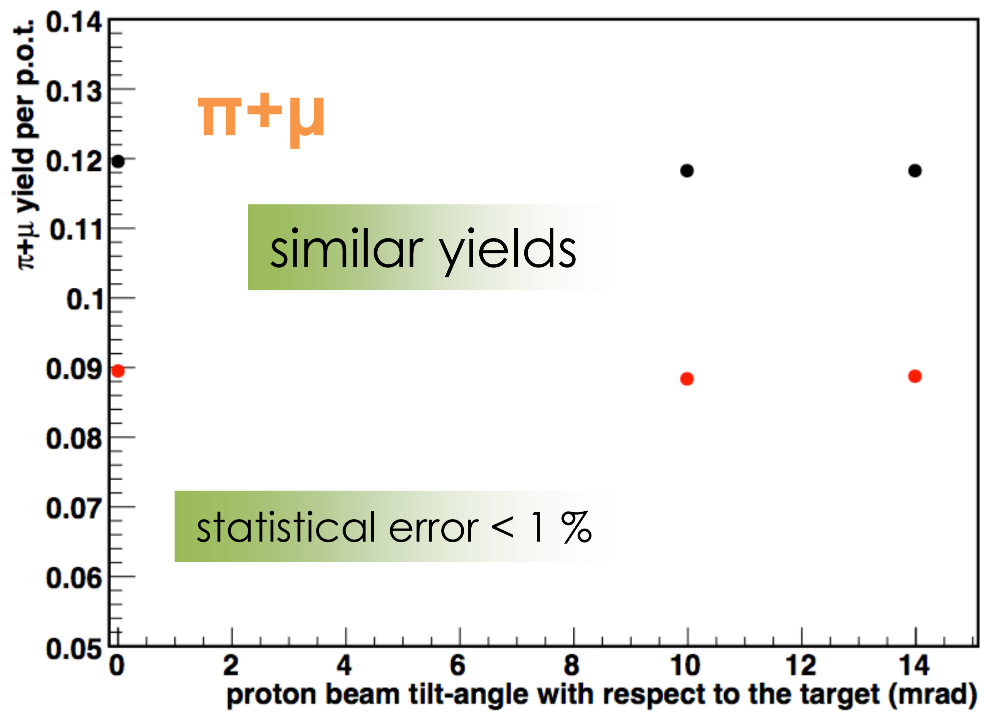


20, 100, 220 mrad
momenta
π+μ
π+μ per p.o.t.
P (GeV/c)
20, 100, 220 mrad
momenta
p
p+ per p.o.t.
P (GeV/c)
100 mrad
transverse mom.
π(x 7)
p
p+ per p.o.t
$r_{helix} = \frac{P_T(MeV/c)}{3*B_z(T)} cm$
P_T (GeV/c)
100 mrad
longitudinal mom.
π(x 3)
p
can be separated
p+ per p.o.t.
$\lambda_{helix} = \frac{2.1*P_L(MeV/c)}{B_z(T)} cm$
P_L (GeV/c)

beam tilt with respect to the target

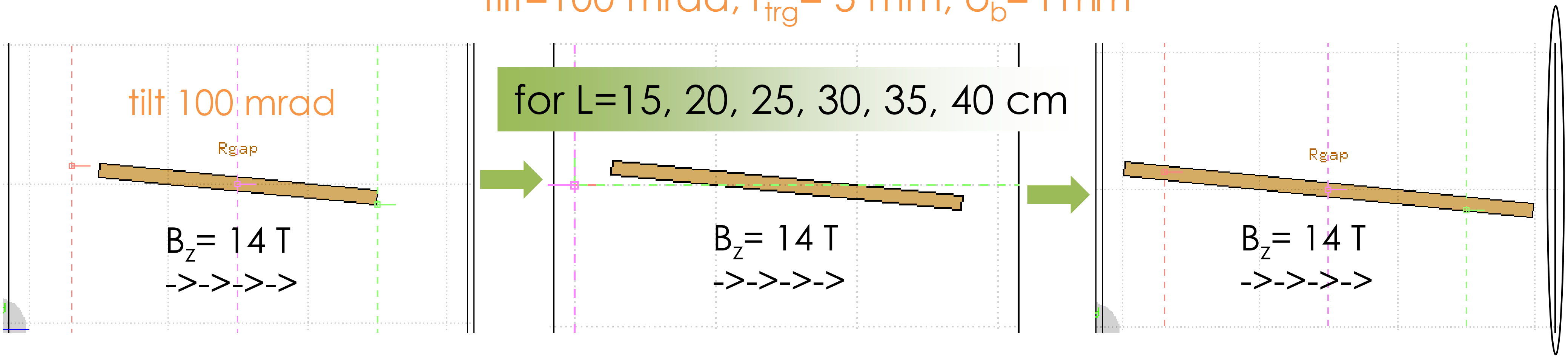


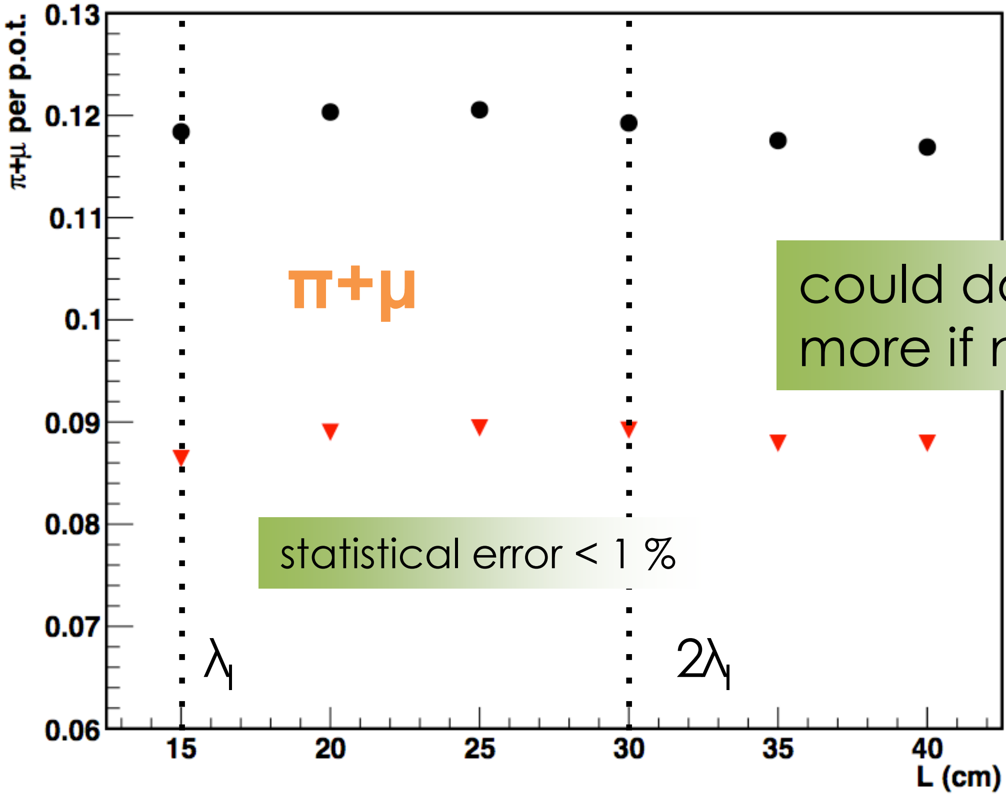




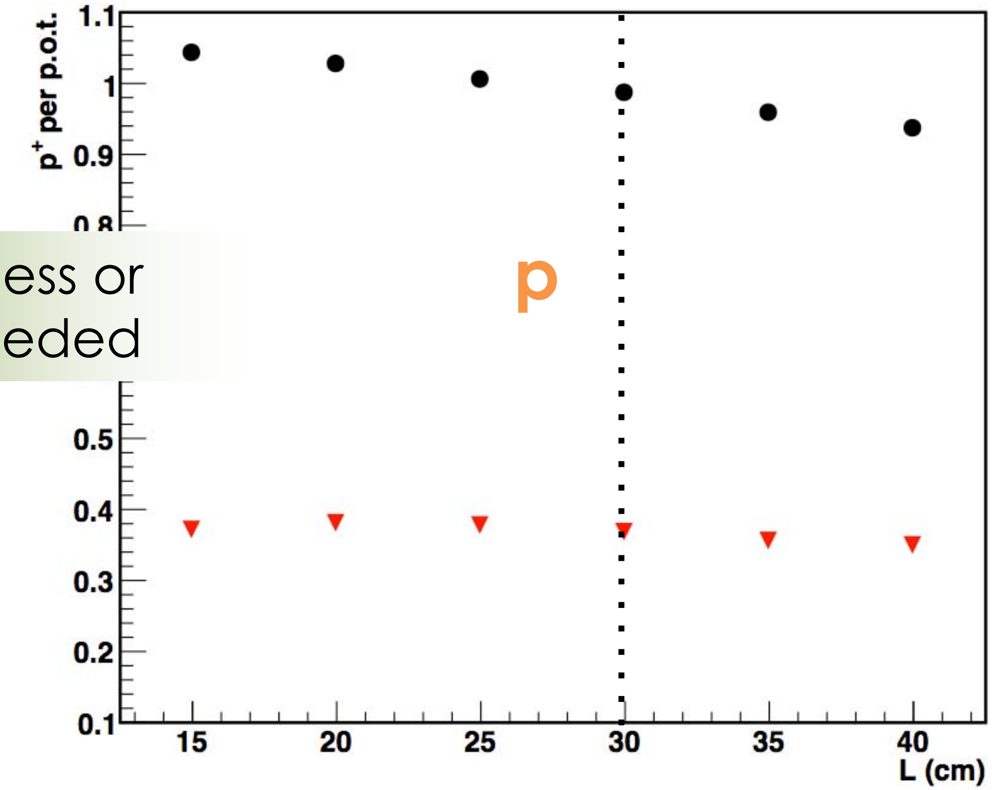
particle yields at the edge of MCS for different target lengths

tilt=100 mrad, r_{trg}= 5 mm, σ_b=1 mm



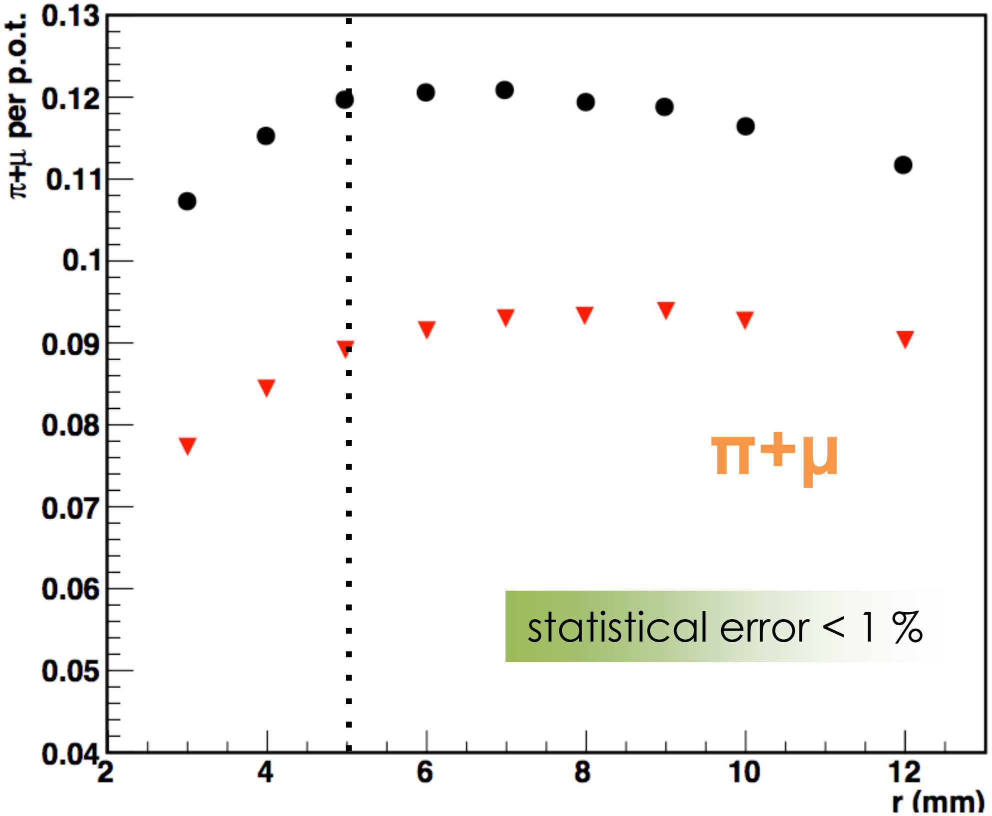


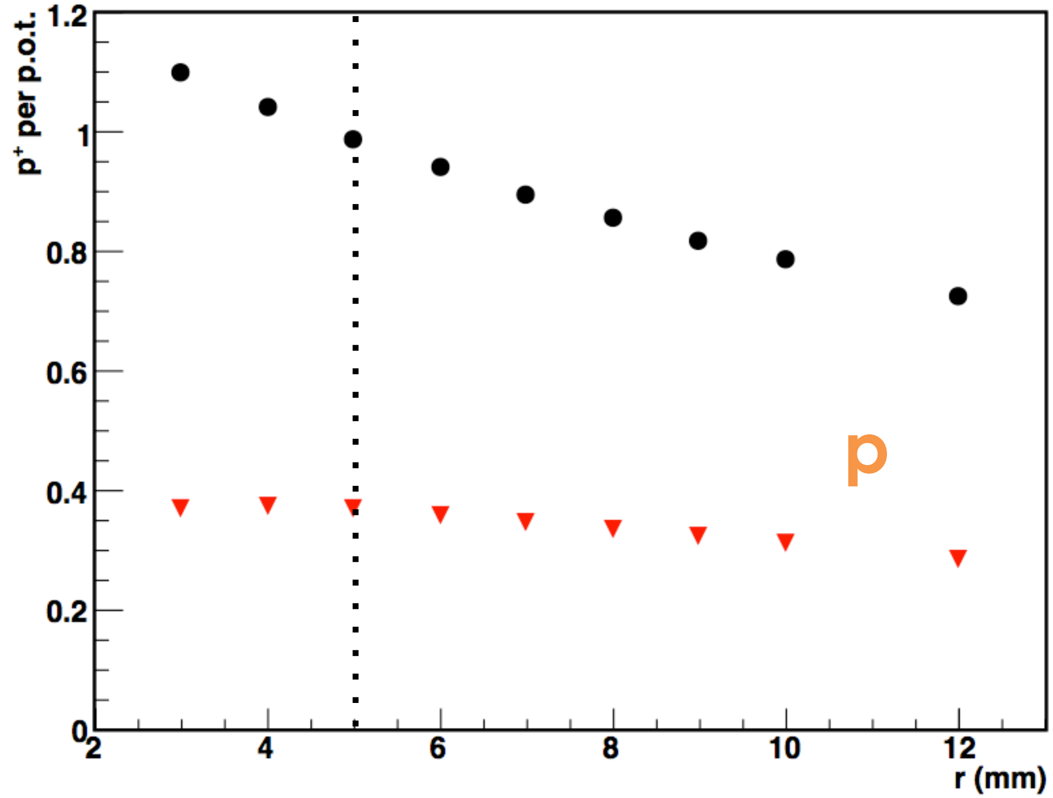
could do less or more if needed



particle yields at the edge of MCS for different radii

tilt=100 mrad, L_{trg}=30 cm, σ_b=1 mm

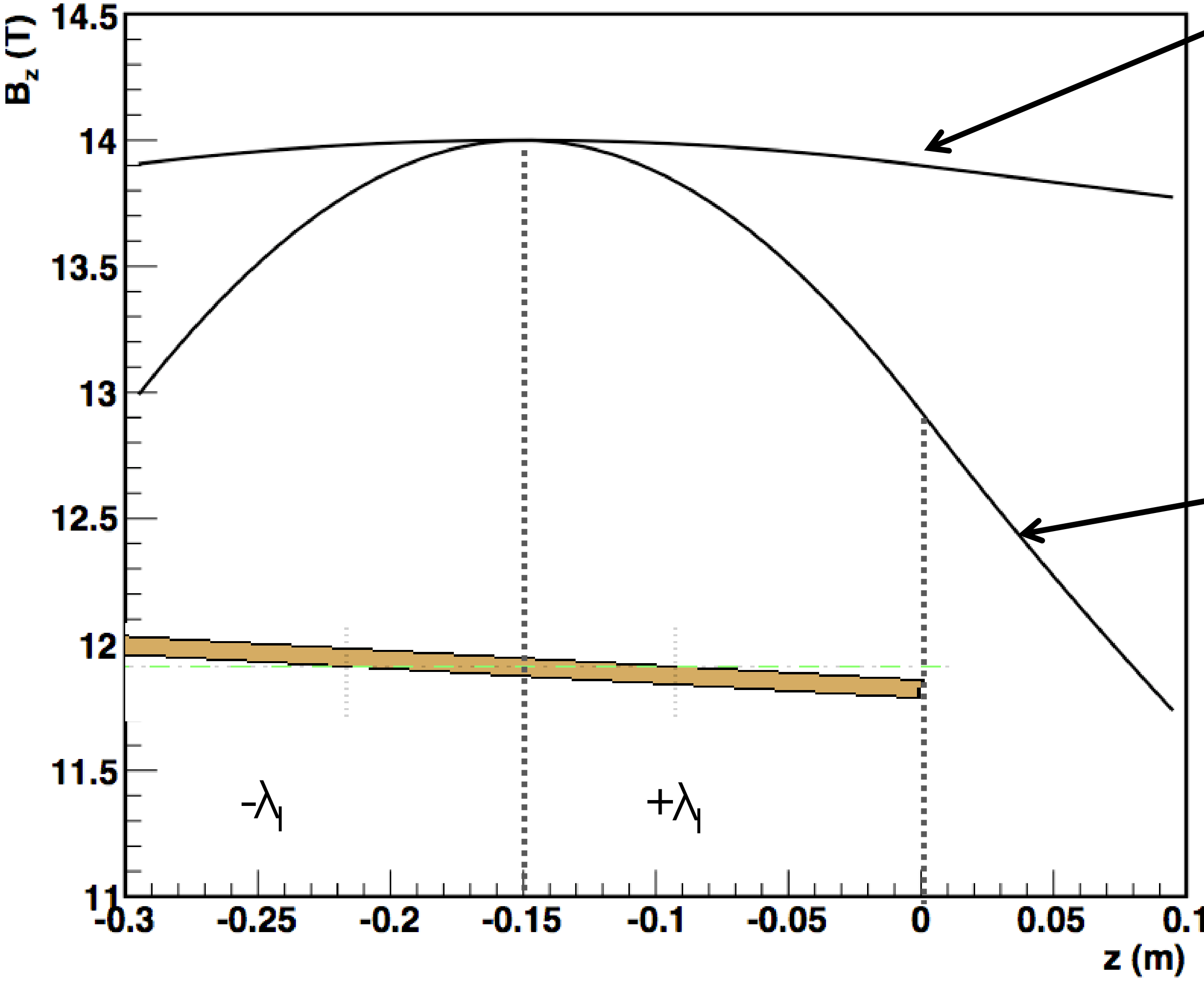


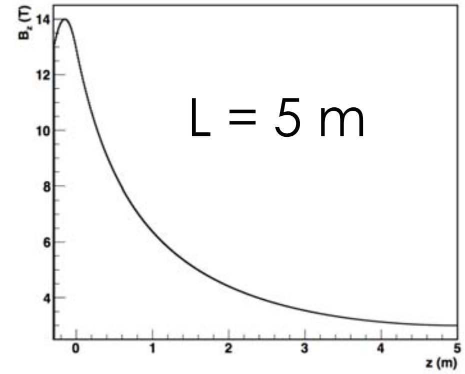


could do more in radius if needed

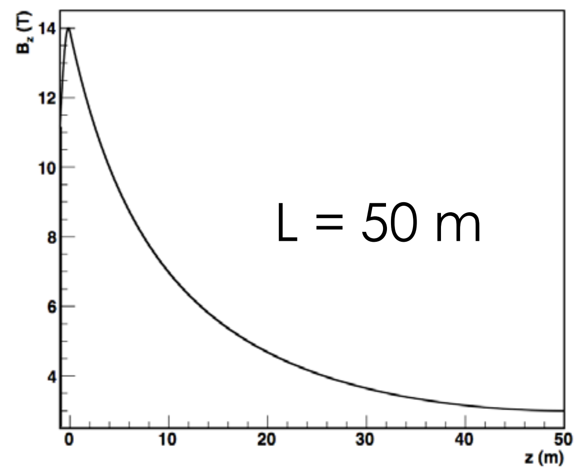
from ideal to Gaussian field for MCS

field as used in MOMENT studies,
0.8 % reduction within $\pm\lambda_I$





gaussian -0.3 m < z < 0.3 m
7% reduction reduction within $\pm\lambda_I$



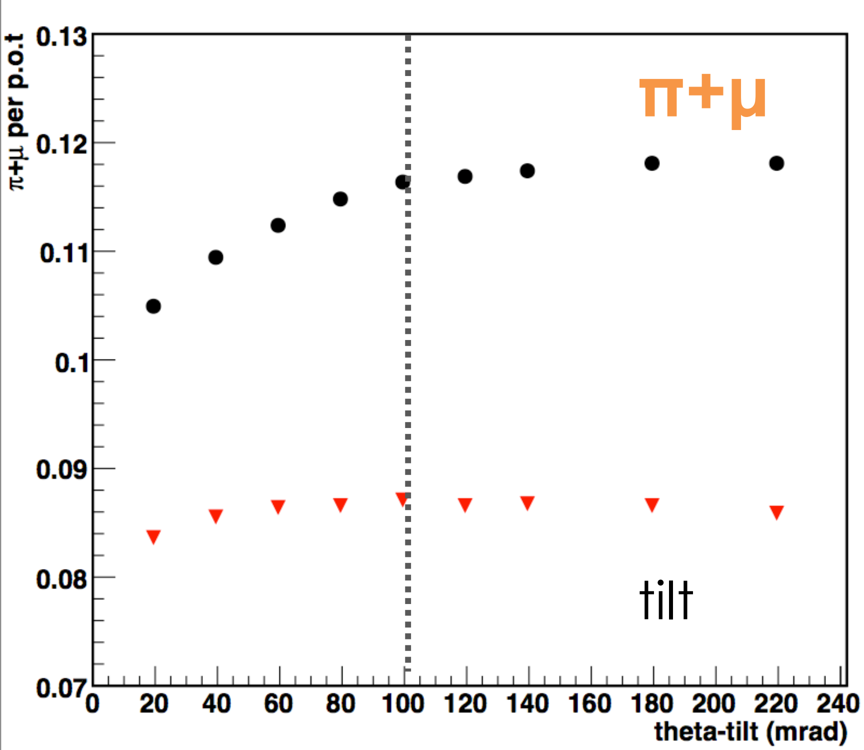
$$B_z(0,z) = B_0 e^{-(z-z_0)^2/2\sigma^2}$$

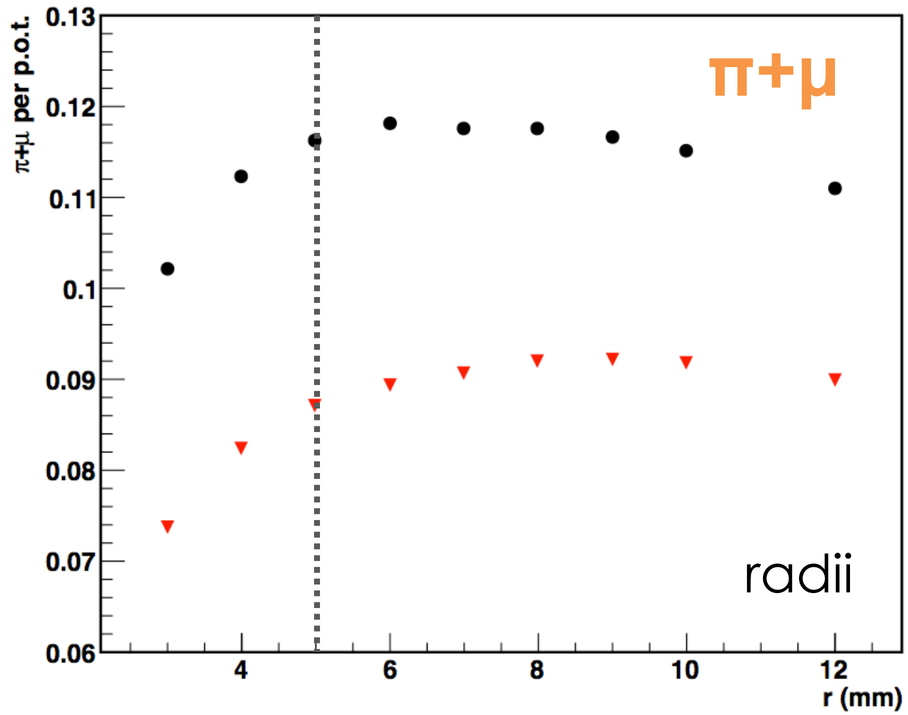
$$B_0 = 14T, z_0 = -15cm$$

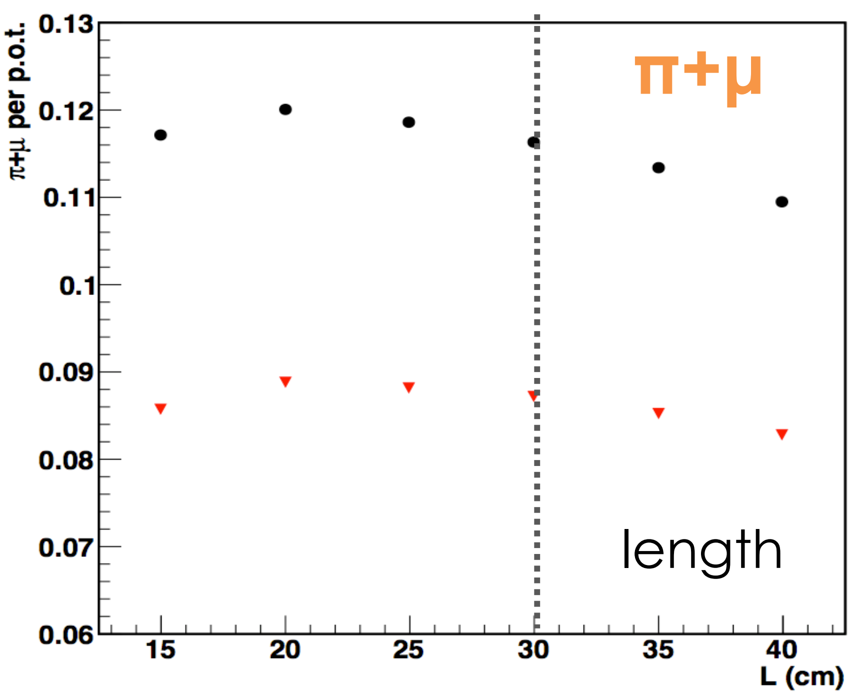
$$B_z(r,z) \approx B_z(0,z)$$

$$B_r(r,z) \approx -\frac{r}{2} * \frac{\partial B_z(0,z)}{\partial z}$$

particle yields at the edge of MCS
for different target parameters
fixed parameters : tilt=100 mrad or L_{trg}=30 cm or r_{trg}=5mm







all momenta in black

selection in red

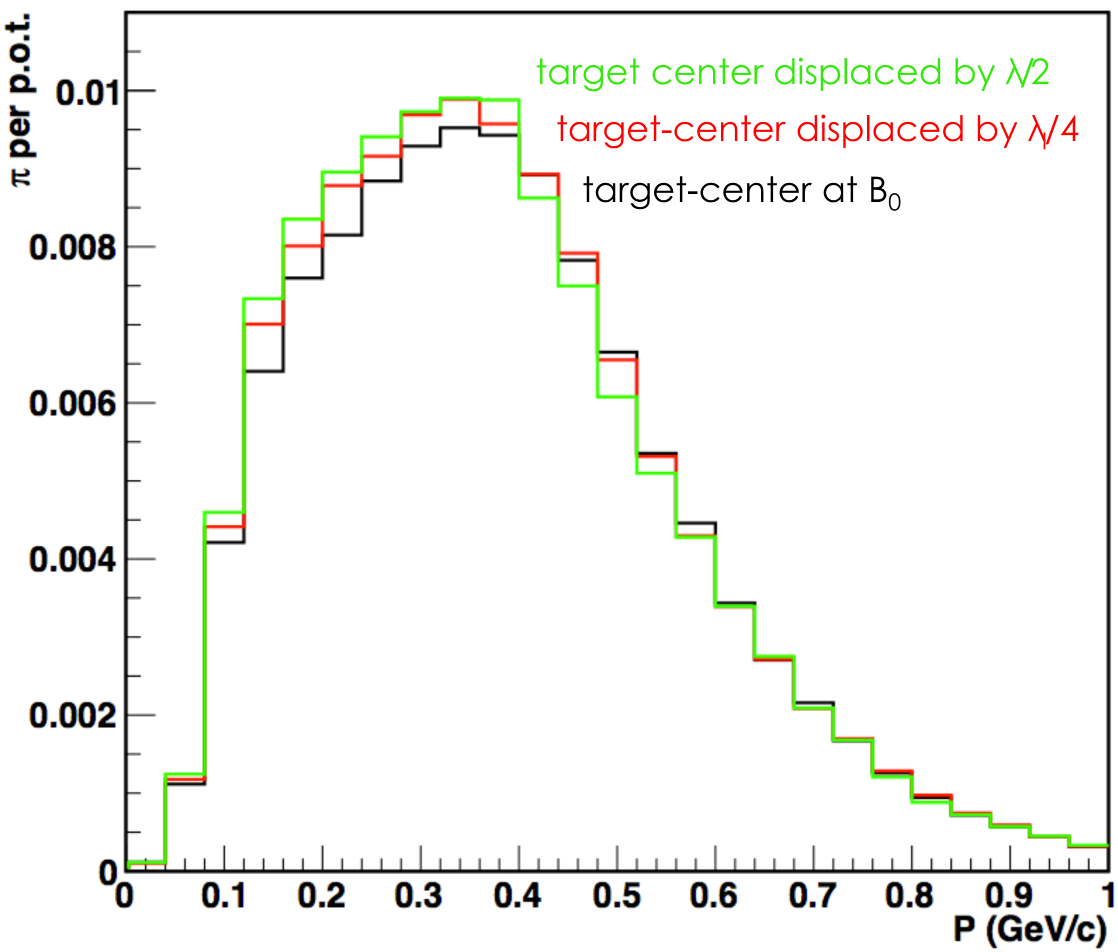
- pions 0.222 < P (GeV/c) < 0.776
- muons 0.111 < P (GeV/c) < 0.438

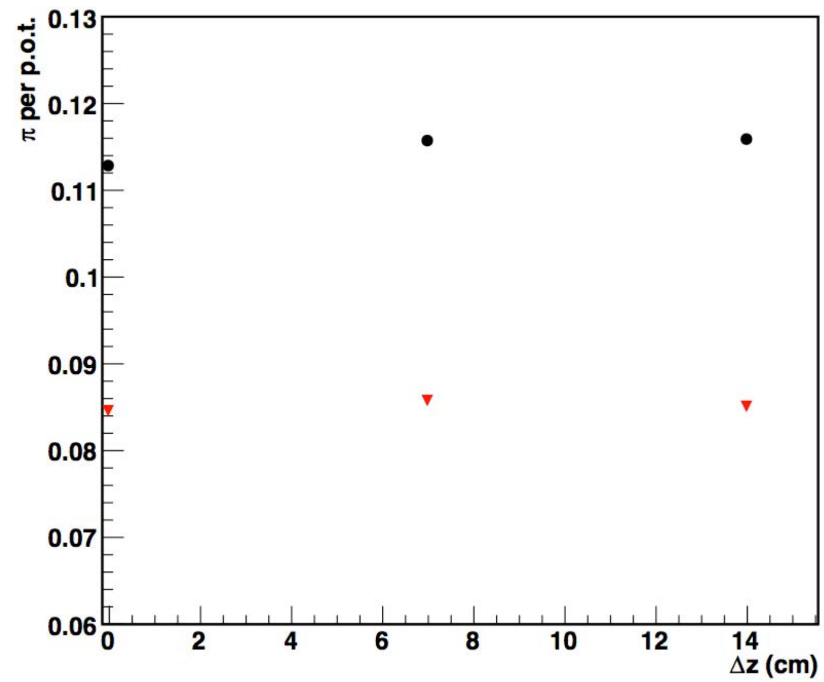
statistical error < 1 %

similar results to the ideal field B_0 = 14 T

target displacement at MCS

target-center displaced by $\lambda_I/2, \lambda_I$
with respect to B_0
r_{MCS} : 20 cm

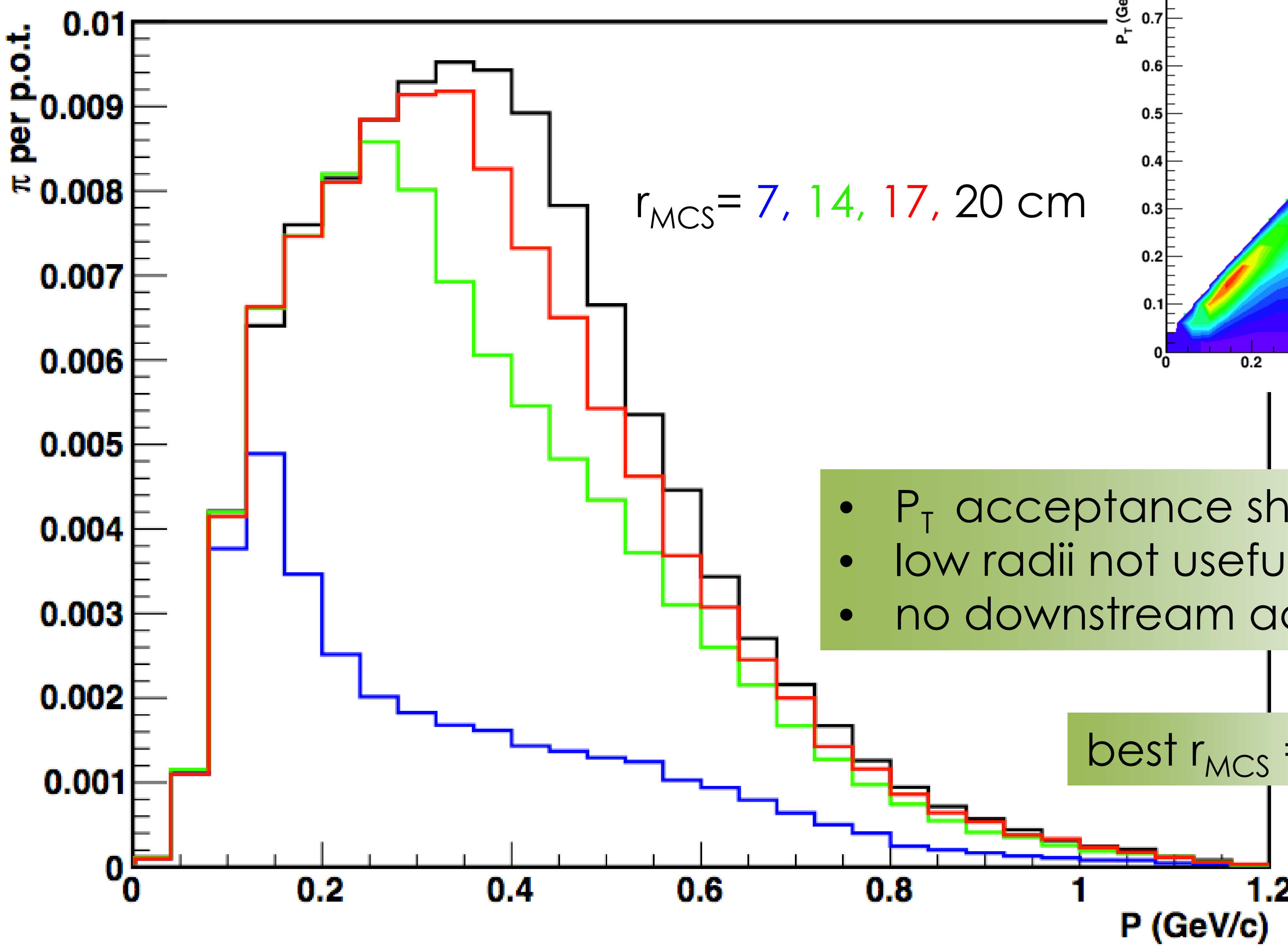


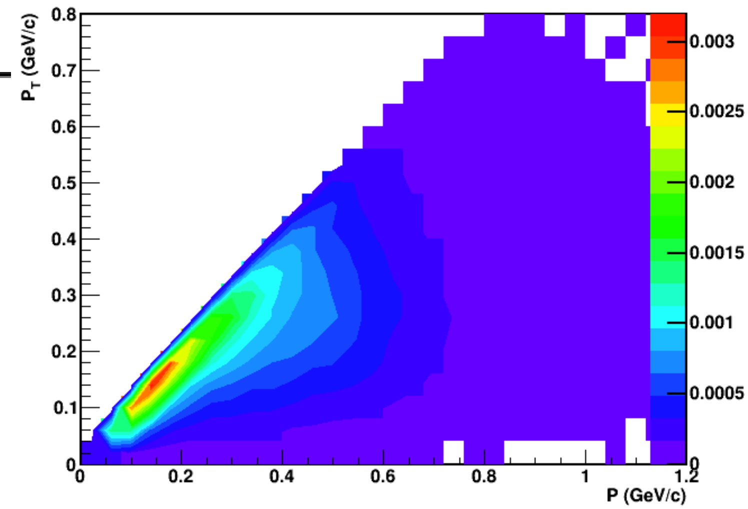


similar yields

MCS radius

- L_{hg}=30 cm, r_{hg}= 0.5 cm, $tilt_{hg}$= 100 mrad
- L_{MCS}=32 cm, r_{MCS} = 7, 14, 30 cm, B_0=14 T, gaussian σ= 45 cm

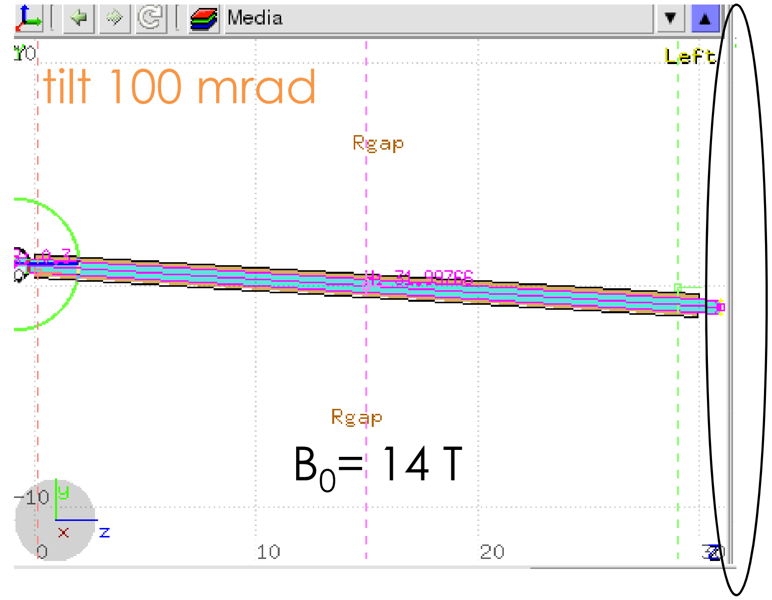




- P_T acceptance shapes the momenta
- low radii not useful for MOMENT
- no downstream acceleration

best r_{MCS} = 17-20 cm

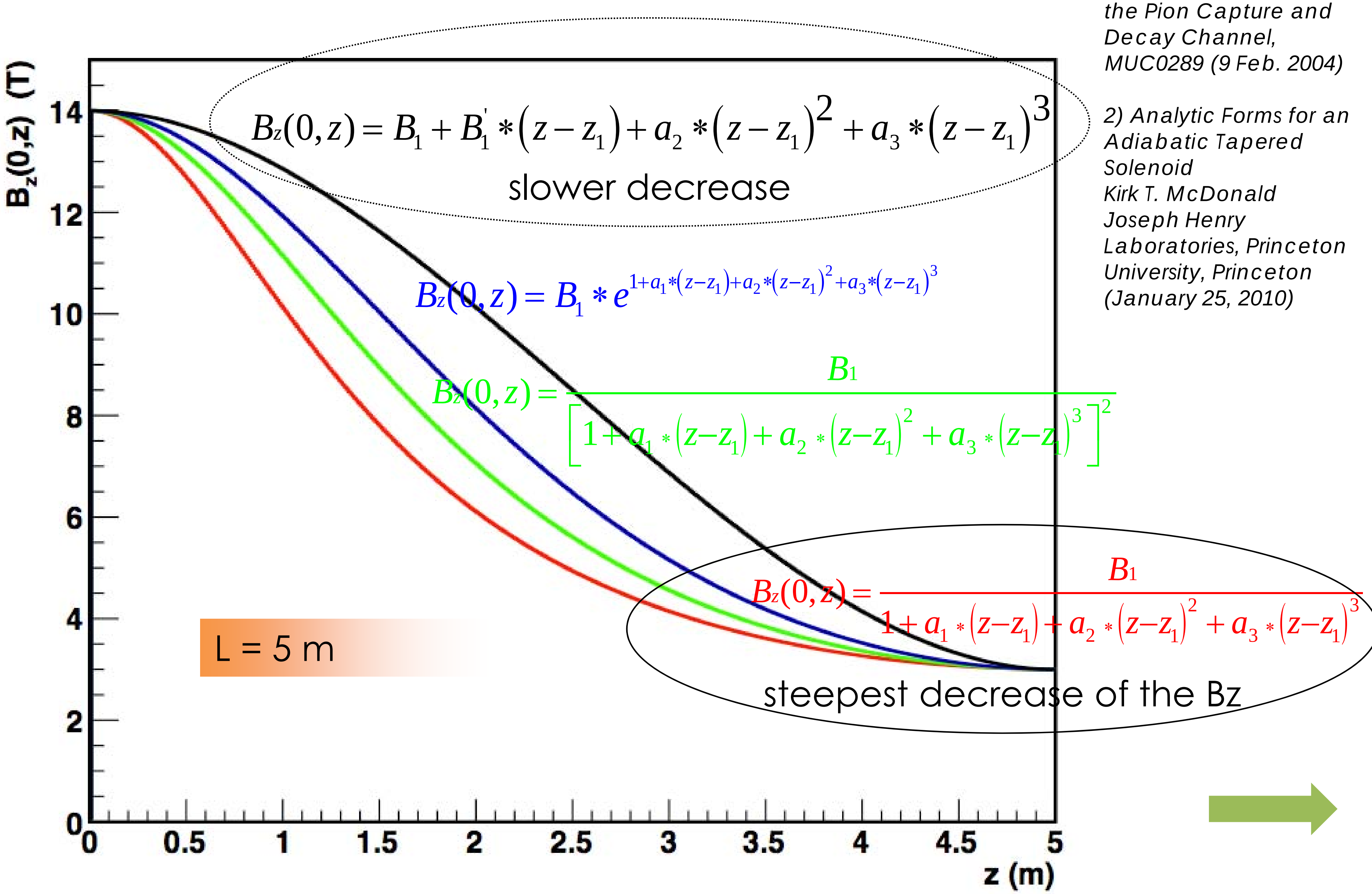
conclusions for the MCS



at MCS edge:

- target-tilt could be more than100 mrad
- target-length, yield is maximal at 2 interaction lengths or slightly less
- target-radius could be increased more than 5 mm for σ_b=0.1cm
- yield remains similar when proton beam-axis tilted with respect to the target-axis -> to be studied with higher angles between the two
- high energy protons could be separated (see Cai's talk)
- MCS radii should be ~ 17-20 cm

adiabatic transport solenoids



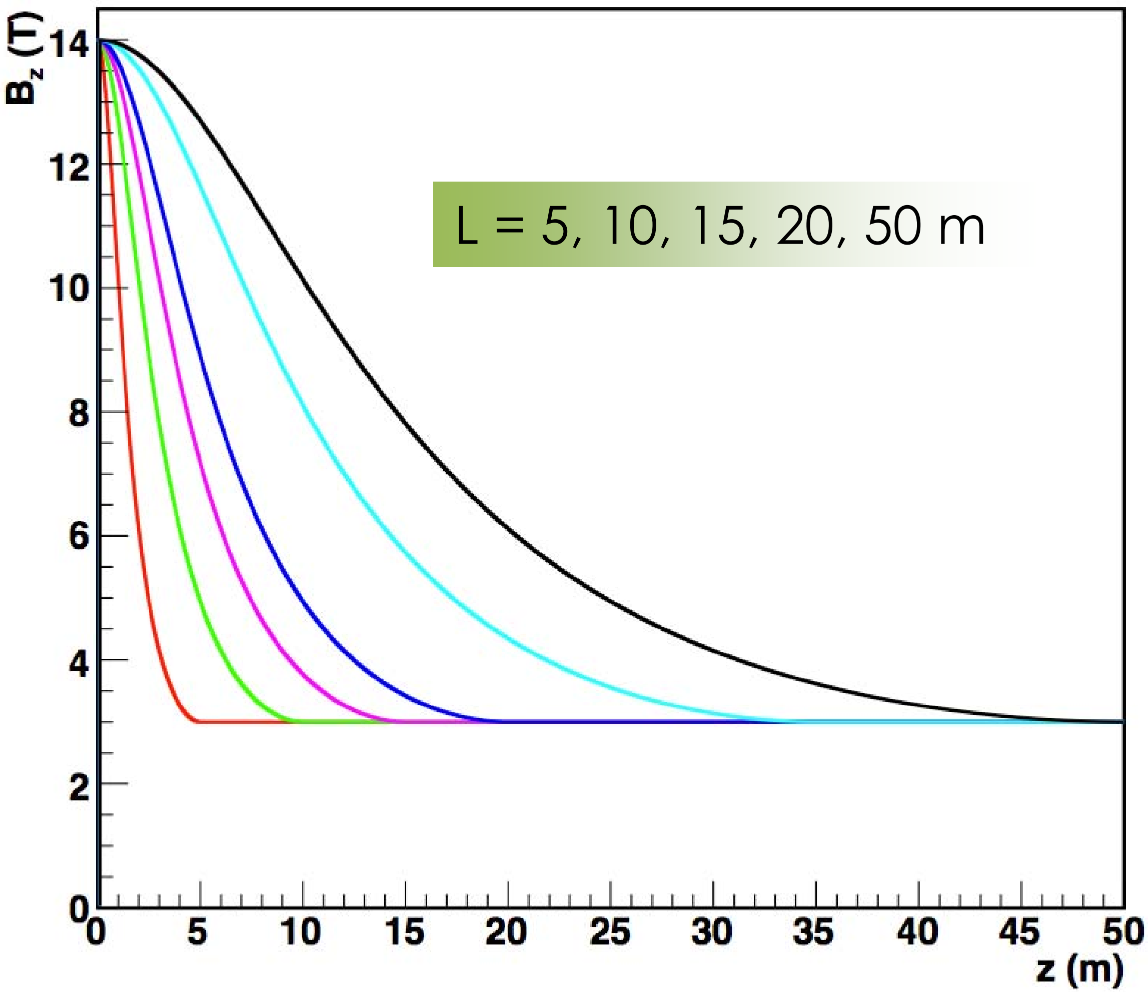
1) K. Paul and C. Johnstone, Optimizing the Pion Capture and Decay Channel, MUC0289 (9 Feb. 2004)

2) Analytic Forms for an Adiabatic Tapered Solenoid Kirk T. McDonald Joseph Henry Laboratories, Princeton University, Princeton (January 25, 2010)

adiabatic inverse taper – 1st degree

(ideal field, steeper field-decrease response)

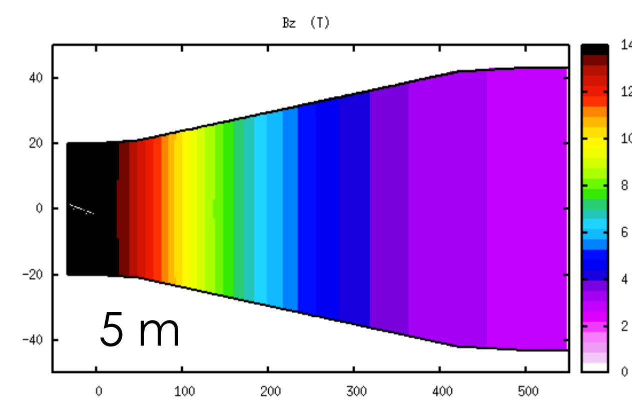
$$B_z(0,z) = \frac{B_1}{1 + a_1 * (z - z_1) + a_2 * (z - z_1)^2 + a_3 * (z - z_1)^3}$$



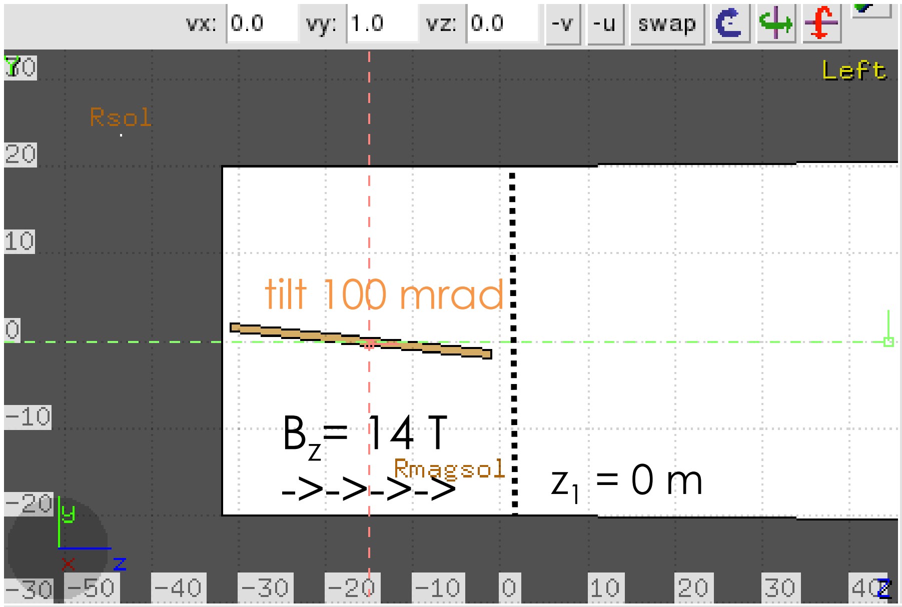
field approximation implemented in FLUKA:

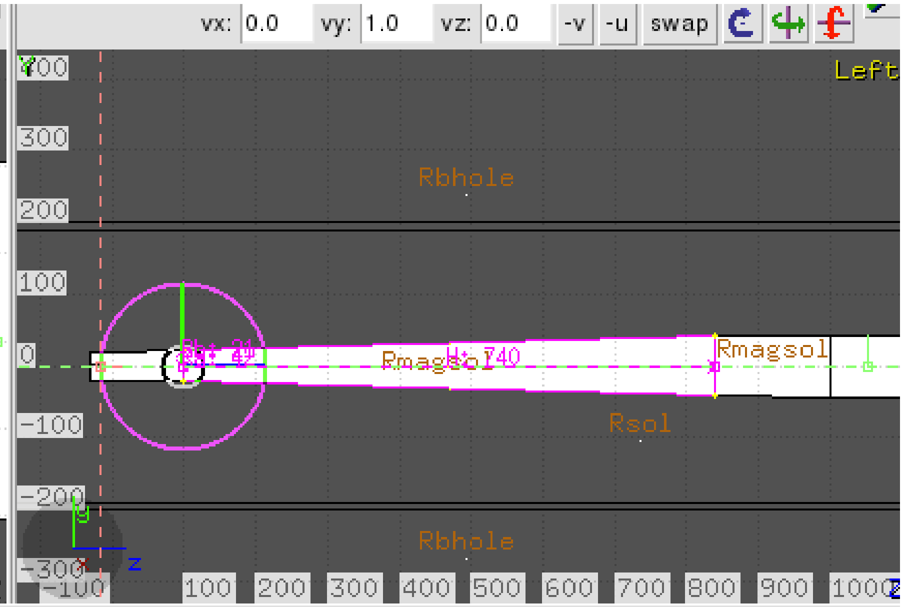
$$B_z(r,z) \approx B_z(0,z)$$

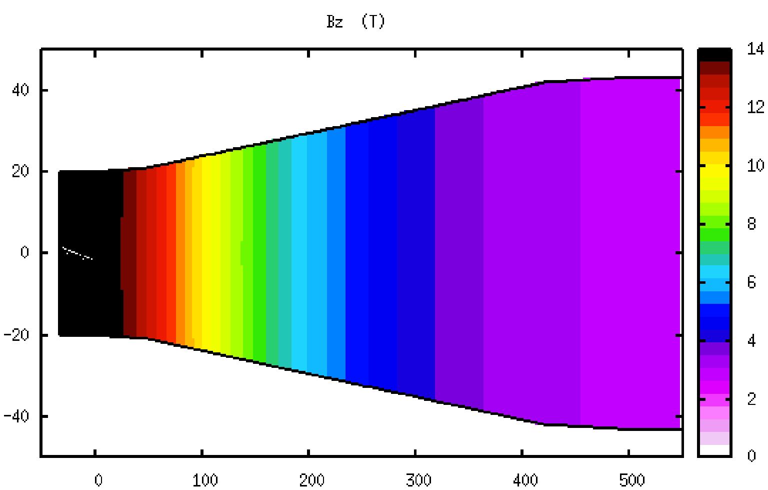
$$B_r(r,z) \approx -\frac{r}{2} * \frac{\partial B_z(0,z)}{\partial z}$$



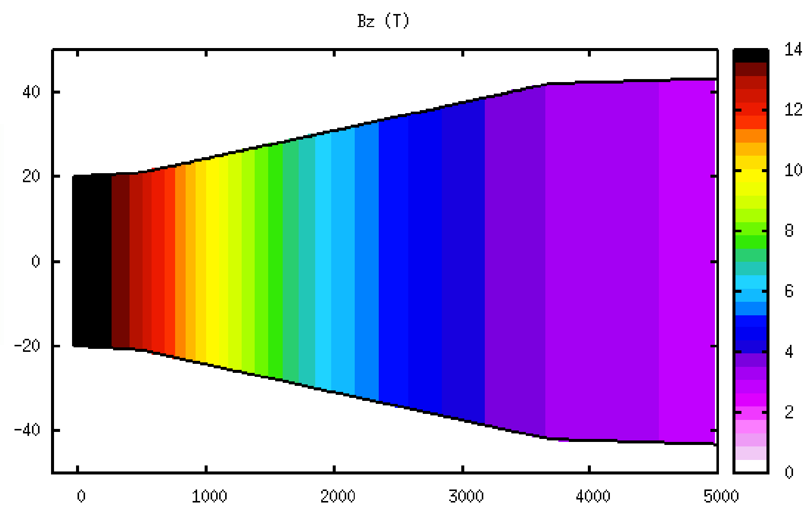
ideal MCS + $B_z(0,z) = \dfrac{B_1}{1 + a_1 * (z - z_1) + a_2 * (z - z_1)^2 + a_3 * (z - z_1)^3}$



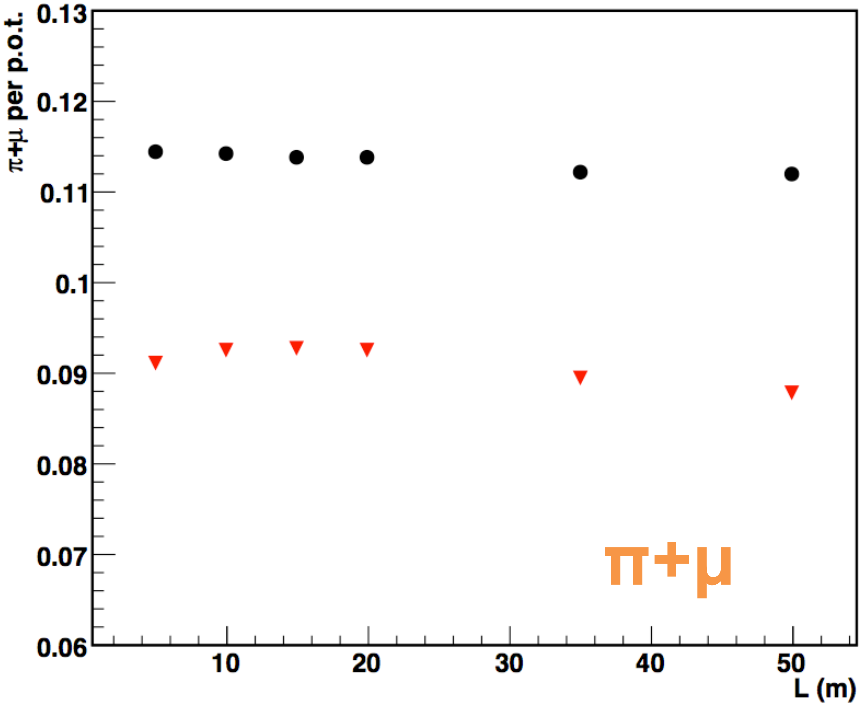




@ z_1= 0 m
r_1= 20 cm, B_1=14 T
@ z_2= 5 -> 50 m
r_2= 43.2 cm, B_2 = 3 T

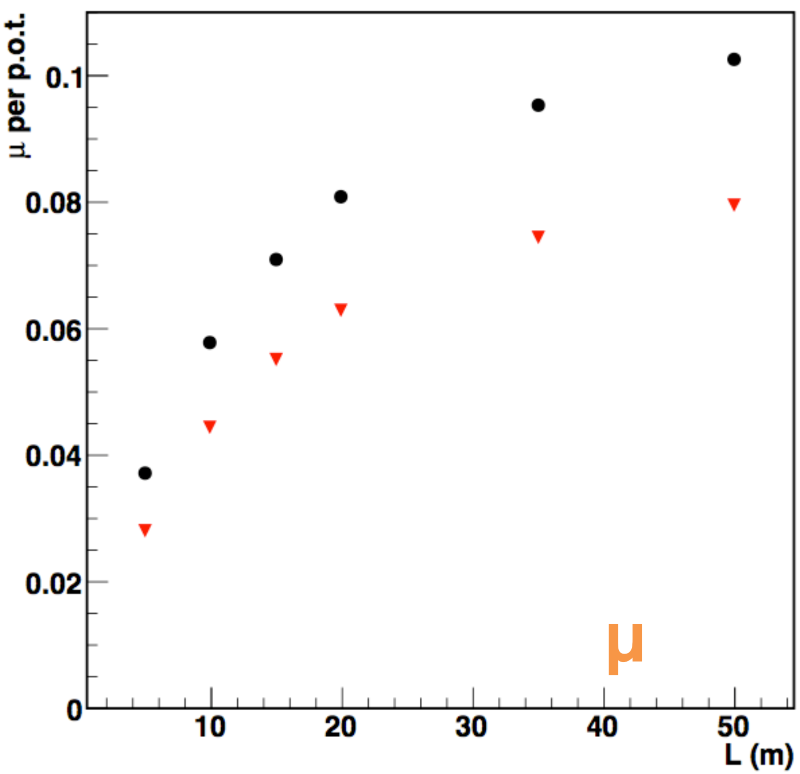


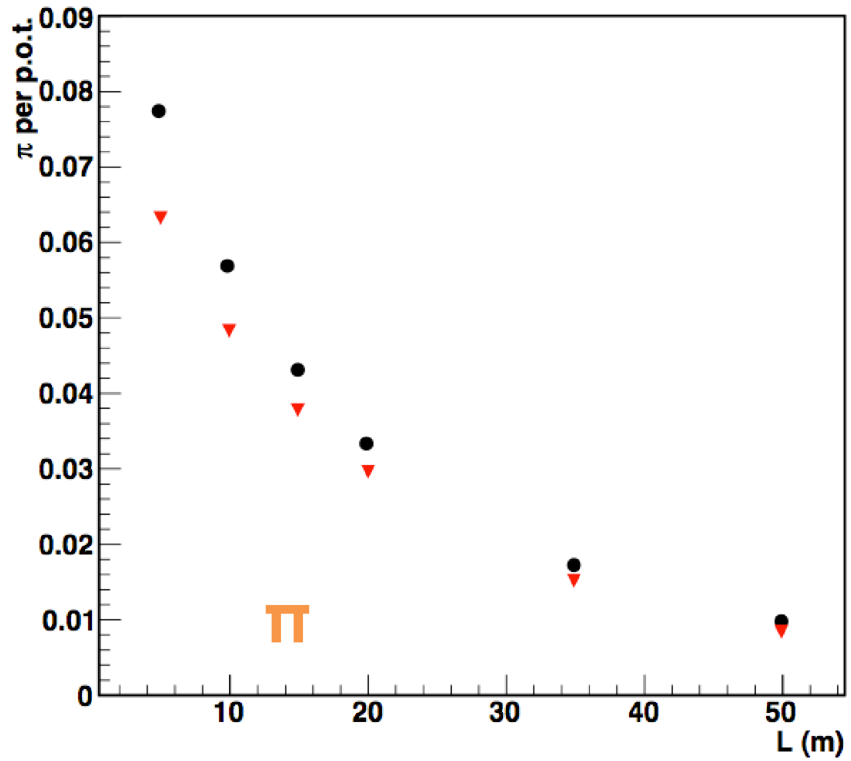
yields at the end of the adiabatic section vs length



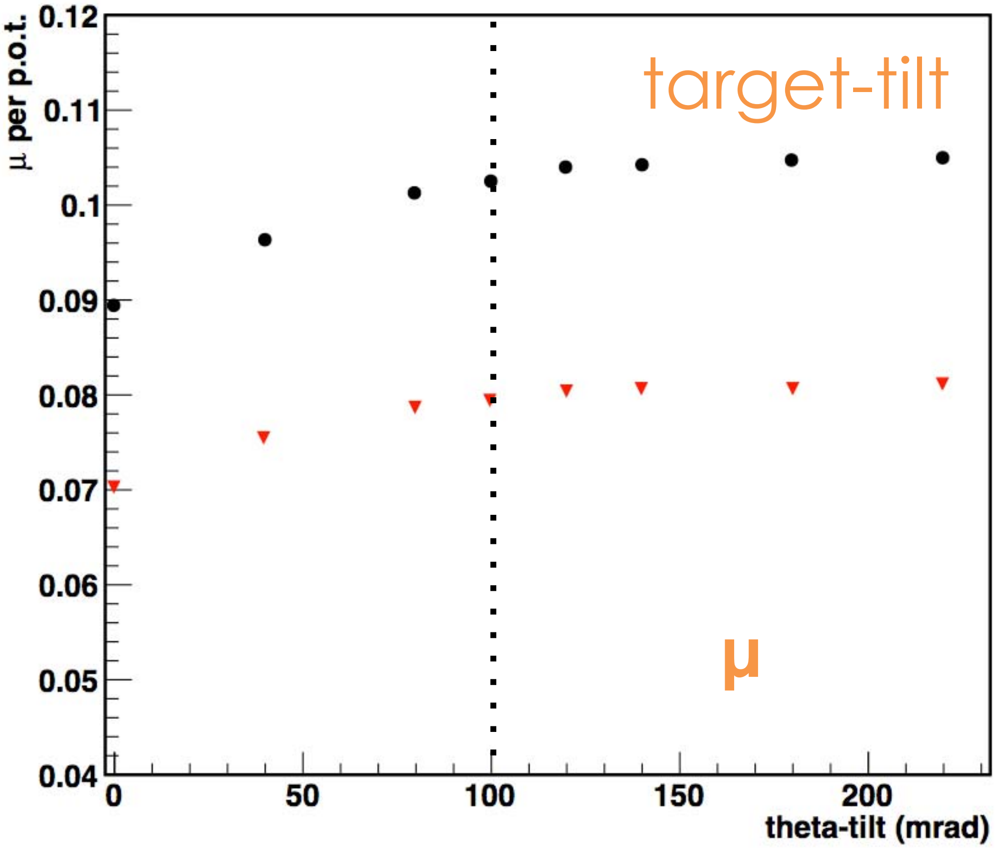
all momenta in black
selection in red
- pions 0.222 < P (GeV/c) < 0.776
- muons 0.111 < P (GeV/c) < 0.438

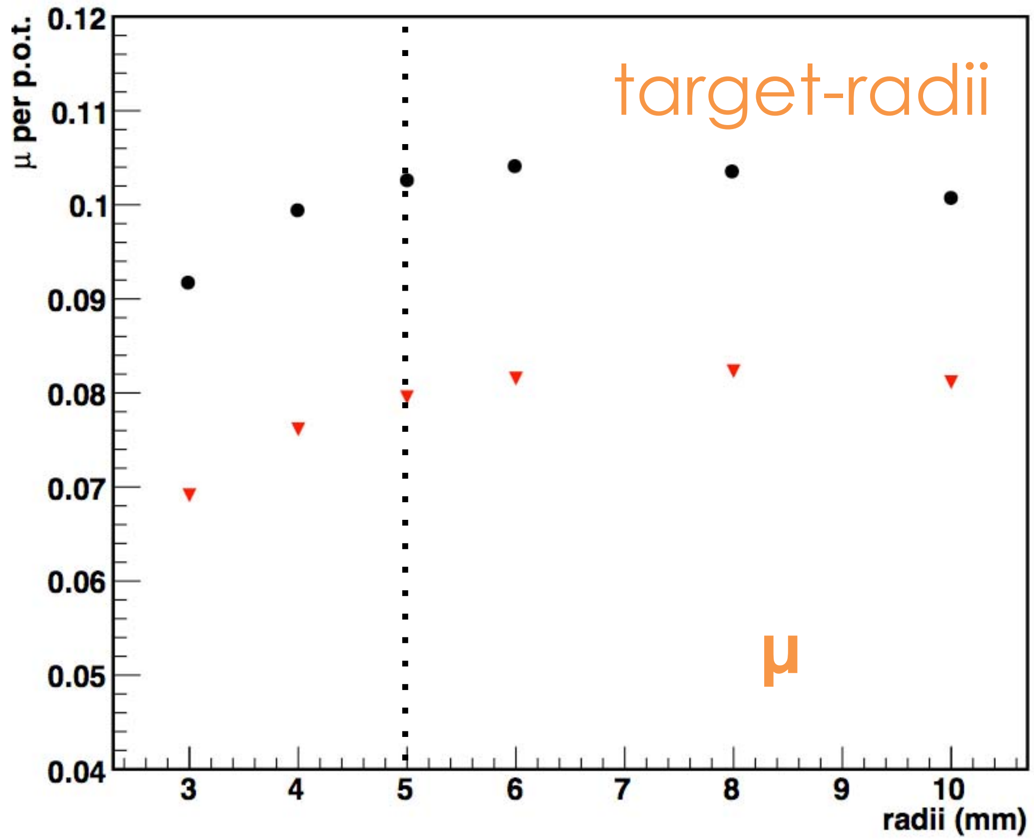
statistical error < 1 %
geometry approximation systematic error





muon yields for inverse taper L = 50 m vs different target-tilts, radii

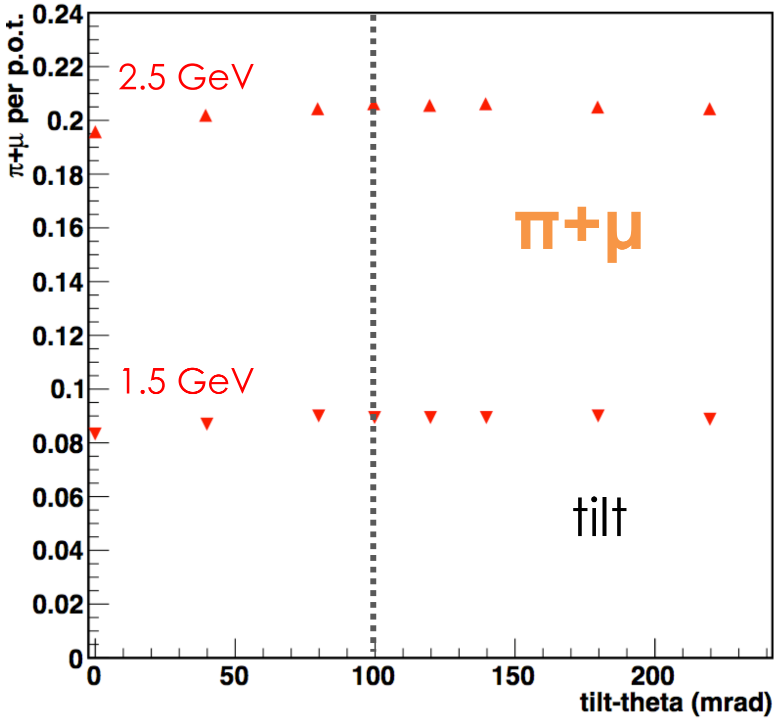




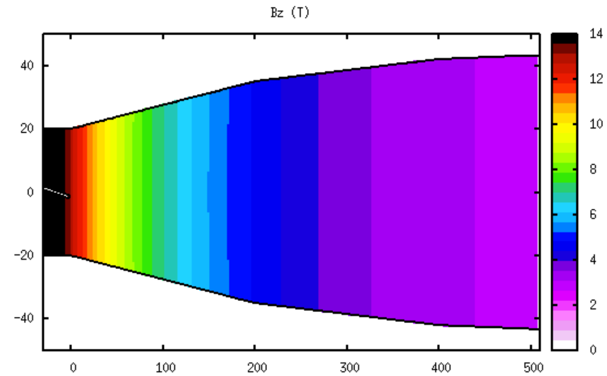
- tilt: plateau after 100 mrad
- radii: could do more

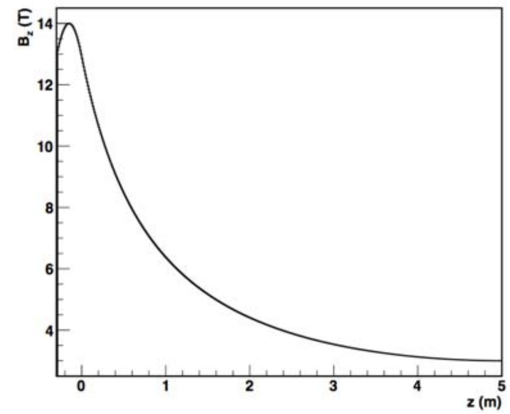
statistical error < 1 %

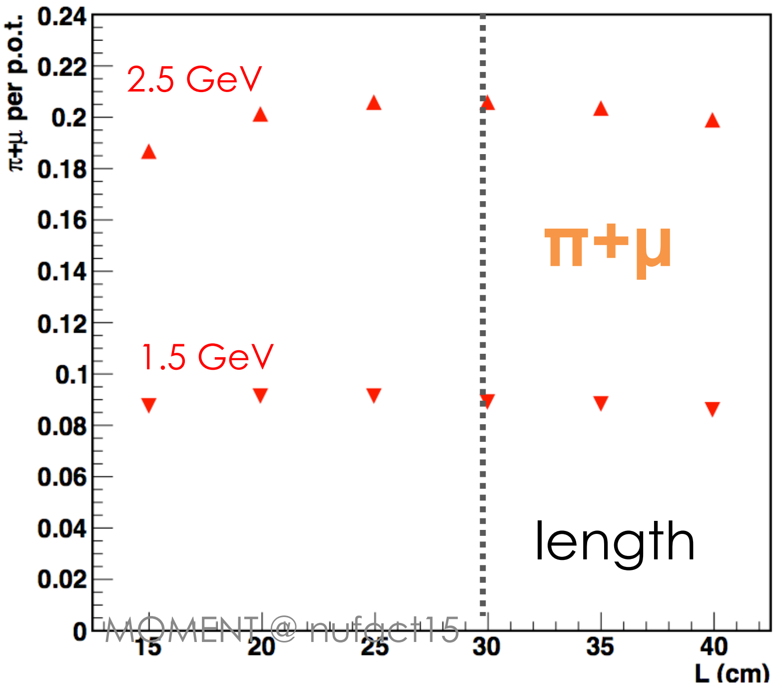
particle yields for L_{taper}=5 m, E_k = 1.5, 2.5 GeV

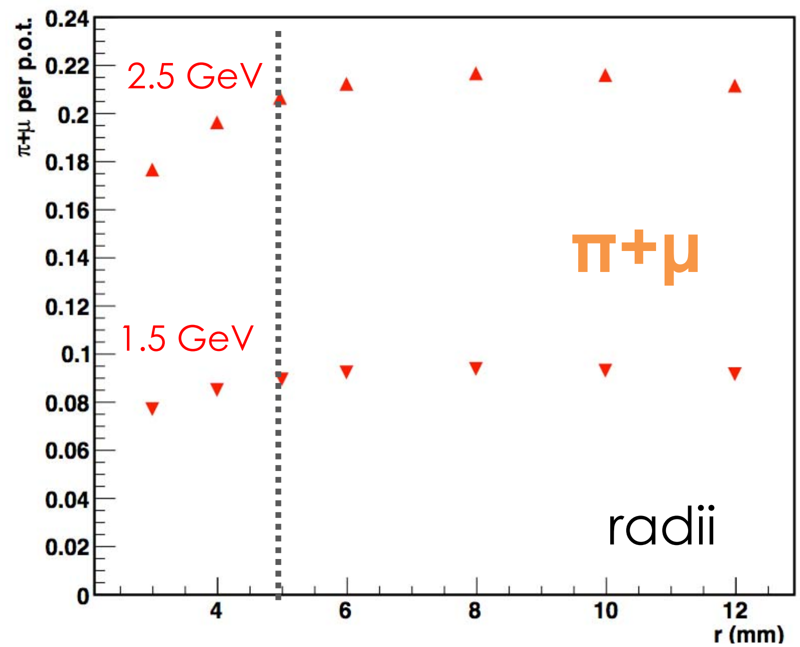


$$B_z(0,z) = B_0 e^{-(z-z_0)^2/2\sigma^2}$$
$$B_0 = 14T, z_0 = -15cm$$
$$+ \quad B_z(0,z) = \frac{B_1}{1 + a_1 * (z-z_1) + a_2 * (z-z_1)^2 + a_3 * (z-z_1)^3}$$

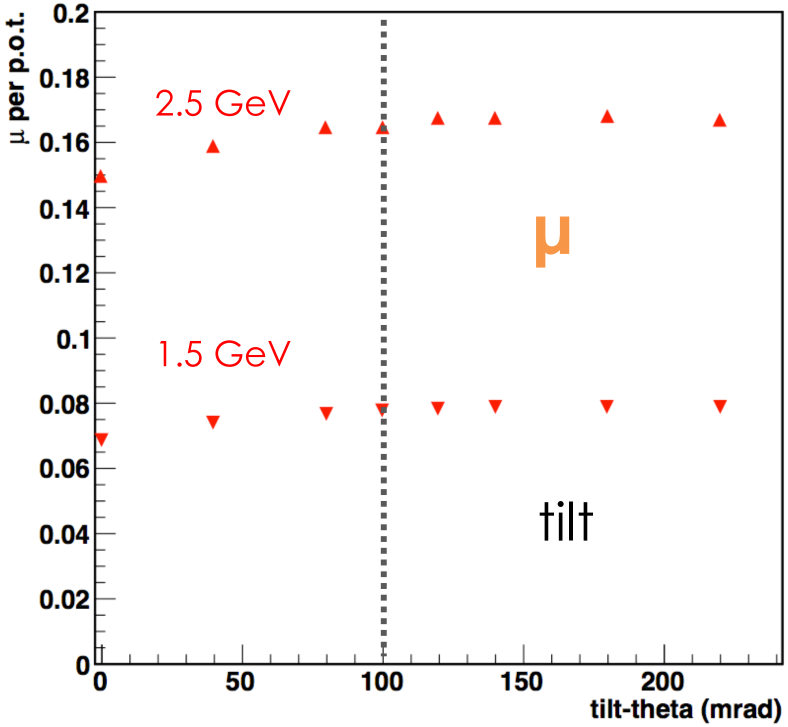








particle yields for L_{taper}= 50 m, E_k = 1.5, 2.5 GeV



$$B_z(0,z) = B_0 e^{-(z-z_0)^2/2\sigma^2}$$
$$B_0 = 14T, z_0 = -15cm$$

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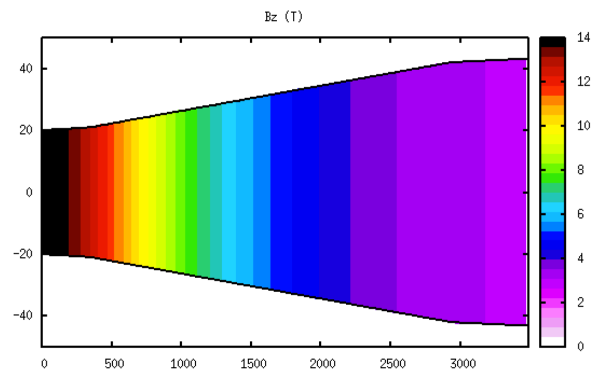
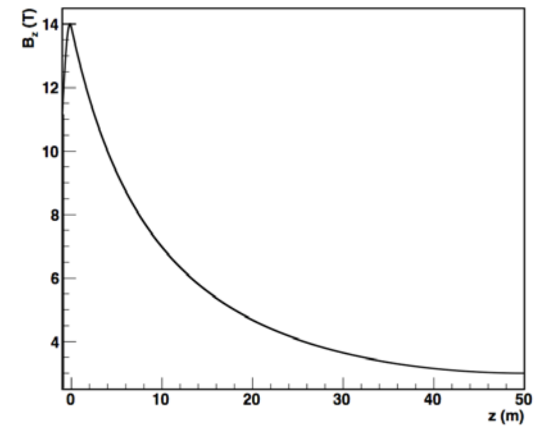
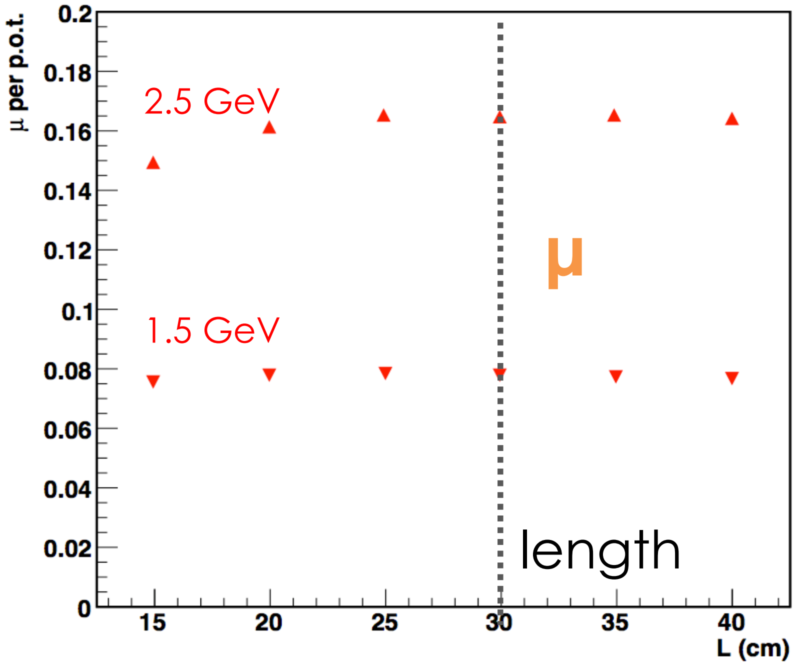
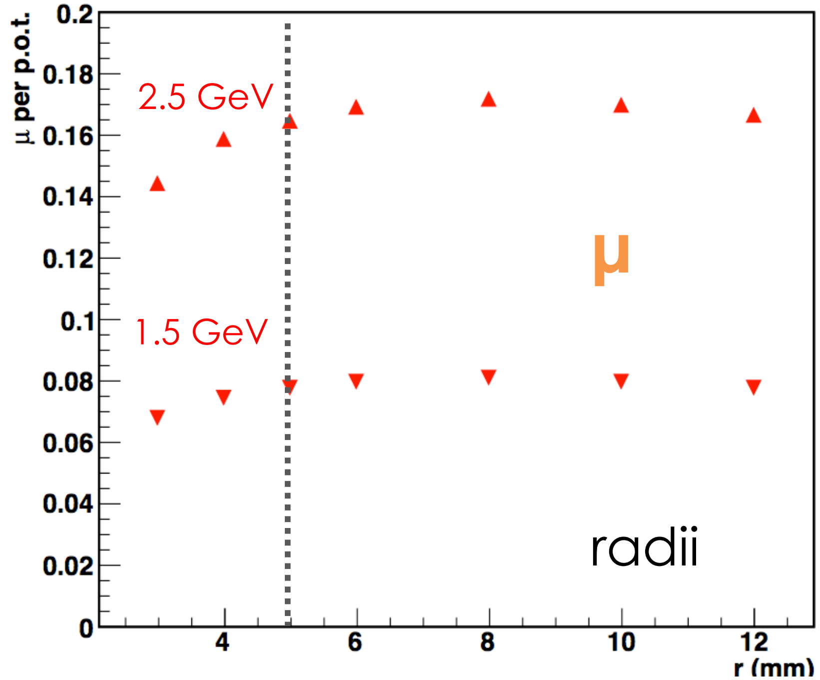
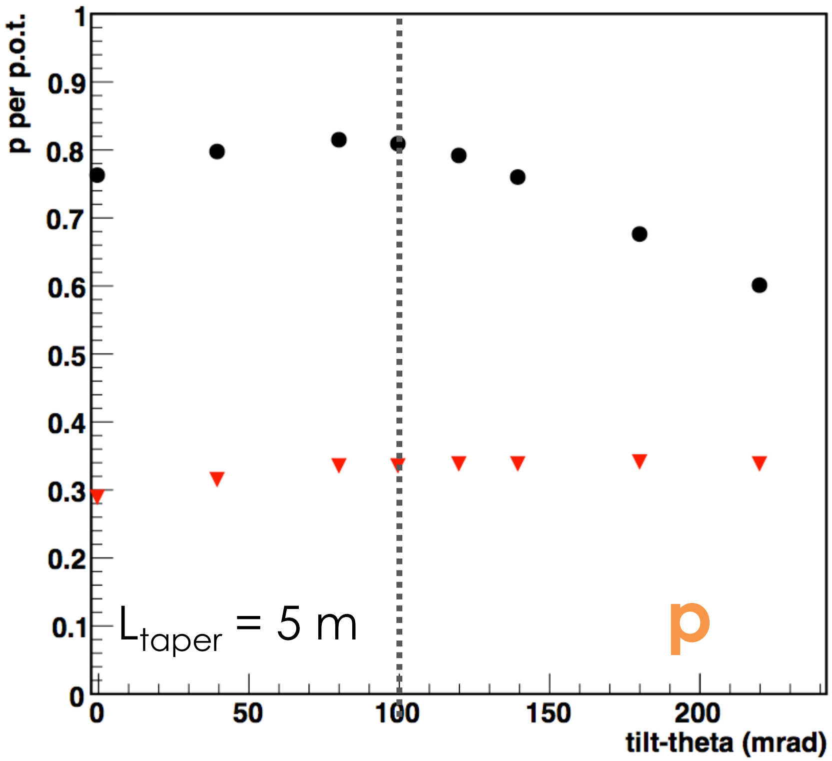


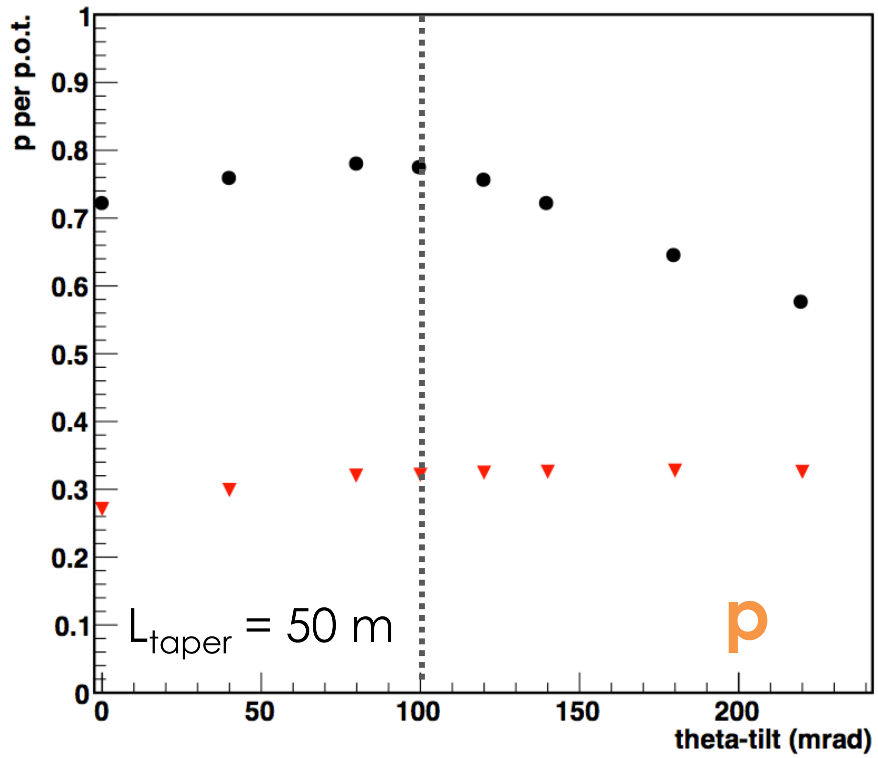






proton yields for different target-tilts and tapers





all momenta in black

selection in red

- proton 0.222 < P (GeV/c) < 0.776

statistical error < 1 %

there is a reduction of higher momentum protons with the tilt

conclusion/further studies

for 5, 50 m gaussian + 1st degree inverse adiabatic solenoid:

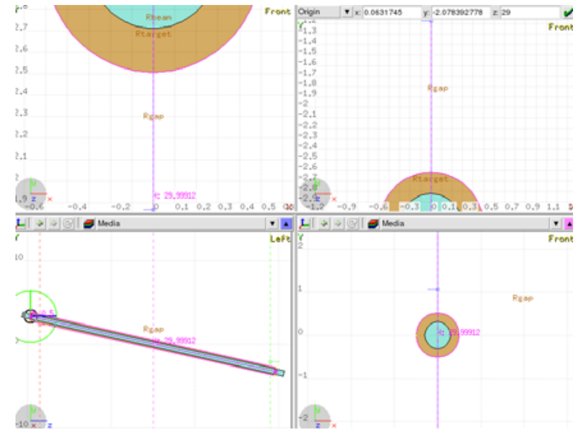
- target-tilt 100 mrad or more
- target-length 25 cm or more
- target-radius 5 mm or more
- higher momentum protons yields decreases with larger target-tilts
- proton E_k= 2.5 GeV doubles the yields

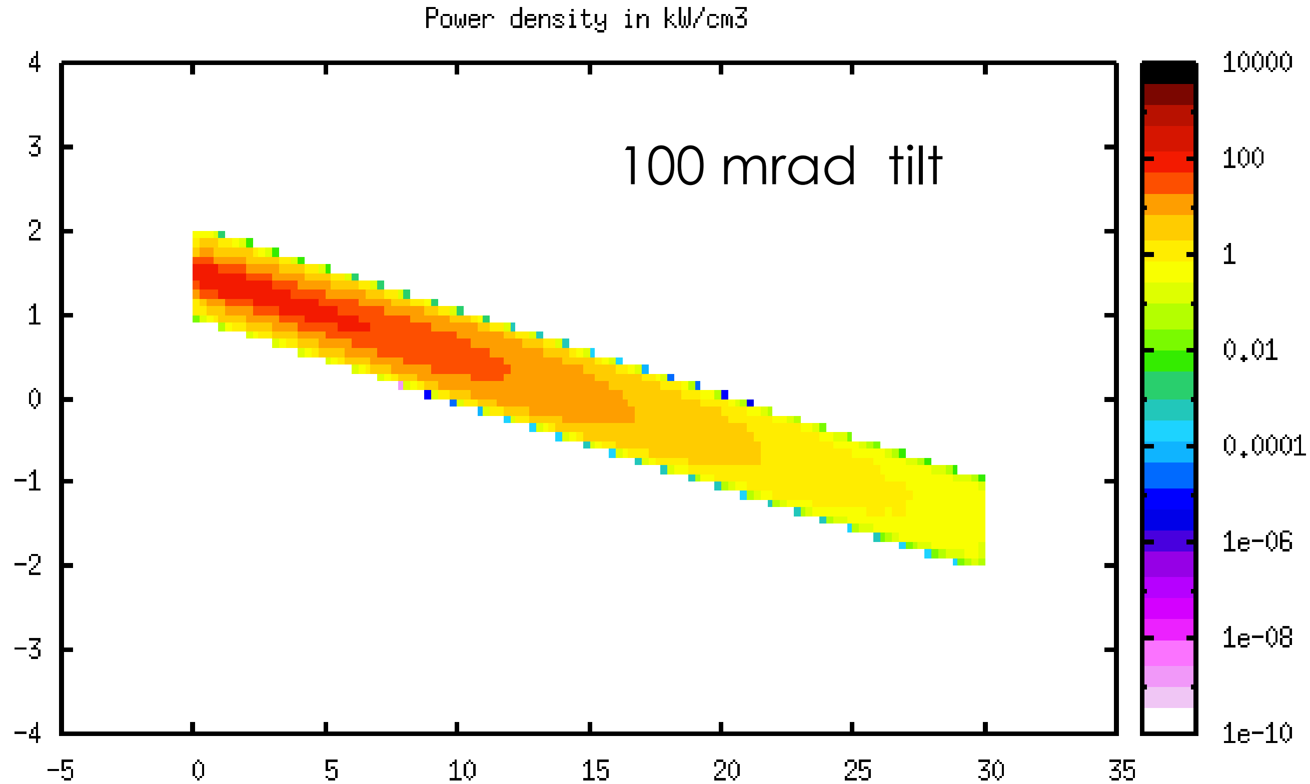
next:

- test the cubic field “slower decrease of the field” (similar results expected)
- test with a different MC (geant4, MARS) to compare the yield patterns and their absolute values

Thanks

Power on target

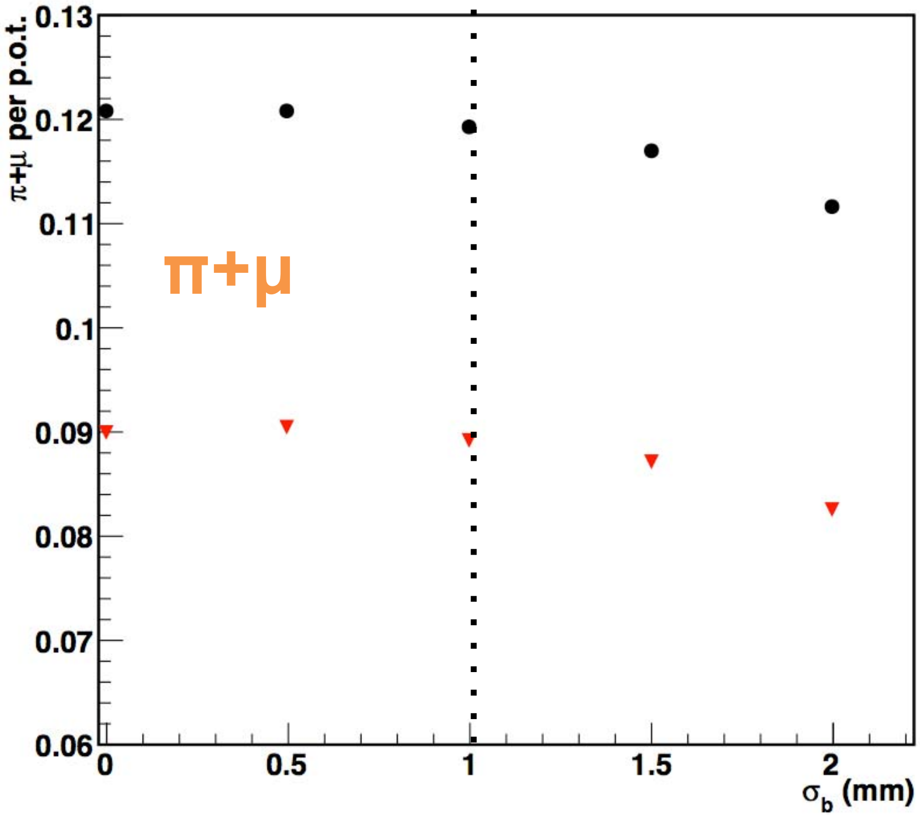


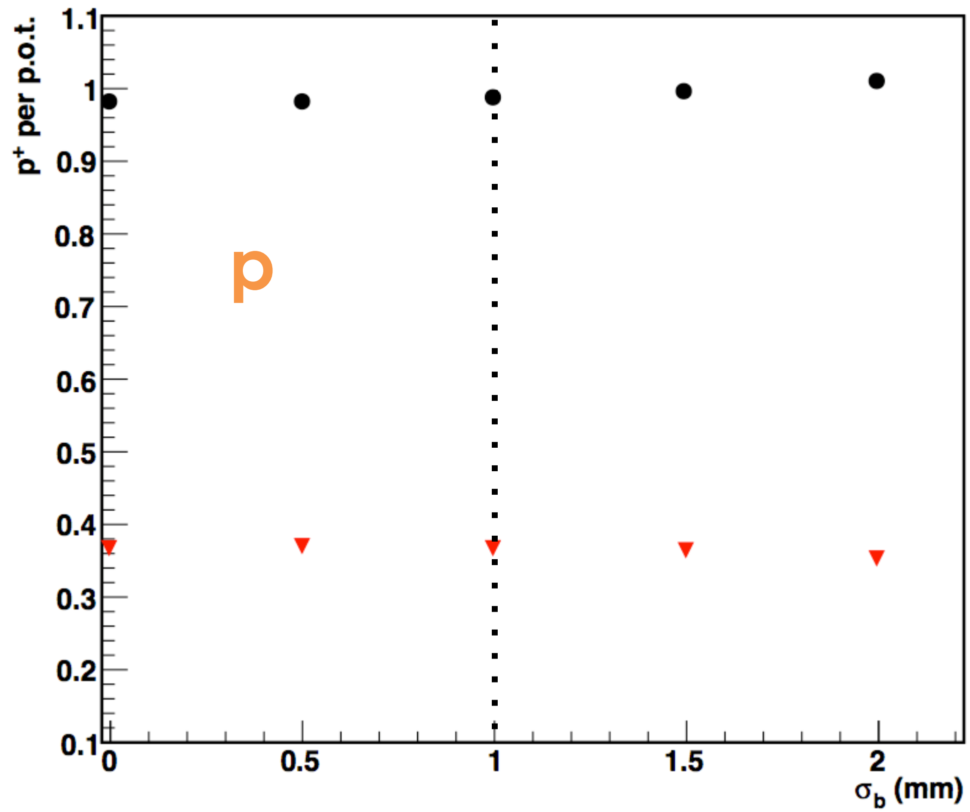


P_{trg} = 2.5 MW

particle yields at the edge of MCS for different beam sizes

tilt=100 mrad, L_{trg}=30 cm, r_{trg}=5 mm



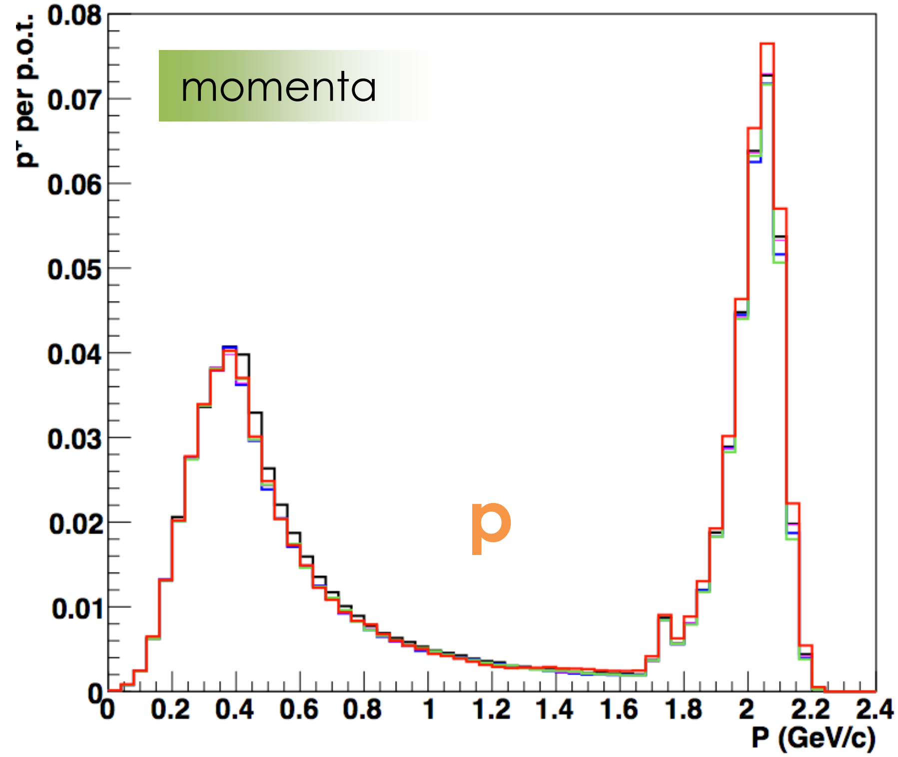


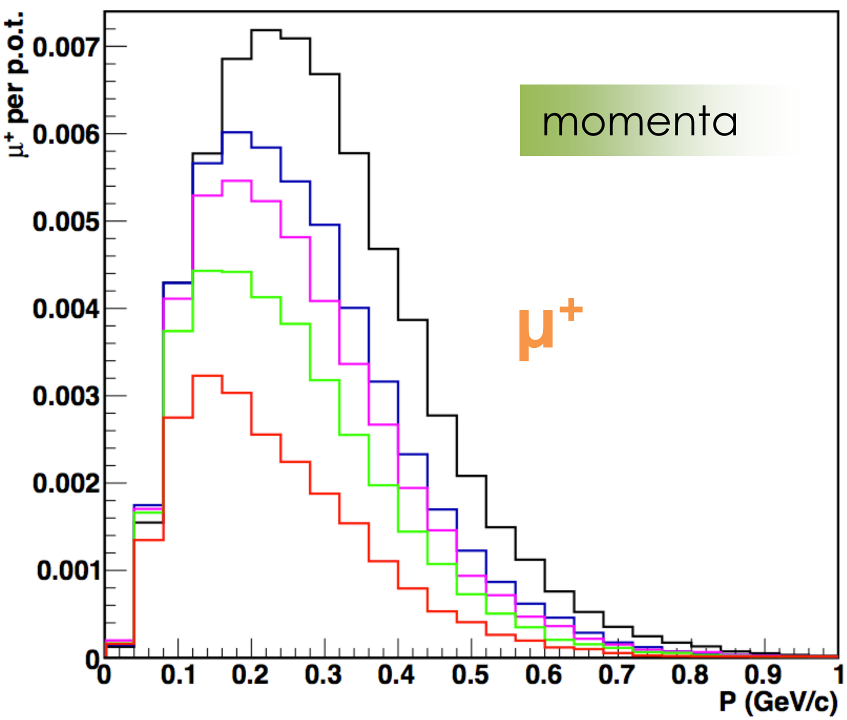
statistical error < 1 %

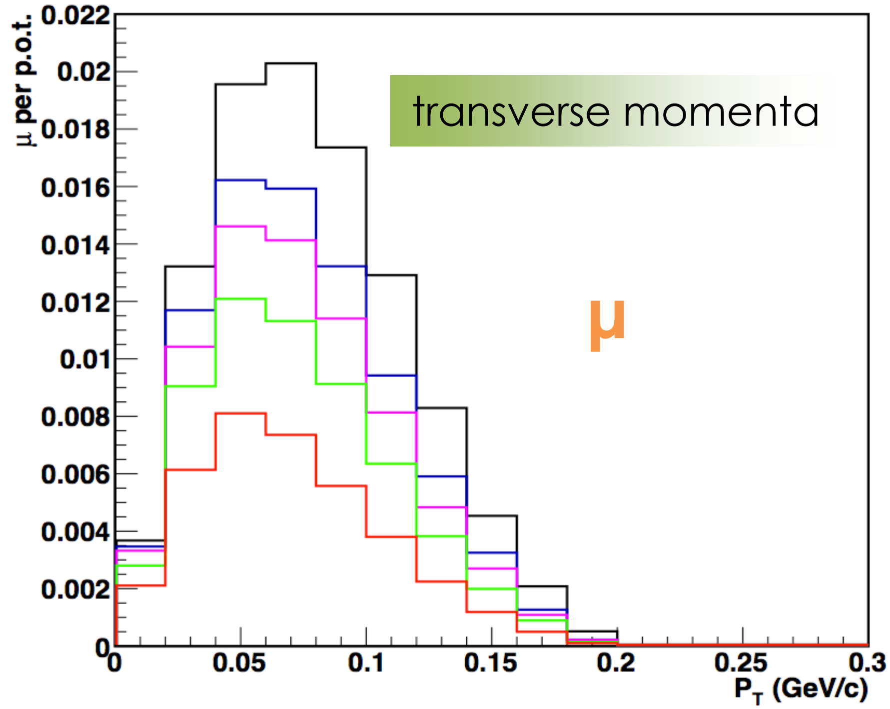
similar, could do less in beam size

momenta distributions (to be updated)

L = 5, 10, 15, 20, 50 m



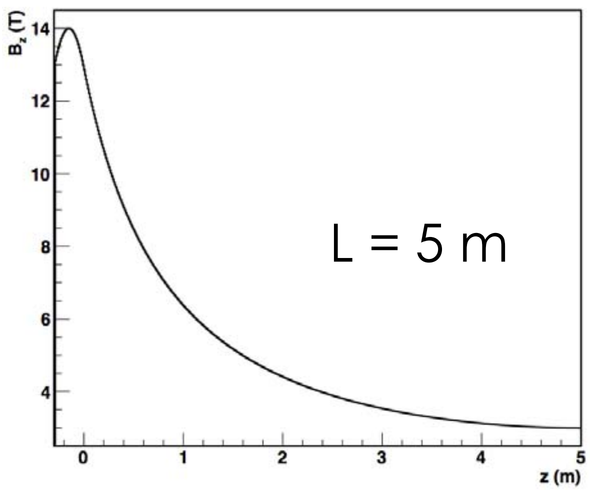


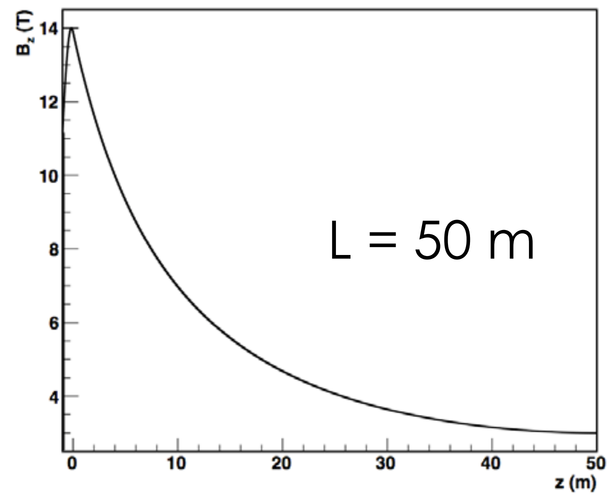


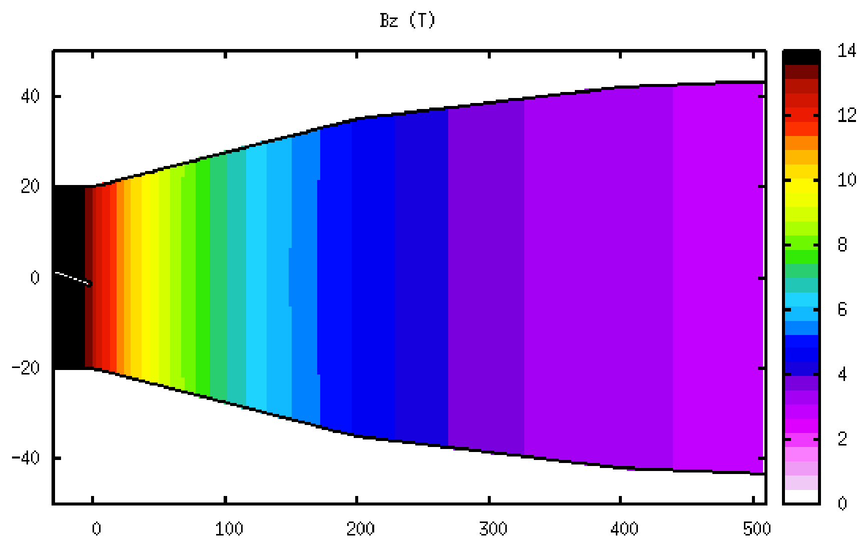
$$B_z(0,z) = B_0 e^{-(z-z_0)^2/2\sigma^2}$$

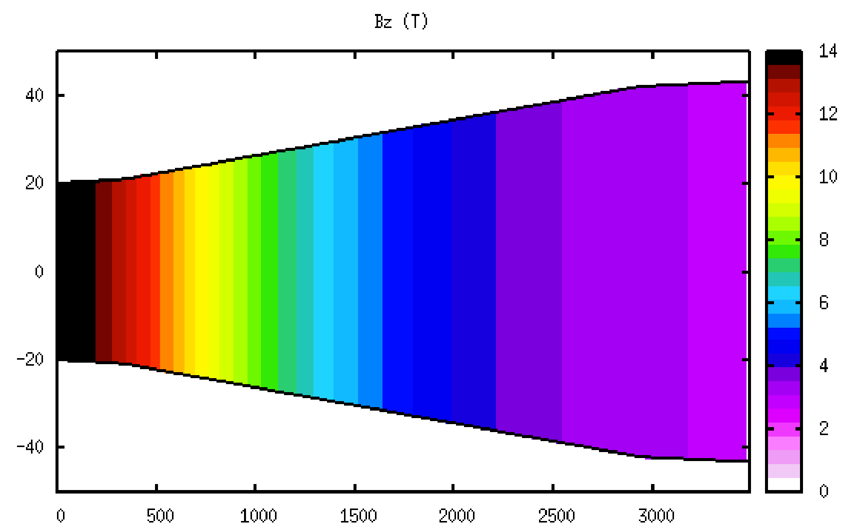
$$B_0 = 14T, z_0 = -15cm$$

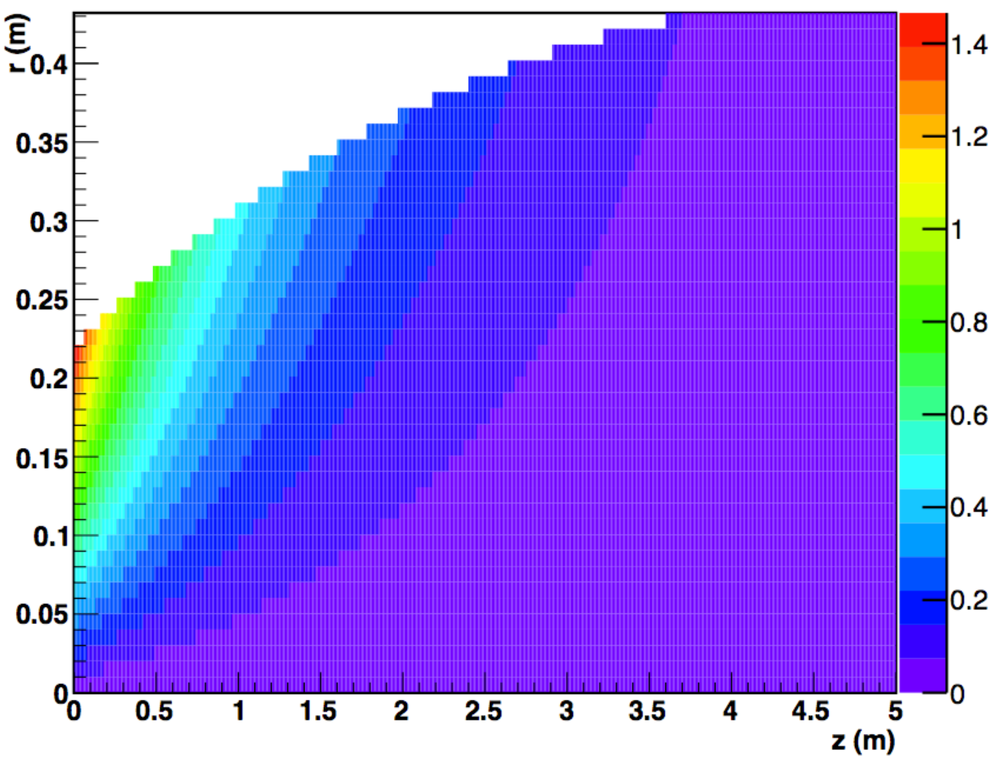
$$+ \; B_z(0,z) = \frac{B_1}{1 + a_1 * (z - z_1) + a_2 * (z - z_1)^2 + a_3 * (z - z_1)^3}$$

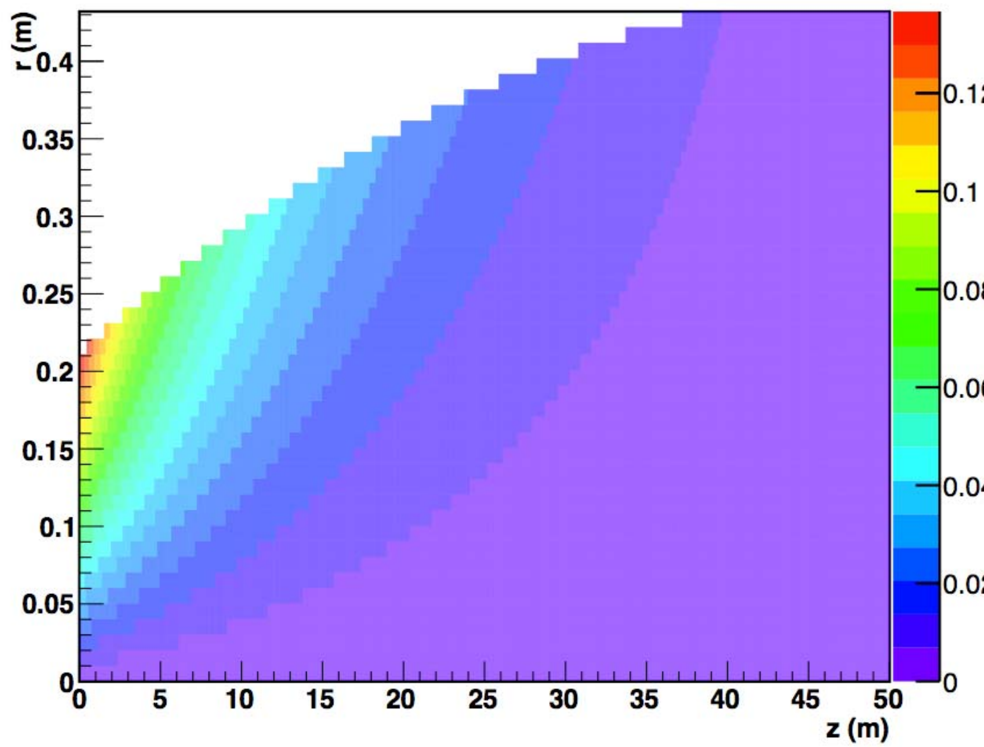




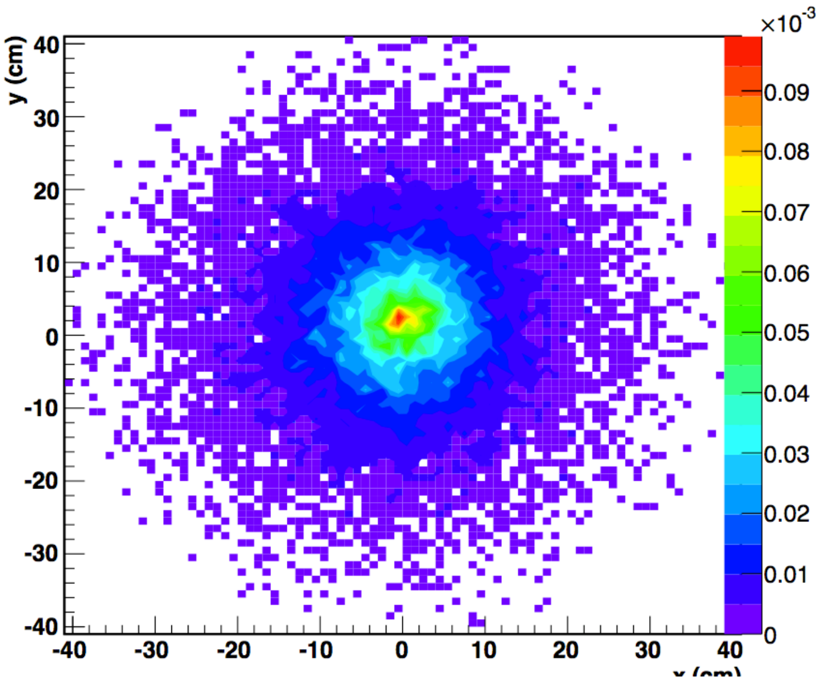


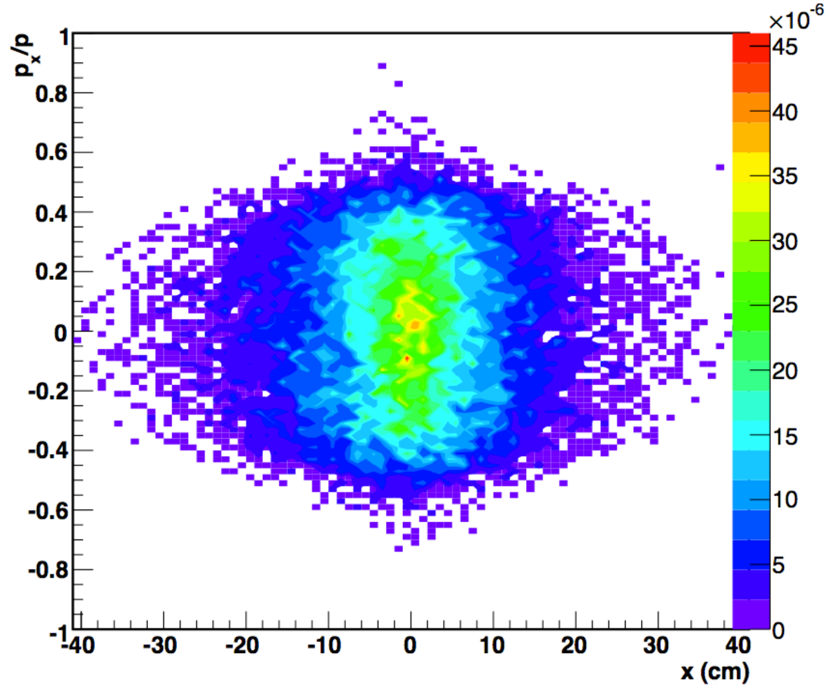



r (m)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
z (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0

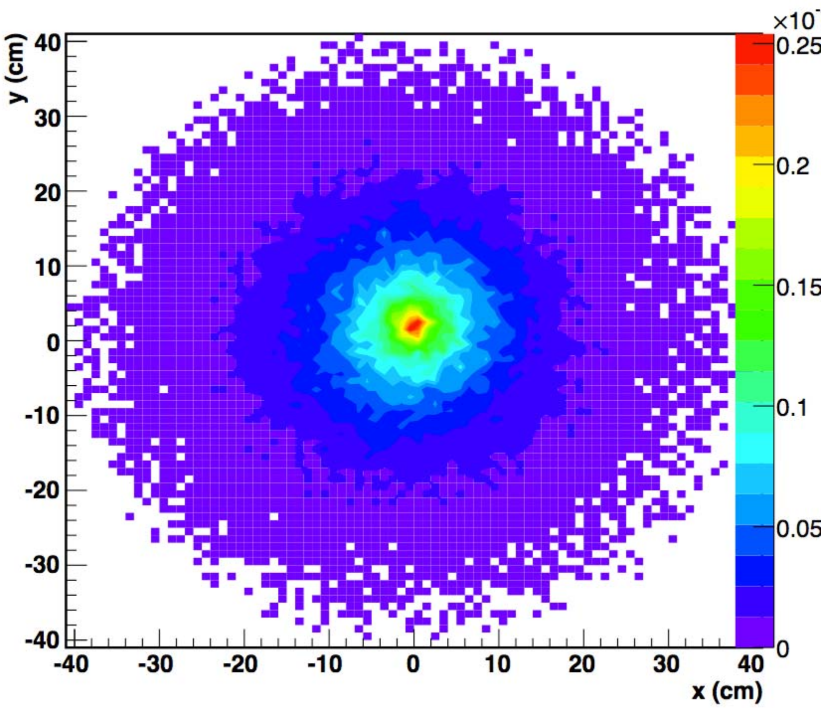

r (m)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5
10
15
20
25
30
35
40
45
50
z (m)
0.12
0.1
0.08
0.06
0.04
0.02
0

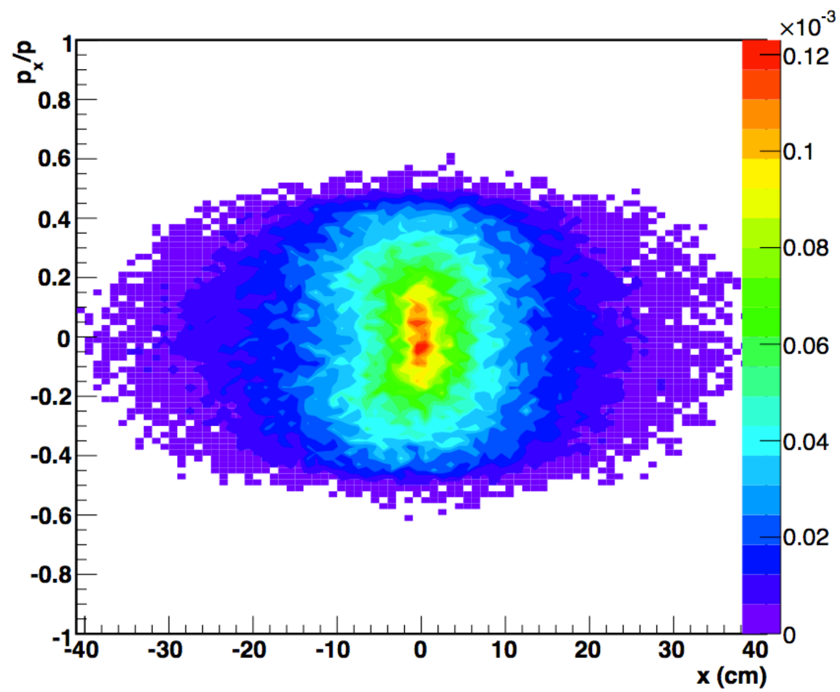
spatial distribution and transverse emittance





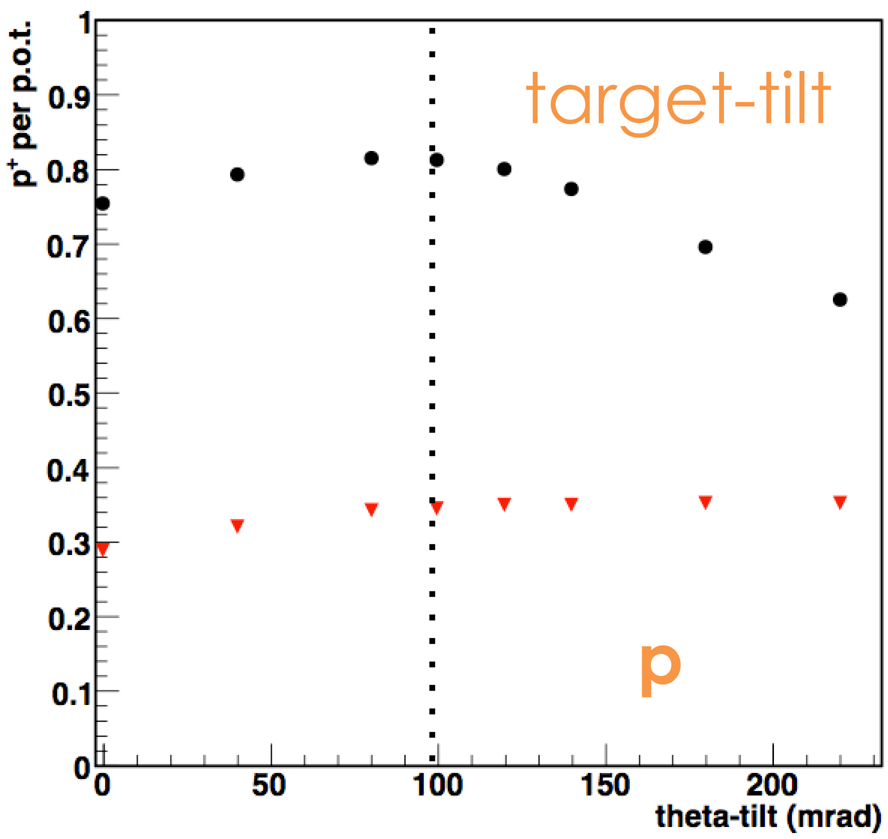
L = 5 m

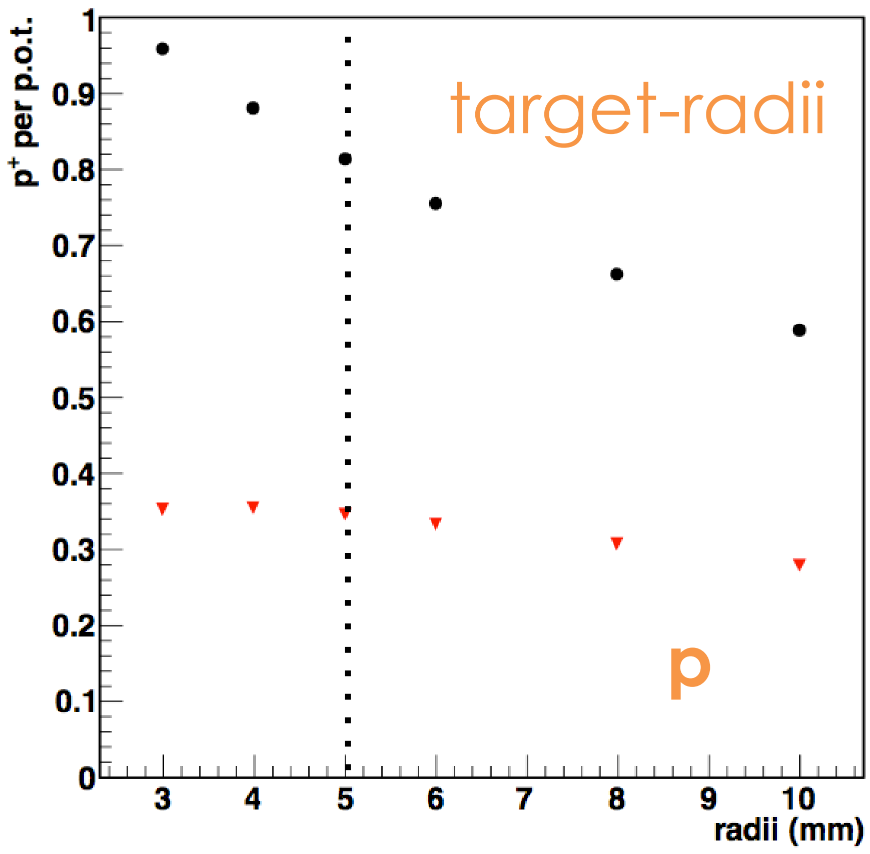




L = 50 m

proton yields for inverse taper L = 50 m vs different target-tilts, radii





statistical error < 1 %