ALTERNATIVE CAPTURE SOLENOID STUDY FOR THE MUON COLLIDER TARGET

HISHAM KAMAL SAYED

Physics Department

BROOKHAVEN NATIONAL LABORATORY

Sept. 28, 2012

BROOKHAVEN NATIONAL LABORATORY

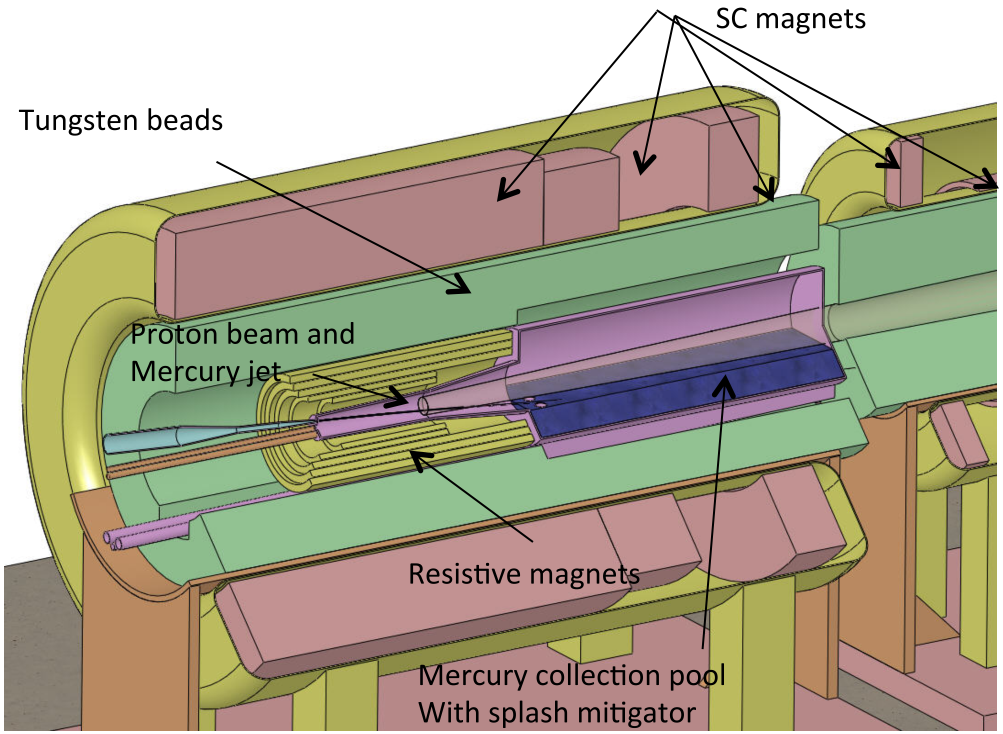
OVERVIEW

- Target layout
- Current baseline parameters
- Solenoid Taper field calculations
- MARS simulation setup
- Tracking through FE with ICOOL
- Muon count
- Transverse position &Momentum distribution
- Conclusion

BROOKHAVEN NATIONAL LABORATORY

Target System Current Baseline Design

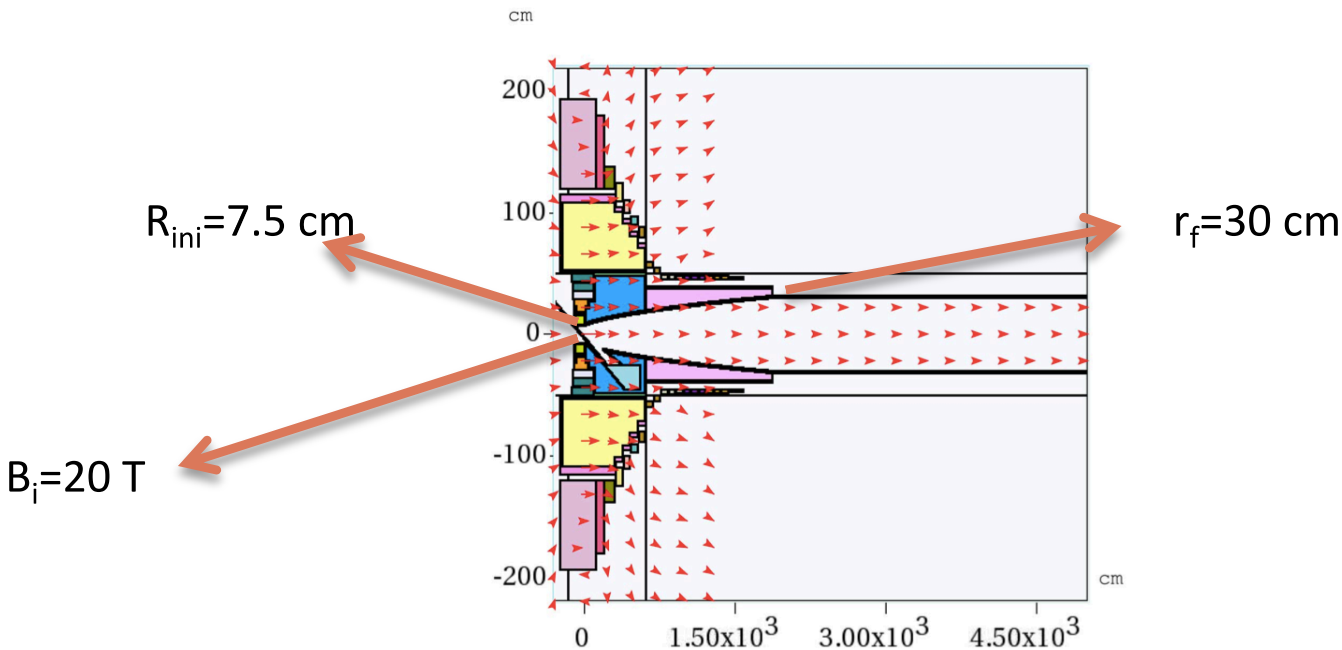
- Production of 10^{14} μ/s from 10^{15} p/s ($\approx$ 4 MW proton beam)
- Low-energy π's collected from side of long, thin cylindrical target
- Solenoid coils can be some distance from proton beam.
  - $\geq$ 10-year life against radiation damage at 4 MW.
- Proton beam readily tilted with respect to magnetic axis.
  - $\Rightarrow$ Beam dump (mercury pool) out of the way of secondary π's and μ's.
- Shielding of the superconducting magnets from radiation is a major issue.
  - Magnet stored energy ~ 3 GJ



5-T copper magnet insert; 10-T Nb3Sn coil + 5-T NbTi outsert.
Desirable to eliminate the copper magnet (or replace by a 20-T HTS insert).

TARGET PARTICLE PRODUCTION WITH 15 T PEAK SOLENOID FIELD

- Particle-capture requirement ($P_t \leq 0.225$ GeV/c)
  - $B \times r$ = 20 T × 7.5 cm = 150 T-cm
  - $B \times r$ = 15 T × 10 cm = 150 T-cm
- Fixed-flux requirement (Aperture requirement)
  - $B \times r^2 = 20 \times 7.5^2$ = 1125 T-cm^2
  - $B \times r^2 = 15 \times 10^2$ = 1500 T-cm^2
- MARS simulations with 15-T peak field & new aperture settings (taper radius r = 30 cm at all z)

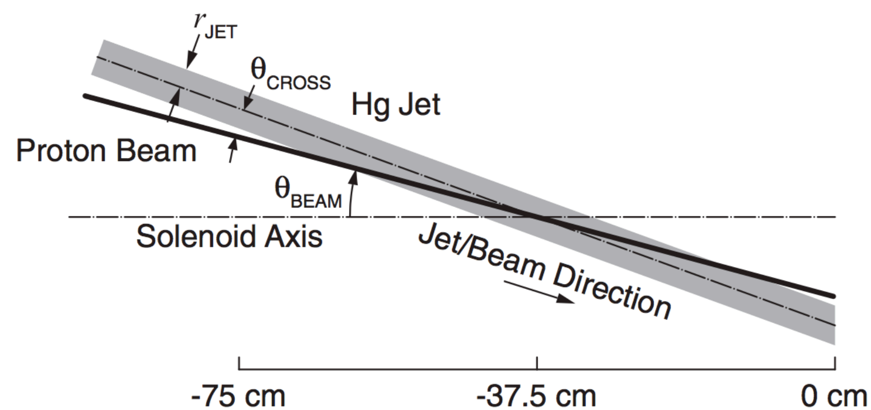


Particle loss due to scrapping with beam pipe !

Current Target Optimized Parameters

(X. Ding et al.)

- Hg Target
  - θ_{Target}=0.137 rad
  - R_{Target}=0.404 cm
- Proton Beam
  - E=8 GeV
  - θ_{Beam}=0.117 rad
  - $\sigma_x=\sigma_y$=0.1212 cm (Gaussian Distribution)
- Solenoid Field
  - IDS120h → 20 T peak field at target position (Z=0)
  - Aperture at Target R=7.5 cm - End aperture R = 30 cm
  - Fixed Field B_z=20 →1.5 T L_{taper}=15 m



- Production: Muons within energy KE cut 40-180 MeV at z=50 m
- 3.27×10^4 ($N_{ini}=10^5$)

Analytic form for Tapered Solenoid

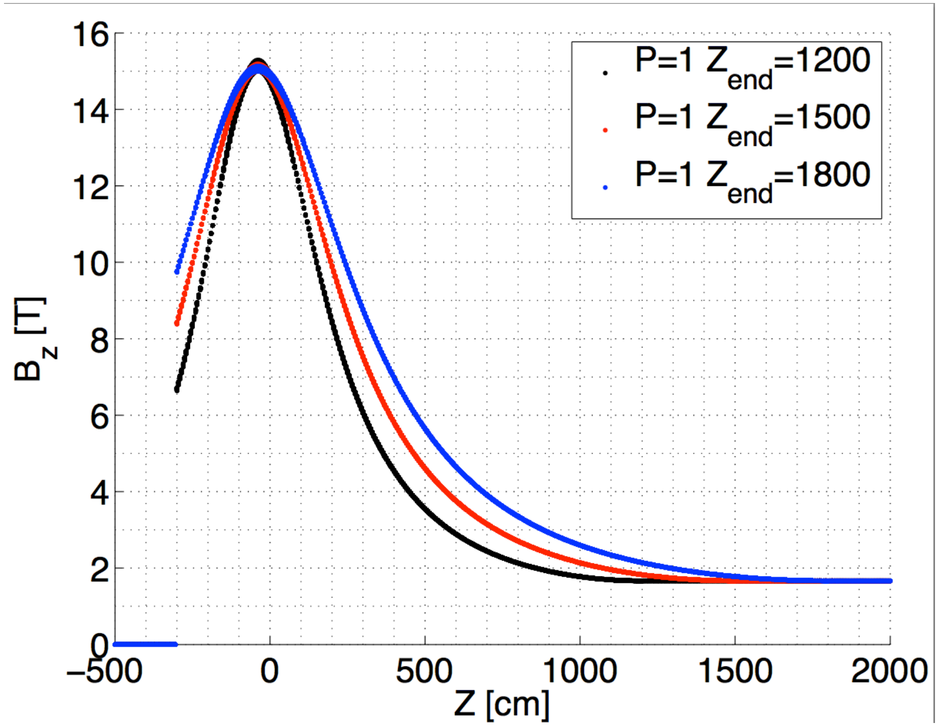
Inverse-Cubic Taper

$$B_z(0, z_i < z < z_f) = \frac{B_1}{[1 + a_1(z - z_1) + a_2(z - z_1)^2 + a_3(z - z_1)^3]^p}$$

$$a1 = -\frac{B_1'}{pB_1} \qquad a_2 = 3\frac{(B_1/B_2)^{1/p} - 1}{(z_2 - z_1)^2} - \frac{2a_1}{z_2 - z_1}$$

$$a_3 = -2\frac{(B_1/B_2)^{1/p} - 1}{(z_2 - z_1)^3} + \frac{a_1}{(z_2 - z_1)^2}$$

Field at R=0



Off-axis field approximation

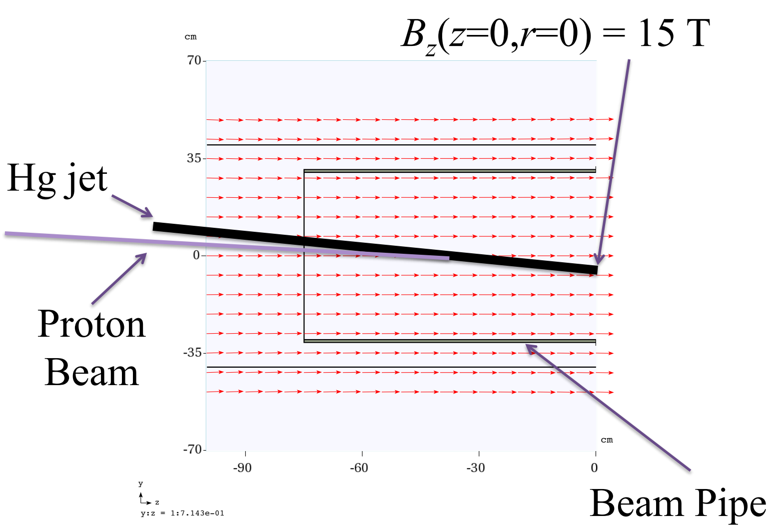
$$B_z(r,z) = \sum_n (-1)^n \frac{a_0^{(2n)}(z)}{(n!)^2} (\frac{r}{2})^{2n}$$

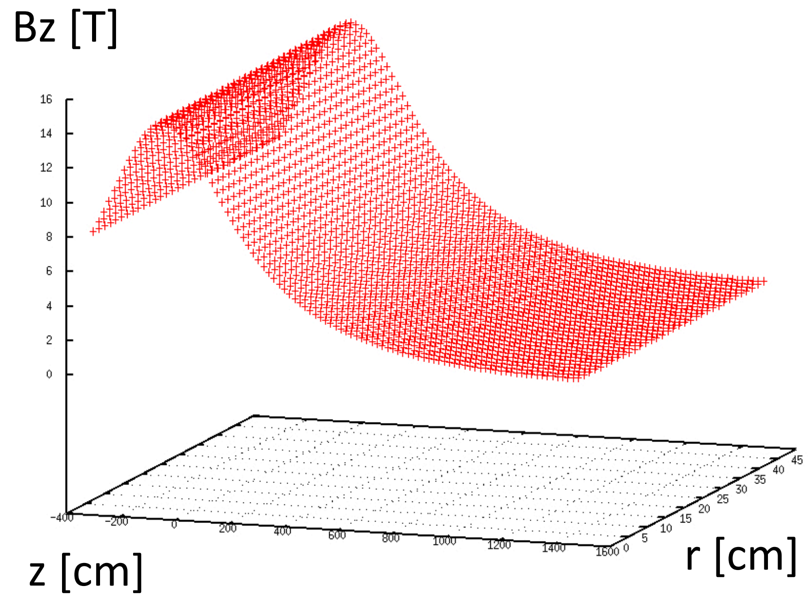
$$B_r(r,z) = \sum_n (-1)^{n+1} \frac{a_0^{(2n+1)}(z)}{(n+1)(n!)^2} (\frac{r}{2})^{2n+1}$$

$$a_0^{(n)} = \frac{d^n a_0}{dz^n} = \frac{d^n B_z(0,z)}{dz^n}$$

MARS Simulation Setup

- Beam Pipe with constant R=30 cm (eliminate particle loss due to scrapping)
- Beam Pipe material changed to “Balckhole” -> speed calculations
- Added subroutine to m1510.f (FIELD- K. McDonald) to calculate the field using inverse cubic equations
- $N_{proton}=5\times10^5$
- Store particles information at z=0
- Select (μ^+ - k^+ - π^+)

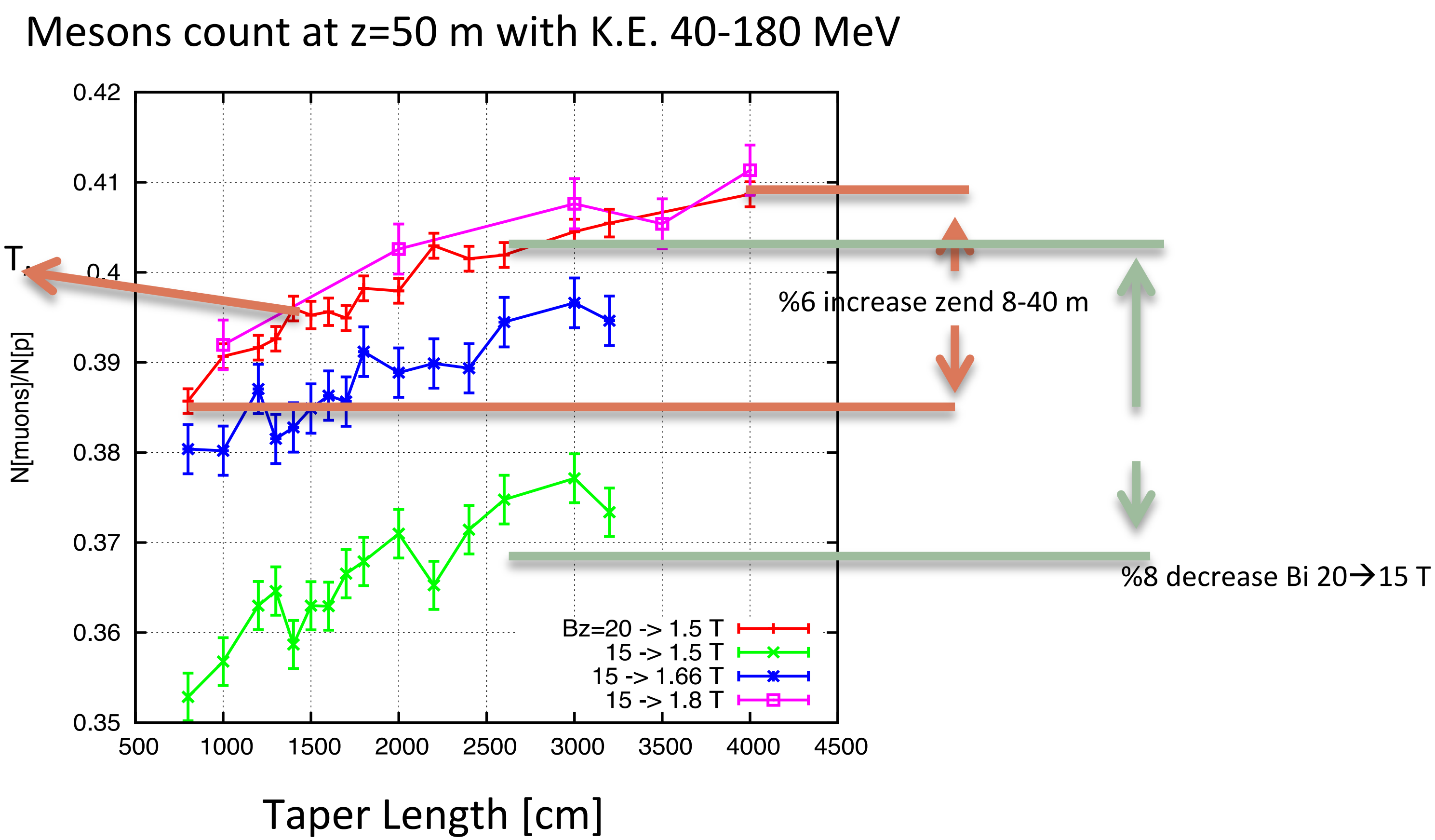




MARS Simulation Results

Tapered field using inverse-cubic field (P = 1)

Present baseline:
B_i = 20 T, B_f = 1.5 T,
z_{end} = 15 m.



Conclusion
End of Decay Channel
Raising final const. Bz <--> Meson Yield
More adiabatic taper <--> Meson Yield

PARTICLE TRACKING THROUGH FRONT END

Taper solenoid field with different settings

$B_z(r=0)$ 20 → 1.5 T Taper Length 8→43 m

$B_z(r=0)$ 15 → 1.5 T Taper Length 8→43 m

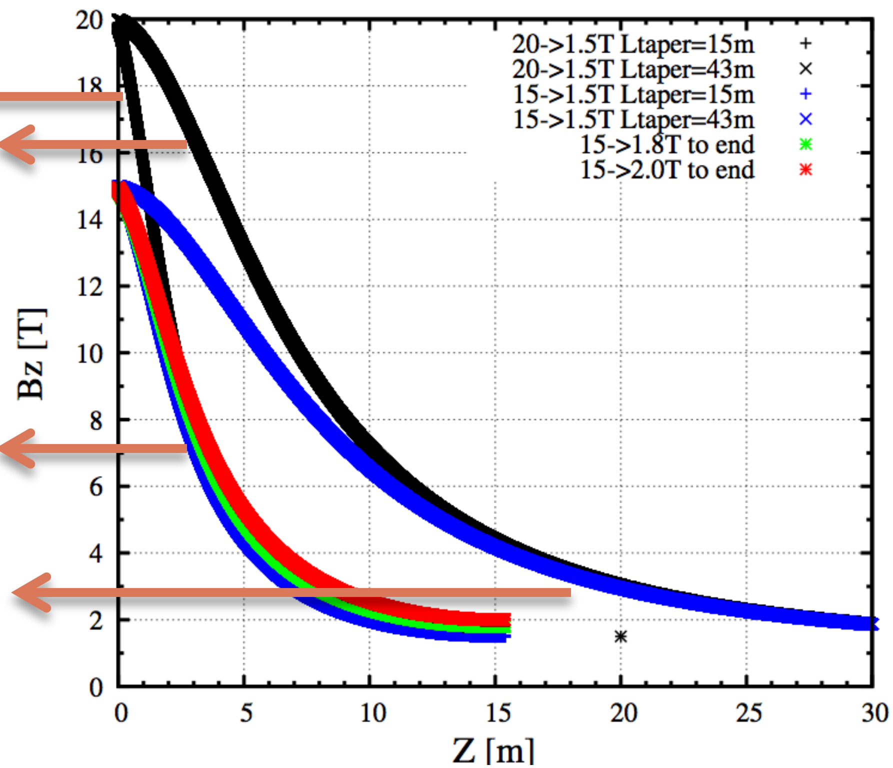
$B_z(r=0)$ 15 → 1.8 T Taper Length 8→43 m

$B_z(r=0)$ 15 → 2.0 T Taper Length 8→43 m

B_z=20 → 1.5 T L_{taper}= 15 & 43 m

B_z=15→ 1.5 T L_{taper}= 15

B_z=15→ 2.0 T L_{taper}= 43



PARTICLE TRACKING THROUGH FRONT END

2- ICOOL applied aperture for decay region R_aperture= 0.4 m & 0.3 m to end

3- Good particles are those who satisfy the following conditions/cuts

1- Survived the phase rotator and cooling sections

2- Fall within required acceleration acceptance cuts (ecalc)

- 0.1 <Pz< 0.3 GeV
- Transverse cut 0.03 m
- Longitudinal cut 0.15 m

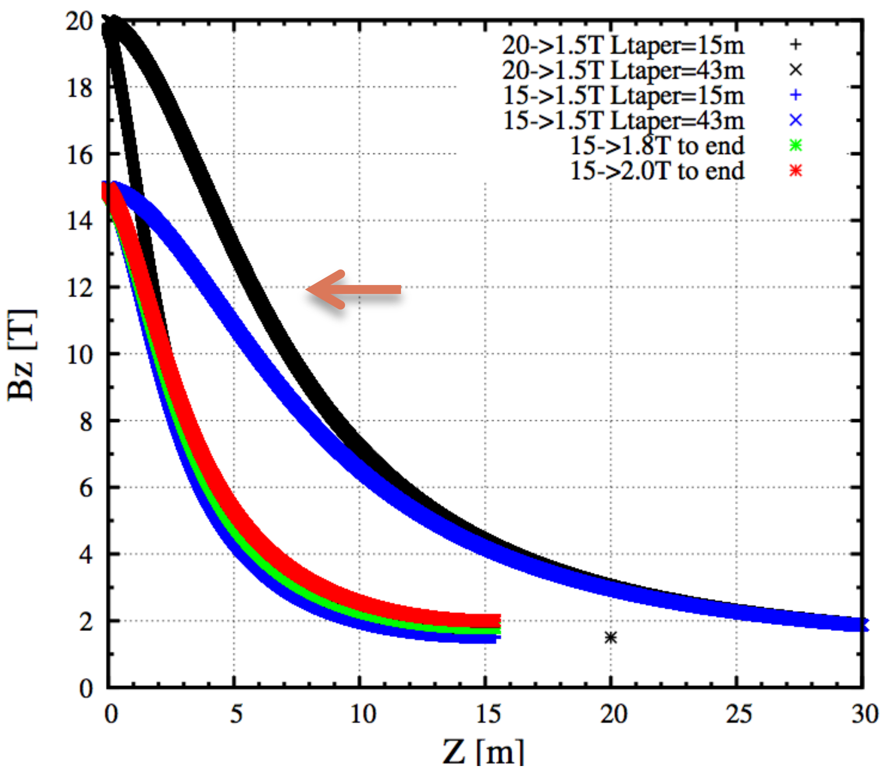
BROOKHAVEN NATIONAL LABORATORY

Muon count at end of "frontend"

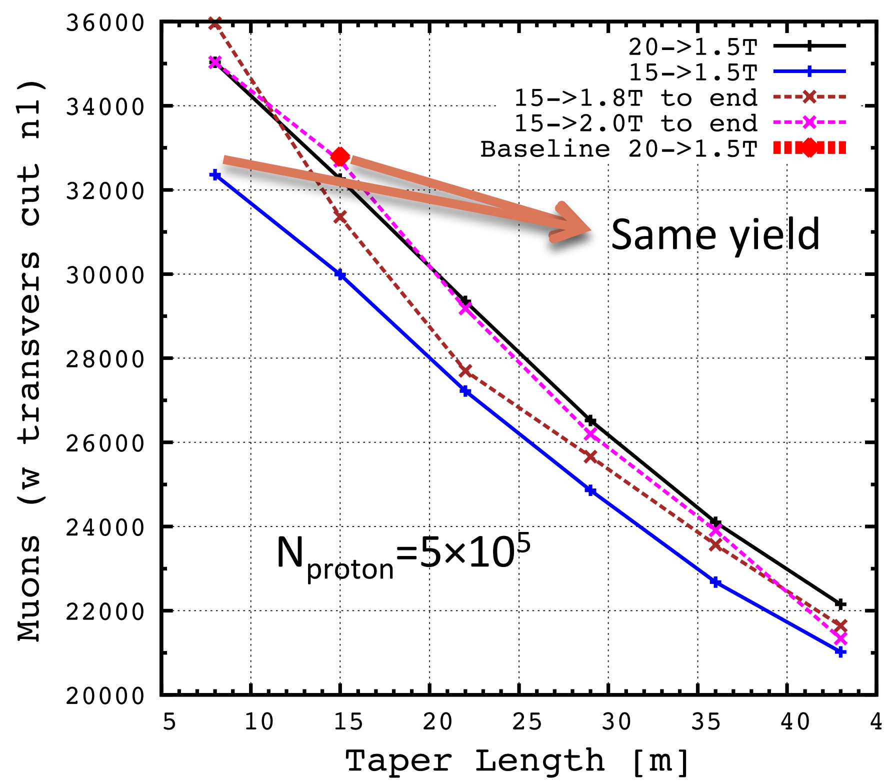
Muons within required acceleration acceptance cuts after cooling section

- $0.1 < P_z < 0.3$ GeV
- Transverse cut 0.03 m
- Longitudinal cut 0.15 m

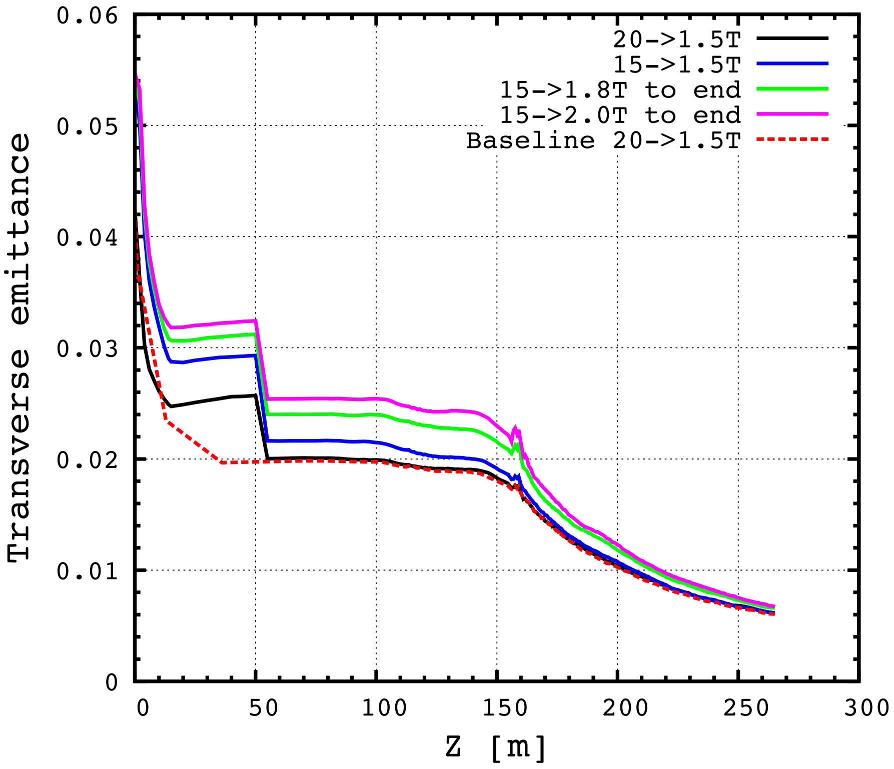
Solenoid Field along z-axis

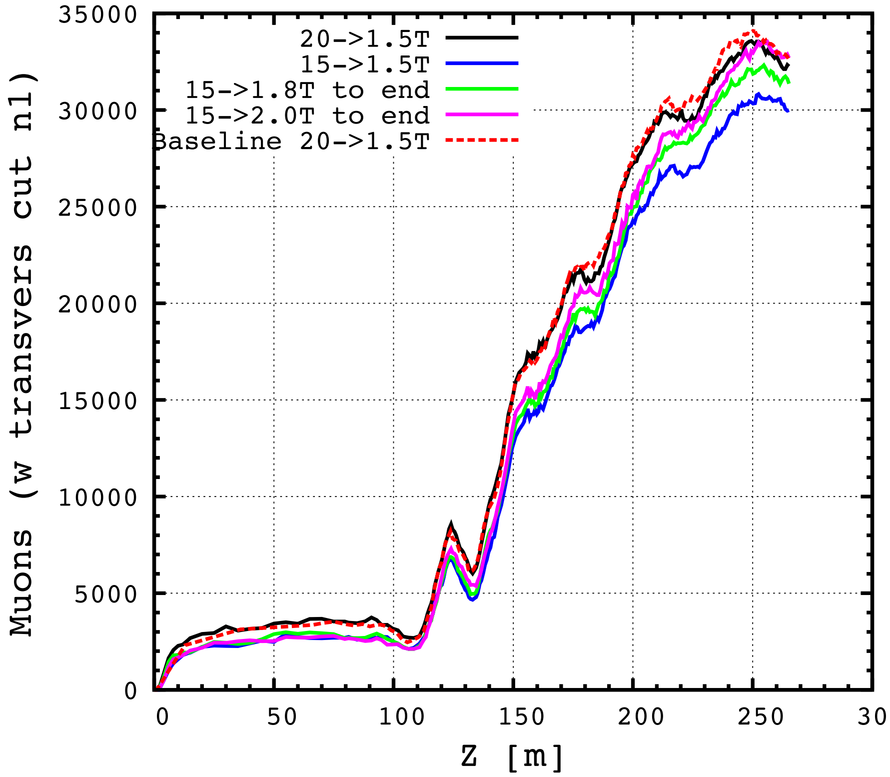


Shorter taper better survive buncher - phase rotator & cooling



TRANSMISSION & TRANSVERSE EMITTANCE

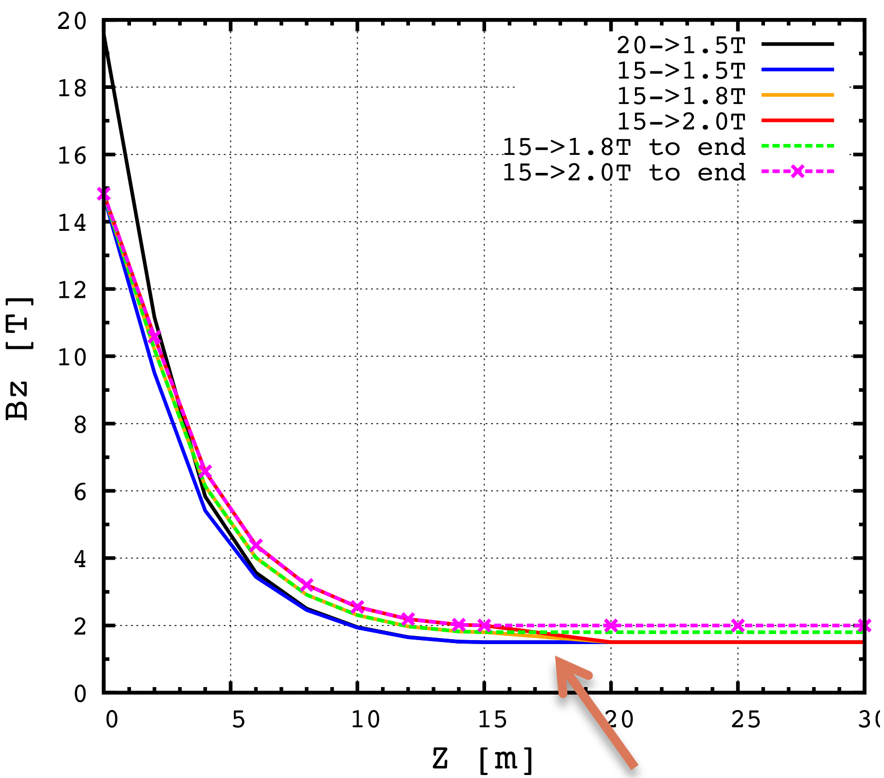




MUON COUNT AT END OF "FRONTEND"

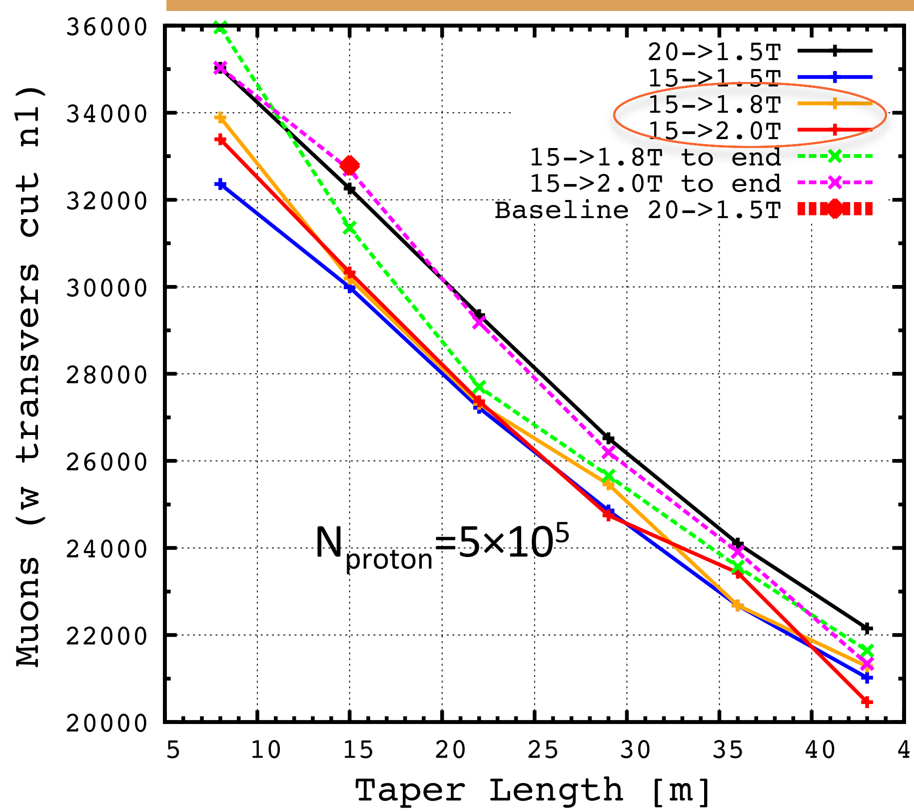
What will happen if we do not raise the constant solenoid field to 1.8/2.0 T ?!

Solenoid Field along z-axis



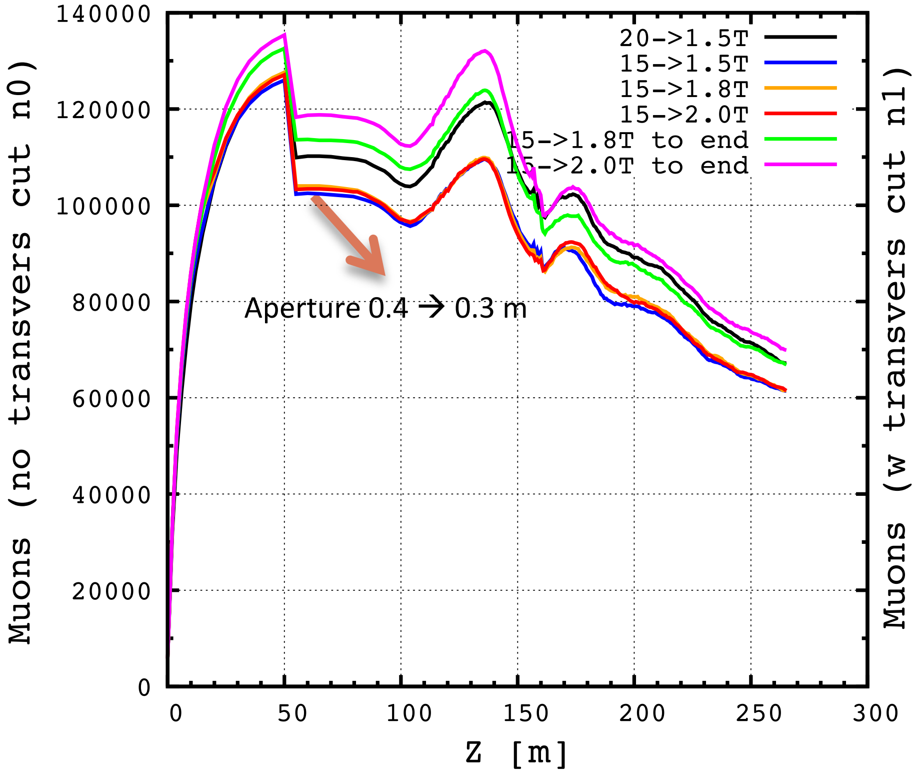
Discontinuity 1.8(2.0) → 1.5 T

Shorter taper better survive buncher - phase rotator & cooling

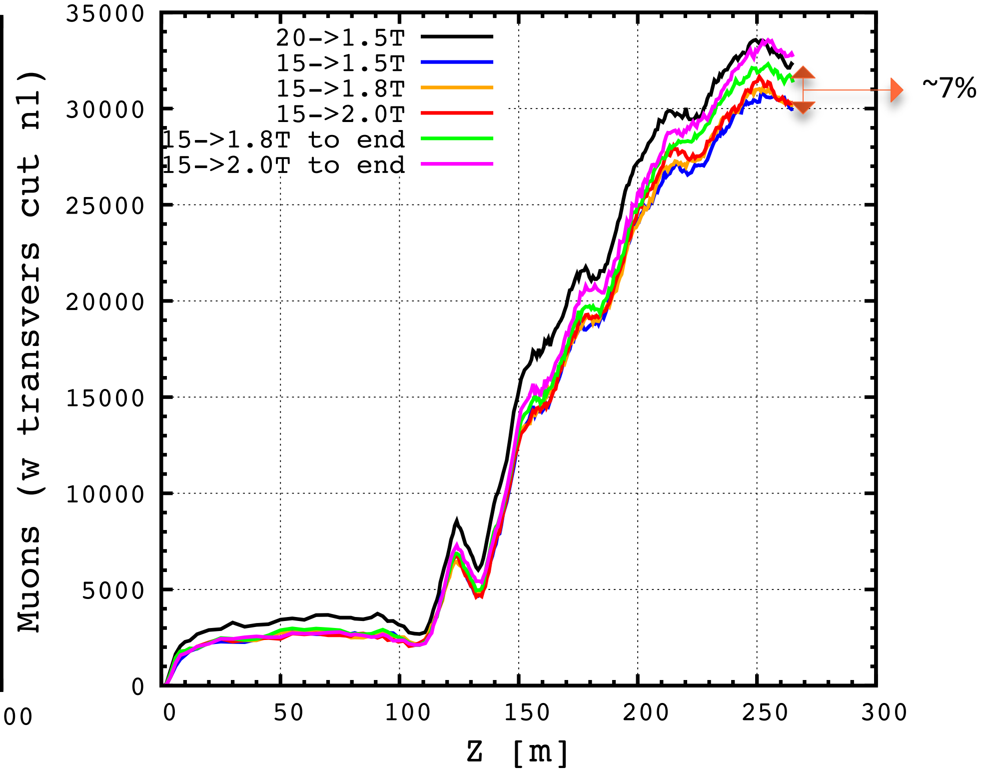


Transmission through front end

Pz & Σ cut

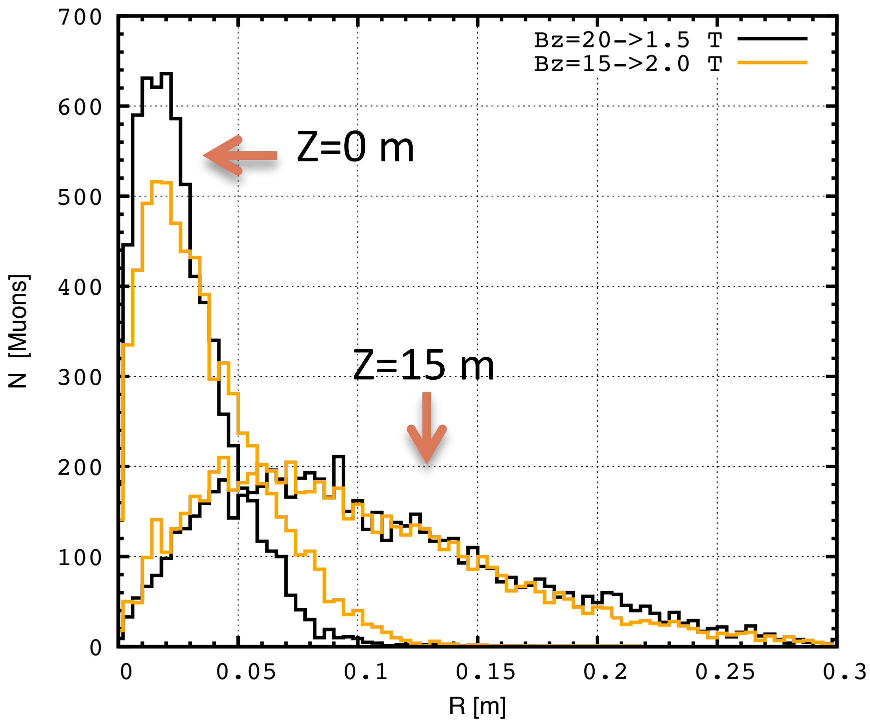


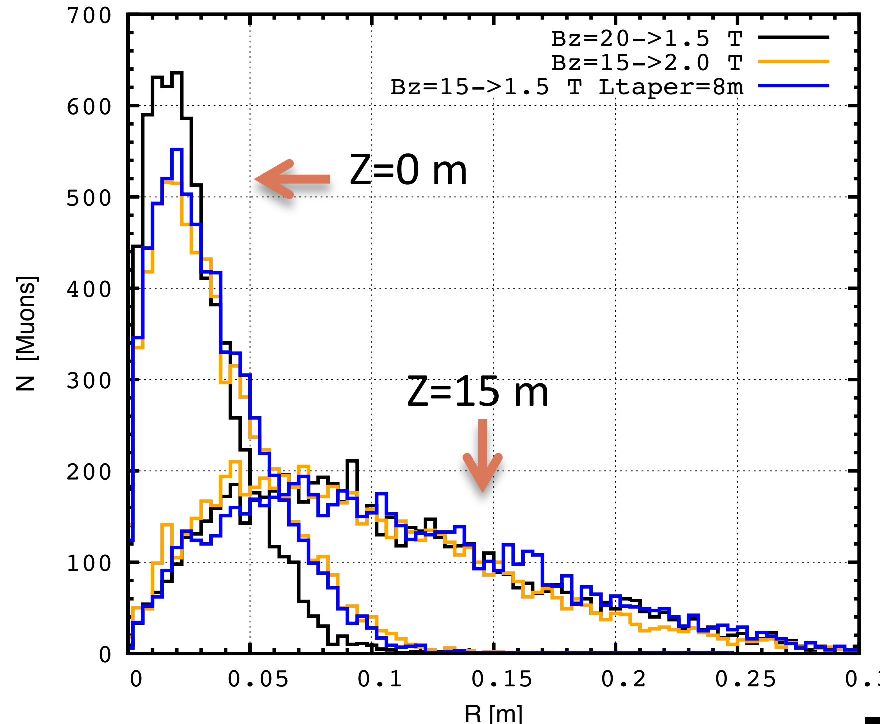
Trans, Pz, & Σ cut



Distributions of particles survived the front end and acceleration cuts

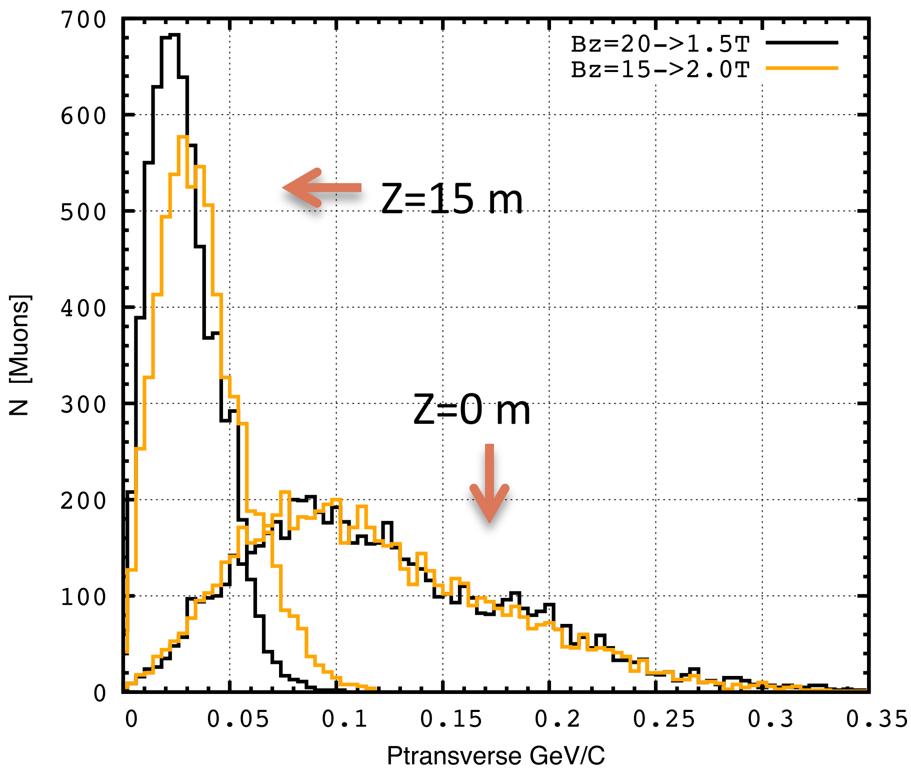
Radii distribution Taper Length =15 m

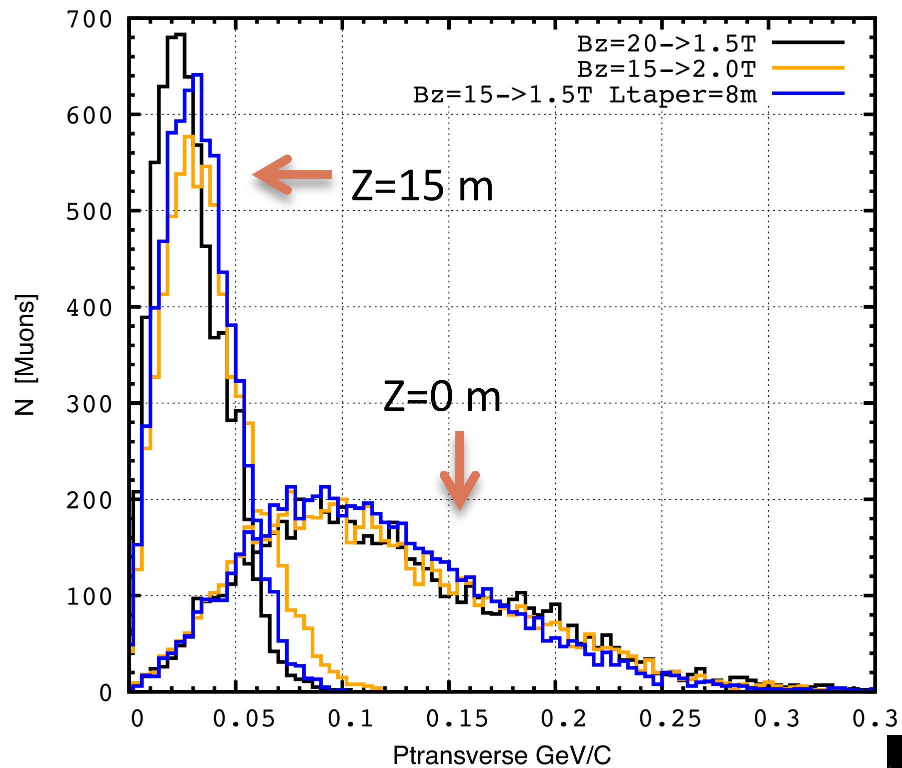




Distributions of particles survived the front end and acceleration cuts

Momentum distribution Taper Length =15 m



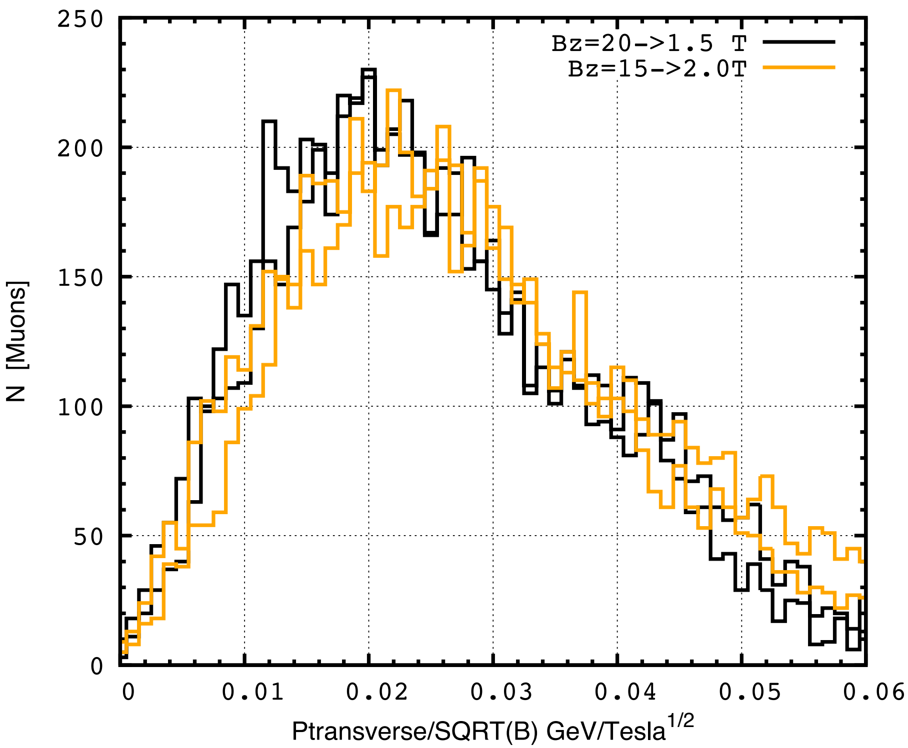


BROOKHAVEN NATIONAL LABORATORY

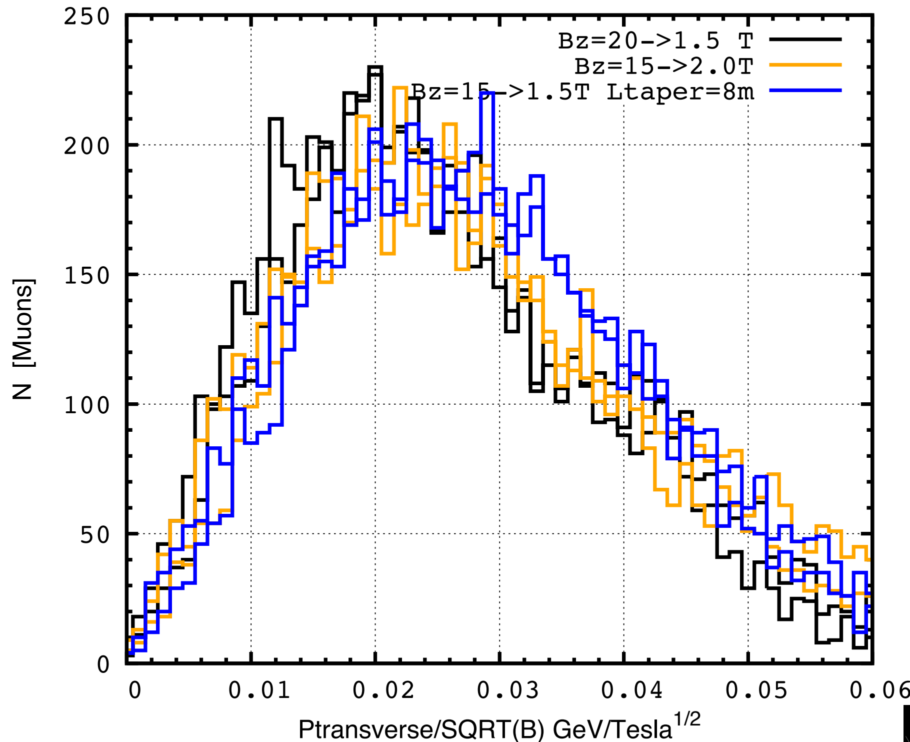
Distributions of particles survived the front end and acceleration cuts

Invariant of motion

Z=0 & 15 m



Z=0 & 15 m



CONCLUSION

- Mesons count within KE cut only at 50 m increases with longer taper.
- Bz=15→1.5T with 8 m taper length production matches the current 20T peak field baseline.
- 15 T peak field case has ~ 7% less yield at end of cooling though it produces about the same number of muons at the target.
- No clear mismatch in the lattice that shows huge particle loss
- Particle radii extends from 0.1 at z=0 to 0.3 m at z=15 m
- Particles transverse momenta extends from 0.3 at z=0 to 0.1 m at z=15 m

Taper Length	End of Decay Channel z=50 m No cuts	End of FE z=265 m Eclac acceleration acceptance cuts
Short		Better
Long	Better	

Needs to be investigated & understood