Progress on The Neutrino Factory Target System Design

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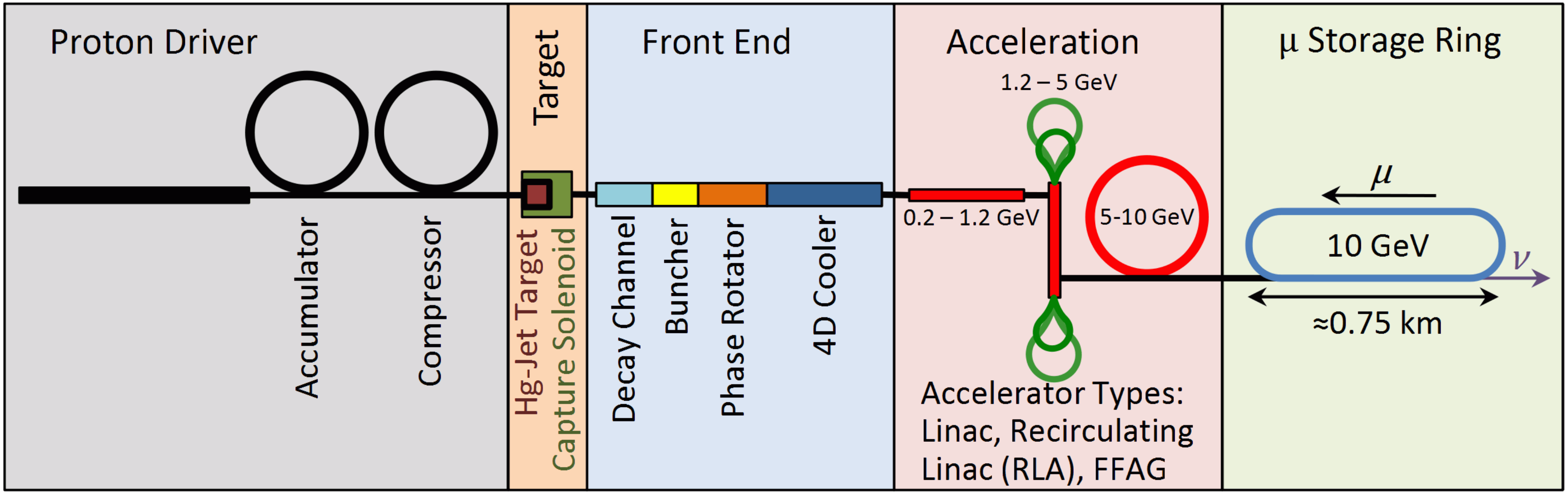
Overview

- Target layout
- Current baseline
- Taper field calculations
- MARS simulation setup
- Muon production & momentum distribution
- Conclusion

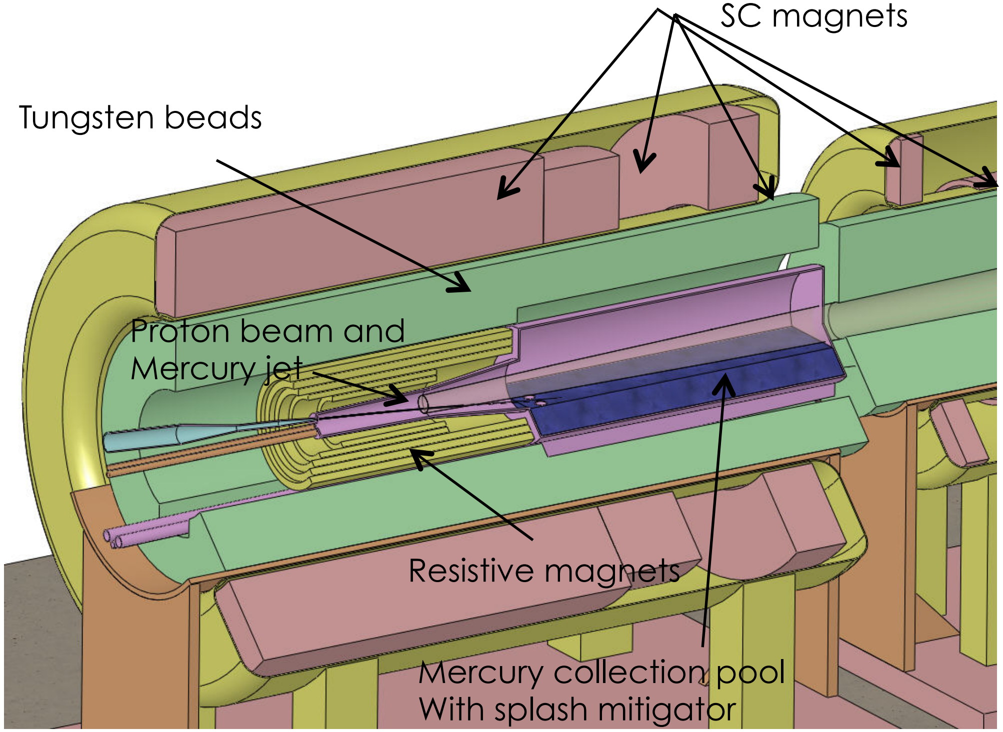
Neutrino FACTORY LAYOUT



Target System Solenoid:
Capture $\mu^{\pm}$ of energies ~ 100-400 MeV from a 4-MW proton beam (E ~ 8 GeV).

Target System Current Baseline Design

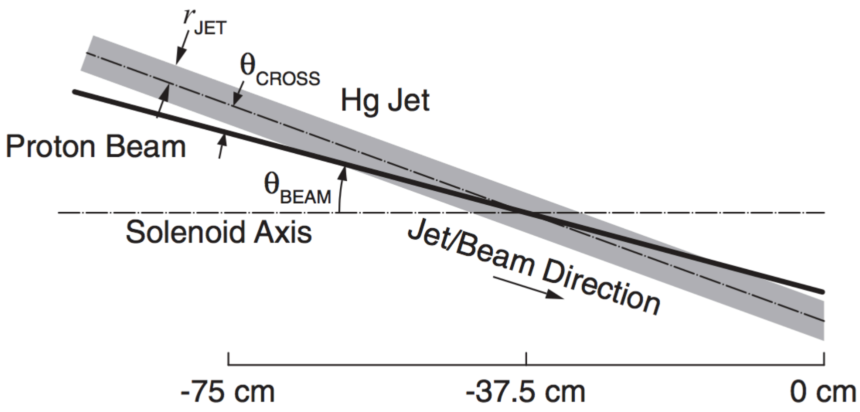
- Production of 10^{14} μ/s from 10^{15} p/s (≈ 4 MW proton beam)
- Low-energy π's collected from side of long, thin cylindrical target
- Solenoid coils can be some distance from proton beam.
  - ≥ 10-year life against radiation damage at 4 MW.
- Proton beam readily tilted with respect to magnetic axis.
  - ⇒ 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).

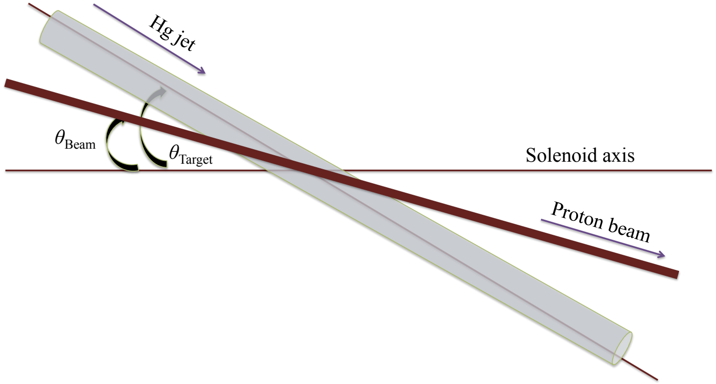
Baseline Optimized Parameters (X. Ding et al)

- Optimization of target parameters for a mercury jet target - 20 T Peak Field



- particle production:
  - Protons KE= 2 -100 GeV.
  - For each KE production optimized by
    - Mercury jet radius
    - Proton beam angle
    - Crossing angle between the mercury jet and the proton beam. With an 8-GeV proton beam
    - Figure of merit: number of muons surviving through the neutrino factory front end channel

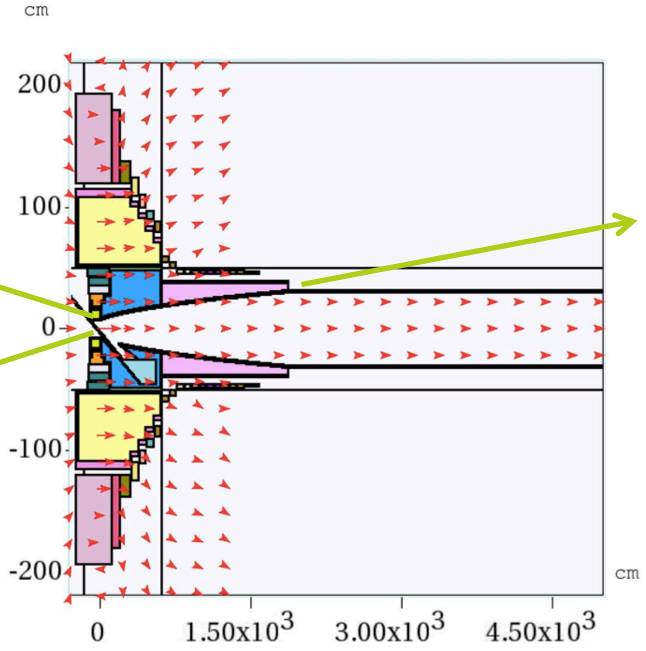
Baseline Optimized Parameters (X. Ding)



- 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=-37.5)
  - Aperture at Target R=7.5 cm - End aperture R = 30 cm
  - Fixed Field Z = 1500 → Bz=1.5 T
- Production: Muons within energy KE cut 40-180 MeV
  - 3.27×10^4 ($N_{ini\ protons}=10^5$)
  - $N_{mesons}/N_{protons}$=0.327

Target Particle Production with 15 T Peak Solenoid Field

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



R_{ini}=7.5 cm

r_f=30 cm

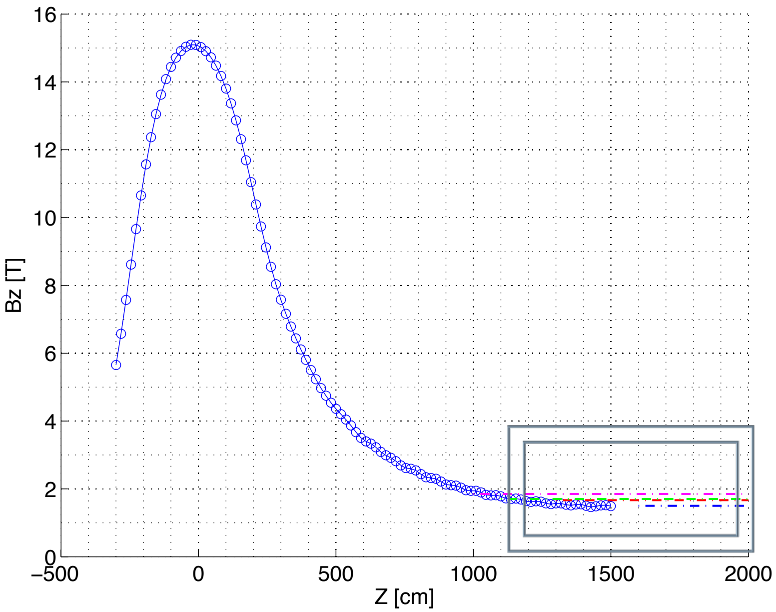
B_i=20 T

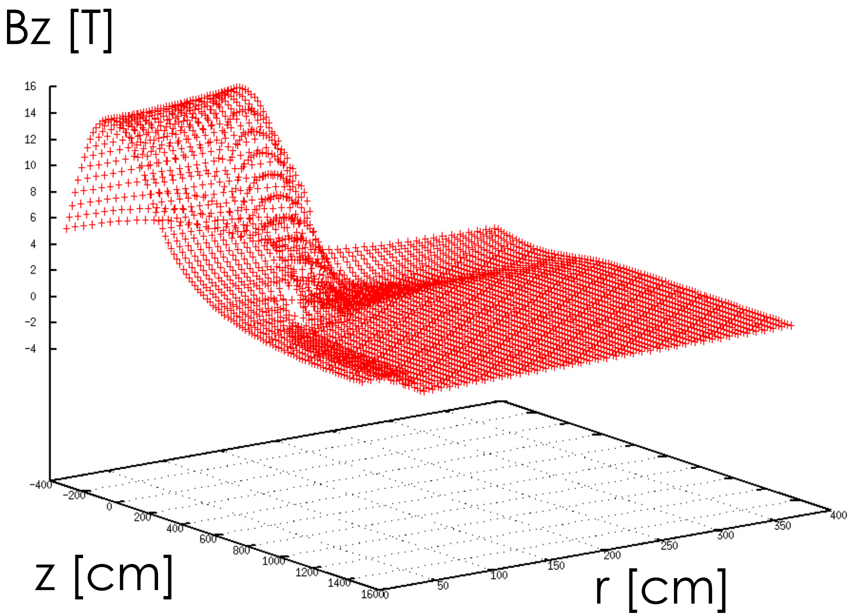
Particle loss due to scrapping with beam pipe !

IDS120H Target Solenoid

- Filed Map from SC coils

IDS120H (R. Weggel)





Analytic form for Tapered Solenoid (K. McDonald)

The magnetic field of the target system varies from B_i at the target to B_f at the front end, over distance z_{end}.

Field Parameters: $B_i(z=-37.5)$ $B_f(z=z_{end})$ z_{end}.

Inverse-Cubic Taper of order P

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

$$a1 = -\frac{B_i^{'}}{pB_i} \qquad a_2 = 3\frac{(B_i / B_f)^{1/p} - 1}{(z_f - z_i)^2} - \frac{2a_1}{z_f - z_i}$$

$$a_3 = -2\frac{(B_i / B_f)^{1/p} - 1}{(z_f - z_i)^3} + \frac{a_1}{(z_f - z_i)^2}$$

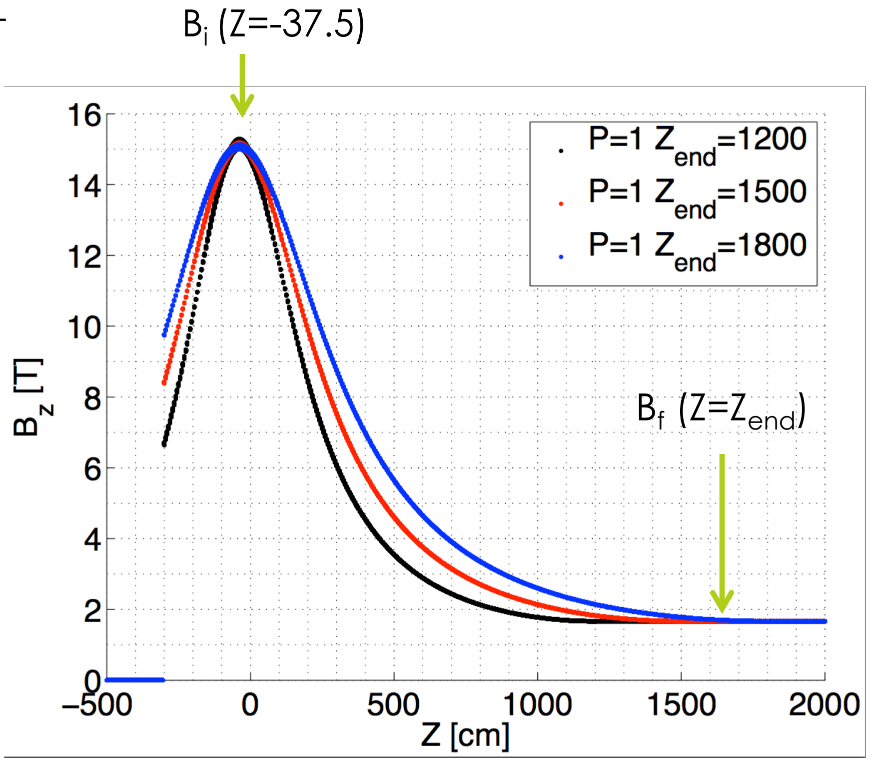
Off Axis Field Calculation

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

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

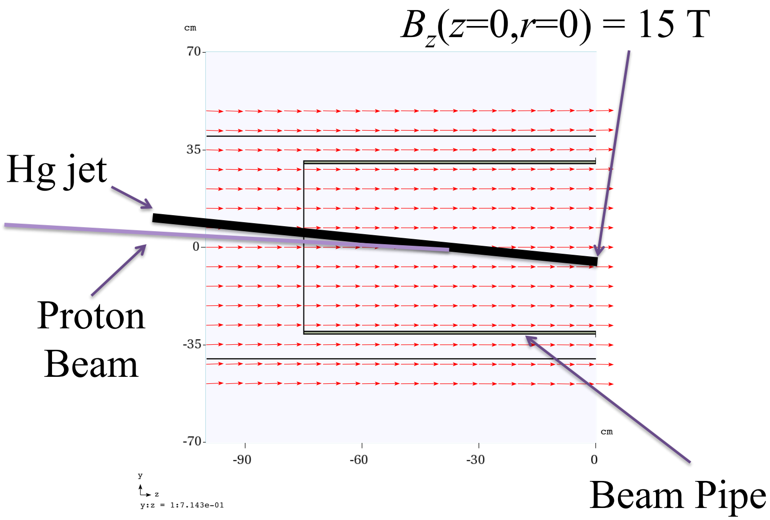
$$a_0^{(n)} = \frac{d^n a_0}{dz^n} = \frac{d^n B_z(0,z)}{dz^n}$$

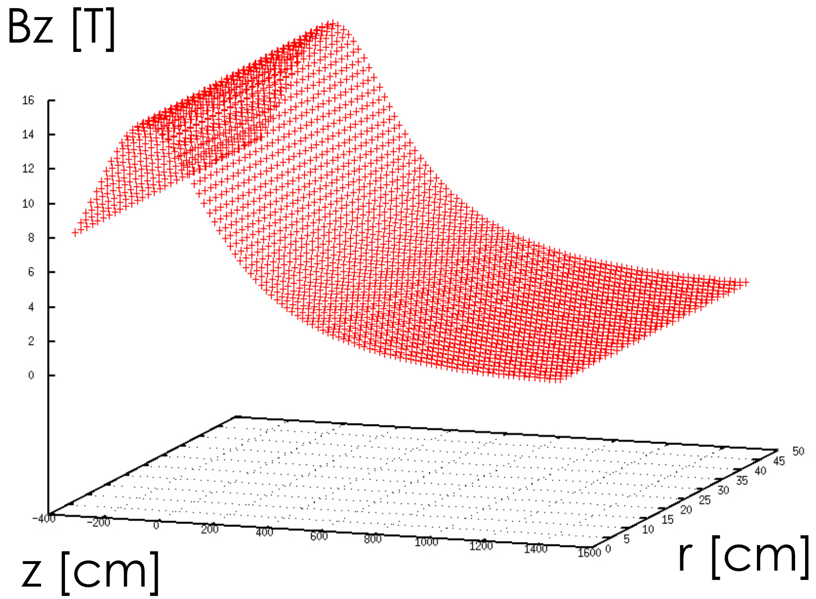
Field at R=0



MARS Simulation Setup

- Beam Pipe with constant R=30 cm (eliminate particle loss due to scrapping)
- Beam Pipe material changed to balckhole to speed calculations
- Added subroutine to m1510.f (FIELD) to calculate the field using inverse cubic equations

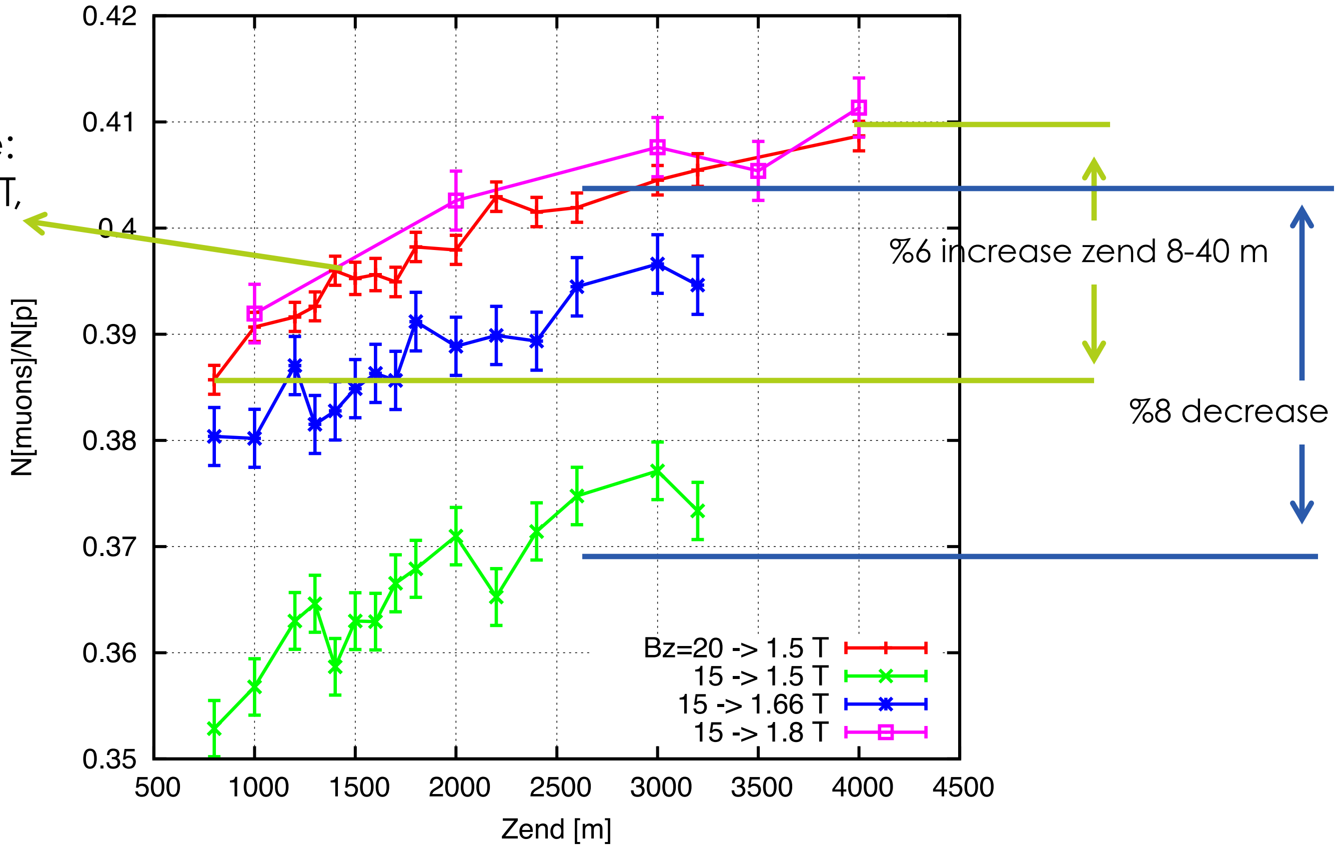




MARS Simulation Results

Muons+Pions count at z=50 m with K.E. 80-140 MeV

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



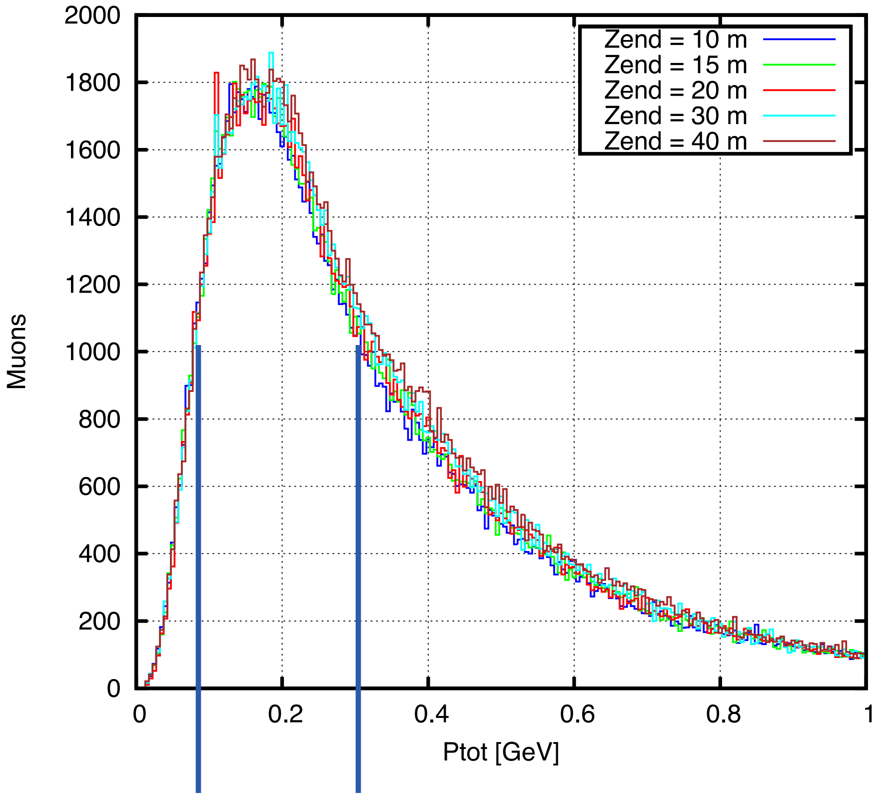
%6 increase zend 8-40 m

%8 decrease Bi 20→15 T

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

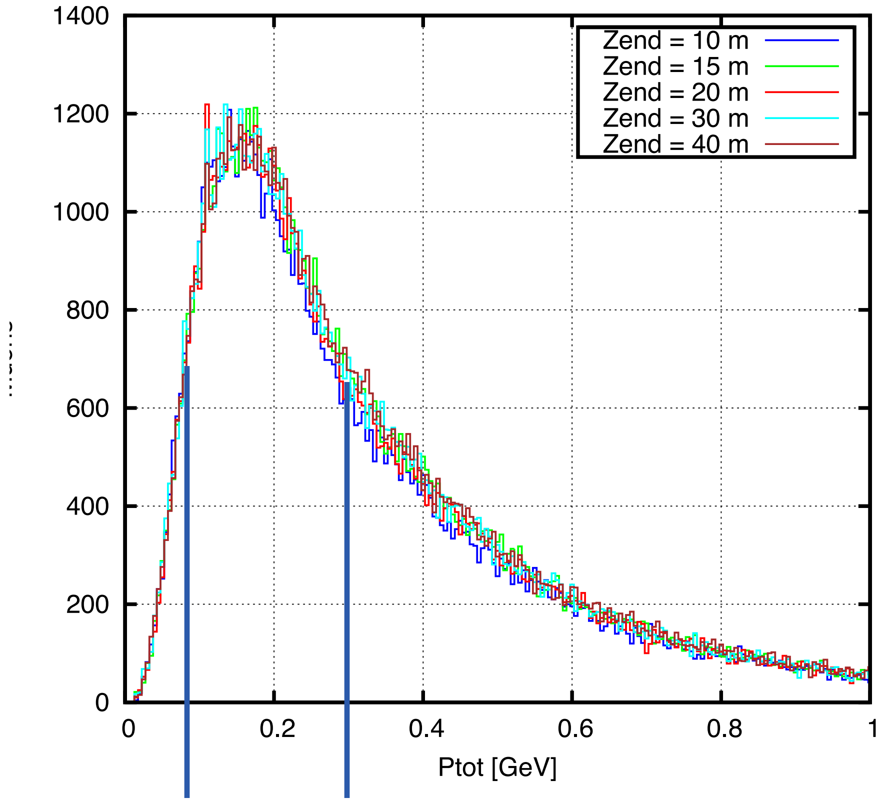
Muons Momentum Distribution at Z=50 m

B_z=20→1.5 T
$N_p=1.6\times10^6$



P_{tot} =100-300 MeV
KE = 40 – 210 MeV

B_z=15→1.8 T
$N_p=4\times10^5$



P_{tot} =100-300 MeV
KE = 40 – 210 MeV

Conclusion

- Alternative capture-solenoid field is presented for the mercury jet target for a neutrino factory or muon collider.
- A peak solenoid field of 15 T at the mercury-target location is studied in comparison to the current baseline value of 20 T.
- Field profile optimized to maximize the “useful” muons 50 m downstream from the target within KE ~ 80-140 MeV.
- Two parameters are considered for optimization :
  - Length z_{end} of the tapered field
  - Field strength in the front end.
- The axial-magnetic-field profile is specified analytically using an inverse-cubic equation and the off-axis field is computed from a series. Simulation is performed using the MARS15 code.
- Promising results for 15-T peak field at the target, particularly if increase z_{end} beyond 15 m and the Front-End magnetic field above the 1.5-T baseline.

Conclusion

- Investigate transmission through the downstream phase rotator & cooling sections, using ICOOL.
- Find adequate aperture radius along the tapering section
- Model Hg target to reflect gravity
- Are 20 T optimized parameters optimum for 15 T peak field?
  - Suitable energy-momentum and transvers position cuts (for robust optimization)
    - Acceptance of phase rotator & cooling channels (may be acceleration phase)
  - Developing mars1510 automated optimization tool (S. Xue)
    - No need to compile mars for every run → done
    - Automated backtracking →done
    - Capability to run small event number runs & combine results → done
    - Capability of run different parameters with different values in parallel → done
    - Robust evolutionary- multivariable algorithms for the production → future
    - Robust evolutionary Multiobjective multivariable system algorithms for the front end → far future