OPTIMIZED CAPTURE MECHANISM FOR A MUON COLLIDER/ NEUTRINO FACTORY TARGET SYSTEM

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NUFACT 2013

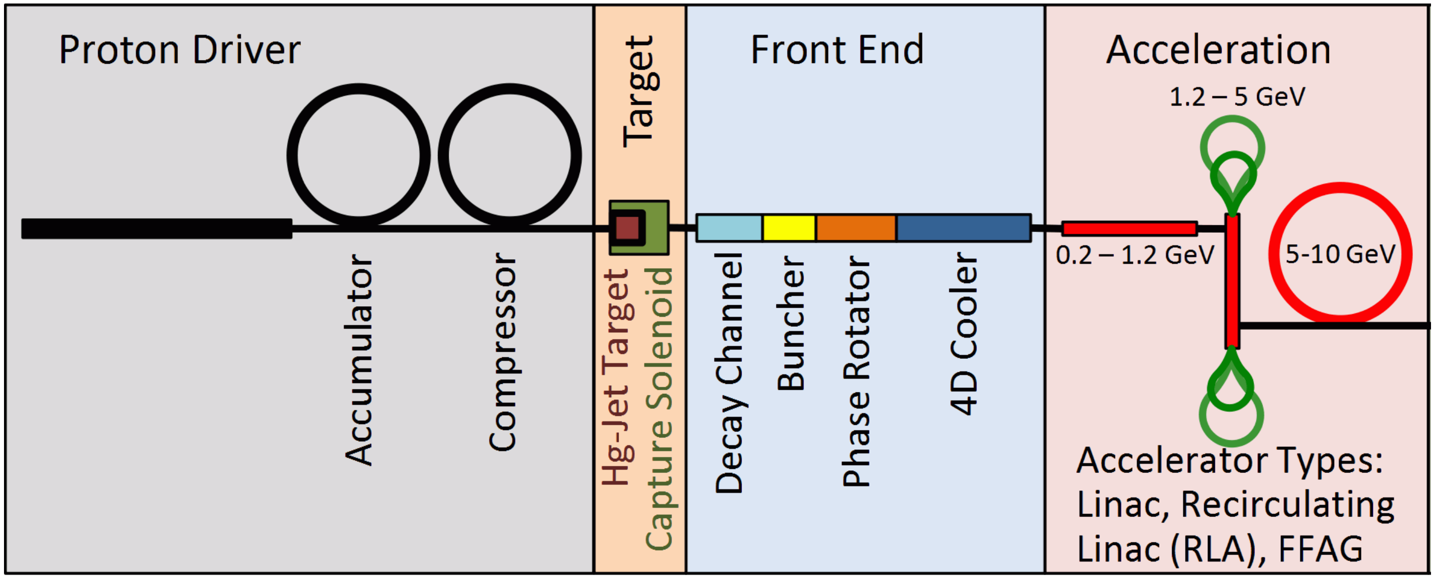
INTRODUCTION & LAYOUT

Muon Capture in Target & Front END

- Capture Solenoid Field Study:
  - Optimizing quantity: Muon (Pions) count – transverse capture
    - Target Solenoid peak field
    - Final end field
  - Optimizing quality: Muon (Pions) longitudinal phase space (transverse-longitudinal coupling) – transverse-longitudinal capture
    - Taper field profile

- LOW ENERGY – LOW POWER "C" TARGET
- Optimizing the time of flight of incident beam (Buncher-Rotator RF phase)
- Transverse focusing field in decay-channel-buncher-rotator
- Match to ionization cooling channel for every end field case 1.5 T → 3.5 T
- Performance of front end as a function of proton bunch length
- Realistic Coil Design & performance optimization

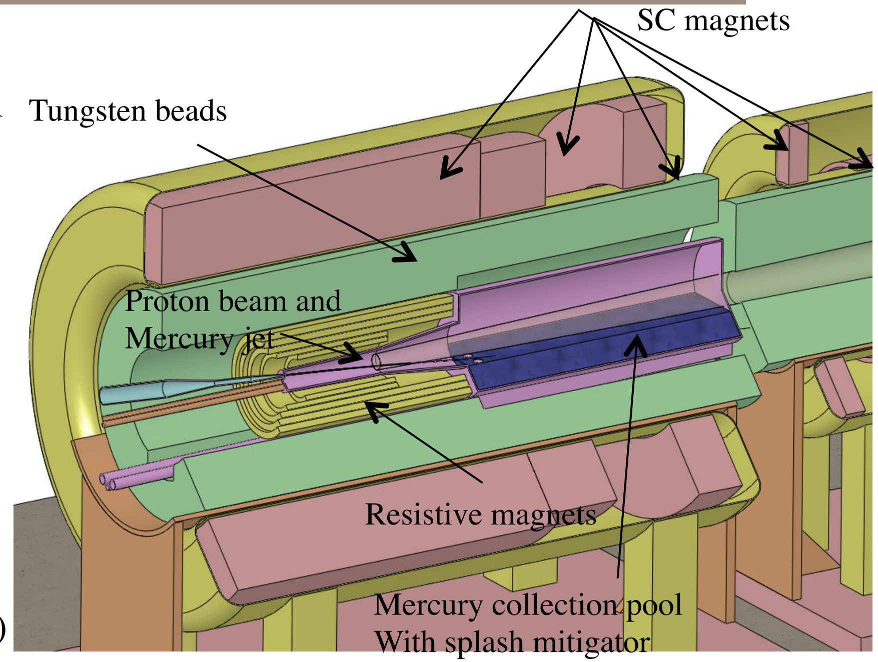
MUON COLLIDER/NEUTRINO FACTORY LAYOUT



Target System Solenoid:
Baseline: Capture $\mu^{\pm}$ of energies ~ 100-400 MeV from a 4-MW proton beam (E ~ 8 GeV).
Low Power: Capture $\mu^{\pm}$ of energies ~ 100-400 MeV from a 1-MW proton beam (E ~ 3 GeV).

Target System Current Baseline Design

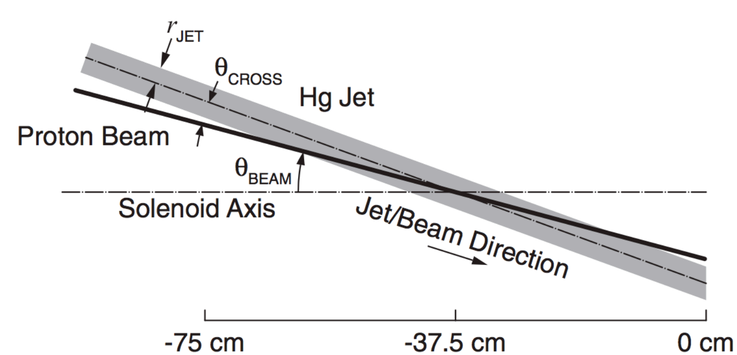
- Production of 10^{14} μ/s from 10^{15} p/s (≈ 4 MW proton beam)
- Proton beam readily tilted with respect to magnetic axis.



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).

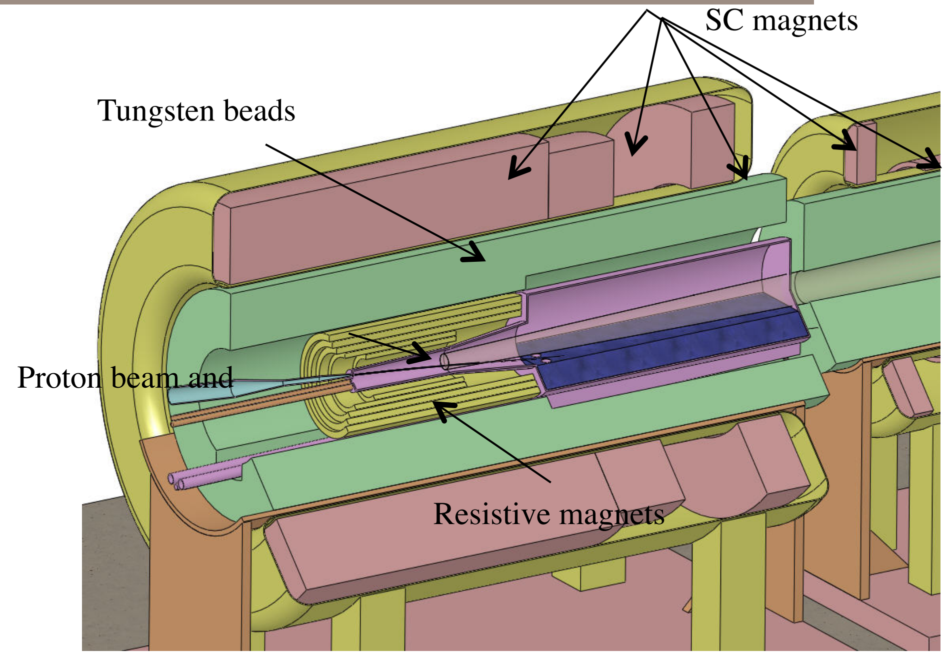
- Hg Target
- Proton Beam
  - E=8 GeV
- Solenoid Field
  - IDS120h → 20 T peak field at target position (Z=-37.5)
  - Aperture at Target R=7.5 cm - End aperture R = 30 cm
  - Fixed Field Z = 15 m → Bz=1.5 T

- Production: Muons within energy KE cut 40-180 MeV end of decay channel
  - $N_{\mu+\pi+k}/N_P$=0.3-0.4



Low energy – low power Target System

- Graphite target
- 1-MW proton beam power E=3 GeV
- Solenoid Field
- IDS120h 20 T peak field at target position
  - LOWER peak field is being considered (20-15T)



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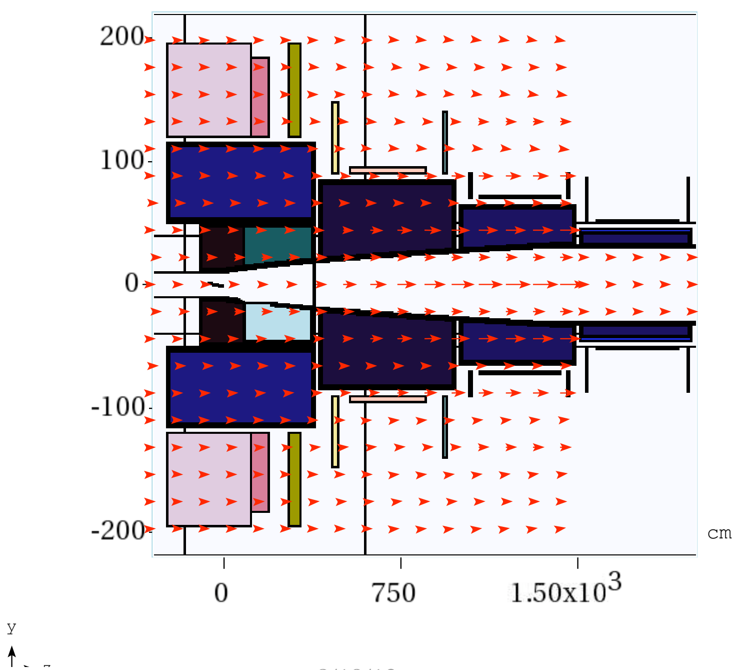
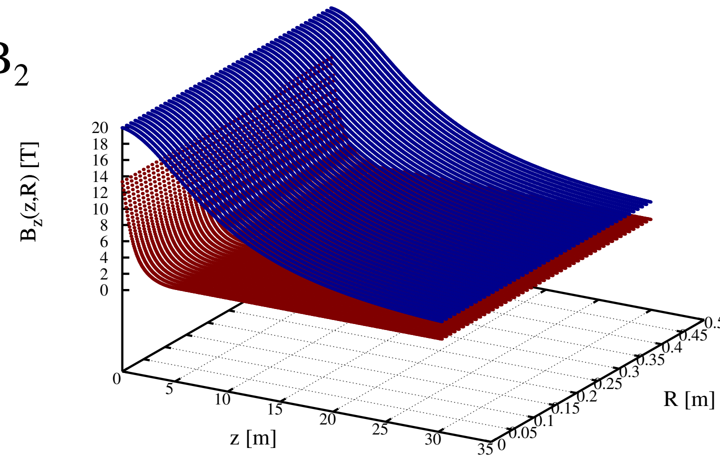


TAPERED TARGET SOLENOID OPTIMIZATION

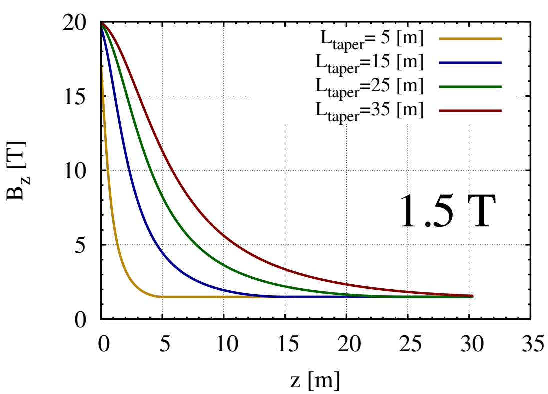
Initial peak Field B_1 – Taper length z – End Field B_2

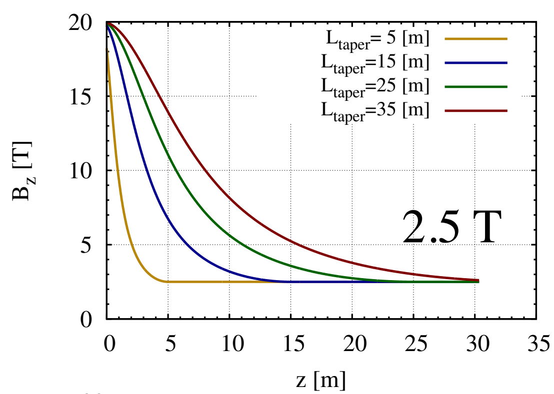


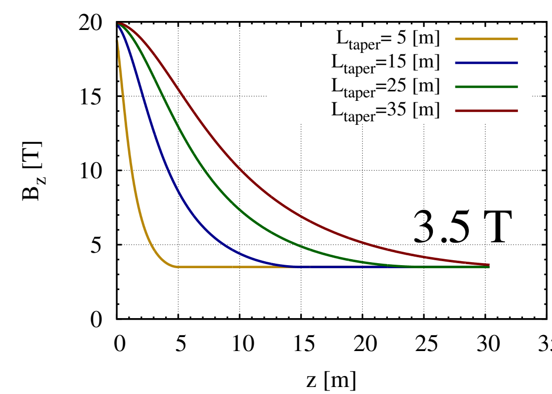
Inverse-Cubic Taper

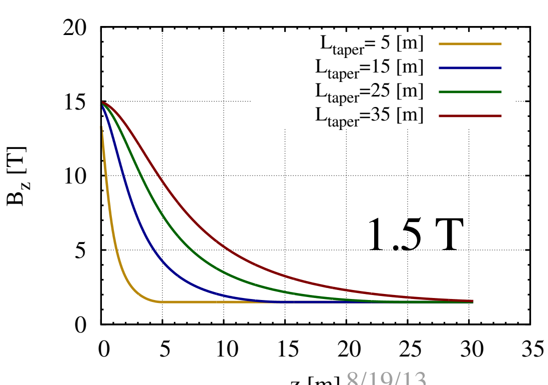
$$B_z(0, z_i < z < z_f) = \frac{B_1}{[1 + a_1(z - z_1) + a_2(z - z_1)^2 + a_3(z - z_1)^3]^p}$$

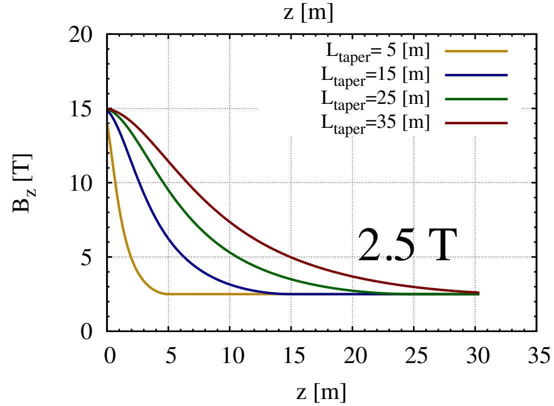
$$a1 = -\frac{B_1^{'}}{pB_1} \qquad a_2 = 3\frac{(B_1/B_2)^{1/p} - 1}{(z_2 - z_1)^2} - \frac{2a_1}{z_2 - z_1} \qquad a_3 = -2\frac{(B_1/B_2)^{1/p} - 1}{(z_2 - z_1)^3} + \frac{a_1}{(z_2 - z_1)^2}$$

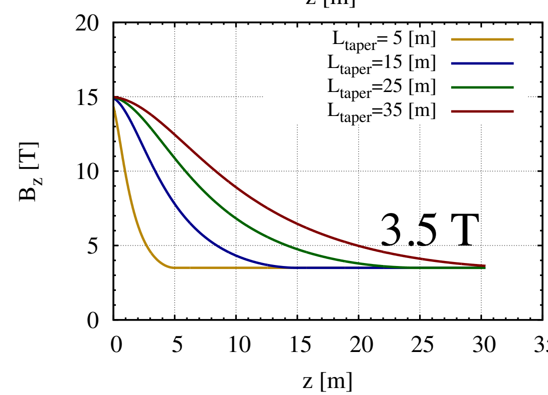










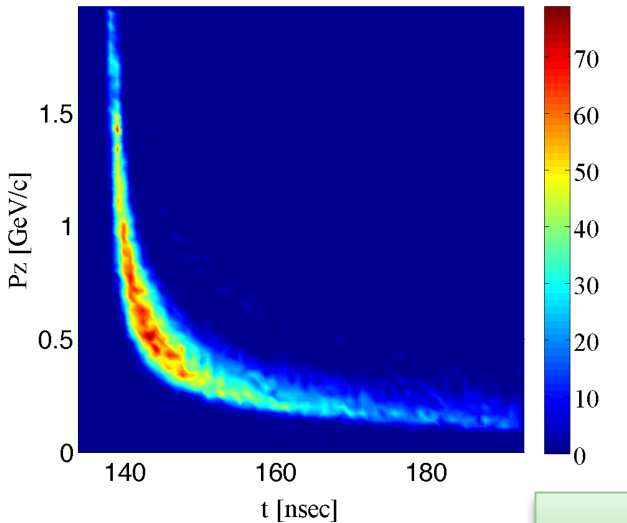


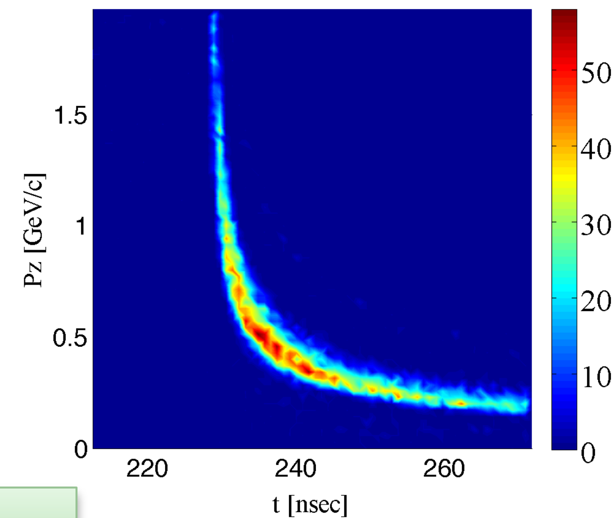
Longitudinal Phase Space Distributions (Short versus long taper)

End of taper

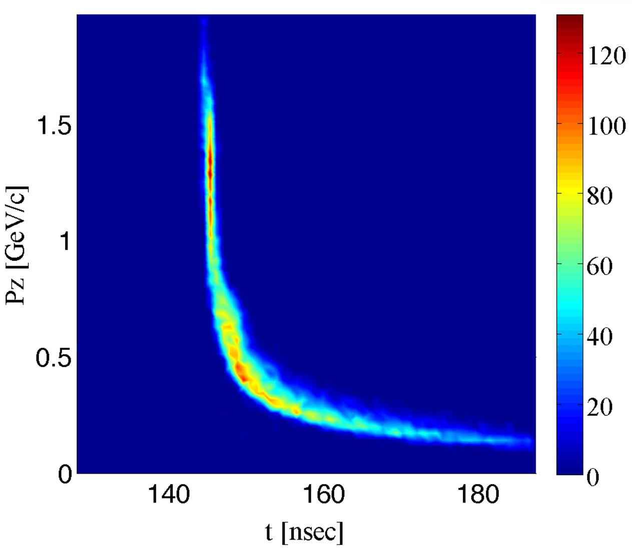
Long adiabatic taper 40 m

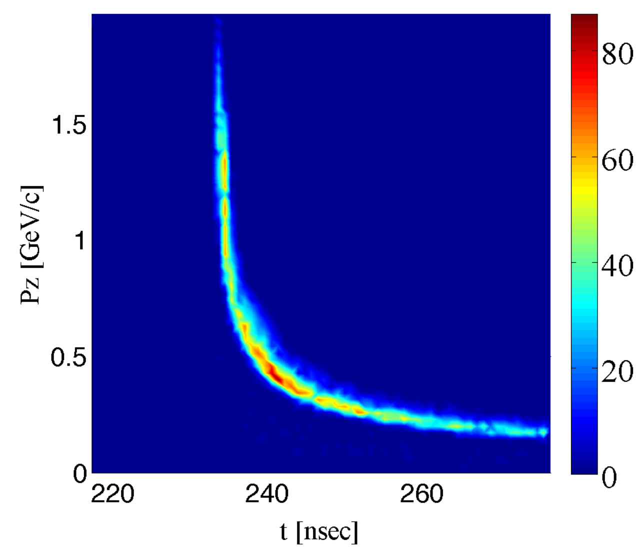
End of Decay





Short taper 4 m

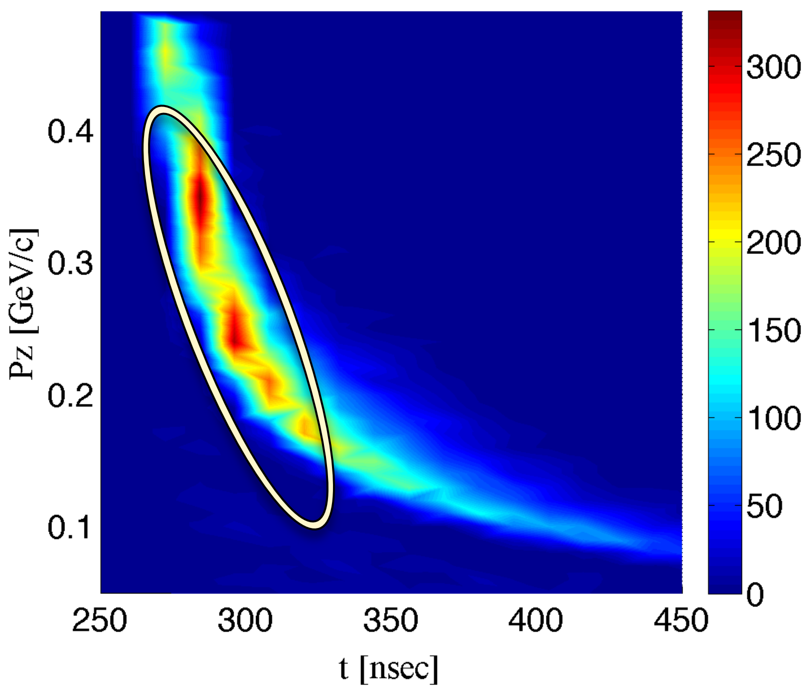




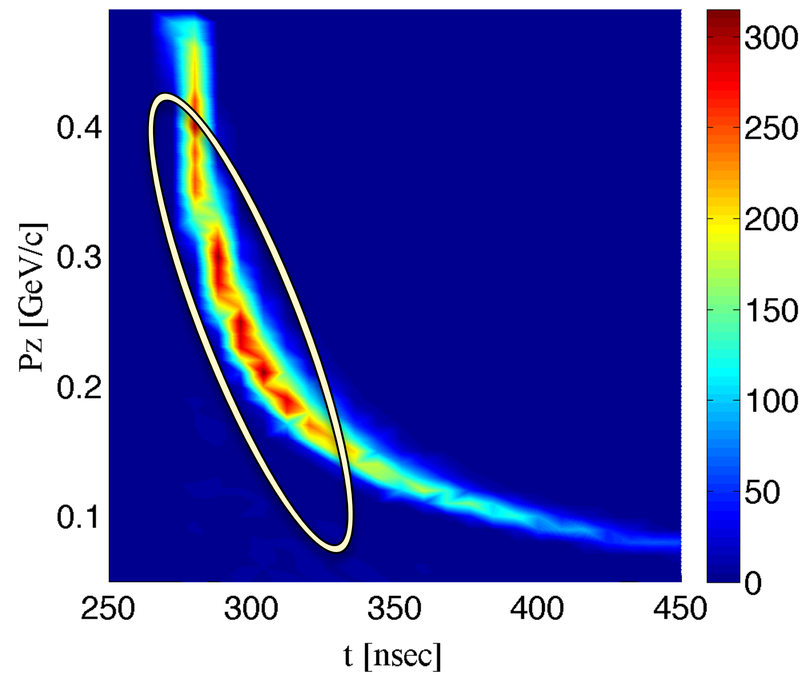
Phase Space Distributions (Short versus long taper)

Longitudinal phase space at end of decay channel

Long Taper 40 m



Short Taper 4 m



Long Solenoid taper:

- ➢ More particles
- ➢ Large time spread → large longitudinal emittance

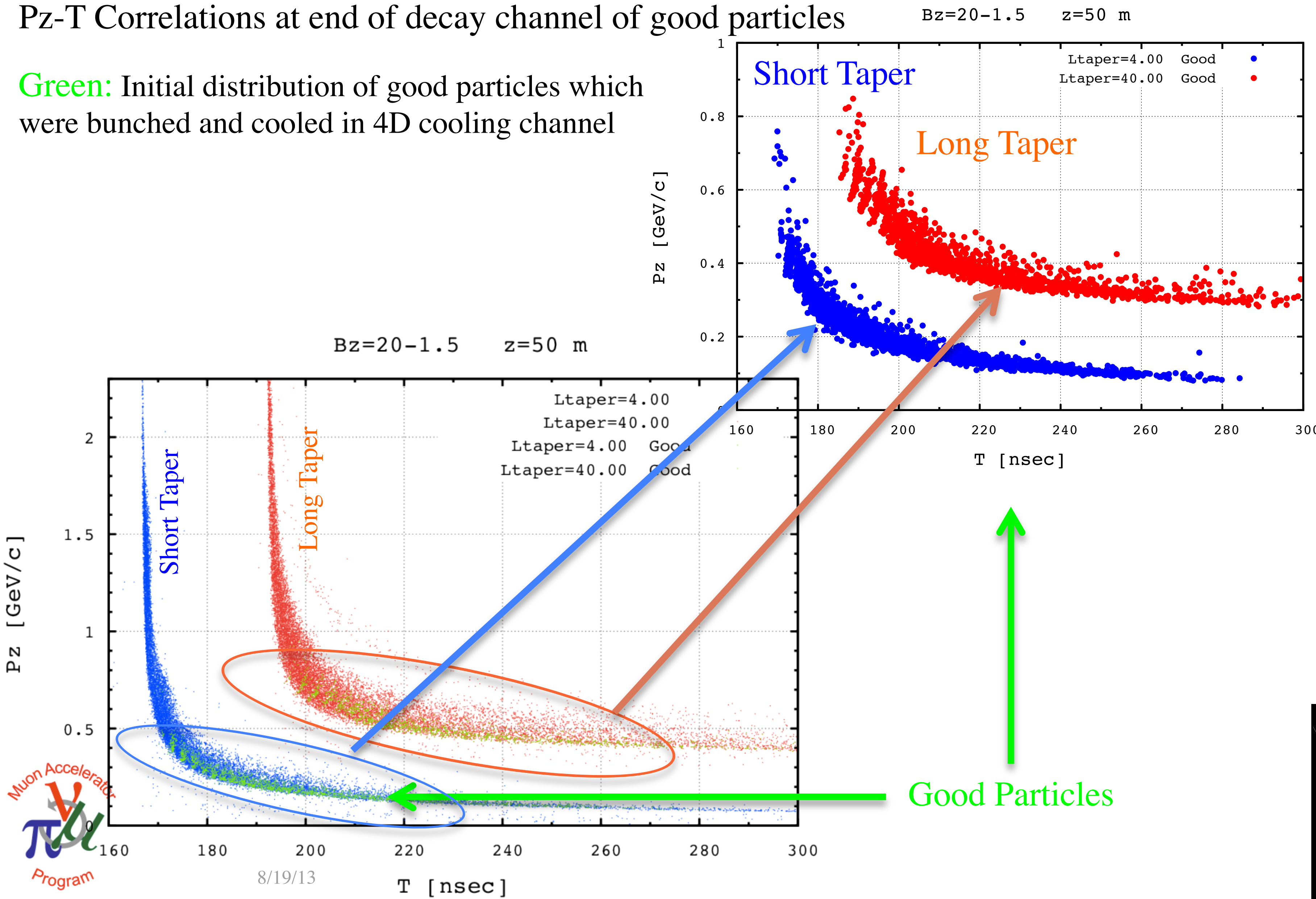
Short Solenoid taper:

- ➢ Smaller time spread → smaller longitudinal emittance
- ➢ Fits more particles within the acceptance of buncher/rotator

Phase Space - Short versus long taper

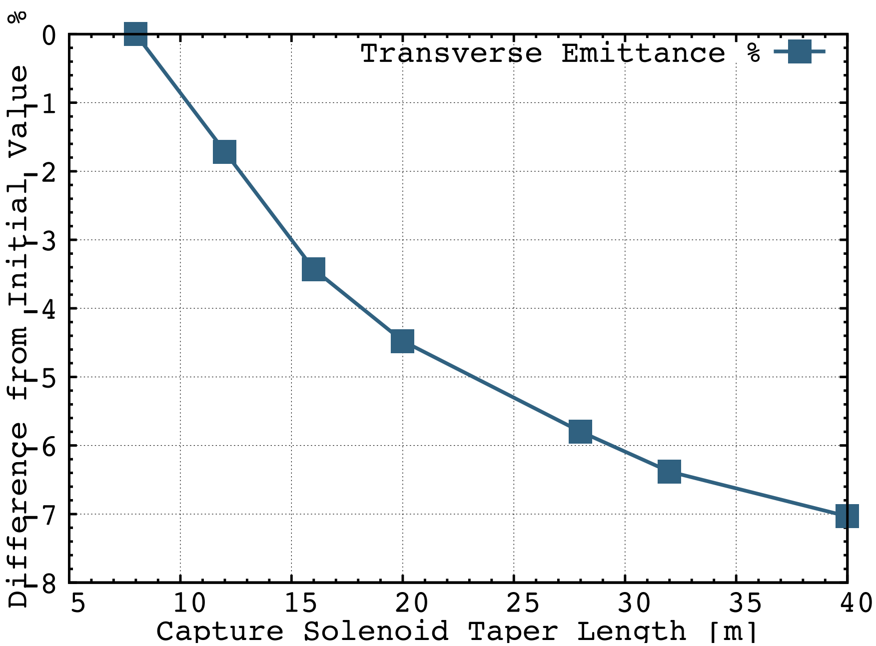
Pz-T Correlations at end of decay channel of good particles

Green: Initial distribution of good particles which were bunched and cooled in 4D cooling channel



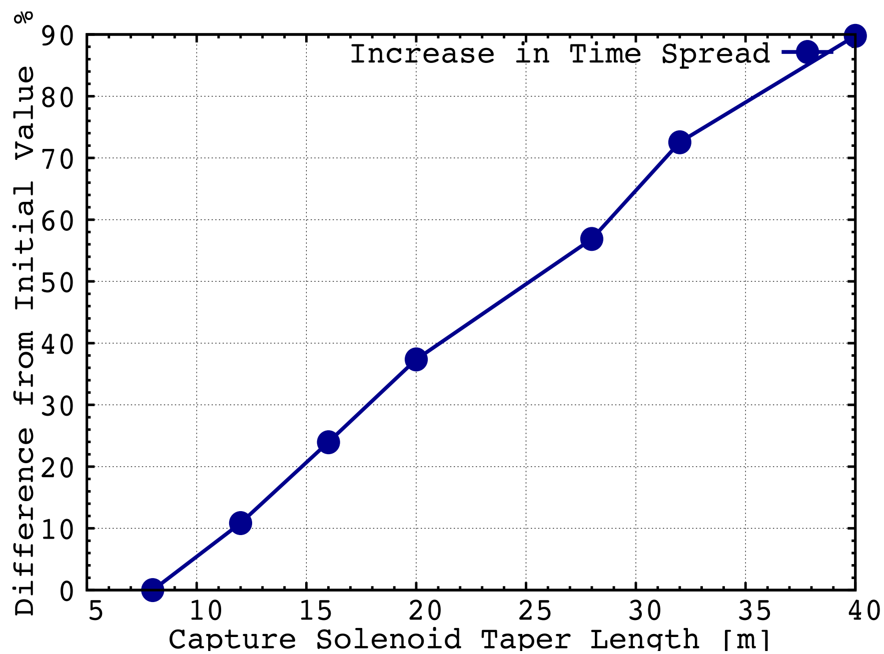
Dependence of time spread & transverse emittance on taper length

Transverse emittance shaped by capture solenoid



Transverse emittance decreases by 8% with solenoid taper length going 8→40 m

Time spread shaped by capture solenoid

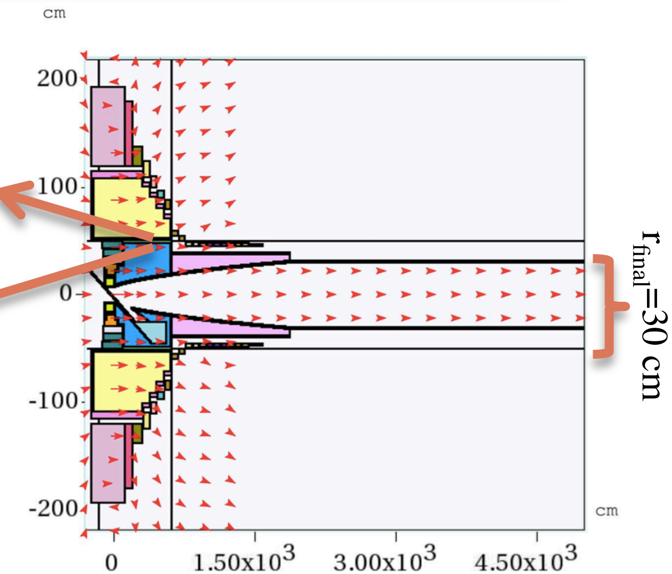


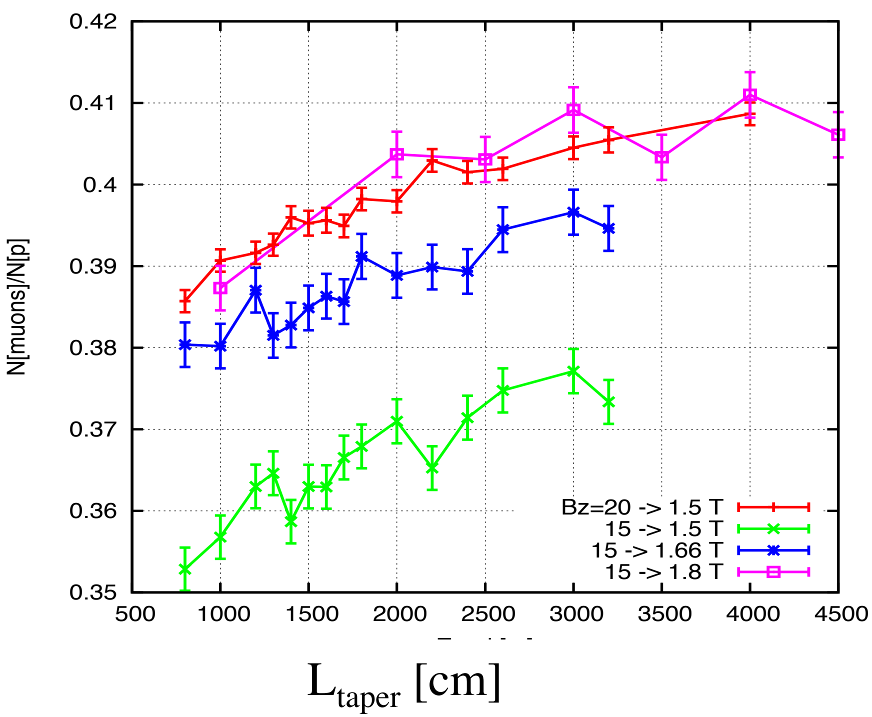
Time Spread increase by 90% with solenoid taper length going 8→40 m

MARS SIMULATIONS & TRANSMISSION

Muon count within energy cut at end of decay channel

MARS15 Simulation:
Counting muons at 50 m with K.E. 80-140 MeV





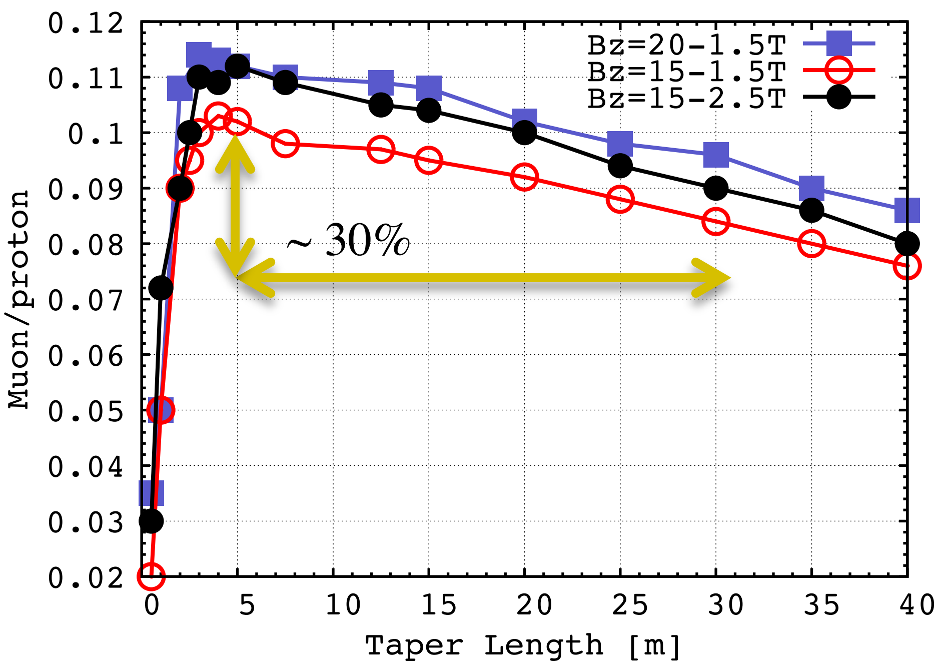
Muon count at z=50 increases for longer solenoid taper

FRONT END PERFORMANCE

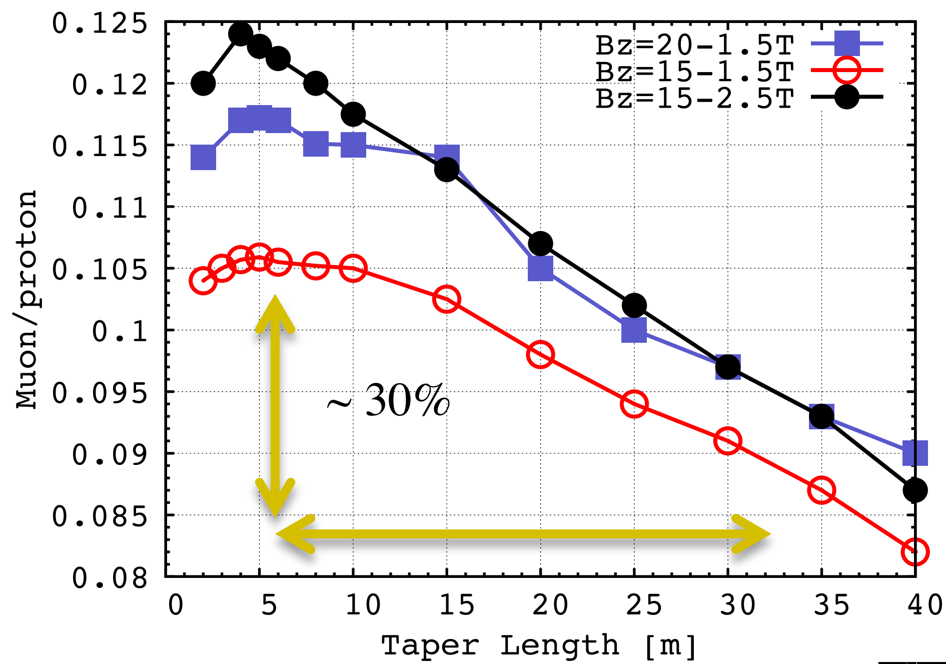
Muon count within acceleration acceptance cuts at end of ionization cooling channel

μ+ only

Before optimizing ionization cooling channel

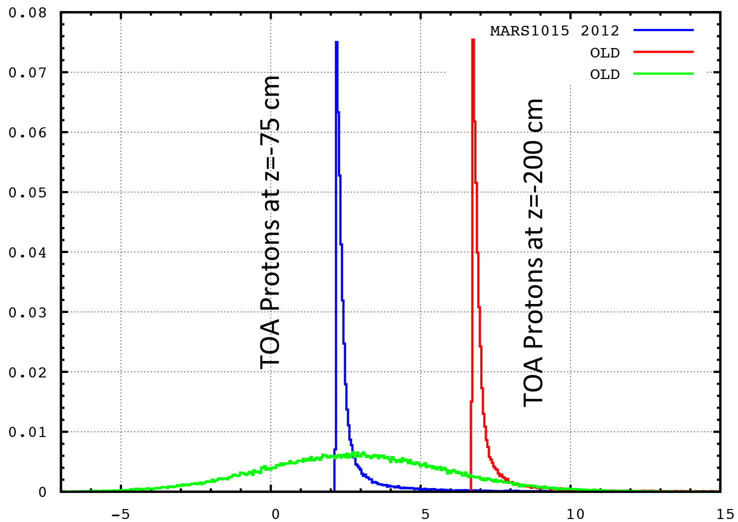


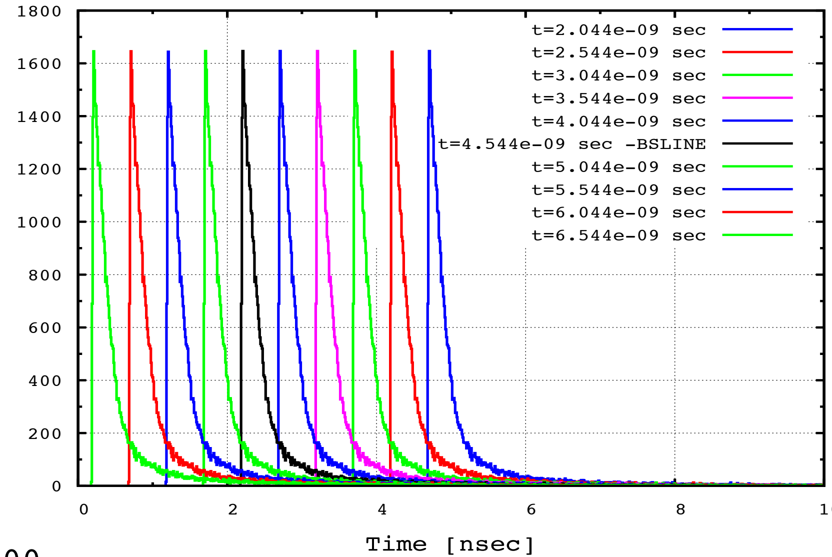
After optimizing ionization cooling channel

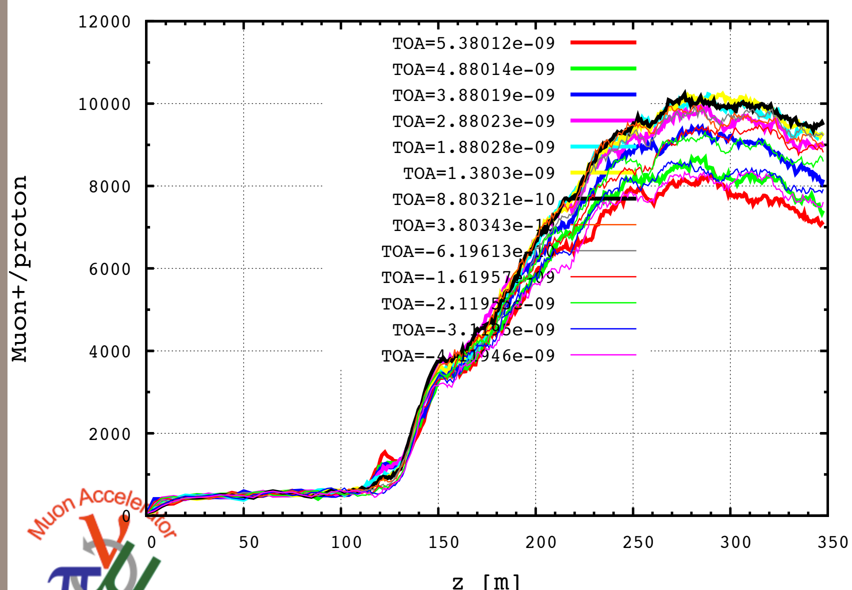


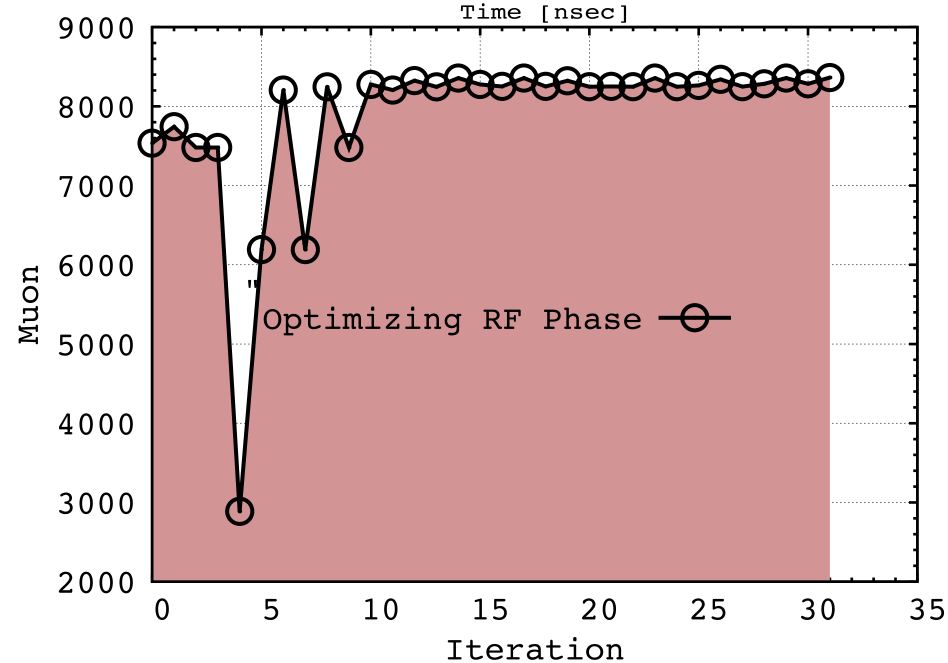
Shorter taper provide better quality muons → More muons at end of ionization cooling channel

Performance dependence on Time of Flight (RF Phase)



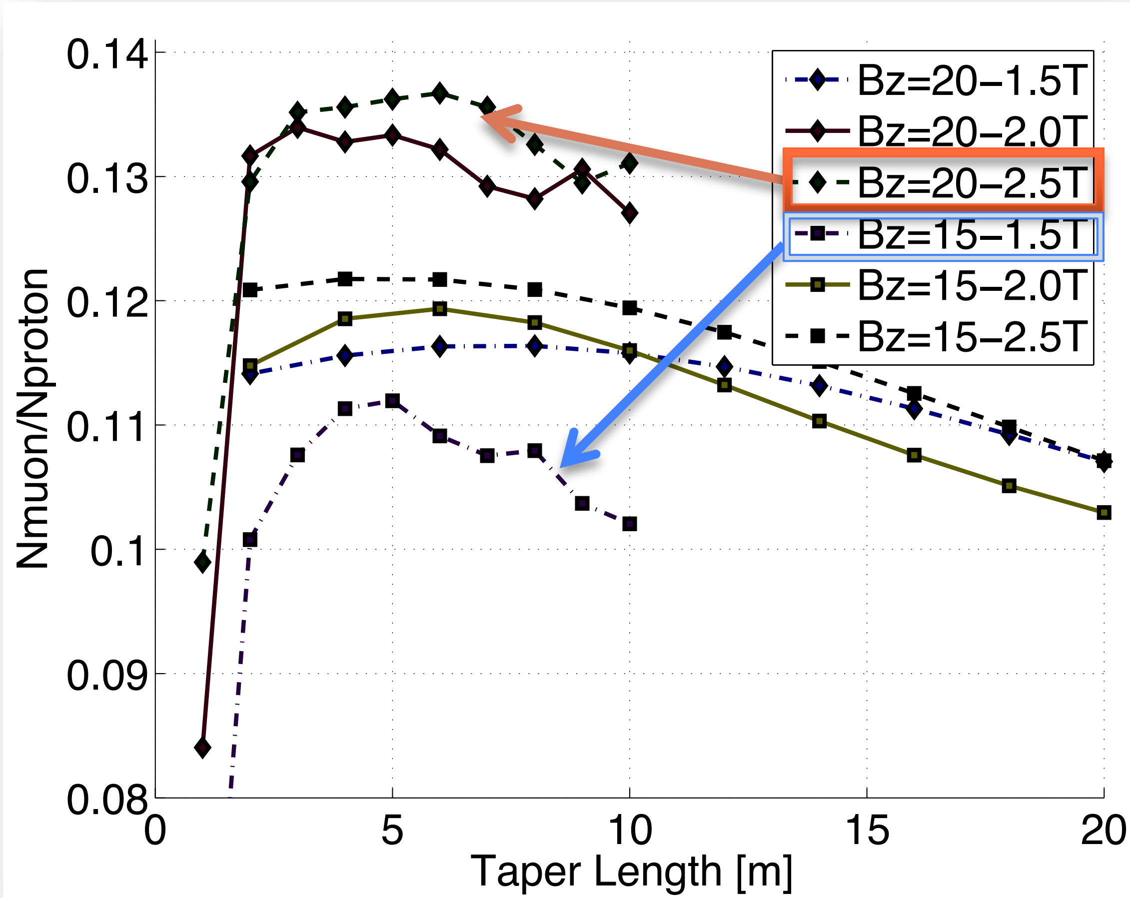






Front End Performance

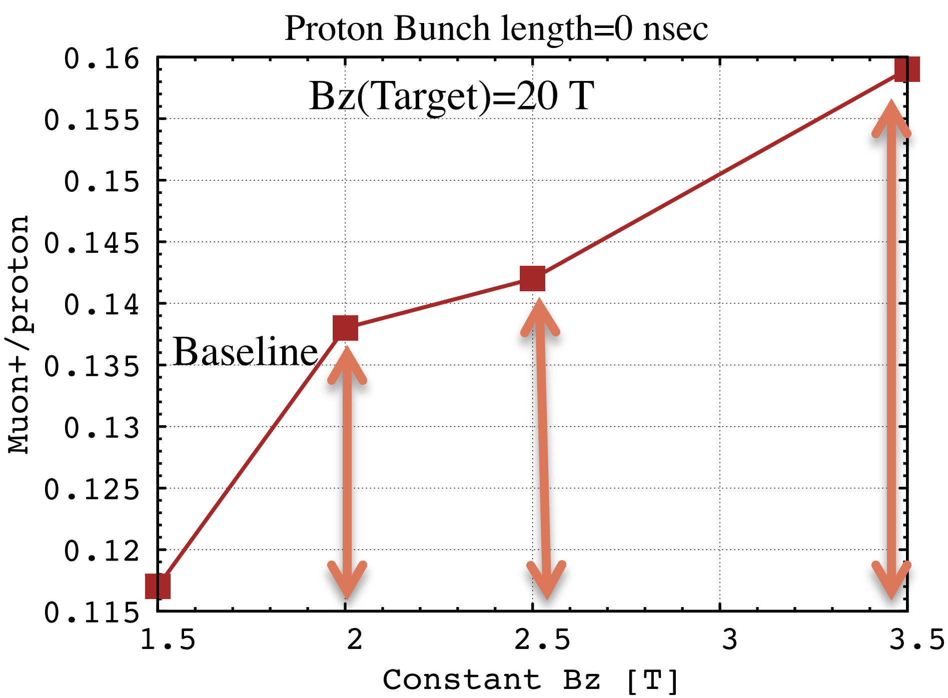
μ+ only



High statistics tracking of Muons through the front end

MUON YIELD VERSUS END FIELD

Performance of FE as function of Constant solenoid filed in Decay Channel – Buncher – Rotator (matched to +/- 2.8 T ionization cooling channel)



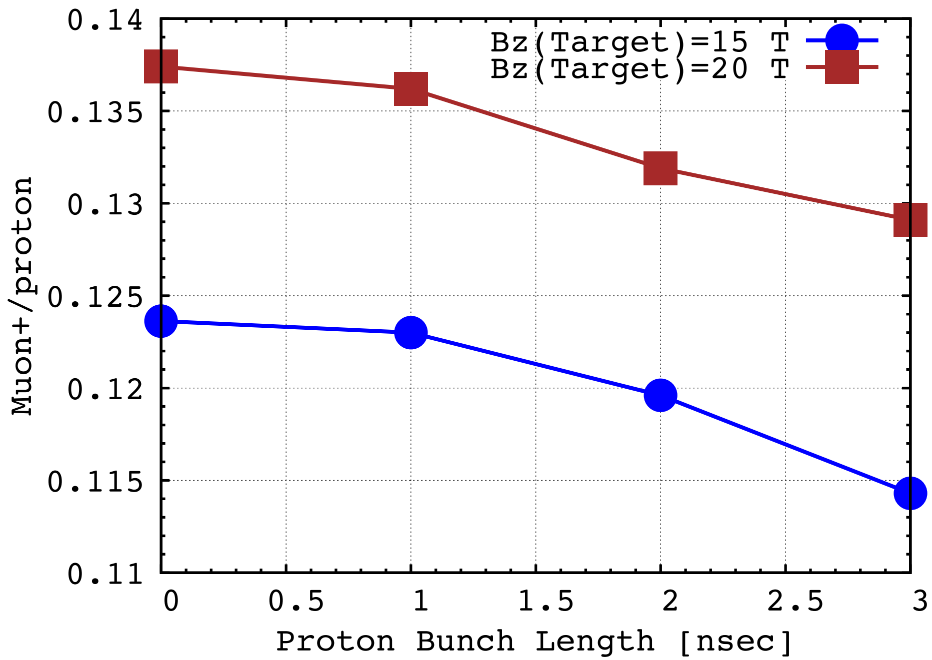
Muon yield versus end field

20% for every 1 T increase in constant field

μ+ only

PROTON BUNCH LENGTH

Muon yield versus Proton Bunch Length

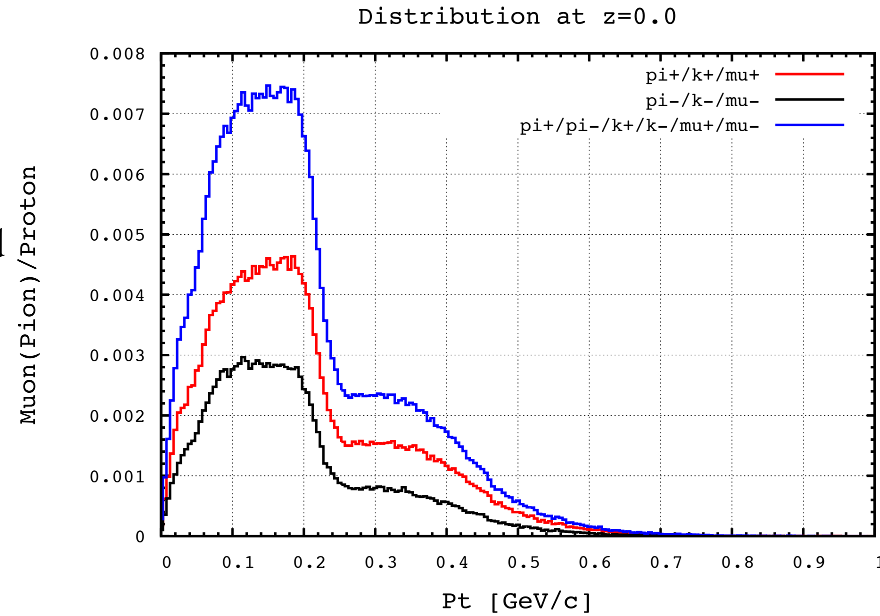


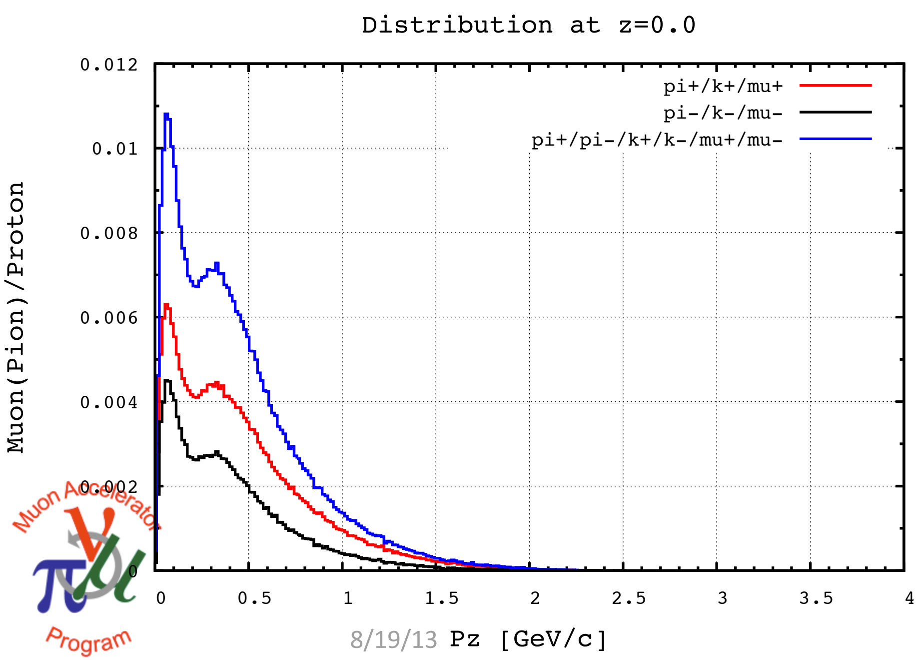
~ 3% loss per 1 nsec increase in bunch length

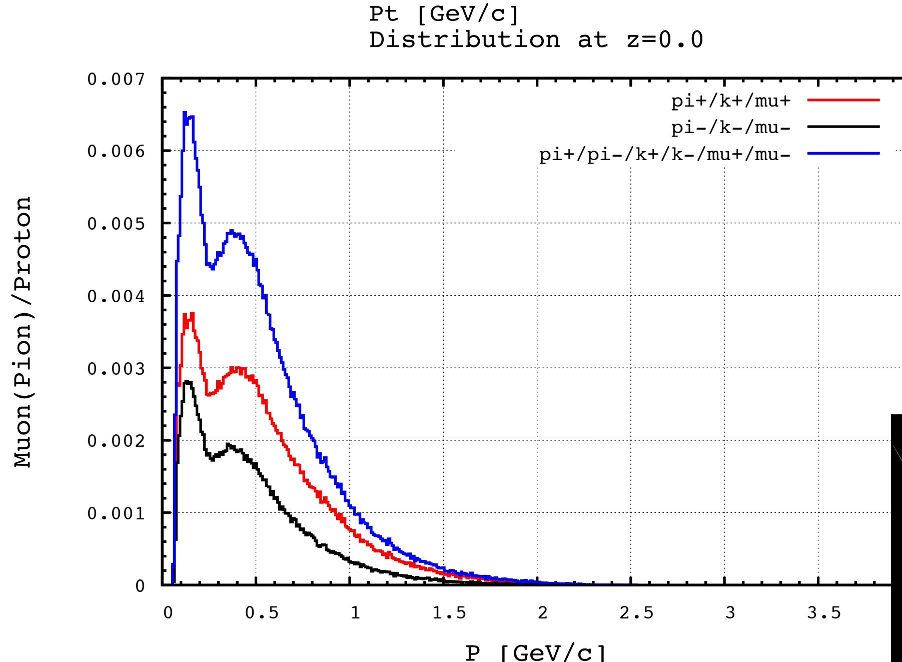
LOW ENERGY – LOW POWER CARBON TARGET

- Graphite target
- 1-MW proton beam power E=3 GeV
- Solenoid Field
- IDS120h 20 T peak field at target position
  - LOWER peak field is being considered (20-15T)

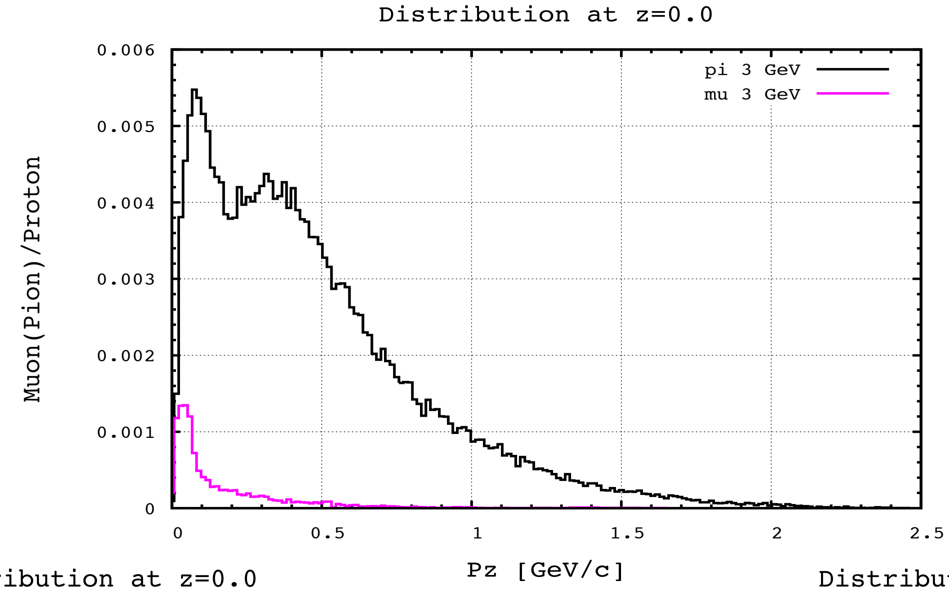
MARS1512 simulations for production

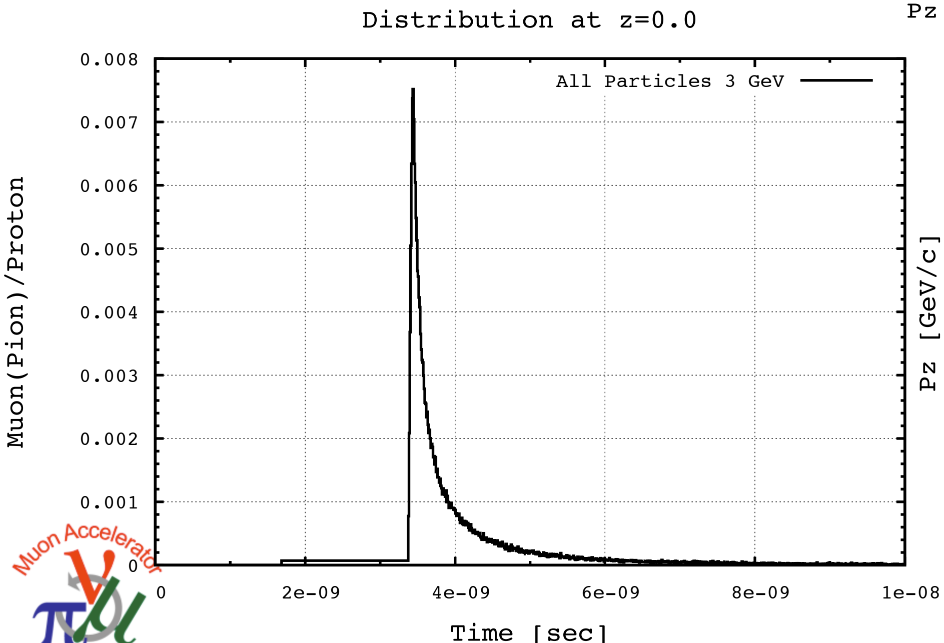


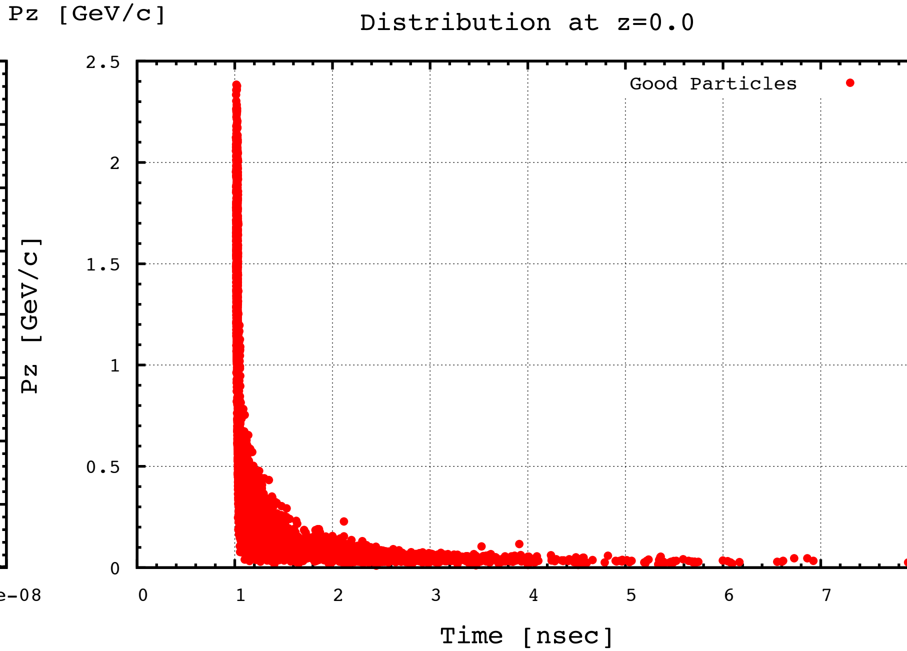




LOW ENERGY – LOW POWER CARBON TARGET





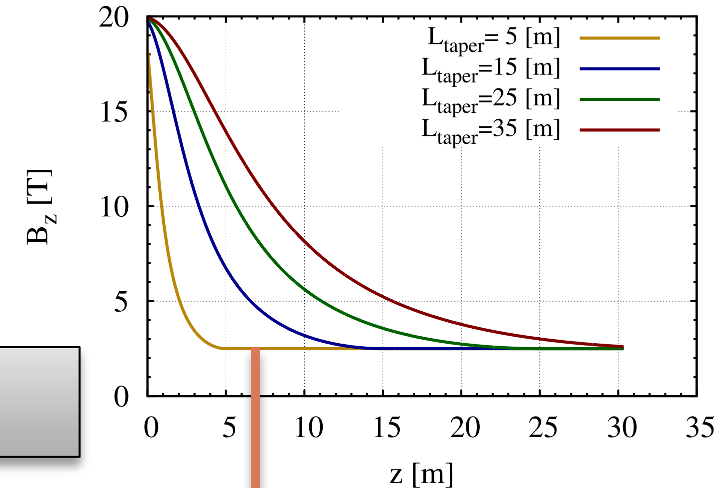


OPTIMIZED CAPTURE/FRONT END

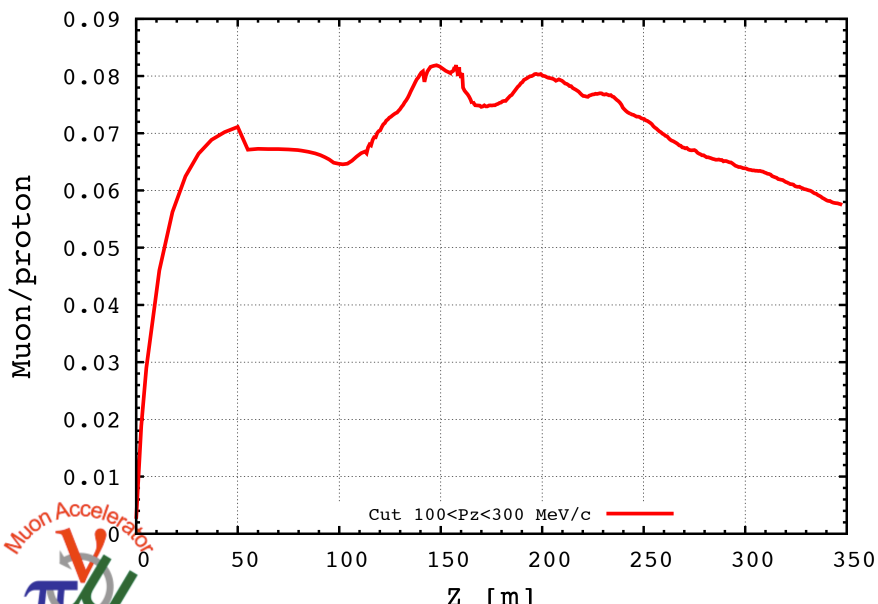
OPTIMZATION:

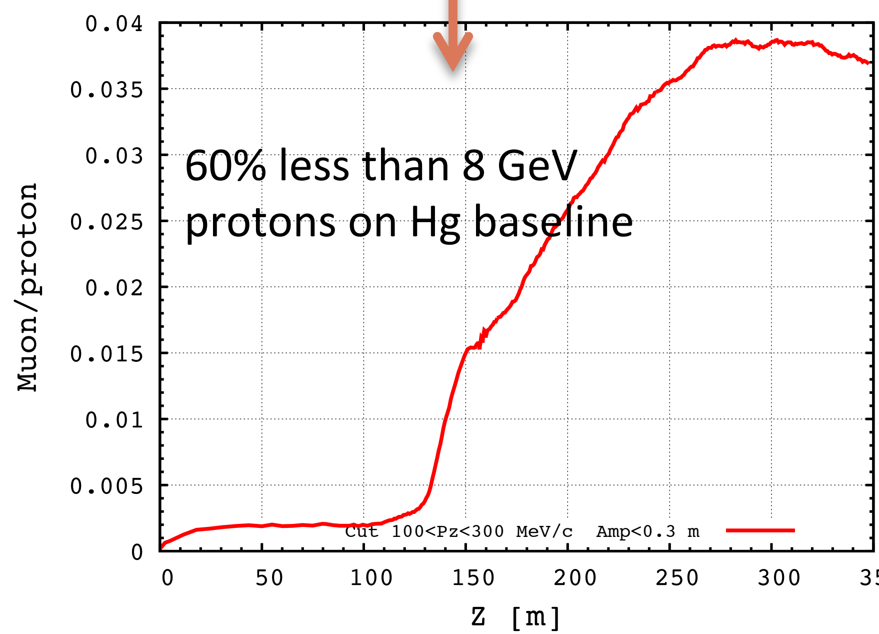
- Solenoid taper profile Bz=20-2.5 T (Ltaper = 5m)
- Solenoid decay channel
- Time of arrival
- Broadband match to ionization cooling channel
- Cooling channel

Optimum Capture Solenoid Field

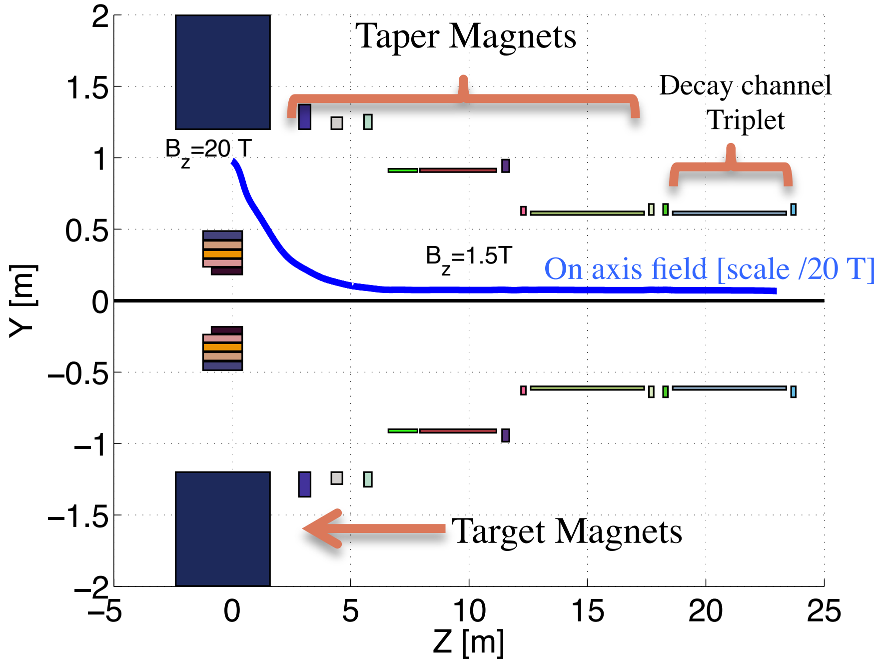


μ+ only

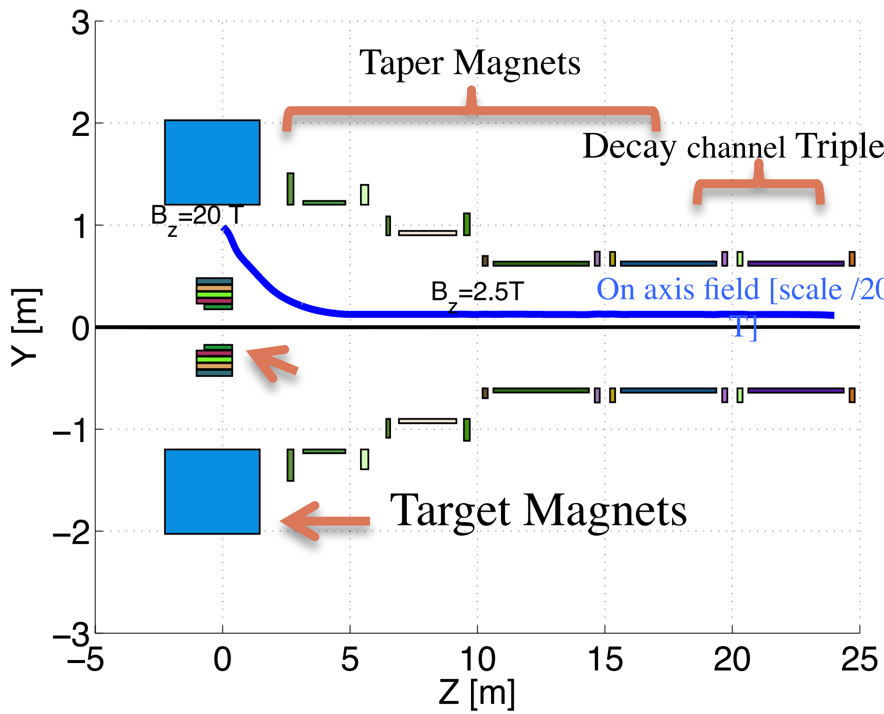




NEW SHORT TARGET CAPTURE REALISTIC MAGNET (WEGGEL)



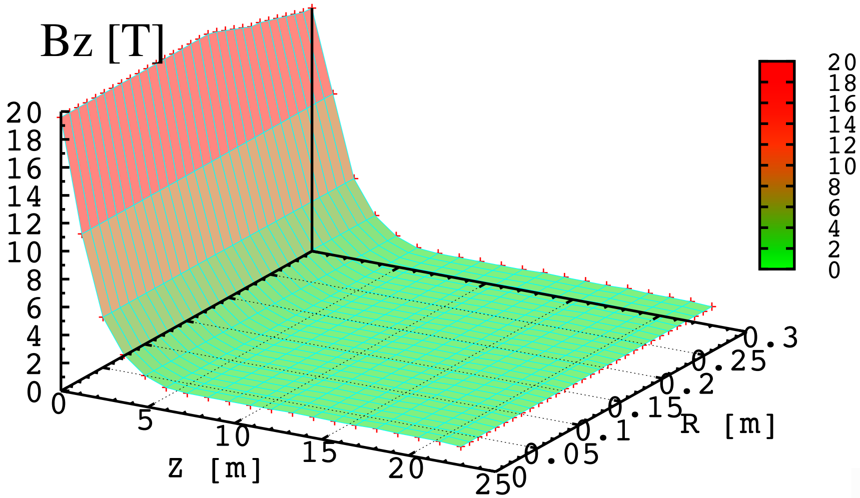
Muon Target Capture Magnet
Short Taper length =7 m- B=20-1.5 T



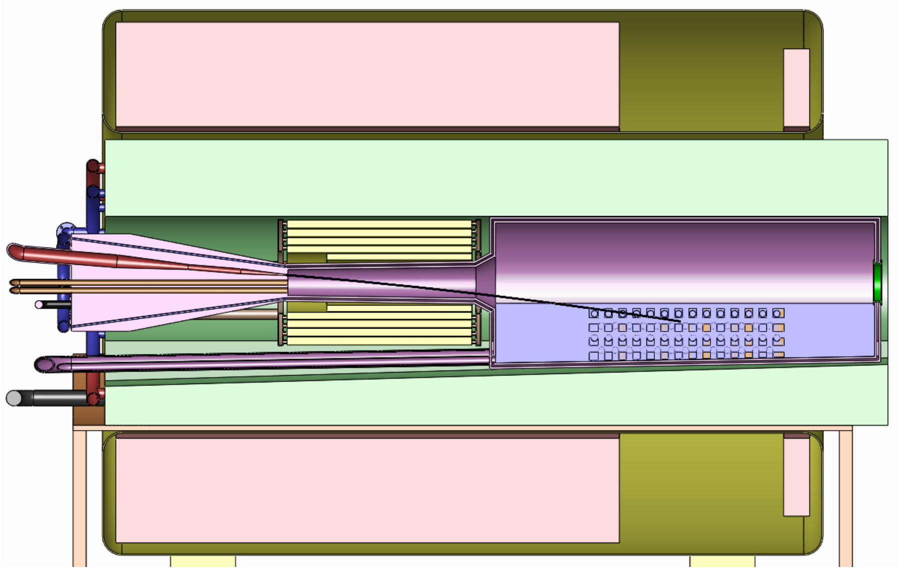
Muon Target Capture Magnet
Short Taper length =5 m- B=20-2.5 T

NEW SHORT TARGET CAPTURE MAGNET (WEGGEL)

Muon Target Short Taper Magnet taper length =7 m- B=20-1.5 & 2.5 T



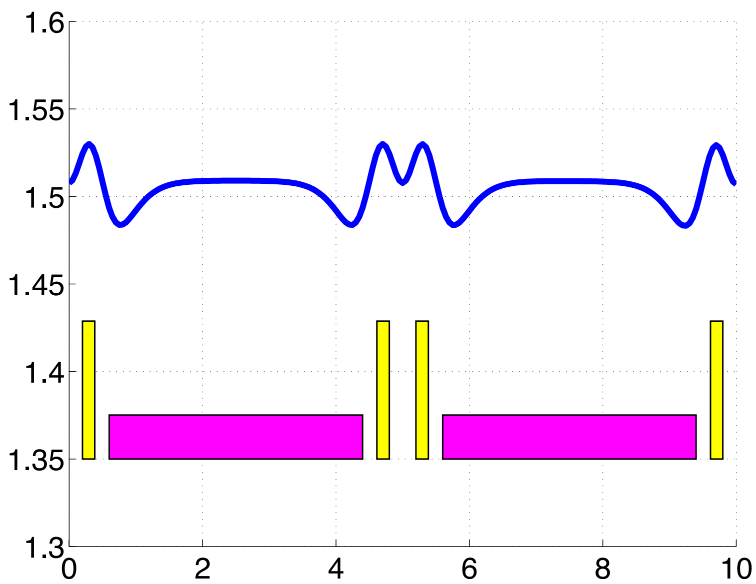
Target SC Magnets Field Map calculated from realistic coils



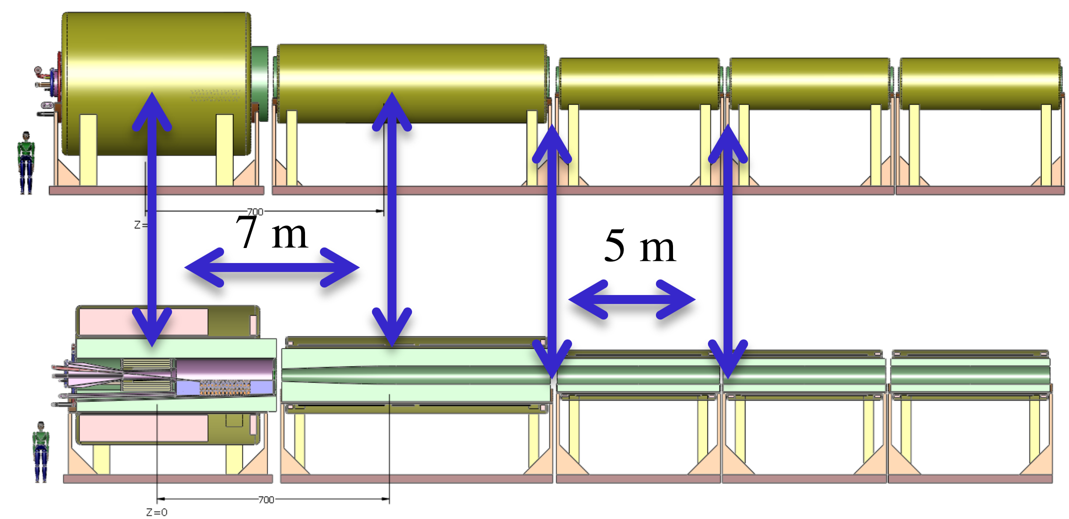
Engineering (V. Grave)
IDS120_20-1.5T7m2+5 Cryo 1

New Decay channel realistic magnet (Weggel)

- The pions produced in the target decay to muons in a Decay Channel (50 m)
- Three superconducting coils (5-m-long) Bz(r=0) ~ 1.5 or 2.5 T solenoid field.
- Suppress stop bands in the momentum transmission.



Axial-field profile of two Decay-Channel modules



IDS120L20-1.5T 7m

Magnet	Length [m]	Inner R [m]	Outer R [m]	J [A/mm²]
1	0.19	0.6	0.68	47.18
2	3.8	0.6	0.63	40.00
3	0.19	0.6	0.68	47.18

Muon Accelerator Program

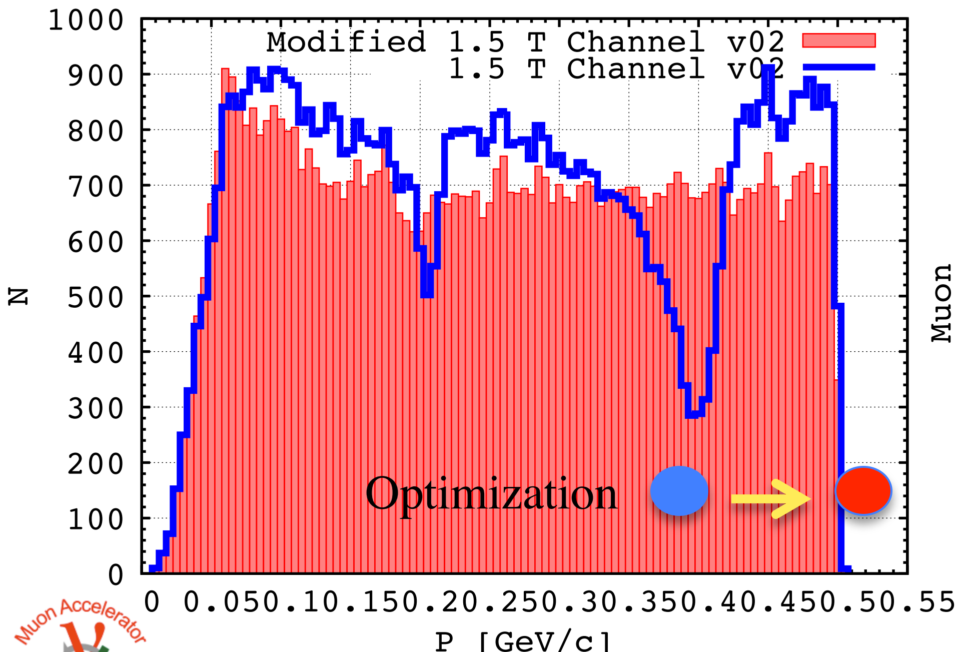
BROOKHAVEN NATIONAL LABORATORY

Realistic Coil based decay channel solenoid stop band study

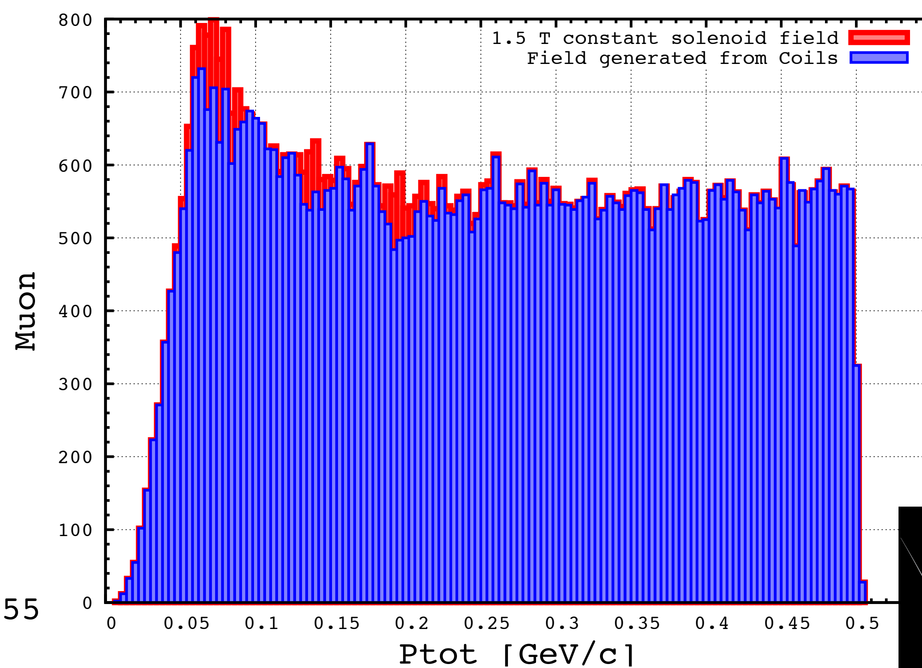
Suppression of stop bands in the Decay Channel:
Tracking muons through decay channel 10 cells (50 m) optimize magnet design for best performance

Transmission:
Constant 1.5 Solenoid Field %67
IDS120L20to1.5T7m %62
Modified IDS120L20to1.5T7m %66

IDS120L20to1.5T7m



IDS120L20to1.5T7m



CONCLUSION & SUMMARY

1- Target Solenoid parameters that affect the particle Capture & Transmission at target or after cooling

Initial peak Field – Taper length – End Field

2- Impact:

Short taper preserves the longitudinal phase-space → muons can be captured efficiently in the buncher-phase rotation sections and more muons at the end of cooling.

The maximum yield requires taper length of 7-5 m for all cases (20-15T) (1.5-3.5T) for any bunch length.

3- Final constant end field increases the yield by 20% for every 1 T increase in the field beyond the 1.5 T baseline

4- Initial proton bunch length influence the muon/proton yield at the end of the cooling channel ~ 3% reduction per 1 nsec increase in bunch length.

5- 1-MW proton beam power E=3 GeV → 0.04 Muon+/proton at end of cooling channel

6- Realistic Coil design for the capture target and decay channel.