Design & Simulation efforts towards a Muon Accelerator Front-End

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Acknowledgement

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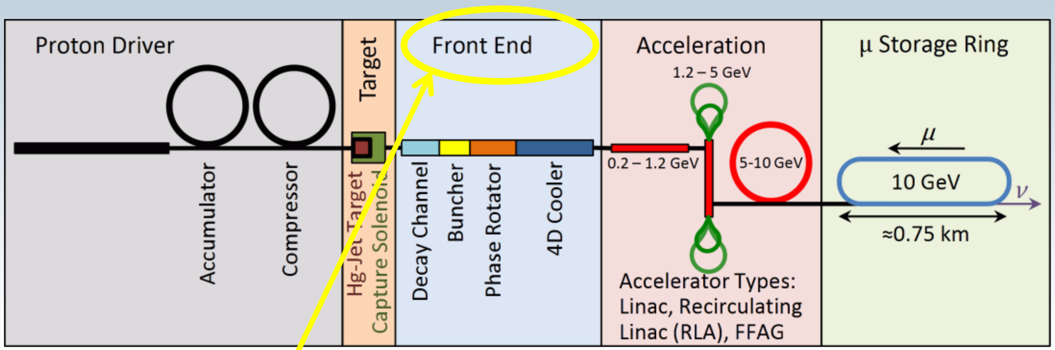
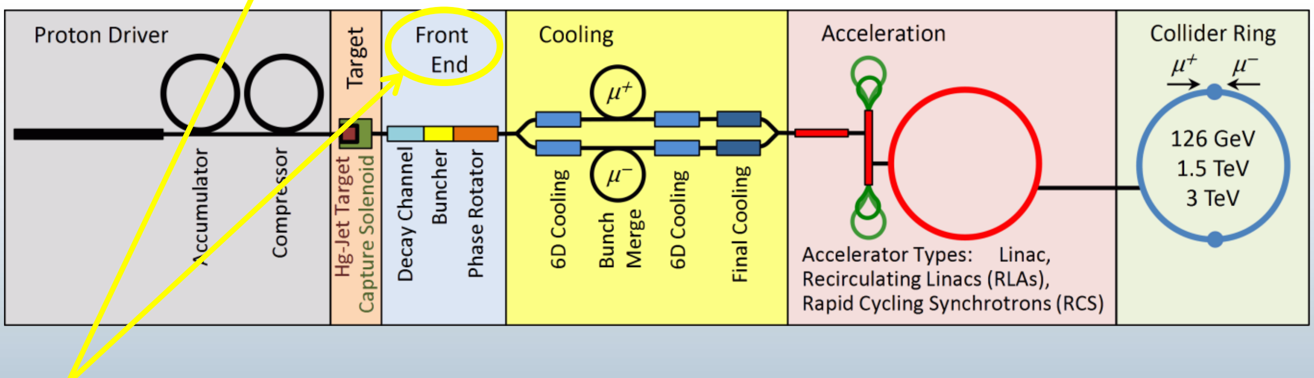
Applications of Muon Accelerators



Neutrino Factory

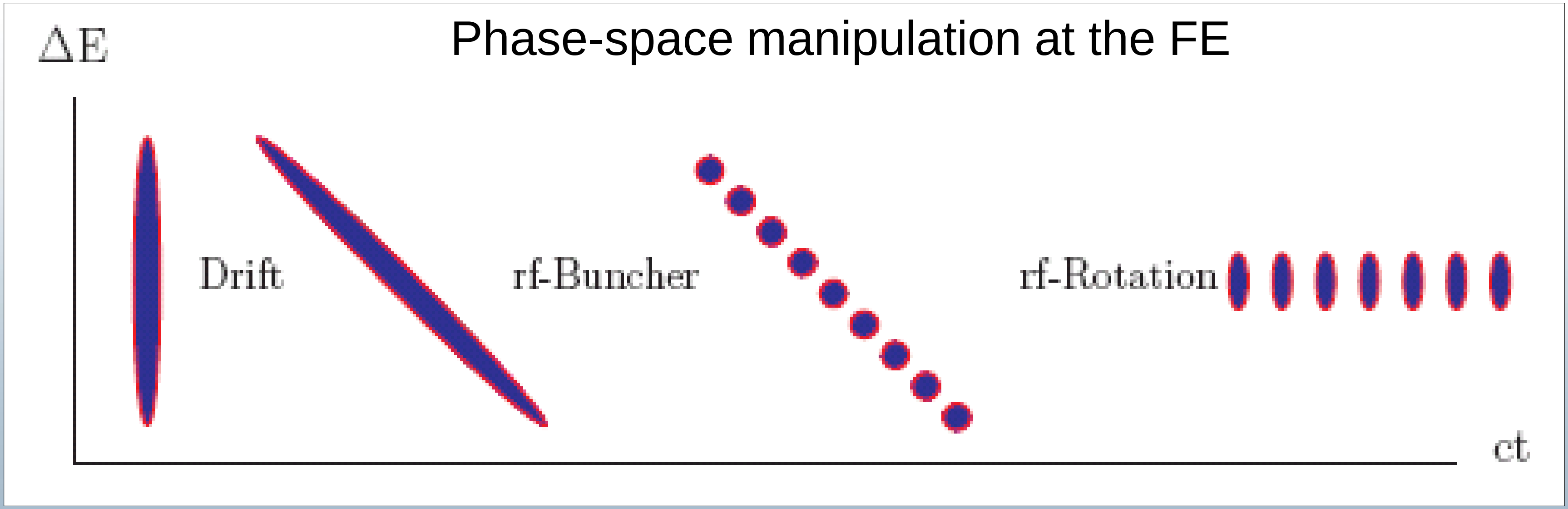


Muon Collider

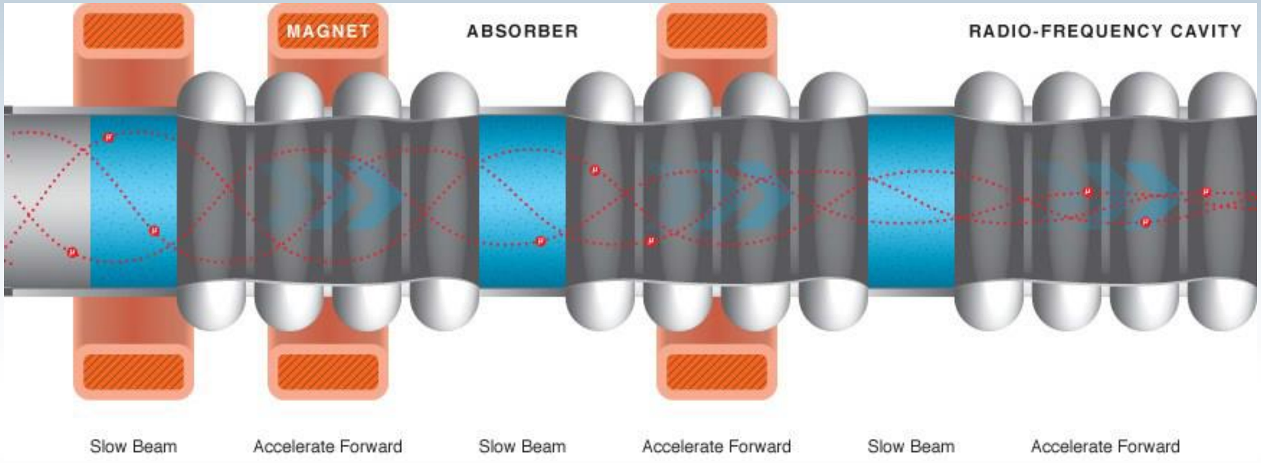
- Front-End is the core building block of a Neutrino Factory and a Muon Collider

Front-End (FE) channel

- Dual Purpose of FE:
  - Capture the muon beam generated at the target
  - Reduce its phase space to meet the acceptance criteria of downstream accelerators



Ionization cooling

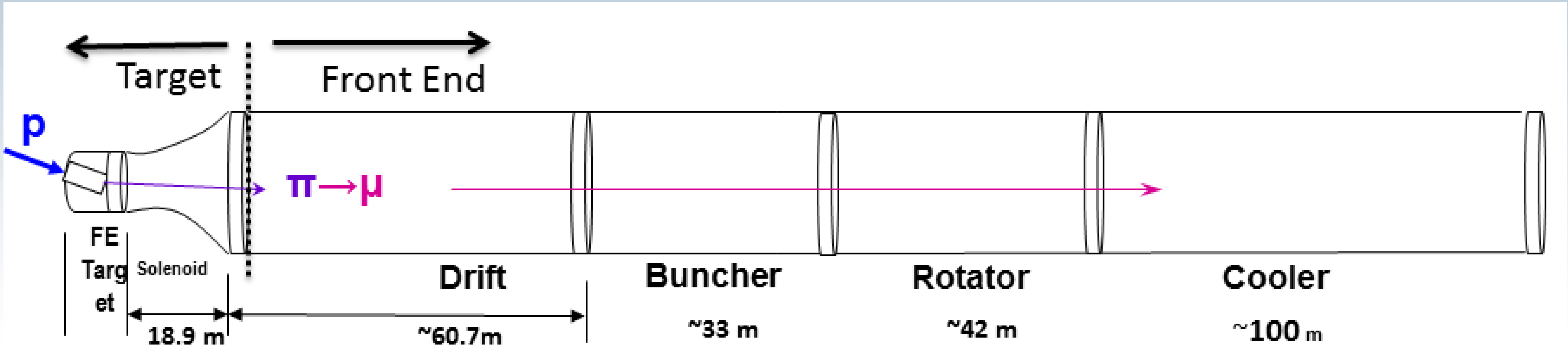


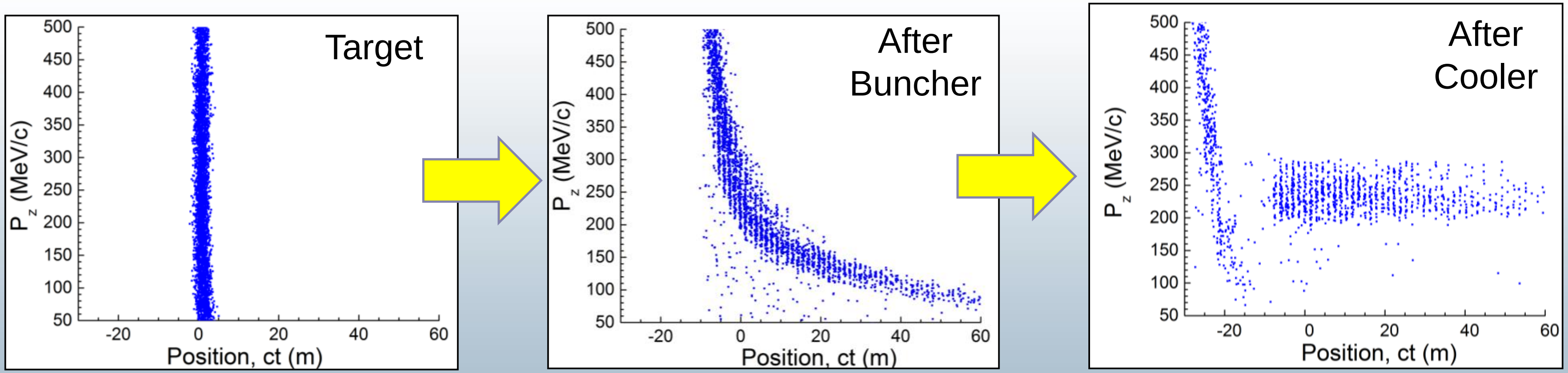
- Energy loss in absorbers
- rf cavities to compensate for lost longitudinal energy
- Magnetic field focusing to confine muon beams
- Leads to a compression of the 4D phase space

Outline

- Overview of major FE subsystems
- Discuss key challenges
  - Engineering constraints
  - Magnetic field constraints
  - Chicane Integration
  - Energy deposition and shielding
  - Optimization of the solenoid taper
  - Extension from 201 MHz to 325 MHz
  - Global optimization algorithms
- Future R&D activities

Major Front-End subsystems

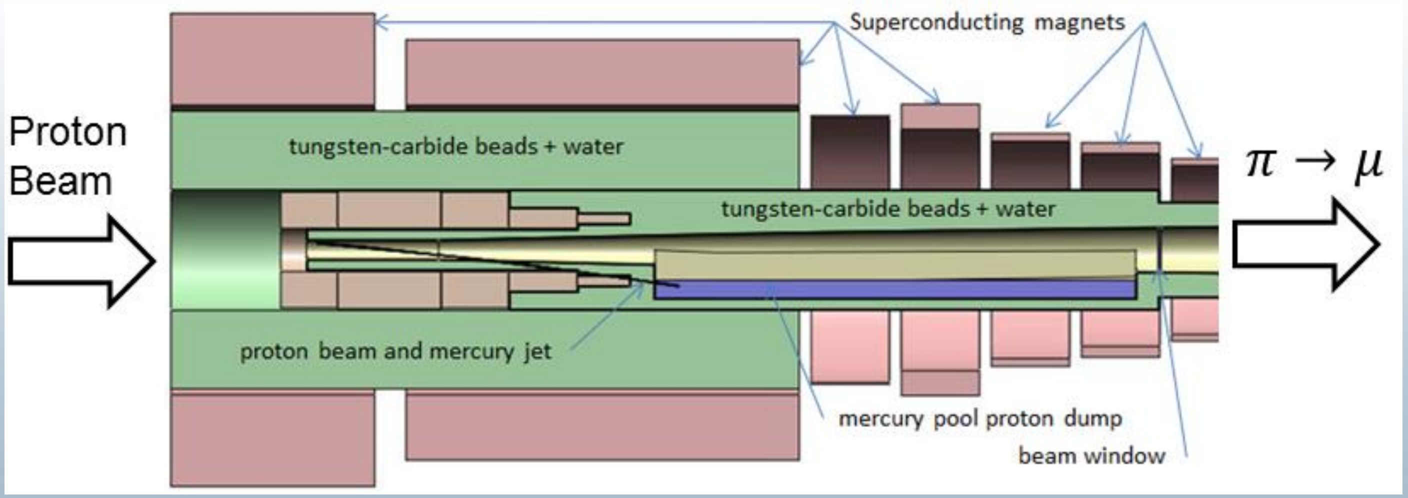




- BONUS: Front-End can process both μ^- and μ^+

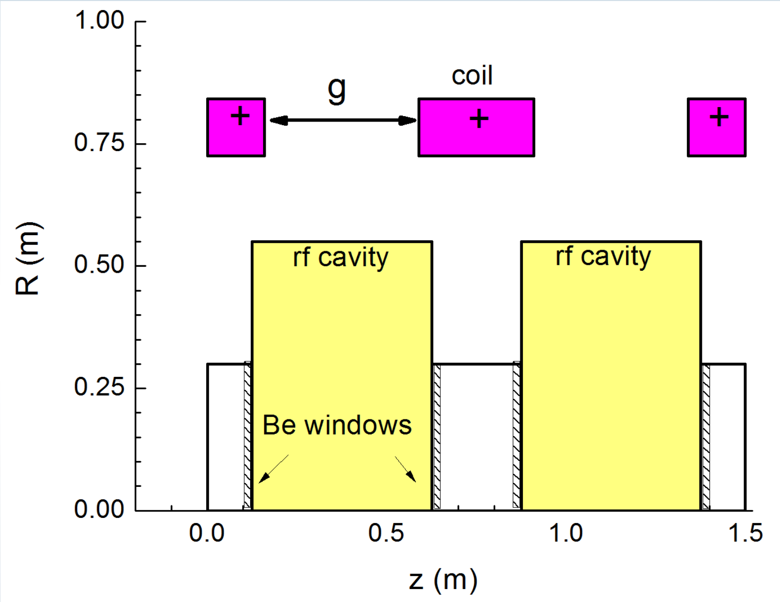
Target & Capture section

- A intense 8 GeV, 4 MW proton beam impacts a mercury jet immersed in a 20 T solenoid
- Create a flux of pions that decay into muons
- 20 T fields of the target tapers to 1.5 T within 15 m



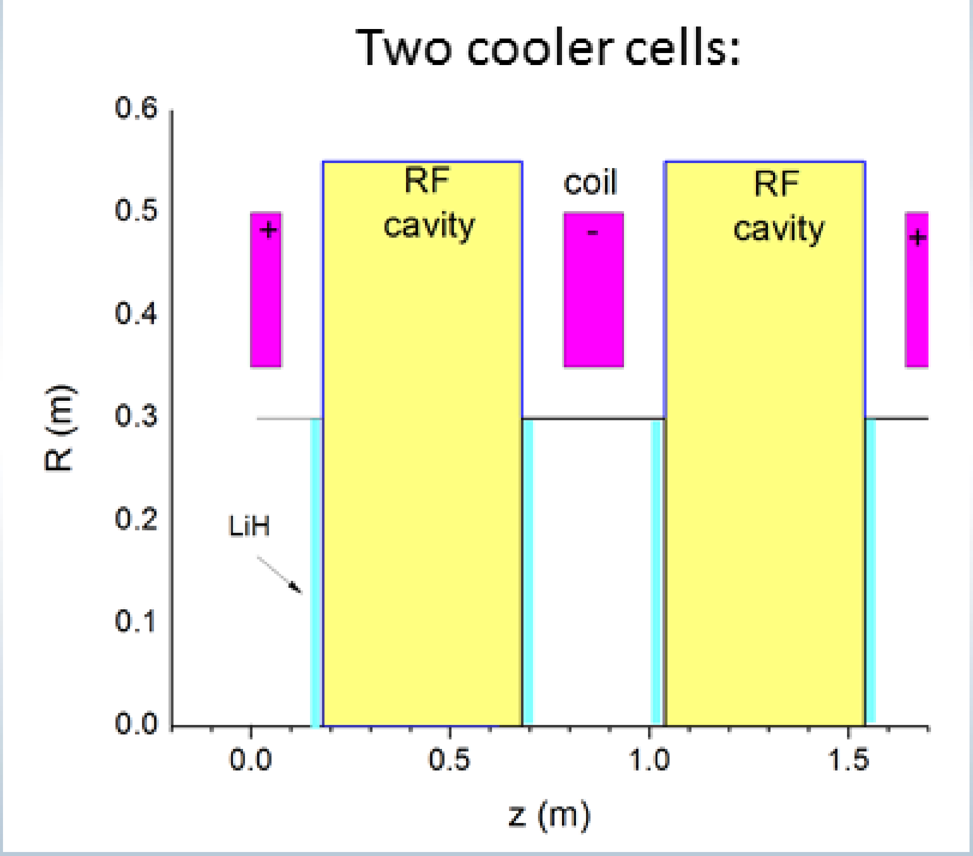
Buncher & Rotator parameters

- Buncher (33 m long)
  - 33 rf cavities
  - 319.6 to 233.6 MHz (13 freq.)
  - RF voltage: 3.4 to 9.0 MV/m
  - 1.5 T magnetic field
- Rotator (42 m long)
  - 56 rf cavities
  - 230.2 to 202.3 MV/m (15 freq.)
  - RF voltage: 13 MV/m
  - 1.5 T magnetic field

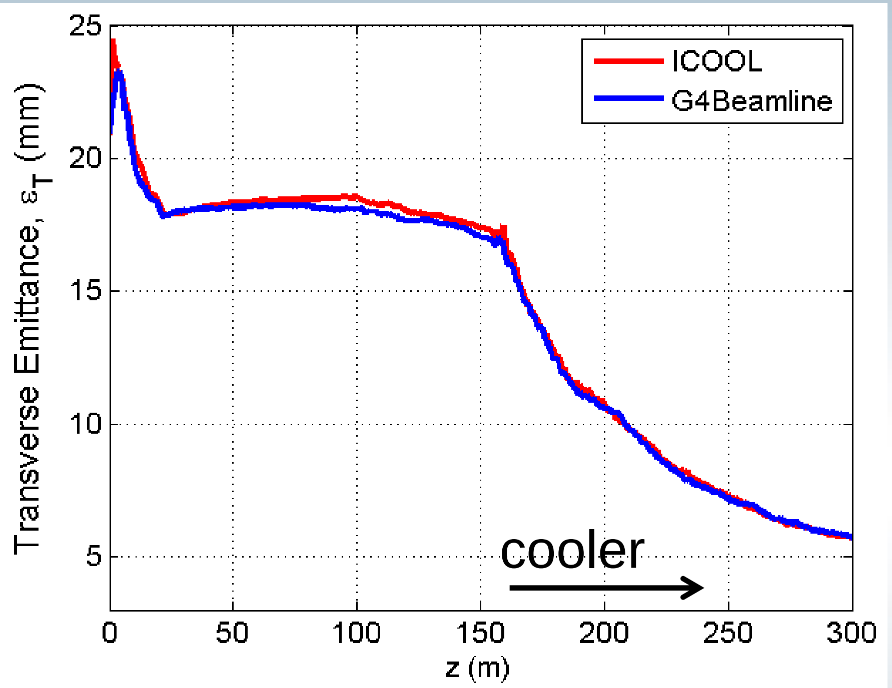


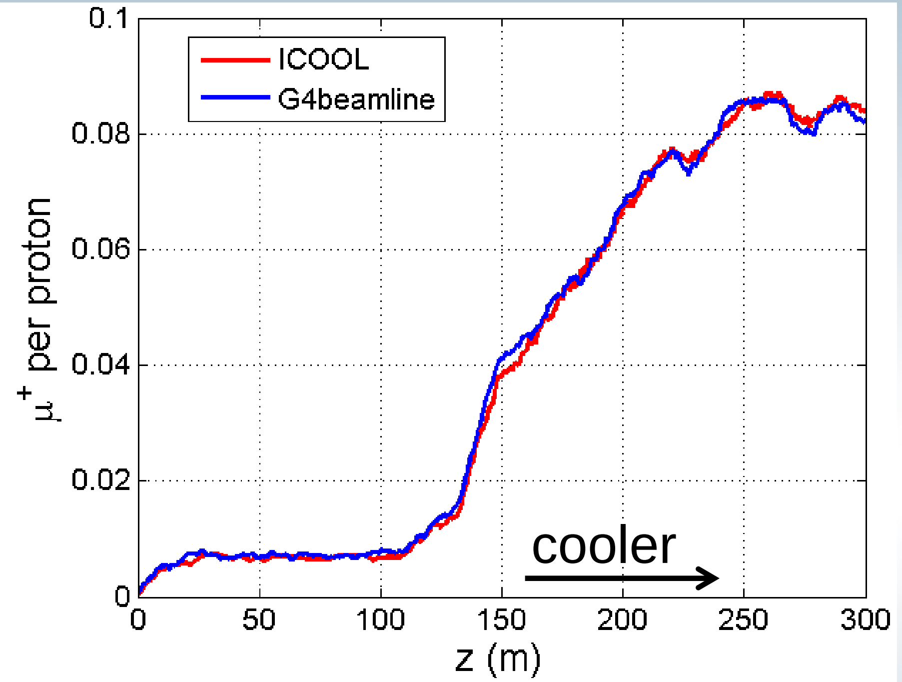
Cooler parameters

- Cooler (~100 m long)
  - 0.75 m cell length
  - 201.25 MHz
  - RF voltage: 16 MV/m
  - 2.8 T peak field on axis
  - 2.7 T field on the iris
  - Lithium Hydride absorber
  - 4D cooling only



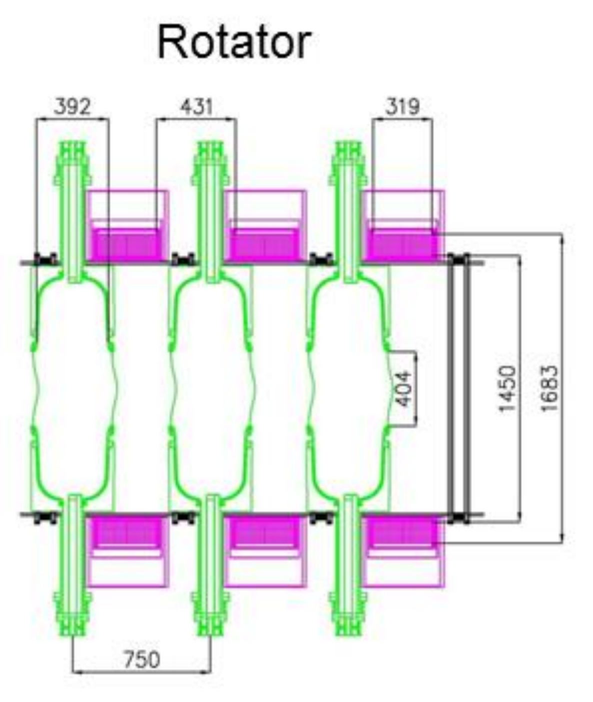
Lattice Performance

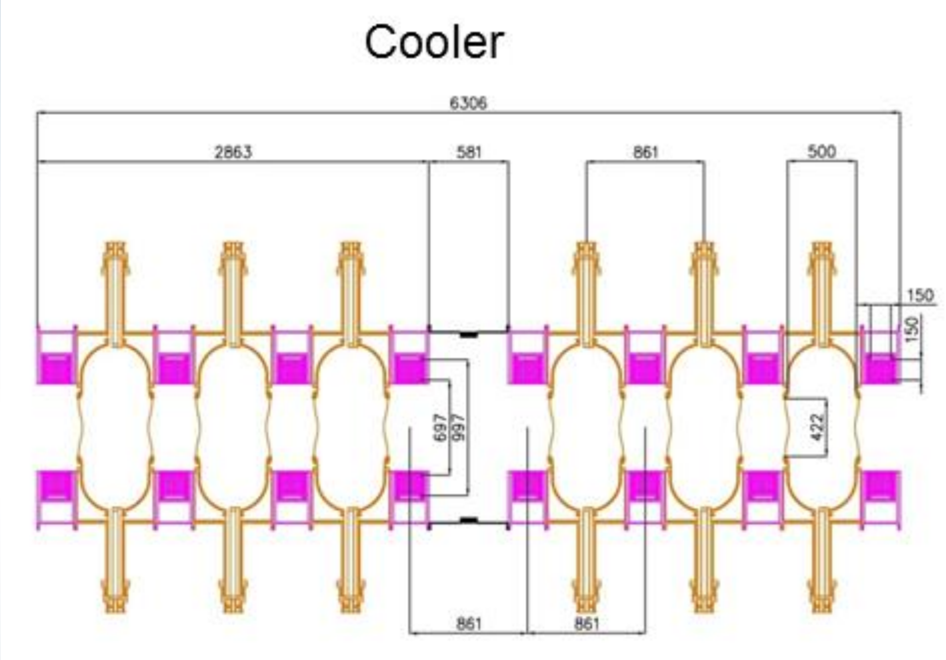




- Result benchmarked with both ICOOL & G4BL
- Acceptance within A_T < 30 mm, A_L< 150 mm and cut in momentum $100<P_z<300$ MeV/c
- Similar result for μ^-

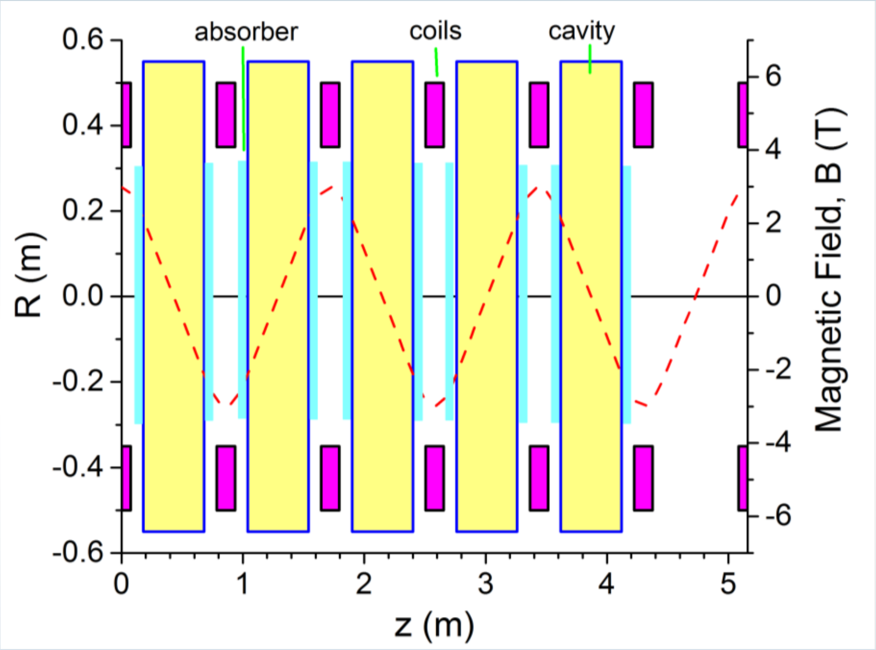
Engineering Constraints

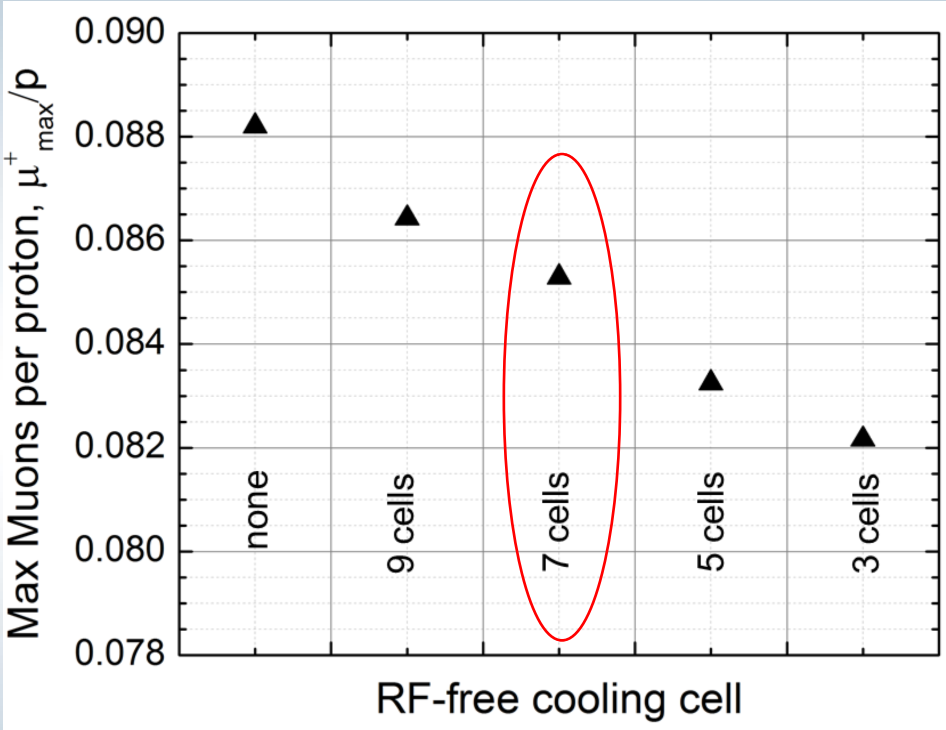




- IDS-NF Engineering studies:
  - Increase gap between coils in buncher &rotator
  - Increase cell length of cooler from 75 cm to 86 cm
  - Add one empty cell after a series of cavities

Lattice feasibility studies



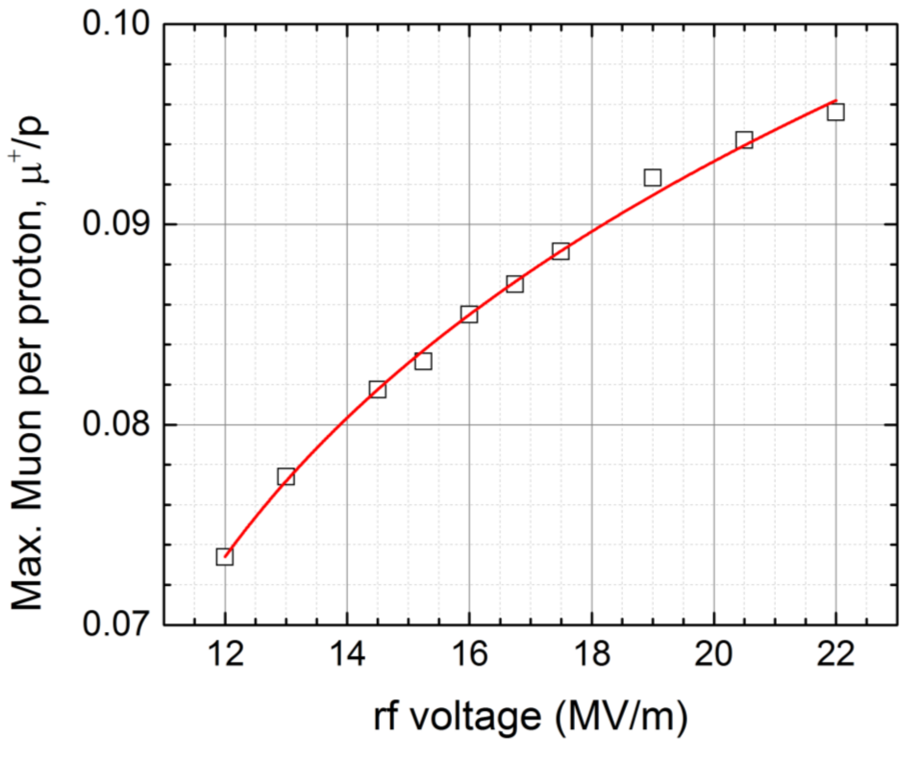


- Results sensitive the location of the “empty cell”
- 7 cell is the optimum but there is a 5% loss

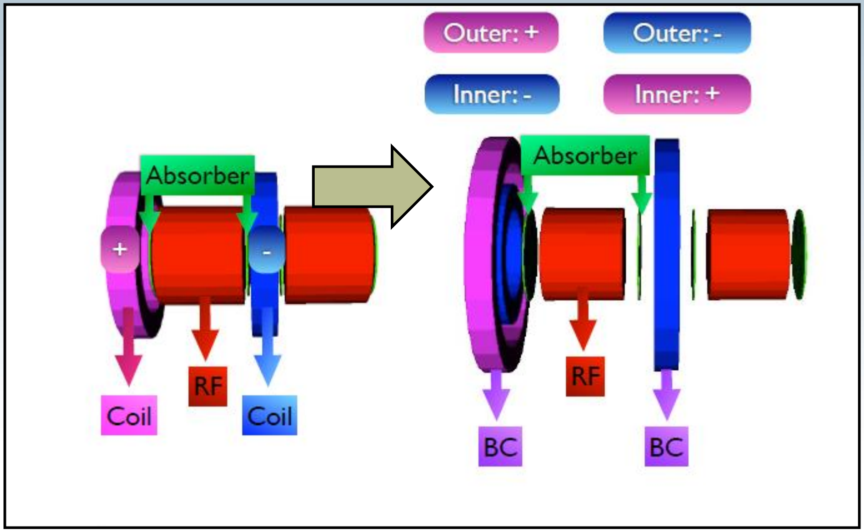
D. Stratakis *et al.,* Proc. of IPAC 2013, TUPFI087

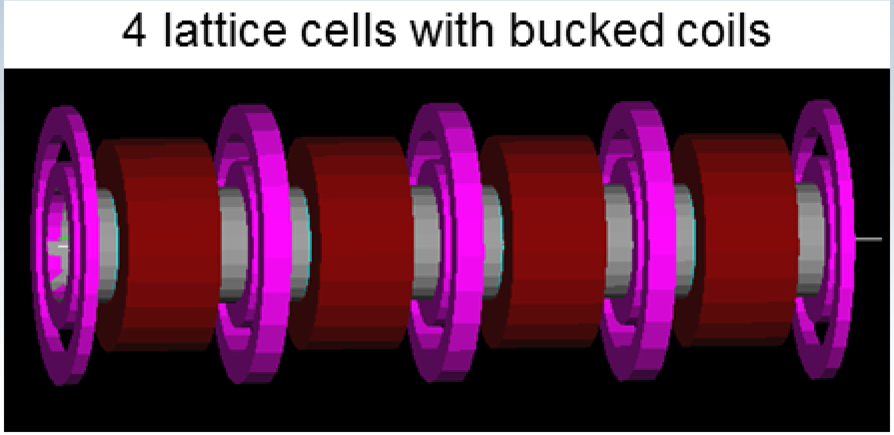
Magnetic field constraints

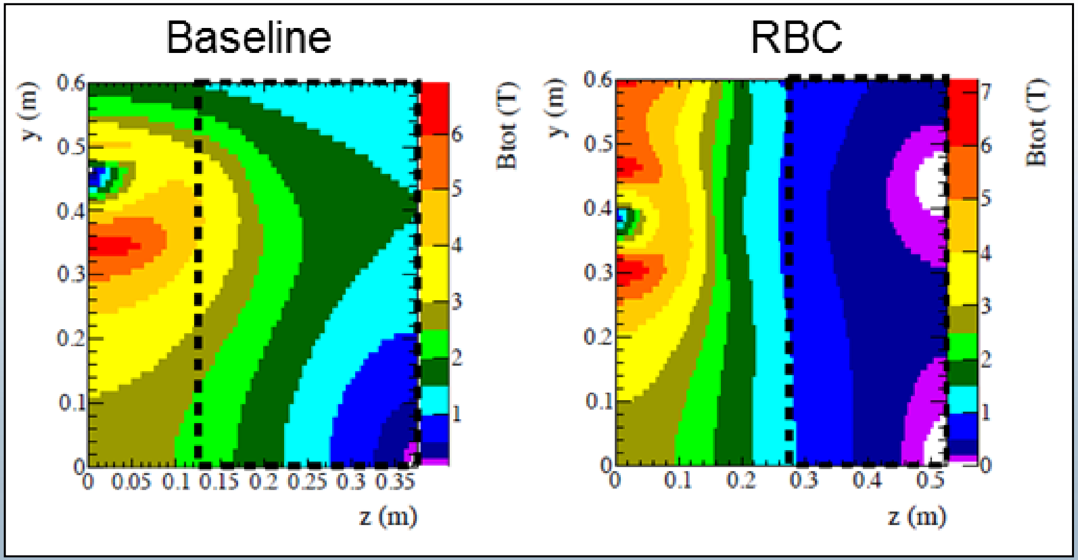
- Machine performance is sensitive to rf gradient limitations
- Alternative cooling options:
  - Magnetic insulation
  - Bucked-Coil Lattice
  - Shielded Coli Lattice
  - High pressure rf cavities



Radial bucked-coil lattice (RBC)

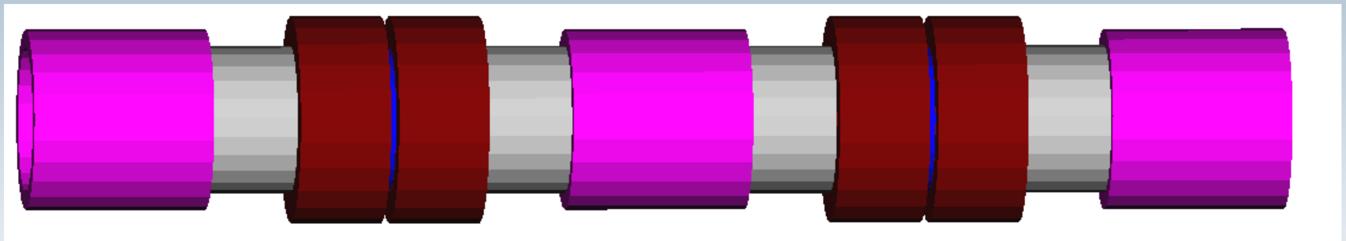


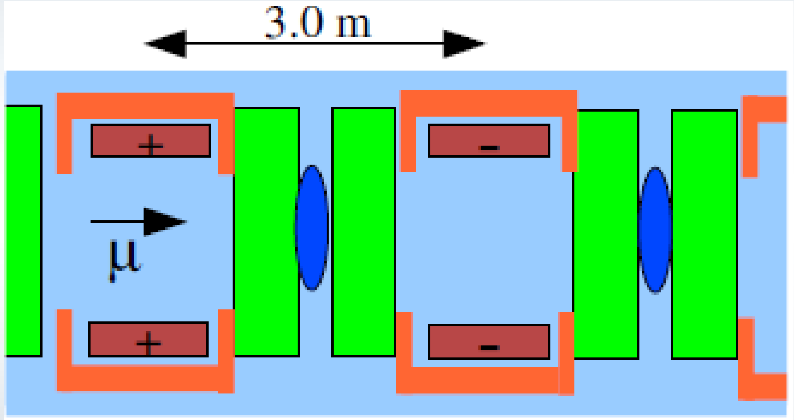


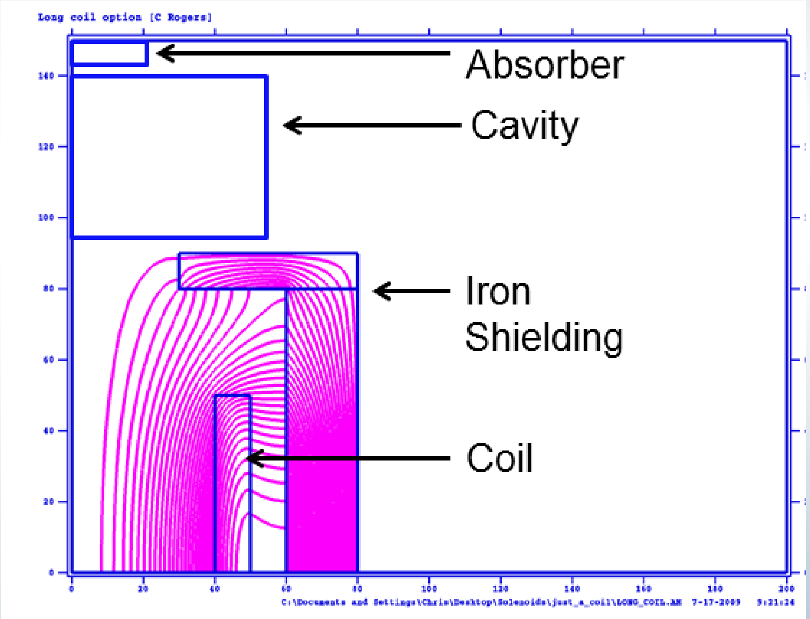


Alekou & Pasternak, JINST 7, P08017 (2012)

Shielded coil lattice (SHLD)



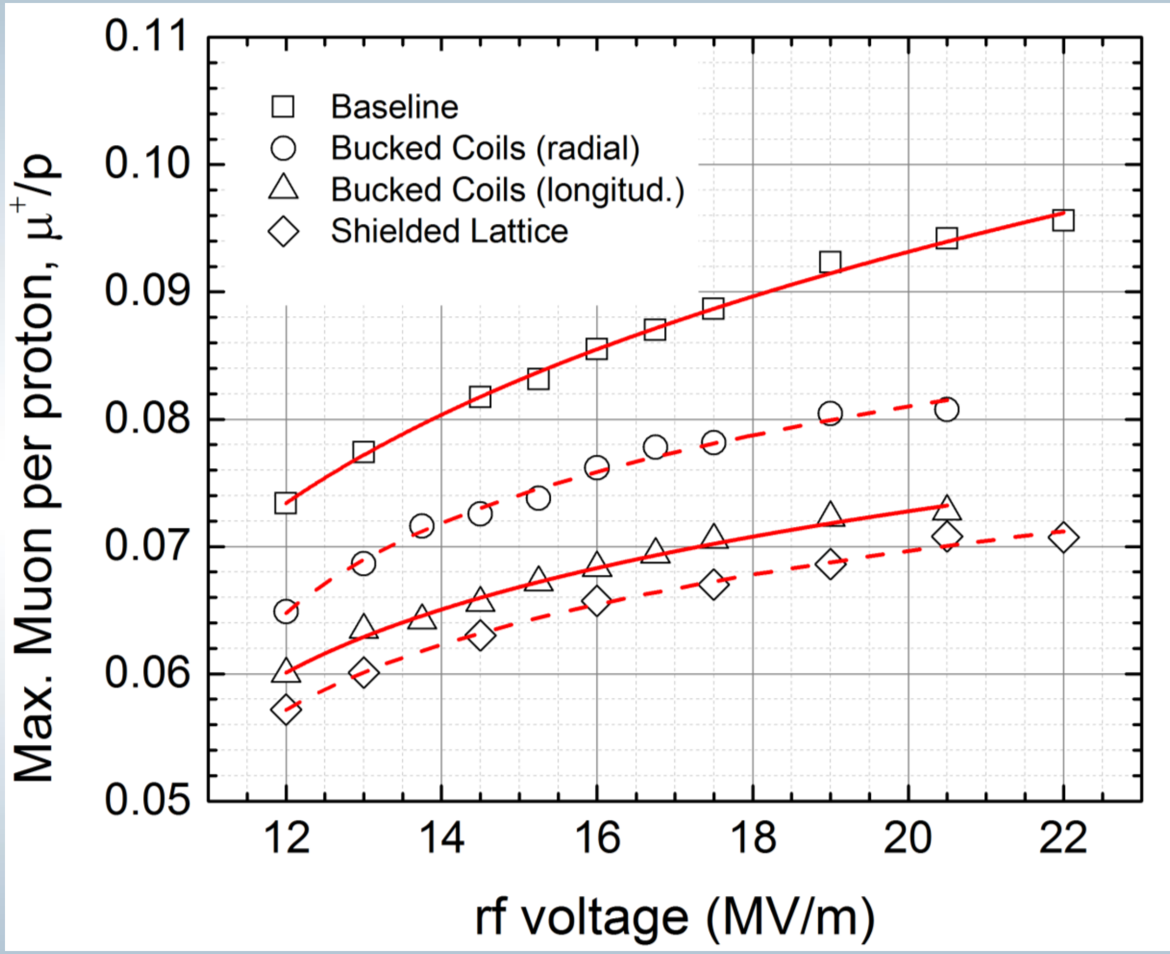




- Increase cell length to remove RF from fringe fields
  - Further shielding with iron
  - Fields below <0.5 T in rf

C. T. Rogers, AIP Conf. Proc.1222, 298 (2010)

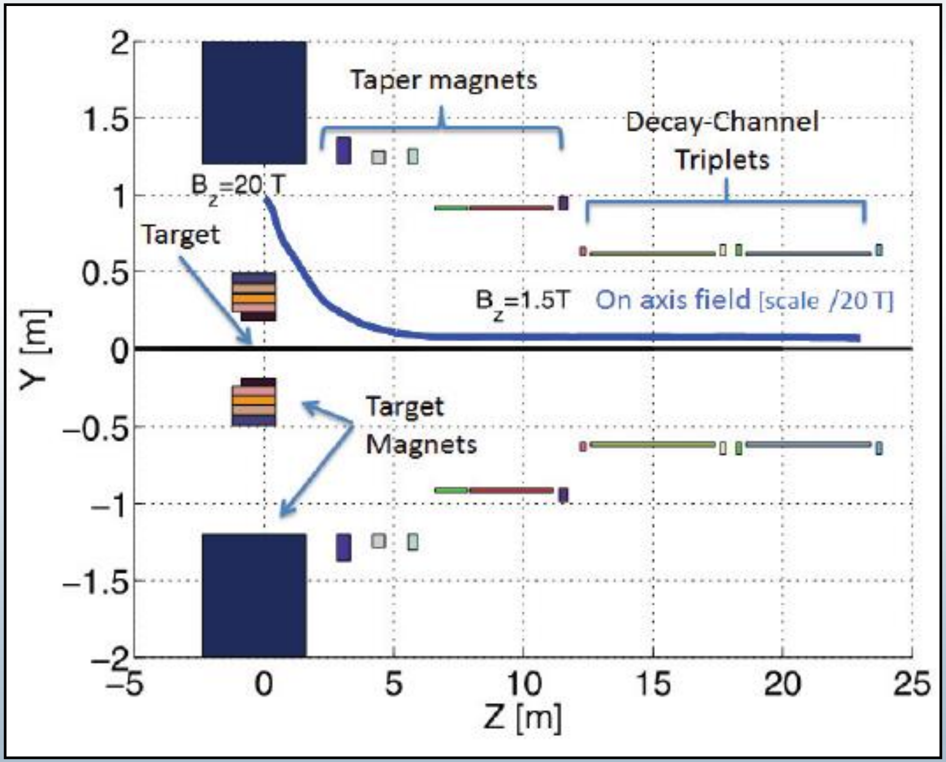
Lattice performances

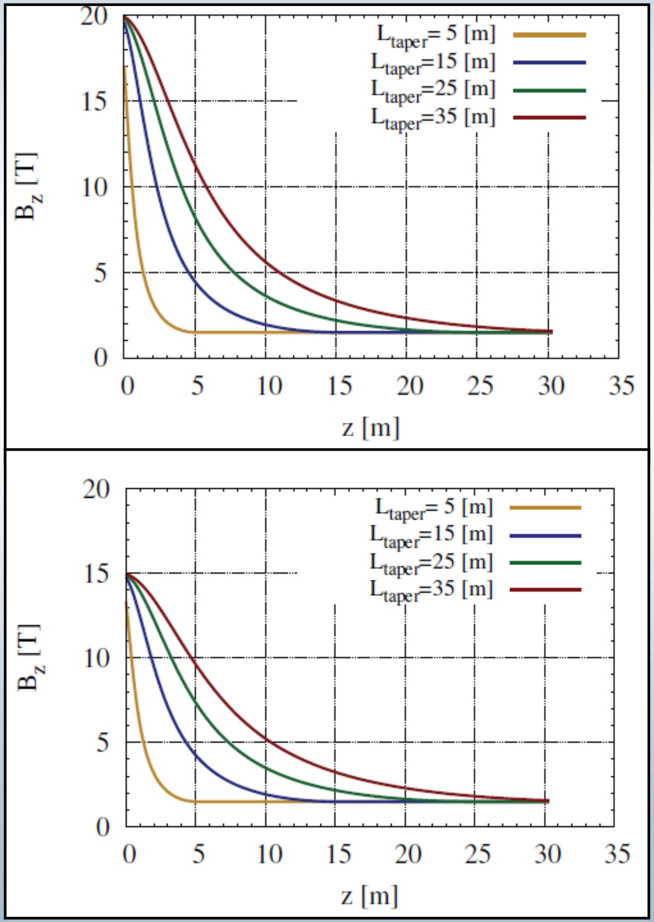


- Bucked Coils lattices are pending matching optimization.

Muon capture optimization

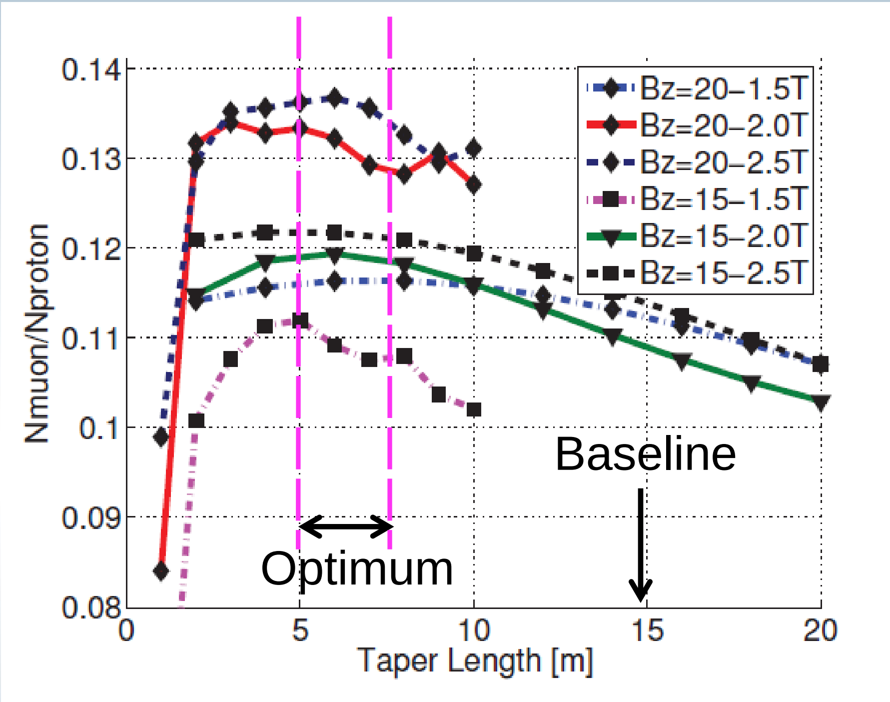
- Reduce peak field at target from 20 T to 15 T
- Results sensitive to taper length

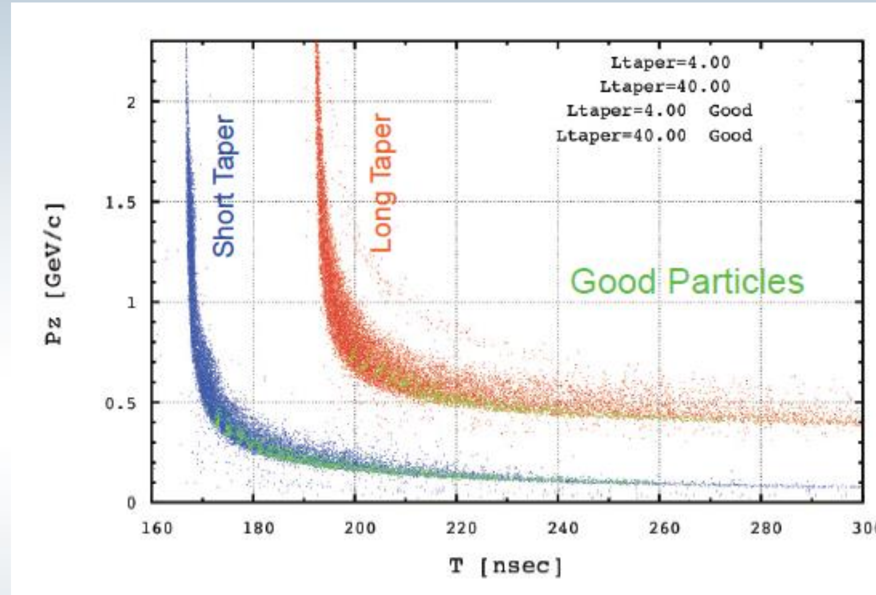




H. Sayed *et al.*, Proc. of IPAC 2013, TUPFI075

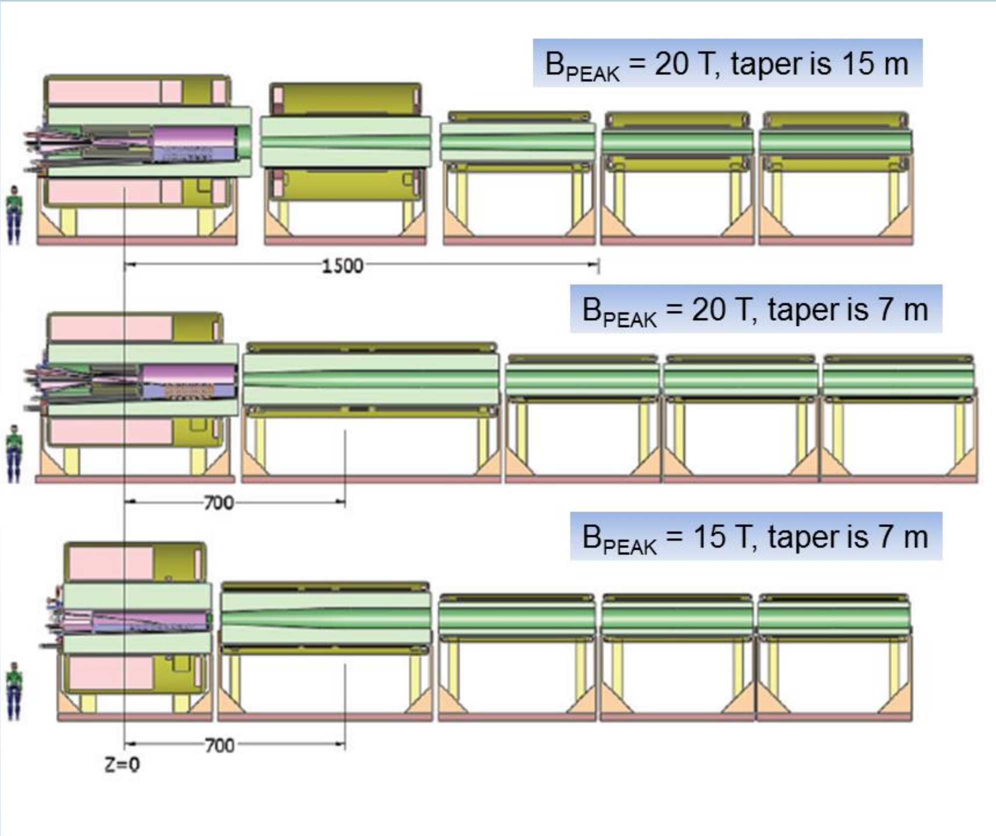
Target taper studies

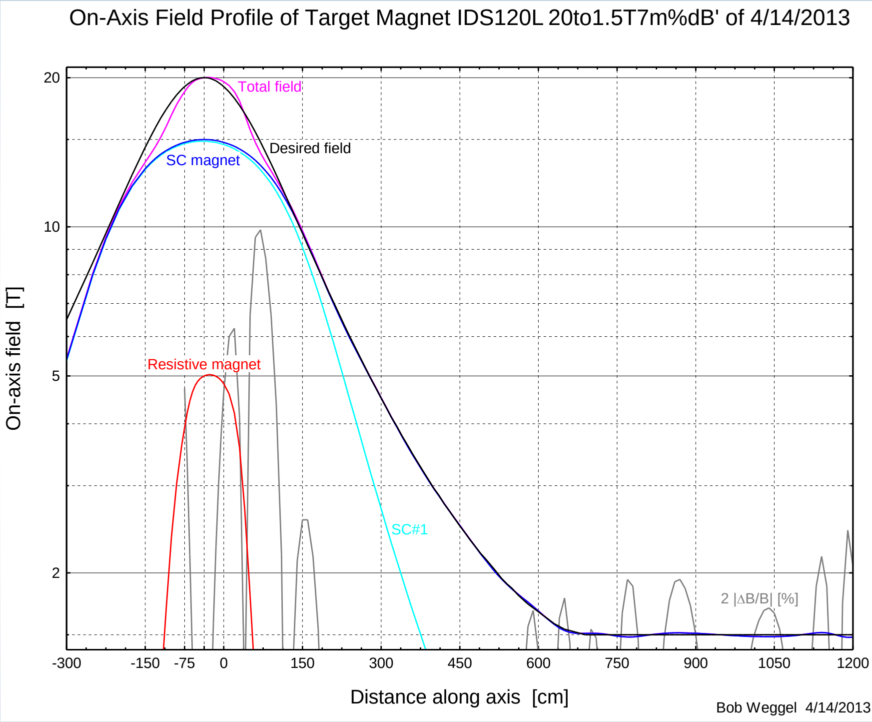




- Enhanced performance for taper lengths between 5 to 7 m
- There is a ~5% decrease when peak field is decreased from 20 T to 15 T.
- **Details: H. Sayed Talk on June 21 @ 2pm**

Realistic coil design for new taper



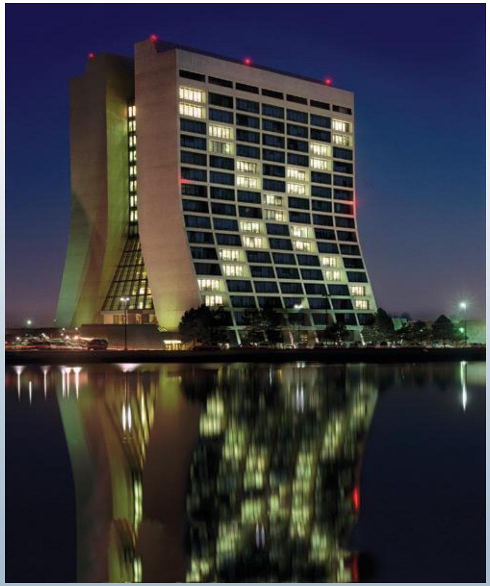


- **Details: R. Weggel Talk on June 21 @ 4 pm**

R. J. Weggel *et al.*, Proc. of IPAC 2013, TUPFI073

FE extension towards 325 MHz

- Muon FE was matched to 201.25 MHz
- Project X is matched to 1300 MHz
  - Use of 162.5 MHz, 325 MHz, 650 MHz
- Redesign FE for 325 MHz cavities to be compatible with Project X
- New challenges:
  - Upgrade from 319 → 500 MHz rf in buncher
  - Apertures are more restricted



Solving for X

Baseline parameters for a 325 MHz

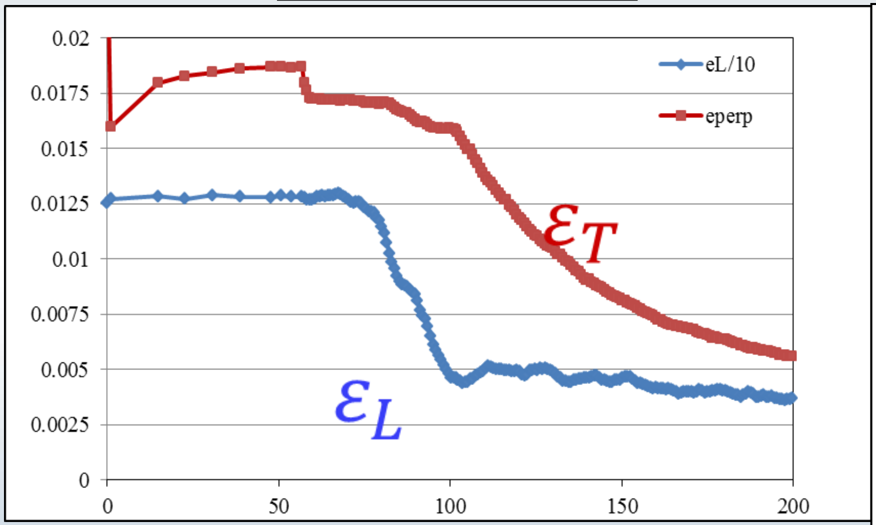
- Drift [42 m, 60 m]
  - 20 T → 2 T (20 T → 1.5 T)
- Buncher [21 m, 33 m]
  - 490 MHz → 365 MHz (319 MHz → 233 MHz)
  - 0 → 15.0 MV/m (3.4 → 9 MV/m)
- Rotator [24 m, 42 m]
  - 364 MHz →326 MHz (232 MHz → 201 MHz)
  - rf voltage: 20 MV/m (13 MV/m)
- Cooler [~60 m, ~100 m]
  - 325 MHz (201 MHz) @ 25 MV/m (16 MV/m)
  - LiH absorbers

NOTE: Red is the 201 MHz FE version

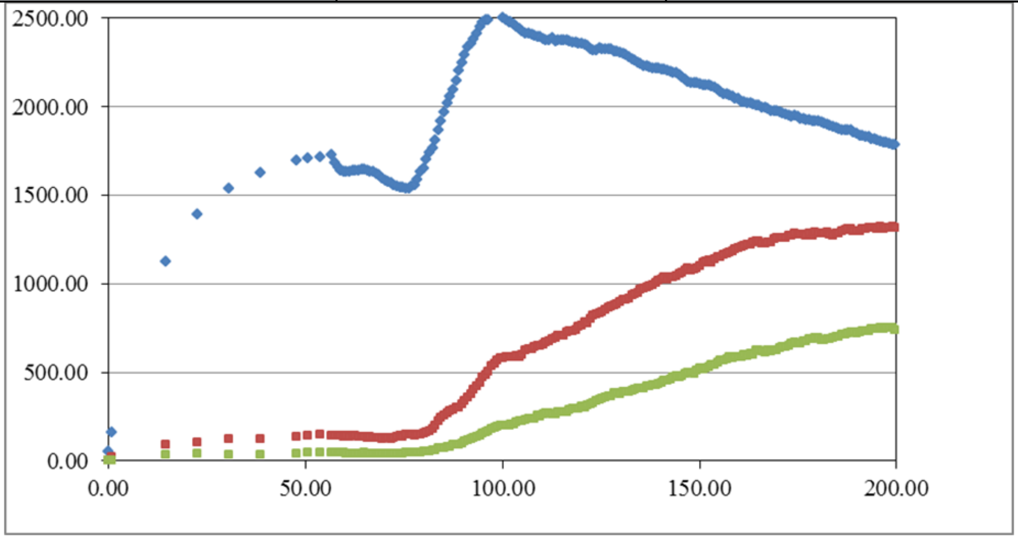
Lattice Performance

- 325 MHz FE version has been simulated with ICOOL

Emittances



Muon rate



μ per 10,000 p within: 0.15 GeV/c $<P_{mu}<$0.35 GeV/c

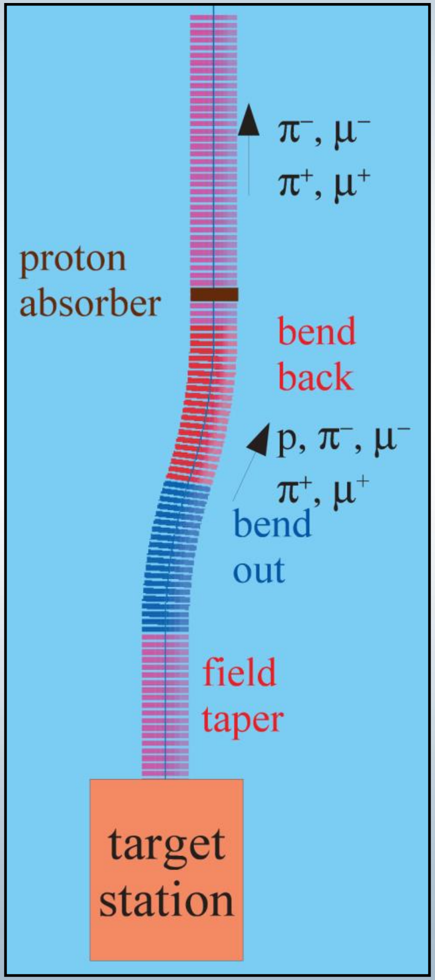
μ per 10,000 p within: $A_T < 0.03$ m, $A_L < 0.2$ m

μ per 10,000 p within: $A_T < 0.015$ m, $A_L < 0.2$ m

- **Details: D. Neuffer Talk on June 21 @ 2:15 pm**

D. Neuffer & C. Yoshikawa, MAP-Note 4355

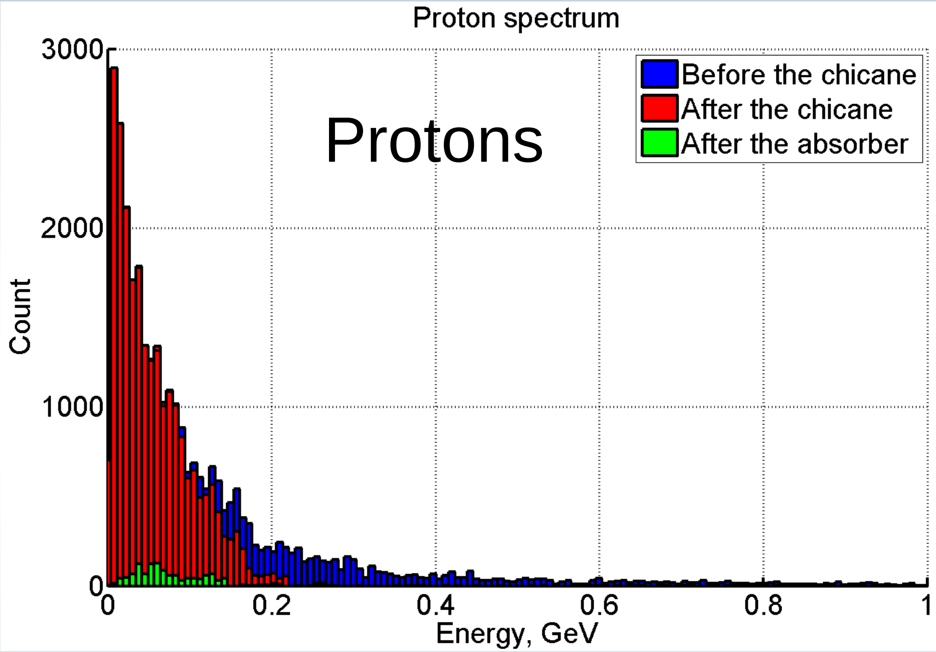
Chicane integration in the FE

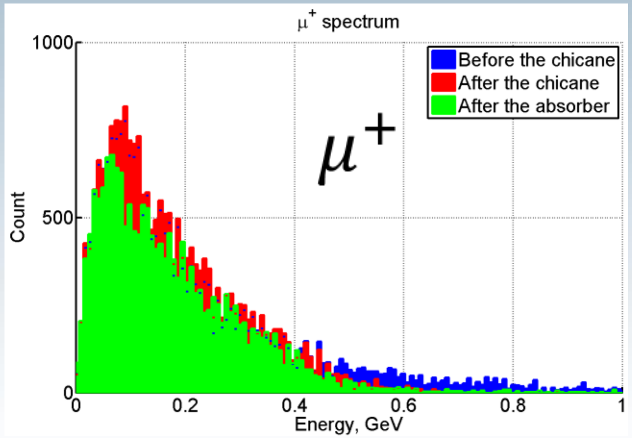


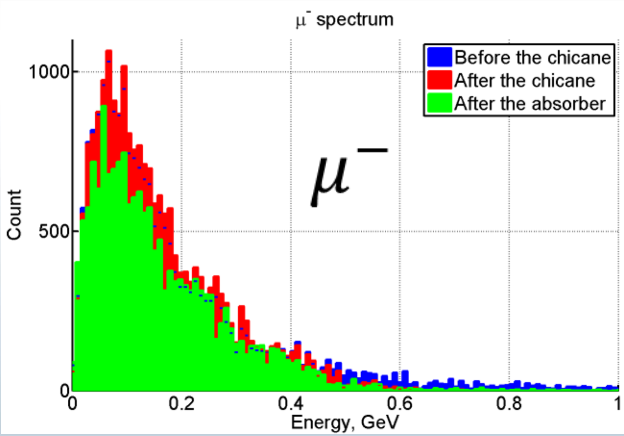
- The goal of the chicane is to remove high energy protons (p> 500 MeV/c)
- The remaining proton are removed by a 10 cm Be absorber
- Adequate for both signs of muons
- Central coils take a serious hit from high-energy particles going straight through.

C. T. Rogers *et al.,* Proc. of IPAC 2012, MOPPC041

FE performance with chicane

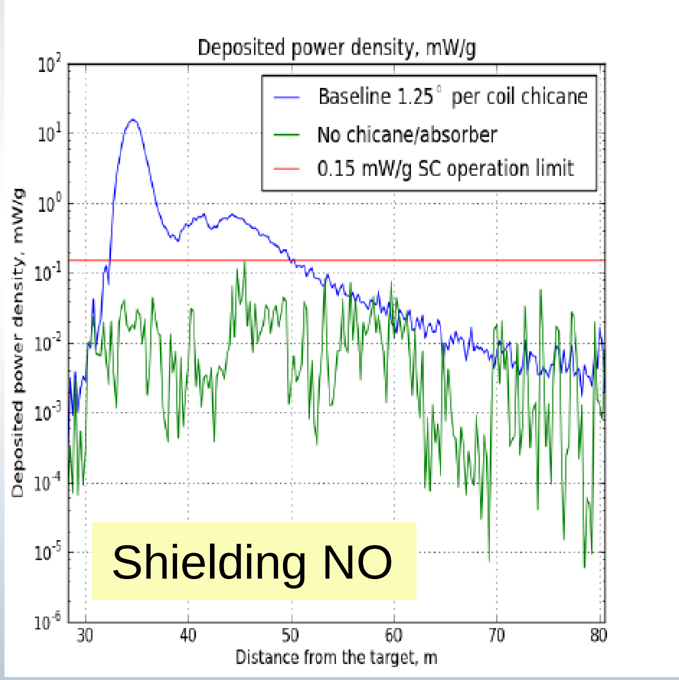


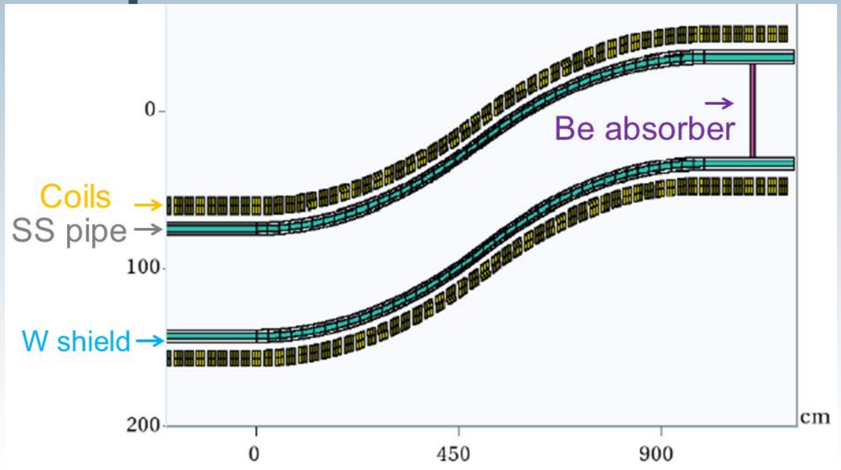


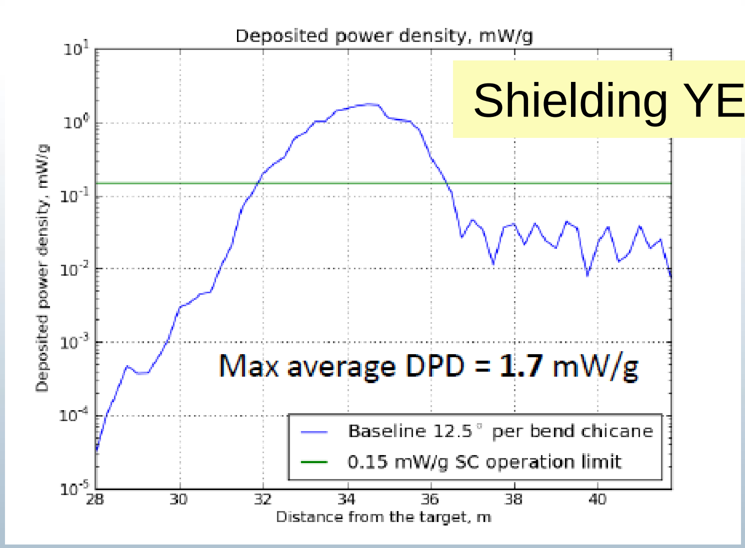


- System efficiently removes unwanted particles
- 10% muon losses compared to baseline (no chicane)

Chicane energy deposition & shielding



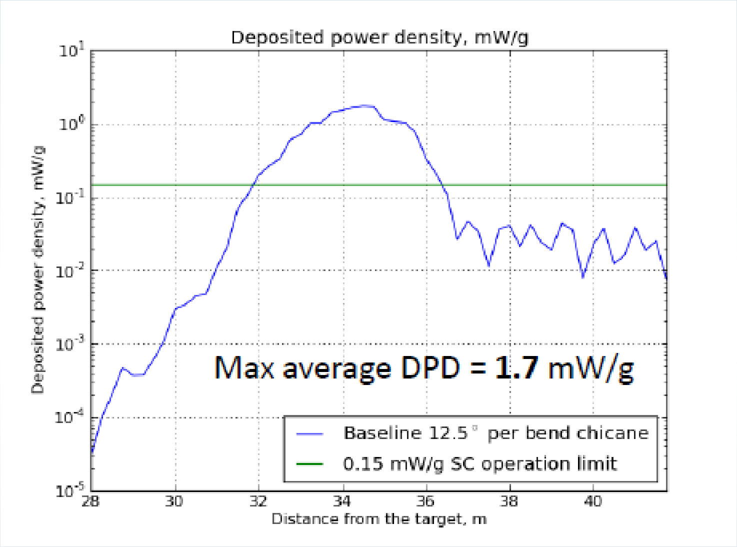


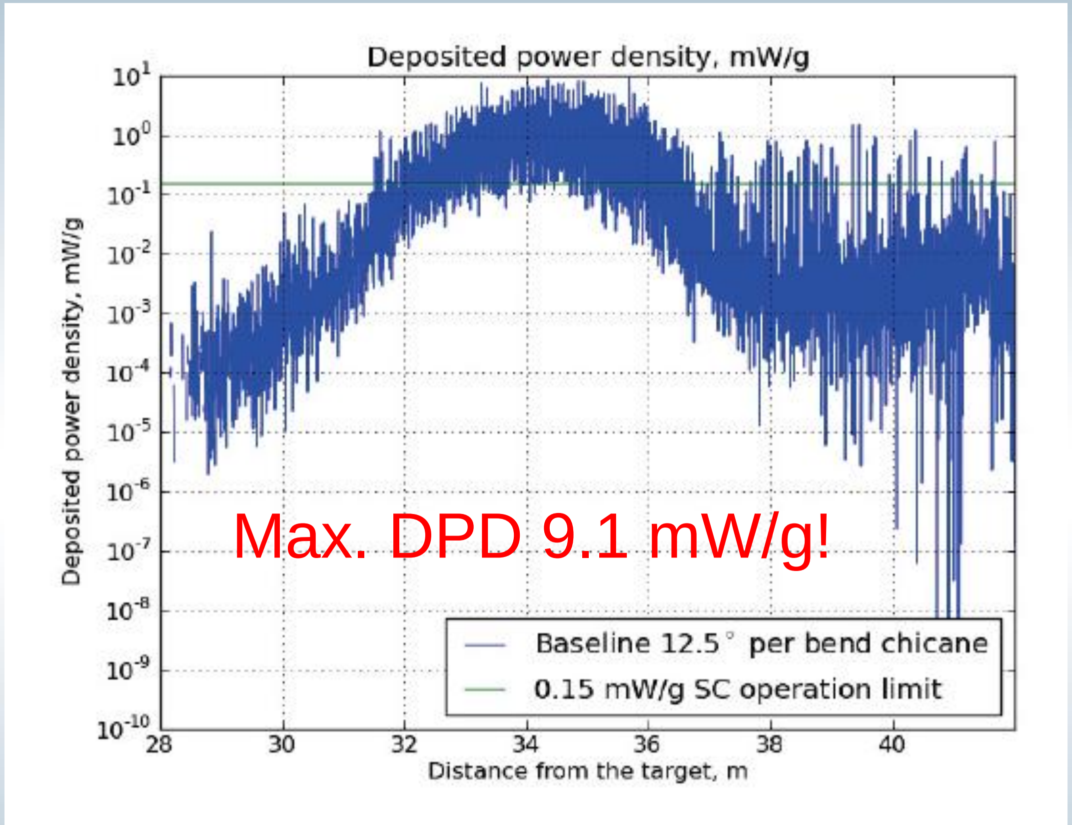


- Note: Deposition on individual coil segments can be larger

P. Snopok *et al*, Proc. IPAC 2013, TUPFI067

Chicane energy deposition & shielding



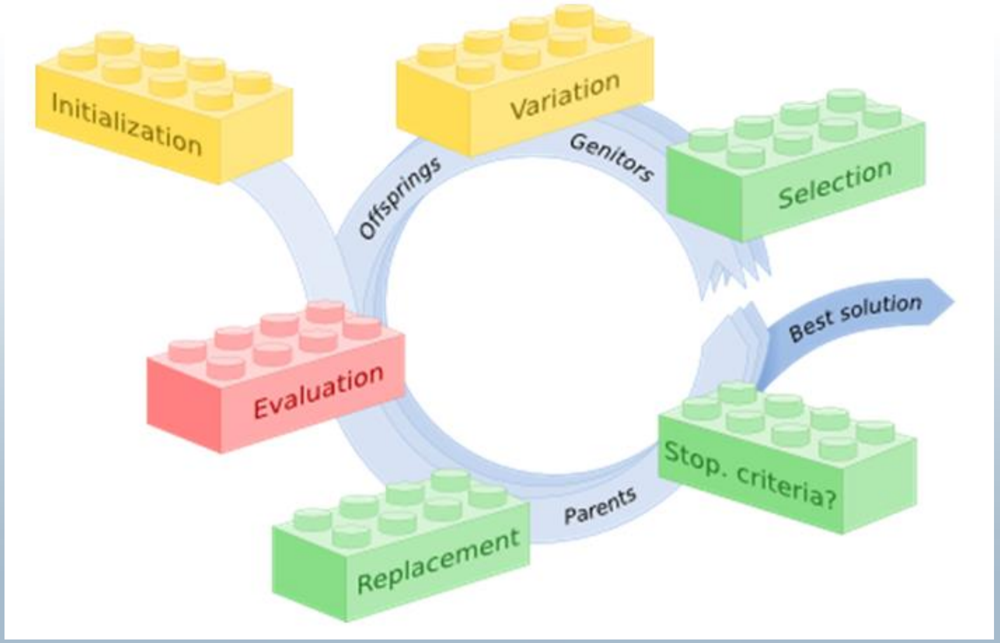


- Deposited power density for individual coil segments is still 100 times bigger than threshold

P. Snopok *et al*, Proc. IPAC 2013, TUPFI067

Optimization Algorithms

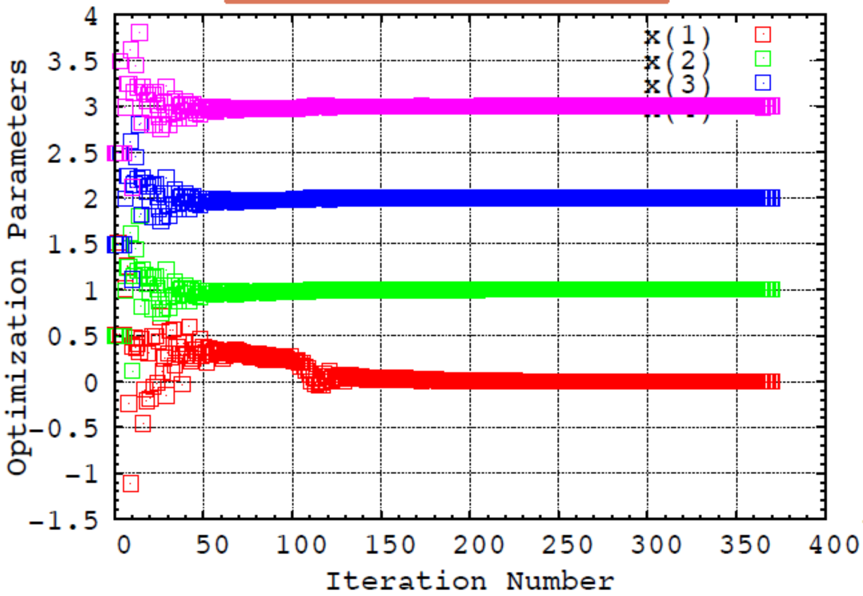
- Finding an exact optimum design parameter of a system often can not be satisfied by the conventional scanning technique
- FE cooler: rf phase, absorber thickness, B-field strength



Optimization Algorithms (H. Sayed)

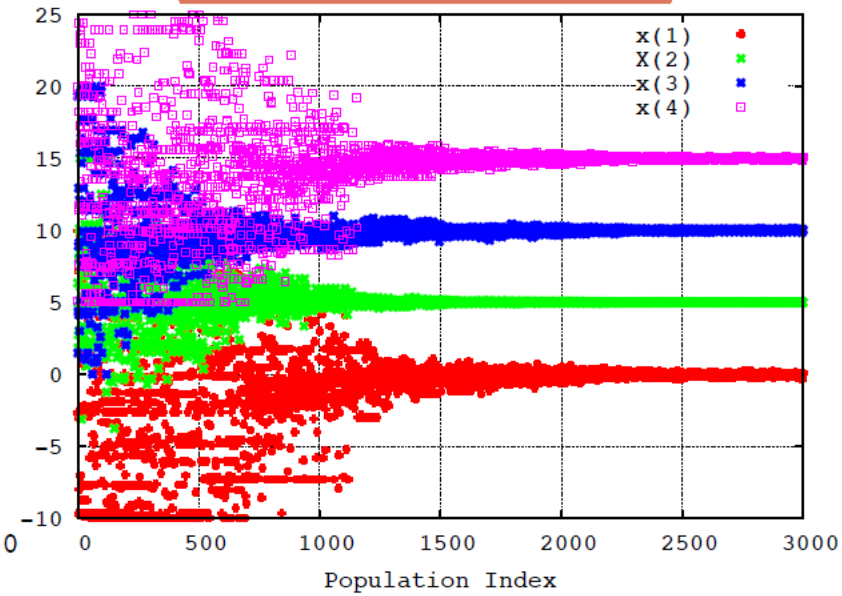
Powell's Test Function: P(0,0,0,0)=0 $(x(1)+10\,x(2))^2+5\,(x(3)-x(4))^2+(x(2)-2x(3))^4+10\,(x(1)-x(4))^4$

Nelder-Mead



- Start with some initial guess
- Did not explore all parameter space
- Converged in 350 function runs
- Did not reach absolute minimum
- (P_{min}=1E-5)

Evolutionary Algorithms

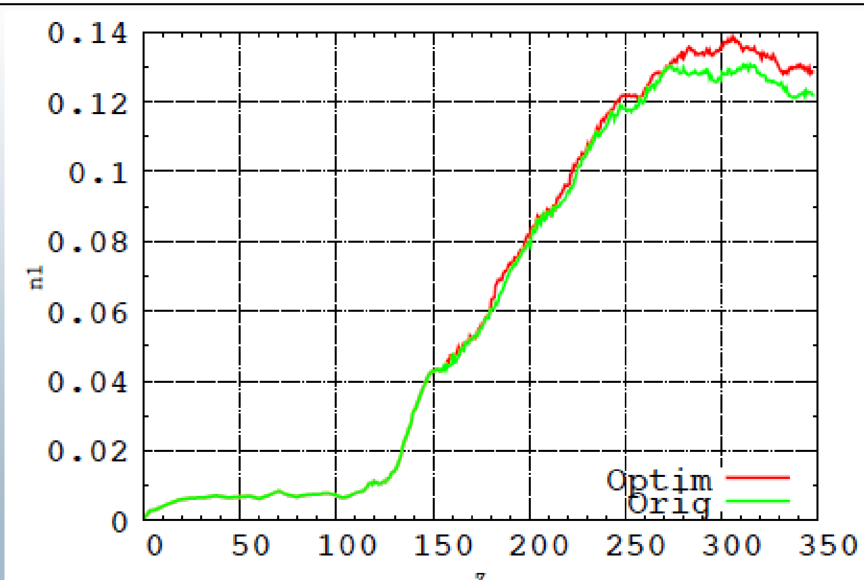


- Start with some random guess
- Explored all parameter space
- Converged in 3000 X 20 function runs
- Found absolute minimum effectively
- (P_{min}=1E-23)

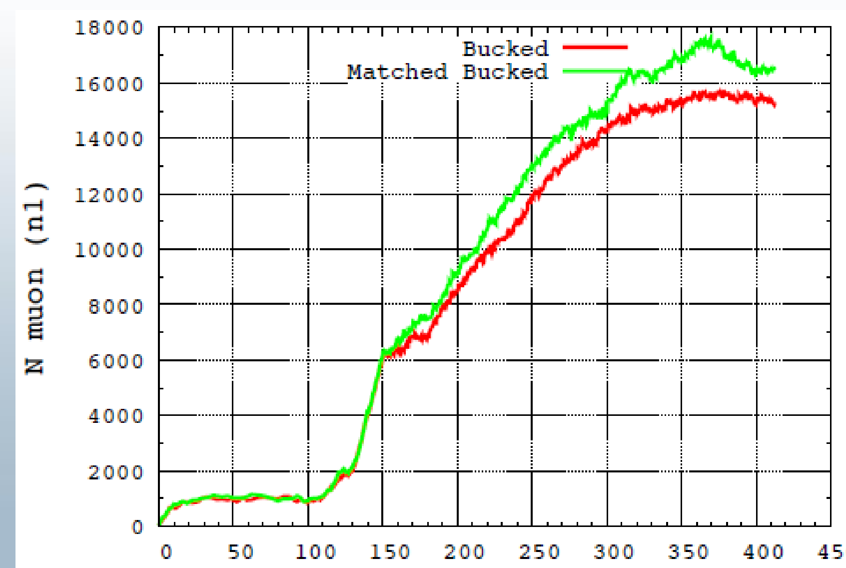
Multivariable Problem

- Matcher to cooler was designed to match 1.5 T solenoid to alternating ±2.8 T cooler channel.
- Not valid for a bucked-coil lattice.
- Goal: Optimize matching coils (9 parameters for 9 coils)

Gain of 7% for a short taper 2T case



Gain of 5% in a bucked-coil lattice



FY13 & FY 14 R&D activities

- Integrate chicane into decay region
  - Energy deposition in the coils, study shielding options
- Respond to new target parameters (3 GeV, 1 MW)
  - Optimize decay channel, buncher, rotator
  - Evaluate front-end performance levels
- Finalize global optimization tools (both ICOOL & G4BL)
- Integration of a 15 T solenoid and short taper in the FE
- Support IDS-NF RDR activities

Summary

- The baseline requirements for a 325 MHz are identified
- Achieves similar performance to the 201 MHz version
- Results are sensitive to the rf voltage. We discussed two alternative options, if this is a problem.
- A chicane/ absorber system to remove unwanted particles from the FE has been simulated. Energy deposition requires further shielding studies.
- A shorter taper scheme enhances performance.
- Global optimization algorithms are underway. So far very promising results