Demonstration of a magnetically insulated front-end channel for a neutrino factory

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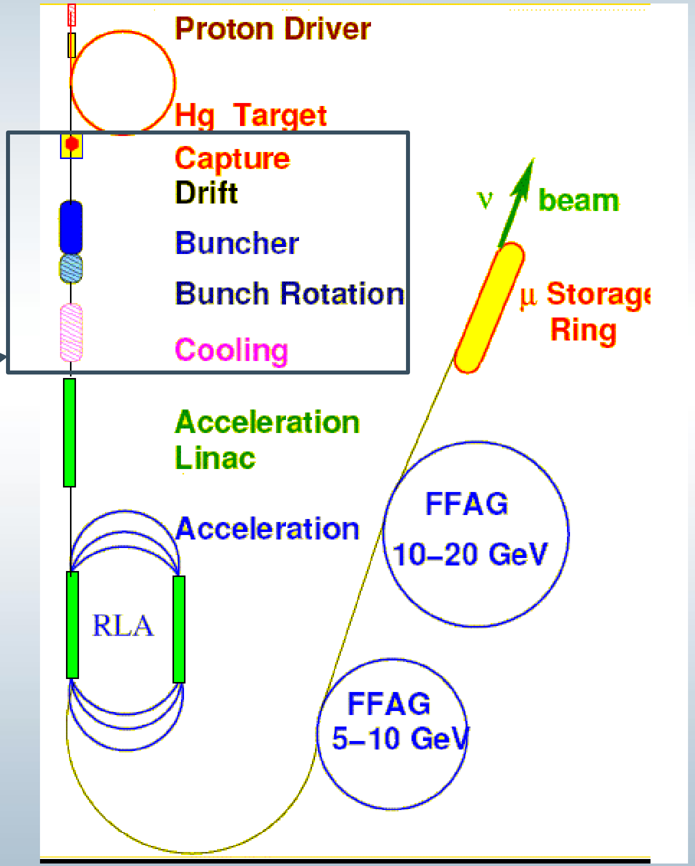
Outline

- Review the existing front-end lattice for a Neutrino factory
- Discuss it’s limitations
- Demonstrate an alternative front-end lattice having magnetically insulated cavities
- Examine it’s performance
- Discuss future steps and derive conclusion

Ingredients of a Neutrino Factory

- Proton Driver
  - ~8 GeV protons
- Target, π Capture
  - π→μ
- **Front-End**
  - μ transport and cooling
- Acceleration
  - Linac, RLAs, FFAG
- Storage & decay ring
- Detectors

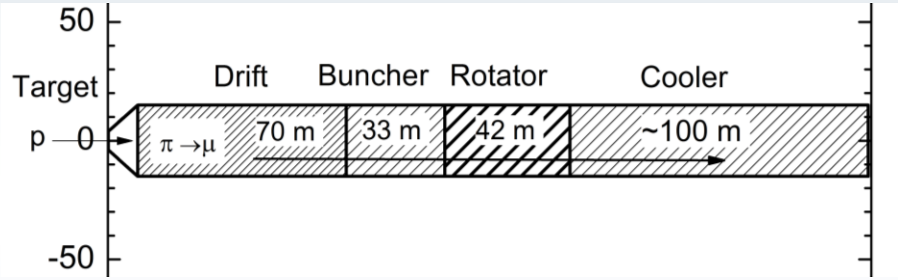


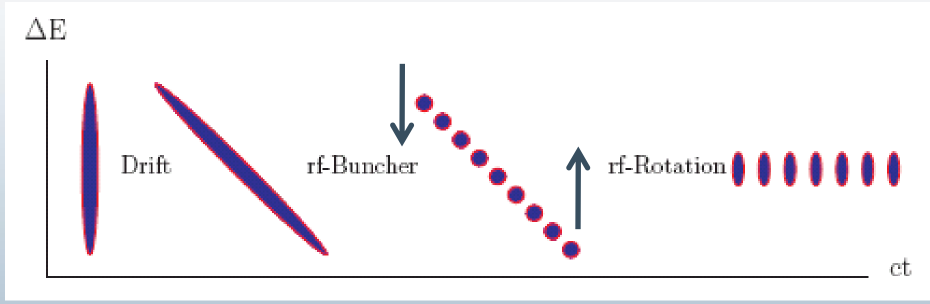
- Front-end costs ~1/3 -> Need to be studied carefully!

Front-End (FE) Channel

- <u>Purpose of FE</u>: Reduce beam phase-space volume to meet the acceptance criteria of downstream accelerators

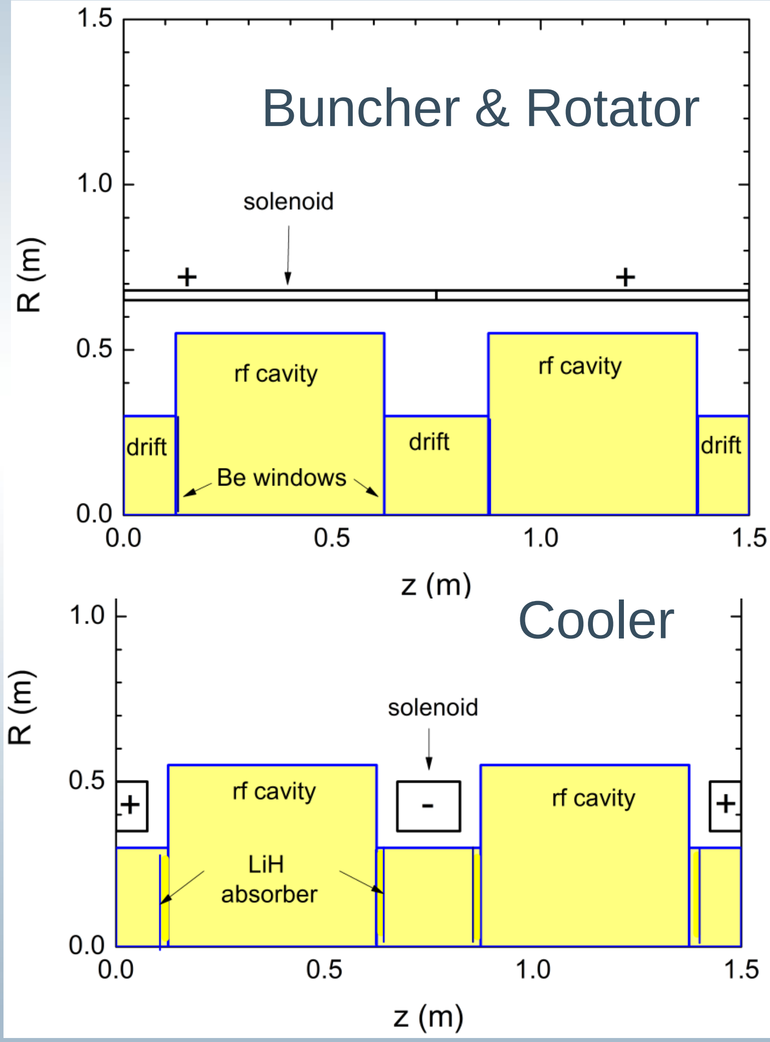
- π capture in a 20T solenoid
- Drift and π→μ
- Progressively increase rf voltage to bunch beam
- Rotate bunches – align to equal energies
- Cool the beam





IDS Front-End Baseline (April 2010)

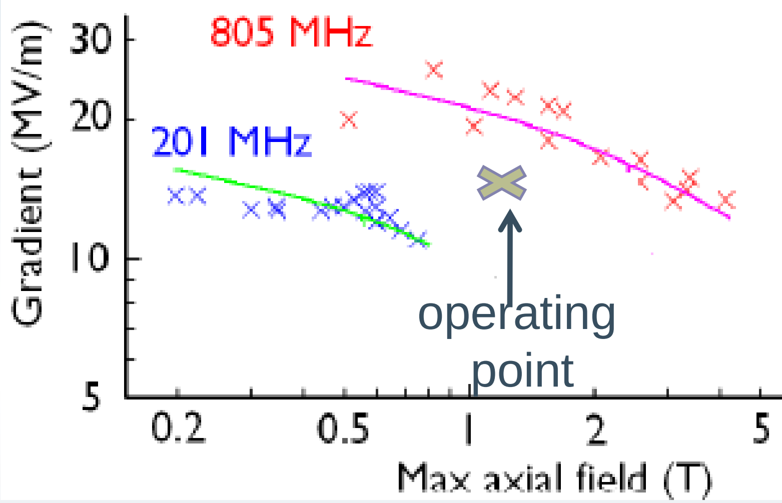
- Buncher – 33 m
  - 325 → 232 MHz
  - **B=1.5 T**, 0 → 9 MV/m
- Rotator - 42 m
  - 232 → 202 MHz
  - **B=1.5 T**, 12 MV/m
- Cooler - ~100 m
  - Ionization cooler
  - Alternating **B ±2.8 T**
  - 1.1 cm LiH, E=15MV/m



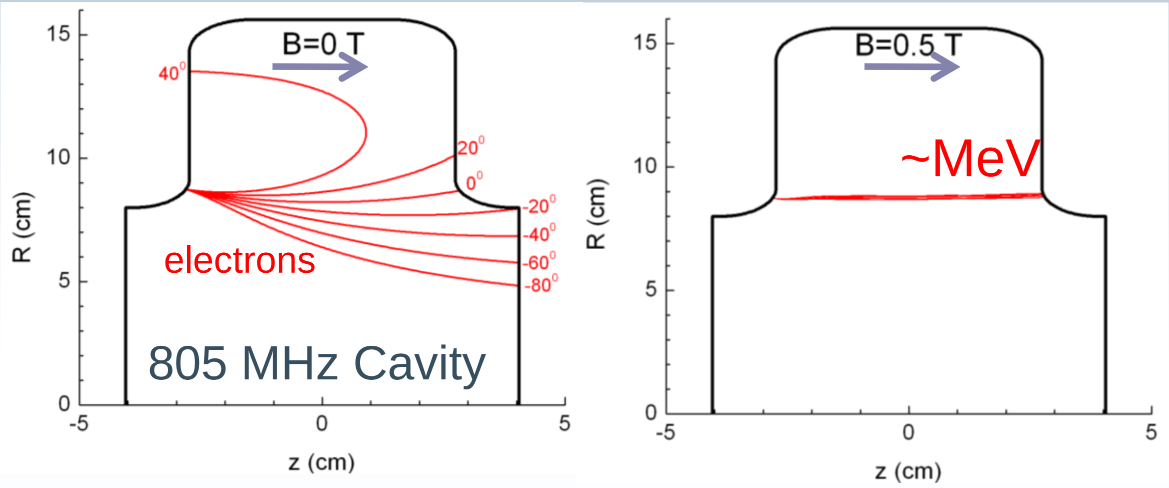
IDS Requirements: 10^{21} μ-decays/year

Motivation

- Baseline requires a 15 MV/m 201 MHz cavity to operate within 1-2 T magnetic fields
- Experimental data show that rf gradient becomes limited in B-fields
- Simulating the front-end with just 3 MV/m less gradient reduces performance by 25%!
- Can we design an alternative front-end?



Possible rf problems in B-fields



- It is likely that if field-emission can be suppressed, breakdown in B-fields may be avoided

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rf breakdown with external magnetic fields in 201 and 805 MHz cavities

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Effects of external magnetic fields on the operation of high-gradient accelerating structures

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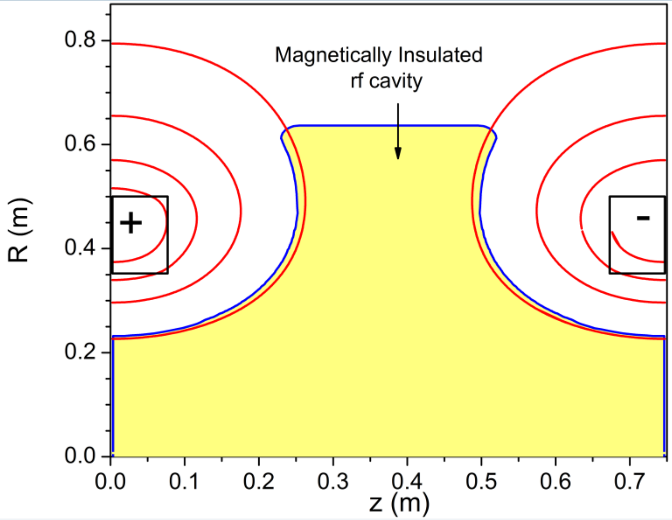
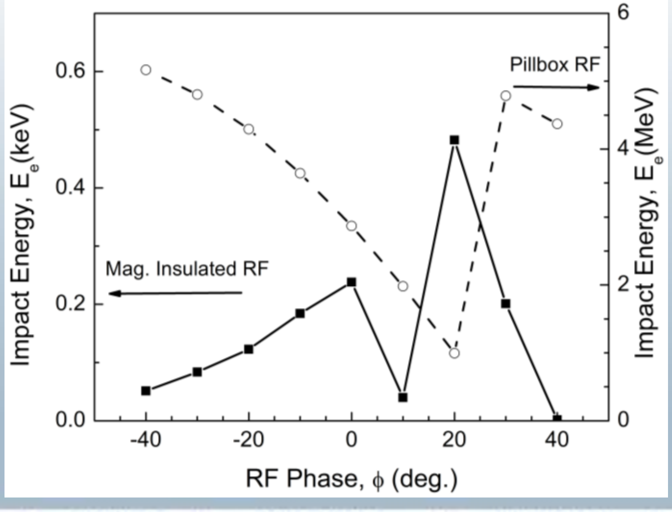
Possible Solution: Magnetic Insulation

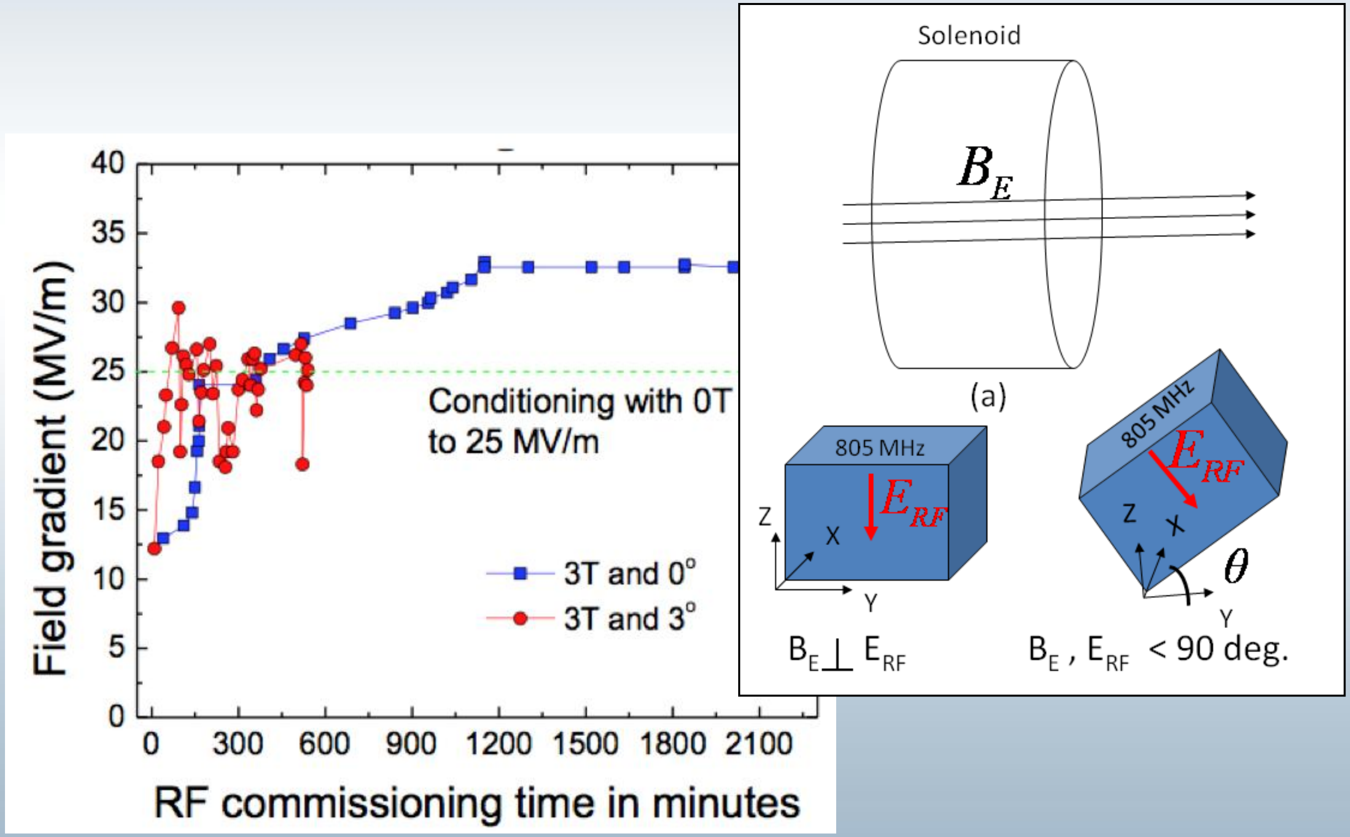
- Use of the concept for rf shielding was proposed by Palmer (Palmer et el. PRST AB 2009).
- Field-emited electrons do not move far from surface but instead come back with low energies.
- The concept has been recently experimentally tested with a box cavity at FemiLab





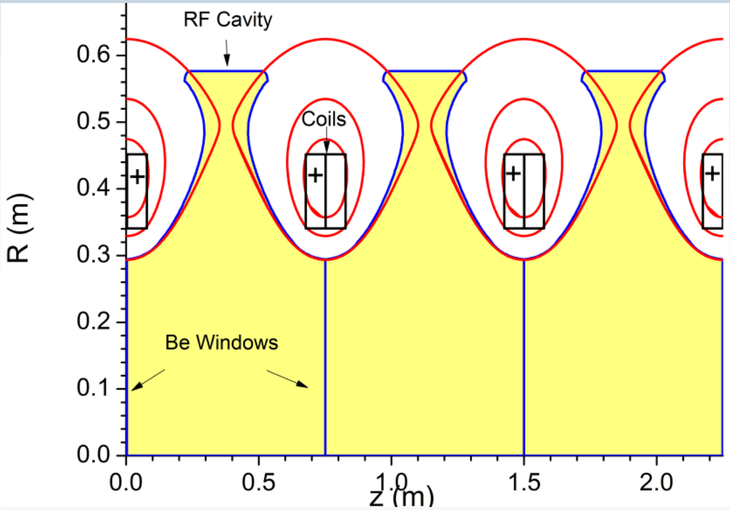
Experimental Verification of Magnetic Insulation at MTA

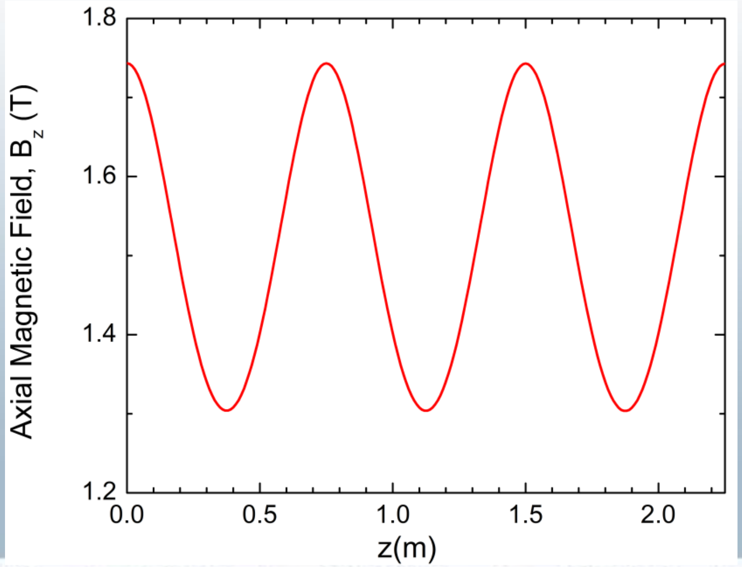
- Presented by M. Chung et al. on June 4, 2010



"Hybrid" Magnetically Insulated Buncher and Phase-Rotator

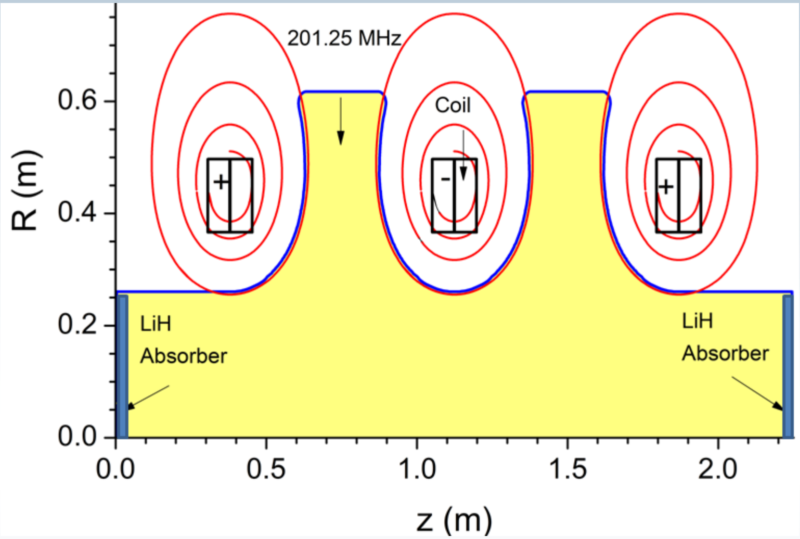
- Coils are brought closer to axis.
- Field lines become parallel to the cavity's surfaces at high-gradient locations
- Field-emission at those surfaces is suppressed
- Some concern about "unprotected" areas in Be-windows. But never saw damage in Be before.

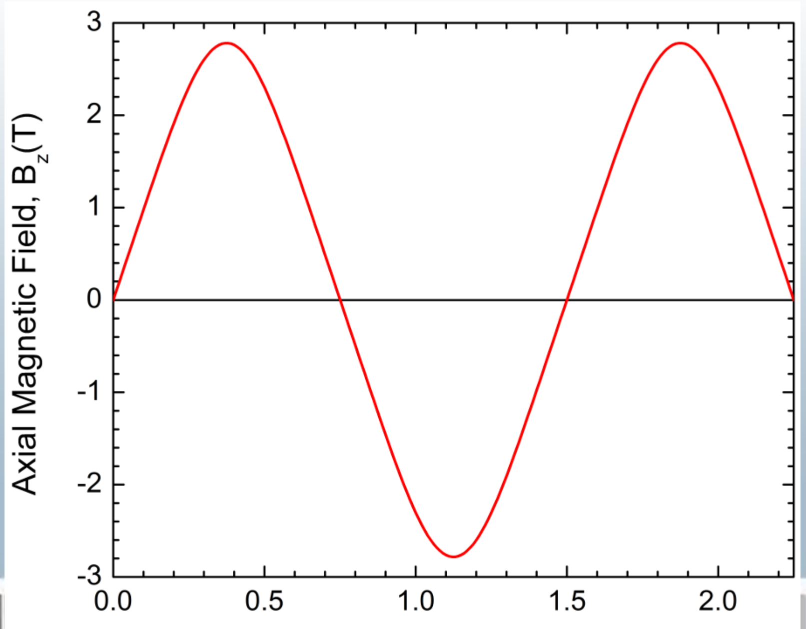




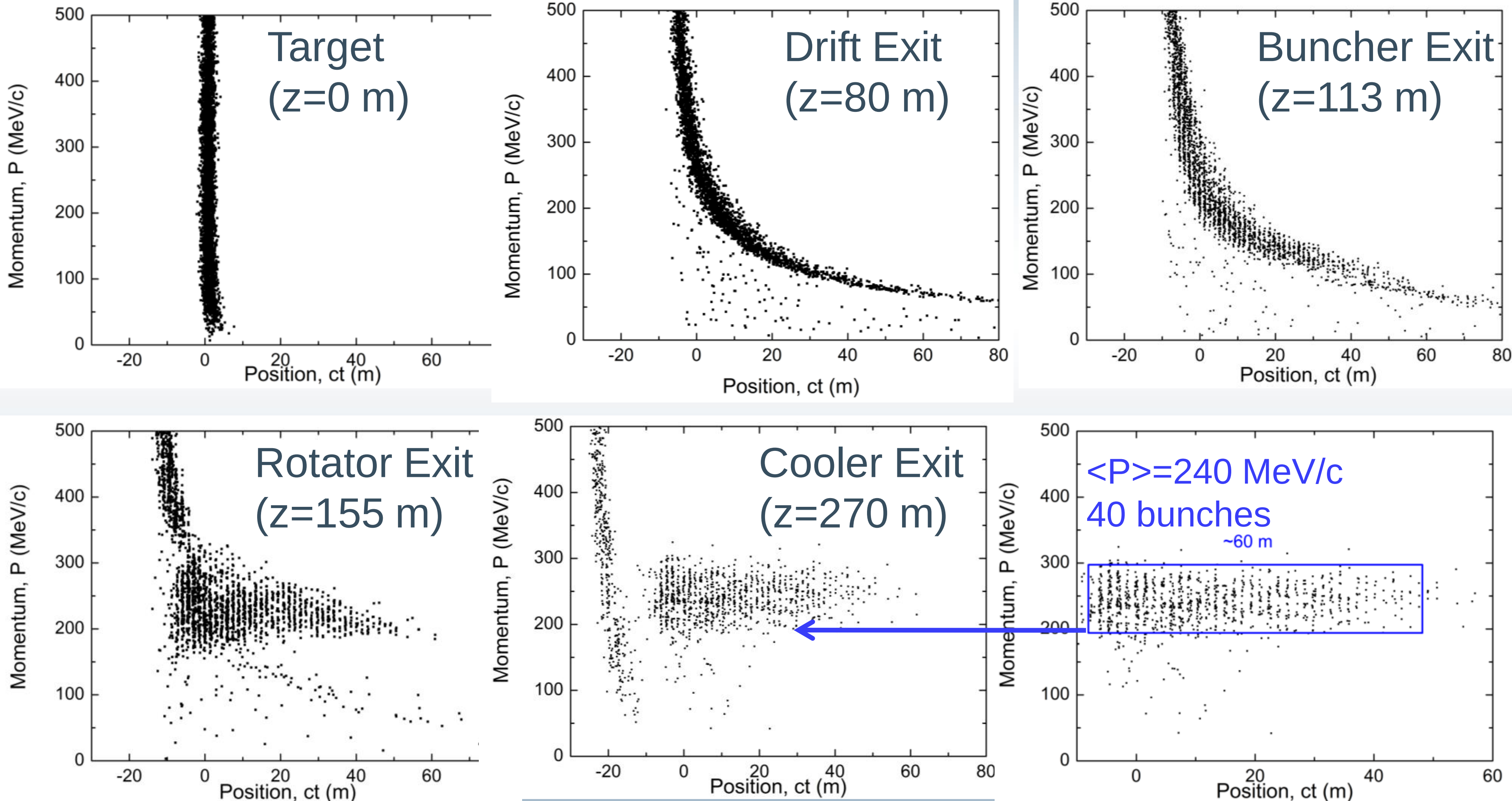
Magnetically Insulated Cooler

- As before, field-emission is suppressed at high-gradient locations
- RF cavities extended on sides, this:
  - Sets the absorber at the location where beam transverse size is minimum→ better cooling
  - Reduces fields on the cavity Be-window → less heating

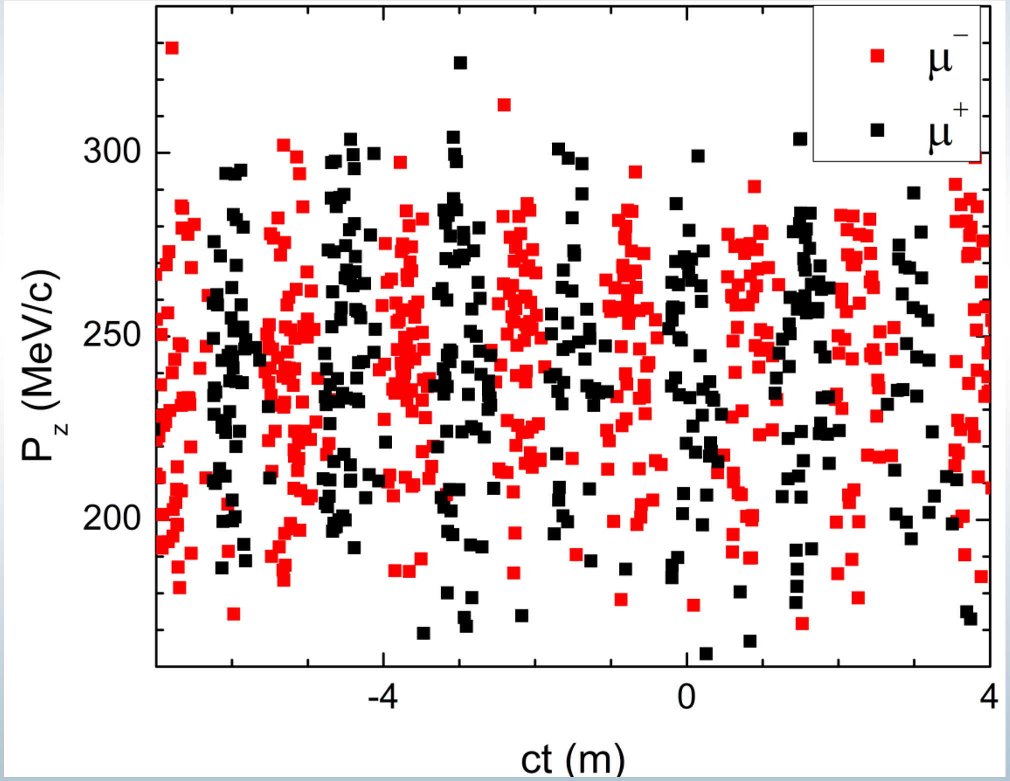




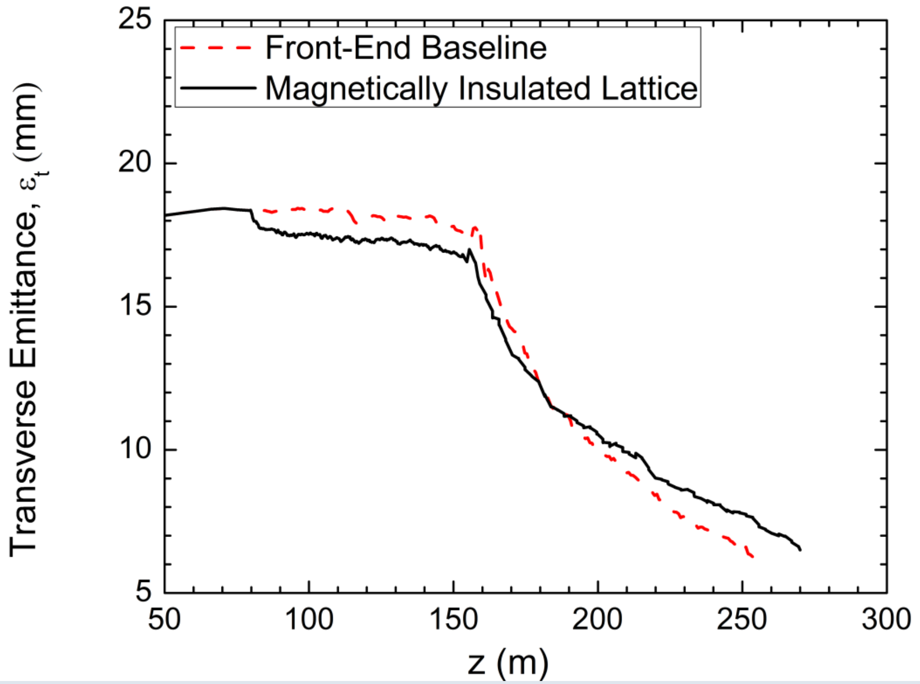
Muon Evolution in a Magnetically Insulated Front-end Channel

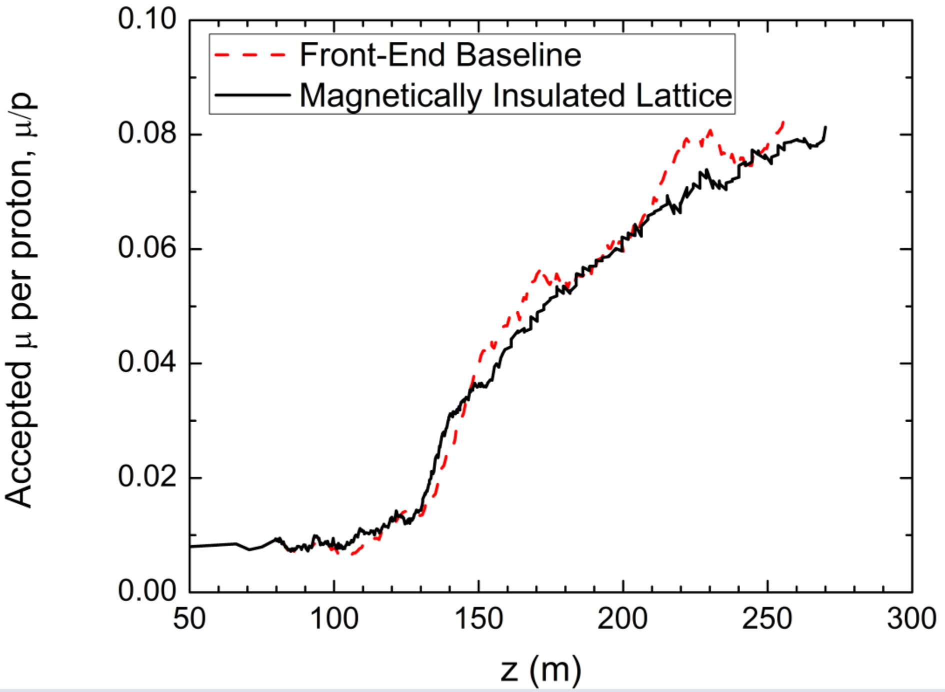


Successful Transport of both μ signs



Overall Performance





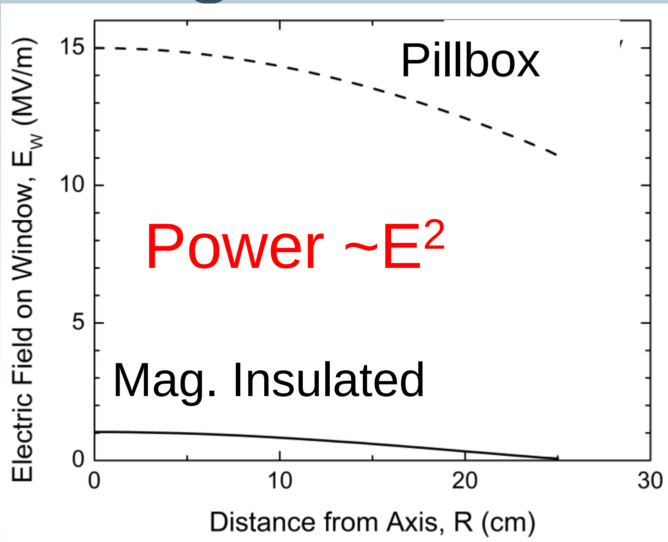
- The μ/p rate within acceptance $A_T < 30$ mm, $A_L < 150$ mm and cut in momentum 100<Pz<300 MeV/c is ~0.082
- Same performance, but the baseline may not operate well in B-fields

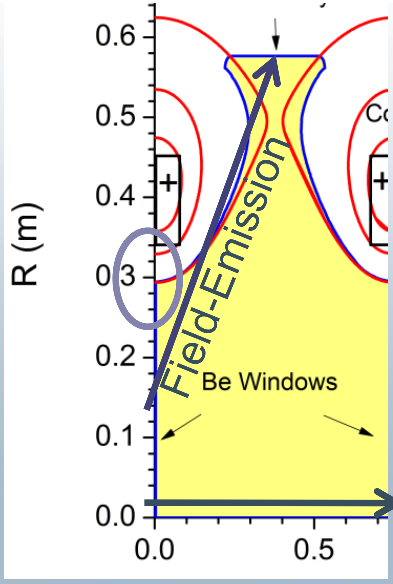
Performance Overview

	IDS Baseline	Magnetically Insulated Channel
Drift length (m)	79.6	79.6
Buncher length (m)	33.0	33.0
Buncher rf frequencies	44 freq. 320→232 MHz	15 freq. 320→232 MHz
→ Buncher rf gradient (MV/m)	0-9	0-11
Rotator length (m)	42.0	42.0
Rotator rf frequencies	56 freq. 232→202 MHz	18 freq. 232→202 MHz
→ Rotator rf gradient (MV/m)	12	14
Cooler length (m)	95	110
→ Cooler rf gradient (MV/m)	15.5	17.5
→ Accepted μ/p for 8GeV p	0.083	0.081
→ Final transverse emittance (mm)	6.3	6.5
rf Be windows buncher\ rotator	200 μm\400 μm	200 μm\400 μm

Advantages & Disadvantages

- MI-channel has better cooling performance because the absorber is placed at minimum beta
- Less heating on Be-window with MI-channel because it is placed at lower rf E-field regions
- MI require more power than pillbox cavities and this can be expensive
- We offer a “hybrid” insulation for rotator & buncher.





There is a lot room for further studies!

Summary

- Baseline for the neutrino factory requires a gradient of 15 MV/m in 1.5 T
- Experiments showed rf gradient limitations when they operate within B-fields.
- An alternative option with magnetically insulated cavity was proposed
- The lattice satisfies the ISS baseline requirements (for cooling and accepted μ/p)
- **We need more studies on lattice optimization, tolerances and power consumption**