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

D. Stratakis, J. C. Gallardo, R. C. Fernow, R. B. Palmer
Brookhaven National Laboratory
D. Neuffer
Fermi National Accelerator Laboratory

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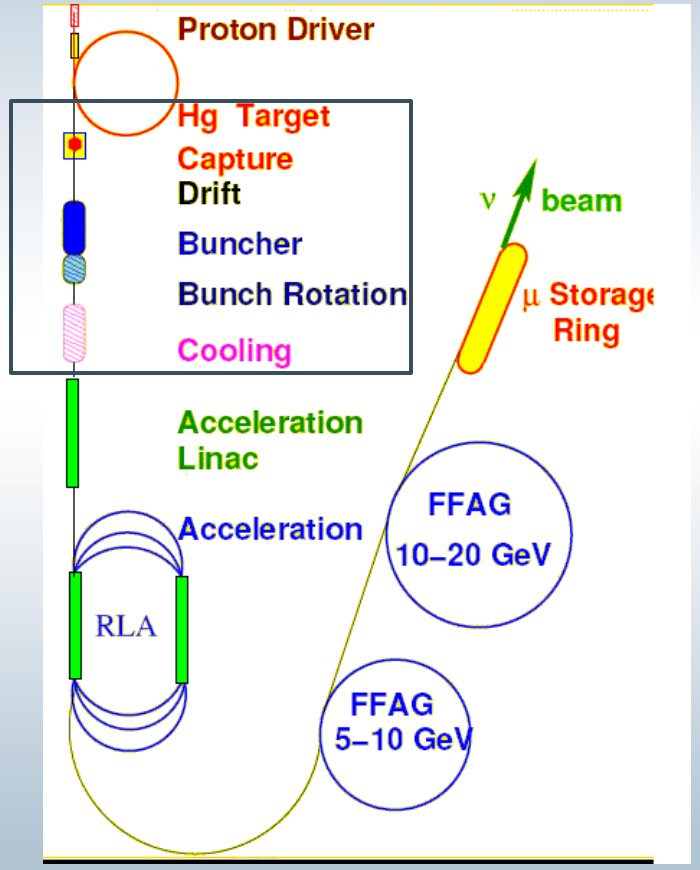
Outline

- 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

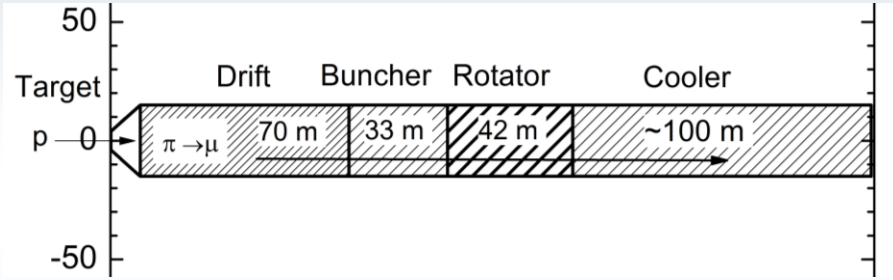
- Proton Driver
  - ~8 GeV protons
- Target, π Capture
  - π→μ
- Drift/Buncher/Rotator/Cooler
  - μ transport and cooling
- Acceleration
  - Linac, RLAs, FFAG
- Storage & decay ring
- Detectors



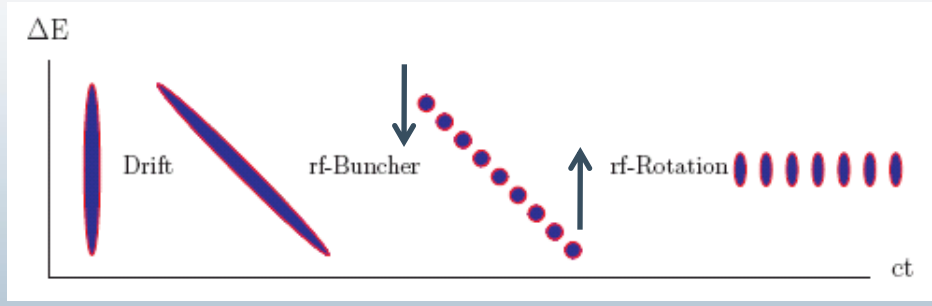
- Front-end costs ~1/3 -> Need to be studied carefully!

Front-End (FE) Channel

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

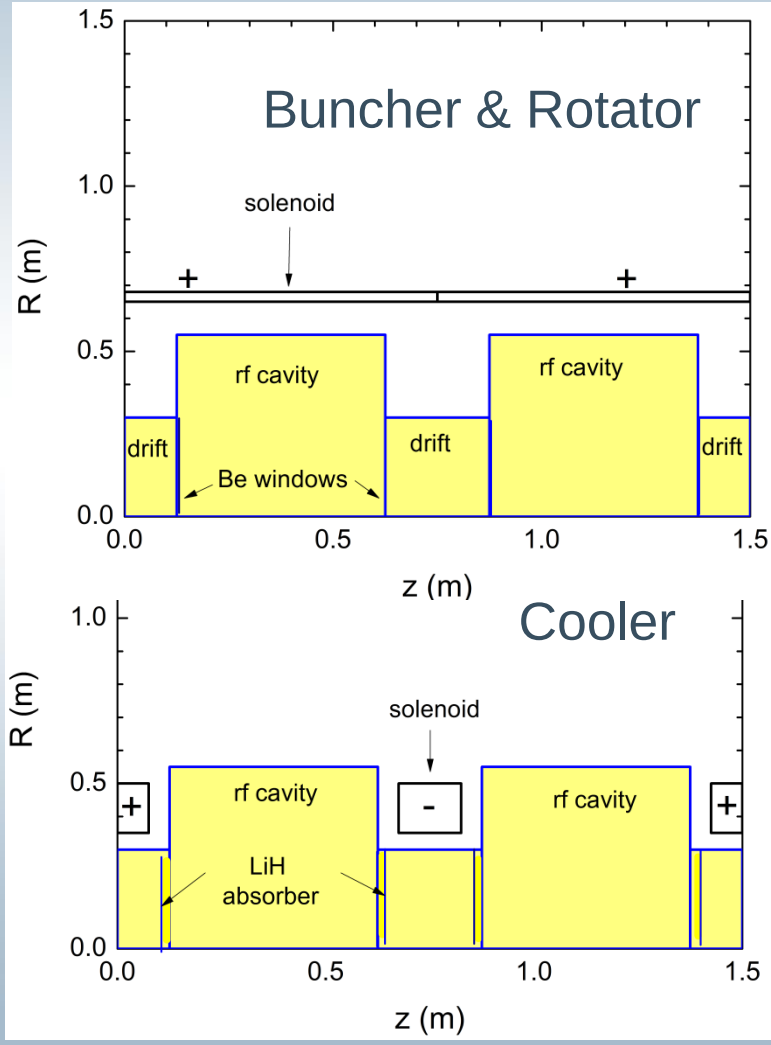


- π capture in a 20T solenoid
- Drift and π⟶μ
- Progressively increase rf voltage to bunch beam
- Rotate bunches – align to equal energies
- Cool the beam



IDS Front-End Baseline (April 2010)

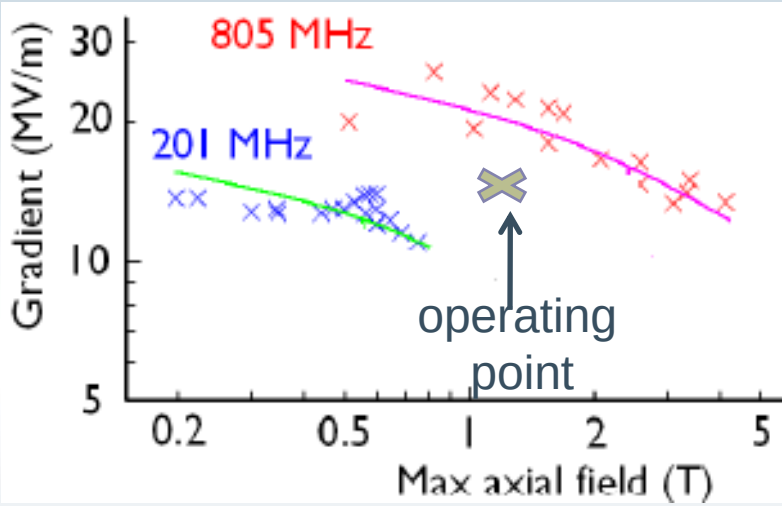
- Buncher – 33 m
  - 325 → 232 MHz
  - **B=1.5 T**, 0 → 9 MV/m
- Rotator - 42 m
  - 232 → 202 MHz
  - **B=1.5 T**, 12 MV/m
- Cooler - ~100 m
  - Ionization cooler
  - Alternating **B ±2.8 T**
  - 1.1 cm LiH, E=15MV/m



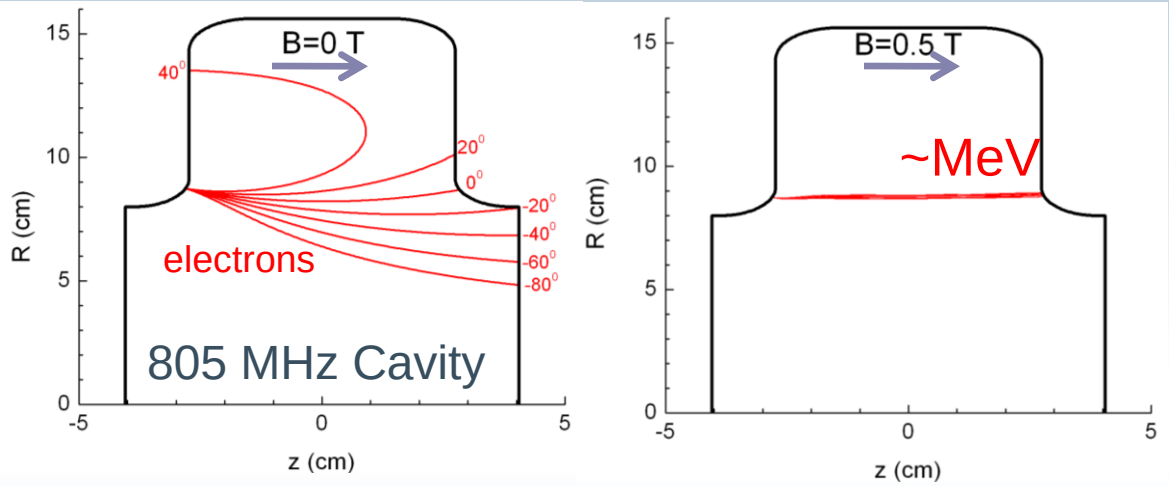
IDS Requirements: 10^{21} μ-decays/year

Motivation

- Baseline requires a 15 MV/m 201 MHz cavity to operate within 1-2 T magnetic fields
- Experimental data show a possibility that the rf gradient is reduced in B-fields
- Thus, it is uncertain if the gradient can reach the baseline parameters
- 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

R. B. Palmer, R. C. Fernow, Juan C. Gallardo, and Diktys Stratakis
Brookhaven National Laboratory, Upton, New York 11973, USA

Derun Li
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
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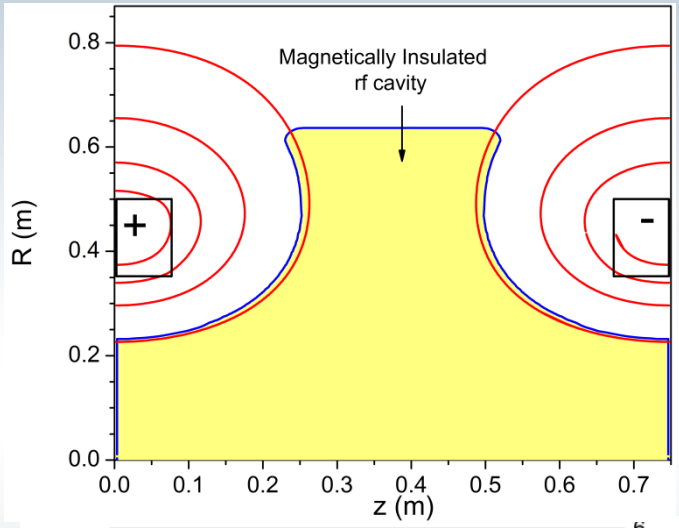
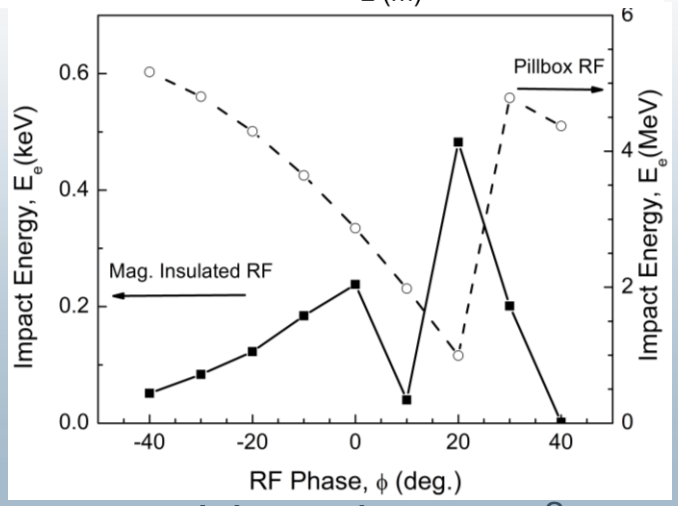
Effects of external magnetic fields on the operation of high-gradient accelerating structures

Diktys Stratakis *, Juan C. Gallardo, Robert B. Palmer

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.

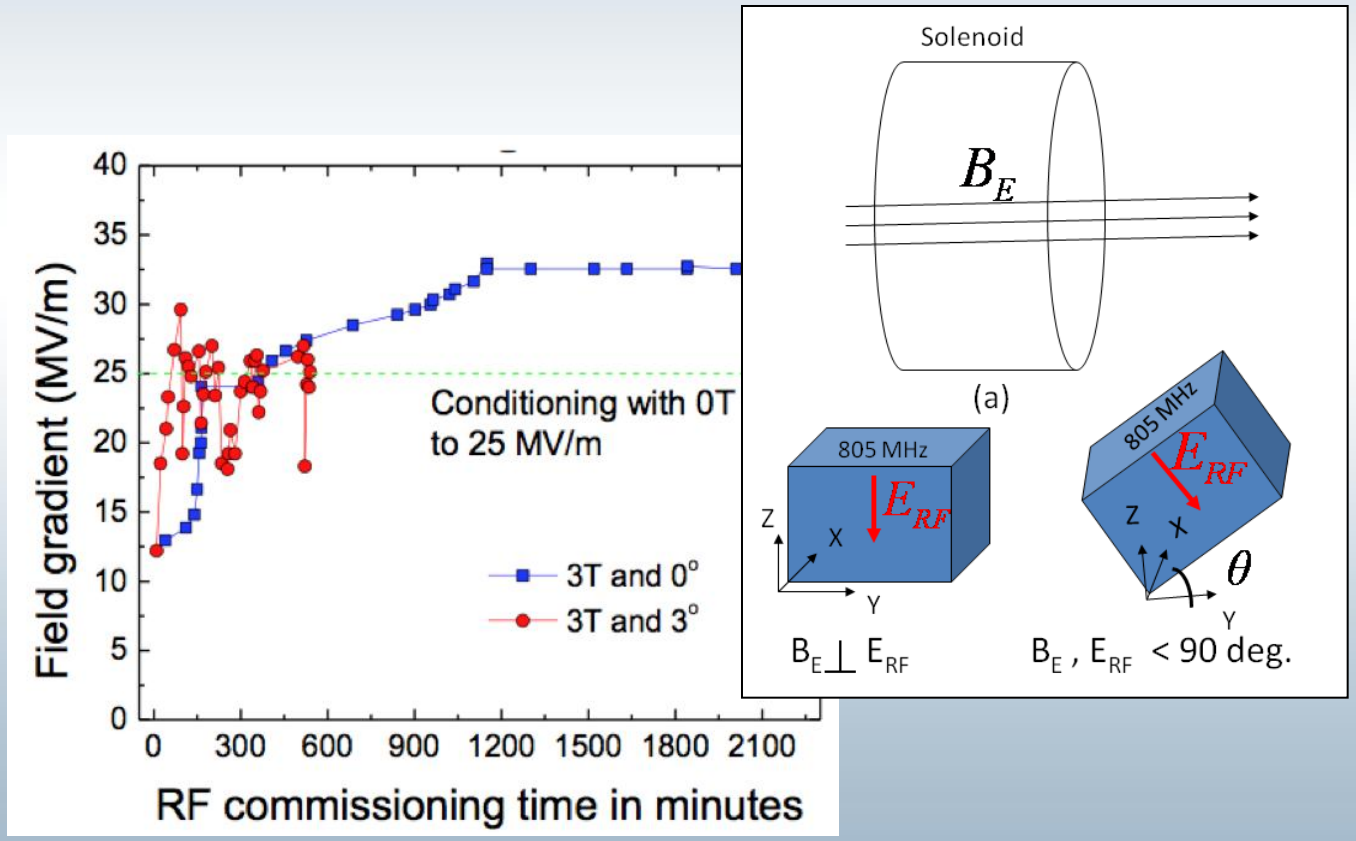




Stratakis et al: J. Phys. G: Nucl. Part. Phys., accepted (2010)

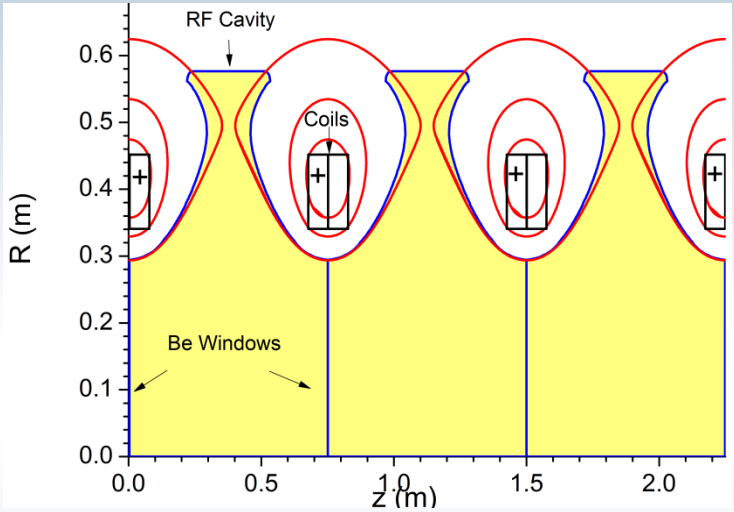
Experimental Verification of Magnetic Insulation at MTA

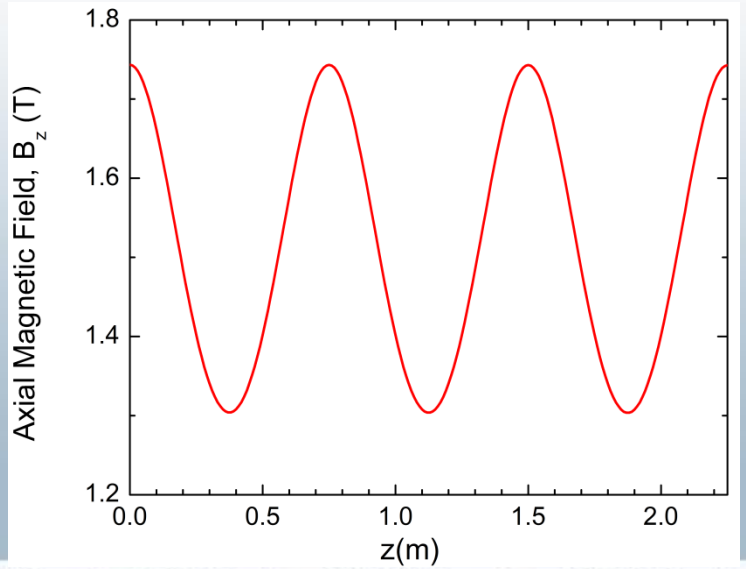
- Presented by M. Chung et al. on June 4, 2010



“Hybrid” Magnetically Insulated Buncher and Phase-Rotator

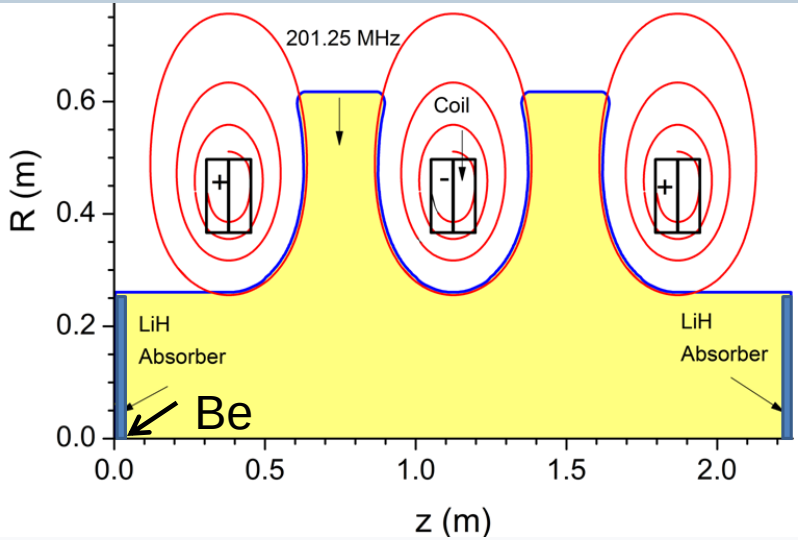
- Coils are brought closer to axis.
- Field lines become parallel to the cavity’s surfaces at high-gradient locations
- Field-emission at those surfaces is suppressed
- Some concern about “unprotected” areas in Be-windows. But never saw damage in Be before.

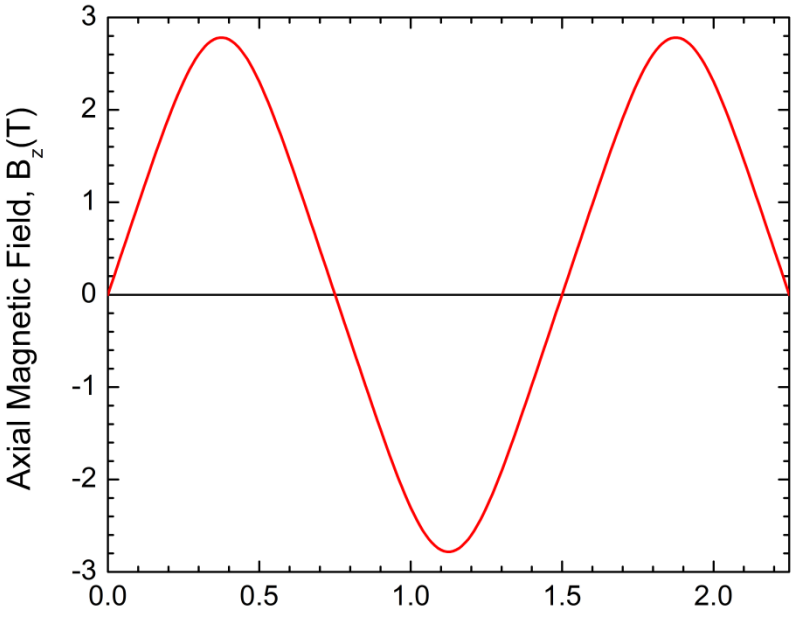




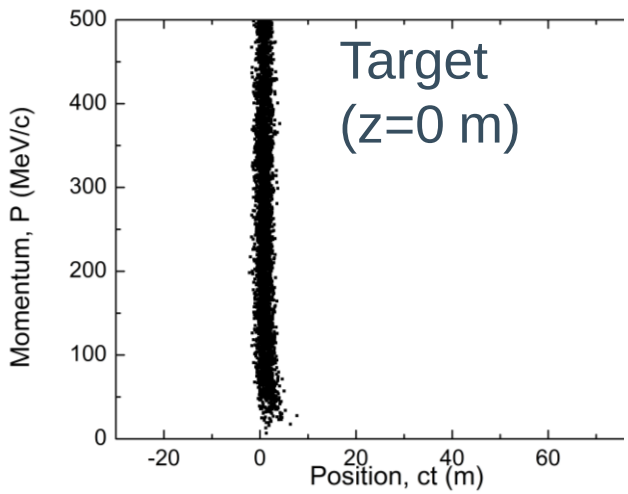
Magnetically Insulated Cooler

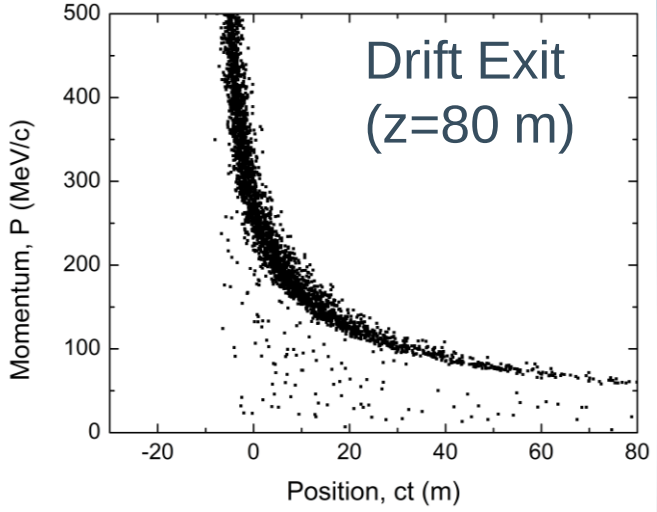
- As before, field-emission is suppressed at high-gradient locations
- RF cavities extended on sides, this:
  - Sets the absorber at the location where beam transverse size is minimum→ better cooling
  - Reduces fields on the cavity Be-window → less heating

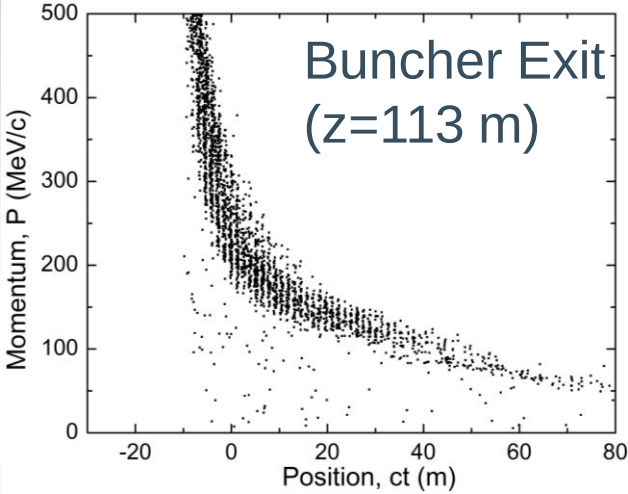


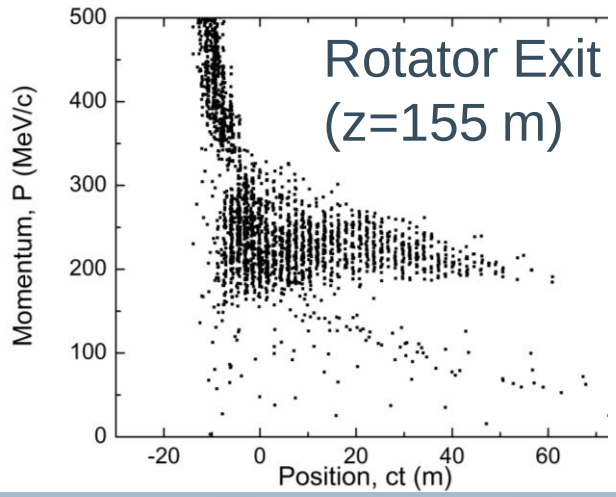


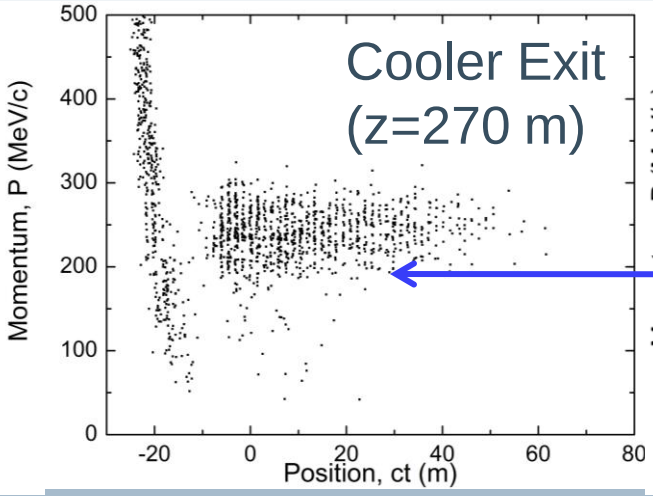
Muon Evolution in a Magnetically Insulated Front-end Channel

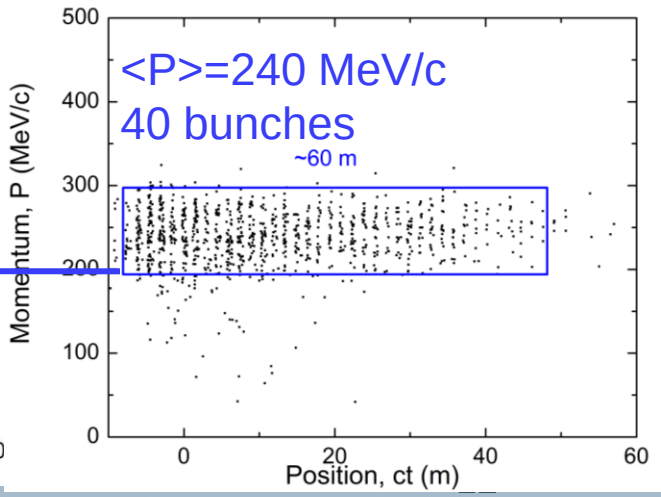




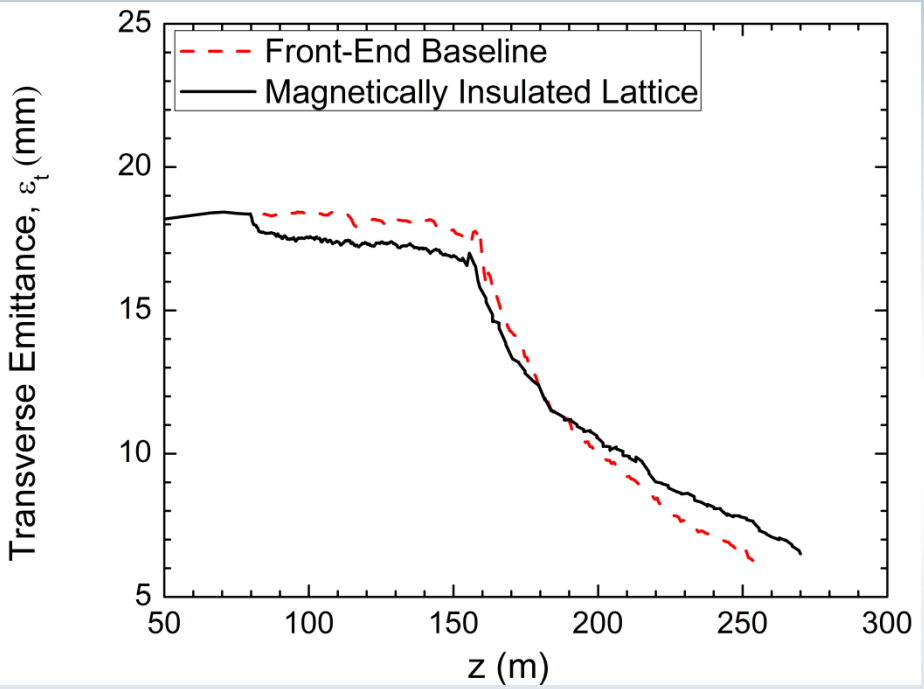


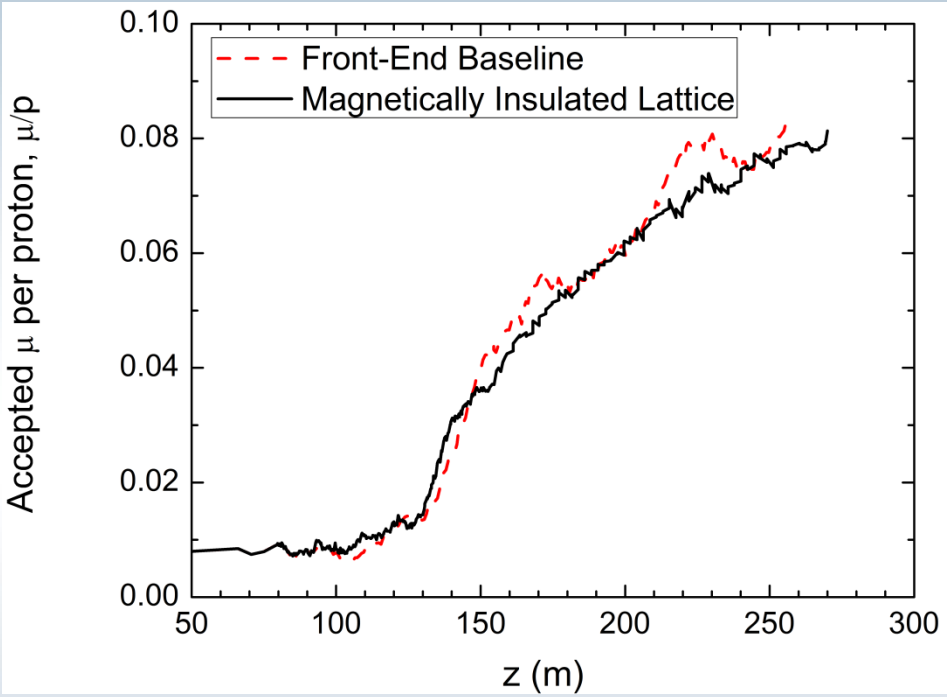






Overall Performance





- 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

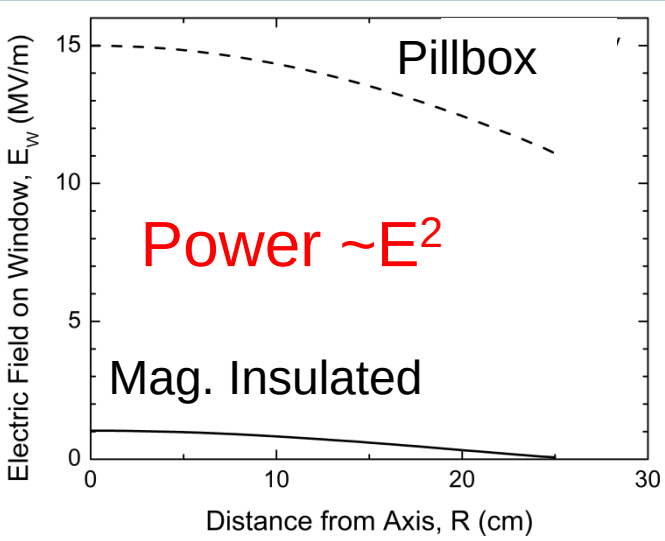
Performance Overview

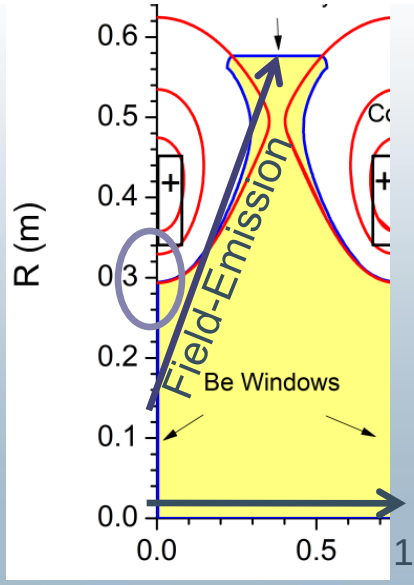
	IDS Baseline	Magnetically Insulated Channel
Drift length (m)	79.6	79.6
Buncher length (m)	33.0	33.0
Buncher rf frequencies	44 freq.	15 freq.
	320→232 MHz	320→232 MHz
Buncher rf gradient (MV/m)	0-9	0-11
Rotator length (m)	42.0	42.0
Rotator rf frequencies	56 freq.	18 freq.
	232→202 MHz	232→202 MHz
Rotator 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

Discussion

- 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**