Performance Comparison Between FSIIA and Bucked Coils for the Neutrino Factory Cooling Lattice

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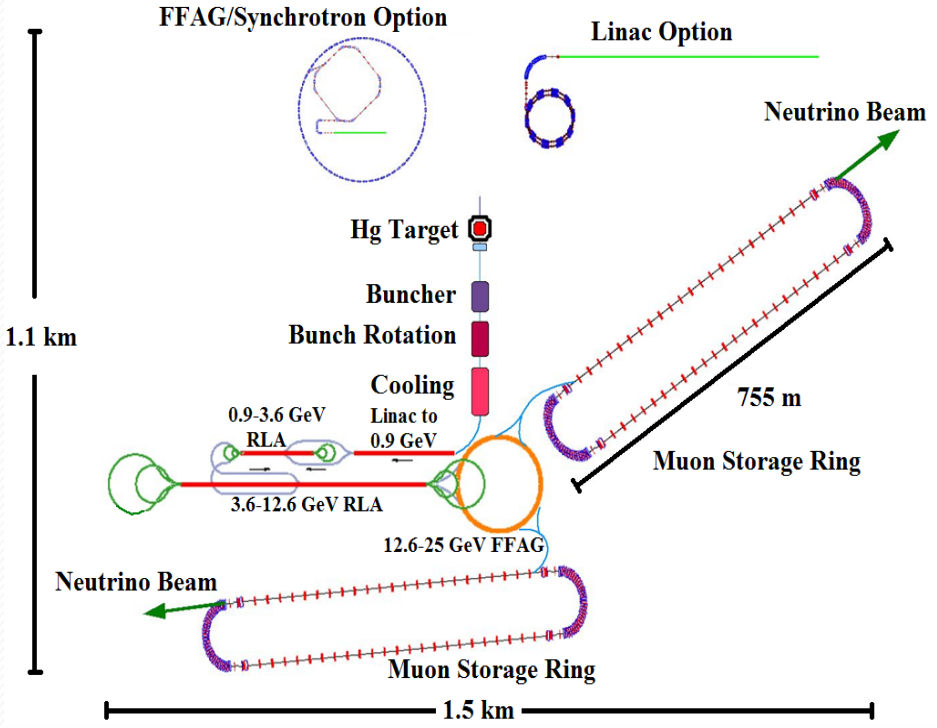
Layout

- Introduction
- Current Baseline Cooling Lattice: FSIIA
- New Alternative Lattice: Bucked Coils, BC
- FSIIA vs BC:
  - Magnetic Field
  - Cooling Dynamics & Transmission
- Towards Engineering Design
- Summary & Future Plans

Introduction (1/2)

- Neutrino Factory:
  - Proposed next generation neutrino physics facility and possibly a front-end of the Muon Collider
  - Will **produce** the most intense and high-energy **neutrino** beam ever achieved, from **stored muon decays**:

    $\mu^- \Rightarrow e^- + \bar{\nu}_e + \nu_\mu$ $\mu^+ \Rightarrow e^+ + \nu_e + \bar{\nu}_\mu$
  - Key to: discover leptonic CP violation, mass hierarchy, precise determination of mixing parameters



Neutrino Factory Layout

Introduction (2/2)

BUT

- Muon beam produced at Neutrino Factory has large initial emittance which needs to be reduced (***cooled***)
- Muons life-time very short (~2.2 μs)

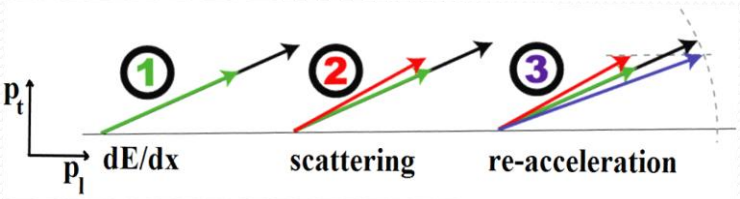
SO

Only viable technique for muon emittance reduction:
Ionization Cooling

Ionization Cooling:

- Muon momentum decreases in **every direction** by ionising **absorber**'s material
- Momentum is restored **only longitudinally** when beam passes through **RF** cavities

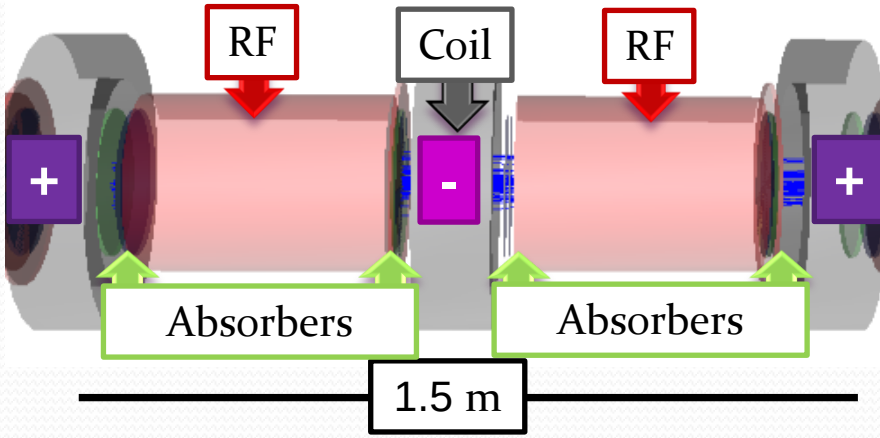
Transverse phase-space reduced



Current Baseline Cooling Channel: FSIIA

FSIIA: Feasibility Study IIA

- Coil-LiH absorber-RF-LiH absorber
- Coil's polarity alternates with every repeat
- Good transmission & emittance reduction



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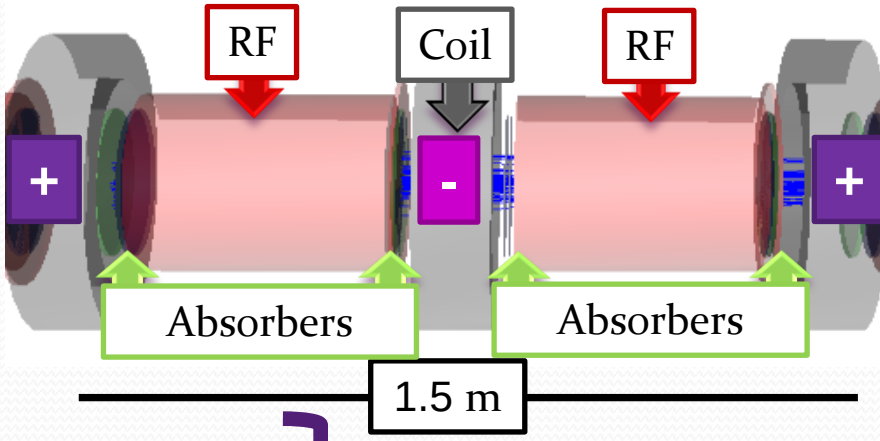
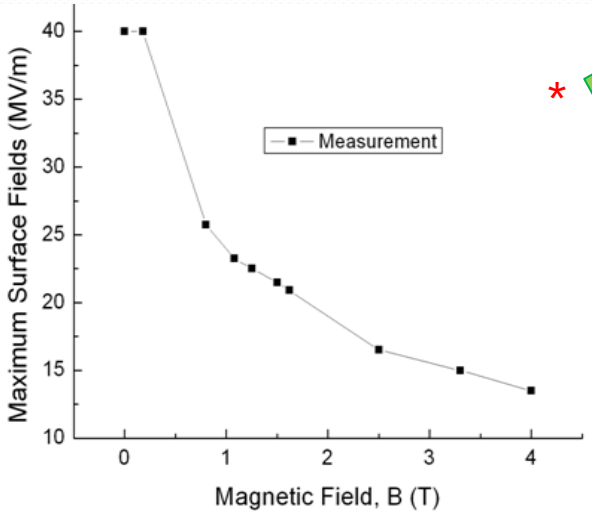


- Coil-LiH absorber-RF-LiH absorber
- Coil's polarity alternates with every repeat
- Good transmission & emittance reduction

BUT

- Recent studies indicate RF performance may be limited when external magnetic field is applied
- **FSIIA has large magnetic field** at RF position(**>4 T**)

Feasibility of FSIIA is questioned!



SO

We are searching for a new solution mitigating the RF breakdown by lowering the magnetic field at the RF cavities while also keeping good transmission and cooling performance

*"Effects of high solenoidal magnetic fields on rf accelerating cavities", A. Moretti, et. al, Physical Review Special Topics - Accelerators and Beams 8, 072001

New Alternative Lattice: Bucked Coils, BC

- The magnetic field at the RF cavities can be decreased by:
  - Increasing cell's length
  - Using **Bucked Coils**:
    - Pair of different radius & opposite polarity coils
    - The pair of coils is placed at the same position along the beam axis (homocentric coils)

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    - Pair of different radius & opposite polarity coils
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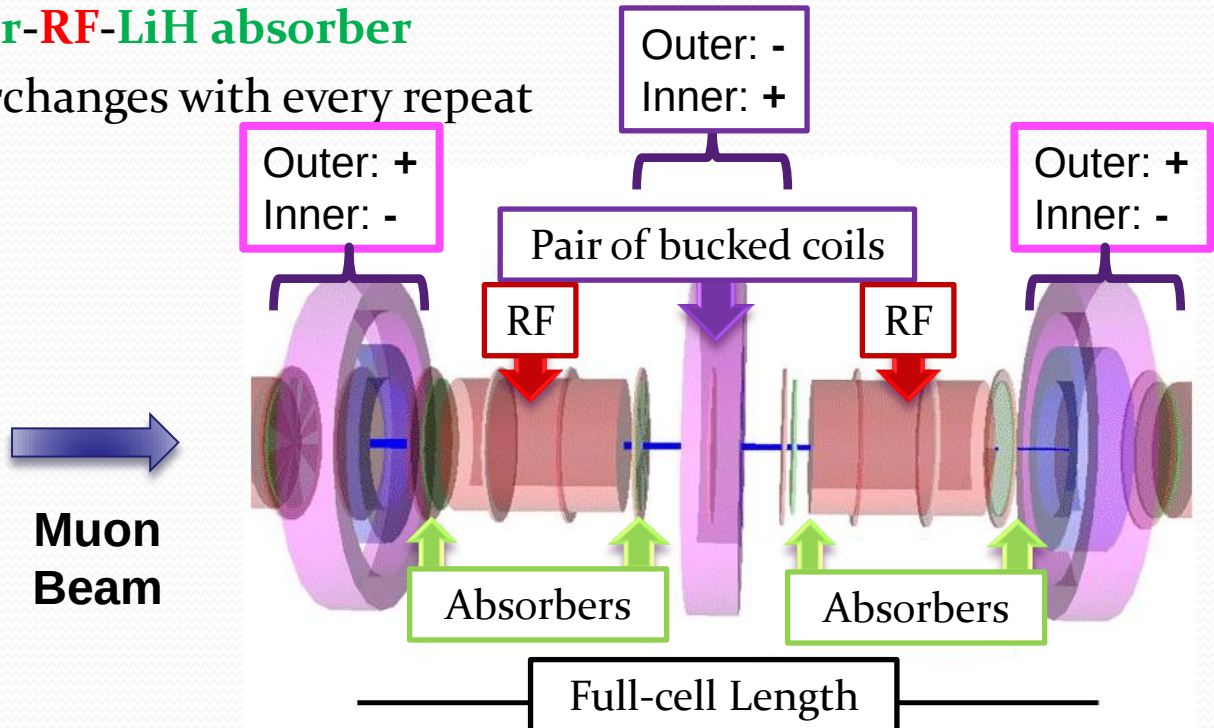
- BC configuration:
  - **PairOfCoils-LiH absorber-RF-LiH absorber**
  - **PairOfCoils**' polarity interchanges with every repeat

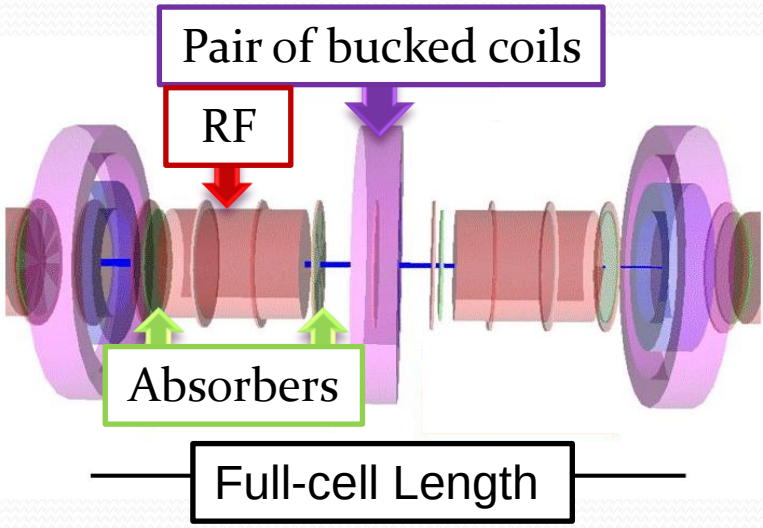


New Alternative Lattice: Bucked Coils, BC

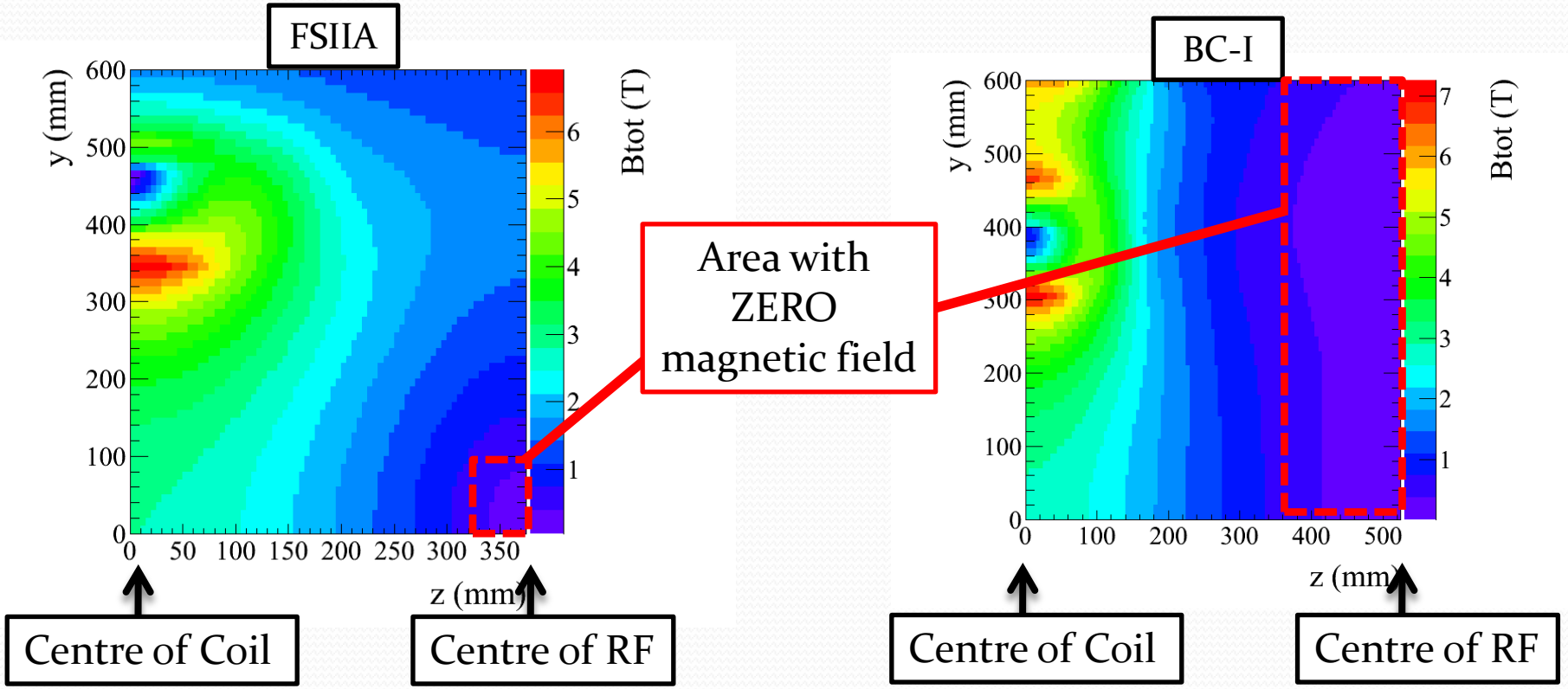
- Three different versions: BC-I, -II, -III
- BC-I, -II, -III: same configurations except for:
  - Full-cell's length
  - Current densities of inner-outer coils

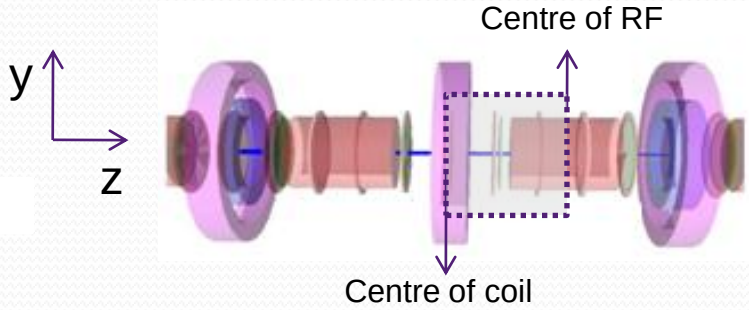
Differences of the BC versions

Lattice	BC-I	BC-II	BC-III
Full-cell Length (m)	2.10	1.80	1.80
Inner Coil Current Density (A/mm²)	90.24	128.10	99.26
Outer Coil Current Density (A/mm²)	120.00	112.80	132.00

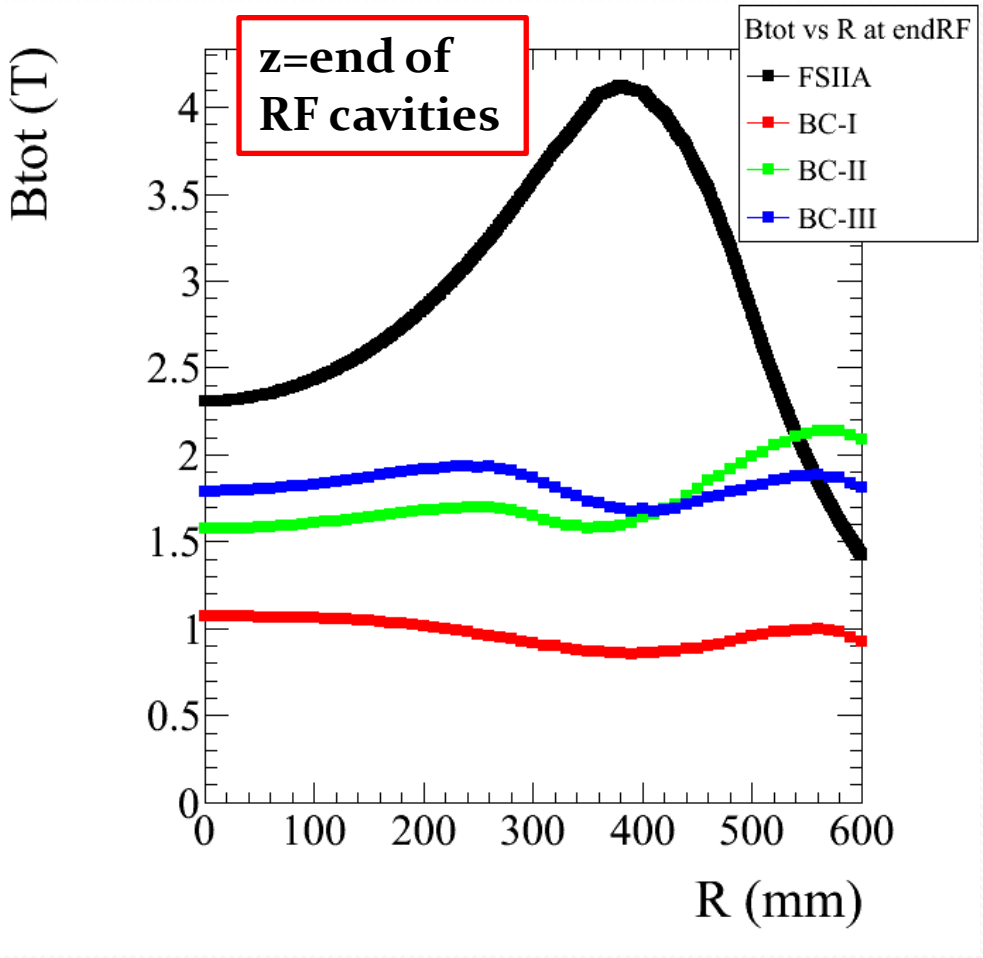


FSIIA vs BC: Magnetic Field



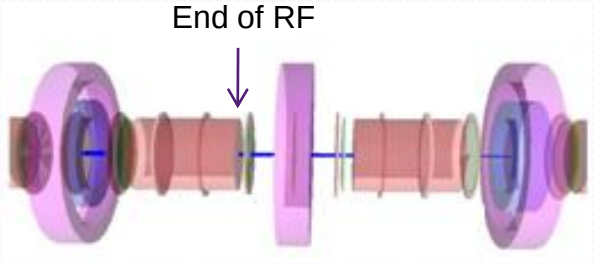


FSIIA vs BC: Magnetic Field

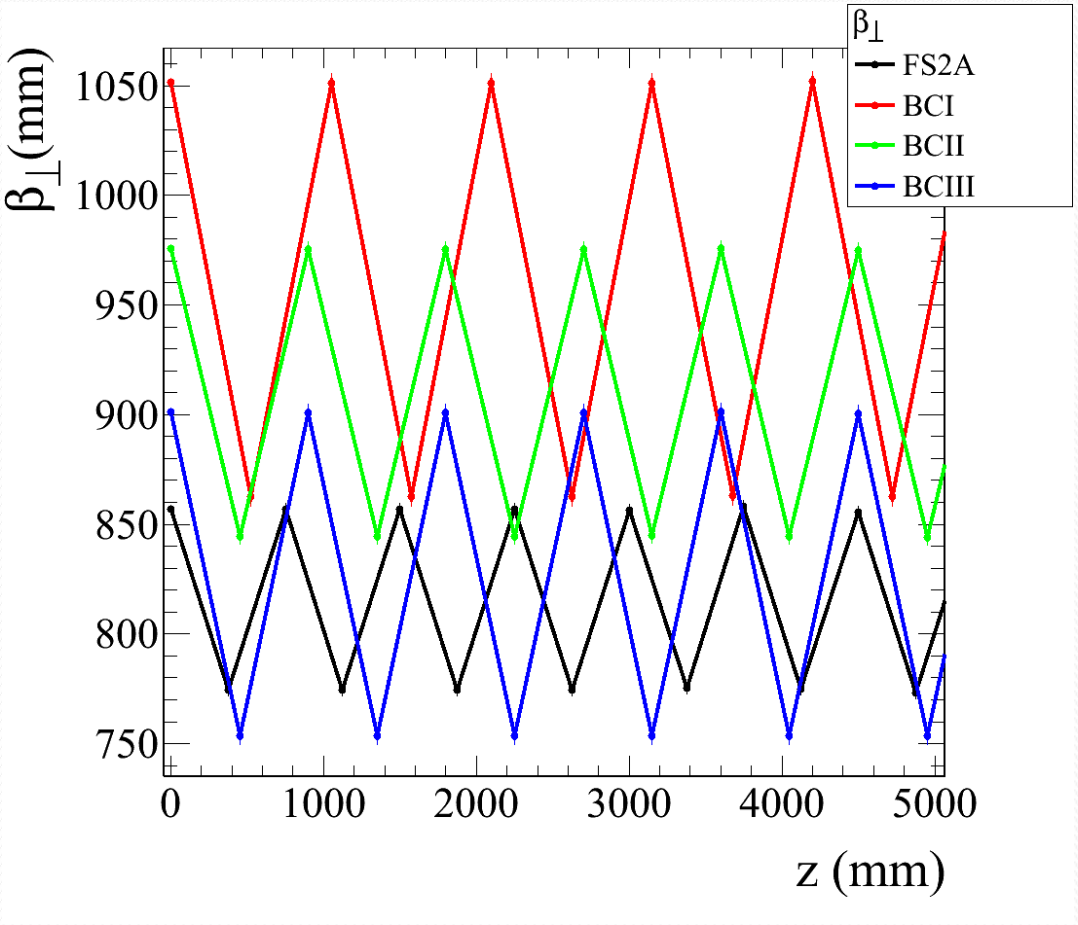


Black: FSIIA
Red: BC-I
Green: BC-II
Blue: BC-III

- **FSIIA: >4 T !!!**
- **BC-I: 4 times lower than FSIIA**
- BC-II and BC-III: 2 times lower than FSIIA



Betatron Function



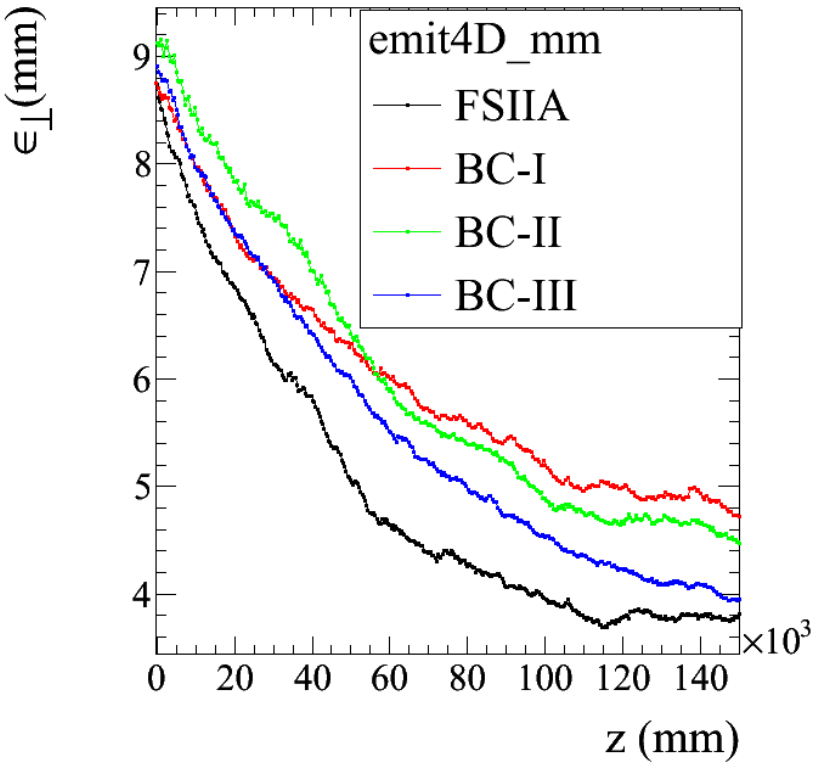
Beam initial characteristics

Lattices were compared using the same initial beam:

- Simulated using G4MICE software
- 1,000 muons
- 10 mm Transverse Emittance
- 0.07 ns Longitudinal Emittance
- P: Gaussian distribution centred at 232 MeV/c

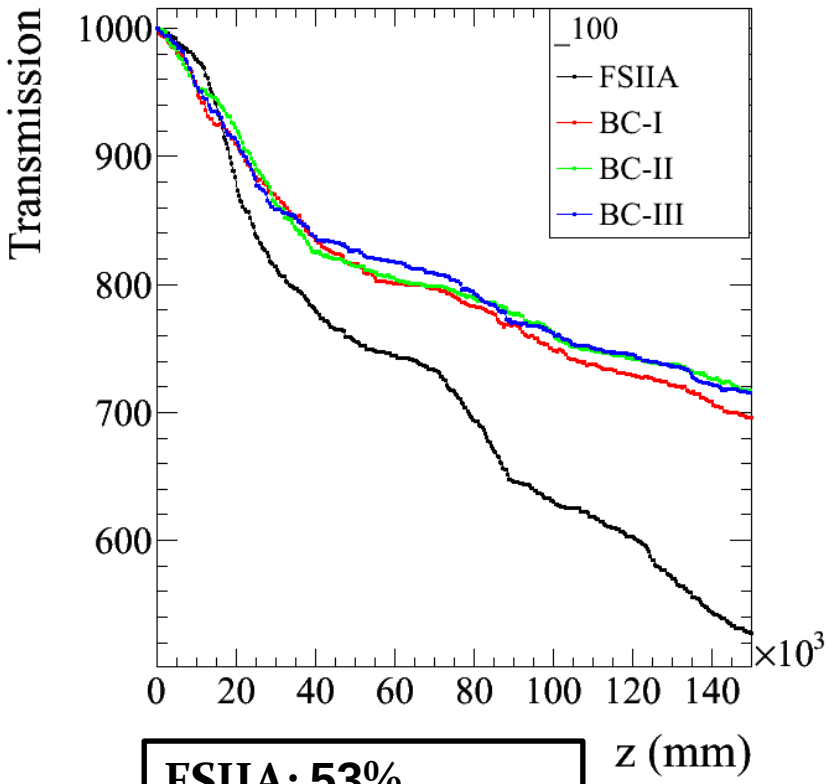
FSIIA vs BC: Cooling Dynamics & Transmission

Transverse Emittance (4D)



Better cooling for FSIIA and BC-III

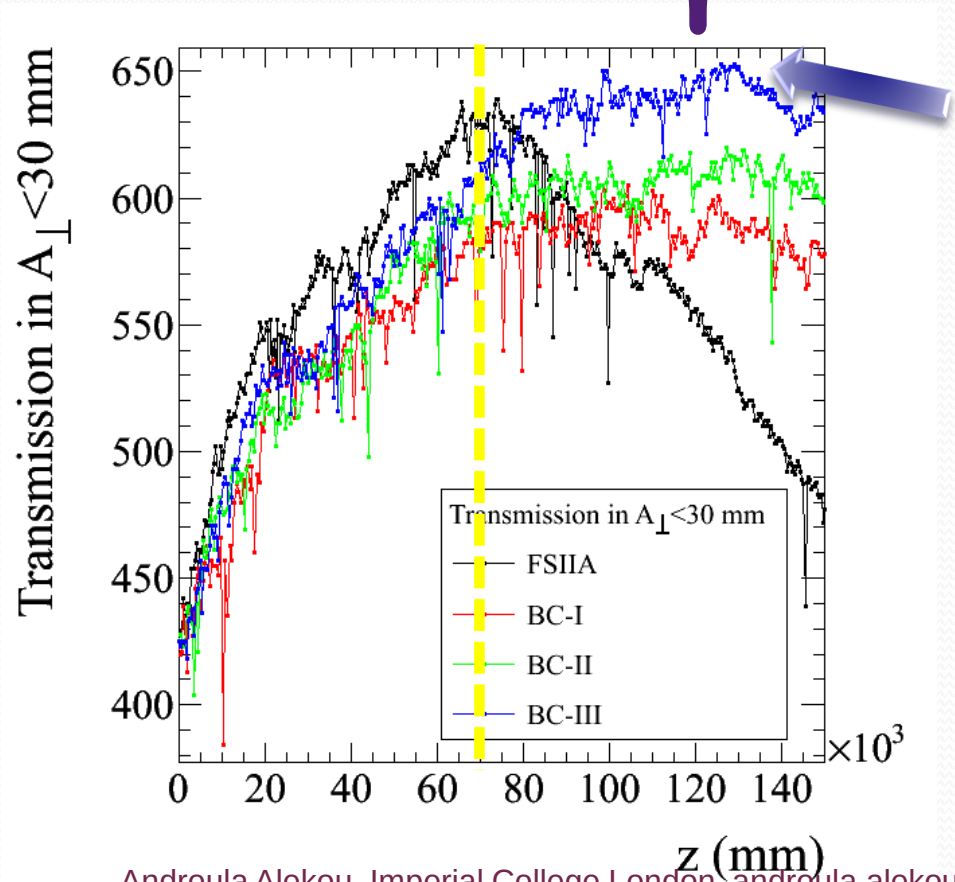
Transmission



FSIIA: 53%
BC-I: 70%
BC-II, BC-III: 72%

FSIIA vs BC: Transmission in A_T<30 mm

Emittance 4D + Transmission



- **BC-III: best transmission over all** at 120 m
- FSIIA maximum at 70 m
- **BC-I: less than 4% lower transmission than FSIIA at 70 m (BC-II and BC-III less than 3%)**

Towards Engineering Design

- We started looking into the Hoops Stress of Bucked Coils→ Larger than FSIIA but within technological limits!
- Superconducting design: BC's look feasible with Nb-Ti
- Still more studies needed including realistic beam losses that could deposit energy into the coils

Summary

- **FSIIA:**
  - Current Neutrino Factory baseline cooling channel
  - Good transmission and transverse emittance reduction
  - Large magnetic field at RF position

BUT

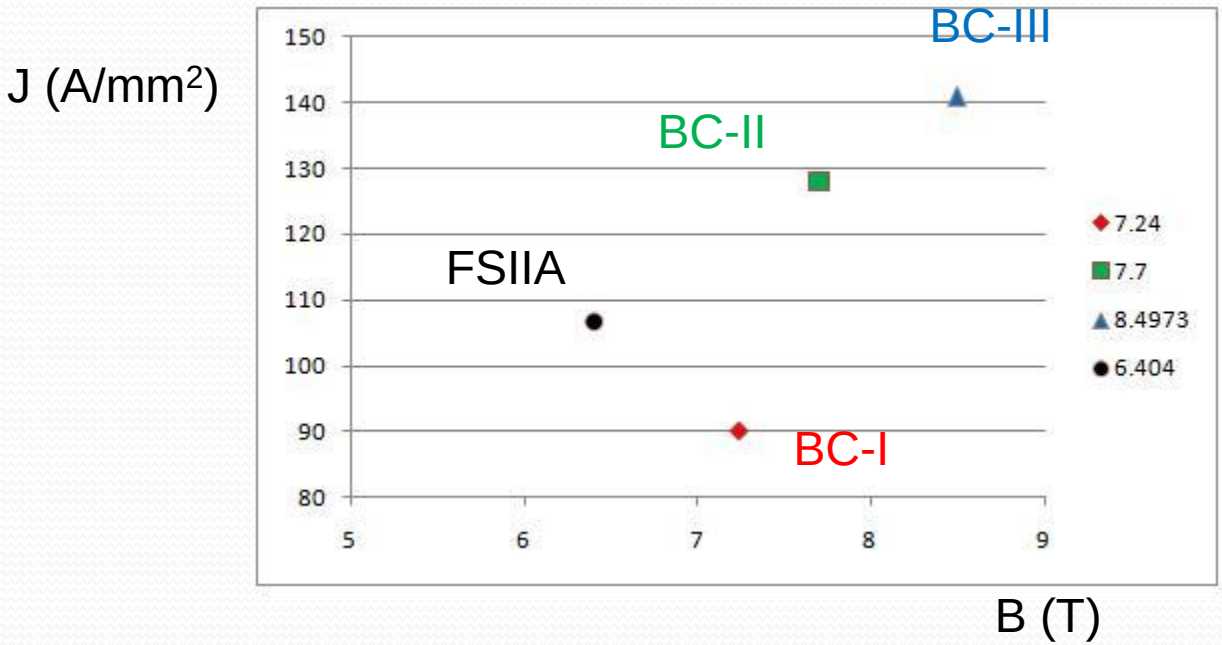
- Recent studies indicate RF performance can be limited when external magnetic field applied→ **Is FSIIA feasible?**
- **Bucked Coils (BC):**
  - New lattices (BC-I, -II, -III), designed to reduce B at RF position
- **BC-I:**
  - **4 times lower magnetic field than FSIIA** at RF position
  - **Less than 4% smaller transmission** within 30 mm A_T than FSIIA

Future Plans

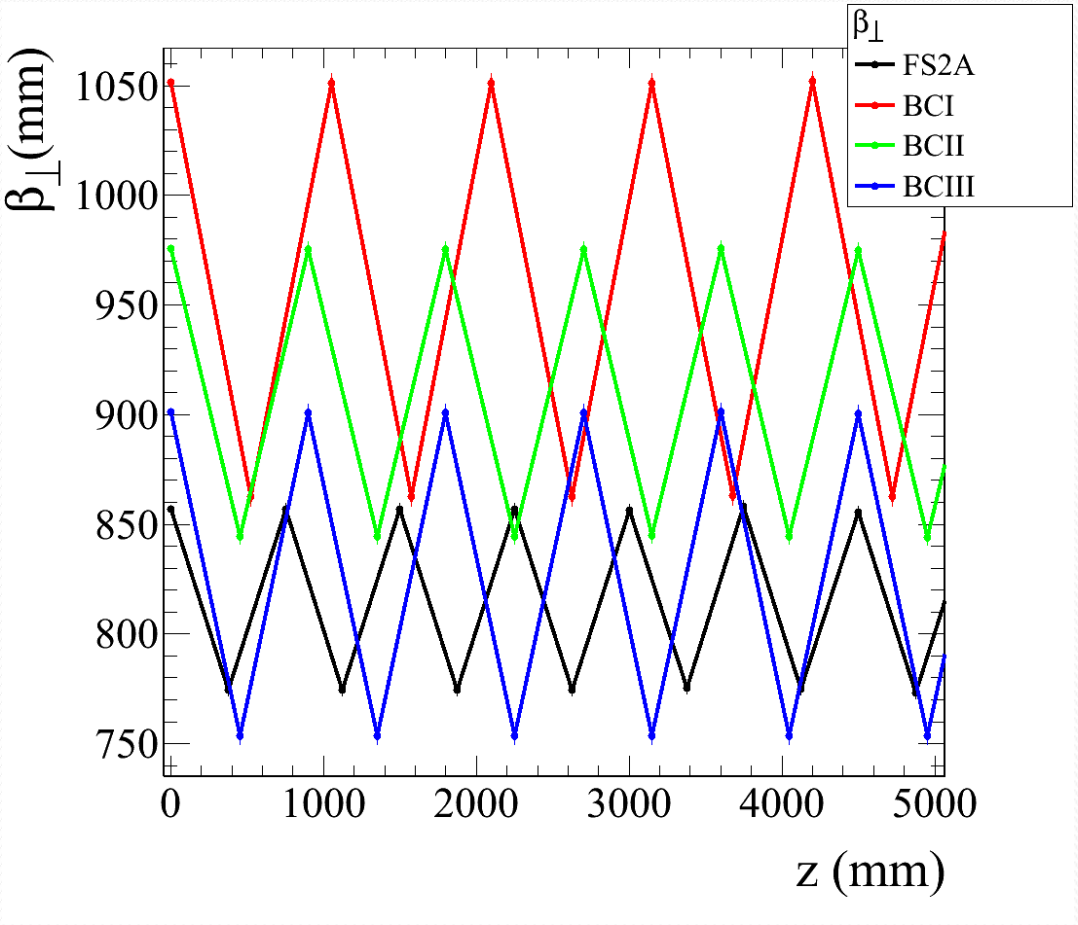
- BC optimisation: lower B & much better transmission than FSIIA
- Paper preparation

Thank you

Current Desnity vs Bmax in Cooling Lattices



Buckup



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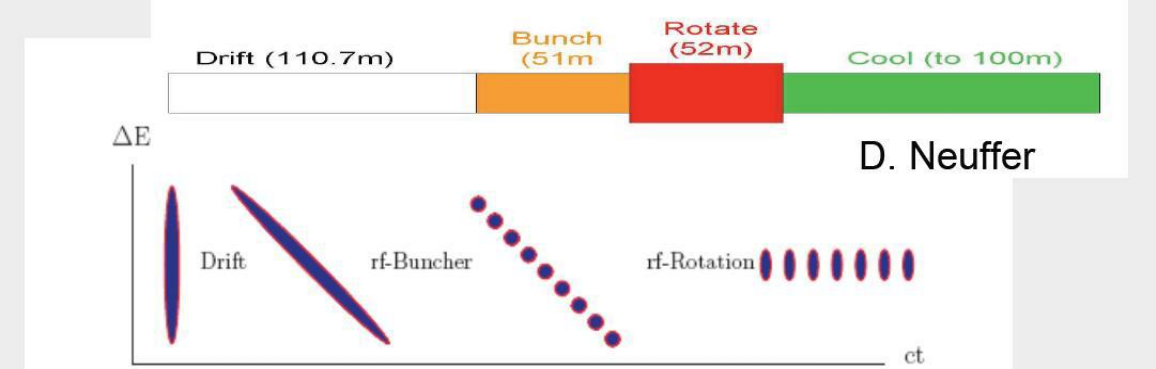

Neutrino Factory Front End

<u>Neutrino Factory Front End:</u>

1. Protons on target → Pions production
2. Drift: Pions decay to muons and bunch lengthens (high energy "head", low energy "tail")
3. Buncher: RF voltages applied to beam → string of different-energy bunches
4. Rotator: Lower energy reference particle moved to accelerating phase