Studies of Ionization Cooling Lattices for the Neutrino Factory

A. Alekou#, Imperial College London, London, U.K.
J. Pasternak, Imperial College London, London/RAL-STFC
C. Rogers, RAL ASTeC

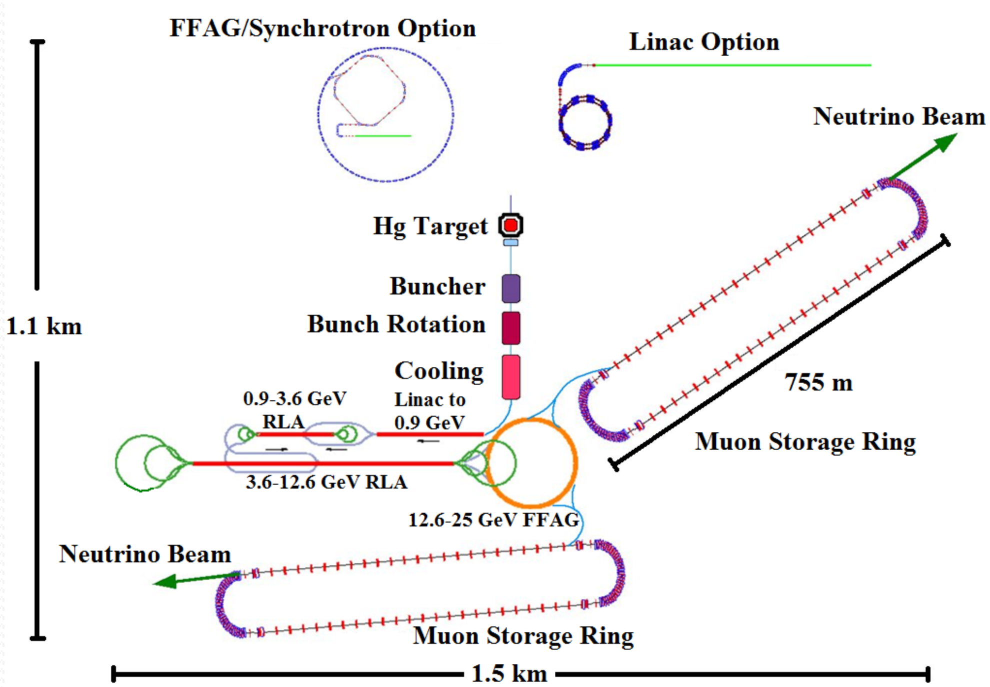
#androula.alekou08@ic.ac.uk

Layout

- Introduction
- Current Baseline Cooling Lattice, FSIIA
- Bucked Coils, BC
- Magnetic Field Comparison
- Cooling Dynamics & Transmission
- Summary & Future Plans

Introduction

- Neutrino Factory:
  - Proposed next generation neutrino physics facility and front-end of the Muon Collider
  - Will produce the most intense and high-energy neutrino beam ever achieved, from stored muon decays
  - Key to: discover leptonic CP violation, mass hierarchy, determine θ_{13}



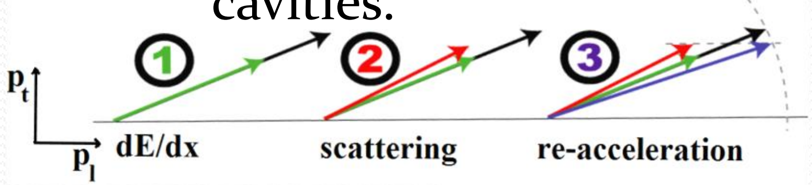
Neutrino Factory Layout

Introduction

- Muon beam produced at Neutrino Factory has <u>large initial emittance</u> which needs to be reduced (or ***cooled***)

Typical emittance: ~μm.
Neutrino Factory emittance: ~cm!!!

  - BUT muons lifetime is very short (~2.2 μs)
  - **SO the only viable technique** for emittance reduction is **ionization cooling**
  - <u>Ionization Cooling:</u>
    - muons momentum decreases in every direction by ionizing the absorber's material
    - longitudinal momentum is restored when the beam passes through RF cavities.



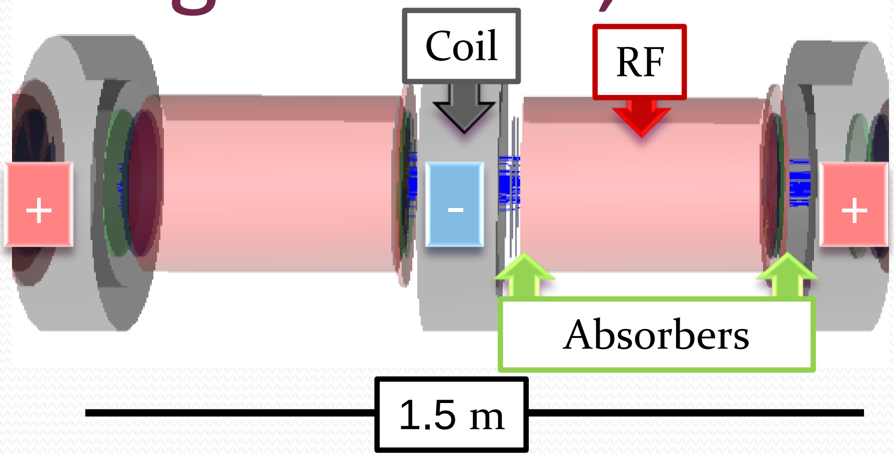
(1) (2) (3)

(1) Ionization (μ, e^- interactions)
(2) Multiple scattering (μ, nucleus)
(3) Reacceleration

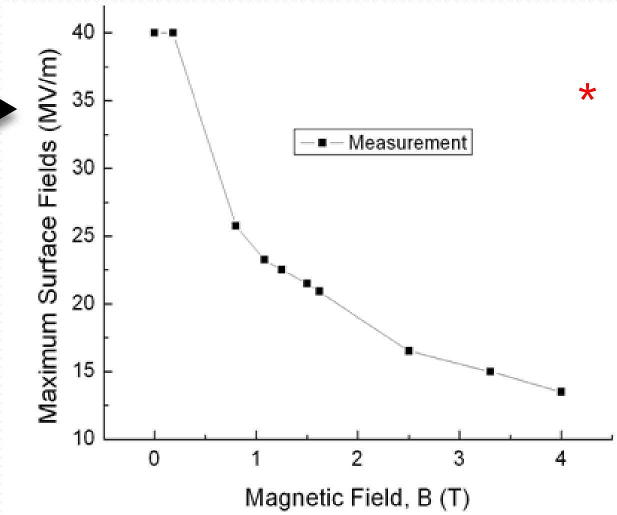
(1), (2) → Absorber
(3) → RF

Current Baseline Cooling Channel, FSIIA

- FSIIA:
  - Coil followed by an RF with a LiH absorber on each side. <u>Every coil has opposite polarity than the previous one</u>
  - *Well established, good transmission and good emittance reduction*



BUT recent studies indicate **RF performance may be limited when external magnetic field is applied** →



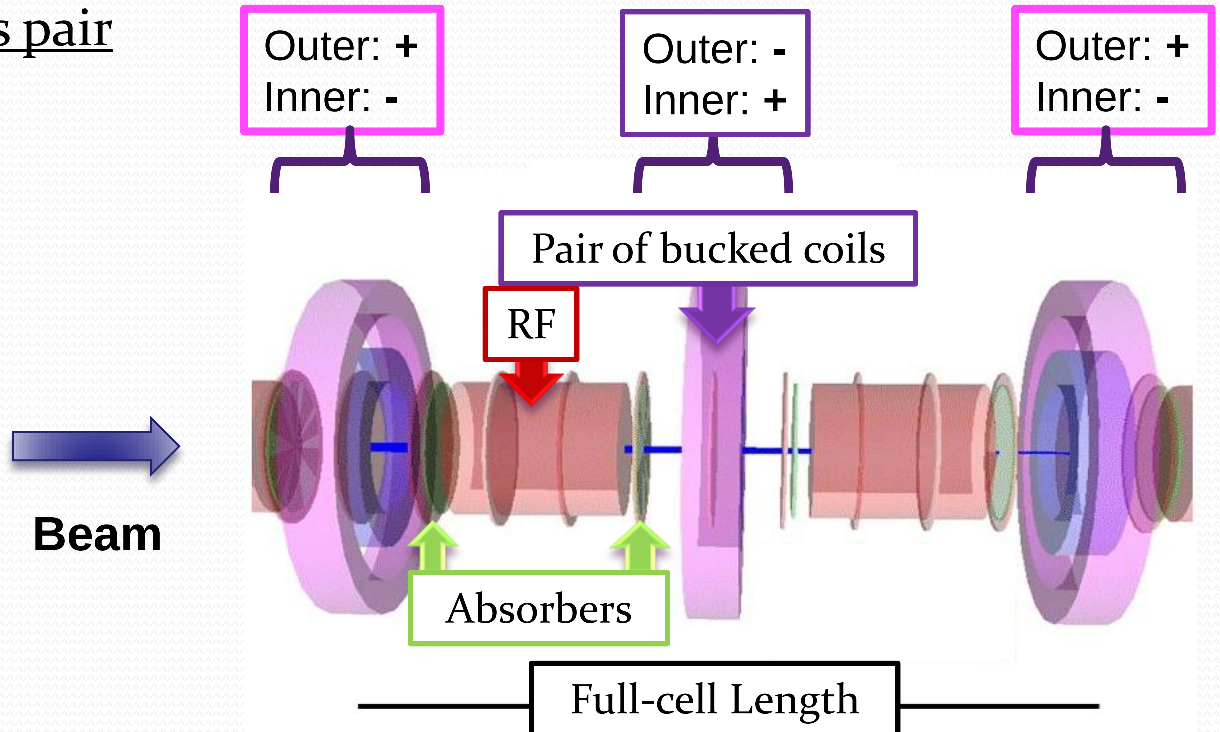
And… FSIIA magnetic field at RF position **very large (>4T)→*<u>Raises a question on its feasibility</u>***

New lattice must be found that obtains good transmission and emittance reduction **AND ALSO** achieves acceptable magnetic field at the position of the RF cavities

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

Bucked Coils, BC

- The magnetic field at the RF cavities can be decreased by:
  - Making the full-cell length larger and
  - Using Bucked Coils: *a pair of different radius and <u>opposite polarity coils</u>, placed at the same position along the beam axis*
- BC configuration: A pair of bucked coils, followed by an RF cavity which has a LiH absorber on each side. <u>Every pair of coils has opposite polarity than the previous pair</u>

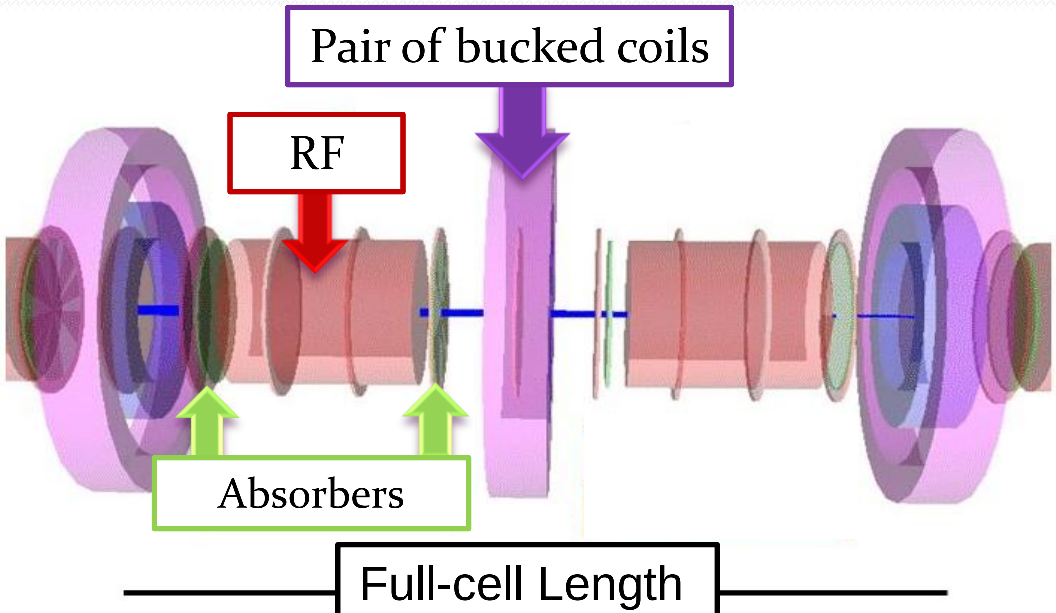


Bucked Coils, BC

Three different versions of BC were studied, BC-I, BC-II, BC-III. They **all have the SAME configuration** **except for**:
- the cell's length and
- the current densities of their coils

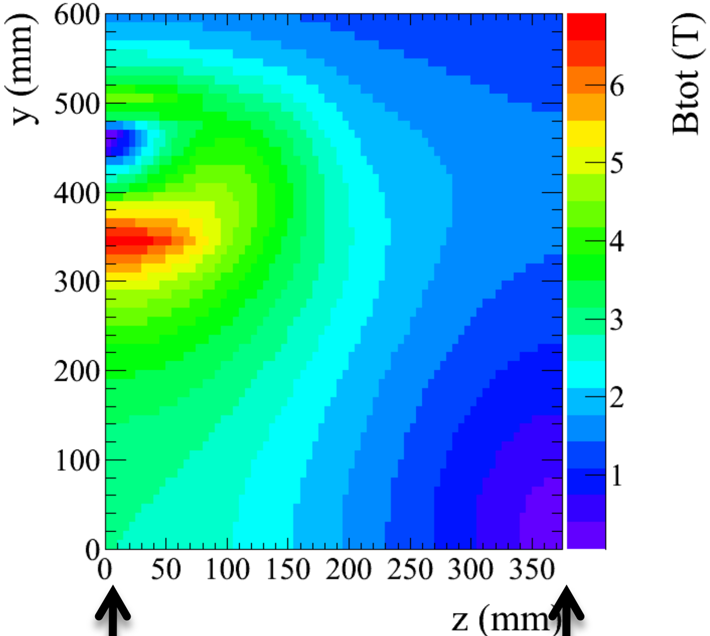
Differences of the BC versions

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

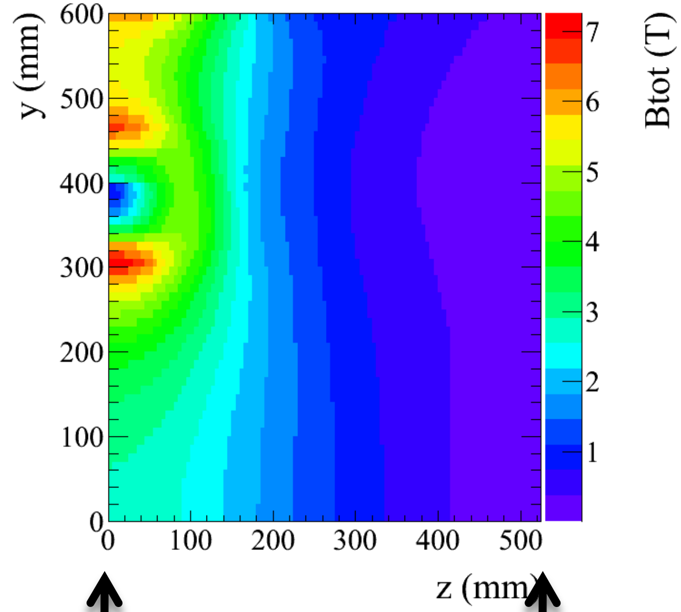


Magnetic Field Comparison

FSIIA



BC-I



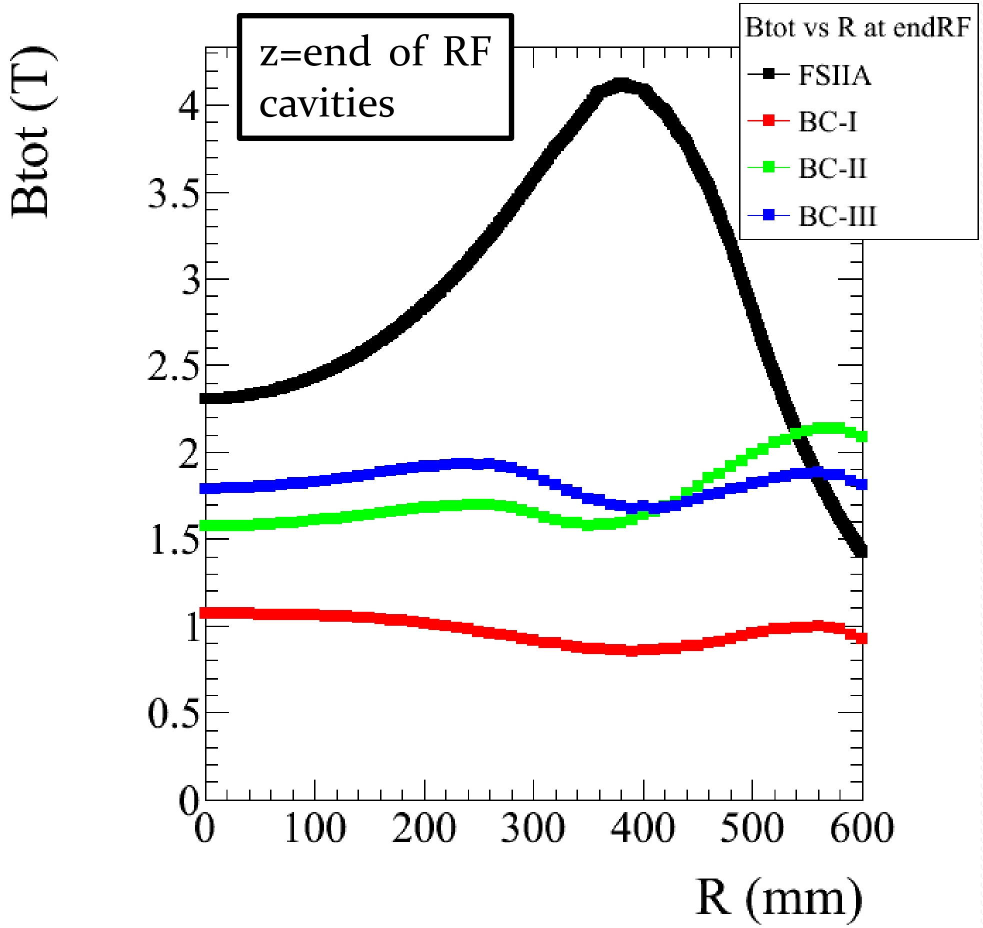
Centre of Coil

Centre of RF

Centre of Coil

Centre of RF

Magnetic Field Comparison



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

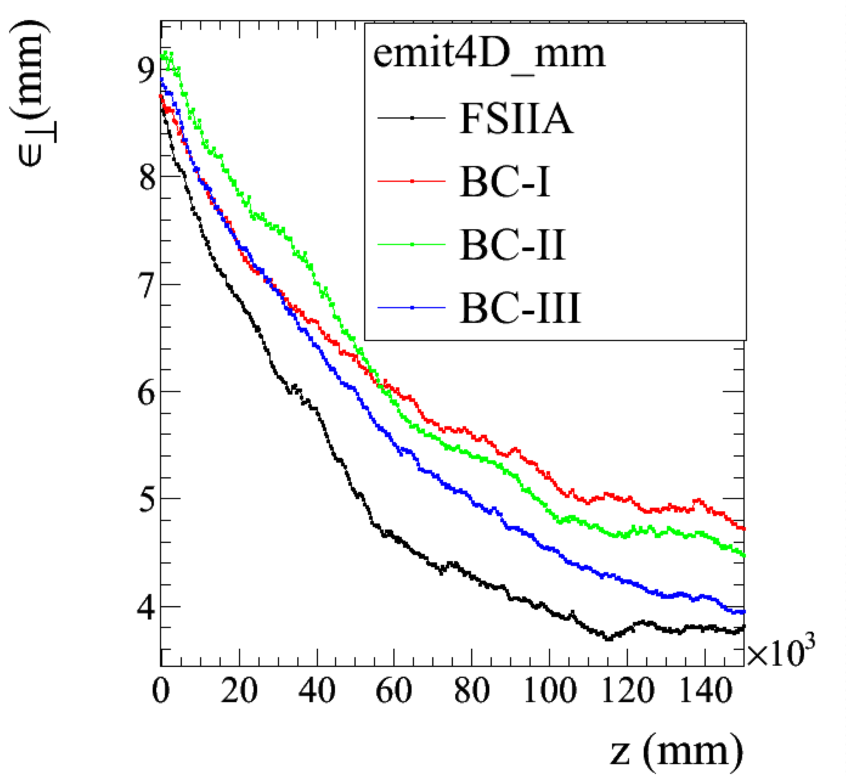
Beam initial characteristics

Lattices were compared using the same initial beam:

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

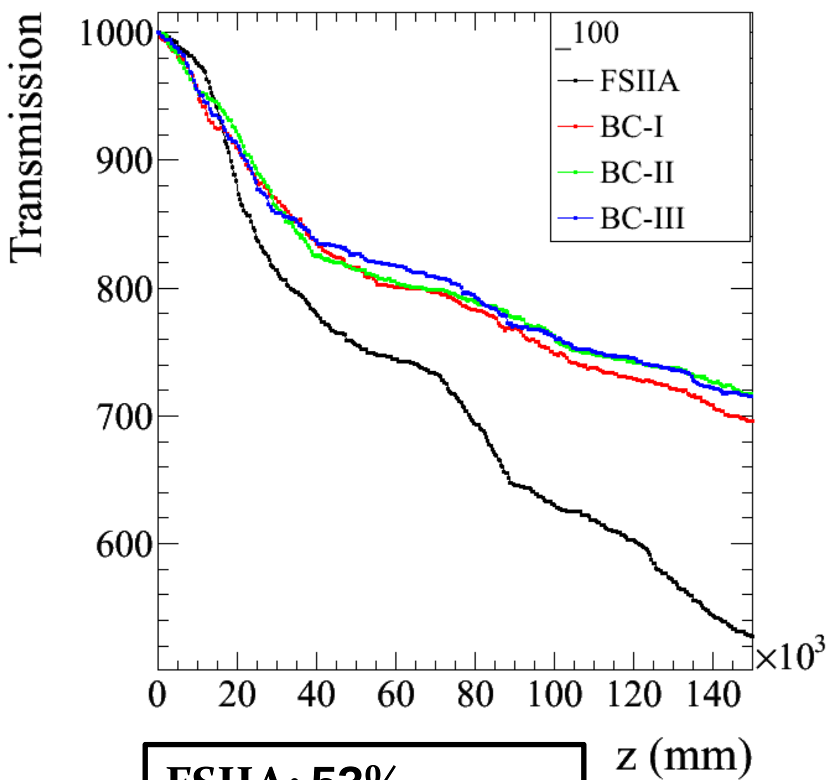
Cooling Dynamics & Transmission

Transverse Emittance (4D)



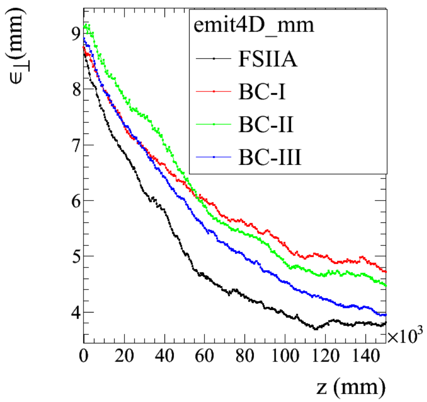
Better cooling for FSIIA and BC-III

Transmission



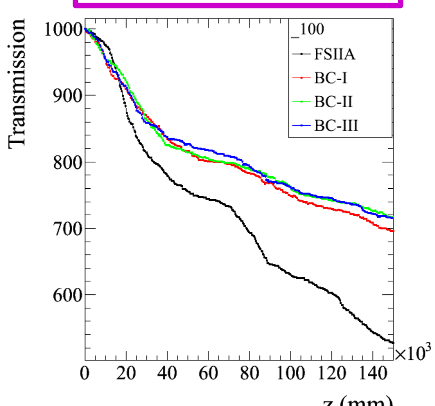
FSIIA: 53%
BC-I: 70%
BC-II, BC-III: 72%

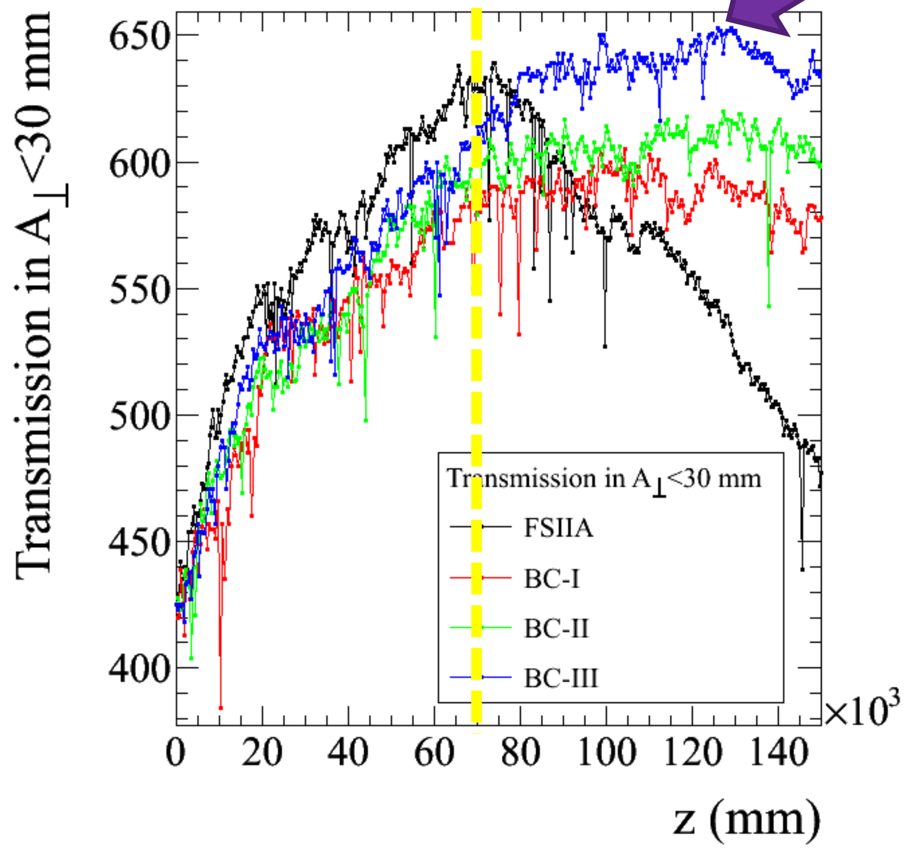
Transmission in A_T<30 mm



Emittance 4D

Transmission





- **BC-III**: **best transmission** 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%)**

Androula Alekou, Imperial College London, androula.alekou08@ic.ac.uk, IOP Meeting, Glasgow

Summary

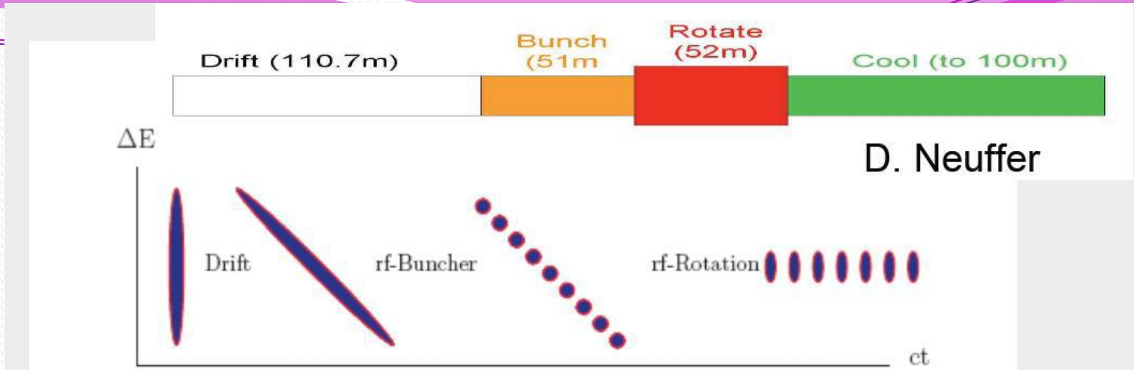
- **FSIIA**, the current Neutrino Factory cooling baseline, gives good transmission and reduction of transverse emittance **BUT** its achieved **magnetic field** at the position of the RF cavities is **large**
- Recent studies indicate the RF performance may be limited when external magnetic field is applied→ **Is FSIIA feasible???**
- **New lattices based on Bucked Coils** (BC-I, BC-II, BC-III) were designed to lower the magnetic field in the RF cavities
- **BC-I, has ~<u>4 times less magnetic field than FSIIA</u> at the position of the RF cavities and transmission within 30 mm A_T <u>only</u> ~4% lower than FSIIA**

Future Plans

- BC optimisation: find an improved lattice with a lower B at the position of the RF cavities **while** *also* providing <u>much better</u> transmission than FSIIA

Thank you

Buckup



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