Toohig Fellowship
Ionisation Cooling for the Neutrino Factory

Androula Alekou
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Layout

- Few words about me
- Experiments I've worked on
- Main work
- Where I could contribute

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- 2004-08: BSci Physics at the University of Cyprus
- 2008-2012: PhD in Particle/Accelerator Physics at Imperial College London; Full scholarship (STFC); PhinisheD ~3 weeks ago

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- There is a thought of replacing the reference cooling lattice cause of the high B it has at the RF position (which can lead to RF breakdown)
- I proposed and designed a new cooling channel for the Neutrino Factory that achieves a significantly lower B at the RF position than the reference lattice while keeping the positive aspects (more in a few slides!!)

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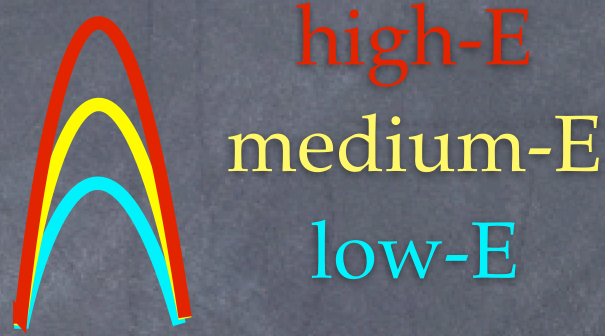

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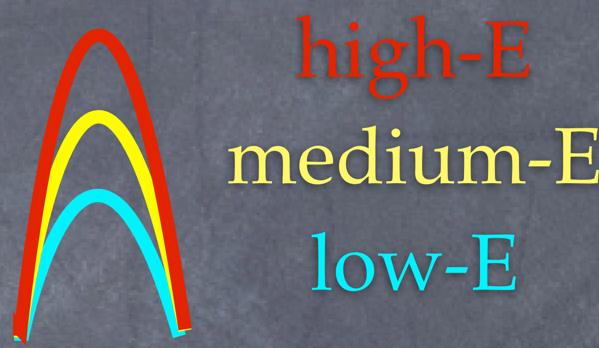

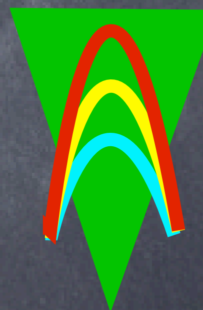

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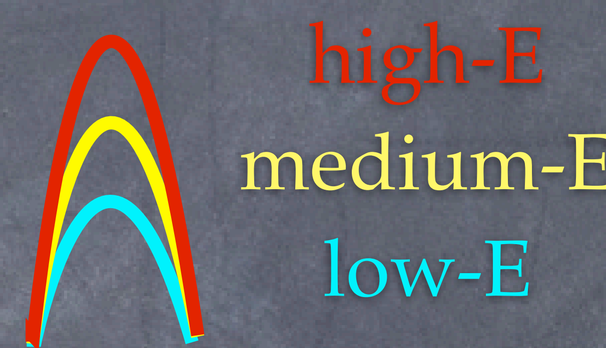

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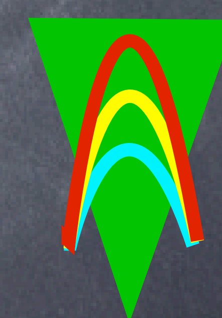

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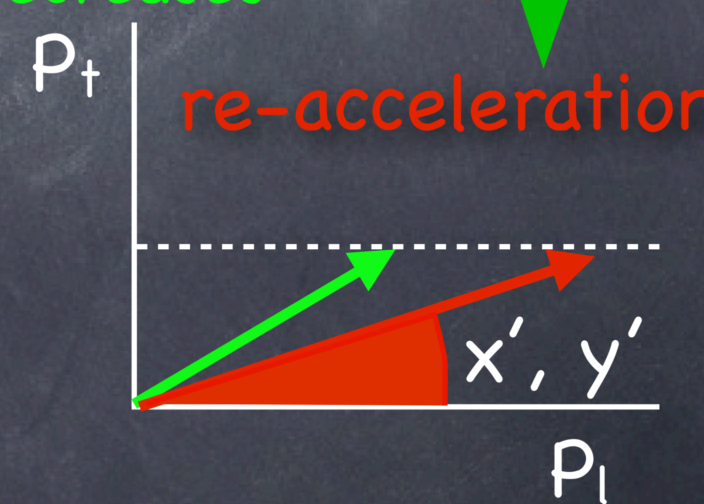

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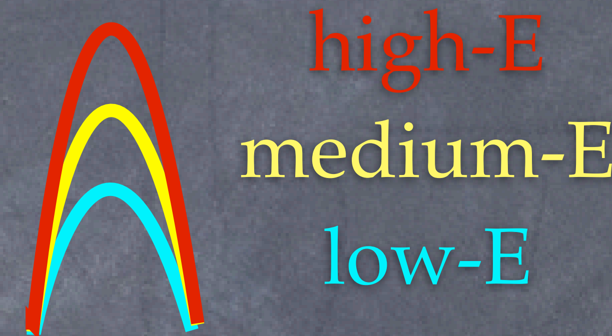

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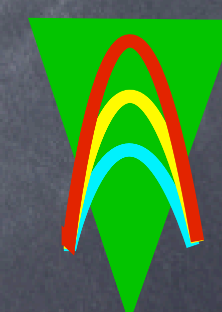

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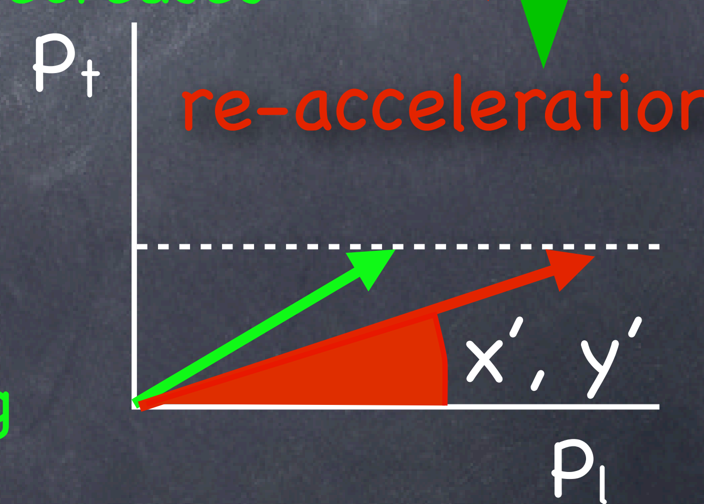

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Monday, 7 May 12

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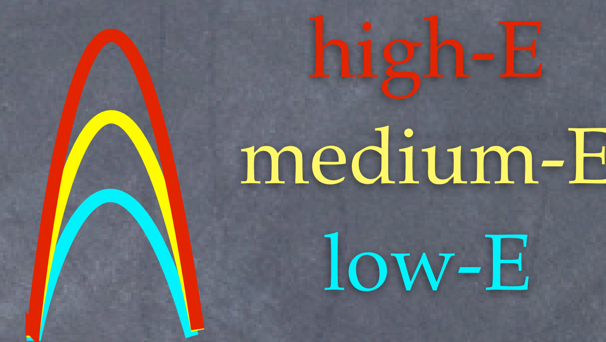

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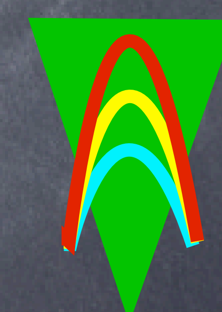

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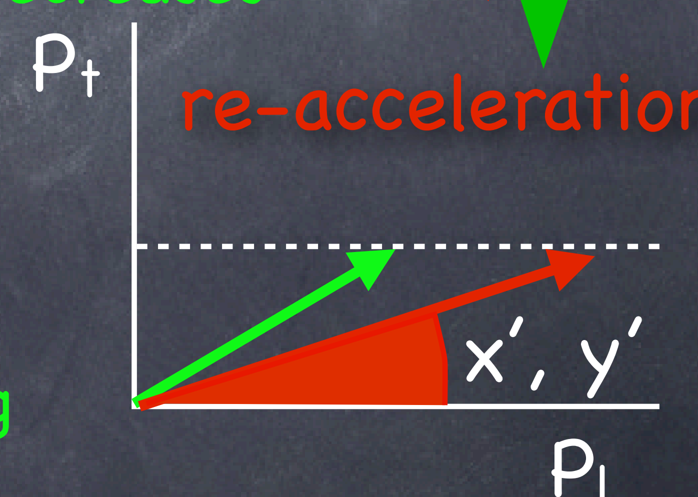

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  - **Tools:** GEANT4 based frameworks, ROOT, C++ (and other programming languages)

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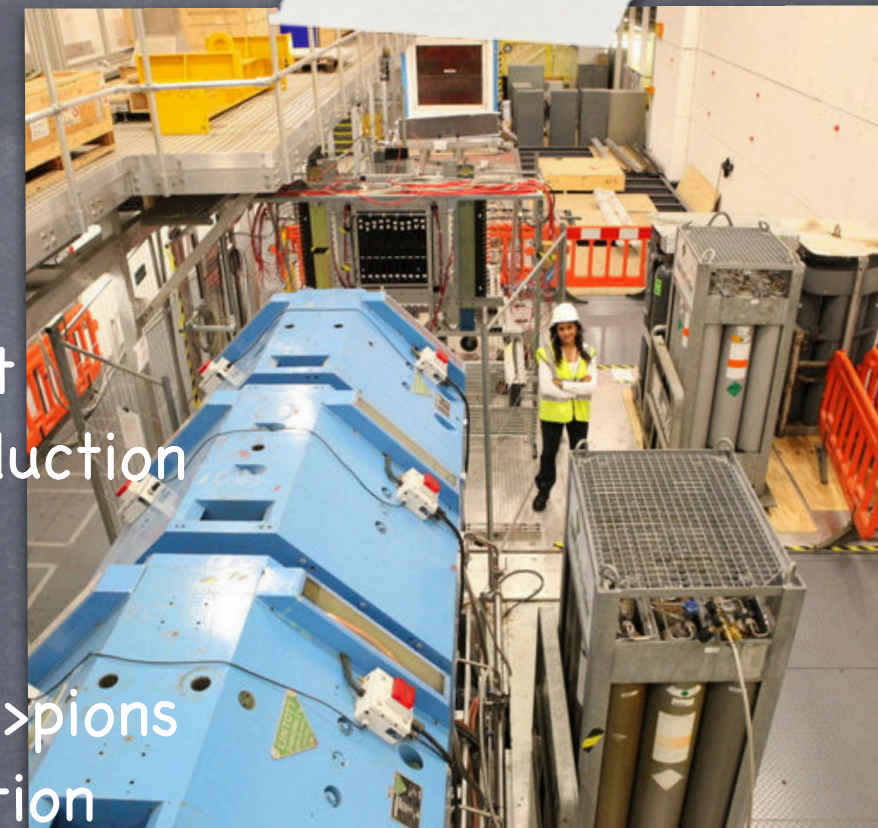

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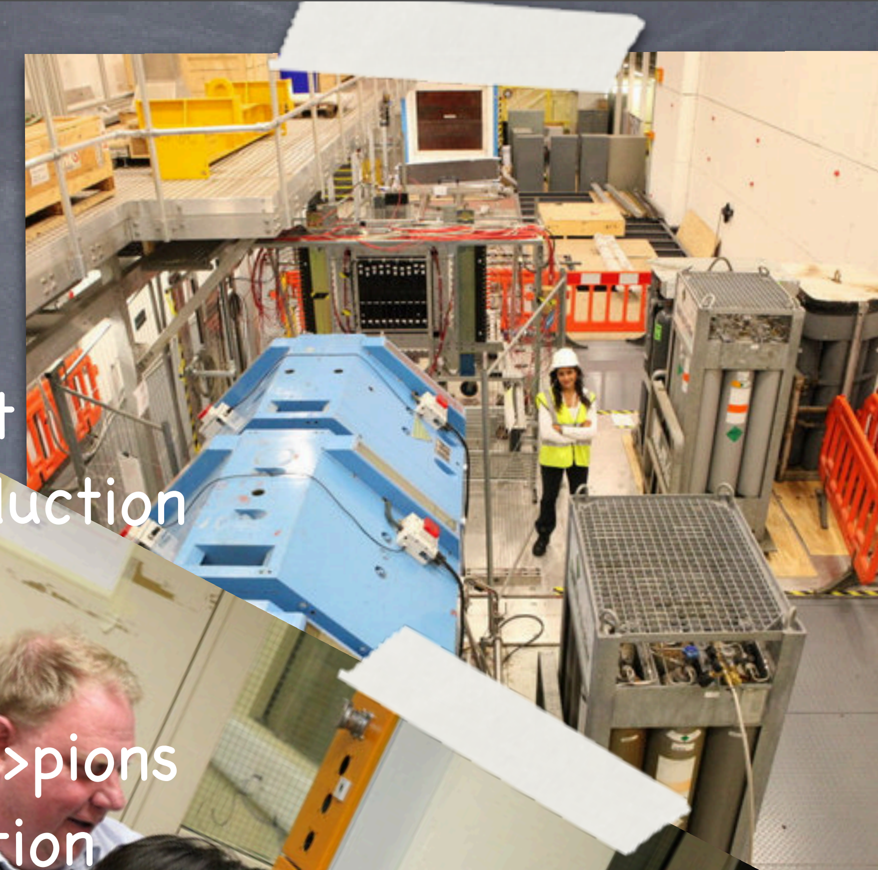

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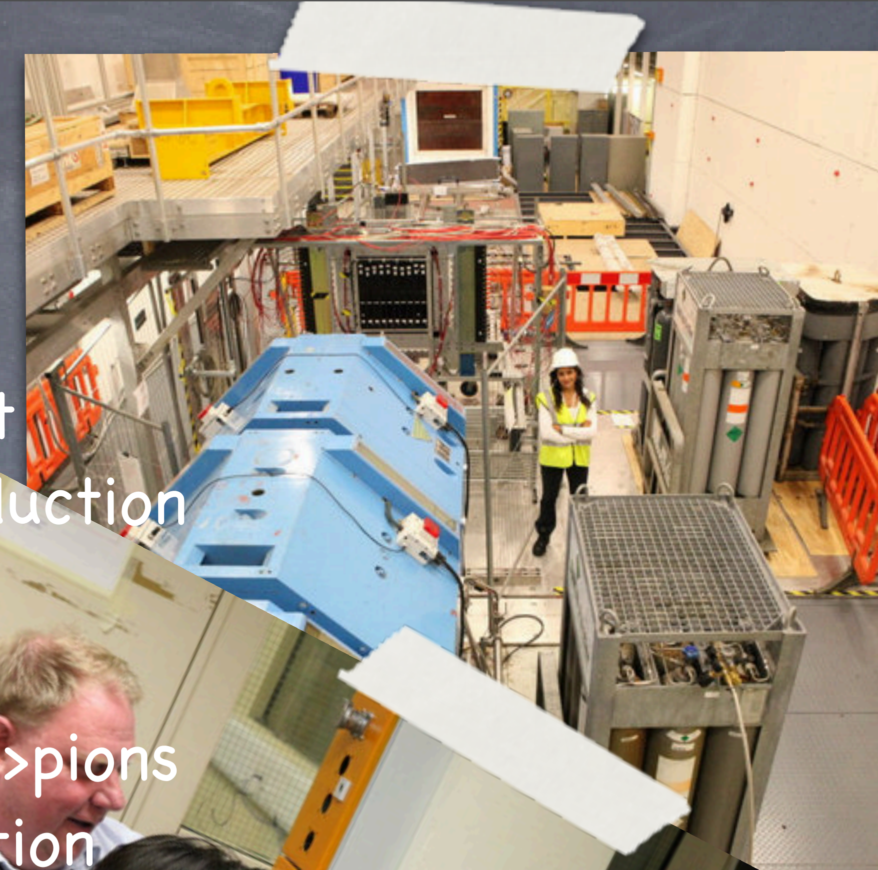

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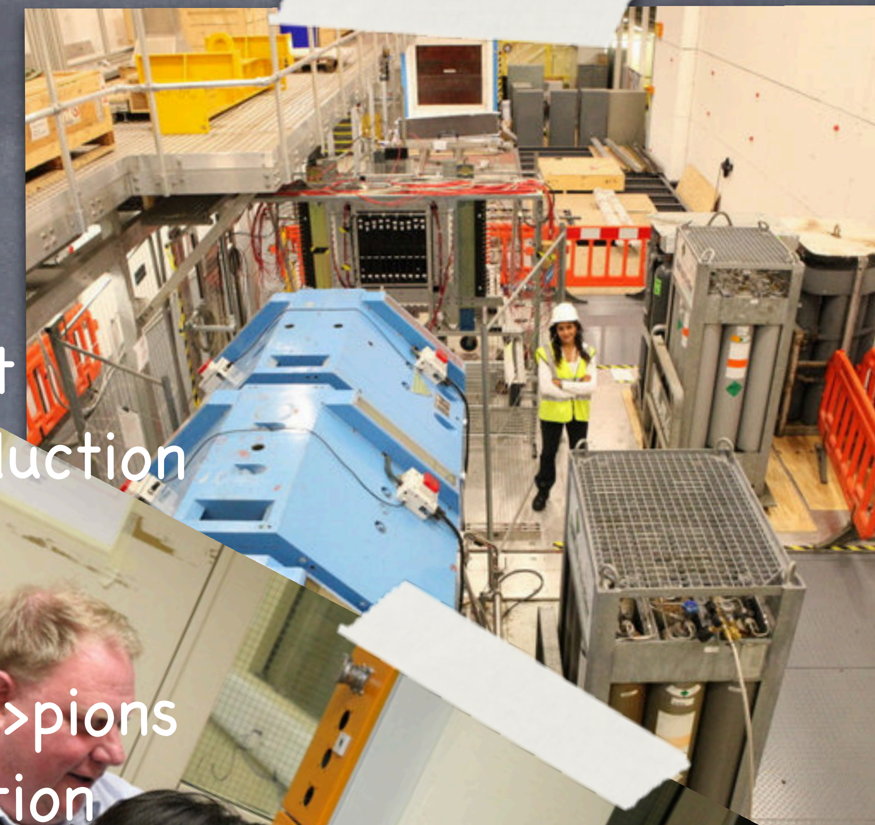

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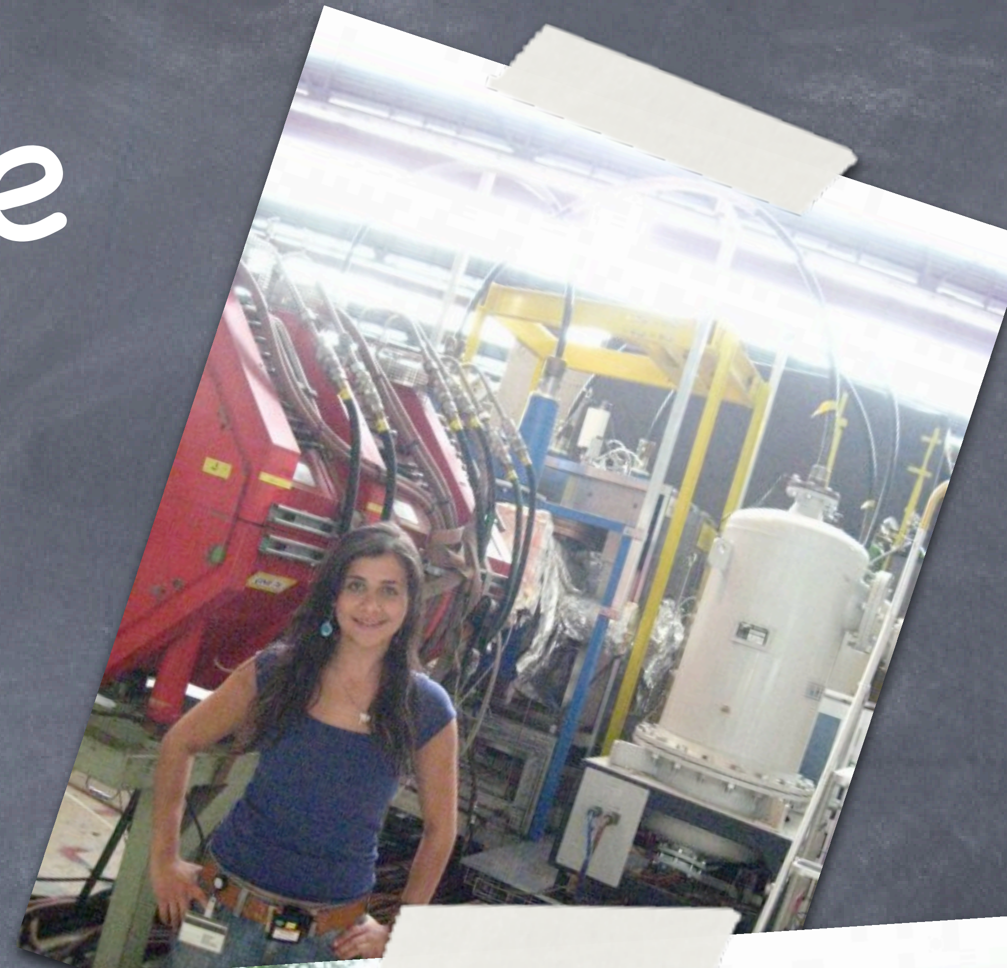

Main work-layout

- Introduction
- Motivation
- My idea & contribution
- Results
- Conclusions

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Problem #2

- ...muons decay fast! So traditional cooling techniques can't work!

- The **only** viable muon cooling technique is **ionisation cooling**

Introduction

- Ionisation cooling:

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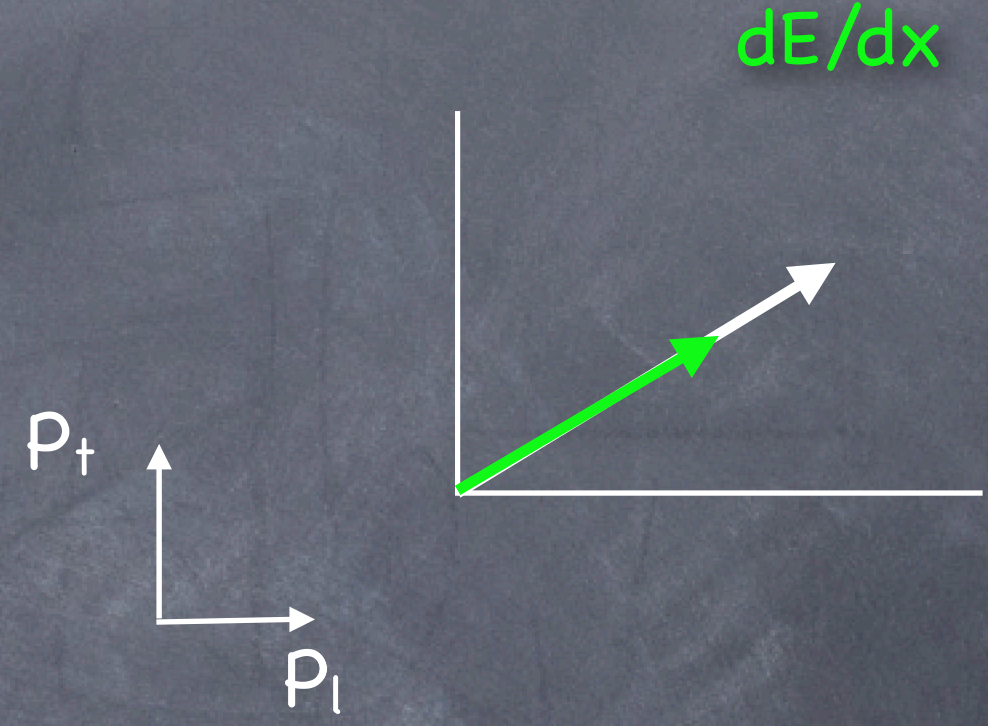
  - Muons pass through absorbers where their momentum decreases in every direction



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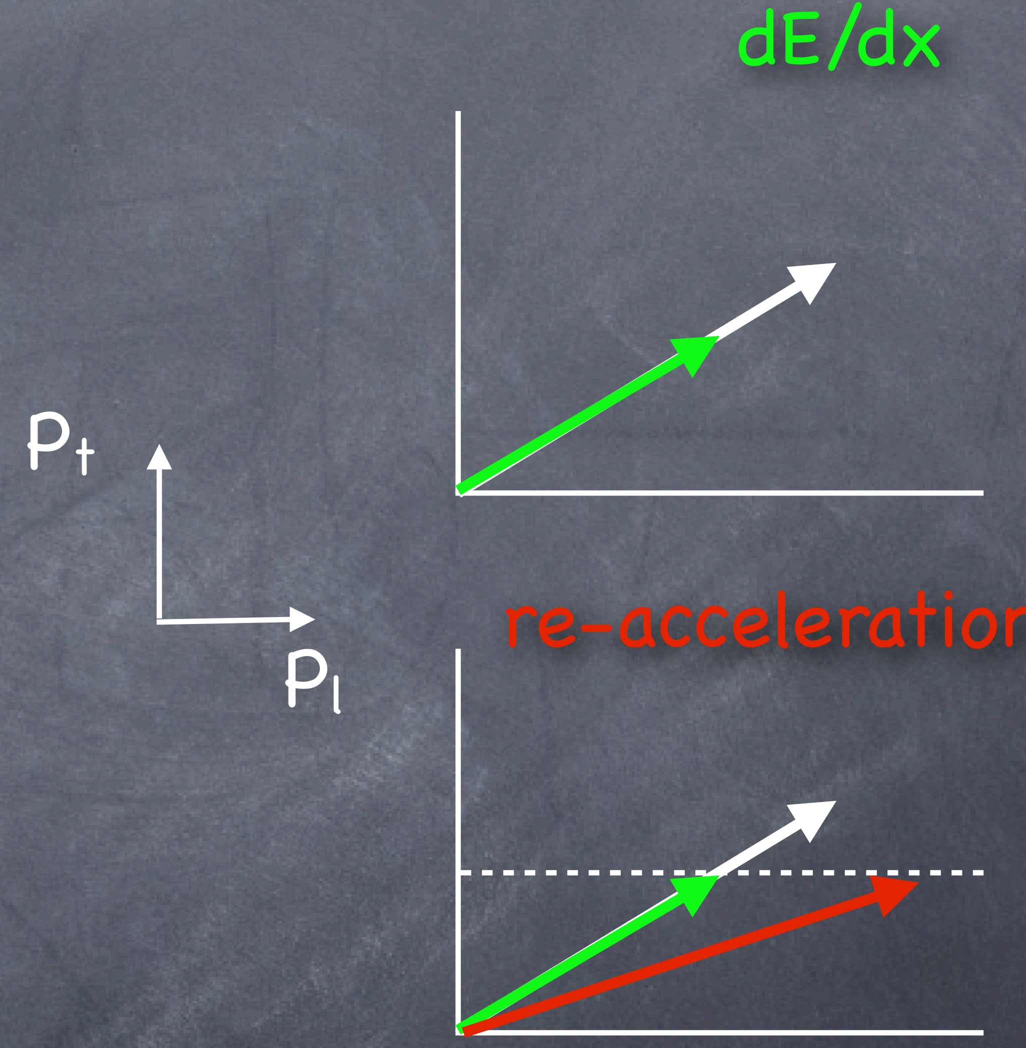

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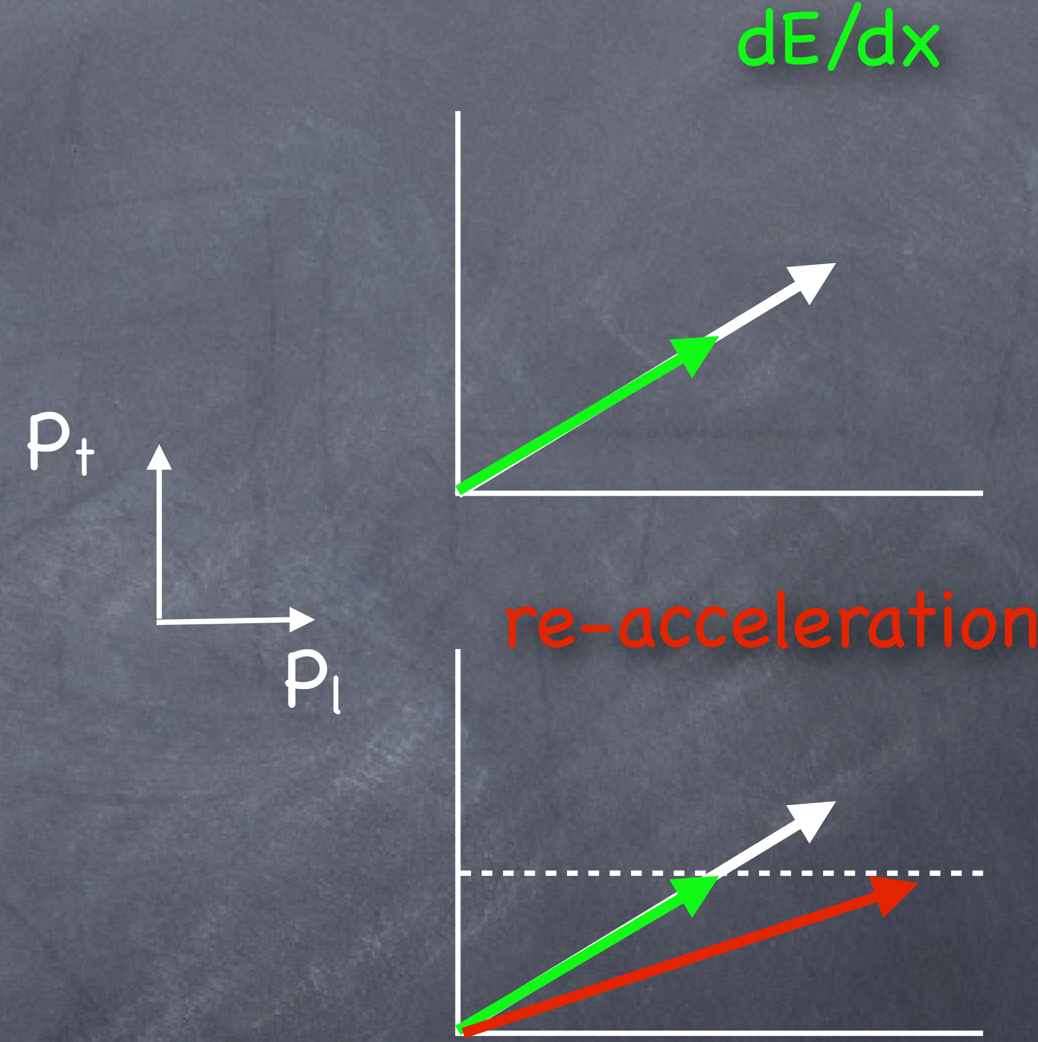
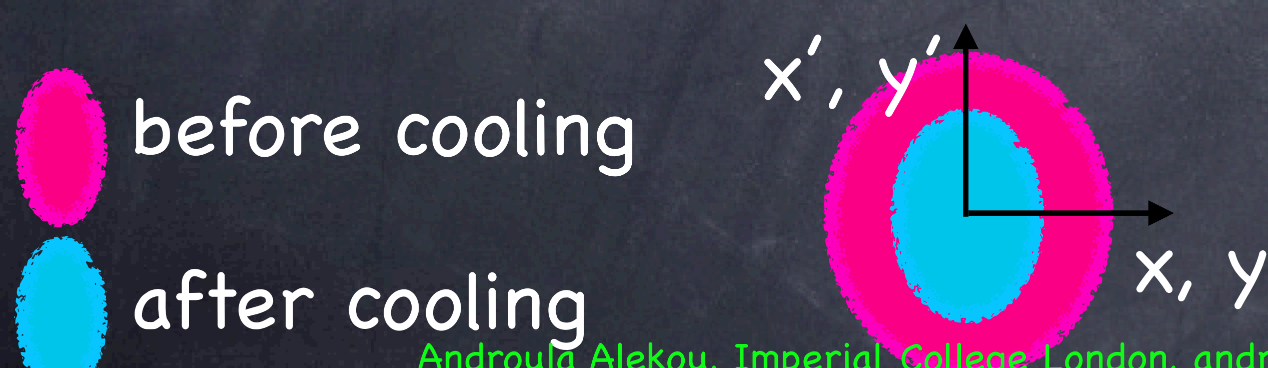
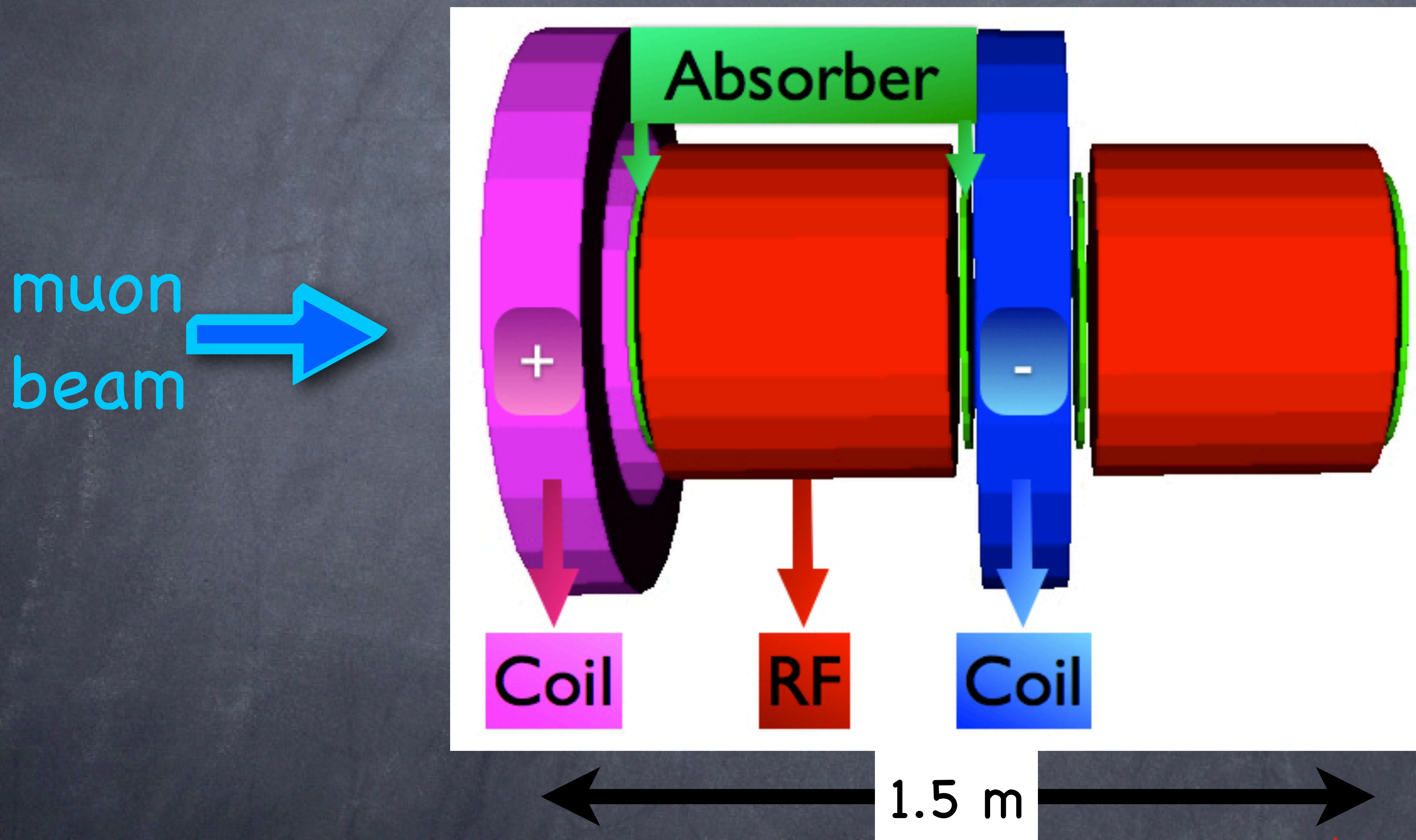
  - Muons pass through absorbers where their momentum decreases in every direction
  - Then they pass through RF cavities, where their energy is restored, but **only** in the longitudinal direction
  - So the transverse phase-space (4D) of the muon beam is reduced!





Motivation (1/3)

- Reference ionisation cooling channel of the Neutrino Factory, FSIIA*: Coil-LiH absorber-RF-LiH absorber



*FSIIA=Feasibility Study IIA

- Performs well with respect to transmission and cooling dynamics, **but...**

Motivation (2/3)

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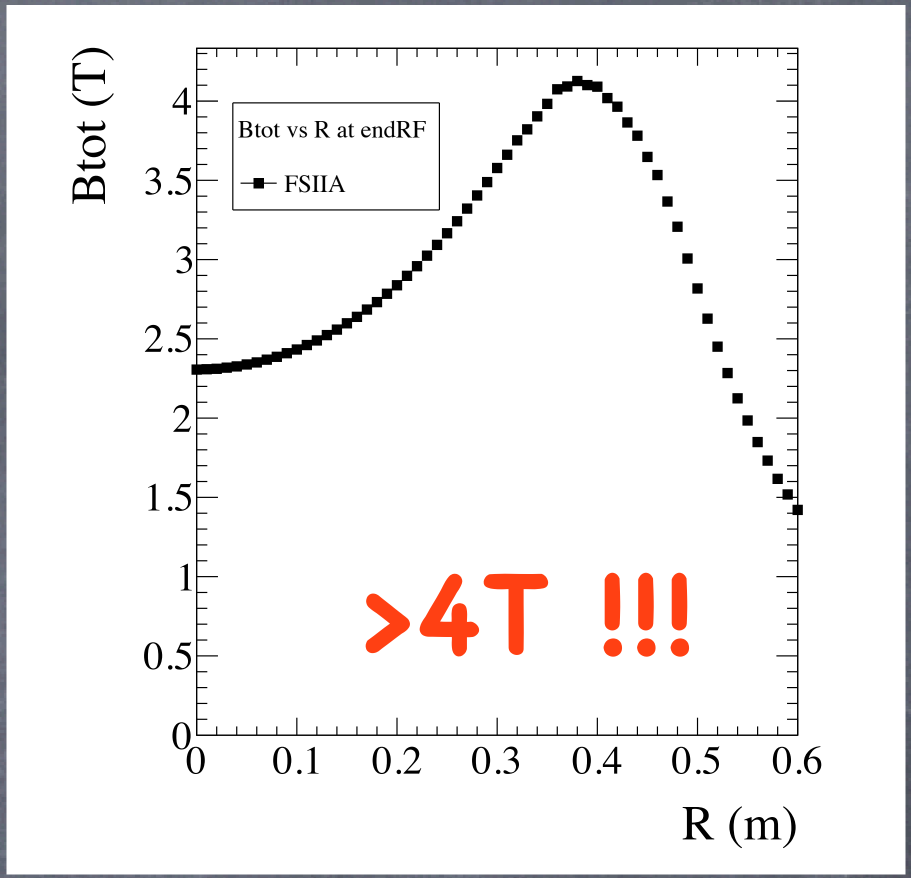
- ...FSIIA has **large B** at the position of the RF cavities...



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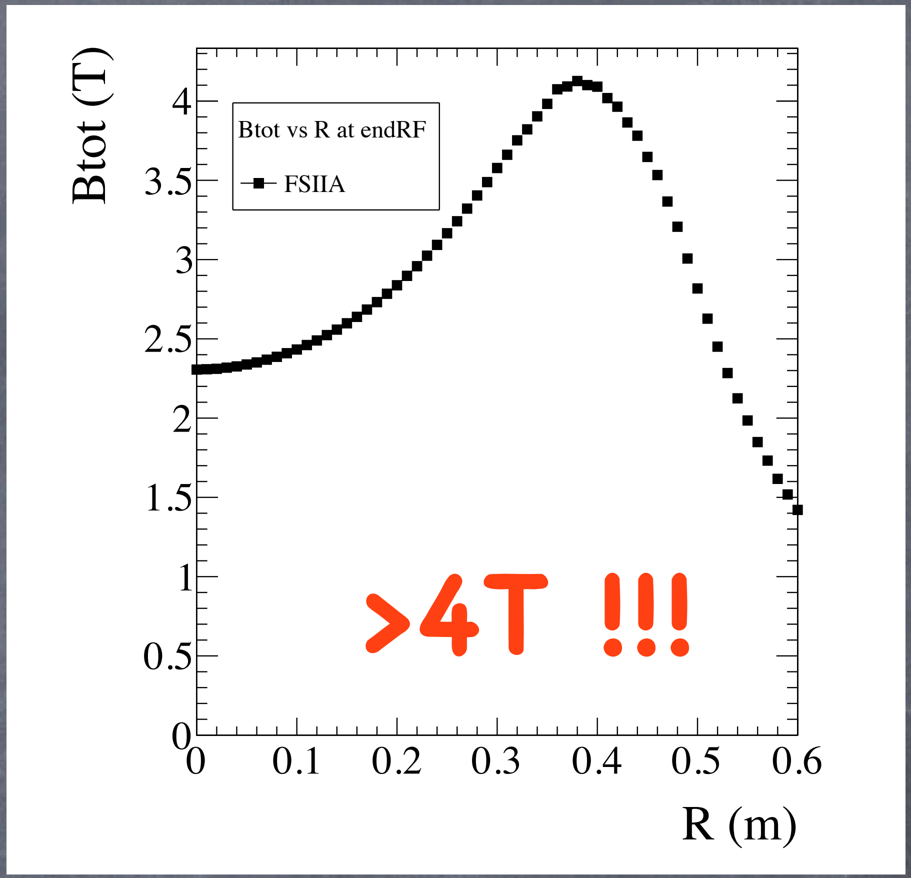
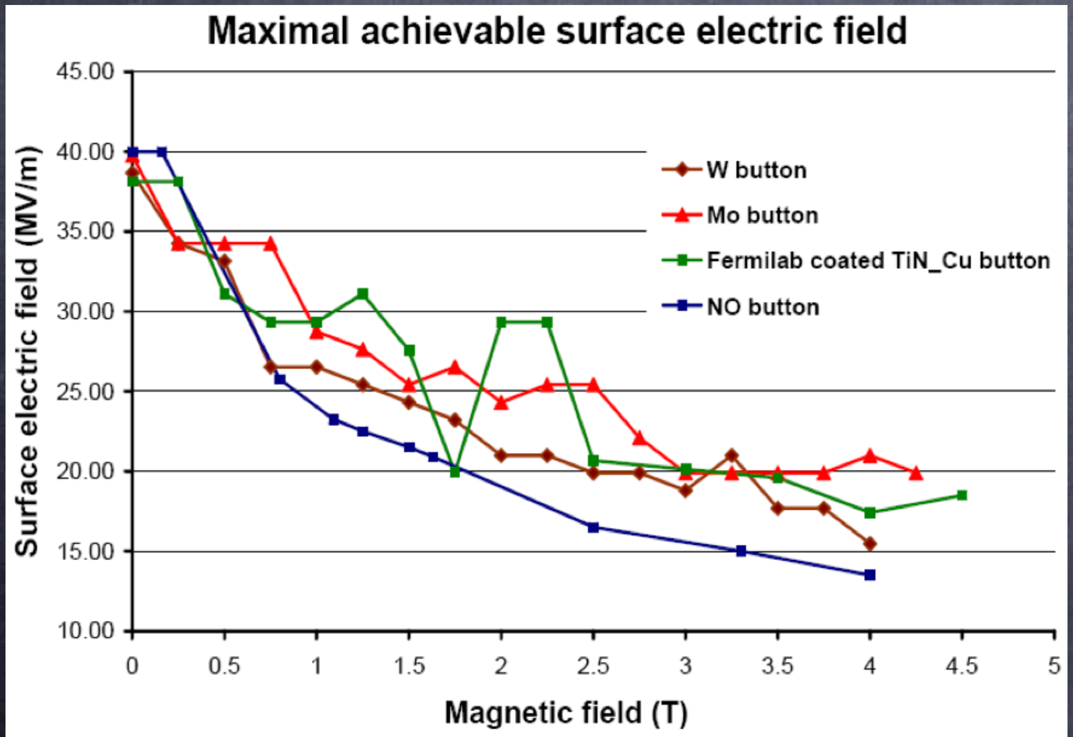
- ...FSIIA has **large B** at the position of the RF cavities...
- ...and recent studies show that high external B at RF cavities can lead to RF breakdown





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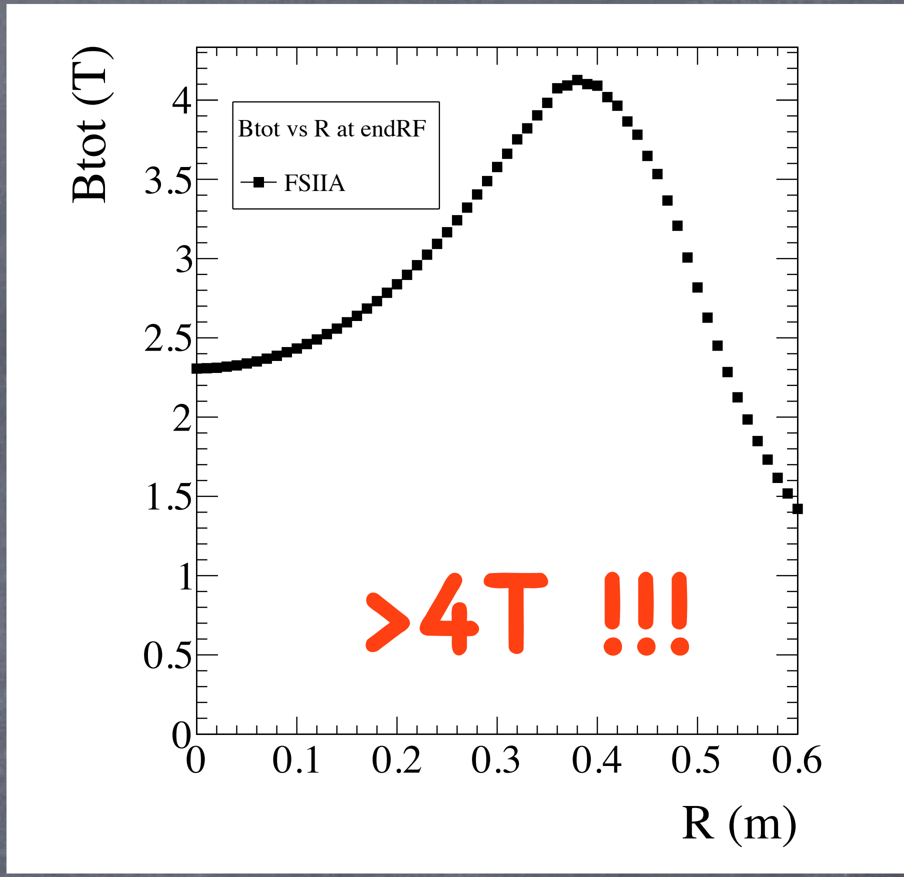
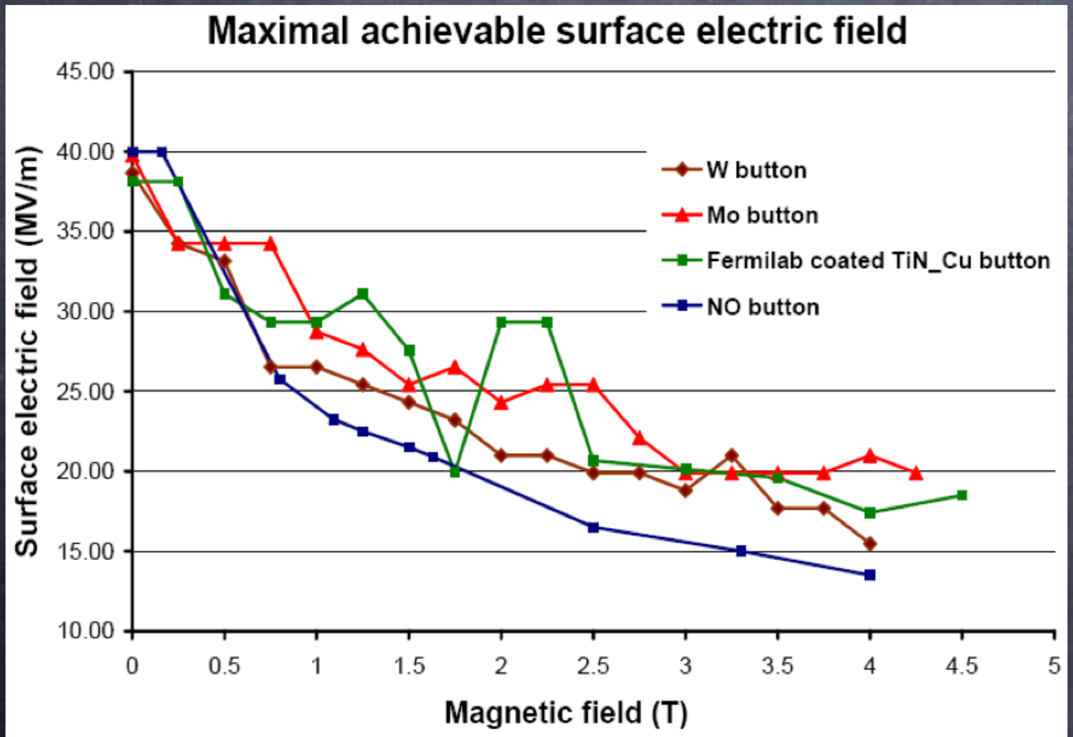




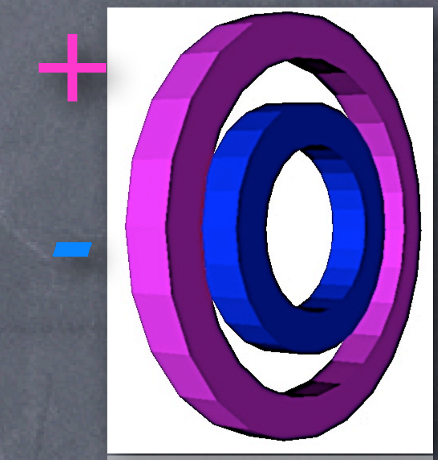
An alternative cooling lattice should be found that will not only **decrease significantly** the **B** at the **RF** position, but that will also achieve a **comparable transmission** and **cooling performance** to FSIIA

Motivation (3/3)

- How do decrease B at RF position:

  a)increase the cell length

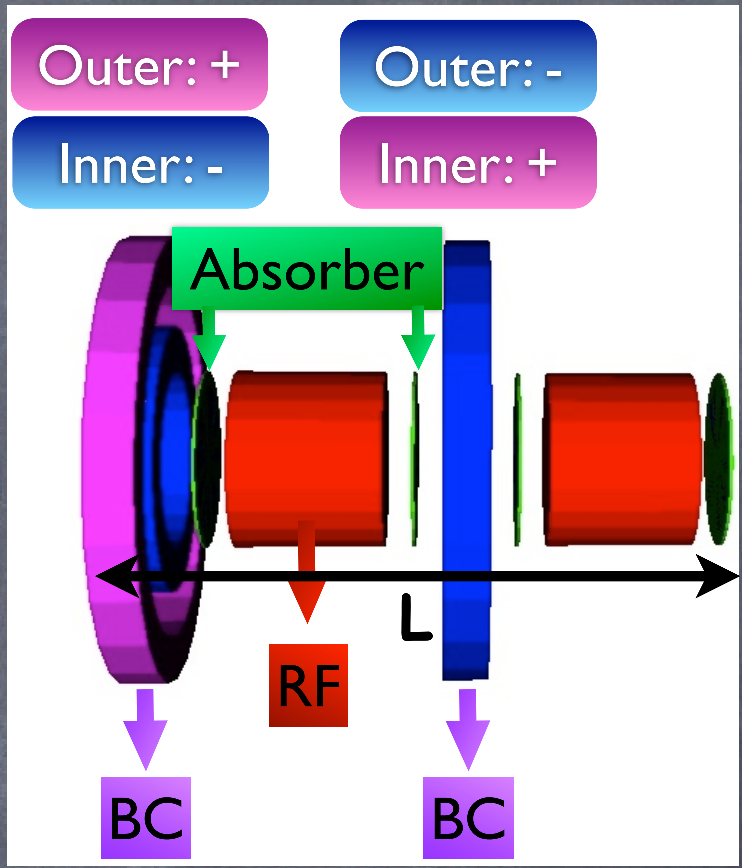
  b)use Bucked Coils: 2 coils of opposite polarity placed at the same position along the beam-axis (homocentric coils)



- With the alternation of the Bucked Coils polarity, B can be reduced at desired off-axis locations

- **Proposed and designed a Bucked Coils Lattice**

Bucked Coils Lattice (BC)



Monday, 7 May 12

Bucked Coils Lattice (BC)

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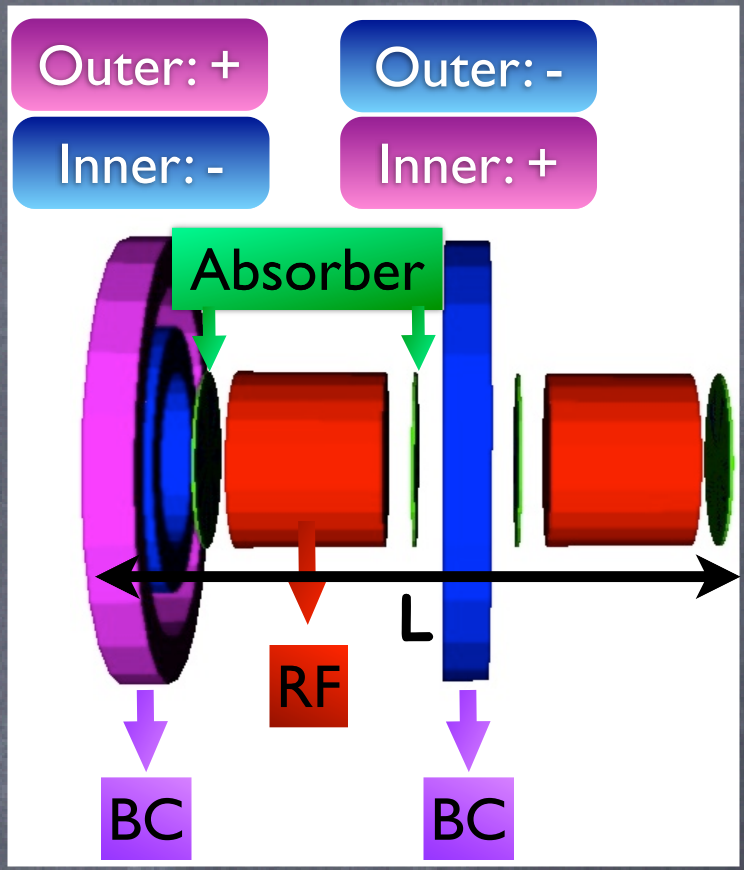
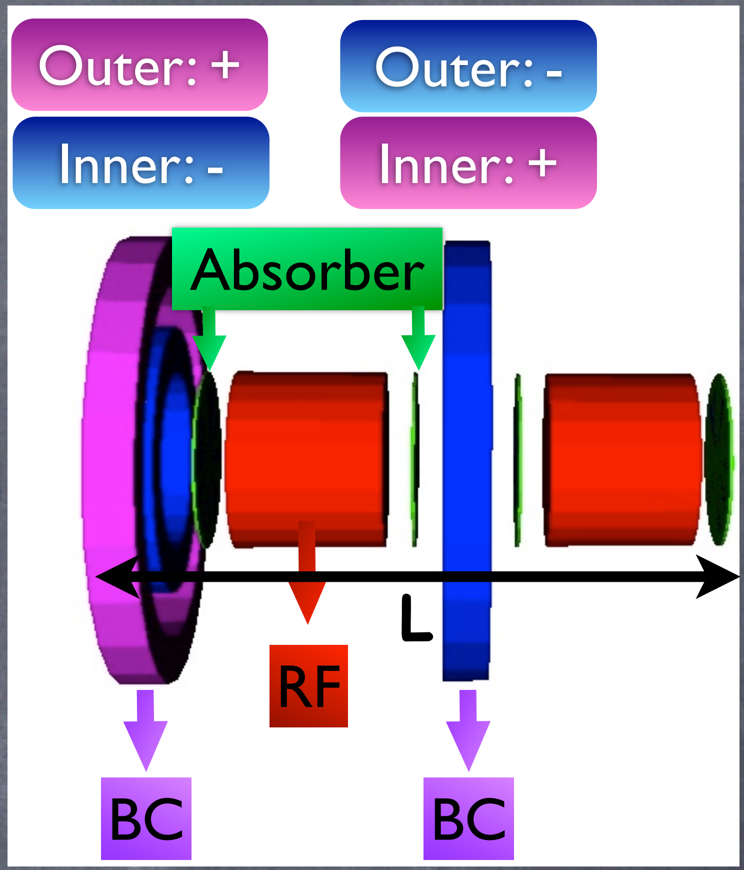


Bucked Coils Lattice (BC)

- PairOfCoils-LiH absorber-RF-LiH absorber
- I will only present 6 different versions: BC-I, -II, -III, -IV, -V, -VI



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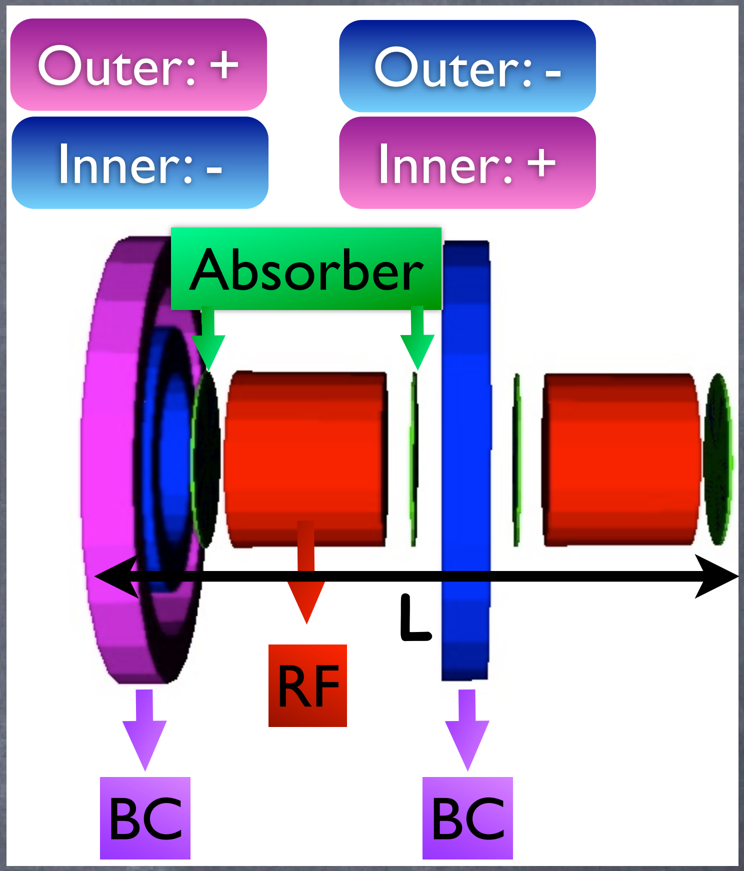

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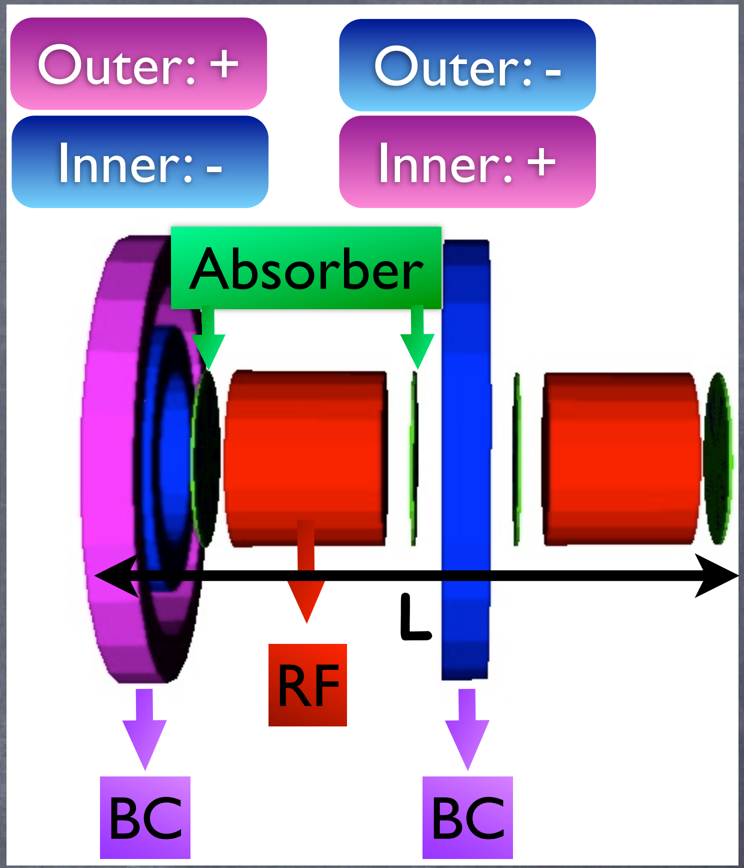
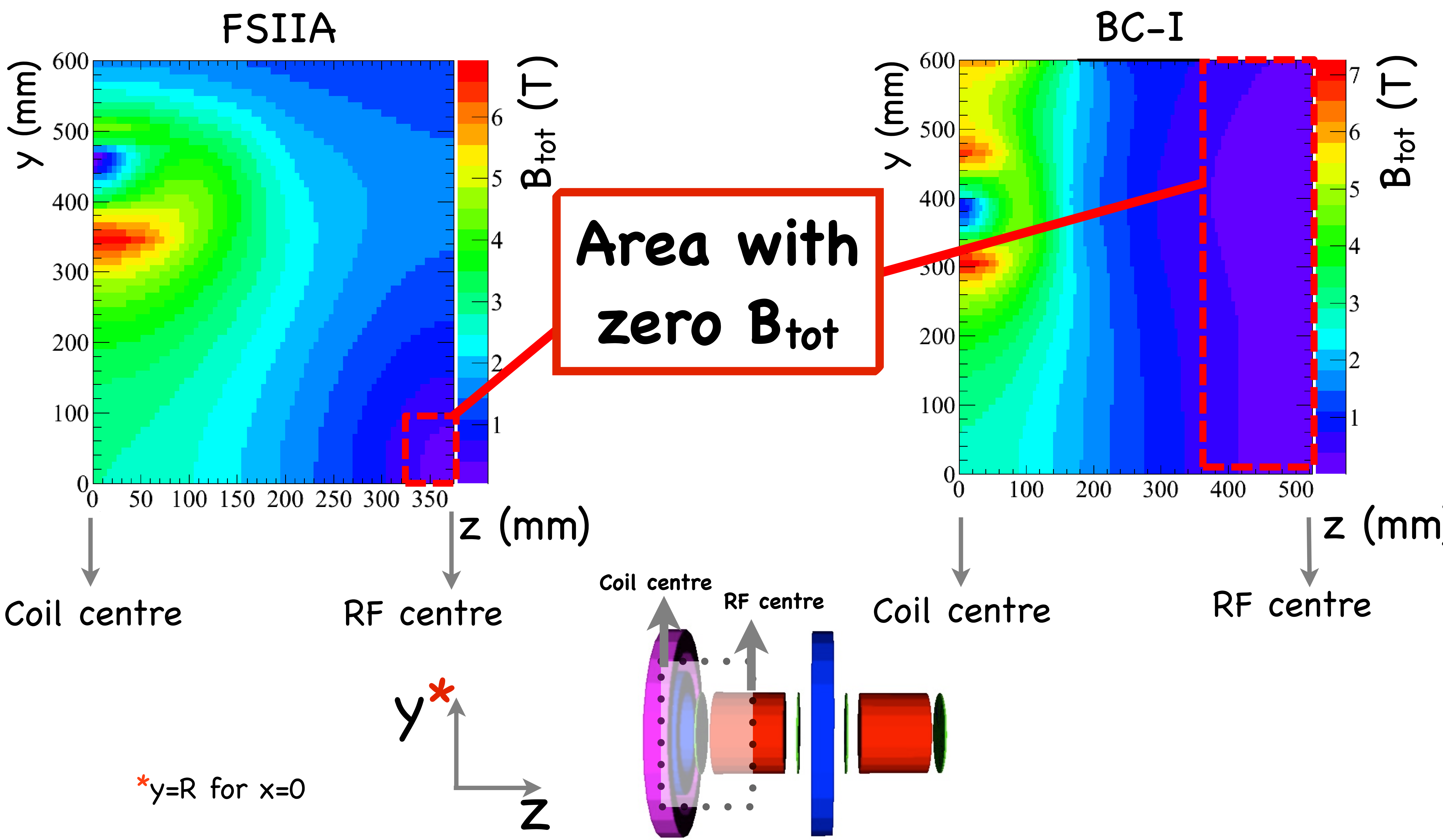


Summary of differences between FSIIA and BC lattices

Lattice	FSIIA	BC-I	BC-II	BC-III	BC-IV	BC-V	BC-VI
Full-cell length, L [m]	1.50	2.10	2.10	2.10	1.80	1.80	1.80
IC [A/mm²]	106.667	120.00	97.20	87.48	132.00	120.00	87.48
OC [A/mm²]	N/A	90.24	77.14	66.73	99.26	90.00	66.73

FSIIA vs BC: Magnetic Field



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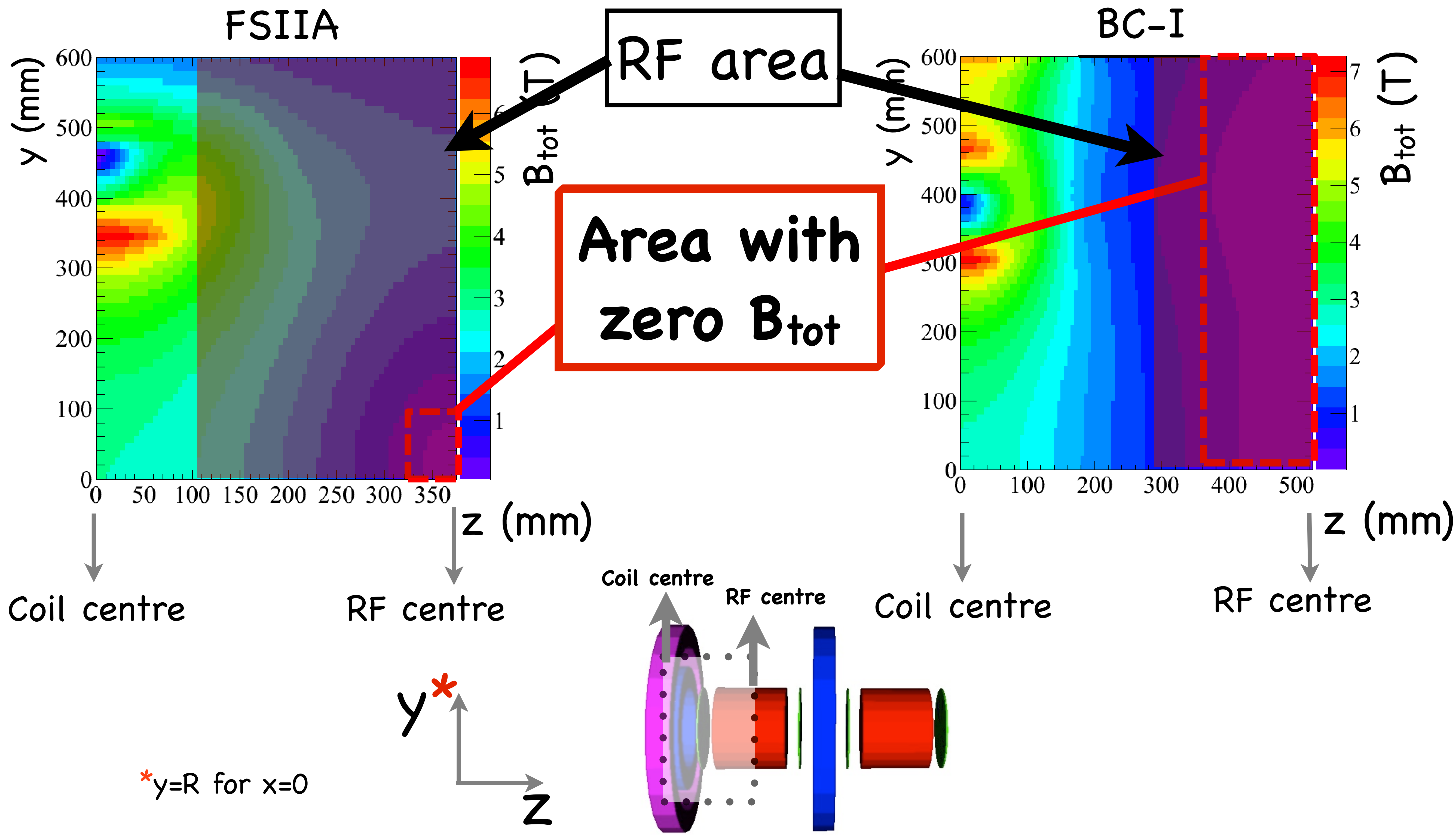

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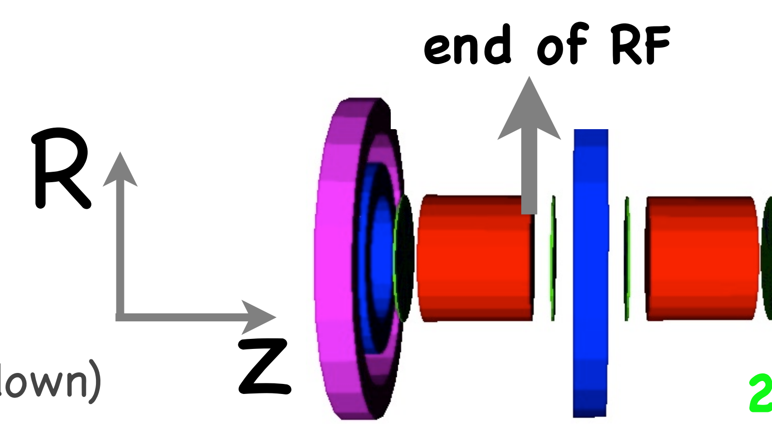

*at z= end of RF (most sensitive location wrt RF breakdown)

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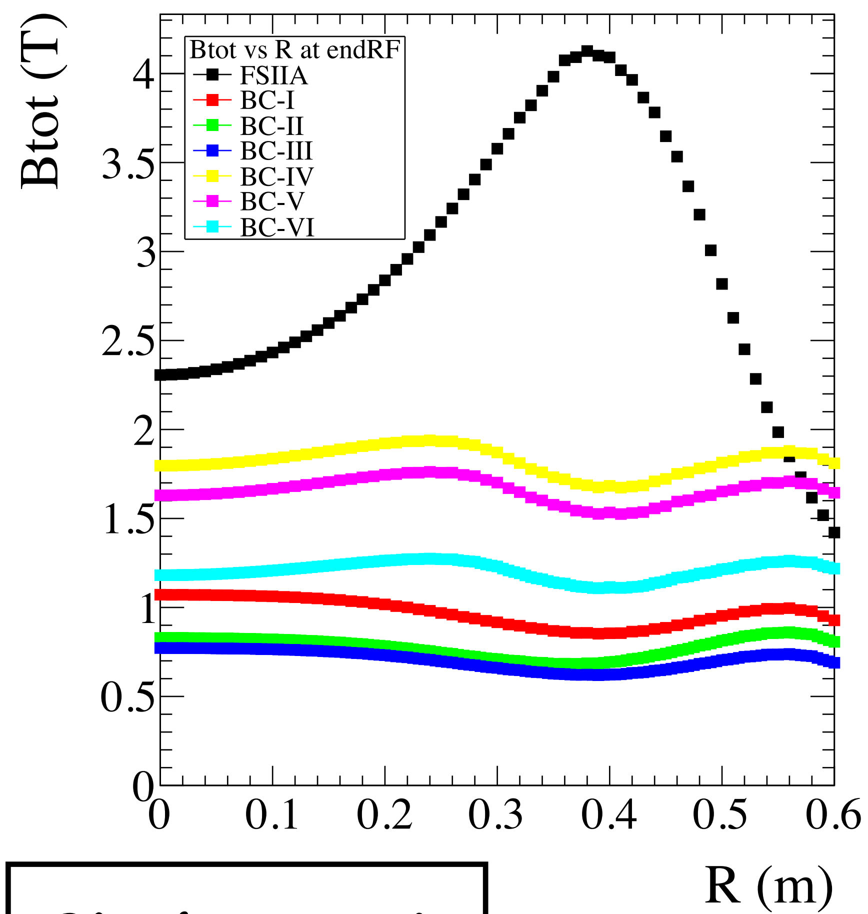

Black: FSIIA
Red: BC-I
Green: BC-II
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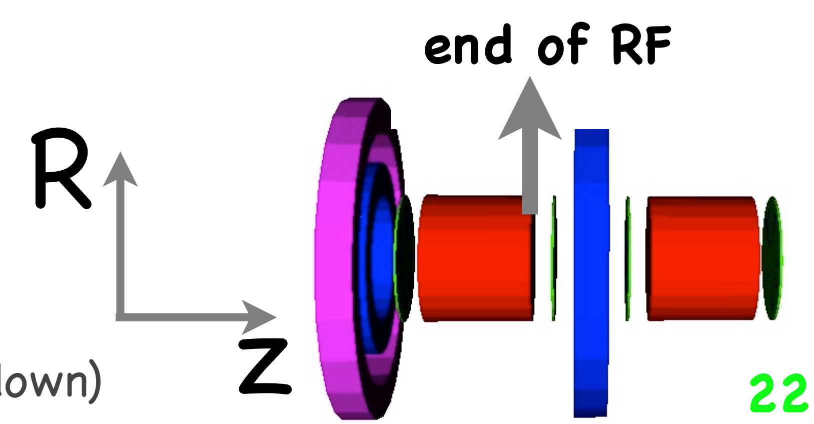
Cyan: BC-VI

FSIIA>4 T

BC-I, BC-II, -III, -VI ~x3.5-5 lower

BC-IV, -V~x2-3 lower



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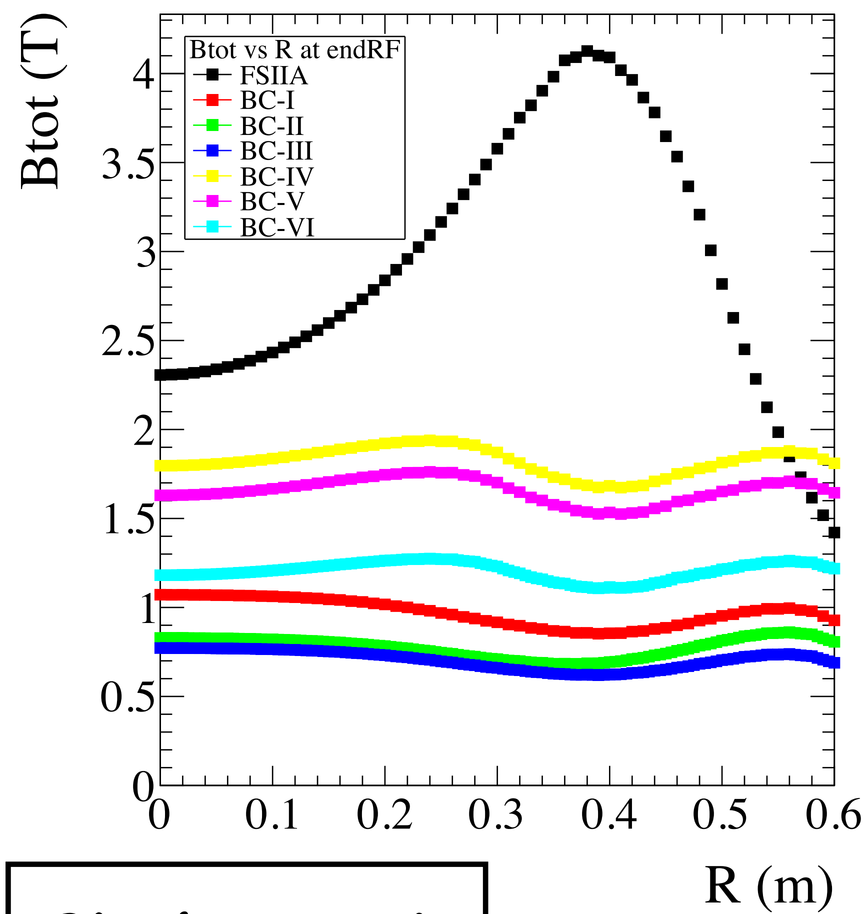

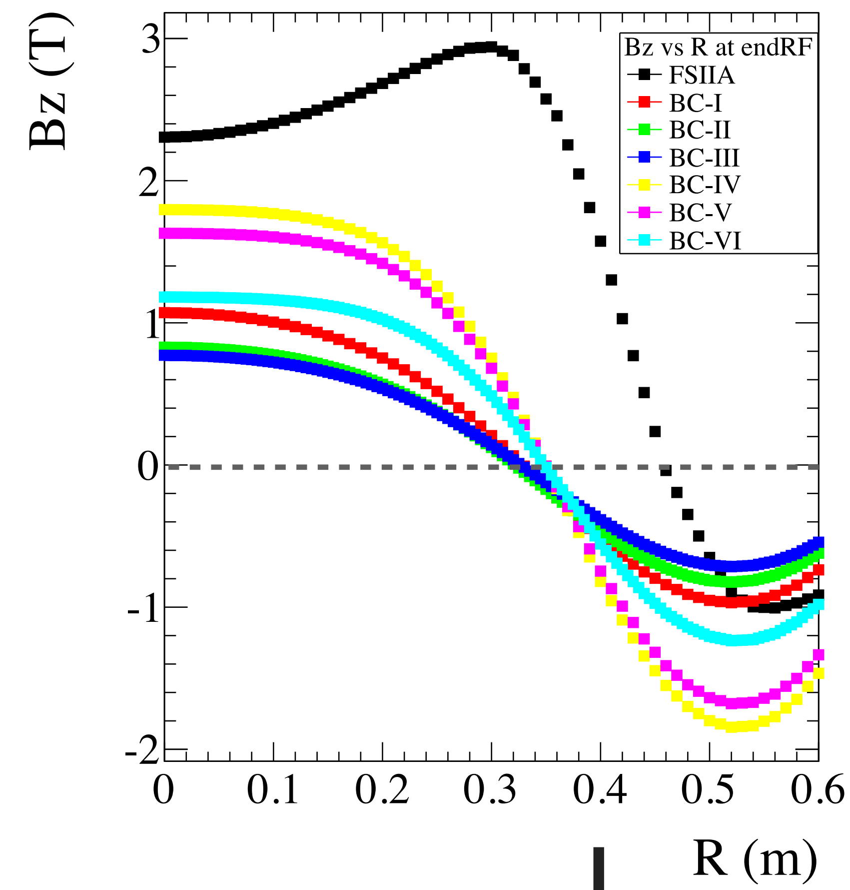

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All BC: 0 T at ~35 cm

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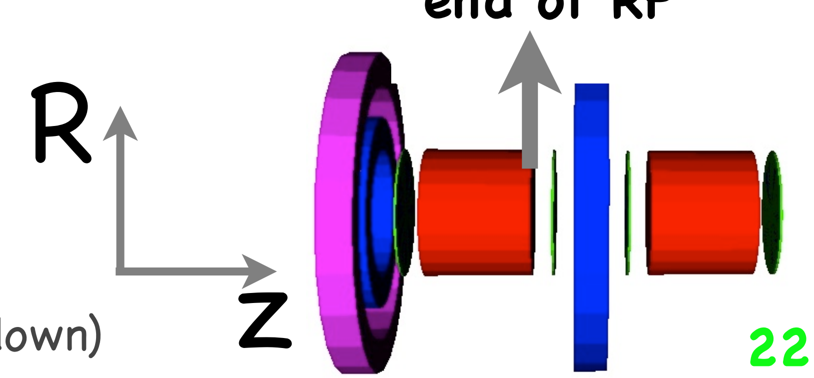

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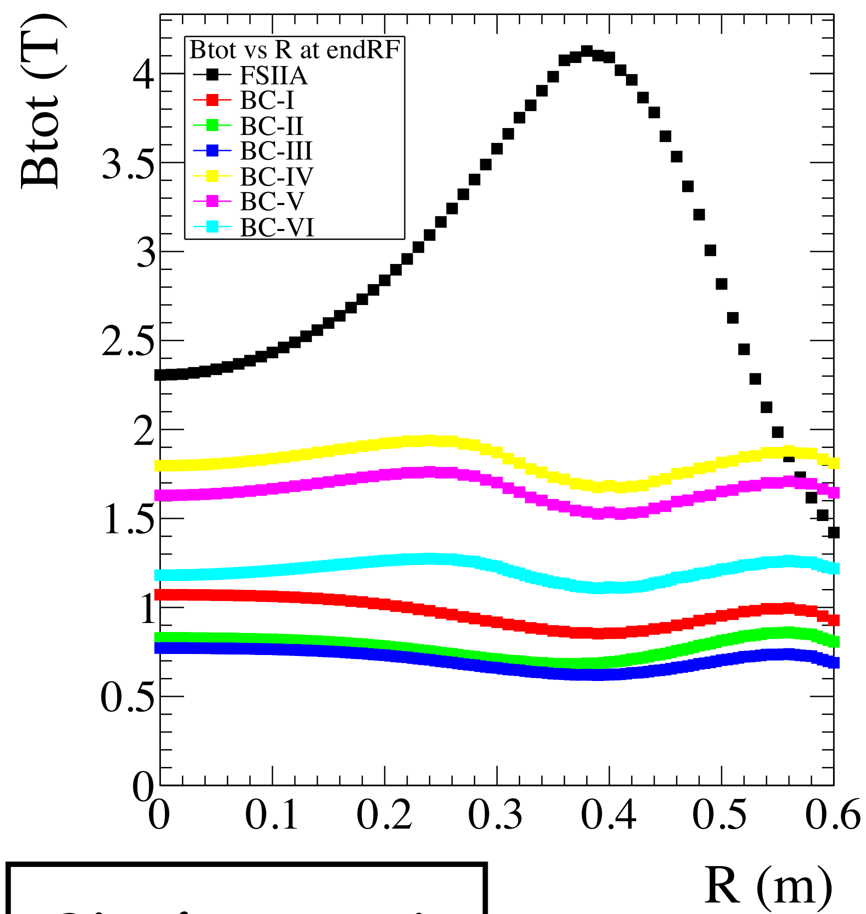

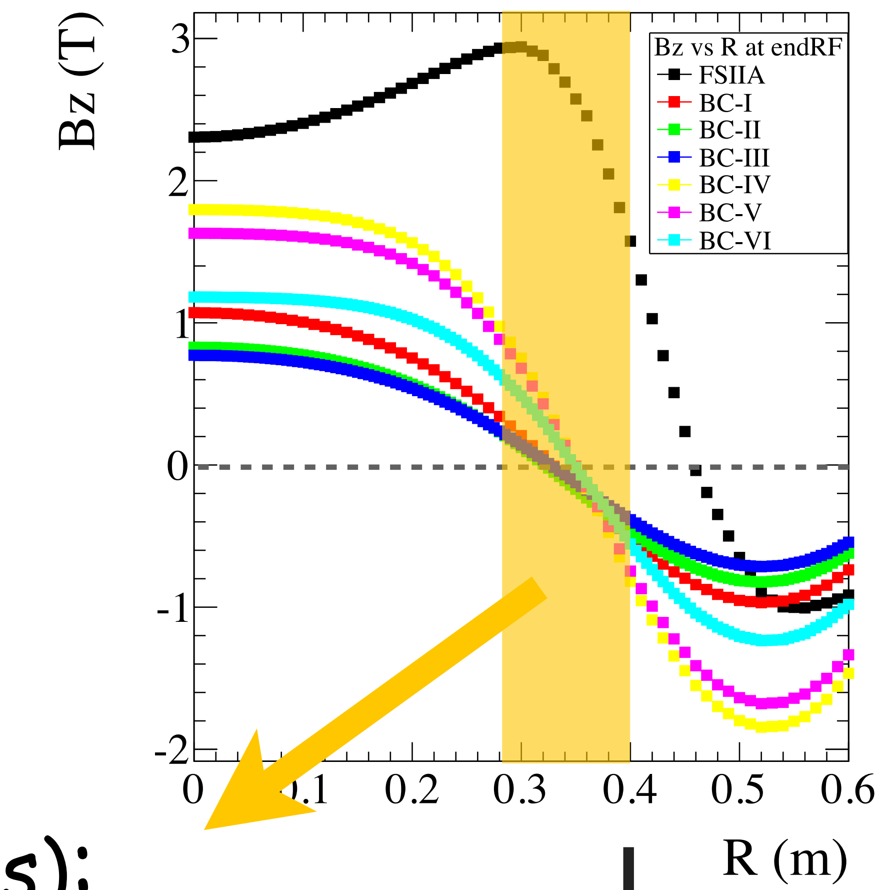

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R~30 cm (iris):

very sensitive area

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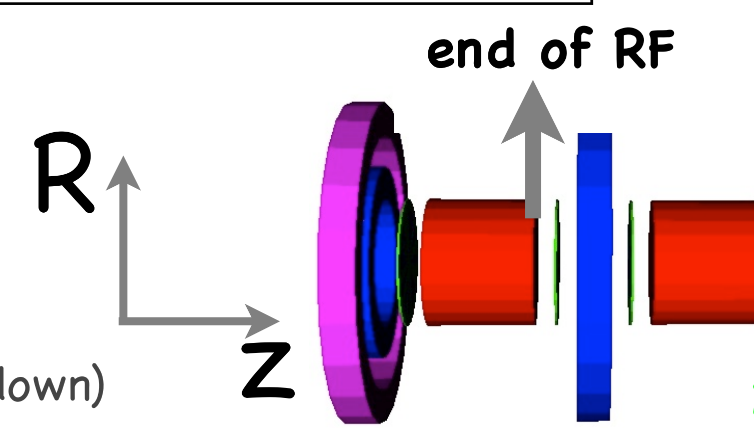

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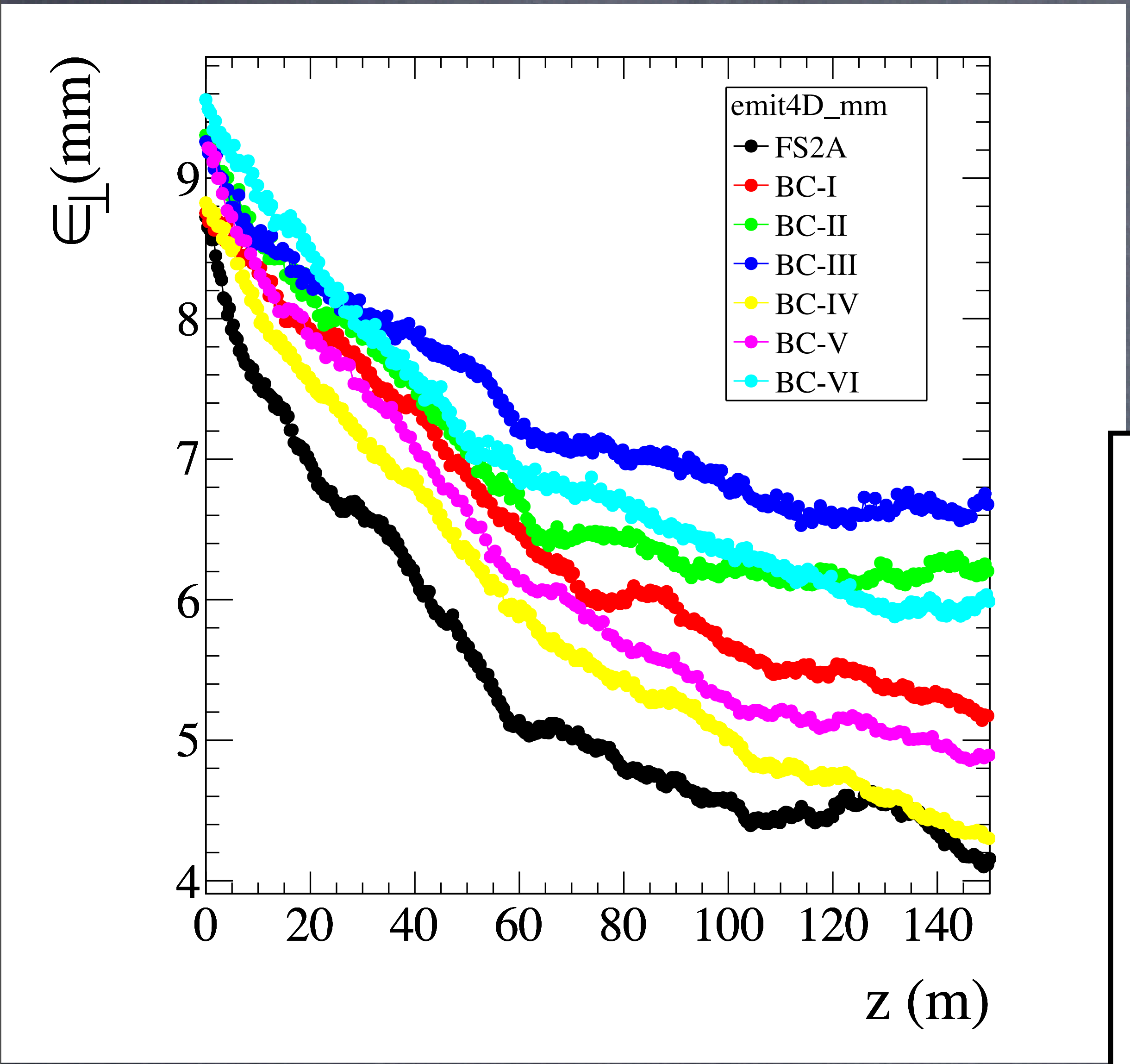
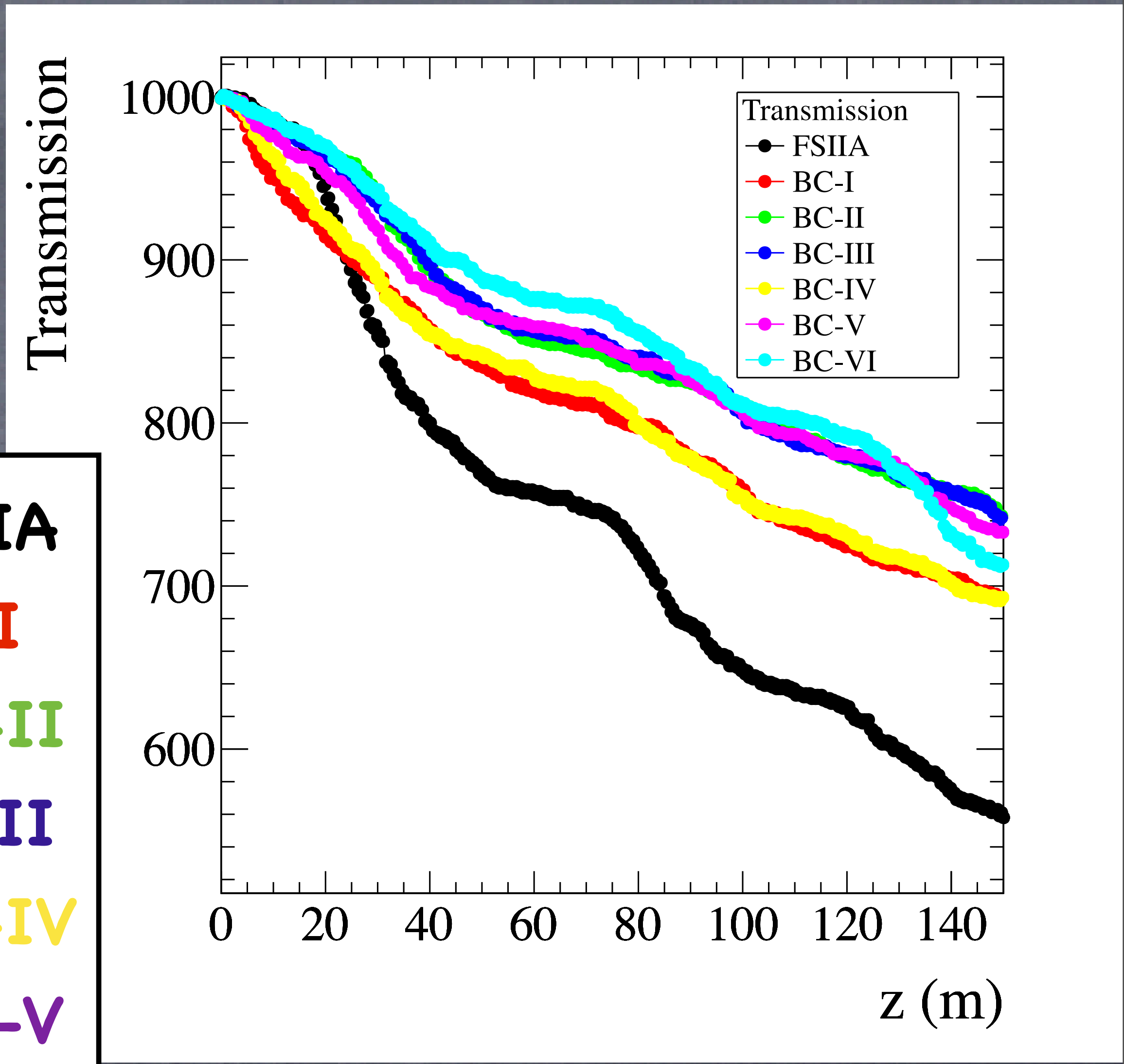
Simulation

- G4MICE (beam also matched using Optics application of G4MICE)
- 1,000 muons
- Gaussian P distribution centred at 232 MeV/c (σ_{RMS}:18.33 MeV/c)
- 10 mm transverse emittance
- 0.07 ns longitudinal emittance
- Muon decays, mcs, straggling: ON

FSIIA vs BC: beam cooling and transmission





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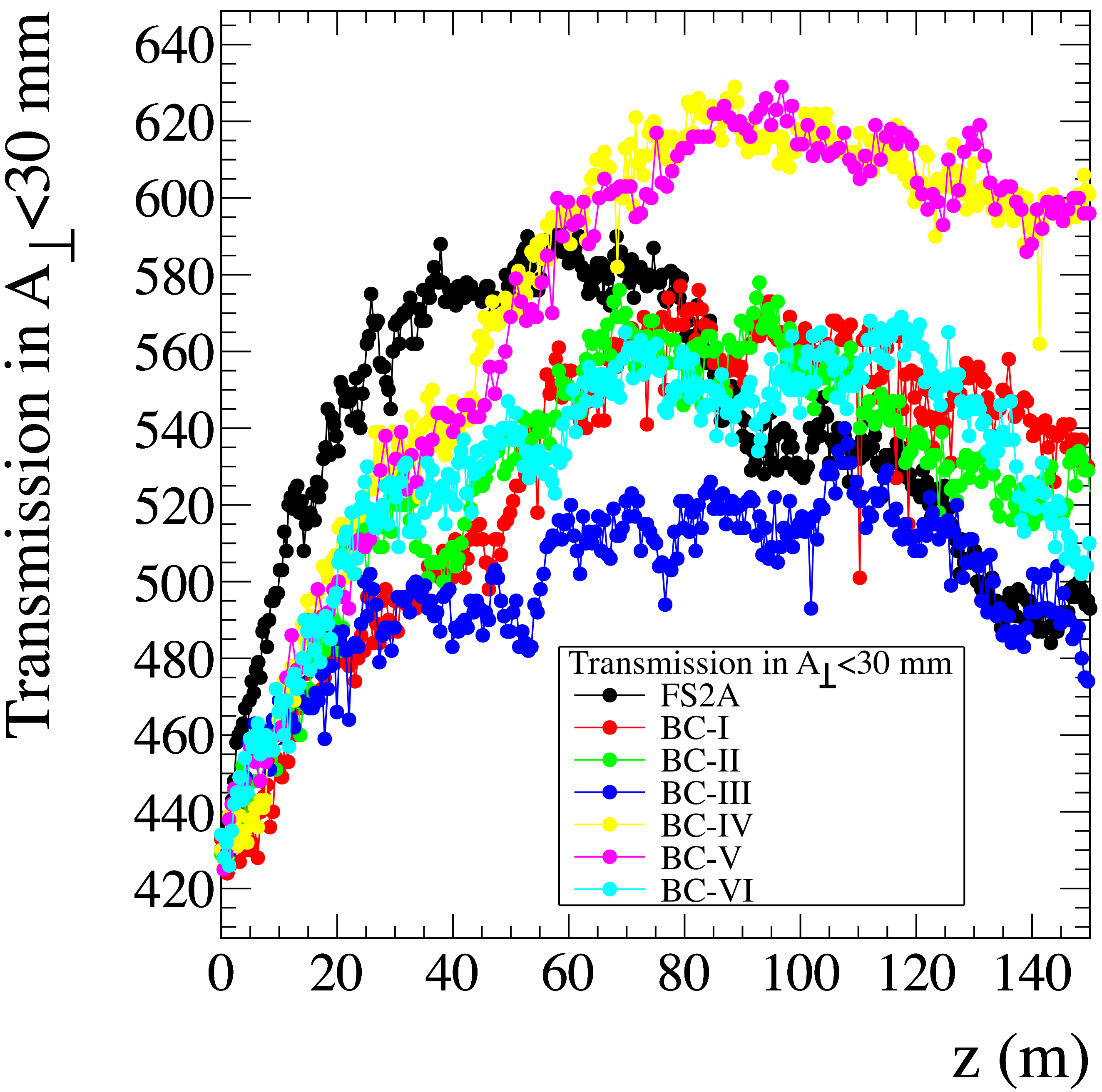
Better cooling for FSIIA and BC-IV

FSIIA: ~55%
BC's: ~70-75%

FSIIA vs BC: transmission in A_T<30 mm



- BC-IV, -V: best transmission at 90 m
- FSIIA max at 70 m
- BC-I, -II, -VI:<2% lower than FSIIA at 70 m
- BC-III:~6-7% lower than FSIIA at 70 m

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Lattice	35 cm
FSIIA	238.9

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BC-II	249.9
BC-III	188.2
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BC-V	304.0
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Only BC-III and BC-VI are below the 200 MPa limit!

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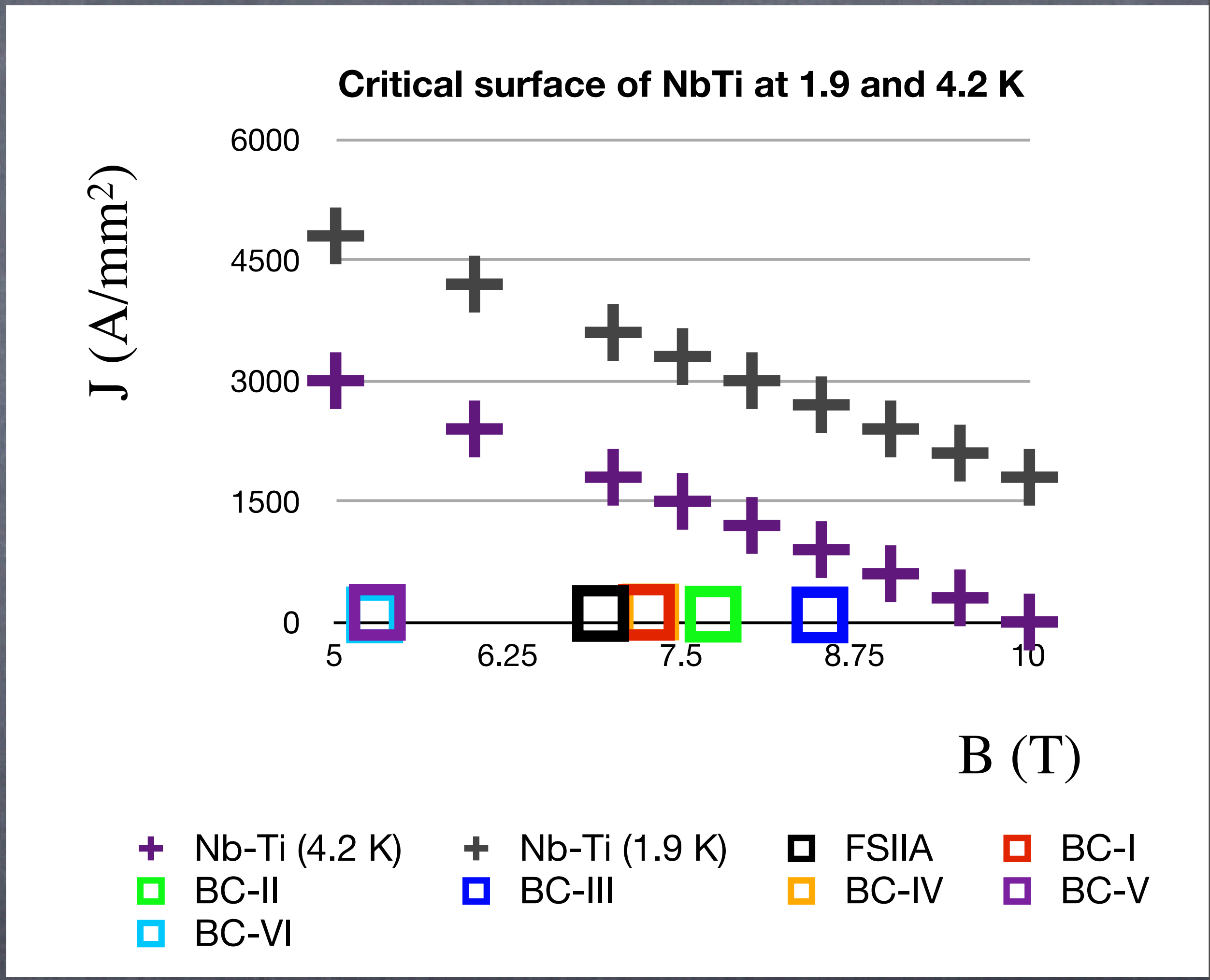

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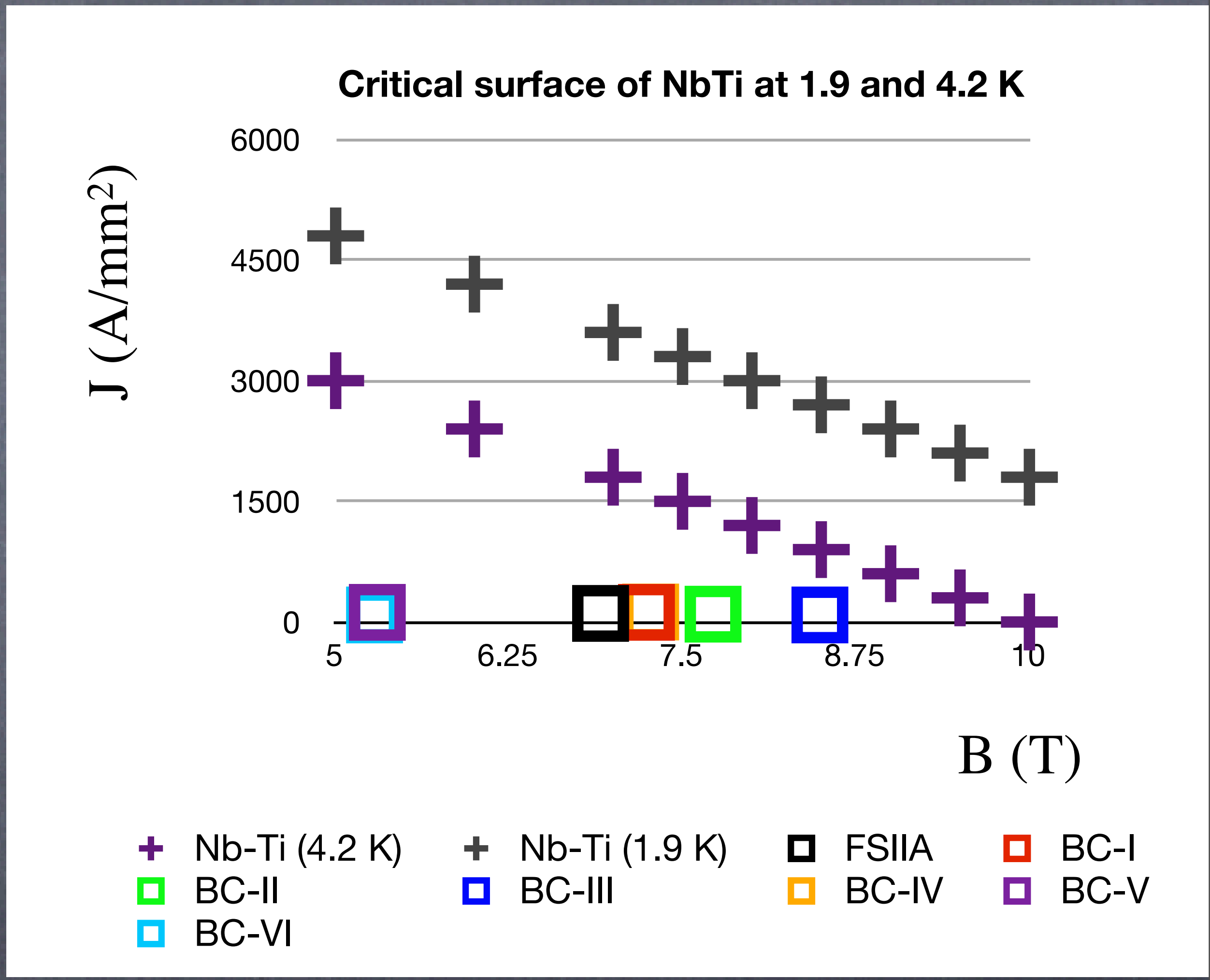

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All lattices are within the limits of superconducting operation

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- There is an effort to verify my results with G4BL and ICOOL (D. Stratakis, Brookhaven National Laboratory)

Conclusions on Bucked Coils

- The reference cooling lattice of the Neutrino Factory, FSIIA, performs well wrt transmission and cooling dynamics **BUT** has large B at RF cavities.
- High B at RF cavities can lead to RF breakdown → **Is FSIIA feasible???**
- My contribution: I proposed and designed a new cooling lattice, Bucked Coils lattice (BC) that uses a pair of bucked coils (rather than one) aiming to reduce B while achieving comparable transmission and cooling dynamics to FSIIA
- 6 versions of BC were presented:
    - all of them reduce **significantly** the magnetic field (B) at the RF position
    - all of them achieve comparable transmission within 30 mm of A_T to FSIIA
- Only 2 lattices are within the hoop stress limit, and both are BC
- There is an effort to verify my results with G4BL and ICOOL (D. Stratakis, Brookhaven National Laboratory)
- My lattice is now the main alternative to FSIIA. In June it will be decided if BC will replace FSIIA

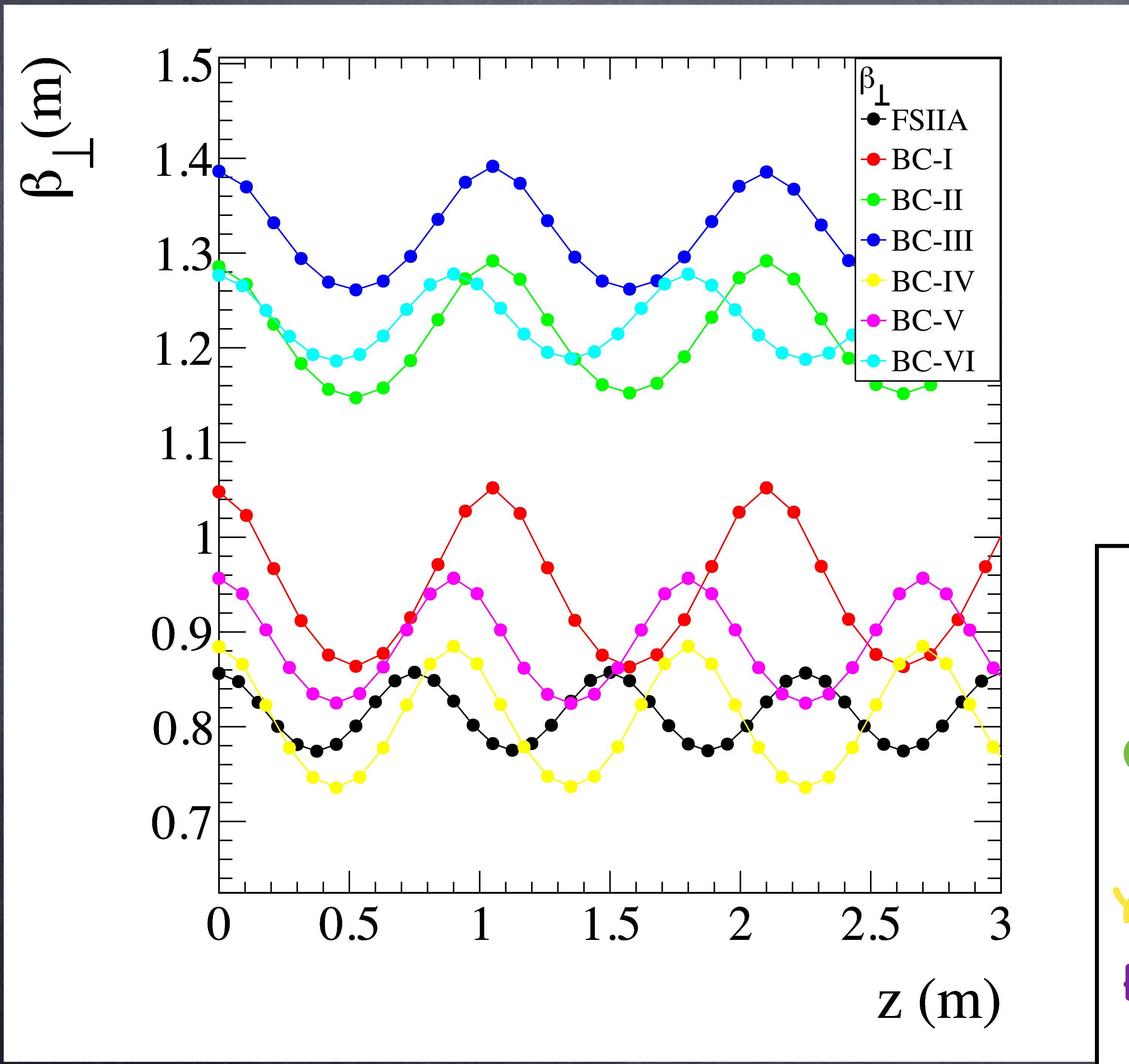
Where I could contribute

- Beam dynamics:
  - emittance reduction
  - beam-matter interactions
  - RF cavity studies
- SC magnet design

Thank you!

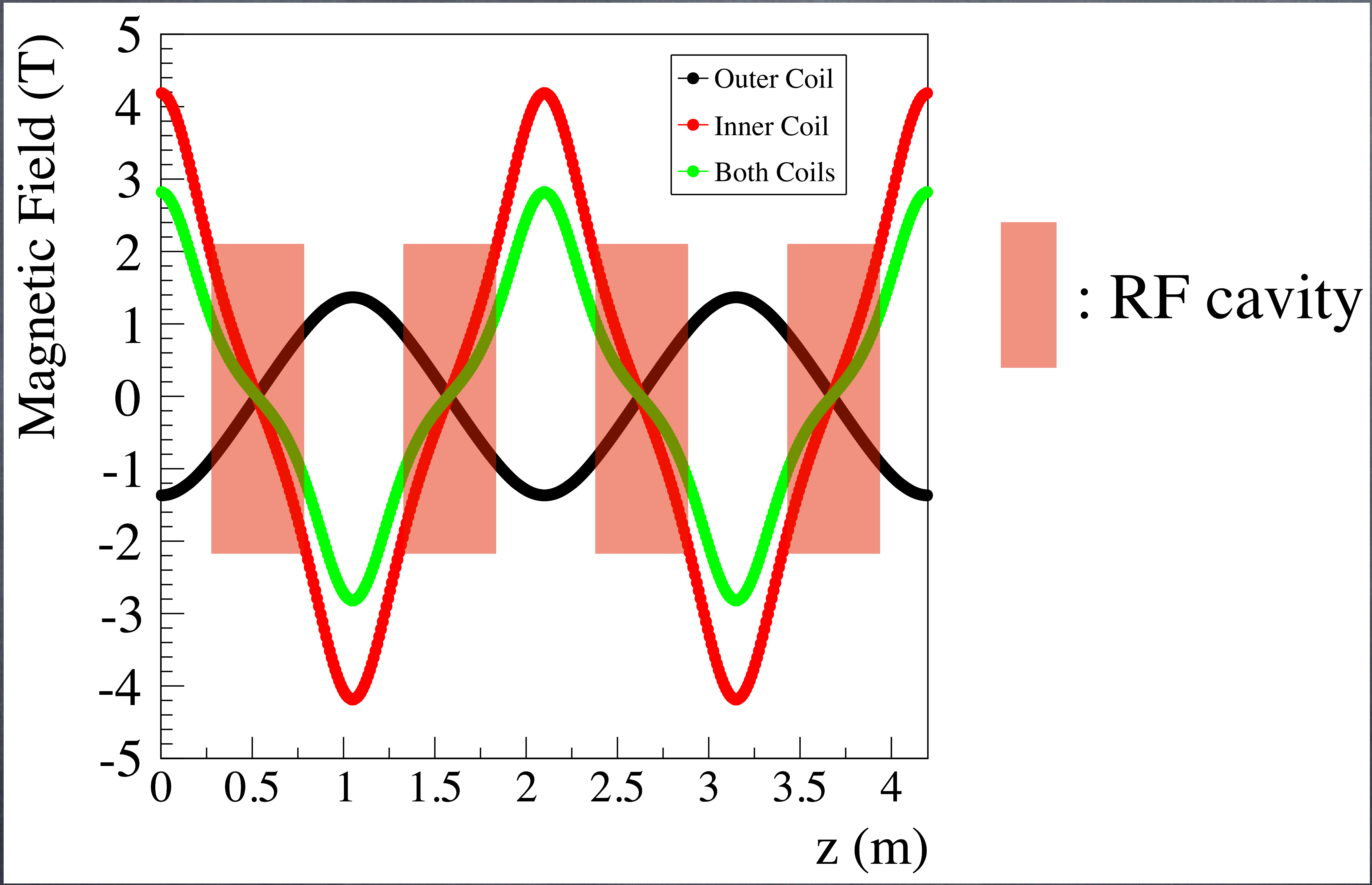
Transverse betatron function

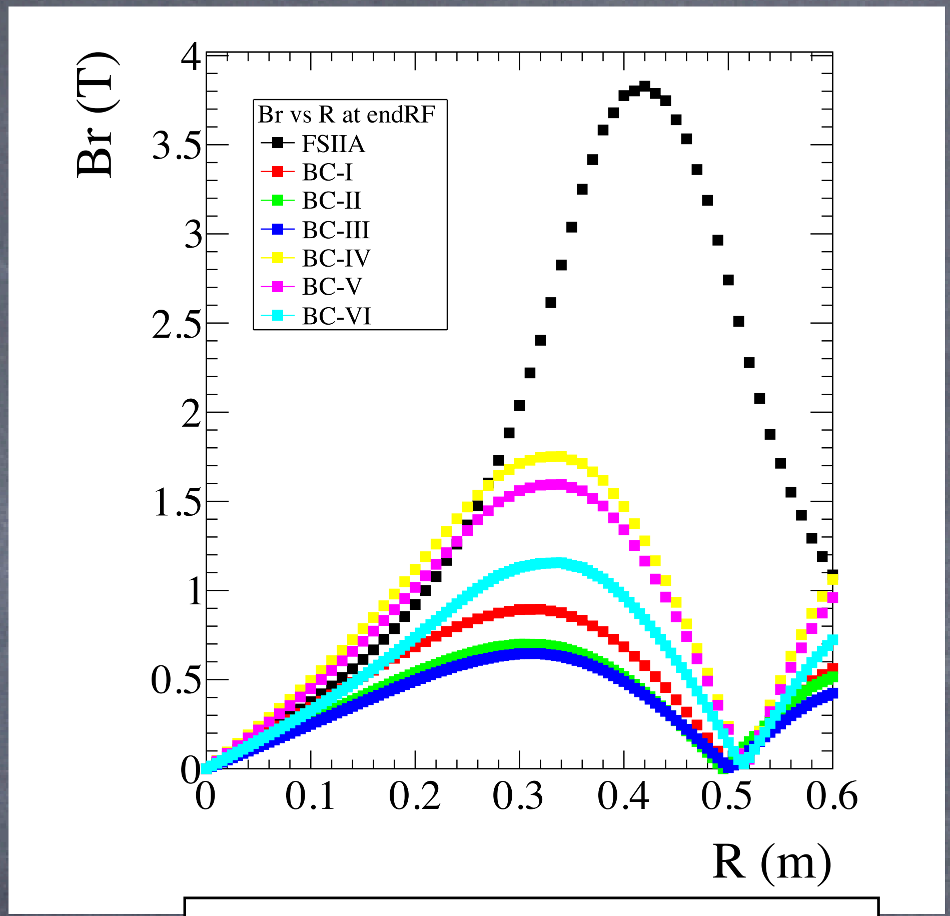
- Using the Optics application of G4MICE



- Lower β_T ->smaller equilibrium emittance ->better cooling
- FSIIA and BC-IV have smallest β_T values-> expect lowest equilibrium emittance
- Expect worse cooling for BC-II, -III and -VI

Black: FSIIA
Red: BC-I
Green: BC-II
Blue: BC-III
Yellow: BC-IV
Purple: BC-V
Cyan: BC-VI


Magnetic Field (T)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.5
1
1.5
2
2.5
3
3.5
4
z (m)
Outer Coil
Inner Coil
Both Coils
: RF cavity



FSIIA~4 T

BC-I, BC-II, -III<1 T

BC-IV, -V, -VI<2T