FFA – Injection and Code Comparison

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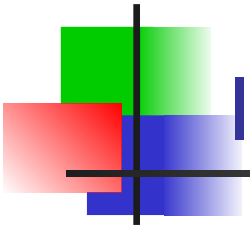
Science & Technology Facilities Council
ISIS

Introduction

- Injection into FFA has been done with H- and charge exchange injection
- Synchrotrons typically use phase space painting techniques
- Can we apply phase space painting techniques in FFA?
  - Particular application to 3 MeV
- Charge exchange injection at 3 MeV
- Injection scheme into horizontal FFA using pulsed magnets
- Code comparison between OPAL, FIXFIELD (JB Lagrange) and SCODE (S Machida)
- Injection scheme into vertical FFA using pulsed magnets

Injection Schemes

- Considering two injection schemes
  - Proton injection with tilted septum and phase space painting
    - C. Prior studying optimisation of painting scheme
    - May require tune control during injection
  - H- charge exchange injection
    - C. Brown (Brunel) studying foil physics at 3 MeV



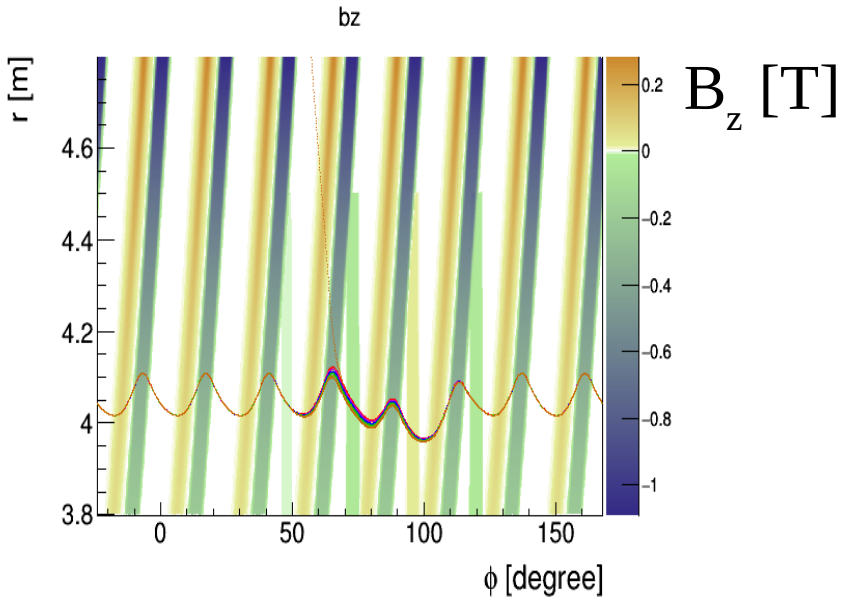
Injection

- Basic scheme is to inject H- ions through a foil
- Foil strips the electrons so we get H+ ions
- Accumulate a beam by painting over many turns
  - Slowly moving the recirculating beam so that we can “paint” an emittance
- Foil:
  - What thickness of foil is required?
    - Keep it as thin as possible to reduce scattering
  - How hot does the foil get?
- Magnets:
  - Can we inject the beam in short straight sections?
  - What field is required?
  - What are the requirements on power supply?

Scaling (horizontal) FFA Injection

Injection From Outer Radius

Energy	3 MeV – 12 MeV
Tune	0.1932 (h), 0.2404 (v)
Number of cells	15
Radius	4.0 – 4.8 m
k	7.2
Spiral Angle	41^{o}

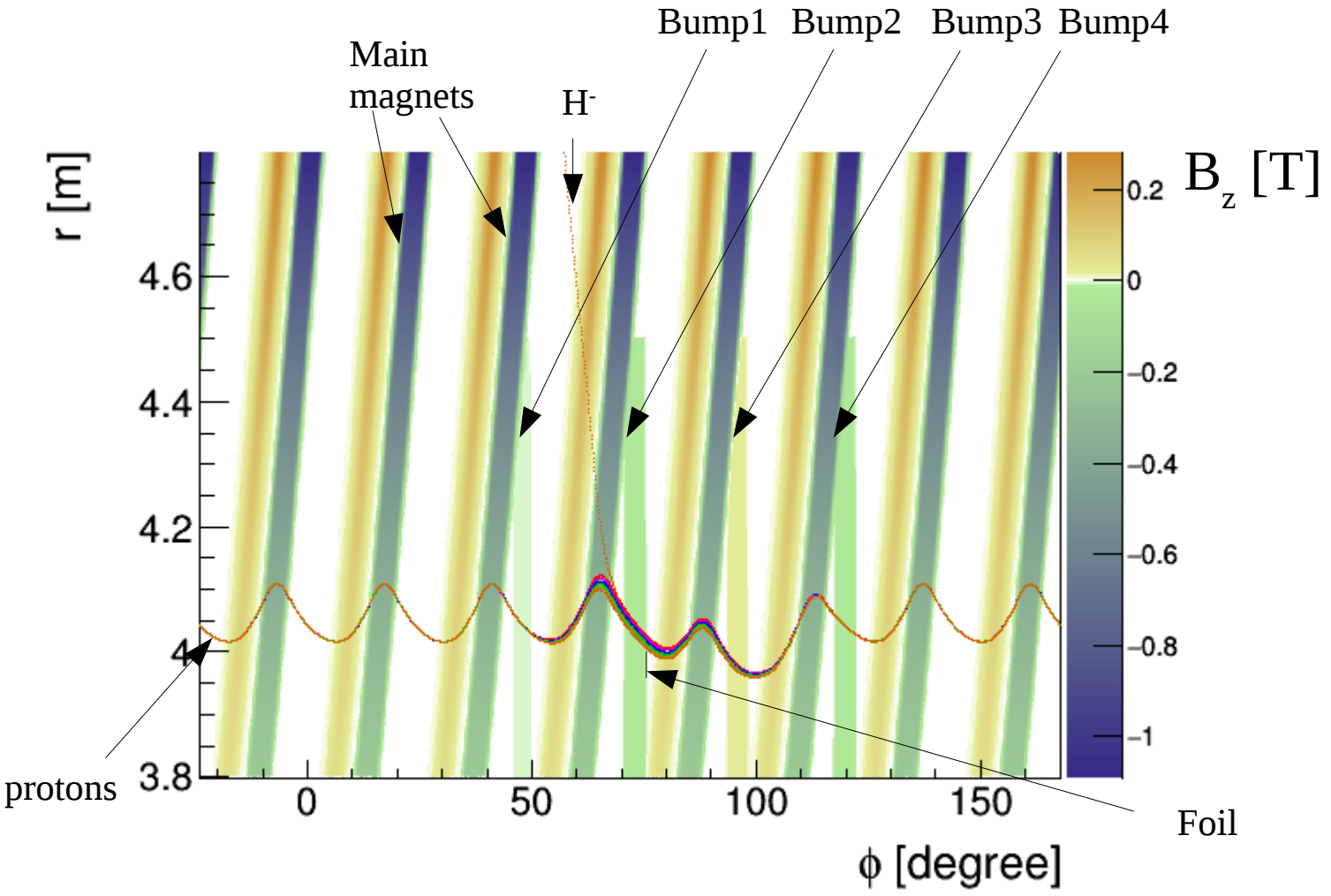


(S. Machida)

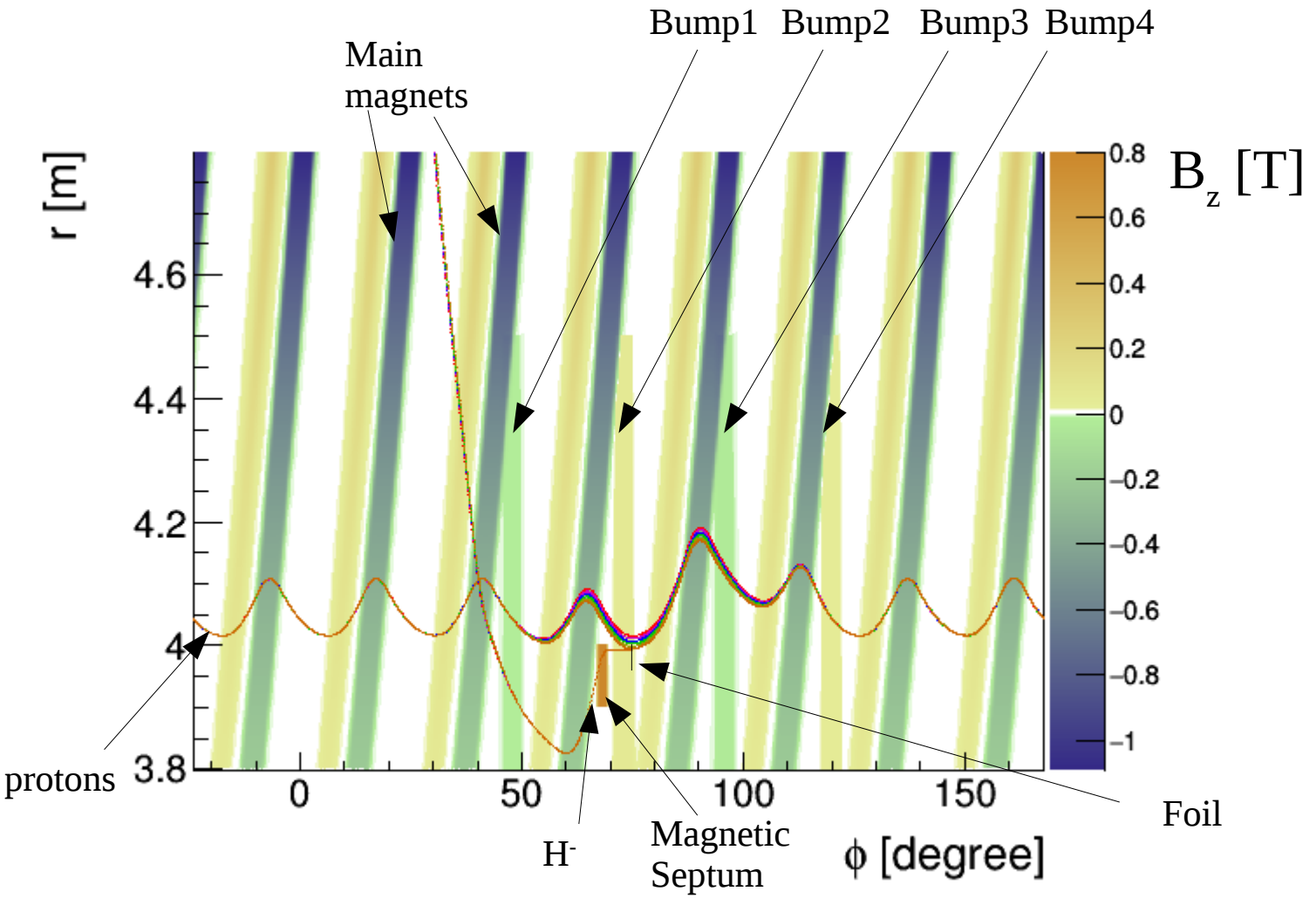
Bump Magnets

- Challenging to find space for bump magnets in a single cell
- Spread magnets over several cells
  - Phase advance ~ 78^{o} per cell
- Use 4 magnets
  - One magnet to control position of H^{+} relative to the foil
  - One magnet to control position of H^{-} relative to injection line
  - Two magnets to capture H^{+} back onto closed orbit (x, x')
- Two injection schemes:
  - From outer radius using bump magnets in cell -1, 0, 1, 2
  - From inner radius using septum and bump magnets in cell -1, 0, 1, 2

Injection From Outer Radius

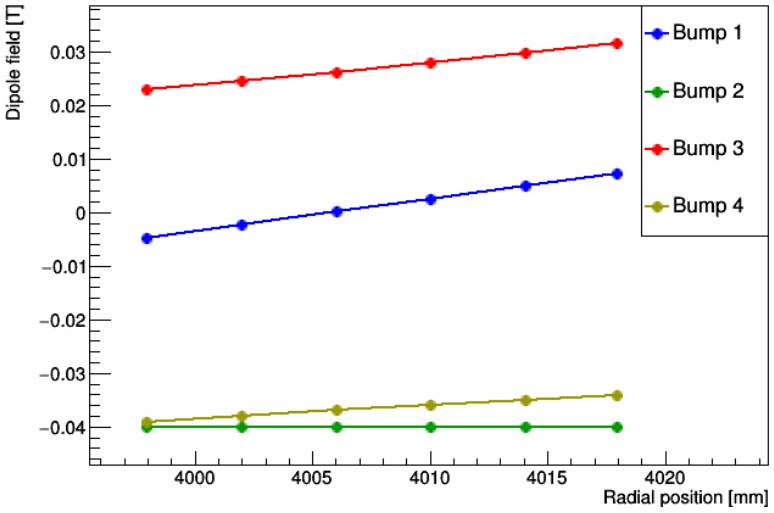


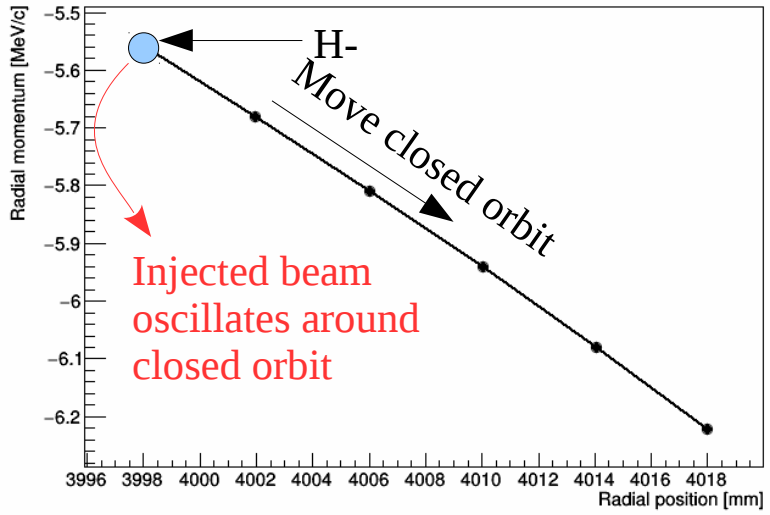
Injection From Inner Radius



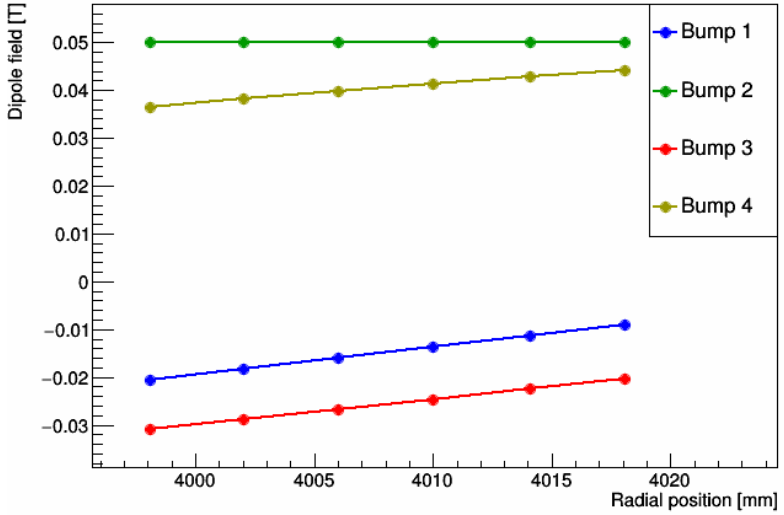
Field Strengths

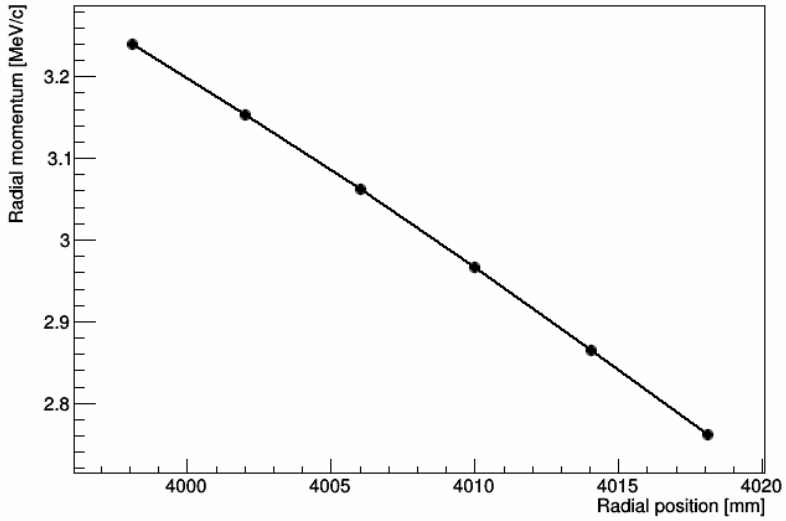
Inject from outer radius



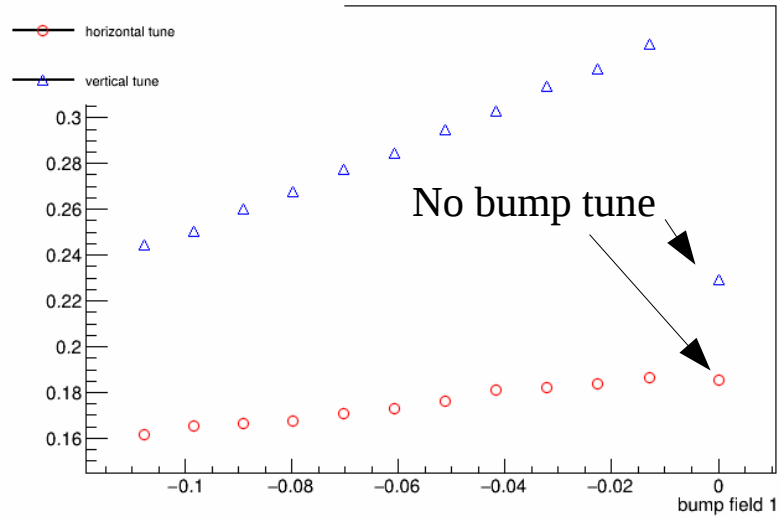


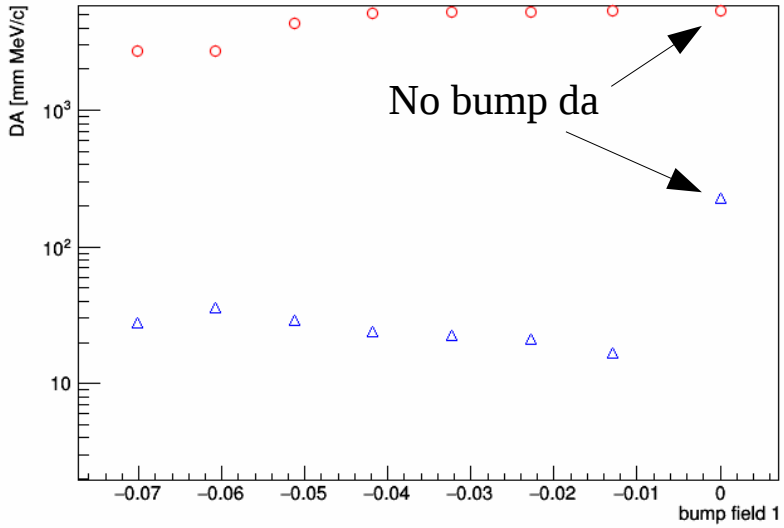
Inject from inner radius





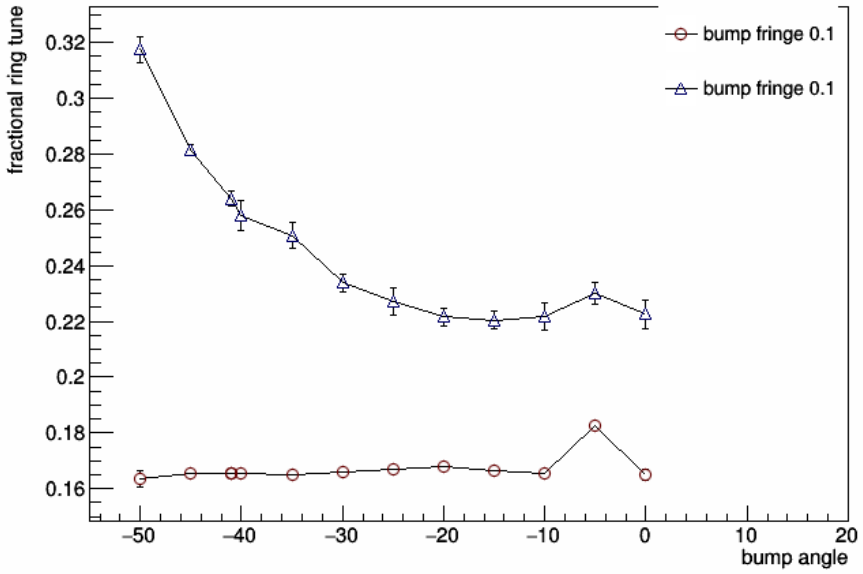
Option 1 – ring tune/DA

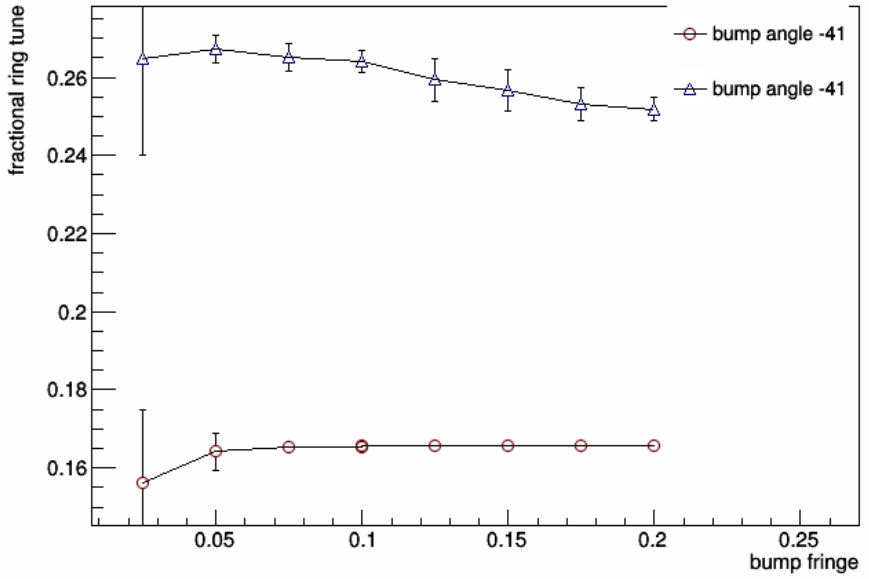




- Option 1
- Significant vertical tune excursion
- Reduced vertical DA (note log scale)
  - Nb dipole fieldmap vertical aperture is 0.2 m
  - Dipole field expanded to 3rd order off-axis with fringe field 10 mm long

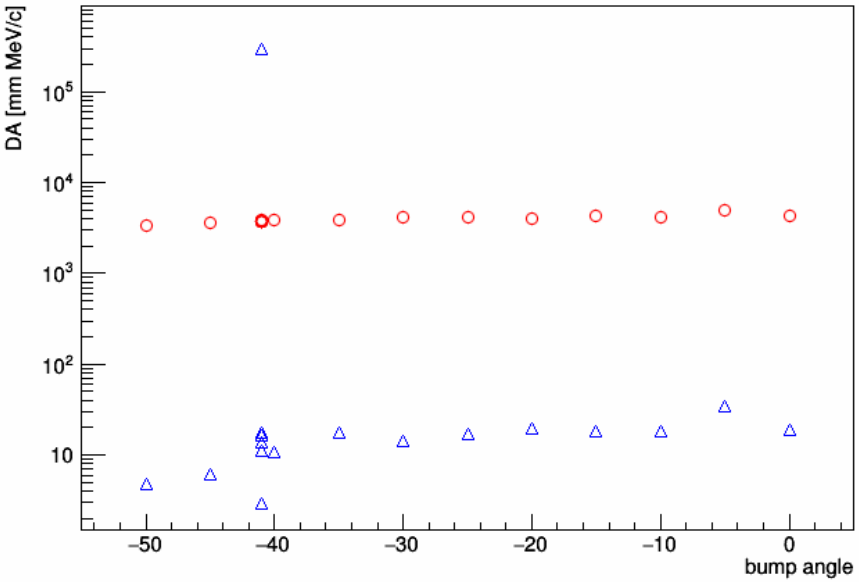
Tune dependence

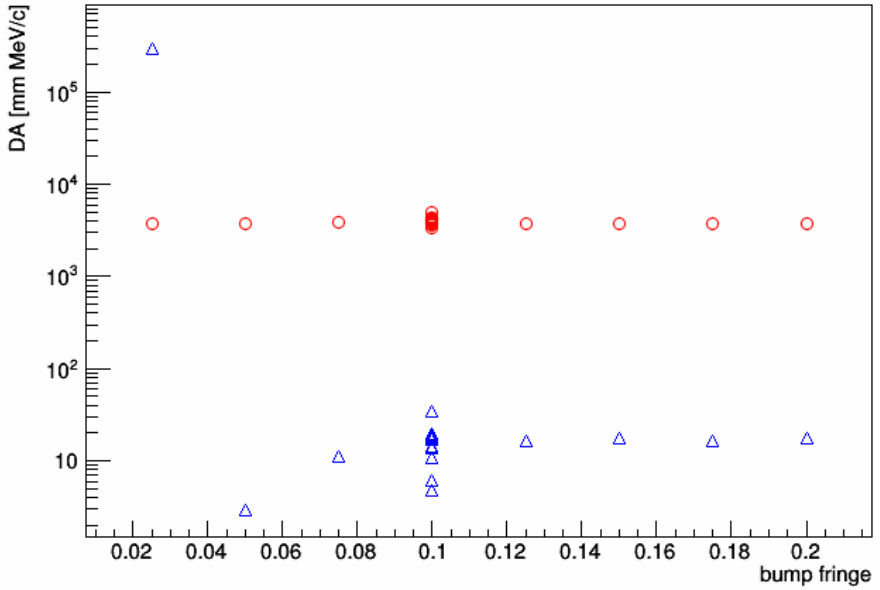




- Tune vs angle
- Tune vs fringe field

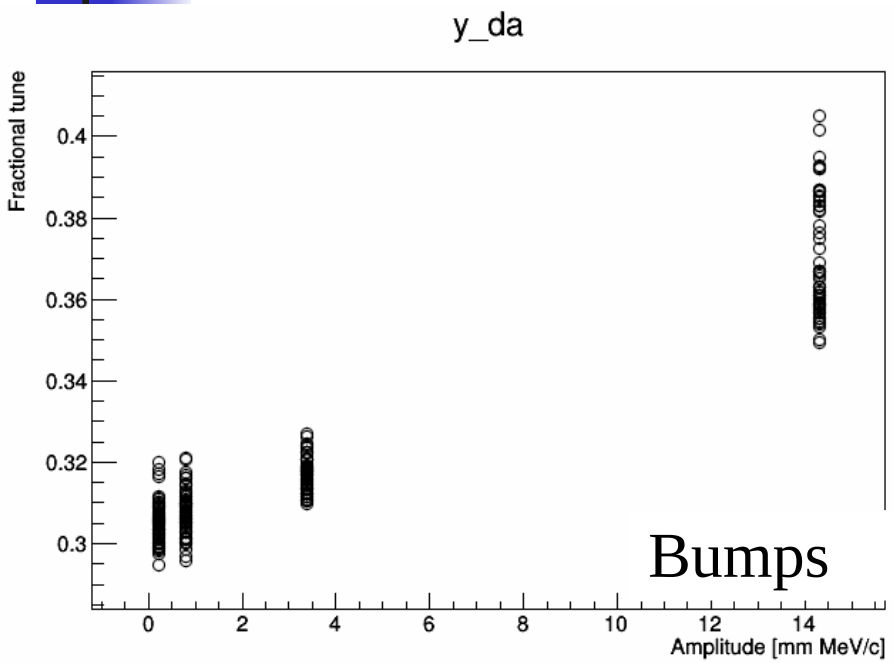
DA dependence

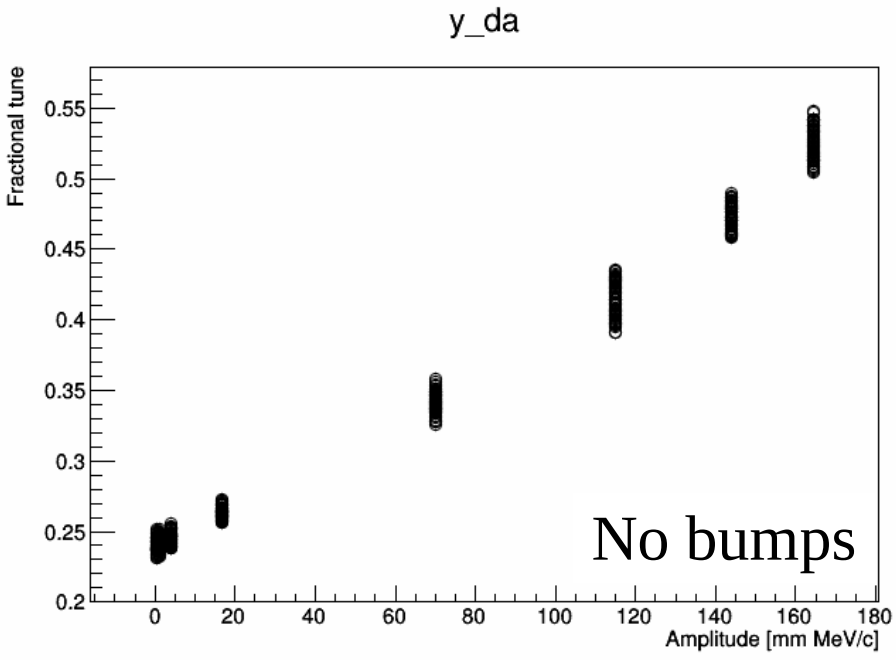




- DA independent of angle
- DA quite independent of bump fringe field extent
- What is causing DA?

What drives dynamic aperture





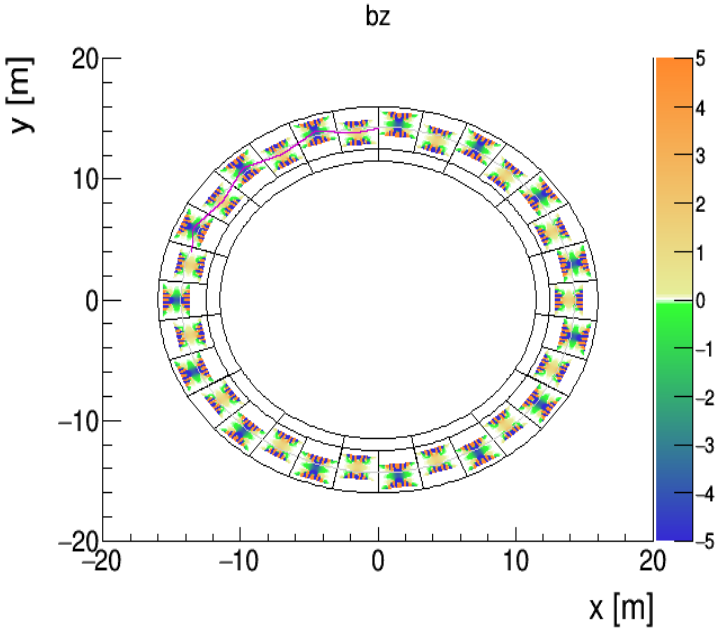
- What drives dynamic aperture?
  - Vertical tune distortion?
- Nonetheless, optics design meets requirements
- Needs study with “realistic” magnets

VFFA – Code Comparison

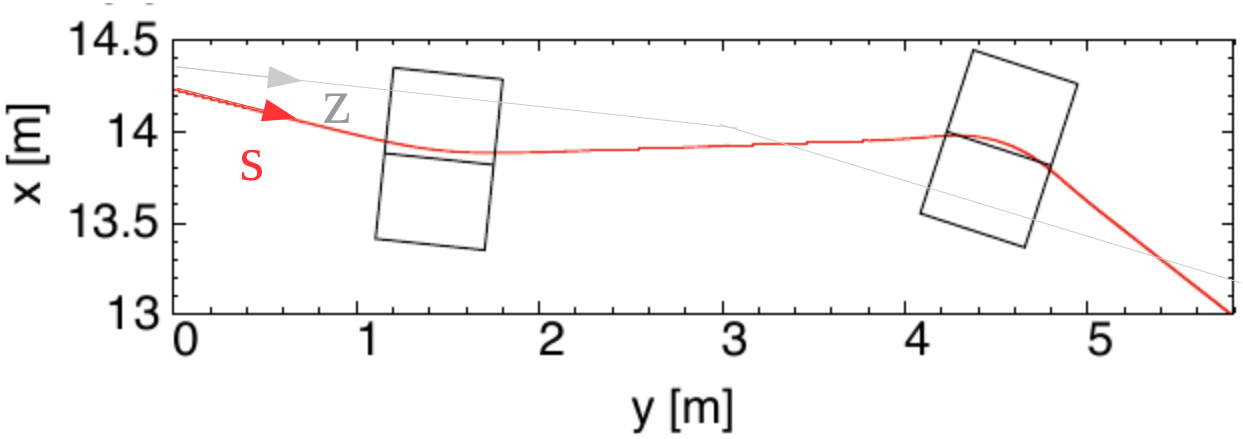
VFFA simulation

- VFFA modelled using usual field expansion
- Track using 4th order Runge Kutta
- OPAL (A. Adelmann et al; FFA mods by C Rogers)
  - Fields are placed in 3D world
  - Particle tracking occurs in 3D world with time as independent variable
- SCode (S. Machida) and FIXFIELD (JB Lagrange)
  - Fields are placed relative to a nominal axis, corresponding to half cell
    - Overlapping fields from neighbouring cells are added
  - Track through half cell
  - FIXFIELD integrates through s
    - Reference particle coordinates
  - SCODE integrates through z
    - Nominal coordinate system for each half cell
  - Rotate into coordinate system of next half cell

OPAL Geometry vs SCode/FIXFIELD

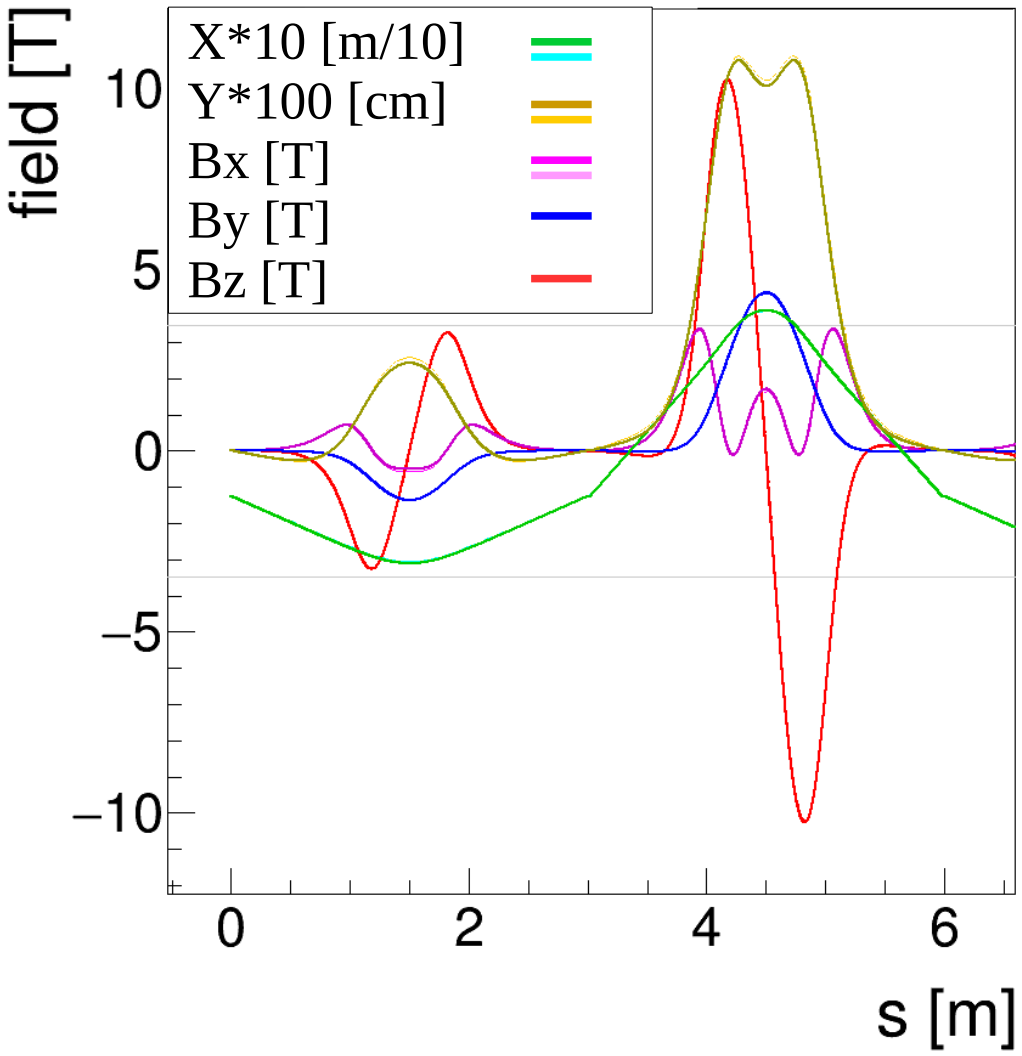


OPAL

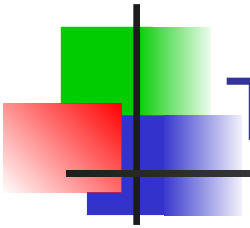


Scode
And FixField

Comparison of Tracking



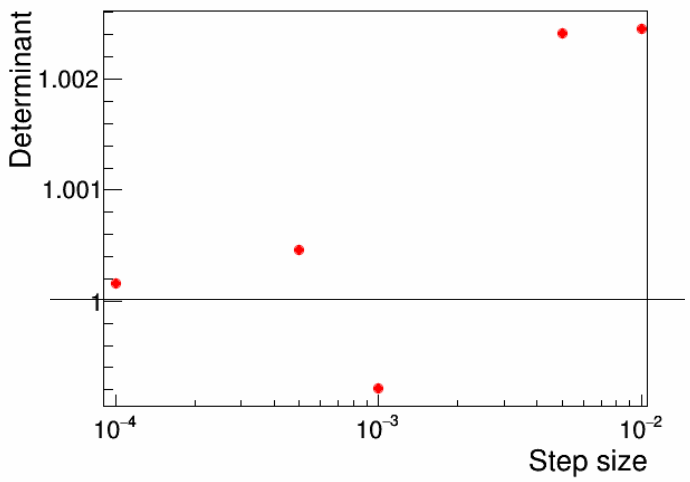
OPAL
vs
SCODE

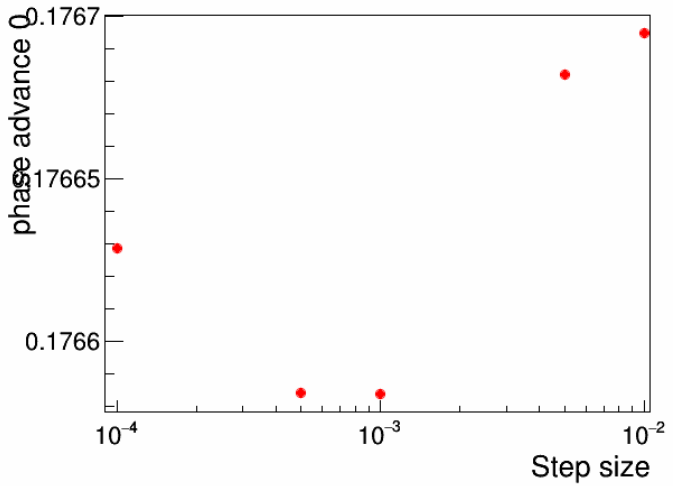


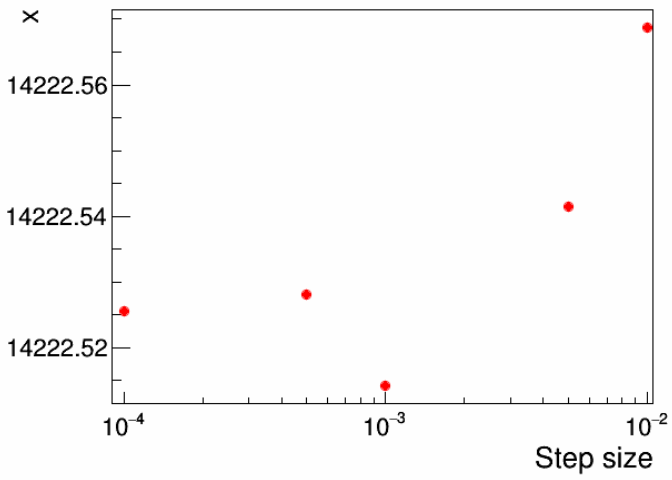
Tune Calculation

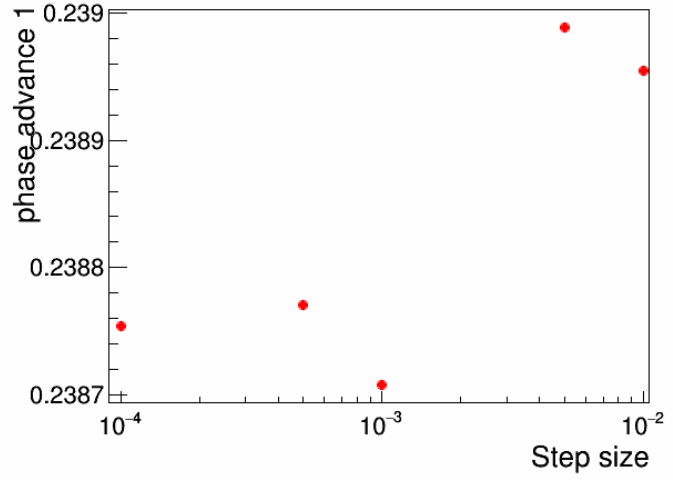
- Numerically calculate transfer matrix
  - Track particles at a small deviation from reference
- Decouple into 2D transfer matrices
  - E.g. Parzen routines
- Calculate tune of each transfer matrix
- OPAL
  - Coordinate system is r, y
- Scode, FixField
  - Coordinate system is transverse to reference trajectory

Tune - OPAL


Determinant
1.002
1.001
1
10^{-4}
10^{-3}
10^{-2}
Step size


phase advance 0
0.1767
0.17665
0.1766
10^{-4}
10^{-3}
10^{-2}
Step size


x
14222.56
14222.54
14222.52
10^{-4}
10^{-3}
10^{-2}
Step size


phase advance 1
0.239
0.2389
0.2388
0.2387
10^{-4}
10^{-3}
10^{-2}
Step size

Tune comparison

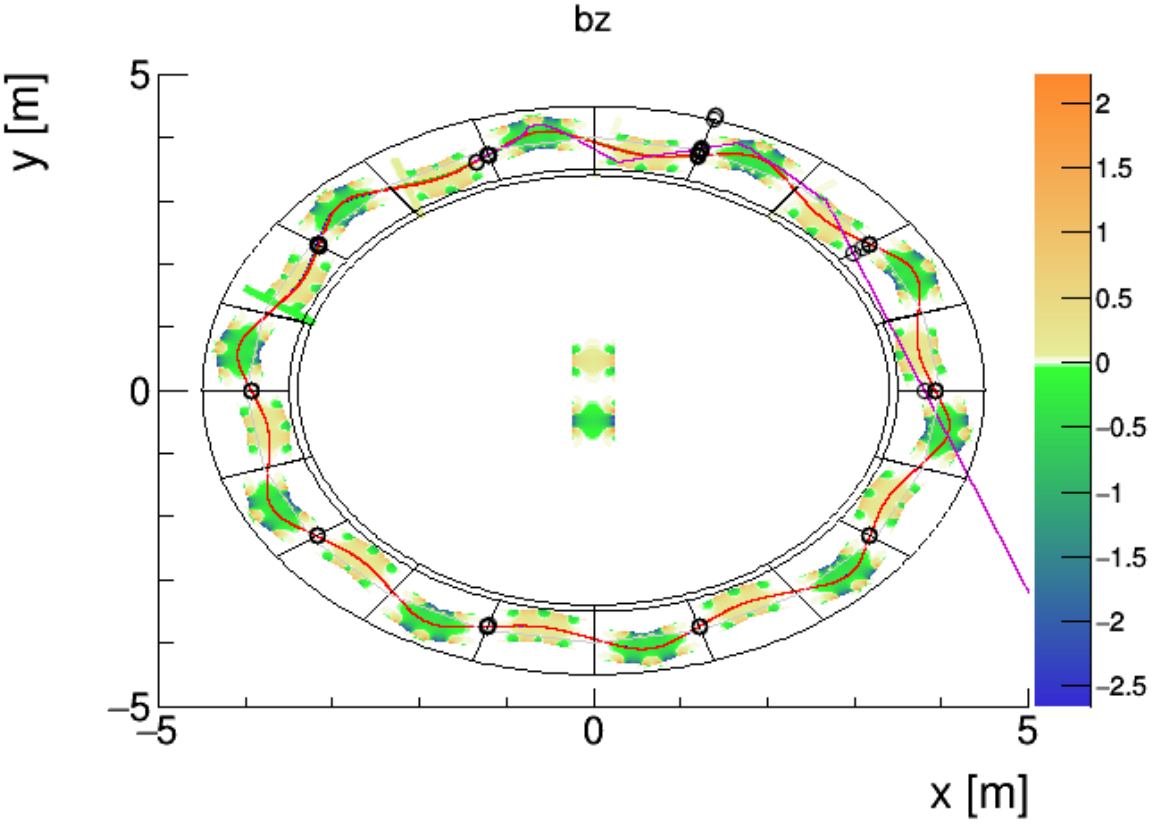
	u tune	v tune
SCODE+	0.184701	0.231858
FIXFIELD	0.18388	0.23218
MUON1	0.187858	0.230659
OPAL	0.17665	0.23876

VFFA – Injection

Questions about injection

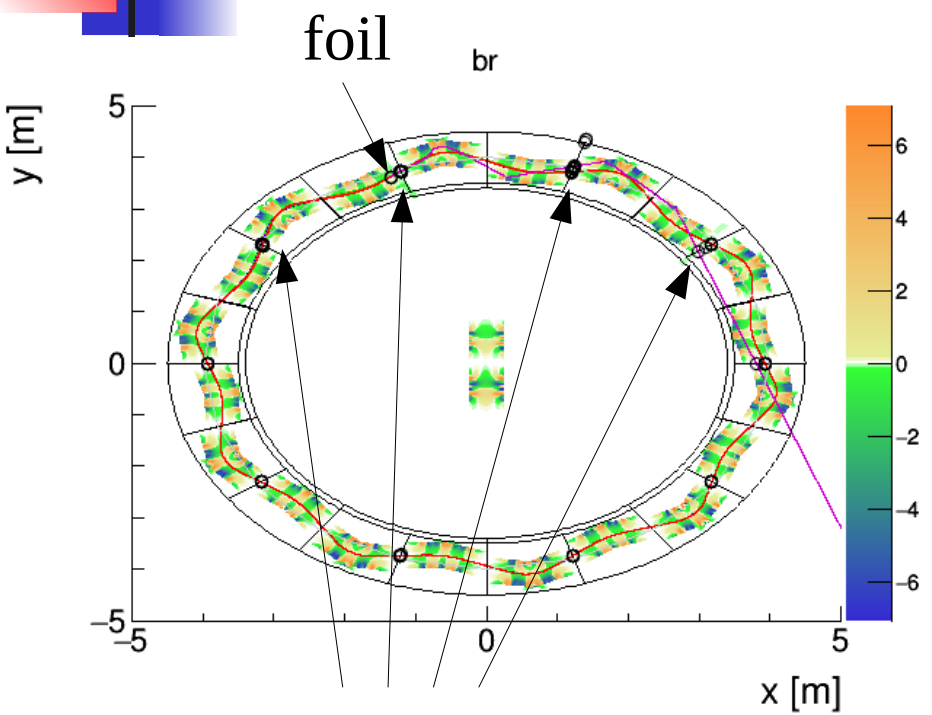
- Is there a feasible injection scheme for vFFA?
  - Can we do a multi-cell bump scheme?
  - Note shorter straights/big fringe field/no symmetry plane
  - Do we need stronger bump magnets?
  - Is vertical injection or horizontal injection preferred?
  - Any dynamic aperture issues as was seen in hFFA?
- Try to do something
  - Consider vertical injection first
  - Assume foil and magnetic septum first
  - Nb: most of these things are not dependent on details of the lattice optics (to 0^{th} order)

July Baseline

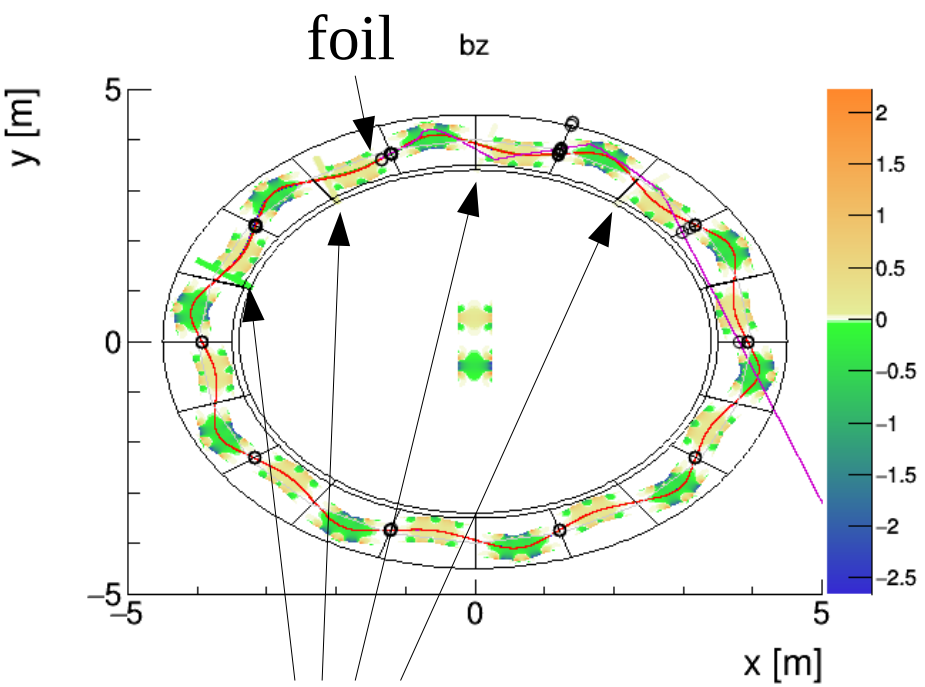


- 10 cell FODO lattice
- Two pairs of rotated rectangular vFFA magnets in each cell
- 3 MeV injection
- Some tuning to get similar tune to Shinji

Layout



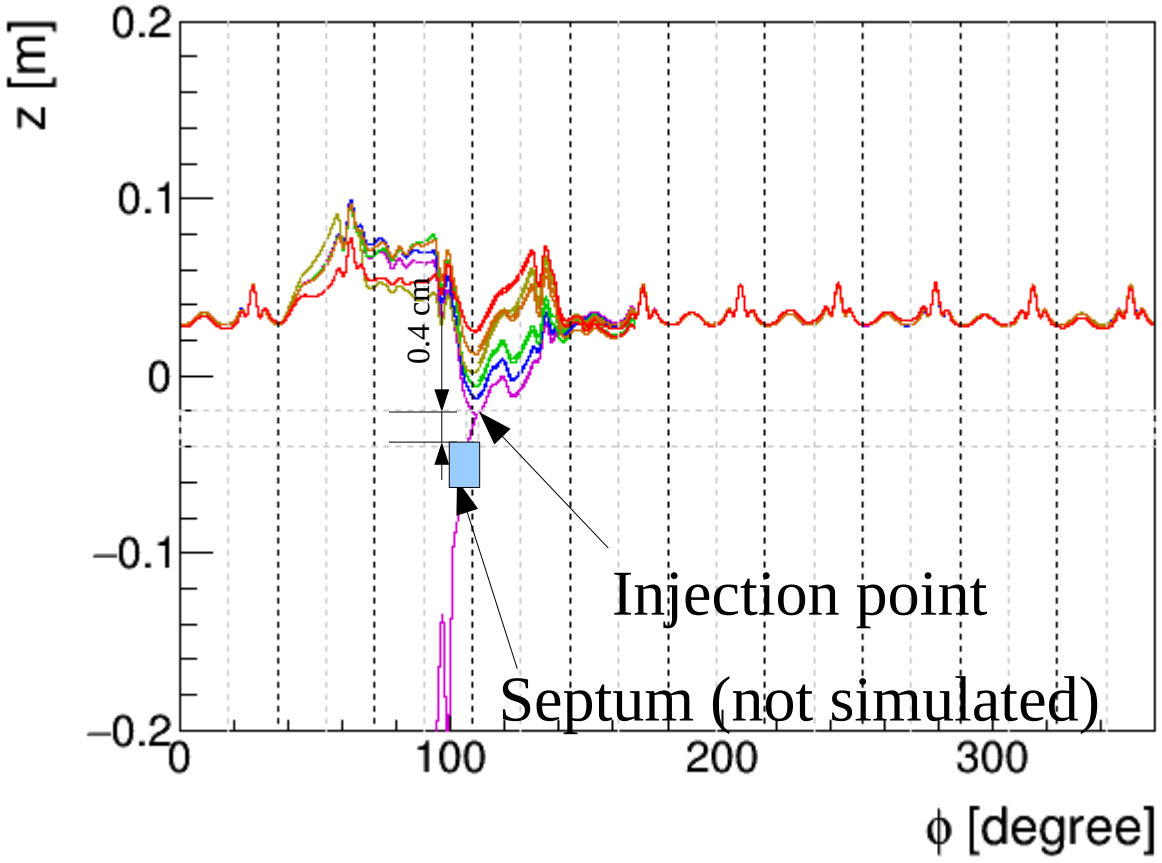
Br → vertical kick



Bz → horizontal kick

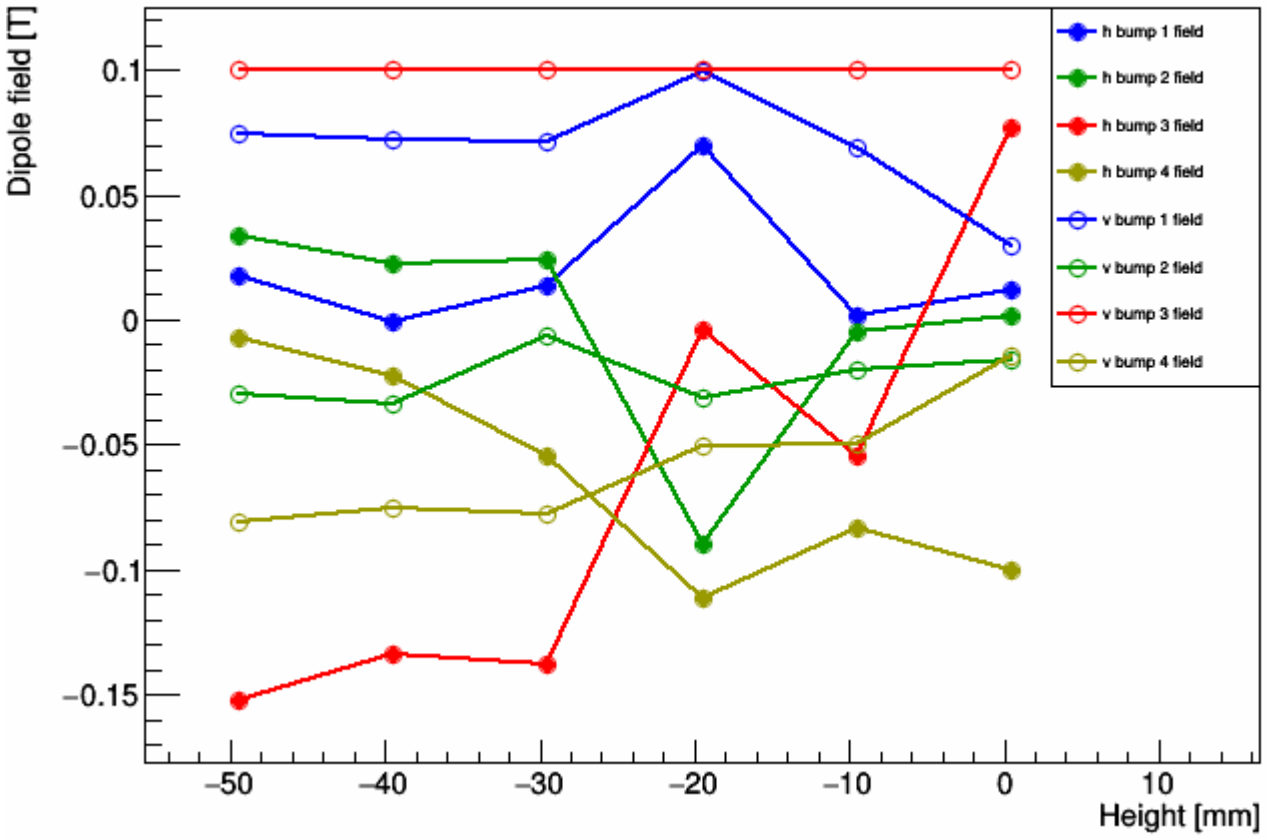
- Vertical bumper to control H-
- Vertical bumper to control position on foil
- Vertical bumper to catch (y and y’)
- Each vertical bumper has a corresponding horizontal bumper
  - Correct horizontal displacement at end of the magnet

Elevation



- Different colours correspond to different magnet settings
  - Not much clearance for septum

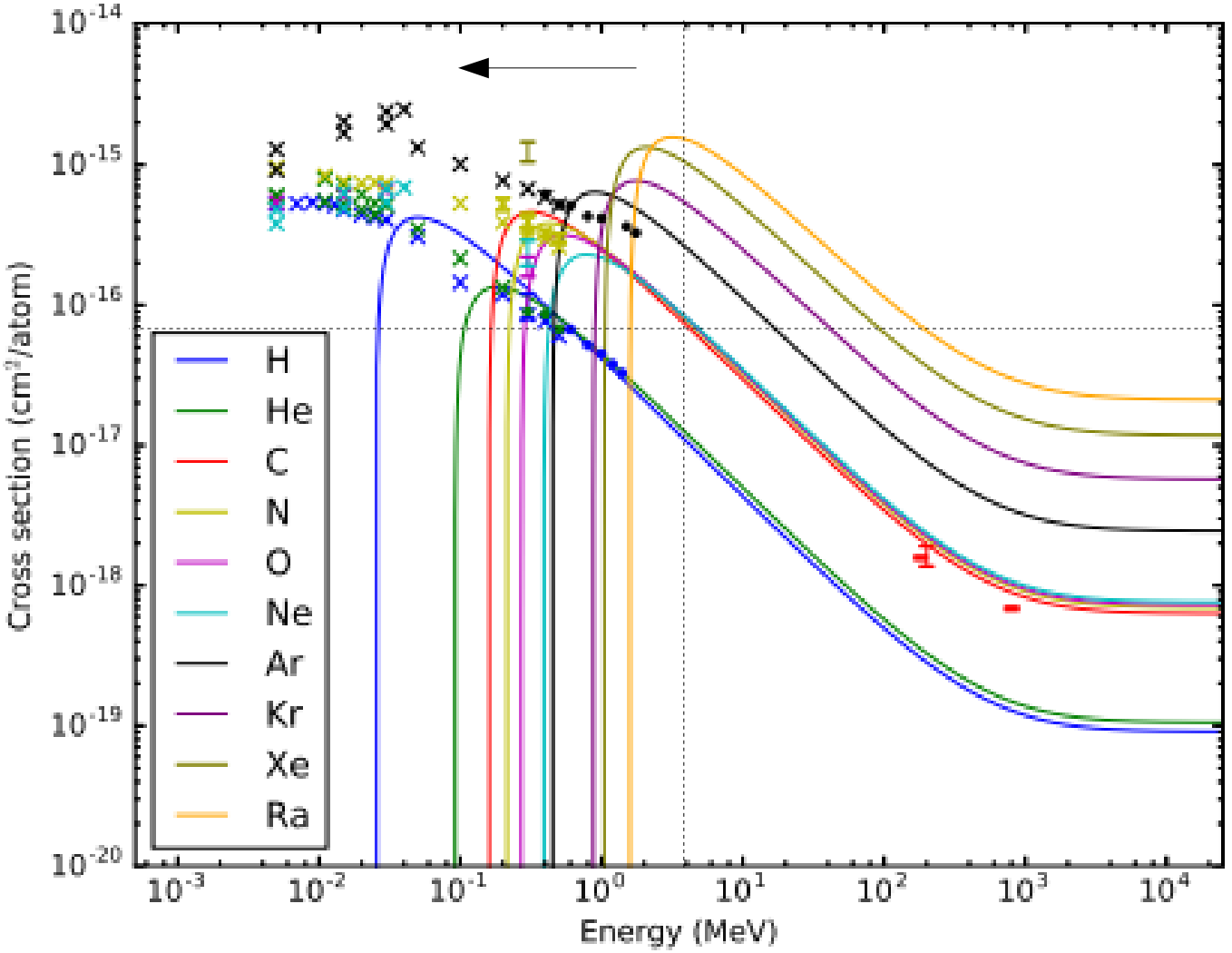
Bump fields



- Bump fields not varying monotonically
  - Underconstrained?

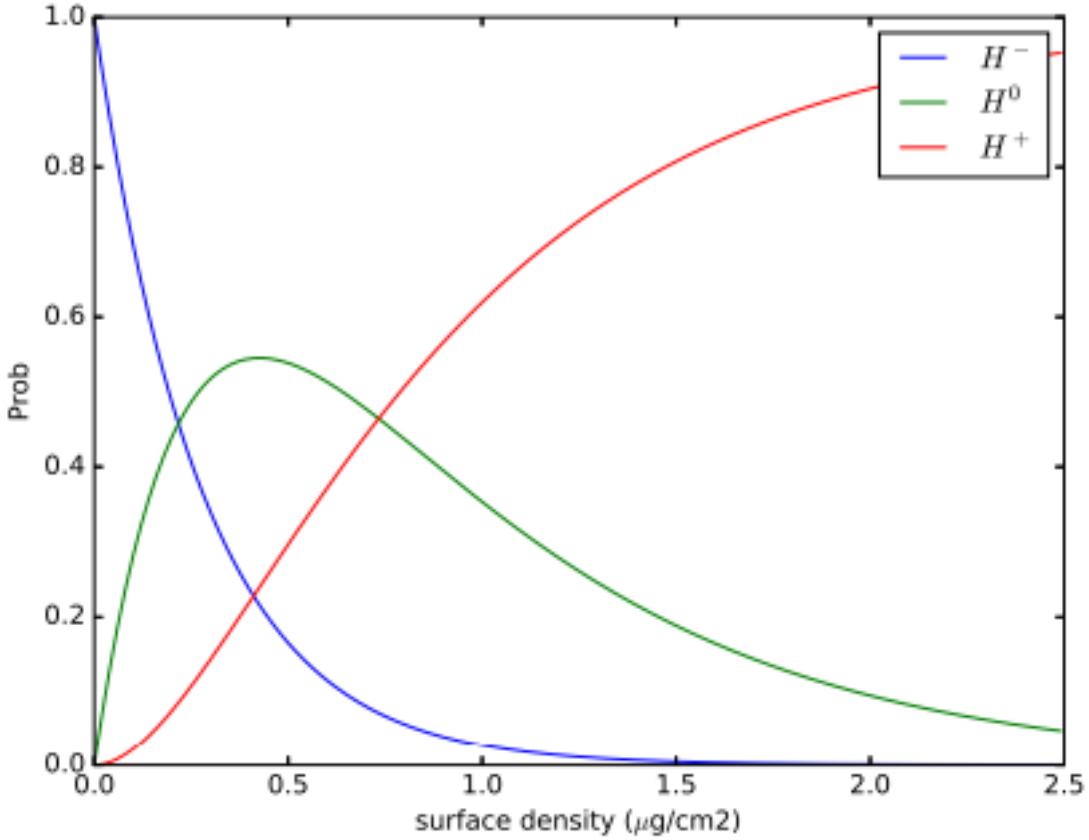
Charge Exchange Injection at 3 MeV

Charge Exchange at 3 MeV



Model breaks down at low E - Born approximation not valid

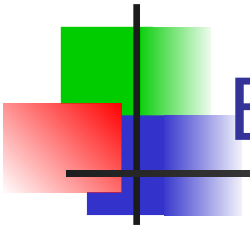
Charge Exchange at 3 MeV



Thin foils to reduce scattering – challenges with handling/etc

Conclusions

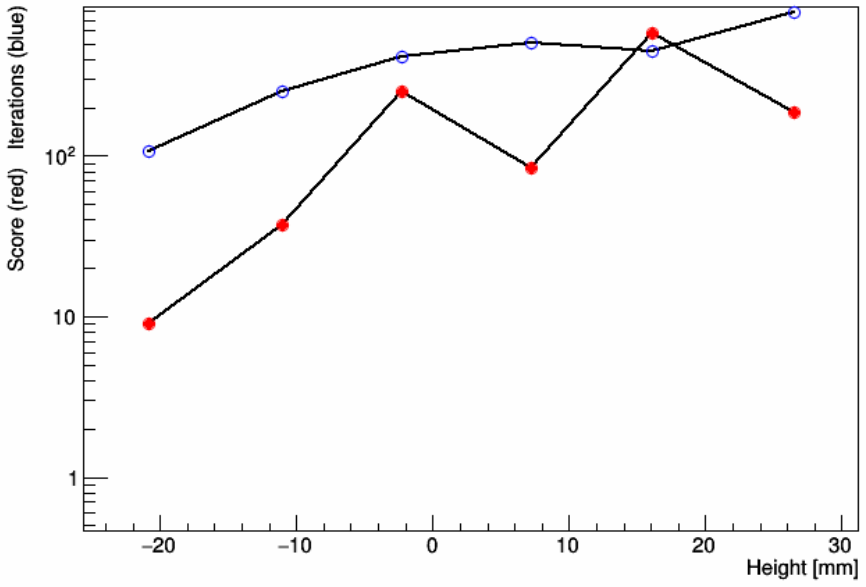
- Painting in scaling FFA looks feasible
  - Reduction in vertical DA from kicker dipoles – needs care
- Painting in VFFA looks feasible
  - Multi-cell injection looks possible
  - Need to evaluate effect on DA of bump magnets
- Charge-exchange injection looks possible at 3 MeV
  - Very thin foils are optimal
  - Handling issues may be a challenge
  - Need to evaluate heat load on the foil
  - Need to evaluate scattering on the foil



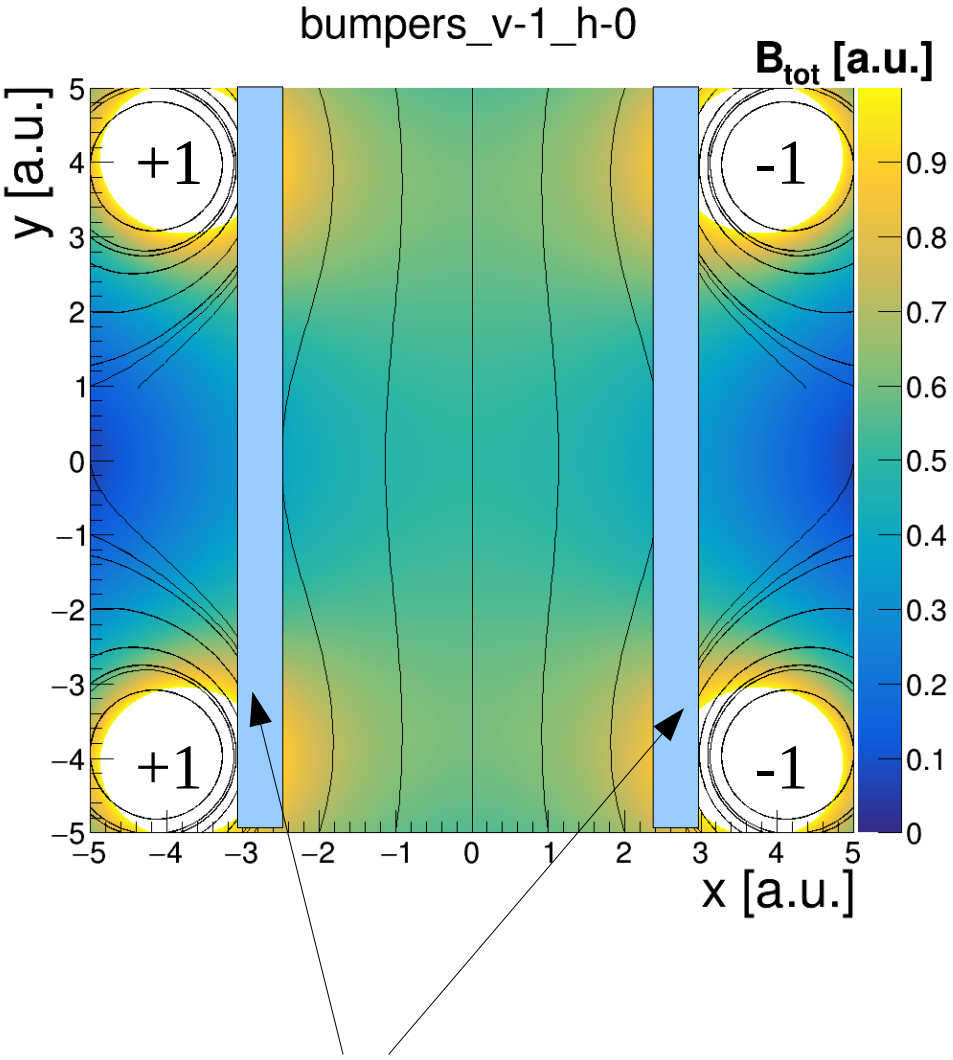
Backup

VFFA Injection Optimisation

- Try up to 5 cm vertical bump
  - From -2 cm to 3 cm
    - -2 cm corresponds to beam on closed orbit
  - Based on experience from hFFA scheme
- Try 0.1 T bump for catching H-
  - Based on specification to hardware designers
  - 10 cm long – spec was 30 cm
- Try to optimise to ~ 100 micron
- Allow up to 1000 iterations
  - Algorithm finishes after few hundred
  - Never quite converges
  - Should be under constrained



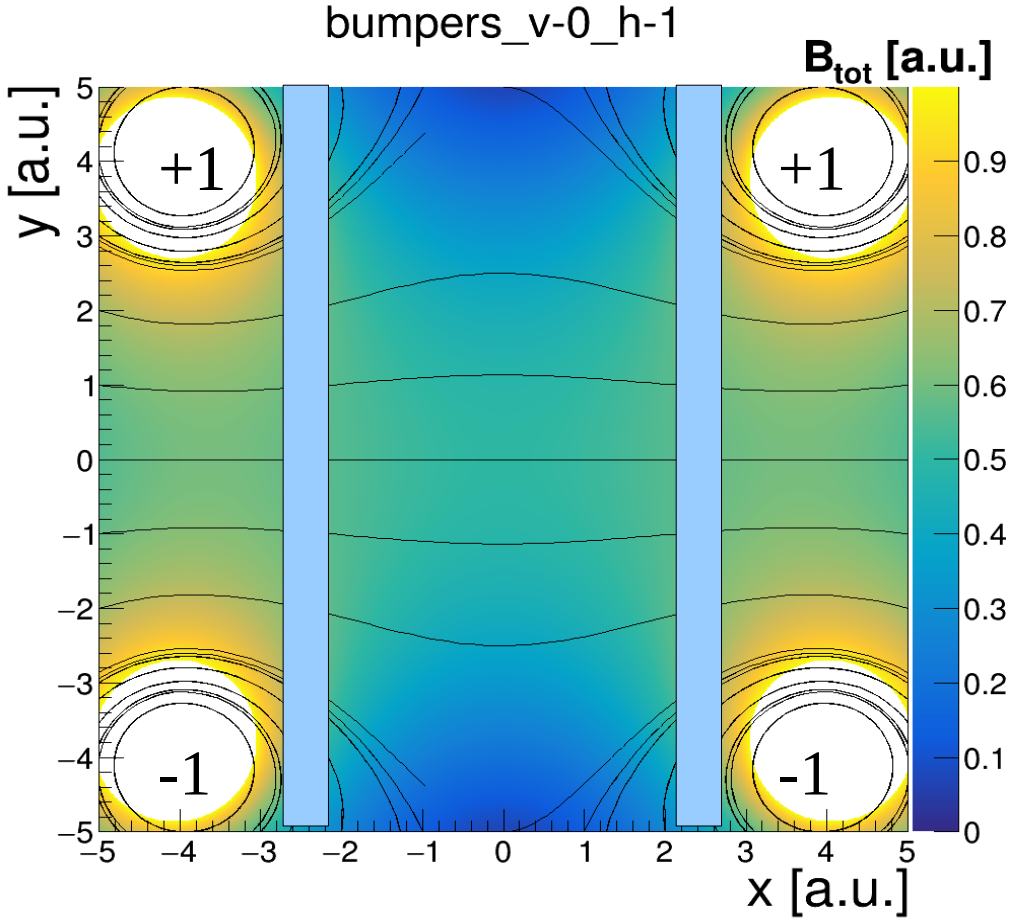
Vertical arrangement



Beam into page

Beam pipe

Vertical arrangement



Vertical arrangement