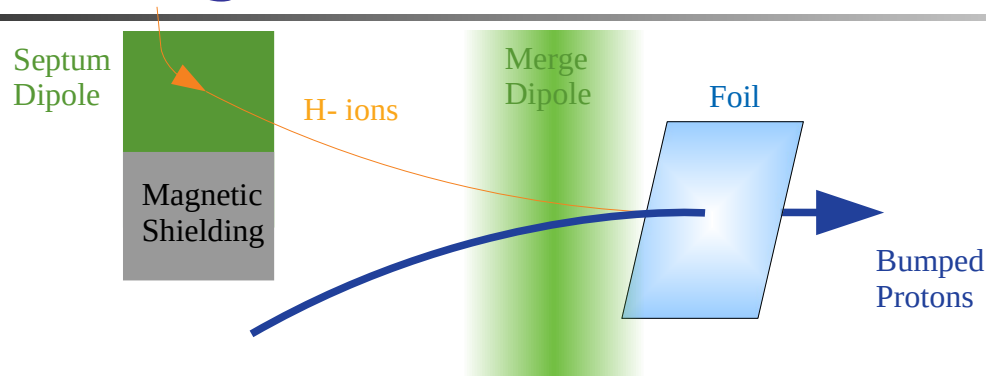


# Modelling H- Injection and Painting in Vertical and Horizontal FFAs Using OPAL

C. T. Rogers



# Charge Exchange Injection + Painting



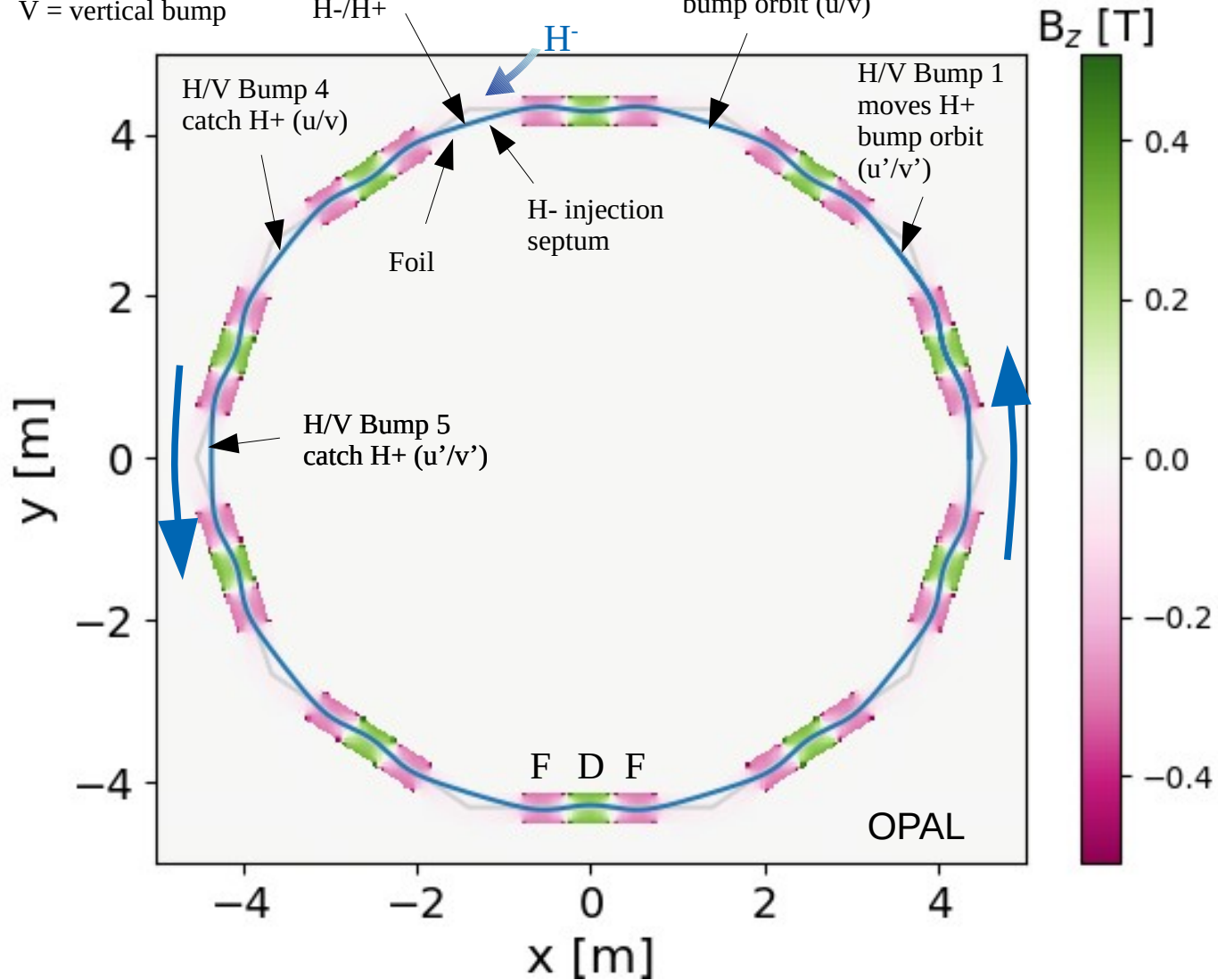
- Ion source generates Hydrogen atoms with an extra electron
  - “H-” ions
- Accelerate and inject H- on top of circulating proton beam
  - H- and protons pass through a dipole at different angles → merge
  - Pass H- through a thin Carbon foil
  - H- are ionised leaving protons
- Painting the beam enables build up of different beam shapes
  - Inject H- at distance from the circulating proton beam core
  - Develop different beams e.g. “correlated” and “anti-correlated”
- Goal: minimise protons passing through foil
- Eventually move beam off foil for acceleration

# Vertical FFA

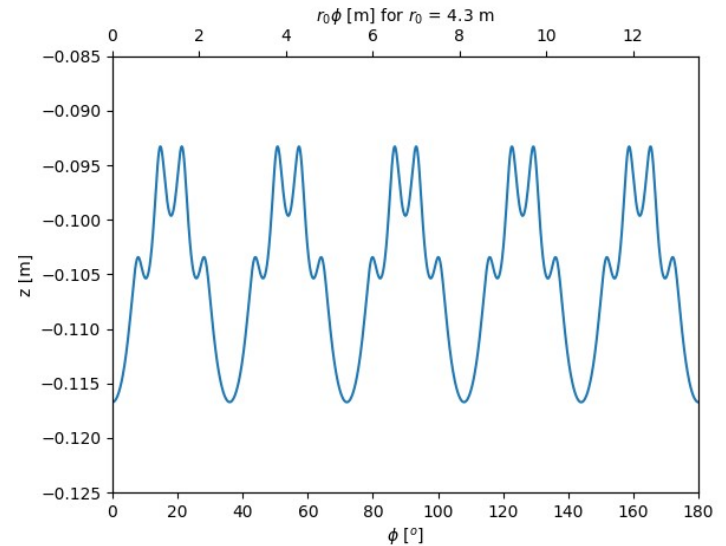
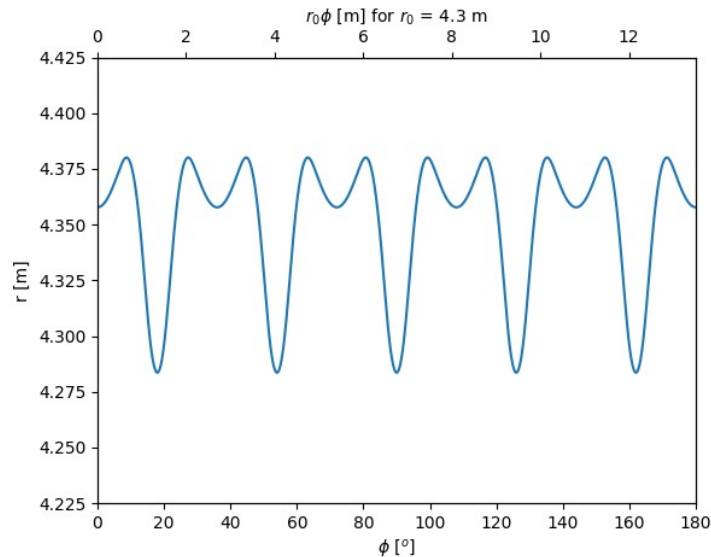
H = horizontal bump  
V = vertical bump

H/V Bump 3 merges  
H-/H+

H/V Bump 2 moves H+  
bump orbit (u/v)



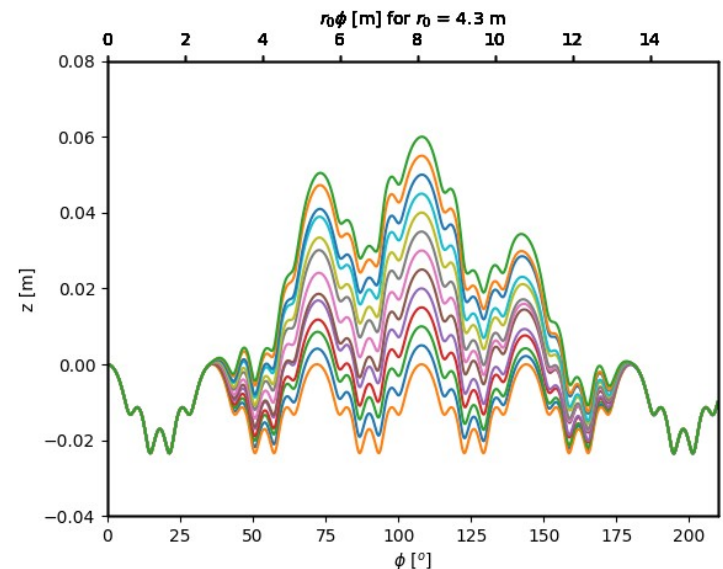
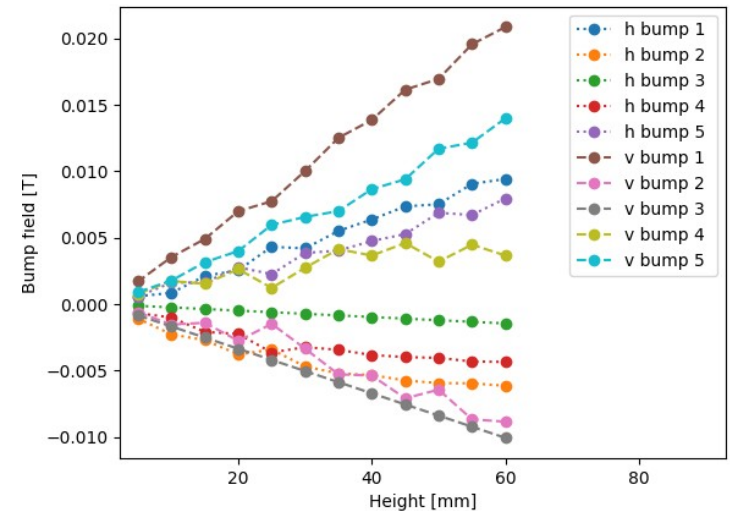
# Tracking simulation - vFFA



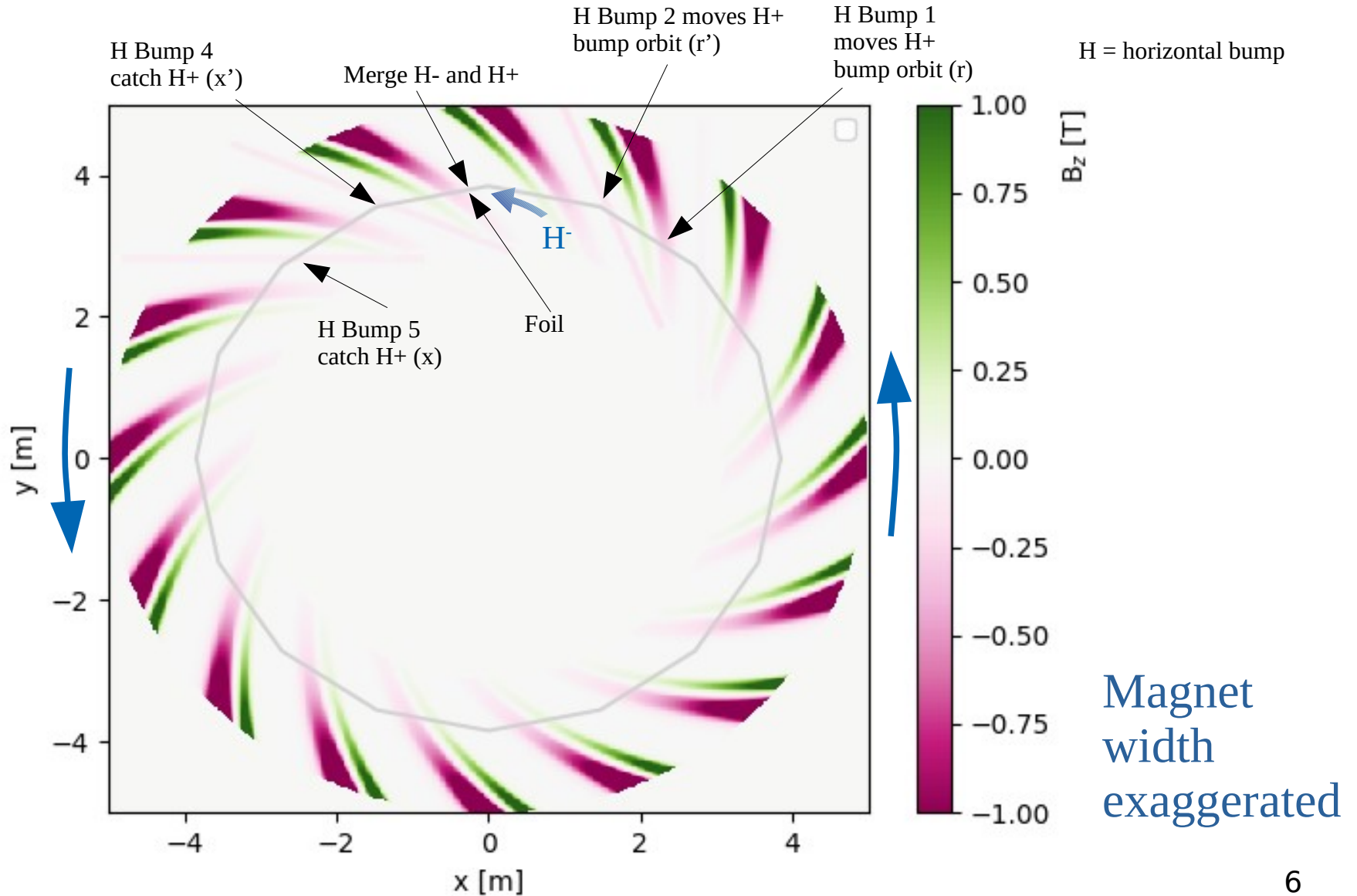
- vFFA has strongly coupled optics, from Maxwell's equations
  - Skew quadrupole focusing in magnet body
  - Solenoid focusing in magnet fringe field
  - Vertical kick in fringe field if beam is not perfectly central

# Injection simulation - vFFA

- Use bump magnet to distort closed orbits
  - Now we need both horizontal and vertical bumps
- Challenging to achieve sufficient DA with good orbit separation
  - Option:- use F magnet to separate H- and H+ orbits



# Horizontal FFA





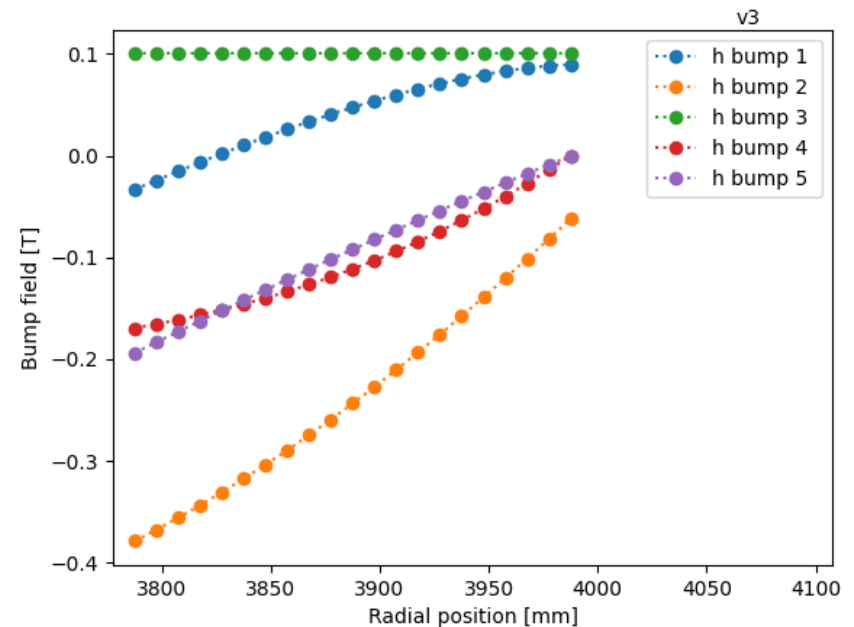
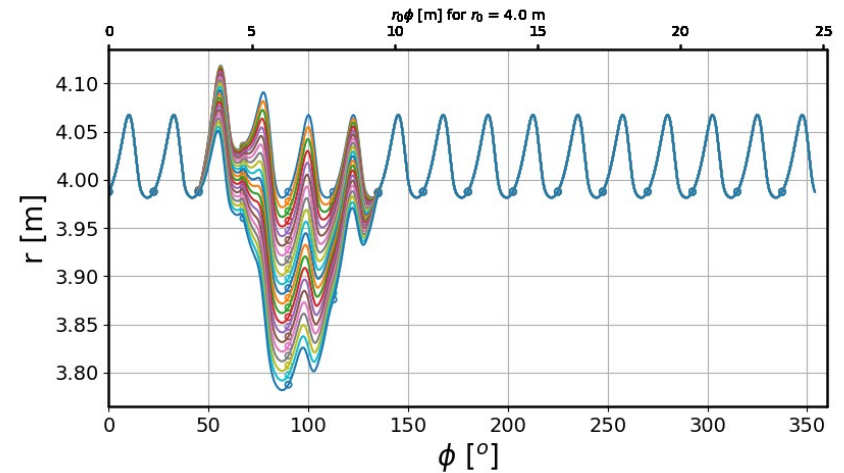
# Challenges

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- Thin foil & foil handling issues
- Maintaining sufficient DA
- Space for septum and H- beam
  - Without disturbing main magnets
- Control/time structure of pulsed magnets
- Management of injection with tune variation
  - Probably choose to move injection orbit

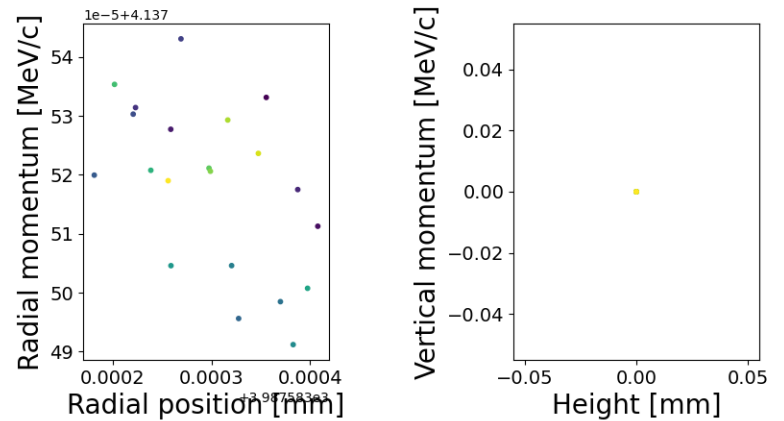
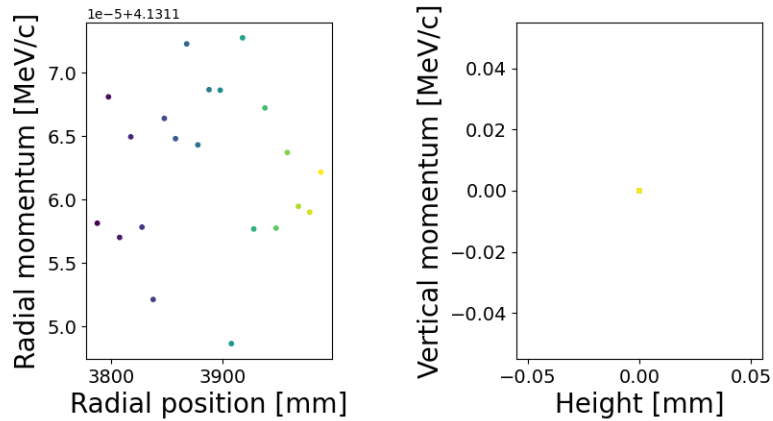
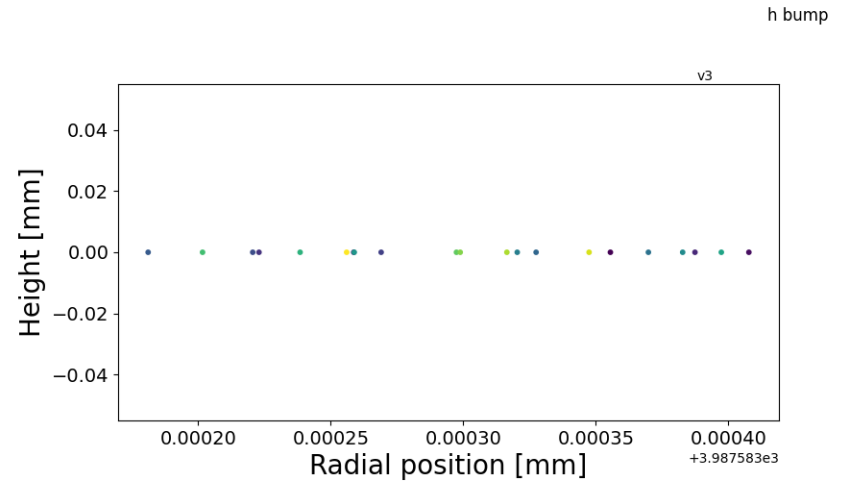
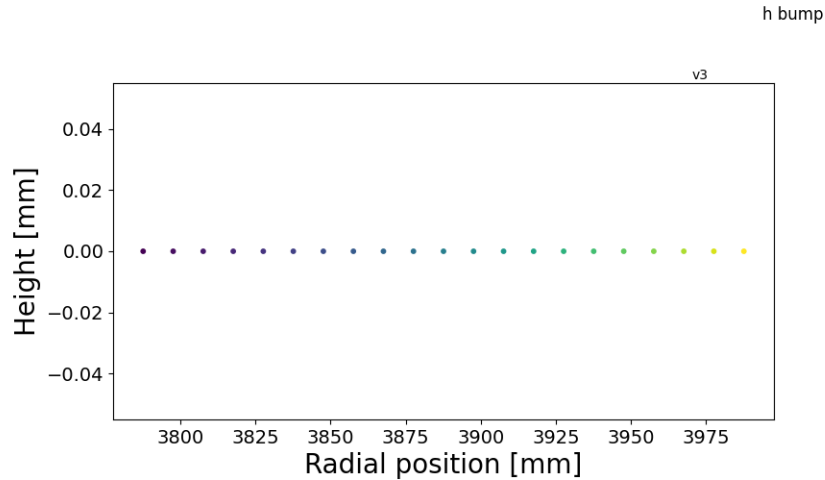
# Injection

- Use bump magnet to distort closed orbits
  - Movement of circulating proton beam over 200 mm
  - 0.1 m long bump magnets
  - Max field  $\sim 0.30$  T
- Concern about DA

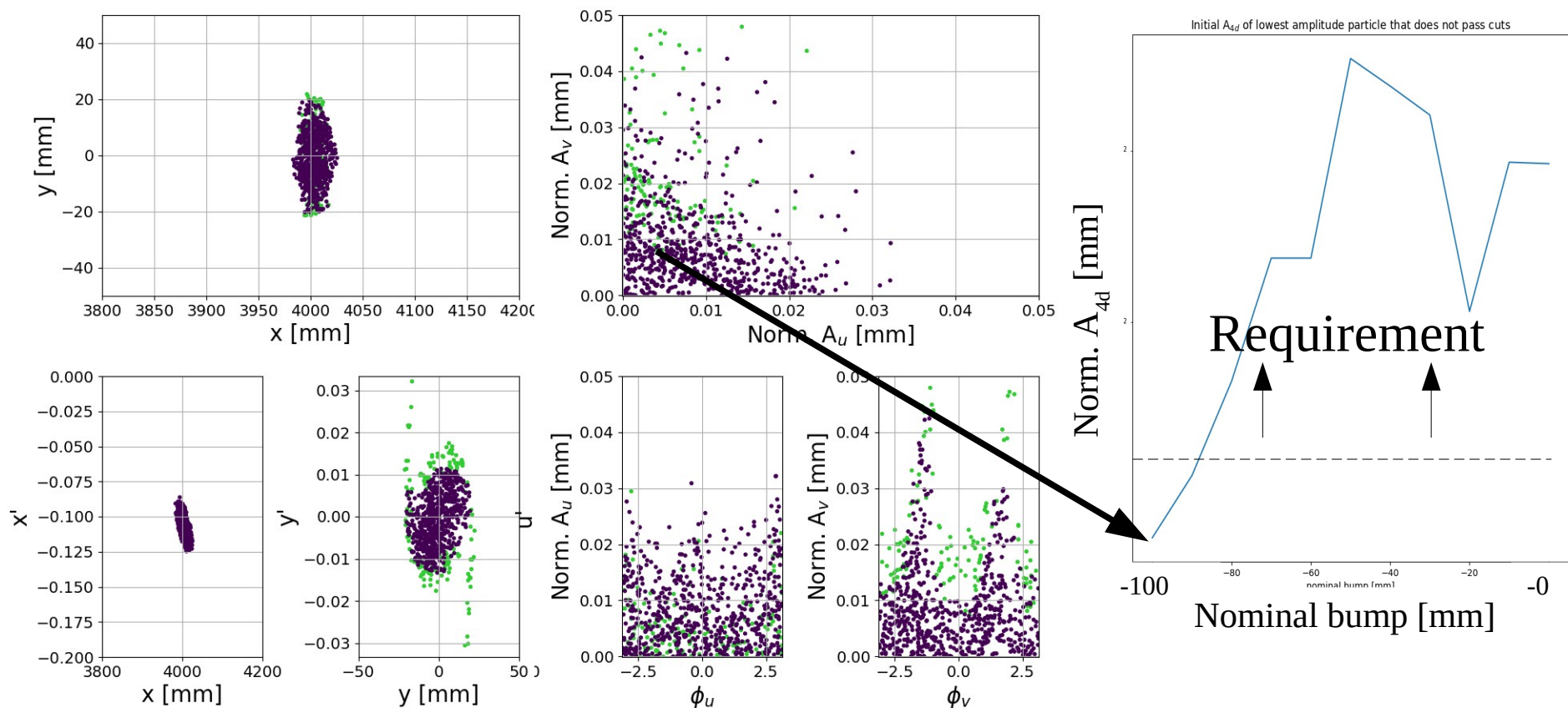




# 0.1 T merge dipole

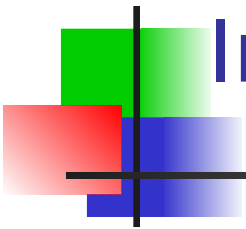


# Dynamic Aperture

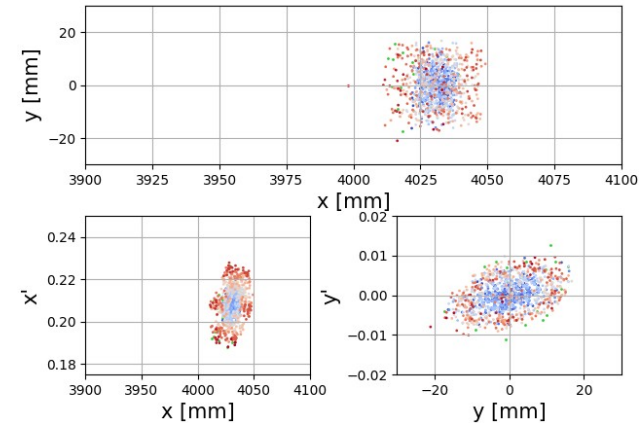
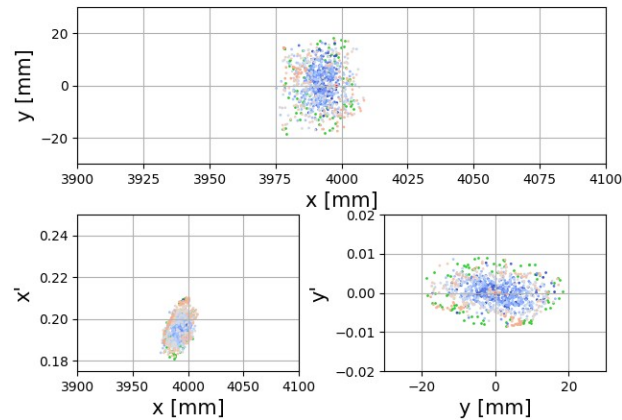
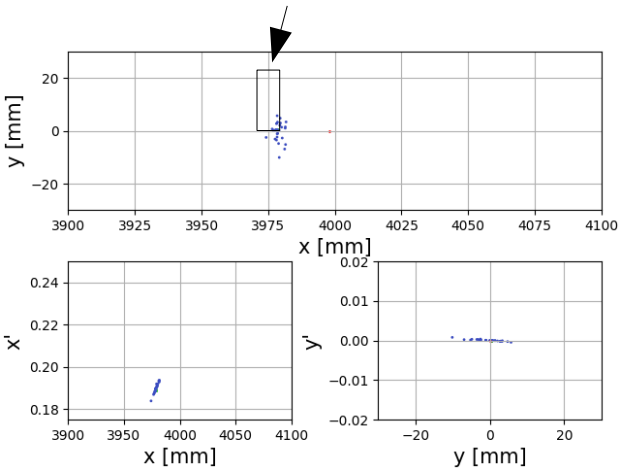


Caveat: Feb 2022 baseline

# Injection process



Foil  
dimension

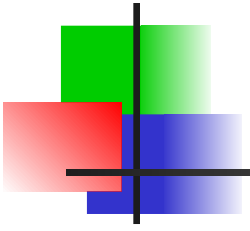


- Inject  $H^-$
- Sweep  $H^-$  beam up
- Sweep  $H^+$  close orbit horizontally

- Paint full phase space

- Collapse bump
- Beam moves clear of foil

Caveat: Feb 2022 baseline

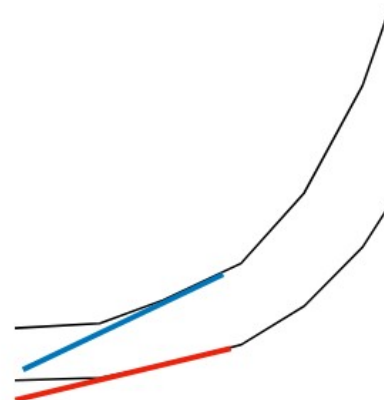
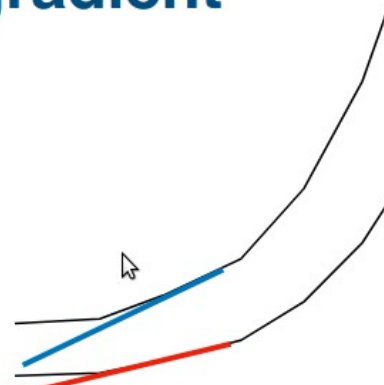
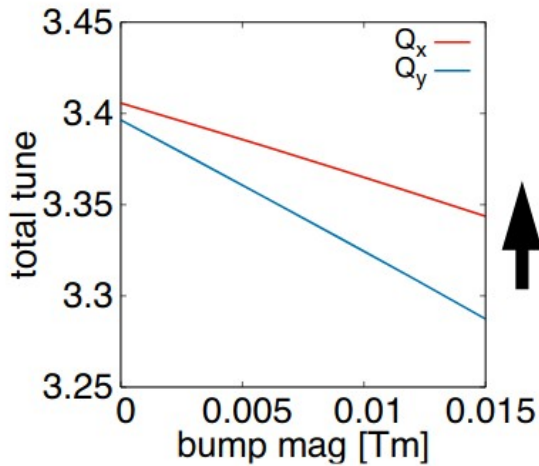


# Movie

# Tune correction (S. Machida)

## Tune shift with different gradient

Tune as a function of bump orbit





# Conclusions

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- Studies of injection in a small test ring
  - HFFA
    - Good closed orbit separation
    - Sufficient DA
    - Need to update for new lattice
    - Need to account for variable tunes (moving proton closed orbit)
  - VFFA
    - Move proton orbit arbitrarily in x-y plane
    - Still looking for good DA with sufficient orbit separation
    - Idea to use foil in F magnet to get orbit separation (WIP)