Injection into a vFFA

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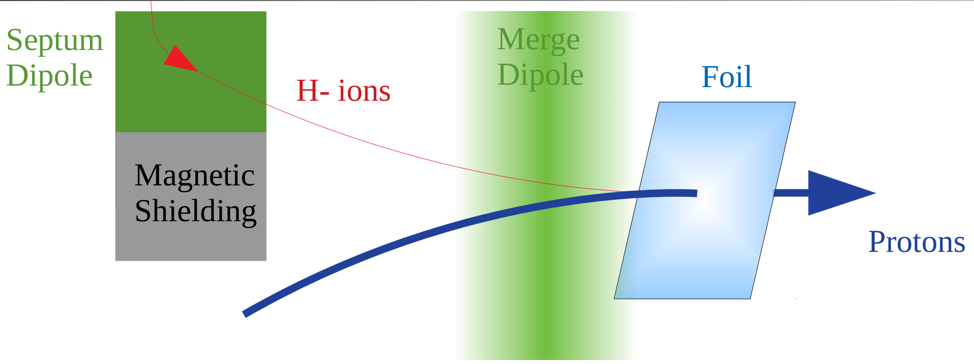
FETS Ring

- FETS vFFA is designed as a demonstrator for high-power operation of a vFFA
  - Accelerate from 3 MeV to 12 MeV
  - Control of orbit and tune
  - Collimation and low loss operation
  - Bunch accumulation at high energy
  - **Clean injection and extraction**
- Seek to develop injection system similar to high power proton accelerators
  - H- stripping
  - Pulsed magnets to control beam on foil during injection
  - Painting of correlated and anti-correlated beams
- Use existing FETS line
  - Relatively large dp/p
  - Relatively large emittance

Charge Exchange Injection + Painting

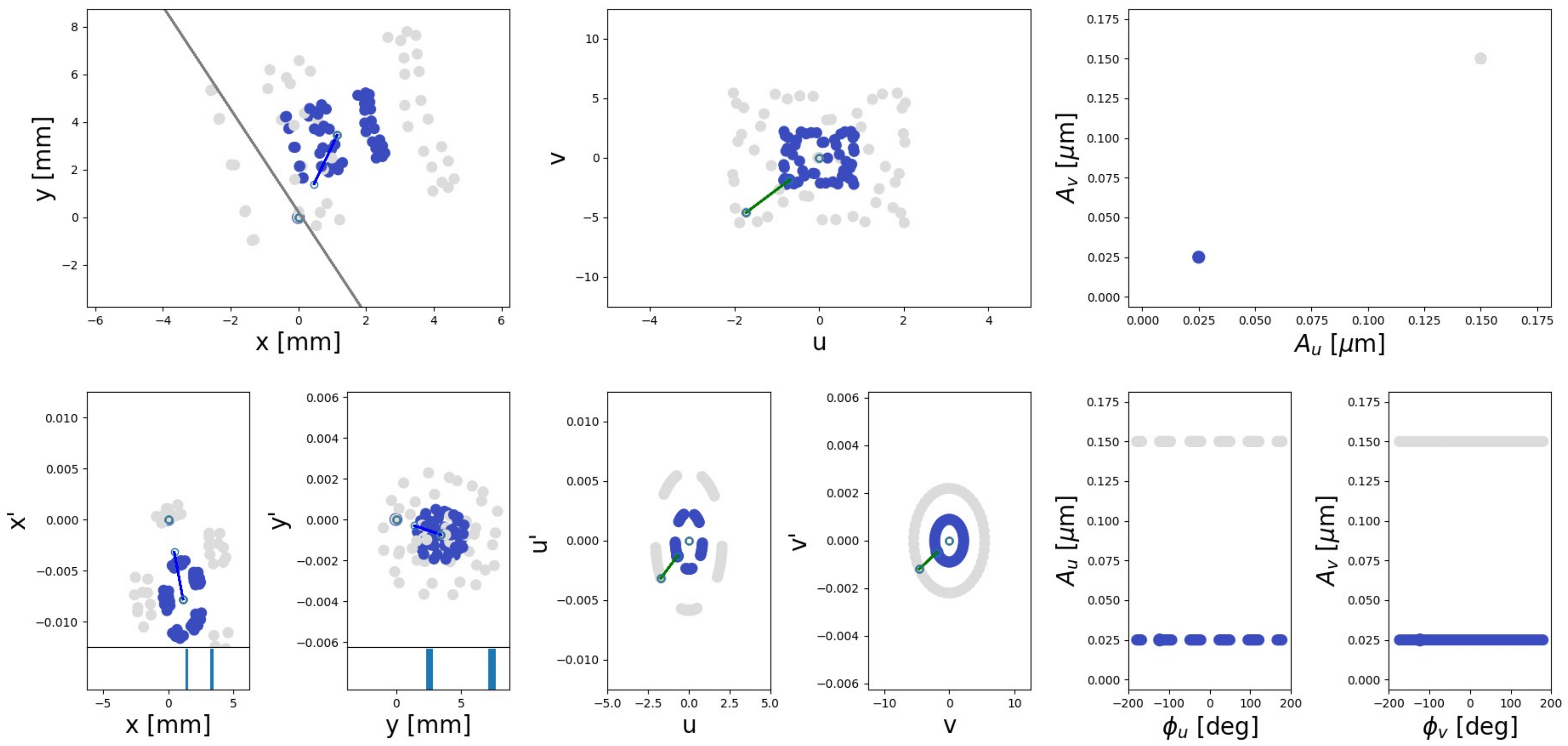


- Ion source generates Hydrogen atoms with an extra electron
  - “H-” ions
- Accelerate and inject H- on top of circulating proton beam
  - H- and protons pass through a dipole at different angles → merge
  - Pass H- through a thin Carbon foil
  - H- are ionised leaving protons
- Painting the beam enables 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”
- Try to minimise protons passing through foil
- Eventually move beam off foil for acceleration

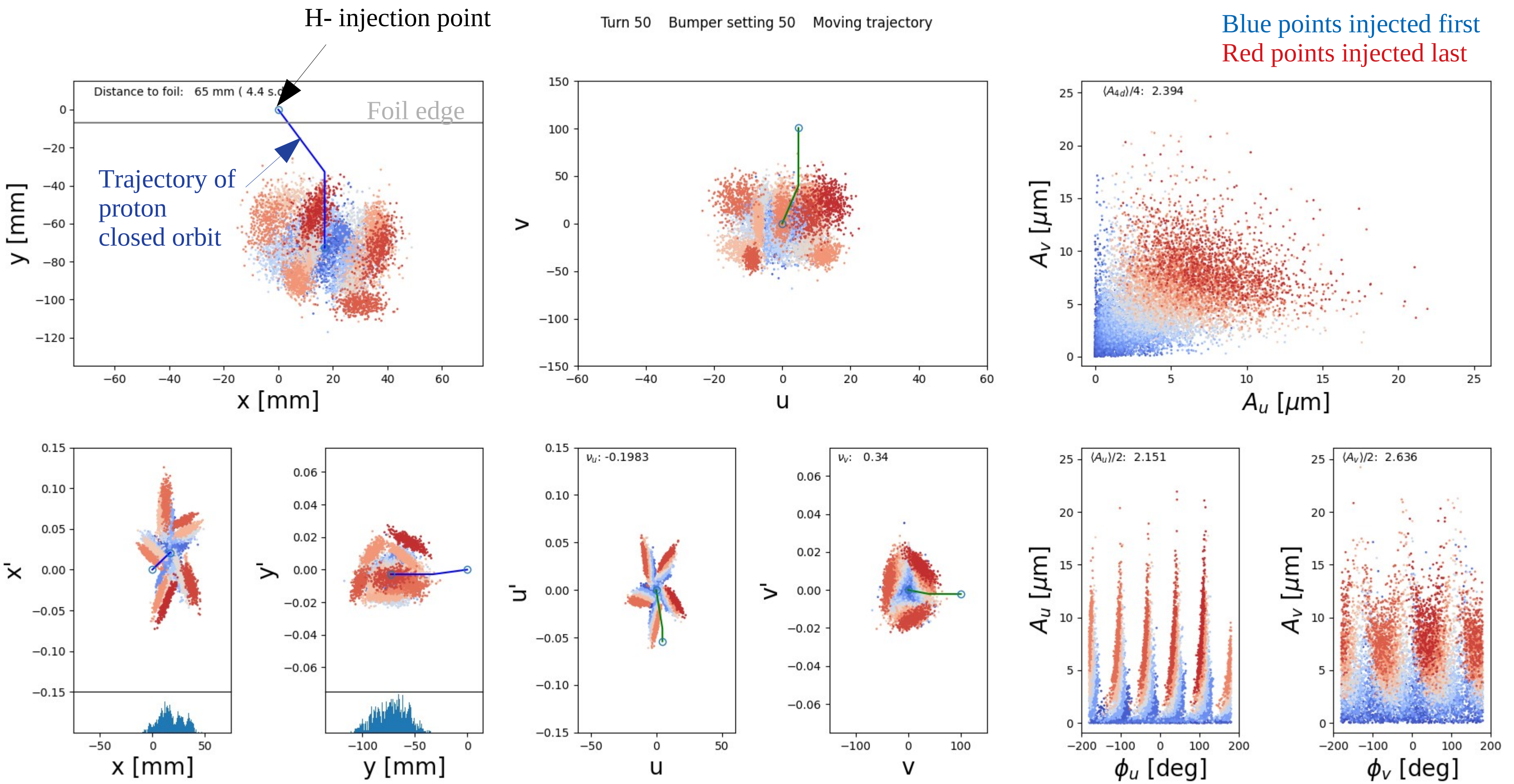
Phase space

- VFFA → (x, x’, y, y’) are coupled
  - In general offset in one coordinate leads to an offset in all others
- Define decoupled (u, u’) and (v, v’) phase space
  - Related to (x, x’, y, y’) by a 4D rotation

Physical | Decoupled | Action-angle

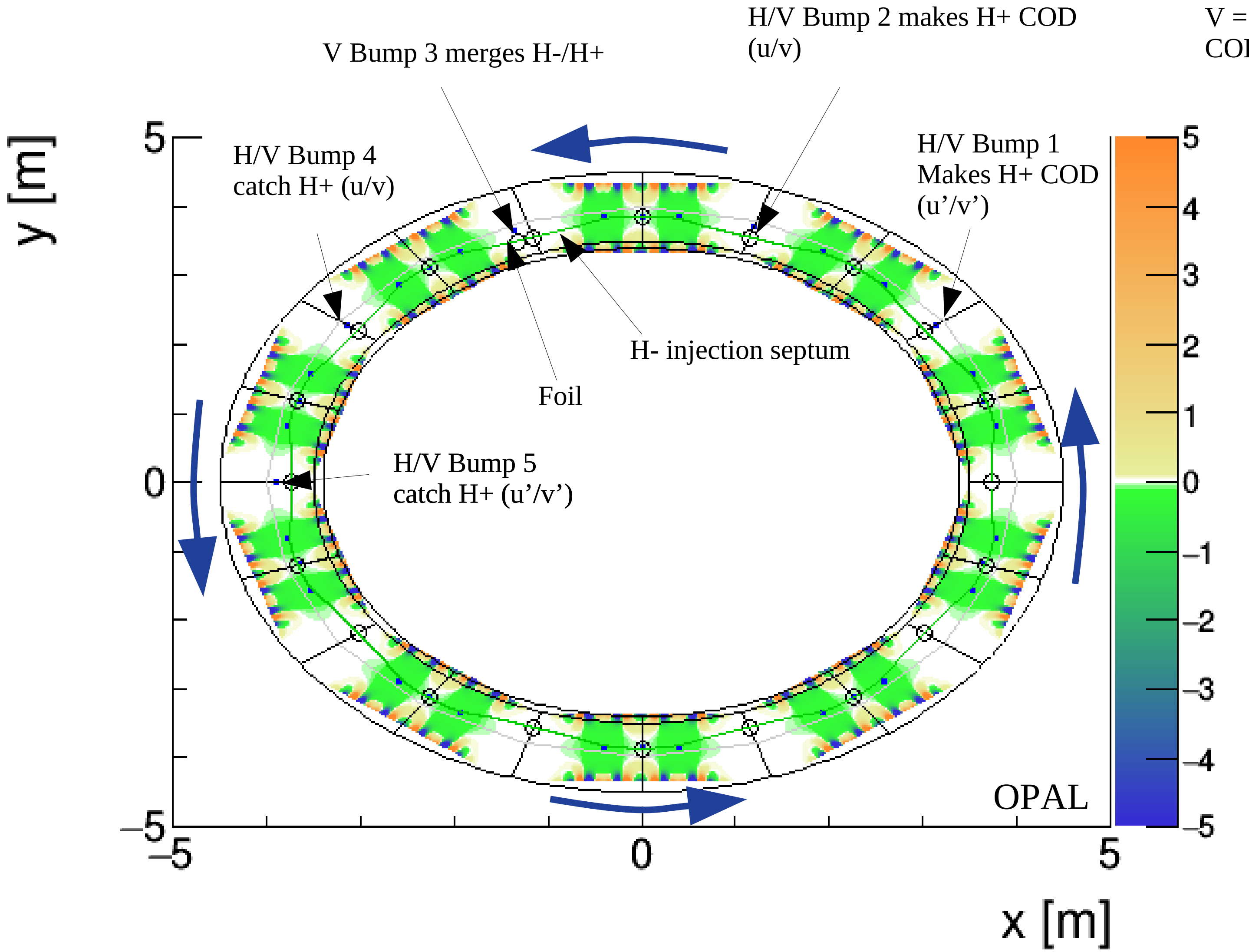


Phase space


H- injection point
Turn 50 Bumper setting 50 Moving trajectory
Blue points injected first
Red points injected last
Distance to foil: 65 mm (4.4 s.d
Foil edge
Trajectory of proton closed orbit
y [mm]
x [mm]
v
u
$\langle A_{4d} \rangle/4$: 2.394
A_v [μm]
A_u [μm]
x'
y'
y [mm]
u'
ν_u: -0.1983
v'
ν_v: 0.34
$\langle A_u \rangle/2$: 2.151
$\langle A_v \rangle/2$: 2.636
ϕ_u [deg]
ϕ_v [deg]

Proposed Injection System

H = horizontal bump
V = vertical bump
COD = Closed Orbit Distortion



Model

- Two models used
  - Linear optics model
    - Model scattering on foil as simple Gaussian
    - Mean energy loss according to Bethe-Bloch
    - Transport using fully coupled one-turn transfer matrix
    - No optical tune distortion
      - E.g. due to closed orbit distortion in FFA magnets
    - No space charge
  - Full tracking model (OPAL)
    - Estimate the bump magnet strengths
    - Estimate closed orbit distortion

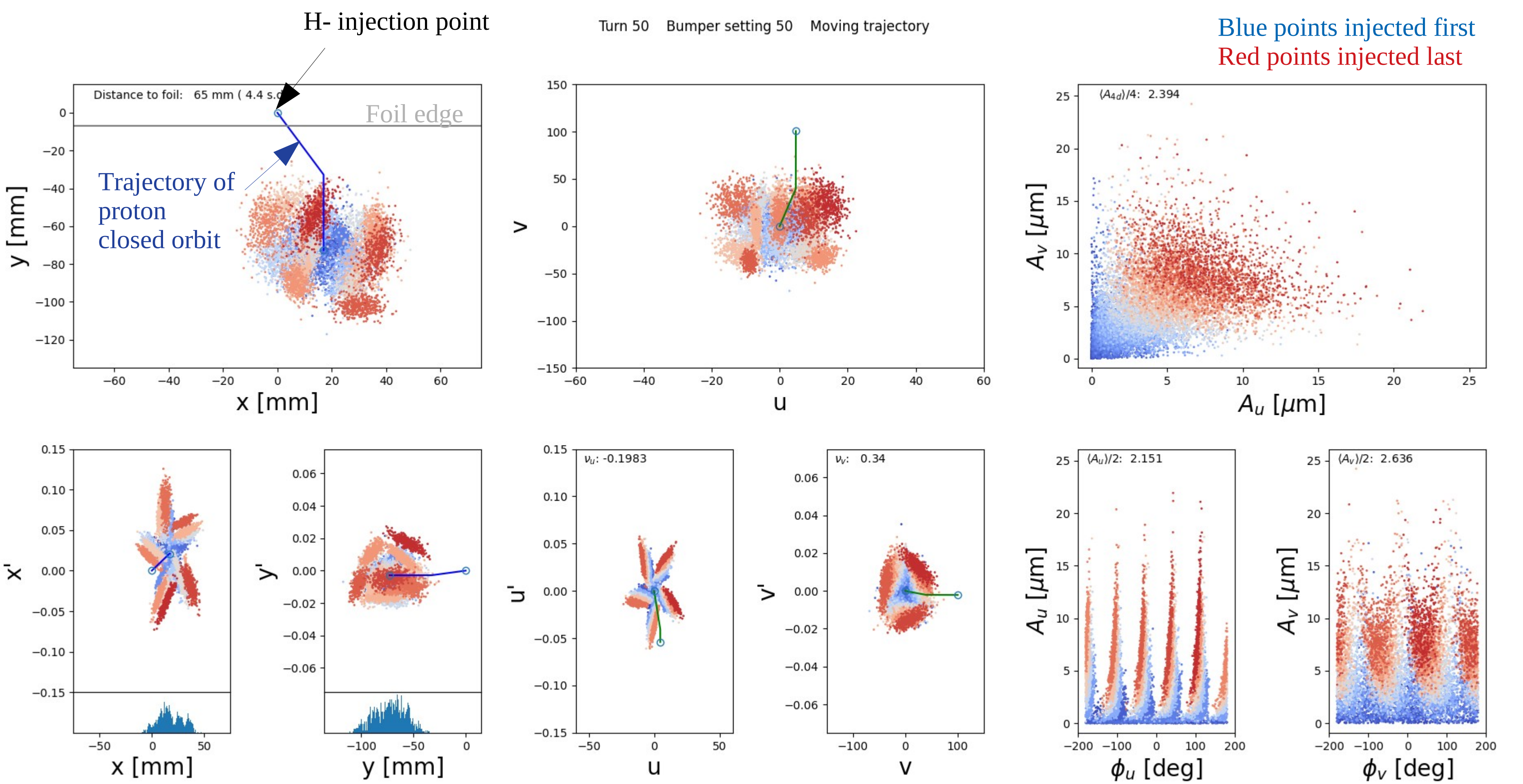
Correlated Painting

- Aim of correlated painting study:
  - Determine requirement for beamline
    - Emittance, Twiss parameters
  - Determine effect of foil thickness
    - Is 20 μg/cm^2 okay?
  - Determine required bumper magnet settings
- Correlated painting
  - Steadily move the circulating protons away from the H-

$$A_u(n) = A_v(n) = nA_0$$

  - Amplitudes A_u and A_v
  - n is turn number
  - A_0 is constant
  - Moving protons (as opposed to H-) reduces the number of foil hits

Phase space



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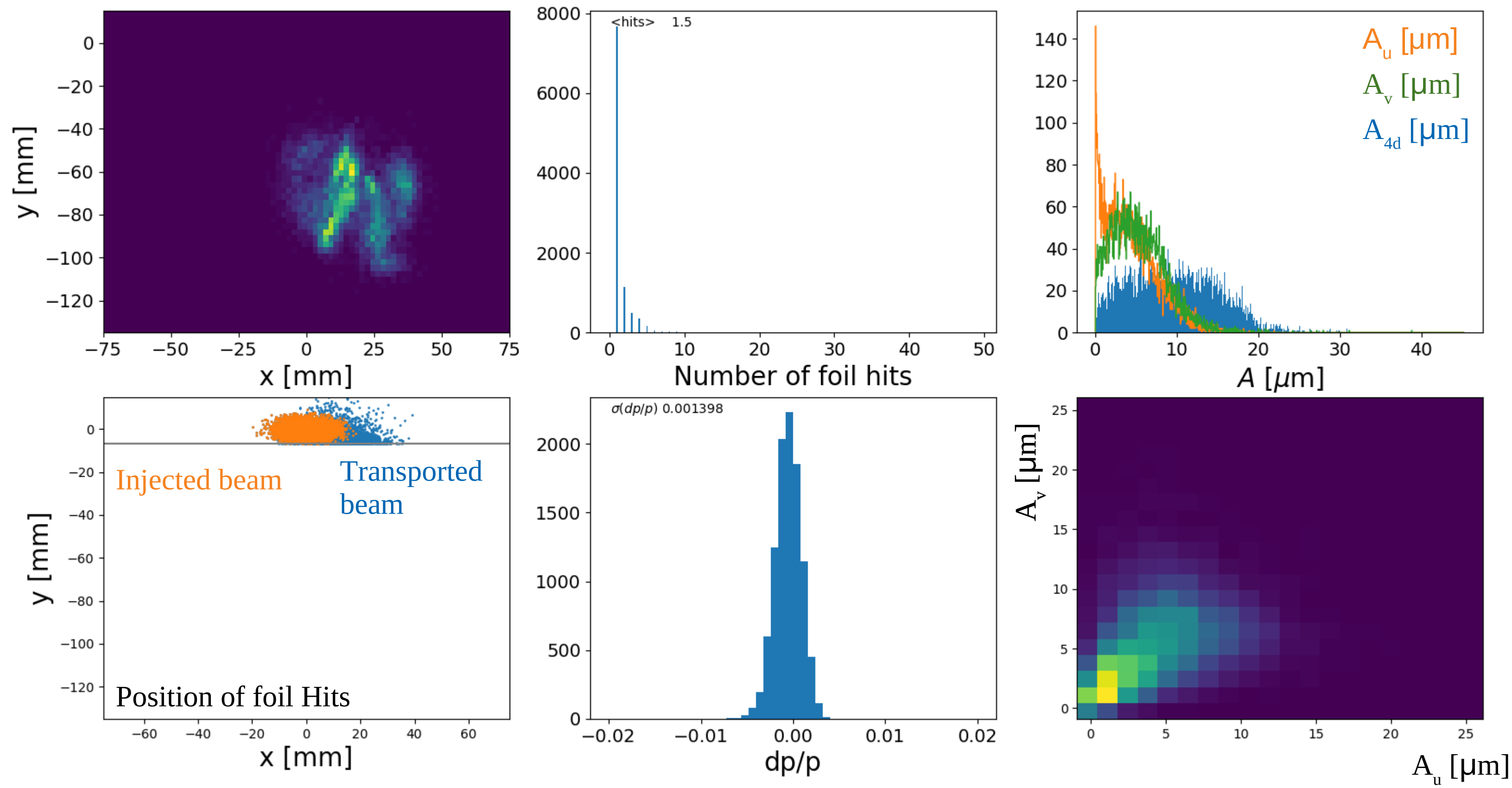
ϕ_u [deg]
ϕ_v [deg]

Summary plots



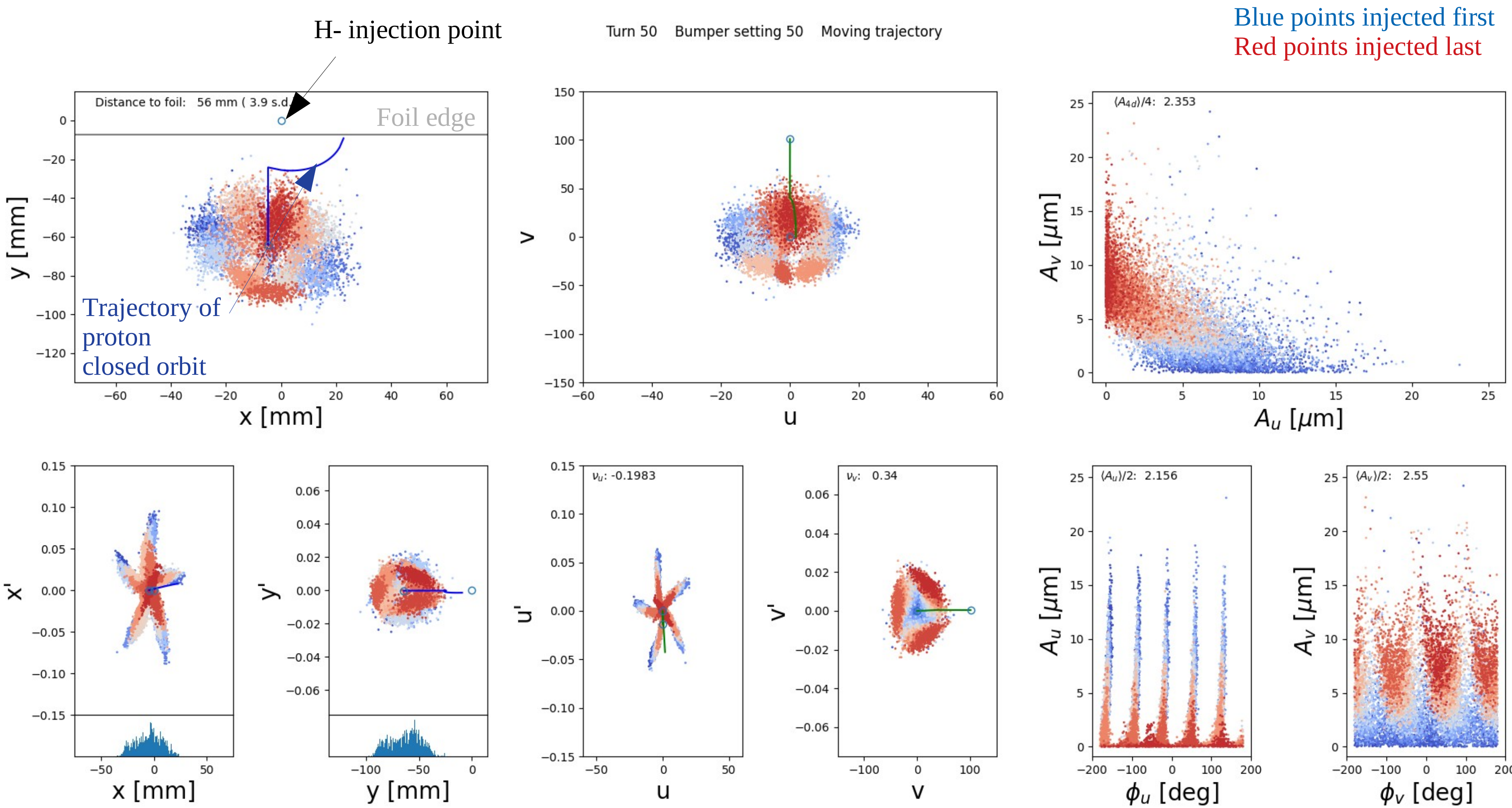
Anticorrelated Painting

- Aim of anticorrelated painting study – as per correlated painting
  - Determine requirement for beamline
    - Emittance, Twiss parameters
  - Determine effect of foil thickness
    - Is 20 μg/cm^2 okay?
  - Determine required bumper magnet settings
- Anticorrelated painting
  - Steadily move the circulating protons away from the H-

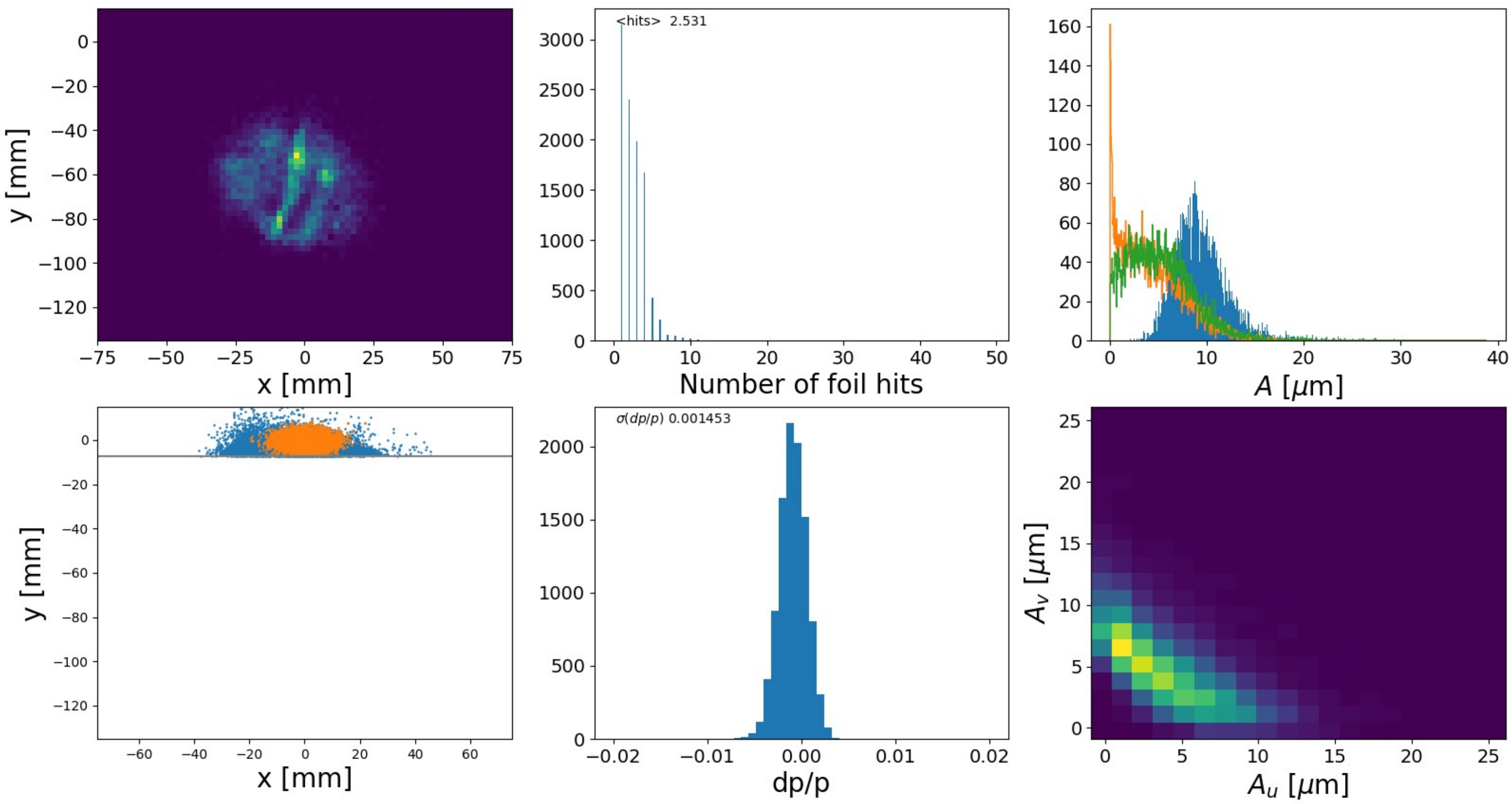
$$(N_0 - n)\, A_u(n) + n A_v(n) = A_0$$

  - n is turn number
  - A_u and A_v are decoupled amplitudes
  - N_0 is total number of injection turns
  - A_0 is constant

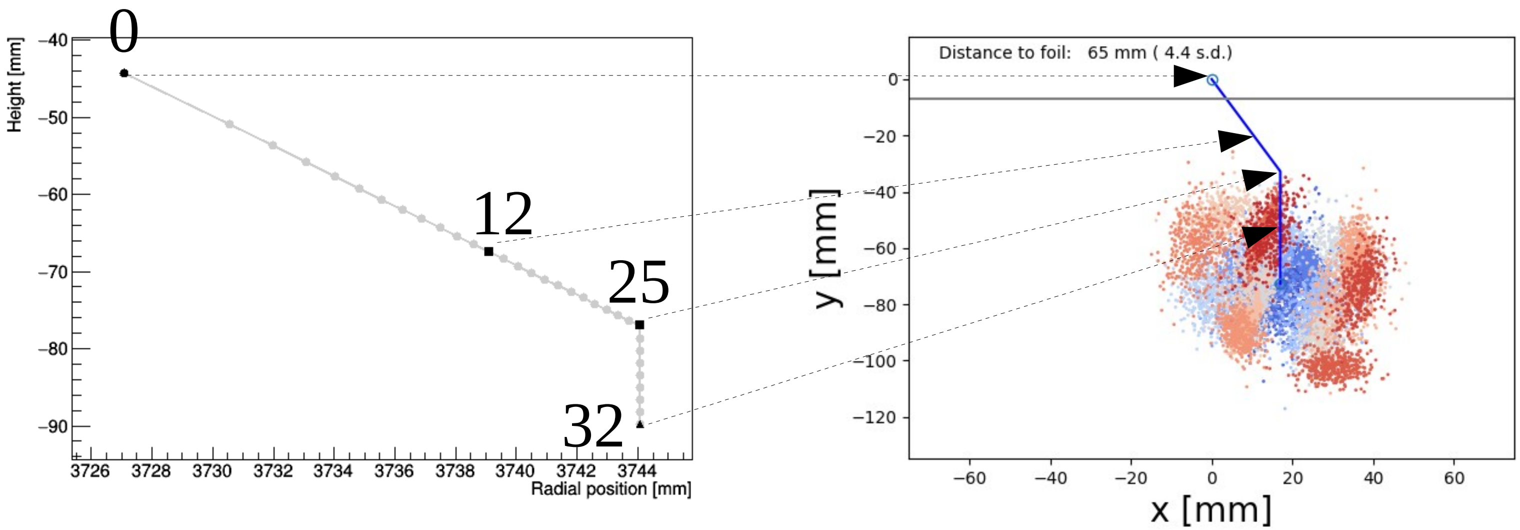
Anticorrelated Painting



Anticorrelated Painting

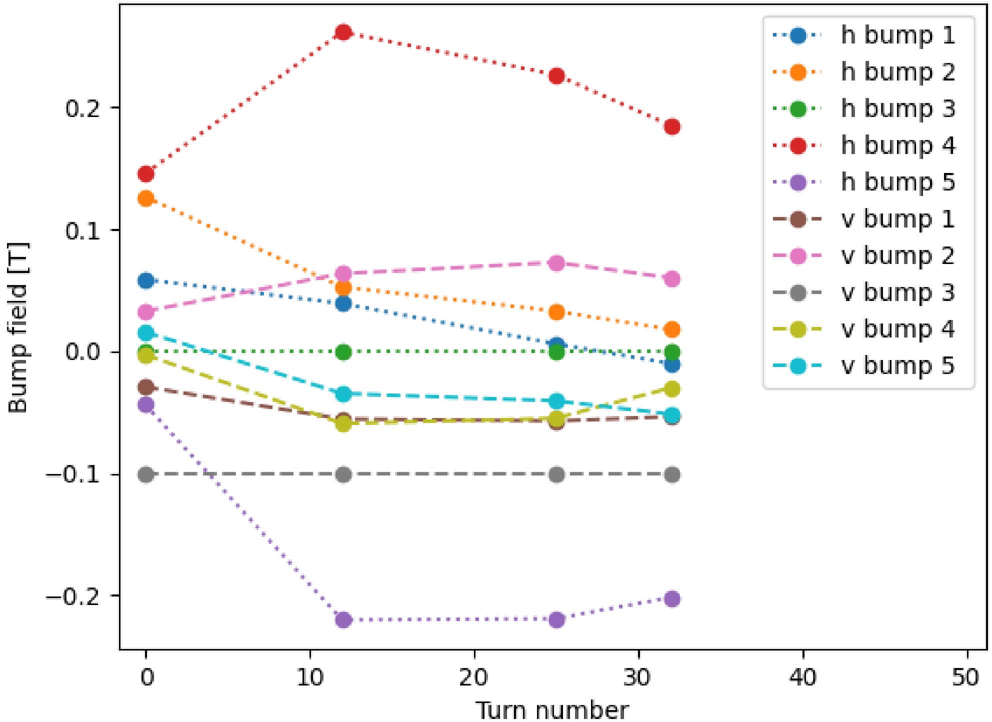


Fields



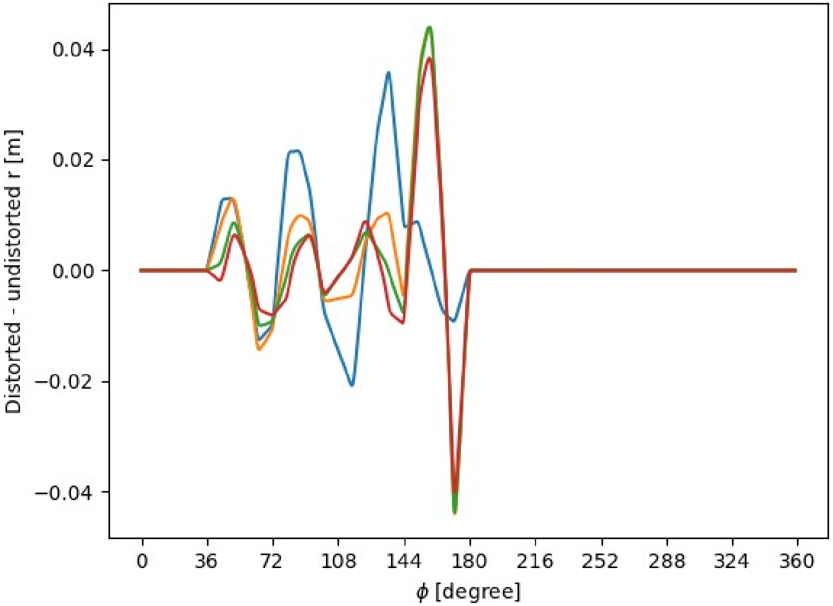
- Optimisation to find the dipole fields for a few points
  - Use full tracking in OPAL
  - Iterate using Minuit MIGRAD routine
  - Yield the bumped proton closed orbit

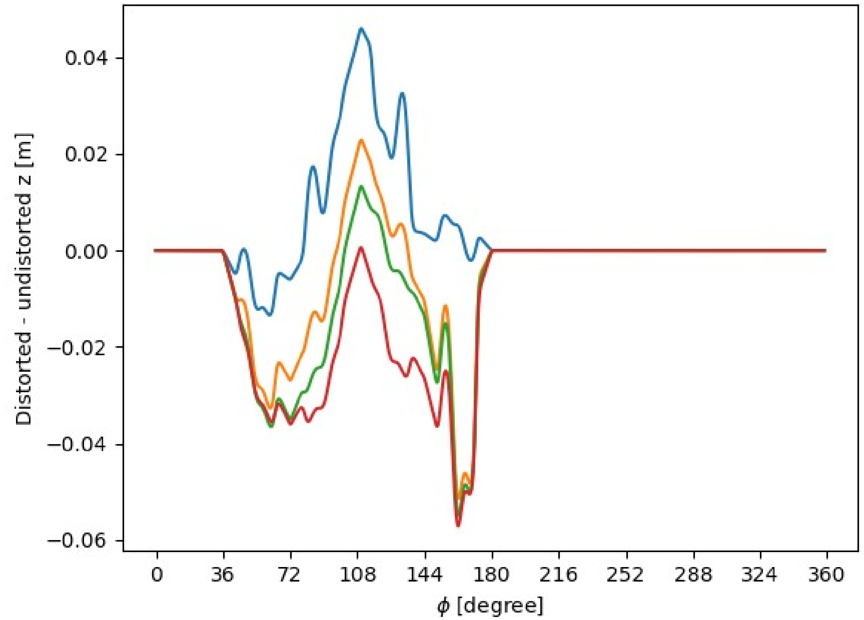
Required dipole settings



- Require dipole fields up to 0.3 T
  - 0.1 x 0.1 x 0.1 metre dipoles
  - Both horizontal and vertical bumpers
  - Fields perpendicular to, and parallel to, the beam pipe
- Change fields ~ 0.01 T per turn

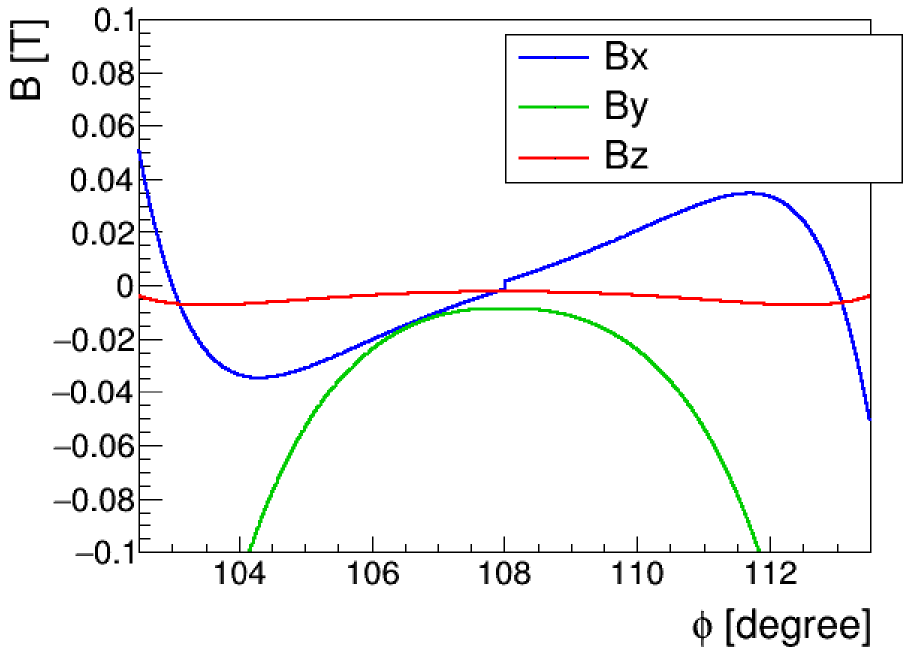
Closed orbit distortion





- Rather large closed orbit distortion introduced
  - Foil has to beyond the edge of the unperturbed beam
- Concern that this may affect the tune
  - To be studied

Magnet fringe fields



- Long fringe field
- Magnetic material in bumpers/septum
  - May perturb the field and ruin the scaling
- Tight injection bend required
  - May cause issues with injected H- beam
- Need to be careful in actual magnet design

Conclusions

- Presented design for painting in vFFA
- Correlated and anti-correlated painting concepts presented
- Bumper dipole requirements look reasonable
- Further study required
  - Closed orbit distortion
  - Effect of injection equipment on main magnet fringe fields
  - Tight bend near to the injection point