Injection into, and Extraction from FETS FFA

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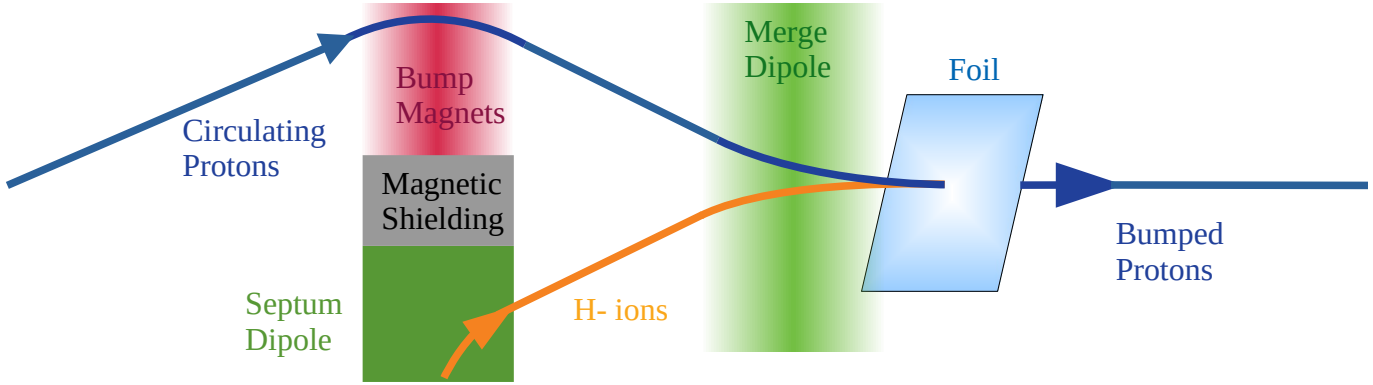
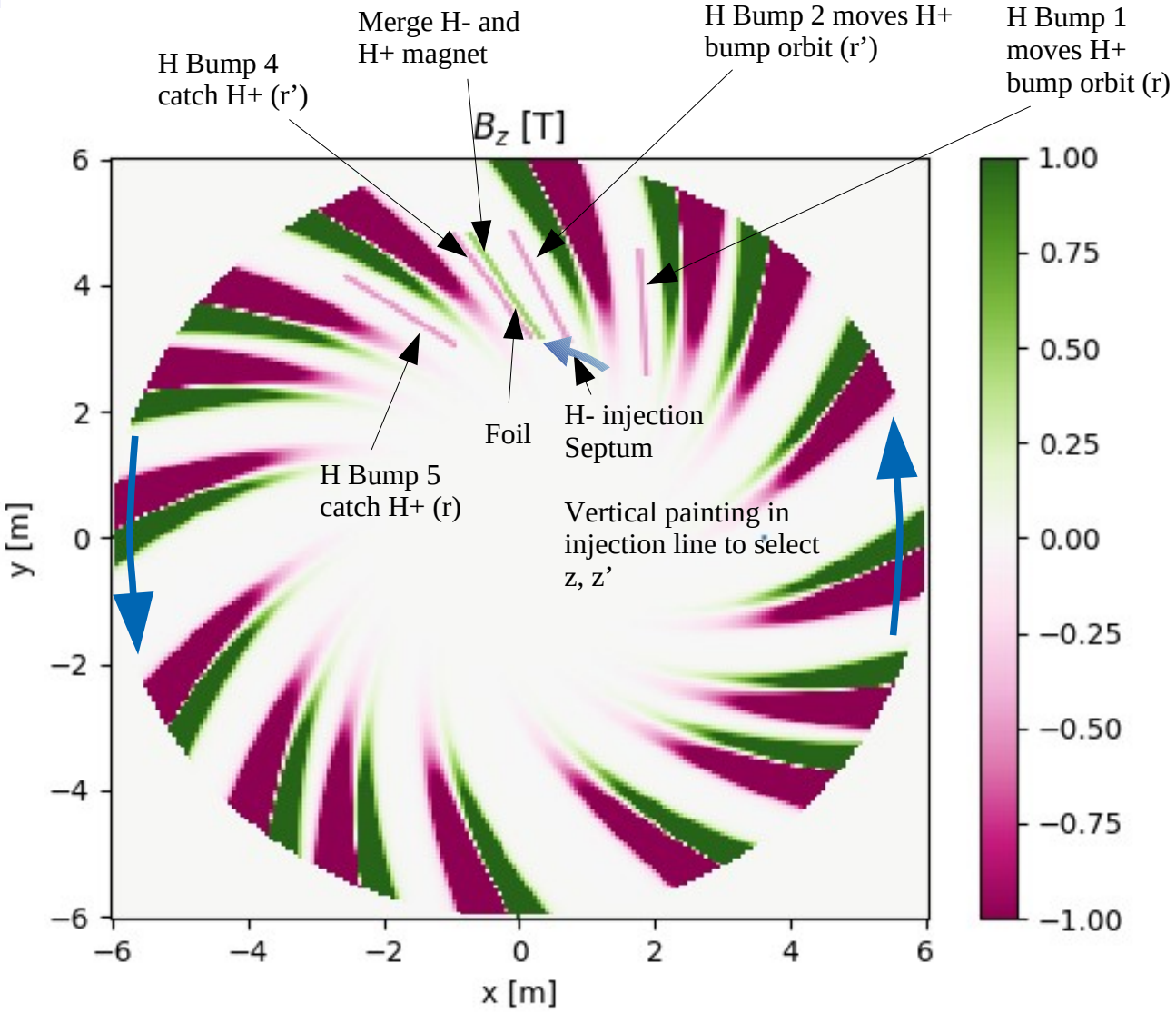
Charge Exchange Injection & Painting



- 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 hence losses
- Eventually move beam off foil for acceleration

Reminder: hFFA injection system



FETS Hall

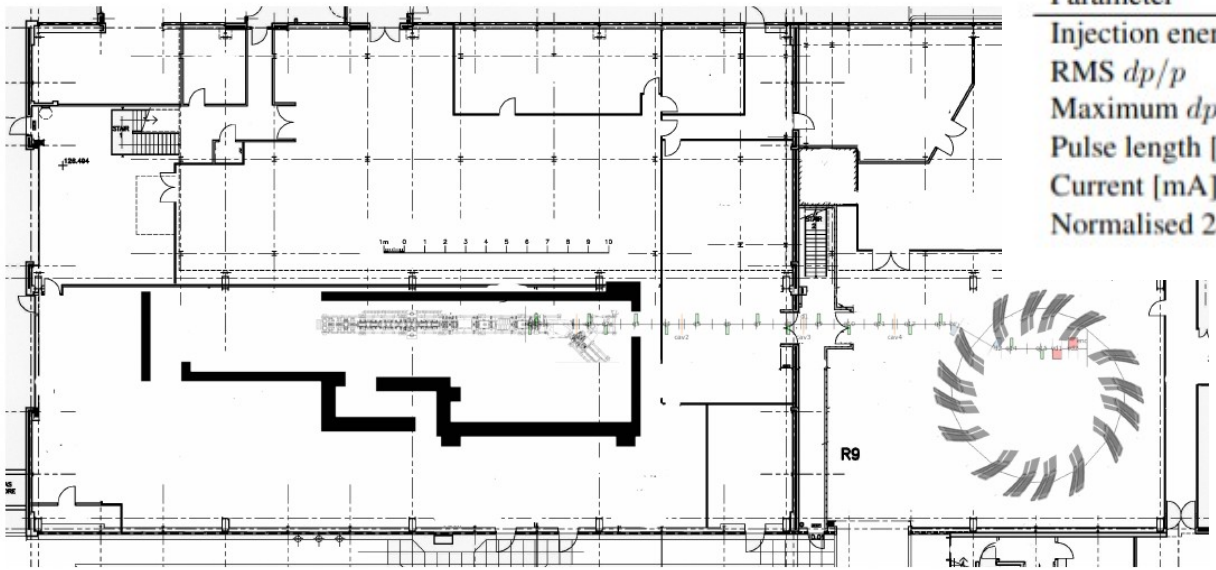
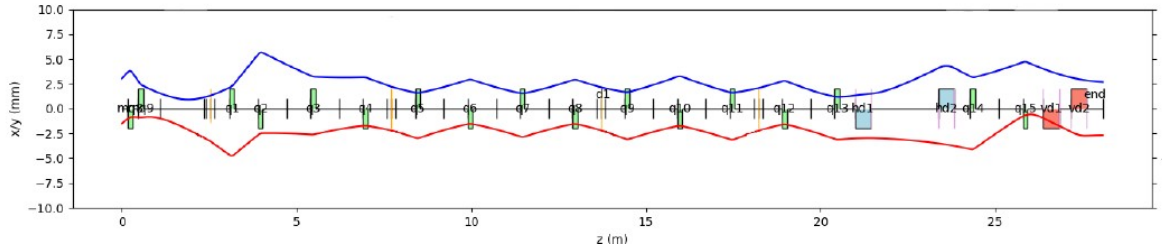


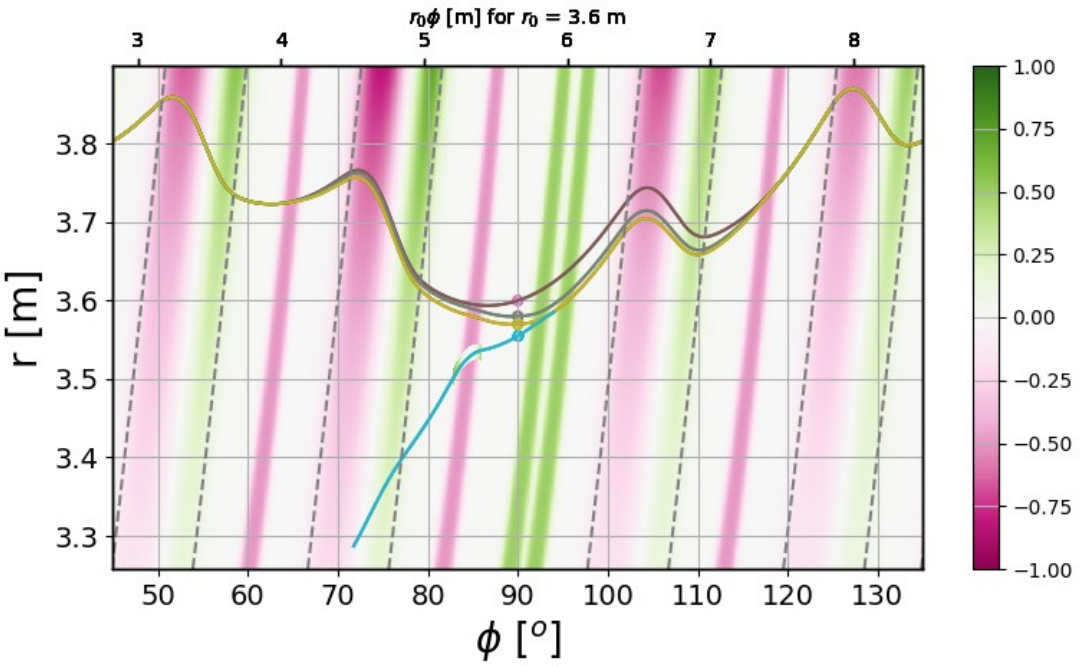
Table 3.1: FETS linac parameters.

Parameter	ECR	Standard FETS
Injection energy [MeV]	3	3
RMS dp/p	0.0013	0.0013
Maximum dp/p	0.0039	0.0039
Pulse length [ns]	350	350
Current [mA]	1	Up to 65
Normalised 2d emittance [μm]	0.026	Up to 0.25



- Transport from FETS requires only modest transfer line
- Final region including matching to ring not yet designed

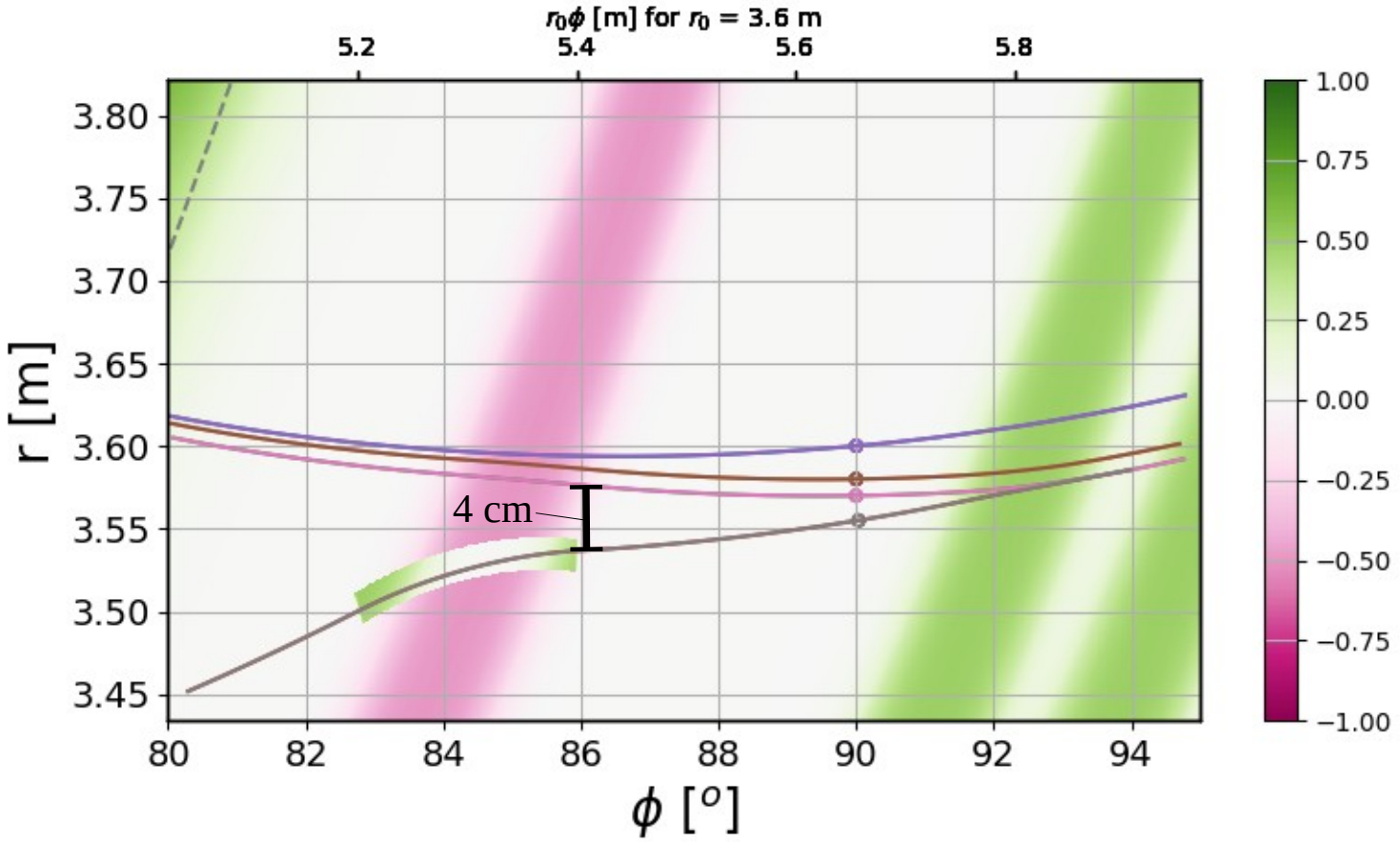
Cylindrical coordinates



Horizontal Bump Length	0.1 m
Horizontal Bump Angle	30°
Horizontal Bump Width	0.1 m
Fringe Field Length	0.020 m
HB1 Azimuthal Position	-26.325°
HB2 Azimuthal Position	-4.725°
HB3 Azimuthal Position	2.700°
HB4 Azimuthal Position	5.400°
HB5 Azimuthal Position	26.550°
Septum Magnet End Azimuthal Position	-4.1°
Septum Magnet Width	0.020 m
Septum Magnet Length	0.200 m
Septum Magnet Field	0.505 T
Septum Magnet Bend Angle	30°
Beam Separation at Septum Entrance	0.040 m

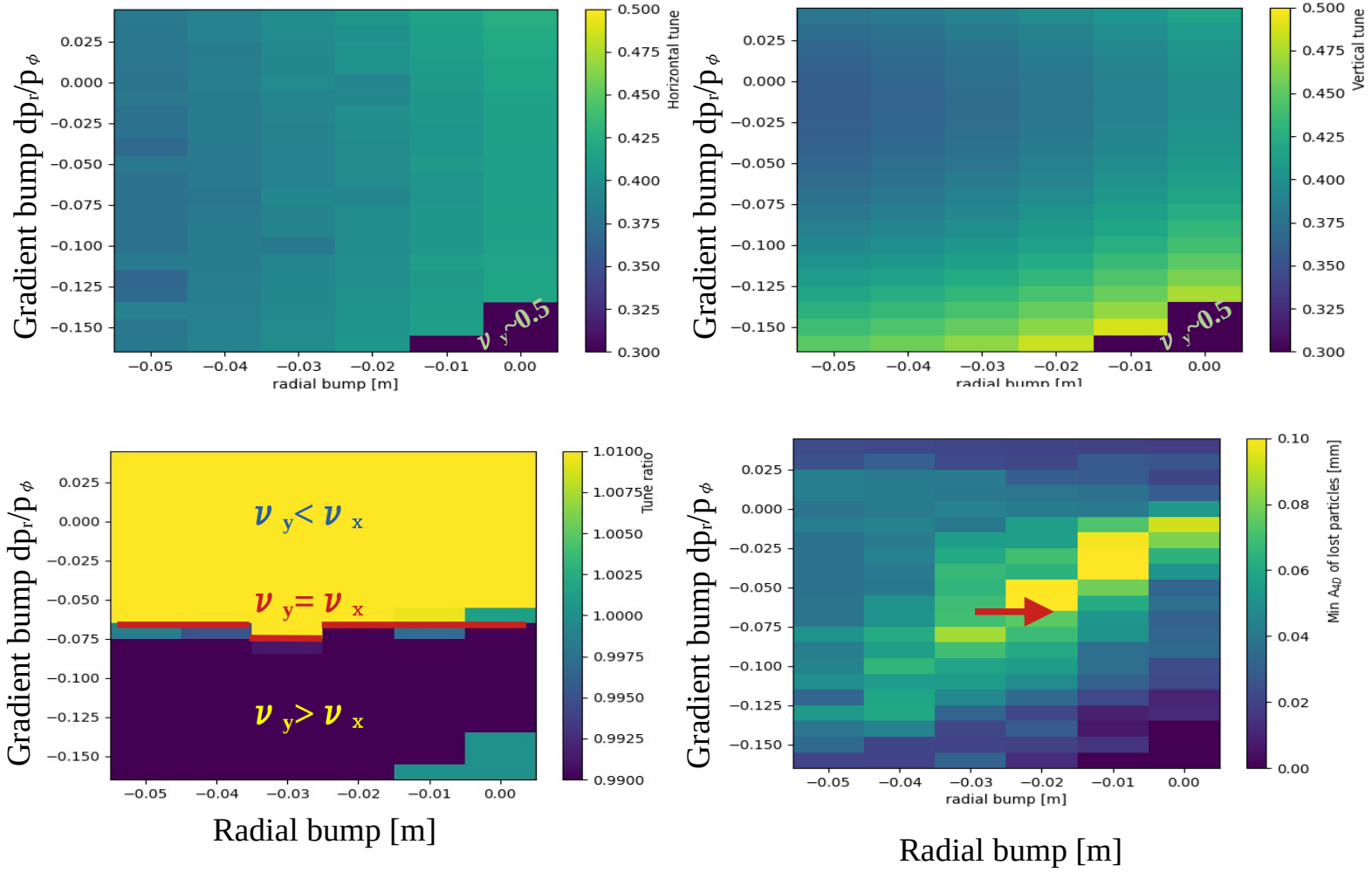
- Sufficient space for injection hardware
- Septum design is not too aggressive

Zoom of injection area



- 4 cm between edge of proton beam and H^- injected beam

Horizontal tune distortion



- Trajectory from (-0.031 m, -0.05) to (-0.020 m, -0.05)

Stripping efficiency

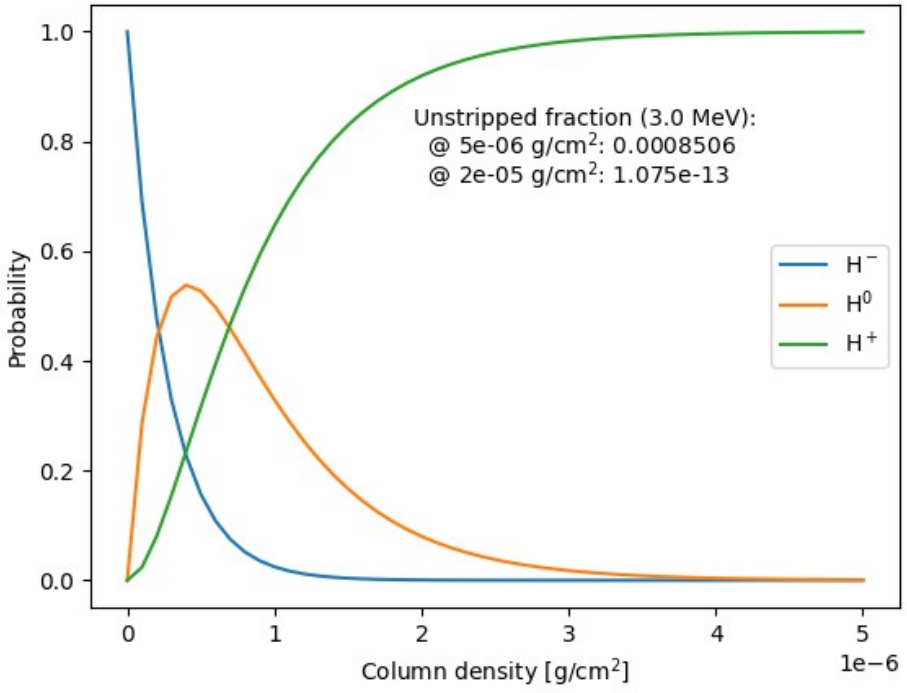
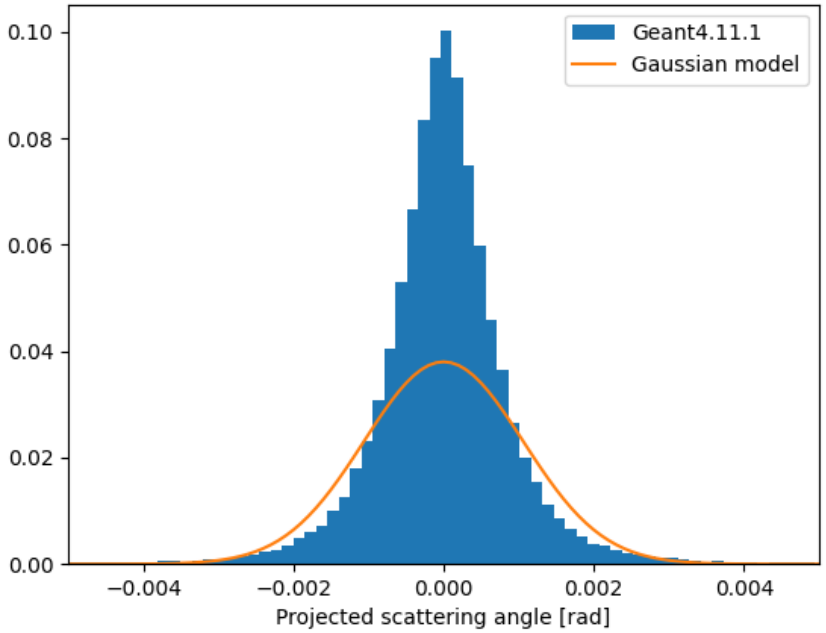


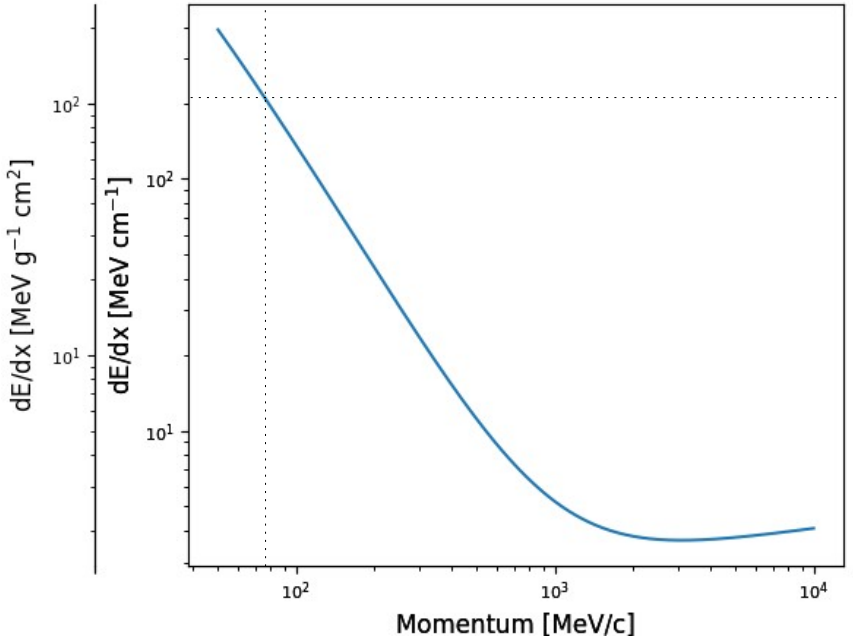
Table 3.3: Foil parameters.

Foil azimuthal position	4°	
Material	Carbon	
Density [g cm^{-3}]	2.0	
Radiation length [cm]	42.70	
Mean excitation energy [eV]	78.0	
Molecular mass [u]	12.0107	
Z	6	
Specific heat [J g^{-1} K^{-1}]	0.71	
Column density [g cm^{-2}]	5×10^{-6}	20×10^{-6}
Thickness [cm]	2.5×10^{-6}	10×10^{-6}
dE/E at 3 MeV (Geant4)	0.000174	0.000696
dE/E at 3 MeV (Bethe Bloch)	0.000178	0.000711
θ_x at 3 MeV (Geant4) [mrad]	0.587	1.26
θ_x at 3 MeV (PDG) [mrad]	0.779	1.56

- 20e-6 g/cm² is known to be possible for manual handling
  - Baseline
- 5e-6 g/cm² is minimum thickness for 99.9 % stripping
  - R&D/Upgrade

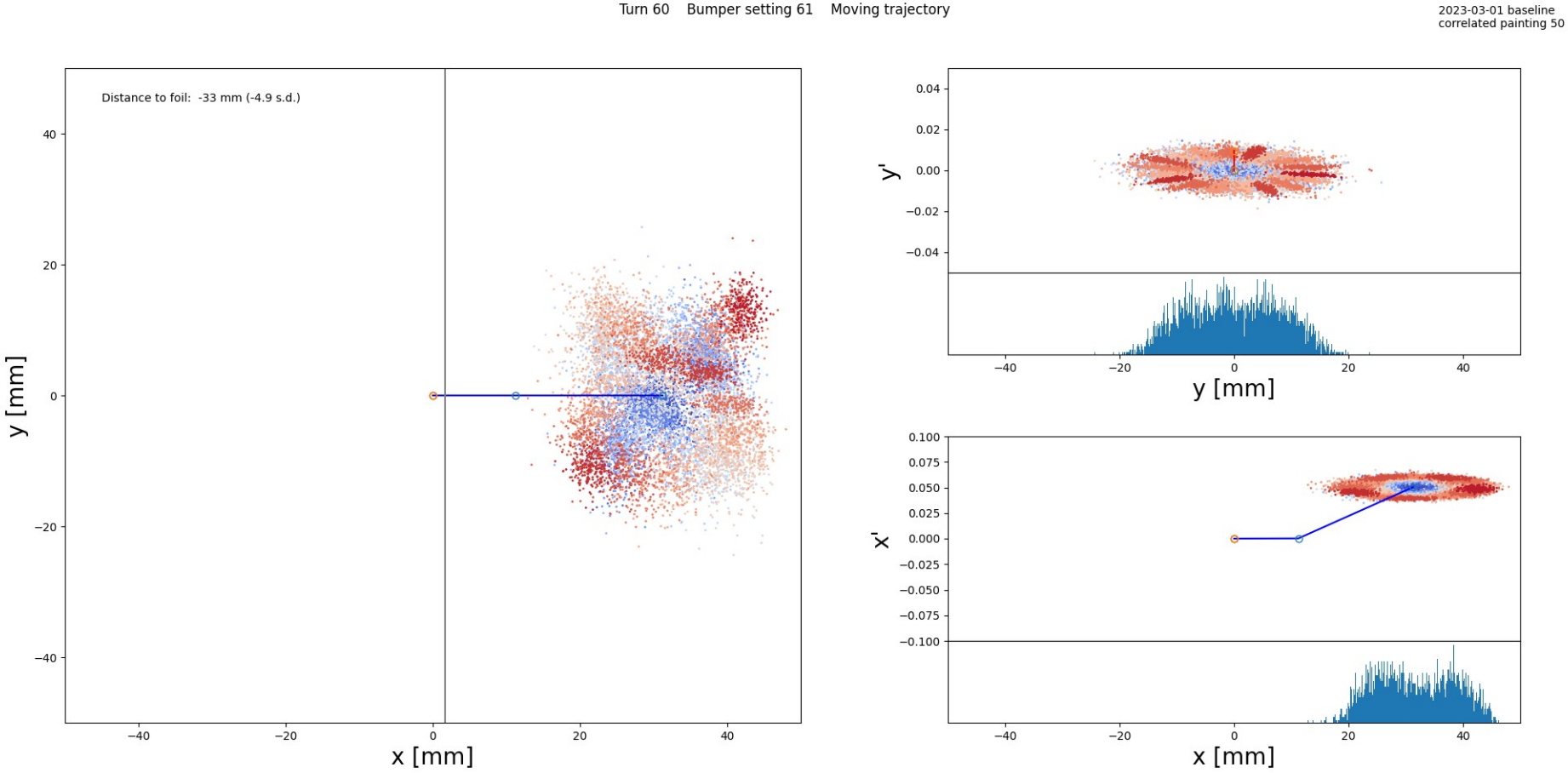
Scattering and Energy Loss



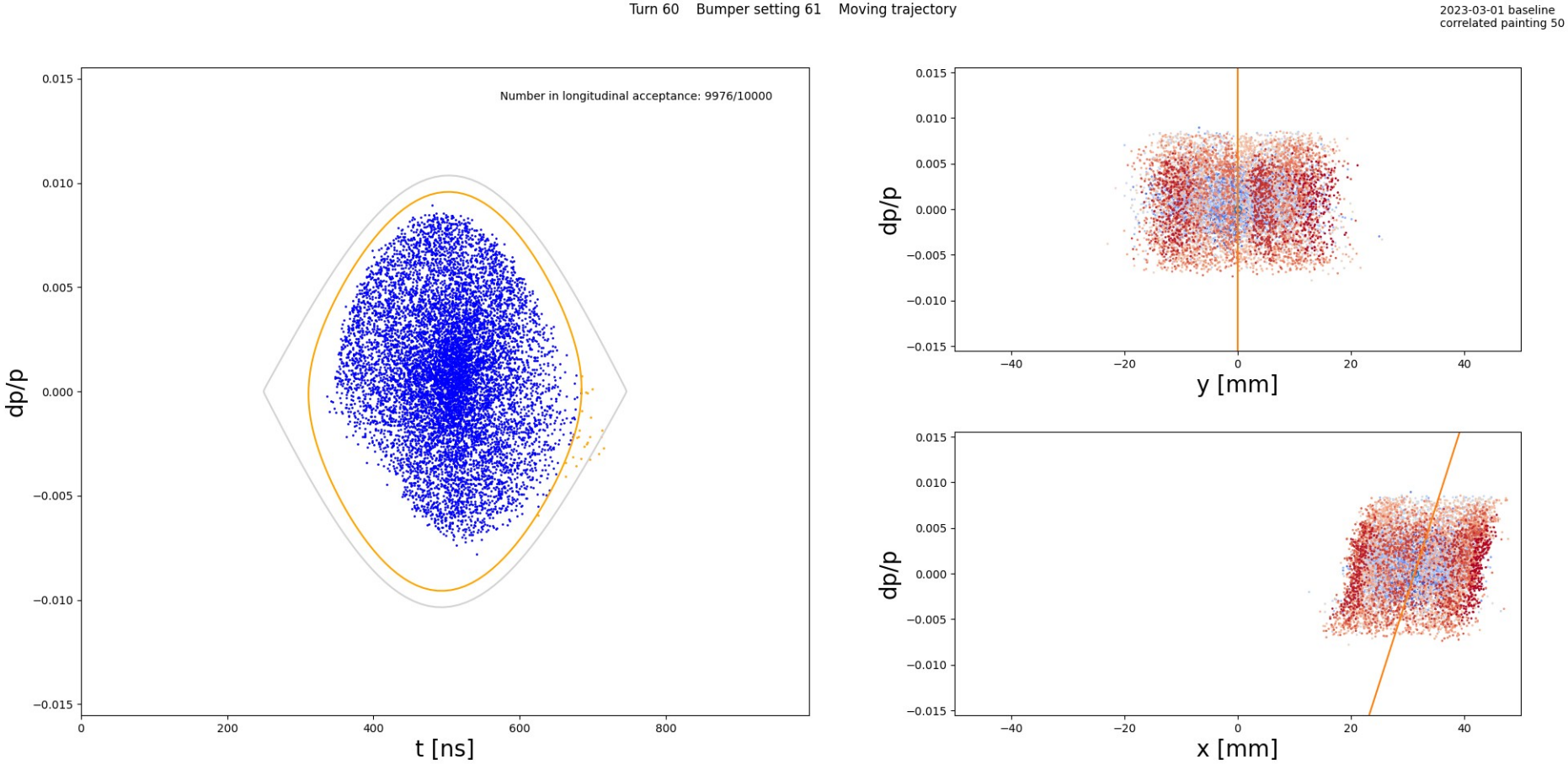


- 20e-6 g/cm^2 amorphous carbon
- Geant4 scattering is slightly optimistic compared to my model

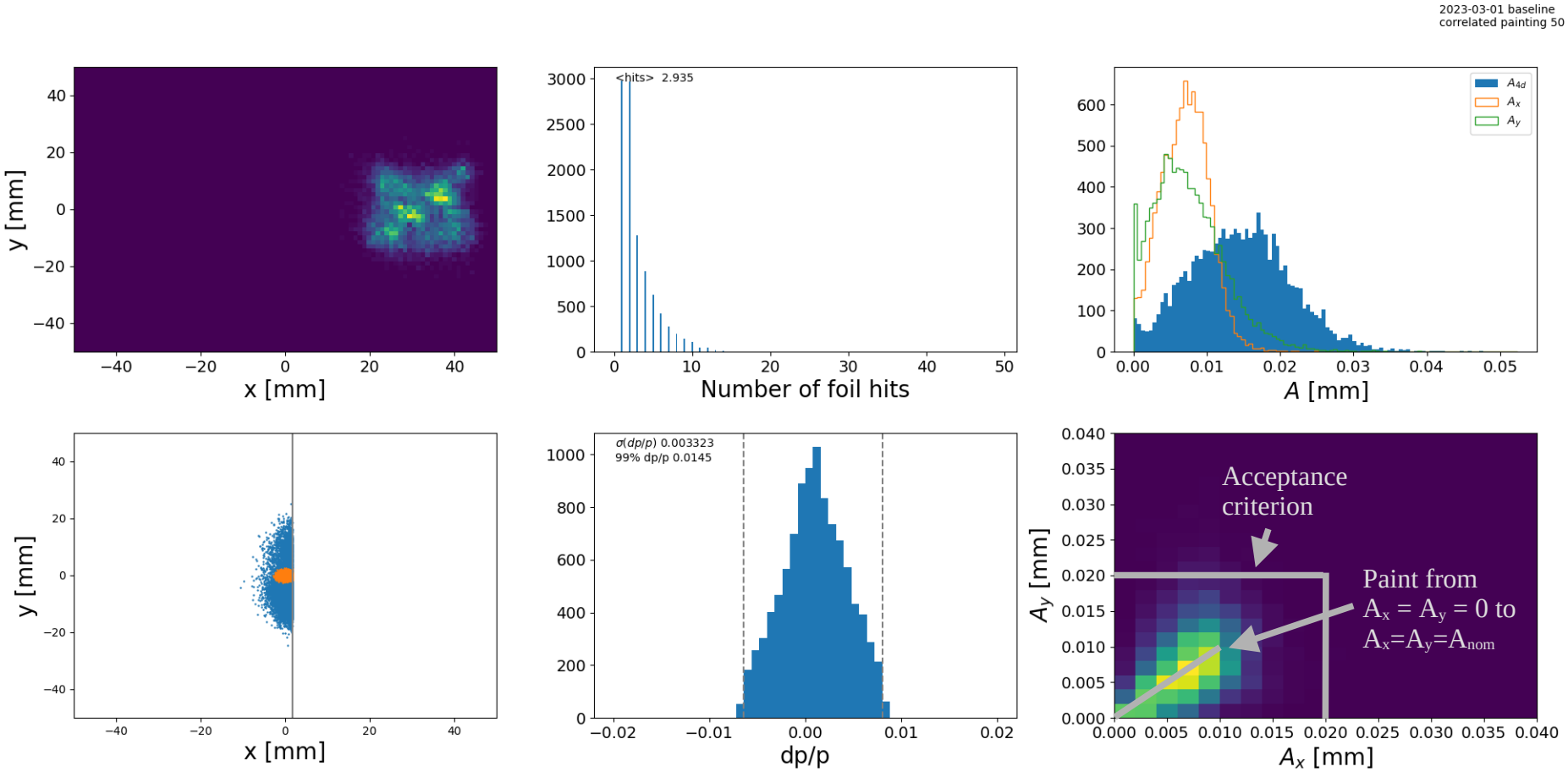
Correlated painting - transverse



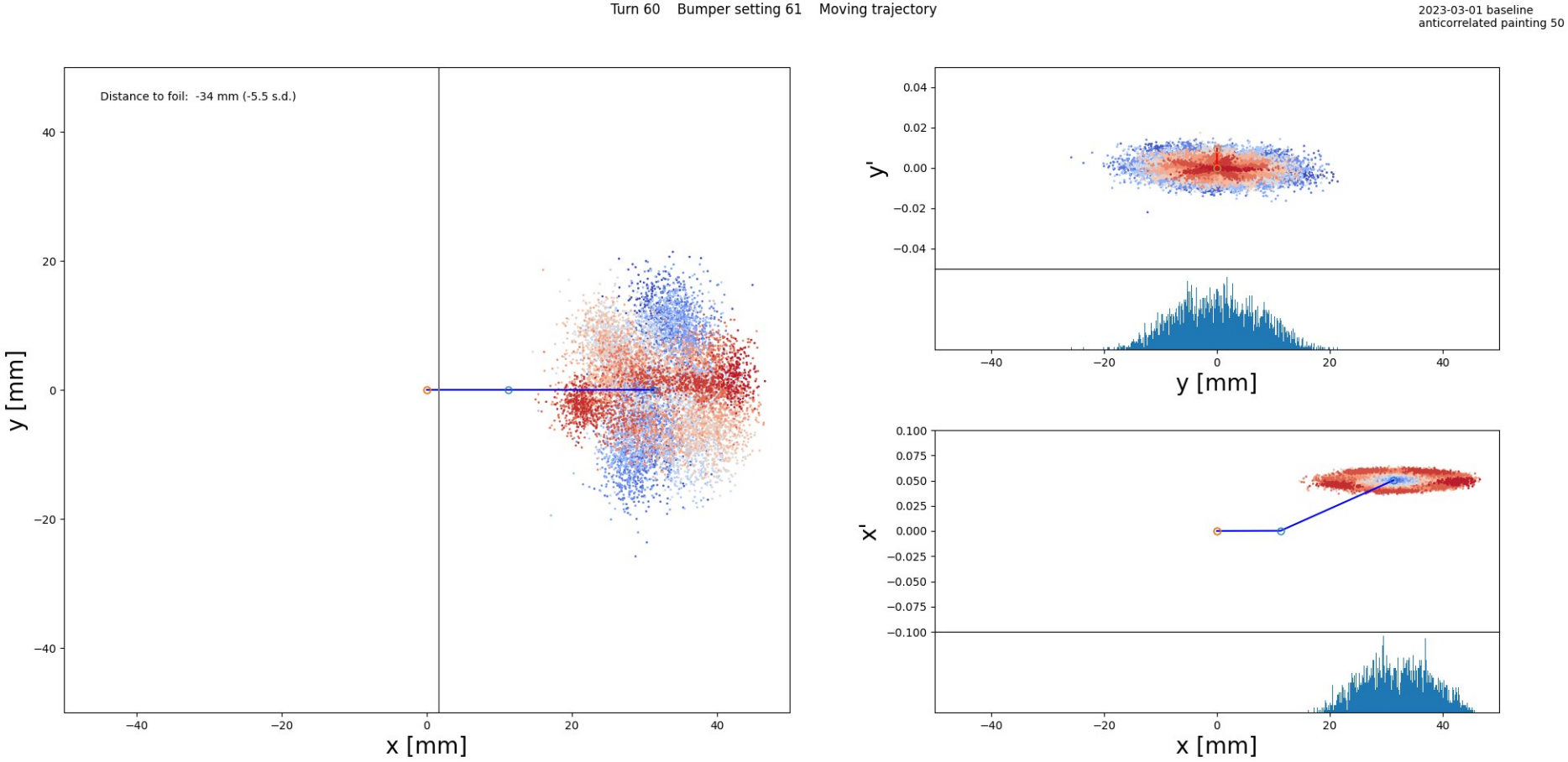
Correlated painting - longitudinal



Correlated painting - summary



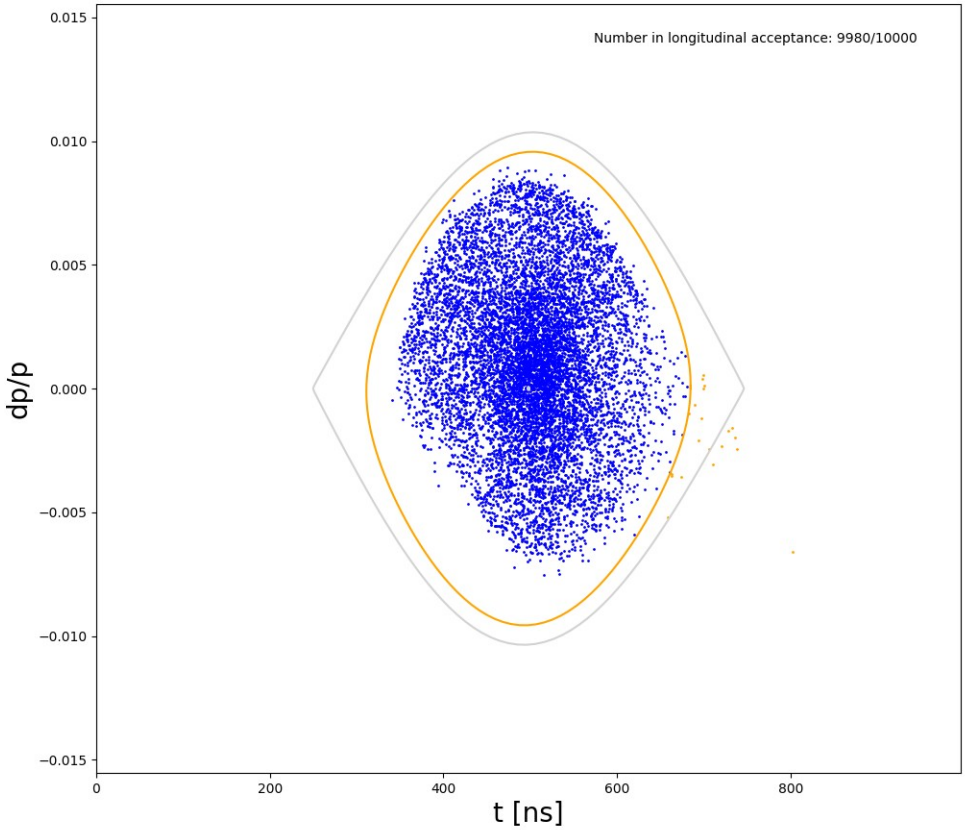
Anticorrelated painting - transverse

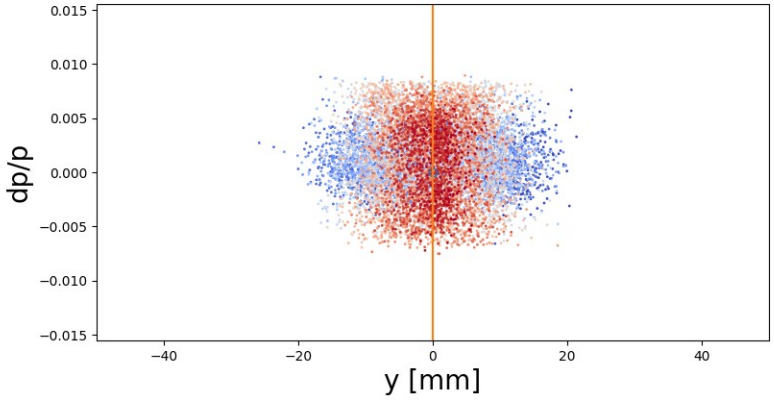


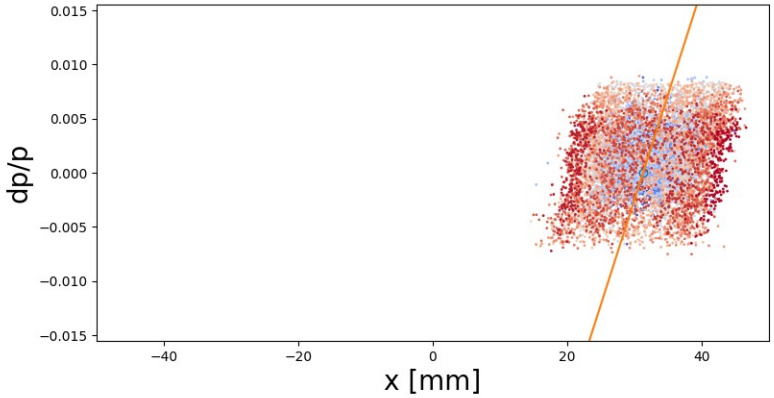
Anticorrelated painting - longitudinal

Turn 60 Bumper setting 61 Moving trajectory

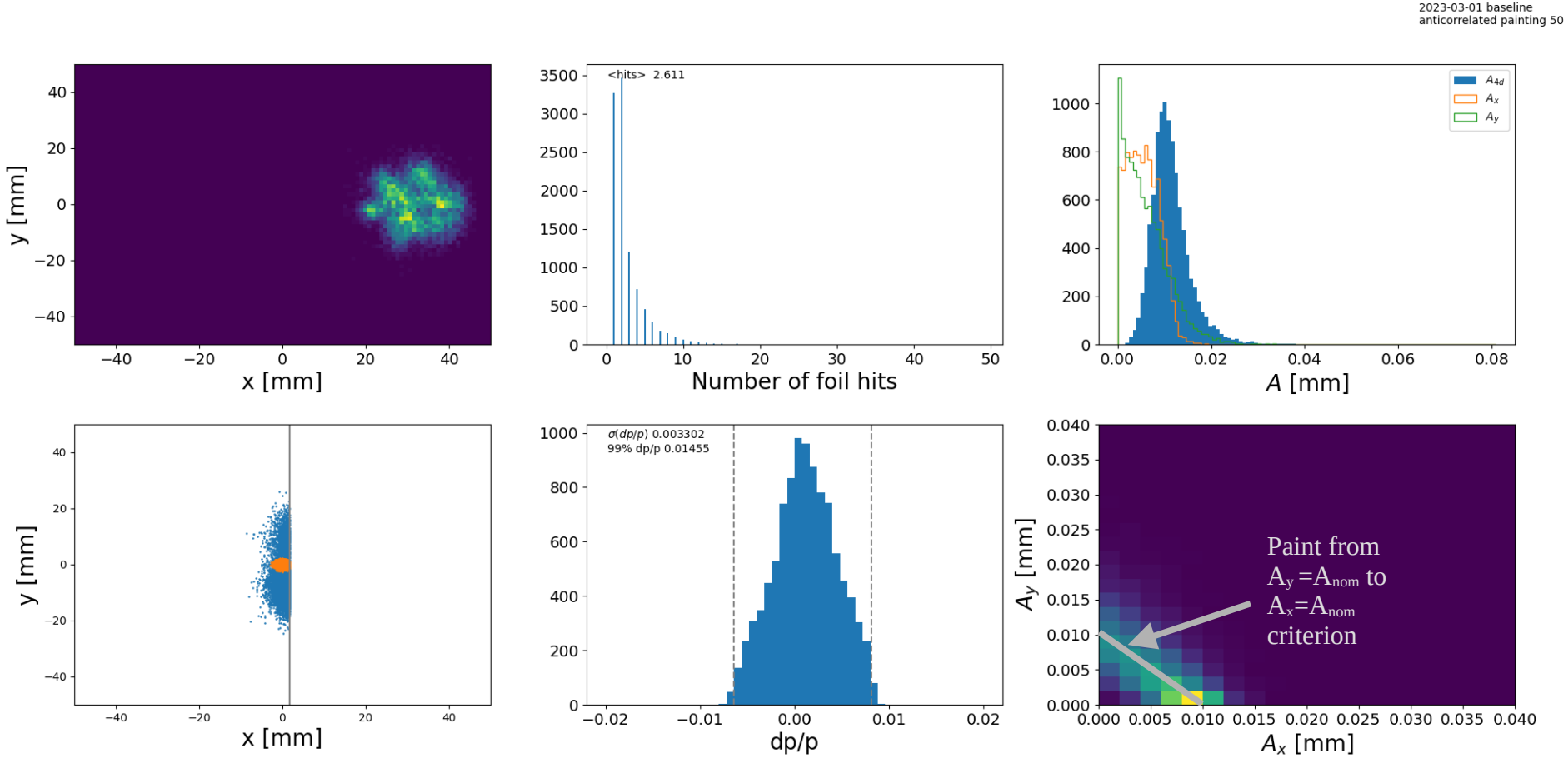
2023-03-01 baseline
anticorrelated painting 50



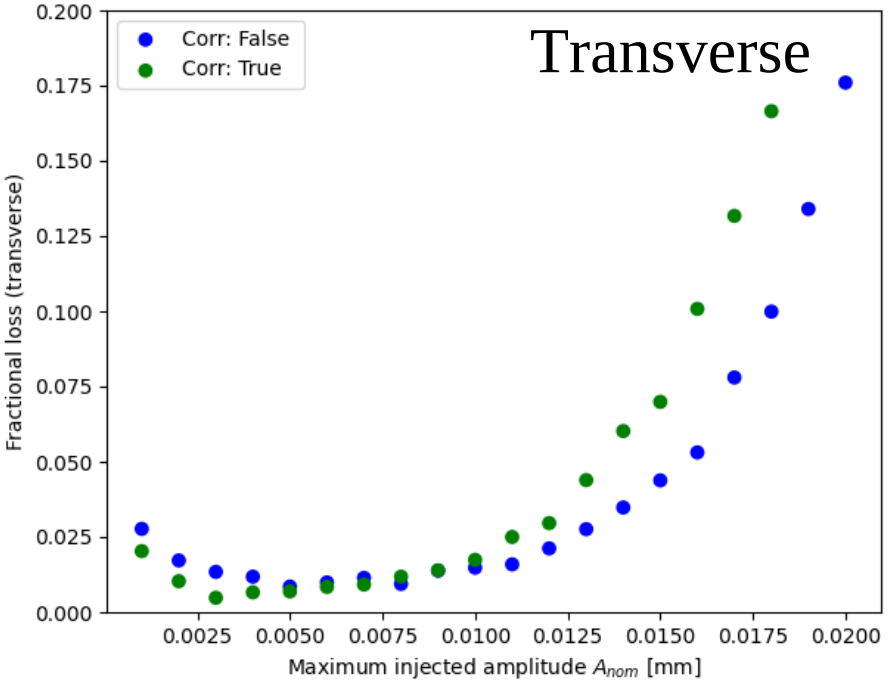


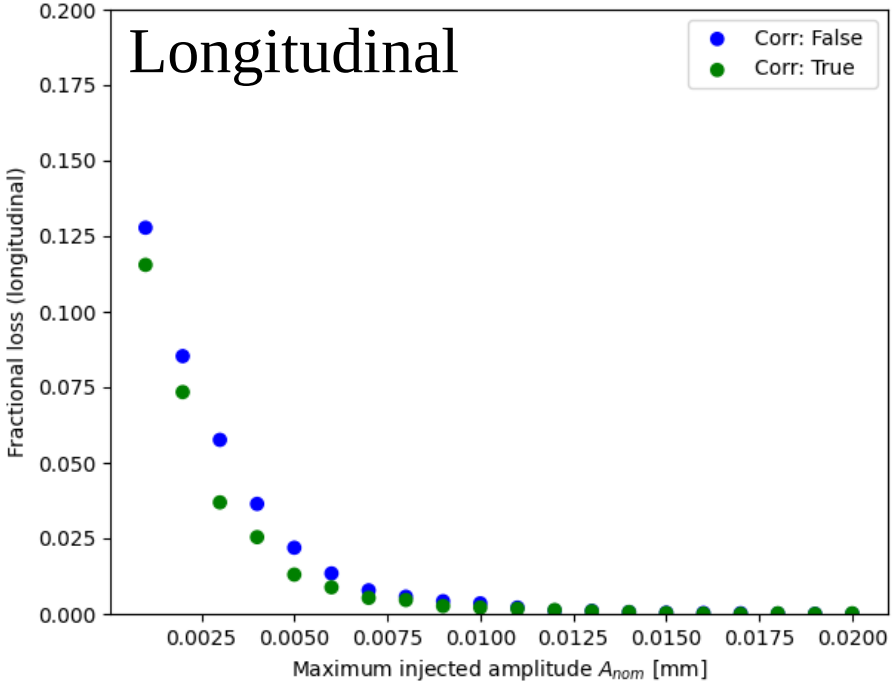


Anticorrelated painting - summary



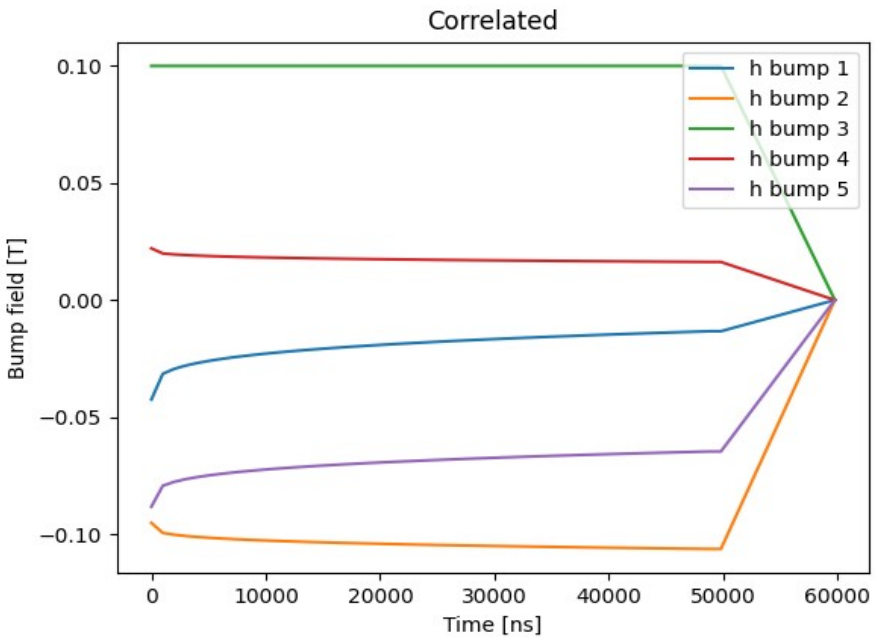
Loss

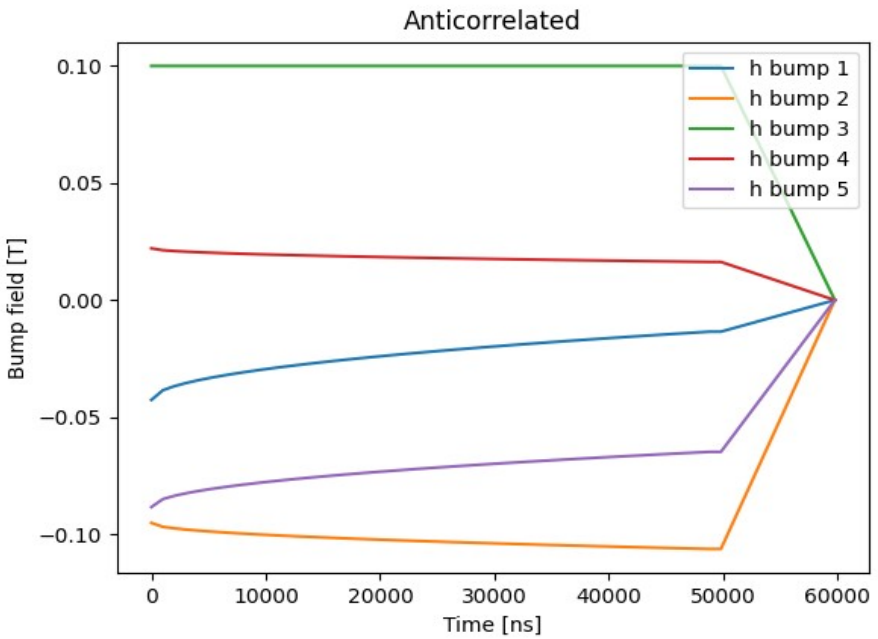




- Loss vs A_{nom}
- At low A_{nom}, beam returns through foil many times
  - Significant energy loss
  - Mostly longitudinal losses
- At high A_{nom}, beam passes close to collimator
  - Mostly transverse losses
  - Scattering and injected beam emittance → losses

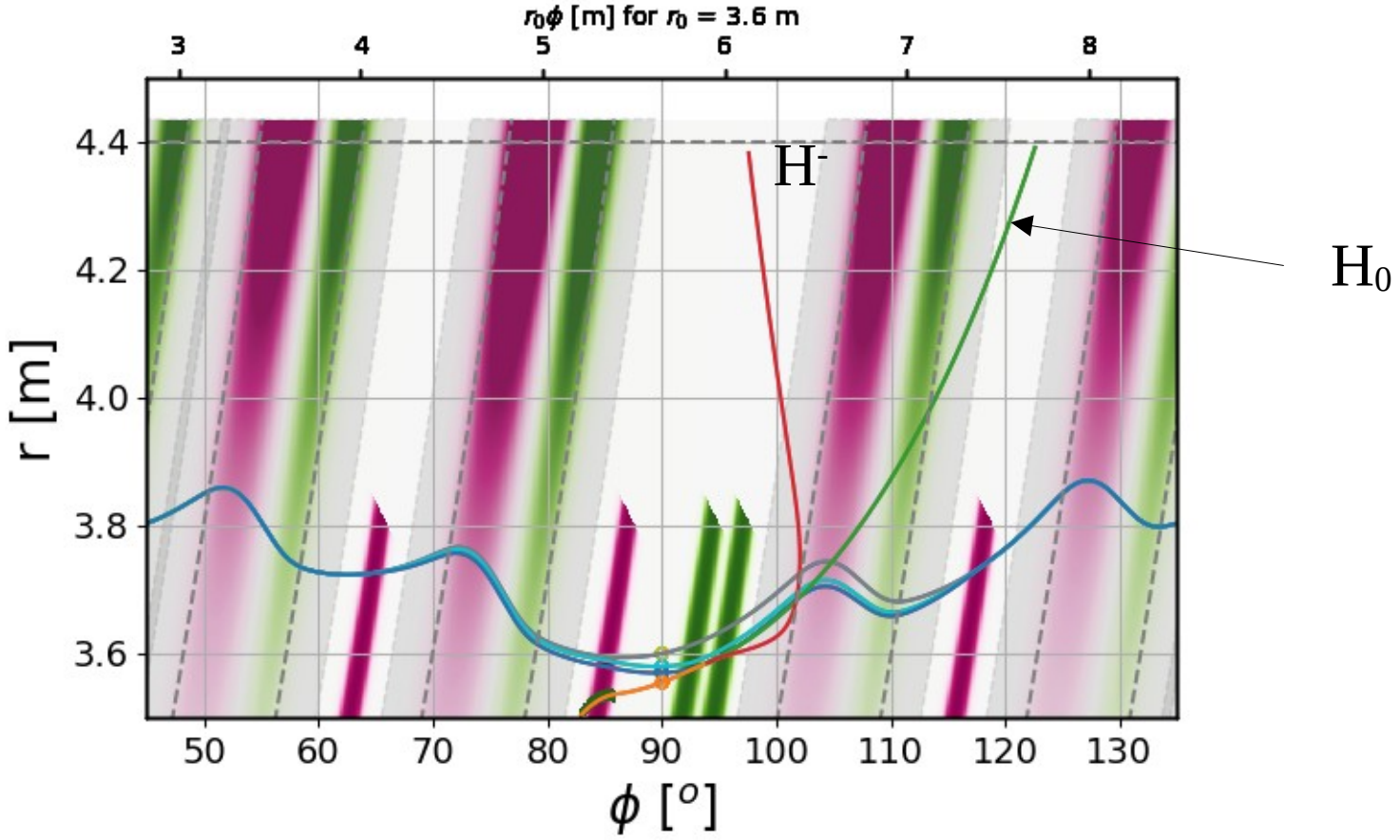
Dipole pulse shape





- Dipole pulse shape
  - Initially rapidly changing as position changes quickly
    - $A \sim x^2$
  - Slows down at higher amplitudes
  - Finally collapse the bump over a few turns

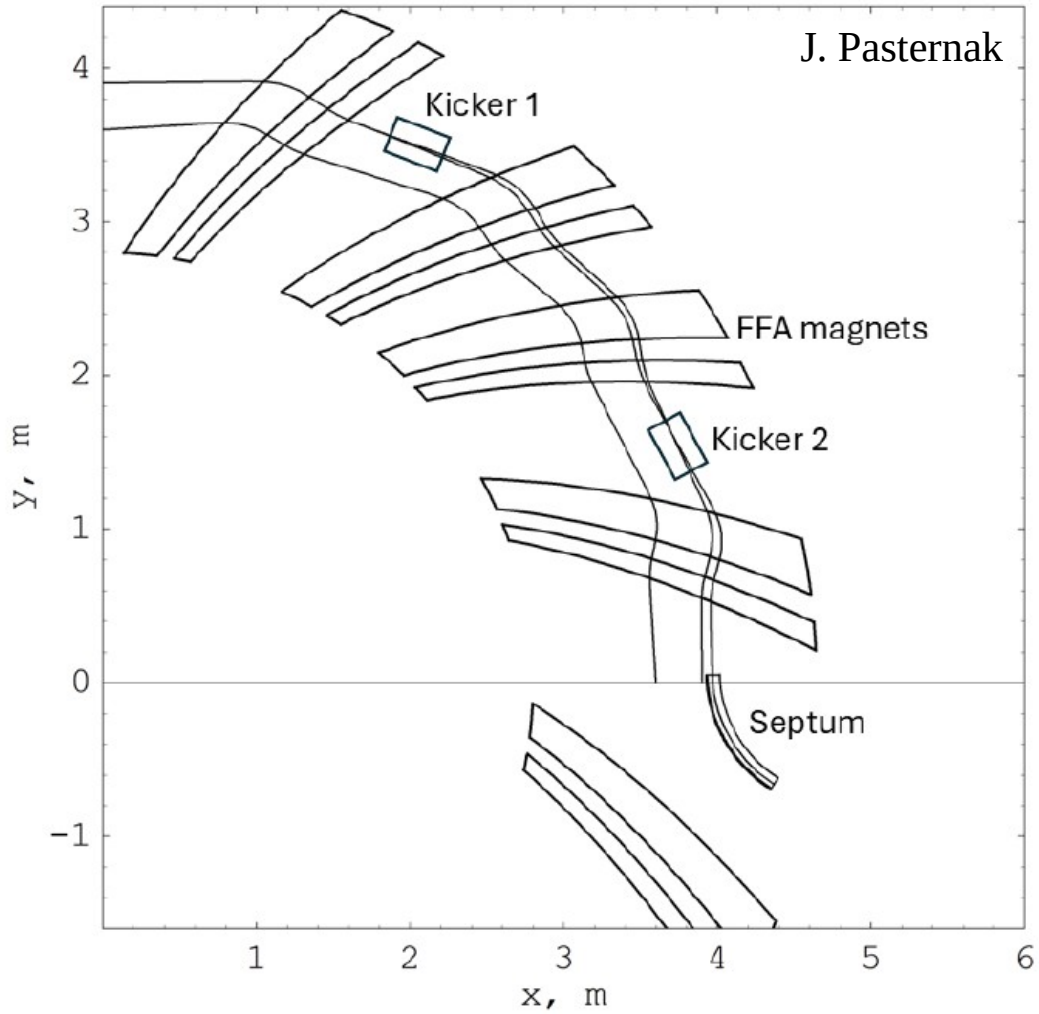
Trajectory of unstripped species



- Trajectory of H^- and H_0 beam
- Relatively low heat load involved
  - Unless incident with full FETS beam

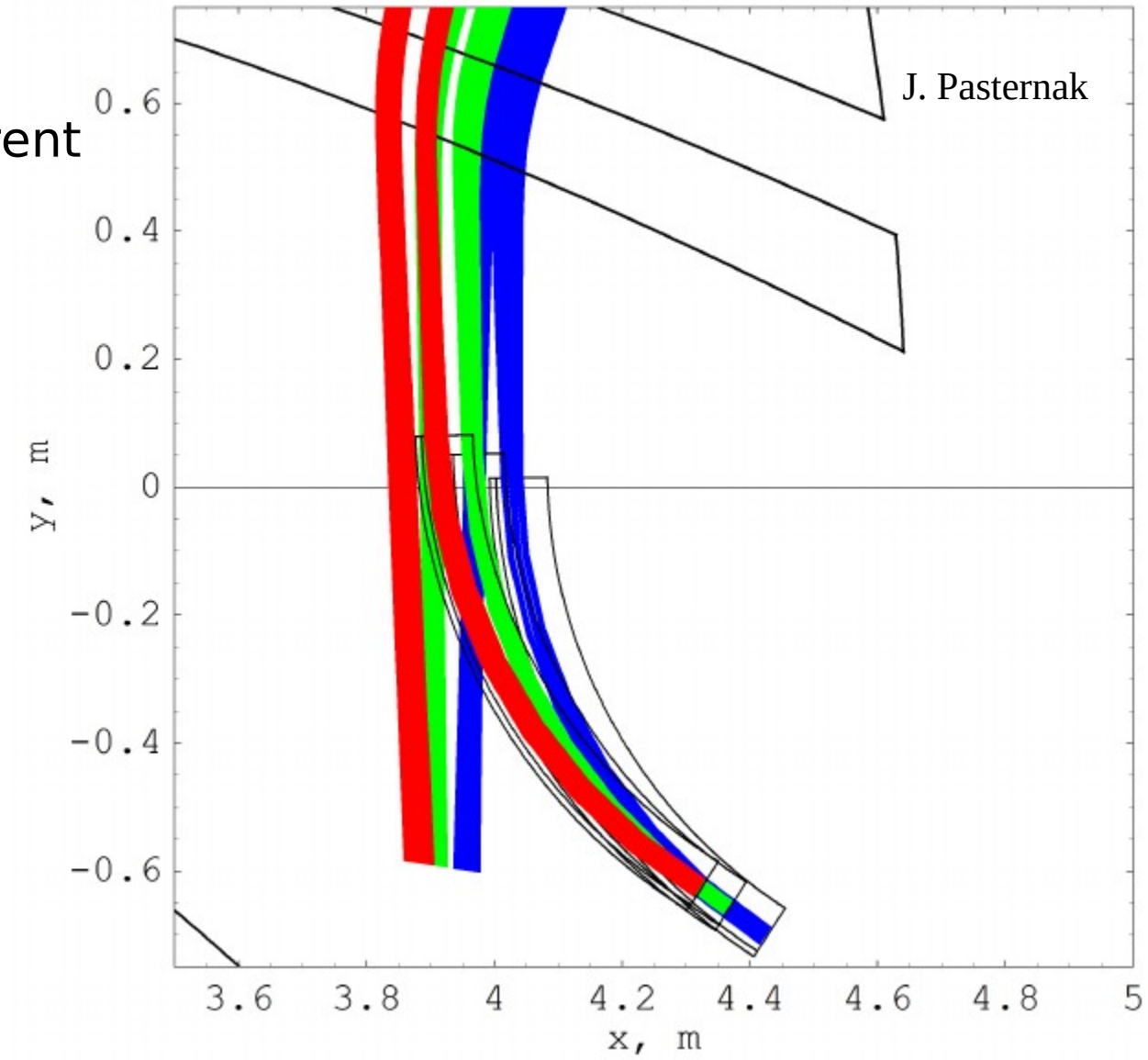
Extraction

- Dual kicker extraction
- For different k-values
  - Moving orbits
  - Wide enough kickers
  - Movable septum



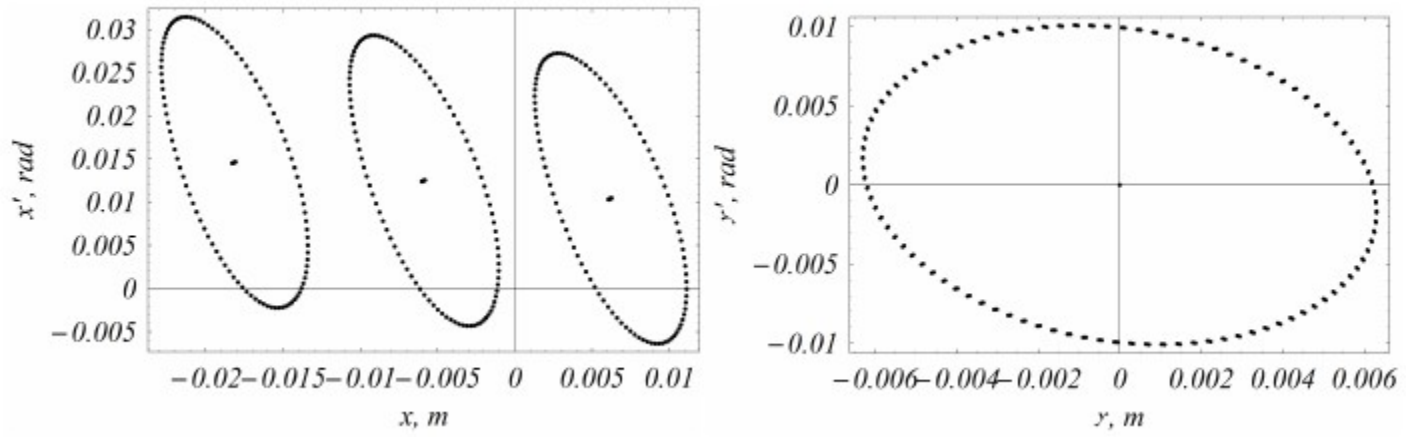
Multiple orbits

- Studied three different closed orbits
- Corresponding to maximum radial displacements



Phase space

J. Pasternak



- Three different orbits incident on the septum
- Returns undistorted phase space in all three cases

Parameter	Kicker	Septum
Direction	horizontal	horizontal
Maximum magnetic field [T]	0.05	0.58
Length [m]	0.39	0.85
Rise time [ns]	122.4	-
Flat top duration [ns]	422.4	DC or pulsed
Thickness [cm]	-	~1
Number of magnets	2	1
Relative longitudinal translation (high k/low k) [cm]	-	-2.91/+3.71
Relative horizontal translation (high k/low k) [cm]	-	-4.87/+6.70

- Reasonable hardware requirements

Summary

- We have designed an injection system for the FFA
- Anticorrelated and correlated painting looks possible
- Non-linearities seem under control
- Tight injection space is manageable
- Would be first ever phase space painting into an FFA