Beam preparation for XFI

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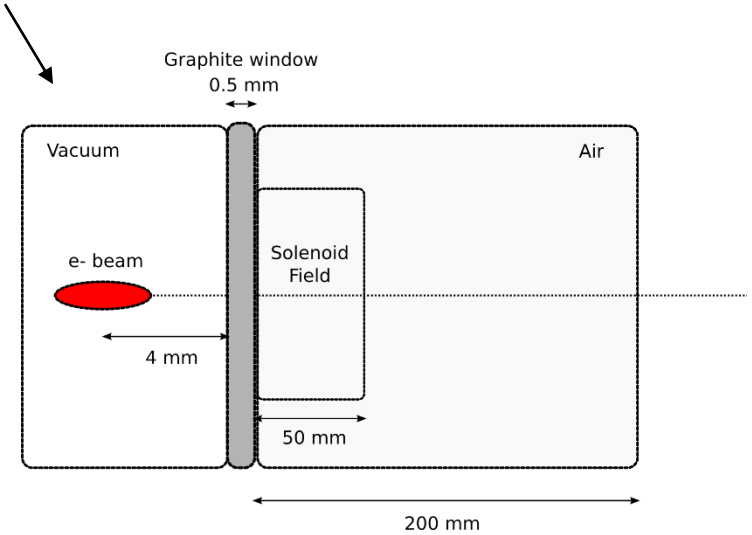
Outline

- Simulation setup
- Particle tracking
- Monte-Carlo simulation
- Conclusion

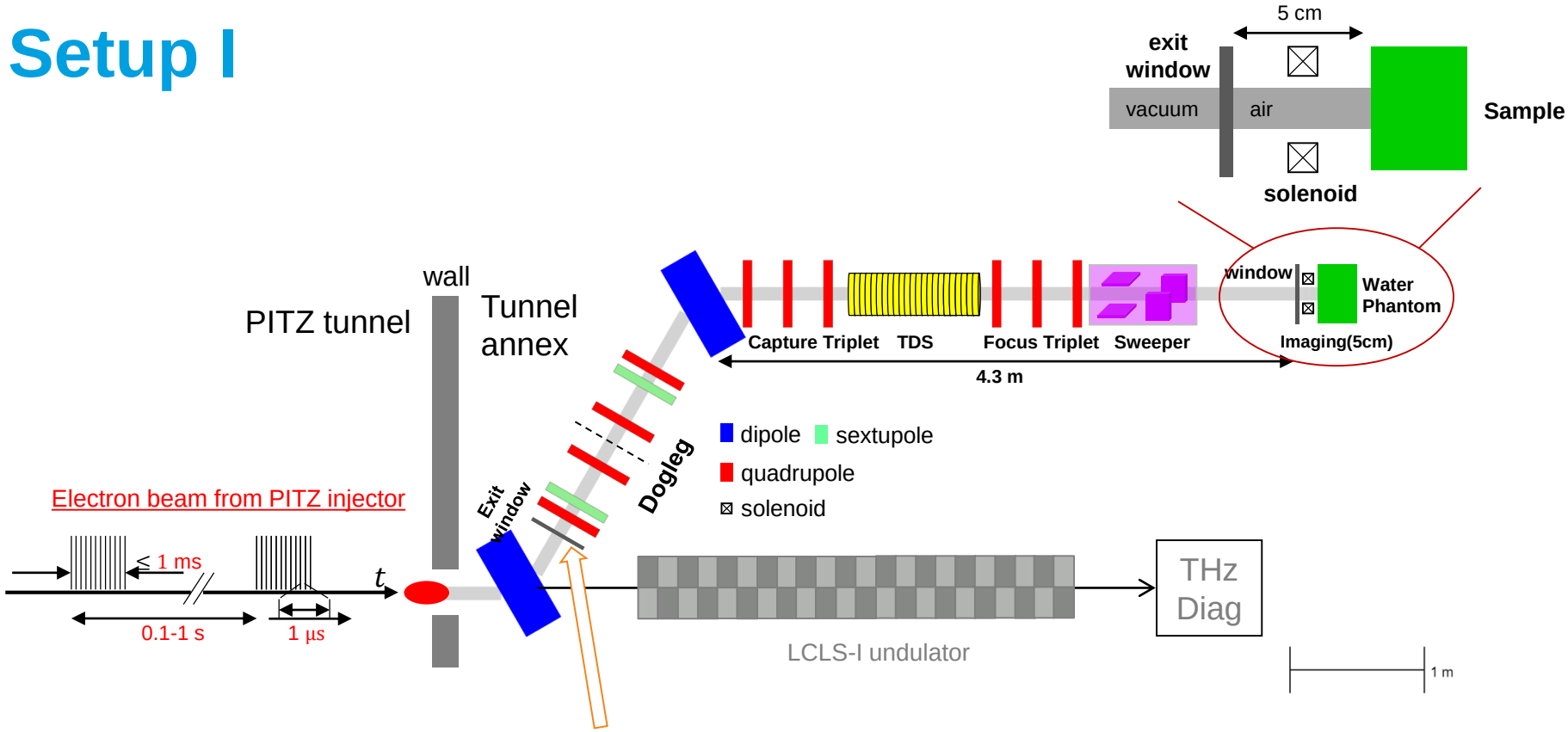
Setup for beam simulation

Requirement for XFI:
FWHM < 1 mm
Bunch charge TBD

- Two bunch charges (100 pC and 1 nC) were considered
  - Beam energy is 22 MeV (or 22.5 MeV/c)
  - Particle tracking (Astra, Elegant and Ocelot) from photocathode to exit window (X.-K. Li)
  - Monte-Carlo simulation in exit window and air with and w/o imaging solenoid (Z. Aboulbanine)

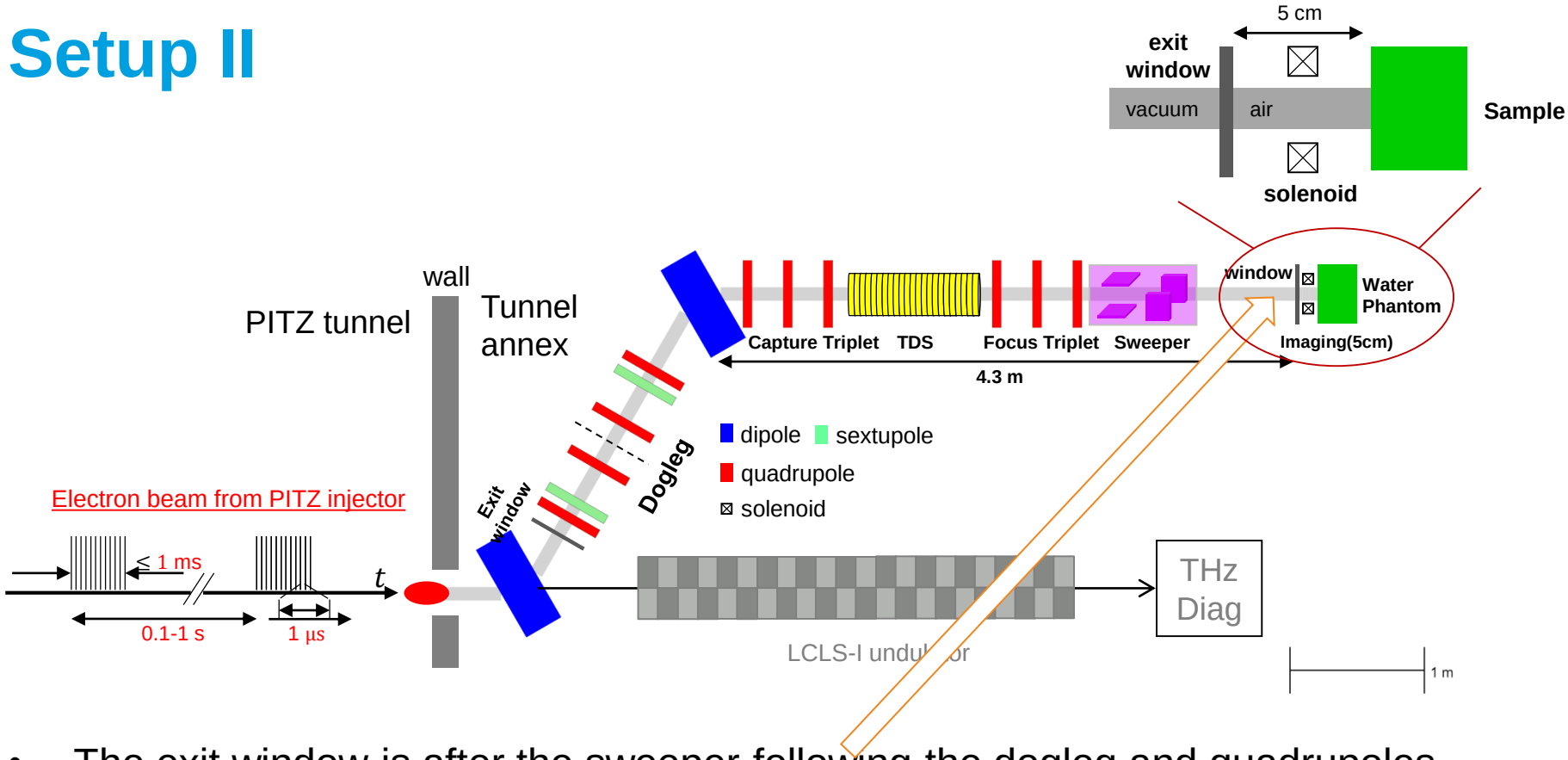


Setup I



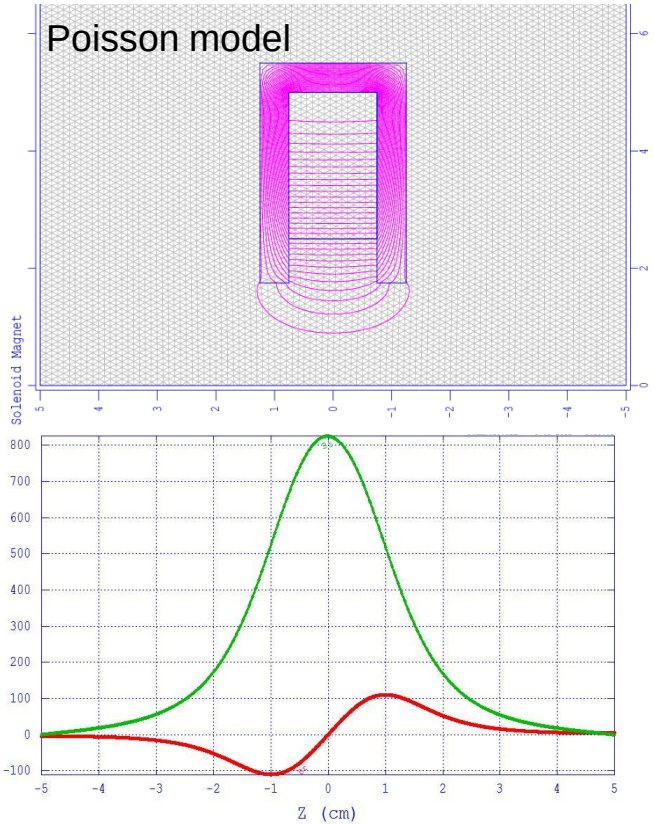
- The exit window is right after the first dipole of the dogleg

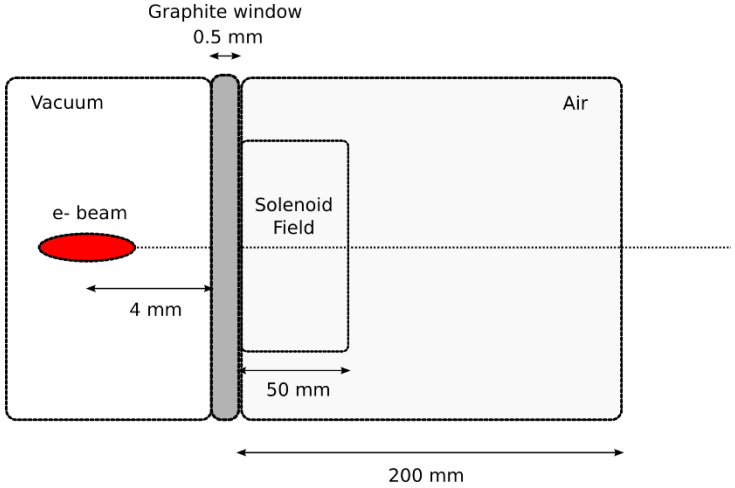
Setup II

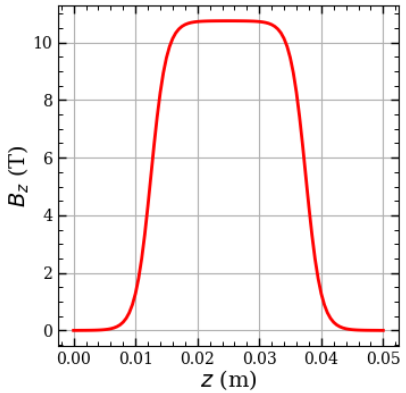


- The exit window is after the sweeper following the dogleg and quadrupoles

Solenoid field





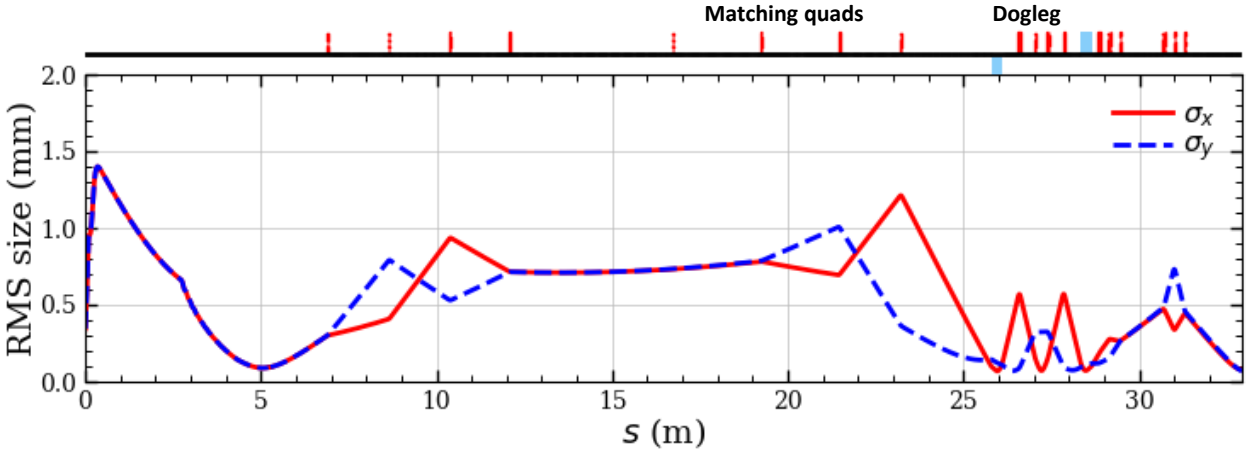


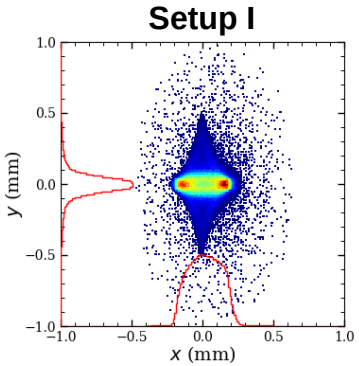
On-axis solenoid field
Used in the MC simulation

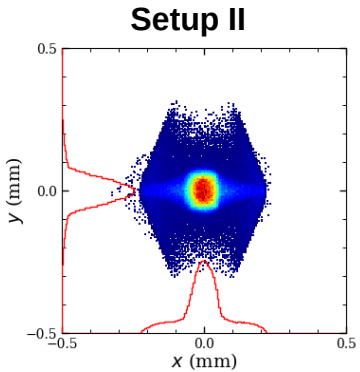
Particle tracking

100 pC

- Laser: 8 ps FWHM; uniform transversely with spot size optimized for small emittance at EMSY1
- Gun: 60 MV/m, MMMG phase
- Booster phase optimized to minimize the energy spread at the dogleg
- Four quadrupoles after the booster to focus the divergent beam
- Four quadrupoles before the wall to match the beam into the dogleg



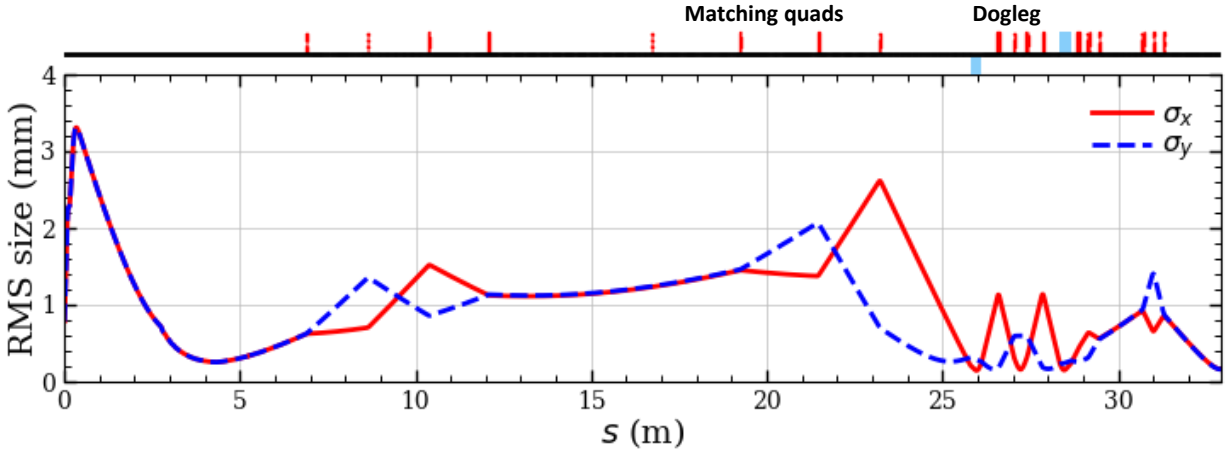




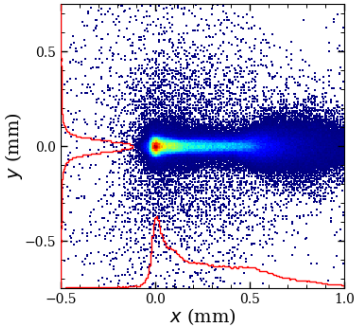
Particle tracking

1 nC

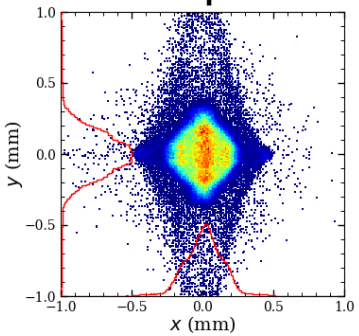
- Laser: 8 ps FWHM; uniform transversely with spot size optimized for small emittance at EMSY1
- Gun: 60 MV/m, MMMG phase
- Booster phase optimized to minimize the energy spread at the dogleg
- Four quadrupoles after the booster to focus the divergent beam
- Four quadrupoles before the wall to match the beam into the dogleg



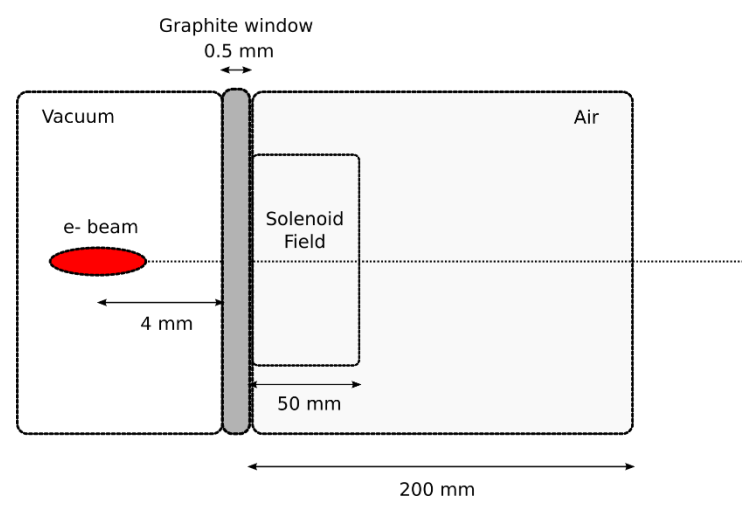
Setup I



Setup II



MC simulation at 100 pC

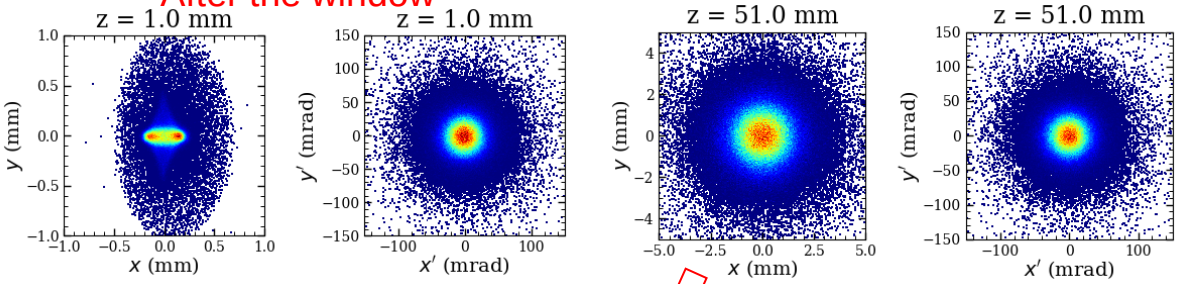


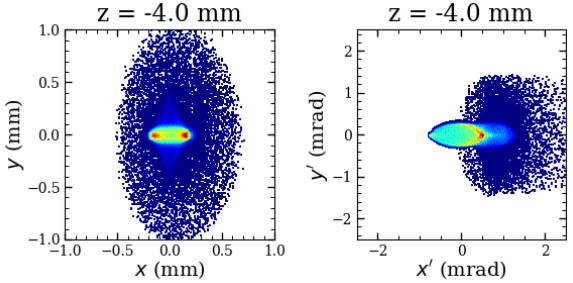
Beam transport in air only

Setup I

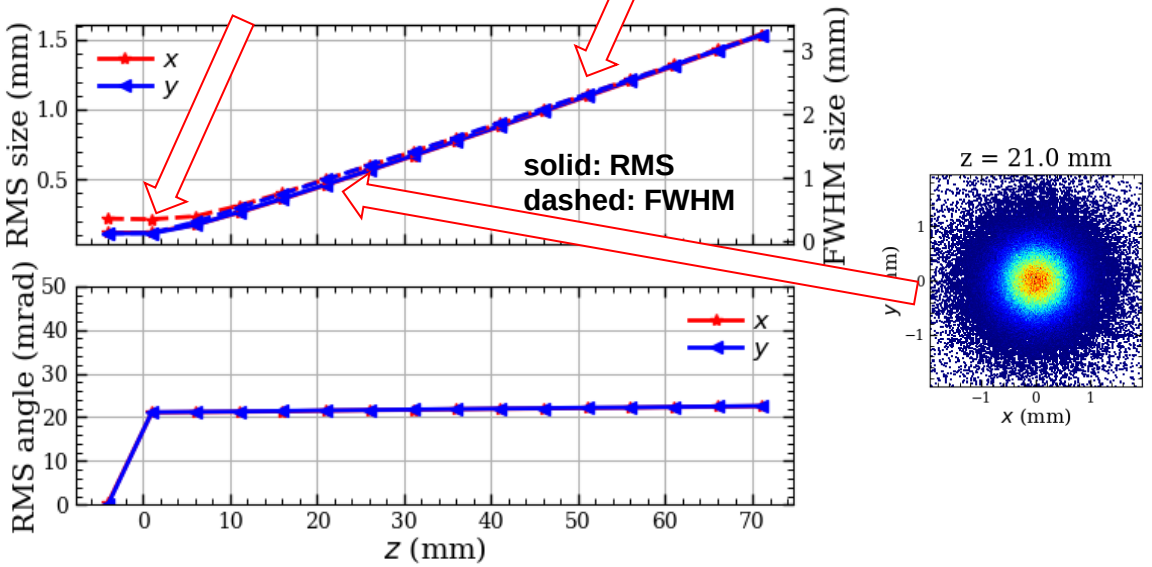
- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 2.3 mm
- FWHM<1 mm for z<21 mm

After the window





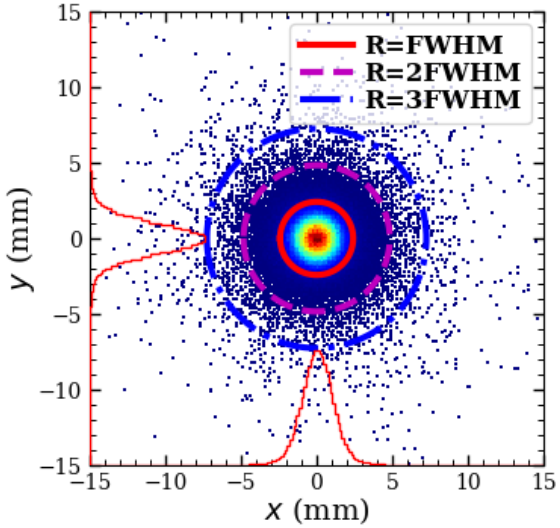
Before the window



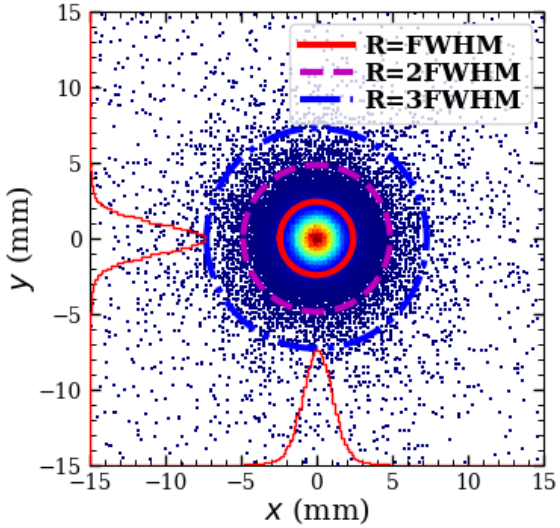
The beam is flat due to dispersion in the dipole

Data analysis for RMS calculation

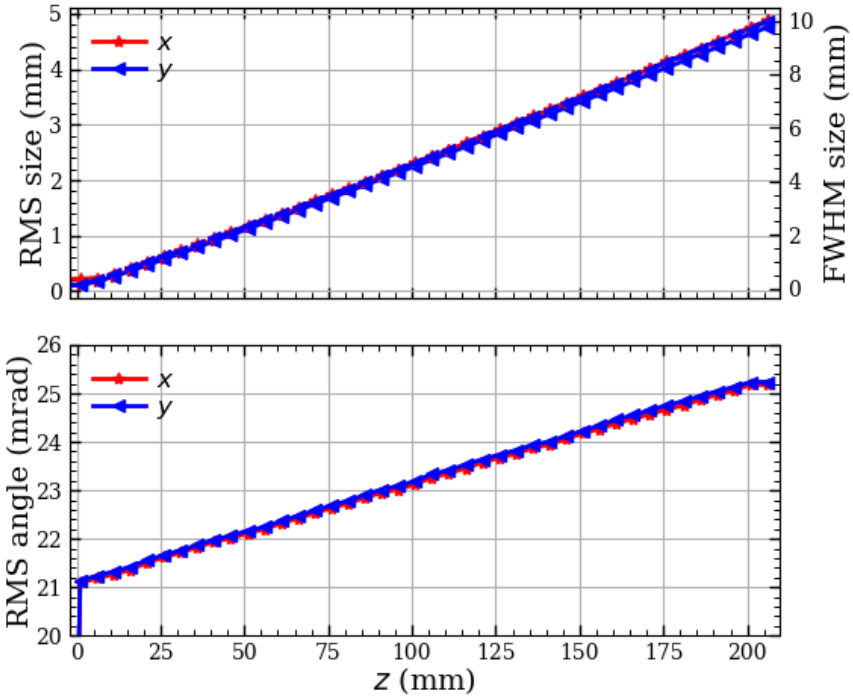
W/O secondaries



W/ secondaries



Scattering effect in air

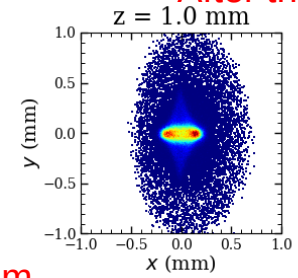


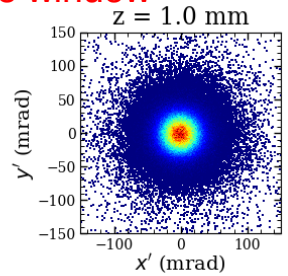
Beam transport in air with solenoid

Setup I

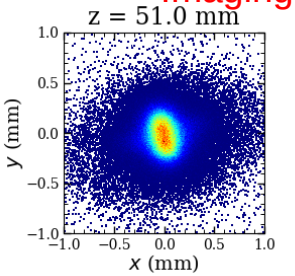
- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 0.26/0.40 mm
- The beam profile at the imaging point has imprints from the beam after the window, e.g., ellipsoidal core and tails on the sides

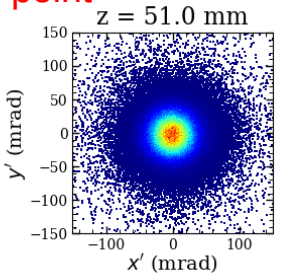
After the window

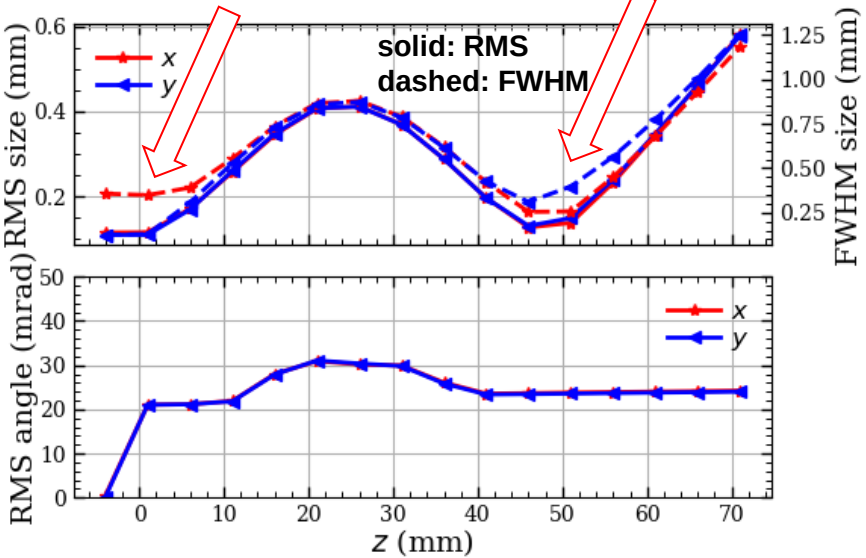




Imaging point





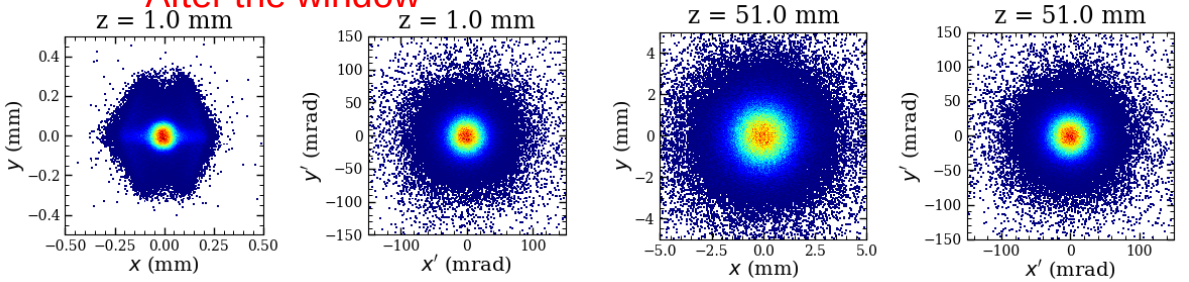


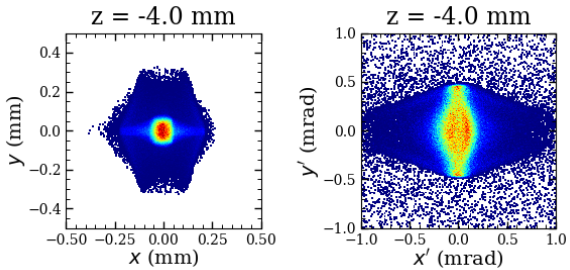
Beam transport in air only

Setup II

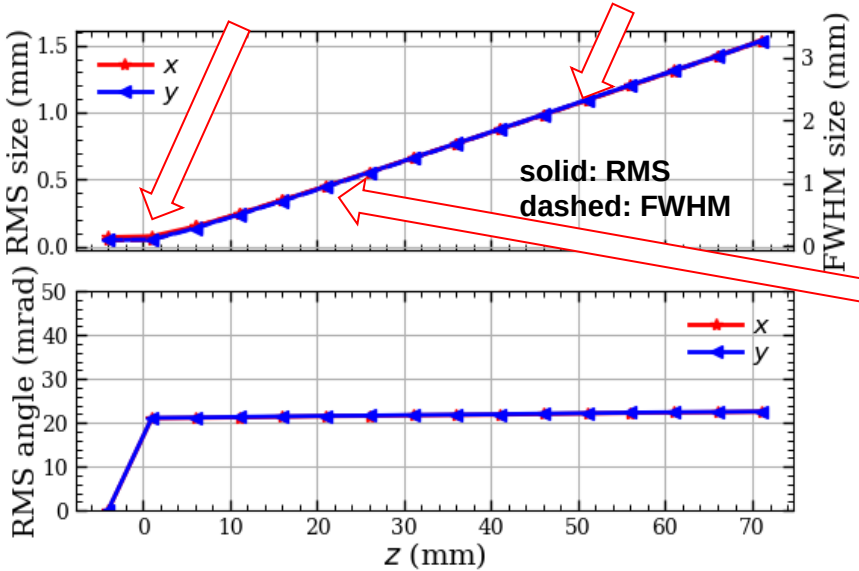
- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 2.3 mm
- FWHM<1 mm for z<21 mm

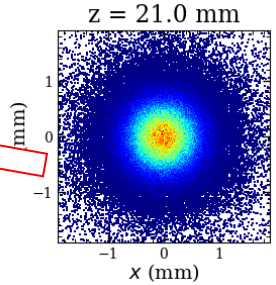
After the window





Before the window





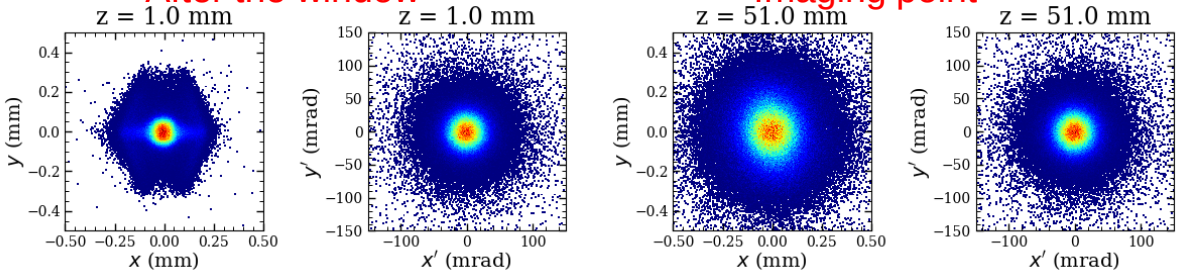
Beam transport in air with solenoid

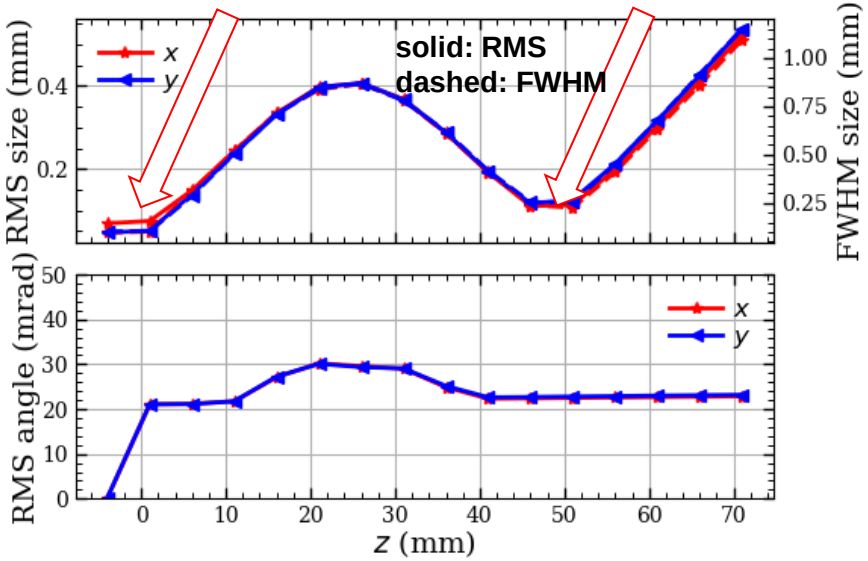
Setup II

- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 0.23/0.25 mm

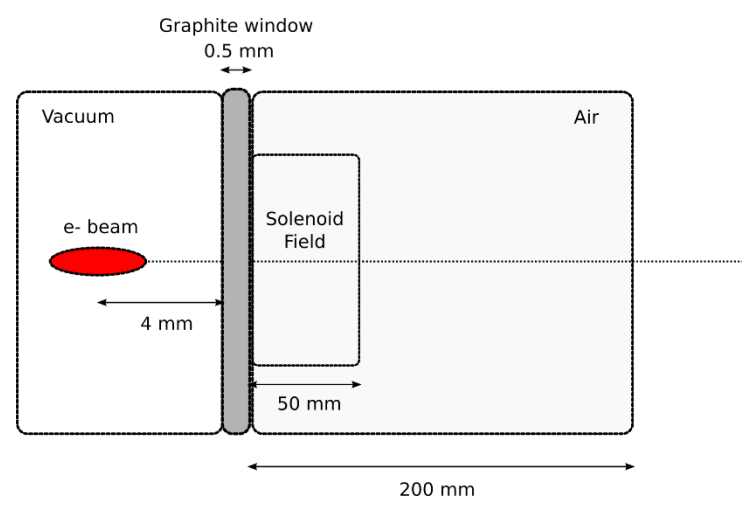
After the window

Imaging point





MC simulation at 1 nC

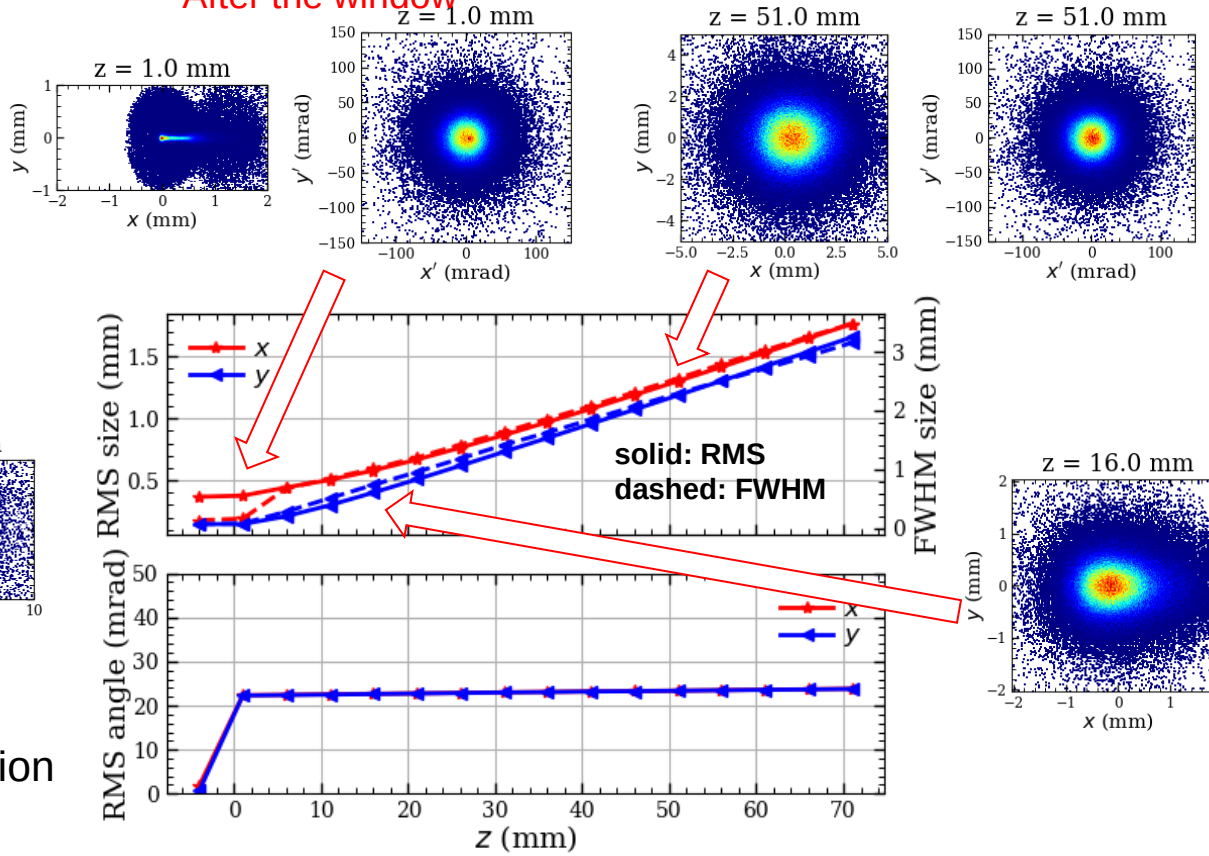


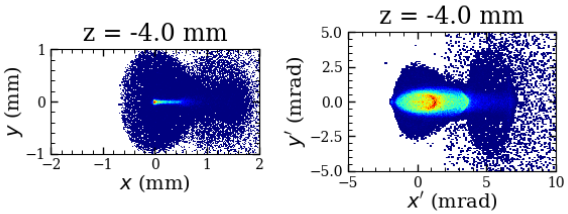
Beam transport in air only

Setup I

- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 2.6/2.3 mm
- FWHM<1 mm for z<~20 mm

After the window





Before the window

The beam is flat due to dispersion in the dipole

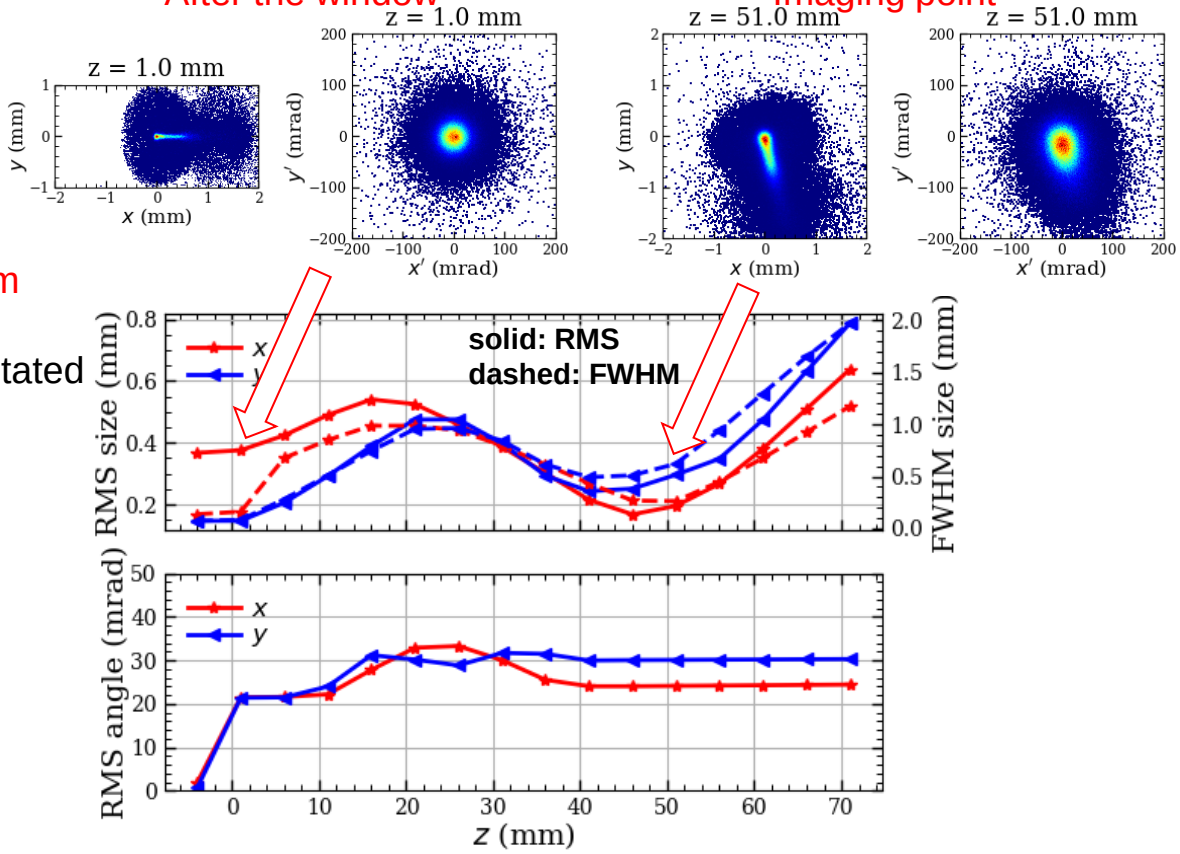
Beam transport in air with solenoid

Setup I

- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 0.26/0.62 mm
- Here, the imaging leads to a rotated beam with a clear tail

After the window

Imaging point

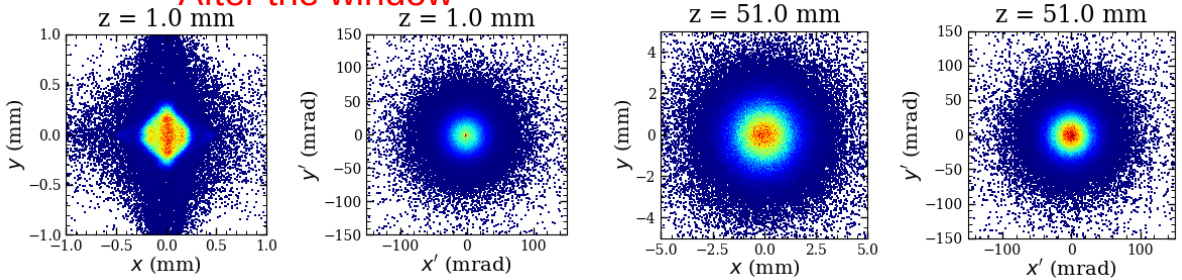


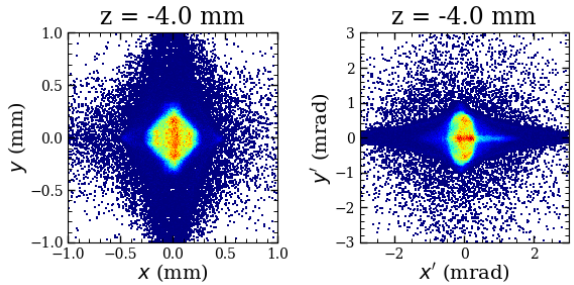
Beam transport in air only

Setup II

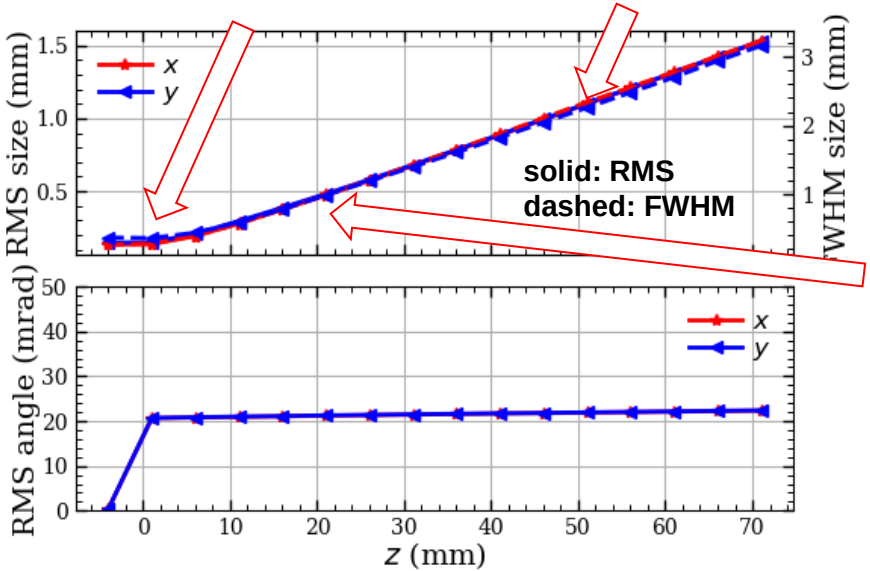
- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 2.3 mm
- FWHM<1 mm for z<21 mm

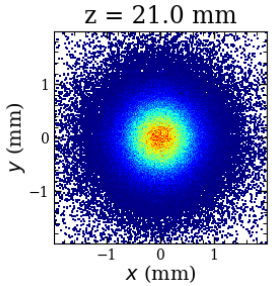
After the window





Before the window



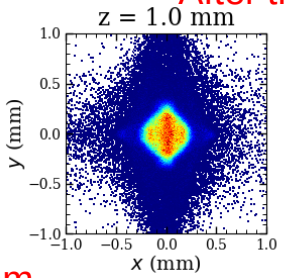


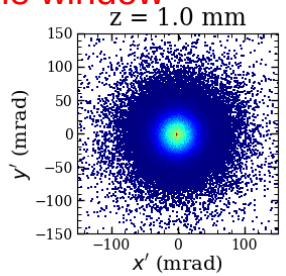
Beam transport in air with solenoid

Setup II

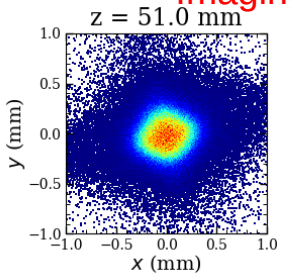
- Exit window starts from 0 mm
- Secondaries removed
- Beam cut at R=2FWHM
- FWHM@51mm ~ 0.44/0.40 mm

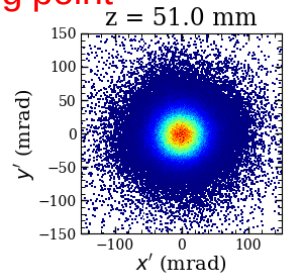
After the window

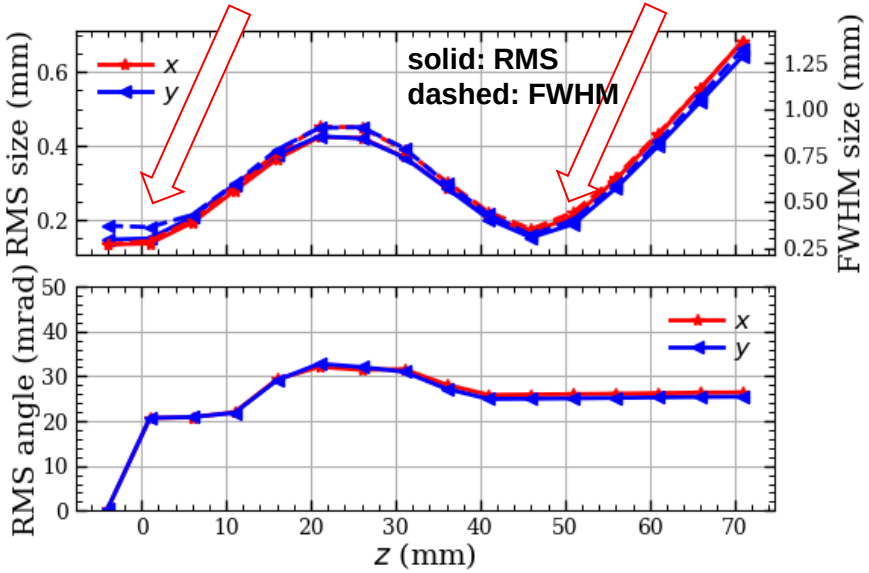




Imaging point

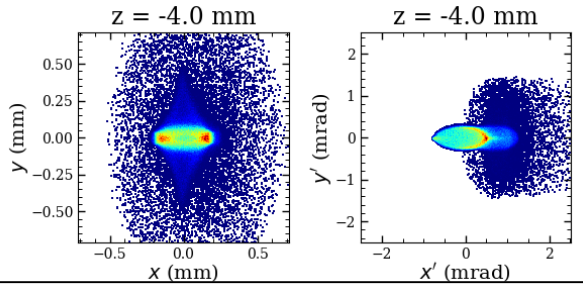
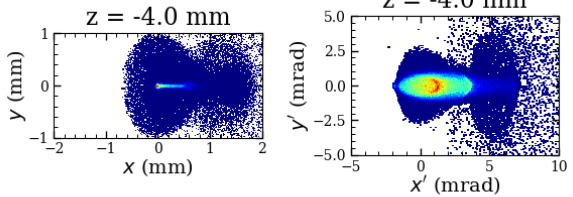
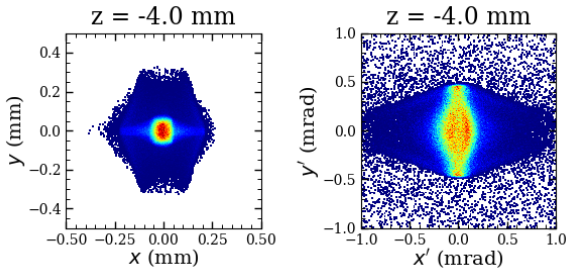
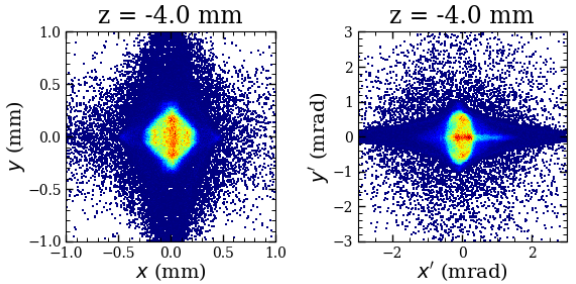






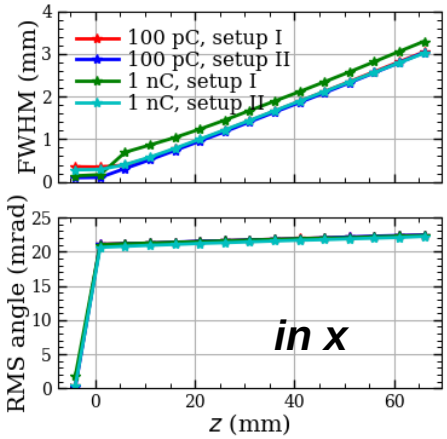
Discussion

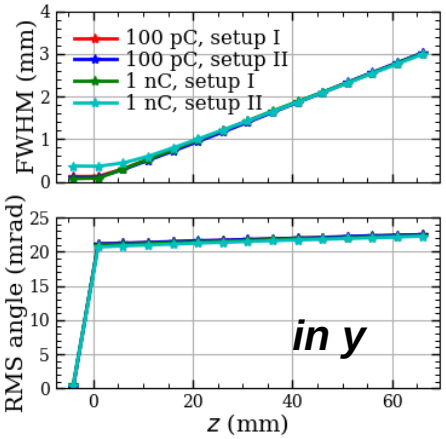
- Beam before the exit window is very different from each other

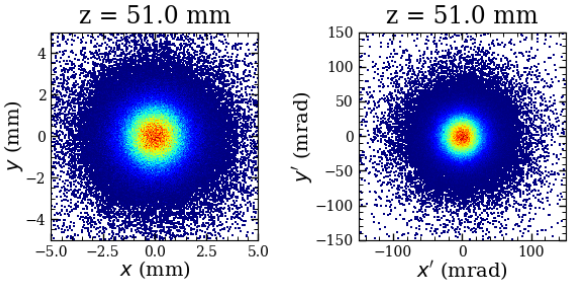
	100 pC	1 nC
Setup I		
Setup II		

Discussion

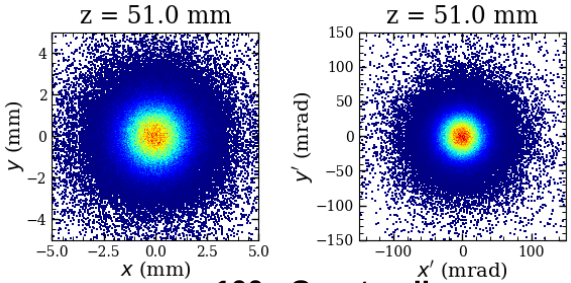
- **BUT** beam size evolution in the window and the air is similar





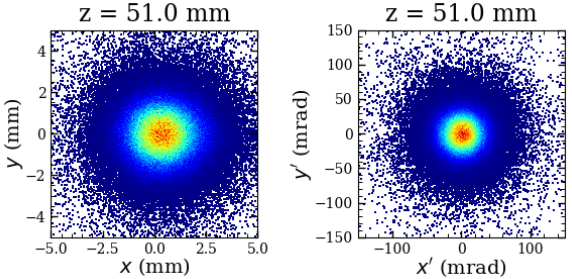


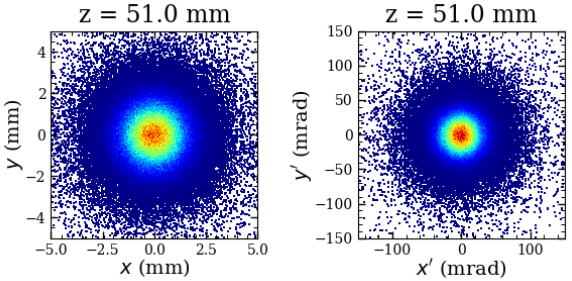
100 pC, setup I



100 pC, setup II

1 nC, setup I





1 nC, setup II

Discussion

- Summary of FWHM beam size

	100 pC, setup I	100 pC, setup II	1 nC, setup I	1 nC, setup II	unit
2 cm w/o sol.	0.99/0.97	0.96/0.94	1.24/0.98	1.00/1.00	mm
5 cm w/o sol.	2.35/2.32	2.32/2.33	2.57/2.32	2.34/2.31	mm
5 cm w/ sol.	0.26/0.40	0.23/0.25	0.26/0.62	0.44/0.40	mm

Conclusion

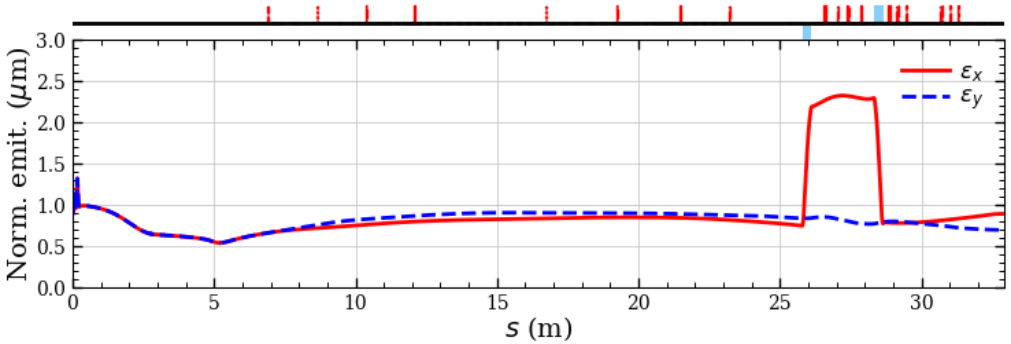
- The start-to-end simulations with PITZ photoinjector and two planned experimental setups for XFI have been performed for the bunch charges of 100 pC and 1 nC
  - By particle tracking, the electron beams have been focused as much as possible at the exit windows;
  - By Monte-Carlo simulations, the electron scattering in the exit window and air have been studied with and without an imaging solenoid
- The beam transverse profile after the window strongly depends on the scattering angles (RMS ~ 20 mrad)
  - By putting the samples closer to the window (~2 cm), the required the beam size (FWHM<1mm) could be reached;
  - The transverse distribution of such a beam is almost Gaussian
- With the imaging solenoid, the beam can be focused well at the imaging point, but
  - The imaging is affected by the air scattering;
  - Even though the imaging is perfect, the distribution of the beam to be imaged is far from Gaussian

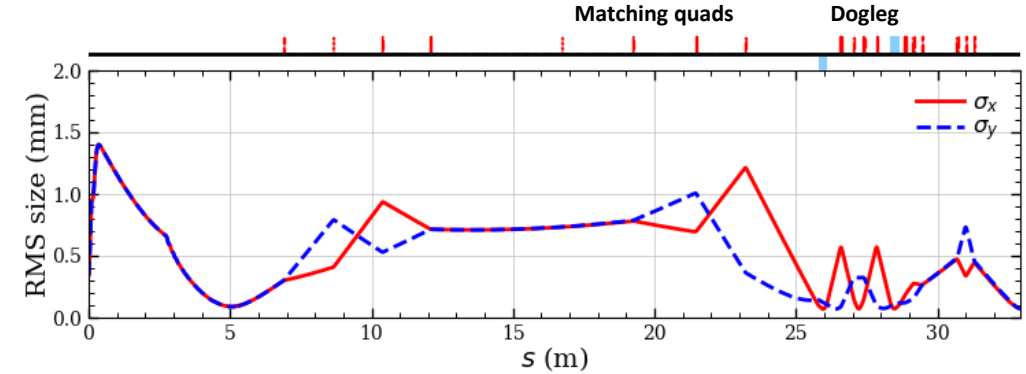
Backup

Start-to-end simulation

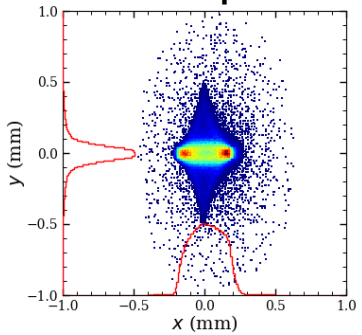
100 pC, setup II

- Software: Astra, Elegant and Ocelot

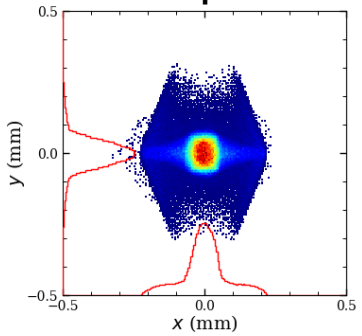




Setup I



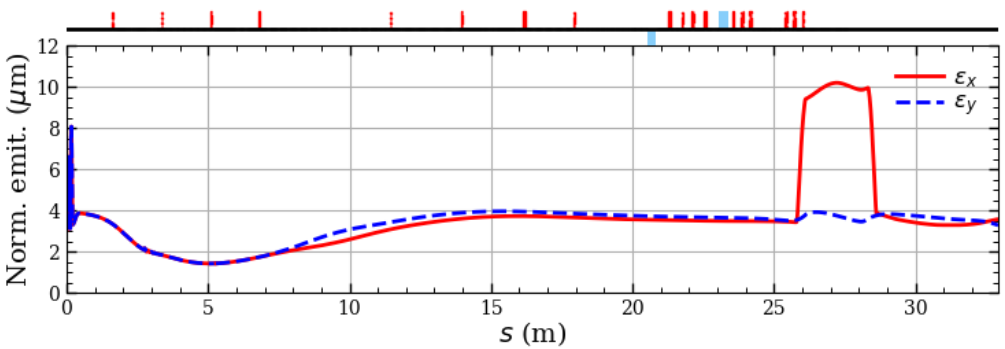
Setup II

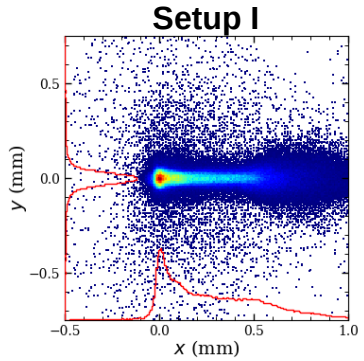


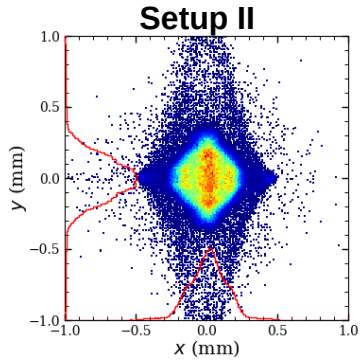
Start-to-end simulation

1 nC, setup II

- Software: Astra, Elegant and Ocelot



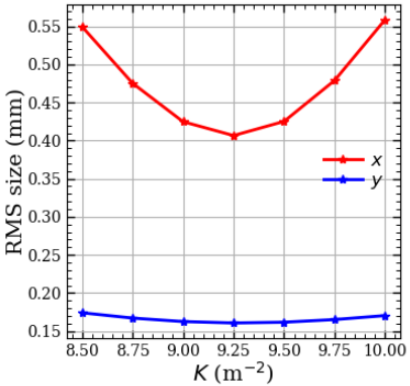


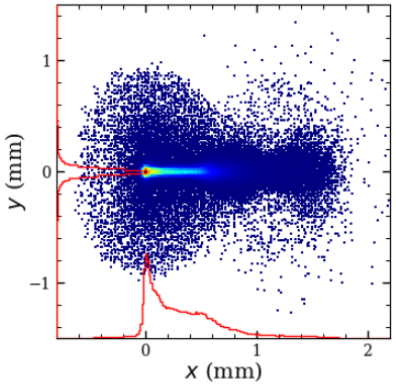


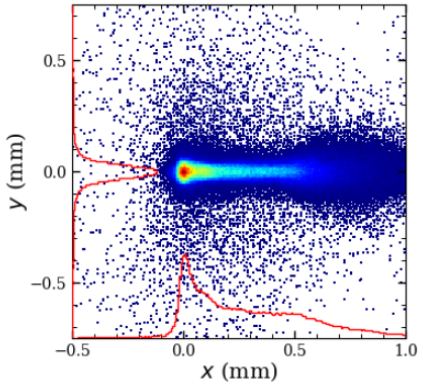
Minimization of beam size after dipole

1 nC, setup I

- The last two quads before the dipoles were optimized for minimal beam size in both horizontal and vertical planes

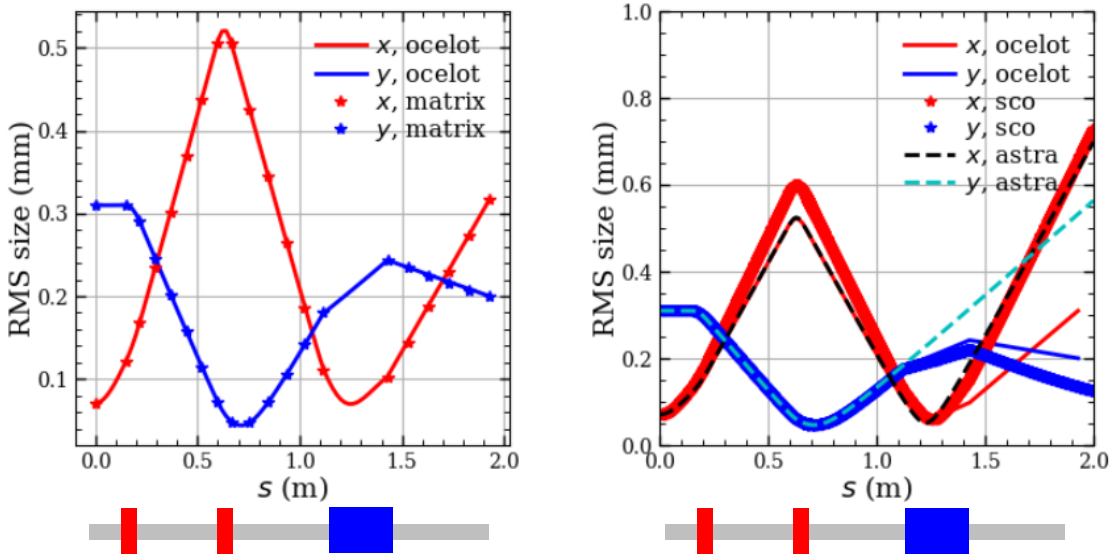






Zoomed view

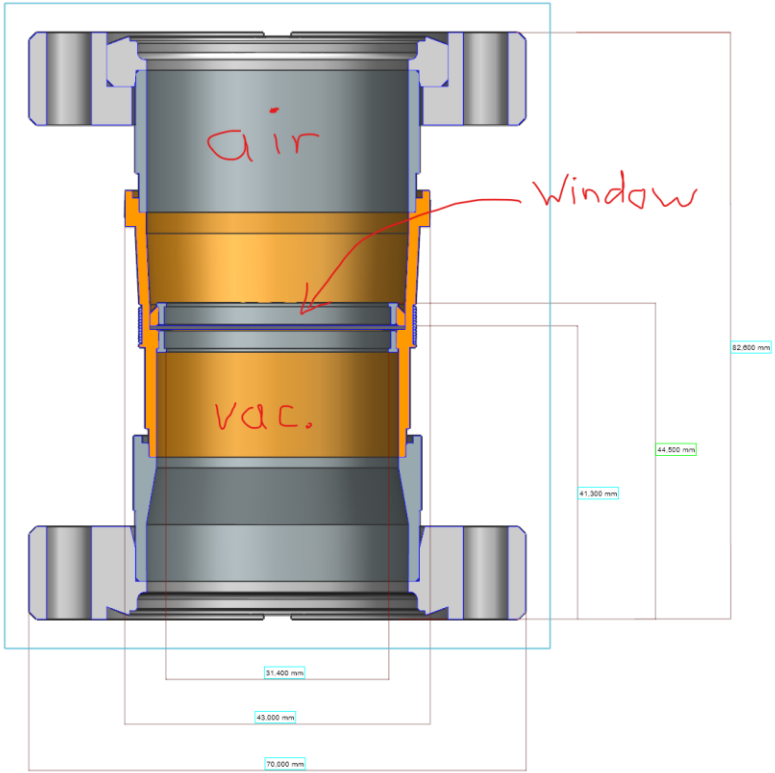
Ocelot vs SCO vs Astra



SCO doesn’t work well when the beam is flat, since its SC model is 2D

Exit window

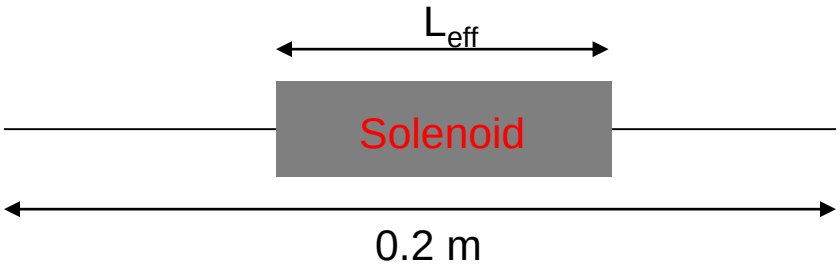
Sebastian Philipp

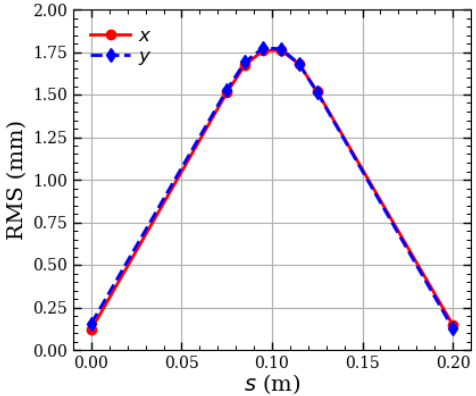


Example of imaging

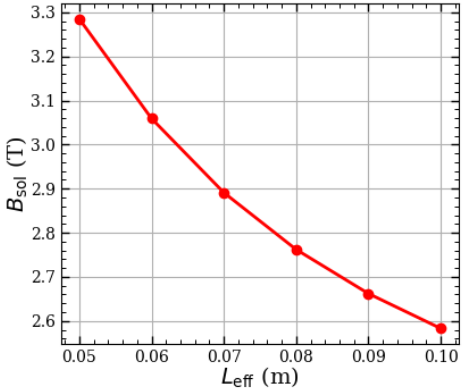
Hard edge model by Elegant and no air scattering

22 MeV beam with 20 mrad RMS angle;
White area is cut by purpose

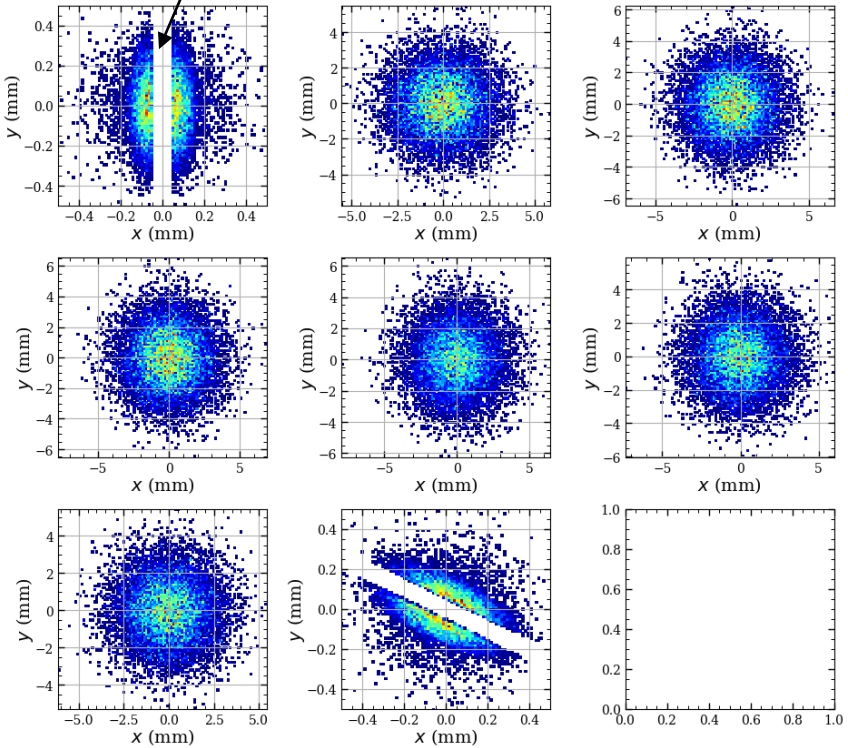




RMS size along beamline



Peak B-field vs effective length



Transverse profile along the beamline