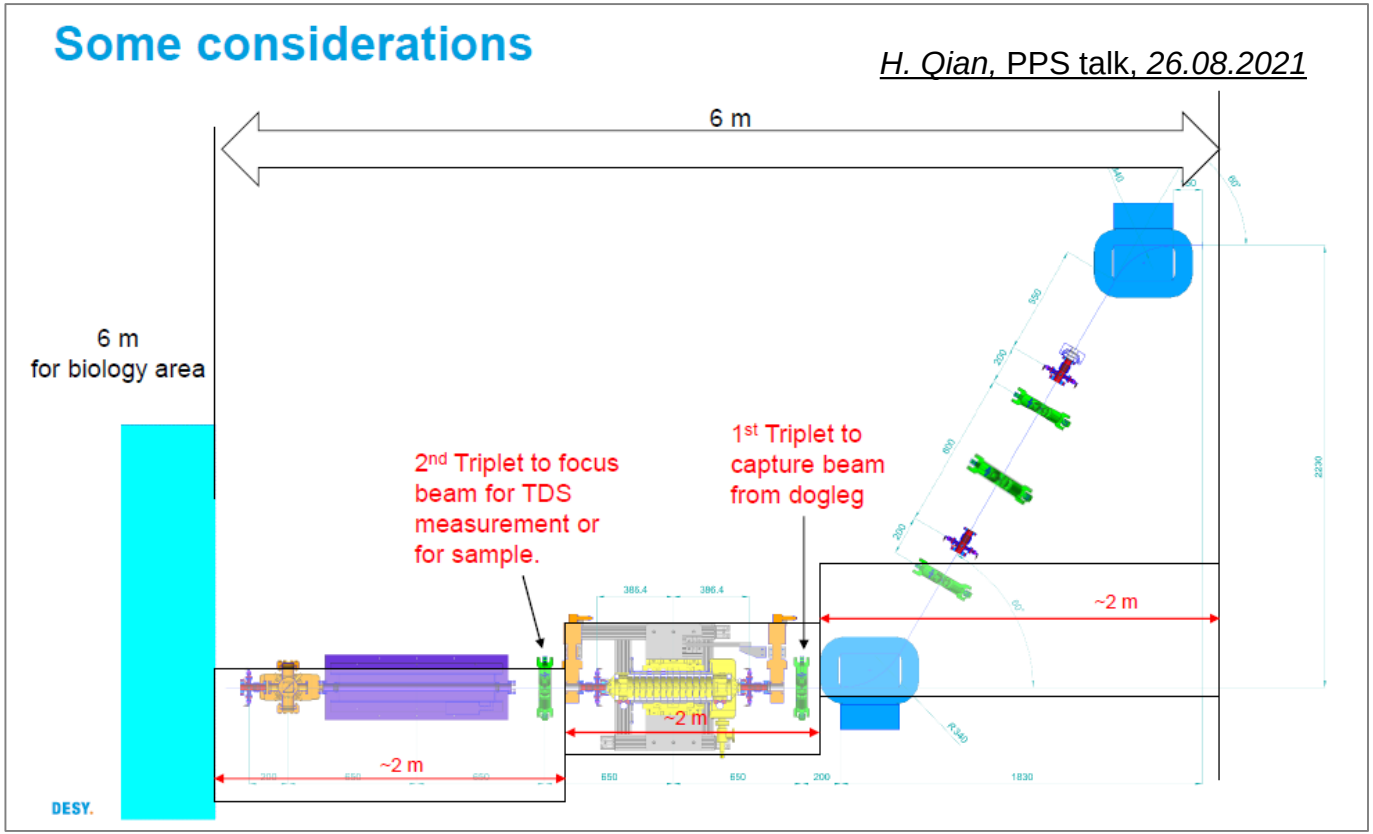
Update on beam dynamics simulation for eFLASH-RT beamline after the dogleg

Xiangkun Li, PPS, November 4, 2021,

Outline

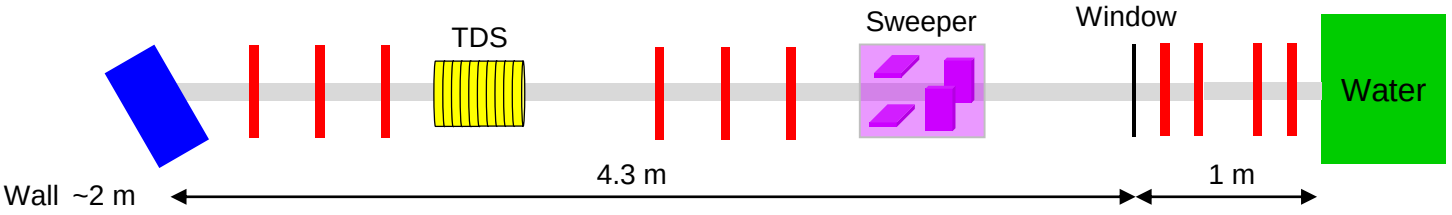
- Layout of the beamline after dogleg
- Beam transport from dogleg to window
- Beam imaging after window
- Discussion & Summary

Layout of the beamline after dogleg



Layout of the beamline after dogleg

- The first three quadrupoles are used to capture the beam from the dogleg
- The second three focuses the beam for minimum beam waist at the exit window
- The last four images the beam from the window to the water phantom

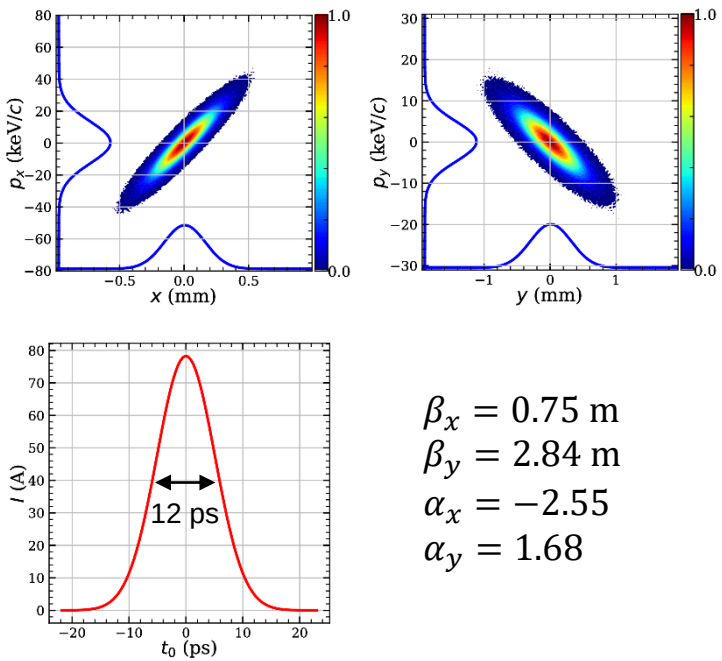


Beam transport from dogleg to window

With first triplet

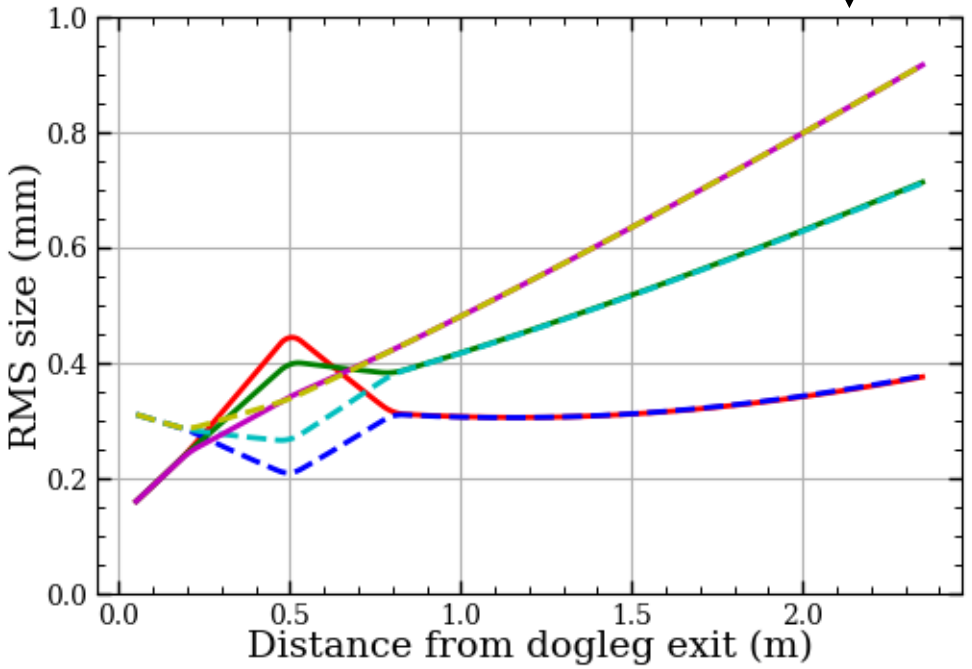
- 1 nC, 1.5 um, 22 MeV

Initial distribution



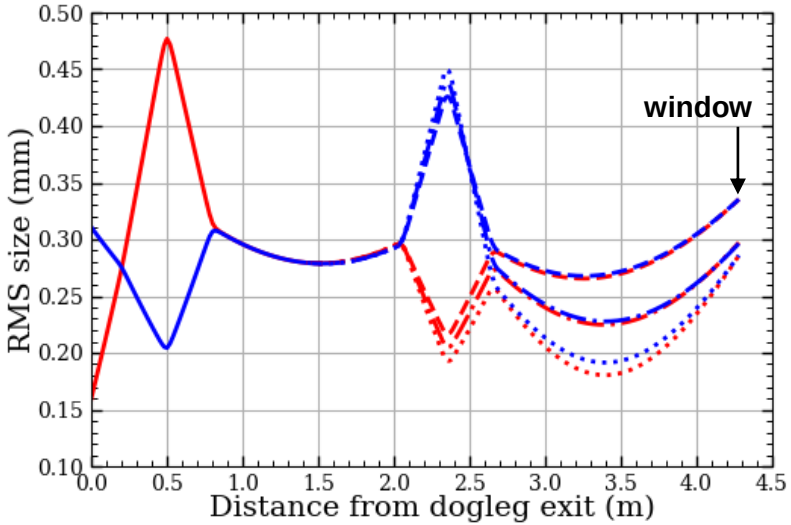
$\beta_x = 0.75$ m
$\beta_y = 2.84$ m
$\alpha_x = -2.55$
$\alpha_y = 1.68$

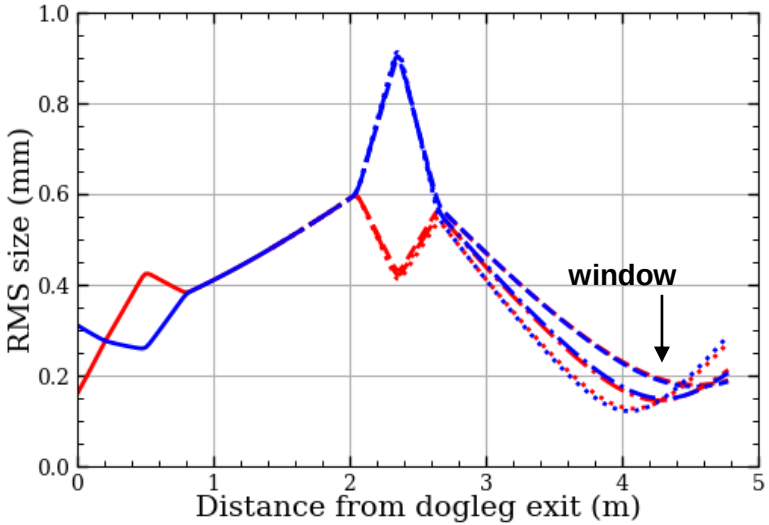
Second triplet



Transport from dogleg to window

With two triplets





The goal is to get minimal beam waist at the window

Beam imaging after window

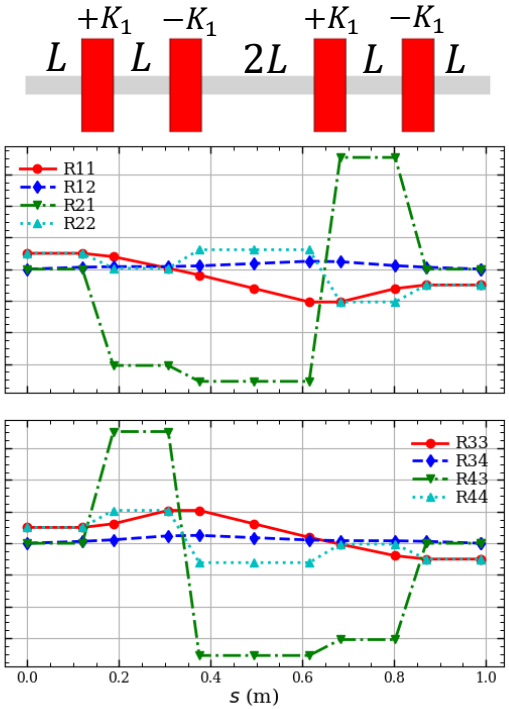
Imaging with four quads

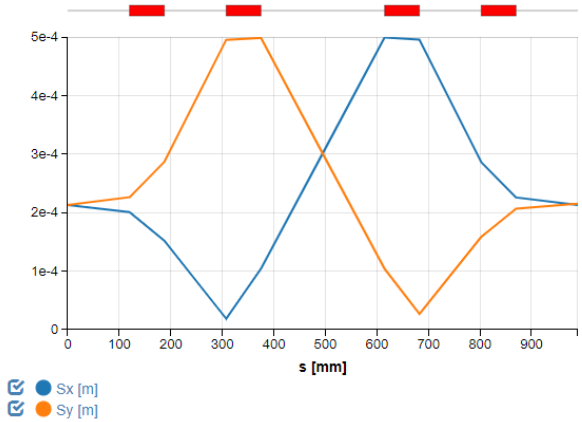
- Tool: elegant
- Goal functions:

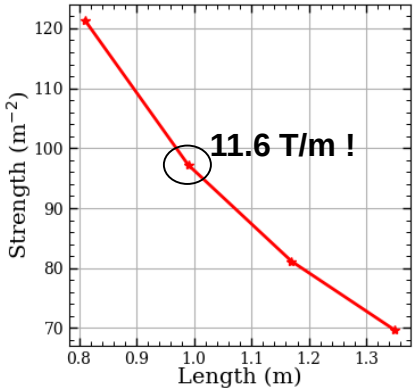
$$R_{11} - R_{22} = 0$$
$$R_{12} = 0$$
$$R_{21} = 0$$
$$R_{33} - R_{44} = 0$$
$$R_{34} = 0$$
$$R_{43} = 0$$

Not necessary

$$R = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

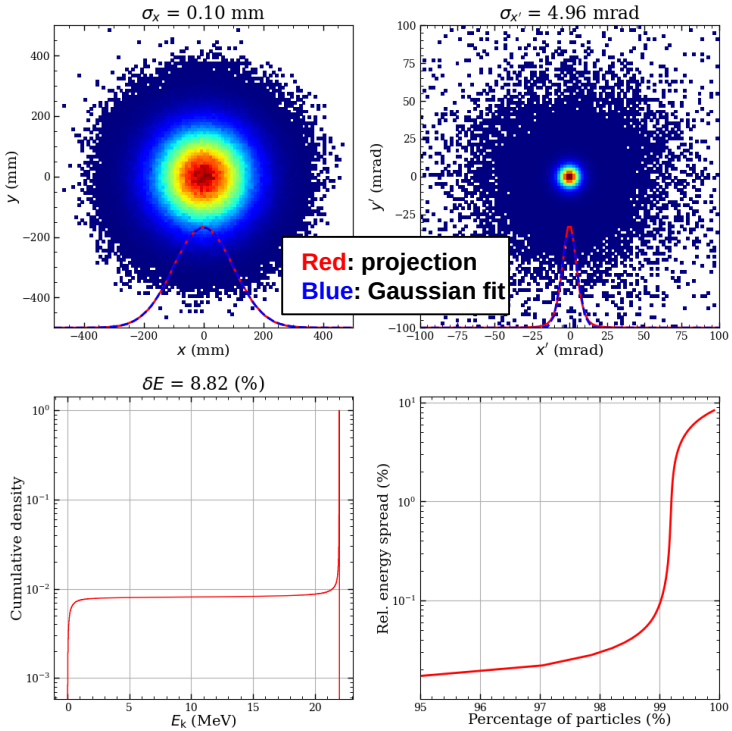




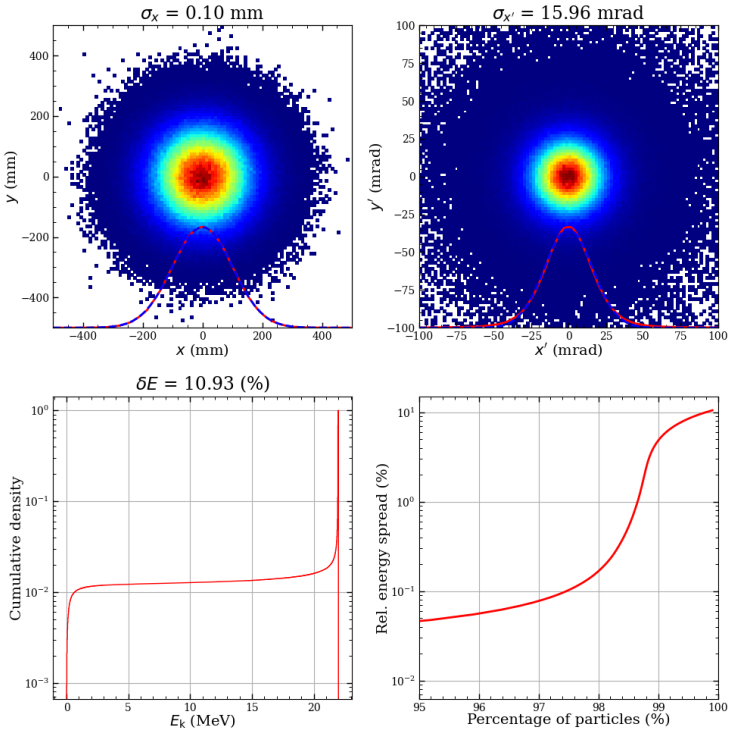


Beam imaging after window

Beam at 50 um window exit



22 MeV, RMS 0.1 mm @50 um Graphite



22 MeV, RMS 0.1 mm @50 um Titanium

Beam imaging after window

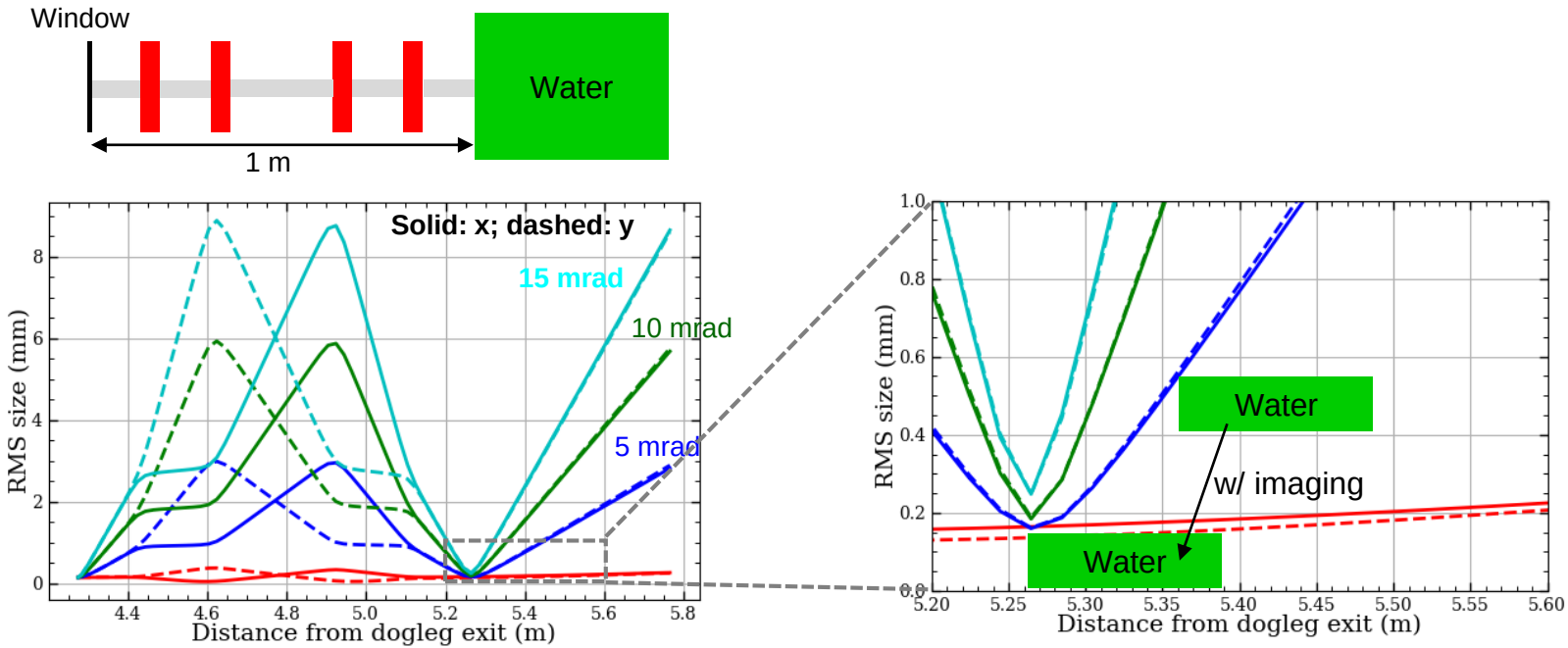
Beam at 50 um window exit

- The transverse distribution (x-y) stays the same and the widening of energy spectrum is negligible at the window exit
- The transverse divergence increases a lot due to the scattering

  → sigma_x' and sigma_y' scaled to 5, 10, 15 mrad (from 0.28 mrad)

  → Pz is modified accordingly by keeping the energy constant for each particle

Beam imaging after window



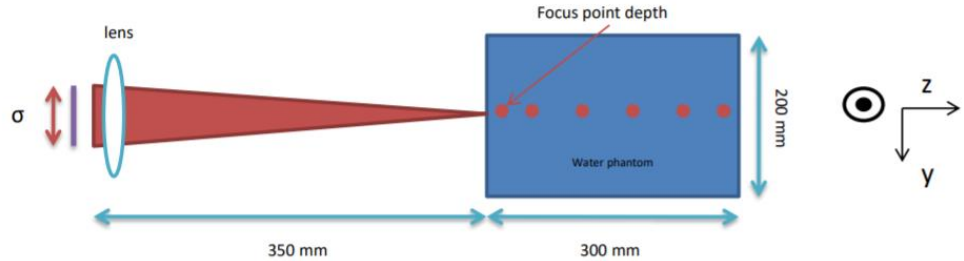
Discussion

How large the beam size could be before focusing

Simulation setup

- TOPAS/Geant4 simulations were carried out.
- Water phantom 20x20x30 cm^3;
- Voxel resolution 1x1x1 mm^3;
- Beam energies E={22, 100, 150, 200, 250, 500} MeV
- Beam size before focusing σ={10, 20, 40, 80, 100} mm
- For beam energy spread σ_E={0, 1, 2, 4, 5}% (percentage of the mean beam energy)
- A beam size of 1 mm is considered at the focus point in air (without phantom) for all simulations.

Z. Aboulbanine, PPS talk *07.10.2021*



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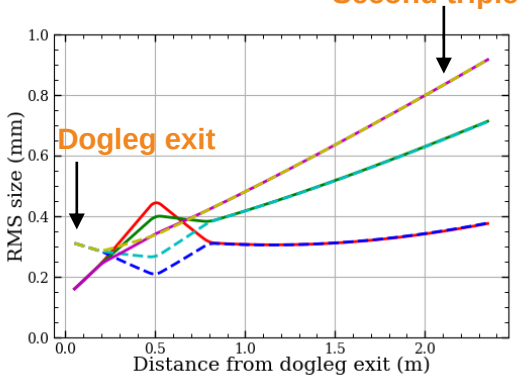
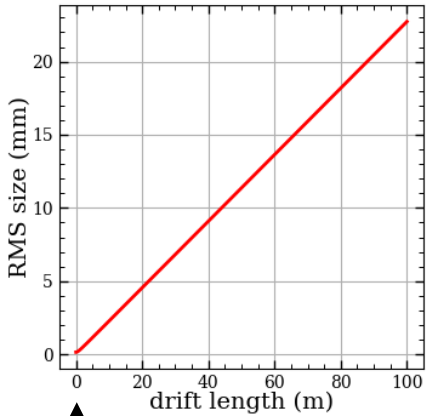


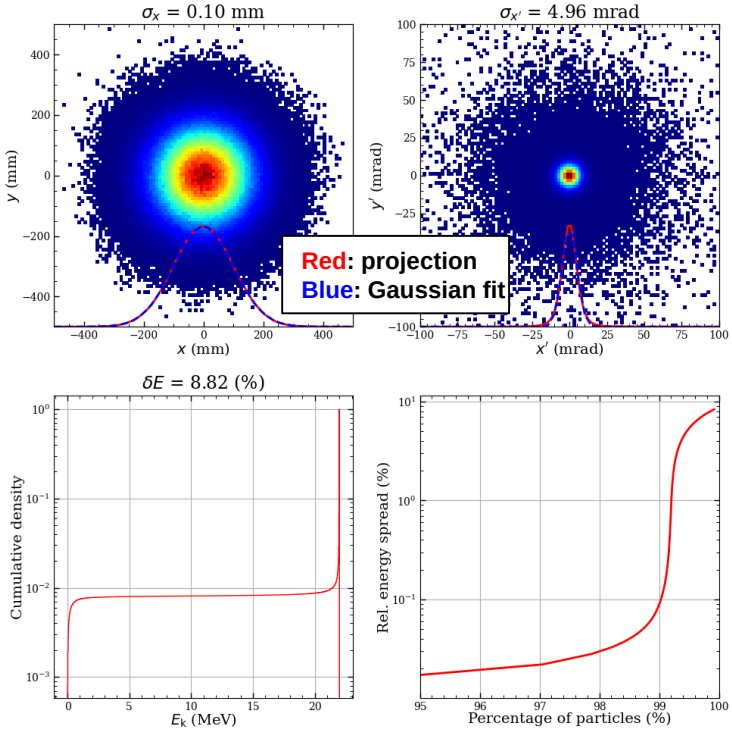


Assumed beam waist with $\varepsilon_x^n = 1.5$ μm, $\sigma_x = 0.15$ mm, $\sigma_{x'} = 0.23$ mrad

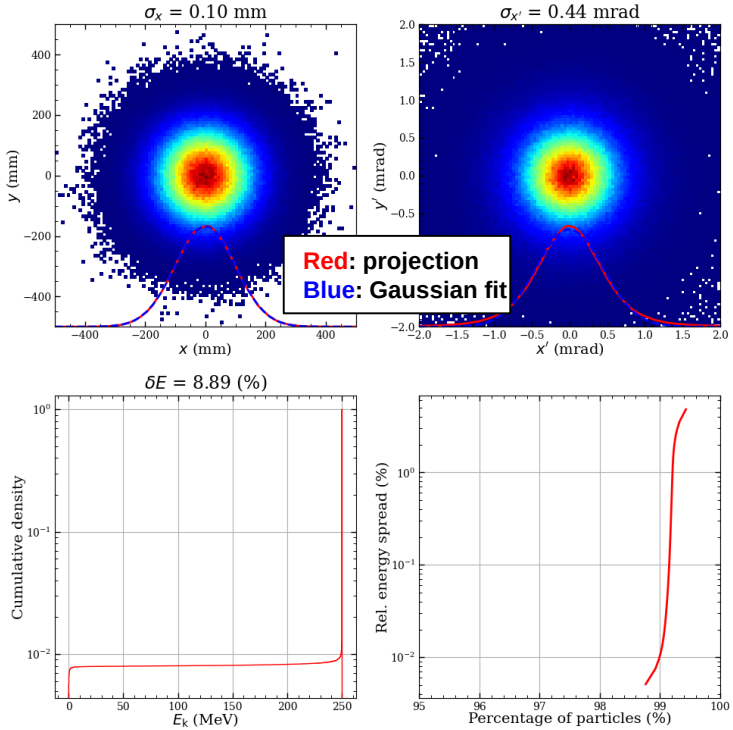
Discussion

Is imaging system necessary for higher energy?

Energy: ~11.4 times larger
Scattering angle: ~11.3 times smaller
Energy loss: 6.7 times larger -> **thicker** window



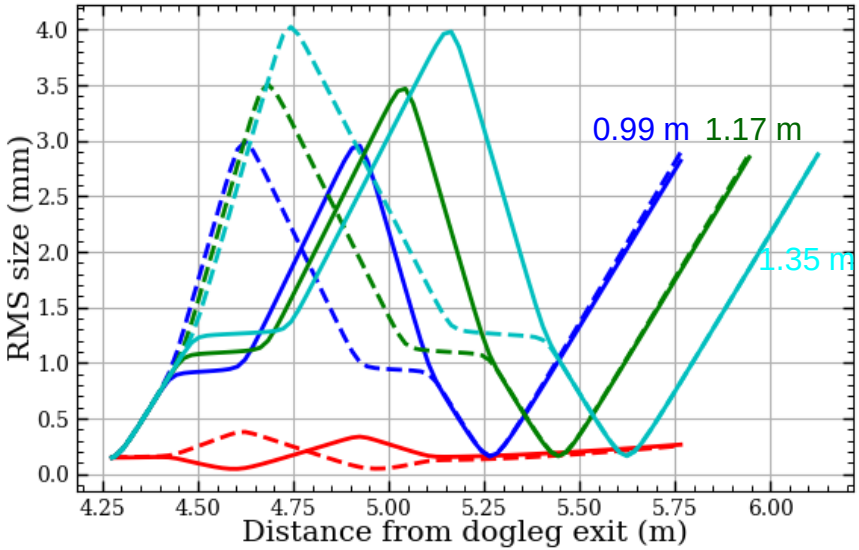
22 MeV, RMS 0.1 mm @50 um Graphite

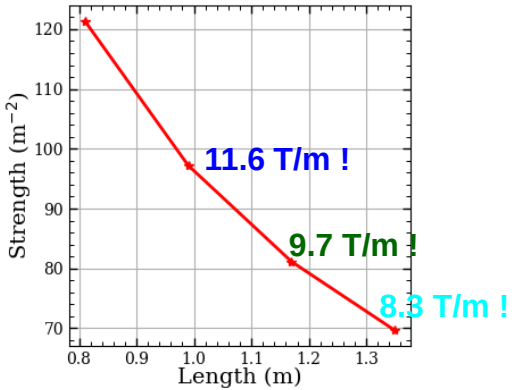


250 MeV, RMS 0.1 mm @50 um Graphite

Discussion

Quadrupole strength vs imaging system length for 22 MeV beam





High1.Q5 calibration -> **~0.65 T/m/A** -> **7.8 T/m@12A**

For a longer imaging system, the quad grad is smaller, but the maximum beam size is larger, meaning a bigger aperture.

Summary

- The eFLASH beamline after the dogleg was studied
- For 1nC, 22 MeV beam, the minimal beam waist is around 0.2 mm RMS
- The imaging system allows to shift the beam waist from the window to the surface of water phantom

Backup

Titanium:

- scattering angle of $\mathbf{17.73 - 84.04}\boldsymbol{mrad}$ for thickness of $\mathbf{50 - 1000}\boldsymbol{\mu m}$.
- Higher energy loss for entire thickness range.
- Acceptable thickness less than $\mathbf{50}\boldsymbol{\mu m}$for $\mathbf{5}\boldsymbol{nC}$ and $\mathbf{1}\boldsymbol{\mu s}$ repetition rate
- Acceptable thickness less than $\mathbf{500}\boldsymbol{\mu m}$ for $\mathbf{5}\boldsymbol{nC}$ and $\mathbf{10}\boldsymbol{\mu s}$ repetition rate

Graphite ($\rho = 1.7\ g/cm^3$):

- scattering angle of $\mathbf{5.72 - 31.83}\boldsymbol{mrad}$ for thickness of $\mathbf{50 - 1000}\boldsymbol{\mu m}$.
- Lower energy loss for entire thickness range.
- Acceptable thickness less than $\mathbf{1000}\boldsymbol{\mu m}$for $\mathbf{5}\boldsymbol{nC}$ and $\mathbf{1}\boldsymbol{\mu s}$ repetition rate

Kapton:

- scattering angle of $\mathbf{5.26 - 29.37}\boldsymbol{mrad}$ for thickness of $\mathbf{50 - 1000}\boldsymbol{\mu m}$.
- Lower energy loss for entire thickness range.
- Acceptable thickness less than $\mathbf{50}\boldsymbol{\mu m}$for $\mathbf{1}\boldsymbol{nC}$ and $\mathbf{10}\boldsymbol{\mu s}$ repetition rate

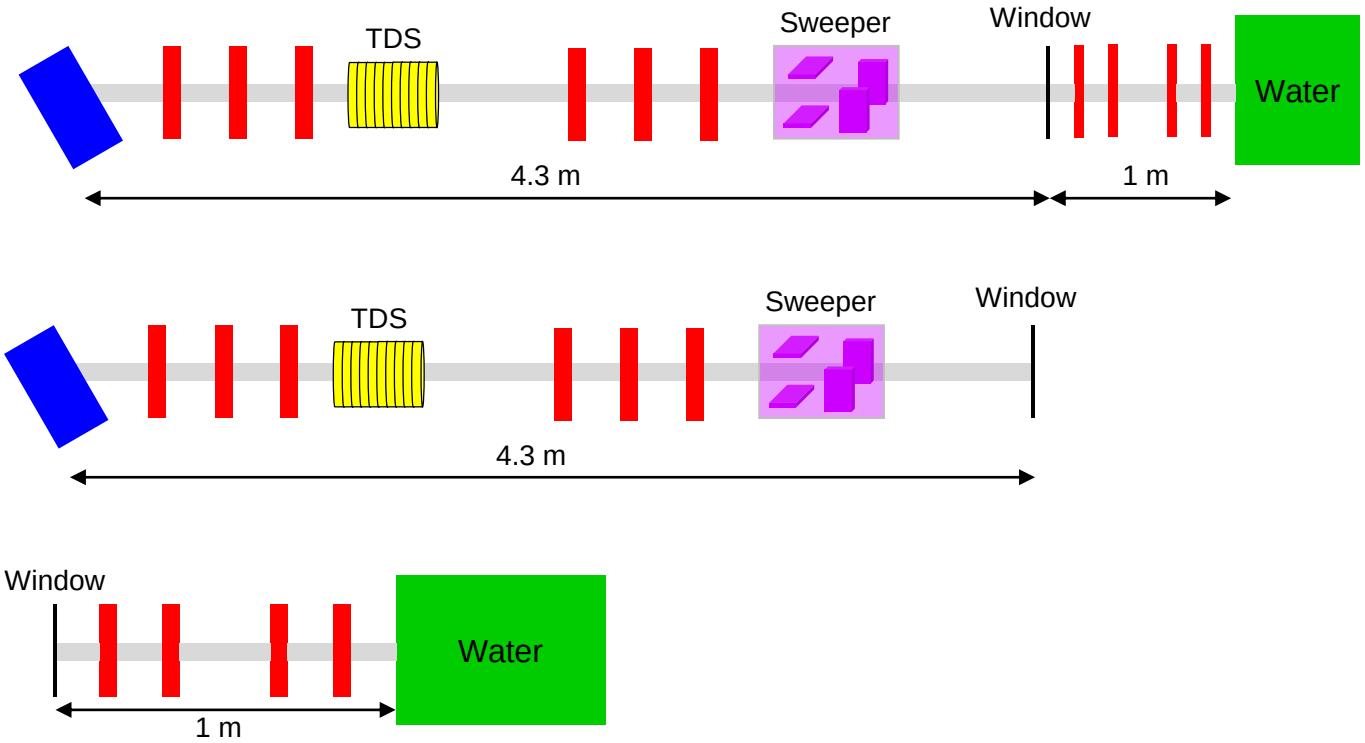
Aluminum:

- scattering angle of $\mathbf{10.49 - 57.67}\boldsymbol{mrad}$ for thickness of $\mathbf{50 - 1000}\boldsymbol{\mu m}$.
- Lower energy loss for entire thickness range.
- Acceptable thickness less than $\mathbf{50}\boldsymbol{\mu m}$for $\mathbf{5}\boldsymbol{nC}$ and $\mathbf{10}\boldsymbol{\mu s}$ repetition rate

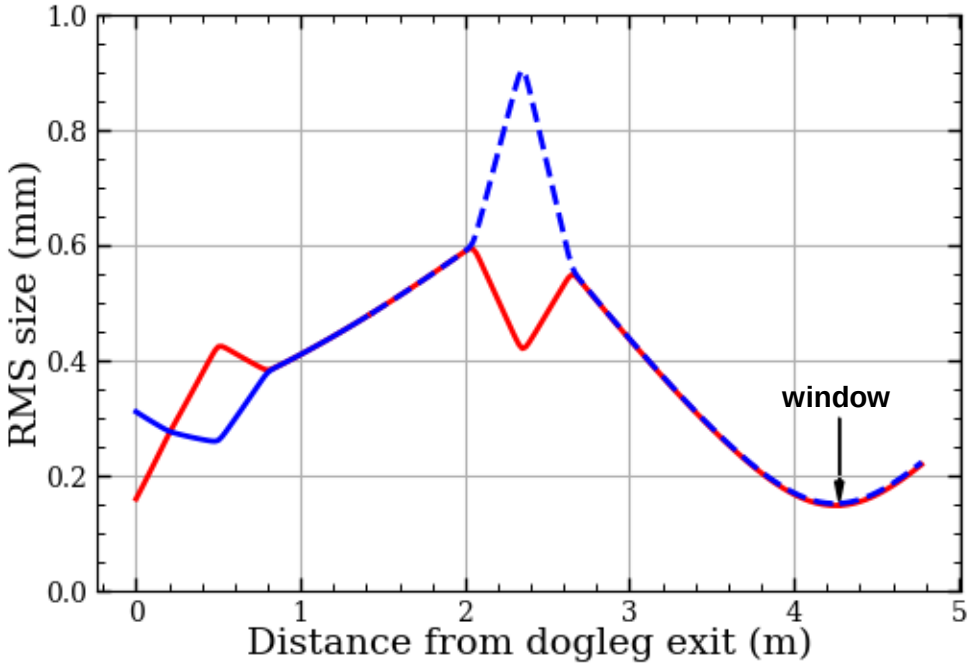
Pyrolytic graphite ($\rho = 2.0 g/cm^3$; $50\mu m$) and graphite ($\rho = 1.5 g/cm^3$):

- scattering angle of $\mathbf{8.65 - 30.73}\boldsymbol{mrad}$ for thickness of $\mathbf{50 - 1000}\boldsymbol{\mu m}$.
- Lower energy loss for entire thickness range.
- Acceptable thickness less than $\mathbf{1000}\boldsymbol{\mu m}$for $\mathbf{5}\boldsymbol{nC}$ and $\mathbf{1}\boldsymbol{\mu s}$ repetition rate

Layout of the beamline after dogleg



Beam transport from dogleg to window



Beam imaging after window

Imaging with six quads

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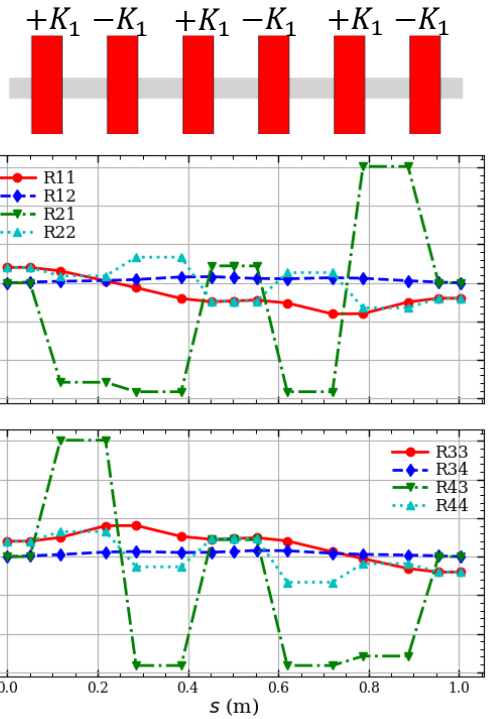
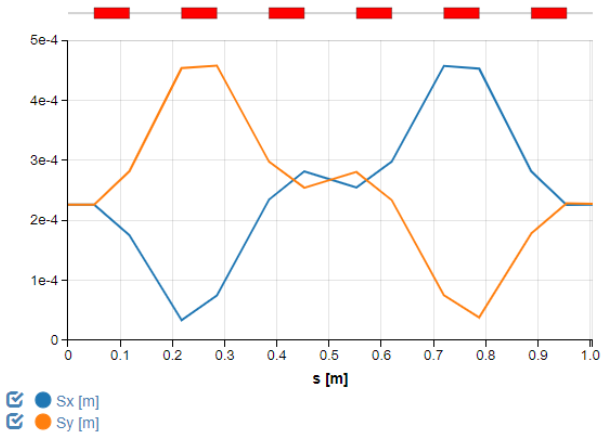
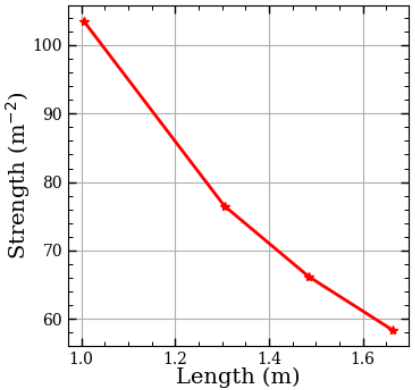
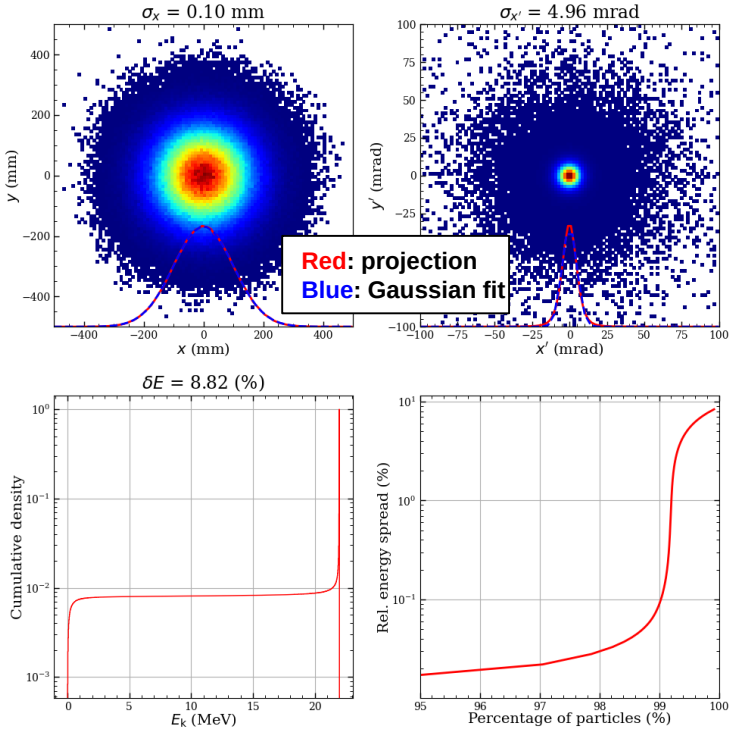




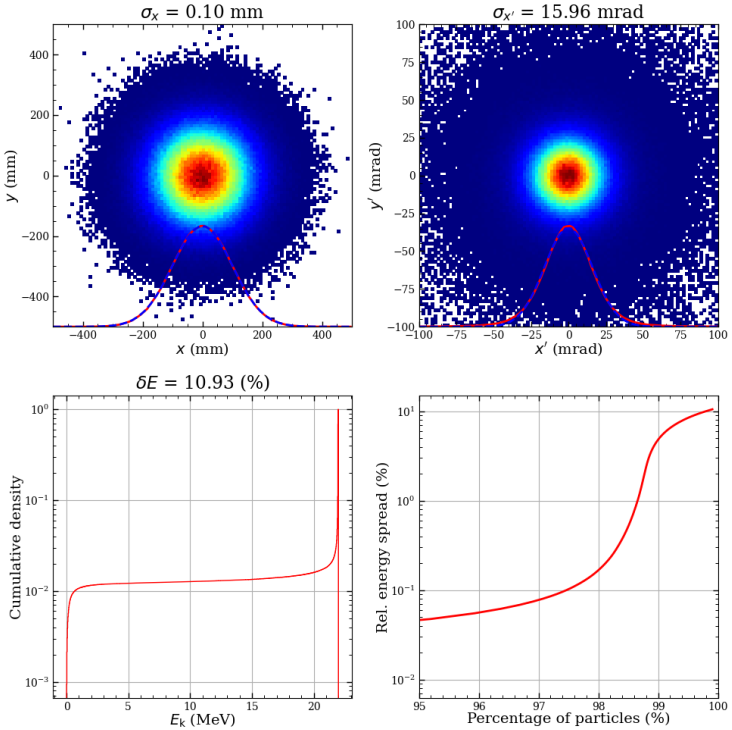


Beam imaging after window

Beam at 50 um window exit



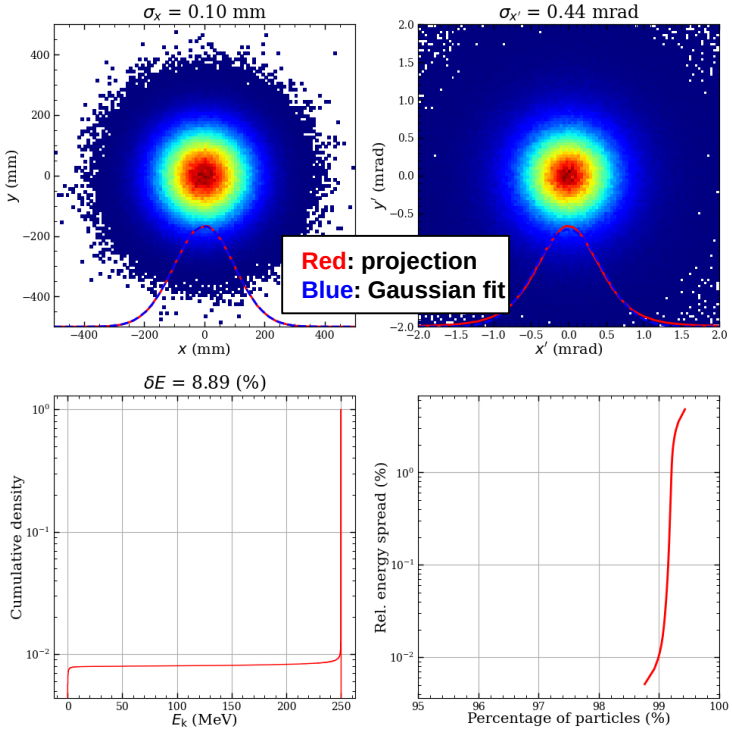
22 MeV, RMS 0.1 mm @50 um Graphite



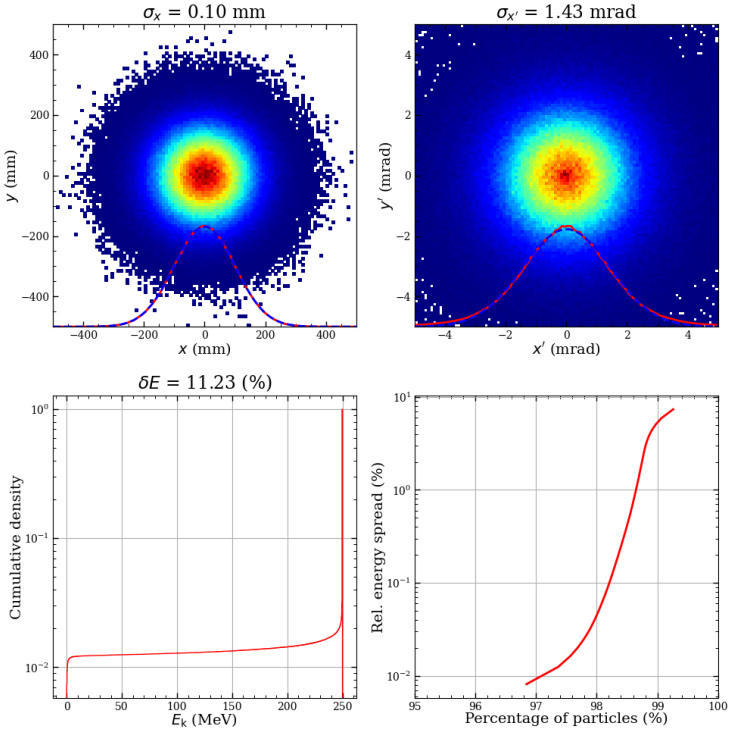
22 MeV, RMS 0.1 mm @50 um Titanium

Beam after exit window

50 um window



250 MeV, 50 um Graphite



250 MeV, 50 um Titanium

Beam imaging after window