Update on beamline design for electron FLASH radiation therapy

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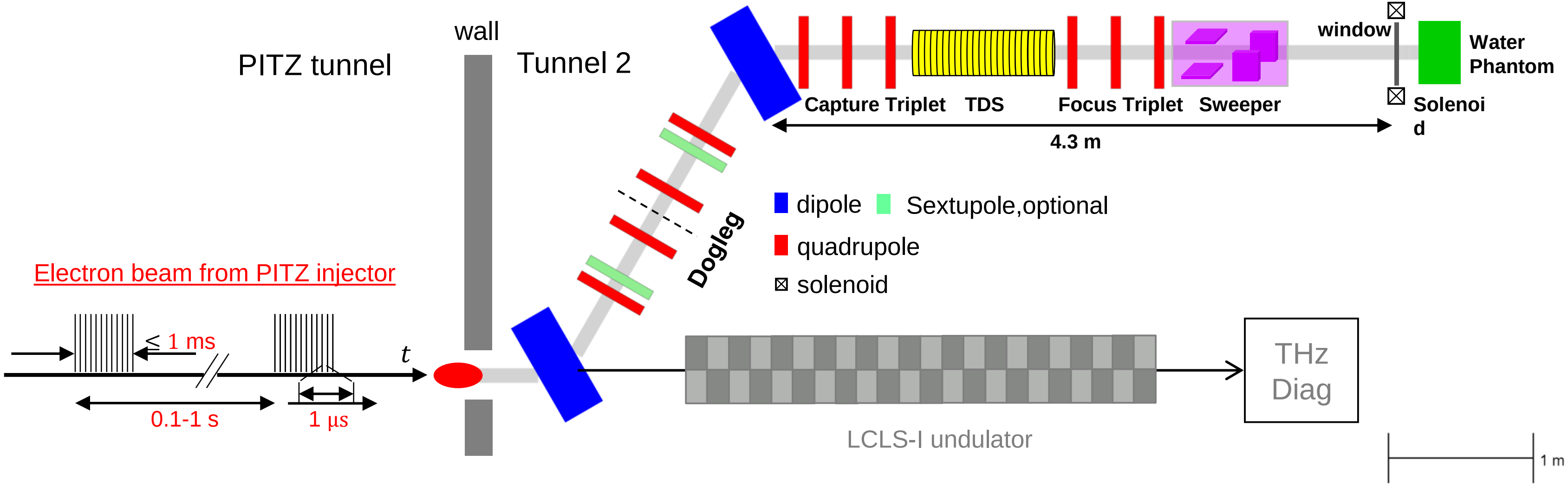
PPS, 16/06/2022

Outline

- Introduction
- Simulation results
  - Optimization of photoinjector
  - Transport and matching
  - Transport after dogleg
- Summary

Introduction

Overview of new beamline



Introduction

- Imaging using quadrupoles after the exit window is given up due to air scattering effects
  - The sample will be brought closer to the exit window (2-5 cm downstream)
  - A pulsed solenoid could be an option for focusing swept beams into samples to produce Bragg-peak like dose distribution

Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

A PULSED SOLENOID FOR INTENSE ION BEAM TRANSPORT*

D. Shuman*, E. Henestroza, G. Ritchie, W. Waldron, D. Vanacek, S.S.Yu, LBNL, Berkeley, CA, USA

tion experiment [3], [4]. The magnet described here is for NDCX-1b and the requirements are: a solenoidal field of 3 T of 5 cm radius over an effective length of 0.4 m, with the field time variation of less than 0.2% over a beam passage period of 4 μsec.

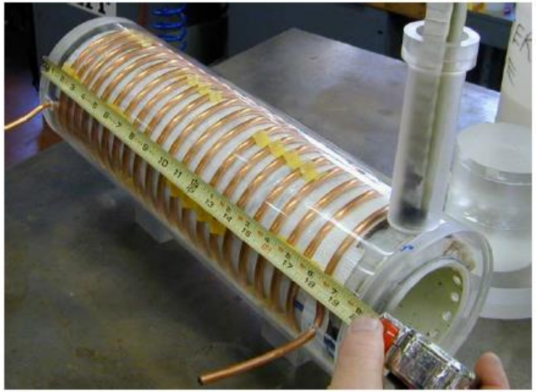


Figure 3: Pulsed solenoid ready for final potting

Introduction

Consideration on S2E simulation

- Full range charge (a few pC to 5 nC) were considered
  - MBI laser: Gaussian, $\sigma_{x,y} = 1\ \mathrm{mm}, \mathrm{FWHM} = 8\ \mathrm{ps}$ → Laser shaping could help at high charges
  - Beam energy is 22 MeV (or 22.5 MeV/c) after the booster
  - Particle tracking with Astra (photocathode to EMSY1), Ocelot (from EMSY1 to exit window)

- Three steps
  - Photoinjector optimization, up to EMSY1@5.28m ← Booster phase scanned to minimize energy spread
  - Beam transport and matching to the dogleg, until 2^{nd} dipole exit
  - Beam transport to exit window (small and big beams)

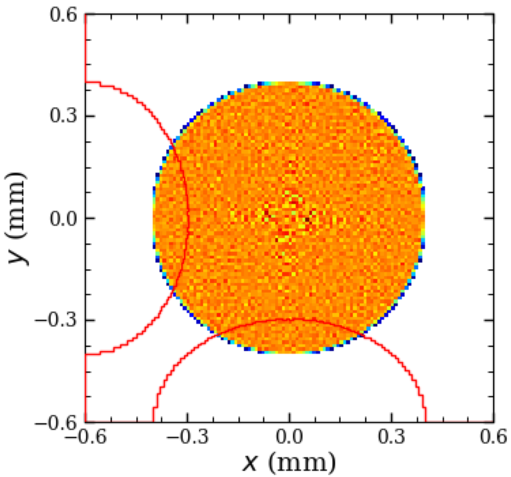
Simulation results

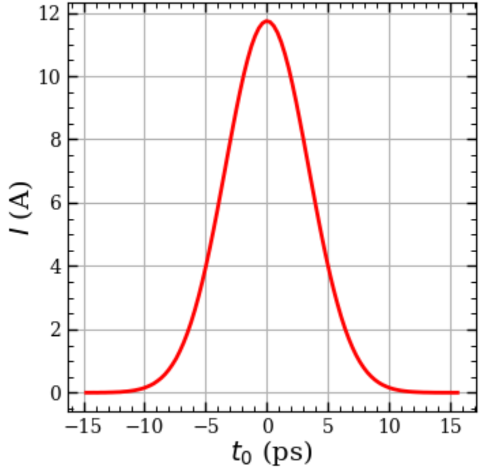
Initial beam

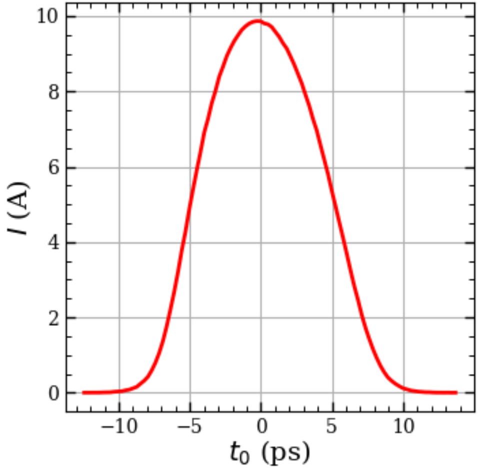
10 pC, 100 pC and 1 nC

- Transverse flattop
- Temporal Gaussian, FWHM = 8 ps

	10 pC	100 pC	1 nC	5 nC	
BSA	0.2	0.8	1.8	4.5	mm
Imain	372	378	388	392	A



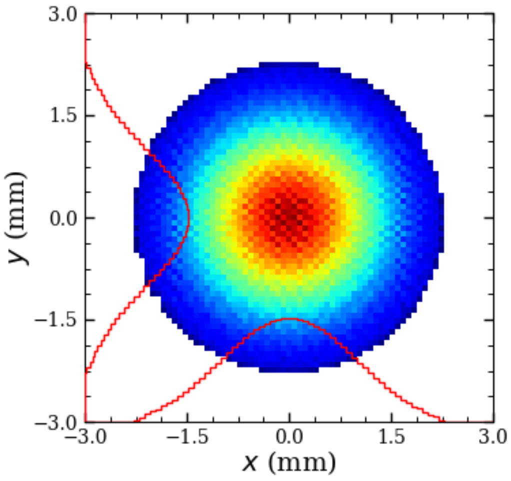


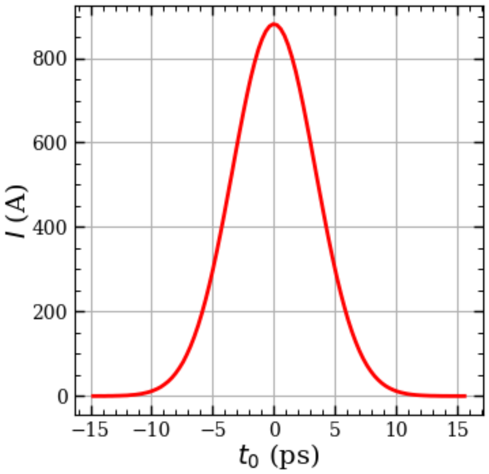


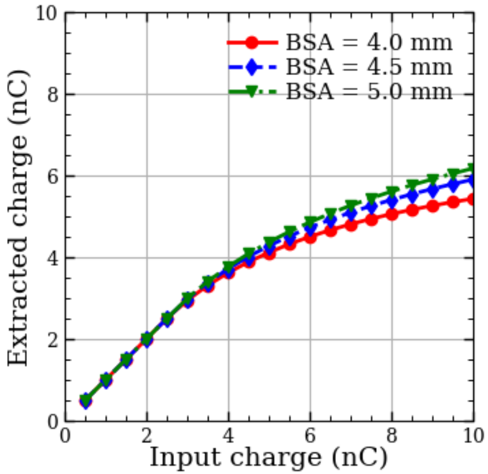
Initial beam

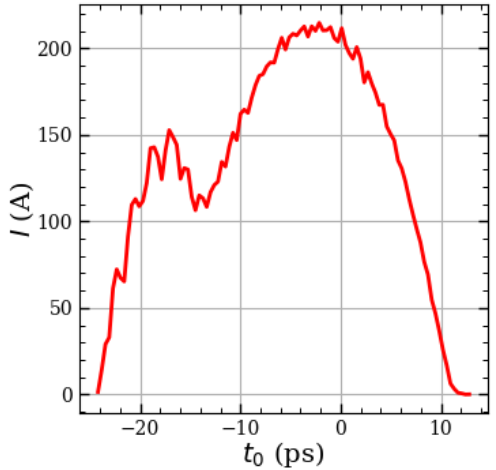
5 nC

- Transverse Gaussian truncated, $\sigma_x = 1\text{mm}$
- Temporal Gaussian, FWHM = 8 ps



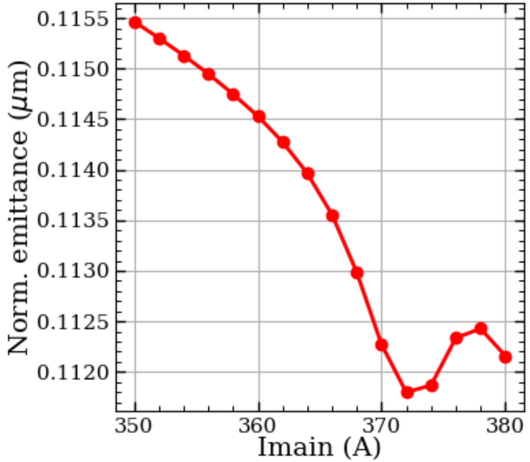




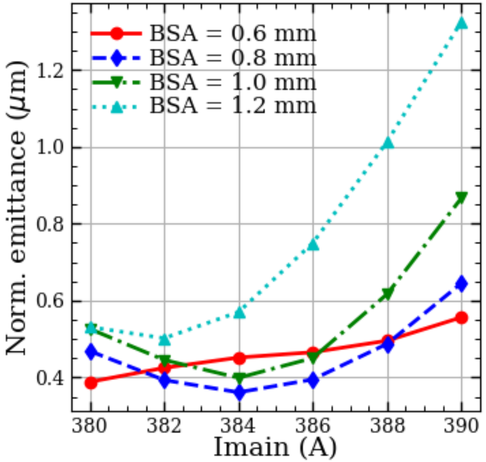


Emittance optimization

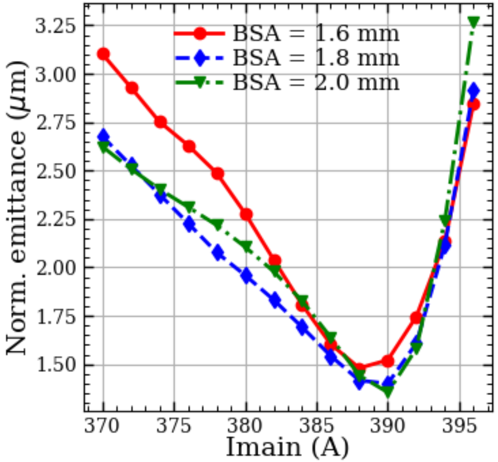
- For 10 pC to 1 nC, optimized solenoid current and BSA size for best emittance at EMSY1
- For 5 nC, gun phase was also optimized for better emittance at EMSY1



10 pC



100 pC



1 nC

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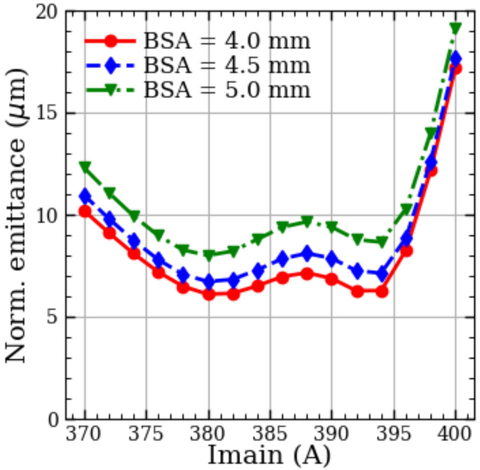
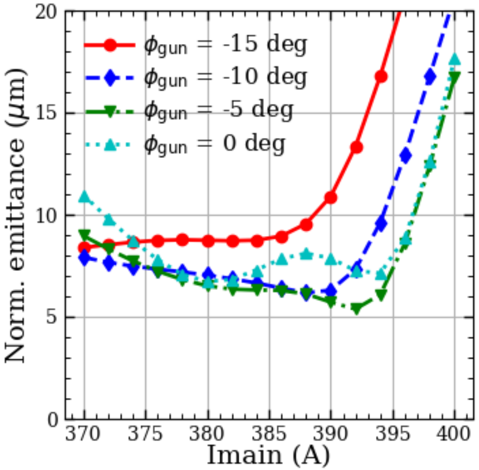
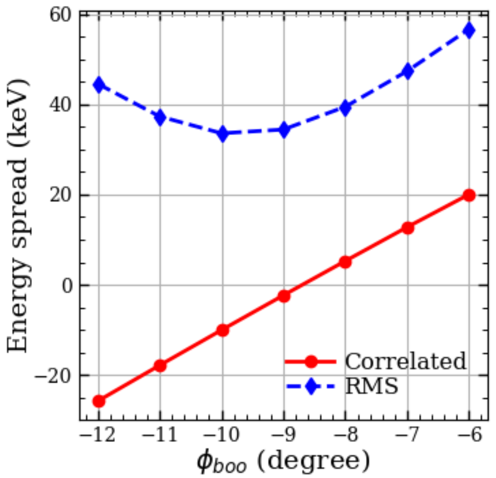




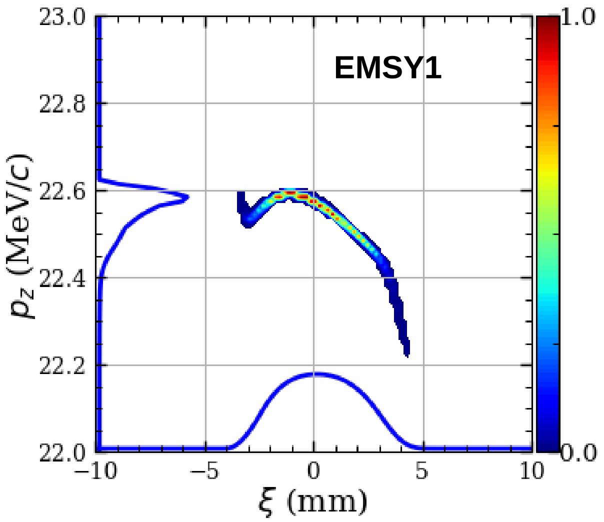
5 nC

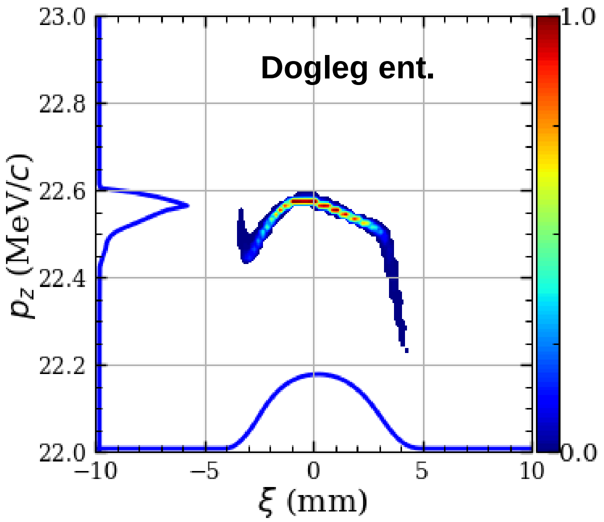
Energy spread minimization

1 nC



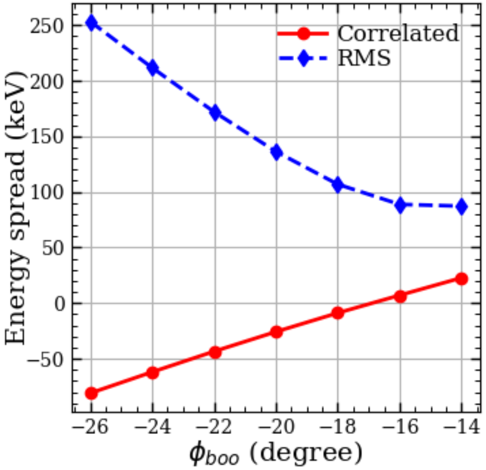
Energy spread at dogleg entrance
Vs booster phase w.r.t. MMMG phase





Energy spread minimization

5 nC



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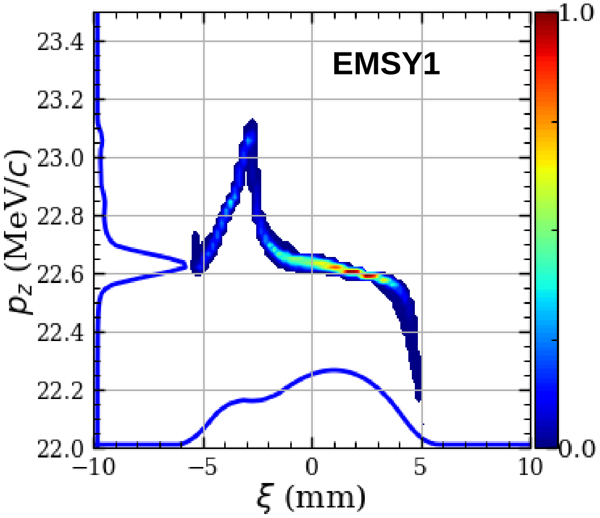
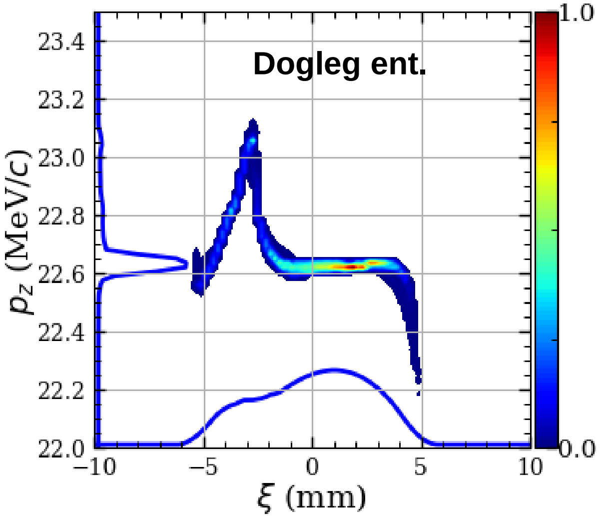
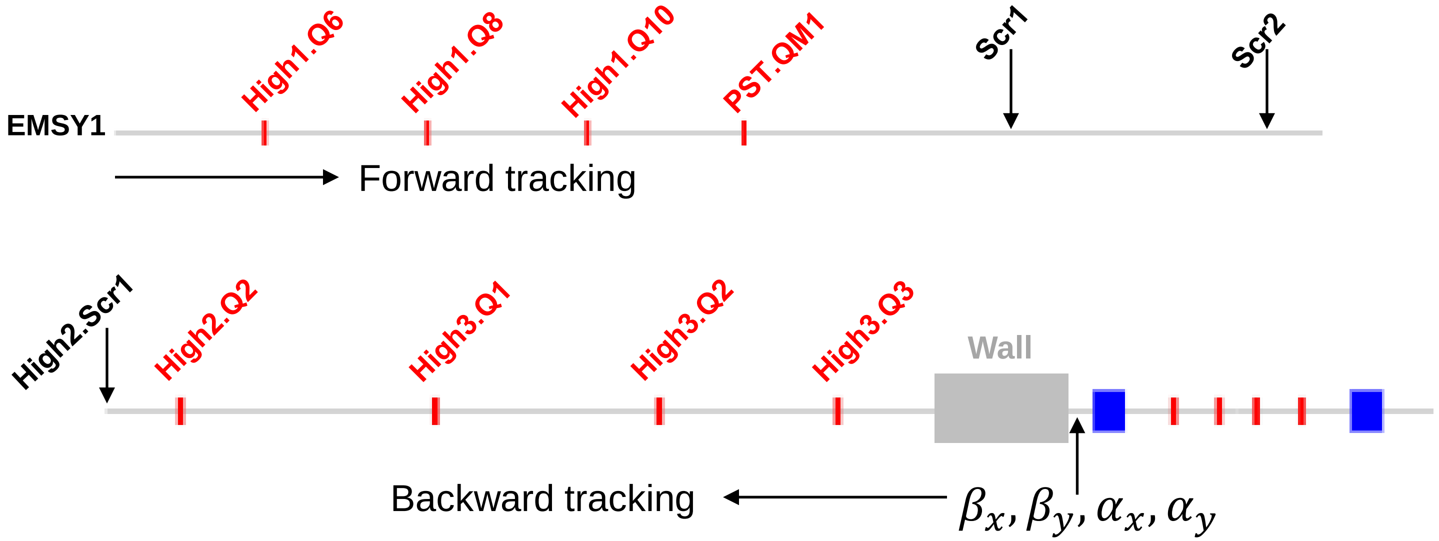




Transport and matching

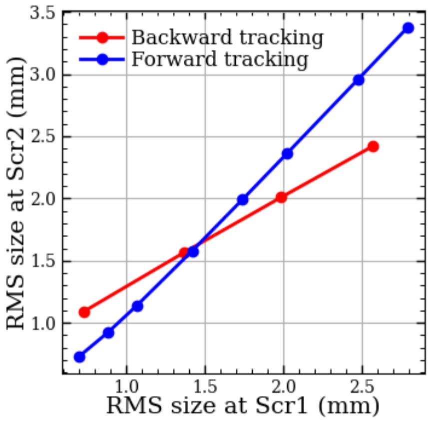
Method

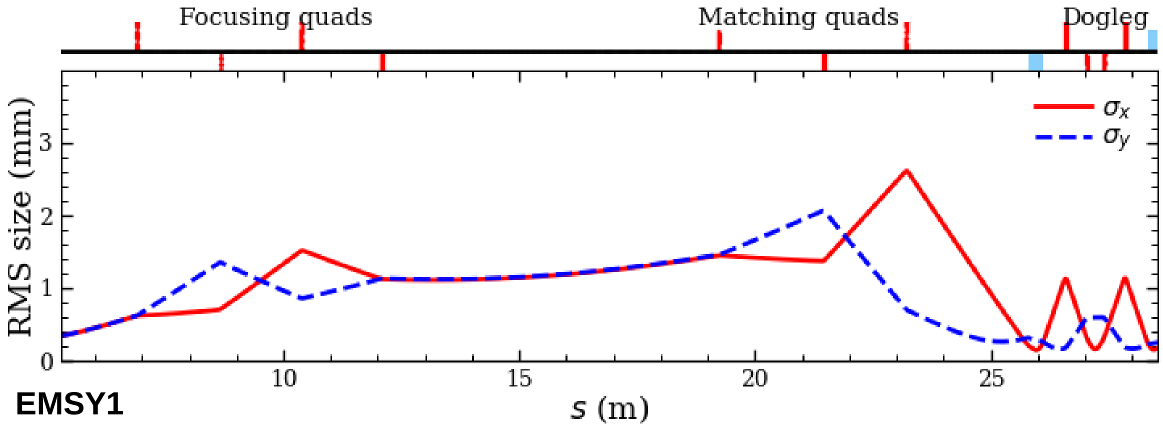
- The last four quadrupoles in the PITZ tunnel are used to produce the matched Twiss parameter, i.e., $\beta_x, \beta_y, \alpha_x, \alpha_y$, at the dogleg entrance



Transport and matching

1 nC





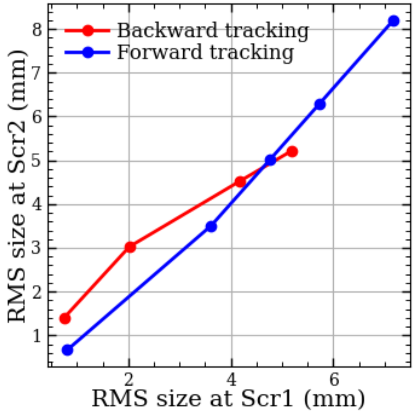
EMSY1

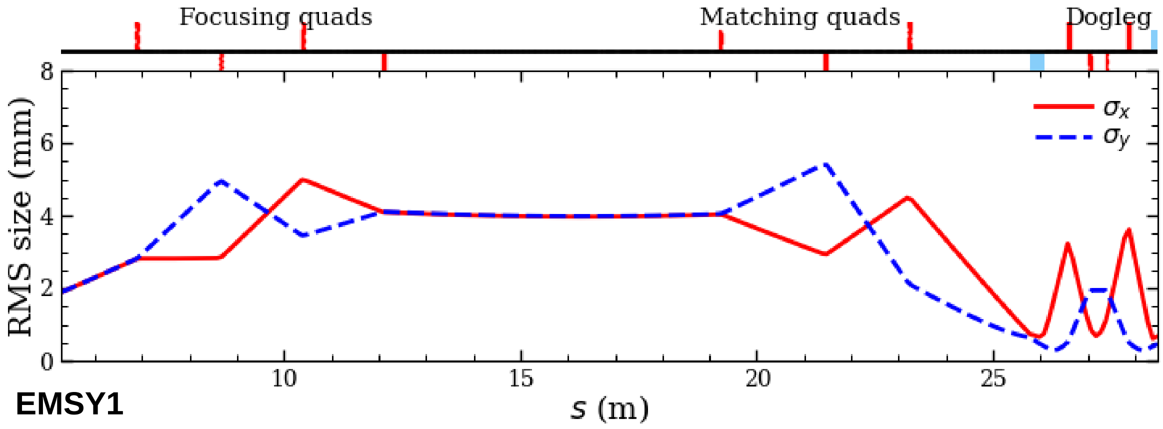
Forward tracking: Astra beam at EMSY1

Backward tracking: Astra beam at dogleg entrance rescaled to matching condition

Transport and matching

5 nC





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Forward tracking: Astra beam at EMSY1

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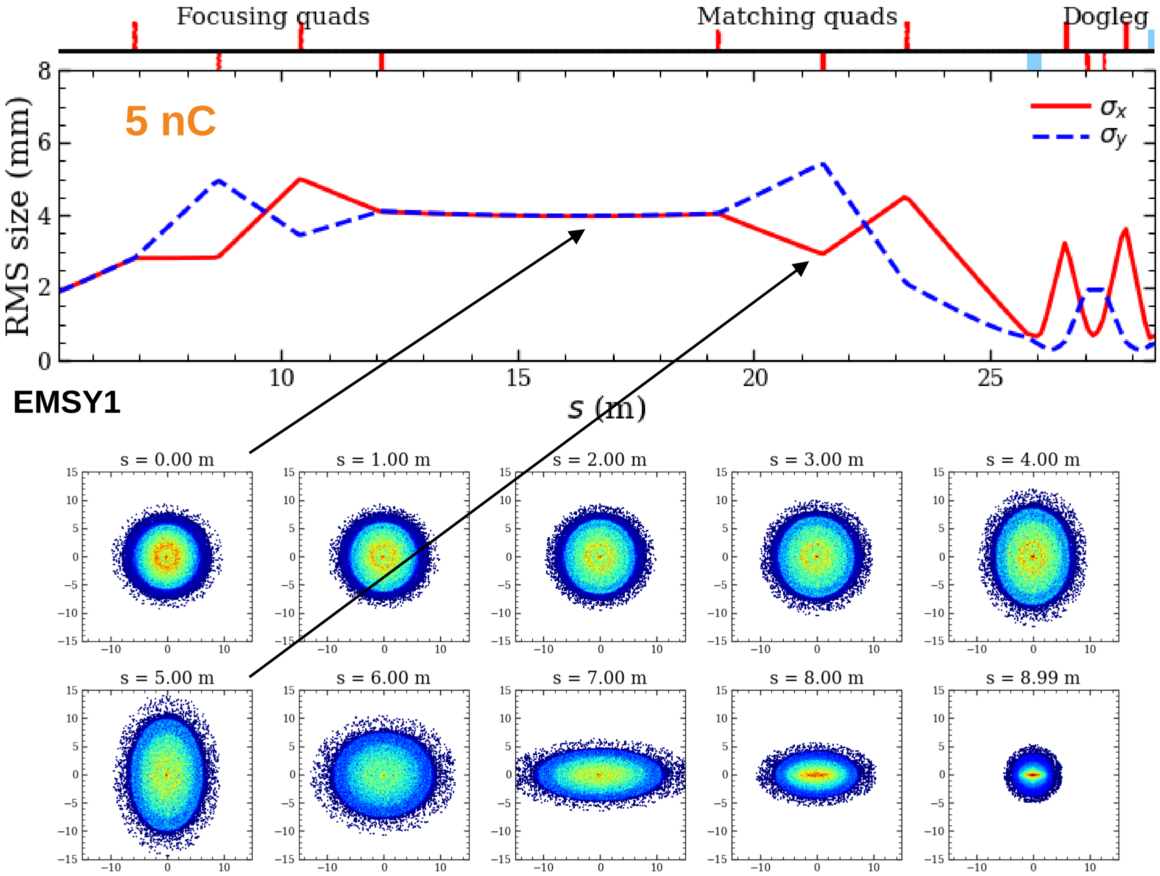
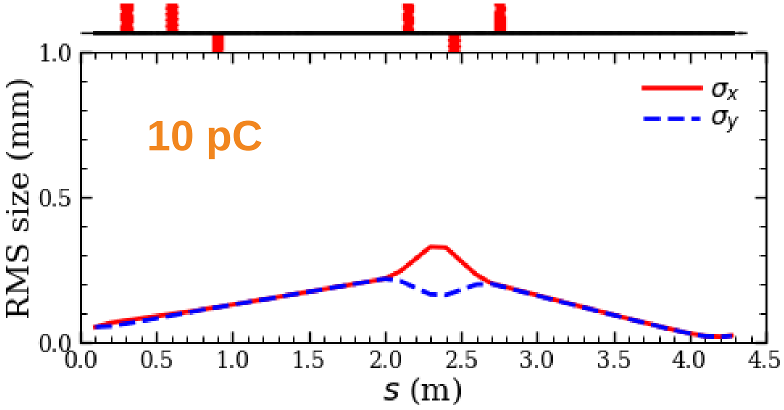
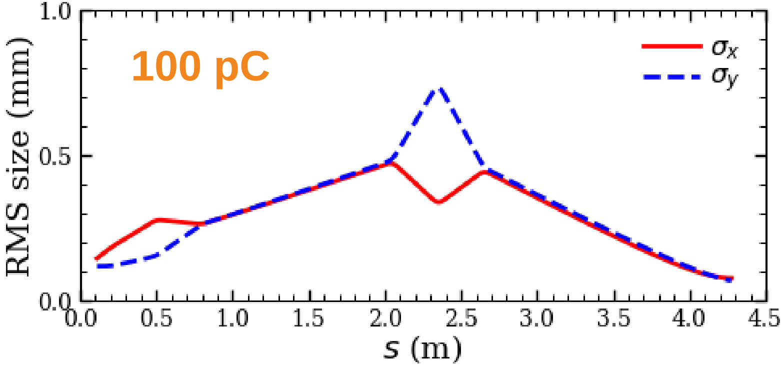

Focusing quads
Matching quads
Dogleg
5 nC
σ_x
σ_y
RMS size (mm)
s (m)
EMSY1
s = 0.00 m
s = 1.00 m
s = 2.00 m
s = 3.00 m
s = 4.00 m
s = 5.00 m
s = 6.00 m
s = 7.00 m
s = 8.00 m
s = 8.99 m

Transport after dogleg

10 pC and 100 pC

Assuming 20 mrad scattering angle





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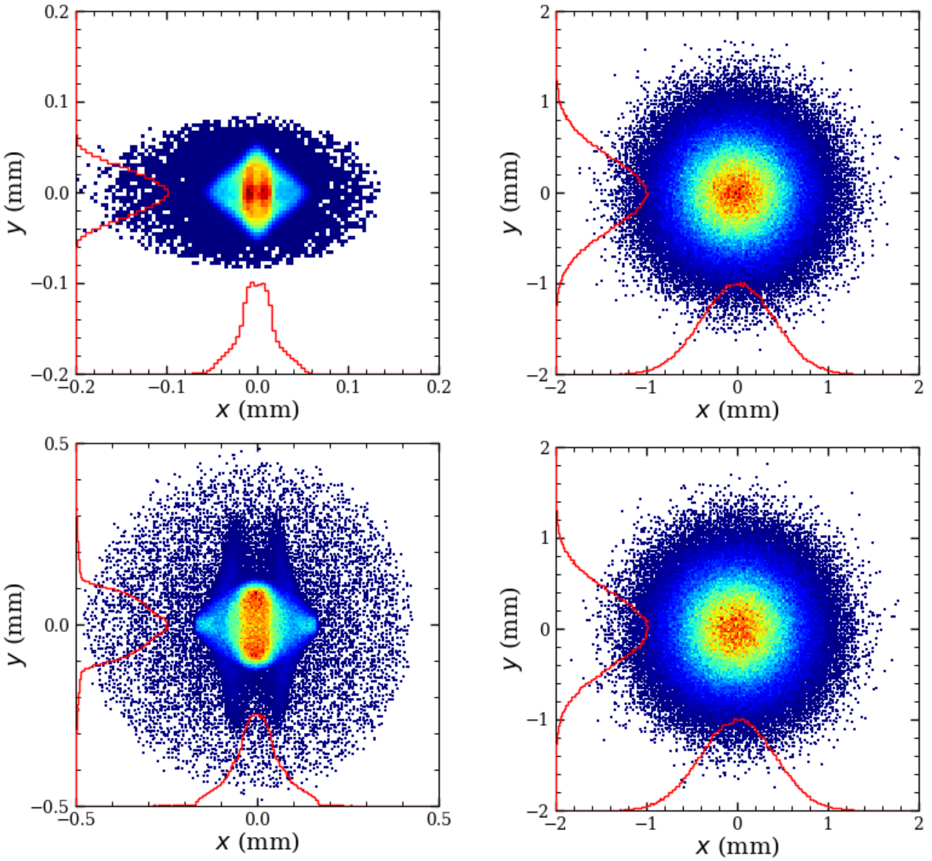
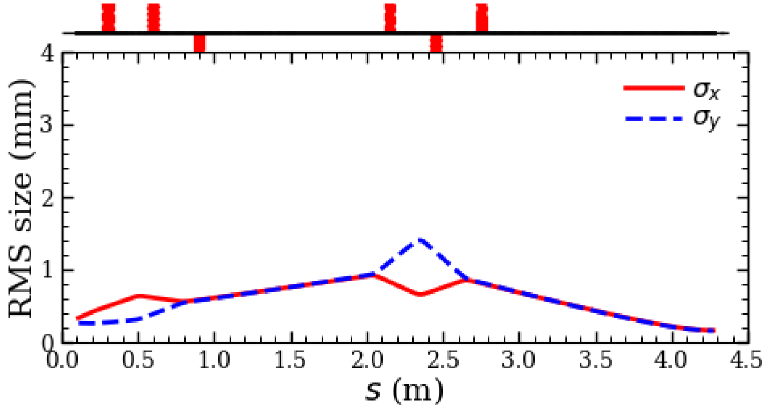
After 2 cm

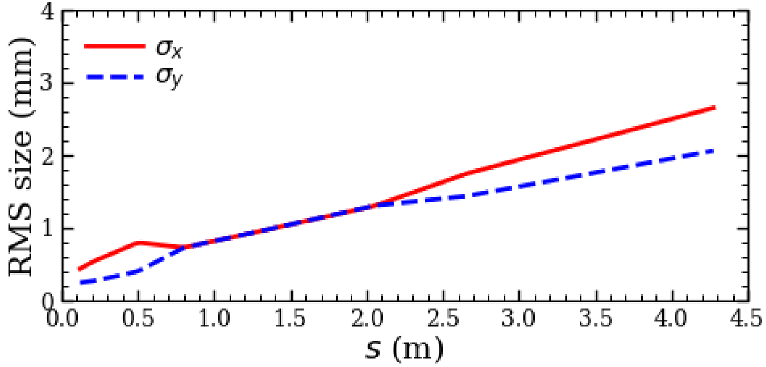


Transport after dogleg

1 nC

Assuming 20 mrad scattering angle





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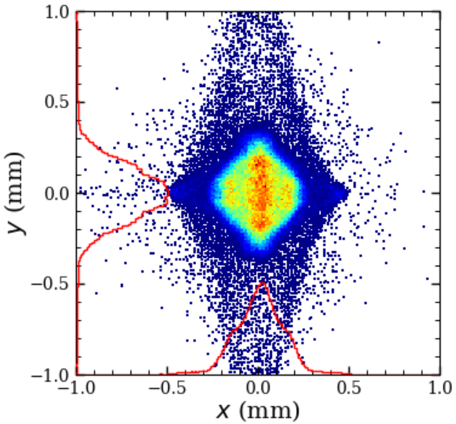
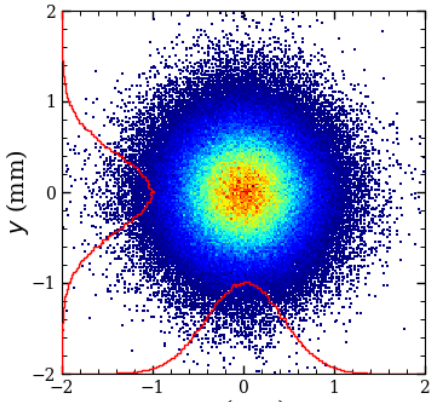
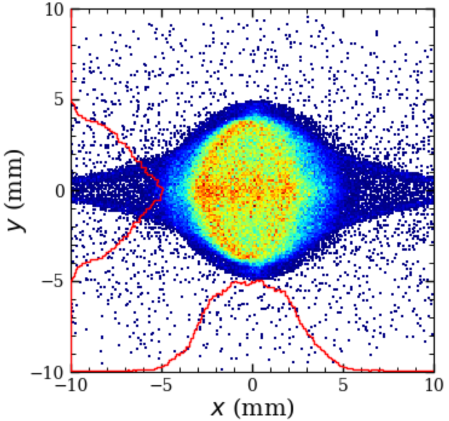
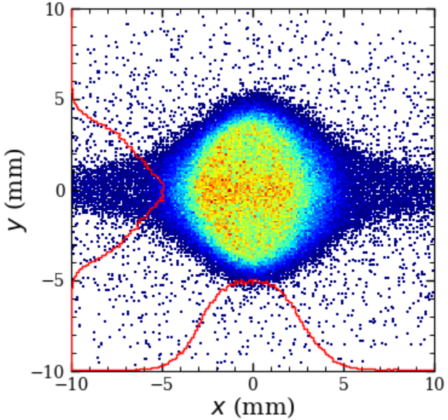
After 2 cm









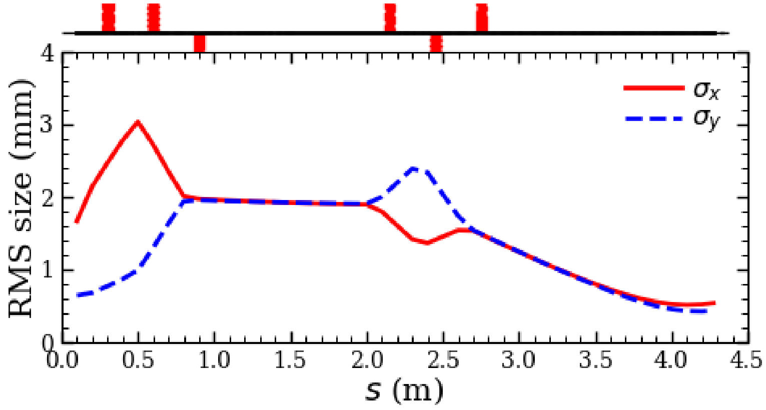
Transport after dogleg

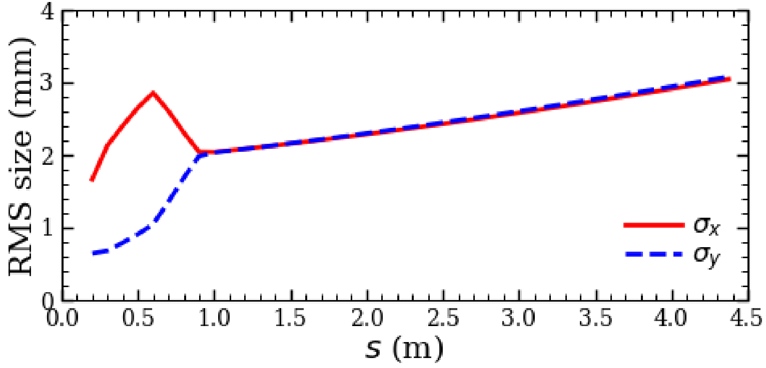
5 nC

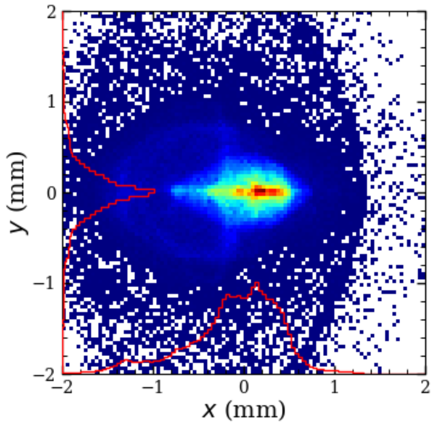
Assuming 20 mrad scattering angle

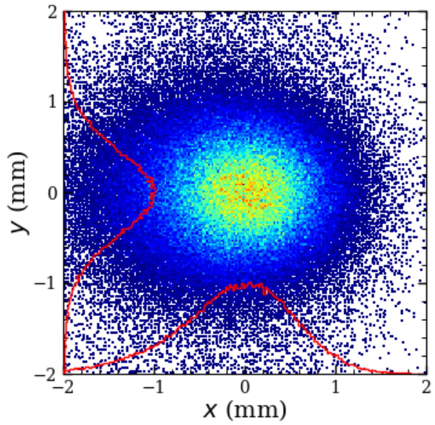
@window

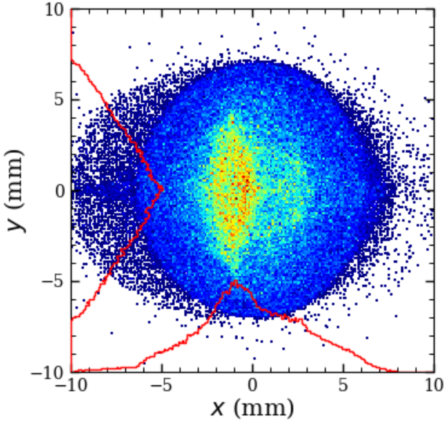
After 2 cm

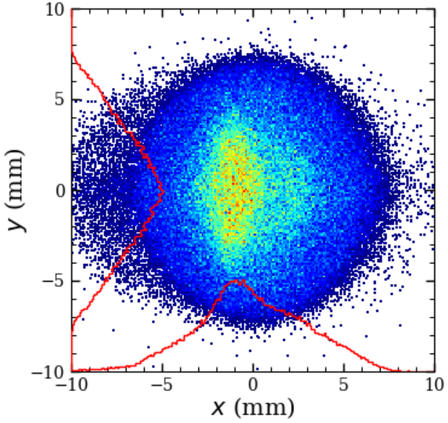








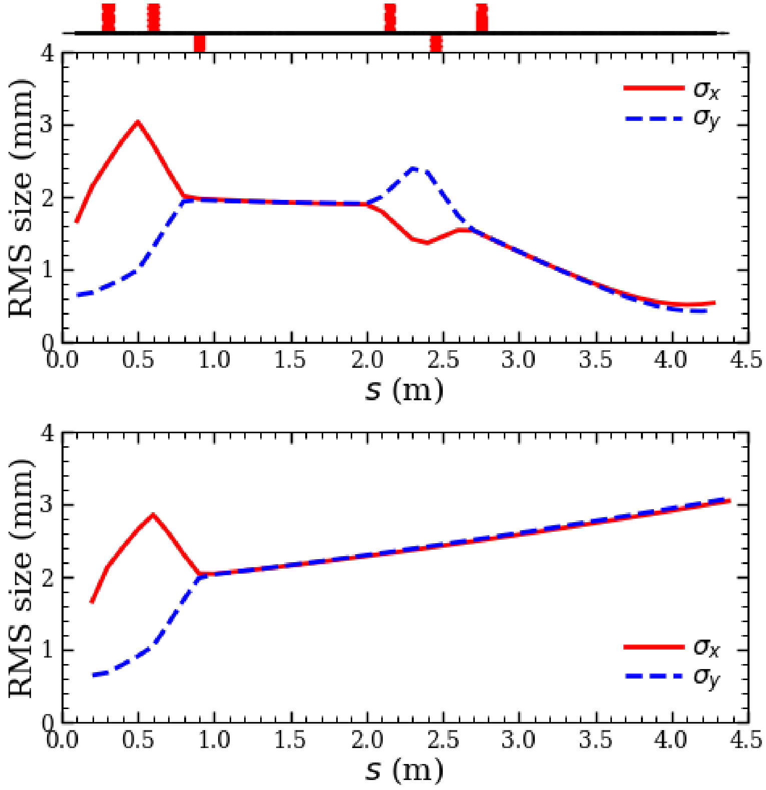




Transport after dogleg

5 nC

Assuming 20 mrad scattering angle



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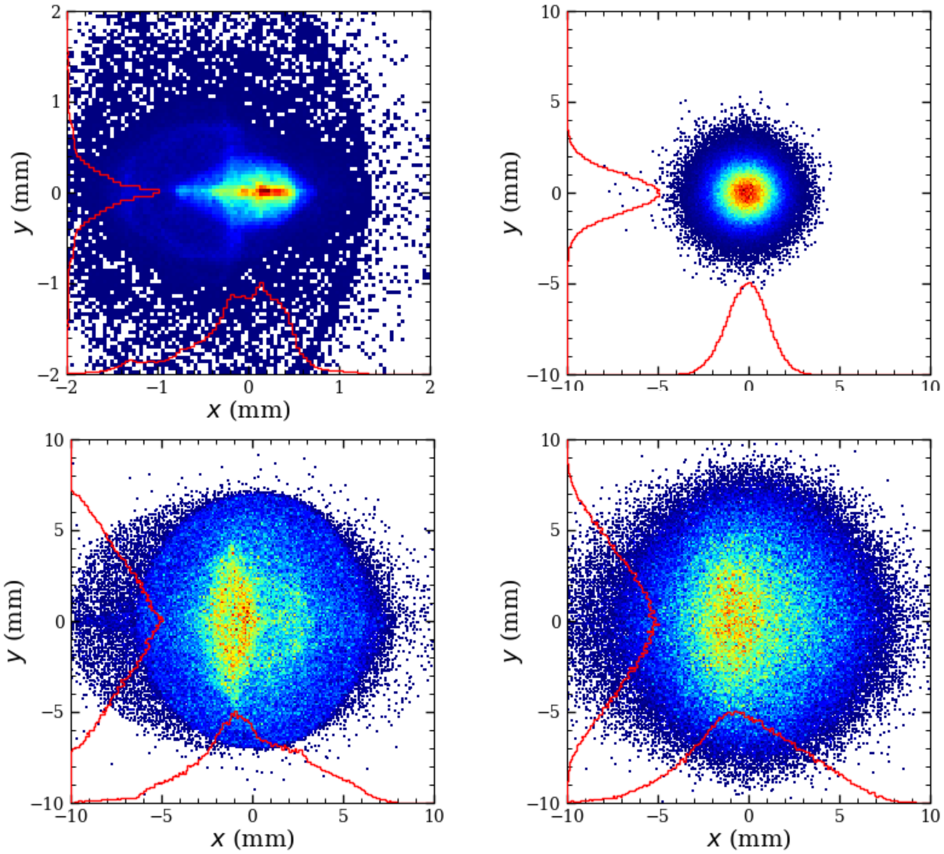
After 5 cm



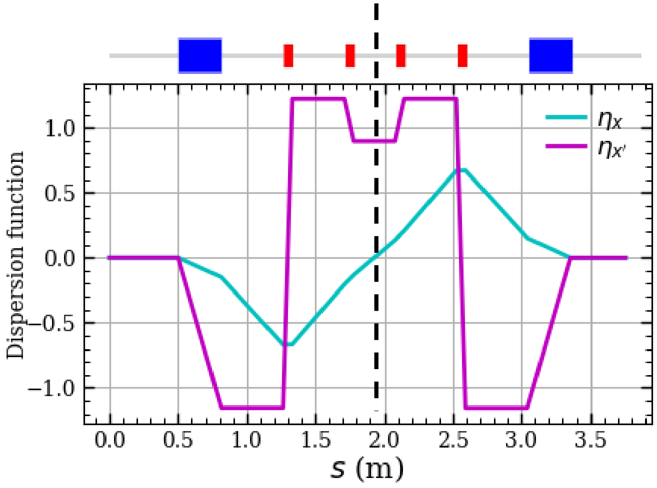
Summary

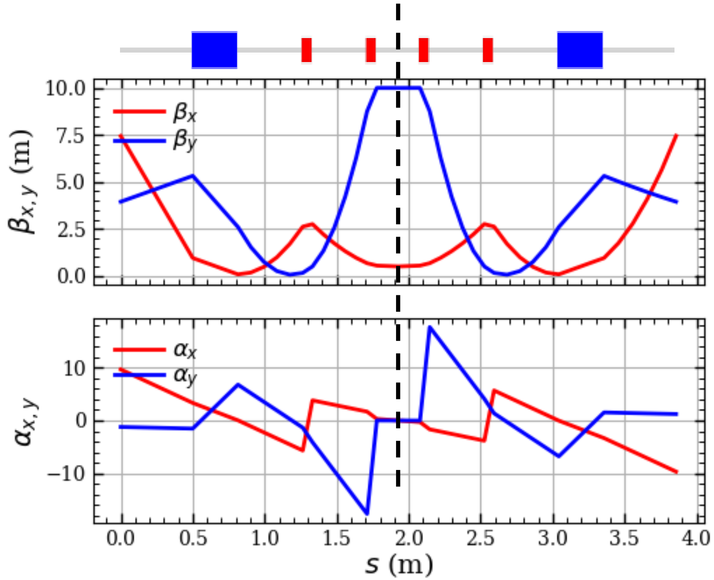
- Start-to-end simulations have been performed for the charge range from 10 pC to 5 nC, providing very flexible beam parameters (RMS sub-mm to several mm) at the samples
  - For focused beam, 2 cm long drift in the air leads to similar Gaussian transverse profiles
  - For enlarged beam, longer drift will help improve the transverse profile

- Next: bunch length manipulation using the dogleg, CSR effects to be studied

Transport and matching

Design of the dogleg

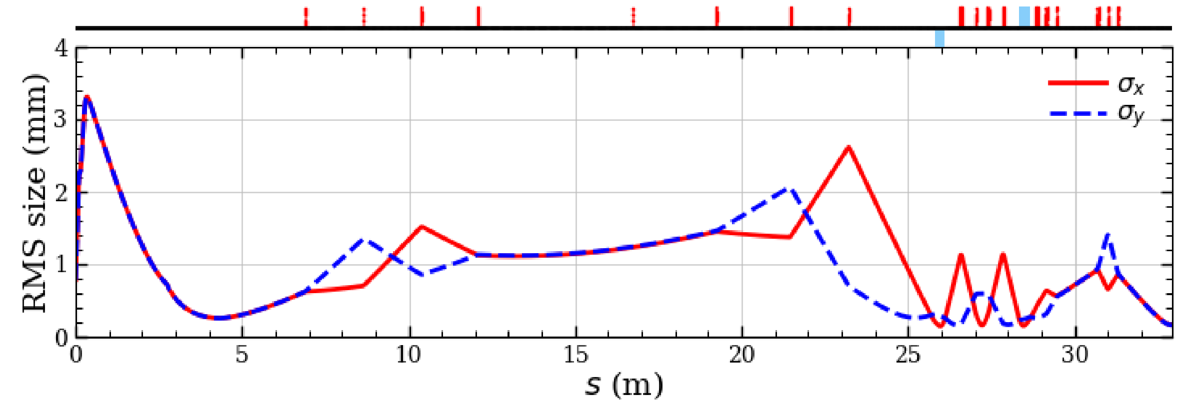


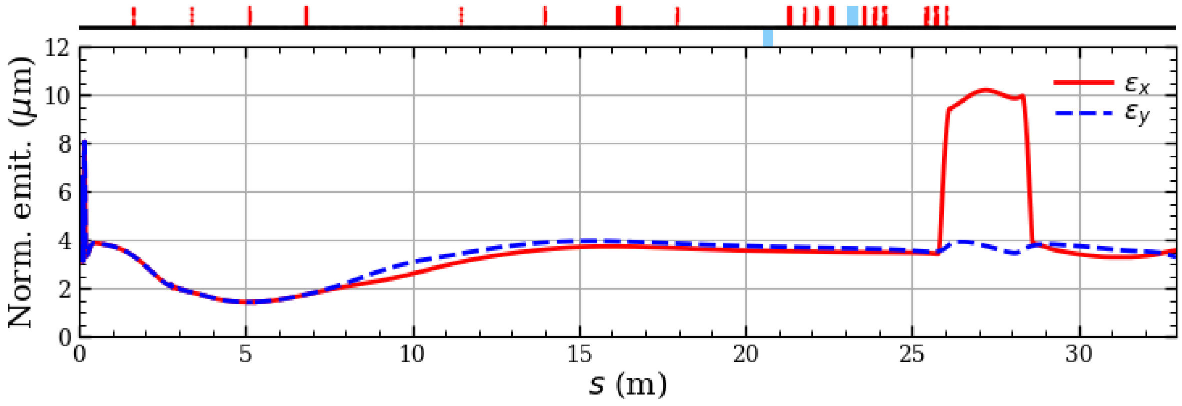


- Assuming zero alpha functions ($\alpha_x = \alpha_y = 0$) and tracking with nonzero beta functions from the midpoint, we get the Twiss parameters at the dogleg exit; because of the symmetry, we then get the Twiss parameters at the dogleg entrance by $\beta_{\text{ent}} = \beta_{\text{exit}}, \alpha_{\text{ent}} = -\alpha_{\text{exit}}$
- Scanning the beta functions at the midpoint ($\beta_{x,\text{mid}}$ and $\beta_{y,\text{mid}}$) will give us a set of transverse phase spaces at the entrance

RMS size and emittance: start-to-end

1 nC





RMS size and emittance: start-to-end

5 nC