Summary of matching strategy study in Run 1

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Outline

- Introduction
- Matching strategy
- Simulations on the matching strategy
- First experimental results
- Summary

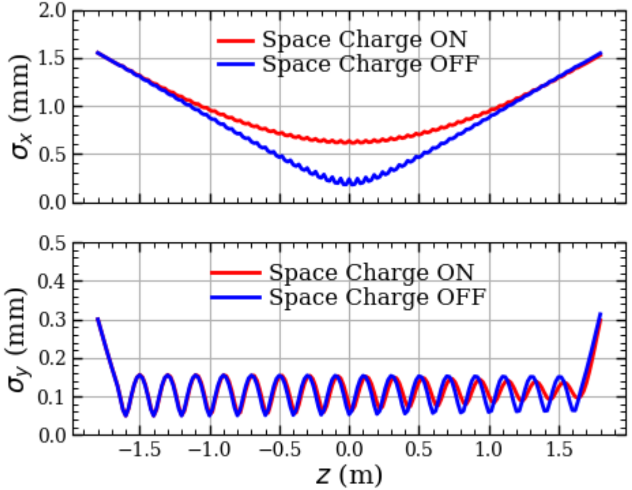
Introduction

Consideration on the beam transport in the LCLS-I undulator

- A small vacuum chamber (11x5 mm) is foreseen in the LCLS-I undulator
- Space charge force and magnetic focusing force from the undulator fields could lead to a rapid growth of the beam size (therefore beam loss), if not well handled

In the horizontal plane, the motion is dominated by the space charge; in the vertical plane, it is dominated by the strong focusing field

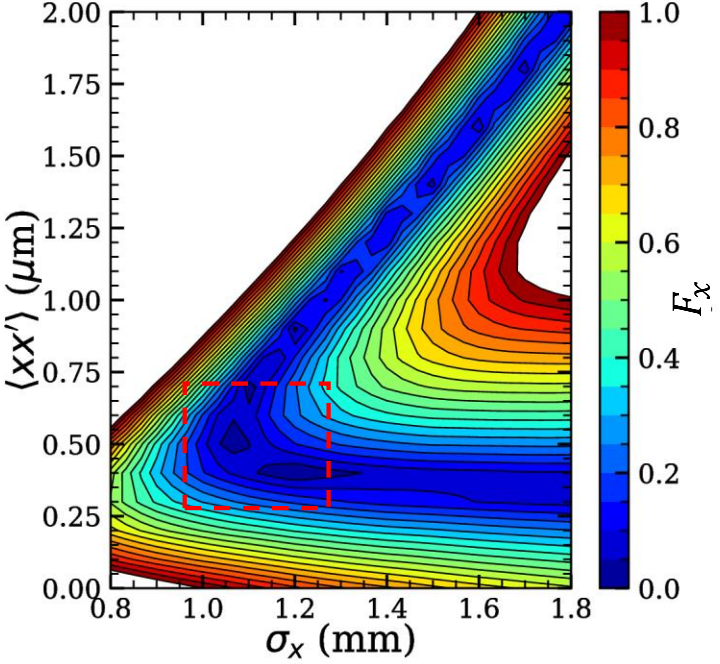
→ Independent parameter scan in the two planes



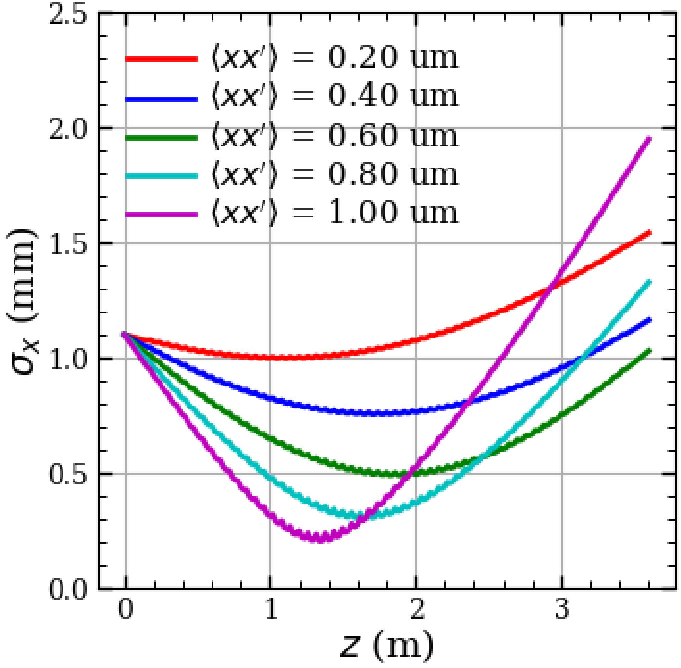
Introduction

Matching condition in the horizontal plane @ 4nC, 22 MeV/c

$$F_x = |\sigma_x^{in} - \sigma_x^{out}|$$



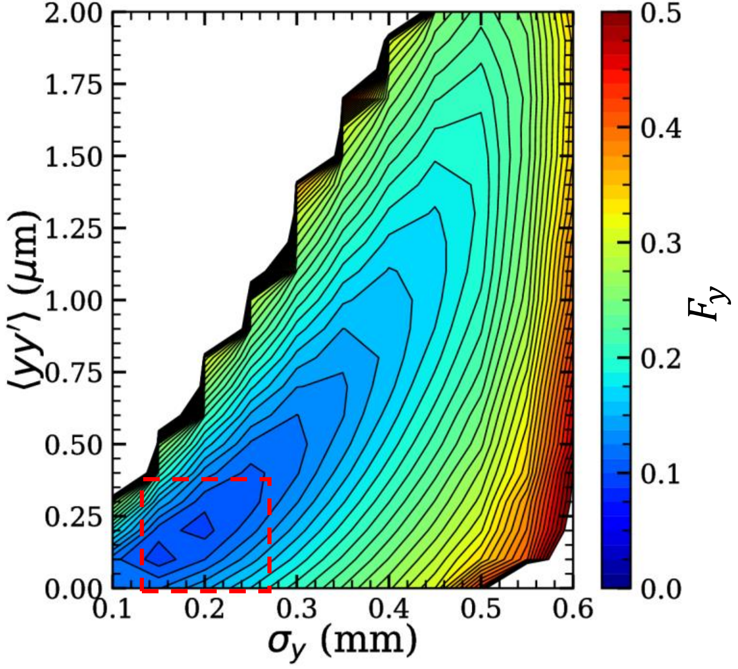
With beam emittance fixed at 4 um

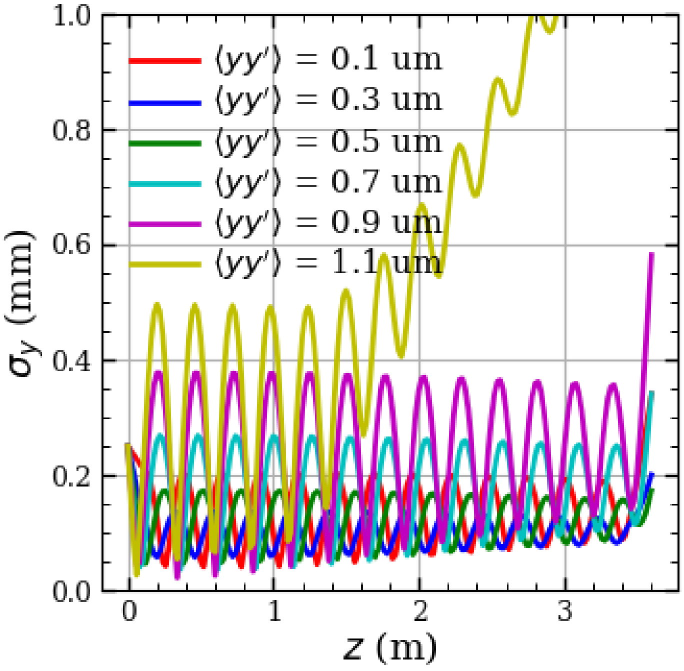


Introduction

Matching condition in the vertical plane @ 4nC, 22 MeV/c

$$F_y = \langle \sigma_y \rangle_{0 \rightarrow L_{und}}$$



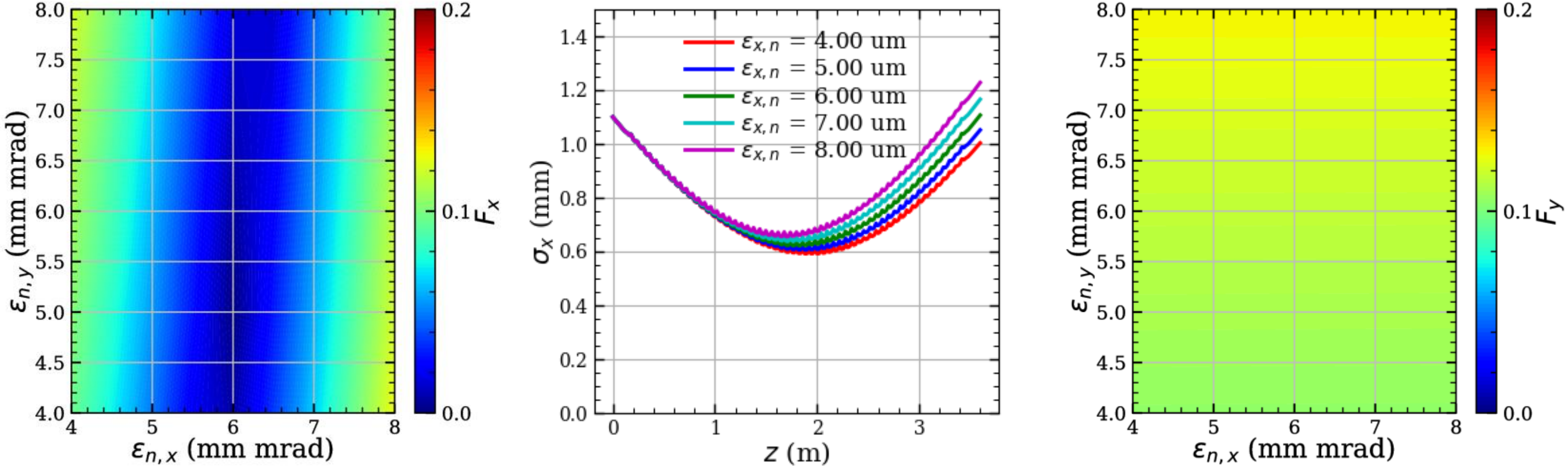


With beam emittance fixed at 4 um

Introduction

Effects of beam emittance

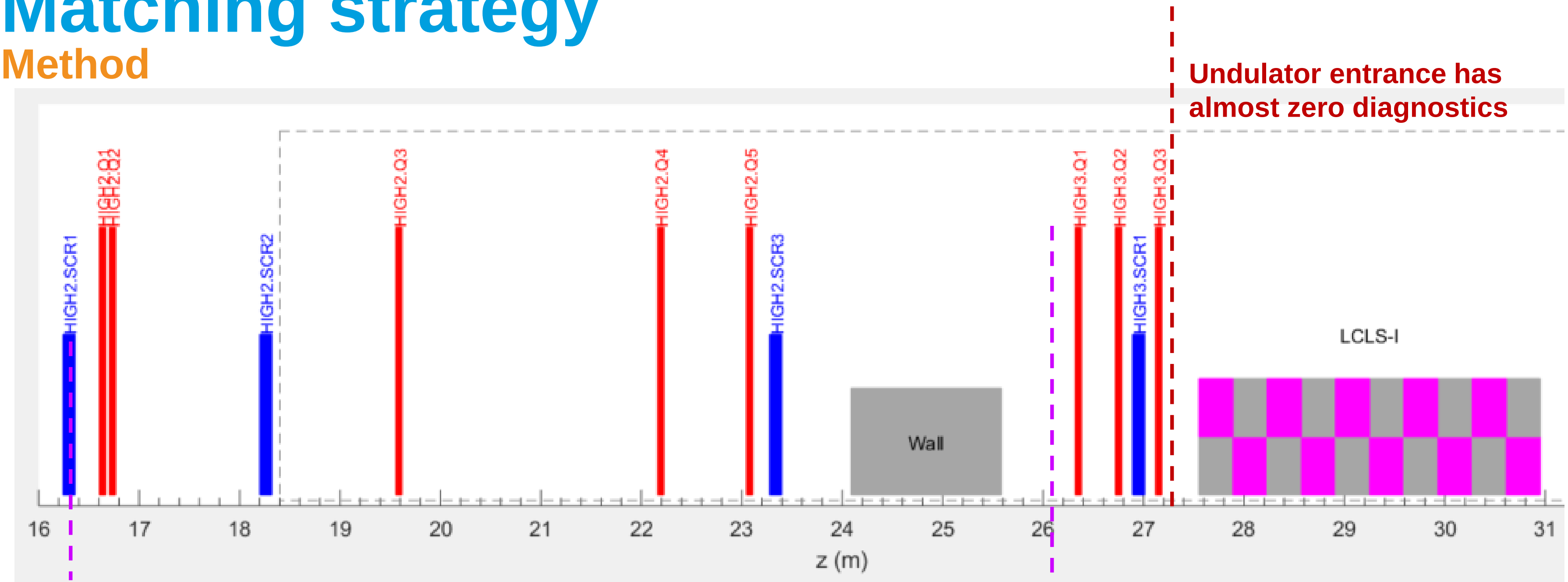
- Here the beam size and covariance are fixed and the x and y emittances are scanned
- The beam envelopes in the undulator are not affected much



Phase space match (6 parameters) → beam size and covariance (4) match !

Matching strategy

Method



Measure the phase space with EMSY3 and then transport the beam with the following **quads** -> X/Yrms and X/Ycov

Or just measure the beam envelope development after the quads using High2.Scr3 and High3.Scr1

1 ←→ Backward simulation: X/Yrms and X/Ycov vs **triplet** strength

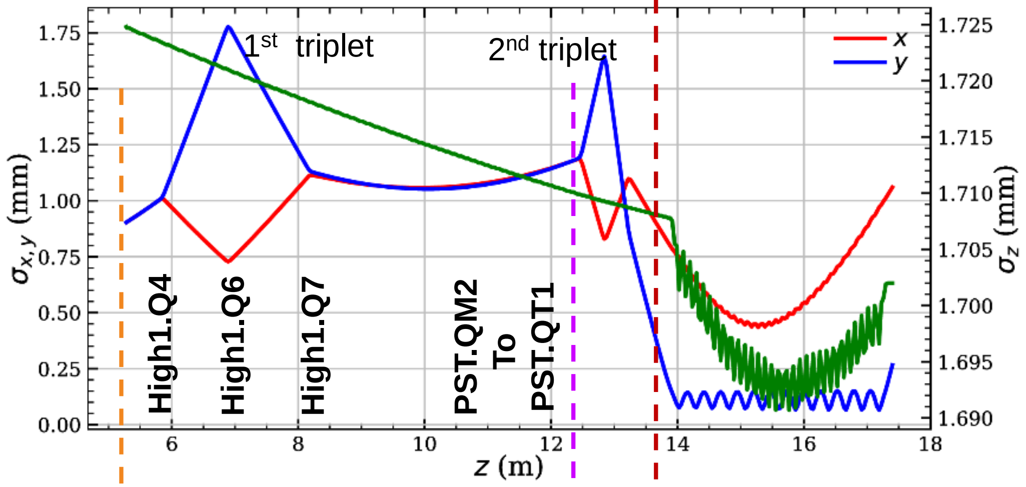
2 ←→ Or beam envelope development (from High2.Scr3 to High3.Scr1) vs triplet strength

- If a round beam transport is made, the matching parameters reduce to two and two free knobs (quads combination after EMSY3 and the triplet before the undulator) are enough

Matching study at PST section

Method

PST.Scr1 (Undulator entrance): special phase space wanted

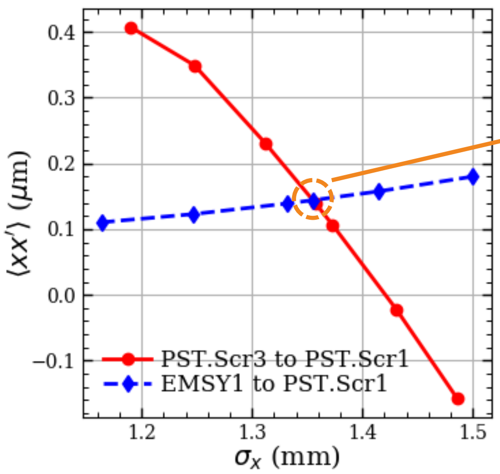


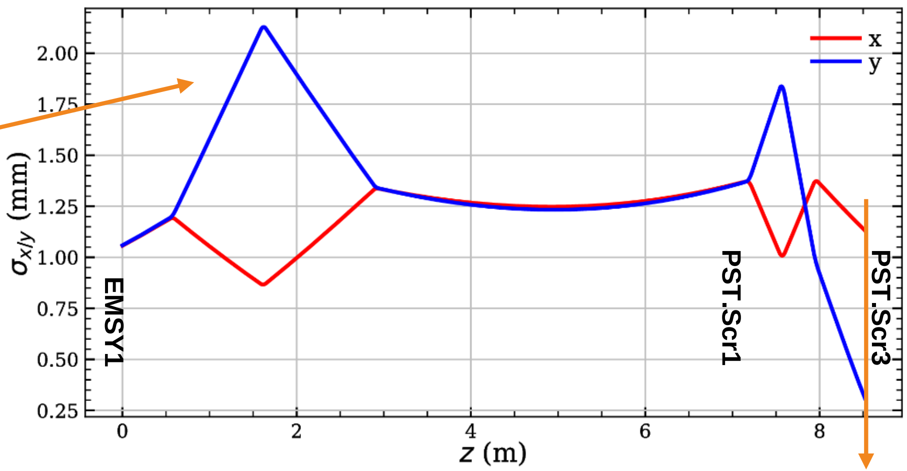
Tracking back to PST.Scr1 and matching the beam envelope (or Xrms and Xcov) there

But how to get Xcov?

Or tracking back to EMSY1: match Xrms and Xcov there

Simulation on matching at PST.Scr1





Expected:
Xrms = 1.10 mm
Yrms = 0.25 mm
Xcov = -0.50 um
Ycov = -0.30 um

Backward tracking:

PST.Scr3 to PST.Scr1, 2nd triplet strength tuned

Forward tracking:

EMSY1 to PST.Scr1, 1st triplet strength tuned

Obtained:
Xrms = 1.13 mm
Yrms = 0.31 mm
Xcov = -0.47 um
Ycov = -0.33 um

Estimation of beam covariance

- The Twiss parameters evolve in a free drift with a length of s as follows:

$$\beta(s) = \beta_0 - 2s\alpha_0 + s^2\gamma_0$$

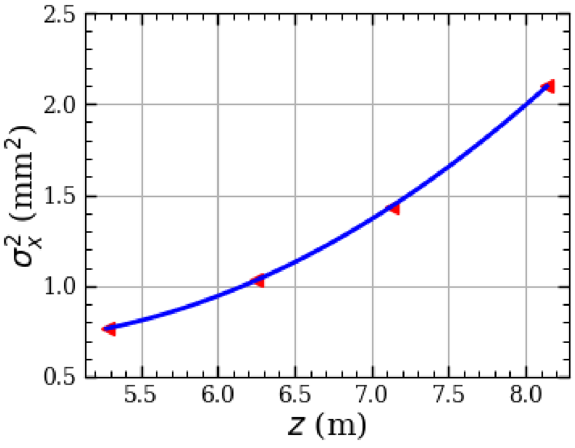
- Assume no/negligible emittance growth during a short drift and replace Twiss parameters with beam parameters:

$$\sigma_x^2 = \sigma_{x_0}^2 + 2\langle x_0 x_0' \rangle \cdot s + \sigma_{x_0'}^2 \cdot s^2$$

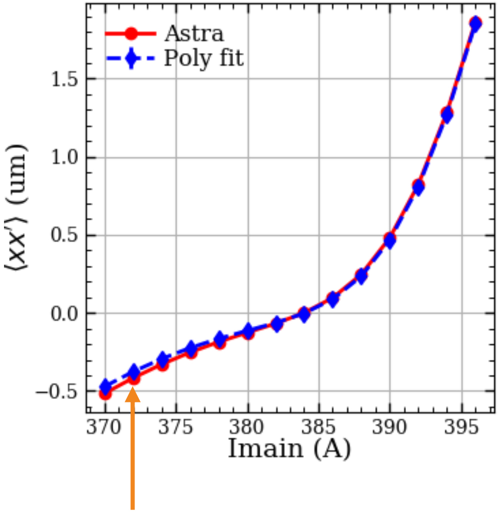
- By fitting $\sigma_x^2 \sim s$, the covariance term $\langle x_0 x_0' \rangle$ can be derived from the first order term coefficient

- To get the covariance at EMSY1, we measure the beam sizes from High1.Scr1 to High1.Scr4; and to get the covariance at PST.Scr1, we measure the beam sizes from PST.Scr1 to PST.Scr4

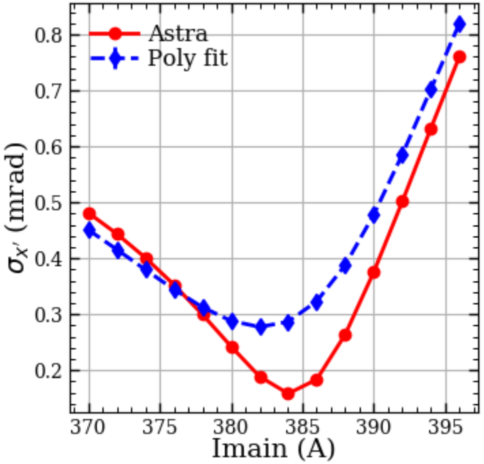
Simulation on beam covariance estimation



$$\sigma_x^2 = \sigma_{x_0}^2 + 2\langle x_0 x_0' \rangle \cdot s + \sigma_{x_0'}^2 \cdot s^2$$



Converging beam, SC playing more role



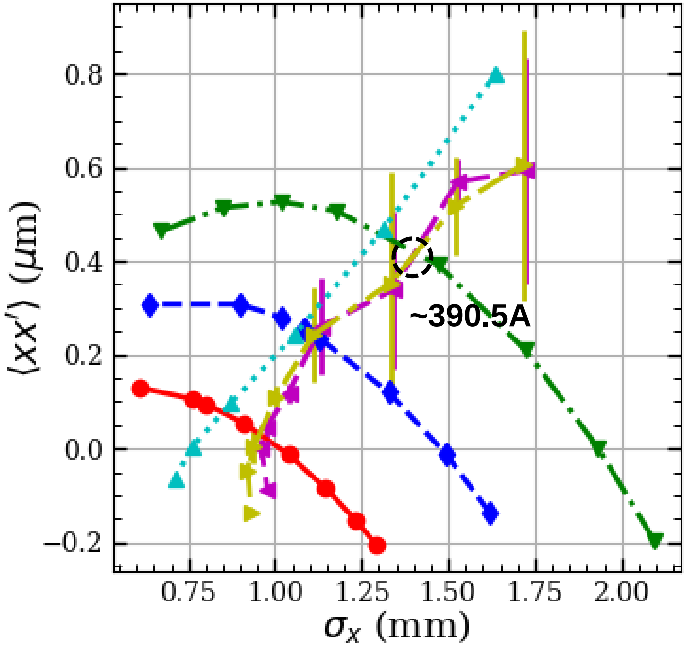
First experimental results (match at EMSY1)

Purpose

- Test the method of estimating the covariance (at EMSY1 so it is possible to compare with slit scan)
- Then match Xrms and Xcov at EMSY1 and transport the beam with corresponding current settings for the two triplets and see if the beam reaches PST.Scr3 (“undulator entrance”) with expected distribution

First experimental results (match at EMSY1)

1. Simulations (Solenoid scan, backward tracking until EMSY1)
2. Measure the covariance vs Imain at EMSY1 (all with gun quads)
3. Compare with backward simulation results and determine the settings of triplets



Backward tracking:

1st triplet scan, each with a different setting of 2nd triplet

Solenoid current scan, sim.

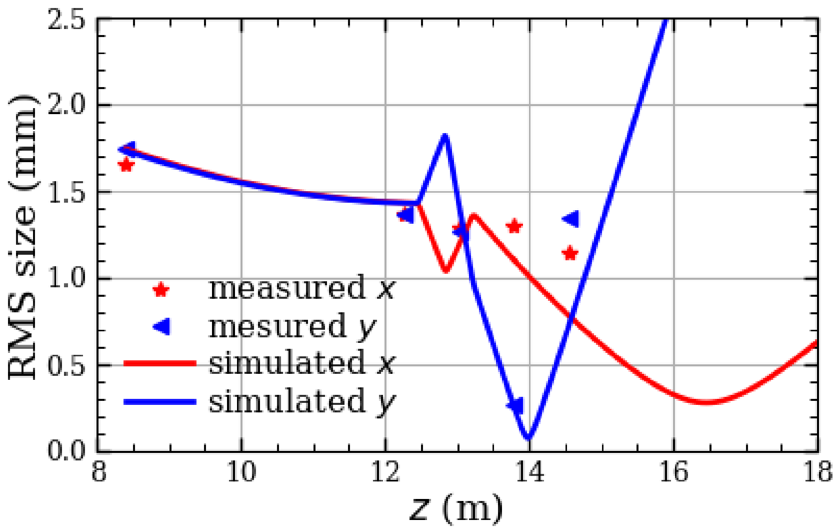
Solenoid current scan, exp.

Poly fit: $\sigma_x^2 = \sigma_{x_0}^2 + 2\langle x_0 x_0' \rangle \cdot s + \sigma_{x_0'}^2 \cdot s^2$

First experimental results (match at EMSY1)

4. Set the currents of 1st triplet and tune a bit (because of measurement errors of beam parameters and errors of quad calibration) to make the beam envelope development as close to simulated one as possible

5. Set the currents of 2nd triplet and measure the beam size and covariance after it (not done yet)



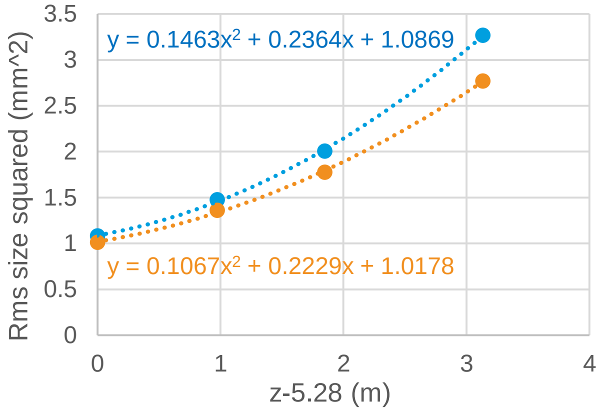
Disagreement may be due to:
1. 1st triplet needs more tuning
2. quads excitated using calibration data of others
3. Simulated beam different from actual beam even though the beam parameters are matched

First experimental results (match at EMSY1)

Problems

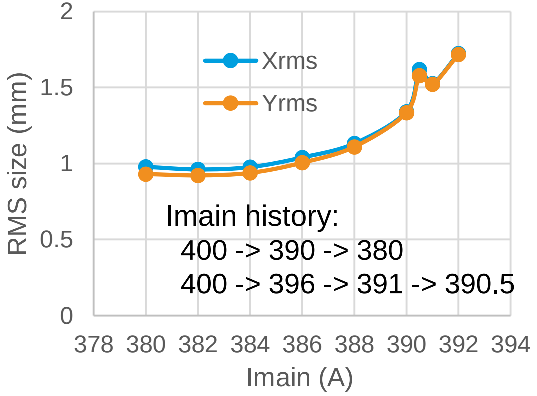
- Measured covariance different from slit scan

  @386 A with gun quads
  0.12/0.11 um for x/y from poly fit
  -0.14/-0.21 um for x/y from slit scan



- Jump of main solenoid focusing

  Beam size inconsistency observed suddenly after reducing Imain in a sequence



- Backward simulation always starts with Gaussian beam; while simulated and measured beams at EMSY1 are not Gaussian

Solenoid scan @ 4 nC, 22 MeV/c

Imain (A)	Xcov (um)	Ycov (um)
390	-0.01849	-0.00934
388	-0.12199	-0.09381
386	-0.26190	-0.16518
384	-0.34586	-0.19474
382	-0.38614	-0.22329

The trend of X/Ycov vs Imain seems fine

Summary

- The matching condition at the undulator entrance is not very critical; since the beam emittance has no significant effect on the beam transport, the matching parameters reduce to four (rms sizes and covariances)
- The matching point under consideration is before the last triplet and by making a round beam transport, the matching parameters reduce further to two
- The matching strategy has been simulated and proves to be working in High1 and PST section
- First matching experiment in High1 and PST sections was done, the results to be improved in the next run; script development is in urgent need