200 A beam transport simulation for THz SASE FEL at PITZ

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Introduction

- In the proposed PITZ SASE FEL experiments, a **4 nC** electron beam will be sent to a LCLS-I type undulator to generate SASE FEL in THz band for the pump-probe experiments at European X-FEL

- The optimized longitudinally **flattop** laser pulse (**FWHM~21.5 ps**) is used for the design **(~200 A**)

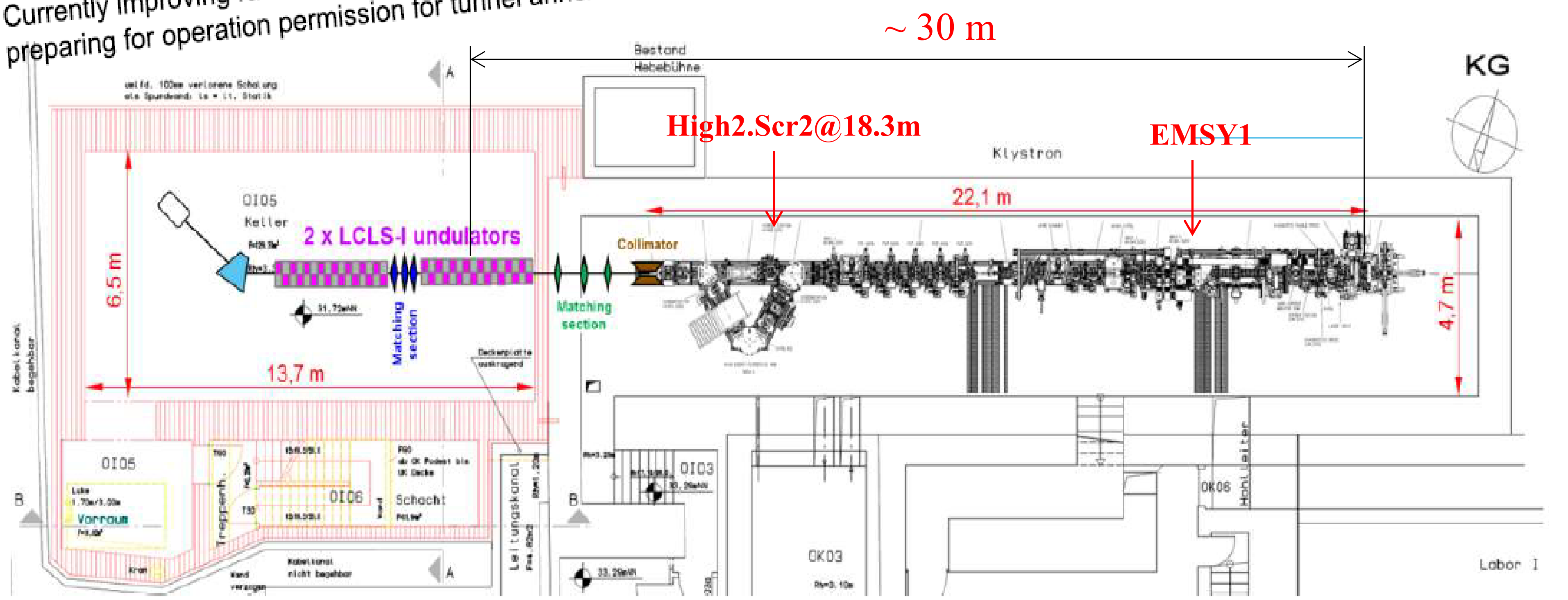
- Currently, a much shorter **Gaussian** pulse (**FWHM~8 ps**) is available
- Therefore, for studying the transport of the beam, **the same peak current** instead of the same bunch charge is considered here

Introduction

Planned installation of LCLS-I undulators in PITZ tunnel annex

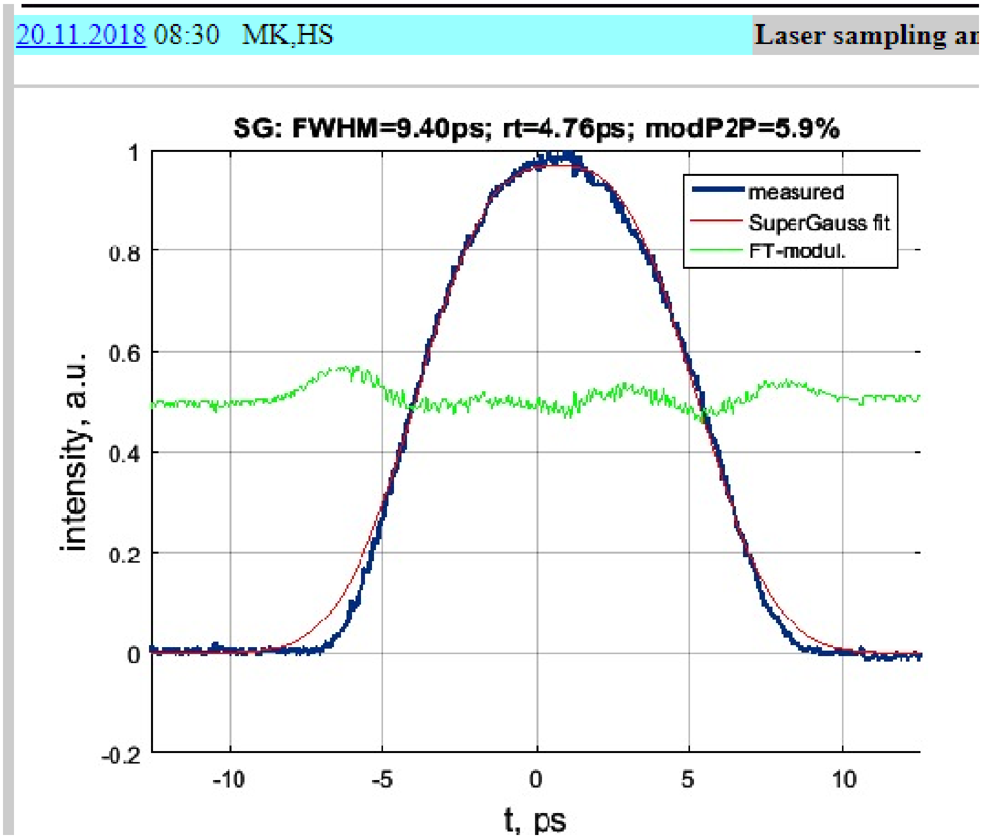
Will be used for proof-of-principle experiments at PITZ

Currently improving radiation shielding and preparing for operation permission for tunnel annex



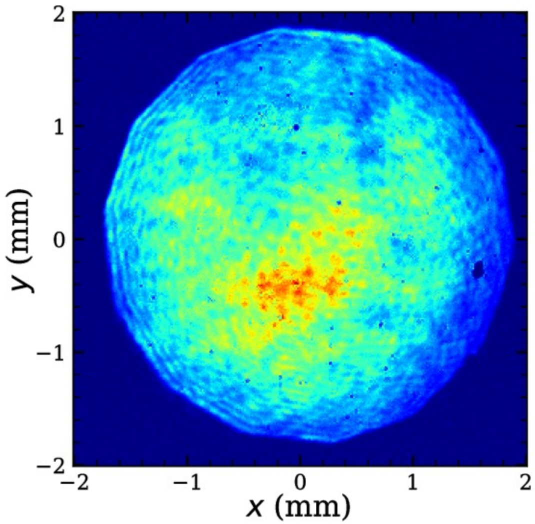
Laser long. distribution

- Super Gaussian fit of measurement

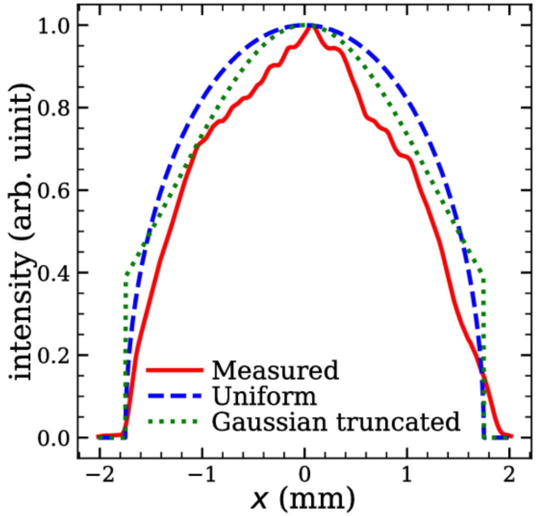


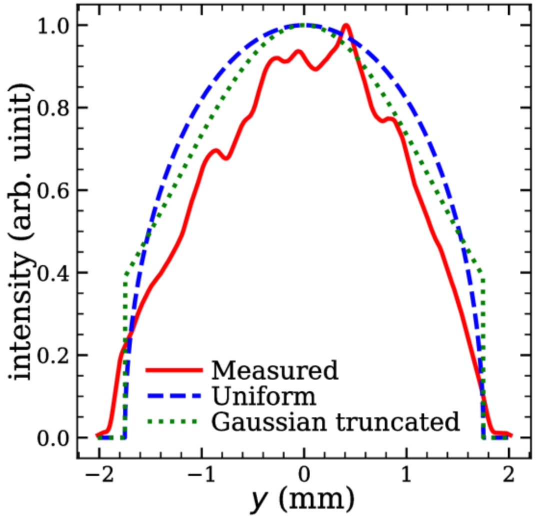
- A Gaussian distribution is taken for Astra simulation

Laser trans. distribution



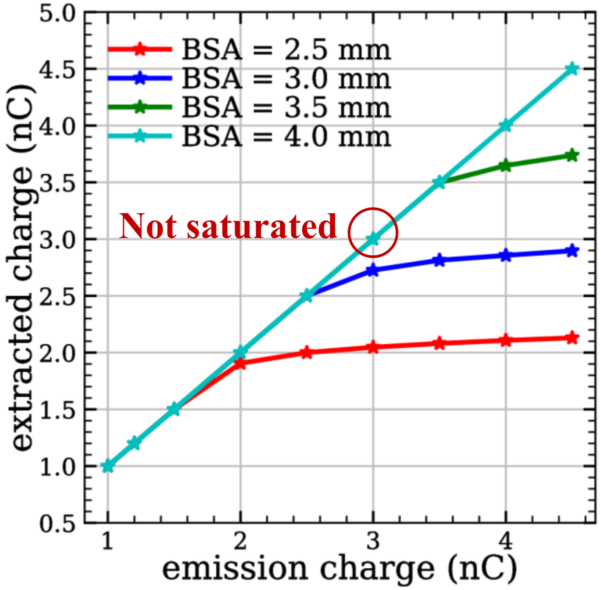
- BSA 3.5 mm, 1p13%
- Uniform or Gaussian truncated?

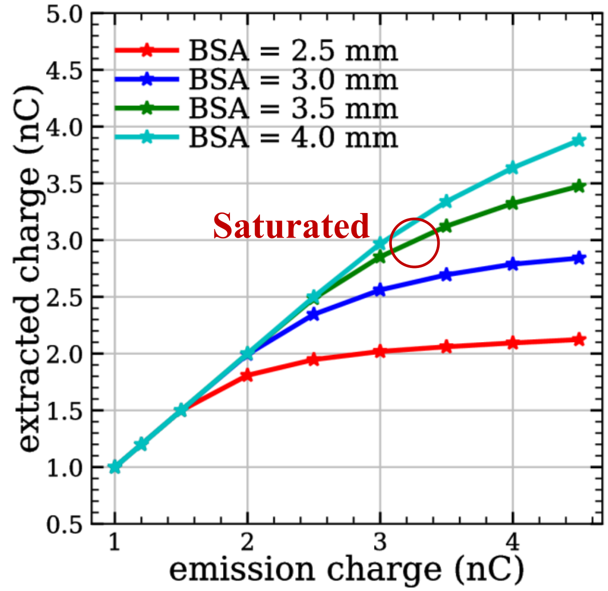




Extracted charge vs emitted charge

- The emission change is scanned for different trans. distribution

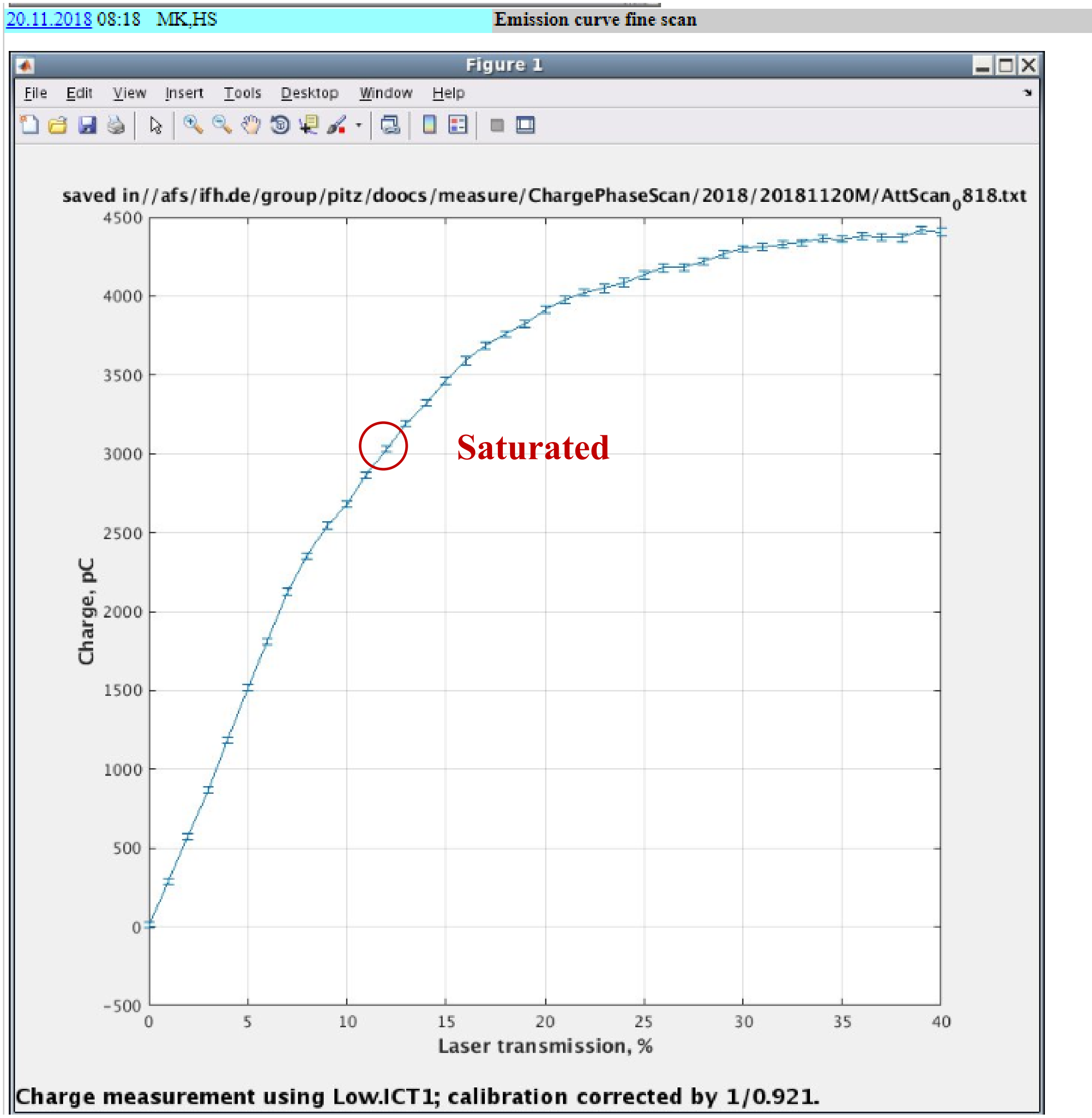




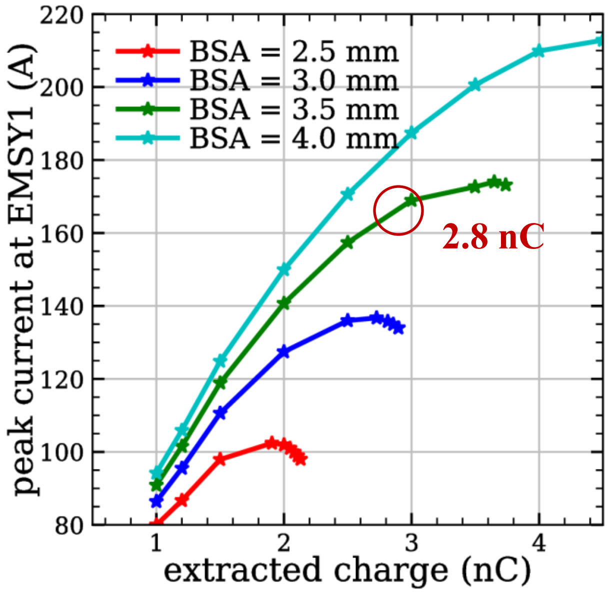
Tran.:	**Uniform**	**Gaussian truncated**
Long.:	**Gaussian**	**Gaussian**

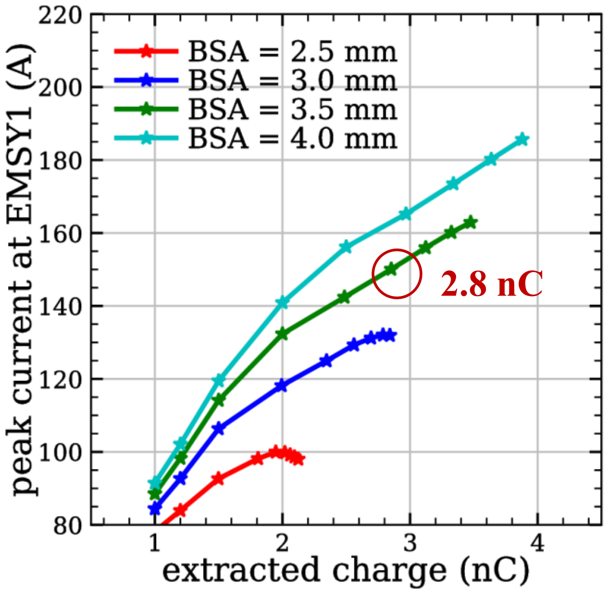
*For Astra simulation, **2D SPCH** is used with 50 k macro particles from gun to the end of beamline without quads; **3D SPCH** is used from EMSY1 to the end with quads

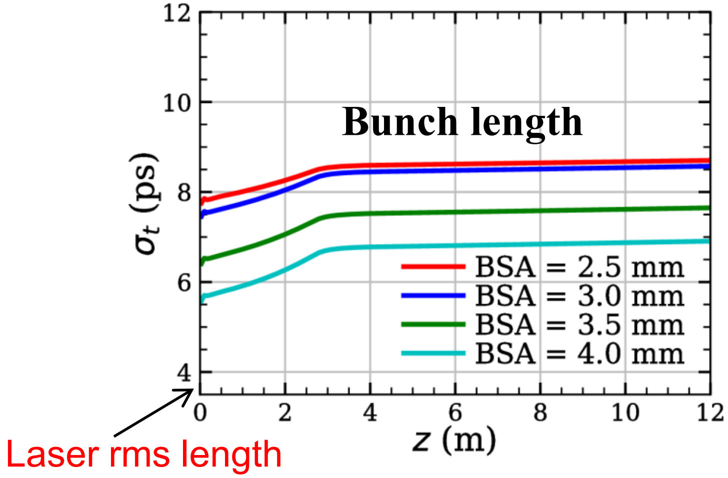
BSA 3.5 mm

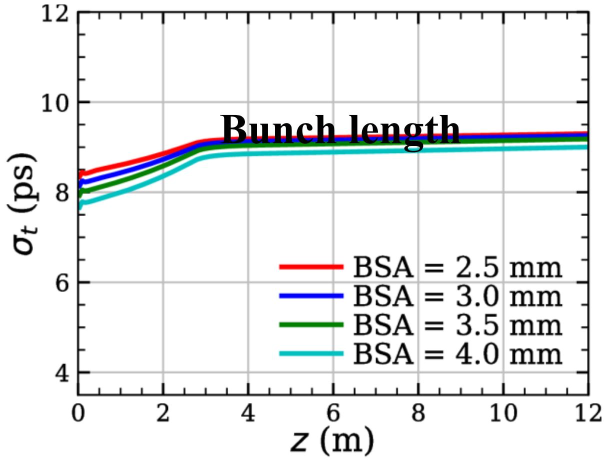

20.11.2018 08:18 MK,HS
Emission curve fine scan
Figure 1
File Edit View Insert Tools Desktop Window Help
saved in//afs/ifh.de/group/pitz/doocs/measure/ChargePhaseScan/2018/20181120M/AttScan_0818.txt
Charge, pC
Laser transmission, %
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
0
5
10
15
20
25
30
35
40
Saturated
Charge measurement using Low.ICT1; calibration corrected by 1/0.921.

Peak current vs extracted charge

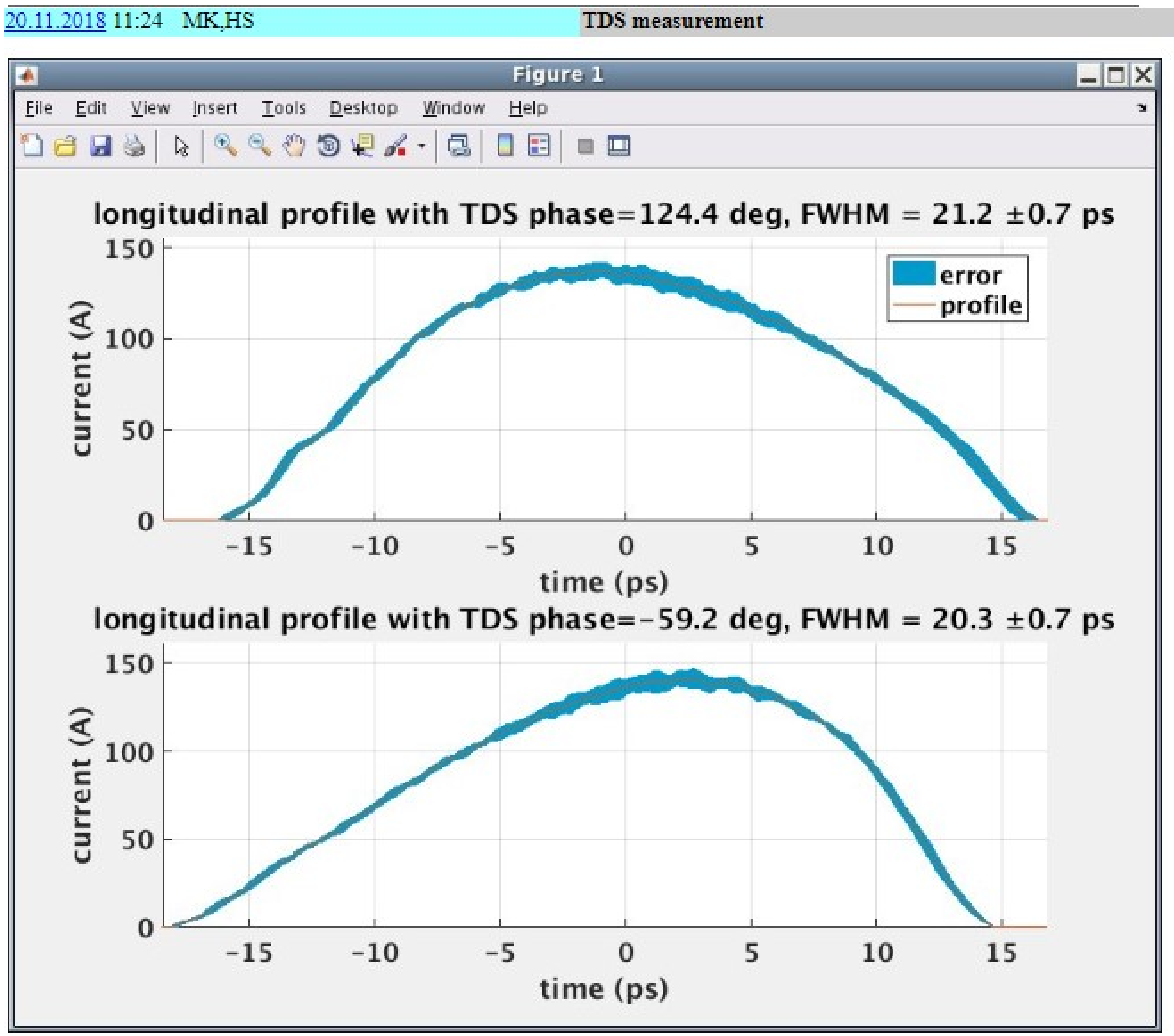








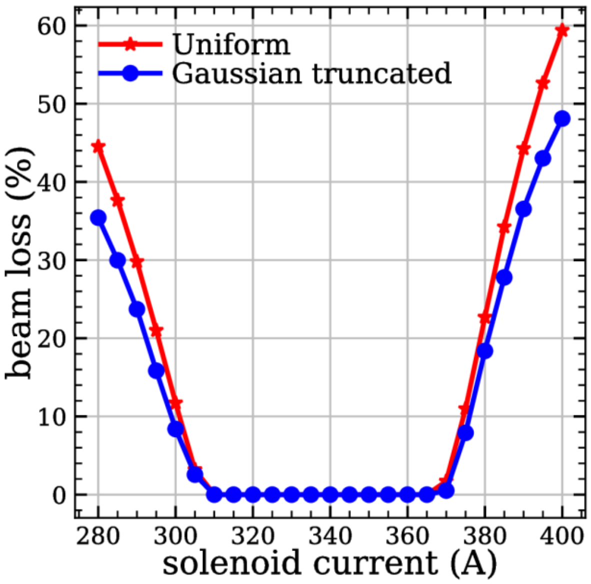
BSA 3.5 mm, 2.8 nC



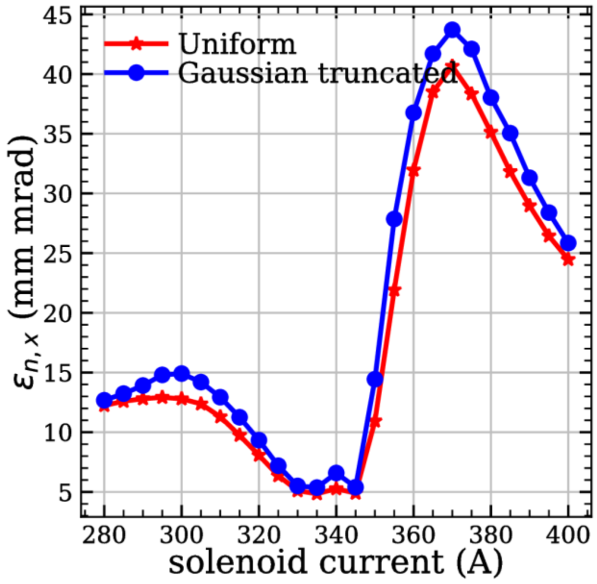
Solenoid current scan

BSA 3.5 mm, 4.5 nC emitted, uniform or Gaussian truncated

- With the gun and booster working at MMMG phases, the solenoid current is scanned

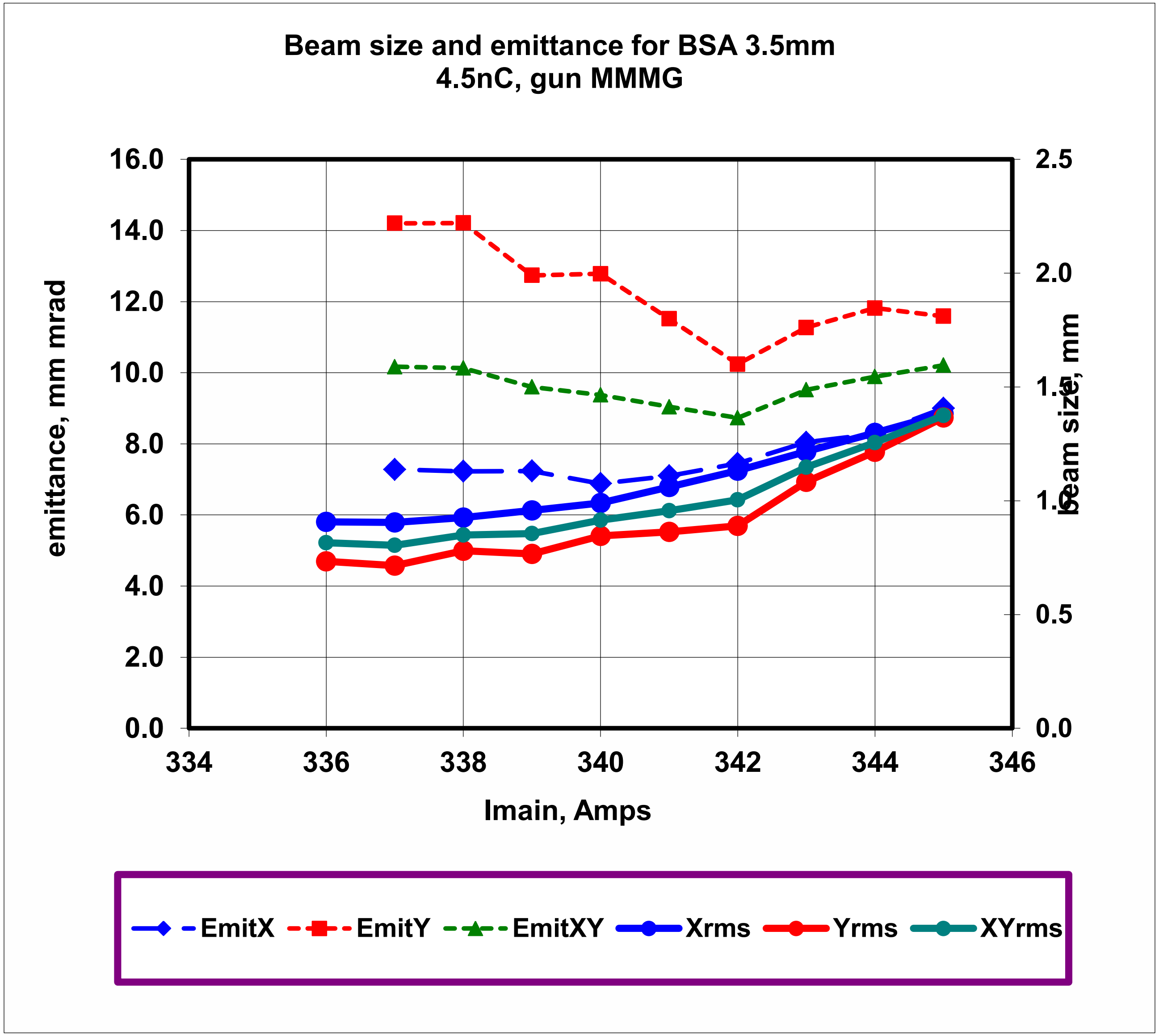


Beam loss on the pipe wall until EMSY1



Beam emittance at EMSY1

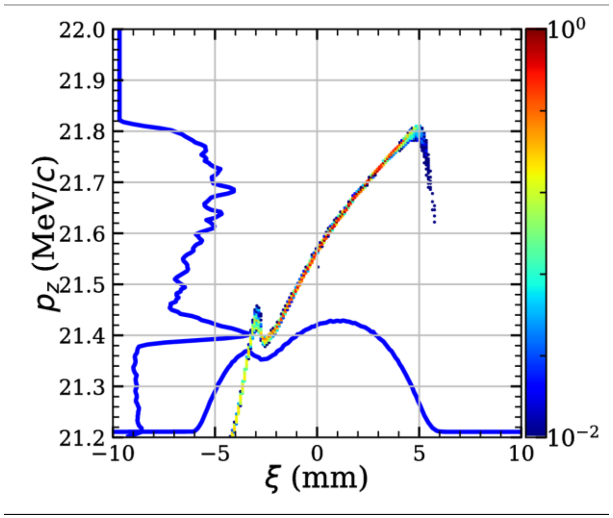
- Around the solenoid current of **335 A**, emittance reaches minimal for both, therefore this current is chosen for further simulations


Beam size and emittance for BSA 3.5mm
4.5nC, gun MMMG
emittance, mm mrad
beam size, mm
Imain, Amps
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2.5
2.0
1.5
1.0
0.5
0.0
334
336
338
340
342
344
346
EmitX
EmitY
EmitXY
Xrms
Yrms
XYrms

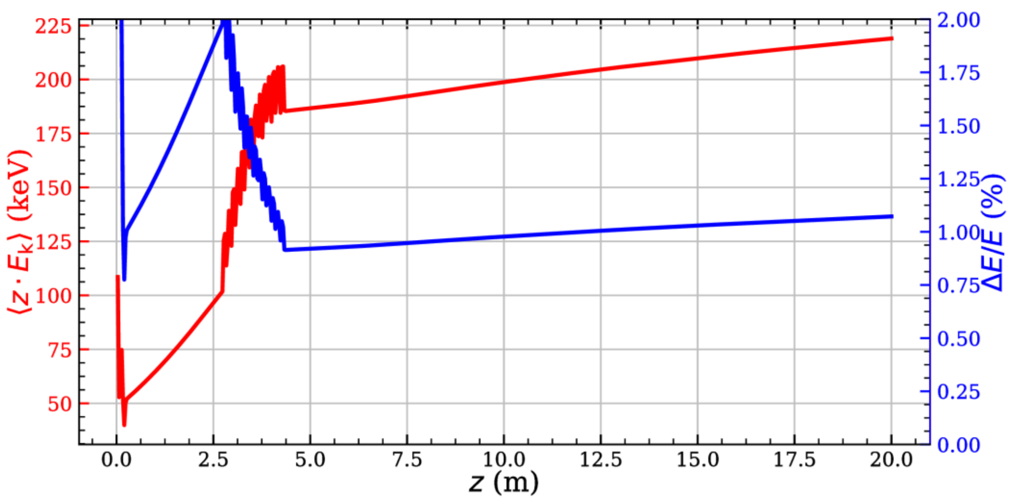
Booster phase scan

BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated

- At MMMG phase, the accelerated beam has a positive energy chirp, leading to an gradually growing energy spread in the following drift due to space charge force



Positive energy chirp at EMSY1



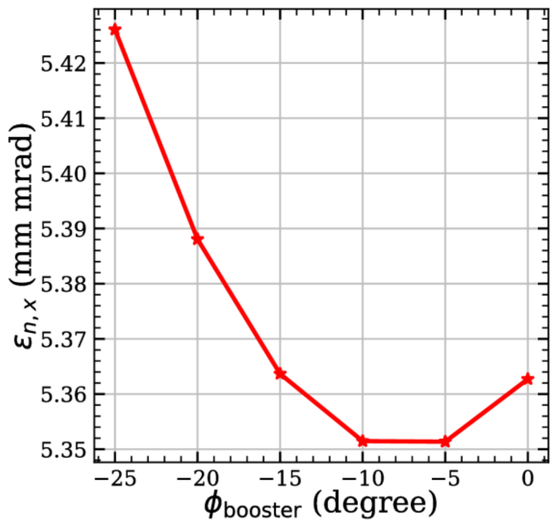
The energy spread becomes larger and larger, as well as the correlation between longitudinal position and energy

Booster phase scan

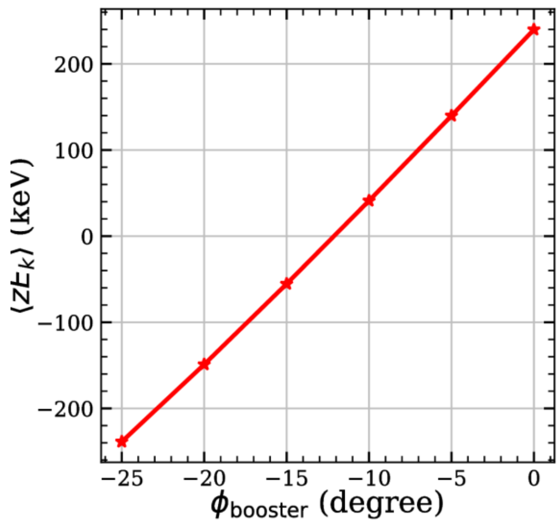
BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated

- The booster phase is then scanned to optimize the longitudinal phase space: the correlation or energy spread
  - Noticing that the correlation evolves almost linearly in the drift (simulation until 20 m), linear fit is taken to estimate the correlation at the supposed **undulator center** (here **28.8 m**, but could also be other position)

Emittance at EMSY1 vs booster phase



Estimated correlation vs booster phase

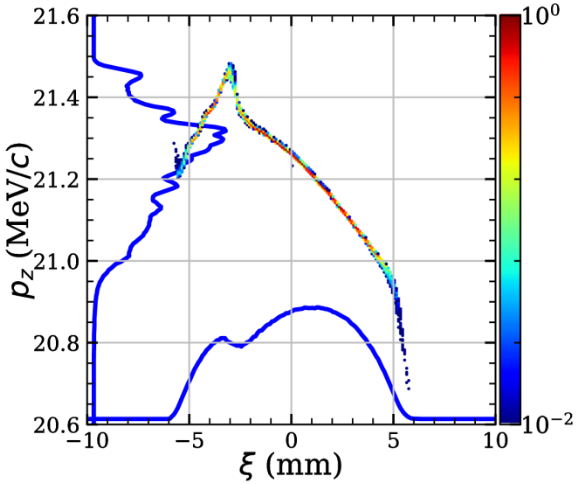


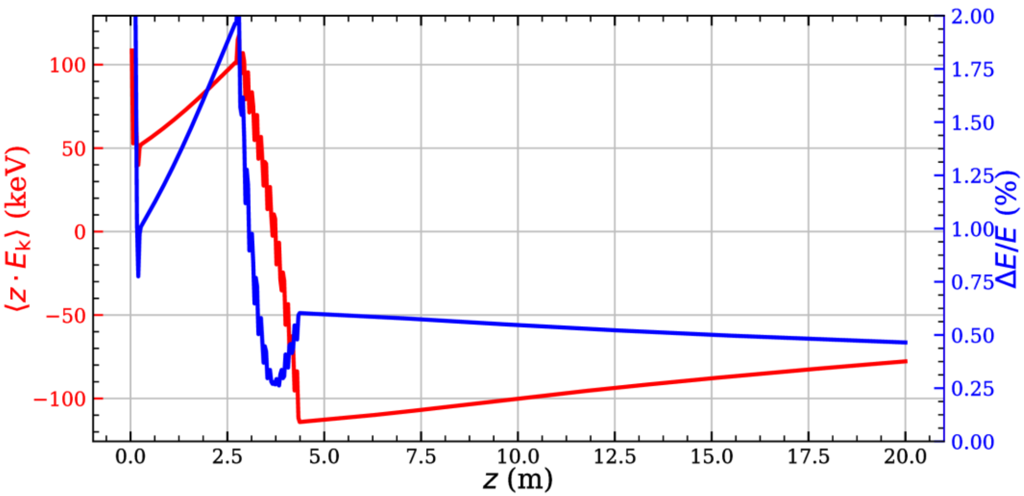
At $\boldsymbol{\phi_{\mathrm{booster}} = -15^{\circ}}$, the correlation at the supposed undulator center is close to zero

Booster phase scan

BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated

- Booster phase at $\phi_{\text{booster}} = -15°$



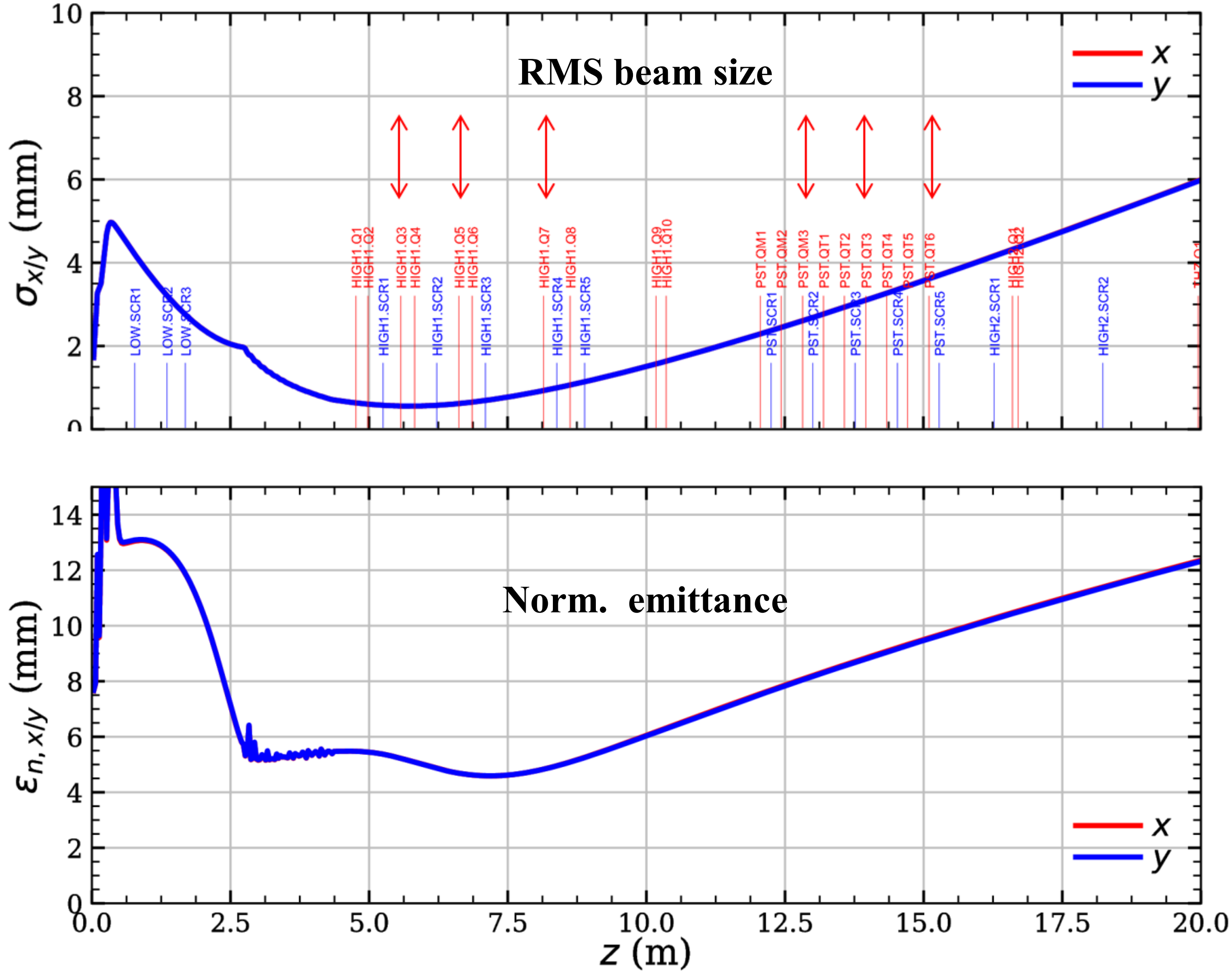


Negative energy chirp at EMSY1

The energy spread is reducing while the correlation gets closer to zero

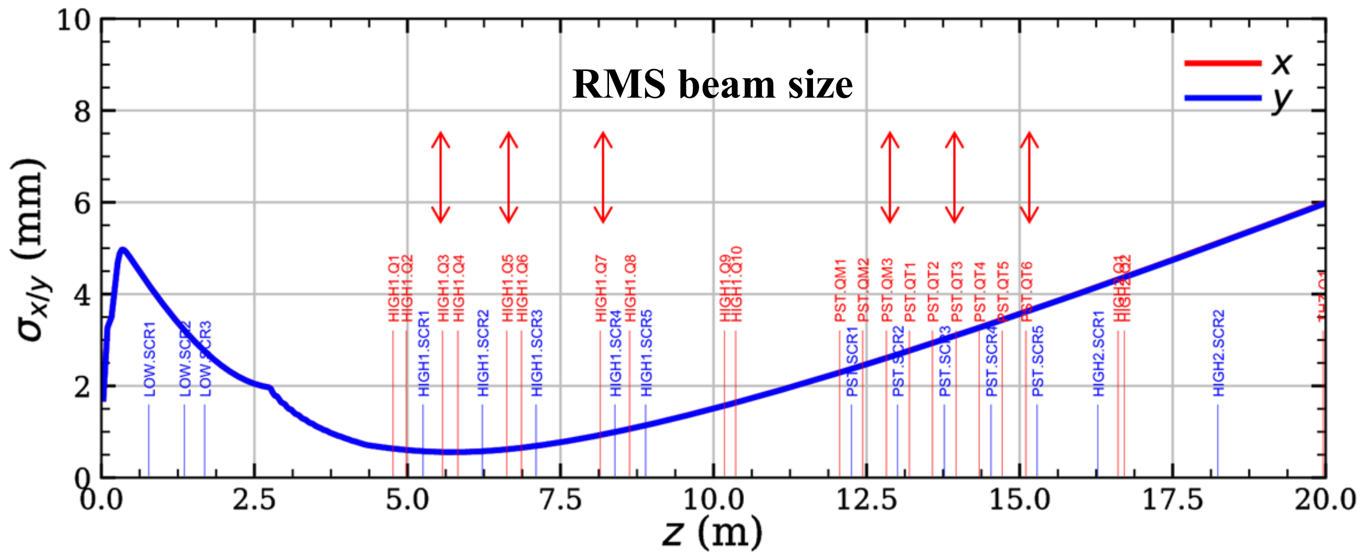
Transport until High2.Scr2

BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated



Transport until High2.Scr2

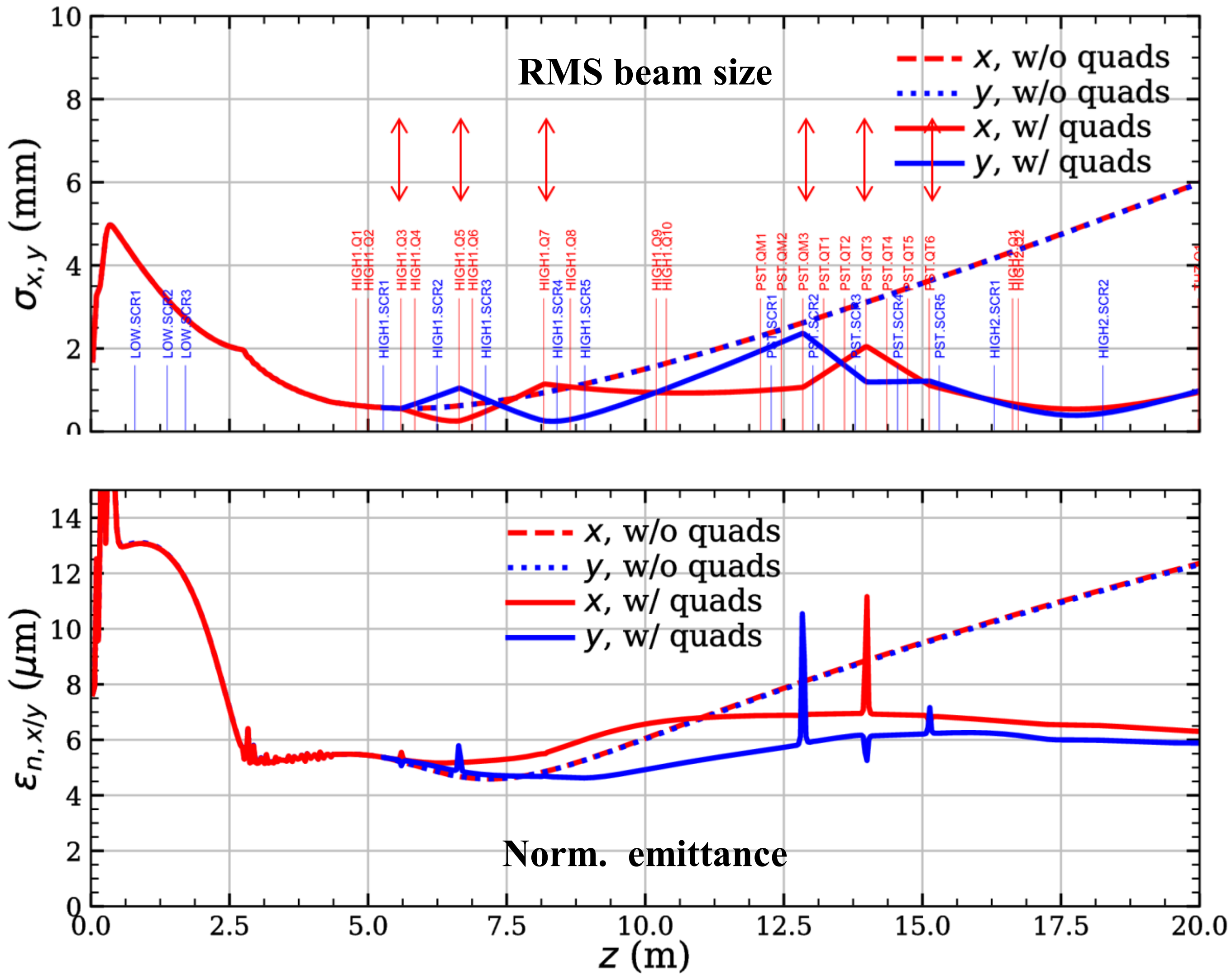
BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated



- SC Optimizer
- HIGH1.Q3/Q5/Q7 + PST.QM3/QT3/QT6
- **Object: Beam waist at High2.Scr2**

Transport until High2.Scr2

BSA 3.5 mm, 4.5 nC emitted, Gaussian truncated



Conclusion

- The transport of ~200 A peak current has been simulated based on the current experiments

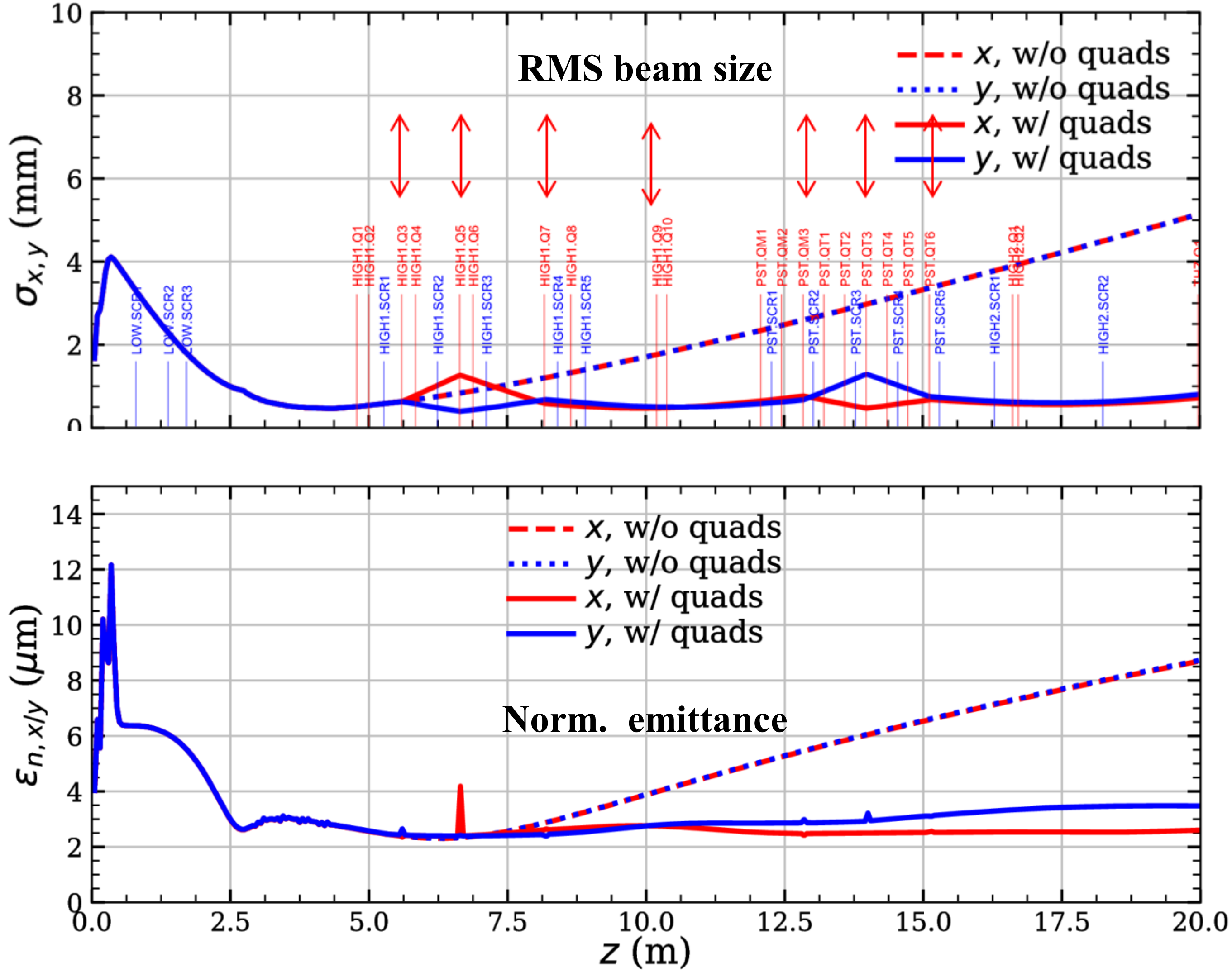
- Space charge and transverse distribution play a dominant role in achieving the peak current
- Tuning the booster phase helps to minimize the energy spread far downstream the beamline (and to reduce the bunch length)
- With quadrupoles, the beam could be focused and well transported to the end of the beamline

- After solenoid alignment and use of gun quads, simulations with the measured laser distribution and actual fields could be conducted to compare with experiments

Thank you for your attention!

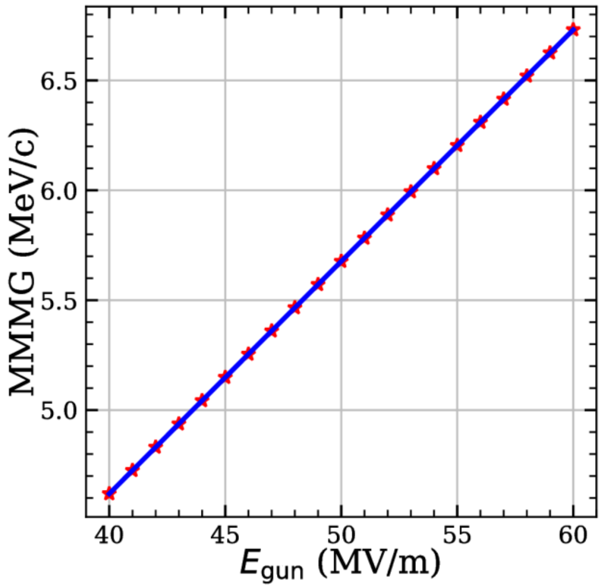
Transport of round beam

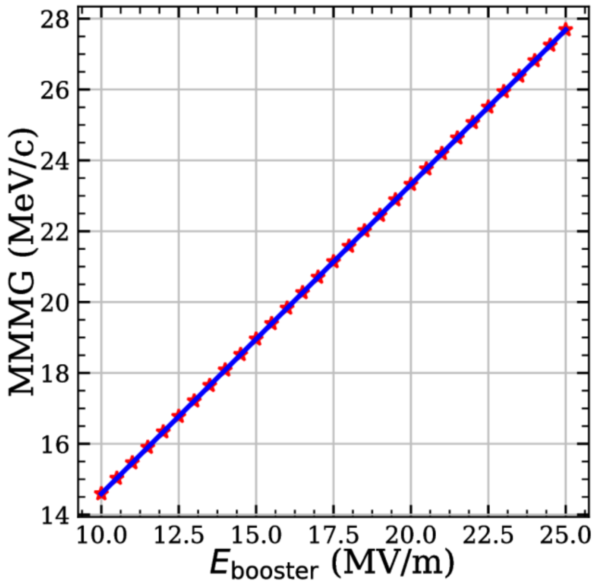
BSA 2.4 mm, 1.6 nC emitted, uniform



Gun and booster gradients scan

- At MMMG phases, the momentum gains in the gun and in the booster are scanned w. r. t. the gradients





The interpolated gun gradient at MMMG = 5.85 MeV/c is 51.64 MV/m

The interpolated booster gradient at MMMG = 21.63 MeV/c is 18.06 MV/m