Start-to-End Simulations for THz SASE FEL with Actual PITZ Beamline

Outline

- Introduction
- Beam Optimization
- Beam Transport
- Simulation of FEL Radiation
- Summary & Outlook

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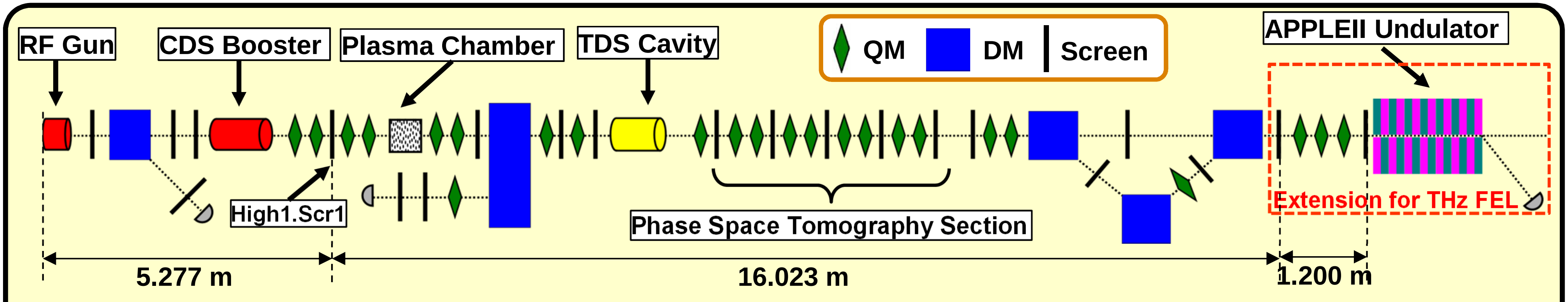
HELMHOLTZ ASSOCIATION

Introduction: IR/THz Sources Project at PITZ

- PITZ infrastructure allows to modify the current beamline for development of IR/THz sources. The aims of development are:
  - Prototype facility for the development of an IR/THz source for pump and probe experiments planned at the European XFEL.
  - Indirect electron beam diagnostics from the radiation properties.
  - Testing of radiation diagnostics devices (in collaboration with HZDR).
- Studies of radiation generation with 2 procedures are on going:
  - SASE FEL for radiation wavelengths of 20-100 µm.
  - Coherent Transition Radiation (CTR) for radiation wavelengths above 100 µm
- Conference proceedings concerning this project:
  - E. Schneidmiller et al., "Tunable IR/THz source for pump probe experiment at European XFEL", in Proc. FEL2012 Conf. (WEPD55), Nara, Japan, 2012.
  - P.Boonpornprasert et al., "Start-to-End simulations for IR/THz Undulator Radiation at PITZ", in Proc. FEL2014 Conf. (MOP055), Basel, Switzerland, 2014.



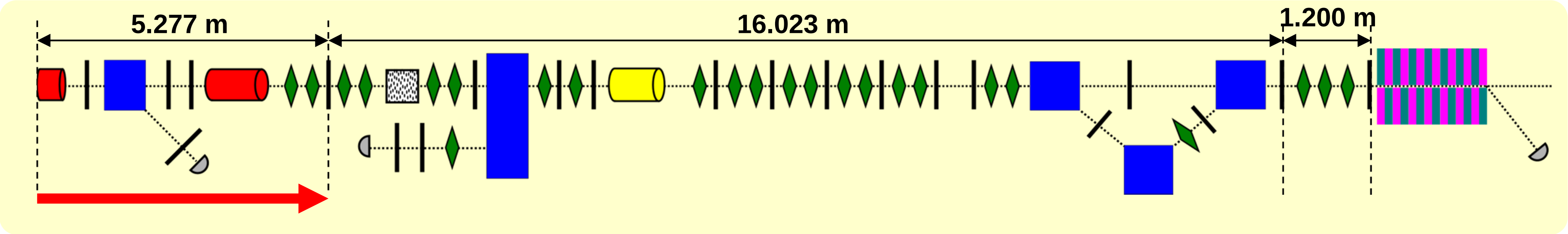
Simplified Layout of Current PITZ Beamline and Extension for THz FEL

Start-to-End Simulation of THz SASE FEL with Actual PITZ Beamline

- **Goal:** Transport the optimized electron beam with **~15 MeV/c** momentum and **4 nC** bunch charge from cathode to the undulator entrance. The beam parameters is optimized for highest FEL gain at radiation wavelength of **100 µm** from a helical undulator with period length of **40 mm**.
- **Working step:**

Beam Optimization → Beam Matching → FEL Simulation

Beam Optimization



- Tracking electron beam with 4 nC bunch charge from cathode to High1.Scr1 (Z = 5.277 m) by using the ASTRA code.

Input Parameters for ASTRA	
laser pulse shape	Flattop
laser temporal time	2 / 21.5 \ 2 ps
rms laser spot size	***scan***
gun peak field	60.5 MV/m
booster peak field	10.5 MV/m
gun phase*	0°
Booster phase*	***scan***
Main solenoid current	***scan***

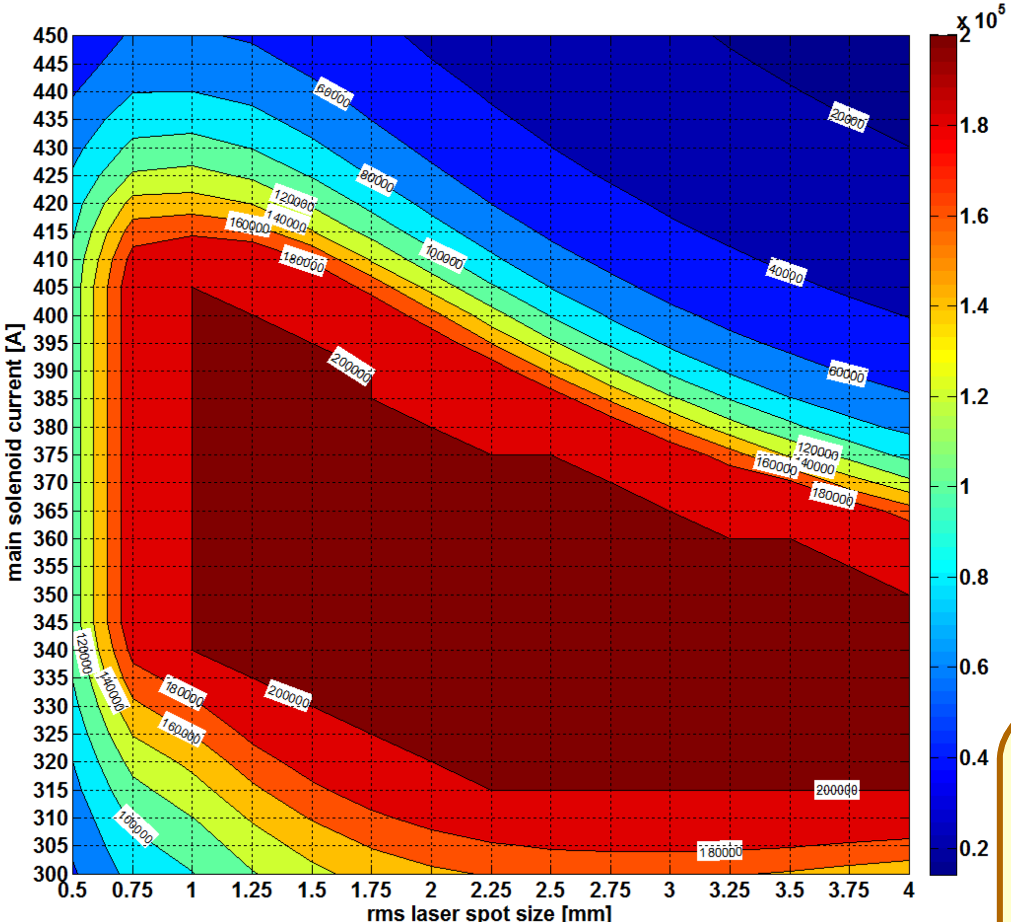
*Relative to maximum mean momentum gain phase

Step 1:
Optimize rms laser spot size for highest peak current.

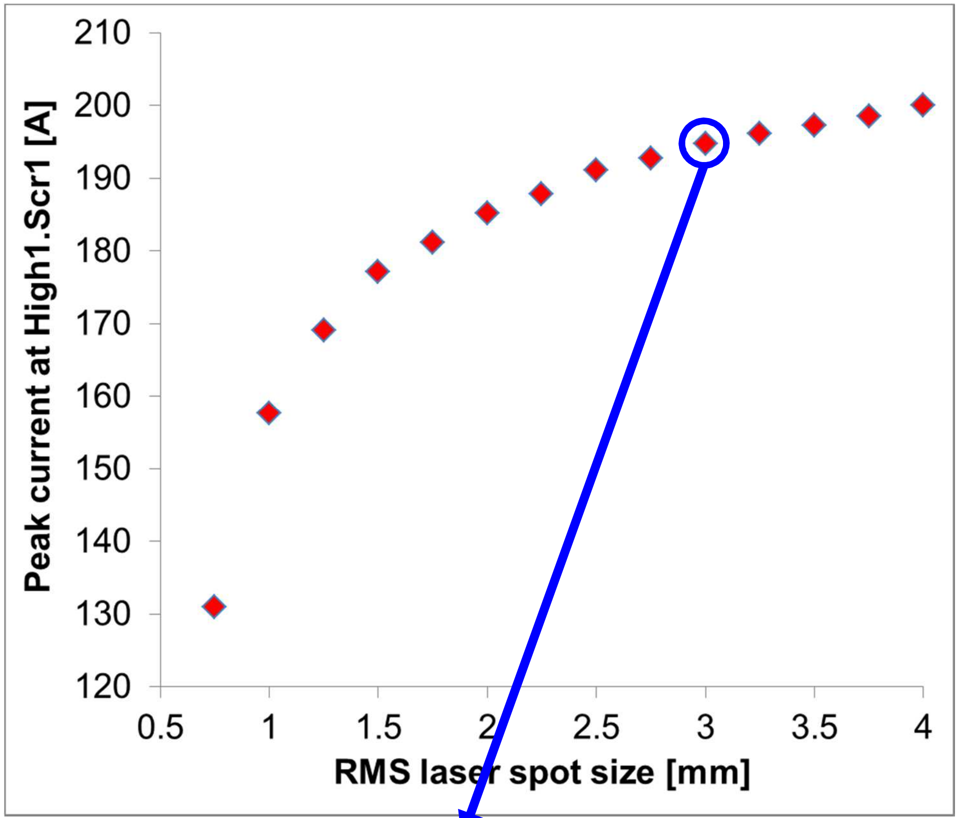
Step 2:
Optimize booster phase and main solenoid current for
- Minimum **energy spread**
- Highest **peak current**
- Minimum **transverse emittance**

Optimization of Rms Laser Spot Size

Number of macroparticles reached High1.Scr1 as a function of rms laser spot size and main solenoid current
(Gun and booster phases are fixed at 0°)

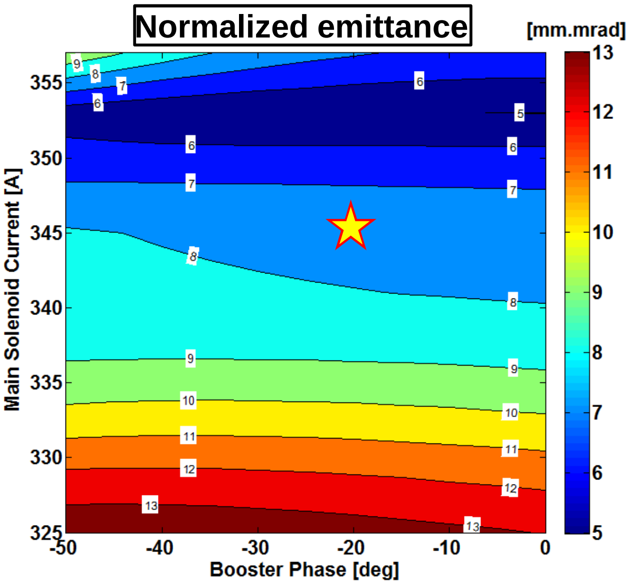


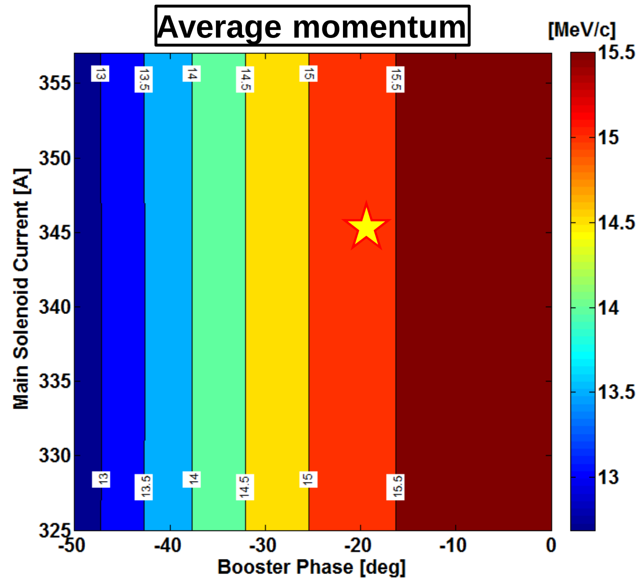
Peak current as a function of rms laser spot size at the fixed main solenoid current of 345 A

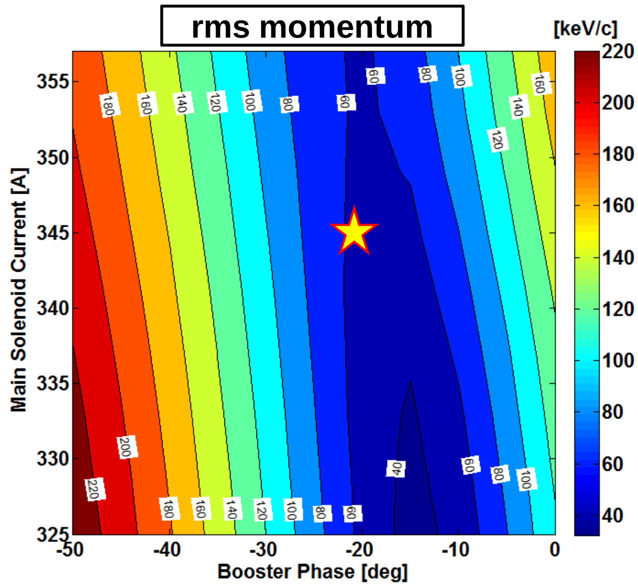


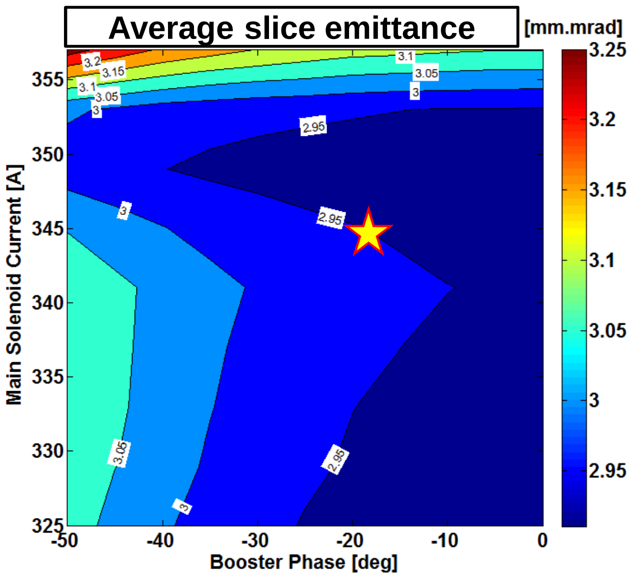
- From these conditions
  - Highest peak current
  - Limitation of cathode coating area (diameter of ~14 mm)
  - Reasonable range for optimization of main solenoid current
- **The optimized rms laser spot size is 3.0 mm**

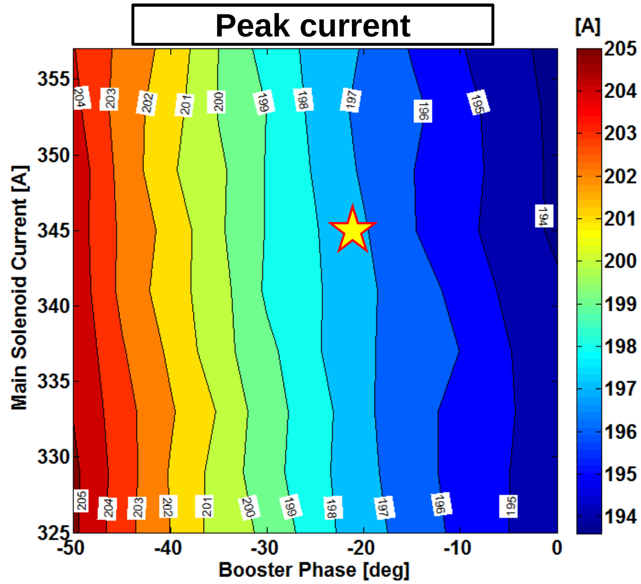
Optimization of Booster Phase and Main Solenoid Current

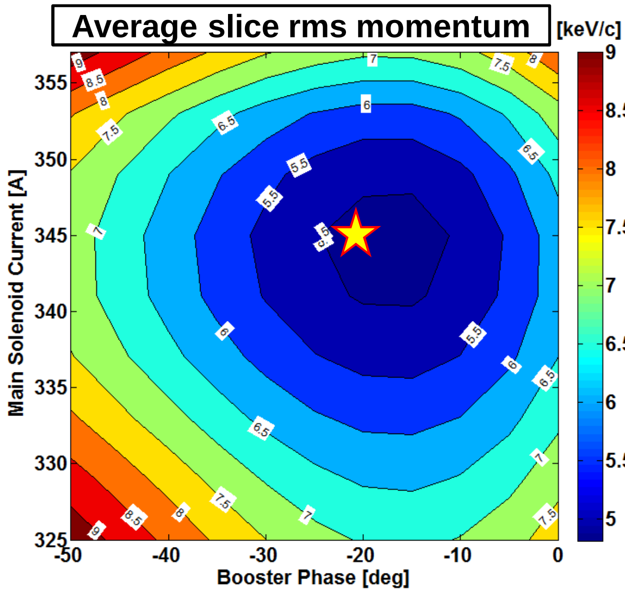






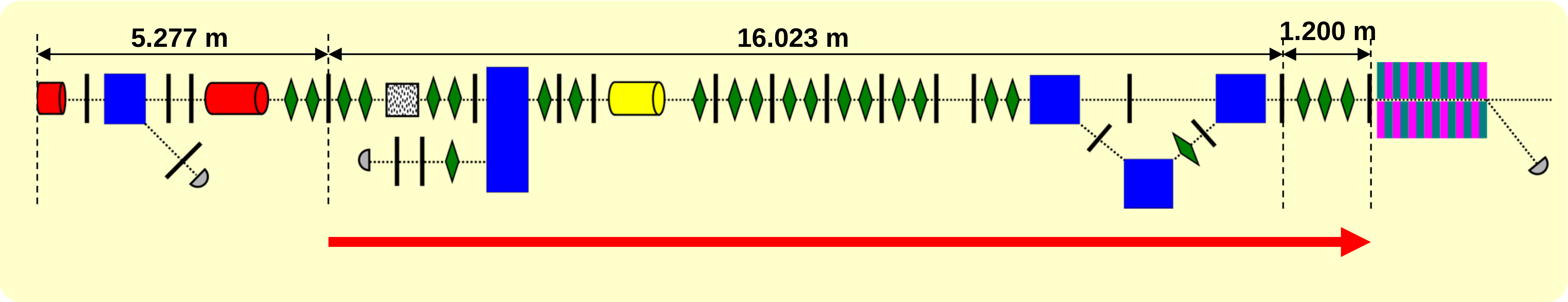






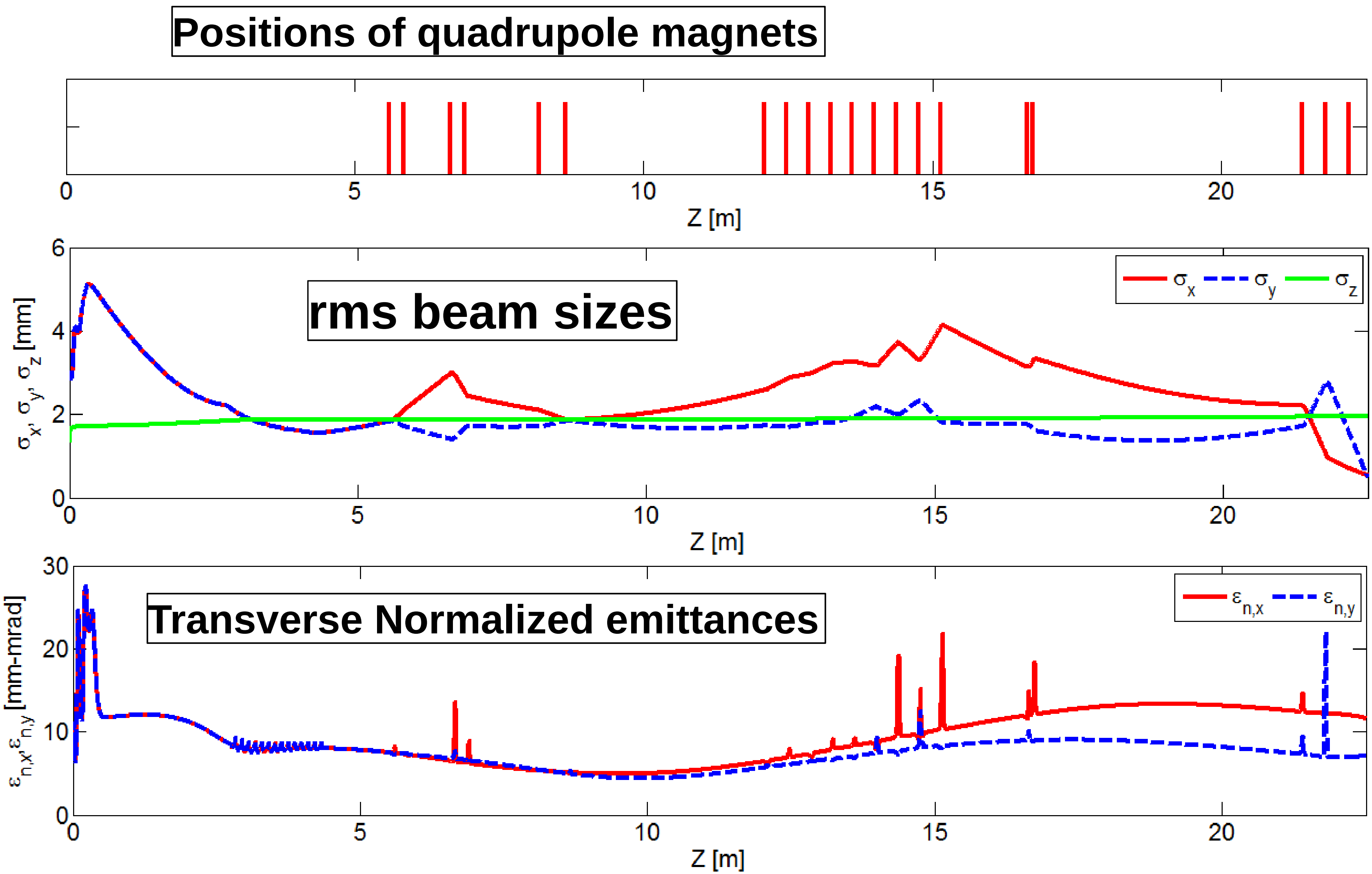
The optimized booster phase is -20°.
The optimized main solenoid current is 345 A (-0.200963 Tesla).

Beam Transport

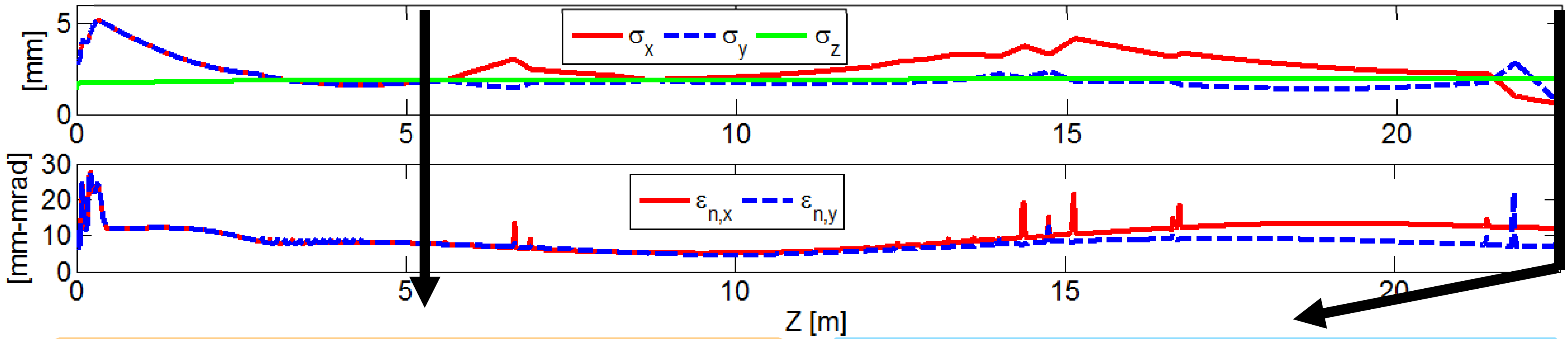


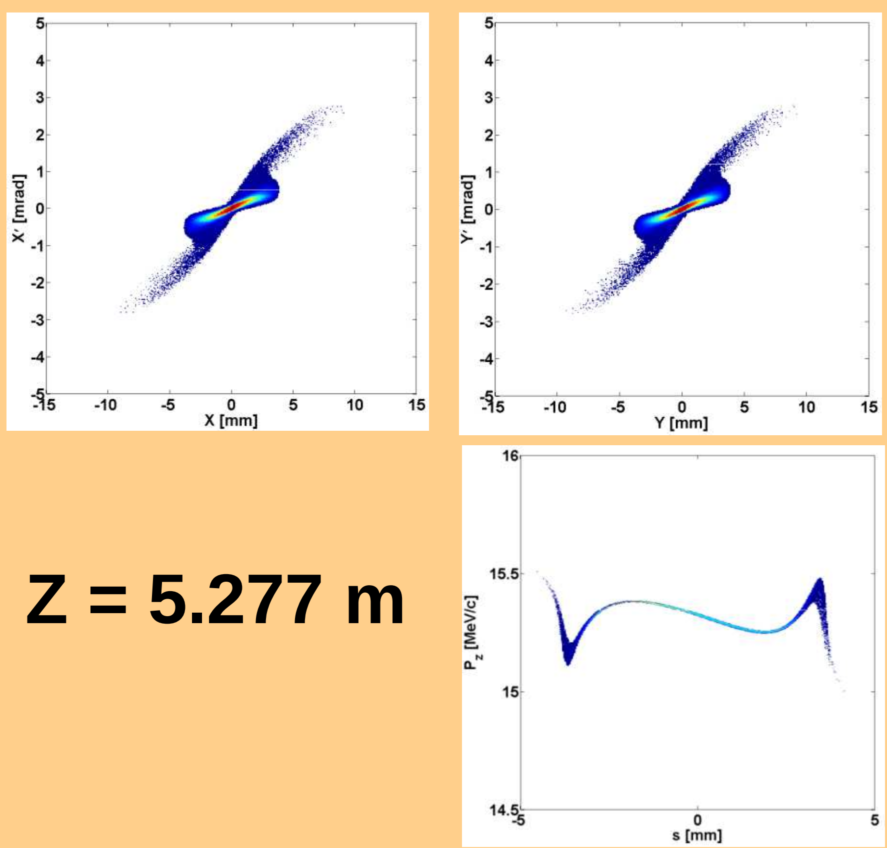
- Track the optimized beam from High1.Scr1 (Z = 5.277) to the undulator entrance (Z = 22.500) by using the ASTRA code.
- MADX is used for beam matching.
- The matching strategy is that the transverse size is slightly focused during the transport in order to have a compromise between the smallest beam size and the weakest beam divergence at the undulator entrance.

Results of Beam Transport

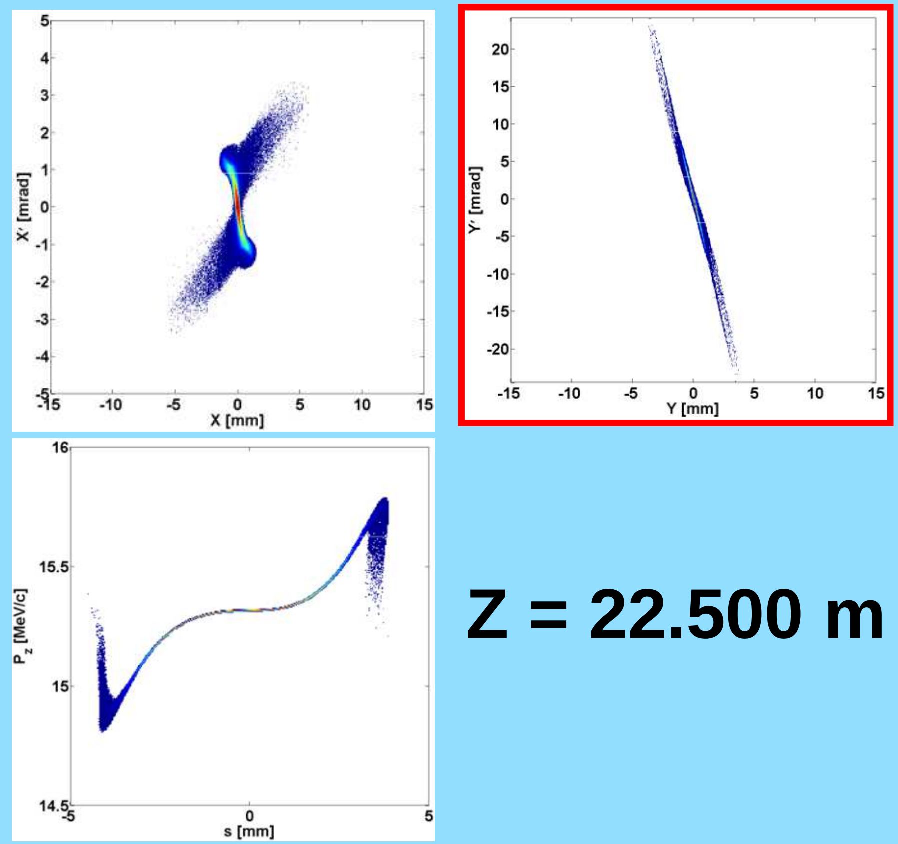


Phase Space Plots of Initial and Final Beams





Z = 5.277 m

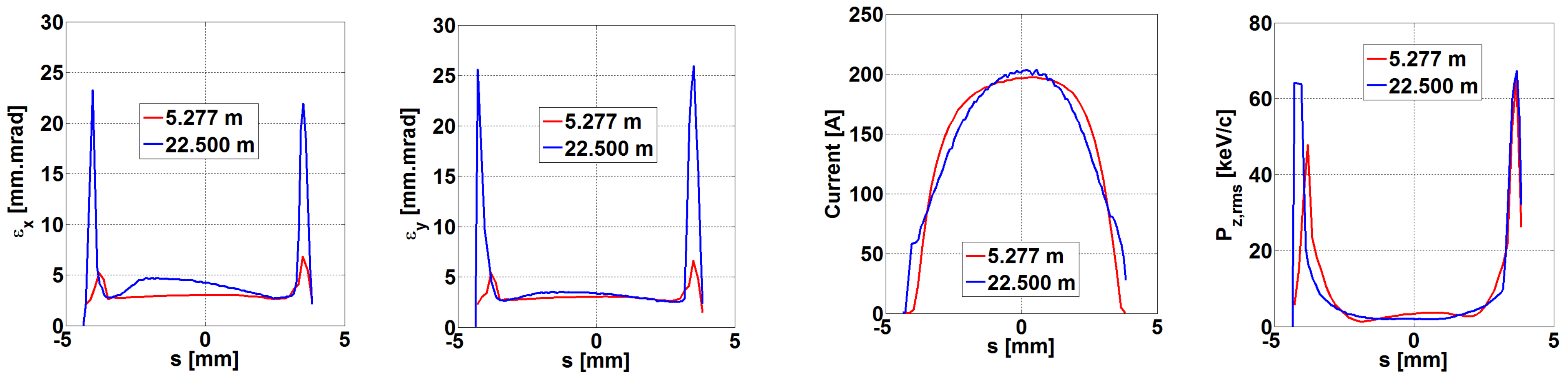


Z = 22.500 m

Comparison of Initial and Final Beam Parameters

Parameters	At High1.Scr1	At undulator entrance	Δ
σx [mm]	1.753	0.488	[redacted]
σy [mm]	1.753	0.472	[redacted]
σz [mm]	1.875	1.954	+4.21%
$\varepsilon_{n,x}$ [mm.mrad]	7.68	11.483	+49.52%
$\langle\varepsilon_{x,slice}\rangle$ [mm.mrad]	2.92	4.01	+37.33%
$\varepsilon_{n,y}$ [mm.mrad]	7.66	8.028	+4.80%
$\langle\varepsilon_{y,slice}\rangle$ [mm.mrad]	2.92	3.63	+24.32%
Peak current [A]	197.5	203	+2.78%
$P_{z,rms}$ [keV/c]	52.07	155.324	+198.30%
$\langle P_{z,rms,slice}\rangle$ [keV/c]	3.81	5.99	+57.22 %

Comparison of Initial and Final Sliced Beam Profiles

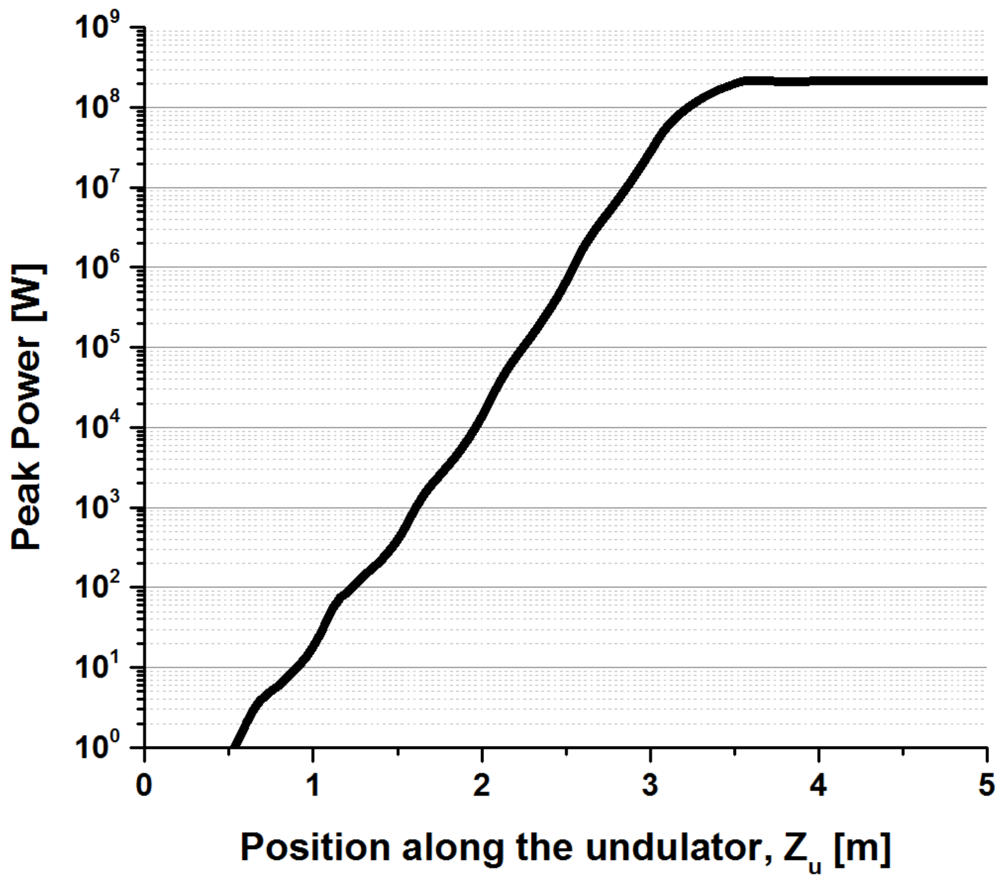


Simulation of FEL Radiation

- FEL simulations were performed by GENESIS1.3 code.
- The calculations in time-dependent mode including space-charge effects were used.
- The input for GENESIS1.3 are:
  - Helical undulator
  - Undulator period length is **40 mm**
  - Number of periods is **125** (total **5 m** long)
  - Resonant radiation wavelength of **100 µm**

Results of FEL Simulation for Radiation Wavelength of 100 µm

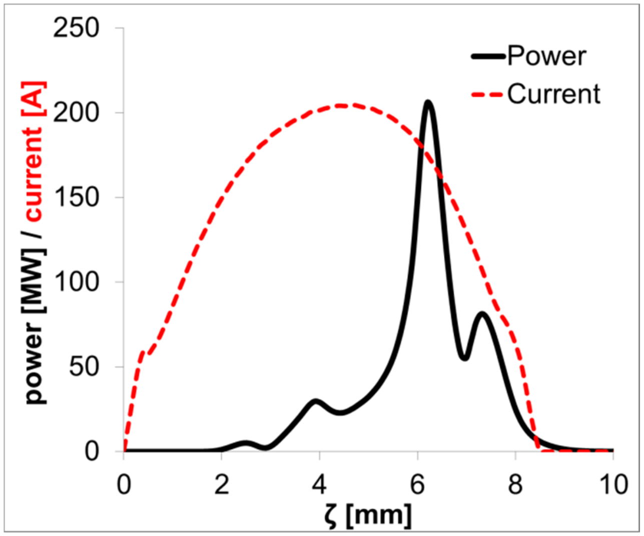
Peak Power along the Undulator axis



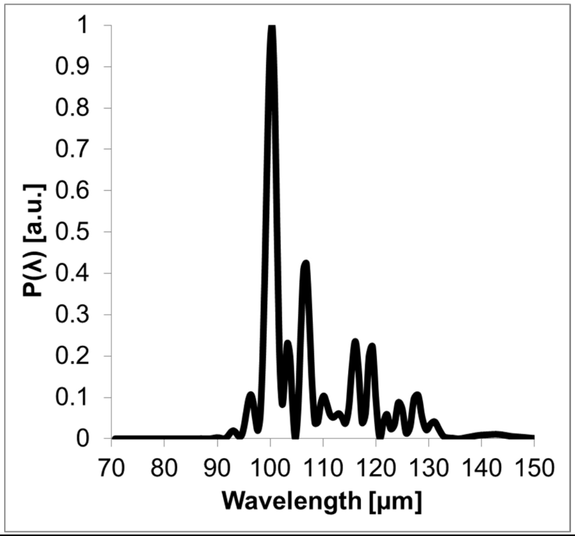
Saturation length (Z_u) is 3.52m.

Peak power at saturation is 206 MW .

Temporal Profile of Radiation Pulse at the Saturation (Z_u = 3.52 m)



Spectral Profile of Radiation Pulse at the Saturation (Z_u = 3.52 m)



Summary and Outlook

Summary

- S2E simulations of the SASE FEL were performed using the ASTRA and the GENESIS 1.3 codes.
- The results show that a radiation peak power of more than 200 MW can be achieved.

Outlook

- Improve the strategy of beam matching. Use HZB code for beam matching. Consider to add more QMs.
- Use Modified GENESIS code from Kyoto University for further simulations. The code is modified to include more options of boundary conditions of beam tube along the undulator.
- Perform start-to-end simulation with
  - Higher beam momentum (~22 MeV/c) using for radiation wavelength of 20 µm.
  - 3D-ellipsoidal cathode laser.

Backup Slides

Results from FEL2014 Conference

P.Boonpornprasert et al., “Start-to-End simulations for IR/THz Undulator Radiation at PITZ”, in Proc. FEL2014 Conf. (MOP055), Basel, Switzerland, 2012.

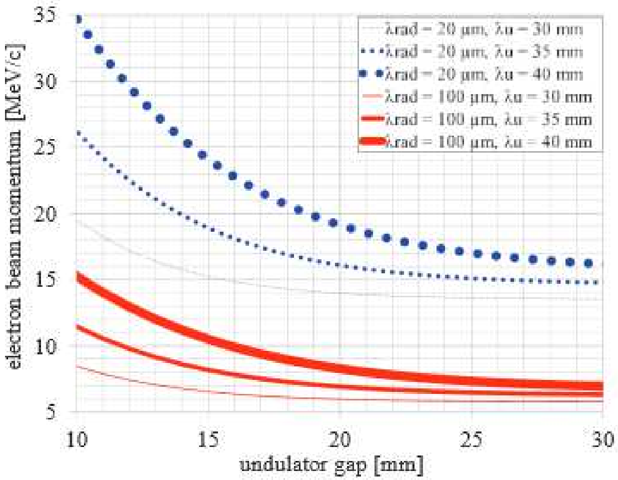


Figure 2: Electron beam momenta for radiation wavelengths of 20 µm and 100 µm as a function of the undulator gap for the different period lengths of the undulator.

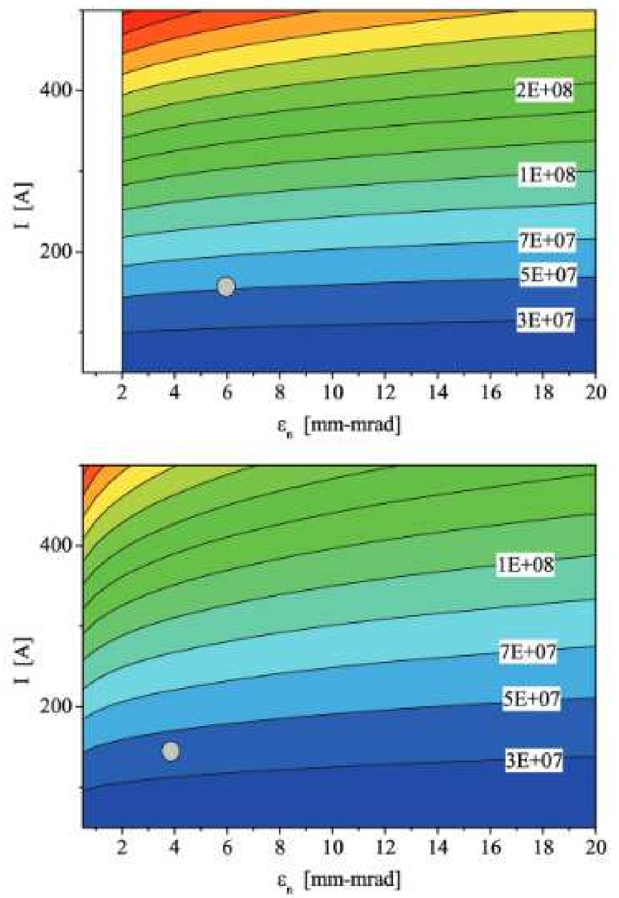


Figure 3: Contour plot for the saturation power [W] versus peak current [A] and emittance [mm-mrad]. Top and bottom plots correspond to the cases of 100 µm using a 15 MeV/c electron beam and 20 µm using a 22 MeV/c electron beam, respectively. The calculations have been performed with the code FAST.

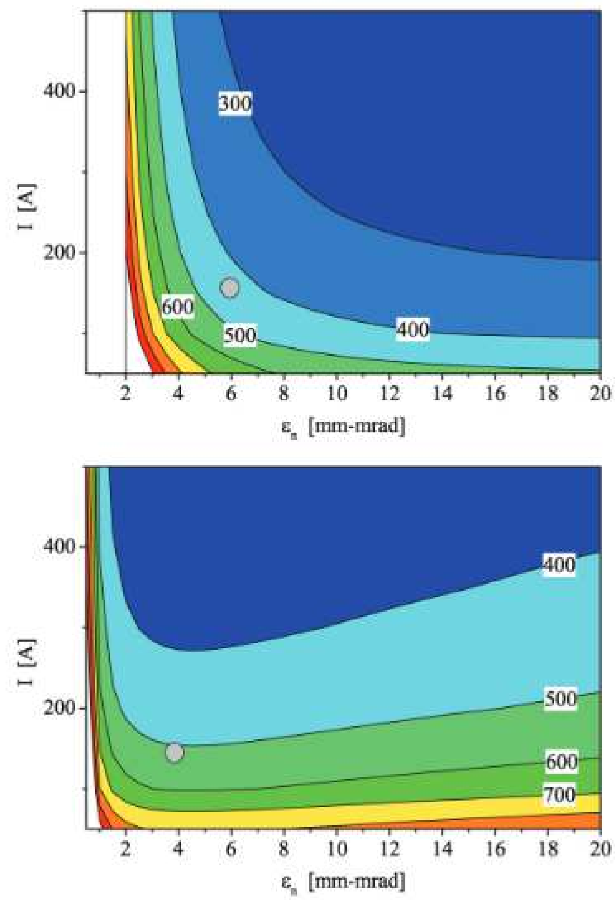
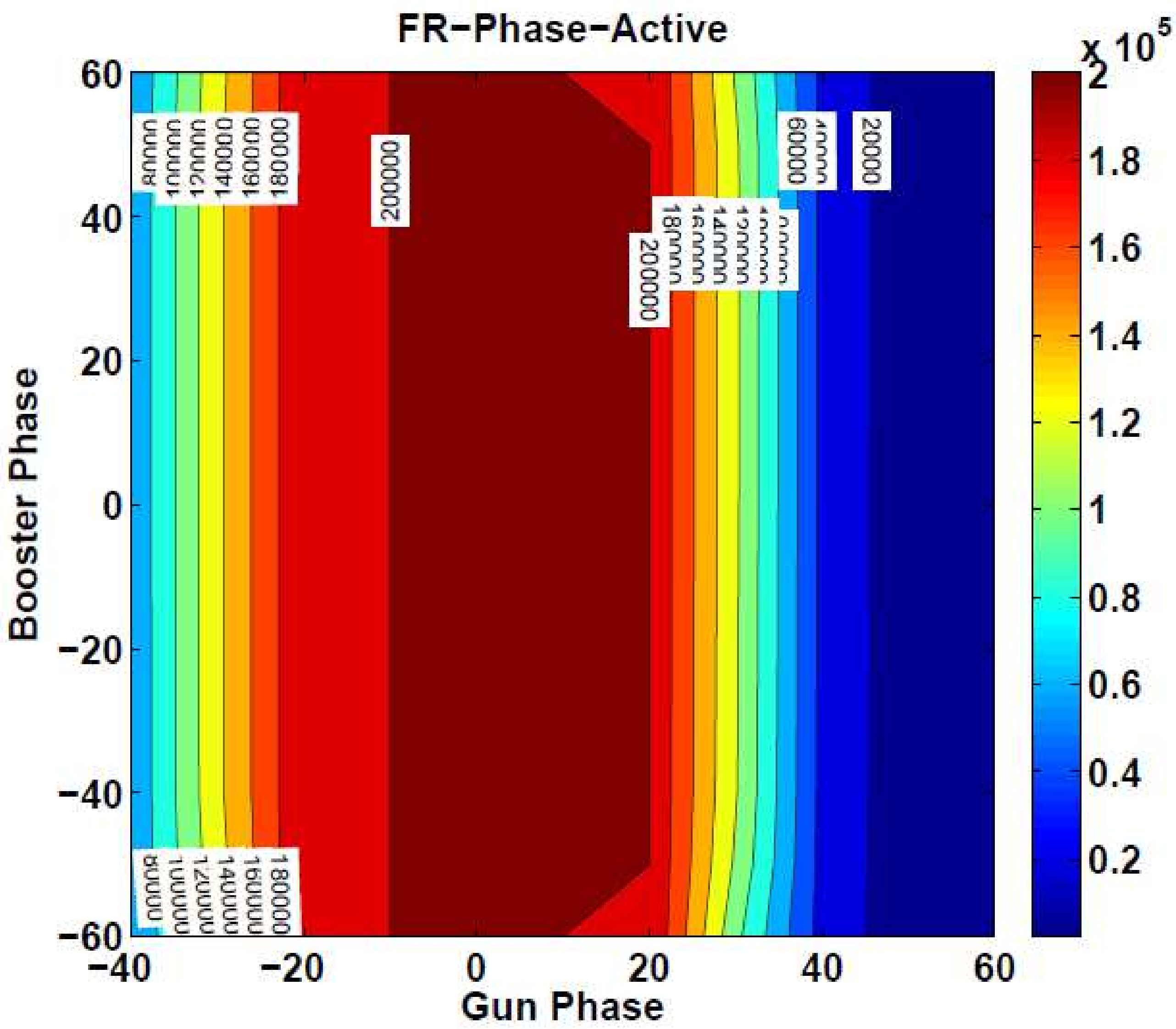


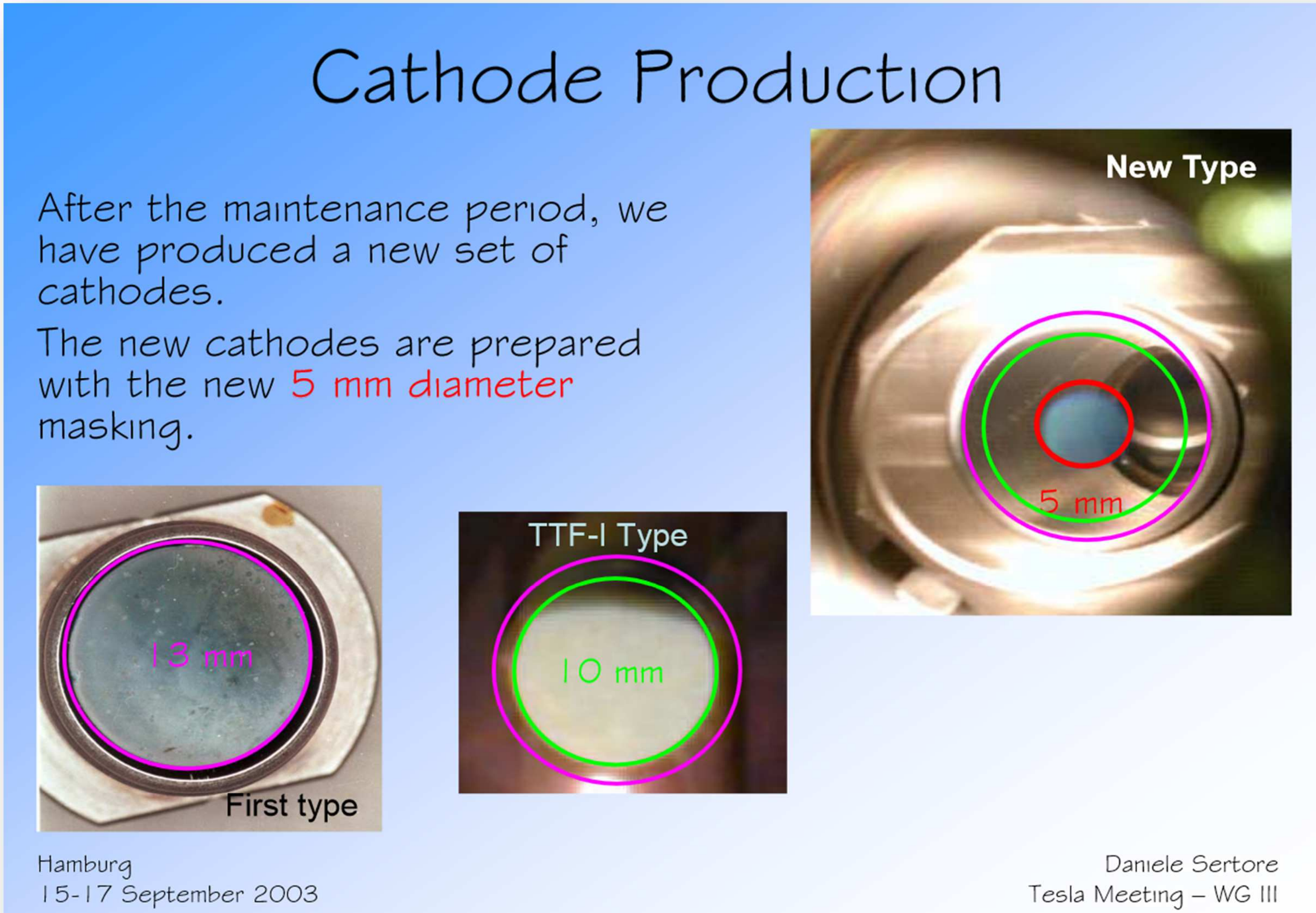
Figure 4: Contour plot for the saturation length [cm] versus peak current [A] and emittance [mm-mrad]. Top and bottom plots correspond to the cases of 100 µm using a 15 MeV/c electron beam and 20 µm using a 22 MeV/c electron beam, respectively. the calculations have been performed with the code FAST.

Active macroparticles as a function of Gun and Booster Phases

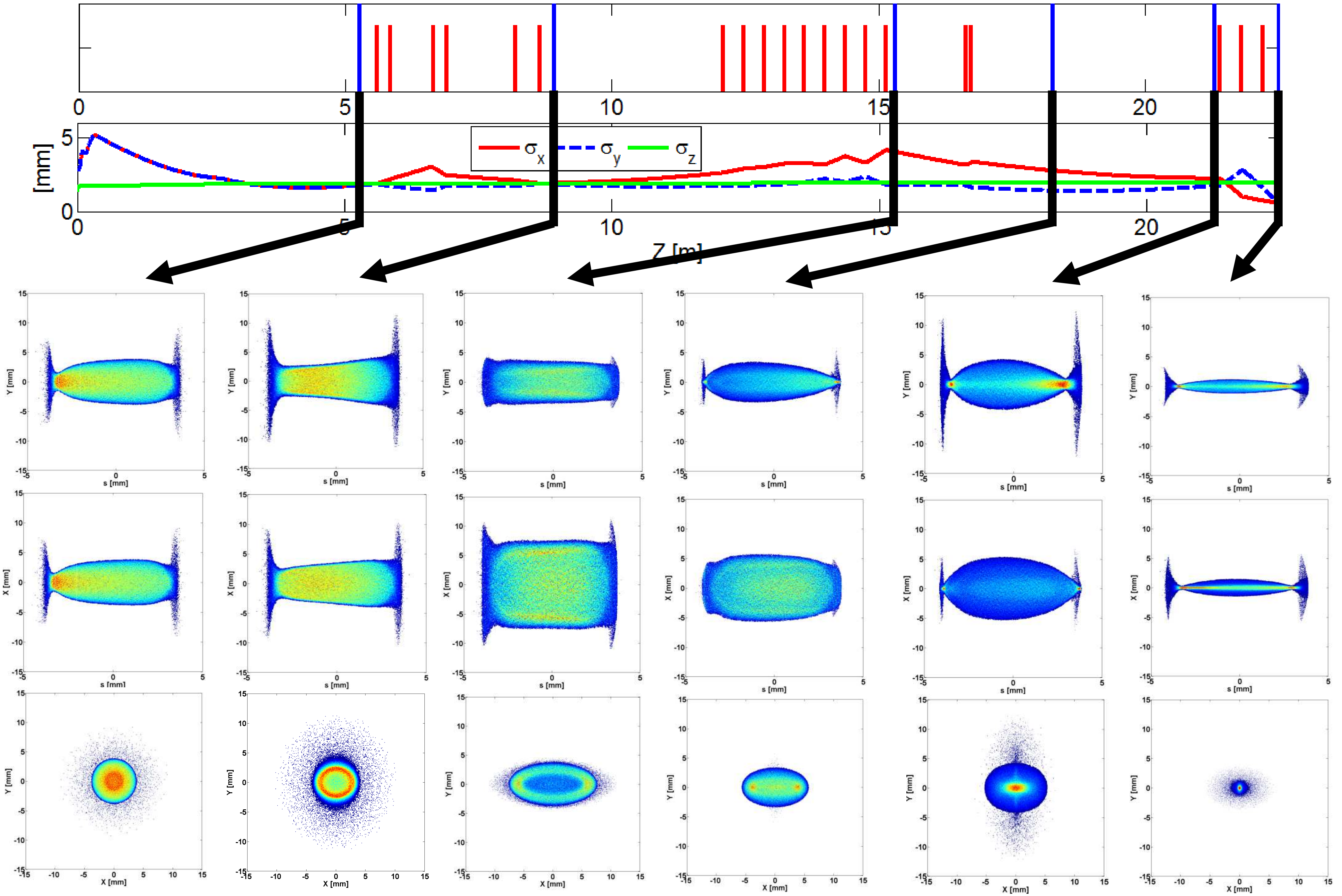


History of Cathode Production

http://tesla.desy.de/new_pages/hamburg_meeting_9_2003/pdf/wg3/sertore_TTFPhotocathodes.pdf



Evolution of Beam Projections



Evolution of Phase Spaces