Simulations and Preparation of DWA experiment at PITZ

Francois Lemery

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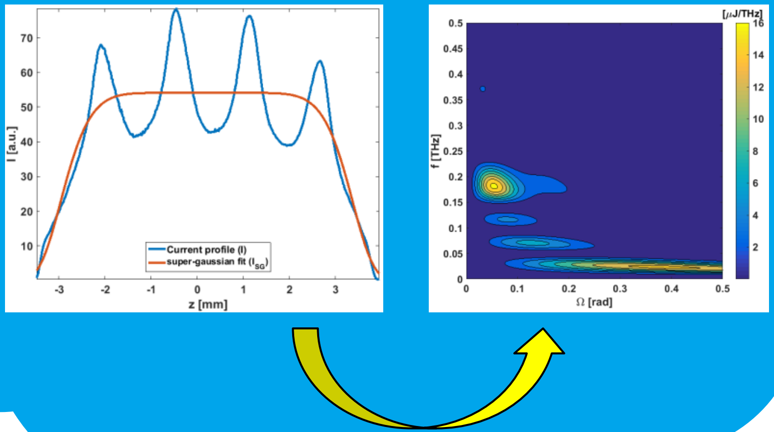
My Motivation



Prach Boonpornprasert

PITZ Physics Seminar

2.3.2017

HELMHOLTZ ASSOCIATION

DESY

Outline

- Introduction
- Technical Information
- Simulations
  - Scan I_{main} for smallest beam size at Low.Scr3
  - ASTRA simulation including wakefield
  - Test of beam transport
- Experimental Preparation at PITZ
- Initial Run Plan for week 10
- Summary and Outlook

Introduction

Reference: F. Lemery and P. Piot, Phys. Rev. ST Accel. Beams 17, 112804

- The axial longitudinal wake function mode supported by a hollow dielectric cylinder with inner and outer radii a and b, and relative electric permittivity ε_r can be written in the form

$$w_{z,m}(\zeta) = \kappa_m \cos(k_m \zeta)$$

where ζ is the position of the observer charge referenced w.r.t. the source electron, κ_m and k_m are respectively loss factor and wave vector associated to the m mode supported by the DLW structure.

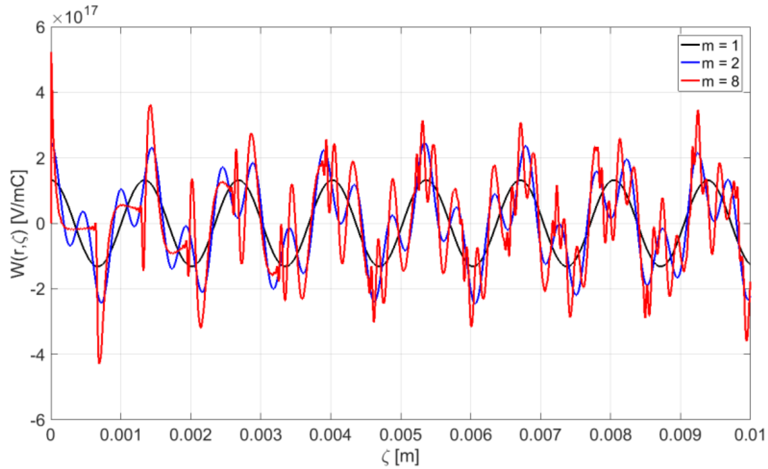
- The expected change in longitudinal momentum for a particle within and behind a bunch with line-charge current distribution $\Lambda(z)$ is obtained from the convolution integral

$$\Delta E(z) = c\Delta p_z(z) = L_{dlw} \int_{-\infty}^{z} \Lambda(z - z')w_z(z')\, dz'$$

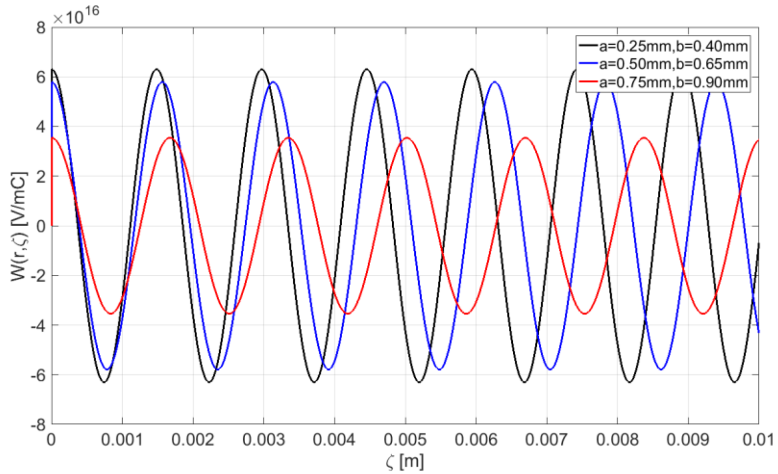
Where L_{dlw} is the length of DLW structure and z is the longitudinal coordinate within the bunch.

Introduction (2)

- Example of the wake functions calculated by using a Python script written by P. Piot



a = 0.25 mm, b = 0.40 mm
$\varepsilon_r = 5.7$



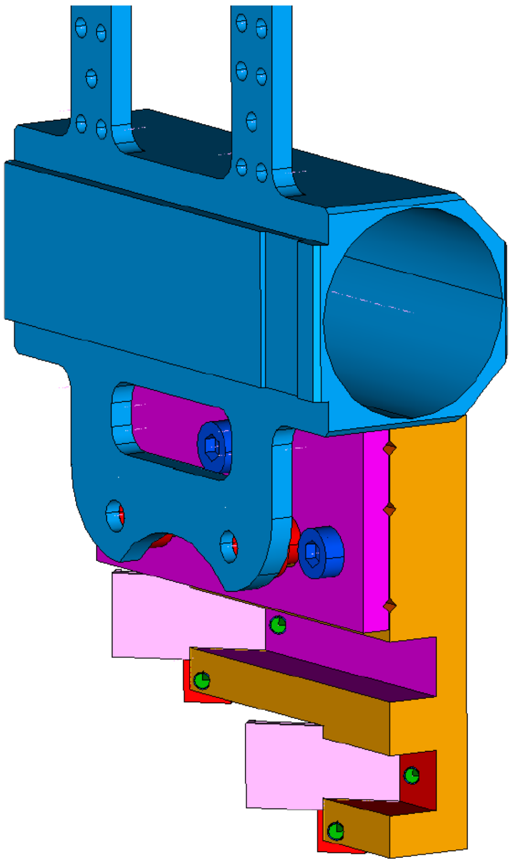
$\varepsilon_r = 5.7$

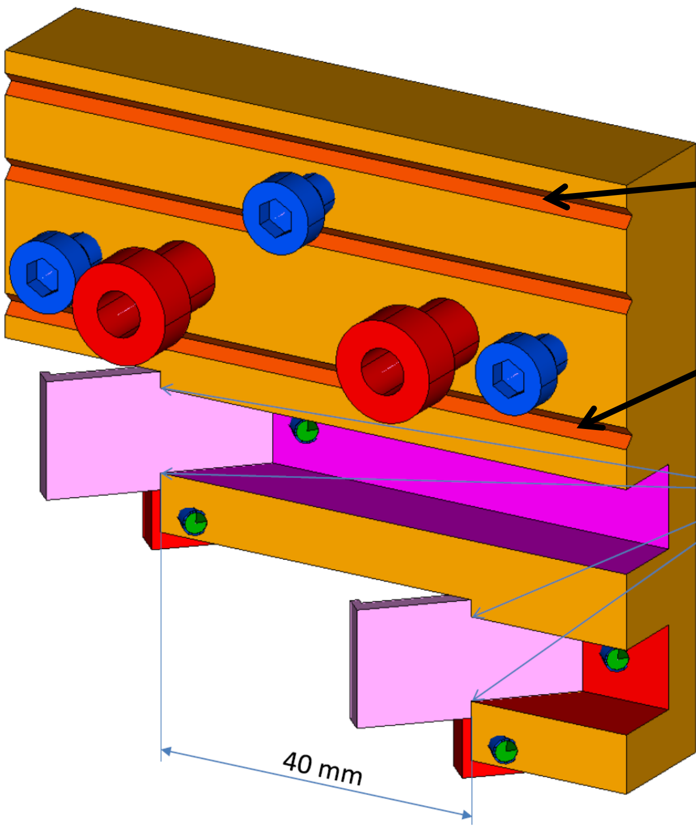
Technical Information

- Dielectric-Line Waveguide (DLW) prepared by F.Lemery and P.Piot.
  - Ordered structures from Vitrocom
    - CV1518 (2a,2b)=(1.5mm, 1.8mm), synthetic fused silica (ε_r = 4.41), 8 cm long (saw cut)
    - CV9011 (2a,2b)=(0.9mm, 1.1mm), synthetic fused silica (ε_r = 4.41), 5 cm long (saw cut)
  - CV9011 is coated (metallic?), CV1518 is uncoated.
- Support/holder (aluminum) machined at DESY Zeuthen ?
  - Design for setup with Low.Scr3 station
  - Holder for 3 structures and 2 YAG-screens
  - 2 YAG-screens use to optimize beam transport through the structure.

Technical Information (2)

S.Philipp, J.Engel

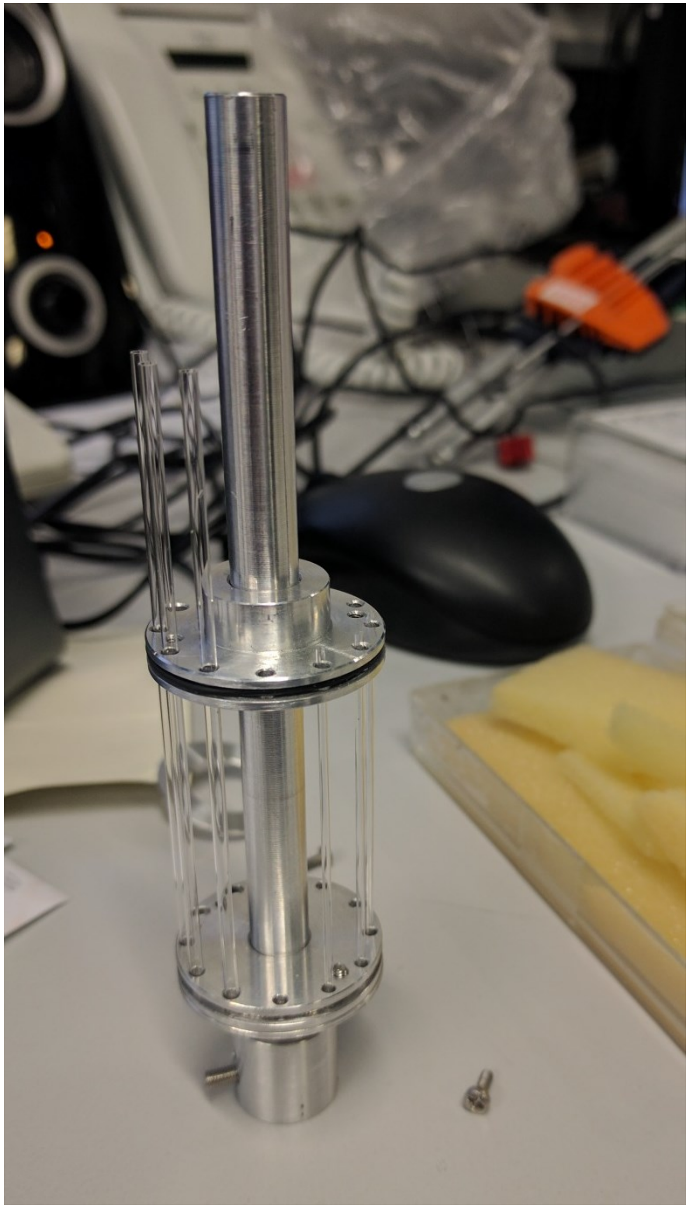


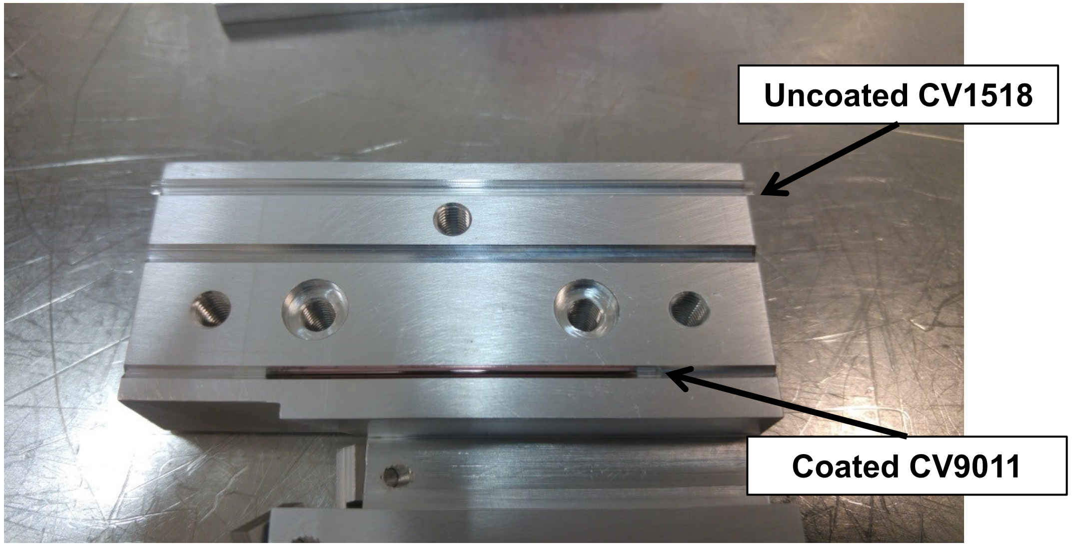


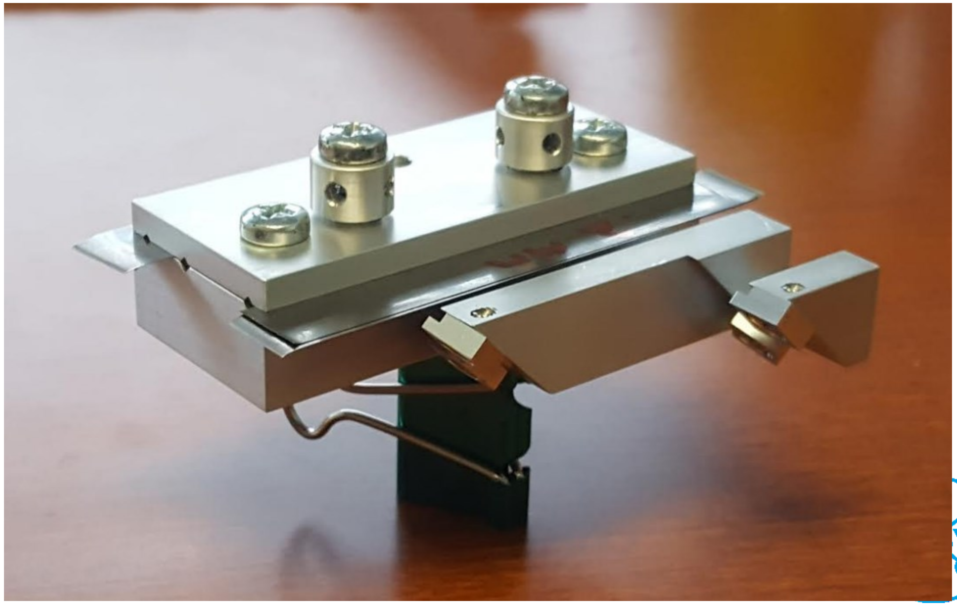
Holder for three structures an two YAG-screens

Technical Information (3)

S.Philipp, J.Engel



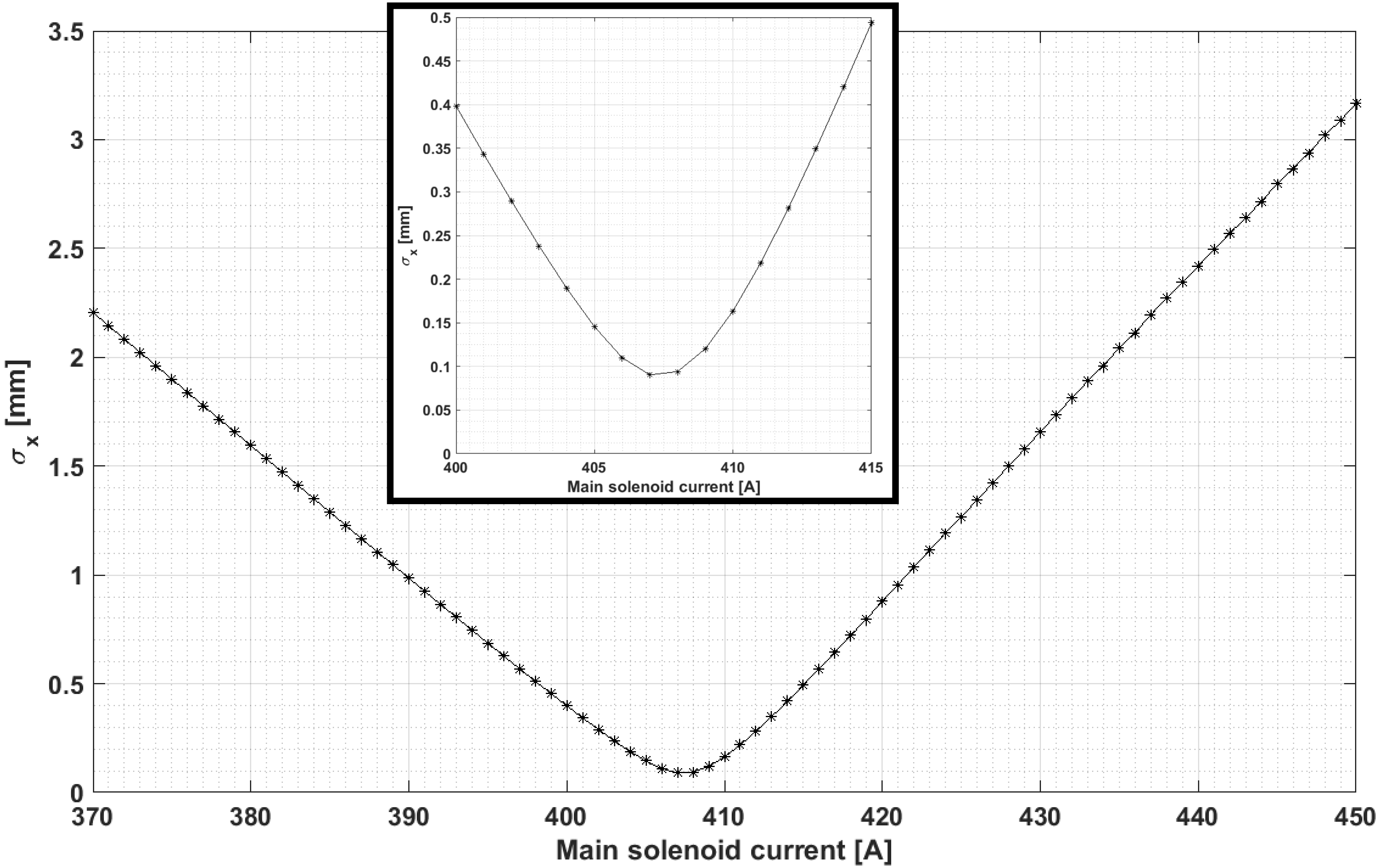




ASTRA simulations

- ASTRA simulations were done with
  - 21.5 ps FWHM flat-top laser profile.
  - Bunch charge of 1.1 nC
  - E_{gun} = 60.5 MV/m, MMMG phase
  - Aperture around Low.Scr3 was set accordingly to the size of DLW CV9011.
- The simulations were done for 2 sets
  - Cathode (z = 0 m) to Low.Scr3 (z = 1.703 m)
    - 2D cylindrical algorithm for space charge calculation
    - Optimize I_{main} for the smallest beam size at Low.Scr3
  - Cathode (z = 0 m) to PST.Scr2 (z = 13.038 m)
    - 2D cylindrical algorithm for space charge calculation
    - Wake function from DLW CV9011was applied.
    - No aperture downstream from the booster
    - No QMs used downstream from the booster
    - $E_{booster}$ = 17.2 MV/m, scan booster phase

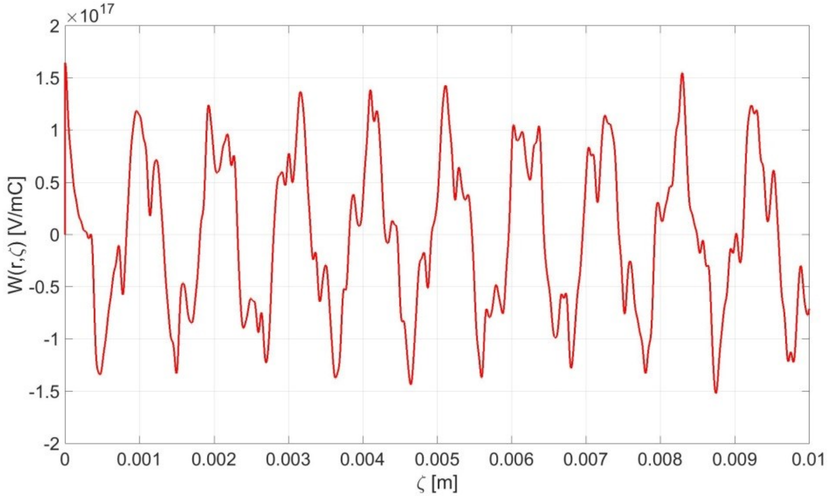
ASTRA: I_{main} for Smallest Beam Size at Low.Scr3



ASTRA simulations including wakefield

Wake function profile of DLW as the ASTRA input

- DLW CV9011 parameters was used for the calculation by using the Python code written by P.Piot.
- Input parameters used in the Python code:
  - ❑ Inner radius; a = 0.45e-3 m
  - ❑ Outer radius; b = 0.55e-3 m
  - ❑ m = 6
  - ❑ epsilon = 4.41
- Output ➔



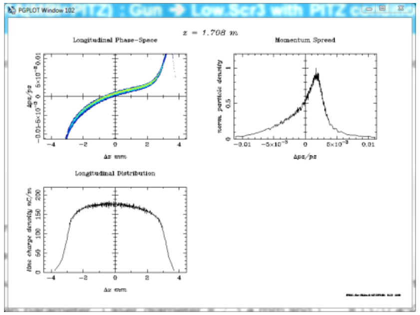
ASTRA simulations including wakefield (2)

Input parameters of the Namelist WAKE

```
&WAKE
LWAKE=TRUE
Wk_Type(1)='Monopole_Method_F'
Wk_filename(1)='../AstraPortal/wake_tmp_CV9011_m6.dat'
Wk_testfile(1)='DLW-BSAAp-2-0.in.wf'
Wk_screen(1)=TRUE
Wk_scaling(1)=0.08
Wk_x(1)=0.000
Wk_y(1)=0.000
Wk_z(1)=1.708
Wk_ex(1)=0.000
Wk_ey(1)=0.000
Wk_ez(1)=1.000
Wk_hx(1)=1.000
Wk_hy(1)=0.000
Wk_hz(1)=0.000
Wk_equi_grid(1)=1
Wk_N_bin(1)=51
Wk_ip_method(1)=2
Wk_smooth(1)=0.500
Wk_sigma_min(1)=0.000
Wk_sub(1)=1
/
```

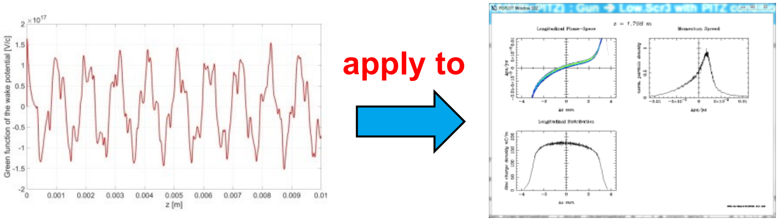
Step of Including Wakefield Effect In ASTRA

1. The e-beam reaches Wk_z(1).

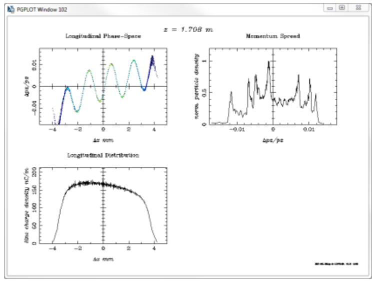


Z = 1.708 m

2. Wk_filename(1) is applied to the e-beam in 1 induces energy modulation.

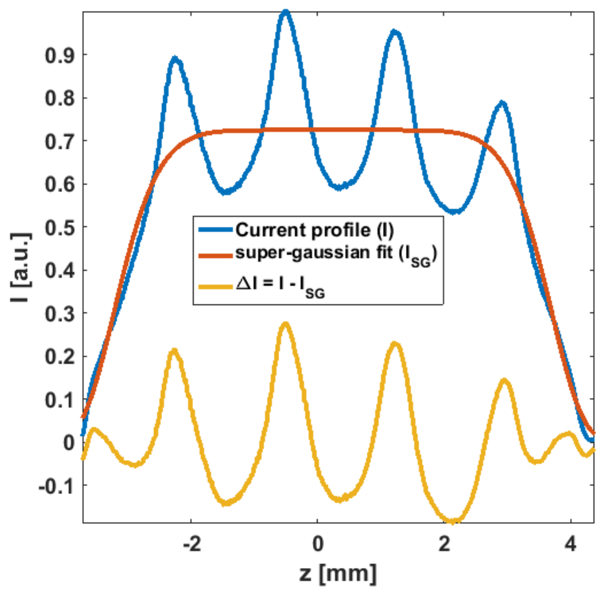


3. The modulated e-beam replaces the e-beam in 1.



Z = 1.708 m

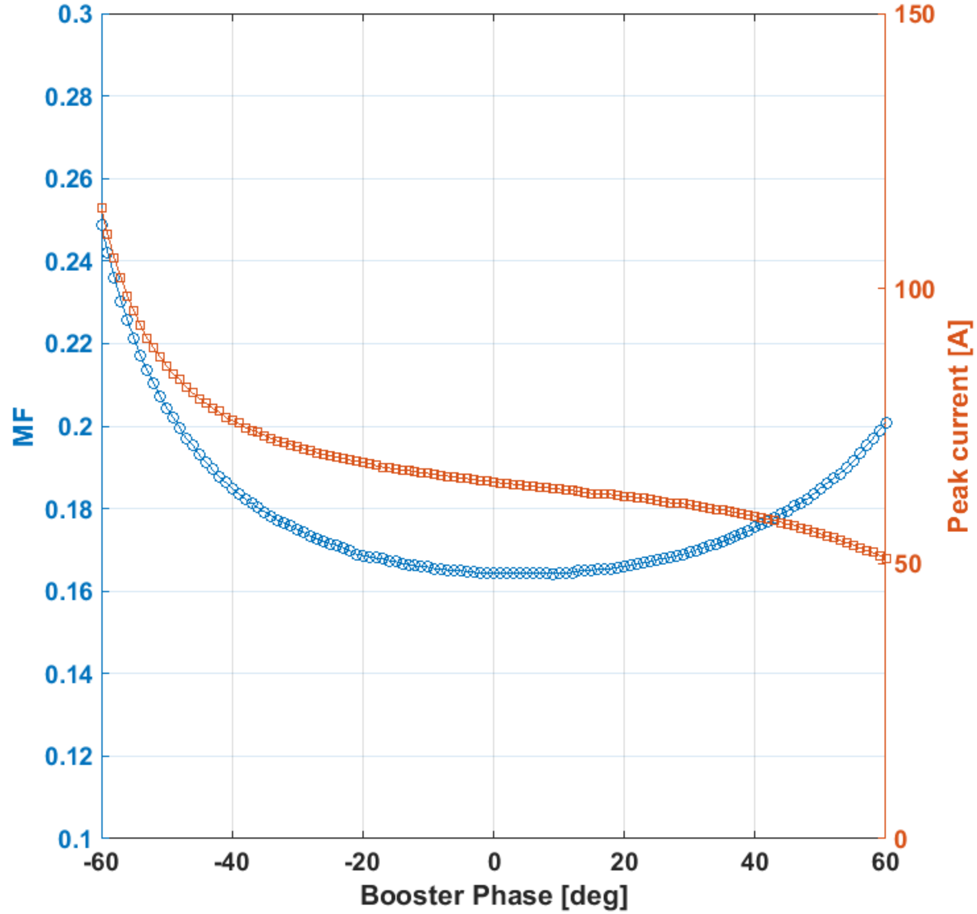
ASTRA Wakefield: Evaluation of Density Modulation



Modulation Factor (MF)

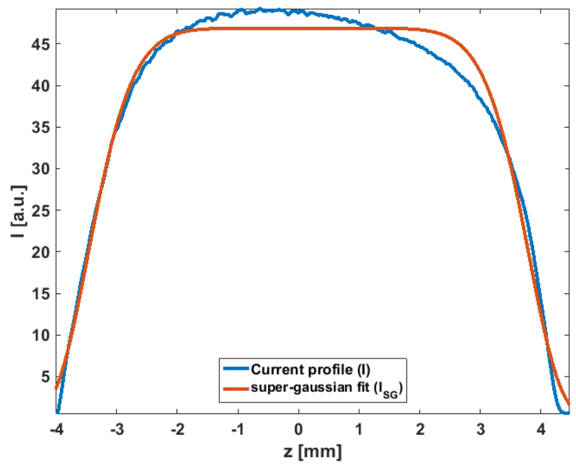
$$MF = \frac{\int |\Delta I| dz}{\int I_{SG} dz}$$

Modulation factor (MF) and peak current as a function of booster phase

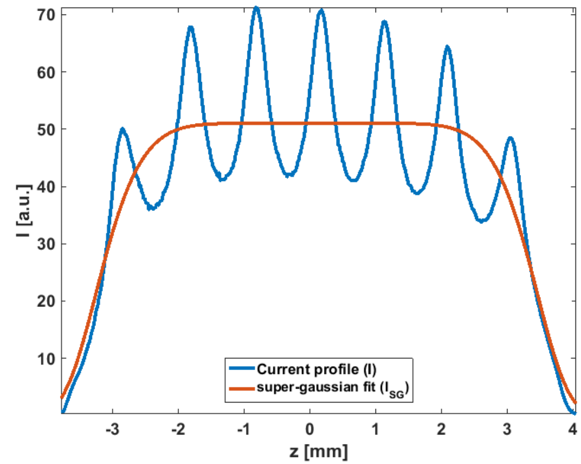


ASTRA Wakefield: Bunch Profiles at various booster phases (w.r.t.MMMG)

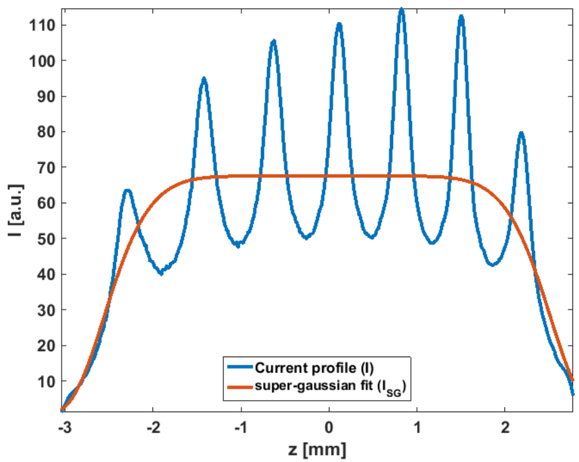
Φ = 0 (no wakefield)



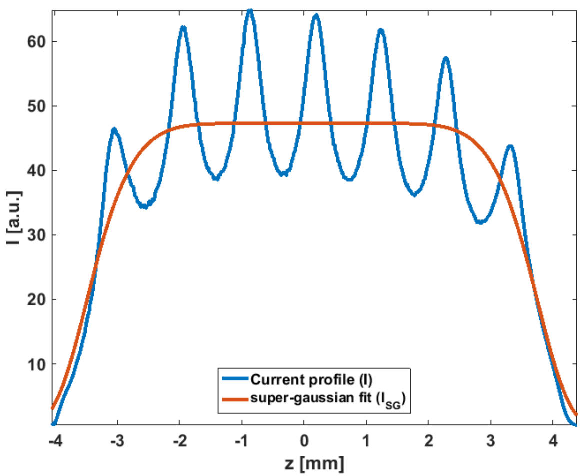
Φ = -30 deg



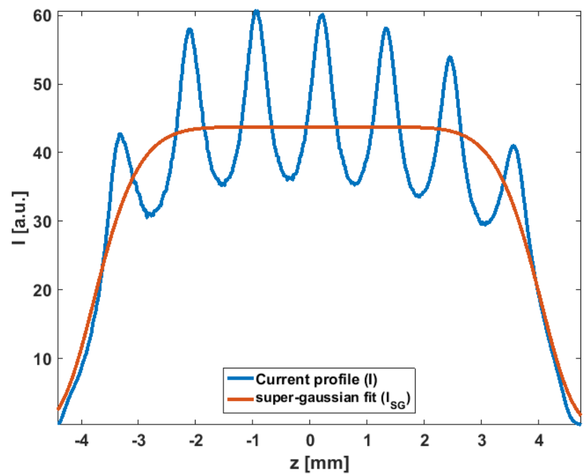
Φ = -60 deg



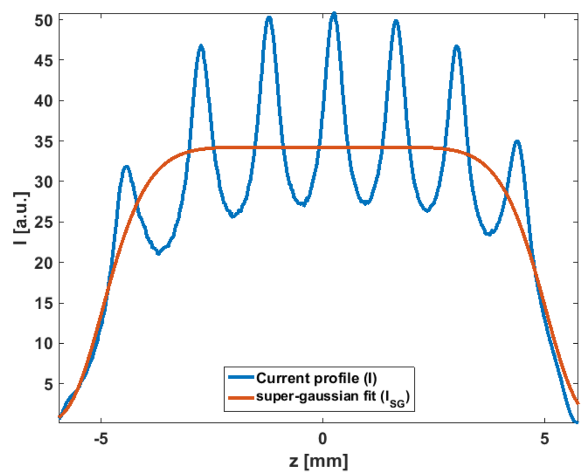
Φ = 0 deg



Φ = +30 deg



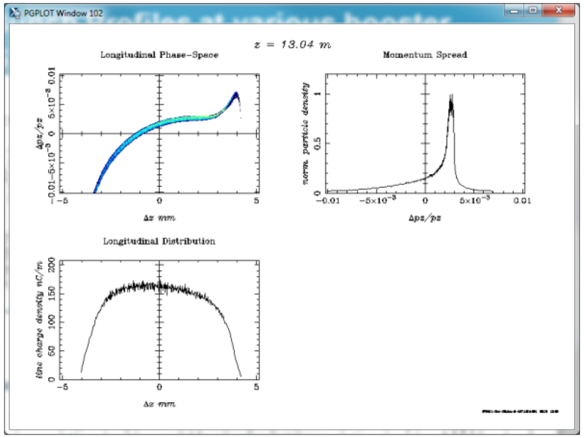
Φ = +60 deg



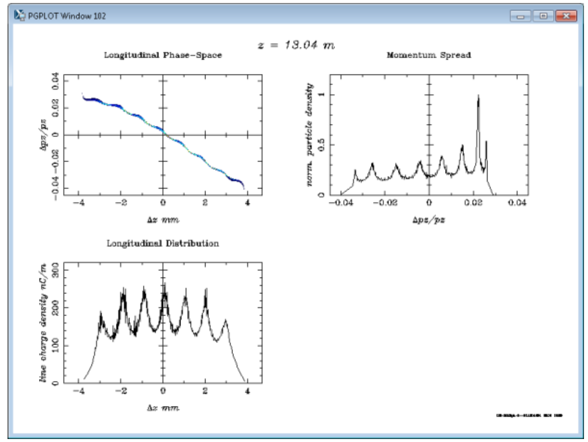
LPS in the next slide ➔

ASTRA Wakefield: Bunch Profiles at various booster phases (w.r.t.MMMG)

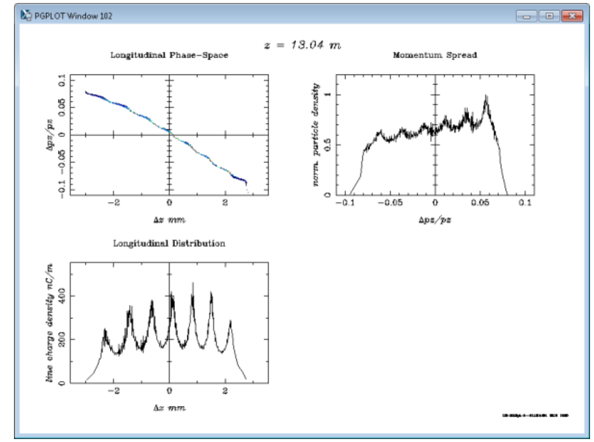
Φ = 0 (no wakefield)



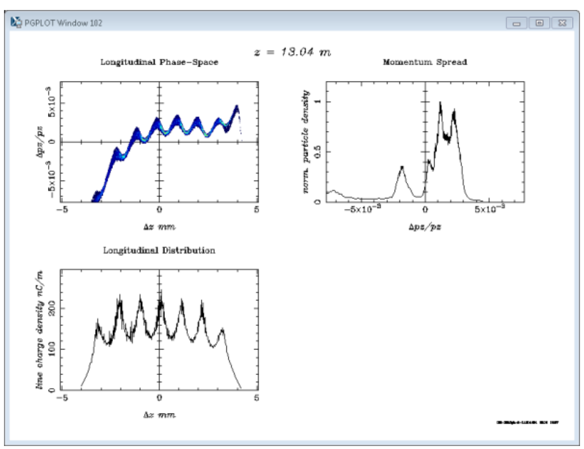
Φ = -30 deg



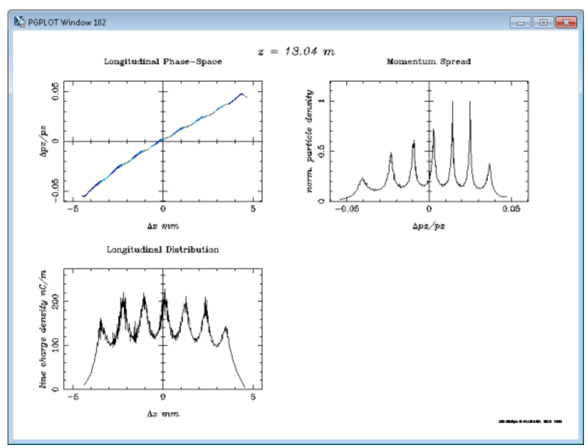
Φ = -60 deg



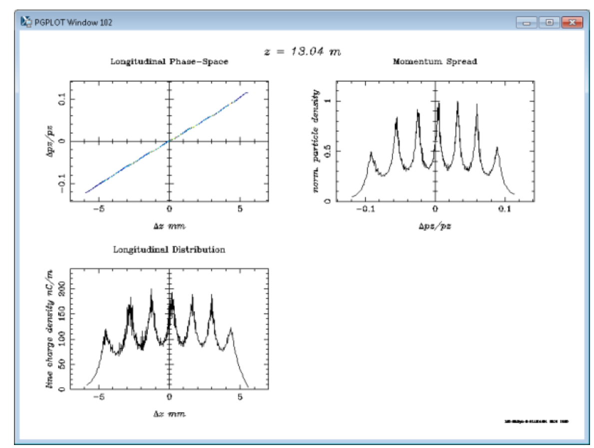
Φ = 0 deg



Φ = +30 deg

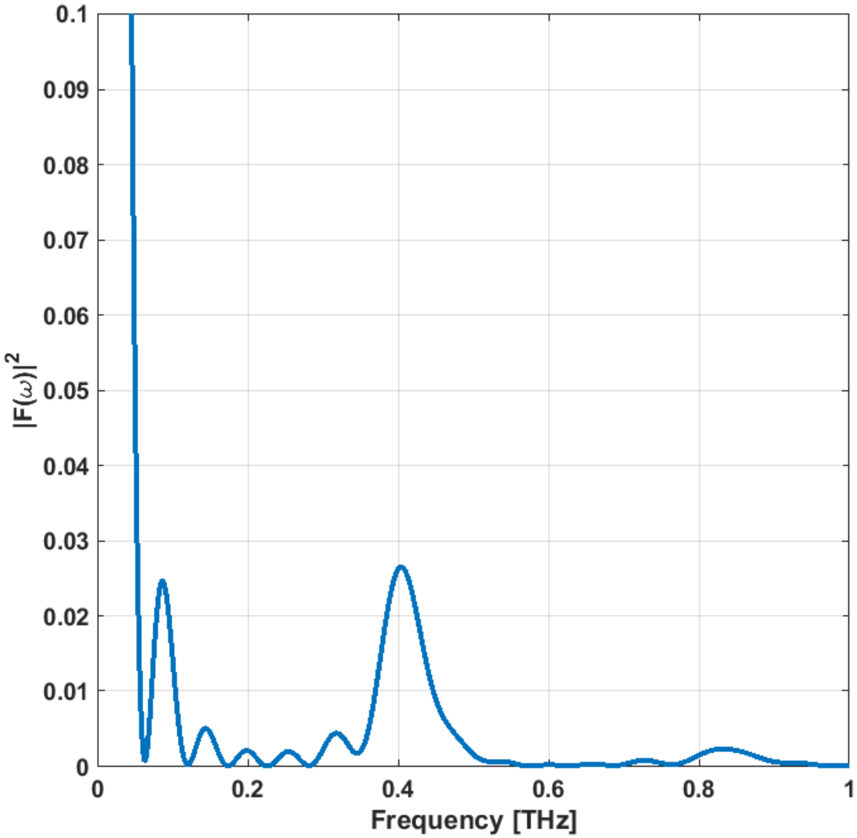


Φ = +60 deg

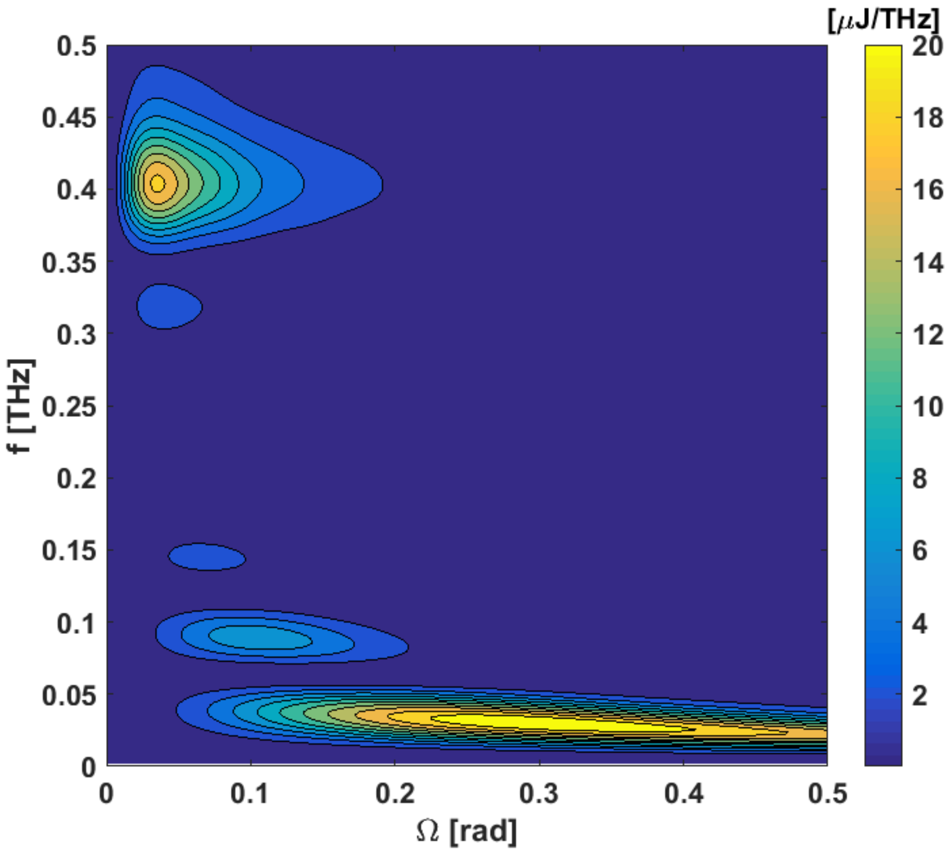


CTR calculation using bunch profile with Φ = - 60 deg

Form factor



CTR energy VS frequency VS emission angle

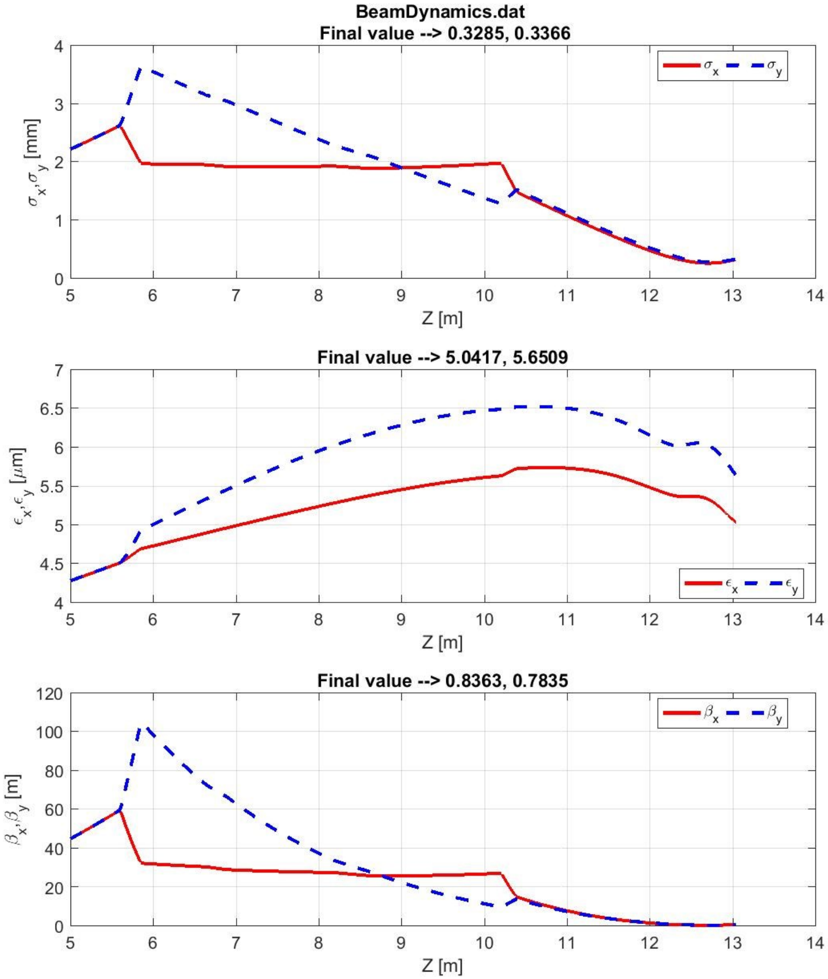


Simulations: Test of Beam Transport

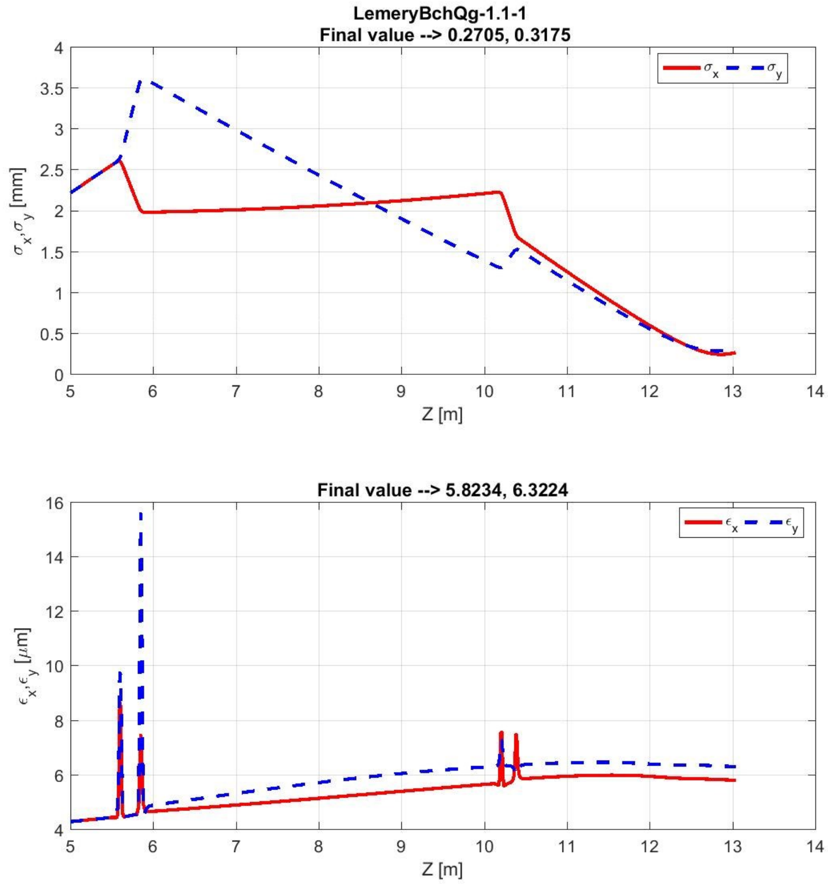
- Initial beam is the example modulated beam (Z = 5 m) simulated by F.Lemery
- Goal: σ_{xy} = 0.1 mm at PST.Scr2.
  - This means β_x, $\beta_y \approx 0.1$ m
- First step, beam matching by using SC Software
  - Use only 4 quadrupole magnets, to avoid practical complications (kicking by not steering-free, chromatic effect of quad focusing, etc.).
  - H1.Q3, H1.Q4, H1.Q9 and H1.Q10 were used.
  - Goal function: constant emittance, β_x, $\beta_y \approx 0.1$ m.
  - Optimized gradients 1.96083 -2.00638 2.22362 -2.10291 T/m
- Second step, particle tracking by using ASTRA
  - Use the files from Lemery as the input beam.
  - Track form 5.0 m to 13.038 m (PST.Scr2 position)
  - Use 3D space charge algorithm with Nx,Ny,Nz = 16,16,16
  - The simulations finished in ~2 hours/file

Simulations: Test of Beam Transport (2)

SC software

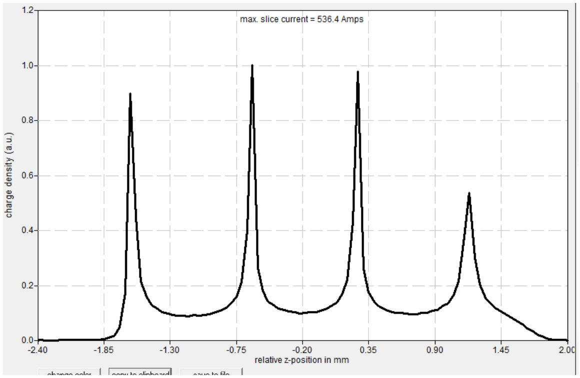


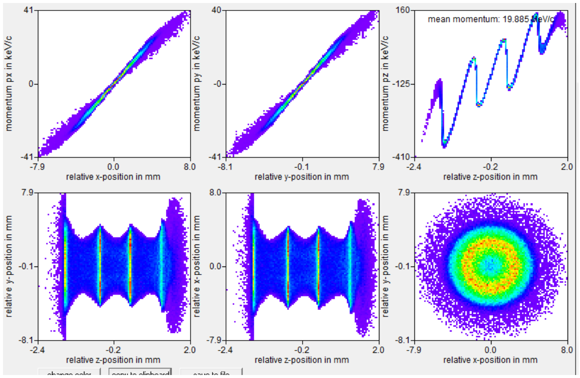
ASTRA



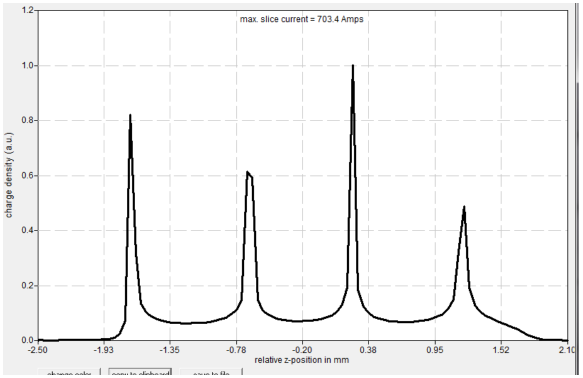
Simulations: Test of Beam Transport (3)

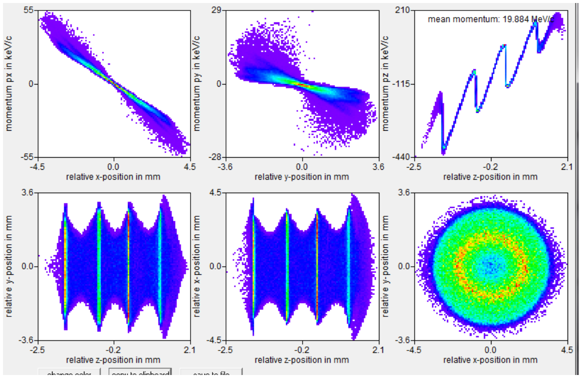
Booster exit
Z = 5.000 m



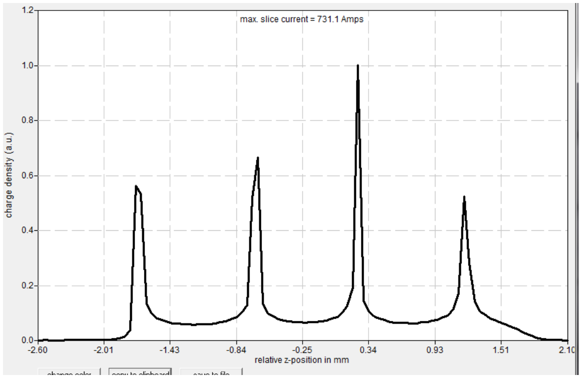


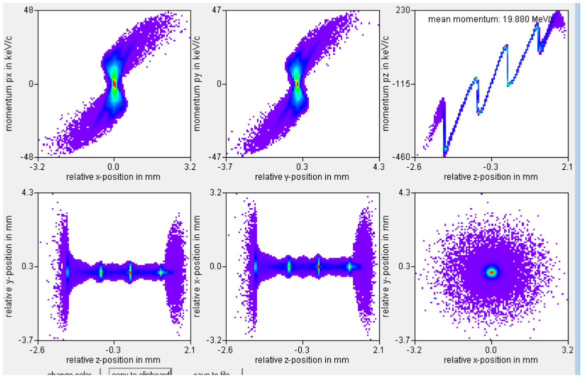
TDS center
Z = 10.985 m





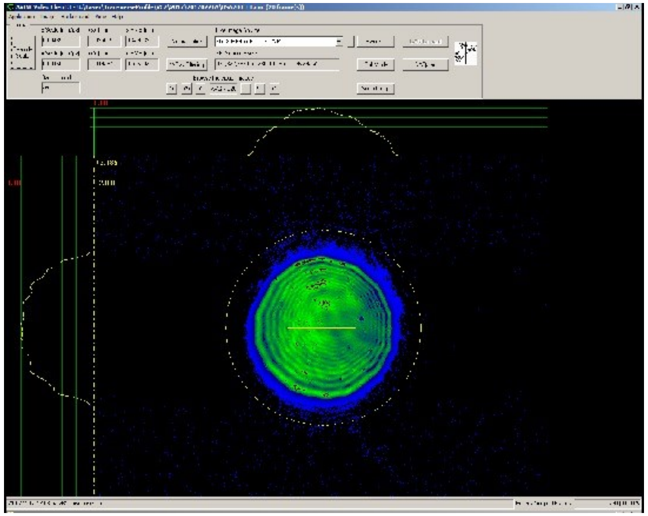
PST.Scr2
Z = 13.038 m



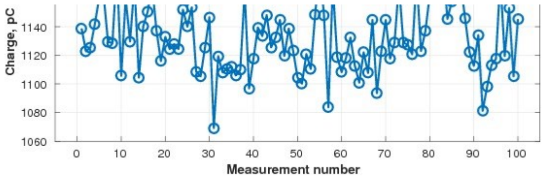


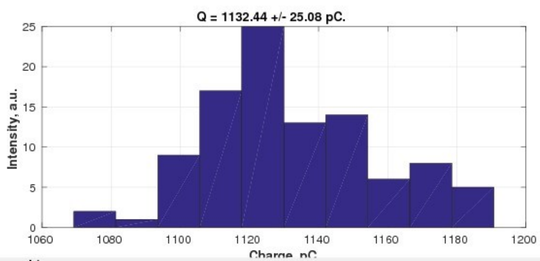
MBI laser (Flattop, BSA=2.0mm): DWA prep. 20.02.2017-21.02.2017

Laser beam at VC2, BSA=2.0mm,
Xrms = 0.48 mm; Yrms = 0.52 mm



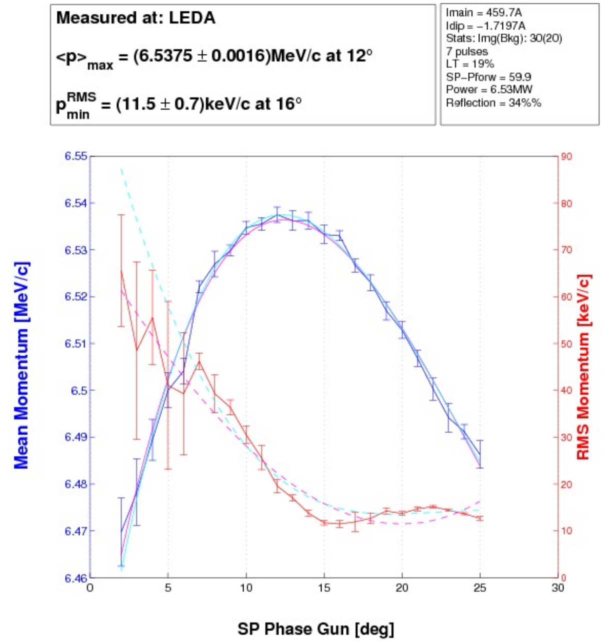
Bunch charge with LOW.ICT1

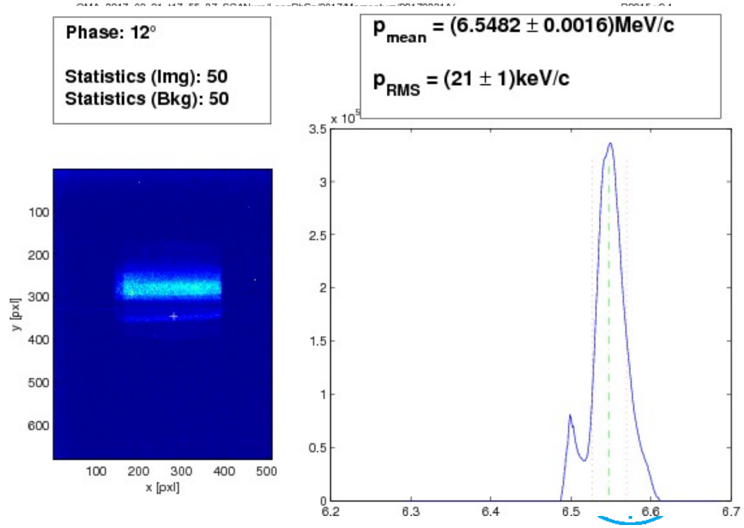




ıta saved to
ıarge measurement using Low.ICT1; calibration corrected by 1/0.921.

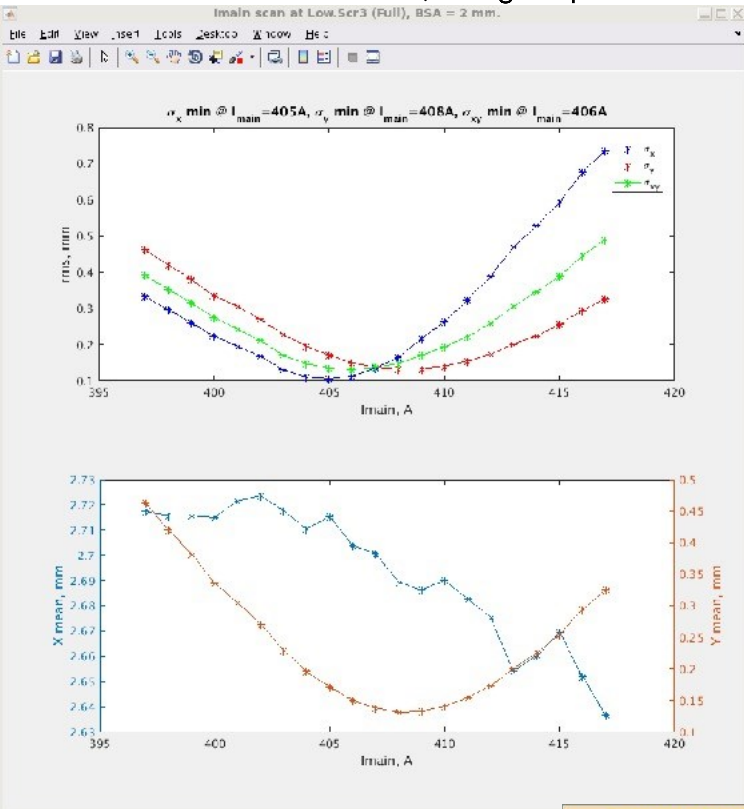
Beam momentum in LEDA



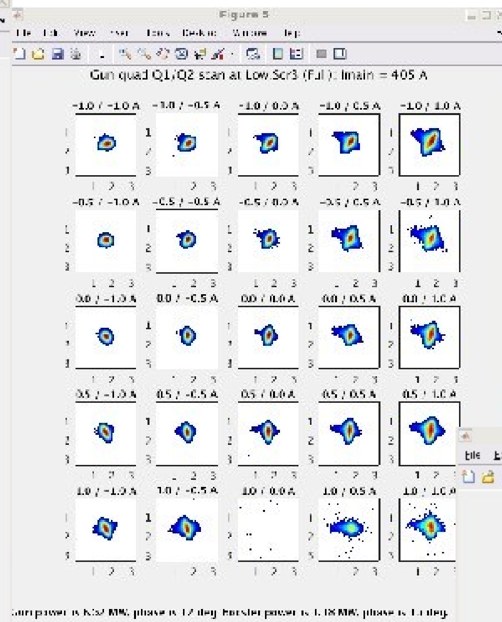


MBI laser (Flattop, BSA=2.0mm): DWA prep. 20.02.2017-21.02.2017

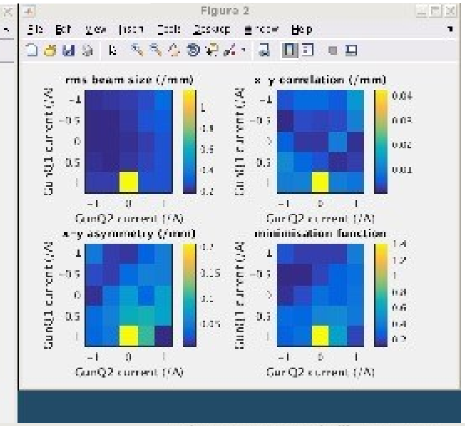
Beam rms size at LOW.Scr3, w/o gun quads

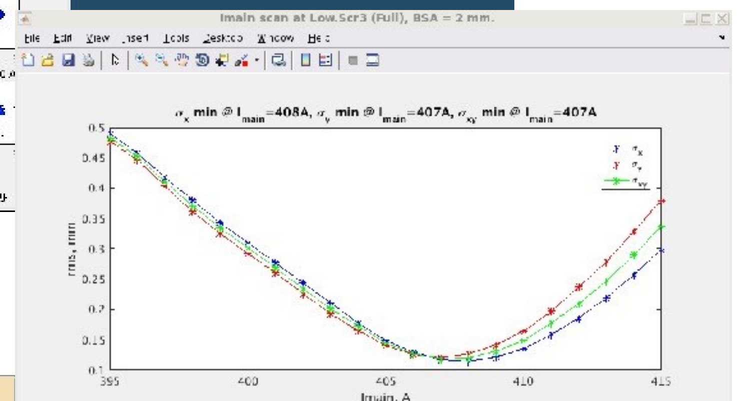


2D (Gun.Quad1;Gun.Quad2) scan

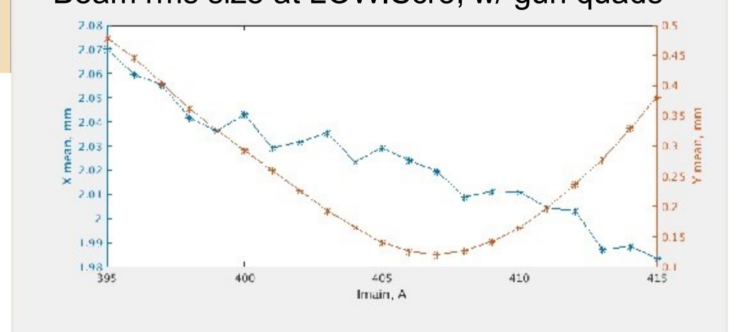


Imain set to 405 A





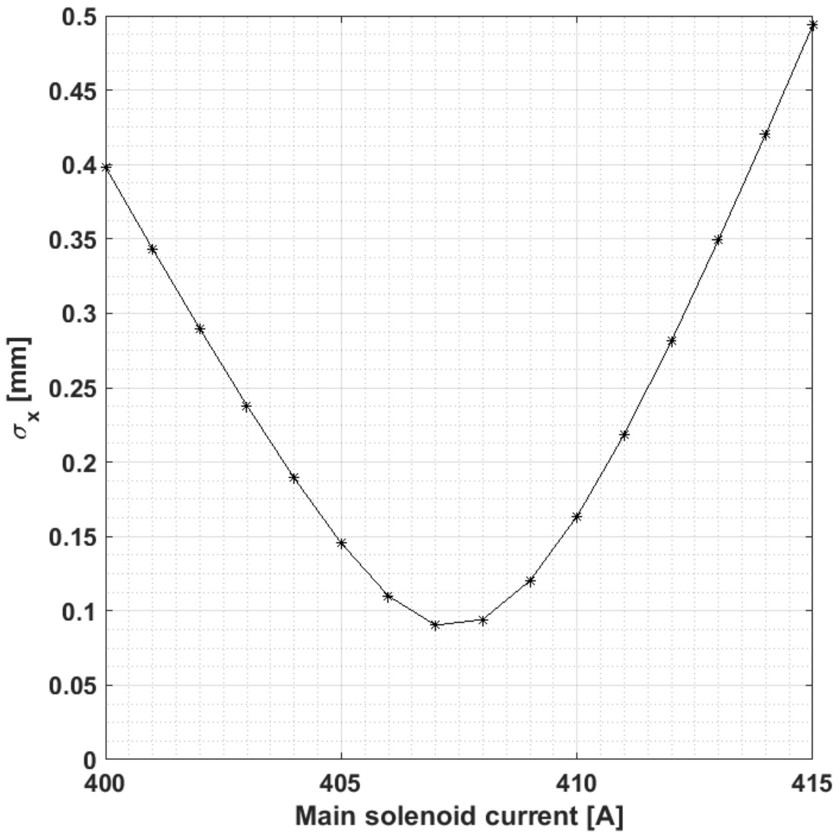
Beam rms size at LOW.Scr3, w/ gun quads



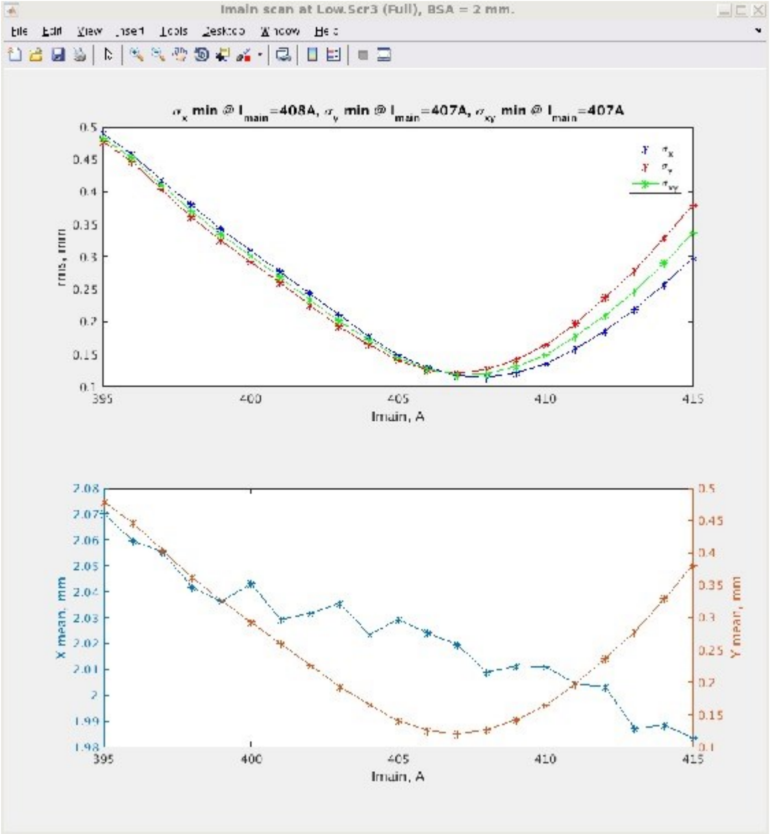
Imain set to 407 A for the focus and symmetric beam

Comparison with Simulations

ASTRA simulations

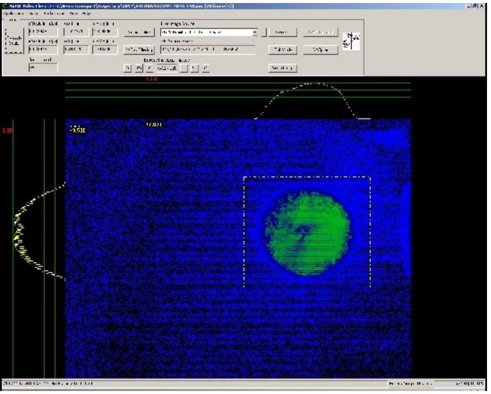


Beam rms size at LOW.Scr3, w/ gun quads

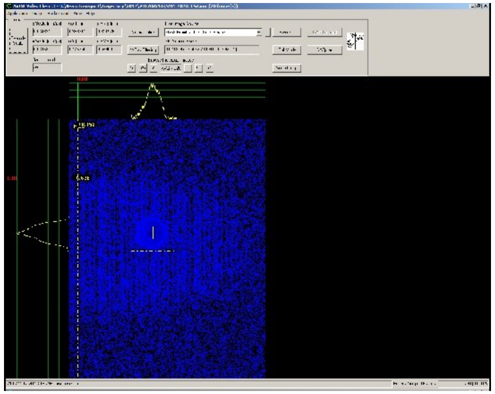


MBI laser (Flattop, BSA=2.0mm): DWA prep. 20.02.2017-21.02.2017

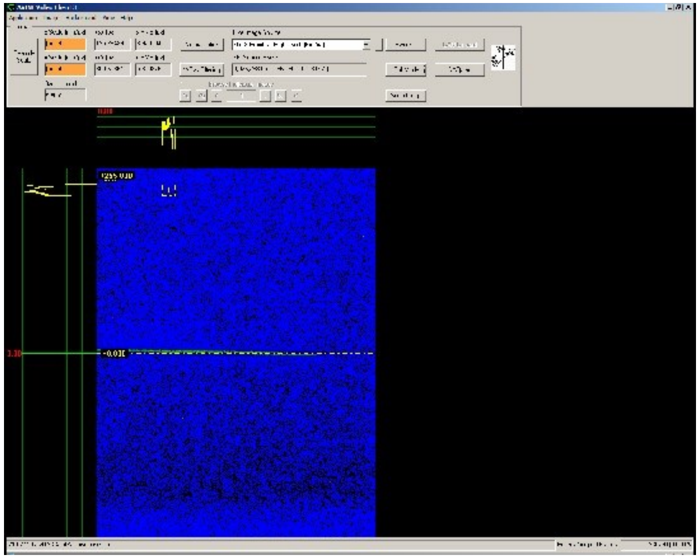
Low.Scr1



Low.Scr2



Beam focused and centered vertically on High1.Scr5 for HEDA1 measurements



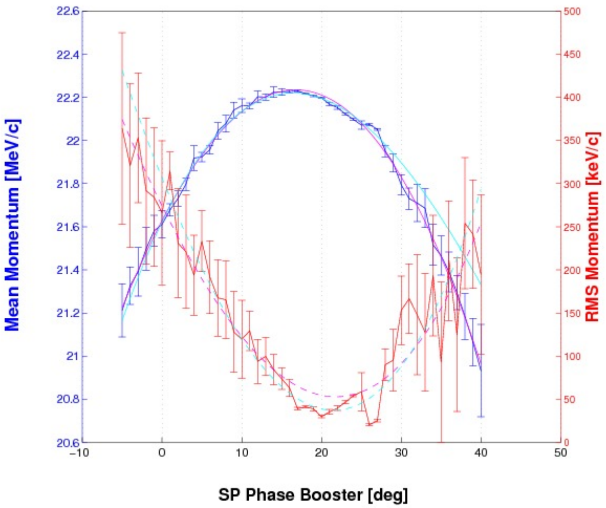
Beam momentum in HEDA1

Measured at: HEDA1 f50 (whole screen)

$\langle p \rangle_{max}$ = (22.230 ± 0.004)MeV/c at 17°

p^{RMS}_{min} = (20.4 ± 1.2)keV/c at 26°

Imain = 406.7A
Idip = −79.782A
Stats: Img(Bkg): 50(10)
1 pulses
LT = 19%
SP−Pforw = 5.0
Power = 3.03MW
Reflection = 60%%

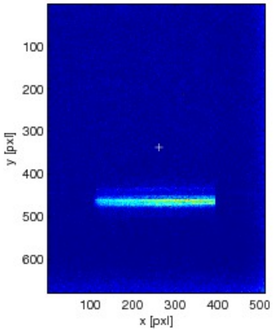


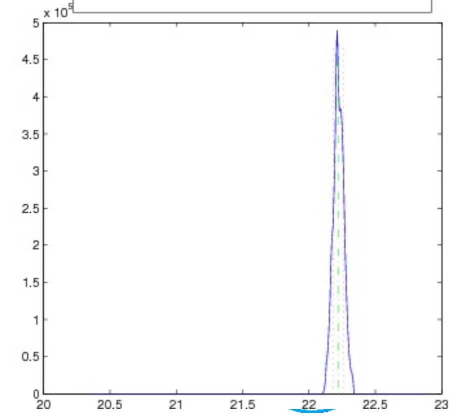
Phase: 17°

Statistics (Img): 50
Statistics (Bkg): 10

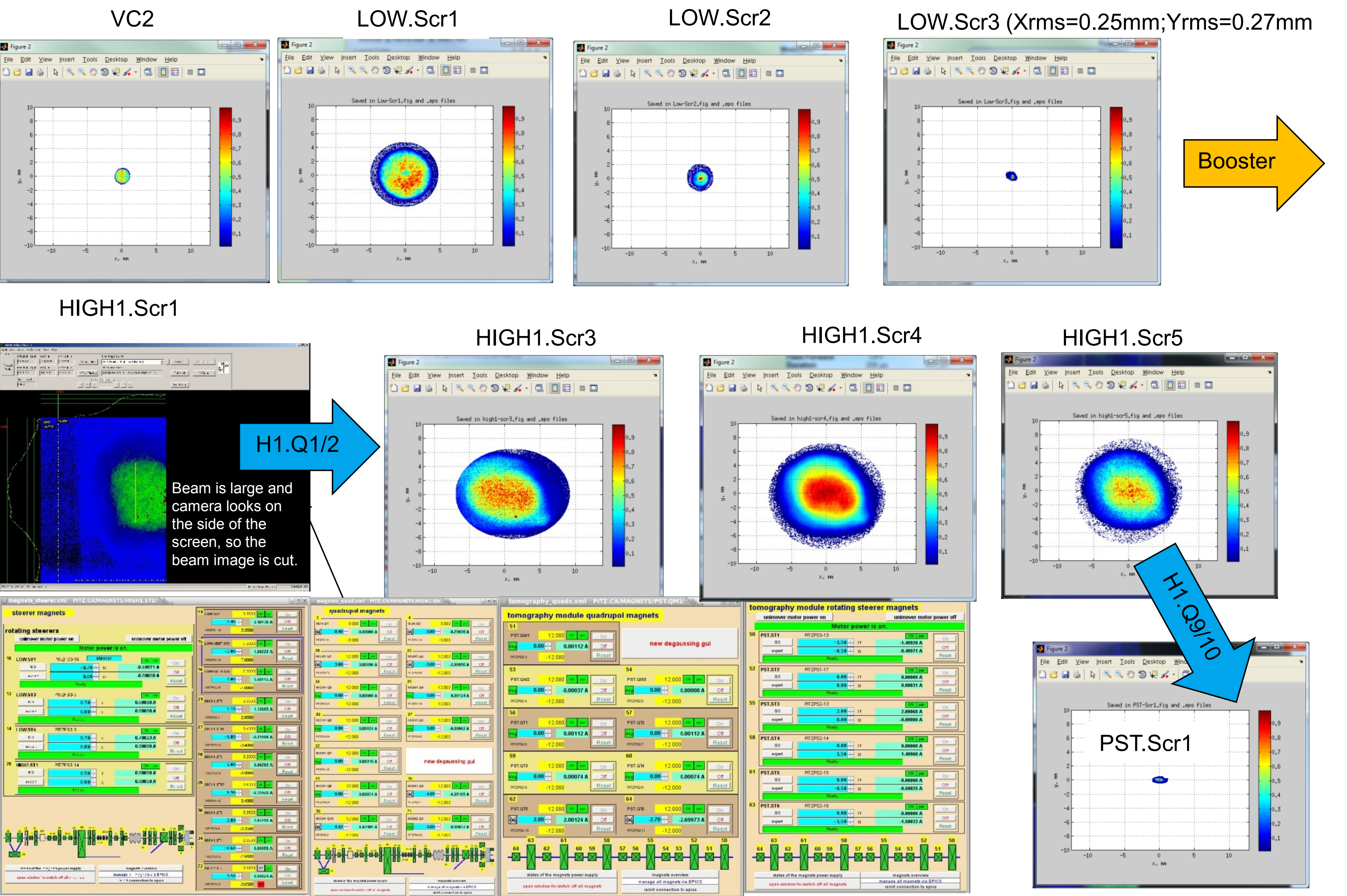
p_{mean} = (22.223 ± 0.004)MeV/c

p_{RMS} = (38.8 ± 0.8)keV/c



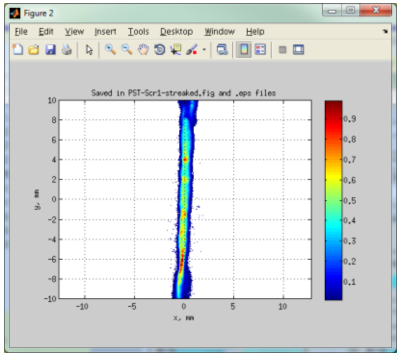


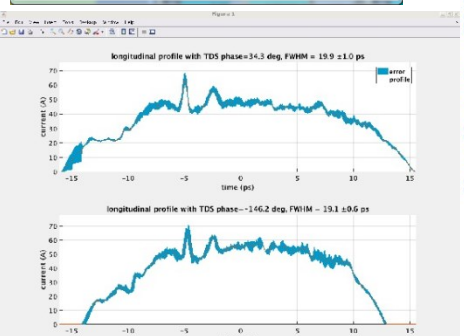
MBI laser (Flattop, BSA=2.0mm): DWA prep. 20.02.2017-21.02.2017



MBI laser (Flattop, BSA=2.0mm): DWA prep. 20.02.2017-21.02.2017

PST.Scr1, streaked





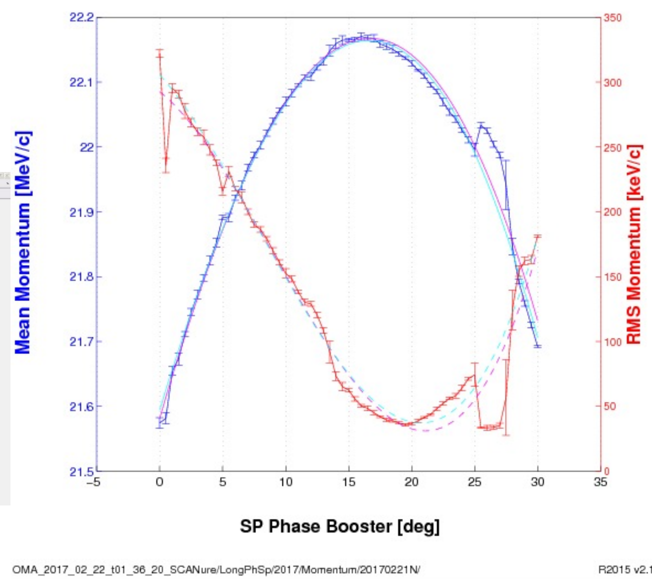
detailed HEDA1 scan

Measured at: HEDA1 f50 (whole screen)

$\langle p \rangle_{max}$ = (22.171 ± 0.006)MeV/c at 16°

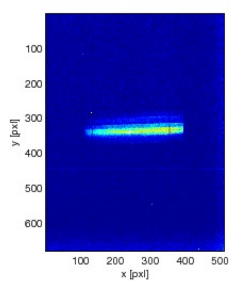
p^{RMS}_{min} = (33.5 ± 1.9)keV/c at 26°

Imain = 406.7A
Idip = −81.781A
Stats: Img(Bkg): 30(10)
1 pulses
LT = 19%
SP−Pforw = 5.0
Power = 3.02MW
Reflection = 68%%



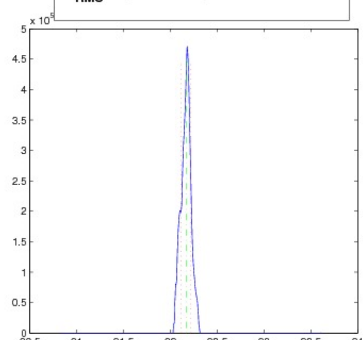
Phase: 16°

Statistics (Img): 30
Statistics (Bkg): 20

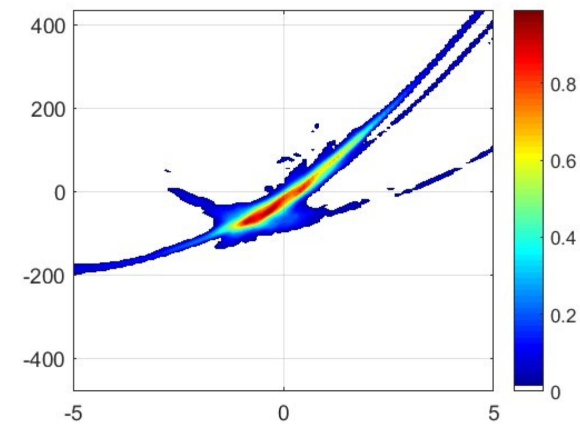


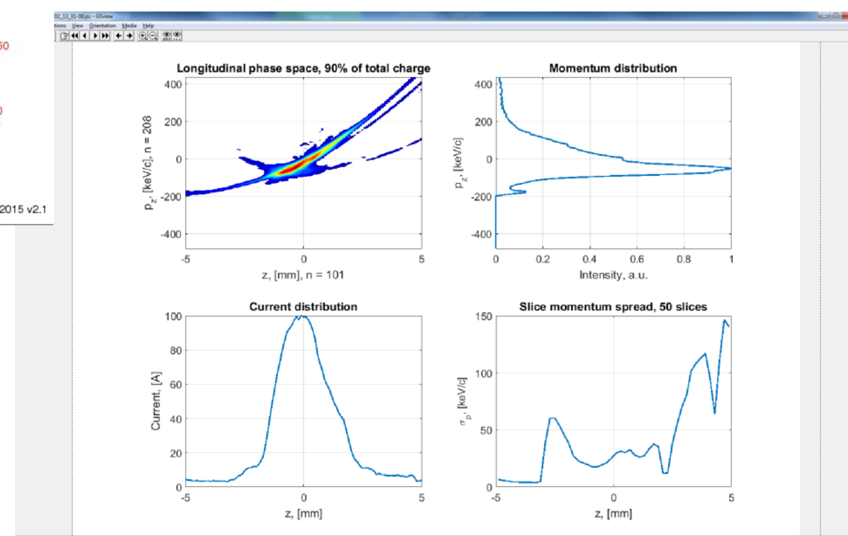
p_{mean} = (22.167 ± 0.002)MeV/c

p_{RMS} = (53.1 ± 1.2)keV/c



longitudinal phase space tomography based on the phase scan in HEDA1





Initial Run Plan for week 10 (prepared by F.Lemery and P.Piot)

Test and Transport

1. Transmission measurements in DLWs (MBI) -- 1 DAY

1.1 Test system, calibrate YaG screen on the dielectric holder

1.2 Check beam transmission for different cathode spot sizes and charge retuning the solenoid each time, measure beam profile on the

1.3 Align beam in structure to ensure minimization of the deflecting mode as observed on a downstream screen. Find a set of optimum settings (spot size on cathode, solenoid strength) for a few case of charges (Qi)

1.4 Investigate shot-to-shot stability (possibly taking correlated data with e.g. charge or phase?)

TDS+PST.Scr1/HEDA2

2. Energy and density -- 2 DAYS

2.1 Propagate beam up to HE point and tune the optics to minimize beta function at the screen. Operate booster cavity on crest. Explore whether the modulation is visible and record the modulation features as phase, amplitude of the booster is varied.

2.2 Turn on the TDS, tune the optics to minimize beta function on downstream screen and quantify density modulation for the same various settings as the one explored in 2.1

2.3 Repeat 2.1 and 2.2 for the several cases of charges devised in 1.3

2.4 For few cases attempt to record the full longitudinal phase space (can we do that?) and see the stair-case phase space and its evolution as function of phase

TDS+PST.Scr1/HEDA2 with Bunch Train

3. Multi-bunch operation -- 2 DAYS

The step 1 and 2 should be preferably done in single bunch mode. Consider the cases of charges (see 1.3) where the transmission is very high and attempt to increase the number of bunch while monitoring the vacuum level close to the DWFA structure

3.1 record energy modulation and density modulation for the possible case of charge

3.2 apply an energy ramp on the booster (is this possible to load a different FF table in the LLRF) to demonstrate chirped modulation along the bunch train (each bunch has a different separation) and record resulting longitudinal phase spaces.

Experiment with 2nd Structure

4. explore the 8-cm long larger structure (uncoated)

Summary

- 2 DLW structures are installed at Low.Scr3 station with 2 YaG screens for beam transport optimization
- ASTRA simulations are done.
  - Imain = 407 A delivers the smallest beam size at Low.Scr3.
  - Density modulation profiles show 7 peaks.
  - Obvious modulation in LPS can be seen when using booster MMMG phase.
  - The modulated bunch profile is possible to keep during beam transport from z = 5 m to the TDS center location.
- CTR from the example beam is calculated. The result shows radiation energy peak at high-order harmonic of 0.4 THz
- Experimental preparations for DWA experiments were done.
- Initial Run Plan for week 10 is prepared.

Outlook

- Transport with QMs and realistic aperture downstream from the booster should be included in ASTRA simulations.
- Find better method for evaluation of density modulation.
- Other parameters scan in ASTRA simulations

- Challenge during experiment
  - ❑Laser Flattop tuning
  - ❑Beam loss
  - ❑Spark or outgassing from the DLW structures
  - ❑Multi-bunch operation
  - ❑Etc.