Beam Dynamics Simulations for the current setup of the EXFEL Photo Injector

Based on setup for the gun quad tests performed on 19-22.10.2017 (I. Isaev, "Gun quadrupole tests at European XFEL ", PPS, 02.11.2017)

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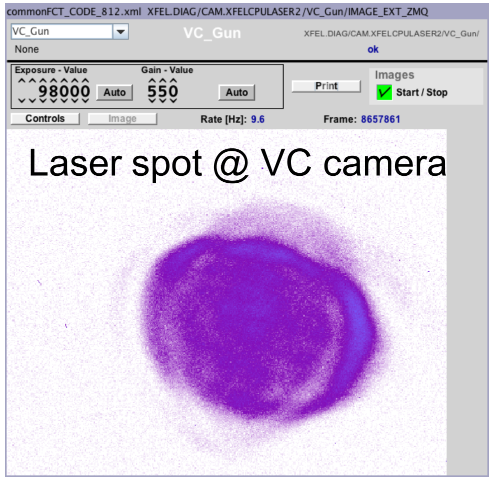
Zeuthen, 09.11.2017

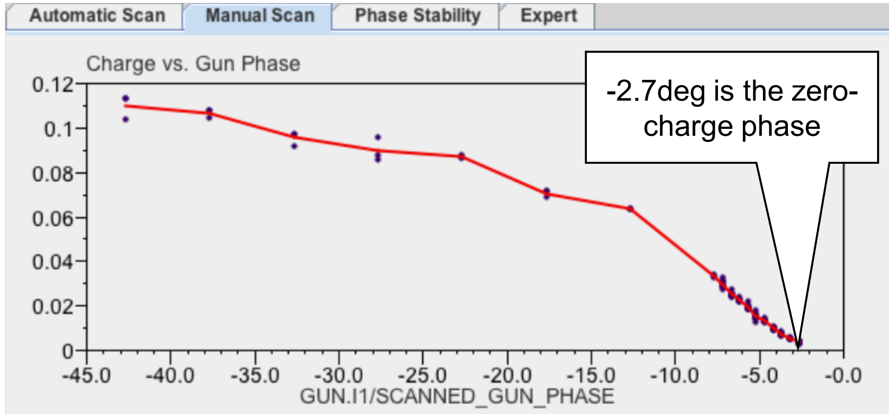
Injector settings → ASTRA input

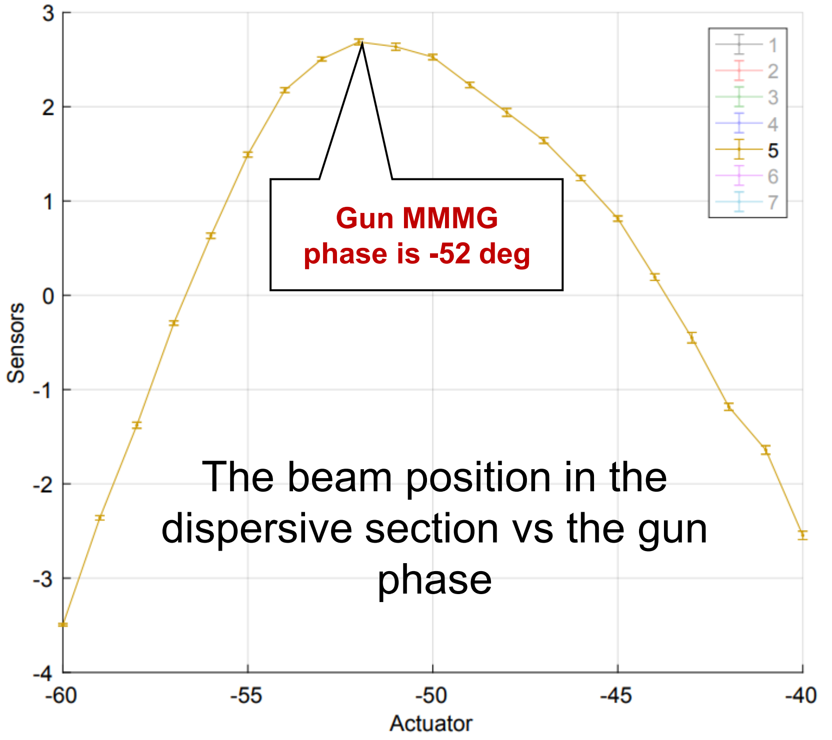
- Gun power: 5.13MW (53MV/m)
- Beam momentum after the gun: unknown
- Gun RF phase: -43deg (w.r.t. zero-charge phase) it is not MMMG phase

Gun phase estimation: ([-52°-(-2.7°)]=49.3°; 49.3°-43°=6.3° → ϕ_{ASTRA}=**MMMG-6°**

- Beam momentum after AH1: 130 MeV/c (after A1 → ~150MeV)
- A1 adjusted for MMMG phase
- Gun main solenoid current 329.5 A
- Gun bucking solenoid current 17.7 A
- Bunch charge: 500 pC
- Laser BSA: 1.2 mm







ASTRA input

Gun:

- Field: gun43cavity.txt (FB=1.048)
- Ecath=53MV/m
- Gun RF phase: **MMMG-6°**

A1:

- Field: 2 x tesla4cav.dat (1st cavity centered at z=4.0401m→1st iris at z=3.637m)
- MaxE=34.42MV/m

Bunch charge: 500 pC, 200000 macroparticles

Laser BSA: 1.2 mm

- Temporal → Gaussian 6 ps rms (14.1 fwhm)
- Radial homogeneous: 1.2 mm → 0.3 mm rms (→ core+halo next step)

Solenoid:

- Field: gunsolenoidsPITZ.txt (bucking → compensation)
- ?Calibration: MaxB=-(0.0000372+0.000588*Imain)

Output:

- Beam at 14.44m (1st quadrupole position)

Main solenoid peak field scan

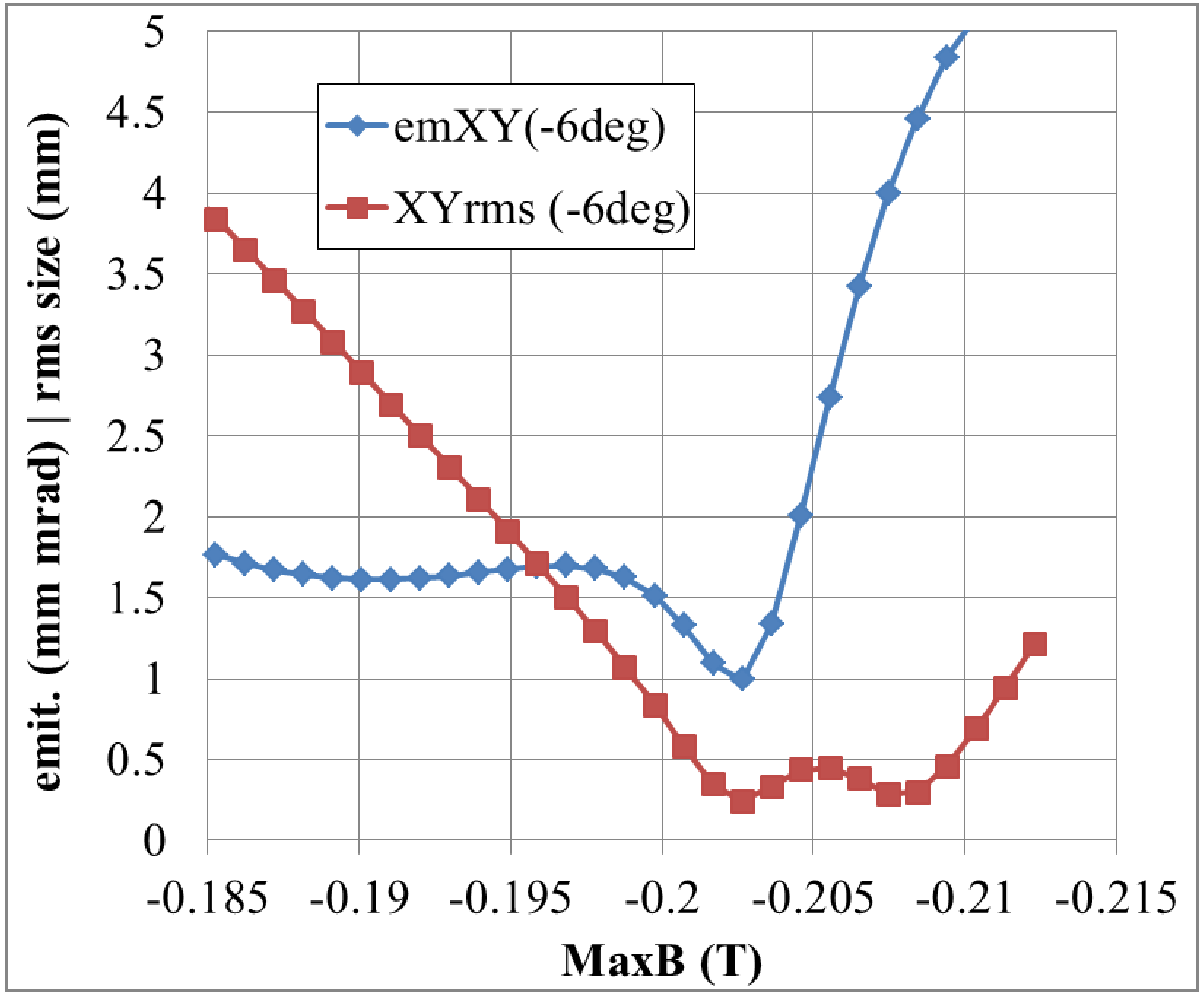
Gun phase=MMMG-6°

Emittance:

- Min (at -0.20265T) → 1.0 mm mrad
- Another min (at -0.19107T) → 1.6 mm mrad

? Main solenoid calibration:
MaxB[mT]=0.4+0.6*Imain[A]
I. Bohnet, K. Fl¨ottmann, Q.Zhao “Magnetic Field Investigations of the Solenoid Arrangement for PITZ”, PITZ Note October 8, 2002

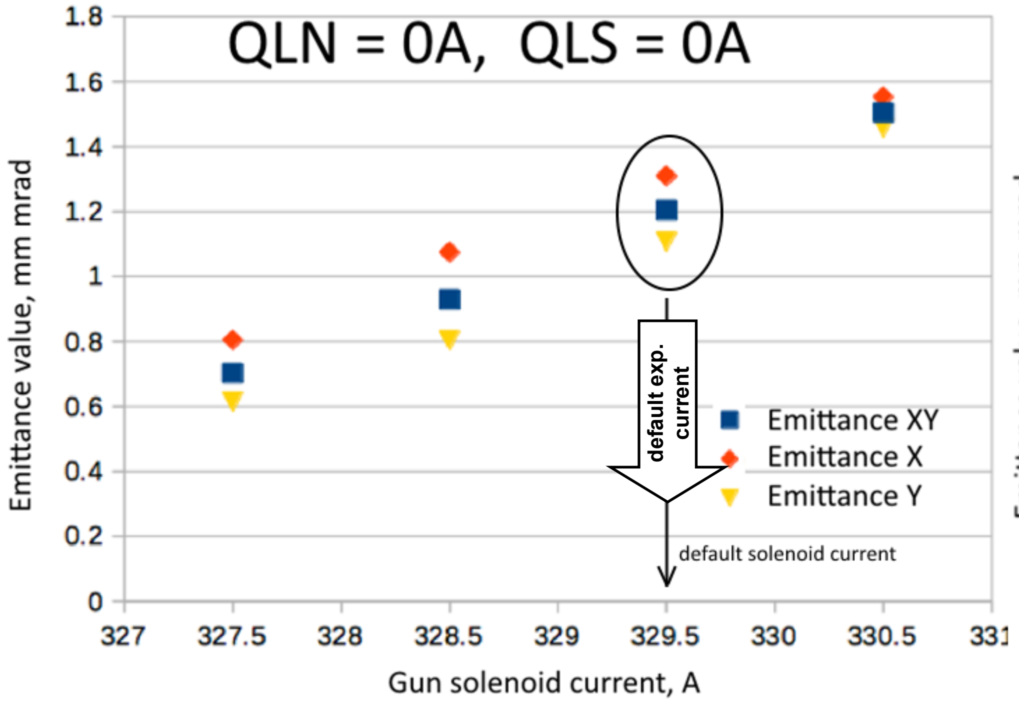
Another Danfysik main solenoid calibration (L. Staykov, 2002):
MaxB[T]=-(0.0000372+0.000588*Imain[A])

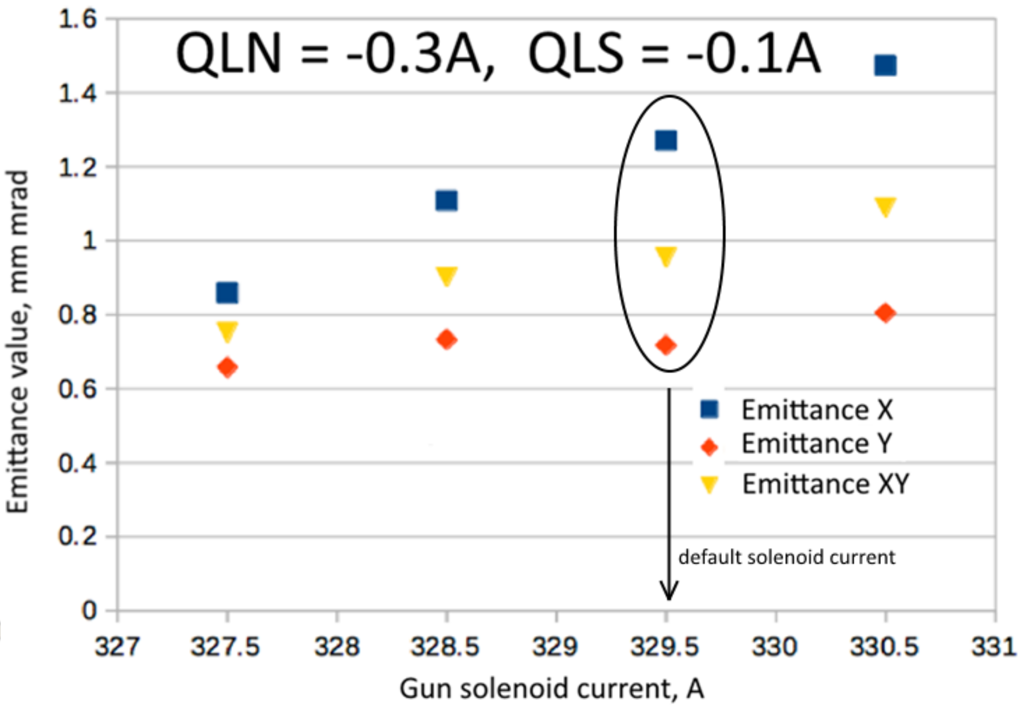


NB: Q(0.5nC, MMMG-6°)=0.4996nC

Some results of the gun quadrupole adjustments (I. Isaev)

2nd experiment: emittance vs solenoid current





- The experiment shows that **the tuning the gun solenoid current can decrease emittance value at least by ~40%**. But in that case the gun quadrupoles must be readjusted for obtaining the smallest emittance.
- The emittance measurements were not done for the solenoid current **lower that 327A** because at these current **a beam loss in the injector section** was observed (non-optimal beam trajectories and collision with the collimator).

Main solenoid current scan

Case1: Gun phase=MMMG-6°

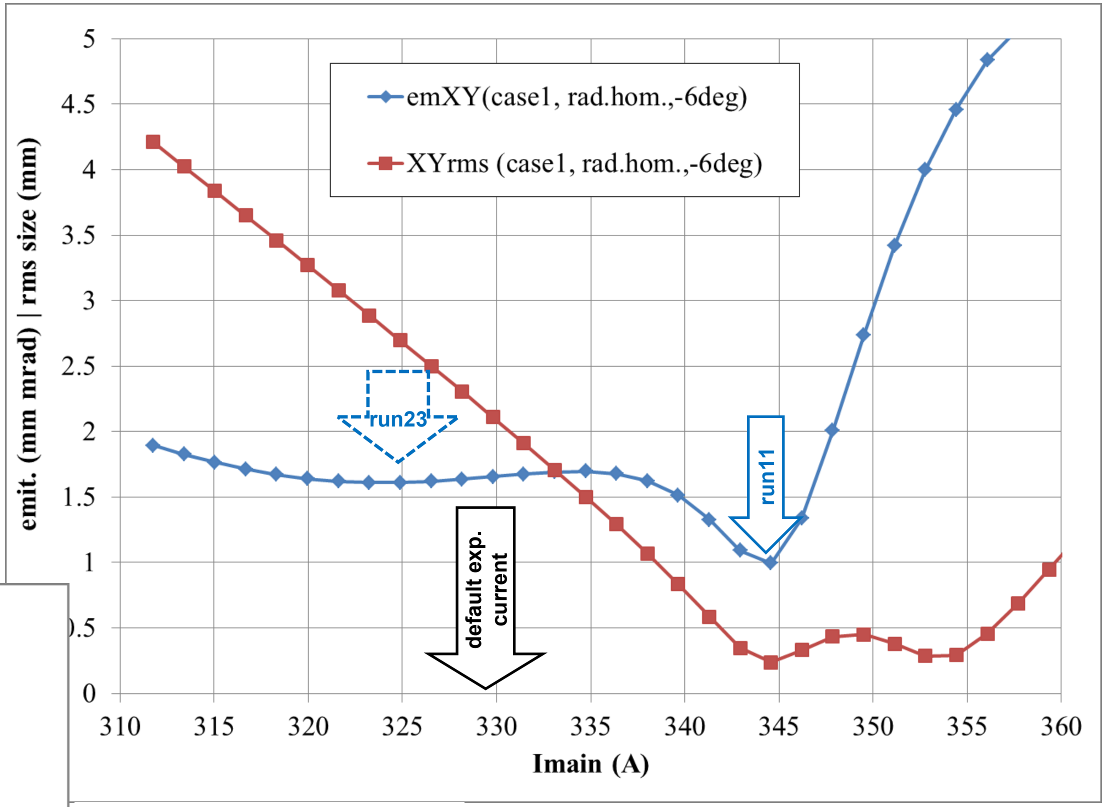
MaxB=-(0.0000372+0.000588*Imain)

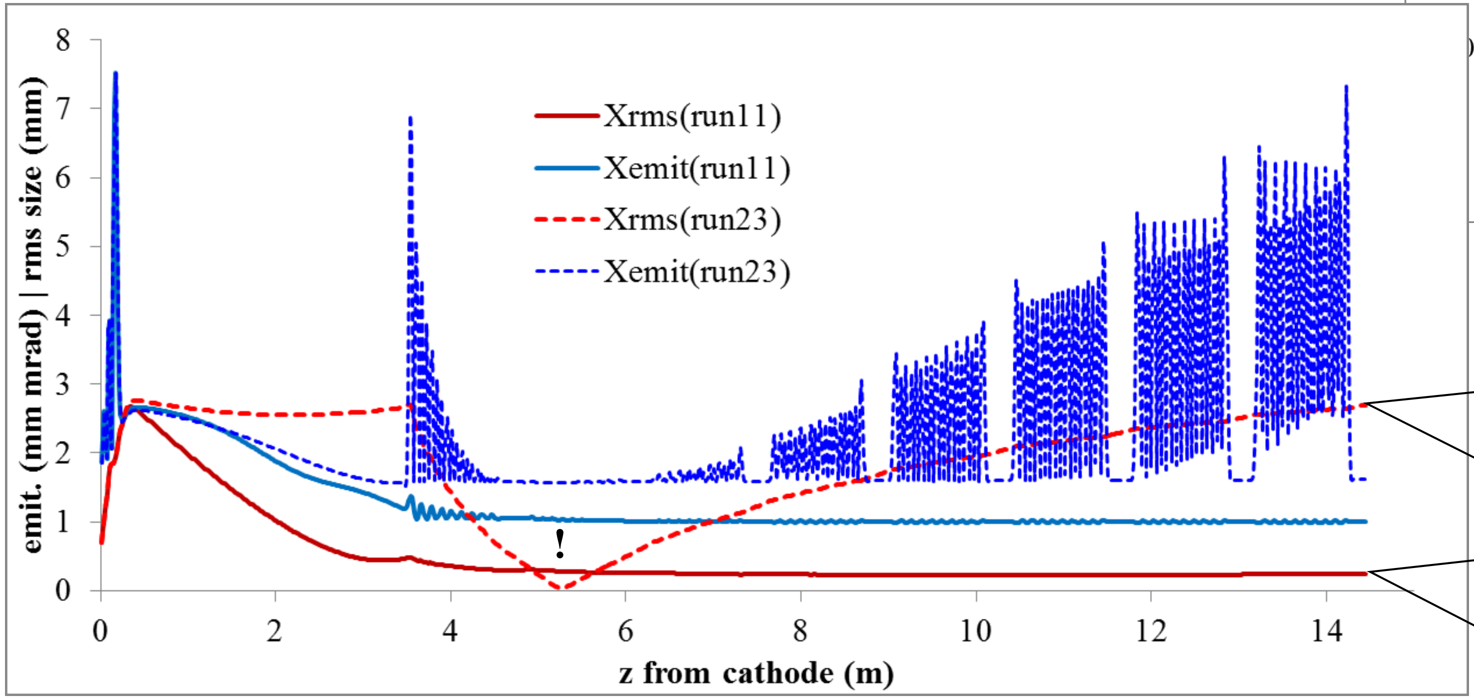
"Correction of the calibration coefficient":

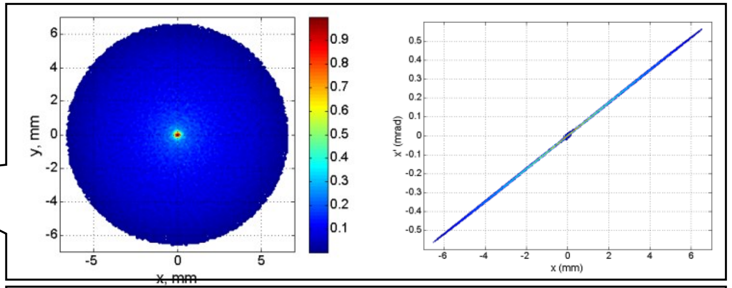
- PITZ (e-beam rms size based) → 0.982
- EXFEL (emittance min based*) → 1.05!

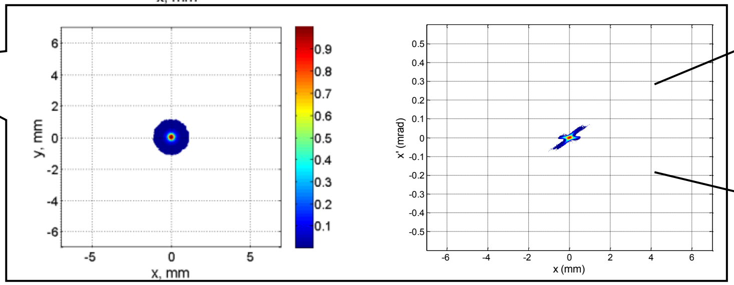
Emittance:

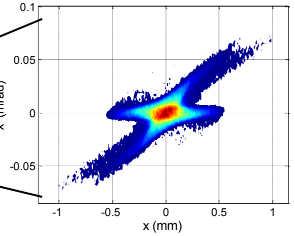
- Min (at 345A) → 1.0 mm mrad ➔ run11
- Another min (at 325A) → 1.6 mm mrad ➔ run23







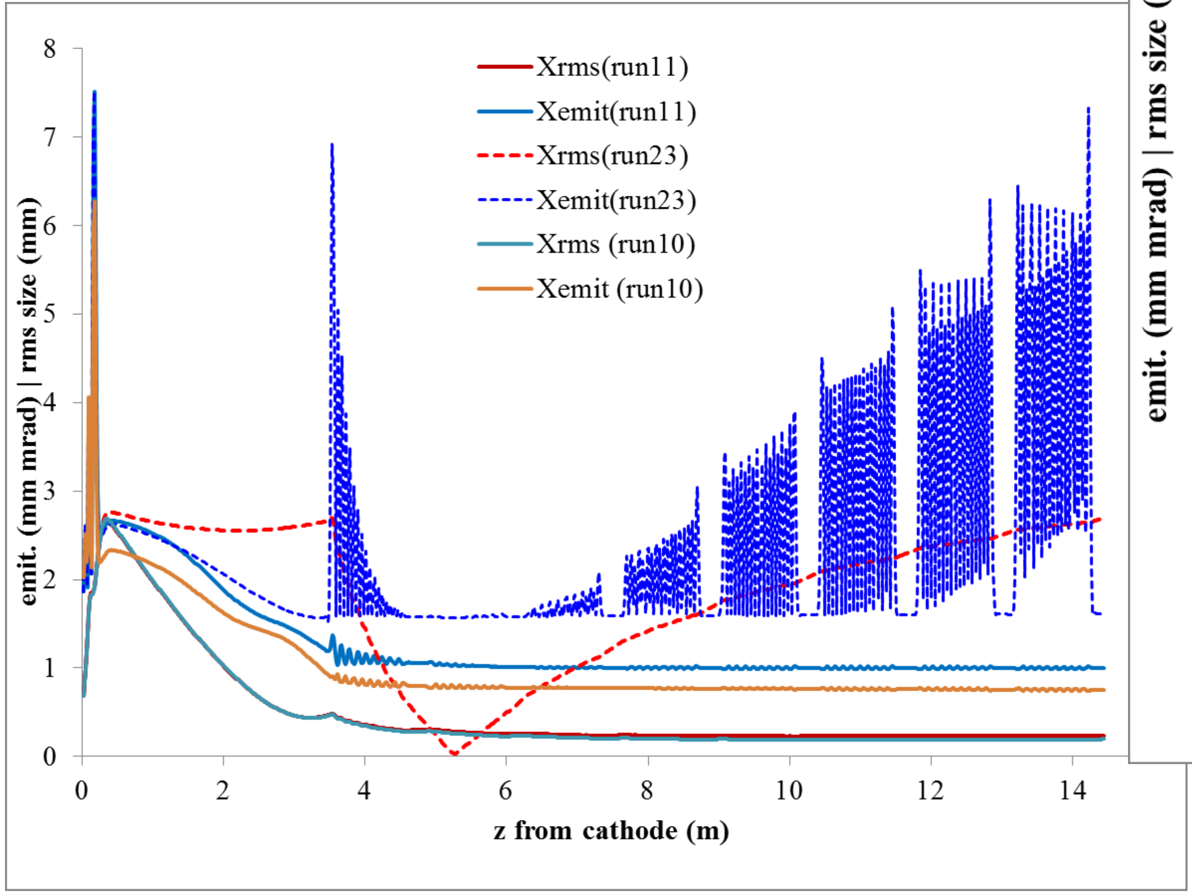


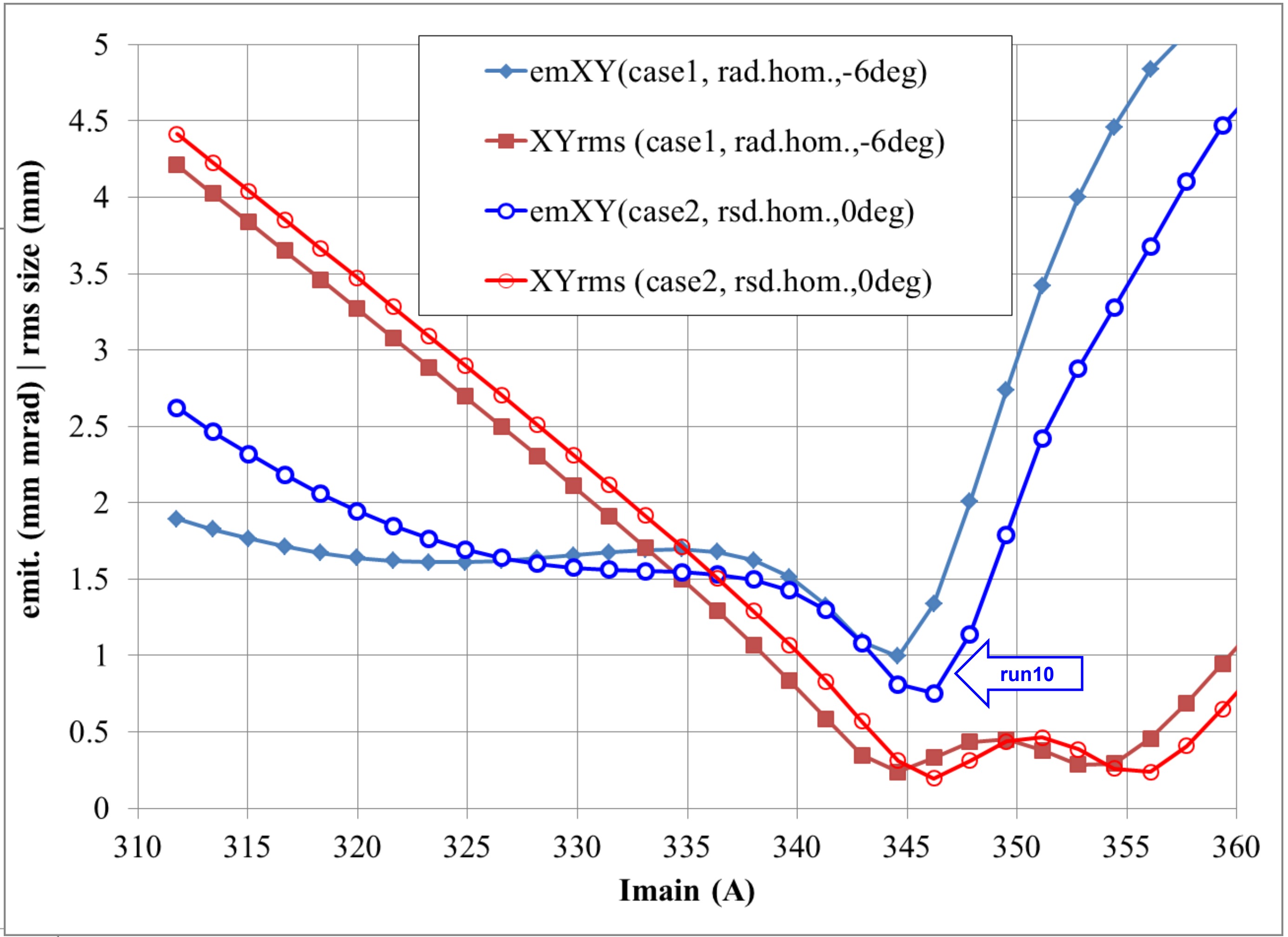


large transverse halo of electron beam → cut during emittance measurements?

Main solenoid current scan

Gun phase=MMMG-6° (case 1) vs. MMMG (case 2)





Emittance (case2):

- Min (at 346A) → 0.75 mm mrad → run10

Q(0.5nC, MMMG-6°)=0.4996nC

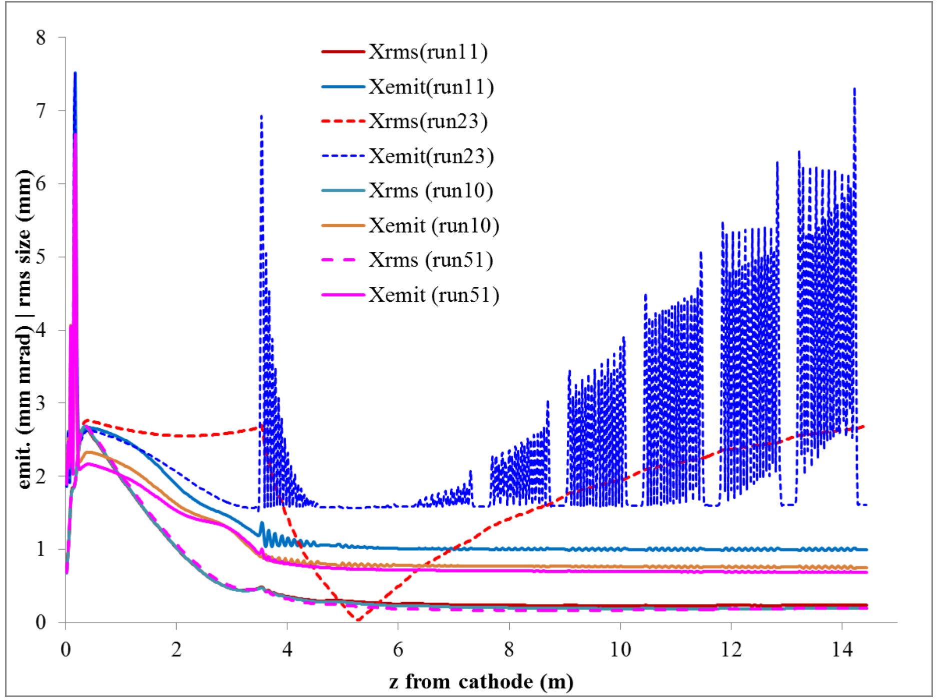
Q(0.5nC, MMMG)=0.5nC

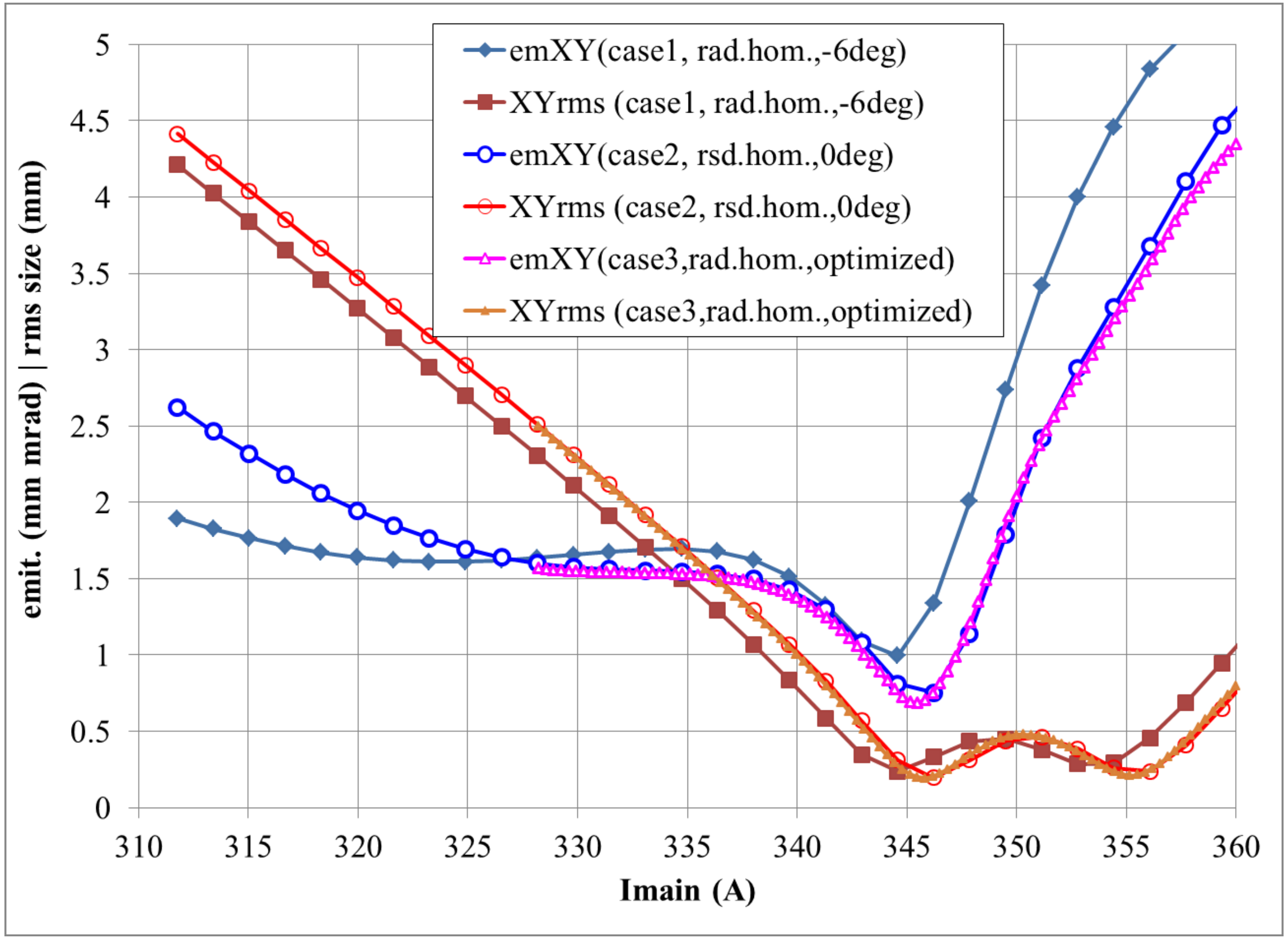
Fine emittance optimization for current setup

Case 3: Optimized parameters: { main solenoid current x laser XYrms x Gun phase}

- Optimized setup:
  - Laser XYrms=0.295mm
  - Gun phase = -1.48°
  - MaxB=-0.20318T

Emittance (case 3):
  - Min (at 345.5A) → **0.687 mm mrad** ➔ run51



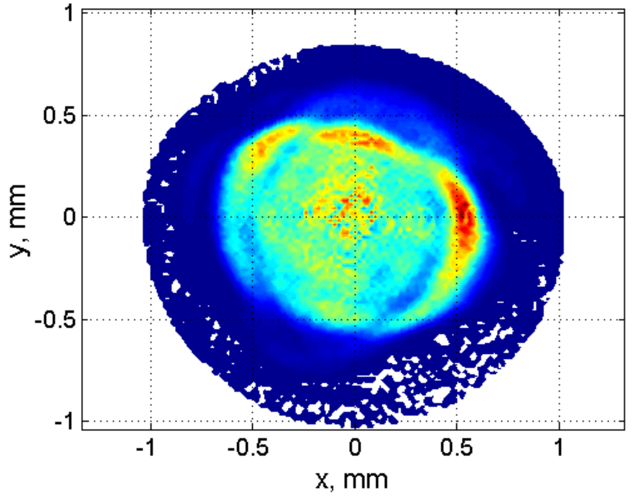


NB: Q(0.5nC, MMMG-6°)=0.5nC

More realistic laser transverse distributions

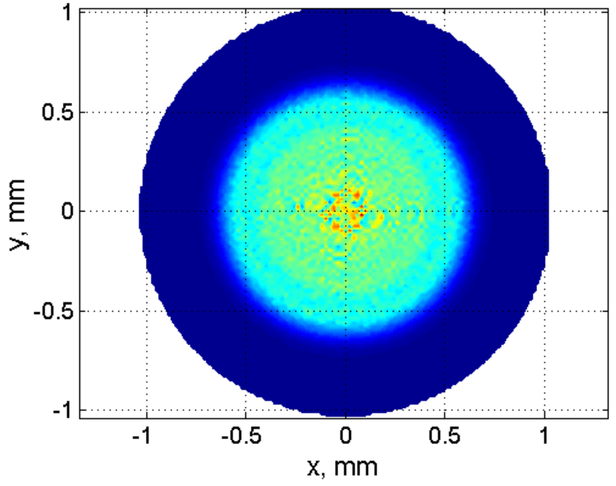
Core+halo = rings and 2D asymmetric distribution

VC measured

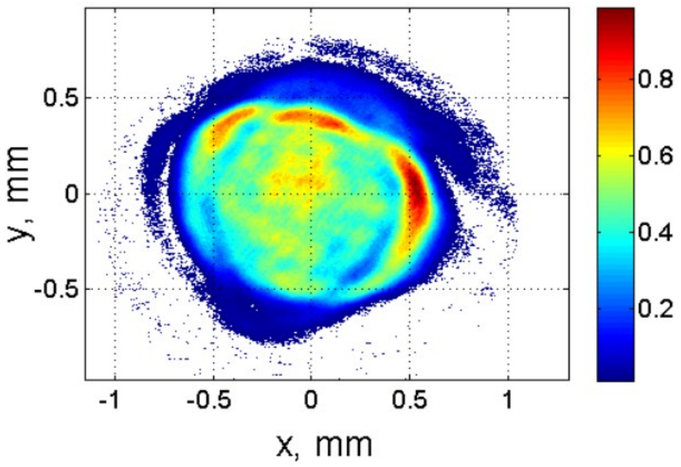


Distribution	σ_x, mm	σ_x, mm	σ_{xy}, mm
VC measured	0.34	0.29	0.31
Rad.homog	0.3	0.3	0.3
Rings	0.31	0.31	0.31
2D asym.	0.34	0.29	0.31

Core+Halo=Rings



2D asymmetric



Case	PC laser transverse	ASTRA SC	Gun phase w.r.t. MMMG
1	Rad.homogen.	2D	-6°
2	Rad.homogen	2D	0°
3	Rad.homogen	2D	optimized
4	Core+Halo=Rings	2D	-6°
5	Core+Halo=Rings	2D	0°
6	2D asymmetric	2D	-6°
7	2D asymmetric	2D	0°
8	2D asymmetric	2D→3D	-6°
9	2D asymmetric	2D→3D	0°

SC: 2D→3D

- Nrad = 50,
- Nlong_in = 100
- L2D_3D=.T
- z_trans=0.1
- Nxf=32, Nyf=32, Nzf=32

Different cased for the gun phase -6°

Cases 1,4,6,8

Case	PC laser transverse	ASTRA SC	Gun phase w.r.t. MMMG
1	**Rad.homogen.**	**2D**	**-6°**
2	Rad.homogen	2D	0°
3	Rad.homogen	2D	optimized
4	**Core+Halo=Rings**	**2D**	**-6°**
5	Core+Halo=Rings	2D	0°
6	**2D asymmetric**	**2D**	**-6°**
7	2D asymmetric	2D	0°
8	**2D asymmetric**	**2D→3D**	**-6°**
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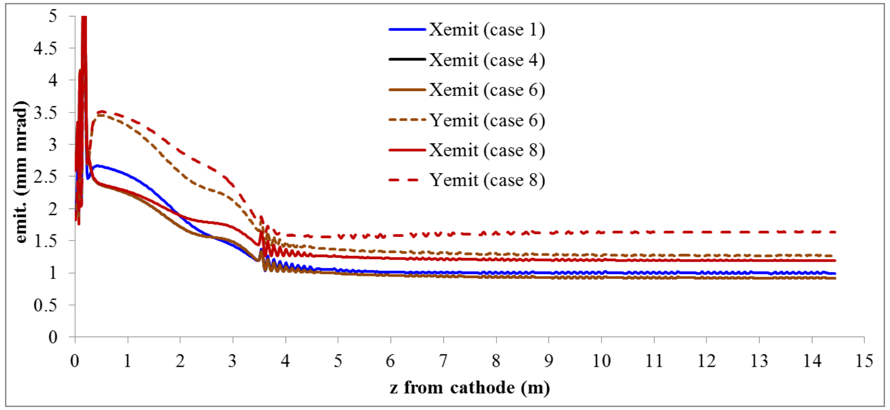

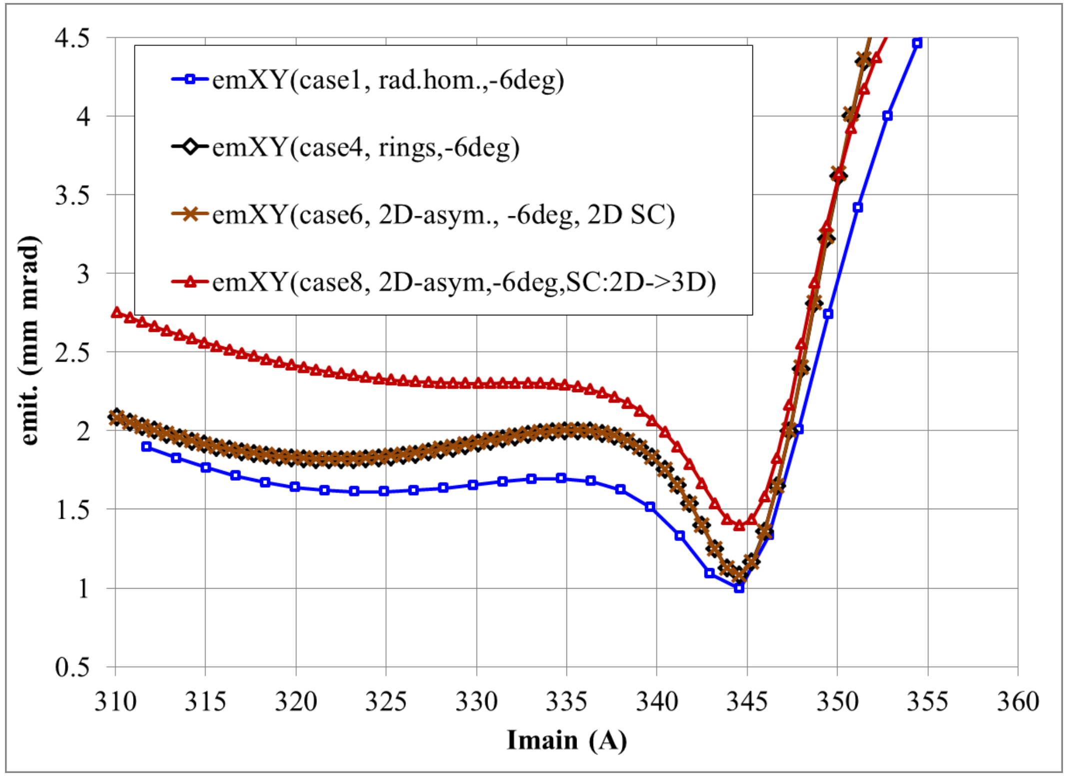

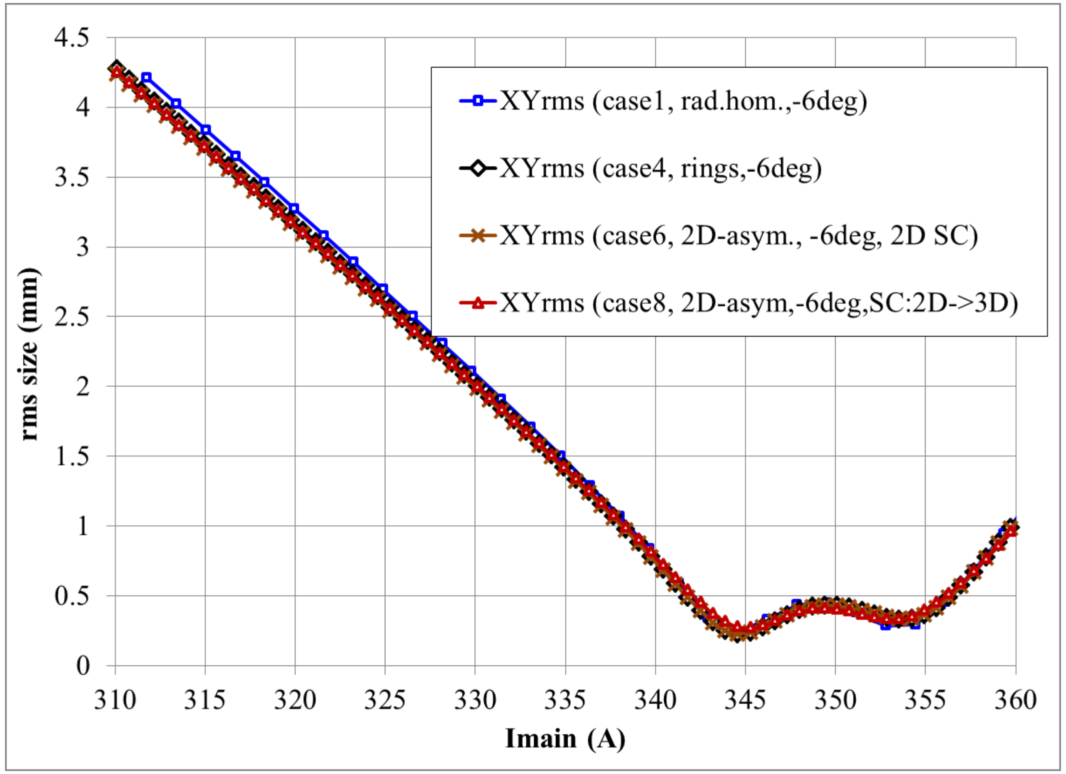

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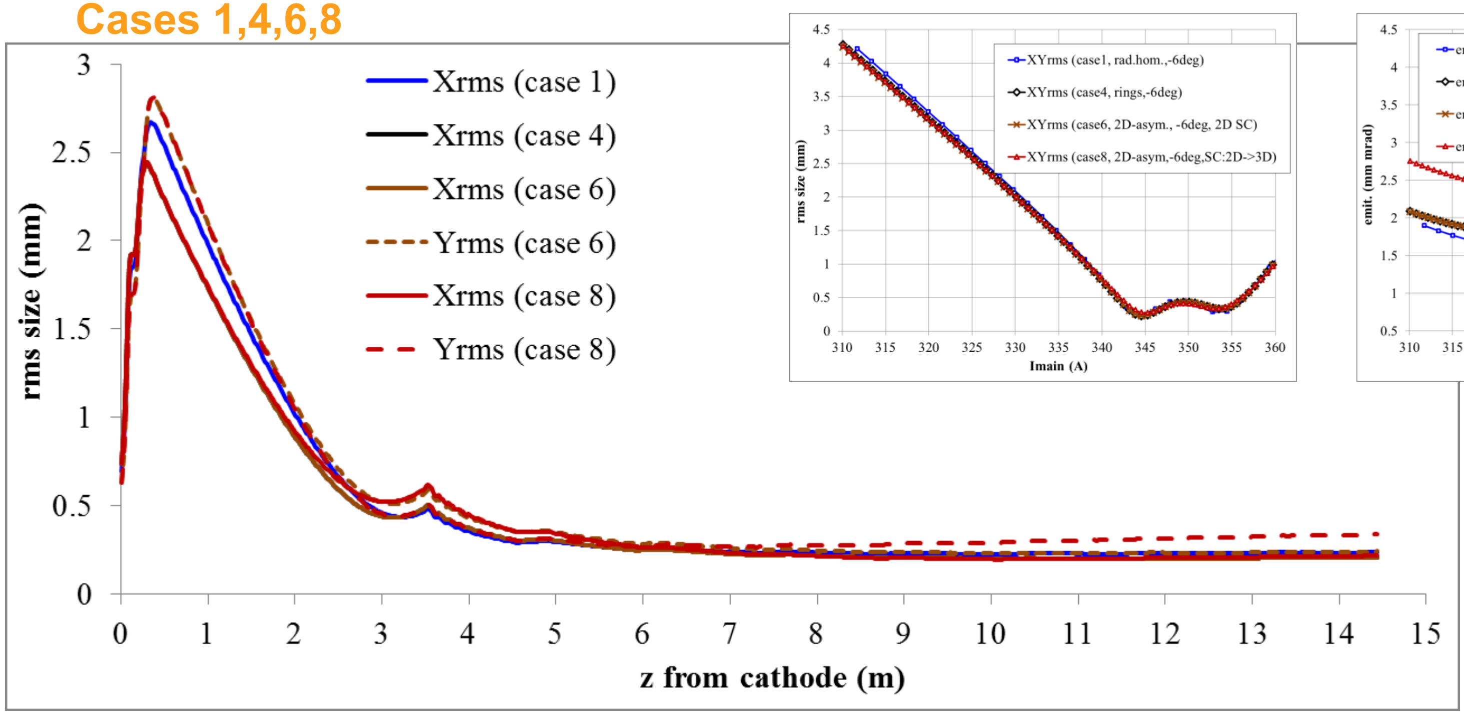

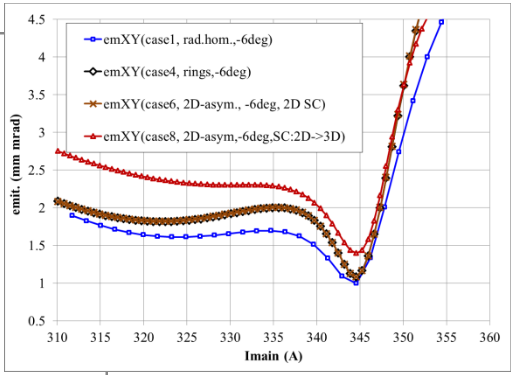

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5	Core+Halo=Rings	2D	0°
6	**2D asymmetric**	**2D**	**-6°**
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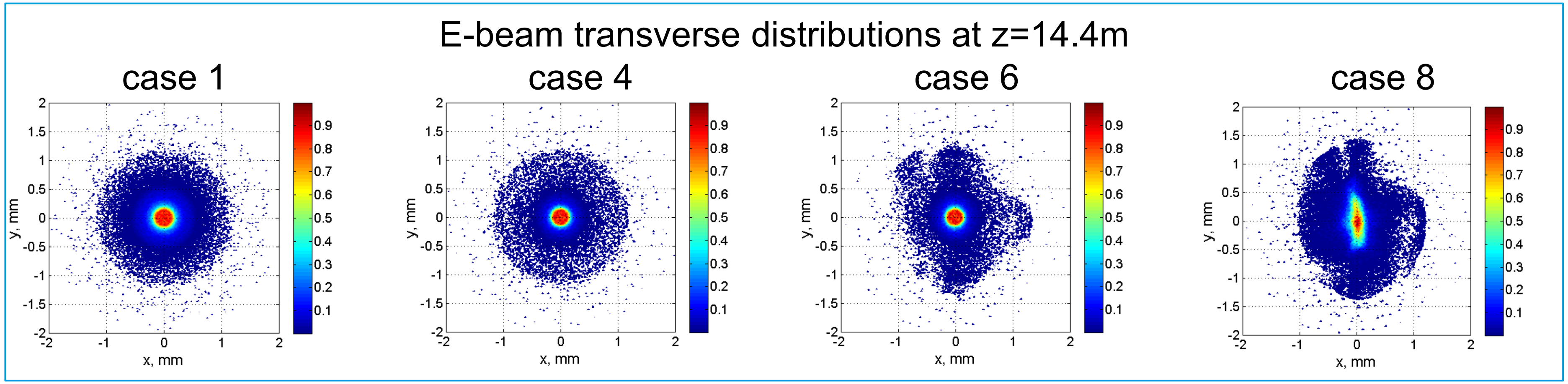

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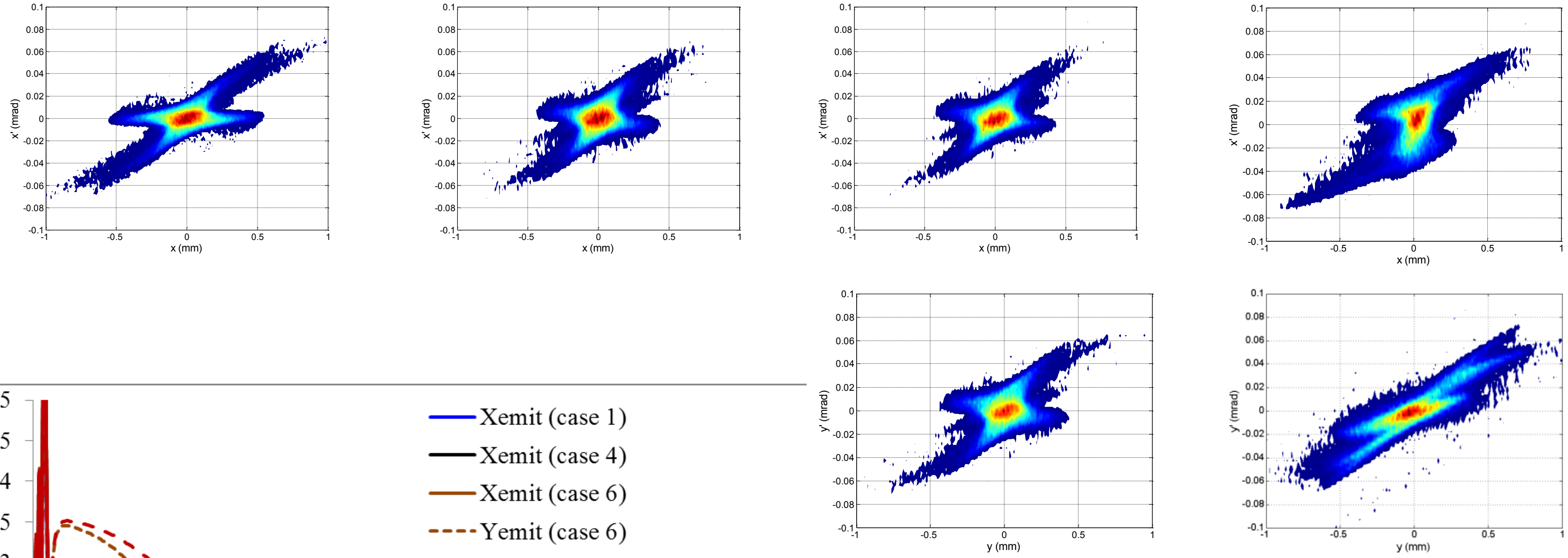
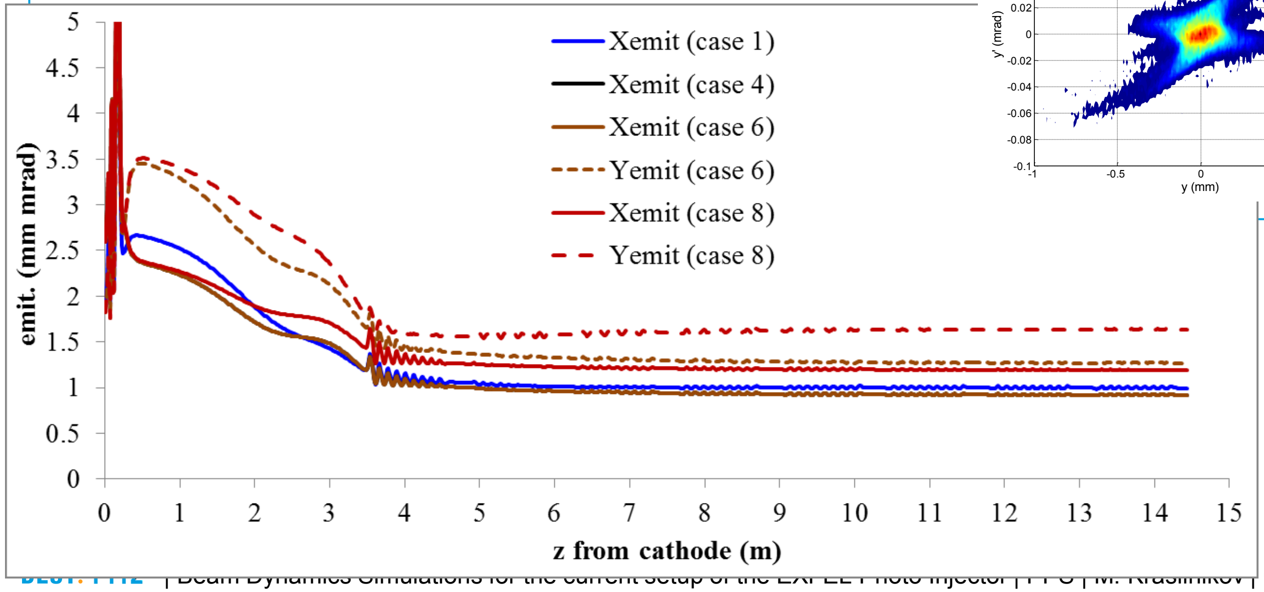
Phase spaces at z=14.4m

case 1 case 4 case 6 case 8



horizontal

vertical



Simulation cases summary

Impact of laser transverse distribution and gun phase onto beam emittance

Case	PC laser transverse	ASTRA SC	Gun phase w.r.t. MMMG	Projected normalized emittance at 14.44m [mm mrad]			
				Imain* [A]	X-emittance	Y-emittance	XY-emittance→min*
1	Rad.homogen.	2D	-6°	344.6	1.00	1.00	1.00
2	Rad.homogen	2D	0°	346.2	0.75	0.75	0.75
3	Rad.homogen	2D	-1.48° (opti)	345.5	0.69	0.69	0.69
4	Core+Halo=Rings	2D	-6°	344.6	1.08	1.08	1.08
5	Core+Halo=Rings	2D	0°	346.6	0.95	0.95	0.95
6	2D asymmetric	2D	-6°	344.6	0.92	1.27	1.08
7	2D asymmetric	2D	0°	346.0	0.77	1.11	0.92
8	2D asymmetric	2D→3D	-6°	344.6	1.19	1.63	1.39
9	2D asymmetric	2D→3D	0°	346.0	1.00	1.48	1.22

Conclusions (preliminary)

- Beam dynamics simulations (ASTRA) have been performed for the EXFEL photo injector setup (19-22.10.2017):
  - Ecath=53MV/m
  - Gun phase = MMMG, MMMG-6° (<Pz>~6.0MeV/c)
  - Photocathode laser: temporal – Gaussian 6 ps rms, BSA=1.2mm (ideal radial homogeneous with 0.3 mm rms, core+halo=rings, 2D asymmetric distribution)
  - A1: Emax=34.42MV/m → final <Pz>~154MeV/c
  - Various space charge options (2D, 2D→3D)

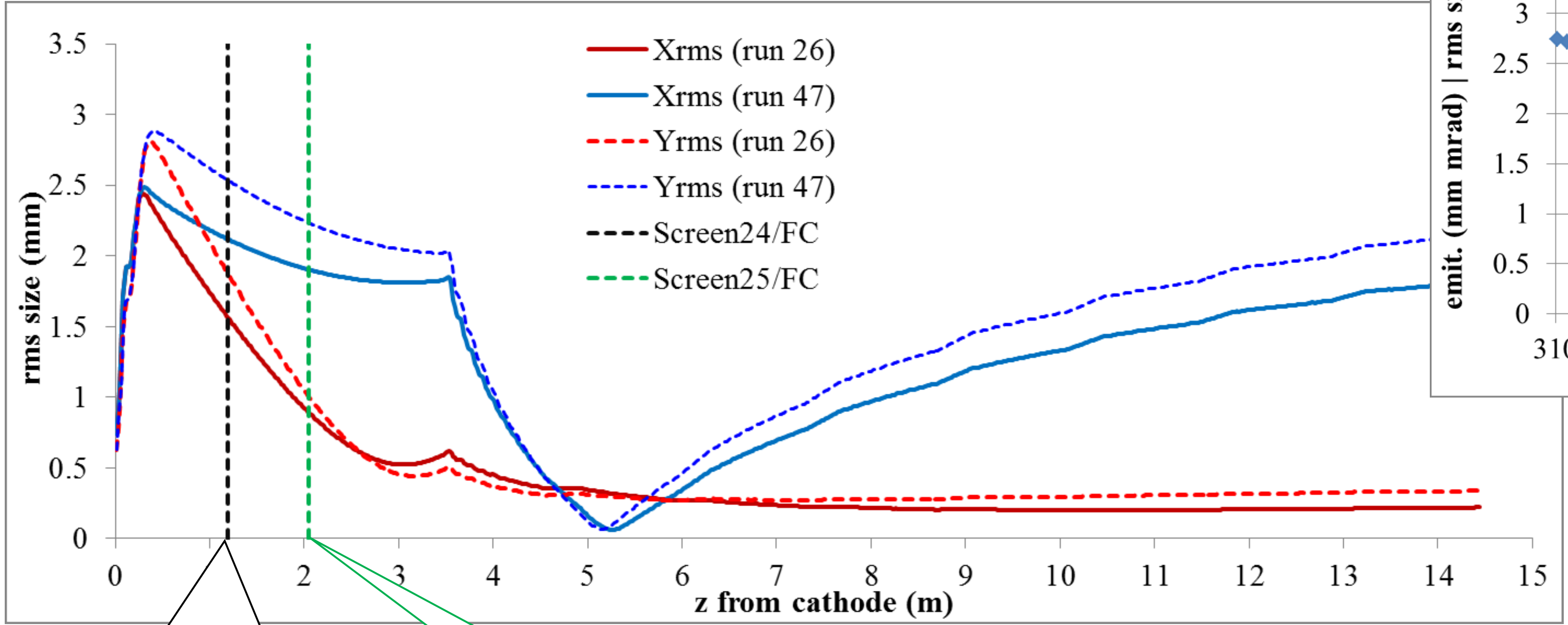
- Applying main solenoid calibration: MaxB[T]=-(0.0000372+0.000588*Imain[A]):
  - Two emittance minima for the gun phase=MMMG-6° found: 325A and 345A, the first $\varepsilon_{n,xy}$(325A)=1.6 mm mrad is improper (strong over focusing in the A1), but it seems to be closer to the default operation conditions (329.5A)
  - Beta functions are rather different for these solenoid currents: β(325A)=1360m, β(345A)=17m
  - The second (proper) minimum $\varepsilon_{n,xy}$(345A)=1.0 mm mrad can be improved by additional tuning (Laser XYrms=0.295mm, Gun phase = -1.48°, MaxB=-0.20318T) to $\varepsilon_{n,xy}$(345A)=0.7 mm mrad → best expected (“ideal” laser)
  - Applying current laser distribution → min “realistic” emittance ~1.0-1.2 mm mrad
  - Results of measurements using quadrupoles could be explained by rather large halo of electron beam while the core is rather compact…

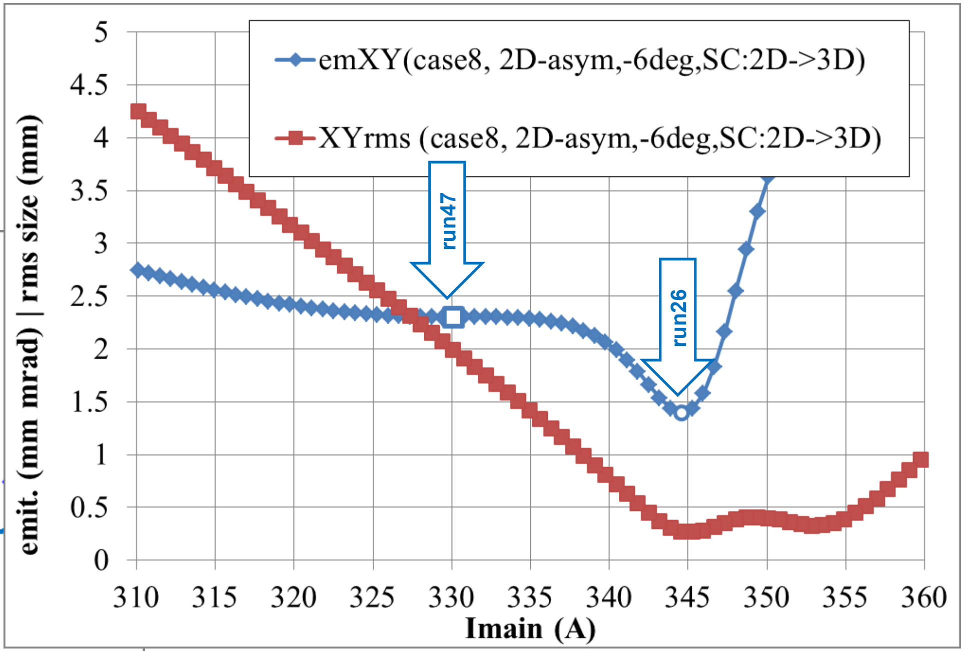
- From PITZ experience a mismatch of 2-6A in the solenoid values are not unusual, but 15-20A is too much!
  - PITZ experience (rms size) → correction factor 0.982; current EXFEL needs 1.05!

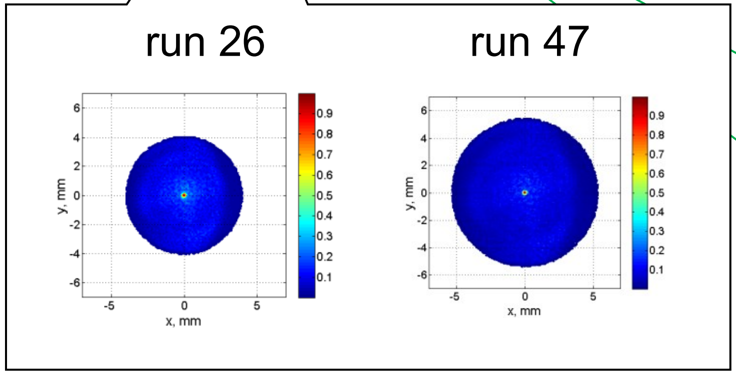
- Next steps (proposals):
  - Measure beam distributions at screens in front of A1 as a function of the main solenoid current, (vs. corresponding simulations)
  - If it works, new beam matching (quadrupoles) has to be found, beam transport etc…

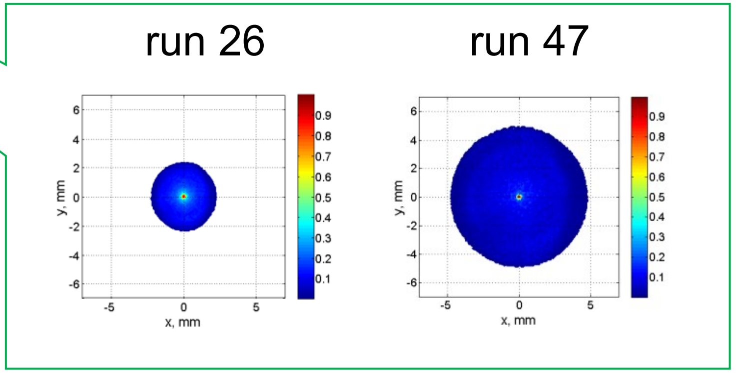
E-beam size along photo injector

Including first two screens in front of A1



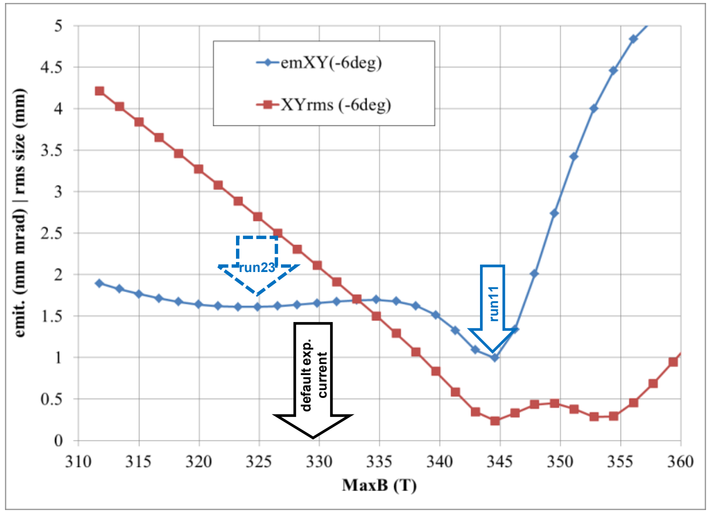


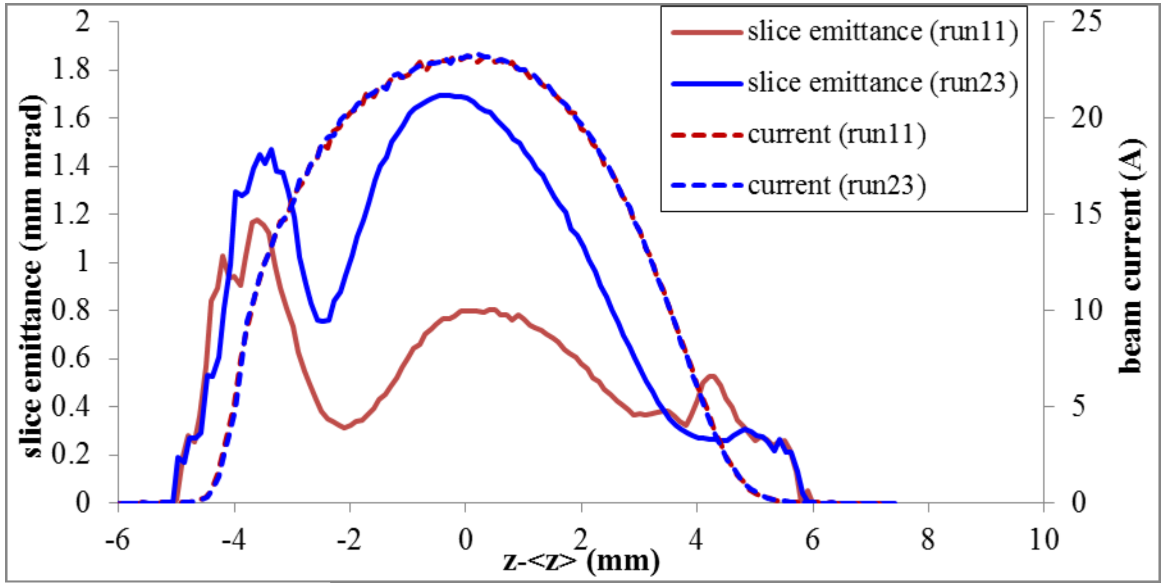


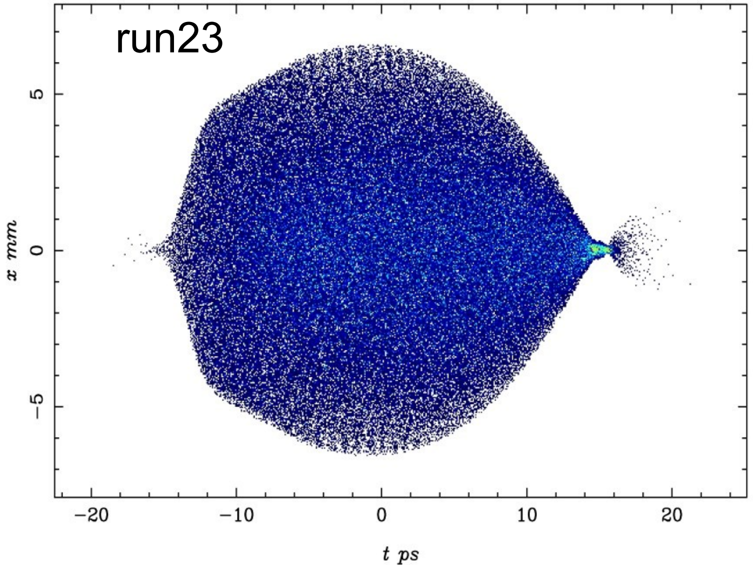


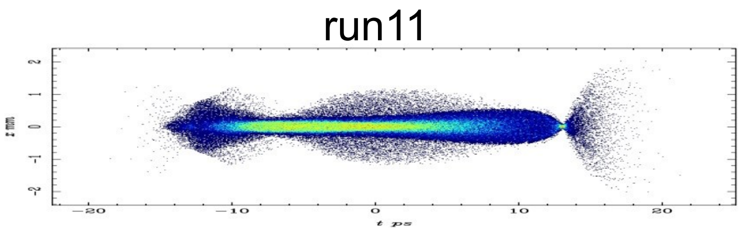
Beam monitors: Runs 11 vs 23

Case 1: Gun phase=MMMG-6°



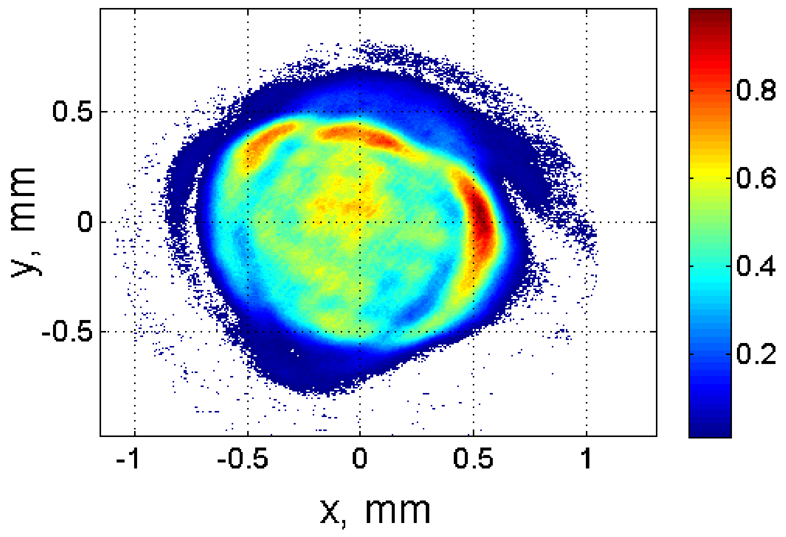






PC Laser BSA=1.2mm

EXFEL 20.10.2017



PITZ 15.09.2017