Electron beam brightness at PITZ in 2011 (measurements and simulations)
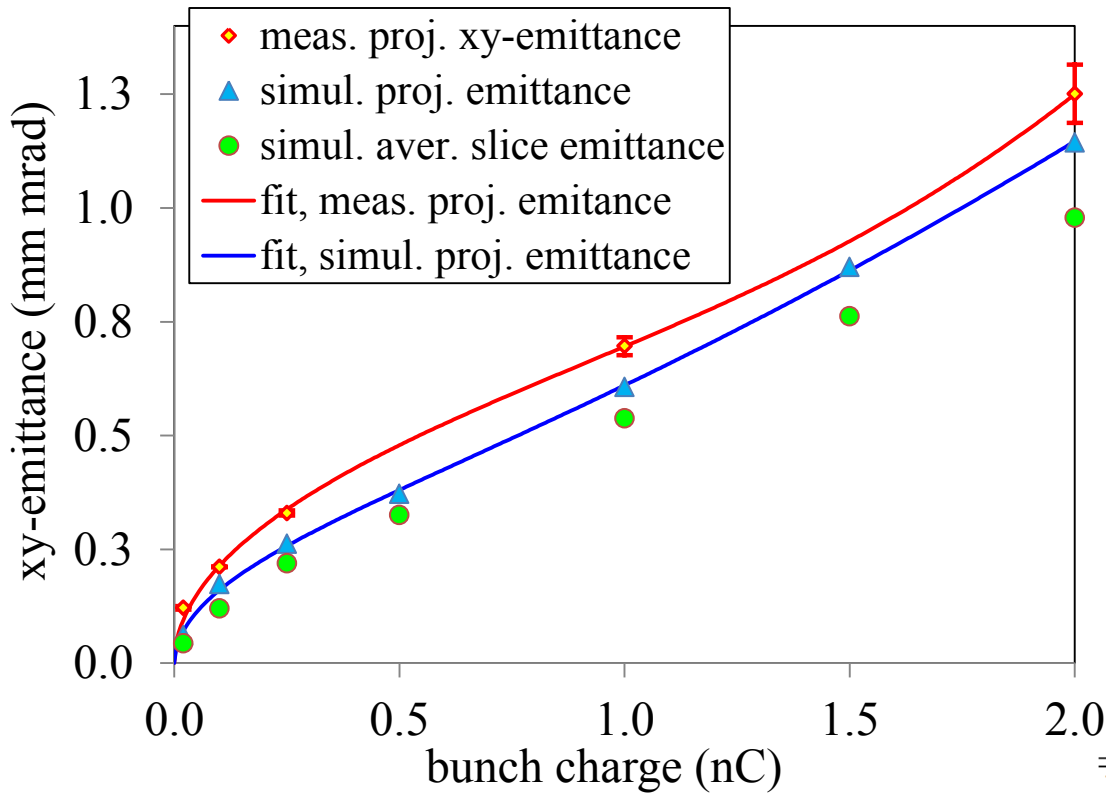
M.Krasilnikov,

PPS 16.05.2013

Emittance 2011: vs. bunch charge

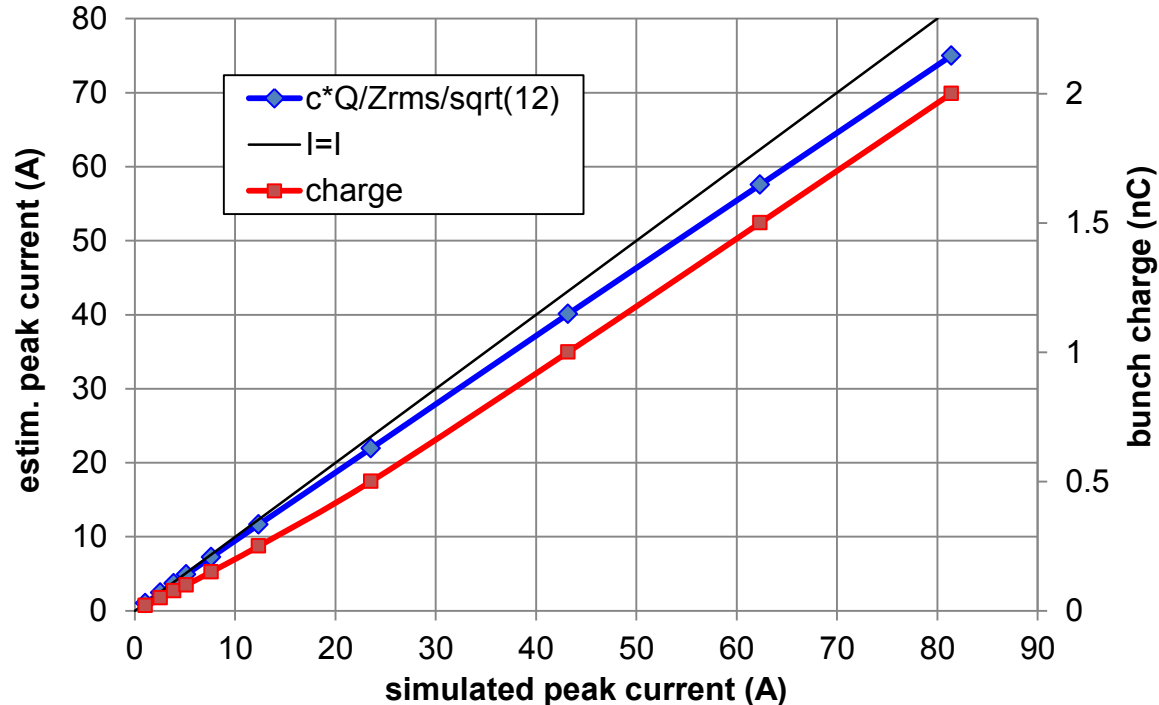$$\varepsilon_{fit}^{sim} = \sqrt{0.255 \cdot q + 0.117 \cdot q^{2.7758}}$$

$$\varepsilon_{fit}^{meas} = \sqrt{0.457 \cdot q + 0.028 \cdot q^{4.56}}$$

bunch charge	gun phase	0%
2.0 nC	0 deg	1.558±0.050
2.0 nC	6 deg	1.251±0.064
1.0 nC	0 deg	0.833±0.038
1.0 nC	6 deg	0.696±0.020
0.25 nC	0 deg	0.328±0.010
0.10 nC	0 deg	0.212±0.006
0.02 nC	0 deg	0.121±0.001

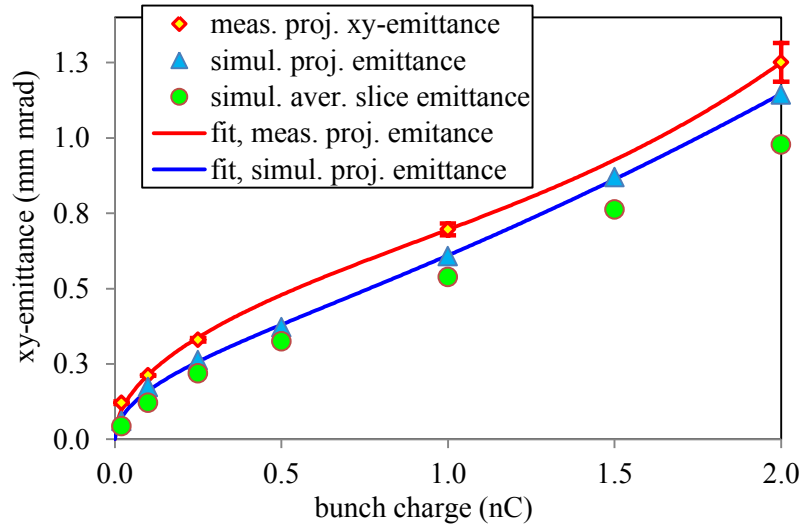M. Krasilnikov, et al., Phys. Rev. ST Accel. Beams 15, 100701 (2012).

Electron beam brightness

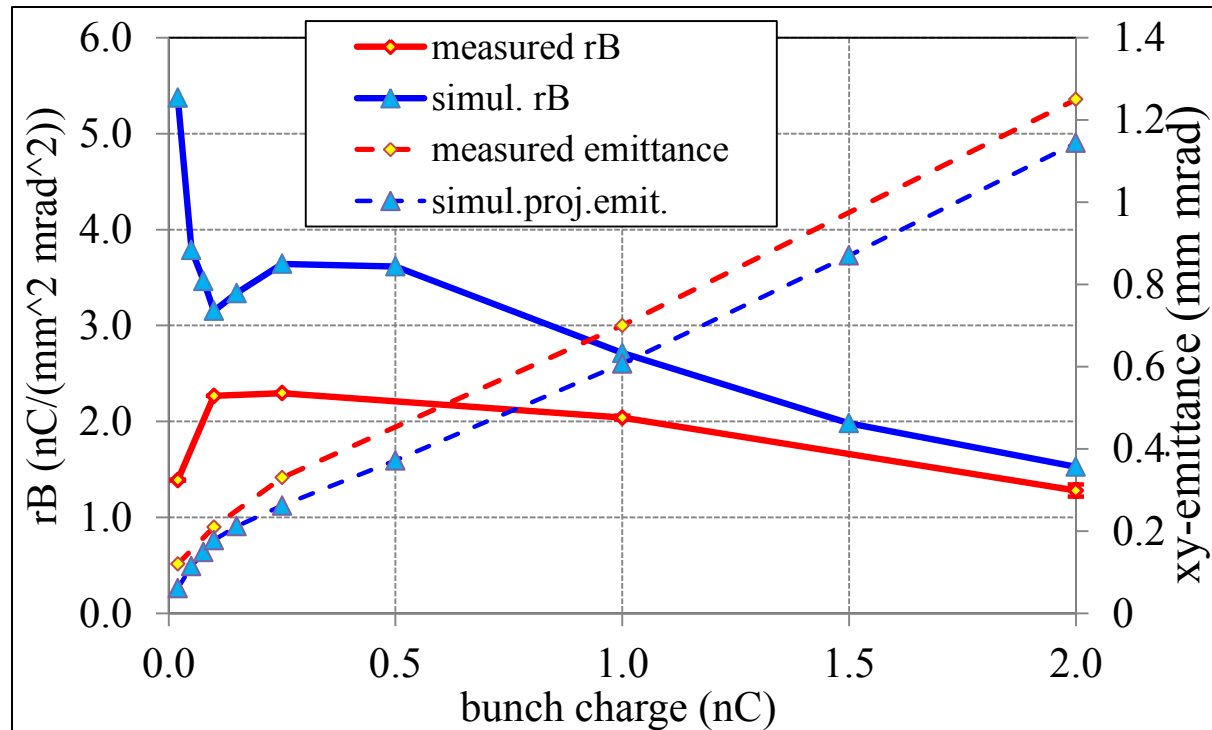$$B = \frac{2I_p}{\varepsilon_x \varepsilon_y}$$

For the PITZ experimental data 2011:

$$rB = \frac{Q}{\varepsilon_x \varepsilon_y}$$

Electron beam brightness rB in 2011

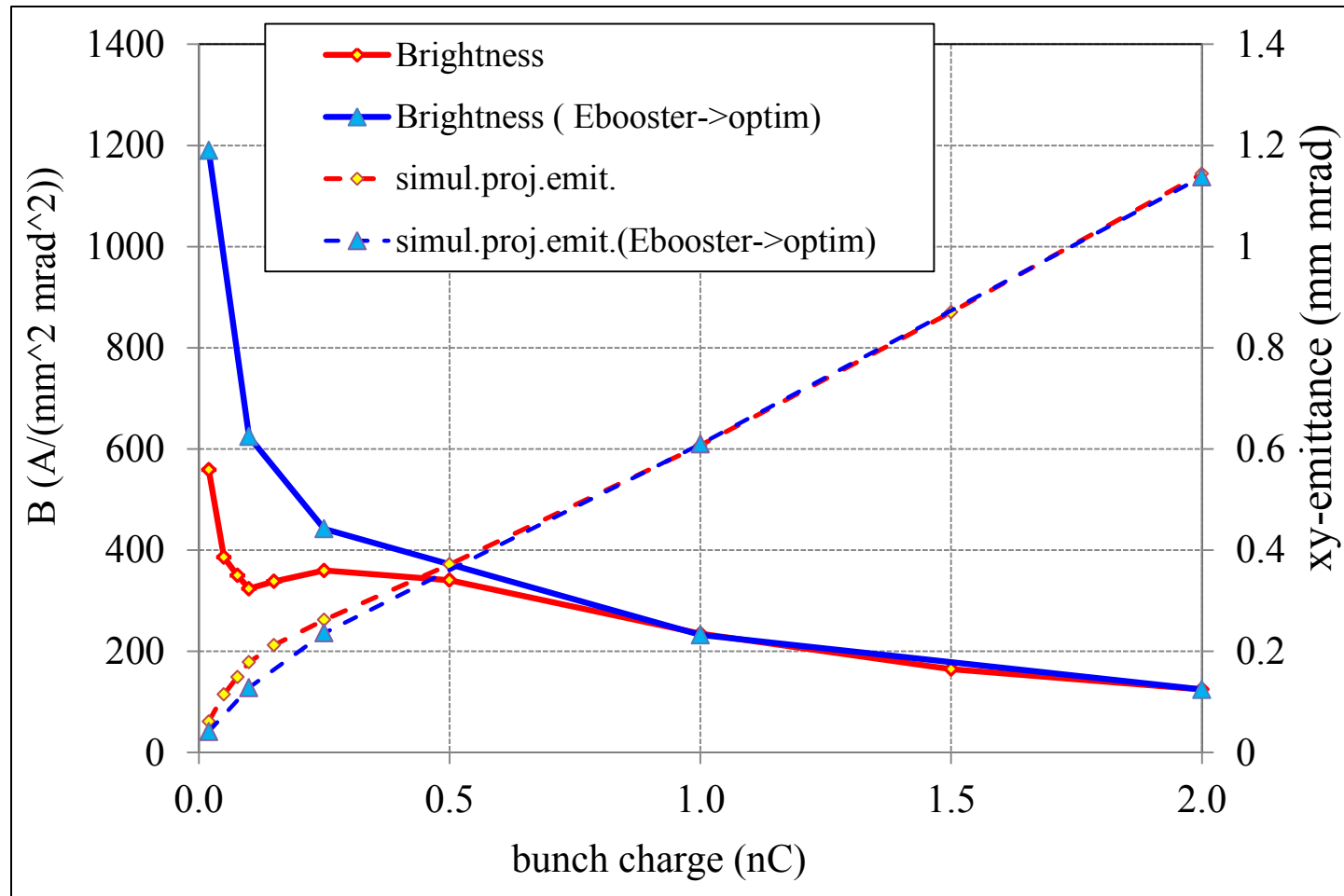$$rB = \frac{Q}{\varepsilon_x \varepsilon_y}$$

Simulated electron beam brightness

$$B = \frac{2I_p}{\varepsilon_x \varepsilon_y}$$

Optimization (ASTRA simulations):
- Minimize the projected emittance at z=5.74m (EMSY1)
- Nominal (Ebooster=20MV/m)*
- Ebooster optimized ➔ Data from G.Vashchenko (e.g. Ebooster(20pC)=0!)

Nominal optimized parameters

|	parameter	unit	20pC	50pC	77pC	100pC	150pC	250pC	500pC	1nC	1.5nC	2nC
cathode laser	temporal	profile	Flat-top									
	transverse	distribution	radial homogen.									
	rt/FWHM\ft	ps	2/21.5\2									
	Trms	ps	6.27									
	XYrms	mm	0.037	0.0702	0.09086	0.1478	0.1845	0.230	0.300	0.401	0.5001	0.600
	Ek	eV	0.55									
	th.emit.	mm mrad	0.031	0.059	0.077	0.125	0.156	0.195	0.254	0.340	0.424	0.508
RF-gun	Ecath	MV/m	60.58									
	phase*	deg	1.43	1.6495	1.384	1.46	1.32	1.01	0.12	-1.40	-2.33	-2.63
	maxBz	T	-0.2243	-0.2265	-0.2269	-0.2268	-0.2269	-0.2272	-0.2275	-0.2279	-0.2281	-0.2284
CDS boost	maxE		20	20	20	20	20	20	18.8	19.76	19.92	20
	phase*	deg	0									
e-beam @EMSY1	charge	nC	0.02	0.05	0.077	0.1	0.15	0.25	0.5	1	1.5	2
	energy	MeV	23.6	23.6		23.6	23.6	23.6	22.6	23.41	23.54	23.6
	rms length	mm	1.74	1.79	1.8147	1.77	1.80	1.86	1.97	2.16	2.26	2.31
	simul.proj.emit.	mm mrad	0.061	0.115	0.149	0.178	0.212	0.262	0.372	0.607	0.870	1.144
	simul. rB	nC/mm^2/mrd^2	5.375	3.787	3.465	3.153	3.338	3.642	3.617	2.714	1.982	1.528
	th./proj.em.	%	51%	52%	52%	70%	74%	74%	68%	56%	49%	44%
	<sl.emit.>	mm mrad	0.044			0.121		0.219	0.325	0.538	0.762	0.978
	LI/Tl ratio		50.8	26.8	20.7	12.7	10.2	8.2	6.3	4.7	3.8	3.1
	Le/Tl ratio		47.0	25.4	20.0	12.0	9.7	8.1	6.6	5.4	4.5	3.9
	SCD	q/XYrms^2/Zrms	8.4	5.7	5.1	2.6	2.5	2.5	2.8	2.9	2.7	2.4
	SCDprojected	q/XYrms^2/cTrms	7.8	5.4	5.0	2.4	2.3	2.5	3.0	3.3	3.2	3.0
	Ipeak	A	1.0	2.5	3.9	5.1	7.6	12.3	23.5	43.2	62.3	81.4
	c*Q/Zrms/sqrt(12)	estim Ipeak	1.0	2.4	3.7	4.9	7.2	11.6	21.9	40.1	57.5	75.0
	Brightness		558.7	385.7	349.9	323.6	338.2	359.7	340.5	234.4	164.7	124.4

Remarks:
- Optimization for several low charges added: 50pC; 77pC: 150pC
- SCD = space charge density
- LI/Tl ratio = cTrms(laser)/XYrms(laser)
- Le/Tl ratio = Zrms(e-beam)/XYrms(laser)

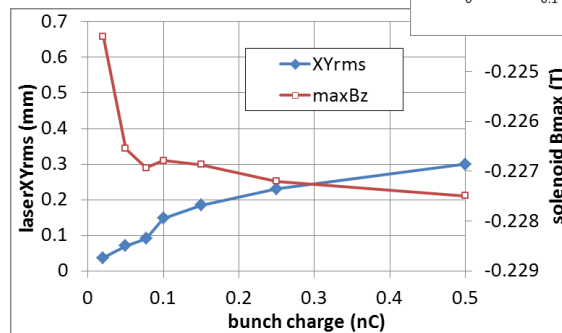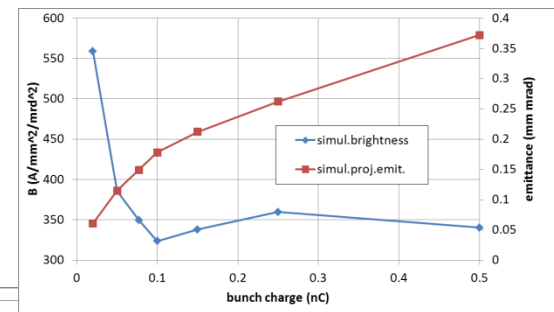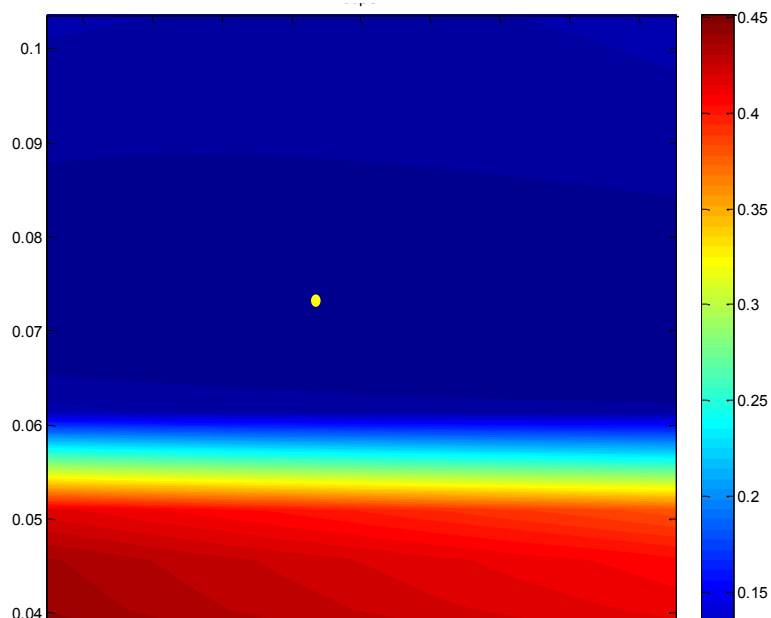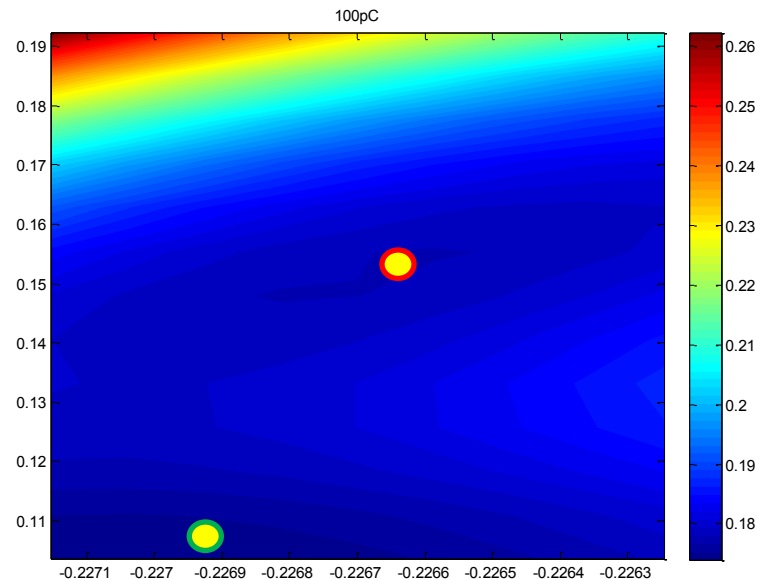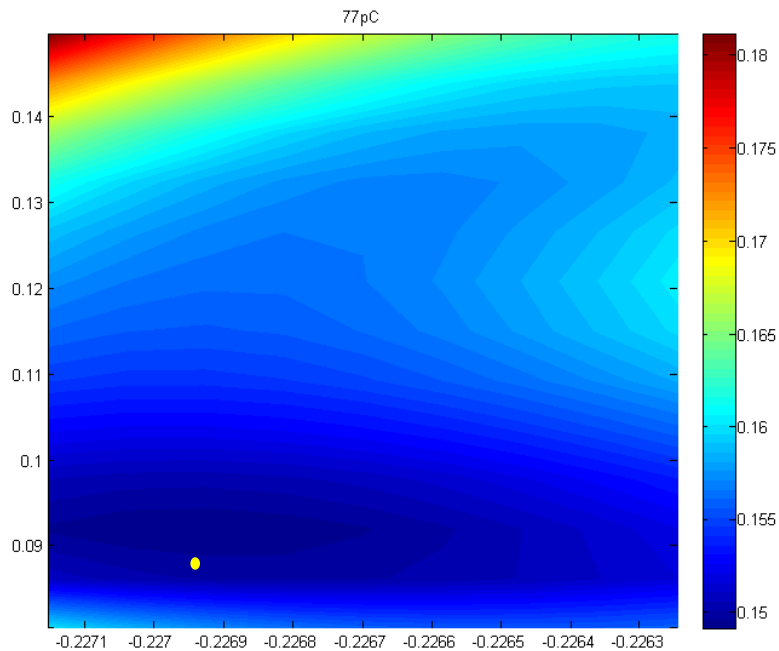# Nominal optimized parameters vs. bunch charge
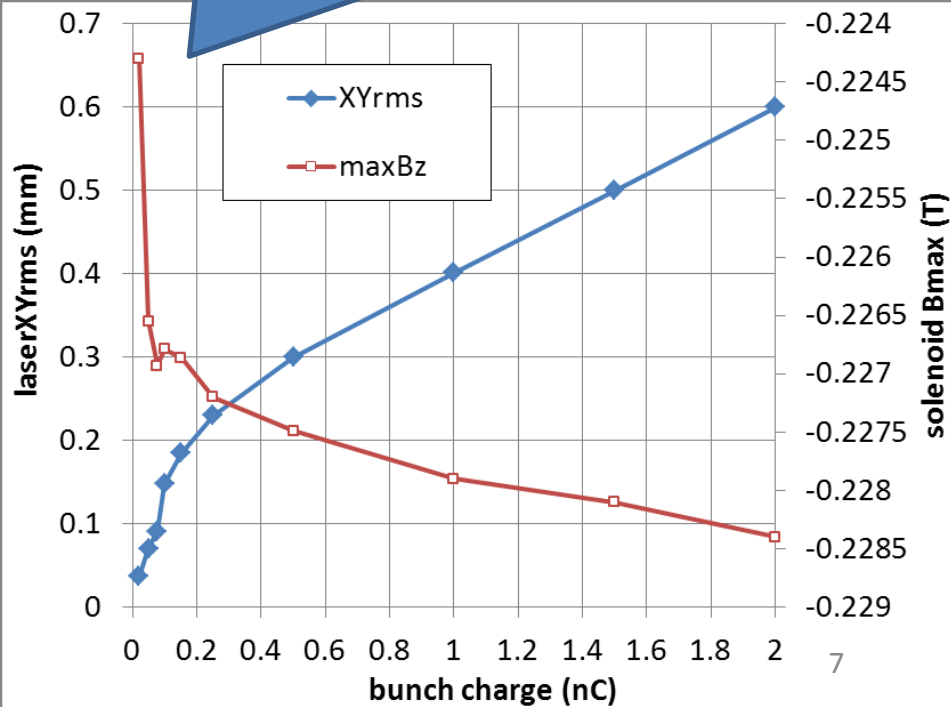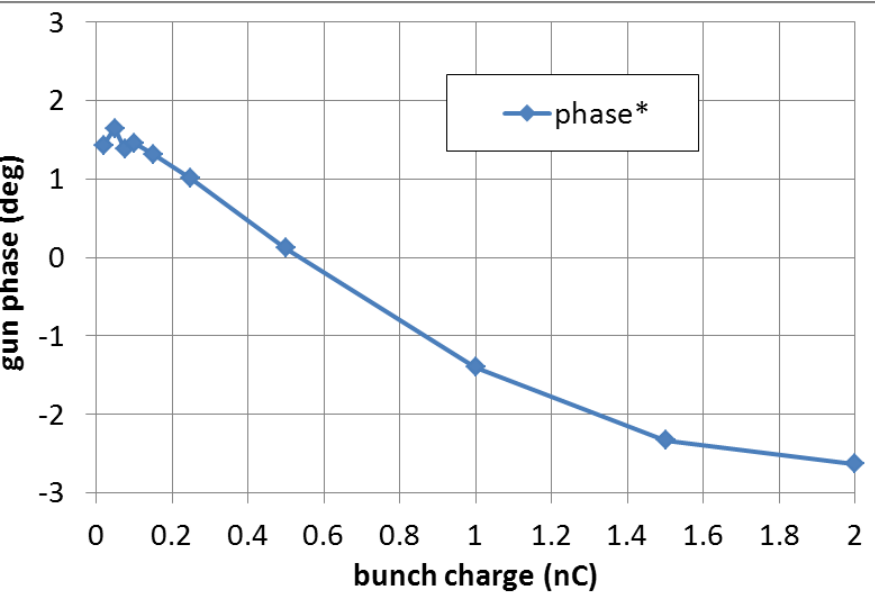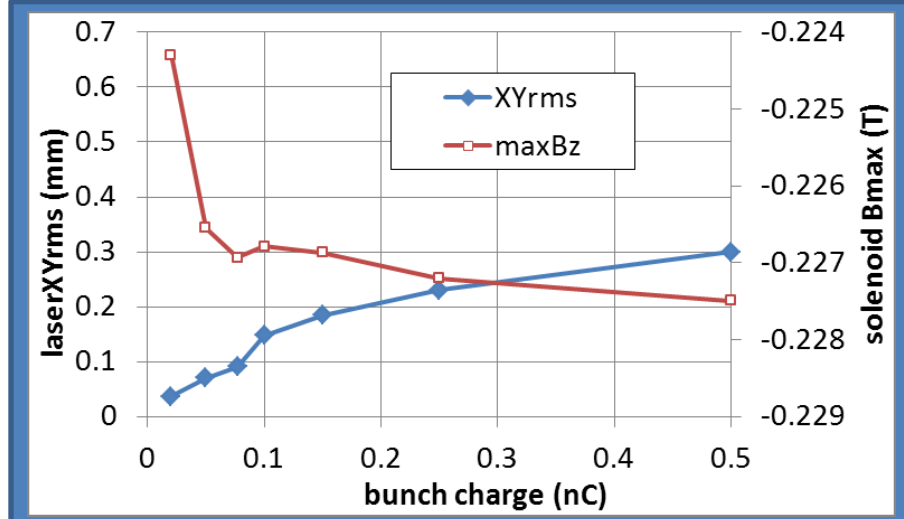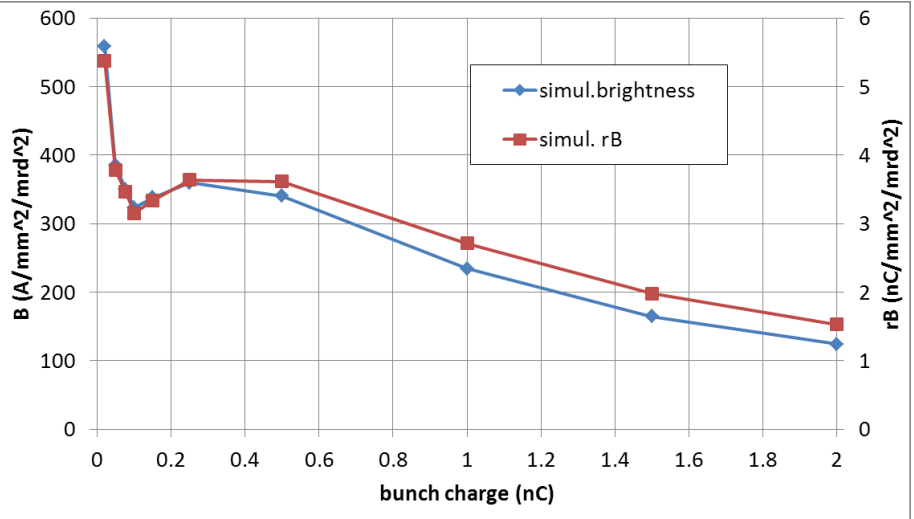
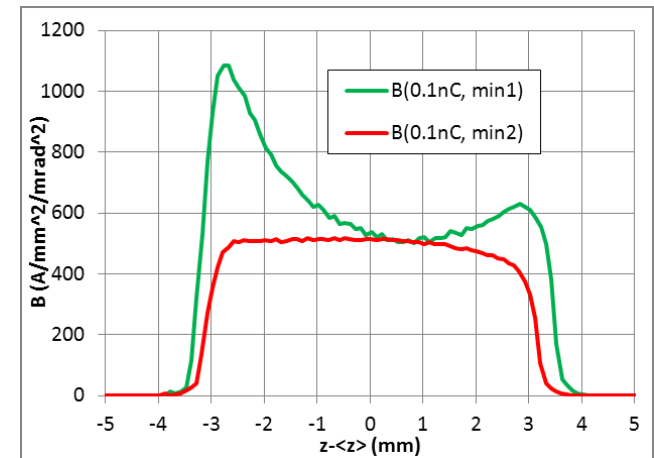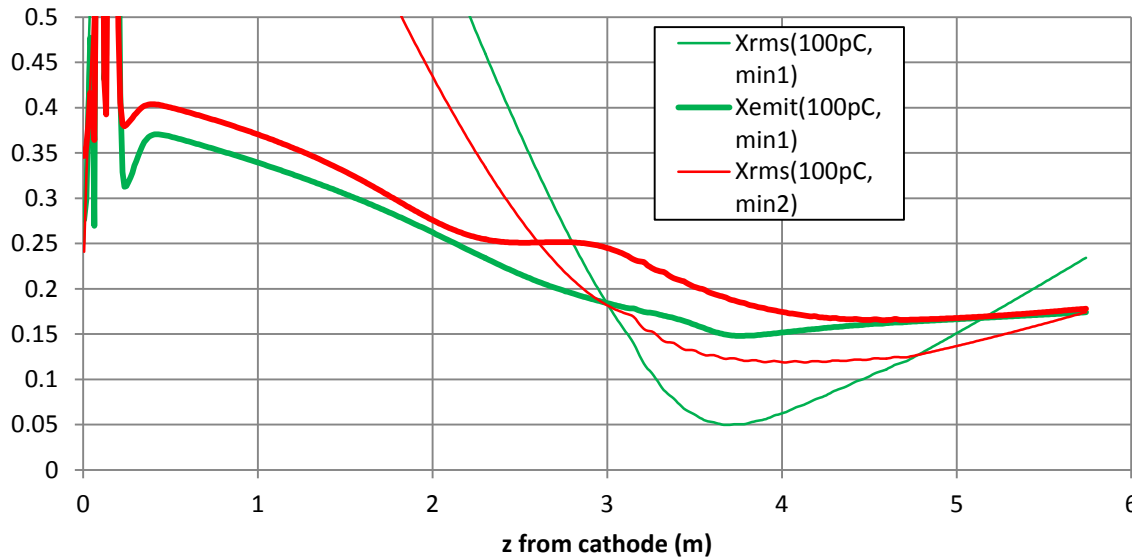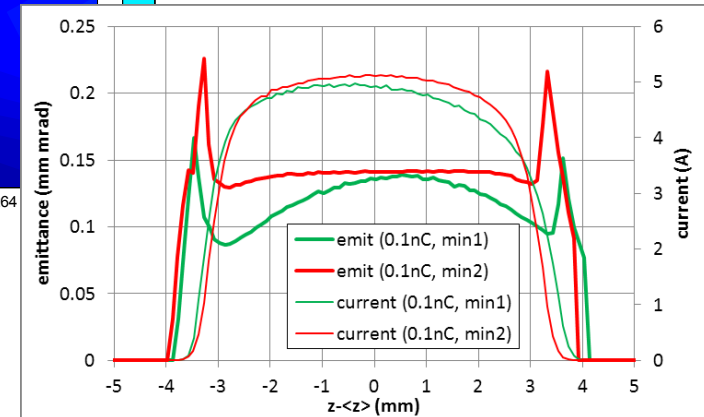# Nominal optimized parameters vs. bunch charge
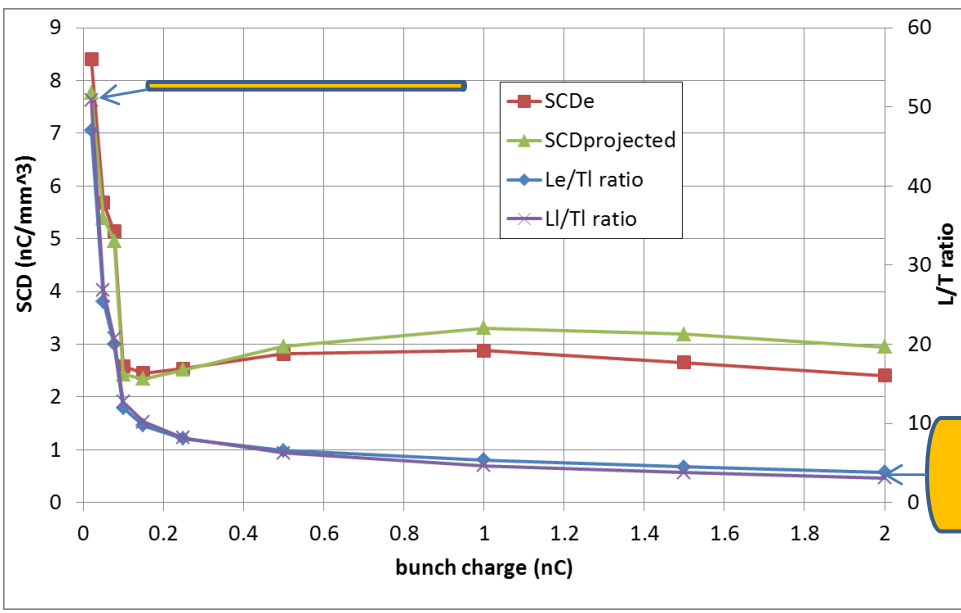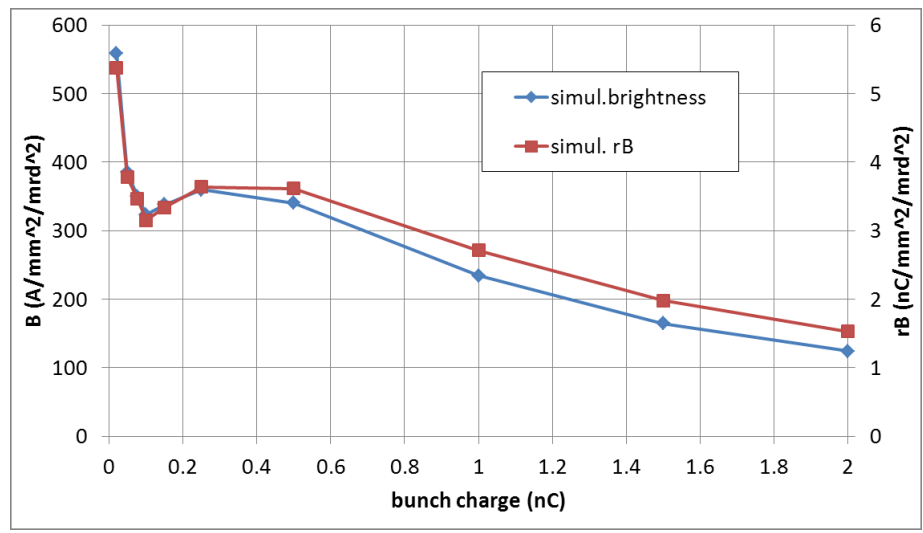
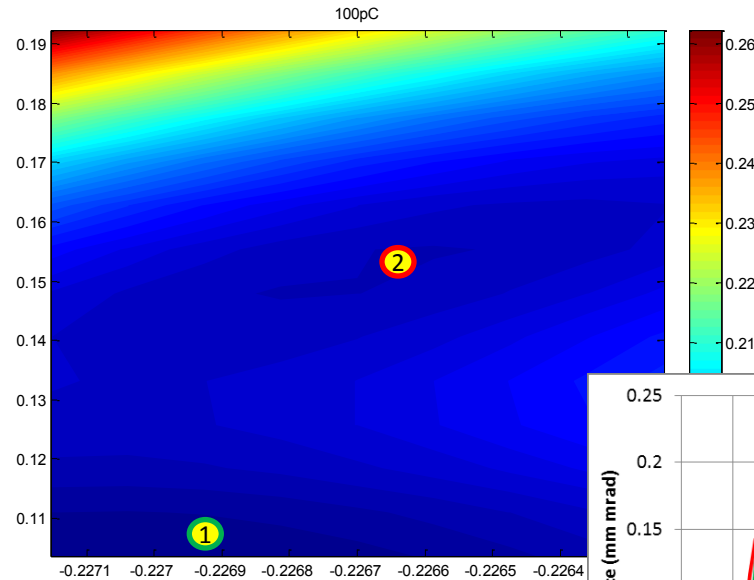SCDe=q/XYrms^2/Zrms

SCDprojected=q/XYrms^2/cTrms

Ll/Tl ratio = cTrms(laser)/XYrms(laser)

Le/Tl ratio = Zrms(e-beam)/XYrms(laser)

Optimization for low charges: Emittance(solBmax,laserXYrms)

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Optimization for 100pC: Emittance(solBmax,laserXYrms)
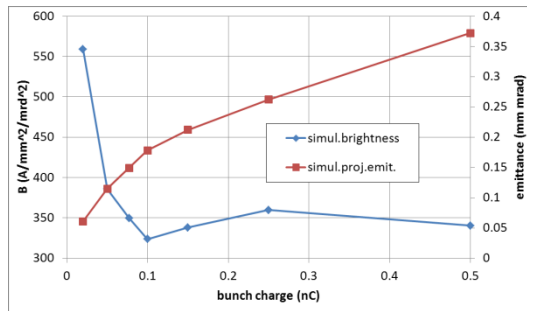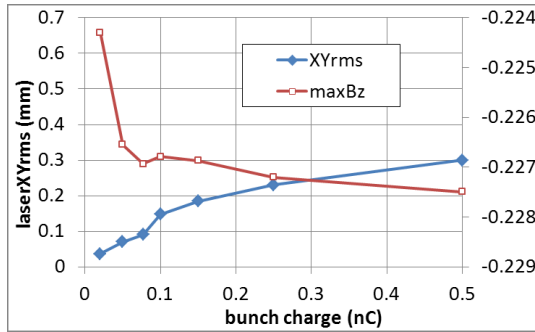
Simulated (slice) brightness

$$B = \frac{2I}{\varepsilon_x \varepsilon_y}$$

Brightness

Legend:
- B (2nC)
- B(1.5nC)
- B(1nC)
- B(0.5nC)
- B(0.25nC)
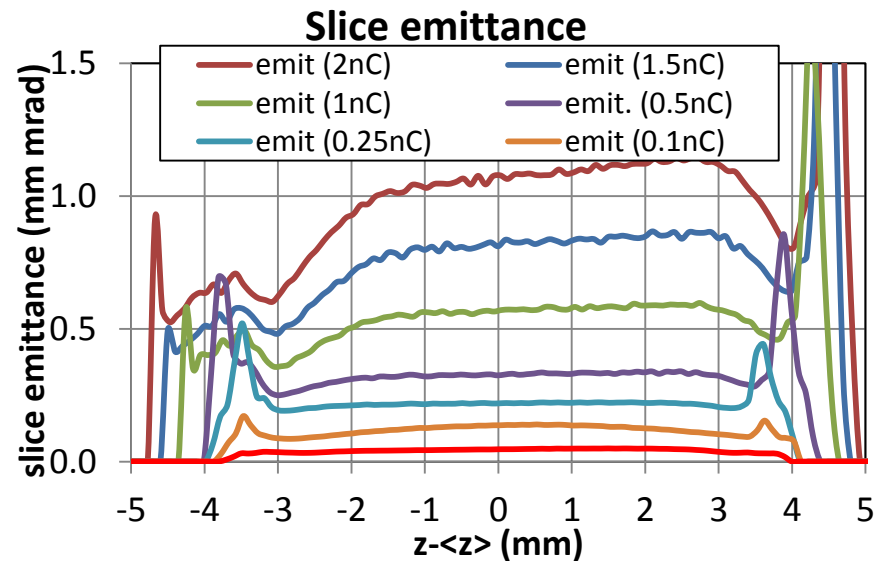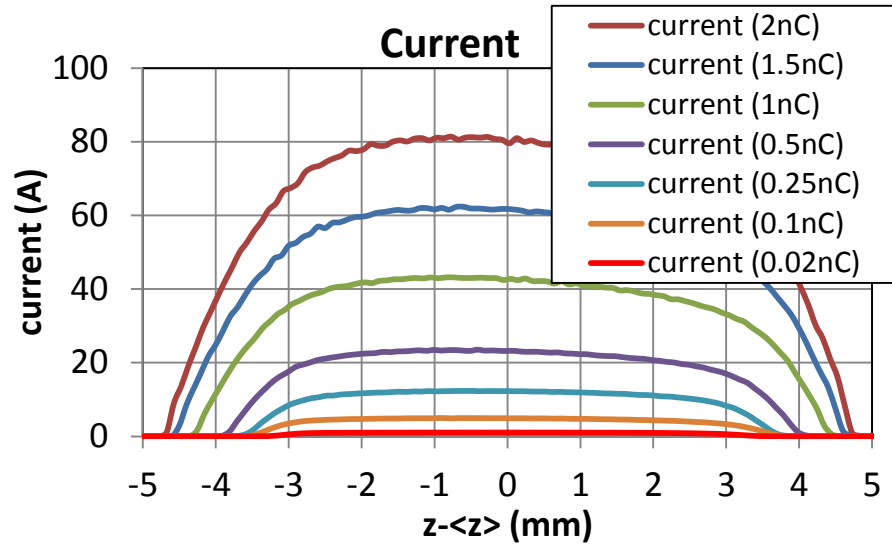- B(0.1nC)
- B(0.02nC)

brightness (A/(mm^2 mrad^2)) vs z-<z> (mm)

Current

Legend:
- current (2nC)
- current (1.5nC)
- current (1nC)
- current (0.5nC)
- current (0.25nC)
- current (0.1nC)
- current (0.02nC)

current (A) vs z-<z> (mm)

Slice emittance

Legend:
- emit (2nC)
- emit (1.5nC)
- emit (1nC)
- emit. (0.5nC)
- emit (0.25nC)
- emit (0.1nC)

slice emittance (mm mrad) vs z-<z> (mm)

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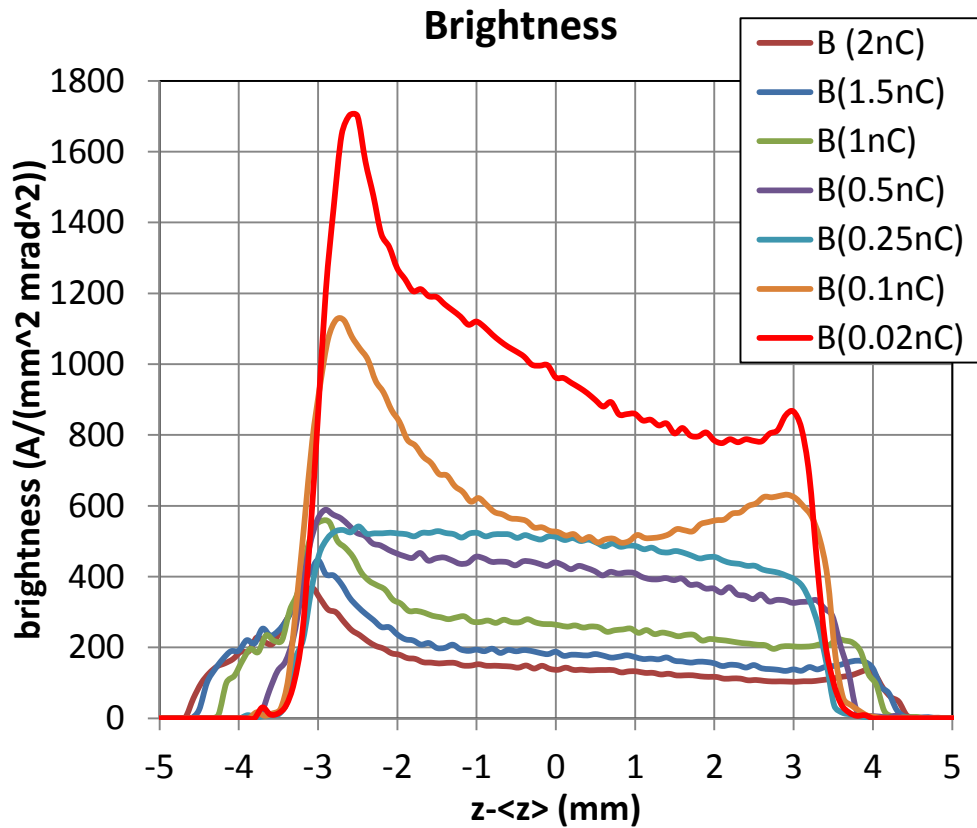
Conclusions and outlook

- Electron beam brightness:
  - Standard definition $B = \frac{2I_p}{\varepsilon_x \varepsilon_y}$ and "reduced" $rB = \frac{Q}{\varepsilon_x \varepsilon_y}$
  - Measured-2011 vs. simulated
  - Measured at 20pC $\downarrow$, whereas the simulated $\uparrow$ ➔
                                    ➔ measurement discrepancy?
- Simulations:
  - Fixed booster gradient vs. optimized ➔ the role of the booster in the beam dynamics in the photo injector
  - Low charge optimization for the fixed setup ➔ double minima in $\varepsilon_{xy}(maxB, laserXYrms)$
  - Slice brightness ➔ its further propagation in linac
  - Direct optimization of the brightness???