Investigation on photogun beam affected by RF coupler kick and solenoid stray or anormlous fields and compensation.

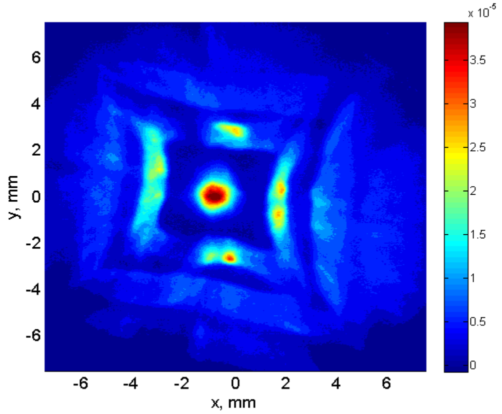
Content:

- Motivation
- General principle and quads model error field effect on the emittance

➔Beam size: critical at imperfect field position

➔Experimental investigations at PITZ

- Emittance compensation by quads corrector
- Summary and conclusion



Quantang Zhao
PPS, ZEUTHEN

13-02-2018

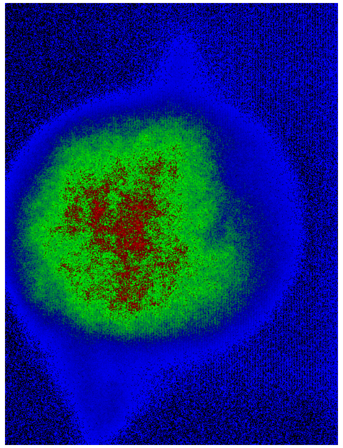
Motivation

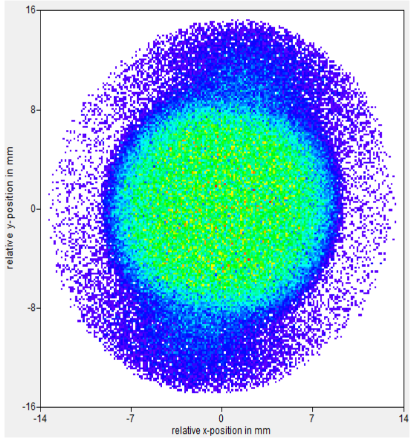
➔Try to better understand the beam dynamics discrepancy from simulation and experiment for PITZ gun

1. **Beam asymmetry observed in experiment and found due to imperfection field from RF coupler and solenoid by simulation.**

2. **Rotated Quadrupole model for these imperfect field can generate beam wings structure, fit good to experiment results.**

3. **How these imperfection fields from RF coupler and solenoid affect the beam dynamics.**



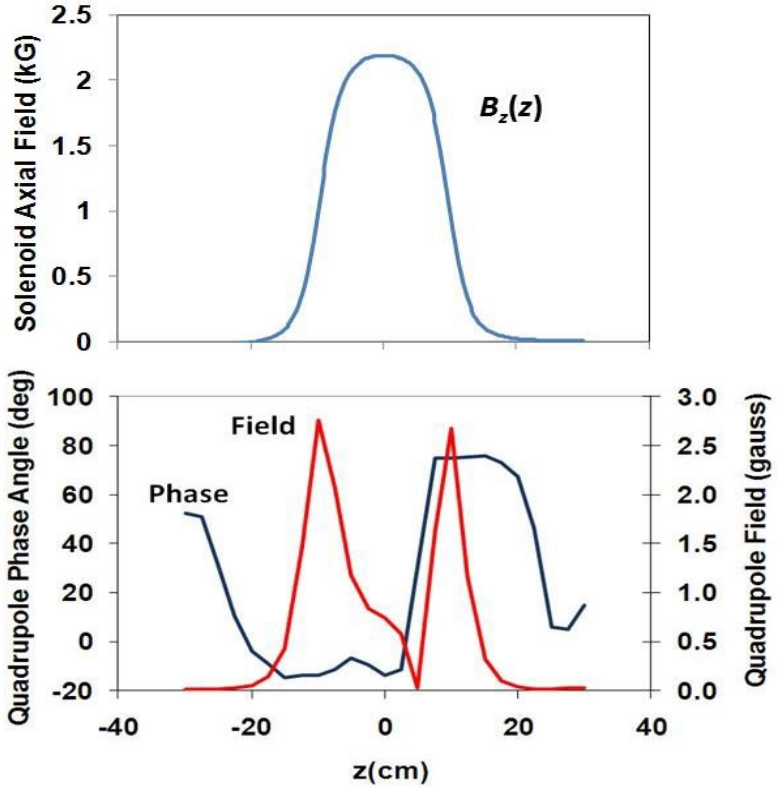


- ➢ The rotated quads position and rotated angle were estimated by ASTRA simulation:
- ✓ Position: around z=0.18m, **at the transition region of coupler to gun cavity**
- • Rotation angle: Skew quads[45 degree(negative polarity) or ~135 degree(positive polarity)].
- • Polarity: same, not effected by solenoid field polarity.
- ✓ Position: around z=0.36m, **near the exit region of the solenoid**
- • Rotation angle: normal quads.
- • Polarity: when change the solenoid polarity, the quads polarity also changed.

General principle

Solenoid fringe and stray or anomalous field

magnetic measurements for the LCLS-I gun solenoid



Solenoid plus rotated quadrupole model

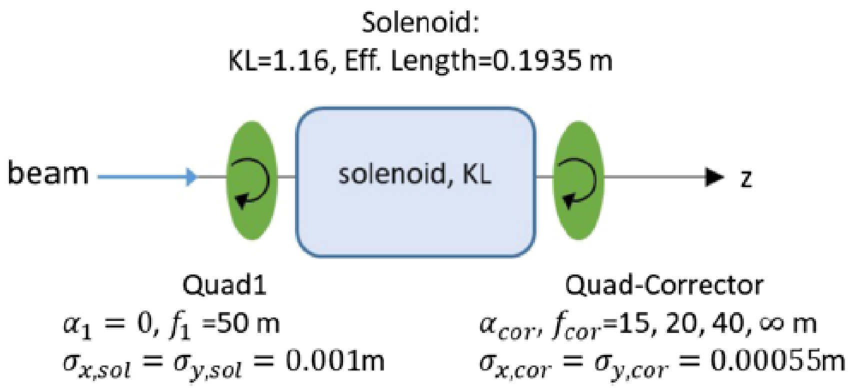


FIG. 5. Quadrupole-solenoid-quadrupole configuration and parameters used to compare emittance growth computed with the analytic model and numerical simulations shown in Fig. 6. The beam energy is 6 MeV.

Quad plus solenoid effect on the emittance:

$$\epsilon_{n,\mathrm{quad+sol}}(\alpha) = \sigma_{x,\mathrm{sol}}\sigma_{y,\mathrm{sol}} \frac{eQ}{mc} |\sin 2(KL+\alpha)|.$$

Compensation by quads corrector:

$$\epsilon_{n,\mathrm{qsq}} = \beta\gamma \left| \frac{\sigma_{x,\mathrm{sol}}\sigma_{y,\mathrm{sol}}}{f_1} \sin 2(KL+\alpha_1) + \frac{\sigma_{x,\mathrm{cor}}\sigma_{y,\mathrm{cor}}}{f_{\mathrm{cor}}} \sin 2\alpha_{\mathrm{cor}} \right|.$$

*David H. Dowell et al., Exact Cancellation of Emittance Due to Coupled Transverse Dynamics in Solenoids and RF Couplers, PHYSICAL REVIEW ACCELERATORS AND BEAMS 21, 010101 (2018)

General principle

RF coupler kick

The normalized emittance for the x-plane is defined as

$$\epsilon_n = \frac{\sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2}}{mc} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2} \tag{31}$$

After some tedious algebra, the coupler-induced emittance is found to be solely due to the cross-term, v_{xy}, of the complex voltage kick,

$$\epsilon_{n,coupler}(s) = \frac{eV_{acc}}{mc^2}\sigma_x^2\left|v_{xy}^r \cos\left(\frac{\omega s}{c} + \phi_{head}\right) + v_{xy}^i \sin\left(\frac{\omega s}{c} + \phi_{head}\right)\right| \tag{32}$$

Here v_{xy}^r and v_{xy}^i are the real and imaginary parts of v_{xy}.

Compensation by quads corrector:

$$\begin{pmatrix} x' \\ y' \end{pmatrix}_{\mathrm{total}} = \begin{pmatrix} x' \\ y' \end{pmatrix}_{\mathrm{coupler}} + \begin{pmatrix} x' \\ y' \end{pmatrix}_{\mathrm{quad}} = \begin{pmatrix} \left\{\tilde{v}_{xx} - \frac{\cos 2\alpha_{\mathrm{cor}}}{f_{\mathrm{cor}}}\right\}x + \left\{\tilde{v}_{xy} - \frac{\sin 2\alpha_{\mathrm{cor}}}{f_{\mathrm{cor}}}\right\}y \\ \left\{\tilde{v}_{xy} - \frac{\sin 2\alpha_{\mathrm{cor}}}{f_{\mathrm{cor}}}\right\}x - \left\{\tilde{v}_{xx} - \frac{\cos 2\alpha_{\mathrm{cor}}}{f_{\mathrm{cor}}}\right\}y \end{pmatrix}.$$

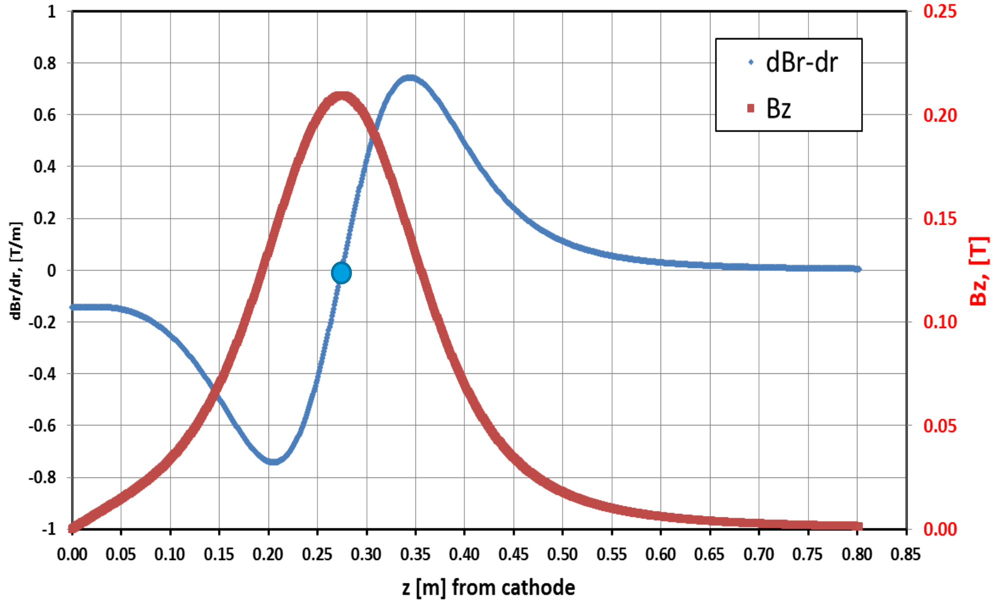
➔ The beam size at the imperfect field positions is critical for emittance and hava large effect on the beam.

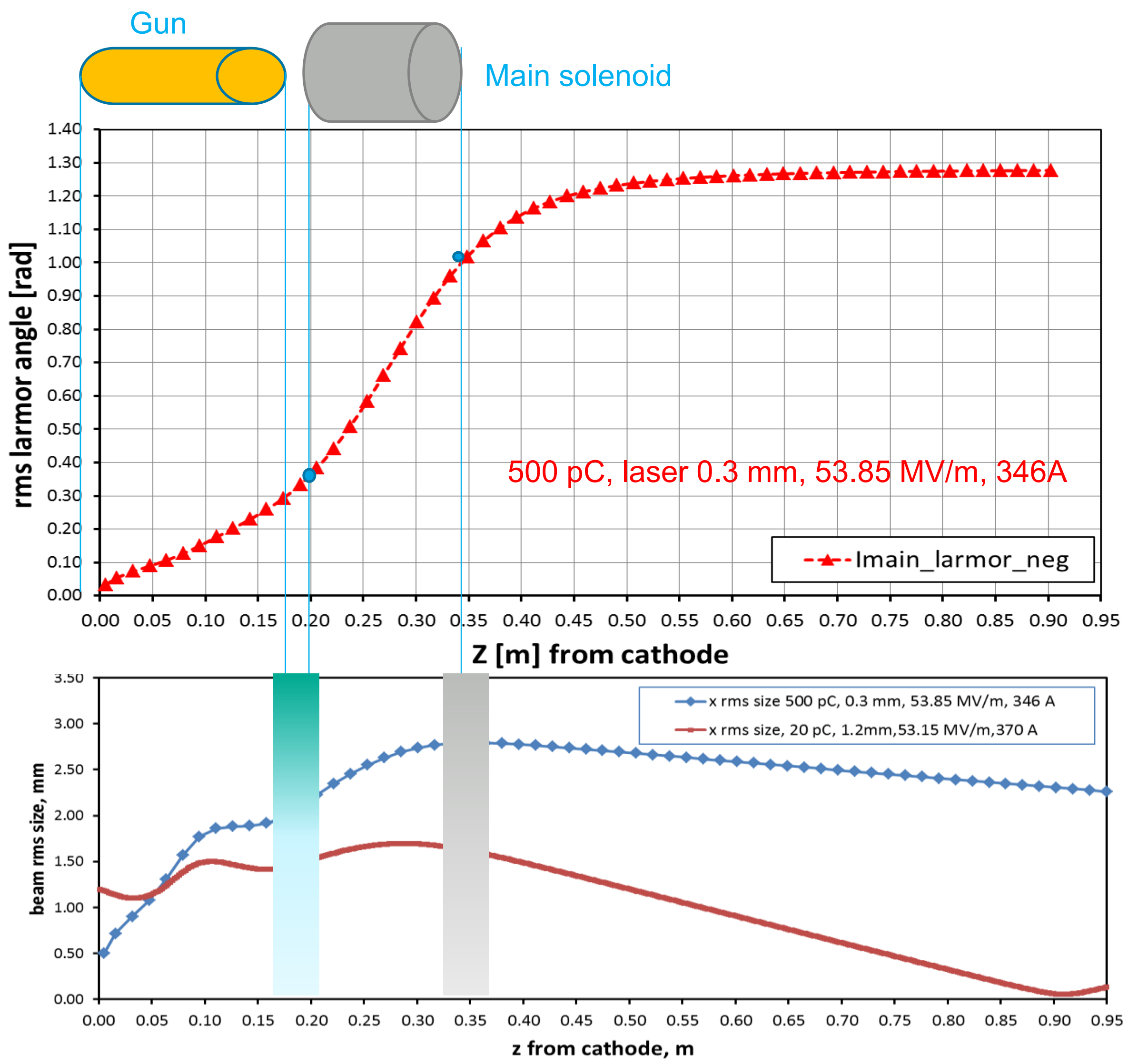
*David H. Dowell et al., Exact Cancellation of Emittance Due to Coupled Transverse Dynamics in Solenoids and RF Couplers, PHYSICAL REVIEW ACCELERATORS AND BEAMS 21, 010101 (2018)

Experimental investigations at PITZ

Beam size at imperfection fields positions.

Solenoid field map, 346 A



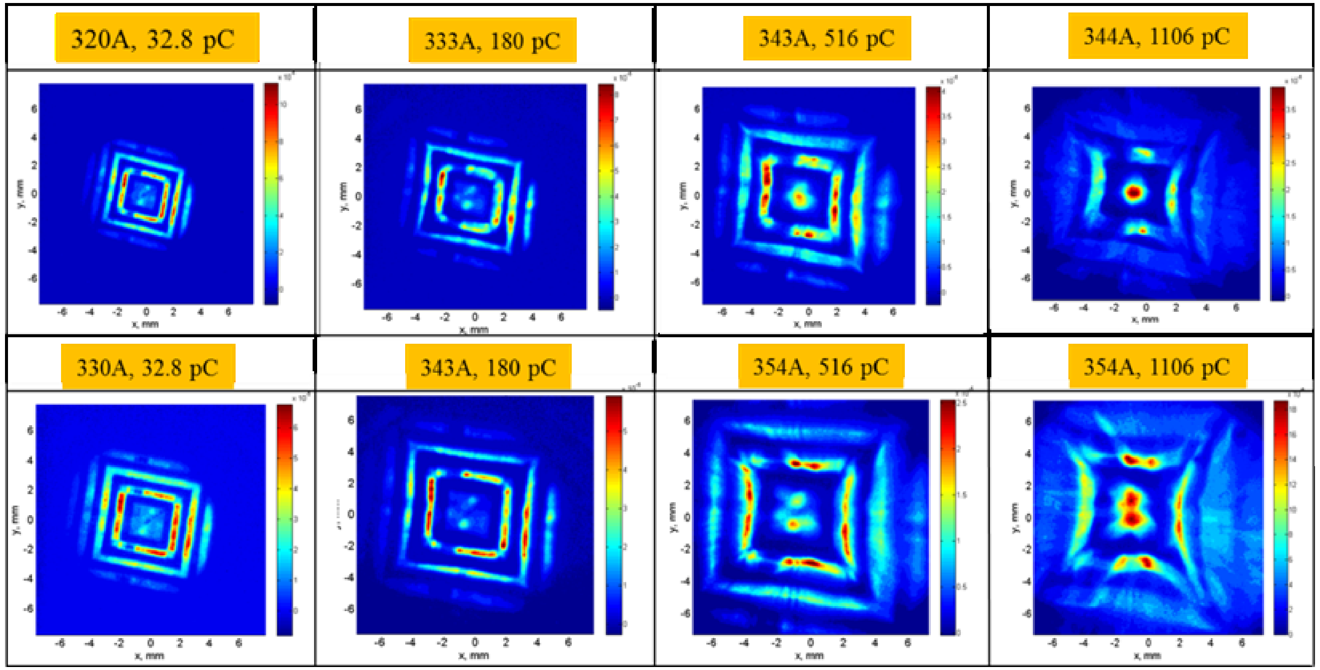


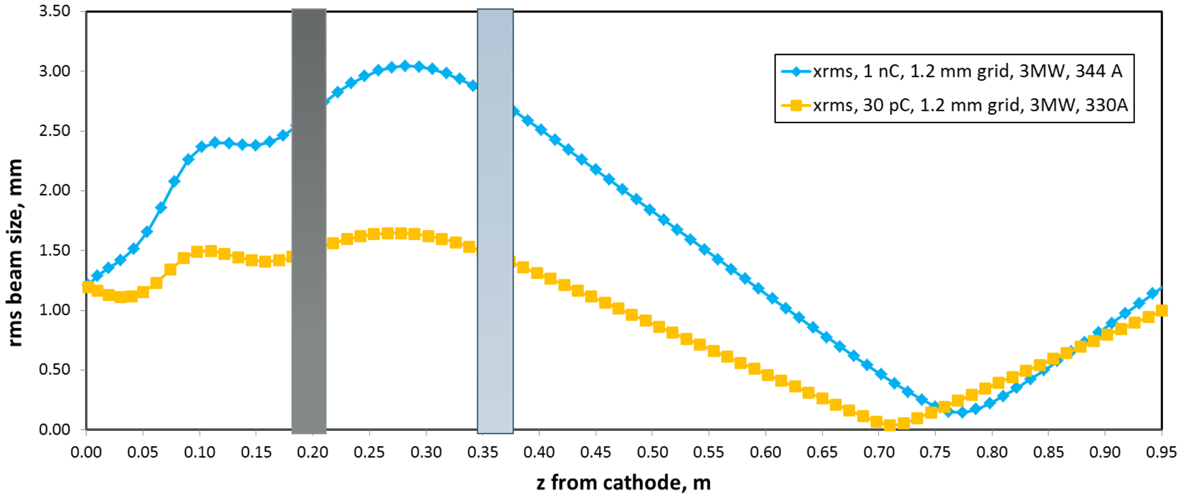
Gun position:
-0.015 m– 0.189 m

Solenoid position:
0.2085 m –0.3435 m

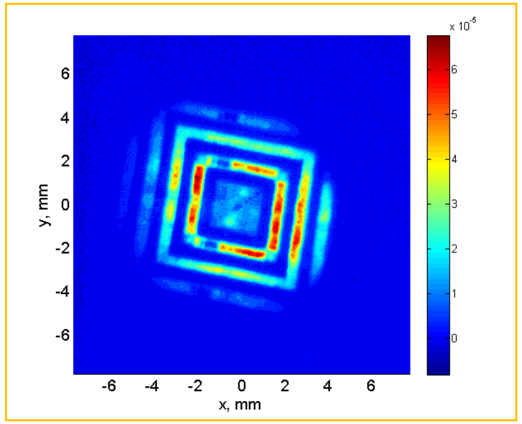
Beam imaging experiment with high bunch charge

Beam envelope is different with different bunch charge

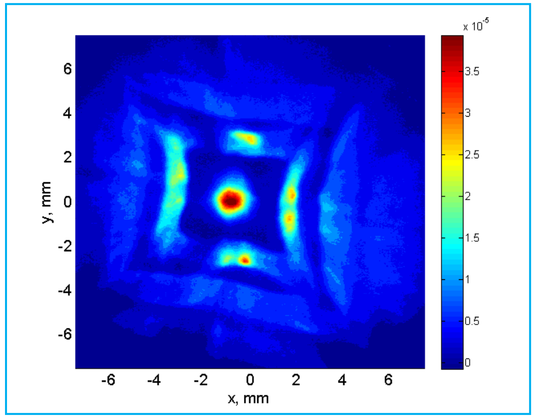




Low scr2, LT= 1%, 32.8pc, 330A



Low scr2, LT= 35%, **1106pc**, 344A

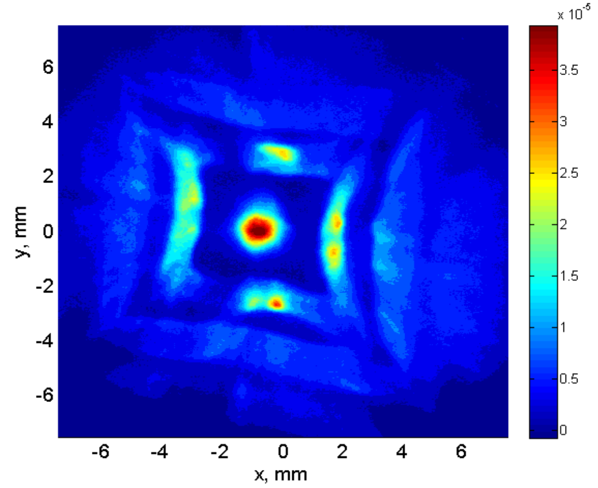


➔ Space charge effect for high bunch charge, cause the big beam size in the gun section.

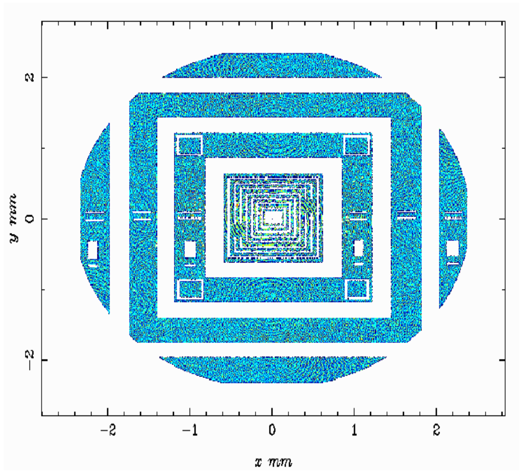
➔ For high bunch charge imaging, the distortion is only because of space charge???

Beam imaging simulation studies

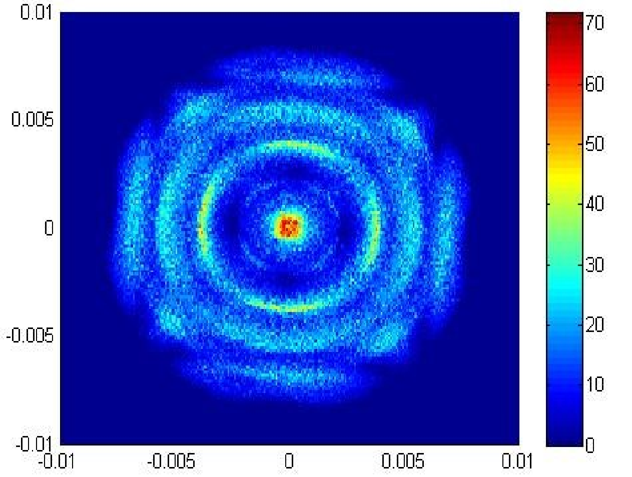
Low scr2, LT= 35%, 1106pc, 344A



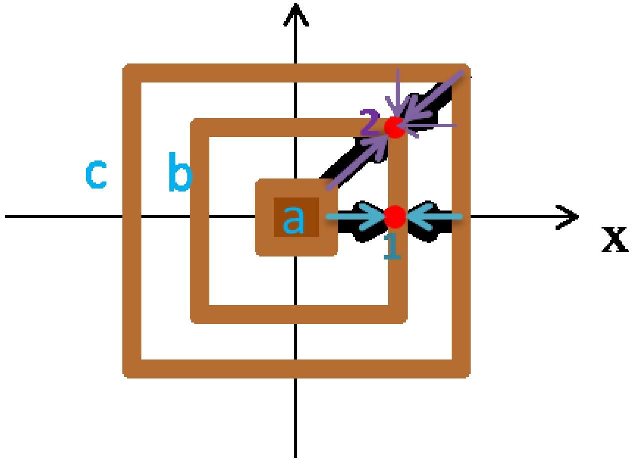
Laser transverse shaping by grid



Simulation results with 3D space charge



Space charge calculation:



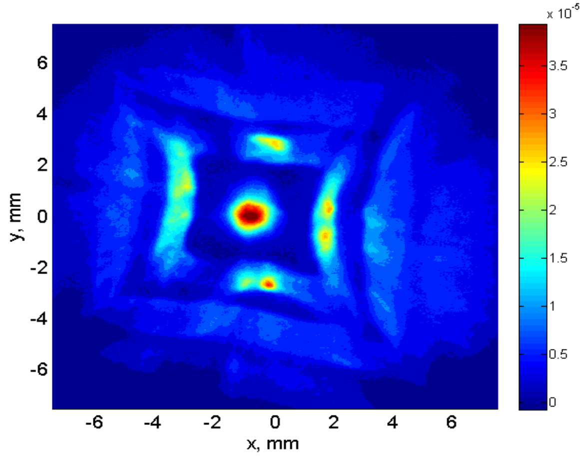
➔Model to calculate the space charge force at b1 point and b2 point due to beam a and c, by which can determin b1 and b2 point which expands further, then the shape of the b can be determined.

particle-particle model. The particle-particle method calculates the self-induced field E generated by N charged particles with the superposition principal. Let the ℓ-th particle have the charge q_ℓ and the position r_ℓ ($\ell = 1, \dots, N$) and let ε_0 denote the dielectric constant, then

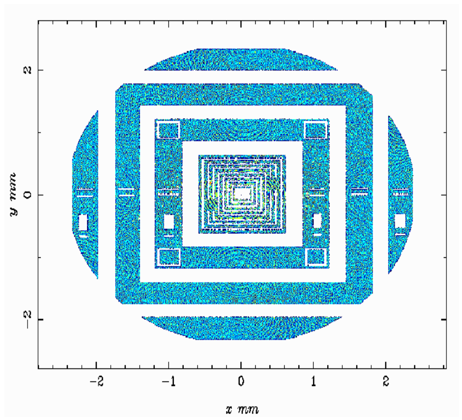
$$E(r) = \frac{1}{4\pi\varepsilon_0} \sum_{\ell=1}^{N} q_\ell \frac{r - r_\ell}{\|r - r_\ell\|^3}, \qquad r, r_\ell \in \mathbb{R}^3,\ r \neq r_\ell,\ \ell = 1, \dots, N. \quad (1)$$

Beam imaging simulation studies with quadrupole model

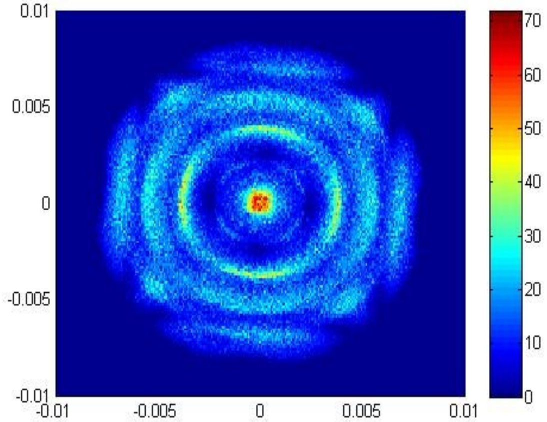
Low scr2, LT= 35%, **1106pc**, 344A



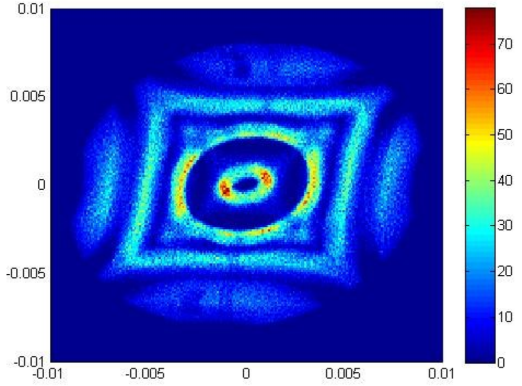
Laser transverse shaping by grid



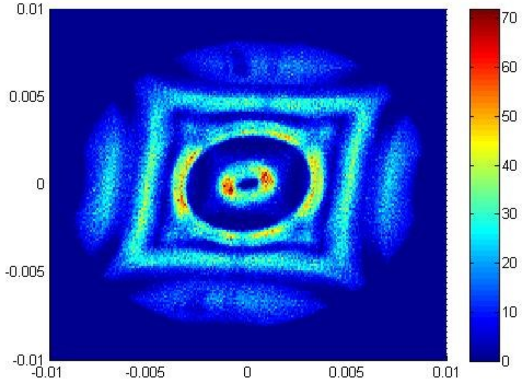
Simulation results with 3D space charge



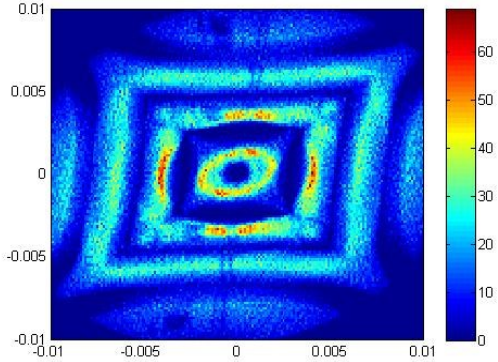
With skew quads,at z=0.18m
Q_g=-0.03 T/m,Q_l= 0.01
With Normal quads, at z=0.36m
Q_g=0.05 T/m,Q_l= 0.01
3D space charge

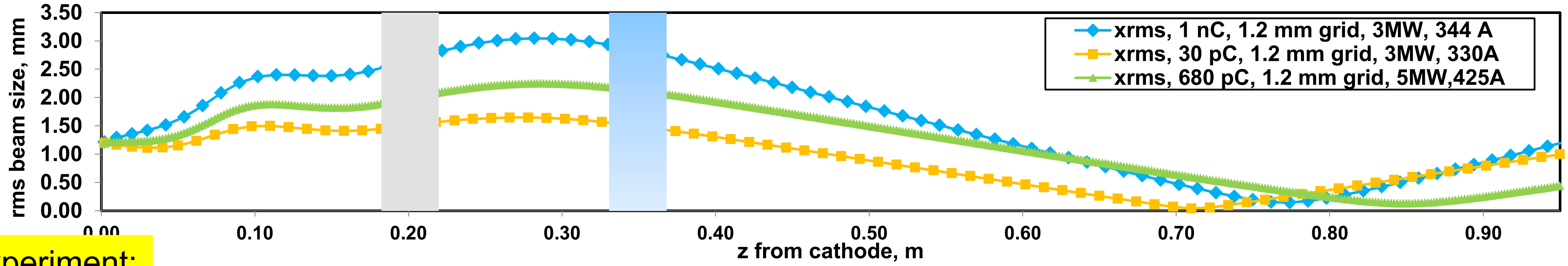


With skew quads,at z=0.18m
Q_g=-0.08 T/m,Q_l= 0.01
With Normal quads, at z=0.36m
Q_g=0.05 T/m,Q_l= 0.01
3D space charge



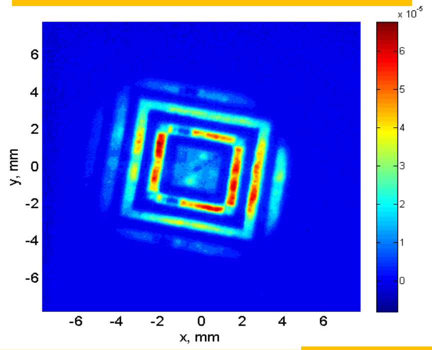
With skew quads,at z=0.18m
Q_g=-0.1 T/m,Q_l= 0.01
With Normal quads, at z=0.36m
Q_g=0.1 T/m,Q_l= 0.01
3D space charge



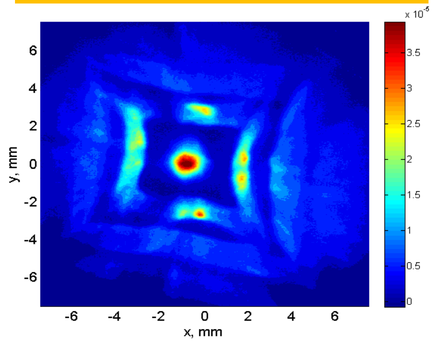


Experiment:

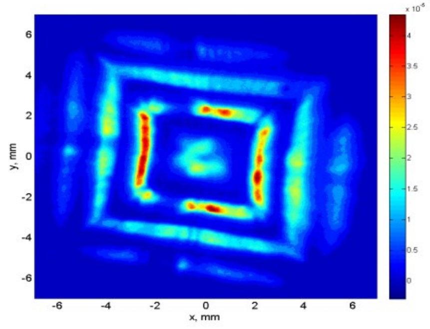
3 MW Low scr2, LT= 1%, 32.8pC, 330A



3MW Low scr2, LT= 35%, **1106pC**, 344A

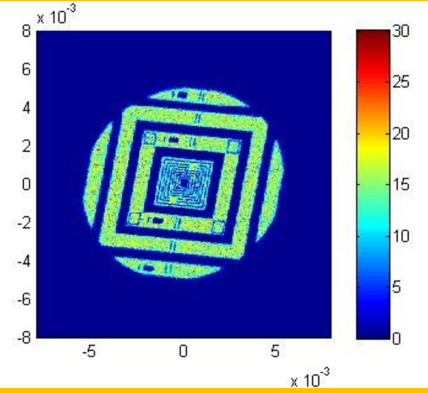


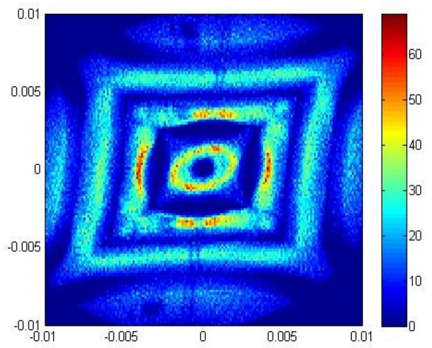
5MW Low scr2, LT= 20%, **683 pC** , 424A

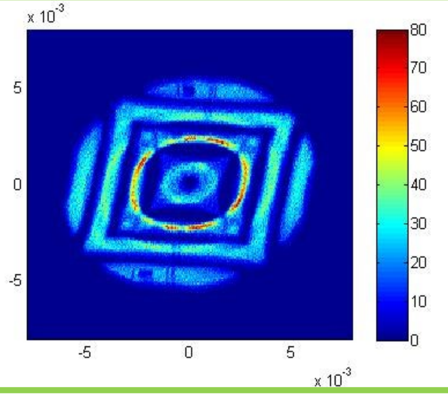


Simulation:

With skew quads,at z=0.18m Q_g=-0.1 T/m,Q_l= 0.01m, With Normal quads, at z=0.36m Q_g=0.1 T/m,Q_l= 0.01m

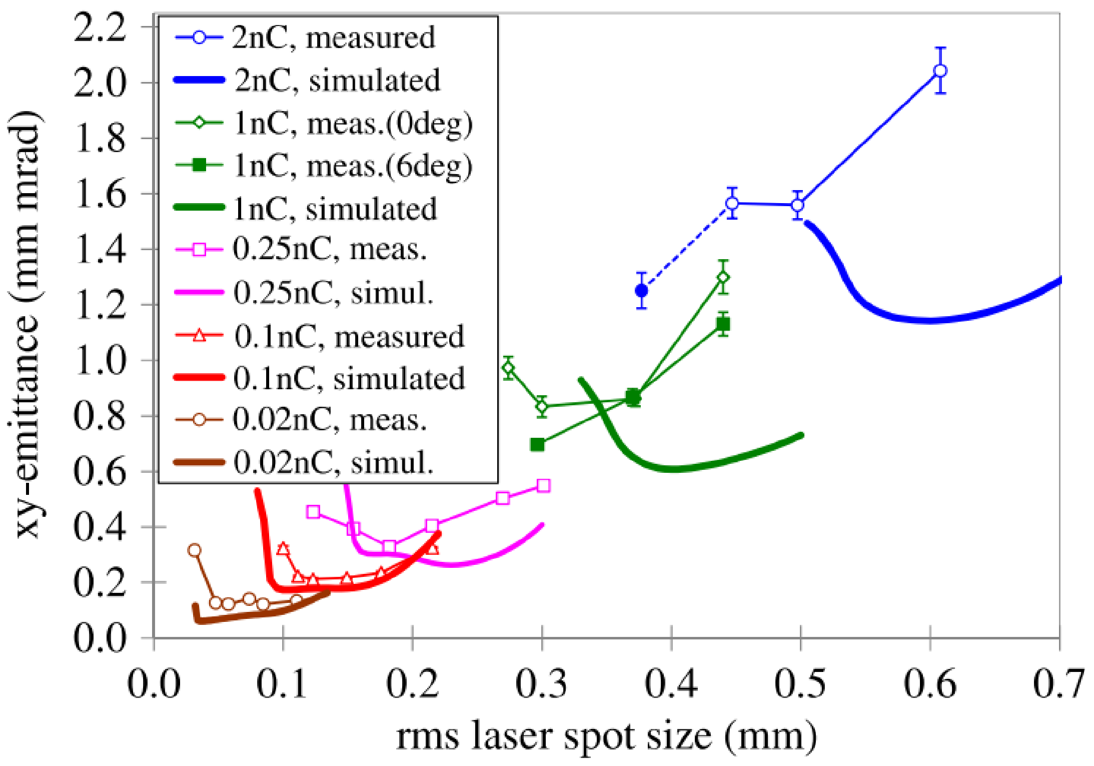






Laser spot size at cathode for minimum emittance

?One possible reason for the optimized laser spot size discrepancy between simulation and experiment



➔For low bunch charge, the simulated minimum laser spot size is colse to the experimental optimized one.

➔For high bunch charge, the large discrepancy for optimization laser spot size between simulation and experiment results can be due to space charge effect and the big beam size at the imperfection field position from RF coupler and solenoid (possible).
In simulation, the imperfection fields effect on the emittance is not included.

*M. Krasilnikov, et al. PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 15, 100701 (2012).

Simulation studies of emittance compensation by quads correctors

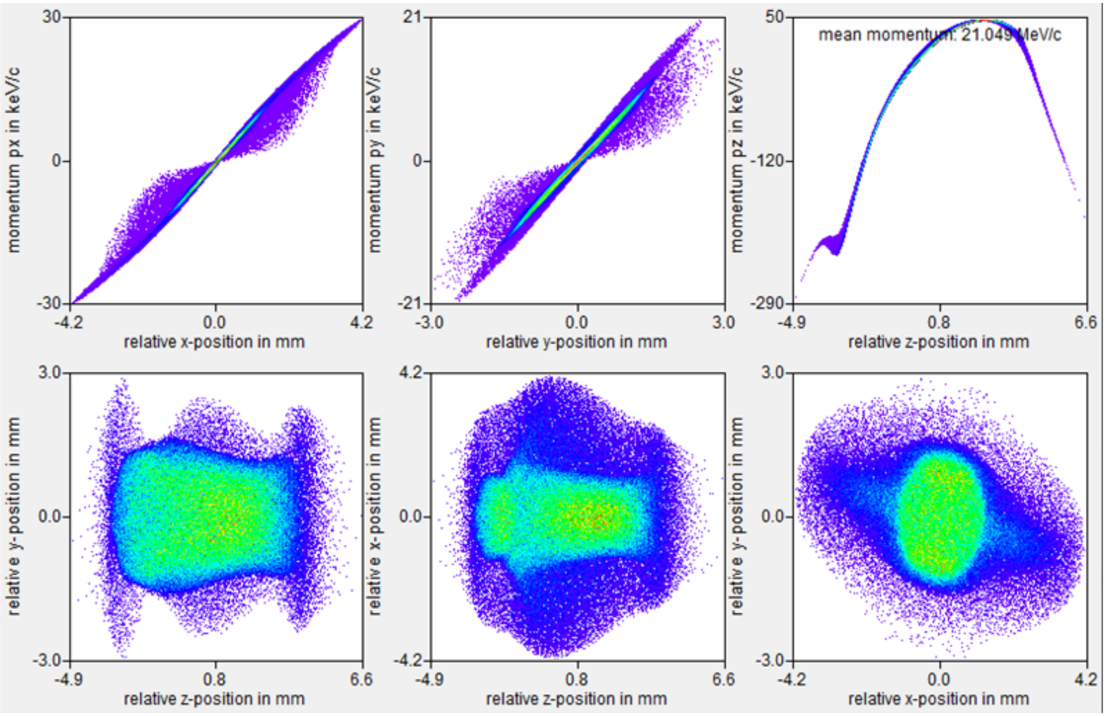
Simulation settings:

- Gun 53.16 MV/m, solenoid 356 A, bunch charge 500 pC, laser rms size 0.4 mm, gaussian beam.
- BeamBooster: 17.2 MV/m.
- Beam measured at EMSY1, 5.277 m.

Quads error fields assumptions:

- ➢ Qs at z=0.18m, Qs=-0.05 T/m, 1 cm length;
- ➢ Qn at z=0.36m, Qn is related to solenoid, for normal current, Qn=0.01 T/m, 1cm length.

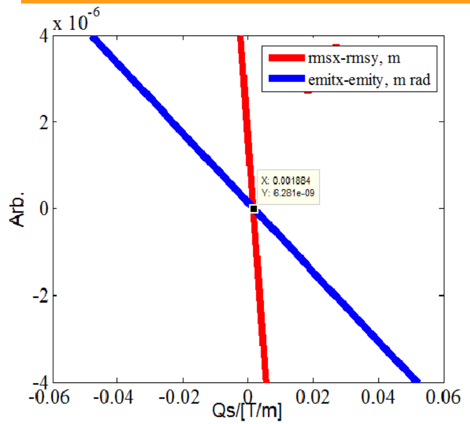
➔Quads corrector consists of a pair of normal and skew quads, same as used in PITZ right now.

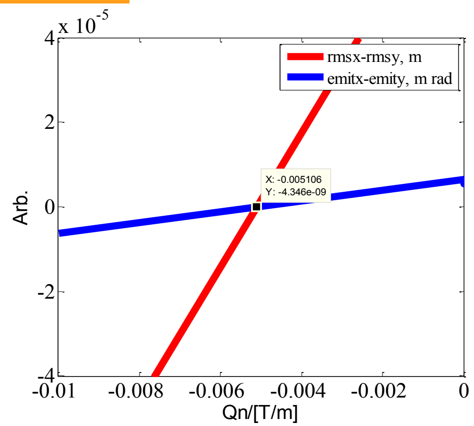


Simulation results of emittance asymmetry compensation by quads

Quads corrector consist of a pair of normal and skew quads, same as used in PITZ right now.

Quads corrector at z=0.40m

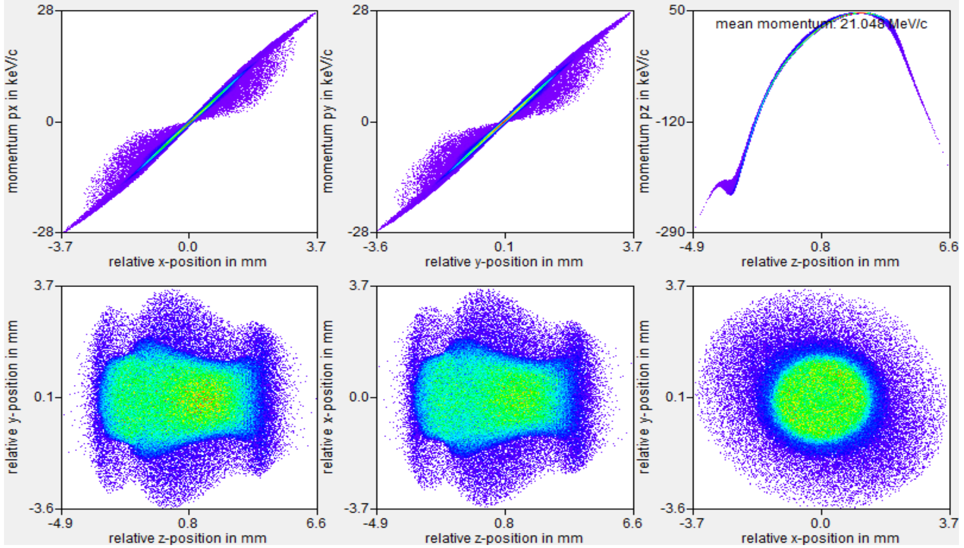




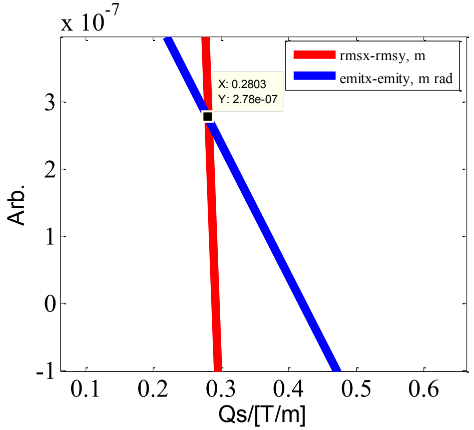
Quads length 5 cm
Qn=-0.005106T/m
Qs= 0.001884 T/m

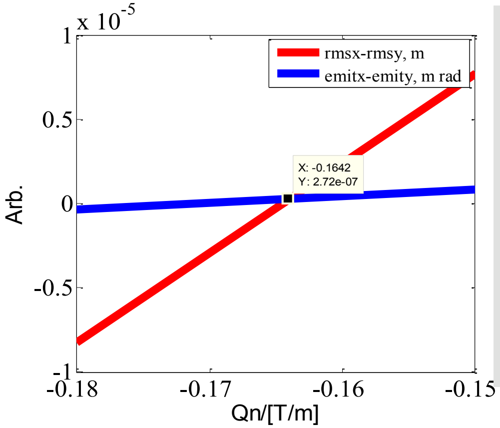
	Emit x mm mrad	Emit y mm mrad	RMS x mm	RMS y mm
With quads error field	2.312	1.152	1.195	0.761
With quas error field and quads corrector at 0.40 m	**1.602**	**1.579**	**0.942**	**0.932**

Beam distribution at z=5.277m with quads corrector at z=0.40m



Quads corrector at z =2.141 m





Quads length 5 cm.
Rmsx-Rmsy=0
Qn=-0.1645T/m
Qs=0.2912T/m

Emitx-Emity=0
Qn=-0.1711T/m
Qs=0.4222T/m

Summary and conclusions

- The effect of imperfection fields from Gun RF coupler and solenoid on the beam depends on the beam size at these positions. specially for high bunch charge(big beam size), it has large effect.
- Another exprimental phenomenon (beam imaging with high bunch charge) can be explained by quadrupole error field model for PITZ gun.
- Simulation studies confirmed the quads error fields induced beam coupling can be cancelled by quads correctors➔place should be at big beam size, colse to solenoid exit.
- Beam size at field imperfection positions is critical, possible reason for the descrepancy of the optimized laser spot size for minimum emittance from simulation and experiment, in simulation which is not included.

Thanks for your attention!