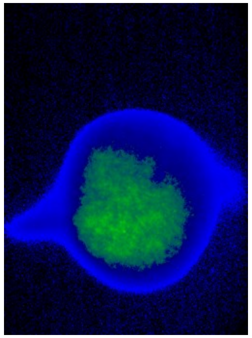
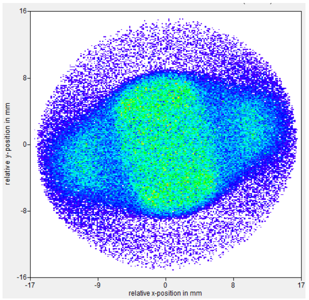
Electron beam asymmetry simulation study with modeled coupler kicker fields

- Motivation
- Idea and Method
- Simulation and results
- Summary





Quantang Zhao

PITZ physics Seminar

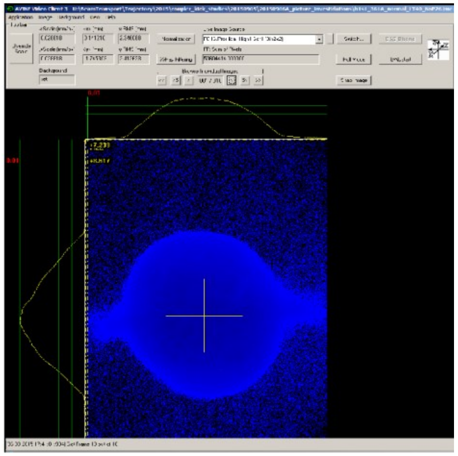
Zeuthen, 09.02.2016

Motivation

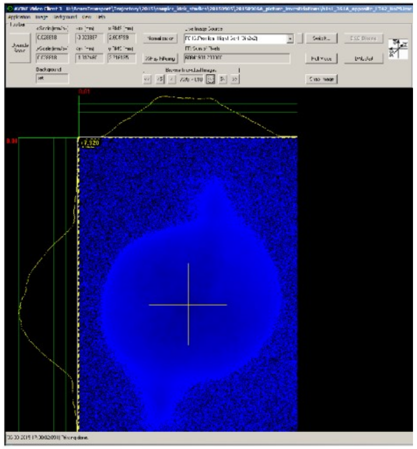
- The asymmetry beam transverse profile was found in the experiment.

beam at High1.Scr1 Imain=361A; Ibucking in compensation NoP=9; LT=42% (~480pC); Gain=12 ,Pgun=5MW , 6.178 MeV/c, **no booster** 05.09A-06.09N.2015.

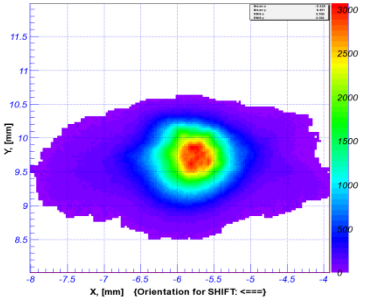
Normal solenoid polarity

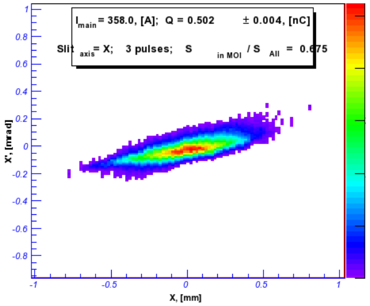


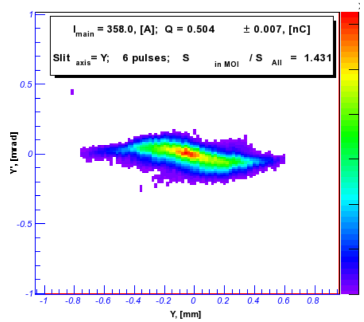
opposite solenoid polarity



- The electron beam asymmetry was observed during emittance measurements.







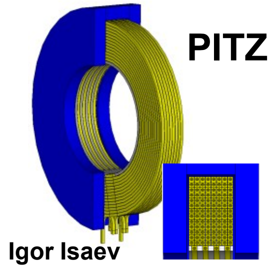
Example: Imain = 358A , BSA1.2mm, 500 pC, beam spot size and phase space, data from 20N.10.2015

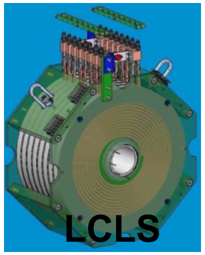
Idea and method

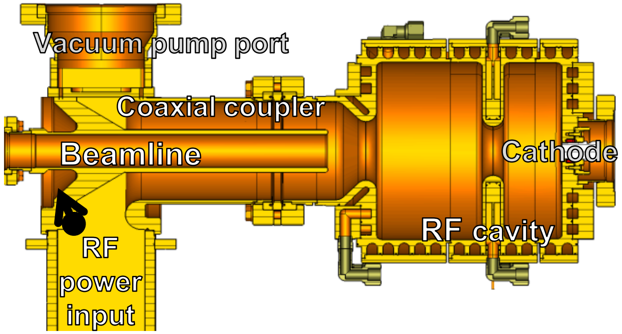
Some results from Igor and Mikhail study and LCLS study:

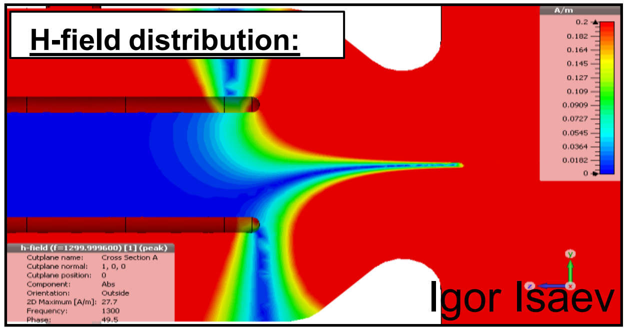
From larmor angle study, two positions are proposed:

- Around Z = 0.18m, coupler kicker fields
- Around Z = 0.28 m, additional solenoid fields



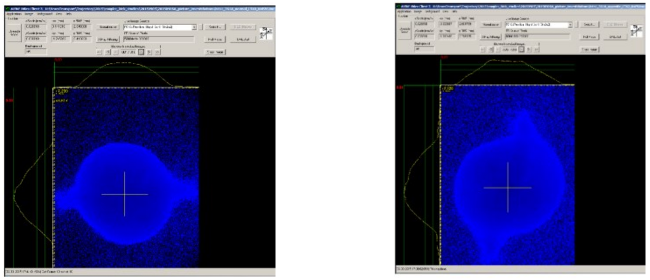






- The coupler kicker asymmetric fields are observed from simulation.

Beam spot size change by reversed solenoid polarity from PITZ.



***Beam spot size change by reversed solenoid polarity from LCLS.**

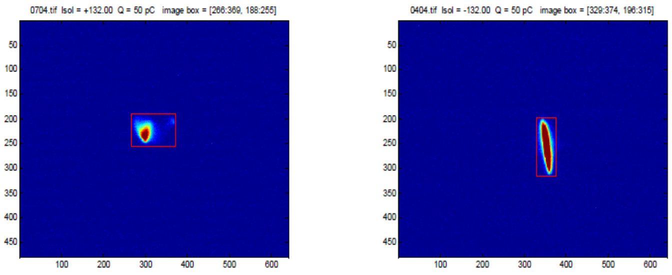


Figure 1: The electron beam image with normal and reversed solenoid polarity.

- The PITZ solenoid seems to have weak additional fields .

- The coupler kicker fields is more possible for the beam asymmetry.

*John Schmerge, LCLS Gun Solenoid Design Considerations, LCLS-TN-05-14,June 2005.

A module of the coupler kicker like fields:
from M. Dohlus and David Dowell

#1 Coupler kicker fields and angle kick:

$$\vec{v}(x,y) = \frac{\vec{V}(x,y)}{\vec{e_z}\cdot\vec{V}(0,0)} \cong \begin{pmatrix} v_{x0} + v_{xx}x + v_{xy}y \\ v_{y0} + v_{yx}x + v_{yy}y \\ 1 + \cdots \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \end{pmatrix}_{coupler} = \frac{eV_{acc}}{\beta\gamma mc^2} Re\left\{\begin{pmatrix} v_{0x} + v_{xx}x + v_{xy}y \\ v_{0y} + v_{yx}x + v_{yy}y \end{pmatrix} e^{i\phi_s}\right\}$$

$$\vec{V}(x,y) = \int\left[\vec{E}(\vec{r}) + c\vec{\beta}\times\vec{B}(\vec{r})\right]e^{i\omega z/c}dz$$

$$\phi_s = \frac{\omega s}{c} + \phi_{head}$$

ϕs : electron a distance s behind the head electron has the phase $\phi s=\omega s/c+\phi head$ with respect to the linac RF.

#2 Rotational thin Quads can be used for compensation the coupler kicker:

$$\tilde{\theta}_q(\phi_s) = \frac{1}{2}\tan^{-1}\frac{v_{xy}^r\cos\phi_s - v_{xy}^i\sin\phi_s}{v_{xx}^r\cos\phi_s - v_{xx}^i\sin\phi_s}$$

$$\frac{1}{\tilde{f}_{q(\phi_s)}} = \frac{eV_{acc}}{\beta\gamma mc^2}\sqrt{\left(v_{xx}^r\cos\phi_s - v_{xx}^i\sin\phi_s\right)^2 + \left(v_{xy}^r\cos\phi_s - v_{xy}^i\sin\phi_s\right)^2}$$

Some conclusions from David Dowell:

1) the coupler optics can be modeled as a rotated quadrupole with focal length and rotation angle given in terms of the complex Voltage kicks.
2) a rotated quadrupole near the coupler is effective at compensating for the coupler kicks, cancelling both the coupler emittance and the astigmatic focusing.

#1 M. Dohlus et al., "Coupler kick for very short bunches and its compensation", Proc. of EPAC08, pp. 580-582, Genoa, Italy.

#2 David Dowell, Analysis and Cancellation of RF Coupler- induced Emittance Due to Astigmatism. LCLS-2 TN-15-05 3/23/2015.

Skew quads for modeling the coupler kicker fields

➢ From **M. Krasilnikov, PPS, 02.02.2016,** beam tilt 45 degree at z =0.18 m was found.
➔Assume the rotational quads are skew quads.

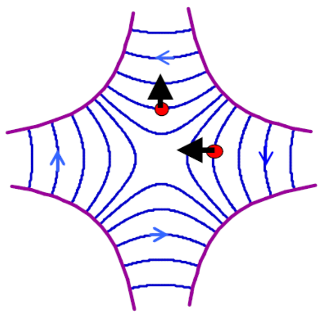
Magnets - quadrupoles

Quadrupoles produce a linear field variation across the beam.

Field is zero at the 'magnetic centre' so that 'on-axis' beam is not bent.

Note: beam that is radially focused is vertically defocused.

These are 'upright' quadrupoles.



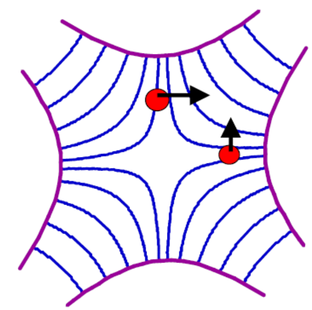
Neil Marks, ASTeC, CI. Conventional Magnets, Spring term 2013

'Skew' Quadrupoles.

Beam that has radial displacement (but not vertical) is deflected vertically;

horizontally centred beam with vertical displacement is deflected radially;

so skew quadrupoles couple horizontal and vertical transverse oscillations.

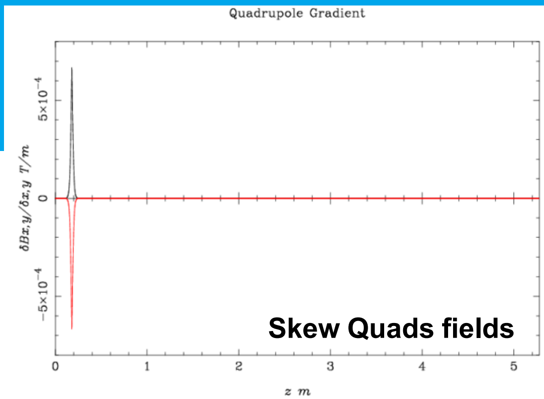


Neil Marks, ASTeC, CI. Conventional Magnets, Spring term 2013

*The particles pass through the skew Quads experience a horizontal deflection proportional to its vertical position(with respect to the magnetic axis) and a vertical deflection proportional to its horizontal position.

*Andrzej Wolski, Beam dynamics in High energy particle accelerators, p210

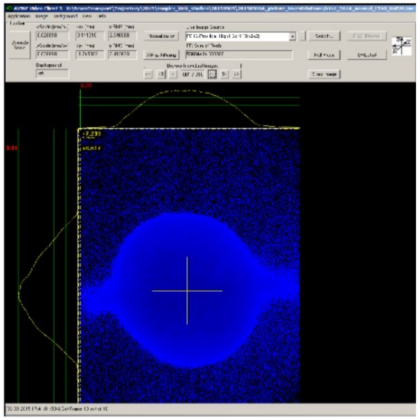
Simulation setup and results



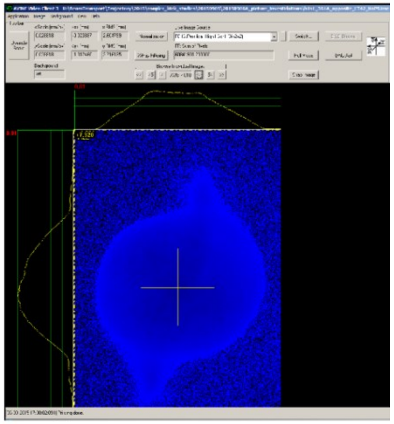
Simulation setup: same with experiment machine parameters.

Simulation study: 5 MW in the gun, BSA 1.2 mm, 500pC, beam at **High1.Scr1**.
Skew quadrupole at position z= 0.18 m, **without booster**.

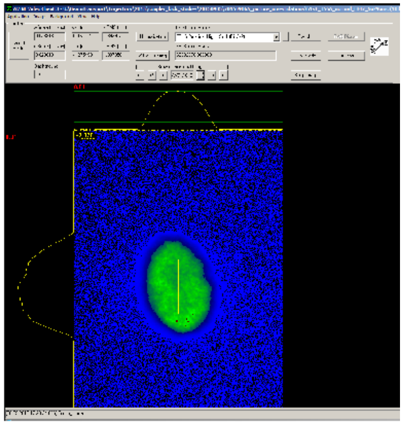
/skew quadrupole
Q_type(1) = 'skew',
Q_length(1)=0.01,
Q_K(1)= -0.2,
Q_pos(1)=0.18,



With skew Quad &Normal polarity

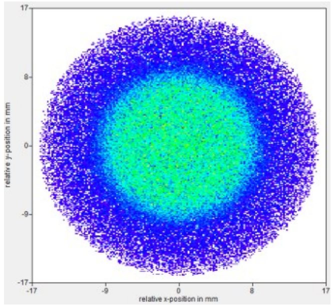


With skew Quad &opposite polarity

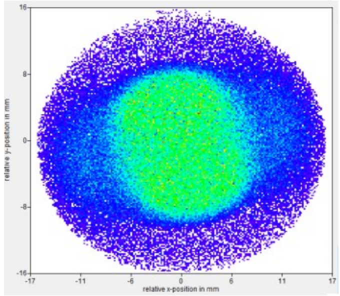


With skew Quad &normal polarity

w/o skew Quad



Imain=360A



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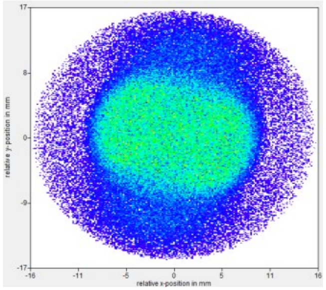
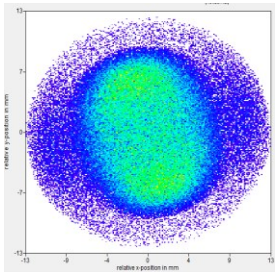


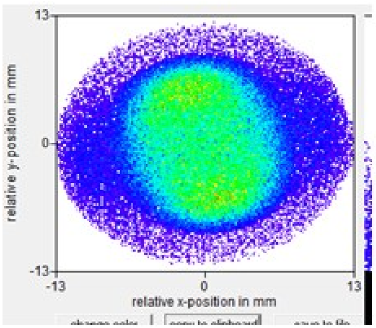
Imain=360A



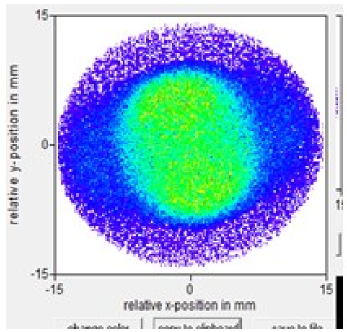
Imain=356A

The wings of the beam change as a function of solenoid current

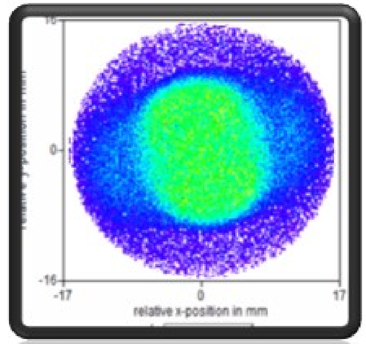
Q_length(1)=0.01,Q_K(1)= -0.2, Q_pos(1)=0.18,



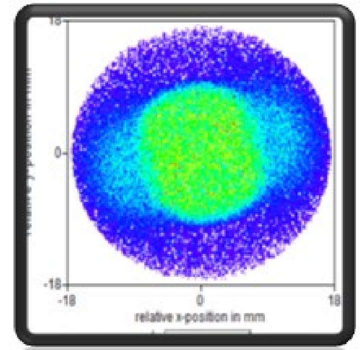
356A



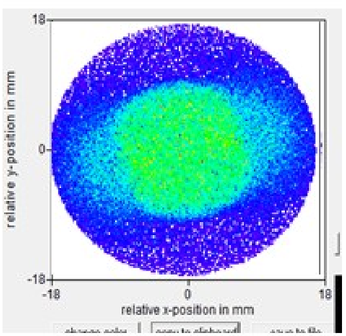
358A



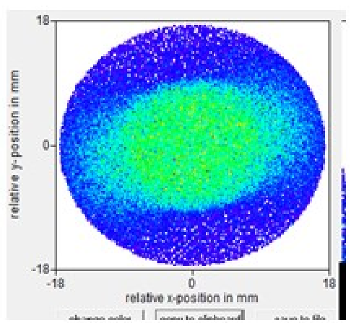
360A



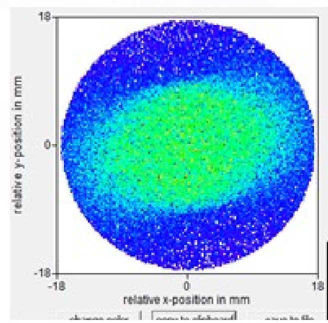
362A



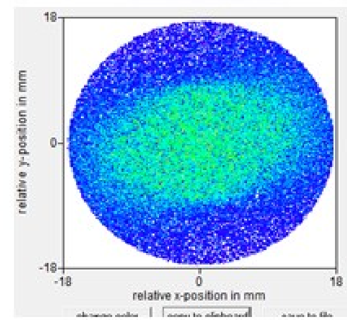
364A



366A



368A

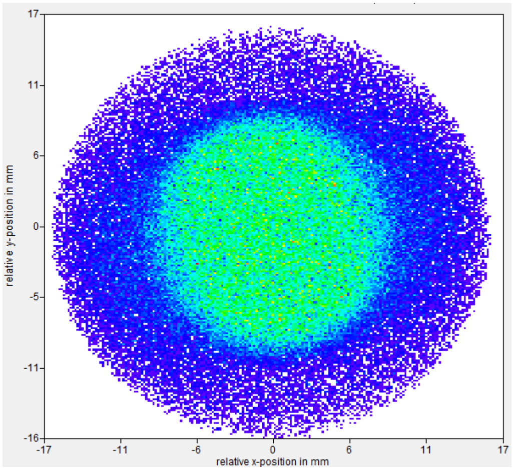


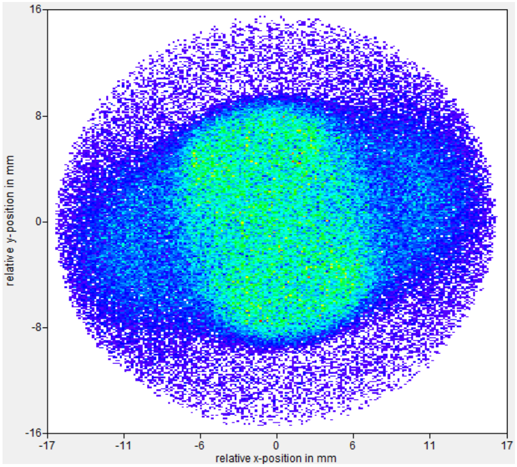
370A

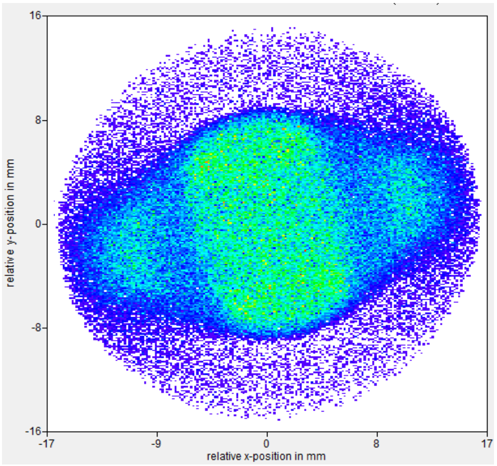
- ➢ The direction of the wings of the beam is not changed by the solenoid current.

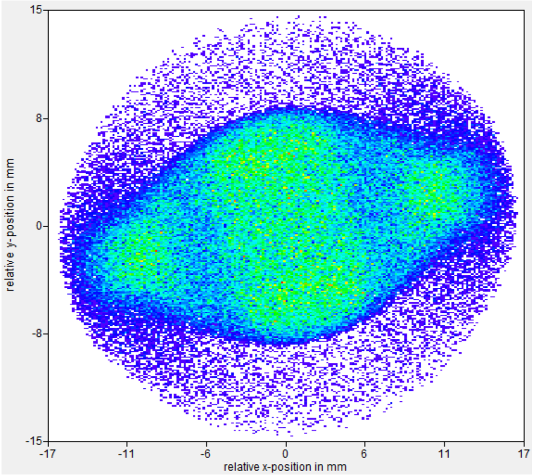
The wings of beam change as a function of skew quad Q_k

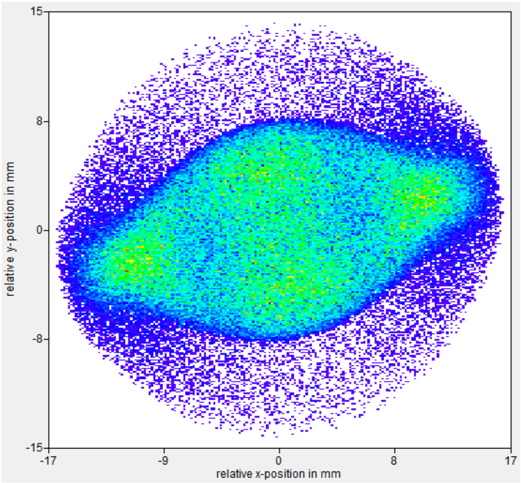
Imain= 360 A, Q_k scan: -0.1 : -0.2 :-0.9, high1.Scr1







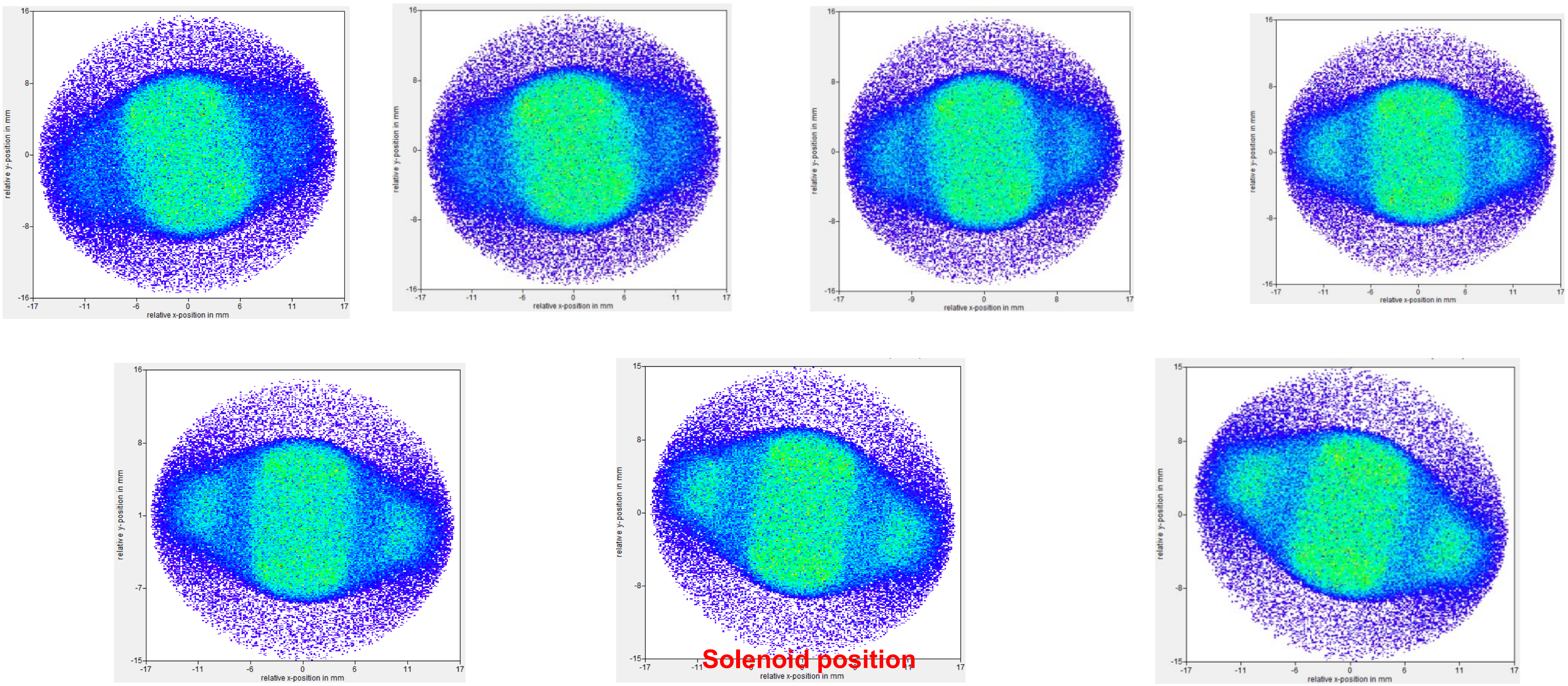




- The dircection of the wings of beam is not changed by the skew quad Q_k.

The wings of the beam change as a function of skew Quads position.

Imain = 360A, Qk=-0.2, skew Quads position scan, 0.18:0.02:0.3

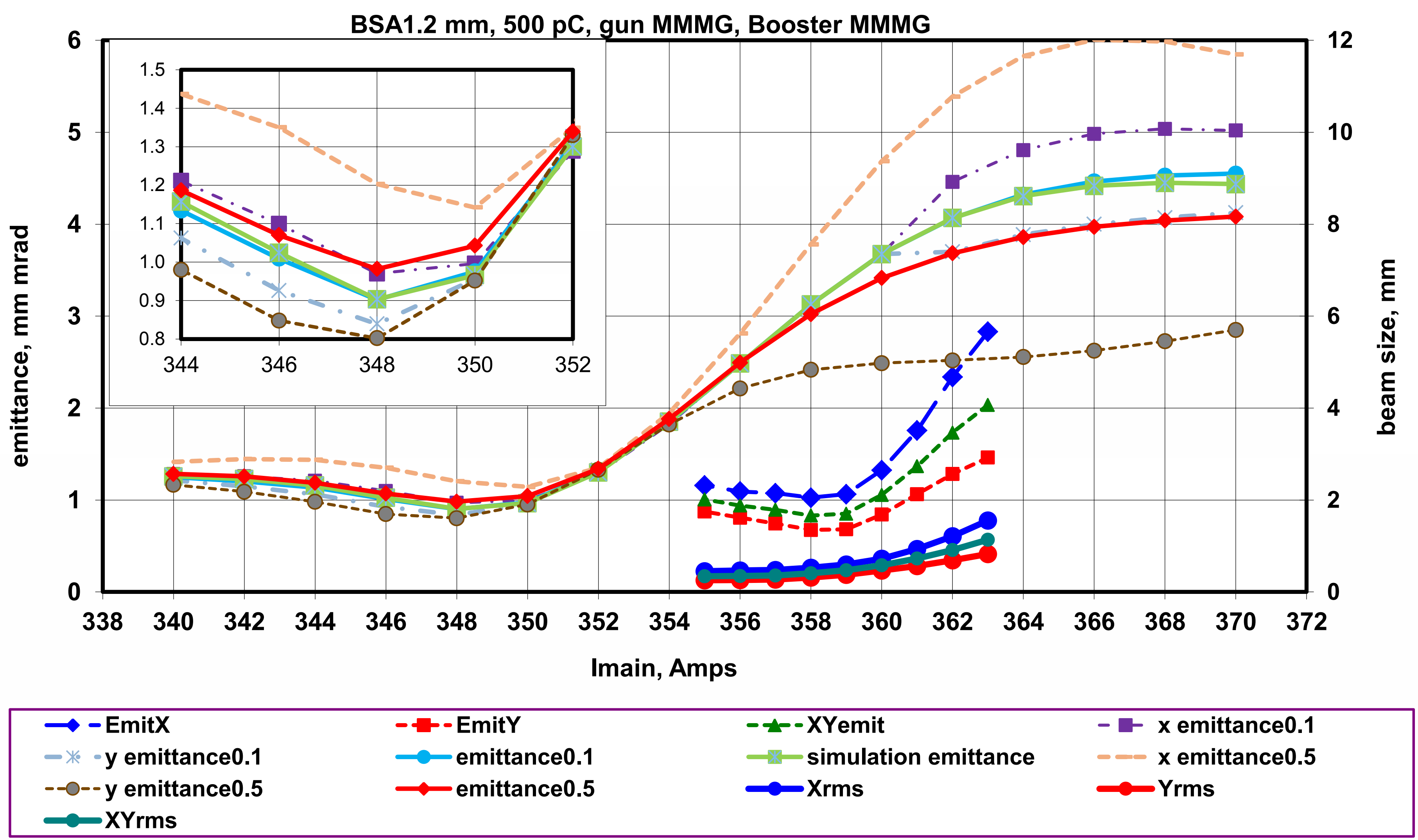


- The wings orientation depends on the skew quads field positions, at around z= 0.18m the simulation results are more consistent with the experiment results.

➔The position of the skew quads like fields for beam wings can be confirmed.

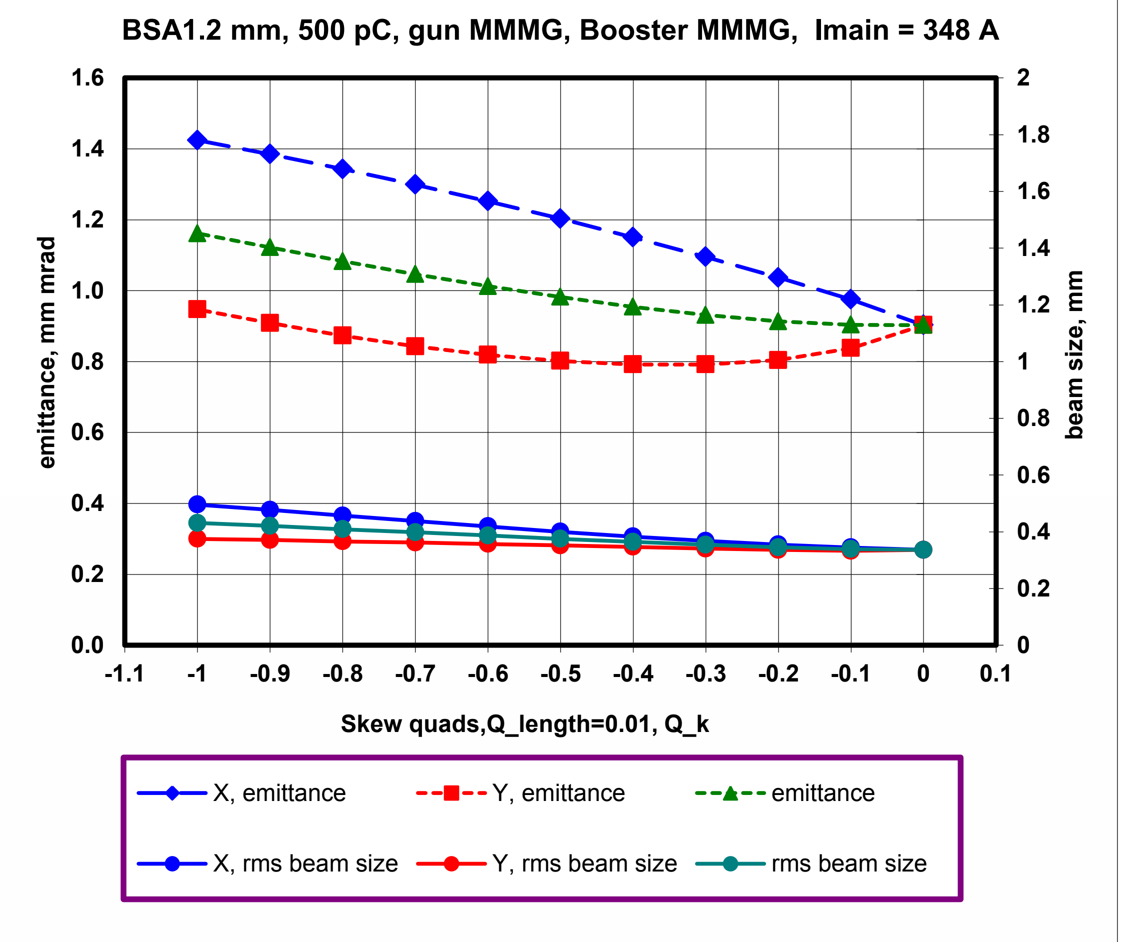
The skew Quads fields effect on the emittance

The emittance asymmetry in x and y is appeared, but the solenoid current shift for minimum emittance from experiment and simulation is not changed. the skew Quads, Q_k = -0.1, -0.5.



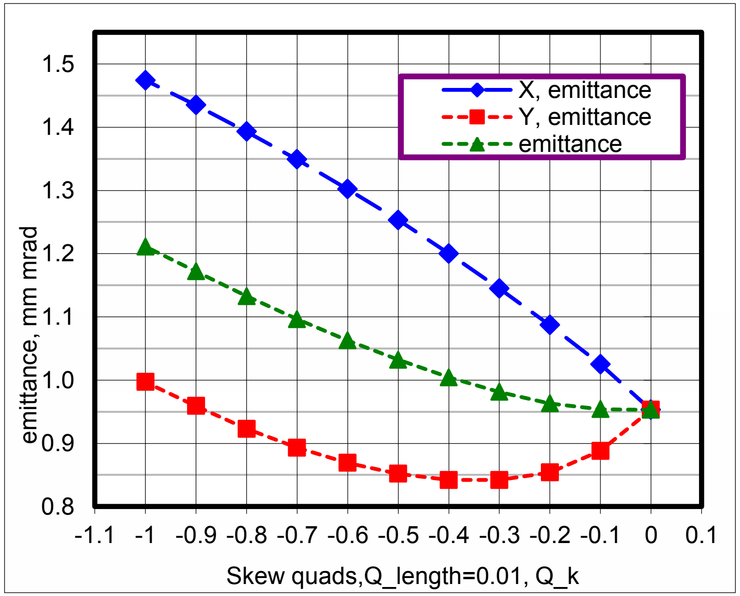
Laser FWHM ~ 12 ps, gaussian shape

The skew Quad Q_k effect on the minimum emittance (solenoid scan)



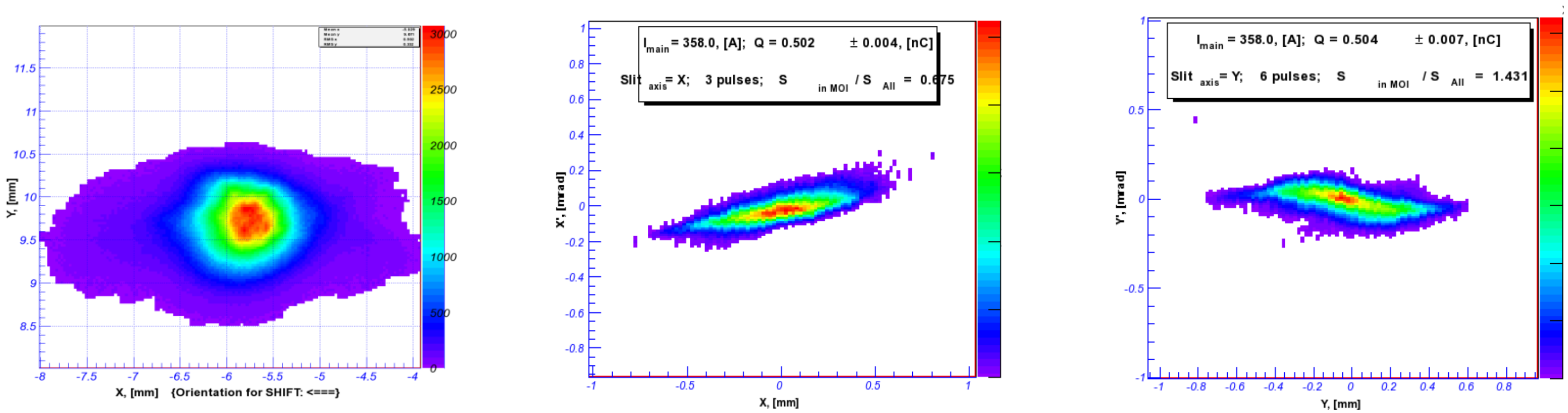
Laser FWHM ~ 12 ps, gaussian shape

- the minimum emittance is increased with increasing skew Quad Q_k with large beam asymmetry.

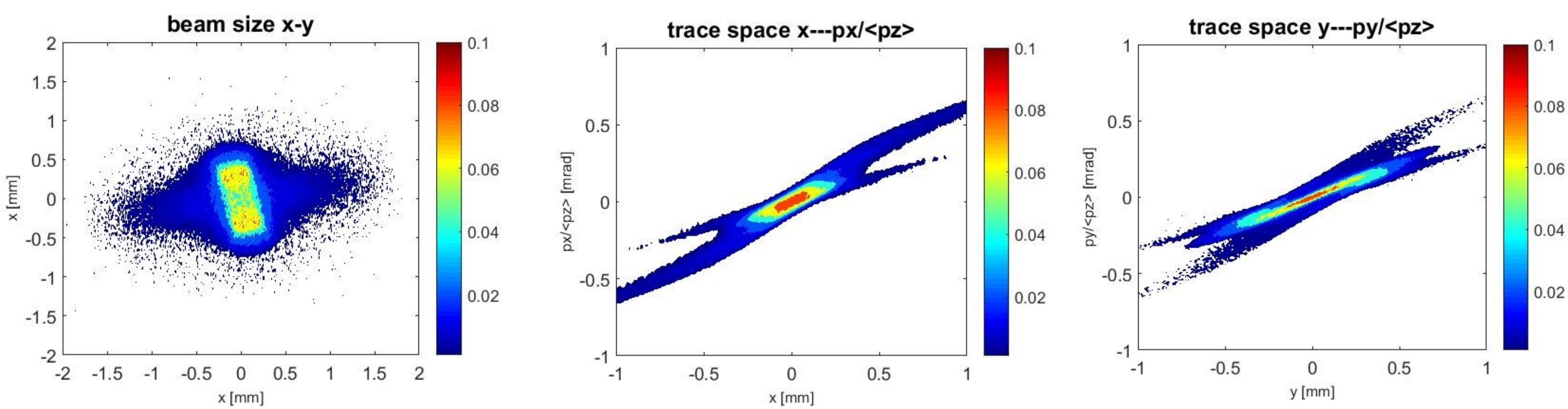


Phase space and beam spot from experiment and simulation

Experiment: 358A minimum emittance, BSA1.2mm, 500 pC.



Simulation with skew Quad, Q_k=-0.5, 348A minimum emittance, BSA1.2mm, 500 pC.



Summary

- The beam asymmetry and wings was observed by simulation with skew Quad field at coupler kicker fields position, consistent with experiment results.
- The reasonable source of the beam asymmetry comes from the fields of RF gun coupler (like skew Quad) at position around z = 0.18 m.
- The minimum emittance was increased by the large skew quads fields (coupler fields) with large asymmetry beam, and the asymmetry of the x and y phase space distribution are also observed from simulation.

From coupler kicker fields, there is also dipole like fields, not including in this simulation study, or maybe also multi-pole fields?

???Further study….

Simulation:

1) beam dynamics simulation with 3D RF fields and/or solenoid fileds.

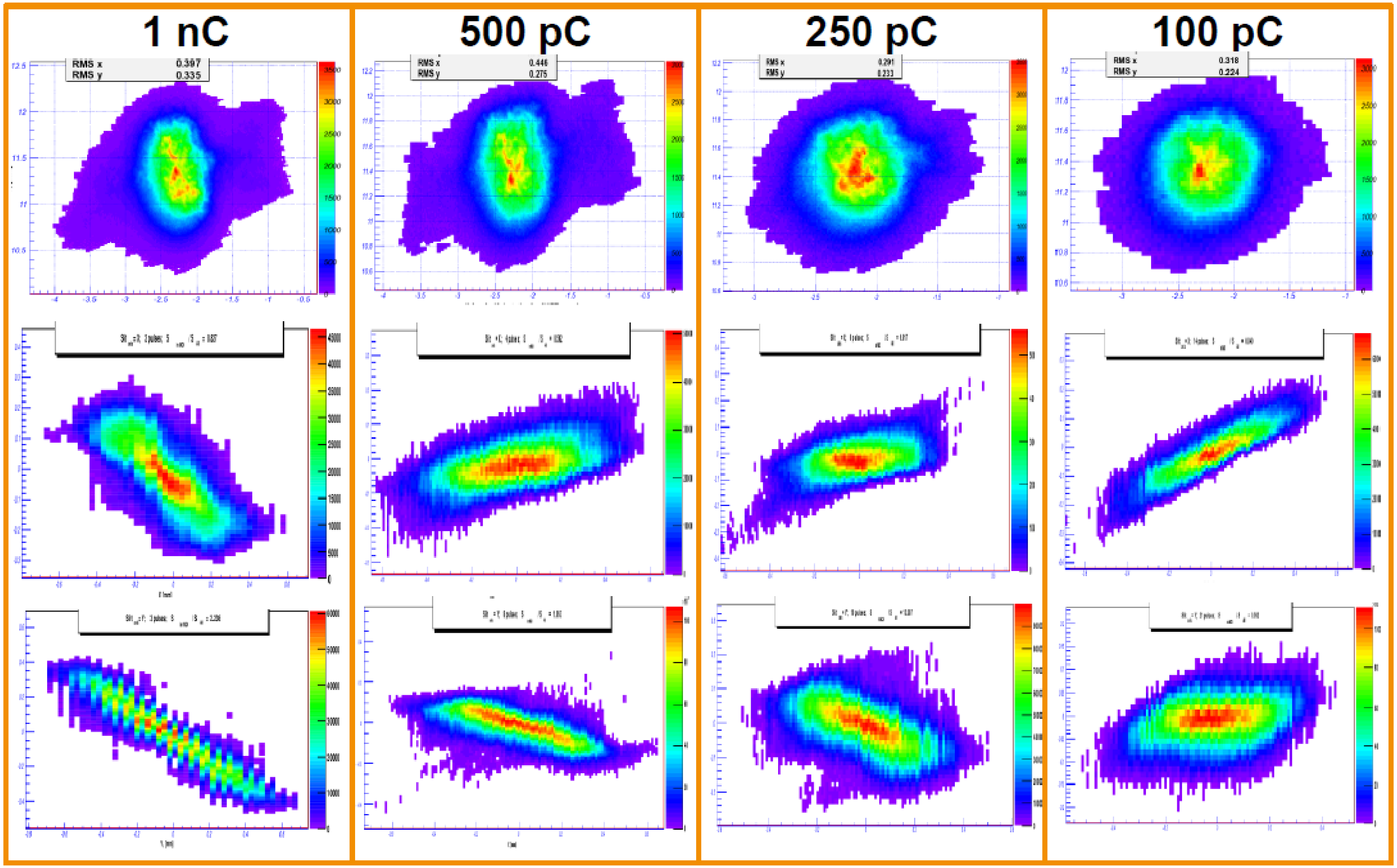
Experiment:

1) Solenoid fields measurement and analysis….(maybe very weak additional fields)
2) A skew/rotational Quad at the position around Z=0.2m for some experiments?

Thanks for your attention!

Back slides

Beam spot and phase space for minimum emittance of different bunch charge.



*Grygorii Vashchenko, PITZ collaboration meeting,Zeuthen, 02-03.06.2015