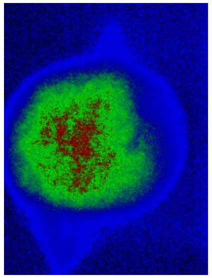
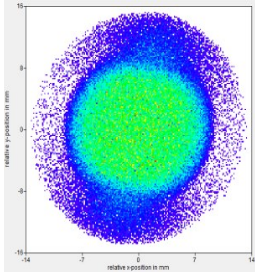
# Simulations with rotation quads model for beam asymmetry studies (updated)

- Basic idea and method.
- Some investigations
  - Based on quads rotation angle and position in ASTRA simulation.
- Beam simulation with rotation quads for beam wings
  - 5 MW in the gun.
  - 3 MW in the gun.
  - 1.5 MW in the gun.
- Conclusions





Quantang Zhao
PITZ physics Seminar
Zeuthen, 26.05.2016

HELMHOLTZ ASSOCIATION

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DESY

# Basic idea: Quads like field from coupler kicker or/and solenoid

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

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

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

* Quantang Zhao
PITZ physics Seminar
Zeuthen, 09.02.2016

## #2 Quads used for compensation of quads like field from the solenoid:

Solenoid multipole field measurement with rotating coil sensor.

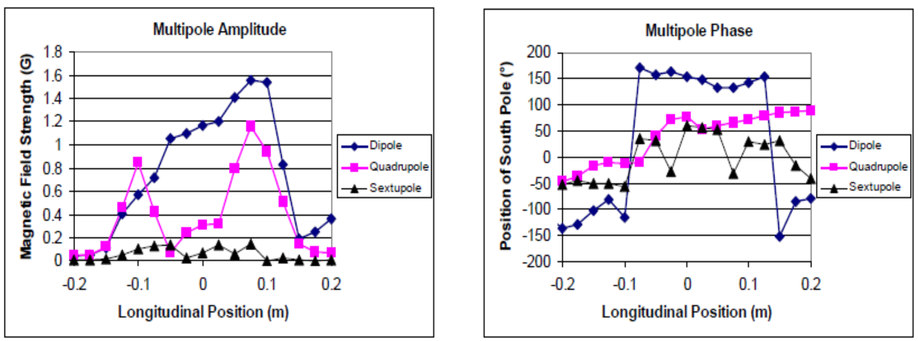



Figure 9: The amplitude and phase of the dipole, quadrupole, and sextupole terms as a function of longitudinal position at a current of 100 A.

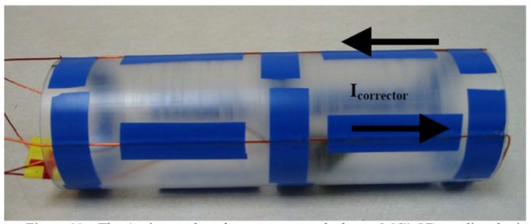



Figure 11: The 4 wire quadrupole corrector attached to a 2.85" OD acrylic tube is shown. The single wire starts and ends on the left. Adjacent wires have identical current but opposite polarity forming a quadrupole in the center of the tube.

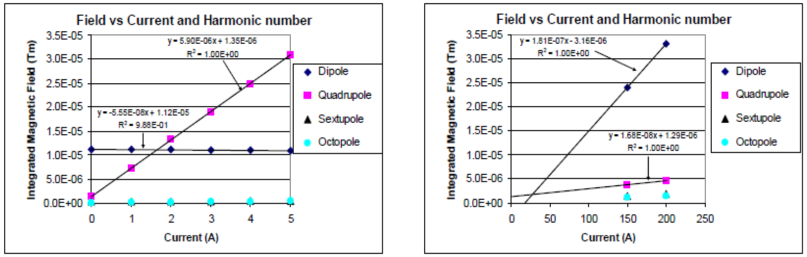



Figure 12: The multi-pole amplitudes as a function of corrector current with the solenoid current at 0 A is plotted on the left. On the right is the multi-pole amplitude as a function of solenoid current with the corrector at 2.7 A and 3.6 A for the solenoid current at 150 A and 200 A respectively.


#1 David Dowell, Analysis and Cancellation of RF Coupler- induced Emittance Due to Astigmatism. LCLS-2 TN-15-05 3/23/2015.
#2 John Schmerge, LCLS Gun Solenoid Design Considerations. SLAC-TN-10-084.

# Method

Use rotation quads model in ASTRA simulation by scanning the rotation angle and z position.

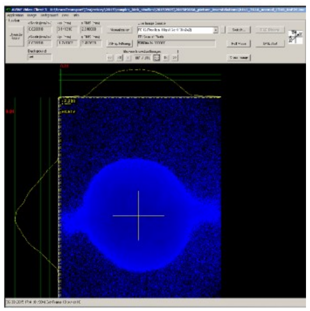
➔ Find the parameters for beam images at high1 scr1 to fit the experiment images, the direction of the beam wings for both solenoid polarity.

➔ 2D-3D space charge used in ASTRA simulation, z_trans=0.12m.

Q_length(1)=0.01,
Q_K(1)= +-0.6,
Q_pos(1)= x.xx,
Q_zrot(1)= y.yy

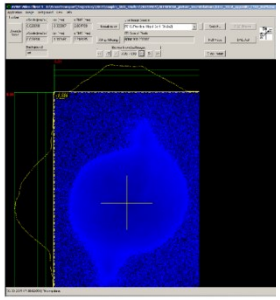
Pgun=5MW, 6.178 MeV/c, gradient is 54.2 MV/c

-361A

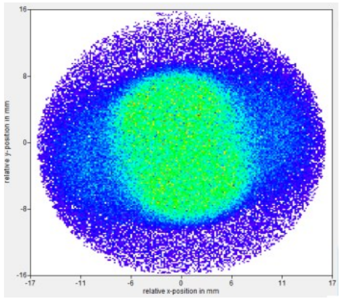


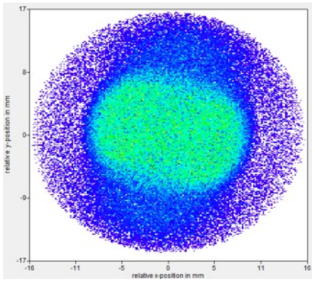
~13 degree

361A



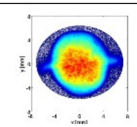
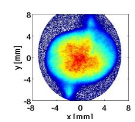
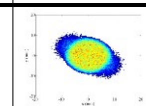
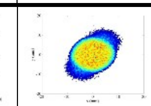
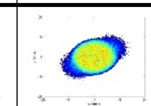
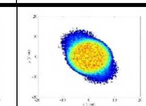
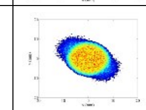
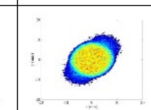
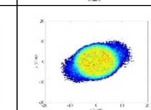
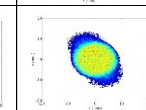
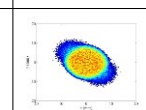
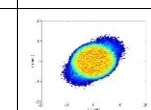
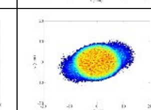
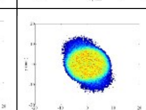
~78 degree



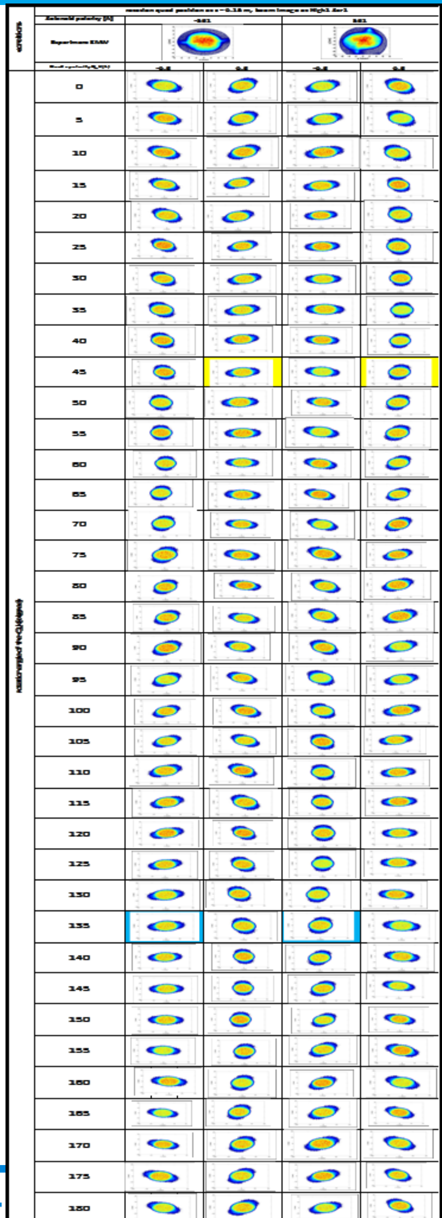


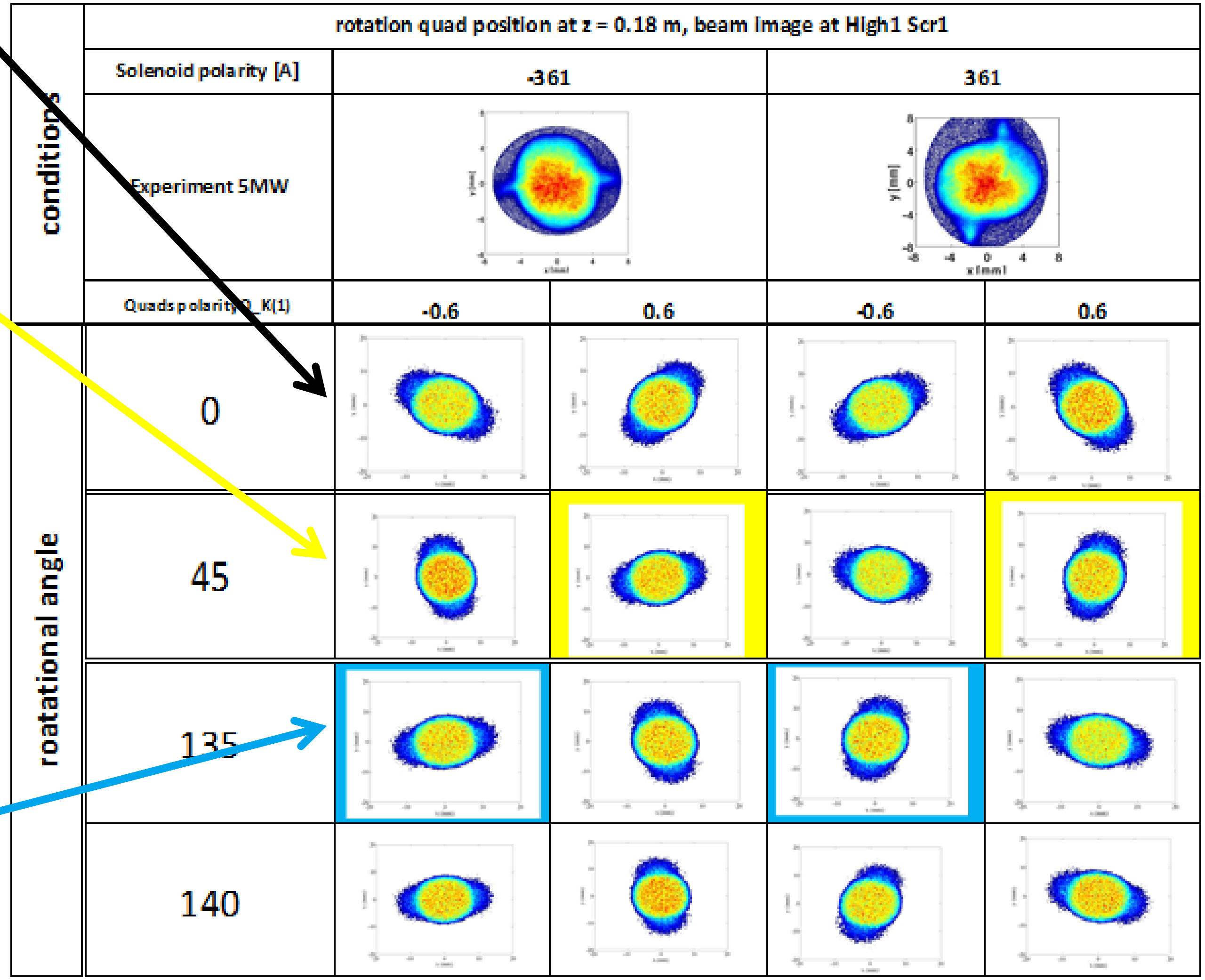
Z=0.18, Q_k=-0.6, Q_zrot=135 degree

Images table from simulation analysis

| | rotation quad position at z = 0.18 m, beam image at High1 Scr1 | | | | |
|---|---|---|---|---|---|
| conditions | Solenoid polarity [A] | -361 | | 361 | |
| | Experiment 5MW |  | |  | |
| | Quads polarityQ_K(1) | -0.6 | 0.6 | -0.6 | 0.6 |
| quads rotational angle [degree] | 0 |  |  |  |  |
| | 5 |  |  |  |  |
| | 10 |  |  |  |  |

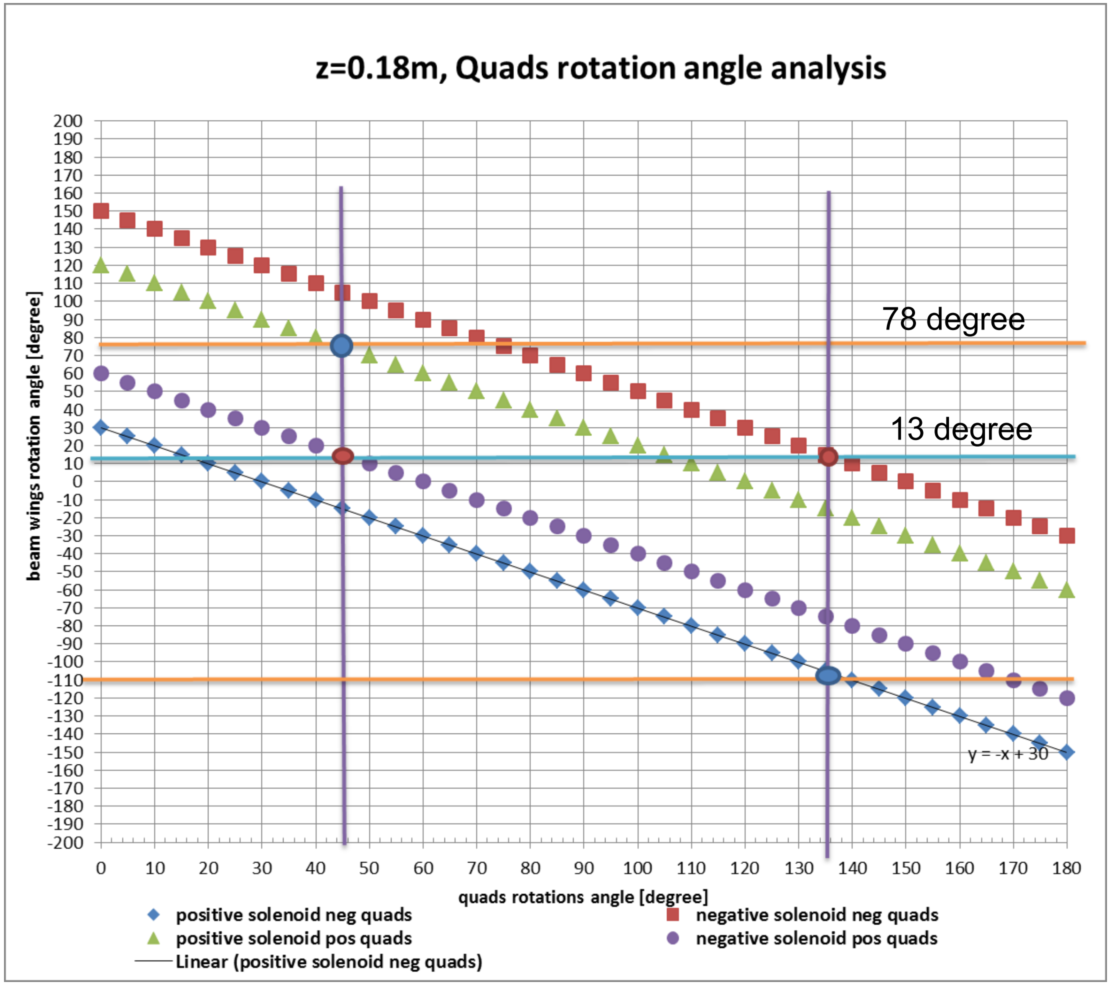
# Rotation quads simulation analysis results, at z = 0.18 m.






*2D-3D space charge, at z_trans=0.12m, Q_k=-0.6 m^-2, Q_length=0.01m

# Rotation quads simulation analysis results: beam wings direction fit. Z =0.18 m



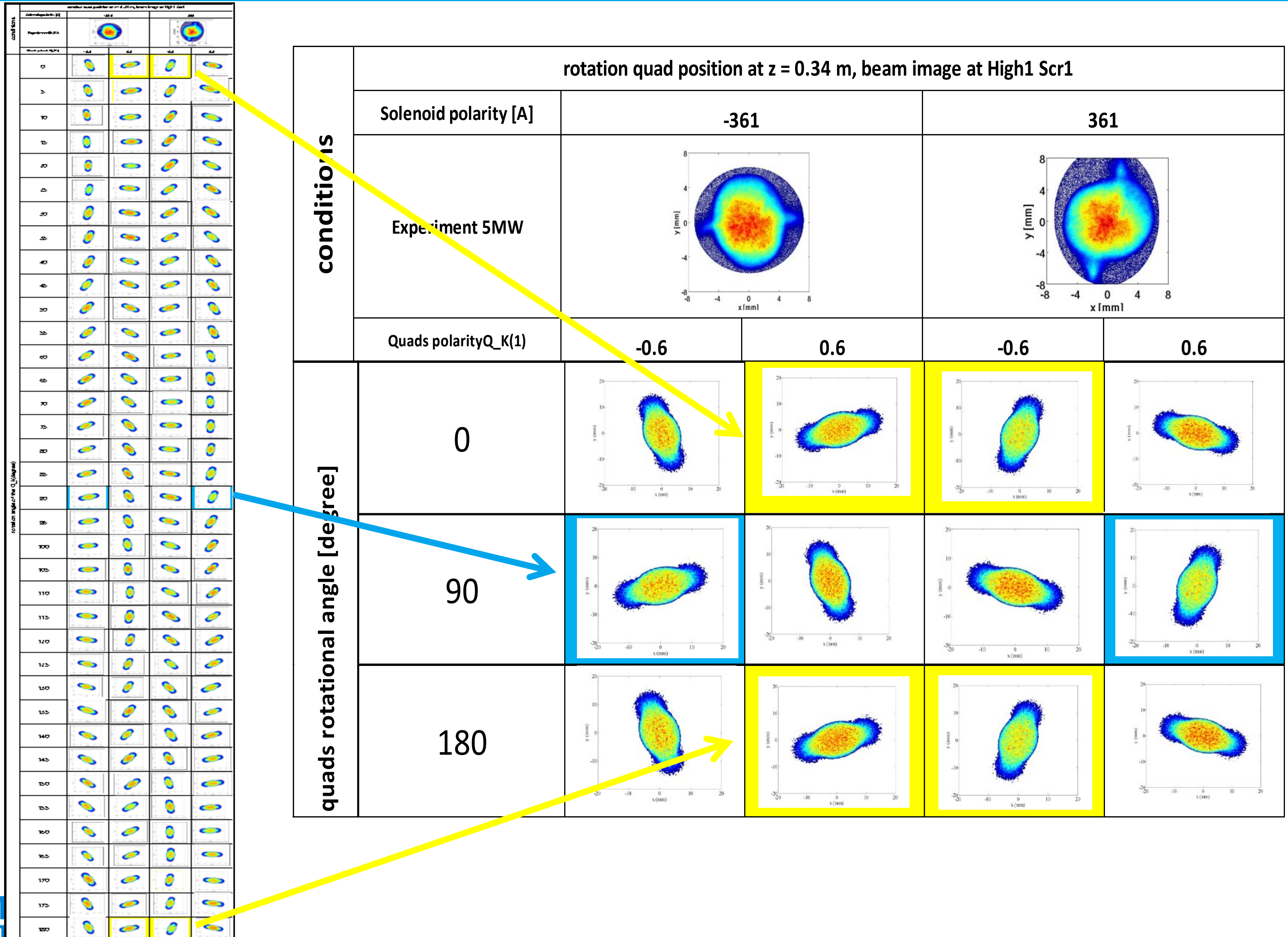

➔ **Skew quads**

The quads rotation angle around 45 degree with positive polarity.

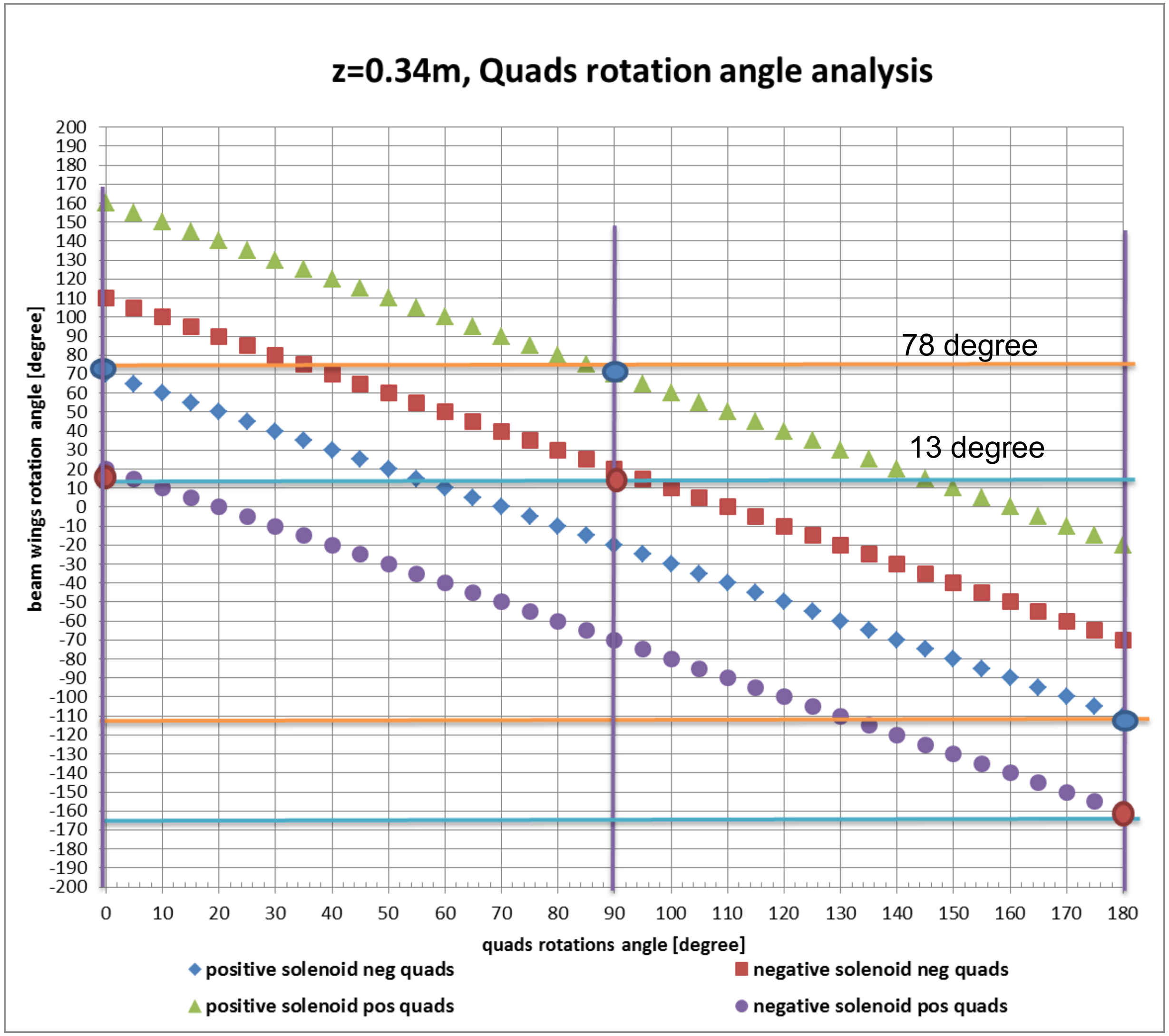
The quads rotation angle around 135 degree with negative polarity.

➔the rotation quads have same polarity when change the solenoid polarity.

# Rotation quads simulation analysis results, z = 0.34 m.



# Rotation quads simulation analysis results: beam wings direction fit, z=0.34m




➔ **nomal quads**
The quads rotation 0, 90, 180 degree.

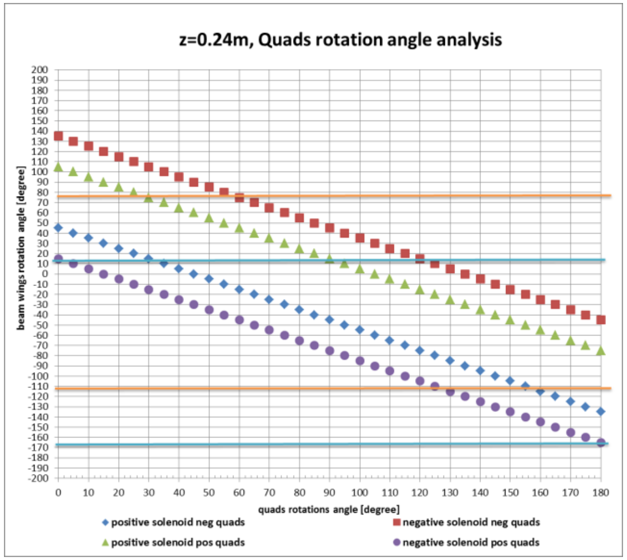
➔ the quads also changes its polarity when change the solenoid polarity.

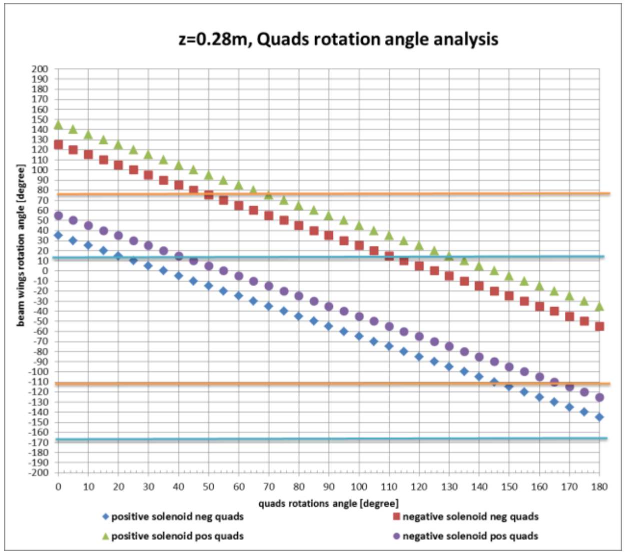
# Rotation quads simulation analysis for other positions

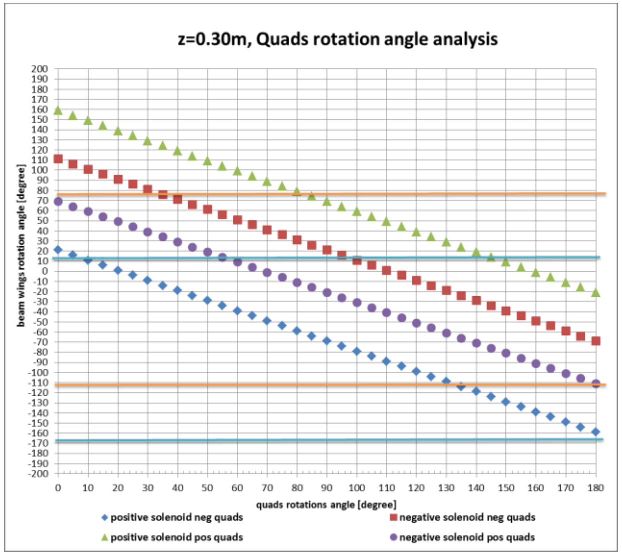
| start angle, 0 degree | nsnq[deg] | nspq[deg] | psnq[deg] | pspq[deg] |
|---|---|---|---|---|
| 0.18 m | 150 | 60 | 30 | 120 |
| 0.28 m | 125 | 35 | 55 | 145 |
| 0.34 m | 110 | 20 | 70 | 160 |

$$y = -x + K$$

K is the beam wings clockwise rotational angle, when the quads rotation angle is 0 degree (initial set value).




- ✓ Rotation quad position at z= 0.24m, 0.28m, 0.30m are also analysed, could not find right rotation angle fit to the beam wings direction for both negative and positive solenoid current.

Data file are saved at N:\4groups\zn_pitz\NFS\Data\Beam_Imperfections_Studies\Simulations\ASTRA_rotational_quads.

# Beam simulation with skew quads at z =0.18m for beam wings

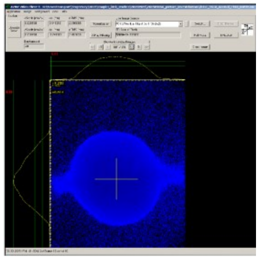
➔All ASTRA simulation set up are same with experiment set up, beam momentum and solenoid current.

➔ When the rotation angle is 135 degree, the quads polarity should be negeative.

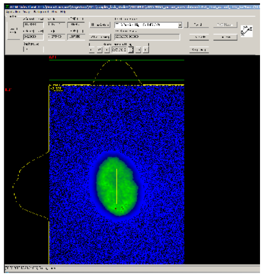
/skew quadrupole
Q_type(1) = 'skew',
Q_length(1)=0.01,
Q_K(1)= XXX,
Q_pos(1)=0.18,

**Pgun=5MW, 6.178 MeV/c, gradient is 54.2 MV/c, no booster** 05.09A-06.09N.2015.

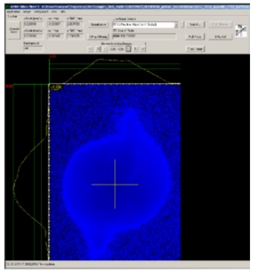
-361A



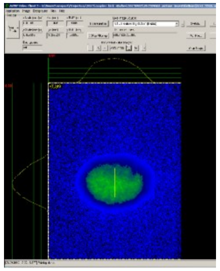
-356A



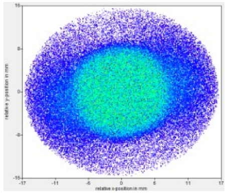
361A

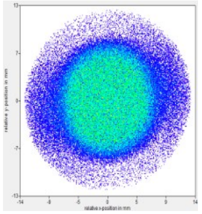


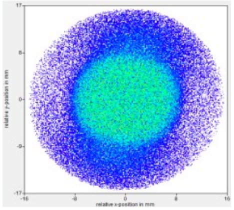
356A

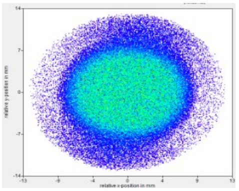


2D-3D space charge, z_trans=0.12m, **Q_k= -0.6**

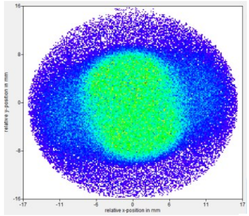


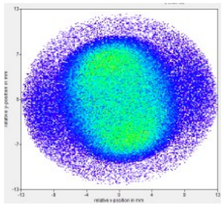


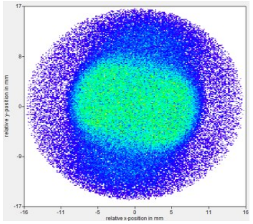


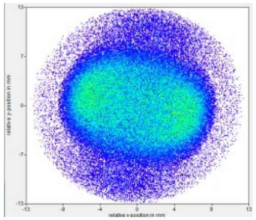


2D space charge, **Q_k= -0.2**









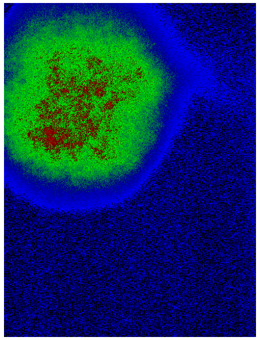
Q_k=-0.6, Q_zrot=135 degree

# Beam wings for 3MW in the gun with skew quads at z =0.18m

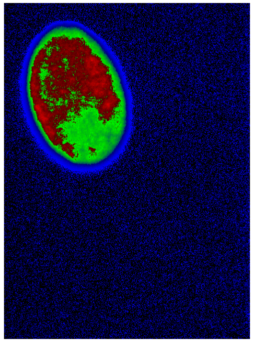
**3MW in the gun, momentum 4.848 MeV/c, gradient 42.2 MV/m**

2015/09/29 Later shift

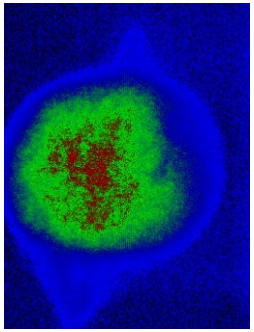
-290A



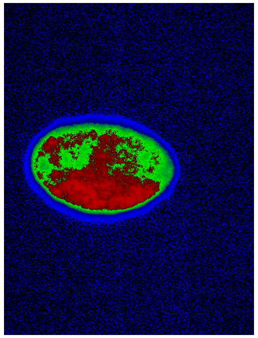
-282A



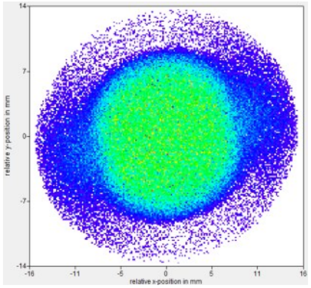
290A

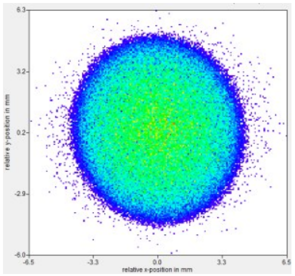


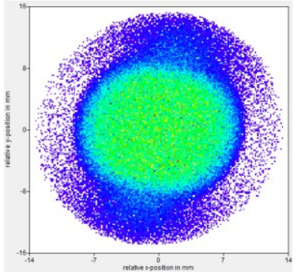
282A

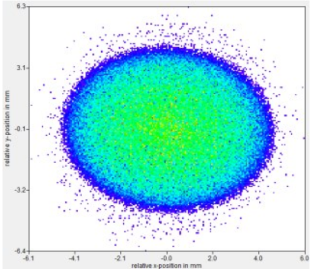


2D to 3D space charge, from z = 0.12m, **Q_K= -1.0**.

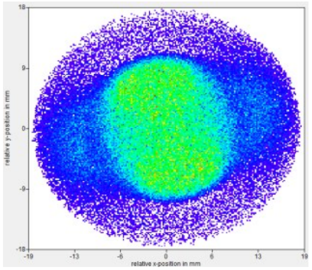


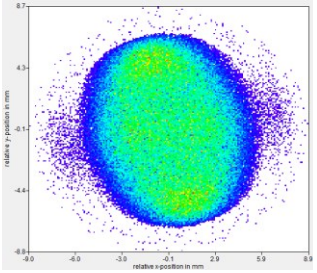


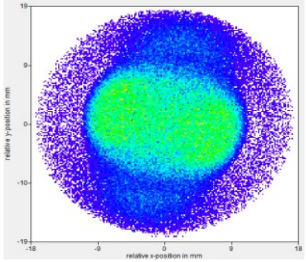


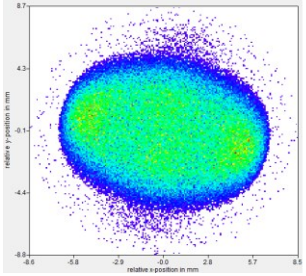


2D space charge, **Q_K= -0.3**.







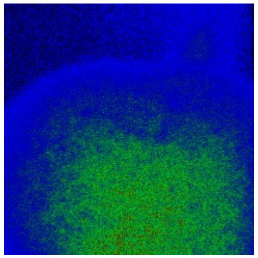


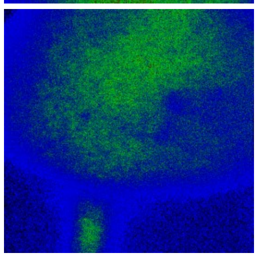
# Beam wings for 1.5 MW in the gun with skew quads at z =0.18m

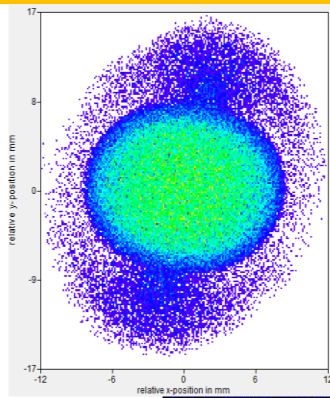
**1.5 MW in the gun, momentum 3.691 MeV/c, gradient 31.4MV/m**

**2D to 3D space charge, from z = 0.12m, Q_k = -2.0**

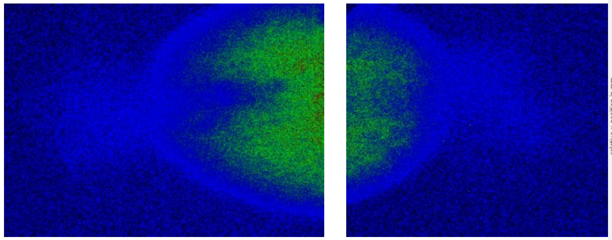
219A

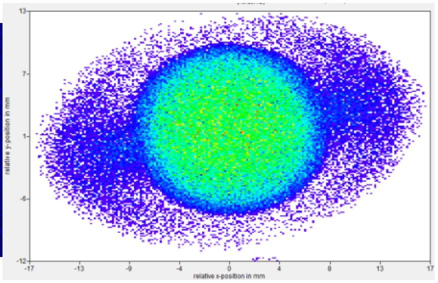




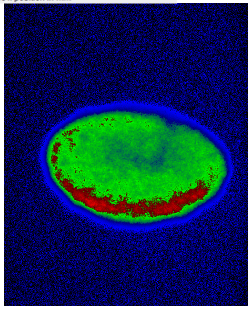


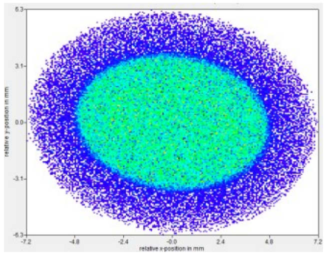
-219A



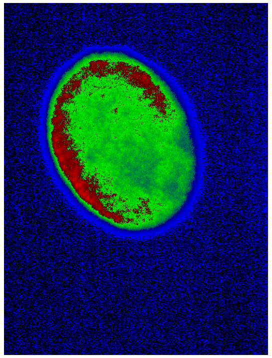


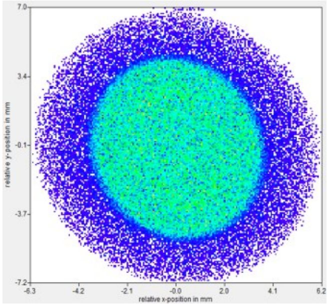
210A





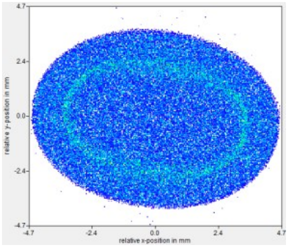
-210A

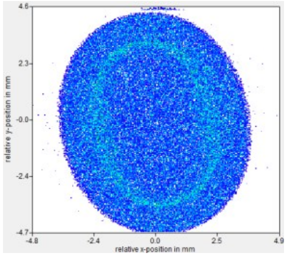




**2D space charge simulation, Q_k = -0.4**

➔The high intensity beam rings in experiment images can also be observed in 2D space charge simulation.





# Summary

➔Beam images at High1.Scr1 fit well with ASTRA simulation with skew quads model at z =0.18m for different gun gradient and different solenoid current.
➔In the table, the skew quads Q_k is the minimum value from simulation when the beam wings can be observed.

Skew quads at z = 0.18 m.

PRELIMINARY

| Power in the gun | **Gradient (MV/m)** | Momentum (exp) (MeV/c) | Charge (pC) | Skew Q_Position (m) | Beam momentum at z = 0.18 (simu) | Skew Q_k (m^-2) (2D space charge/ 2D-3D space charge) | **Skew_Q [Gradient*q]** | Skew Q_length (m) | **Solenoid current(A) (for wings/tilt)** |
|---|---|---|---|---|---|---|---|---|---|
| 5MW | **54.2** | 6.1 | 500 | 0.18 | 6.074 | **~ < -0.2**<br>**~ < -0.6** | **~ < -1.22**<br>**~ < -3.64** | 0.01 | **361/356** |
| 3MW | **42.2** | 4.84 | 334 | 0.18 | 4.818 | **~ < -0.3**<br>**~ < -0.6** | **~ < -1.44**<br>**~ < -2.89** | 0.01 | **290/282** |
| 1.5 MW | **31.4** | 3.69 | 334 | 0.18 | 3.685 | **~ < -0.4**<br>**~ < -1.5** | **~ < -1.47**<br>**~ < -5.52** | 0.01 | **219/210** |

$$B_0\rho = \frac{P_0}{q} \qquad k(s) = \frac{g(s)}{B_0\rho} \qquad g(s) = k(s)\cdot P_0/q$$

# Beam simulation with normal quads at z =0.34m for beam wings

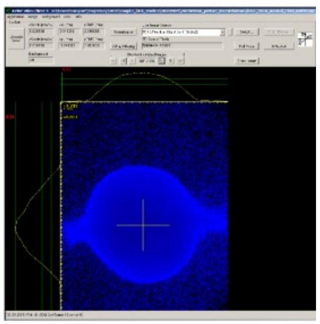
➔All ASTRA simulation set up are same with experiment set up, beam momentum and solenoid current.

➔ When the rotation angle is 90 degree, the quads polarity should be same with solenoid polarity for beam wings fit to experiment.

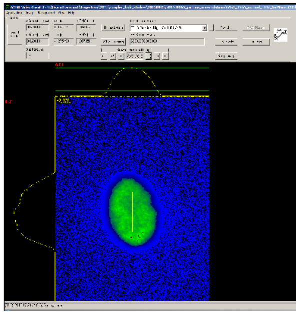
Q_length(1)=0.01
Q_K(1)=xxx
Q_pos(1)=0.34
Q_zrot(1)=1.5708 (90 degree)

**Pgun=5MW, 6.178 MeV/c, gradient is 54.2 MV/c, no booster** 05.09A-06.09N.2015.

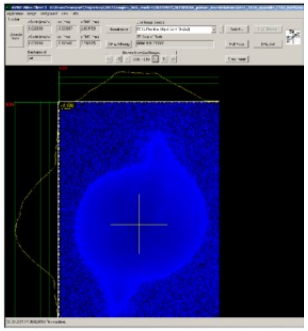
-361A



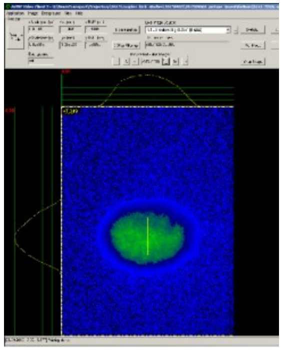
-356A



361A



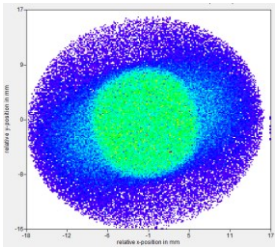
356A

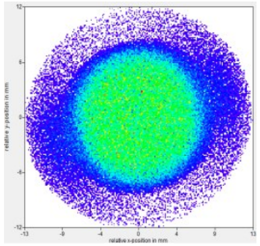


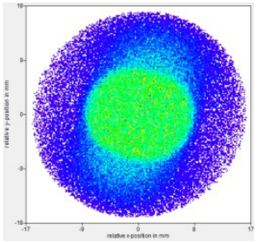
2D-3D space charge, z_trans=0.12m

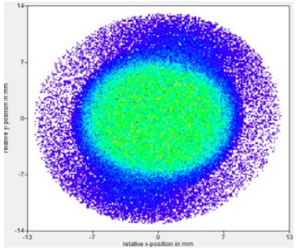
**Q_k= -0.2**

**Q_k= 0.2**







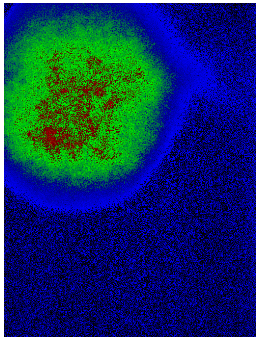


# Beam asymmetry for 3MW in the gun, rotation angle 90 degree, at z =0.34m .

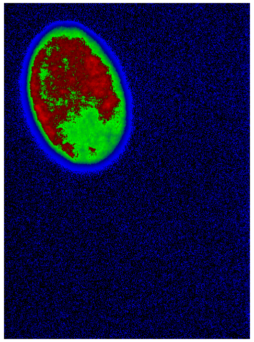
2015/09/29 Later shift

**3MW in the gun, momentum 4.848 MeV/c, gradient 42.2 MV/m**

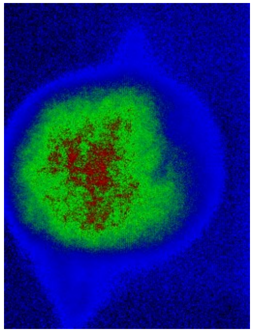
-290A



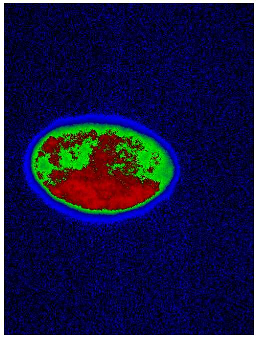
-282A



290A

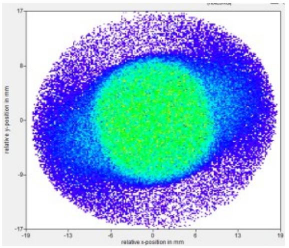


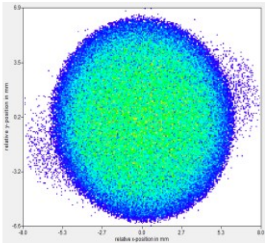
282A



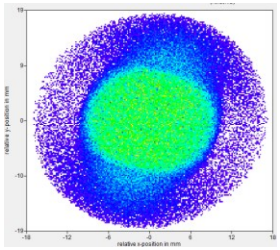
2D to 3D space charge, from z = 0.12m

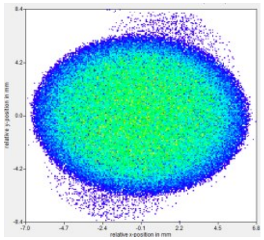
**Q_K= -0.3**





**Q_K= 0.3**

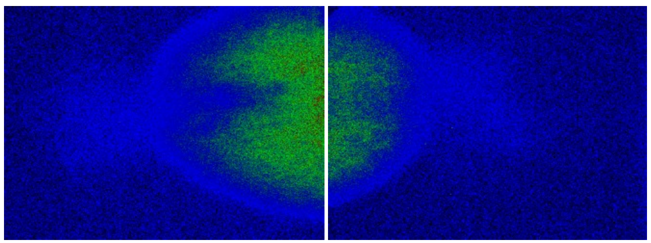




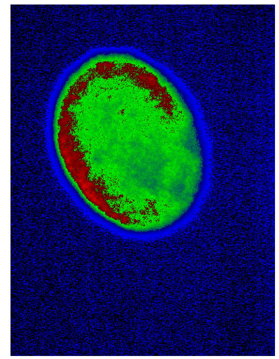
# Beam asymmetry for 1.5MW in the gun, rotation angle 90 degree at z =0.34m .

## 1.5 MW in the gun, momentum 3.691 MeV/c, gradient 31.4MV/m

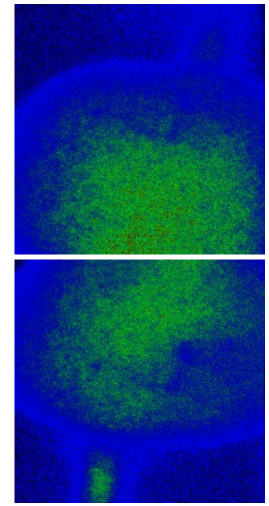
-219A



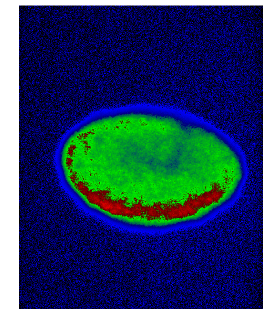
-210A



219A

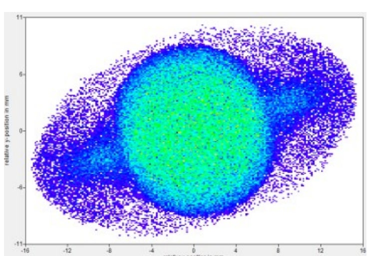


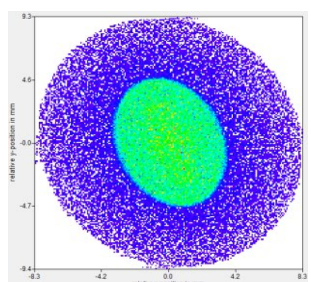
210A



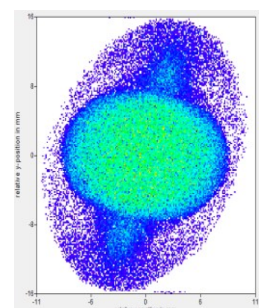
**2D to 3D space charge, from z = 0.12m**

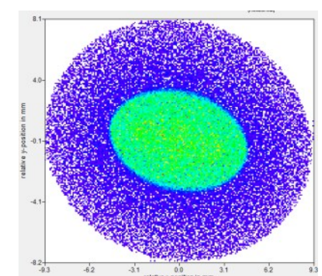
**Q_K= -1.0**





**Q_K= 1.0**





# Conclusions

- Beam images at High1.Scr1 fit well between experiment and ASTRA simulation with rotation quads model for different gun gradient and different solenoid current.

- The rotation quads position and rotation angle can be estimated by ASTRA simulation:
  - ✓ Position: around z=0.18m
    Rotation angle: Skew quads[45 degree( negative polarity) or ~135 degree( positive polarity)].
    Polarity: same, not effected by solenoid field polarity.
  - ✓ Position: around z=0.34m (~0.36m)
    Rotation angle: normal quads.
    Polarity: when change the solenoid polarity, the quads polarity also changed.

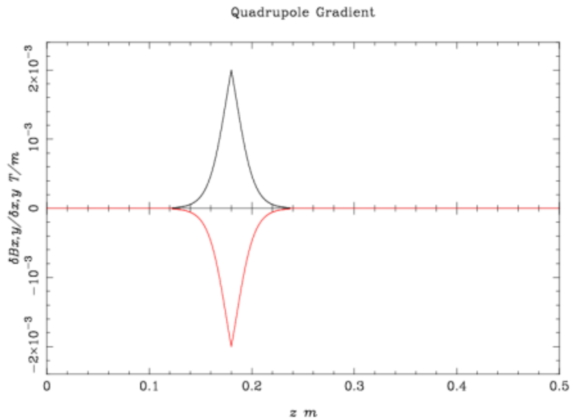
- The non-ideal field for beam asymmetry are most probably around at z = 0.18 m, the skew quads at the transition region of coupler to gun cavity, or/and at z = 0.34 m, the normal quads near the exit region of the solenoid.

- Consider and design the skew quads and normal quads for beam asymmetry compensation with beam test….

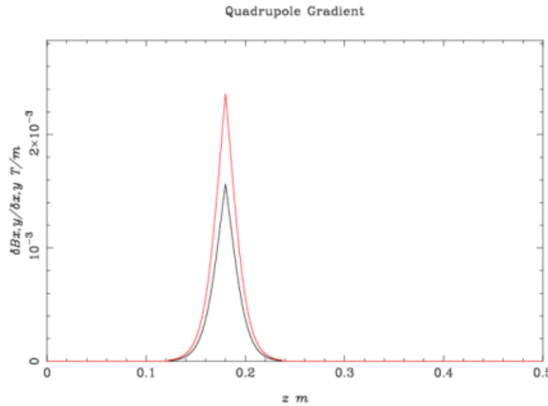
# Back slides

Z= 0.18, Q_k= -0.6, different quad rotational angle field plot from ASTRA

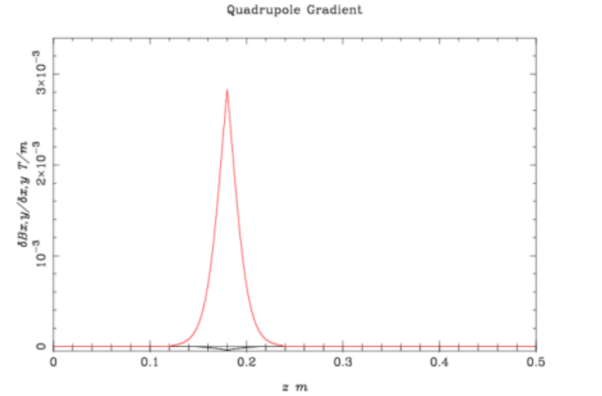
Skew(135 degree)



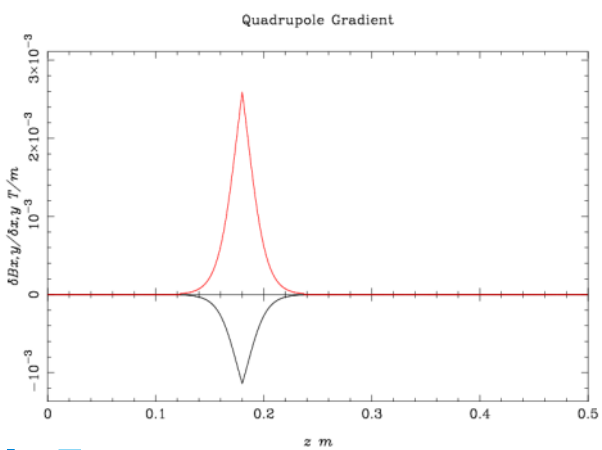

0.1 rad, 5.73 degree



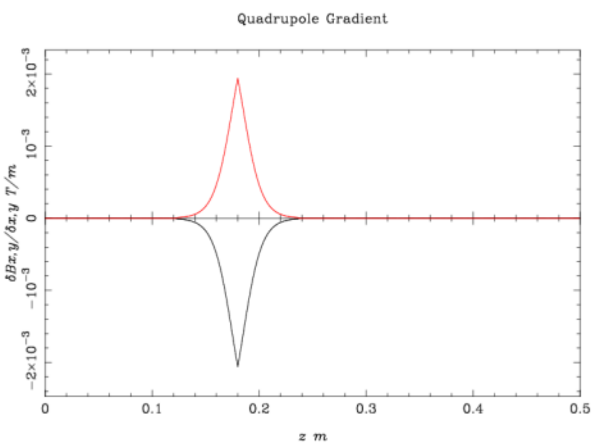

0.4 rad, 22.9 degree



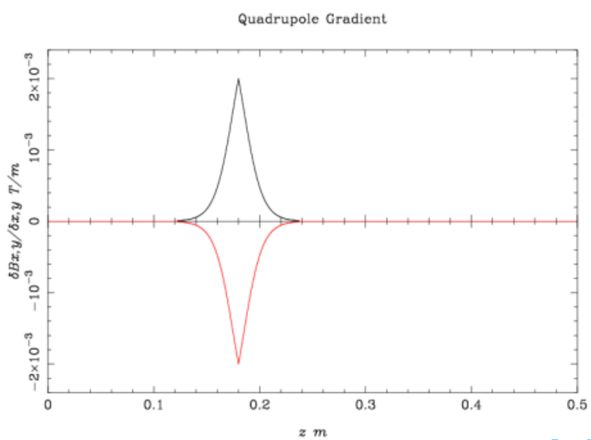

0.6 rad, 34.4 degree




0.8 rad, 45 degree

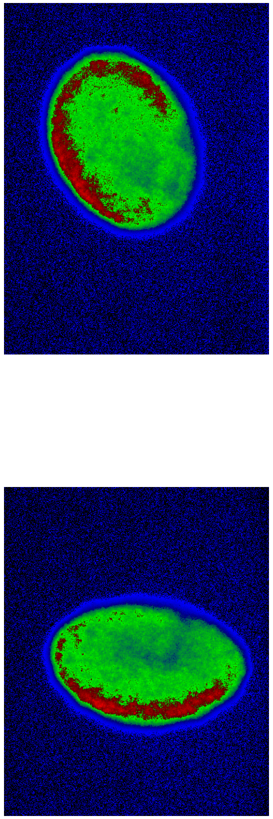


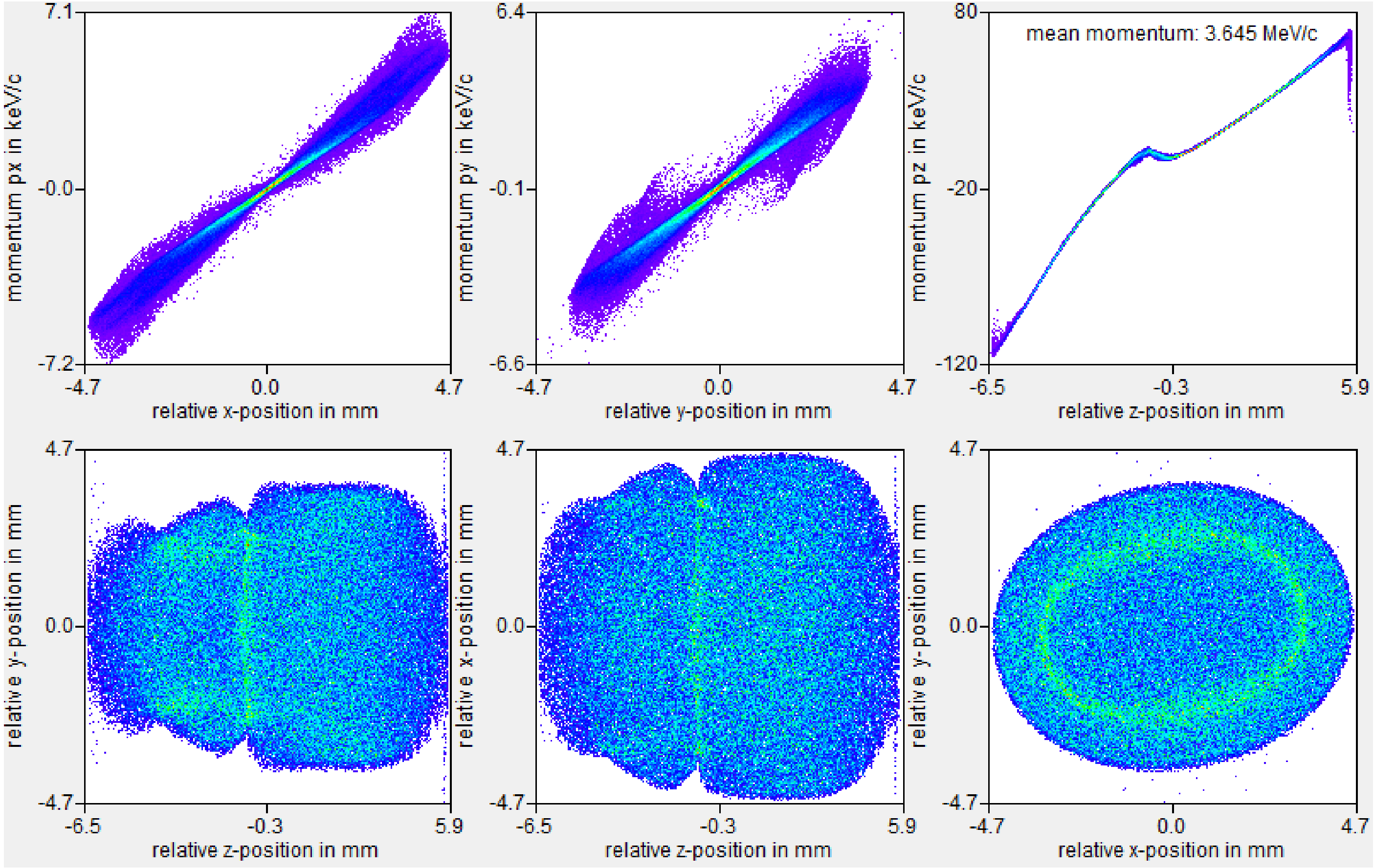

2.356 rad, 135 degree



# Beam ring from 1.5 MW simulation

-210A, 1.5 MW, 2D space charge







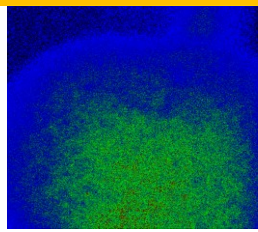
!Not flip horizontal

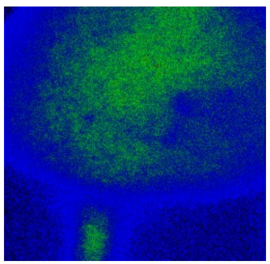
# Beam asymmetry for 1.5 MW in the gun (core+halo GV model)

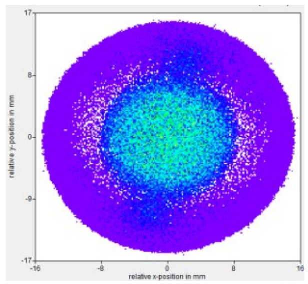
**1.5 MW in the gun, momentum 3.691 MeV/c, gradient 31.4MV/m**

**2D to 3D space charge, from z = 0.12m, Q_k = -2.0**

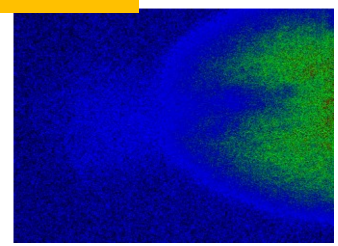
-219A

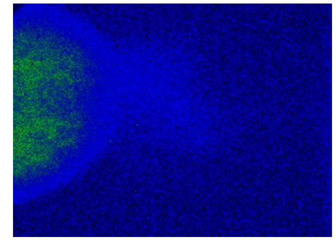


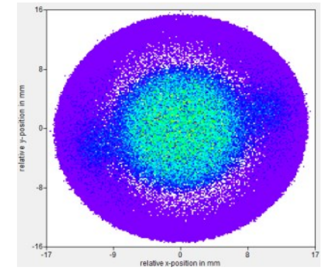




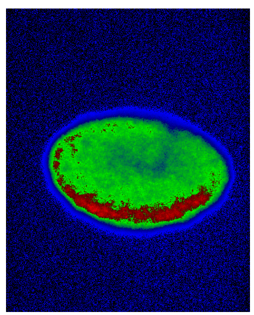
219A

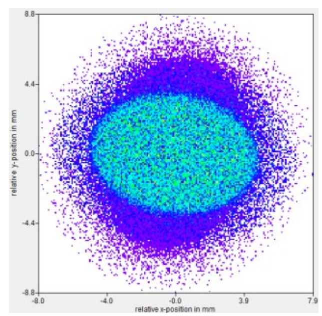




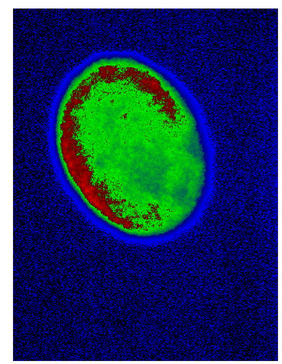


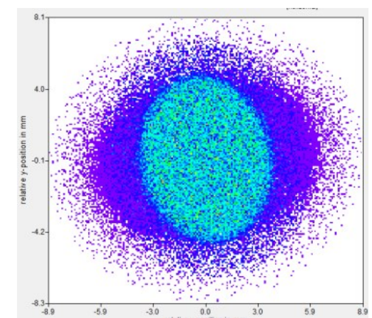
-210A



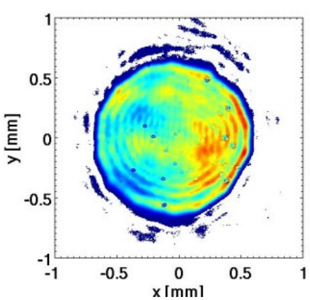


210A

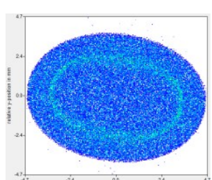




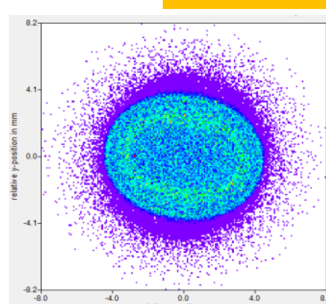
BSA 1.2 mm laser Distribution.

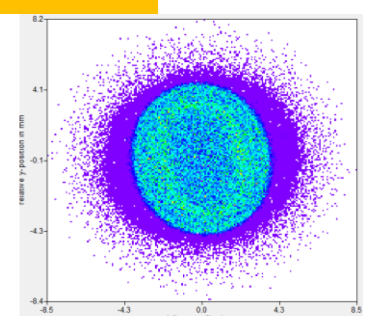



W/o halo



**2D space charge simulation**





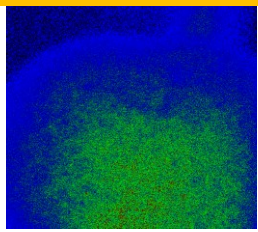
**Q_k = -0.4**

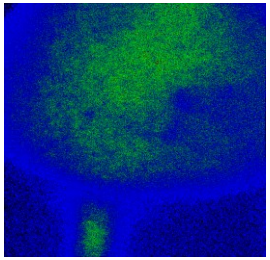
# Beam asymmetry for 1.5 MW in the gun (core+halo MK model)

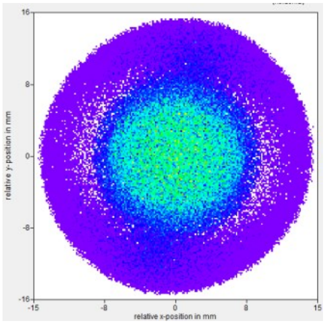
**1.5 MW in the gun, momentum 3.691 MeV/c, gradient 31.4MV/m**

**2D to 3D space charge, from z = 0.12m, Q_k = -2.0**

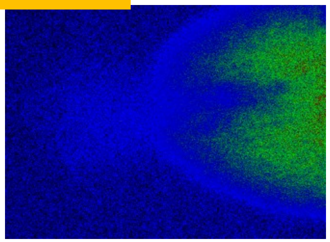
-219A

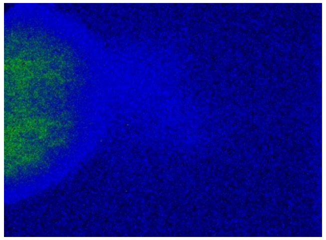


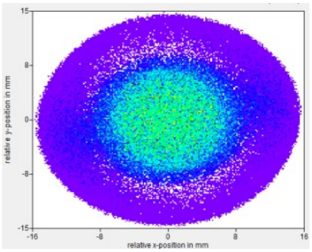




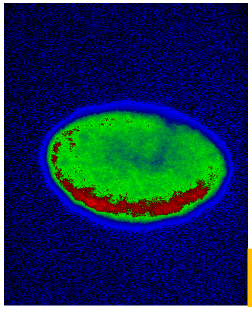
219A

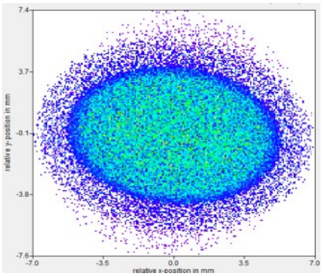




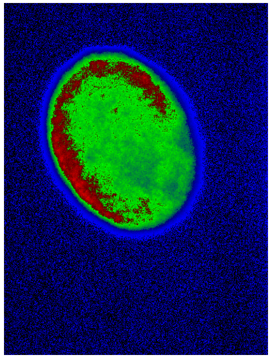


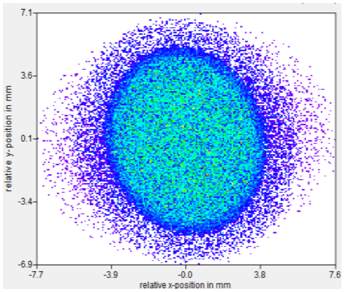
-210A



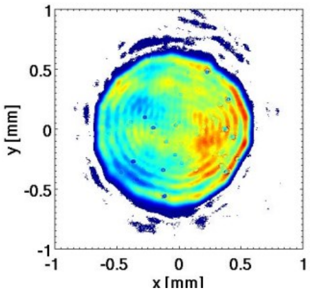


210A

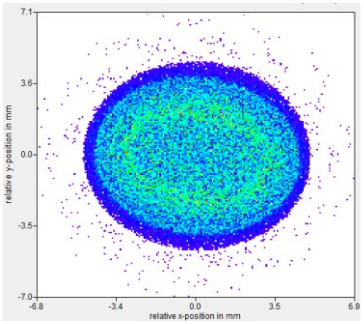


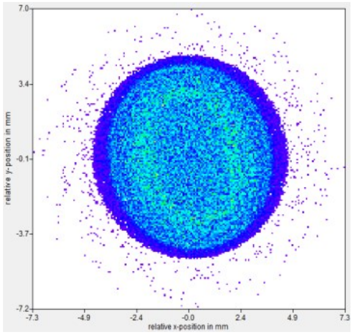


BSA 1.2 mm laser Distribution.




**2D space charge simulation**





**Q_k = -0.4**