# Investigations on electron beam imperfections at the PITZ photo injector

**M. Krasilnikov, DESY-TEMF meeting, 15.01.2016, Hamburg**

Imperfections studies at PITZ:

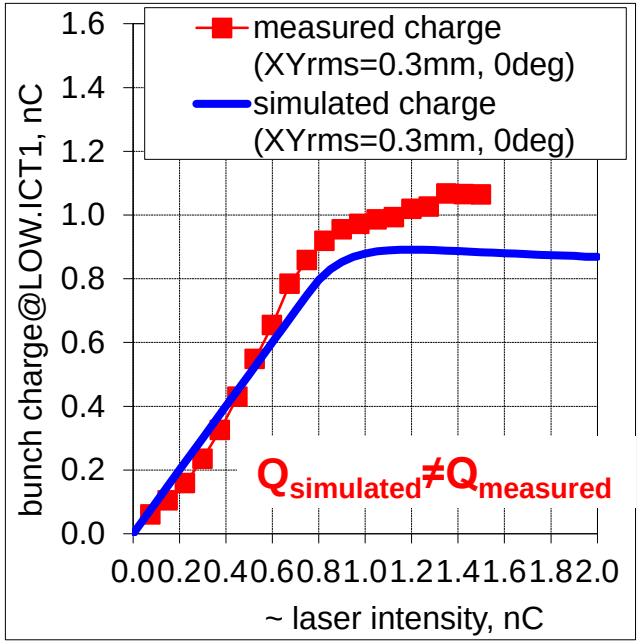
- photoemission studies: core+halo model
- electron beam imaging: main solenoid calibration with a beam
- electron beam asymmetry investigations – RF coupler kick studies

HELMHOLTZ ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

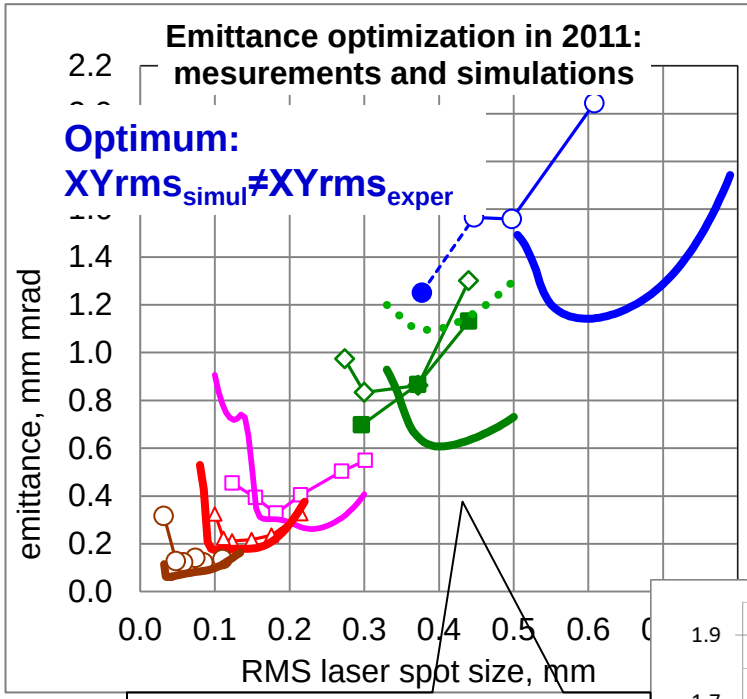
DESY

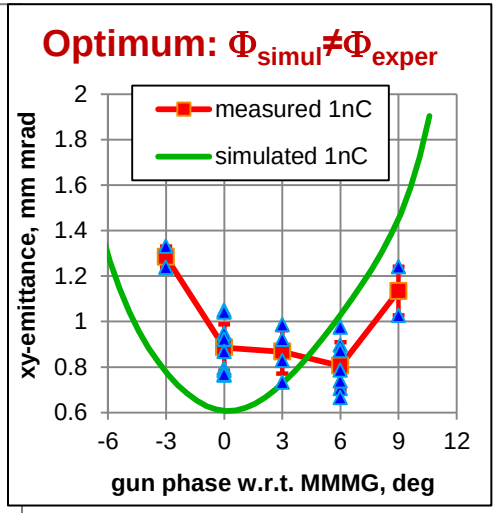
# Investigations on electron beam imperfections: motivation



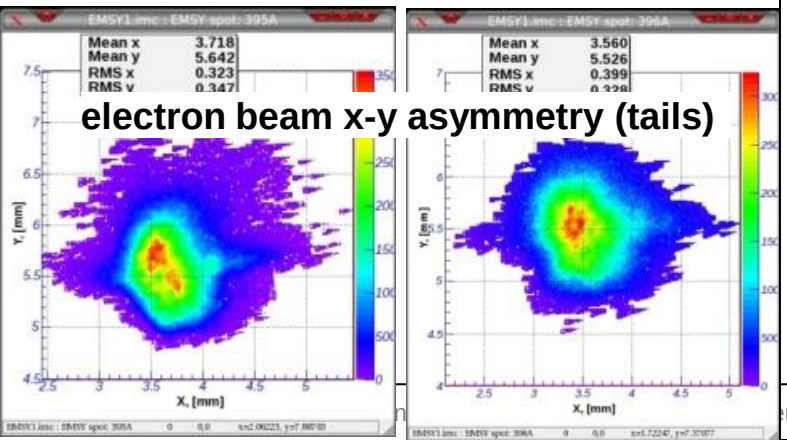

**Optimum machine parameters (laser XYrms, gun Φ, $I_{main}$ )**

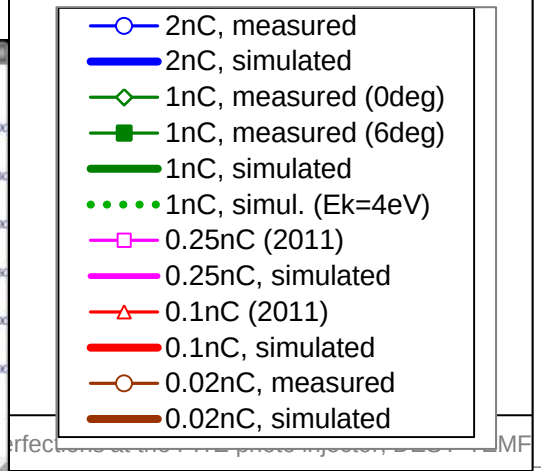
**experiment ≠ simulations**

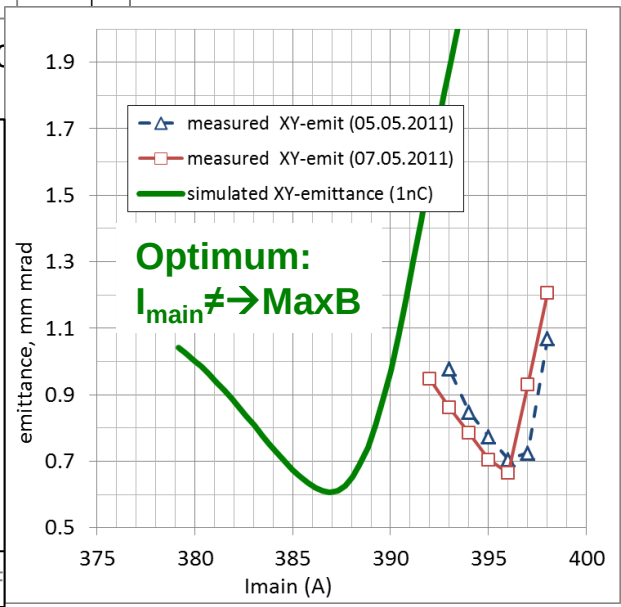



- **photoemission studies**
- **electron beam imaging**
- **electron beam asymmetry investigations**



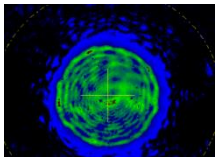



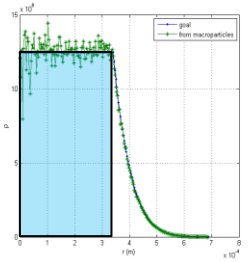



# When the core+halo initial distribution is utilized, ASTRA shows good agreement with extracted charge measurements

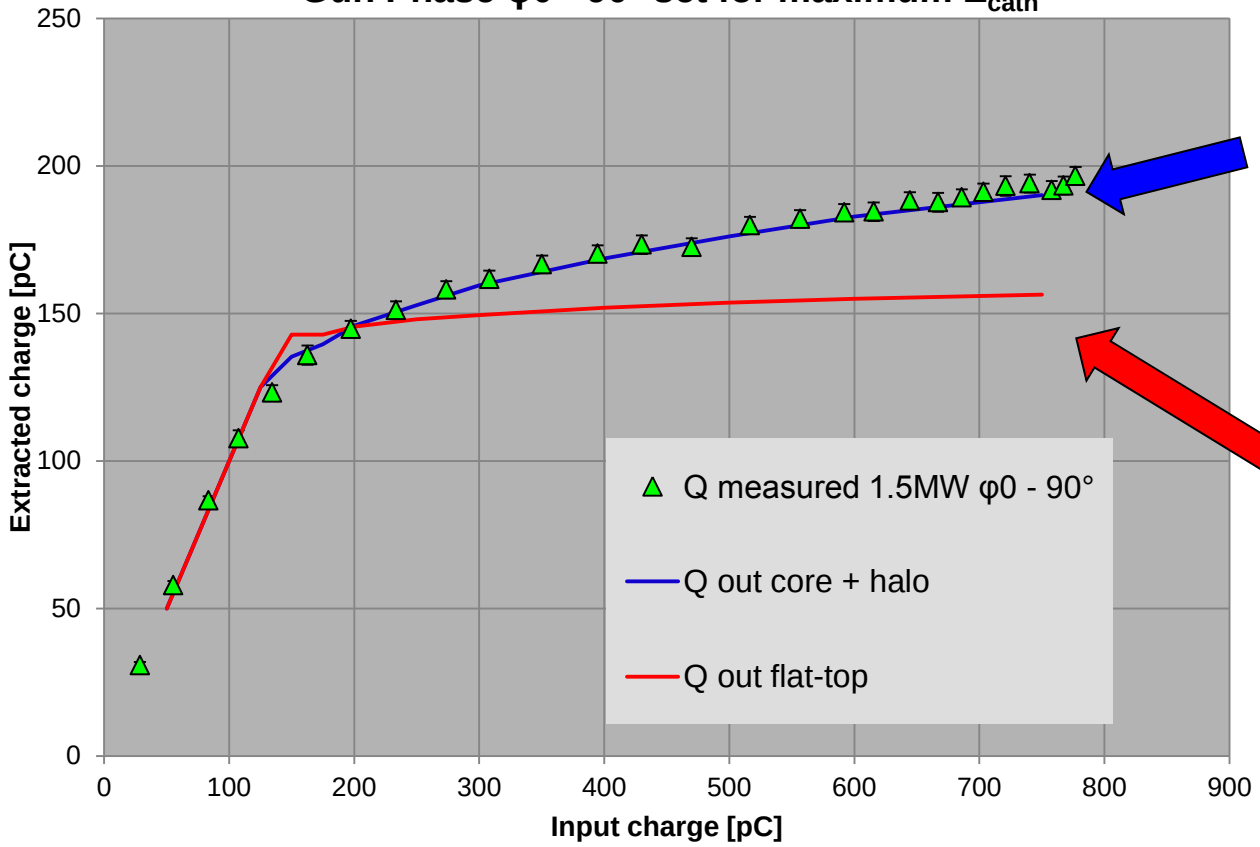
**If a uniform distribution is used instead, the charge saturates**

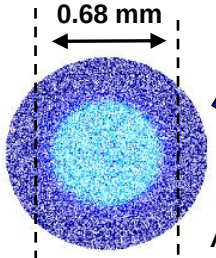
Laser radial distribution image





**Extracted charge vs laser pulse energy for temporal Gaussian $\sigma_t$=1.5 ps BSA=0.8mm Gun Power = 1.5MW and Gun Phase φ0 - 90° set for maximum $E_{cath}$**

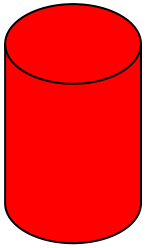



Transverse radial profile core + halo

Generated ASTRA input distribution core + halo


Nominal ASTRA input uniform distribution

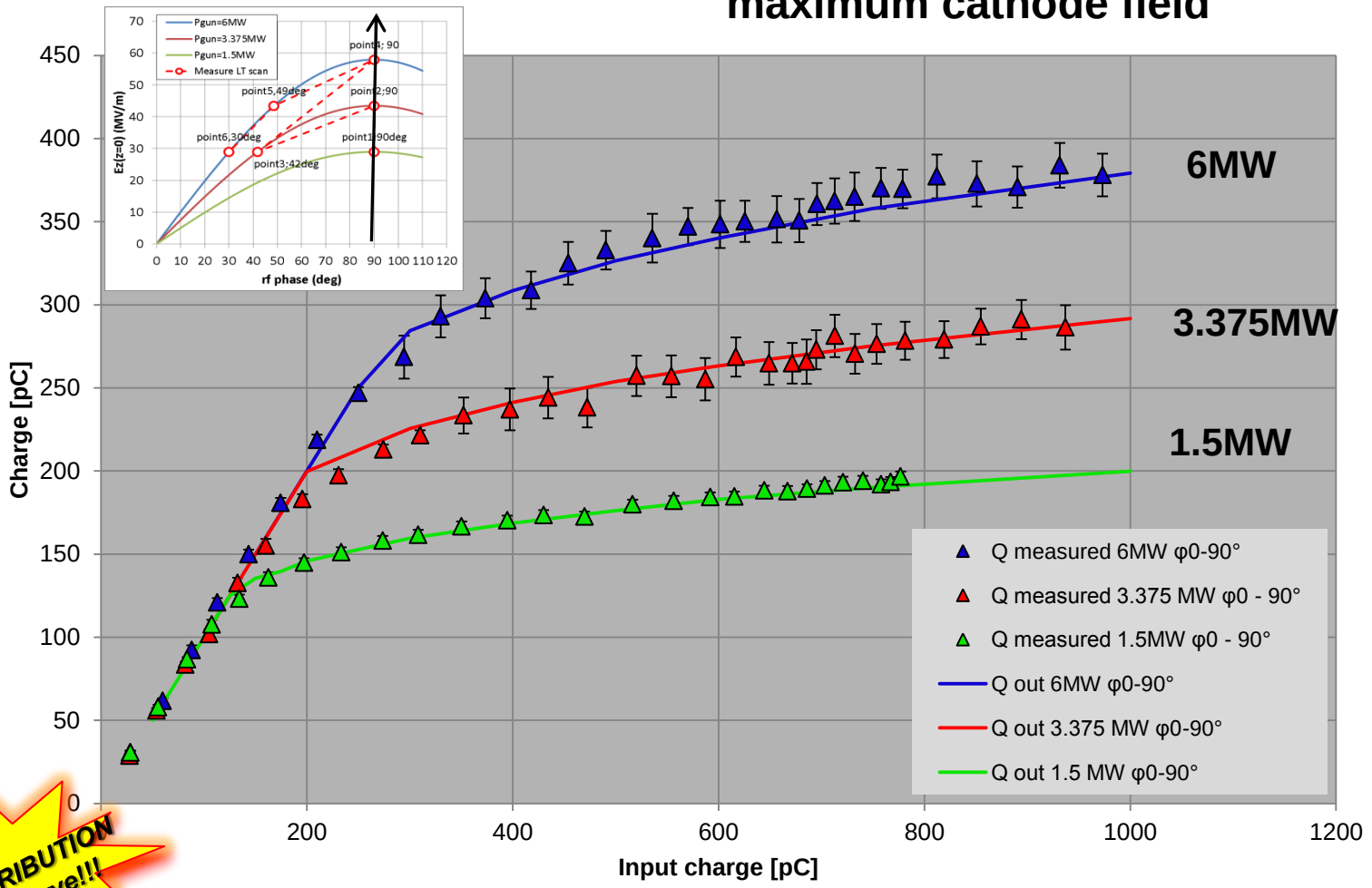


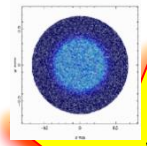
Nominal transverse uniform radial profile

C. Hernandez-Garcia, Emission measurements, Feb-March 2015

# Once a fit is found, the core + halo input distribution fits the experimental data…

**Extracted charge with core + halo for 0.8 mm beam diameter with 1.5 ps rms Gaussian temporal at maximum cathode field**



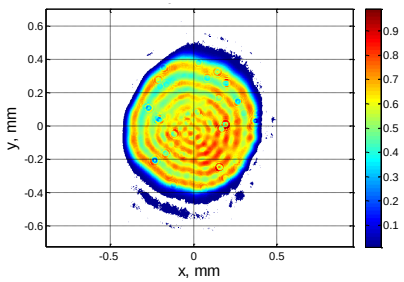



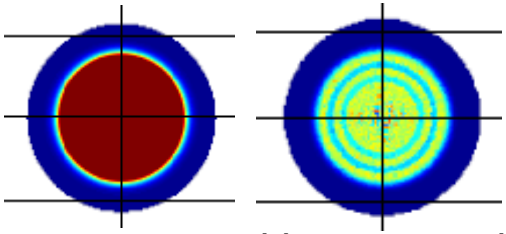
SAME DISTRIBUTION For each curve!!!

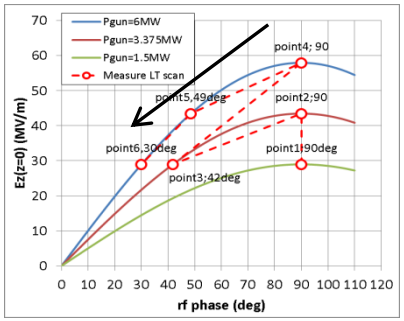
C. Hernandez-Garcia, Emission measurements, Feb-March 2015

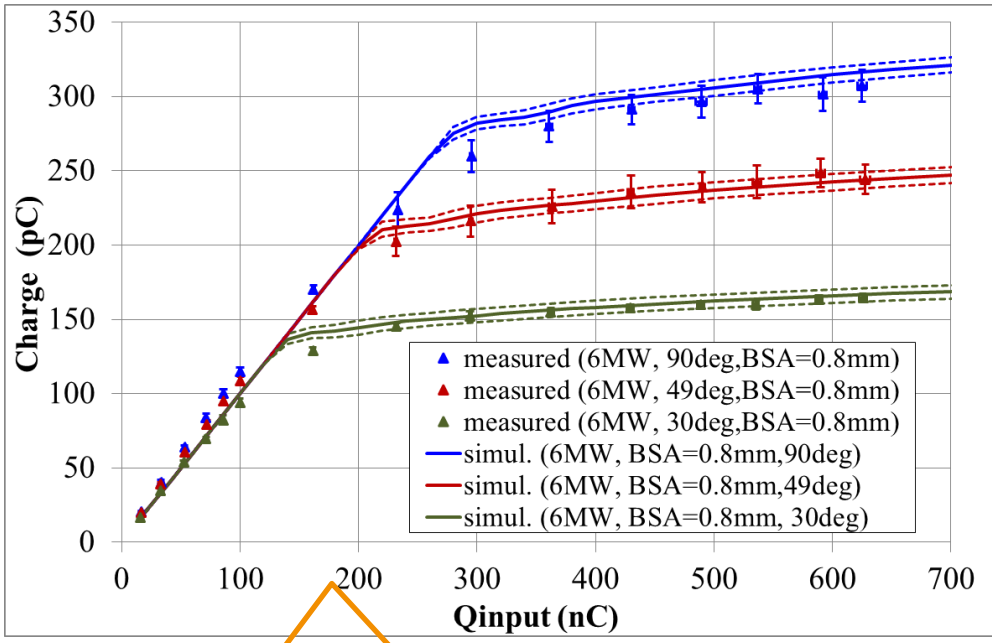
# New emission measurements: October-November 2015

Measured at VC2

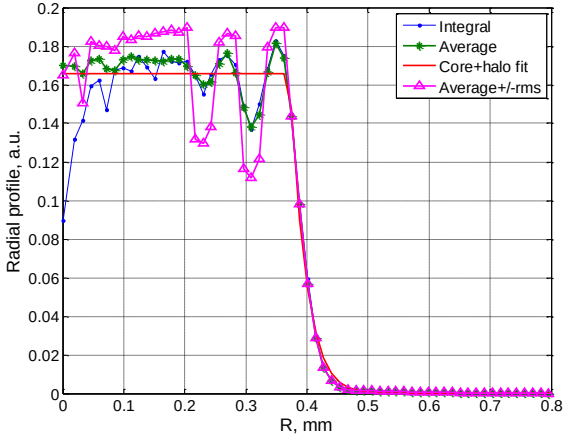





Used in ASTRA simulations




Solid curves = mean (runs 4,13,14,17,10)
Dashed curves = min and max (runs 4,13,14,17,10)

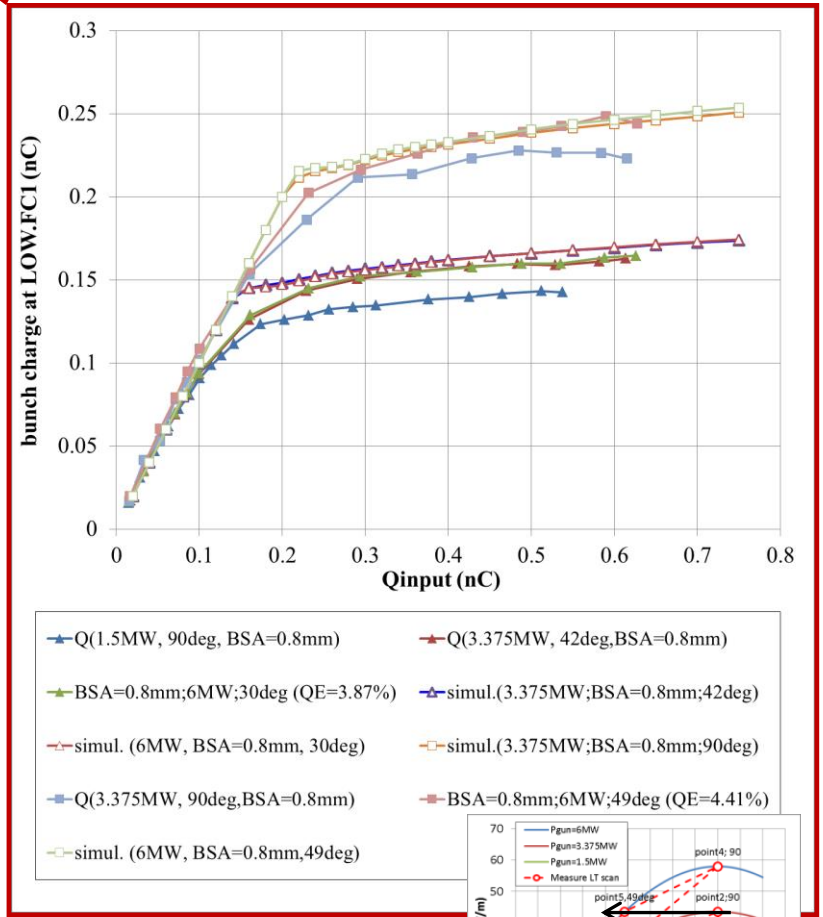
| Run | $\sigma_t$ (ps) | Ecath (MV/m) | $\Delta\Phi$ (deg) | Radial profile: XX-core + Gaussian halo |
|---|---|---|---|---|
| 4 | 0.85 | 59.569 | 0 | Flattop core |
| 13 | | | -1 | Average core |
| 14 | | | 0 | Average core ± $\sigma_\phi$ |
| 17 | | | -1 | |
| 10 | | 58 | -1 | Flattop core |

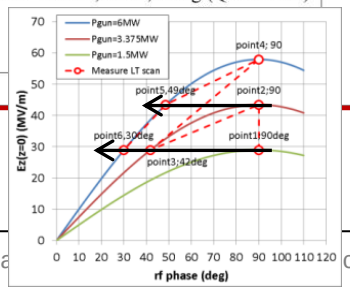
Simulated charge for 90deg w.r.t zero-crossing phase systematically higher than measured

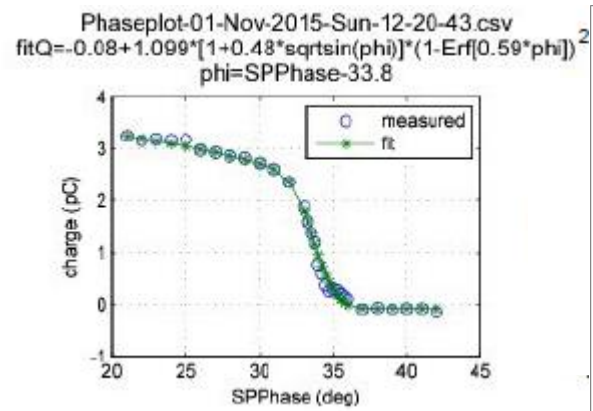
# New emission measurements: October-November 2015

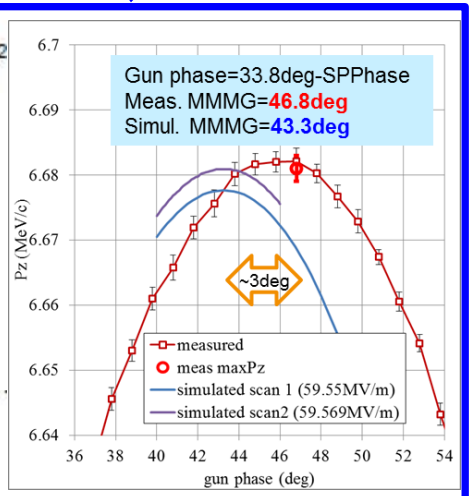
Still not understood:

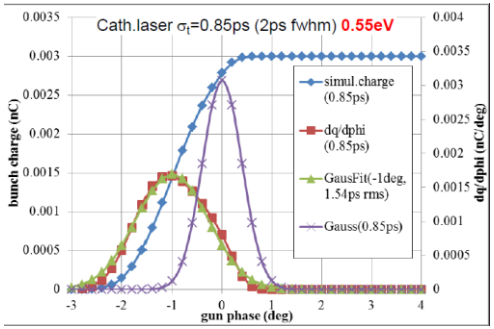
1. Measured charge for 90deg w.r.t zero-crossing phase:
   - systematically lower than corresponding simulations (especially at QE→SC transition)
   - systematically lower than the charge measured at lower phases (30, 49deg) with higher gradients ($E_{cath}$), but same $E_{emission}$
2. Zero-crossing phase ←→ MMMG phase ➔ 2-3 deg phase shift between measurements and simulations

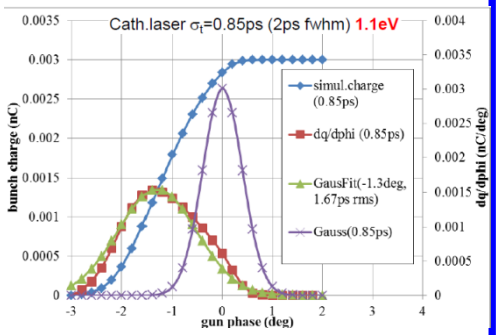


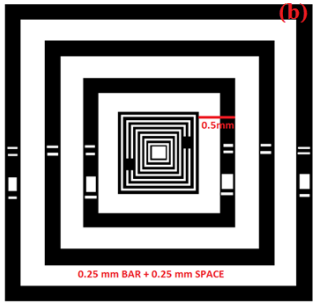



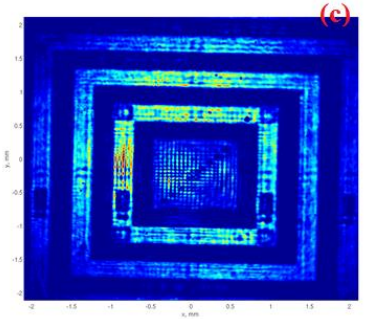

| cathode laser | | Ekin (eV) | delta phi | dq/dphi-Gauss.fit | fit-$\sigma_t/\sigma_t$ |
|---|---|---|---|---|---|
| $\sigma_t$ (ps) | fwhm (ps) | | deg | fit-$\sigma_t$ (ps) | |
| 0.85 | 2 | 0.55 | -1 | 1.54 | 1.81 |
| 0.85 | 2.6 | 1.1 | -1.3 | 1.67 | 1.96 |

# Electron beam imaging studies (Q. Zhao)

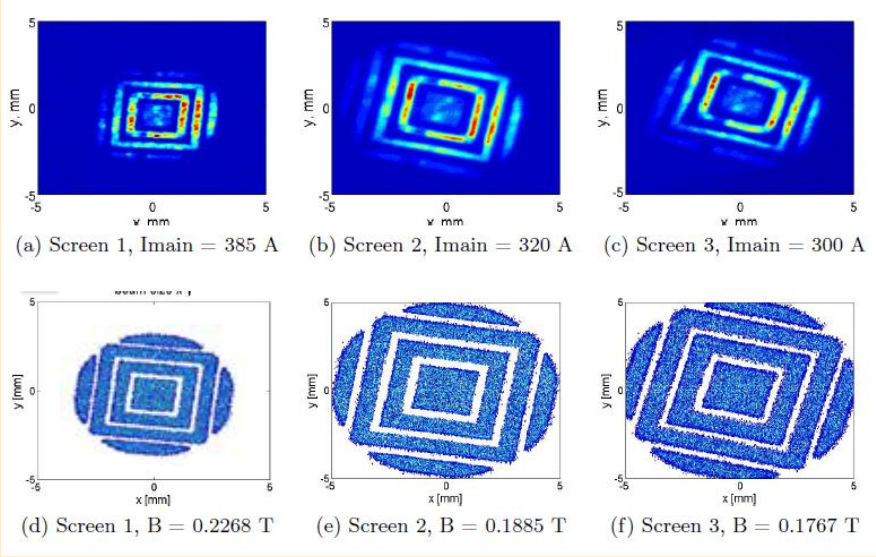
**Main idea**: beam dynamics w/o space charge to confirm RF gun + solenoid electron optics, e.g. the main solenoid calibration: $B_{z,main}[T]=5.889\times10^{-4}*I_{main}[A]+7.102\times10^{-5}$

**Tools**: grid at the BSA location → to be imaged onto the cathode, then electron image at LOW.Scr1,2,3 for various RF peak power level ($E_{cath}$) by $I_{main}$ tuning

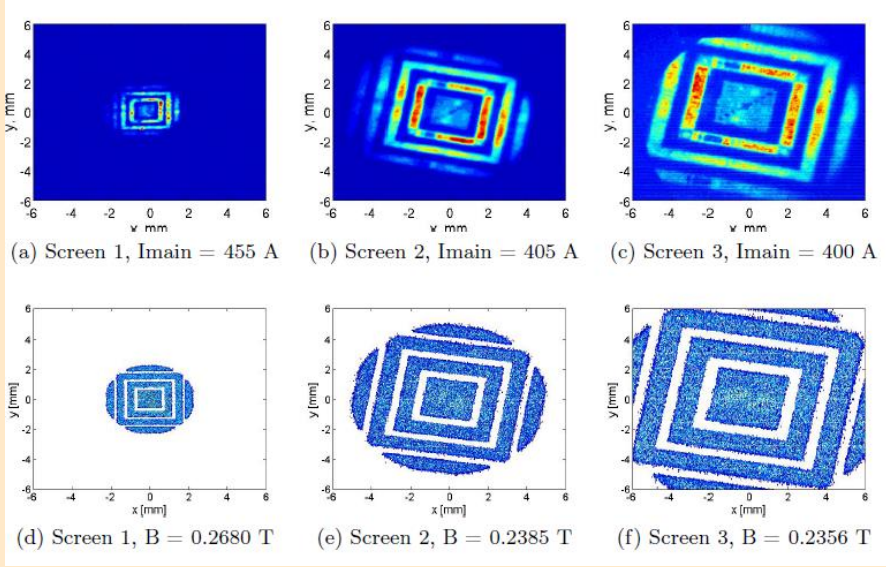



$P_{gun}$=3MW (42.5MV/m → 4.84MeV/c)

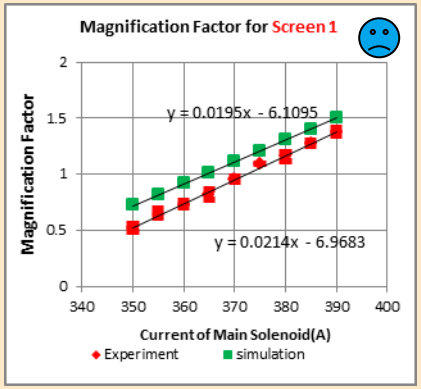


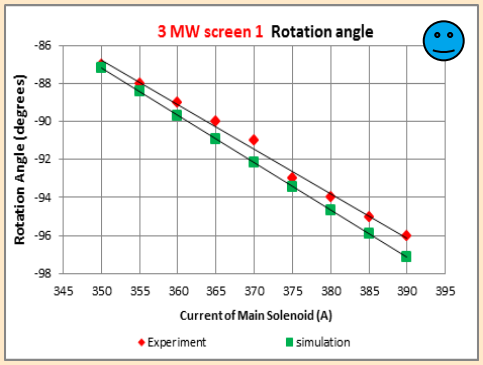

$P_{gun}$=5MW (54.4MV/m → 6.07MeV/c)

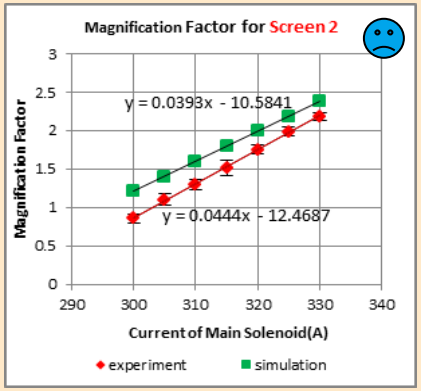


# Electron beam imaging studies (Q. Zhao)

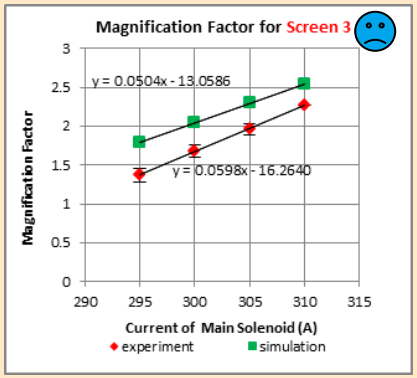
## $P_{gun}$=**3MW** (42.5MV/m → 4.84MeV/c)

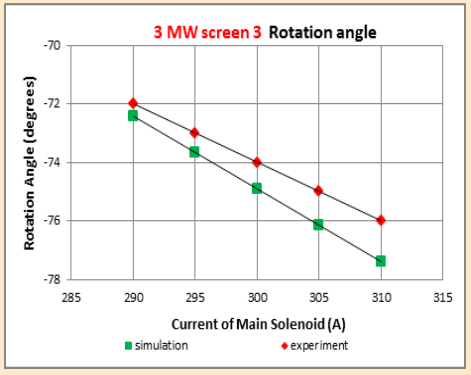


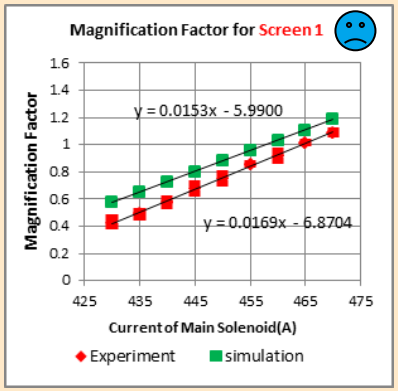



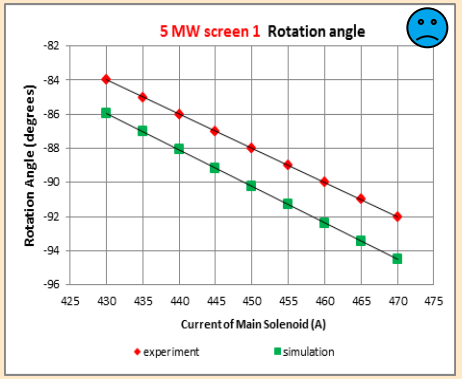

- Measurement-simulation discrepancy in magnification factor for **ALL** screens (resolution?)
- ΔI~**6A** Measured-Simulated → emittance (with space charge)

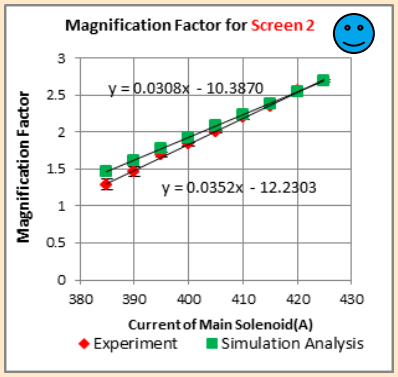


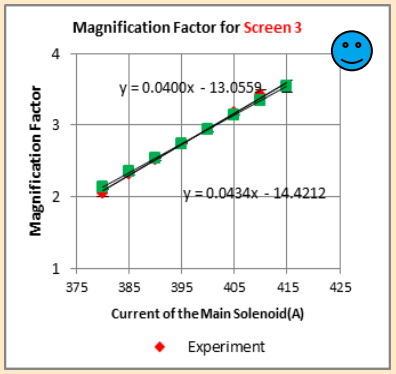

## $P_{gun}$=**5MW** (54.4MV/m → 6.07MeV/c)

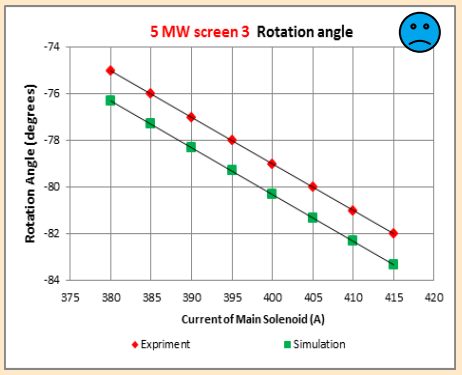



- Measurement-simulation discrepancy in magnification factor for **LOW.Scr1 only**
- ΔI~6A Measured-Simulated → rotation angle and magnification factor at LOW.Scr1

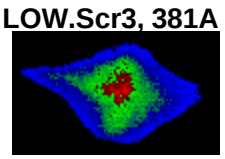


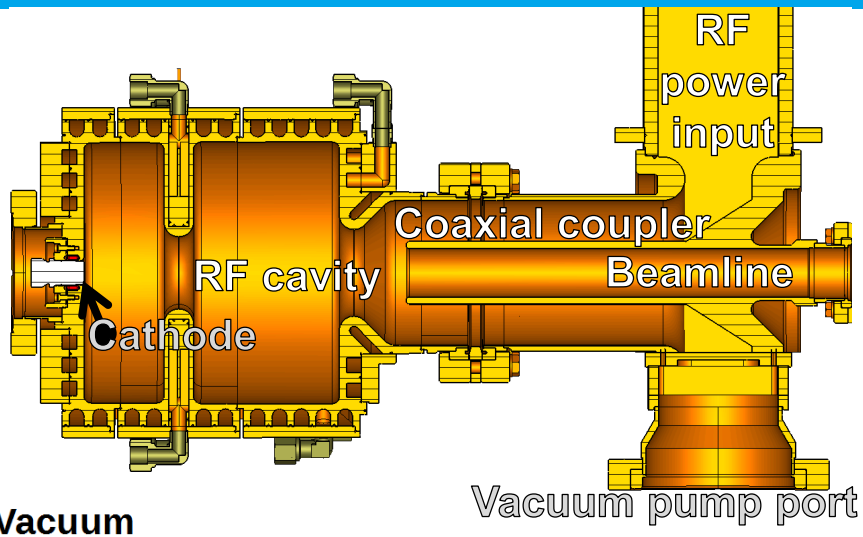



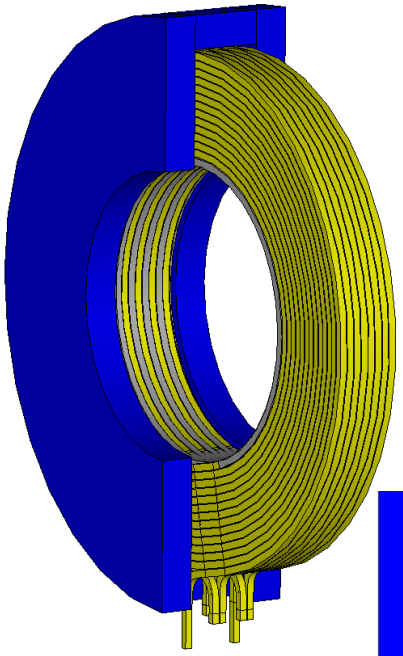

The discrepancy is still to be understood

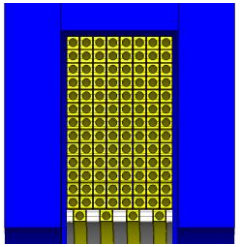
# Electron beam asymmetry: possible reasons

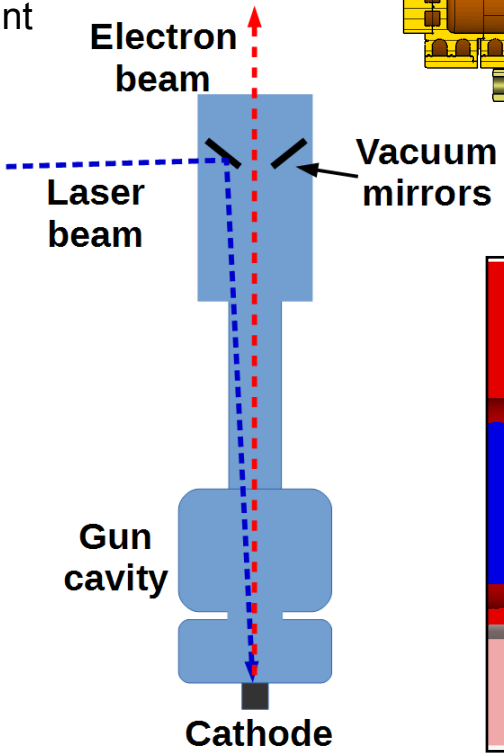
- Vacuum mirror:
  - Steering around
  - 2nd vacuum mirror
- Solenoid imperfections:
  - E-beam for various solenoid tilts
- RF coupler field asymmetry:
  - Scan of the cathode
  - “No forwards power” experiment
  - Larmor angle measurements

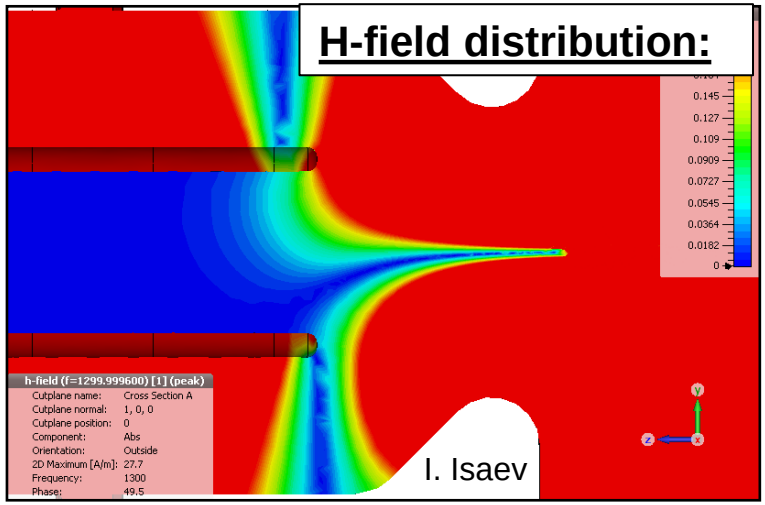




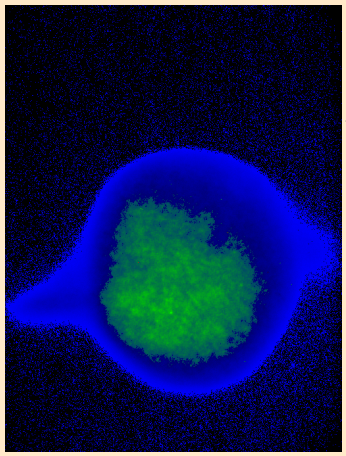


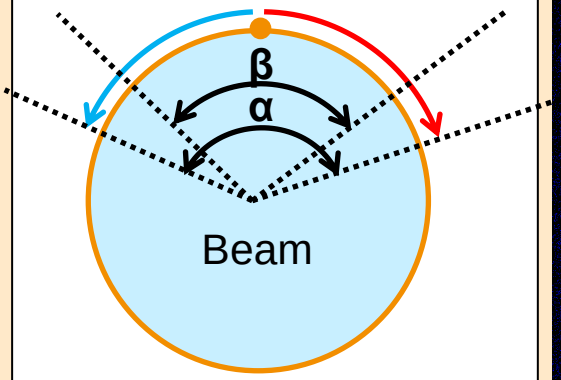



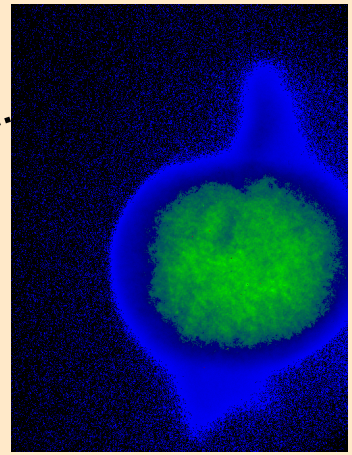

→ of fundamental importance for FLASH + XFEL

# E-beam transverse tails investigations: Larmor angle

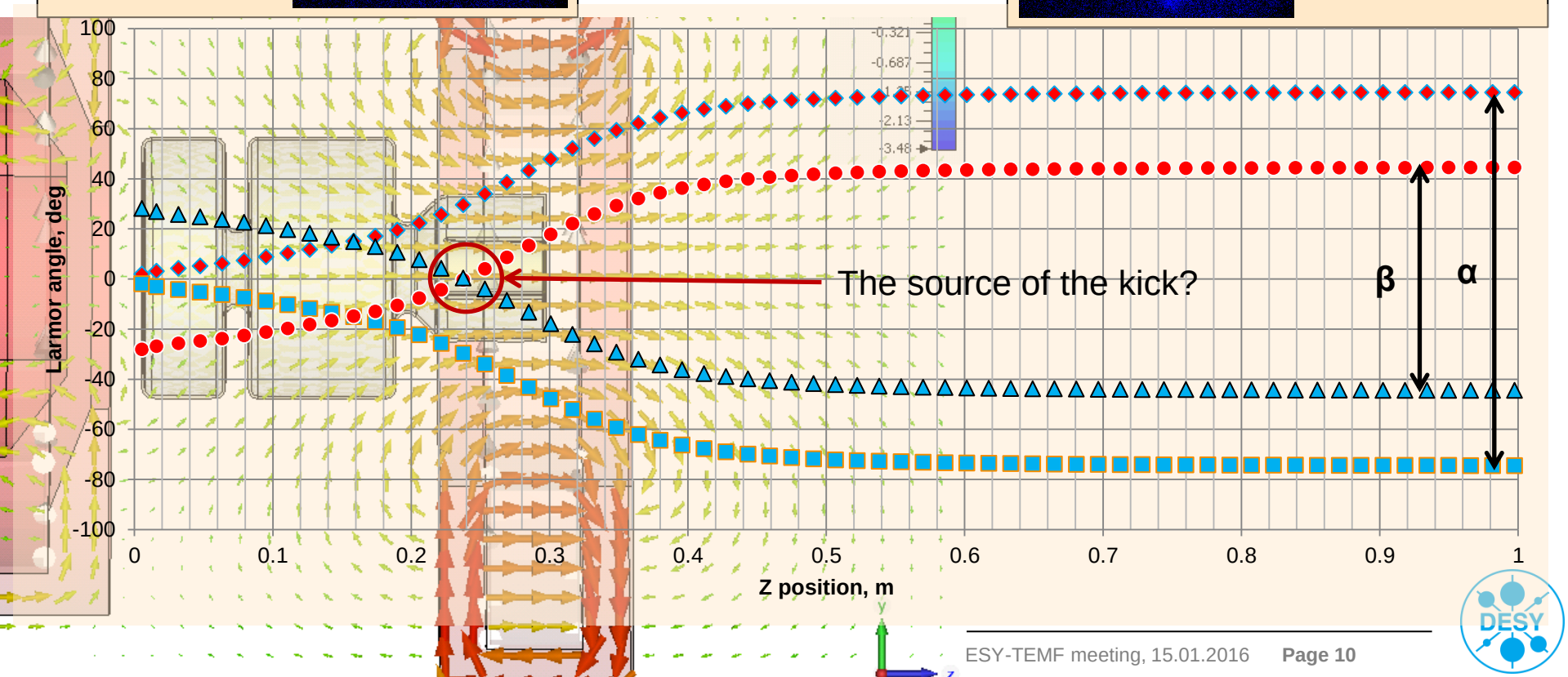
E-beam at HIGH1.Scr1, Imain=+360 A, **Normal polarity,** Ibucking=0A, No booster



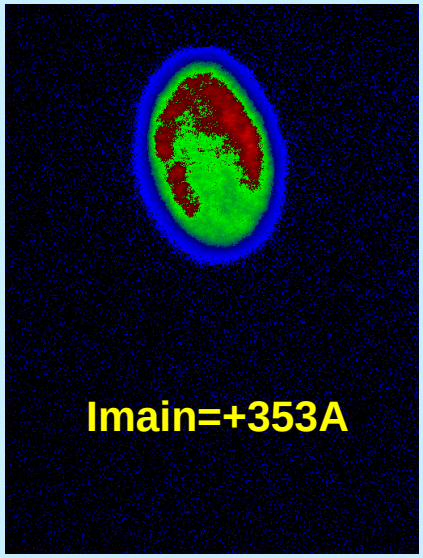


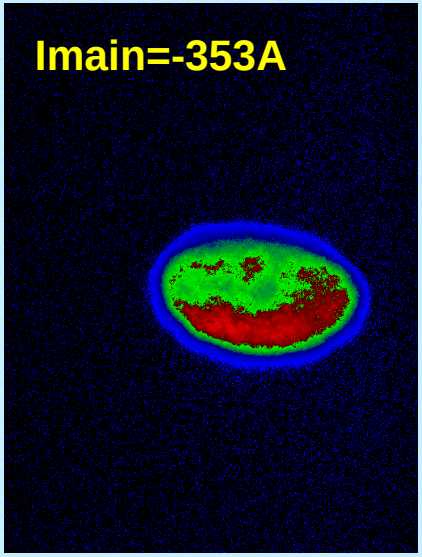
E-beam at HIGH1.Scr1 Imain=-360 A, **Opposite polarity,** Ibucking=0A, No booster

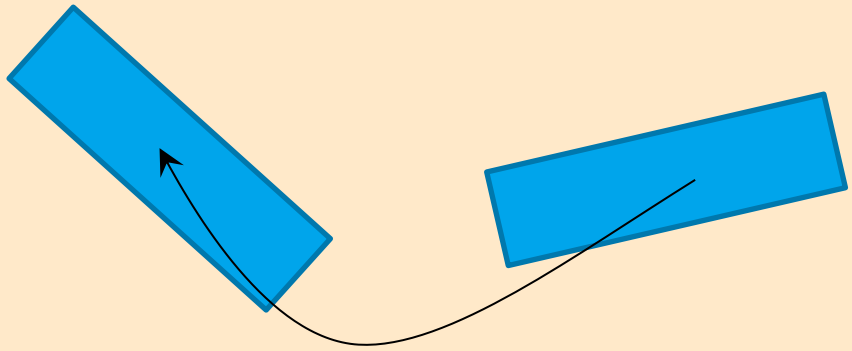


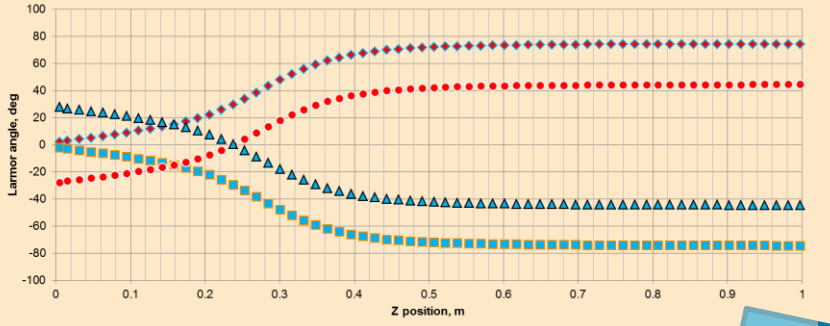
# Larmor angle experiment: beam at HIGH1.Scr1

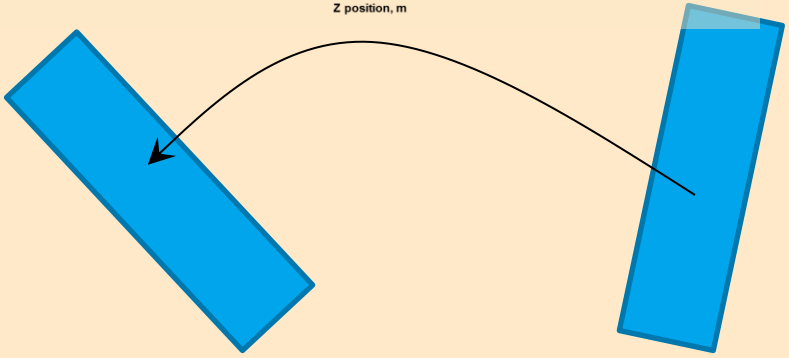


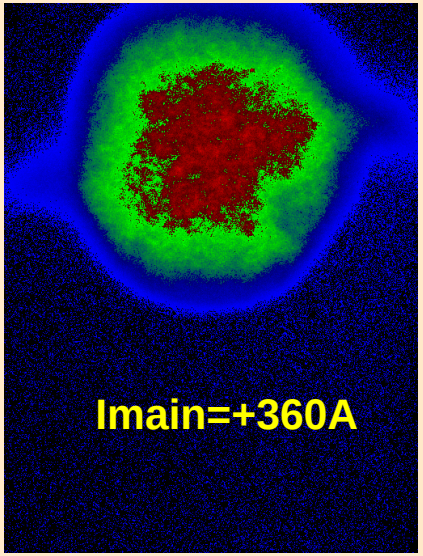

Quad in solenoid?

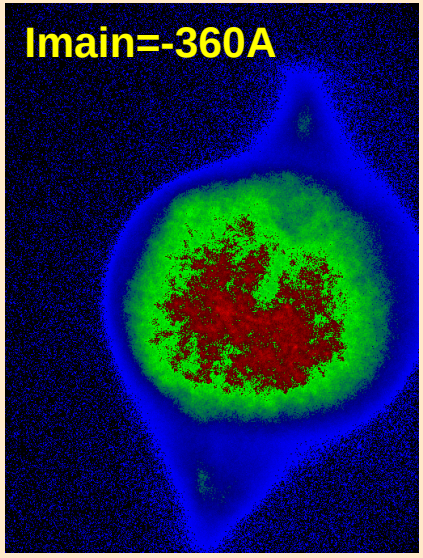




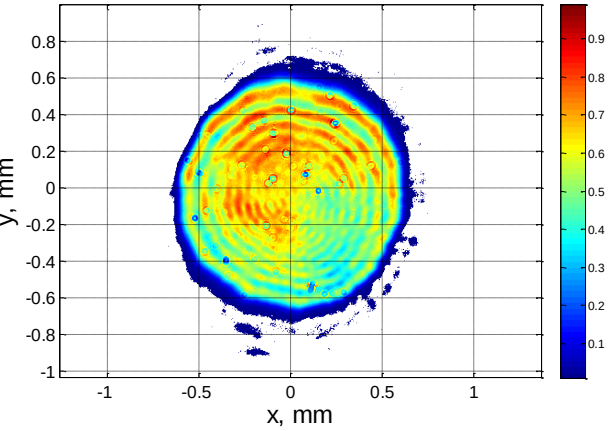


# Larmor angle measurements on 29.09.2015M-A

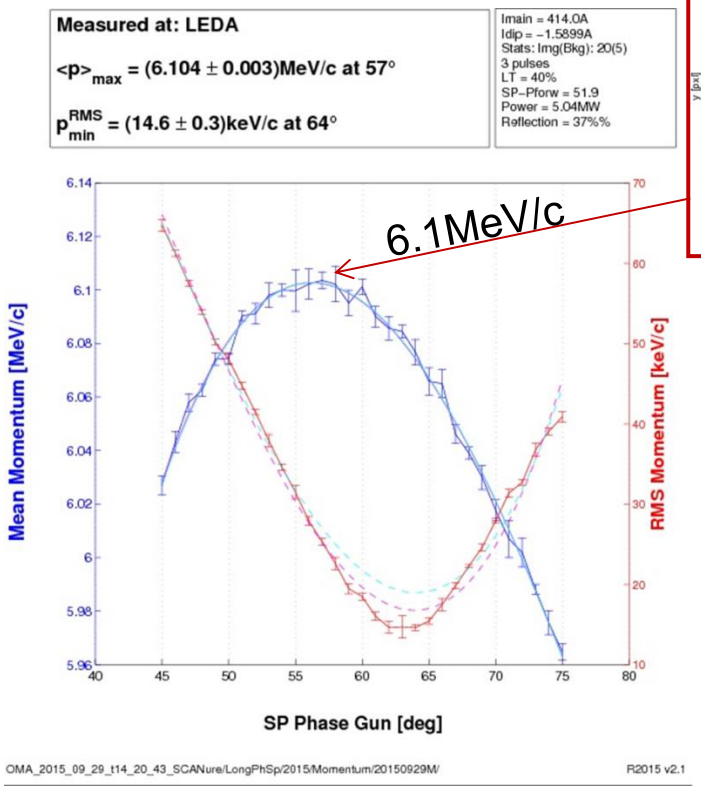
RF gun + Cathode laser setup was recorded →
→ to be reproduced in simulations

Laser BSA=1.2mm

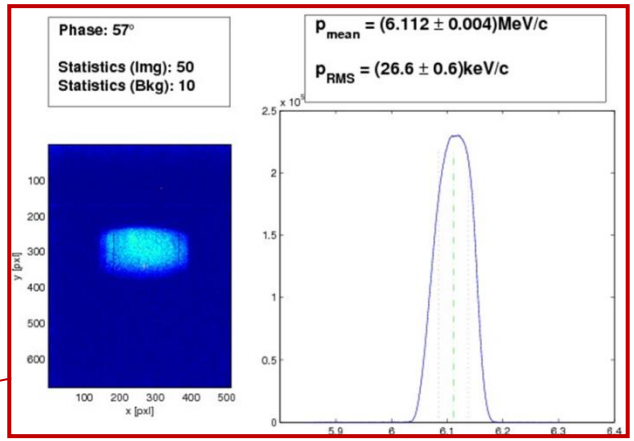


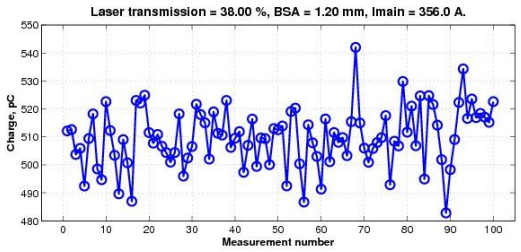

Temporally cathode laser:
Long Gaussian (estimated)
$\sigma_t$=4.7ps (10.5ps FWHM)

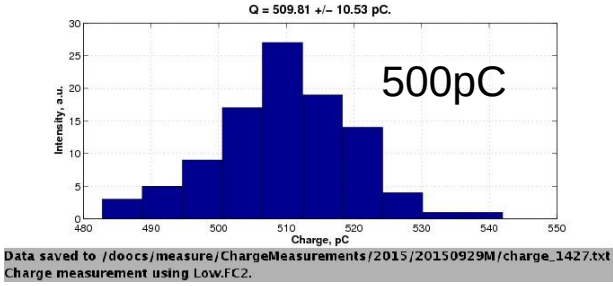
Pgun=5.0MW




MMMG SP phase=57deg

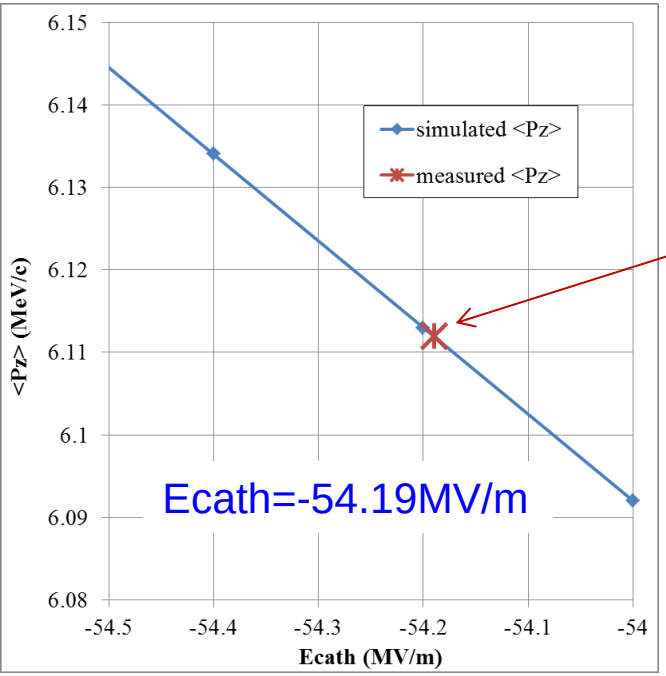


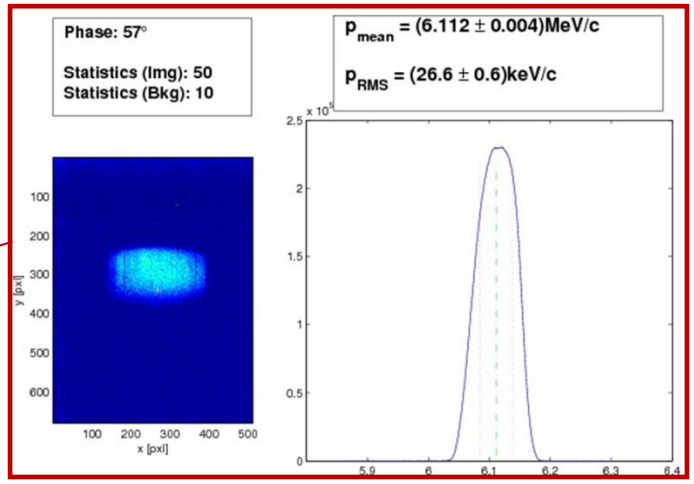



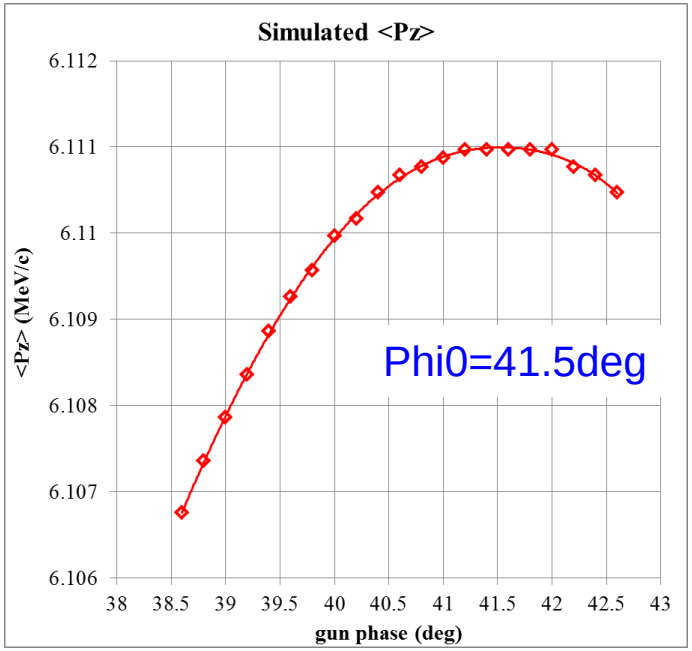




No booster applied ➔ electron beam to be observed at HIGH1.Scr1 (z=5.28m from the cathode)

# ASTRA simulations, 1st step: E@cathode ←→ <Pz>



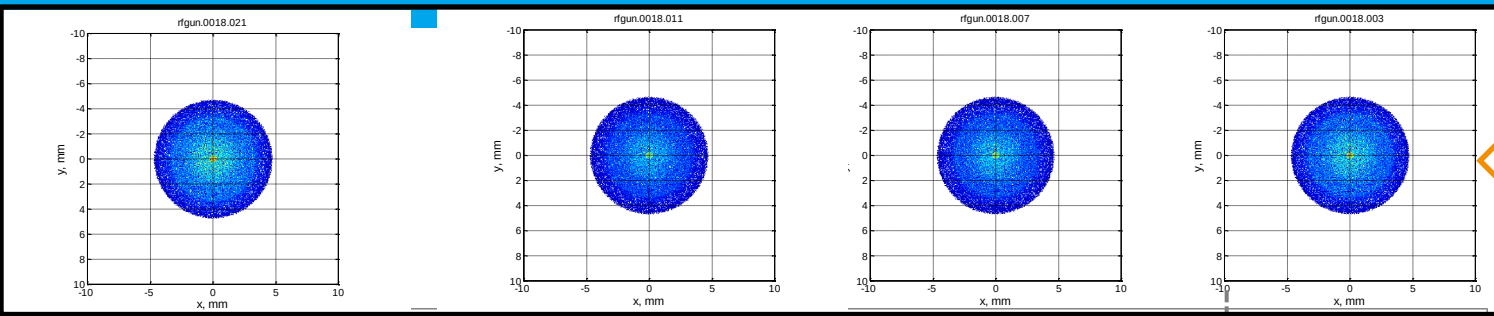



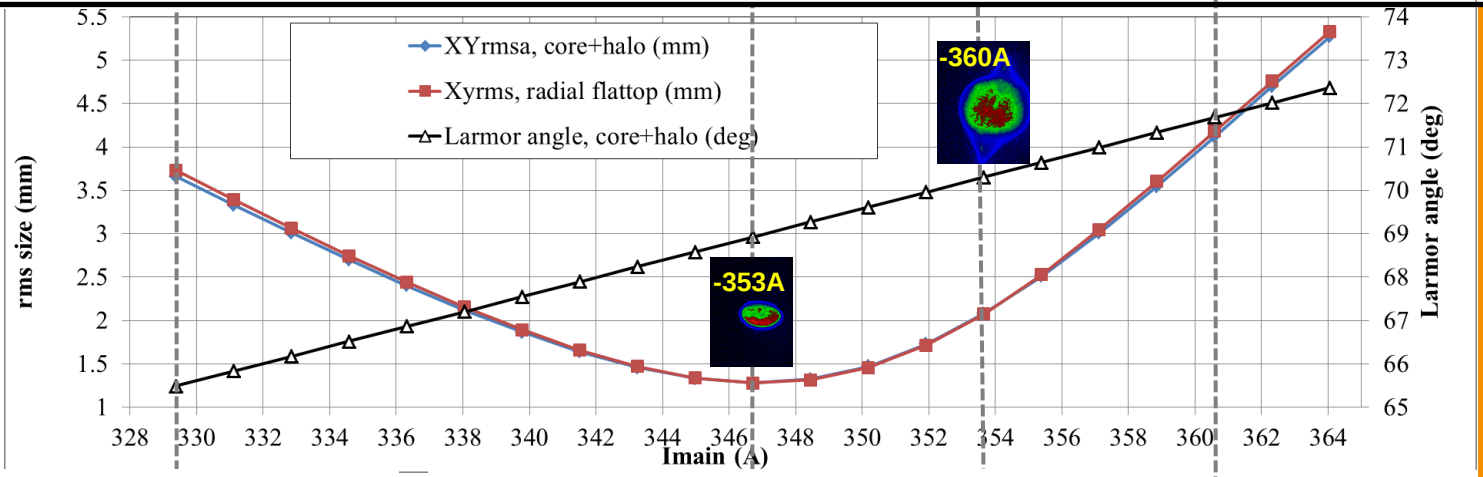

Max. mean momentum is reproduced in simulations: (54.2MV/m; 41.5deg)

# ASTRA simulations: E-beam at EMSY1 (Ecath=54.19MV/m)

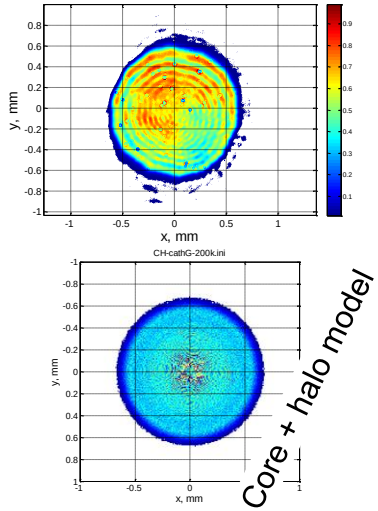
## Main solenoid scan: *MaxB(1)=-(7.102e-5+5.899e-4*Imain)*

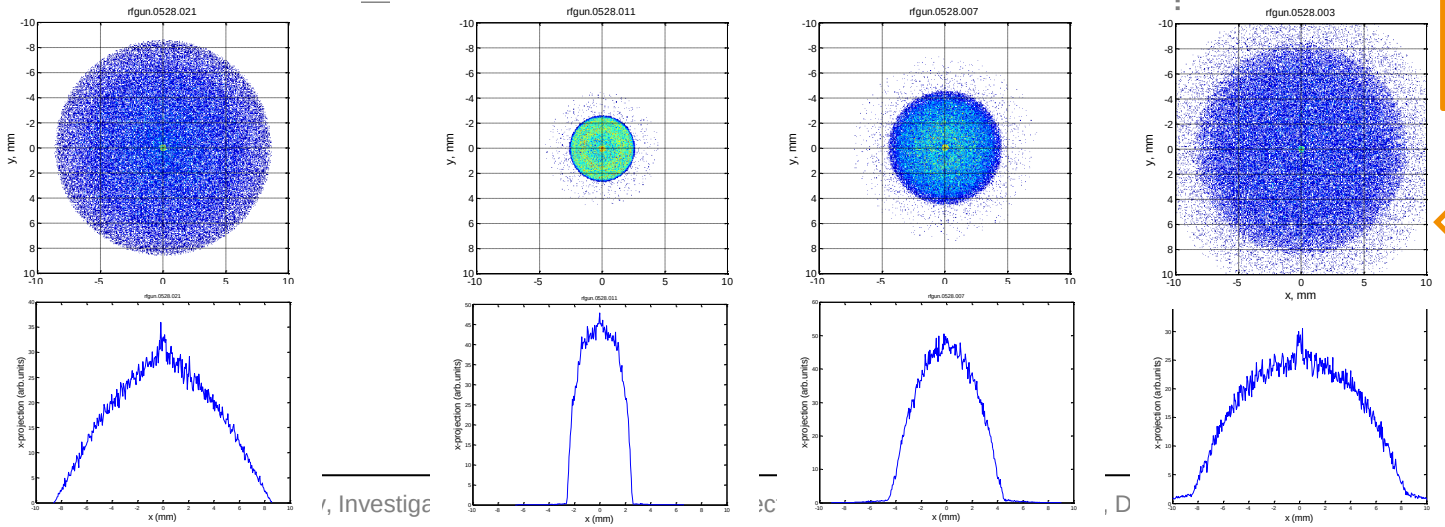



Simulated XY at z=0.18m (coaxial coupler antenna end)



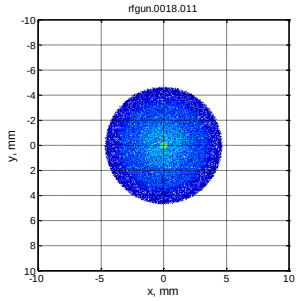

Cathode laser

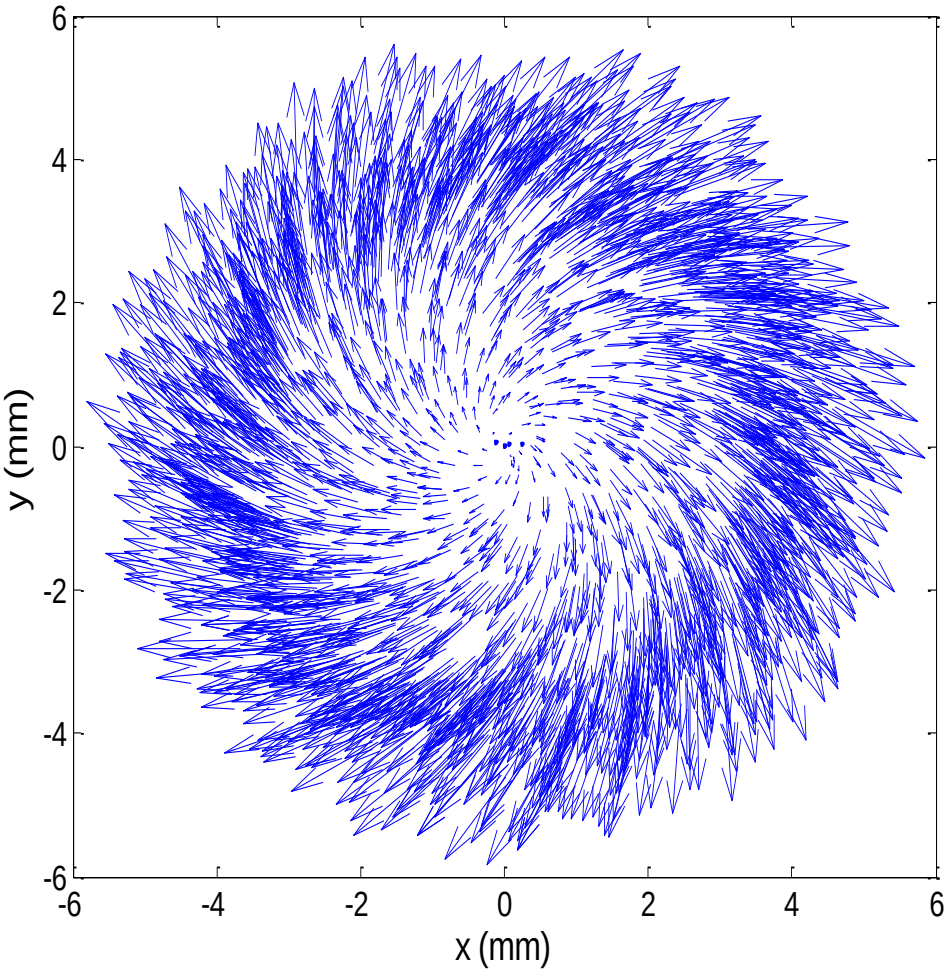


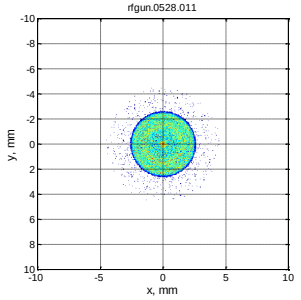



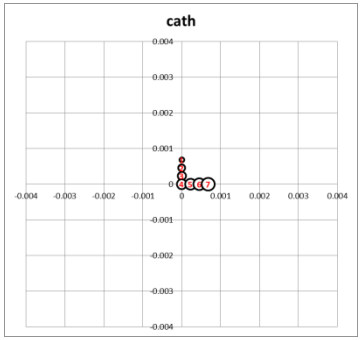

Simulated XY at z=5.277m (EMSY1)

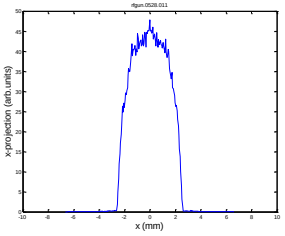
# E-beam at z=0.18m: vector plot {Px,Py}(x,y)

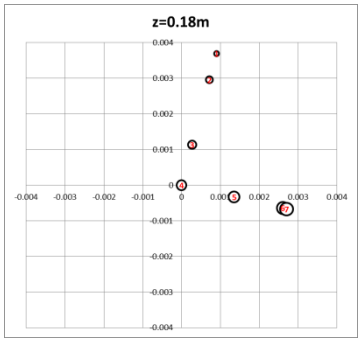


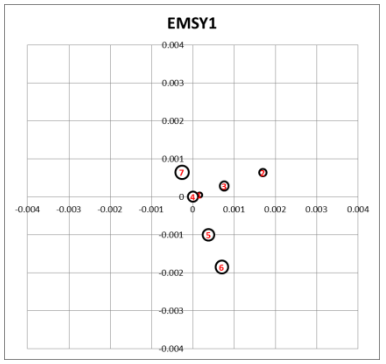



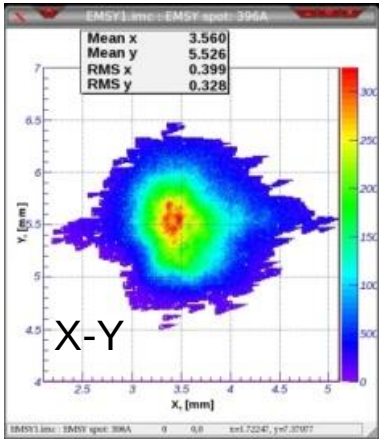




**?How to model the kick to reproduce the e-beam shape at EMSY1?**

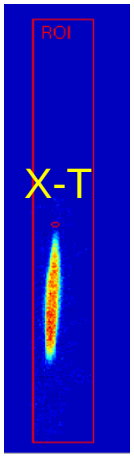
# Investigations on electron beam imperfections

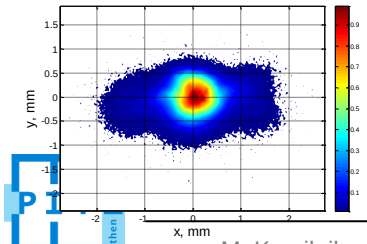
- **Photoemission studies**:
  - Core+halo model could explain (at least partially) charge production curves, but not measured phase space. Still some discrepancy in QE-SC transition region remains →*
  - Bunch length measurements (w.r.t to the simulations) also show discrepancies
- **Electron beam imaging**
  - Some discrepancy in the main solenoid calibration revealed, but not systematic (gun power and observation screen dependent)
- **Electron beam asymmetry investigations:**
  - Second vacuum mirror (VM) experiment → VM excluded
  - Solenoid imperfections → weak quad only? →*
  - **Coaxial coupler kick** → major candidate (up to now) → Larmor angle experiment →*

→* = help would be appreciated








Observed: X-Y; X,Y-Pz; X-T ***correlations*** → complications for further compression!

**LOLA measurements at FLASH (24.11.2015 11:43)**