Photo Injector Test facility at DESY, Zeuthen site.

Emittance at PITZ in 2017

Mikhail Krasilnikov (DESY)

PPS, 12.10.2017

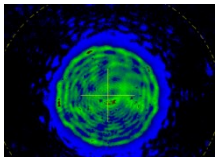
HELMHOLTZ ASSOCIATION

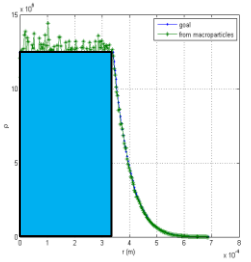
DESY

Core + Halo Model applied to ASTRA simulations

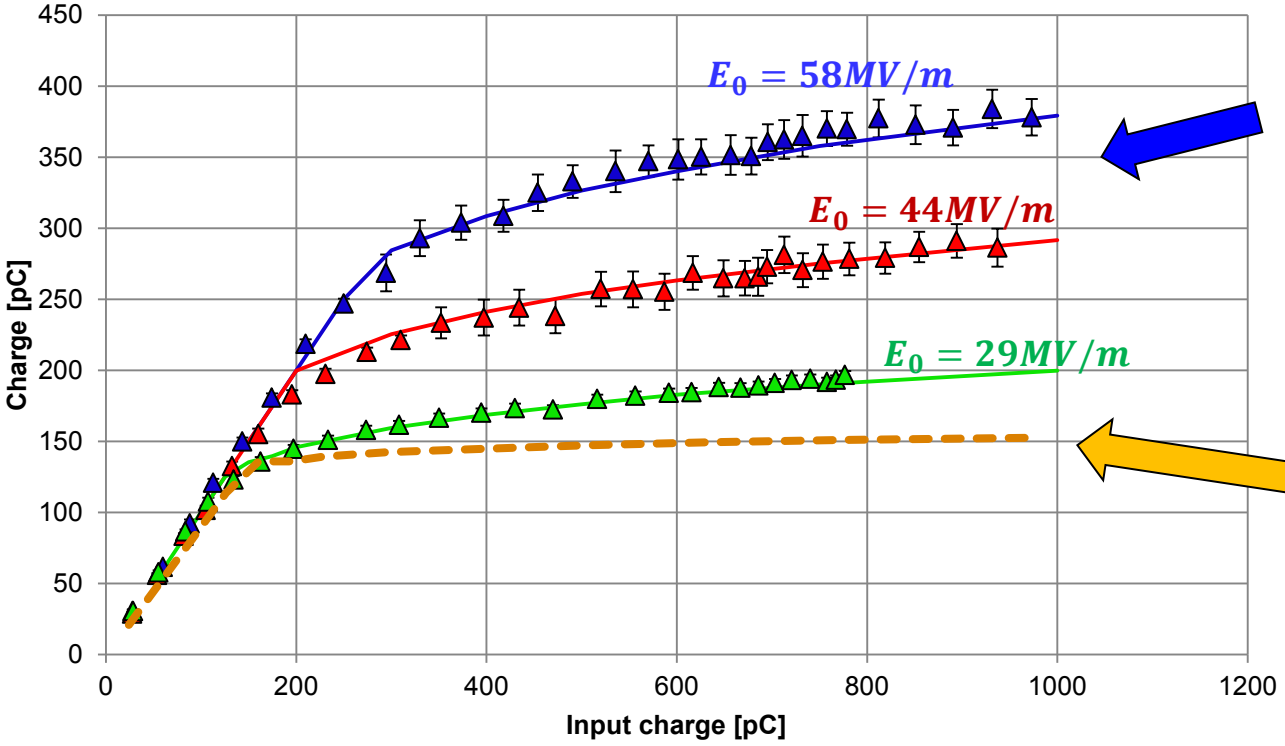
If a uniform distribution is used instead, the charge saturates

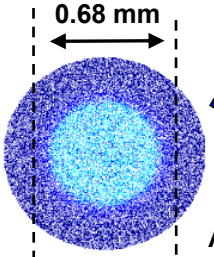
Laser radial distribution image





Extracted charge with core + halo for 0.8 mm beam diameter with 1.5 ps rms Gaussian temporal at maximum cathode field (ϕ_0=90°)





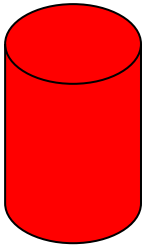
0.68 mm

Transverse radial profile core + halo

Generated ASTRA input distribution core + halo

0.80 mm

Nominal ASTRA input uniform distribution



Nominal transverse uniform radial profile

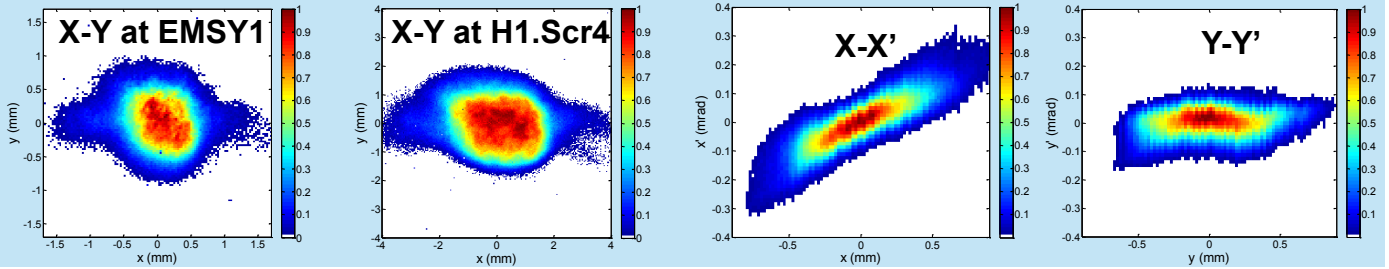
C. Hernandez-Garcia et al., NIM A 871 (2017) 97–104

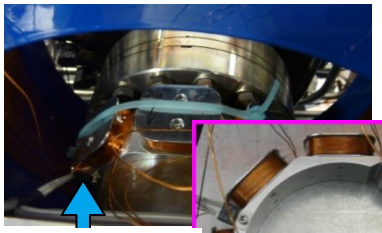
Electron beam X-Y asymmetry compensation with gun quads

(0.5nC, Gaussian photocathode laser pulse)

measured

Electron beam measurements without gun quadrupoles

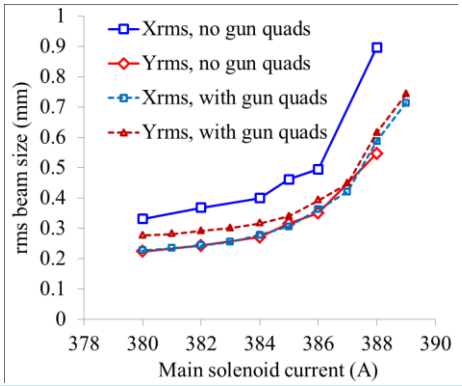


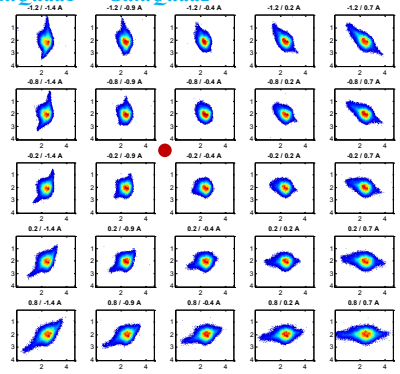


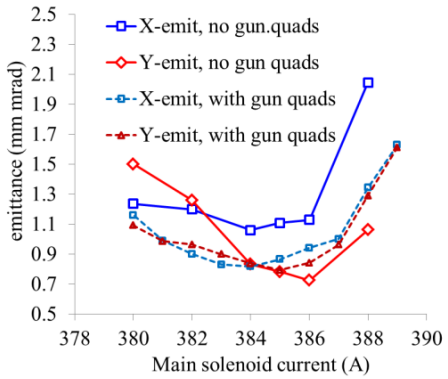
Normal→
→Gun.Quad1

Skew→
→Gun.Quad2

($I_{Gun.Quad1}$; $I_{Gun.Quad2}$) scan at EMSY1

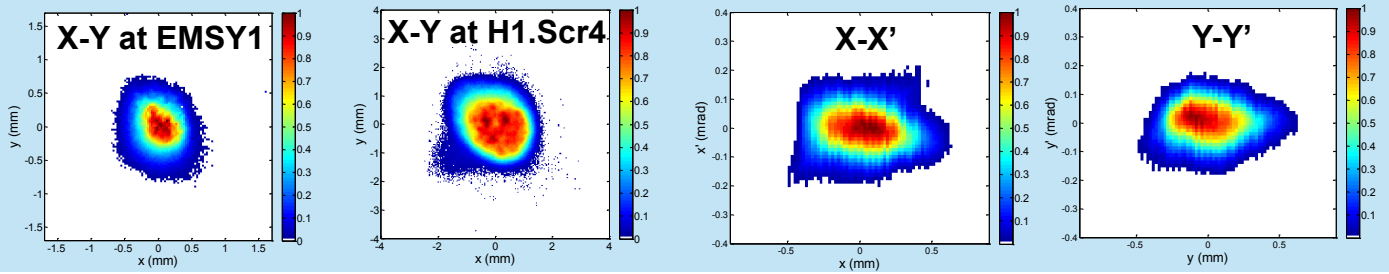






Electron beam measurements with gun quadrupoles

($I_{Gun.Quad1}$=-0.6A; $I_{Gun.Quad2}$=-0.5A)

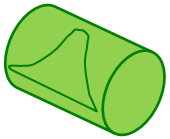


	No gun quads	With gun quads
I_{main}(A)	386	384
$I_{gun.quad1}$ (A)	0	-0.5
$I_{gun.quad2}$ (A)	0	-0.6
σ_x@EMSY1 (mm)	0.50	0.28
σ_y @EMSY1 (mm)	0.35	0.32
$\varepsilon_{x,n}$ (mm mrad)	**1.13**	**0.82**
$\varepsilon_{y,n}$ (mm mrad)	**0.73**	**0.84**
$\sqrt{\varepsilon_{x,n}\varepsilon_{y,n}}$ (mm mrad)	**0.91**	**0.83**
β_x (m)	6.53	3.18
β_y (m)	6.49	3.24
γ_x (mrad)	0.56	0.32
γ_y (mrad)	0.16	0.31

M. Krasilnikov et al.,FEL2017 proceedings, WEP007

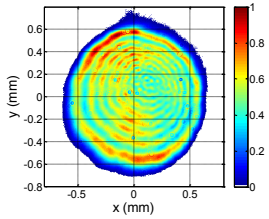
ASTRA simulations for Gaussian pulses using Core+Halo

- BUT for flattop photocathode laser pulses

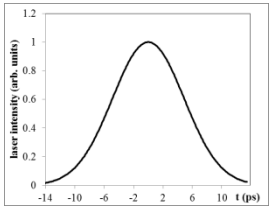


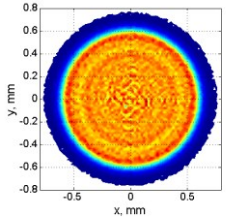
measured

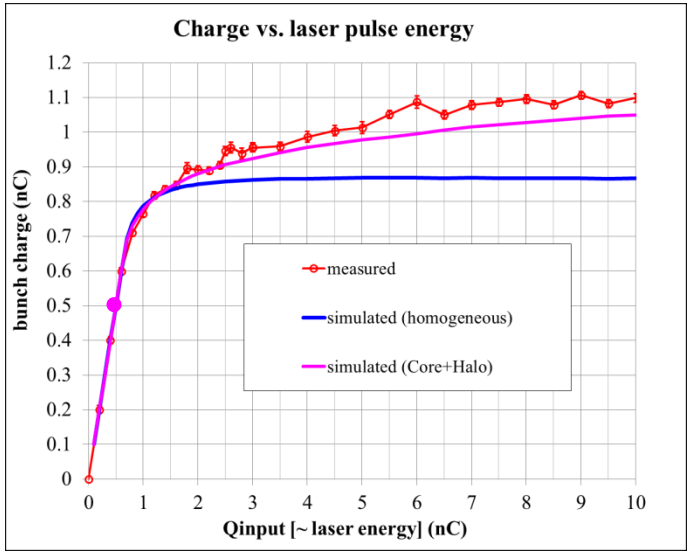
?



Used in simulations

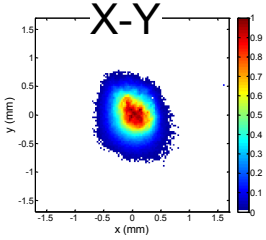






measured

X-Y



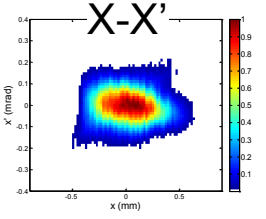
ϕ_{gun}=MMMG

Q=0.5nC

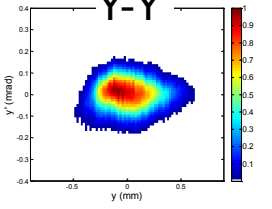
ε_x=0.82 mm mrad

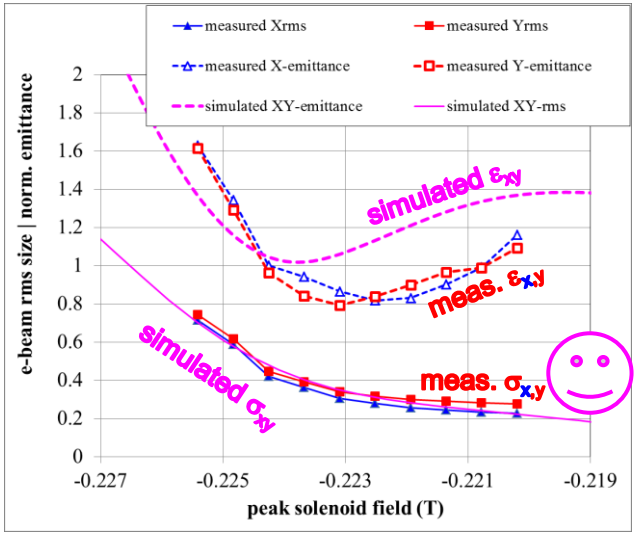
ε_x=0.84 mm mrad

X-X'



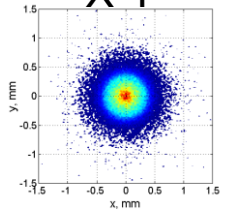
Y-Y'



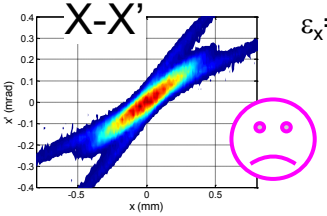


simulated

X-Y



X-X'



Parameters "plugged" from measurements:

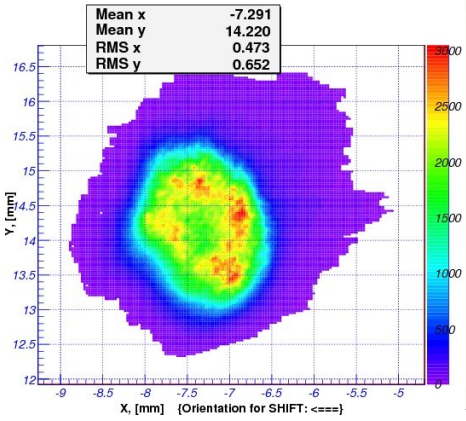
ϕ_{gun}=MMMG

Q=0.5nC

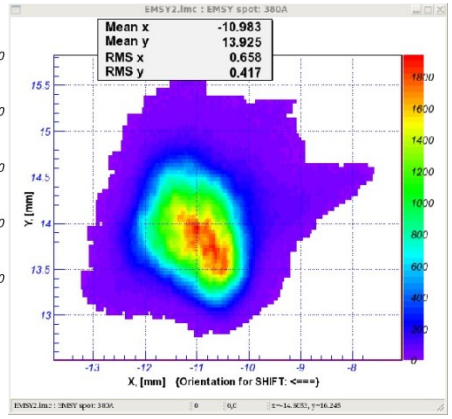
ε_x=1.05 mm mrad

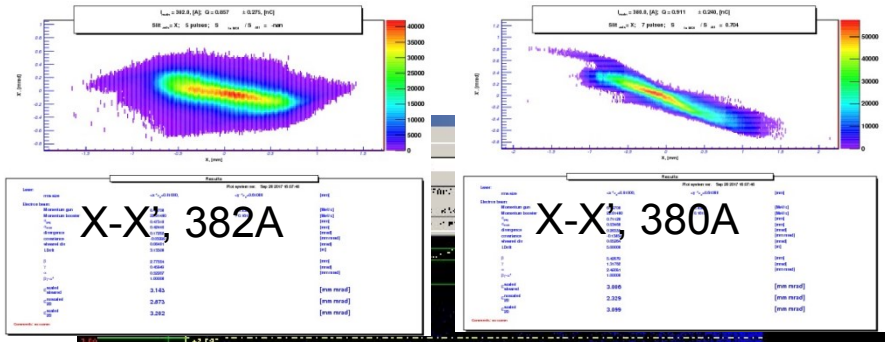
Some recent beam measurements (short Gauss PC laser)

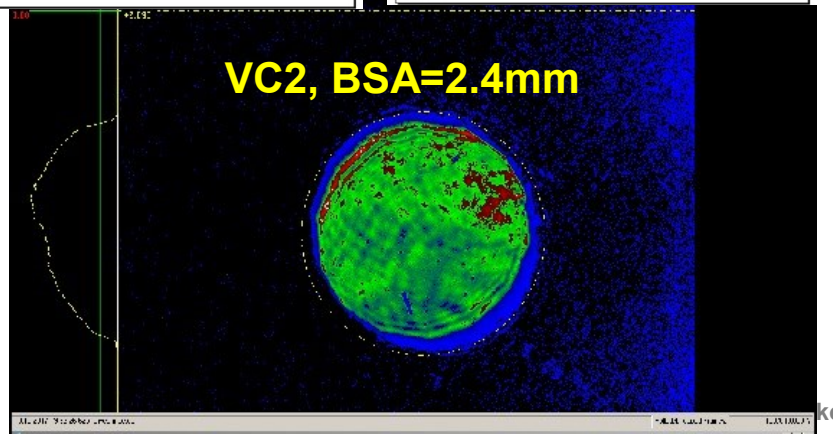
EMSY1, 382A



EMSY2, 380A



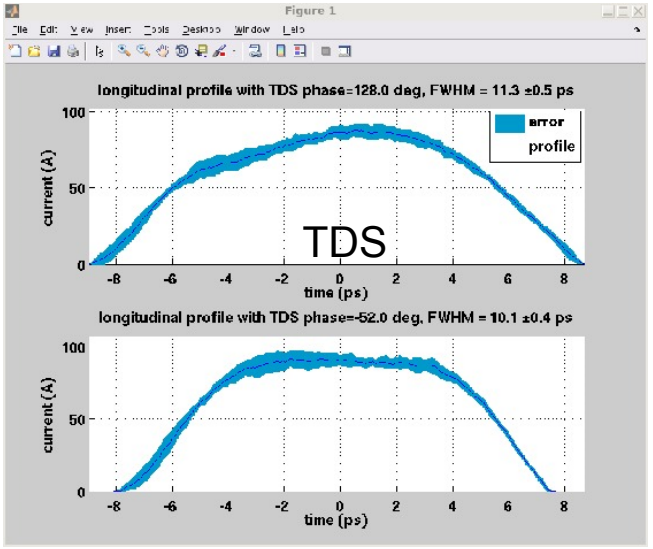




"Smoke ring" beam at PITZ?

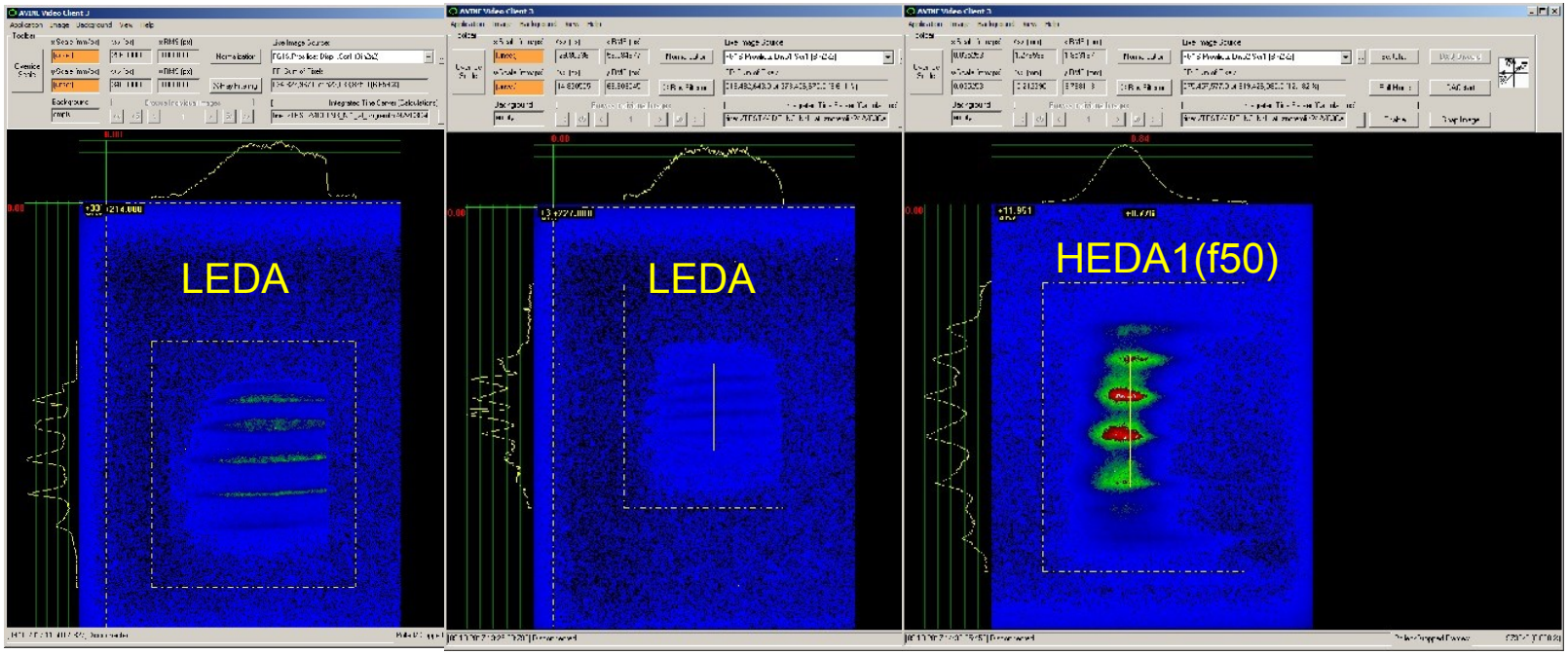
10.10.2017A:

- **Short Gaussian** PC laser pulse (2ps?)
- BSA=2.4mm (0.6mm rms)
- Q=1nC
- Beam momentum: 6.5MeV/c (gun); 22.6 MeV/c (final after booster)
- Emittance (EMSY1) ~3.5 mm mrad (380-382A)
- Emittance (EMSY1) ~3.2 mm mrad (380A)
- Bunch length ~10-11ps (FWHM)



PC laser pulse shaping

- Good flattop is not possible currently
- Long Gaussian -> always modulated (Lyot filter impact)!



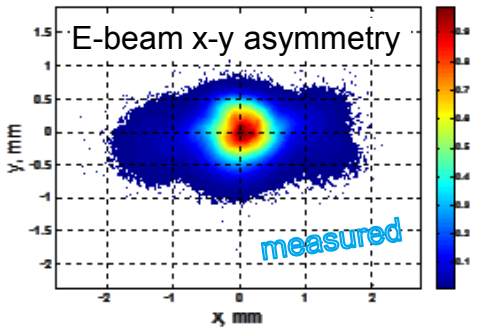
➔ THz measurements with modulated Gaussian?

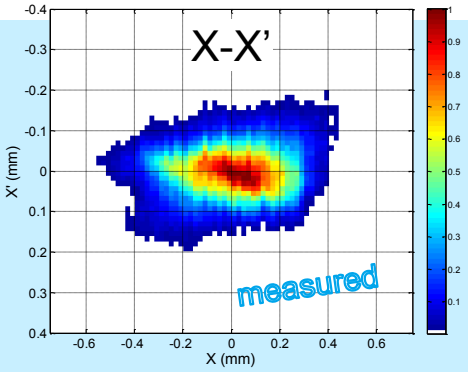
- Short Gaussian → OK, currently used

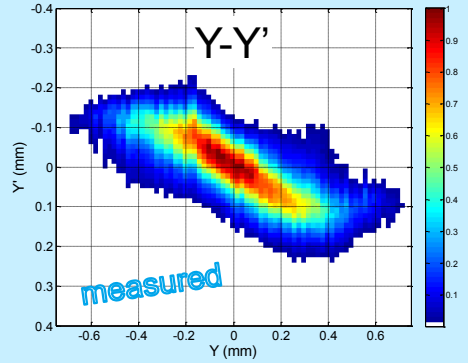
Back up slides

PITZ: Simulations versus Measurements

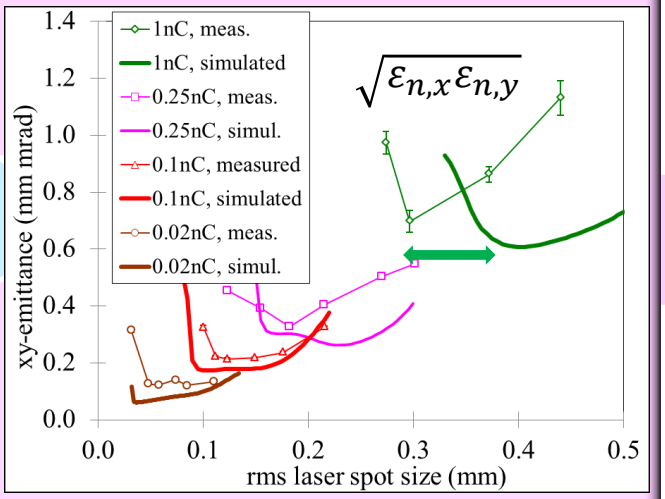
Asymmetry → kick?



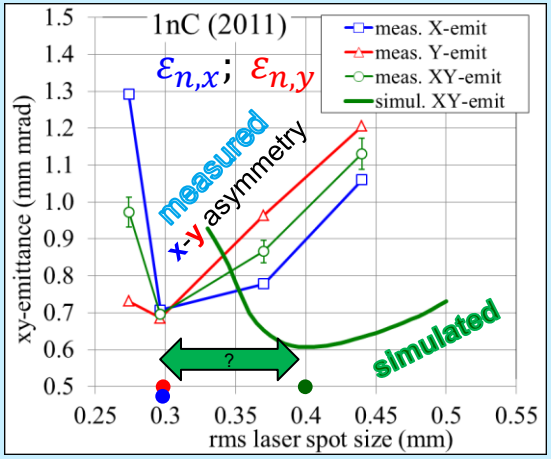




Space charge

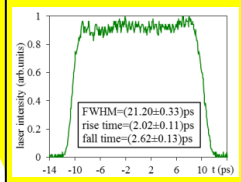


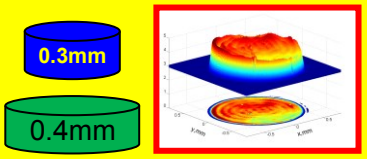
M. Krasilnikov et al., PRSTAB 15, 100701, 2012.

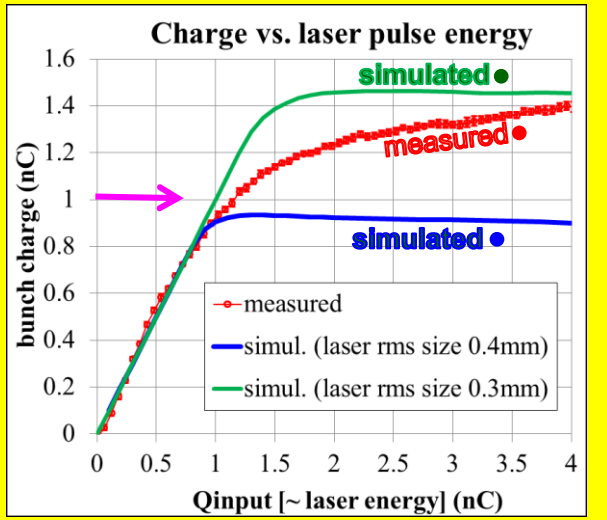


Charge production

Photocathode laser







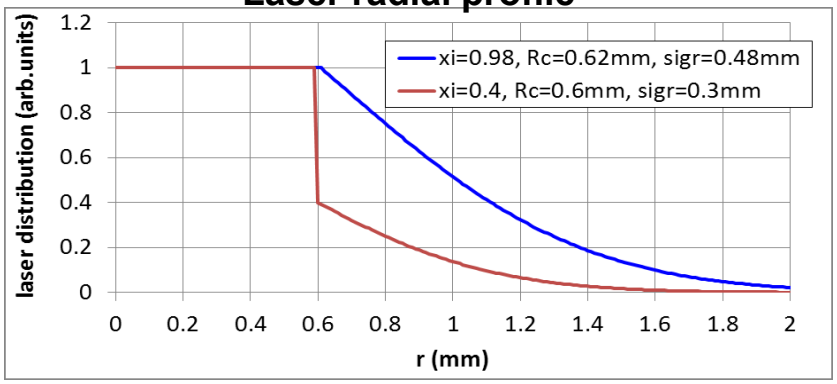
Experimental emittance minimization: optimum PC laser spot size (space charge density) ➔ **transition**: linear (QE-limited) to saturated (SC limited) regime

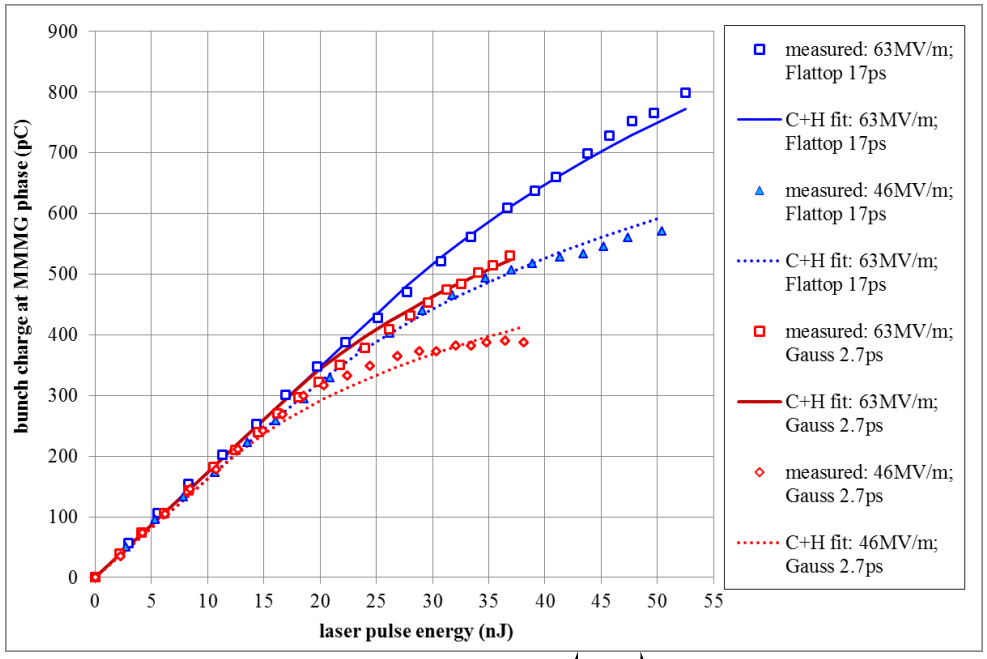
Photoemission: laser transverse halo modeling

Laser transverse distribution:
Core + Halo model (C+H)

$$F_l(r) = \frac{E_l}{\pi R_c^2 + 2\pi\xi {\sigma_r}^2} \begin{cases} 1, & if\ \ r \le R_c \\ \xi e^{\frac{R_c^2 - r^2}{2\sigma_r^2}}, & if\ r > R_c \end{cases}$$

Laser radial profile





$$Q = Q_{core} + Q_{halo}$$

$$Q_{core} = \frac{1}{1 + \xi \cdot \eta} \begin{cases} Q_{exp}, & if\ \ Q_{exp} \le Q_{max} \\ Q_{max} & if\ \ Q_{exp} > Q_{max} \end{cases}$$

$$Q_{halo} = \frac{\eta}{1 + \xi \cdot \eta} \begin{cases} \xi \cdot Q_{exp}, & if\ \ \xi \cdot Q_{exp} \le Q_{max} \\ Q_{max} \cdot \left(1 + \ln \frac{\xi \cdot Q_{exp}}{Q_{max}}\right) & if\ \ \xi \cdot Q_{exp} > Q_{max} \end{cases}$$

$$Q_{max} = \rho_{scl} \cdot \left(\pi R_c^2 + 2\pi\xi {\sigma_r}^2\right)$$

$$\frac{\rho_{scl}(flat-top)}{\rho_{scl}(Gaussian)} \approx 1.51$$

SC

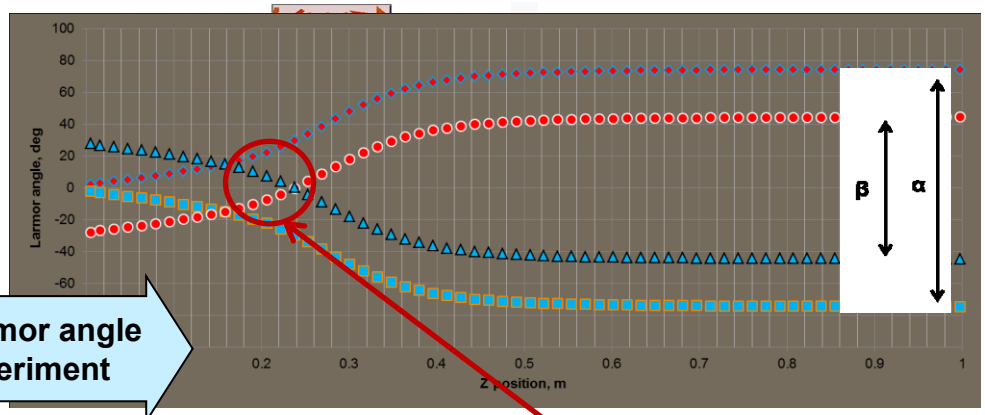
Cathode laser pulse length (FWHM) ratio ~6

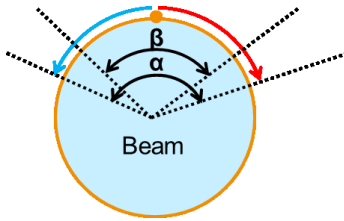
C+H → charge exceed

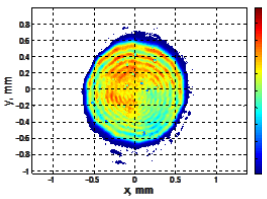
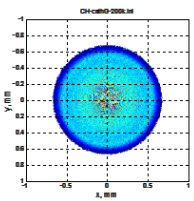
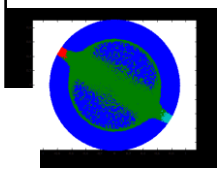
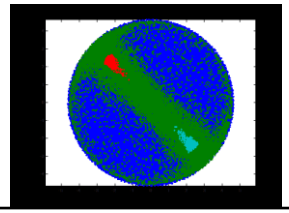
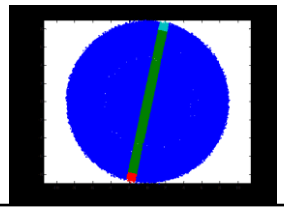
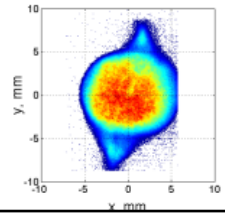
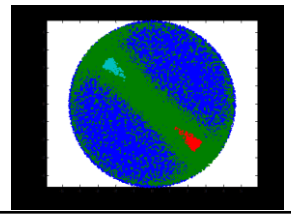
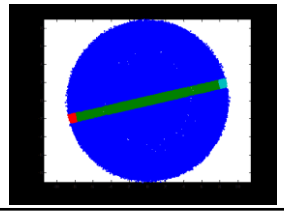
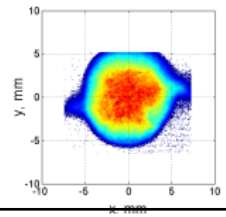
Electron beam X-Y asymmetry studies at PITZ

Possible sources of the beam asymmetry:

- ~~**Vacuum mirror**~~
- ~~**Stray magnetic fields**~~
- ~~**Related to the laser polarization**~~
- ~~**Particular cathode**~~
- **…**
- **RF coupler field asymmetry**
- **Solenoid imperfections (anomalous quadrupole fields)**



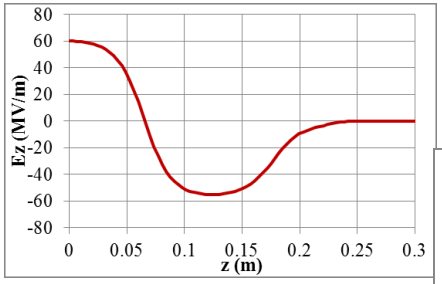


Main solenoid max[B_z], (I_{main} for meas.)	Laser X-Y distribution at cathode		Electron beam X-Y distribution simulated at z=0.18 m	E-beam X-Y distribution at z=5.277 m	
	Measured at VC2	Used in simulations		Simulated	Measured at EMSY1
-0.2087T (-360A) opposite polarity		Core + Halo  			
+0.2087T (+360A) normal polarity					

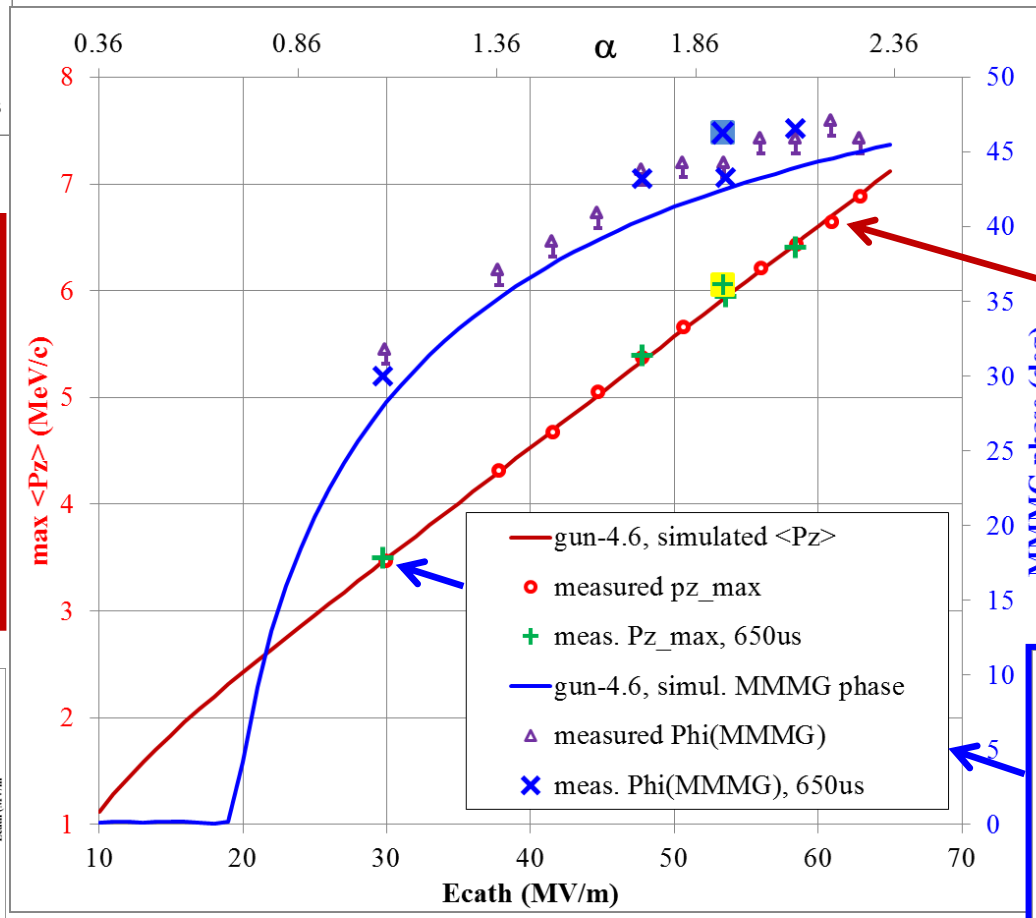
?45° Kick at z~0.2m → skew quadrupole?

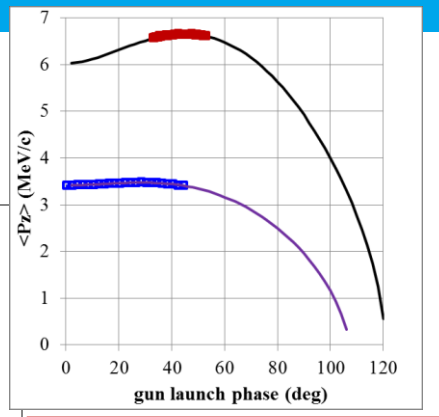
Some experimental observations
might be related to photoemission issues

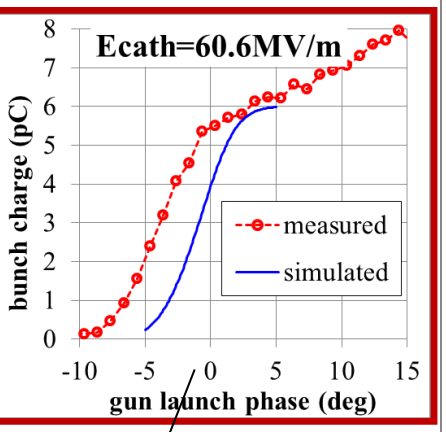
Gun-4.6 (PITZ): mean momentum and MMMG phase

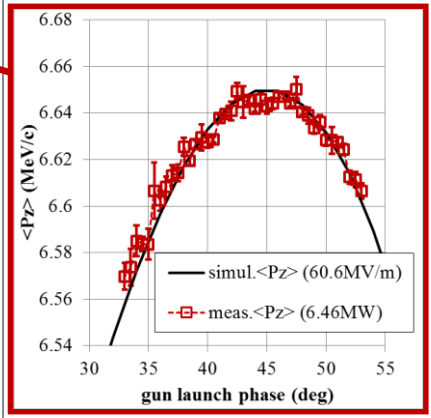


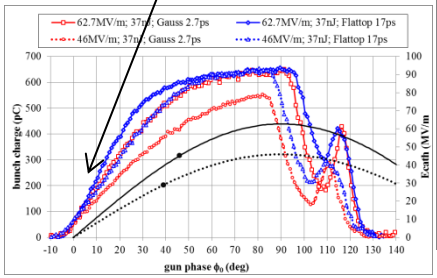
Measurements vs. Simulations

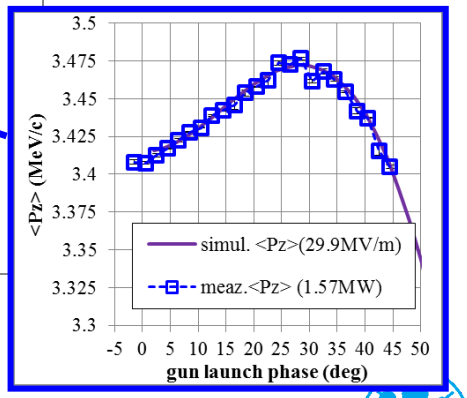










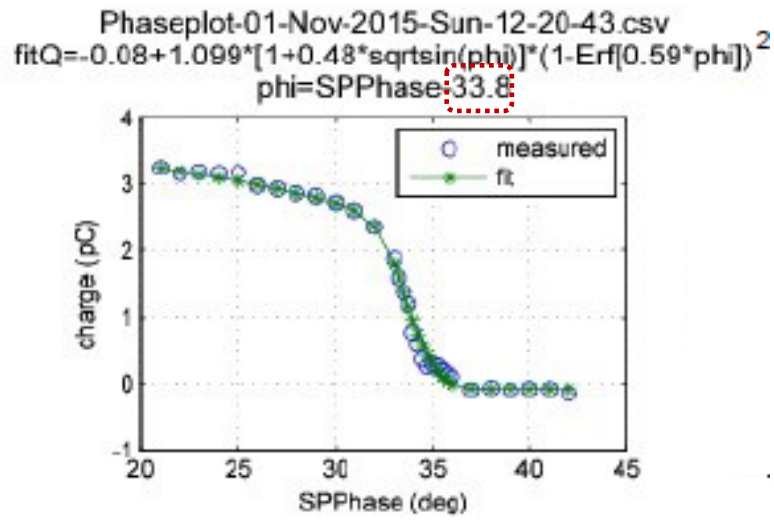


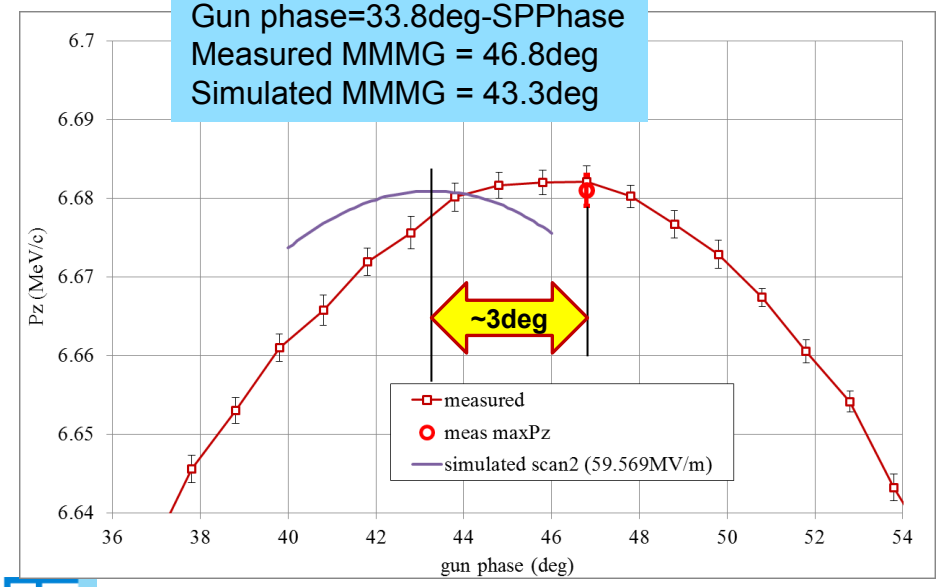
MMMG = Maximum Mean Momentum Gain

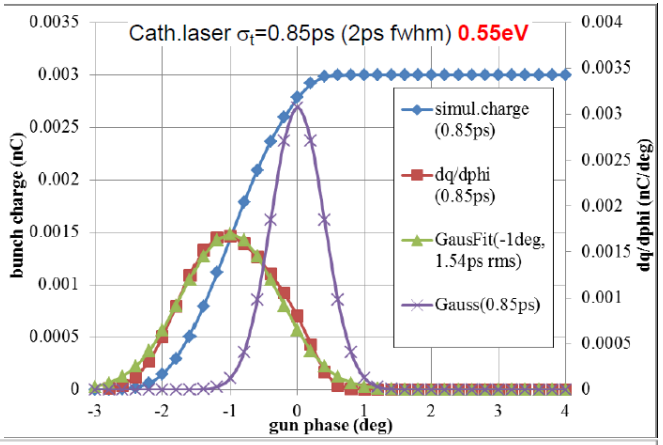
$$\alpha = \frac{eE_{cath}}{2mc^2k} \approx 0.047\,\frac{E_{cath}[MV/m]}{f[GHz]}$$

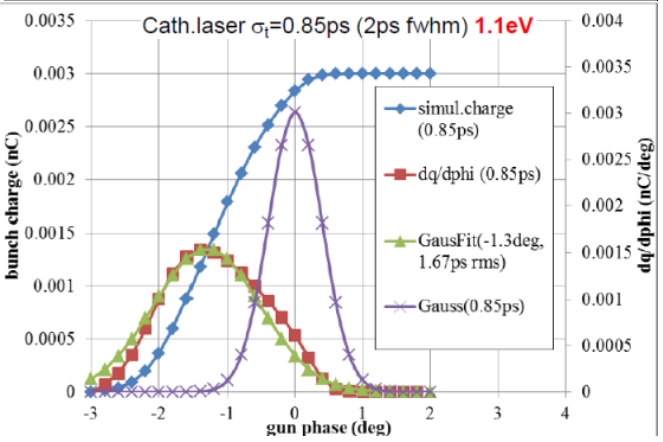
Zero-crossing phase determination

Still not understood: 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-σ_t/σ_t
σ_t (ps)	fwhm (ps)		deg	fit-σ_t (ps)	
0.85	2	0.55	-1	1.54	1.81
0.85	2.6	1.1	-1.3	1.67	1.96

phase shift

widening

Another emission related topic at PITZ: slice energy spread

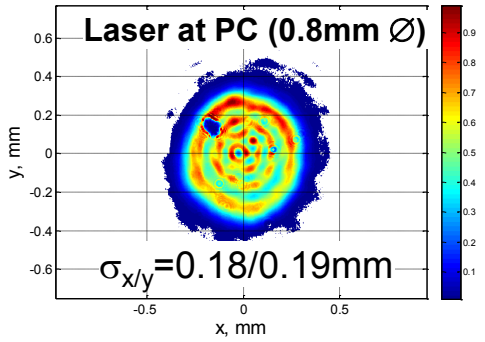
Main idea → δE measurements using TDS + HEDA2 dipole for various photo injector parameters (photocathode laser pulse temporal profiles, SC effect, etc.)

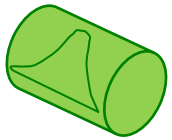
$$\delta_E^{measured} \approx \sqrt{\left(\delta_E^{real}\right)^2 + \left(\delta_E^{\beta}\right)^2 + \left(\delta_E^{TDS}\right)^2}$$

Still resolution on the slice energy spread seems to be a limiting factor:

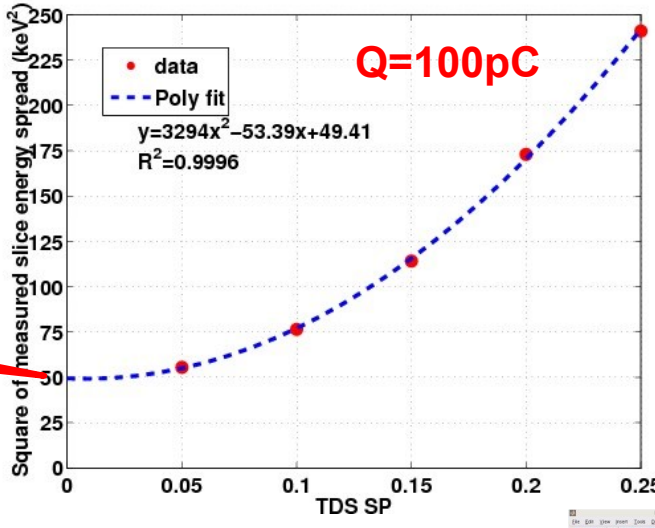
- Beam transverse size in the HEDA2 dipole (beta function)
- TDS induced energy spread (estimated $\frac{d(\delta E)}{dSP(TDS)} \sim 3 \frac{eV}{MV}$)

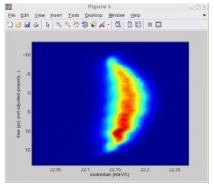
δE≈6.8 keV for TDS SP=0

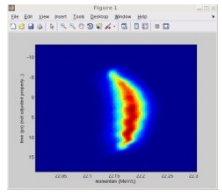


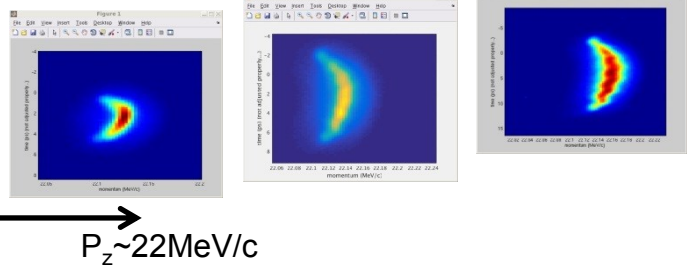


Longitudinal Phase Space (LPS) measurements: TDS SP scan in HEDA2 (**Long** Gaussian PC laser pulse, **11.5ps** FWHM)







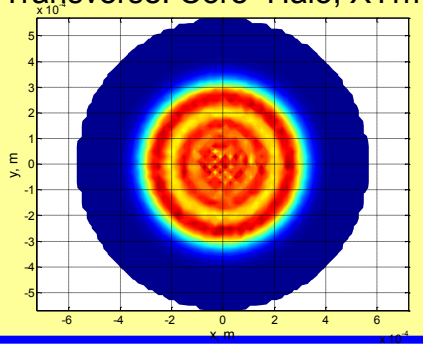


Similar measurements for **short** Gaussian (**2 ps** FWHM) PC pulses: **δE≈ 8.2 keV** for TDS SP=0

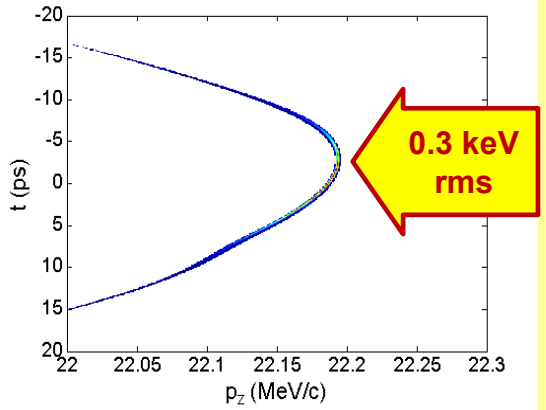
Slice energy spread: measurements vs. ASTRA simulations

ASTRA simulations:

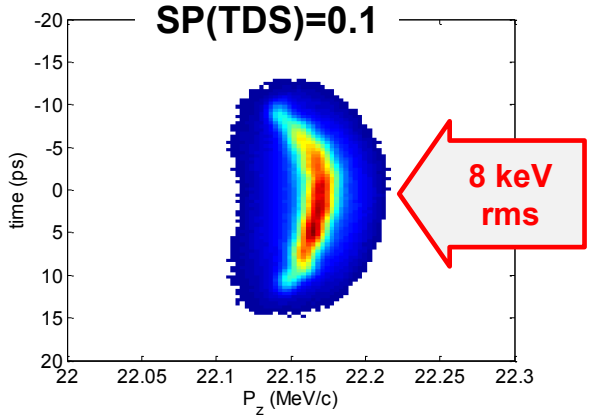
- Q=100pC
- Gun+Booster → =measurements
- PC laser pulse parameters
  - Temporal: Gaussian (11.5 ps FWHM)
  - Transverse: Core+Halo, XYrms=0.186mm

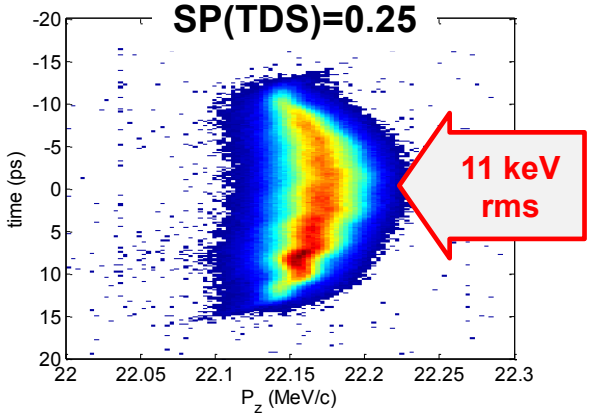


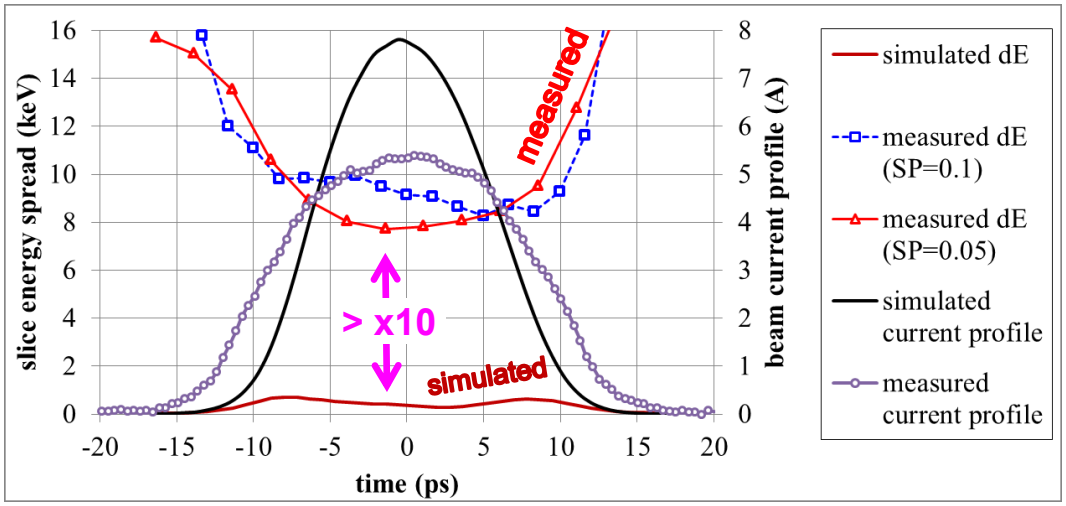
Simulated Long. Phase Space



Measured Long. Phase Space

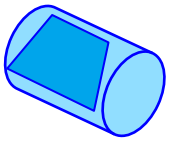




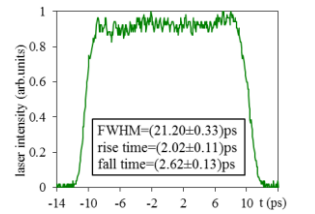


ASTRA simulations for 2011 case using Core+Halo

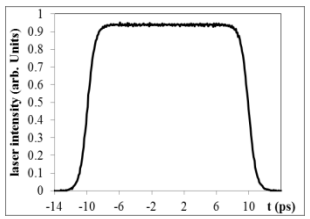
- BUT for flattop photocathode laser pulses

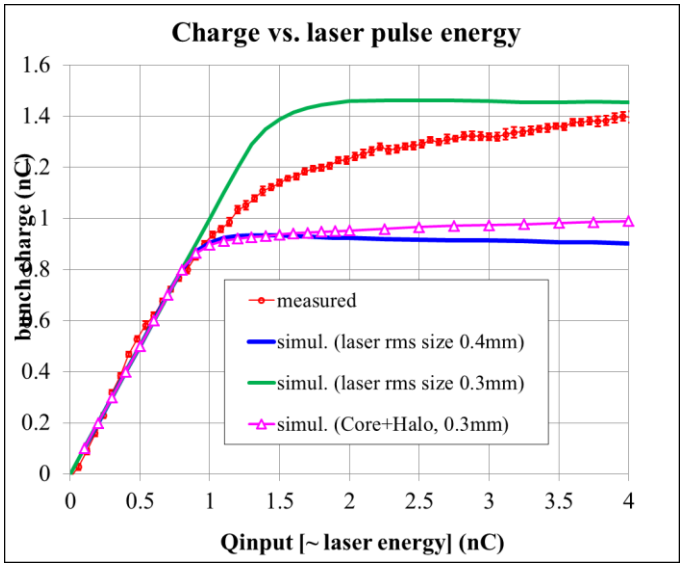


measured

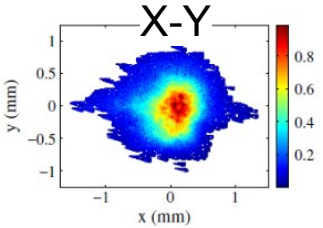


Used in simulations





measured

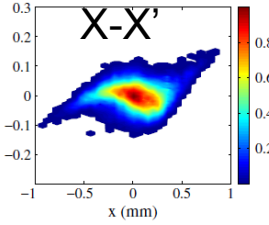


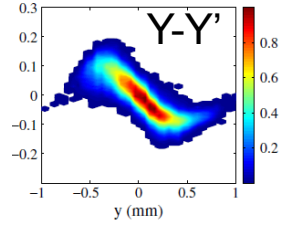
ϕ_{gun}=MMMG+6°

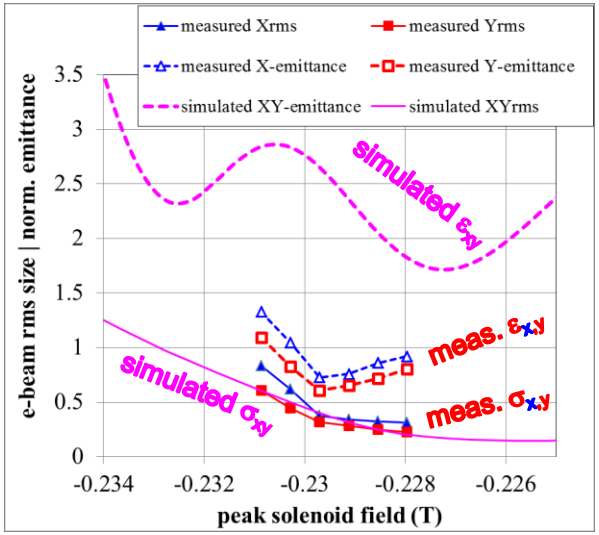
Q=1nC*

ε_x=0.72 mm mrad

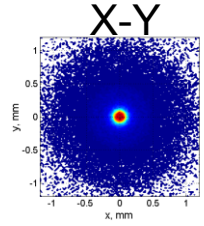
ε_x=0.60 mm mrad

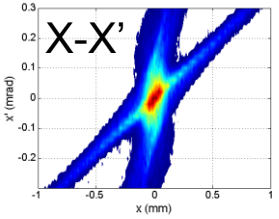






simulated





Parameters "plugged" from measurements:

ϕ_{gun}=MMMG+6°

Q=0.97nC

ε_x=2.5 mm mrad