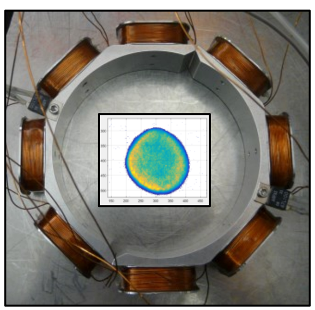
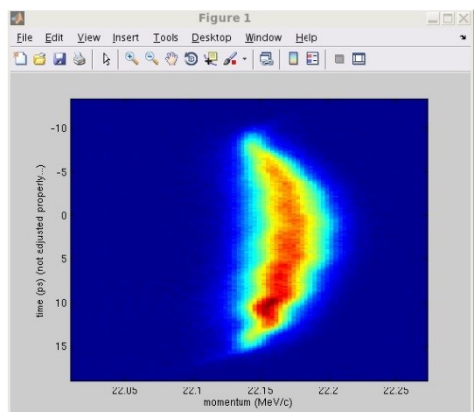
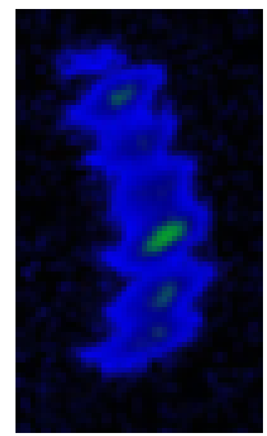
Selected Beam Studies at PITZ in 2016 (2^{nd} ½)

- **Motivation**
- **Correction of electron beam asymmetry**
- **Slice energy spread and longitudinal phase space measurements**
- **Studies on spiky structure of electron beam trains**
- Some issues of the flattop pulse shaping







HELMHOLTZ
ASSOCIATION

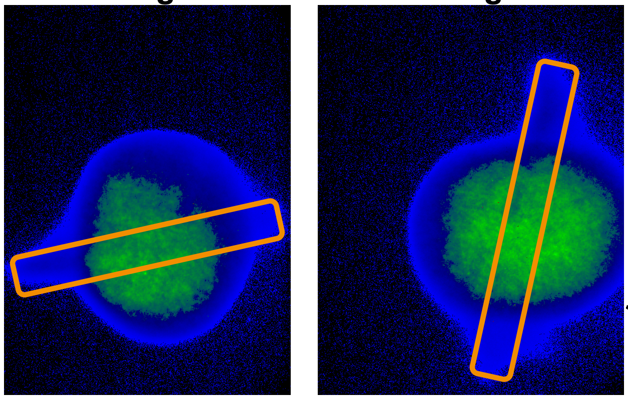
M. Krasilnikov
DESY-TEMF-Meeting , 23.01.2017

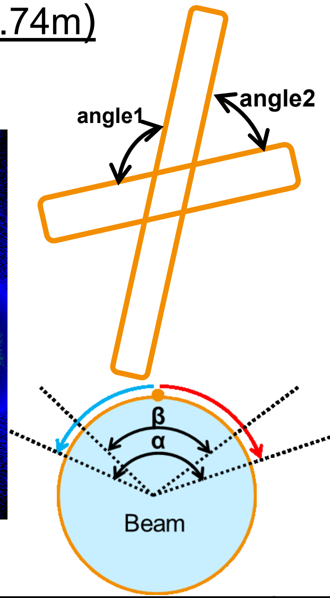
DESY

E-beam X-Y asymmetry: Larmor angle experiment

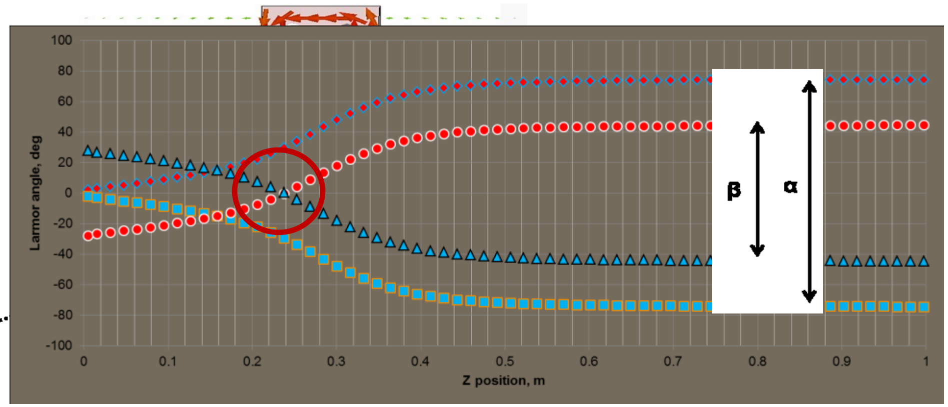
Beam at High1.Scr1 (EMSY at z=5.74m)

I main = - 361 A, I bucking = 0 A	**I main = + 361 A, I bucking = 0 A**





Main solenoid current is 361 A, normal and opposite polarity, bucking current is 0

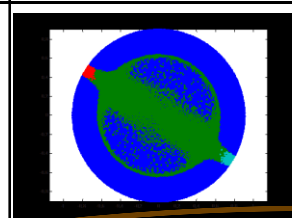
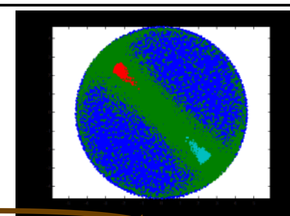
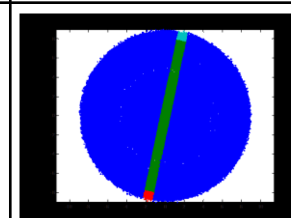
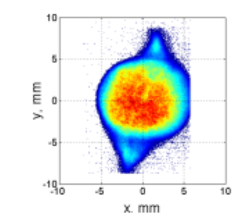
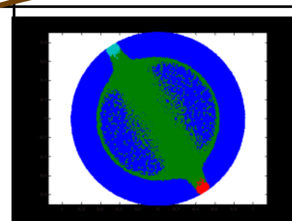
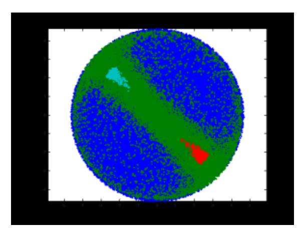
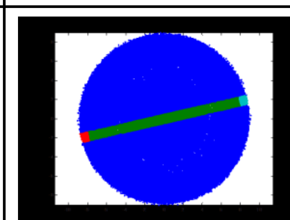
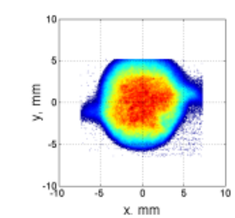


Measurements (**29.09.2015M-A**):

- P_{gun}=5MW (6.1MeV/c max)
- Launch phase: MMMG
- Cathode laser:
  - Gaussian 11.5 ps FWHM (expected)
  - BSA=1.2mm (VC2)
- Charge 0.5 nC

45° kick at z=0.18m →skew quadrupole?

“Tracking back” towards cathode

	Cathode	Z=0.18m	EMSY (z=5.74m)	
I main = +361A				
I main = -361A				

Simulations with rotation quads model (Q. Zhao)

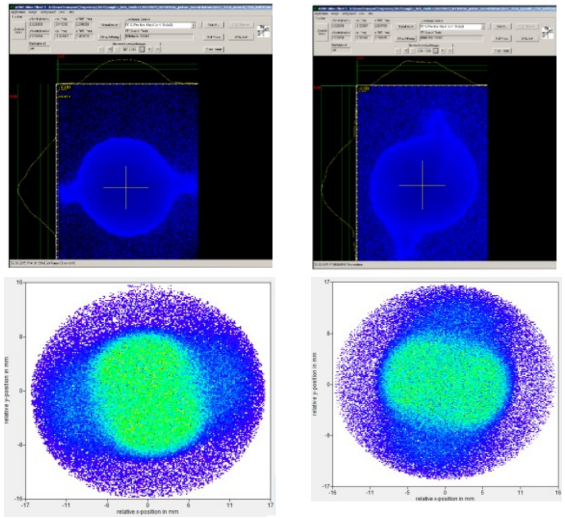
Use rotation quads model in ASTRA simulation by scanning the rotation angle and z position.

➔ 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.

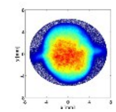
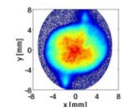
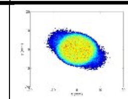
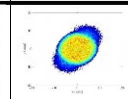
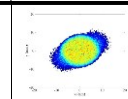
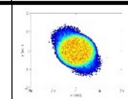
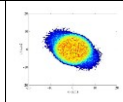
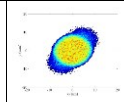
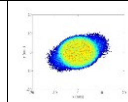
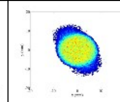
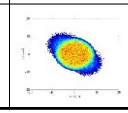
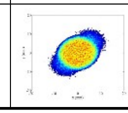
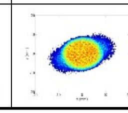
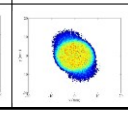
Experimental setup:
Pgun=5MW ,
6.178 MeV/c,
gradient is 54.2 MeV/c,
500 pC
no booster
05.09A-06.09N.2015.

I main = -361A | I main = +361A



~13 degree | ~78 degree

Images table from simulation analysis

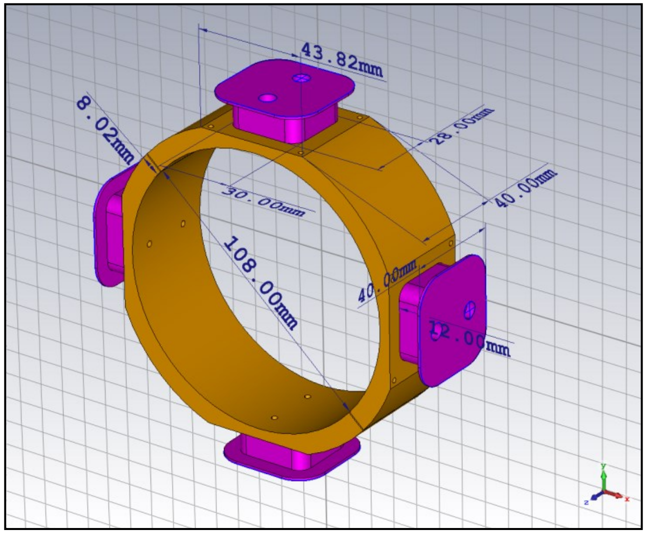
	rotation quad position at z = 0.18 m, beam image at High1 Scr1				
conditions	Solenoid polarity [A]	-361		361	
	Experiment 5MW				
	Quads polarityQ_K(1)	-0.6	0.6	-0.6	0.6
quads rotational angle [degree]	0				
	5				
	10				

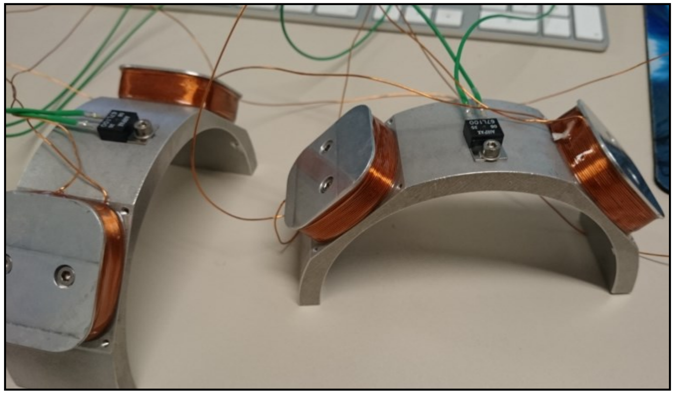
Q_length(1)=0.01,
Q_K(1)= +-0.6,
Q_pos(1)= x.xx,
Q_zrot(1)= y.yy

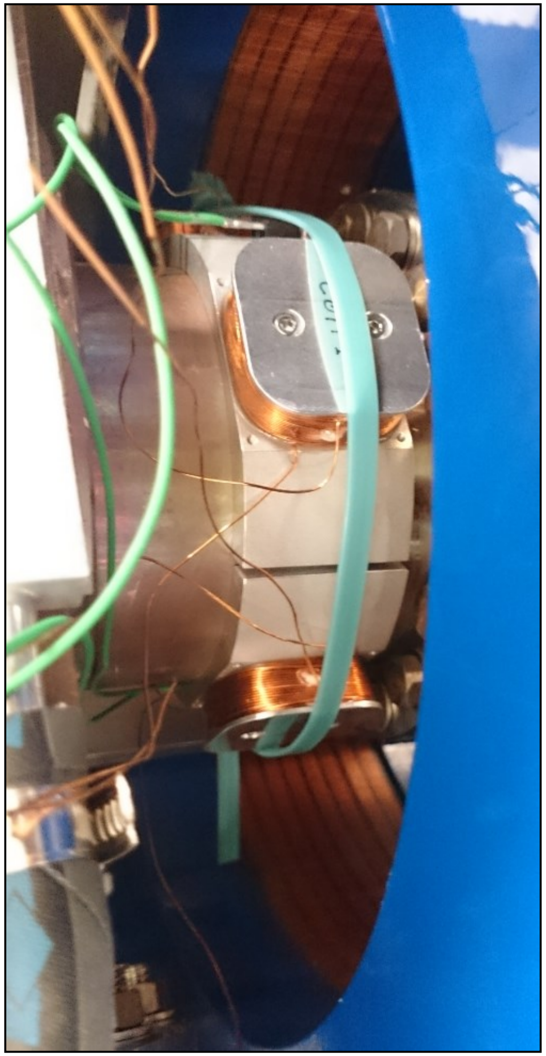
Summary of the simulations:

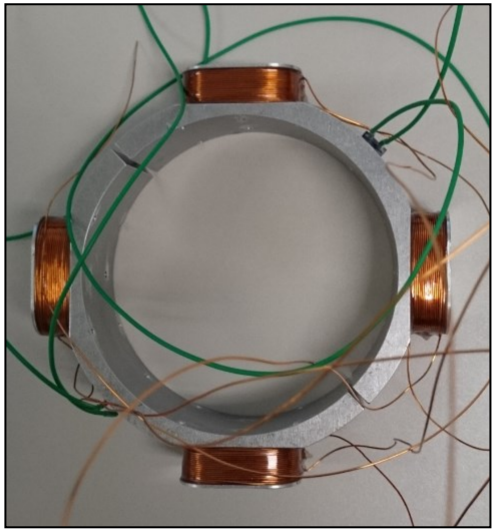
- ✓ Position: around **z=0.18m**
  - Rotation angle: **Skew quads**: 45 degree(negative polarity) / 135 degree(positive polarity).
  - Polarity: same, not effected by solenoid field polarity.
- ✓ Position: around **z=0.34m**
  - Rotation angle: **Normal quads**.
  - Polarity: when change the solenoid polarity, the quads polarity also changed.

First design of the GUN Quad (I. Isaev)





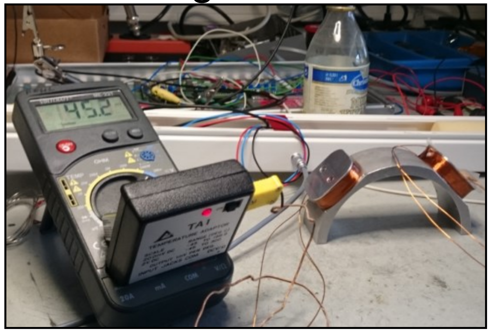


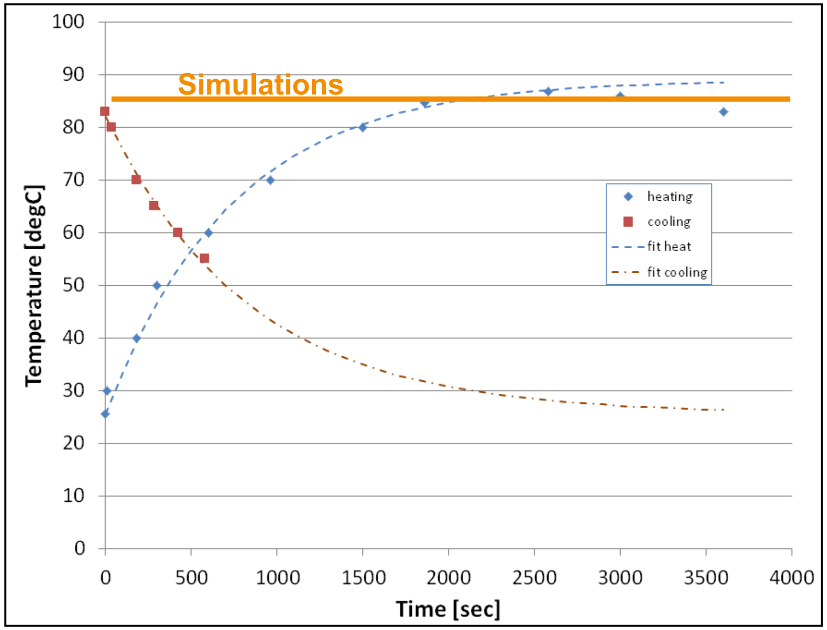


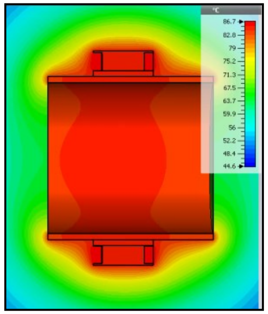
- Aluminum frame
- 0.56 mm copper cable
- 180 windings per coil
- 2 thermal switchers (80 degC max)
- Non-magnetic screws
- Fixed by radiation-hard cable tie
- Usage with 3A power supply

Gun Quad tests (I. Isaev)

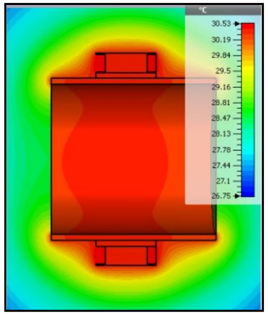
> Heating test at 3A





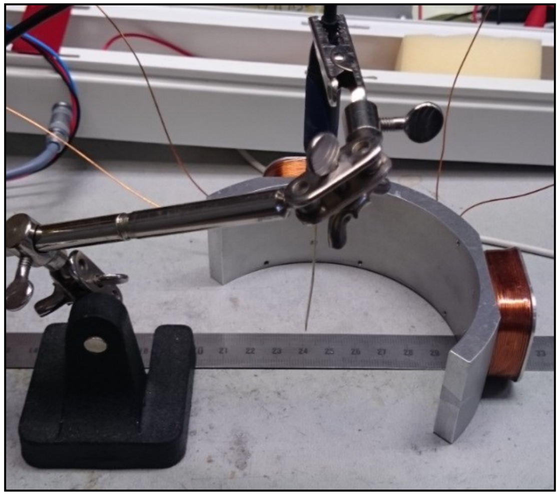


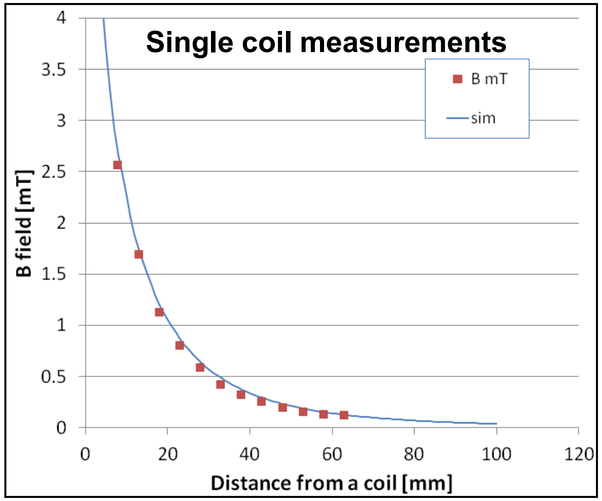
I = 3 A
T surface:
84.7 degC
T max:
86.7 degC

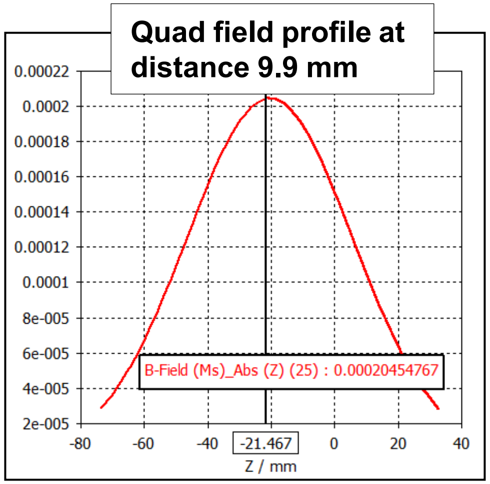


I = 1 A
T surface:
30.4 degC
T max:
30.5 degC

> Field measurements





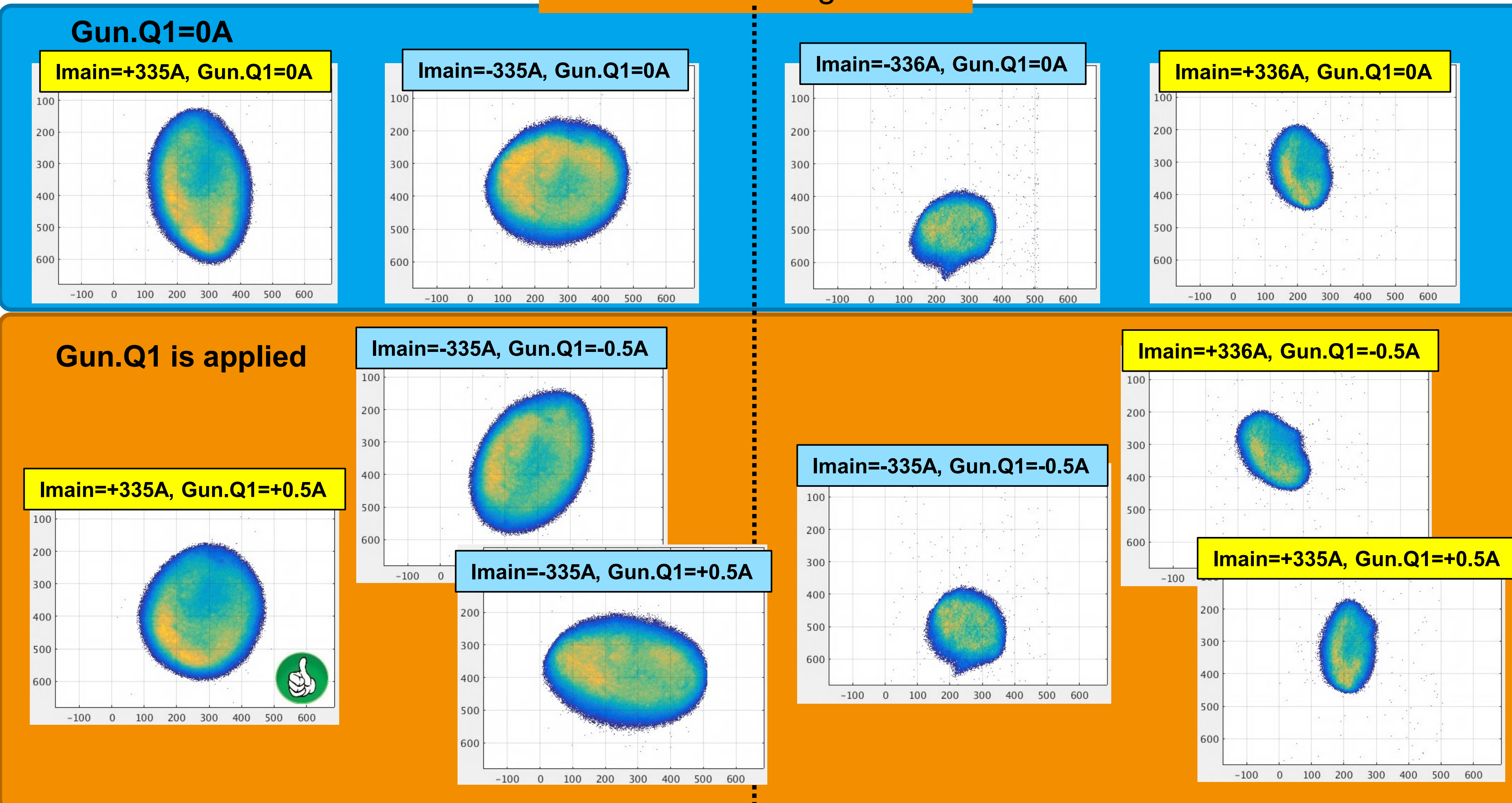


Q_grad = 0.0207 T/m @ 1A

Experiment with single gun quad

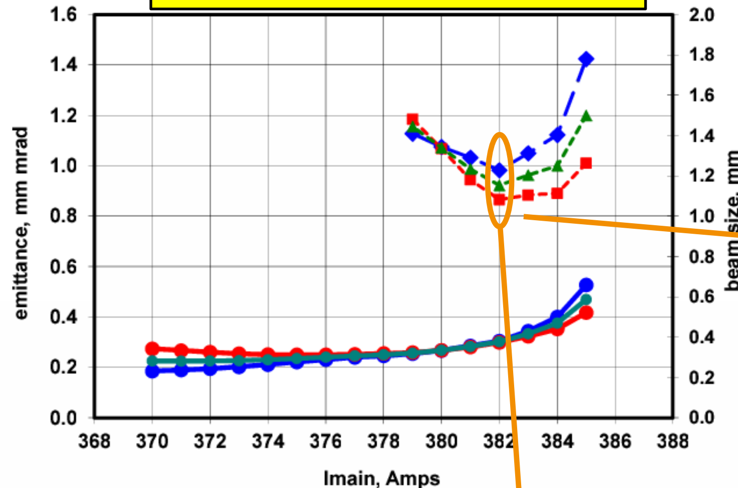
Experimental setup: BSA = 1.2mm / Gun power = 5MW / GunPhase = MMMG / Charge = 500pC / I_Bucking = 0A / Booster OFF.

Normal oriented Gun Quad | E-beam X-Y at High1.Scr1 | **Skew oriented Gun Quad**

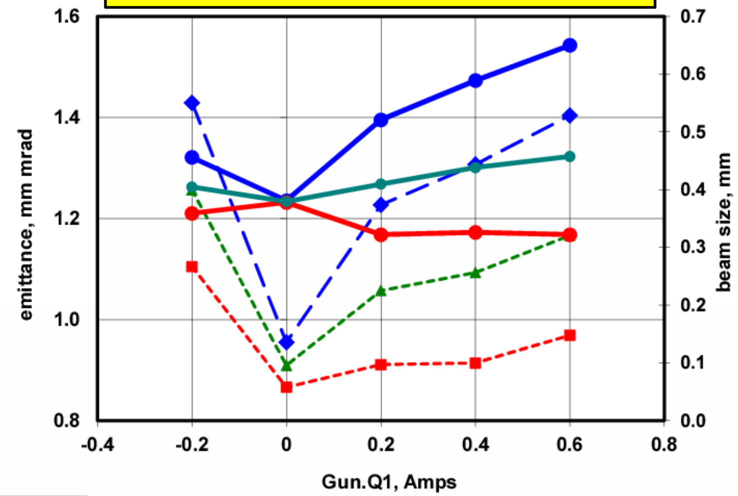


Emittance measurements with single gun quad

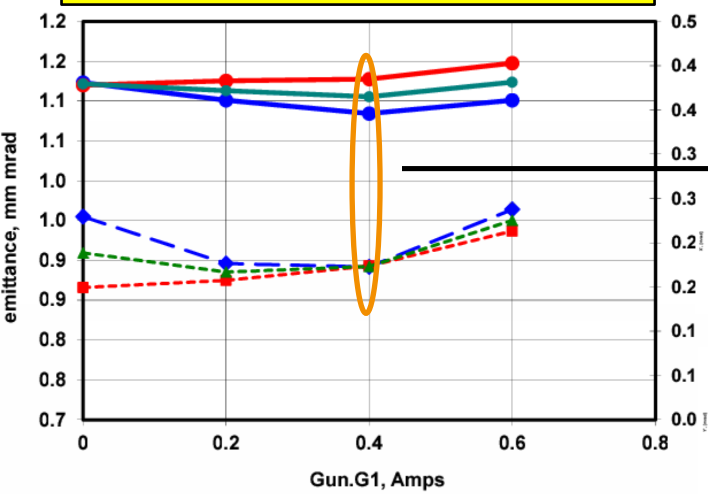
Gun.Quad = 0A

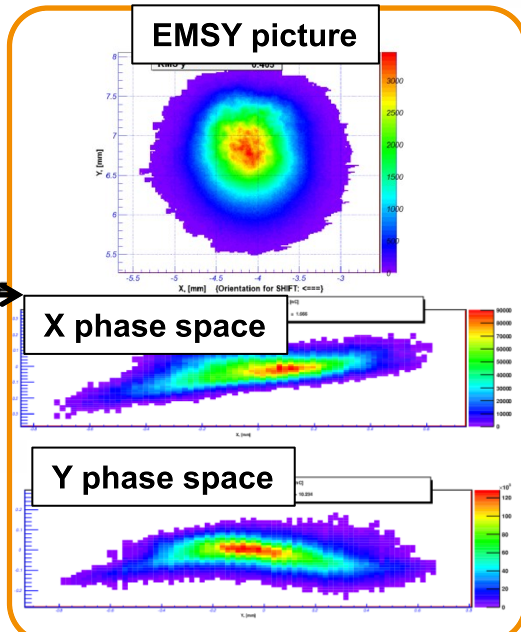


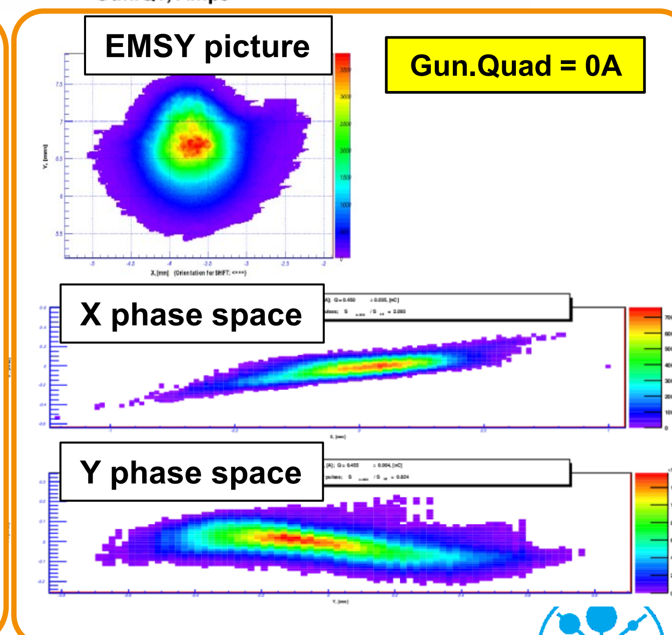
Skew oriented Gun Quad



Normal oriented Gun Quad

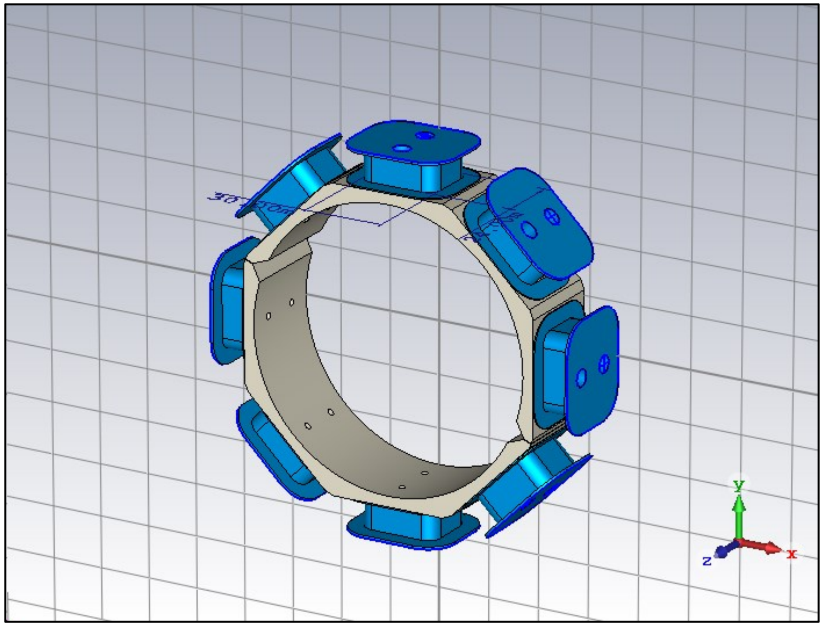


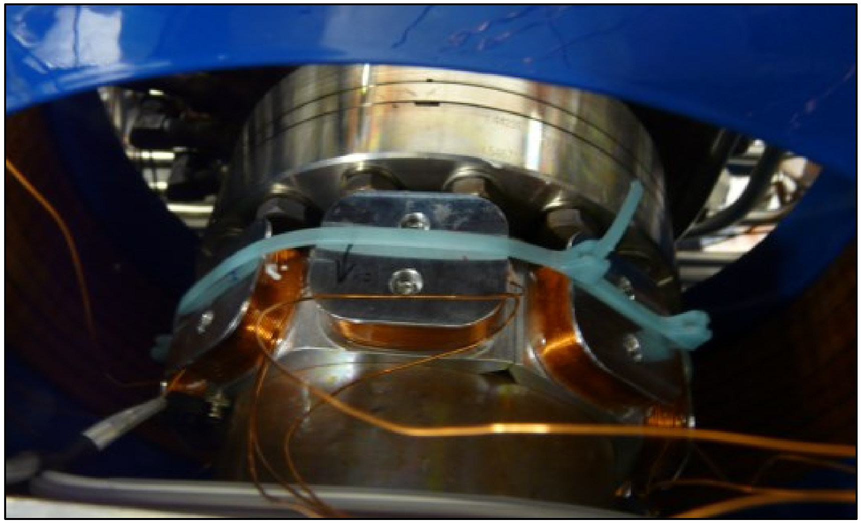


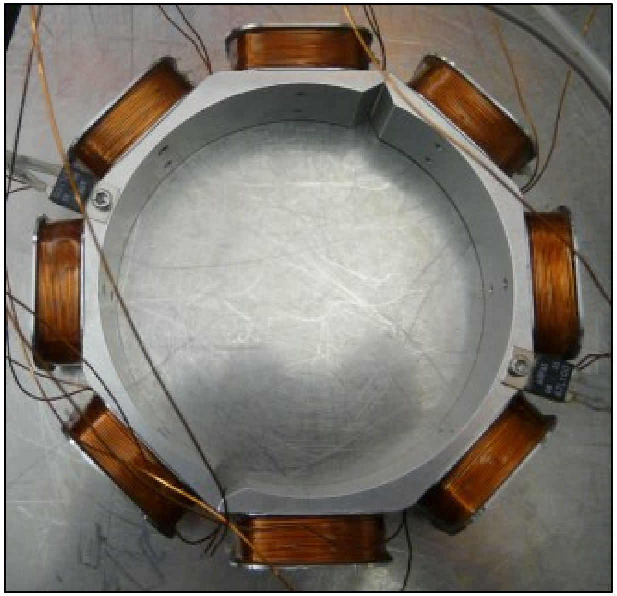


EmitX | EmitY | EmitXY | Xrms | Yrms | XYrms

Second design: Gun.Q1 and Gun.Q2 (I. Isaev)







Parameters:

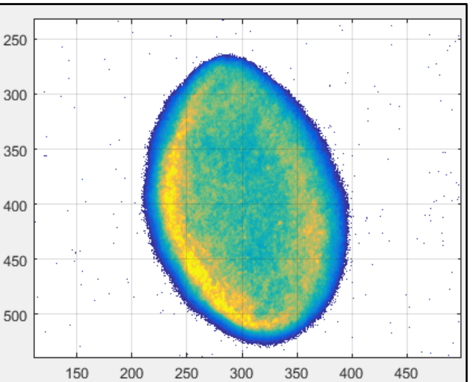
- Combination of a normal and a skew quads
- Aluminum frame
- 0.56 mm copper cable
- **140** windings per coil
- 2 thermal switchers (80 degC max)
- Non-magnetic screws
- Fixed by radiation-hard cable tie
- **Q_grad = 0.0117 T/m @ 1A**

Experiment with two quads

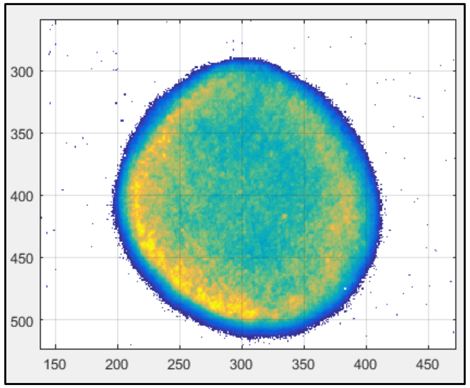
Experimental setup: BSA = 1.2mm / Gun power = 5MW / GunPhase = MMMG / Charge = 500pC / I_Bucking = 0A / Booster OFF.

E-beam at High1.Scr1

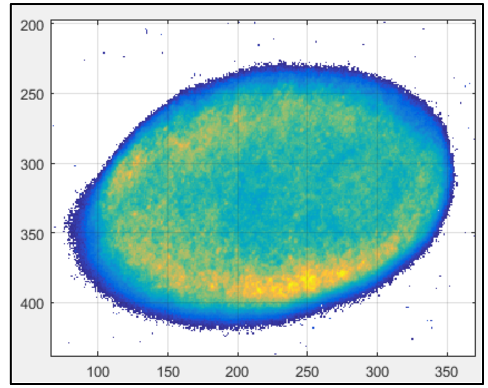
I main = +341A
Gun.Q1 = 0A
Gun.Q2 = 0A



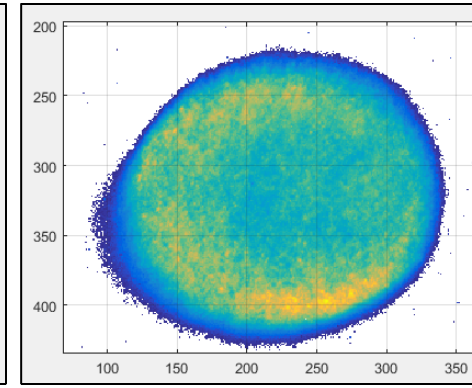
I main = +341A
Gun.Q1 = -0.6A
Gun.Q2 = -0.2A



I main = -341A
Gun.Q1 = 0A
Gun.Q2 = 0A

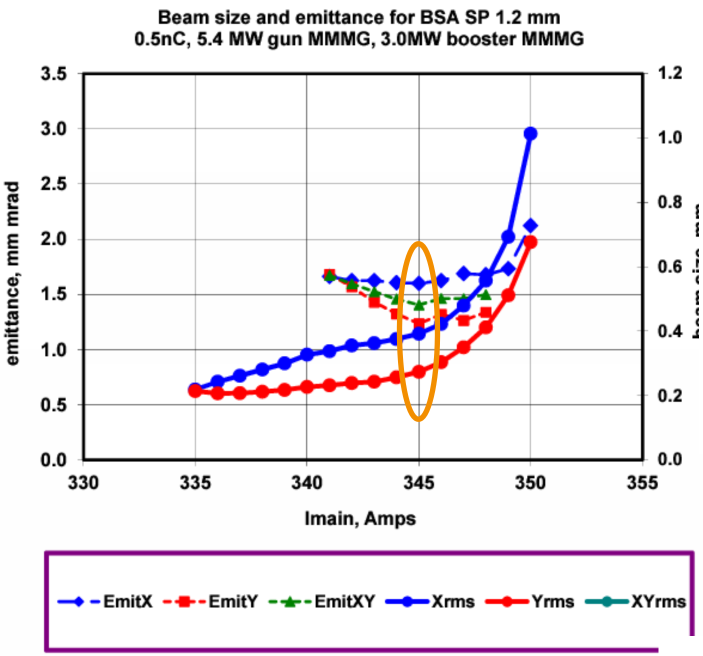


I main = -341A
Gun.Q1 = 0.2A
Gun.Q2 = -0.5A

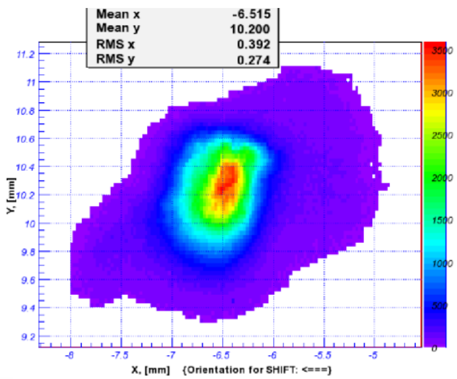


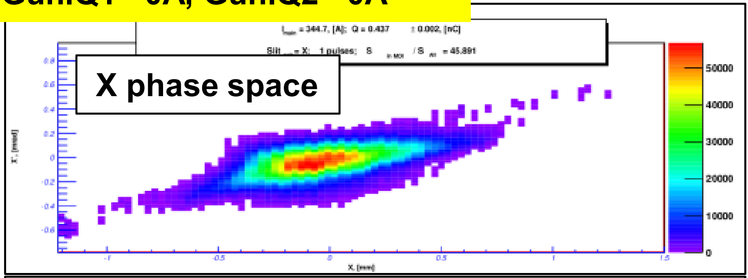
	I main, A	-381	+381	-371	+371	-351	+351	-350	+350	-341	+341	-336	+336
Low.Scr2	GQ1, A	0.7	-0.3										
	GQ2, A	-0.2	-0.6										
Low.Scr3	GQ1, A			0.4	-0.7								
	GQ2, A			0.0	-0.7								
Hihg1.Scr1	GQ1, A					+0.55	-0.55	0.2	-0.6	0.2	-0.6	0.5	-0.9
	GQ2, A					-0.45	-0.45	-0.5	-0.5	-0.5	-0.2	-0.7	0.1
High1.Scr3	GQ1, A									0.2	-0.6	0.5	-0.9
	GQ2, A									-0.5	-0.2	-0.7	0.1

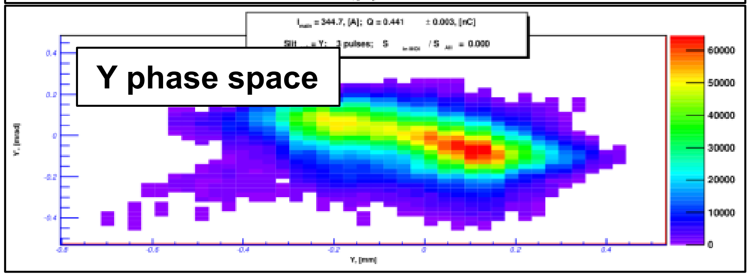
Influence on measured emittance



Gun.Q1= 0A, Gun.Q2= 0A





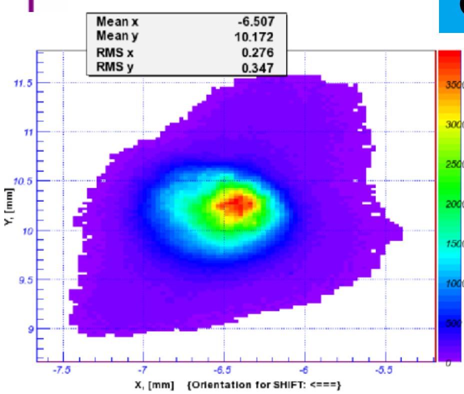


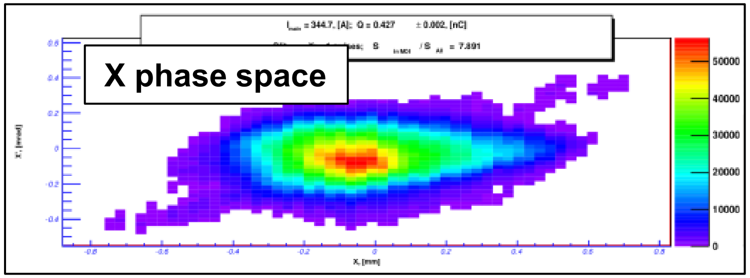
Xemit=1.60mm mrad

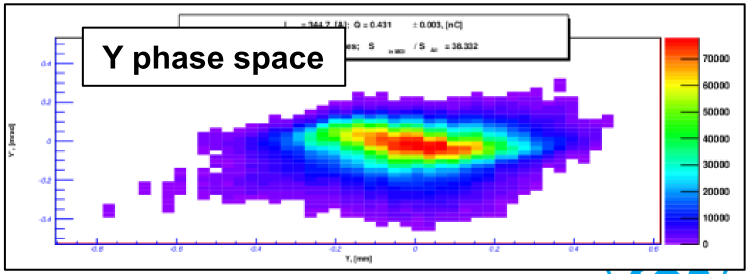
Yemit=1.23mm mrad

XYemit=1.41mm mrad

GQ1= -0.6A GQ2= -0.6A





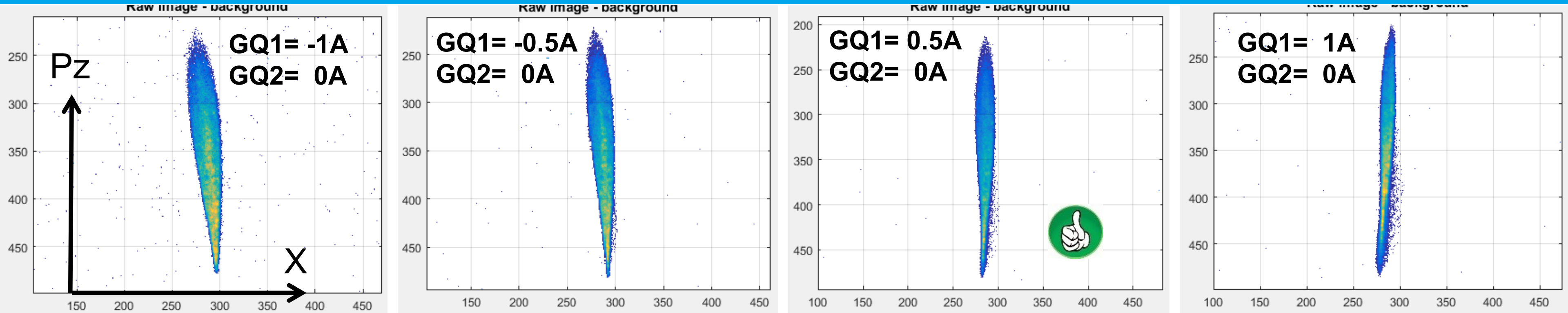


Xemit=1.34mm mrad

Yemit=1.47mm mrad

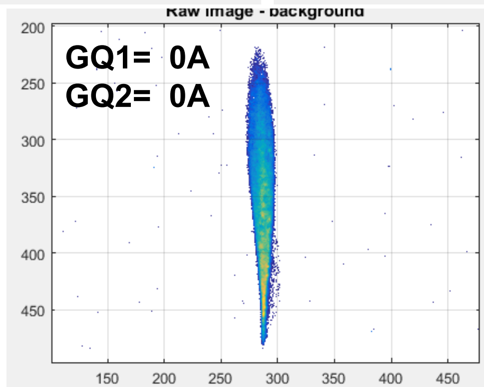
XYemit=1.41mm mrad

Experiment on beam tilt in LEDA

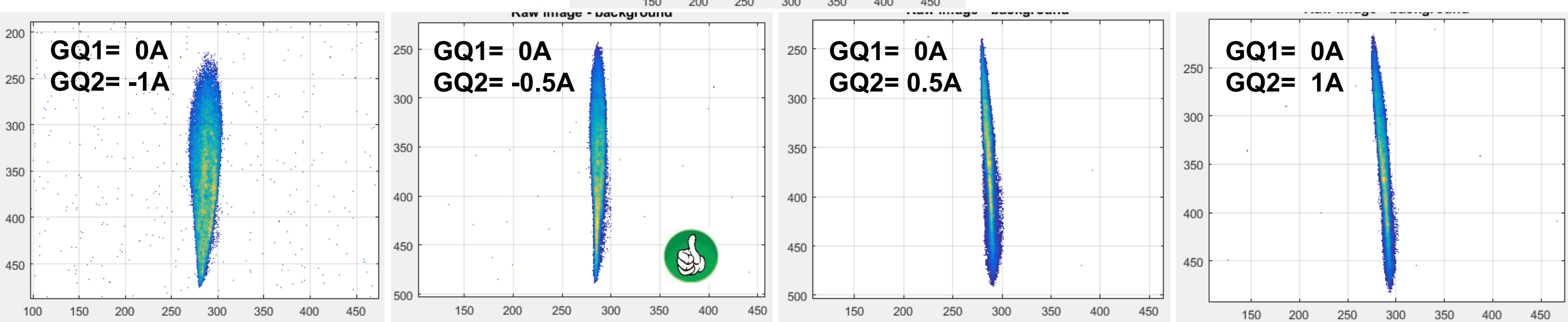


Parameters:

- 5.04 MW in the gun
- 5.9 MeV/c
- MMMG phase
- Dipole current = -1.55A
- Imain= **380A** (407A was used for momentum measurements)



GQ1 – normal quad
GQ2 – skew quad



Beam asymmetry: Summary and Outlook

- Two gun quad designs are modeled, produced and tested
- It is possible (partially) compensate the beam X-Y asymmetry for all solenoid settings (current and polarity)
- Compensation of the beam asymmetry requires 2 quads (N- and Skew) setup, which is currently in the operation
- E-beam tilt in LEDA can be compensated
- Gun quads make emittance and transverse phase space more symmetric, but not smaller*

- A beam shape evaluation and optimization algorithm has to be improved
- Further experiments on emittance with optimized beam steering (trajectory) and on beam tilt in LEDA for systematic dependencies GQ1/2=F(Imain, Pgun, GunPhase,…) have to be prepared
- The position and geometry of the gun quads must be optimized for better beam asymmetry compensation

δE-program at PITZ (from the last meeting)

Idea: establish δE measurements (best resolution and flexibility) and measure δE for various conditions (temporal profiles, SC effect, etc.)

<u>Motivation from DESY-HH</u>:

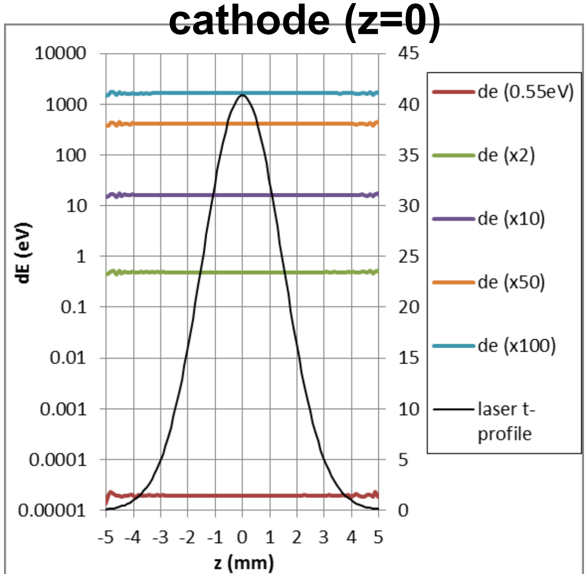
- Initial δE for micro-bunching instability studies (M. Dohlus)

<u>Motivation from PITZ:</u>

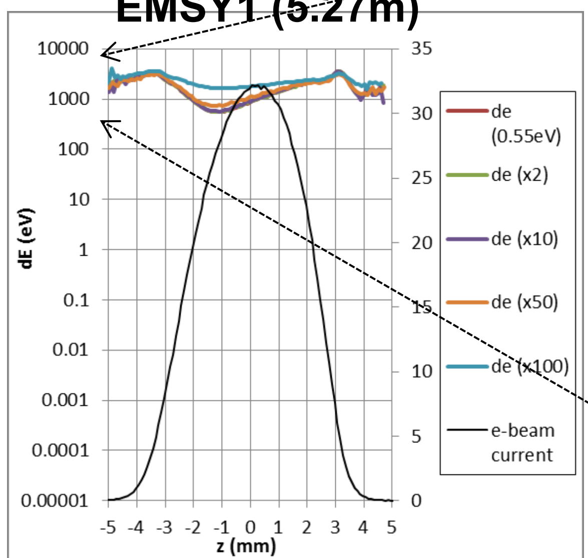
- Measurements vs. simulations
- Improve measured σE (projected) understanding
- ?Detailed emission modeling (e.g. zero-crossing phase)

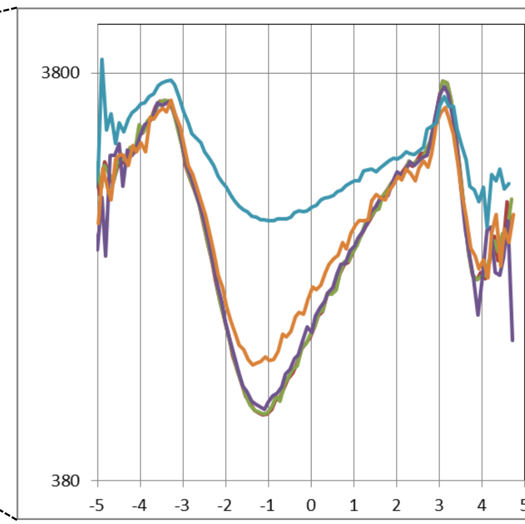
ASTRA simulations with “Pz-heater” at cathode

cathode (z=0)



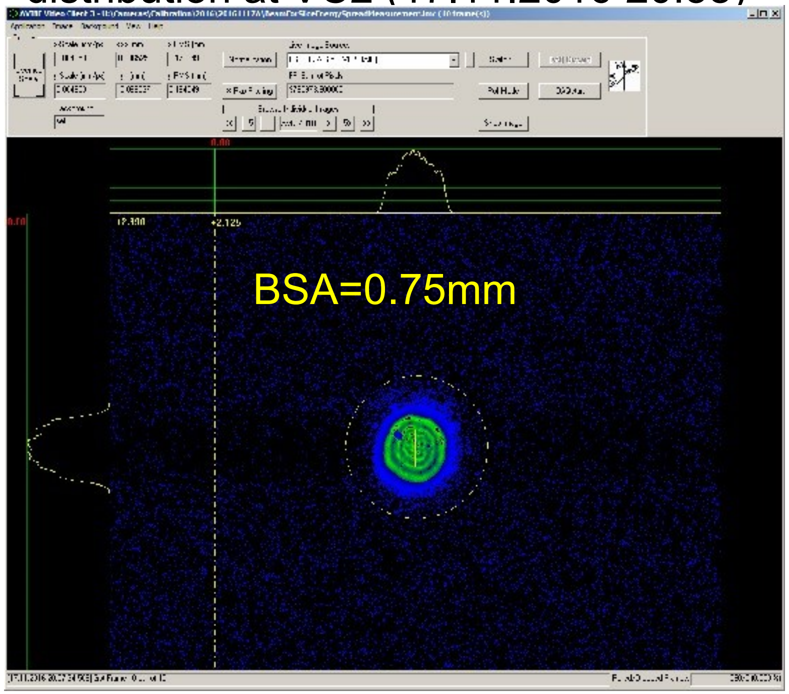
EMSY1 (5.27m)





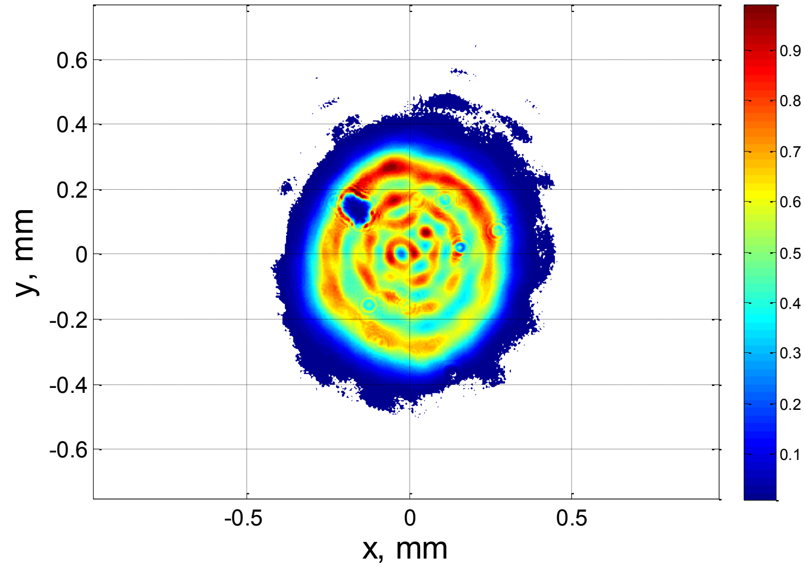
δE Measurements with long Gaussian on 17.11.2016A-N: VC2

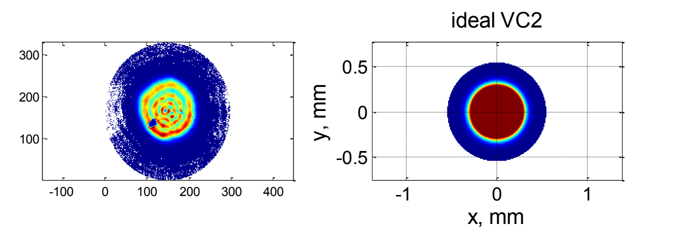
- Photocathode laser: transverse distribution at VC2 (17.11.2016 20:58)

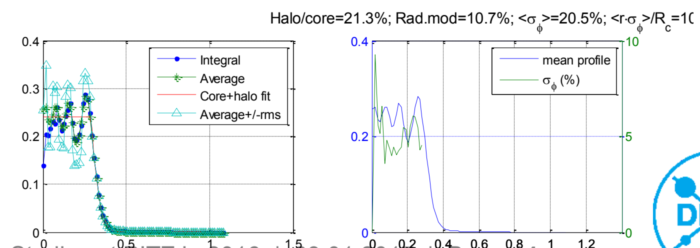


Xrms=0.179mm
Yrms=0.194mm

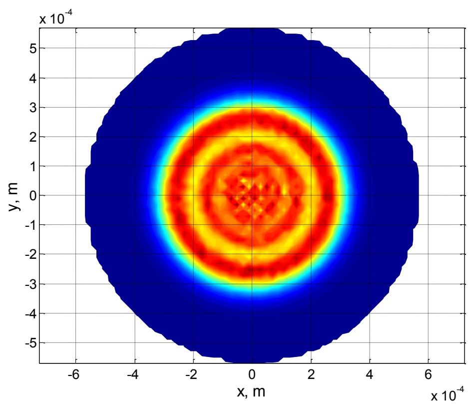
XYrms=0.186mm





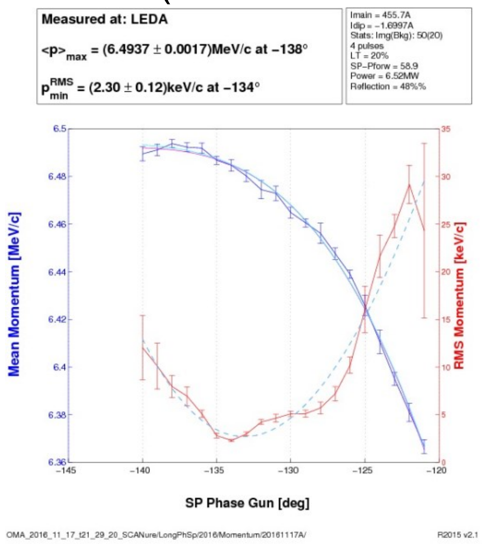


Used in ASTRA simulations
XYrms=0.186mm
Trms=4.88ps
(11.5ps FWHM)

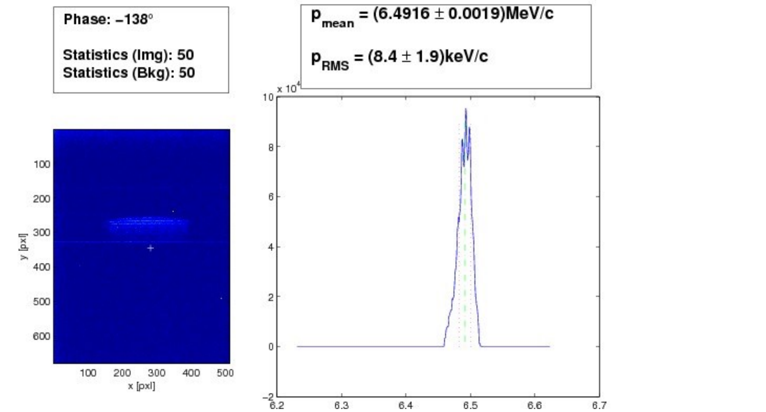


δE Measurements with long Gaussian on 17.11.2016A-N: Pz-gun

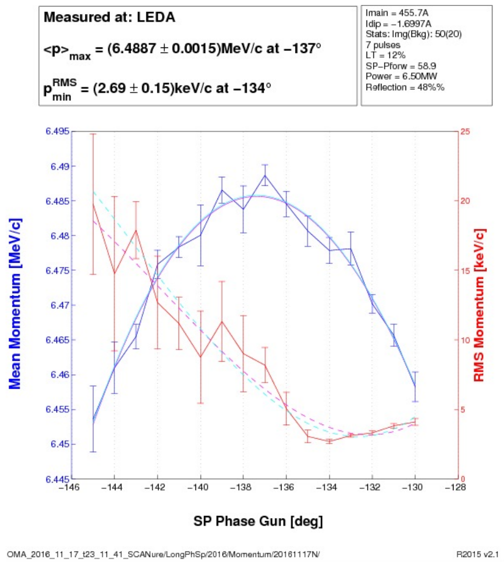
- LEDA scan (17.11.2016 21:29)



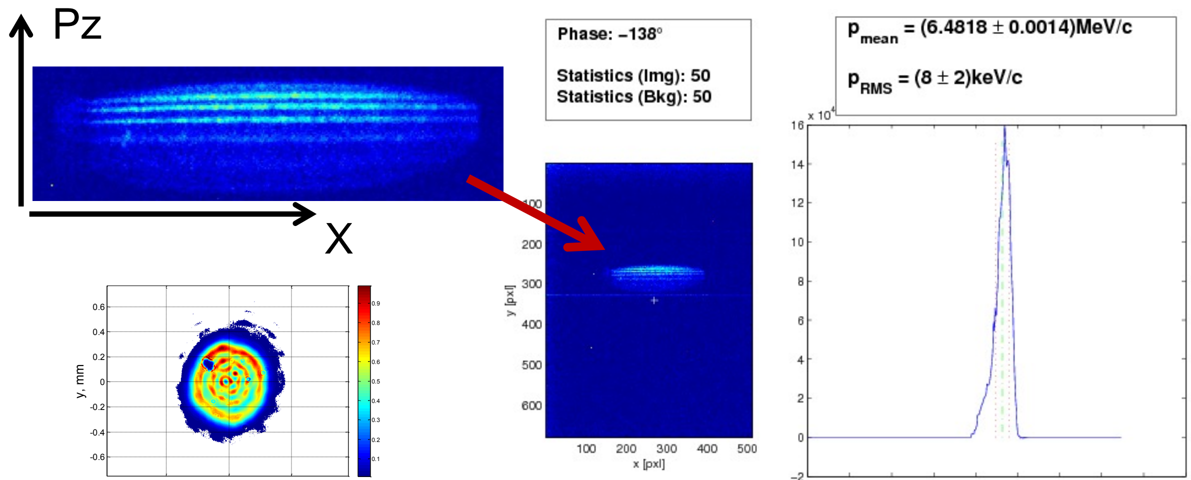
- LEDA projection at MMMG phase, -138 deg (17.11.2016 21:30)



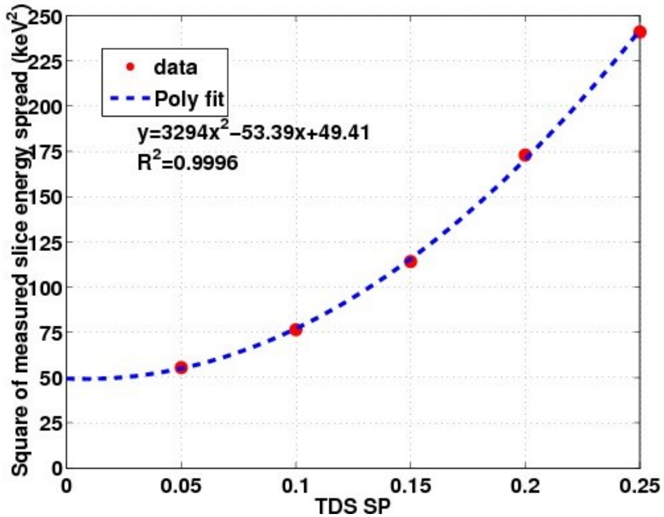
- LEDA scan (17.11.2016 23:11)

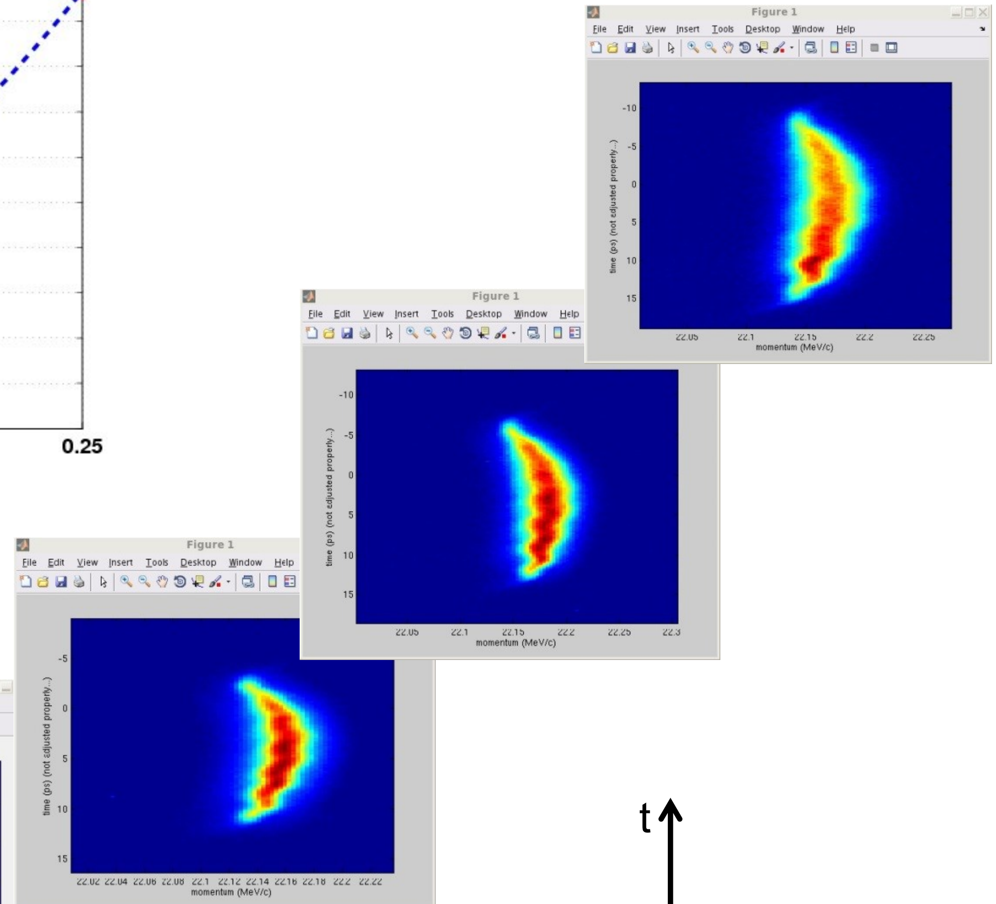


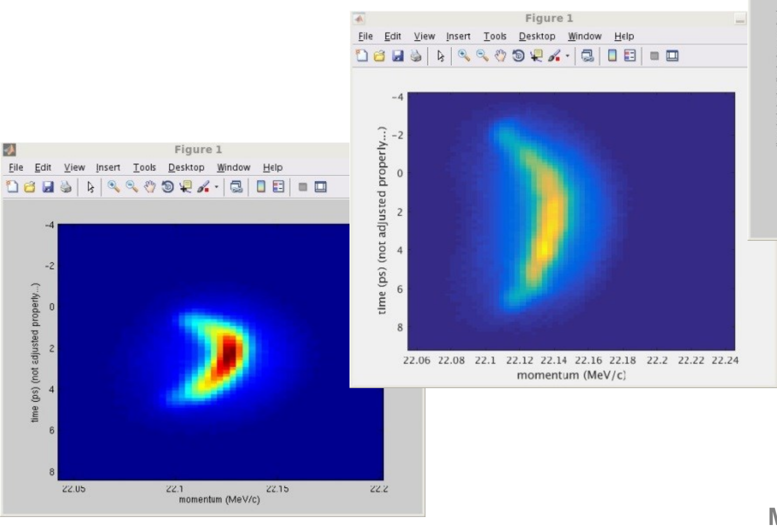
- LEDA projection at MMMG phase, -138 deg (17.11.2016 23:30), + fine tuned solenoid

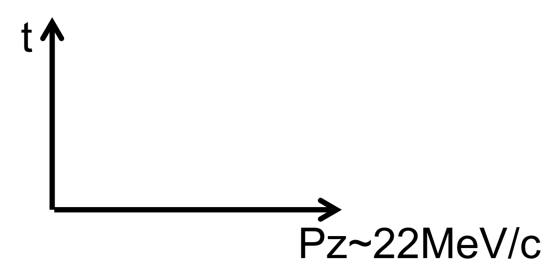


Longitudinal Phase Space measurements: TDS SP scan in HEDA2







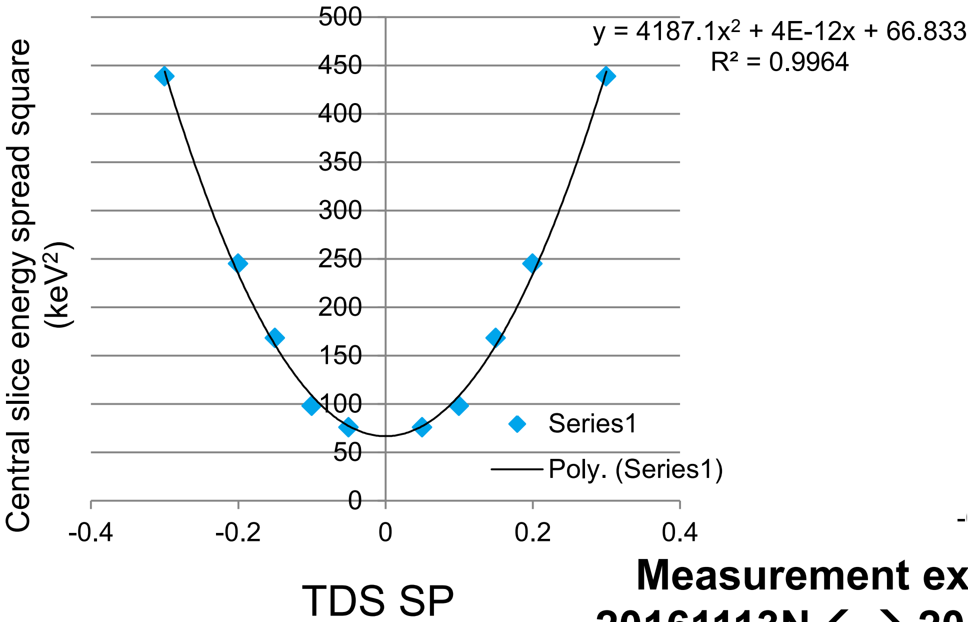


Slice energy spread: systematic errors estimation

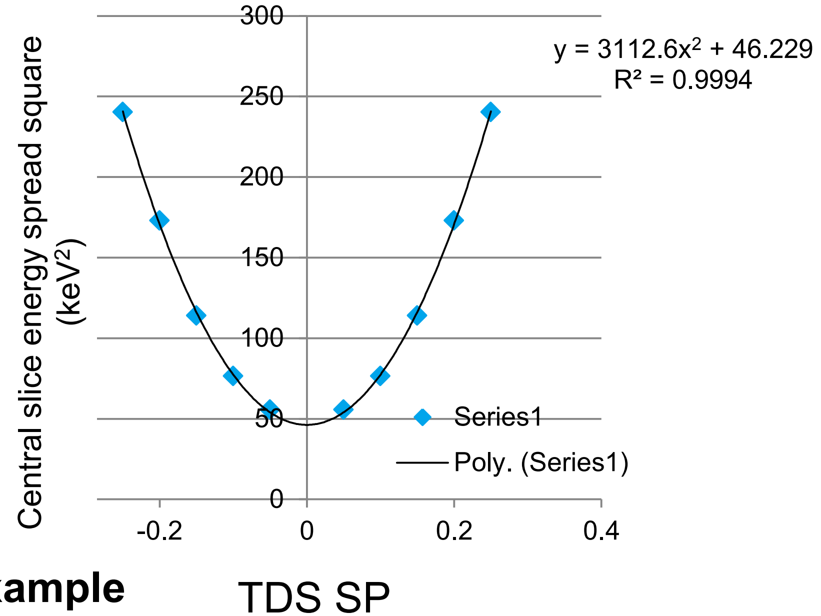
- Slice energy spread measurement
  - Real slice energy spread
  - TDS contribution
  - Beta function contribution

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

8.2 keV for TDS zero (**Short** Gaussian)



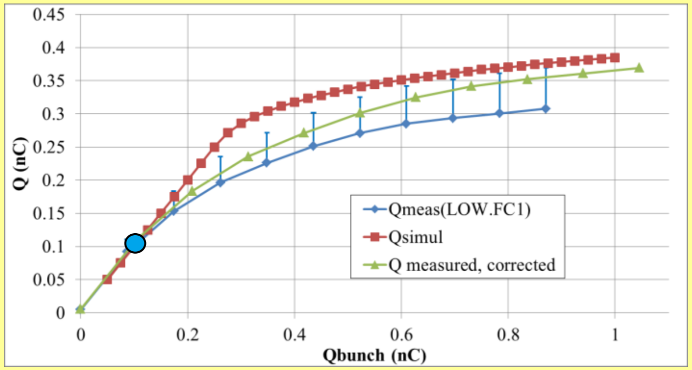
6.8 keV for TDS zero (**Long** Gaussian)

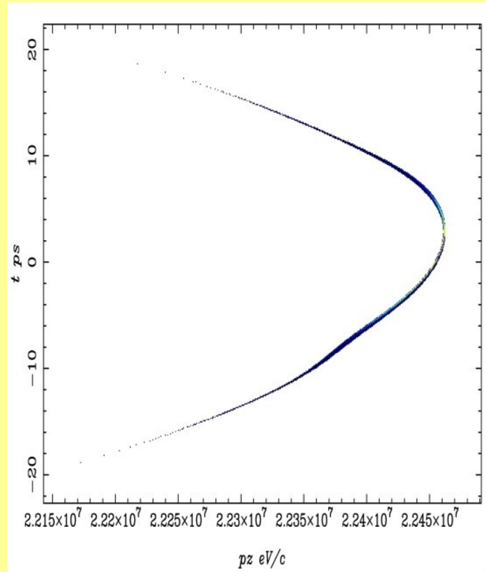


Measurement example
20161113N ←→ 20161117N
100 pC, 0.75 mm

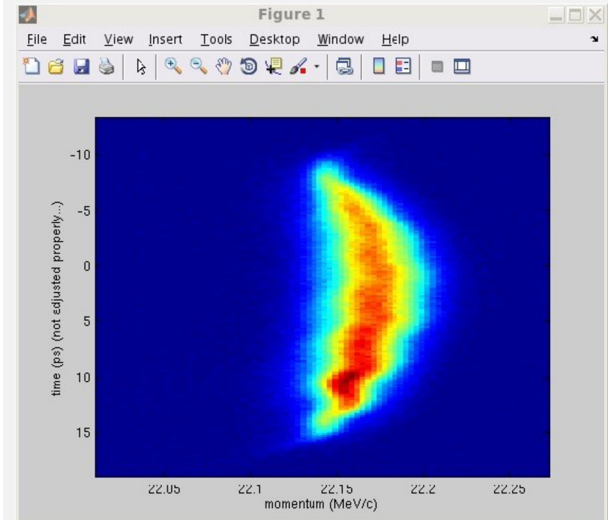
…+ ASTRA simulations

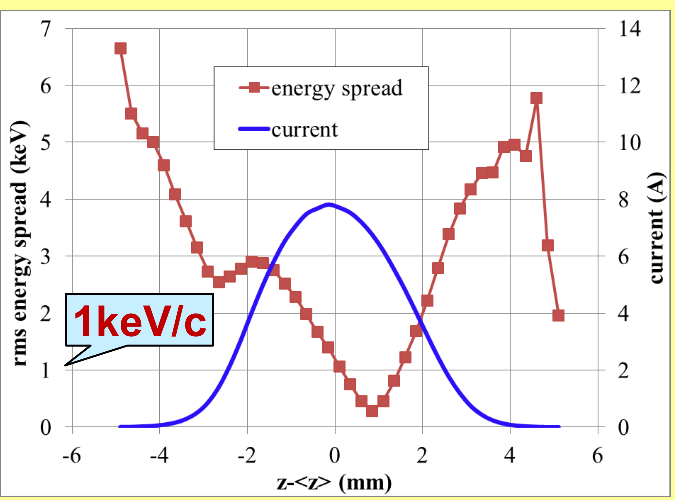
ASTRA simulations with long Gaussian (11.5 ps FWHM) photocathode laser pulse

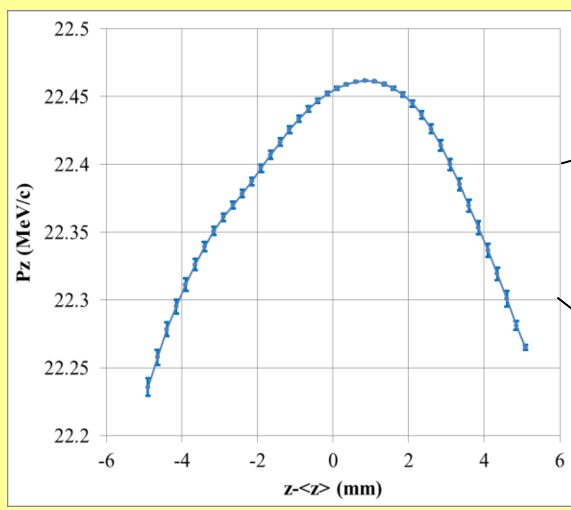


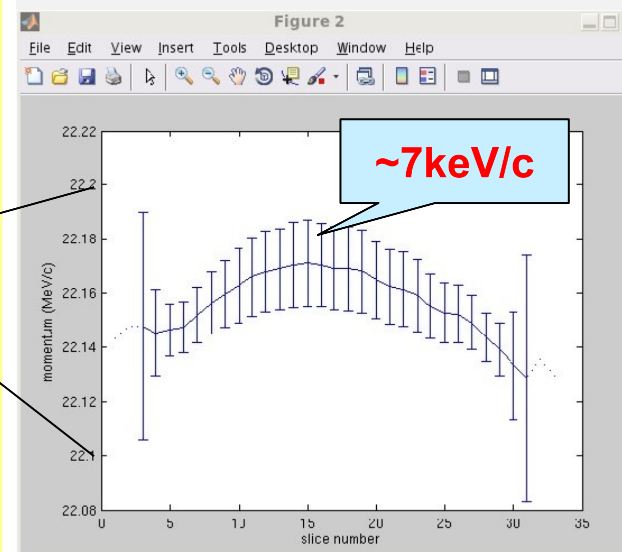


Measurements SP(TDS)=0.25





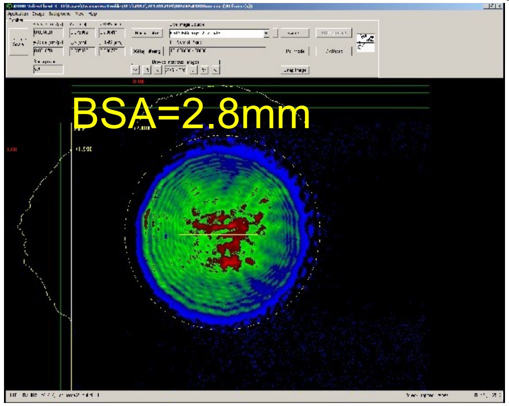


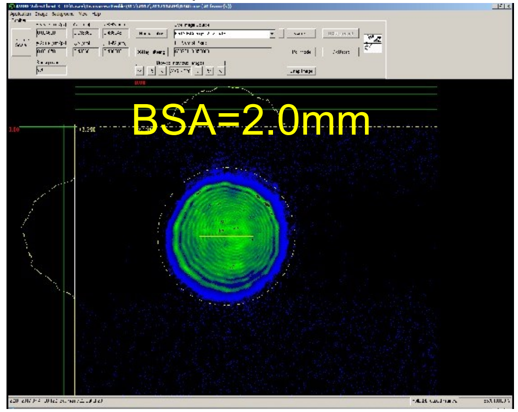


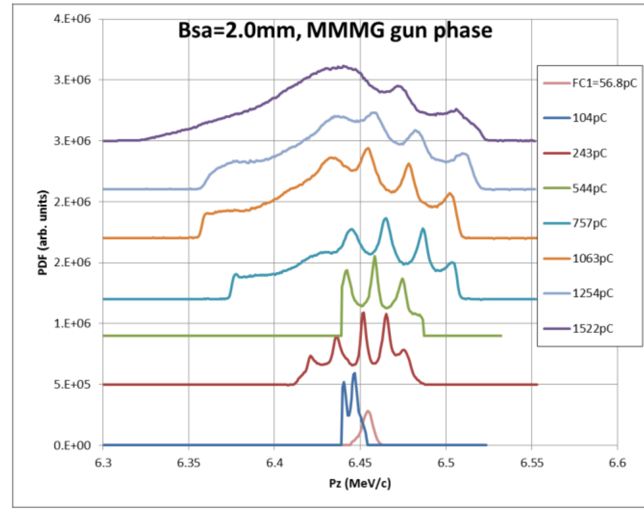
Some recent observations (21-22.01.2017M)

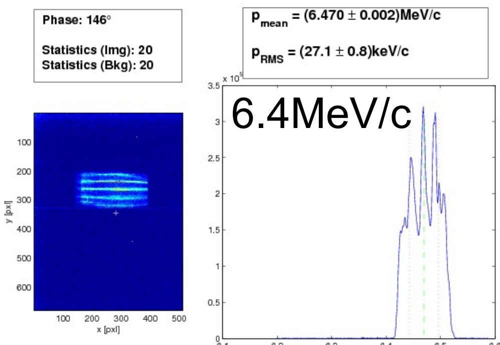
Temporal profile	FWHM
Long Gaussian	~11-11.5ps

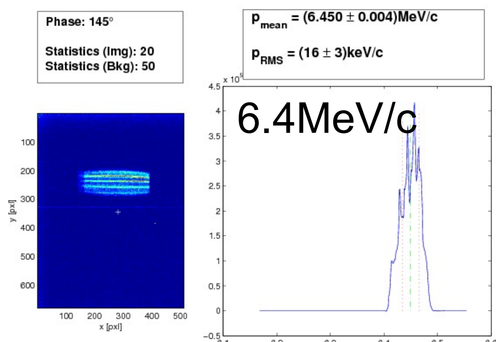
- E-beam momentum modulations observed in:
  - LEDA (Pz~6.4MeV/c)
  - HEDA1 (Pz~22.1MeV/c)

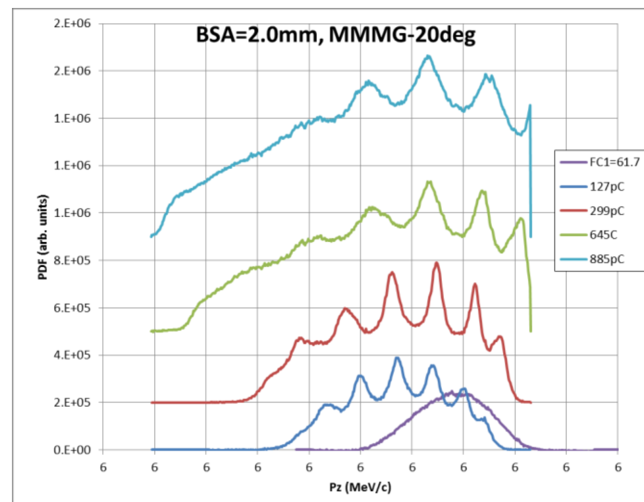


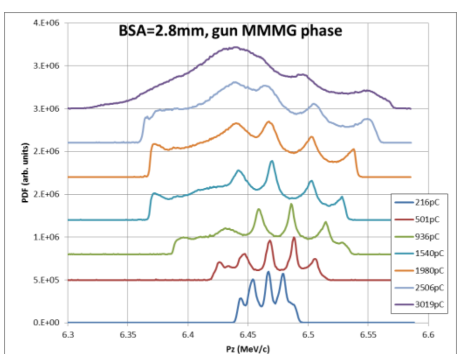


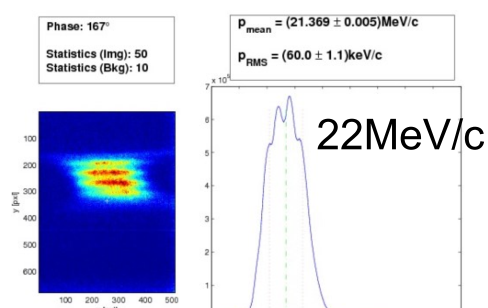












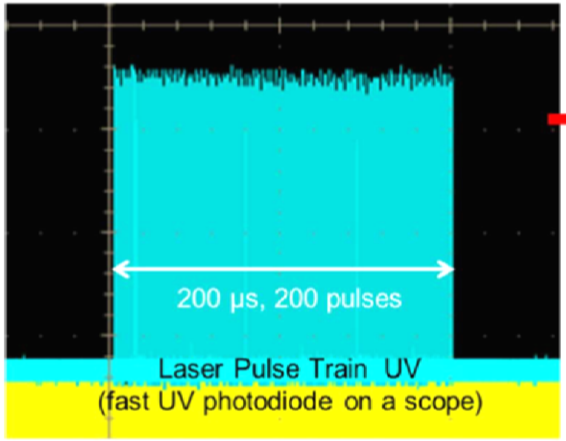
Slice energy spread at PITZ: Conclusions and outlook

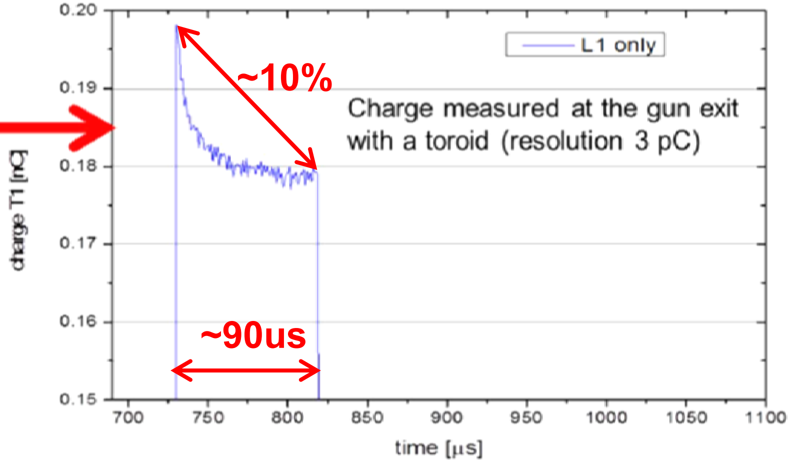
- LPS (δE) measurements with Gaussian photocathode laser pulses (short 2ps and long 11.5ps) yield the measured rms slice energy spread of 6-7keV/c (whereas ASTRA→<1keV/c for long Gaussian pulses)
- Still resolution on the slice energy spread seems to be a limiting factor:
  - Beam transverse size in the HEDA2 dipole (beta function)
  - TDS induced energy spread (estimated $\frac{d(\delta E)}{dSP(TDS)} \sim 3\frac{eV}{MV}$)
- Measured longitudinal phase space (LPS) shows modulation even with long Gaussian cathode laser pulses:
  - “MB-instability” at the photocathode (observed already in LEDA)?
  - Space charge effect while transport?
  - Measurement artifact (but observed at 3x locations)?
  - Up to now was not observed in e-beam temporal profile
- TDS in the low energy section would be useful
- Any ideas (to explain measurements and to refine them) are welcomed

Studies on profile of electron bunch trains – „Q-train“ (Y. Chen) Motivation (/Observation at FLASH)

> Emission issue of fresh cathode 73.3 (and some others) at FLASH[1-2)]

Fresh cathode in the gun 4-Feb-2015; QE=10%





- A **flat** energy distribution of the **laser pulse train produces** a **'spike'** at the **head** of the **electron bunch train** emitted from a **fresh cathode**
- **Spike** strength **depends** on **laser energy density** and **accelerating field** on cathode
- The **decay time** decreases slowly with time over weeks

1) Siegfried Schreiber, Sven Lederer, FEL Seminar DESY, 2016
2) S. Schreiber, S. Lederer, FEL15', Daejeon, Korea, 2015

„Q-train“ studies: Start-up measurements at PITZ

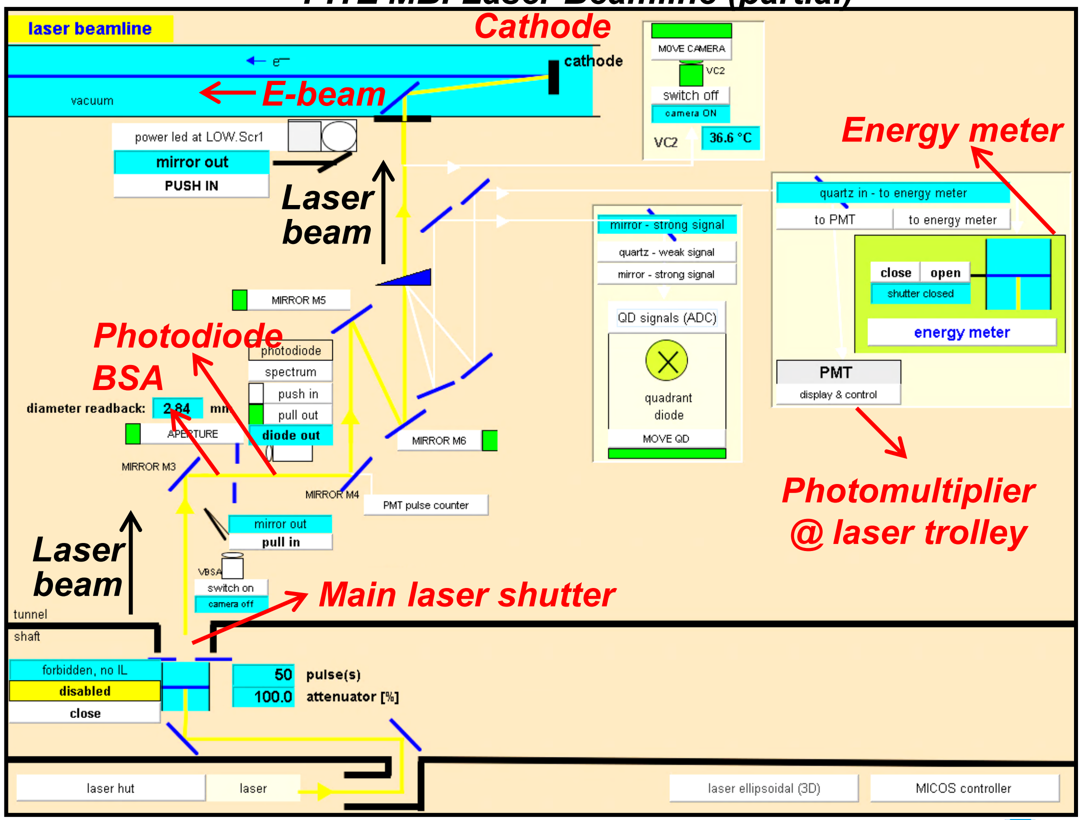
- **RF stabilities along charge pulse train (amplitude and phase)**
  → following emission model, full field at cathode influences QE
  → simultaneous recording gun field amplitude and phase@uTCA

- **Cathode laser energy distribution along charge pulse train**
  → check laser energy profile using **photodiode after BSA** and **photomultiplier at laser trolley**

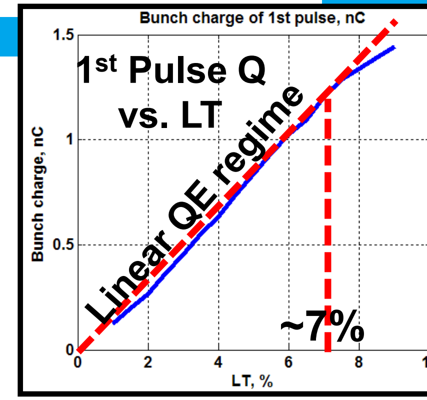
- **Charge measurements using LOW. ICT1 @ADC and FCs @Scope**

- **Plays to correlate relevant parameters**
  - BSA size
  - Cathode laser energy
  - Accelerating field gradient

PITZ MBI Laser Beamline (partial)



$$\text{"Effective QE"} = \frac{\text{Charge, nC}}{\text{Photodiode (or PMT) voltage, V}}$$



- **Fixed BSA SP ≈ 2.2395 mm, 6.5MW @ MMMG phase, cathode #682.1 (fresh)**
  - As laser intensity (or photon density) increases,
    - QE decaying time increases
    - QE decreasing trends more pronounced