SLICE EMITTANCE MEASUREMENTS USING AN ENERGY CHIRPED BEAM IN A DISPERSIVE SECTION AT PITZ

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HELMHOLTZ ASSOCIATION

PITZ

DESY

TALK OUTLINE

- **Introduction to PITZ**
  - Photo injector characterization
  - PITZ diagnostics
- **Projected and slice emittance**
  - Solenoid compensation
  - Simulation results
- **Slice emittance measurements at PITZ**
  - PITZ setup for slice emittance
  - Results
- **Conclusions**

HIGH-BRIGHTNESS PHOTO INJECTOR

- **Charged particle source brightness**

$$B \propto \frac{Q}{\varepsilon_x \varepsilon_y \varepsilon_z}$$

- **High-brightness electron source transverse emittance requirement for the European X-FEL**
  - **< 0.9 mm mrad projected emittance after the gun section**
  - **< 1.4 mm mrad slice emittance in front of the undulator section**
- **PITZ optimizes the injector setup by minimizing transverse projected emittance.**

PHOTO INJECTOR

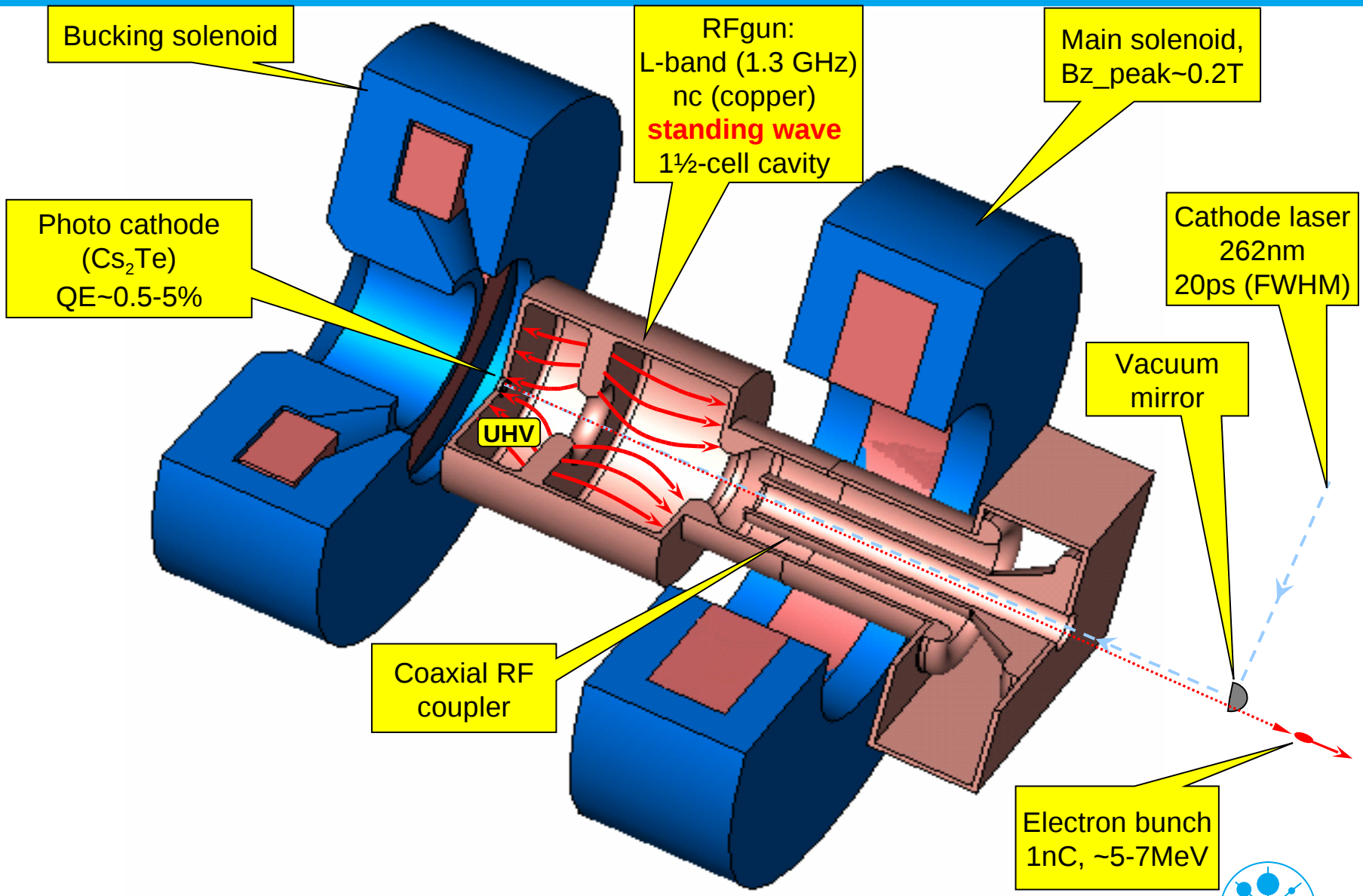
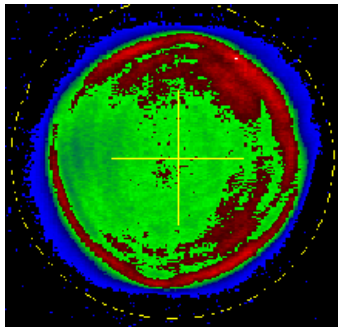
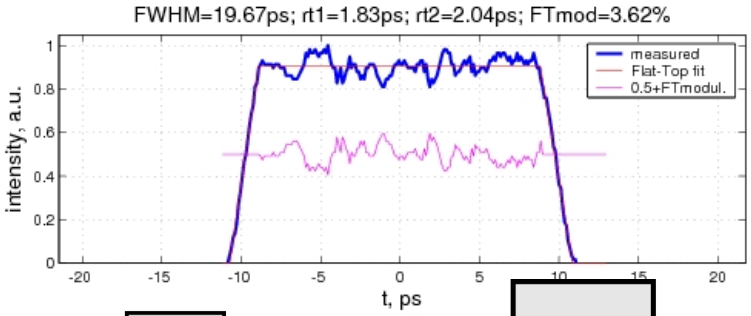
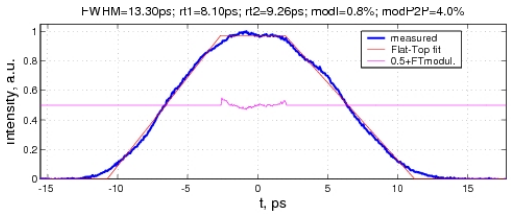
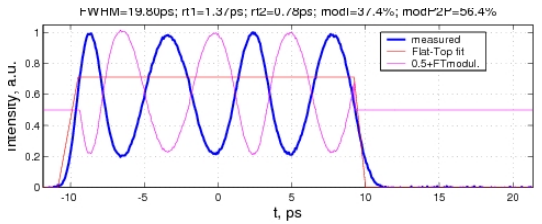


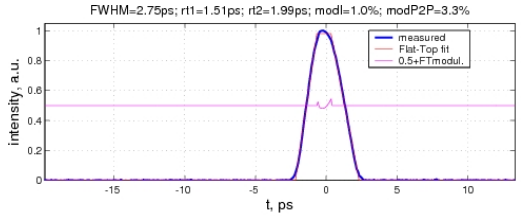
PHOTO INJECTOR LASER

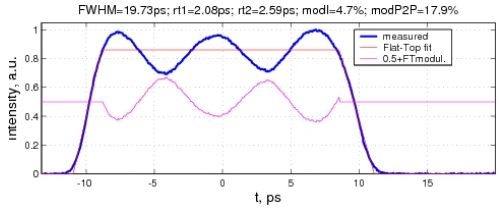




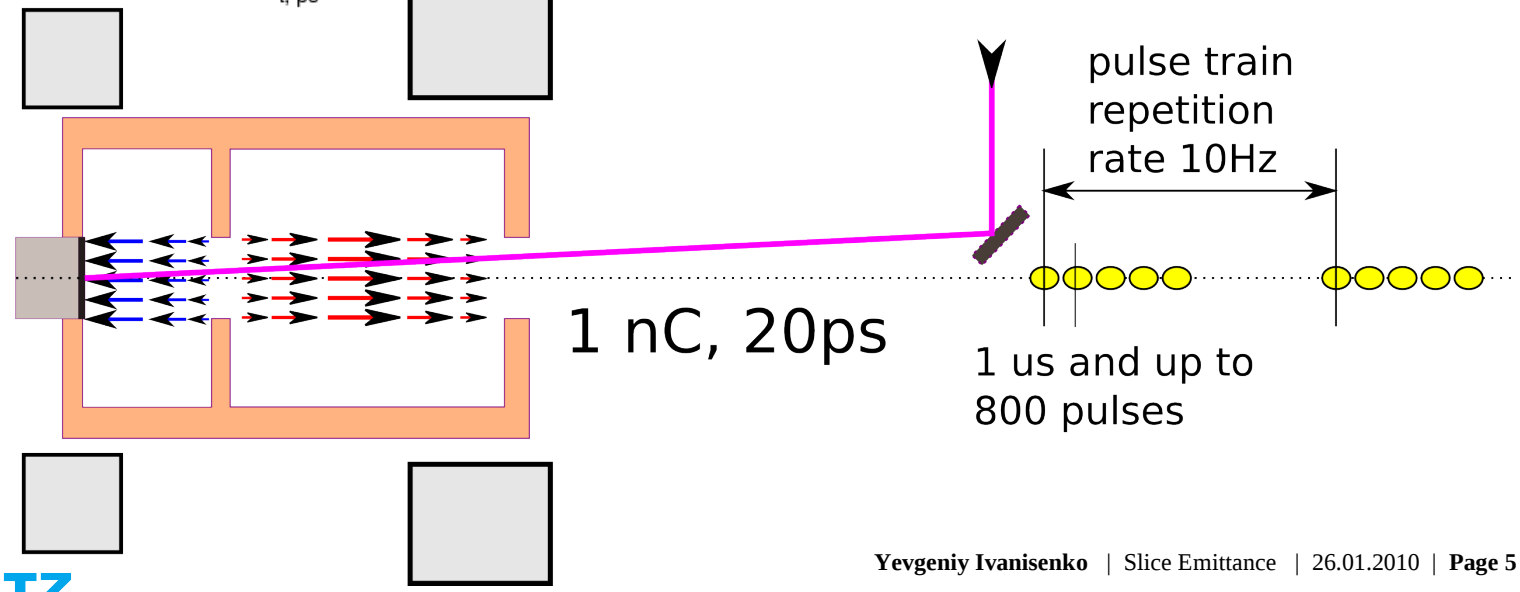








- **Nominal shape is a flat-top pulse with FWHM ~ 20ps**



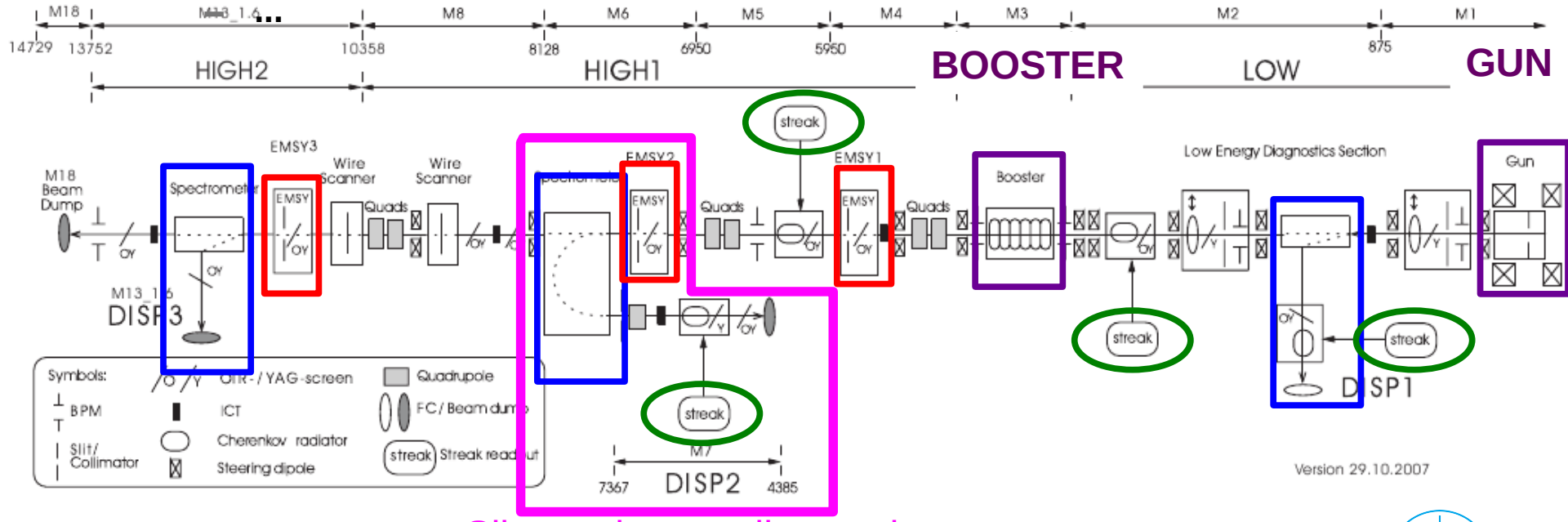
PITZ

DESY

PITZ DIAGNOSTICS

Beamline 1.7

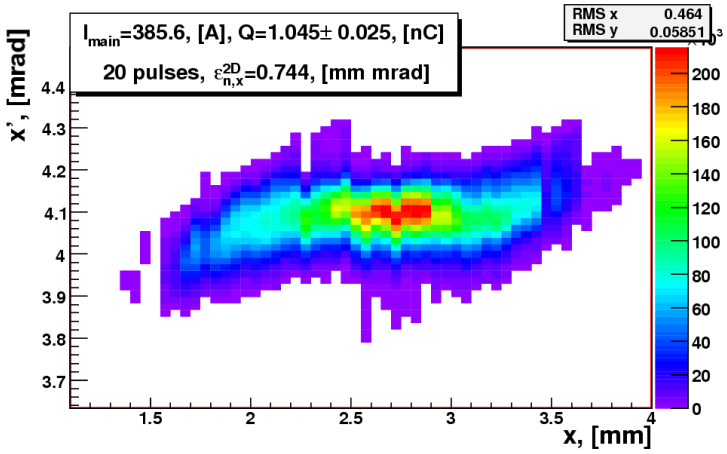
- Beam momentum distribution, bunch length
  - Three dispersive sections
  - Streak readouts
- Beam trajectory, size, transverse emittance
  - Screen stations
  - EMSYs
  - Quads

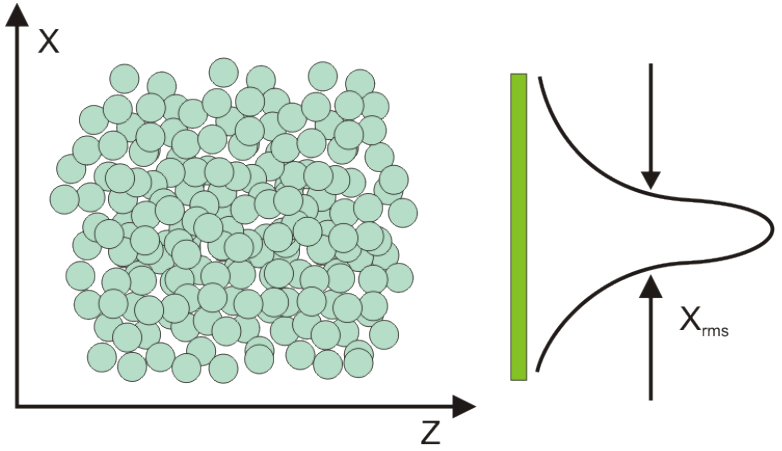


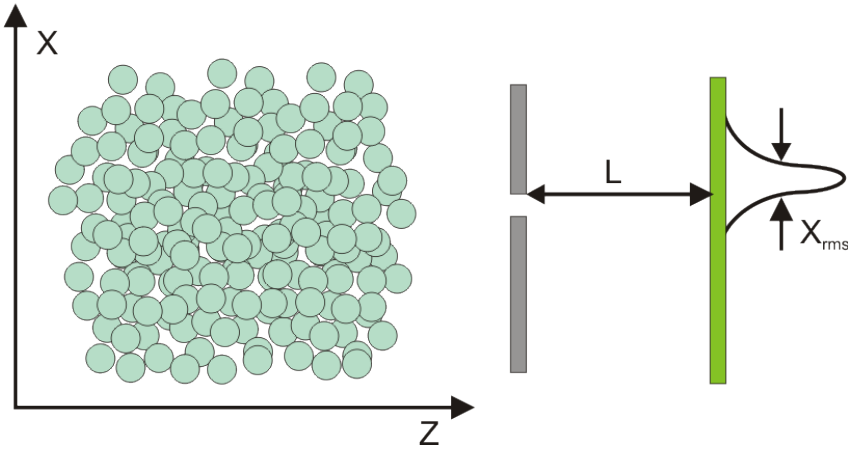
Slice emittance diagnostics

EMITTANCE MEASUREMENT SYSTEM

- **EMSY – emittance measurement system:**
  - Contains slit masks for both transverse plains
  - Slit position is scanned along the transverse beam size
  - Reference beam size measurement at EMSY



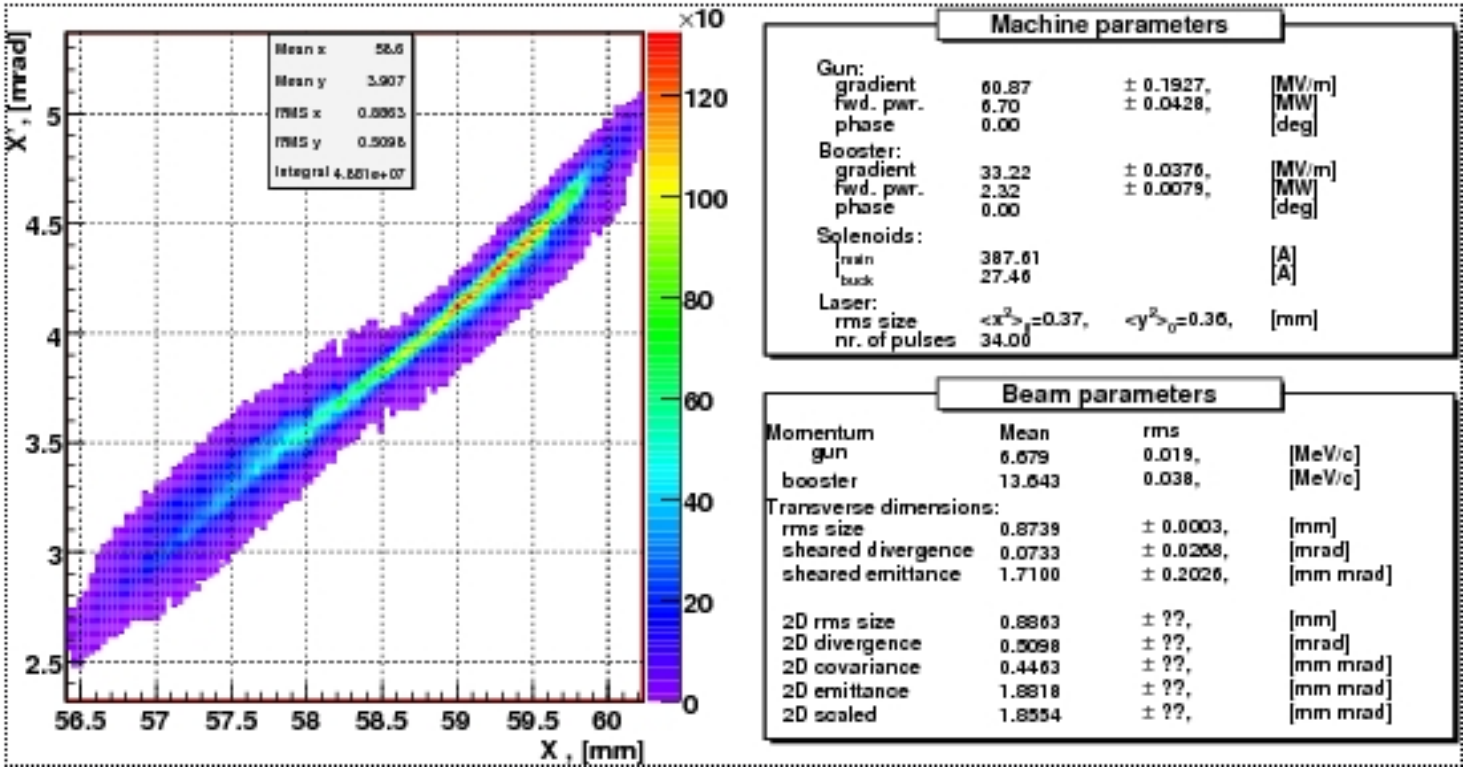




TRANSVERSE EMITTANCE DEFINITION

- **Normalized transverse projected emittance**

$$\varepsilon_{rms} = \beta\gamma \sqrt{\overline{x^2} \cdot \overline{x'^2} - \overline{x \cdot x'}^2}$$



Machine parameters

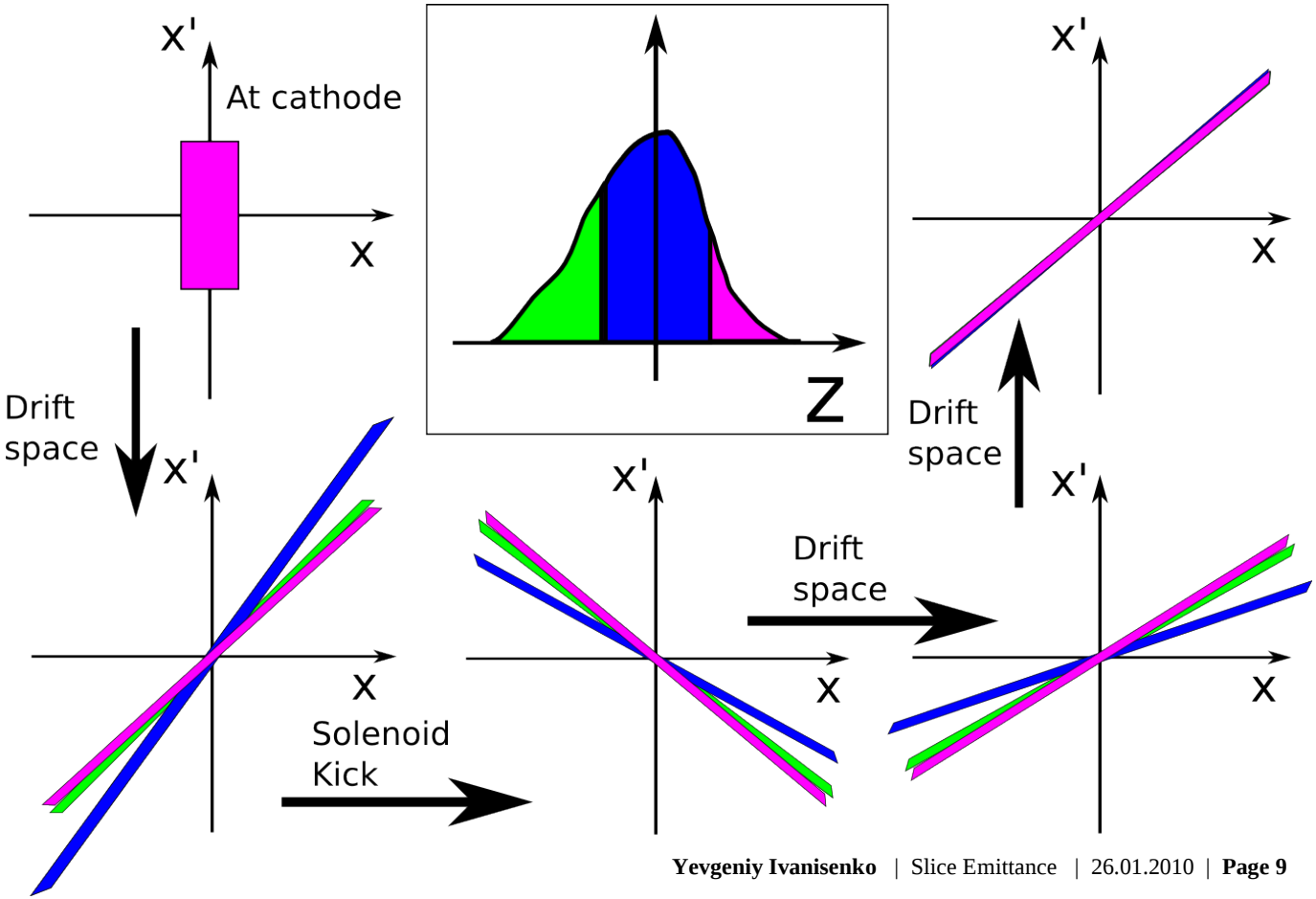
Gun:			
gradient	60.87	± 0.1927,	[MV/m]
fwd. pwr.	6.70	± 0.0428,	[MW]
phase	0.00		[deg]
Booster:			
gradient	33.22	± 0.0376,	[MV/m]
fwd. pwr.	2.32	± 0.0079,	[MW]
phase	0.00		[deg]
Solenoids:			
I_{main}	387.61		[A]
I_{buck}	27.46		[A]
Laser:			
rms size	$\langle x^2 \rangle_0$=0.37,	$\langle y^2 \rangle_0$=0.36,	[mm]
nr. of pulses	34.00		

Beam parameters

Momentum	Mean	rms	
gun	6.679	0.019,	[MeV/c]
booster	13.643	0.038,	[MeV/c]
Transverse dimensions:			
rms size	0.8739	± 0.0003,	[mm]
sheared divergence	0.0733	± 0.0268,	[mrad]
sheared emittance	1.7100	± 0.2026,	[mm mrad]
2D rms size	0.8863	± ??,	[mm]
2D divergence	0.5098	± ??,	[mrad]
2D covariance	0.4463	± ??,	[mm mrad]
2D emittance	1.8818	± ??,	[mm mrad]
2D scaled	1.8554	± ??,	[mm mrad]

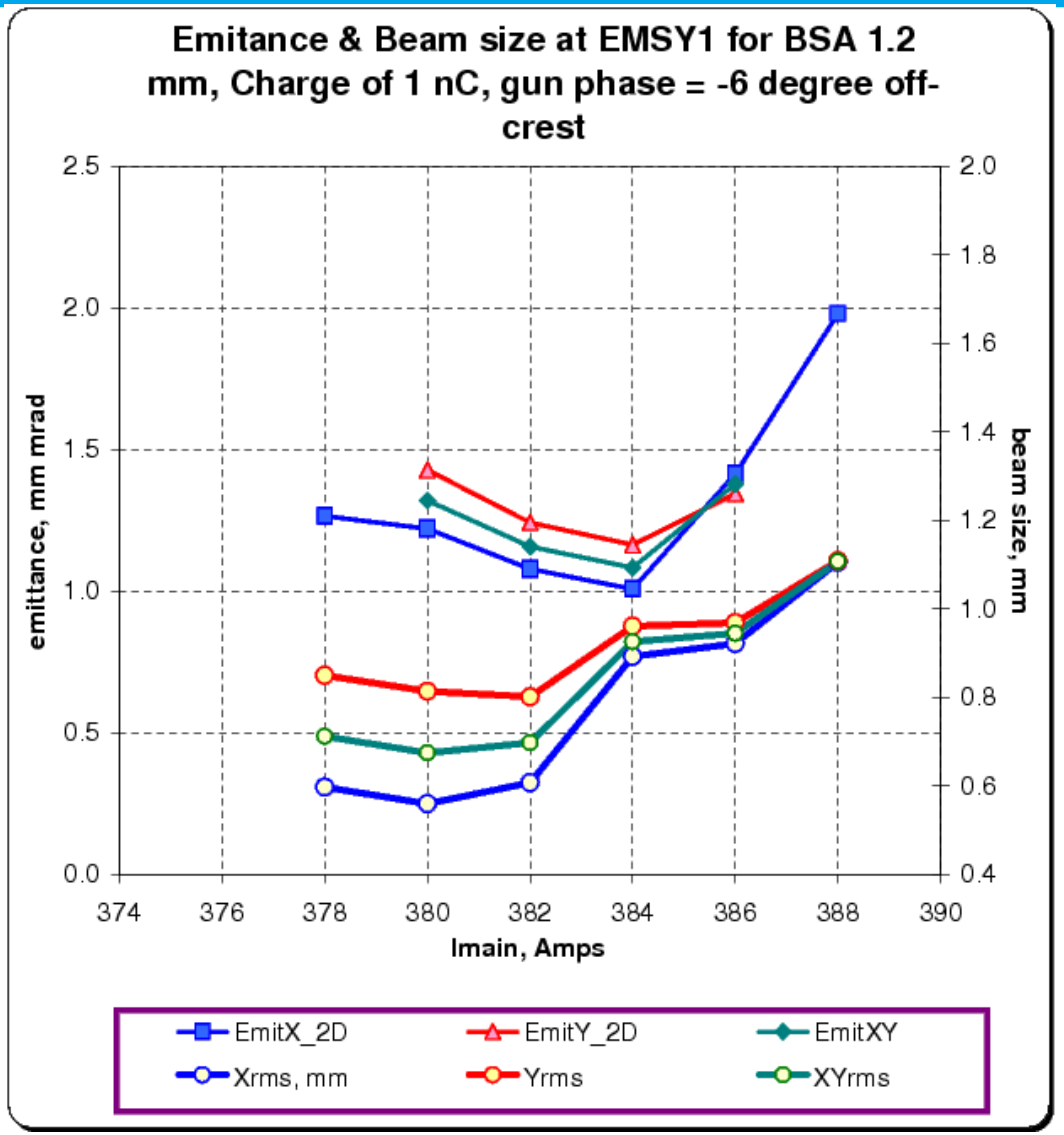
SOLENOID SCAN

- **Charge density changes along bunch. That leads to a twisting of the transverse phase space along z. 6D emittance does not change. Projected rms emittance increases.**



EXPERIMENTAL PROJECTED EMITTANCE RESULTS

- **Projected emittance VS main solenoid current at the position of EMSY1**

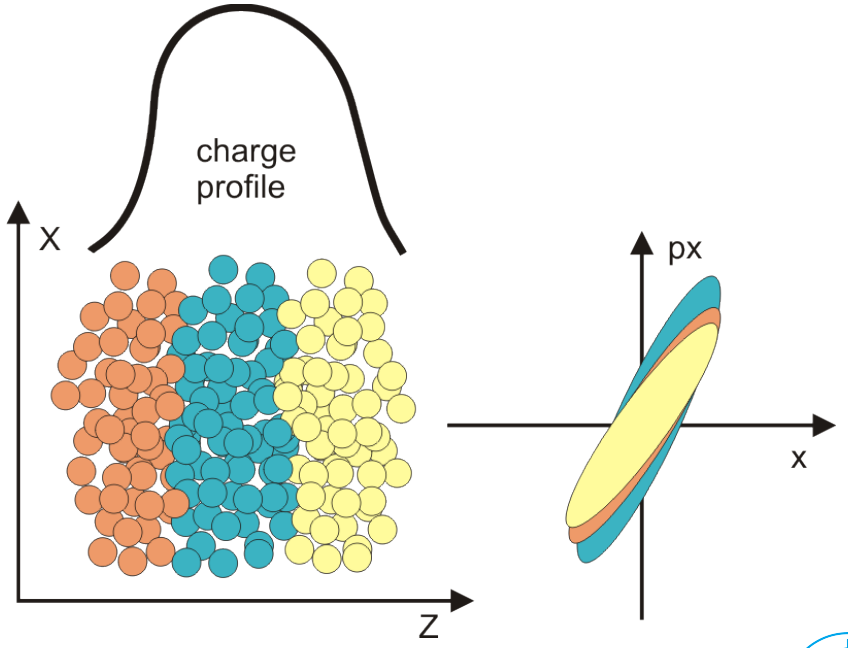


SLICE EMITTANCE

- **Slice emittance – transverse emittance of a longitudinal fraction of a bunch.**

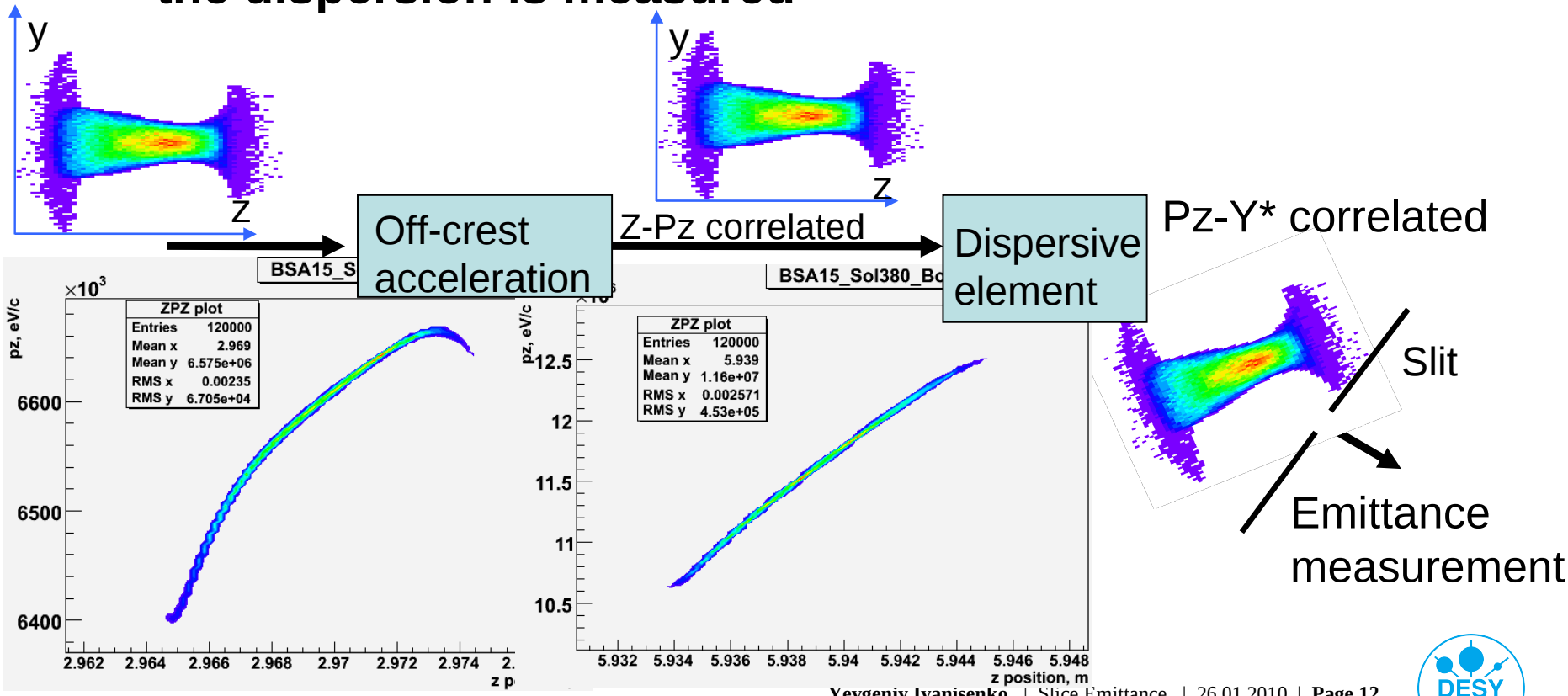
$$\varepsilon_{rms}(\Delta z) = \beta\gamma \sqrt{\overline{x(\Delta z)^2} \cdot \overline{x'(\Delta z)^2} - \overline{x(\Delta z) \cdot x'(\Delta z)}^2}$$

- **Average slice emittance <= Projected emittance**



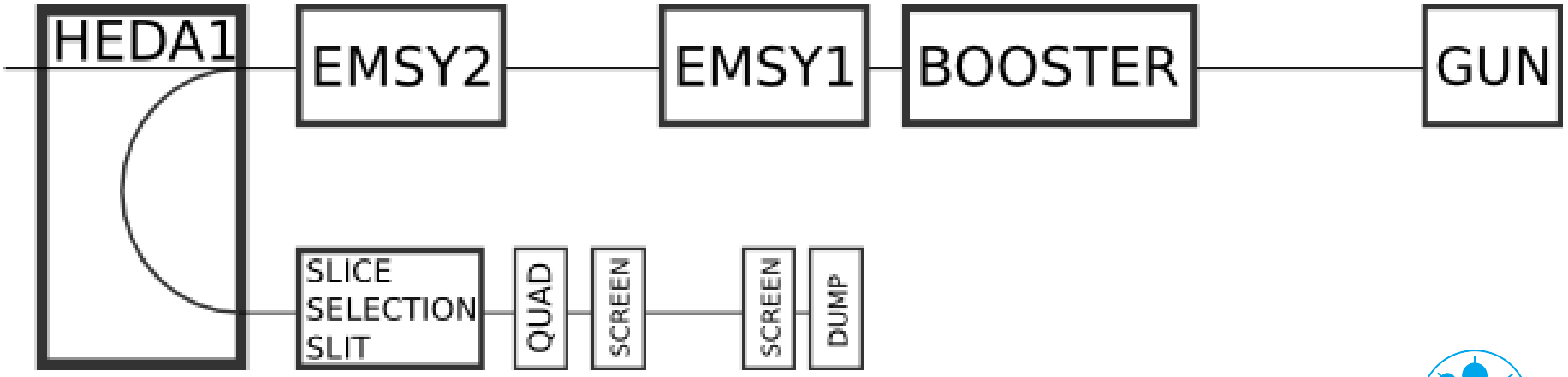
BEAM SLICING IN DISPERSIVE SECTION

- **Off-crest acceleration correlates Z to Pz**
- **Dispersive element converts the Pz distribution into a Y distribution**
- **Emittance of a bunch part that passes through the slit after the dispersion is measured**



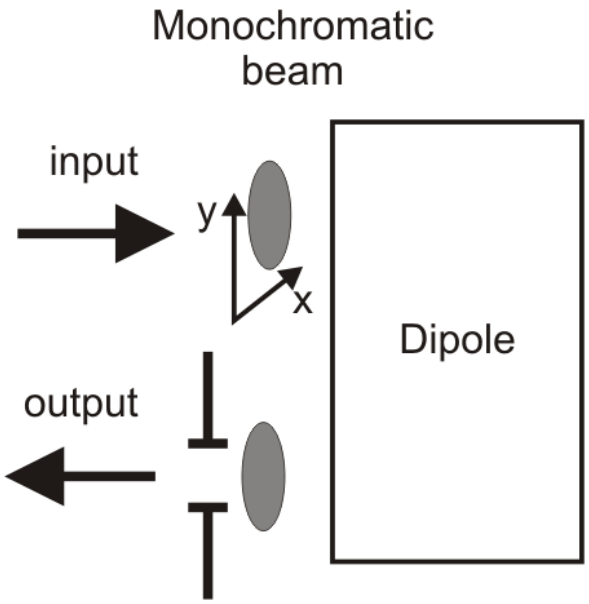
SLICE EMITTANCE SETUP AT PITZ

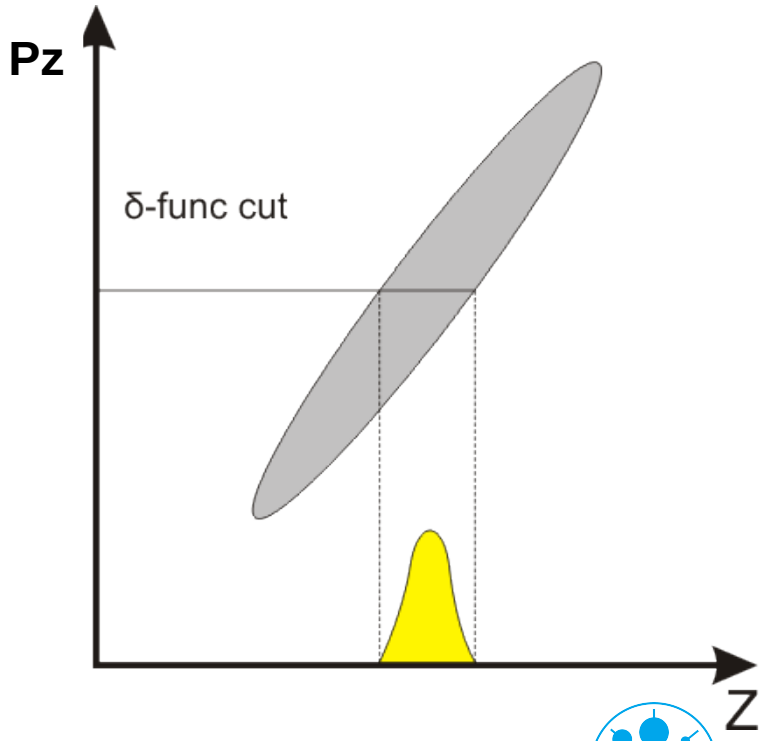
- Produce an electron bunch in the gun section
- Accelerate off-crest in the booster – introduce momentum-longitudinal position correlation.
- HEDA1 dipole converts the momentum distribution in a transverse distribution. A slit on the dipole output selects a part of the bunch along the dispersive direction.
- Transverse emittance of the bunch fraction is measured using the quad scan or the slit scan at EMSY2.



TEMPORAL RESOLUTION

- **Slicing procedure can be a part of the image processing. Temporal resolution is affected by**
  - **Phase off-crest**
  - **Infinitely narrow slice in momentum corresponds to a finite width longitudinal slice due to the local momentum spread.**
  - **Beam size at the dipole entrance**

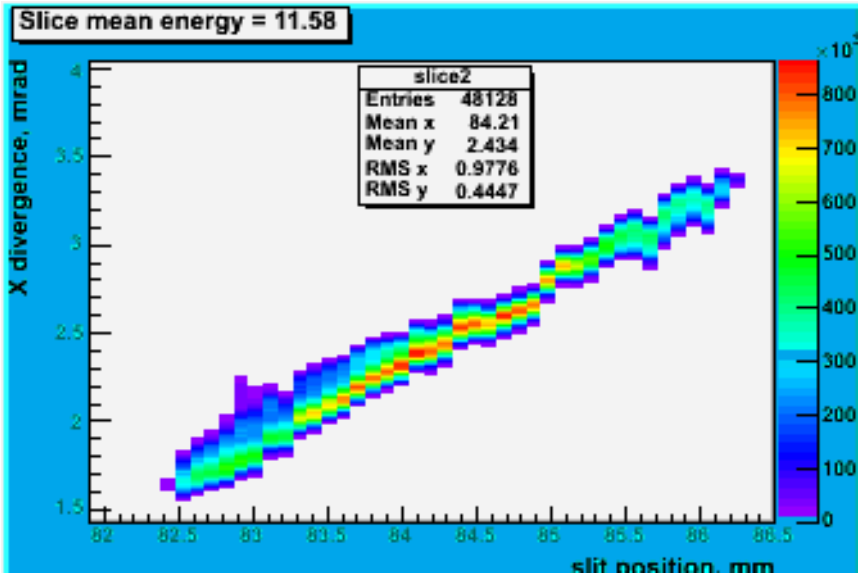




EMITTANCE MEASUREMENT PROCEDURE

Slit scan

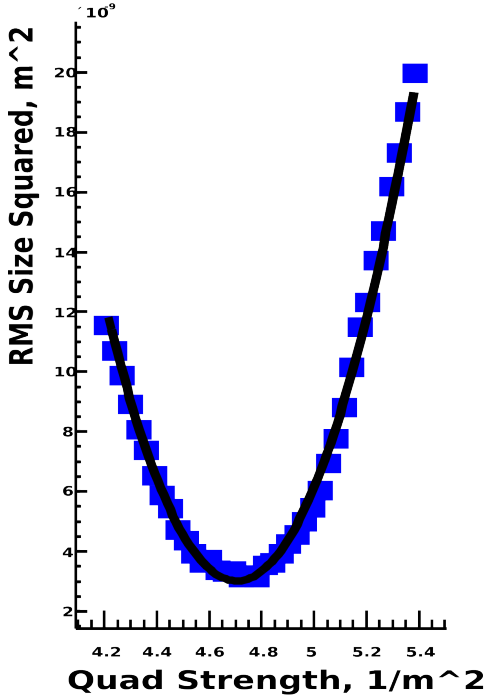
- Phase space distribution
- Low intensity, only multi-bunch measurements



Quad scan

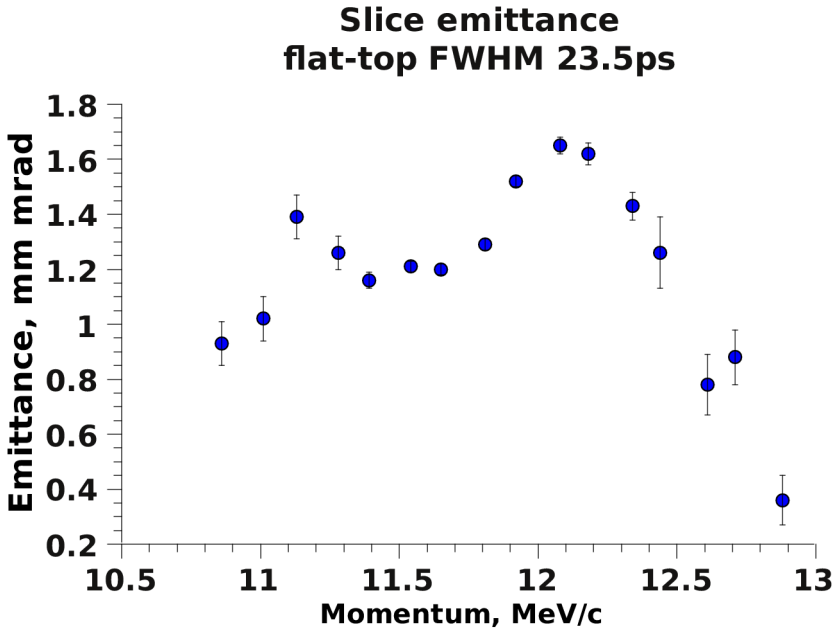
- Signal to noise is high, single bunch measurements
- The hardware has no sensitive mechanics

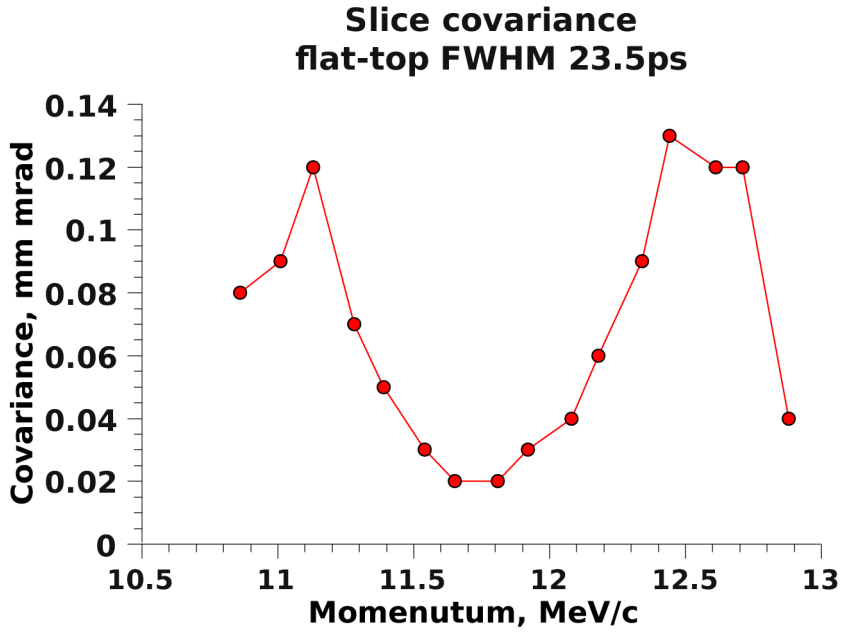
$\sigma_x, \sigma_{x'}, covariance_{xx'}$



RESULTS

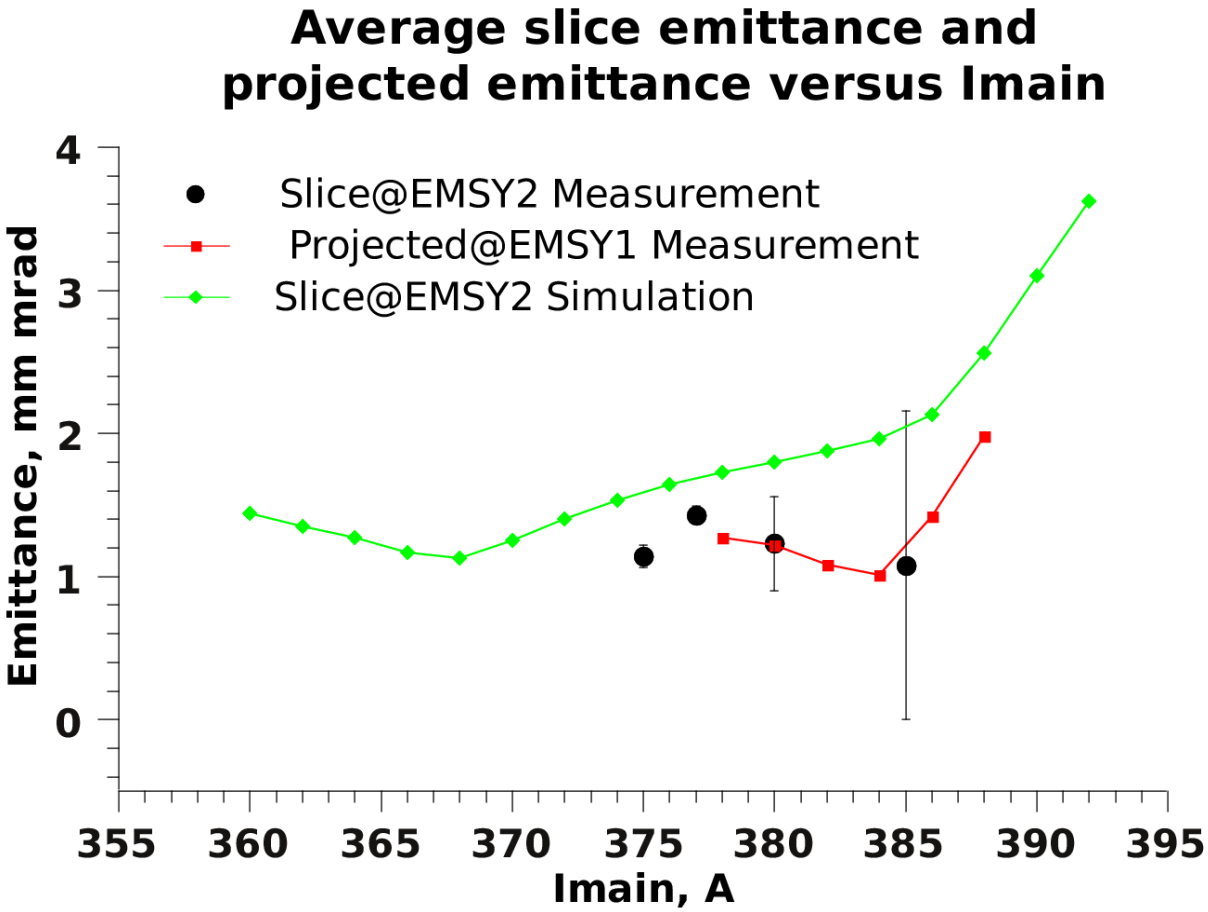
- **20090904**
  - Laser: Flat top FWHM=23.5ps, Laser spot diameter 1.5mm, 1nC
  - Booster phase = -50 deg off-crest
  - Slit scan, rms temporal resolution is 1ps
- **Error bars include only statistics over several frames taken**





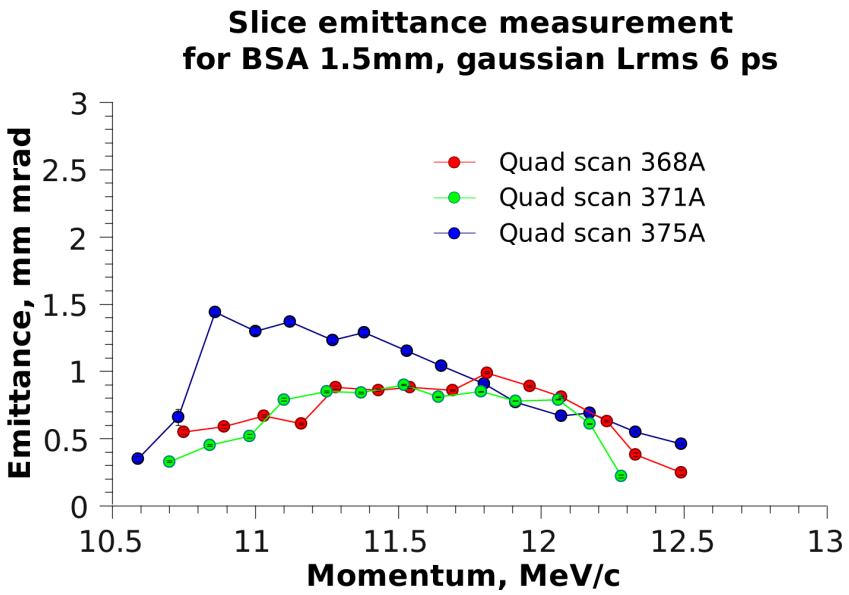
RESULTS OF SLIT SCAN

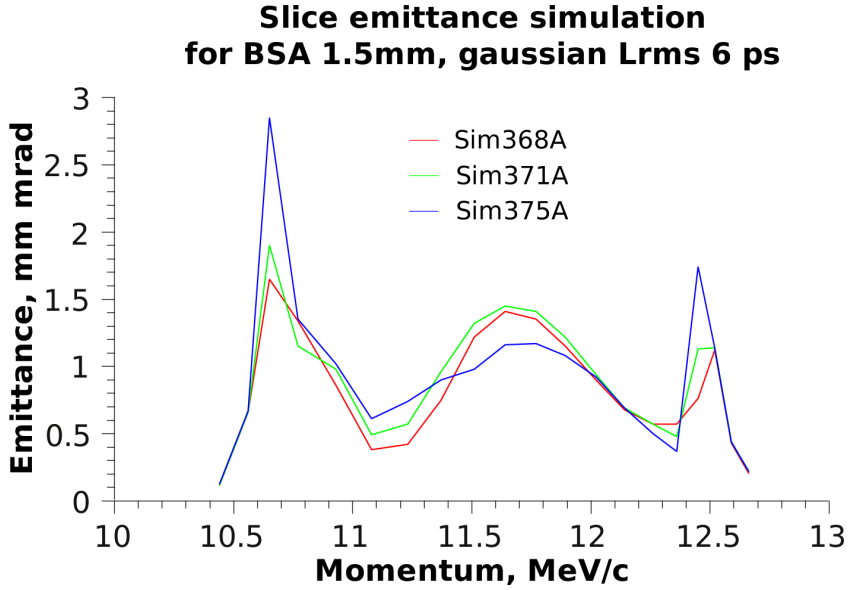
- **Simulation result compared to the slit scan slice emittance and projected emittance**



SICE EMITTANCE RESULTS

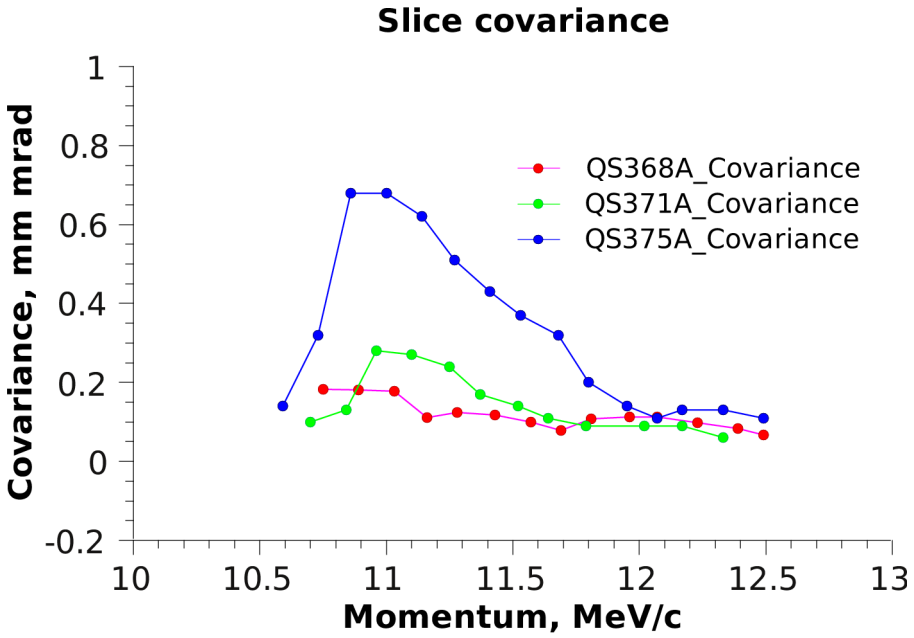
- **20091018**
  - **Laser: Gaussian Lrms=6ps, Laser spot diameter 1.5mm, 1nC**
  - **Booster phase = -50 deg off-crest**
  - **Quad scan, rms temporal resolution is 1ps**
- **Simulation represents sharp edge slicing . Slice width is 1ps.**

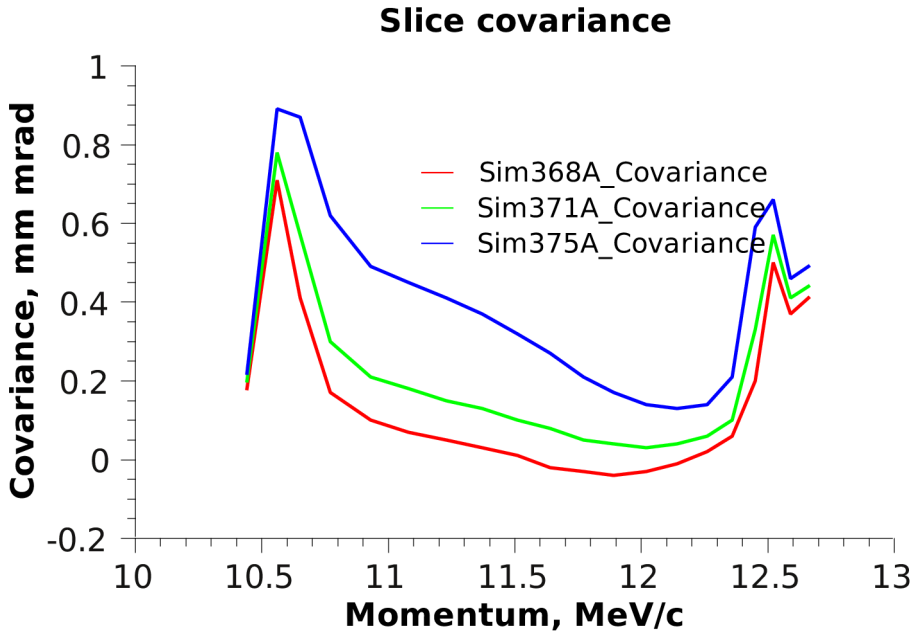




SLICE COVARIANCE

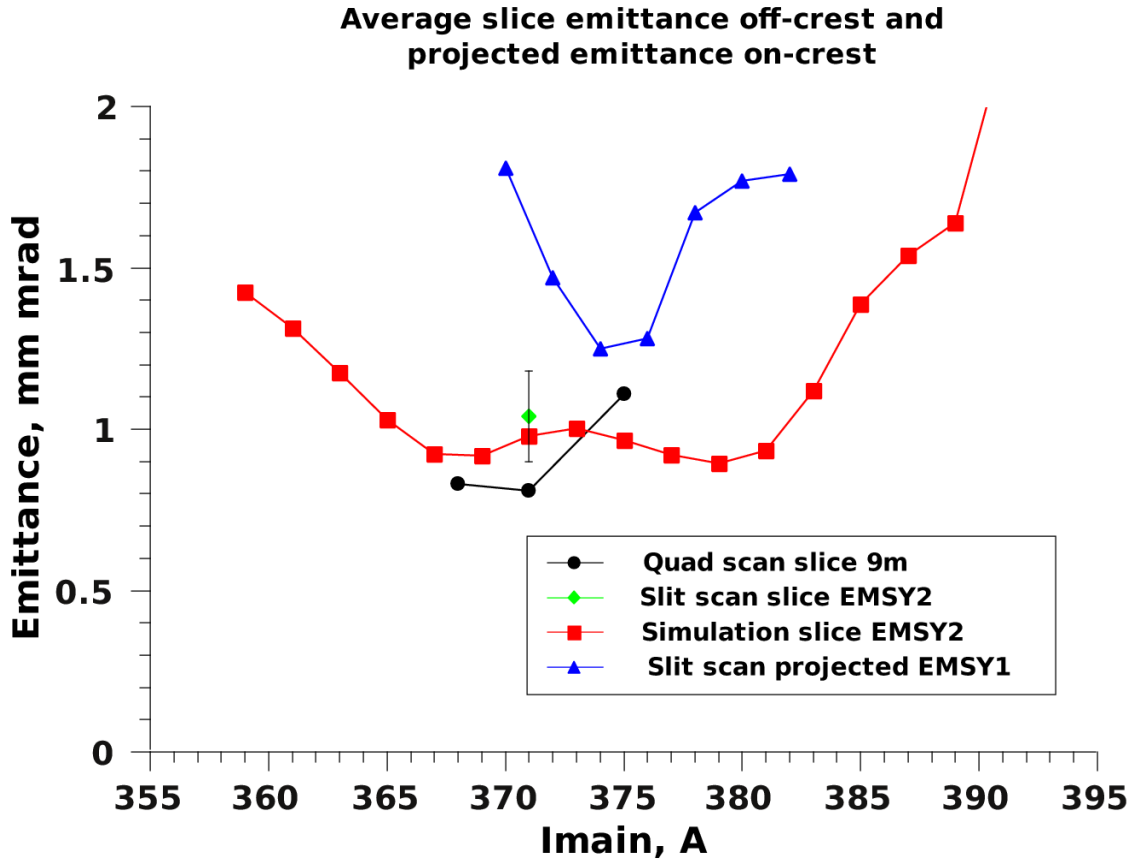
- **Covariance is a merit of slice phase space orientation**





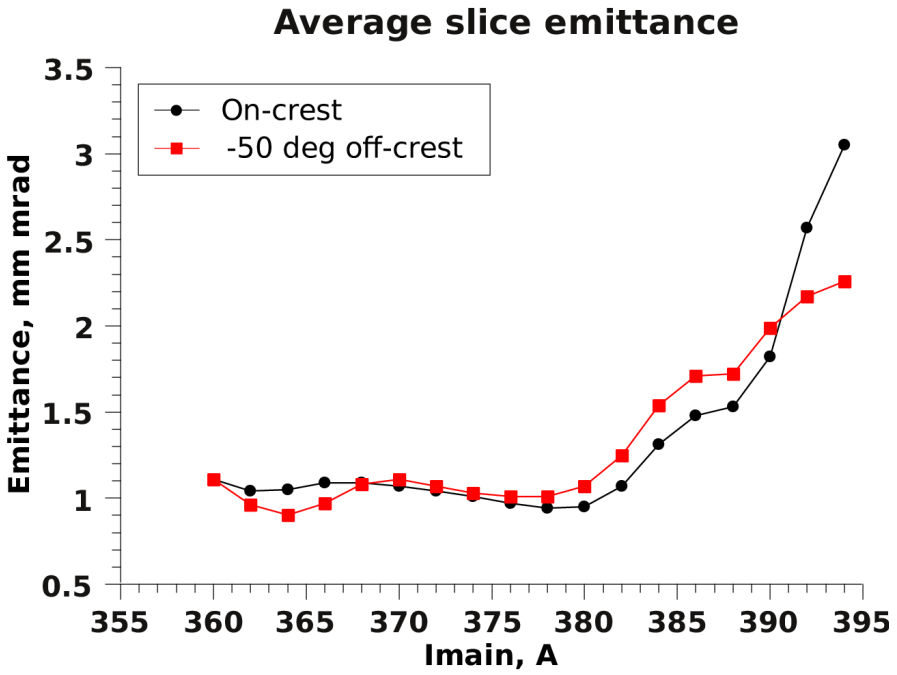
AVERAGE SLICE EMITTANCE

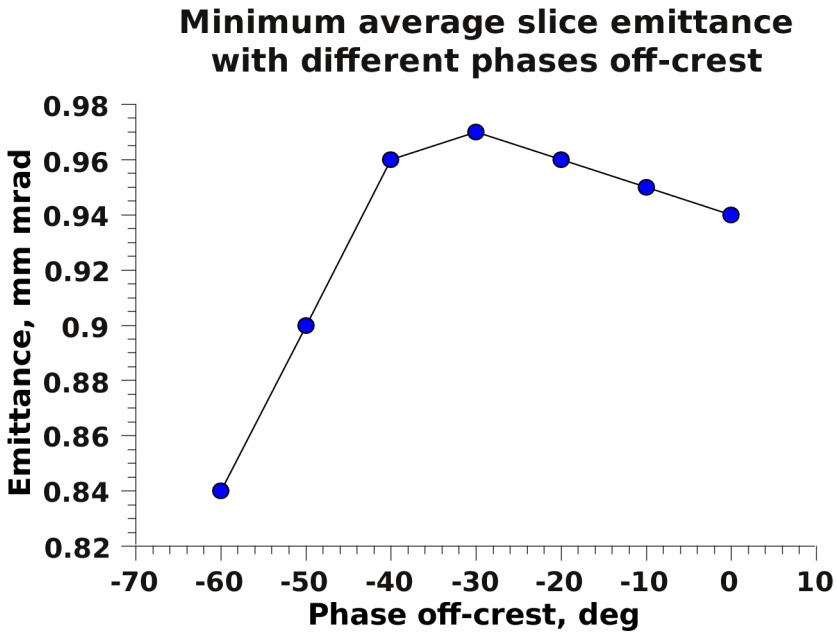
- **Summary plot of average slice emittance vs main solenoid current. As a reference the projected emittance curve is presented.**



OFF-CREST AND ON-CREST

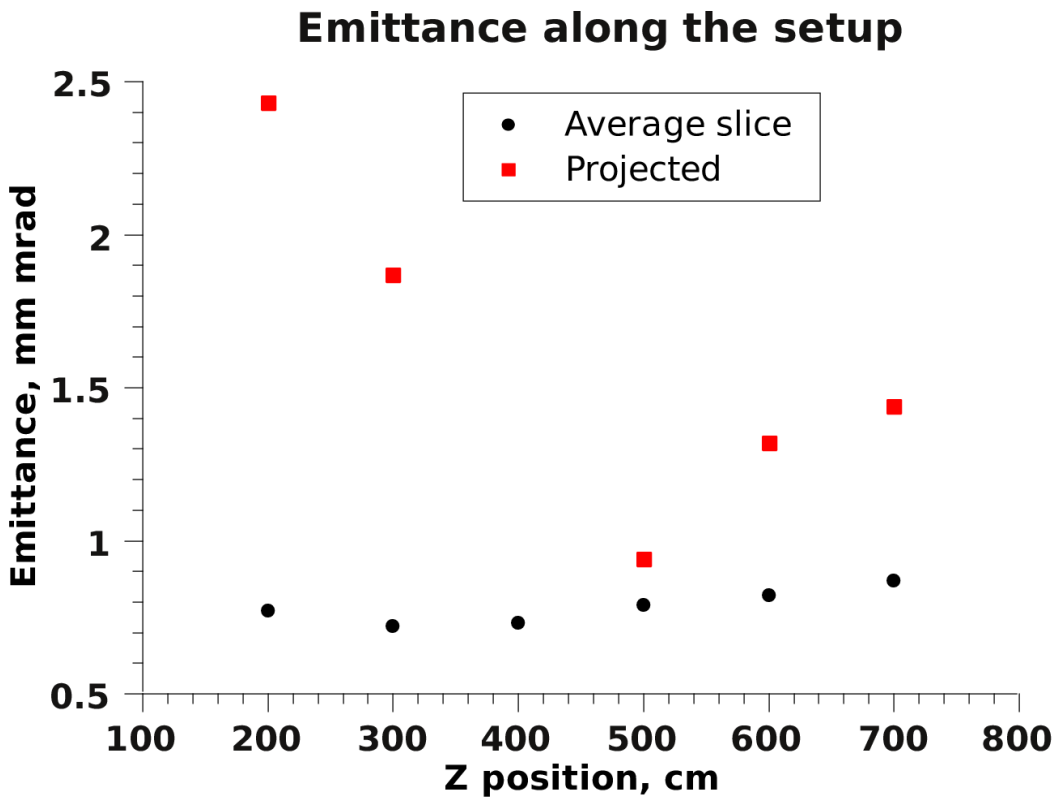
- What is different about average slice emittance value of a beam accelerated on-crest and off-crest?
- Simulation shows average slice emittance versus Imain for an on-crest and an off-crest beams





AVERAGE SLICE EMITTANCE VS PROJECTED EMITTANCE

- **Simulation describes how minimum average slice emittance and minimum projected emittance change along the setup downstream from the gun.**

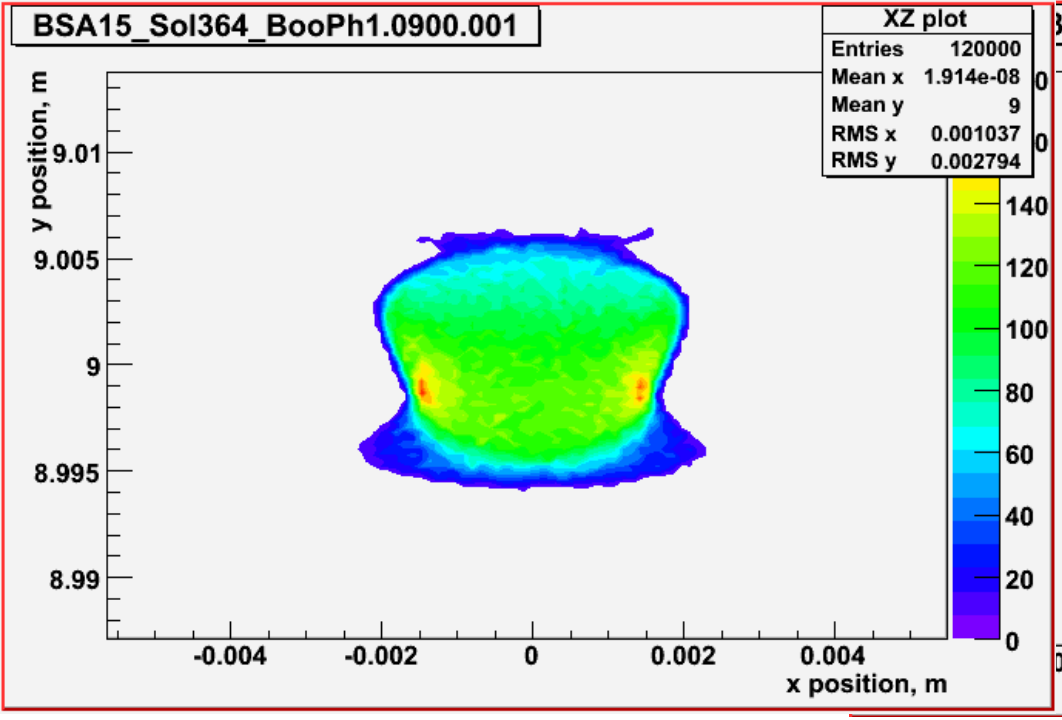


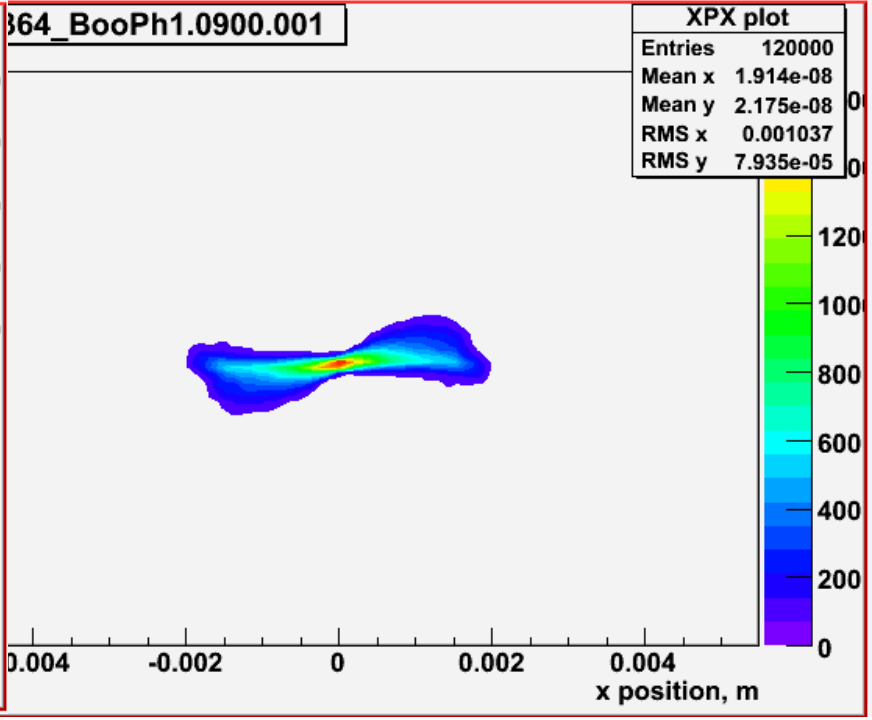
CONCLUSIONS

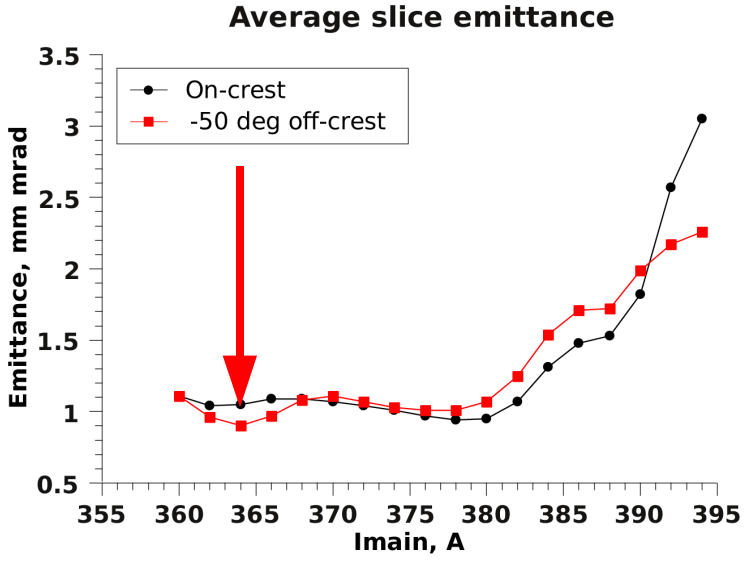
- The slice emittance diagnostics is in operation at PITZ
- Two emittance measurement methods are applied
  - Quad scan delivers higher signal to noise
  - Both methods are compared for consistency
- Two consistent data sets were taken and analyzed and have shown good consistency with simulations:
  - Flat-top laser pulse FWHM 23ps with the slit scan
  - Gaussian pulse sigma=6ps with the quad scan, and the slit scan for one solenoid current
- Slice emittance measurement can be correlated to the laser pulse structure. Momentum to time calibration can be done using a longitudinal phase space measurement in HEDA1
- Comparison of different laser pulse shapes with a help of the slice emittance diagnostics is less sensitive to the booster and measurement point position.
- Optimization criterion of minimum average slice emittance off-crest does not correspond to the optimized projected emittance on-crest. Nevertheless minimum average emittance can be considered as a merit of beam quality

PLANS FOR THE DIAGNOSTICS

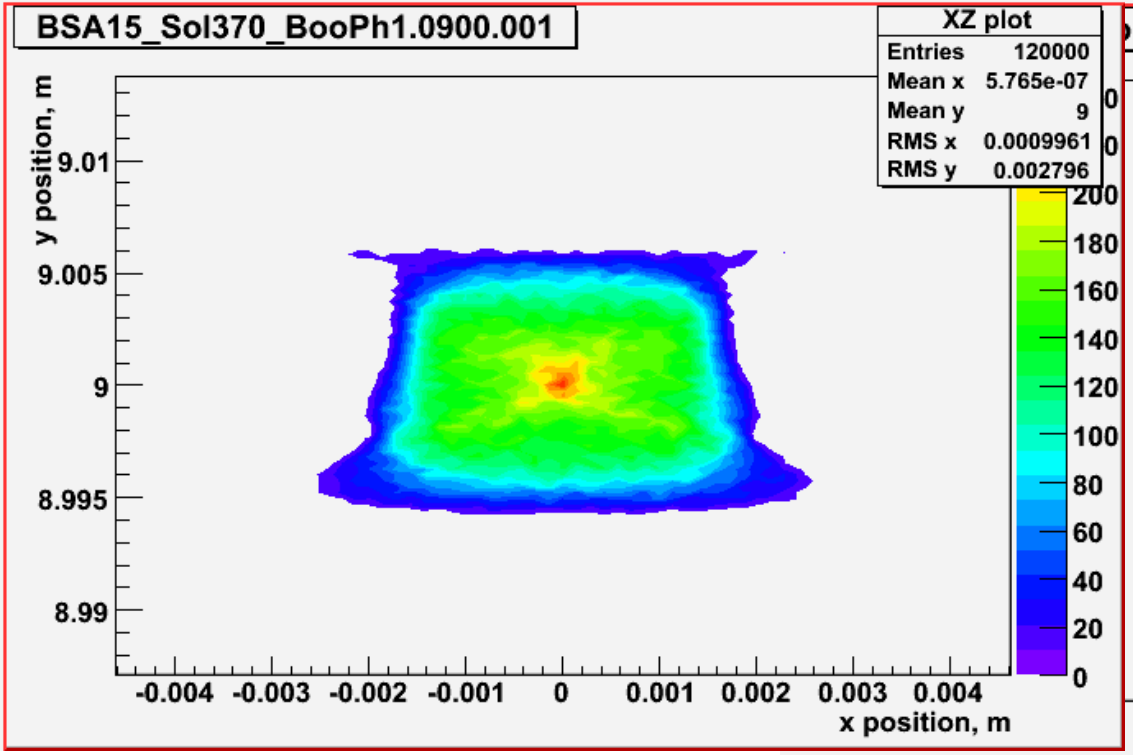
- **Different laser shapes**
  - Up to now quad scan only with long Gaussian
- **Thermal emittance**
  - It might allow measurements of thermal emittance with a long flat top laser pulse.
- **CDS Booster**
  - Higher energy gain
  - Stable operation

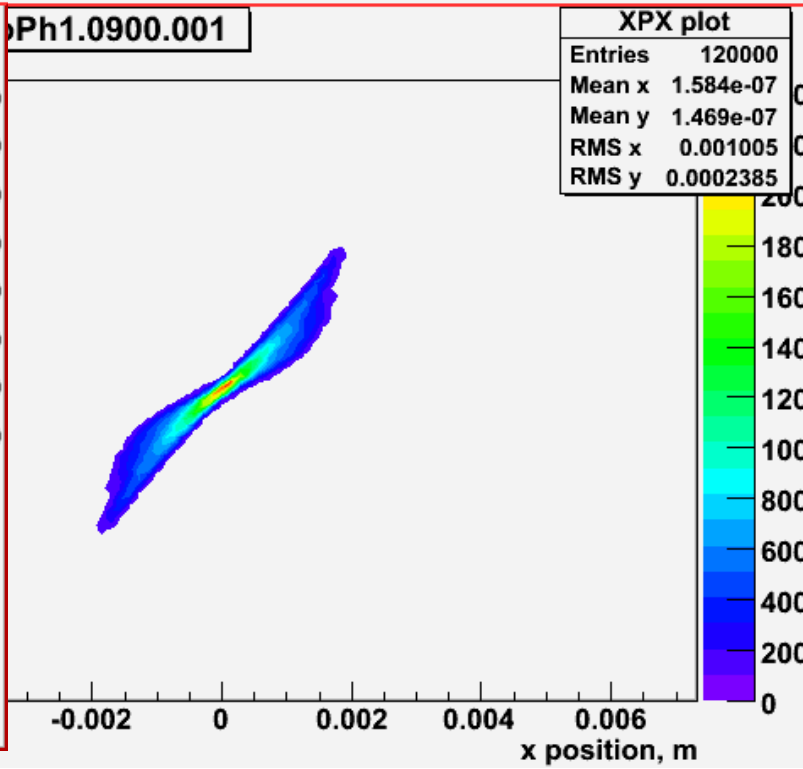

BSA15_Sol364_BooPh1.0900.001
XZ plot
Entries 120000
Mean x 1.914e-08
Mean y 9
RMS x 0.001037
RMS y 0.002794
y position, m
9.01
9.005
9
8.995
8.99
-0.004
-0.002
0
0.002
0.004
x position, m
140
120
100
80
60
40
20
0

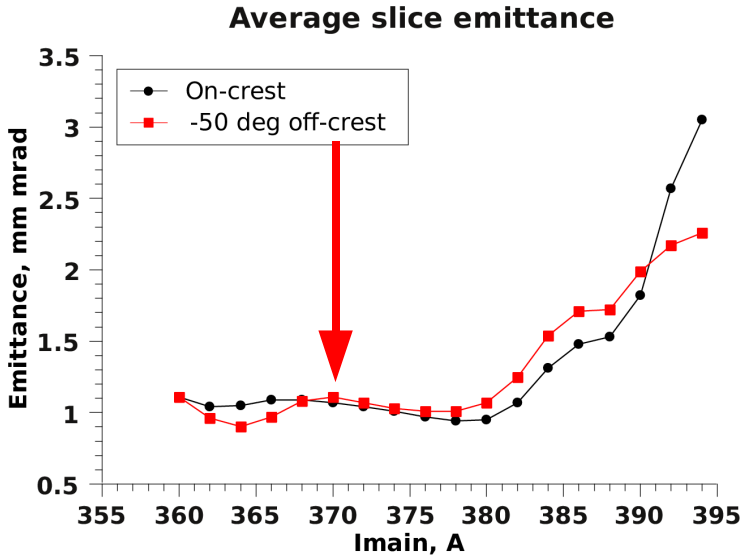

364_BooPh1.0900.001
XPX plot
Entries 120000
Mean x 1.914e-08
Mean y 2.175e-08
RMS x 0.001037
RMS y 7.935e-05
0.004
-0.002
0
0.002
0.004
x position, m
120
100
800
600
400
200
0


Average slice emittance
On-crest
-50 deg off-crest
Emittance, mm mrad
3.5
3
2.5
2
1.5
1
0.5
355
360
365
370
375
380
385
390
395
Imain, A

PITZ

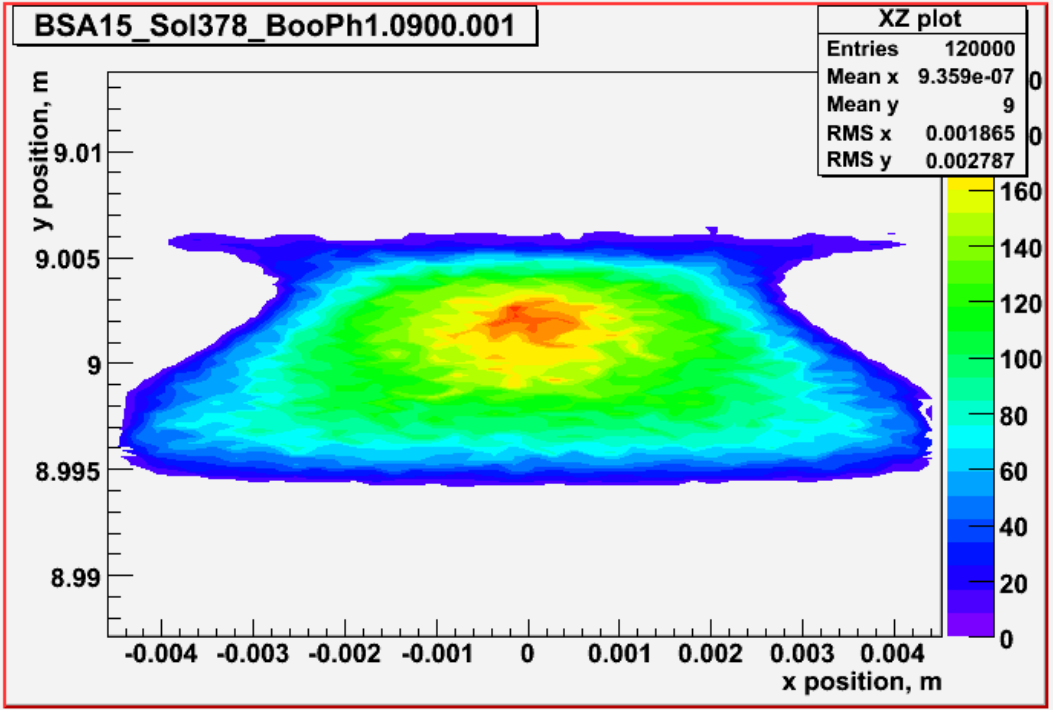


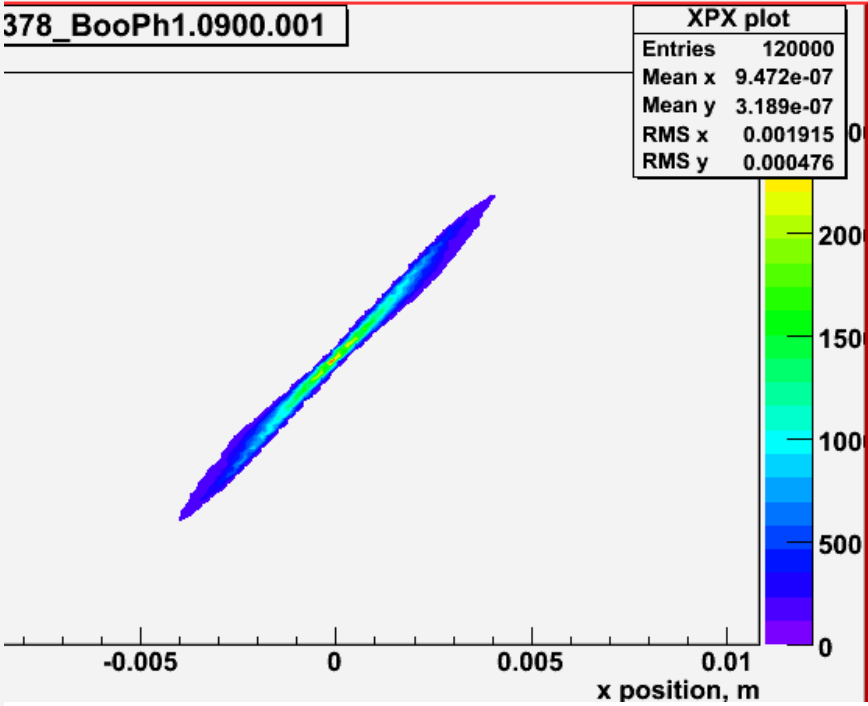


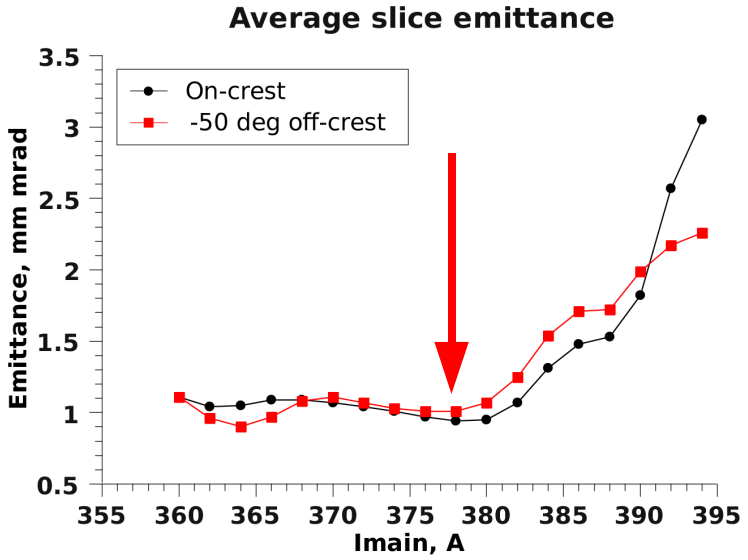


PITZ

Yevgeni


BSA15_Sol378_BooPh1.0900.001
XZ plot
Entries 120000
Mean x 9.359e-07
Mean y 9
RMS x 0.001865
RMS y 0.002787
y position, m
9.01
9.005
9
8.995
8.99
-0.004 -0.003 -0.002 -0.001 0 0.001 0.002 0.003 0.004
x position, m
160
140
120
100
80
60
40
20
0


378_BooPh1.0900.001
XPX plot
Entries 120000
Mean x 9.472e-07
Mean y 3.189e-07
RMS x 0.001915
RMS y 0.000476
-0.005 0 0.005 0.01
x position, m
200
150
100
500
0


Average slice emittance
On-crest
-50 deg off-crest
Emittance, mm mrad
3.5
3
2.5
2
1.5
1
0.5
355 360 365 370 375 380 385 390 395
Imain, A