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

Rehearsal

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HELMHOLTZ
ASSOCIATION

PITZ

DESY

TALK OUTLINE

- Introduction to PITZ
  - Photo injector characterization
  - PITZ diagnostics
- Projected and slice emittance
- Slice emittance diagnostics
- PITZ setup for slice emittance
- Results
- Conclusions

PHOTO INJECTOR TEST FACILITY IN ZEUTHEN

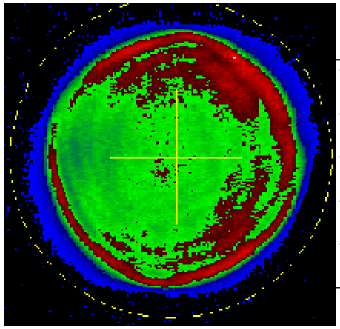
- High-brightness electron sources
  - Required for FEL
- Brightness is a density of charge in 6D (x,y,z,px,py,pz) phase space

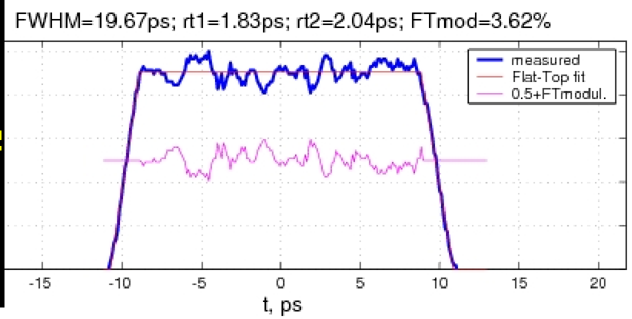
$$B = \frac{Q}{\varepsilon_x \varepsilon_y \varepsilon_z}$$

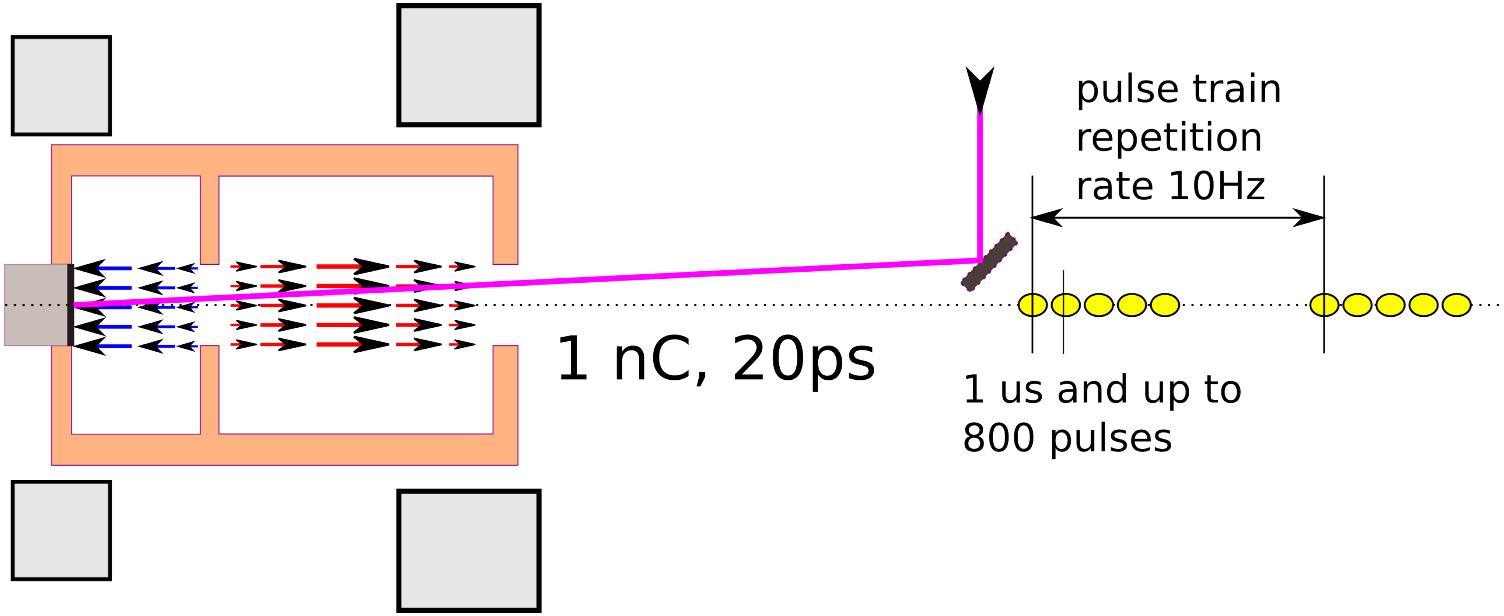
- PITZ optimizes the injector setup by minimizing transverse projected emittance.

PHOTO INJECTOR

- Cathode: Cs2Te
- Laser: λ=257.5nm, flat-top
- Gun: 1.6 cells cavity, 60 MV/m
- Focusing Solenoid

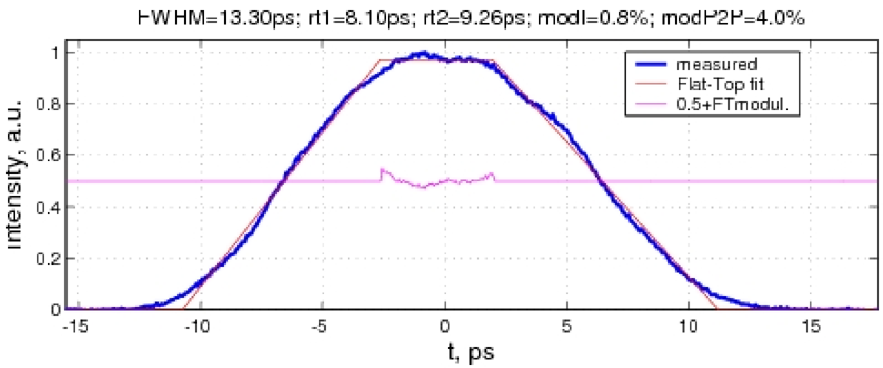


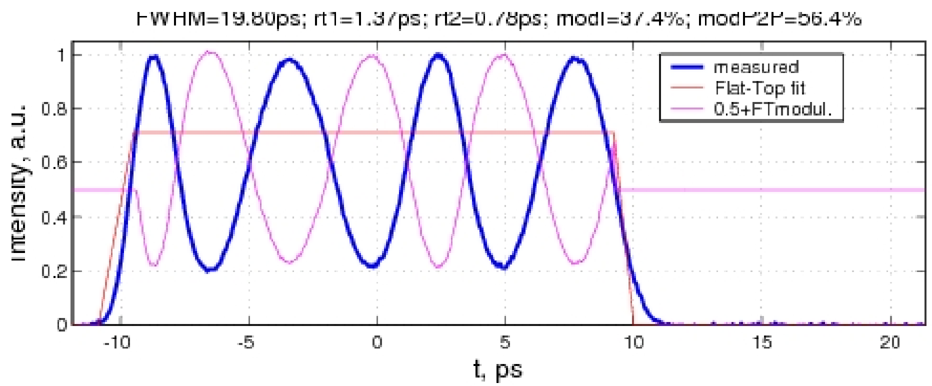


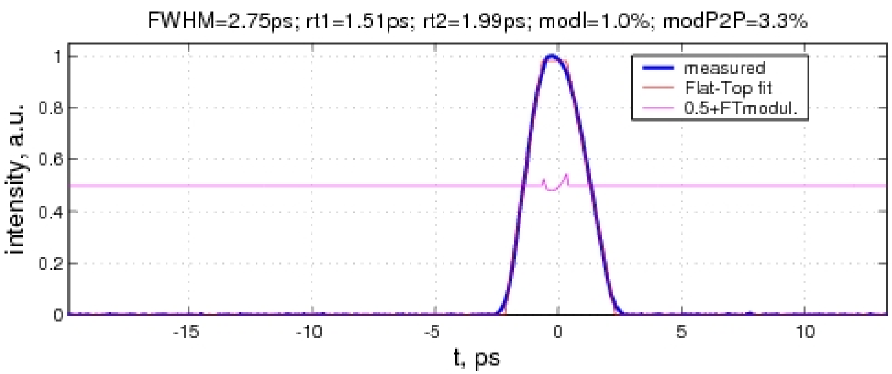


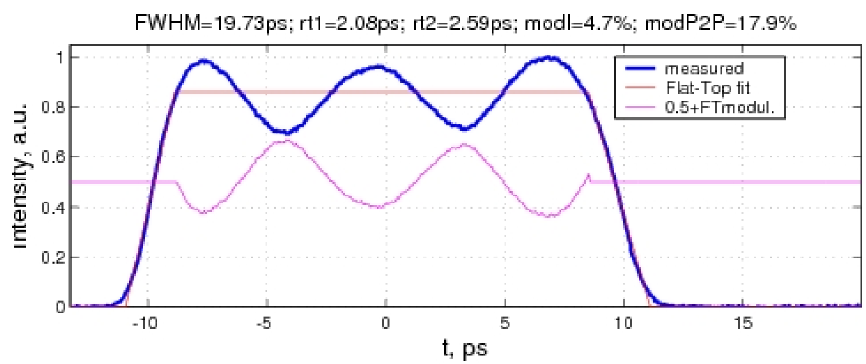
LASER SYSTEM

- The PITZ laser system can produce different longitudinal shapes
- Several transverse sizes of the laser spot on the cathode are realized with a beam shaping aperture.





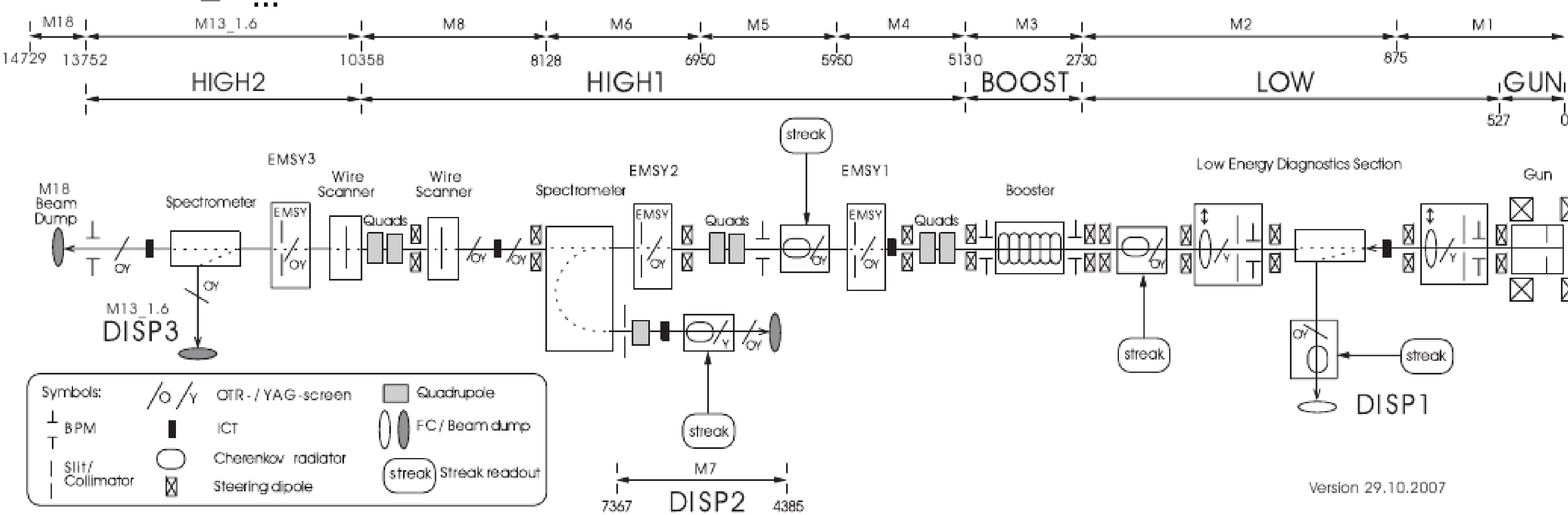




PITZ DIAGNOSTICS

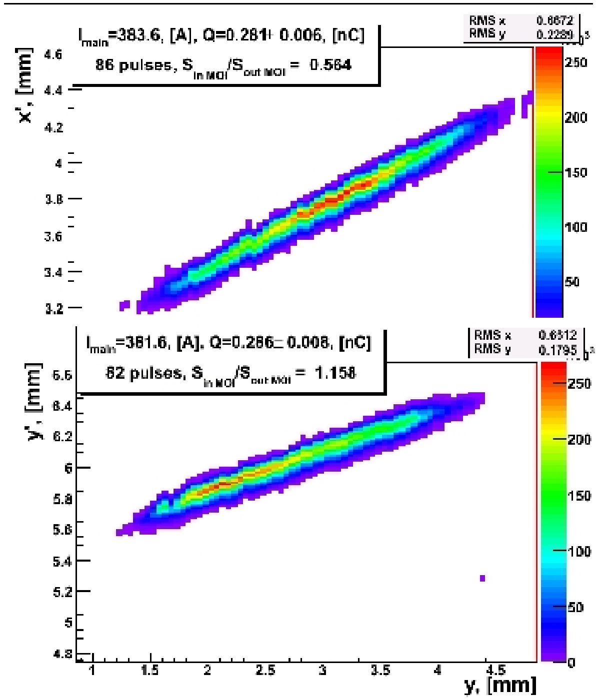
Beamline 1.7

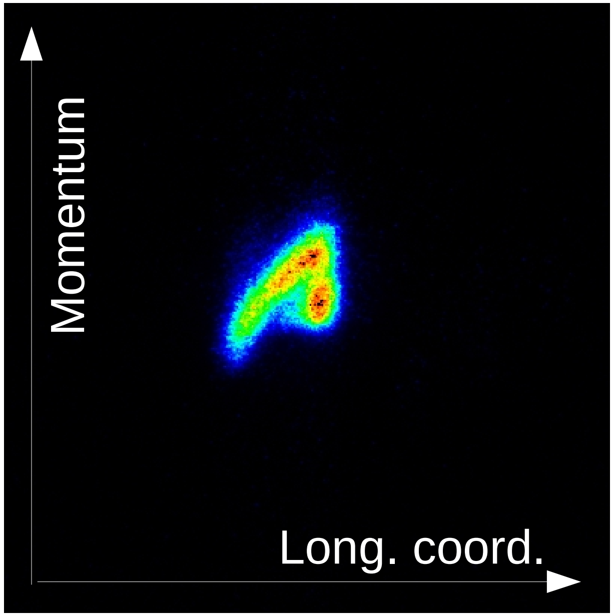
- Beam momentum distribution, bunch length
  - LEDA, HEDA1, Disp3
  - Streak readouts
- Beam trajectory, size, transverse emittance
  - Screen stations
  - EMSYs
  - Quads
- ...



BEAM PROPERTIES

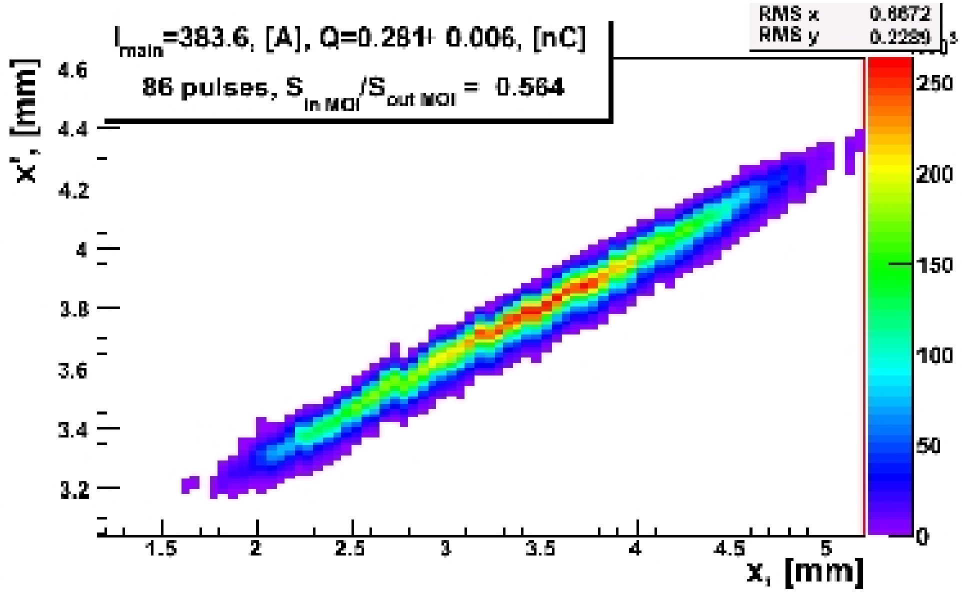
- The bunch evolution is determined by six initial parameters and the acting forces along the trajectory in six dimensional phase space.
- At PITZ
  - Longitudinal phase space: bunch length, momentum distribution
  - Transverse trace space: projected emittance is measured in two transverse planes independently.

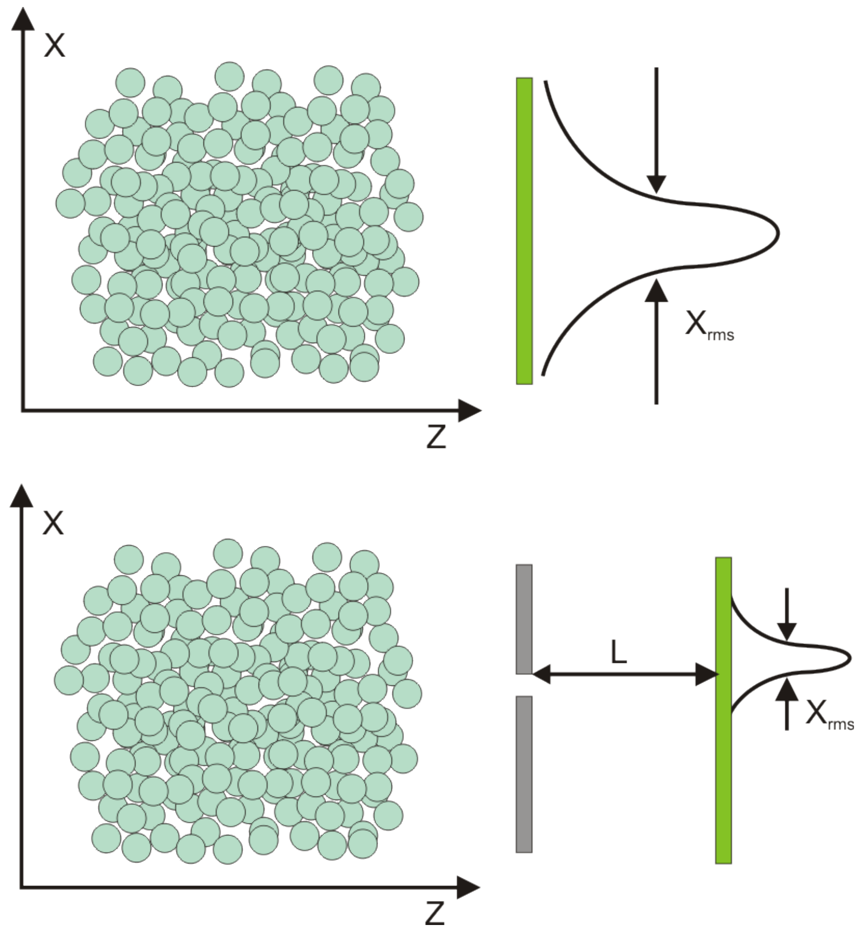




EMITTANCE MEASUREMENT SYSTEM

- EMSY – emittance measurement system:
  - Contains slit masks in both transverse plains
  - Slit position is scanned along the transverse beam size
- Projected emittance





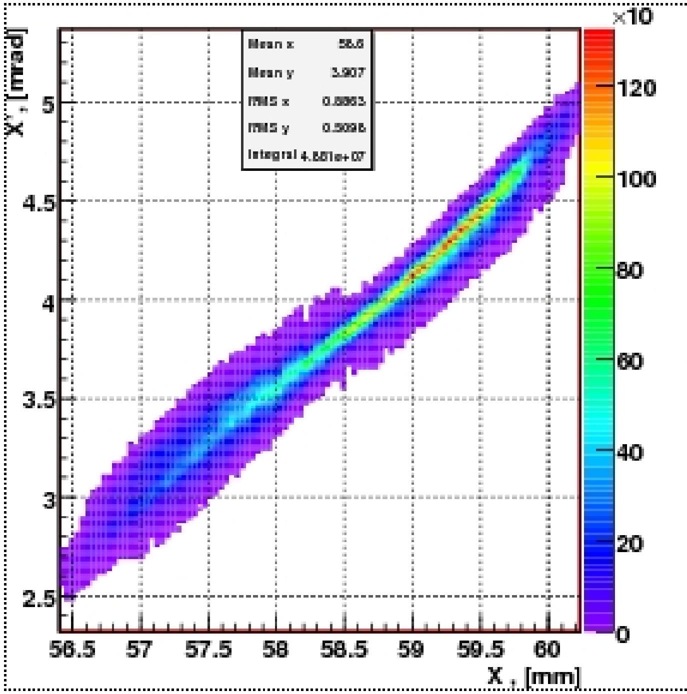
PITZ DESY

TRANSVERSE EMITTANCE DEFINITION

- Normalized transverse projected emittance

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

  - RMS volume
  - Trace space volume is obtained experimentally
  - Trace space emittance normalization is required to avoid beam energy influence on the emittance value



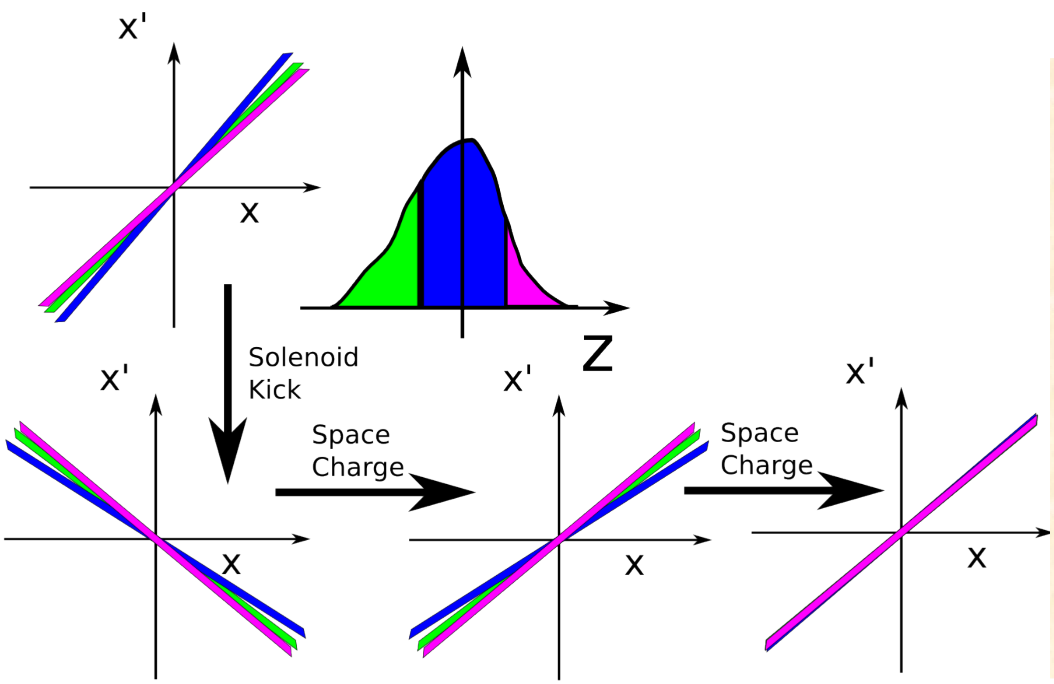
- Charge density changes along bunch. That leads to a twisting of the transverse phase space along z. 6D emittance does not change. Result of projected rms emittance measurement is changed.

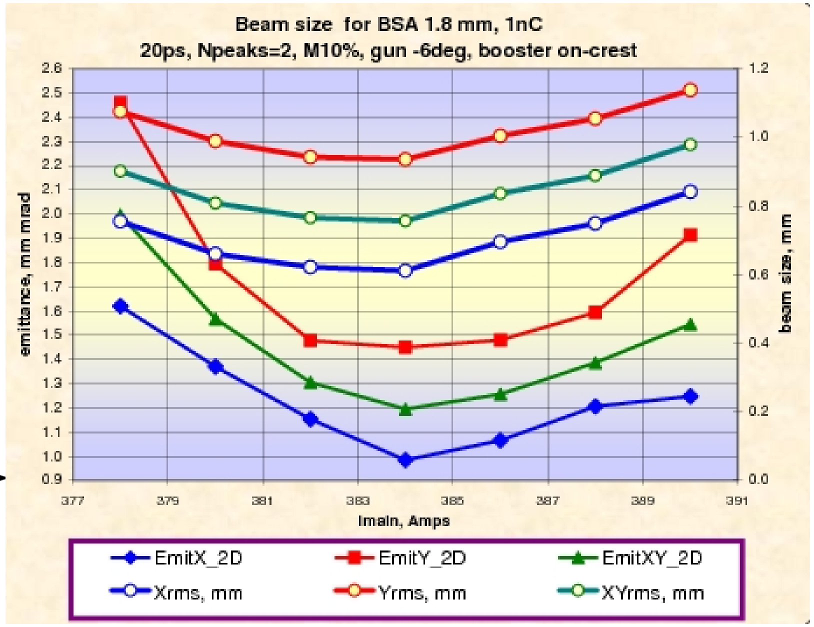
PITZ

DESY

SOLENOID SCAN

- The best emittance compensation can be found in the solenoid scan.
- Compensation has to occur at EMSY position. Min projected emittance value of degree of compensation depends on EMSY and the booster position relative to the gun.





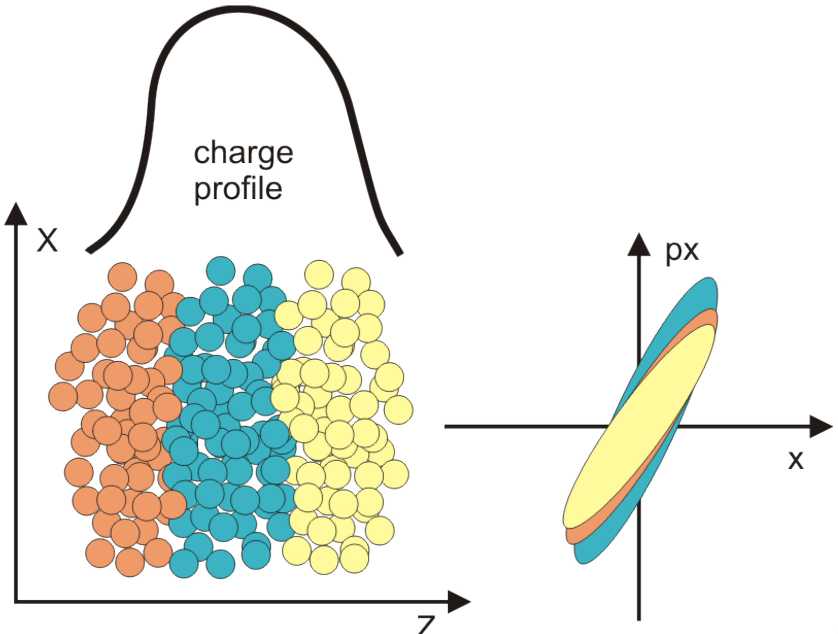
SLICE EMITTANCE

- Slice emittance – transverse emittance of a longitudinal charge 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

- Average slice emittance must be less sensitive to the measurement position and the position of the booster

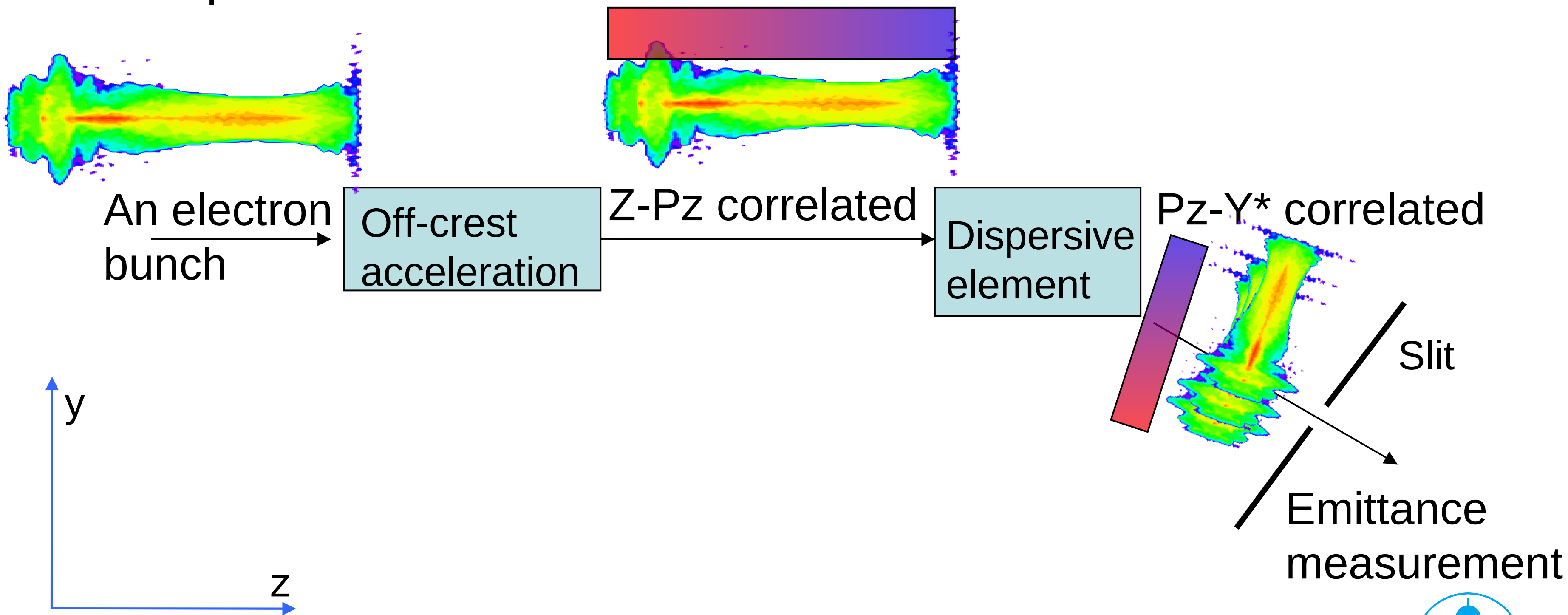


PITZ

DESY

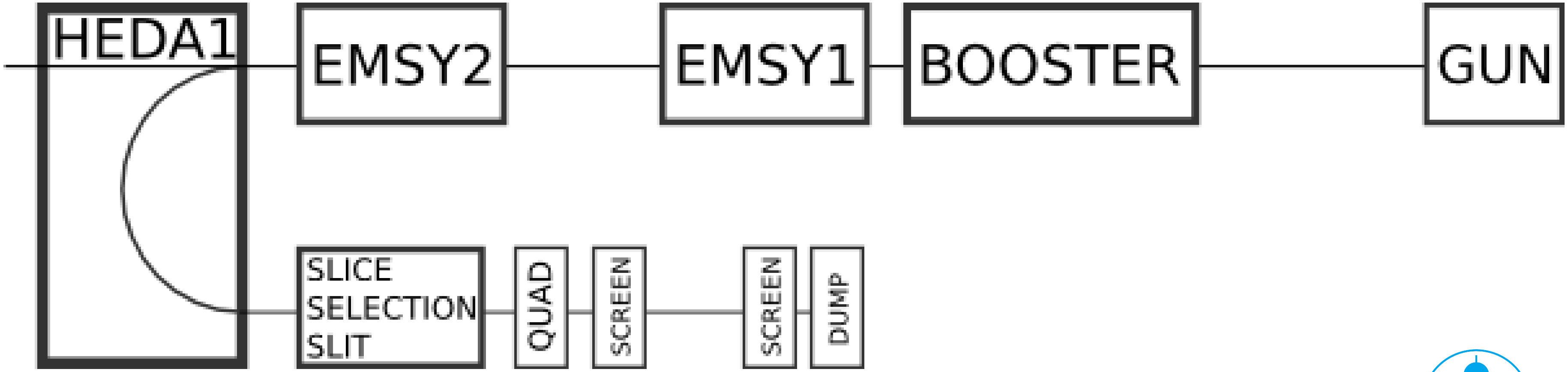
BEAM SLICING IN DISPERSIVE SECTION

- 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.



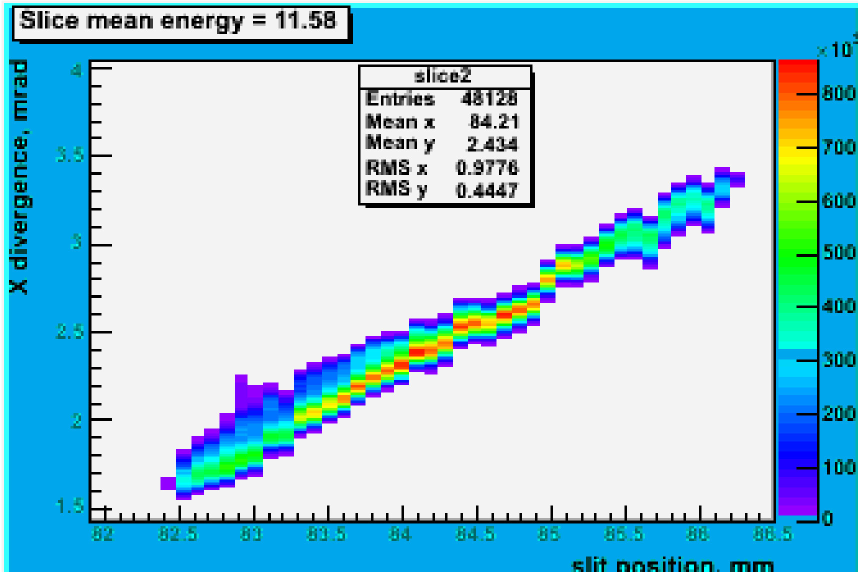
EMITTANCE MEASUREMENT PROCEDURE

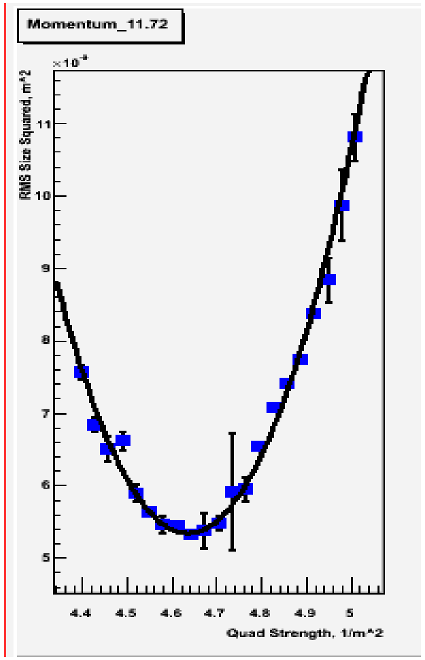
Slit scan

- Phase space distribution
- Low intensity, only multi-bunch measurements
- Does not need the slit for slicing: rms resolution (-50 deg) ~ 1ps

Quad scan

- Signal to noise is high, single bunch measurements
- The hardware has no sensitive mechanics
- Needs a slit for slicing: rms resolution(-50 deg) ~2ps



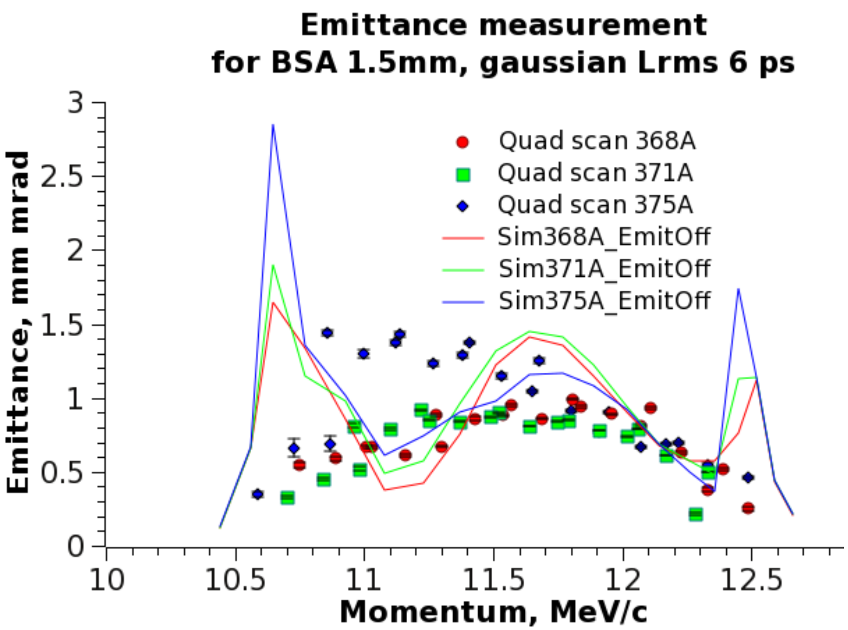


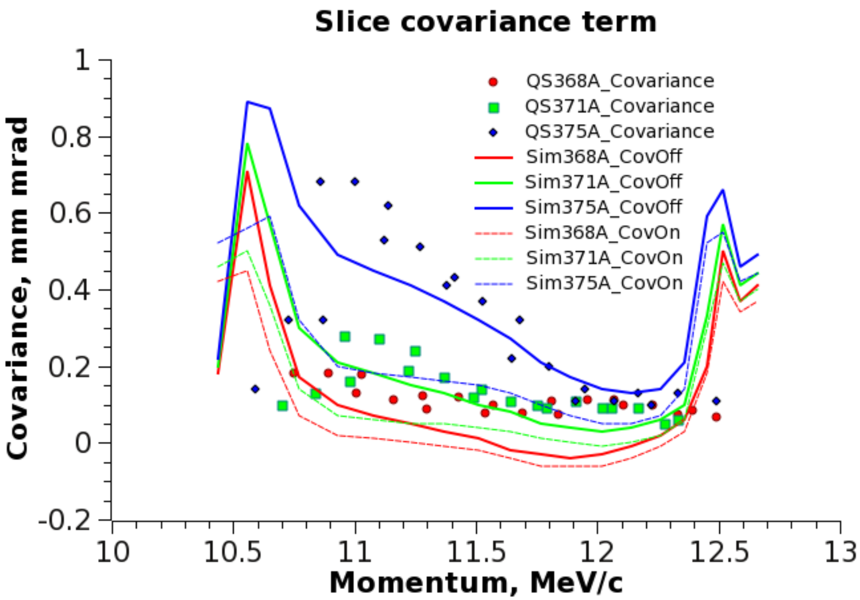
→ $\sigma_x, \sigma_{x'}$, $covariance_{xx'}$

PITZ DESY

MEASUREMENT RESULTS

- 20091018
  - Laser: Gaussian profile sigma=6ps, BSA 1.5mm
  - Booster -50 deg off-crest (1ps rms resolution)
- The “horns” might not be observed due to
  - Low intensity on the edges
  - Quad scan rms longitudinal resolution of 2ps



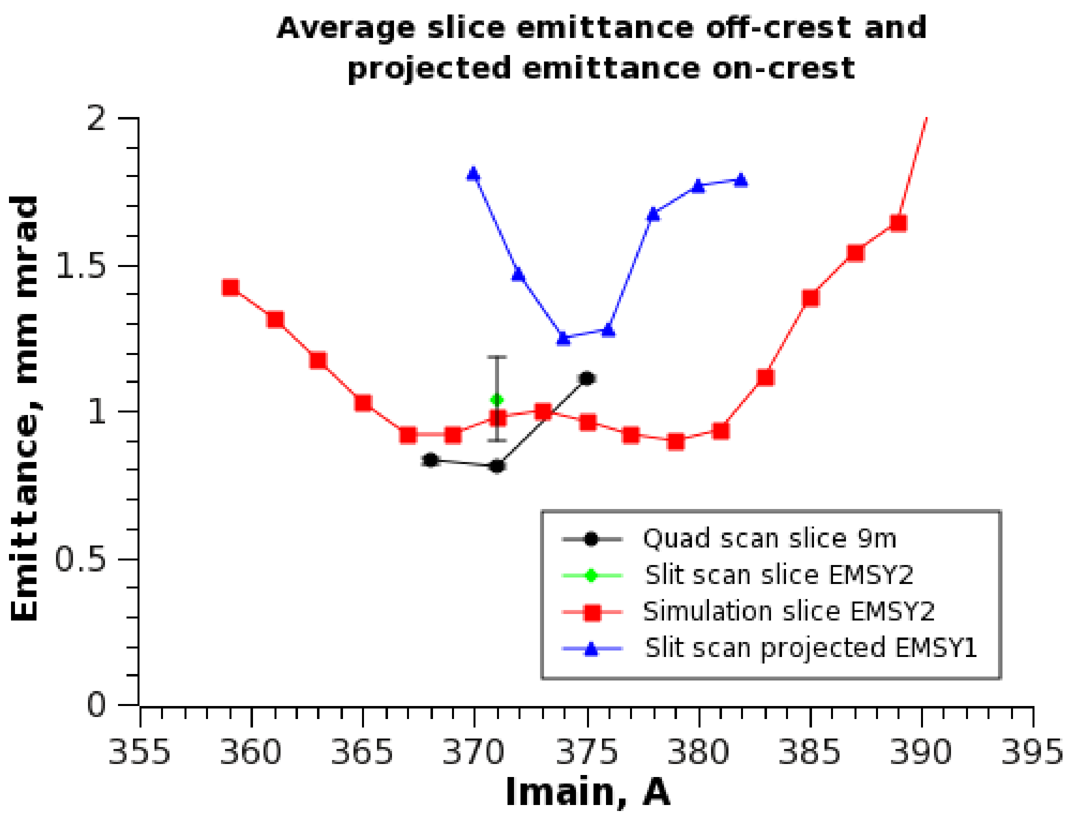


PITZ

DESY

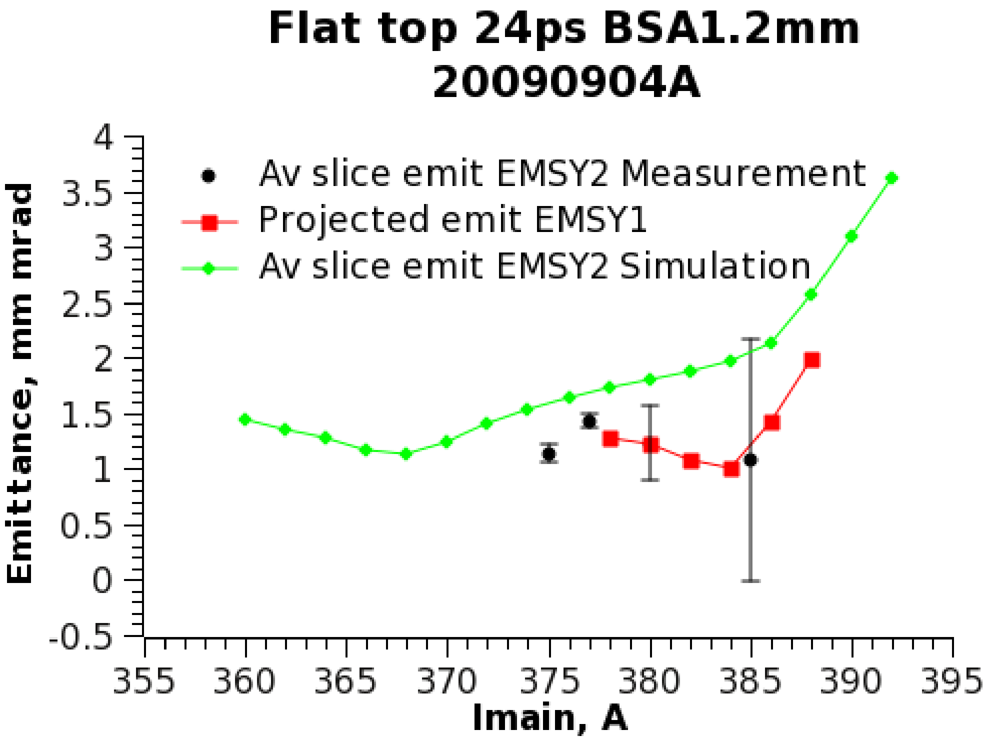
AVERAGE SLICE EMITTANCE

- The PITZ setup (elements position) is not optimized for projected emittance measurements of a relatively short gauss.
- Average slice emittance is less sensitive to the positioning of the booster cavity and EMSY



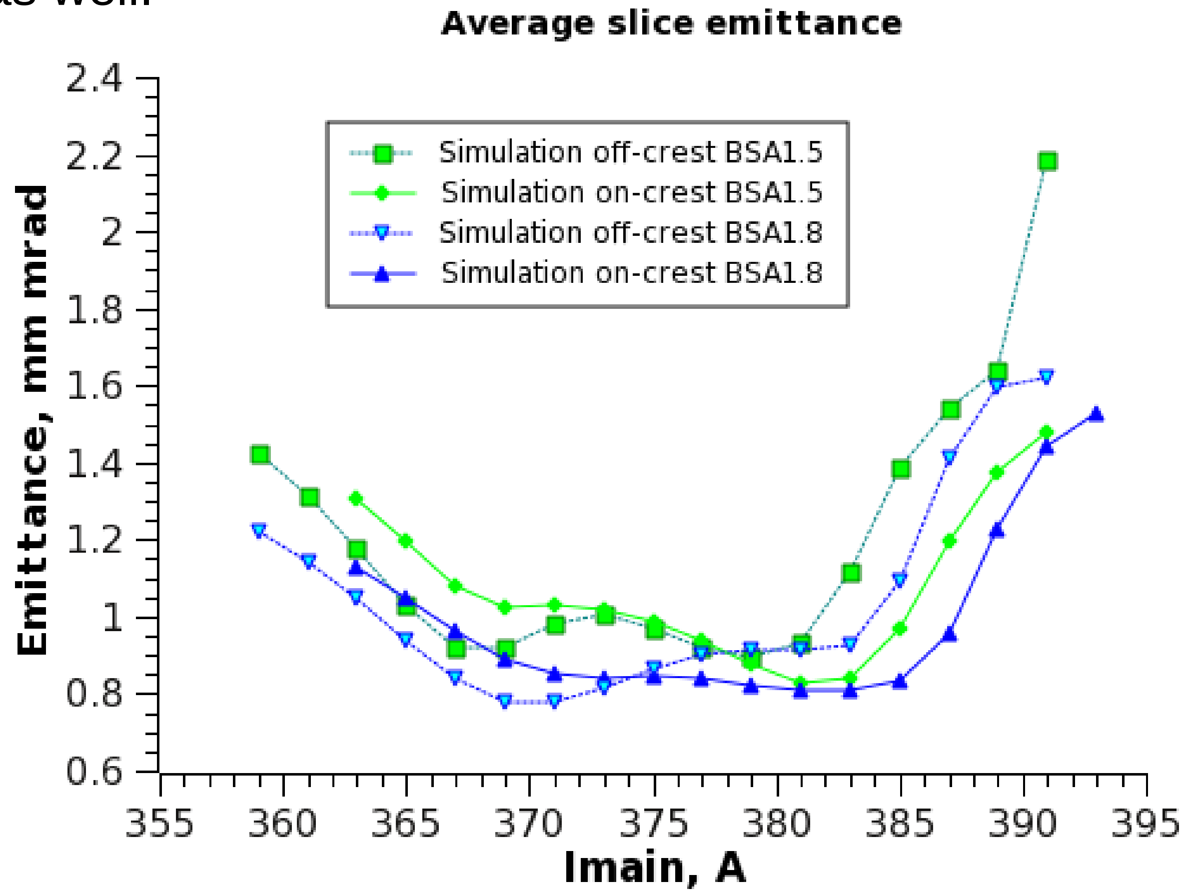
20090904

- Laser: Flat top FWHM=23ps, BSA 1.5mm
- Booster -50 deg off-crest



OFF-CREST AND ON-CREST

- Off-crest acceleration introduces linear twist of the phase space along z. This distortion of the phase space breaks a relation between projected and slice emittance optimization. The minimum slice emittance value is different as well.



CONCLUSIONS

- The slice emittance diagnostics is in operation at PITZ
- Two emittance measurement methods are applied
  - Quad scan delivers higher signal to noise
  - Slit scan has better temporal resolution at the same booster phase off-crest
- Two consistent data sets were taken and analyzed:
  - 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 EMSY and the booster position.
- Optimization criterion of minimum average slice emittance does not correspond to the optimized projected emittance on-crest.

PLANS FOR THE DIAGNOSTICS

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

THANK YOU FOR YOUR ATTENTION!

BEAM AT CATHODE

- Particles trace space just after emission. The trace space depends on cathode and laser properties.
- Free electrons experience
  - Accelerating longitudinal RF el. field
  - Focusing radial RF el field
  - Focusing mag field of the solenoid
  - Decelerating field of the mirror charge
  - radial defocussing space charge field
  - Longitudinal space charge suppression of the field gradient at the cathode .
- When the particles are accelerated
  - Space charge radial repulsion is reduces as $\frac{1}{\gamma^2}$

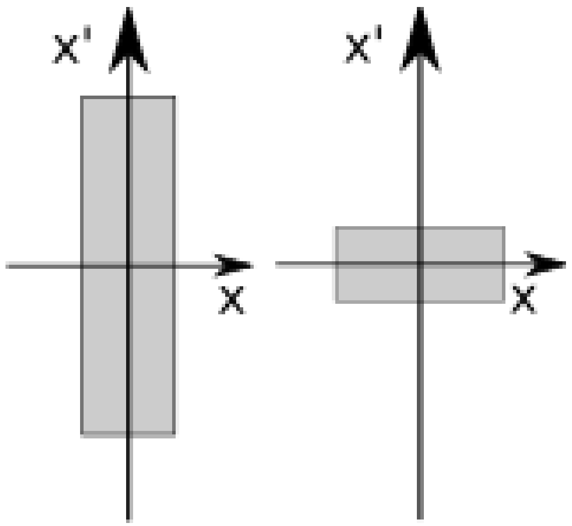


Photo cathode Thermo cathode

PITZ DESY

BEAM IN THE INJECTOR

- Linear transverse space charge effect can be compensated by proper solenoid focusing
- The beam is space charge dominated and in the focus point particles do not cross the beam axis, hence their trajectories are quasi laminar. This is position for the first accelerator module. After the energy boost the beam becomes emittance dominated.
- Space charge dominated beam introduces projected emittance growth due to