Transverse Deflecting Cavity for the Photo Injector Test Facility (PITZ)

PITZ review, main accelerator elements

Emittance definitions and measurement techniques

TDS Simulations

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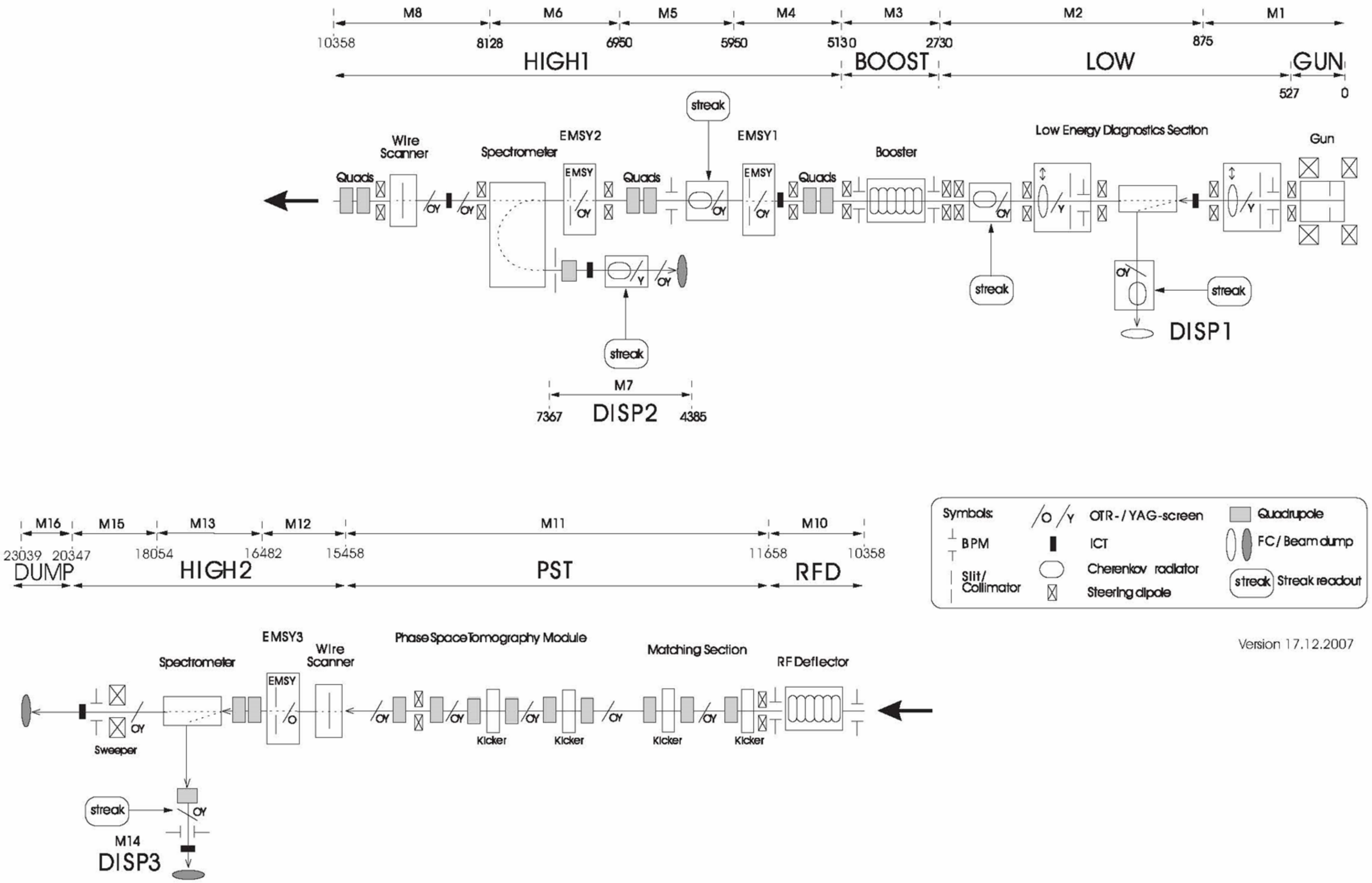
Research seminar
12th of November 2010

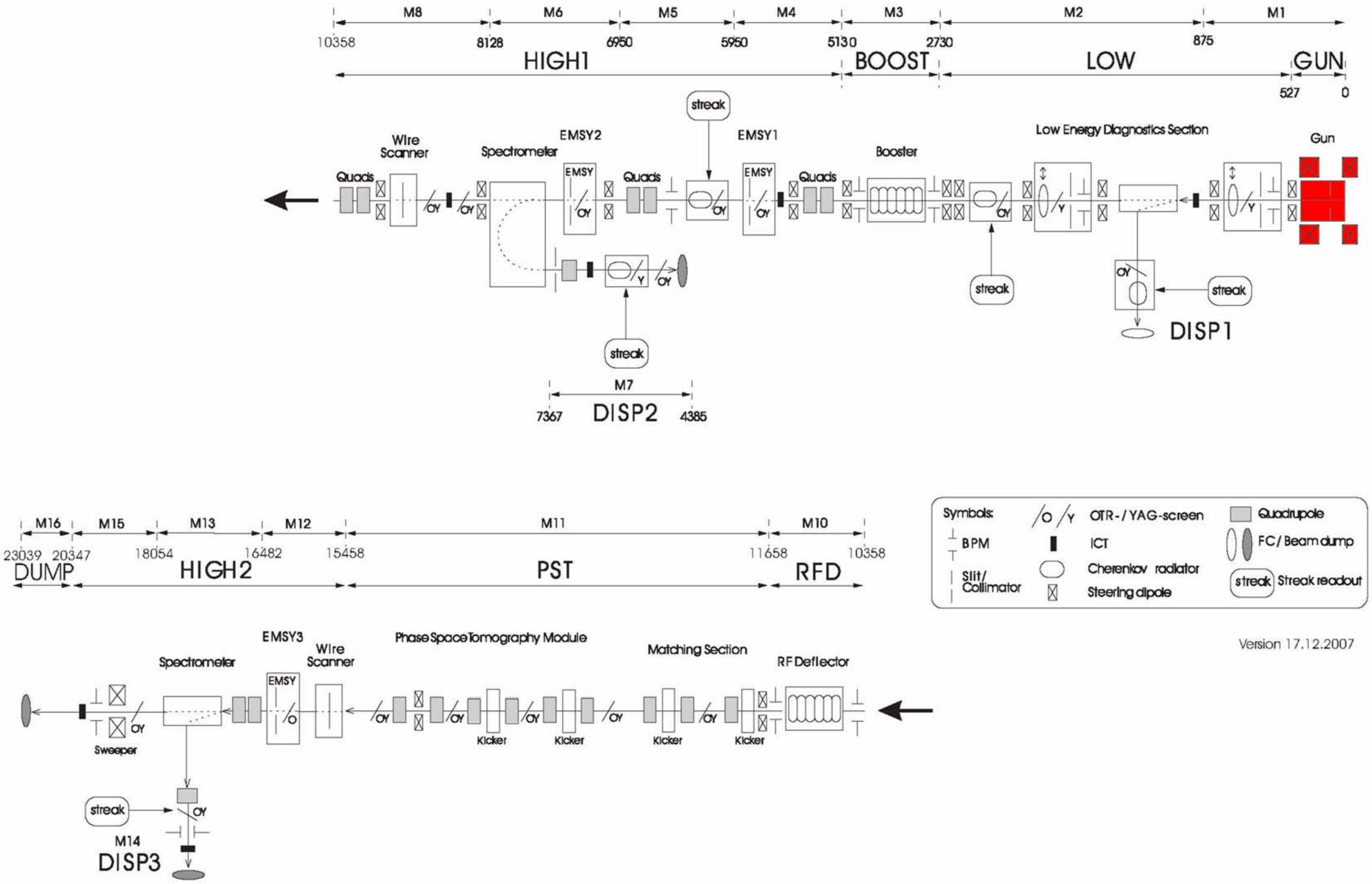
HELMHOLTZ | GEMEINSCHAFT

DESY

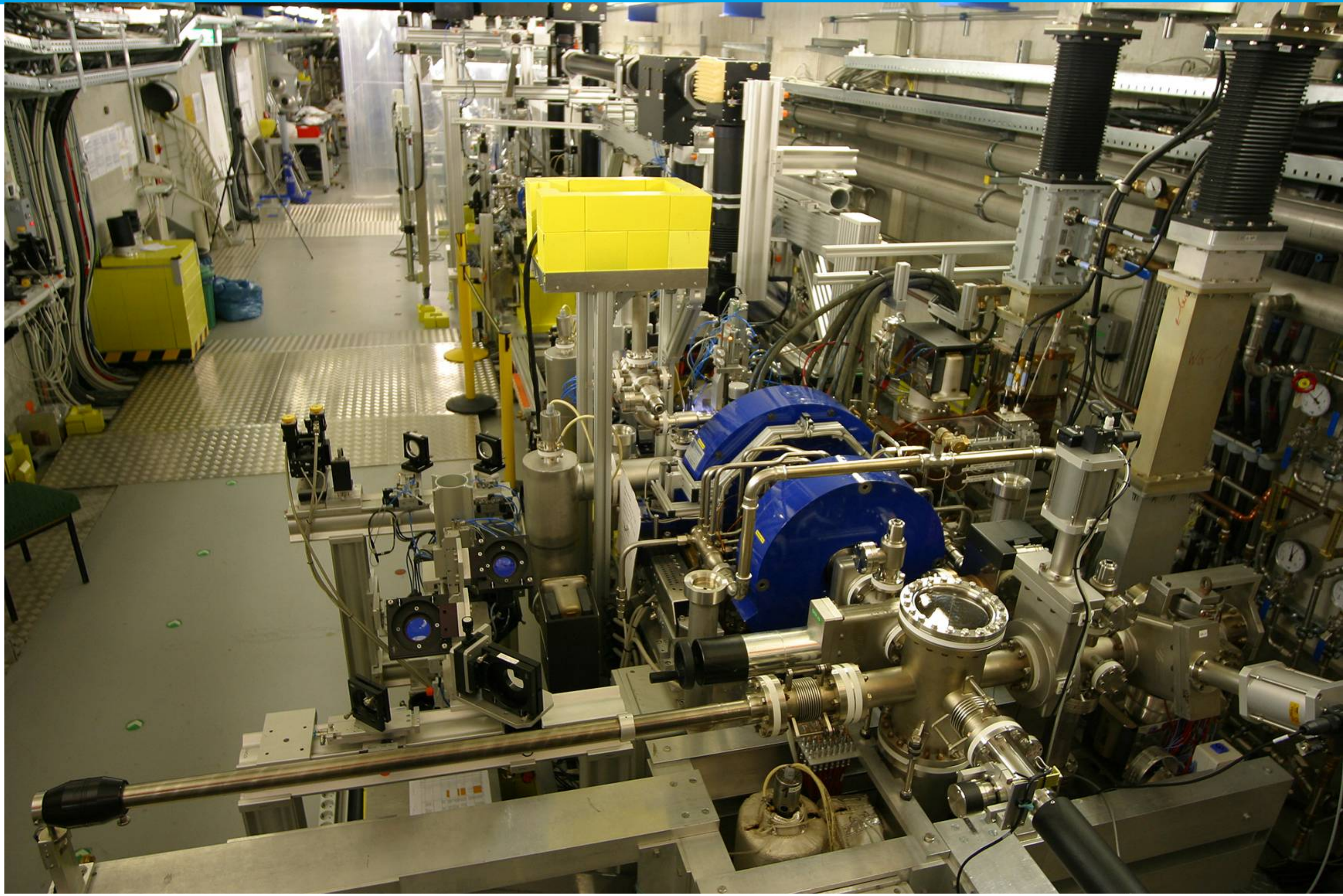
PITZ 2.0 setup



PITZ 2.0 setup - Gun



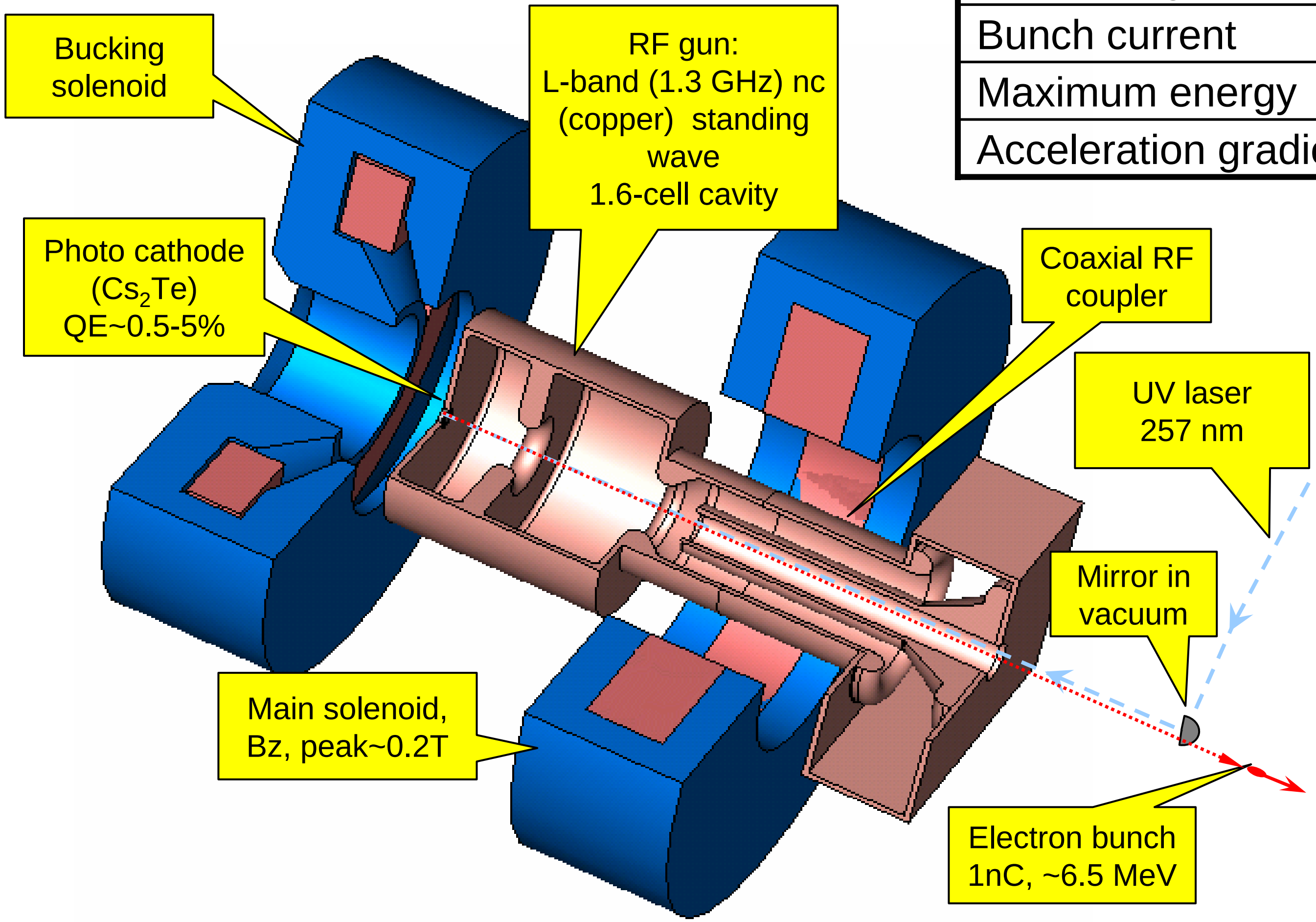
PITZ tunnel



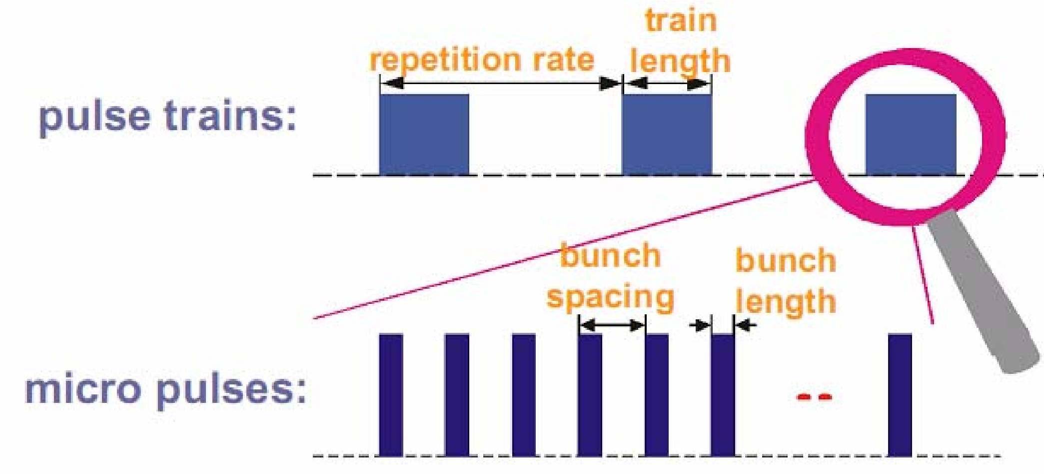
PITZ photo gun

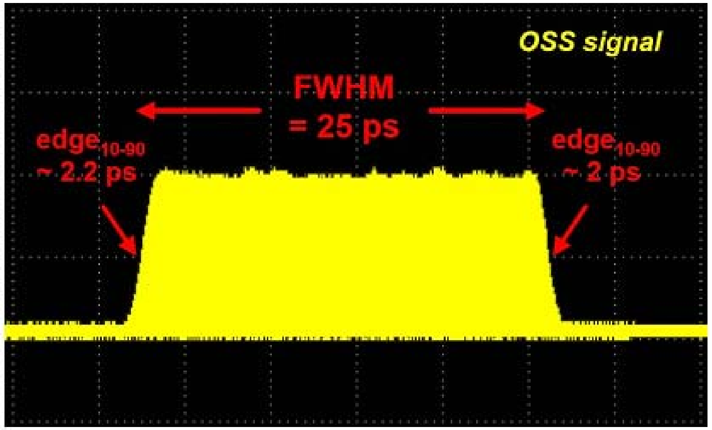
Typical output electron beams

Bunch charge	1 nC
Bunch length	20 ps
Bunch current	50 A
Maximum energy	6.5 MeV
Acceleration gradient	60 MeV/m



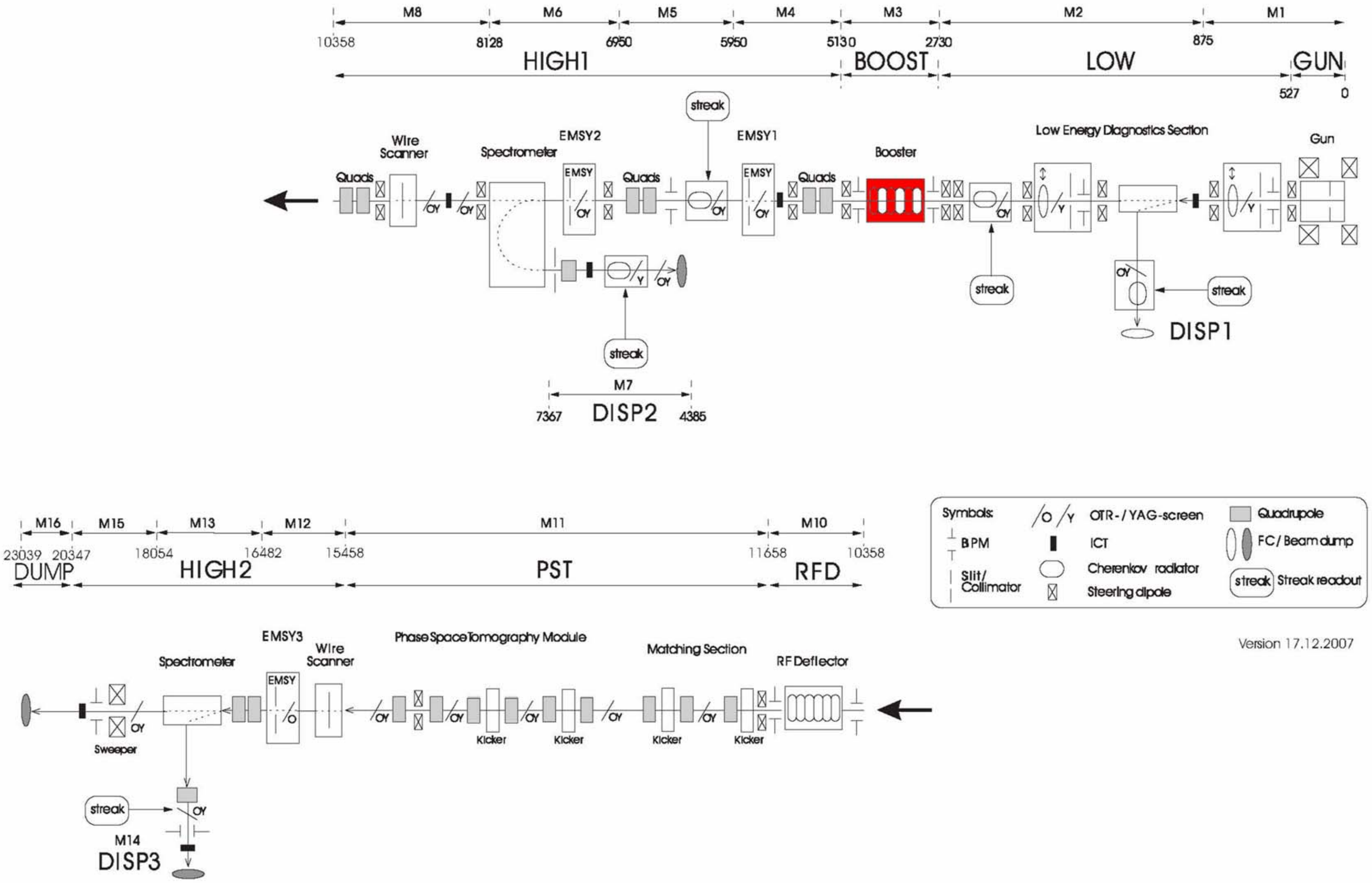
PITZ Laser parameters



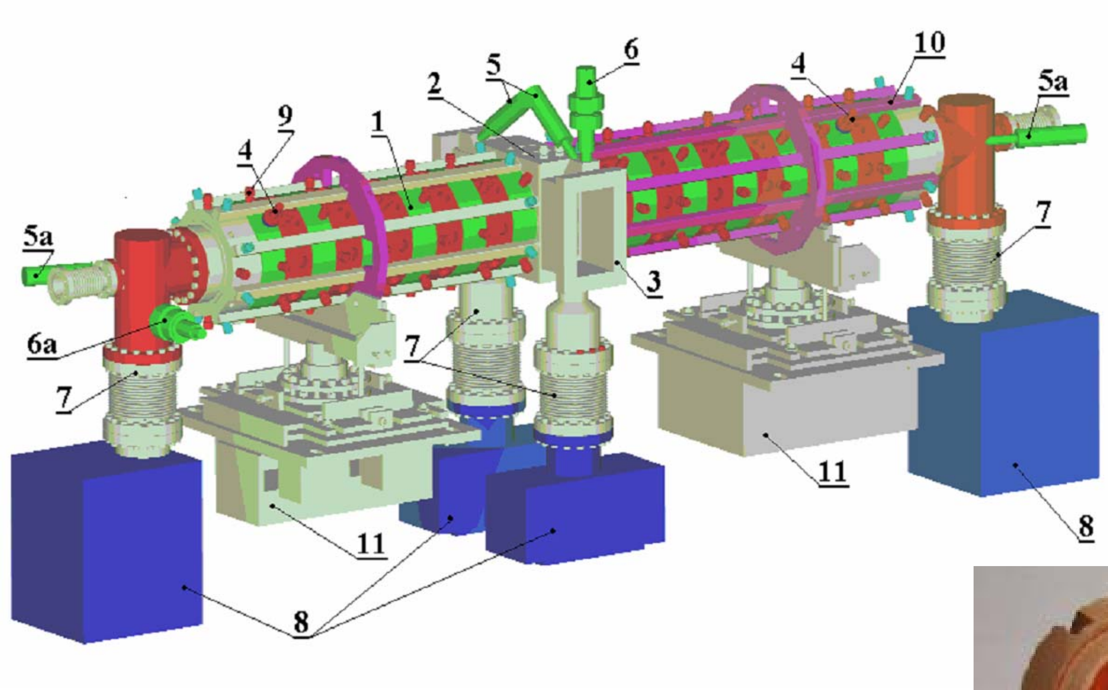


Parameters	PITZ/FLASH	European XFEL
bunch charge	1 nC	1 nC
max. repetition rate	10 Hz	10 Hz
max. train length	800 µs	650 µs
bunch spacing	1 µs	0.2 – 1 µs

PITZ 2.0 setup - Booster



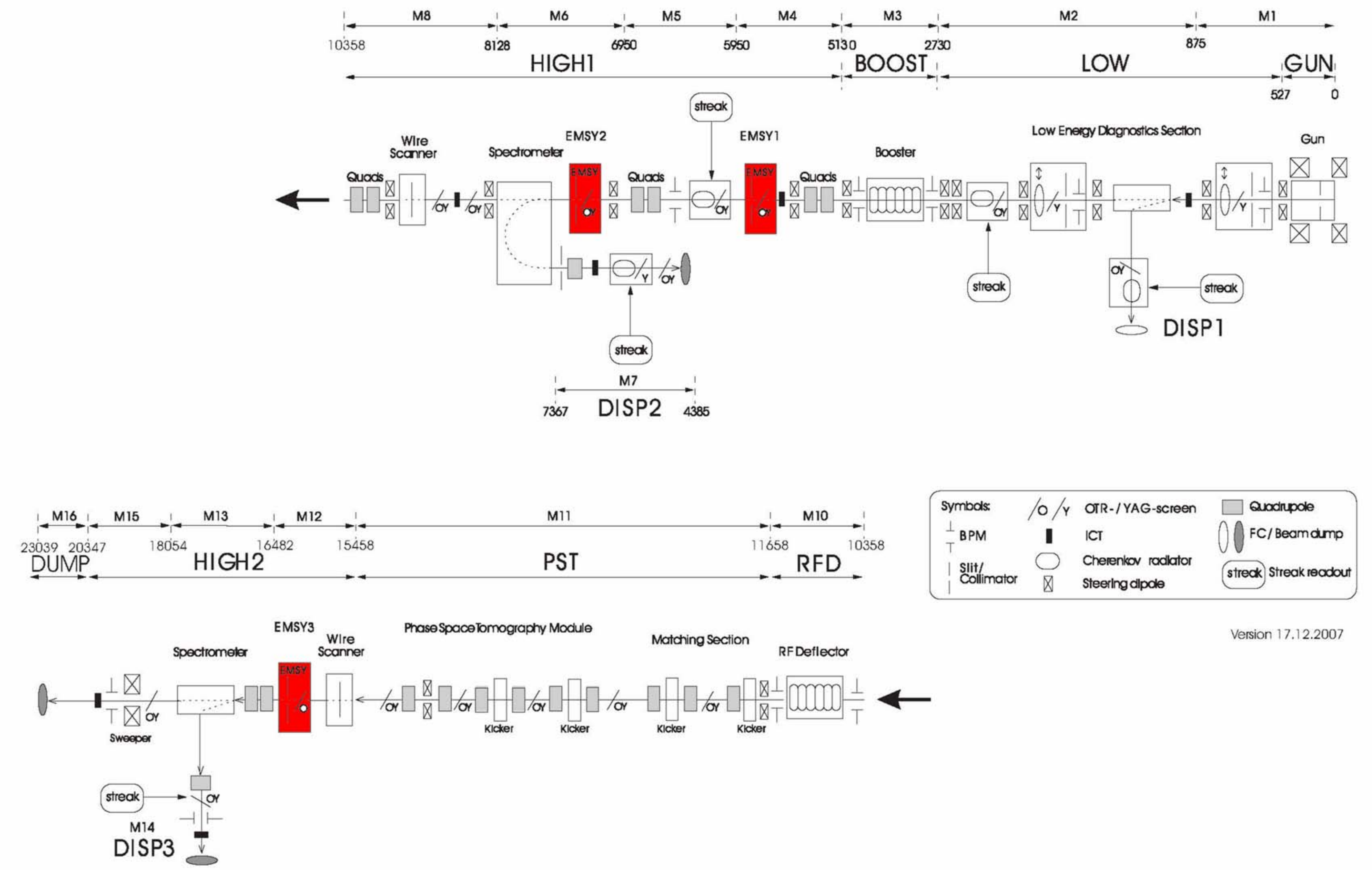
CDS booster (Cut Disk Structure)



Scheme of the booster structure:
1 - regular cells,
2 - RF coupler cell,
8 - ion pumps,
11 - support and adjustment.

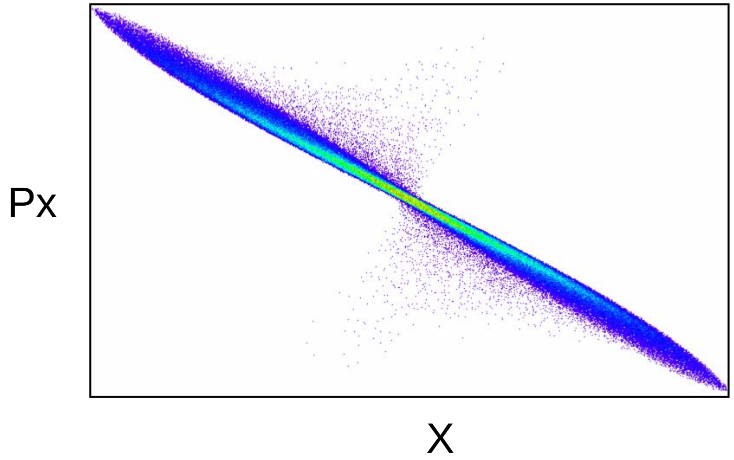
Operating frequency	1300 MHz
Maximum acceleration gradient	14 MeV/m
Maximum energy gain	20 MeV
Pulse duration	900 us

PITZ 2.0 setup - EMSY



Transverse Phase Space, Emittance

Phase space plot



$$A = \iint dp_x dx$$

$$B = \frac{2 \cdot I}{\varepsilon_x \varepsilon_y}$$

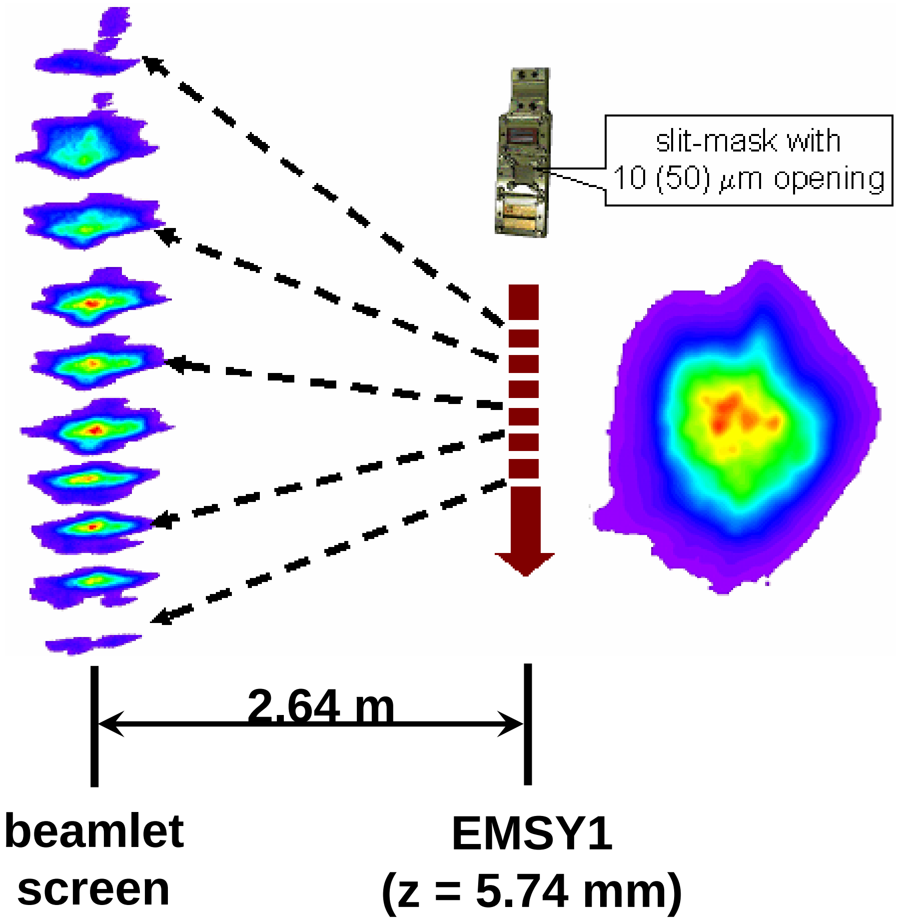
$$\varepsilon = \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}$$

$$\varepsilon_n = \beta\gamma \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}$$

γ is the relativistic factor, β speed of particles in relative units.

$\langle x^2 \rangle$ and $\langle x'^2 \rangle$ are the second central moments of the electron beam distribution in the trace phase. $x' = p_x / p_0$ is the angle of the single electron trajectory with respect to the whole beam trajectory. $\langle xx' \rangle$ covariance.

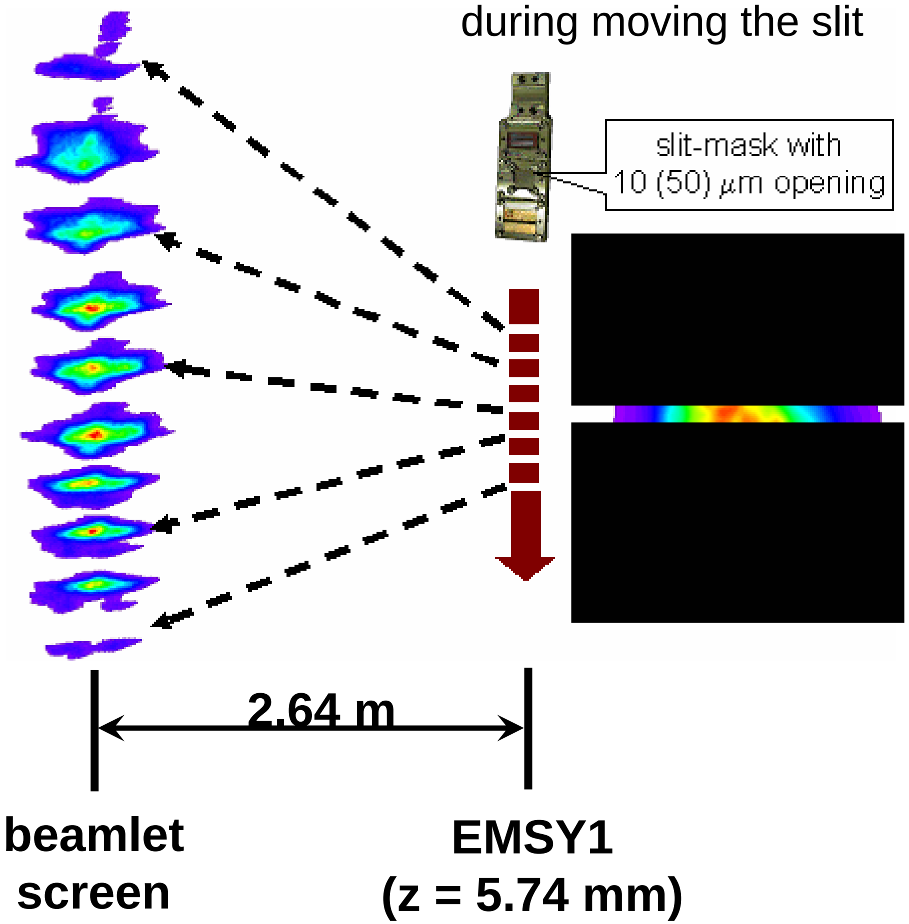
Slit emittance measurement technique



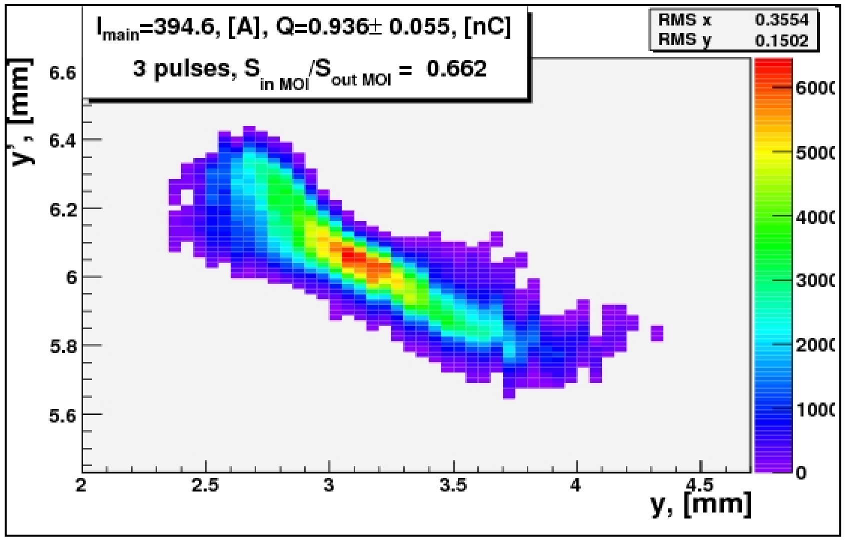
Beamlet image grabbing during continuously moving the slit

Slit emittance measurement technique

Beamlet image grabbing continuously during moving the slit



full transverse phase space for Y



Scaled Transverse Emittance

2D Scaled normalized RMS emittance

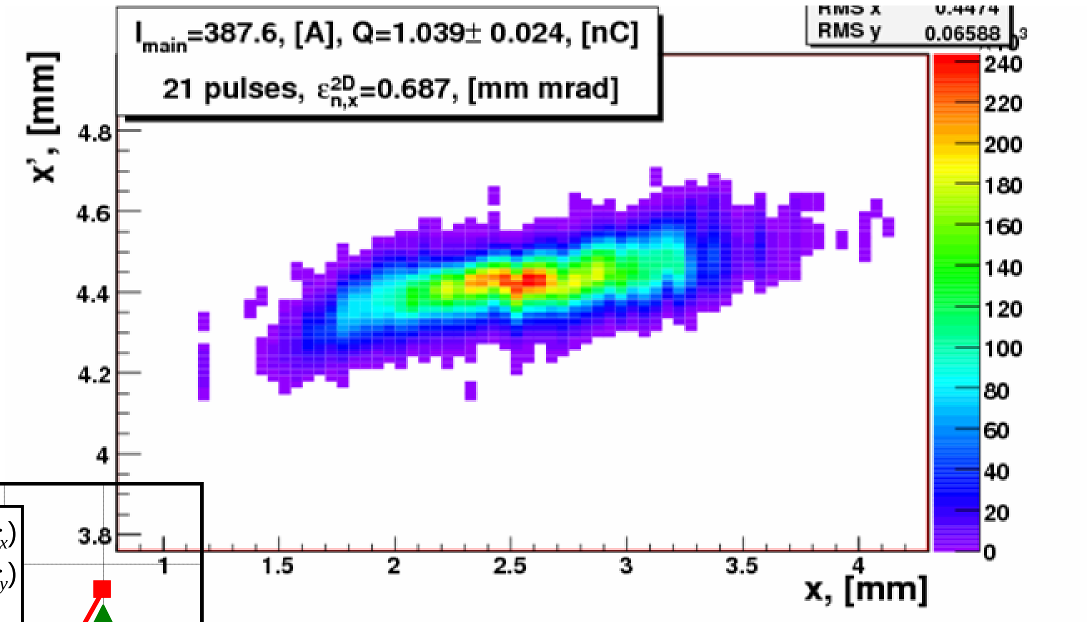
$$\varepsilon_n = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}$$

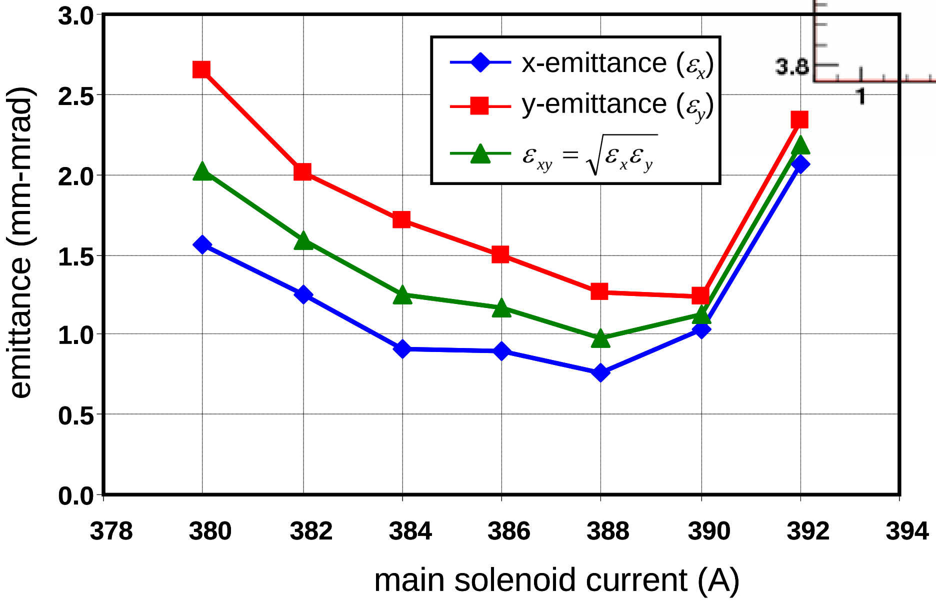
σ_x is the RMS beam size measured at the slit location.

$\sigma_x / \sqrt{\langle x^2 \rangle}$ is introduced to correct for low intensity losses from the beamlet measurement.

Transverse emittance measurements results

Transverse phase space

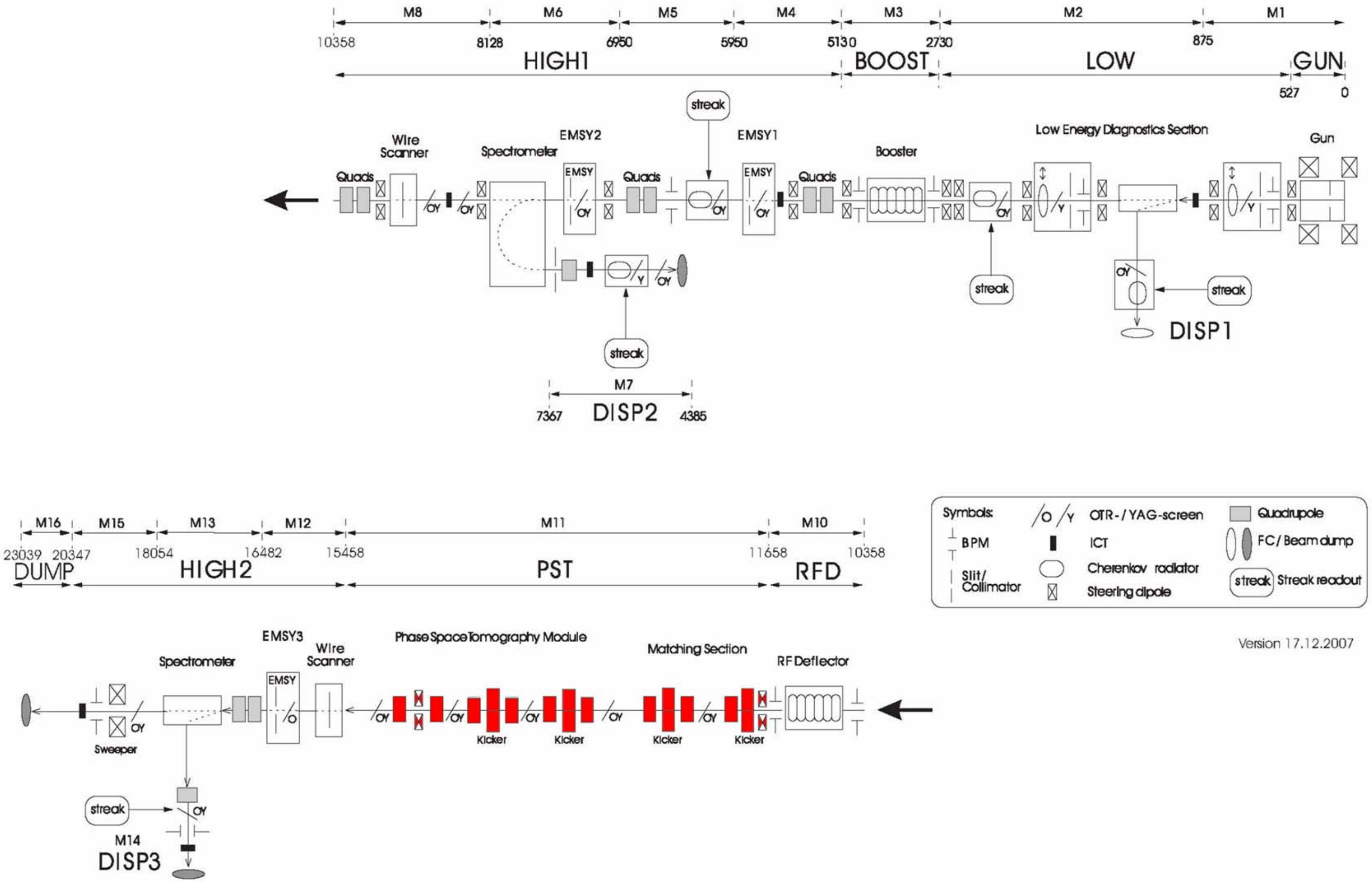




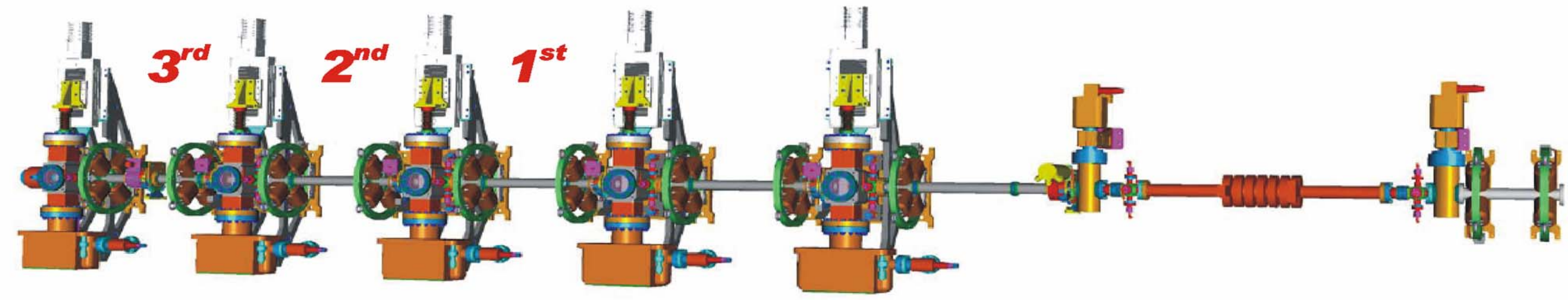
Scaled transverse normalized emittance versus solenoid current

S. Rimjaem, IPAC 2010

PITZ 2.0 setup – Phase Space Tomography



Tomography module

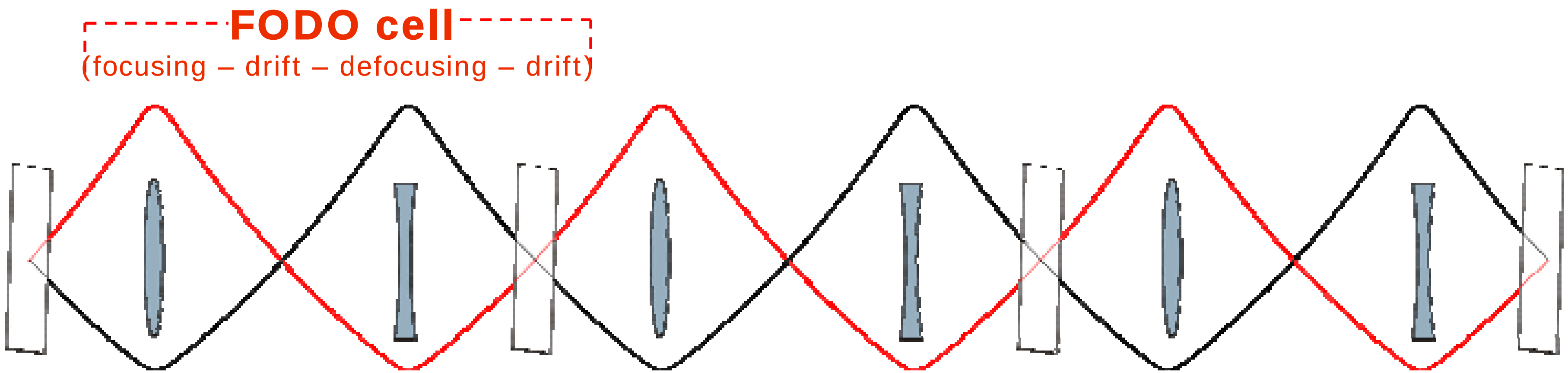


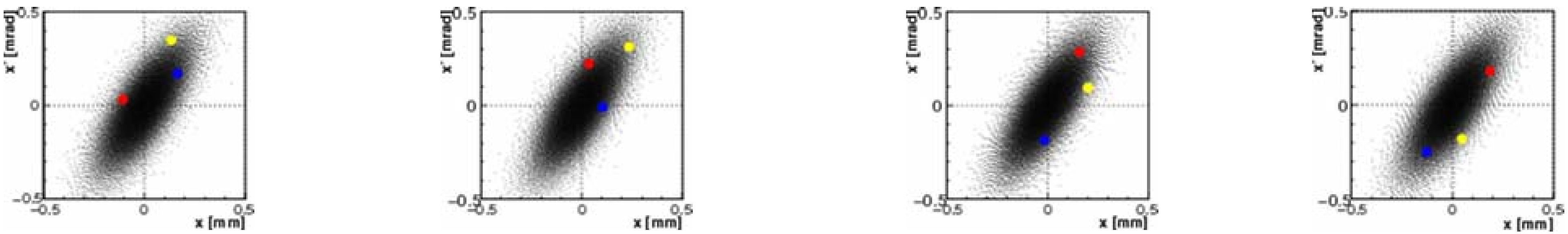
Screen stations

TDS

- Resolve both transverse planes simultaneously
- Design for 15-30 MeV/c, 1 nC
- Stringent alignment tolerances
- Slow and complicated analysis

Tomography: Basic idea

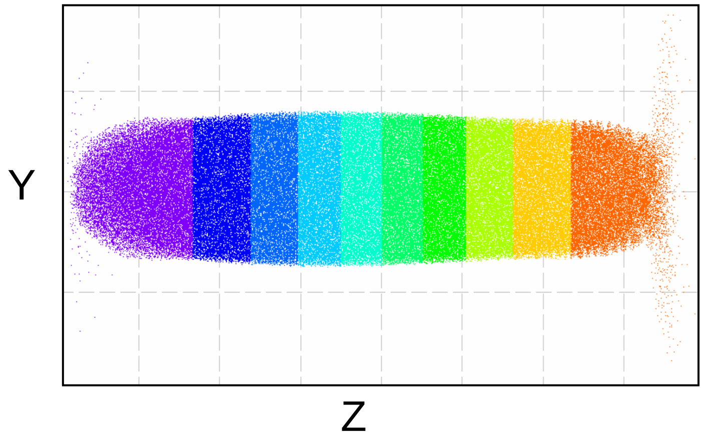


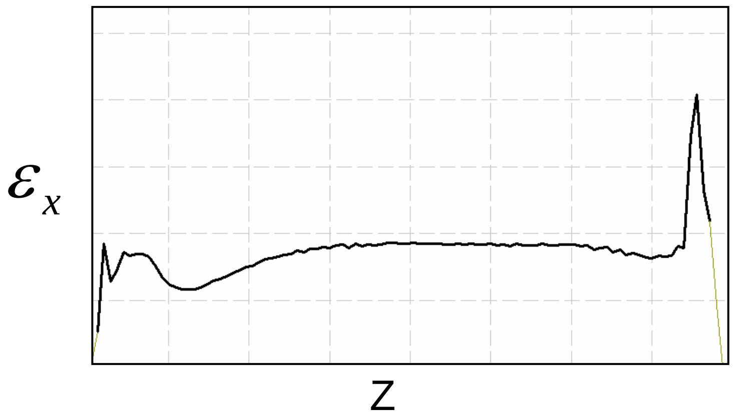


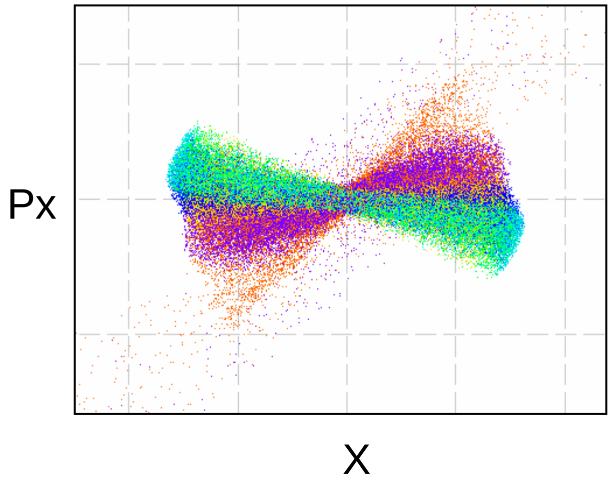
- equidistant angular steps between the screens for both planes (2D)
- rms spot size is unchanged
- the data treatment assumes linear transport between the screens

Slice emittance

$$\varepsilon_n(\Delta z_i) = \beta\gamma\sqrt{\left\langle x(\Delta z_i)^2\right\rangle \cdot \left\langle x'(\Delta z_i)^2\right\rangle - \left\langle x(\Delta z_i)x'(\Delta z_i)\right\rangle^2}$$



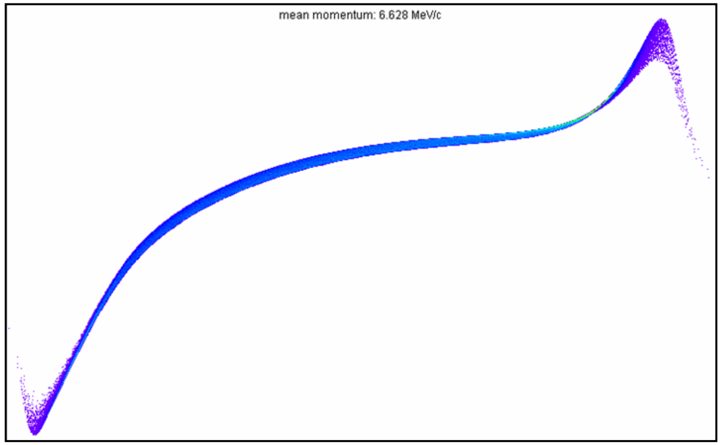




Longitudinal phase space

Phase space plot

Pz



Z

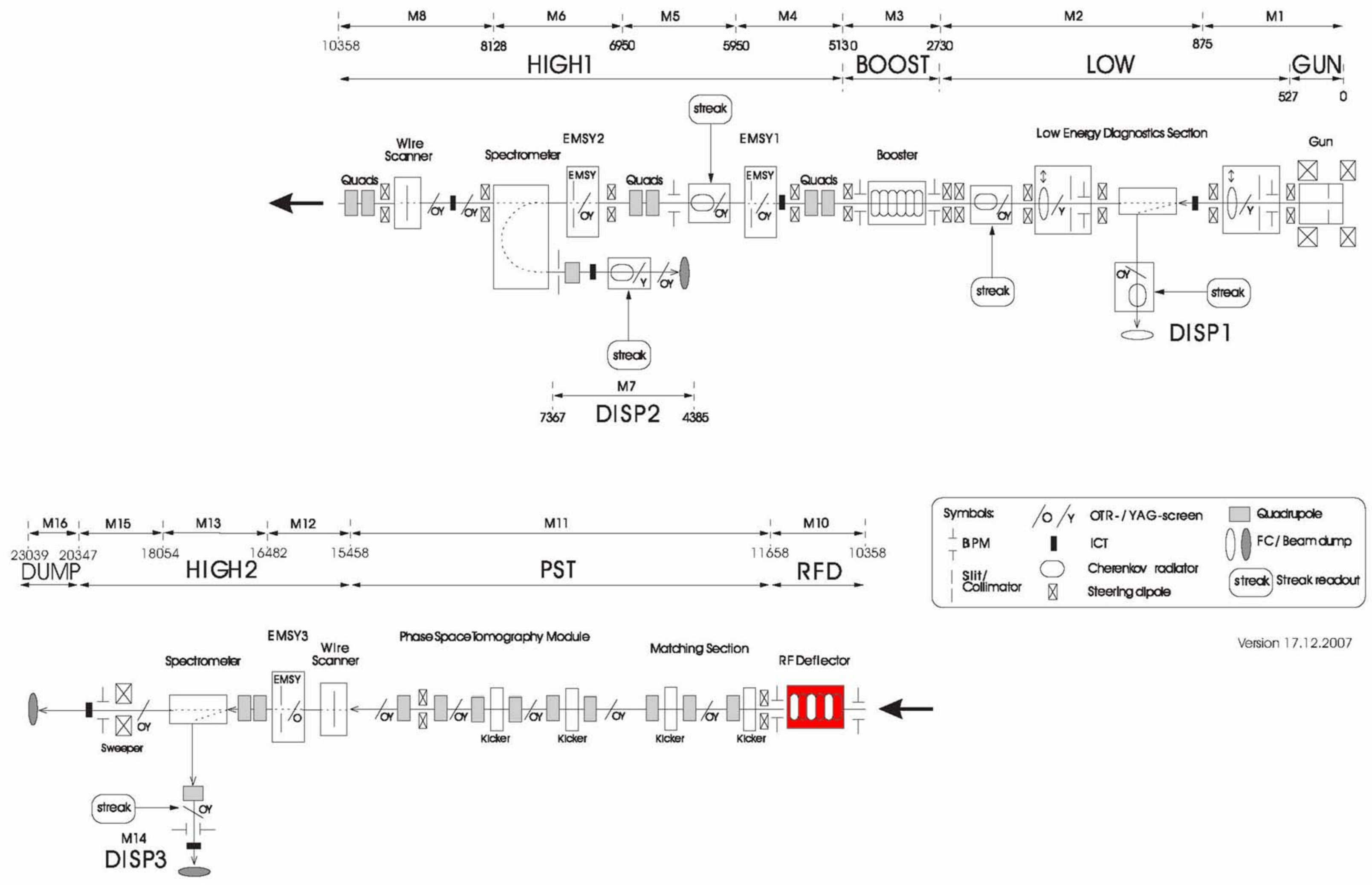
$$A = \iint dp_z dz$$

$$\varepsilon = \sqrt{\langle z^2 \rangle \cdot \langle pz^2 \rangle - \langle z \cdot pz \rangle^2}$$

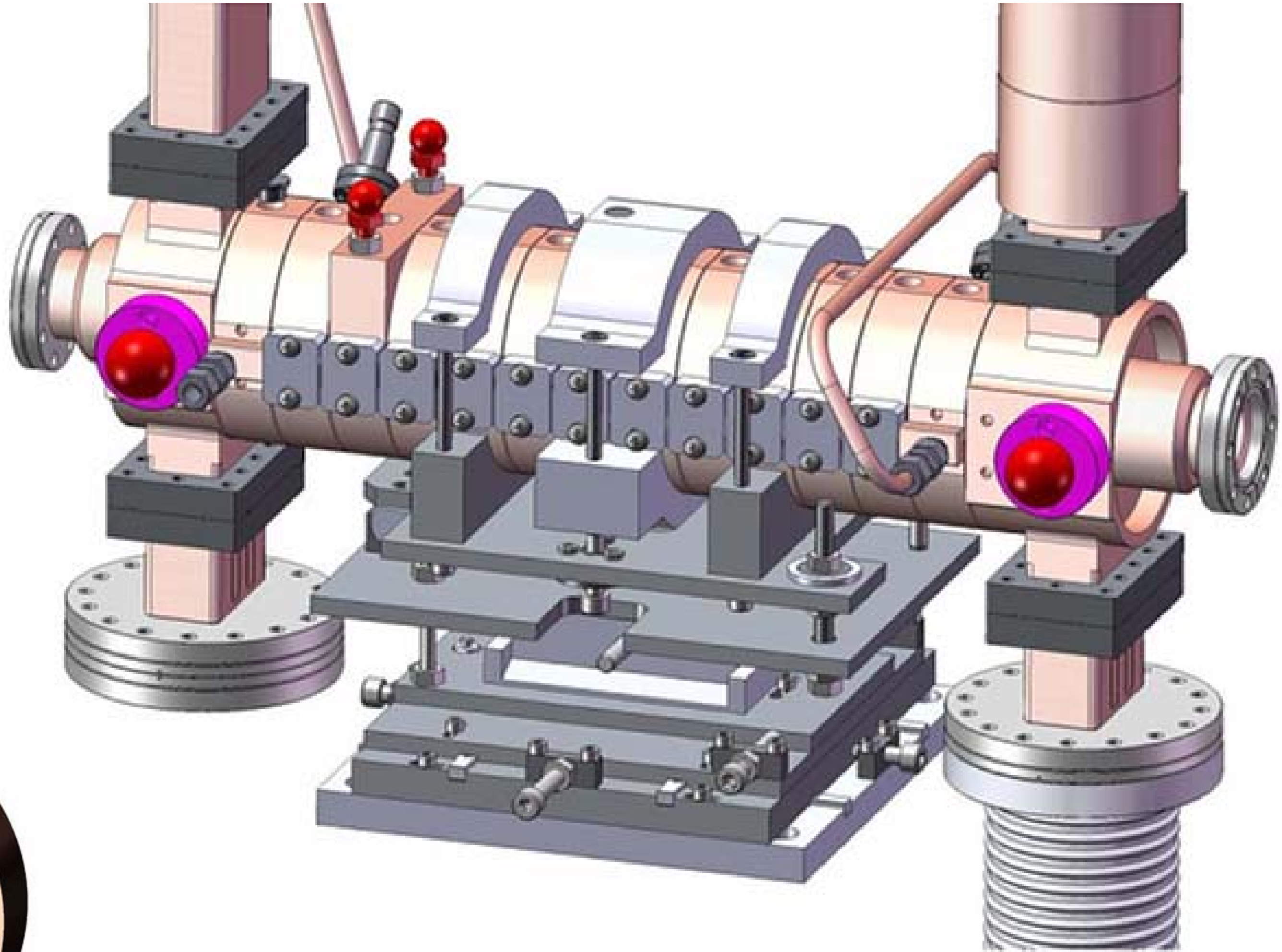
$\langle z^2 \rangle$ and $\langle pz^2 \rangle$ are the second central moments of the electron beam distribution in the trace phase.

$\langle z \cdot pz \rangle$ covariance.

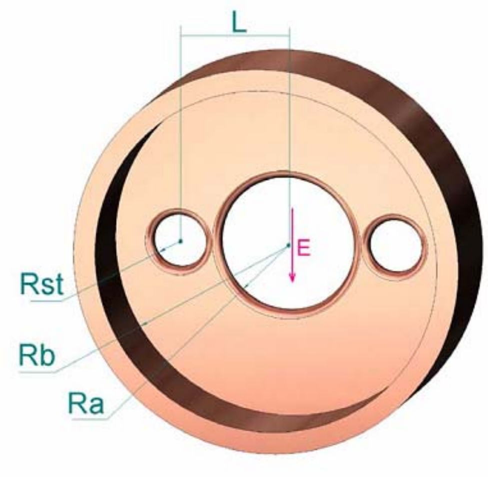
PITZ 2.0 setup - TDS



Engineering design of TDS

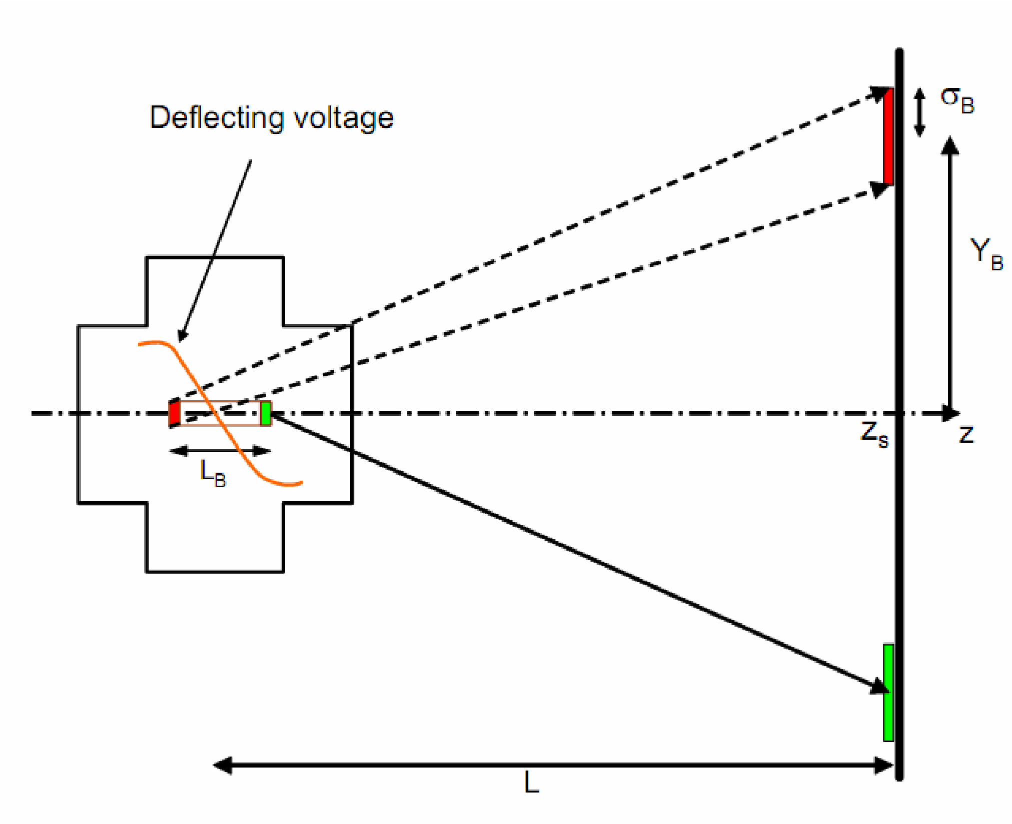


One cell



disk-loaded structure
with two stabilization holes

TDS: Basic idea



$$Y_B = \frac{e \cdot V_\perp \cdot \pi \cdot f_{RF} \cdot L_B}{\beta^3 \cdot E \cdot c} \cdot L$$

$V_\perp$ transverse deflecting voltage

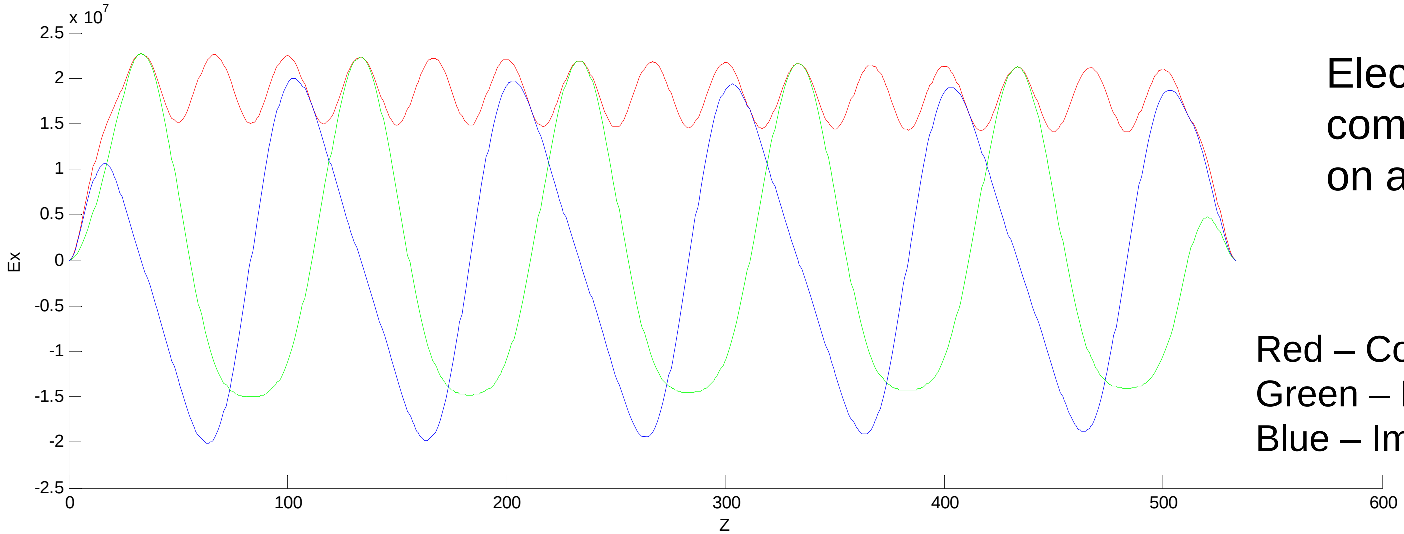
f_{RF} frequency

E beam energy

$$N_{slices} = \frac{Y_B}{\sigma_B}$$

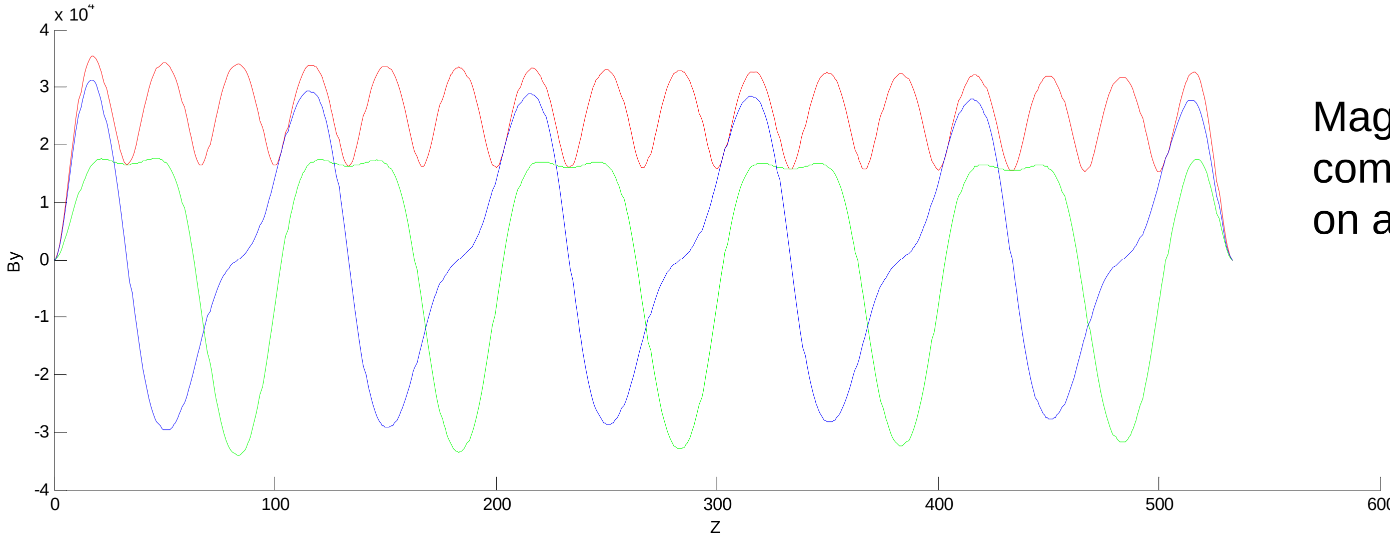
$$L_{res} = \frac{L_B}{N_{slices}} = \frac{L_B \cdot \sigma_B}{Y_B} = \frac{\beta^3 \cdot E \cdot c \cdot \sigma_B}{e \cdot V_\perp \cdot \pi \cdot f_{RF} \cdot L}$$

Electromagnetic fields for whole structure



Electric field components on axis

Red – Complex amplitude
Green – Real part
Blue – Imaginary part

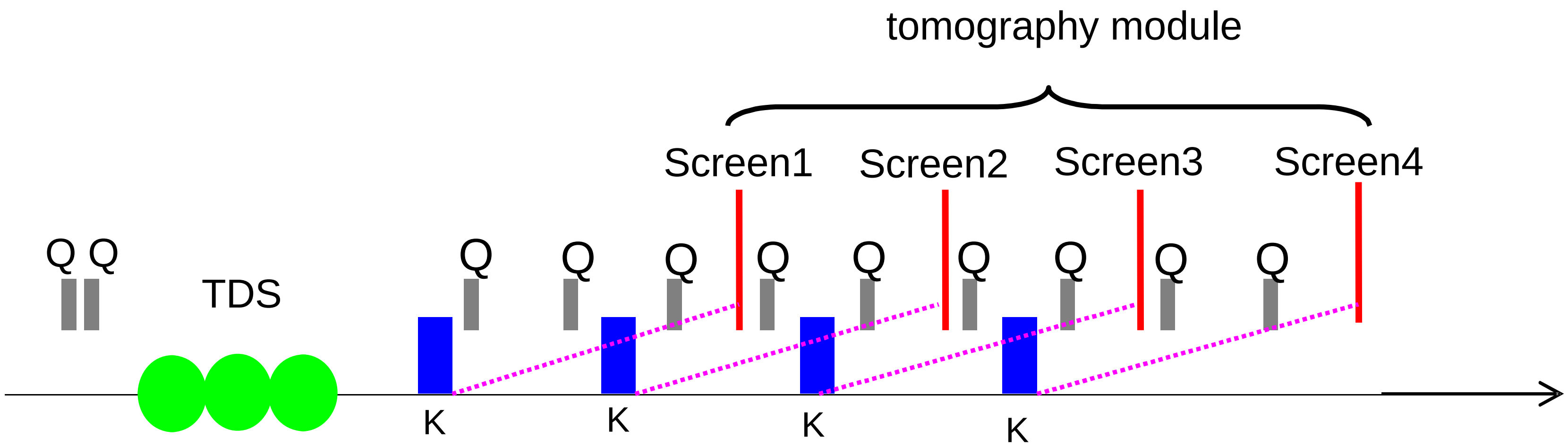


Magnetic field components on axis

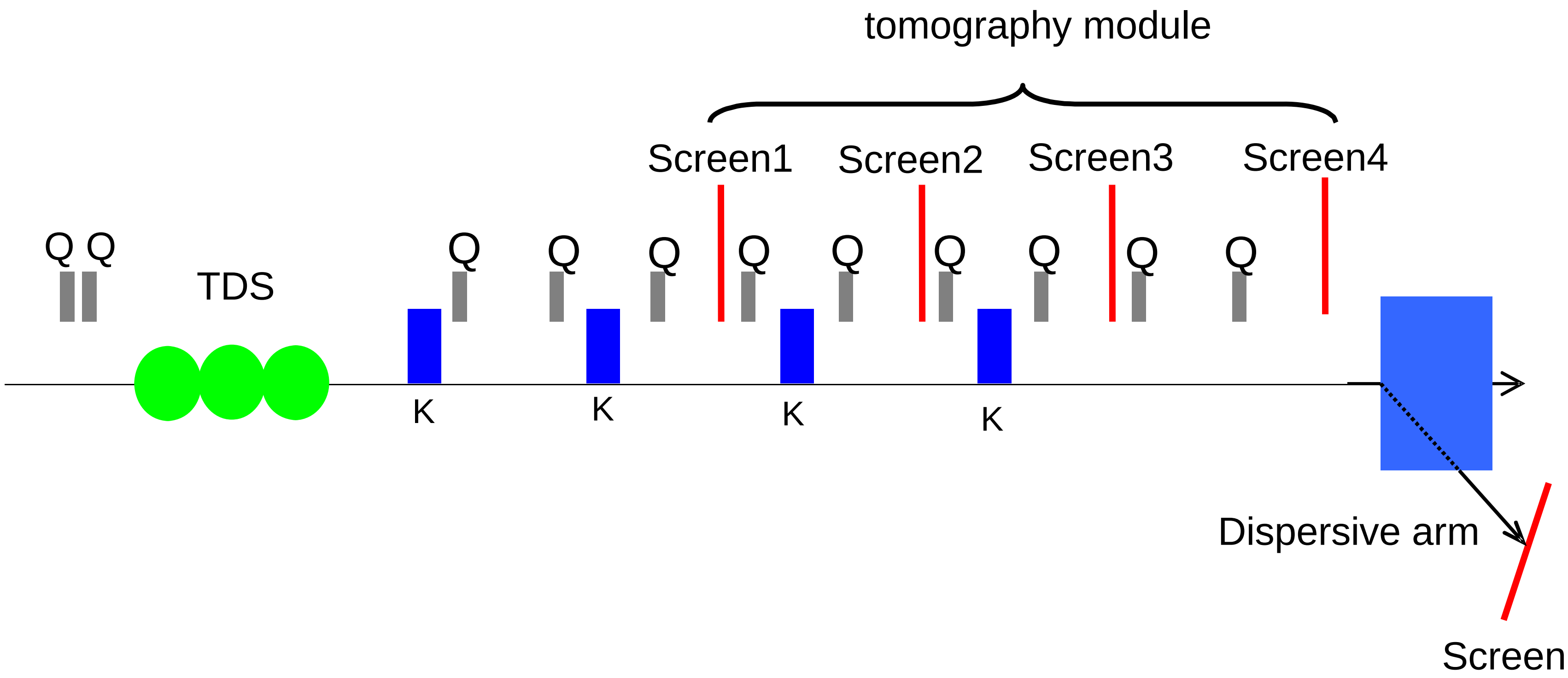
TDS main parameters

Frequency	**3 GHz**
Numbers of cells	**16**
Deflecting Voltage	**0.2 – 1.7 MV (2.5MW)**
Pulse duration	**0.7 – 3.1 us**
Filling time	**< 120 ns**
Filling + decay time	**< 200 ns**

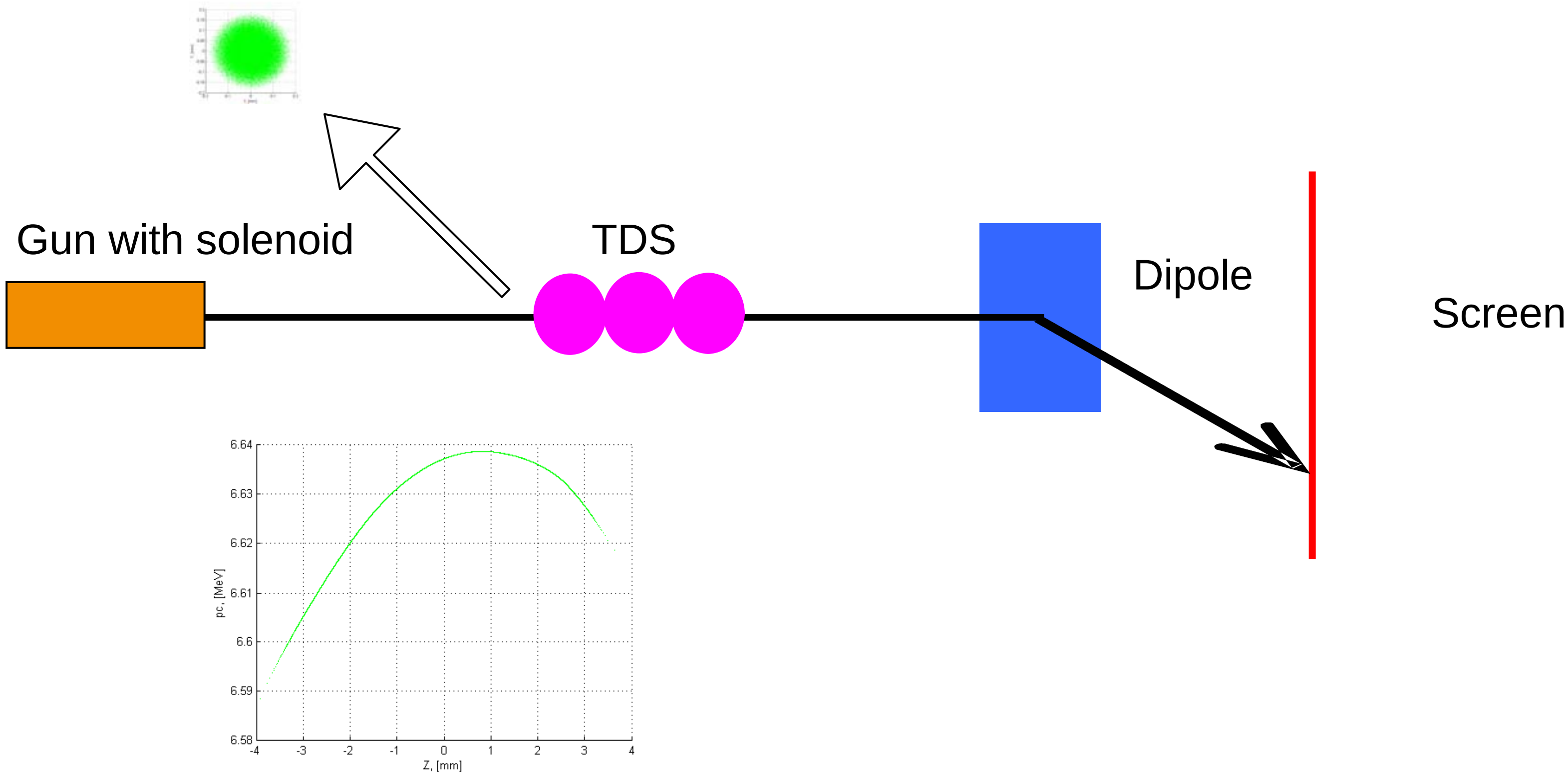
TDS and Tomography section for slice emittance



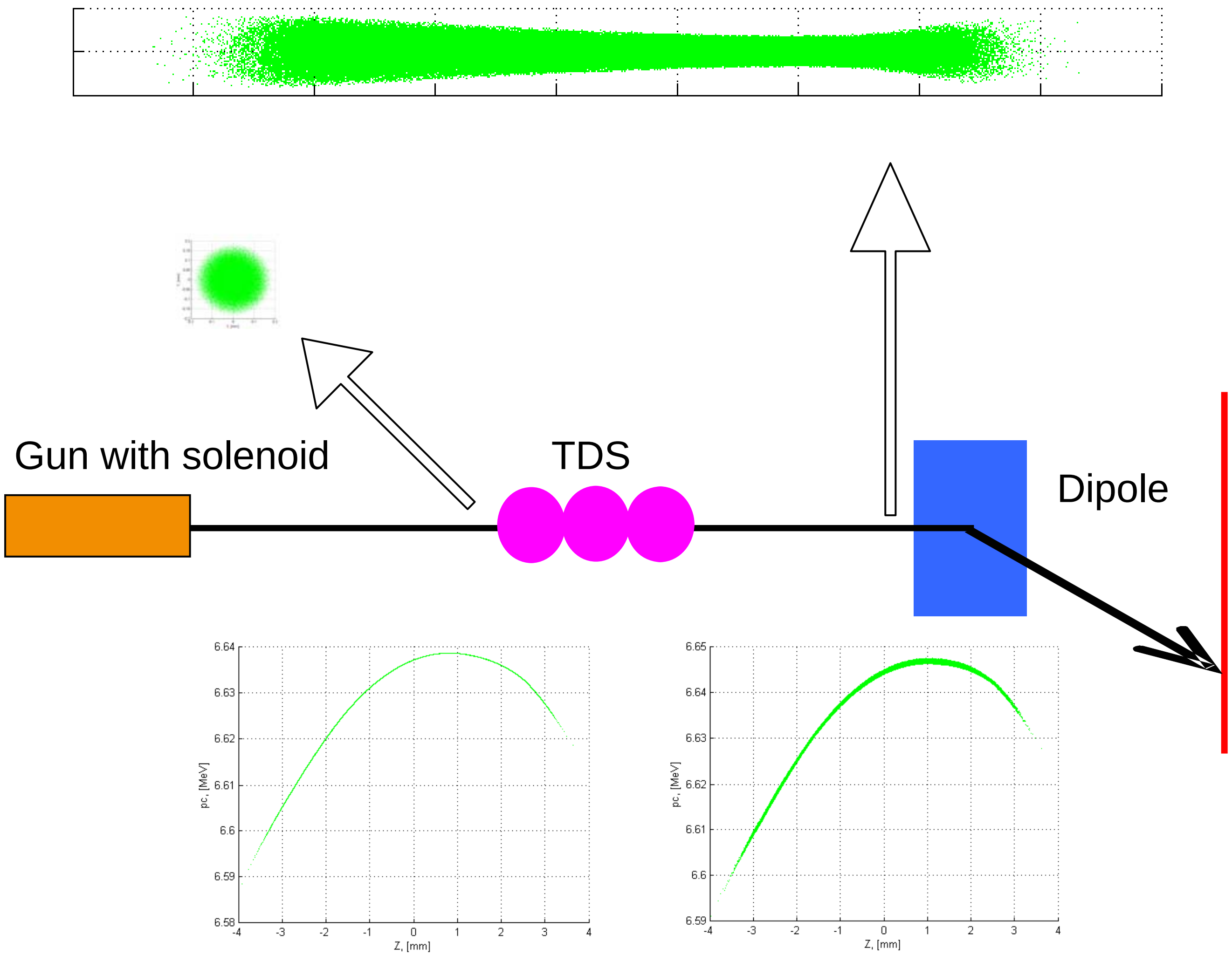
TDS and dipole for longitudinal phase measurements



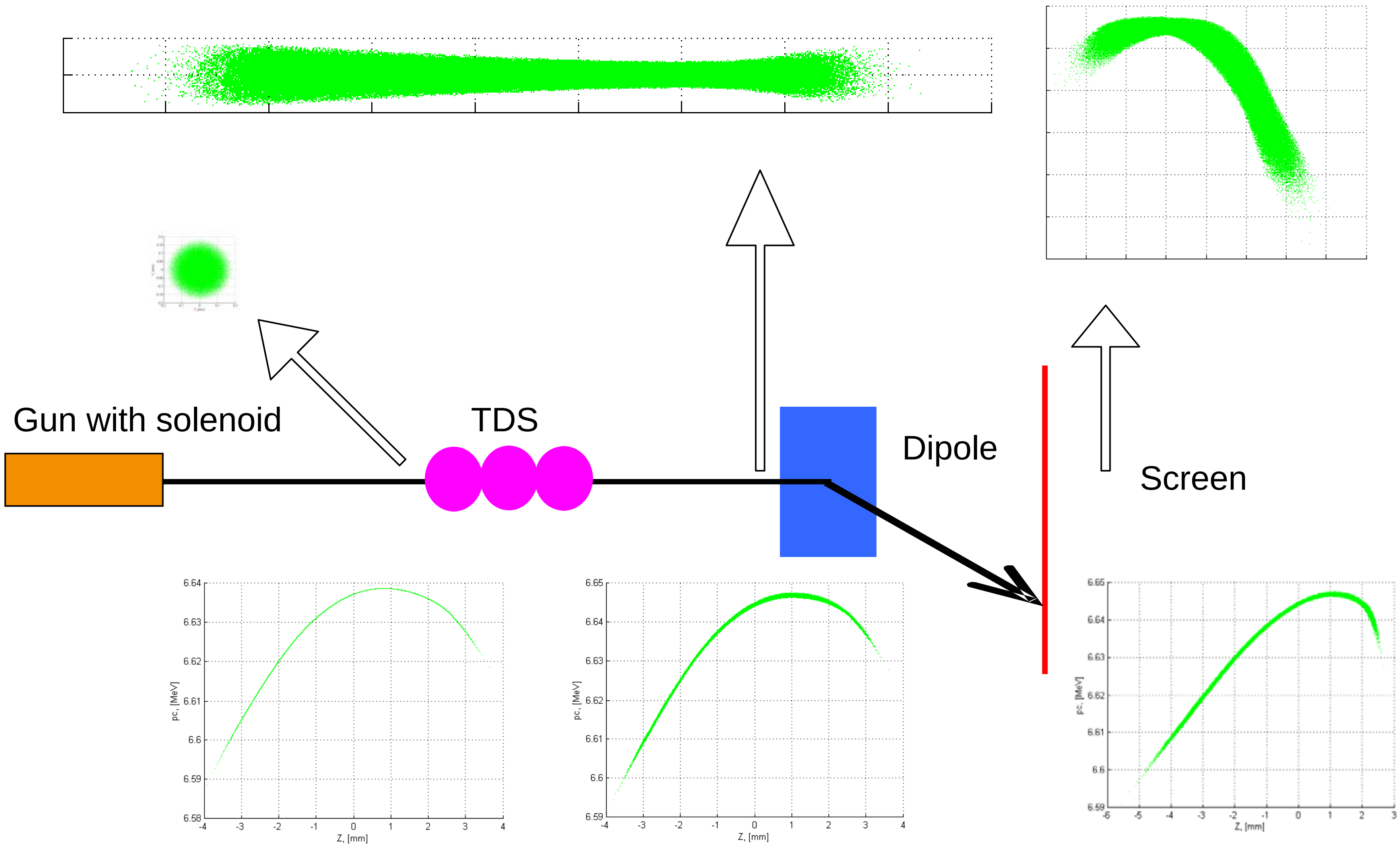
TDS simulation



TDS simulation

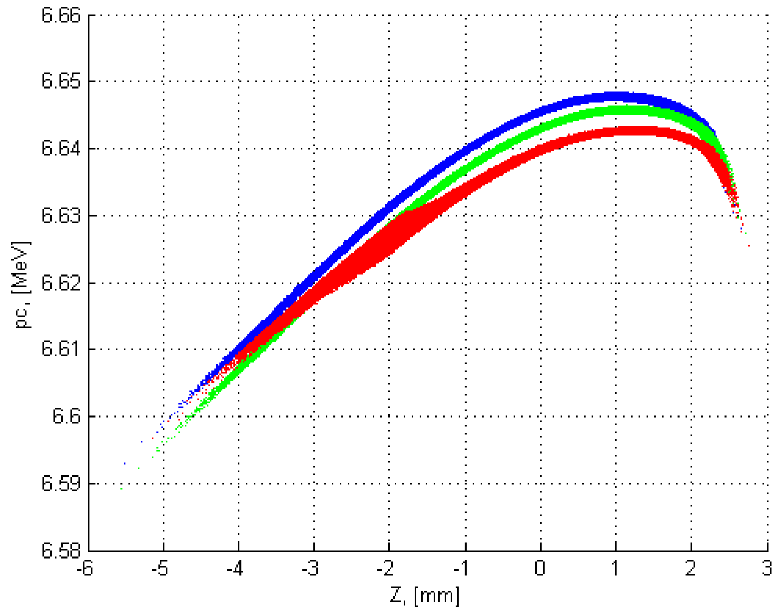


TDS simulation

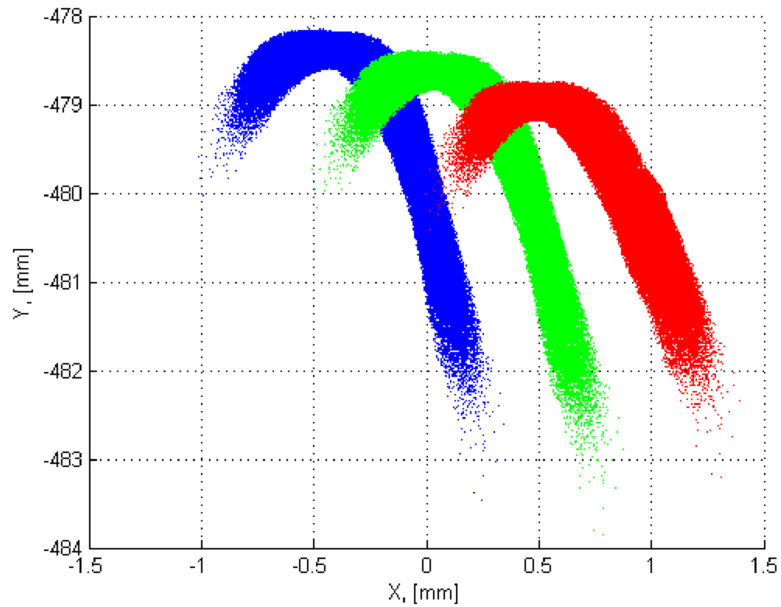


TDS simulation

Longitudinal phase space



XY projections



for different TDS phase, blue – 0 degree, green – 10 degree, red – 20 degree.

Conclusion

TDS structure at PITZ will allow to measure:

- slice transverse emittance, with slice resolution better then 1ps
- longitudinal phase space (longitudinal emittance), with time resolution better then 1ps.

Projected transverse emittance

$$\epsilon_{x,\mathrm{rms}} = \sqrt{\langle x_0^2 \rangle \langle {x'_0}^2 \rangle - \langle x_0 x'_0 \rangle^2}$$

Twiss parameters

$$\begin{pmatrix} \beta_{x_0} \\ \alpha_{x_0} \\ \gamma_{x_0} \end{pmatrix} = \begin{pmatrix} \langle x_0^2 \rangle / \epsilon_{x,\mathrm{rms}} \\ -\langle x_0 x'_0 \rangle / \epsilon_{x,\mathrm{rms}} \\ \langle {x'_0}^2 \rangle / \epsilon_{x,\mathrm{rms}} \end{pmatrix}$$

Basic idea: image size and resolution

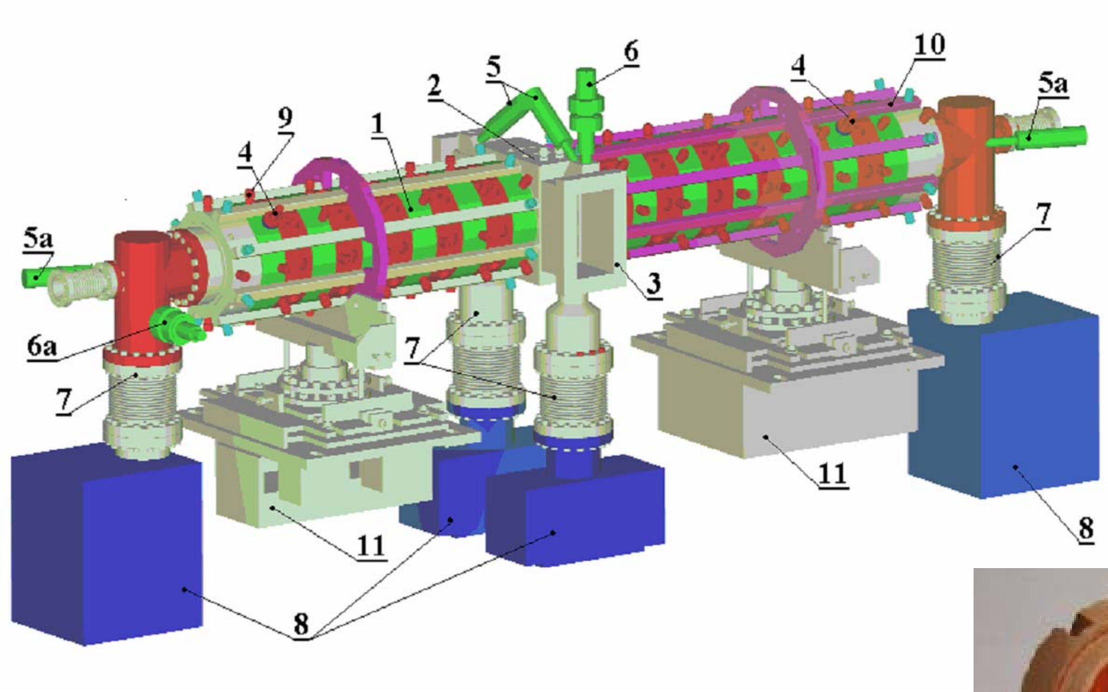
$$\theta = \frac{F \cdot dt}{\gamma \cdot m \cdot \beta \cdot c} = \frac{e \cdot E_0 \cdot \sin(\omega \cdot t) \cdot dt}{\gamma \cdot \beta \cdot m \cdot c} = \frac{e \cdot E_0 \cdot \omega \cdot \frac{L_B}{2 \cdot \beta \cdot c} \cdot \frac{L_c}{\beta \cdot c}}{\gamma \cdot \beta \cdot m \cdot c}$$

$$\theta = \frac{e \cdot E_0 \cdot L_c \cdot \pi \cdot f_{RF} \cdot L_B}{\beta^3 \cdot \gamma \cdot m \cdot c^2 \cdot c} = \frac{e \cdot V_\perp \cdot \pi \cdot f_{RF} \cdot L_B}{\beta^3 \cdot E \cdot c}$$

$$\boxed{Y_B = \frac{e \cdot V_\perp \cdot \pi \cdot f_{RF} \cdot L_B}{\beta^3 \cdot E \cdot c} \cdot L}$$

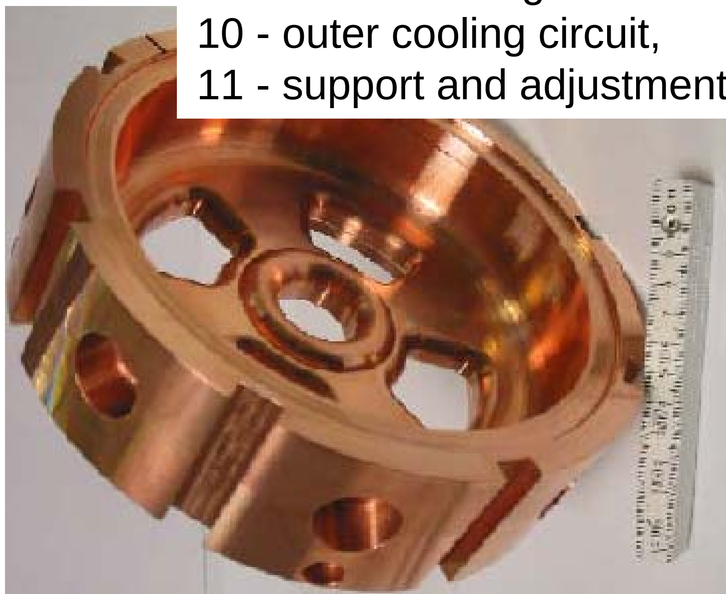
$$\boxed{L_{res} = \frac{L_B}{N_{slices}} = \frac{L_B \cdot \sigma_B}{Y_B} = \frac{\beta^3 \cdot E \cdot c \cdot \sigma_B}{e \cdot V_\perp \cdot \pi \cdot f_{RF} \cdot L}}$$

CDS booster (Cut Disk Structure)



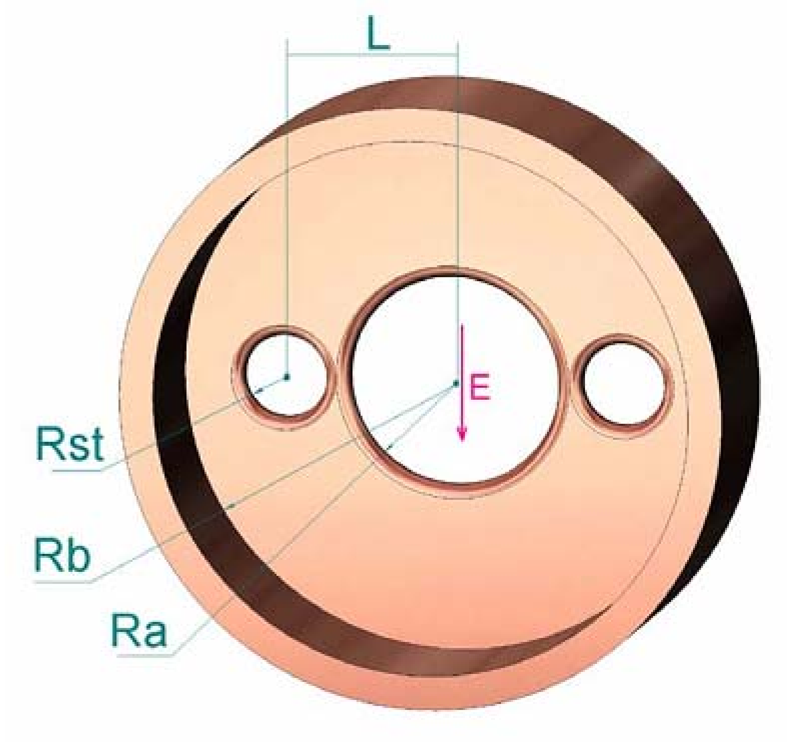
Scheme of the booster cavity.
1 - regular cells,
2 - RF coupler cell,
4 -RF probes,
5 - photo multipliers,
5a - reserve photo multipliers,
6 - vacuum gauge,
6a- reserve vacuum gauge,
7 - pumping tubes with bellows,
8 - ion pumps,
9 - internal cooling circuit outlets,
10 - outer cooling circuit,
11 - support and adjustment.

Operating frequency	1300 MHz
Maximum accelerator gradient	14 MeV/m
Maximum energy gain	20 MeV
Pulse duration	900 us



Engineering design of TDS

One cell parameters



L = 34.65mm
Rst = 9.0mm
Ra = 21.55mm
Rb = 55.27mm