Simulation of the different type of measurement with the RF deflecting structure at PITZ

1. PITZ2.0 design, new components
2. TDS basic principle, resolution and limitation
3. Longitudinal phase space measurement
4. Bunch length measurement
5. Slice emittance measurement
6. Summary

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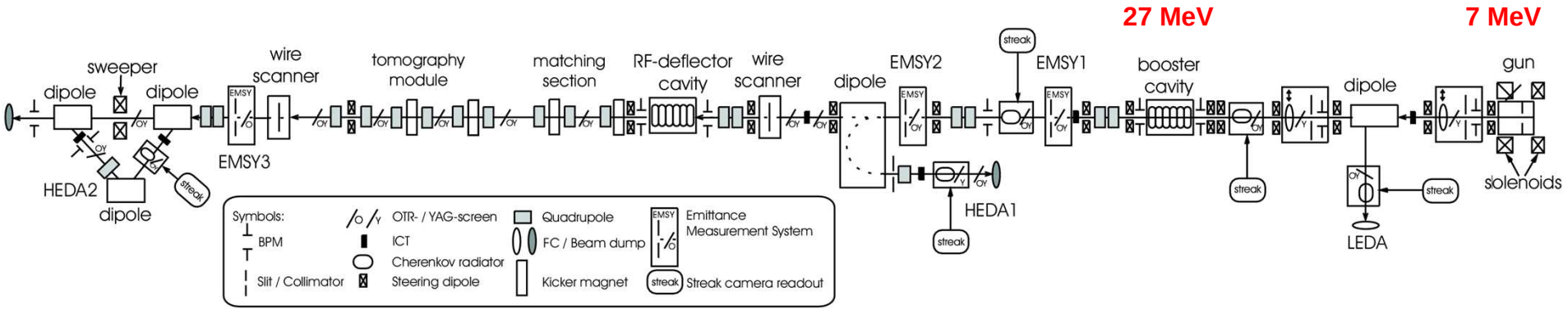
Forschungsseminar SS 2012
Humboldt-Universität zu Berlin
8th of June 2012

HELMHOLTZ GEMEINSCHAFT

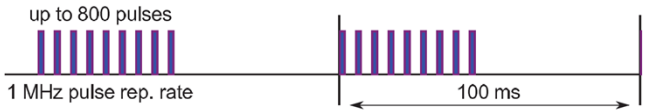
DESY

PITZ2.0 design

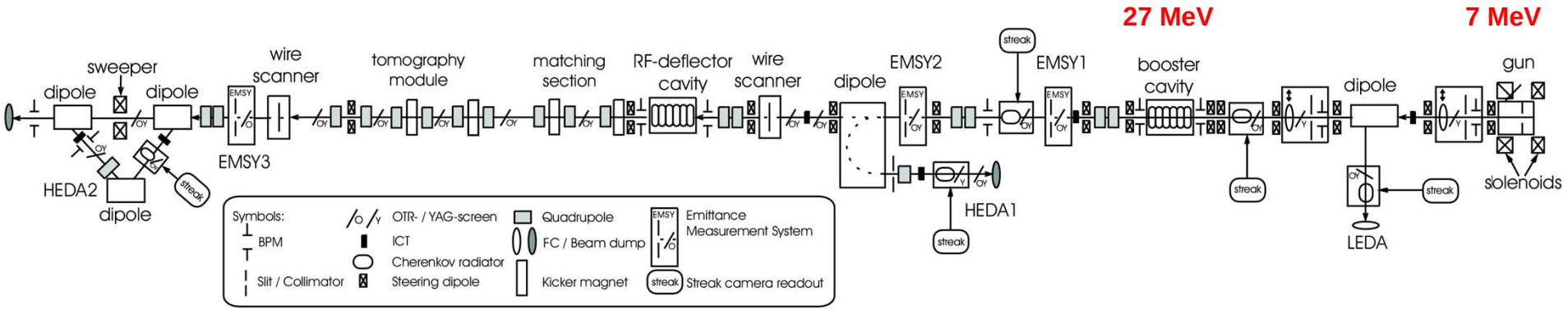


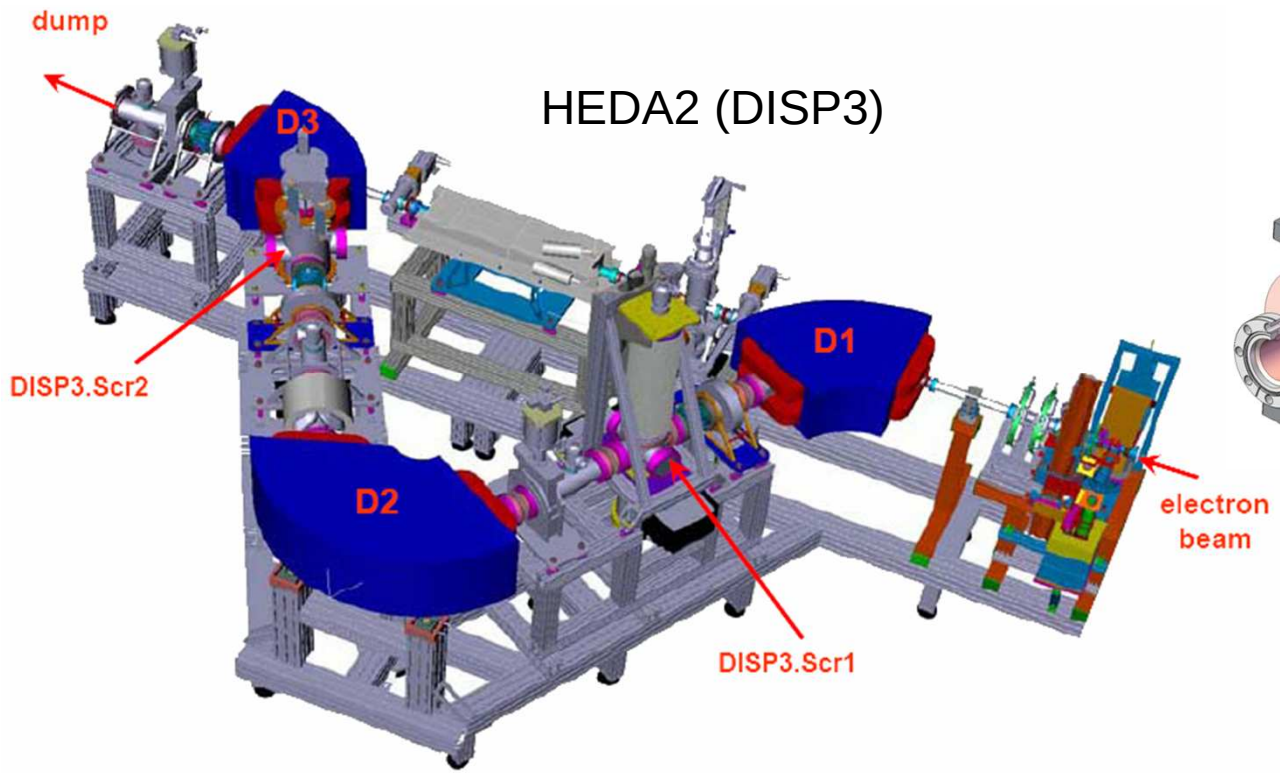
Main parameters:

Bunch charge	1 pC … 2 nC
Repetition rate	10 Hz
Beam energy after gun	1 … 7 MeV
Beam energy after booster	1 … 27 MeV
Number of bunches	1 … 800
Bunch spacing	1 us
Laser pulse temporal shape	2 ps Gauss … 22 ps flat-top



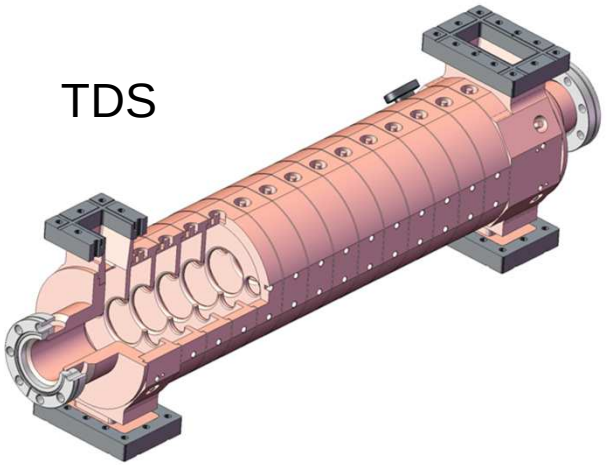
PITZ2.0 design



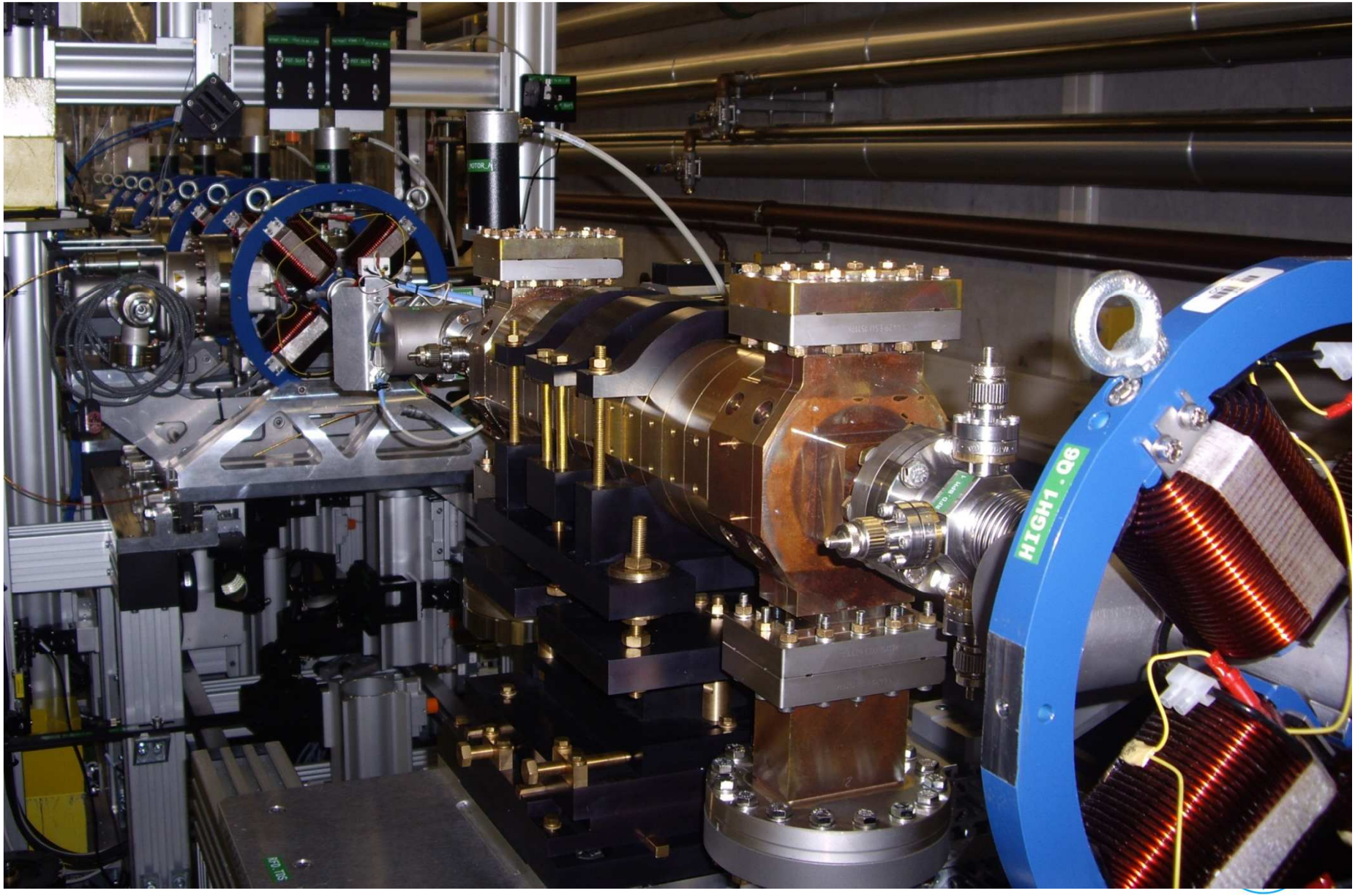


HEDA2 (DISP3)

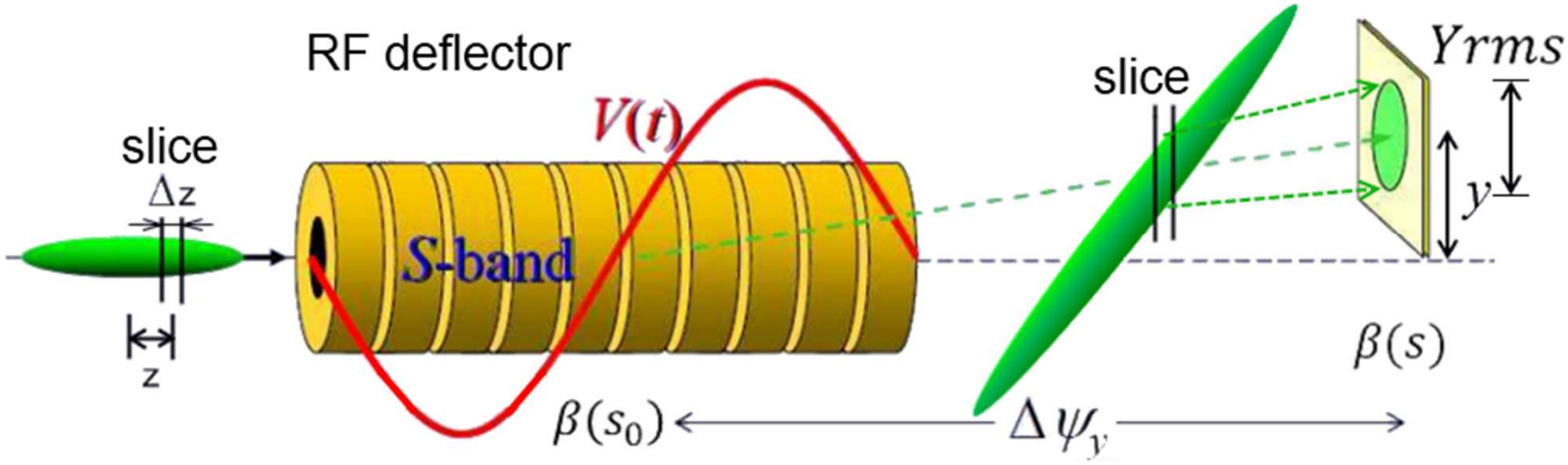
TDS



TDS in the PITZ beamline



TDS basic principles



$$y = \theta \cdot L = \frac{eV_0 k}{pc} \cdot z \cdot L = S \cdot z,$$

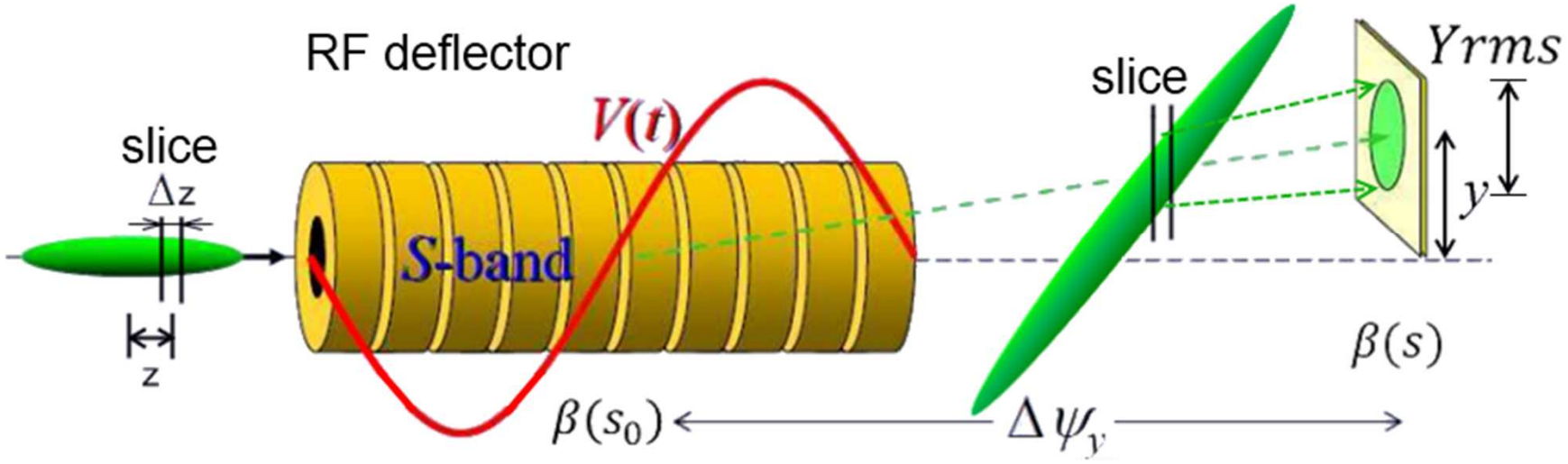
$$S = \frac{eV_0 k}{pc} L, \quad \text{in case of drift space}$$

where z – slice longitudinal position,
L – distance between TDS and screen,
V_0 – deflecting voltage, k – wave number,
pc – beam momentum, S – shear parameter,
y – slice vertical position at screen

$$S = \sqrt{\beta(s) \cdot \beta(s_0)} \cdot \sin(\Delta\psi_y) \cdot \frac{eV_0 k}{pc}$$

in the general case, where $\beta(s)$ - beta function at screen, $\beta(s_0)$ – beta function at TDS position, $\Delta\psi_y$ - beta function phase advance between TDS and screen.

TDS Longitudinal resolution



Δz – slice length
$V(t)$ – deflecting voltage (artistic view)
$\beta(s_0)$ – beta function inside TDS
$\beta(s)$ – beta function at screen
$\Delta\psi_y$ – beta function phase advance
$Yrms$ – slice vertical RMS size at screen

$$y = S \cdot z;\ Yrms^2 = \varepsilon\beta(s) + (S \cdot \Delta z)^2,$$

$$y \geq Yrms,$$

$$S \cdot z \geq \sqrt{\varepsilon\beta(s) + (S \cdot \Delta z)^2},$$

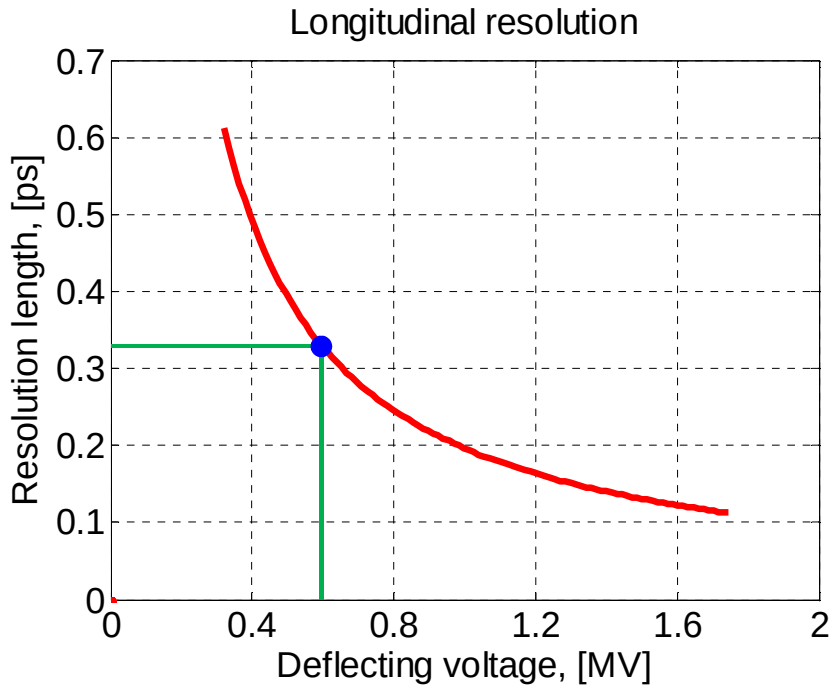
for $\Delta z \to 0$, we will get resolution length σ_z as:

$$\sigma_z = \frac{\sqrt{\varepsilon\beta(s)}}{S} = \frac{\sqrt{\varepsilon_{N,y}/\gamma}}{\sqrt{\beta(s_0)} \cdot \sin(\Delta\psi_y)} \cdot \frac{pc}{eV_0 k}$$

TDS Longitudinal resolution

$$\sigma_z = \frac{\sqrt{\varepsilon\beta(s)}}{S} = \frac{\sqrt{\varepsilon_{N,y}/\gamma}}{\sqrt{\beta(s_0)}\cdot\sin(\Delta\psi_y)}\cdot\frac{pc}{eV_0k}$$

For TDS deflecting voltage 0.6MV parameter S will be about 3.2, and for transverse RMS beam size 0.3 mm at screen (TDS OFF), longitudinal resolution will be 0.1 mm or 0.3 ps.

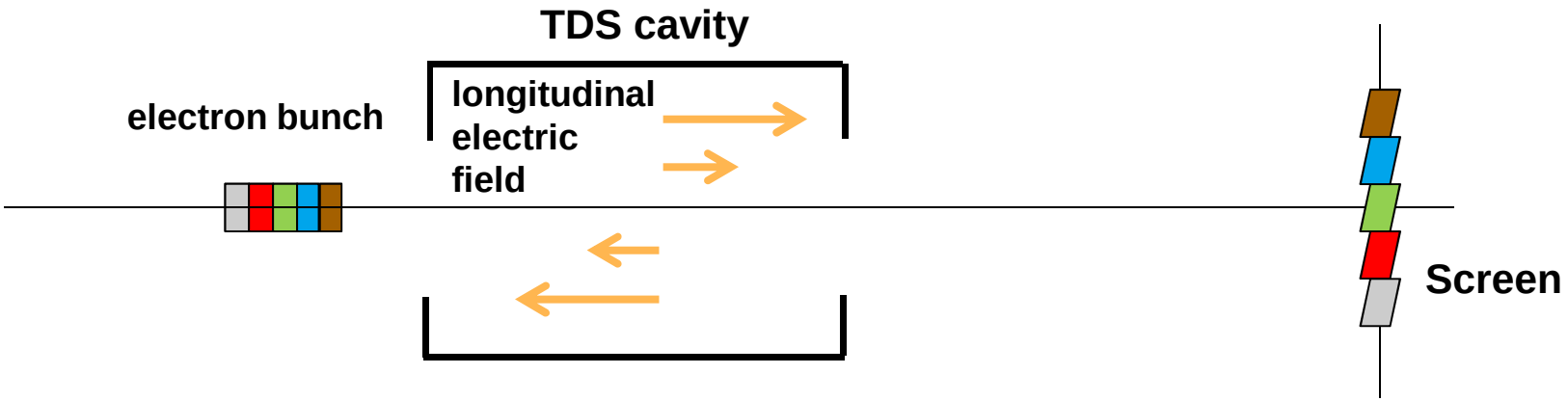


PITZ bunch typical parameter:

charge: 1 nC

length: 8 mm (24 ps)

TDS induced energy gain?

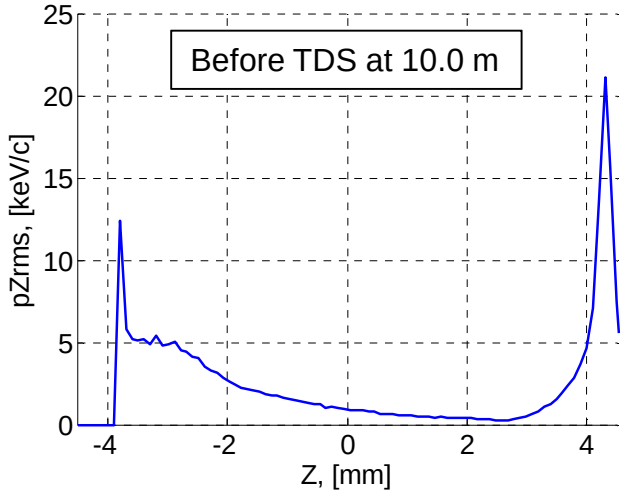


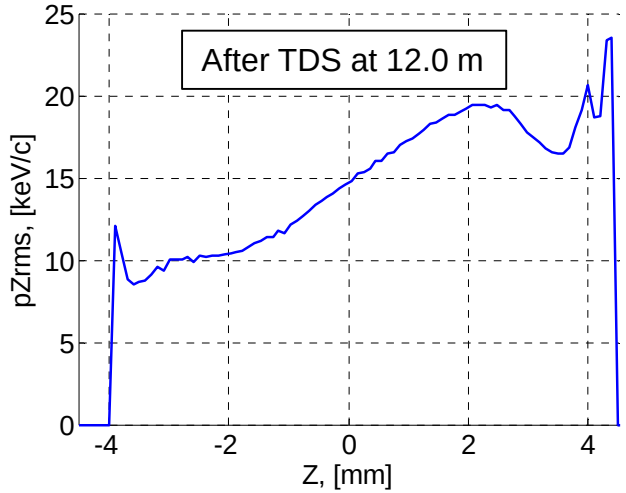
Panofsky-Wenzel theorem $\frac{\partial}{\partial z} F_\perp = -\nabla_\perp F_\parallel$

$$F_\perp = -\nabla_\perp \int_{-\infty}^{+\infty} eE_\parallel \, dz$$

$$\sigma_\delta = \frac{eV_0 k}{p_0 c} \cdot \sigma_y(s_0)$$

TDS induced energy spread

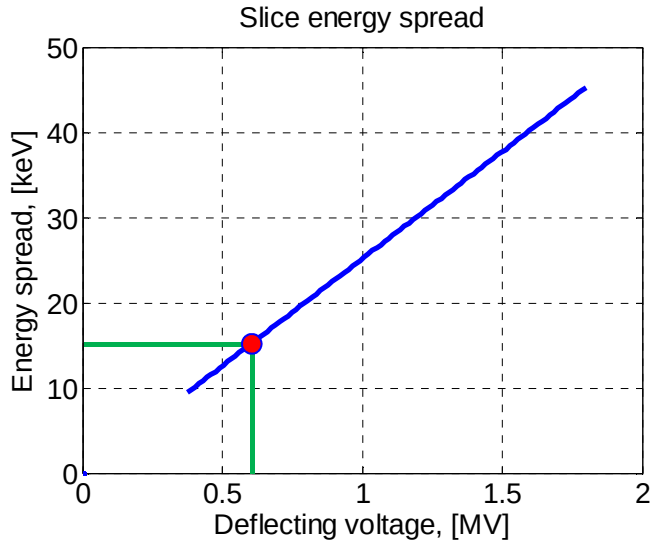




For V_0 = 0.6 MV, and beam size inside TDS σ_y = 0.4 mm

$$\sigma_\delta = \frac{eV_0 k}{p_0 c} \cdot \sigma_y(s_0)$$

For the V_0 = 0.6 MV, relative energy spread will be $7*10^{-4}$, which is about 15 keV for 25 MeV beam.



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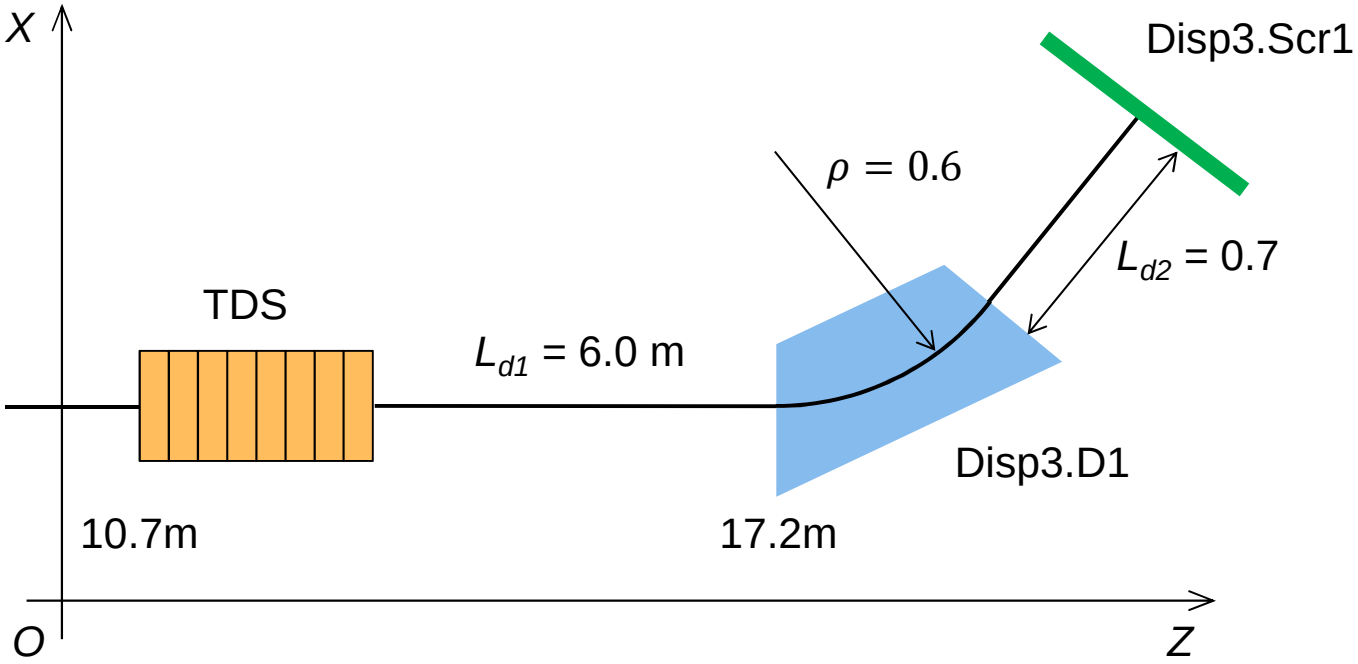
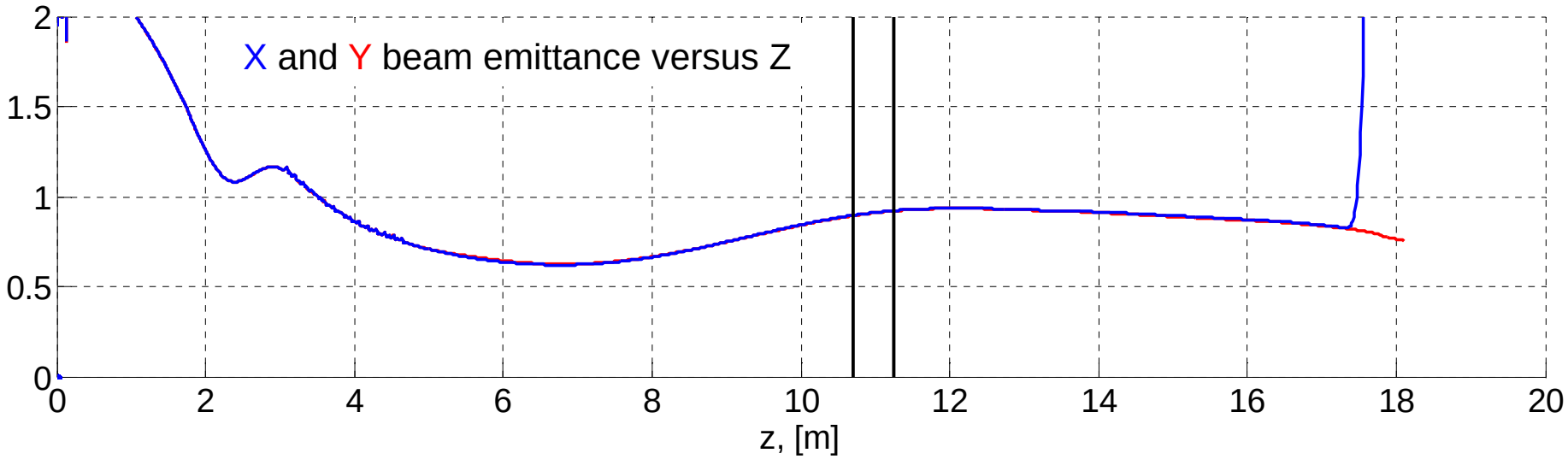
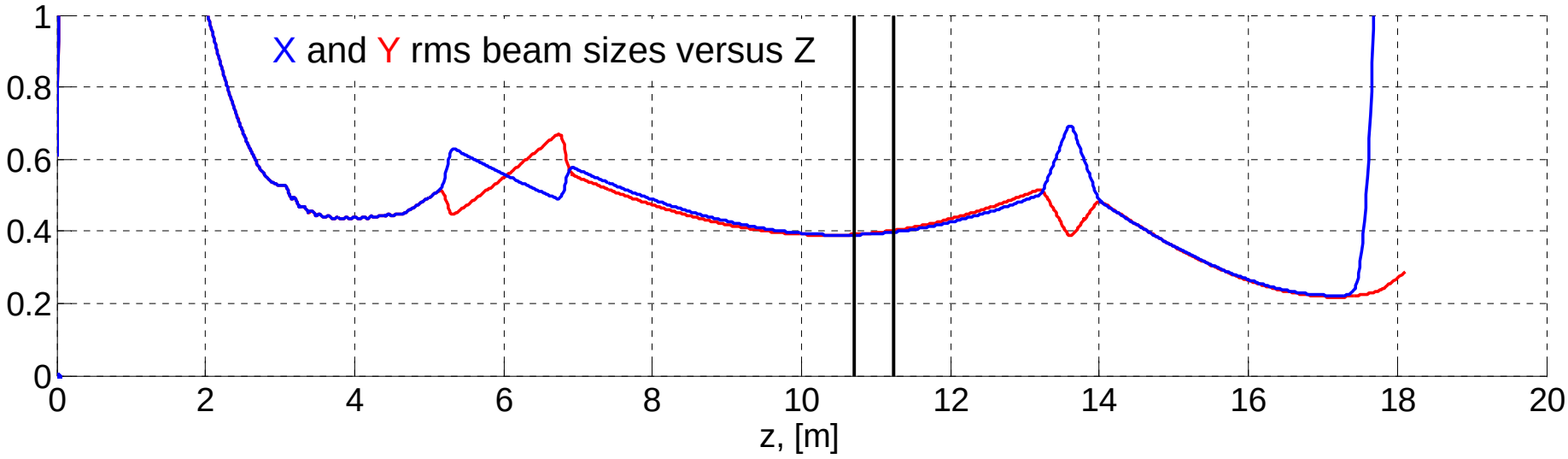
DESY

TDS measurement setup

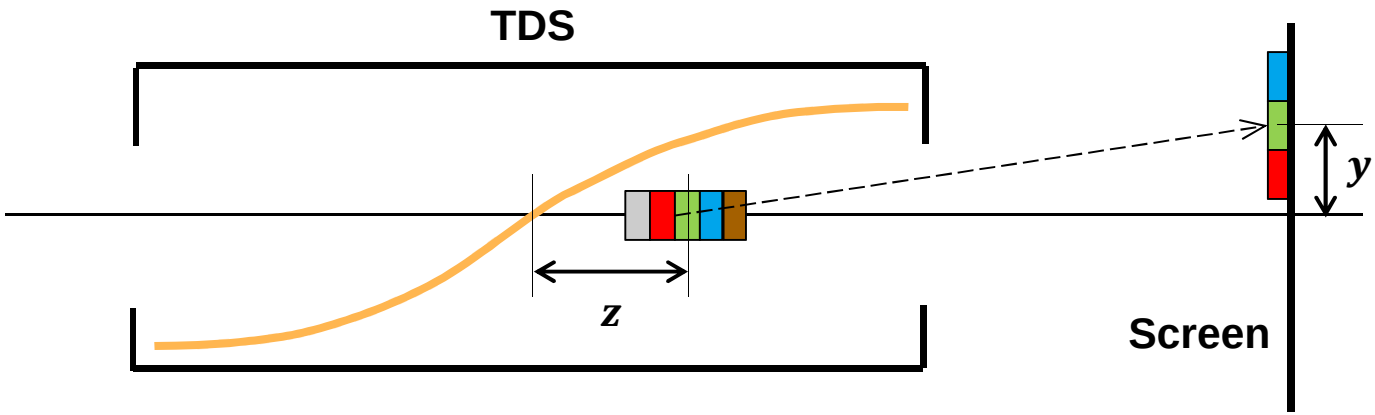


TDS beam optics, emittance and beam size





TDS calibration



$$S = \sqrt{\beta(s) \cdot \beta(s_0)} \cdot \sin(\Delta\psi_y) \cdot \frac{eV_0 k}{pc}$$

$$y = S \cdot z,$$

$$z = \beta \cdot c \cdot \Delta t = \frac{\beta \cdot c \cdot \Delta\varphi}{2 \cdot \pi \cdot f},$$

$$y = \frac{S \cdot \beta \cdot c}{2 \cdot \pi \cdot f} \cdot \Delta\varphi = \frac{S \cdot \beta \cdot c}{360 \cdot f} \cdot \Delta\Phi$$

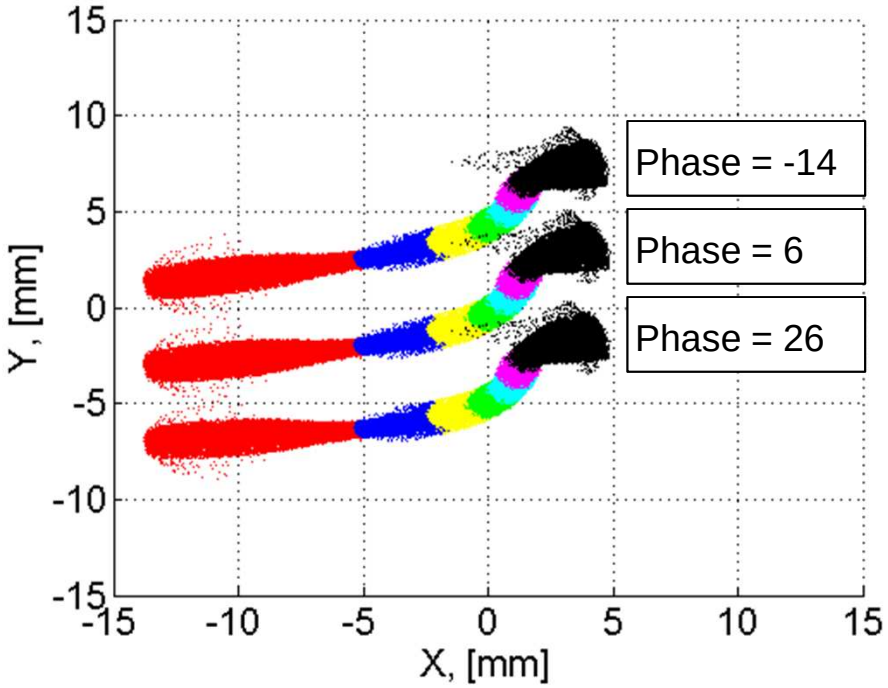
$y = K_1 \cdot \Delta\Phi$, where

$$K_1 = \frac{S \cdot \beta \cdot c}{360 \cdot f}$$

or

$$S = \frac{K_1 \cdot 360 \cdot f}{\beta \cdot c}$$

TDS calibration, beam position versus RF phase

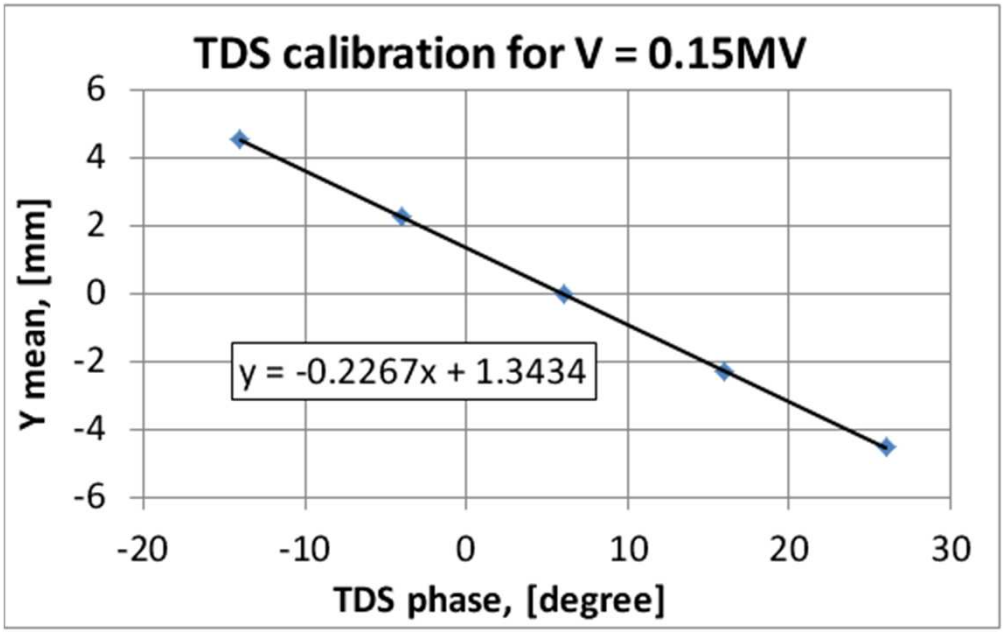


Bunch image for three different TDS RF phase, 0.15MV deflecting voltage.

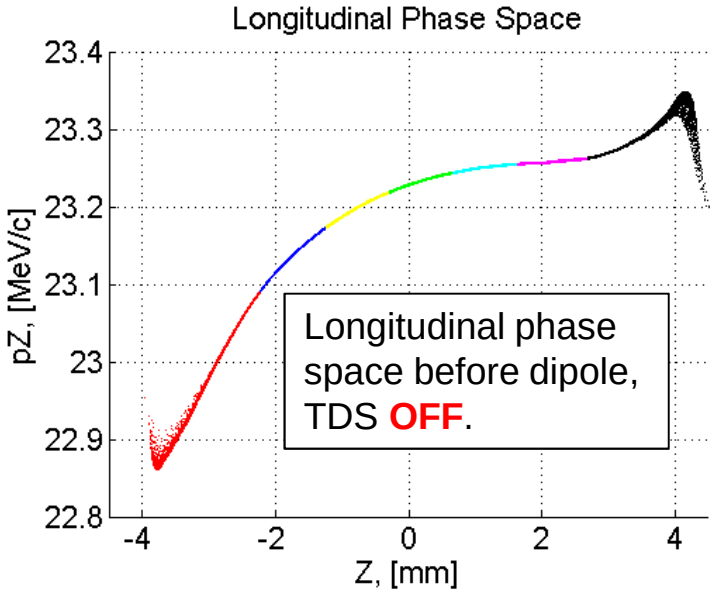
For $K_1 = 0.2267 \cdot 10^{-3}$

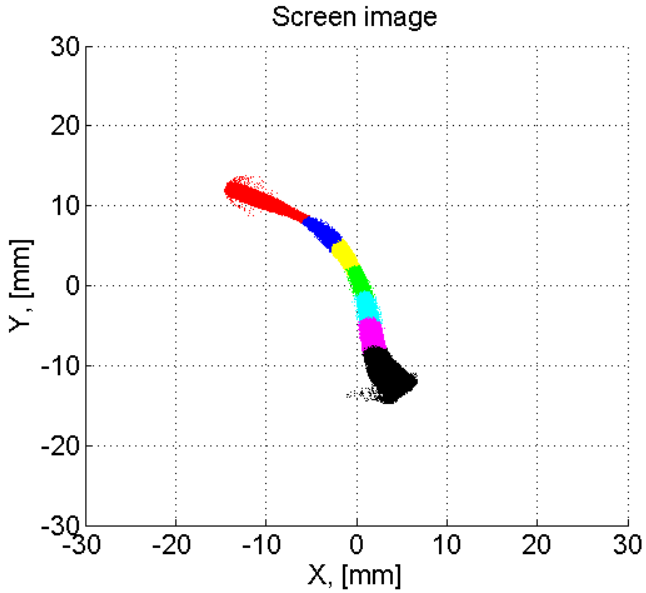
$S = 0.817$ (0.15MV), or

$S = 3.266$ (0.60MV)

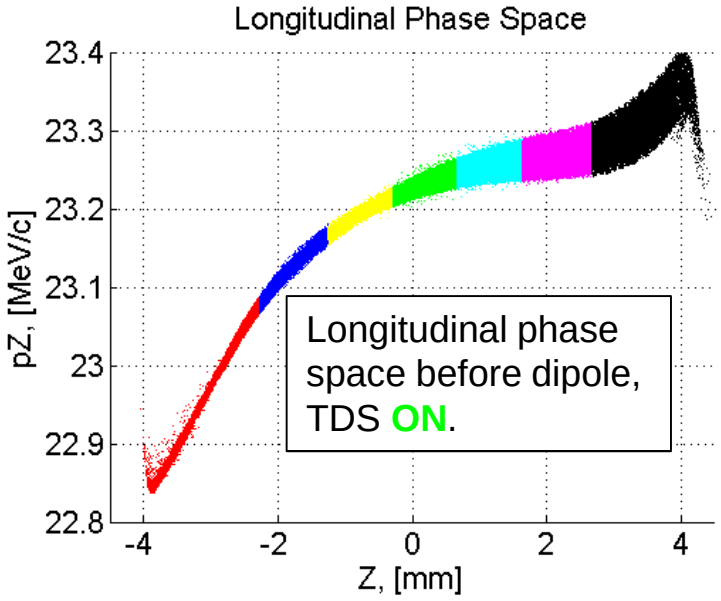


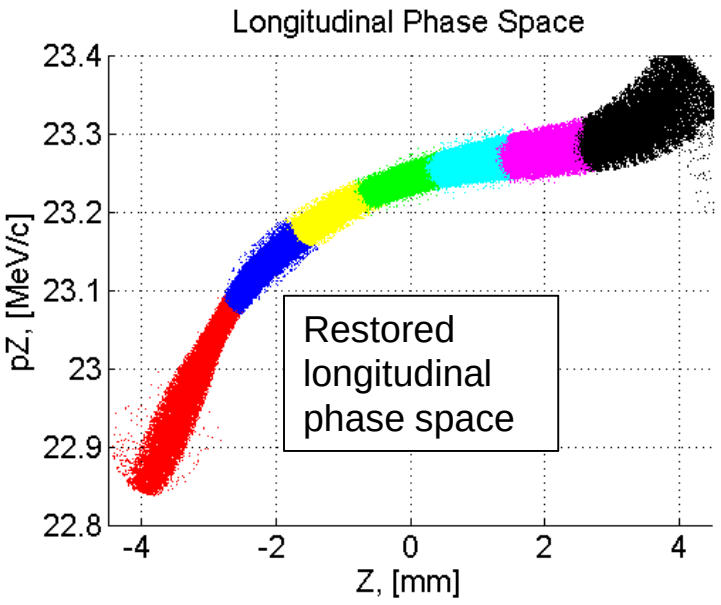
TDS longitudinal phase space measurement





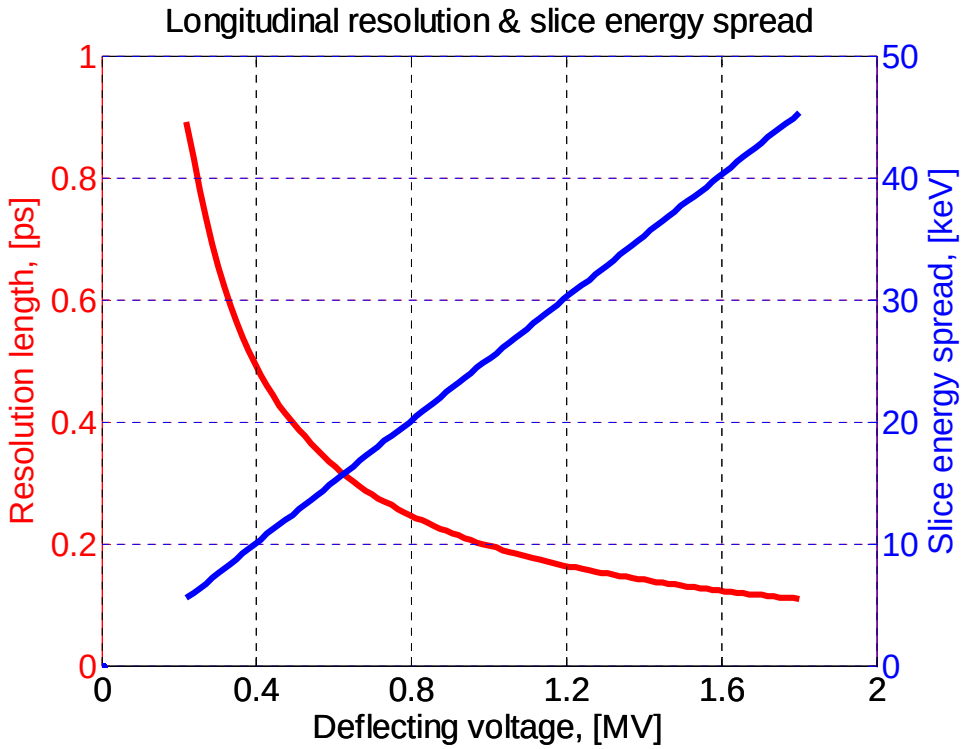
Beam image on screen after dipole, for TDS field 0.6MV





Summary

- TDS longitudinal resolution for 0.6 MV deflecting voltage – 0.3 ps.
- TDS induced slice energy spread is about 15 keV.



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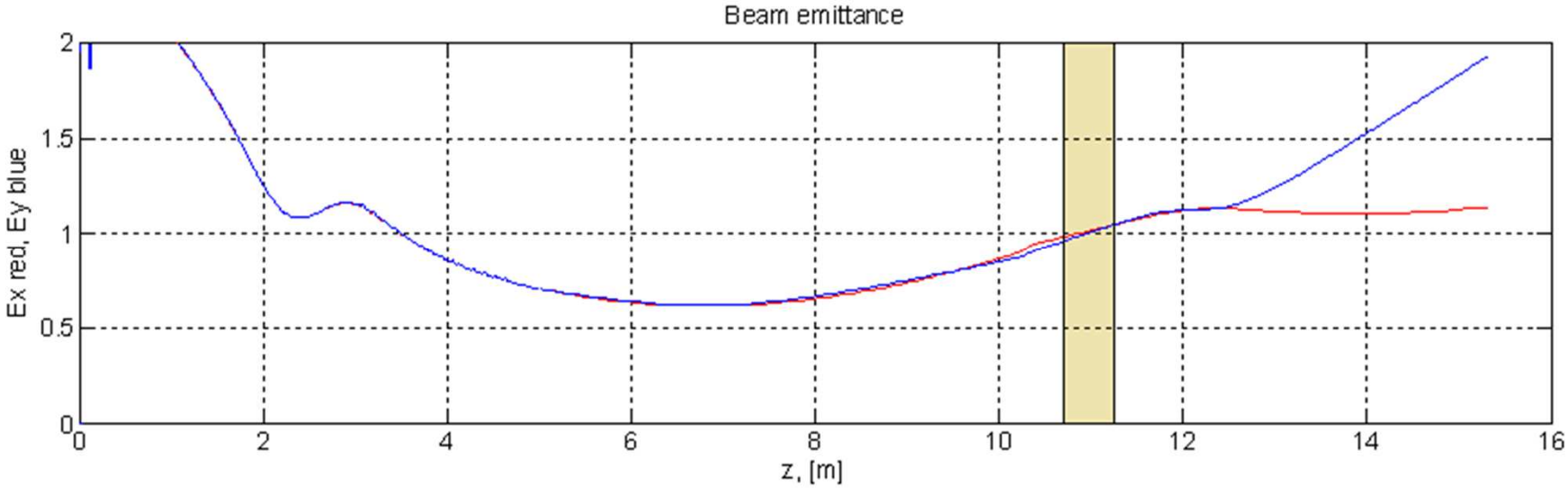
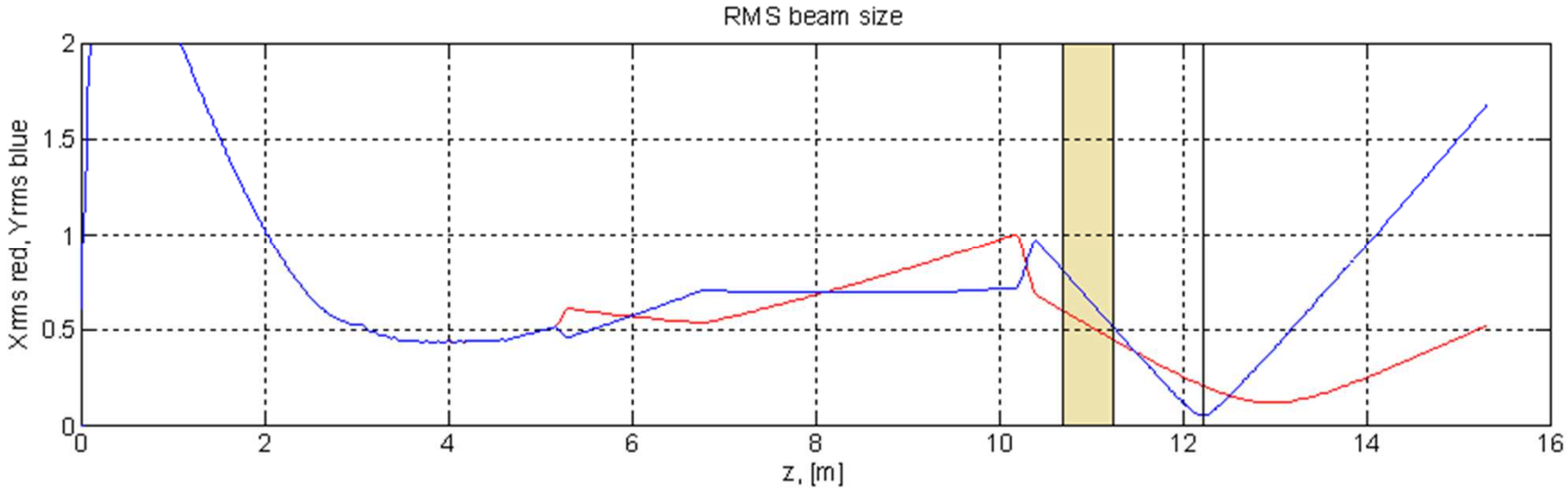
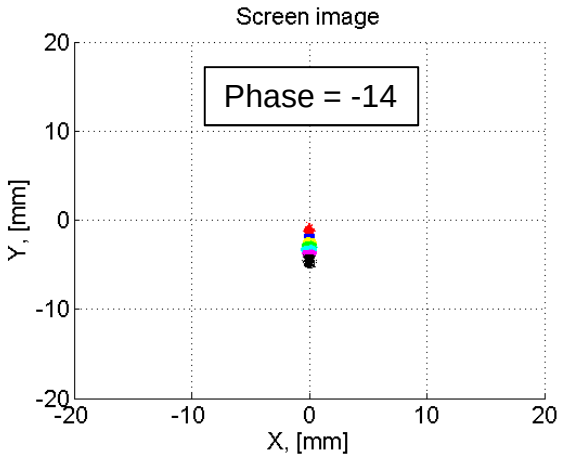
DESY

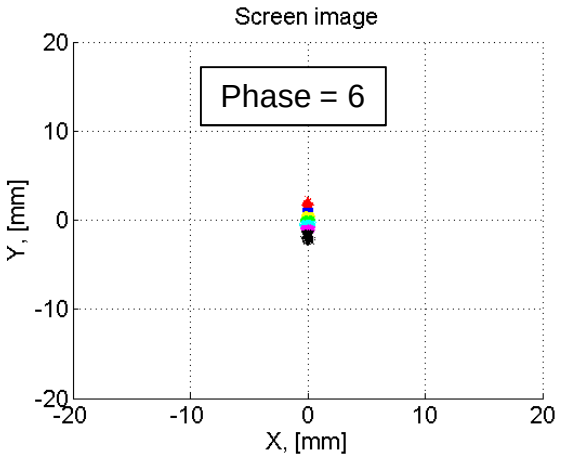
Beam optics, ASTRA simulation, 1nC

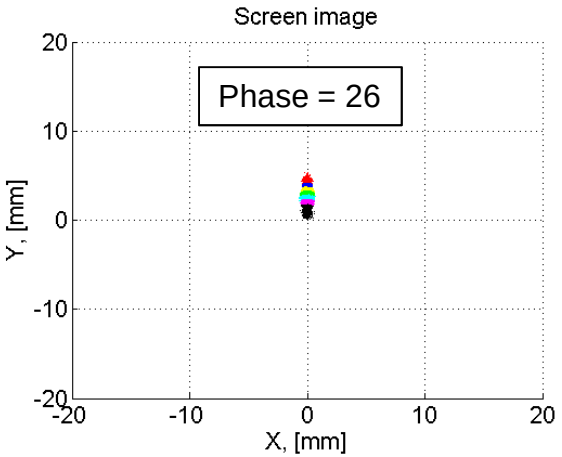


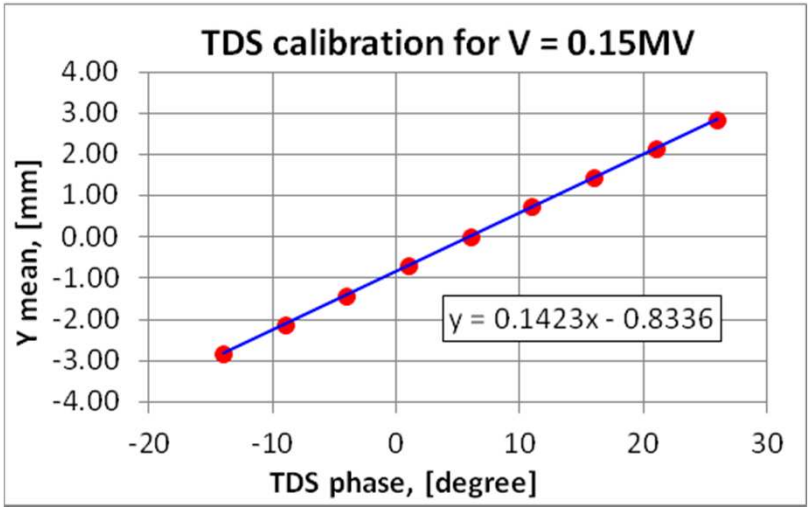


TDS calibration at PST.Scr1, 1nC bunch charge









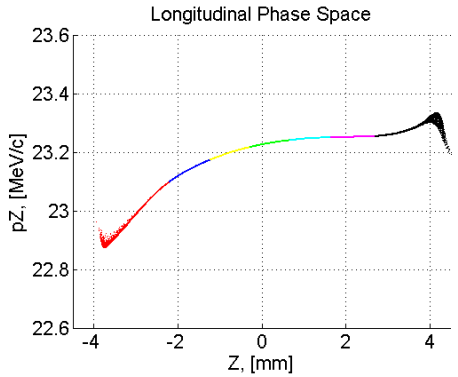
$$S = \frac{K_1 \cdot 360 \cdot f}{\beta \cdot c} = 0.51$$

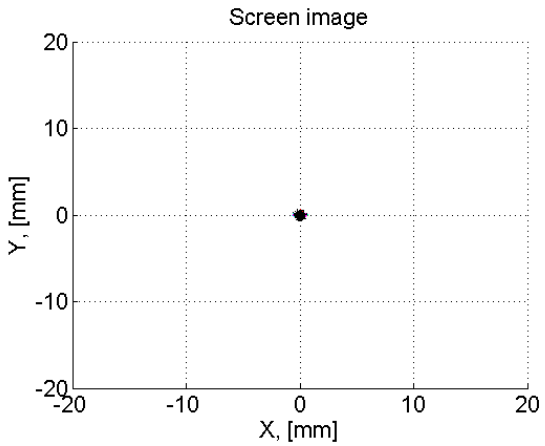
$$S(0.6MV) = 2.046$$

$$S(1.2MV) = 4.092$$

First screen after TDS at 12.238m (PST.Scr1), 1nC

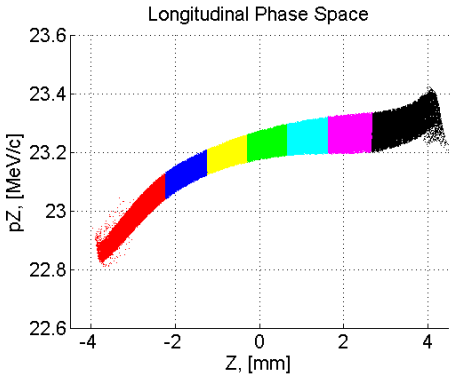
V_0=0.0MV

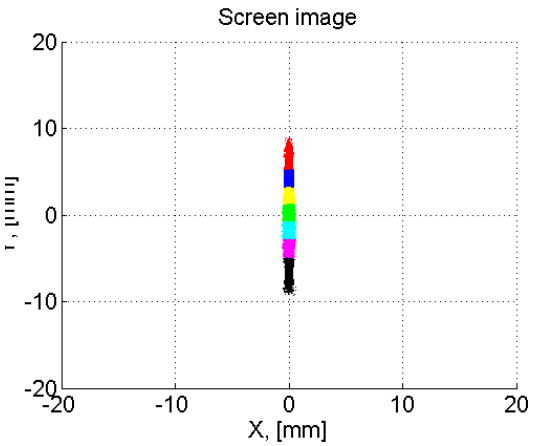




Xrms = 0.21mm
Yrms = 0.05mm

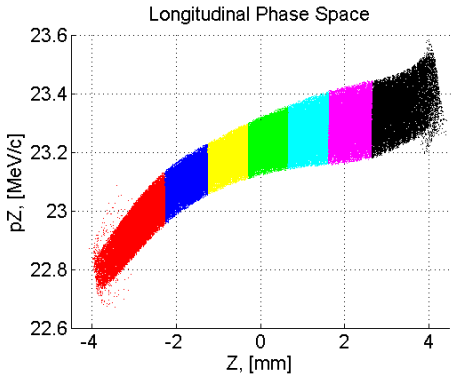
V_0=0.6MV

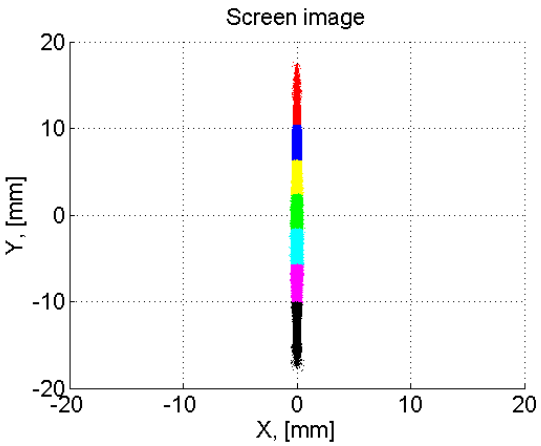




S = 2.0
σ_z= 25um = 80fs

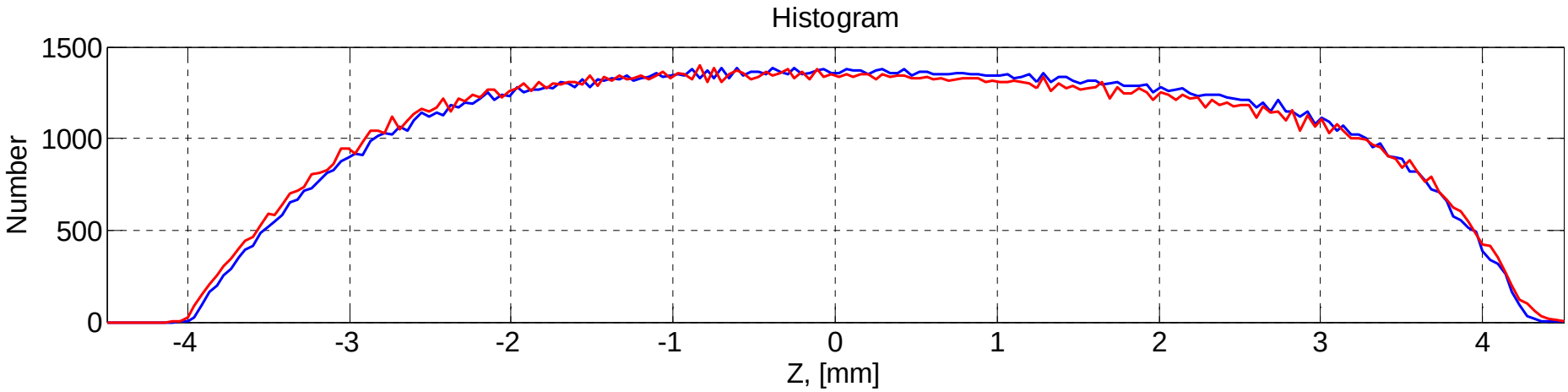
V_0=1.2MV





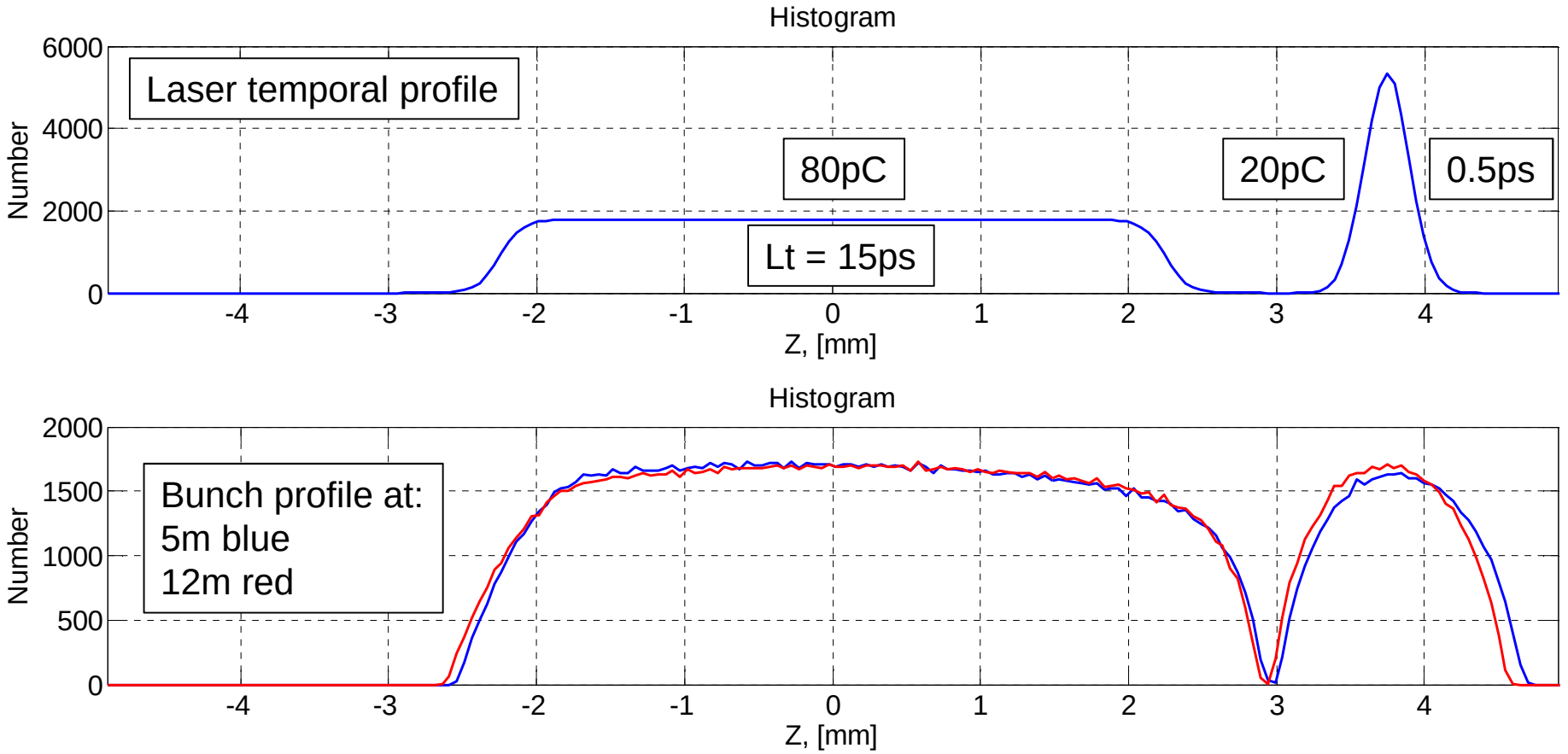
S = 4.0
σ_z= 12um = 40fs

Bunch longitudinal profile, 1nC

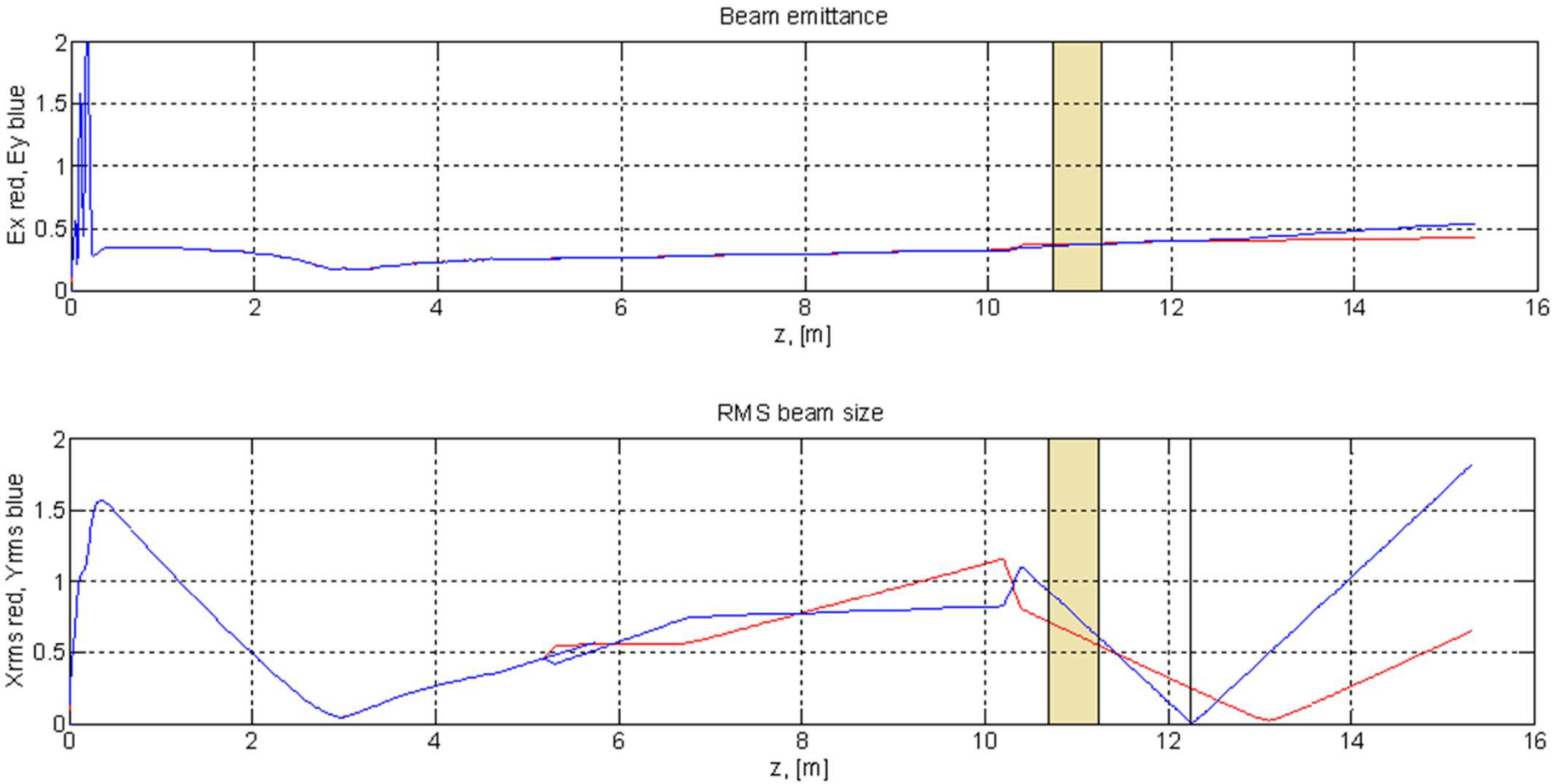


Blue line – bunch longitudinal profile at screen position
Red line – vertical profile of bunch image at screen scaled with S = 4.1.

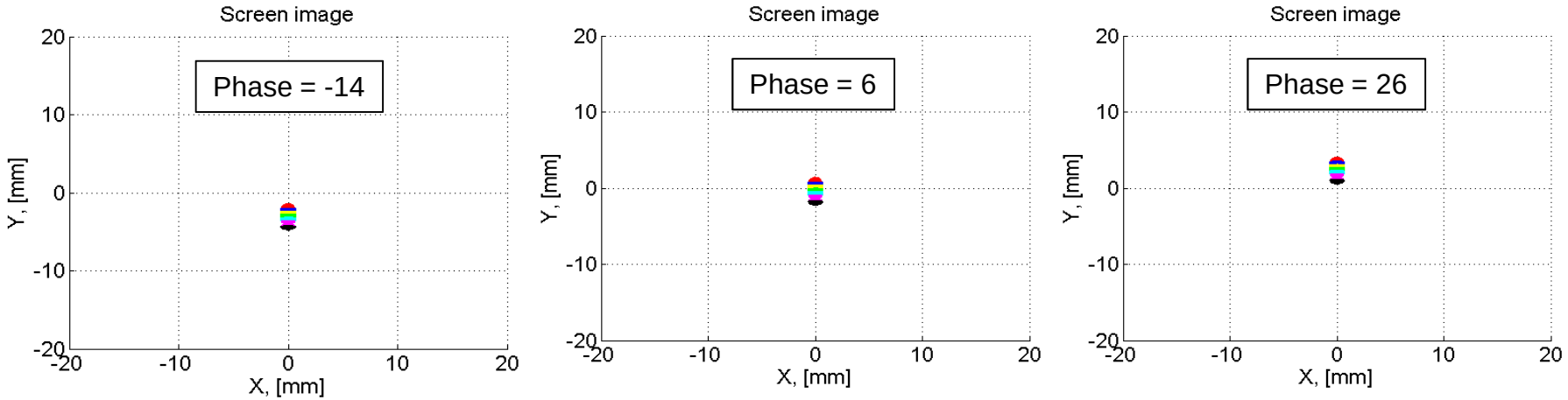
Simulation with 100pC, special profile

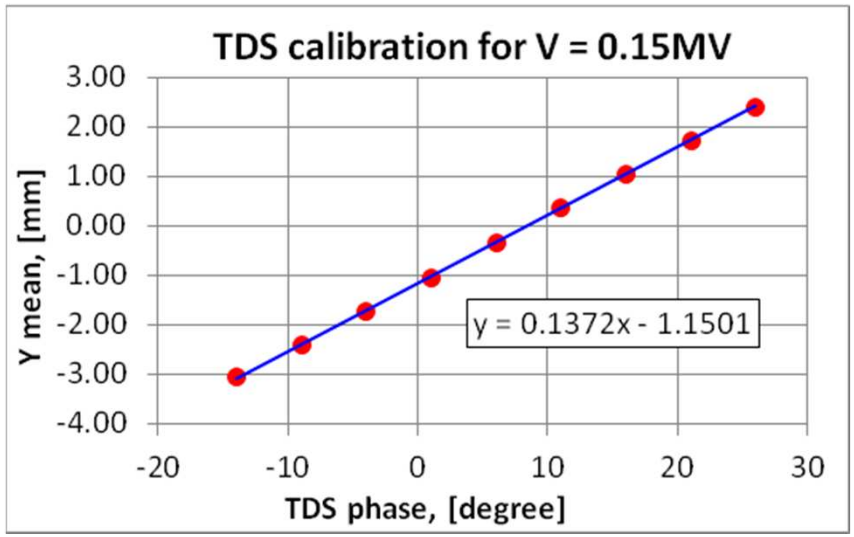


Beam optics, ASTRA simulation, 100pC



TDS calibration at PST.Scr1, 100pC bunch charge





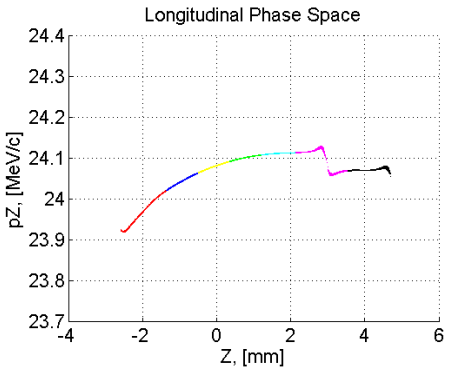
$$S = \frac{K_1 \cdot 360 \cdot f}{\beta \cdot c} = 0.49$$

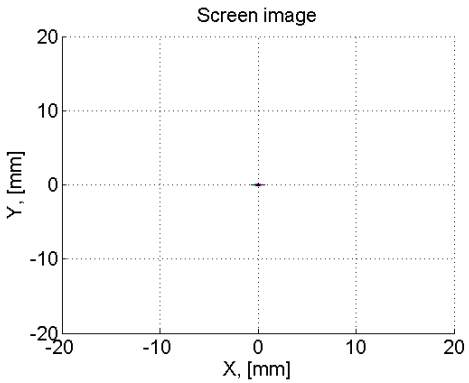
$$S(0.6MV) = 1.977$$

$$S(1.2MV) = 3.954$$

First screen after TDS at 12.238m (PST.Scr1), 100pC

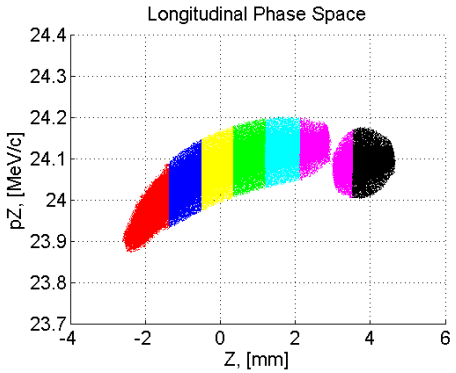
V_0=0.0MV

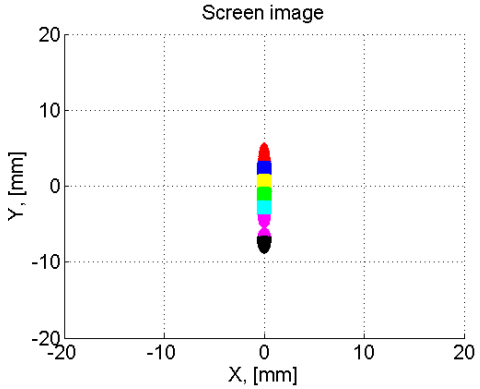




Xrms = 0.256mm
Yrms = 0.024mm

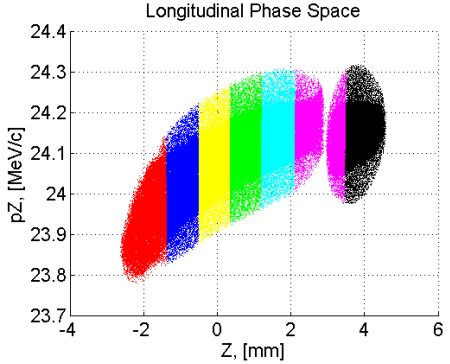
V_0=0.6MV

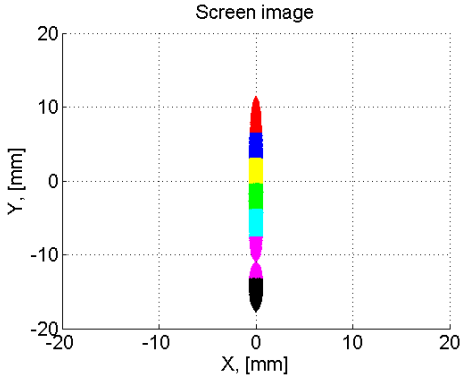




S = 2.0
σ_z= 12um = 40fs

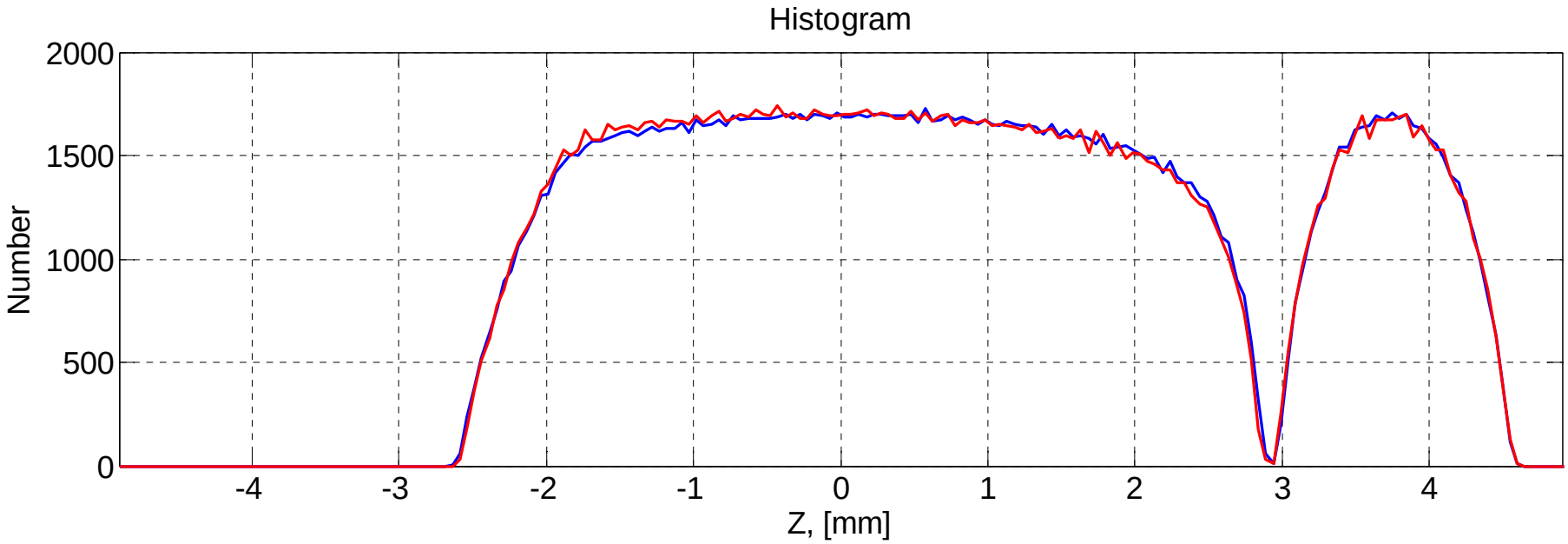
V_0=1.2MV





S = 4.0
σ_z= 6um = 20fs

Bunch longitudinal profile, 100pC



Blue line – bunch longitudinal profile at screen position
Red line – vertical profile of bunch image at screen Scaled with S = 4

Conclusion

- Measured bunch longitudinal profile looks identical to the real one (both are results of simulation).
- Achievable longitudinal resolution is **6um** or **20fs** for **100pC** bunch, and **12um** or **40fs** for **1nC** bunch charge.

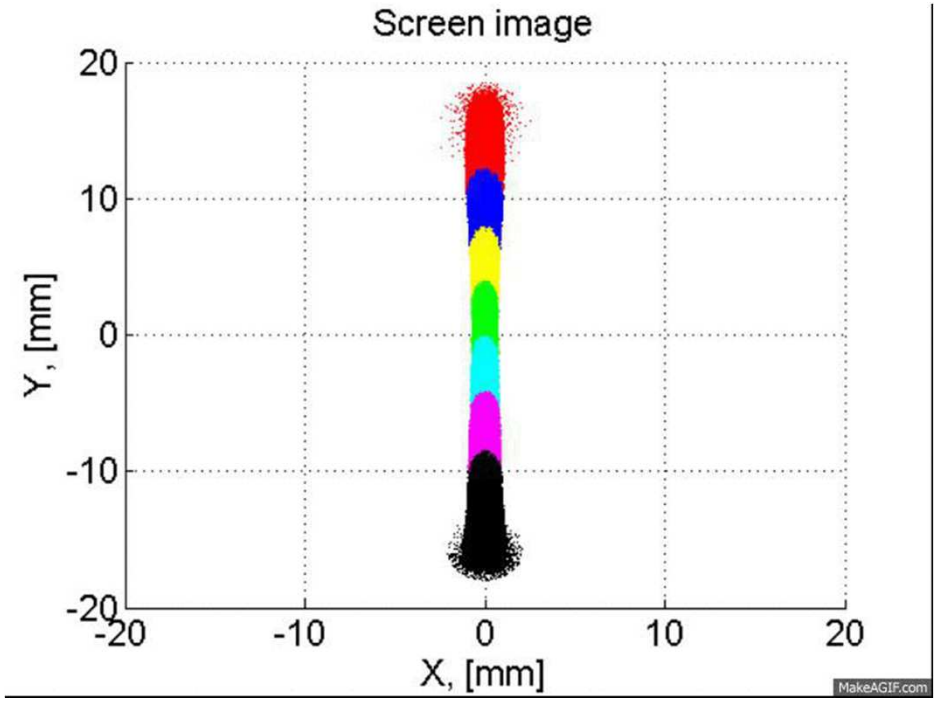
Simulation of the different type of measurement with the RF deflecting structure at PITZ

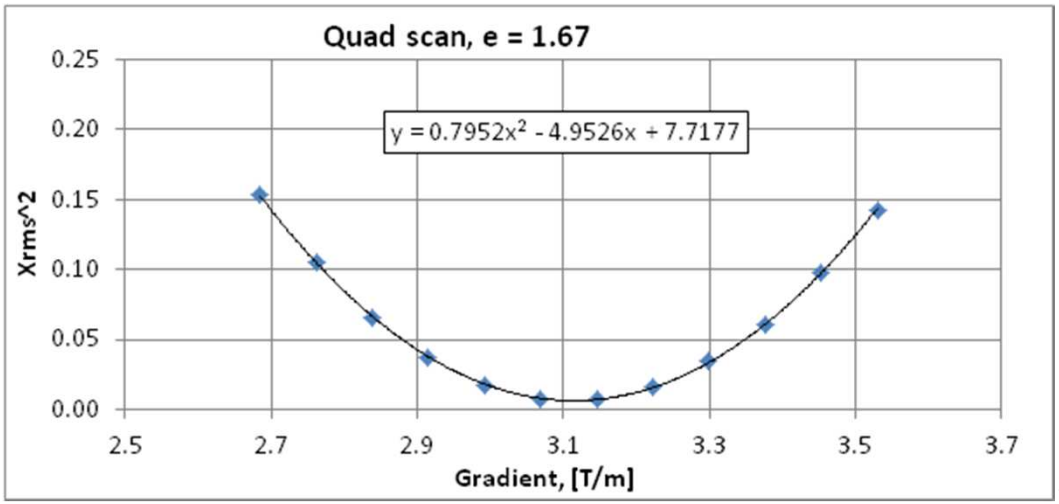
1. PITZ2.0 design
2. TDS basic principle and resolution
3. Longitudinal phase space measurement
4. Bunch length measurement
5. **Slice emittance measurement**
6. Conclusion and outlook.

HELMHOLTZ GEMEINSCHAFT

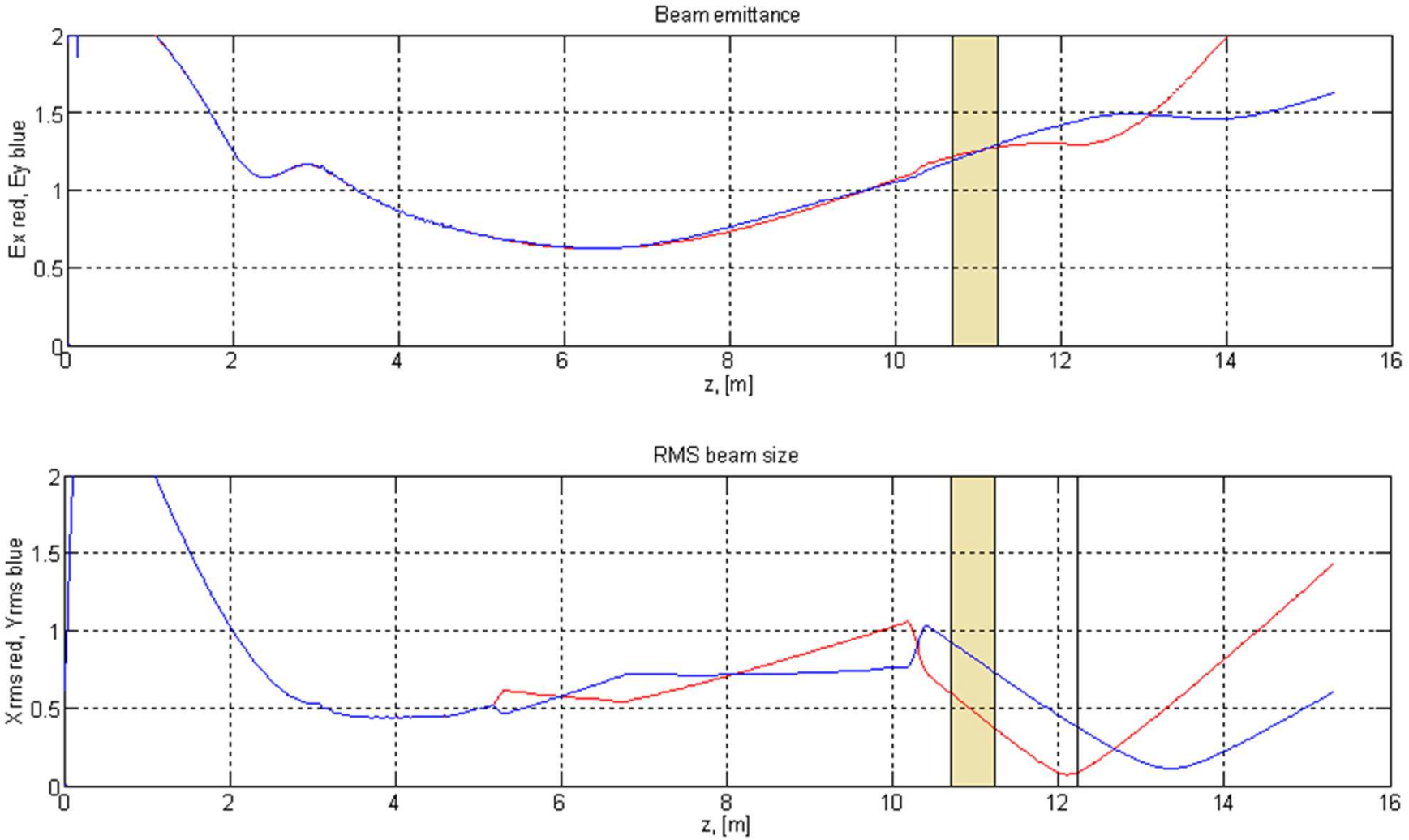
DESY

Quad scan (H1.Q6) with TDS deflecting voltage 1.2 MV.

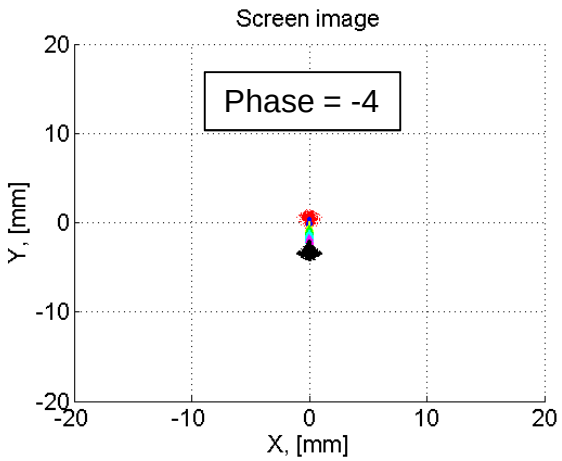


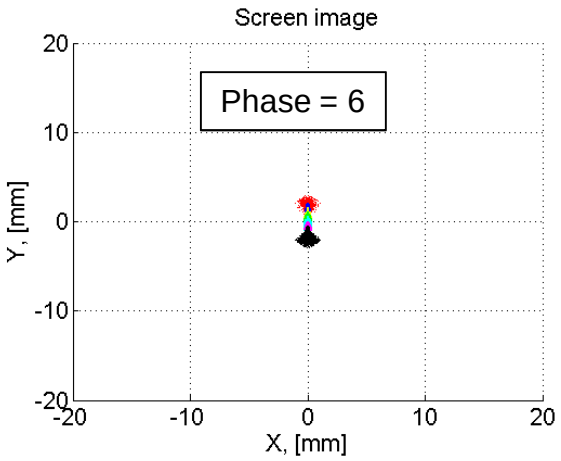


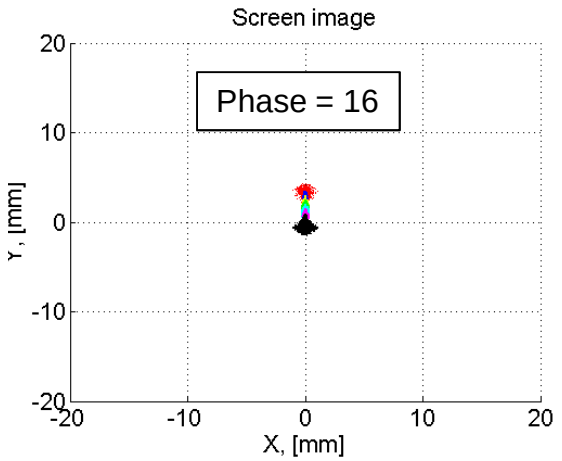
Beam optics, ASTRA simulation, 1nC

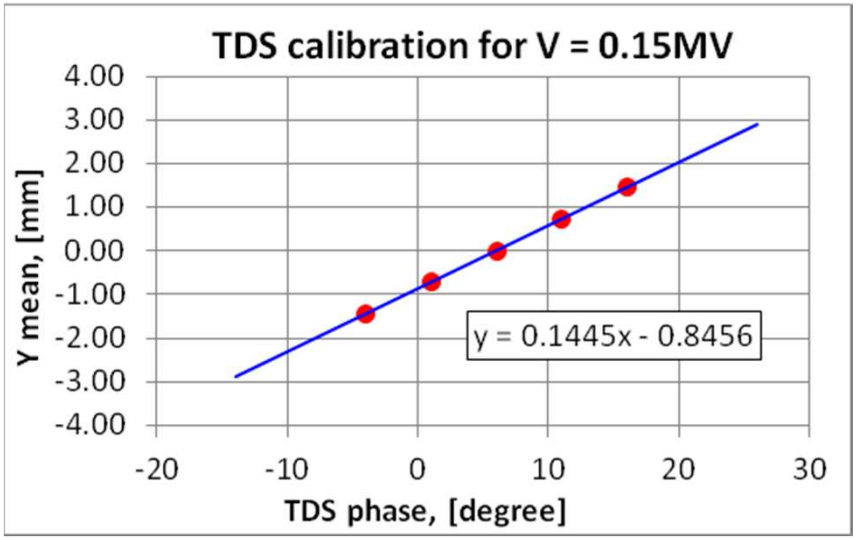


TDS calibration at PST.Scr1, 1nC bunch charge







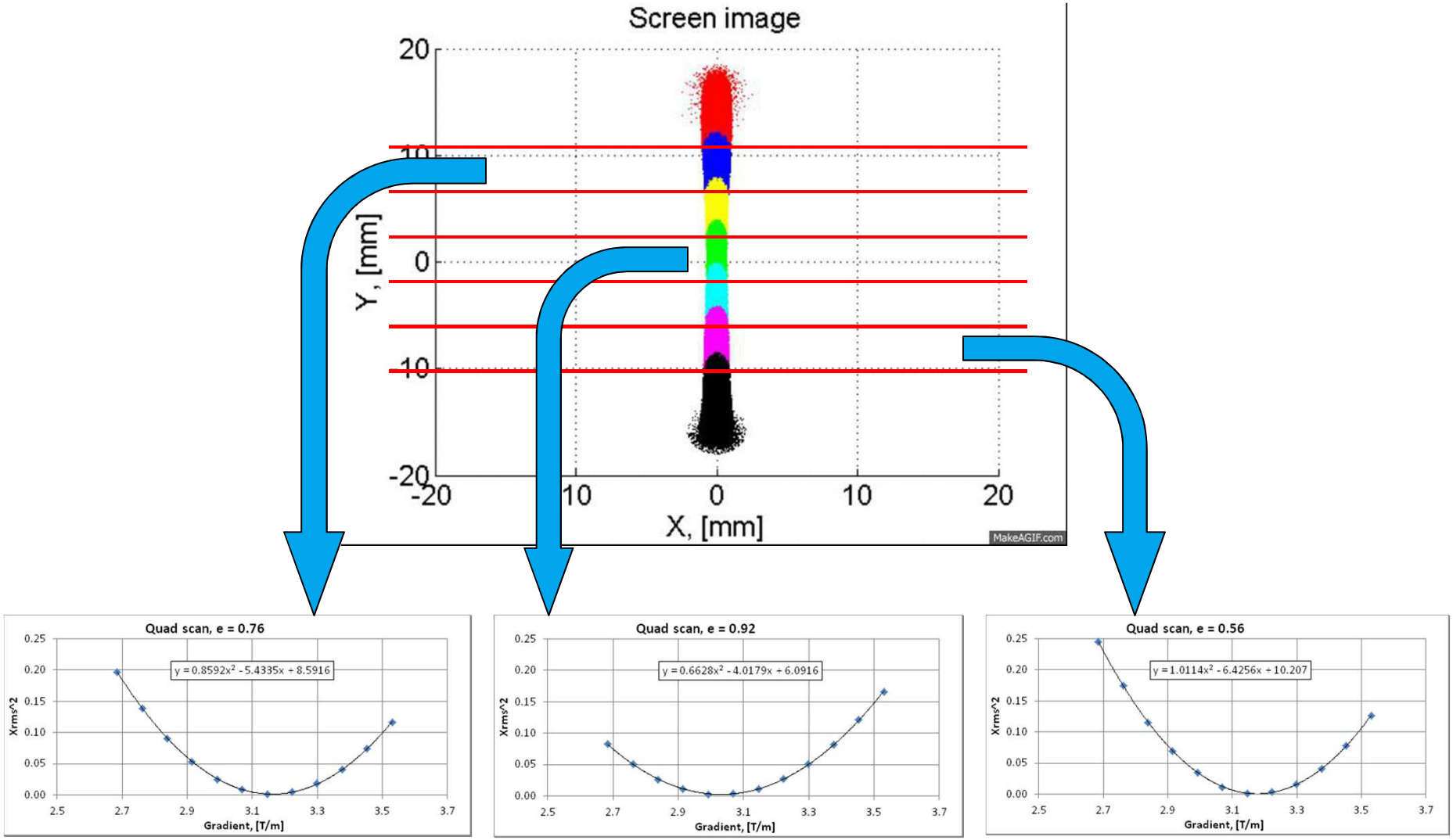


$$S = \frac{K_1 \cdot 360 \cdot f}{\beta \cdot c} = 0.5121$$

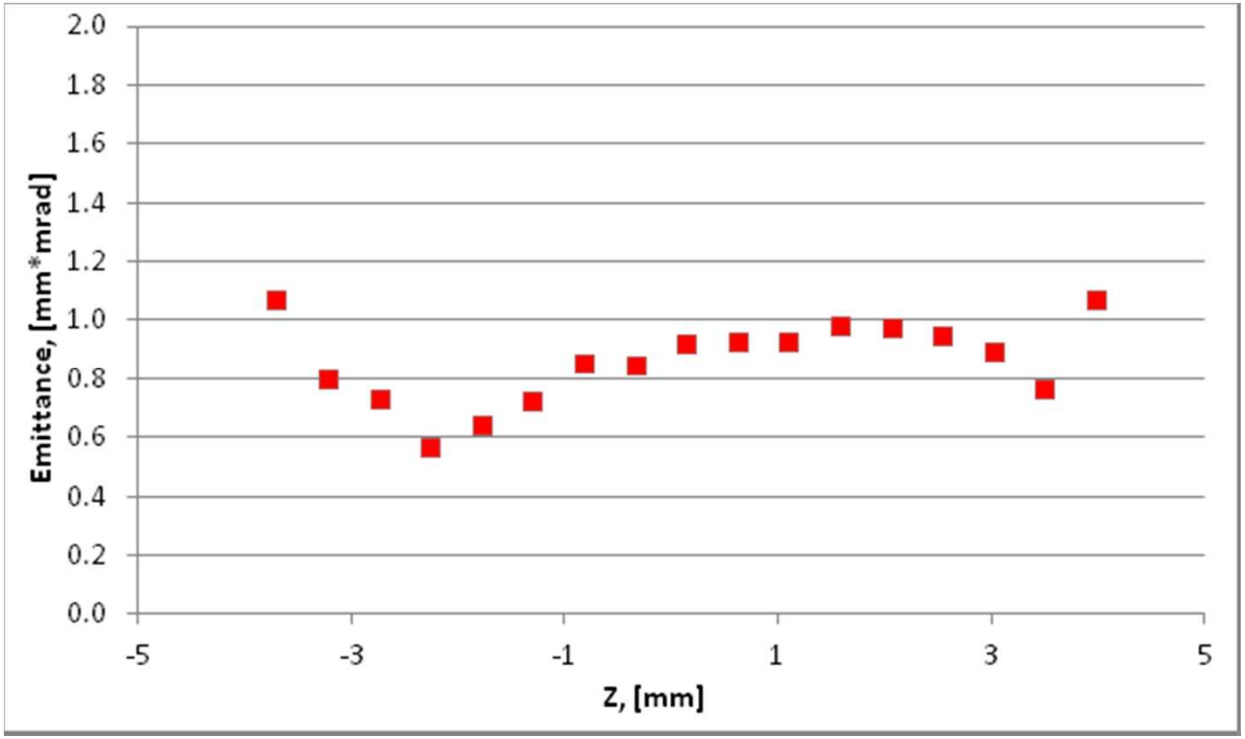
$$S(0.6MV) = 2.083$$

$$S(1.2MV) = 4.165$$

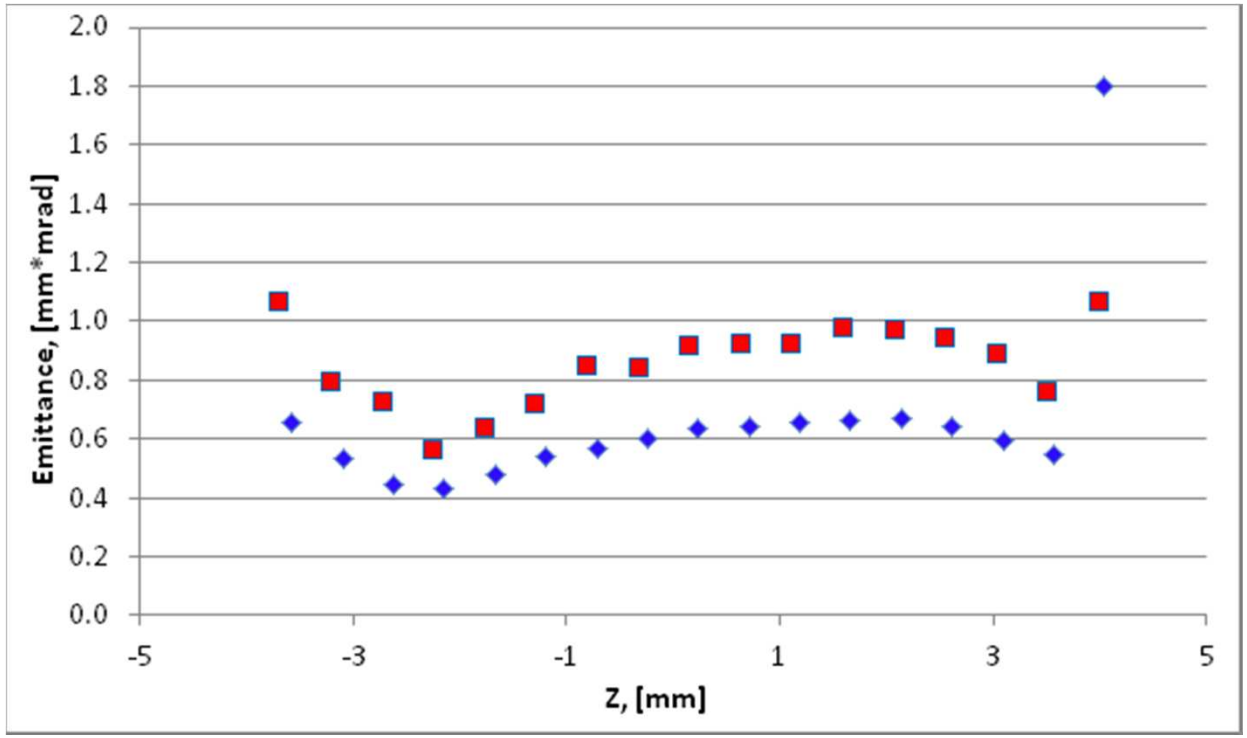
Quad scan (H1.Q6) with TDS deflecting voltage 1.2 MV.



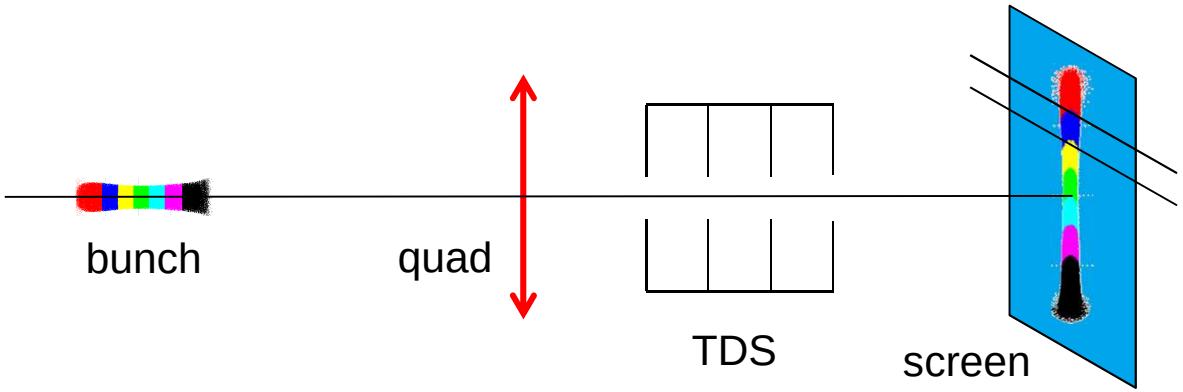
Quad scan summary

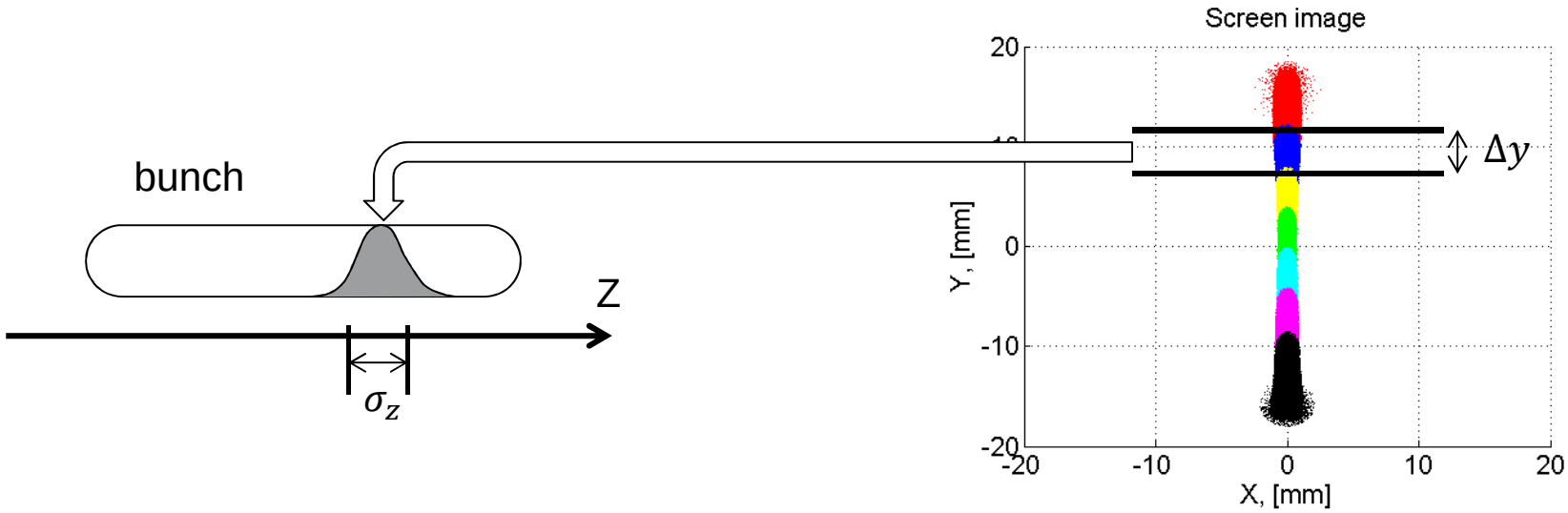


Quad scan summary, compare results

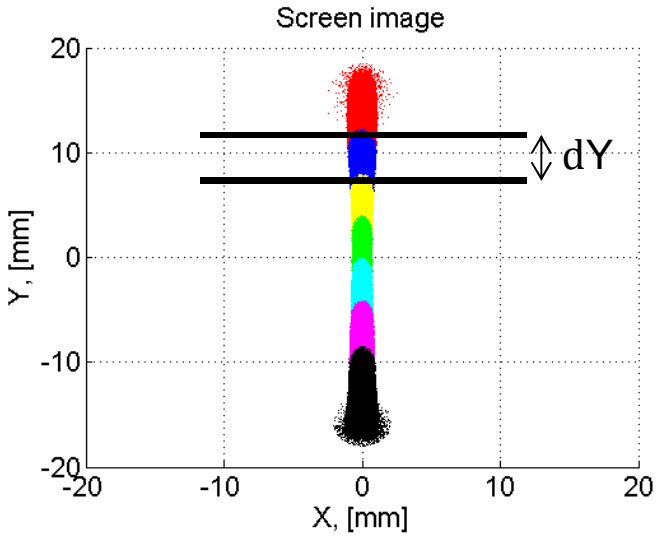


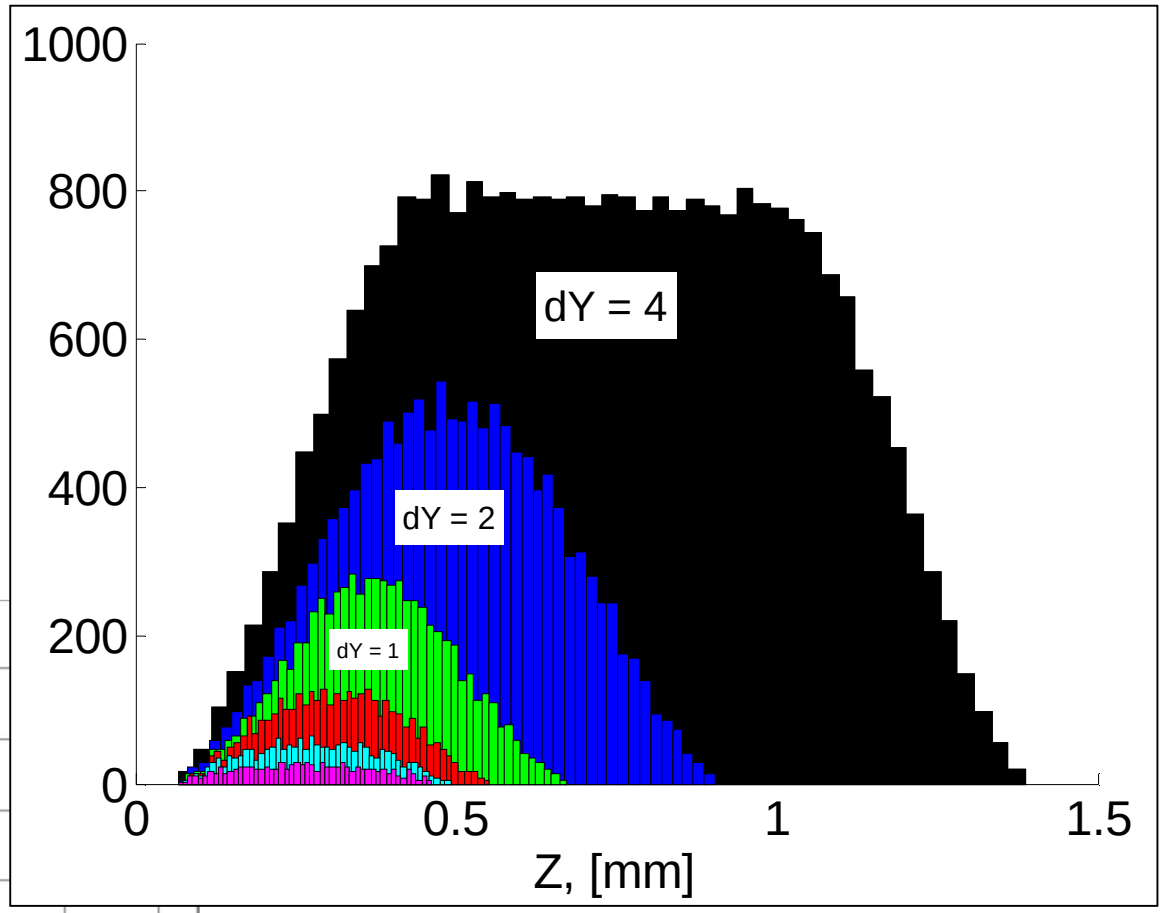
Longitudinal resolution

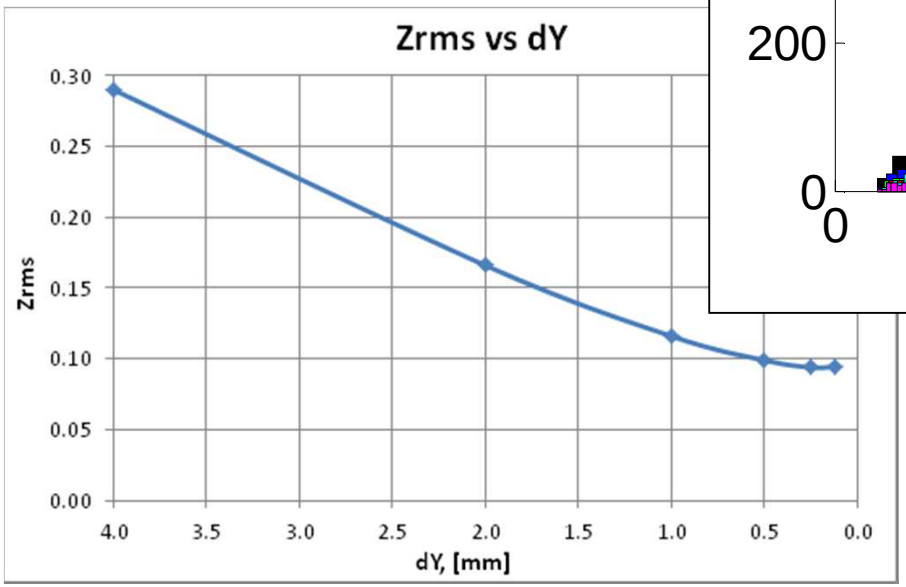




Slice resolution, slice length Zrms and stripe width dY







Conclusion

- Slice emittance measurement simulation done in ASTRA for 1nC bunch charge
- Achieved longitudinal resolution is about 0.1mm* (RMS), which gives us about 80 slices per bunch.

*for Gaussian distribution RMS = 0.1mm corresponds to FWHM = 0.24mm

Summary

- Simulation of the longitudinal phase space measurement, bunch length measurement and slice emittance measurement were done with the ASTRA simulation code.
- Simulated results are in good agreement to what was expected.
- Achievable resolutions are:
  - 0.3 ps (0.1 mm) for longitudinal phase space measurement
  - 0.04 ps (0.012 mm) for bunch length measurement
  - 0.3 ps (0.1 mm) for slice emittance measurement