Self-modulation studies: Electron beam longitudinal phase space after beam-plasma interaction

- **Matching of 22 MeV electron beam for beam-plasma interaction**
- **Further beam transport after plasma until HEDA2**

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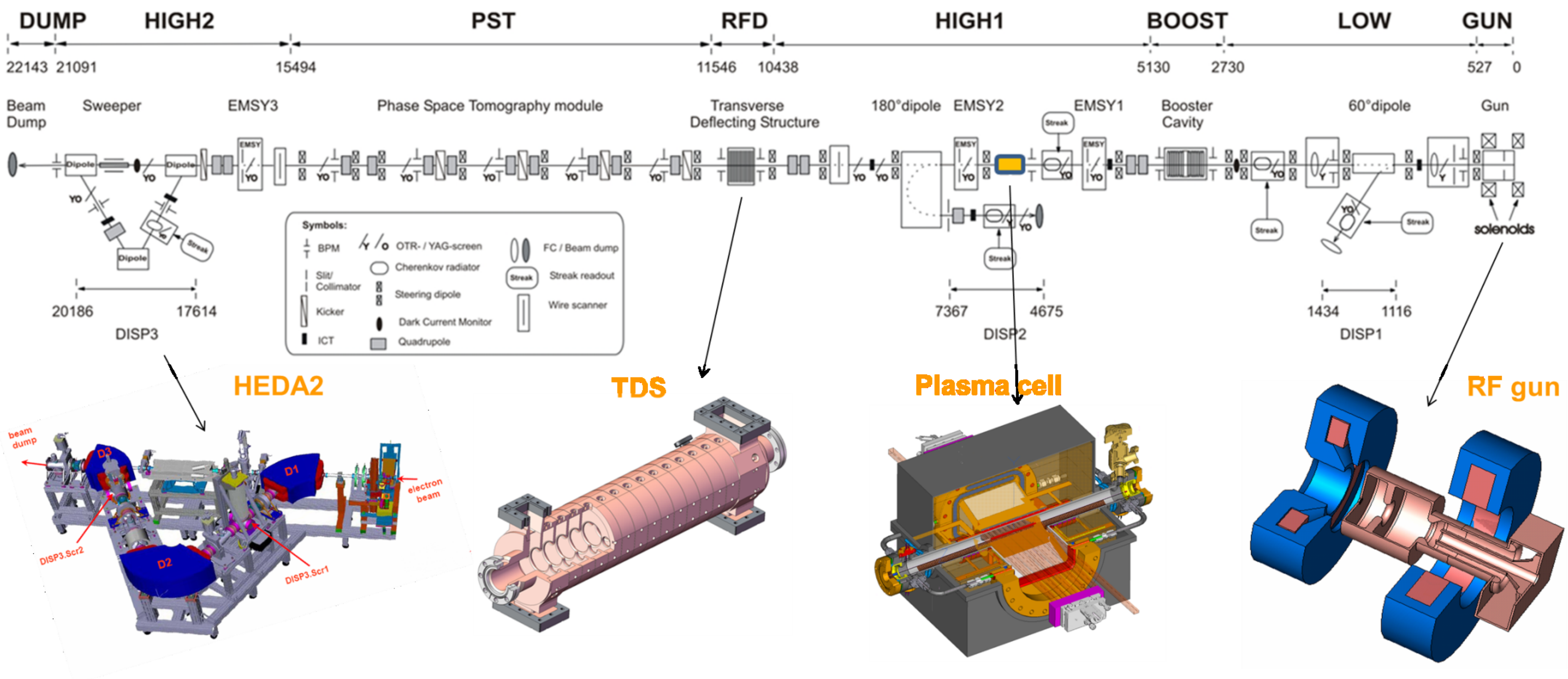
DESY

PITZ beamline for self-modulation studies



← **Direction of e-beam propagation**

Goal and parameters for ASTRA simulations

Requirements for 100pC electron beam:

- Smooth beam transverse focusing at the entrance / middle of plasma cell (z = 6.25 m)
- Transverse beam rms size while entering plasma → $\sigma_{xy} = \sqrt{\sigma_x \cdot \sigma_y} \leq 50 \mu m$
- Beam output after plasma (simulations by Alberto) → input for further beam transport up to HEDA2
- Vertical beam size through TDS (~11 m) → as small as possible induced energy spread by TDS
- Horizontal phase space while entering Disp3.Dipole1 (~17.2 m) → best momentum resolution
- Vertical beam size at Disp3.Scr1 (~18.6 m) → best temporal resolution

Setup for beam simulations

- Laser: Longitudinally flat-top → 2/22\2 ps. Transverse rms spot size on the cathode → 0.3 mm
- Gun: Gradient of 61 MV/m (6.73 MeV/c after gun at on-crest phase), phase fixed to on-crest
- Booster: Gradient of 17.5 MV/m (22 MeV/c final beam momentum for gun and booster on-crest phases), phase fixed to on-crest
- Booster starting position: Z=2.67 m
- Solenoid scan for e-beam focus on EMSY1 (Z=5.34 m)
- Many quadrupoles for further beam transport until HEDA2
- 100pC charge (200kp in ASTRA)

Quadrupoles used for the beam transport until HEDA2

4 quadrupoles were used for beam transverse focusing through the plasma cell:

- High1.Q1 → position 4.79 m, focusing gradient: g(T/m)=0.3674
- High1.Q2 → position 5.15 m (5 m), focusing gradient: g(T/m)=-2.204
- High1.Q3 → position 5.55 m (5.6 m), focusing gradient: g(T/m)=4.188
- High1.Q4 → position 5.75 m (5.85 m), focusing gradient: g(T/m)=-3.27

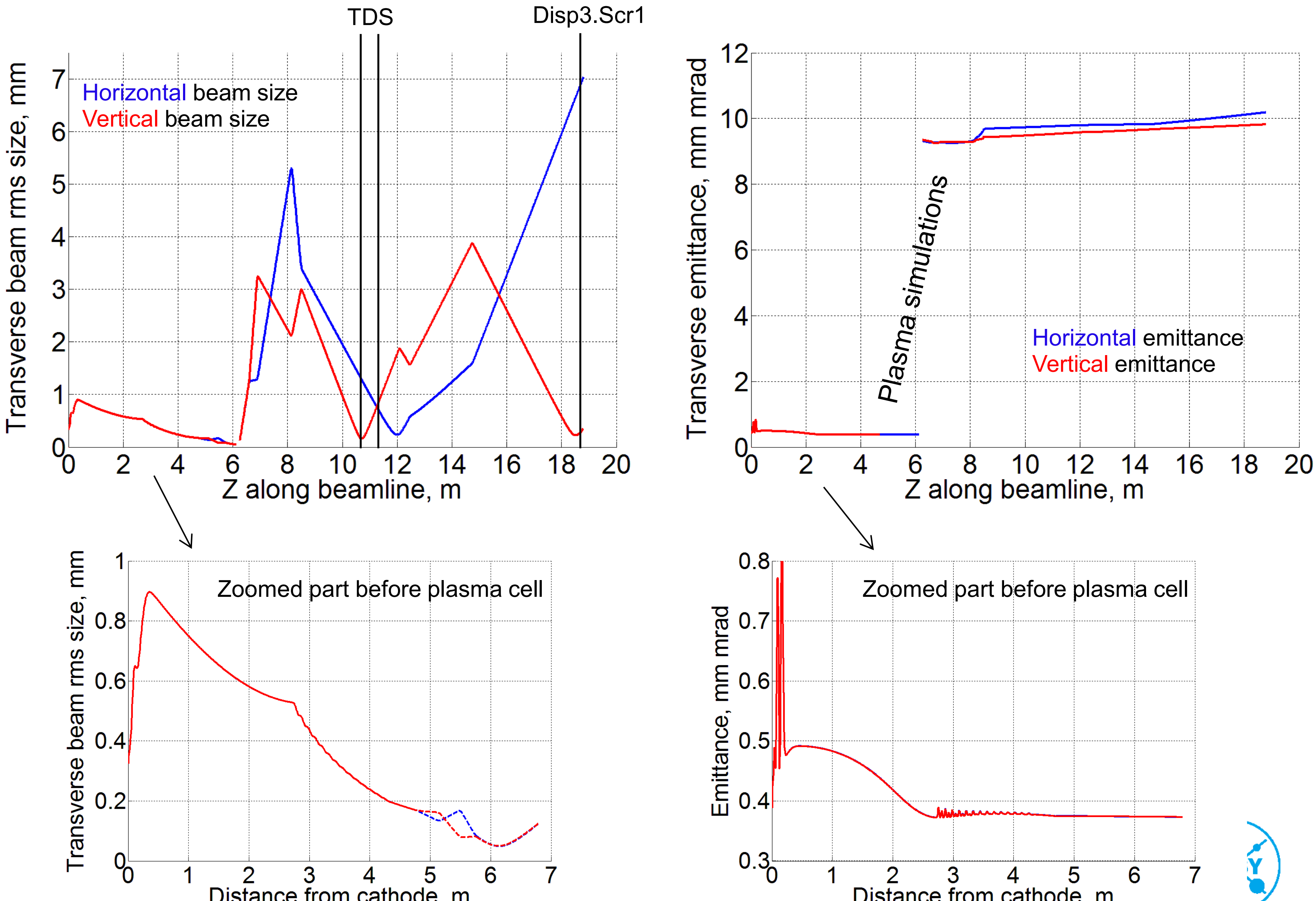
4 quadrupoles were used for catching the beam after the plasma and going through the TDS:

- High1.Q5→ position 6.6 m (6.65 m), focusing gradient: g(T/m)=4.033
- High1.Q6 → position 6.9 m, focusing gradient: g(T/m)=-3.667 (6.9m)
- High1.Q7 → position 8.15 m (8.18 m), focusing gradient: g(T/m)=2.567
- High1.Q8 → position 8.5 m (8.655 m), focusing gradient: g(T/m)=-2.053

3 quadrupoles were used for further beam transport from TDS up to HEDA2:

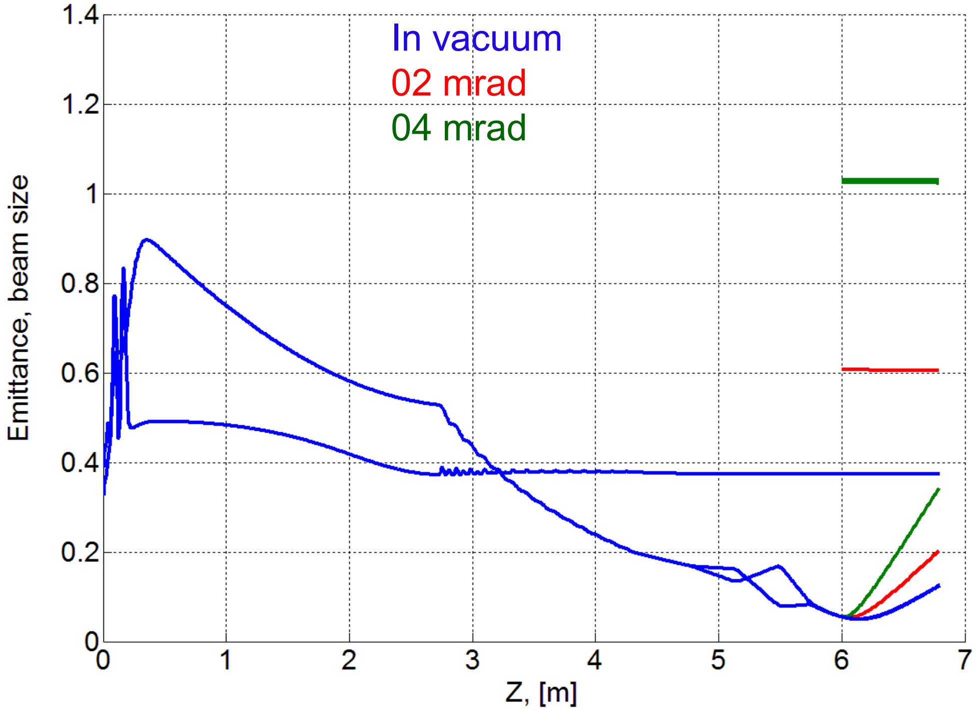
- PST.QM1 → position 12.088 m, focusing gradient: g(T/m)=-1.833
- PST.QM2 → position 12.468 m, focusing gradient: g(T/m)=1.833
- PST.QT5 → position 14.748 m, focusing gradient: g(T/m)=-0.8067

Beam transverse focusing through the plasma cell



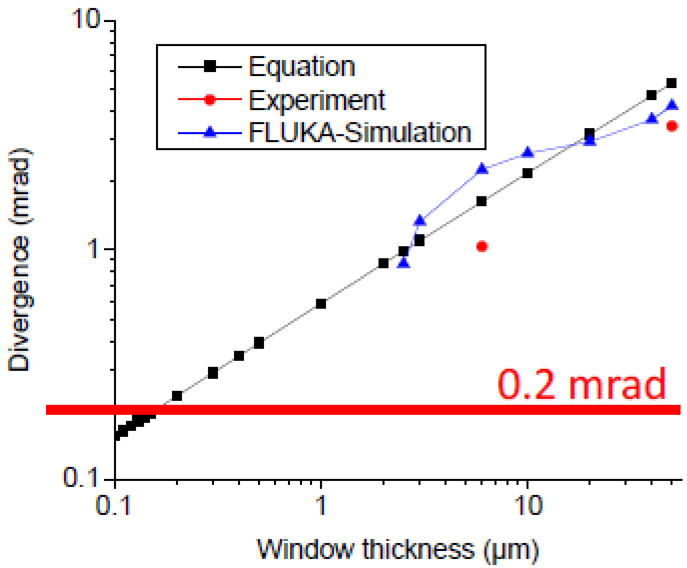
Vacuum-plasma-vacuum transition studies

- Study of beam transverse focusing with additional beam divergence due to electron scattering on the window material → 0.2 mrad and 0.4 mrad were artificially added into the beam distribution
- FLUKA simulations indicate that ~0.05 mrad induced divergence should be possible



Transverse emittance and beam size along the beamline.

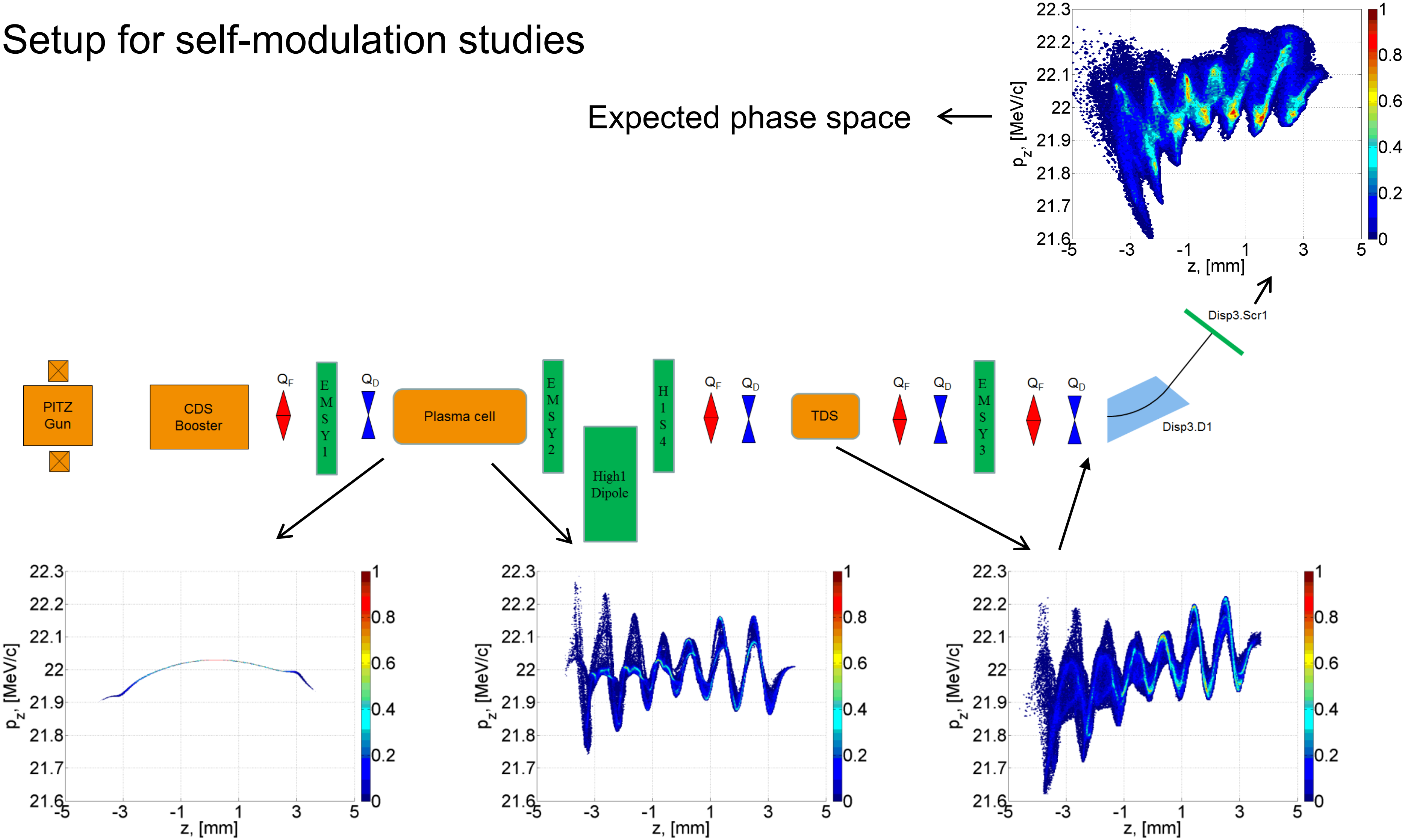
Courtesy by R. Schuetze



Induced beam divergence as function of thickness of window.

Setup of self-modulation experiment

Setup for self-modulation studies

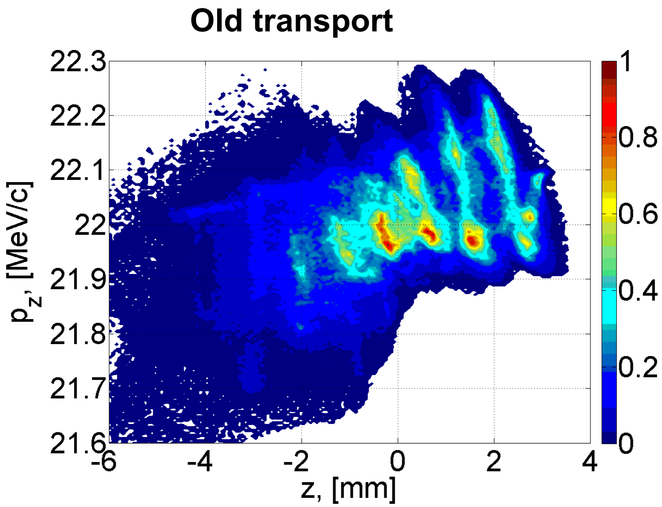


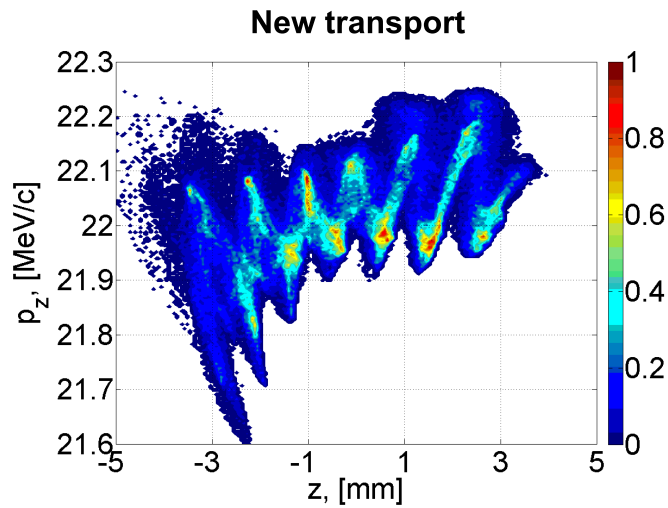
In front of plasma cell

After plasma cell
(assuming zero initial energy spread)

In front of dipole

Resolution issues





Momentum resolution

Current case → $\delta p_0 = x' \frac{R_{12}}{D} \approx 3.8 \cdot 10^{-3} \Rightarrow \Delta p = \delta p_0 \cdot p_0 \approx 84 \, {keV}/{c}$

Best case → $\Delta p = \delta p_0 \cdot p_0 \approx 1 \, {keV}/{c}$

Temporal resolution

Current case → $\delta z = \frac{\varepsilon_y}{\sigma_y \cdot \sin(\varphi_y)} \cdot \frac{p_0 c}{e V_0 k} \Rightarrow \delta z \approx 0.2 mm$

TDS induced momentum spread → $\delta p = \frac{e V_0 k}{p_0 c} \sigma_y \Rightarrow \Delta p \approx 37 \, {keV}/{c}$

Summary

Conclusions

- Electron beam was transported starting from cathode, through the TDS until HEDA2:
- Much better results were obtained compared to the previously done simulations !
- Expected temporal resolution for the current case → ~0.2 mm
- Expected momentum resolution for the current case → ~84 keV/c (HEDA2) + 37 keV/c (TDS)
- Expected momentum resolution for the best case → ~1 keV/c (HEDA2) +8 keV/c (TDS)

Outlook

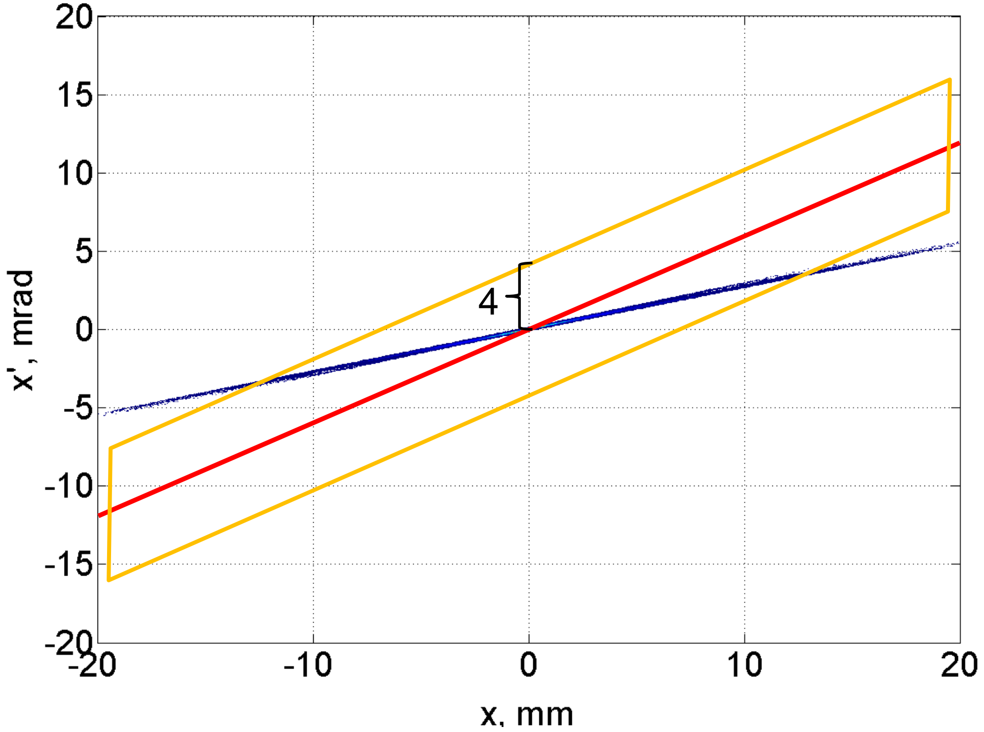
- Slight readjustment of quadrupole currents still needed to get the e-beam waist at Z=6.25 m
- Preliminary studies show that e-beam still can be well focused if the beam divergence induced due to plasma-to-vacuum transitions is less or equal to 0.2 mrad
- E-beam transport after plasma to HEDA2 can still be improved in terms of momentum resolution (temporal resolution not very critical)

Issues to discuss…

- Could the e-beam matching (through the plasma cell) be improved such that the emittance growth is minimized ?

Thank you for attention !!

Electron beam distribution in horizontal phase space when entering the first dipole in HEDA2



$$x_1 = R_{11}x_0 + R_{12}x_0' + R_{16}\delta p_0$$

$$R_{11} = -0.516$$

$$R_{12} = 0.867$$

$$R_{16} = 0.905$$

$$\left|R_{11}x_0 + R_{12}x_0'\right| < R_{16}\delta p_0$$

$$x' = x\frac{R_{11}}{R_{12}} = 0.595x$$

Current case → $x' \approx 4\cdot 10^{-3} \Rightarrow \delta p_0 = x'\frac{R_{12}}{R_{16}} \approx 3.8\cdot 10^{-3} \Rightarrow \Delta p = \delta p_0 \cdot p_0 \approx 84\, {keV}/{c}$

Best case → $x' \approx 0.2\cdot 10^{-3} \Rightarrow \Delta p = \delta p_0 \cdot p_0 \approx 4\, {keV}/{c}$