Self-modulation studies: Simulations of longitudinal phase space measurements after beam-plasma interaction

- **Transporting 22 MeV electron beam with shifted positions of booster, EMSY1 and plasma cell:**
- **until plasma cell**
- **after plasma cell through the TDS up to HEDA2**

Martin Khojoyan, Dmitriy Malyutin
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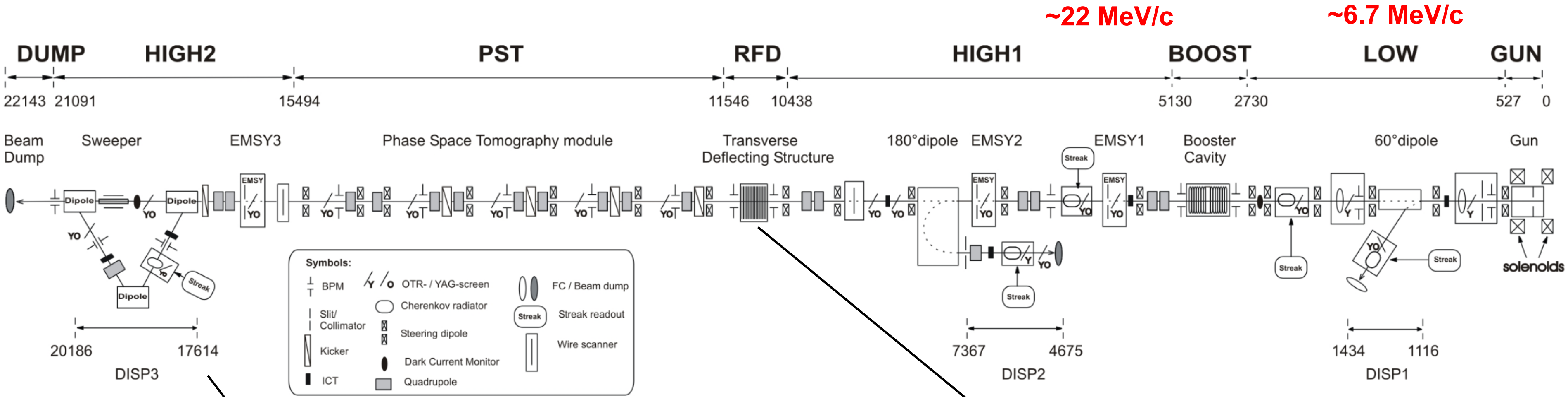
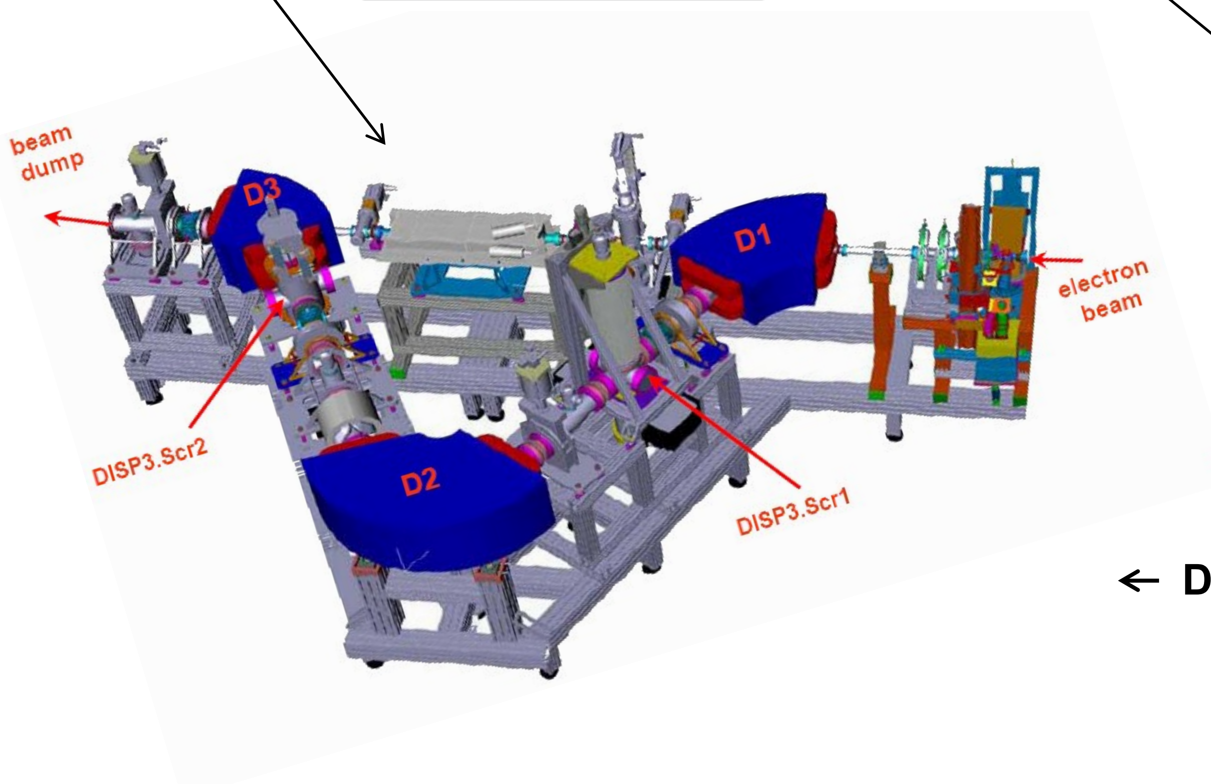
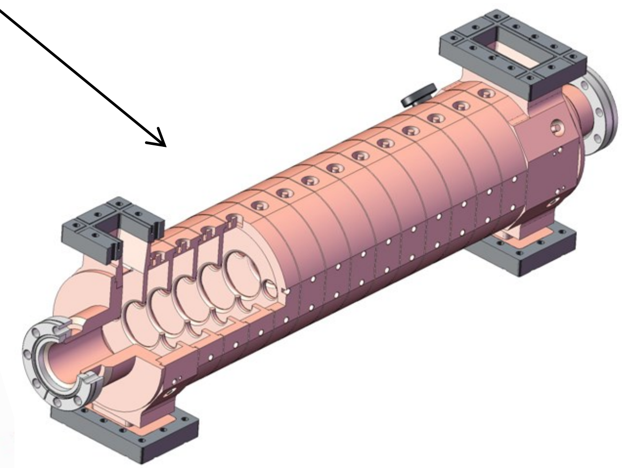
DESY

Diagnostic view of the current PITZ beamline







← 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 = [6.15-6.25] 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

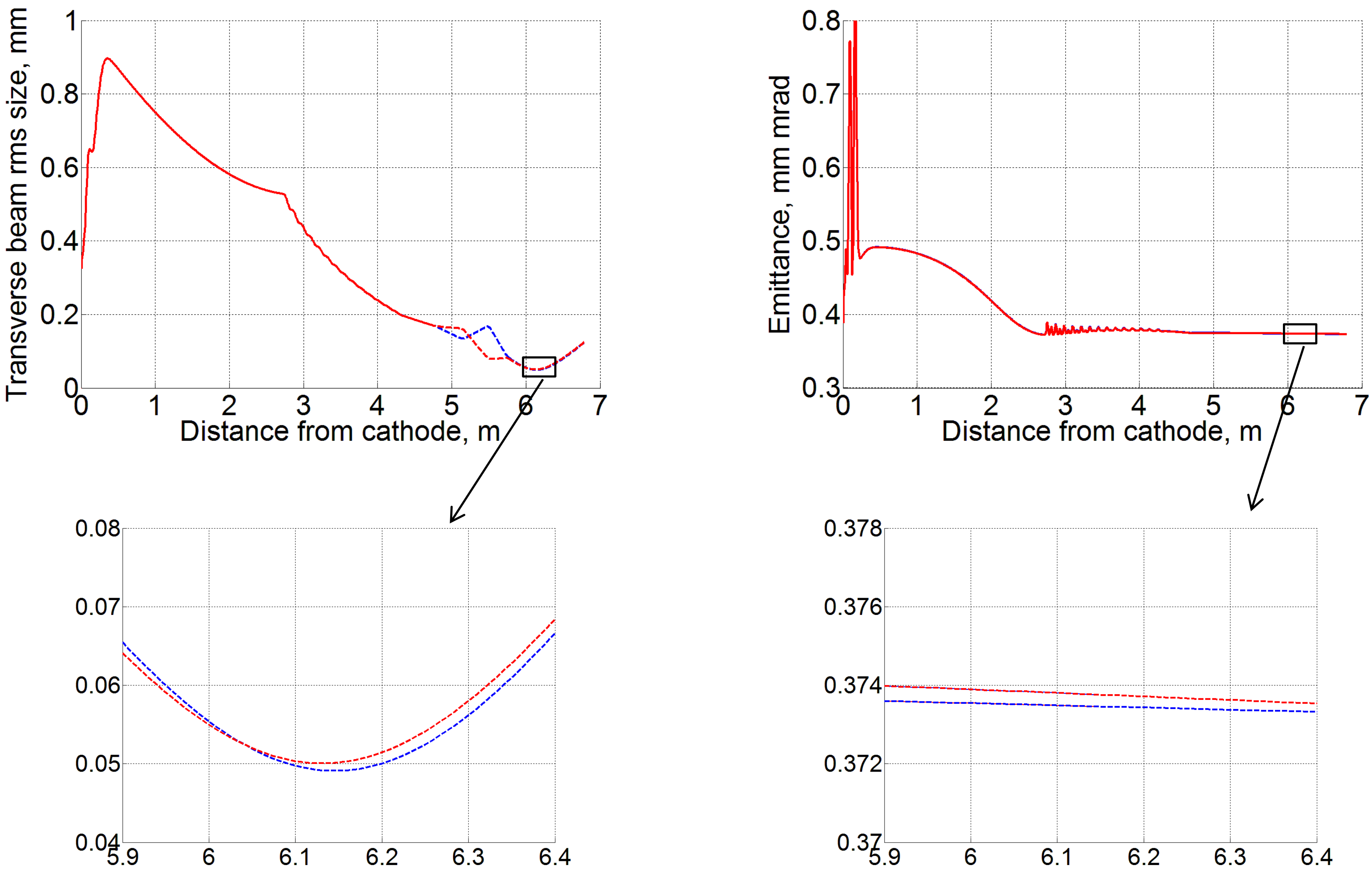
Setup for beam simulations

- 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)

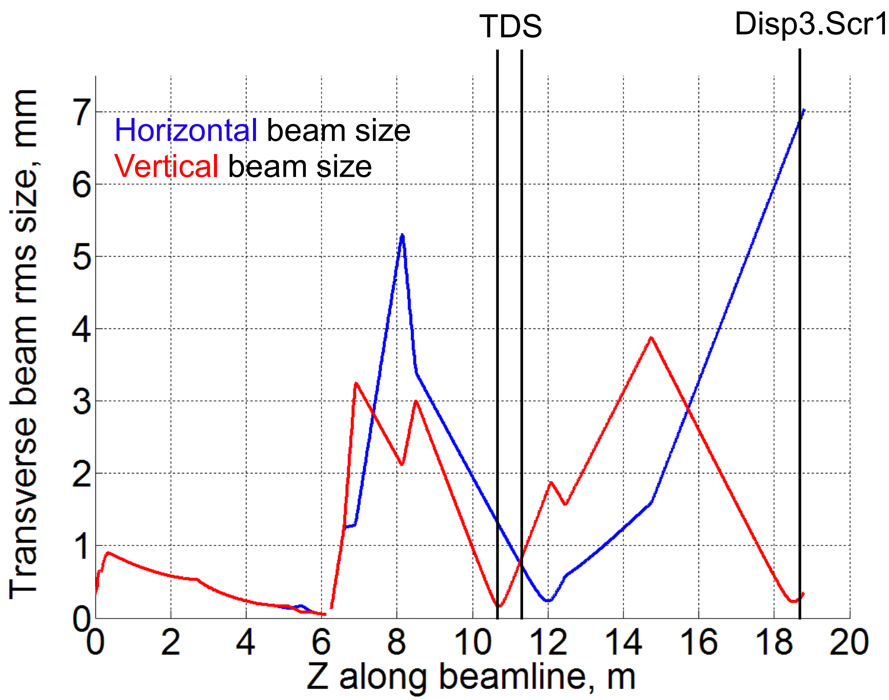
Quadrupoles used for the beam transport until HEDA2

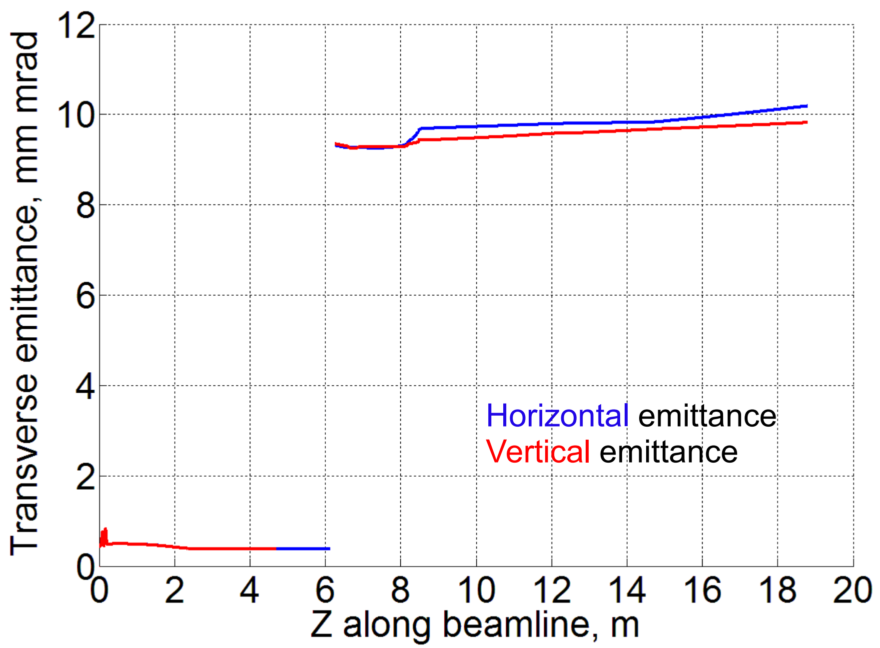
- **4 quadrupoles were used for beam transverse focusing through the plasma cell:**
- High1.Q1 → position 4.79m, focusing gradient: g(T/m)=0.3674 (to be replaced)
- High1.Q2 → position 5.15m, focusing gradient: g(T/m)=-2.204 (to be replaced)
- High1.Q3 → position 5.5m, focusing gradient: g(T/m)=4.188 (to be replaced)
- High1.Q4 → position 5.75m, focusing gradient: g(T/m)=-3.27 (to be replaced)
- **4 quadrupoles were used for catching the beam after the plasma and going through the TDS:**
- High1.Q# → position 6.6m, focusing gradient: g(T/m)=4.033 (to be situated)
- High1.Q# → position 6.9m, focusing gradient: g(T/m)=-3.667 (to be situated)
- High1.Q# → position 8.15m, focusing gradient: g(T/m)=2.567 (to be situated)
- High1.Q# → position 8.5m, focusing gradient: g(T/m)=-2.053 (to be situated)
- **3 quadrupoles were used for further beam transport until HEDA2:**
- PST.QM1 → position 12.088m, focusing gradient: g(T/m)=-1.833
- PST.QM2 → position 12.468m, focusing gradient: g(T/m)=1.833
- PST.QT5 → position 14.748m, focusing gradient: g(T/m)=-0.8067

Beam transverse focusing through the plasma cell



Transverse beam size and emittance along beamline





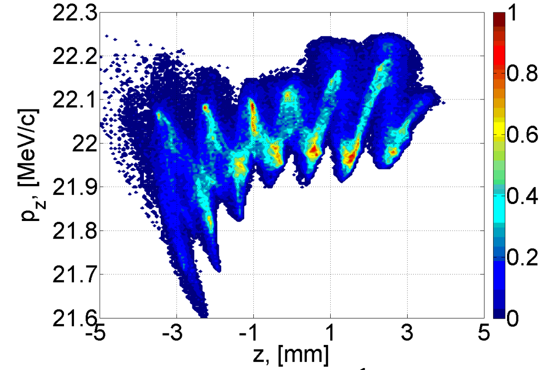
Temporal resolution → $\sigma_z = \frac{\sigma_y}{S} \approx \frac{0.25mm}{1.5} \approx 0.2mm$

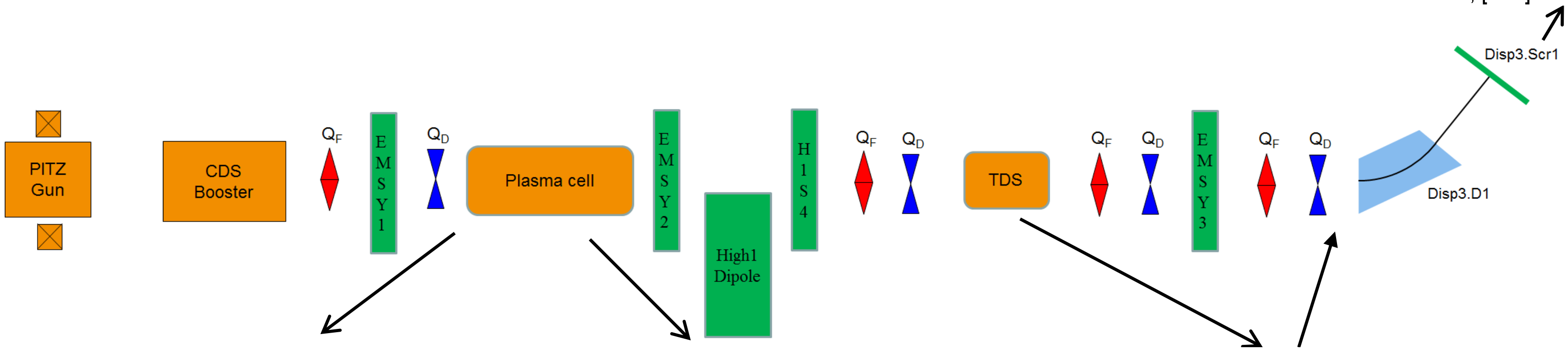
TDS induced momentum spread → $\delta p = \frac{eV_0 k}{p_0 c} \sigma_y \approx 1.7 \cdot 10^{-3} \Rightarrow \Delta p \approx 37 \, {}^{keV}\!/_{c}$

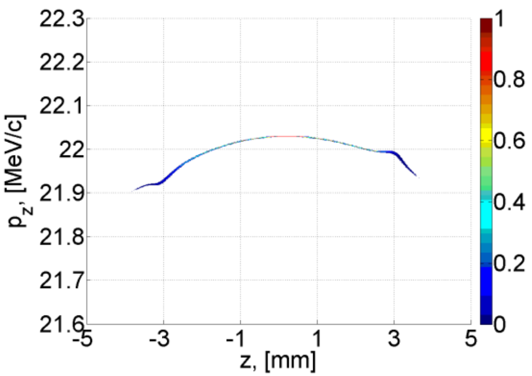
Setup of self-modulation experiment

Setup for self-modulation studies

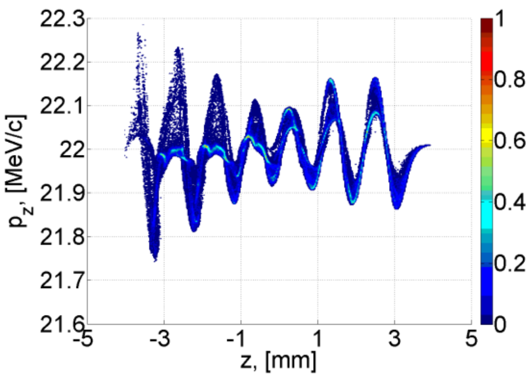
Expected phase space ←





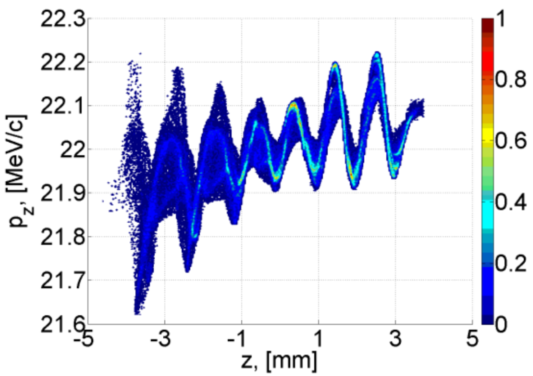


In front of plasma cell



After plasma cell

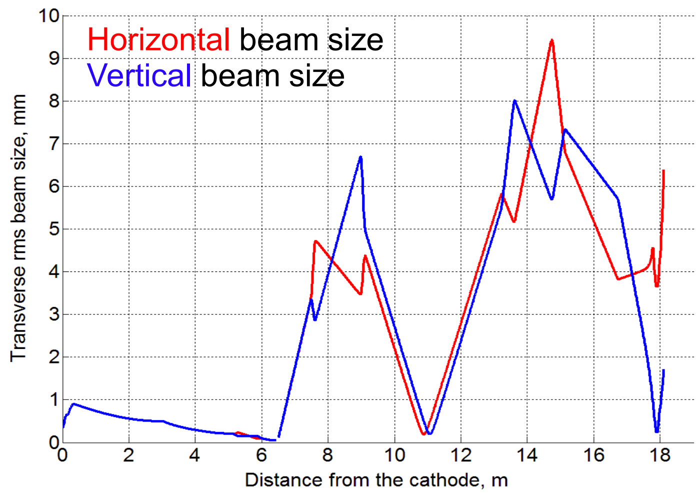
(assuming zero initial energy spread)

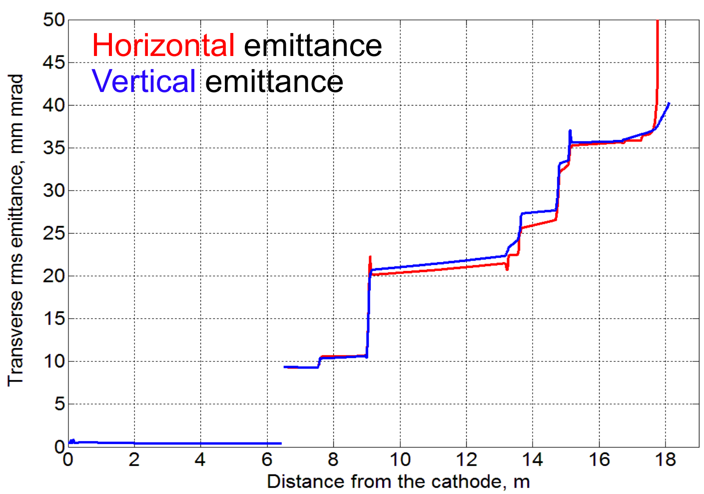


In front of dipole

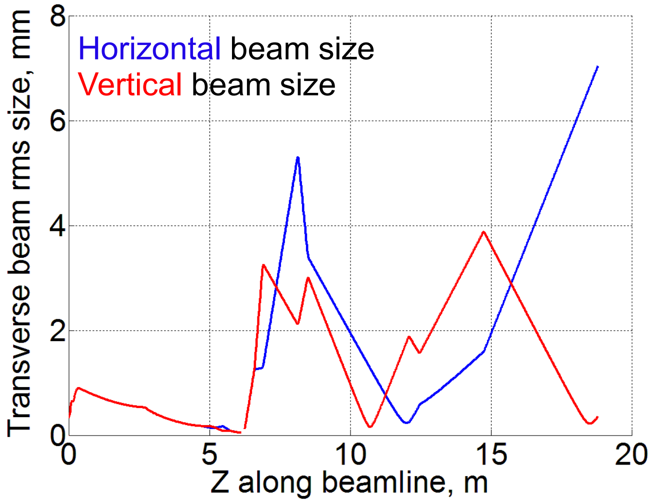
Comparing old and new results

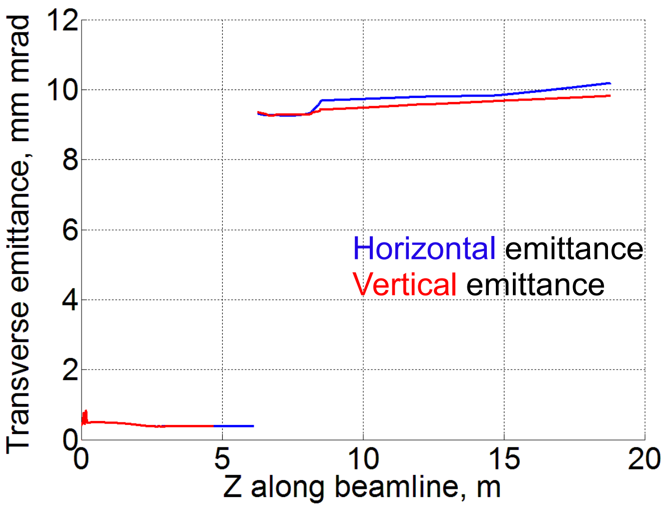
Old transport





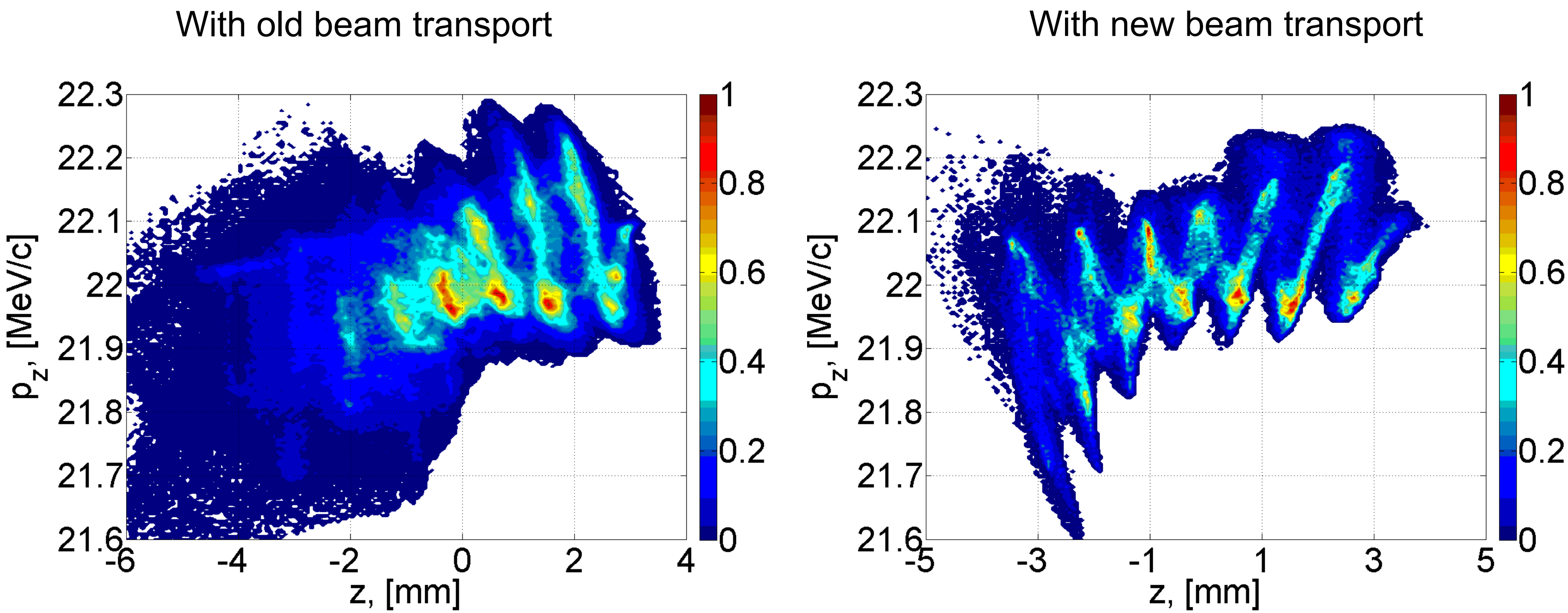
New transport





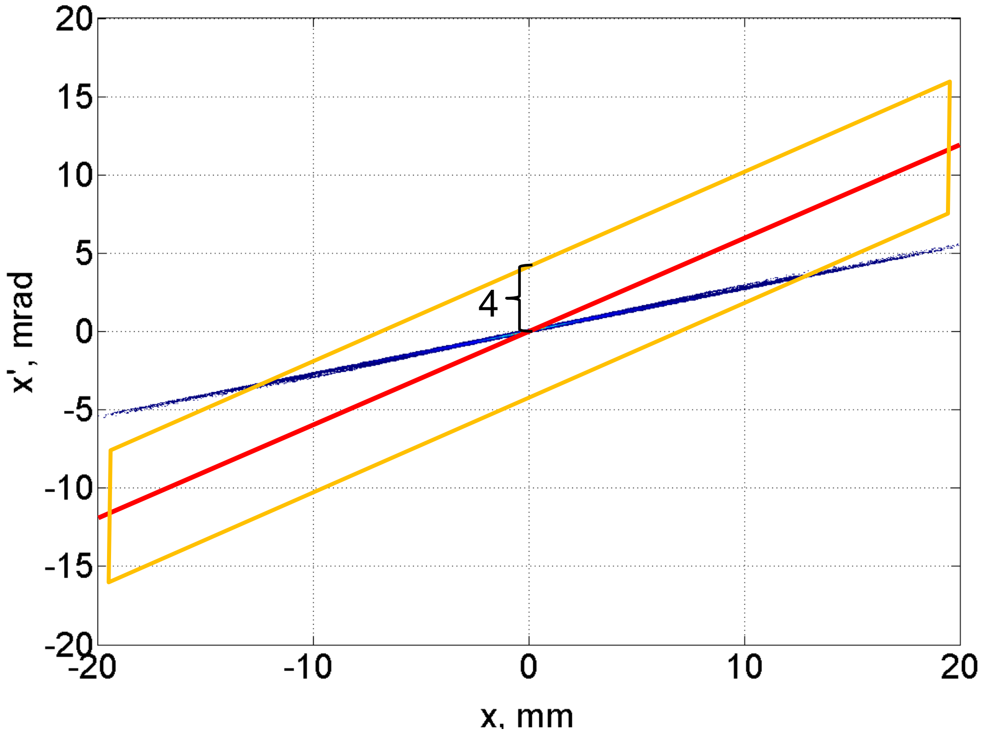
Transverse beam properties along the PITZ beamline with old and new setups.

Expected longitudinal phase space at Disp3.Scr1



E-beam distribution in longitudinal phase space at Disp3.Scr1.

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

Conclusion and outlook

- 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 → ~4 keV/c (HEDA2) + ?? keV/c (TDS)

- Electron beam output at the entrance of plasma cell was given to Gaurav for HiPACE simulations (with non-zero energy spread)
- E-beam transport after plasma to HEDA2 can still be improved !

Thank you for your attention !!