Study of the electron cooling force for undulatory electron beam trajectories of various periods and amplitudes in the cooling section

PARTI meeting

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Electron Cooler

Electron beam generated and accelerated in a Van-de-Graaff type electrostatic accelerator (Pelletron).

Cooling section consist of 10 solenoids, 2 m-long where electrons mix with anti-protons; B≈100 G

There are 20 dipole correctors in each solenoid

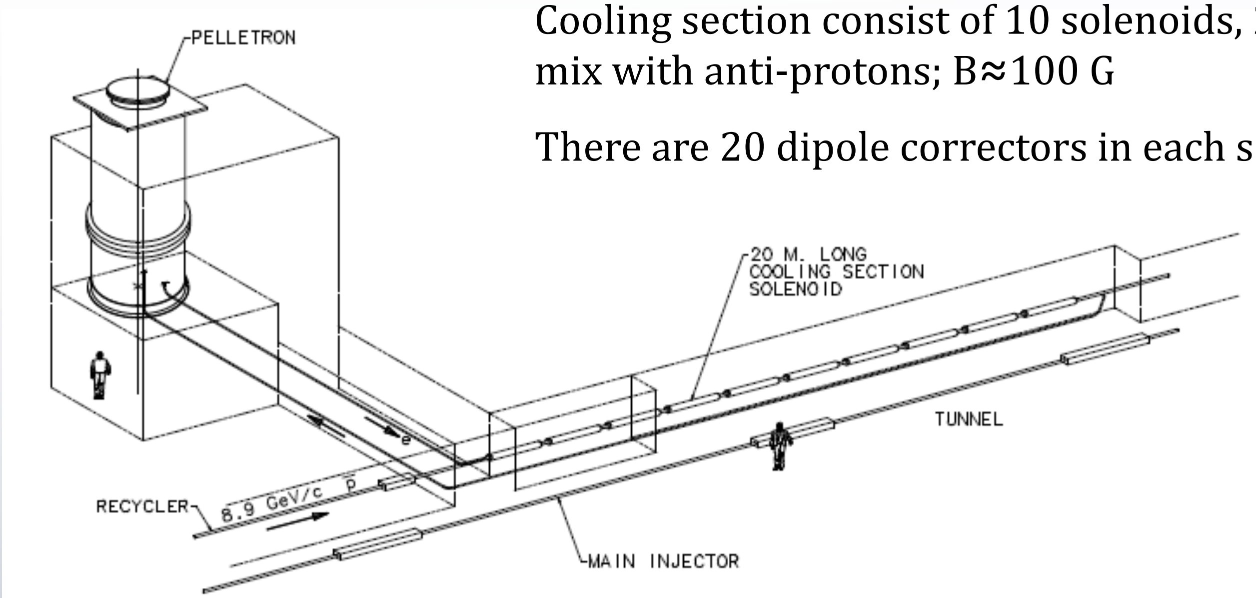


Figure 1. Schematic picture of electron cooler at Fermilab

Cooling force

Non- magnetized model

- the influence of the magnetic field is neglected
- the electrons velocities are assumed to be described by a Gaussian distributions

$$\mathbf{F} = 4\pi n_e m_e r_e^2 c^4 L_c \eta \int_{-\infty}^{+\infty} f(\mathbf{V}_e) \frac{\mathbf{V}_{rel}}{|\mathbf{V}_{rel}|^3} \mathrm{d}^3\mathbf{V}_e \qquad (1)$$

n_e – an electron density in beam rest frame

m_e – electron mass

r_e – an electron classical radius

$\mathbf{V}_{rel}$ – a relative velocity of electron and pbar beams

L_c – the Coulumb logarithm

$\mathbf{V}_e$ – an electron velocity in beam rest frame

$f(\mathbf{V}_e)$ – Gaussian distribution

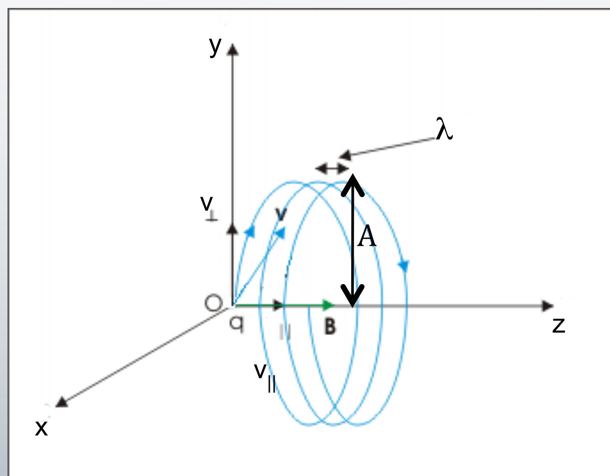
η – a ratio of ring length, occupied by Cooling Section to the Recycler ring circumference

Purpose of studies

No undulations Ve_t – rms transverse velocity spread

$Ve\_t = \gamma\beta c\alpha_0$ (2) α_0 – rms angle spread $\alpha_0 \sim 110\,\mu rad$

$F(Ve\_t) = ?$ Can we use non-magnetized model?



Undulations

$$\alpha_{und} = \frac{2\pi A}{\lambda} \quad (3)$$

Undulatory motion

Undulatory trajectory is created by kicking the beam with each corrector in certain direction and with certain force. In result beam three-dimensional trajectory will be helix with specified period in Z direction and amplitude in X and Y directions.

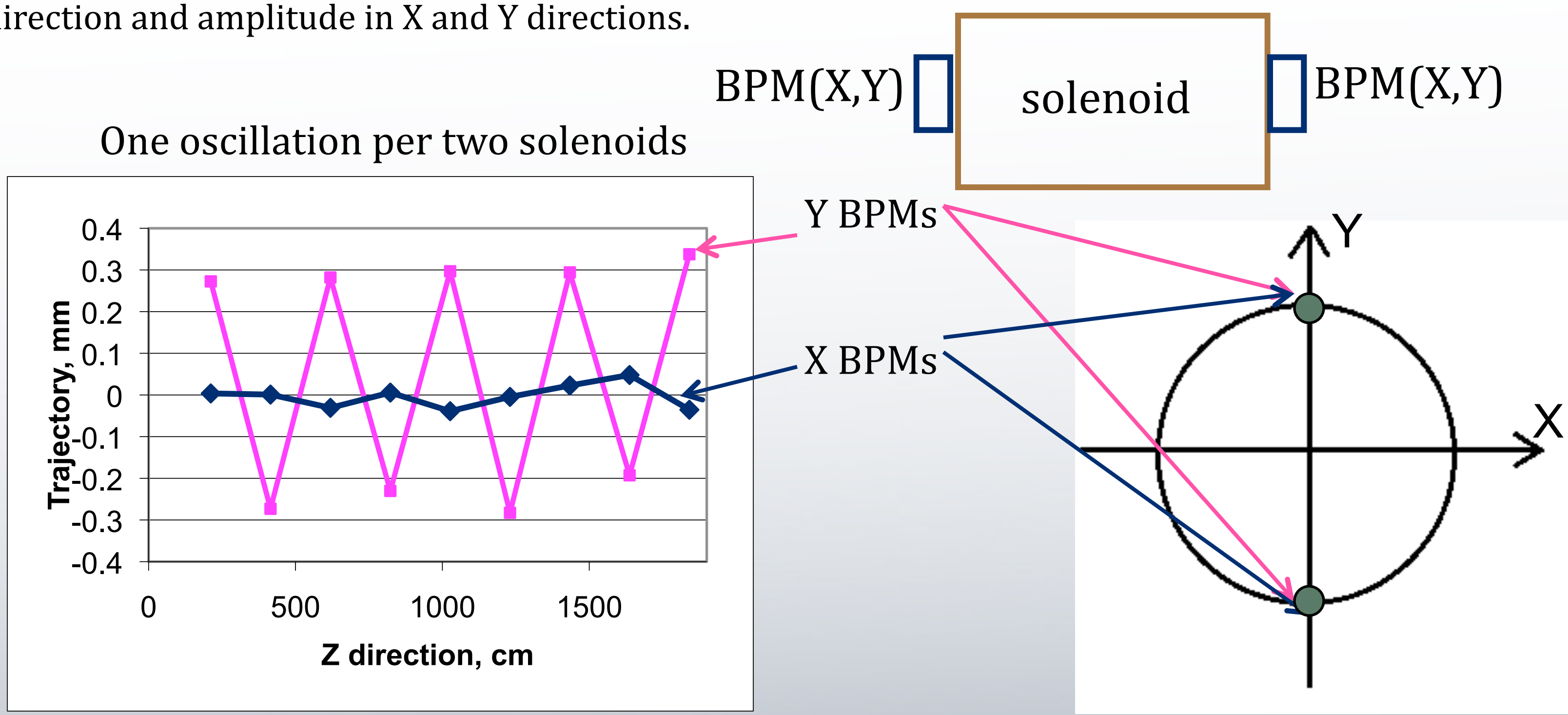


Figure 2. Electron beam differential trajectory at X and Y

Drag-rate measurements

In every experiment of studies the drag-rate was measured to determine the cooling force.

pbars~ $1*10^{10}$

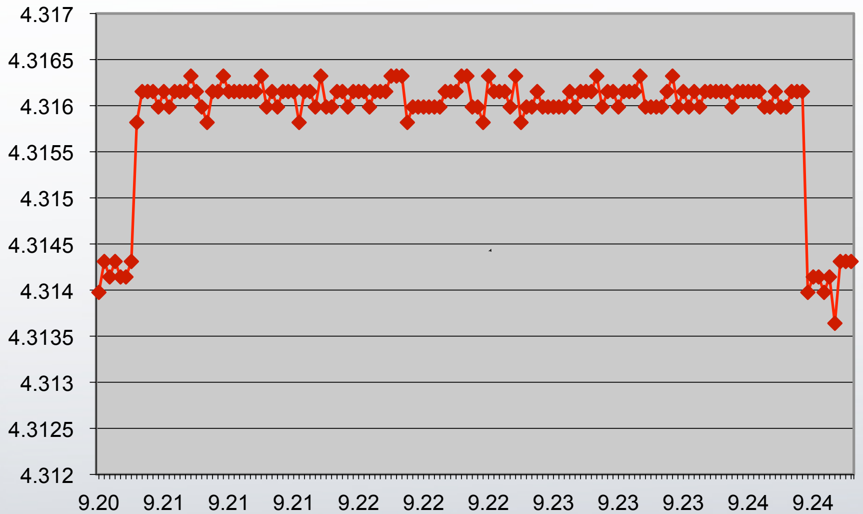


Figure 3. Voltage jump

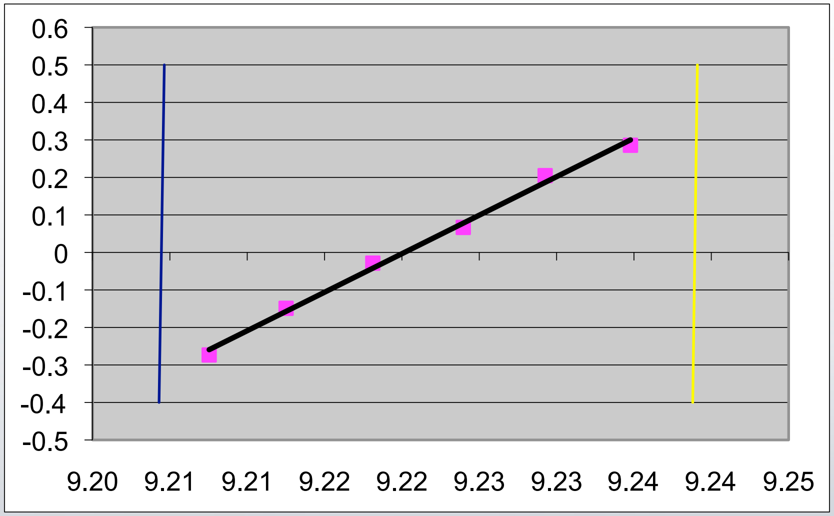


Figure 4. Pbar momentum change during voltage jump

Realization of undulatory trajectories

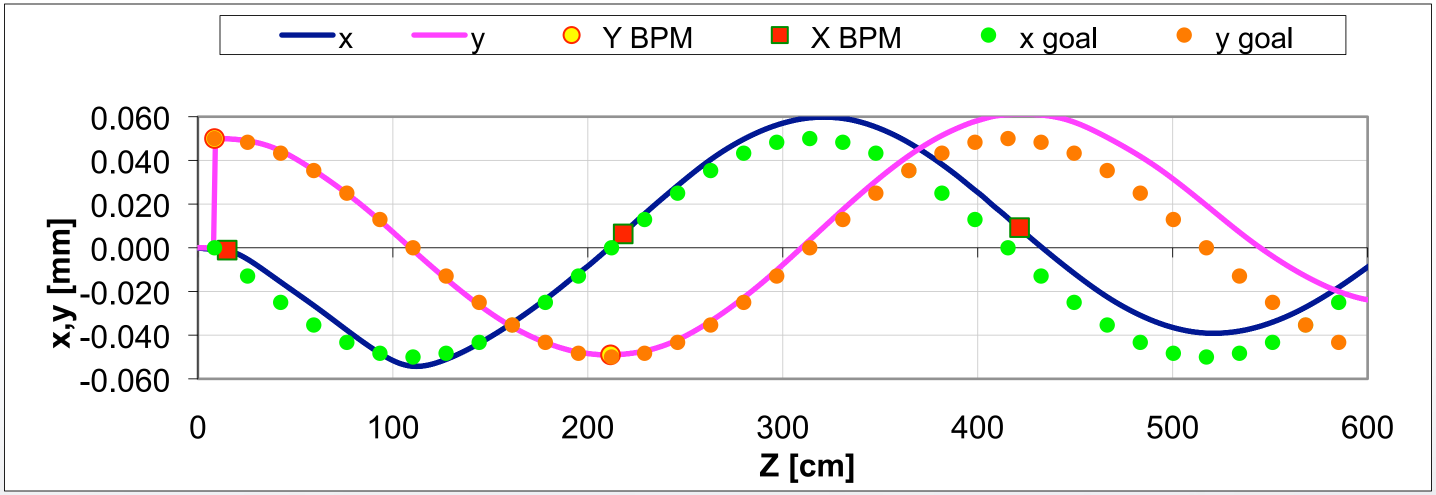


Figure 5. Goal and calculated trajectories of electron beam

Obtained series:

1 oscillation per solenoid, $\alpha_{und\_max} = 0.5 mrad$

1 oscillation per 2 solenoids, $\alpha_{und\_max} = 0.4 mrad$

1 oscillation per 3 solenoids, $\alpha_{und\_max} = 0.5 mrad$

Results

$$\mathrm{Fund}(U) := \frac{4\cdot\pi\cdot me\cdot re^2 c^2 ne\cdot\eta}{I(U)}\cdot\left[\int_0^{3\cdot Ve\_t+U}\int_0^{2\pi}\int_{-3\cdot(Ve\_l)}^{3\cdot(Ve\_l)}\frac{Lc(vt,vl,\varphi,U)\cdot f(vt,vl,U)\cdot(\Delta Vz+vl)\cdot vt}{\left[(vt\cdot\cos(\varphi))^2+(vt\cdot\sin(\varphi)+U)^2+(vl+\Delta Vz)^2\right]^{\frac{3}{2}}}\,dvl\,d\varphi\,dvt\right] \quad (4)$$

$$I(U) := 2\pi\cdot\int_0^{3\cdot Ve\_t+U}\int_{-3\cdot(Ve\_l)}^{3\cdot(Ve\_l)} f2(vt,vl,U)\cdot vt\,dvl\,dvt \quad (5)$$

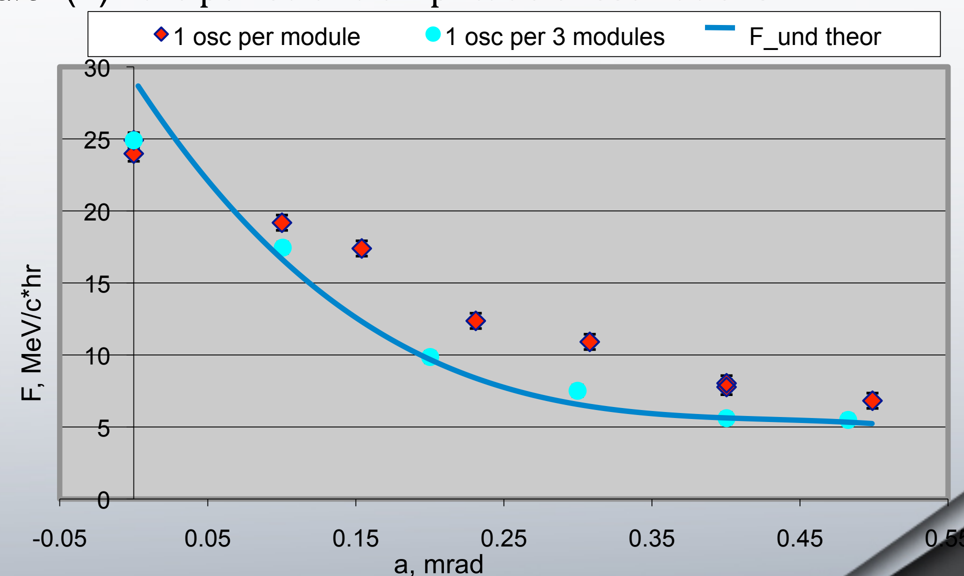
U – undulatory velocity

vl – longitudinal velocity

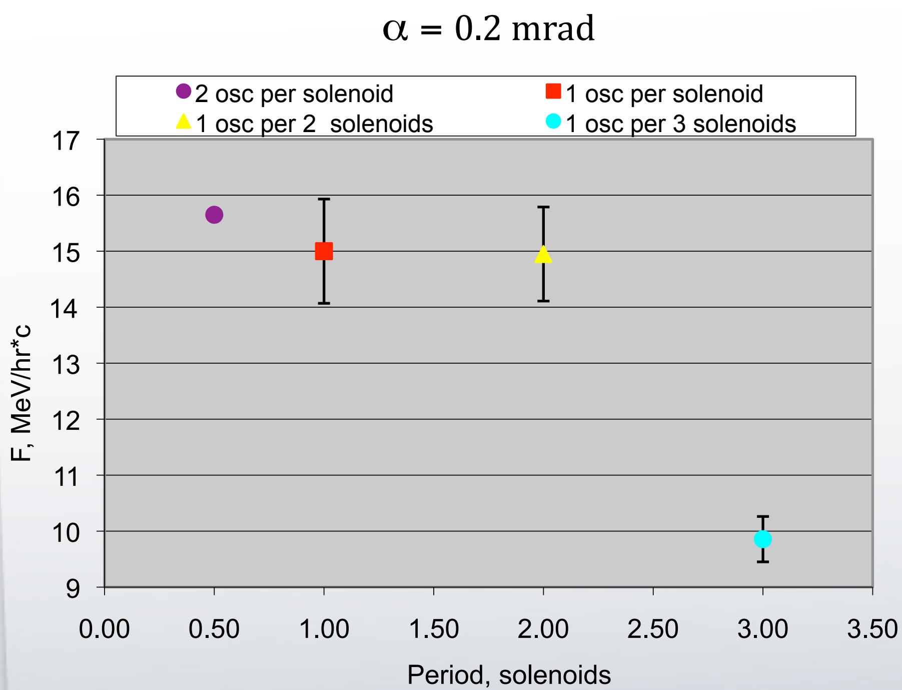
vt – transverse velocity

Ve_l – rms longitudinal velocity spread

Figure 6. The dependence of electron-cooling force on the period and amplitude of oscillations.



Results



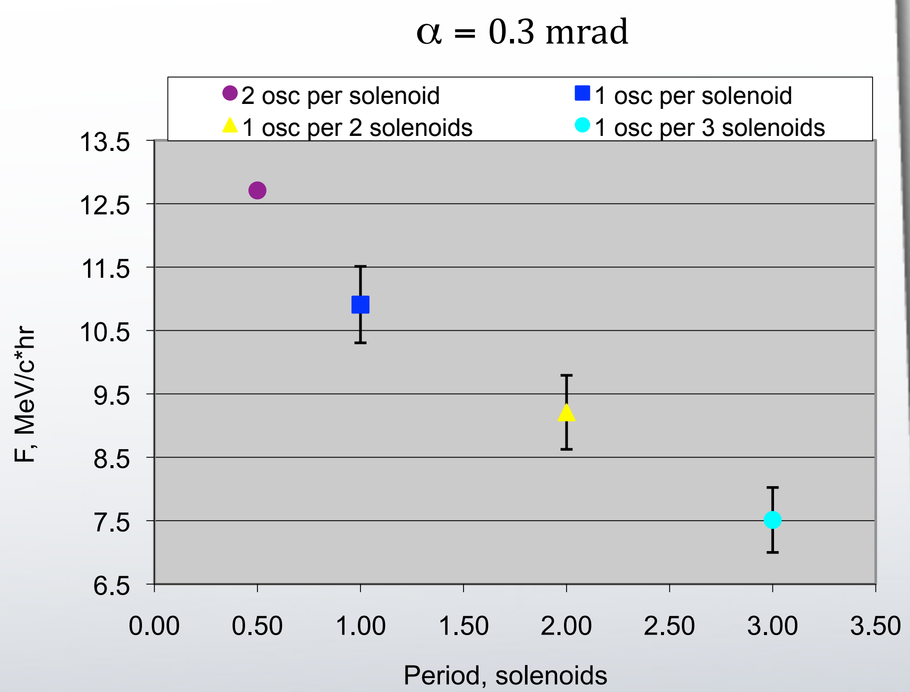


Figure 7. The dependence of electron-cooling force on the period of oscillations for different undulatory angles.

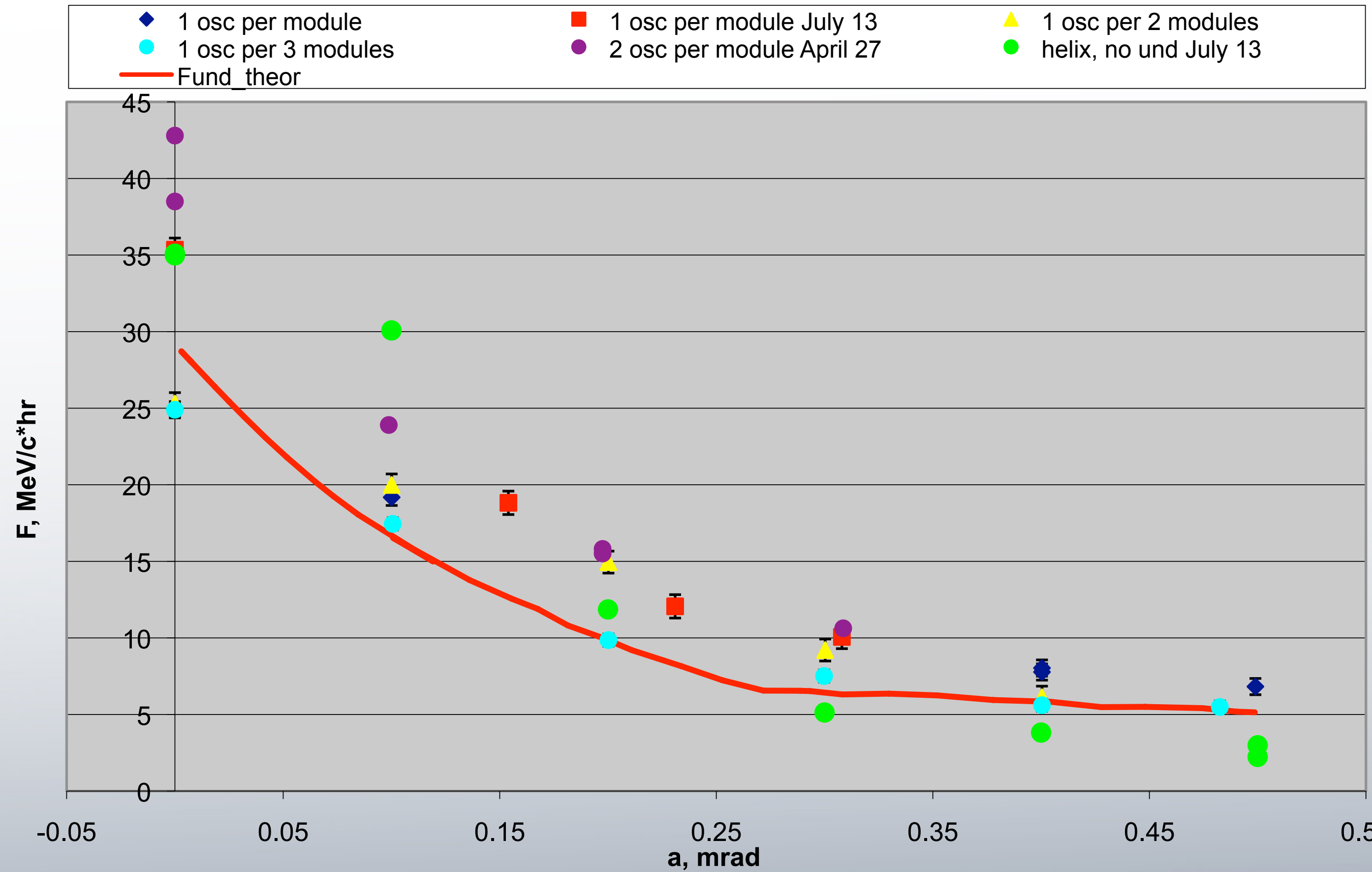
Conclusion

- For big periods of oscillation non-magnetized model gives good agreement with data
- With a decrease of period, the difference could be ~ 40%

What was planed	Was it achieved?
- Calculate parameters for correctors in each module to produce an undulatory trajectory of electron beam	+
- Participate in measurements	+
- Experimentally investigate the dependence of electron-cooling force on the period and amplitude of oscillations	+
- Process obtained data	+
- Build a model that would explain that dependence	+/−

Bonus Slides

The dependence of electron-cooling force on undulatory angle for all series of data.



The dependence of electron-cooling force on undulatory angle for all series of data in one scale.