Bunch compression studies for inner target collisions within ELENA ring

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E-Beam Group Meeting #10

21/04/2021

Outline

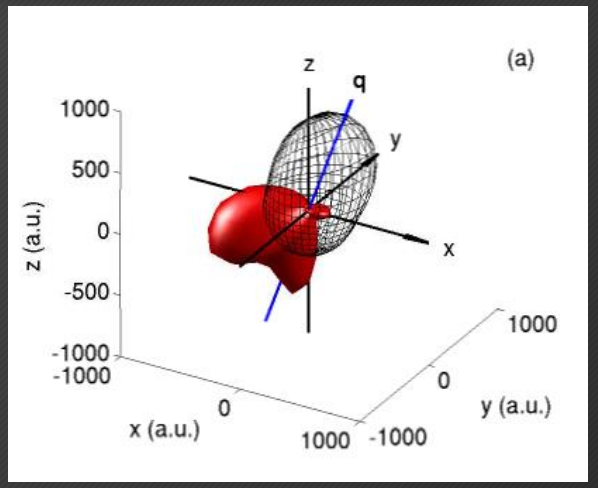
- Reasons and ideal target conditions
- Bunch compression studies
- Impact of collective effects
- Conclusion

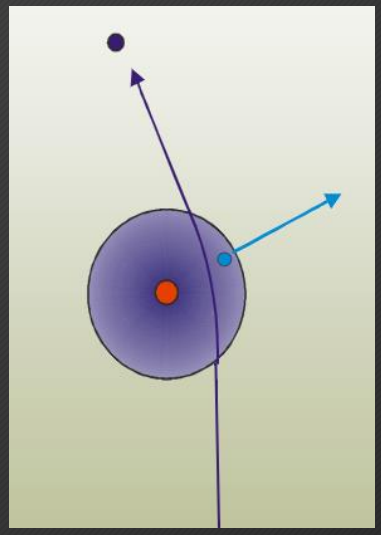
Reasons and ideal target conditions

- Idea suggested before in 2012:

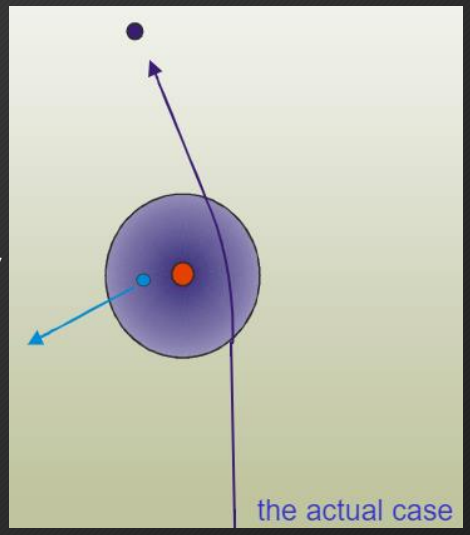
ReMi source

- Difference between Born approximation and proposed theory
- Possible elements for study atomic and molecular H and He





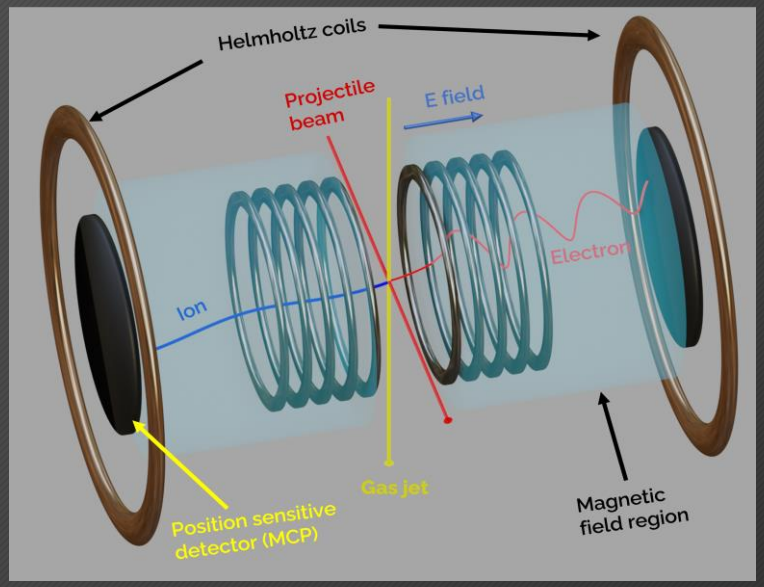
or

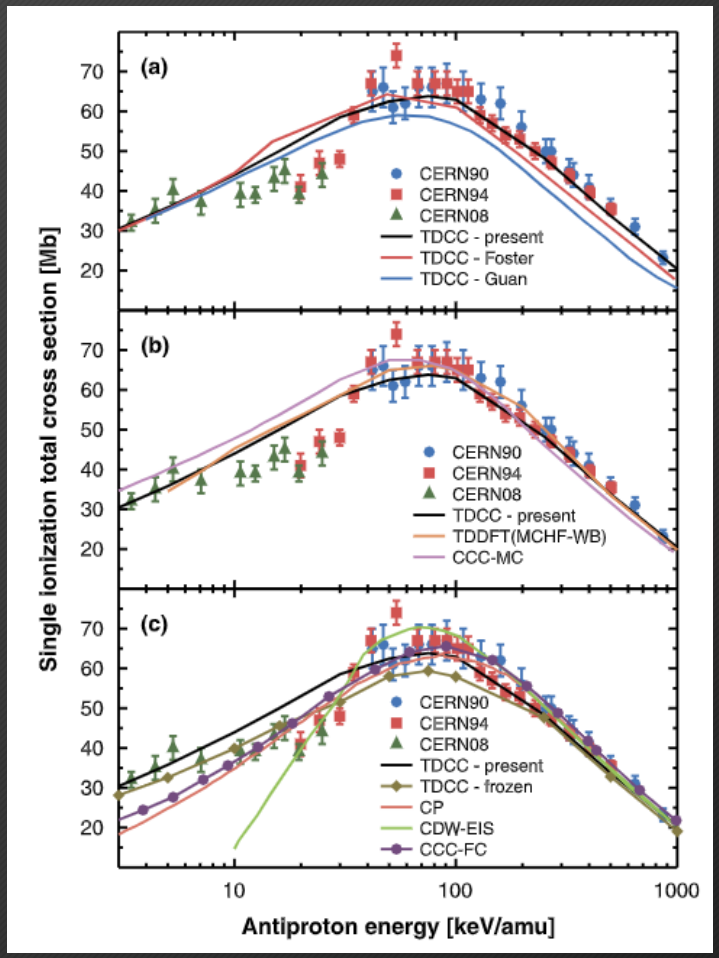


M. McGovern 2009, Phys. Rev A

Reasons and ideal target conditions

- Total cross-sections were previously measured
- Possible setup for differential measurements using high density gas jet()





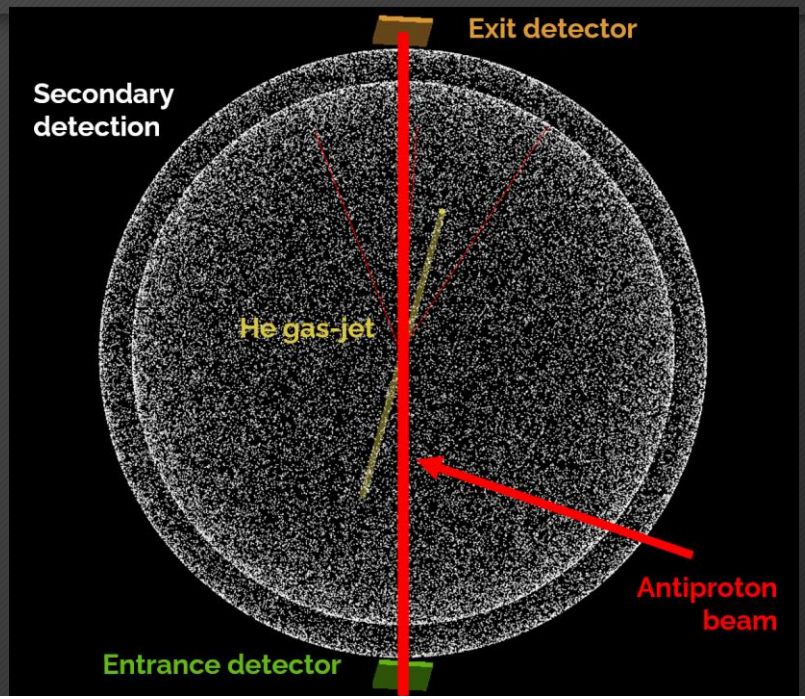
T. Kirchner, 2020

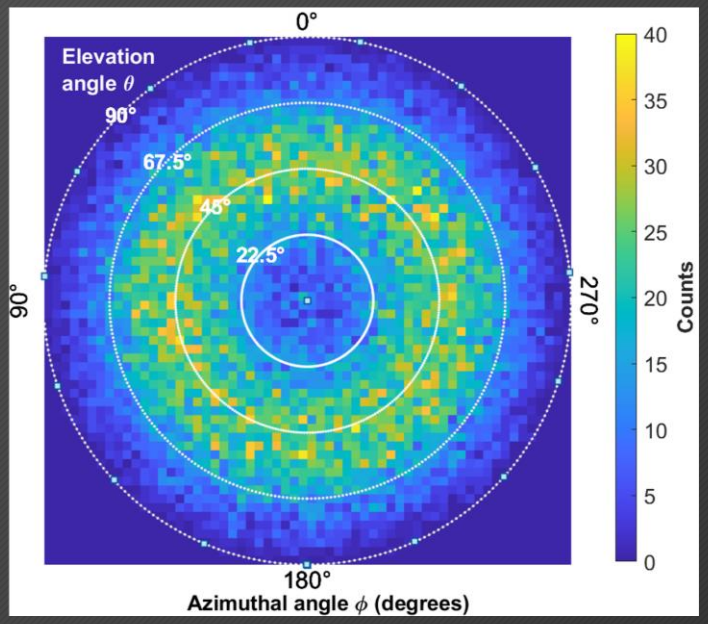
V. Rodin

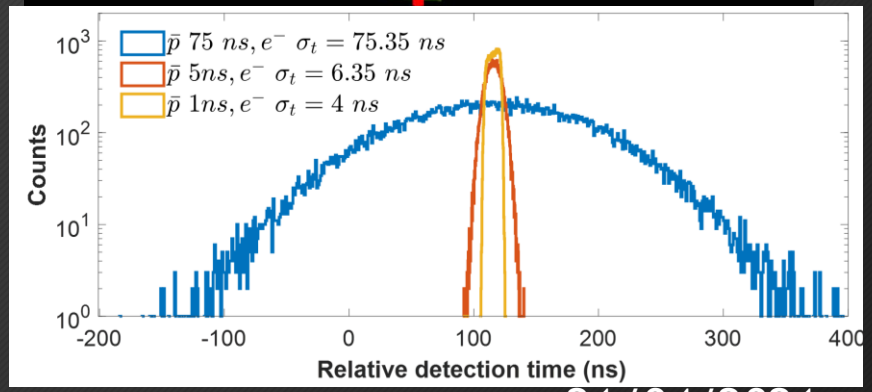
21/04/2021

Ideal target conditions: rough estimation in Geant4

- N ~10E14 atoms/cm^3
- 2σ beam = jet width
- Cross-section ~64 Mb







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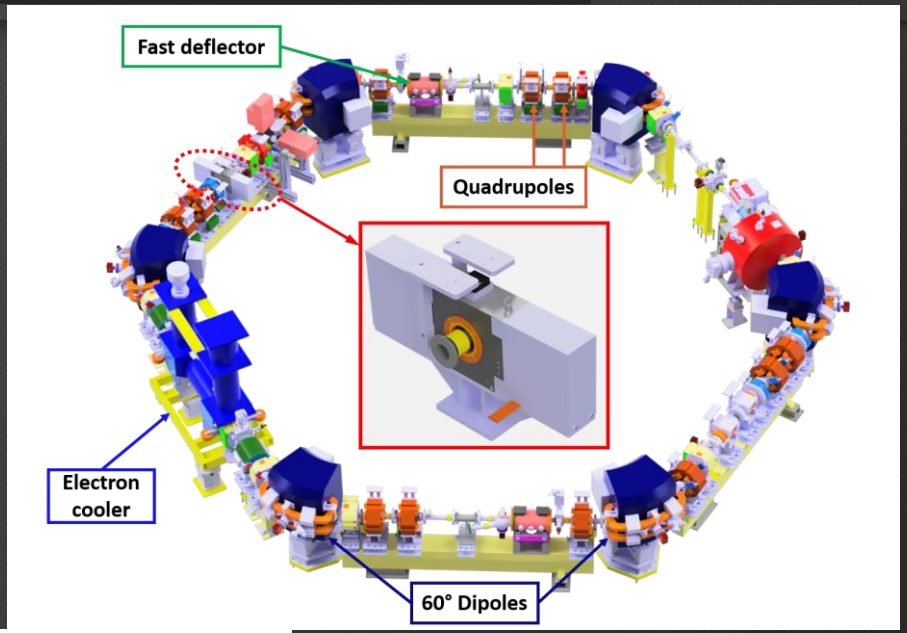
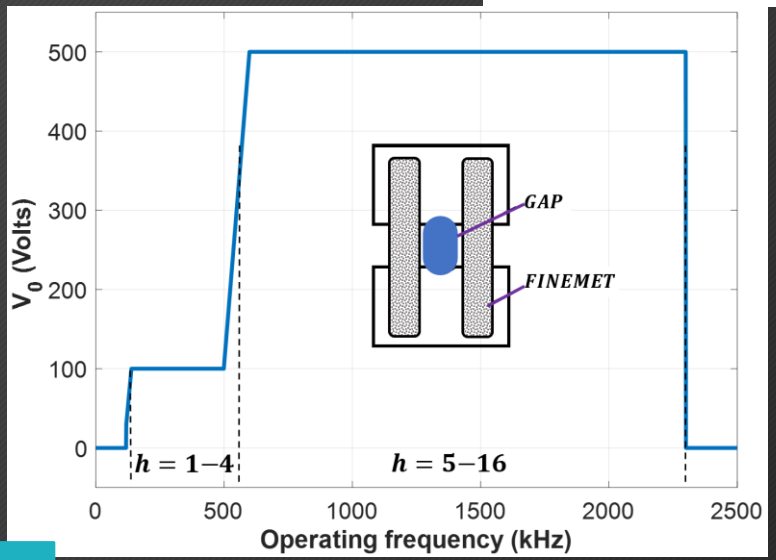
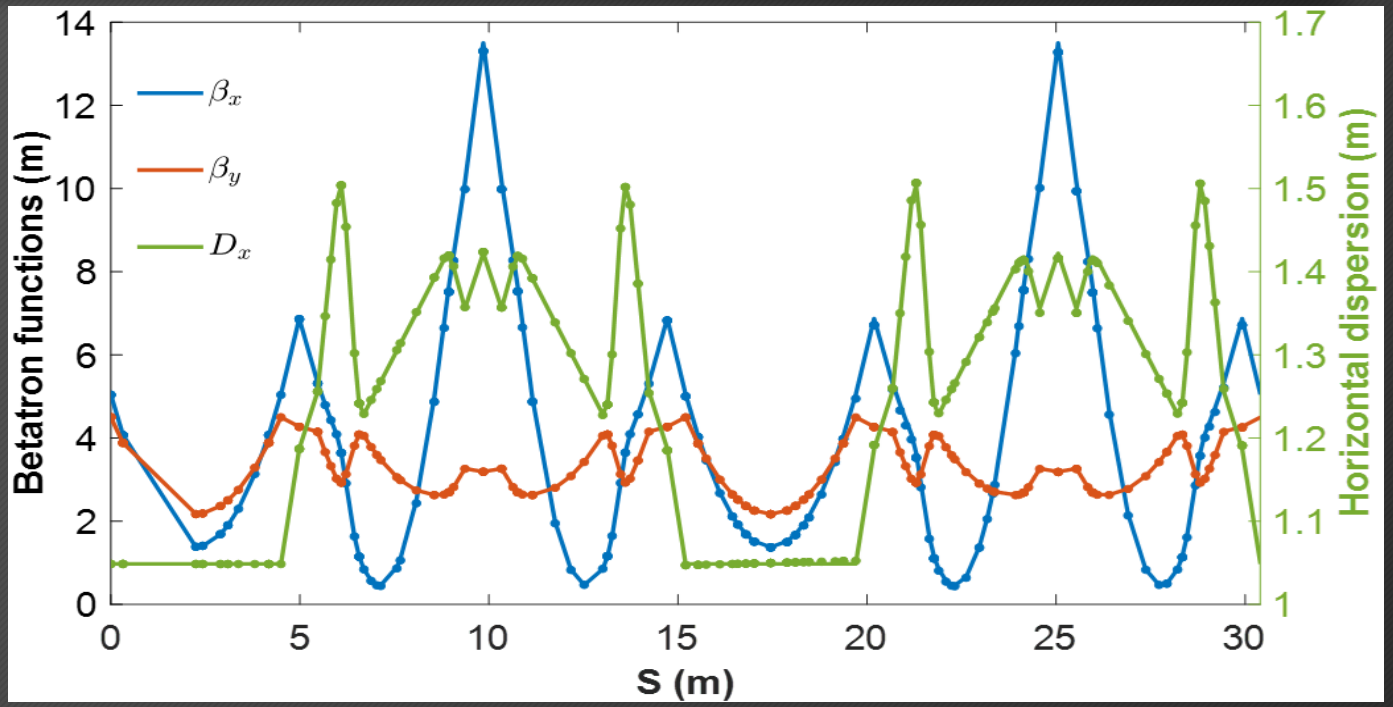
Bunch compression studies

- Investigation of achievable bunch length with h=1
- N_b=4.5E6
- Further compression of previously obtained 75 ns bunches



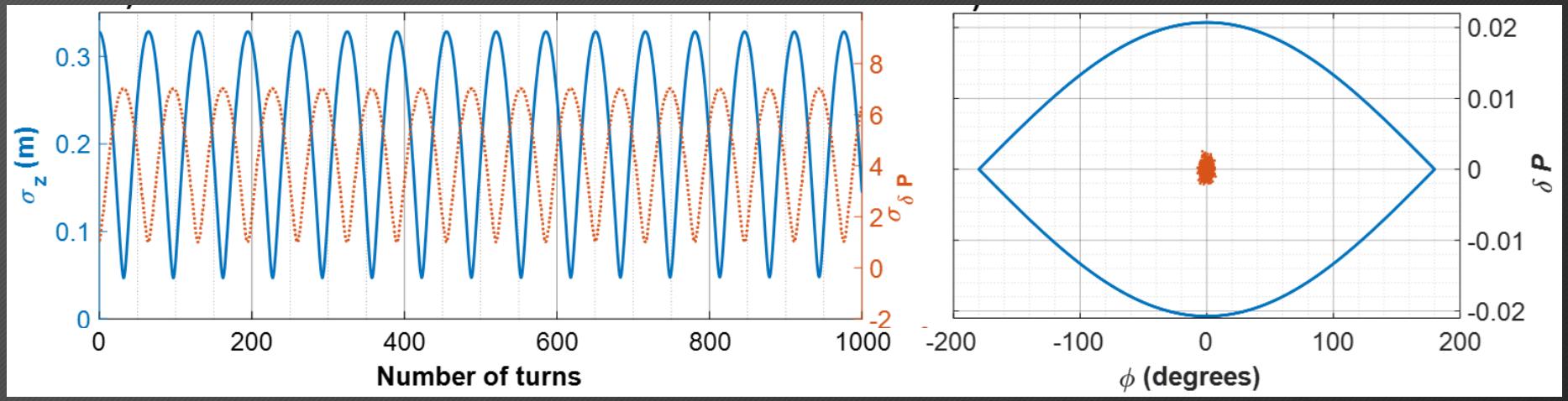


Bunch compression studies: Optics and beam



- Tunes: Qx=2.454, Qy=1.416
- σ_δ=1E-4
- RF voltage 100 V
- Emittances 2.5 or 1 mm mrad
- 100 keV
- Charge – 0.72 pC

Bunch compression studies: BMAD



- Optimal number of turns is 34
- Compression achieved ~ σ_t=10 ns

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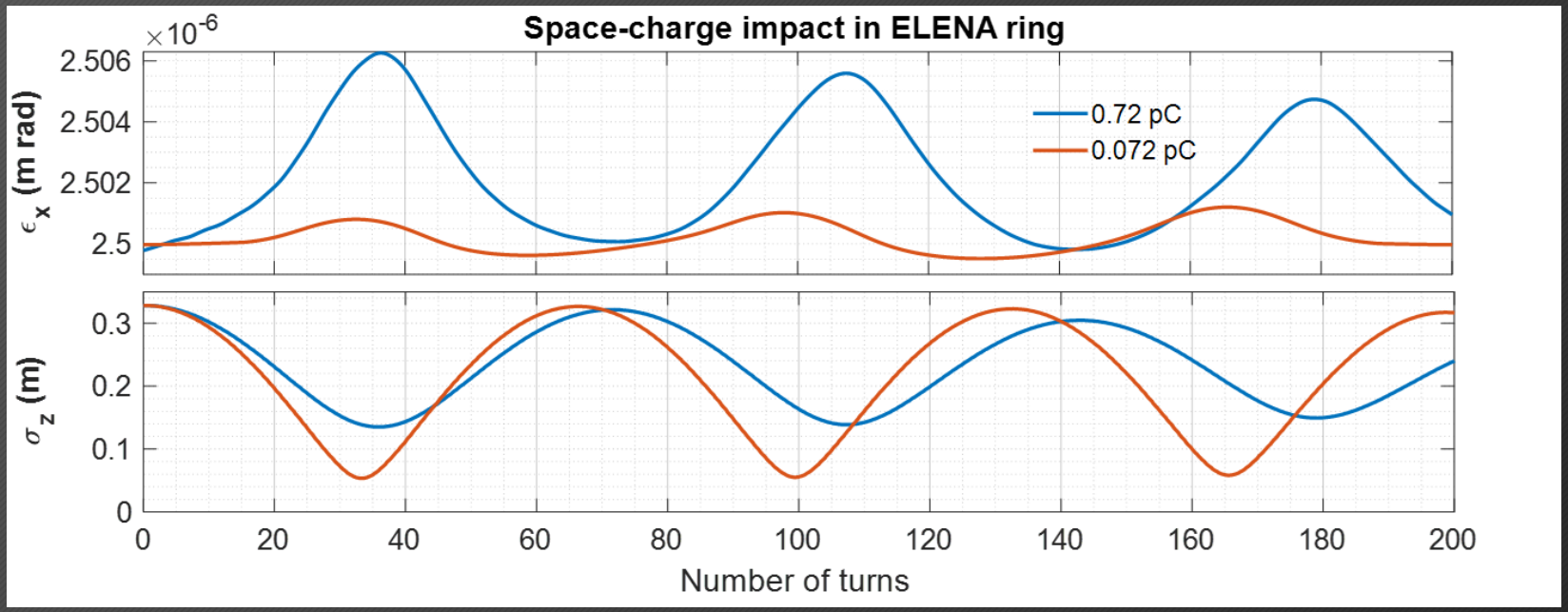
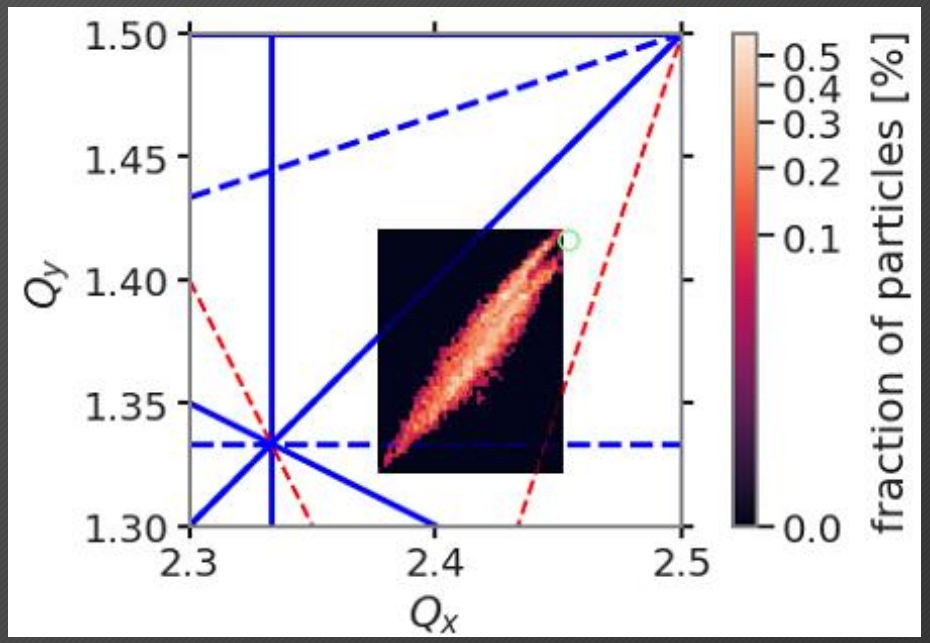
Impact of collective effects: space-charge

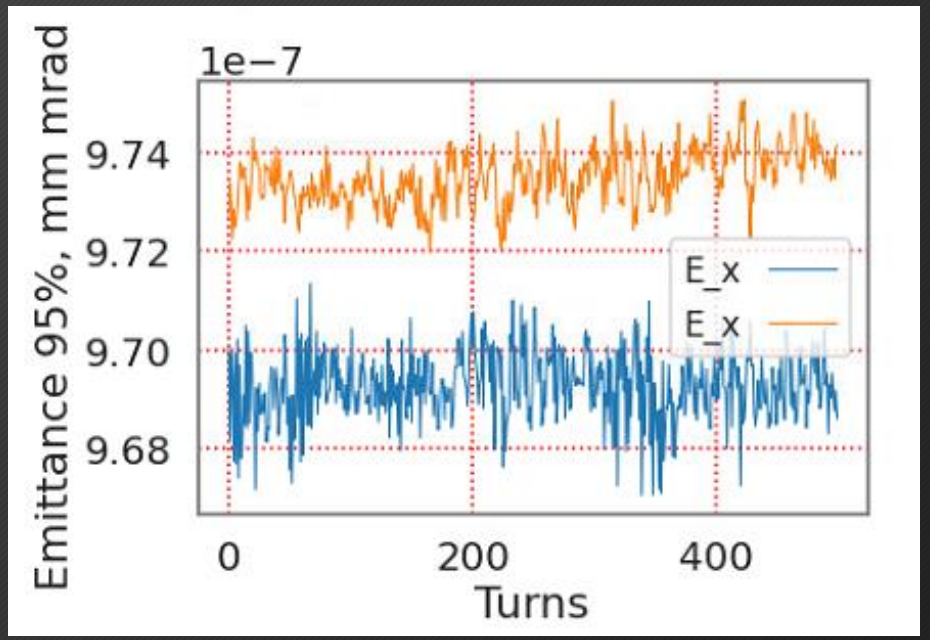


- BMAD has 3D PIC space charge tracking module
- Intensity is too high
- +incoherent shift problems

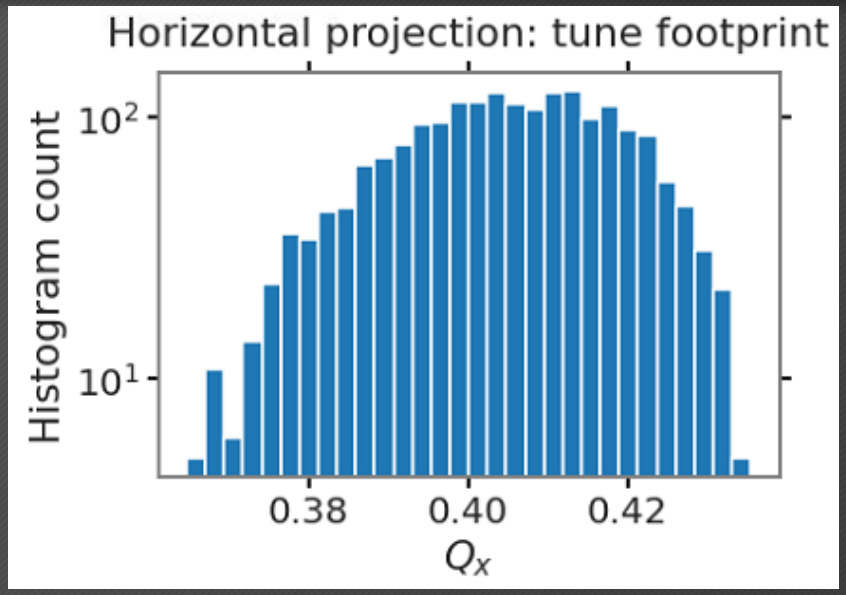
Impact of collective effects: Tune shift

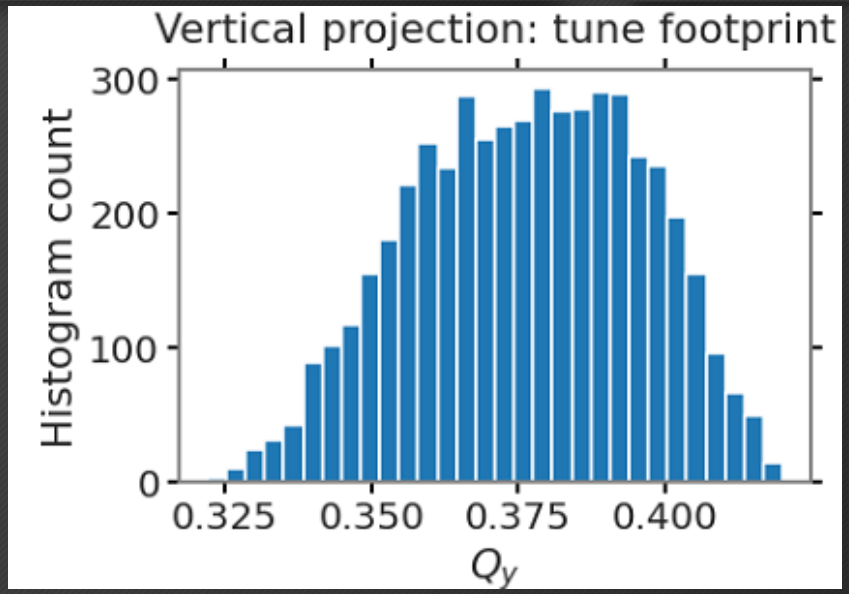
- Emittance decreased to 1 mm mrad - more interesting case
- Nominal 75 ns





Impact of collective effects: Tune shift





~ 0.07

~ 0.098

- Comparison to theory: ΔQx, ΔQy = 0.067,0.1

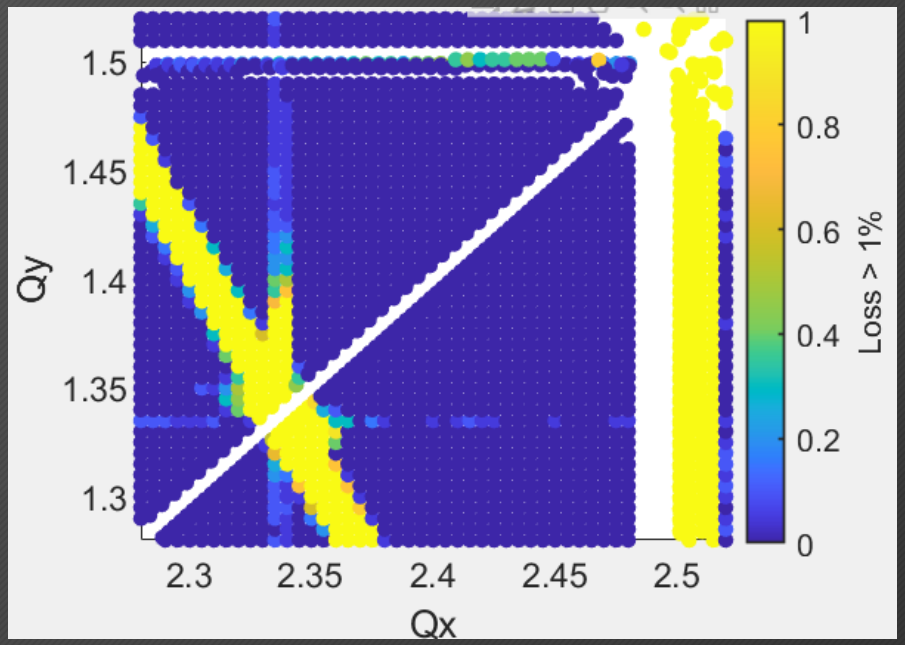
$$\Delta Q_{x,y} = -\frac{r_0 \lambda}{2\pi\beta^2\gamma^3} \frac{\langle\beta_{x,y}\rangle R}{\sigma_{x,y}(\sigma_x + \sigma_y)}$$

- Large values without rotation

Impact of collective effects: Machine errors – rough estimation

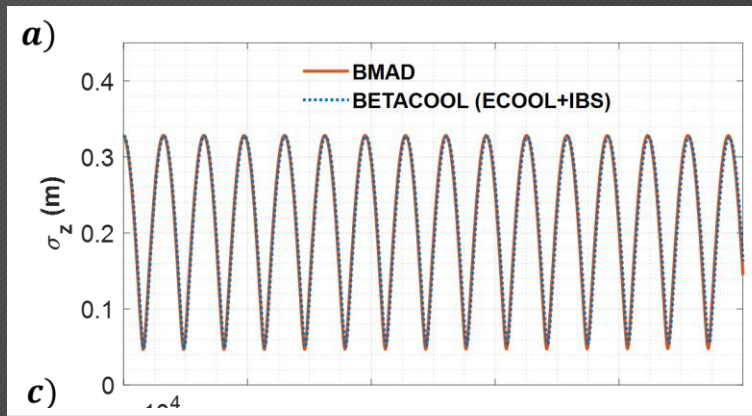
- Dipole and quadrupole errors were implemented up to 3rd order
- Mostly simulation values:

1e-4+Gauss(1e-4)

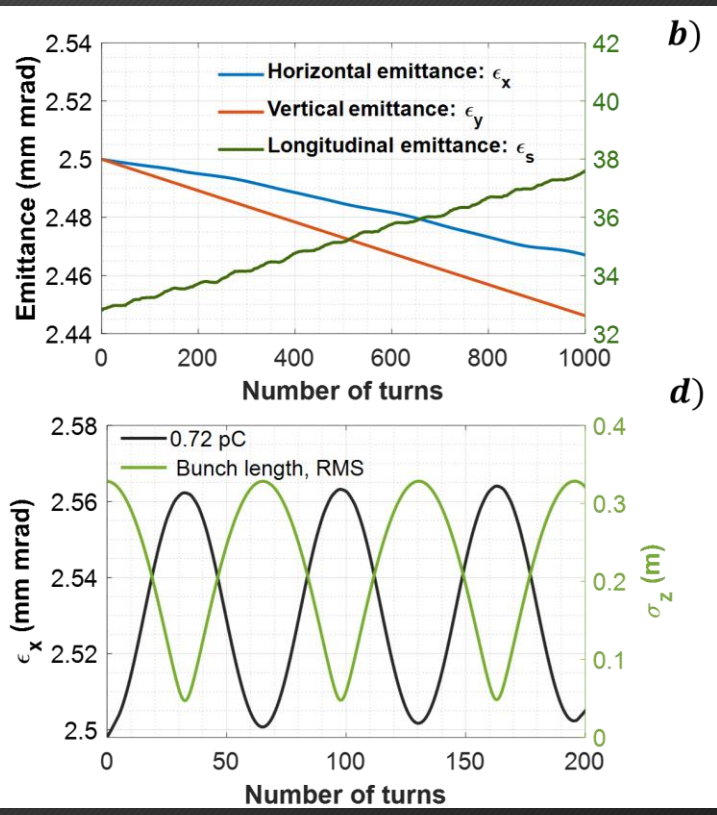


Impact of collective effects: IBS and electron cooling

- Martini and Parkhomchuk models at 2.5 mm mrad



Parameter	Value
Electron beam energy (eV)	55
Beam current (mA)	1
Density of the beam (m^{-3})	1.41e+12
Length of the interaction drift (m)	0.85
Magnetic field in the drift region (kG)	0.1
Electron beam radius (cm)	2.5
Effective temperature of electron beam (eV)	2e-4
Betatron functions $\beta_{x,y}$ (m)	2.103, 2.186
Horizontal dispersion D_x (m)	1.498



Benchmark of simulation tools

- ELENA lattice with 2.5 mm mrad emittance and 75 ns for bunched beam
- Coasting with 2.5E7 intensity

The growth rates for bunched beam are:

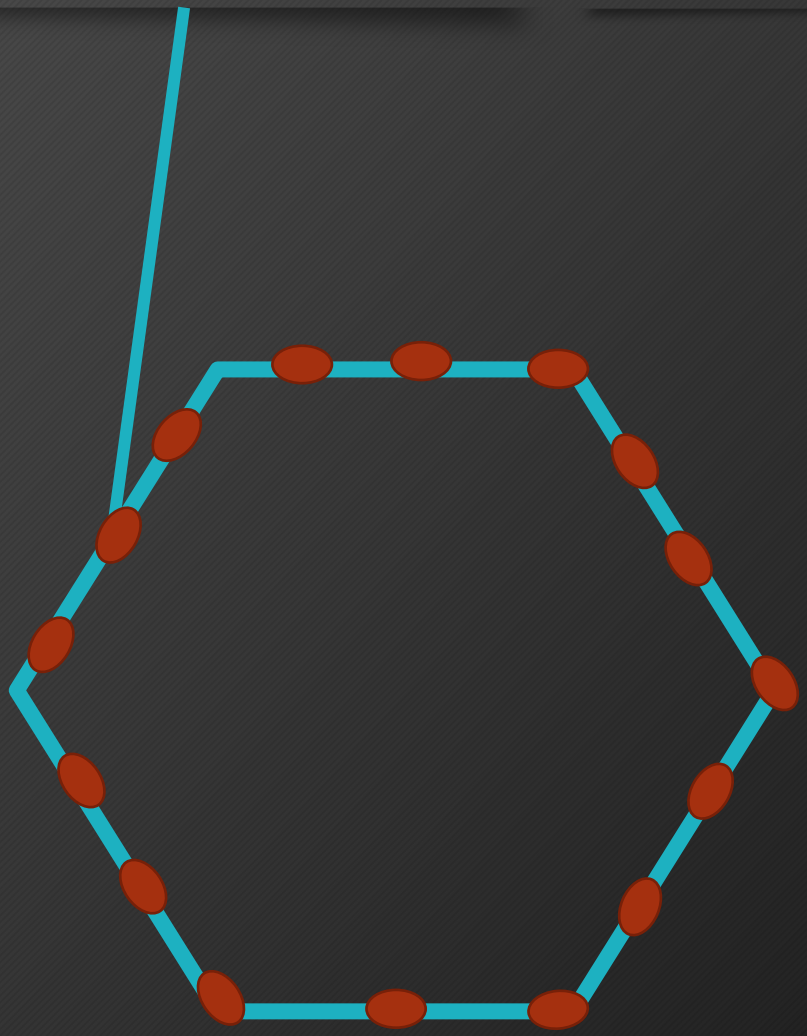
Code name	Tau_x	Tau_y	Tau_l
MAD-X	2.109e-01	-3.033e-01	5.248e+01
JSPEC	2.177e-01	-3.045e-01	5.210e+01
BETACOOL	2.211e-01	-3.096 e-01	5.3225e+01

The growth rates for coasting beams accordingly :

Code name	Tau_x	Tau_y	Tau_l
MAD-X	4.748e-02	-1.295e-02	1.507e-01
JSPEC	4.822e-02	-1.317e-02	2.978e-01
BETACOOL	5.14e-0.2	-1.298e-02	2.944e-01

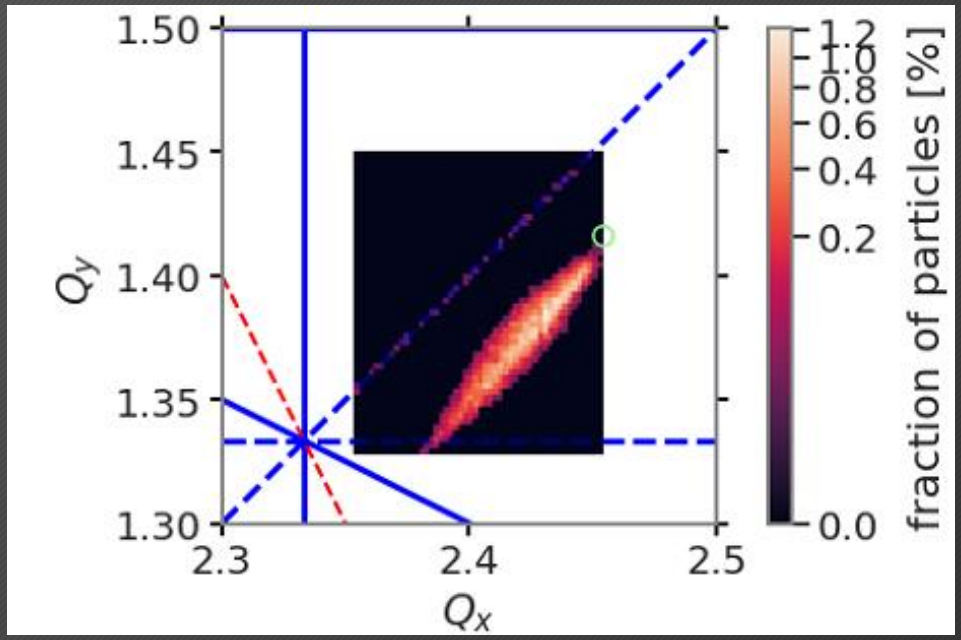
Impact of collective effects: Mitigation

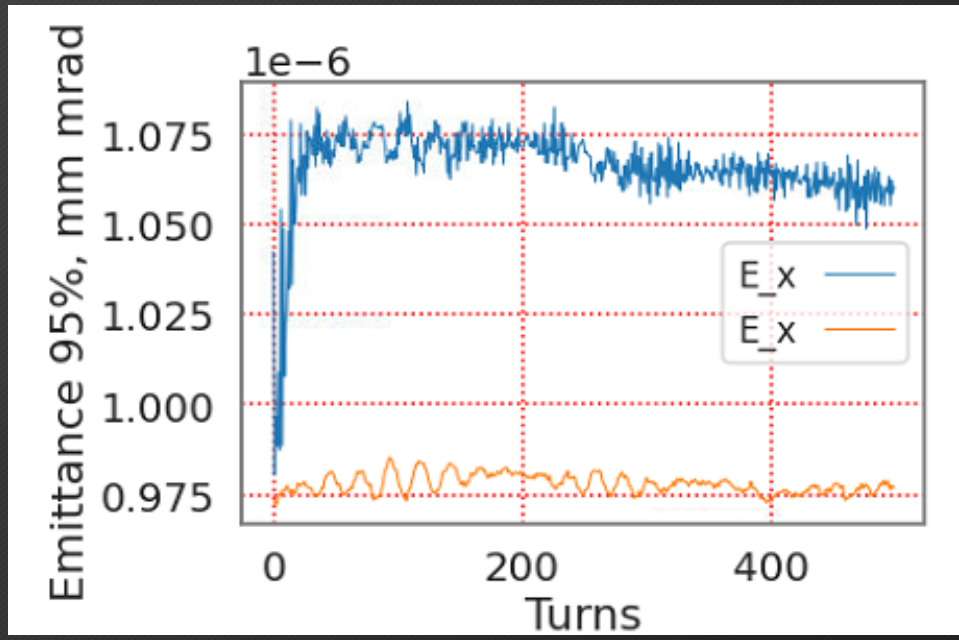
- Decrease in bunch population is required by factor >10
- Compression by de-bunching and re-bunching could solve the problem
- Adiabatic bunching with h>10 or bunch splitting (no possibility)



Impact of collective effects: space charge 1/16 of intensity

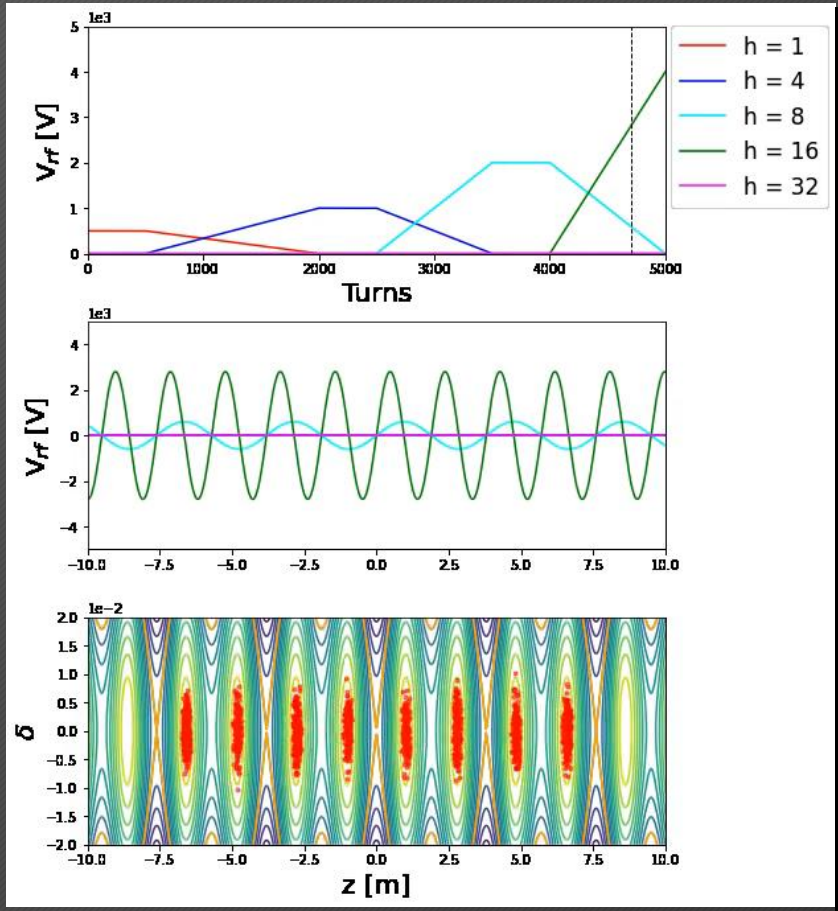
- Emittance decreased to 1 mm mrad
- Bunch length ~ 5 ns
- With errors
- V_rf=500 and h=16



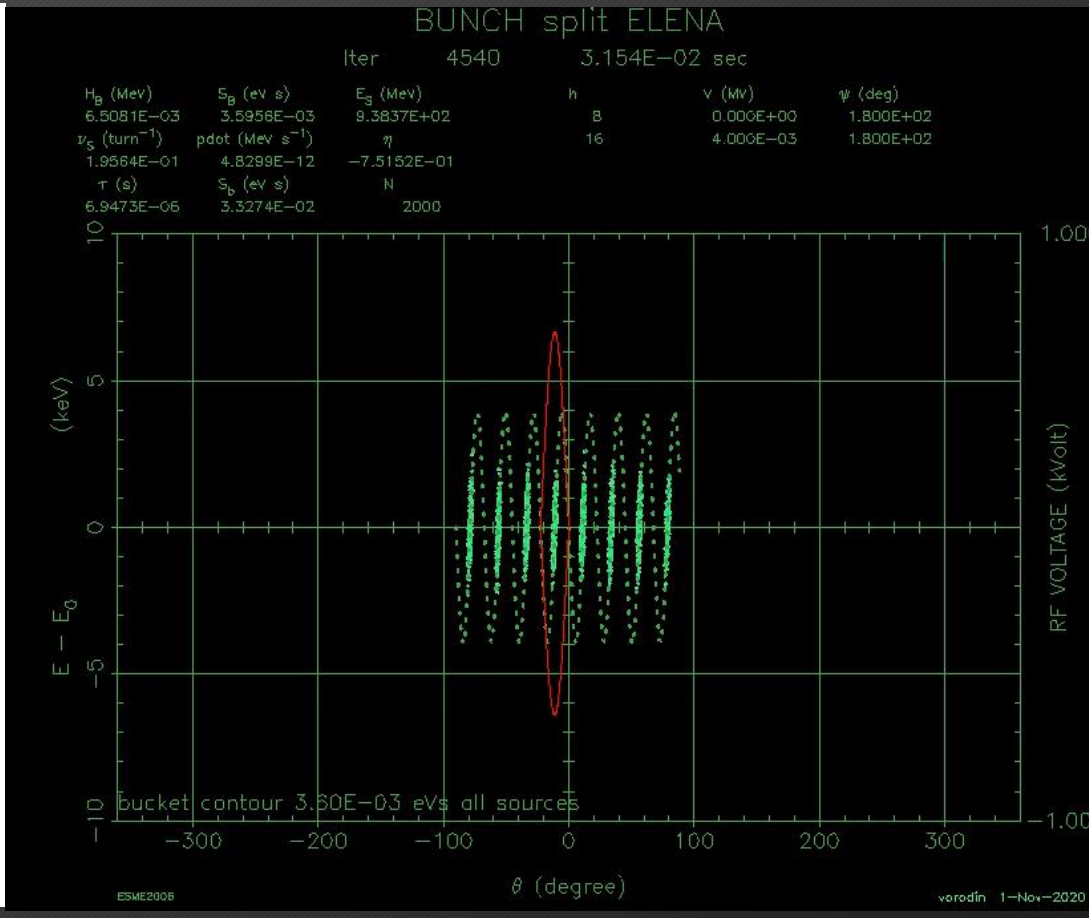


Impact of collective effects: bunch splitting (2 harmonics needed)

- PyHEADTAIL

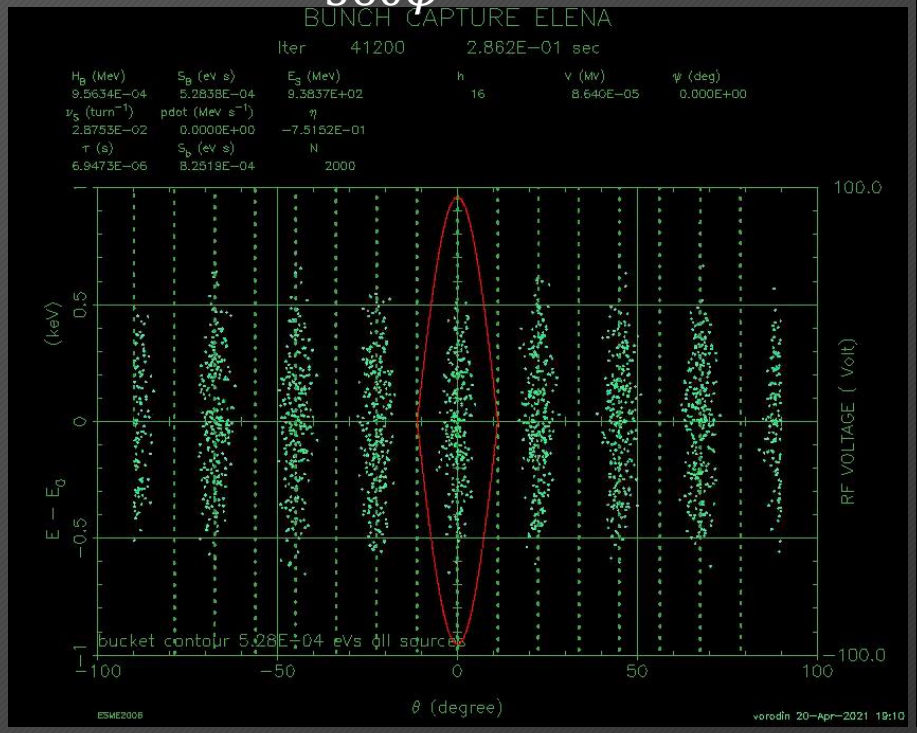


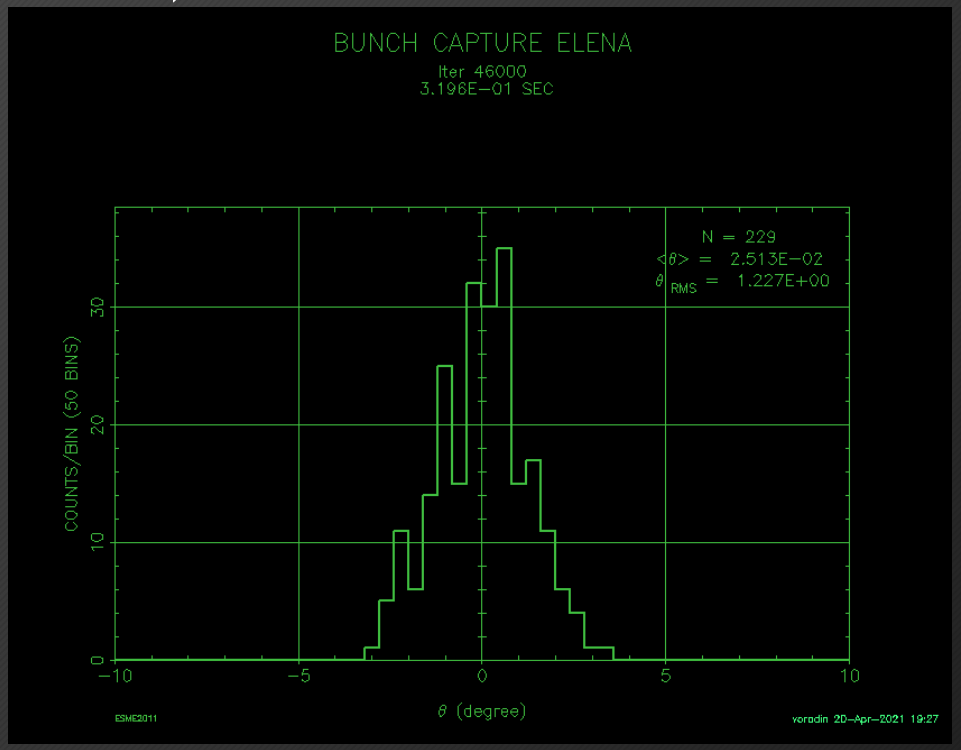
- ESME



Impact of collective effects: re-bunching

- $dE/E = 0.4\ keV$
- $\sigma_t = \frac{\theta_{RMS}}{360\varphi}$=1.22/(360*16*144000)=1.5 ns!





Outlook

- Implement IBS model into PyHEADTAIL
- Adjust magnet errors
- Fine tune bunch splitting algorithm