Bunch compression limits for single and multi-turn collisions with solid and gas targets

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Introduction

Purposes

- Create a new modeling approach for validation of present and future antimatter machines and experiments
- Use realistic descriptions of each element and effect
- Module based simulation allowing machine study as a whole
- Simple multi-goal optimization

ELENA

- Extra Low ENergy Antiproton ring
- Lower energy beams, 100 keV, for better trapping efficiency

Transfer lines(TL)

- All optical elements are electrostatic
- Includes horizontal and vertical bends

Methods

Possible bunch compression schemes

- Such low energy region permits longitudinal bunch(>100ns) shrinking via RF cavity, two possible options were considered:

Velocity bunching in TL

$$R_{56} = L\frac{1}{\gamma^2}$$

Optimal length $L = \frac{\lambda mc^2\beta^3\gamma^3}{2\pi q V_0}$,

where V_0 is cavity voltage. The greater V_0, the shorter the drift

Pros: simultaneous experiments operation

Multi-turn compression

$h = -\frac{2\pi eV_0}{\lambda E_f} sin(\phi_{rf})$, energy chirp

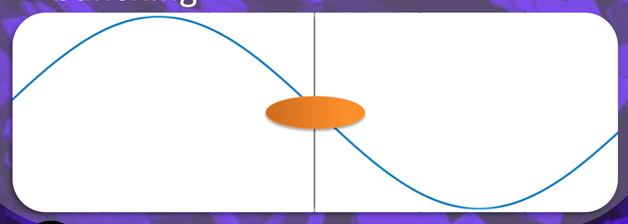
$$\sigma_{t_f} = \sqrt{(1+hR_{56})^2\sigma_{t_i}^2 + \left(\frac{E_i}{E_f}\right)^2 R_{56}^2\sigma_{\delta_i}^2}$$

$$\sigma_{\delta_f} = \sqrt{h^2\sigma_{t_i}^2 + \left(\frac{E_i}{E_f}\right)^2 R_{56}^2\sigma_{\delta_i}^2}$$

- The second option includes velocity bunching intrinsically

Cavity parameters and drift space

- The first harmonic frequency for the good compression – 144 kHz
- Operating voltage: 100 -500-50kV determines the optimal method
- Same as ELENA in-built cavity but with higher voltage for velocity bunching



Results

Collision with target: gas jet/foil

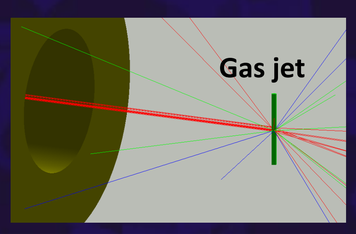
- Utilizing Python interface between BMAD<- - -> G4BL/Geant4

Velocity bunching in TL

L=19.65 m

V_0=50 kV

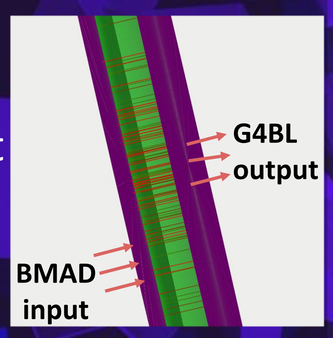
Compression factor=300



Multi-turn compression

Sandwich structure:

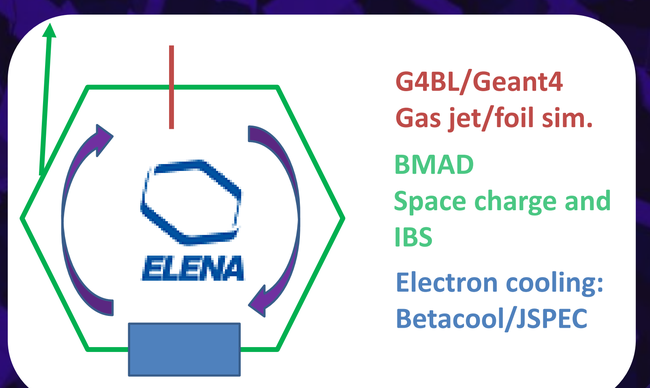
Gas jet diameter is 1 mm with support detectors thickness equal 0.5 μm to minimize errors



Possible to build-up detection system for produced secondaries!

Unified simulation scheme

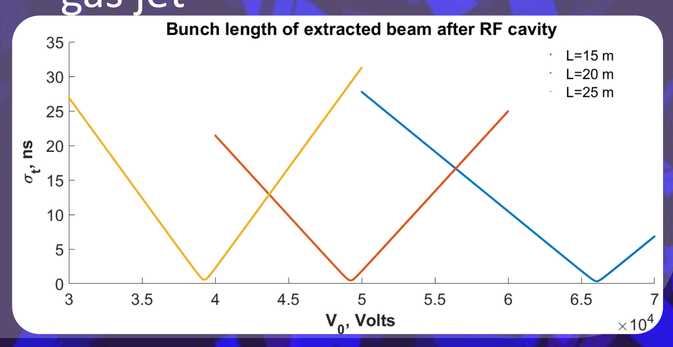
- BMAD/G4BL/extra: continuous tracking, including an injection and extraction stages



Outlook

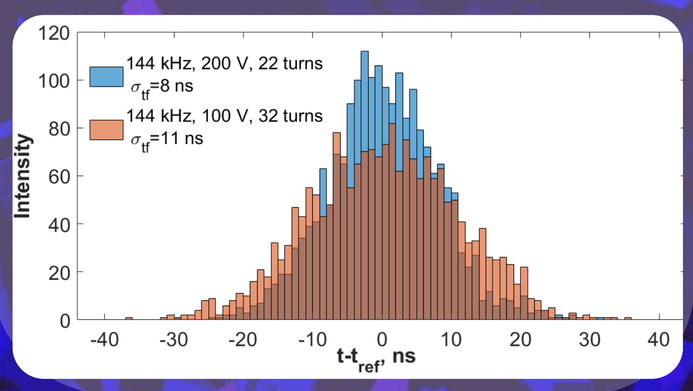
Velocity bunching

- Optimal drift length with varied voltage from the extra cavity
- Cons: Poor statistics with the gas jet



Multi-turn compression

- The final bunch length depends on operating mode of RF cavity in ELENA



Future plans

- Presented results assume an ideal variant of tracking where collective effects were not taken into account
- The next comparison will include space charge and intrabeam scattering impact utilizing BMAD/G4BL features
- Velocity bunching in G4BL is well agreed with BMAD model

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