Bunch merging with drifts

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Introduction

- Bob Palmer presented a new collider cooling scenario in 2006
- starts with bunch train from NF front end
- ends with a single bunch for the collider
- a crucial feature is the **bunch merging** stage
- done in middle after some initial transverse & longitudinal cooling
Cooling scenario

- Full: Preliminary simulated design
- Dashed: Not yet designed

- 50-60 T Solenoids (Muons Inc)
- 1/2 scale RFOFO Guggenheim
- 400 MHz

- Initial
- Standard Study 2a Capture and Phase Rot → 20 bunches

- Combined → 1 bunch
- 200 MHz RFOFO Guggenheim

- 1/3 scale 800 MHz Ring or Guggenheim
Bunch Merging
Using negative k FFAG’s to maximize momentum compaction

- Initial bunches from RFOFO are short (Long Emit=1.7 pi mm)
- First rotation with sawtooth RF rotates all bunches individually
- Second rotation with single ramp rotates all bunches
- Merged bunches captured with standard 200 MHz RFOFO RF
Initial simulations

- very encouraging
- over 80% bunching efficiency including decay losses
Comments

- previous simulation used a number of simplifications
  formulas used for effect of RF and pathlength changes
  both effects applied simultaneously
  negative-k scaling FFAGs don’t appear feasible
  no attempt to match into capture section
  no transverse emittance included

→ need to reproduce results with a more detailed tracking model
examine using drift space or wiggler for compression
I will discuss our preliminary drift space results here
Juan will discuss results using a wiggler
Tracking simulation model

- use ICOOL
- use external optimizer to help set parameters
- Gaussian initial beam with $\varepsilon_{TN} = 1.4$ mm and $\varepsilon_{LN} = 1.7$ mm
  - use best 21 contiguous bunches from NF train
  - weight bunch distribution from Study 2a
- continuous 1 T solenoid for focusing, 20 cm radial aperture
- pillbox RF cavities
- 10 cells of RFOFO-like lattice to measure bunch capture
  - include 1 cm of LiH per cell
Model 1

- use single section of low frequency RF for bunch rotation

Layout

- drift 49 m
- HF RF 3
- LF RF 130
- drift 246
- capture 28
- Total 455 m
High frequency rotation

- want to reduce energy spread before starting LF rotation
- 200 MHz plus 3 harmonics works well
Low frequency rotation (model 1)

- want to put chirp on the train as a whole
- want low energy particles at front of the bunch
- using 5 MHz plus 3 harmonics
Compression (model 1)

- want high energy particles to catch up
- using velocity difference in simple drift space

\[ p_z \text{ [GeV/c]} \]
\[ c t \text{ [m]} \]

- note distortion: \( \Delta t \) is larger for low energy particles
Results for model 1

• at end of 28 m long RF capture section
• decay loss was 31%.
• 59% of remaining beam captured in single 200 MHz bunch
• overall single bunch efficiency (SBE) = 41%
Model 2

- use ideas of **non-distorting phase rotation** from Study 2
  - split LF rotation into 2 parts
  - use first part to get uniform energy spacing of bunches
  - use second part to get bunches to line up in time
  - separate code was used to determine required waveforms
- Fourier analysis used to pick corresponding RF frequencies
- optimizer code helped set parameter values

**Layout**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>drift</td>
<td>49 m</td>
</tr>
<tr>
<td>HF RF</td>
<td>3</td>
</tr>
<tr>
<td>LF1 RF</td>
<td>120</td>
</tr>
<tr>
<td>drift</td>
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</tr>
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</tr>
<tr>
<td>drift</td>
<td>21</td>
</tr>
<tr>
<td>capture</td>
<td>28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>297 m</strong></td>
</tr>
</tbody>
</table>
LF rotation & compression (model 2)

• using 5 MHz plus 2 harmonics for first rotator
• using 25 MHz plus 2 harmonics for second rotator
• a lot of the compression overlaps the rotation
• haven’t found a good solution yet for removing distortion

Looks ugly, but note expanded scale
Results for model 2

• after 28 m long RF capture section
• decay loss was 22%.
• 54% of remaining beam captured in single 200 MHz bunch
• overall SBE = 42%
• got same efficiency as model 1 in 150 m shorter channel
  → encouraging for further optimization work
Space charge tune spread

- approximate expression for center of a gaussian bunch

\[ \frac{\Delta \nu}{\nu} \approx \left( \frac{1}{2\sqrt{2\pi}} \right) \frac{N_\mu \beta_T r_\mu}{\beta \gamma^2 \sigma_z \varepsilon_{TN}} \]

- look at the single bunch after the merge

\[ \frac{\Delta \nu}{\nu} = 0.2 \times 10^{12} \quad 0.4 \text{ m} \quad 1.4 \times 10^{-17} \text{ m} \]

\[ \left/ 1 \right. (1.9)^2 \quad 0.07 \text{ m} \quad 1.4 \times 10^{-3} \text{ m} \]

\[ = 0.01 \]

- looks OK
Summary

• simplified simulations suggested bunch merging is possible
• working now on more realistic modeling
  improve efficiency
  add more detail to simulations, e.g. discrete coils
• non-distorting approach looks promising
• designs with drift space compression are ~40% efficient
• this is a factor of ~2 from goal
• space charge does not appear to be a problem for bunching