Study of beam losses in TT20
CERN Summer Student Programme 2019

Martin Duy Tat
Slow extraction from SPS to TT20

Modelling the TT20 transfer line and beam transport

Diffuser

Electrostatic Septum

Silicon Crystal

Conclusion
Slow extraction from SPS to TT20
Introduction
Short background

- Slow extraction of 400 GeV protons from SPS to TT20 with electrostatic septum (ZS)
- North Area
- 3 target stations, 2 splitters
Slow extraction schemes

- COSE, Constant Optics Slow Extraction
- Octupole Slow Extraction
Aim of this study

• Beam losses induce radioactivation of the accelerator equipment and surrounding environment

• Aim is to explore different methods for reducing beam losses at Splitter 1 to
  • reduce radiation dose to personnel in the area
  • increase machine availability and reliability
Modelling the TT20 transfer line and beam transport
Shape of TCSC (MSSB), Lambertson septum

COSE

Octupole

September 18, 2019 Study of beam losses in TT20
Shape of TCSC (MSSB), Lambertson septum

COSE

Octupole
Histogram of vertical position

COSE

Octupole

Nominal beam, vertical position

Nominal beam, vertical position
Simulation

- Transfer matrix from MADX for beam transport
- Twiss parameters from fitting ellipse in phase space
- MADX matching to get nominal Twiss parameters downstream of Splitter 1
- TCSC and MSSB geometric shapes modelled in Python
- Straight line tracking through TCSC and MSSB
Ellipse fit
Simulation

- Split in the middle, 50/50
- Sweep vertical position by $\pm 2.5\,\text{mm}$
- Sweep horizontal position by $\pm 2.5\,\text{mm}$
- Almost no dependence on $x'$ and $y'$
Schemes for beam loss reduction

- Squeezing (not suitable)
- Passive scatterer (diffuser)
- Short Electrostatic Septum (ES)
- Silicon Crystal
Diffuser
Diffuser principle

- Grid of Tungsten-Rhenium (WRe) wires
- Scattering at the wires reduce the density near TCSC gap
- Multiple Coulomb scattering
- Elastic nuclear scattering
- Inelastic nuclear scattering
Demonstration of an ideal diffuser

Phase space directly behind Diffuser

Phase space at TCSC
Ideal position for diffuser
Formulae for the interested

MC scattering angle:

\[ \langle \theta_{MC}^2 \rangle^{1/2} = \frac{13.6}{p[GeV] \beta c} \sqrt{\frac{L}{X_0}} \left( 1 + 0.038 \ln \left( \frac{L}{X_0} \right) \right) \text{mrad} \]

Elastic scattering angle and probability:

\[ \langle \theta_e^2 \rangle^{1/2} = \frac{197}{A^{1/3} p[GeV]} \text{mrad}, \quad p_e = 1 - \exp \left( - \frac{L}{\lambda_e} \right) \]

Inelastic scattering probability: \( p_i = 1 - \exp \left( - \frac{L}{\lambda_i} \right) \)
Beam losses vs diffuser length

Beam loss vs diffuser length

Beam loss vs diffuser length
Beam losses vs diffuser width

![Graph showing beam loss vs diffuser width]

September 18, 2019 Study of beam losses in TT20
Beam losses vs diffuser position
Histogram of reduced density

COSE

Octupole

Diffuser beam, vertical position

Diffuser beam, vertical position
Plot of reduced density

COSE

Sept. 18, 2019 Study of beam losses in TT20
Results

COSE: Beam losses reduced from 2.44% to 1.61%

- Length: 12 mm
- Width: 0.2 mm
- Position: 184, 581 m

Octupole: Beam losses reduced from 5.84% to 3.78%

- Length: 15 mm
- Width: 0.4 mm
- Position: 183, 580 m
Diffuser position

\[ \approx 30 \text{ m upstream} \]
Electrostatic Septum
ES principle

- Short electrostatic septum with thin wires
- Small kick to create a small gap
- Diffuser scattering (small effect)
- Insert extra quadrupole to reduce beam divergence at ES
Ideal position for ES

Vertical beam divergence

Vertical phase advance
Ideal position for ES

Vertical beam divergence

Vertical phase advance
Plot of $\beta_x$

Beta_x, COSE beam

Beta_x, COSE beam with quad
Plot of $\beta_y$

Beta_y, COSE beam

Beta_y, COSE beam with quad
Plot of $D_x$
Plot of $D_y$
Demonstration of an ideal ES

Phase space directly behind ES

Phase space at TCSC
Formula for the interested

Deflection from ES kick:

\[ \Delta \theta = \frac{E \times L}{pc} \]
Beam losses vs ES length
Beam losses vs ES width

[Graph showing the relationship between beam loss and ES width with a linear increase as ES width increases.]
Beam losses vs ES field

Beam loss vs ES field

Beam loss vs ES field

ES field (MV^-1)
Histogram of reduced density

COSE

Octupole

ES beam, vertical position

ES beam, vertical position
Plot of reduced density

COSE

Octupole
Results

COSE: Beam losses reduced from 2.44% to 0.43%

- Length: 0.8 m
- Width: 0.1 mm
- Field: 5.0 MV m$^{-1}$

Octupole: Beam losses reduced from 5.84% to 0.32%

- Length: 1.0 m
- Width: 0.1 mm
- Field: 5.0 MV m$^{-1}$
ES position

(≈ 520 m upstream)
Silicon Crystal
Silicon Crystal principle

- Bent silicon crystal
- Channeling
- Volume reflection ← I use this regime
- Amorphous scattering
- Multiple aligned crystals
PDF for the interested
Demonstration of an ideal crystal

Phase space directly behind crystal

Phase space at TCSC
Beam losses vs crystal number

![Graph of Beam loss vs Number of crystals](image-url)
Beam losses vs crystal width

[Graph showing beam loss vs crystal width]
Beam losses vs crystal position

![Graph 1: Beam loss vs Crystal position](chart1)

![Graph 2: Beam loss vs Crystal position](chart2)
Histogram of reduced density

COSE

Octupole

Crystal beam, vertical position

Crystal beam, vertical position
Plot of reduced density

COSE

Octupole
Results

COSE: Beam losses reduced from 2.44% to 0.44%
  - Number of crystals: 4
  - Width: 0.6 mm
  - Position: 183, 580 m

Octupole: Beam losses reduced from 5.84% to 2.71%
  - Number of crystals: 5
  - Width: 0.4 mm
  - Position: 183, 580 m
Crystal position

(≈ 30 m upstream)
Conclusion
## Summary of results

### Losses relative to total number of particles

<table>
<thead>
<tr>
<th>Beam losses</th>
<th>COSE</th>
<th>Octupole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>2.44%</td>
<td>5.84%</td>
</tr>
<tr>
<td>Diffuser</td>
<td>1.61%</td>
<td>3.78%</td>
</tr>
<tr>
<td>ES</td>
<td>0.43%</td>
<td>0.32%</td>
</tr>
<tr>
<td>Crystal</td>
<td>0.44%</td>
<td>2.71%</td>
</tr>
</tbody>
</table>
### Summary of results

#### Beam loss reduction factor

<table>
<thead>
<tr>
<th>Beam losses</th>
<th>COSE</th>
<th>Octupole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diffuser</td>
<td>1.52</td>
<td>1.54</td>
</tr>
<tr>
<td>ES</td>
<td>5.67</td>
<td>18.25</td>
</tr>
<tr>
<td>Crystal</td>
<td>5.55</td>
<td>2.15</td>
</tr>
</tbody>
</table>
Advantages and disadvantages

• Diffuser
  • Advantage: Cheap and simple to set up
  • Disadvantage: Only a small beam loss reduction

• ES
  • Advantage: High beam loss reduction for both distributions
  • Disadvantage: Very expensive, and long cables

• Crystal
  • Advantage: Cheap and efficient for COSE distribution
  • Disadvantage: New crystal technology required (multi-crystal array in VR)
Conclusion

- Crystal is a good choice for COSE
- ES performs really well for the Octupole distribution
- Diffuser has a relatively limited performance, but it’s a cost-effective option
## Summary of parameters

<table>
<thead>
<tr>
<th>Diffuser</th>
<th>Length</th>
<th>Width</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSE</td>
<td>12 mm</td>
<td>0.2 mm</td>
<td>184, 581 m</td>
</tr>
<tr>
<td>Octupole</td>
<td>15 mm</td>
<td>0.4 mm</td>
<td>183, 580 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ES</th>
<th>Length</th>
<th>Width</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSE</td>
<td>0.8 m</td>
<td>0.1 mm</td>
<td>5.0 MV m$^{-1}$</td>
</tr>
<tr>
<td>Octupole</td>
<td>1.0 m</td>
<td>0.1 mm</td>
<td>5.0 MV m$^{-1}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Number</th>
<th>Width</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSE</td>
<td>4</td>
<td>0.6 mm</td>
<td>183, 580 m</td>
</tr>
<tr>
<td>Octupole</td>
<td>5</td>
<td>0.4 mm</td>
<td>183, 580 m</td>
</tr>
</tbody>
</table>
Thank you!

Thanks to:

- TE-ABT-BTP
- Yann Dutheil and Matthew Fraser