INJECTION BEAM LINE OPTIMIZATION
at COSY

March 6, 2019 | Benat Alberdi (on behalf of JEDI collaboration) | IKP-2, FZ-Juelich
Outline

- COSY facility overview
  - Beam source
  - JULIC Cyclotron
  - Injection Beam Line
  - Injection

- Optimization
  - IBL optimization
  - Tracking
  - Emittance measurement

- Next steps
Facility overview
Facility overview

\[ p = \frac{\text{zero.pnum}}{\text{three.pnum}} \cdot \frac{\text{seven.pnum}}{\text{GeV/c}} \]

\[ L = \frac{\text{one.pnum}}{\text{eight.pnum}} \cdot \frac{\text{four.pnum}}{\text{two.pnum}} \cdot \frac{\text{two.pnum}}{\text{seven.pnum}} \]
Facility overview

\[ p = 0.3 - 3.7 \text{ GeV/c} \]
\[ L = 184 \text{ m} \]
Facility overview

\[ p = 0.3 - 3.7 \text{ GeV/c} \]

\[ L = 184 \text{ m} \]
Beam source
Beam source
Beam source

- 2.0-4.5 KeV/A beams.
- Polarization up to 80%.
JUelich Light Ion Cyclotron (JULIC)

Originally built for light ions up to Ar, nowadays only $H^-$ and $D^-$. 

$\frac{f}{2} = \frac{1}{2} - \frac{1}{3}$ MHz.

$\langle B \rangle_{\text{max}} = \frac{1}{3.5}$ T.

Extraction $4.5$ MeV $H^-$ or $7.6$ MeV $D^-$ beams. 

$200$ ms cycles.
JUelich Light Ion Cyclotron (JULIC)
JUelich Light Ion Cyclotron (JULIC)

Originally built for light ions up to Ar, nowadays only $H^-$ and $D^-$.  
- 700 tons of iron.  
- $f = 20 - 30 MHz$.  
- $< B >_{max} = 1.35 T$
JUelich Light Ion Cyclotron (JULIC)

Originally built for light ions up to Ar, nowadays only $H^-$ and $D^-$. 

- 700 tons of iron.
- $f = 20 - 30\text{MHz}$.
- $< B >_{\text{max}} = 1.35\text{T}$

Extraction

- 45 MeV $H^-$ or 76 MeV $D^-$ beams.
- 20ms cycles.
Injection Beam Line (IBL)

Provides the connection between JULIC cyclotron and COSY. It is nine meters long. Composed by two quadrupole magnets, two dipole magnets and a steerer magnet. Diagnostic tools included along the IBL: eight probe grids and three phase probes. Injection dipole at the end.
Injection Beam Line (IBL)

Provides the connection between JULIC cyclotron and COSY. It is nine meters long. Composed by four quadrupole magnets, two dipole magnets, and one steerer magnet. Diagnostic tools included along the IBL: eight profile grids and three phase probes. Injection dipole at the end.
Injection Beam Line (IBL)

Provides the connection between JULIC cyclotron and COSY.

- It is 94m long.
- 30mm of vertical offset.
- Composed by 42 quadrupole magnets, 12 dipole magnets and 14 steerer magnets.
- Diagnostic tools included along the IBL: 8 profile grids and 3 phase probes.
- Injection dipole at the end.
Injection Dipole

Injection in COSY is performed by stripping injection into a "distorted orbit". Injection dipole is responsible to align the beam coming from the cyclotron with the beam cycling in COSY.
Injection Dipole

- Injection in COSY is performed by stripping injection into a "distorted orbit".
- Injection dipole is responsible to align the beam coming from the cyclotron with the beam cycling in COSY.
Injection in COSY is performed by stripping injection into a "distorted orbit".

Injection dipole is responsible to align the beam coming from the cyclotron with the beam cycling in COSY.
Injection

Bumper magnets

Dipole magnets

Stripping foil

50mm
Optimization

The goal is to make the injection of particles into COSY as efficient as possible. Steps:

1. Develop a model for the IBL.
2. Match design specifications.
3. Control injection point parameters.
4. Match IBL emittance with COSY acceptance.
Optimization

Overview

The goal is to make the injection of particles into COSY as efficient as possible. Steps:

- Develop a model for the IBL.
- Match design specifications.
- Control injection point params.
- Match IBL emittance with COSY acceptance.
Optimization

Overview

The goal is to make the injection of particles into COSY as efficient as possible. Steps:

- Develop a model for the IBL.
- Match design specifications.
- Control injection point params.
- Match IBL emittance with COSY acceptance.
Injection optimization

IBL

Not all the quadrupoles are independent → one.pnum/two.pnum free parameters.

Constraints
Optimized according to INTERATOM design:
Sections /two.pnum,/four.pnum,/six.pnum: FODO structures.
Sections /one.pnum, /three.pnum+/four.pnum+/five.pnum and /seven.pnum achromats.
Section /eight.pnum controls injection.
Injection optimization

Not all the quadrupoles are independent → one.pnum/two.pnum free parameters.

Constraints optimized according to INTERATOM design:
Sections /two.pnum, /four.pnum, /six.pnum: FODO structures.
Sections /one.pnum, /three.pnum+/four.pnum+/five.pnum and /seven.pnum: achromats.
Section /eight.pnum controls injection.
Injection optimization

Not all the quadrupoles are independent → 12 free parameters.

Constraints

Optimized according to INTERATOM design:

- Sections 2, 4, 6: FODO structures.
- Sections 1, 3+4+5 and 7 achromats.
- Section 8 controls injection.
Injection optimization

IBL and tracking
Injection optimization
IBL and tracking
Injection optimization
IBL and tracking

Acceptance X

IBL Acceptance X

X [mm]

X' [mrad]
Injection optimization
IBL and tracking
Injection optimization
Tracking at COSY
Injection optimization

Tracking at COSY
Injection optimization

Tracking at COSY
Combined tracking

Phase Space X

- COSY acceptance
- IBL exit

X [mm]

X' [mrad]
Injection optimization

Emittance measurement

\[
M = \left(\frac{1}{\text{pnum}}\right) \cdot \left(\cos(\sqrt{KL}) - \sqrt{K} \sin(\sqrt{KL}) \cos(\sqrt{KL})\right)
\]
Injection optimization

Emittance measurement

\[ M = \frac{\sqrt{K} \sin(\sqrt{KL})}{\sqrt{K}} - \sqrt{K} \sin(\sqrt{KL}) \cos(\sqrt{KL}) \]
Injection optimization

Emittance measurement

\[ M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{KL}) & \frac{1}{\sqrt{k}} \sin(\sqrt{KL}) \\ -\sqrt{k} \sin(\sqrt{KL}) & \cos(\sqrt{KL}) \end{bmatrix} \]
Injection optimization

Emittance measurement

\[ M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{KL}) & \frac{1}{\sqrt{K}} \sin(\sqrt{KL}) \\ -\sqrt{K} \sin(\sqrt{KL}) & \cos(\sqrt{KL}) \end{bmatrix} \]
Injection optimization

Emittance measurement

\[ M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{K'L}) & \frac{1}{\sqrt{K'}} \sin(\sqrt{K'L}) \\ -\sqrt{K'} \sin(\sqrt{K'L}) & \cos(\sqrt{K'L}) \end{bmatrix} \]
Injection optimization
Emittance measurement

Plot of beam size squared vs quadrupole strength for Q17, Y axis.
Outlook

The planned upcoming steps for optimizing the injection are:

- Analyze the injection dipole.
- Find steerer magnets which allow for independent $X$ and $X'$ variation of the injected beam in the stripping foil.
- Combine IBL and COSY in a simulation for a full tracking, including the orbit bump at injection.
- Match phase space at IBL exit with COSY acceptance.
- Improve the emittance measurement at IBL. Look for other methods.
Thank you!
References


C. Weidemann (2016) COSY injection and tuning Workshop on Beam Dynamics and Control studies at COSY.

Spare slides
Spare slides
Spare slides
Spare slides

Beam Size X vs Quadrupole Strength

\[ \chi^2/\text{ndf} = 2.83\times10^{-4}/3.0 \text{ m}^2 \]

\[ K_{017} [1/m^2] \]

Fit
Data

Residuals [m²]
Emittance Measurement:
Quadrupole Scan Method

\[ \Sigma_{\text{beam}}(s) = M \cdot \Sigma_{\text{beam}}^0 \cdot M^T \]

where

\[
\begin{align*}
\Sigma_{11} &= \langle x^2 \rangle \\
\Sigma_{12} &= \Sigma_{21} = \langle xx' \rangle \\
\Sigma_{22} &= \langle x'^2 \rangle
\end{align*}
\]

Finally:

\[ \Sigma_{11} = \langle x^2 \rangle = M_{11}^2 \Sigma_{11}^0 + 2 M_{11} M_{12} \Sigma_{12}^0 + M_{12}^2 \Sigma_{22}^0 \]

And:

\[ \epsilon = \pi \sqrt{\det(\Sigma_{\text{beam}})} = \pi \sqrt{\Sigma_{11}^0 \Sigma_{22}^0 - (\Sigma_{12}^0)^2} \]
First order approximation:
\[
\begin{aligned}
\cos(x) & \approx 1 + O(x^2) \\
\sin(x) & \approx x + O(x^3)
\end{aligned}
\]
\[\Sigma_{11} = \langle x^2 \rangle = f(K^2, K) \Rightarrow \text{Parabolic fit with: } g(K) = AK^2 + BK + C\]

Second order approximation:
\[
\begin{aligned}
\cos(x) & \approx 1 - \frac{x^2}{2} + O(x^4) \\
\sin(x) & \approx x - \frac{x^3}{3!} + O(x^5)
\end{aligned}
\]
\[\Sigma_{11} = \langle x^2 \rangle = f(K^4, K^3, K^2, K) \Rightarrow \text{Fourth order fit: } g(K) = AK^4 + BK^3 + CK^2 + EK + F\]