INJECTION BEAM LINE OPTIMIZATION

February 18, 2019 | Benat Alberdi (on behalf of JEDI collaboration) | IKP-2, FZ-Juelich

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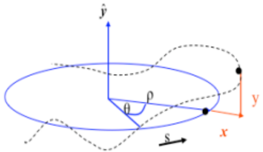
Summary

- Brief introduction to accelerator physics.
- COSY facility overview
  - Beam source
  - JULIC Cyclotron
  - Injection Beam Line
  - Injection
- Optimization
  - IBL optimization
  - Tracking
  - Emittance measurement
- Next steps

Introduction

Introduction



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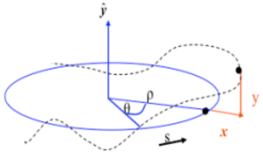

$$\begin{bmatrix} x \\ x' \end{bmatrix}_{s_1} = M(s1, s0) \cdot \begin{bmatrix} x \\ x' \end{bmatrix}_{s_0}$$

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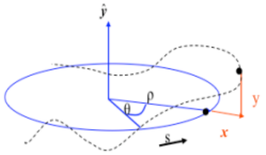

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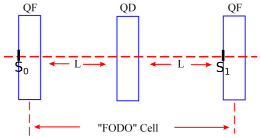

$$M = M_D \cdot M_{QD} \cdot M_D \cdot M_{QF}$$

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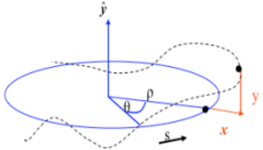

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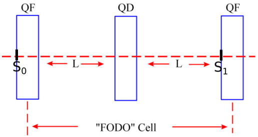

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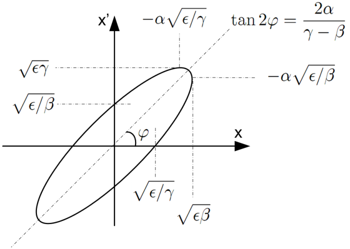

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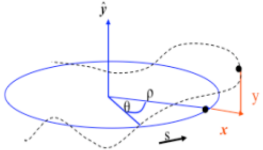

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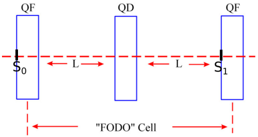

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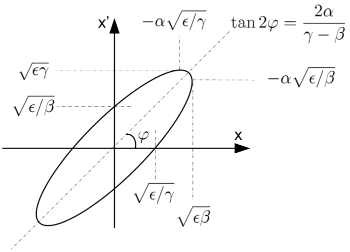


Rms beam size:

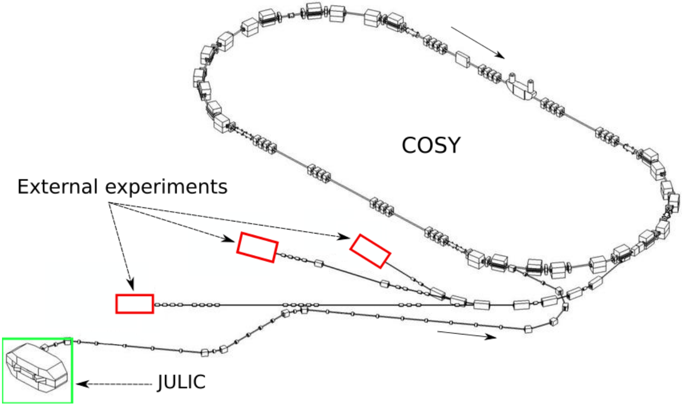
$$\sigma_{rms} = \sqrt{\epsilon\beta}$$

Geometrical emittance:

$$\varepsilon = \pi\epsilon$$

Facility overview

Facility overview



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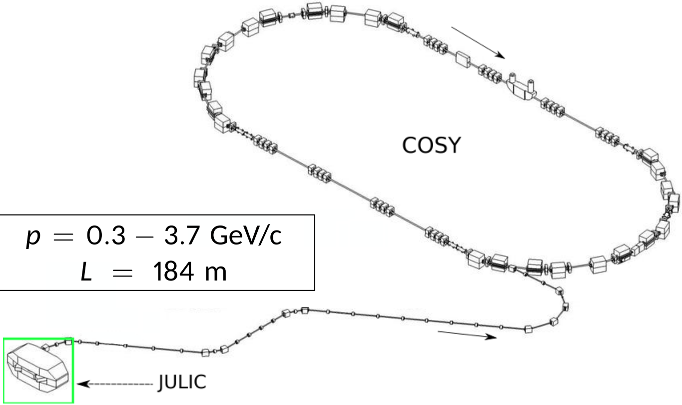
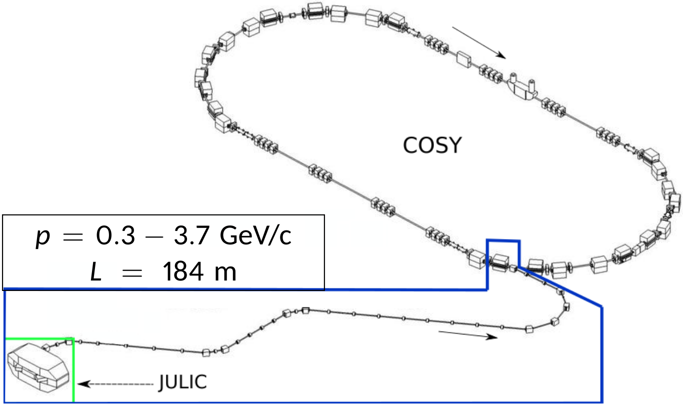


$$p = 0.3 - 3.7 \text{ GeV/c}$$
$$L = 184 \text{ m}$$

Facility overview



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Beam source

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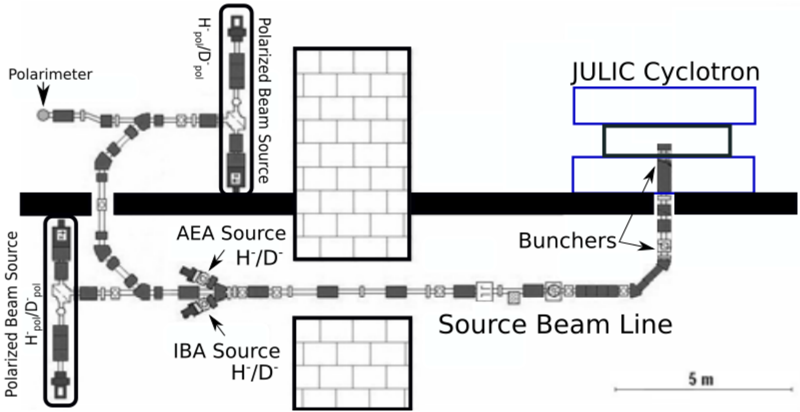
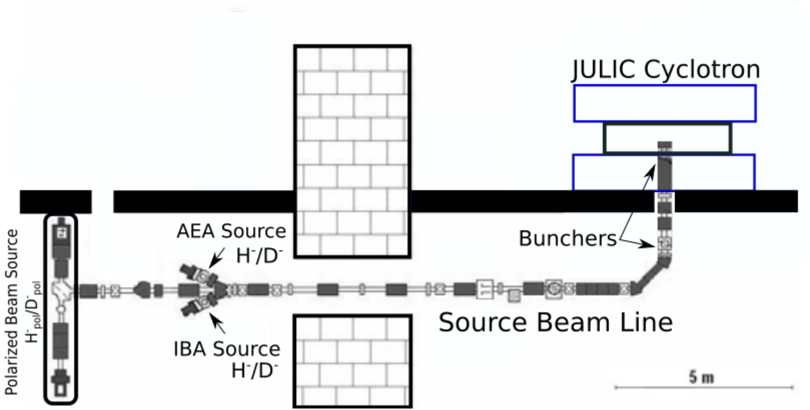

Polarimeter
H^-_{pol}/D^-_{pol}
Polarized Beam Source
JULIC Cyclotron
AEA Source
H^-/D^-
Bunchers
Polarized Beam Source
H^-_{pol}/D^-_{pol}
Source Beam Line
IBA Source
H^-/D^-
5 m

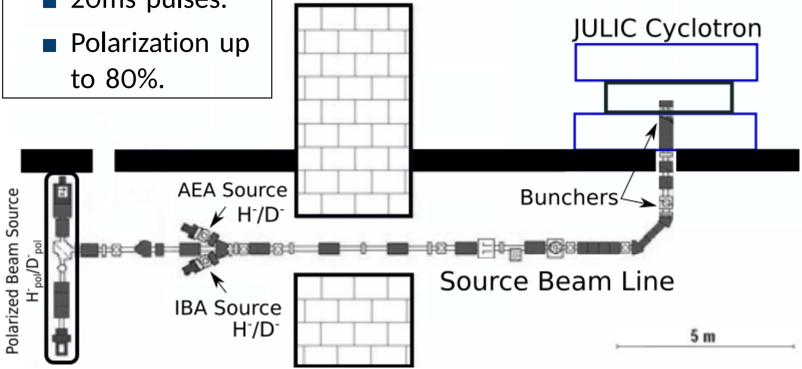
Beam source



JULIC Cyclotron
AEA Source
H^-/D^-
Bunchers
Polarized Beam Source
H^-_{pol}/D^-_{pol}
Source Beam Line
IBA Source
H^-/D^-
5 m

Beam source

- 2.0-4.5 KeV/A beams.
- 20ms pulses.
- Polarization up to 80%.



JULIC Cyclotron

JULIC Cyclotron

Commissioned in 1968. Upgraded in 1992.

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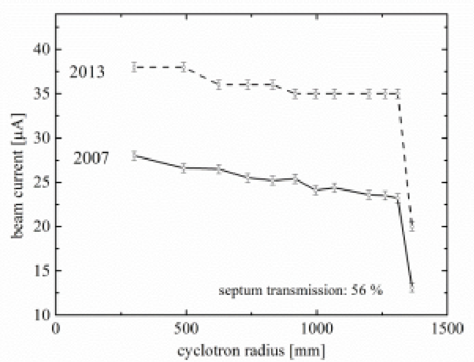
Commissioned in 1968. Upgraded in 1992.

Originally built for light ions up to Ar.
Nowadays only used for H^- and D^-.

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

JULIC Cyclotron

JULIC Cyclotron



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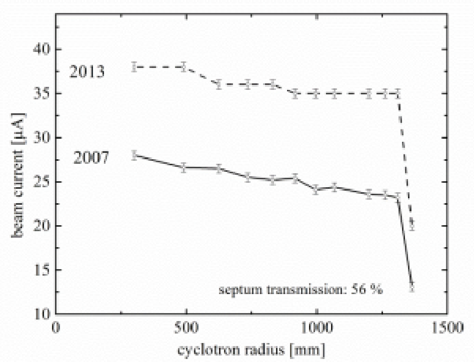
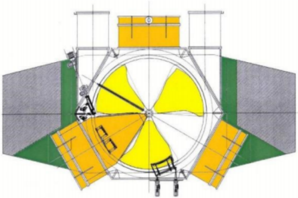
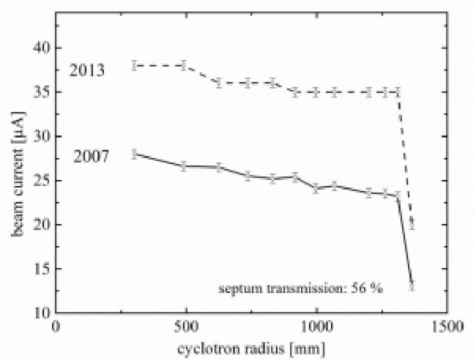
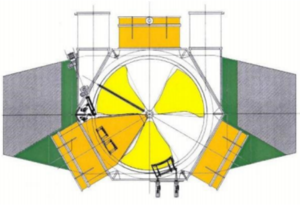




JULIC Cyclotron





- $I_{max} = 0.1mA$ at extraction.

Provides 45 MeV H^{-} or 76 MeV D^{-} beams with 20 ms cycles.

Injection Beam Line (IBL)

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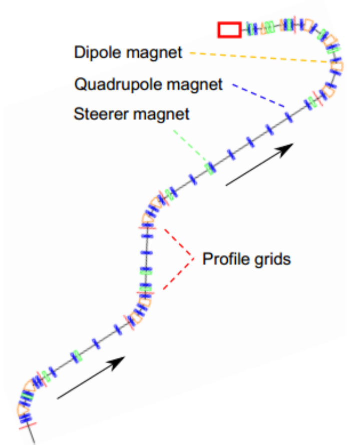

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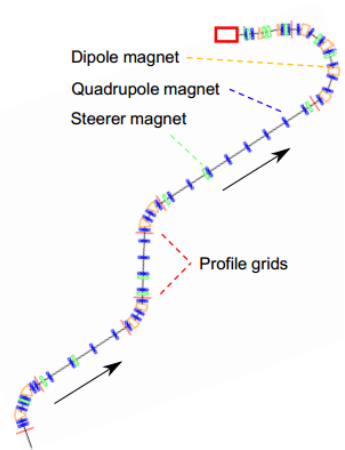

Provides the connection between JULIC cyclotron and COSY.

- 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 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.

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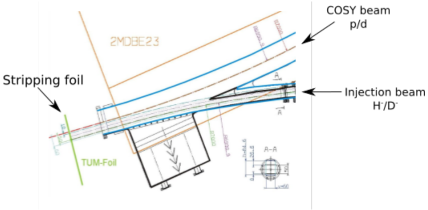

Injection

Distorted orbit

Displacement x can be controlled by the steerer magnets, but not the angle x'.

Injection

Distorted orbit

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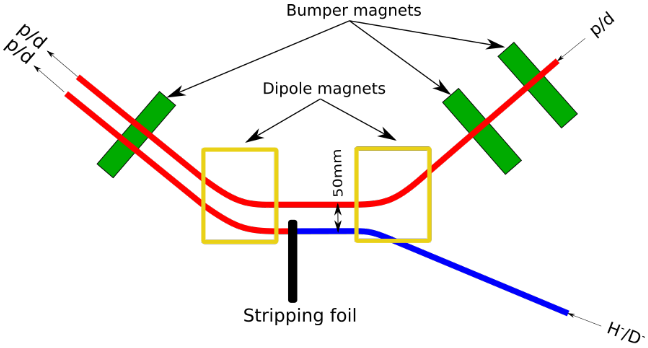

Optimization

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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.

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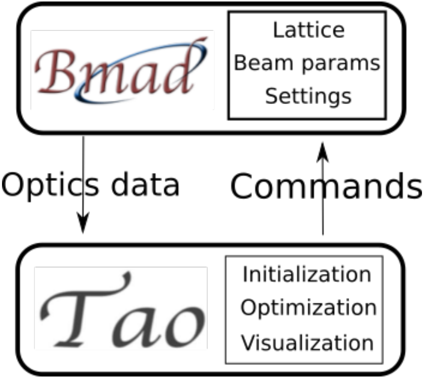

Injection optimization

IBL

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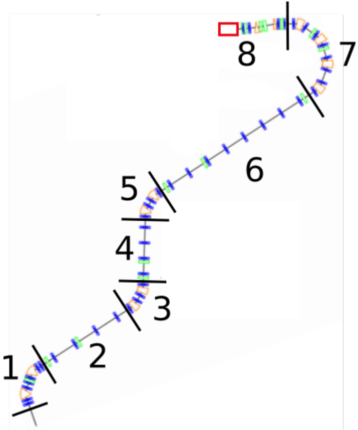
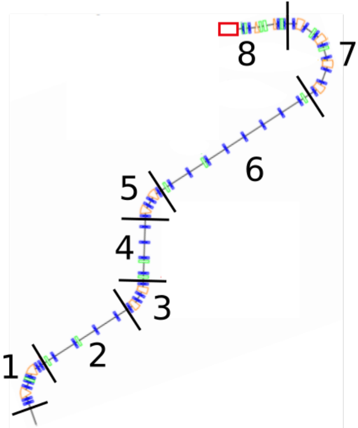


Injection optimization

IBL



Not all quadrupoles independent $\rightarrow$ 12 free parameters.

Constraints

Optimized according to INTERATOM:

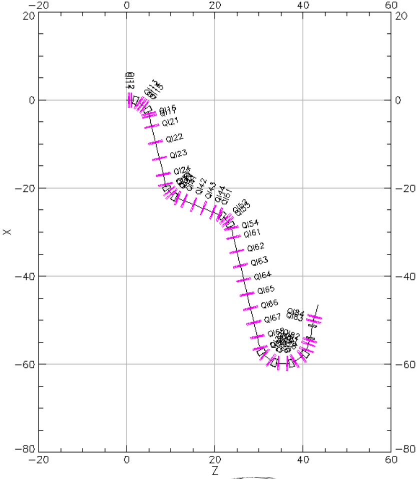
- Sections 2,4,6: FODO structures
- Sections 1, 3+4+5 and 7 achromats.
- Section 8 controls injection.

Injection optimization

IBL

Injection optimization

IBL



Injection optimization

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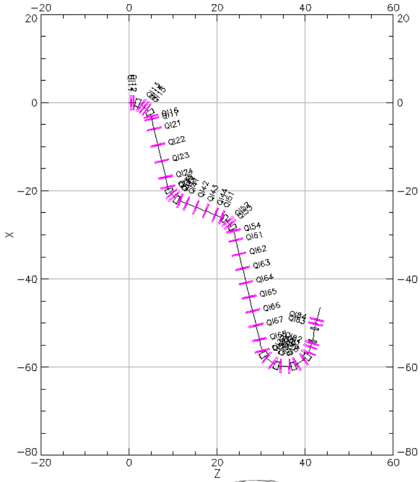
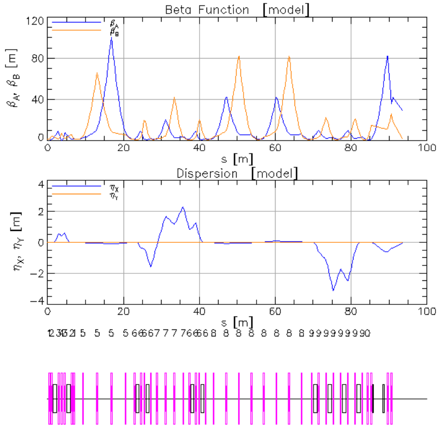
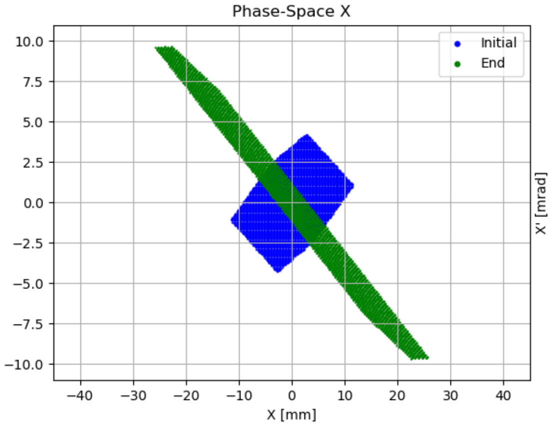




Injection optimization

Tracking at IBL

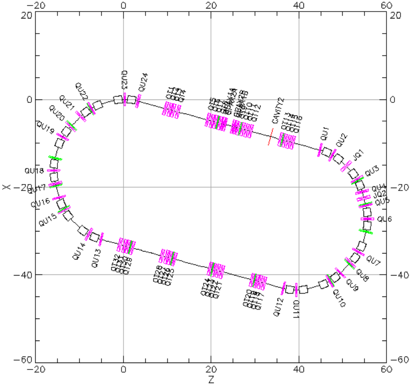


Injection optimization

Tracking at COSY

Injection optimization

Tracking at COSY



Injection optimization

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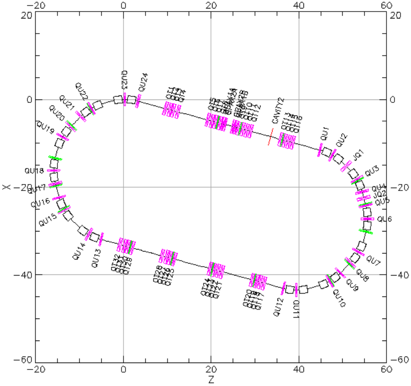

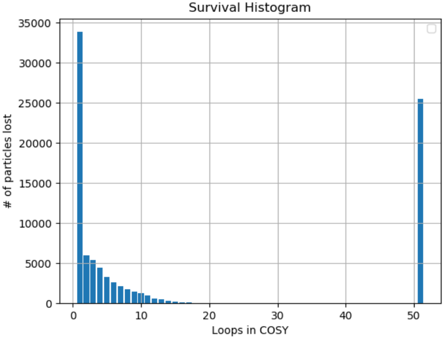

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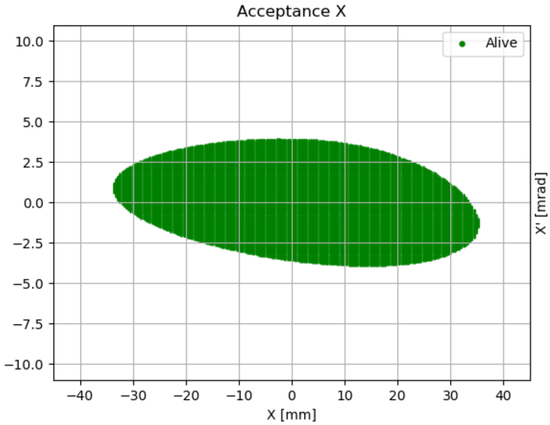

Injection optimization

Emittance measurement

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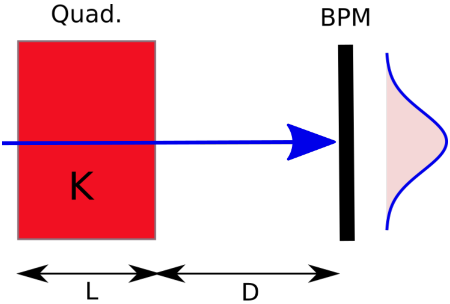

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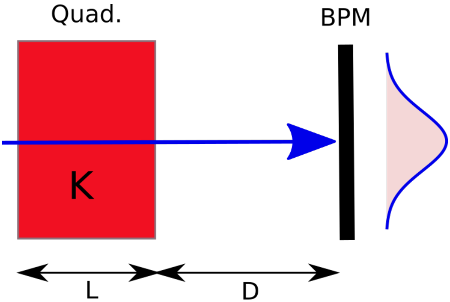
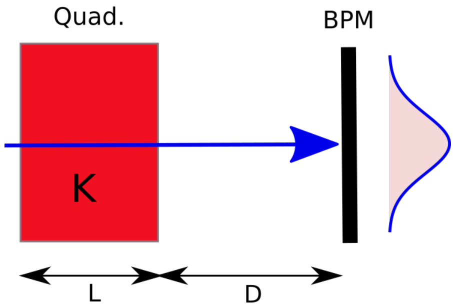
Emittance measurement

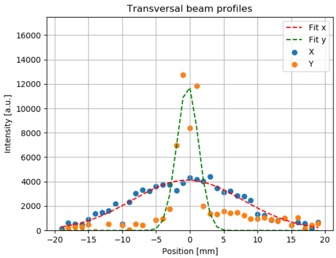


$$M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{K}L) & \frac{1}{\sqrt{K}} \sin(\sqrt{K}L) \\ -\sqrt{K}\sin(\sqrt{K}L) & \cos(\sqrt{K}L) \end{bmatrix}$$

Injection optimization

Emittance measurement





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Injection optimization

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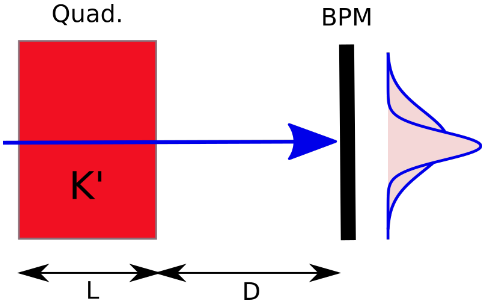
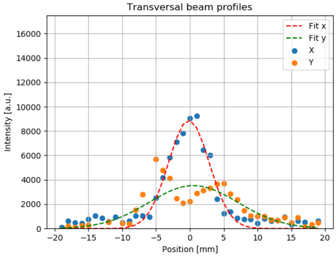


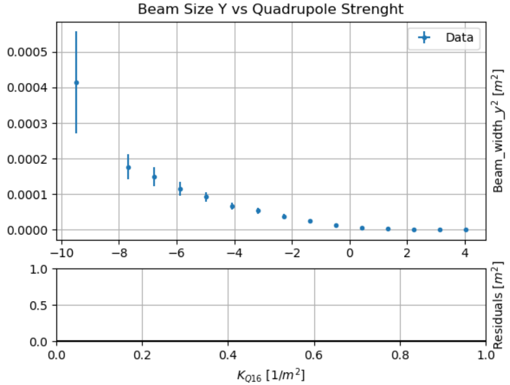


$$M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{K'}L) & \frac{1}{\sqrt{K'}}\sin(\sqrt{K'}L) \\ -\sqrt{K'}\sin(\sqrt{K'}L) & \cos(\sqrt{K'}L) \end{bmatrix}$$

Injection optimization

Emittance measurement

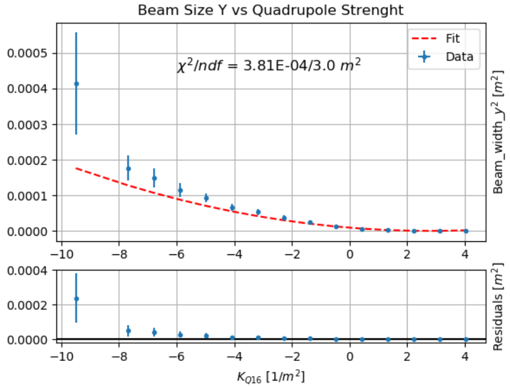
Plot of beam size squared vs quadrupole strength for Q17, Y axis.



Injection optimization

Emittance measurement

Fit using first order approximation of M matrix.



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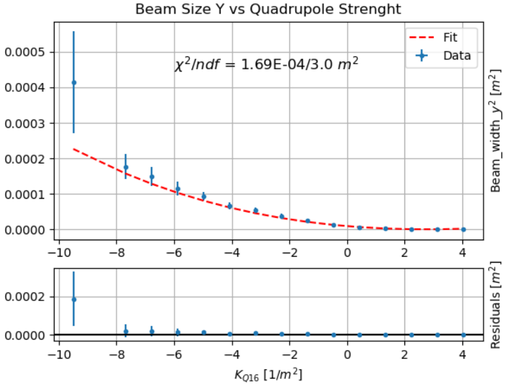

Next steps for optimization

The planned upcoming steps for optimizing the injection are:

- Analyze the injection dipole.
- Try to find steerer magnets which allow for x and x' variation of the injected beam in the stripping foil.
- Connect IBL and COSY in a simulation for a full tracking including the orbit bump at injection.
- Try to match phase space at IBL exit with COSY acceptance.
- Improve the emittance measurement at IBL. Look for other methods.

References

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20 years of JULIC operation as COSY's injector cyclotron
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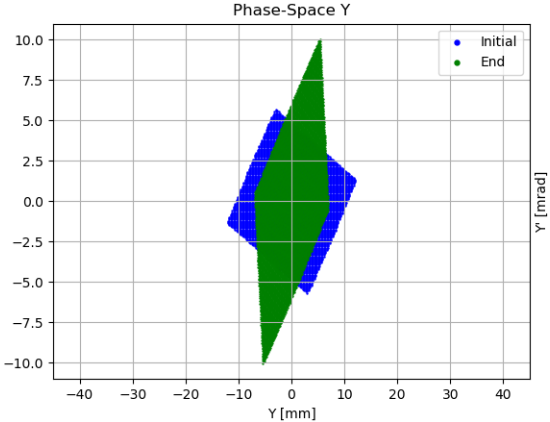
Implementation of quadrupole-scan emittance measurement at Fermilab's Advanced Supercomputing Test Accelerator (ASTA)
6th International Particle Accelerator Conference.

Spare slides



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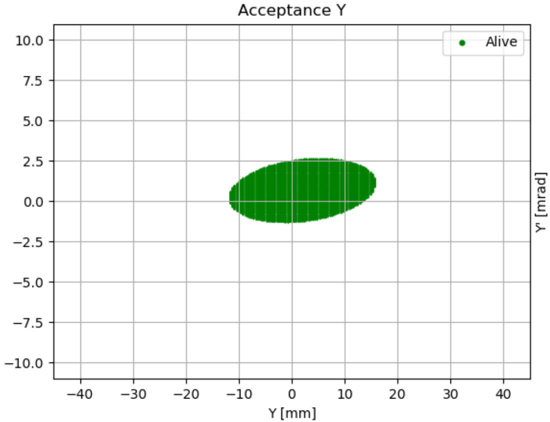

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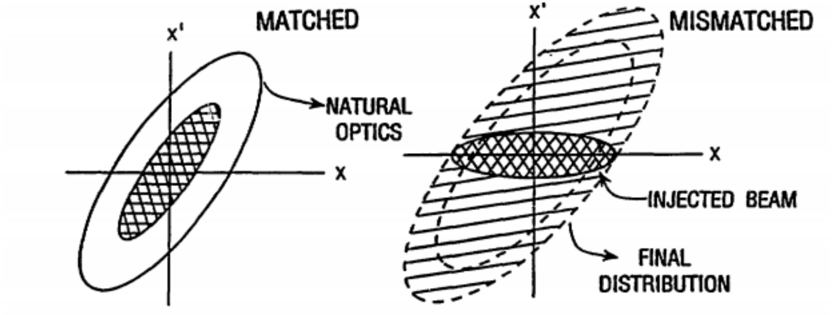

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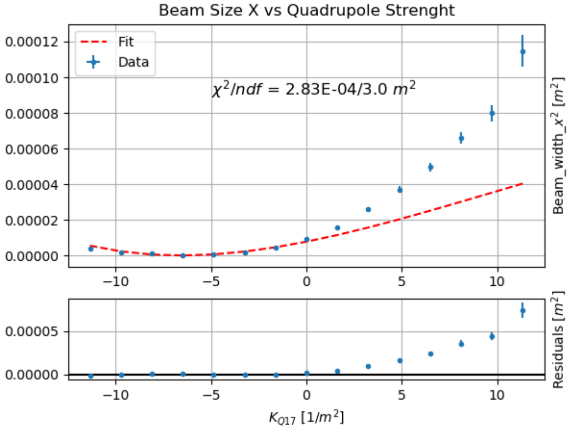
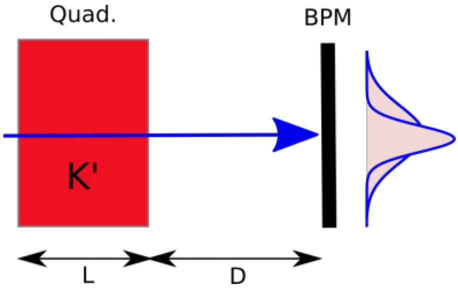


Emittance Measurement:
Quadrupole Scan Method



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7

$$\Sigma_{beam}(s)=M*\Sigma^0_{beam}*M^T$$

where
$$\begin{cases}\Sigma_{11}=\langle x^2\rangle\\ \Sigma_{12}=\Sigma_{21}=\langle x x'\rangle\\ \Sigma_{22}=\langle x'^2\rangle\end{cases}$$

Finally:

$$\Sigma_{11}=\langle x^2\rangle=M^2_{11}\Sigma^0_{11}+2M_{11}M_{12}\Sigma^0_{12}+M^2_{12}\Sigma^0_{22}$$

And:

$$\boxed{\varepsilon=\pi\sqrt{det(\Sigma_{beam})}=\pi\sqrt{\Sigma^0_{11}\Sigma^0_{22}-(\Sigma^0_{12})^2}}$$

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First order approximation: $\begin{cases} \cos(x) \approx 1 + O(x^2) \\ \sin(x) \approx x + O(x^3) \end{cases}$

$\Rightarrow$ $\Sigma_{11} = \langle x^2 \rangle = f(K^2, K) \Rightarrow$ Parabolic fit with: $g(K) = A K^2 + B K + C$

Second order approximation: $\begin{cases} \cos(x) \approx 1 - \frac{x^2}{2} + O(x^4) \\ \sin(x) \approx x - \frac{x^3}{3!} + O(x^5) \end{cases}$

$\Rightarrow$ $\Sigma_{11} = \langle x^2 \rangle = f(K^4, K^3, K^2, K) \Rightarrow$ Fourth order fit: $g(K) = A K^4 + B K^3 + C K^2 + E K + F$