# INJECTION BEAM LINE OPTIMIZATION at COSY

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

Physics Institute III B | RWTH AACHEN UNIVERSITY

JEDI

JÜLICH Forschungszentrum

# Outline

- COSY facility overview
  - Beam source
  - JULIC Cyclotron
  - Injection Beam Line
  - Injection
- Optimization
  - IBL optimization
  - Tracking
  - Emittance measurement
- Next steps

# Facility overview

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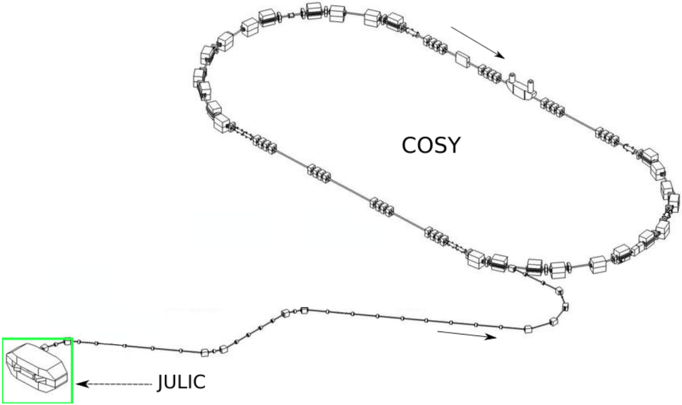

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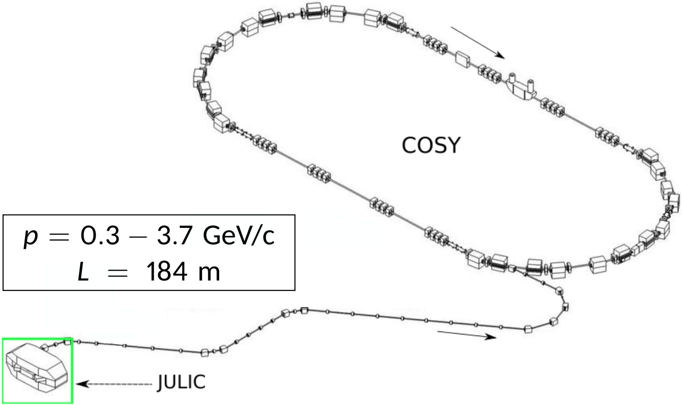


$$p = 0.3 - 3.7 \text{ GeV/c}$$
$$L = 184 \text{ m}$$

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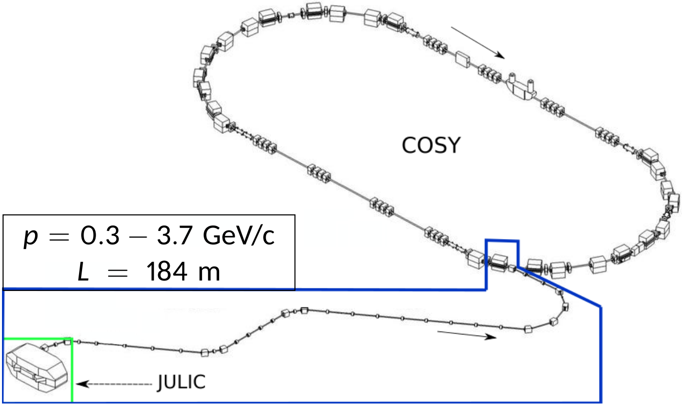


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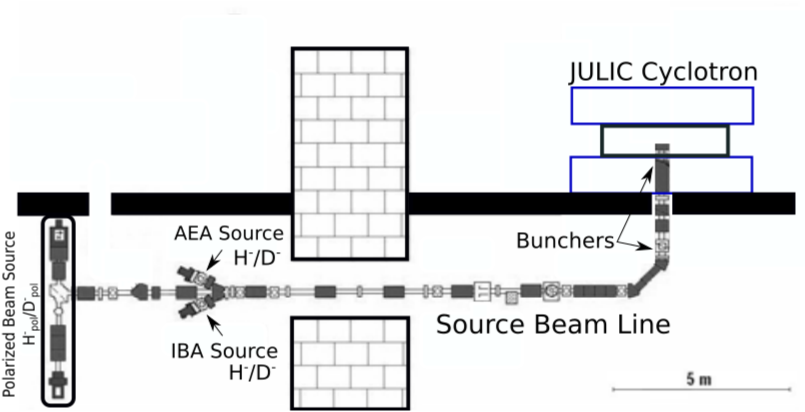
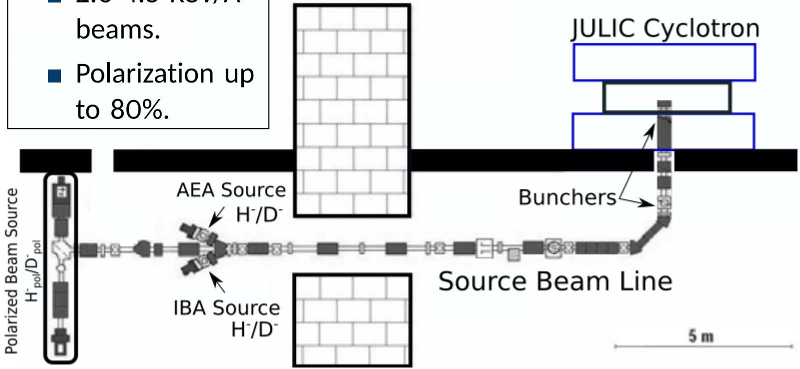


JULIC Cyclotron
AEA Source
H⁻/D⁻
Bunchers
Polarized Beam Source
$H^-_{pol}/D^-_{pol}$
Source Beam Line
IBA Source
H⁻/D⁻
5 m

# Beam source

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



# JUelich Light Ion Cyclotron (JULIC)

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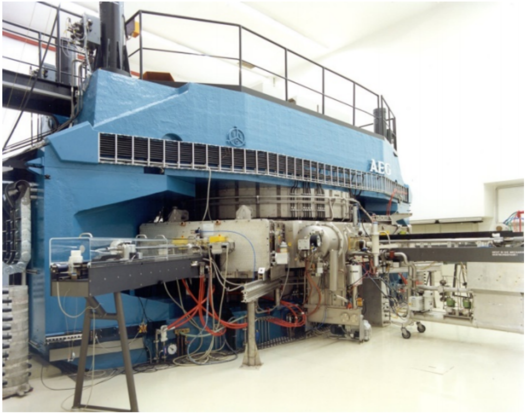

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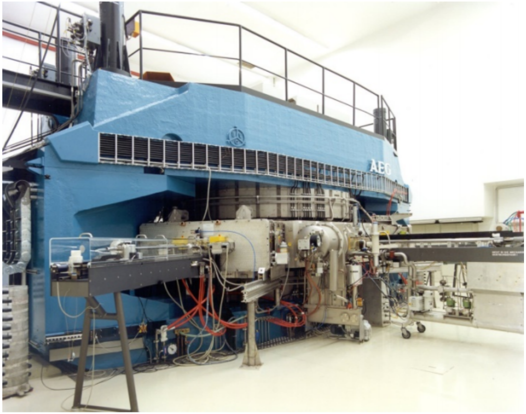


Originally built for light ions up to Ar, nowadays only $H^-$ and $D^-$.

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

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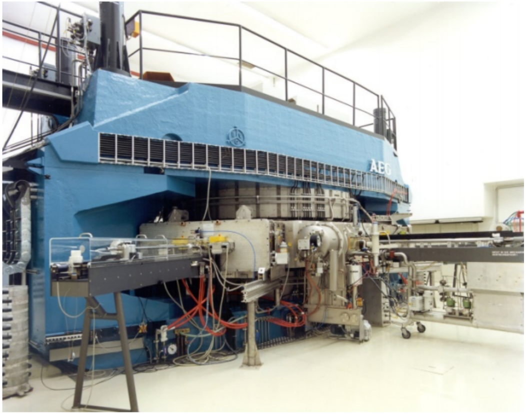

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## Extraction

- 45 MeV $H^-$ or 76 MeV $D^-$ beams.
- 20ms cycles.

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# Injection Beam Line (IBL)

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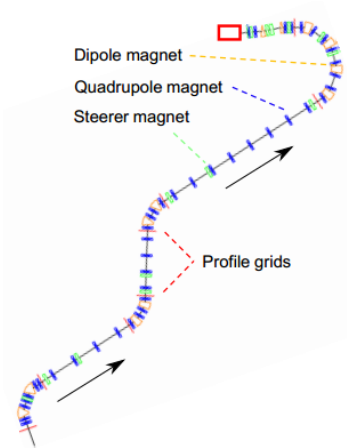
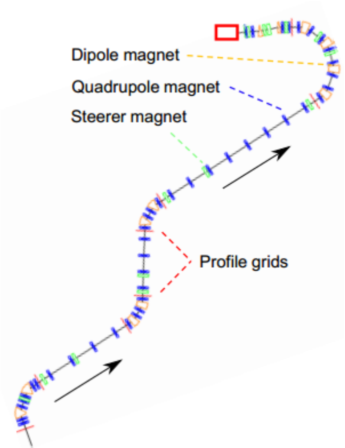


# Injection Beam Line (IBL)




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

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- 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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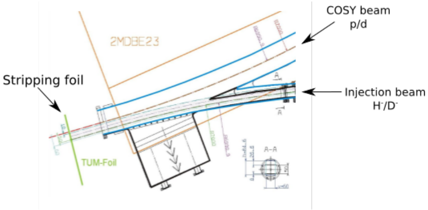
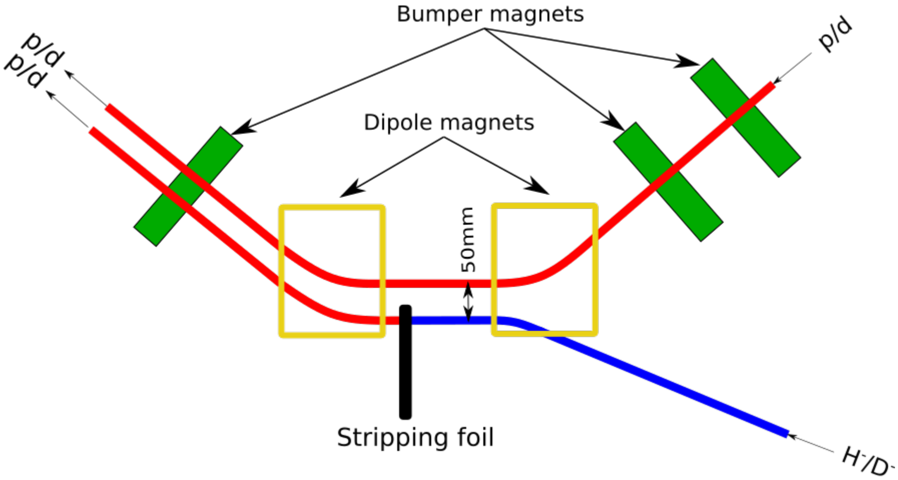


# Injection



Bumper magnets
p/d
p/d
p/d
Dipole magnets
50mm
Stripping foil
H⁻/D⁻

# Optimization

# 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.

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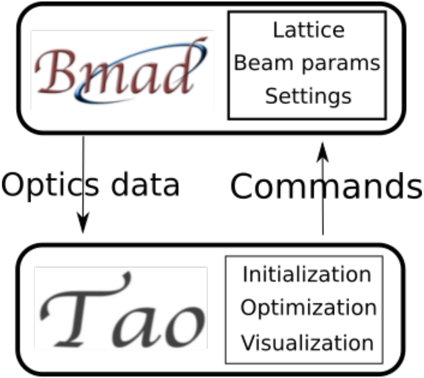

# Injection optimization

## IBL

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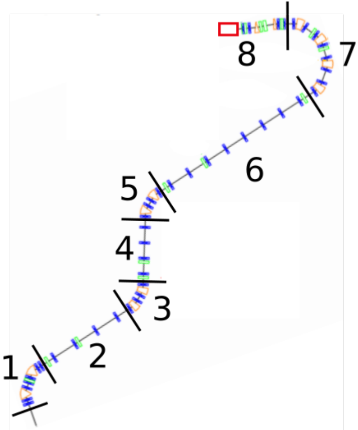
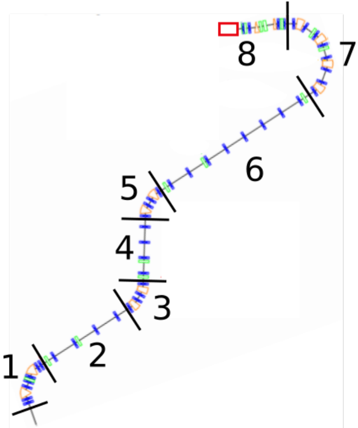


# Injection optimization

## IBL




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

### Constraints

Optimized according to INTERATOM design:

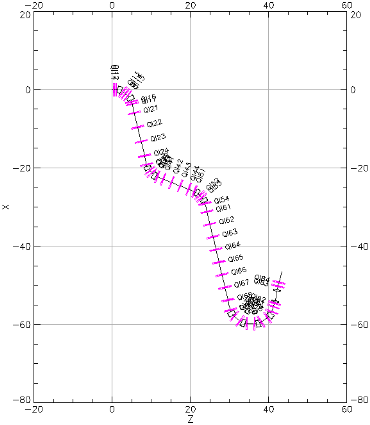
- Sections 2,4,6: FODO structures.
- Sections 1, 3+4+5 and 7 achromats.
- Section 8 controls injection.

# Injection optimization

## IBL and tracking

# Injection optimization

## IBL and tracking



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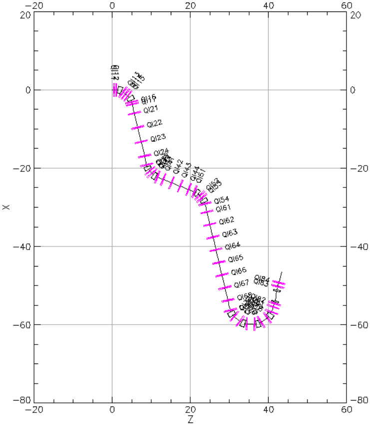
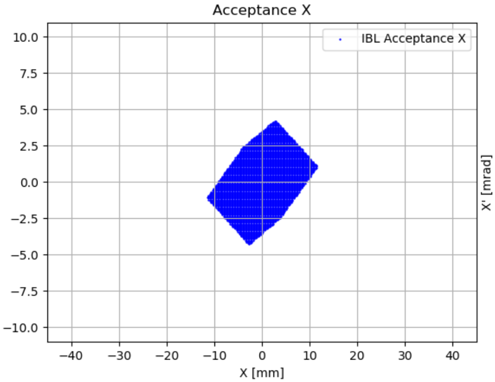
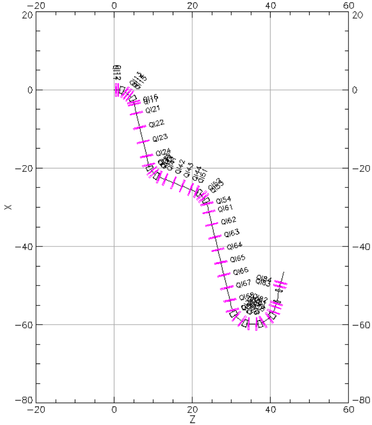
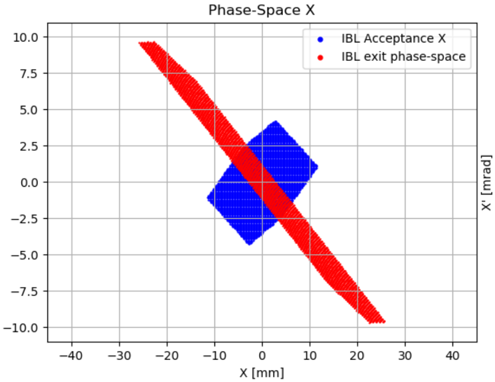


# Injection optimization

## IBL and tracking



# Injection optimization

## Tracking at COSY

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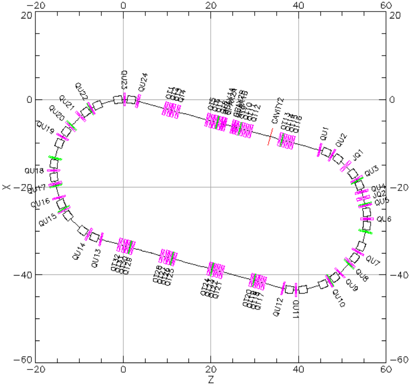

# Injection optimization

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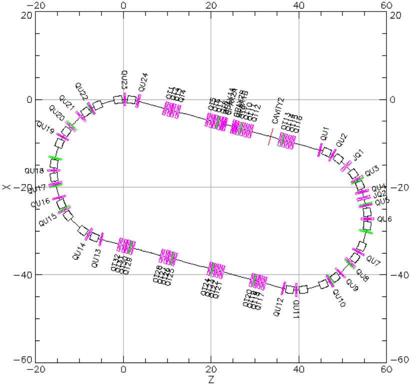
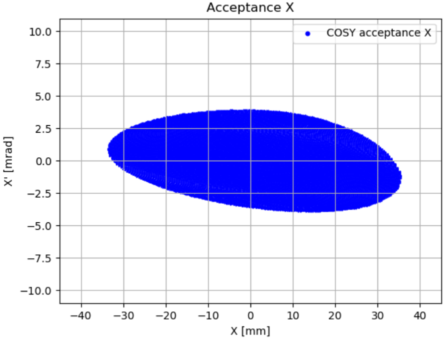
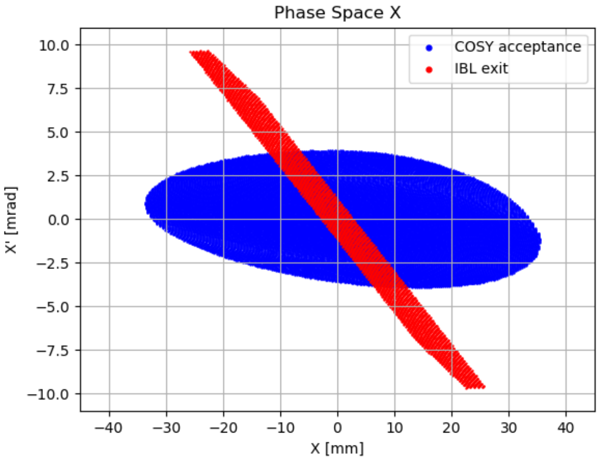


# Combined tracking



# Injection optimization

## Emittance measurement

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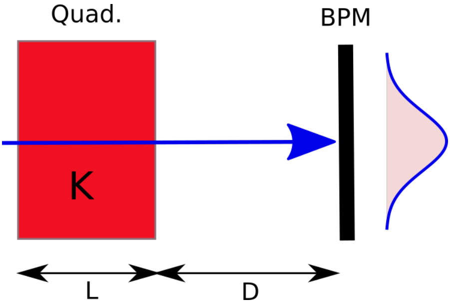

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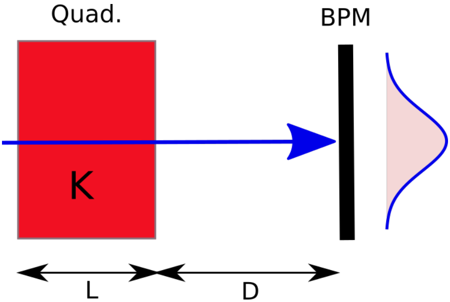


$$M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{K}L) & \frac{1}{\sqrt{K}}\sin(\sqrt{K}L) \\ -\sqrt{K}\sin(\sqrt{K}L) & \cos(\sqrt{K}L) \end{bmatrix}$$

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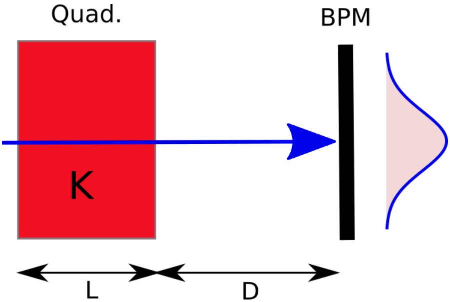
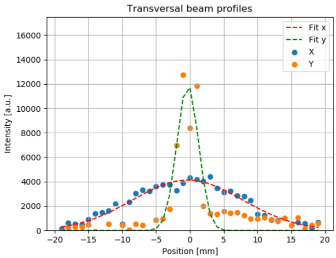
## Emittance measurement

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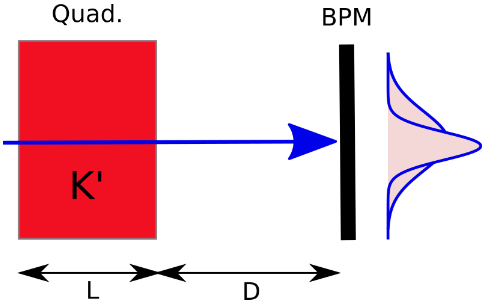
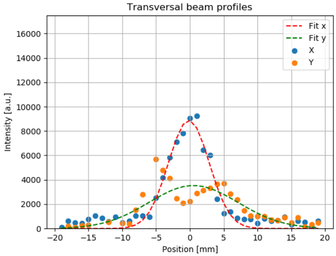


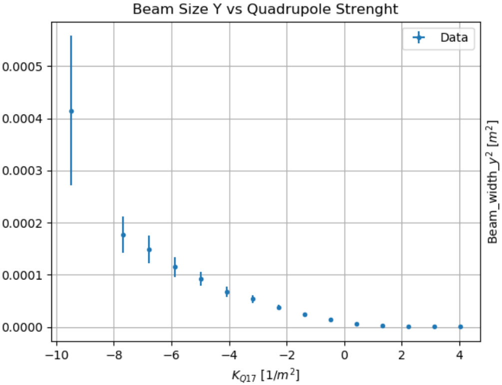




$$M = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\sqrt{K'}L) & \frac{1}{\sqrt{K'}}\sin(\sqrt{K'}L) \\ -\sqrt{K'}\sin(\sqrt{K'}L) & \cos(\sqrt{K'}L) \end{bmatrix}$$

# Injection optimization

## Emittance measurement

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



# Outlook

The planned upcoming steps for optimizing the injection are:

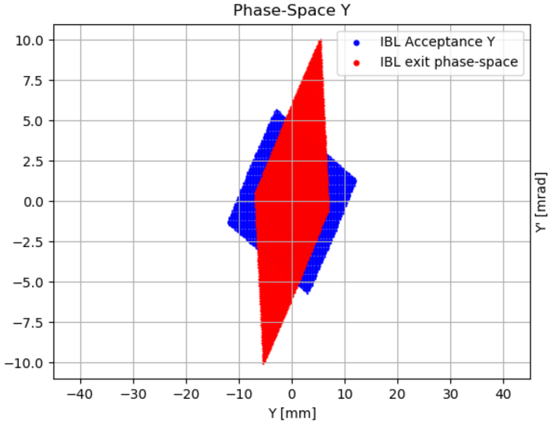
- Analyze the injection dipole.
- Find steerer magnets which allow for independent X and X' variation of the injected beam in the stripping foil.
- Combine IBL and COSY in a simulation for a full tracking, including the orbit bump at injection.
- Match phase space at IBL exit with COSY acceptance.
-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

Thank you!

# References


- R. Gebel, R. Brings, O. Felden, R. Maier, S. Mey, D. Prasuhn (2013)
  20 years of JULIC operation as COSY's injector cyclotron
  Proceedings of Cyclotrons 2013, Vancouver, BC, Canada.
- C. Weidemann (2016)
  COSY injection and tuning
  Workshop on Beam Dynamics and Control studies at COSY.
- A. T. Green, Y. M. Shin (2015)
  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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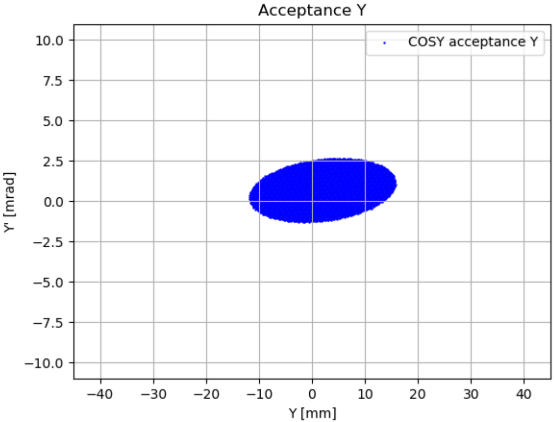

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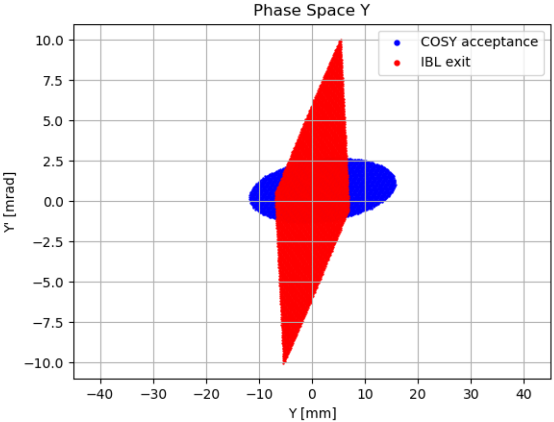

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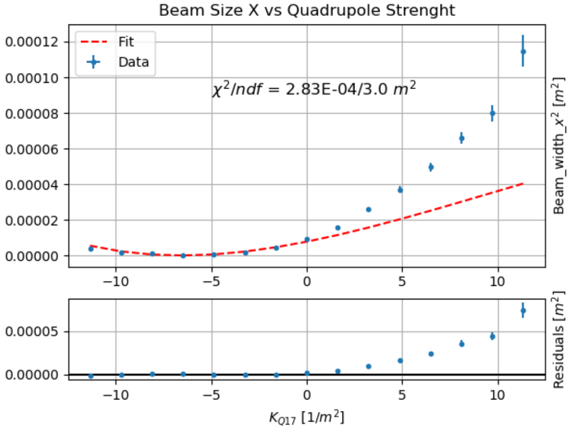
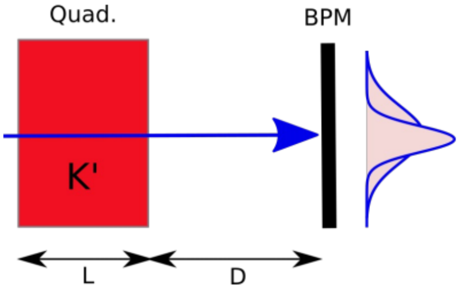


# Emittance Measurement:
## Quadrupole Scan Method

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7

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

where

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

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:

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

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: $g(K) = A K^4 + B K^3 + C K^2 + E K + F$