Report on the senior fellowship activities

95th ISOLDE Collaboration Committee meeting

Niels Bidault (BE-OP-ISO)
CERN, 1211 Geneva 23, Switzerland

November 7th, 2022

Conceptual design studies on the beamlines of a new experimental hall

New experimental all at ISOLDE

Scope for the fellowship

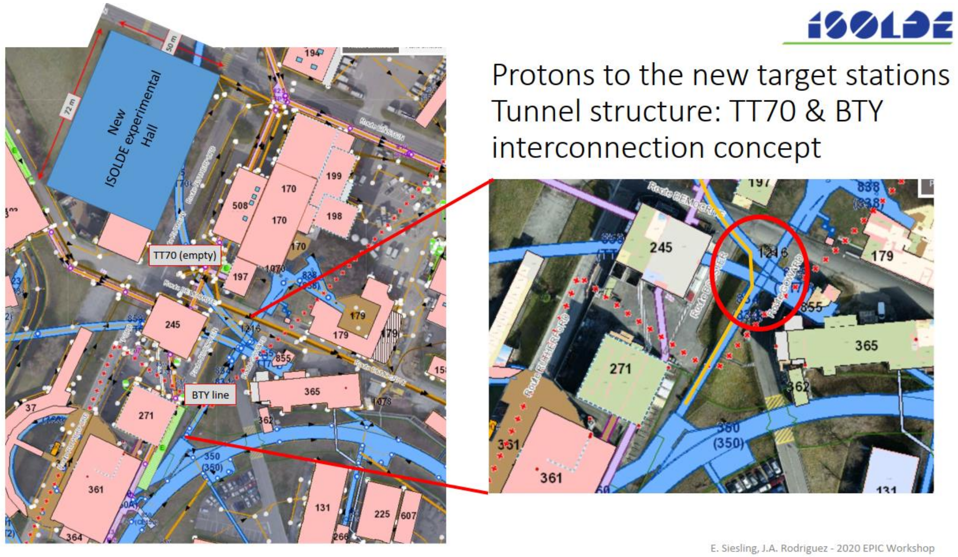
Report on the design of beamlines for the new ISOLDE experimental hall.

Context

One vision for the future of ISOLDE is to use the building B133 for a new experimental hall, that would receive protons through a new proton transfer line. The construction would benefit from the existing tunnel TT70 and underground structures, such that the installation work will not compromise the operation of the existing ISOLDE facility.

Motivation

- Increased capability: beam purification, new beams, LINAC upgrade.
- Increase capacity: more yields from 2 GeV protons at higher intensities, simultaneous delivery of RIB, multiple target ion sources, more stations.
- Increased synergies with AD and n-TOF, enabling promising new physics.
- Free space in the existing facility for experiments with HIE-ISOLDE.
- Keep ISOLDE competitive in the long-term horizon.

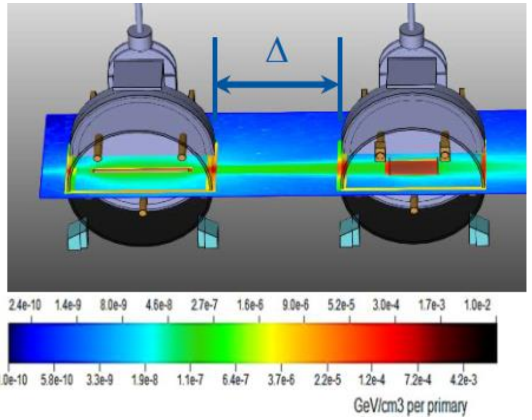


Protons to the new target stations
Tunnel structure: TT70 & BTY interconnection concept

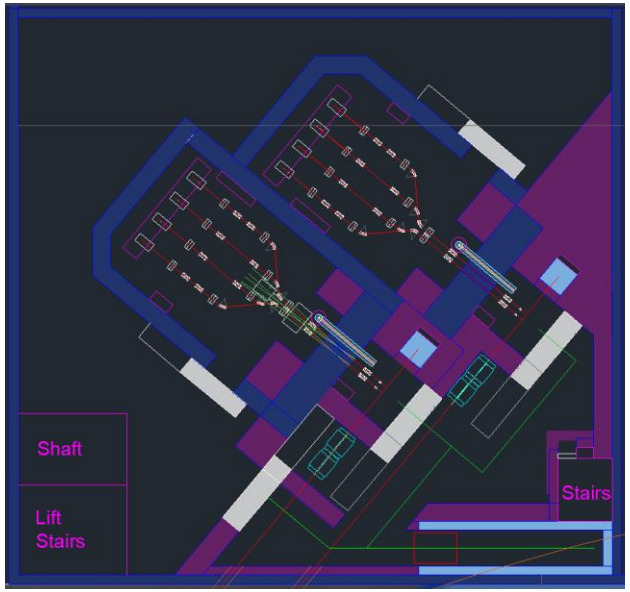
E. Siesling, J.A. Rodriguez - 2020 EPIC Workshop

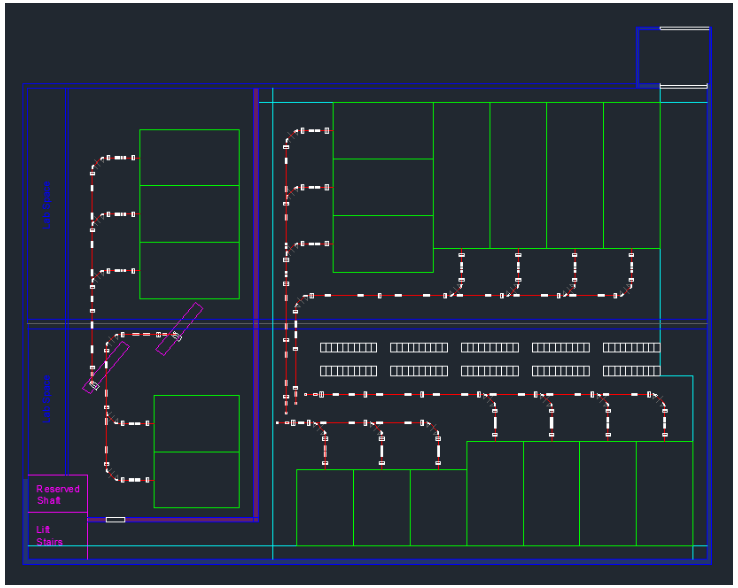
EPIC Workshop 2020, *J. A. Rodriguez* & *E. Siesling*

Preliminary concepts



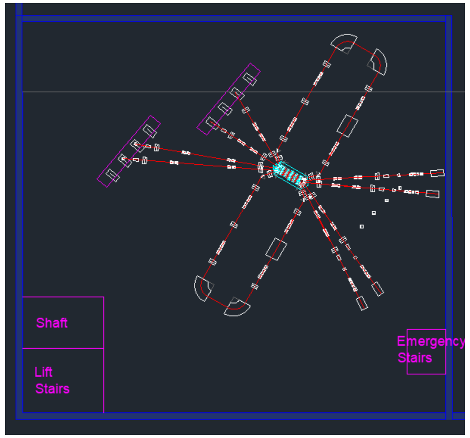
Studies by *C. Duchemin* on the irradiation of two targets using Fluka





Objectives

- Parallel experiments and maximize the use of protons
- Assure maximum beam transport from the target ion sources
- Maximize the repeatability of FODO lattices
- Minimize the amount of specific transport elements
- Beam matching optimized for the separators and switchyards
- Mass-resolving power for molecular beams of mass 350 amu
- Control over the waist for injection into the experimental stations

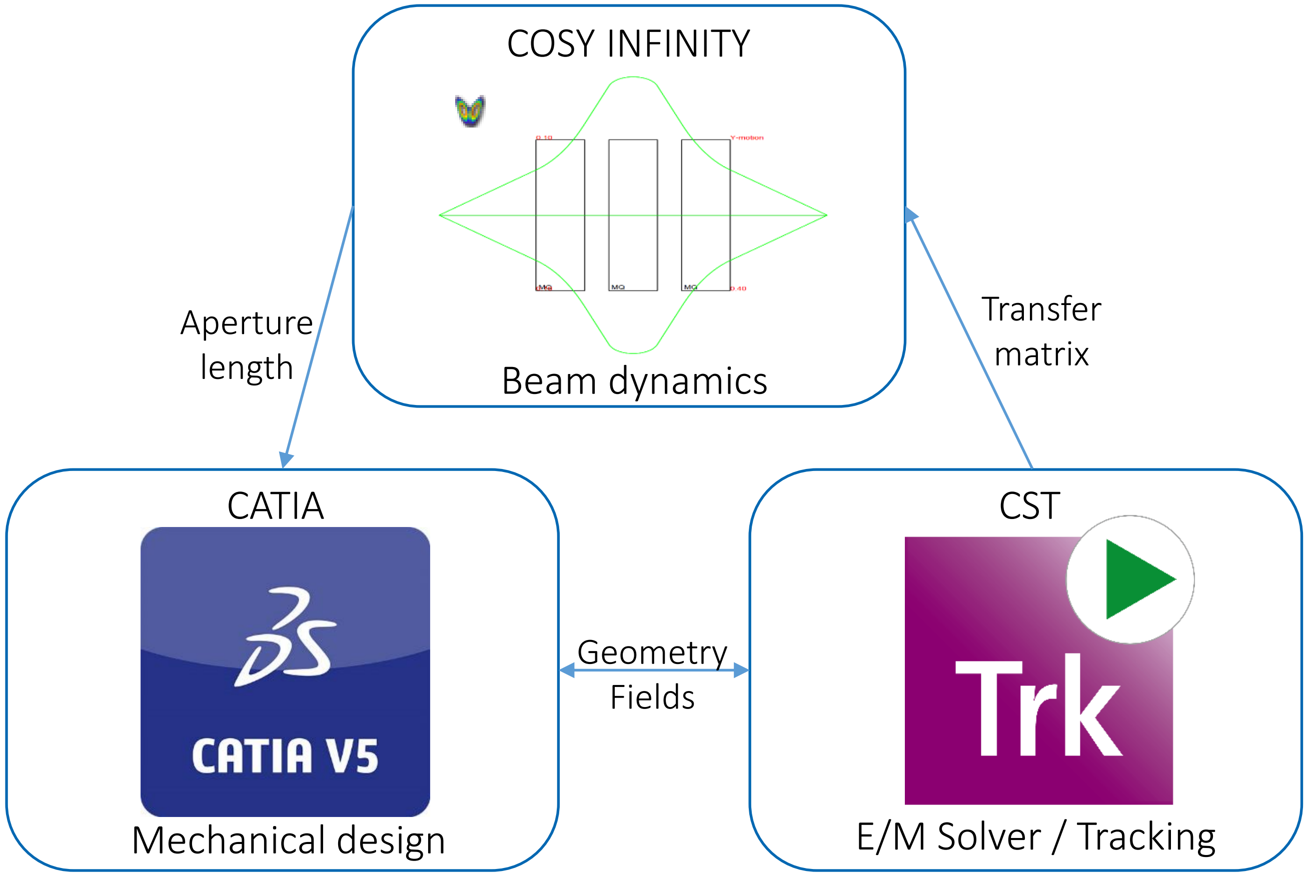


First layouts of the beamlines in the experimental area, the frontends and separator zone, and of the compact beam switchyard.
Switching between the fast and slow release for collections.
Work by *J. A. Rodriguez*.

Beam dynamics studies

Initial beam parameters from the frontends:

- Energy up to 100 keV
- Emittance up to 50 pi.mm.mrad (non-normalized)



COSY INFINITY

Beam dynamics

Aperture length

CATIA

Mechanical design

Geometry Fields

CST

E/M Solver / Tracking

Transfer matrix

Design parameters

- Beam lattice for h-v transport and injection
- Specifications of the electrostatic elements (size, voltage)
- Geometry and dimensions of the electrodes

Environmental constrains

- Infrastructure geometry and space for maintenance
- Radiation shielding and equipment protection
- Supply in electricity and cabling

Important cost-driving technical aspects

- Beam optics lattice repeatability
- Manufacture of individual beamline transport element
- Reasonable power supply specifications
- Standard vacuum equipment

Important cost-driving technical aspects

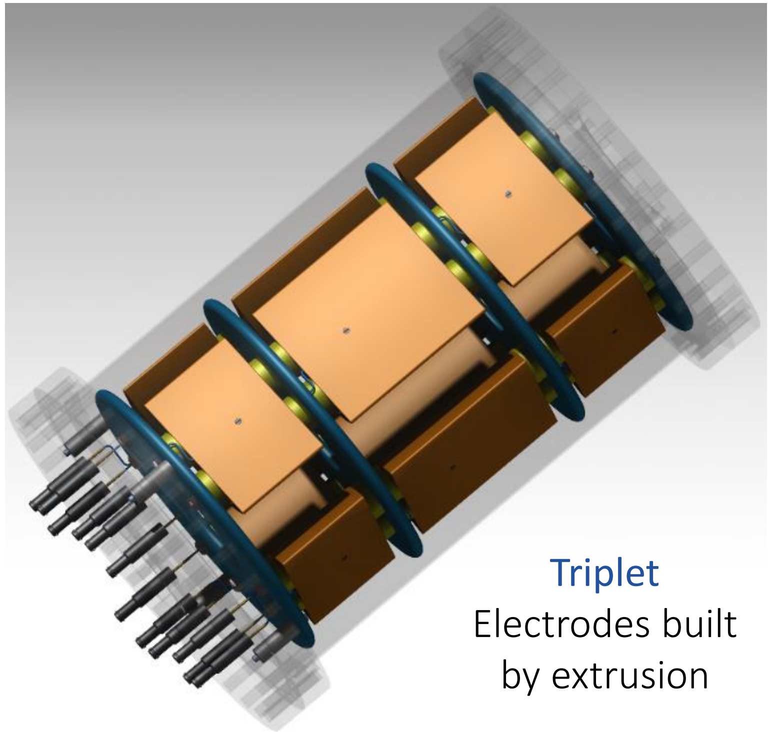
- Time distributed ion pulses
- Applicable common techniques of beam characterization

Conceptual design studies on the beamlines of a new experimental hall

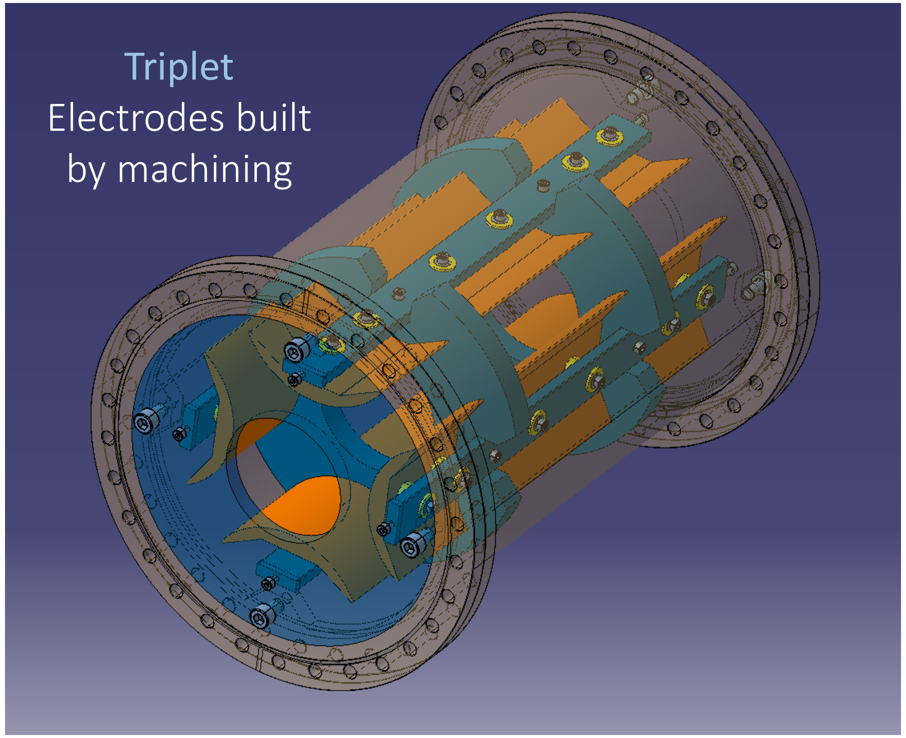
Mechanical design of electrostatic elements

Design rules

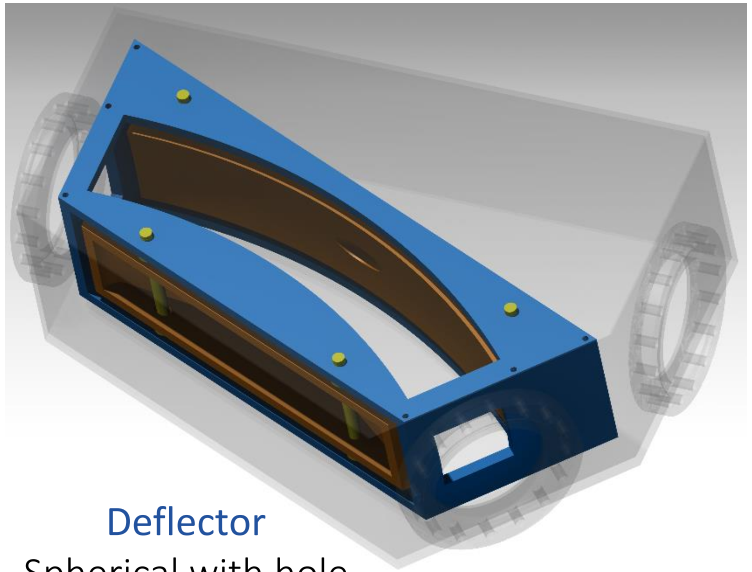
- Cost effective technological solutions
- Guarantee the field quality with respect to the beam dynamics constrains
- Vacuum compatible and respecting electrical standards preventing sparking or creepage
- Practical assembly, alignment and disassembly



Triplet
Electrodes built
by extrusion



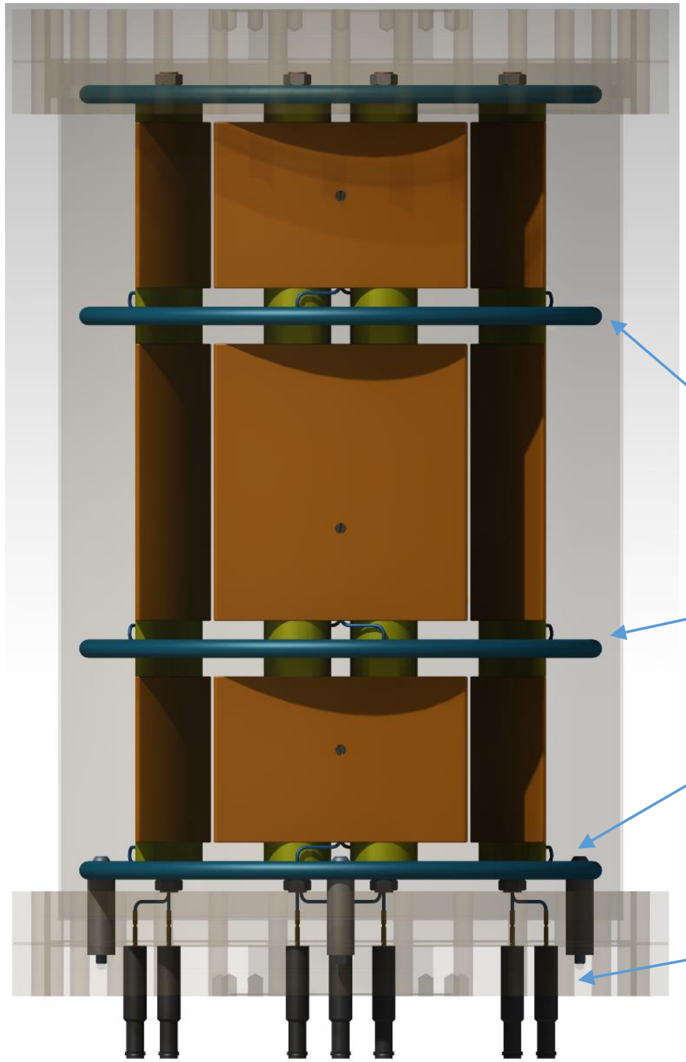
Triplet
Electrodes built
by machining



Deflector
Spherical with hole
for beam switching

Acknowledgements to Thomas Marroux (summer student), EN-MME-FS, EN-MME-EDS, BE-GM-ESA, TE-VSC-BVO and SY-ABT-SE.

CAD models of quadrupoles



Inner flanges to limit fringe fields are connected to the chamber (grounded)

Rounded edges

Complexity of the assembly reduced

Feedthroughs only on one CF flange

Advantages Low cost of fabrication, high repeatability, control over the geometry, low rugosity.

Disadvantages Potential need of end caps to prevent sparking, prototyping may be costly.

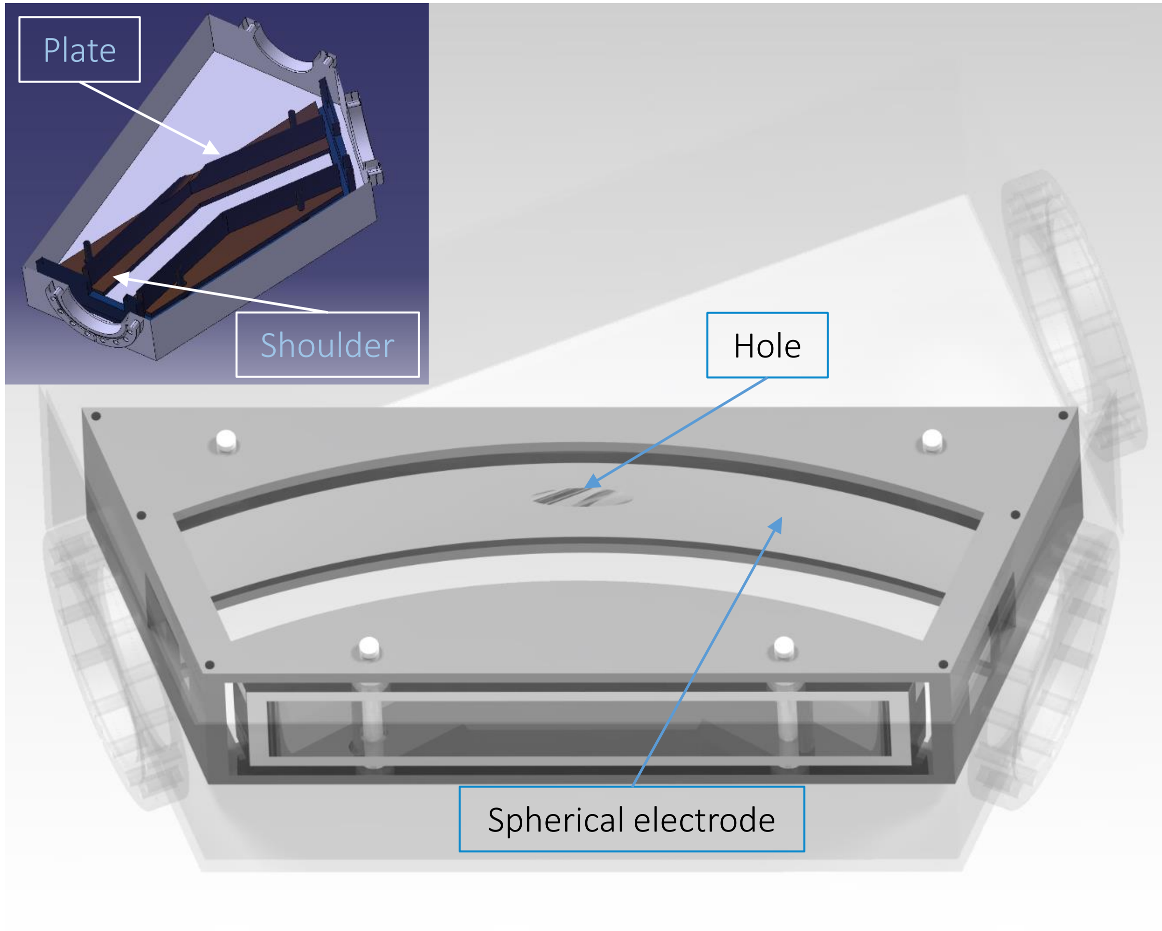
Models of triplets, doublets and single quadrupole were designed, with the characteristic dimensions as free parameters:

- Electrode gap
- Lengths of the electrodes and in between them
- Radius of the electrodes

Technological solutions:

- Standard CF fixed and rotatable flanges to the vacuum chamber and standard CF zero length flanges.
- Commercial alumina insulators with standard geometry
- Commercial feedthroughs (10 kV), connectors and coaxial cables to the electrodes

CAD models of deflectors



Models of spherical deflectors were designed, with the characteristic dimensions as free parameters:

- Bending radius and angle
- Gap between electrodes
- Hole size for straight transport

For different electrode geometries:

- Perfectly spherical
- Emulating the spherical electrode fields with flat electrodes

Technological solutions

- Inner assembly frame inspired by the deflector designs for ELENA
- Chamber manufactured from metal sheets
- Commercial alumina insulators with standard geometry, feedthroughs (15 kV) and connectors

Remaining questions

- Accessibility inside the vessel - possible options are proposed
- Electrode geometry and the implied fabrication cost – CST

Simulations with CST

Objective Determination of the transfer matrix using the technique described in:
Set the input beam with $\alpha_i = 0$,
Probe the output Twiss parameters as a function of the input beta function:

Transfer matrix calculation for ion optical elements using real fields, P.M. Mishra, K. Blaum, S. George, M. Grieser, A. Wolf, N. I. M. in Phy. Res., A 885 (2018) 124–133

$$\beta_f = \frac{{M_{12}}^2 + {M_{11}}^2{\beta_i}^2}{\beta_i} \qquad \alpha_f = \frac{-{M_{12}}^2 M_{22} + M_{11}{\beta_i}^2 - {M_{11}}^2 M_{22}{\beta_i}^2}{M_{12}\beta_i}$$

Fitting of the quadratic response to determine the transfer matrix:

$$R(s) = \begin{pmatrix} M_{11} & M_{12} & 0 & 0 & M_{15} \\ M_{21} & M_{22} & 0 & 0 & M_{25} \\ 0 & 0 & M_{33} & M_{34} & M_{35} \\ 0 & 0 & M_{43} & M_{44} & M_{45} \\ M_{51} & M_{52} & M_{53} & M_{54} & M_{55} \end{pmatrix}$$

Quadrupole

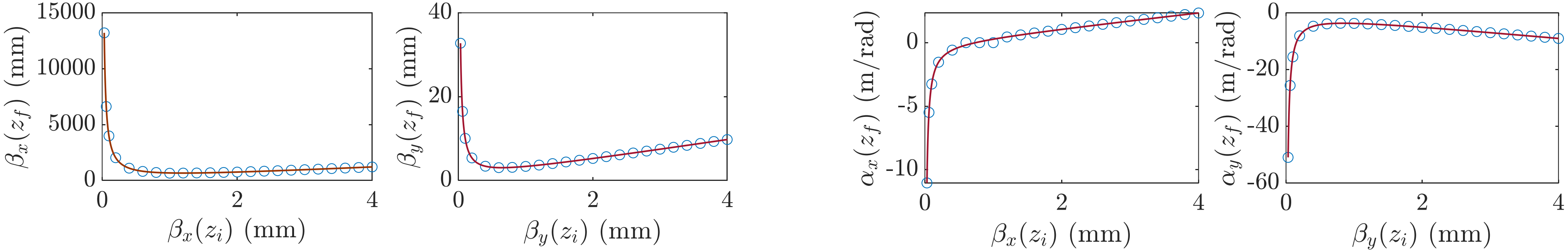
$$(M_{hor})_q = \begin{pmatrix} \cos\left(\sqrt{K}s\right) & \frac{1}{\sqrt{K}}\sin\left(\sqrt{K}s\right) \\ -\sqrt{K}\sin\left(\sqrt{K}s\right) & \cos\left(\sqrt{K}s\right) \end{pmatrix},$$

$$(M_{ver})_q = \begin{pmatrix} \cosh\left(\sqrt{K}s\right) & \frac{1}{\sqrt{K}}\sinh\left(\sqrt{K}s\right) \\ \sqrt{K}\sinh\left(\sqrt{K}s\right) & \cosh\left(\sqrt{K}s\right) \end{pmatrix}$$

Deflector

$$(M_{hor})_{sph} = (M_{ver})_{sph} = \begin{pmatrix} \cos\left(\frac{s}{r_g}\right) & r_g \sin\left(\frac{s}{r_g}\right) \\ -\frac{\sin\left(\frac{s}{r_g}\right)}{r_g} & \cos\left(\frac{s}{r_g}\right) \end{pmatrix}$$

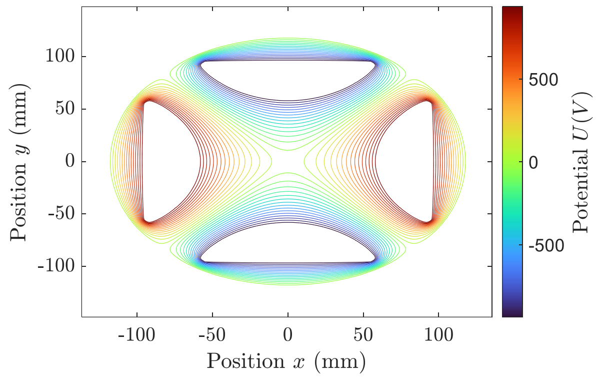
Developed a Matlab application for **iterative calls of CST**, with different input beam parameters and monitoring.



Simulations with CST: quadrupoles

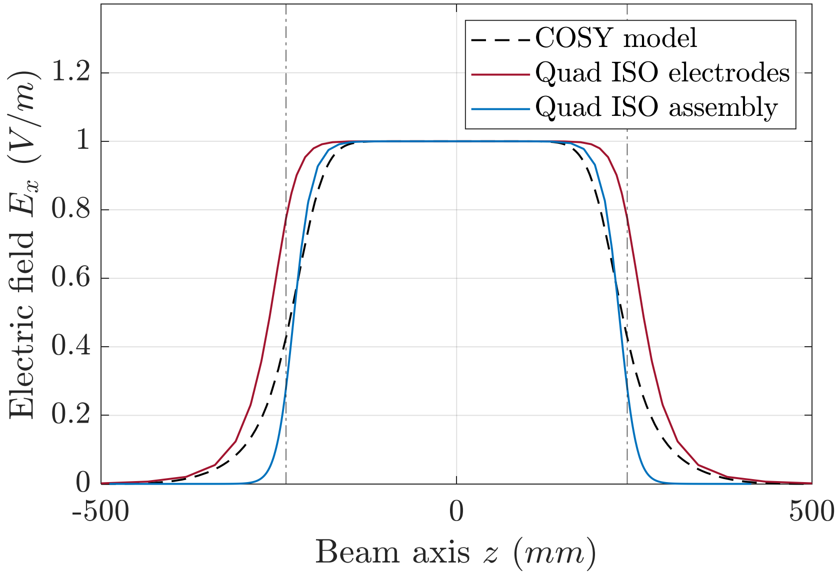
Studies on the electrode gap, radius and shape:

- The cylindrical shape present no significant difference compared with hyperbolic shape
- Pole to pole diameter of 140 mm, so electrode radius if 80.28 mm - ratio from H. Wollnik Optics of Charged Particles

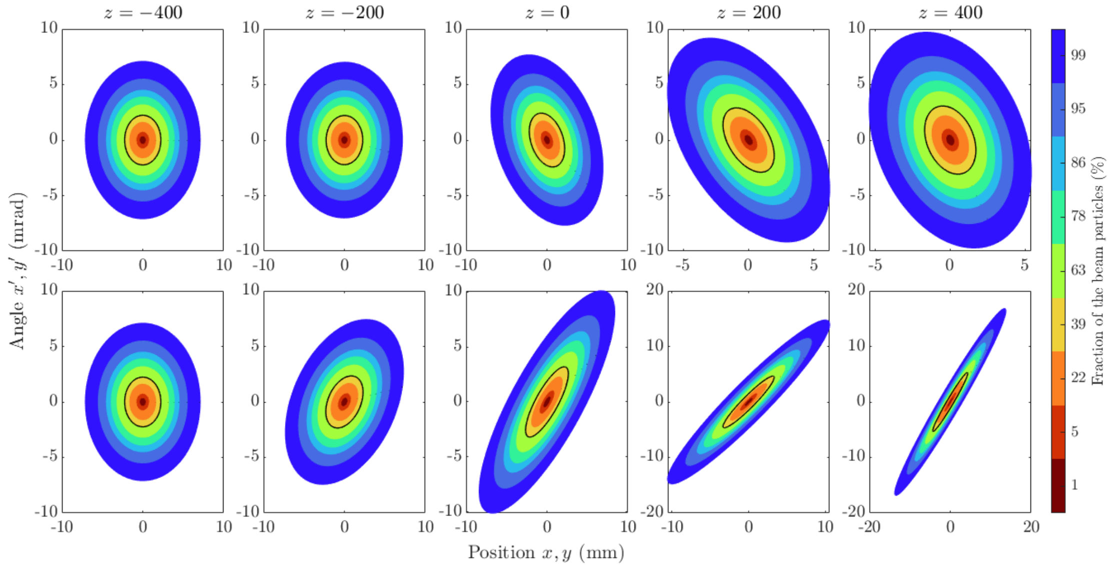


Studies on the fringe field:

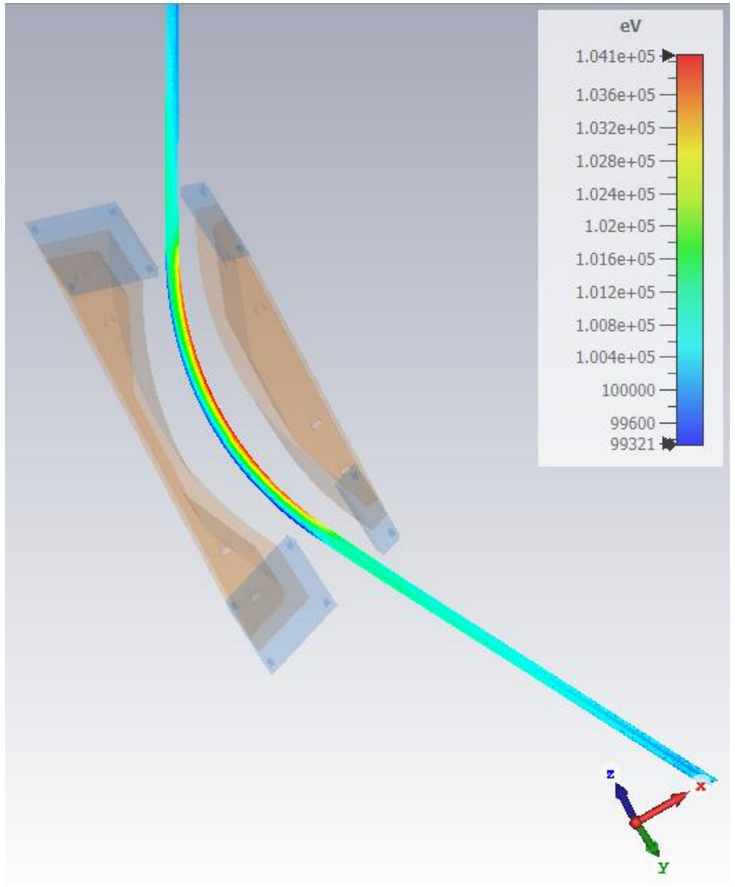
- Optimization on the inner grounded flanges
- Approach theoretical transfer matrix
- Determination of the effective voltage or the effective focusing strength



Example of ellipse tracking through a quadrupole with CST:



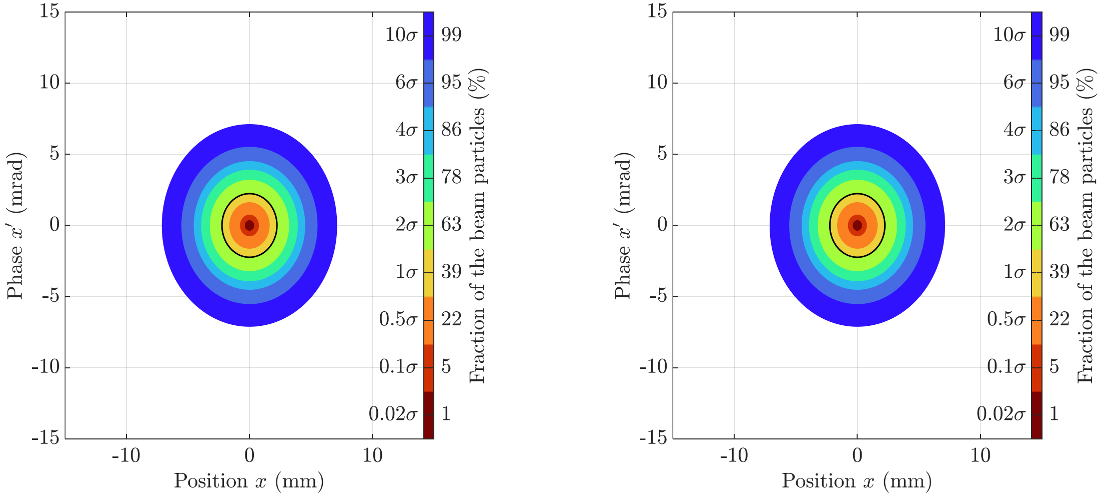
Simulations with CST: deflectors



Deflectors Studies on the electrode gap, radius and shape:

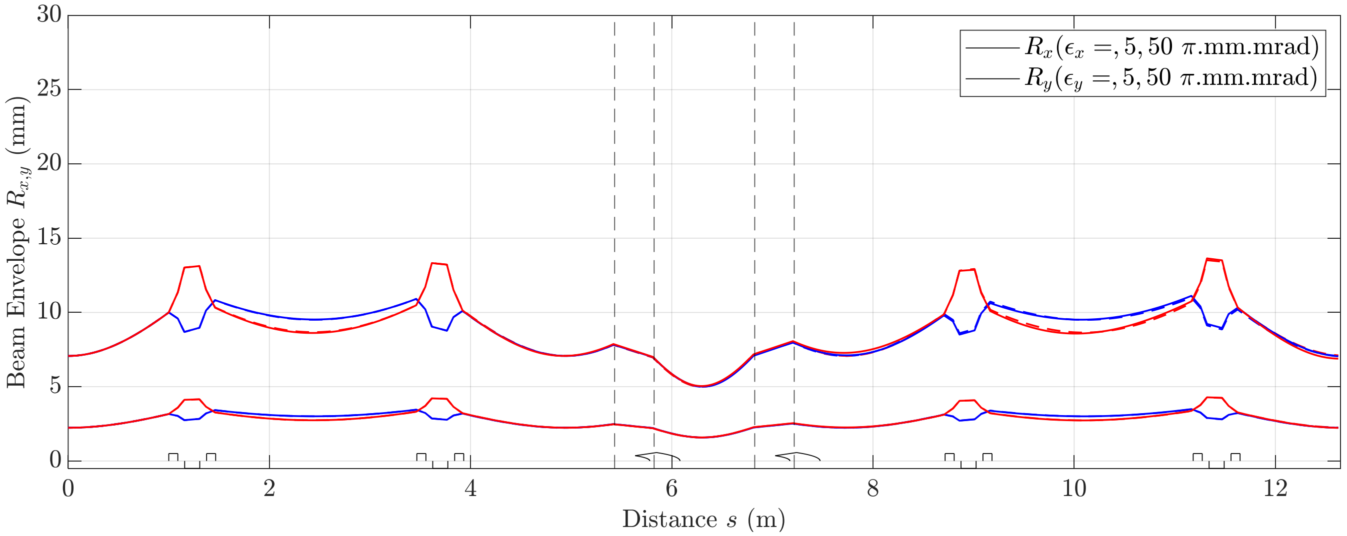
- Gap values of minimum 4 cm
- Need to increase the electrode height
- Radius 0.5 m possible but with benefits for higher values
- Voltages < 20 kV
- Plates with ‘shoulders’ to emulate spherical electrodes can emulate the focusing
  - Significant deformation for repetitive tracking
  - Ideal shape is still under study

Output phase space after two 45 deg. deflection for symmetric beam

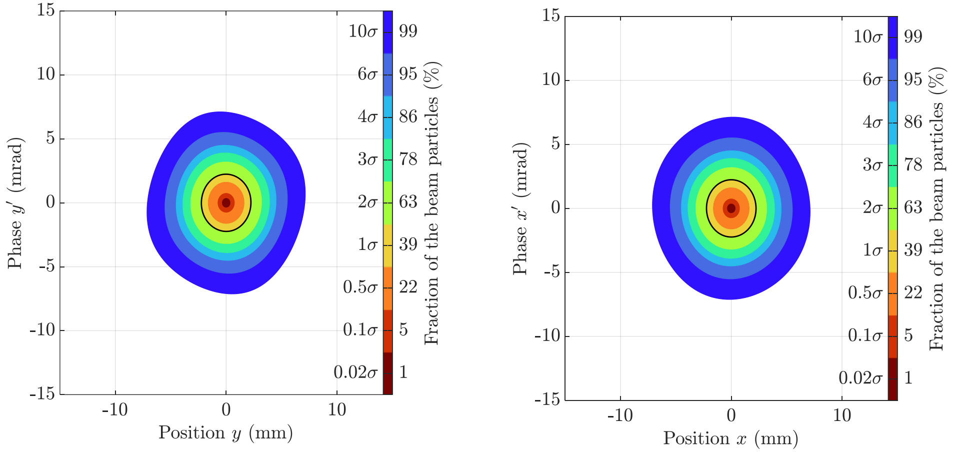


Beam dynamics with COSY Infinity

Separator zone Source -> Triplet -> Concrete wall -> Triplet -> Two 45 deg. Deflections -> Triplets to Separator magnets

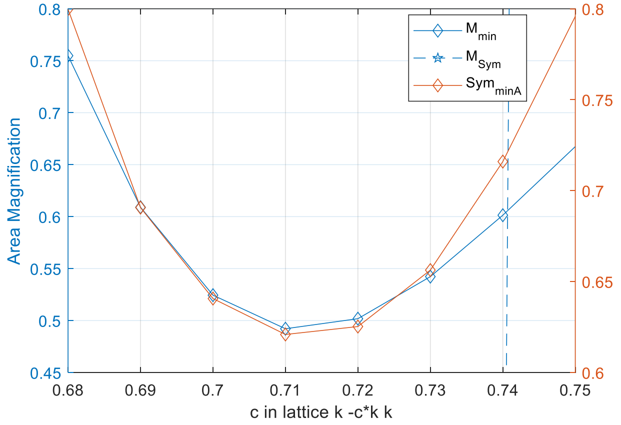


Output phase space for symmetric beam



Beam **matching** to the separator magnets:

- Triplet L_{QP} = 0.9 m / 0.15 m / 0.9 m
- Last Distance to the magnets of 1 m
- Control the waist of the beam in x or y planes



High-level Matlab application to model with COSY Infinity any beam transport line with modulable characteristic lengths, comprised of:

- FODO: doublet lattices.
- Triplet lattices
- 45-deg. deflectors

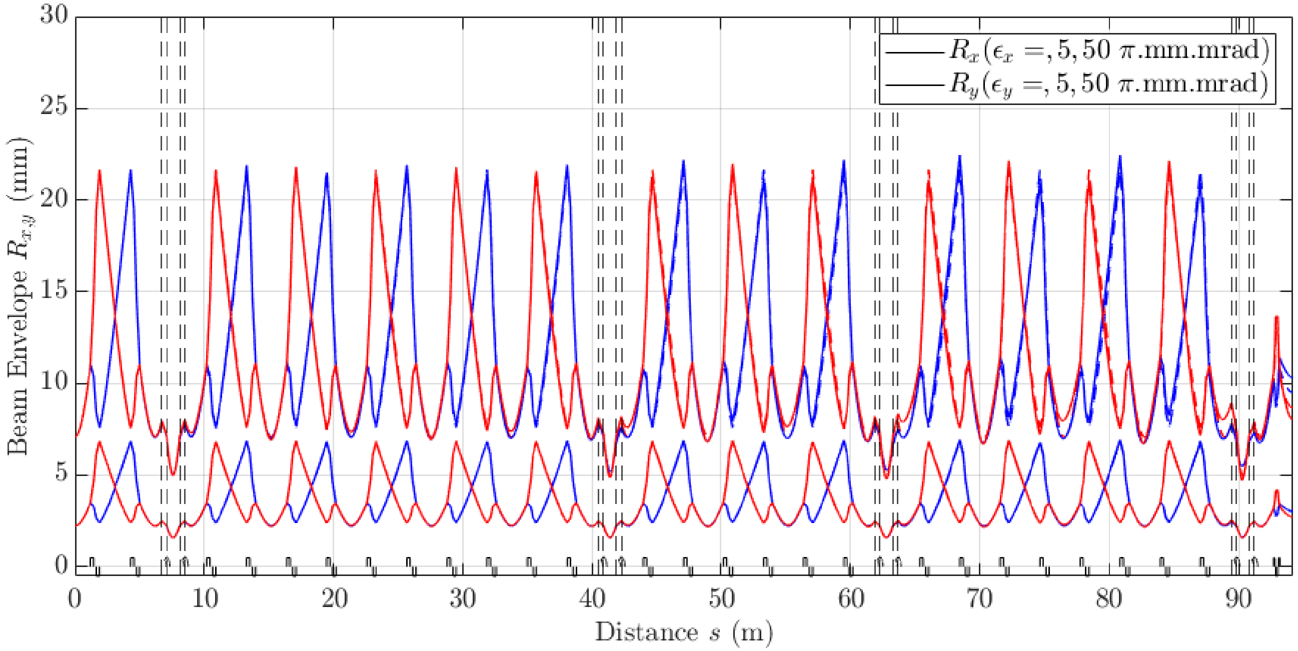
Conclusion

- Voltages < 10 kV for quadrupoles / 20 kV for deflectors
- Focusing distance to the magnet < 2 m
- Control the waist of the beam in x or y planes

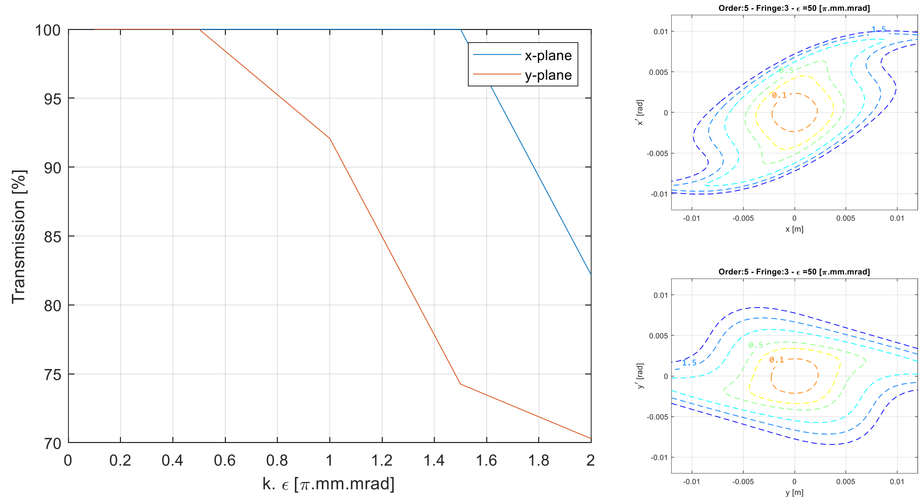
To do

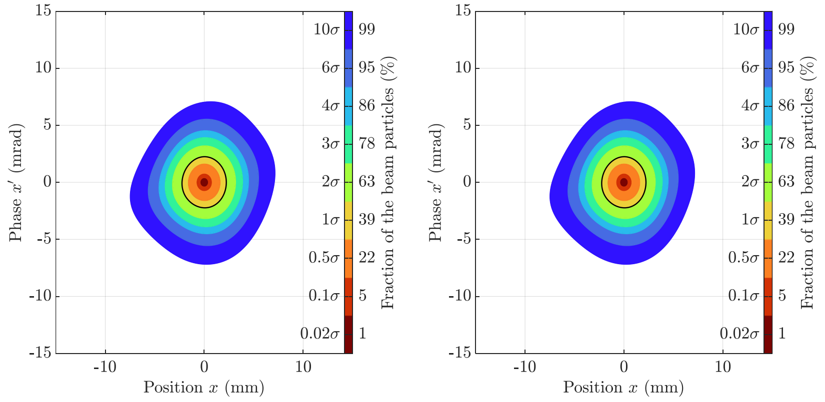
- Complement the studies on the separator magnets

Repetitive tracking with COSY Infinity



Example of realistic repetitive tracking (30 times)
for a FODO-FODO lattice with a length of 8 m





Conclusion

- Implemented the realistic beam transfer matrix of doublets from CST into COSY Infinity
- Choice of Triplet L_{QP} = 0.25 m / 0.25 m as good compromise between losses and repeatability
- Defined the maximum lengths acceptable for the lattices
- Guarantee beam transport for a maximum ellipse of 50 pi.mm.mrad
- Maximize the number of double lattices

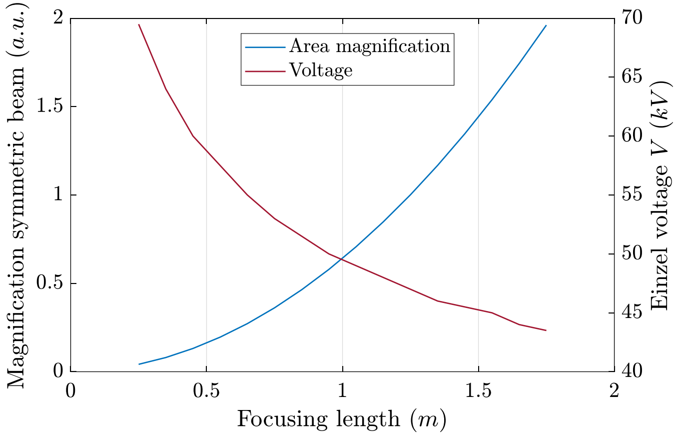
To do

- Beam matching with realistic Twiss parameters from the separator magnets
- Complement the studies on the compact beam switchyard

Injection into experimental stations

Einzel lens

- Compact element to provide strong focusing
- High voltage required
- Einzel focusing power is dependent on the geometry and the voltage ratio
- Decelerating mode requires lower voltage
- Less spherical aberrations with accelerating mode



Gridded Einzel lens

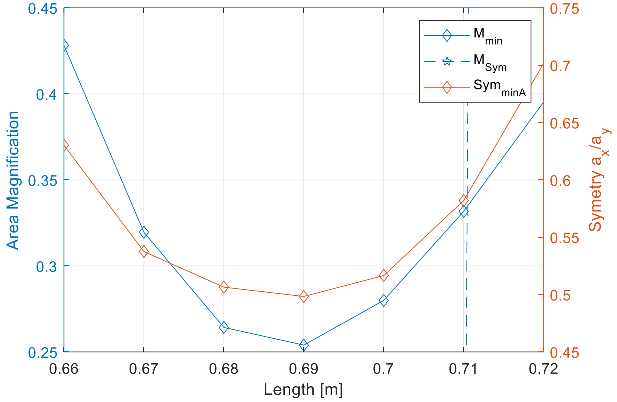
Spherical Aberration Corrections for an Electrostatic Gridded Lens, 2008, A. Pikin

Numerical simulation of gridded electrostatic lens Rev. Sci. Instrum. 83, 02B907 (2012) G. N. Kropachev, N. N. Alexeev, A. I. Balabin, et al

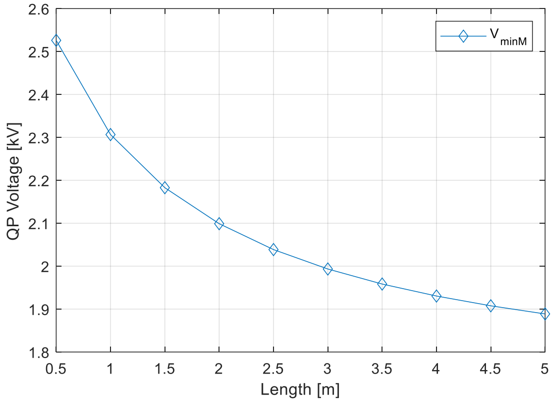
Triplet

- Single triplet will not necessarily preserve the beam symmetry
- Not a lot of margin on the focusing distance
- Voltages can be kept < 10kV

Focusing for a Triplet L_{QP} = 0.25 / 0.4 / 0.25 m



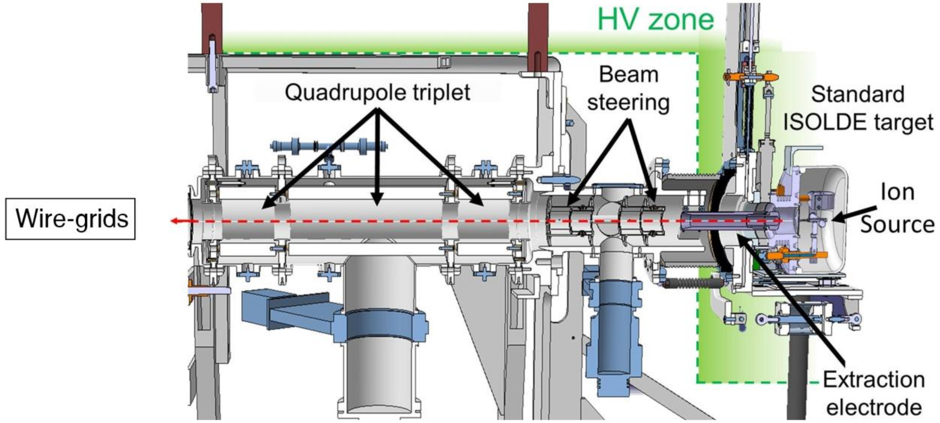
Maximum voltage required for a 60 keV beam



Conceptual design studies on the beamlines of a new experimental hall

- Introduction to the context of the beam dynamics studies
- Designs of the electrostatic elements and transport simulations
- Emittance measurements at ISOLDE and OFFLINE2
- Other activities and conclusion

Emittance from the target ion sources



Setup and results

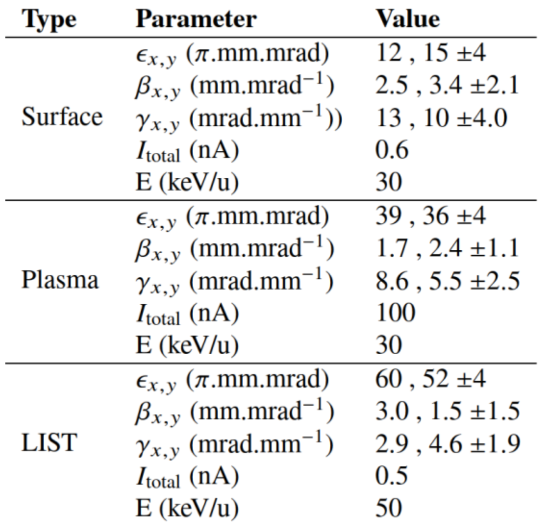
Use the wire grids at ISOLDE, with spacing of 0.5 mm.

The recently measured emittances are larger than historical measurements:

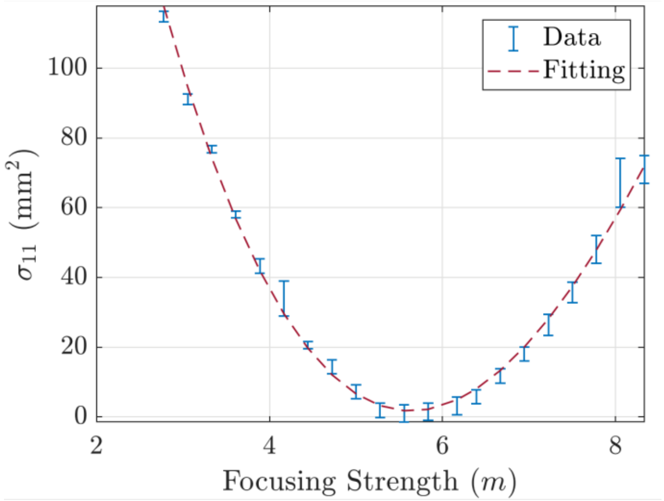
Transverse emittance investigation of the ISOLDE target-ion sources
F. Wenander, NIM Phy. Res. B, Vol. 204, May 2003, Pages 261-266.

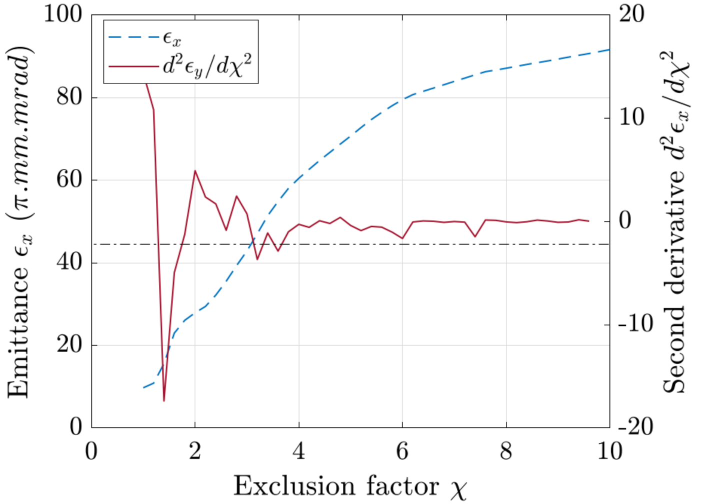
Uncertainty on the quadrupole focusing strength:

- Triplet design recently reproduced in CATIA
- Integration in CST to determine a realistic transfer matrix



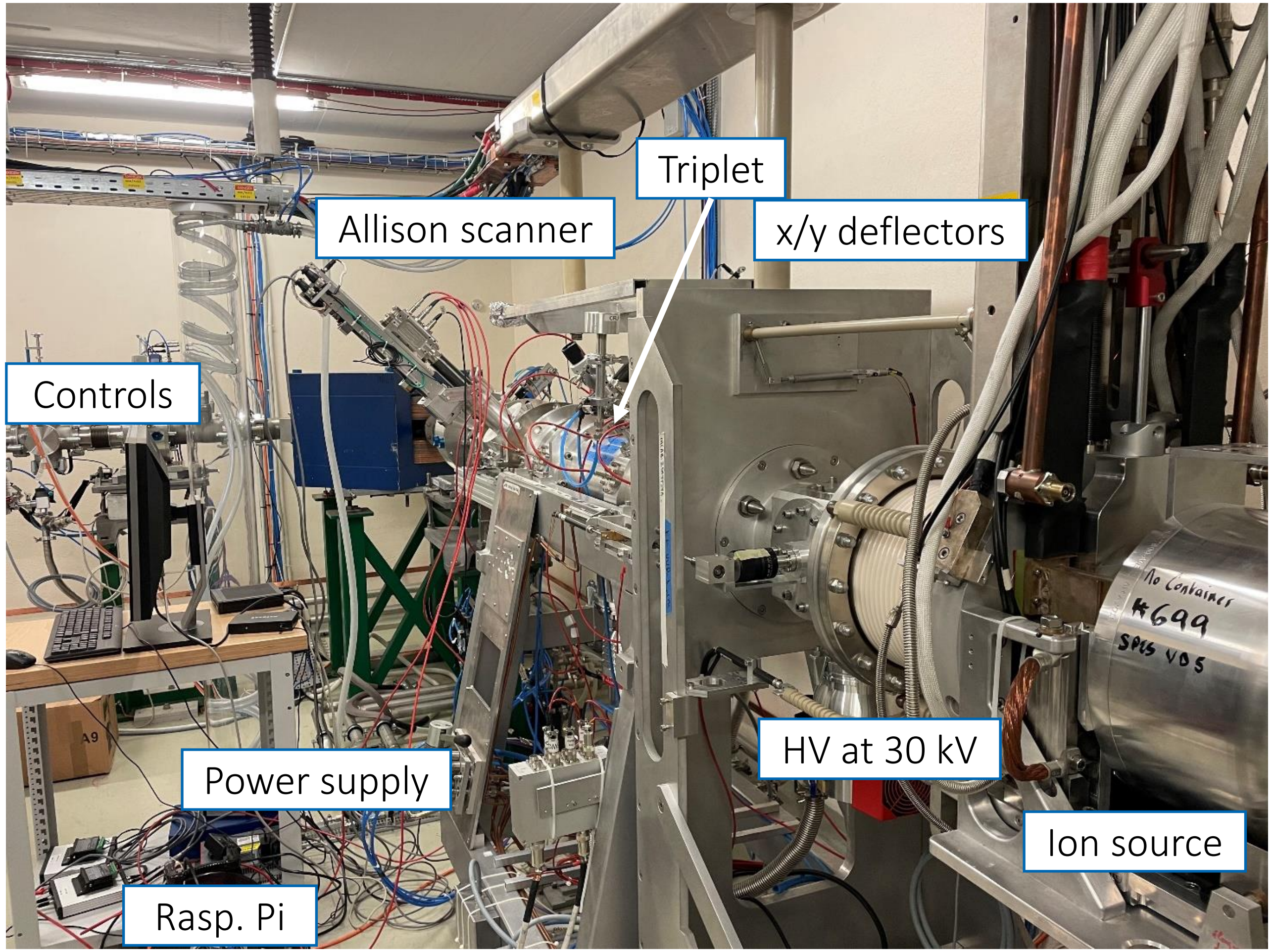
Type	Parameter	Value
Surface	$\epsilon_{x,y}$ (π.mm.mrad)	12 , 15 ±4
	$\beta_{x,y}$ (mm.mrad^{-1})	2.5 , 3.4 ±2.1
	$\gamma_{x,y}$ (mrad.mm^{-1}))	13 , 10 ±4.0
	I_{total} (nA)	0.6
	E (keV/u)	30
Plasma	$\epsilon_{x,y}$ (π.mm.mrad)	39 , 36 ±4
	$\beta_{x,y}$ (mm.mrad^{-1})	1.7 , 2.4 ±1.1
	$\gamma_{x,y}$ (mrad.mm^{-1})	8.6 , 5.5 ±2.5
	I_{total} (nA)	100
	E (keV/u)	30
LIST	$\epsilon_{x,y}$ (π.mm.mrad)	60 , 52 ±4
	$\beta_{x,y}$ (mm.mrad^{-1})	3.0 , 1.5 ±1.5
	$\gamma_{x,y}$ (mrad.mm^{-1})	2.9 , 4.6 ±1.9
	I_{total} (nA)	0.5
	E (keV/u)	50

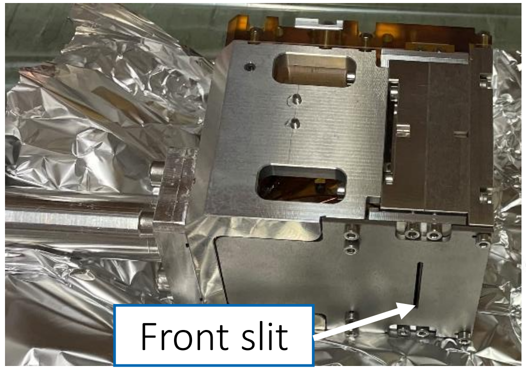


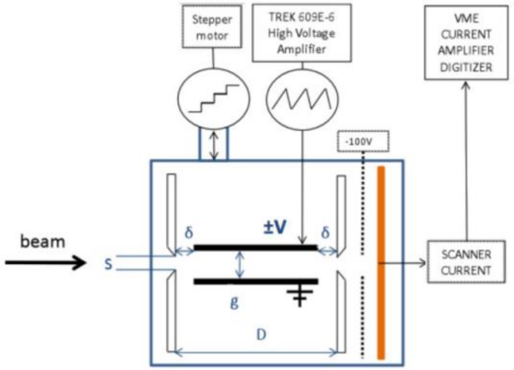


Transverse Emittance Measurements of the Beams Pproduced by the ISOLDE Target Ion Sources, N. Bidault, Proceedings of IPAC2022, Bangkok, Thailand.

Allison scanner from TRIUMF at OFFLINE2







Specifications

Can be used for beams up 100 keV
Geometrical resolution of 0.03 mm-mrad
Faraday cup for beams > 1 nA or a channeltron for lower intensities

Schedule

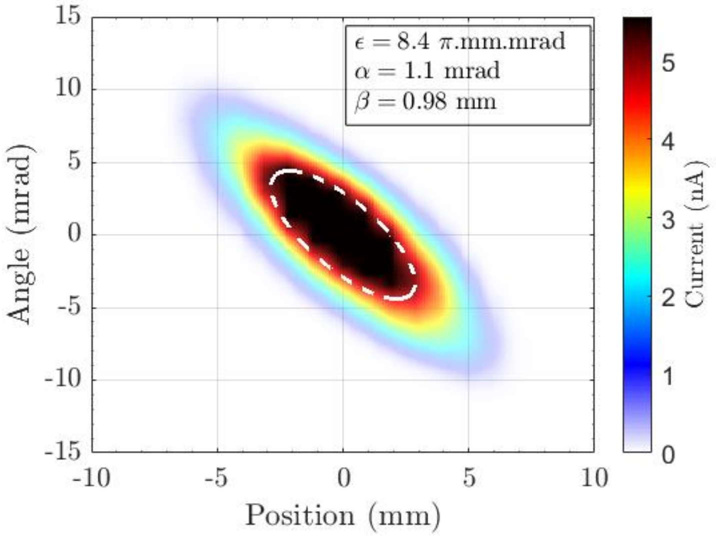
Feb.: Received from TRIUMF
Mar. – Aug.: Fabrication, assembly, and preparation for integration
Sept.: Installation at OFFLINE during Sept. 2022
Sept. – Dec.: Troubleshooting / commissioning
Oct.: First measurements
Nov.: Installation at ISOLDE

Allison Scanner Emittance Diagnostic Development At TRIUMF, A. Laxdal et al., Proceedings of LINAC2014, Geneva, Switzerland.

Emittance measurements at OFFLINE2

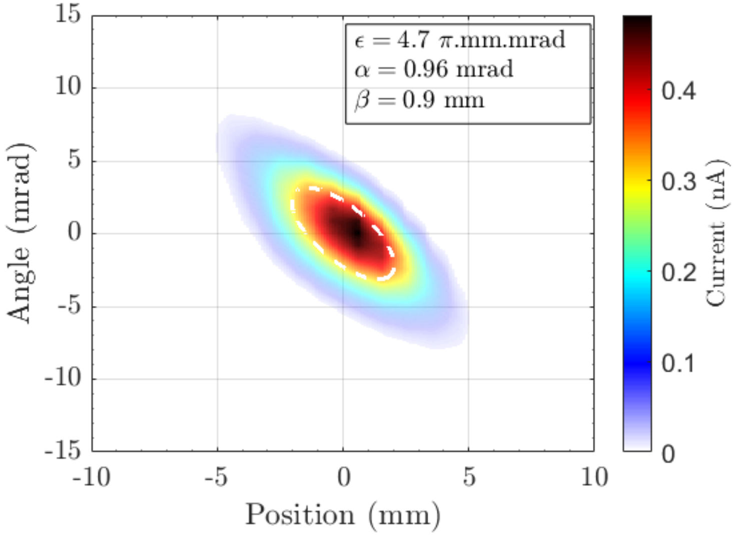
Results from the Allison scanner

30 keV total beam from a plasma ion source
Intensity 410 nA



Flat-top and potential saturation

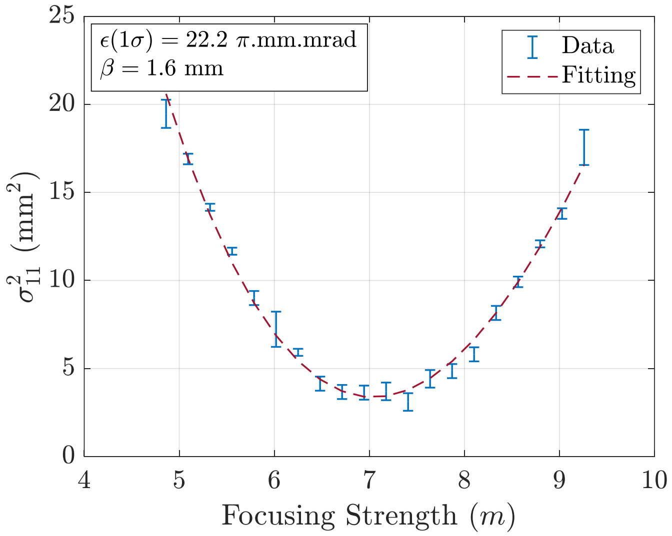
No B-field in the source
Intensity 20 nA



Closer to bi-Gaussian

Results from quadrupole scan

30 keV total beam from a plasma ion source
Intensity 410 nA



Twiss parameters at different location

Preliminary conclusion and Perspective

- The quadrupole-scan methods needs to be better understood, in particular the focusing strength model.
- PUMA project integration of the Allison scanner at the end of the RC6 line ongoing and emittance measurements planned before the YETS.
- More systematic characterization of the beam parameters extracted from different ion sources, at OFFLINE2.

Conceptual design studies on the beamlines of a new experimental hall

- Introduction to the context of the beam dynamics studies
- Designs of the electrostatic elements and transport simulations
- Emittance measurements at ISOLDE and OFFLINE2
- Other activities and conclusion

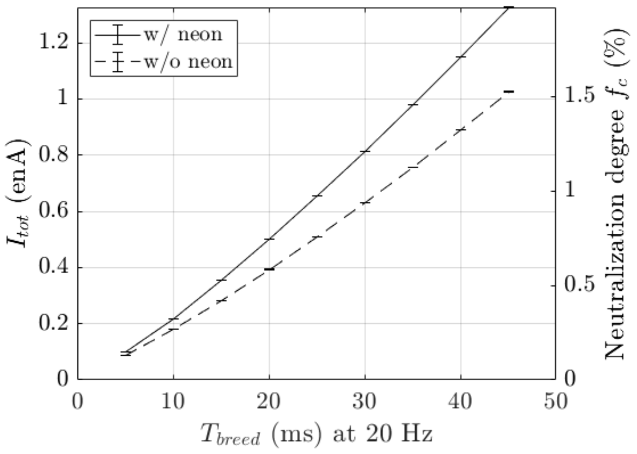
Other activities

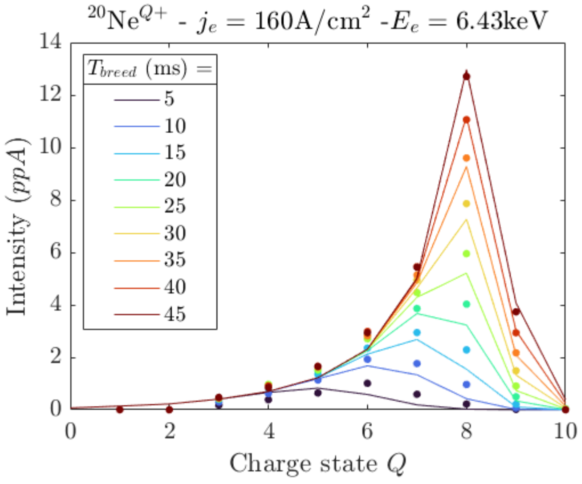
Beam switching project

- Start of the project: push/pull Behlke switches with ISEG power supplies.
- Evaluation of the specifications for switching beams into REXTRAP.

Operation and measurements with REXEBIS

- Helping with the operation of the silicon detectors and maintenance
- Support for the Slow Extraction setups and improvement of the application: idea of a feedback loop from the experimental station.
- Characterization of the electron gun performances during year, notably after the issue with the solenoid.





- Very stable performance of the IrCe cathode
- Effective current density of 180 A/cm2 at 200 mA
- Studies of the longitudinal distribution of the current density, to compare with Brillouin flow.
- Studies on the compensation of the electron beam with residual gas, for high ion intensity EBIS.
- Invited review article:

  Charge breeders: Development of diagnostic tools to probe the underlying physics, L. Maunoury, N. Bidault, J. Angot, A. Galata, R. Vondrasek, and F. Wenander, Rev. of Sci. Instrum. 93, 021101 (2022)

Your new and dedicated scientific secretary of the FOM

Conclusion

What is done

- Sizing of the main focusing lattices
- Possibility to easily change the beamline geometry with COSY Infinity
- Implementation of realistic models from CST for the quadrupoles
- Optimization on the dimensions of the optical elements
- Mechanical designs of the main electrostatic elements
- Emittance measurements with an Allison-scanner and quadrupole-scans

What is left

- Finish the optimization of the deflector with flat electrodes
- Complement the beam dynamics studies on the separator magnets
- Verify the specifications for the compact beam switchyard
- Finalize the beam matching lattices
- Understand the discrepancy between quad-scans and the measurements from the Allison-scanner
- Write a report on the activities

Thank you for your attention