Work of the IAP
on
IFMIF deliverables

D2 : “ Final Layout of Injector “

and

D8 : “ Multiparticle simulations from ion source to DTL”

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Need / Motivation :

Beam transport in the IFMIF LEBT is dominated by the space charge forces. Beam transmission of more than 90 % is necessary to deliver a 140 mA D^+ beam at the RFQ entrance. Emittance growth has to be minimized to avoid particle losses and activation. Therefore the transmission and emittance growth as a function of beam current, noise and residual gas pressure as most important factors had to be studied under consideration of space charge compensation effects.

D 2d: "The final layout of the injector"
Particle losses induced by interactions between residual gas and beam ions have to be considered as well as the results of the ion optical simulations (D 8a).

D 8a: "Multiparticle calculations from source to RFQ"
Emittance growth induced by space charge effects and aberations for different LEBT systems including space charge compensation effects (correlated by the pressure with D 2d) and source noise (D 2b) have to be studied.

Main parameters influencing Low energy beam Transport for IFMIF

Particle losses :

- Charge exchange reactions with residual gas
- Emittance growth

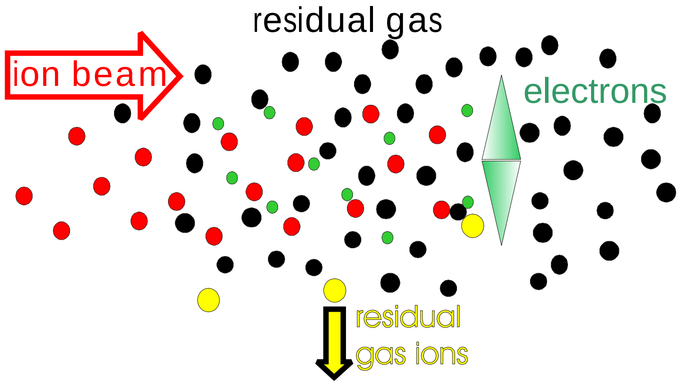
Emittance growth :

- Aberations due to non linear fields
- Redistributions due to space charge forces
- Increase of the effective Emittance by time depending effects (noise)

Space charge forces :

- Can be reduced by space charge compensation

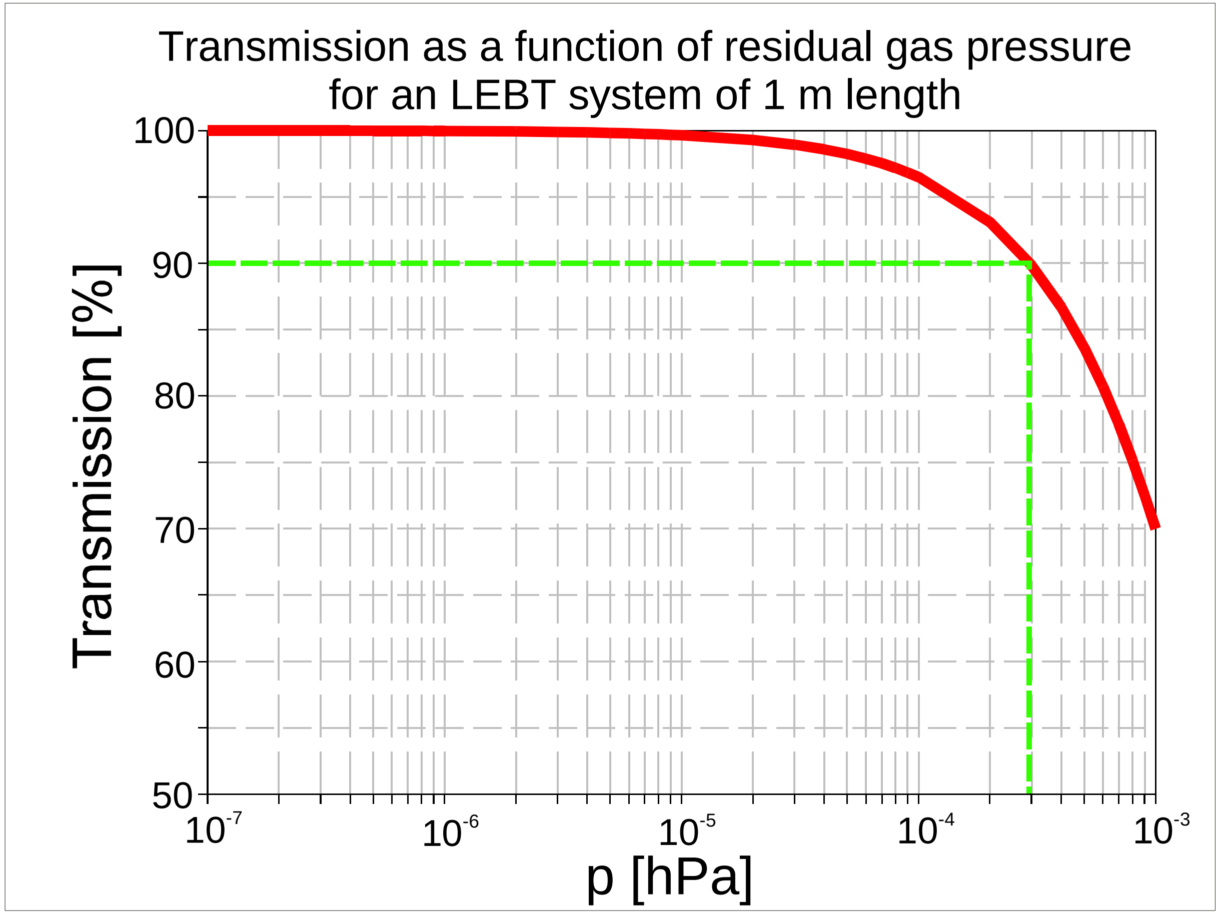
Particle losses by interaction between beam ions and resiudal gas



$$T = \frac{n_{loss}}{n_{BI}} = e^{-(n_{RGA} \cdot \sigma_{loss} \cdot s)}$$

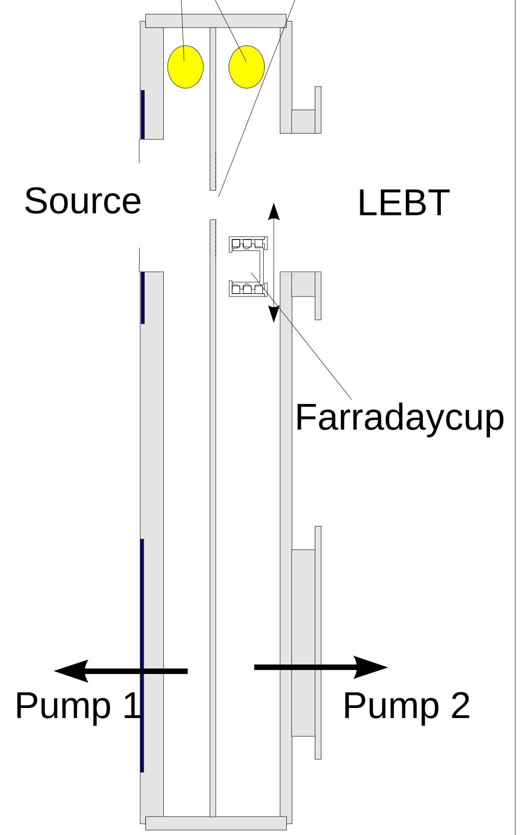
$$s = 1m$$

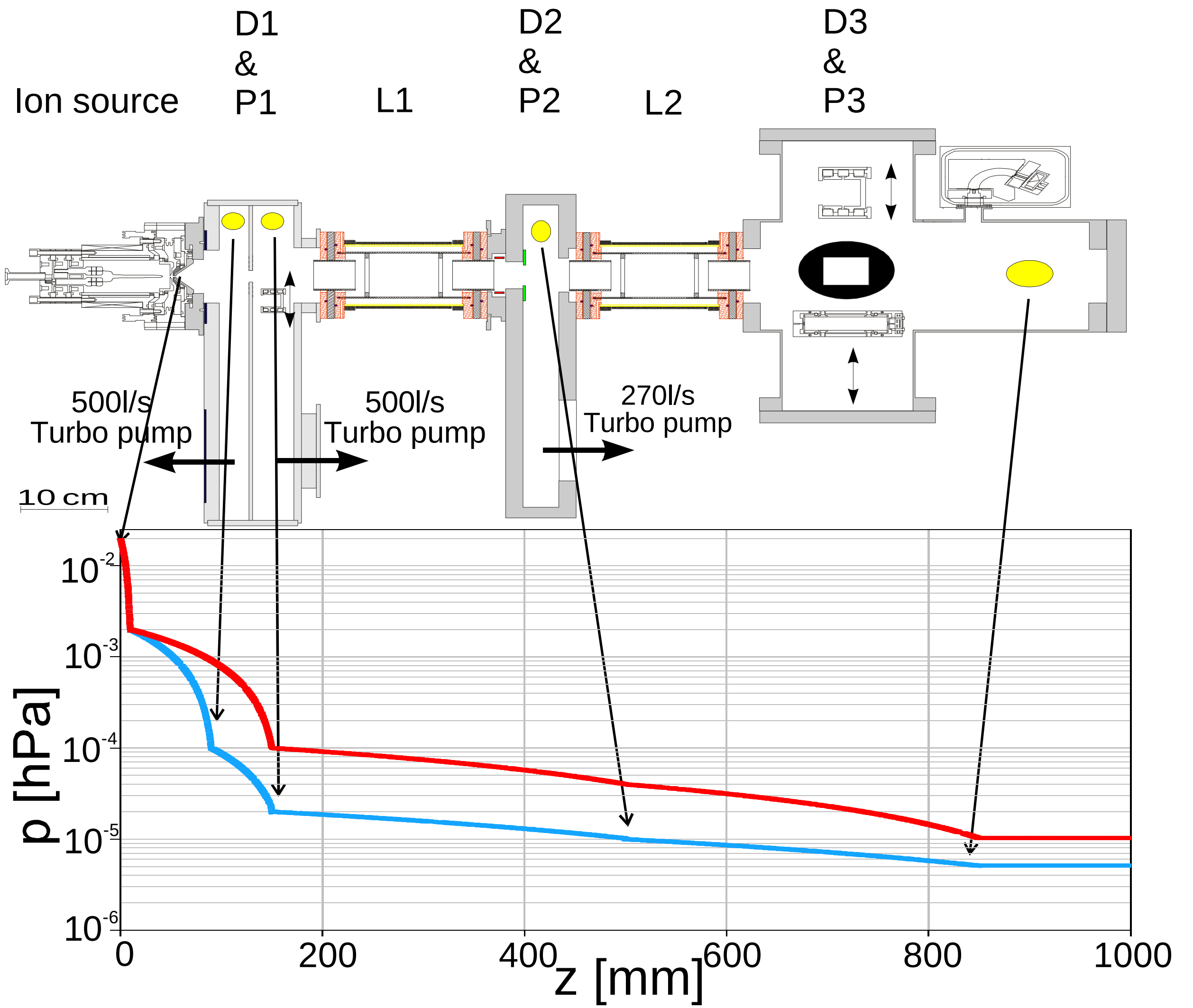
$$\sigma_{loss} = 1 \cdot 10^{-20} m^2$$



Differential pumping for efficient reduction of residual gas pressure

(measured values)





Calculation of beam transmission within the injector

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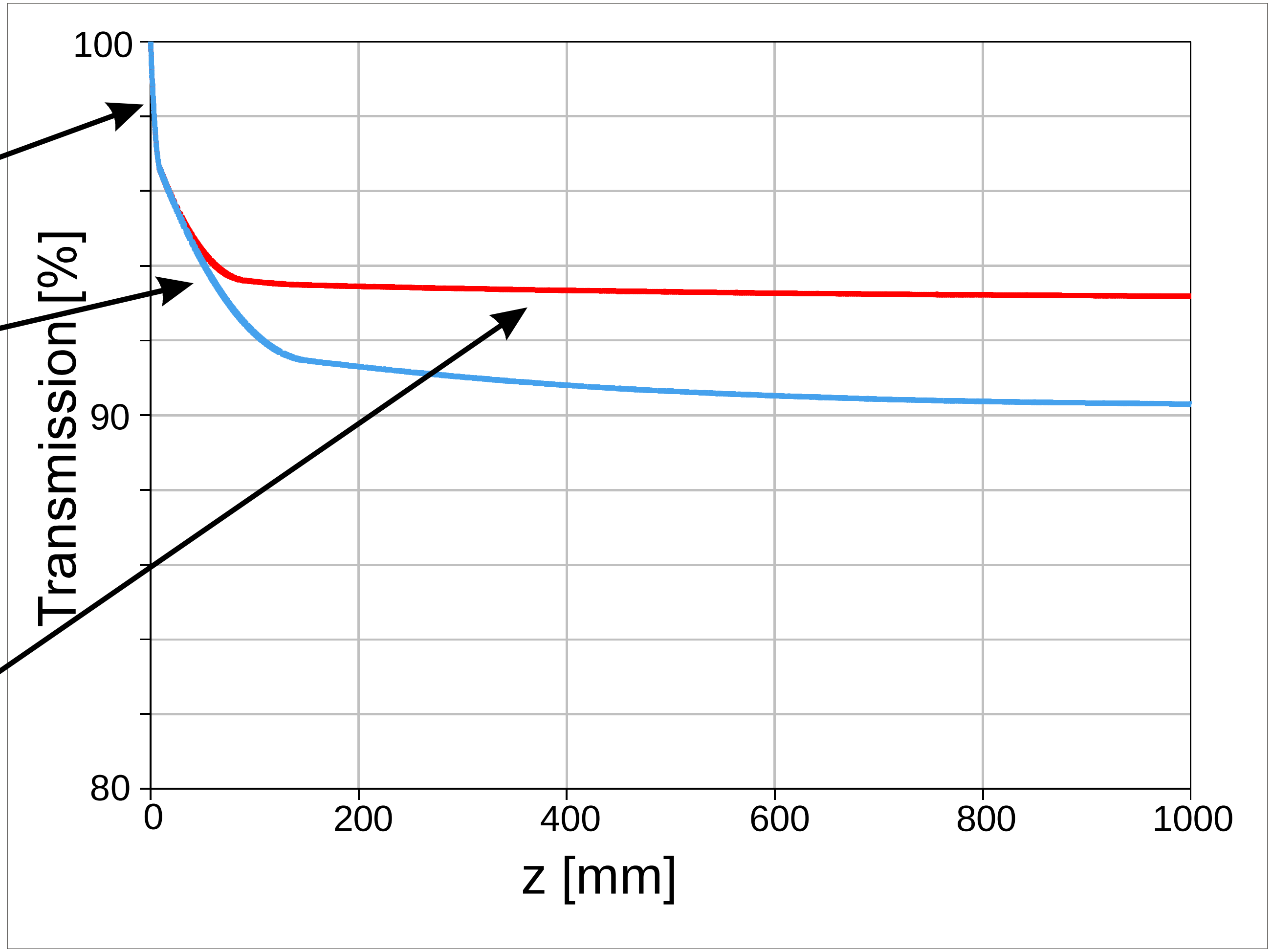
To fullfill the IFMIF requirements (90%) :

The gas pressure 10 mm behind thePlasmaelectrode has to be below $2*10^{-3}$ hPa. (30% losses).

A differential pumping system reduces further losses by 50 % and enhances safety margin.

After reduction of the pressure within 150 mm only minor losses (<0.1 % / m) occure.



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Beam transport of theIFMIF beam within the injector is dominated by space charge forces

Beam transport calculation

neglecting
collisions
and
emittance growth
by use of

Envelopequation

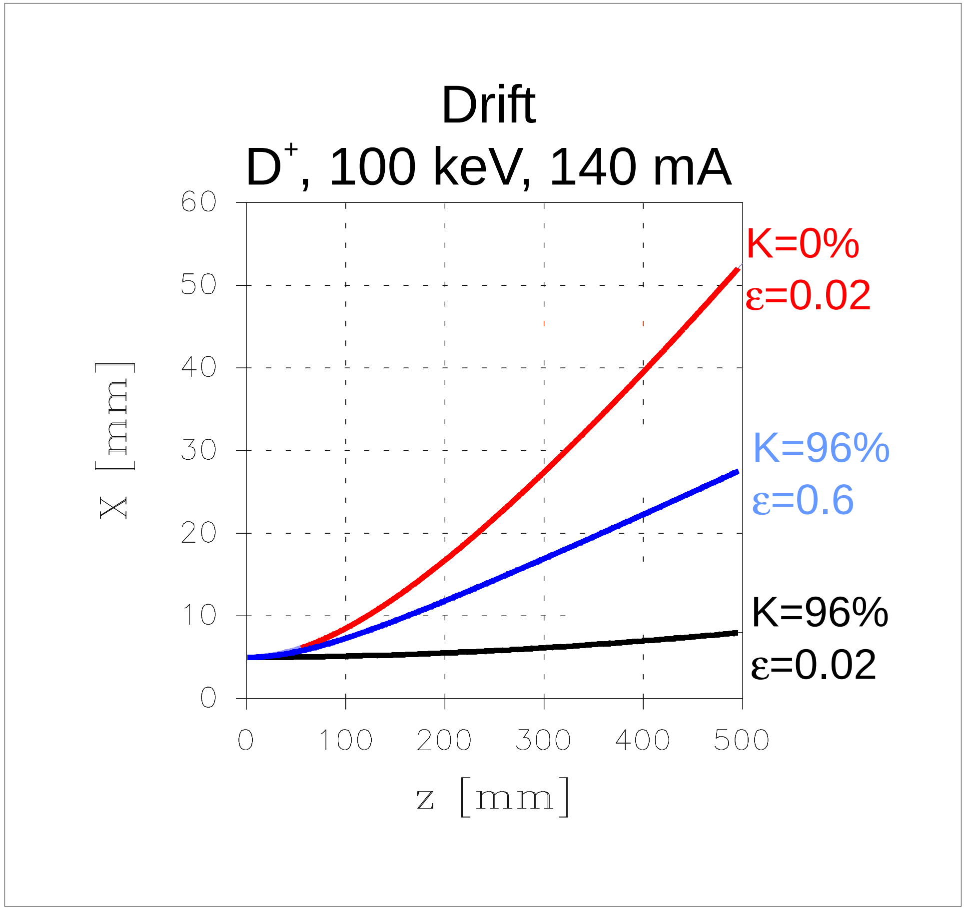
$$\frac{d^2X}{dz^2} = \frac{\left\langle \varepsilon_{rms,x} \right\rangle^2}{X^3} + \frac{K}{2(X+Y)} - k_x^2 X$$

emittance

lenses

gen. perveance (space charge)

$$K = \frac{\Delta U}{U} = \left(\frac{1}{4\pi\varepsilon_0} \sqrt{\frac{Am}{2e\zeta}} \right) \frac{I}{U^{3/2}}$$



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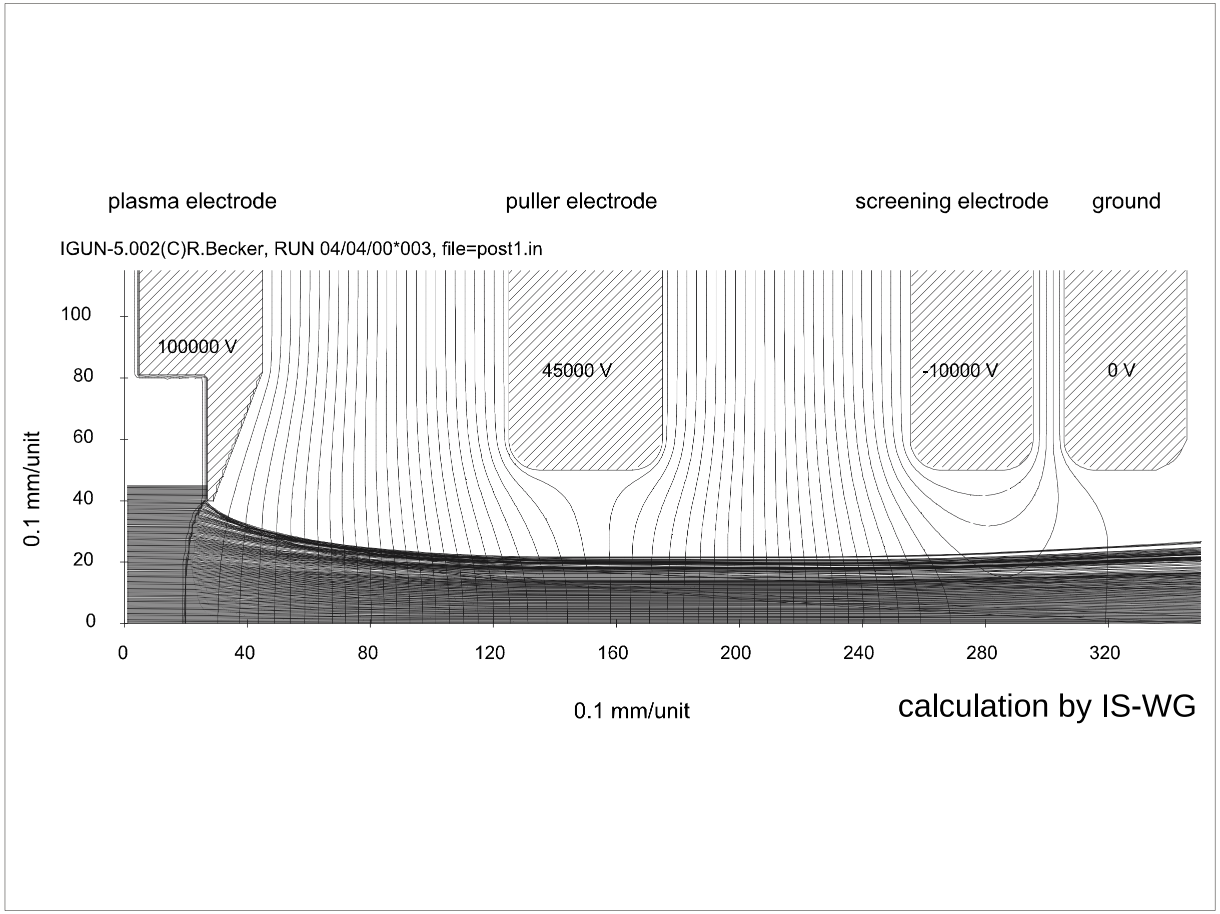
Simulations of beam transport 1: Beam extraction and post acceleration

For optimized extraction and lowest beam emittance a post acceleration from extraction voltage to the beam energy at RFQ injection is favourable.

The requirements of IFMIF can be fullfilled.



$\varepsilon_{rms,calc}$=0.0575 πmmmrad

$\varepsilon_{rms,meas.}$=0.062 πmmmrad

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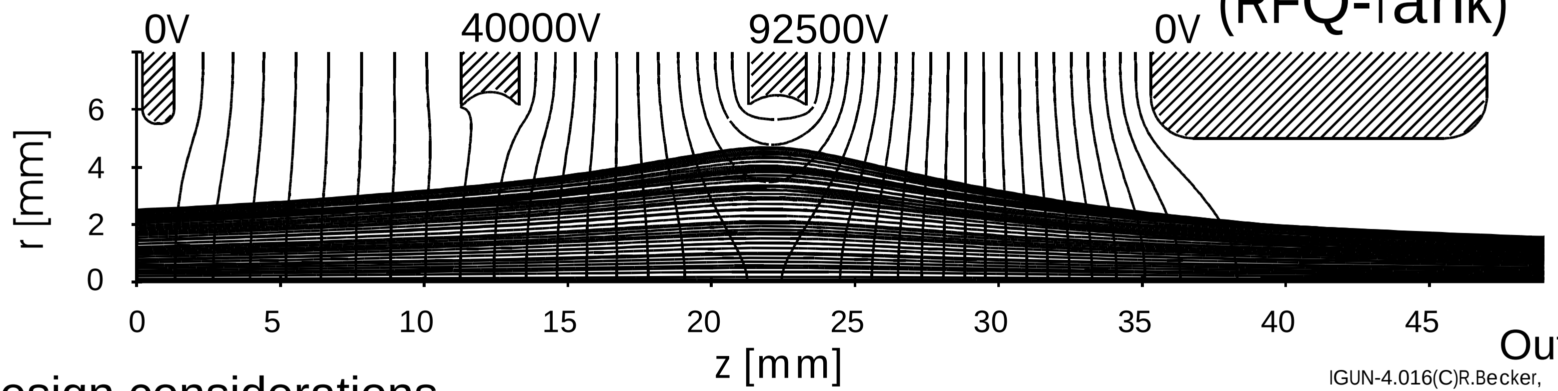
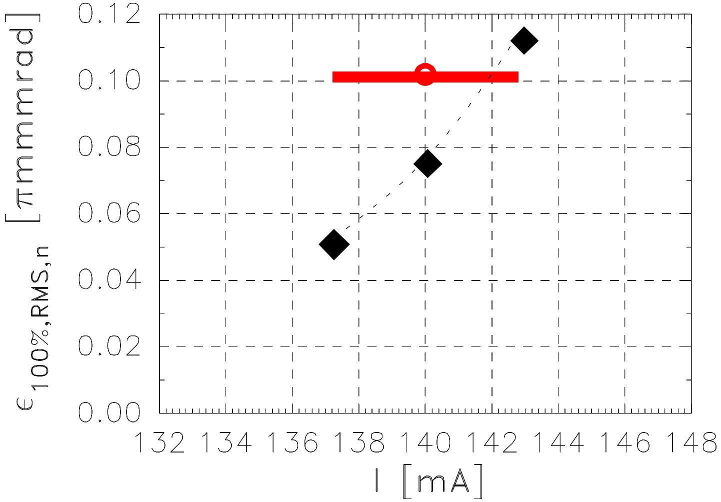
Simulations of beam transport 2: Electrostatic LEBT



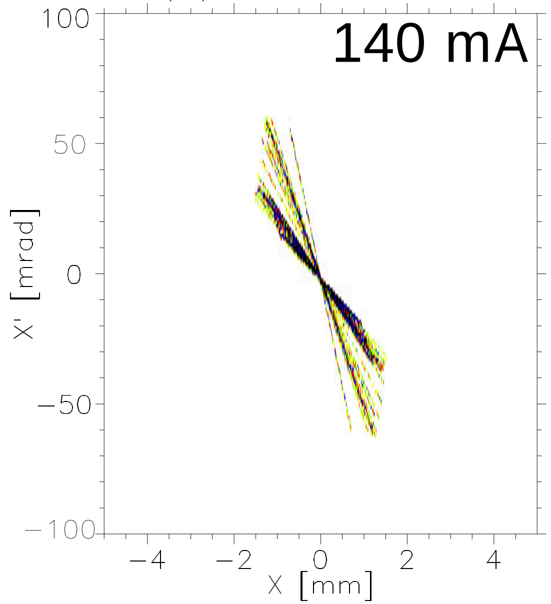
Design considerations

- due to space charge as short as possible (35mm)
- to prevent HV-breakdown $E_{z,max}$ <7.7 kV/mm
- for nominal current emittance growth app. 50 %
- highly sensitve to noise
- effective emittance larger vorseen for IFMIF.

RMS-emittance as a function of beam current



Output emittance



An electrostatic LEBT system does not fullfill the IFMIF requirements.

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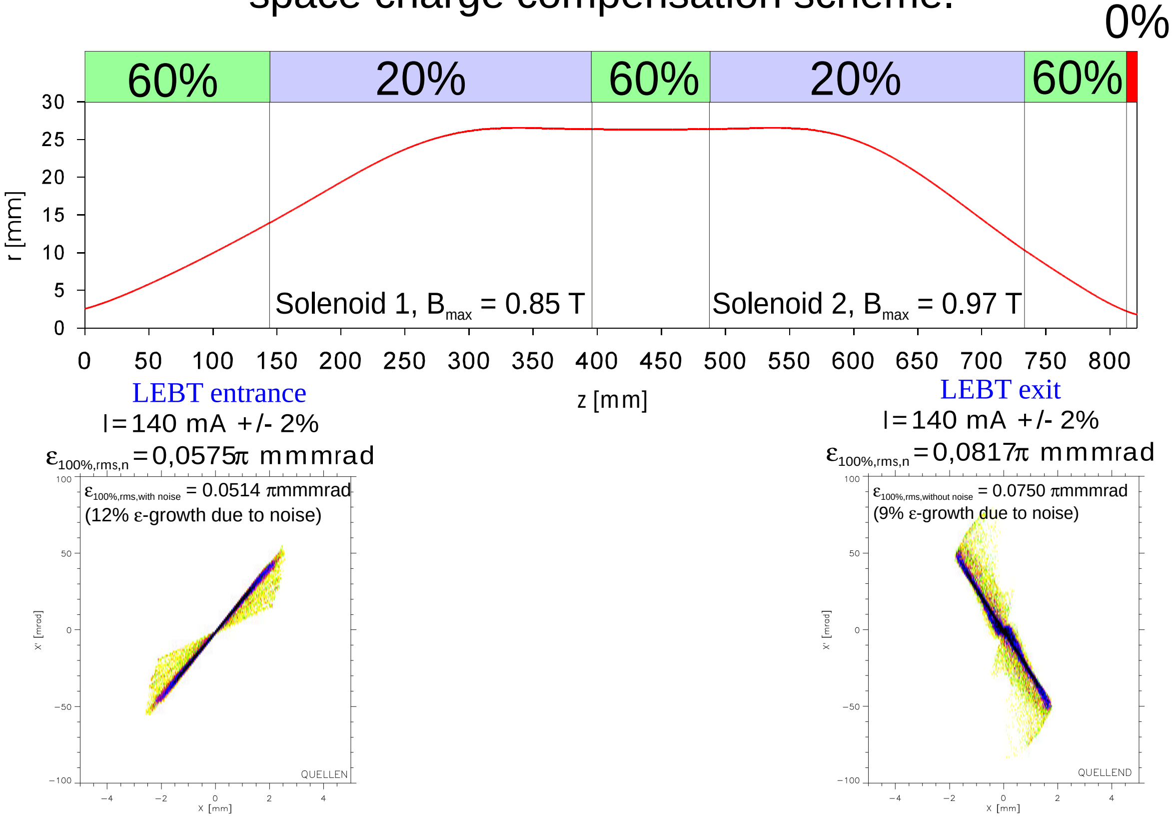
Simulations of beam transport 3 : Magnetic LEBT using soleniods

Beam transport calculations include beam current fluctuations of **+/- 2 %** at **100 kHz** and conservative estimations about the compensation degree:

In the drift sections **60 %**, **20 %** inside the solenoids and **0 %** at the RFQ entrance. (worst case scenario!)

A magnetic LEBT system consiting of solenoids can fullfill the IFMIF requirements and is at reasonable costs technical realizable.

Multiparticle calculations (n=30000 particles) including fringe fields, source noise and a detailed space charge compensation scheme.



Simulations of beam transport 4 :
Principle of space charge focussing

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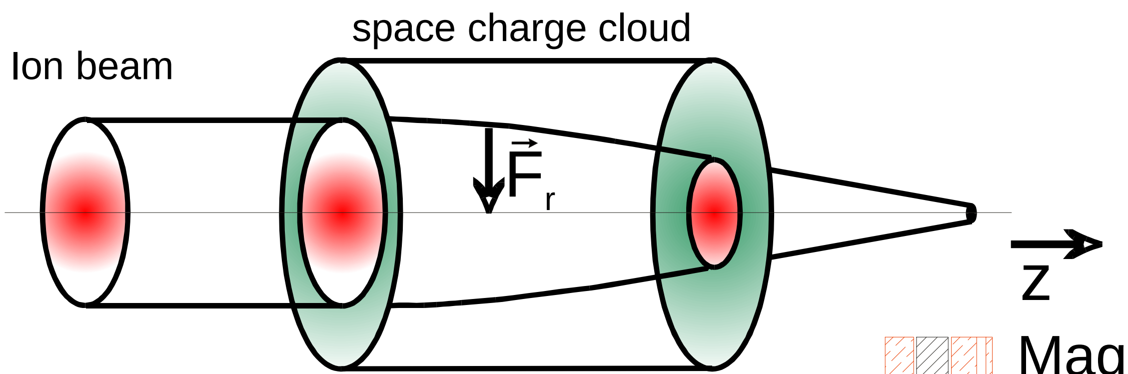
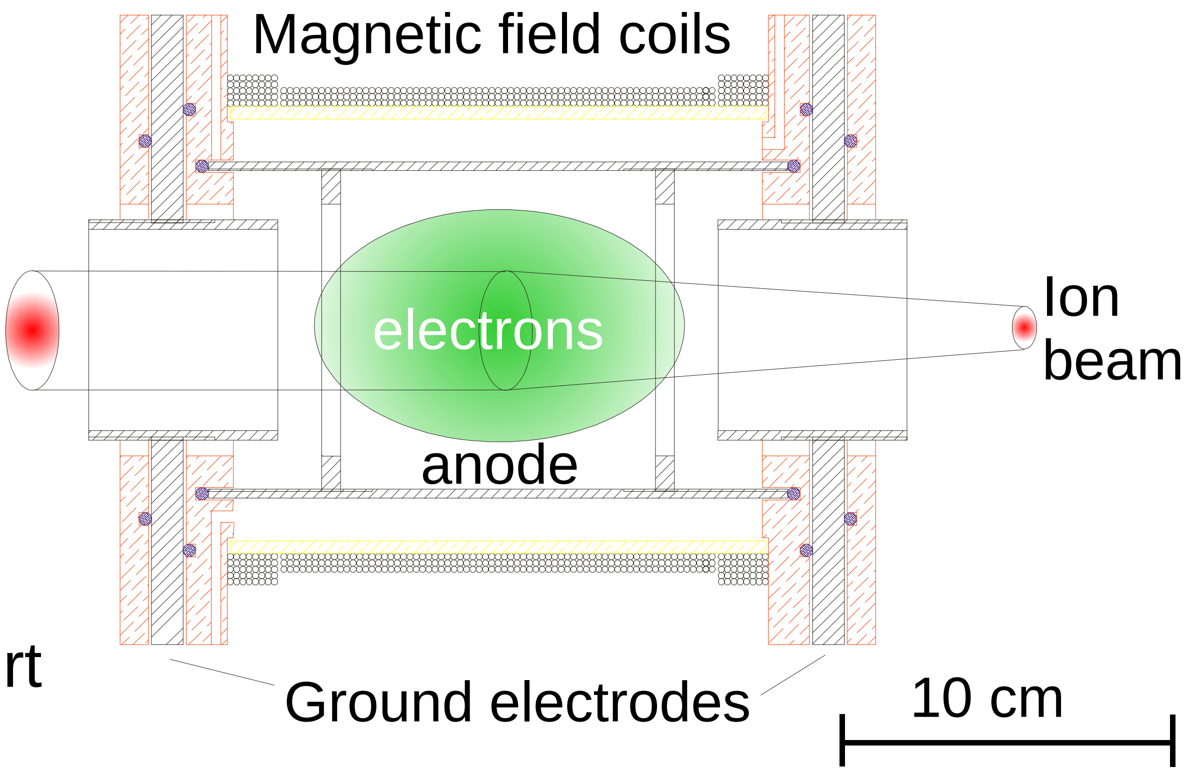


Advantages :
- strong zylindersymetric focussing
- preservation of space charge compensation
- small external fields
- linear forces
- insensitive to noise



set up in Frankfurt

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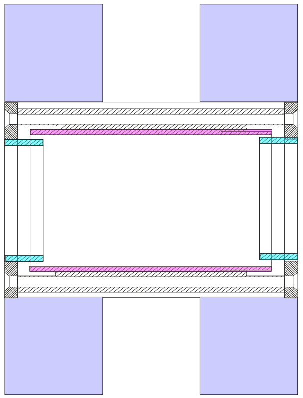
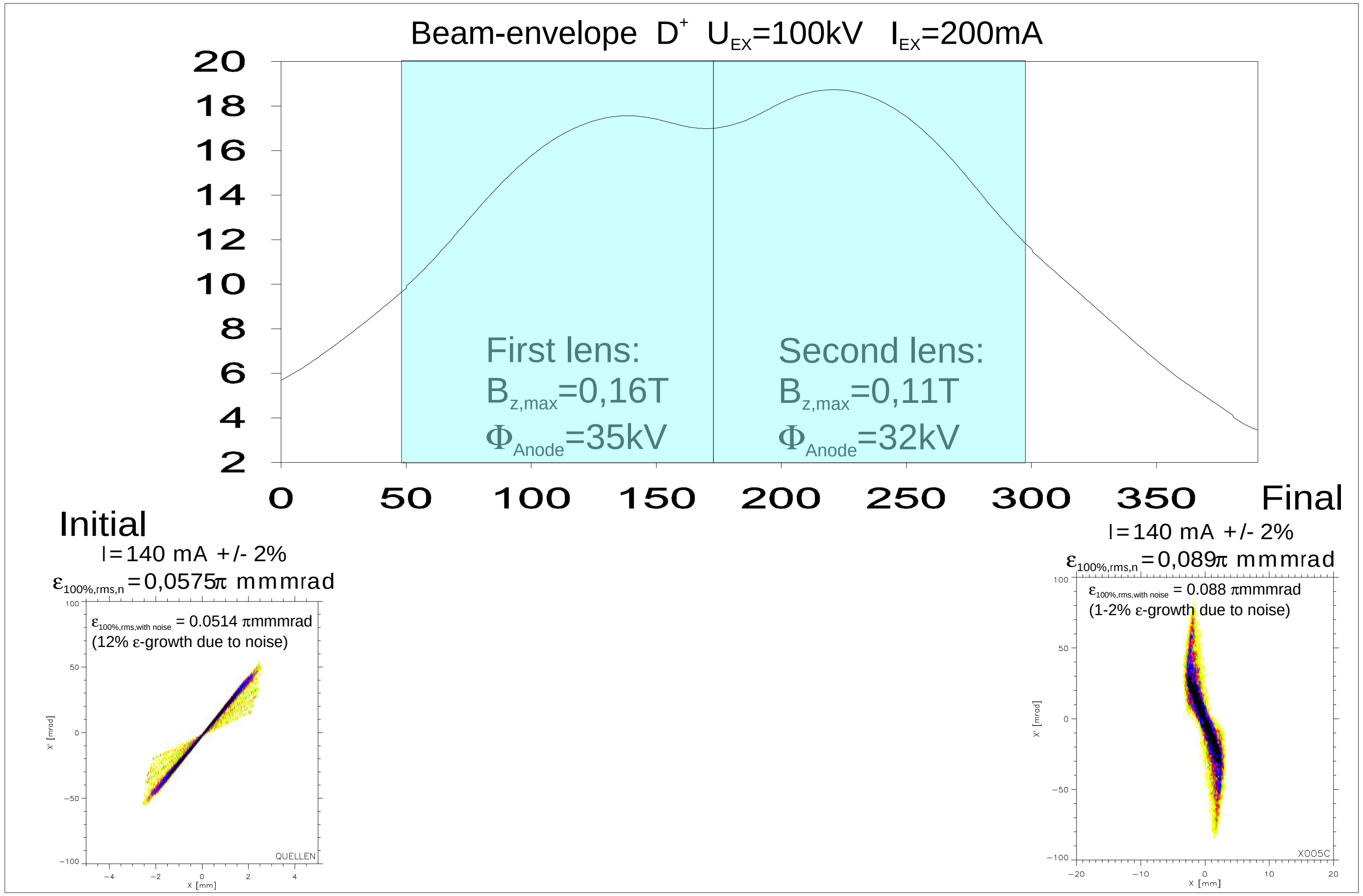
Simulations of beam transport 4 : Beam transport using Gabor Lenses

Helmholtz - coils
$B_{z,max}$ = 0,2 T
with
Gabor lens electrods





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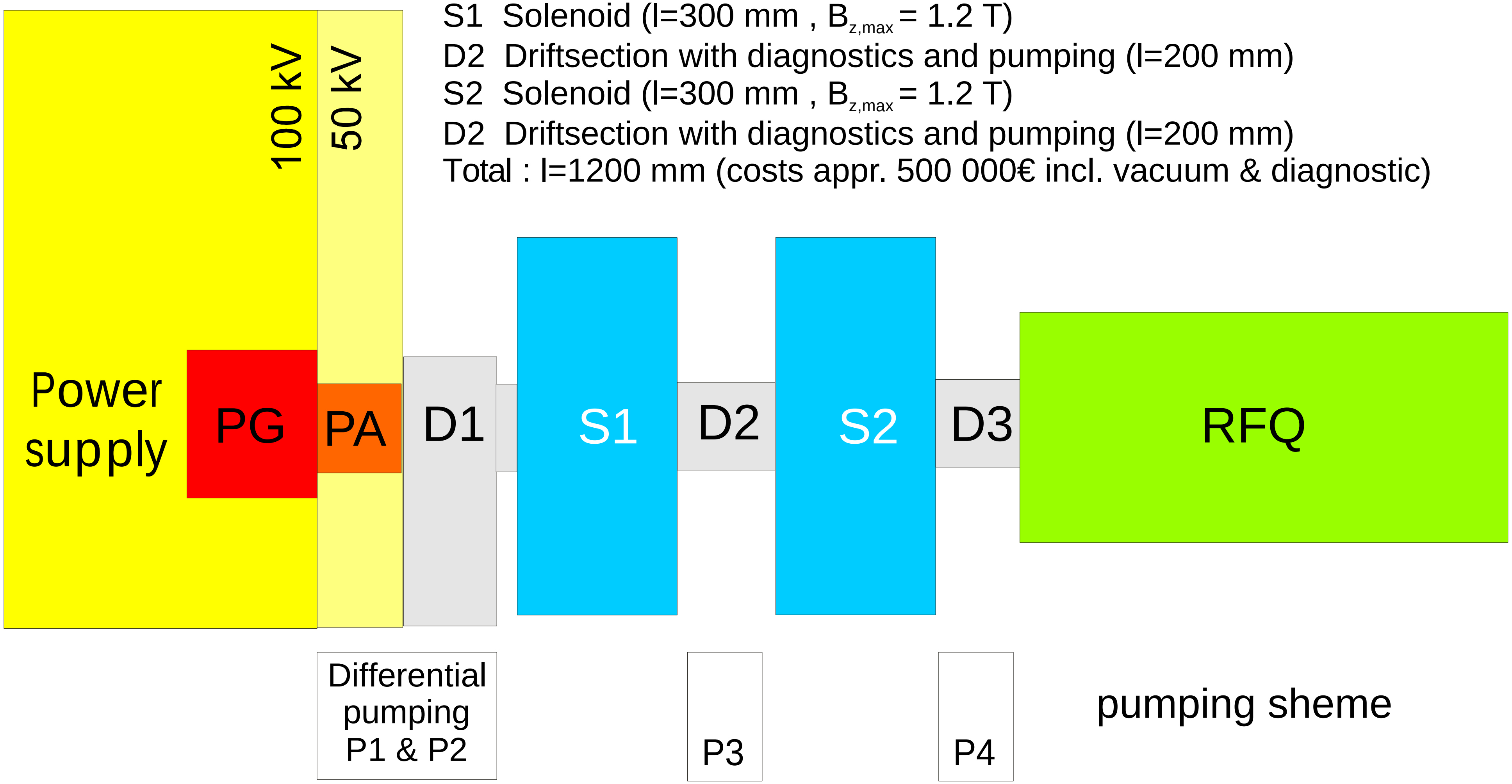
Final layout of injector

PG Plasma generator delivering a beam of 140 mA at 55 keV
PA Postacceration to 100 keV and first differential pumping stage
D1 Driftsection with diagnostics and second pumping stage (l=200 mm)
S1 Solenoid (l=300 mm , $B_{z,max}$ = 1.2 T)
D2 Driftsection with diagnostics and pumping (l=200 mm)
S2 Solenoid (l=300 mm , $B_{z,max}$ = 1.2 T)
D2 Driftsection with diagnostics and pumping (l=200 mm)
Total : l=1200 mm (costs appr. 500 000€ incl. vacuum & diagnostic)



Conclusion :

Beam transport in the IFMIF LEBT is dominated by the space charge forces. Beam transmission of more than 90 % is necessary to deliver a 140 mA D^+ beam at the RFQ entrance. The following activities have been successfully performed at the IAP:

D 2d: "The final layout of the injector"

Detailed studies on beam particle losses by residual gas interactions.

=> Requirements on vacuum system to fullfill IFMIF defined.
=> Magnetic solenoid system using space charge compensation recomended to fullfill IFMIF requirements.
=> Draft report written.

D 8a: "Multiparticle calculations from source to RFQ"

Detailed particle simulations including fringe fields and noise performed.

=> Electrostatic transport system does not fullfill IFMIF requirements.
=> Magnetic solenoid system fullfills IFMIF requirements.
=> Gabor lenses are able to fullfill IFMIF requirements.
=> Deliverable report written and accepted, Deliverable finished.

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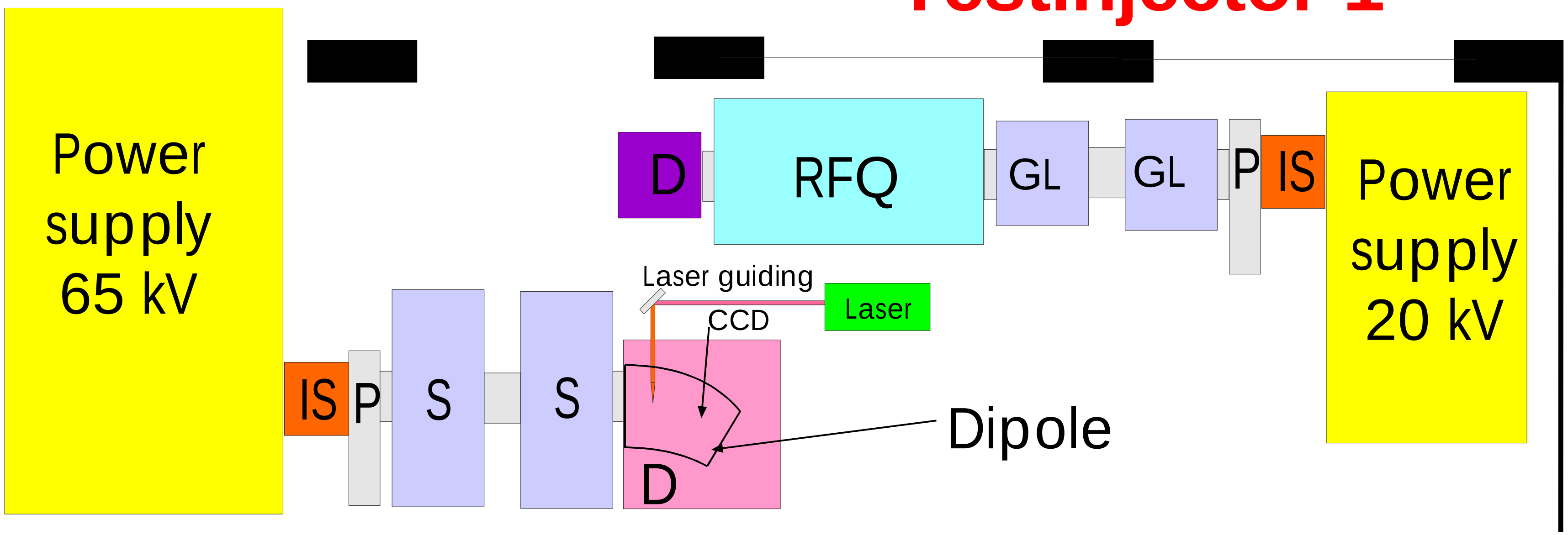
Work on LEBT in transition year 2003

Testinjector 1



Testinjector 2

IS Ion source
P (diff.) pumping system
S Solenoid
D Diagnostic box
GL Gabor ens

Exchange of lens systems between Injector 1 and 2 to directly compare solenoids and Gabor lenses.