Physics Design on Ion Source and LEBT

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Outline

- ECR ion source
- Design of the LEBT
- Solenoid lens design
- Space charge compensation
- Beam simulation of the LEBT

ECR proton source

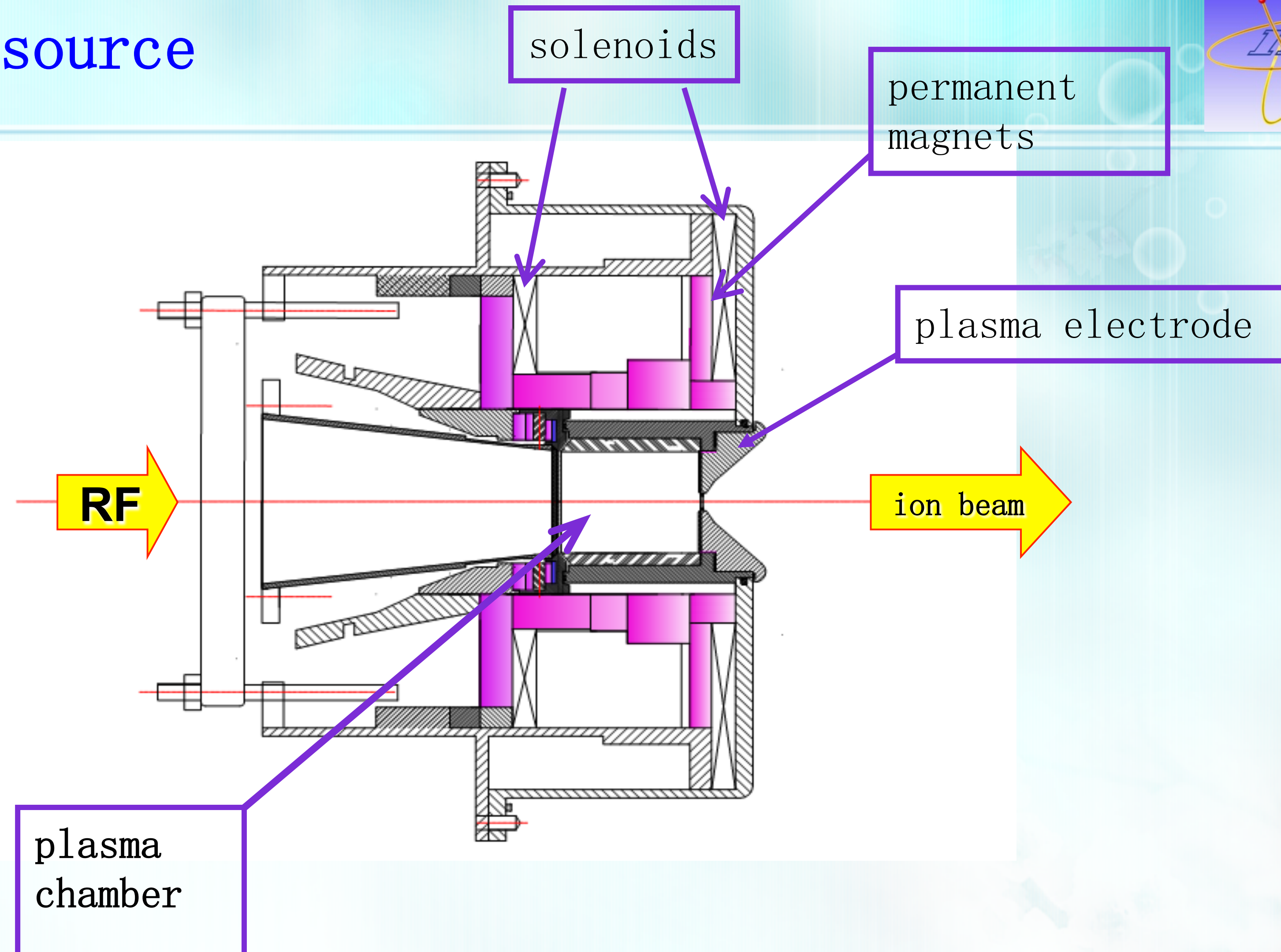
C-ADS

Beam energy (keV)	35
Proton intensity (mA)	20~30
Microwave frequency (GHz)	2.45
Microwave power (kW)	1~1.5
Emittance (rms, πmm mrad)	goal: 0.15~0.2
Proton fraction	>85%
Reliable operation	>120 h

We have just accomplished the design and structure of a high current ECR proton source and a LEBT for the CPHS (Compact Pulsed Hadron Source) project at Tsinghua University, and accumulated much experience.

CPHS ion source

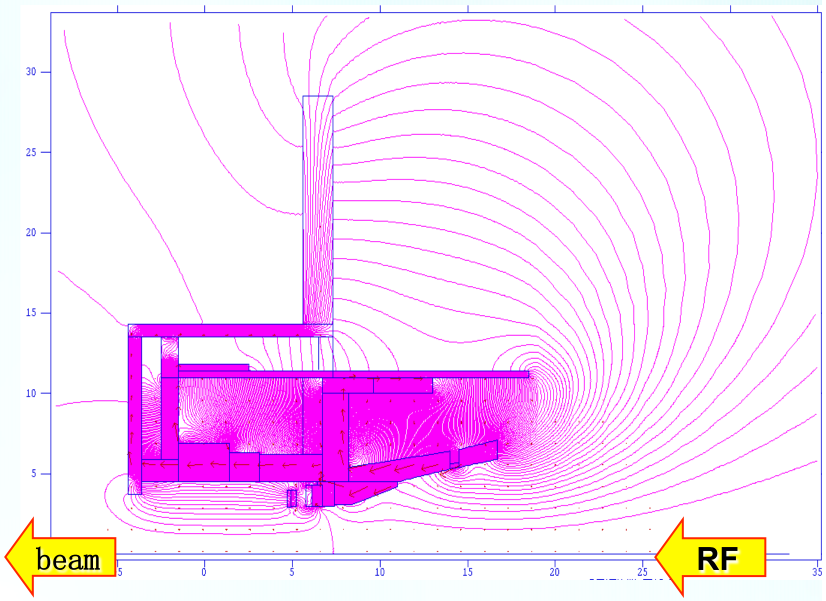
CPHS source



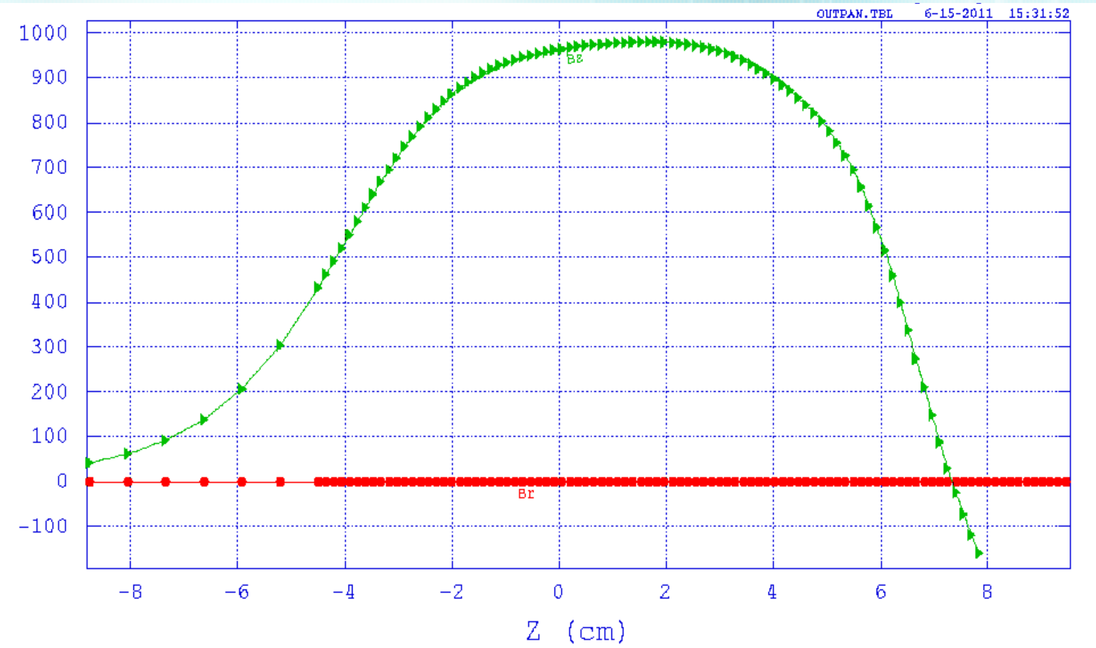
Φ=62 mm, L=64 mm

General structure of ECR ion source

CPHS source



Magnetic field simulation of ECR ion source

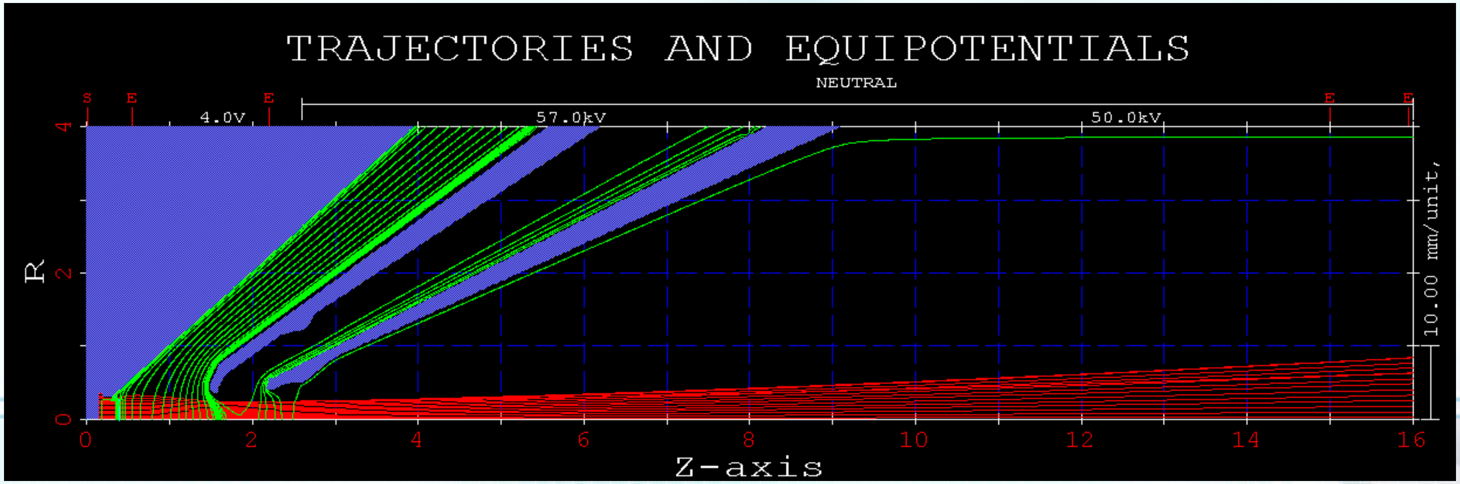


Axial magnetic field B_z

CPHS source

➢ Low emittance extraction

Three-electrode system	plasma electrode	extraction electrode	grounded electrode
aperture	Φ6mm	Φ7mm	Φ7.5mm
voltage	50 kV	-2~ -7 kV	0



PBGUNS simulation of extracted beam (50kV/75mA)

C-ADS proton source

Several issues to achieve:

1. Permanent magnets & solenoids for Magnetic field of source body
2. Plasma electrode aperture Φ=4.5mm, lowering down the initial beam emittance and improving the vacuum in the extraction area
3. Minimizing the stray magnetic field at large radius in the high voltage zone.
4. Coating the inner surface of ceramic high-votage insulation tube to avoid charge accumulation on it

•••••• to reduce high-voltage spark

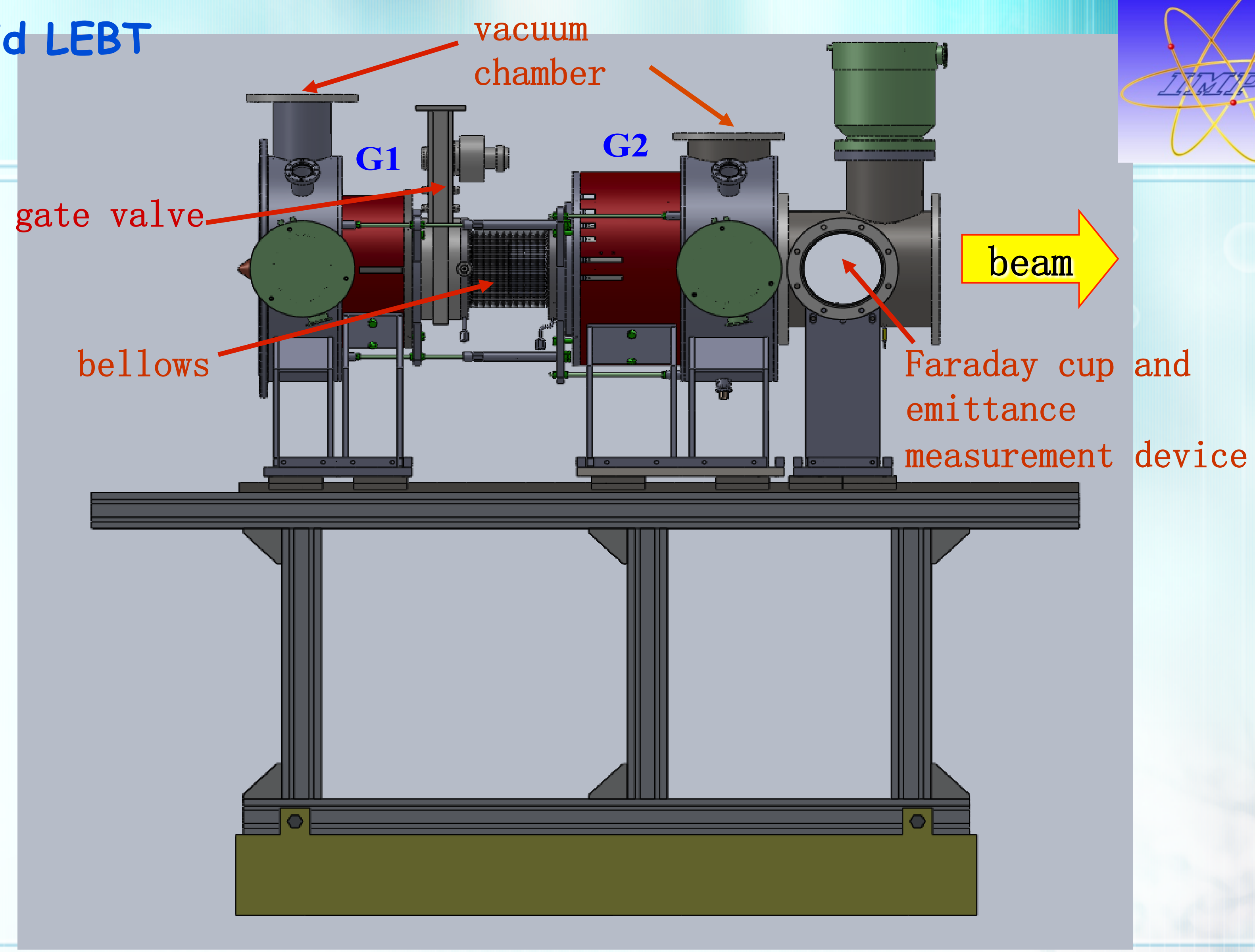
2-solenoid LEBT

The LEBT is to transport the beam from the ion source to the RFQ with minimizing the emittance growth.

Important issues:

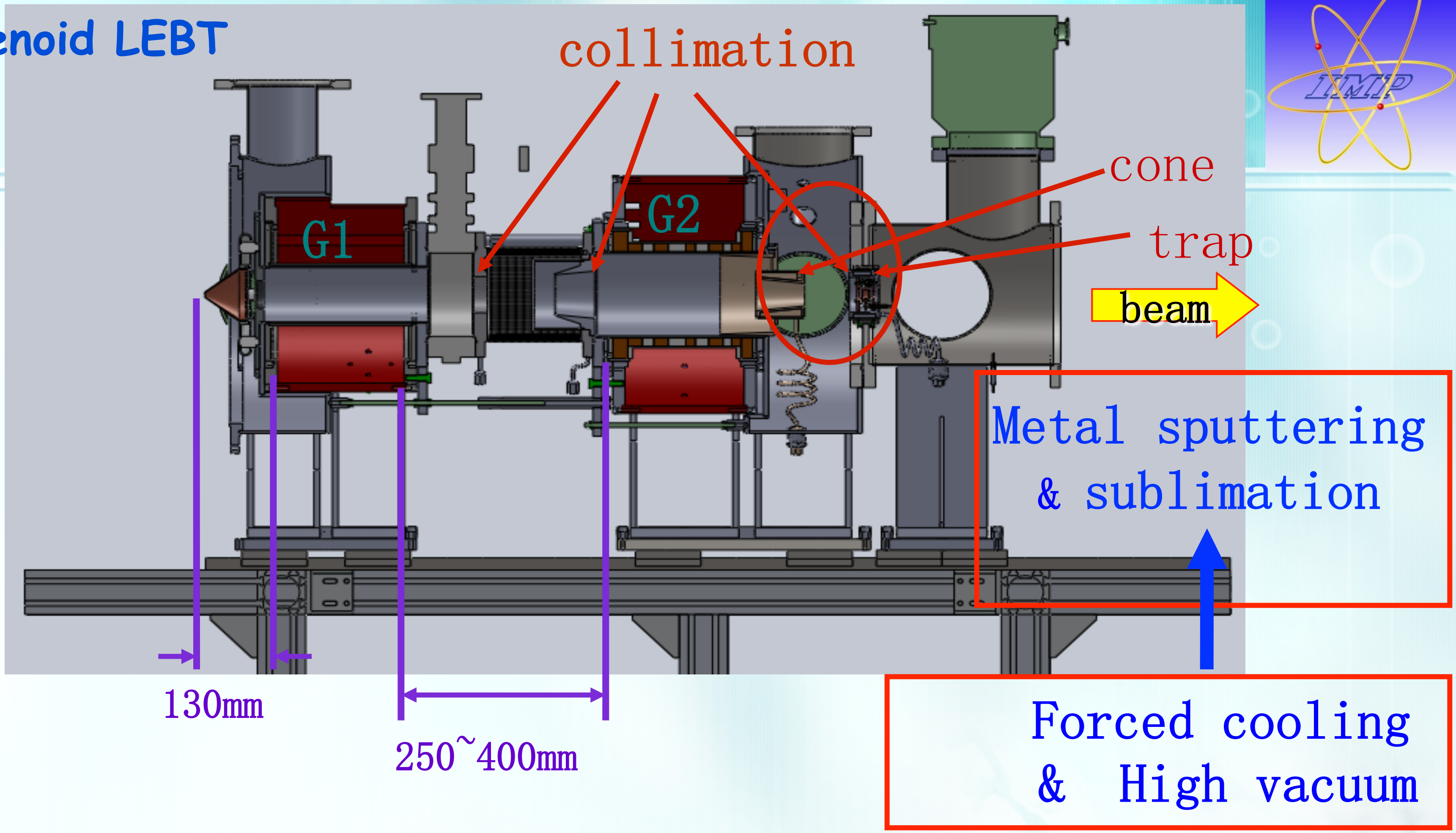
- Beam transmission efficiency
- Spherical aberration of solenoids
- Space charge compensation
- Match with the RFQ

2-solenoid LEBT



This device will be constructed for experiments. Final design will be based on the experimental results !

2-solenoid LEBT



- The length from the extraction electrode to the edge of G1 ~ 130mm
- The adjustable distance from G1 to G2 ~ 250mm to 400mm (bellows connected)
- Total length (extraction electrode to RFQ entrance) ~ 1091mm to 1241mm
- The pipe diameter ~ 98mm (front)/148mm (end)

challenges and solutions

- spherical aberration of solenoid
- space charge effects

1) Shortening the distance from ion source to LEBT

In the extraction area of the ion source, the particle beam has a small size, and space charge compensation by residual gas ionization is relatively low. The non-linear forces will lead to beam divergence and emittance growth quickly. Besids,too many electrons may cause electrode **spark**, so shortening the distance of the extraction area is a good solution.

2) Solenoid lens field optimizing by using permanent magnets

3) Shortening the total length of the LEBT

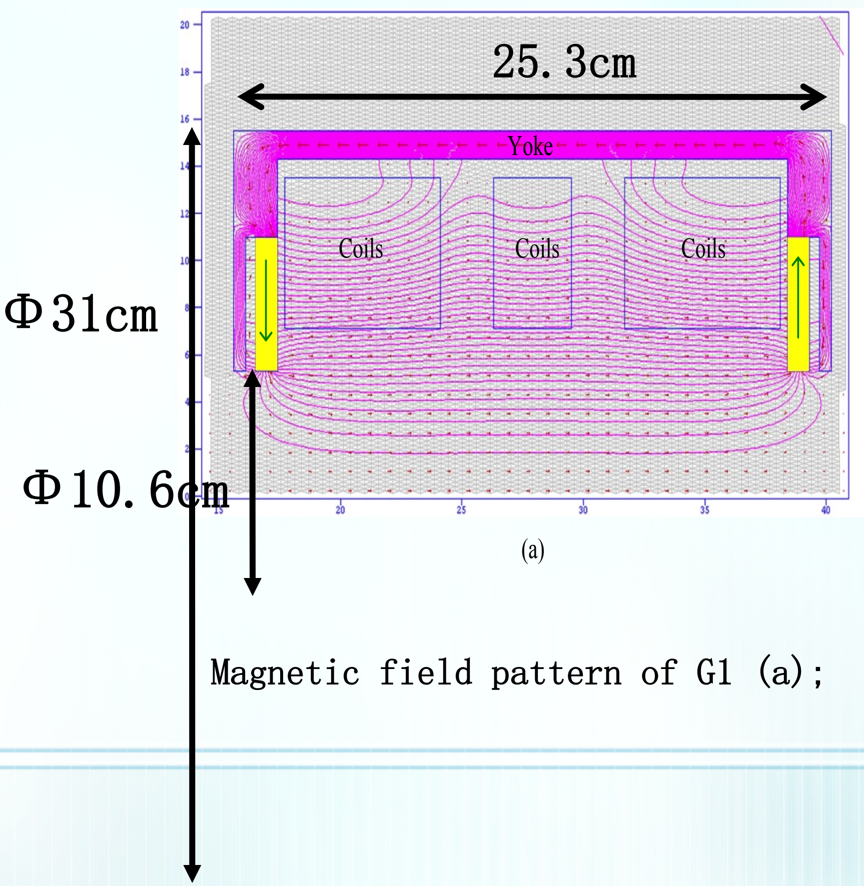
4) Shorter solenoids

5) **Methods research on effective space charge compensation**

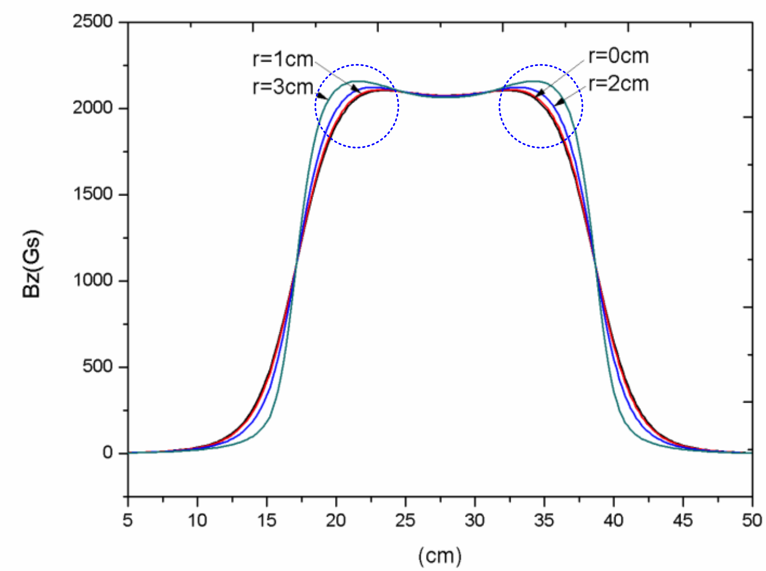
solenoid lens

weaker spherical aberration of the solenoid lens.

G1



(a)



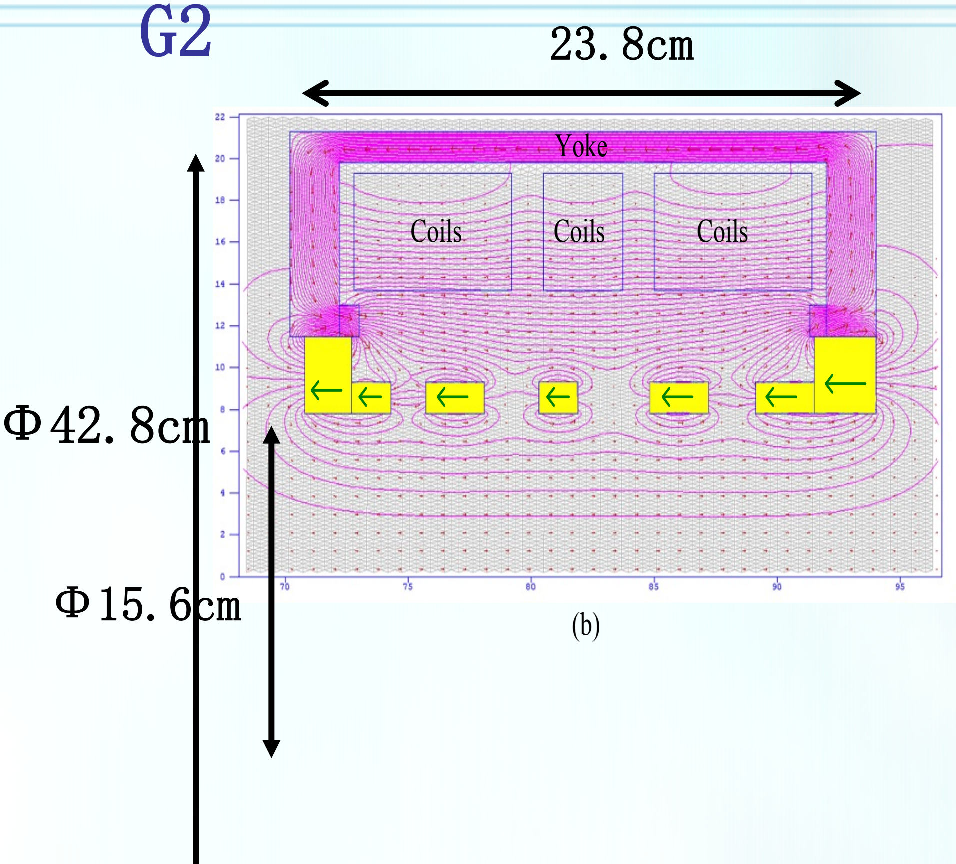
(c)

Magnetic field pattern of G1 (a);

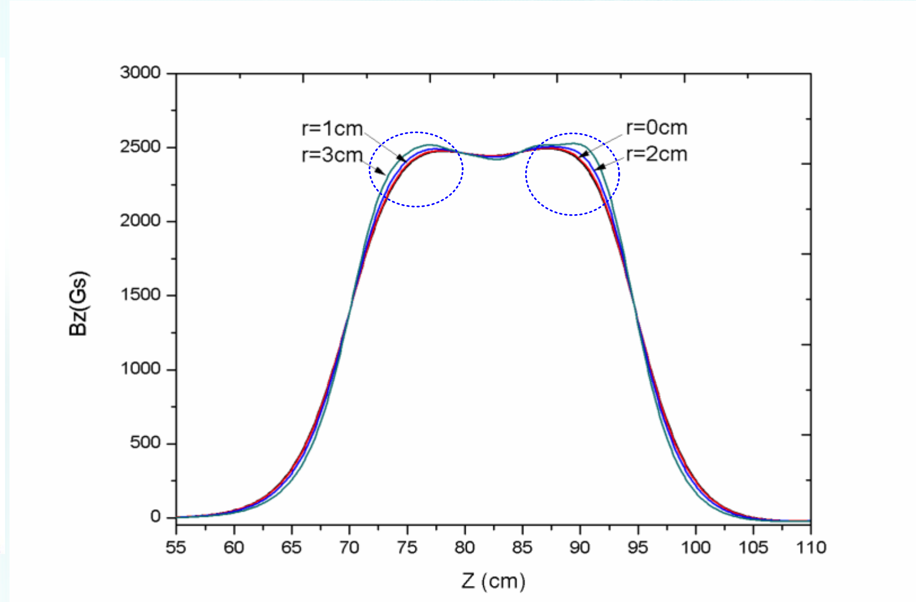
Map of longitudinal fields $Bz(z,r)$ at radius of 0-3cm of G1 (c).

solenoid lens

G2



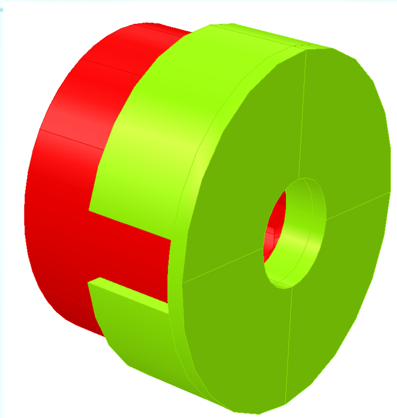
(b)

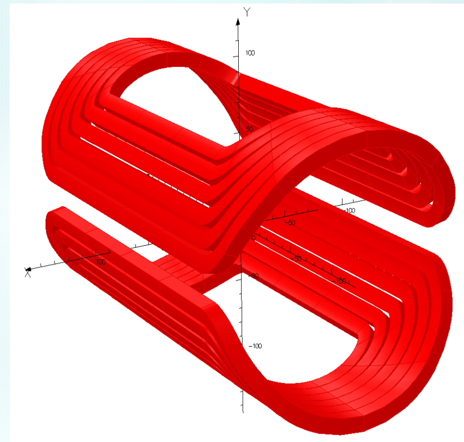


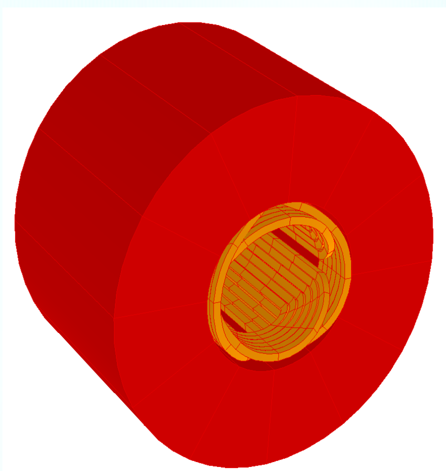
(d)

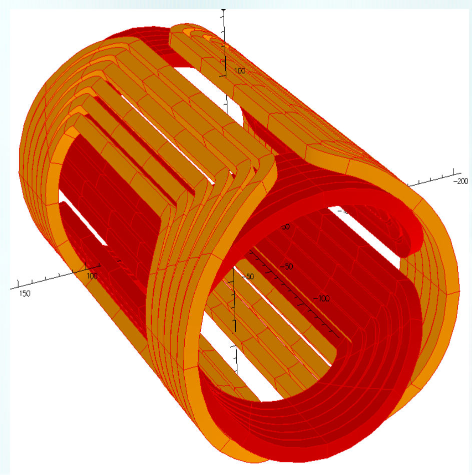
Magnetic field pattern of G2 (b)Map of longitudinal fields $Bz(z,r)$ at radius of 0-3cm of G2 (d).

- LEBT solenoids with steerers inside:









Space charge compensation design

- Space charge compensation in the extraction region
- Space charge compensation inside of the solenoid
- Space charge compensation in the region near the RFQ entrance

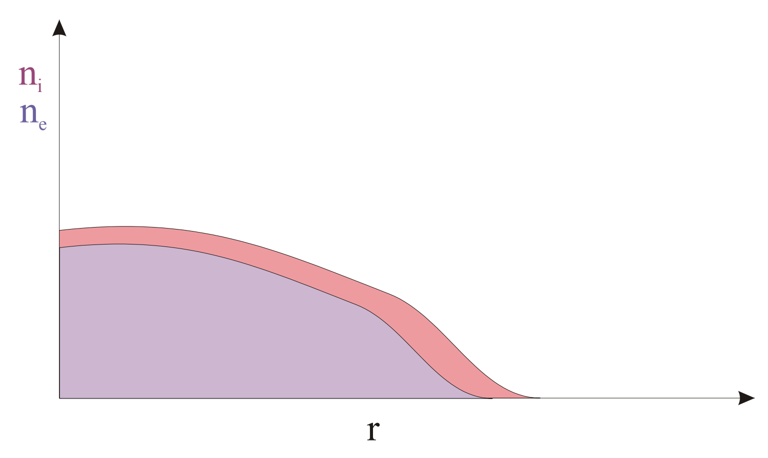
- Residual gas ionization

$$H^+ + H_2 \rightarrow H^+ + H_2^+ + e^-$$

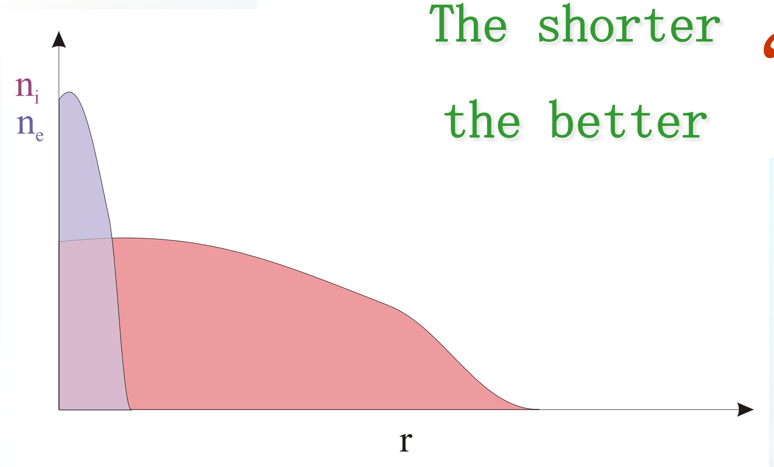
$$(H^+ + A_r \rightarrow H^+ + A_r^+ + e^-)$$

Generally, electrons are confined in the beam and secondary ions are repelled towards the walls.

- **Space charge compensation degree can reach close to 97% in drifts but in solenoid magnetic field, the compensation dramatically "changes".**



•particle density distribution outside of the solenoid



The shorter the better ?

•particle density distribution inside of the solenoid

Electrons injection

The experiments are under design!!!

ferroelectric cathode

- Low requirement of vacuum. (good capability against "poisoning")
- Strong emission of electrons.
- Simple and inexpensive.
- Low working function & low extration electric field.

Negtive charged gas (strong affinity with electrons)

SF_6 , CCl_4 , BF_3......

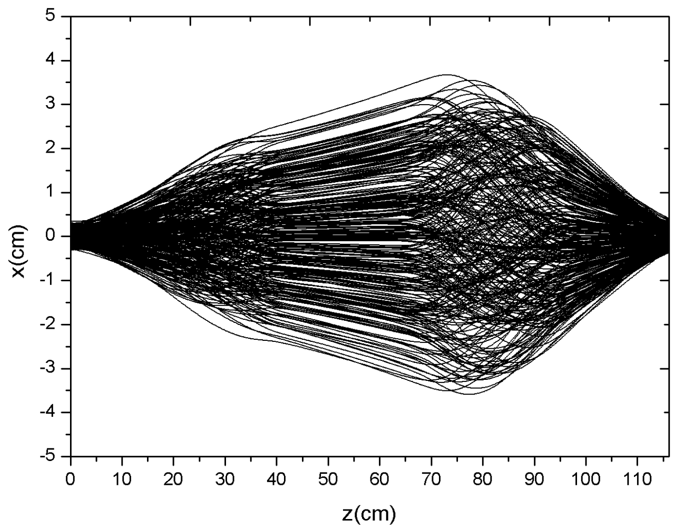
Negtive charged ions have:

- larger mass than electrons
- Smaller compond cross-section with low energy positive ions than electrons

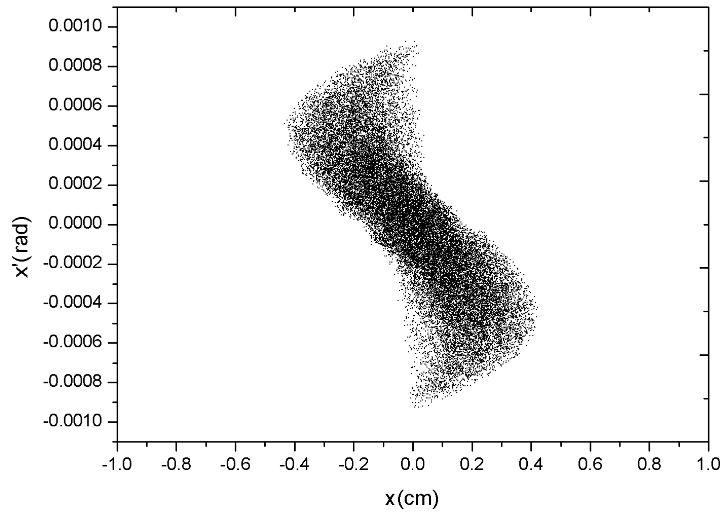
Beam simulation of the LEBT

@ 10mA

B1=2100Gs, B2=2490Gs



BEAMPATH code simulation of the x beam trajectory along the length of the LEBT



BEAMPATH simulation of phase space (x-x') distributions of the beam at the RFQ match point.

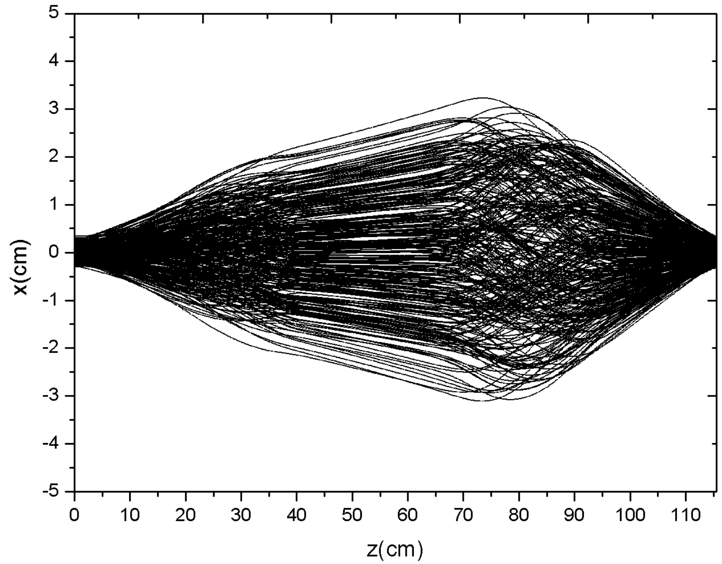
Twiss Parameters at RFQ match point

	α	β (cm/mrad)
x	1.36	6.81
y	1.33	6.66

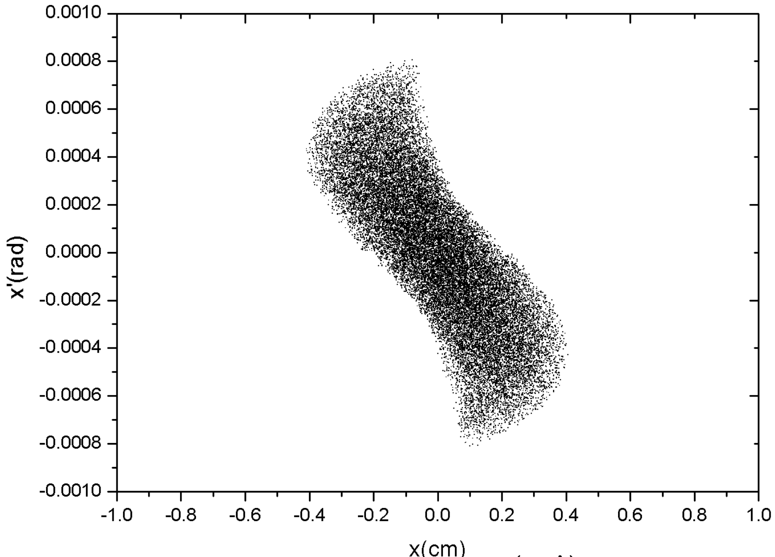
Effective emittance at this point increases by 33% higher than the initial point. Space charge effect is the biggest culprit.

@ 5mA

B1=1950Gs, B2=2450Gs



BEAMPATH code simulation of the x beam trajectory along the length of the LEBT



BEAMPATH simulation of phase space (x-x') distributions of the beam at the RFQ match point.

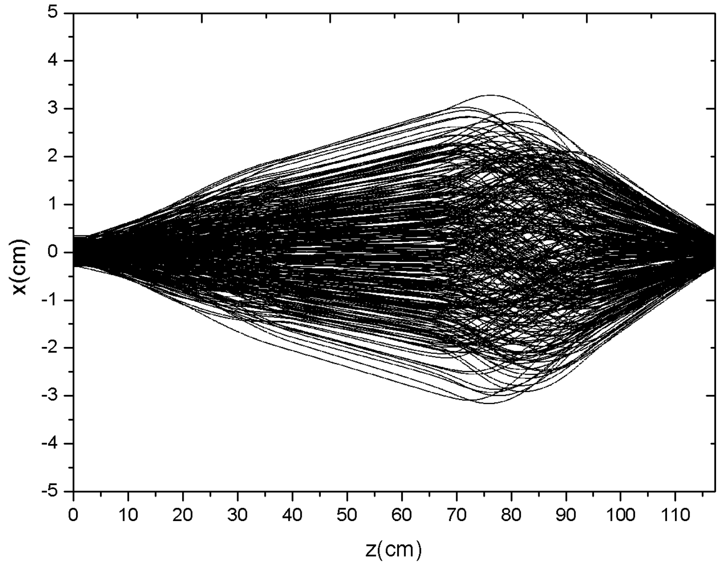
Twiss Parameters at RFQ match point

	α	β (cm/mrad)
x	1.35	6.86
y	1.34	6.78

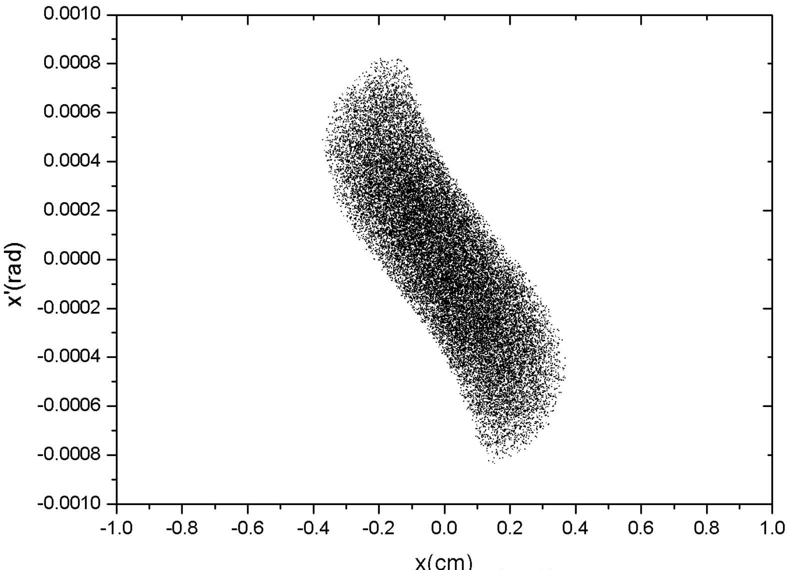
Effective emittance increases by 11.9% higher than the initial point

@ 1mA

B1=1490Gs, B2=2330Gs



BEAMPATH code simulation of the x beam trajectory along the length of the LEBT



BEAMPATH simulation of phase space (x-x') distributions of the beam at the RFQ match point.

Twiss Parameters at RFQ match point

	α	β (cm/mrad)
x	1.35	6.72
y	1.35	6.68

Effective emittance increases by 4.0% higher than the initial point

Thank you for your attention ！

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