Measurements and Simulations of the Beam Extraction from the ESS Proton Source

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17th International Conference on Ion Sources, October 15-20 2017

Abstract

A proton source with a Low Energy Beam Transport (LEBT) will be delivered to ESS in January 2018 by INFN-LNS. In order to prepare for the commissioning of this system at ESS, understanding the beam dynamics of the beam extraction and transport at low energy is important. The ion source and LEBT were commissioned at INFN-LNS in 2016-17 with measurements of the beam current, fractions of different ion species (H^+, H_2^+, and H_3^+), and emittance. In this paper we compare IBSimu simulations with these measured data. The goal is to reproduce different beam distributions at the exit of the ion source, which will help to optimize the beam optics and transmission to match the RFQ acceptance.

LEBT beam measurement

- Extracted beam current: 100 mA.
- Ion species: 80 % protons, 15 % H_2^+, 5 % H_3^+.
- Faraday cup current: 72 mA.
- Emittance in commissioning tank:
  $\varepsilon_{\text{norm.rms}} = 0.24$ mm mrad
  $\alpha = -3.5$
  $\beta = 0.78$ m
- Solenoid settings:
  Solenoid 1: 300 A, 0.25 T
  Solenoid 2: 200 A, 0.17 T
- Gas pressure:
  Pumping box 3.6×10^{-5} mbar
  Permanent tank 1.6×10^{-5} mbar
  Commissioning tank 0.55×10^{-5} mbar

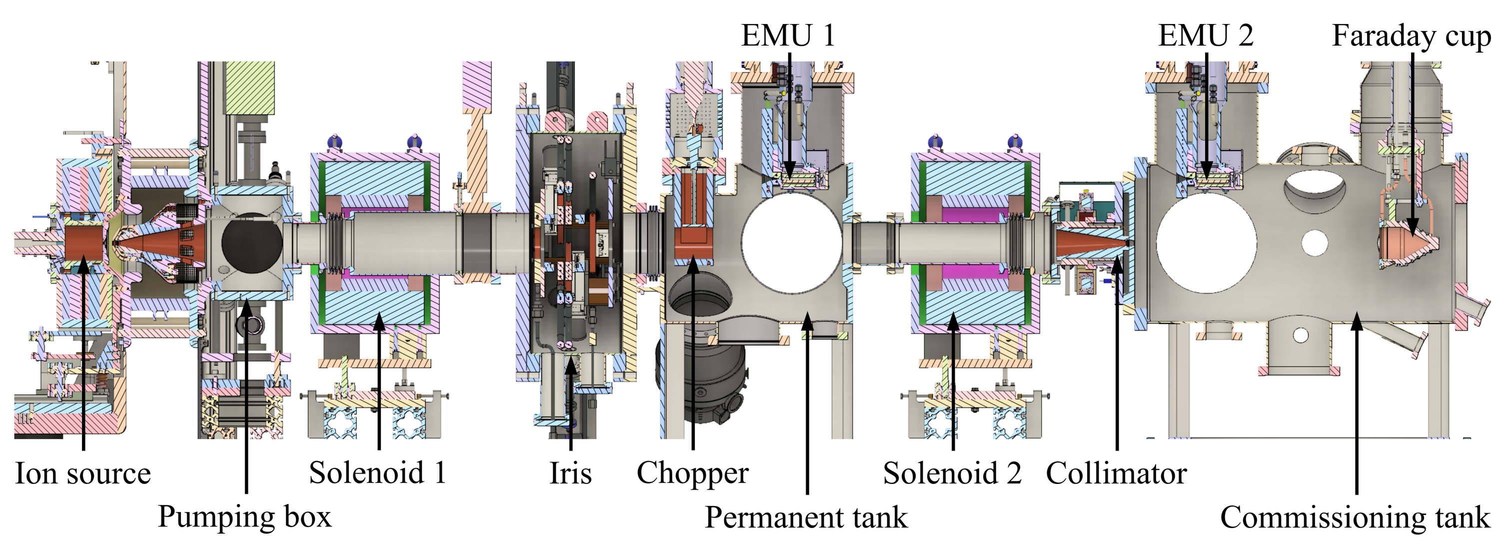

Figure 1: Layout of the ion source and LEBT.

Simulation of beam extraction and transport with IBSimu

- Two-stage simulation of beam extraction from microwave discharge ion source with a cylindrical symmetry, and beam transport through the LEBT:
  1: Beam extraction from a plasma with 0.4 mm mesh size
  2: Beam transport with 2 mm mesh size
- Input plasma parameters:
  Plasma potential: 20 V
  Transverse ion temperature: 1 eV
  Electron temperature: 10 eV
  Initial ion energy: 10 eV
- Ion species: 80 % protons, 15 % H_2^+, 5 % H_3^+
- 80,000 trajectories

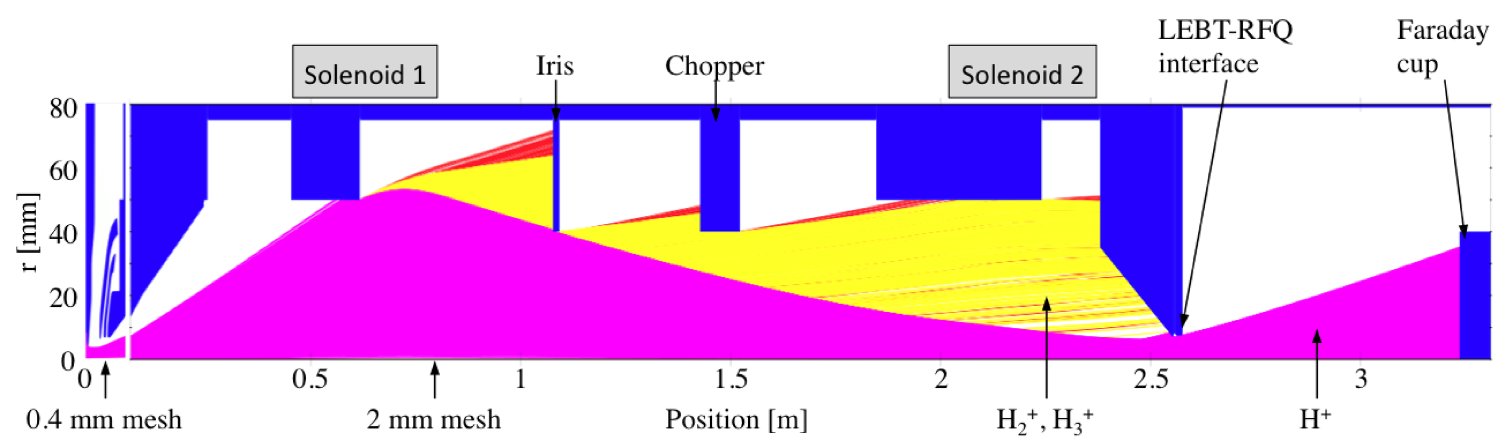

Figure 2: IBSimu simulation of beam extraction from a plasma, and beam transport through the LEBT.

Qualitative comparison of measurements and simulations

- Measured and simulated values of Faraday cup current [mA], normalized rms emittance (ε) [mm mrad], and Twiss α [-] and β [m] as a function of solenoid 2 current [A].

Solenoid 2 current	0	100	150	200				200	200	200
					Permanent tank			Commissioning tank		
	Faraday cup current				ε	α	β	ε	α	β
Measurement	55	65	72	72	0.22	9.6	9.2	0.24	-3.5	0.78
Simulation	58	72	77	77	0.38	5.9	4.9	0.31	-0.48	0.32

Simulation of transmitted current through the LEBT as a function of the current on solenoid 1 and 2

- Simulations with three different levels of space charge compensation: 87 %, 90 %, and 94 %.
- The black circles indicate the settings of the measurements.
  The result for 87% SCC shows signatures of the sensitivity against the solenoid 1 setting as well as a moderate current reduction along with the solenoid 2 reduction
  The results for the 90% and 94% SCC are consistent with our observation of reduced current for N_2 injection with no solenoids adjustment
- The contours in the figures indicate the regions where the beam is matched to the RFQ acceptance.
- M is the mismatch parameter, which takes into account both Twiss parameters α and β.

$$M = \left\{1 + \frac{\Delta_M + [\Delta_M(\Delta_M+4)]^{1/2}}{2}\right\}^{1/2} - 1,$$

where $\Delta_M = (\Delta\alpha)^2 - \Delta\gamma\Delta\beta$.

- For the calculation of M, we used the anticipated values of α: 1.02 , and β: 0.11 m, at the RFQ entrance.

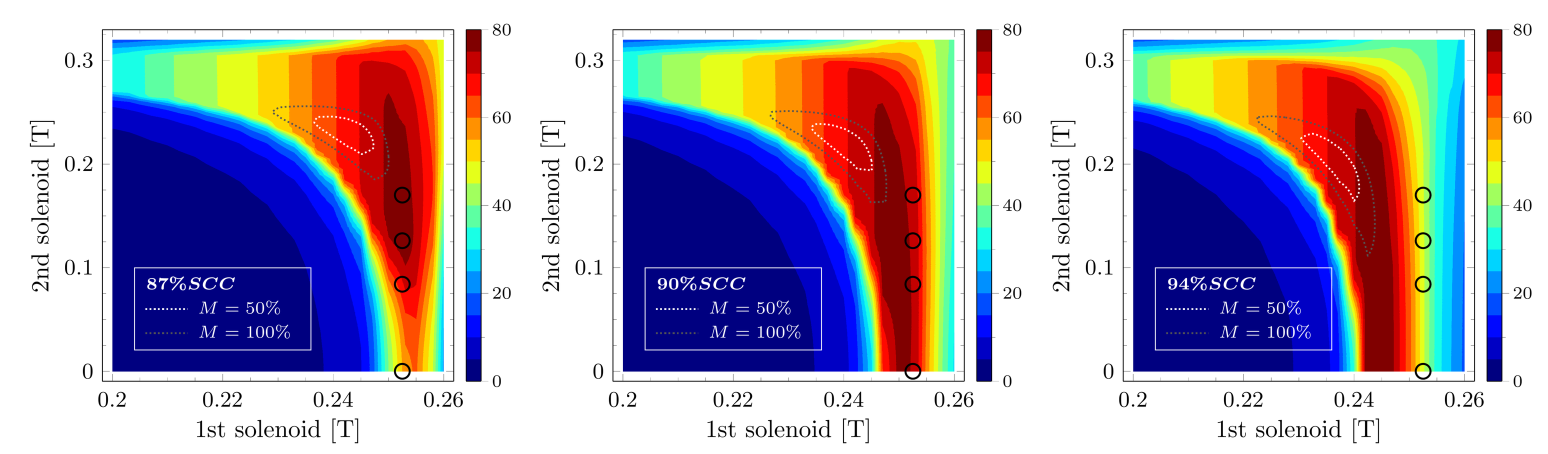

Figure 3: Simulations of transmitted current as a function of the B-field on solenoid 1 and solenoid 2.

Comparison of phase space plots

- Solenoid 1: 300 A, solenoid 2: 200 A.

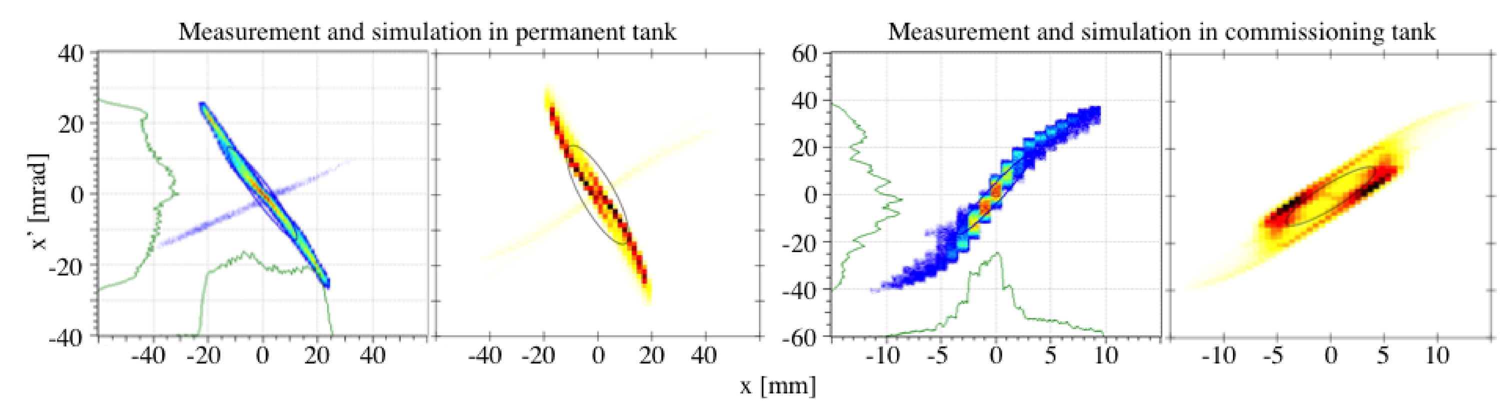

Figure 4: Phase space plots from emittance measurements in the permanent tank and commissioning tank.

CONCLUSION

- The simulations of the ion source and LEBT show that the beam transport and quality is sensitive to the level of space charge compensation.
- The beam is also sensitive to the settings of the solenoids, especially solenoid 1.
- Further beam studies will be done by scanning the full parameter space of solenoid current settings for different levels of injected N_2 gas for space charge compensation.
- Additional tests are being made at INFN-LNS with different extraction system electrode shapes to reduce the divergence of the extracted beam.