Extraction and low energy beam transport models used for the IFMIF/EVEDA RFQ commissioning

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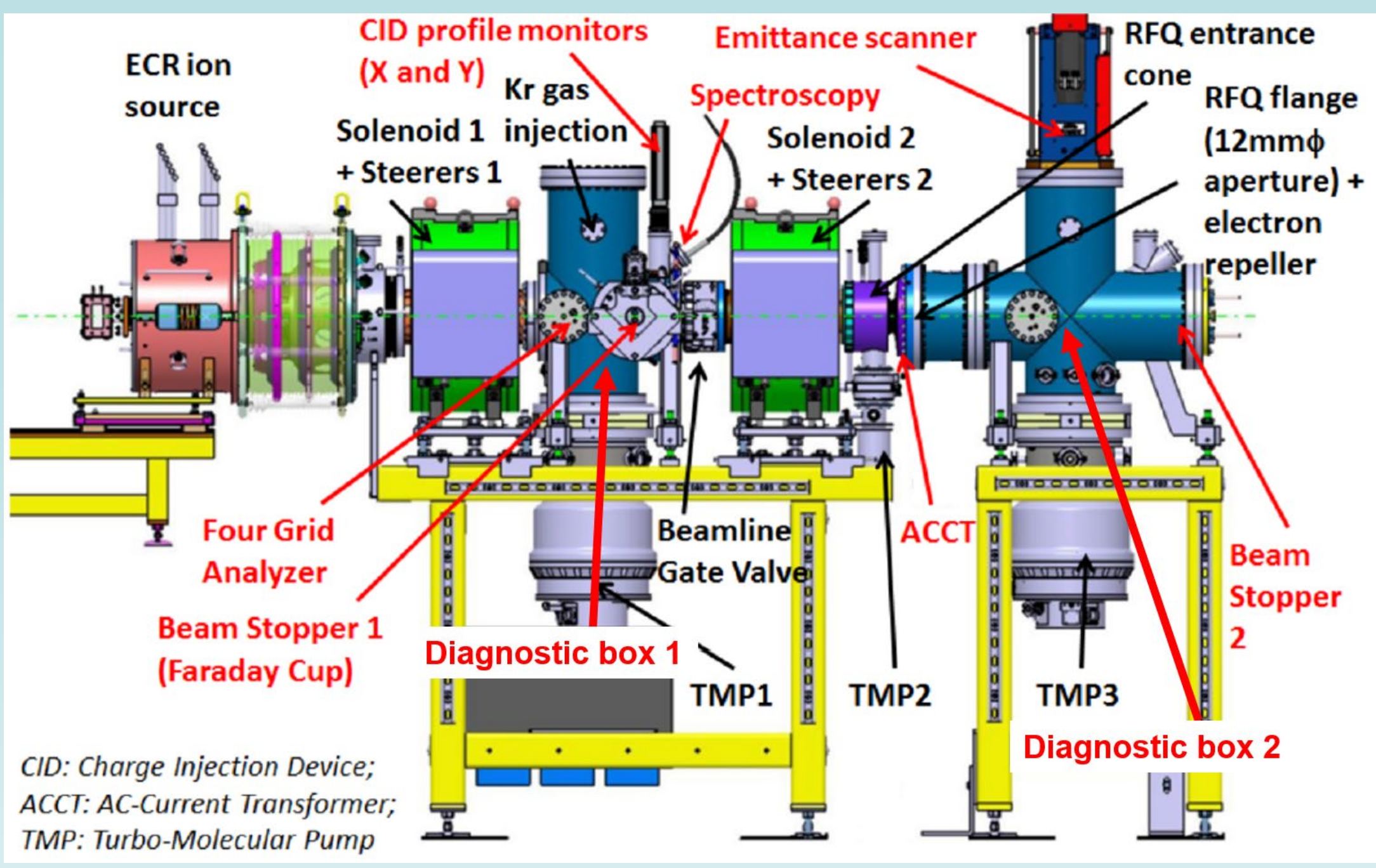
Introduction

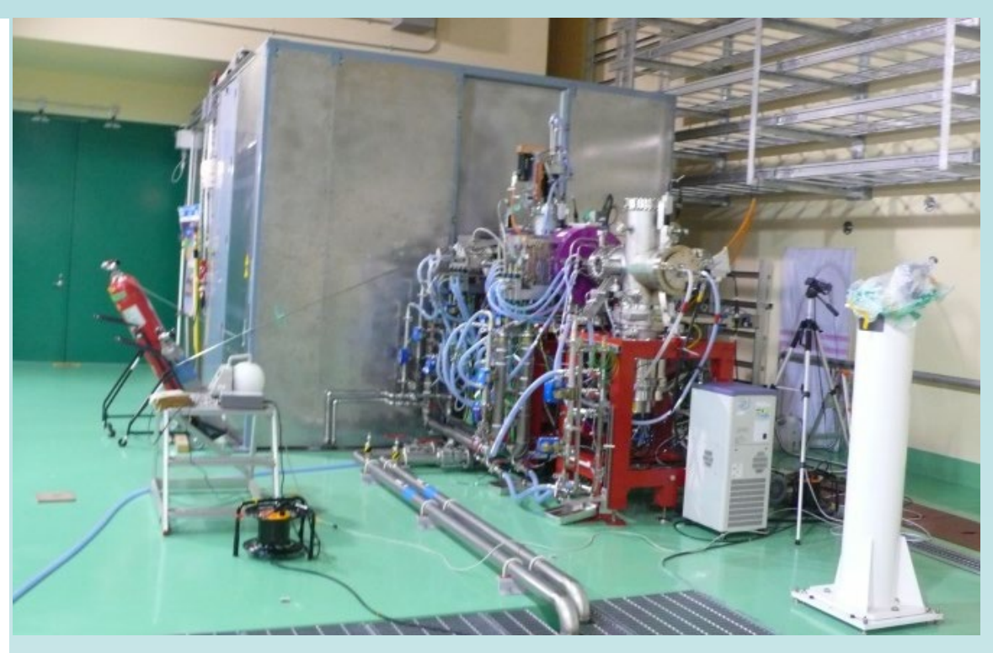
The Linear IFMIF Prototype Accelerator (LIPAc) is a high intensity D+ linear accelerator; demonstrator of the International Fusion Material Irradiation Facility (IFMIF). In summer 2019 the IFMIF/EVEDA Radio Frequency Quadrupole (RFQ) accelerated its nominal 125 mA deuteron (D+) beam current up to 5 MeV, with 90% transmission for pulses of 1 ms at 1 Hz. This success was possible thanks to an intense previous campaign of modelization and measurements in order to characterize the RFQ input beam, which is affected by the ECR ion source extraction and the low energy beam transport. The simulation models used with the measurement benchmarks are here presented. The ECR (Electron Cyclotron Resonance) consists of a 2.45 GHz RF power source with two coils magnetic structure. The nominal CW beam extracted consists in 140 mA D+ at 100 kV. For commissioning purposes, the source can extract also tens of mA of H+ at 50 kV and can work in pulse mode. From the beam dynamics point of view, these beams are characterized by a high perveance beam transport: the general perveance (un-compensated) ranges from 5×10^{-4} for the probe up to 5×10^{-3} nominal beam. In order to preserve the beam quality from the ion source up to the RFQ injection point (the LEBT), two magnetic solenoids and two repellers, one in the extraction and one at the RFQ entrance, are used in order to allow the space-charge compensation to take place.

General layout of the LEBT during its commissioning



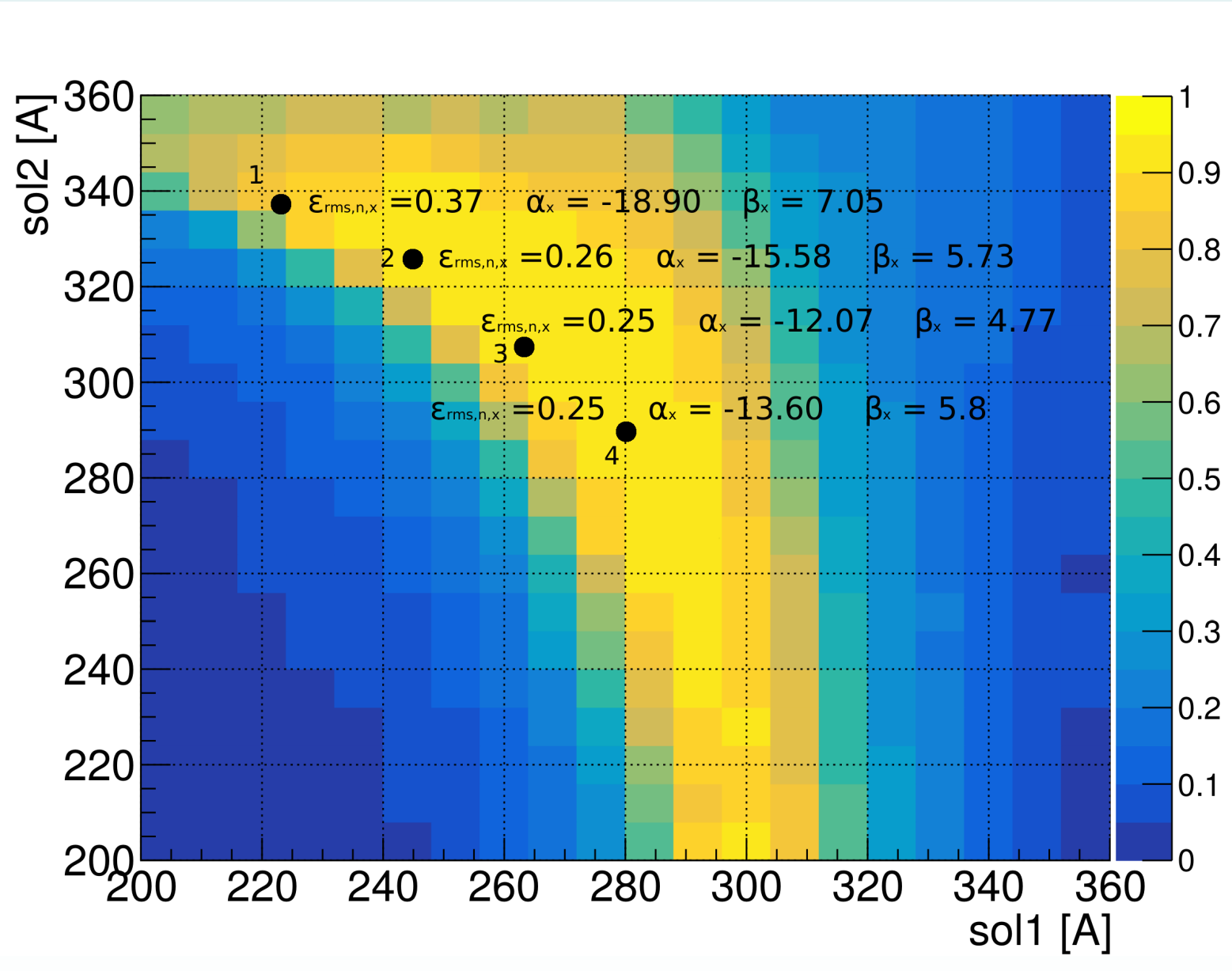
CID: Charge Injection Device;
ACCT: AC-Current Transformer;
TMP: Turbo-Molecular Pump

Sketch of the injector equipment

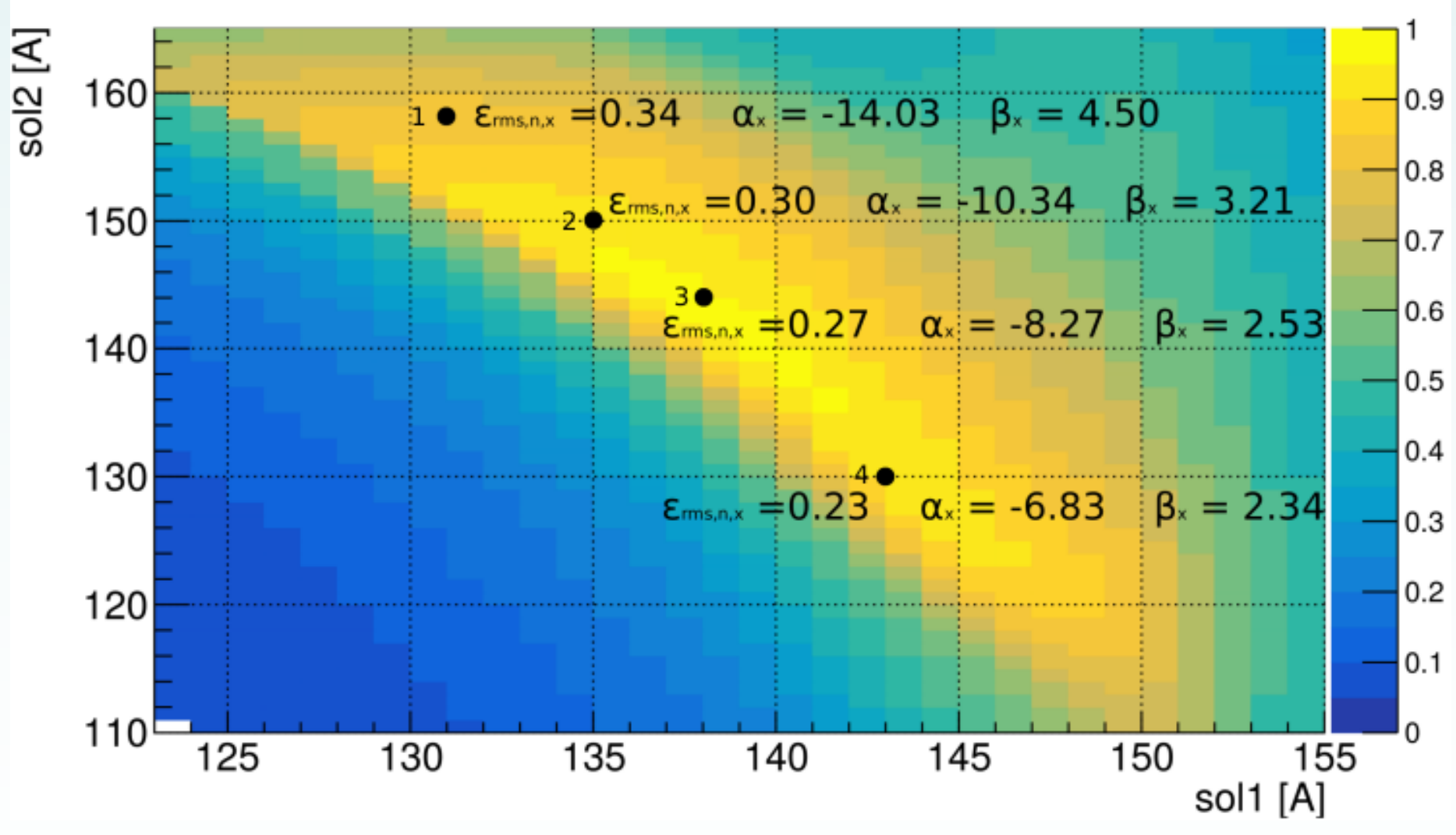


LIPAc Injector at the Rokkasho site

Examples of solenoid scan for proton and deuteron beam. The z direction shows the transmission from the extraction up to the second diagnostic box, after the RFQ cone.



155 mA deuteron 100 keV solenoid scan



85 mA proton beam 50 keV solenoid scan

Models

RMS Trace-Forward method:

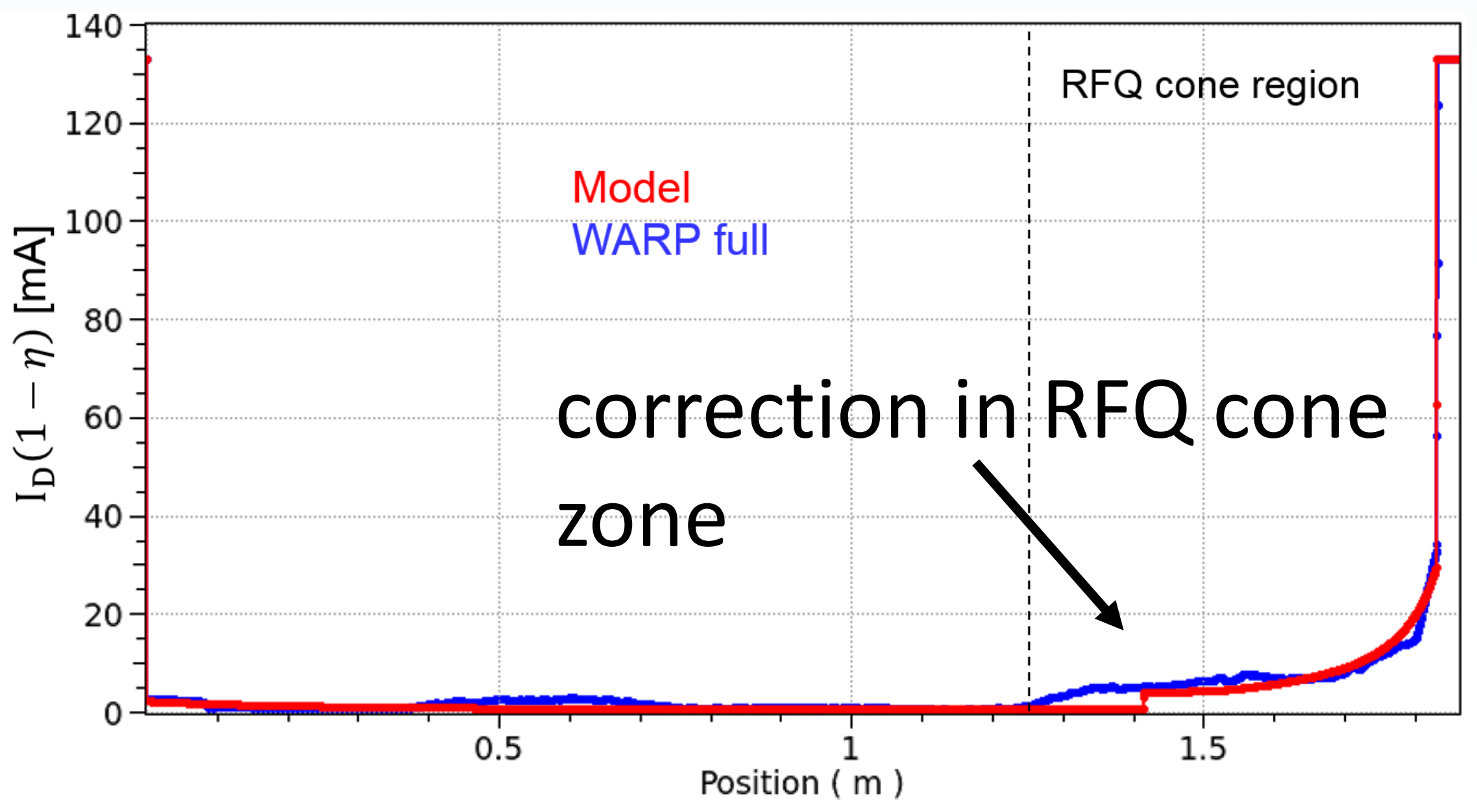
- Emittance evolution depends on the solenoid values
- This is due to both the combined effect of the solenoid aberrations and, in first approximation, the dependence of the space-charge compensation with respect beam radius
- Space charge compensation factor, η, increases the difficulty of the convergence.
- Validity of a certain value of η, found in the loop, limited within 15% of fixed solenoid values.

RMS Trace-Forward method, self consistent evolution of secondary plasma:

- Model with secondary electrons and ions from residual gas and collisions
- The collisions of the main beam and contaminants with the LEBT metallic wall modify the space charge compensation due to the secondary electron emission.

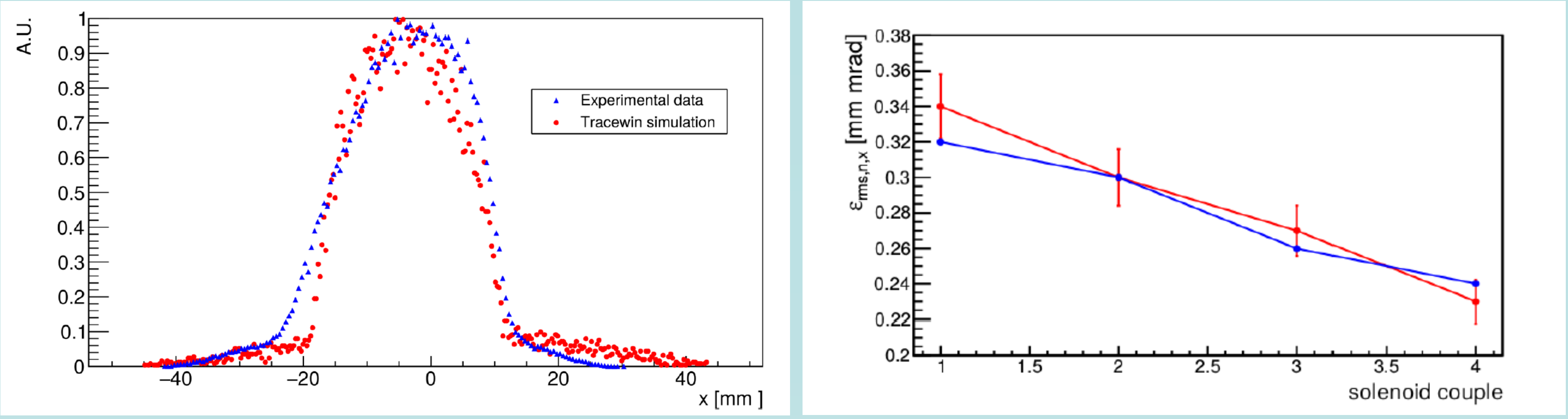
Semi-empirical method (extraction included):

- Calculates η based on beam radius, current, vacuum level, residual gas composition and other factor, using the model explained in [1].
- Two main corrections on the s.c.c. trend need to be implemented close to the source and RFQ repellers (external electric fields) and in the RFQ cone area (secondary electron emission from the beam with the cone).



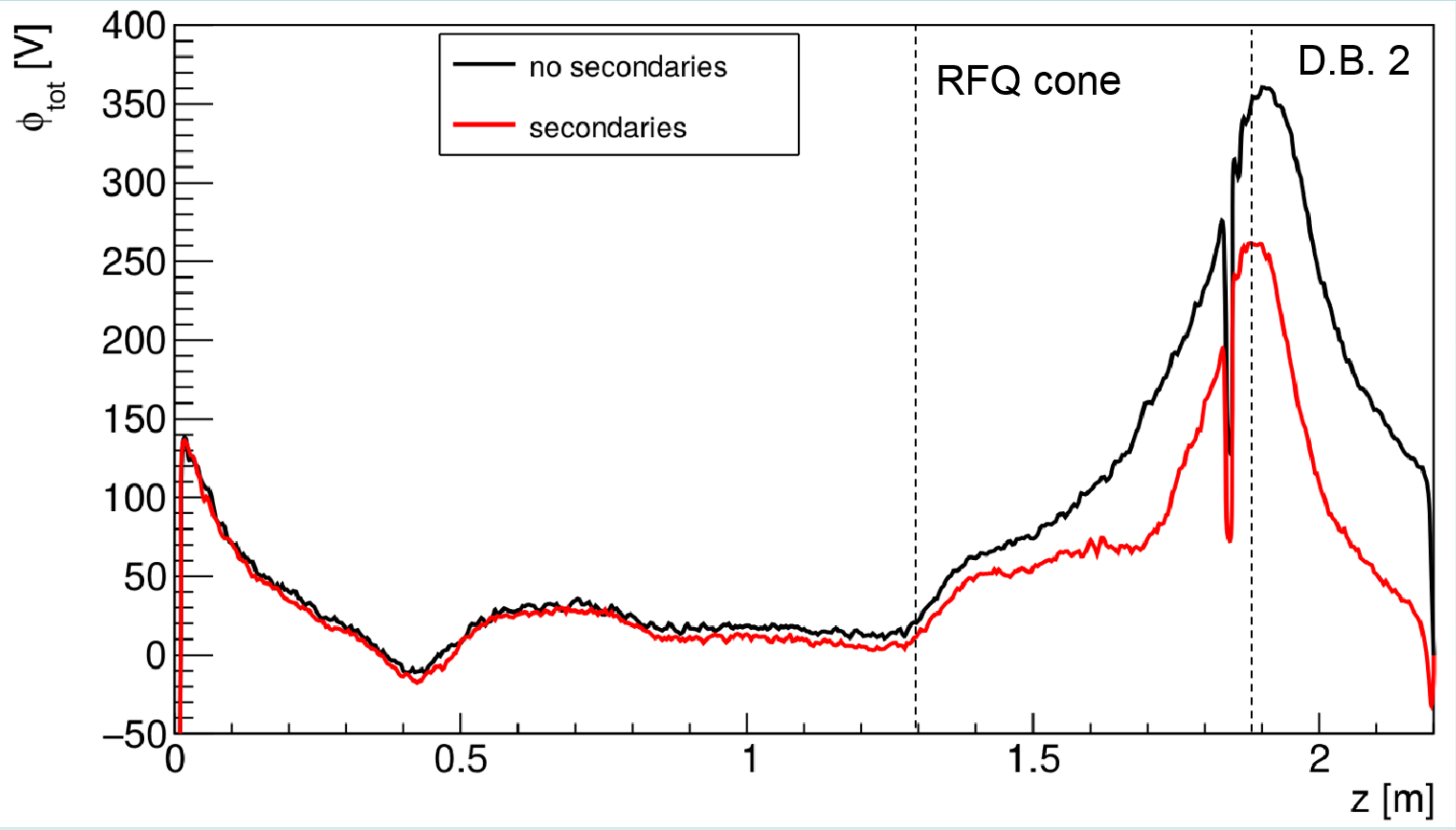
[1] Winklehner D and Leitner D 2015 JINST 10 T10006

Main results



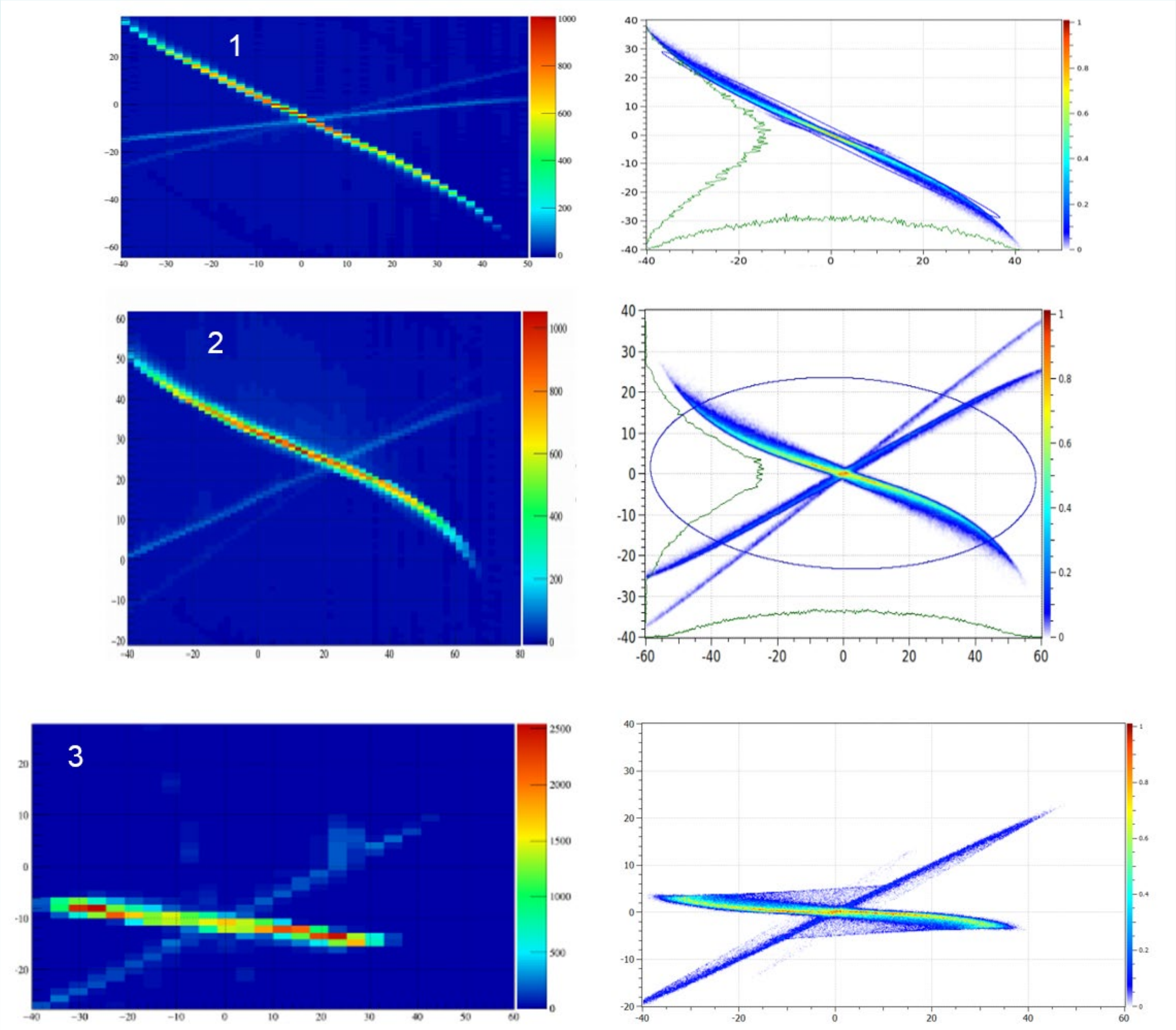
Results of RMS Trace Forward method benchmark

The beam considered is **85 mA** total **proton** beam at **50 keV**



Result of simulated total potential along axis

The beam considered is **155 mA** total **deuteron** beam at **100 keV**



Results of semi-empirical method

N	Sp.	Energy [keV]	I_{ext} [mA]	$\epsilon_{exp}/\epsilon_{sim}$	$\alpha_{exp}/\alpha_{sim}$	β_{exp}/β_{sim}
1	H^+	50	70	0.25/0.25	14.8/10.7	14.7/13.6
2	H^+	50	87	0.38/0.34	7.3/5.8	18.3/17.4
3	D^+	100	163	0.19/0.19	2.2/1.4	20.7/18.0

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