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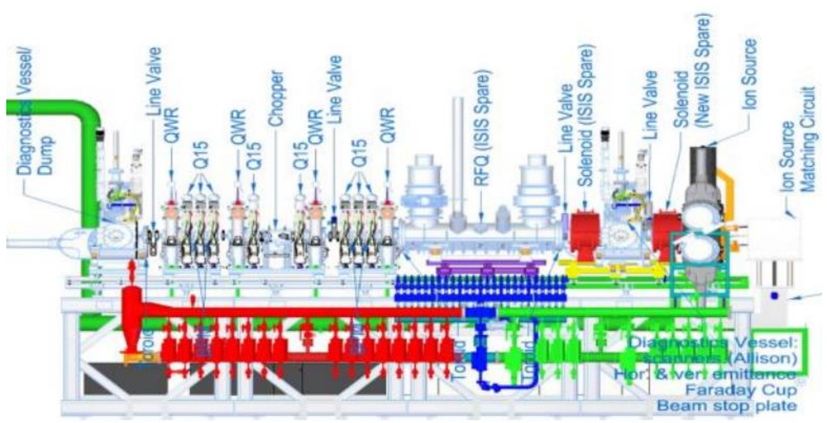
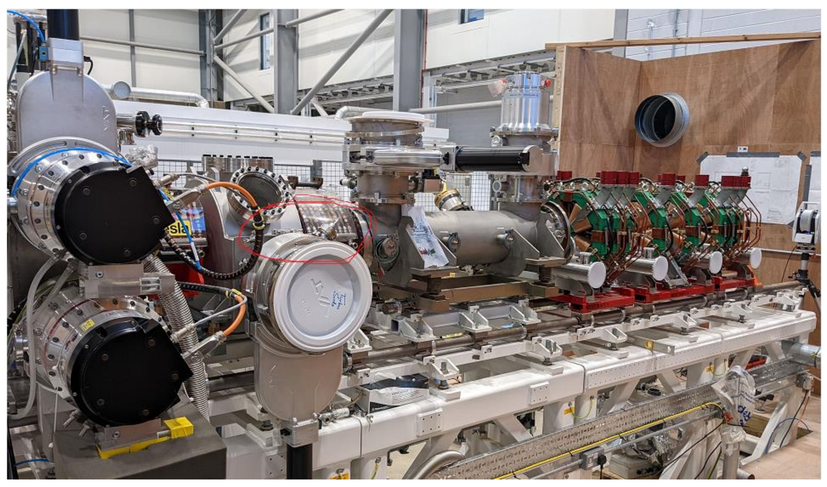
Simulation Studies on the Low Energy Beam Transfer (LEBT) System of the ISIS Neutron Spallation Source

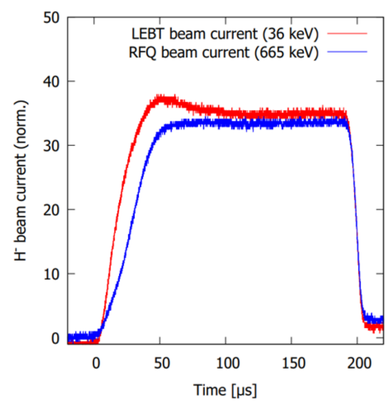
Abstract

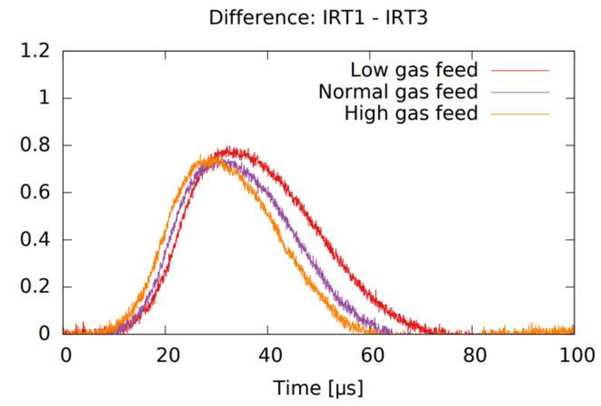
The transmission efficiency and beam dynamic parameters of the low-energy beam transfer (LEBT) section of proton accelerators, serving as a neutron spallation source, have a critical impact on beam loss in subsequent sections of the linear accelerator. Due to variations and mismatches, the beam parameters at the entrance of the radio-frequency quadrupole (RFQ) change, significantly affecting the transmission efficiency of the RFQ and the matching between RFQ and drift tube linac (DTL) structures. Recognizing the importance of this concept, particle-in-cell studies were conducted to optimize the LEBT section of the ISIS accelerator. This study presents the results of simulations





Drawing and picture of ISIS low energy section including ion Source, LEBT, RFQ and MEBT

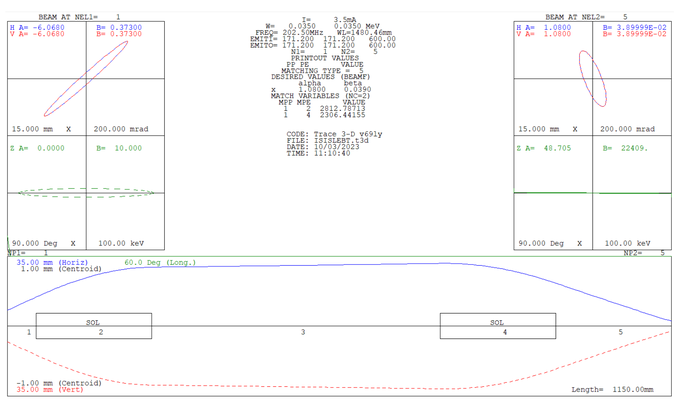


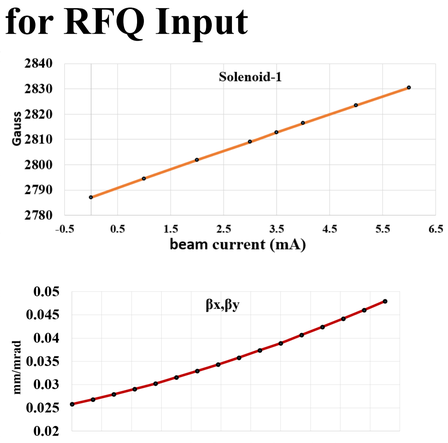


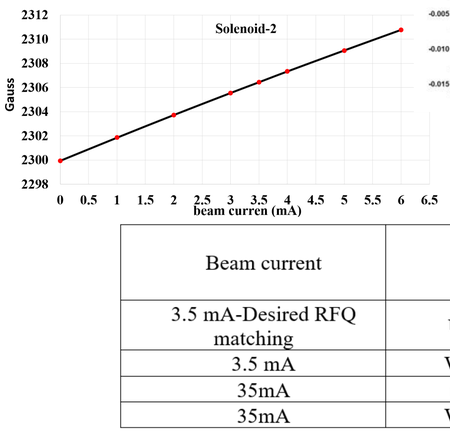
Space-charge compensation time (Left) experimental measurement (Right) Test in different vacuum pressures.

Parameters	αx	βx (mm/mrad)	αy	βy (mm/mrad)	αz	εx-unnorm (π·mm-mrad)	εy-unnorm (π·mm-mrad)
RF ion source	-6.068	0.373	-6.068	0.373	0.0	34.24	34.24
Penning ion source	-5.05	1.49	-2.62	1.07	0.0	46	46
Desired beam at RFQ entrance	1.08	0.039	1.08	0.039	-0.127		

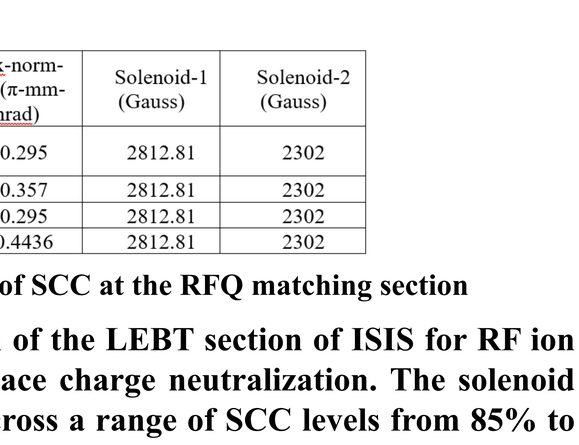
Beam Parameters at Output of RF and Penning Ion Sources and Desired Parameters for RFQ Input



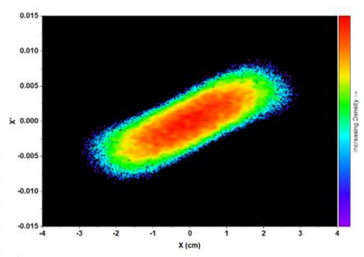


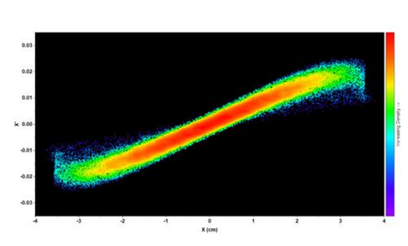


Beam transverse phase space distribution in X-X' at the (a) extraction point of ion source, (b) measurement location, (c) at the entrance to RFQ.



Beam parameters for three different initial beam distributions along the LEBT (a) rms beam size, (b) normalized emittance





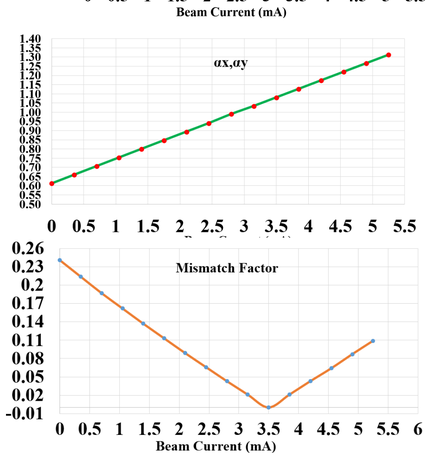
Beam phase space in diagnostic box for 3.5 mA (left) and 35 mA (right)

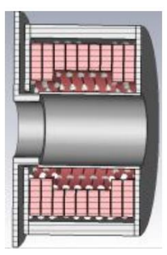
Beam current		αx	βx (mm/mrad)	εx-norm-rms (π-mm-mrad)	Solenoid-1 (Gauss)	Solenoid-2 (Gauss)
3.5 mA-Desired RFQ matching	Uniform	1.08	0.039	0.295	2812.81	2302
3.5 mA	Waterbag	1.0879	0.0474	0.357	2812.81	2302
35mA	uniform	5.208	0.347	0.295	2812.81	2302
35mA	Waterbag	3.69	0.406	0.4436	2812.81	2302

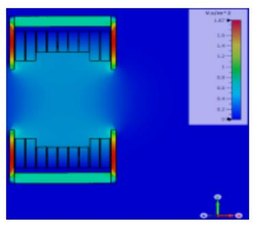
comparison of beam parameters before and after transient of SCC at the RFQ matching section

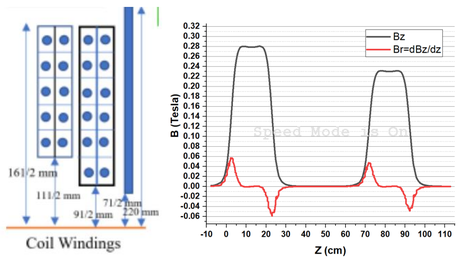
ISIS neutron spallation source LEBT section modelling in Trace beam envelope code.

The variation in Twiss parameters and mismatch factor in response to different levels of beam space-charge compensation (a) βx, βx, (b) αx, αx, (c) Mismatch factor.









Solenoid magnet design for ISIS LEBT section.

This study was done to estimate the design and optimization of the LEBT section of ISIS for RF ion source operation, specifically focusing on achieving 90% space charge neutralization. The solenoid values required for beam matching to RFQ were assessed across a range of SCC levels from 85% to 100%. The study also explored the variation in beam Twiss parameters for different SCC values with respect to 90% adjustments, revealing a linear variation in α and a nonlinear variation in β. Mismatch factors were evaluated for each scenario and change between 0.01 to 0.23.

Preliminary design and positioning estimates, including solenoidal field requirements, were carried out, leading to the design of solenoids using CST Studio Suite that is 2800 and 2300 Gauss for solenoids 1 and 2, respectively. Subsequently, comprehensive Particle-in-Cell (PIC) simulations of the LEBT section were conducted with Parmila for three distinct beam distributions: KV, waterbag, and gaussian. The study involved plotting beam emittance growth and beam size along the LEBT. A comparison was made between beam behaviour in transient and steady-state situations of space charge compensation.

Notably, the study revealed that the main loss and halo formation occurred due to the transient behaviour of the beam, particularly in the transient section of time characterized by completely mismatched Twiss parameters. These findings provide valuable insights into operation of the LEBT section to interpret the cause of losses during transient phases of operation of the machine and make some estimates for interpreting of experimental results.