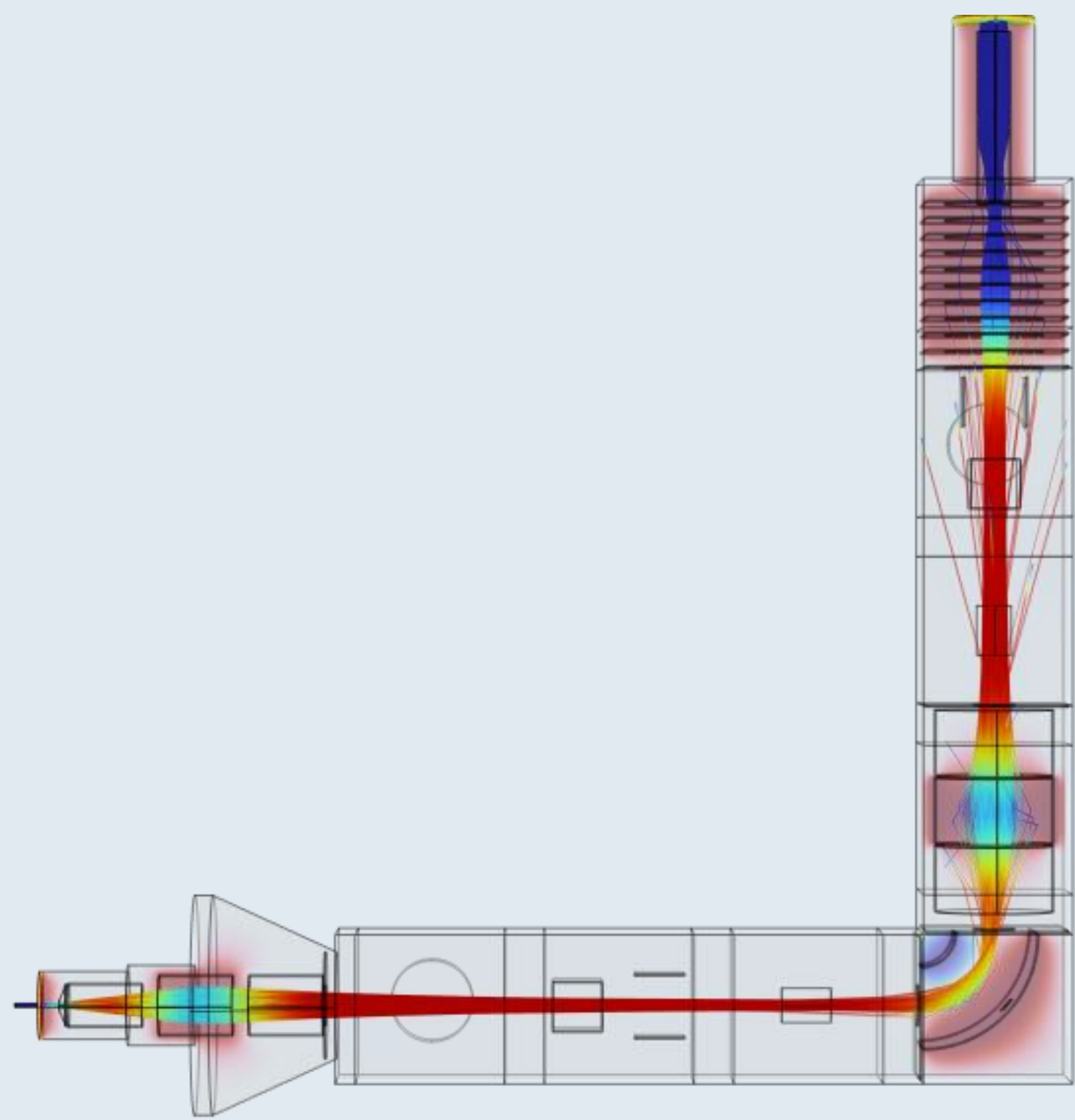




Design of the IOTA Ion Beam Transport System for Nuclear Physics and Medical Applications

Simulation-driven framework for efficient ion extraction and transport: charged particle motion in electrostatic fields with space charge effects, and gas pressure distributions are modelled to optimise beam transport before commissioning.

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Introduction & Goals

Large-scale accelerator facilities used for nuclear physics research and medical isotope production, such as TRIUMF-ARIEL (Canada) and CERN-ISOLDE (Switzerland), offer limited opportunities for dedicated ion source optimization studies due to their high demand and operational costs. In contrast, dedicated offline facilities such as the Ion source Optimisation and Testing Apparatus (IOTA), currently under development at the University of Manchester, provide a flexible environment for ion source development, testing, and beam transport studies.

Goals for **IOTA design**:

- Optimise extraction and transport efficiency
- Minimise energy spread
- Quantify the impact of space-charge effects on beam transport
- Evaluate vacuum performance for the proposed pumping configuration

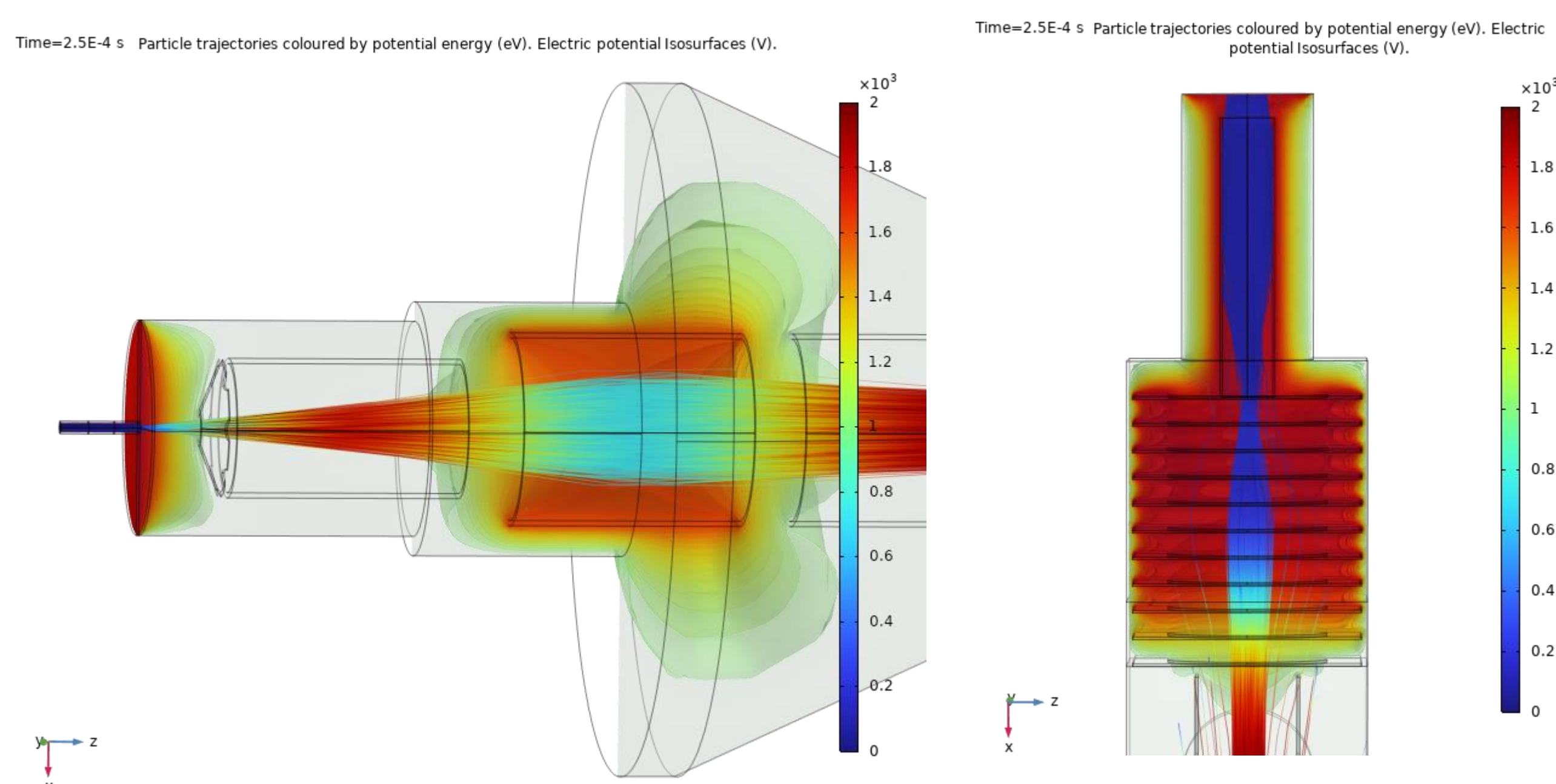


Figure 1. Simulated equipotential surfaces and Sm^+ ion trajectories (colored by potential energy, eV) for a 1 pA beam current. Left: ion extraction from a 2 kV ion source. Right: end of the beamline.

Methodology

A 3D COMSOL Multiphysics® model of the IOTA beamline was developed to optimize the extraction and transport of singly charged samarium ions. Electrostatic field calculations were coupled with Charged Particle Tracing, including space-charge effects through bidirectional coupling. Each simulation tracked 5,000 macroparticles, with the beam current represented through an appropriate charge multiplication factor. Convergence was achieved when the relative change of a global parameter between successive iterations fell below 1%. Vacuum performance was evaluated using the Free Molecular Flow interface. An extremely fine mesh was used throughout the model. Parametric studies of electrode geometries and operating voltages were performed to optimize transmission efficiency, energy spread, and time-of-flight characteristics, which were evaluated using Python-based post-processing.

Results

The results demonstrate the capability of the integrated model **to guide beamline optimization prior to manufacture and commissioning**, reducing the need for costly experimental iterations.

For a beam current of 1 pA, the model predicts **a transmission efficiency of 93%** with an **energy spread of approx. 16 eV** at an extraction voltage of 2 kV. At 1 μA , space-charge effects become more significant, reducing the transmission efficiency to 30% and increasing the energy spread to 22 eV. For the expected gas load, pressure levels as low as 4×10^{-5} mbar were predicted within the beamline.

Future work will focus on further refinement and validation of the COMSOL model, including investigations of higher extraction voltages (5 kV and 10 kV) to achieve the target energy spread of 10 eV. Experimental commissioning of the IOTA beamline is expected to begin towards the end of 2026, enabling direct comparison of simulation predictions with measured beam transport and vacuum performance.

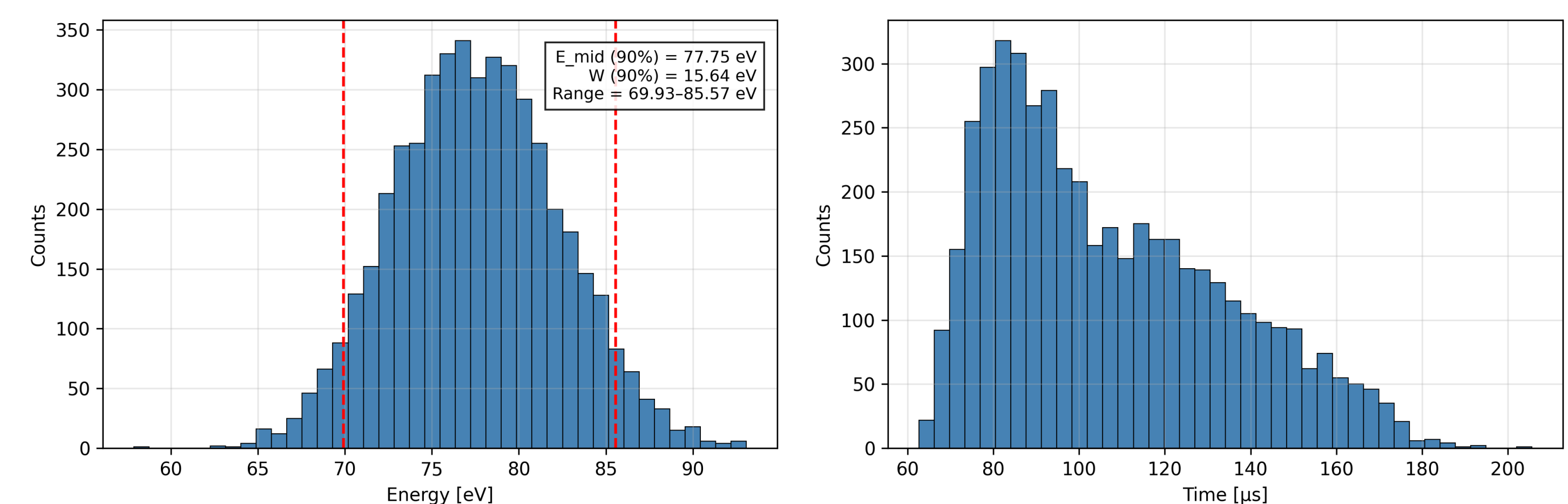


Figure 2. Ion beam at the end of the beamline for a 1 pA beam current with space-charge effects (5,000 macroparticles). Left: energy distribution with a 90% width of 16 eV centered at approx. 78 eV. Right: time-of-flight distribution of the transmitted ions.

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