

# RFQ beam dynamics design for the FAIR Proton Linac\*

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The FAIR (Facility for Antiproton and Ion Research) Proton-Linac (P-LINAC) will be started with a 325.224 MHz, 3 MeV Radio-Frequency Quadrupole (RFQ) accelerator. To ensure that a beam intensity of  $\geq 35$  mA can be injected into the downstream synchrotrons, the design beam intensity of this Proton-RFQ (P-RFQ) has been chosen as 70 mA. Based on the so-called NFSP (New Four-Section Procedure) method, two new beam dynamics designs with varying and constant transverse focusing strength, respectively, have been worked out to meet the latest design requirements using a compact structure.

## Background

The old reference design (D2009) realized by using the NFSP method [1] and published in 2009 [2] was optimized for 45 mA and can provide good beam performance e.g.  $\geq 95\%$  transmission efficiency for up to 100 mA input beams. This 3.2 m long RFQ is very compact at 95 keV such a relatively high input energy  $W_{in, RFQ}$  (when considering the  $W_{in, RFQ}$  values adopted by other comparable machines e.g. CERN LINAC4, J-PARC RFQ-III, and SNS), as the length of the adiabatic bunching section is proportional to  $\beta^3$  [3].

The recently updated design requirements for the P-RFQ have two main changes: 1) the design beam intensity  $I_{in}$  has been fixed as 70 mA for more safety; 2) the allowed maximum surface electric field  $E_{s, max}$  is lowered to 33 MV/m, corresponding to a Kilpatrick Factor ( $KF$ ) of 1.87 (formerly  $KF \leq 2.0$ ).

An important goal of the new design study is to minimize the output longitudinal emittance for making the matching to the downstream DTL easier and avoiding beam losses in the high-energy range.

## Design Method & Results

Due to the success with the old reference design, the NFSP method is still adopted for both new designs. Different than the traditional LANL method, this method is characterized by a soft and symmetric pre-bunching, a fast main bunching, and then a fine bunching with a mixture of bunching and acceleration in the longitudinal plane as well as a varying focusing strength in the transverse plane which is adapted to the changing space-charge situation along the bunching process.

Besides a new NFSP design (D2014a), to meet the possible demands for the 4-vane RFQ version, another new design (D2014b) with a constant mid-cell aperture  $r_0$  has been also developed using a so-called modified NFSP (mNFSP) method [4]: it has a NFSP-style longitudinal bunching but with a constant transverse focusing strength

throughout the main RFQ.

For both of the new designs [5], the RFQ structure is even 10 cm shorter than that designed in 2009. As a result of the lowered  $E_{s, max}$ , the beam transmission efficiencies  $T$  are now slightly lower, but still  $\geq 90\%$ . However, in both cases, the difference in  $T$  for transported and accelerated particles is only 0.1%, which means most particles are well bunched and accelerated (see Figure 1). Meanwhile, from D2009 to D2014b and D2014a, the longitudinal output emittance was significantly reduced by 86% (all particles) / 20% (accelerated particles) and 91% (all particles) / 18% (accelerated particles), respectively.

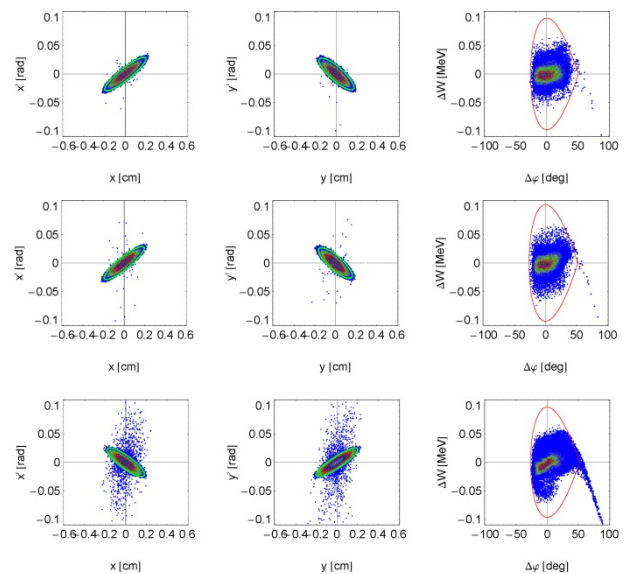


Figure 1: Output Phase Spaces (top: D2014a; middle: D2014b; bottom: D2009).

## References

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