Efficient Heavy Ion Acceleration with High Brilliance

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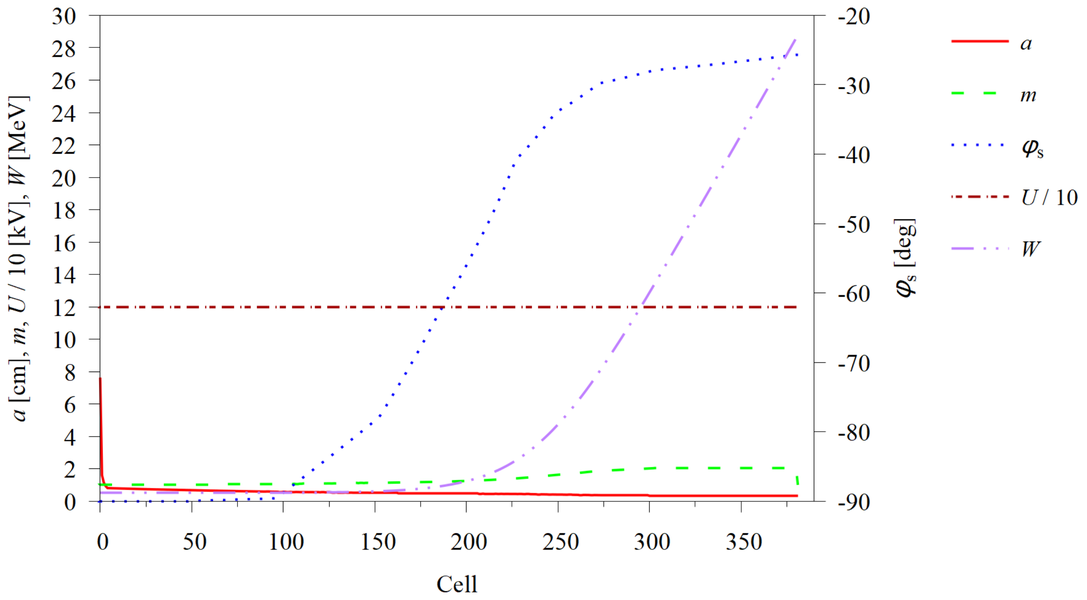
It is challenging to realize an efficient and brilliant RFQ for accelerating high current heavy ion beams, as space charge effects are most pronounced at the low energy end. Here "efficient" means an as short as possible accelerating structure with minimum RF power consumption, while "brilliant" means high beam transmission and low emittance growth. Using the > 9 m long HSI RFQ accelerator, one of the longest RFQs in the world, as an example, a promising solution has been presented.



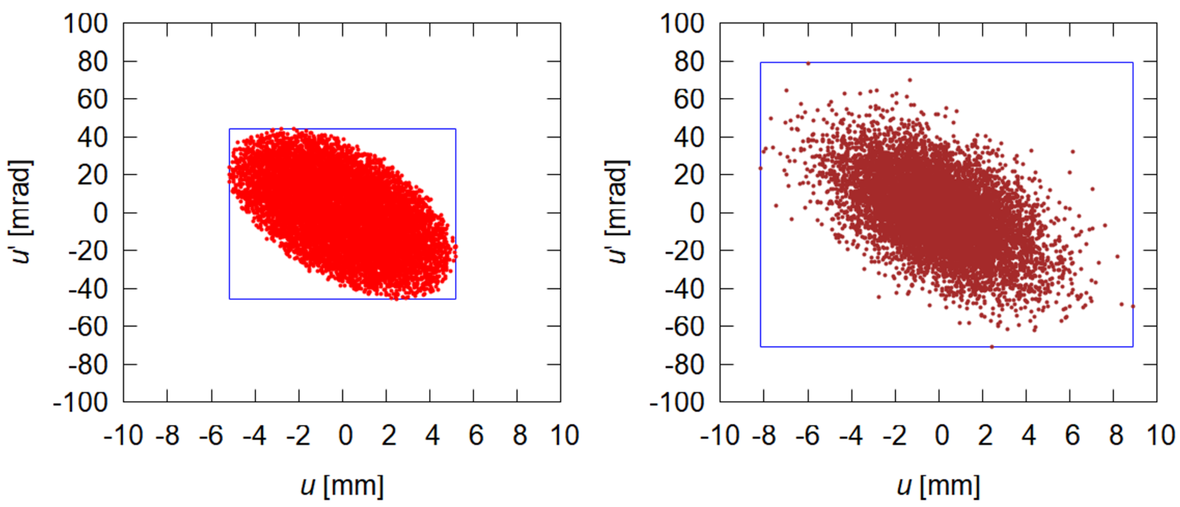
Main design parameters of the Design-2022 HSI RFQ, where a is the minimum electrode aperture, m is the electrode modulation, φ_s is the synchronous phase, U is the inter-vane voltage, and W is the beam energy.

Design parameters of the constructed and proposed HSI RFQs.

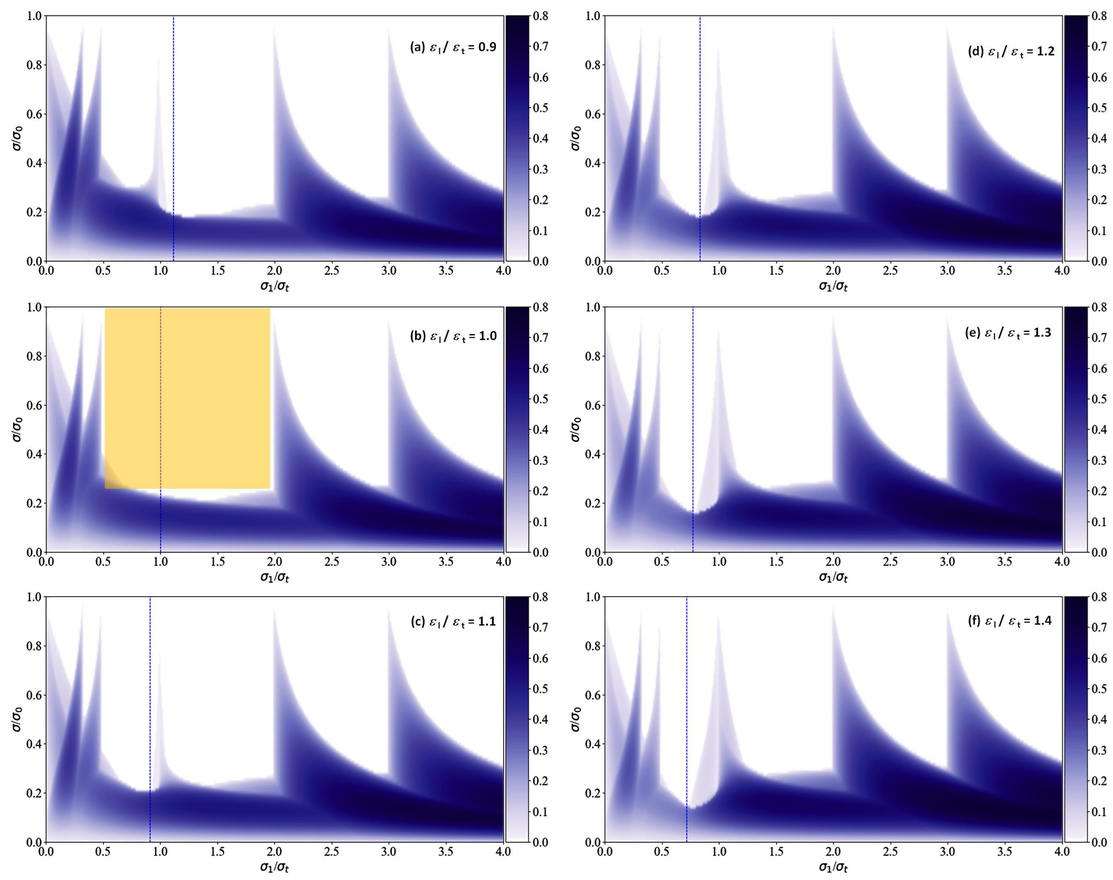
Parameters1	Version-1998	Version-2008	Design-2022
W [keV/u]	2.2 – 120	2.2 – 120	2.2 – 120
U [kV]	125	155	120
I_{in} [emA]	16.5	20	20
$\varepsilon_{t,\,in,\,un,\,total}$ [π mm-mrad]	138	210	210
$\varepsilon_{t,\,in,\,n,\,rms}$ [π mm-mrad]	0.050	0.076	0.076
$\alpha_{Twiss,\,t,\,in}$	0.43	0.6	0.6
$\beta_{Twiss,\,t,\,in}$ [cm/rad]	4.6	13.6	13.6
$E_{s,\,max}$ [MV/m]	31.8	31.2	29.9
$r_{0,\,avg.}$ [cm]	0.61	0.60	0.58
Total number of cells	357	409	381
L [cm]	921.749	921.7	920.1
T [%]	89.5	88.5	96.2

For the new HSI RFQ design with U = 120 kV (Design-2022):

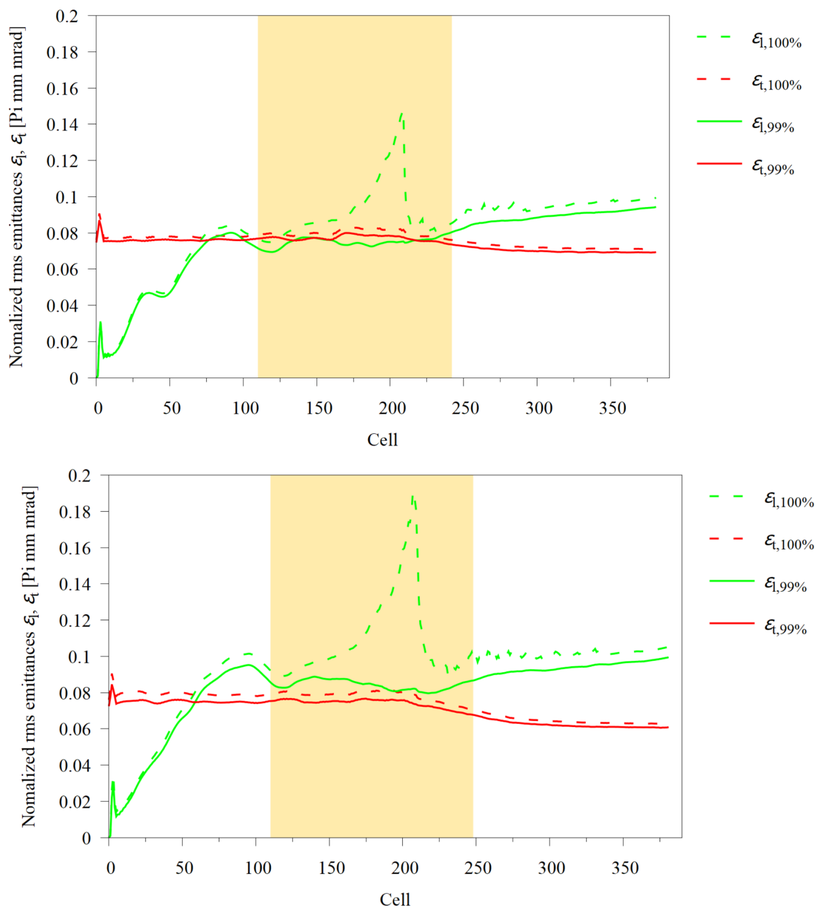
- **high efficiency ⇒ New Four Section Procedure that supports to realize a fast main bunching with a relatively low U under balanced transverse and longitudinal forces**
- **high brilliance ⇒ MEGLET (Minimizing Emittance Growth via Low Emittance Transfer) method, which doesn't try to avoid emittance transfer like previously proposed methods but allows and even takes advantage of emittance transfer to minimize emittance growth.**



4D Waterbag (left) and Gaussian (right) transverse input distributions.



Hofmann charts for the emittance ratios ε_l / ε_t = 0.9 – 1.4. The rectangle marked in orange covers the safe area for tune footprints.



Evolution of emittances for 100% and 99% of particles along the Design-2022 HSI RFQ (top: Waterbag case, bottom: Gaussian case).

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