HB2008: RFQ Matching Code

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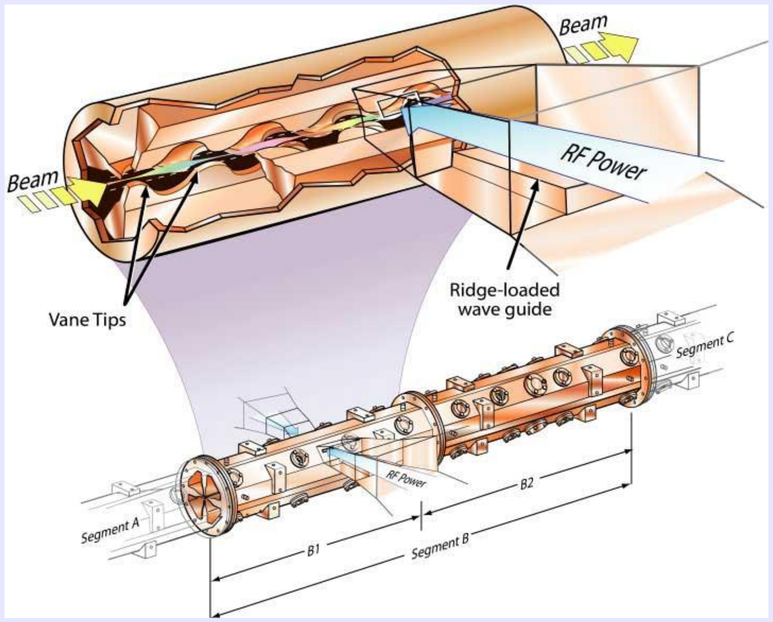
RFQ linac *(Invented by Kapchinsky, Teplyakov)* are the most adequate for low-β, high-current beams, bridging ion source, DTLs and other RFQs.

Motivation: RFQ Dynamic matching (Input/Output RFQ optimization)

RFQ Idea:

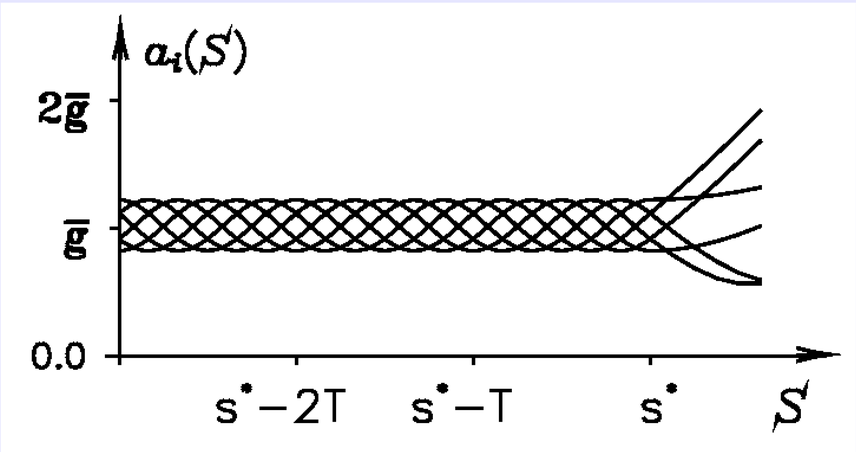
Focusing & Acceleration combined

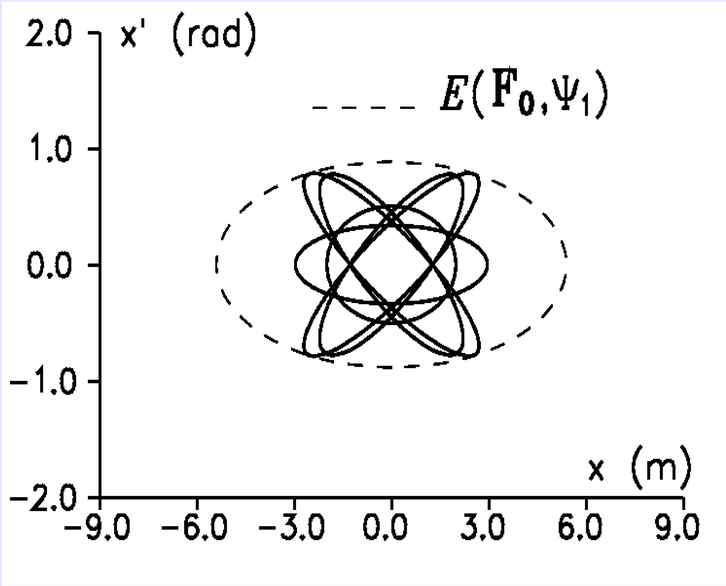
Layout



Plot by L.M. Young, et al. LANL

Horizontal beam envelopes & phase ellipses at $s=s^*$
for (y,y') - similar

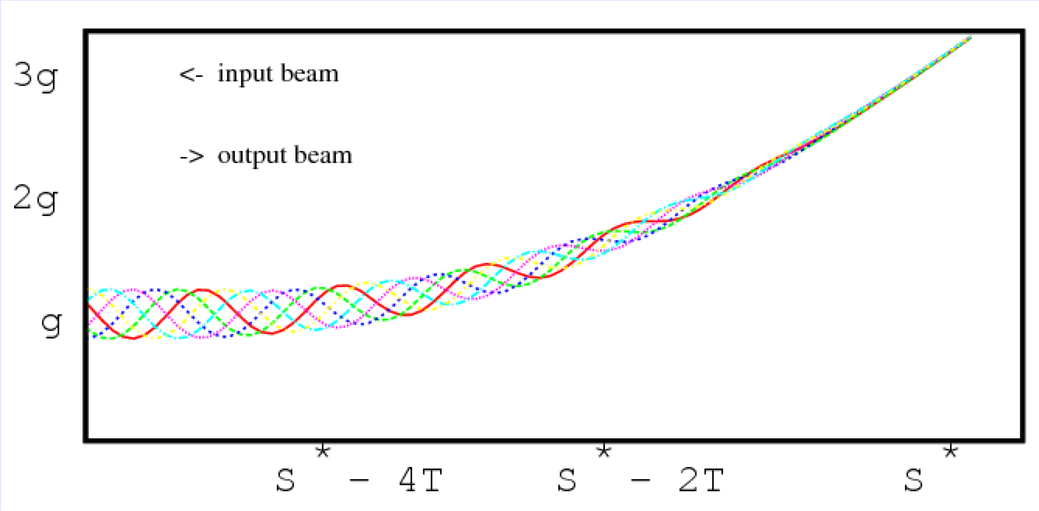




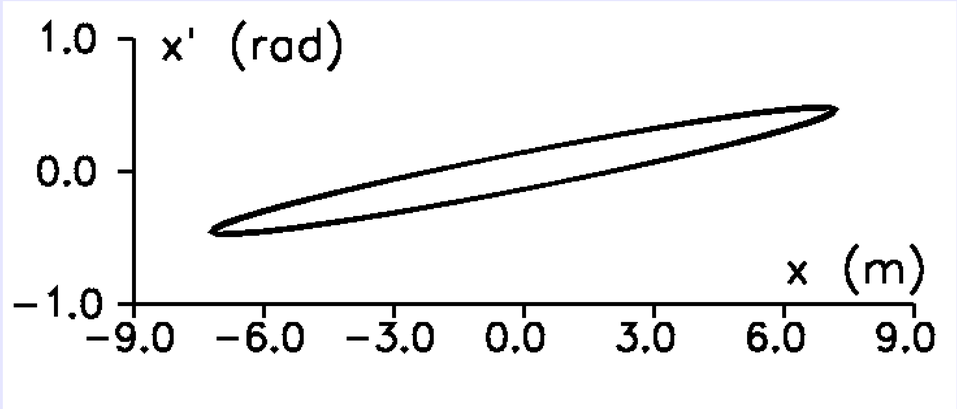
HB2008: RFQ Matching

Conventional RFQ matching:
Long adiabatic sections for transverse & longitudinal matching.

Envelopes



Phase ellipses at $s=s^*$



Matching Goal: High current, narrow aperture, short length (=higher acceleration rate).
Optimization: Non-adiabatic matching sections to be found: ***F(s).***

"Shape function" ***F(s)*** is implanted into $K_{x,y}(s)$ in Beam Equations (KV model):

$$\begin{cases} a_i''(s) + K_x(s)a_i(s) - \dfrac{Q}{a_i(s)+b_i(s)} - \dfrac{\varepsilon_x^2}{a_i(s)} = 0 \\ b_i''(s) + K_y(s)a_i(s) - \dfrac{Q}{a_i(s)+b_i(s)} - \dfrac{\varepsilon_y^2}{b_i(s)} = 0 \end{cases}$$

$$K_x(s) = \alpha F(s)\cos(2\pi s/T + \theta_i), \quad K_y(s) = -K_x(s)$$

$$i = 1,\ldots N; \quad Q = 4qI / AI_p(\beta\gamma)^3, I_p = 3.13\times 10^7 \text{ A}$$

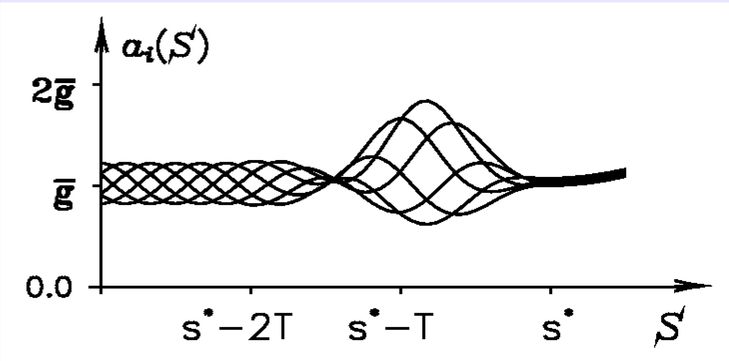
HB2008: RFQ, Non-adiabatic matching sections

Goal function: $\Phi(F(s)) \rightarrow \min$

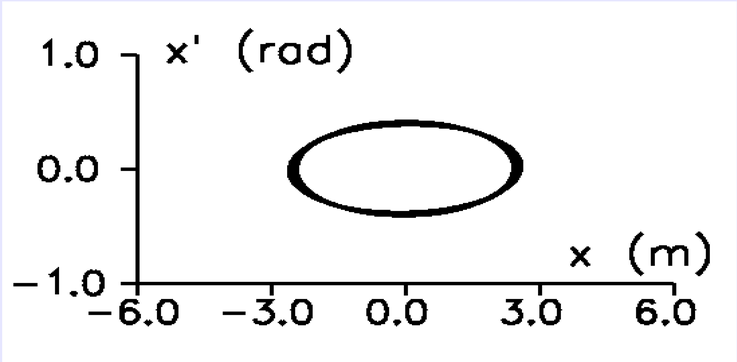
"Φ" estimates quantitatively the matching quality (E.G.: stationary beam waist, the fixed length of matching section, current insensitivity, etc.)

Method: Gradient projection upon the constraint tangent hyperplane (see Refs.)

Envelopes

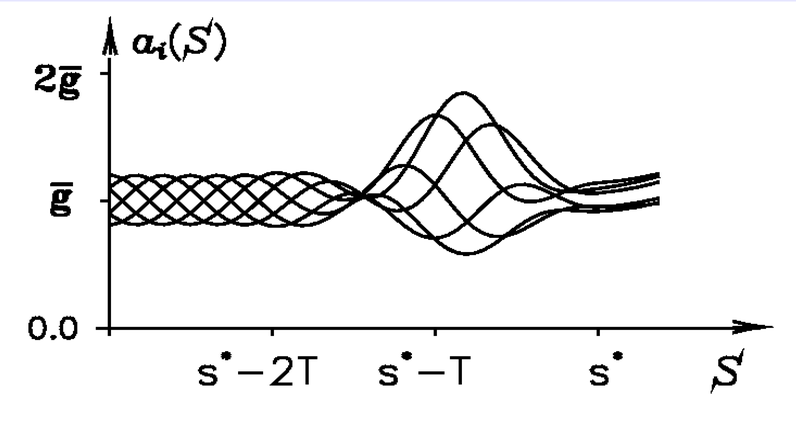


Phase ellipses at $s=s^*$

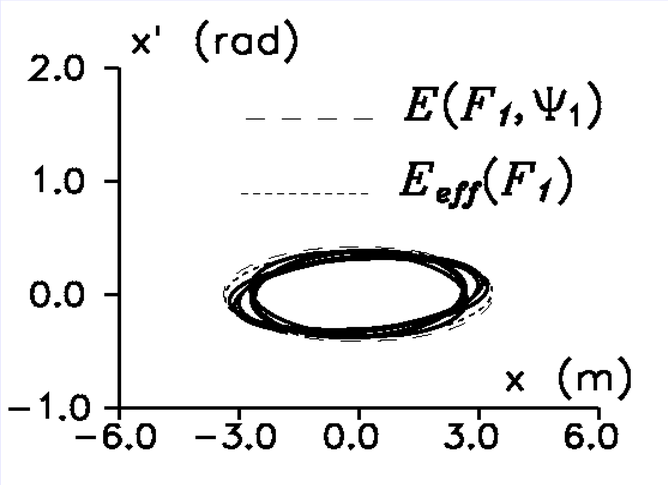


OPTIMIZATION #1: Stationary, Short, but Sensitive to current variations:

Envelopes



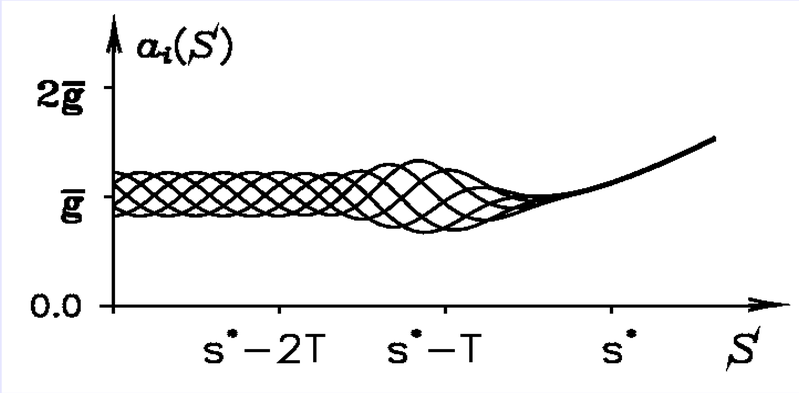
Phase ellipses at $s=s^*$



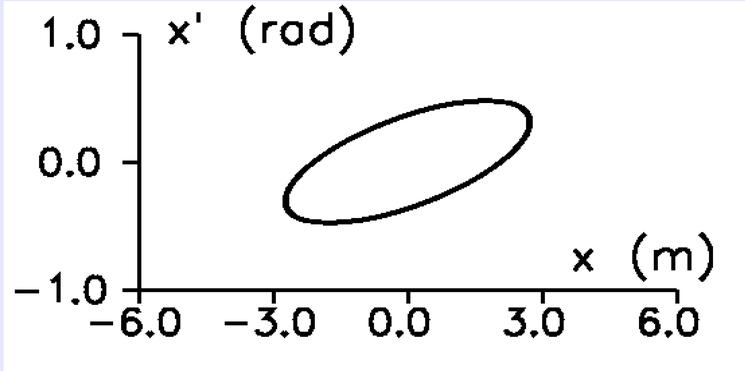
HB2008: RFQ, Optimal non-adiabatic sections

Optimal solution #2: Insensitive to current variations

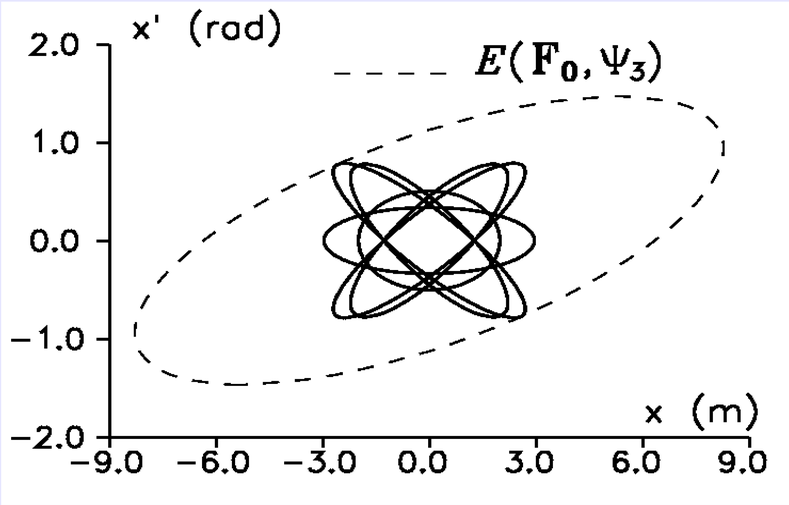
Optimal Envelopes



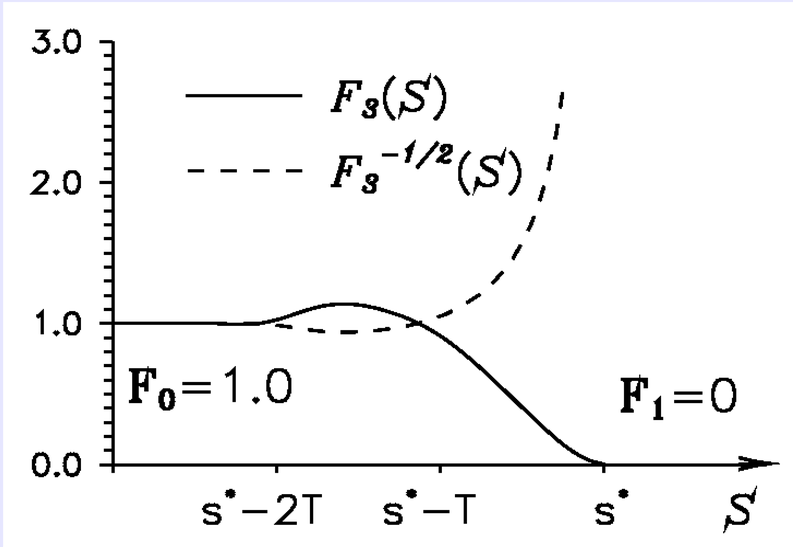
Optimal Phase ellipses at $s=s^*$



Phase ellipses at $s=s^*$ before optimization



Solid line – focusing strength
Dashed line – RFQ vanes profile



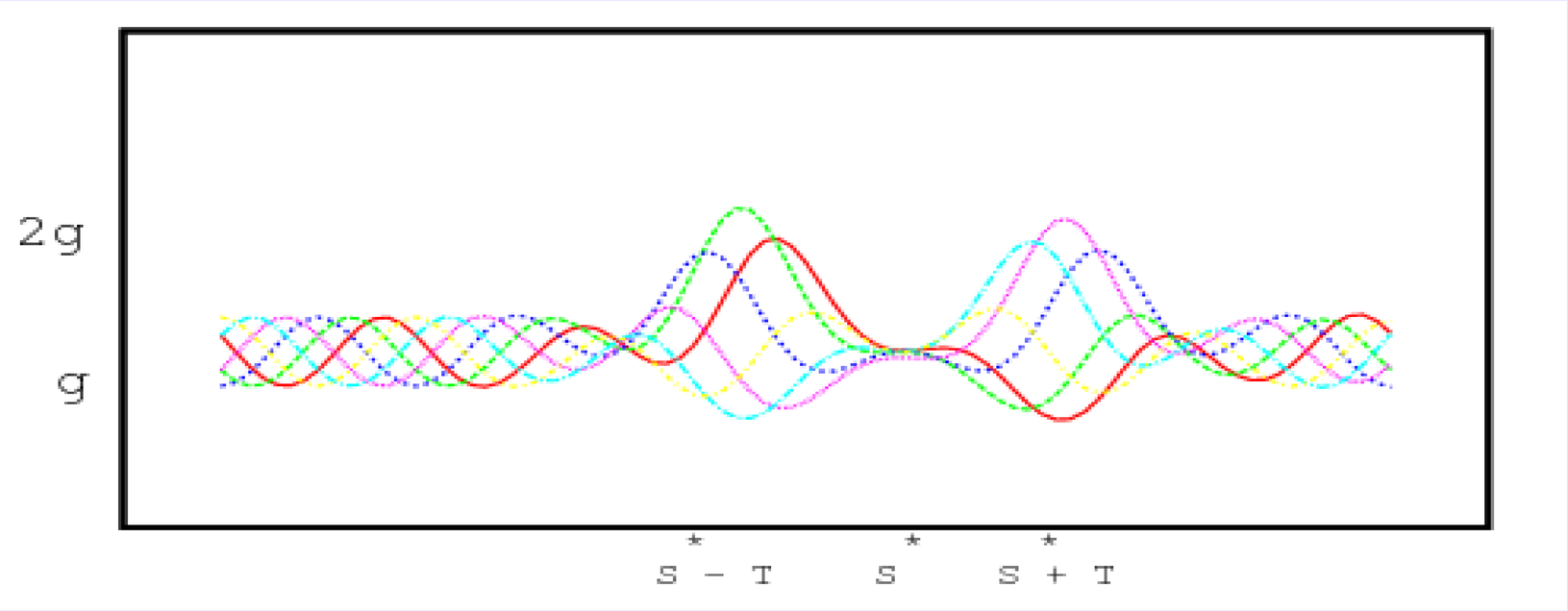
HB2008: Applications, RFQ Linac tree

Heavy Ion Driven Inertial Fusion: Accelerator Driver = RFQ linac-tree + Resonant Linacs + Long Transport (Compression) + FFS (as in HIBALL)

Matching of RFQ with the ion source, DTLs, etc.

RFQ funneling tree in HIDIF driver: Matching of 2 or several RFQs

RFQ1 with lower frequency **RFQ2 with higher frequency**



Envelopes with different phases are plotted with different linestyles

HB2008: RFQ Summary/References

RFQ matching code generates vane profiles, providing:

- Stationary waist / diverging / converging beam
- Low sensitivity to current variations
- High acceleration rate due to short length

Works both for RFQ input & output; for continuous and bunched beam.

References

- **Optimizer (theory and algorithm):**
  L.G. Vorobiev, D.G. Koshkarev: Preprint ITEP-4, ITEP, Moscow, Russia (1992).
- **RFQ matching sections:**
  D.G. Koshkarev, L.G. Vorobiev: NIMA, vol 336, pp.291-300. Full text:
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- **Optimal shaping for optics and other beam applications:**
  L.G. Vorobiev, R.W. Müller: GSI-96-06 Report , GSI-98-02 Report, GSI-98-03 Report; Darmstadt, Germany. Full texts:
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