# ESS-BILBAO RFQ STATIC TUNING ALGORITHM AND SIMULATION

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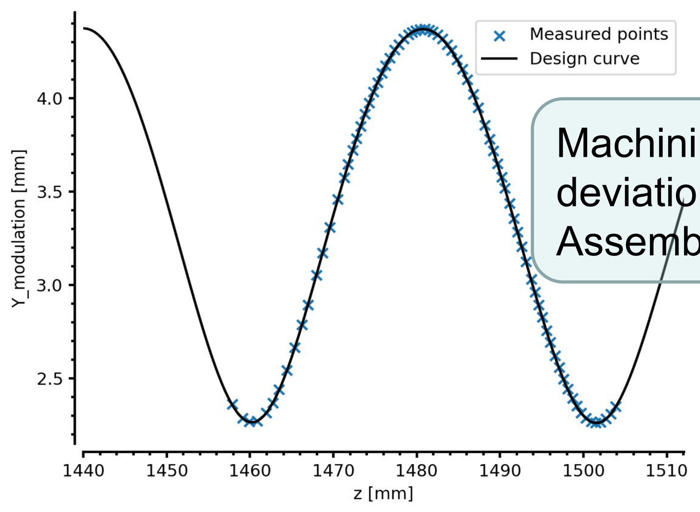
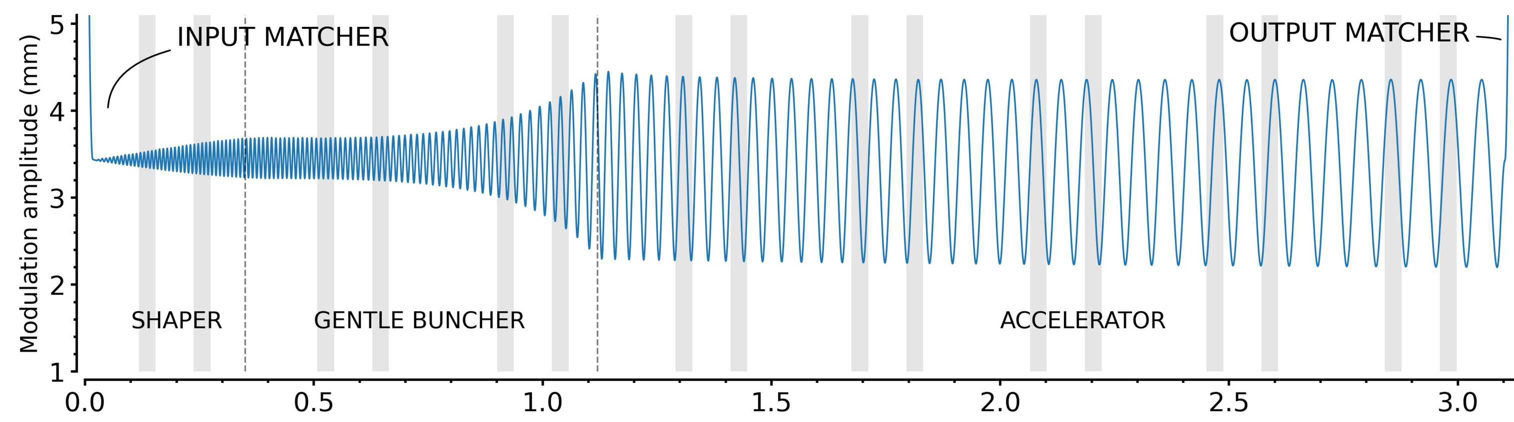
## ESS-Bilbao RFQ

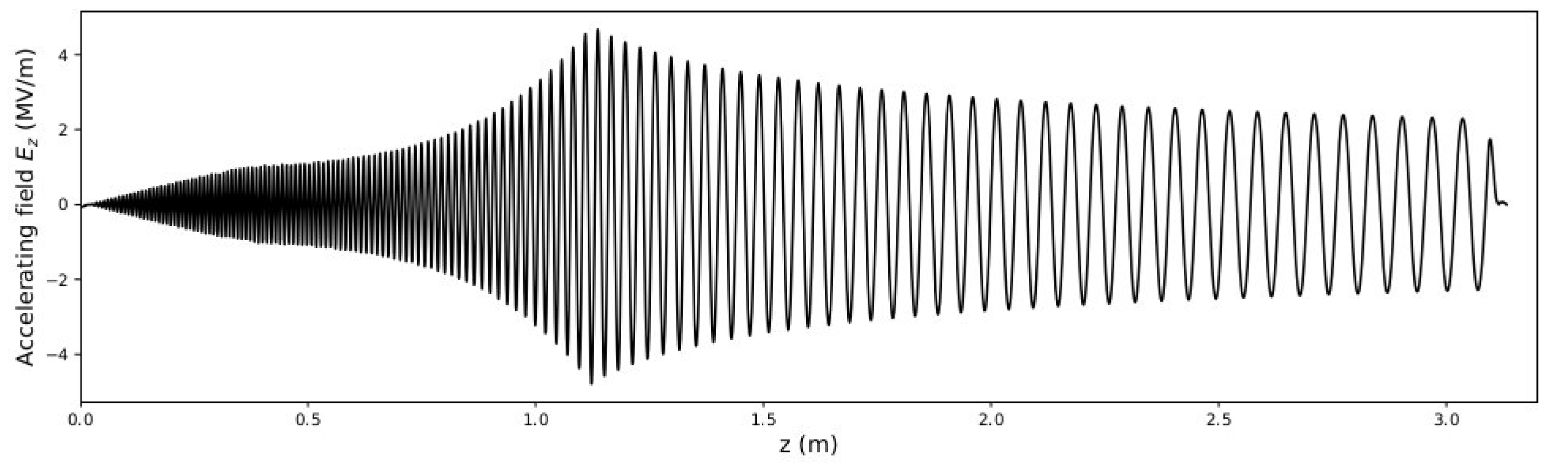
**Table 1.** ESS-Bilbao RFQ Main Characteristics.

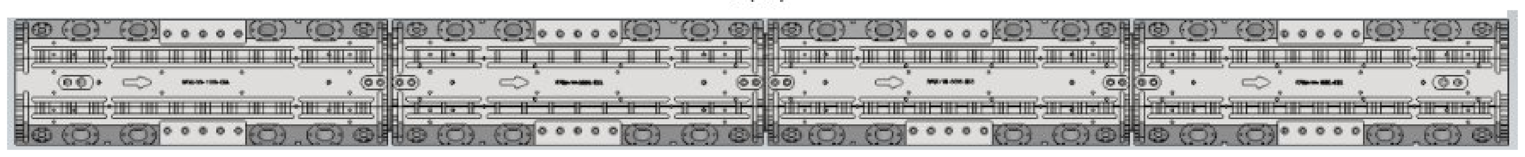
| | ESS-Bilbao RFQ |
|---|---|
| Type | 4 vane |
| Particle | Protons |
| RF frequency | 352.2 MHz |
| Innervate Voltage | 85 kV (uniform) |
| Energy | 45 keV ⟶ 3.0 MeV |
| Design current | 60 mA |
| Input emittance (rms norm) | 0.25 $\pi$ mm mrad |
| Duty cycle | Up to 10% |
| Kilpatrick factor | 1.85 |
| Number of cells | 273 |
| $R_0$ | 3.44 mm |
| $\rho/R_0$ | 0.85 |
| Input/Output matcher | 16.674 mm / 14 mm |
| Total length | 3.12 m (3.66 $\lambda$) |
| Number of segments | 4 (about 800 mm each) |
| Method of assembly | Polymeric gaskets + RF seals |
| Plunger tuner ports | 16 per segment |




Machining modulation deviations < 30 um. Assembly < 50 um



$$\frac{\delta V_0(z)}{V_0} = -8\frac{\delta\omega_0}{\omega_0}\left(\frac{l_V}{\lambda}\right)^2 \sum_{m=1} \frac{\cos(m\pi z_0/l_V)\cos(m\pi z/l_V)}{m^2}$$

### ❑ Modulation

**Vane modulation** generates the design **accelerating field** only if intervane voltage is $V(z) = V_0 = 85\ kV$.

But **vane modulation**, together with 3D geometry features, assembly/machining errors, etc., also changes local capacity $C=C(z)$, so local $f = f(z)$ and $V(z) \neq V_0$

The process of compensating the non uniform $V(z)$ to get again $V(z)=V_0$, is the RFQ tuning procedure. This is done by the action of the plunger tuners.

## RFQ tuning

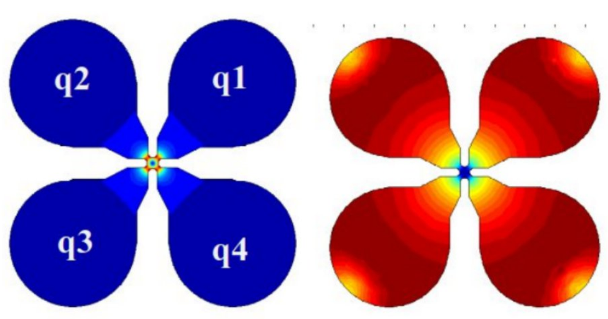
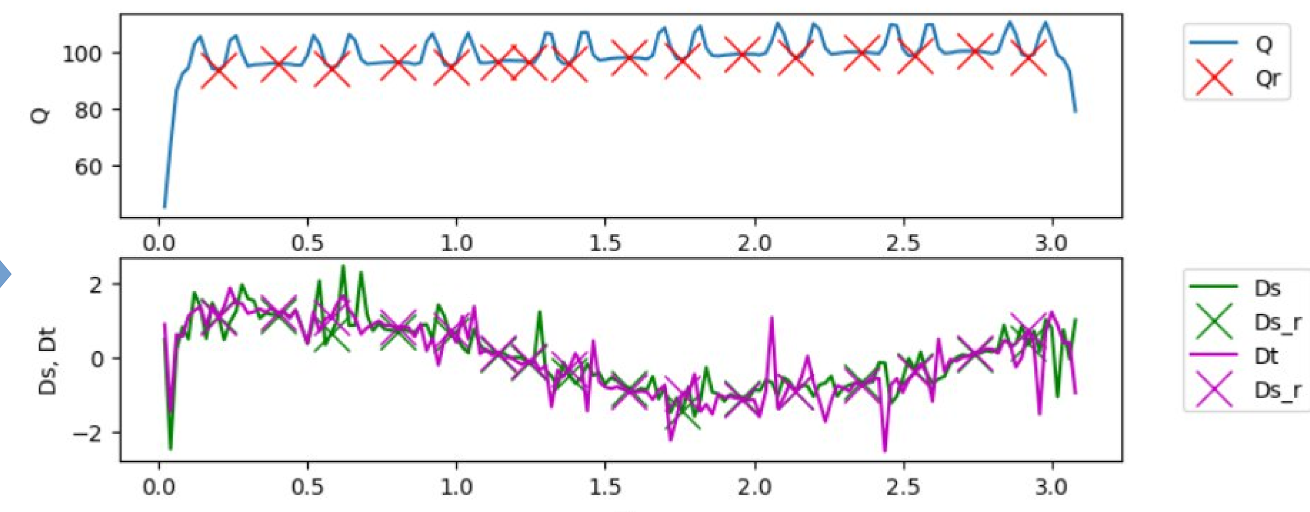



Figure 1: Electric (left) and magnetic (right) field maps for the cross section of the RFQ, with the quadrant naming specified in the electric field map.

Bead pull measurements / RFQ FEM simulations

$$Q = (q_1 - q_2 + q_3 - q_4)/4$$
$$D_s = (q_1 - q_3)/2$$
$$D_t = (q_2 - q_4)/2$$




Curves discretized in $P$ points (total $3P$)

$$\vec{V} = V_j - V_{0j},\ j = 1 \to 3P$$

Linear RFQ model

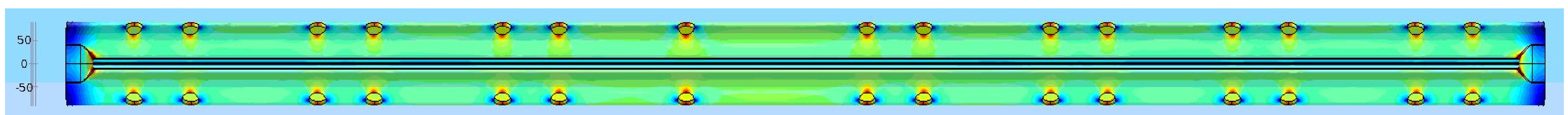
$$\Delta V_j = m(i,j)\Delta T_i = \frac{\partial V_j}{\partial T_i}\Delta T_i$$
$$\vec{V} = M \cdot \vec{T} \ \to\ \vec{T} = M^{-1} \cdot V$$

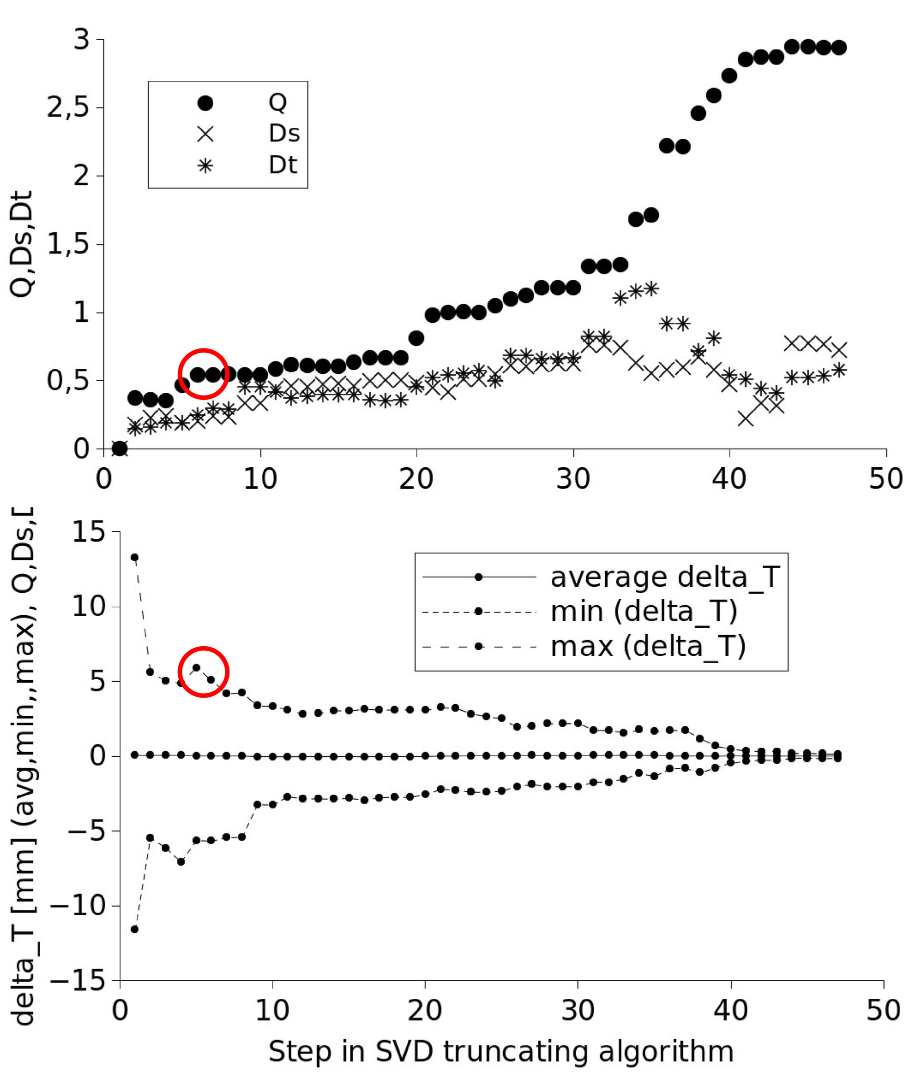
Tuners (total $N$)

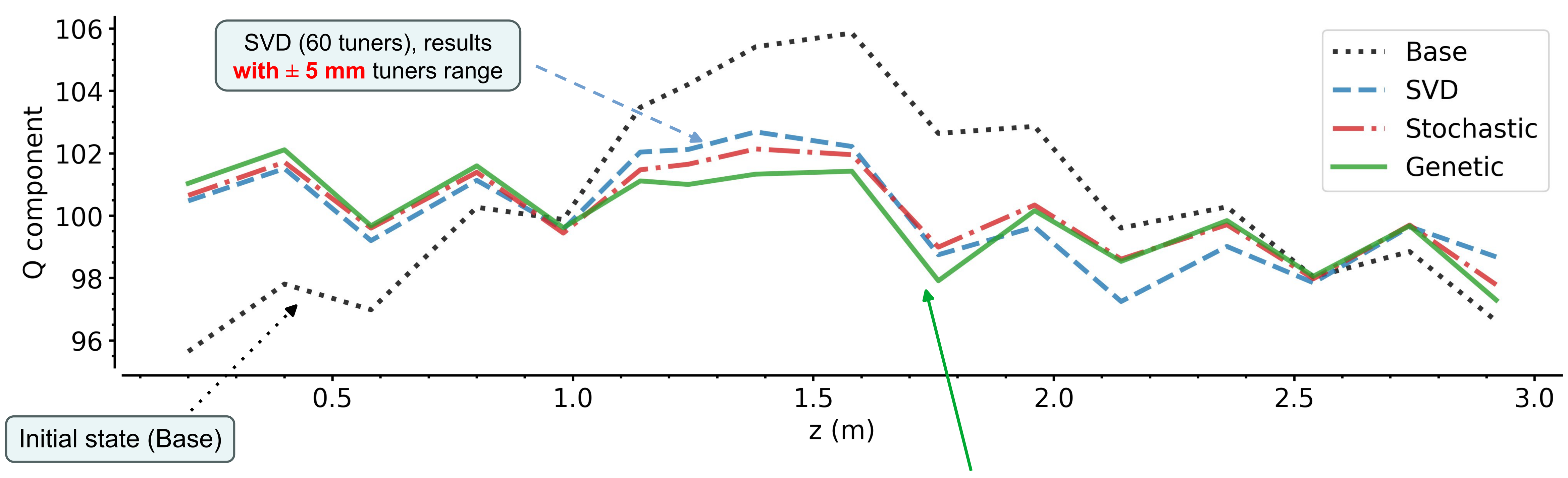
$$\vec{T} = T_i - T_{0i},\ i = 1 \to N$$

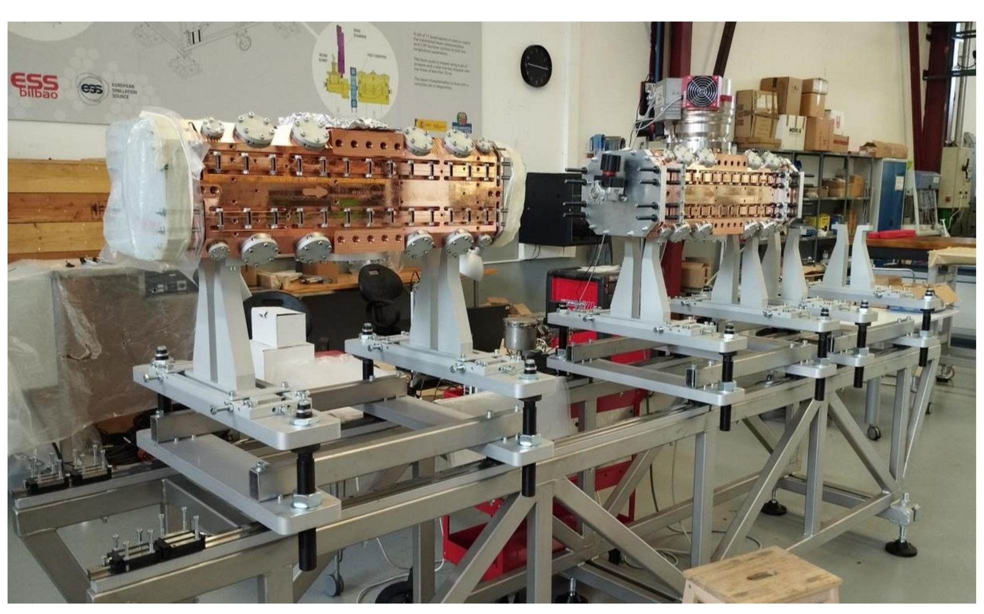
## Tuning algorithms

- ❑ All results extracted from FEM simulations
- ❑ Conventional SVD algorithm:

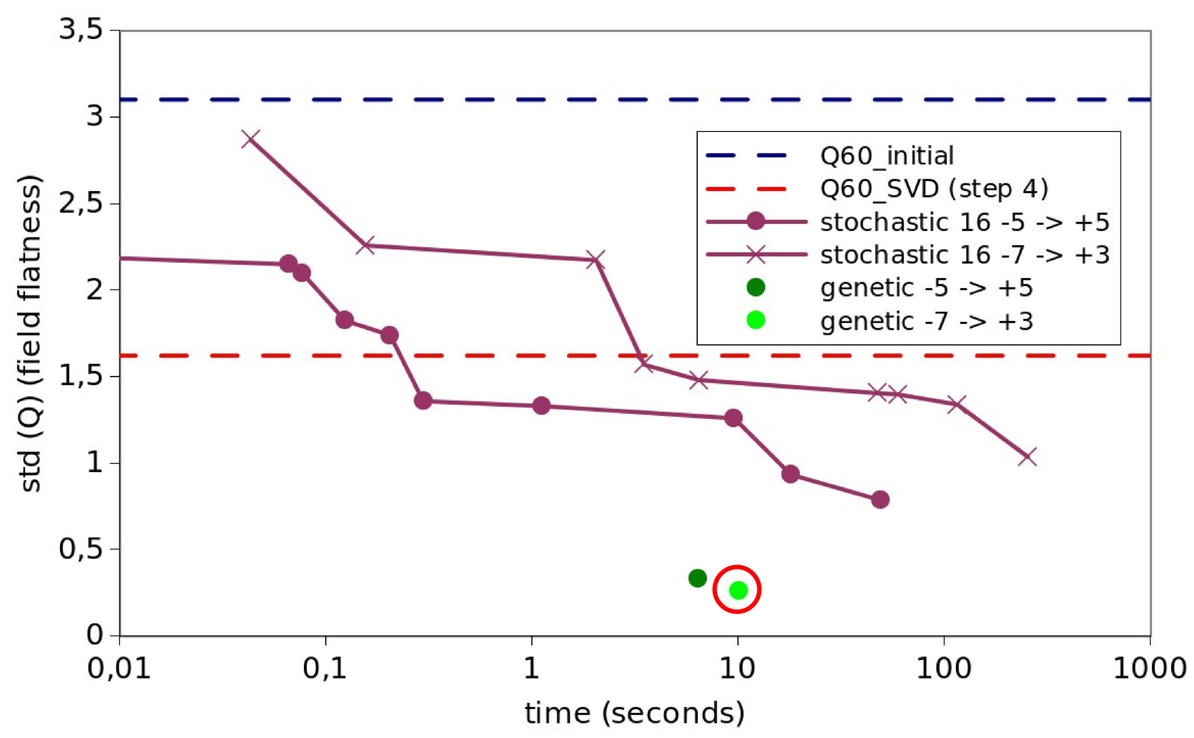




### ❑ Stochastic and genetic algorithms




**Stochastic** and **genetic** algorithms yield a better solution, in very short time, with much lower tuner penetration range **(-7 /+3 mm)**

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