TQ scan and safety factor evolution during cold and hot ITER VDEs

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VDEs. Safety factor analysis

In the past we were focused on…

- **Obtaining cases with as large halo current as possible**
- **Fixing typical post-TQ Te around 30 eV. (It can be relaxed a little).**
- **BUT… We we ran 3D simulations, we observed very small sideways forces**

We also need q(a) to decreasing in time after the TQ in order to have MHD activity

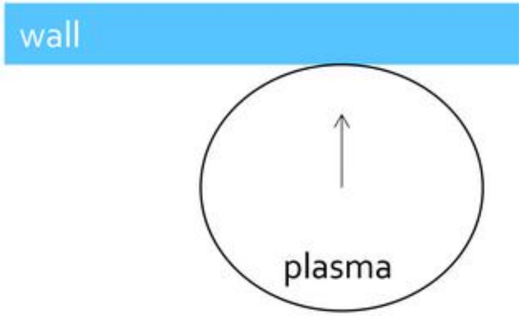
Some considerations (Jardin's slide)

Ratio of VDE time to current quench time matters

$$q(a) \cong 2\pi \frac{B_T a^2}{R \mu_0 I_p} \qquad a = Z_{wall} - Z_p$$

$$Z_p = Z_0 e^{\gamma_{VDE} t}$$

$$I_p = I_{p0} e^{-\gamma_{CD} t}$$



q(a) will decrease during the CQ only if $\gamma_{VDE} > \frac{1}{2}\gamma_{CD}$

If q(a) doesn't decrease during the CQ, there will be very little MHD activity and sideways force

Constraint: both γ_{VDE} and γ_{CD} are related

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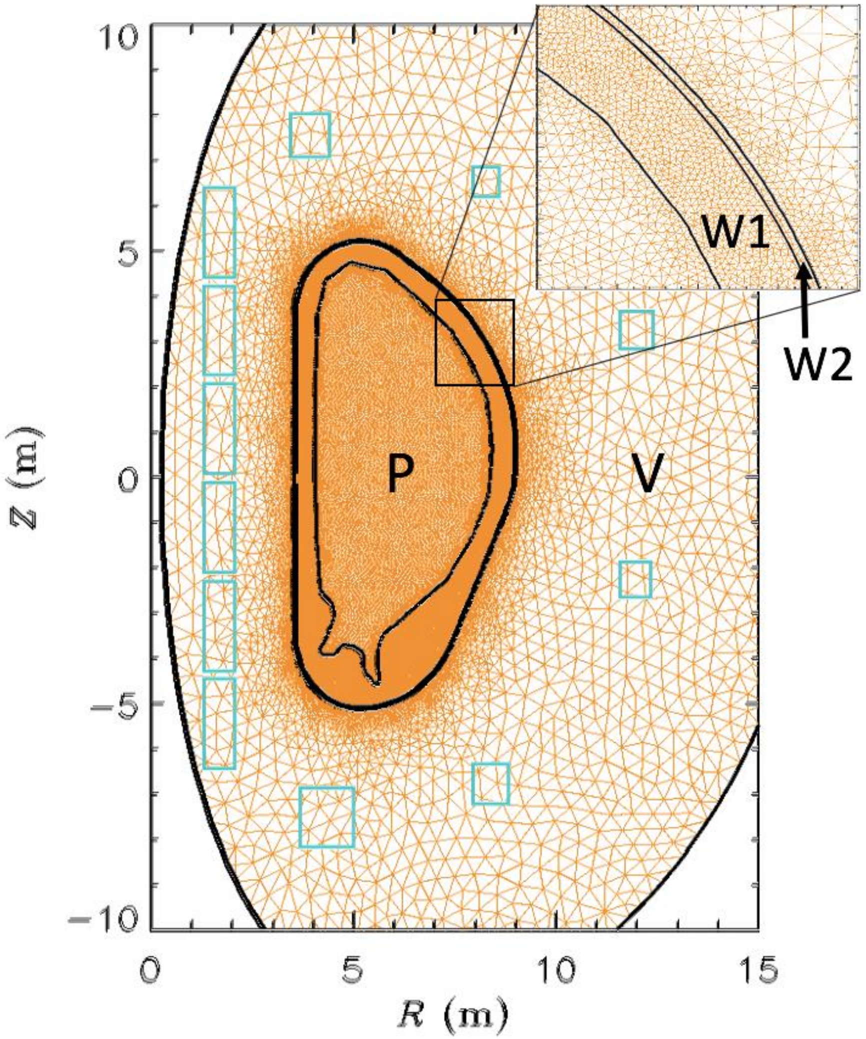
Even though they are related, we change the $\boldsymbol{\gamma_{VDE}/\gamma_{CD}}$ ratio:

- Change post-TQ Temperature
- Change halo current contribution
- Change geometry/resistivity (L/R time)
- Elongation

- Plasma **current quench (CQ)** is mostly determined by the post-thermal quench temperature (through plasma Spitzer resistivity)
  - Without TQ: There is no CQ and thus $\gamma_{CD} \to 0$
  - With very low post-TQ temperature: fast current decay $\gamma_{CD} \to \infty$
  - $0 < \gamma_{CD} < \infty$

- The VDE has an 'intrinsic' growth rate given basically by $\tau_w = L/R$
  - BUT, the CQ induces additional currents in the wall, speeding up the vertical movement.
  - $\gamma_{VDE,\infty} < \gamma_{VDE} < \infty$

New ITER multi-layer mesh with anisotropic resistivity



W1: poor toroidal conductor
good poloidal conductor
W2: good both toroidal and poloidal conductor

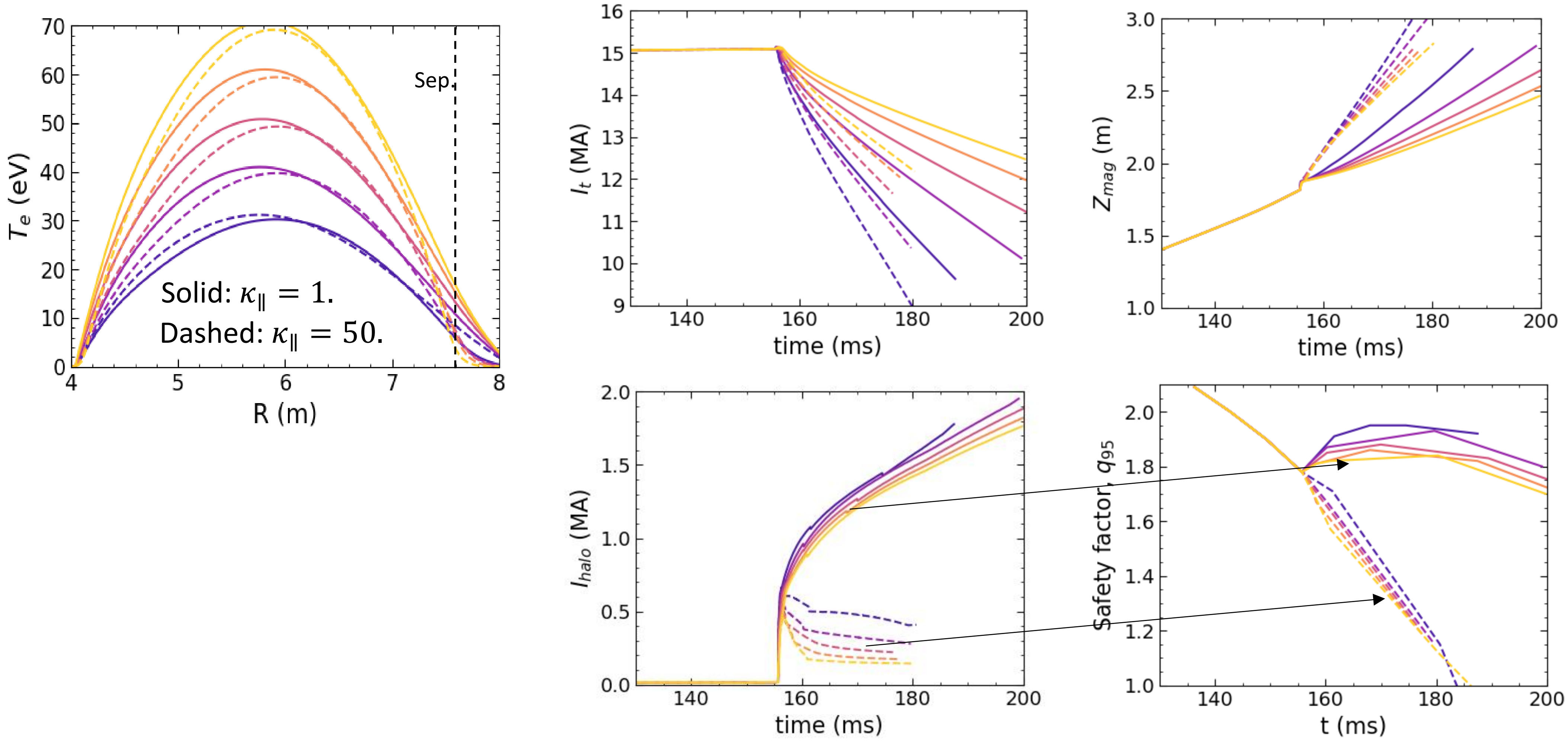
New time:
L/R = 138 ms → This is much shorter than widely used values (~250 - 500 ms)

In ITER the CQ time is targeted to be
$50\ (35)\text{ms} < \tau_{CQ} < 150\ \text{ms}$

Usual assumptions that $\tau_{CQ} \ll \tau_{VDE}$ can be compromised

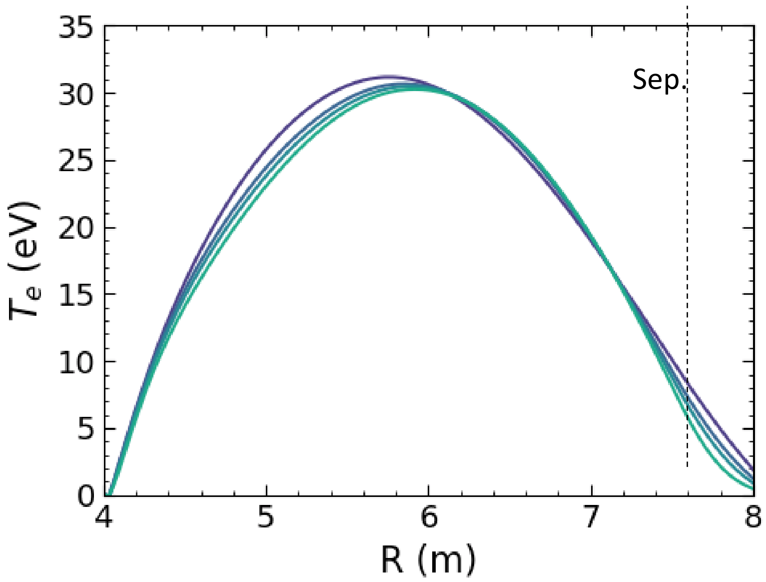
ITER – Hot VDEs – scanning over Te

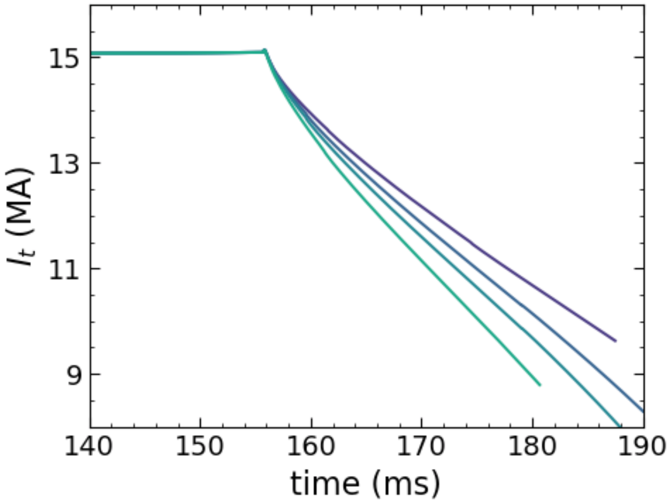
We started from equilibrium (I=15 MA – Te=25 keV).
TQ is triggered after the VDE is initiated by increasing the thermal heat flux via $\kappa_\perp$.
$\kappa_\perp$ used to produce different post-TQ Te. $\kappa_\parallel$ used to change halo contribution

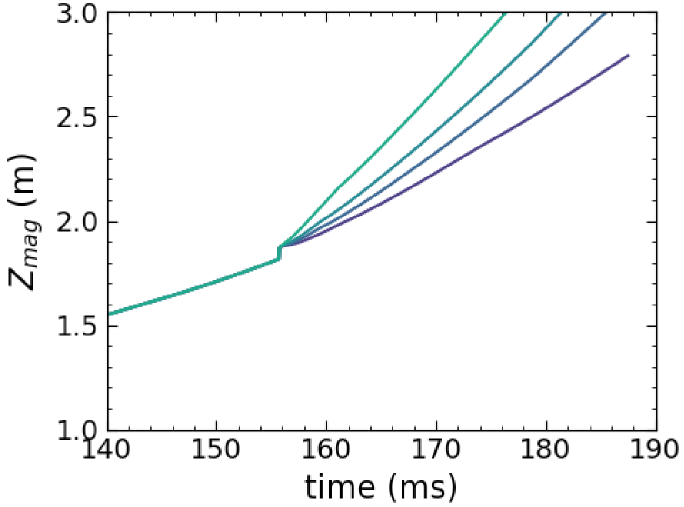


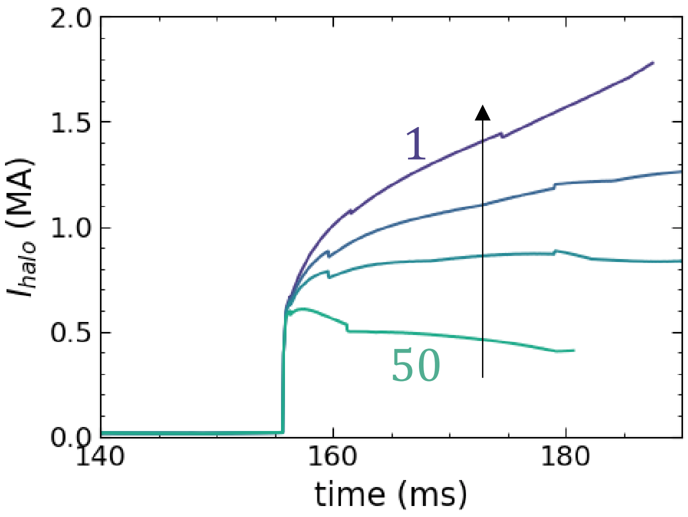
ITER – Hot VDEs – post-Te=30 eV

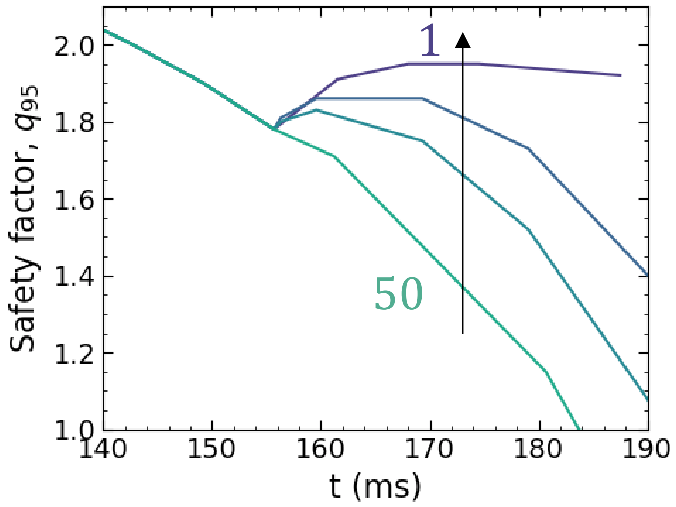
Different $\kappa_{\parallel} = 50, 20, 10, 1$ … From small halo to large halo







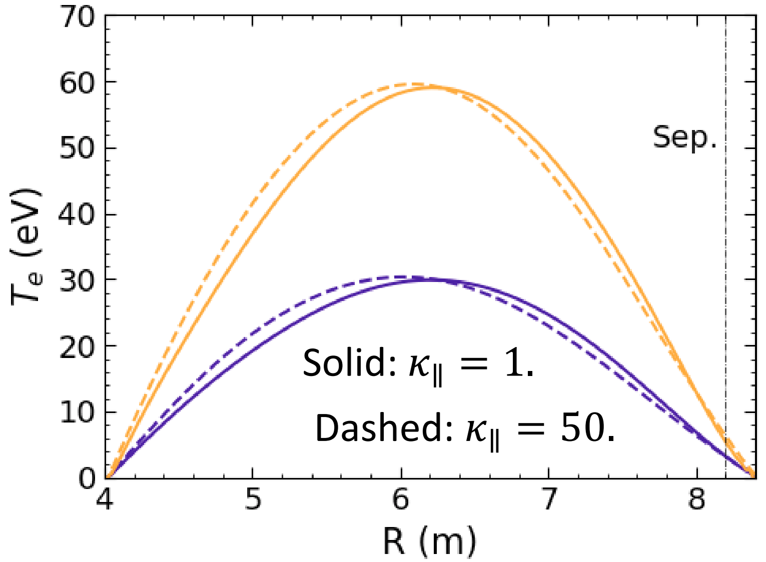


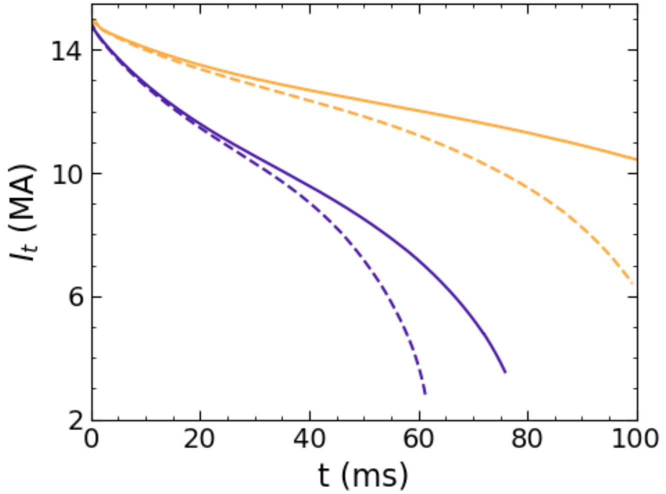


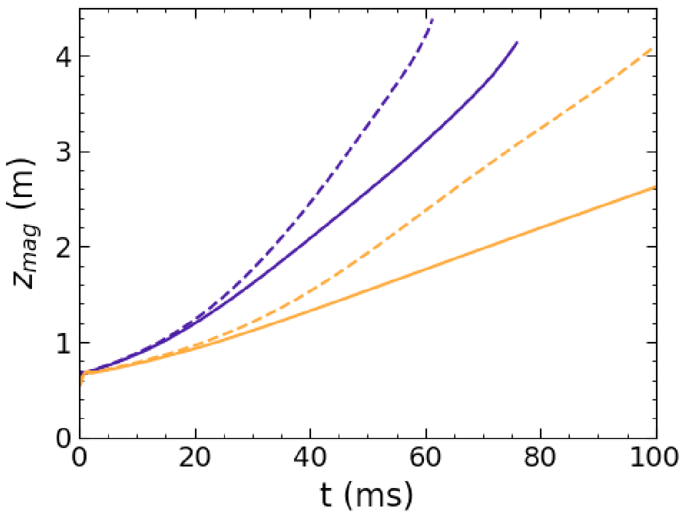
Green: Jardin 3D case in progress with similar transport values.

ITER – Cold VDEs – two different post-TQ Te

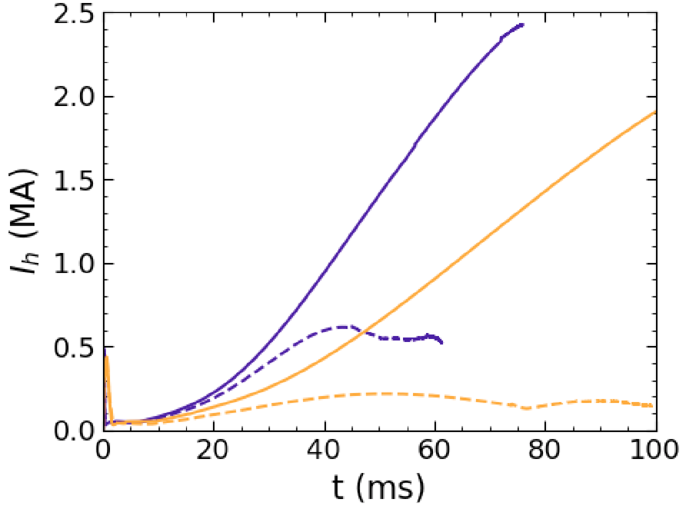
We started from equilibrium (I=15 MA – Te=25 keV).
TQ is triggered at time=0 by increasing the thermal heat flux via $\kappa_\perp$.
$\kappa_\perp$ used to produce two different post-TQ Te. $\kappa_\parallel$ used to change halo contribution

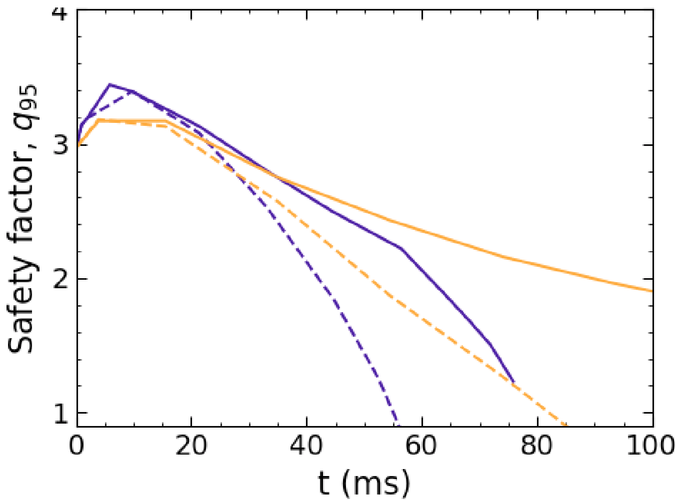






For each temperature
Dash lines: small halo cases
Solid lines: large halo cases





Comparison with analytical models

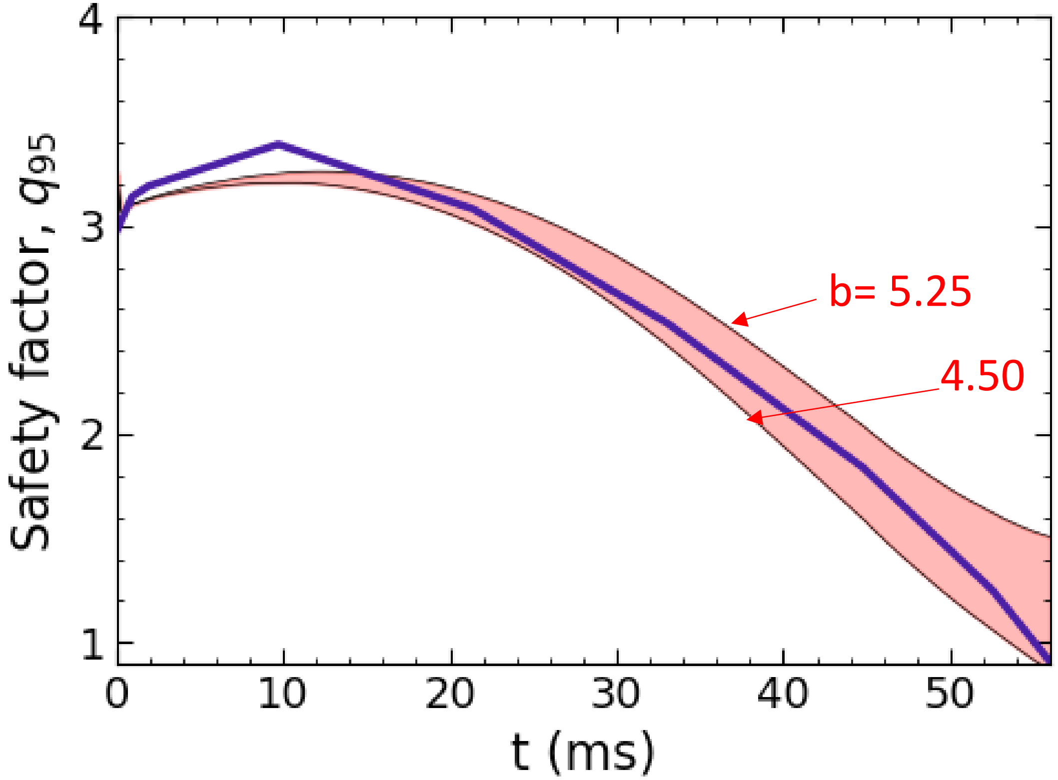
Figure shows a comparison of one of our previous cases (post-Te=30 eV and $\kappa_{\parallel}$ = 50) with fast CQ time and small halo contribution.

We compare with the circular cross-section formula

$$q = \left(1 - \frac{|Z_{mag} - Z_{m,0}|}{b}\right)^2 \frac{q_0 I_0}{I}$$

(b is taken from iter cross section figure)

Results are in fair agreement



The initial increase in the safety factor is well explained here in terms of the current decay and vertical motion. This also should explain the initial increase in the safety factor in Hot VDEs when halo currents are important.

I haven't compared this formula with a case with larger halo current.