AWP 2022
Title: Review of 2D simulations of plasma disruptions
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Electromagnetic events and plasma scenarios

Electromagnetic events analysed for the DTT facility:

- Vertical Displacement Events
- Major Disruptions
- Fast Discharge of all Toroidal field coils

Among all possible plasma scenarios that will be tested in DTT, SN configuration is expected to be the most conservative (5.5 MA), even if a preliminary comparison between SN and XD shows comparable global force on VV (see next slides)

Abbreviation	Configuration	Plasma current [MA]
SN	Single Null (reference)	5.5
XD	X-Divertor	4.5
NT	Negative Triangularity	4.0
DN	Double Null	5.0
SF	SnowFlake	4.5

Load case parameters of electromagnetic events of the DTT facility

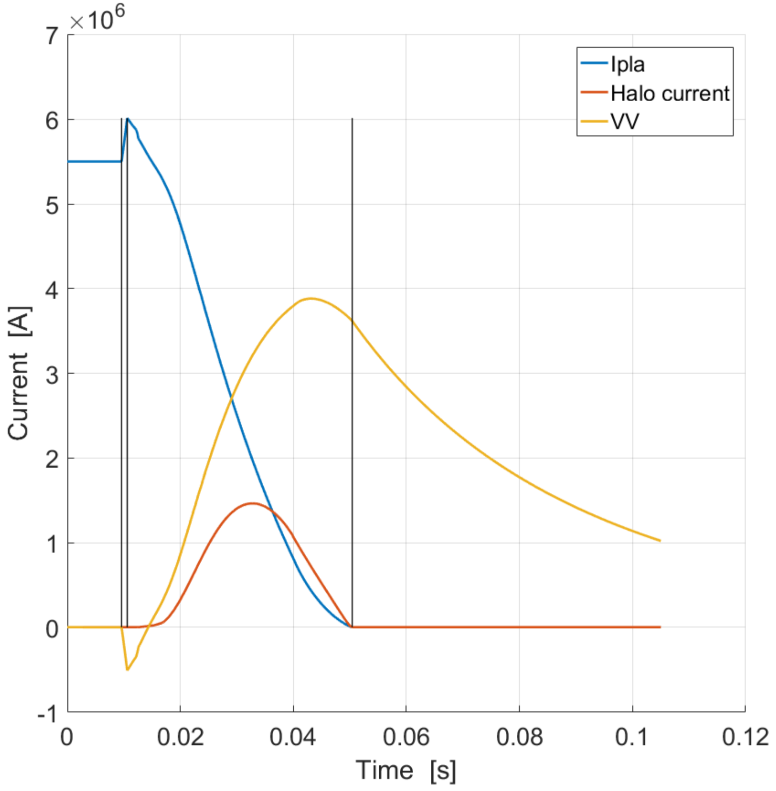
#	Load case identification	Load case description	Cycles	Service level	Priority
L5b	MD fast (MD III/MD IV in ITER)	Current quench duration: 4-6 ms (26/36 ms in ITER) Thermal quench duration: around 0.5 ms Halo factor (I_{halo}/I_{plasma}): around 0.1-0.2 Expected occurrence: a few times in the machine life	200 (1-2 in ITER)	C	1
L5f	MD slow (MD II in ITER)	Current quench duration: 40 ms (36 ms in ITER) Thermal quench duration: around 0.5 ms Halo factor (I_{halo}/I_{plasma}): around 0.1-0.2 Expected occurrence: likely event	1750 (400 in ITER)	A	2
L5c	VDE fast, downward (VDE III fast, downward in ITER)	Current quench duration: 4-6 ms (26 ms in ITER) Halo factor (I_{halo}/I_{plasma}): around 0.4-0.6 Expected occurrence: a few times in the machine life Sideways load and tilting moment due to asymmetric toroidal halo current: included	750 (4-8 in ITER)	C	1
L5d	VDE slow, downward (VDE III slow, downward in ITER)	Current quench duration: 40 ms (50-100 ms in ITER) Halo factor (I_{halo}/I_{plasma}): around 0.4-0.6 Expected occurrence: a few times in the machine life Sideways load and tilting moment due to asymmetric toroidal halo current: included			1
L5g	VDE fast, upward (VDE III fast, upward in ITER)	Current quench duration: 4-6 ms (26 ms in ITER) Halo factor (I_{halo}/I_{plasma}): around 0.4-0.6 Expected occurrence: a few times in the machine life Sideways load and tilting moment due to asymmetric toroidal halo current: included			2
L5h	VDE slow, upward (VDE III slow, upward in ITER)	Current quench duration: 40 ms (50-100 ms in ITER) Halo factor (I_{halo}/I_{plasma}): around 0.4-0.6 Expected occurrence: a few times in the machine Sideways load and tilting moment due to asymmetric toroidal halo current: included			2
L5e	TFD, all coils (MFD II in ITER)	Discharge on resistors: 5 s Expected occurrence: likely event	600 (50 in ITER)	A	1

Maxfea simulations
MD 1 (upward development) 1/3

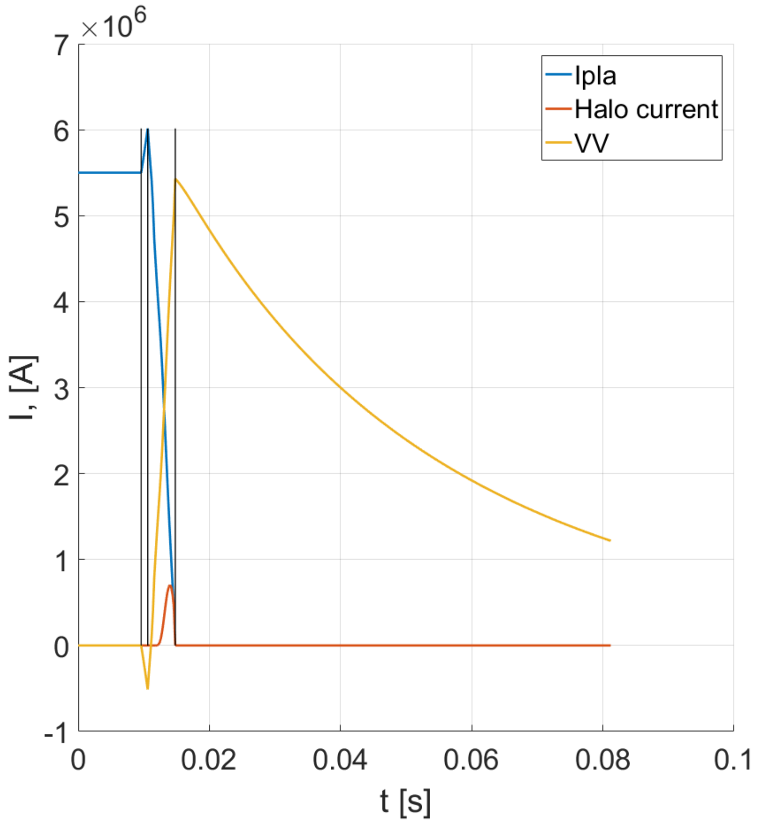
Plasma evolves naturally upward

Graphs with time evolution of plasma current, halo current, and vessel current

- UMD slow
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.27



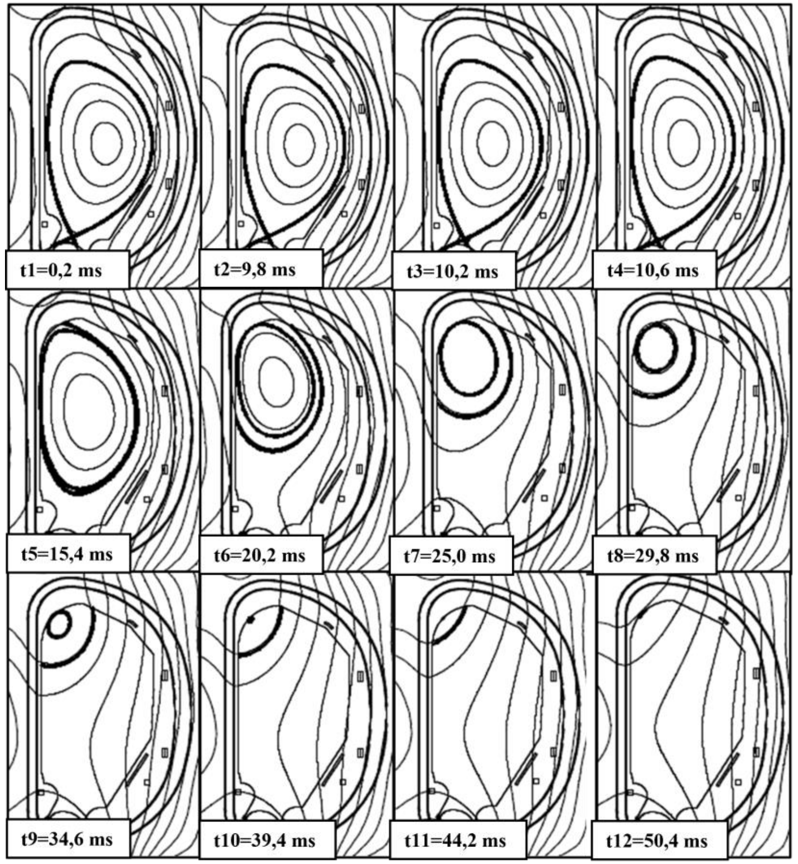
- UMD fast
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.13



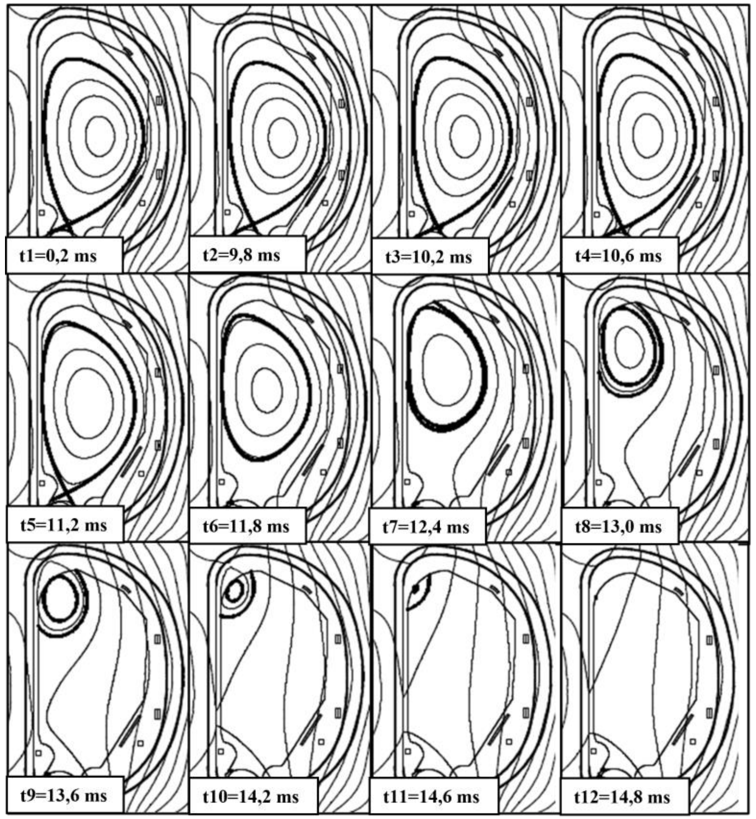
Maxfea simulations
MD 1 (upward development) 2/3

Images of shape evolution of the simulated plasma with positions of plasma boundary approaching the surfaces of in-vessel components is shown in the sequence with reference to the simulation time steps

- UMD slow



- UMD fast



Halo currents path
MD 1 (upward development) 3/3

Alternative scenarios for entrance and exit points of halo currents:

UMD (MD1) slow/fast, scenario 1, priority 2:

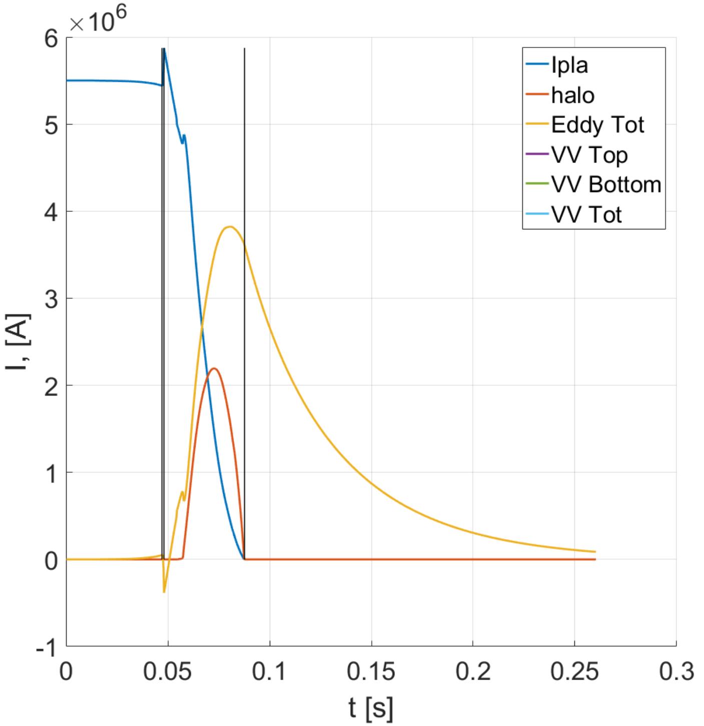
Almost all the halo current is expected to circulate in the top FW (for both slow and fast events)
→ conservative scenario for vessel verification with higher forces at the interface between vessel & divertor (DVDE scenario 1)

Maxfea simulations
MD 2 (downward development) 1/3

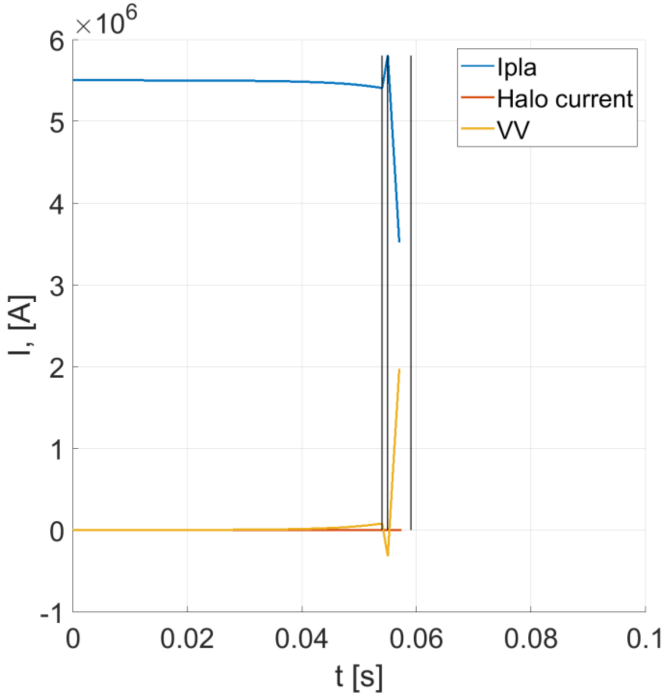
A destabilizing kick is imposed to force the plasma downward movement, TQ when ZJ < 0 (still central disruption but plasma develops a downward vertical instability)

Graphs with time evolution of plasma current, halo current, and vessel current

- DMD downward slow
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.40



- DMD downward fast
- Maximum halo factor (I_{halo}/I_{plasma}) = to be determined

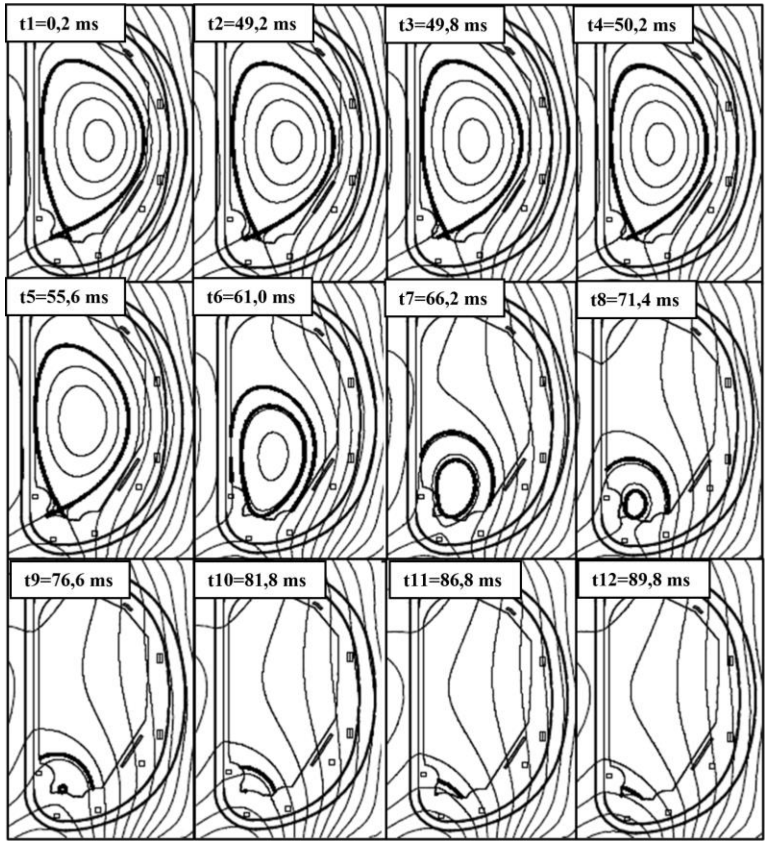


- At the moment it is not possible to simulate MD downward fast for all the CQ duration due to MAXFEA convergence issues

Maxfea simulations
MD 2 (downward development) 2/3

Images of shape evolution of the simulated plasma with positions of plasma boundary approaching the surfaces of in-vessel components is shown in the sequence with reference to the simulation time steps

- DMD slow
- DMD fast



Halo currents path
MD 2 (downward development) 3/3

Alternative scenarios for entrance and exit points of halo currents:

DMD (MD2) fast, scenario 1, priority 1:

Almost all the halo current is expected to circulate in the divertor
→ conservative scenario for vessel verification with higher forces at the interface between vessel & divertor
(DVDE scenario 1)

DMD (MD2) fast, scenario 2, priority 1:

Halo current circulating in the vacuum vessel (in particular 100%) with longer path and higher B_{tor}
→ significant for the verification of vacuum vessel and in-vessel components
(DVDE scenario 2)

DMD (MD2) slow, scenario 1, priority 2:

Almost all the halo current is expected to circulate in the divertor
→ conservative scenario for vessel verification with higher forces at the interface between vessel & divertor
(DVDE scenario 1)

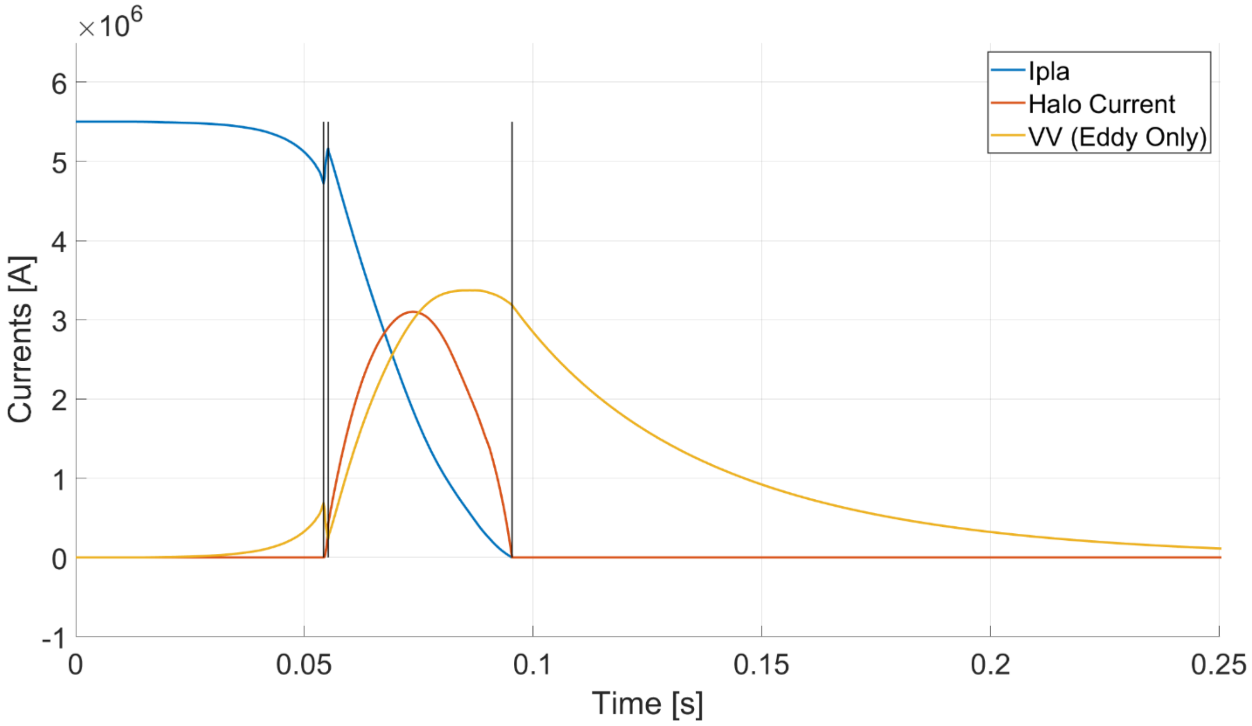
DMD (MD2) slow, scenario 2, priority 2:

Halo current circulating in the vacuum vessel (in particular 100%) with longer path and higher B_{tor}
→ significant for the verification of vacuum vessel and in-vessel components
(DVDE scenario 2)

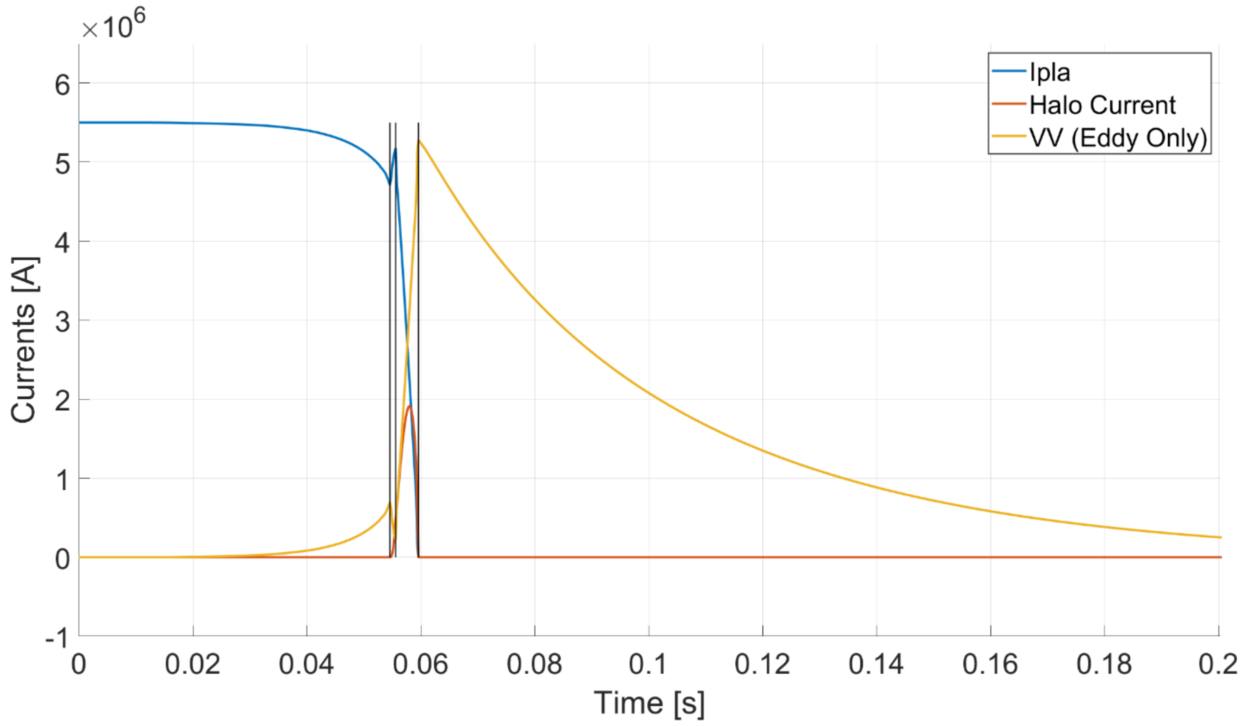
Maxfea simulations
Downward VDE 1/2

Graphs with time evolution of plasma current, halo current, and vessel current

- DVDE slow
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.564



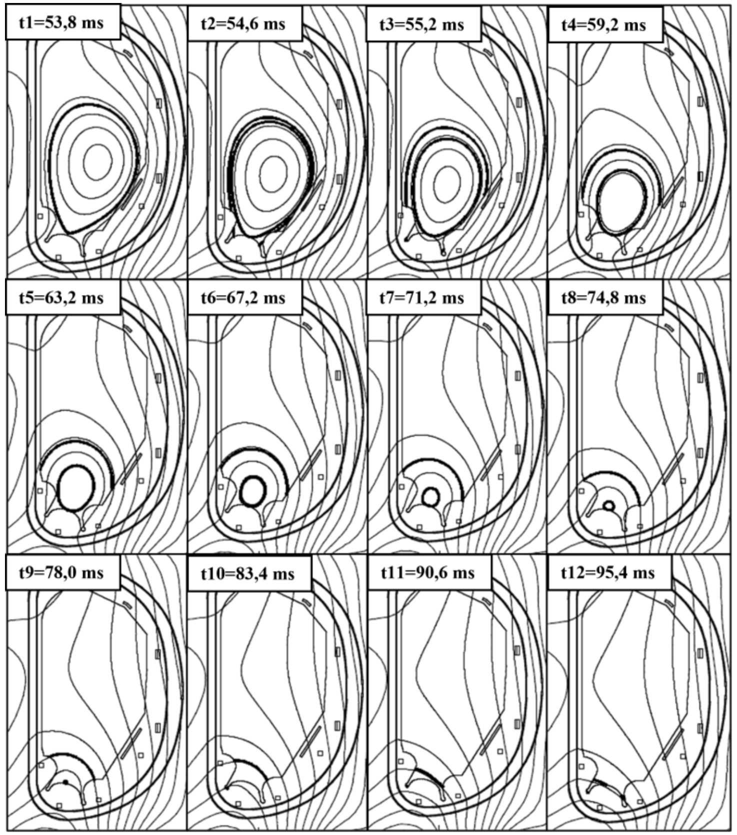
- DVDE fast
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.348



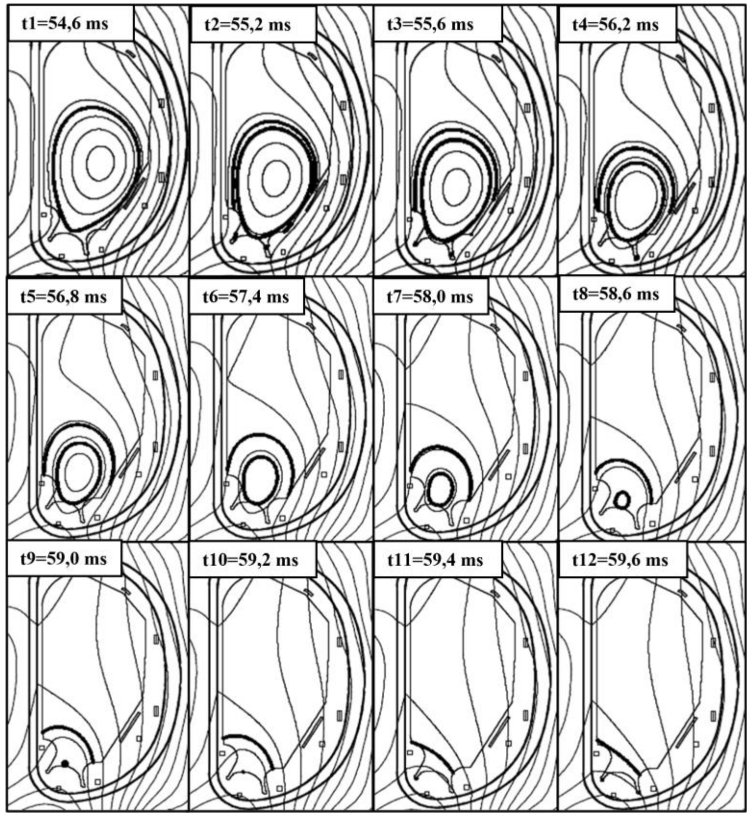
Maxfea simulations
Downard VDE 2/2

Images of shape evolution of the simulated plasma with positions of plasma boundary approaching the surfaces of in-vessel components is shown in the sequence with reference to the simulation time steps

- DVDE slow



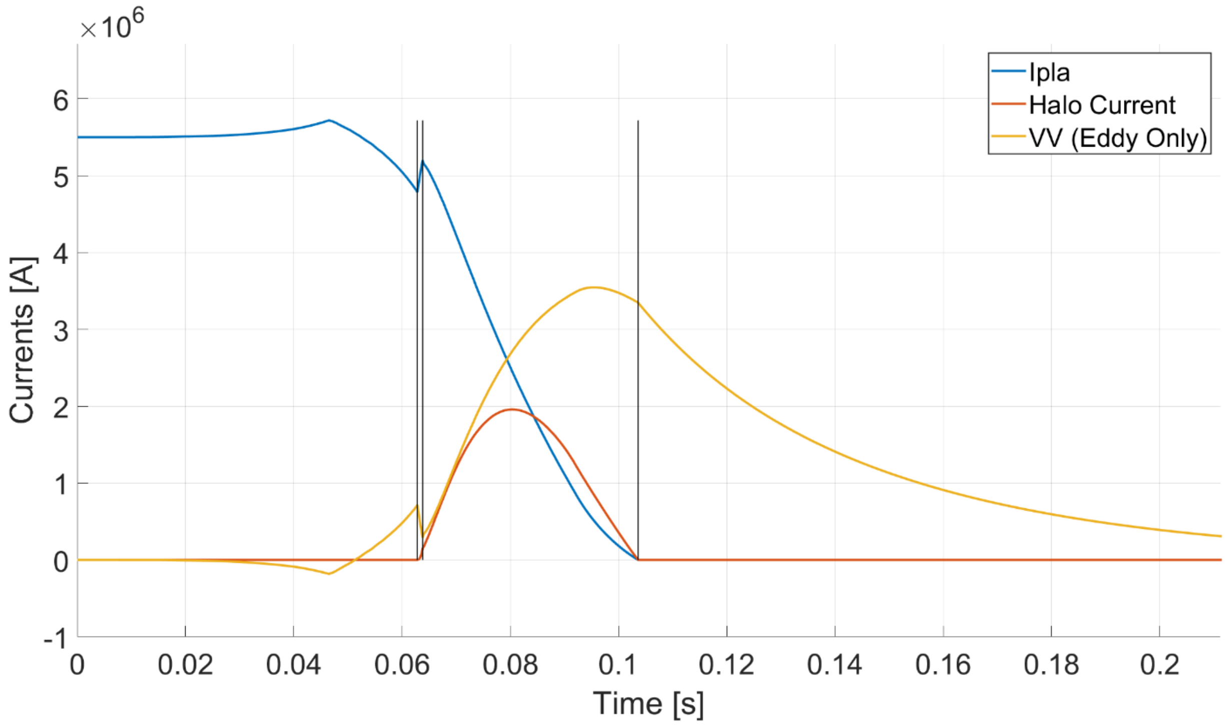
- DVDE fast



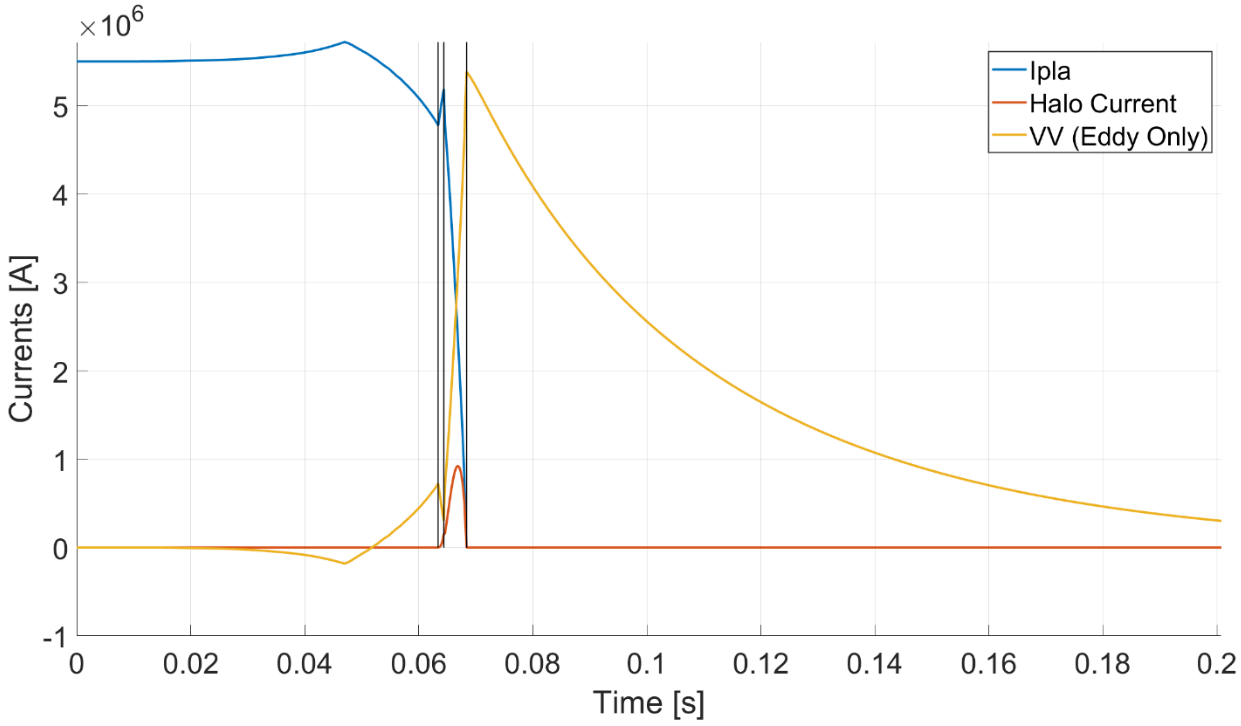
Maxfea simulations
Upward VDE 1/2

Graphs with time evolution of plasma current, halo current, and vessel current

- UVDE slow
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.356



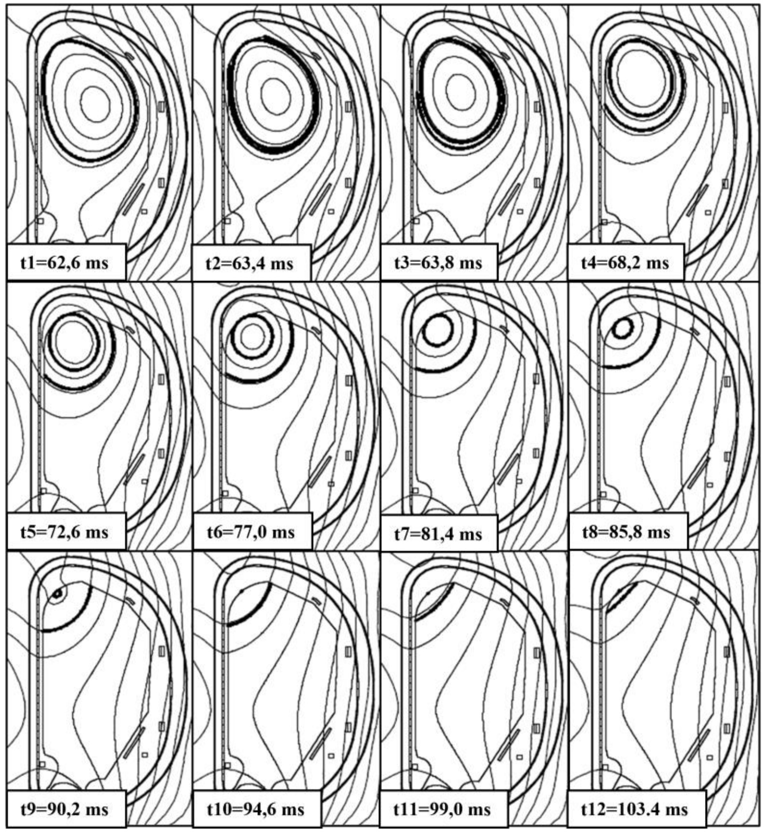
- UVDE fast
- Maximum halo factor (I_{halo}/I_{plasma}) = 0.168



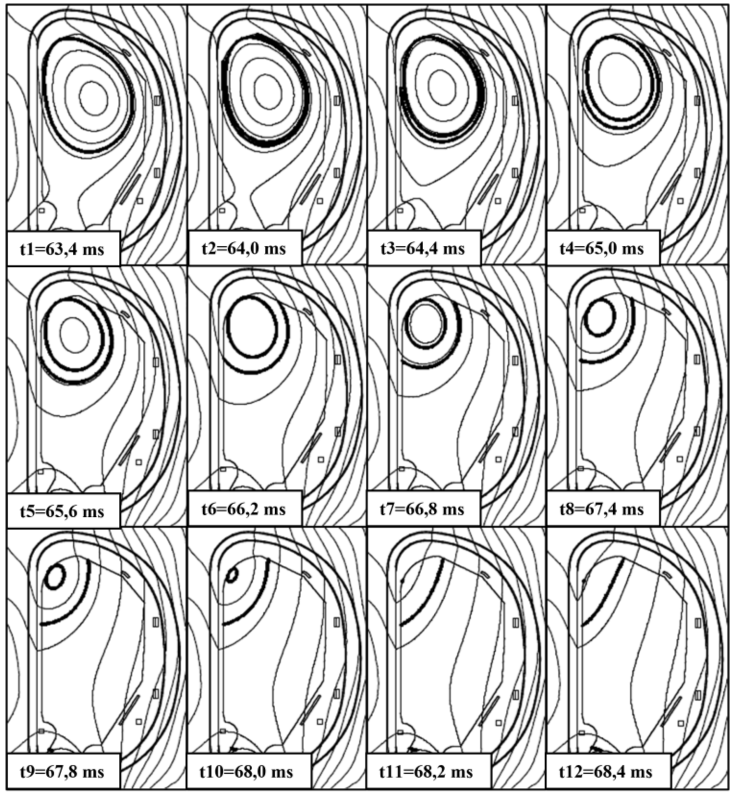
Maxfea simulations
Upward VDE 2/2

Images of shape evolution of the simulated plasma with positions of plasma boundary approaching the surfaces of in-vessel components is shown in the sequence with reference to the simulation time steps

- UVDE slow



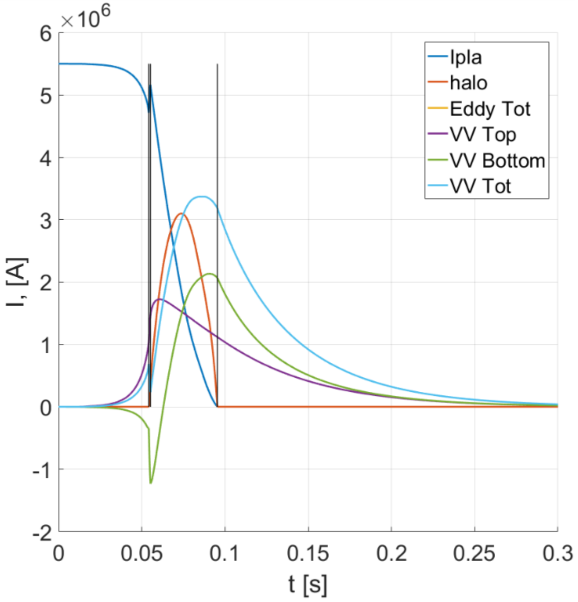
- UVDE fast

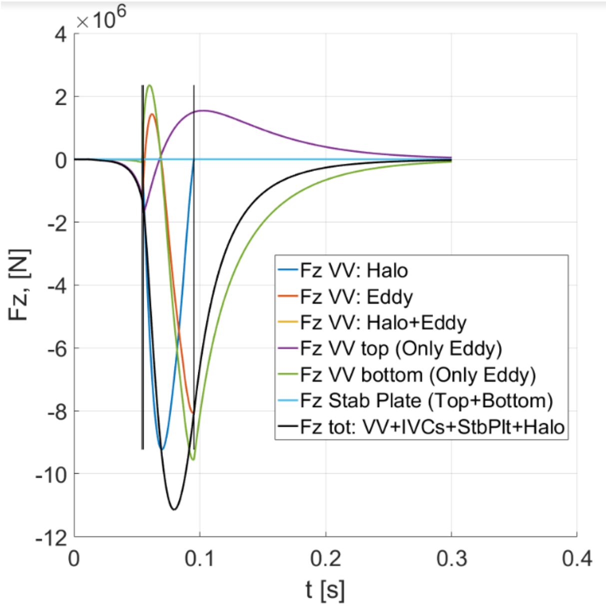


Maxfea simulations – DVDE in SN and XD

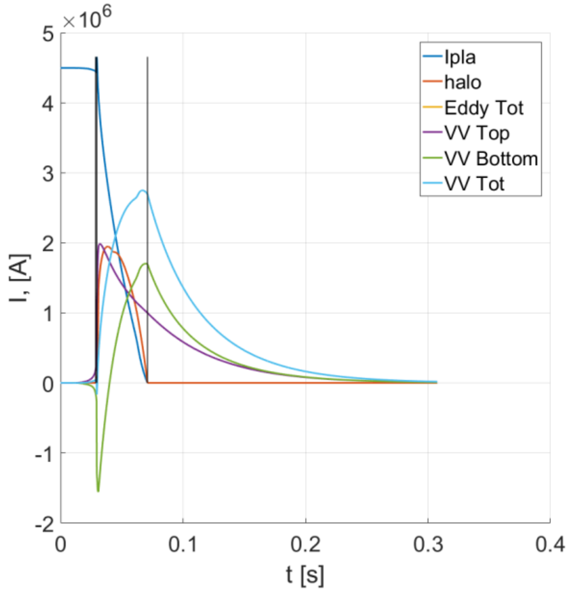
DVDE slow

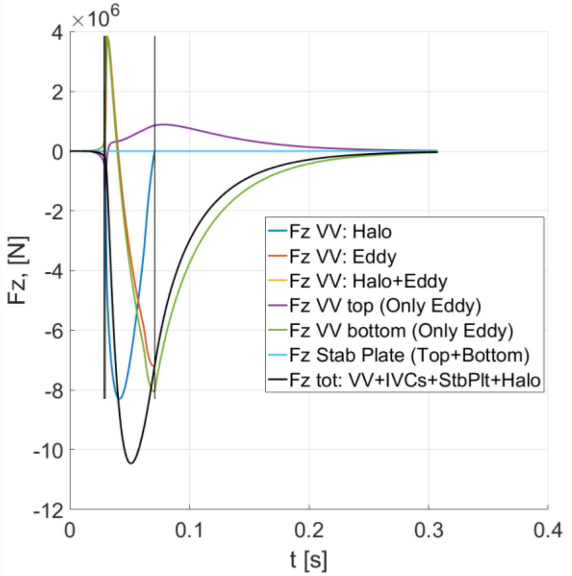
SN





XD



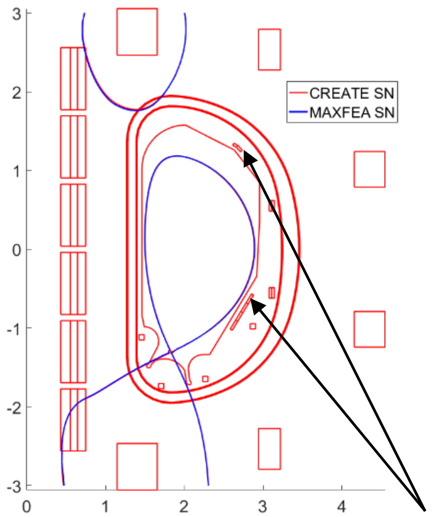


	SN	XD
Fz [MN]	-11.1	-10.5
Halo factor	0.56	0.43
Max eddy [MA]	3.37	2.75

- Comparable total Fz with small eddy and halo currents
- Probably XD has lower force concentrations (smaller currents) - under investigation

Maxfea simulations
Eddy currents assumptions - halo factor

- Plasma excitation analyses (MAXFEA) consider only the vacuum vessel as passive component for current circulation, whereas also in-vessel components will contribute slowing down the evolution of plasma events
  - ➢ analyses produce higher currents circulating in the vacuum vessel and faster plasma events corresponding to conservative scenarios for the purpose of these analyses
  - ➢ reliable results although the plasma evolution is not consistent when including also the in-vessel components

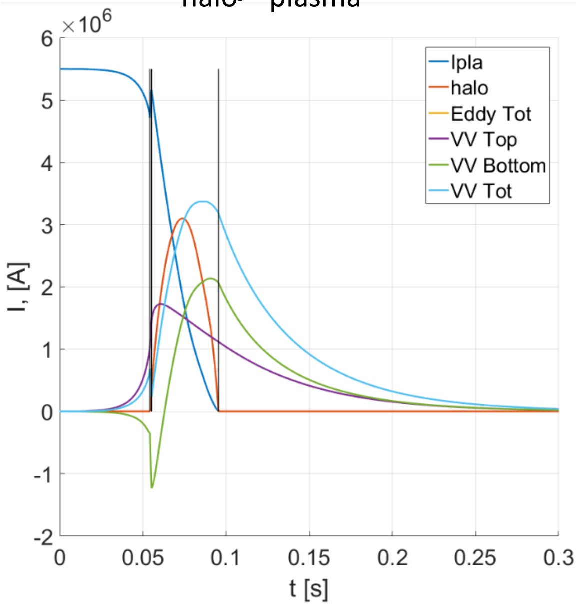


STAB PLATE

DVDE slow

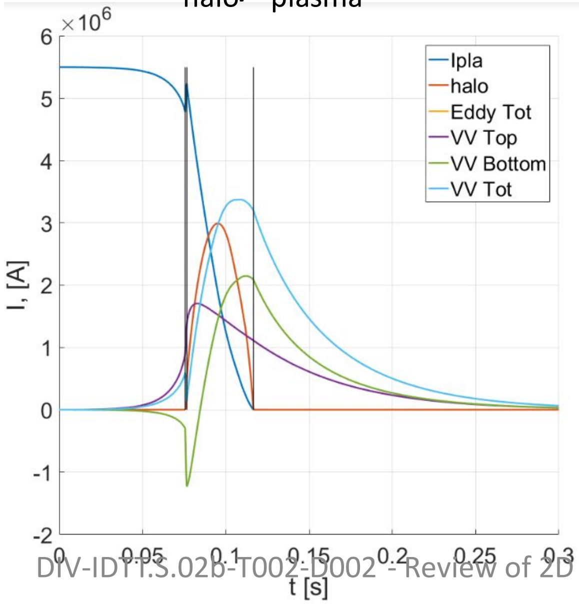
ONLY VV

$I_{halo}/I_{plasma} = 0.56$



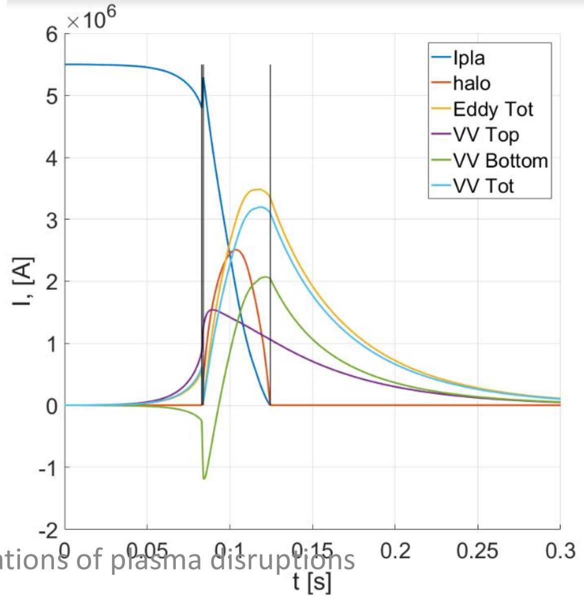
VV + STAB PLATE (ANTISERIES CONNECTION)

$I_{halo}/I_{plasma} = 0.54$

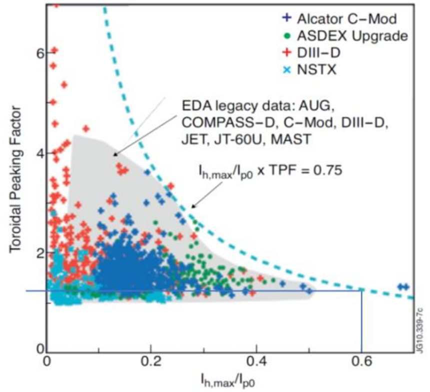


VV + STAB PLATE (TOROIDAL CONTINUOS)

$I_{halo}/I_{plasma} = 0.45$

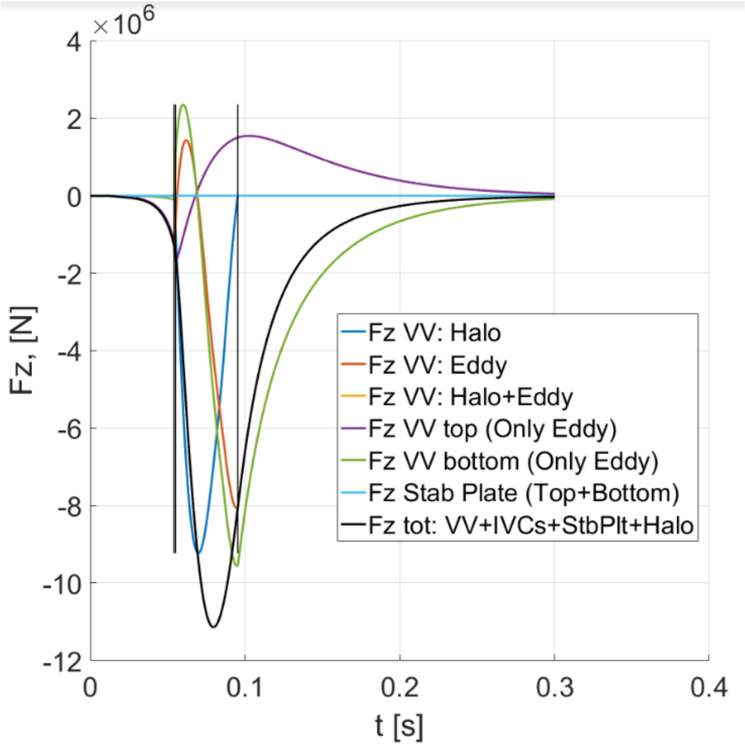


- MAXFEA computes the halo current needed to stabilize the plasma starting from the force balance
- The observed halo factor in ITPA database is lower than the MAXFEA predicted ones

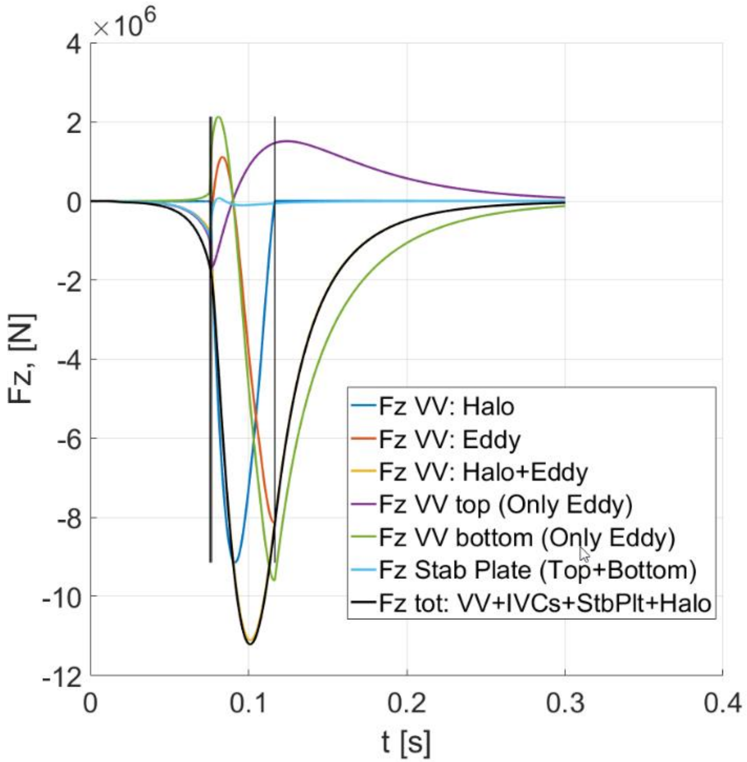


Maxfea simulations
Eddy currents assumptions - forces

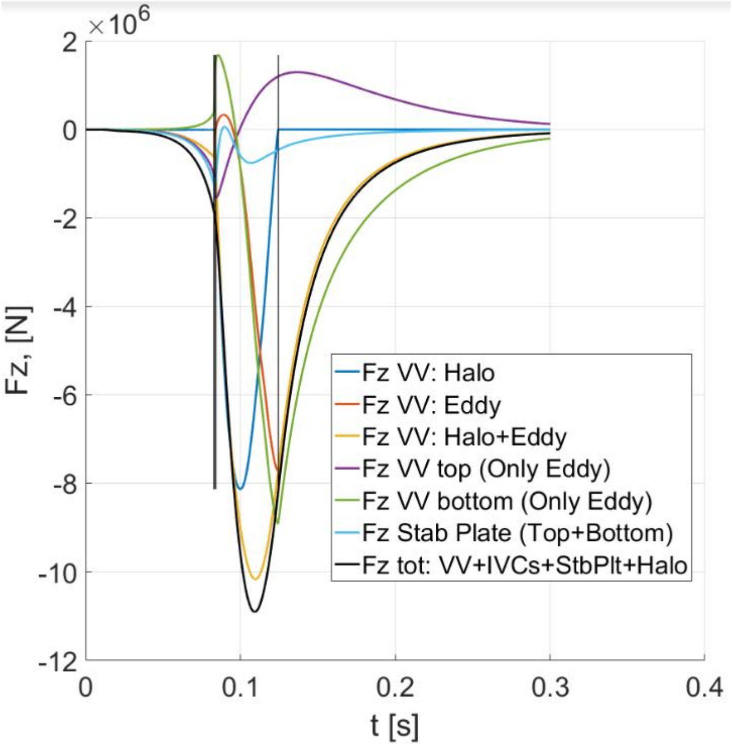
ONLY VV



VV + STAB PLATE
(ANTISERIES CONNECTION)



VV + STAB PLATE
(TOROIDAL CONTINUOS)



Halo currents path
Assumptions

- Loads due to the poloidal halo currents in the vessel are considered for MDs and VDEs
- Loads correspond to the point in time when the halo current reaches its peak
- Entrance and exit points of halo currents are assumed for alternative scenarios:
    1. almost all the halo current is expected to circulate in the in-vessel component involved in the discharge (e.g. divertor) with current entrance/exit positioned at the ends (longer path) of the component
       → conservative scenario for vessel verification with higher forces at interfaces btw vessel & component
    2. halo current circulating in the vacuum vessel (in particular 100%)
       → significant for the verification of vacuum vessel and in-vessel components
- Combinations of scenarios 1 & 2 with distribution of current fractions can be considered in the next analysis stage
- Longer halo current paths are considered at the inboard or outboard wall resulting in a more severe and hence conservative pressure load
- Directional electrical properties of simulated components are implemented in the FE model, in particular at the vessel supports on the vessel
- Electrical properties define all possible paths of halo and eddy currents
  → calculated paths of halo and eddy currents depend on actual resistances and inductances