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Current flows towards the divertor during VDEs at COMPASS

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Motivation: Asymmetric Toroidal Eddy Currents

Asymmetric toroidal eddy currents (ATEC)

- [Roccella *et al*., Nucl. Fusion 56, 2016]
- Plasma touches the wall
- Short-circuit between divertor plates occurs
- Eddy currents flow in the divertor tiles and through the gaps between them

Consequences:

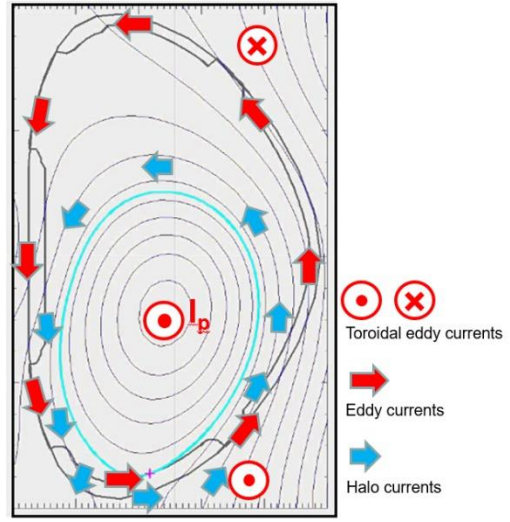
- Force acting on the in-vessel components (vertical current current flowing from the vessel to the tile interacts with the toroidal magnetic field)
- Misinterpretation of magnetic coils measurements (in case they are located behind divertor/limiter structures)

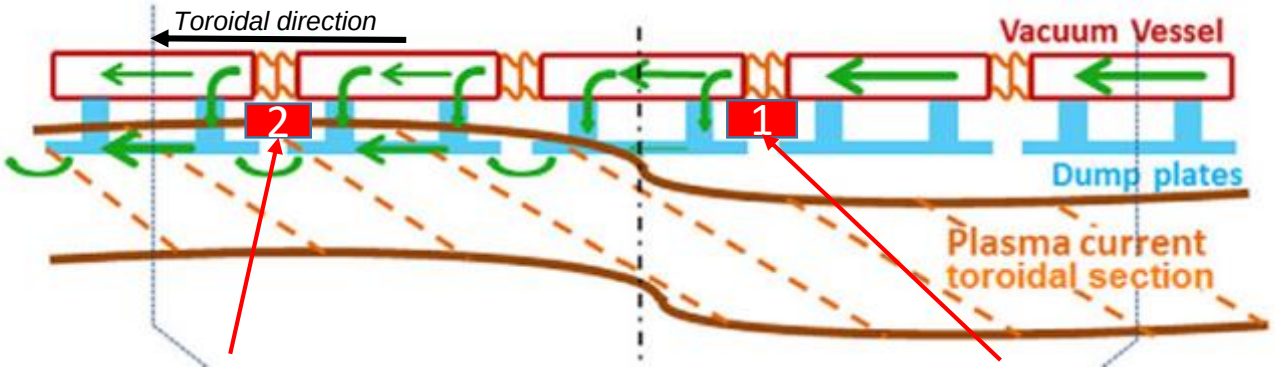
Aim of the experiment:
Test ATEC model using special divertor tiles

Current quench → currents in the wall

Inductive:
Toroidal and poloidal currents in the wall

Halo currents:
In plasma:
flow along open magnetic field lines
In the wall:
path is not restricted by magnetic field





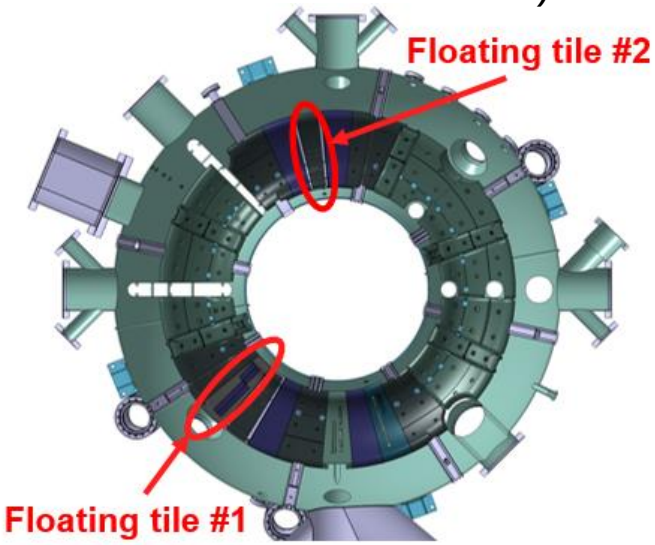
Magnetic coil detects I_p and part of eddy current flowing between the divertor tiles

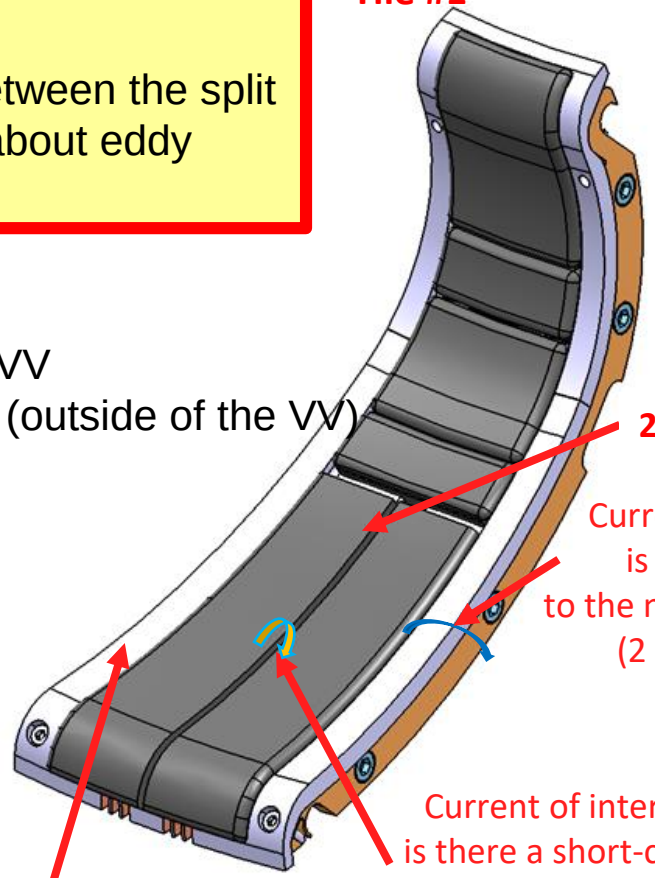
Magnetic coil detects I_p

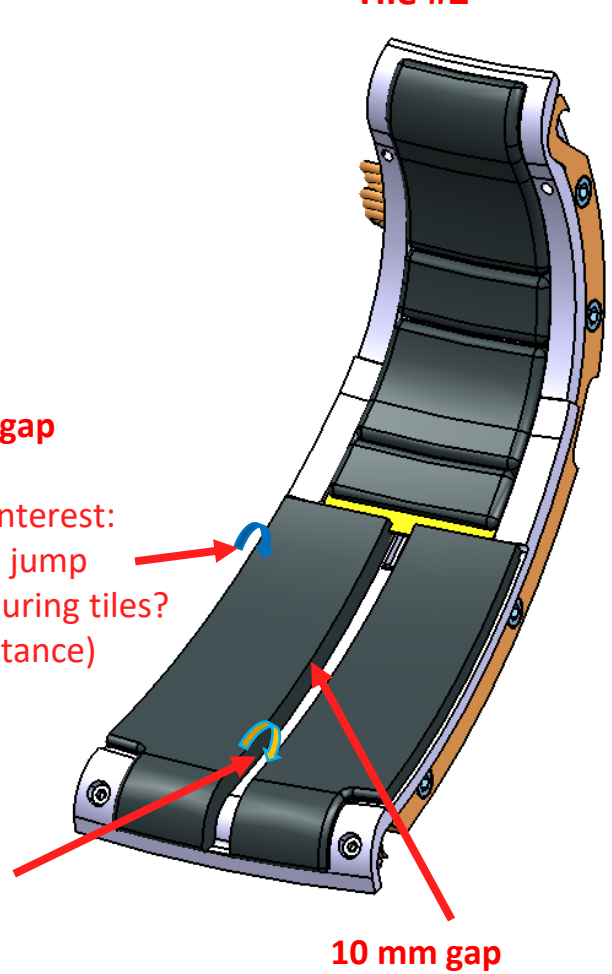
Special divertor tiles

- 2 special divertor tiles with gaps
- Measurements of current flows to the tile's segments separated by the gap during disruption. Difference between the split segments measurements might provide information about eddy currents path

- Tile is insulated from the wall inside the VV
- Each tile has 6 measuring segments
- Each segment is connected to the wall outside of the VV
- Current in the segment is measured by Rogowski coil (outside of the VV)
- LFS segments are separated toroidally by gaps (2,5 mm at tile #1 and 10 mm at tile #2)







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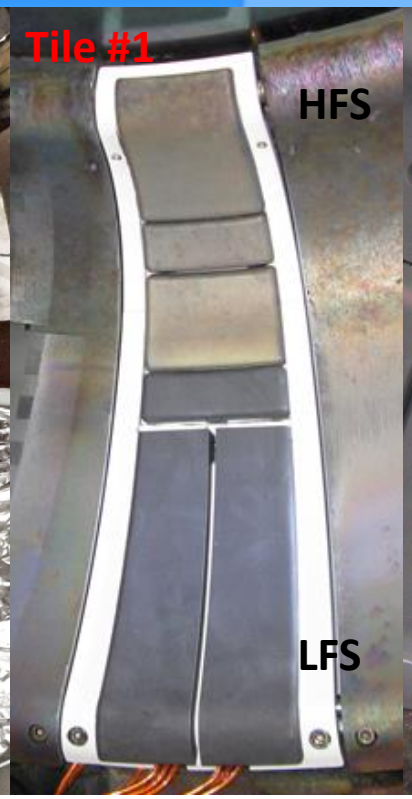
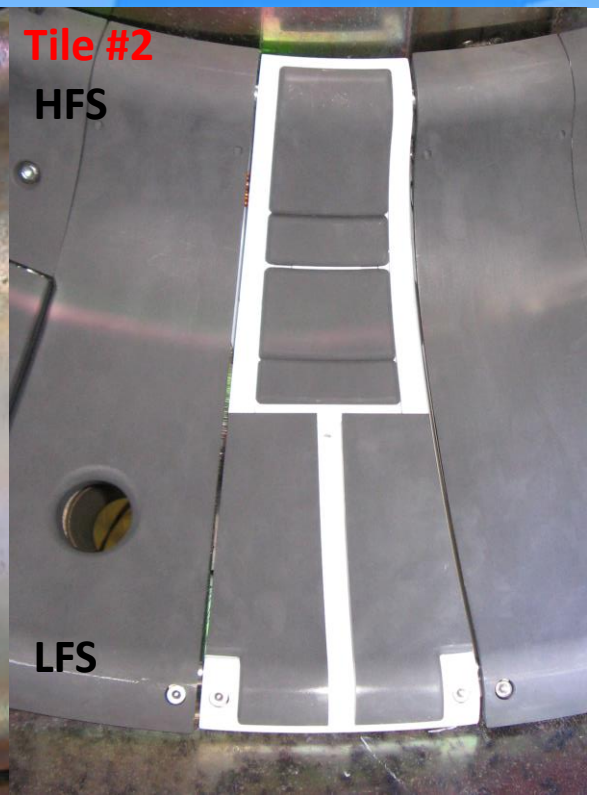
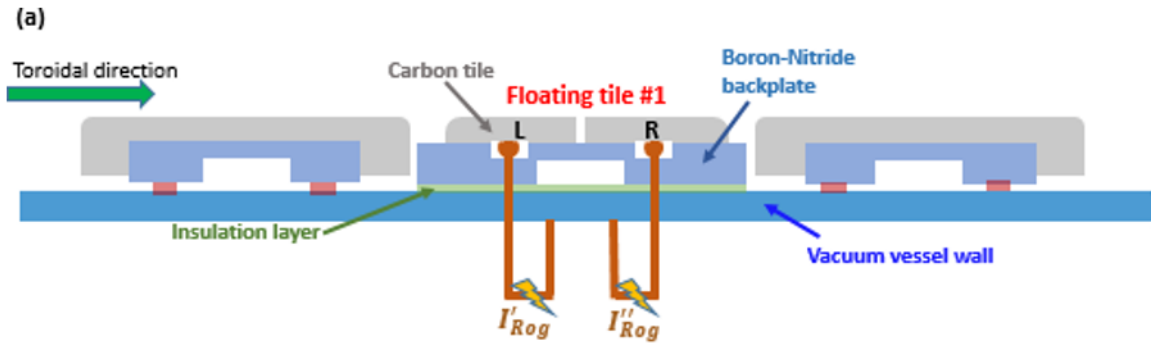
Experiments







- Tile is insulated from the wall inside the VV
- Each tile has 6 measuring segments
- Each segment is connected to the wall outside of the VV
- Current in the segment is measured by Rogowski coil (outside of the VV)
- Focus on LFS segments Left (L) and Right (R) (separated toroidally by gaps) (2,5 mm at tile #1 and 10 mm at tile #2)

Experiments:

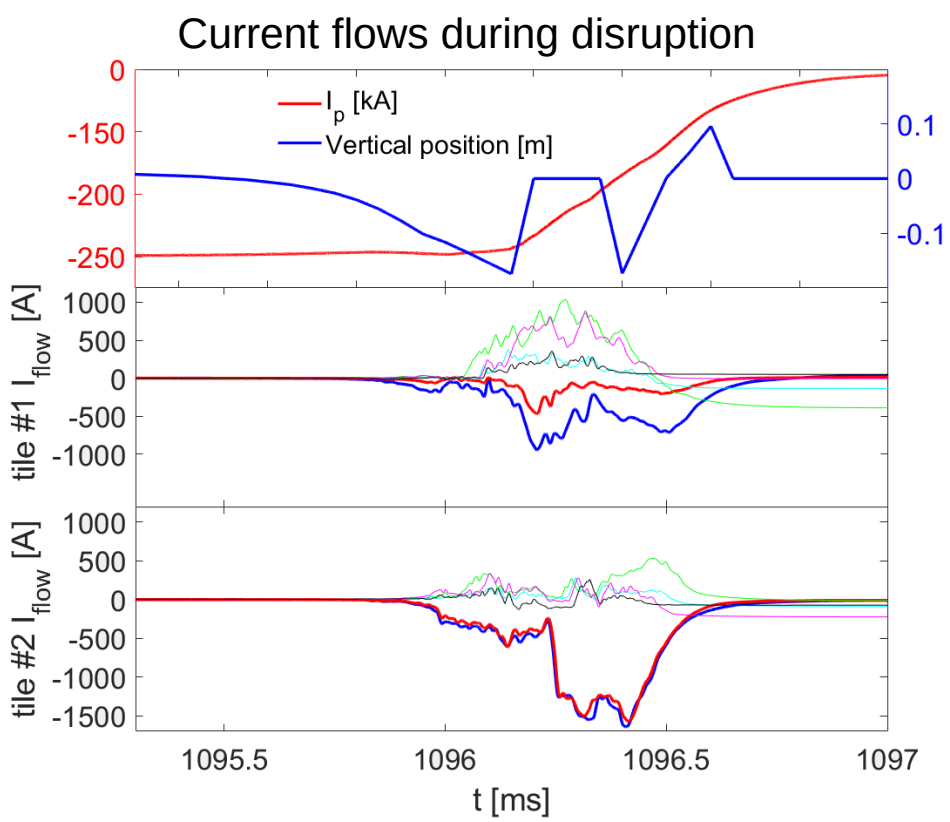
- Forced downward disruption (towards divertor tiles)
- 102 dedicated discharges
- Repeat the same plasma parameters I_p = 300 kA (with standard and reversed I_p a B_t)
- The tiles are left in the VV as a piggyback experiment

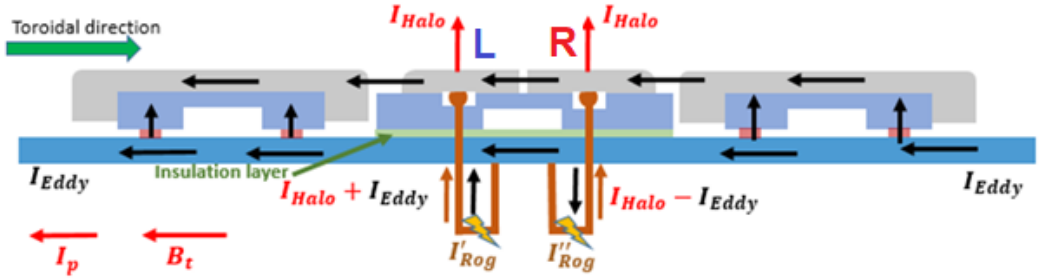
Results

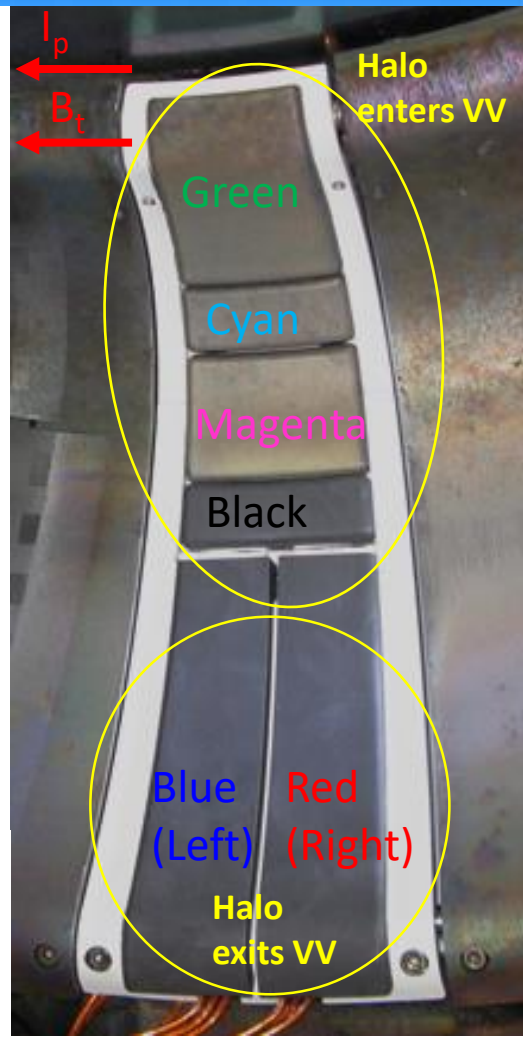
Tile's segments measure:
- **Halo current** (we assume that it is symmetric for the Left and Right segments)
- **Part of the eddy current** from neighboring segments
  (if there is a short-circuit through the gap)

Grounded segments:
- Tile is insulated from the wall inside the VV
- Segments are connected to the VV (outside of the VV)
- Currents up to 1.5 kA are measured
- LFS and HFS segments have different signs: Halo current enters the VV at HFS and exits at LFS

- Tile #1: Left and right segments' measurements are not symmetric. What is the reason?
- Tile #2: Left and right segments' measurements are symmetric







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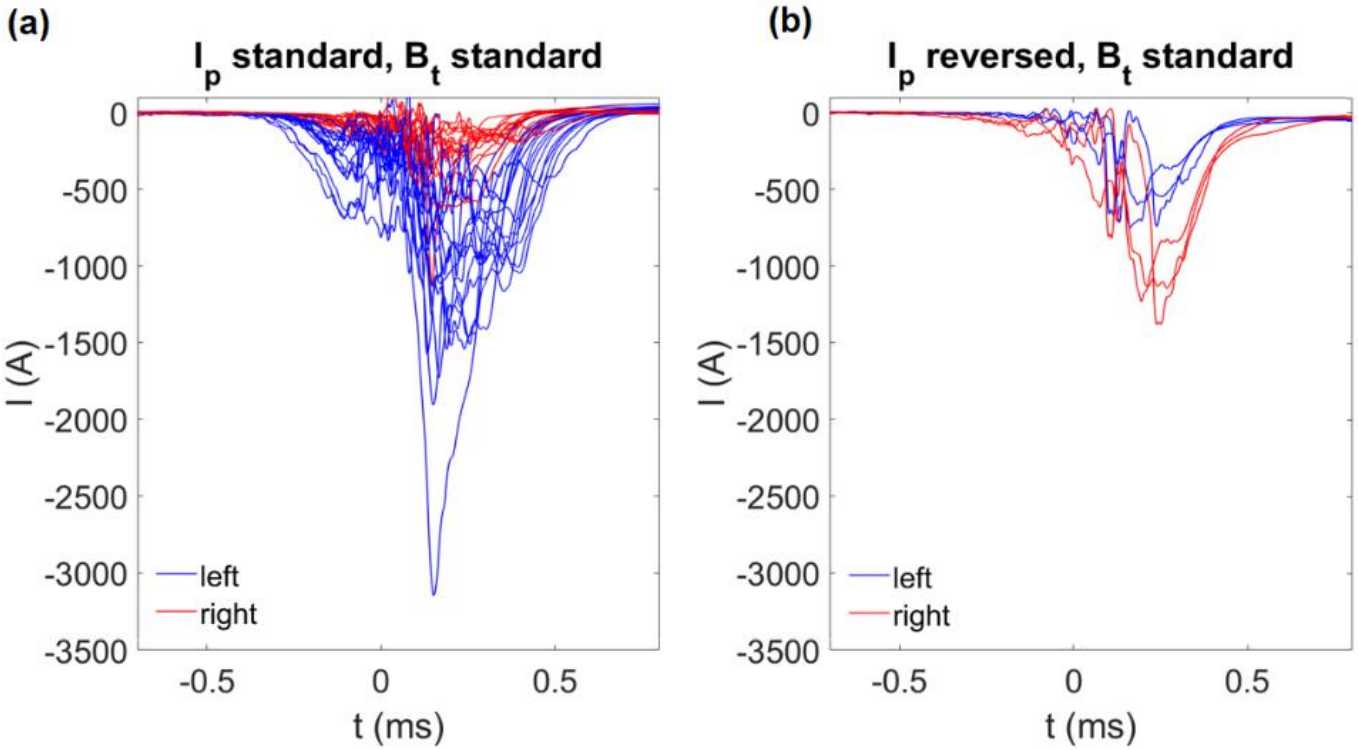
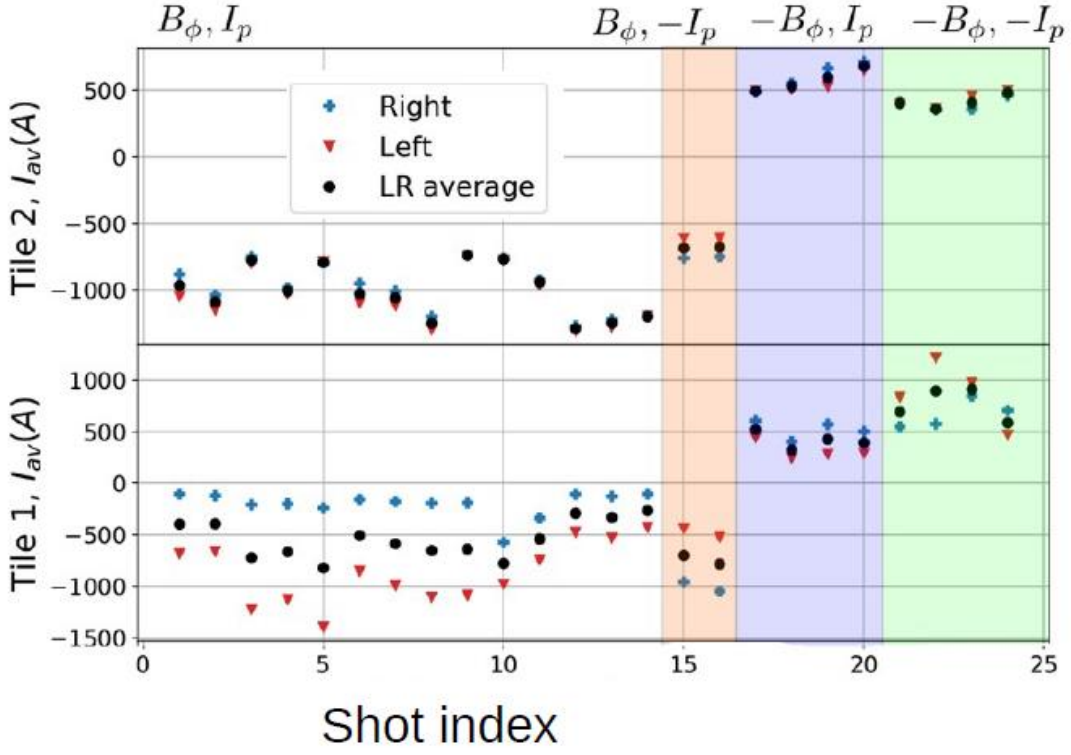
Results: Dependence on I_p and B_t direction

Find out the reason behind Tile #1 non-symmetric current flows:
- Dependence on I_p and B_t direction is observed

Tile #1 $\lvert I_{flow} \rvert$	Standard I_p	Reversed I_p
Standard B_t	left > right	right > left
Reversed B_t	right > left	left > right





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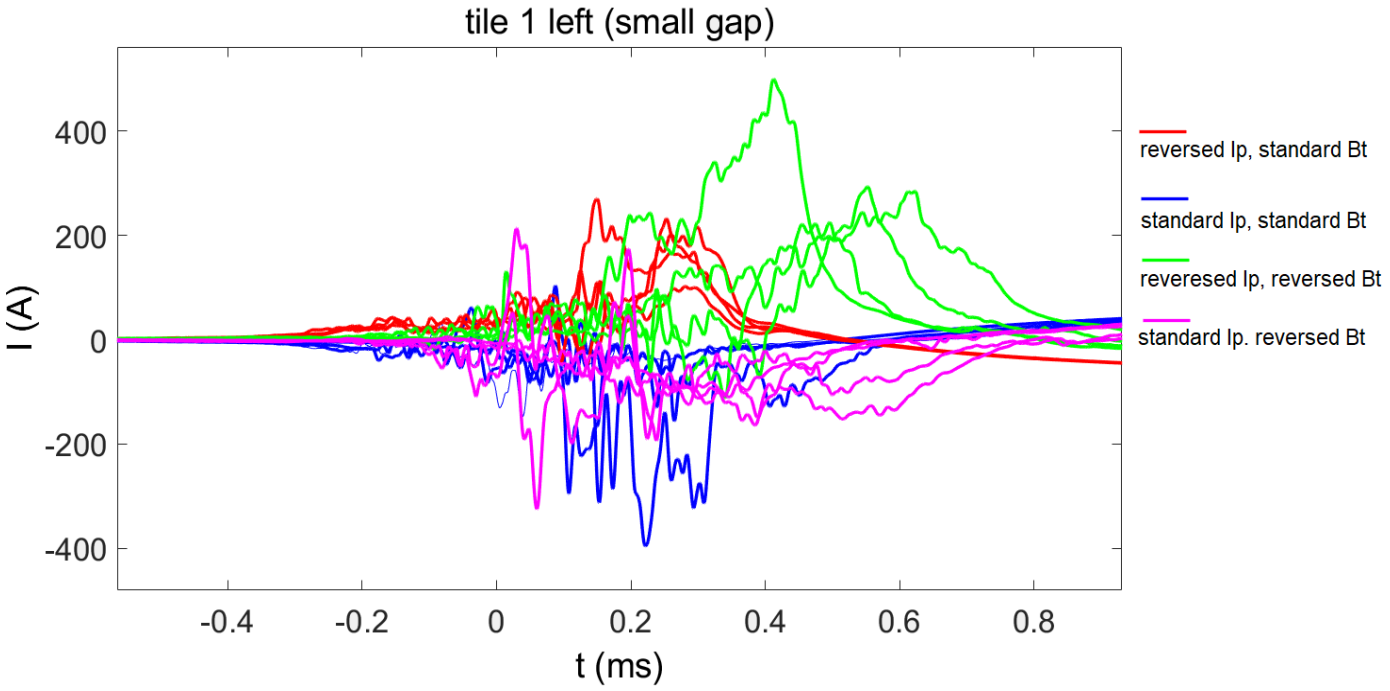
Results: Floating mode

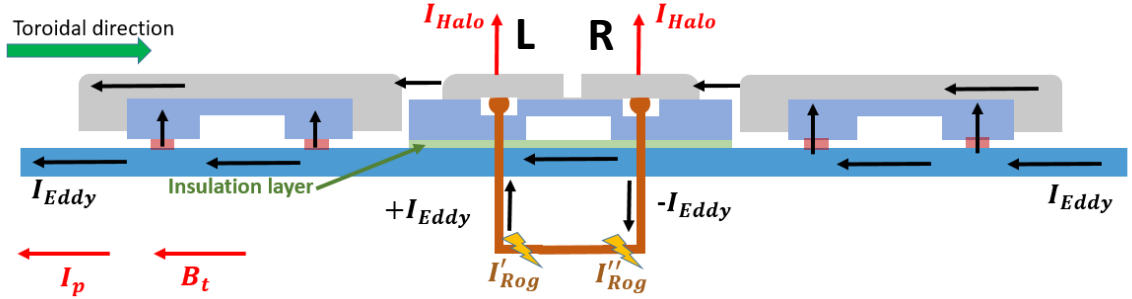
Floating segments:

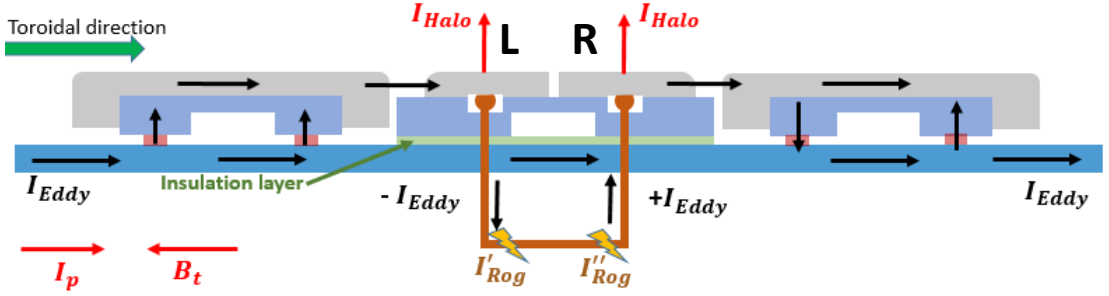
- The Left and Right segments are connected to each other outside of the VV
- There in no connection to the VV
- Currents up to 1 kA are observed
- Current flows depend on I_p and B_t directions

Tile #1	Standard I_p	Reversed I_p
Standard B_t	co-I_p	co-I_p
Reversed B_t	co-I_p	co-I_p

Tile #2	Standard I_p	Reversed I_p
Standard B_t	counter-I_p	counter-I_p
Reversed B_t	co-I_p	co-I_p







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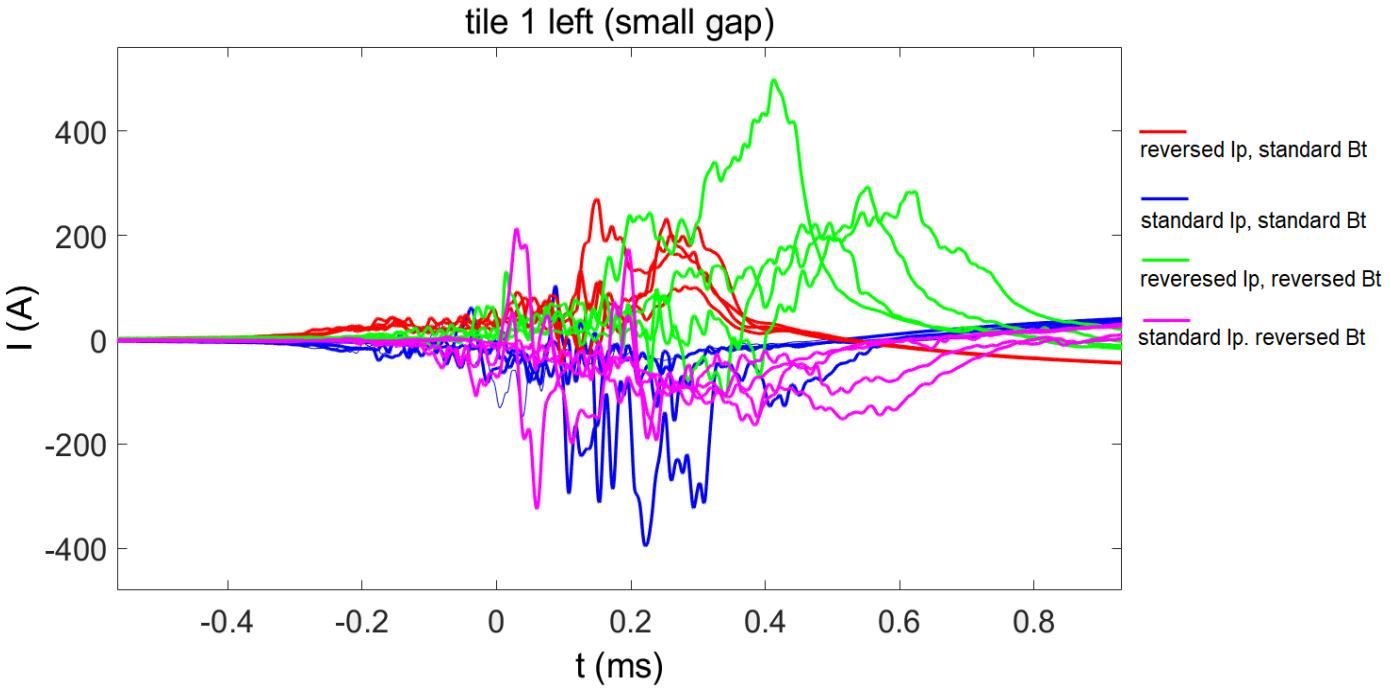
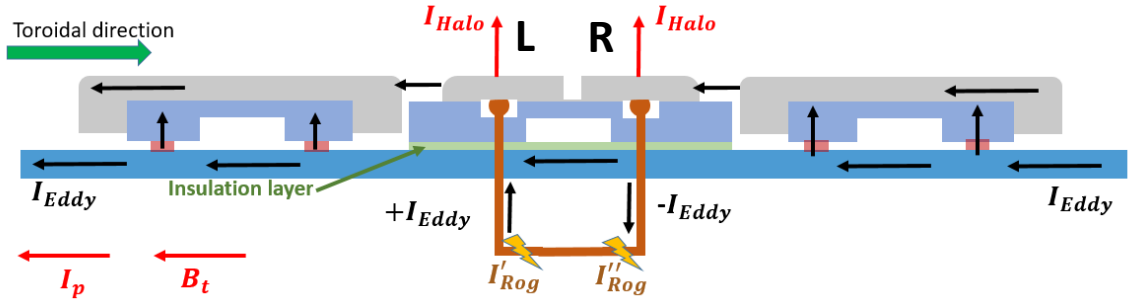
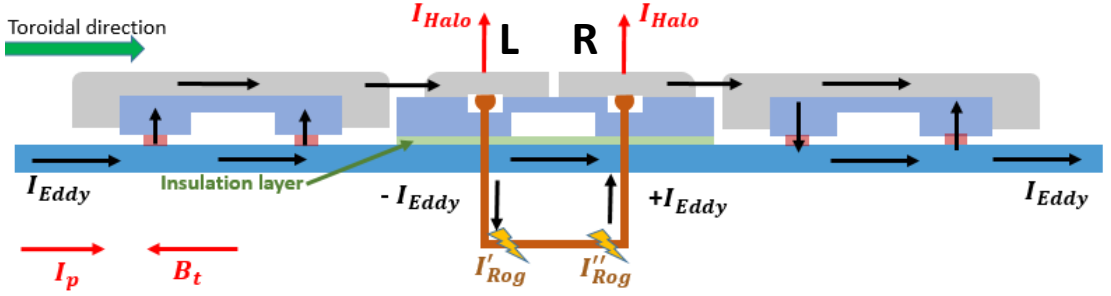
Results: Floating mode

Floating segments:

- Current flows observed in floating mode (up to 1 kA) are comparable to those measured in grounded mode (up to 1.5 kA)
- This is a sign of a shorts-circuit
- It is not clear where does this short-circuit occur. Possible options:
  1) through the gaps
  2) through the open magnetic field linen going to some other part of the vessel → short-circuit through the vessel





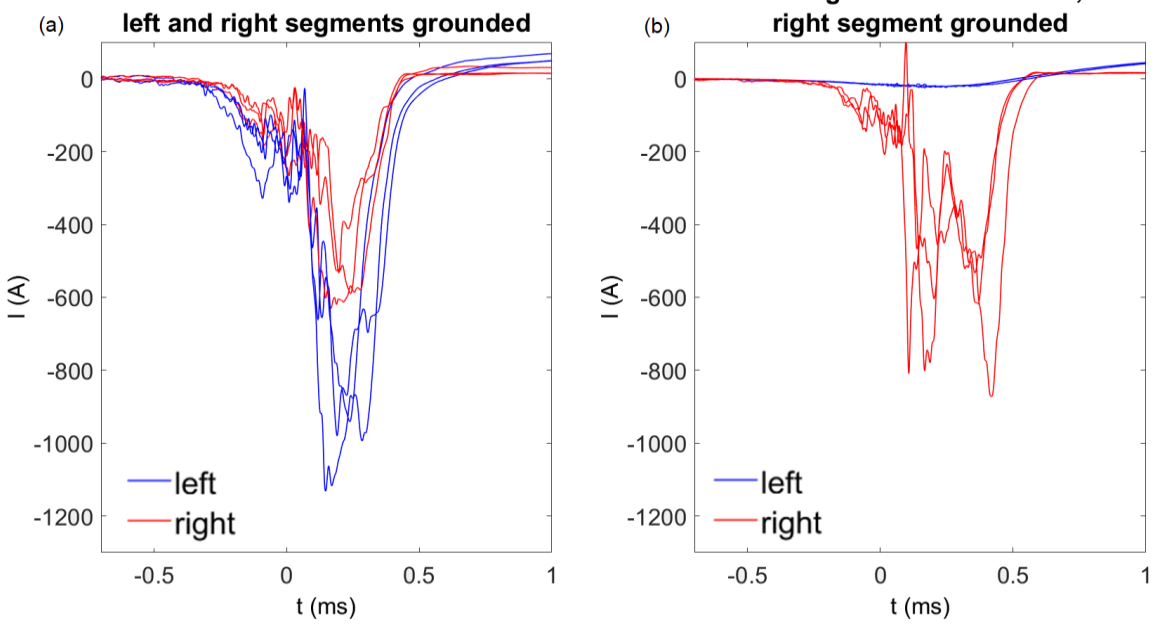


Results: Disconnected mode

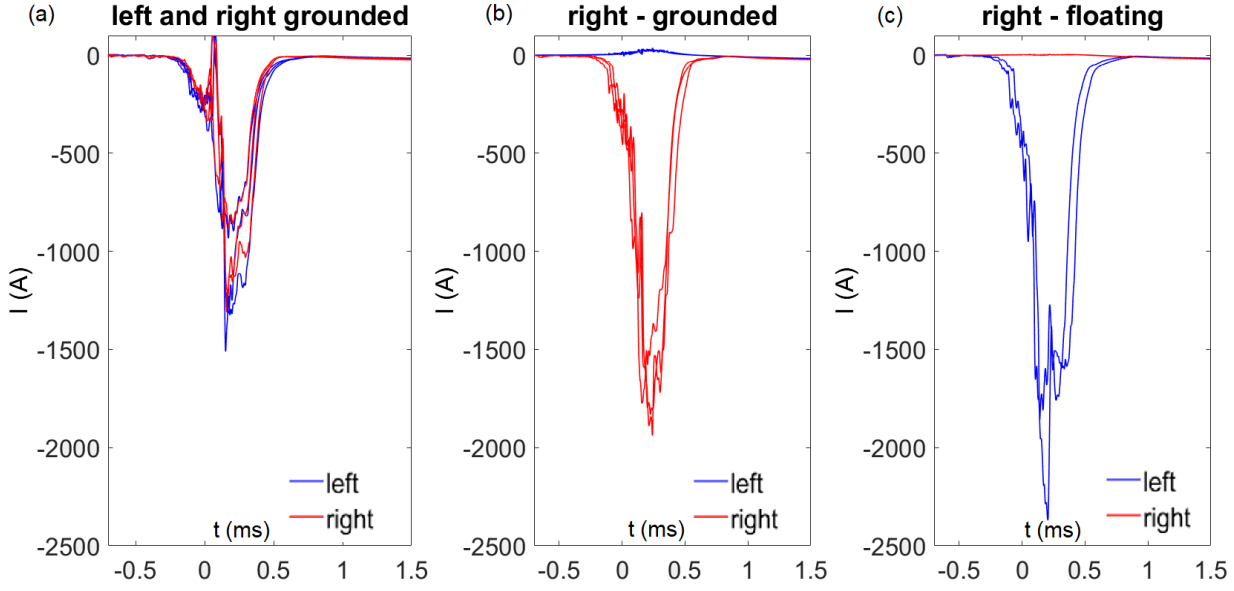
One segments is disconnected, its neighbour is connected to the VV:

- Does disconnection of one segment affect its neighbor? Could be a sign of eddy current flowing in the disconnected segment and transferred to its neighboring segment.
- Disconnection of one segment leads to slight increase of magnitude in the other segment. The effect is observed for both tile #1 and tile #2, but more statistics is needed

Tile #1



Tile #2



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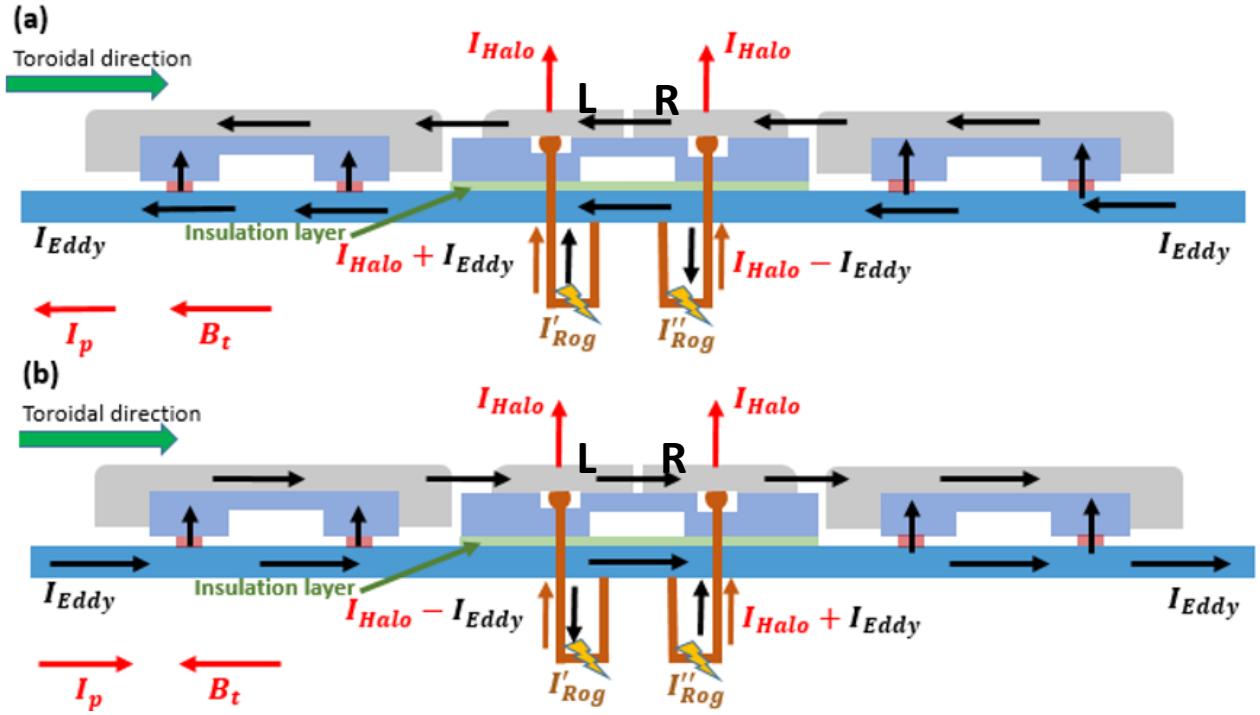
Hypothesis: Combination of Halo and eddy currents

Assumptions:
- Halo current to left and right segments is symmetric
- Gaps separating the segments toroidally are short-circuited (support ATEC model)

Measurements:
- Halo currents depend on B_t direction, but not I_p
- Eddy currents depend on I_p direction, but not B_t
- The segments measure sum or difference of Halo and eddy current across the gap depending on I_p and B_t directions

→ asymmetry between the left and right segments



Justifications:
- Tile #1 measurements (non-symmetric Left and Right segments)
- Significant currents observed in floating mode

Contradictions:
- Tile #2 do not exhibit the asymmetry

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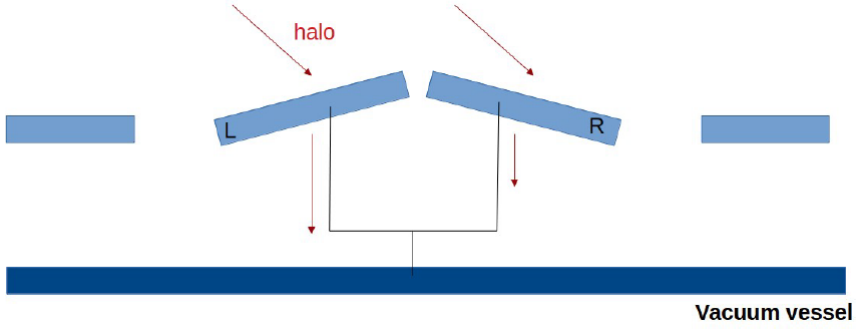
Hypothesis: Different wetted areas of the segments

Assumptions:
- Tile segments might be misaligned or shadowed by neighbouring
in-vessel structures

Measurements:
- Different Halo current is collected
depending on field lines incident angles

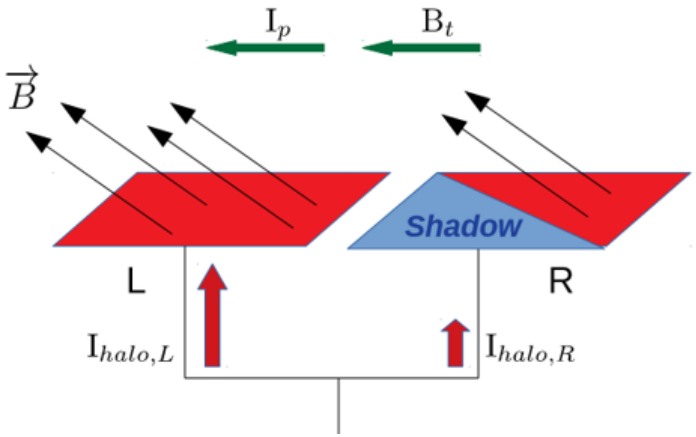
Justifications:
- Tile #1 and tile #2 exhibit different behaviour
- Shadowing of the tile #1 segments is observed, depends on I_p and B_t directions (fast visible camera)

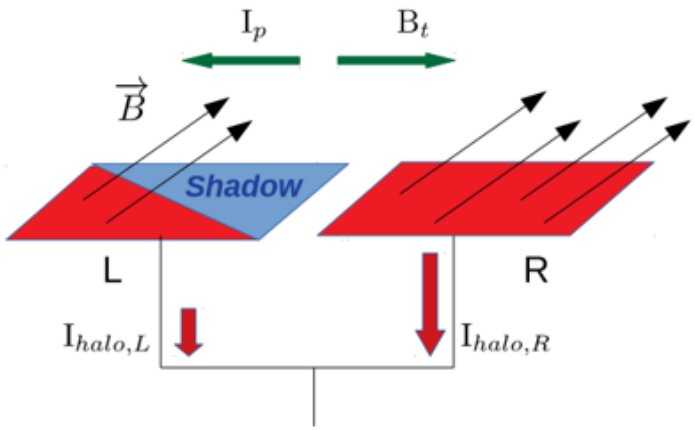
Contradictions:
- Tile #2 has significant current in floating mode
- Disconnection of one segment seem to affect its neighbour



#19509, Frame 728, t = 1095.6 ms

#19503, Frame 727, t = 1095.4 ms





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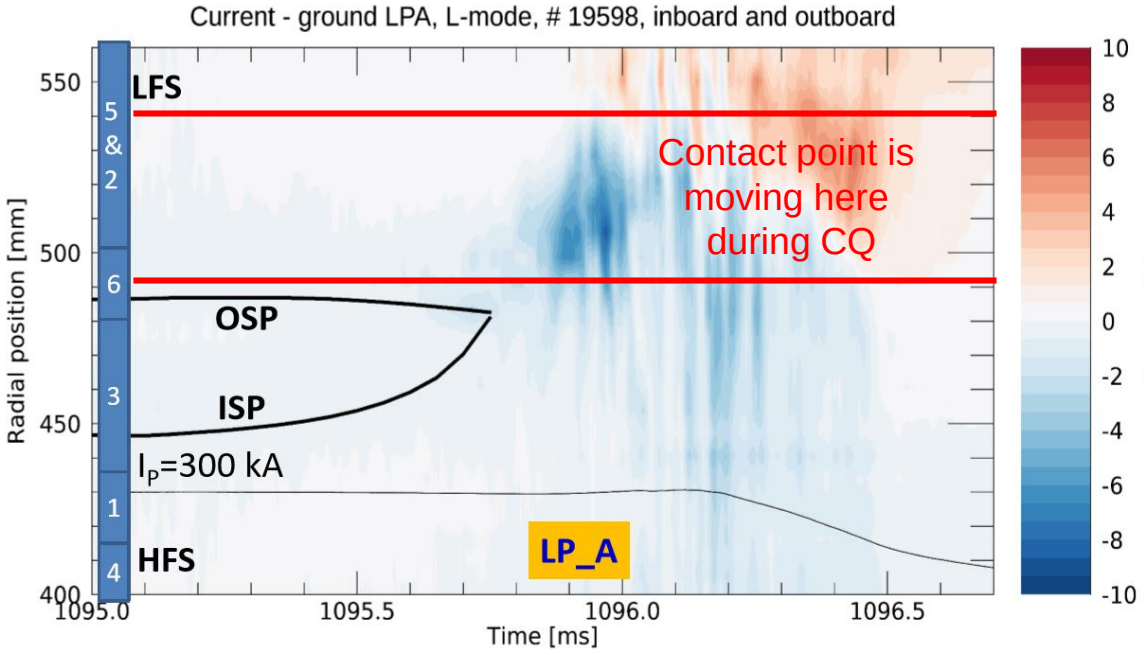
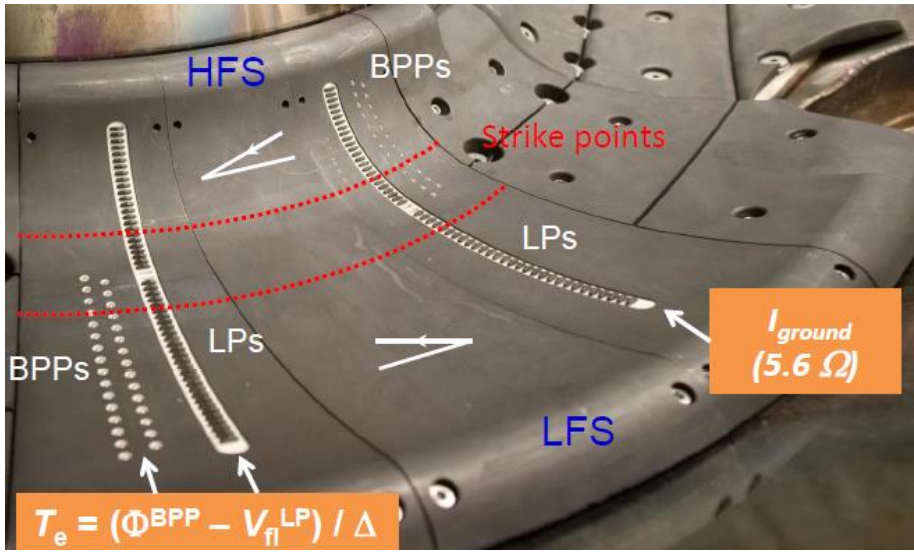
Results: Divertor probes

- Two arrays of divertor Langmuir probes allowing measurements of floating potentials with 1μs resolution
- The probes can be switched to grounded mode → current density profile detection
- Plasma limiter point is observed by the probes and is at the position where Left and Right segments of the special divertor tiles are located.
- Large positive floating potential is observed compared to T_e (~10 eV), broad current density profile (1-2 MA/ m^2).

It is suggested that Halo current might be limited by ion saturation current.
A separate dedicated experiment has been performed to confirm this





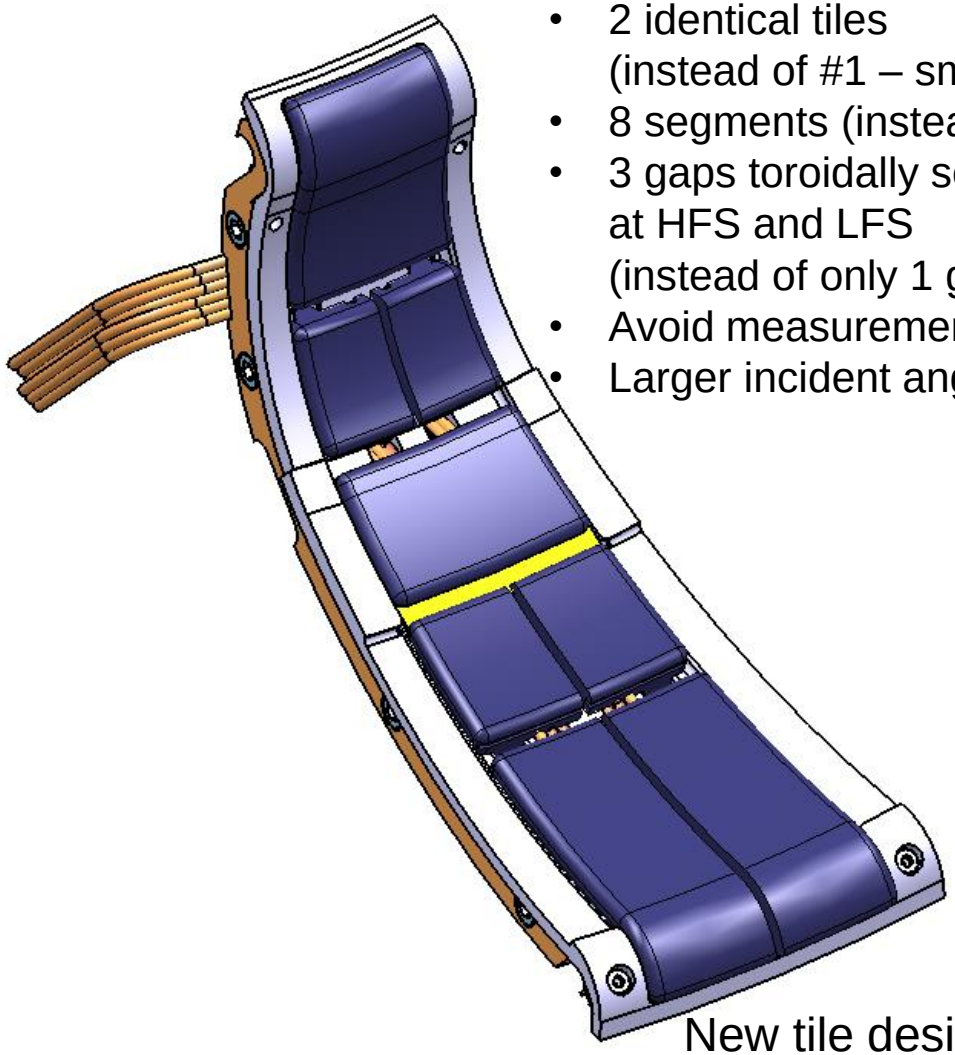
Conclusions and future plans

Conclusions:

- Current flows vary significantly from discharge to discharge with similar plasma parameters
- Tile #1 and tile #2 exhibit different trends: tile #1 has strong asymmetry between the toroidally separated segments in grounded mode, depends on I_p and B_t directions while tile #2 is almost symmetrical
- Significant currents are observed in floating mode for both tile #1 and tile #2, their nature is not always clear

New experiments with modified tiles' design:

- Exclude / confirm hypotheses:
  - Different wetted areas of the segments
  - ATEC model (combination of Halo and eddy currents is measured)



New tile design

- 2 identical tiles
  (instead of #1 – small gap, #2 – large gap)
- 8 segments (instead of 6)
- 3 gaps toroidally separating segments at HFS and LFS
  (instead of only 1 gap at LFS)
- Avoid measurements near the contact point
- Larger incident angles