MQXFA17 quenches

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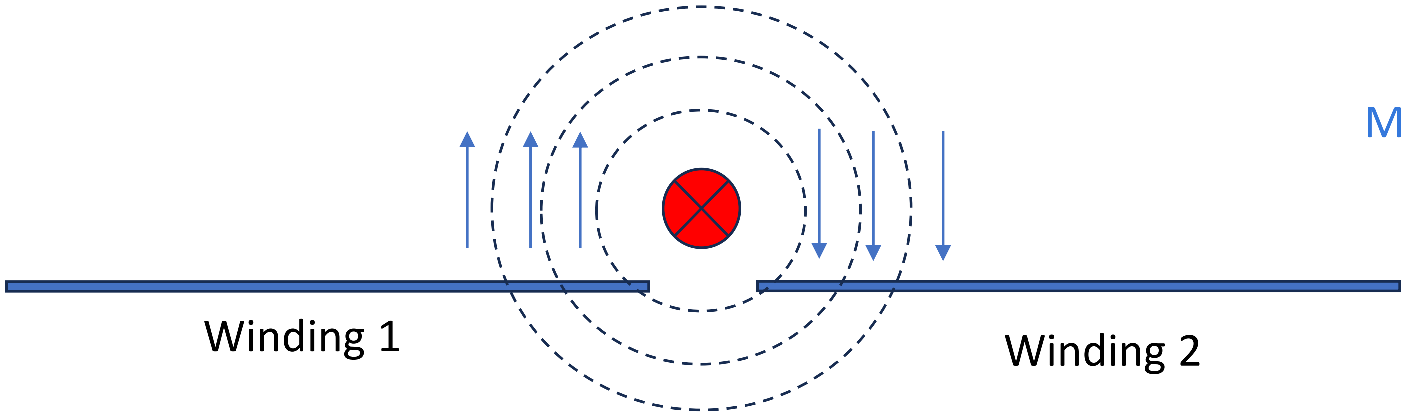
MQXFA QA basics



MQXFA QA are comprised of winding loops.

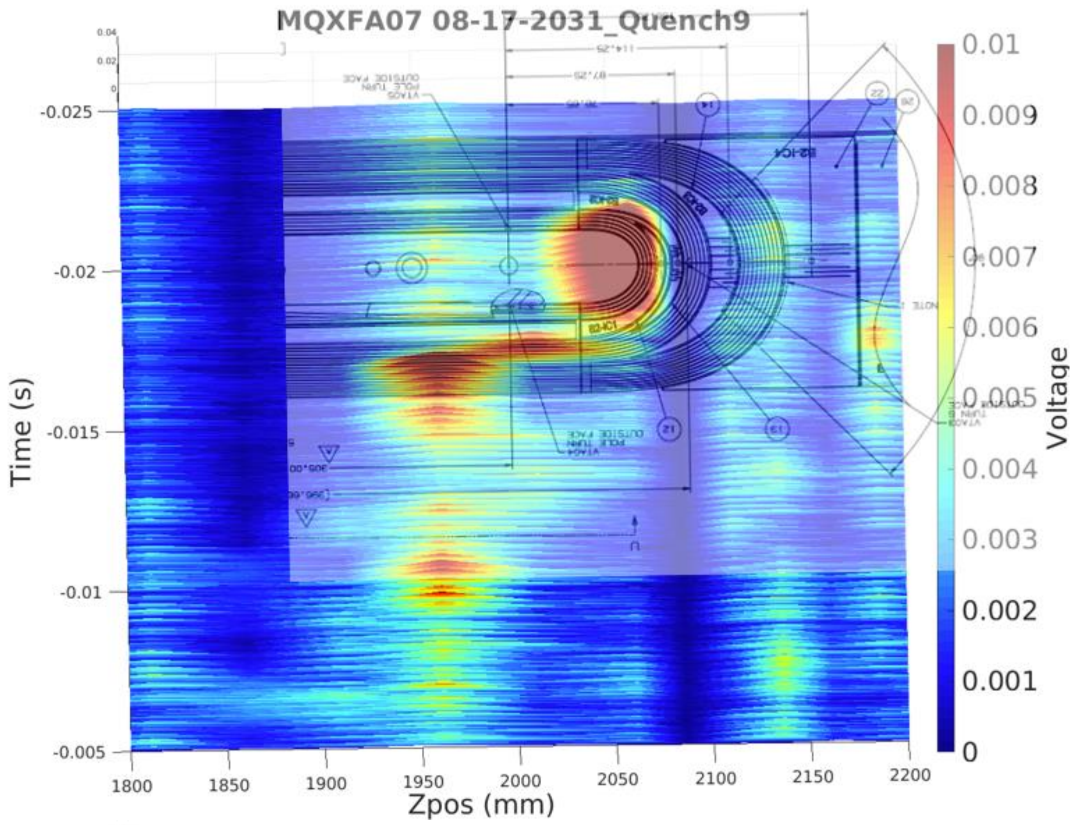
For the current line (red) and flux lines shown, Winding 1 and Winding 2 will measure opposite sign voltages if the flux changes – if we connect them in series, we'll measure nothing.

However, we can connect them in series with opposite polarities and then we'll measure double of what we measure with a single winding in the configuration shown.
We can denote the polarity of each winding as "+" or "-", and note that each 10 cm-long MQXFA QA Z-channel is comprised of six such "windings", in alternating +/- polarity azimuthally (sextupole symmetry), to cover the full 360 degrees at each Z position.

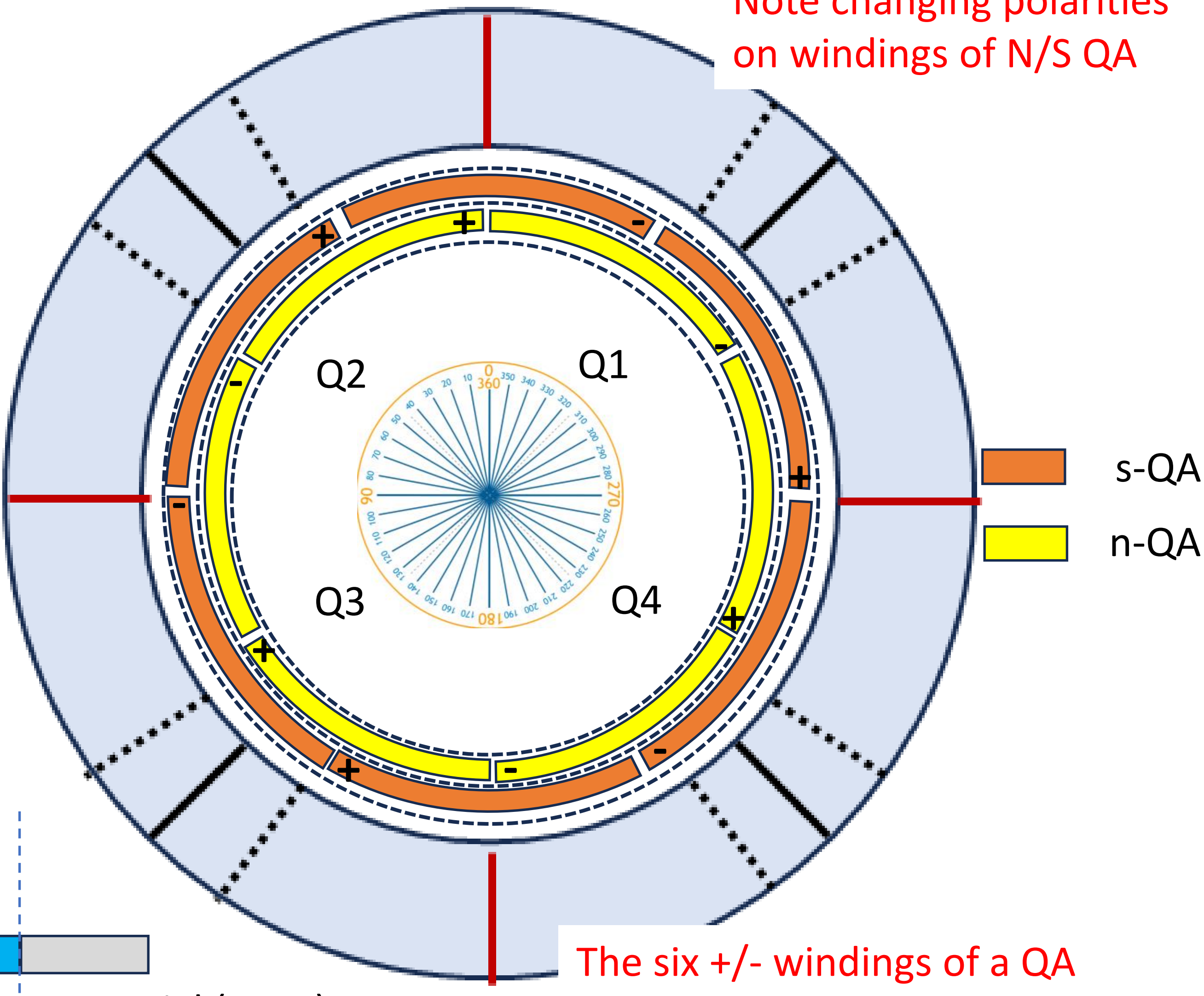
Individual windings are most sensitive for "events" close to the winding edges. For example, if the current line shown above is moved to the middle of one of the windings, no voltage is measured because the opposite flux changes are all contained within a single winding and thus cancel out. In general, these may partially cancel depending on the distance of the current line to the winding edges. So that there are no 'blind spots' azimuthally, a second QA with its set of 6 windings is placed together with the first, but shifted by half the winding width (30 degrees in the sextupole symmetry). These two types are designated "Normal" (N) and "Skew" (S).

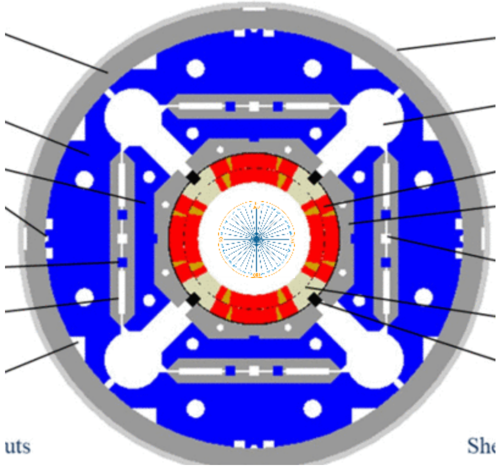
s-QA and n-QA, azimuthal placement, z-locations

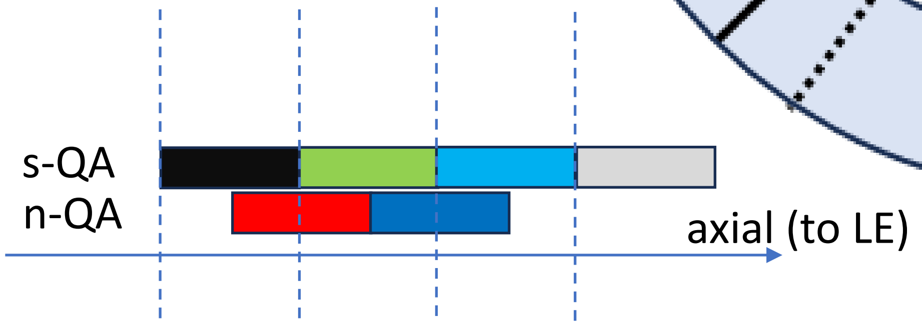
A07
Q9



Note changing polarities on windings of N/S QA







The six +/- windings of a QA are connected in series, each is 100 mm long in Z (axial).

QA names Z4100 Z4200 Z4300

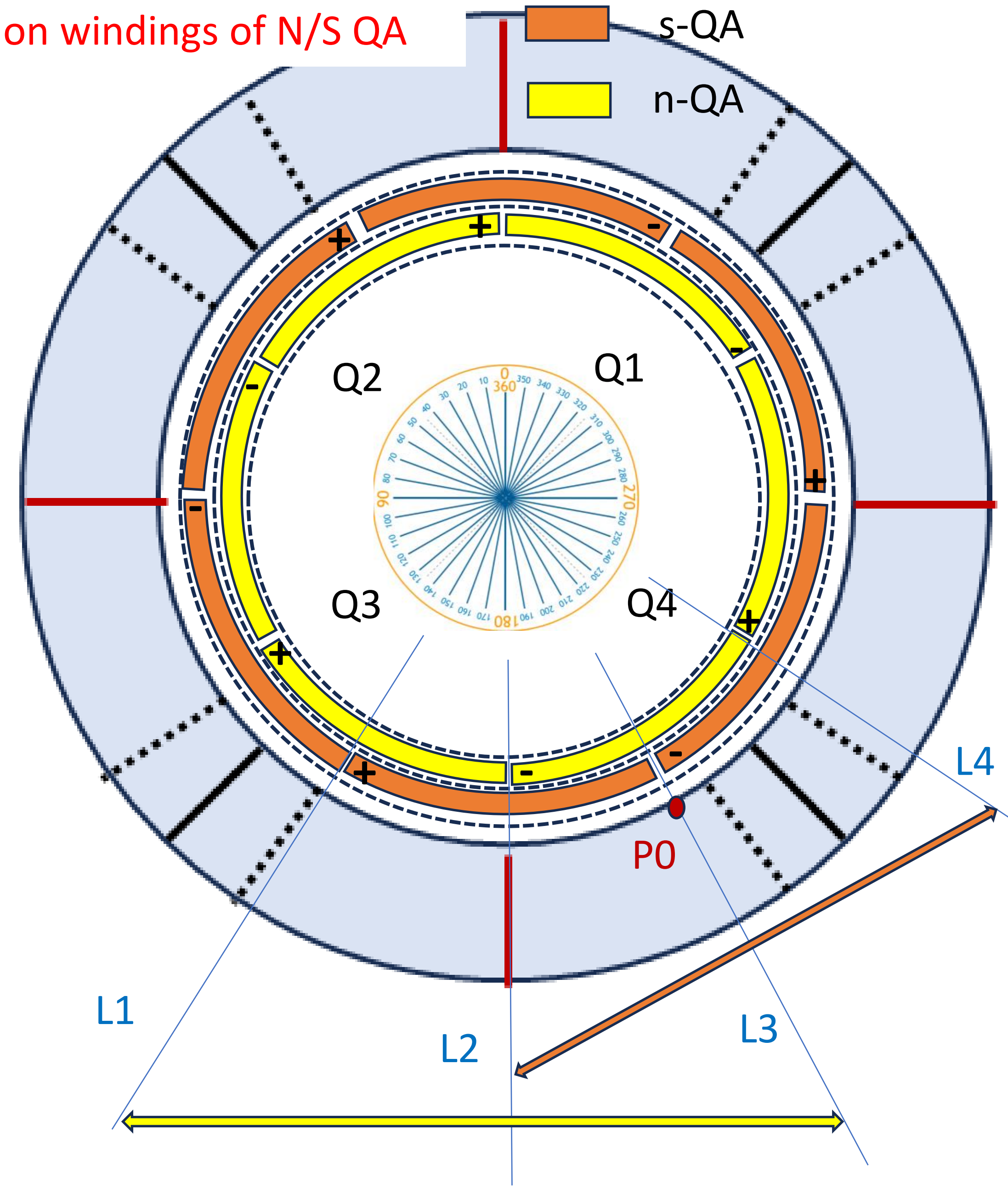
(z = 1861 mm) (z = 2061 mm)

(z = 1961 mm)

The red numbers are positions wrt magnet center, and are to the axial centers of the QA elements, not their edges

s-QA and n-QA, polarities

Note changing polarities on windings of N/S QA

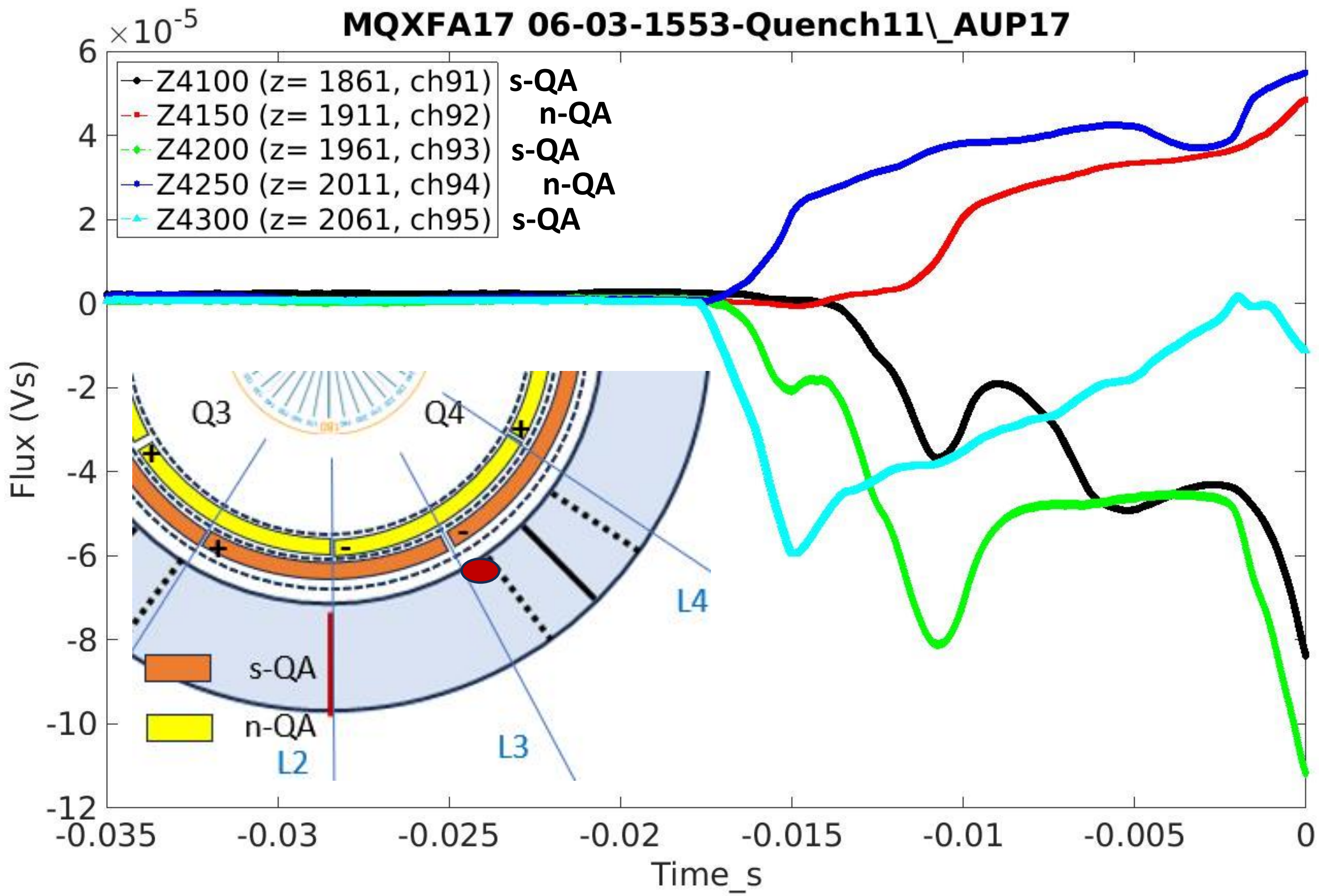


L1 and L3 denote +/- borders of one of six windings of s-QA. L2 and L4 denote +/- borders of one of six windings of n-QA. Because s-QA and n-QA are shifted by exactly 50% of their width (azimuthally), each border line is also a center line for the other type (that is, n-QA and s-QA). Winding edges are most sensitive to flux change for individual windings (further augmented by the flipped polarity between windings). Winding centers remain less sensitive – virtually insensitive for currents normal to the page.

If current runs (changes) normally through the P0 point in such a direction that it induces negative voltage on the s-QA segment between L2 and L3, then the flux lines would induce opposite (positive) voltage between L3 and L4 on a similar segment; however, the polarity of that segment is flipped in the actual QA configuration, and the QA will see double negative voltage (this is the augmentation). If the source is moved on the L2 or L4 lines – no voltage will be seen in s-QA as those are middle segment points. This means that for sources between L2 and L4, with the same current direction as above, the s-QA will only see negative signals (easy to relate to the "-" sign placed close to the center at L3). Similarly, for sources between L1 and L3 n-QA will only see negative signals. Similar reasoning holds for the remaining windings of the QA with alternating polarity every **60º**.

Signal development and quench location

One of the limiting quenches (Q#17) in MQXFA17, Q4



Z4300 (s-QA) and Z4250 (n-QA) flux signals have opposite signs. Z4300 (s-QA) has higher and faster rising signal amplitude at quench.

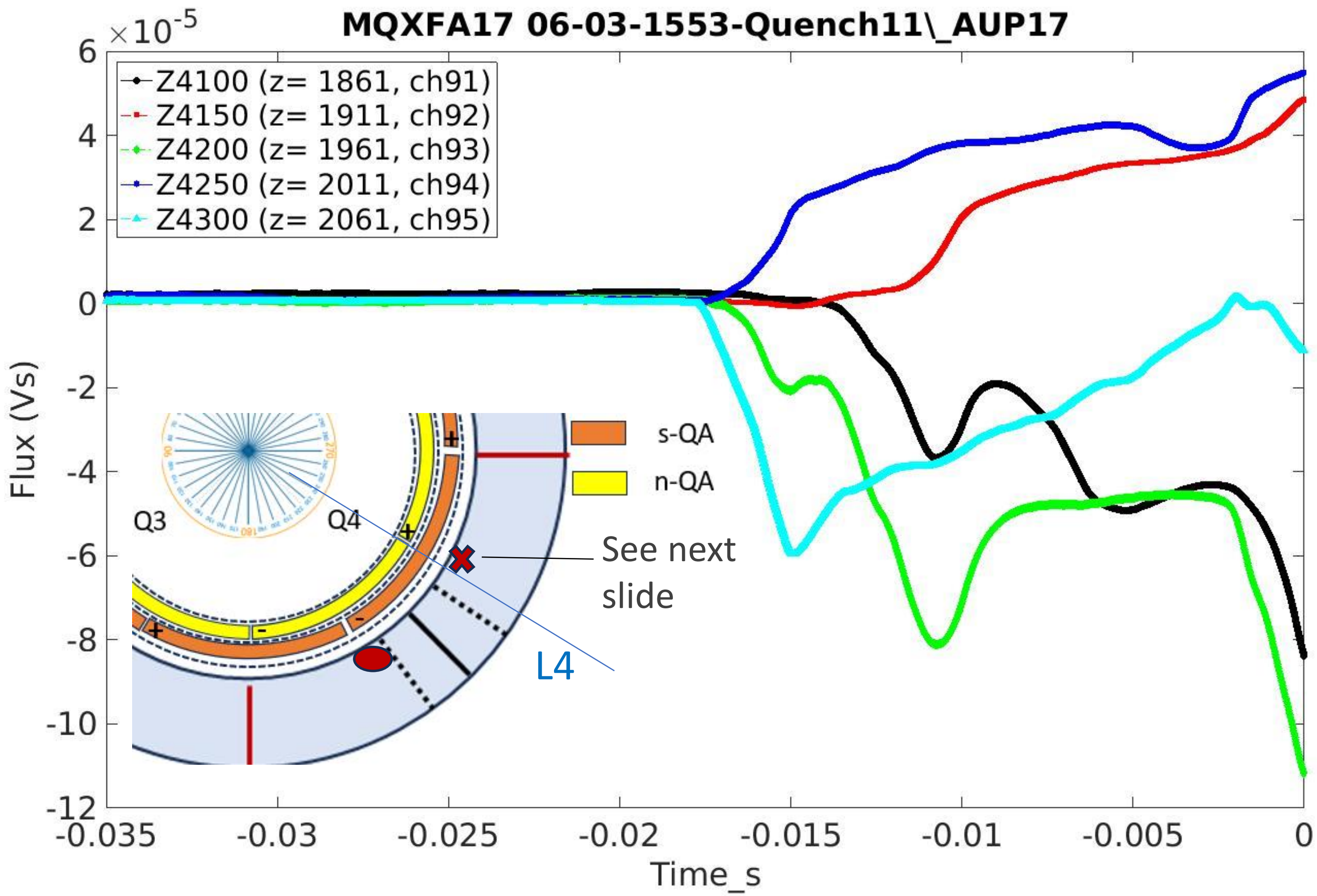
Given that QA are most sensitive at edges and much less sensitive in the middle (for local disturbances), and that the quench is in Q4:

The negative signal in s-QA suggests it is between L2 and L4. The positive signal in n-QA suggests it is beyond L3, thus between L3 and L4. The initial onset of the s-QA vs n-QA signal suggests it is closer to L3 than to L4 (which is less sensitive area for s-QA).

The precision on the drawings is few degrees but can be much improved with better geometry matching (not done here).

Signal development and quench location

One of the limiting quenches (Q#17) in MQXFA17, Q4



Z4300 (s-QA) and Z4250 (n-QA) flux signals have opposite polarities. Z4300 (s-QA) has higher and faster rising signal amplitude at quench.

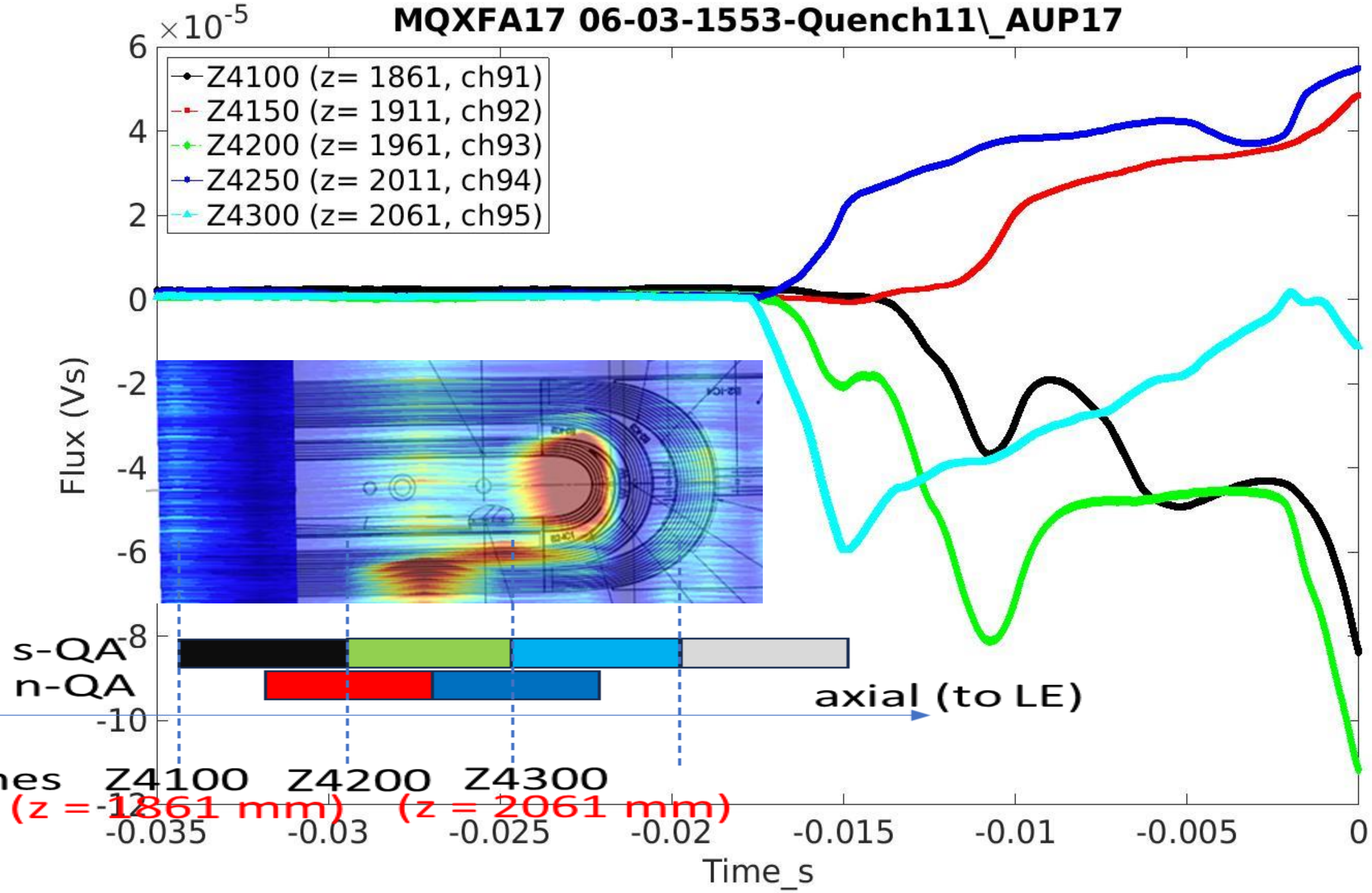
Quickly increasing negative Z4300 is consistent with a source in between +/- windings of the s-QA, as indicated (current flows mostly perpendicular to the page).

Time is not enough to consider turn-to-turn propagation (and we assume a single quench source)

So, s-QA and n-QA will show opposite polarities of the signal, all consistent with the indicated location (ellipse).

Current redistribution propagation

One of the limiting quenches in MQXFA17, Q4



The red numbers are positions wrt magnet center, and are to the axial centers of the QA elements, not their edges

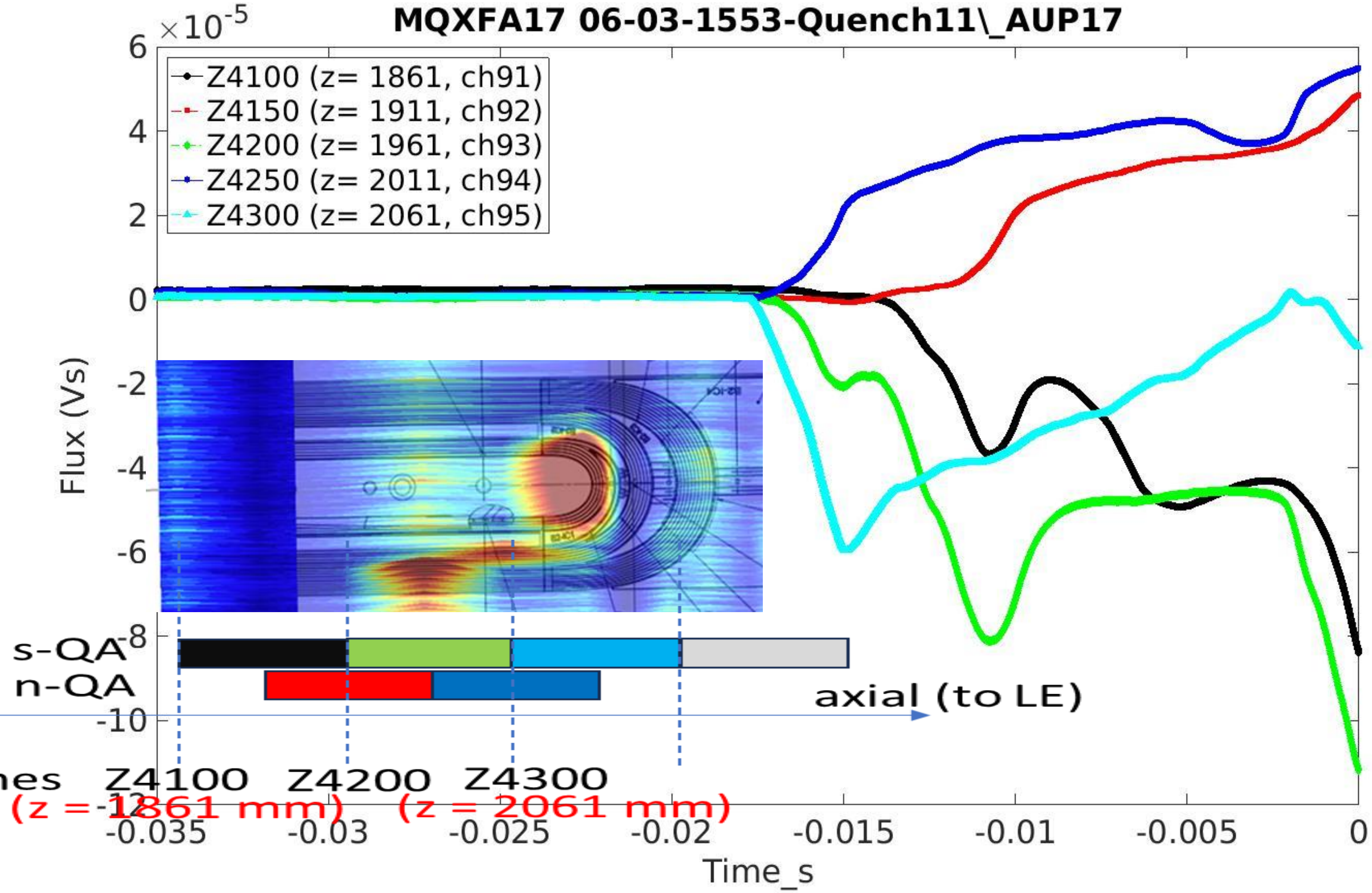
Z4300 rises in magnitude and then drops to ~0 Vs. This means that the current at ~ -3 ms is distributed the same way as before quenching.

The shape of Z4300 suggests most if not all of the cable of that Z-element quenches: the moment close to t=0, where the signal starts increasing in magnitude again, may indicate that the current redistribution reached the Z-end of the QA element on the opposite side of the pole.

However, the opposite pole side has current flowing in opposite direction (on the azimuthal drawing too, see slide 6) and is close to the L4 line. The current direction change flips the signal sign and in-order to see negative polarity in s-QA the source should be beyond L4 (see slide 6, ‘X’-sign) which flips the polarity as well. This appears to be slightly geometrically inconsistent but to resolve it one needs to know azimuthal geometry to better than one degree (which is possible). Nevertheless, the present data suggests the quench is not at the pole turn (if QA are aligned correctly!).

Current redistribution propagation

One of the limiting quenches in MQXFA17, Q4



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Z4300 rises in magnitude and then drops near 0. This means the current is distributed the same way as before.

If the current redistribution front reached the other side of the pole and the end of the QA (in Z), then the other s-QA, Z4200, should see significant change at the same time too, and it does (near – 3 ms). Z4100 follows closely but has lower magnitude as it is further away. Nevertheless, it shows that whatever is seen in a QA sensor it can be sensed in the neighboring one 10 cm away.

The current redistribution has much more complicated directional characteristics and the present analysis is mostly qualitative.
Proper simulation is a good way forward, which can resolve some weak points present in the analysis.

S-QA and n-QA

Note changing polarities on windings of N/S QA