



IMSE measurements of current redistribution at the sawtooth crash.

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Sawteeth

Measurements of q-profile evolution during sawtooth crash are difficult and so far inconsistent, showing either complete reconnection (q_0 returning to $q_0 \geq 1.0$) or incomplete (q_0 stays below 1.0).

MSE is one of the best tools to measure this but it measures only polarisation angle:

Pitch Angle

Polarisation $\theta \propto \gamma = \frac{B_z}{B_\phi}$ ← so we effectively measure B_z

Both measurement and interpretation are extremely difficult. Analysis using standard equilibrium codes is useless without assessment and separation of uncertainties from:

- Statistical error of diagnostic.
- Systematic error of diagnostic - (absolute MSE calibration is almost never achieved).
- Systematic errors of assumptions in equilibrium analysis.

For (c) Bayesian/Integrated analysis is required (R. Fischer) but to understand simply, we can relate the measurement θ directly to q :

[CC.Petty Nucl. Fus. 2002]

$$\mu_0 J_\phi \approx - \left(1 + \frac{1}{\kappa^2} \right) \frac{dB_z}{dR}$$

Current Density Elongation

Derivative of measurement

$$q_0 \approx \frac{-2B_\phi}{R \left(1 + \frac{1}{\kappa^2} \right) \frac{dB_z}{dR}}$$

Large aspect ratio approximation:

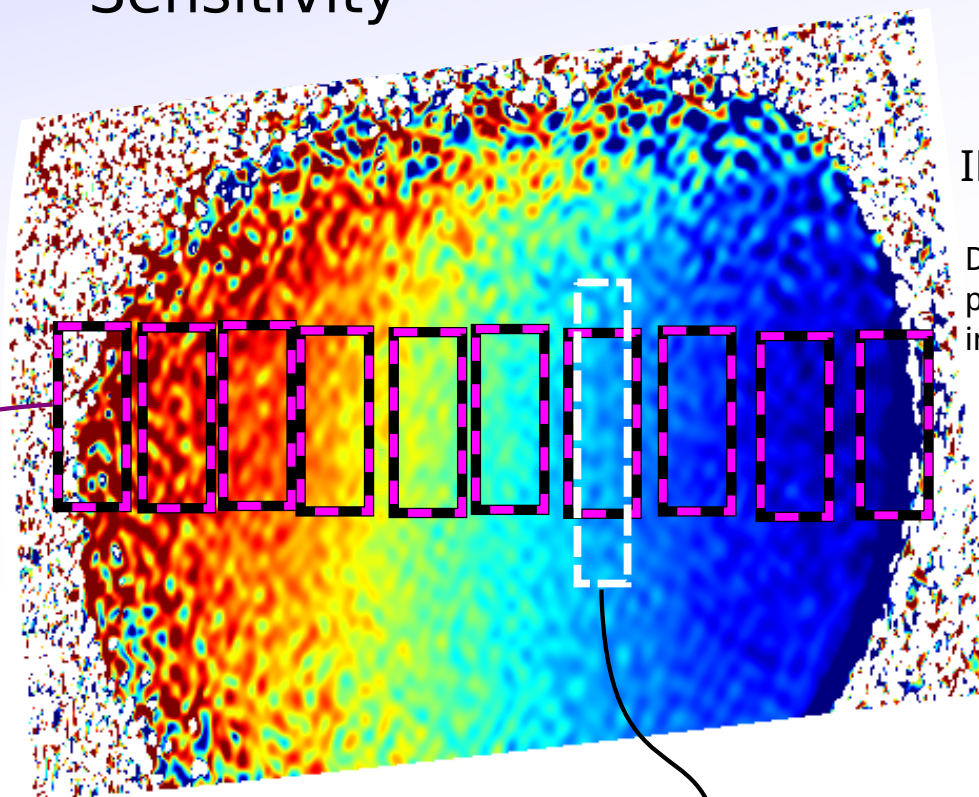
$$q_0 \approx \frac{2B_\phi}{\mu_0 j_0 R}$$

Needs care!

We want to change the elongation and it directly affects the measurement interpretation!

Sensitivity

Comparing the new IMSE to the old MSE system on a similar plasma discharge, we get good agreement, higher time resolution and with a new a fast CMOS imaging camera (15k€), a much higher sensitivity.

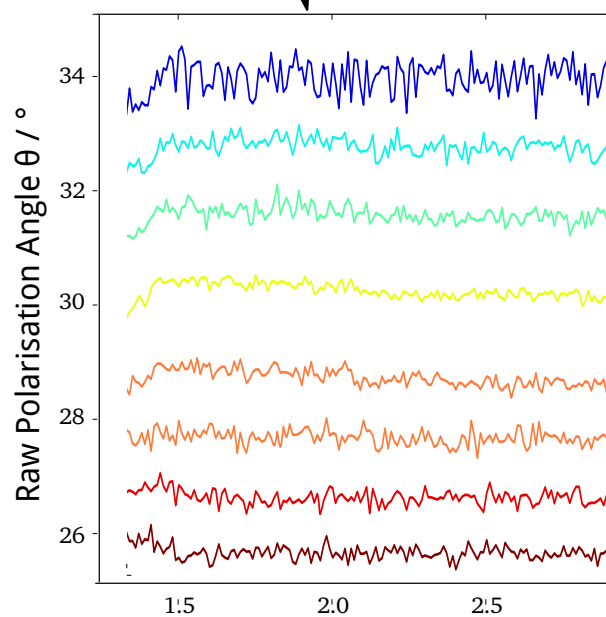
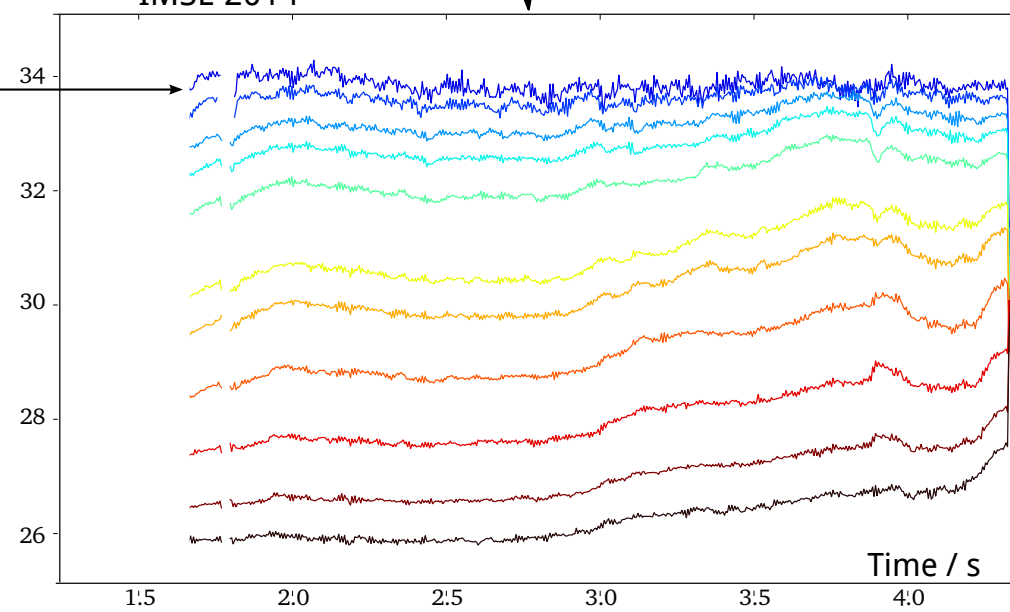


IMSE 2014

Demodulated
polarisation angle
imageMSE equivalent
areas

MSE

IMSE 2014

Core
(Interesting
physics)

Time / s



Prototype IMSE

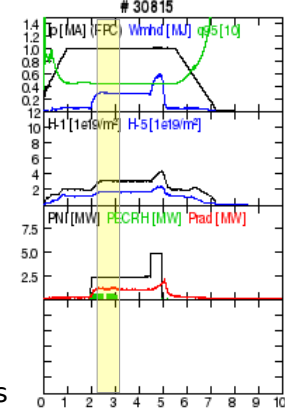
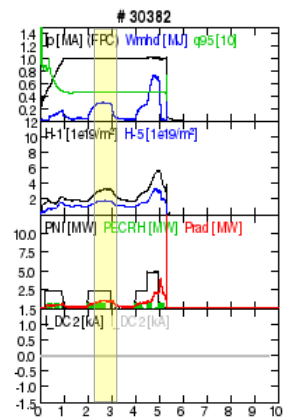
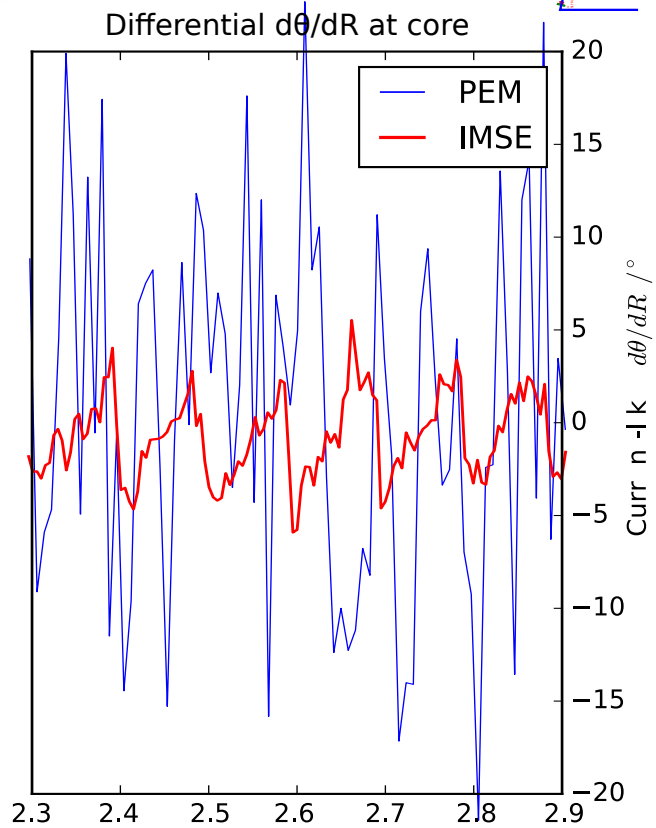
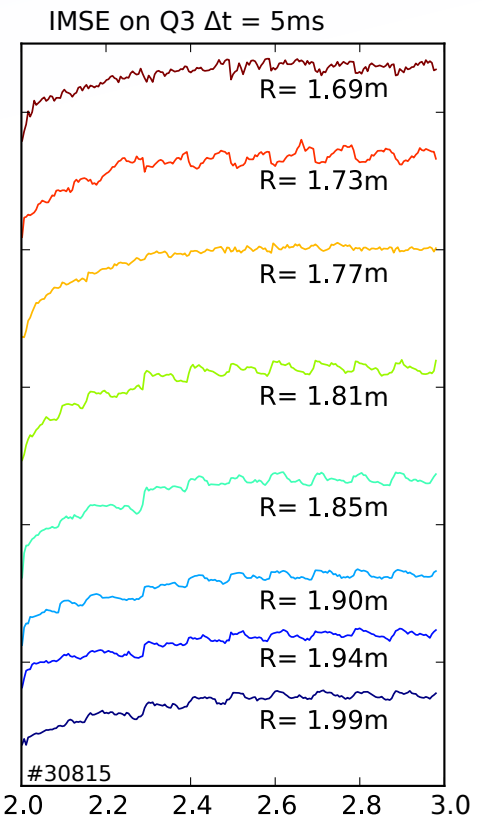
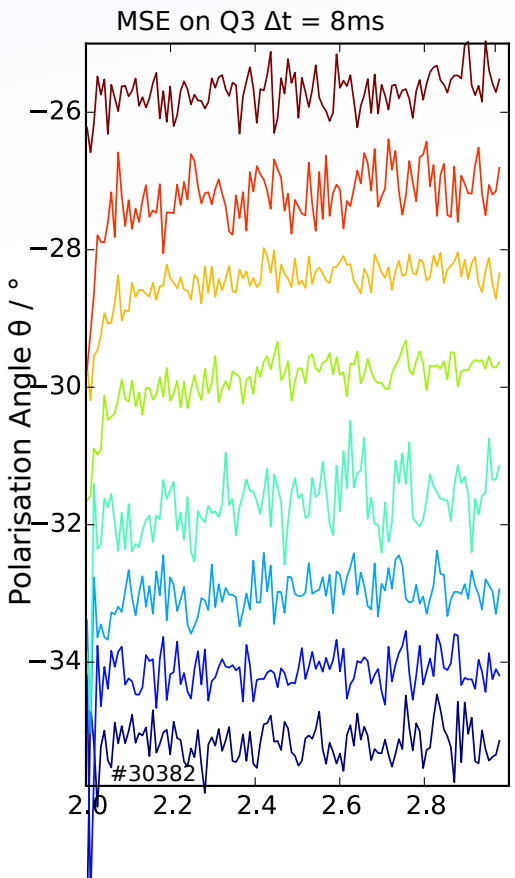
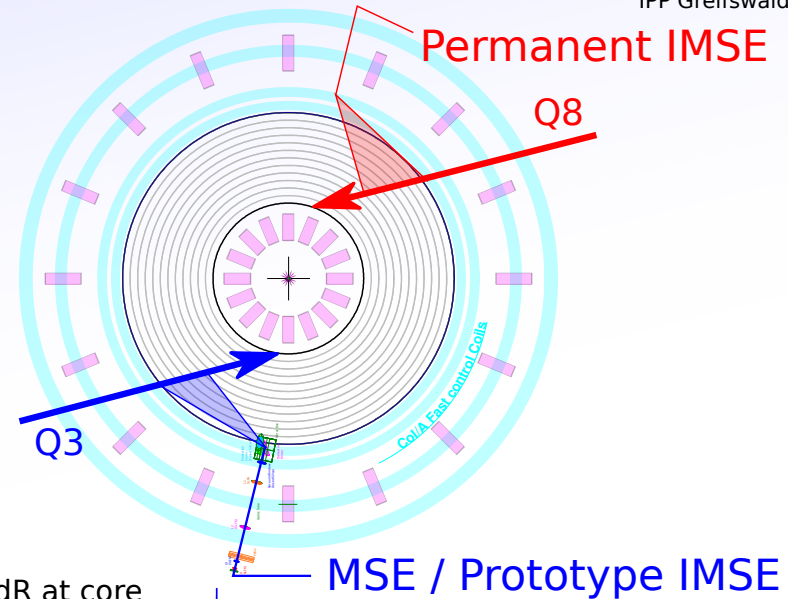
Do we have enough sensitivity to measure sawteeth?

MSE: On NBI beam 'Q3':

MSE system at AUG does not have required S/N to see even large sawtooth crashes in θ , definitely not $d\theta/dR$!

[V. Igochine EPS 2011 P2.079]

2013: Installed 'prototype' IMSE on beam Q3 which measured changes due to sawteeth in θ and in $d\theta/dR$!



~ Same considerations

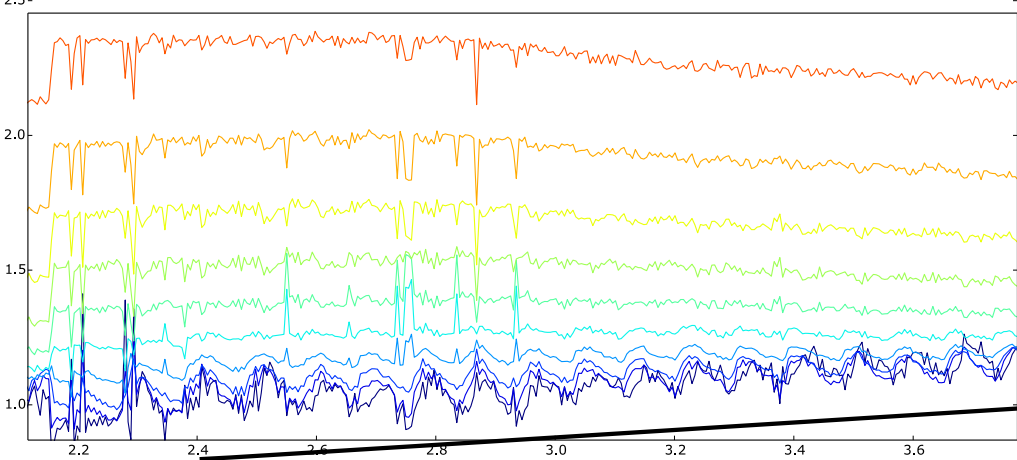
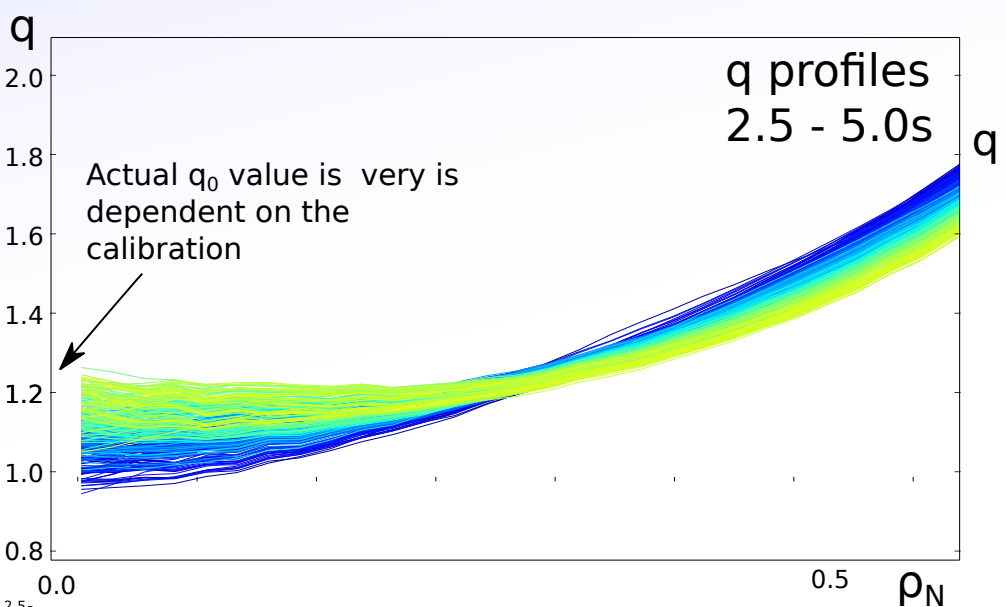


Prototype IMSE

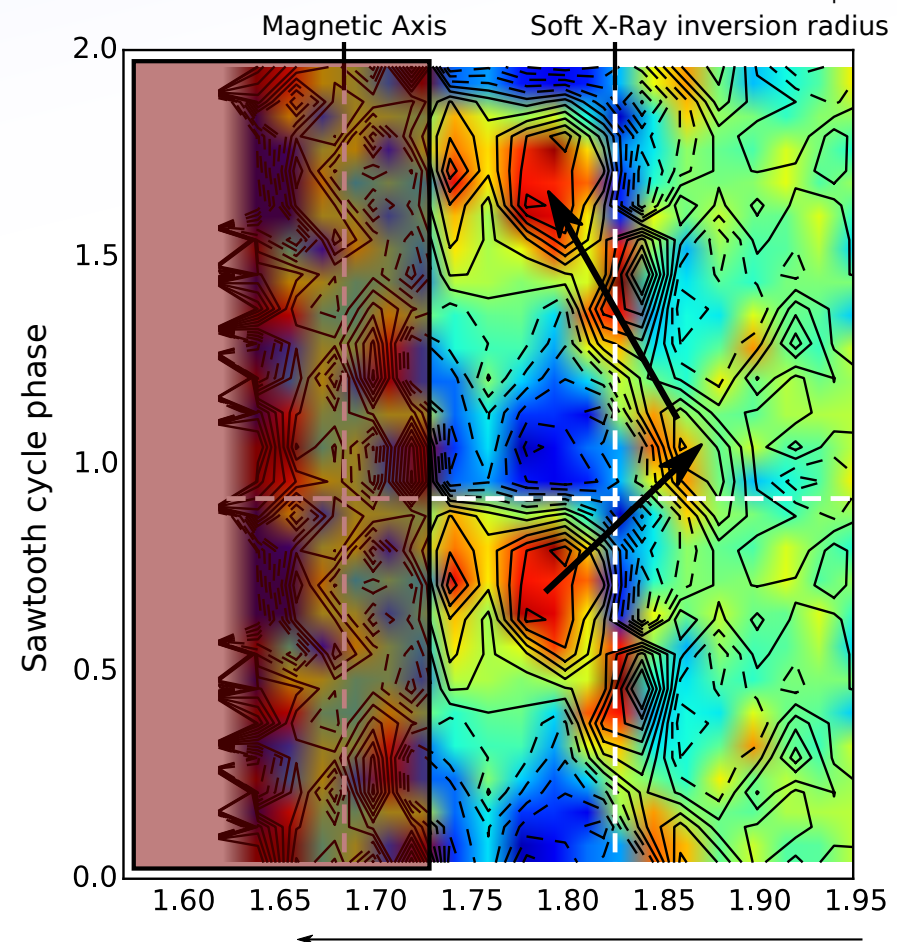
Do we have enough sensitivity to measure sawteeth?

2013: Installed 'prototype' IMSE on beam Q3 which measured changes due to sawteeth in θ and $n_i d\theta/dR$!

However, prototype IMSE had no good calibration tracking and there was no other way to find absolute q_0 .



Time evolution of raw data derivative $d\theta/dR \sim j_\phi$:



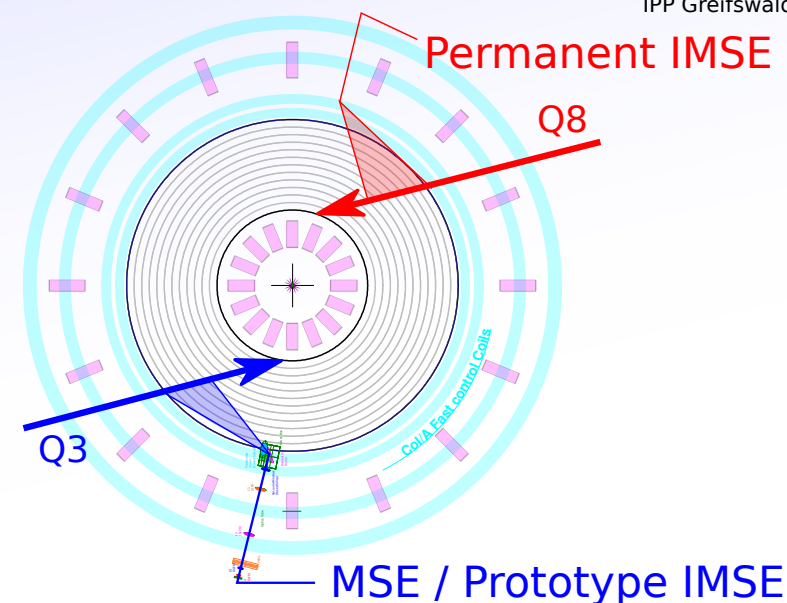
For q_0 , we **must measure $d\theta/dR$ past the magnetic axis**. Prototype IMSE could not see past magnetic axis. Permanent IMSE is optimised for this.

Permanent IMSE

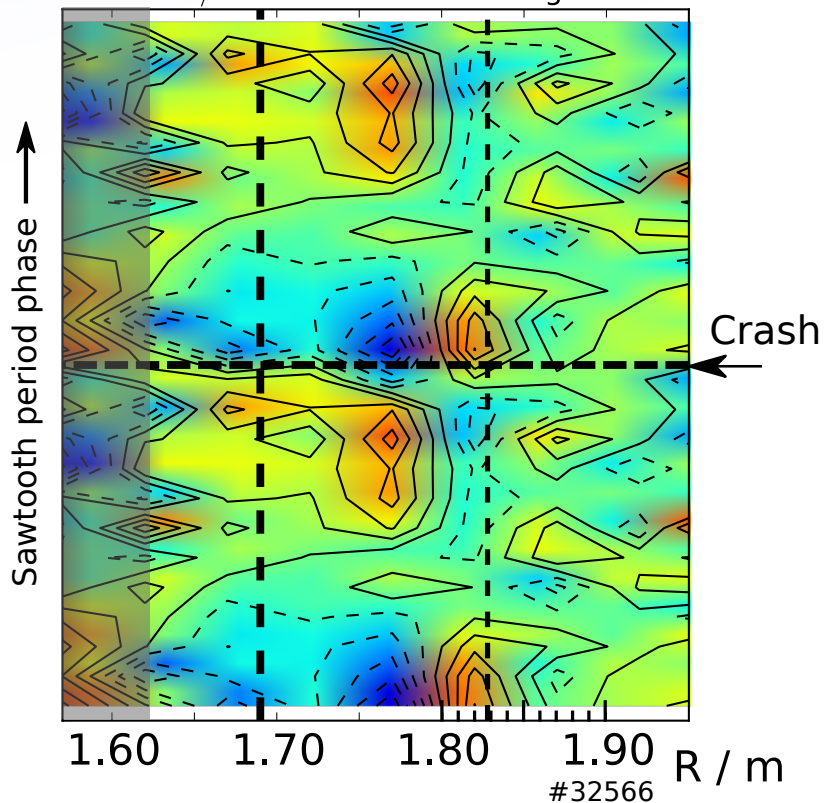
July 2015: New IMSE system installed on opposite NBI box.
Optimised for view of Q8, which is similar but not exactly
the same as Q3. (Different energy, slightly different position)

Since Jan 2016, performance of diagnostic is good and it measures
well past the magnetic axis. No absolute calibration yet, but we are
close and angle looks stable.

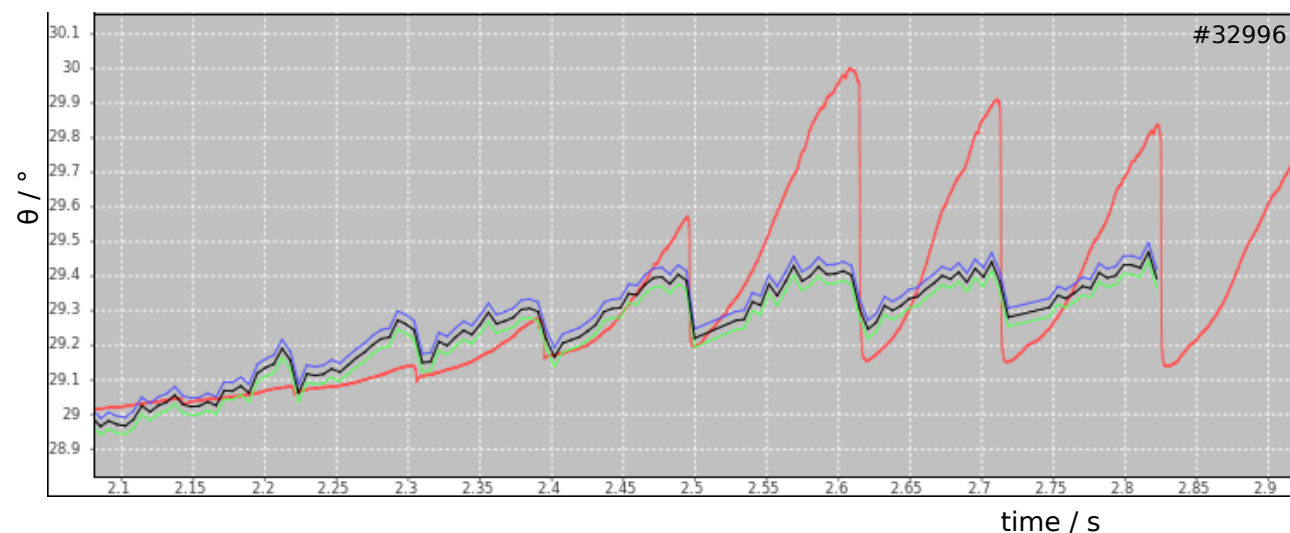
So far, sawteeth achieved with Q8 have been faster ($\sim 60\text{ms}$)
and relatively weak so time evolution in core has not yet been
seen clearly. Best was:

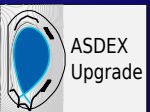


$d\theta/dR$ difference to average



Yesterday (16/02/2016) we had the first good sawteeth with Q8,
but the IMSE camera crashed after 2 periods. We cannot repeat
the shot exactly as the heat-shield overheated, but we will try
something similar tomorrow.





Summary IMSE

With the IMSE, we can now measure polarisation/pitch angle accurately enough and with fast enough time resolution (6ms) to see the current redistribution in the sawtooth cycle evolution.

As soon as we have a good enough shot with sawteeth, we will calculate (and publish) the q-profile evolution using as few assumptions as possible (for whatever shot it is).

We can then investigate how this depends on various plasma parameters (e.g. elongation [MPPC & V. Igochine]) and look at how the data compares to different models and modelling codes (e.g. models in IDE [R. Fischer]).

Issues:

- Finding stable, reproducible scenario for big, slow sawteeth with Q8 (for IMSE).
Can we search for all AUG shots with Q8 and good sawteeth?
- Absolute calibration for IMSE pitch angles.
- IMSE Reverse $B\phi$ calibration shots (experimental - we will try this on the same day)
- Measure q_0 using fast particle modes [P. Lauber et.al] in same shot as IMSE sawtooth measurements.

Other things we need / want:

- CXRS for Er compensation. [AUG CX Group]
- Polarimetry for cross-check of q profile [A. Mlynek]
- IDE analysis [R. Fischer / A. Bock]
- Soft X-Ray for sawtooth synchronisation [V. Igochine]