# Noll forces, stiffness model of the vacuum vessel, and displacement data on JET

IAEA TM on Plasma Disruptions and their Mitigation, ITER Headquarters, France, 20–23 July 2020

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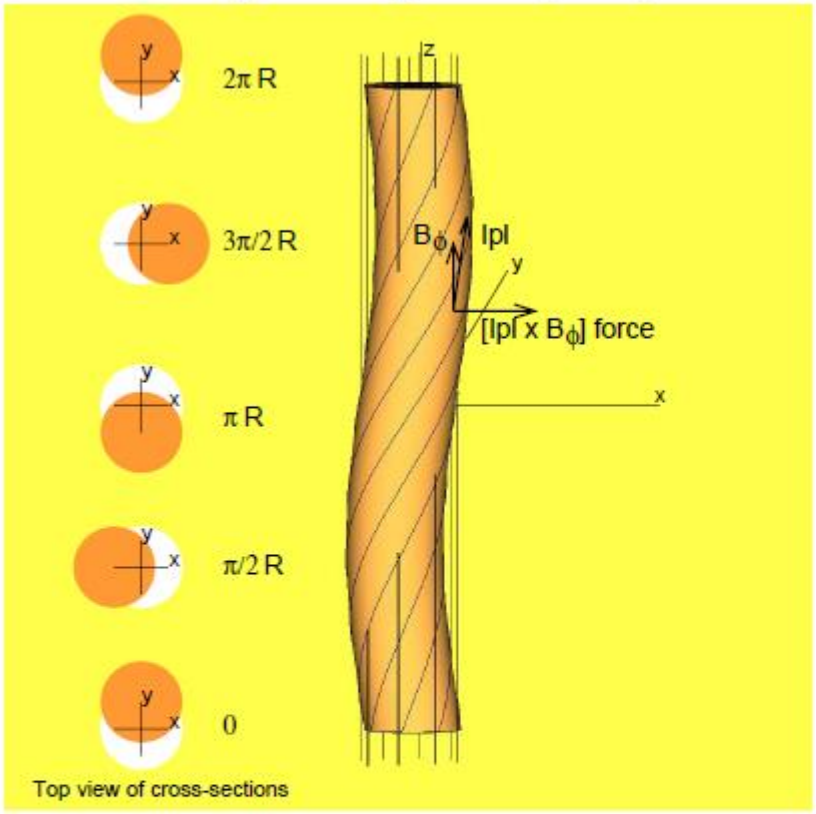
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Partially supported by the US DoE, Grant DE-SC0019068.

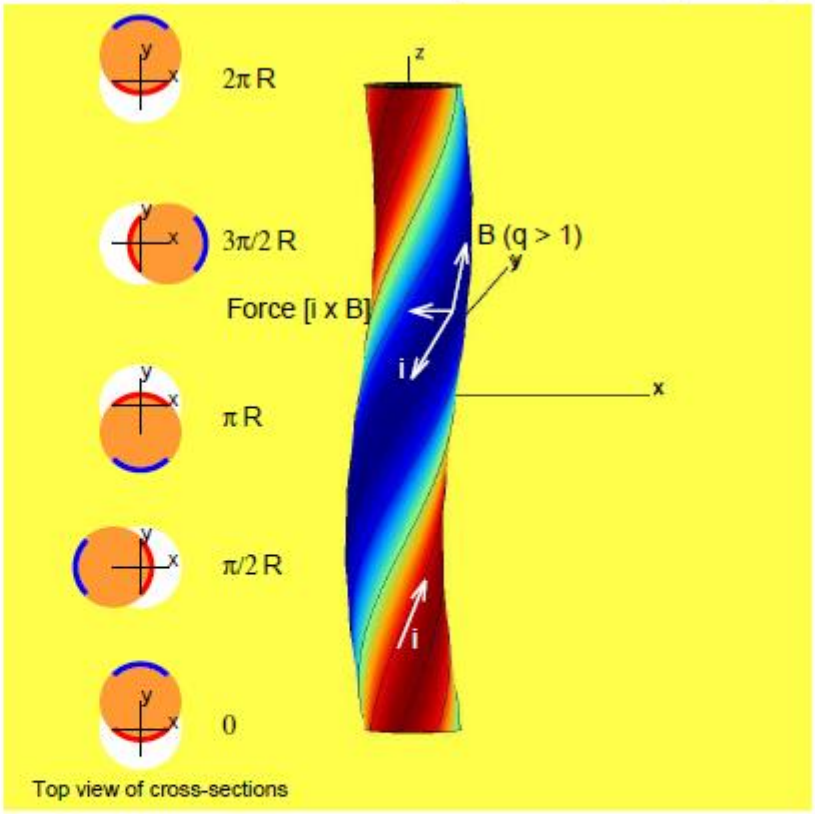
# Content

# 1. Noll's formula for sideways forces

*Kink mode by JET engineers (1996)*




*Shafranov's kink mode by Zakharov (2007)*




*Both models lead to Noll's formula for sideways forces:*

$$F_x = \frac{\pi}{2} B_{tor} \cdot \Delta M_{IZ,y}. \qquad (1.1)$$

*Original engineering model, right in force, conflicted with direction of wall currents. Plasma physics model (Zakharov PoP, 2008) explained wall currents (Hiro currents).*

# 2. Progress is invisible since 2007

*Large forces predicted by scaling JET to ITER as well as physics behind Eq. (1.1) were challenged after 2007*

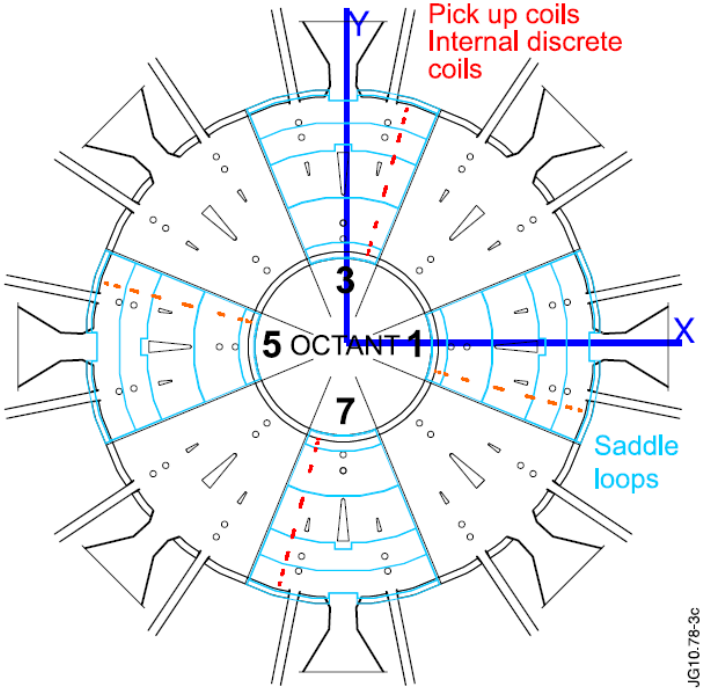
- *by theories of resistive wall modes (in old academic formulation)*
- *by numerical simulations (like M3D, full of subsitutions, algebraic mistakes, conflicts with Ampere law, and basic plasma properties)*
- *by rejection of inductive MHD effects in favor of "halo" currents (negligible on JET)*
- *by predictions of much smaller than 40 MN sideways forces for ITER.*

*At the same time*

- *no attempts to reproduce the waveforms in JET AVDE as it was done in 2007-08,*
- *no steps in development of AVDE disruption physics beyond the forces.*

*Here, the Noll's forces together with stiffness model of VV were tested against vessel displacements $\Delta_x(t), \Delta_y(t)$ waveforms on JET*

# 3. Stiffness model of JET vacuum vessel




***Harmonic oscillator with damping for VV displacements*** $\Delta_x, \Delta_y$

$$m\frac{d^2}{dt^2} + m\omega^2 + k_m\tau_1\frac{d}{dt}\begin{Bmatrix}\Delta_x\\ \Delta_y\end{Bmatrix} = \begin{Bmatrix}-F^{Noll}_{7->3}\\ F^{Noll}_{5->1}\end{Bmatrix}, \qquad (3.1)$$

$$m = 2\cdot 10^5, \quad \tau_1 = 0.008,$$
$$k_m = 49\cdot 10^6 B^2, \quad \omega = 2\pi/0.175.$$

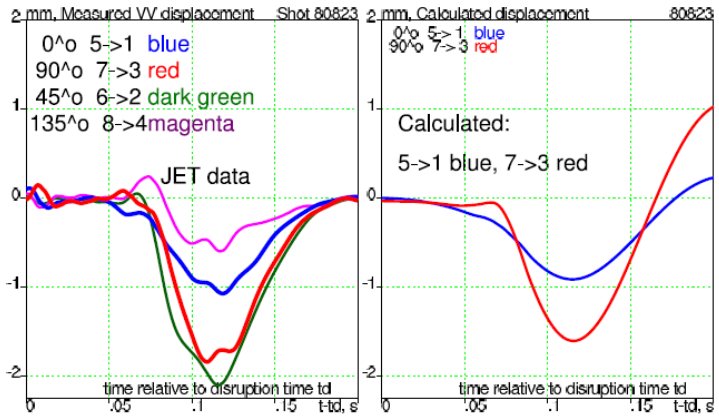
- ***Noll's force is expressed in terms of magnetic measurements in octants 1,5 and 3,7.***
- ***4 VV sideways displacements are expressed in terms of measurements in 8 octants:***

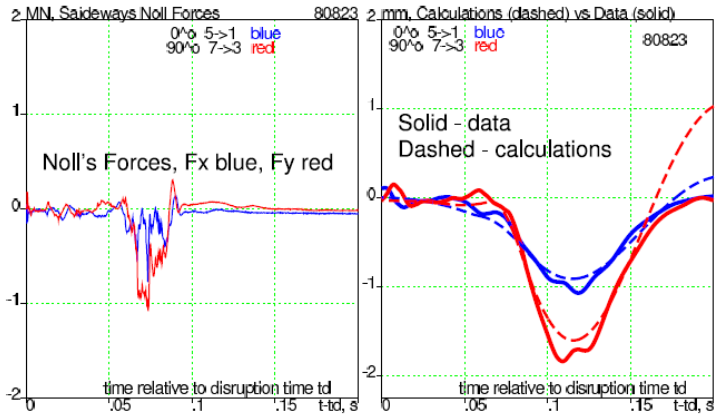
$$\Delta_x = \Delta_1 - \Delta_5,\ \Delta_y = \Delta_3 - \Delta_7, \qquad \underbrace{\Delta_{6->2},\ \Delta_{8->4}}_{not\ used}.$$

- ***1735 AVDE cases have been processed (# 80331 - # 92500).***

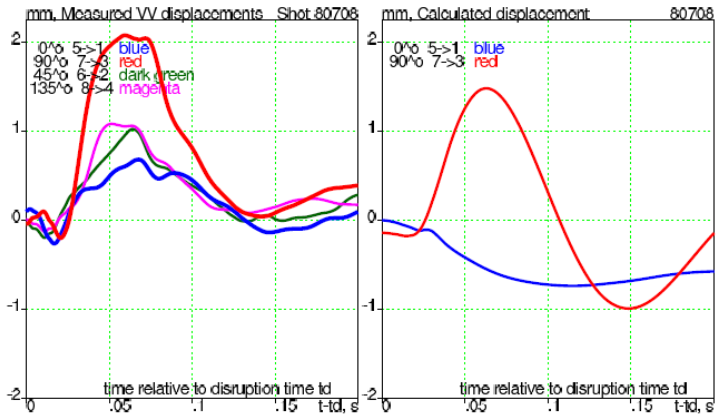
  ***23 of them have large*** $|\Delta_x|$ ***or*** $|\Delta_y| > 1$ ***mm. They are presented here.***

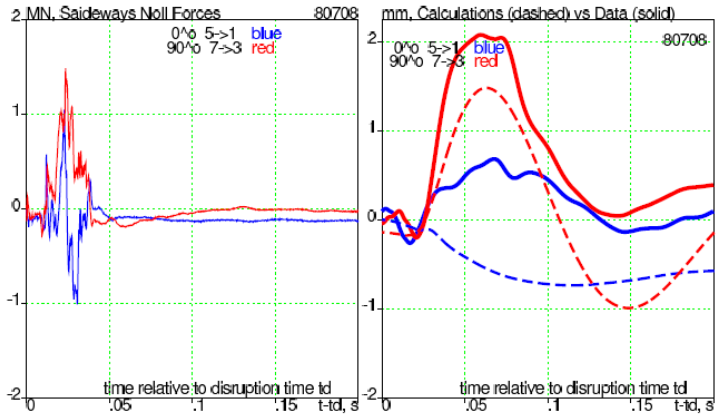
# 4. Characteristic examples




***Example of a "good"-looking case***



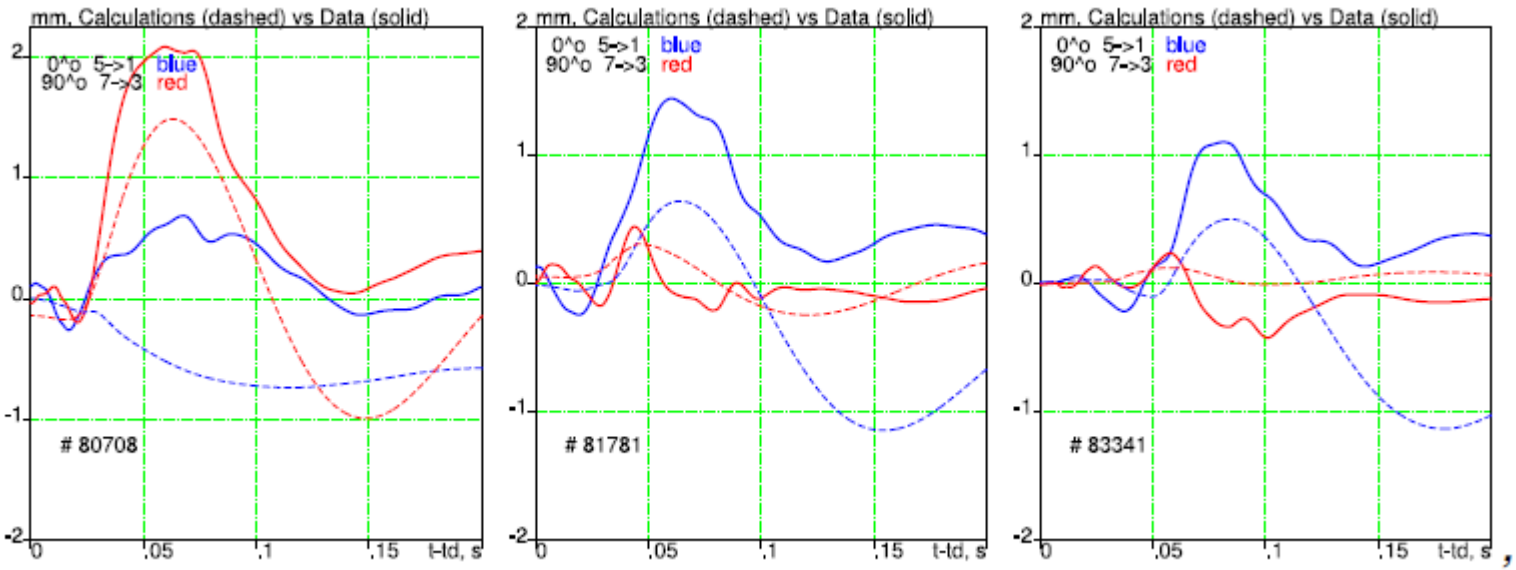




***Example of a "bad"-looking case***

***In all cases Noll's forces are in right phase with VV displacement.***

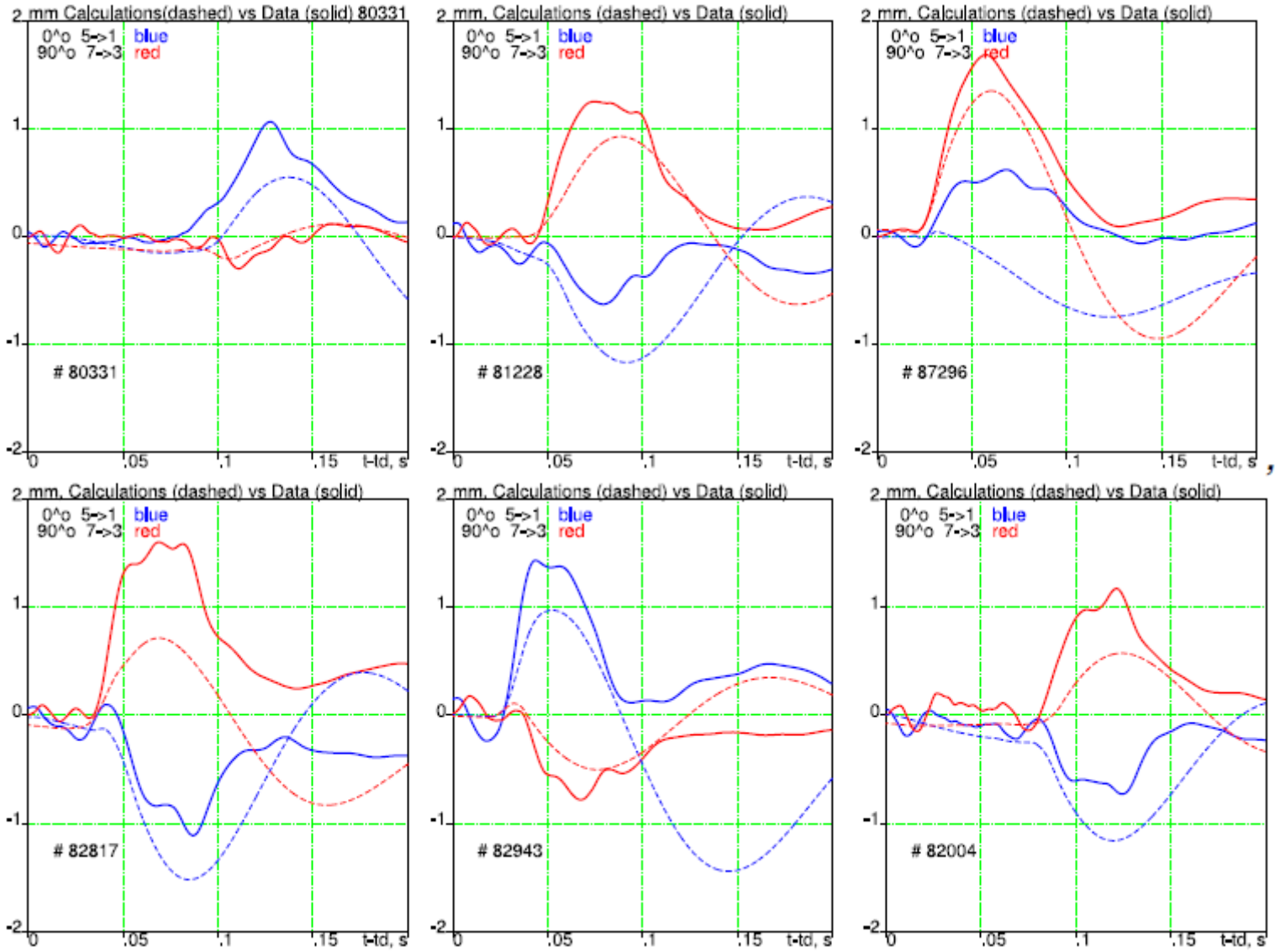
***In looking "good" (12 cases) and "not-so-good" (8 cases) the reconstruction is much better than expected 50 % inaccuracy of the stiffness model.***

# 5. Looking “bad” examples (3 of total 23)



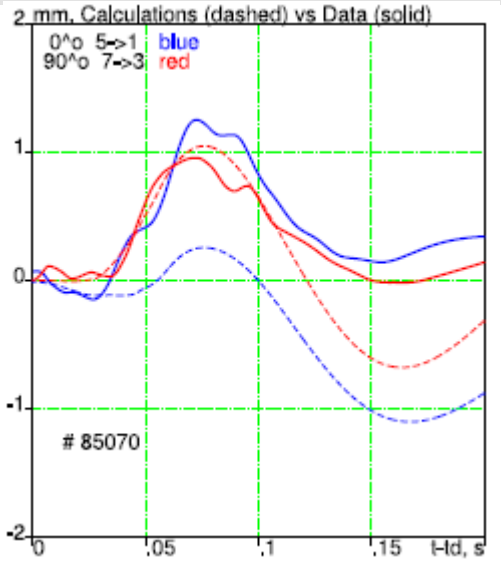

At least the phase of largest signal is reproduced

# 6. Looking “not-so-bad” examples (6 of 23)



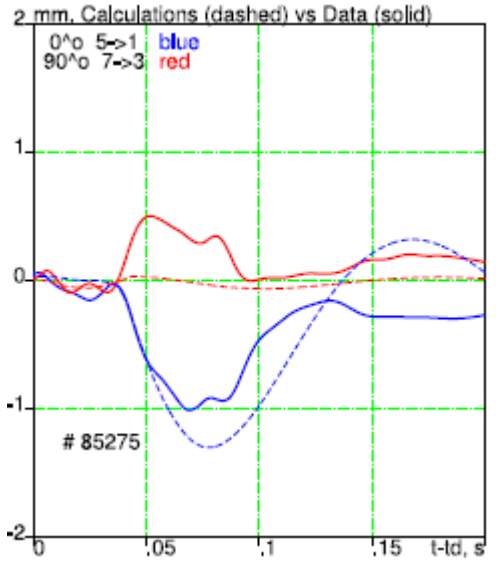

Some amplitudes are reasonably reproduced

# 7. Looking “not-so-bad” examples (+2 of 23)




The displacement octants 7 -> 3 is well reproduced

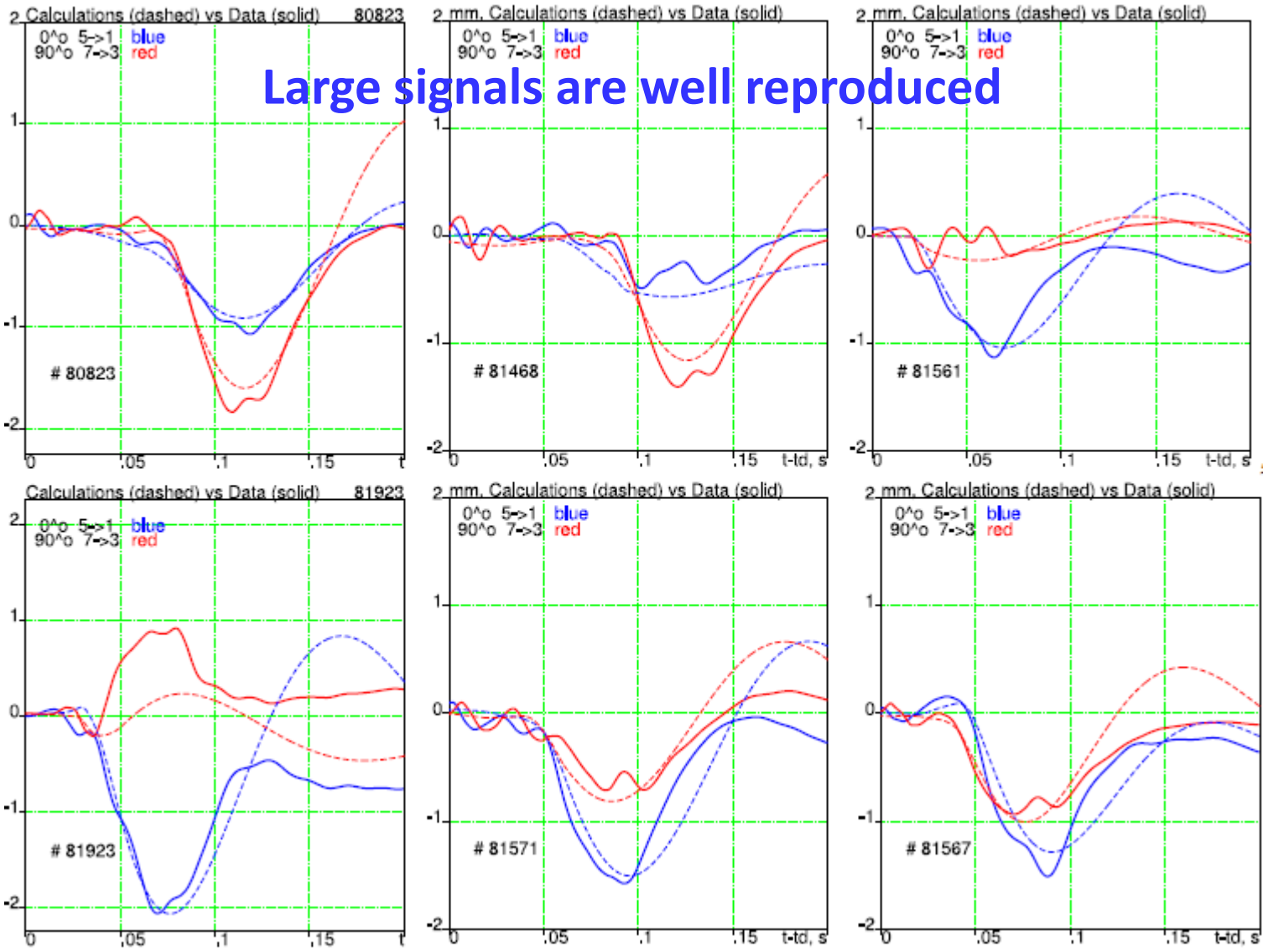
The phases of both displacements are reproduced




The displacement octants 5 -> 1 is well reproduced

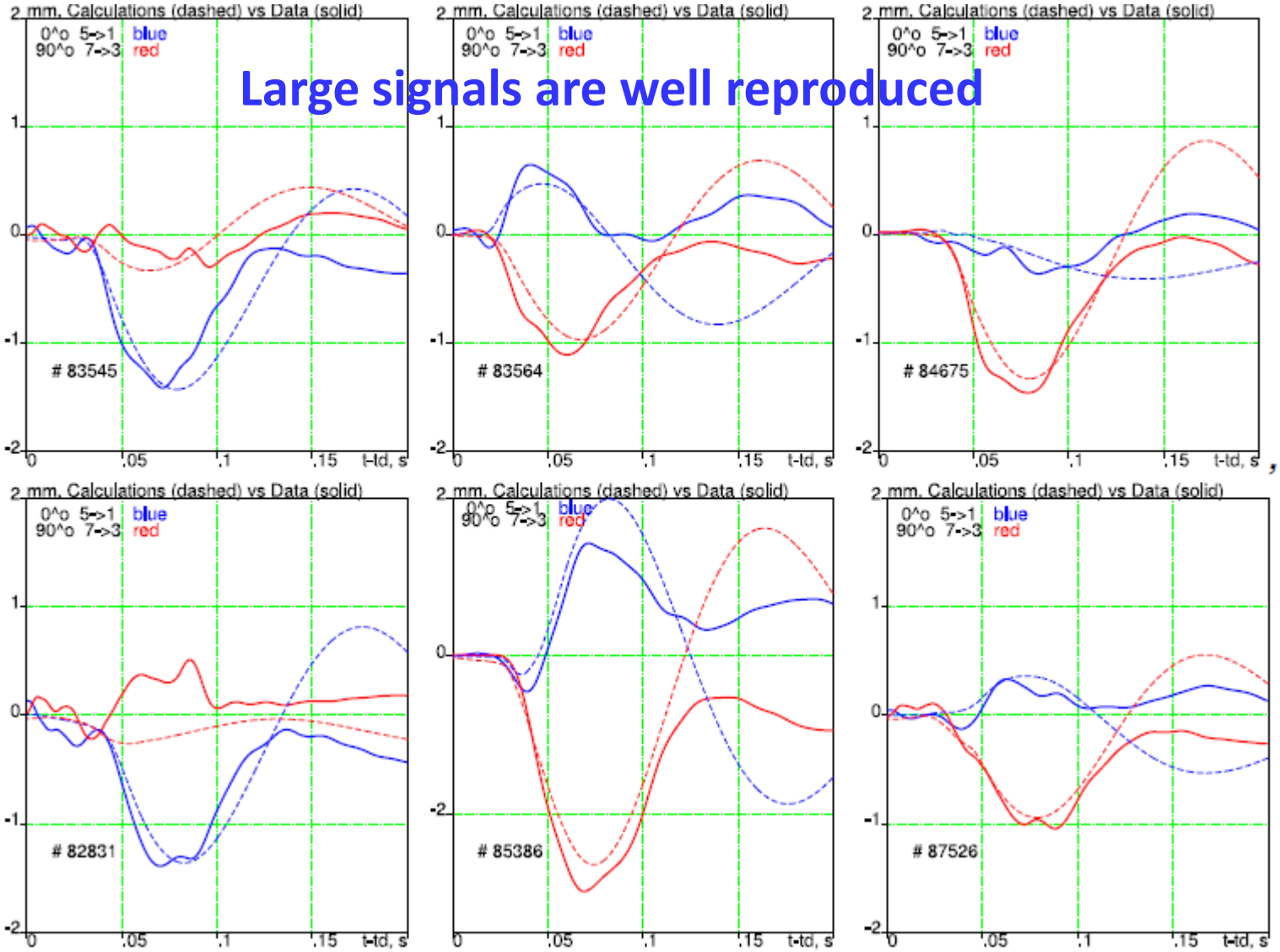
Its phase is reproduced as well

# 8. Looking “good” examples (6 of 23)




**Large signals are well reproduced**

# 9. Looking “good” examples (+6 of 23)




**Large signals are well reproduced**

# Summary

*Of course, it is not possible to describe the vessel oscillations by a simple harmonic oscillator.*

*Nevertheless, stiffness model & Noll's forces*

- *reproduce well the phase of the experimental waveforms;*
- *reproduce the amplitude better than expected 50 % tor the first 100 ms after disruption;*
- *slightly underestimate the vessel displacement in most cases.*

*This result devalues the alternative reduced estimates of forces and emphasizes potentially dangerous asymmetrical disruptions for ITER.*

*JET data and Noll's scaling with the strong physics behind it remain the most reliable source for assessment of the forces in ITER AVDE.*

*The additional effect expected from the theory of Noll's forces is potential leading edge-like deposition of the plasma thermal and magnetic energy on plasma facing component in AVDE.*