Real-time magnetic equilibrium enhancements

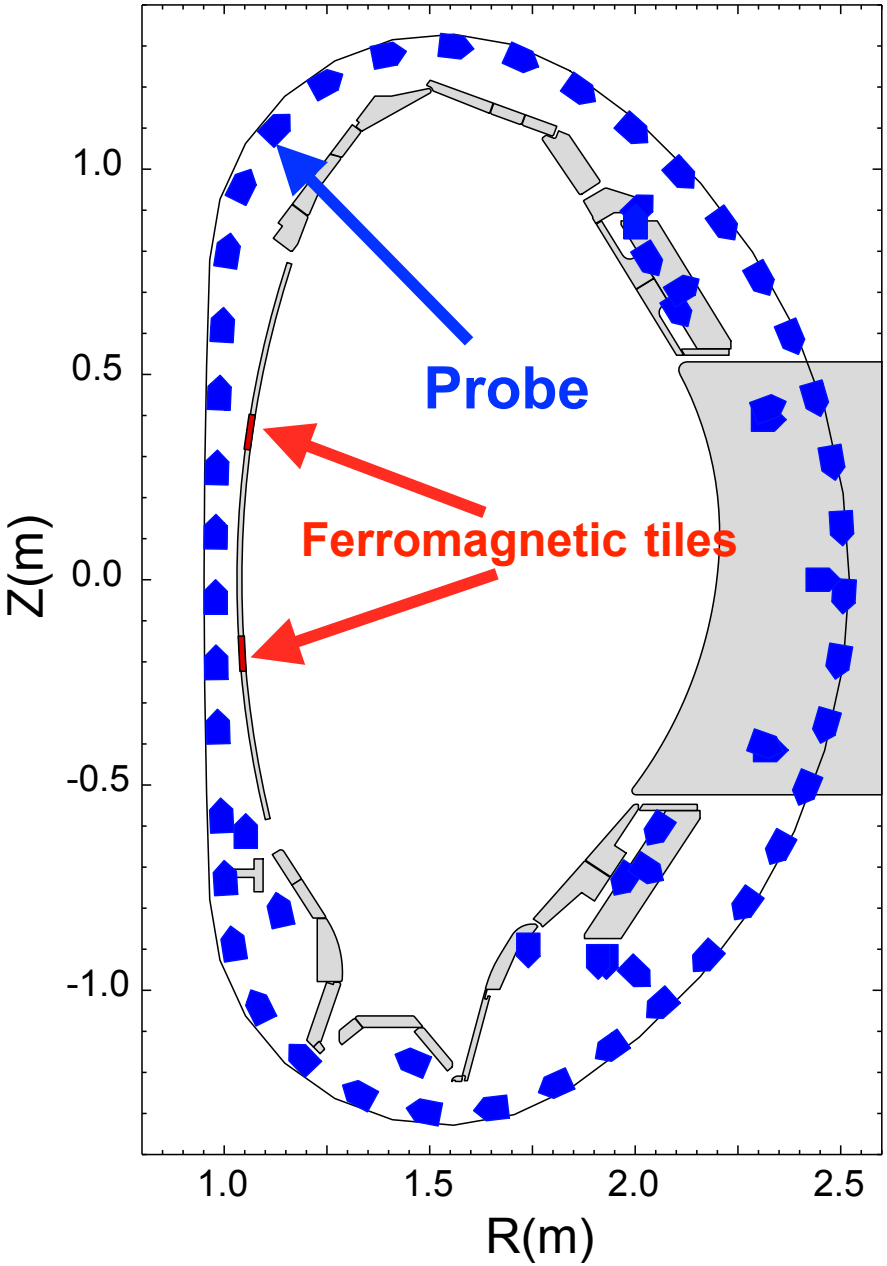
JANET : Just ANother Equilibrium code for Tokamaks

L.Giannone, R.Fischer, P.J.McCarthy, T.Odstrcil, A.Bock, G.Conway, J.C.Fuchs, A.Gude, V.Igochine, A.Kallenbach, K.Lackner, M.Maraschek, A.Mlynek, C.Rapson, K.H.Schuhbeck, W.Suttrop, I.Zammuto and AUG Team

R.Cole, M.Fitzek, K.Lueddecke (UCS)

A data acquisition system for real-time magnetic equilibrium reconstruction on ASDEX Upgrade and its application to NTM stabilization experiments
L.Giannone, M.Reich et. al, Fusion Eng. Des., 88, 3299, 2013

Ferromagnetic tiles



Two rows of low cost, low activation, neutron resistant ferromagnetic material (P92) EUROFER foreseen for DEMO

Expected perturbations to magnetic probes near these tiles need to be taken into account for magnetic equilibria

Boundary condition

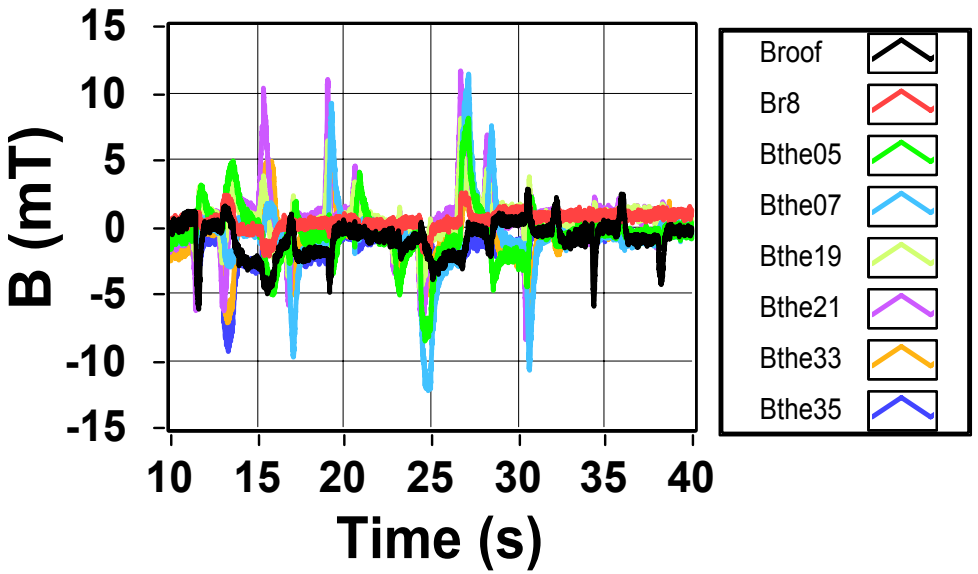
$$B_{//i} / \mu_{eff} = B_{//e}$$

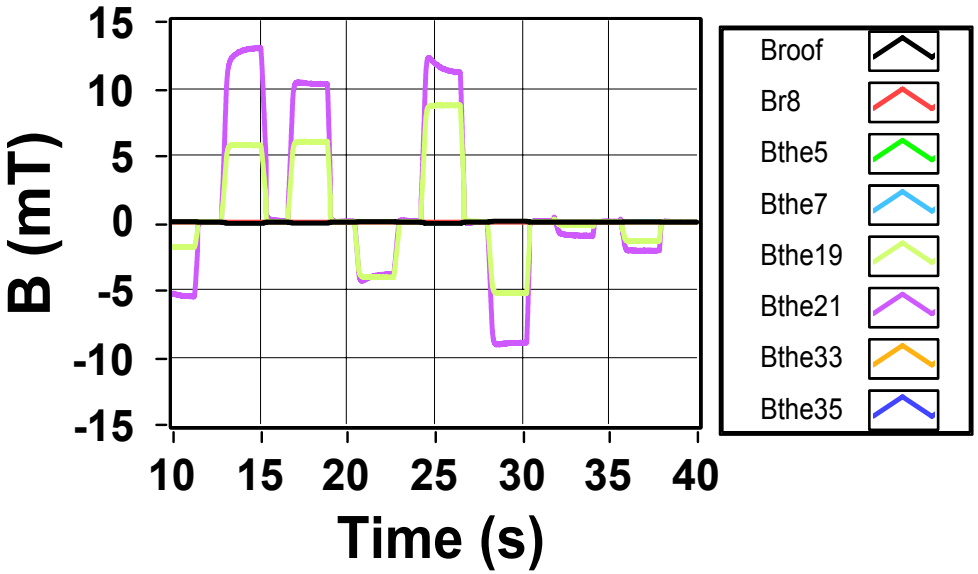
Model magnetisation by surface currents on tile

FM tiles and PF calibration shots

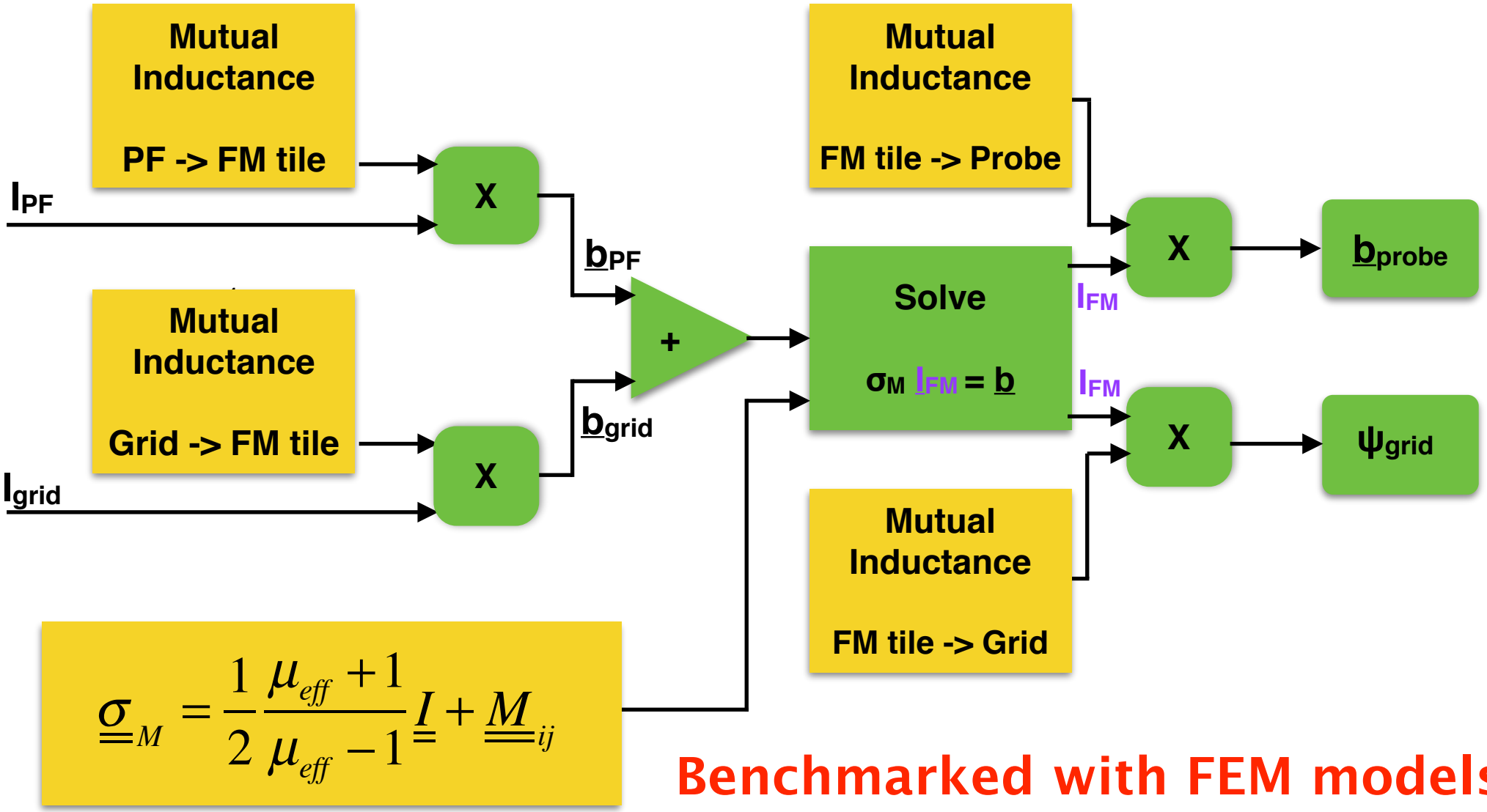
Magnetic probe signals due to surface currents on ferromagnetic tiles for calibration discharge with excitation of individual poloidal field coils

Difference of calculated and measured probe signals indicate that modelling of tiles is successful for calibration discharge with excitation of individual poloidal field coils



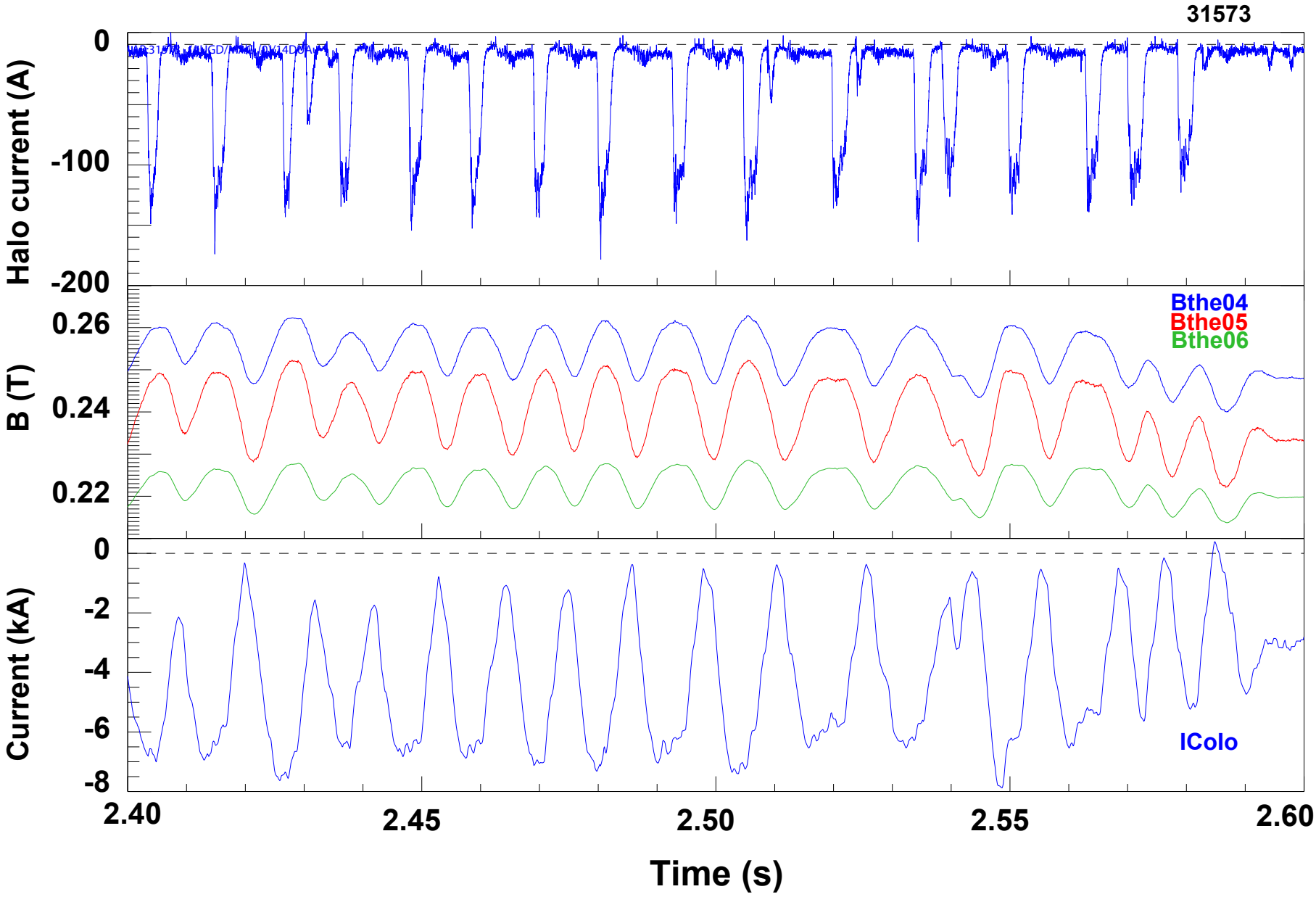


Ferromagnetic tile calculations

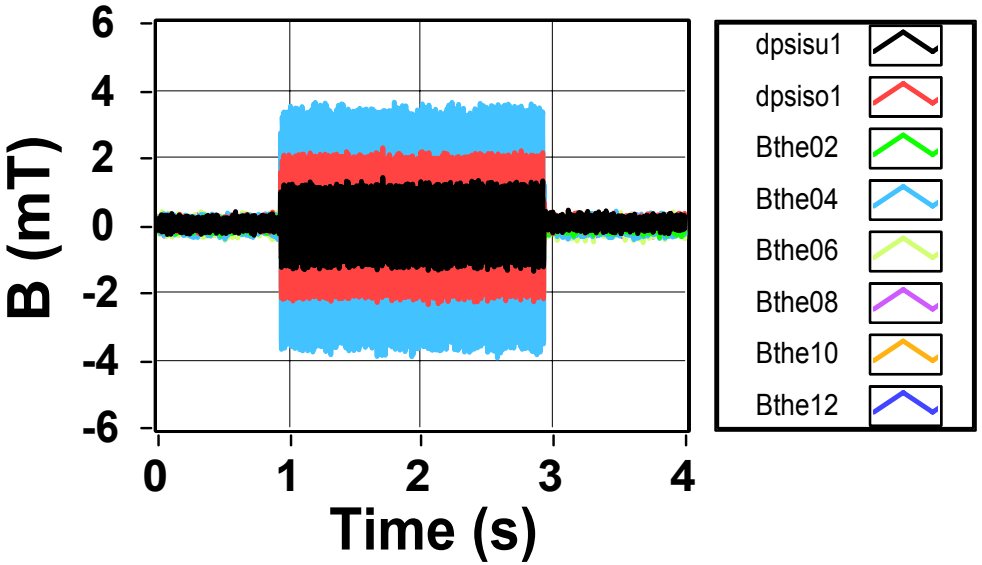


Benchmarked with FEM models (I.Zammuto)

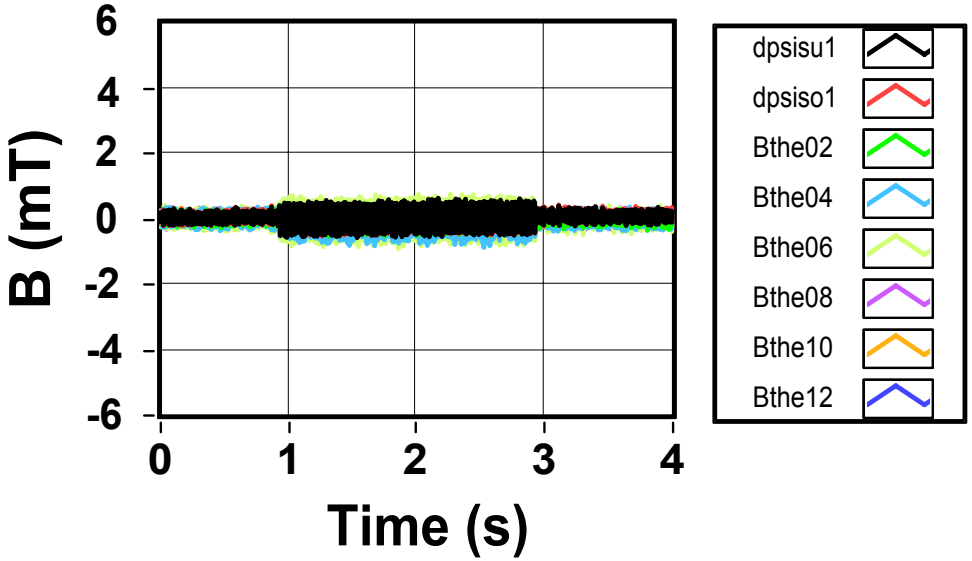
Colo perturbations due to ELM's



Probe compensation of Colo current



Difference in calculated and measured probe signal without accounting for low pass filtering of vacuum vessel

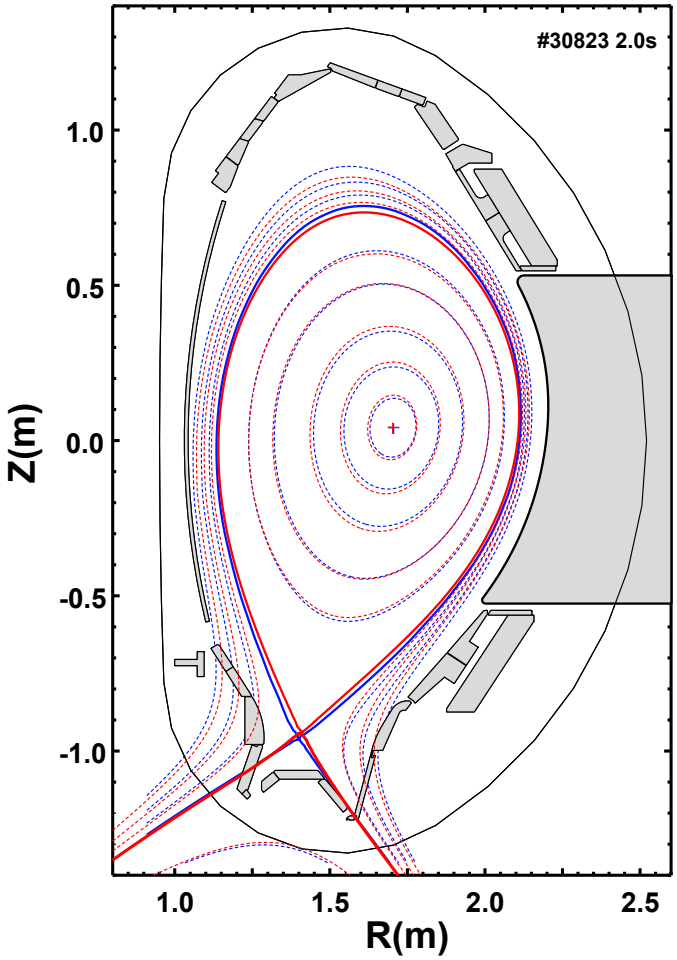


Difference in calculated and measured probe signal when accounting for low pass filtering of vacuum vessel

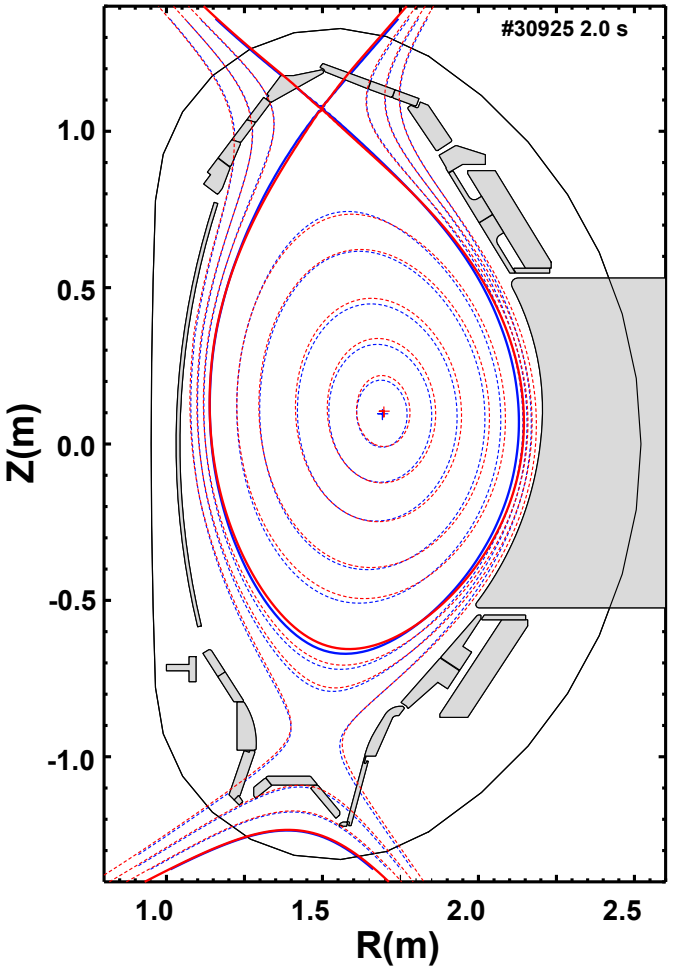
Equilibrium comparison

EQH (64x128) offline (CLISTE)
EQR (33x65) real-time (JANET)

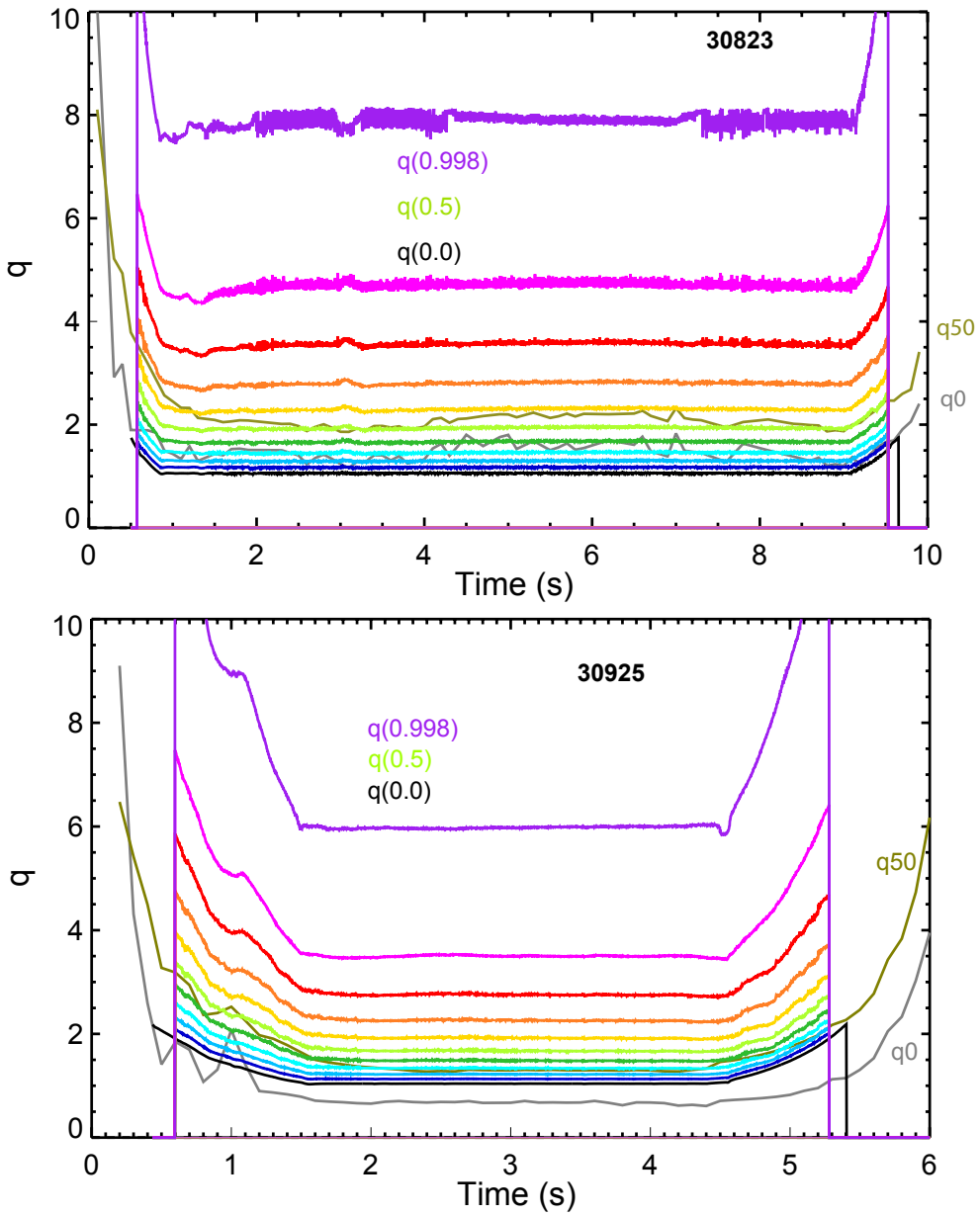
Ip = 0.8 MA, PNBI = 12.5 MW, PECRH = 2.6 MW



Ip = 1.0 MA, PNBI = 2.6 MW, PECRH = 2.4 MW



q(0) constraint



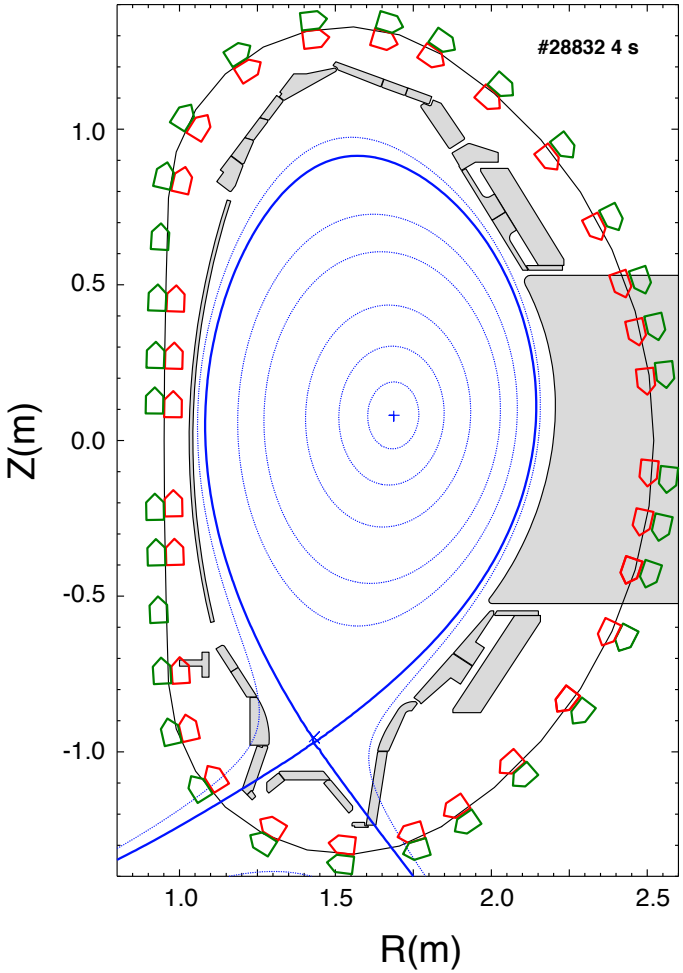
Comparison of time evolution of offline EQH (q0,q50) and real-time EQR q(r) profiles show that the offline q0 can significantly differ from 1

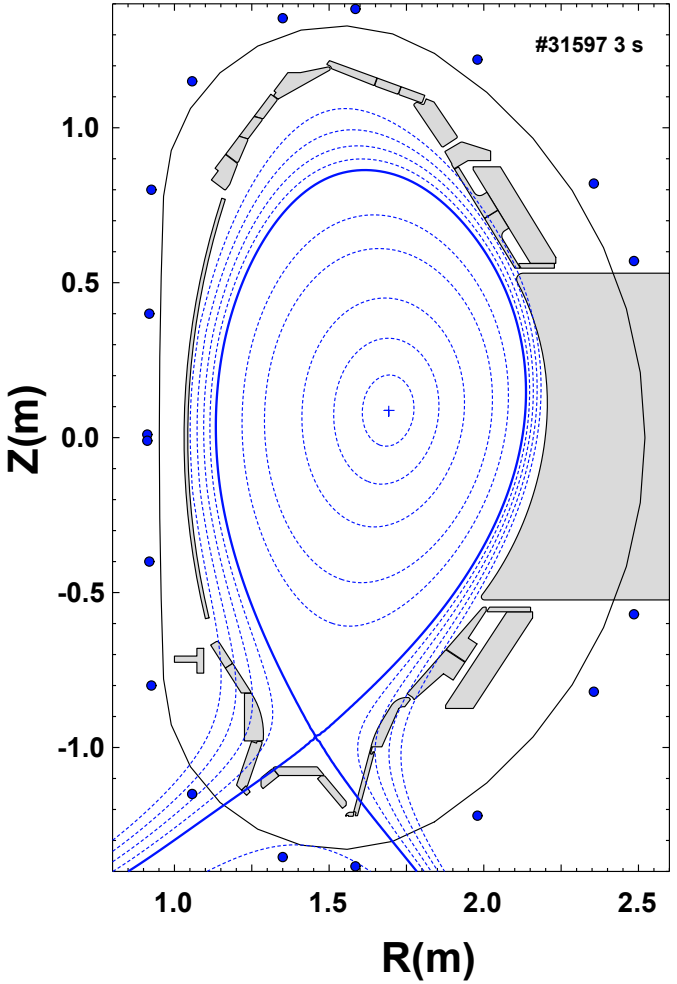
Internal constraints from polarimetery or MSE in addition to the magnetic probe measurements are absolutely necessary to fix the value of q(0)

Now 6 P´ and 6 FF´ coefficients with regularisation for basis functions -> lookup table

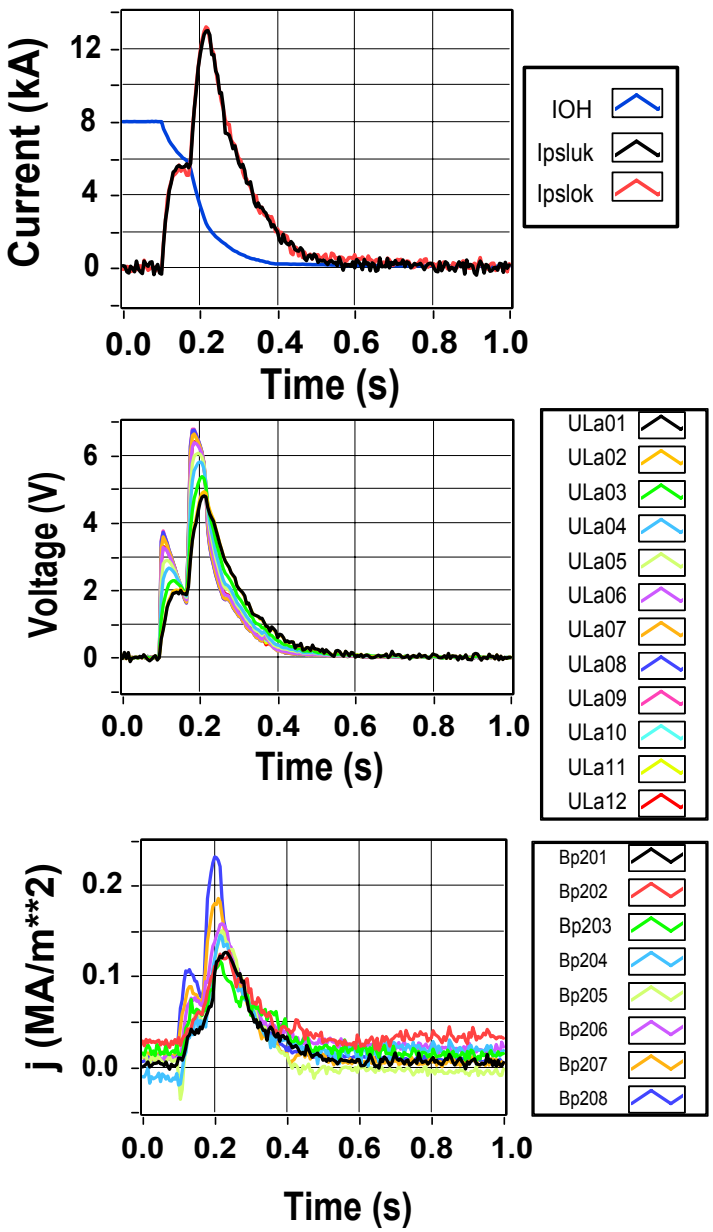
Inner/outer probe array + ULa

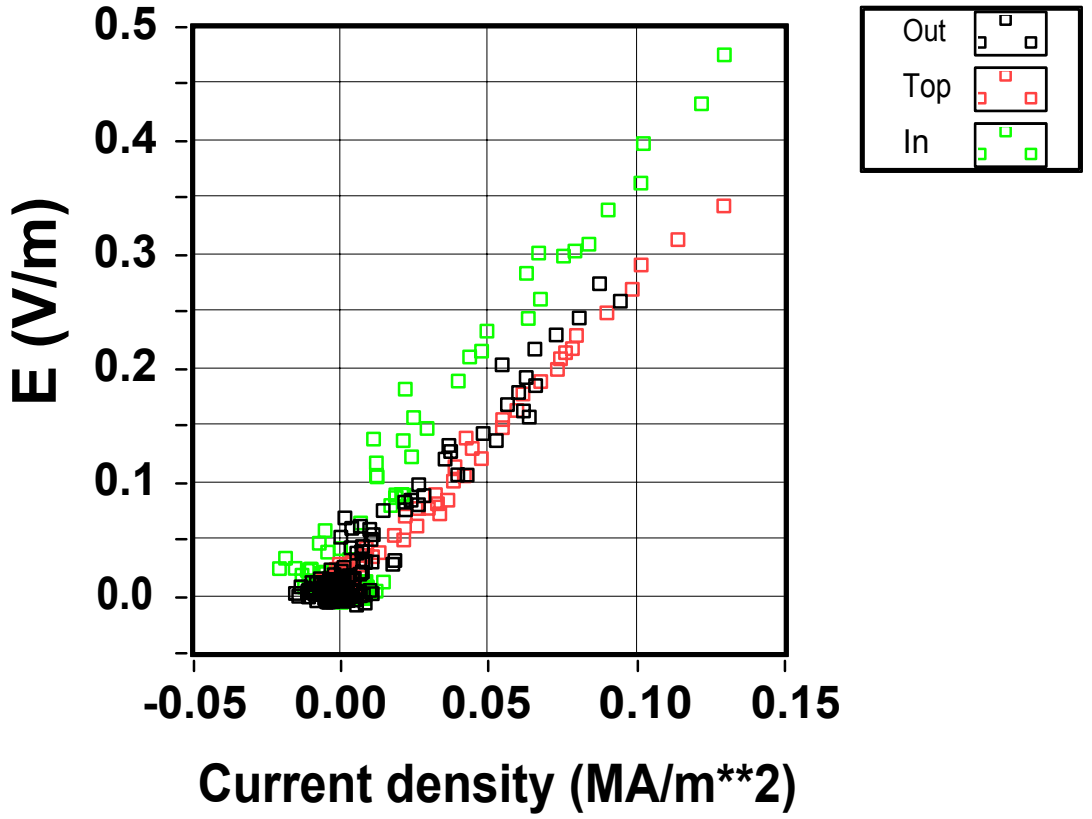
30 pairs of inner and outer magnetic probes
18 loop voltages external to vessel





j(vessel) measurements





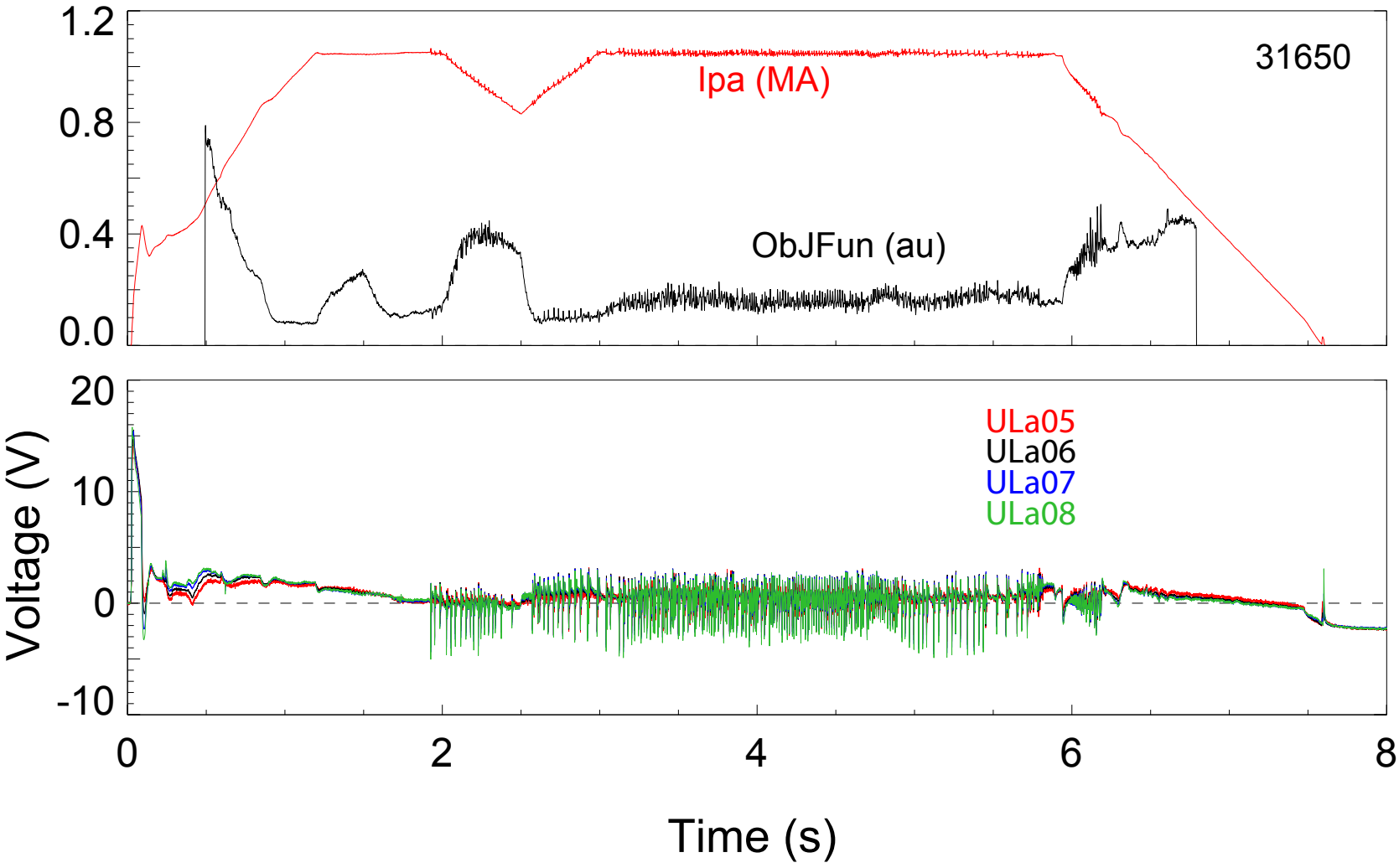
$$\rho_{SS304} = 7.2 * 10^{-7}\,\Omega m$$

$$\rho_{MESS} = 3 * 10^{-6}\,\Omega m$$

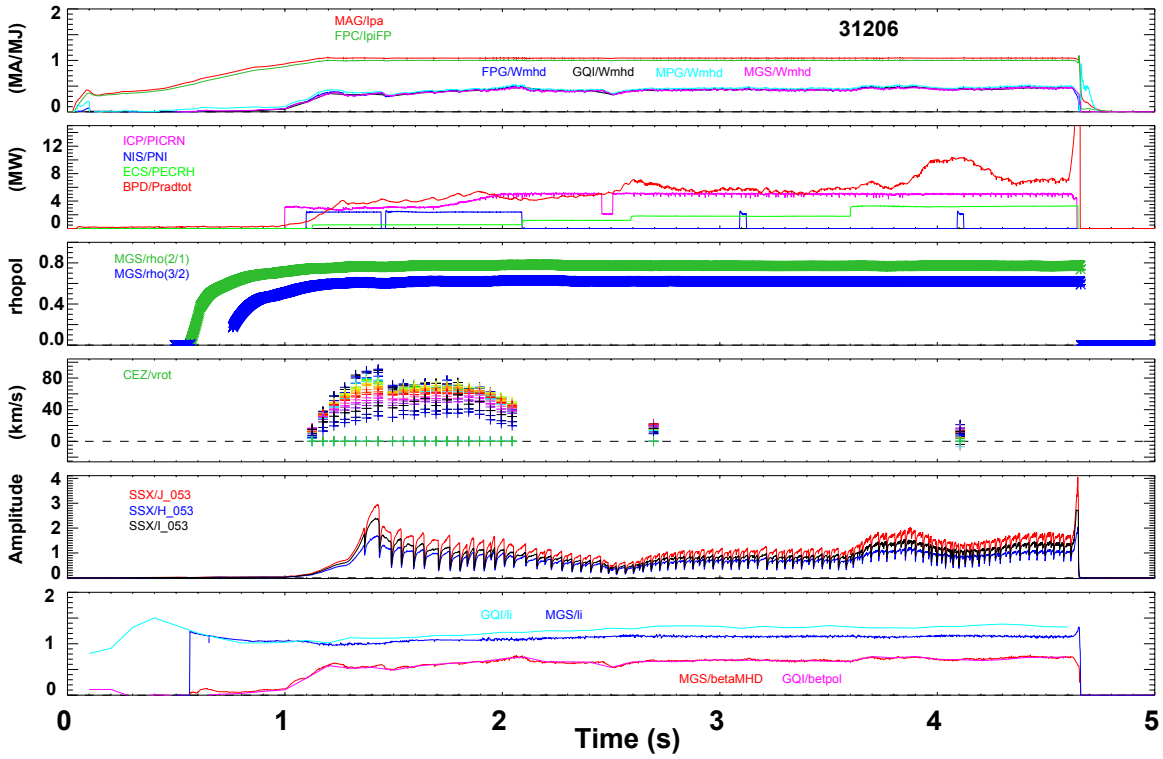
$$\mu_o jwL = (B_i - B_e)L$$

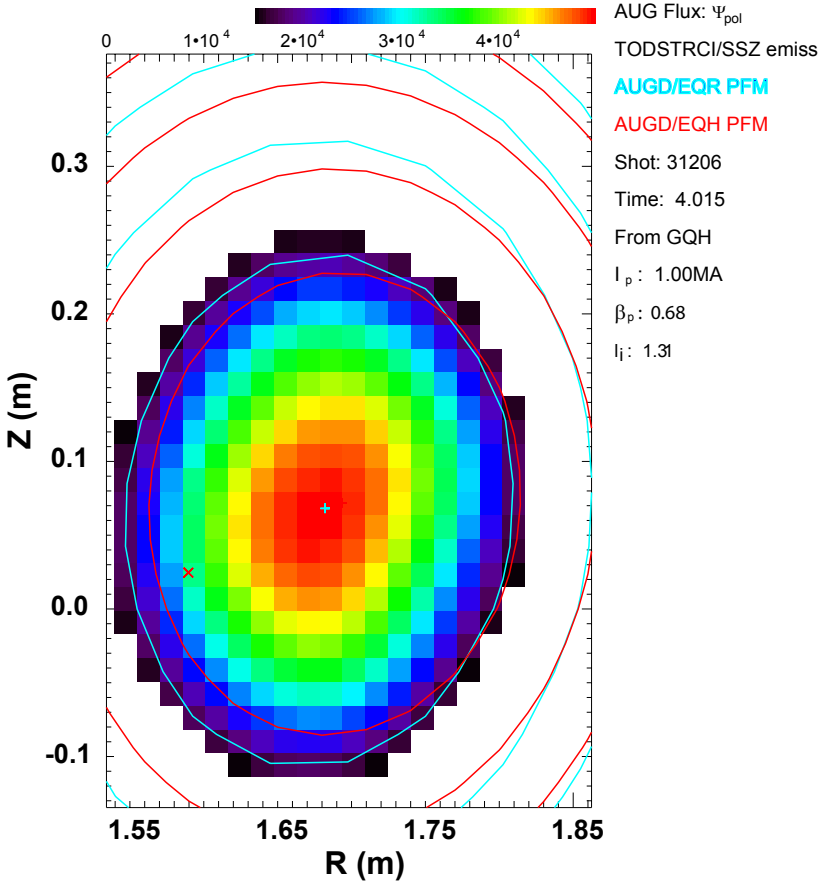
j(vessel) from ULa?

➡ **reduce fitting errors in current ramp**



SXR tomography and equilibrium





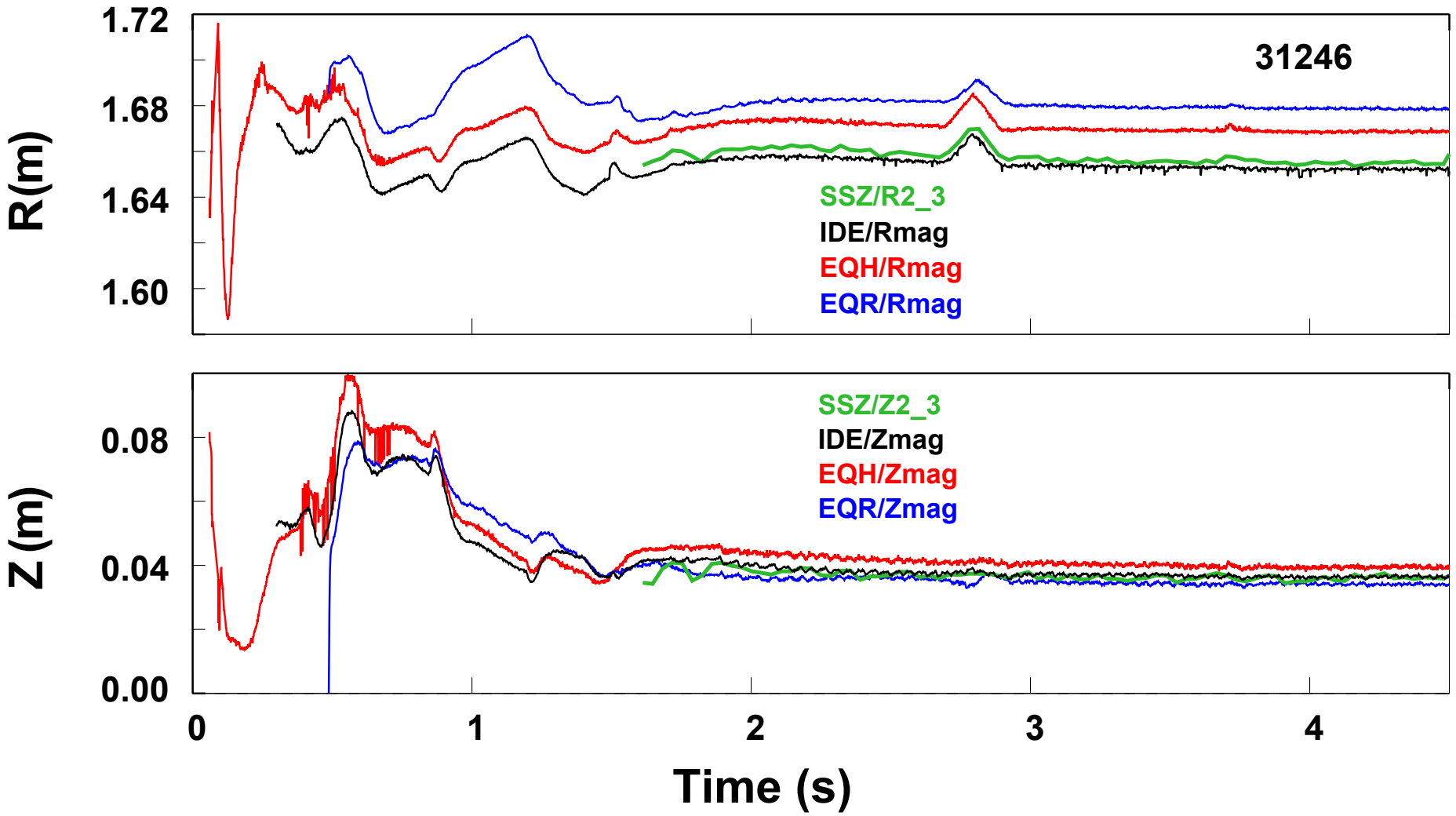
J.P.Qian, L.L.Lao, Q.L.Ren et. al, Nucl. Fusion, 025003, 2009

Equilibrium reconstruction of plasma profiles based on soft x-ray imaging in DIII-D

D. Mazon, D. Vezinet, D. Pacella, et. al, RSI 83, 063505, 2012

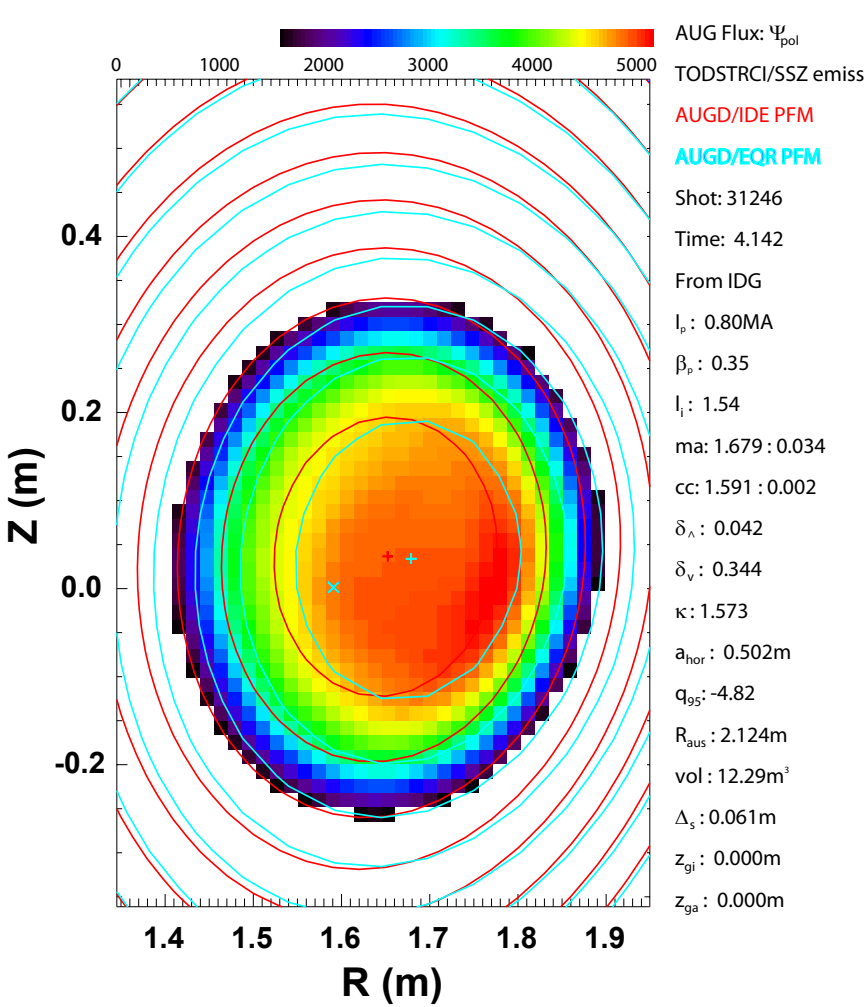
Soft x-ray tomography for real-time applications (Tore Supra)

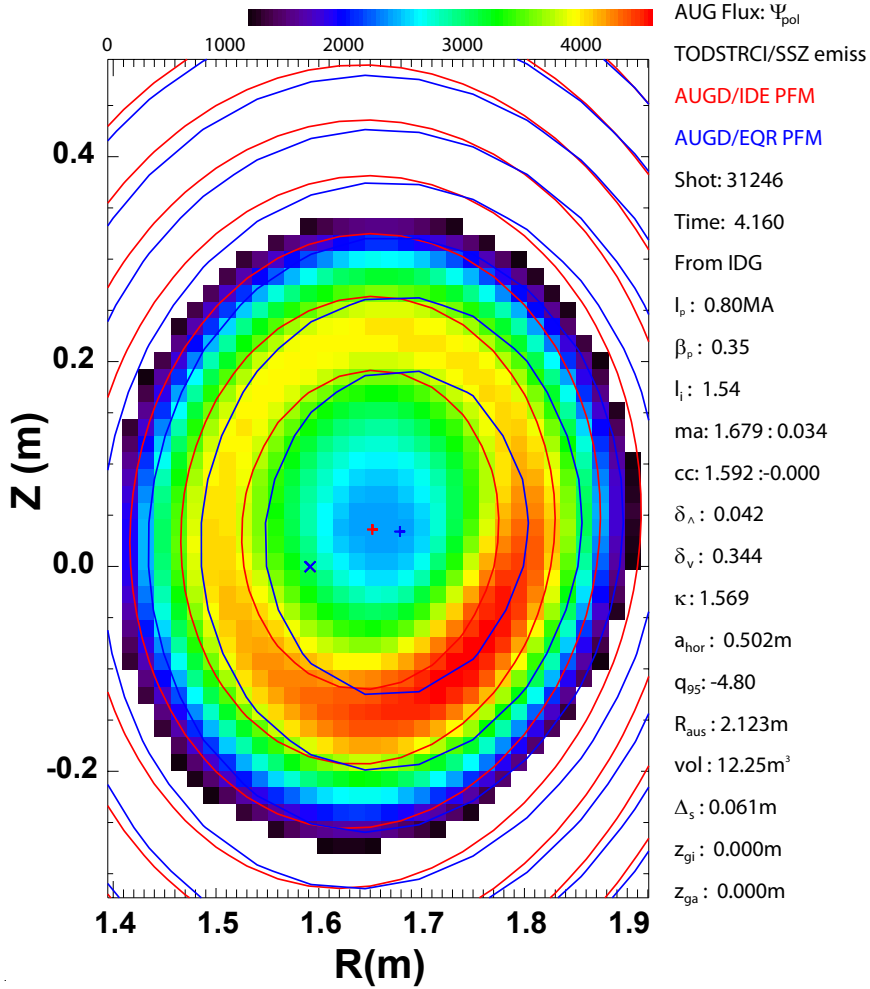
SXR tomography and magnetic axis



SXR tomography and equilibrium

T.Odstrcil (SSZ tomography shot files), G.Conway(cview)

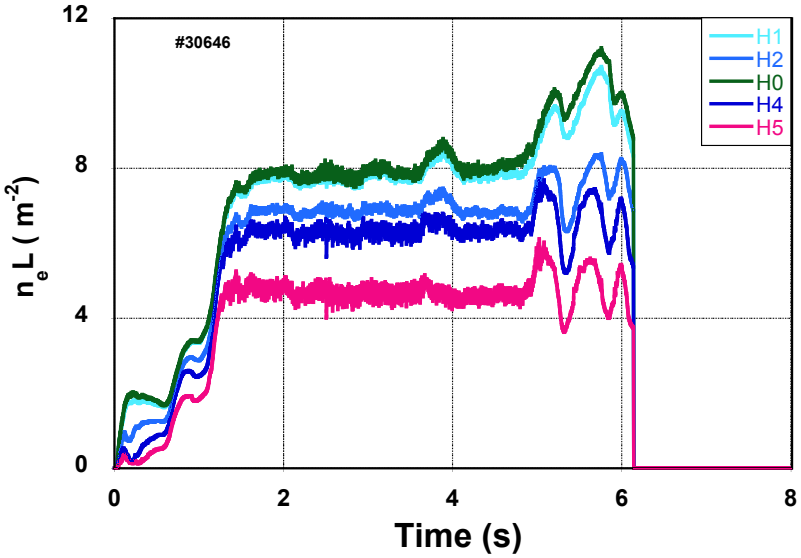


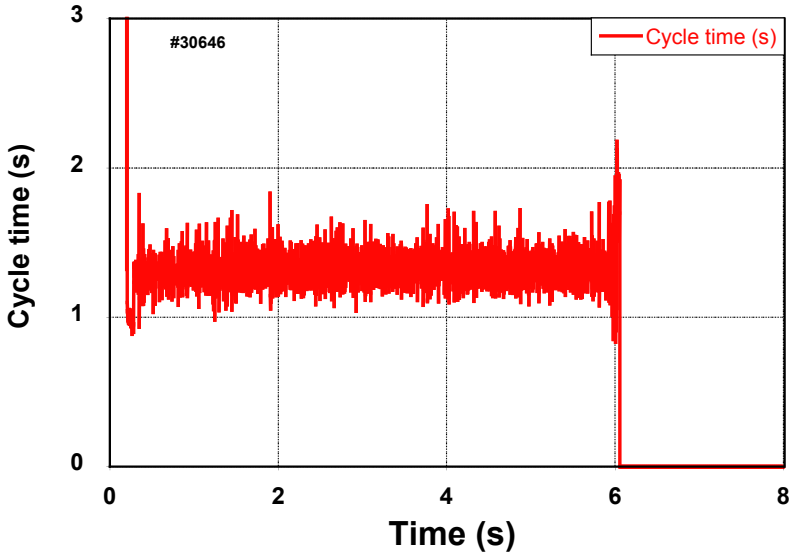


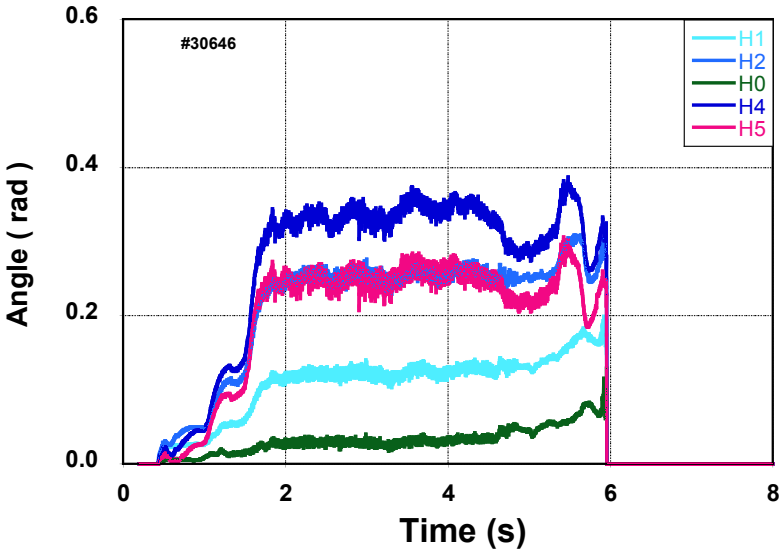
Soft x-ray tomography for real-time applications ….

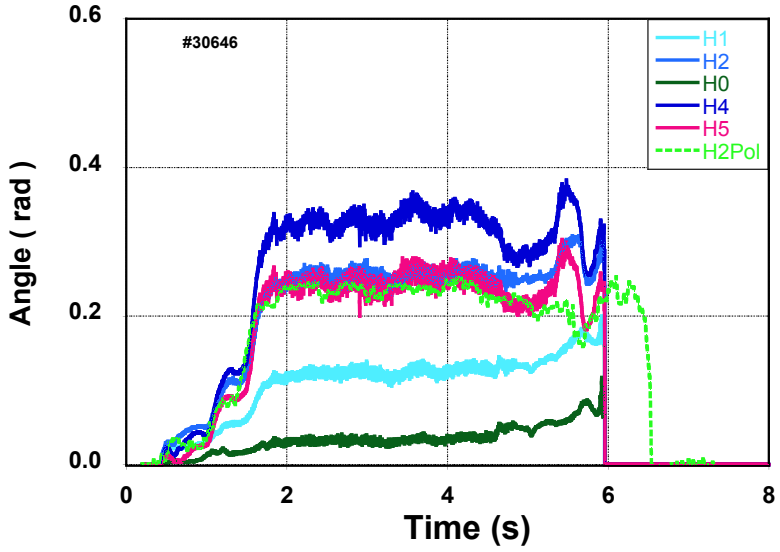
D. Mazon, D. Vezinet, D. Pacella, et. al, RSI 83, 063505 (2012)

Polarimeter constraints



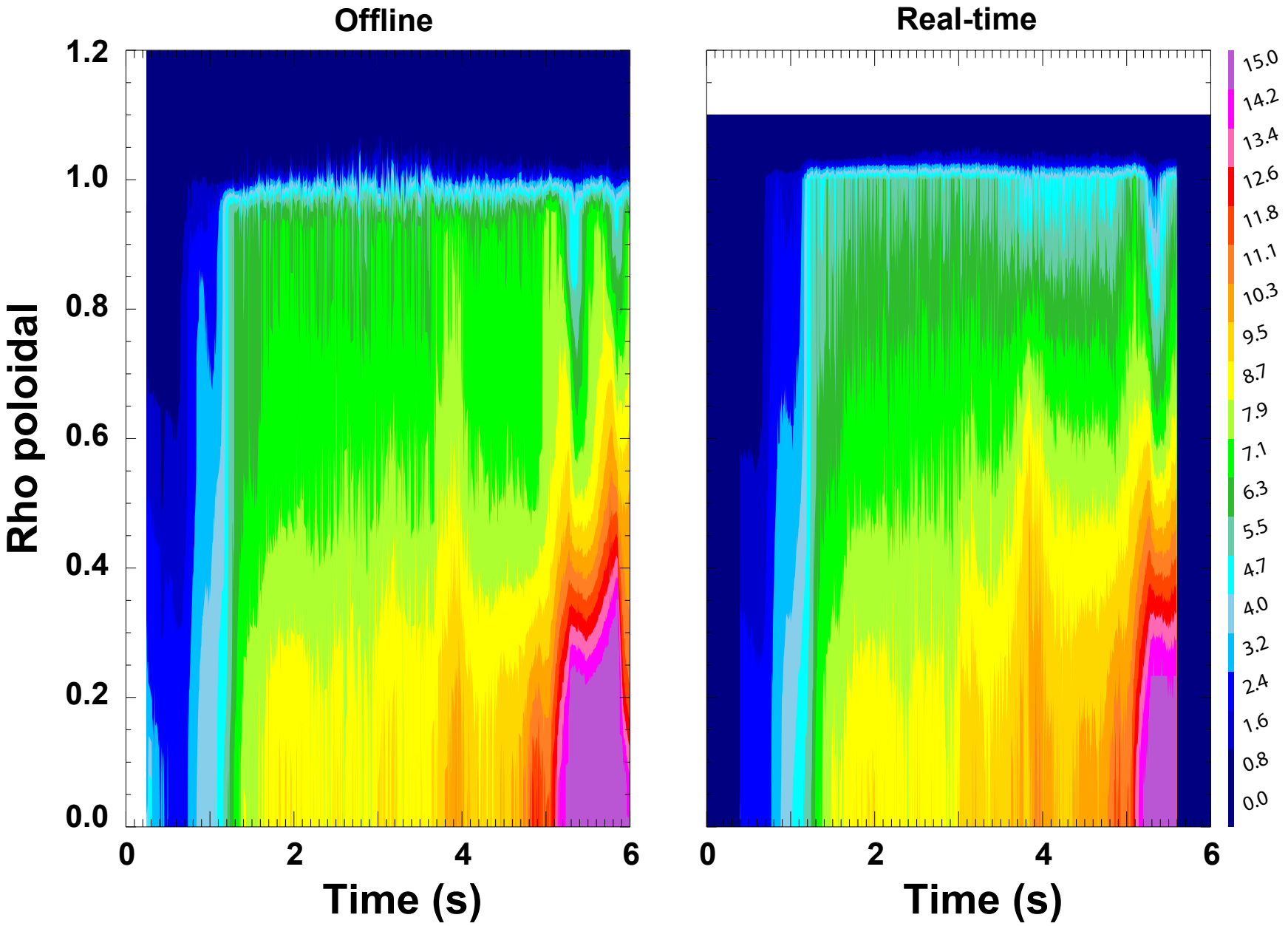






Density profile

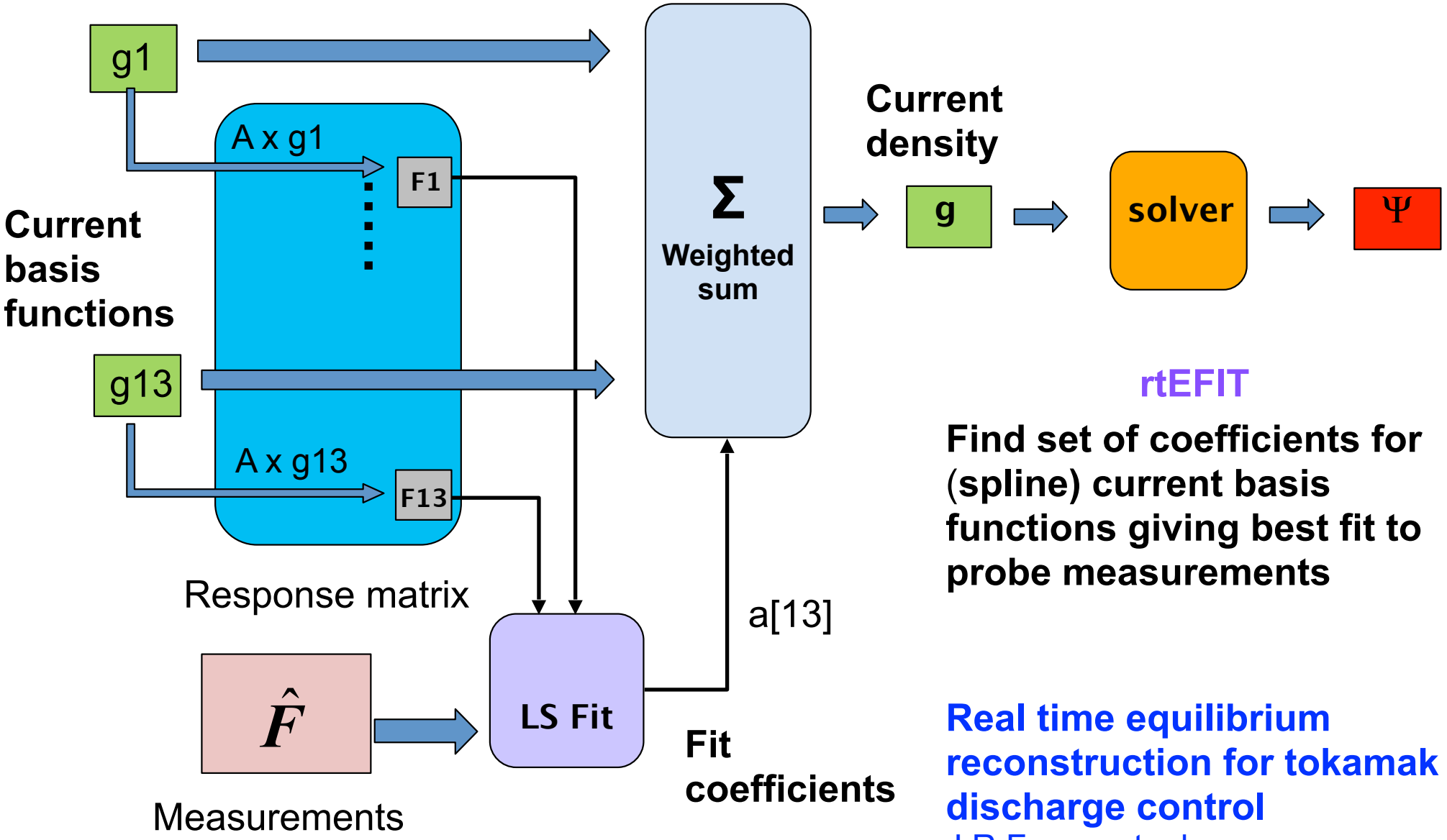
#30646



Summary

- ★ Real-time magnetic equilibria routinely available with 2 ms cycle time for NTM stabilisation and disruption avoidance experiments
- ★ Using 6 spline basis functions for P´ and FF´
- ★ q(0) = 1 constraint
- ★ Low pass filter applied to CoI to account for vacuum vessel shielding
- ★ Ferromagnetic tiles included in RT equilibria
- ★ Vessel currents/polarimeter to be included in RT equilibria
- ★ Soft x-ray tomography and equilibrium comparison started

rtEFIT algorithm



rtEFIT

Find set of coefficients for (spline) current basis functions giving best fit to probe measurements

Real time equilibrium reconstruction for tokamak discharge control

J.R.Ferron et. al,
Nucl. Fusion, **38**, 1055, 1998

Col coil currents

Transfer function measured by recording probe response at 10, 20, 40 and 80 Hz