EUROfusion

MST Task Force activities on disruptions and runaway electrons

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Theory and Simulation of Disruptions in Tokamaks Workshop, PPPL, 20-22/07/2016

***http://www.euro-fusionscipub.org/mst1**

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 gran agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Special thanks to:

- **The MST Task Force Leaders**: M. Beurskens, S. Coda, T. Eich, A. Hakola, H. Meyer

- A. Kallenbach, Y. Martin and the AUG and TCV teams

- J. Decker, B. Esposito, F. Felici, M. Gobbin, G. Granucci, M. Maraschek, E. Nardon, G. Papp, R. Paccagnella, G. Pautasso

Purpose of this talk

To provide a quick overview on the (experimental) activities on disruption and runaway electrons in the EUROfusion medium size tokamak task force.

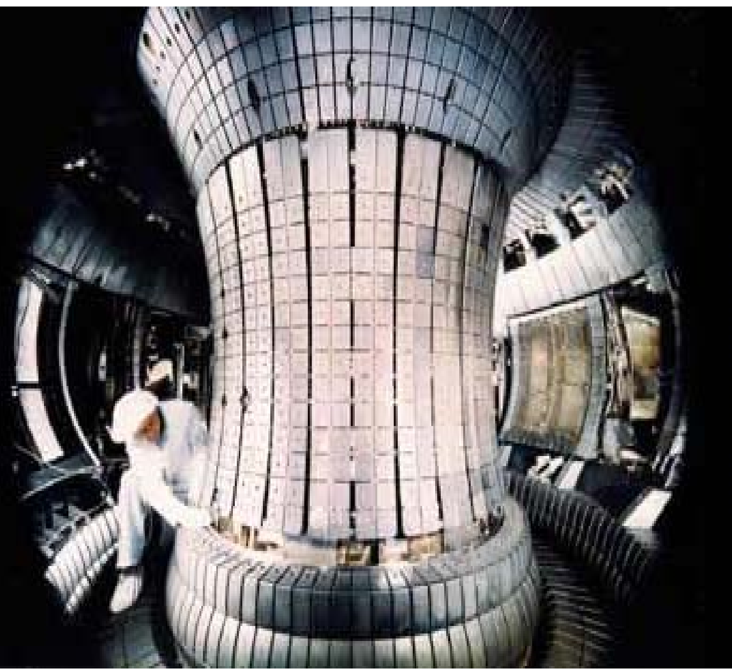
The Medium Size Tokamak (MST) Task Force

Manages the EUROfusion part of the scientific program in 3 tokamaks

ASDEX Upgrade
2014
2015/16

TCV
2015/16

MAST-U
2017

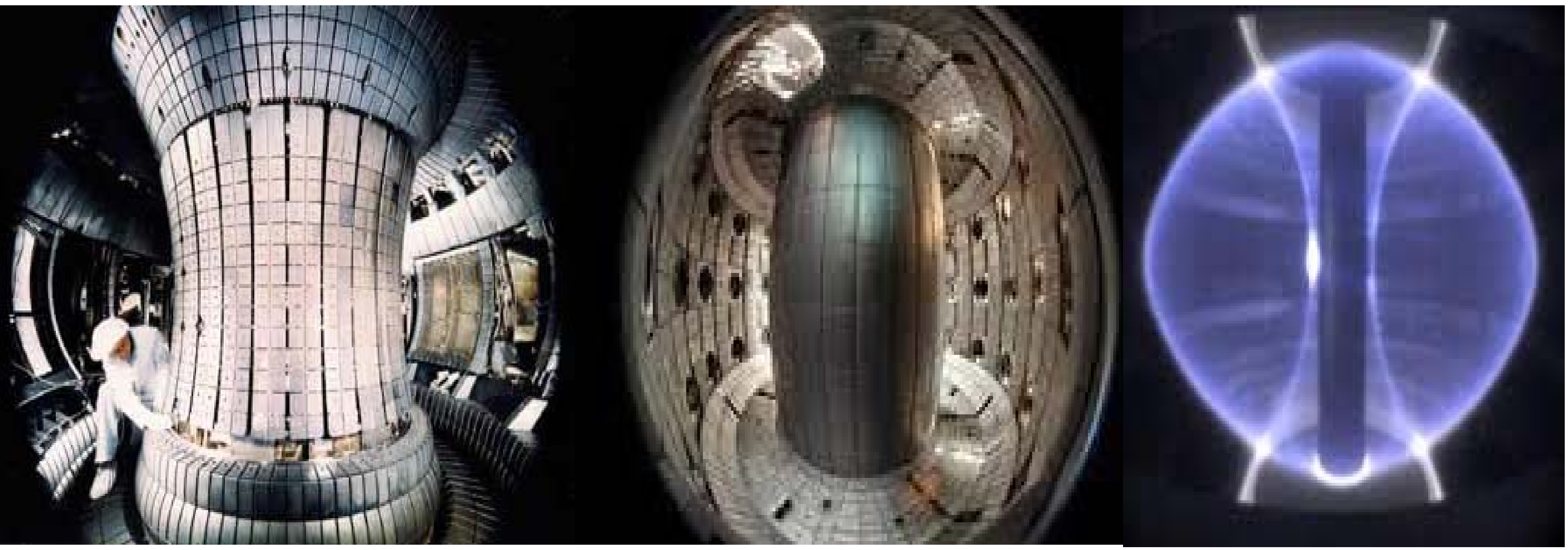


The Medium Size Tokamak (MST) Task Force

2015/16 campaign

- AUG: 48 experiment, 697 shots, 298 scientists
- TCV: 39 experiment, 732 shots (and counting), 156 scientists

Program open to international collaborations



2016 3 top objectives

1. Understand the effect of density versus collisionality and operation with an all metal wall for ELM mitigation/suppression with pellets and resonant magnetic perturbations.

2. **Increase efficiency and understanding of methods for disruption mitigation or avoidance and runaway electrons control**

3. Increase the operational margin for ITER and DEMO relevant scenarios with high P_{SOL}/R and tolerable target heat loads.

MST heavily invests on disruption and RE studies

AUG15-1.3-1	Disruption mitigation via Massive Gas Injection	Duval Pautasso	TCV15-1.3-1
AUG15-1.3-2	Disruption avoidance via applied magnetic perturbation	Maraschek Paccagnella	
AUG15-1.3-3	Disruption avoidance using ECCD in high beta conditions	Esposito Maraschek	TCV15-1.3-3
AUG15-1.3-4	Disruption avoidance using the transport simulator RAPTOR	Felici	TCV15-1.3-4
AUG15-1.3-5	Runaway electrons: scenario, physics and mitigation via Massive Gas Injection	Papp Pautasso	TCV15-1.3-5
AUG15-1.3-6	Runaway electrons: decorrelation via applied magnetic perturbation	Gobbin Papp	TCV15-1.3-6

Shots dedicated to disruptions and RE

108 shots performed in AUG

104 shots performed in TCV (and counting)

In addition non-MST tokamaks contributing to these topics

- **Compass, FTU, RFX-mod**

Outline

1. Disruption avoidance
    - ECRH
    - RMP

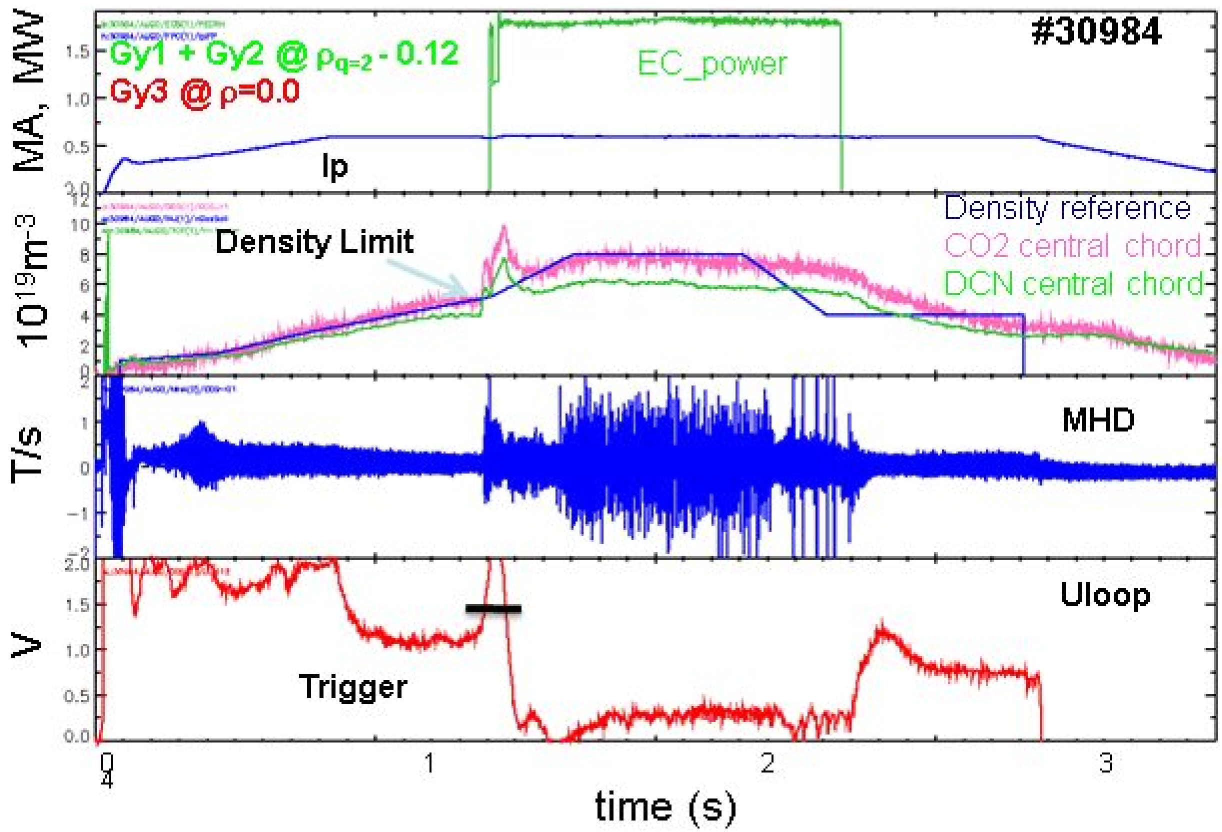
2. Disruption mitigation
    - MGI

3. Runaway Electron generation and control

Disruption avoidance

- ECRH
- RMP

disruption avoidance via ECCD achieved in past campaign

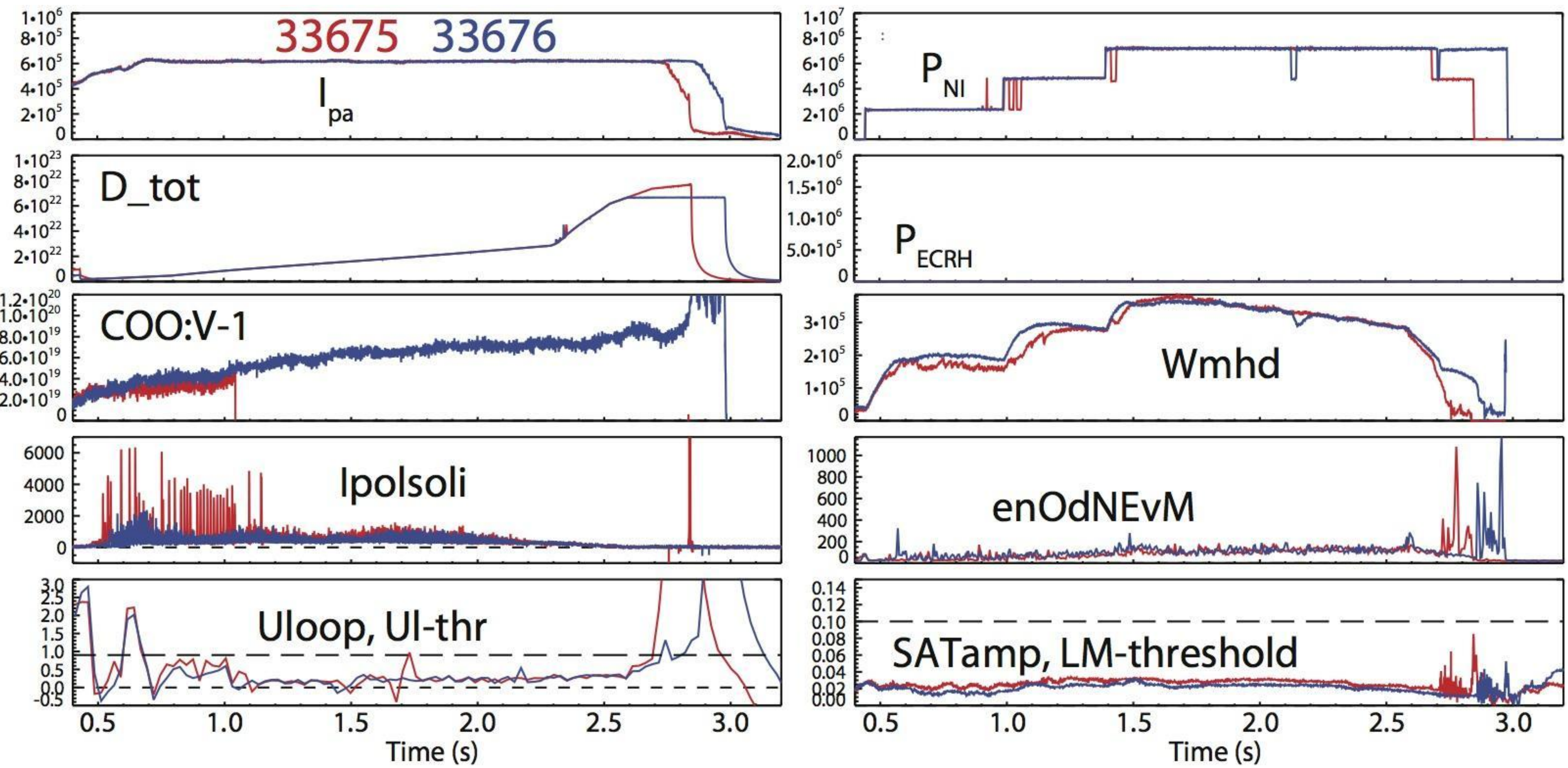


Feedback-controlled n_e-rise to $n_{e,max} \approx 2\, n_{e,disruption}$
ECCD at q=2 triggered by U_{loop}, i.e. MHD typically just too late

Goal: apply to H-mode density limit

Maraschek et al., EPS 2015

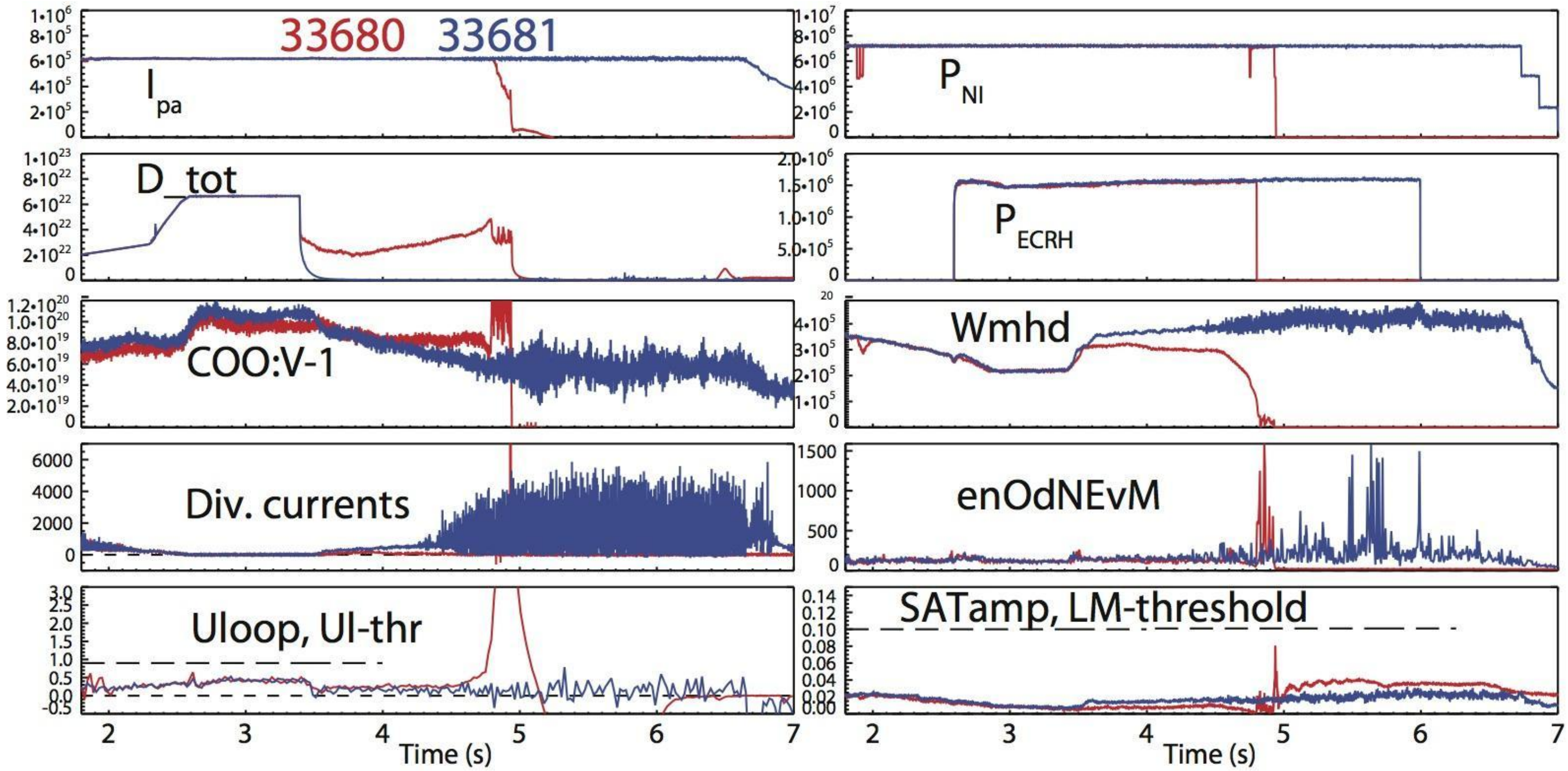
Reference



Esposito, Maraschek, AUG/TCV 15-1.3-3

H-mode density limit disruption avoidance

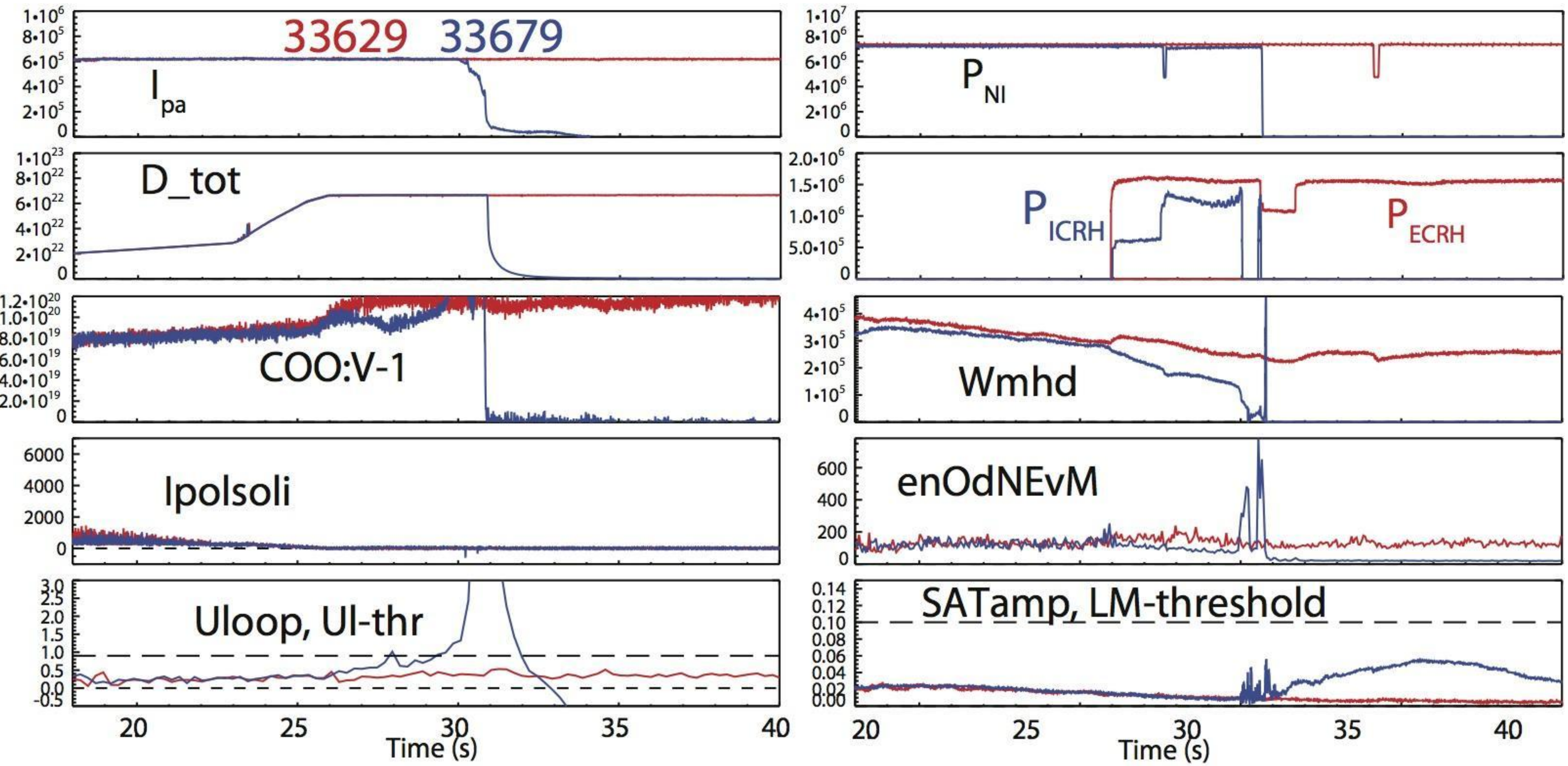
stationary avoidance at high n_e for 1s (up to 3.5s reached)



Need effective trigger development

Esposito, Maraschek, AUG/TCV 15-1.3-3

ECCD vs. ICRH



33629 - ECCD

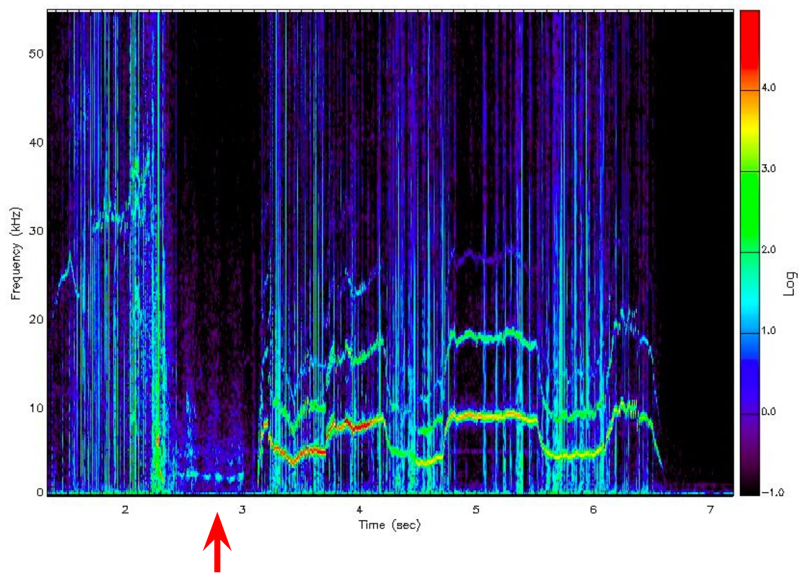
$\rho_{dep}=\rho_{2/1}$ - 0.05

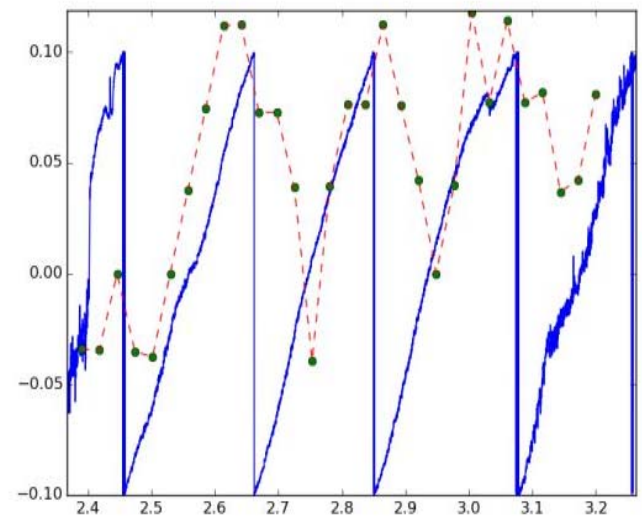
33679 - ICRH central

Esposito, Maraschek, AUG/TCV 15-1.3-3

Locked mode entrainment to slow RMP (5 Hz)

Anchor mode to external perturbation to avoid or delay disruption





Locked mode saddle coil signal and **island position from ECE**

No disruptions have been observed with the B coils at P_{NBI} < 10 MW, but **no firm conclusions yet**

Marascheck, Paccagnella AUG 15-1.3-2
Paccagnella, EPS 2016

Disruption avoidance based on real-time physics modeling and supervision

Implement a model-based plasma scenario supervision system based on RAPTOR that compares

- the physics expectation for the evolution of the plasma with diagnostic measurements
- and the state of the plasma with known limits

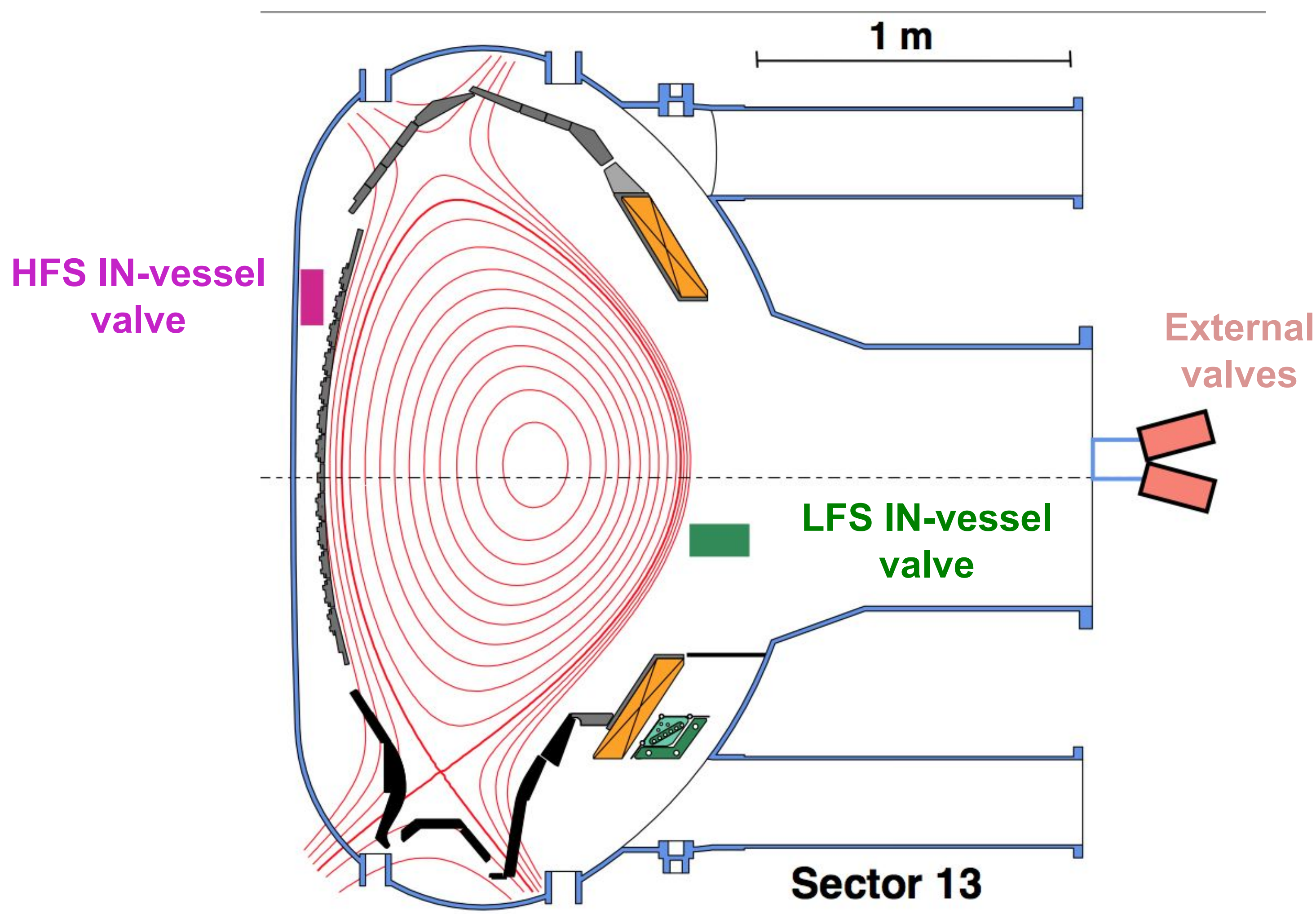
Implement and test safe ramp-down strategies to actuate a soft-stop if threshold violations are detected.

Felici Exp. AUG/TCV 15-1.3-5

Disruption mitigation

- **MGI**

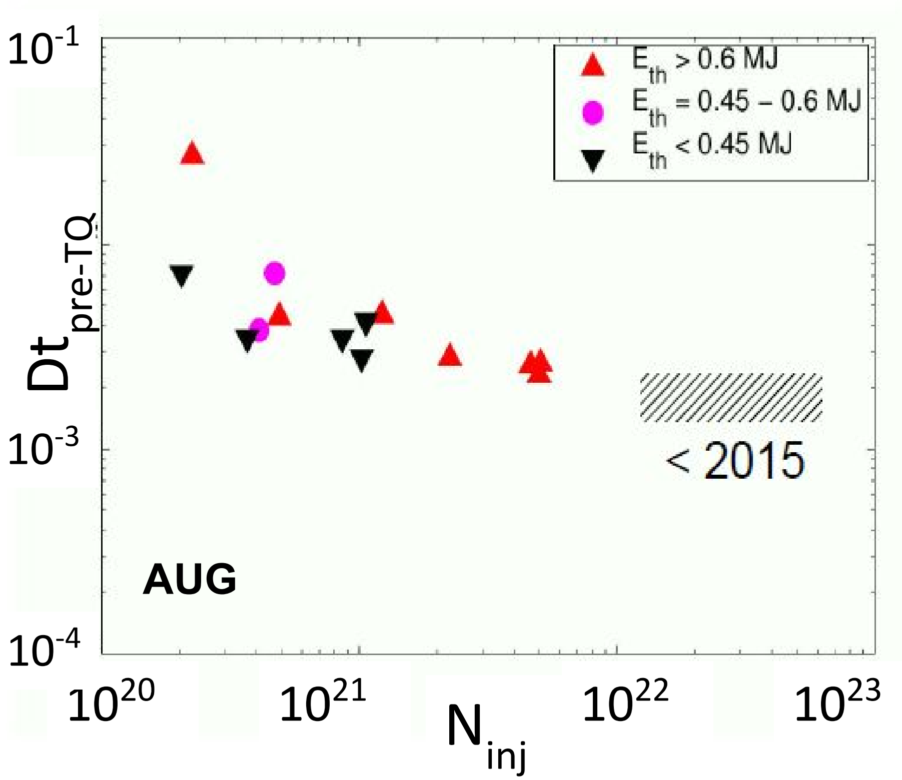
MGI in AUG


1 m
HFS IN-vessel valve
External valves
LFS IN-vessel valve
Sector 13

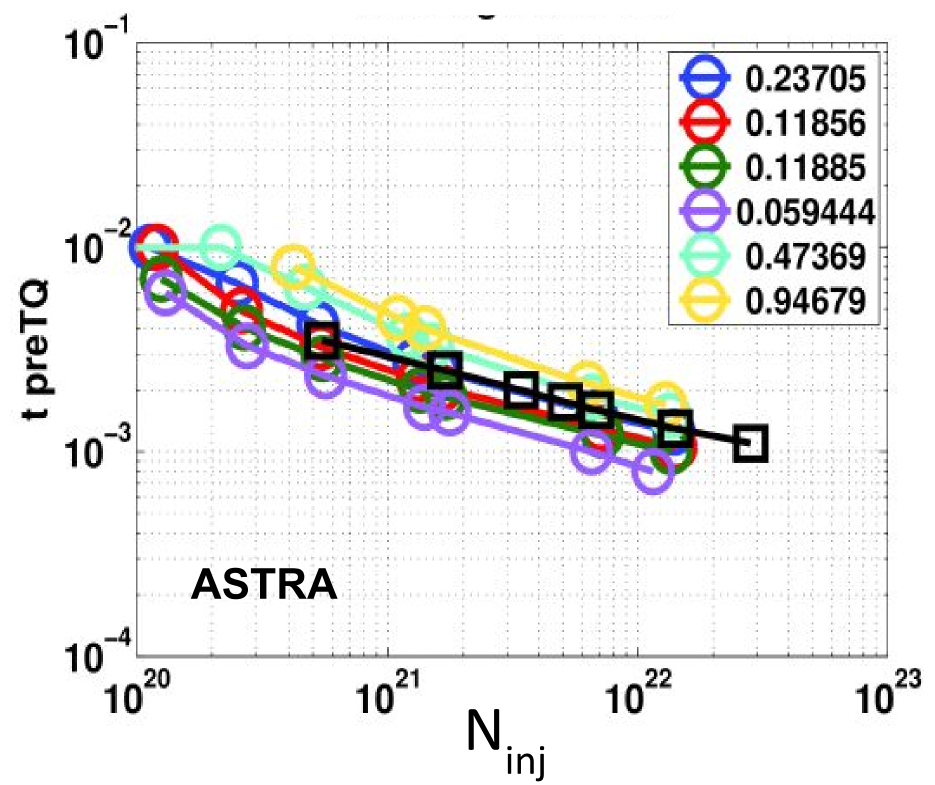
Disruption mitigation with small neon quantities

AUG compared with ASTRA-STRAHL 1D simulations of Ne injection

Good agreement: interesting for extrapolation to ITER

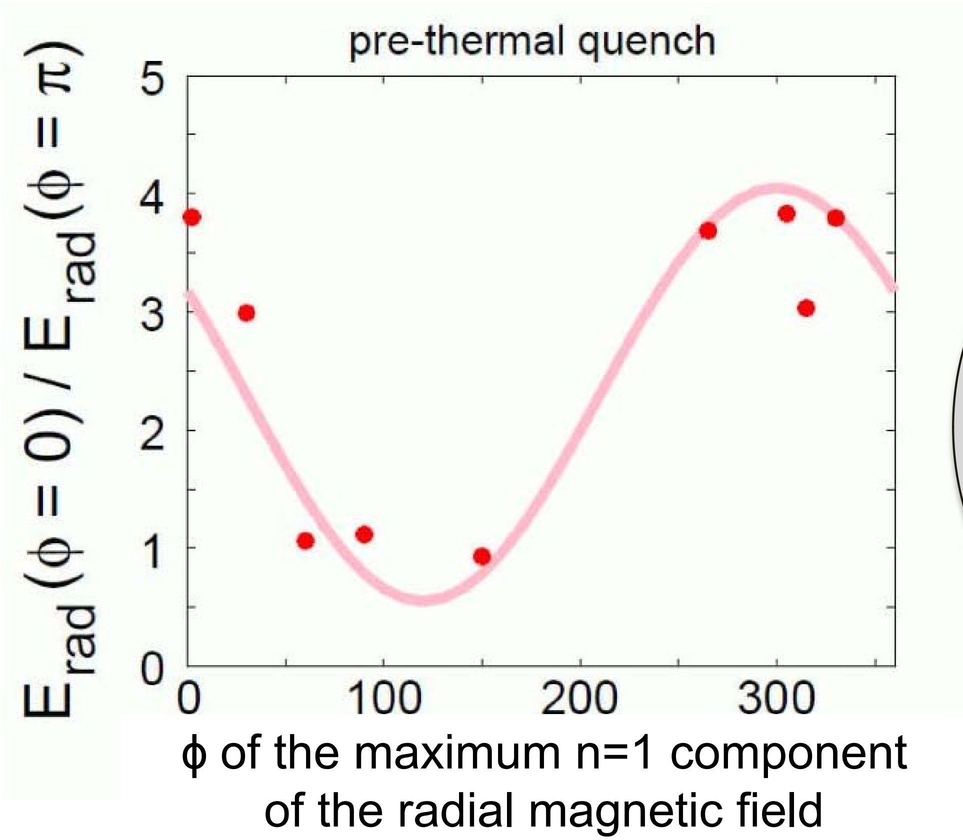


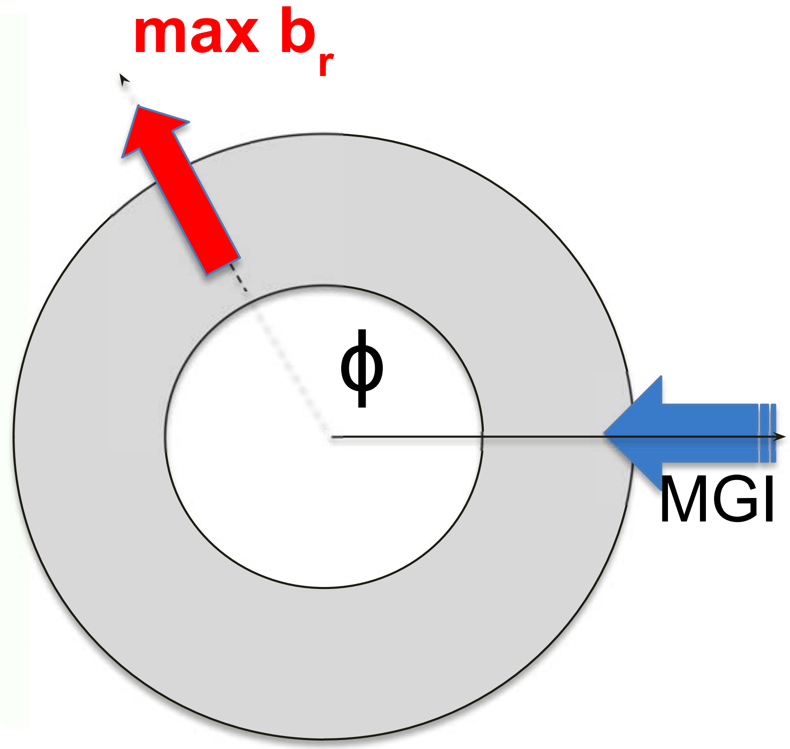
Duval, Pautasso, Exp. AUG15-1.3-1
Pautasso, EPS 2016 invited and EPS 2015 Oral



Fable et al. Nucl. Fusion 2015

Radiation asymmetry



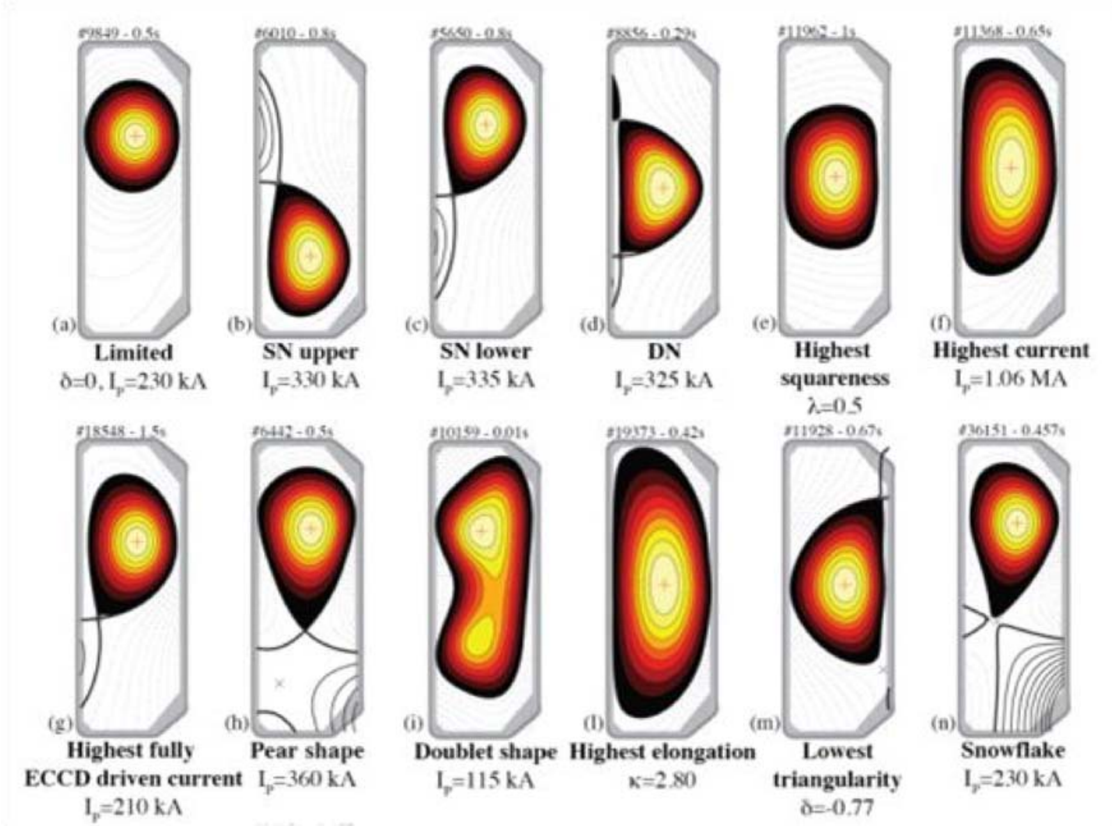


NIMROD ➔relative position of valve, with respect to the n=1 X point strongly influences the magnitude of the asymmetry

maximum P_{rad} occurs when the impurities are injected into the X point (Izzo, PoP 2013)

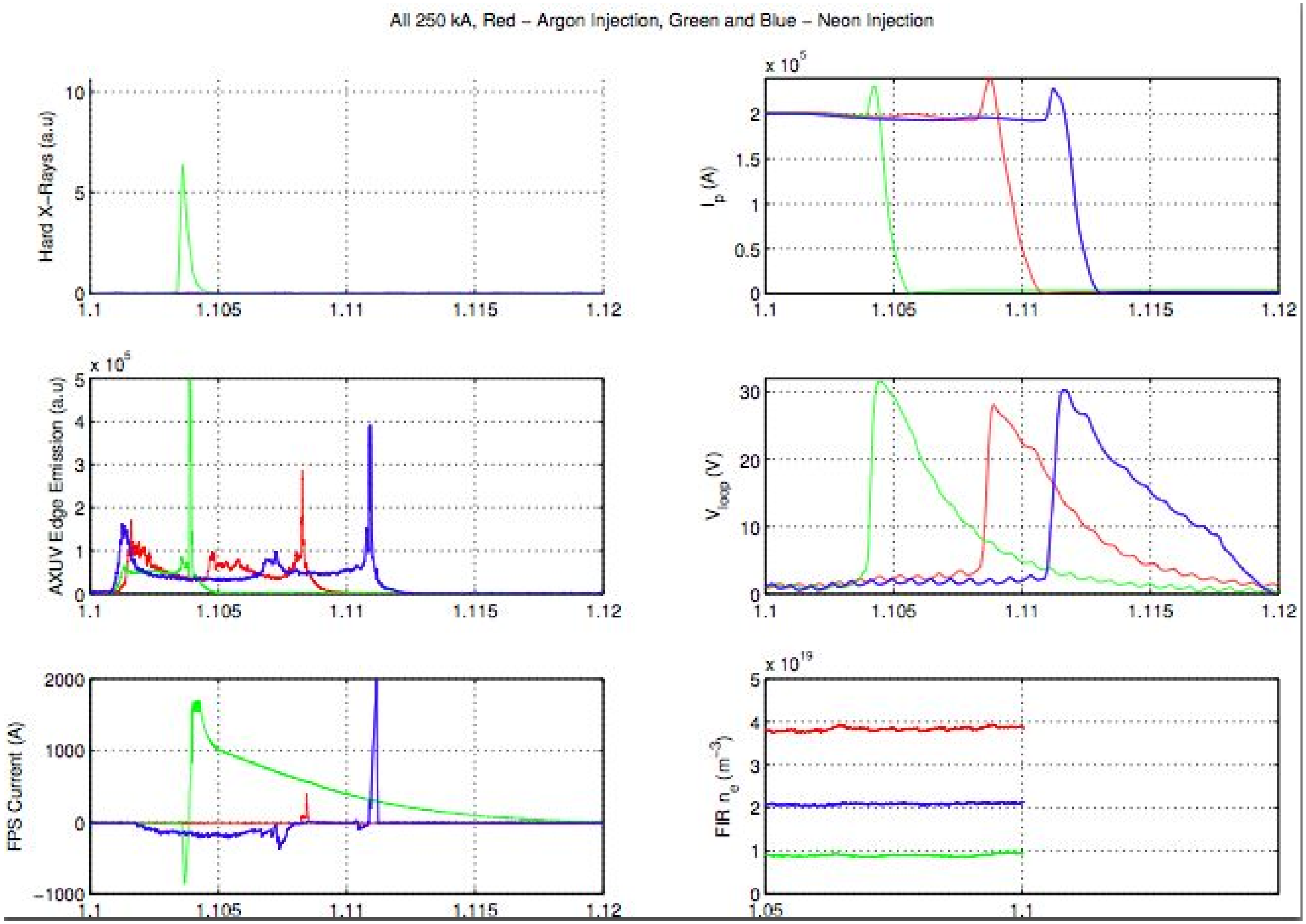
Duval, Pautasso, Exp. AUG15-1.3-1
Pautasso, EPS 2016 invited

Experiments recently started in TCV with one valve



Duval, Umar Exp. TCV15-1.3-1

Initial MGI experiments in TCV

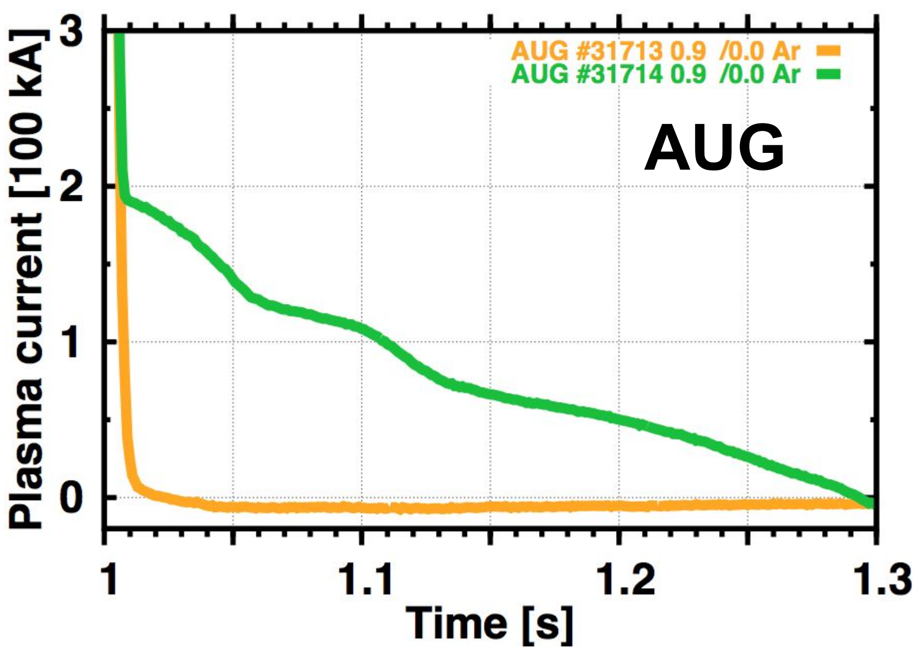


Runaway electron mitigation

Runaway electrons in AUG and TCV

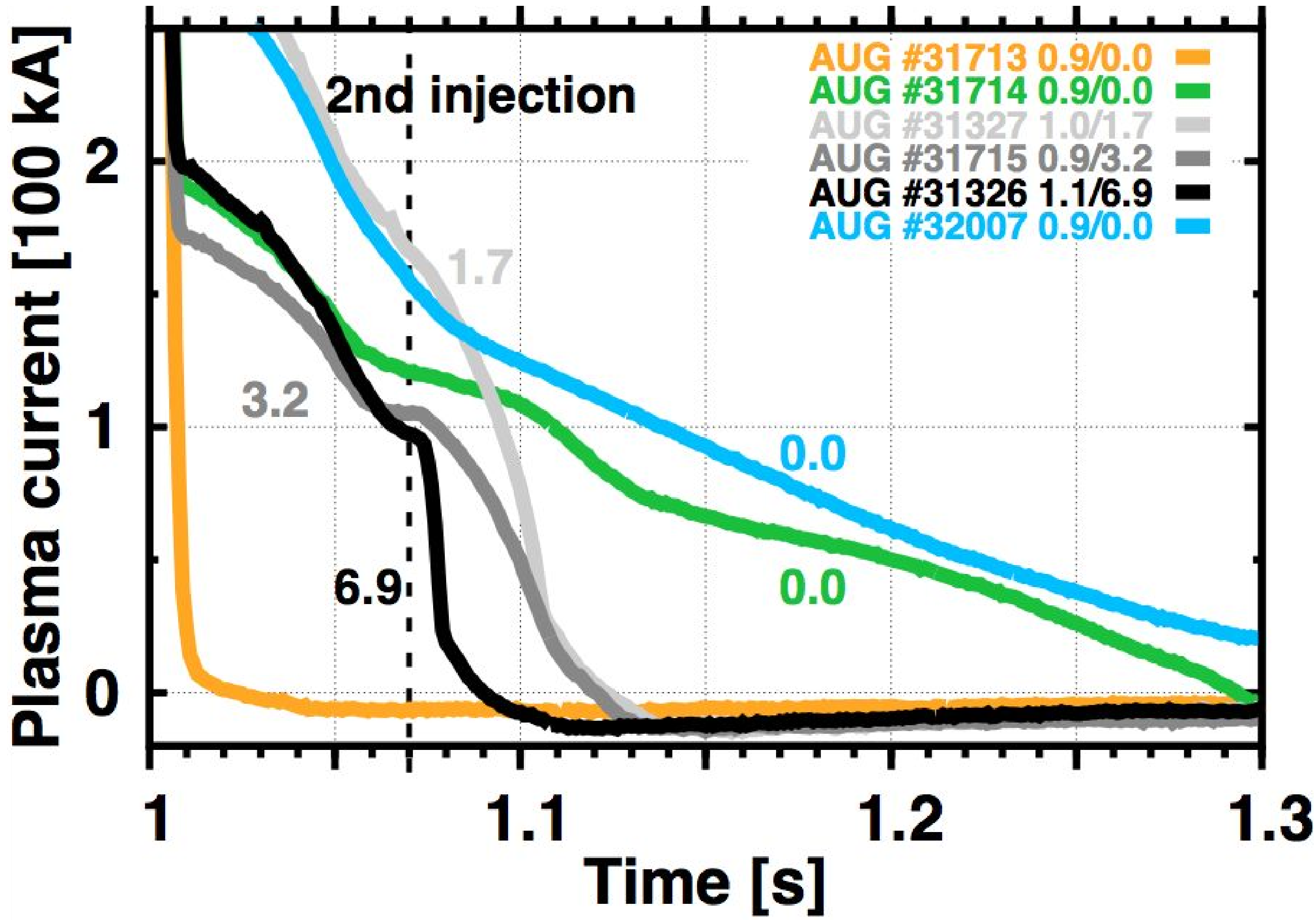
Both devices had access for the first time to reproducible RE regimes, following gas injection

- **AUG:** 0.8 MA, 2.5 T, 2-3x10^{19} m^{-3} circular plasma, 2.5 MW ECRH
- T_{e0} ~ O(10) keV
- Disruption triggered with 0.5-1 bar Argon at 1 s (~1.7x10^{21} particles)



Papp, Pautasso, Exp. AUG15-1.3-5

Second Ar injection kills runaway

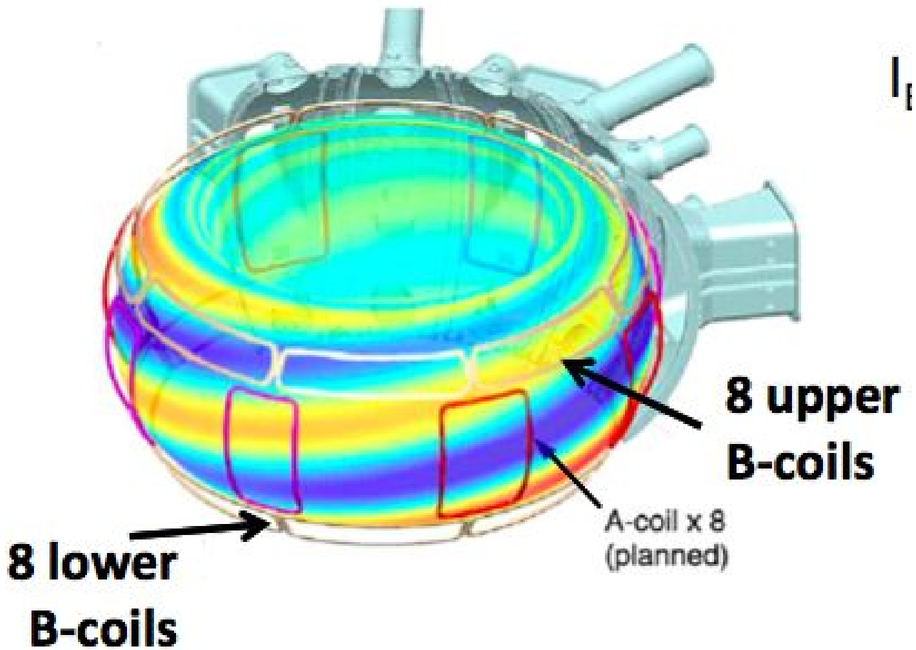


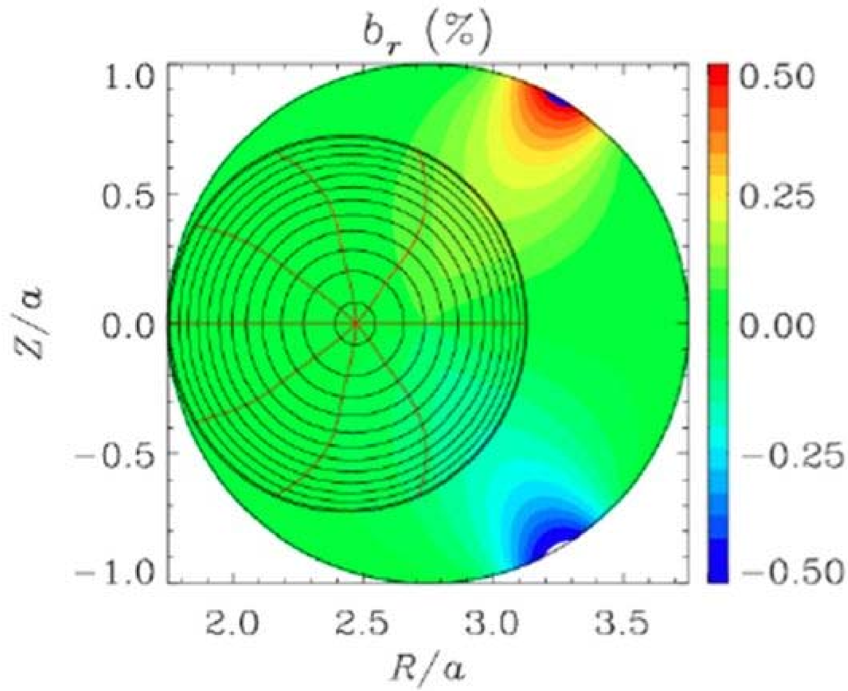
Papp, Pautasso, Exp. AUG15-1.3-5

RE control via magnetic perturbation

AUG post-disruption equilibria resilient to applied MP

- plasma is far from the coils
- high value of q at the edge (≃13-15)



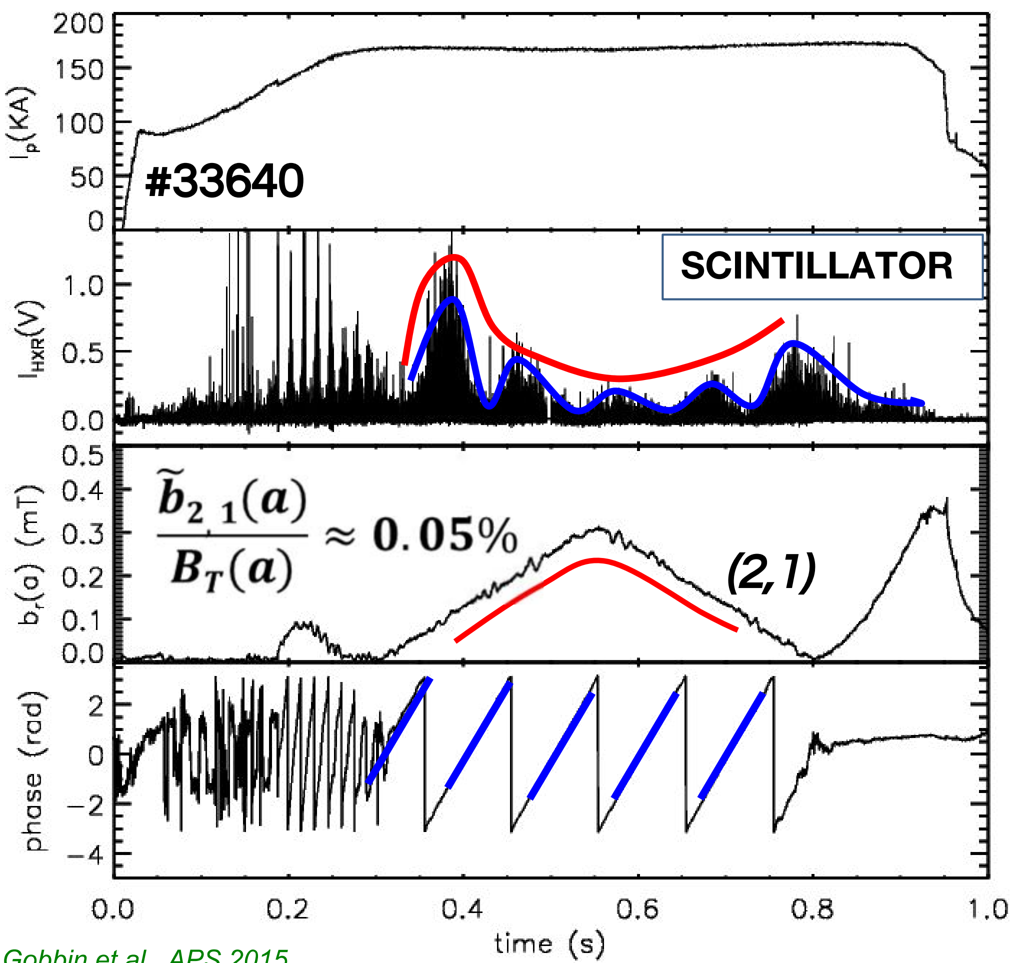


Gobbin, Papp, Exp. AUG15-1.3-6

Inspired by RFX-mod experiment

RE mitigation by MP application (flat-top)

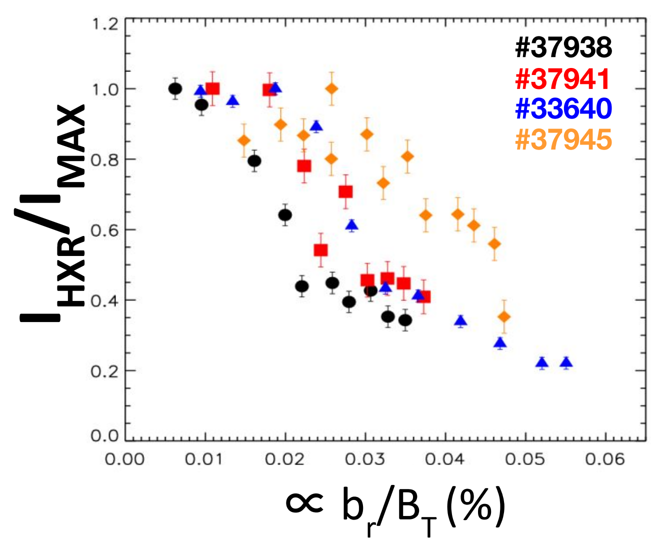
Application of rotating (2,1) MP with scan in amplitude to investigate effects on RE



Gobbin et al., APS 2015

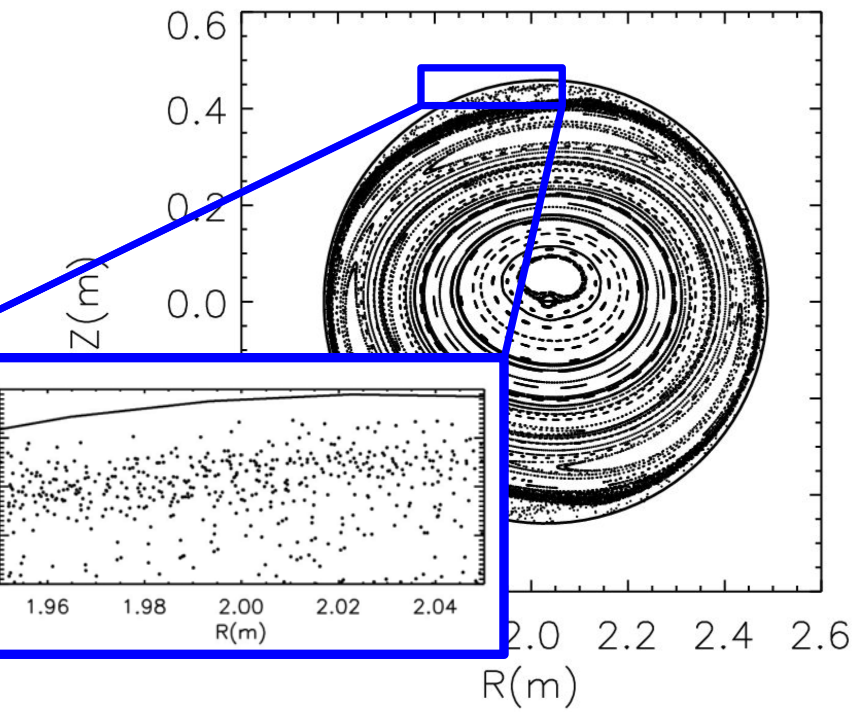
- modulation of HXR signal correlated with **mode rotation**;
- Slow variation of HXR signal **correlated with (2,1)** mode amplitude;

HXR signals scale with mode amplitude



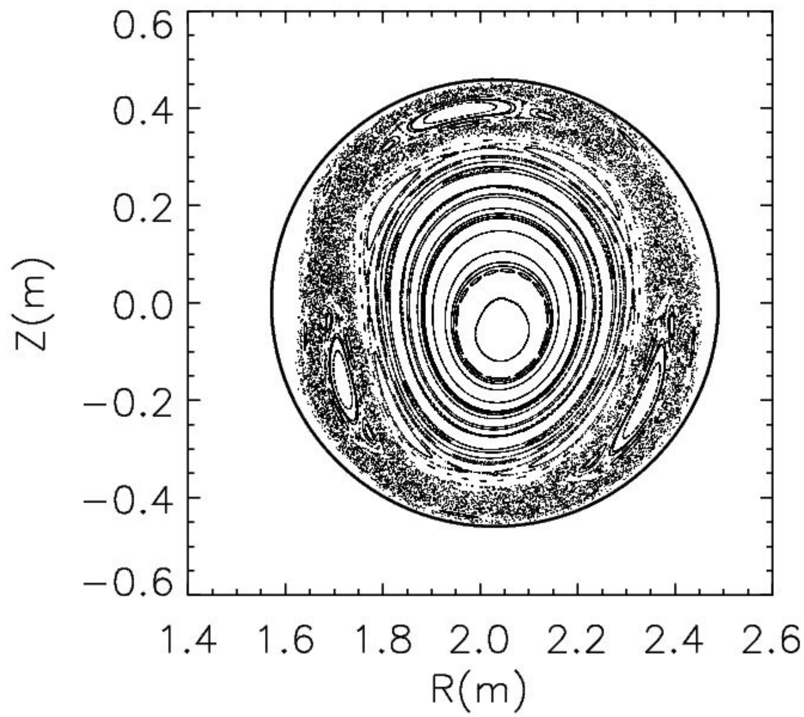
RFX RE losses due to increase of stochasticity at edge

- ***500keV*** eletron **orbits** space;
  $b^r_{2,1}(a)/B_T(a) \simeq 0.03\%$



*stochasticity in the **outer region** but not in the core of the plasma*

- ***500keV*** eletron **orbits** space;
  $b^r_{2,1}(a)/B_T(a) \simeq$ **0.1%**



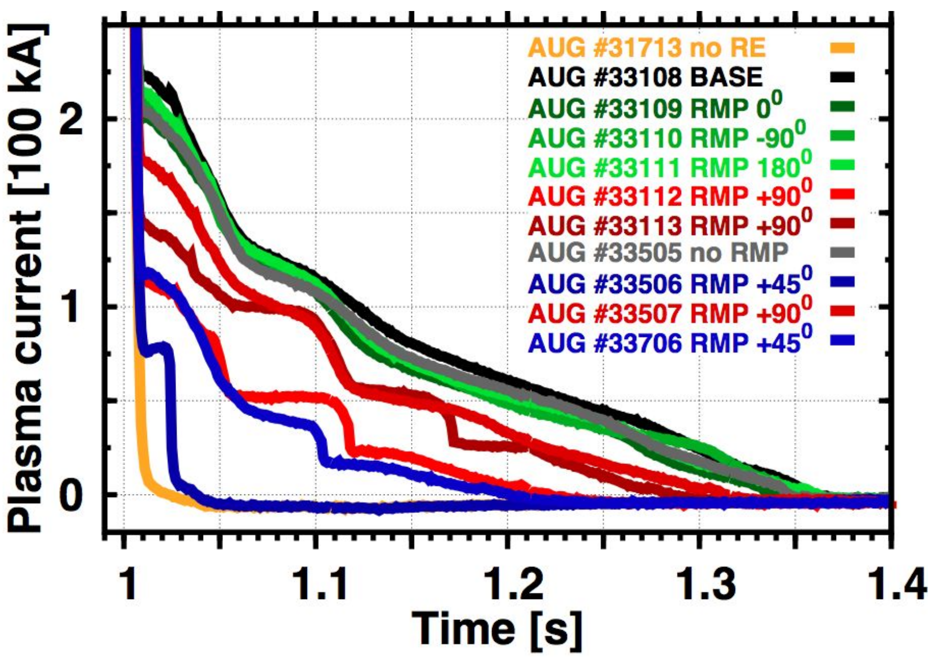
increase of edge stochasticity in with the mode amplitude

Gobbin et al., APS 2015

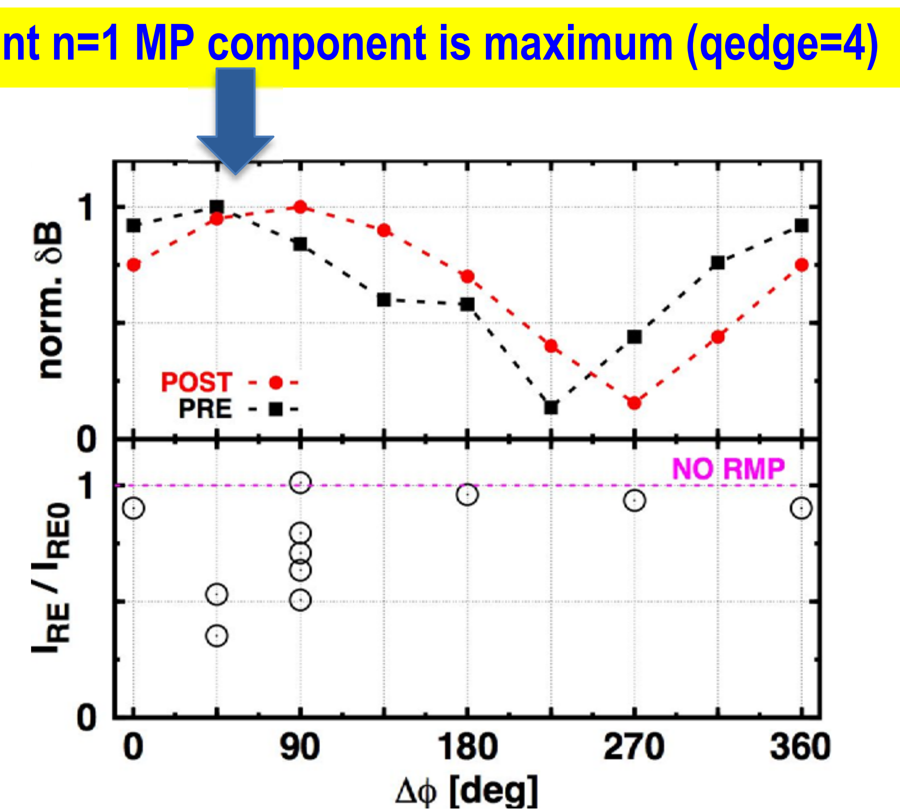
MP strongly influences RE behaviour in AUG

Magnetic Perturbation (applied before disruption with proper phasing) **kills RE beam**

Influences disruption dynamics, not orbit losses

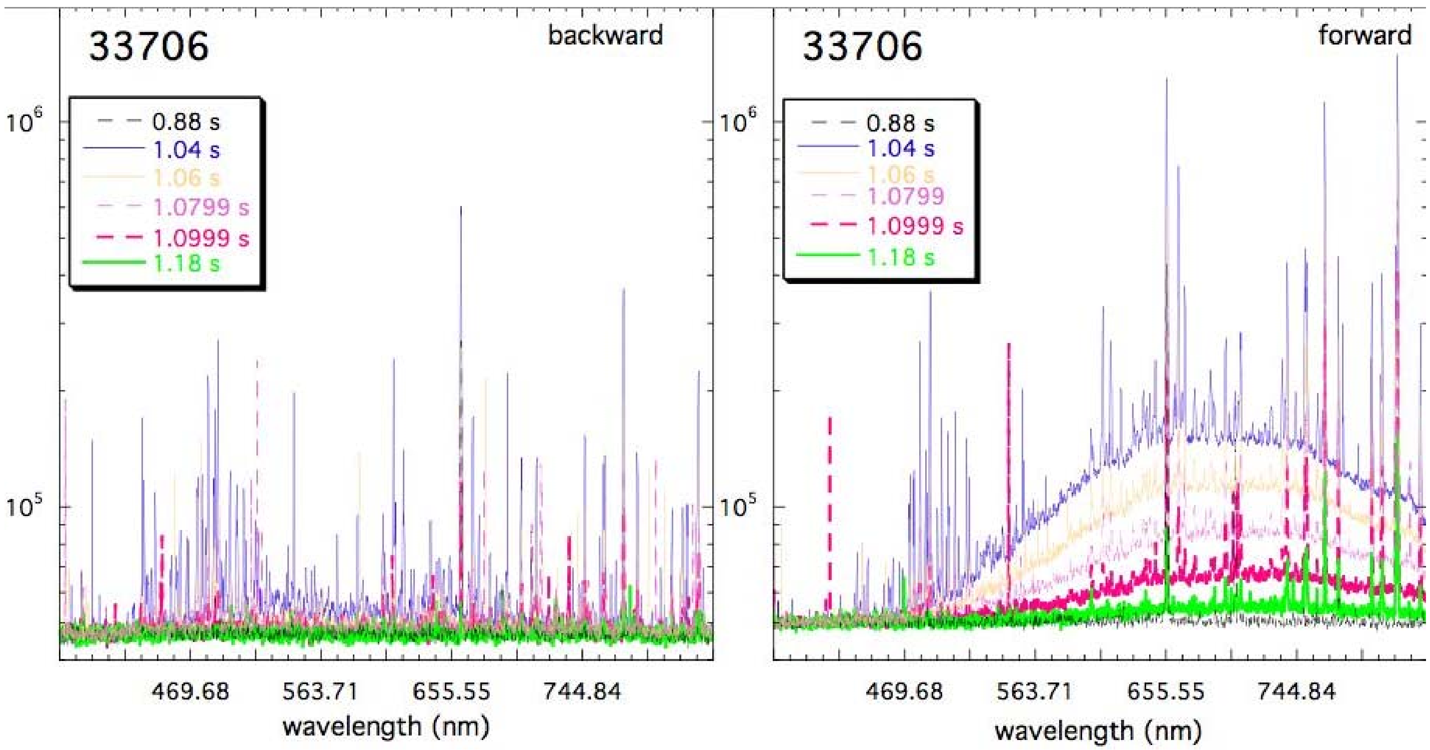


Gobbin, Papp, Exp. AUG15-1.3-6



Syncrothron radiation shows MP effect

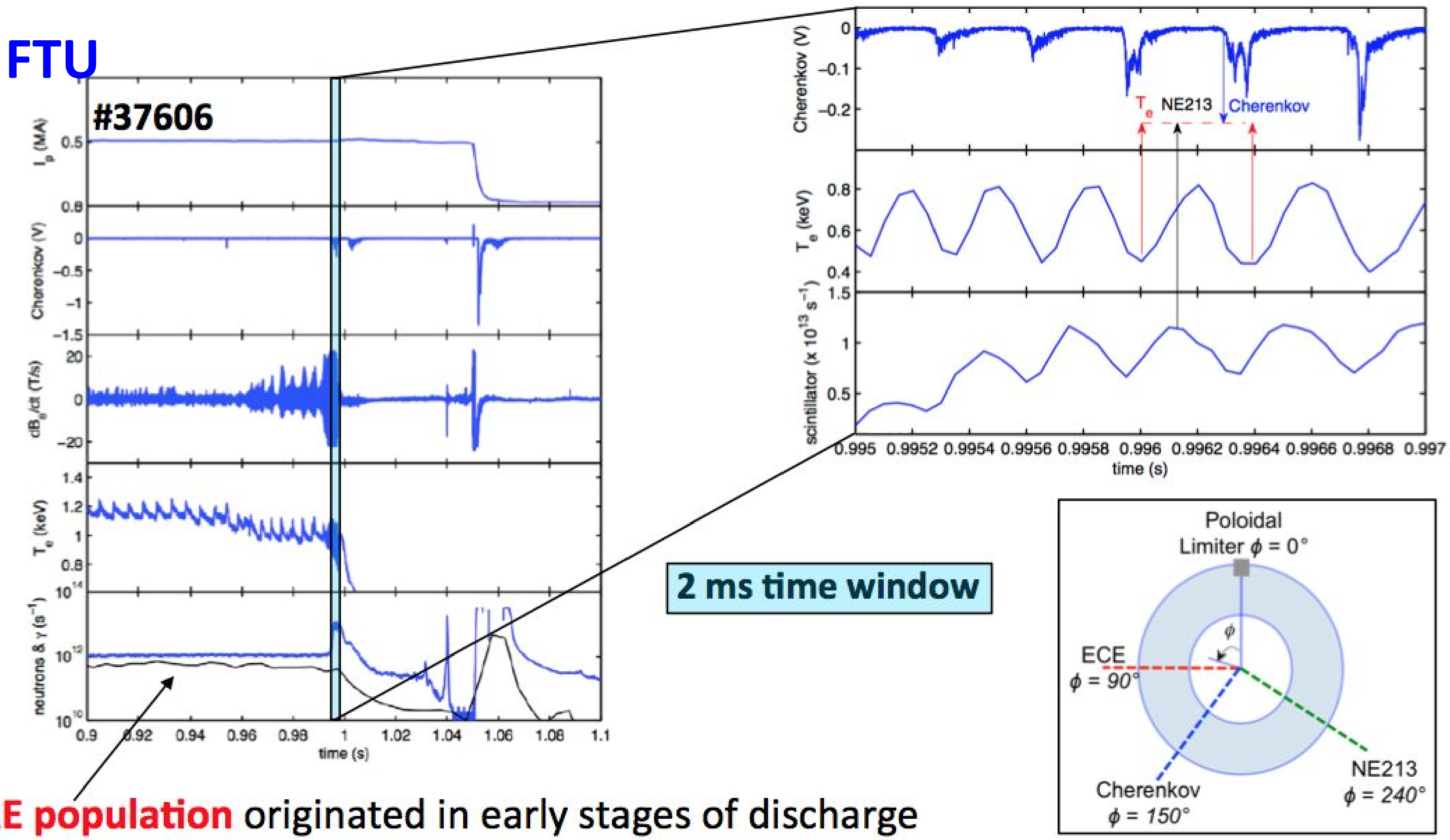
Runaway Electron Imaging and Spectrometry (REIS) system developed for FTU



Esposito et al., MST2 project 2016
Esposito et al., EPS 2015

Losses due to spontaneous MHD in FTU

FTU

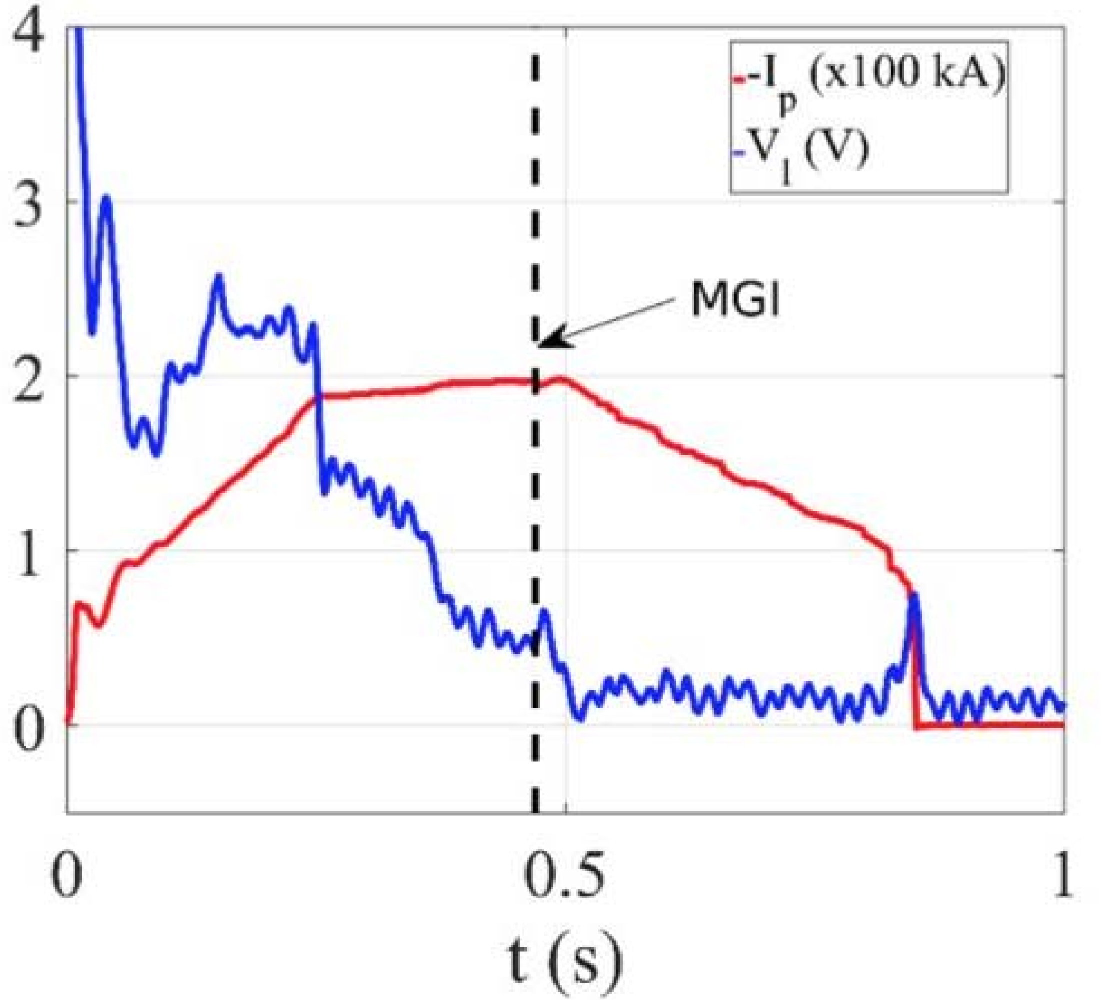


RE population originated in early stages of discharge

FTU developed innovative tool for RE magnetic control via OH circuit ➔ ported to TCV

Esposito, EPS invited 2016-submitted to PPCF

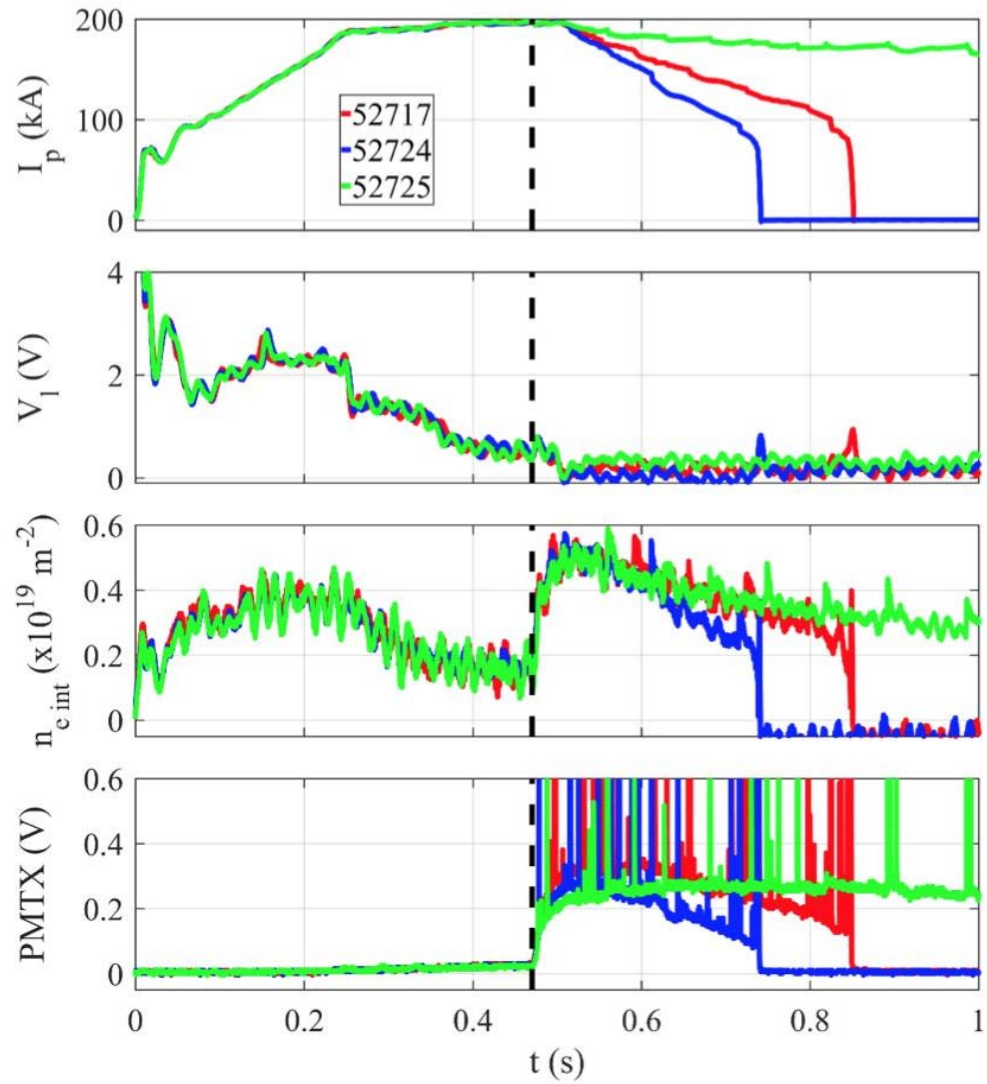
Runaway electrons in TCV



Decker, Carnevale, Gobbin, Esposito, Exp. TCV15-1.3-6

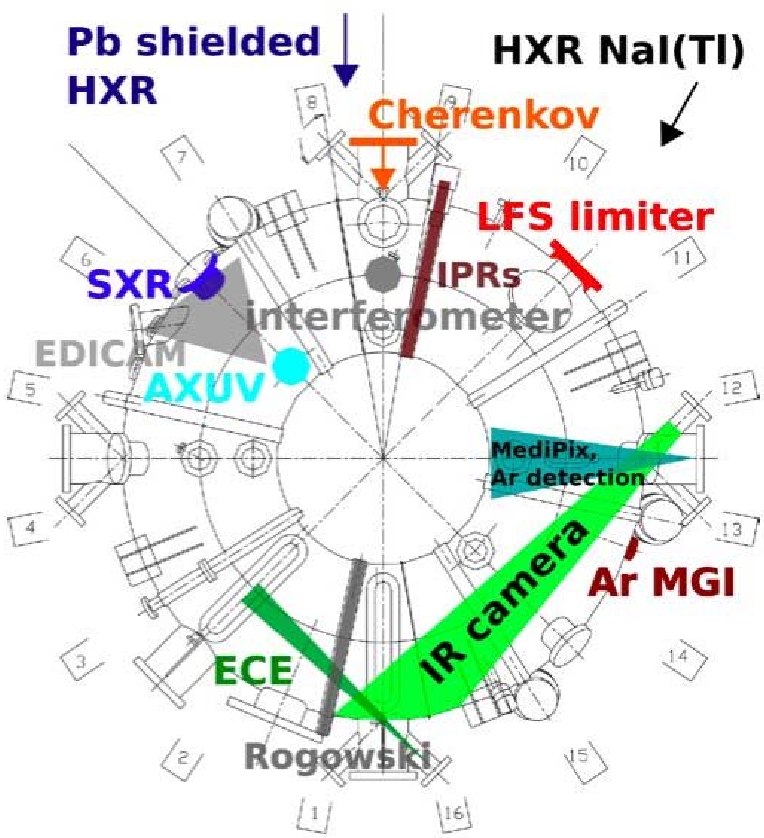
Runaway control in TCV via ohmic circuit

- 52717 $dI_{OH}/dt=0$
- 52724 $dI_{OH}/dt<0$
- 52725 $dI_{OH}/dt>0$

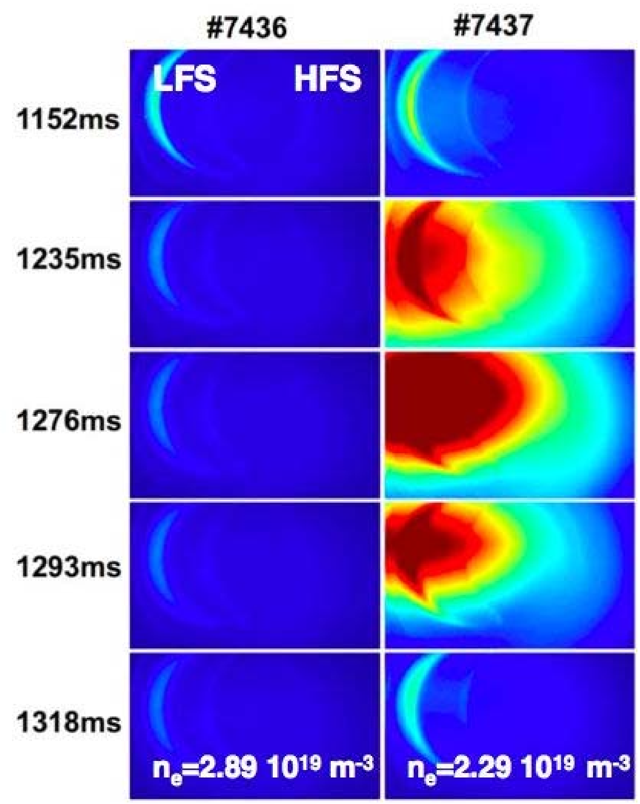


Decker, Carnevale, Gobbin, Esposito, Exp. TCV15-1.3-6

Compass well equipped for RE studies



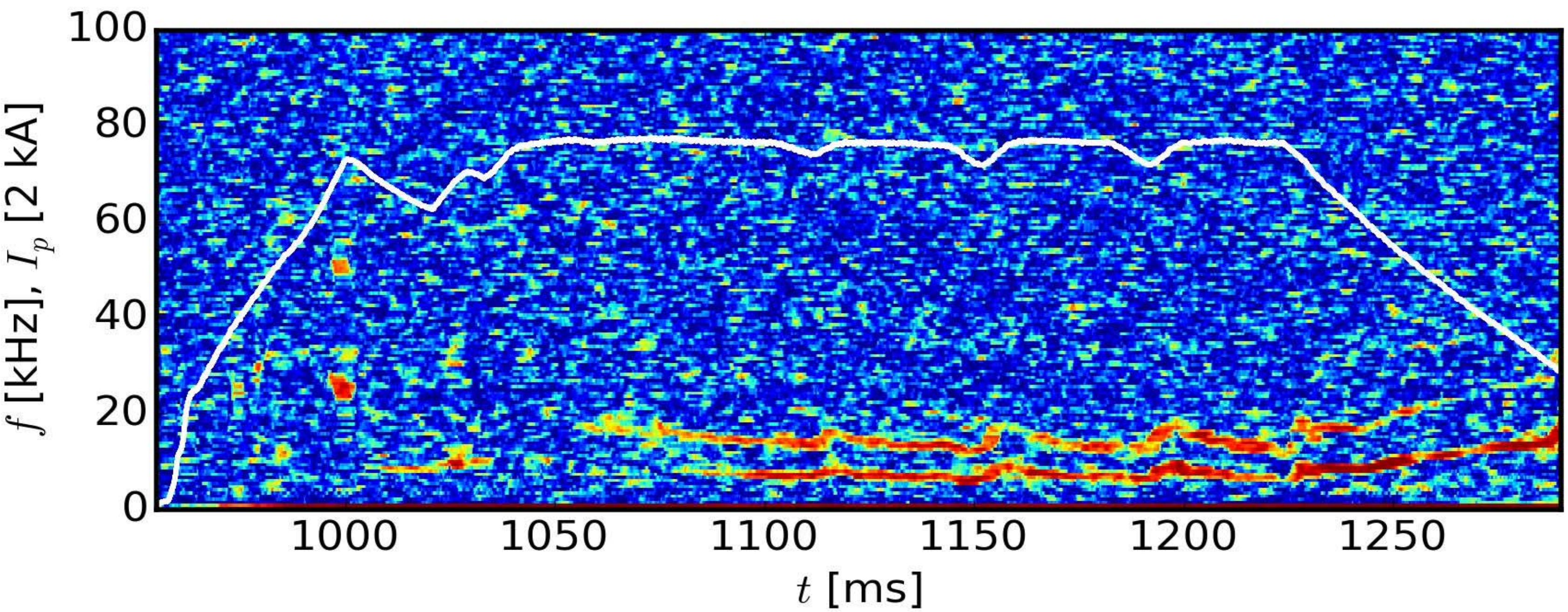
Syncrotron emission



M. Vlainic et al., EPS Lisbon, ECA Vol 39E, P4.108 (2015)
J. Mlynar et al., EPS Lisbon, ECA Vol 39E, P4.102 (2015)

RE pushed out by islands in COMPASS

Coherence diagram of HXR and Mirnov coil signal (#10004)
When islands are present, RE losses are (almost) always correlated



M. Vlainic et al., EPS Lisbon, ECA Vol 39E, P4.108 (2015)
J. Mlynar et al., EPS Lisbon, ECA Vol 39E, P4.102 (2015)

Conclusions

Conclusions

- Broad experimental effort on disruption and RE physics and control in the MST campaign
- Supported by numerical work (JOREK, ASTRA-STRAHL, ORBIT…)
- Contribution from non-MST devices (exploratory studies then ported to MST tokamaks)

- Topics will maintain high priority in 2017