# Disruption study advances in the JET metallic wall

E. Joffrin 1), M. Barruzo 2), P. de Vries 3), P. Drewelow 4), A. Fil 1), S. Gerasimov 5), T. Hender 5), S. Jachmich 6), U. Kruezi 7), M. Lehnen 3), B. N'Konga 8), A. Murari 2), R. Moreno 9), E. Nardon 1), I. Nunes 10), R. Paccagnella 2), A. Pau 11), C. Reux 1), V. Riccardo 5), R. Roccella 3), C. Sozzi 12), H. Strauss 13), J. Vega 9), F. Villone 14), and JET Contributors*

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# Team of authors

**E. Joffrin 1), M. Barruzo 2), P. de Vries 3), P. Drewelow 4), A. Fil 1), S. Gerasimov 5), T. Hender 5), S. Jachmich 6), U. Kruezi 7), M. Lehnen 3), B. N'Konga 8), A. Murari 2), R. Moreno 9), E. Nardon 1), I. Nunes 10), R. Paccagnella 2), A. Pau 11), C. Reux 1), V. Riccardo 5), R. Roccella 3), C. Sozzi 12), H. Strauss 13), J. Vega 9), F. Villone 14), and JET Contributors***

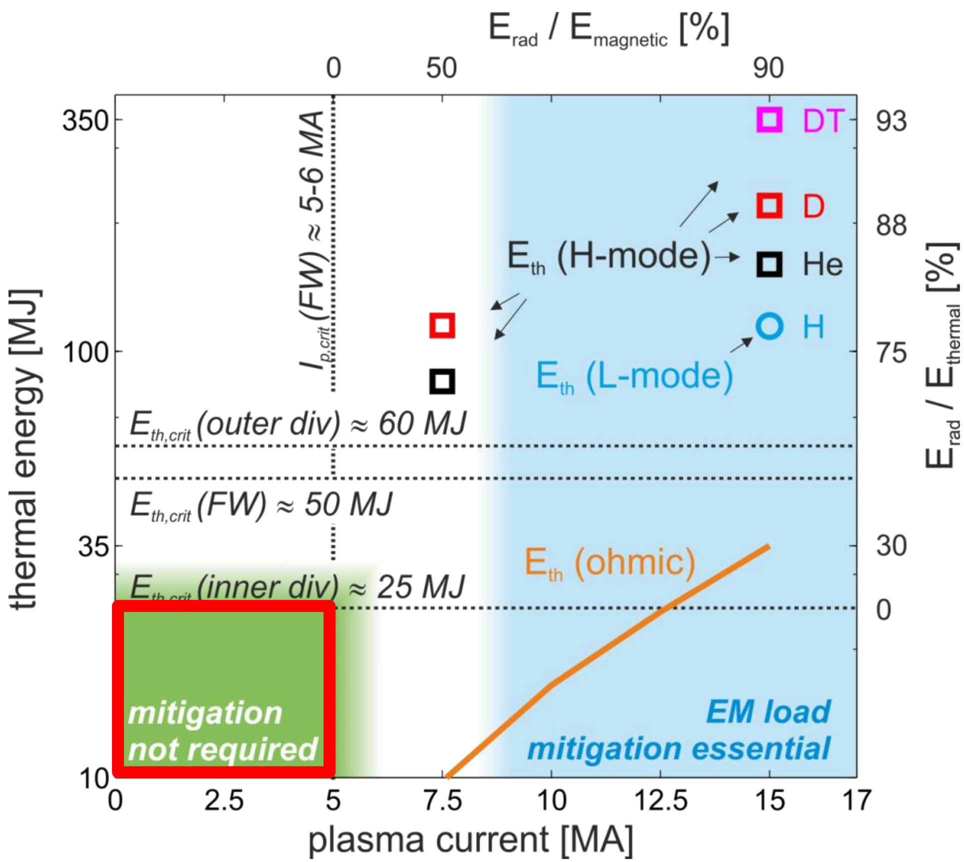
***EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK***

1) *CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France.*
2) *Consorzio RFX, Corso Stati Uniti, 4 – 35127 Padova, Italy*
3) *ITER-Organisation, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France*
4) *Max-Planck Institut für Plasmaphysik, Euratom Association, Greifswald, Germany*
5) *CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK*
6) *Laboratory for Plasma Physics, Ecole Royale Militaire/Koninklijke Militaire School, EURATOM Association, "Belgian State", Brussels, Belgium*
7) *Institut fur Energie-und Klimaforschung, IEK-4, FZJ, EURATOM Assoc., TEC, 52425 Julich, Germany*
8) *Laboratoire J.A.Dieudonné, Université de Nice Sophia-Antipolis, Parc Valrose, 06108 NICE Cedex 2*
9) *Laboratorio Nacional de Fusión. CIEMAT, 28040 Madrid, Spain*
10) *Istituto de plasmas e fusao nuclear, Lisboa, Portugal*
11) *Electrical and Electronic Engineering Dept.-University of Cagliari, Italy*
12) *IFP-CNR, Via R Cozzi, 5, 20152 Milan, Italy*
13) *HRS Fusion, West Orange NJ, USA 07052*
14) *EURATOM/ENEA/CREATE, DAEIMI, Università di Cassino, Italy*

* See the Appendix of F. Romanelli et al., Proceedings of the 25nd IAEA Fusion Energy Conference 2014, Saint-Petersburg, Russia.

# Disruption is the highest risk for ITER operation

**Thermal & Electro-magnetic loads boundaries for disruptions in ITER**




*Lehnen et al., EX/P6-39*

- **The domain where mitigation is not required is very small (Ip<5MA; W<25MJ).**
- **High current operation requires high mitigation success rate (EM loads)**
- **High efficiency >90% needed at high energies**

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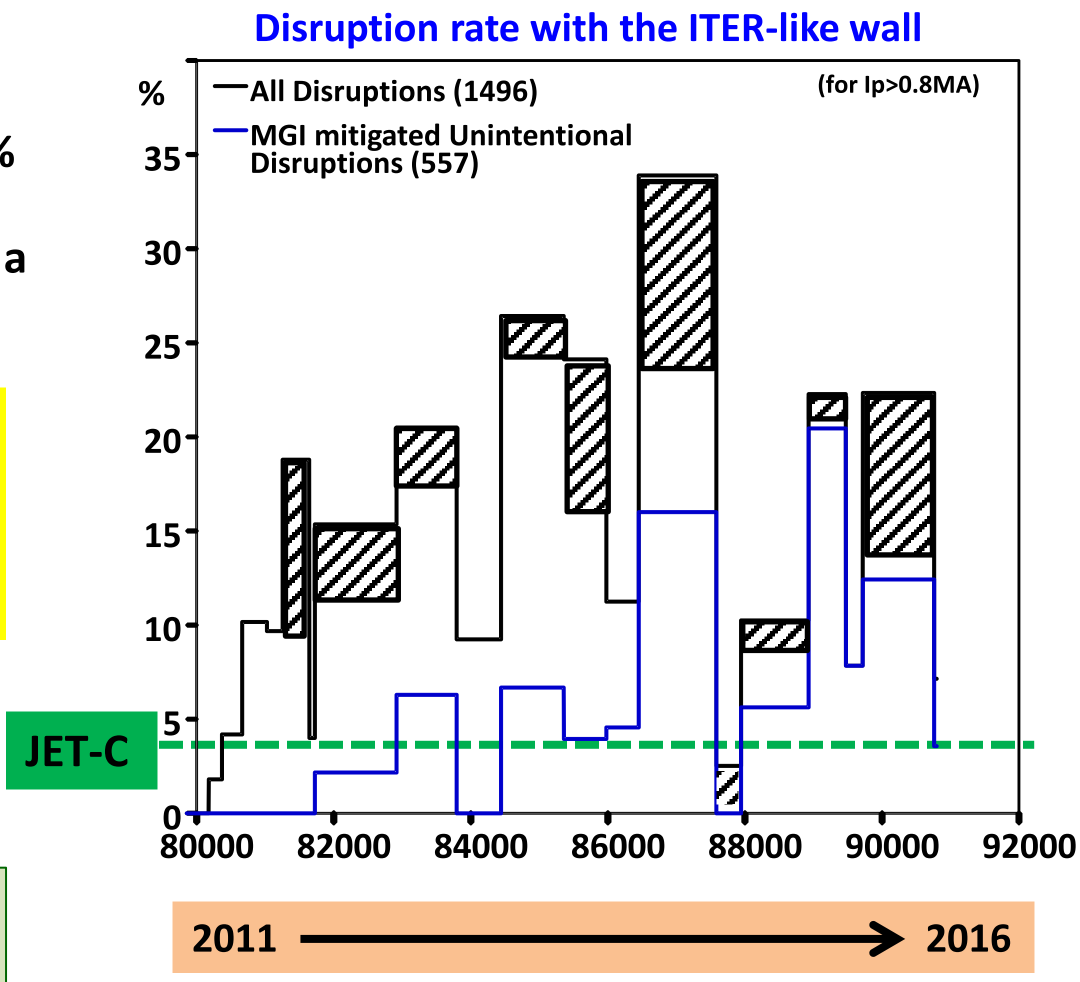
# JET disruption rate has dramatically increased with the ITER-like wall

- Disruption rate with the JET-C: ~3.4%
- Operation with ILW showed a marked increase in disruption rate.

Massive gas injection mandatory in JET operation for:
- Ip > 2MA OR
- $W_{TH}+W_{MAG}$ > 5MJ

JET has led a significant programme on disruption mitigation physics in the past 5 years.

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# Outline

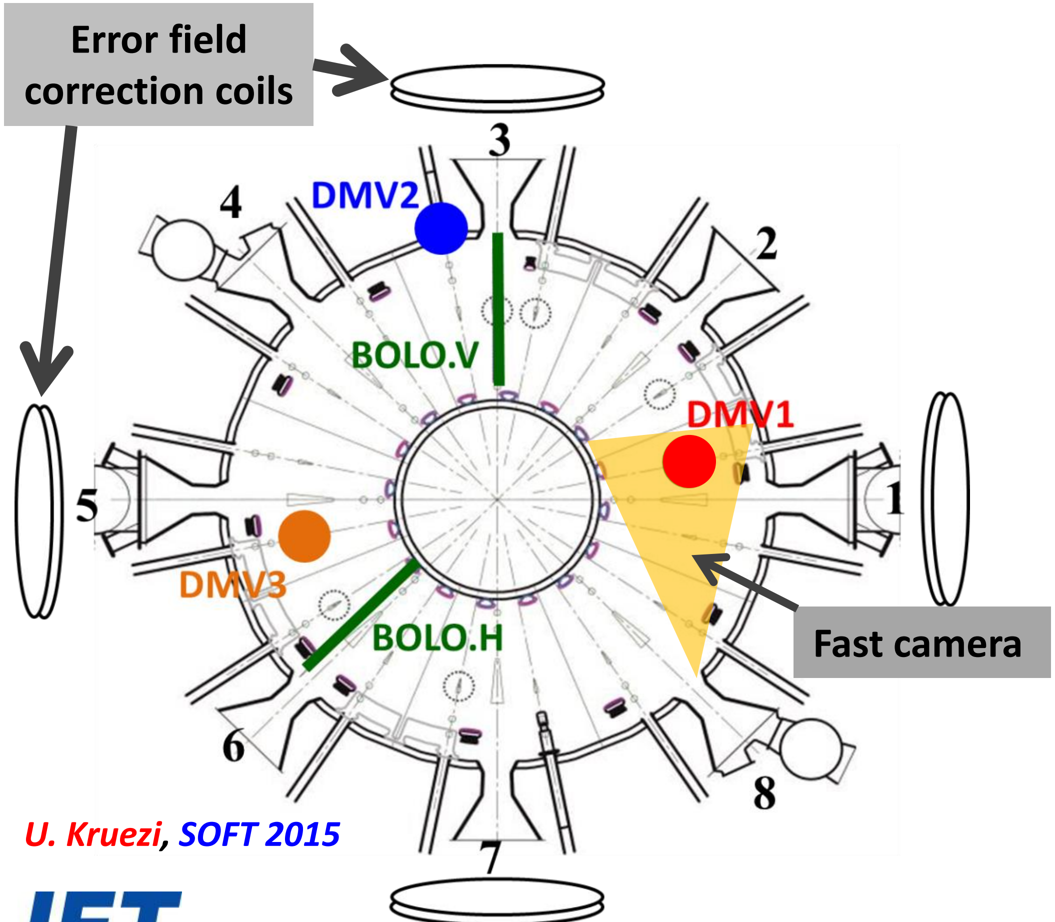
- JET disruption mitigation system (DMS)
- Optimisation of disruption mitigation
- Disruptions radiation asymmetries
- Disruption prediction/avoidance
- Run-aways mitigation and outlook for 2018-2019

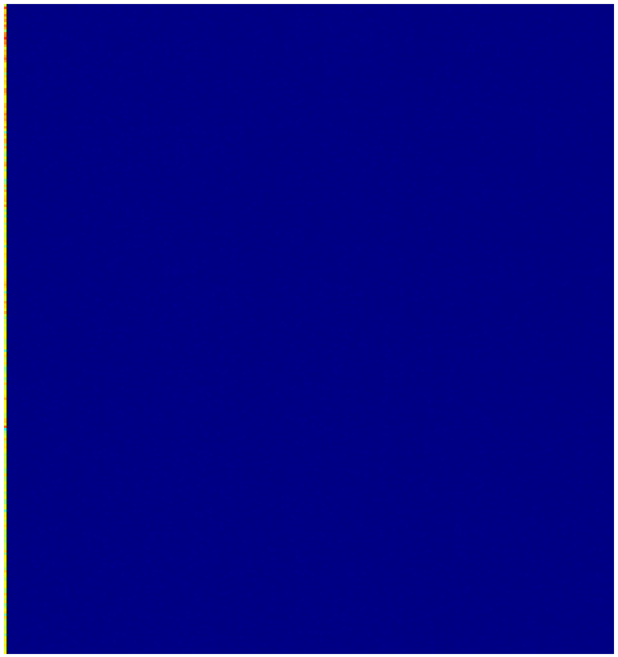
# JET is equipped with a comprehensive disruption mitigation system (DMS)

| | | | |
|---|---|---|---|
| DMV1 | Upper port | 4.6m to LCFS | 1.8ms |
| DMV2 | Horiz. port | 2.8m to LCFS | 1.0ms |
| DMV3 | Upper port | 2.4m to LCFS | 0.8ms |

**D2+ 10%Ar**

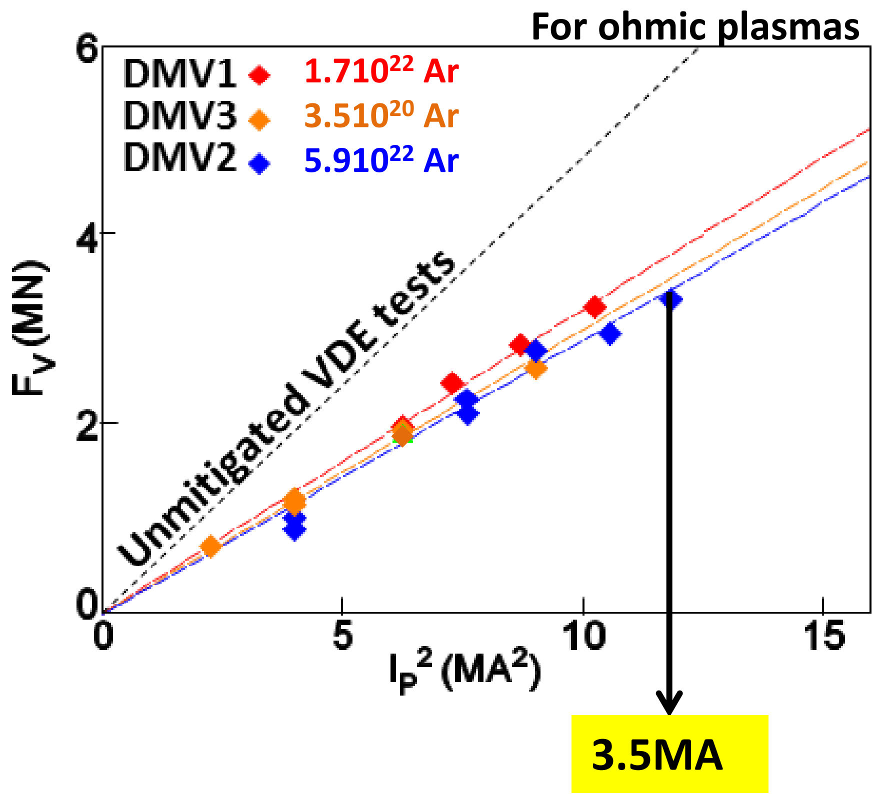
**The fast camera can be equipped with Argon filter**



*U. Kruezi, SOFT 2015*

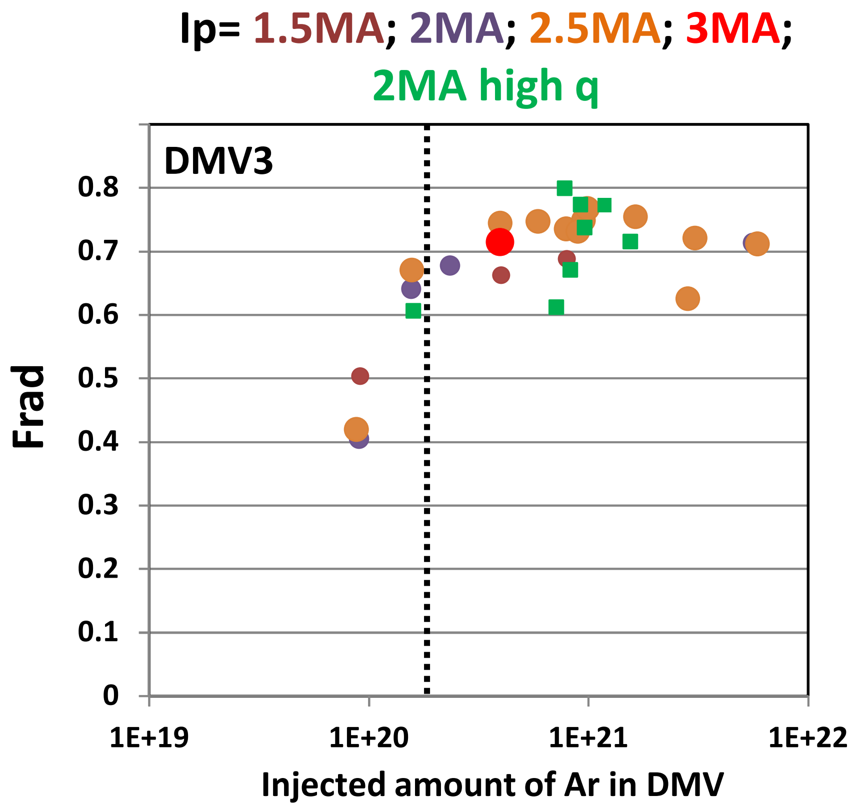
# EM forces can be mitigated up to 30-40% for a given magnetic configuration




- ❑ **Vertical force measured by strain gauges on the vessel support.**
- ❑ **Independent from the DMV location**
- ❑ **Note that Fv is not purely the result of halo current but may also include forces induced by Eddy currents and poloidal coils.**

*S. Jachmich, PSI & EPS 2016*

# Disruption efficiency does not dependent on plasma current and q




*V. Riccardo, 2016*

- Below an Argon quantity less than ~$2.10^{20}$, the efficiency of the disruption mitigation decreases dramatically.
- Radiation fraction degradation at the current quench does not depend on plasma current nor safety factor.
- This is observed for both horizontal and vertical bolometers

→ Impact of massive gas injection on operation (gas inventory, cryogenic, conditioning) can be minimised.

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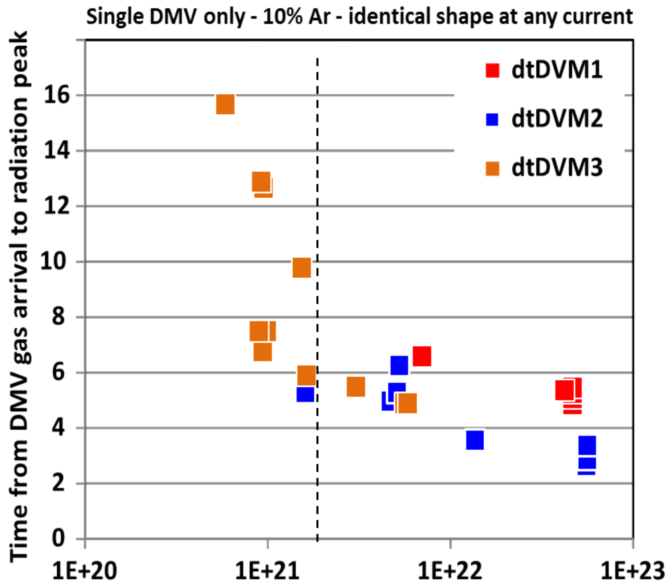
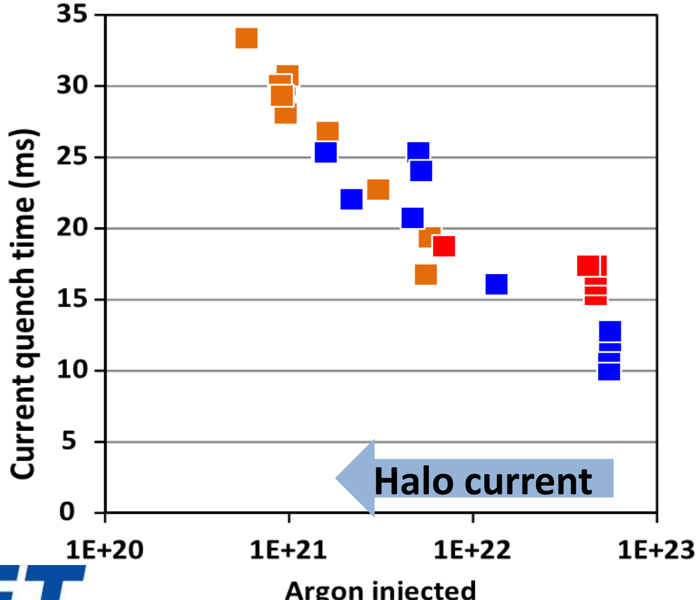
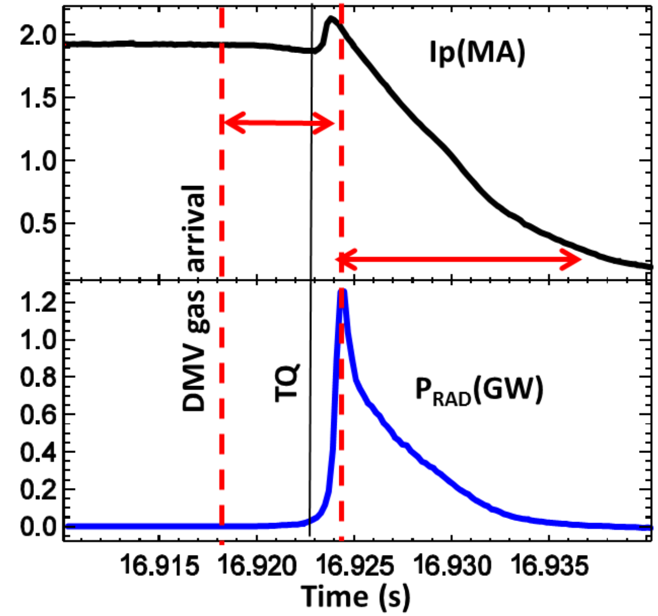
# Radiative gas quantity is a key parameter for improving disruption mitigation efficiency

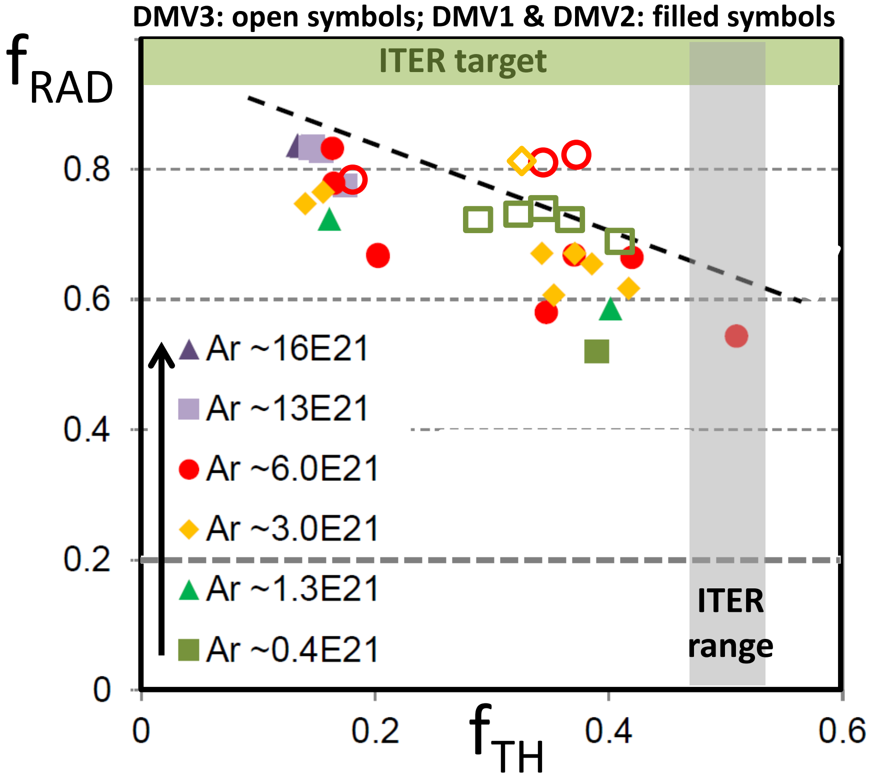



- Argon quantity is a key parameter for controlling the disruption time.
- DMV1 looks slightly less efficient than the new DMVs closer to the plasma.
- The current quench duration is decreasing with the quantity of injected Argon

# Radiative energy fraction at disruption degrades with the thermal energy fraction




- The mitigation efficiency degrades with the thermal energy.
- The drop is less severe at high Argon injection amount.
- DMV3 looks slightly more efficient that the other DMVs.
- This decay indicates that the mitigation is less efficient during TQ.

→ At the TQ a significant fraction of the thermal energy can be lost by conduction when the plasma becomes stochastic.

$f_{RAD} = W_{RAD}/(W_{MAG}+W_{TH}-W_{COUPLED\ TO\ COILS})$

$f_{TH} = W_{TH}/(W_{MAG}+W_{TH}-W_{COUPLED\ TO\ COILS})$

**Integrated over the disruption sequence**

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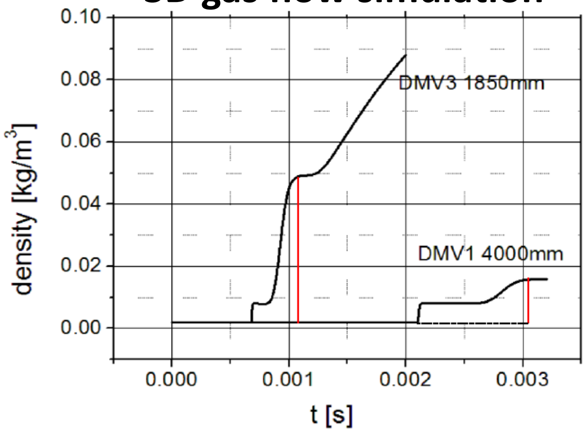
*S. Jachmich, PSI & EPS 2016*

# Mitigation produces a chain of magnetic islands leading to ergodisation at TQ

Ad-hoc gas source adjusted to match interferometry data

OR

3D gas flow simulation



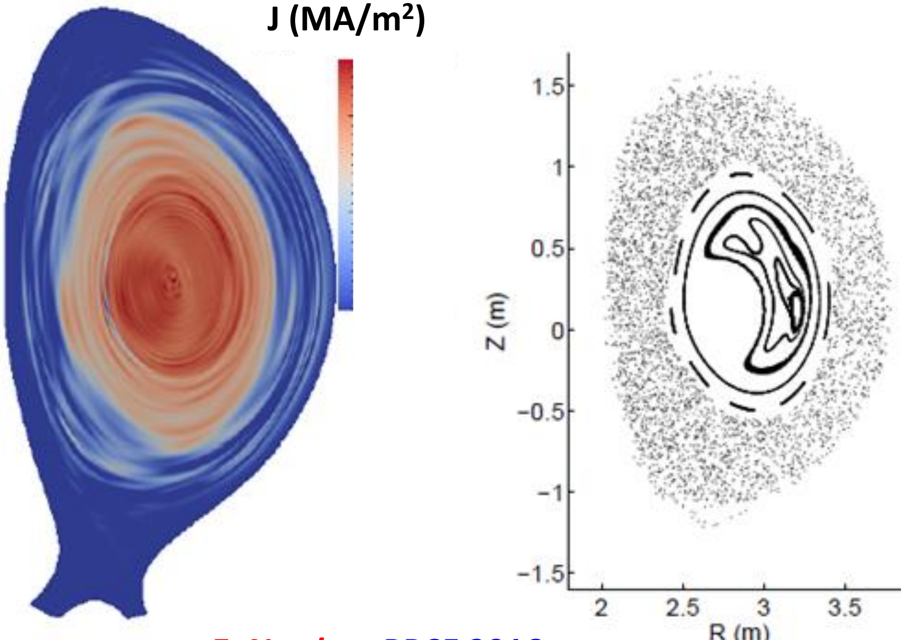

**JOREK**

3D non-linear MHD

Neutral included

η=2-20xSpitzer

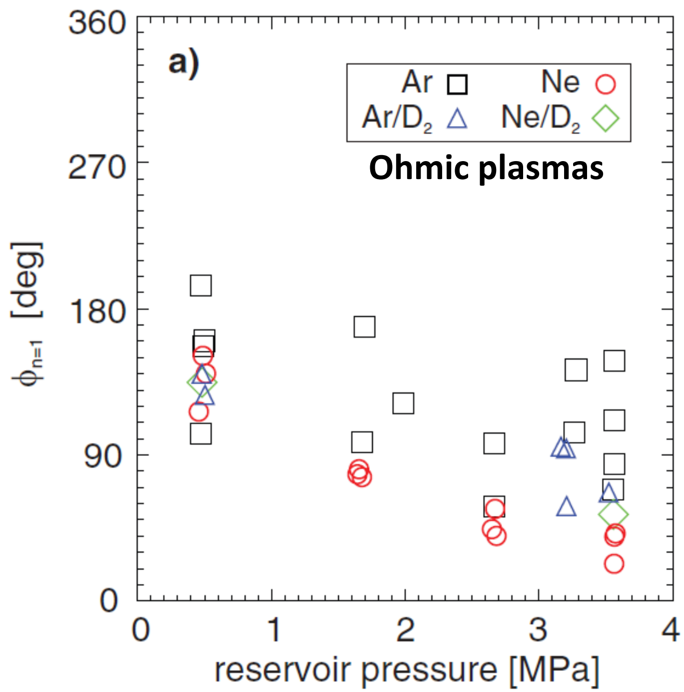
JOREK simulation at the thermal quench with D2 only




*E. Nardon, PPCF 2016*

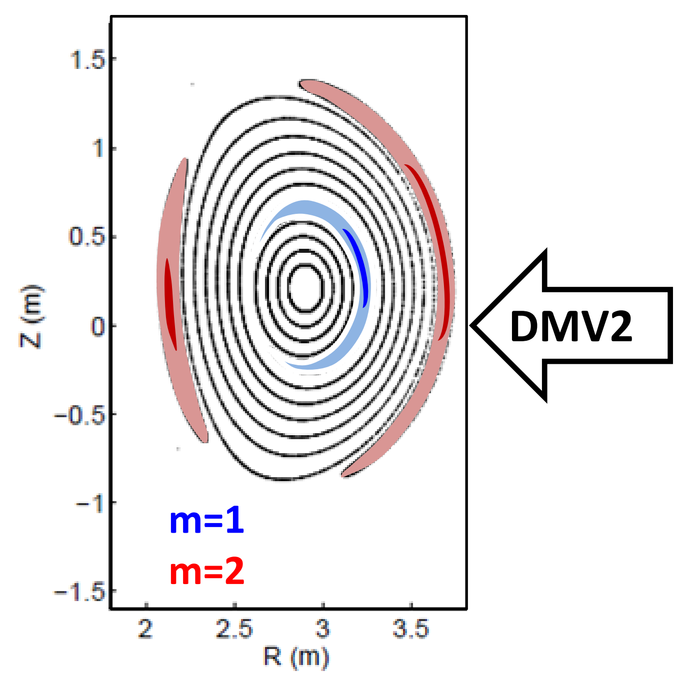
2/1 island ➔ chain of island ➔ stochatization ➔ loss of thermal energy at TQ

# DMV can create radiation asymmetry: island O-point is "attracted" at DMV location




*Lehnen, Nuc. Fus. 2015*

JOREK simulation




*Nardon, PPCF 2016*

Cold front produced by DMV → Local resistivity increase → Local suppression of current profile → Drives the island with O-point close to injection location

**Note:** this effect is not observed in NBI-heated plasma (i.e. with rotation)

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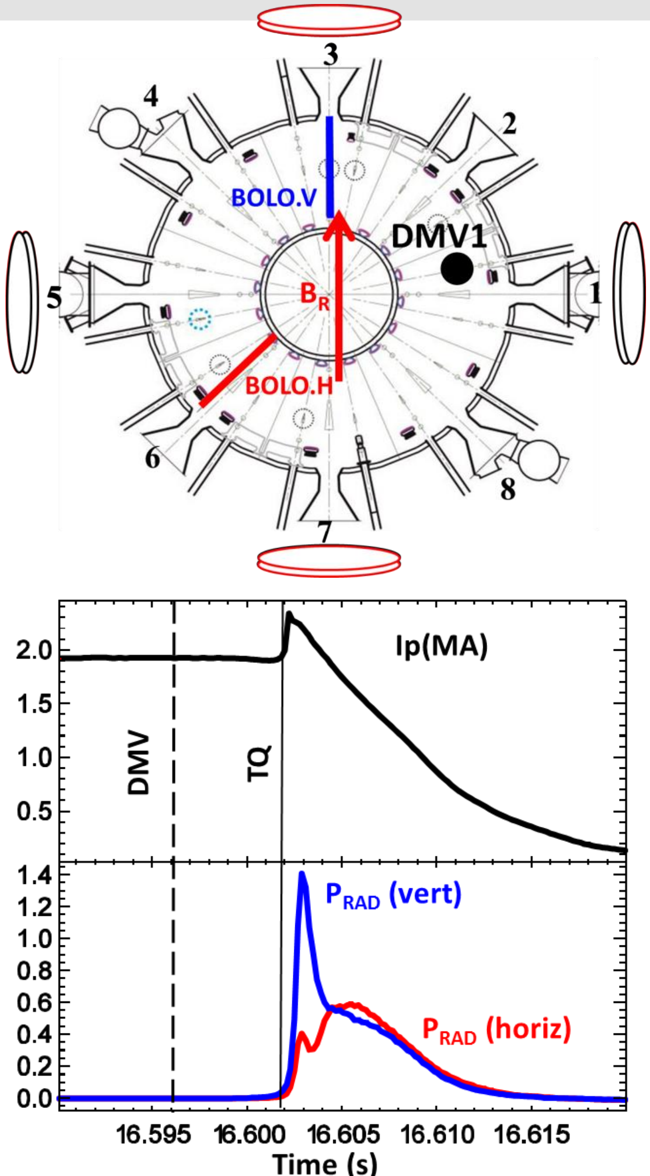
# The n=1 mode creates toroidal radiation asymmetries




- ❑ The phase of the n=1 mode on radiation asymmetry can imposed at JET using the EFCC polarity to seed the mode.
- ❑ Radiation asymmetries are observed when toroidal location of seeded n=1 mode is changed.
- ❑ The radiation asymmetry is larger for injection into the O-point of the island.

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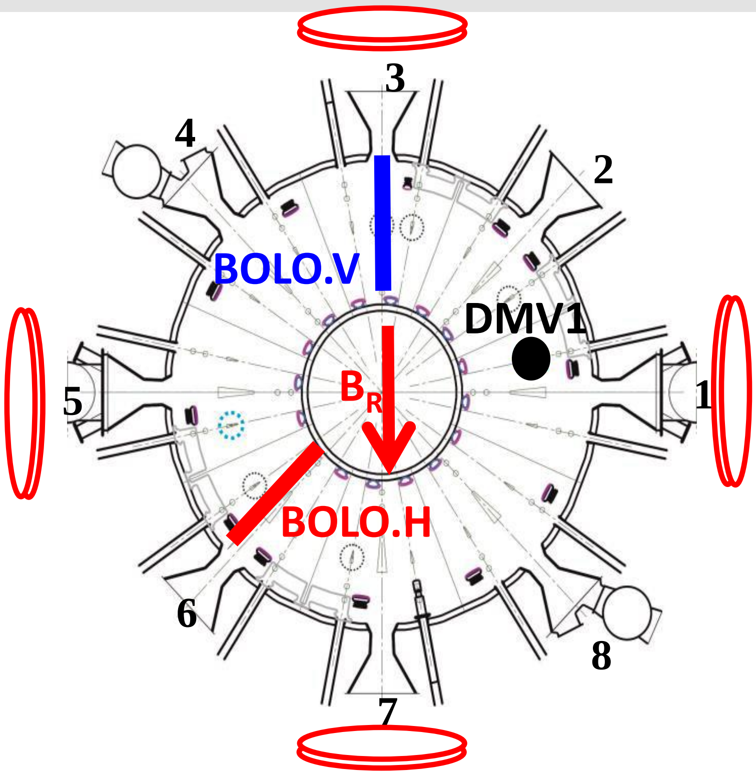
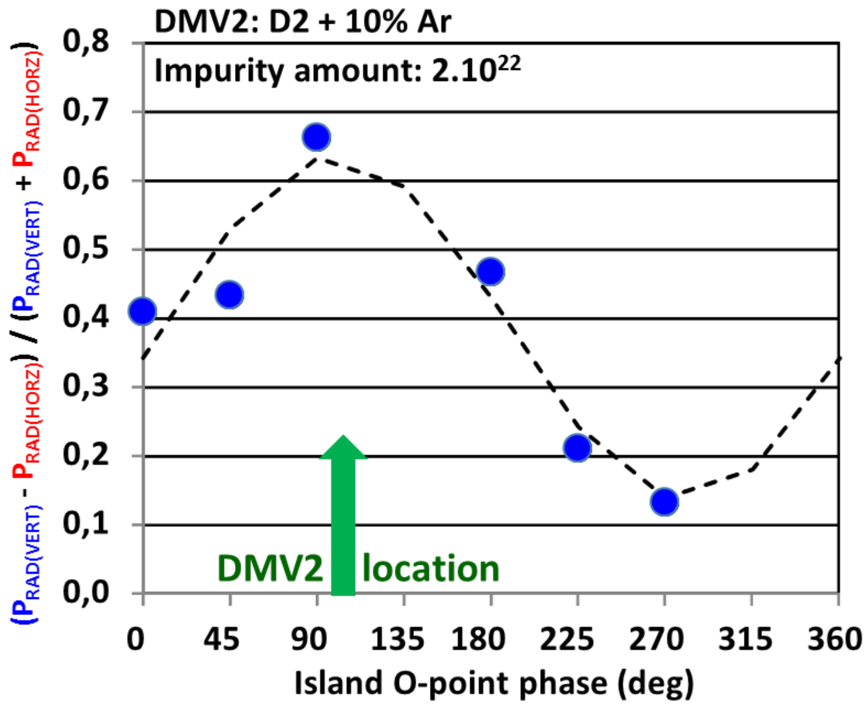
*Jachmich, EPS 2016*

# Radiation peaking determined by 1/1 phase and massive gas injection



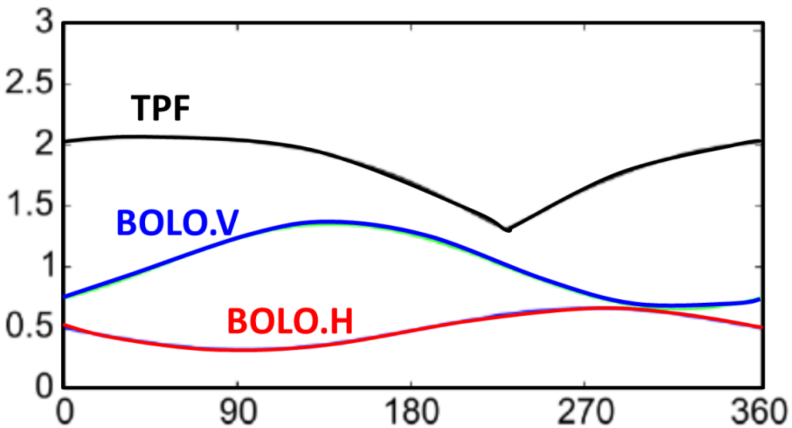




$n_i$ from DMV

X

n=1 phase

$$TPF=\frac{Pradmax}{<Prad>}$$




*Lehnen Nuc Fus , 2015*

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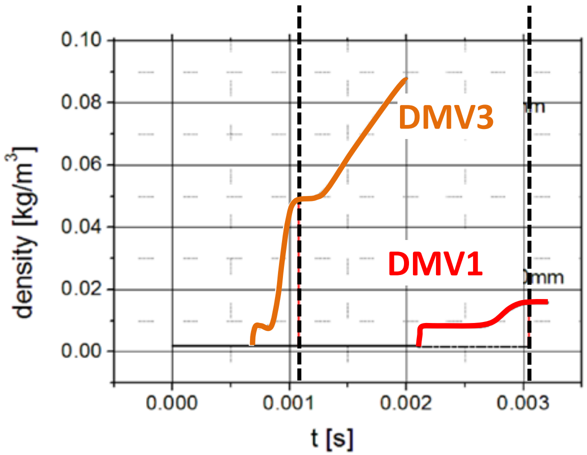
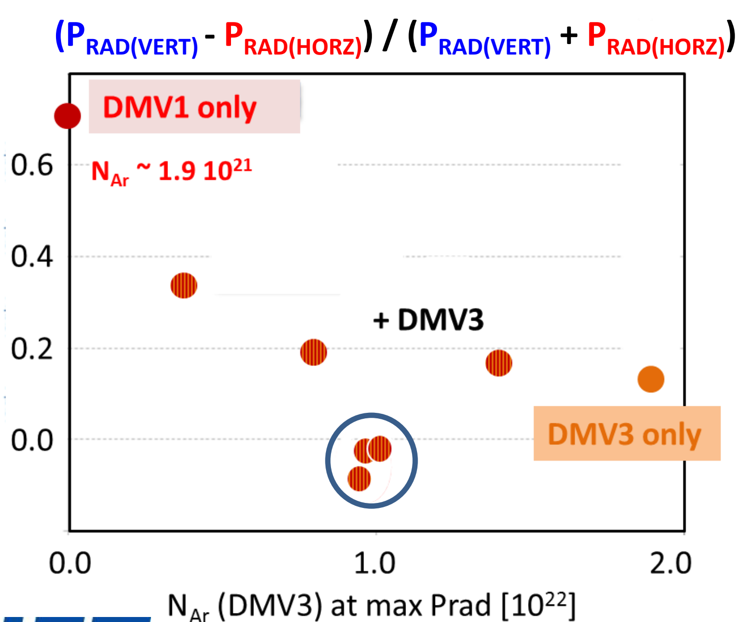
# Dual DMV injection could lead to the reduction of radiation asymmetries

Gas amount varied by timing DMV3



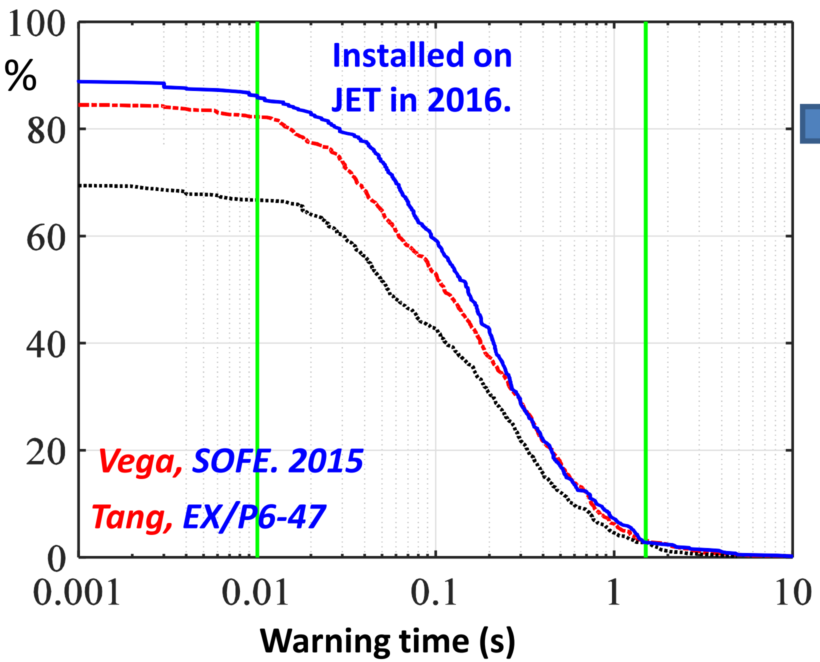

*Drewelow, 2016*

## ❑ Dual injection with opposite DMVs:

- **The reduction of radiation asymmetry is very sensitive to the relative DMV timing (<0.5ms)**
- **There is a reproducible sweet spot for which radiation asymmetry is close to 0.**
- **Still unexplained presently by the analysis (aadditional data collected last week).**

# Disruption predictor not requiring advanced training is installed in JET.

Cumulative fraction of detected disruptions




Lock-mode amplitude threshold detector

Former predictor relying on training of several signals including locked-mode (FEC 2014)

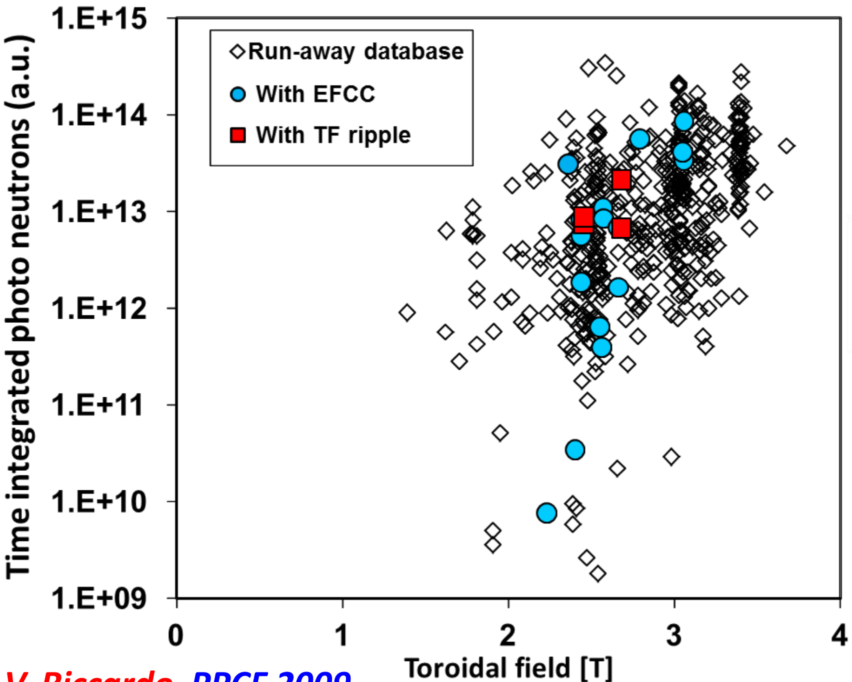
New predictor (WITHOUT TRAINING) based on anomalies in the locked mode signal data flow.

Tested on 1738 JET-ILW pulses and 566 unintentional disruptions with the JET-ILW.

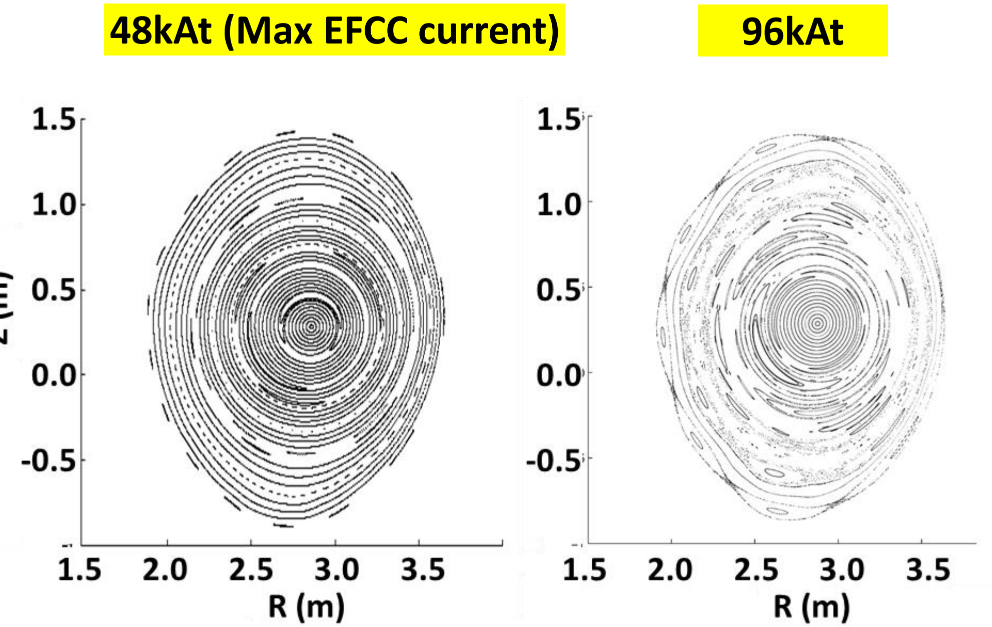
In JET-ILW H-mode scenario development, more than 50% of the disruption cause is core radiation.

➔ Earlier alarm required for disruption avoidance in the JET-ILW should include signals representative of the disruption root causes radiation peaking, MHD precursors…

# Magnetic perturbations are inefficient in mitigating run-aways in JET.



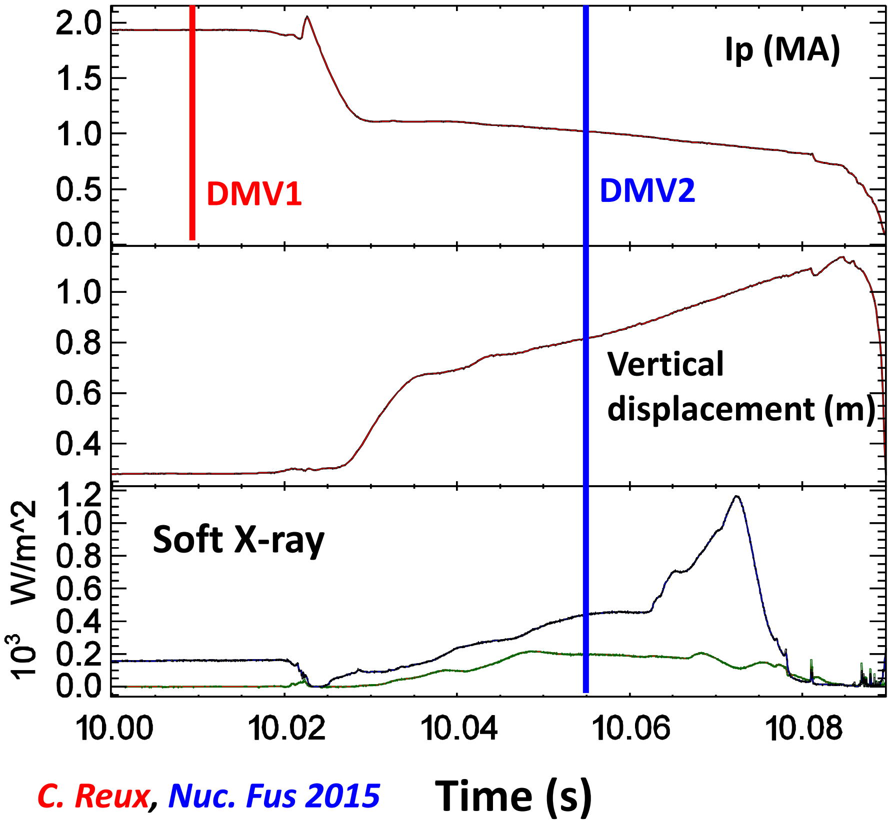

*V. Riccardo*, *PPCF 2009*




*R. Paprok*, *PPCF 2016*

- **EFCC and TF–ripple do not lead to a reduction of RE population in JET**
- **Relativistic (5-20MeV) electron particle motion modelling predicts no stochastization of trajectories at maximum EFCC coil currents.**

# In JET Massive gas injection is also inefficient in mitigating run-aways

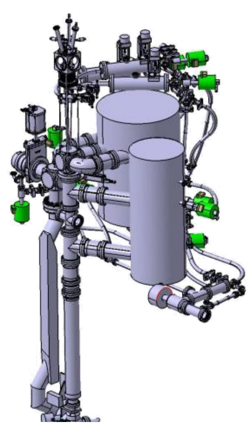



*C. Reux, Nuc. Fus 2015*

- ❑ Massive gas injection inefficient at JET for mitigating RE for different gas (Ar, Kr, Xe,…) and pressures.
- ❑ Run-away beam can be mitigated by MGI in DIII-D, Tore Supra and ASDEX Upgrade.
- ❑ Hypotheses: the machine size or the surrounding plasma has a screening effect.

➔ JET experiments this month to test this hypothesis

➔ Shattered pellet injector installion in JET for the 2018-19 campaigns



**SPI in lieu of DMV1**

# Conclusions / outlook

- JET-ILW has a DMS for studying disruption in support of ITER.
- Massive gas injection can reduce the vertical force by up to 30-40%
- The disruption efficiency does not depend on plasma current.
- Radiation fraction decreases with increasing thermal energy.
- Disruption radiation asymmetries is created by a combination of the n=1 mode and massive gas injection location.
- Dual injection appears necessary for reducing radiation asymmetry. (Note: most of these studies are made for "healthy plasmas".)
- Disruption predictors without advanced training are installed on JET

- Installation of the SPI in JET in 2018 under international framework:
  - Disruption mitigation with more efficient gas penetration
  - Run-away beam mitigation in conditions closer to ITER.

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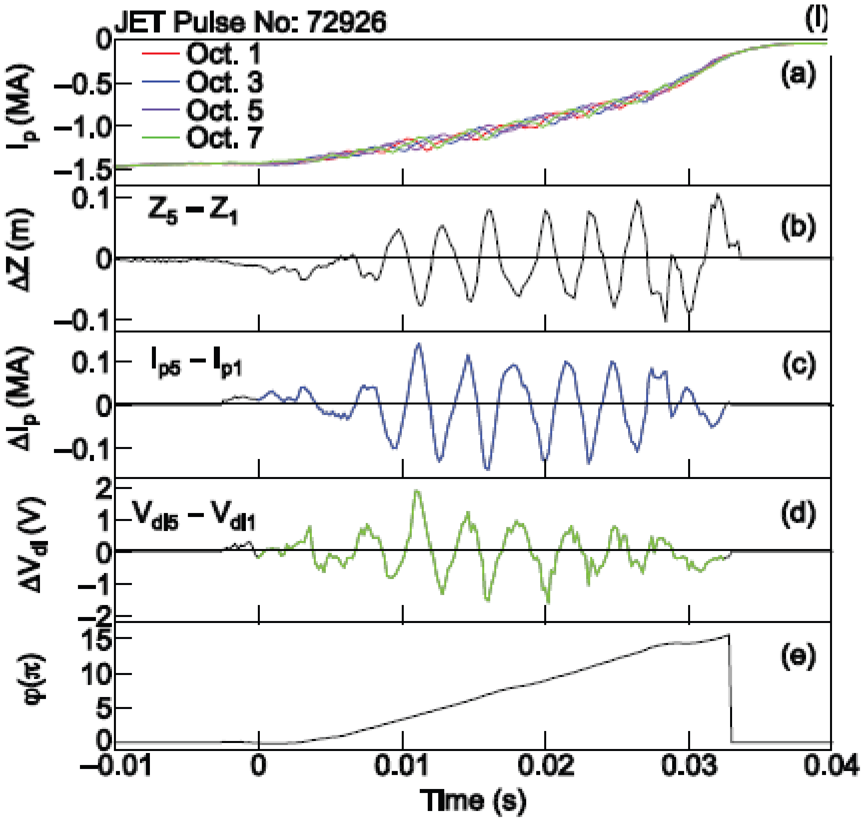
See next talk

# Current asymmetry observed and modelled with M3D for pure vertical disruption event (VDE)




*Gerasimov, Nuc. Fus. 2015*