Overview of the FTU results

G. Pucella

on behalf of FTU Team and Collaborators

presented by: ***G. Calabrò***

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Outline

- Introduction
- Experimental results
- Contributions

Runaway electrons generation and control
- Threshold electric field for runaway electron generation (EX/P2-50)
- Runaway electrons control (EX/P2-48)

ECW experiments
- Real time control of MHD instabilities (EX/P2-47)
- Amplification of (N)TM by central EC power (EX/P2-54)
- EC assisted plasma start-up (EX/P2-51)

Lithium Limiter experiments
- Thermal load on the new lithium limiter (EX/P2-46)
- Elongated plasmas

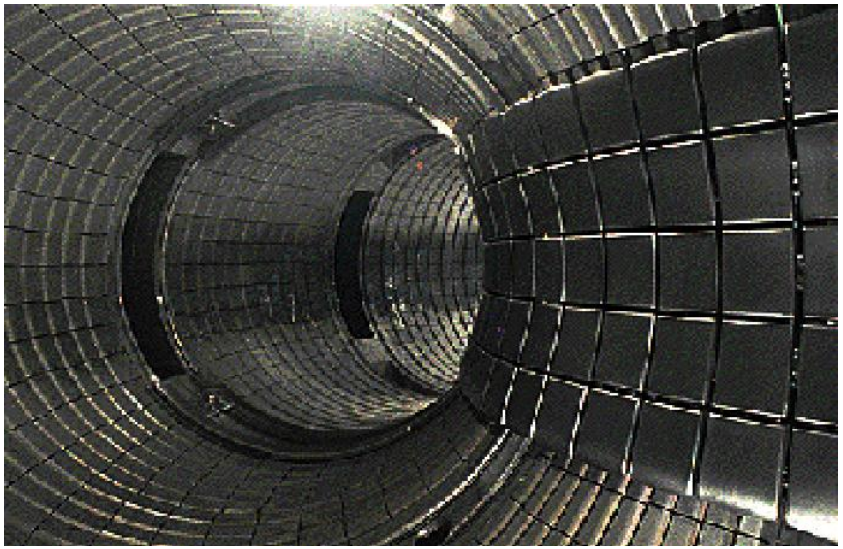
Plasma response to neon injection
- Peaked density profiles (EX/P2-52)
- Tearing mode instabilities (EX/P2-53)

MHD signals as disruption precursors

Scrape-Off Layer studies

Diagnostics
- Cherenkov probe (EX/P2-49)
- Gamma camera
- Laser Induced Breakdown Spectroscopy

Frascati Tokamak Upgrade



- Stainless steel vacuum chamber
- High field side Mo belt limiter
- Outer Mo poloidal limiter
- Li poloidal limiter

Compact high magnetic field machine

R_0	0.935	m	*Major radius*
a	0.30	m	*Minor radius*
B_T	2 ÷ 8	T	*Toroidal field*
I_p	0.2 ÷ 1.6	MA	*Plasma current*
n_e	0.2 ÷ 4.0	10^{20} m^{-3}	*Plasma density*
Δt	1.5	s	*Pulse duration*
EC	140 GHz / 1.5 MW		*Electron Cyclotron*
LH	8 GHz / 2.0 MW		*Lower Hybrid*

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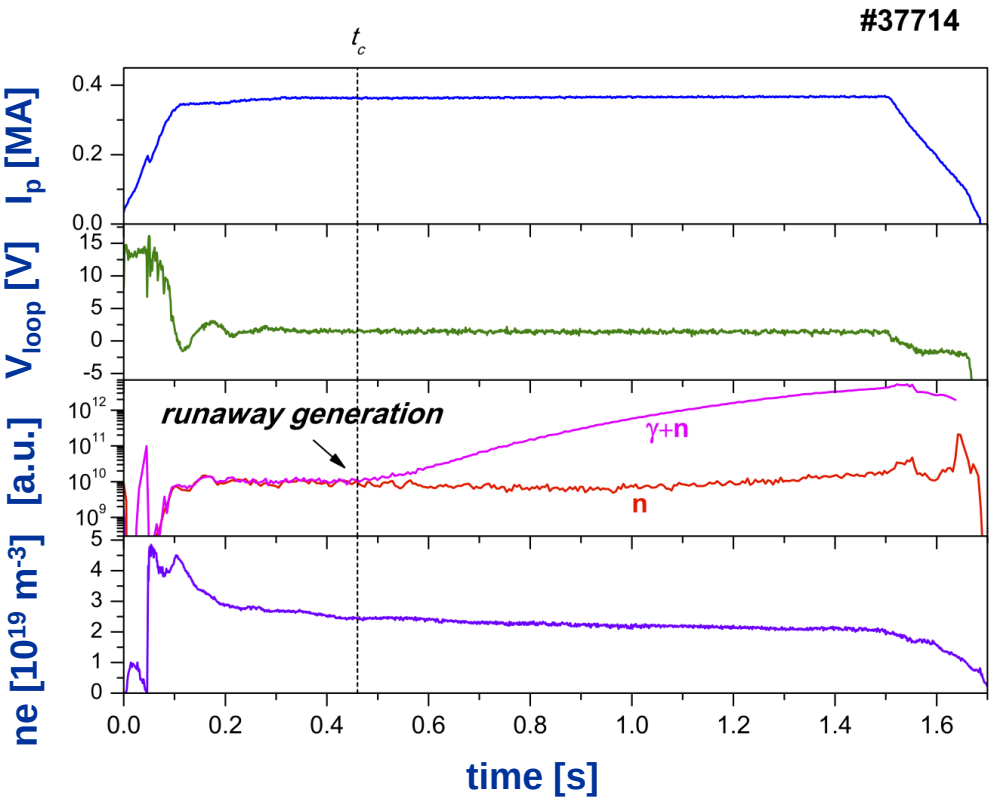
Runaway electrons generation

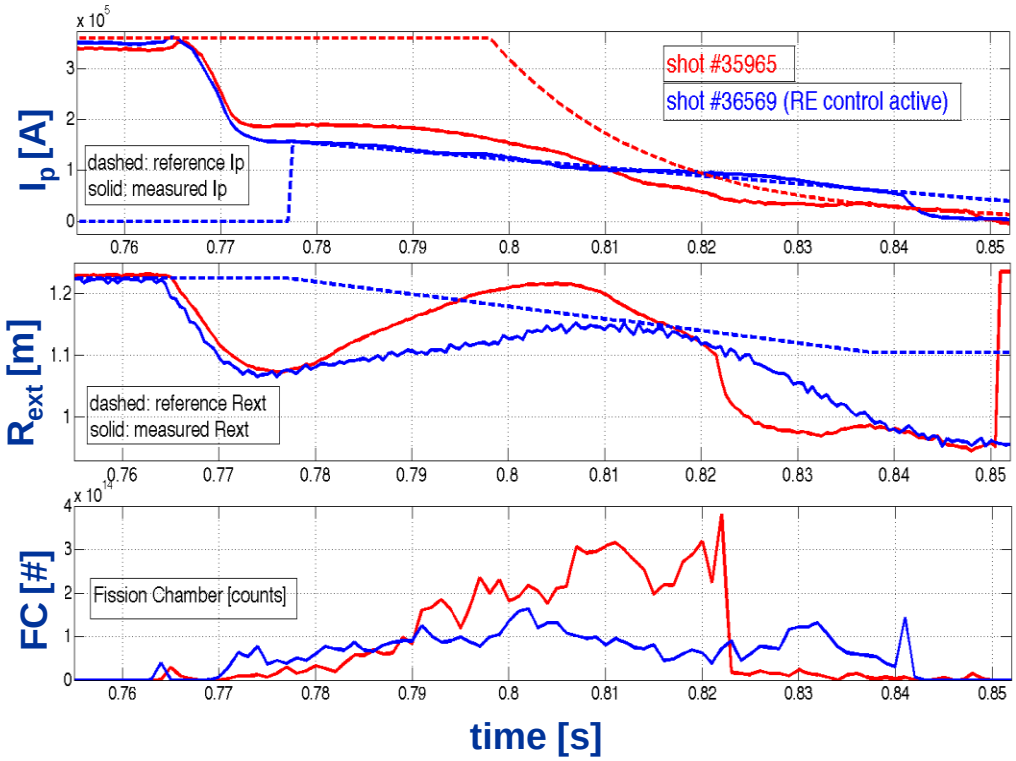


- Conditions for RE generation in ohmic pulses investigated for a wide range of toroidal magnetic fields and plasma currents.
- Critical electric field for RE generation 2÷5 times larger than the one from collisional theory.
- Results agree with the new threshold calculated including synchrotron radiation losses.

- **Determination of the threshold density value to be achieved by means of massive gas injection for RE suppression in ITER.**

Esposito B. IAEA EX/P2-50 (2014)

Runaway electrons control



- New RE control algorithm tested for real-time control of disruption-generated RE beam.
- Minimize interaction with plasma facing components while RE current is ramped-down by induction.
- Fission chambers signals show reduced plasma facing components interaction with the new controller.

Reduction of the dangerous effects of RE during disruptions in ITER operation.

Carnevale D. **IAEA EX/P2-48 (2014)**

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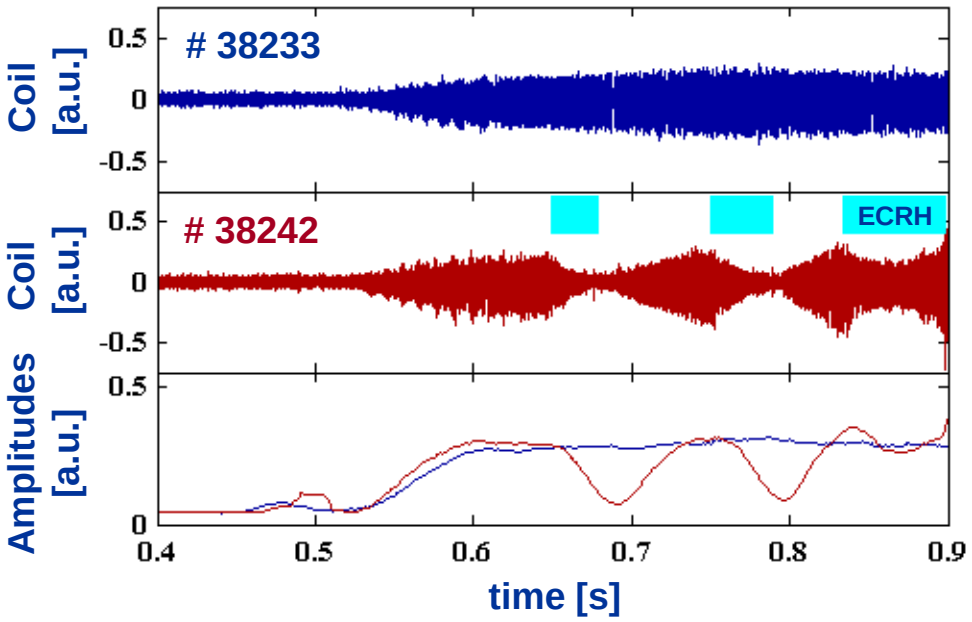
Real time control of MHD instabilities

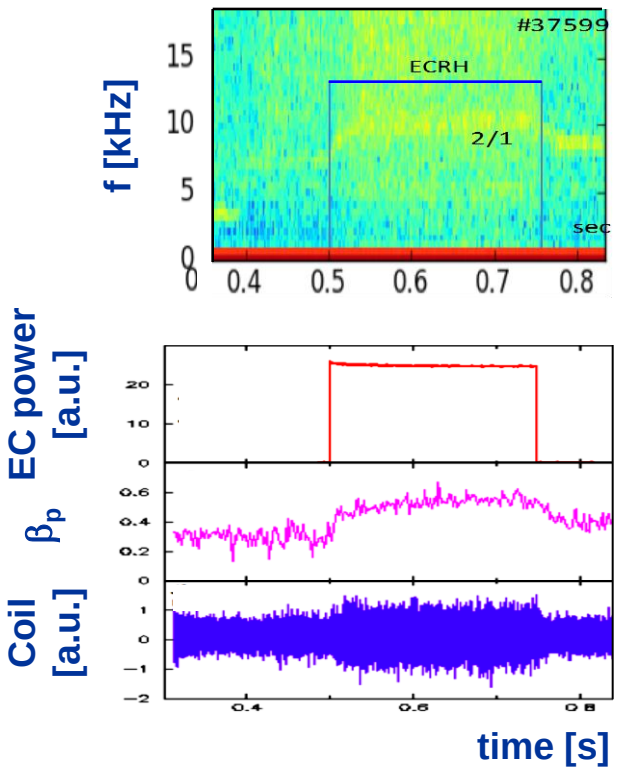


- Real time control of MHD instabilities using the new EC launcher with fast steering capability (1 deg / 10 ms).
- Low-order tearing modes induced by neon injection or by near-limit density.
- The data show a marked sensitivity of the resulting instability amplitude to the ECW deposition location.

- **The experimental condition (control tools essential and based on a minimal set of diagnostics) mimics the situation of a fusion reactor.**

Sozzi C. **IAEA EX/P2-47 (2014)**

Amplification of (N)TM by central EC power



- Amplification mechanisms by EC due to:
  - Modification of the local plasma current density and of the mode stability parameter Δ'_0.
  - Increased bootstrap effect proportional to β_p.

2/1 NTM classification due to the instability amplification by increased bootstrap effect

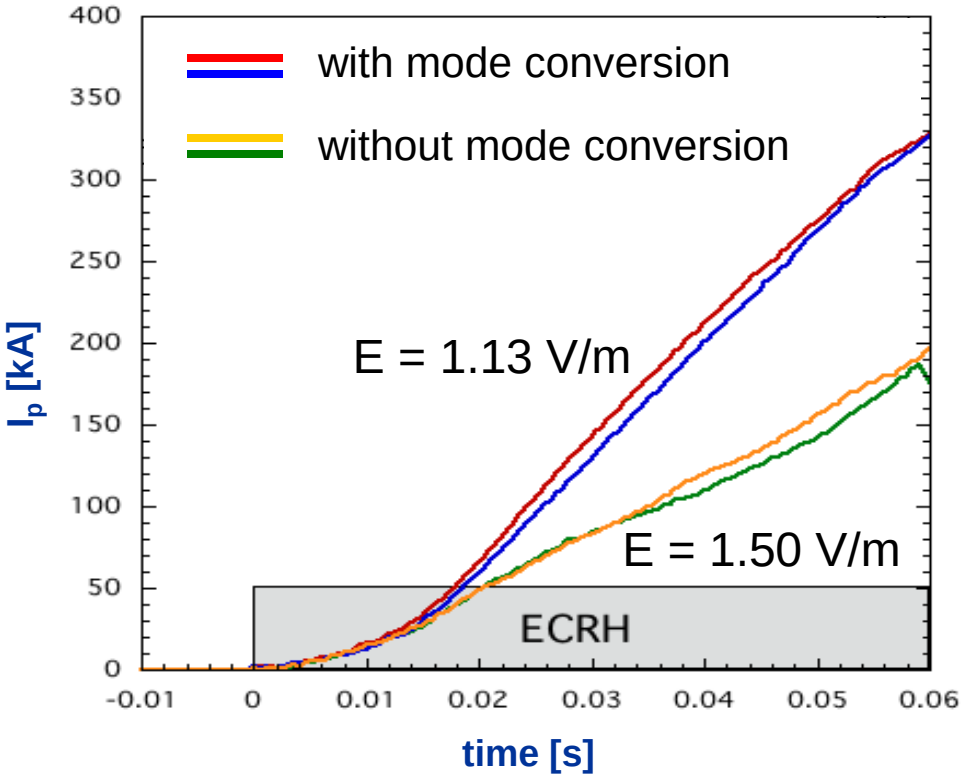
- Frequency increase due to torque action originated from the applied co-ECCD.

No effect due to modification of rotation (ion polarization effect) because of the amplified size of existing perturbation.

- **Important issue for the fusion plasma operations to avoid the degradation of the plasma confinement due to resistive instabilities.**

Nowak S. **IAEA EX/P2-54 (2014)**

EC assisted plasma start-up



- Variations of launching angle: OX polarization conversion at reflection from inner wall → better power absorption → higher T_e → lower resistivity.
- Variations of field null position via external vertical magnetic field.

- **Experiments focused on ITER start-up issues: start-up at low toroidal electric field (0.5 V/m), even in presence of a large stray magnetic field (10 mT).**

Granucci G. **IAEA EX/P2-51 (2014)**

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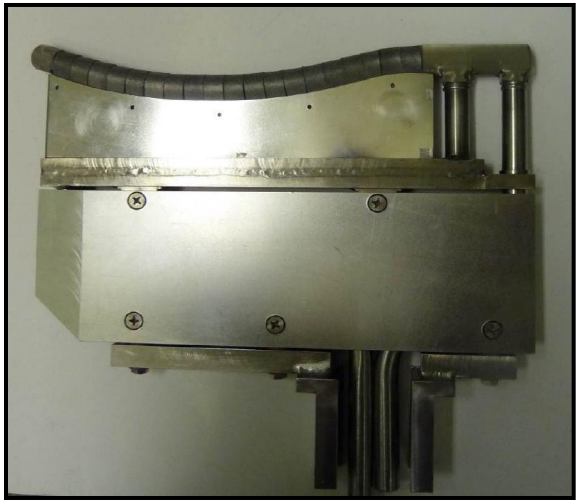
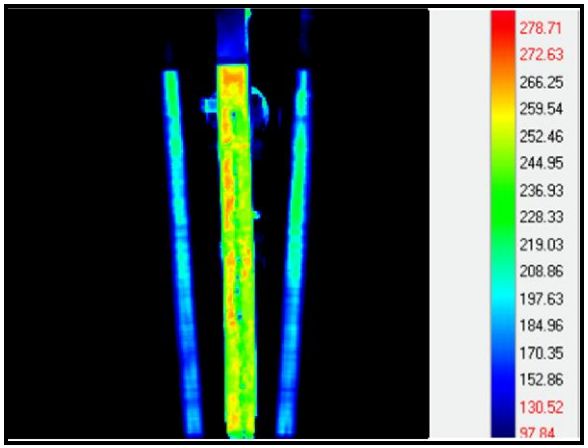
Thermal load on the new lithium limiter



- New actively Cooled Lithium Limiter (CLL) with 200°C pressurized (30 bar) water circulation. 10 MW/m^2 target heat load.
- CLL inserted close to the LCMS (2 MW/m^2), without any damage to the limiter surface.

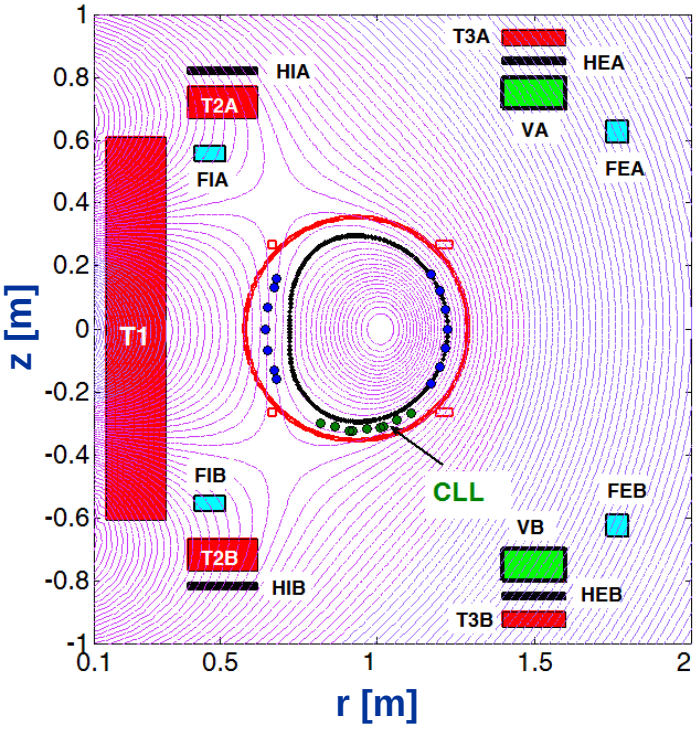


- Heat load on the CLL from fast IR camera (■ 230°C).
- 5 s dedicated pulses in preparation.

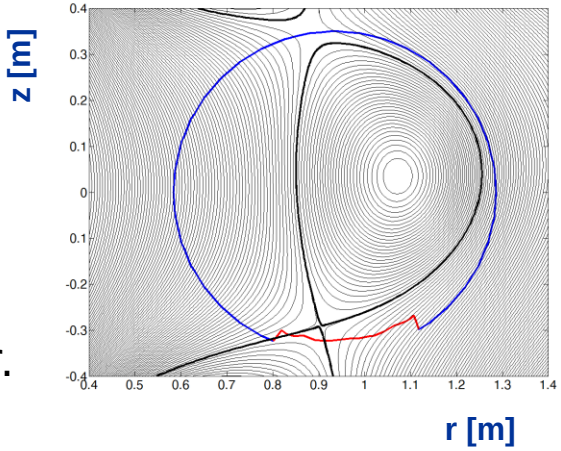
- **Liquid metals could be a viable solution for the problem of the power load on the divertor for steady state operation on the future reactors.**

Mazzitelli G. **IAEA EX/P2-46 (2014)**

Elongated plasmas



- Elongated plasmas (5.5 T, 200 kA, k~1.2) with ECW additional heating (500 kW).
- Vary local magnetic shear (flux surfaces opening) at the CLL.
- Study on-going: X-point configuration with a magnetic single null inside the chamber.



- **Aim at investigating H-mode access, thus having the possibility to study the impact of ELMs on the CLL used as first limiter.**

Calabrò G., EPS P4.005 (2014) – Ramogida G., SOFT P2.014 (2014)

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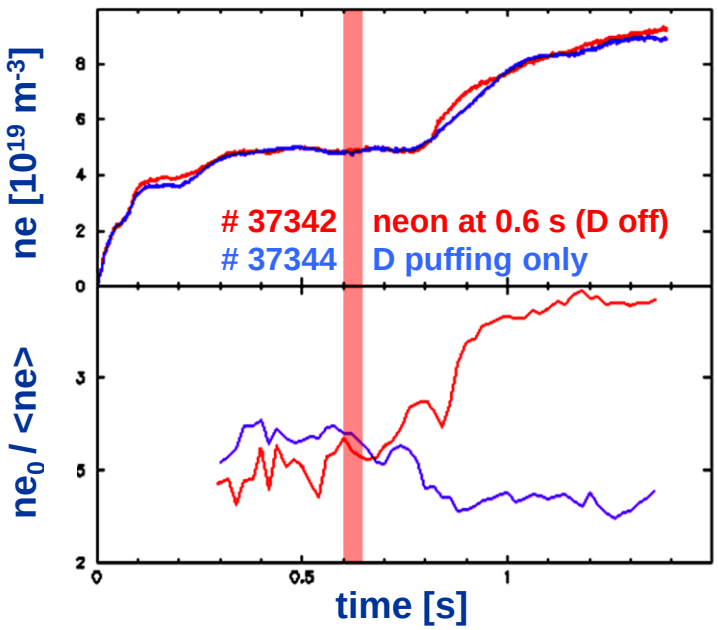
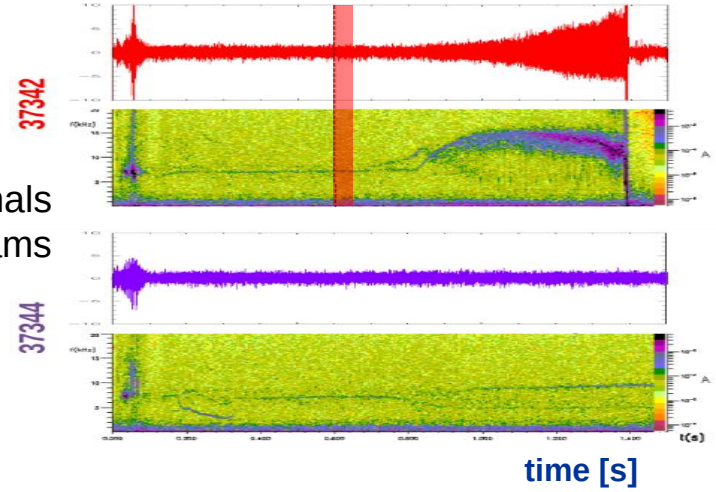
Plasma response to neon injection



- Density peaking increases in response to neon puffing.
- More inward pinch than in the reference case at the same density without neon puffing.

Mirnov coil signals and Spectrograms



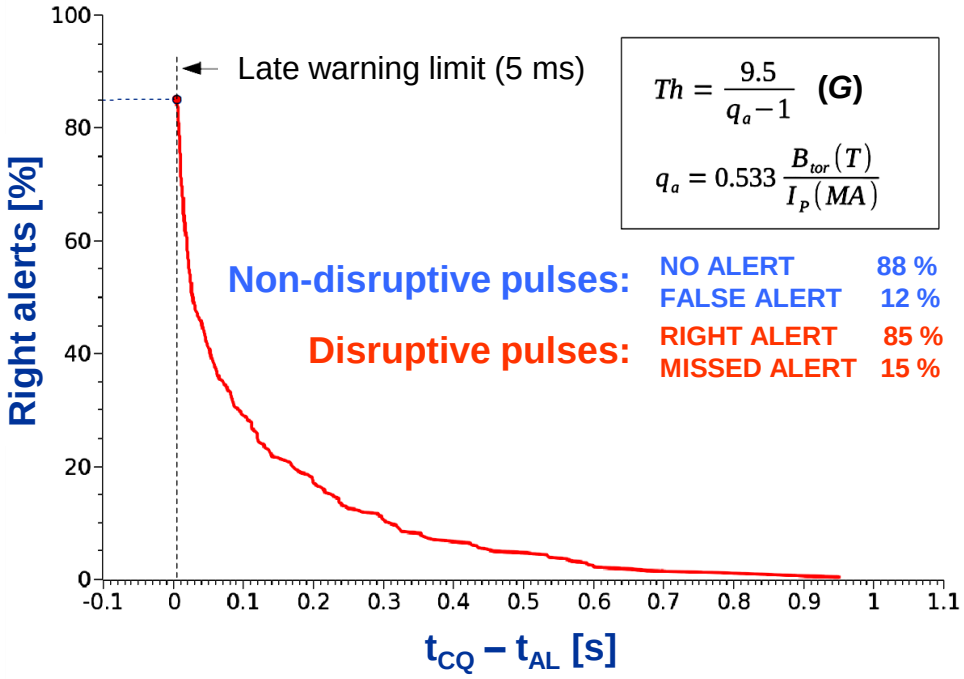
- Onset or amplification of low-order tearing modes.

- **It is important to determine the conditions of an increase of particle confinement while minimizing the amount of impurities needed.**

Mazzotta C. IAEA EX/P2-52 (2014)

Botrugno A. IAEA EX/P2-53 (2014)

MHD signals as disruption precursors

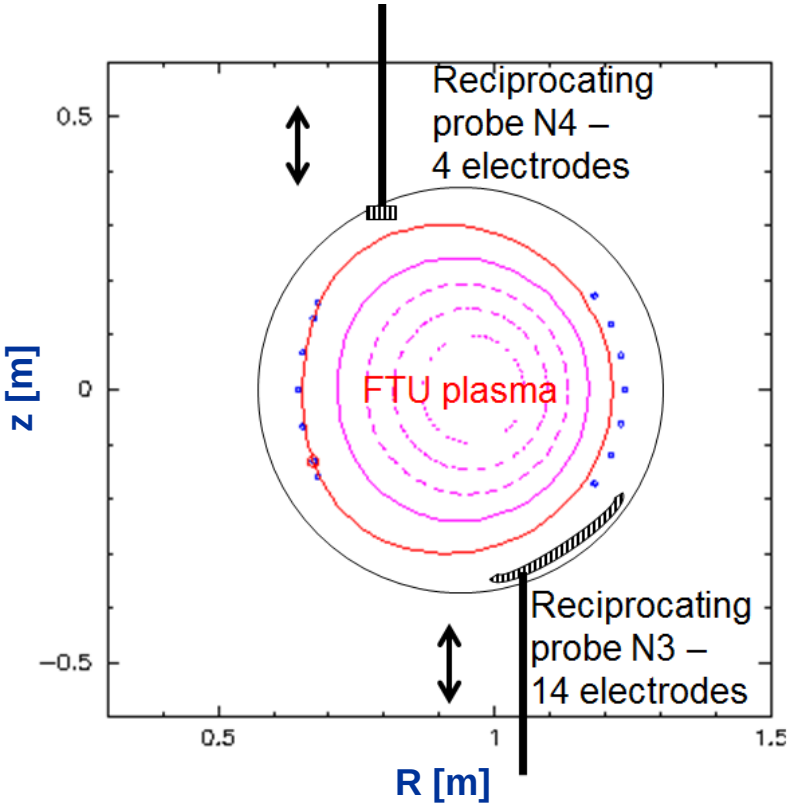


- Full real-time algorithm for disruption prediction, based on MHD activity signals from Mirnov coils.
- Threshold parameterization in terms of plasma parameters (B_T, I_p) optimized for maximum of timely right alerts and minimum of false alerts.
- Threshold optimization on 2000 pulses covering a wide range of physical parameters.

- **The definition of suitable disruption precursors is of crucial importance in order to trigger actions for avoiding or at least mitigating disruptions.**

Cianfarani C., EPS P5.165 (2013)

Scrape-Off Layer studies



- Data collected by two arrays of reciprocating Langmuir probes.
- Scaling of the heat flux e-folding length λ in the scrape-off layer with:
  - toroidal magnetic field (B_T)
  - plasma current (I_p)
  - line-averaged density (n_e)
  - power to SOL (P_{SOL})

Strong dependency of λ on I_p ($\sim I_p^{0.6}$) and P_{SOL} ($\sim P_{SOL}^{-0.8}$)

- **This experiment contributed to the multi-tokamak scaling of SOL heat flux width of ITER limiter start-up plasma.**

Viola B., EPS P1.119 (2013)

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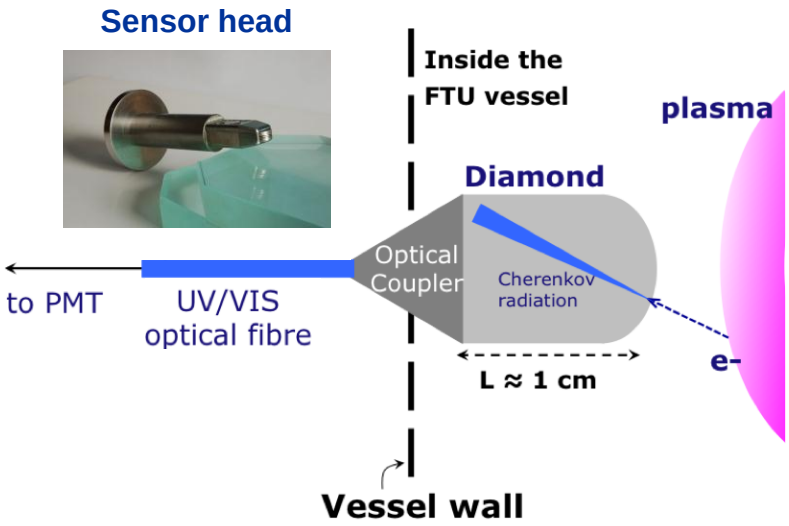
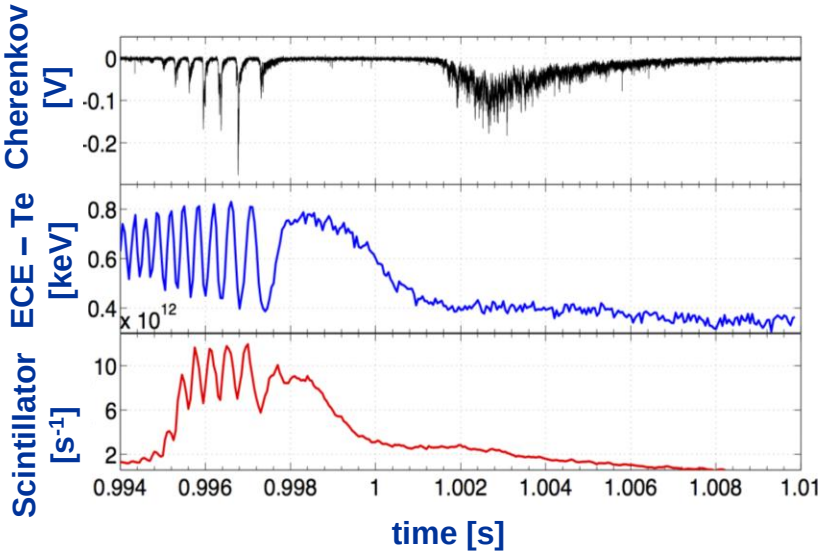
Cherenkov probe



- Collaboration with NCBJ.
- Escaping fast electrons detected by Cherenkov radiation emitted in diamond probe.

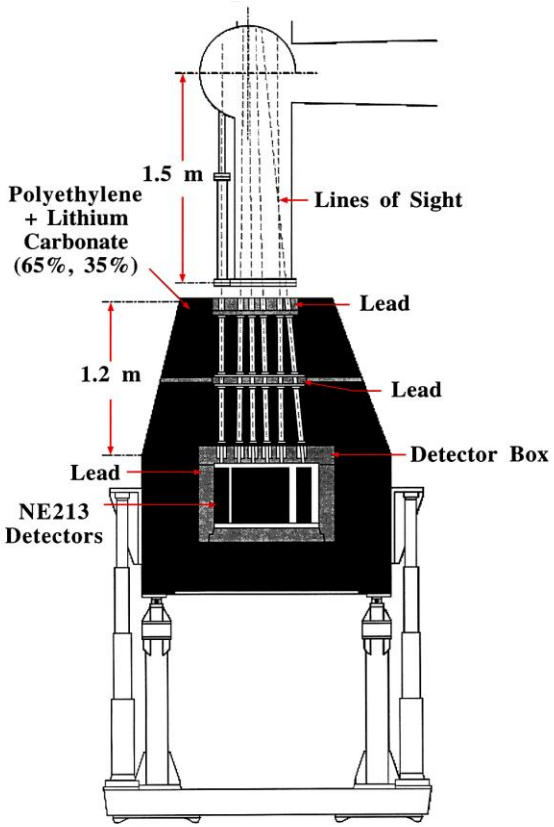


- Correlation between Cherenkov signal and magnetic island rotation.
- Modelling and simulations (HMGC).

Loss of confinement of fast electrons in the presence of high amplitude magnetic islands.

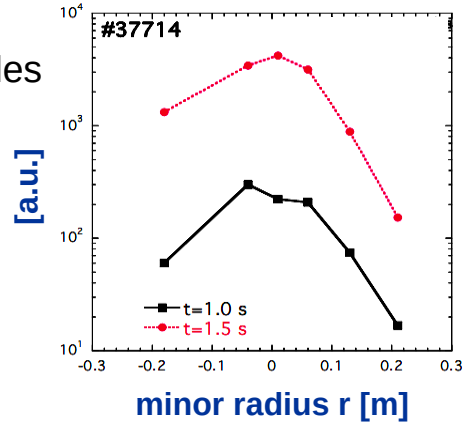
Causa F. **IAEA EX/P2-49 (2014)**

Gamma camera



- Gamma-ray camera for in-flight runaway electrons emission produced by in-plasma bremsstrahlung.
- Six radial lines of sight equipped with liquid organic scintillators (NE213).
- n/γ discrimination in conditions of very high count rate.

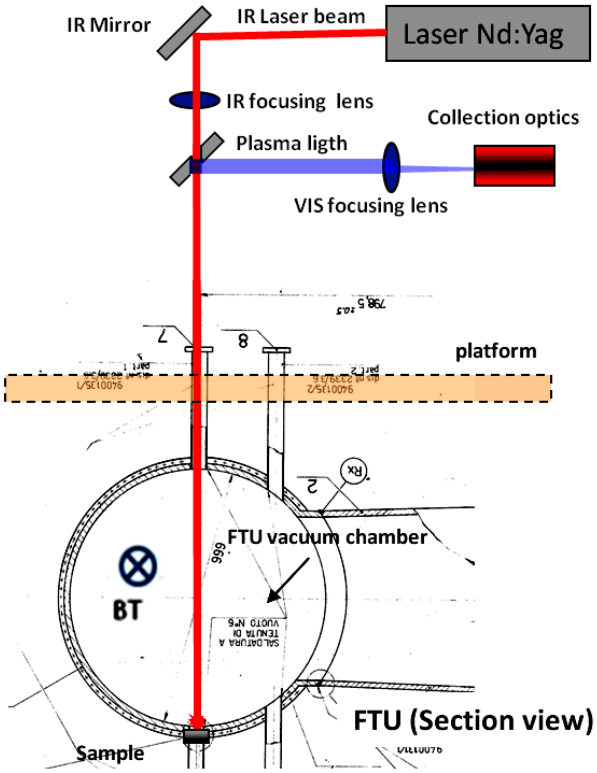
Hard x-ray profiles



- **Study of the RE population during the current ramp-up, flat-top and ramp-down phases with sub-ms time resolution.**

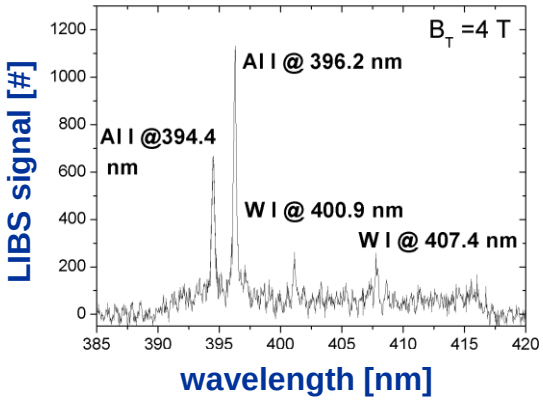
Marocco D., SOFT P2.046 (2014)

Laser Induced Breakdown Spectroscopy



- Laser Induced Breakdown Spectroscopy measurements performed on samples placed in FTU vacuum with toroidal field on (up to 4 T).
- Experiments demonstrate the feasibility of in situ LIBS diagnostic of surface composition.

Sample W-Al-C



- **Useful information on the surface elemental composition and fuel retention in present and future tokamaks, such as ITER.**

Maddaluno G., EPS P5.102 (2013)

Contributions to IAEA – FEC 2014

- **Pucella G.**, “Overview of the FTU results”, **OV/5-4**
- **Mazzitelli G.**, “Thermal loads on FTU actively cooled liquid lithium limiter”, **EX/P2-46**
- **Sozzi C.**, “Experiments on magneto-hydrodynamics instabilities with ECH/ECCD in FTU using a minimal real-time control system”, **EX/P2-47**
- **Carnevale D.**, ”Runaway electron control in FTU”, **EX/P2-48**
- **Causa F.**, “Cherenkov emission provides detailed picture of non-thermal electron dynamics in the presence of magnetic islands”, **EX/P2-49**
- **Esposito B.**, “On the measurements of the threshold electric field for runaway electron generation in FTU”, **EX/P2-50**
- **Granucci G.**, “Experiments and modelling on FTU tokamak for EC assisted plasma start-up studies in ITER-like configuration”, **EX/P2-51**
- **Mazzotta C.**, “Peaked density profiles due to neon injection on FTU”, **EX/P2-52**
- **Botrugno A.**, “Driving m/n=2/1 tearing instability by neon injection in FTU plasma”, **EX/P2-53**
- **Nowak S.**, “(N)TM onset by central EC power deposition in FTU and TCV tokamaks”, **EX/P2-54**