FAST THERMAL HELIUM BEAM DIAGNOSTIC: IMPLEMENTATION AND RESULTS IN RFX-MOD

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THERMAL HELIUM BEAM

Thermal **H**elium **B**eam is a diagnostic for measuring density and temperature of the edge plasma

Useful ranges: $10 < T_e < 100$ eV $\quad 5\ 10^{18} < n_e < 1\ 10^{20}$ m^{-3}

Principle: puffing neutral He in the edge and measuring the HeI line emission

Successfully applied to many devices:

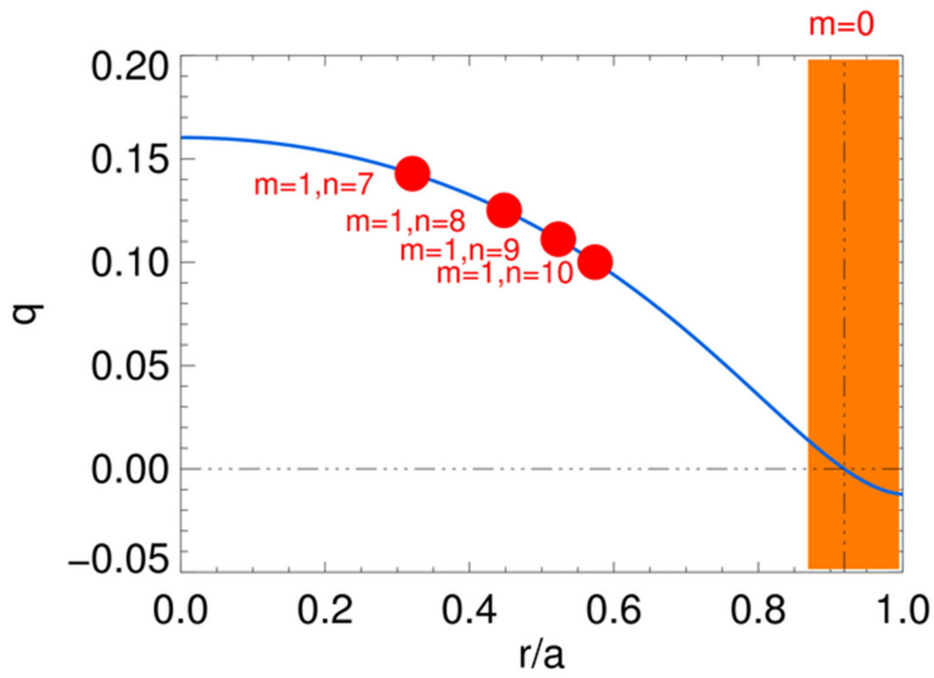
PISCES-B	[A. Pospieszczyk et al. NIMPR **B72** (1992) 207]
TEXTOR	[O Schmitz et al. , PPCF **50** (2008) 115004, and many others]
TJ-II	[E.de la Cal et al., PPCF **53** (2011) 085006]
H-1	[S.Ma et al, RSI **83** (2012) 033102]
RFX-mod	[M.Agostini et al., RSI **81** (2010) 10D715]
Alcator C-Mod	[C.S. Pitcher et al. APS 2000]

SUMMARY

- Reversed field pinch configuration and RFX-mod experiment
- Thermal Helium Beam diagnostic
- Fast THB in RFX-mod
- Edge profiles and interaction with 3D magnetic field
- Turbulence studies
- Application at NSTX-U?

REVERSED FIELD PINCH

- Magnetic configuration with $B_\phi \approx B_\theta$
- Toroiald field changes sign at the edge
- Monotonic decreasing q profile
- m=1 modes resonating inside the plasma
- At the reversal surface all the m=0 modes resonate



RFX-MOD

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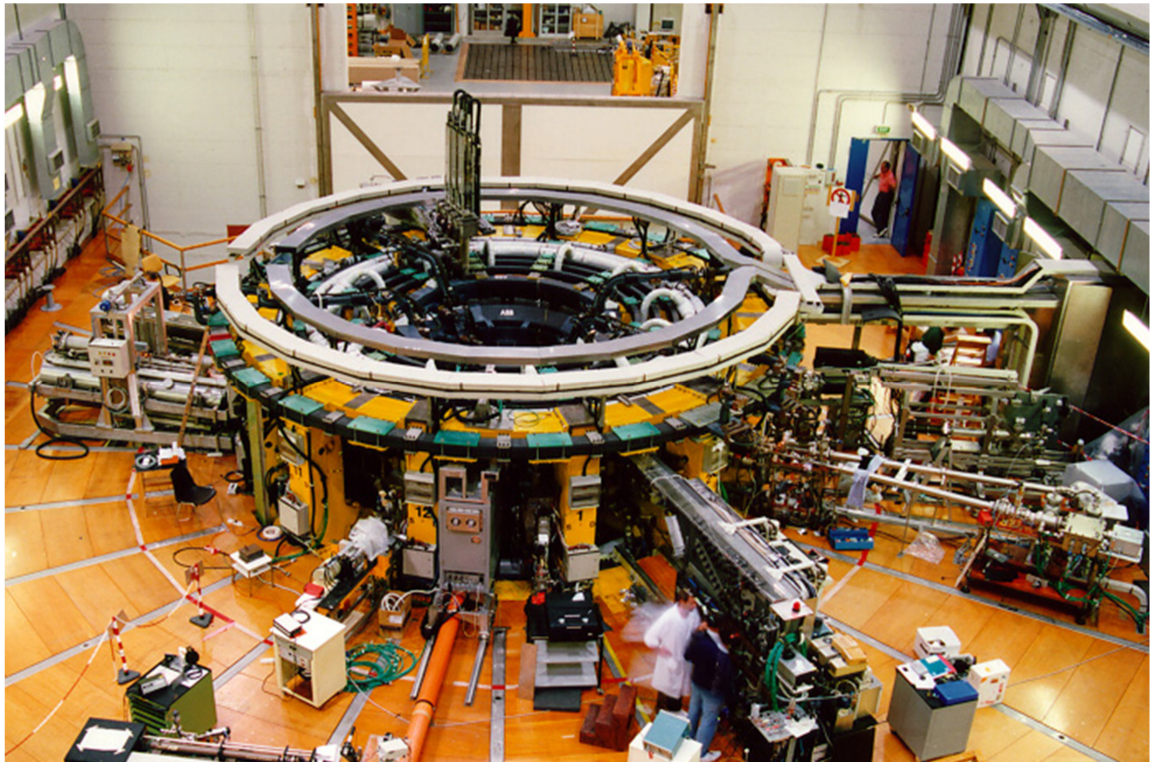
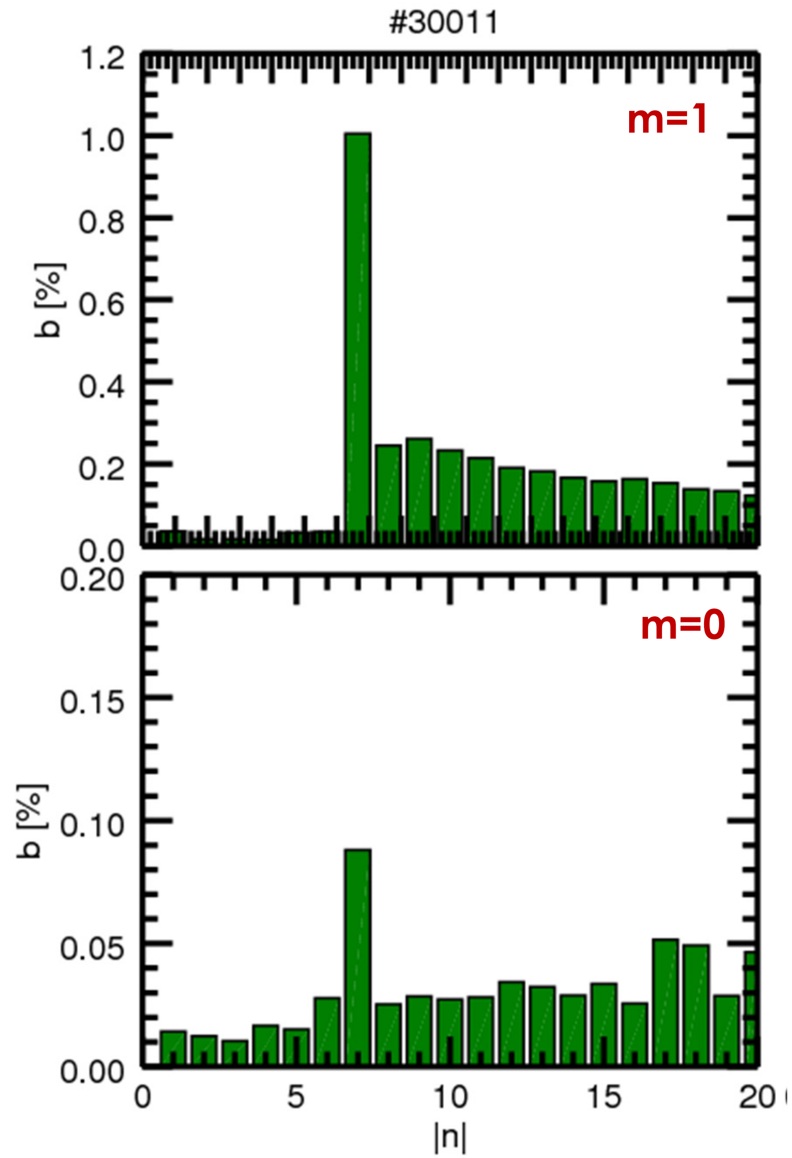


- ✓ $R = 2$ m
- ✓ $a = 0.5$ m
- ✓ $I_p \leq 2$MA

- ✓ 192 saddle coils for active feedback control of tearing modes and MHD instabilities

P.Martin et al., NF **53** 104018 (2013)
L.Marrelli et al., PPCF **49** B359 (2007)

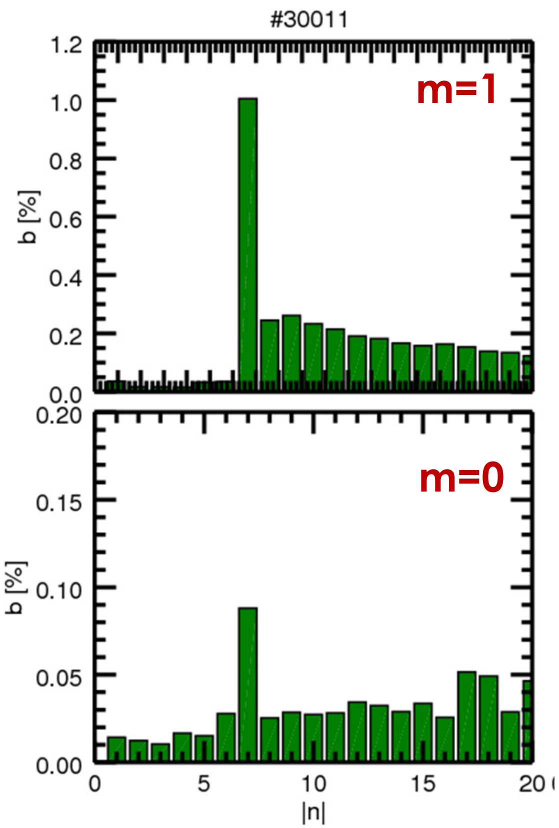
MAGNETIC TOPOLOGY



At high current the m=1, n=-7 spontaneously increases and becomes dominant

The plasma develops a 3D structure in the core

MAGNETIC TOPOLOGY



At high current the m=1, n=-7 spontaneously increases and becomes dominant

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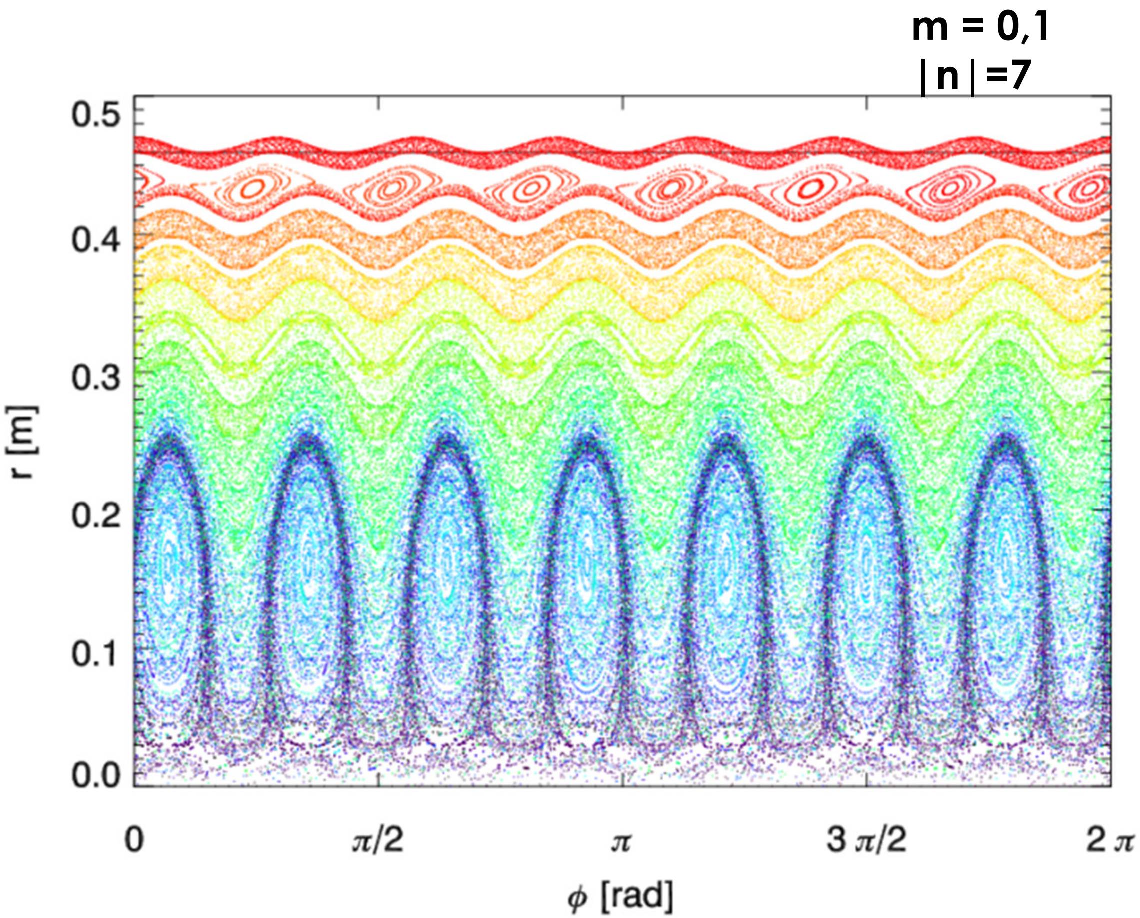

Residual (1,-7) ripple is present also in the plasma edge

The edge is affected also by the m=0 islands

P.Scarin et al., NF **51** 073002 (2011)

PRINCIPLE OF THB

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Neutral helium puffed into the plasma edge

He is excited by electron collisions

Three lines of HeI are suitable for measuring n_e and T_e

$$\frac{667.8\,nm}{728.1\,nm} \propto n_e$$

$$\frac{728.1\,nm}{706.5\,nm} \propto T_e$$

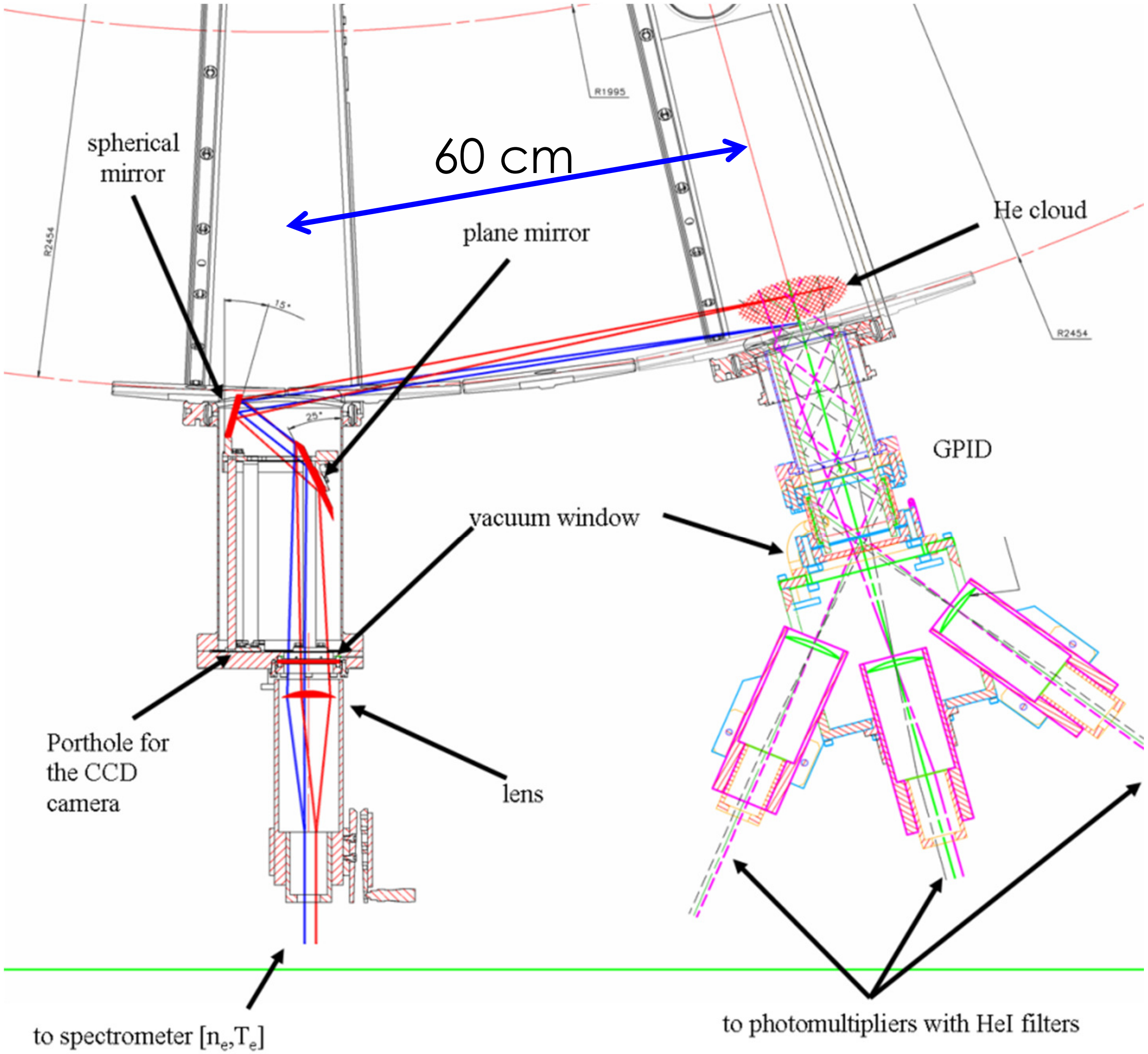
The existing THBs are used for measuring “low” frequency fluctuations, with characteristic time of 1-5 ms

The one of RFX is designed to measure also at higher frequency

B.Schweer et al. J.Nucl.Mater **266-269** 679 (1999)
O.Schmitz et al. PPCF **50** 115004 (2008)

FAST THB DIAGNOSTIC AT RFX-MOD

THB PLASMA INTERFACE



- Neutral He puffed in the edge
- He density: few 10^{17} m^{-3}
- n_e: 10^{18}- 5 10^{19} m^{-3}
- 8 radial points
- 5 mm spatial resolution

R.Cavazzana et al., RSI **75** 4152 (2004)
M.Agostini et al., RSI **81** 10D715 (2010)

THB REVELATION SYSTEM

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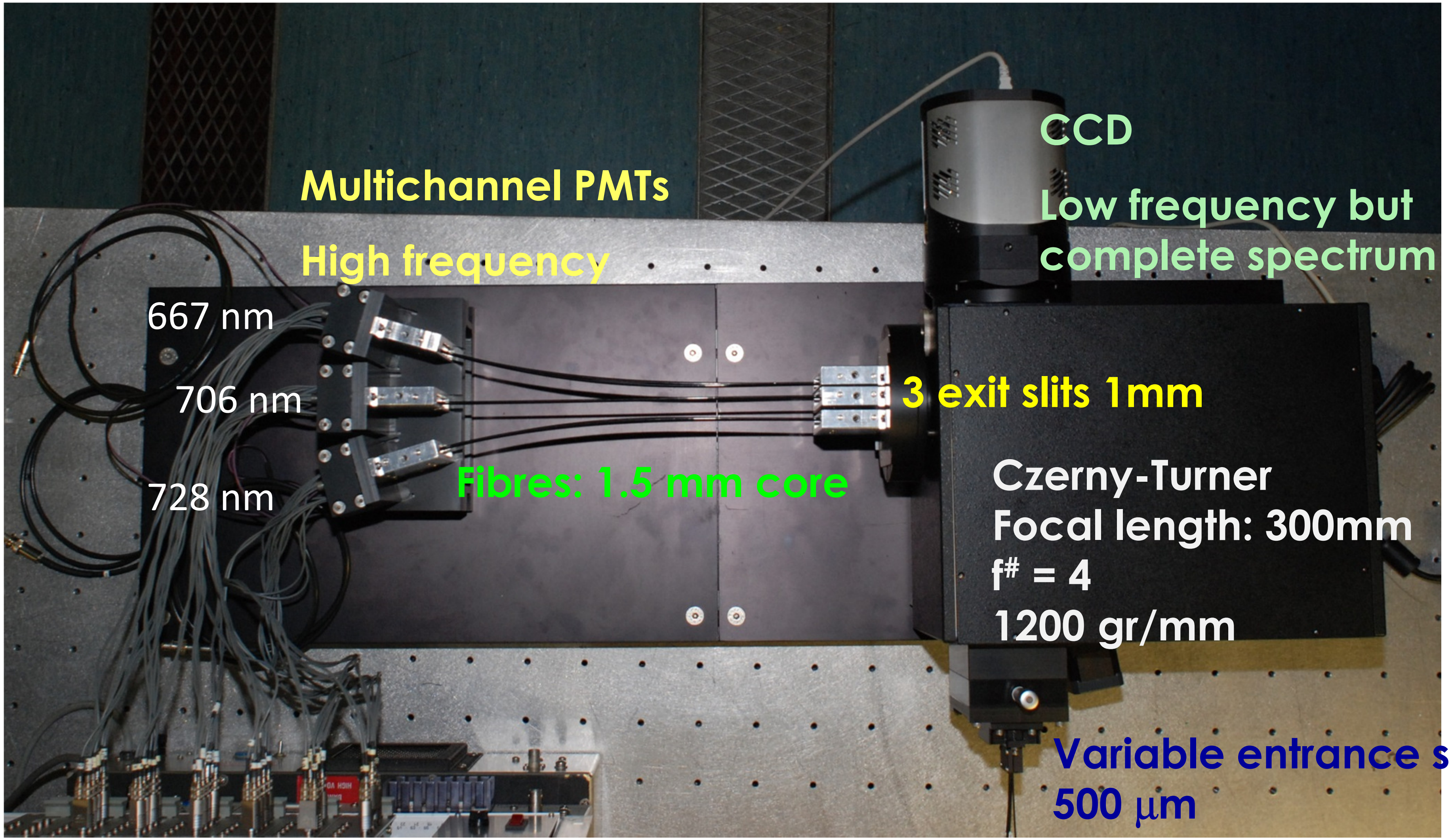

Bandwidth: 500 kHz

8 fibres: 1 mm core diameter

EDGE SPECTRUM

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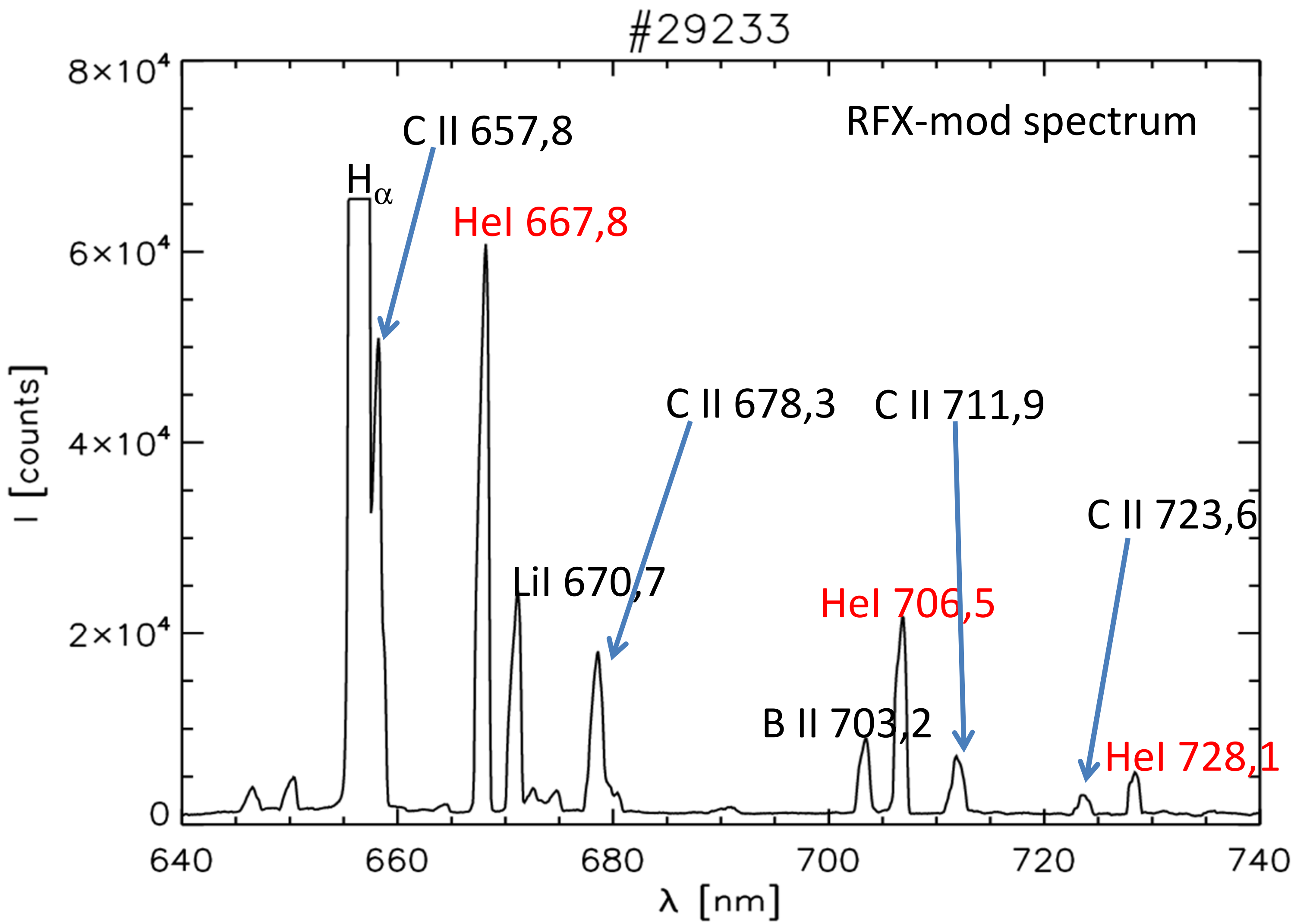

Spectrum during He puffing

The three HeI lines are detectable and well isolated

M.Agostini et al., PPCF **51** 105003 (2009)

EDGE SPECTRUM: 706.5 nm

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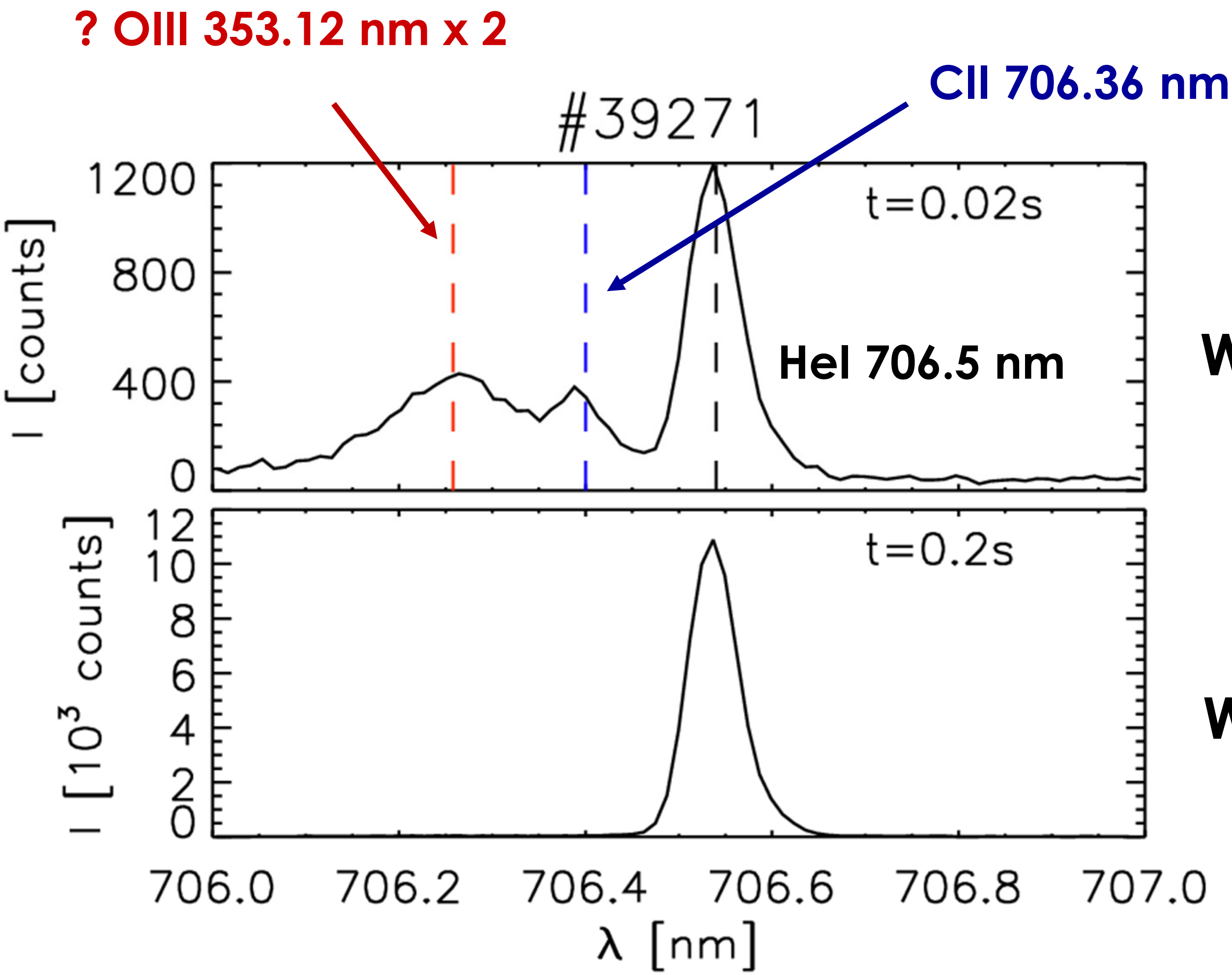
There are other lines near the 706.5 nm one

They do not have an important impact in the measurements



Without He puffing

With He puffing

EDGE SPECTRUM: 706.5 nm

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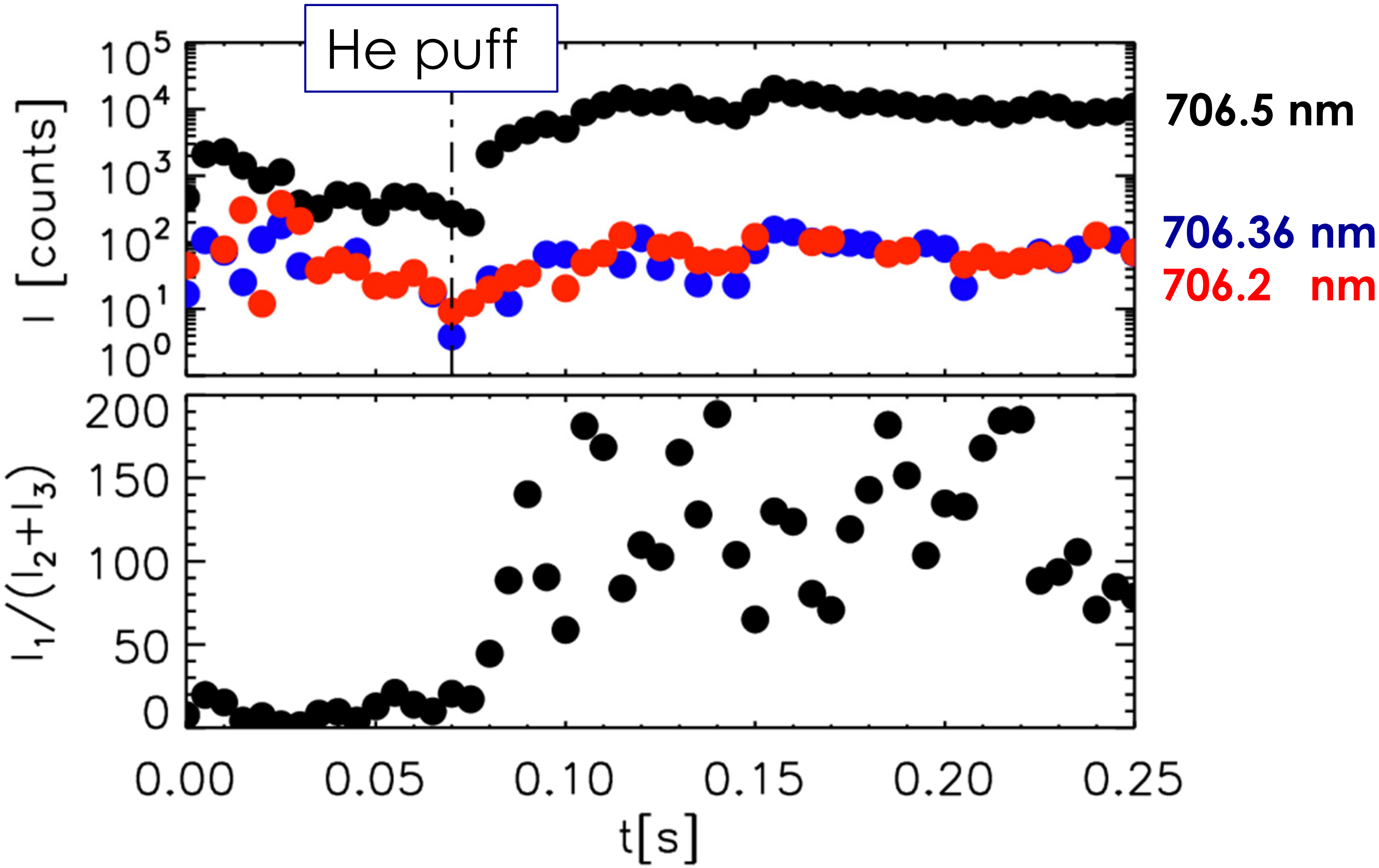
With He puff intensity of the 706.5 line larger then the impurities

The effect on the measurement is negligible



INSTRUMENTAL FUNCTION

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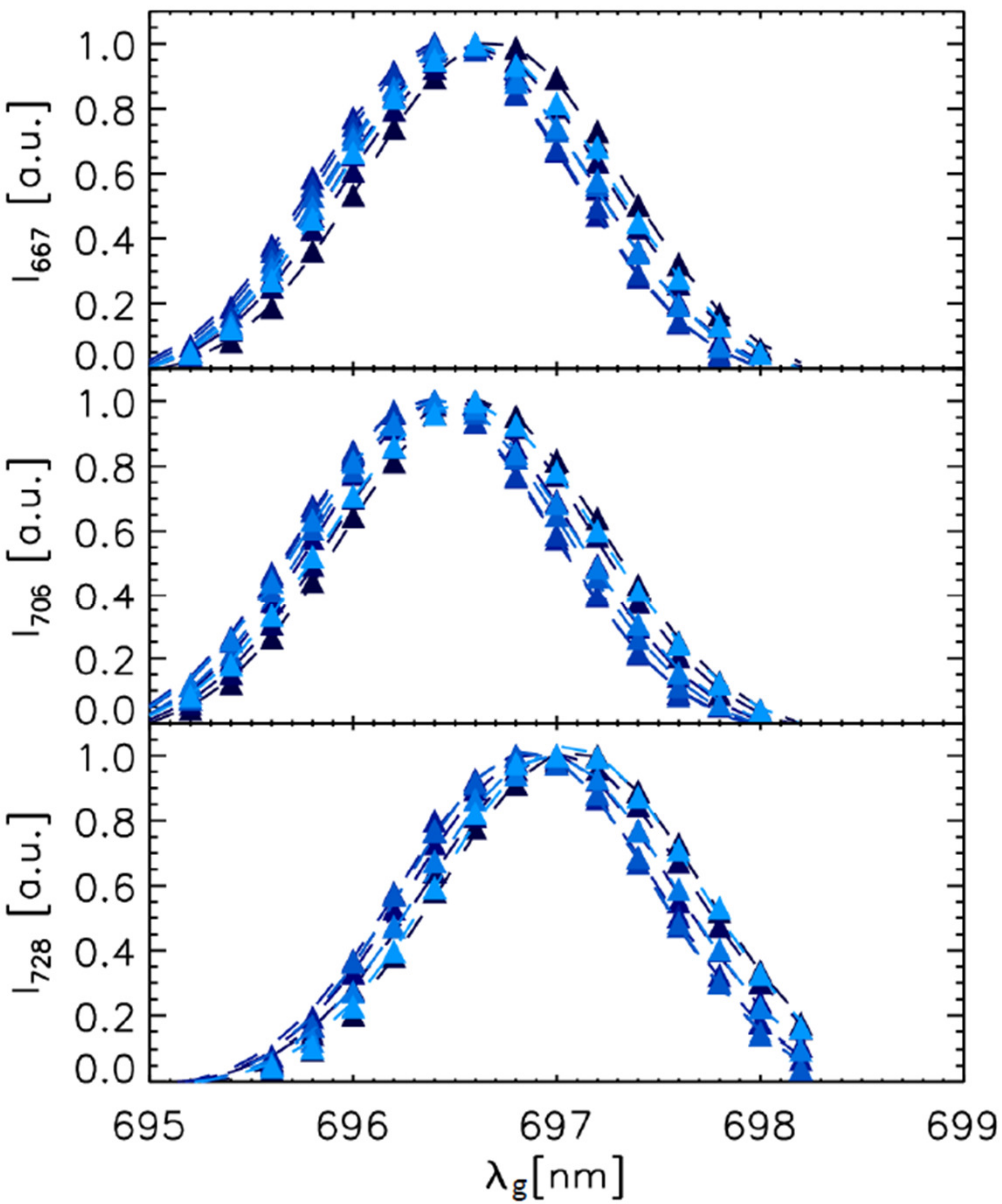
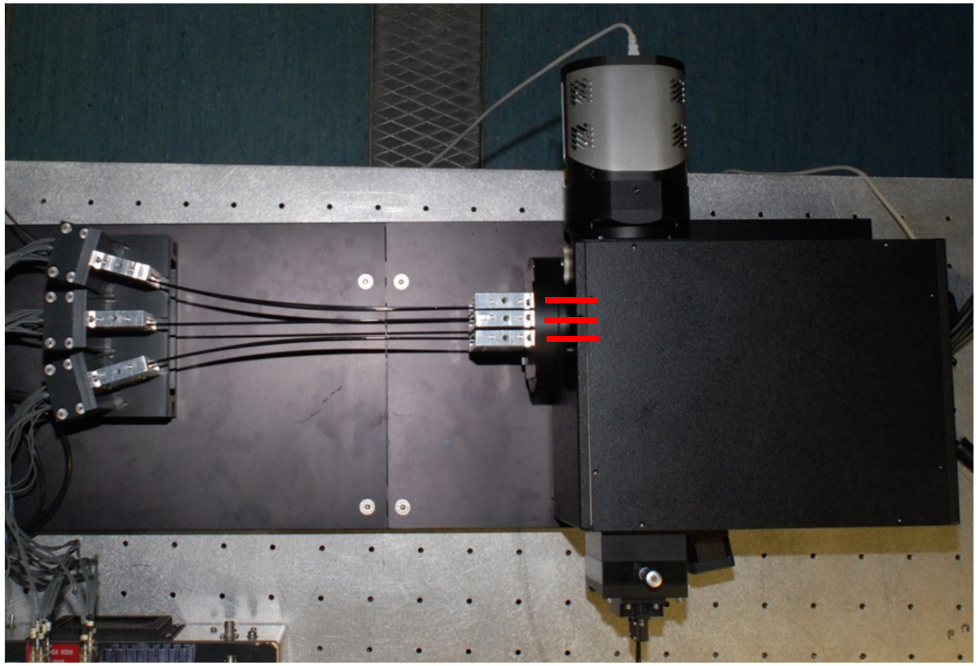


- Each multichannel PMT measures one emission line for the 8 optical fibres
- Instrumental function with He lamp and moving the grating
- Small misalignment for the 728 nm line: error in the position of the exit slit

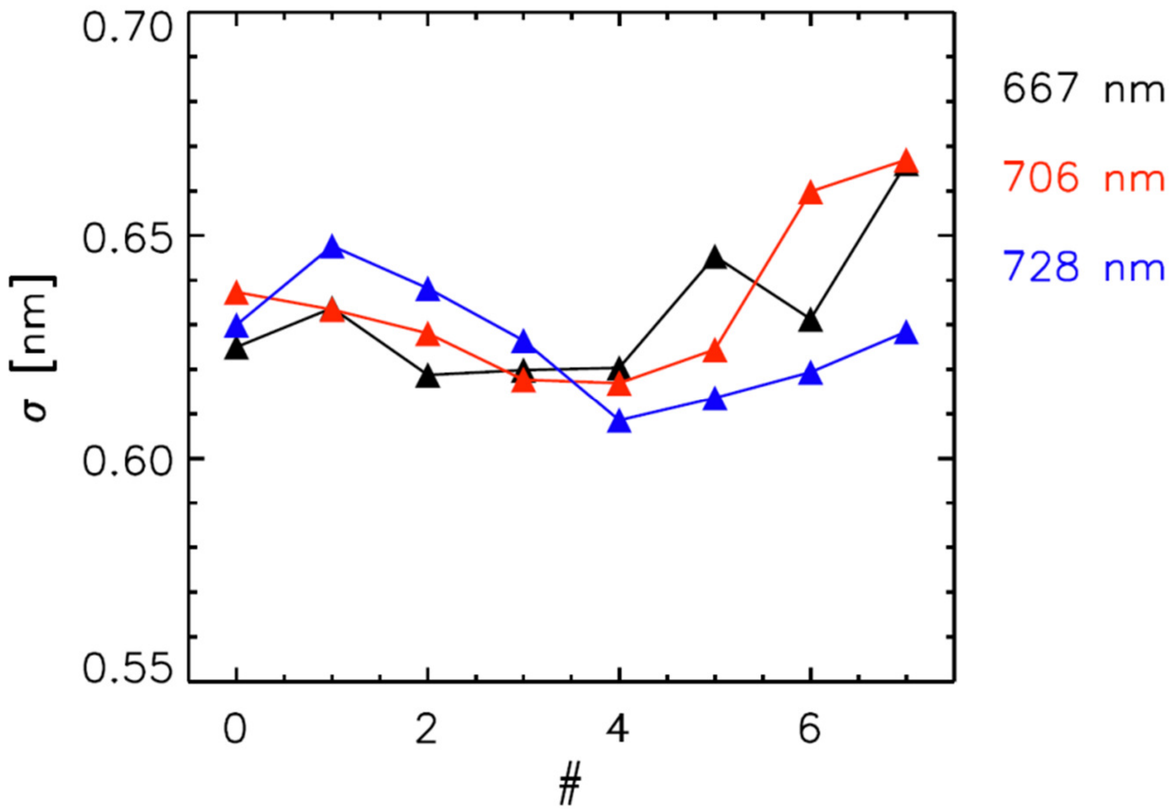


INSTRUMENTAL FUNCTION

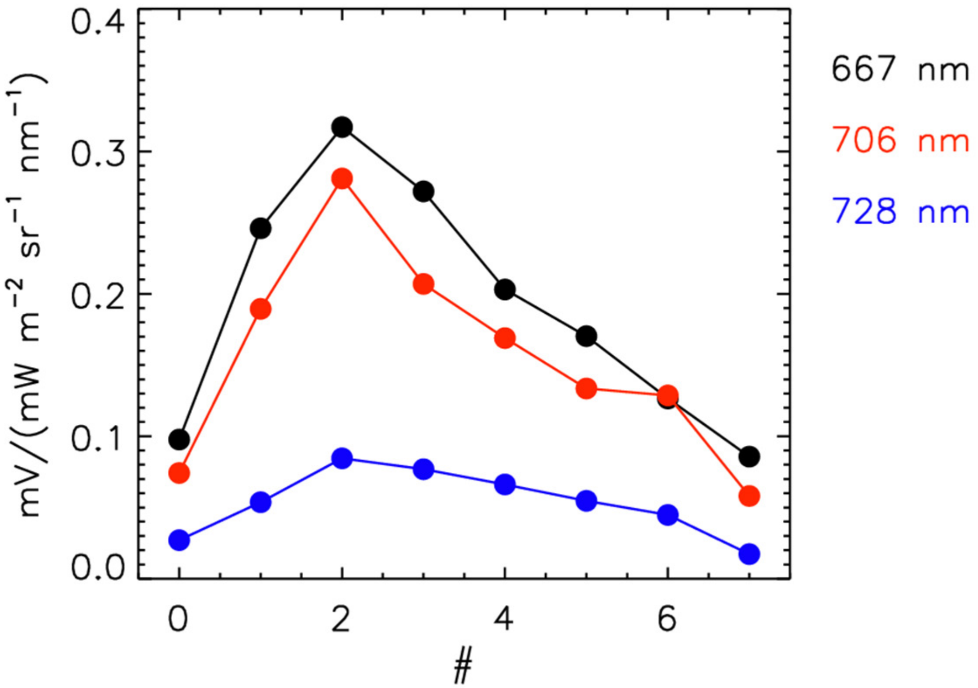
Gaussian fit of the instrumental functions gives similar width σ

$\sigma \approx 0.63$ nm

FWHM ≈ 1.5 nm



WAVELENGHT CALIBRATION



- ✓ Calibration obtained by an integrating sphere
- ✓ From the PMT output the lines emissivities can be obtained
- ✓ Lowest sensitivity for the 728 line: optical fibres absorption

N_e T_e MEASUREMENTS IN RFX-MOD

EVOLUTION OF THE PROFILES

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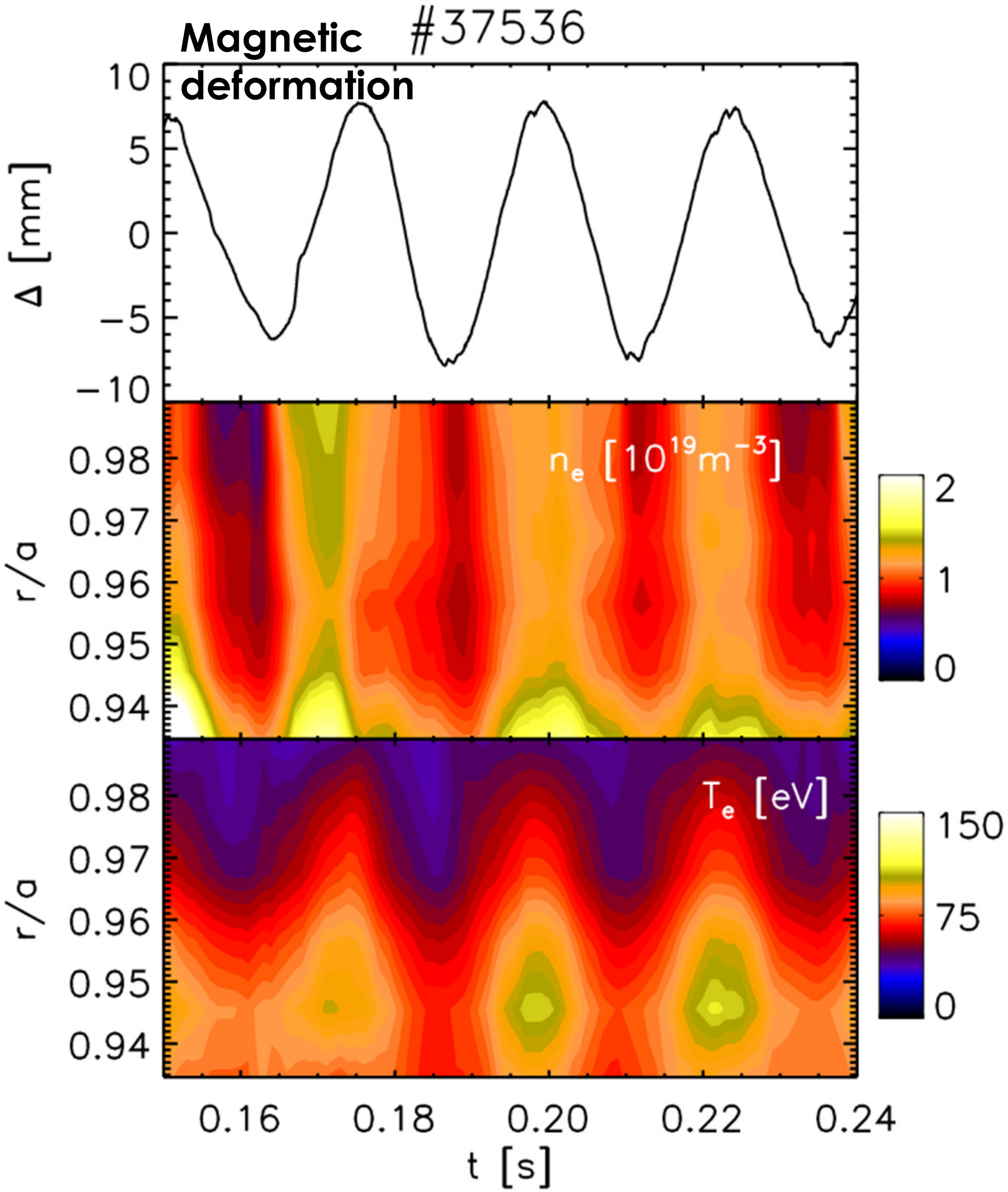


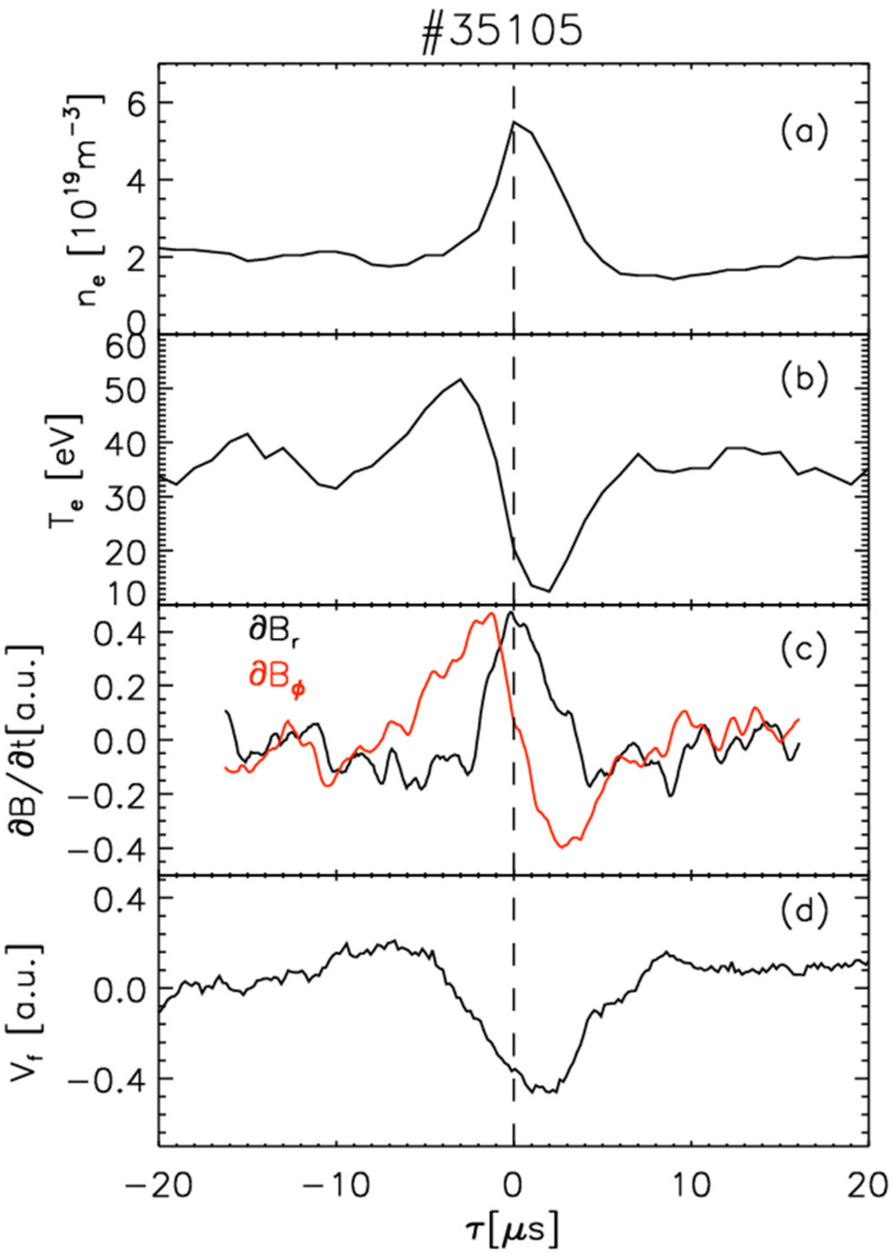
Low frequency (3ms) time behaviour of the edge profiles

The presence of the resonant (1,-7) mode causes periodical oscillation in the magnetic edge deformation Δ

Edge profiles are modified by the local magnetic deformation

Density and temperature increases during positive shift Δ

TURBULENCE MEASUREMENTS



High frequency fluctuations can be measured

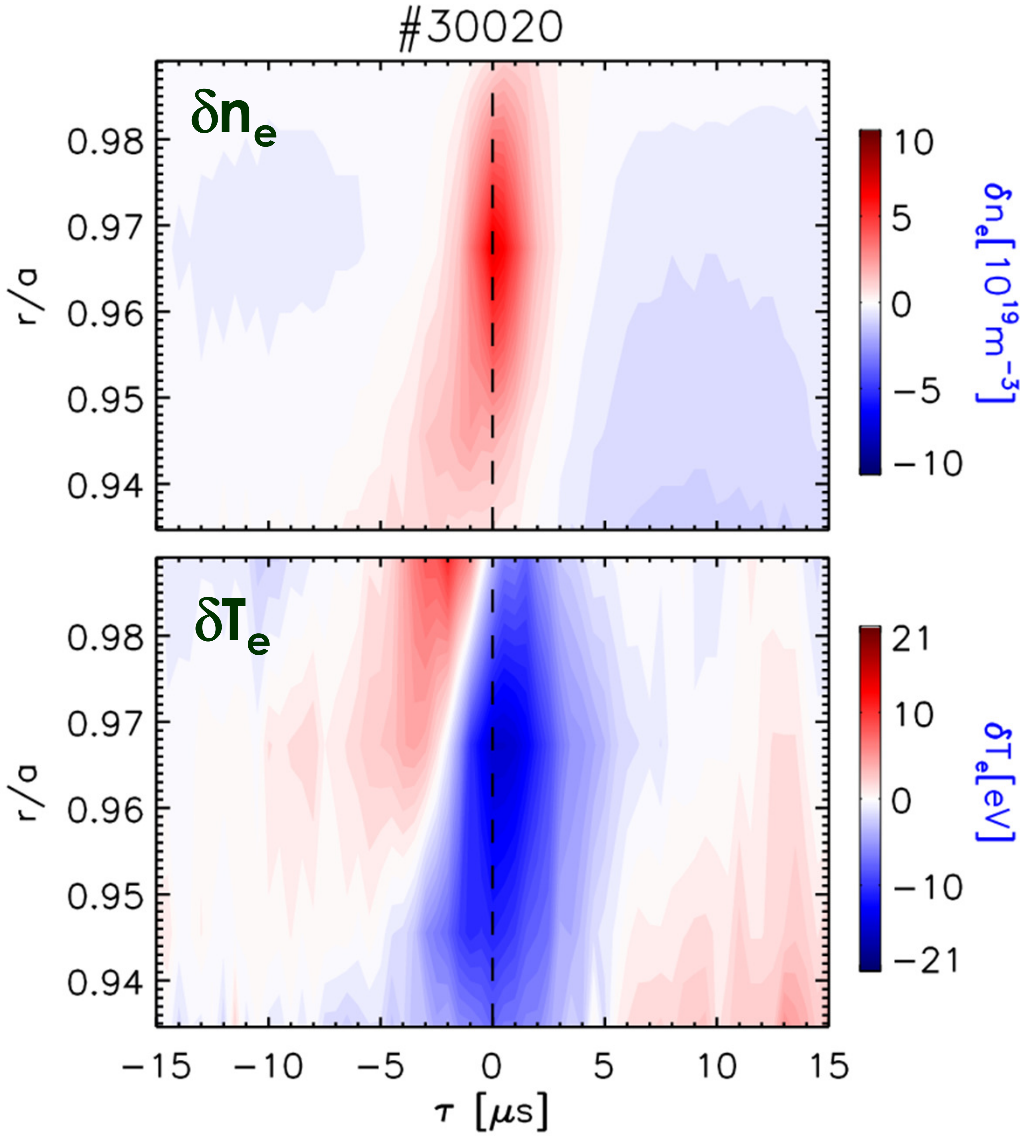
Edge coherent structures are detected in the GPI time-signal

Conditional average applied to the THB signals

A blob is a density peak, a temperature valley, with magnetic and electrostatic structure

M.Spolaore et al., PRL **102** 165001 (2009)
M.Agostini et al., PPCF **56** 095016(2014)

EDGE COHERENT STRUCTURES

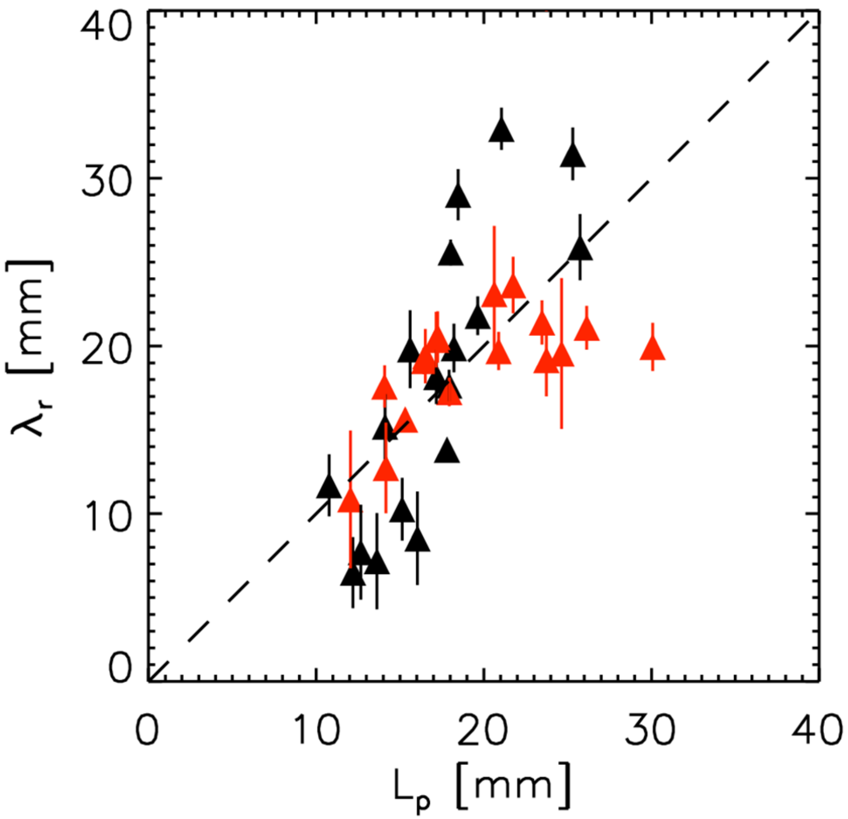


The radial structure of the blob can be analysed

It has a radial extension of about 3 cm

It has a double structure in T_e: valley and peak

STRUCTURES Vs PROFILE



λ_r = characteristic radial length of the edge turbulence

L_p = characteristic radial length of the edge pressure profile

Radial dimension of the turbulence comparable with L_p

Pressure radial profile sets the turbulence dimension

POSSIBLE IMPLEMENTATION AT NSTX-U

THB AT NSTX-U

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Why?

Measure time evolution of SOL n_e T_e profiles (~ ms)

Study interaction with 3D magnetic fields

Characterize n_e T_e of the edge blobs (~ tens μs)

How?

Using the existing GPI He puff

Using the same porthole of the GPI optics

The RFX-mod THB can be easily used

New optics at the plasma side needed

NEW OPTICS

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New optics for the plasma side tested

KOWA ZOOM LMZ45T3 18 -108mm with fiber optics holder

It allows 8 lines of sight,   FOV 270-40mm

FIRST SIMULATIONS

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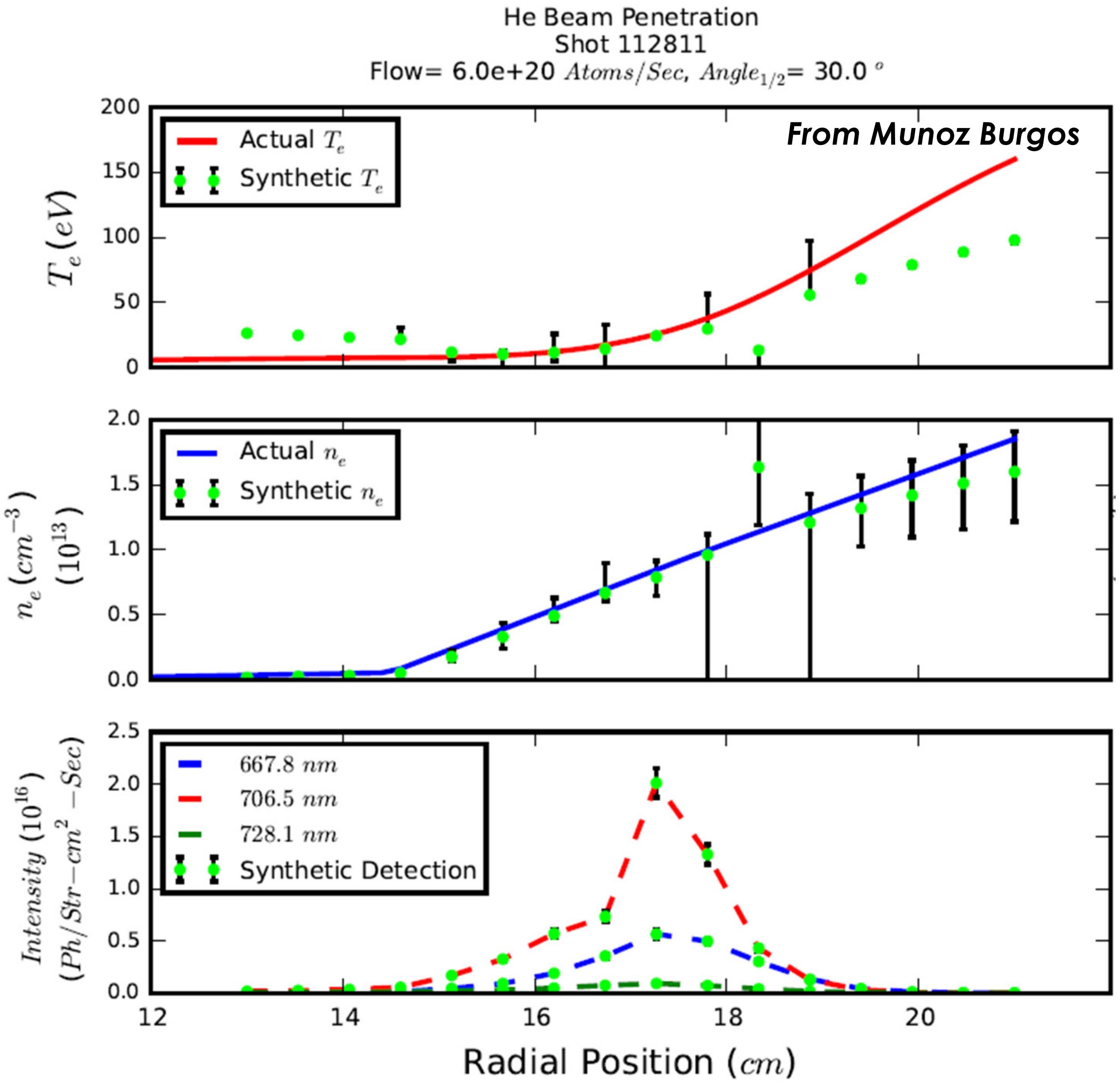

Simulations predict good signals 3-4 cm radially around the maximum of emissivity

The critical line to be detected is the 728 nm

J. M. Munoz Burgos et al., *Evaluation of thermal helium beam and line-ratio fast diagnostic on NSTX-U*, submitted to PPCF

MINIMUM MEASURABLE SIGNAL

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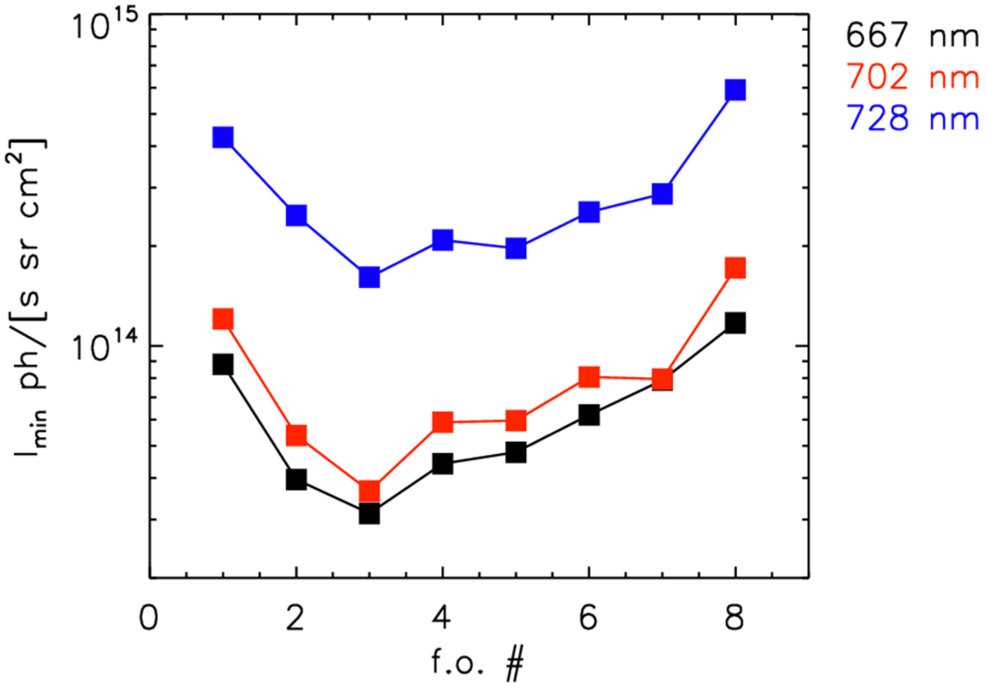

THB absolutely calibrated with an integrating sphere

Minimum measurable signal: 100mV (background)

Due mainly to the fibre optics transmission the weakest line is 728nm

This line is detectable if I > 4 10^{14} ph s^{-1} $sr^{-1}cm^{-2}$

Simulations predict enough signal 3-4 cm radially around the maximum

RFX-mod THB can be used in NSTX-U edge

CONCLUSIONS

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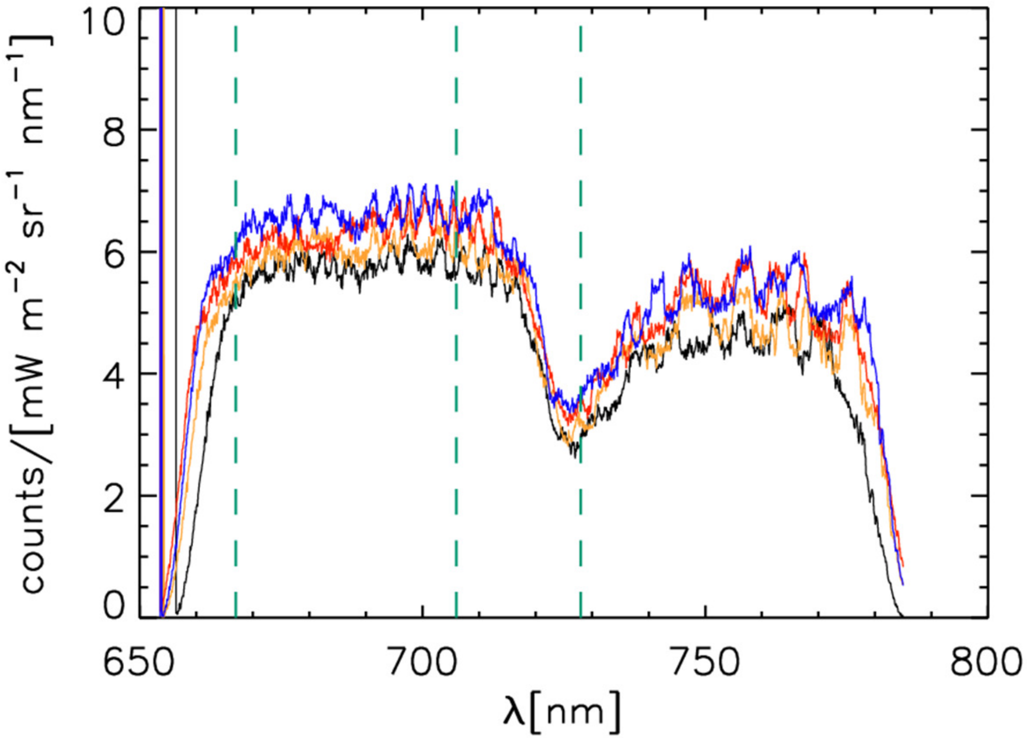
- THB implemented for RFX-mod suitable for measuring edge n_e T_e
- Time evolution of radial profiles measurable up to ~ 3 ms
- Characterization of n_e T_e of edge turbulence for fluctuations ~ 10 μs
- It is possible to study the interaction between turbulence and edge gradients

- Easily exportable to NSTX-U using GPI puffing and viewing porthole
- Enough signals in the SOL
- It would allow measurements of profiles and high frequency fluctuations in the edge

CCD CALIBRATION



Integrating sphere used to illuminate

Emissivity measured with the CCD

Four colours are four different binning of the CCD

This measure is indispensable for calibrating the CCD

Similar behaviour for the 667 and 706 nm lines

Absorption peak near the 728 nm line due to the 35 m optical fibres*

Regular oscillations due to the etaloning (back illuminated CCD)

* D.B.Keck et al., *Appl.Phys.Lett.* **22** *307 (1973)*

RAW THB DATA

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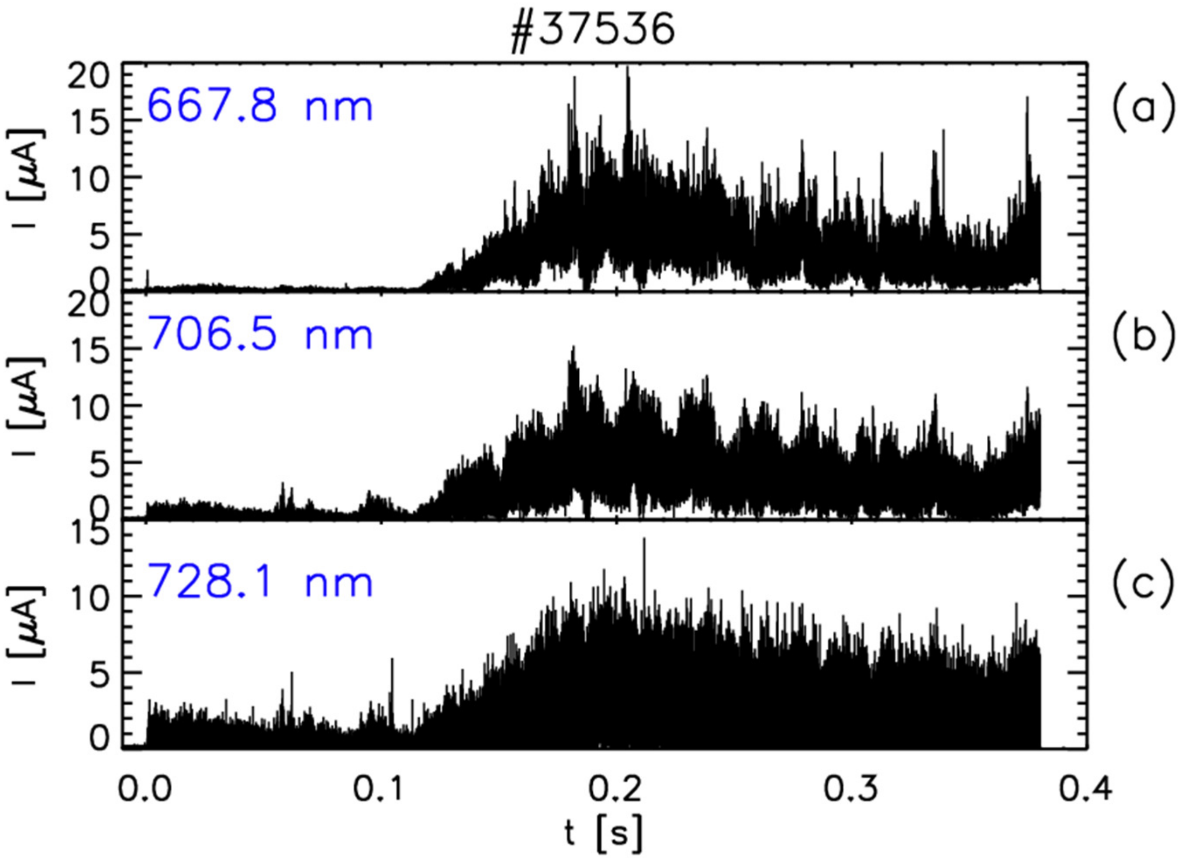


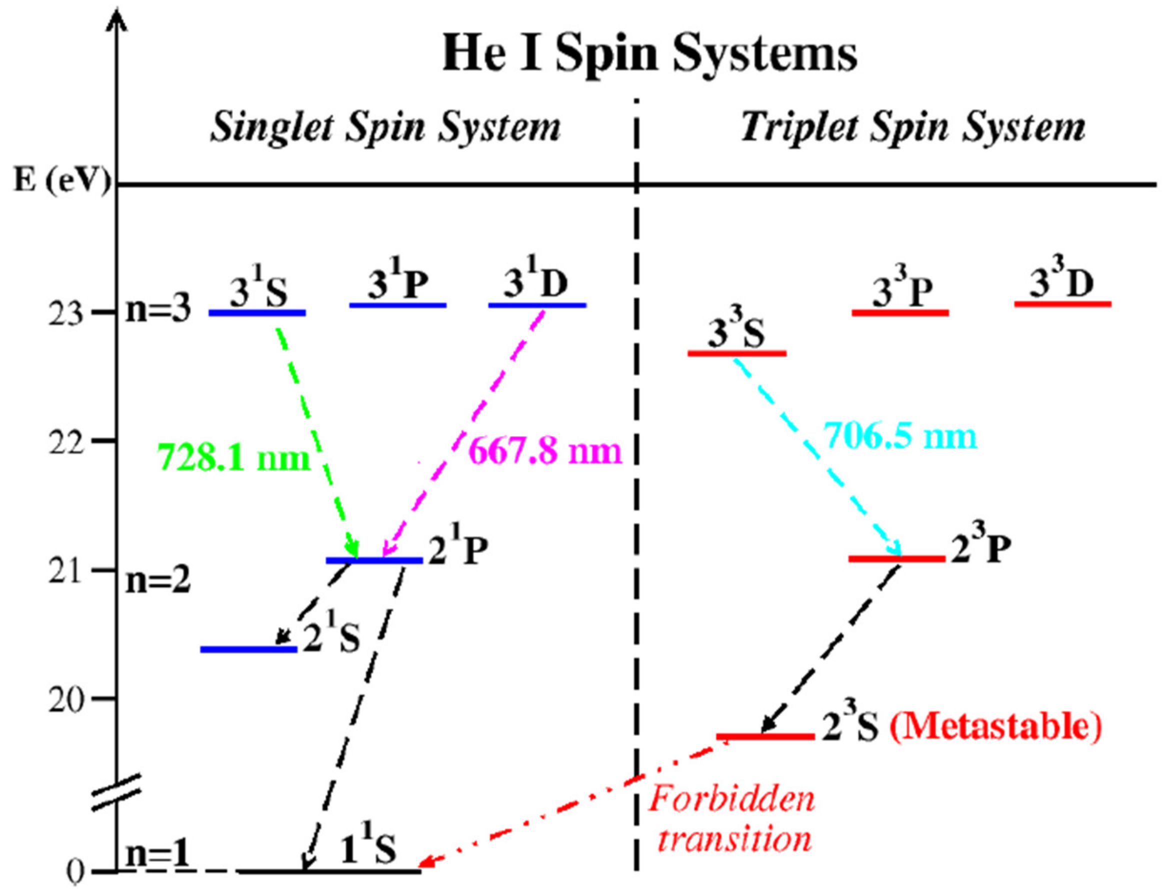
$V_{PMT} = 600V$

$V_{PMT} = 700V$

$V_{PMT} = 800V$

- Different voltages used due to different signal levels
- He puff starts at 100 ms: signals increase
- Background measured for t < 100 ms
- Background due mainly to background He collected all along the line of sights

HE TRANSITIONS



HeI spin systems

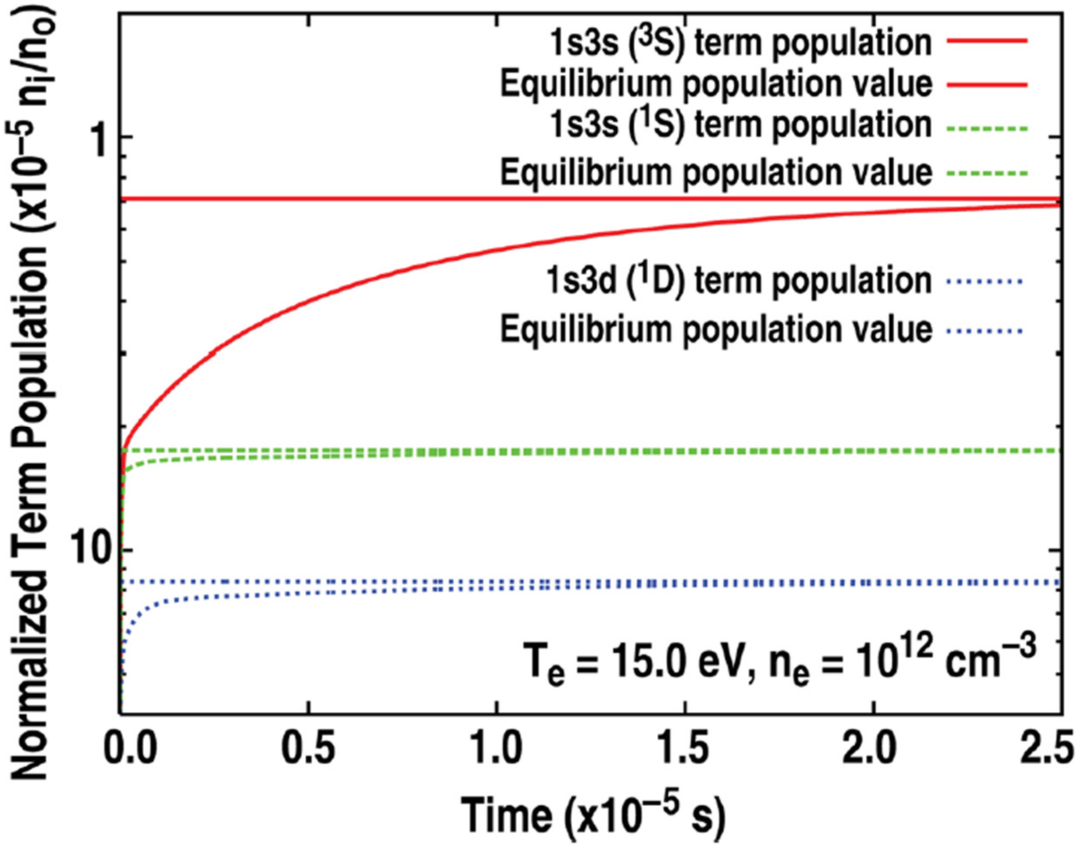
Metastable level causes long relaxation time for the 706 nm line

Relaxation time increases with decreasing density

$\tau_{relax} \approx$ 20-30 μs at $n_e = 10^{18} m^{-3}$

J. M. Munoz Burgos et al., *Evaluation of thermal helium beam and line-ratio fast diagnostic on NSTX-U*, submitted to PPCF

LEVELS POPULATION



Time dependent term population solutions for the different HeI levels normalized with respect to the ground state at ne = 10^{18}m^{-3}

J. M. Munoz Burgos et al., *POP **19** 012501 (2012)*

EVOLUTION OF THE PROFILES

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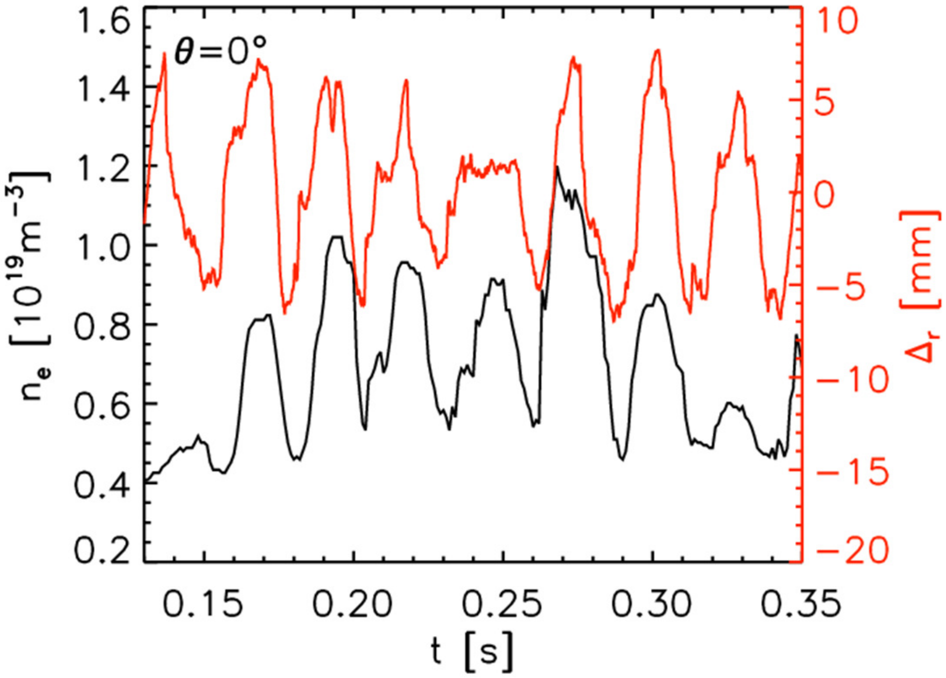
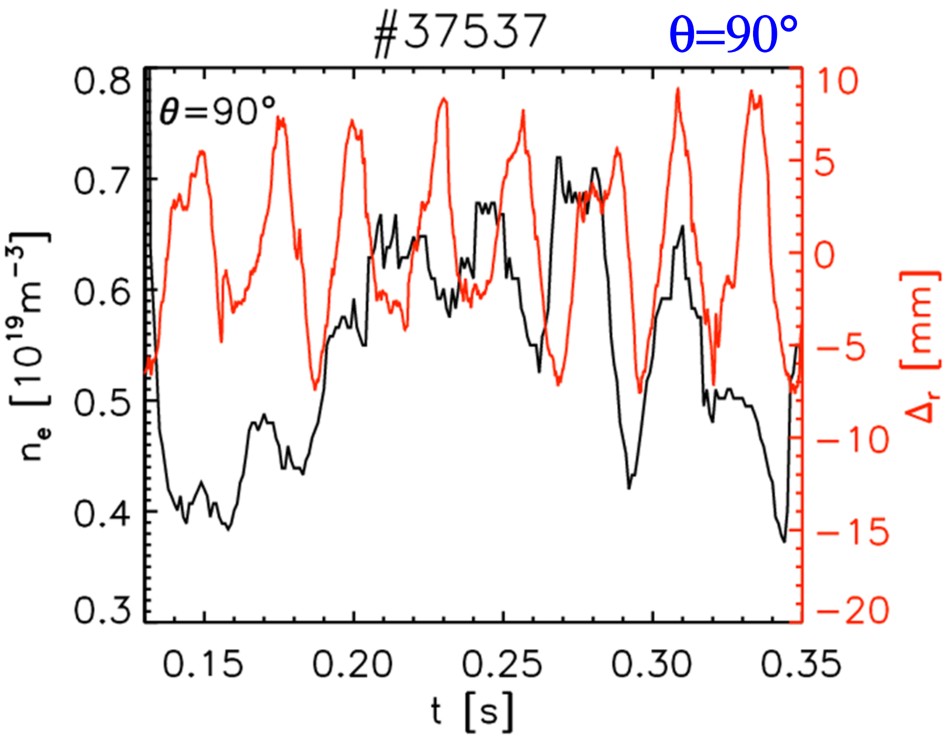
θ=0°



In RFX-mod n_e, T_e measured in two poloidal (=parallel) points

θ=90°



PRESSURE AND TOPOLOGY

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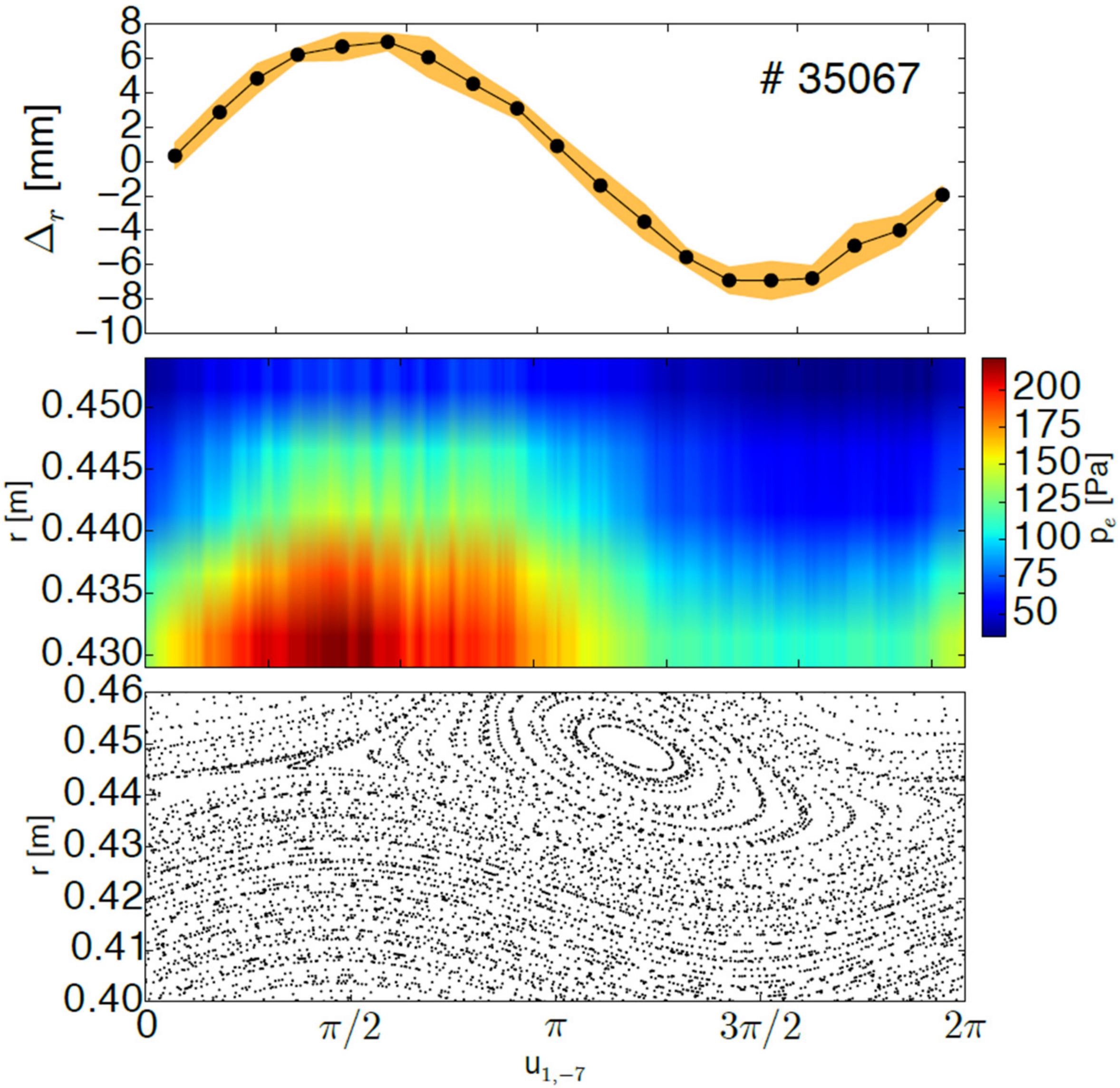

- To compare the local magnetic topology at different toroidal locations (different diagnostics) the helical angle u is used
- $u_{m,n} = m\theta - n\phi + \Phi_{mn}$
- It is linked with the magnetic deformation:
  - $\Delta_r = A \sin(u)$

AVERAGE BEHAVIOUR

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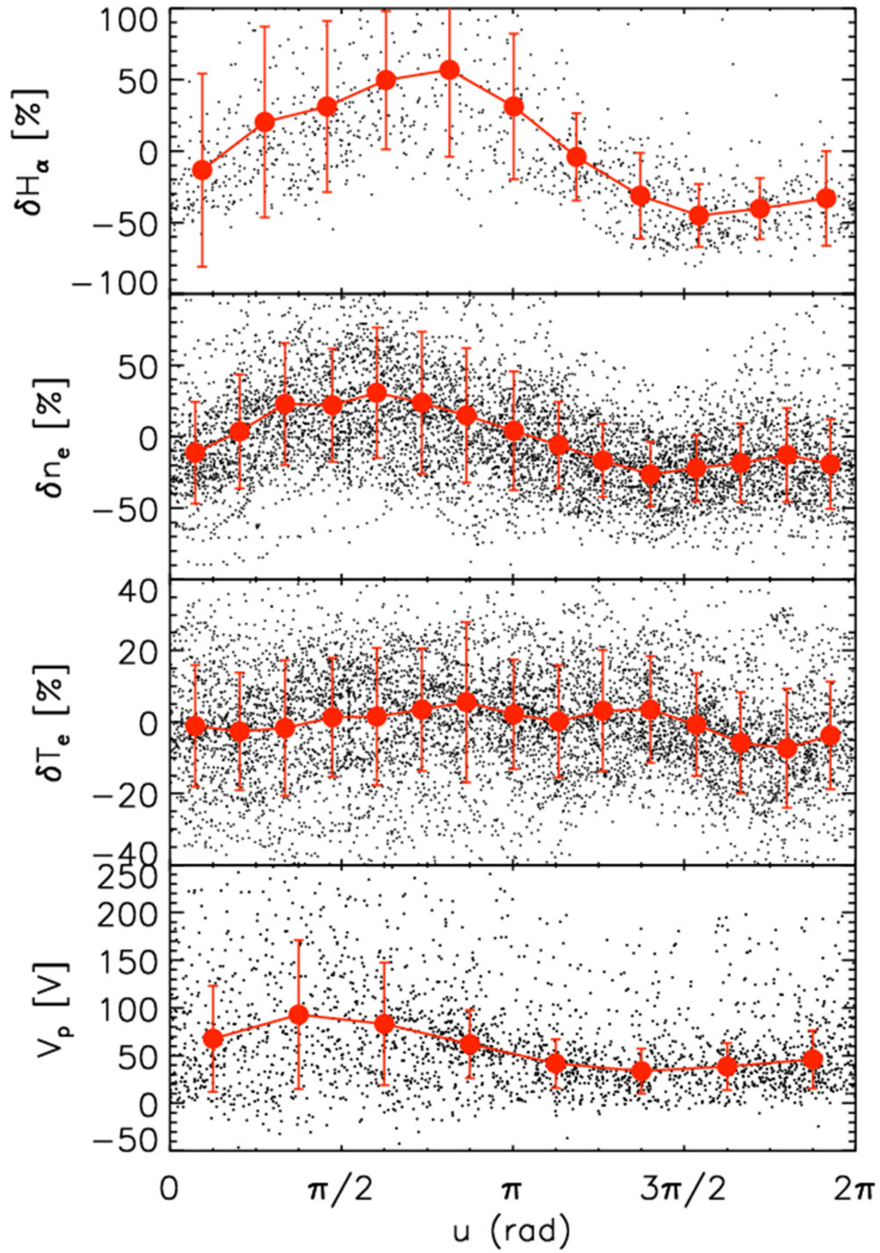

At the (1,-7) O-point:

Maximum plasma wall interaction (H_α)

Maxium edge density

Not clear behaviour of edge Te

Maximim floating potential