The data acquisition system of WEST's New Thomson Scattering diagnostics

C. Bouchand, Y. Moudden, B.Vincent, G. Colledani, R. Sabot, L. Schiesko, N. Fedorczak, M. Carole, G. Moureau, A. Barbuti, A. Magnino and the WEST team – CEA, IRFM, 13108, Saint-Paul-Lez-Durance, France.
E. Delagnes and T. Chaminade - Université Paris-Saclay, CEA, IRFU, 91191, Gif-sur-Yvette, France.

Email: christophe.bouchand@cea.fr or yassir.moudden@cea.fr

WEST, the Tungsten Environment Steady state Tokamak at IRFM (France), is currently being equipped with two new plasma-monitoring systems based on Thomson Scattering (fig 1). The intensity and spectrum of the scattered fraction of photons of an incident LASER pulse holds information on the density and temperature of electrons in the plasma, which are two essential parameters for plasma physics and real-time plasma control. Nearly fifty optical viewing lines will be installed to collect diffused light near the core plasma region and in the plasma pedestal. This contribution describes and discusses the performances of the real-time data acquisition and processing system to which the collected pulses of Thomson scattered light are propagated.

Three different Thomson Scattering diagnostics

- **Core Measurements :** 20 lines of sight, duplexed optical fibers
- **Edge Measurements :** 32 lines of sight using duplexed and singles fibres, 14 far SOL views monitored with simple fibres, 16 pedestal views monitored with duplexed fibres
- **Core & Edge Alignement :** 2 lines for each endoscope

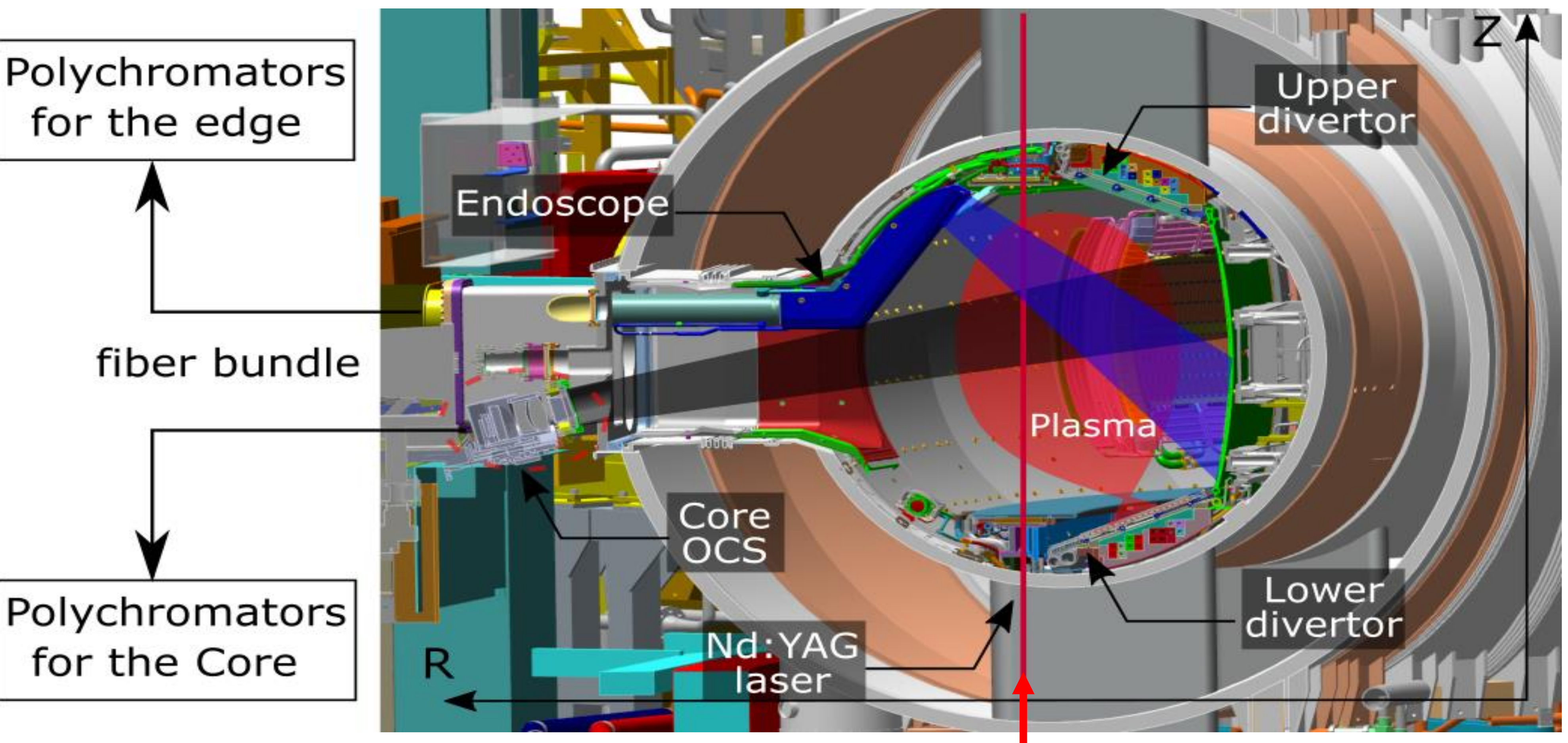


Fig 1. Sectional view of the WEST Tokamak

Design Specifications

- Millimetric resolution at the plasma edge and centimetric in the plasma core
- Upper-half plasma coverage with some overlap between edge & core channels

Design Constraints

Real time measurements possible

- Edge channels
  - ❖Covering the Pedestal and the SOL in most configurations of WEST's Plasmas
  - ❖Temperature: 1 keV (pedestal) to few eV (far SOL) - No ECE measurement in the edge
- Core channels
  - ❖Temperature: 10 keV (pedestal) to 100s eV (pedestal top) - Cross check with ECE diagnostic
  - ❖Reflectometry and interferometry cannot resolve hollow ne profile

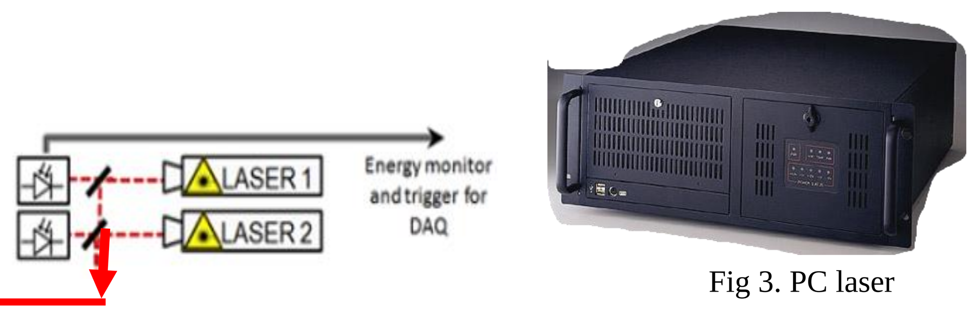
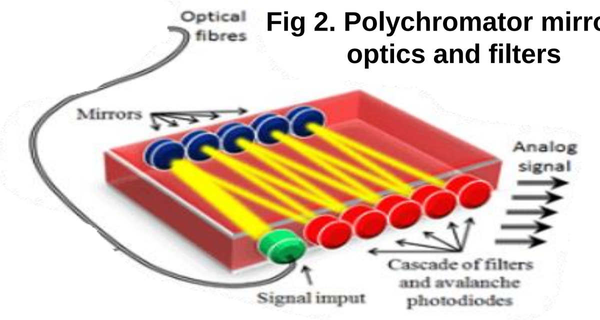


Fig 3. PC laser

Fig 2. Polychromator mirrors, optics and filters



The plasma photons are captured in the core and edge endoscopes, which include mirror, window, lens, and fiber optic bundle. The signals collected are sent by bundles of single or multiplexed optical fibers, over lengths between 25m and 45m.These optical signals are transmitted to polychromators (Manufactured by UK Atomic Energy Authority), which transform the optical information into electric pulses through 5 stages of optical filters, in a domain of 5 spectral bands: Ch1= (1064ns) Ch2 = (1064ns-1055ns), Ch3 (1055ns-1040ns), Ch4 (1040-980ns), Ch5 (980ns-830ns). Each filtered stage includes an APD detector (C30950E) then two processing channels, an HF channel (AC or DC, gain 1 to 8) and a LF channel (DC-gain 1 to 8). Then the signals are connected to our acquisition card the NEcTARINe-12Voies, which processes 6 HF channels and 6 LF channels, with a Trigger (Laser), a clock chronology, and a RAZdate.

The New Electronic NEcTARINe-12 Channels

✓**Chip NECTAR 2 (IRFU)**

✓Analogue bandwitch > 400 MHz
✓1024ns windows sampling
✓Two channels/chip (3 chips/board)
✓ Sampling frequency : > 1Gs/s-3,2 Gs/s
✓ Amplitude resolution : ~12 bits
✓Consommation : 210mW/ chip
✓Technology low cost 0.35um CMOS

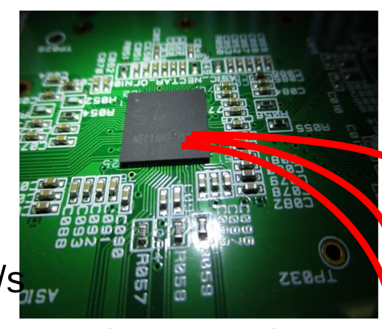


Fig 4 The NECTAR2 Chips

✓**NEcTARINe Board features**

✓Based on NECTAR2 chips (analog memory = 1024ns),
✓Nb : 3 NECTAR2 / board
✓6 HF Channels for density and temp (1Gs/s-3,2 Gs/s)
✓6 BF Channels ADC 24-32 Bits (10Hz-1MHz), slow noise
✓1 Input Clock, Raz date, Trigger
✓ Low noise power AC-DC -RMS < 9mV CC
✓30 Hz LASER periodic trigger rate
✓Full scale range channel HF: 0V-3V, BF : -5V,+5V
✓Traitement Microzed , processor XILINX 7020
✓Consommation : ~44W
✓Program : VHDL, C embedded client and C++ backend server

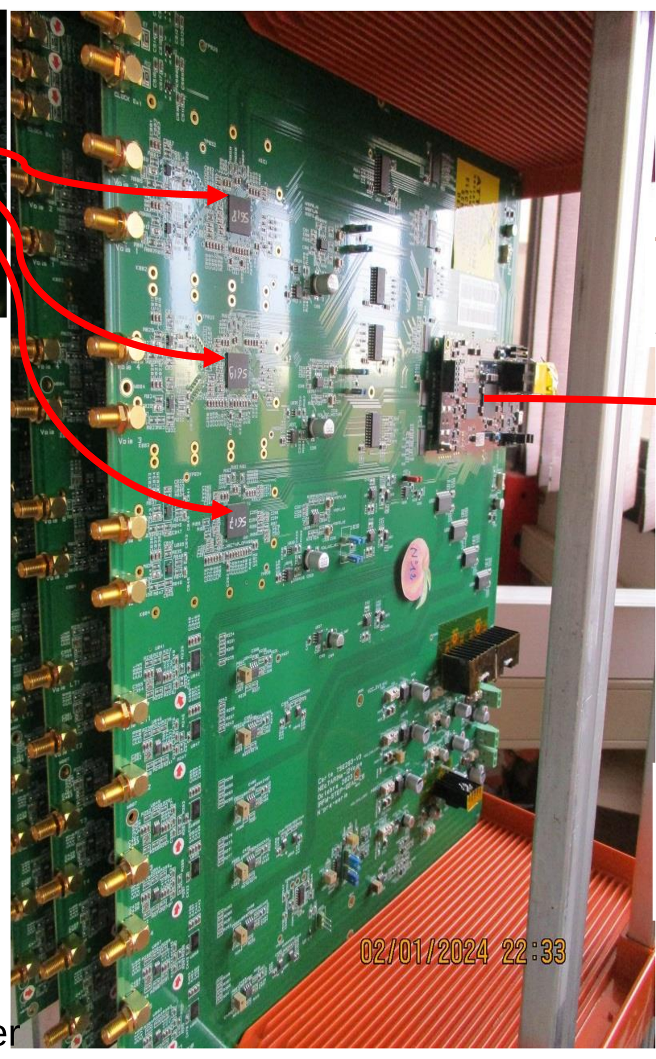


Fig 5 The Nectarine data acquisition board

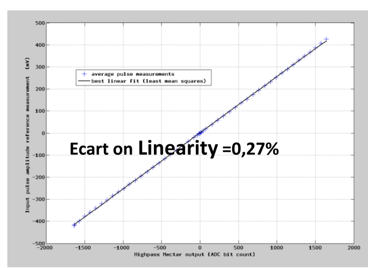


Fig 6 Hight pass linearity curve Vin Fct Count ADC

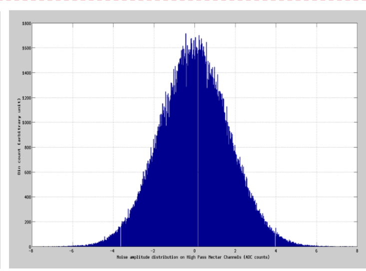


Fig 6bis Hight pass ecart type 1.7 coups d' ADC counts eq = 420uV

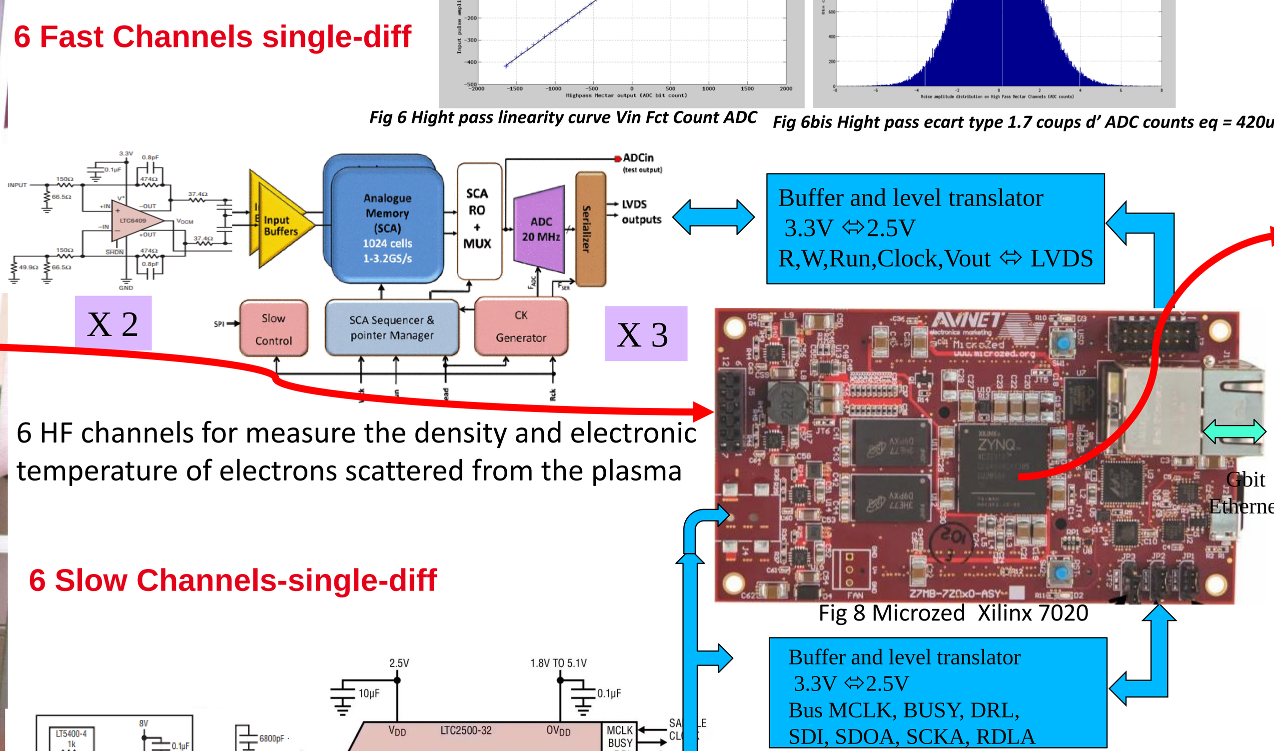
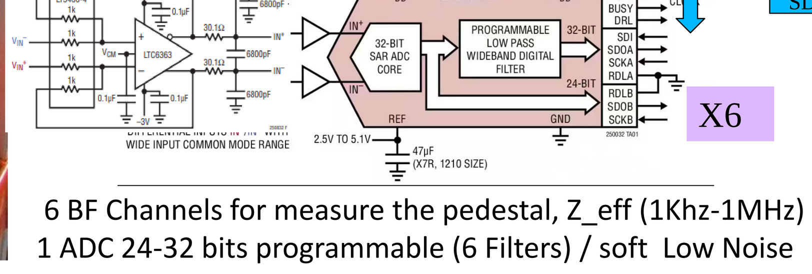


Fig 8 Microzed Xilinx 7020



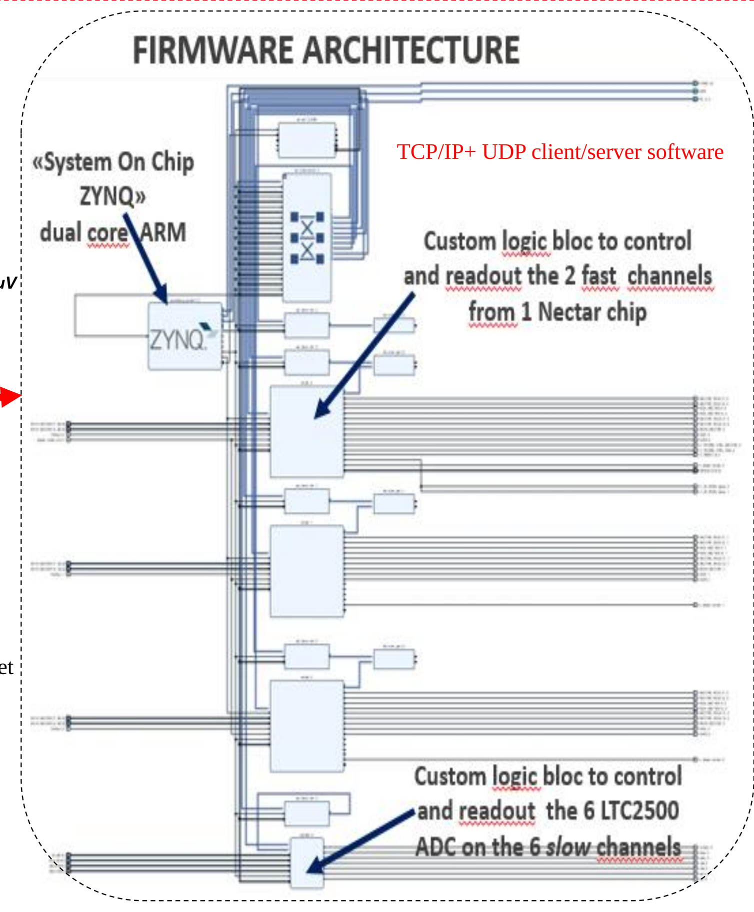


Fig 7 Firmware Architecture « system on chip ZYNQ»

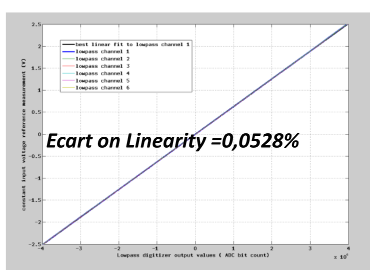


Fig 9 Low pass linearity curve Vin Fct Count ADC

The incoming signals on the HF Channels are transformed into single-diff (PGB= 10Ghz, Gain =2), before being buffered, memorized (memory depth =1us) and clocked by the slow control stages of the Nectar chip (SCA sequencer, the SCA RO + mux) and the 12 bit ADC. The data is then serialized over 2 LVDS pairs to the translator buffers to the Xilinx 7020 Zynq SOM (Microzed). The incoming signals on the LF channels are transformed from single to differential (BP-3db-35MHz) through an LTC6363 and then sent to a 24 bit ADC (LTC2500-32). The 6 LF channels are connected to a common slow control bus via level translator buffers. The digitized LF signals are read out by the Xilinx 7020 Zynq SOM. The current design of the Zynq firmware allows handling the 6 HF input channels (sampling rate 1GS/s, repetition rate limited by Nectar readout at around 300 us) , as well as the 6 LF channels at a sampling rate between 300 and 1Mhz. The data is transmitted via UDP through a gigabit Ethernet switch to the backend PC.

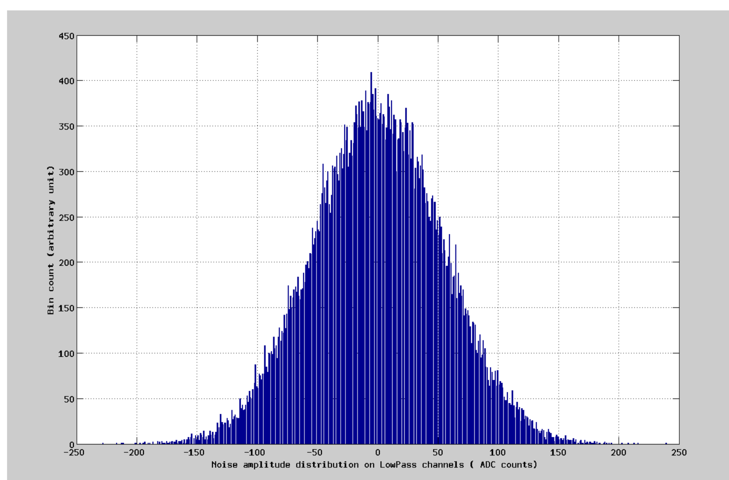


Fig 10 Low pass noise 53.6 ADC counts eq = 34.7uV

System Architecture

✓ ~180 data acquisition channels
✓ 7-15 ns diffused LASER light pulses
✓ 300 Hz LASER periodic trigger rate
✓ Data acquisition window : 1µs for each trigger
✓ Sampling frequency : > 1Gsample

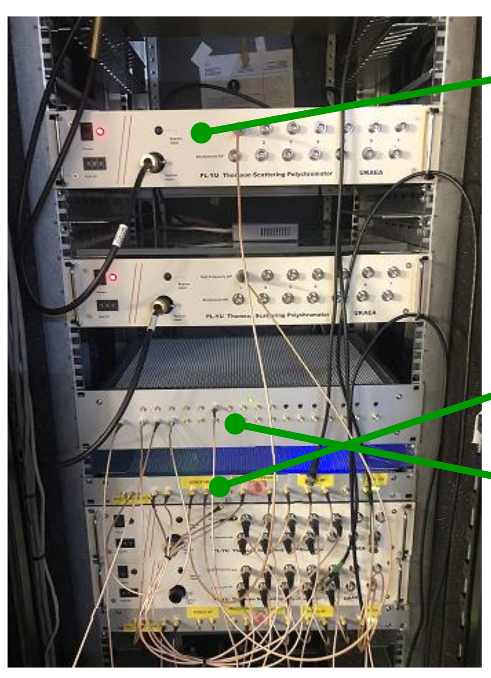


Fig 11 Acquisition bay

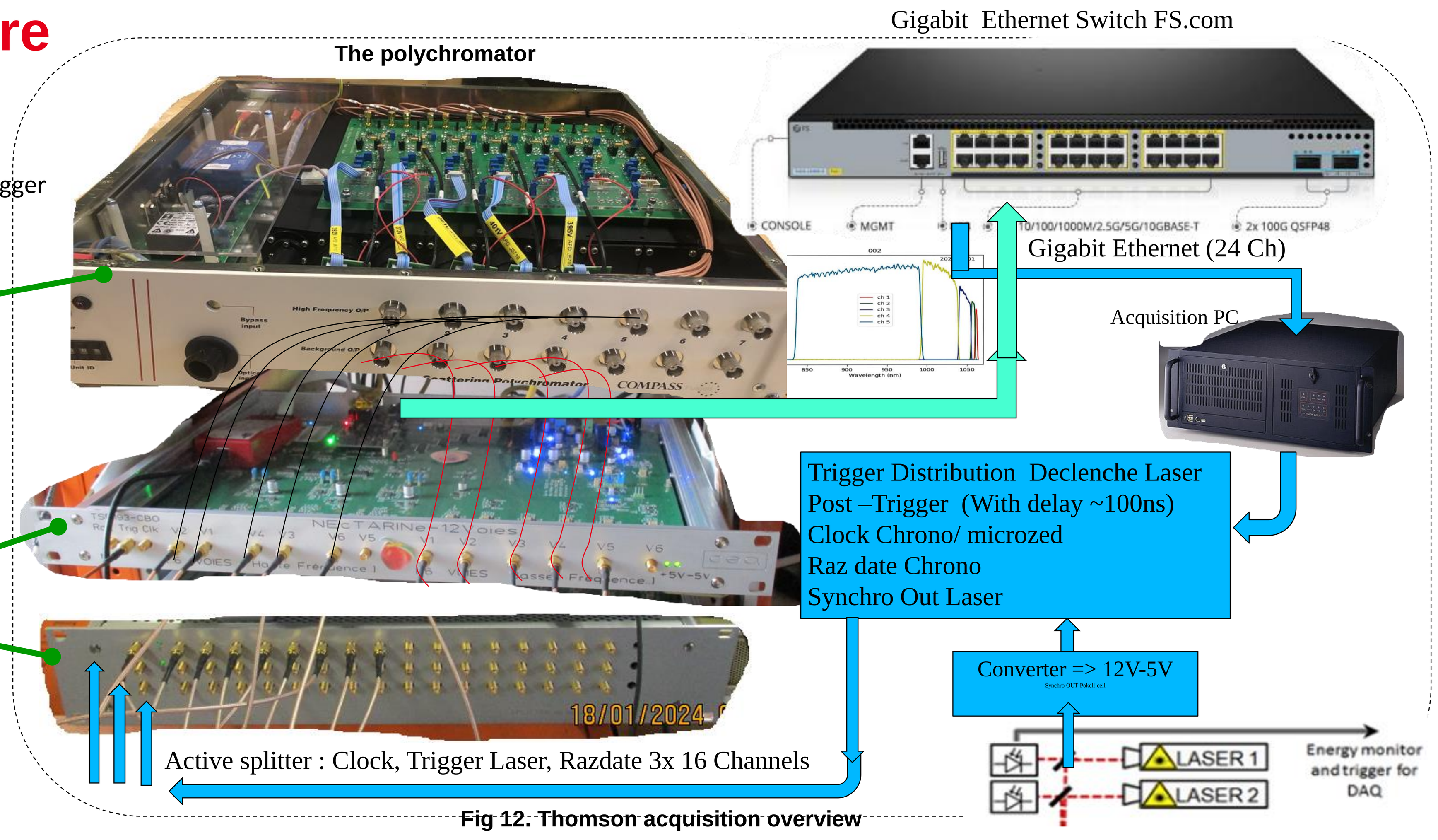
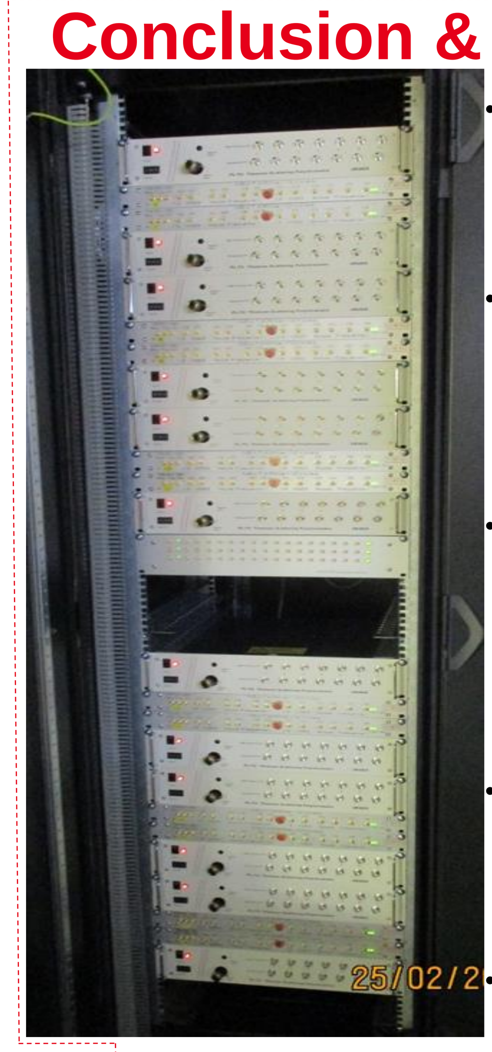


Fig 12. Thomson acquisition overview

Conclusion & Work in Progress



- First measurements were performed successfully all through WEST's C9 experimental campaign (first quarter of 2024, two Thousand Twenty Four) allowing some final tuning and system debugging in the very stringent Tokamak environment.
- Thanks to the designed data acquisition system's very low noise, high sensitivity and very high time resolution, the collected scattered light pulses on 4 duplex optical channels using 2 Nectarine boards could be succesfully used to estimate plasma electron denstiy and temperature.
- For WEST's C10 experimental campaign (Q4 2024) , the full system will be installed : 36 Nectarine boards + polychromators inside three cubicles. The backend hardware and software including ethernet switchs will need some adjustment to accomodate the non standard « triggered » data flow from the front end boards.
- The embedded ressources available on each Nectarine board and backend PC are being investigated for realtime electron temperature and density estimation for plasma control applications.
- The good performances of the Nectarine board have attracted interest from other diagnostics on WEST. For instance, current developpements also include customization of Nectarine boards for realtime reflectometry for plasma control on WEST.

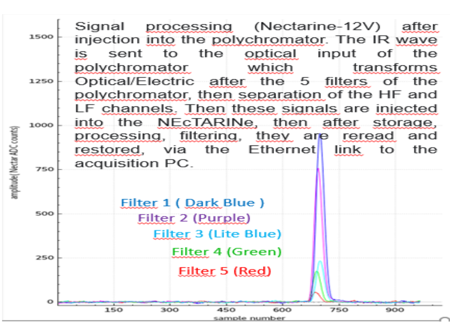


Fig 13. Test with diode IR (Polychromateur + Nectarine) read 5 channels

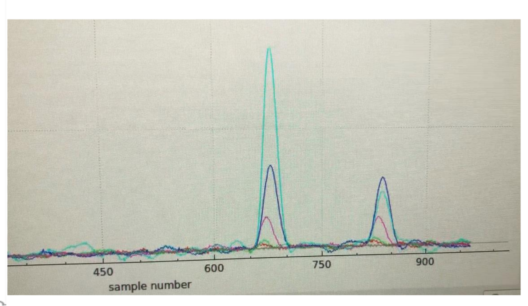


Fig 14. Test with Laser in plasma (Polychromateur + Nectarine) read 5 channels with multiplex FO (25m + 45m)

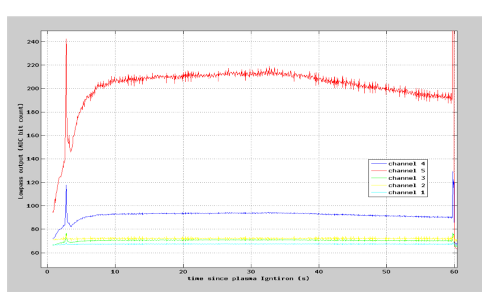


Fig 15 Measurement on plasma with the 5 BFChannels (Chocs 60s)

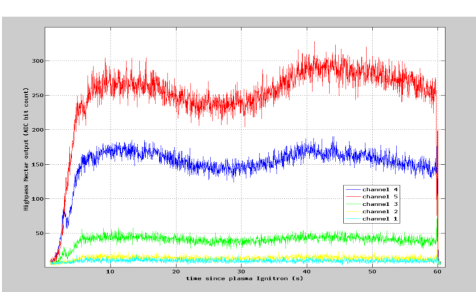


Fig 16 Measurement on plasma with the 5 HF Channels (Chocs 60s)

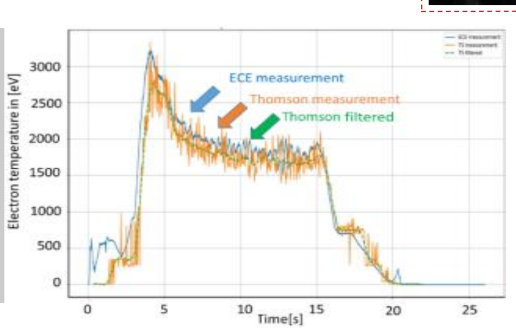


Fig 17 Measurement on plasma Electron Temperature Te (eV) / fct Time (s) for shot 59902

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