# Development of a LIDAR Thomson scattering diagnostic for DTT

Leonardo Giudicotti

on behalf of the
Physics of Fusion Plasmas group

# Members and activities



**Piero Martin** – experimental physicist, MHD expert. Presently serving as chief physicist for the Divertor Tokamak Test facility (DTT) experiment.

**Lidia Piron** – experimental physicist, MHD instabilities in fusion devices. Scientific coordinator in JET and MAST experiments (CCFE, UK) and ASDEX-U (IPP, FRG).

**Leonardo Giudicotti** – experimental physicist, advanced experimental methods for plasma diagnostics by lasers in various fusion experiments: RFX, JET (UK), ITER, W7-X (FRG), LHD (Japan), JT60-SA (Japan), DTT.

Activities in close collaboration with Consorzio RFX

- RFX toroidal plasma device
- NBTF Neutral beam test facility for ITER

External members: G. Serianni, T. Bolzonella, E. Martines, M. Zuin (CNR-RFX)

# DTT Divertor Test Tokamak



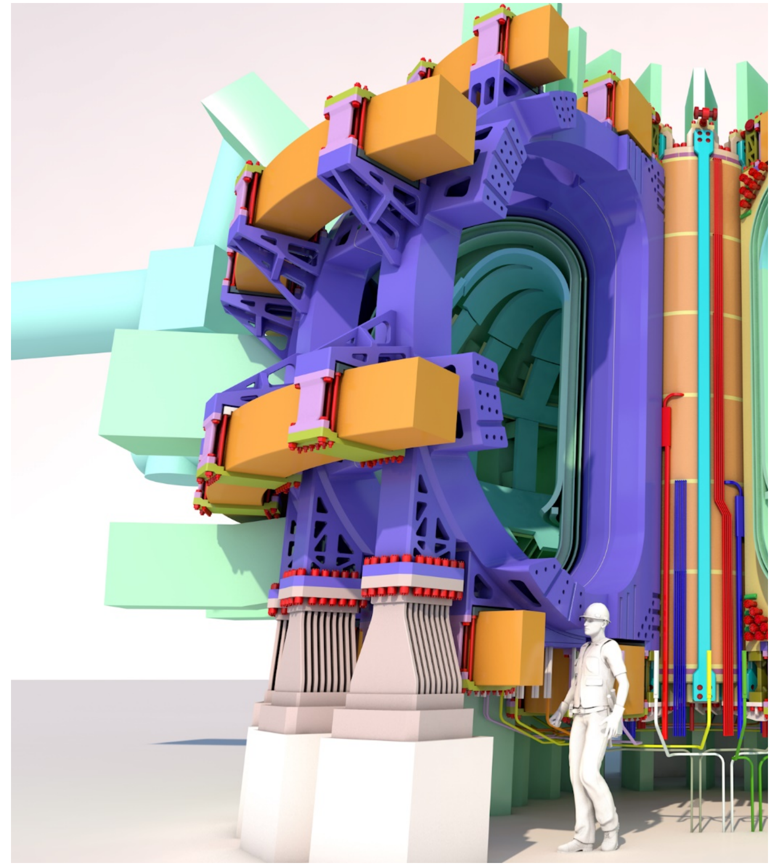
DTT is new tokamak experiment, that will be built in Italy at the ENEA center in Frascati

Main scientific goals:

- Investigate energy and particle exhaust systems to withstand the loads expected in fusion power plants
- Investigate physics of core and edge plasma interplay to support ITER and DEMO

Start of operations in 2026, presently under design

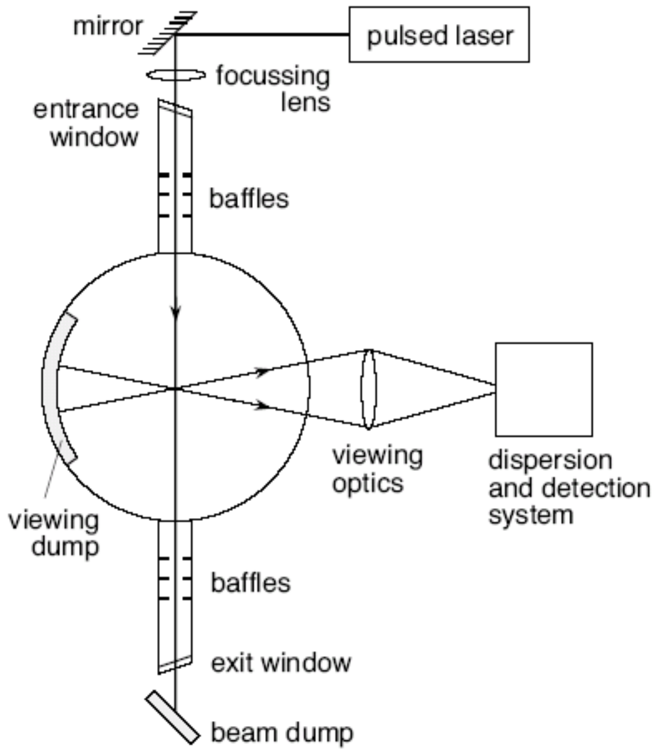
Large and demanding effort, involving a large part of the italian fusion community (physics and engineering)



The DTT device

# Thomson scattering diagnostics





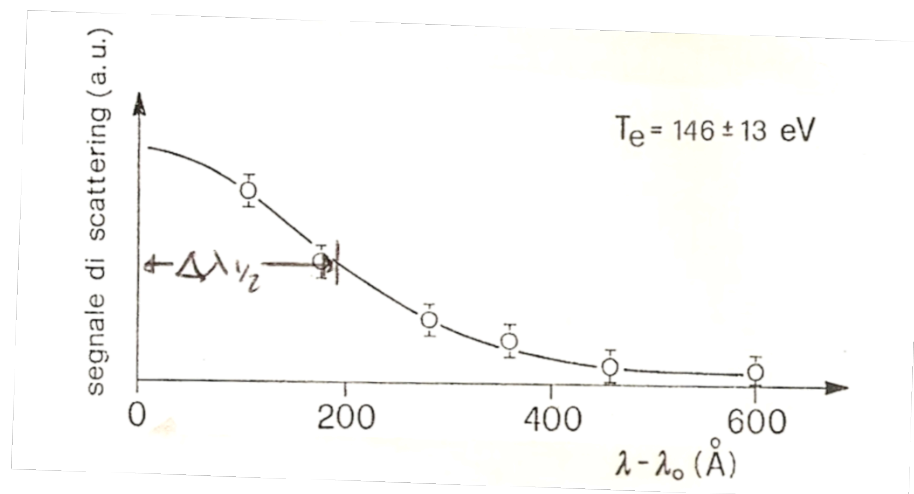

A high power, pulsed laser (3 J, 10 ns, 50 Hz) beam traverses the plasma.

The light diffused at an angle $\theta$ (the scattering angle) from a plasma volume (~ 2-3 cm) is collected by an optical system and spectrally analysed.

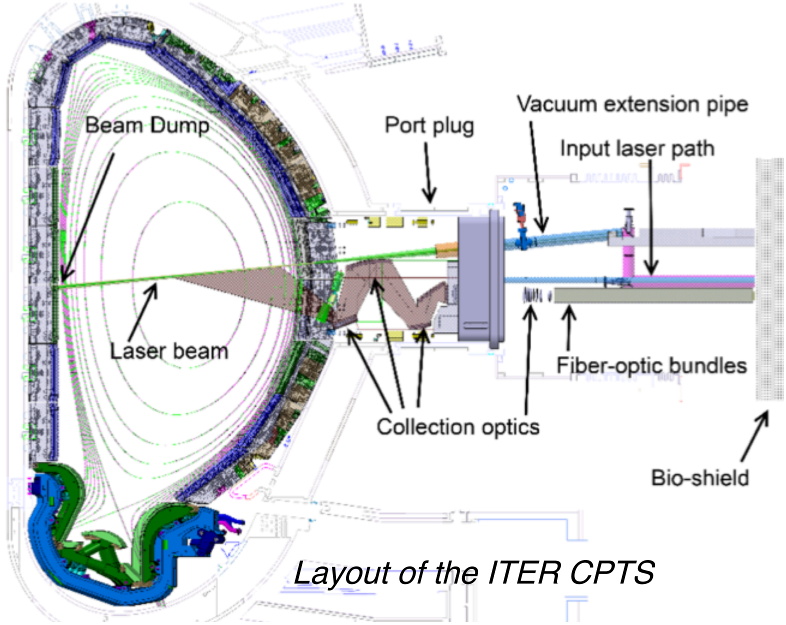
The spatial resolution (10 cm – 1 mm) is determined by the dimensions of the scattering volume. The time resolution is determined by the repetition time of the laser (~ 20 ms)

The electron temperature $T_e$ is measured by the width of the spectrum (doppler broadening)

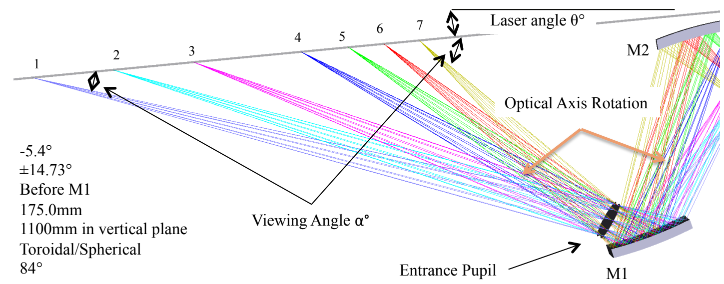
The electron density $n_e$ is measured by the total intensity of the scattering signal.



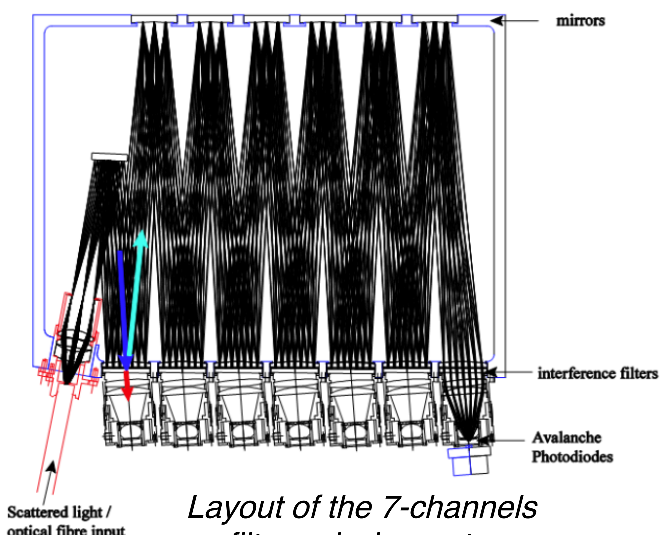
# Conventional TS in ITER (CPTS)




*Layout of the ITER CPTS*




*ITER CPTS collection optics*




*Layout of the 7-channels filter polychromator*

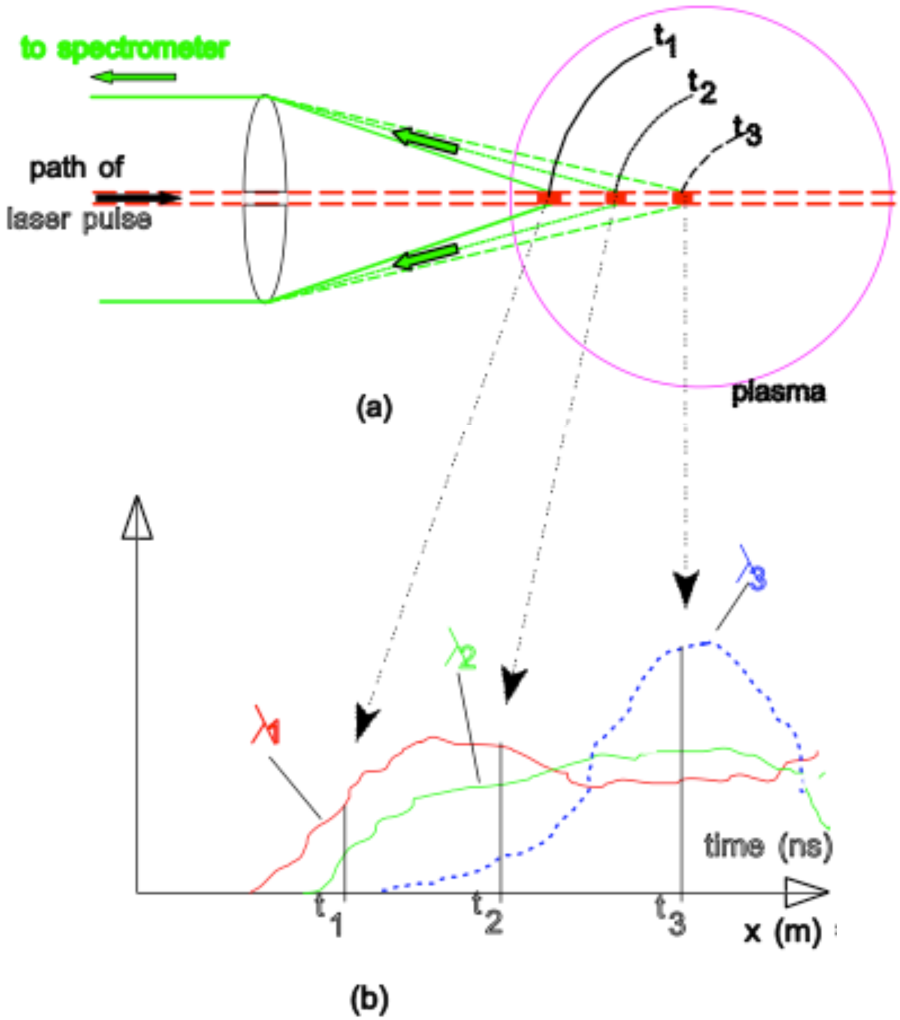
Well proven technology based on:

- Nd:YAG laser ($\lambda$ = 1064 nm)
- imaging optics whit fiber bundles
- Si APD detectors (post-amplified)

All measurements in parallel: in ITER [1]
~ 80 polychromators,
~ 560 APDs and data acquisition channels
~ active control of laser aligment


[1] R. Scannell, et al., JINST 12 C11010 (2017)

# LIDAR Thomson scattering in JET




Scattering signal in different spectral channels

A 320 ps (FWHM) laser pulse ( $L = 9.6$ cm) is sent into the plasma

The scattering signal is collected from the back ($\theta = 180^\circ$) and recorded a function of time as the pulse traverses the plasma

By analysing the spectrum as a function of time, the entire spatial profiles of $T_e$ and $n_e$ are determined.

Advantages:

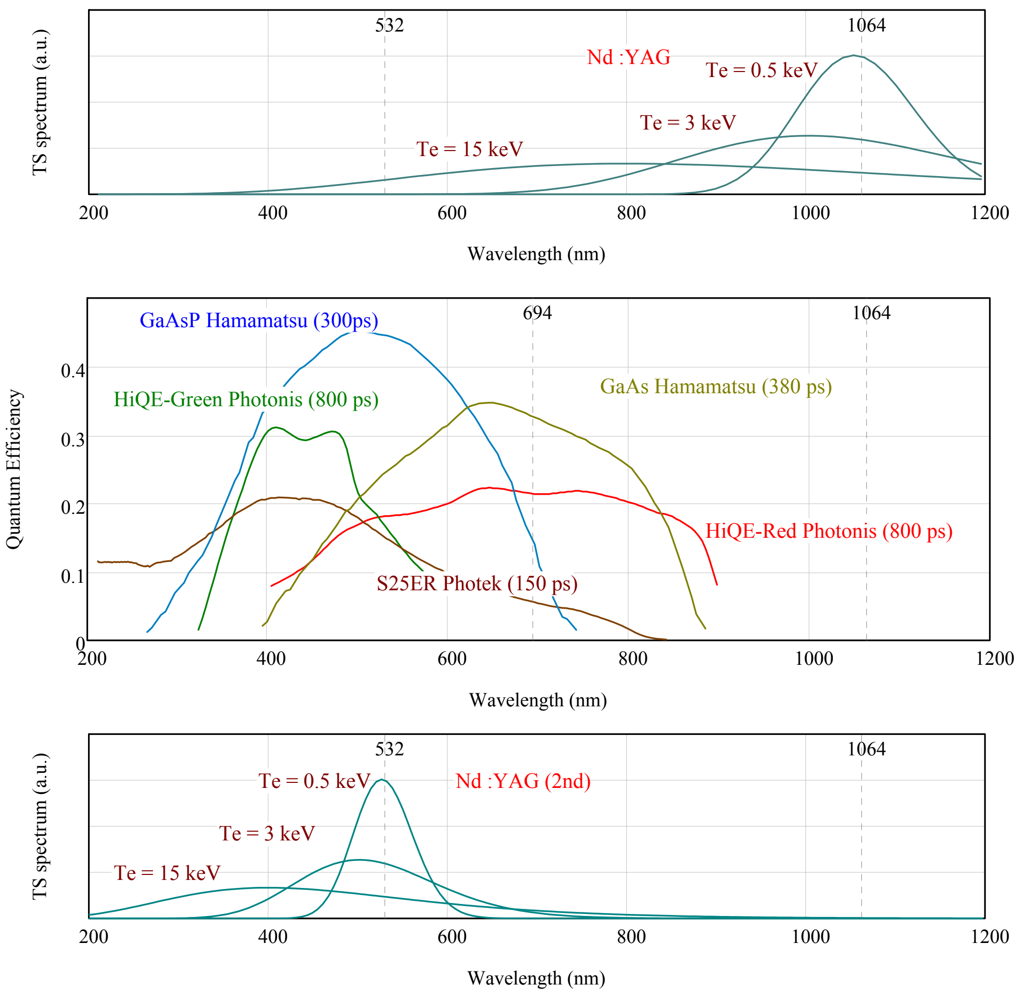
- Only one polychromator is necessary with only a set of detectors and data acquisition channel
- simpler, non imaging optics (no fibers), insensitive to disalignement

But:

- more demanding laser requirements
- fast (~ 300 ps pulse response) large area (1cm dia.) detectors
- high bandwidth ( >10 GHz) and sampling rate digitizers

- limited in spatial resolution (~ 7 cm) (detectors & laser)
- limited in time resolution (4 Hz) (ruby laser)

# Fast MCP-MCP for LIDAR TS




TS spectra and spectral QE of MCP PMT photocathodes

A Nd:YAG laser is the best choice to fulfill the time resolution requirements (2.5 J, 180 ps, 50 Hz) (reliable and commercially available)

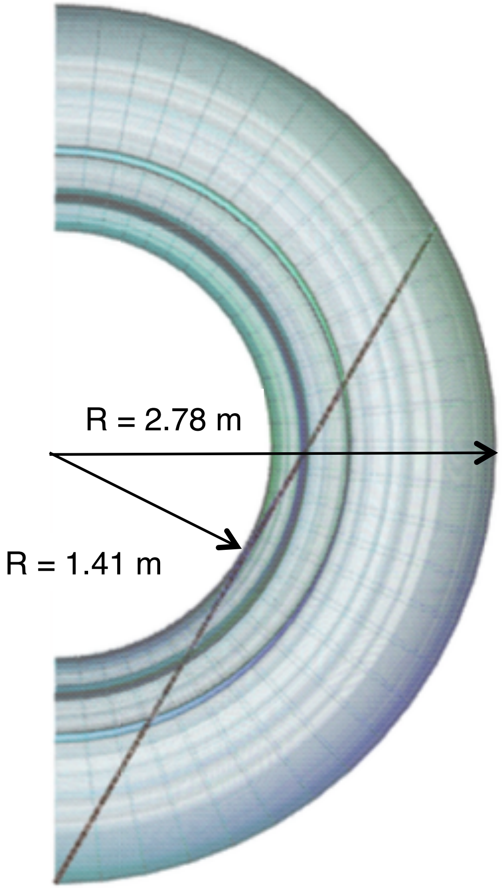
A MCP-PMT is the only possible choice (1 cm dia., $G \gtrsim 3\times10^5$, rise time $\lesssim$ 100 ps)

With Nd:YAG @ 1064 nm a detector sensitivity gap (850-1064 nm) prevents measurements for $T_e \lesssim 1$ keV

Addition of a second Nd:YAG @ 532 nm extends the measureable $T_e$ range to 0.1−15 keV

# LIDAR TS in DTT






Laser path in the equatorial plane of DTT

Two laser pulses ($\lambda$ = 1064 nm & 532 nm)
E = 2.5 J (50 Hz), Δt = 180 ps (FWHM), with ~ 1$\mu$s time separation, are injected tangentially ($L$ = 4.75 m)

Detectors are 1cm dia. MCP-PMT (Photonis HiQE-Red)
180 ps (FWHM) pulse response soon available.

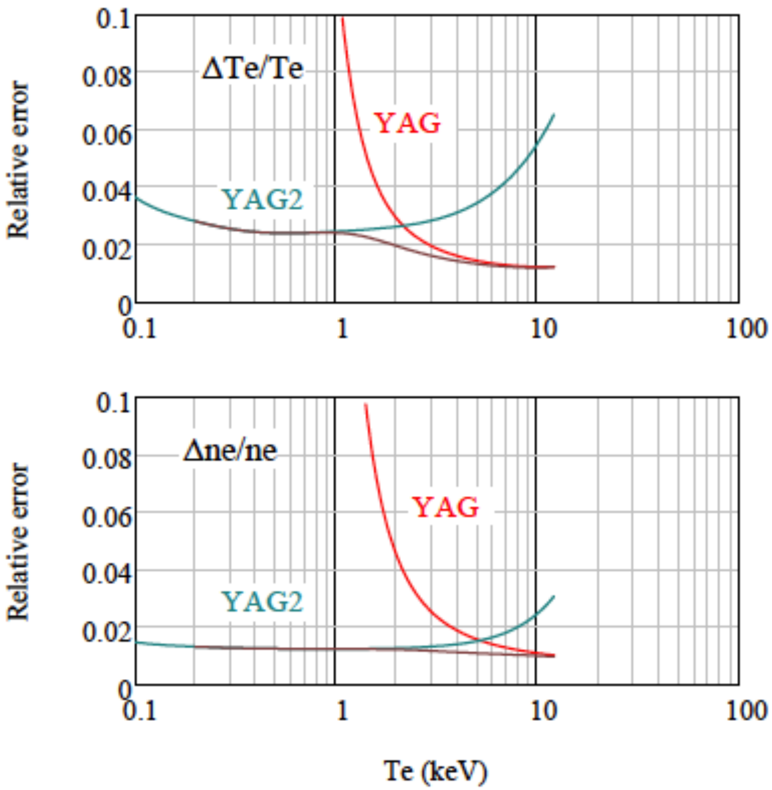
Collection optics (from the back) based on the "no-vignetting" concept [2][3]. Spatial sensitivity determined by solid angle (known), insensitive to laser beam disaligment

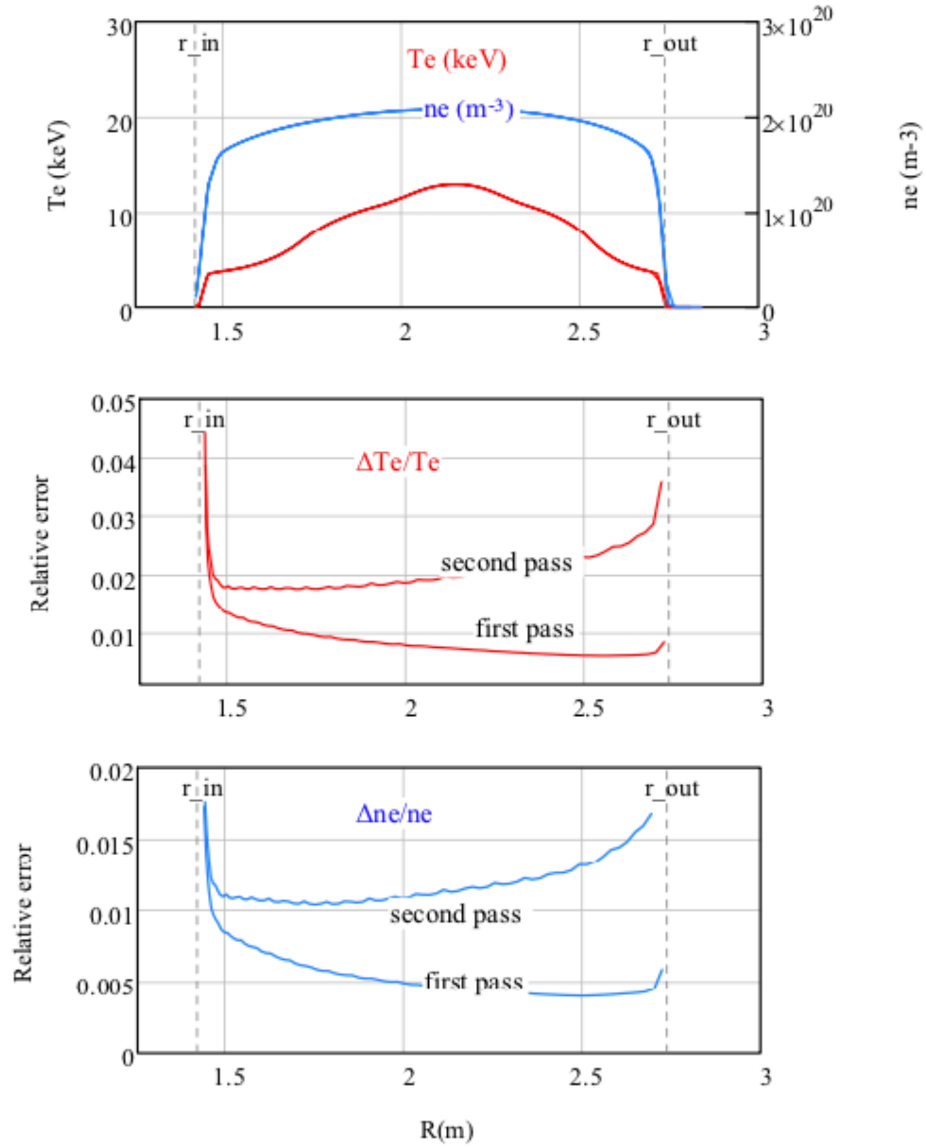
Spatial resolution Δx = 3.8 cm along the beam
Radial resolution enhaced by angular effect (3 – 0.5 mm)

Use of two different wavelengths allows continuous monitoring of the system spectral calibration (self-calibrating TS) [4]

[2] P. Nielsen et al. , JINST 14 C11018 (2019)
[3] L. Giudicotti et al., JINST 15 C01042 (2020)
[4] O. McCormack, L. Giudicotti et al., Plasma Phys. Control. Fusion 59, 055021 (2017)

# Expected performances




This dual-laser, with the tangential access and the chosen detectors fulfils the DTT requirements.

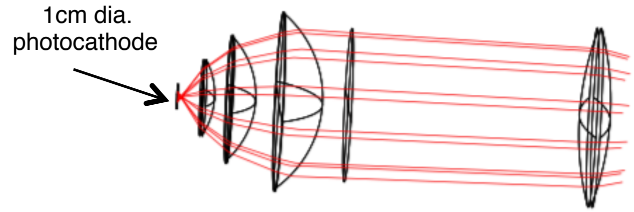
# Tests of MCP - PMT

Prototypes of the chosen detectors will be available soon by Photonis for tests:

Test of the pulse response by using the Nd:YAG pumped, OPA source availbale at DFA (18 ps, 100 $\mu$J @ 600 nm, tunable 450 – 2200 nm)

Test of the dependence of the spectral QE from the incidence angle and polarization [5]

Test of the pulse linearity (gain saturation and recovery time) [5][6]




F/1 input optics

QE enhancement by internal diffraction/reflection

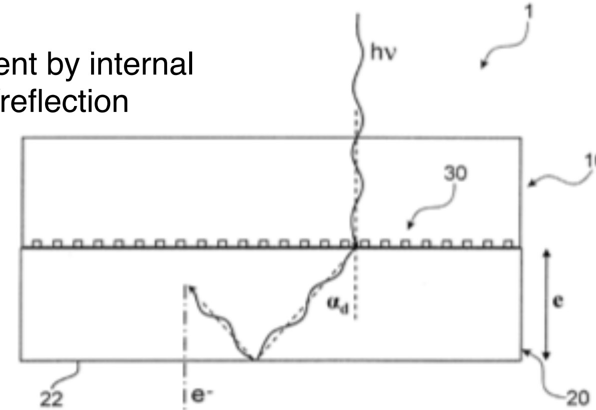
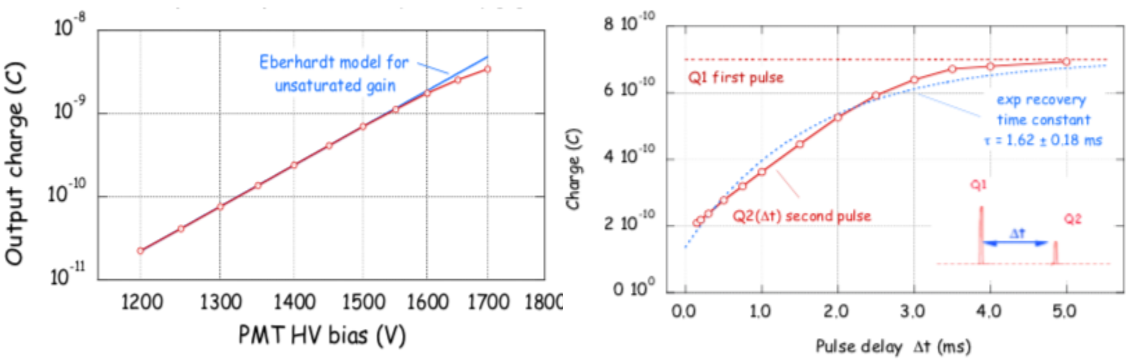
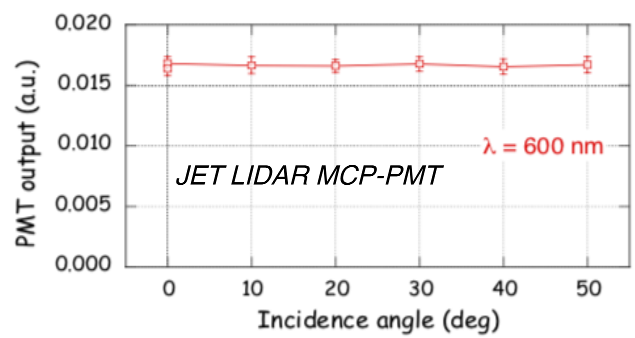



Fig. 6




*Linearity and gain recovery of JET LIDAR MCP-PMT*

Angular dependence of QE





[5] L. Giudicotti and R. Pasqualotto, JINST 7 C02037 (2012)
[6] L. Giudicotti, Nucl. Instr. and Meth. A 659 p. 336–347 (2011).

# High resolution LIDAR by pulse dilation

Technique first published in 1976 for improving the speed of oscilloscopes [7].

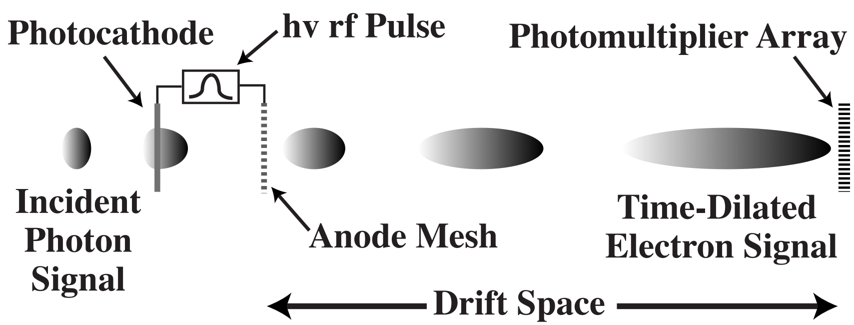
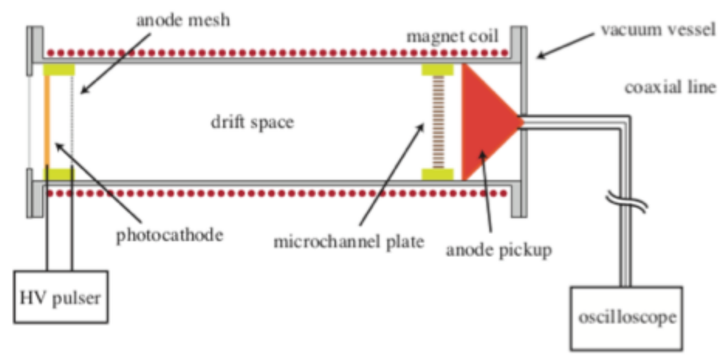
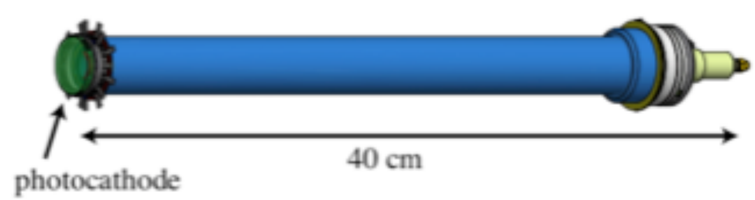



FIG. 1. Principle of pulse-dilation: Photoelectrons are accelerated with a time varying electric field and the resulting energy dispersion causes the signal to stretch axially as it traverses the drift region resulting in reduced effective temporal resolution when sampled with a gated microchannel plate.



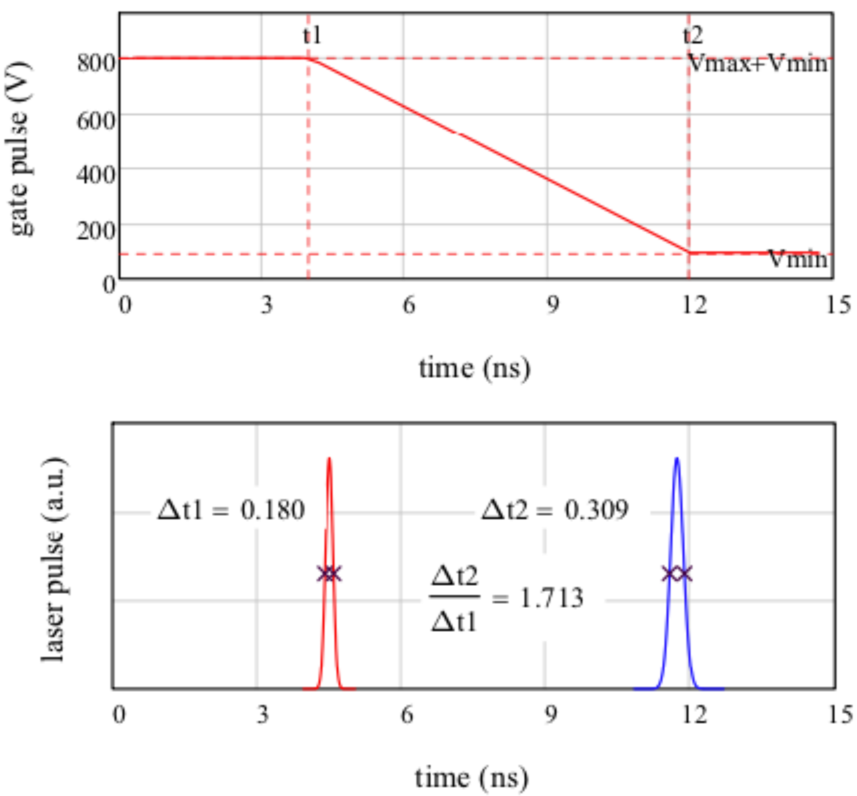

Several devices (mostly X-ray cameras) built from 2010 for diagnostics of inertial plasmas [8][9].

MCP-PMT with S20 photocatode (10mm dia.) and 10 ps resolution (25 x) [10].

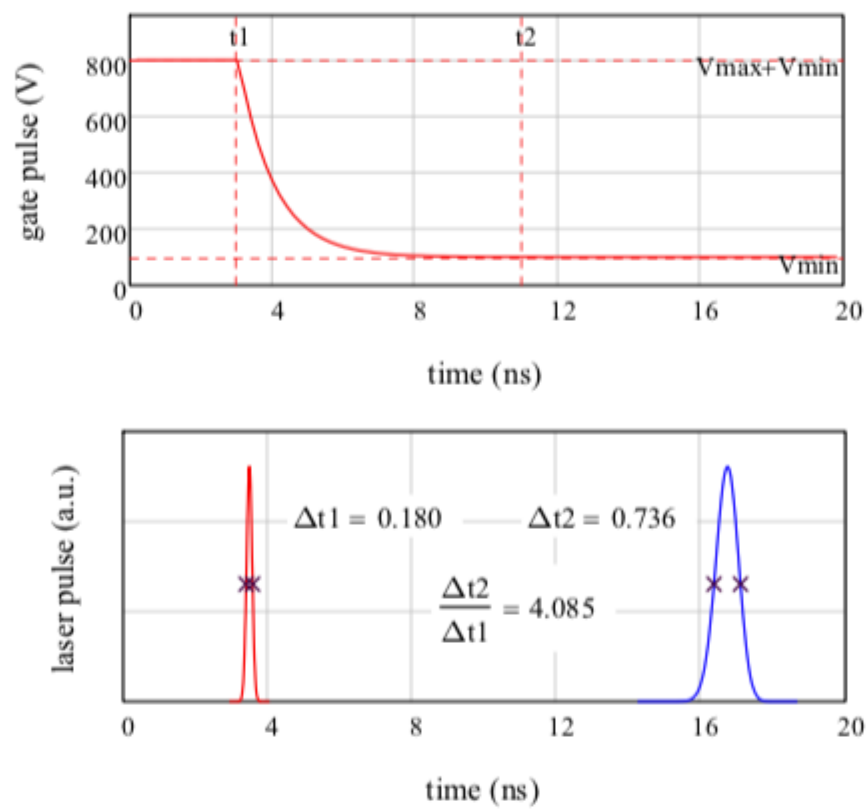

[7] R. D. Prosser, J. Phys. E: Sci. Instrum. 9, 57 (1976)
[8] T. J. Hilsabeck et al, Rev. Sci. Instrum. 81, 10E317 (2010)
[9] S.R. Nagel et al., Rev. Sci. Instrum. 83,10E116 (2012)
[10] J. D. Hares et al., J. of Phys: Conf. Series, 717, 012093 (2016)

# Compact MCP PMT with pulse dilation

Linear ramp 75V/ns  M = 1.7




Exponential ramp RC= 1 ns  M = 4.1




Ideal, compact design: 5 cm accelerating region, no drift region, V < 1kV

# Conclusions



A LIDAR TS system in under development for DTT

Thanks to technology advancements in lasers and detector technology the limitations of spatial and time resolution of past systems can be overcome.

Further improvements of the spatial resolution are possible by the pulse dilation technique.

This work will show that the LIDAR TS approach can achieve performances comparable to those of conventional TS systems, at lower cost and complexity.