EUROfusion

Summary of FP8 work on Enhancements

C. Sozzi

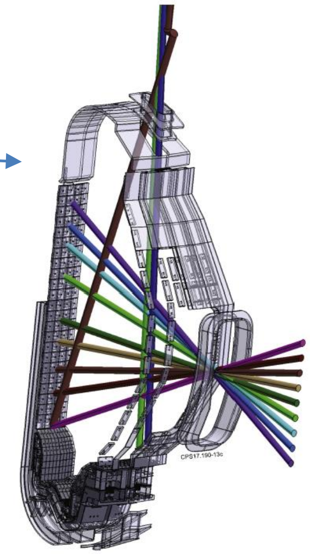
ISTP

JT-60SA Advanced Superconducting Tokamak BA-Satellite Tokamak Program

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

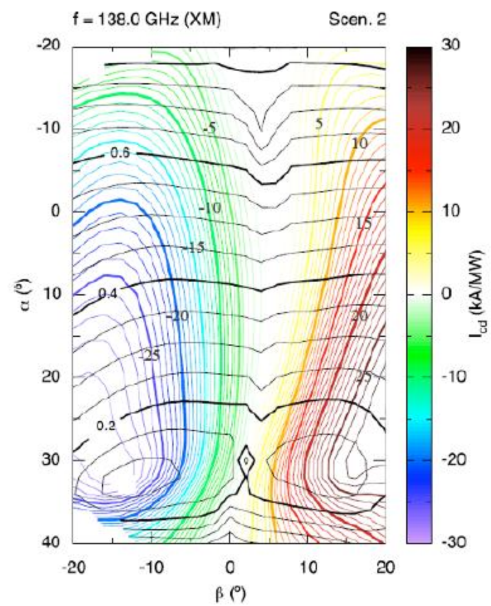
Enhancements area in FP8

- Completed feasibility studies
  - Polarimetry diagnostics
  - Beam Emission Spectroscopy (Li and D beams)
  - EC Stray radiation – phase 1



- Performance evaluation (ECRF)
- Gas exhaust analysis system

- Diagnostics Requirements evaluation
  - pedestal diagnostics
  - disruption diagnostics



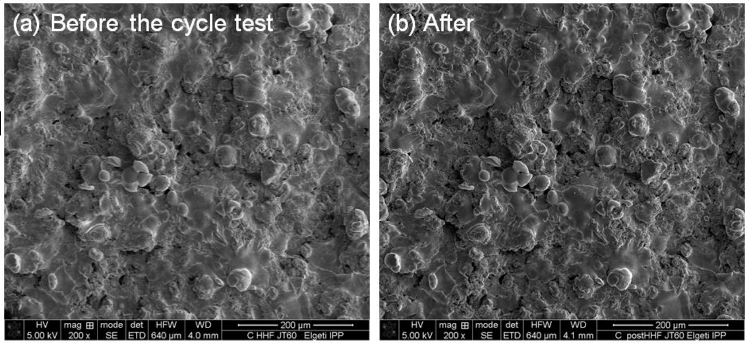
- Preparation of the Transition to W-PFCs
- Full documentation in the FP8 wiki page

More on completed diagnostics studies:
https://users.euro-fusion.org/iterphysicswiki/index.php/Annual_reports_for_EUROfusion

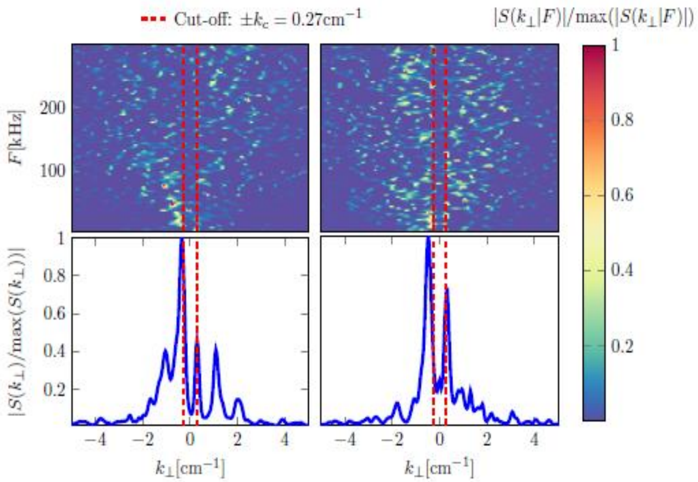
JT-60SA Advanced Superconducting Tokamak BA-Satellite Tokamak Program

Studies on future enhancements

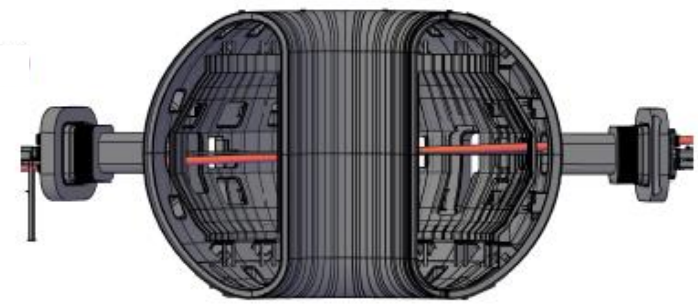
- **Transition to W-PFC**
  - long term project (→ 2029), however estimated timeline could be ~10 years
  - interaction EUROfusion-F4E started
  - simulations of W scenario ongoing
  - component tests on GLADIS (IPP/Garching)
  - Moved to WPDIV



- **Phase Contrast Imaging diagnostic**
  - collaboration **EPFL** (S. Coda) – **NIFS** (K. Tanaka)
  - extensive feasibility study completed →
  - **very positive output, basis for further discussion and decision**



- **Doppler reflectometry proposal**
  - **preliminary study** by EU team ongoing
  - **synergies** with analogous study by **NIFS**

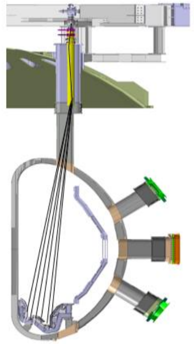


- **in general, area to initially propose further ideas**

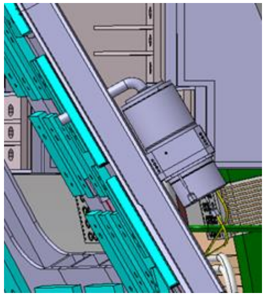
Enhancements (implementation started in FP8 => extended to 2022 with the same rules)

- From 2016 some of the enhancements feasibility studies entered the implementation phase
  - EDICAM fast survey camera (pilot project) – INSTALLED, IN COMMISSIONING
  - Divertor cryo-pumping system – PROCUREMENT
  - Pellet injector - DESIGN/PROCUREMENT
  - MGI (massive gas injection)- PROCUREMENT
  - Edge Thomson Scattering (TS) -DESIGN/PROCUREMENT
  - VUV spectrometry) - DESIGN/PROCUREMENT
  - FILD (fast ion loss detection) - DESIGN
- EUROfusion Scientific drive, Proposals, Design, personnel, led by the team in WPSA
- Key support from F4E for sharing in financing, procurement process, engineering support

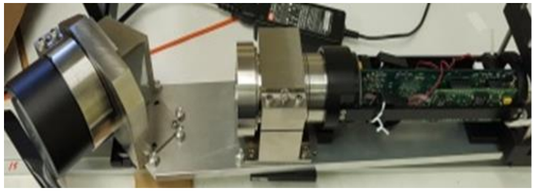
VUV Divertor Spectrometer



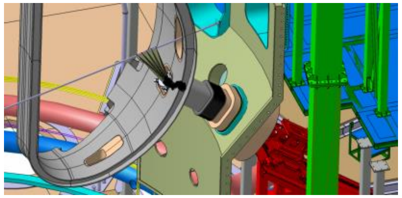
MGI



EDICAM wide-angle camera

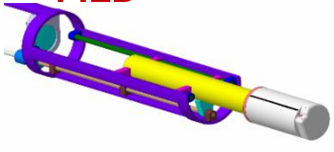


Edge Thomson Scattering

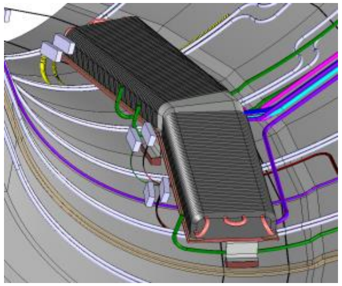


Pellet Launching System

FILD



Divertor Cryopumps

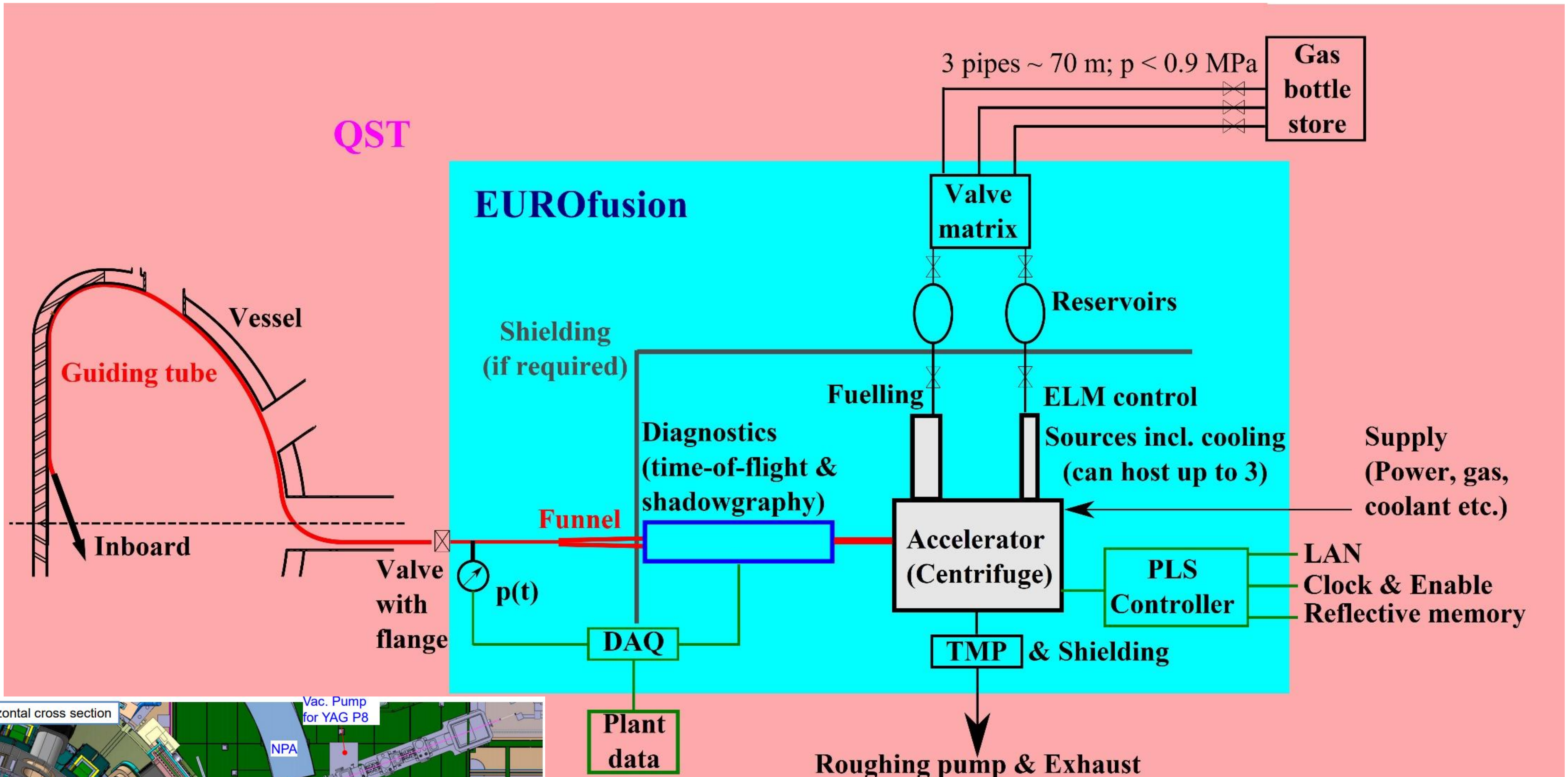


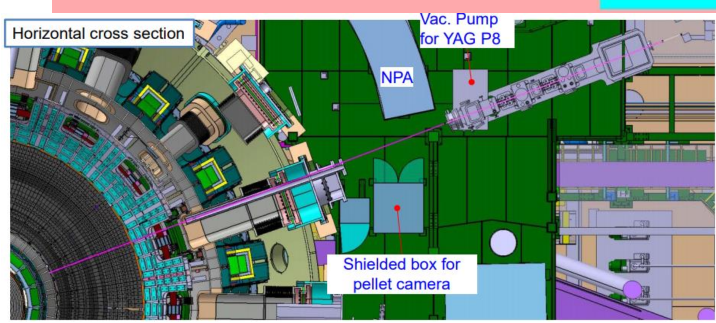
EP: Participating Institutes

Enhancement Project	**Enhancement Project Leader (leading Lab)**	**Participating Institutes**	**Hardware funding**
EDICAM	T. Szepesi (Wigner RCP)	Wigner RCP, Budapest (Hungary)	EUROfusion
		Budapest University of Technology and Economics, Budapest (Hungary)	
Thomson Scattering	R. Pasqualotto (RFX)	Consorzio RFX, Padova (Italy)	F4E + EUROfusion
		ICIT (Institute of Cryogenics and Isotopic Technologies), Rm. Valcea (Romania)	
		CNR-IFAC (Institute of Applied Physics Nello Carrara), Firenze (Italy)	
VUV	M. Valisa (RFX)	Consorzio RFX, Padova (Italy)	EUROfusion
		ICIT (Institute of Cryogenics and Isotopic Technologies), Rm. Valcea (Romania)	
		ENEA, Frascati (Italy)	
		CCFE, Culham (UK)	
		IPPLM, Warsaw (Poland)	
FILD	M. Garcia-Muñoz (Sevilla University)	Sevilla University, Sevilla (Spain)	EUROfusion
		CIEMAT, Madrid (Spain)	
		CNR-IFP (Istituto di Fisica del Plasma), Milano (Italy)	
		University of Milano - Bicocca, Milano (Italy)	
Cryopumps	C. Day (KIT)	KIT, Karlsruhe (Germany)	F4E
Pellets	P. Lang (MPG)	MPG-IPP, Garching (Germany)	F4E
MGI	M. Dibon (MPG)	MPG-IPP, Garching (Germany)	EUROfusion

PELLET LAUNCHING SYSTEM LAYOUT

PLS scheme with projected responsibility as shared between QST and EUROfusion

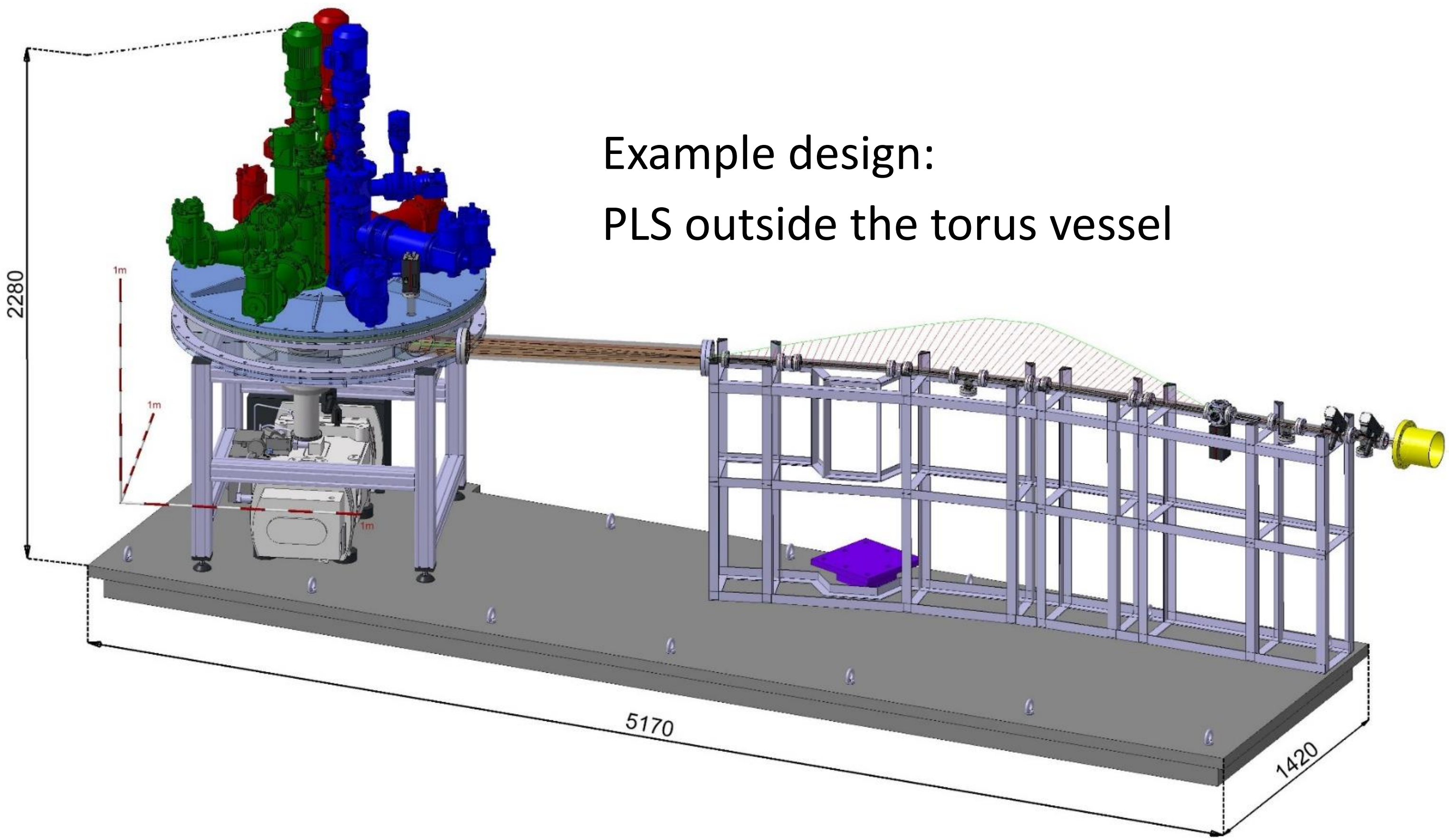




Assembly and commissioning in IPP pellet lab (Garching)

PELLET LAUNCHING SYSTEM

Steady-state ice extruders (100 s pulse length) under construction
Centrifuge launcher can host up to 3 different pellet sources
Pellets injected from torus inboard, transfer via guiding tubes



Example design:
PLS outside the torus vessel

PELLET LAUNCHING SYSTEM

The JT-60SA Pellet Launching System (PLS): Potential prototype for multi-purpose reactor solution

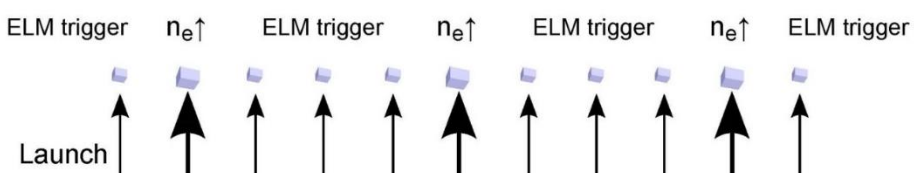
- PLS based on AUG type “stop cylinder” centrifuge launcher
- Several “state of the art” pellet sources/extruders

➔ Almost steady state injection of precisely timed different pellets

➔ Serving different purposes: Fuelling – ELM pacing – *Seeding …*

JT-60SA Research Plan “Research Objectives and Strategy “

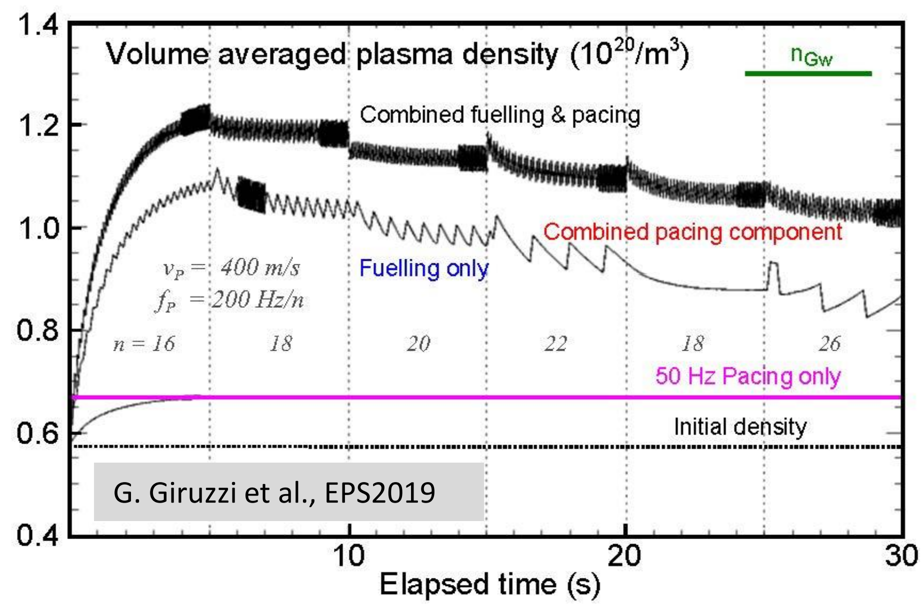
Compose multi purpose pellet train



Consider cross-talk of actuations:

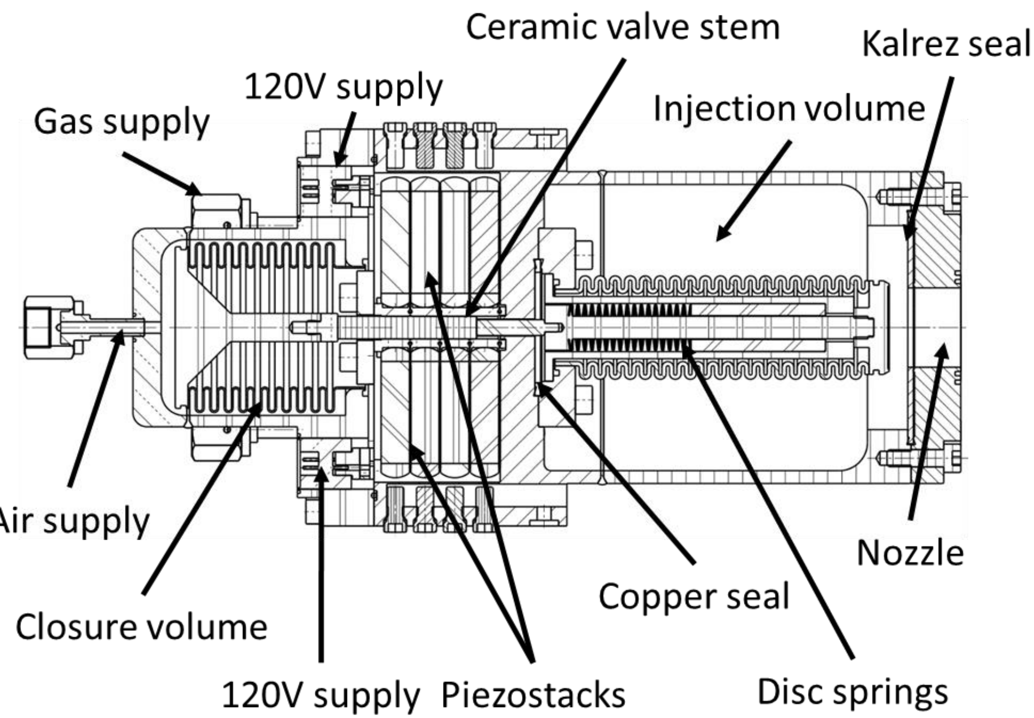
Pacing pellets do fuel

Fuelling pellets can pace



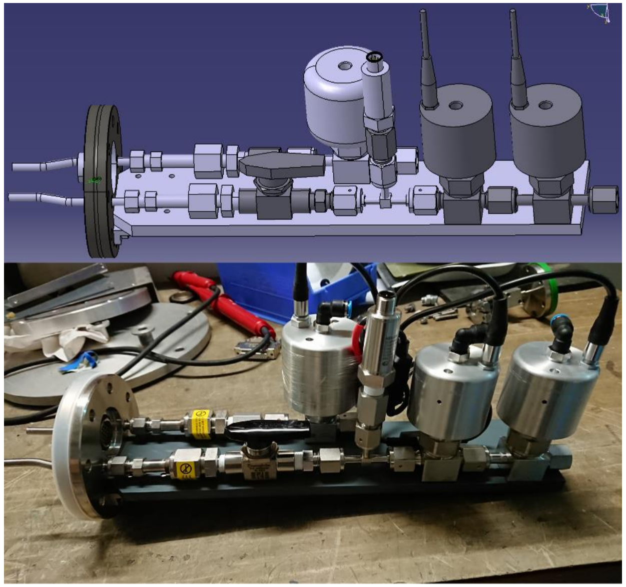
MGI: Current valve design

- Two valves in Ports 9&18, fixed against stabilizing plate
- Two different gas species available simultaneously

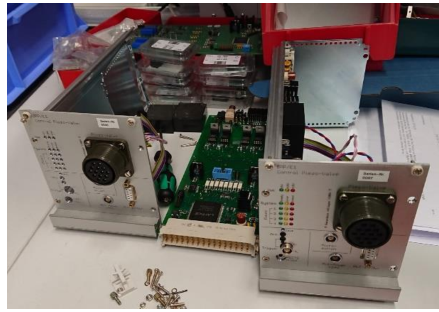


	Valve Type 5
Gas reservoir [cm³]	815
Max. gas pressure [MPa]	7.2 (design pressure 8 MPa)
Max. gas amount [Pam³]	5868
Max. inj. Particles	$1.4*10^{24}$
Opening time [ms]	< 2
Valve plate lift [mm]	7
Nozzle diameter [mm]	28
Size l [mm] x b[mm] x h[mm]	140 x 110 x 292
Piezoelectric stacks	8
Required air pressure [MPa]	1.5 (design pressure 2 MPa)
Closure volume [cm³]	53

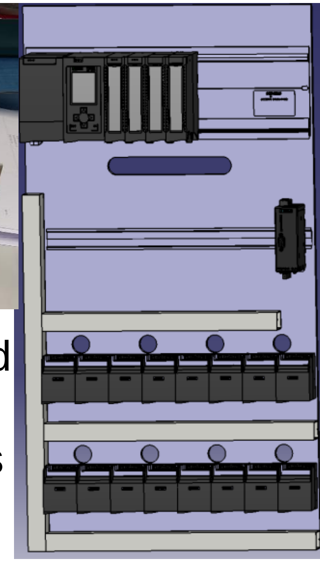
MGI: system's components (close to completion)

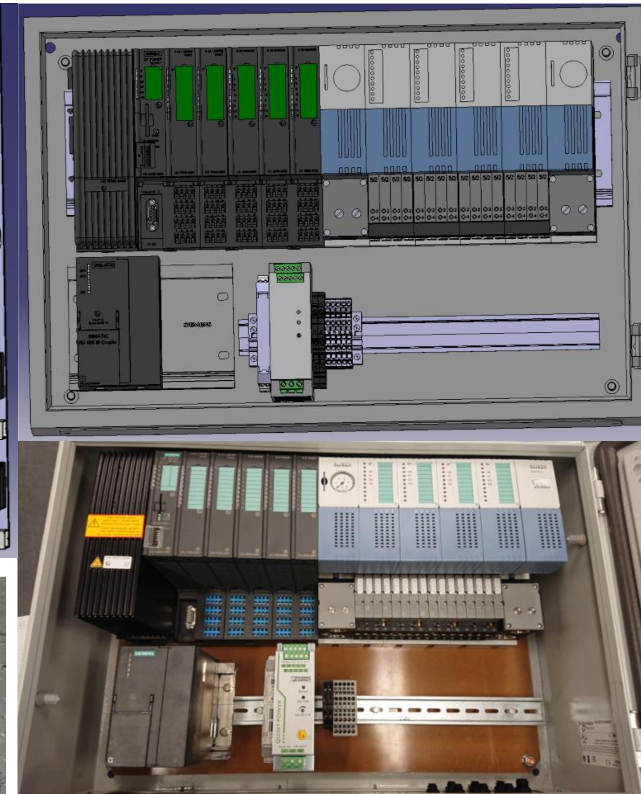


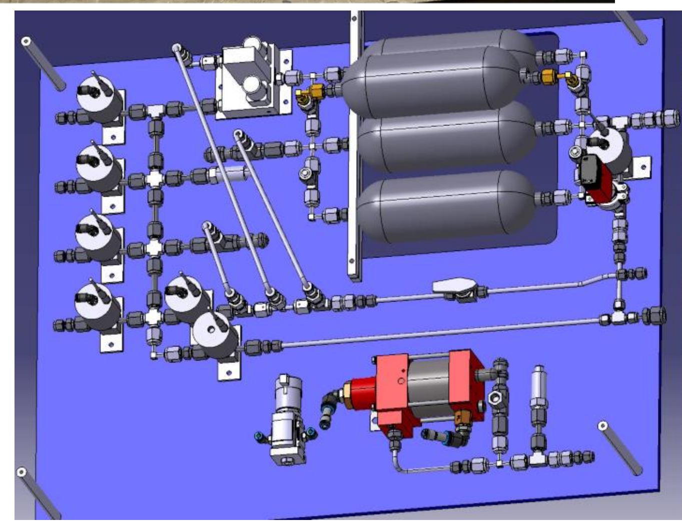
Vacuum feedthroughs

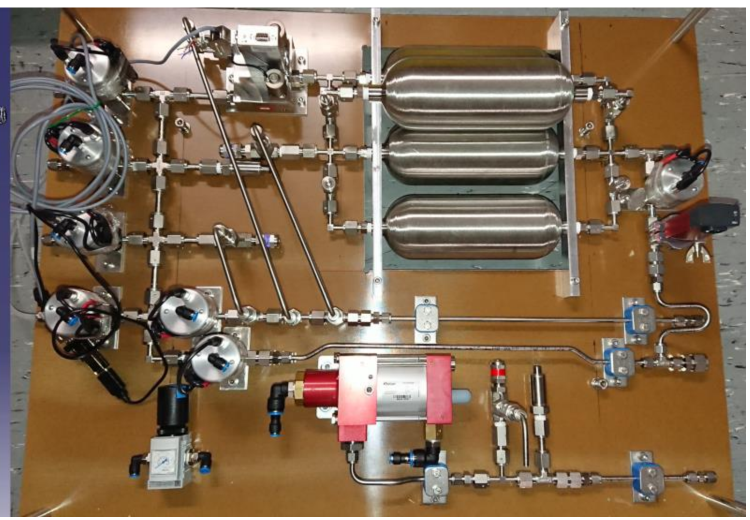


Trigger and Control Electronics PLC









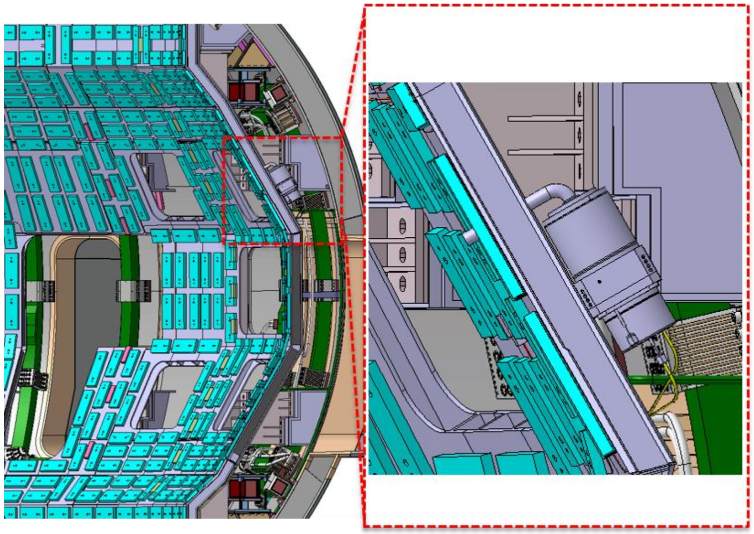
Gas preparation system with Electronic pressure controller) for automated gas mixing

MGI Control system

Software programming will start once the hardware is completed

Three operating modes for each valve foreseen:

- Manual mode
    - Each valve in the gas supply system can be opened and closed manually
    - Good for leak testing, needs practice in operation
- Automatic experimental mode
    - Gas mixtures are defined manually
    - Automated filling procedure started manually
    - Valves open and close automatically to create the desired mixture and MGI valve is filled
- Automatic machine protection mode
    - Pre-defined gas mixture (90 % D2 + 10 % Ne)
    - Automated filling procedure started before first plasma discharge of the day
    - Valves open and close automatically to create the desired mixture and MGI valve is filled
    - If MGI valve fires, automated filling procedure is started before next discharge
    - MGI valve is emptied after last discharge (i.e. 10 pm)



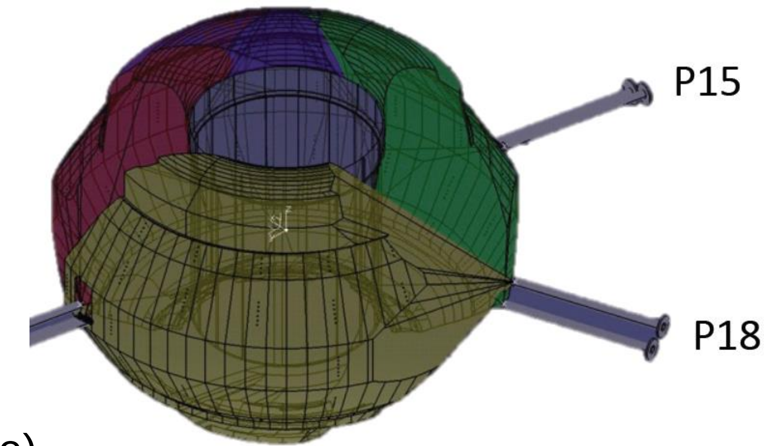
Once filled, MGI valves can always be triggered manually, on a plasma event or at a predefined time into the discharge

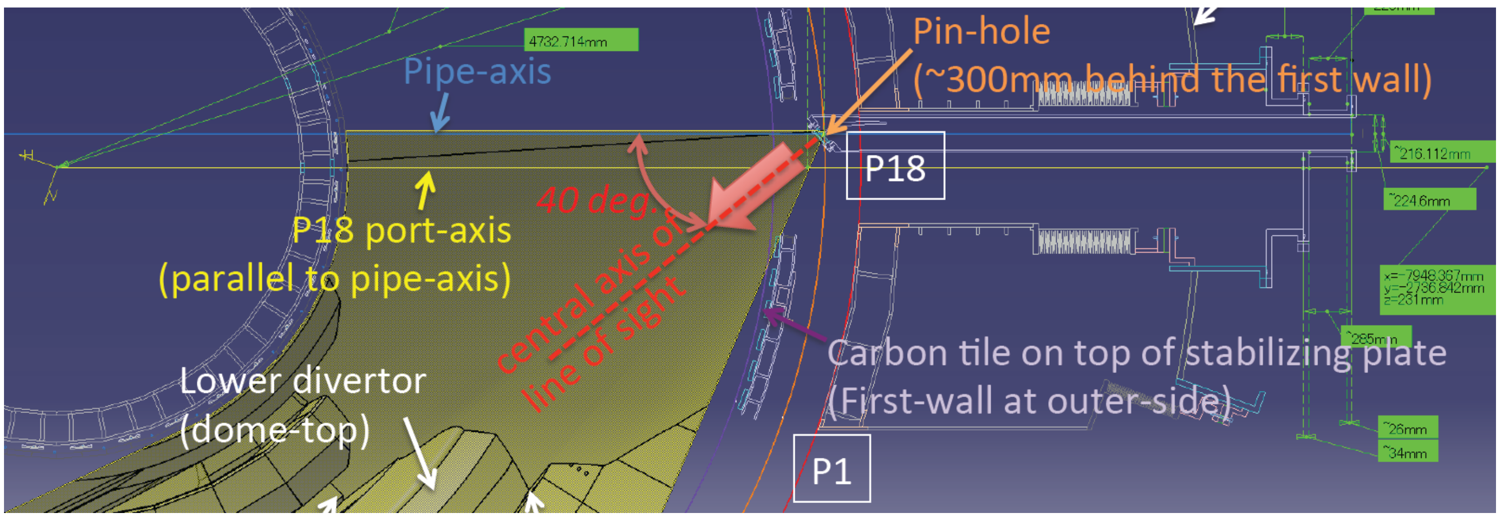
EDICAM: Main features

Single channel wide-angle fast video diagnostics

Features

- Field-of-view: 80° (wide-angle)
- Tangential view
- Temporal resolution: 100 Hz
  - → max. 400 Hz full frame, up to 20 kHz for ROIs
- Spatial resolution: better than 13 mm (over 3-8 m distance)





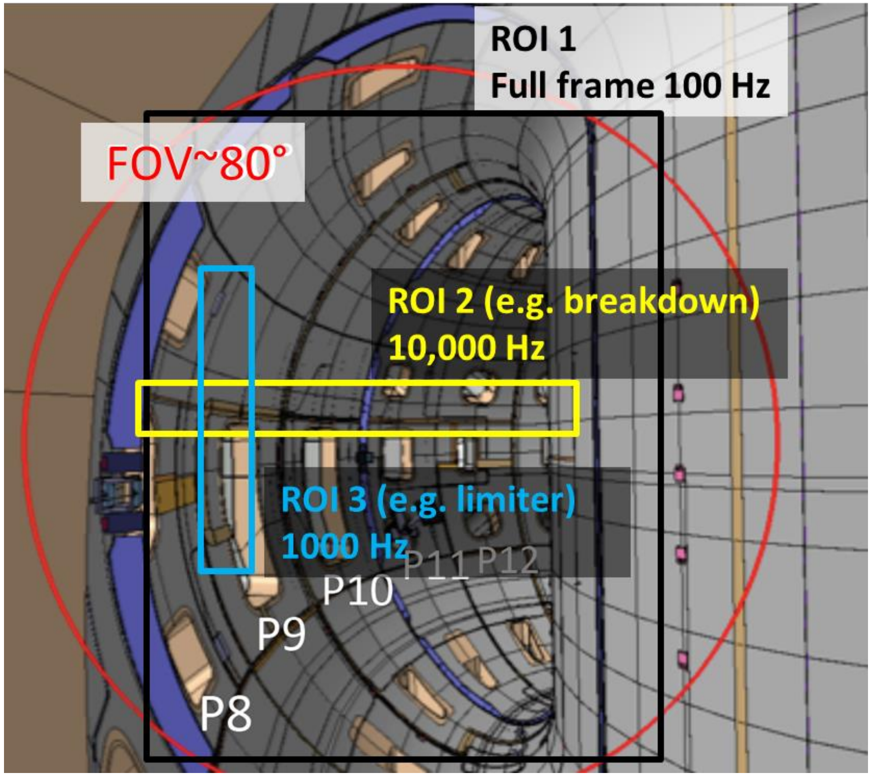
Set-up

Wide-angle view: ca. 1/5 of torus

- ROI 1: full frame overview
  - → 1280x1024 @ 100 Hz
- ROI 2, 3, …
  - → fast observations

→ refine ROIs using real image

EDICAM: Aims for the first campaign



Technical

- commissioning of the EDICAM system, to confirm:
  - → reliable camera operation
  - → production of raw and processed data
  - → reliable shutter operation

Operational / safety

- observe breakdown
- determine plasma size and position
- observe radiation collapse / disruption
- detect ECRH shinethrough
- detect hot-spots, UFOs
- observe radiation during ECWC
- asymmetries (poloidal)

Scientific

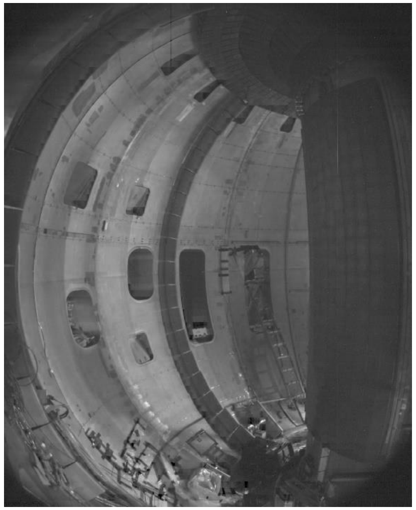
- study breakdown and plasma behavior
- high-fps observations for any emerging phenomena

Completion

- acceptance tests passed / 11 July 2019
- delivered to Naka / 22 July 2019

Installation

- port plug installed / 10 April 2020
- first in-vessel images / 16 April 2020
- first high-quality images / 14 May 2020

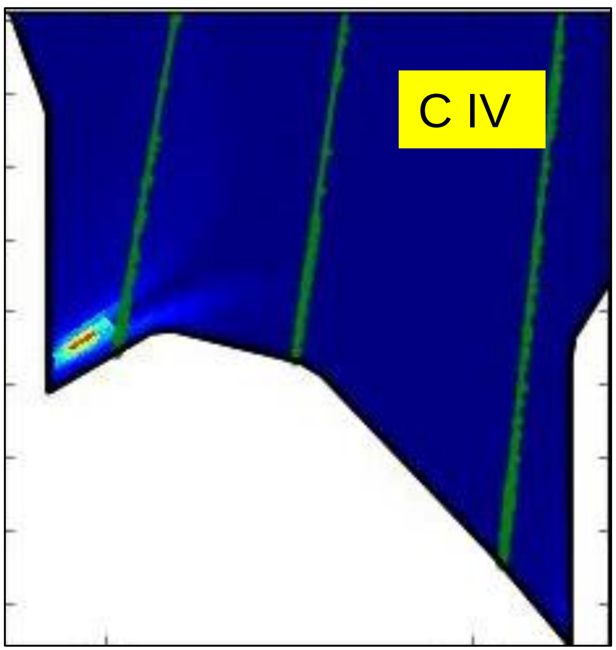


Commissioning

- individual linkage test / Nov 2019
- 4x integrated linkage tests in 2020
  - → in last one overperform specifications
- software update / March 2021

VUV spectrometer: Scientific aims

- Contribute to the divertor studies
- Qualify the radiation losses at the X-point and at the two divertor legs due to intrinsic and extrinsic impurities while approaching the detachment
- Identify the divertor status: recombining/ionizing

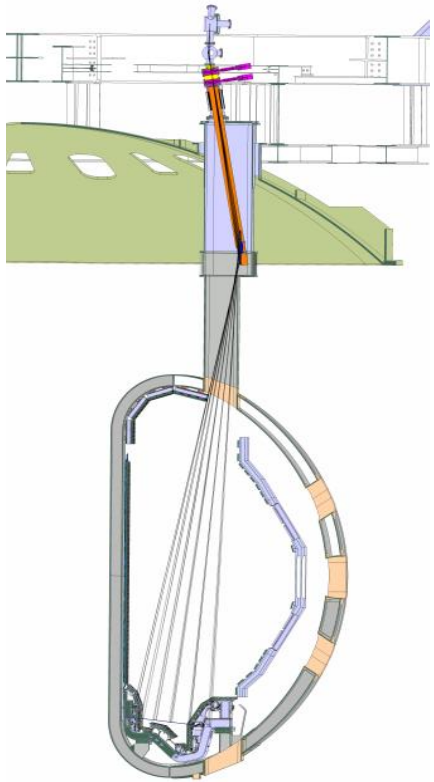


SOLEDGE simulation of the C IV distribution in scenario 2 (Balbinot)

First synthetic C spectra to be presented in 47th EPS conf June 21-25, 2021 *(Carraro et al)*

VUV spectrometer: Main specs

- Resolve emission from intrinsic (C, O , Ni, Cr ….W) and extrinsic (N, Ar, Ne , Kr) impurities to evaluate the relative/absolute contribution to radiation losses.
- Resolve C and Ne lines to be able to detect volume recombination processes (in the proximity of detachment) See *Nakano T et al Nucl Fusion 47(2007) 1438* and *Nakano T et al JNM 438 (2013) S291*
- Help physics studies of the divertor by distinguishing radiation from inner, outer legs and Xpoint
- Use spectrum slope for Zeff (requires proper calibration and depends on stray light “noise” supposed the detector noise is negligible)



Wavelength ranges. 10-48 and 44- 125 nm

Space resolution : - 5-10 cm (over a 1 m divertor)

Time resolution: 1-50 ms (depending on # of spectra) and selected region of interest)

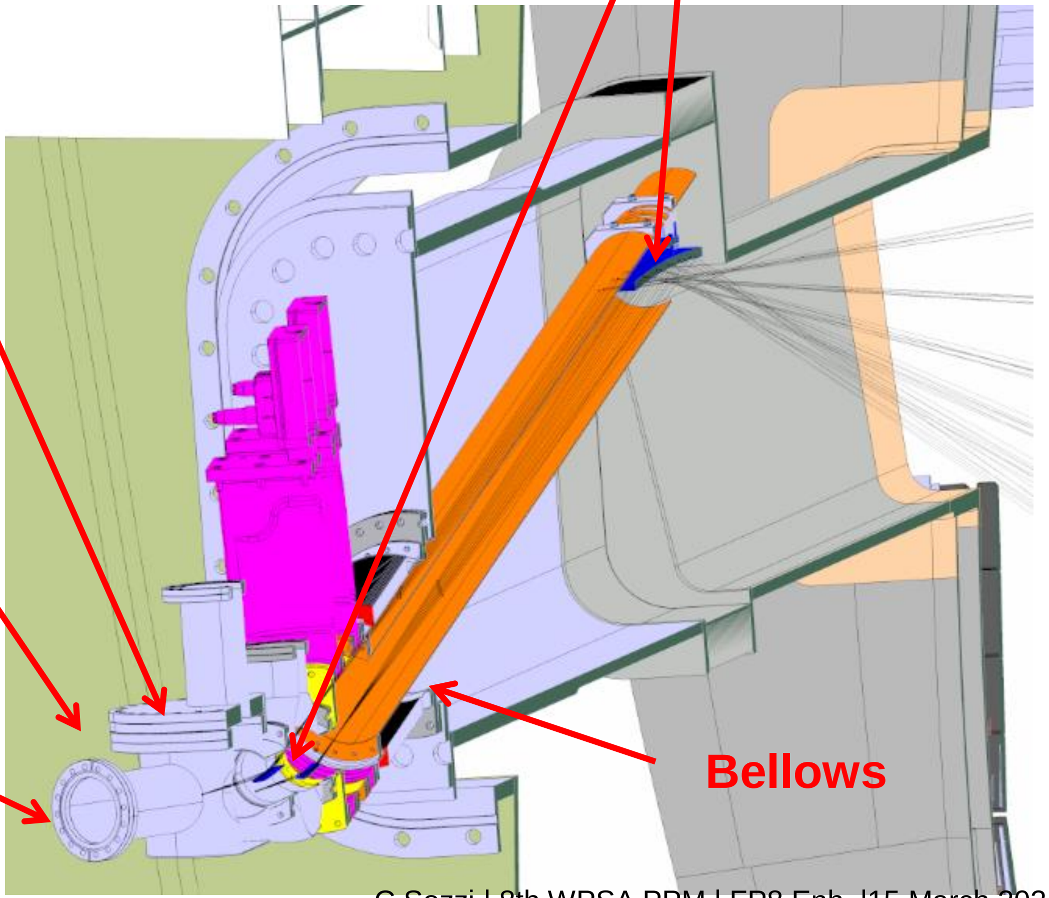
VUV spectrometer: Main components

Gratings. Custom toroidal holographic
(design by W Biel)
λ *resolution*: 0.1 and 0.2 nm /respectively

Collecting mirrors: Toroidal mirrors

Spectrometer:
modified
Double SPRED
251 McPherson

Detectors:
2D CCD
2048x512 (13 μm pix.) / raw
shift time < *5* μ*s*



VUV spectrometer: Project Status

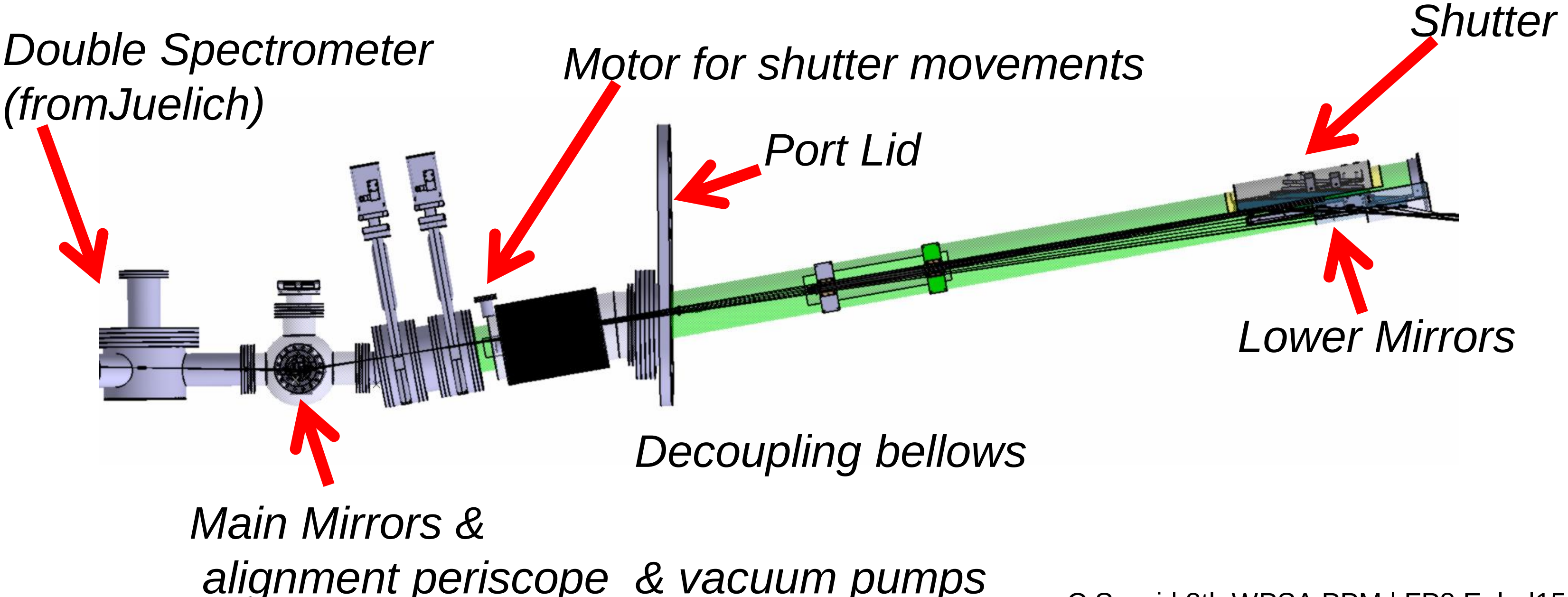
Design almost complete .

Includes: - remote upper mirrors adjustments

- protecting shutter
- alignment periscope

Thermal and em analysis ongoing

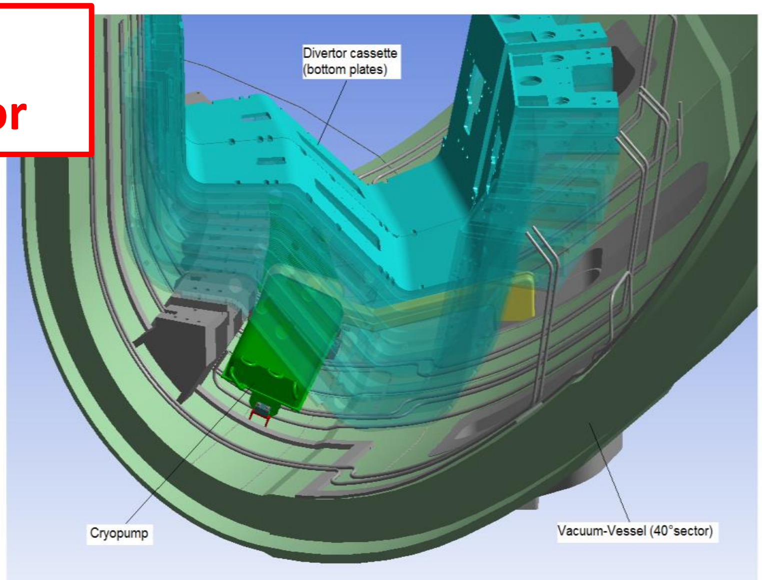
Mirrors and gratings procurements being finalized

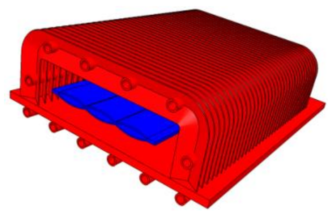


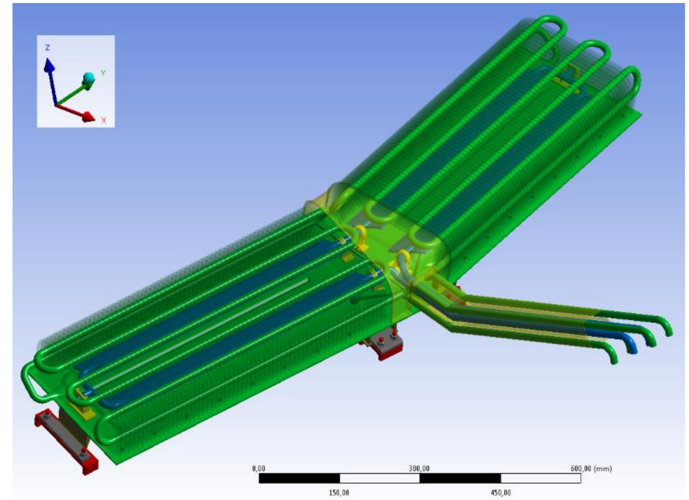
Cryopump design

Contract: 9 identical cryopump 40° units + 1 spare

40° sector

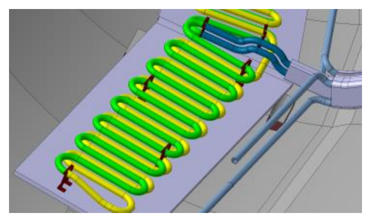


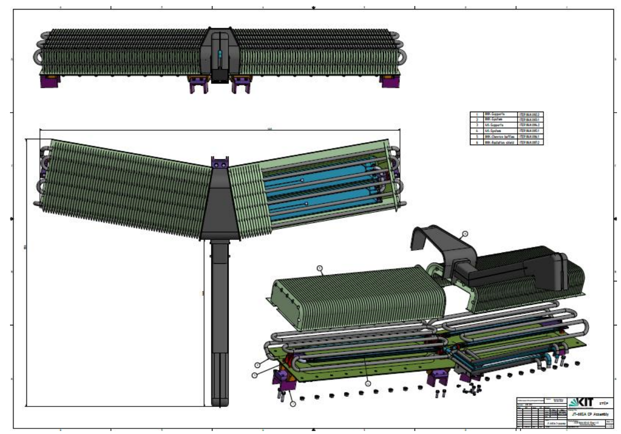




Cryosorption concept:

Two sub-systems: 3.7 K and 80 K.





Each cryopump unit consists of 2 systems:

- The 3.7 K system: adsorption surfaces (cryopanels) cooled by 3.7 K supercritical helium. In order to efficiently pump helium by cryosorption, the cryopanels are coated with activated charcoal granules.
- The 80 K system: thermal radiation shield surrounding the cryopanels made of a base plate and an inlet chevron baffle. These two sub-systems (base plate and inlet baffle) are cooled in parallel by 80 K gaseous helium.

Divertor Cryopumping: Four party scope sharing

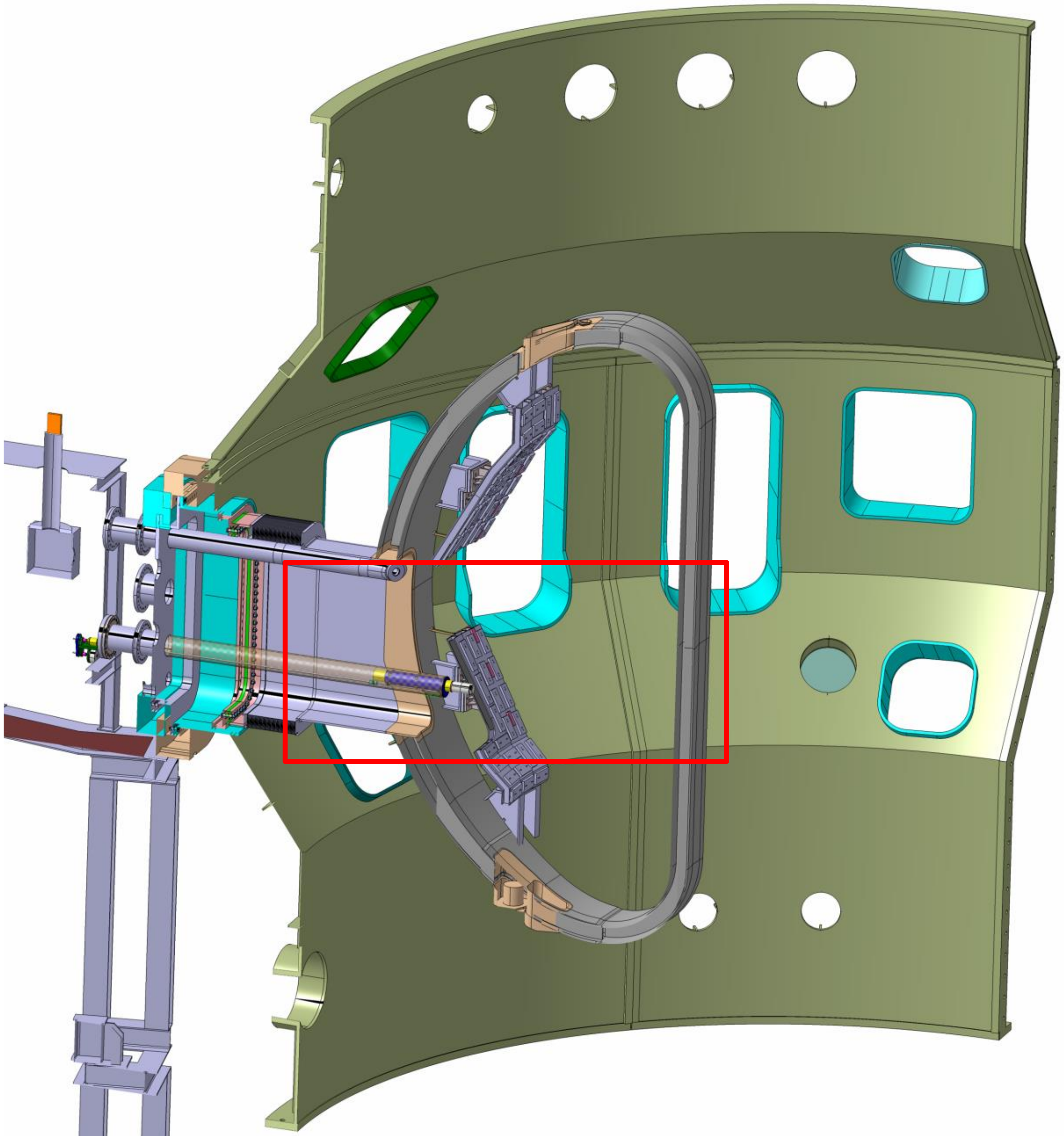
- KIT under EUROfusion WPSA delivers the engineering design of the system, validation and according documentation.
- F4E does the procurement and delivers the cryopump system hardware, utilizes KIT under EUROfusion for contract follow-up.
  - 3.7 K coated cryopanels equipped with heaters fully cabled to the cable interface
  - 80 K base plate and thermal shield plates
  - 80 K chevron baffle, blackened (absorptive) where needed
  - Temperature sensors attached and with cabling to reach the cable ports
  - All parts required to mount the pumps and connecting to in-vessel cryopiping
- QST provides:
  - the electric feedthroughs
  - the recording of the signals, conversion and control.
  - Isolation of the cryopumps from the cryostat by potential breaks in the supply pipes
  - The power supplies of the heaters
  - The cable trays for the heater and sensor cables to guide them from the odd to the even numbered lower ports

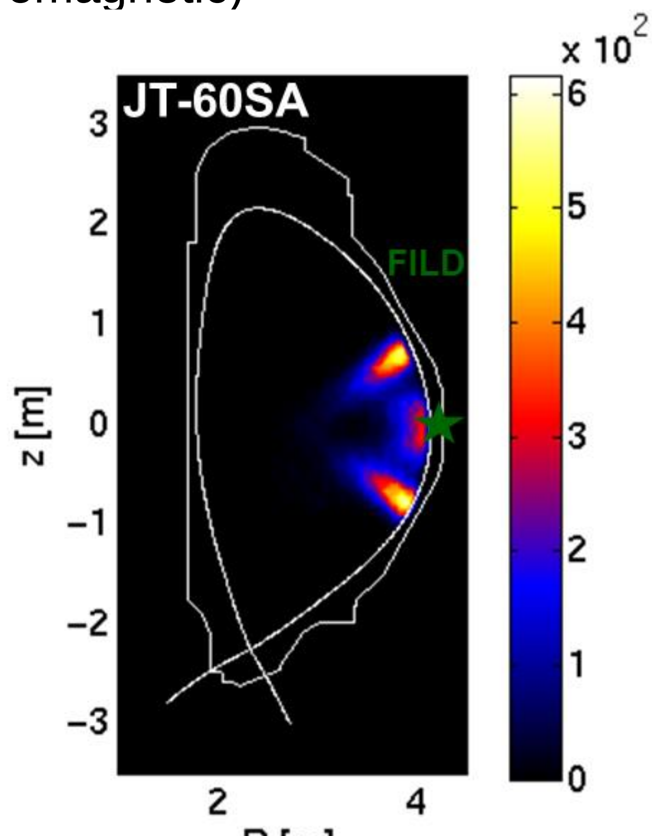
Cryopump: Present status

- By April 2020, the ´final´ design was established.
- After that, further additional design work (and consequential assessments) was needed to resolve many clashes that appeared during integration into the tokamak model with components (cable trays, cooling/fueling pipes,…) that have not been in the model when we started. This was only finished late 2020.
- However, a set of 2D drawings were extracted that allowed F4E to issue a call for tender in May 2020.
- After prolongation, re-negotiation and final evaluation, a successful tenderer was identified, and the contract of manufacturing started end January this year.
- This manufacturer will also deliver an ´as made´- version of the CAD file.
- There are three deliveries to QST:
  - The supports in July 2021
  - The first batch of the cryopumps by end Feb 2022
  - The remaining cryopumps by end April 2022

Fast Ions Loss Detector

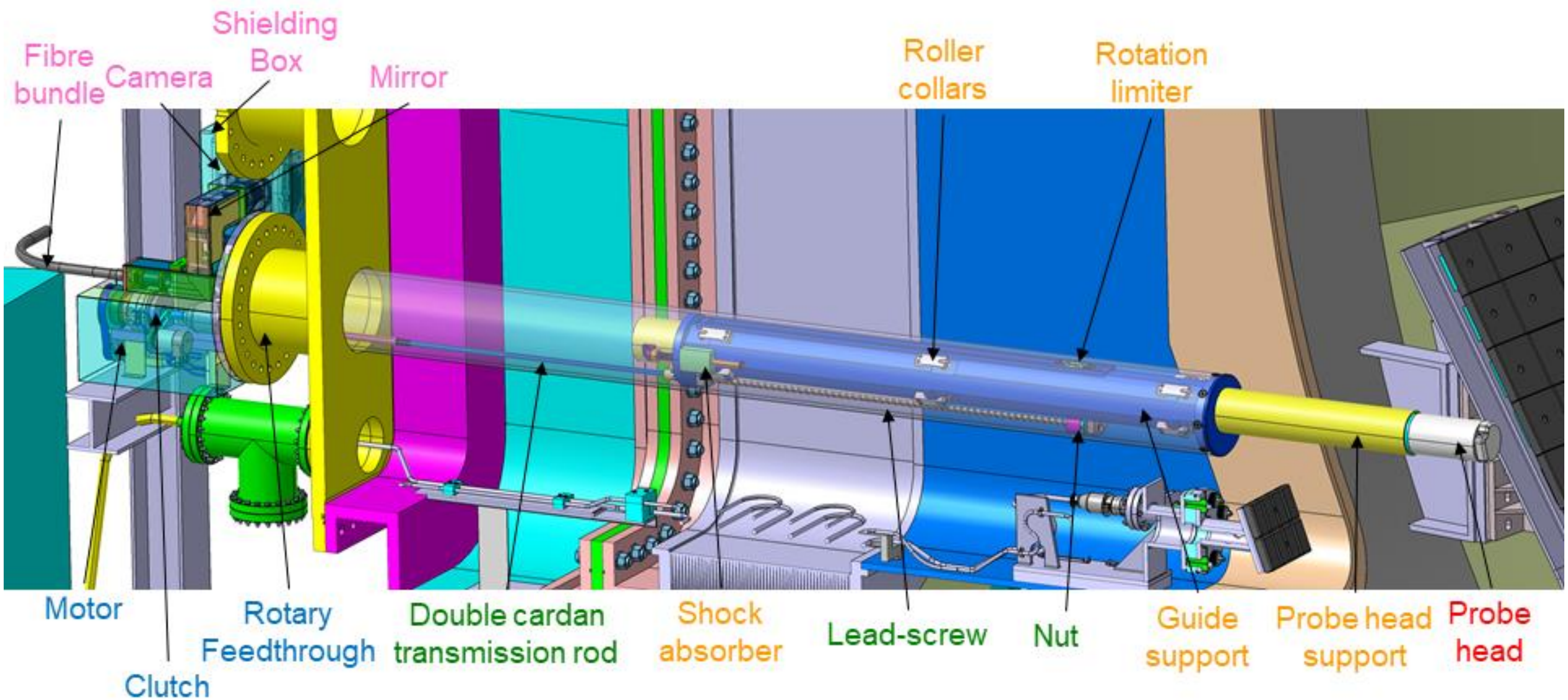
- Located at Equatorial Port 15, Slightly Below Midplane
- Search for optimal radial position is a trade-off between signal levels (Ascot) and detector head loads (thermal + electromagnetic)





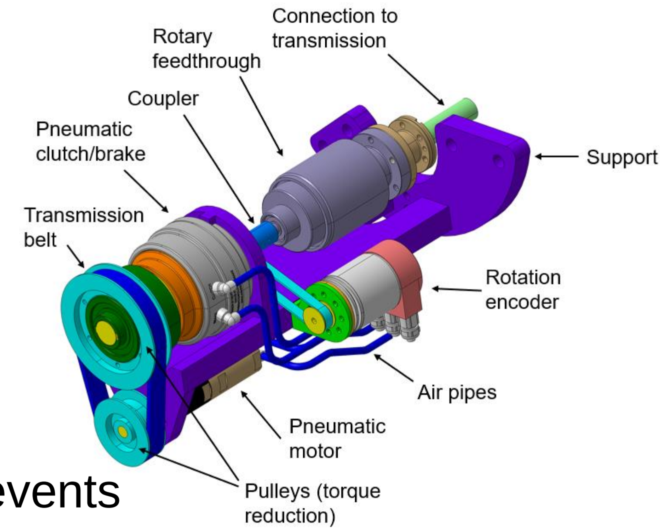
J. Ayllon-Guerola

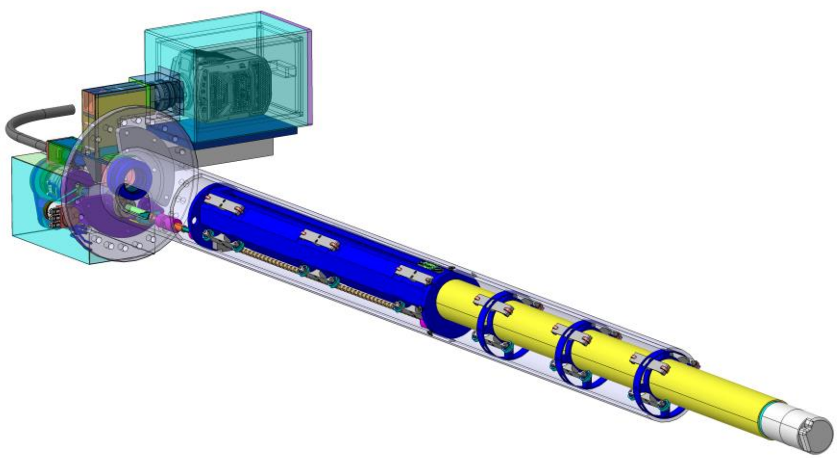
FILD components



FILD design status

- Significant progress in FILD design during 2020
  - Detailed mechanical design
  - Light acquisition system conceptual design
  - Pneumatics and electronics conceptual design
  - Selection of commercial components
  - Motion simulator developed
  - Thermal simulations during full plasma pulses
  - Mechanical assessment during EM and seismic events
  - Acceptance tests definition
  - Progress on Procurement Agreement





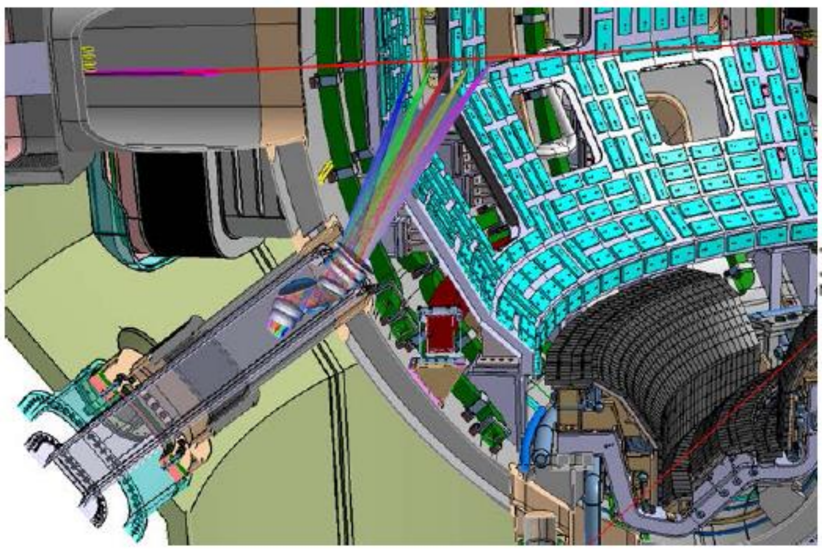
FILD project status

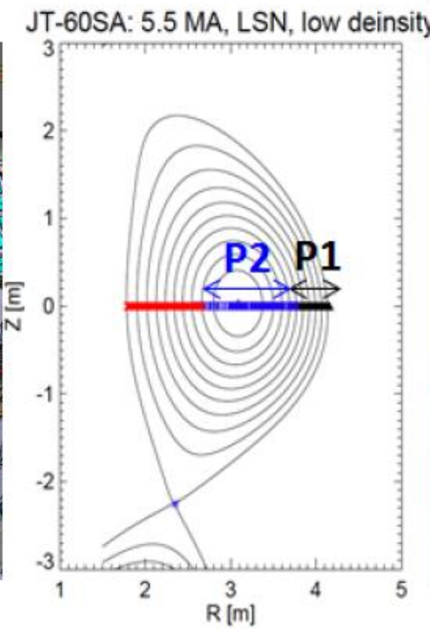
- FILD detailed design subject to Design Review Meeting (EUROfusion, QST and F4E)
  - Very positive outcome:
    - Mechanical design accepted
    - EM assessment validated
    - Seismic assessment validated
  - Some comments received:
    - Study effect of Halo currents
    - Increase length of Port Plug to reduce stroke
- FILD design presented at SOFT conference and article published in Fusion Engineering Design
- Next steps (2021)
  - Complete final design (ongoing)
  - Start manufacturing
  - Start acquisition of commercial components

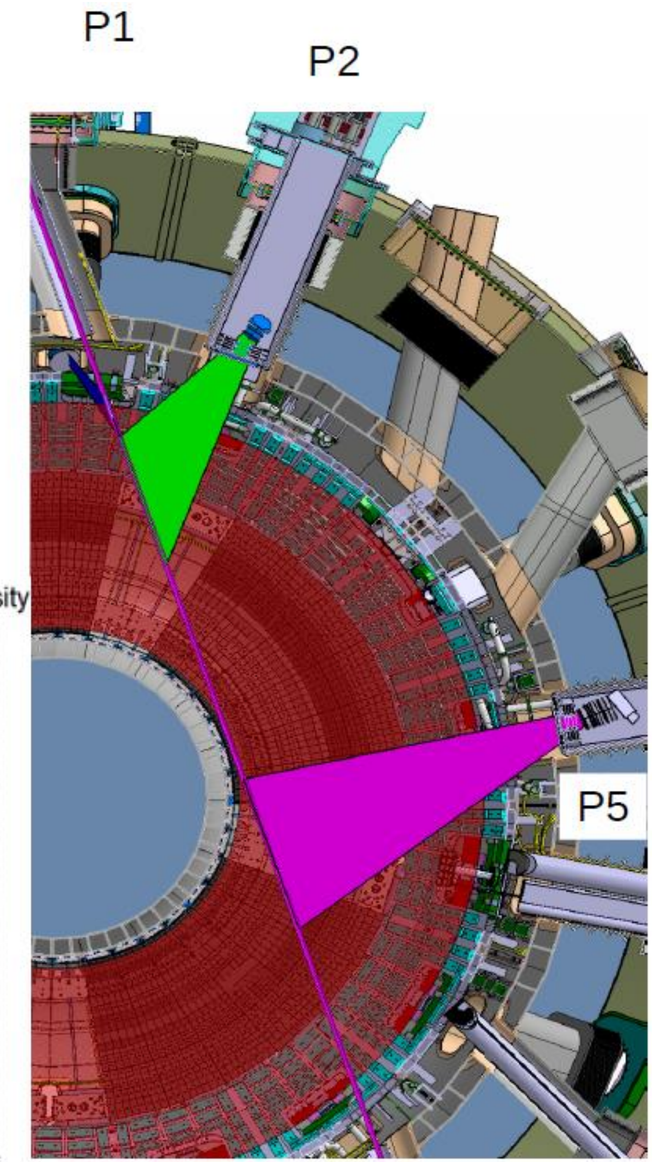
Thomson Scattering in JT-60SA

- Three systems in JT60 SA: P1 (edge), P2 (core), P5 (HFS)
  - P1, P2 under finalization
  - P5 to be installed later (design of collection optics still under optimization).

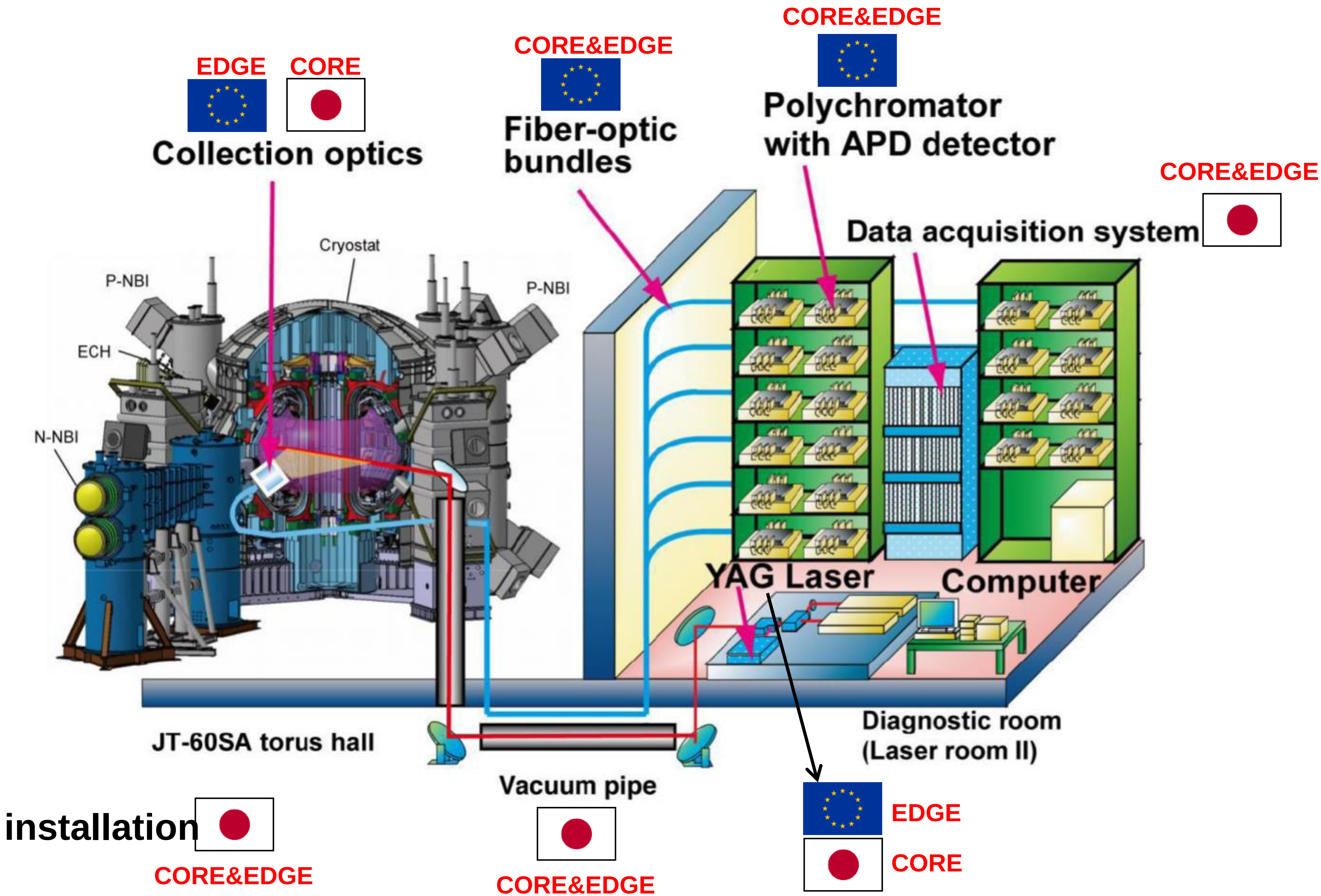
- Divertor TS (not shown) in the wish list







TS diagnostics layout in JT60-SA



Performance requirements

The core TS system (P2) shall measure electron temperature Te and density ne profiles

- **46 positions** from R=2.6m to R=3.725m,
- scattering volume length **15 mm** ,
- radial spatial resolution (points distance) **25 mm**
- dynamic range **0.1-30 keV**
- Laser pulse repetition rate will be **50 Hz**.

The edge TS system (P1) shall measure electron temperature Te and density ne profiles

- **49 positions** from R=3.7m to R=4.17m,
- scattering volume length **5.5 mm**,
- radial spatial resolution (points distance)
  25 mm at R<3.9 m, **5 mm** at R>3.99 and **10 mm** in between
- dynamic range **0.01-10 keV**.
- Laser pulse repetition rate will be **100 Hz**.

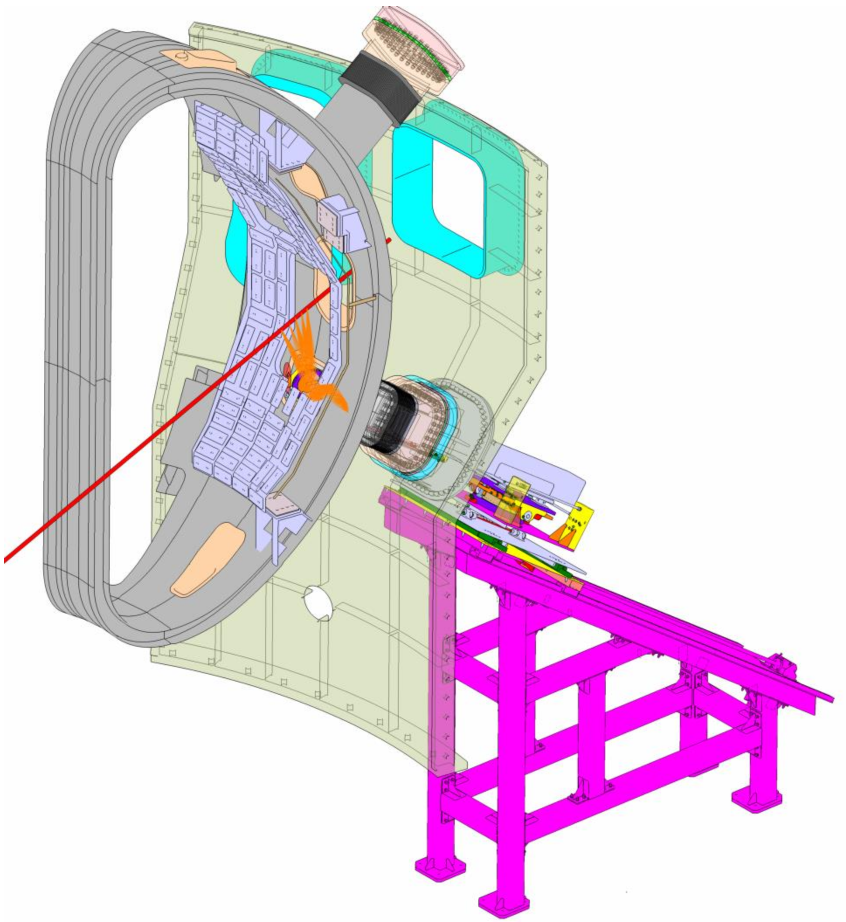
For both systems:
The **accuracy** is expected to be better than 10% for T_e and 5% for n_e, at $n_e = 1 \times 10^{19}\ m^{-3}$ (from simulation) → ***Best Effort***

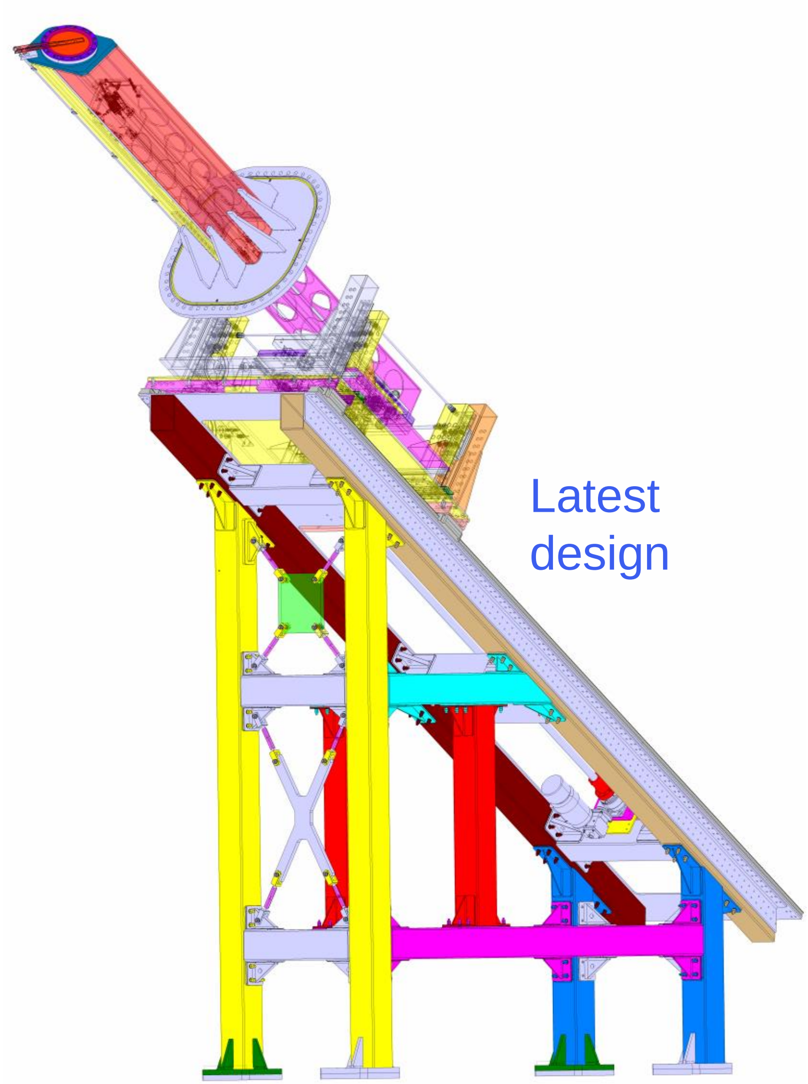
Status design & procurement

- **Annex B for PA:** Signed
- **Fibers** (1100 km): KOM on 16-06-2020
  First delivery (300km) to QST on 15 March; documentation of each fiber spool
  Second delivery ready end March
- **Polychromators:** KOM on 03-11-2020
  Supplier Design ready end of March; detector unit prototype OK
- **Optics edge TS (P1)**: KOM on 24-11-2020
  Supplier design completed and integrated in support structure CAD
  Telecentric lens matches the fibers numerical aperture
- **Laser for edge TS (P1)**
  Technical specification done; single tender: Russian supplier; contract in April
- **Mechanics edge TS (P1)**
  Preliminary review in 10-2020: interferences, vacuum leak test, welds
  CAD model, Installation procedure & loads analysis finalised; 2D drawings started

edge TS layout

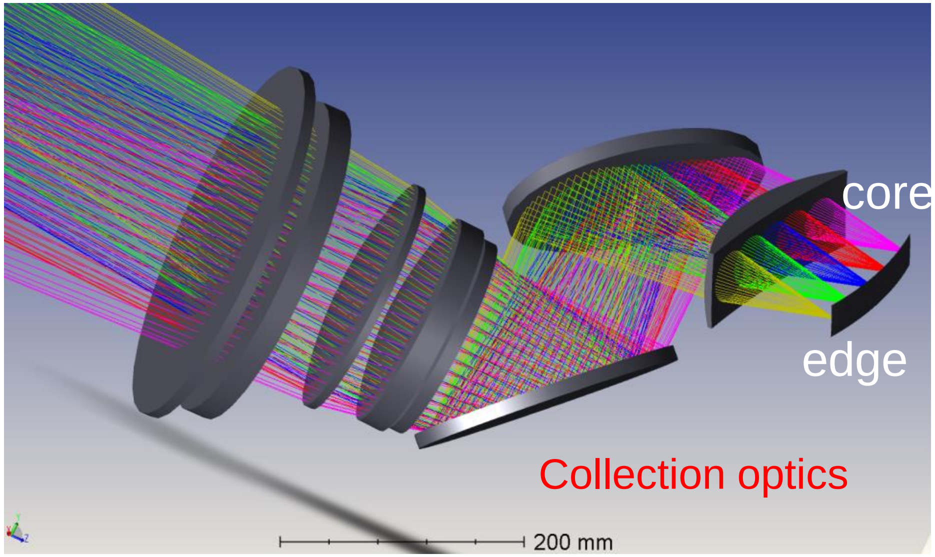
- Collection optics on a retractable arm
- Decoupled from cryostat
- On supporting structure standing on floor
- Same structure to install port plug

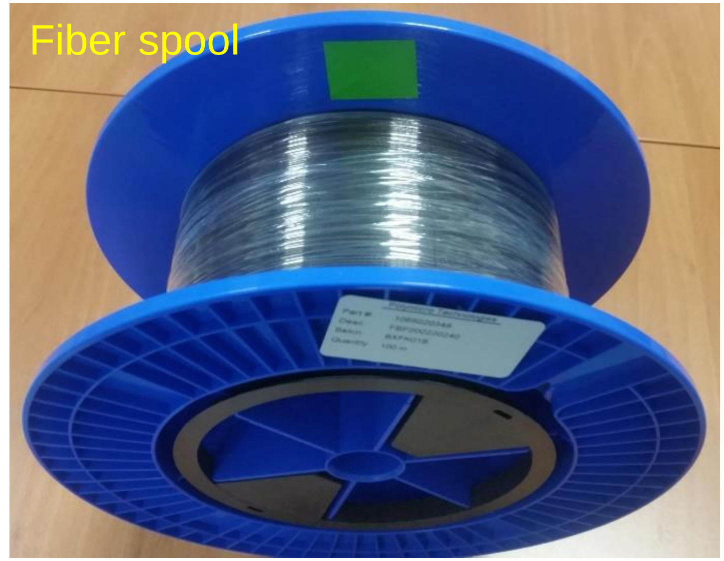


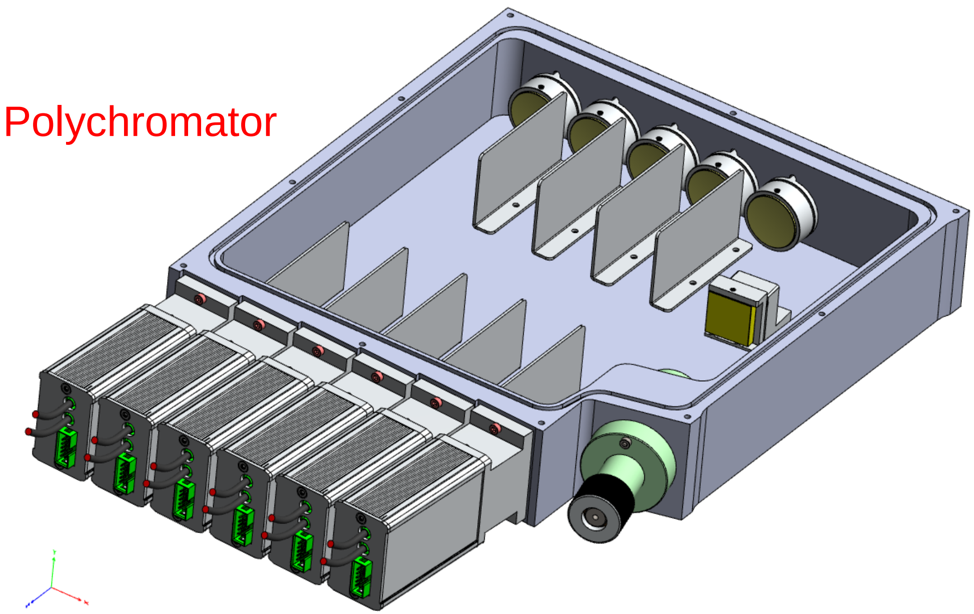


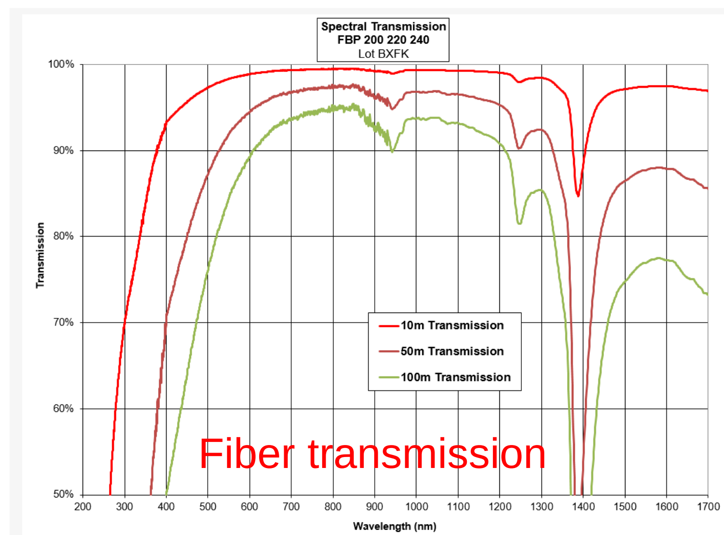
Latest design

Progress on edge TS

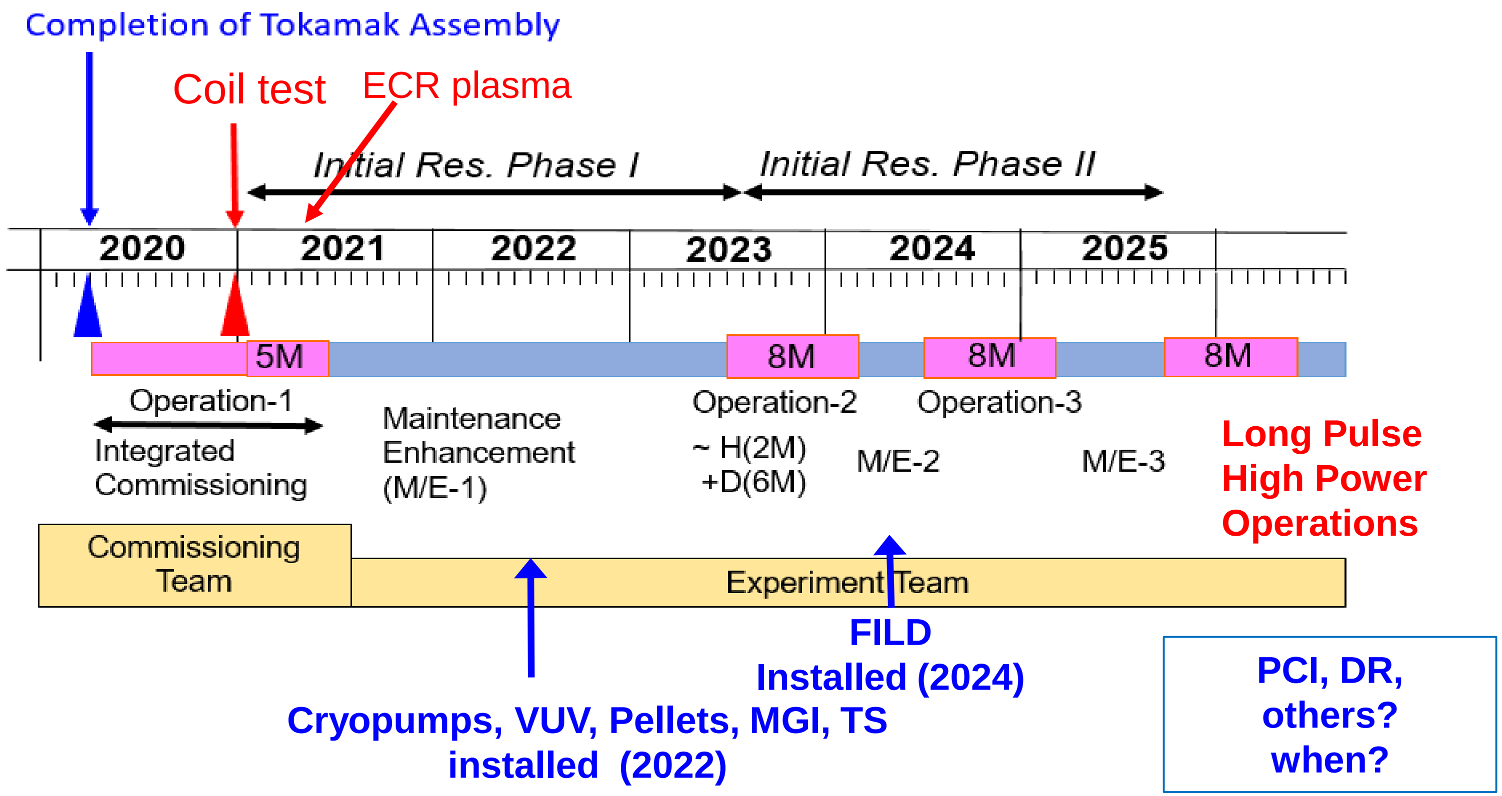








JT-60SA timeline



- Key factors for new diagnostics proposals:
  - Machine capabilities and scientific objectives focused in the various campaigns according with EU strategic priorities and in interaction with the Experiment Team
  - Transition C-W (~2029 in the present schedule, but planning revisions ongoing)
  - ITER research plan and needs
  - Overall support for diagnostics enhancements and enhancements in general (funding, know-how availability etc.)