MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Progress report on the PLS commissioning preparation: System and supply contract status, documentation, commissioning template preparation

ASDEX Upgrade

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FUSION FOR ENERGY

WPSA Enhancements Progress Meeting, VC, October 28., 2026

EUROfusion

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PELLET LAUNCHING SYSTEM TASK

Main research needs (from JT-60SA Research Plan)

Physics:

- High density operation in ITER and DEMO relevant plasmas

- Explore accessibility to densities in vicinity of the Greenwald density

- Investigate power exhaust, develop radiation layers in scenarios

- ELM control

Engineering:

Actuator "pellet injection" on electron density and ELMs

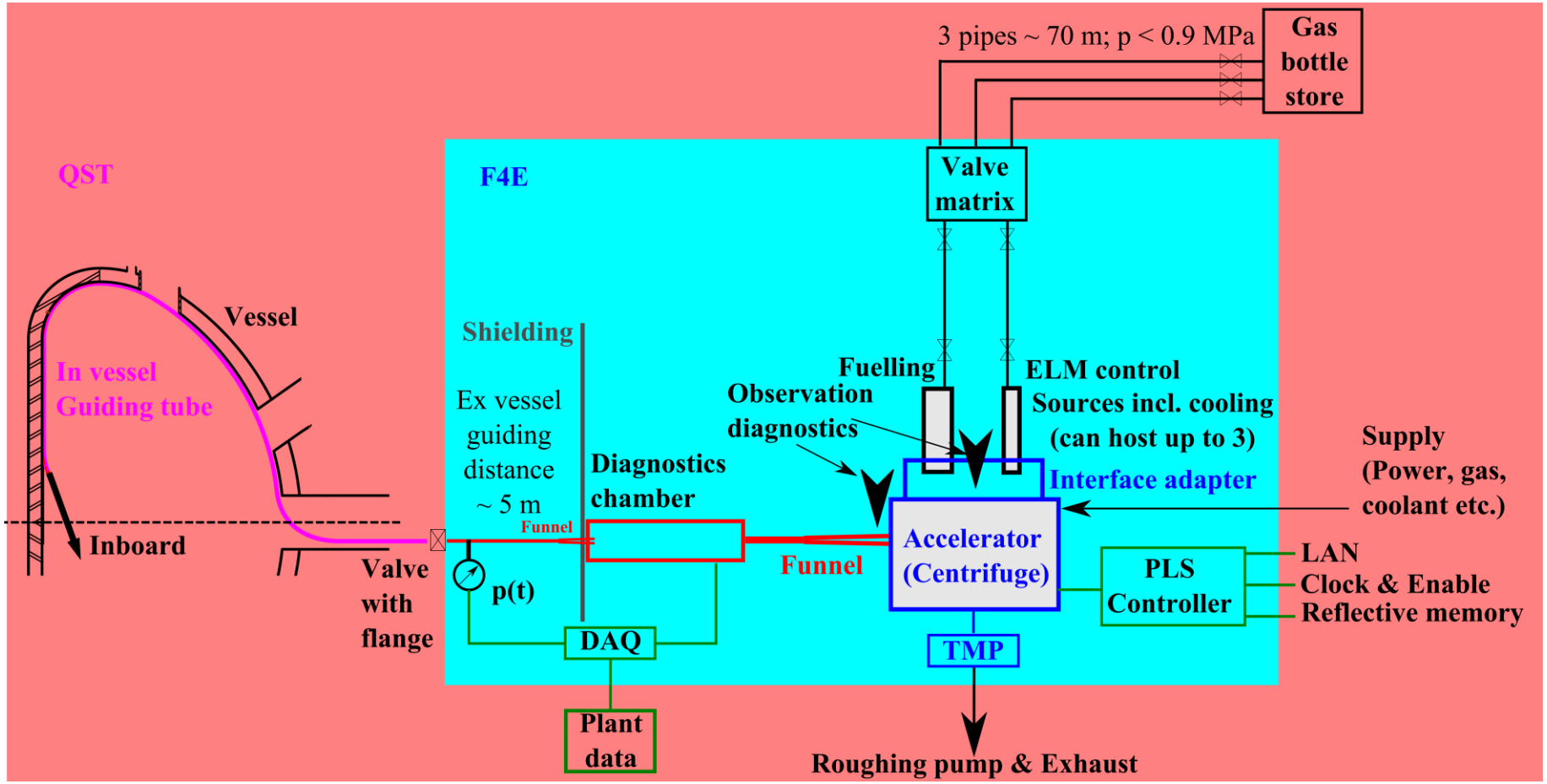
Quantify actuation (in open loop) during the initial research phase I

Prepare closed-loop control experiments in the initial research phase II

➔ **Pellet actuation for fuelling (density gradient) and ELM control within the advanced real-time control scheme**

PELLET LAUNCHING SYSTEM LAYOUT

PLS scheme with projected responsibility as shared between QST and F4E



Initial PLS tests and commissioning in the IPP pellet lab ➔ Performance reference

Full commissioning after (re)-installation in torus environment: Safety – Operation - Control

WPSA coverage: the IPP tasks

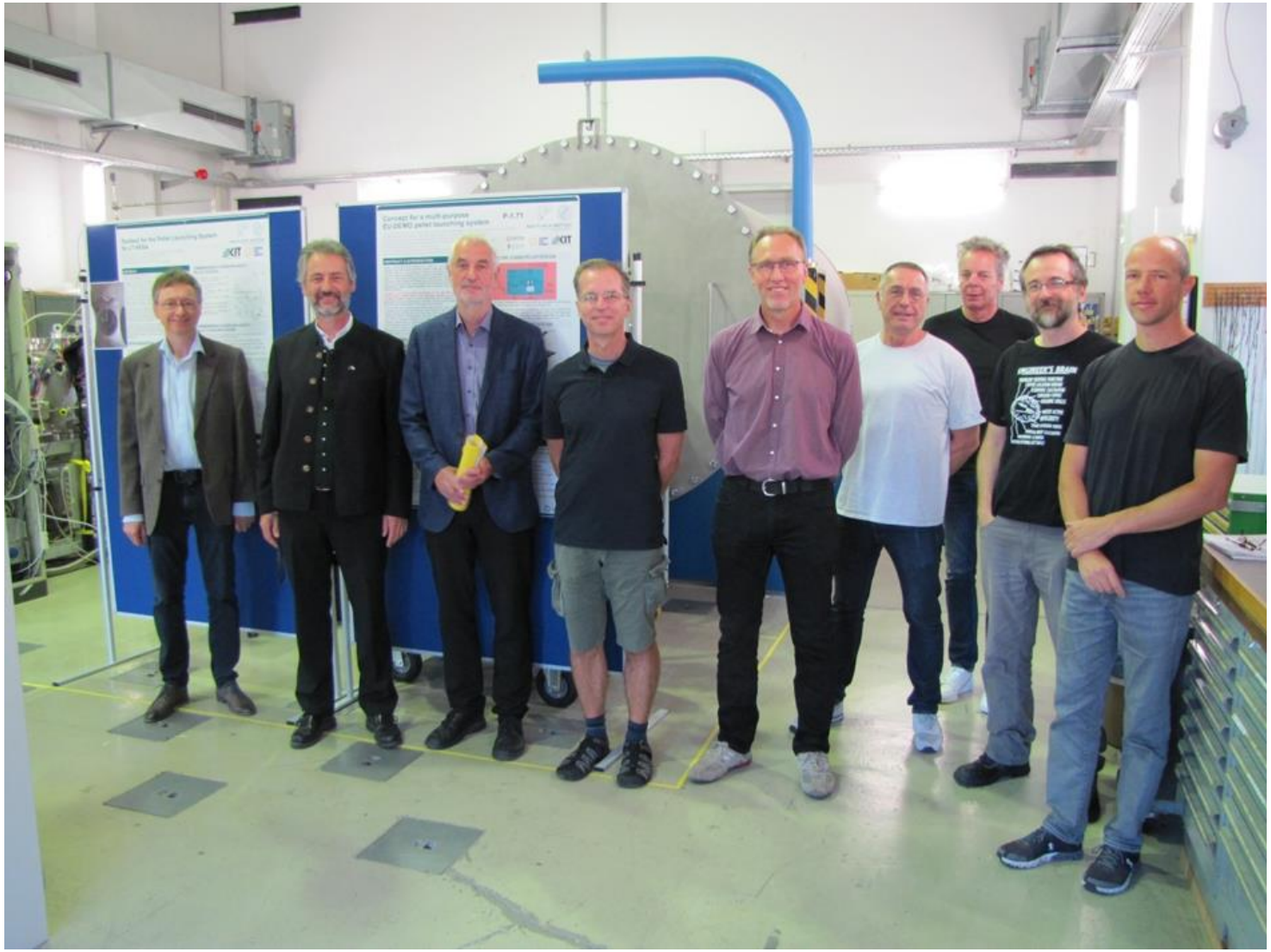
The procurement arrangement of the PLS is a contract between QST and F4E

Within WPSA, **IPP experts contribute by supporting F4E**

Task title: 2026 Support pellet injection system design and procurement
Task description:
- Check documentation by SENER
- Witness factory tests at the site where the SENER unit will be tested
- Preparation of arrival of the SENER unit in the IPP lab
- Delivery into the lab, installation and provisional start up
- Safety assessment including ATEX certification by notified body
- Start up and test of system
- Integration into the control system
- Preparation of the interfaces to the QST control system
- Preparation of the installation at the QST site
- Support of a new procurement for pellet sources

Budget: 8 PM in 2026, 6 PM in 2027

PELLET TEST LAB & SUPPLY CONTRACT F4E - IPP



Supply contract F4E-OPE-1354 signed August 2023 valid for 3 years

KOM September 9., 2023

Lab readiness demonstration September 21., 2023
ADP submitted October 10., 2023
Approved November 20., 2023

IPP received payment for “Fixed part” & “Pre-financing”
➔ Ready to conduct procurements requested by F4E

PELLET TEST LAB & SUPPLY CONTRACT F4E - IPP

Lab with 10 m^3 dump tank ready since Oct. 2021
Set up for testing of first pellet source (fueling size pellets) expected from PELIN LLC St. Petersburg

Supply contract F4E-OPE-1354
extended until the end of 2027

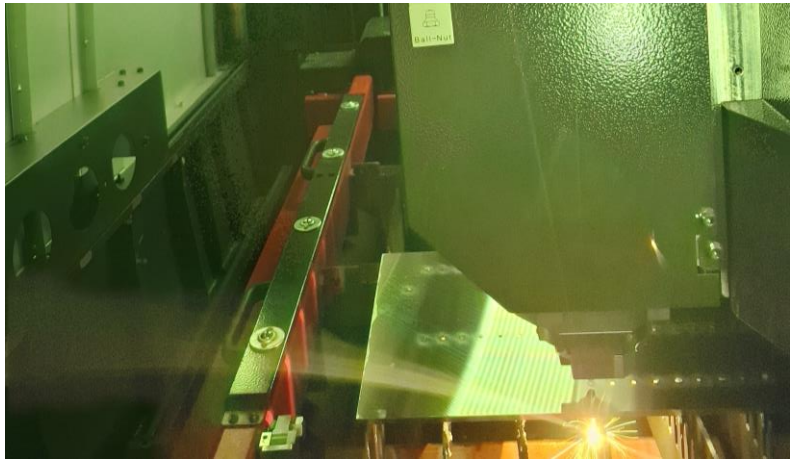
So far 21 “minor procurements”: components needed in order to progress with system integration ordered by IPP as requested by F4E
(and installed as well)
Budget ceiling has to be considered

F4E assumes lab needed at least until summer 2028, longer term use for Mk2 launcher considered

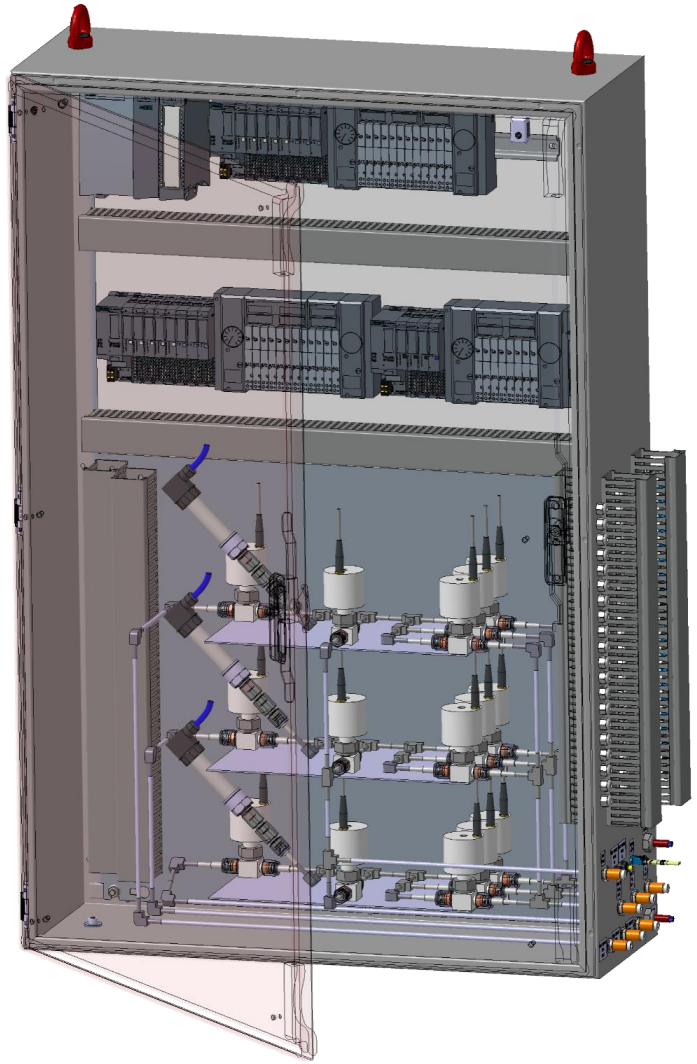


SUPPLY CONTRACT: IPP lab amendments

New valve box designed and manufactures in stainless steel cubicle

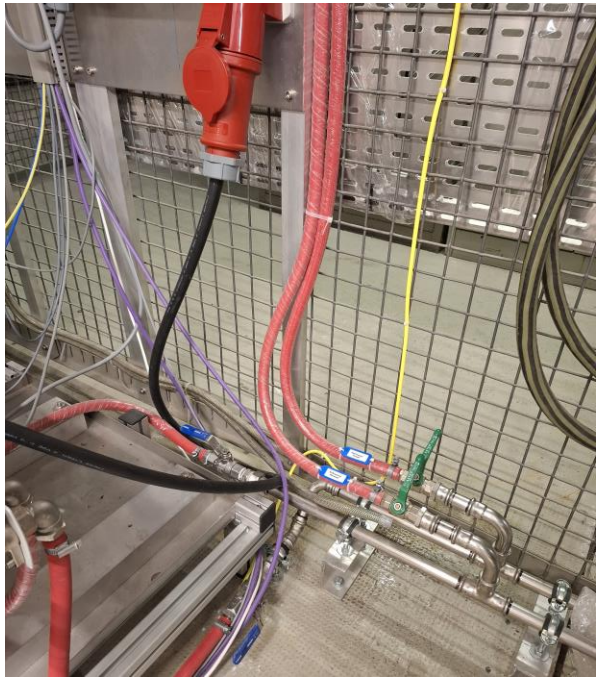


Old one produced from ferromagnetic steel will serve for test of final pellet sources

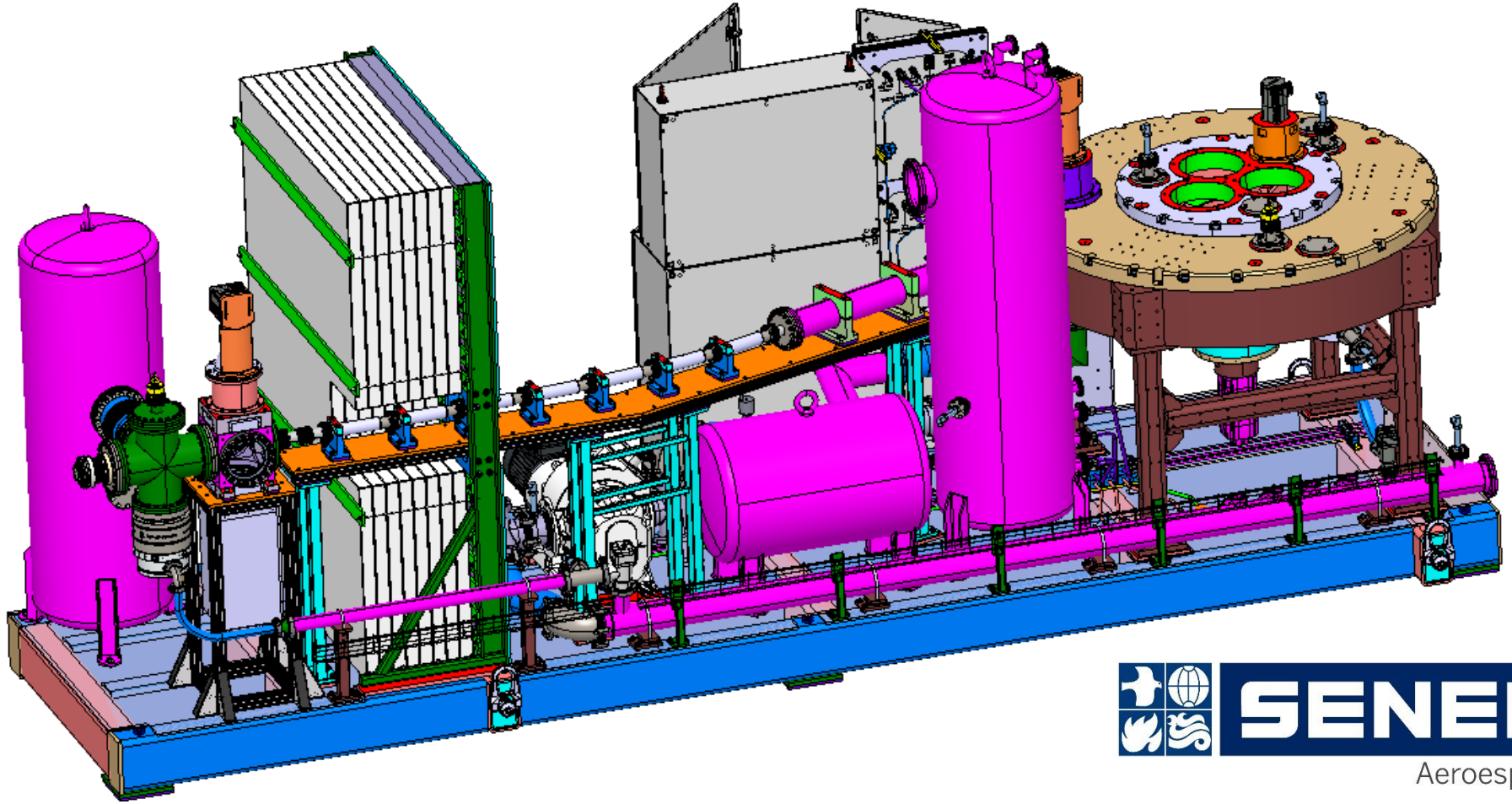




Additional cooling water circuit for revised launcher design



PELLET LAUNCHING SYSTEM: SENER



Design of the launching system ready to accept 2 pellet sources and 1st diagnostics unit
Taken from JT-60SA Centrifuge Accelerator Design Description by SENER (DEL1 package)

PELLET LAUNCHING SYSTEM: SENER (at LEADING) FAT 1

Centrifuge manufactured by and at LEADING (SENER sub-contractor)

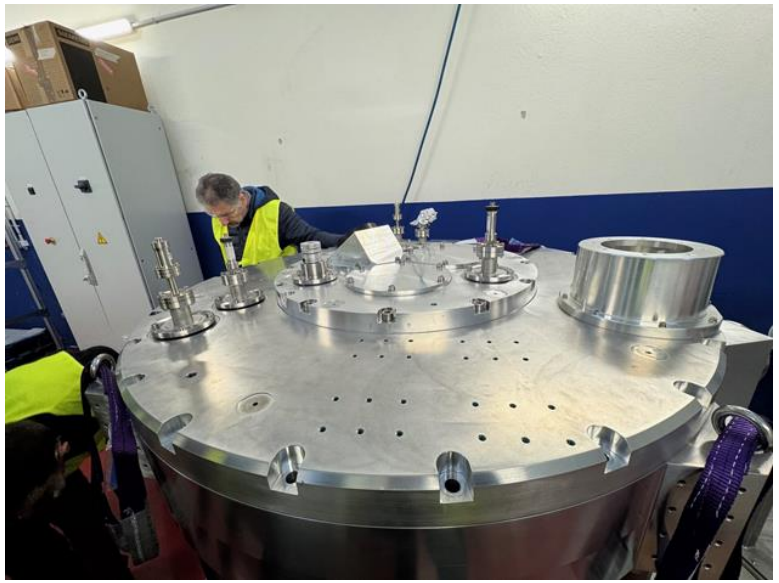
Factory acceptance test (1) lasting 3 days performed at LEADING site (near Santander)

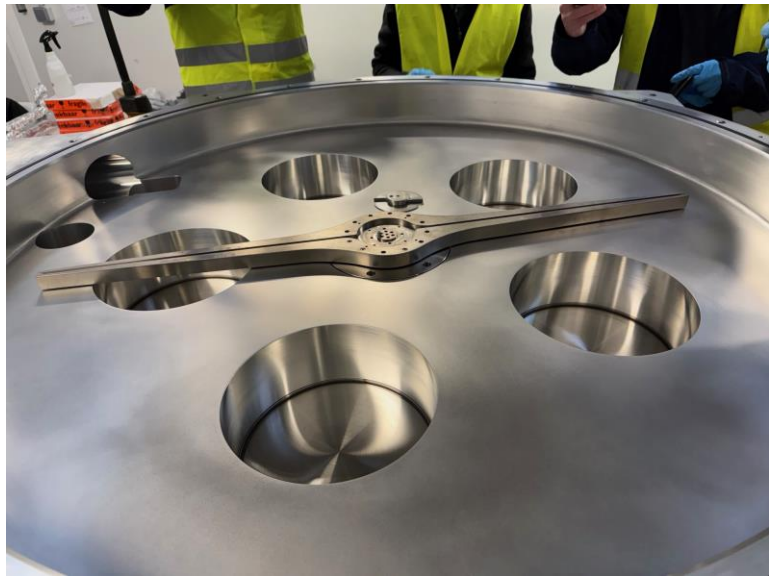
Witnessed by F4E and IPP team – regarded successful

F4E gave o.k. for endurance tests

Endurance tests revealed an issue with the rotating blade bearing (overheating), afterwards solved by changing type of bearing and water cooled feed through

Considered as a substantial change of design ➔ Redo FAT and then redo endurance test







PELLET LAUNCHING SYSTEM: SENER (at home) FAT 2

For full details see:

B. Ploeckl et al., “Recent progress in manufacturing the pellet launching system for JT-60SA”

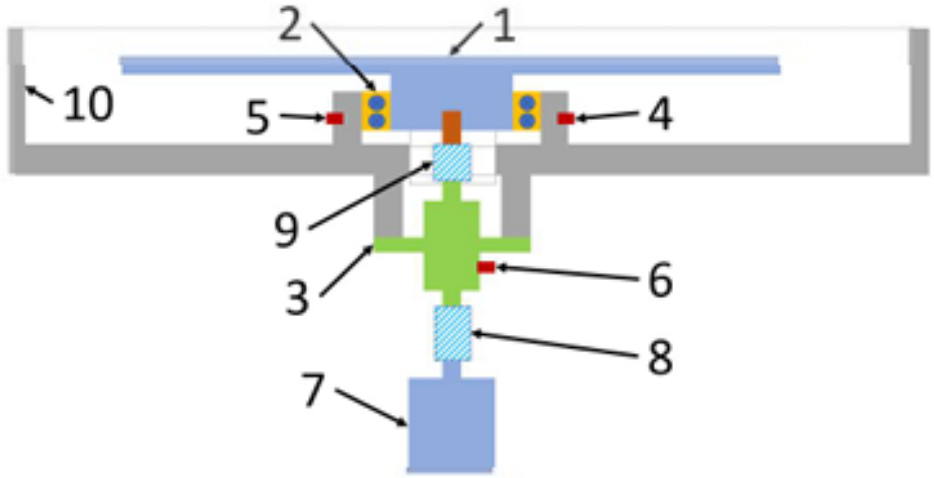
Presentation at SOFT 2026 (Poster P2-BO-036), manuscript submitted to FED

REVISED BEARING DESIGN

The initial proposed solution is an over-constrained system of ball bearings, resulting in high bearing temperatures and a significantly reduced lifetime, particularly in the rotary feedthrough, see reference (3).

The present design introduces two flexible couplings (8,9) minimizing the radial load on the rotor bearings (2) and the feedthrough (3).

The relevant temperature sensors are fitted in the rotor bearing housing (4,5) and on the rotary feedthrough (6).



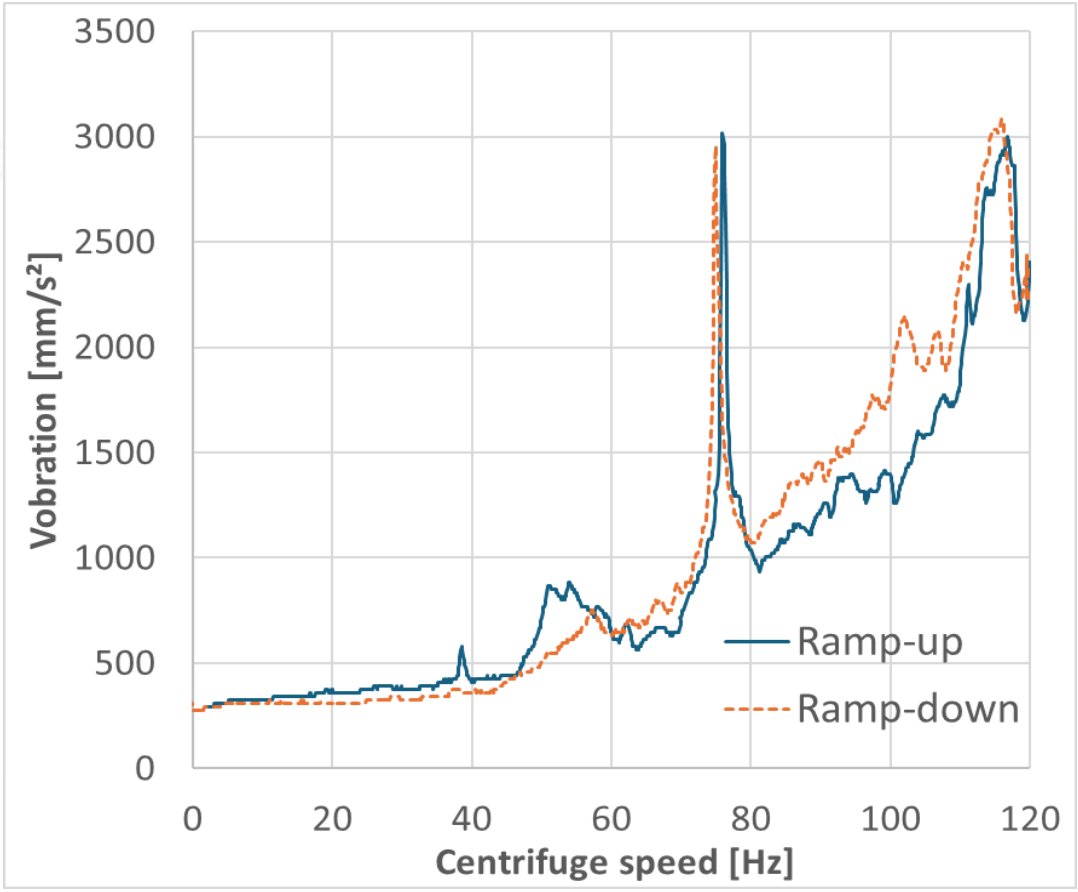
The rotor (1) is situated in the vacuum chamber (10) and driven by the motor (7).

PELLET LAUNCHING SYSTEM: SENER (at home) FAT 2

DYNAMIC TEST

Target: centrifuge to be operational within 80% of the speed range 100 m/s to 600 m/s (20 Hz to 120 Hz).

- Test procedure: speed-up and ramp-down with a gradient of 0.2 Hz/s.
- A small resonance band found between 74 and 77 Hz and one around 115 Hz.
- Accessible pellet speed range: 100 m/s up to 500 m/s.
  Banned region: 370 -385 m/s.



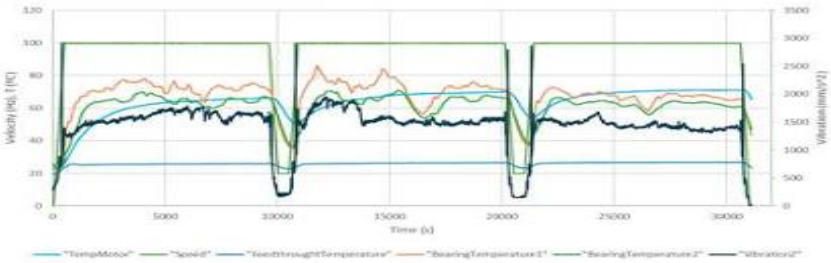
PELLET LAUNCHING SYSTEM: SENER Endurance tests

Short plasma pulses lasting 5 seconds are repeated in groups of 10, with 90 seconds of idle time between each shot. The total number of shots per day is 50. This is mimicked by a sequence involving a 10-minute ramp-up, 79 minutes at 100 Hz and a 10-minute ramp-down. The test mimics 45 operational days and is carried out over 13 days.

Parameter	Value
Total time @ 20 Hz	~33 h
Total time @ 100 Hz	60 h
# of cycles	40
# of revolutions	2.6E7

Discussion of results:

- Feedthrough temperature stable thanks to water cooling.
- Motor temperature stabilizes below 70°C.
- Bearing temperatures oscillating around its individual mean value, but below 85°C.

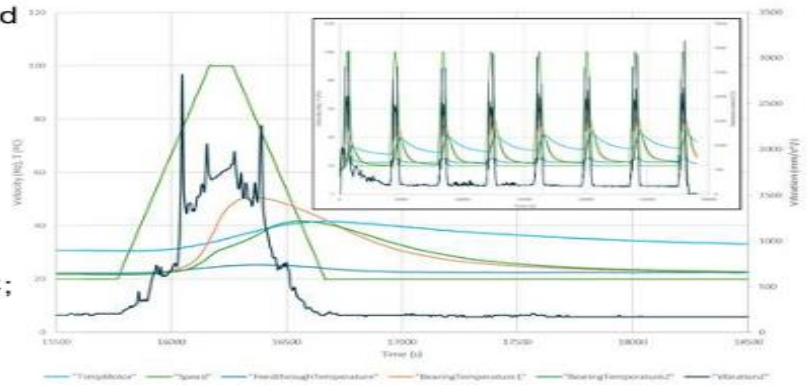


Long plasma pulses last for 100 seconds, whereas the idle time is 3,000 seconds. This test mimics 10 shots per day for five days. The ramp-up and ramp-down times are 10 minutes.

Parameter	Value
Total time @ 20 Hz	42 h
Total time @ 100 Hz	1.4 h
# of cycles	50
# of revolutions	5.7E6

Discussion of results:

- Feedthrough temperature stable thanks to water cooling.
- Motor temperature does not exceed 42°C over the day.
- Ball bearing temperatures remain below 45°C and do not reach equilibrium.
- The vibration during flat top is ~1750mm/s².



Stop criteria for both tests are:

- Rotor bearing temperature >120°C;
- motor torque >1.5 Nm;
- feedthrough temperature >90°C;
- vibration >3000 mm/s²

PELLET LAUNCHING SYSTEM: SENER Endurance tests

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Total time @ 100 Hz	60 h
# of cycles	40
# of revolutions	2.6E7

Discussion of results:

- Feedthrough temperature stable thanks to water cooling.



With FAT and endurance test passed:

➔ System delivery to/into IPP test stand approved

SENER to pack system and responsible for deliver to lab front gate

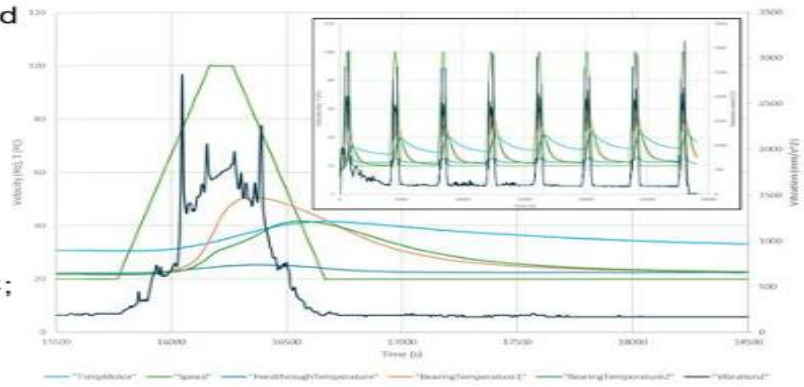
IPP organised (Minor procurement 15) and performed unpacking and transfer into lab

# of revolutions	5.7E6

- Feedthrough temperature stable thanks to water cooling.
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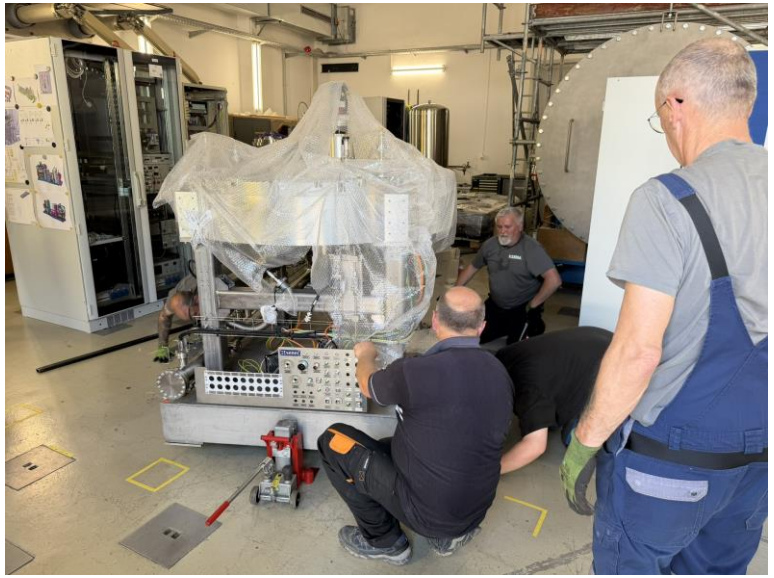


PELLET LAUNCHING SYSTEM: Delivery to IPP test stand









PELLET LAUNCHING SYSTEM: Delivery to IPP test stand



PELLET LAUNCHING SYSTEM: Preparation of installation

Centrifuge delivery to IPP test stand: June 1., 2026

Between delivery and installation (July 21. - 23.)

Sort out final issues (e.g. still missing or malfunction components, spare parts, documentation..)

Prepare installation plan:

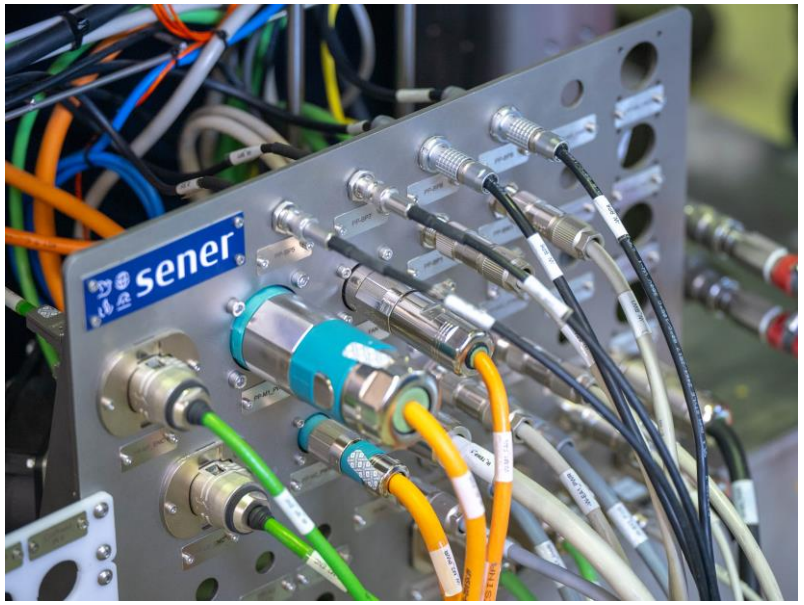
- Get the system into the configuration as during FAT2. System must be fully operational.
- Full installation of all components delivered by SENER, incl. shielding.
- Inspection of the guiding tube surface quality.
- Integration of system into lab environment.
- Connection to the MasterPLC.
- Get control over the system by the MasterPLC.
- Full sync. test with diagnostics 1
- Demonstrate centrifuge ramp-up to 100 Hz, keep it running for 100 s, ramp-down. Record vibrations and compare to results from FAT2.

PELLET LAUNCHING SYSTEM: Installation



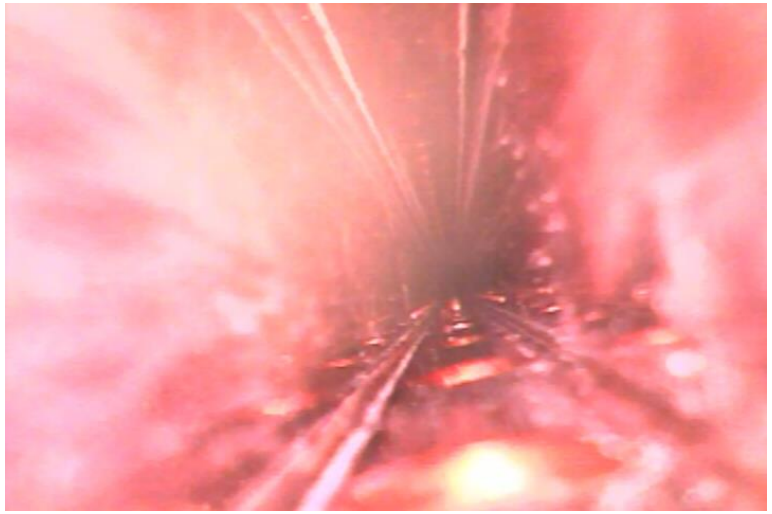


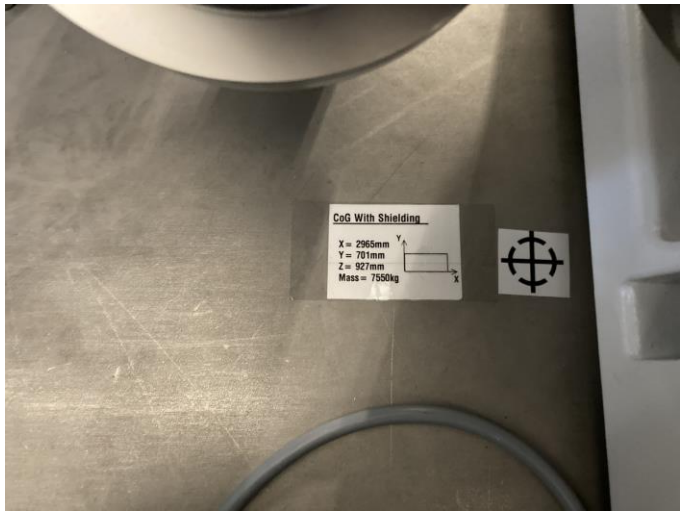




PELLET LAUNCHING SYSTEM: Installation

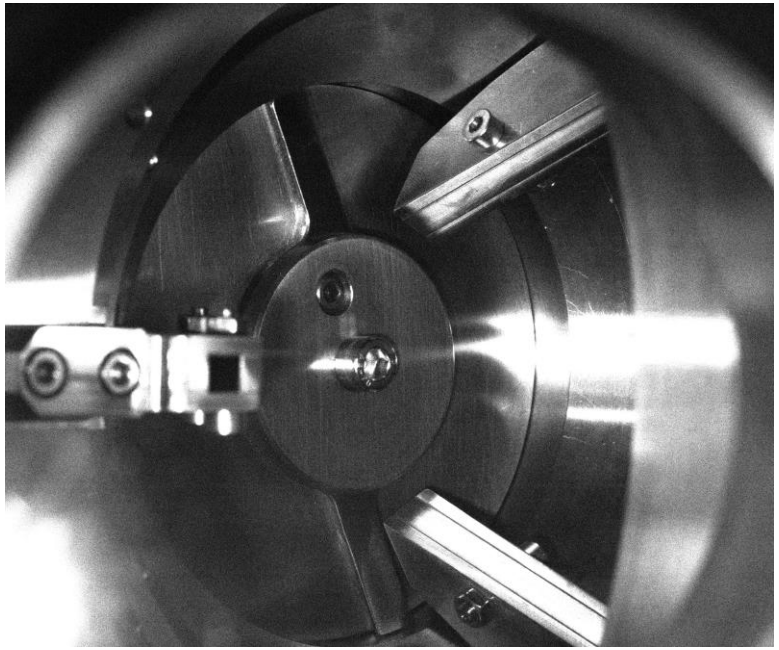
Endoscope:
Guiding tube
Inside

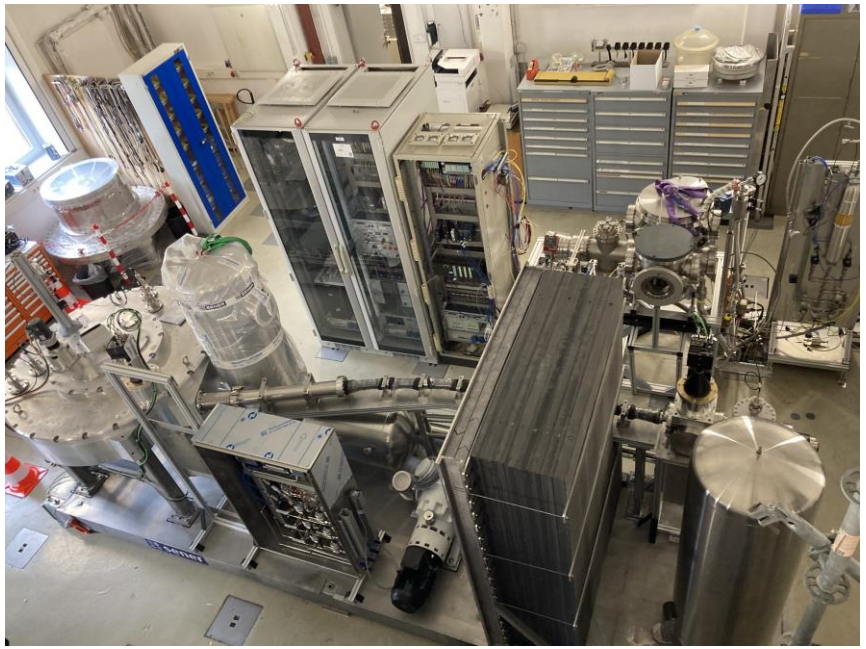




Marks:
Centre of
gravity
(**with** or *without*
shielding)

Stroboscope:
Stop cylinder
area with yet
double inner
arm rotating at
100 Hz





PELLET LAUNCHING SYSTEM: Post installation test

In order to prove the system is functional and can be operated without SENER:
September 8., 2026: On Site Test – Operation of centrifuge and static vibration loads

F4E/IPP team started HMI, turbo pumps and centrifuge
Frequency ramp in 10 Hz steps from 20 – 100 Hz
Keep every frequency stable for 5 minutes, record vibration level
Ramp down centrifuge, shutdown centrifuge, turbo pumps and HMI

Reproduced behavior as demonstrated by SENER when concluding installation as final point of their installation task list

PELLET LAUNCHING SYSTEM: Remaining tasks

Work in progress:

Safety assessments

- Electric safety assessment according to EN 60204-1 (Oct. 7., 2026)
  ➔ Findings to be corrected in the SENER document “General Electrical Layout”, missing ground connection

…

Check of sensor/actuator labelling ➔ Inconsistent with reference documents

Improper handling of lasers of class 3B (safety issue)

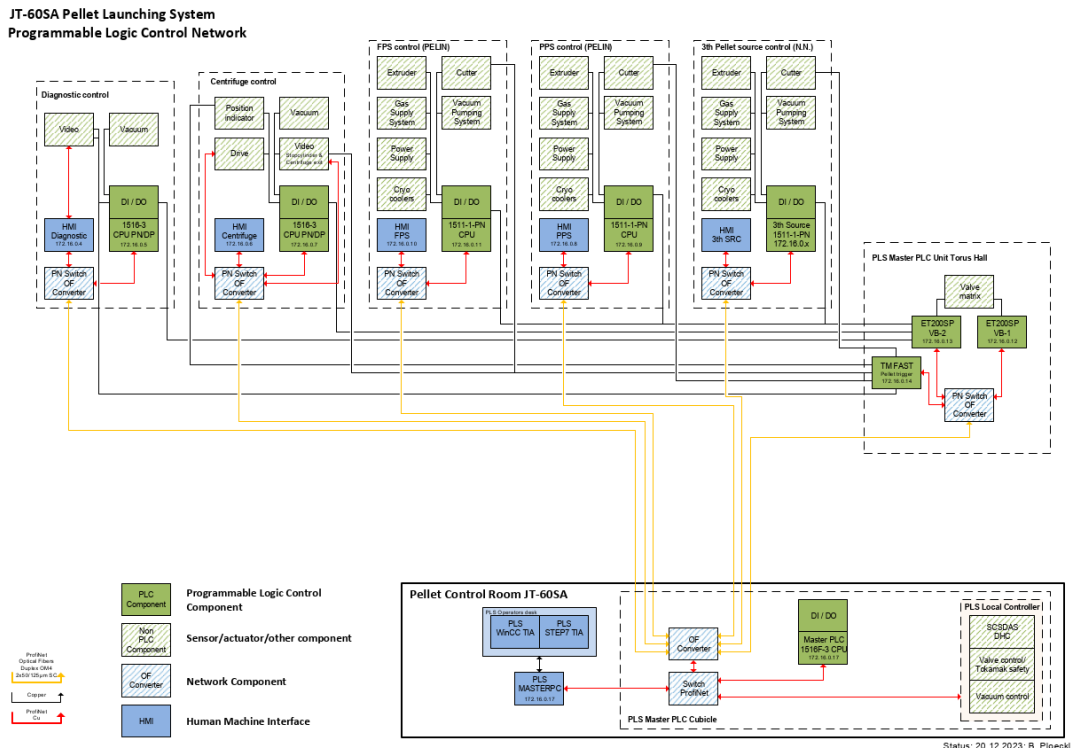
Vacuum components still missing to connect ice dump, roots pump and collector

….

Change stop cylinder configuration from double to single inner arm

PLS main component status & plans: IPP contributions

- MasterPLC supervising all sub systems
- Mockup sent to QST
- Operators desks in separated control room
- New valve matrix from stainless steel
- ATEX (hydrogen safety) certification for AUG pellet source passed, for further equipment still needed



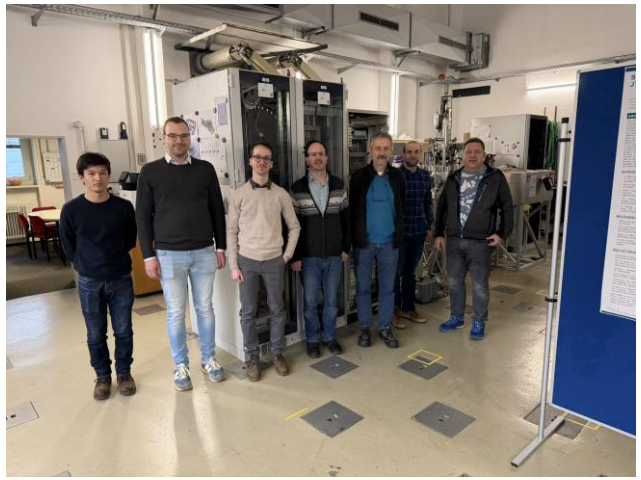
Initial installation/integration of launcher until ~ end of 2026
Final integration work after delivery of preliminary pellet sources for delivery to QST in 2028
F4E considers procurement of Mk2 launcher and make IPP lab long term facility for research

IPP lab acting as a “pellet fuelling exposition location”

A couple of visitors took the opportunity to have a look at the system and to discuss relevant issues















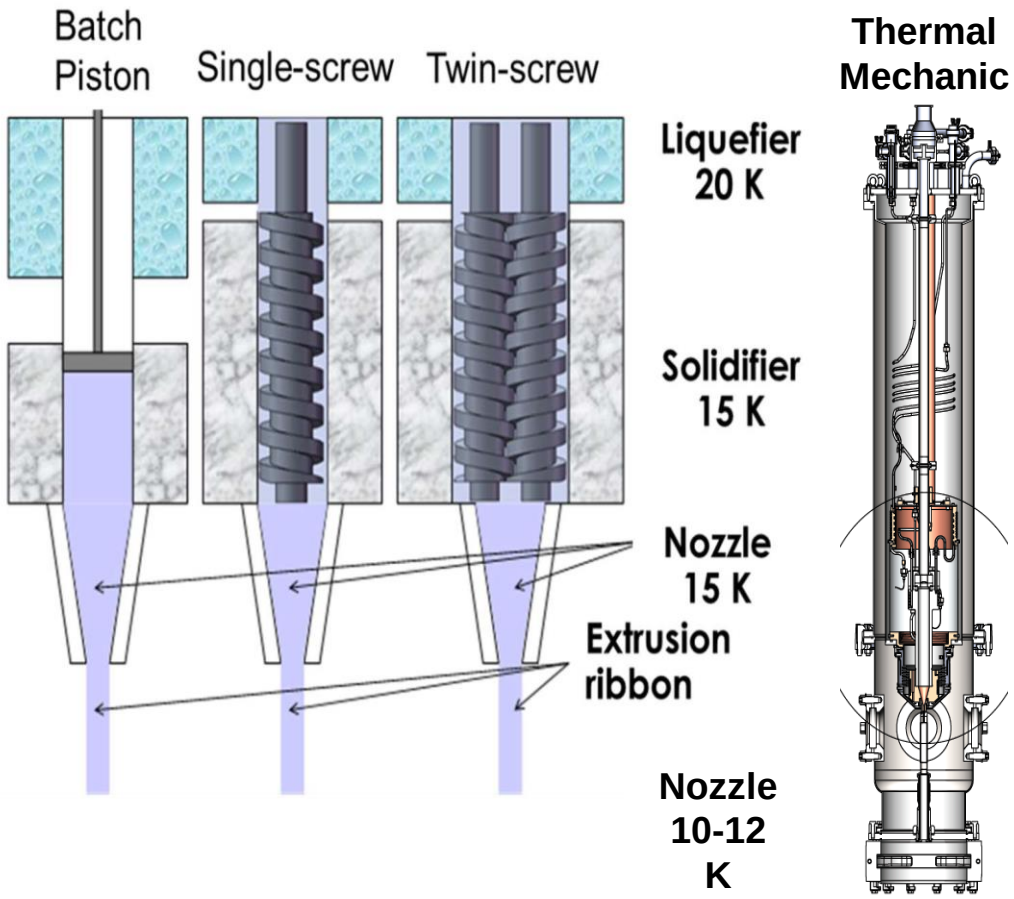
PLS main component status & plans: Pellet sources

- Call for tender 2019/2020, order for steady state fuelling and pacing source to PELIN St. Petersburg
- Envisaged delivery for fuelling source Oct. 2021 first delayed, then suspended, then terminated
- F4E went to new call, now stepwise approach:

- Temporary sources (5 s pulses) **fuelling first**
- Final sources (100 s pulses)

- Integration of temporary sources and delivery to QST until June 2028
- Testing of final sources and replacing preliminary sources at QST until September 2030

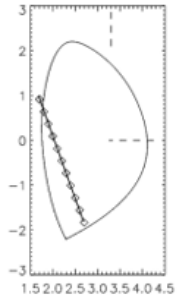
4 offers received for call, decision awarding 2 lots in 2026, first task order launch expected January 2027
Delivery of first source by Mid-2027 at the earliest



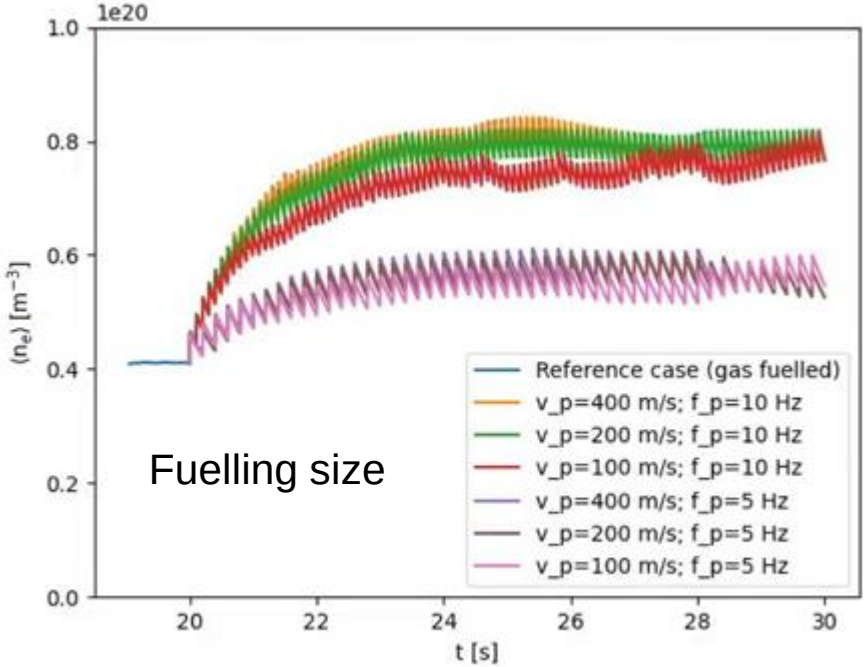
Pellet source prioritisation

Report by S. Gabriellini, L. Garzotti and D. Taylor: Modelling of the plasma response to pellet injection in JT-60SA

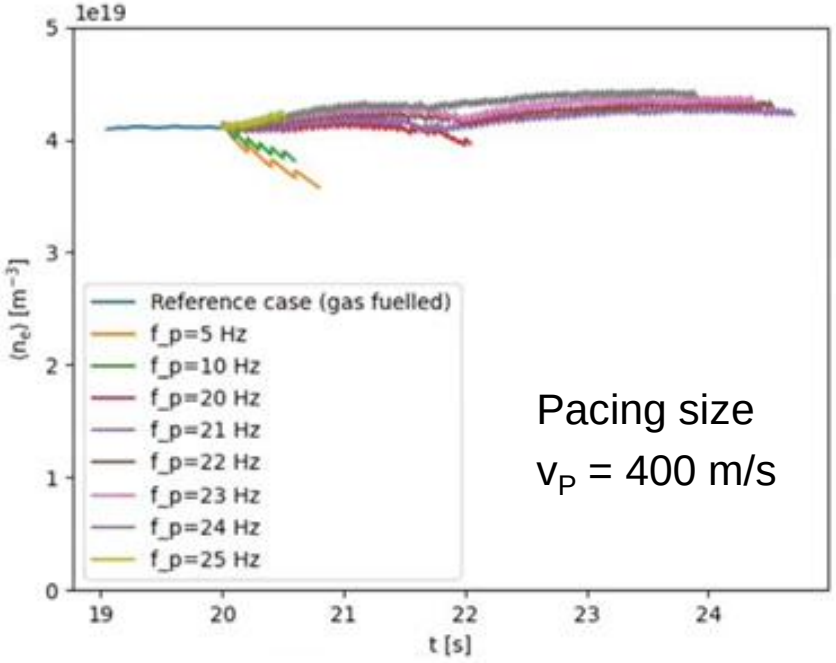
The plasma scenario considered was the JT-60SA baseline scenario designed for operation phase two, I_p=4.6 MA, B_T=2.25 T, q_{95}~3 and P_{aux}=19 MW the modelling of which is described in [1].



Pellet geometry („No final limit“) used in the modelling



Fuelling size



Pacing size
v_P = 400 m/s

JETTO with the Bohm/gyro-Bohm transport model keeping constant the pressure at the top of the pedestal

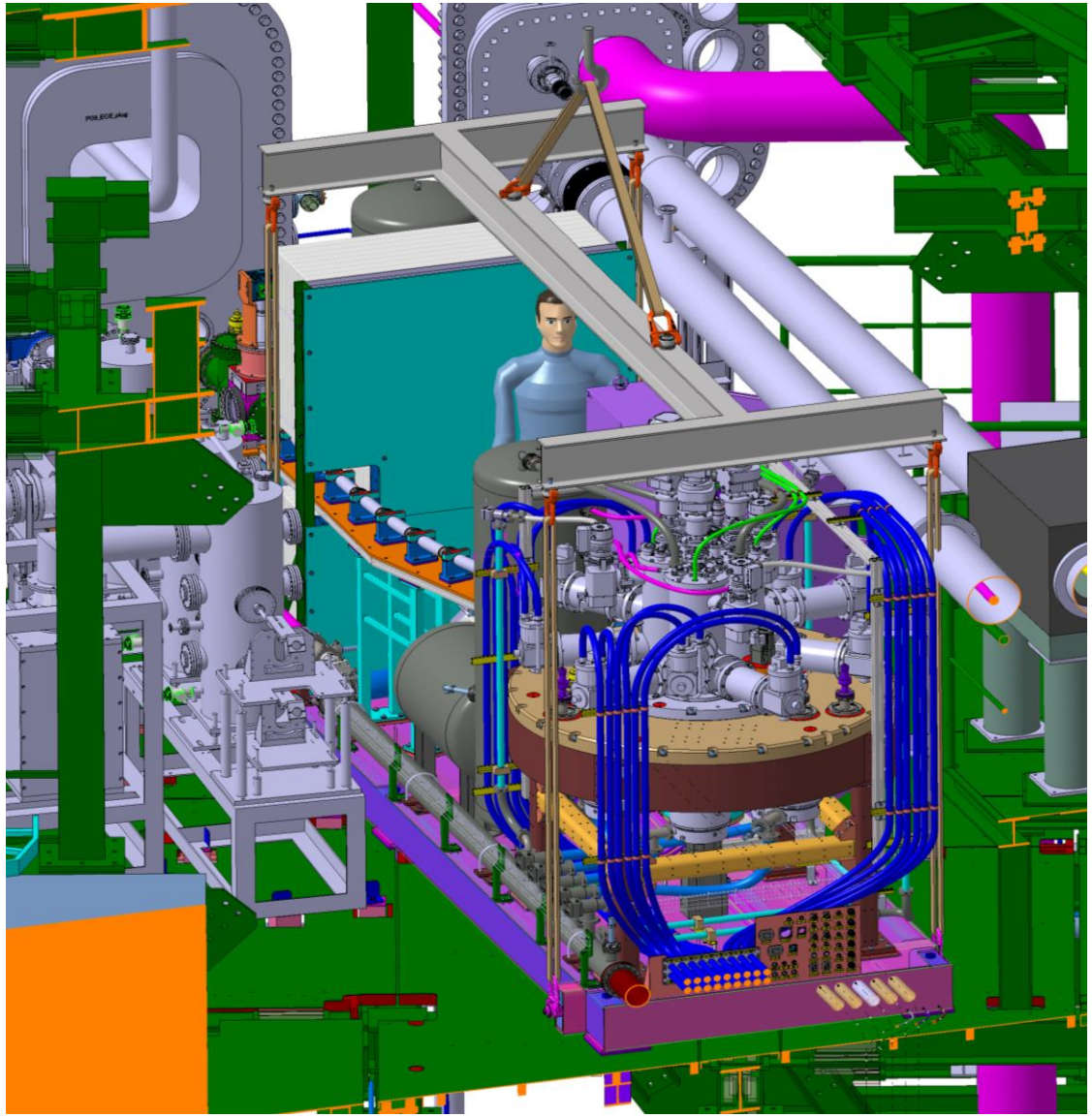
Finally, in our opinion, **fuelling and particle transport studies should be prioritized**, delaying the pellet ELM triggering experiments and the development of schemes where fuelling and ELM triggering pellets are applied simultaneously to later operational phases where a fully developed, reliable and robust ELMying H-mode scenario will be available.

PLS main component status & plans: On-site / QST

Monthly PM with QST

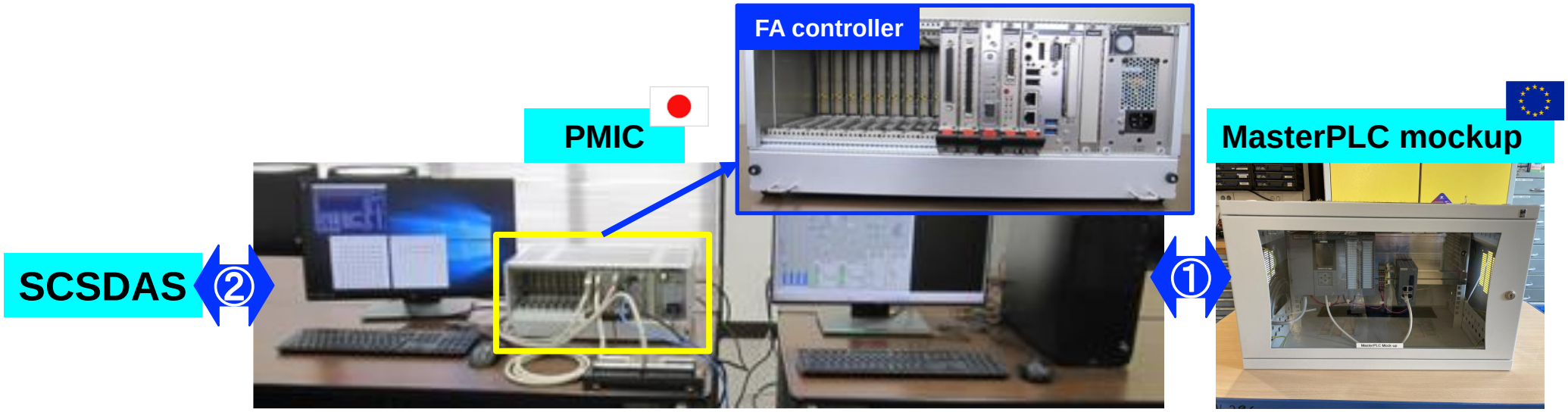
- In-vessel guiding tubes installed
- Master PLC mockup imported from F4E/IPP
- Development of “PLS/MGI local controller (PMIC)” serving as interface between SCSDAS (QST) and pellet control system PLC (EU) in progress
- Modification of P10 common stage taking into account PLS configuration on skid (incl. front shielding) envisaged
- Use provided CAD model to plan “fly in” and installation
- Preparation for PLS arriving for (ME2 or) ME3

Transfer of ownership after delivery to torus hall before transfer to P10 common stage
Functional tests after installation at P10



QST: Controller interface

- QST is developing “PLS/MGI local controller (PMIC)” to serve as interface between SCSDAS (QST) and pellet control system PLC (EU).
- Master PLC mockup has already been imported from EU.
- PMIC hardware equipped with real-time OS and refrective memory has been completed.
- We are currently developing software for connection among SCSDAS and master PLC mockup.



QST: Controller interface

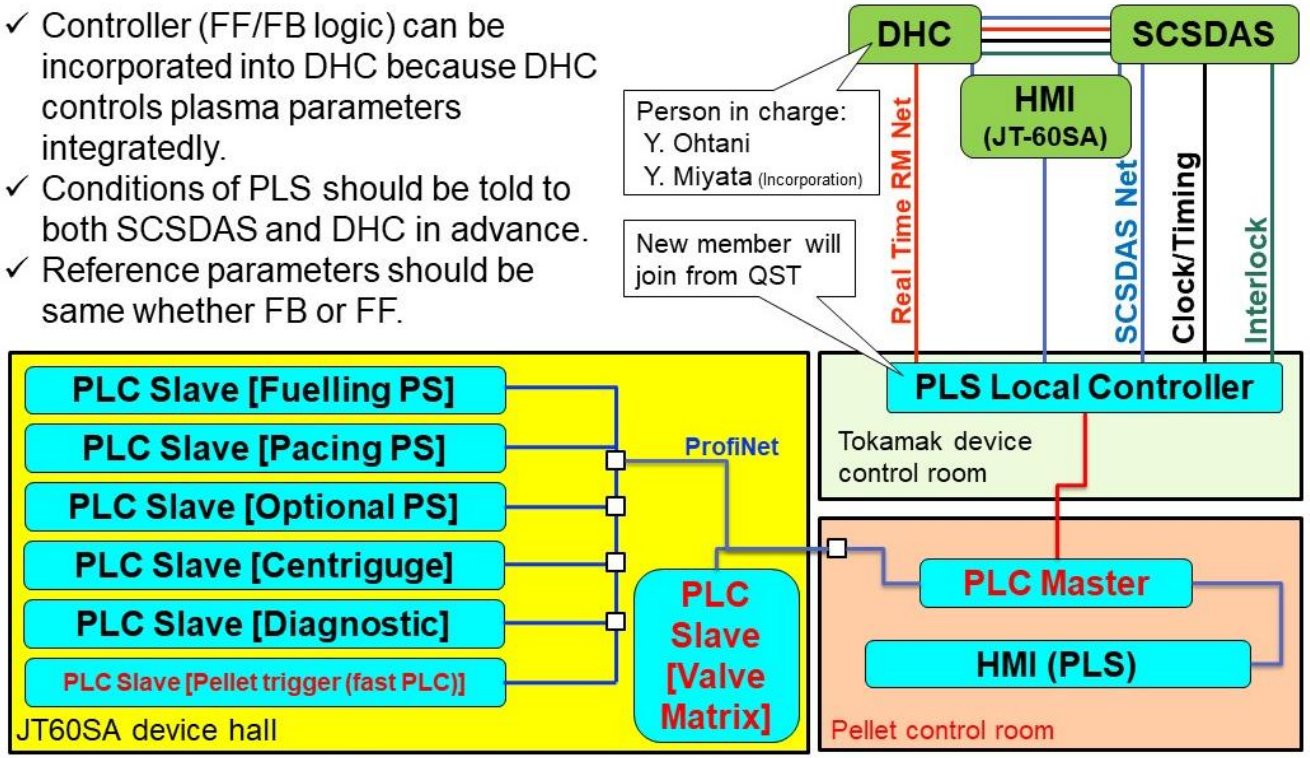
Mock-up of PLS MasterPLC prepared at IPP

Shipped to QST

Enables development of PLS local controller

Replaced by “real” one and serves as spare part

- ✓ Controller (FF/FB logic) can be incorporated into DHC because DHC controls plasma parameters integratedly.
- ✓ Conditions of PLS should be told to both SCSDAS and DHC in advance.
- ✓ Reference parameters should be same whether FB or FF.





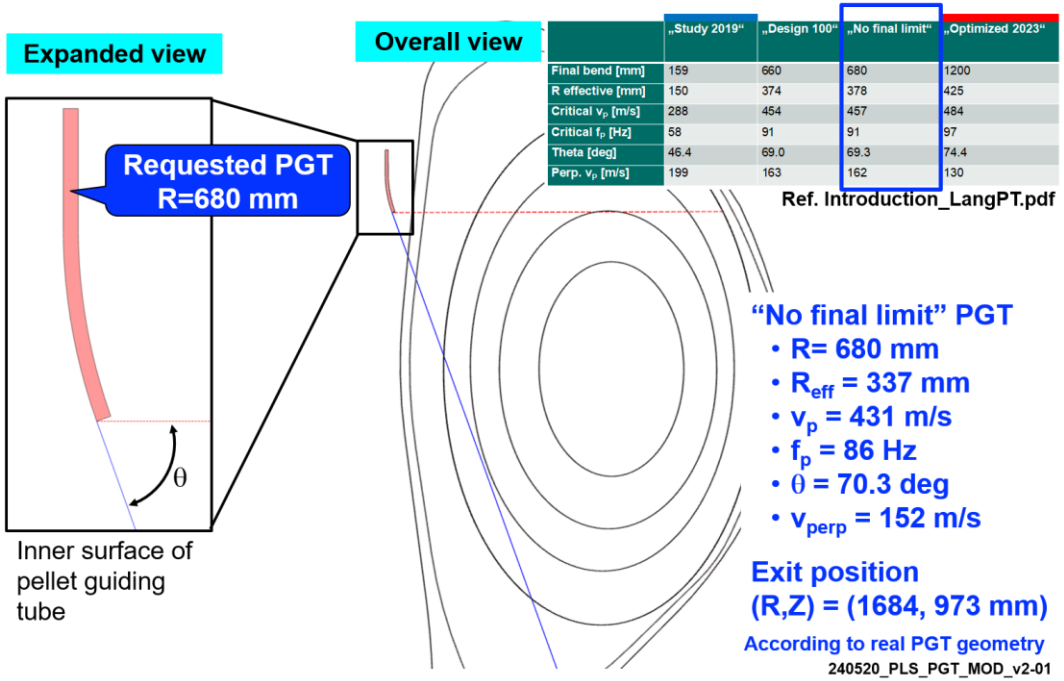


QST: In-vessel guiding system and launcher layout adapted

Pellets leaving launcher enter torus via double gate, transfer through QST in-vessel guiding tube

Maximum expected transfer speed for fuelling pellets about 450 m/s, slightly higher for pacing pellets

Design of “No final limit” PGT



Layout of centrifuge covers launch speed range 100 – 500 m/s adapted to this configuration

COMMISSIONING PLAN “IN A NUTSHELL”

Initial discussion 09/2021 – 07/2022

https://wiki.euro-fusion.org/wiki/WPSA_Operations:_Pellet_Injection

#	Commissioning phase	Aim
0	Off-site commissioning and characterisation in test bed	Elaborate target performance for on-site commissioning
Transfer of ownership F4E ➔ QST		
1a	Functionality tests of the PLS infrastructure	Proof safe local non-cryogenic operation of hardware
1b	Pellet production, acceleration and transfer to torus entrance gate valve	Proof safe local cryogenic operation of hardware
2a	On plasma safety tests	Proof safe integrated cryogenic operation of hardware
2b	Pellet acceleration and transfer into torus Optimising pellet production Establish and confirm pellet arrival in plasma	Proof fundamental integrated cryogenic operation of hardware
2c	Optimising the performance on plasma	Proof sound integrated cryogenic operation of hardware
End of the (formal) commissioning phase		
3	Controlled plasma operation	Proof sound controlled integrated cryogenic operation of hardware
4	Enhanced capabilities (optional)	Proof sound controlled integrated cryogenic operation of hardware beyond specs

Updated according to PA boundary conditions

Up-to-date version of the official template is a delivery at the end of 2026

Kept afterwards still “a living document”

COMMISSIONING PLAN: EXCEPTIONAL CHALLENGES

- Alternating status with respect to PLS internal pressure

Before pellet sequence: (almost) high vacuum conditions
During pellet sequence: up to 1 mbar – this is a fuelling system!
Handling of torus access (opening of torus gate valve and keeping it open)
AUG : Check high vacuum shortly before plasma pulse – “gated omitting” during actuation

- “Unstoppable pellets”

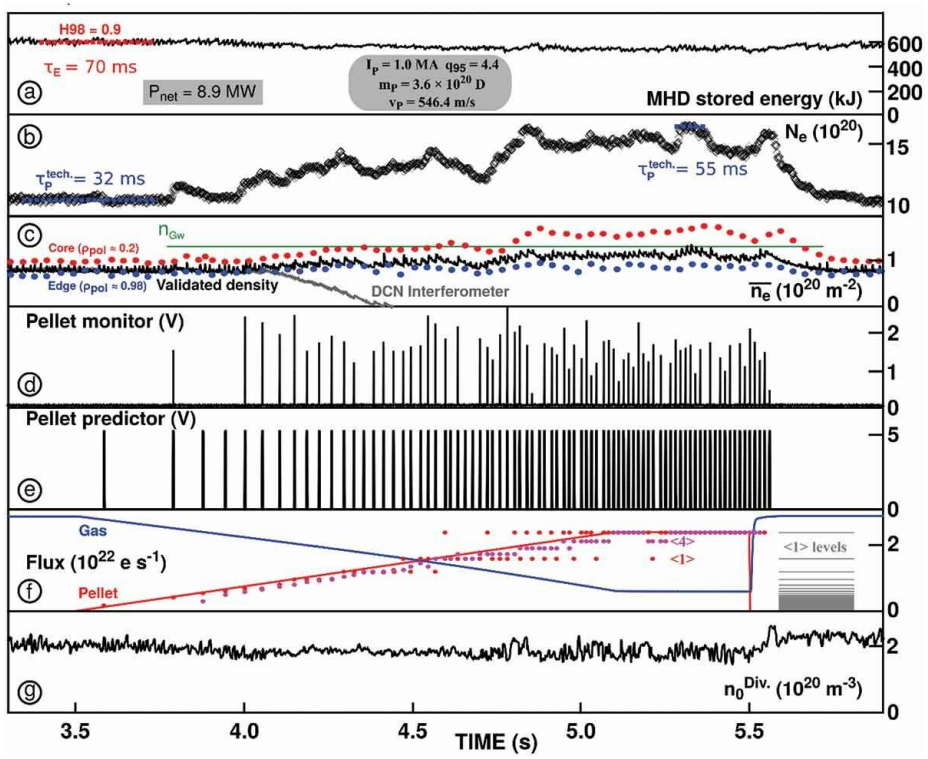
A requested pellet cannot be stopped anymore – once cut, its accelerated and launched
Delivery time up to 200 ms – Repetition rate up to 70 Hz ➔ Up to 15 pellets
Pellet arriving after pulse termination (request) in vacuum vessel
AUG: Impact causes no problem, no deleterious effect found during disruption phases

- Safe combination Pellet fuelling – ECR heating needs notching

Pellet can create transient high density layer in plasma – opaque for ECRH ➔ stray radiation
Can be avoided by “notching” of ECRH pulse
Long SCSDAS response time ➔ long off-phases ➔ strong reduction of averaged P_{EC}

IMPORTANT OPERATIONAL ISSUE: INTERPOLATED FLUX/PACING RATE

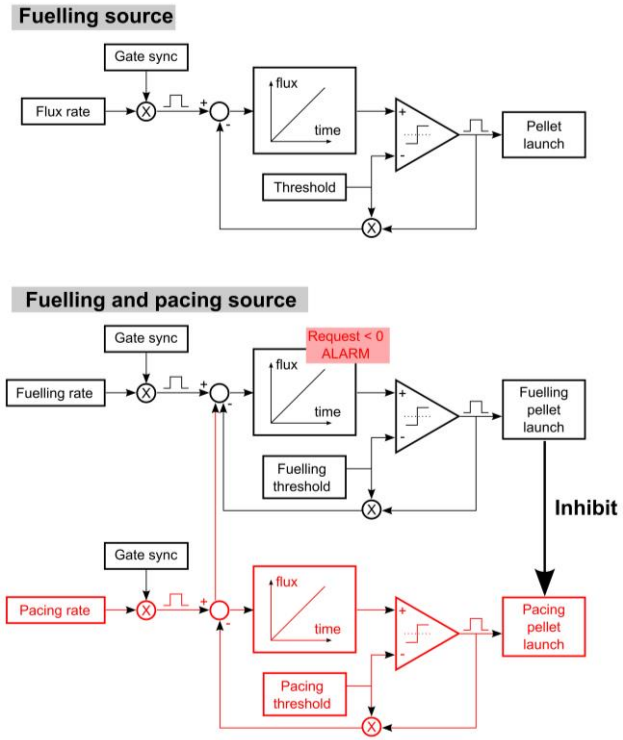
Pellets are discontinuous events ➔ Flux/pacing rate has “granular” structure
Centrifuge accelerator allow for regular launching slots (one per revolution)
➔ Filling of possible launching slots in order to achieve best match of request “on average”
AUG: Demonstration for fuelling flux (only single pellet source)



AUG:
Fuelling only

JT-60SA:
Fuelling or pacing

Fuelling & pacing
Cross talk considered
First multi- actuator
PLS ever!



Documentation (Restricted access!)
IPP test stand

In principle not relevant for on-site commissioning

Lab readiness document (Acceptance Data Package) –

Storage in idm@f4e “https://idm.f4e.europa.eu/default.aspx?uid=336XKG”

ATEX expertise

F4E-OPE-1354_Minor_Procurement_01 (Assessment of hydrogen safety of PLS in IPPlab)

Storage in idm@f4e

Planned:

ATEX certifications after (i) arrival of pellet source; (ii) after installation of entire system

Results of off-side (IPP test stand) commissioning

Documentation (Restricted access!)
Pellet sources

PELIN documentation for both sources (Contract No. F4E-OPE-1044)

Available but obsolete

Technical Project “JT-60SA FUELLING PELLET SOURCE”

Saint-Petersburg November 20., 2020

Technical Project “JT-60SA PACING PELLET SOURCE”

Saint-Petersburg December 29., 2020

Documentation from selected suppliers for lot 1 and 2 yet to come

Documentation (Restricted access!)
SENER launcher

Documentation supplied steadily by SENER

Checked by F4E and IPP experts

“Deliverables” Uid 2W5384

- Risk analysis *(32UEZ2_v2_0)*
- Quality Management Plan *(32V2AN_v2_0)*
- JT-60SA Centrifuge Accelerator Local Control System Design Description *(369QQP_v1_0)*
- JT-60SA Centrifuge Accelerator EBOM, Material List and Spare Part List *(35KLNB_v1_0)*
- JT-60SA Centrifuge Accelerator Delivery note 23-12-14 *(36AMVM_v1_0)*
- Hazard Analysis *(3382U2_v2_0)*
- Design Description *(338EBQ_v3_0)*
- 30P0121-2201 JT-60SA Centrifuge Accelerator *(36ABR5_v1_0)*
- JT-60SA Centrifuge Accelerator P&ID Diagram *(369WN4_v1_0)*
- Inspection & Test Plan *(32UVJ8_v2_0)*
- Compliance Matrix *(32V9XM_v2_0)*
- CIDL *(338R6G_v2_0)*

DEL 1: Detailed Design Report

4 F4E documents, 12 supplier documents ->

DEL 2:

2 F4E documents, 6 supplier documents (test procedures)

Final compilation and storage in progress

Documentation (Restricted access!) QST interface

Mock-up of PLS MasterPLC arrival at QST
➔

Documents at idm@F4E:

PLS Control Modes Interfaces

Uid: 38WTWA (Version 1.2)

PLS Infrastructure Requirements

Uid: 38WCUD (Version 1.3)




THANK YOU
FOR YOUR
ATTENTION

Backup slides

QST: IN-VESSEL GUIDING TUBE SUPPORT

Discussion for optimum injection geometry ongoing since 2015

➔ Decision to go for inboard launch

“Narrow bend solution” 2019 led to high revolution centrifuge design (short arm, f_c = 300 Hz)
Final section with narrow bend (R = 159 mm) with 46^o declination (w.r.t. horizontal) injection

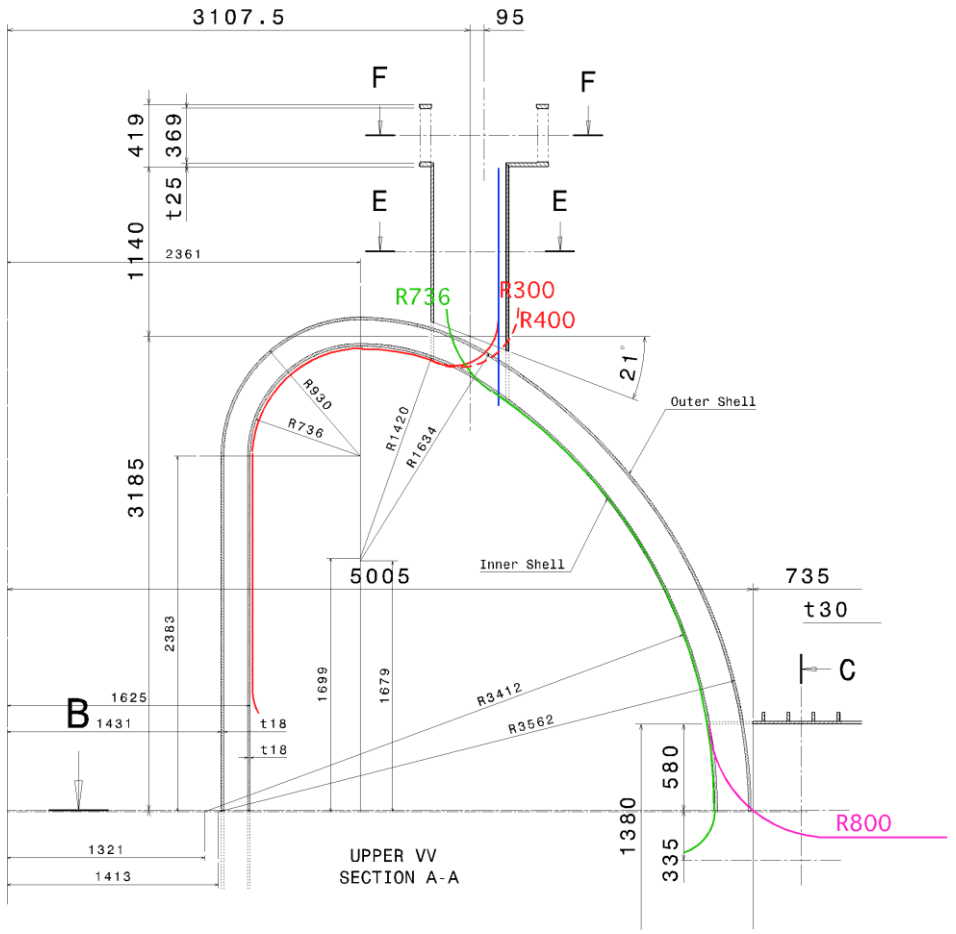
Optimised layout and 100 ms response time of SCSDAS density and heating controller

➔ Agreed on “Design 100”

Longer arm, design point v_P = 500 m/s @ f_c = 100 Hz

➔ Final section with wider bend (R = 660 mm) and more 69^o declination

Optimising “perpendicular” pellet speed



Potential solutions worked out by T. Nakano in 2015

QST: IN-VESSEL GUIDING TUBE SUPPORT

February 2023
QST revised guiding tube ignoring launch parameter optimisation

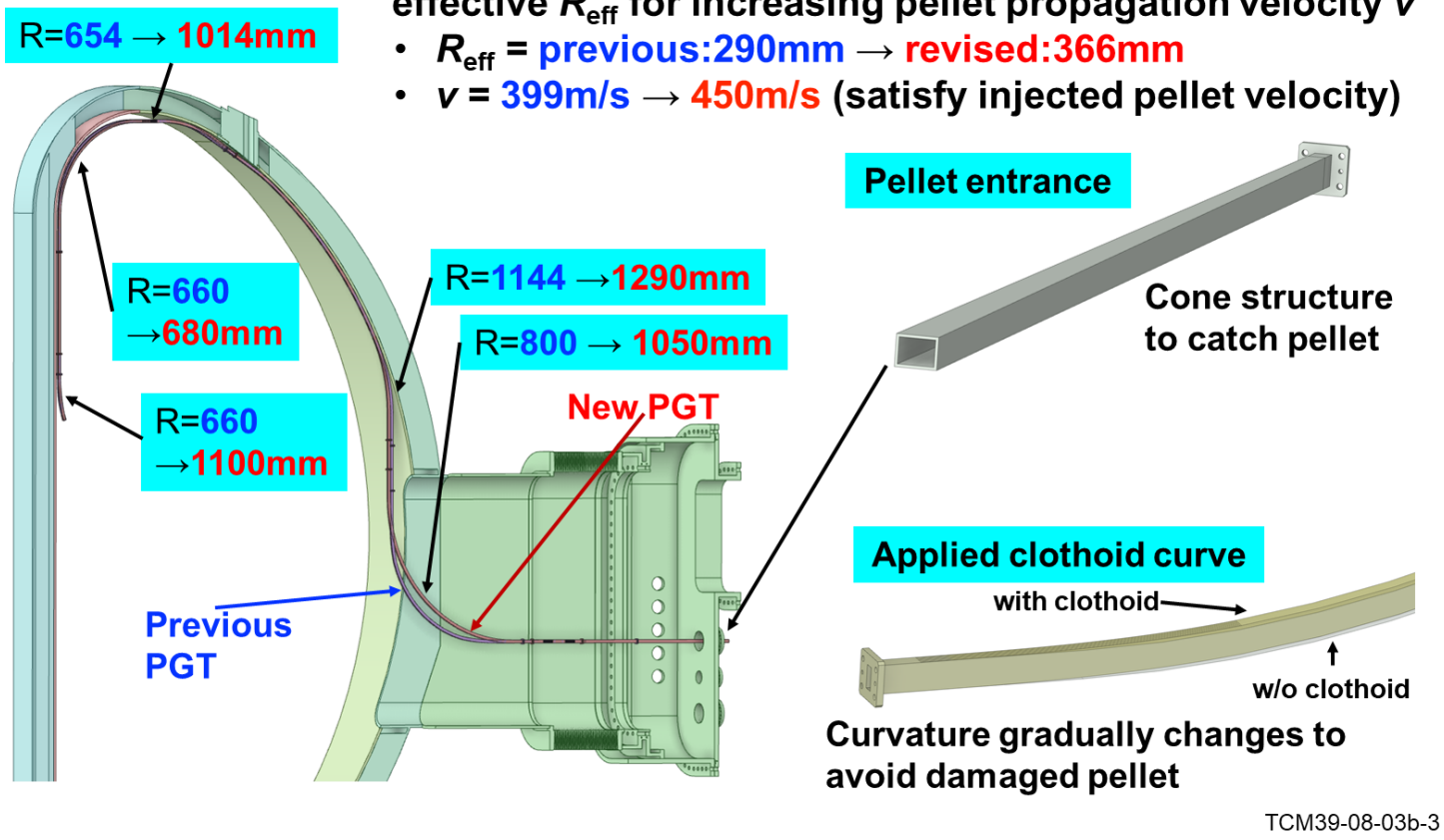
„Pellet meeting“ July 20., 2023
Decision:
Back to final R = 660 mm
($v_P^{max} \approx 400$ m/s, $f_P^{max} \approx 80$ Hz)

February 2024
QST announced:
Final bend back to R = 159 mm!

➔ „Pellet meeting“ April 18., 2024
Installed version with final R = 680 mm (“No final limit” $v_P^{max} \approx 450$ m/s)

REVISED PELLET GUIDING TUBE

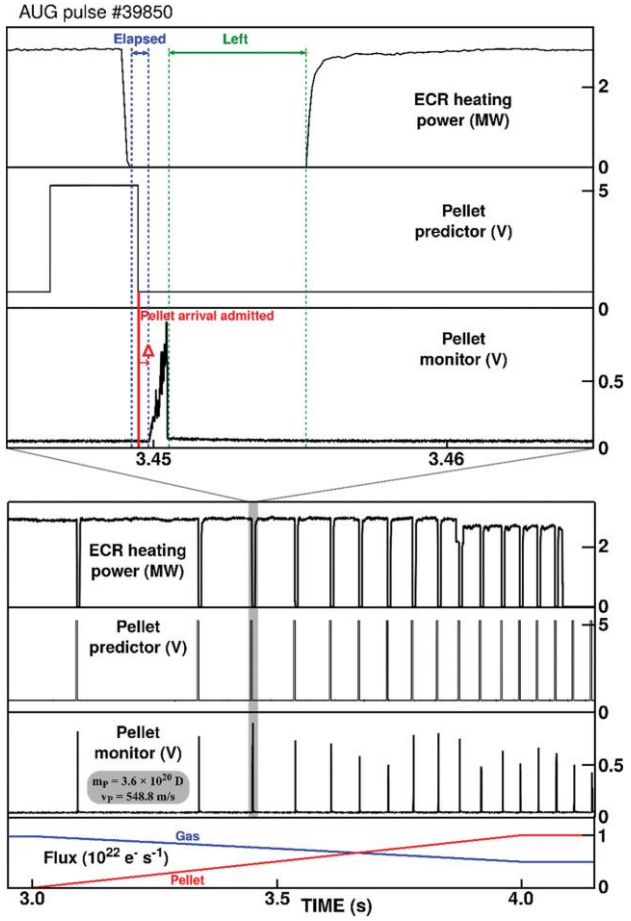
✓ **Pellet guiding tube (PGT) is upgraded to have large effective R_{eff} for increasing pellet propagation velocity v**
- **R_{eff} = previous:290mm → revised:366mm**
- **v = 399m/s → 450m/s (satisfy injected pellet velocity)**

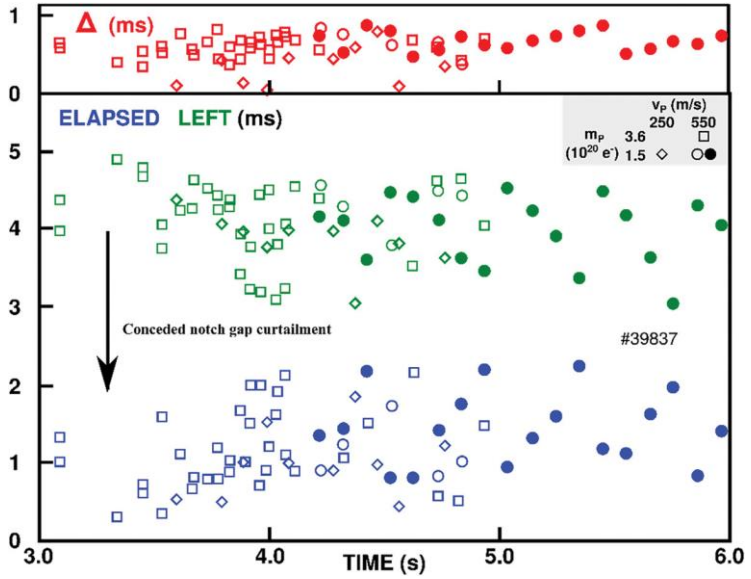


COMMISSIONING PLAN: EXCEPTIONAL CHALLENGES

- Safe combination Pellet fuelling – ECR heating needs notching

AUG: Demonstration precise pellet arrival prediction and fast controller actuation allow for very notches ➔ only modest and predictable (= can be compensated) reduction of averaged P_{EC}





Notch time ≈ 2 ms (ablation + arrival jitter) + 1-2 cycle time
SCSDAS/HDC @ 100 Hz ➔ ≈ 12 – 22 ms
Pellet rate approaching maximum (70 Hz) ➔ P_{EC} approaches 0
➔ Need for faster control handling (PIC?)