MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Kick-off meeting WPSA Enhancements Pellet Launching System

ASDEX Upgrade

P. T. Lang for the PLS Team

FUSION FOR ENERGY

Kick-off Meeting, VC, April 20., 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

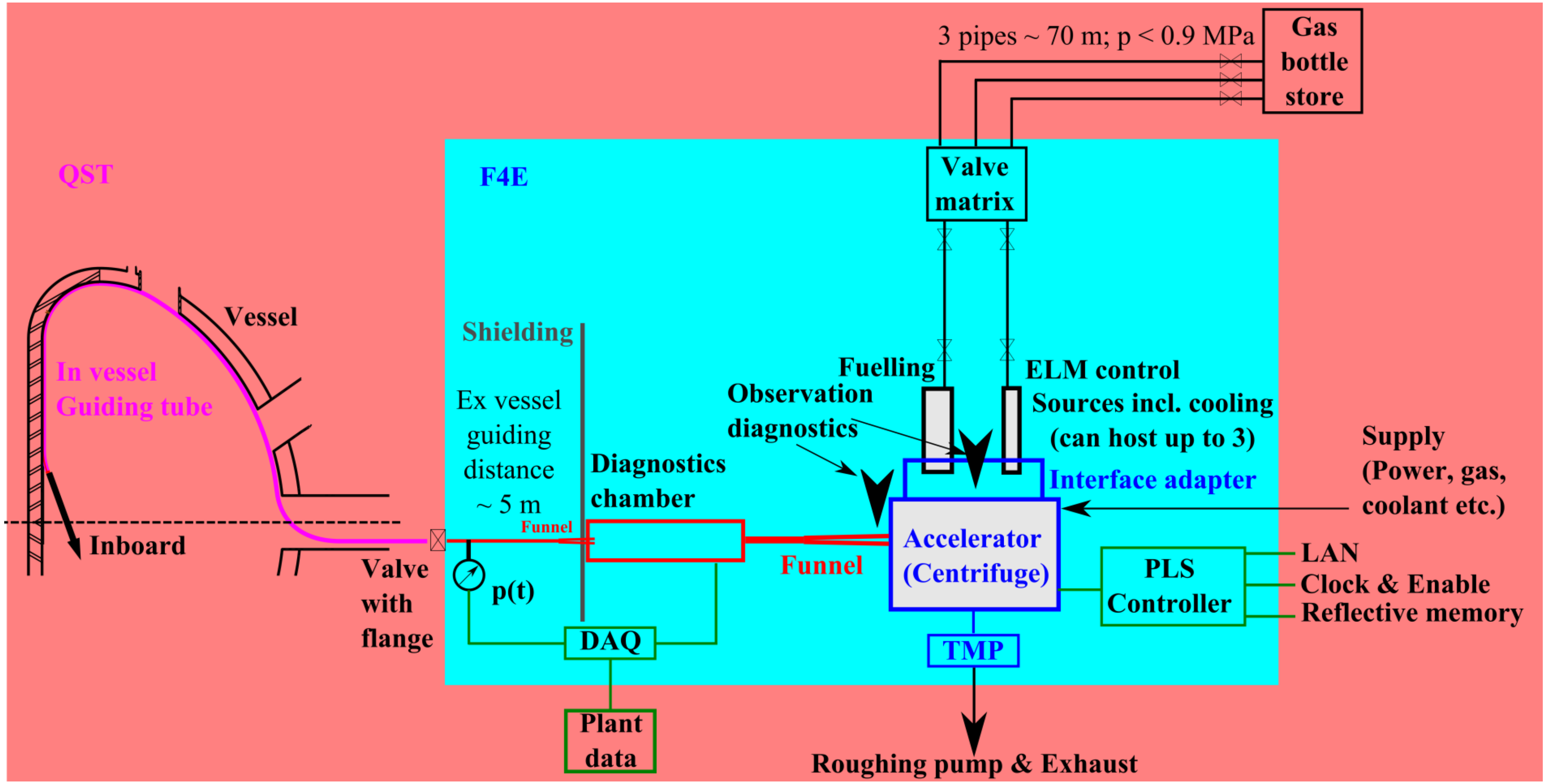
Quantify actuation (in open loop) during the initial research phase I

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/EUROfusion

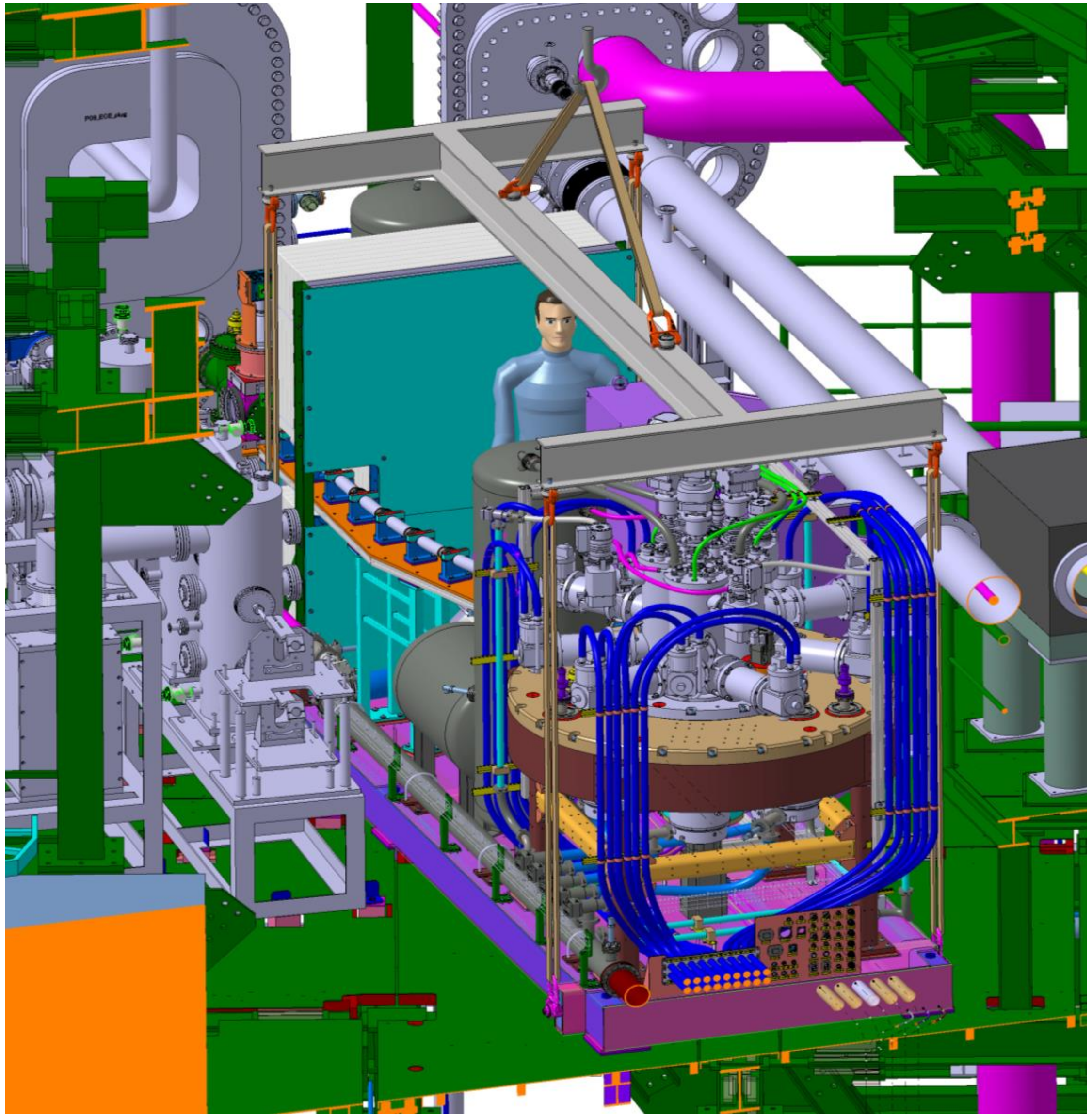


Initial PLS tests and commissioning in the IPP pellet lab ➔ Performance reference

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

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

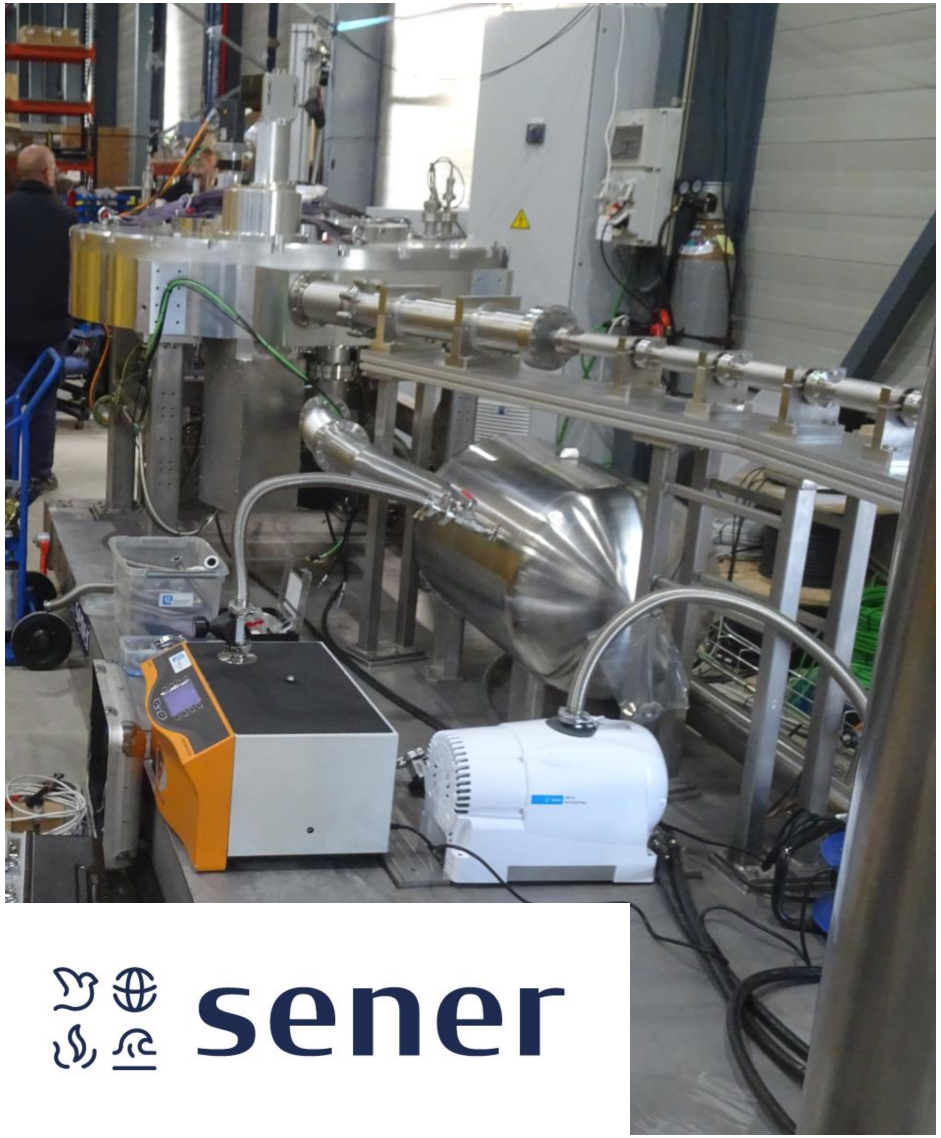
- In-vessel guiding tubes installed
- Master PLC mockup imported from F4E/IPP
- Development of "PLS/MGI local controller (PMIC)" serving as interface between SCSDAS (QST) and pellet control system PLC (EU) in progress
- Modification of P10 common stage taking into account PLS configuration on skid (incl. front shielding) envisaged
- Ferritic components handling: roots pump, cubicles, *valve matrix*
- 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



PLS main component status & plans: Launcher & Diagnostics

- Factory acceptance test 2 passed after reconfiguration of bearing and feedthrough
- Endurance tests in progress
- Final installations under way (e.g. extension of panel to host additional piping for coolant supply)
- Dismount resp. secure components for shipment
- Delivery to IPP lab until end of June latest
- Placing in IPP lab and reassembly
- Integration (vacuum system, MasterPLC, …)
- Demonstration of diagnostics systems

Initial installation/integration until ~ end of 2026
Final integration work after delivery of first preliminary pellet source



PLS main component status & plans: IPP lab & MasterPLC & …

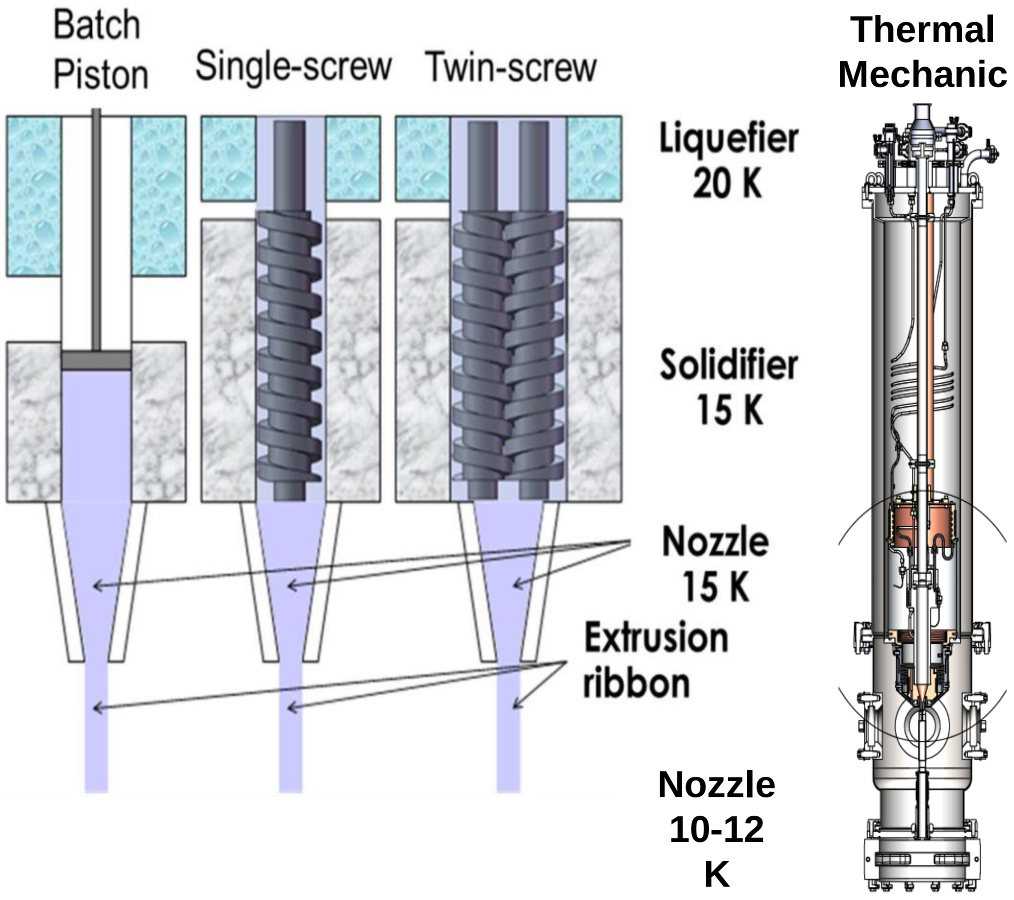
- Lab with 10 m^3 dump tank ready since Oct. 2021
- MasterPLC set up & mockup sent to QST
- New valve matrix from stainless steel
- ATEX (hydrogen safety) certification for lab passed, for further equipment still needed
- Transfer system from SENER container into lab
- Installation and integration of SENER unit
- Change set up from double to single inner arm
- Demonstrate accelerator is operational
- Demonstration of diagnostics systems

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

PLS main component status & plans: Pellet sources

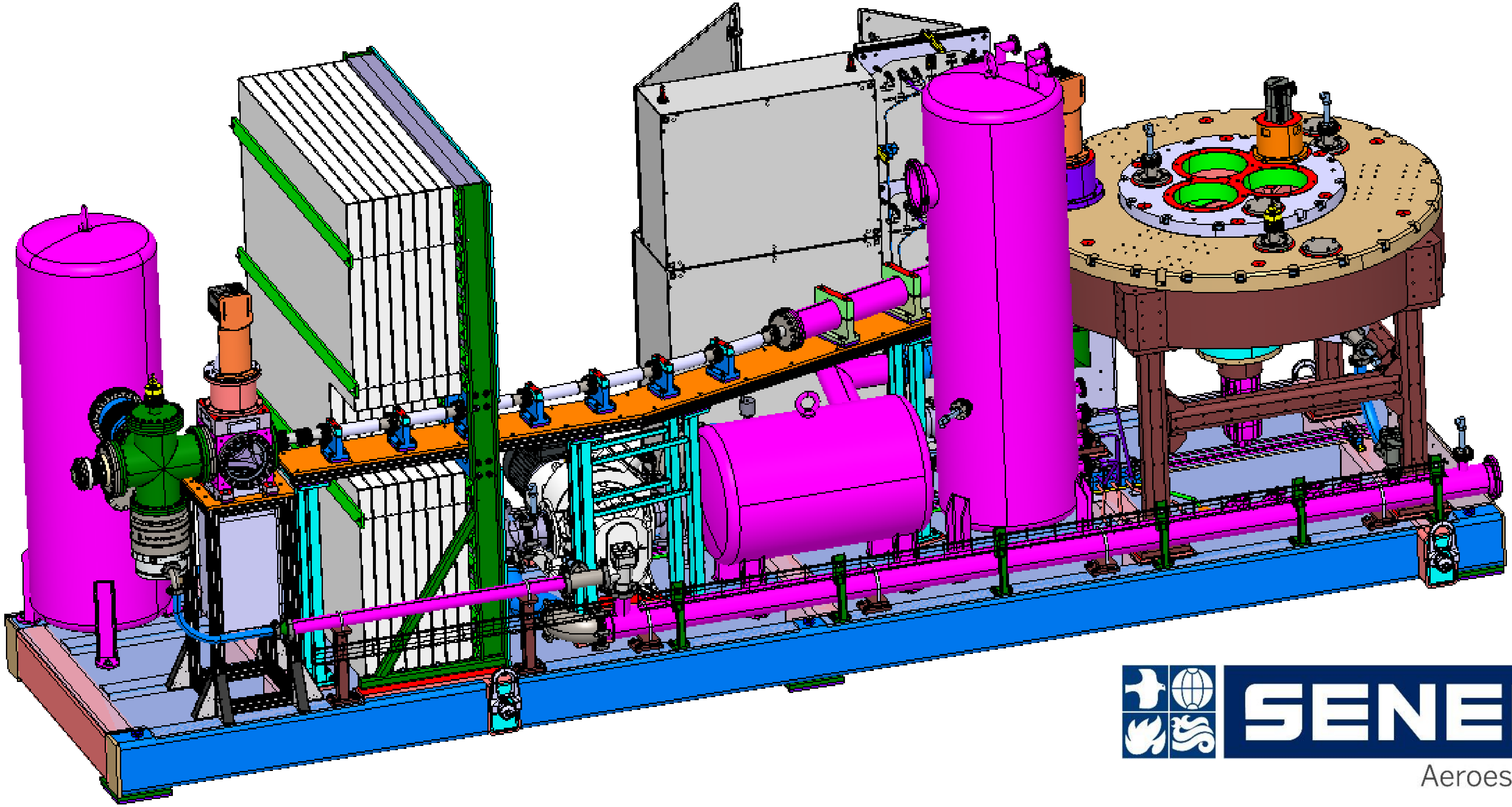
- Call for tender 2019/2020, order for steady state fuelling and pacing source to PELIN St. Petersburg
- Envisaged delivery for fuelling source Oct. 2021 first delayed, then suspended, then terminated
- F4E went to new call, now stepwise approach:
  - Temporary sources (5 s pulses) fuelling first
  - 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

Several offers received for call, negotiations for orders in progress
Note: IPP lab contract needs extension, coverage of IPP support task after 2027 still to be sorted out



Backup slides

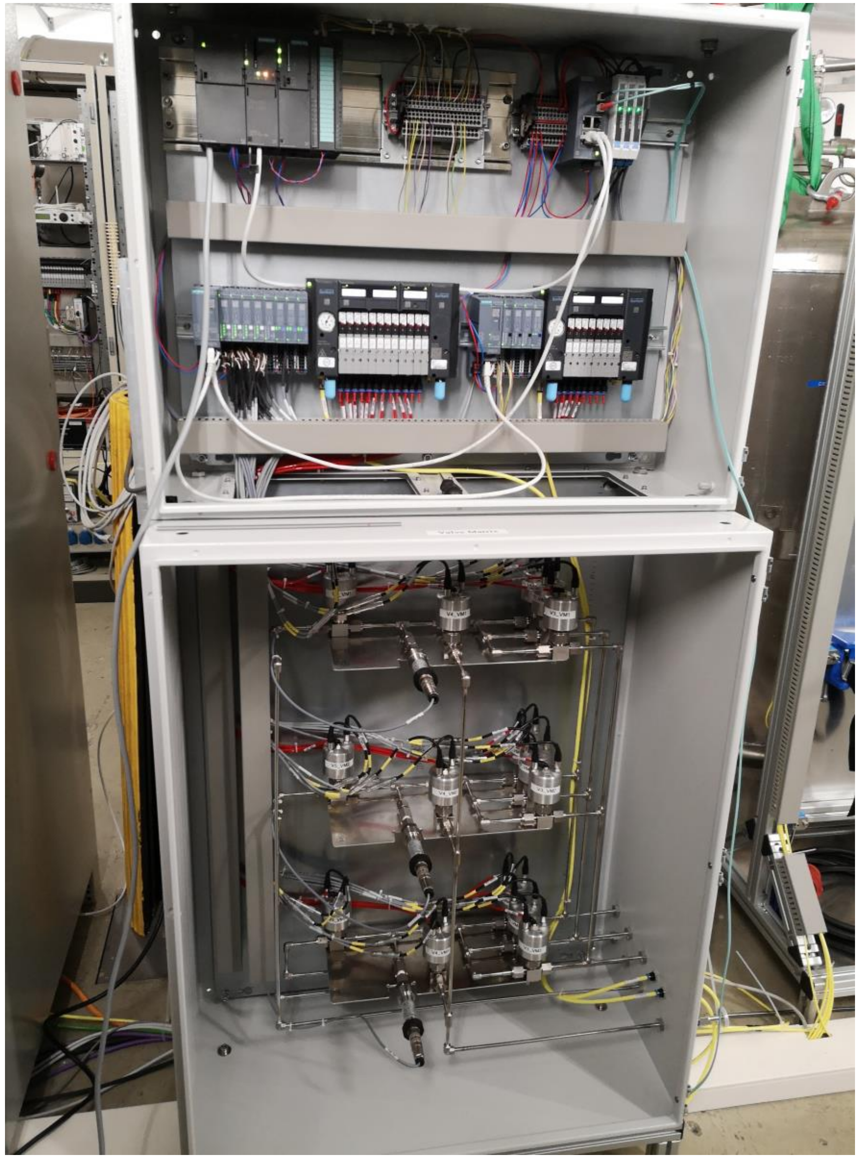
PELLET LAUNCHING SYSTEM: SENER



SENER
Aeroespacial

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 TEST LAB & SUPPLY CONTRACT

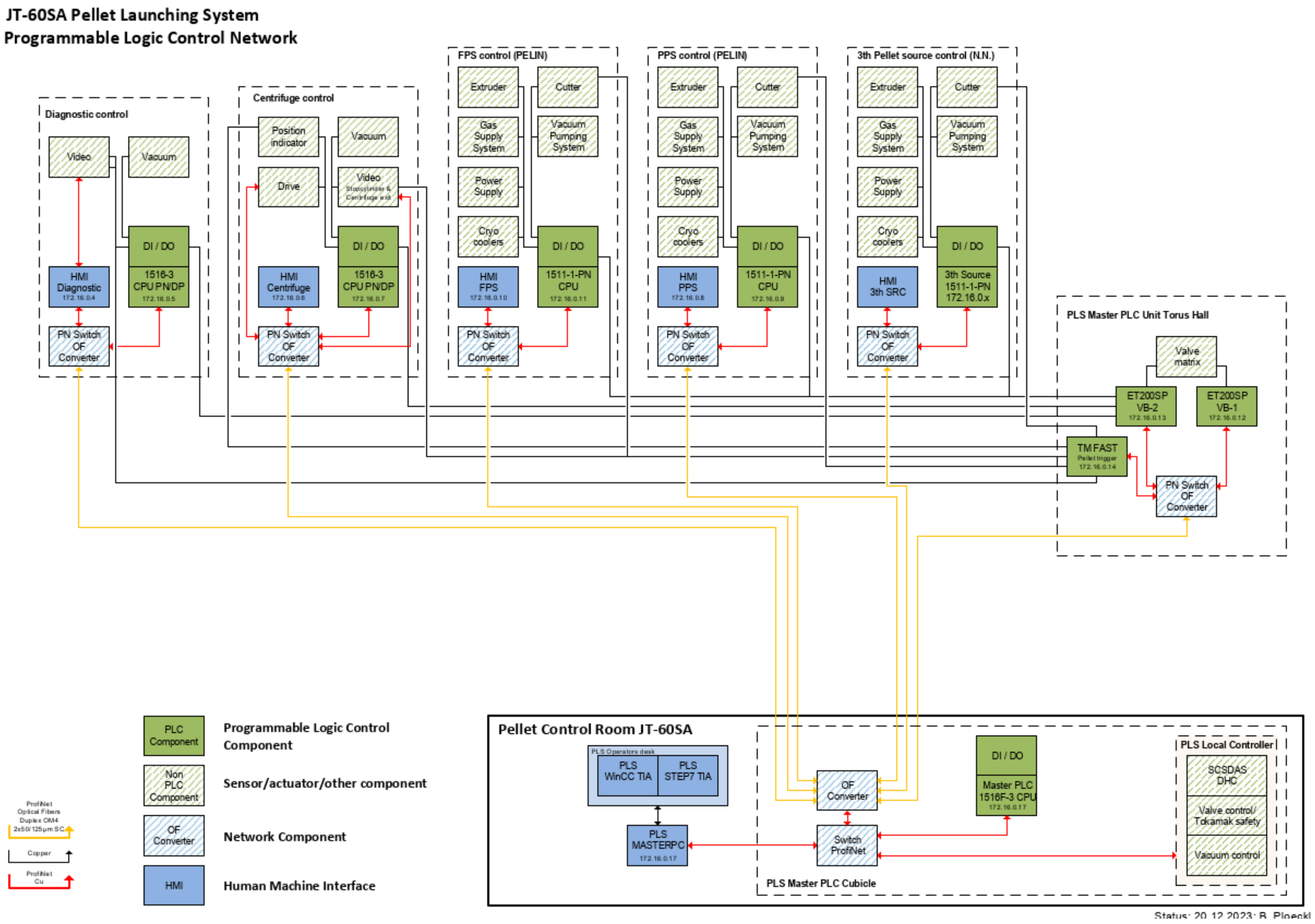


Valve matrix PLC (upper)
Valve matrix capable to connect 3 gas supply lines to 3 pellet sources (lower)
←

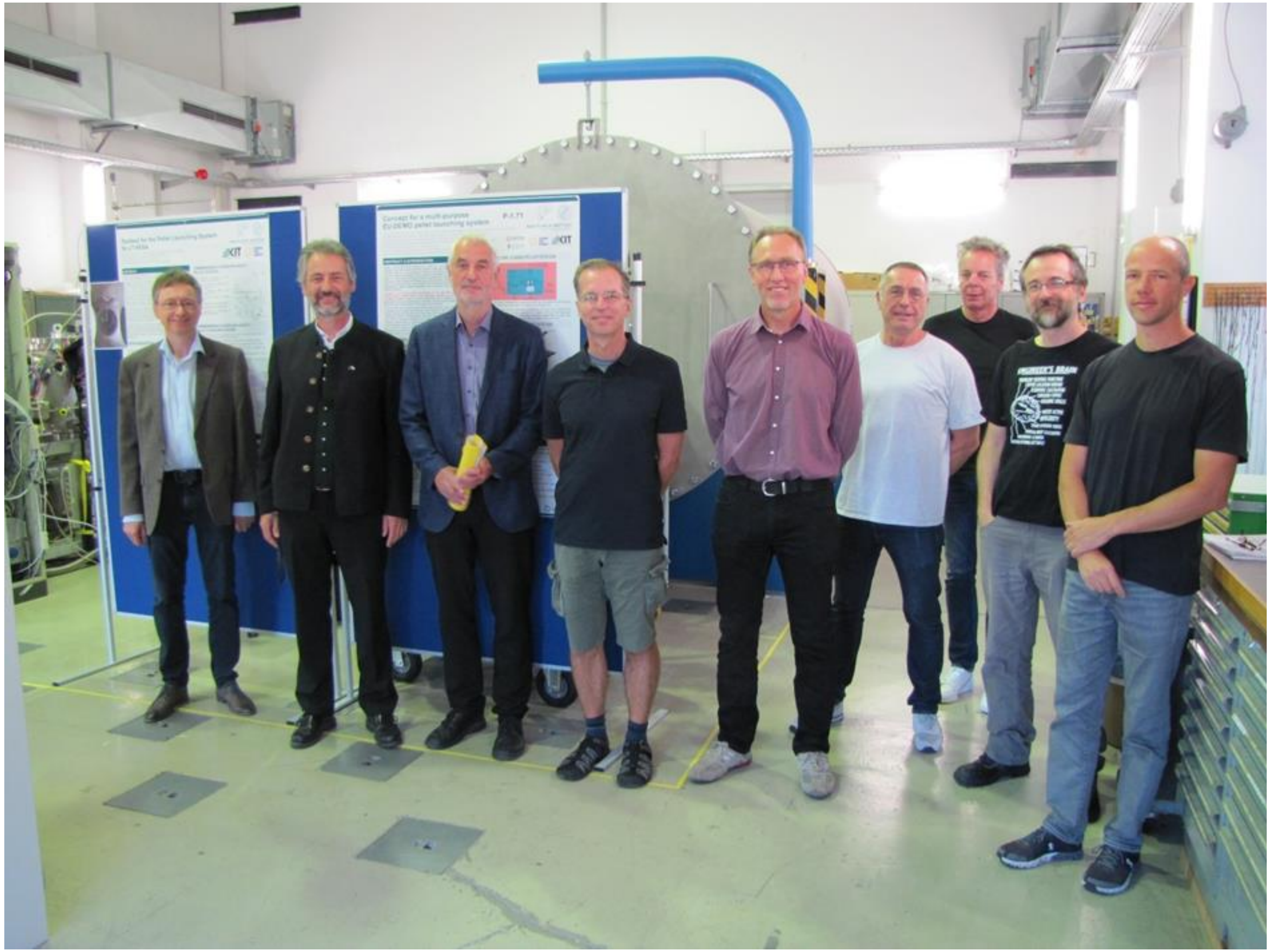
→

ATEX fore pump (Leybold DV650) with power supply (sockets and power switch) as mounted in the basement below the lab

PELLET TEST LAB & SUPPLY CONTRACT



PELLET TEST LAB & SUPPLY CONTRACT



Supply contract F4E-OPE-1354 signed August 2023

KOM September 9., 2023

Lab readiness demonstration September 21., 2023

ADP submitted October 10., 2023

Approved November 20., 2023

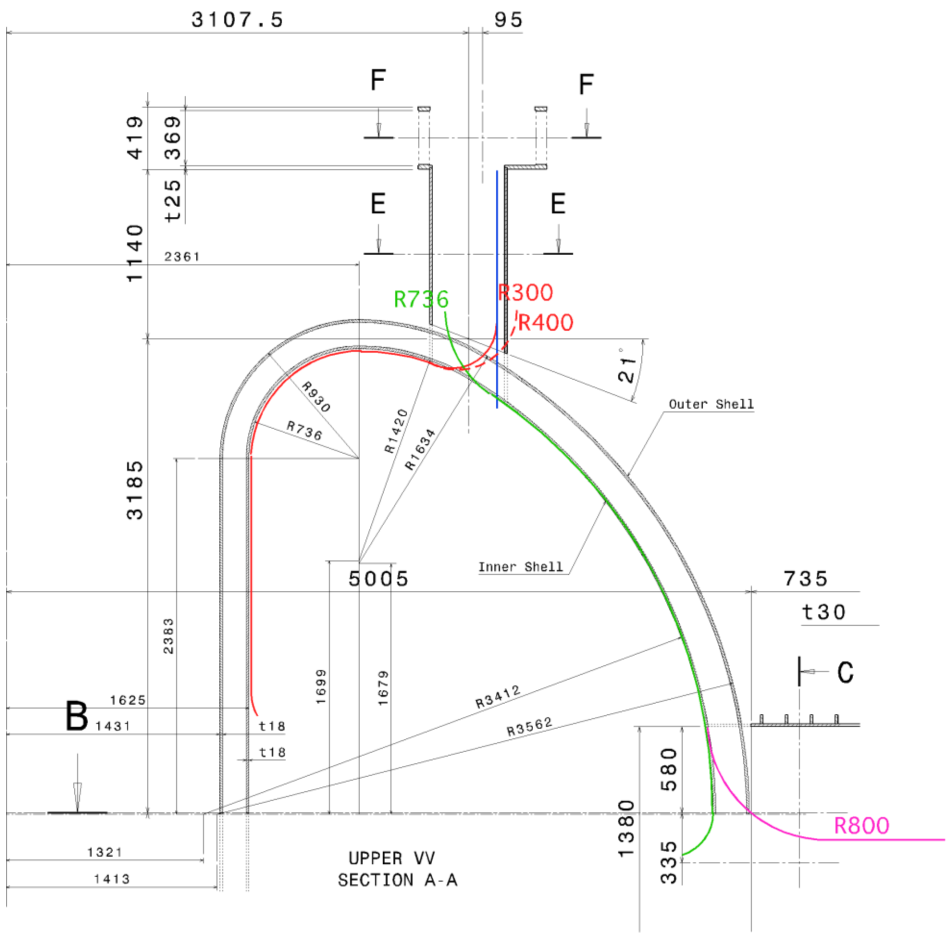
IPP received payment for
“Fixed part”
“Pre-financing”
➔ Ready to conduct procurements requested by F4E

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 46º 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 69º declination
Optimising “perpendicular” pellet speed



Potential solutions worked out by T. Nakano in 2015

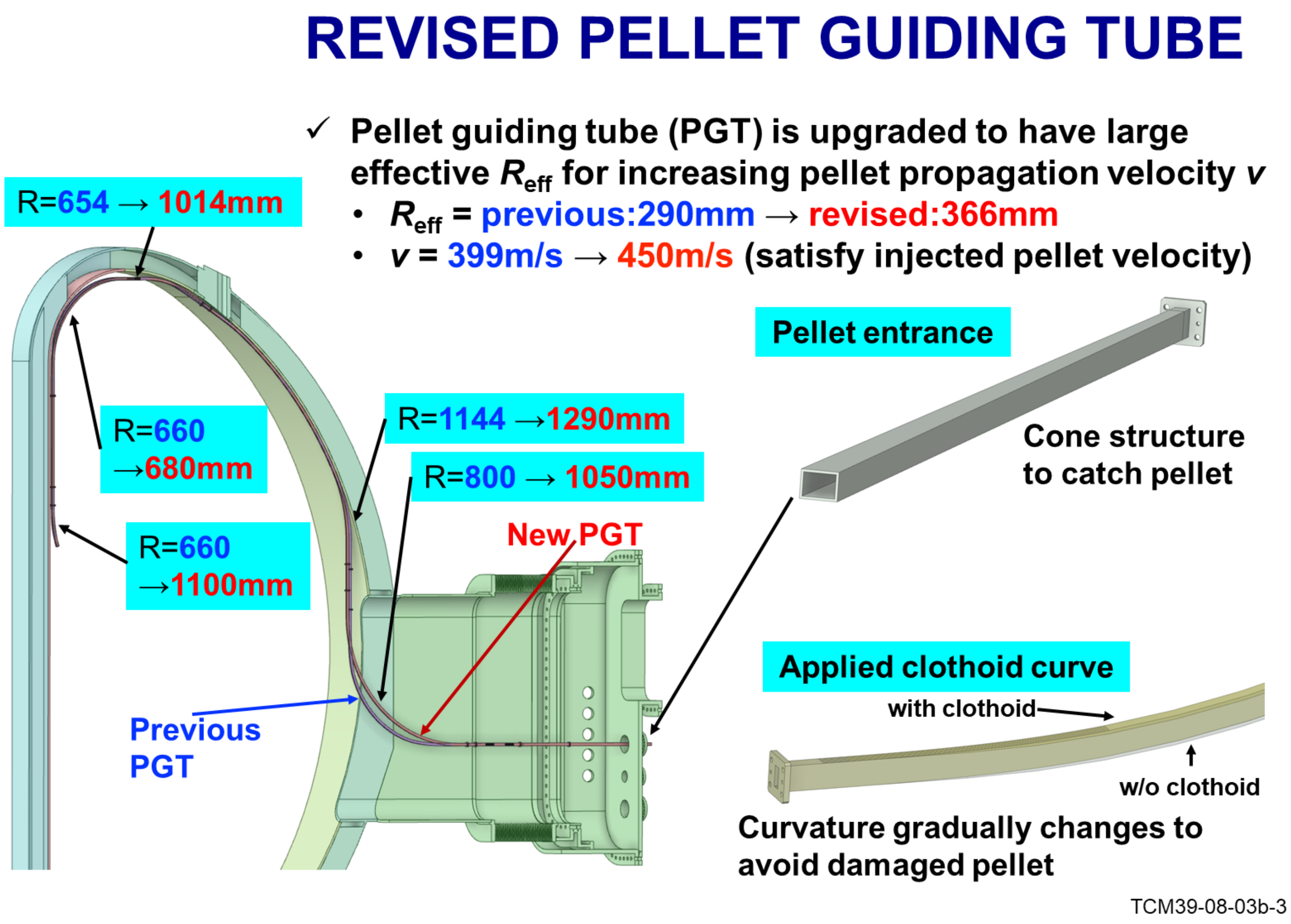
QST: IN-VESSEL GUIDING TUBE SUPPORT

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)

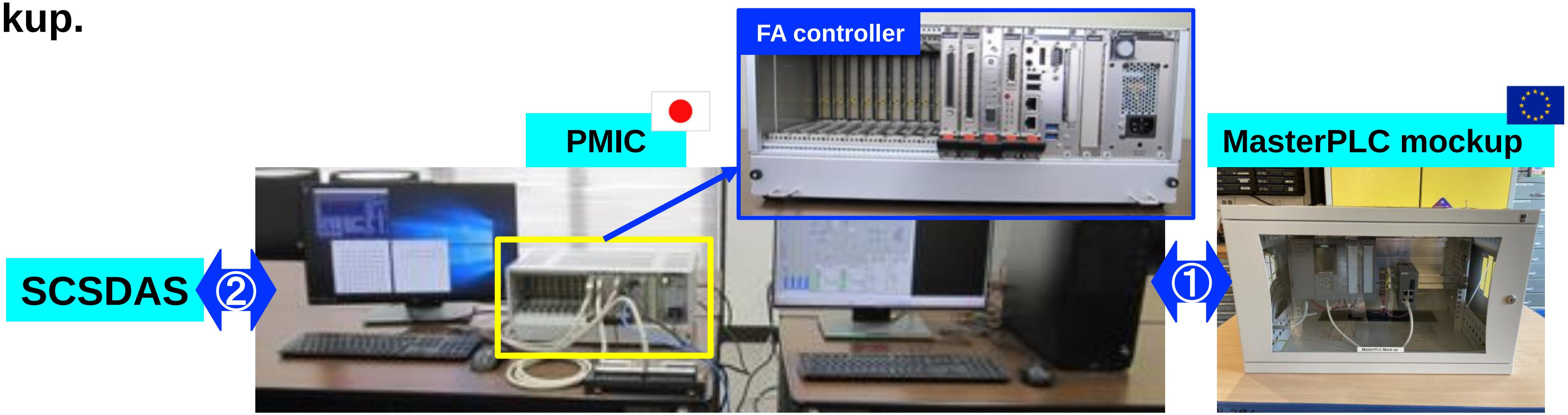
February 2024
QST announced:
Final bend back to R = 159 mm!

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



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.



- SCHEDULE
  ① ~ Feb. 2026: Linkage test with master PLC mockup.
  ② Feb.~Apr. 2026: Indivisual linkage test with SCSDAS and master PLC mockup.

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
1a	Functionality tests of the PLS infrastructure	Proof safe local non-cryogenic operation of hardware
1b	Testing and optimising pellet production, acceleration and transfer to torus gate valve	Proof safe local cryogenic operation of hardware
2a	On plasma safety tests	Proof safe integrated cryogenic operation of hardware
2b	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
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

Full “preliminary” report considering yet technical and physics reasoning available
Formal one adapted to official template will be delivered at the end of 2024

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

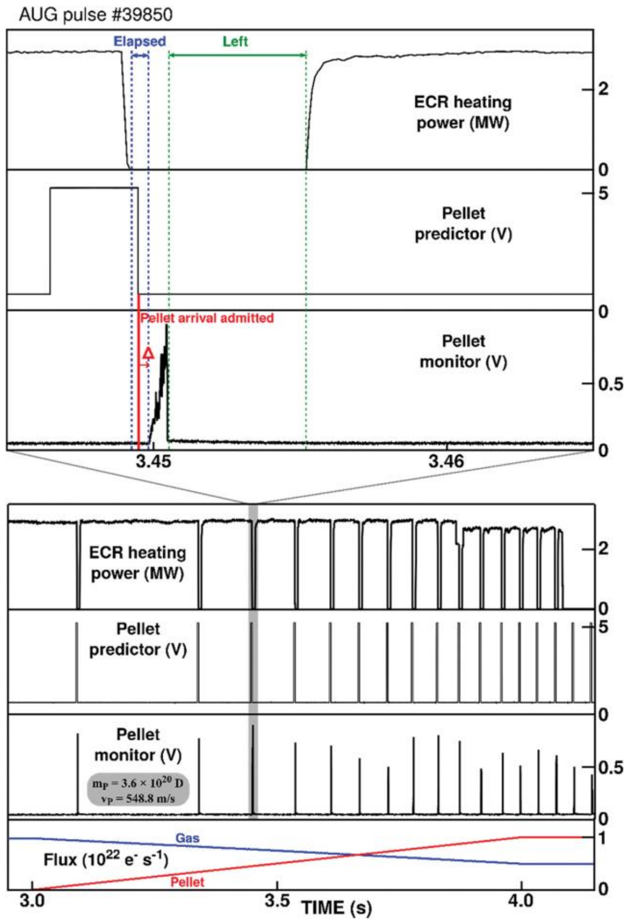
- Safe combination Pellet fuelling – ECR heating needs notching

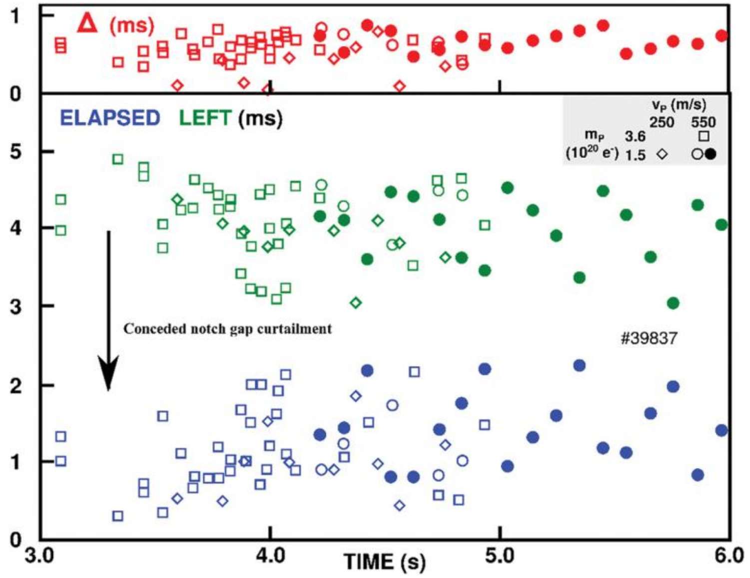
Pellet can create transient high density layer in plasma – opaque for ECRH ➔ stray radiation
Can be avoided by “notching” of ECRH pulse
Long SCSDAS response time ➔ long off-phases ➔ strong reduction of averaged P_{EC}

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}





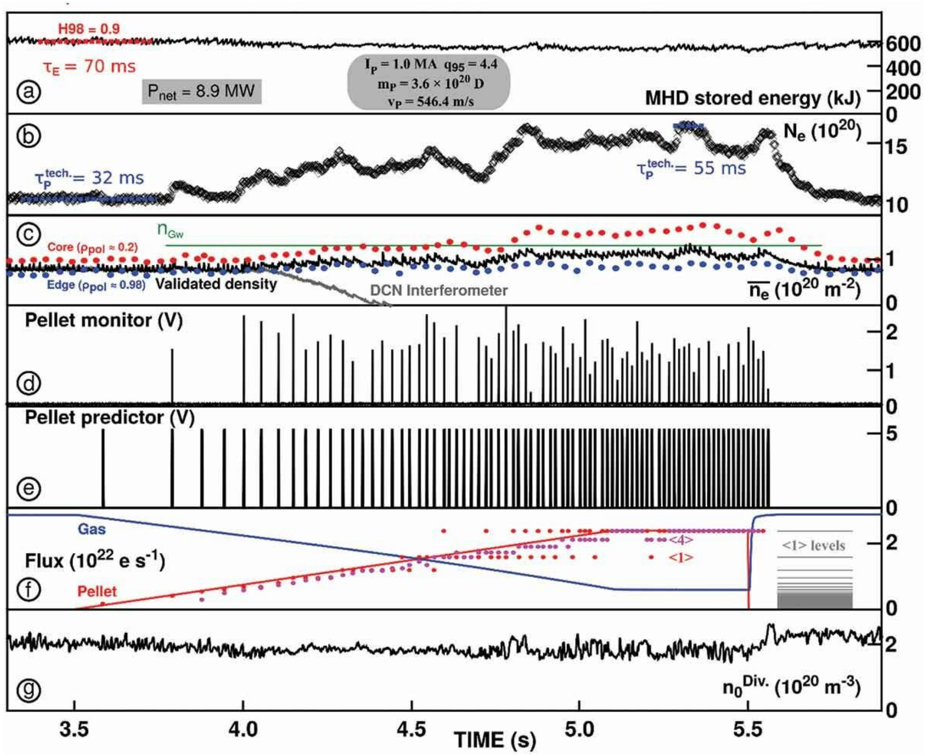
Notch time ≈ 2 ms (ablation + arrival jitter) + 1-2 cycle time SCSDAS/HDC @ 100 Hz ➔ ≈ 12 – 22 ms

Pellet rate approaching maximum (70 Hz) ➔ P_{EC} approaches 0

➔ Need for faster control handling (PIC?)

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!