EUROfusion

Status Report for WPTE

Tokamak Exploitation Project Board – N03
Project Board | 14th March 2022

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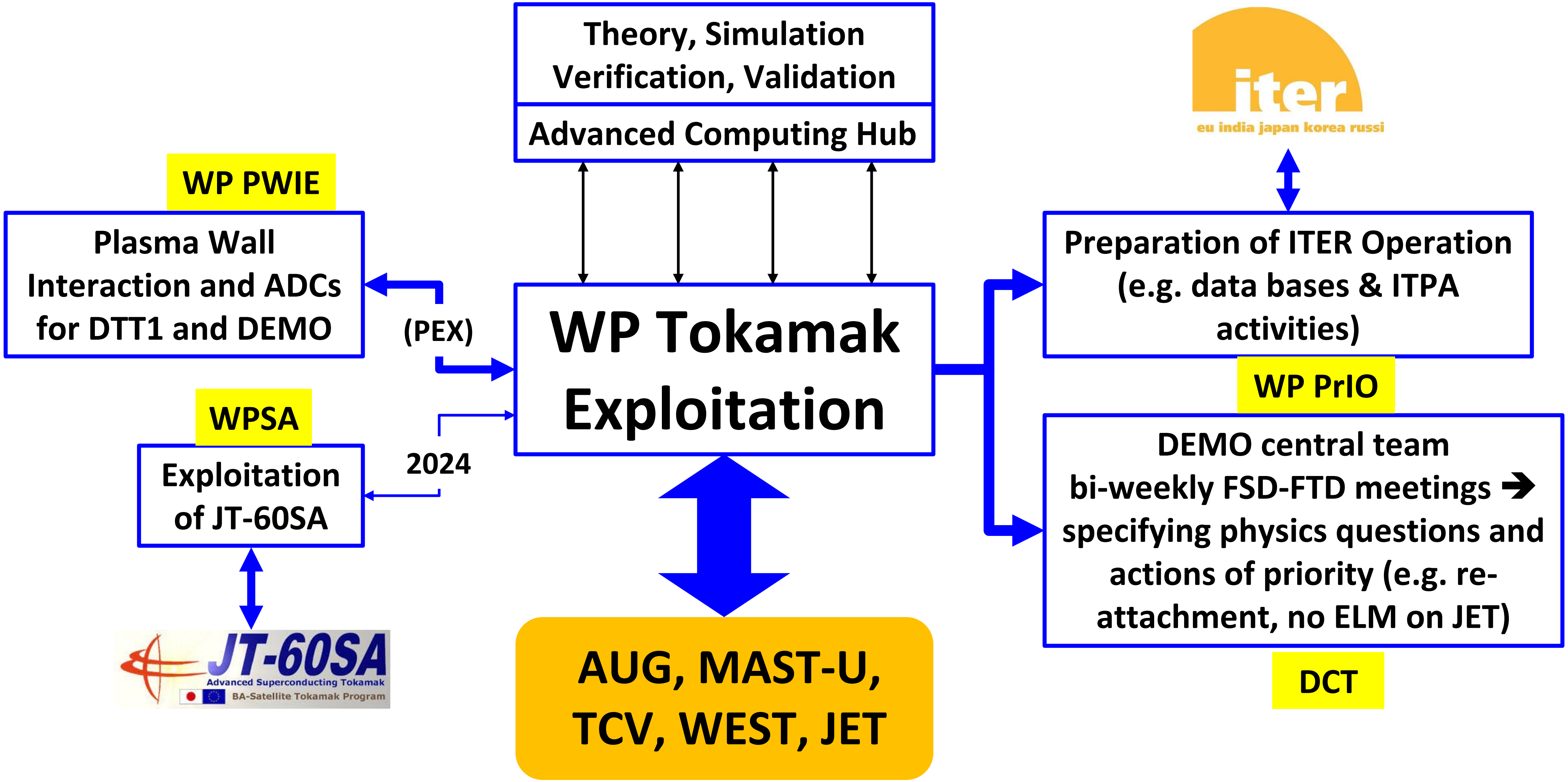
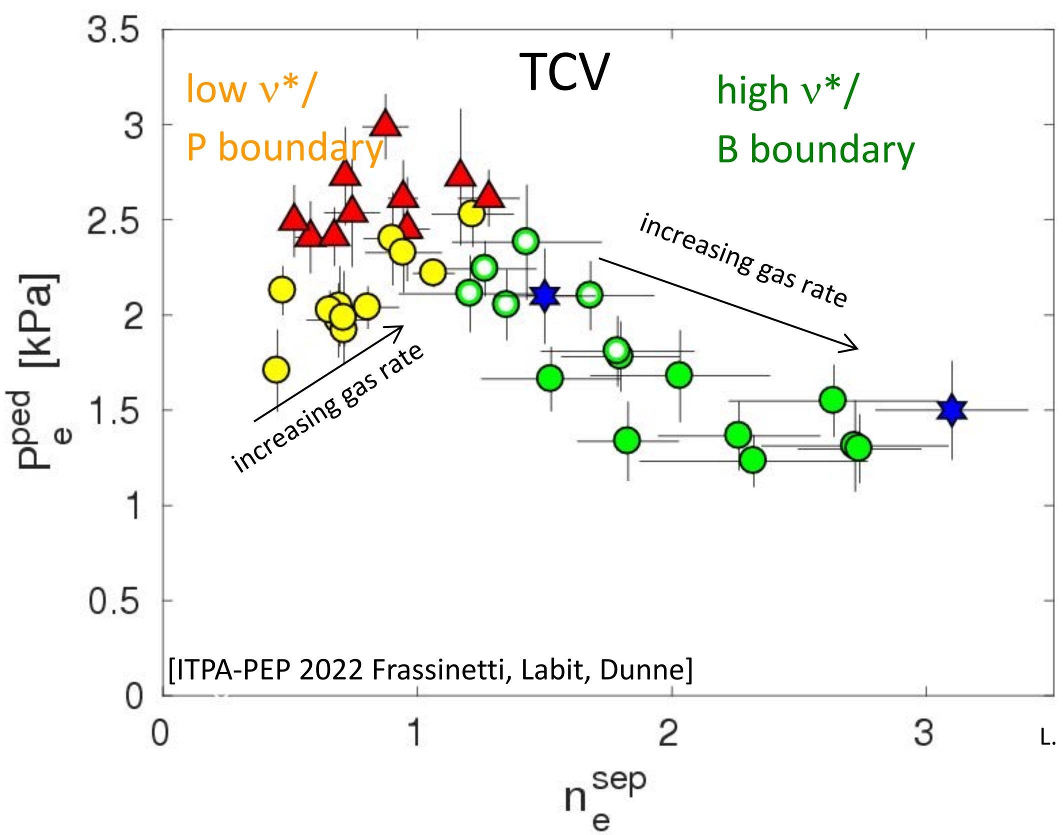

Theory, Simulation
Verification, Validation
Advanced Computing Hub
WP PWIE
Plasma Wall Interaction and ADCs for DTT1 and DEMO
(PEX)
WPSA
Exploitation of JT-60SA
2024
WP Tokamak Exploitation
AUG, MAST-U, TCV, WEST, JET
Preparation of ITER Operation (e.g. data bases & ITPA activities)
WP PrIO
DEMO central team
bi-weekly FSD-FTD meetings ➔ specifying physics questions and actions of priority (e.g. re-attachment, no ELM on JET)
DCT

2 –Summary of Achievements ITER: Mission 1 RT02
Different Behavior at the Peeling Boundary



Progress through additional ECRH heating available on TCV and promising progress towards Grant Deliverable TE.D01

low ν* / high-δ / 150kA / NBI+ECRH / gas scan

low ν* / low-δ / 150kA / NBI+ECRH / gas scan

high ν* / low-δ / 170kA / NBI / gas scan (with different types of baffles)

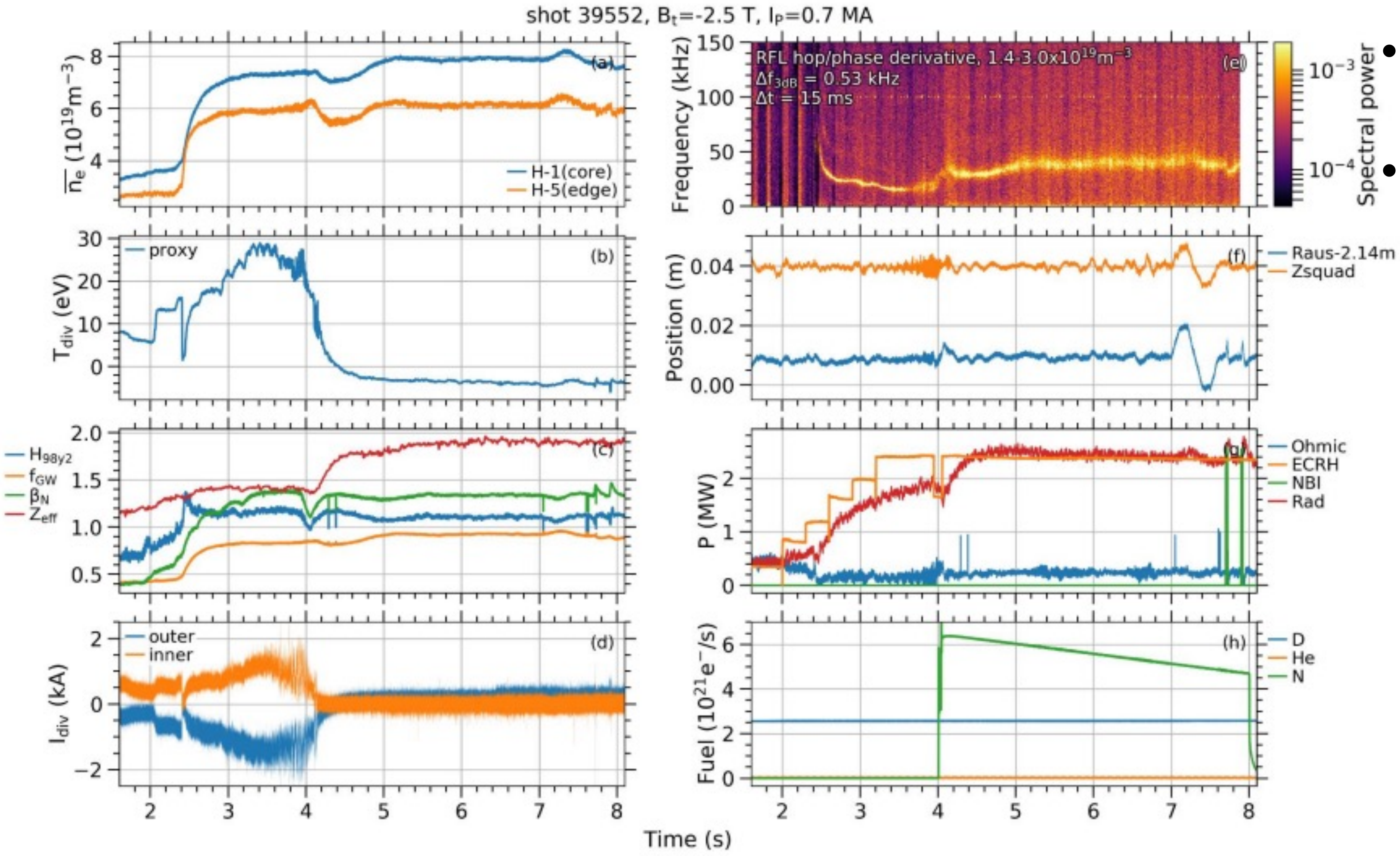
high ν* / low-δ / 170kA / NBI / gas scan (no baffles)

L. Frassinetti| WPTE-TFM | 10/3/2022

- Reference dataset (high ν*):
  - decreasing p_e^{ped} with increasing n_e^{sep}
  - similar to AUG and JET [Dunne PPCF2017, Frassinetti NF2019]
- low ν* dataset:
  - increasing p_e^{ped} with increasing n_e^{sep} (especially at low-δ)
  - consistent with DIII-D results [Snyder NF2015, Snyder NF2019]

EDA H-mode compatible with radiative scenario for detachment maintaining confinement ➔ identified as proposed candidate of no ELM regimes to be tested on JET for 22/23

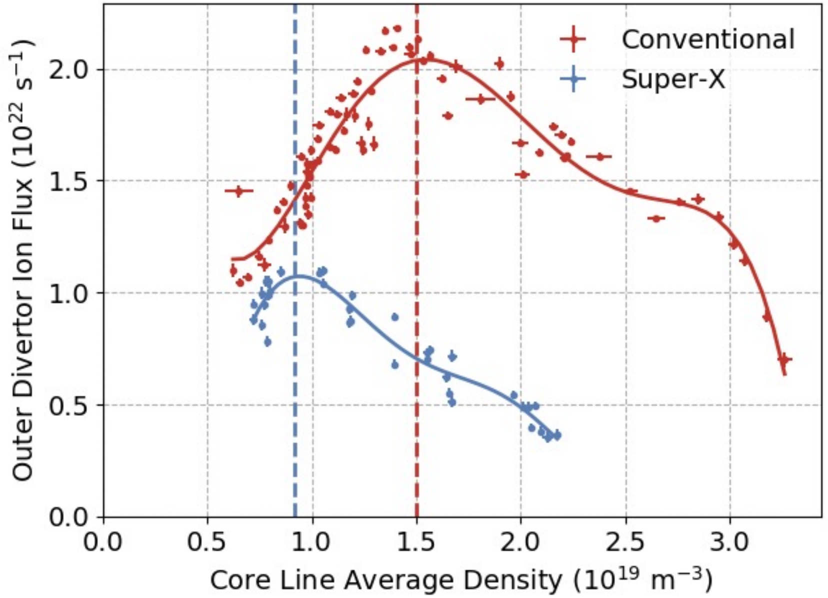
AUG



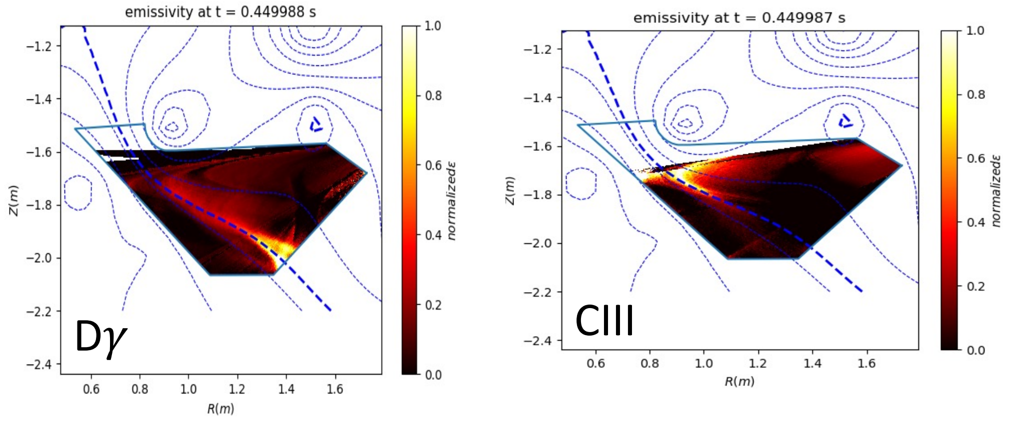
- N2 seeding reduces divertor Te and heat loads
- Approaching detachment while keeping stationary condition with no ELMs and high H_{98}

- Preliminary analysis of MEM suggest that QCM significantly enhance the radial particle transport across separatrix

Total flux expansion and detachment

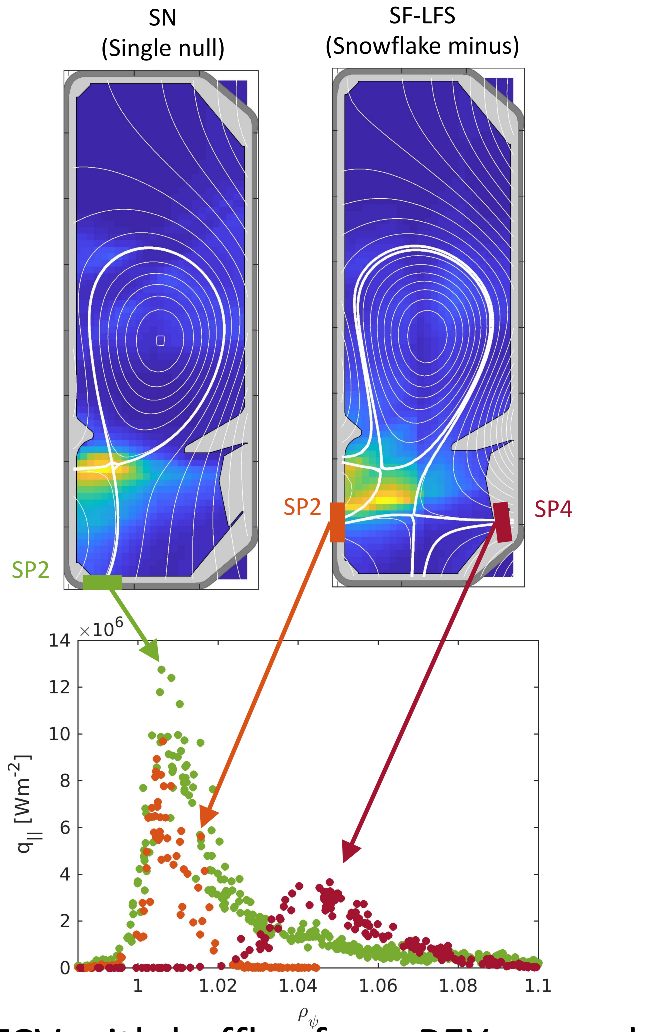


L-mode MAST-U with Super-X divertor (PEX)



Snowflake with intrinsic impurities in L-mode

- RT18: 18% of pulses on MAST-U, 26% of pulses on TCV
- Grant deliverable TE.D.02



TCV with baffles from PEX upgrade

2 - Advances of subjective Readiness of Scientific objectives: Mission 1

Level	Emerging	Exploratory	Judgemental	Mature-needs underpinning	Mature-needs support	Established

RT	Title	D1	D2	D3	D4	D5	D6
RT01	IBL scenarios towards low collisionality and detachment			X			
RT02	H-mode entry and pedestal dependence with impurities and isotopes						
RT03	RF-assisted breakdown and current ramp-up optimization	X					
RT04	Disruption avoidance and control for ITER and DEMO						
RT05	Run-away electron generation and mitigation			X	X		
RT06	ELM mitigation and suppression in ITER/DEMO relevant condition						
RT07	Negative triangularity scenarios as an alternative for DEMO			X			
RT08	QH-mode and I-mode assessment in view of DEMO	X	X	X			
RT09	Extension of EDA and QCE performance towards DEMO				X		
RT10	Fast-ion physics with dominant ICRF heating						
RT11	Impact of MHD activity on fast ion losses and transport						
RT12	Development of the steady state scenario	X					

Lack of power in TCV and MAST-U

X – deliverables having advanced in readiness level

2 - Advances of subjective Readiness of Scientific objectives: Mission 2

Level	Emerging	Exploratory	Judgemental	Mature-needs underpinning	Mature-needs support	Established

	Title	D1	D2	D3	D4	D5
RT13	X-point radiation and control				X	
RT14	Physics of plasma detachment / impurity mix/ heat load patterns					
RT15	Extrapolation of SOL transport to ITER and DEMO				X	
RT16	PFC damage evolution under tokamak conditions					
RT17	Material migration and fuel retention mechanisms in tokamaks					
RT18	Alternative divertor configurations	X				

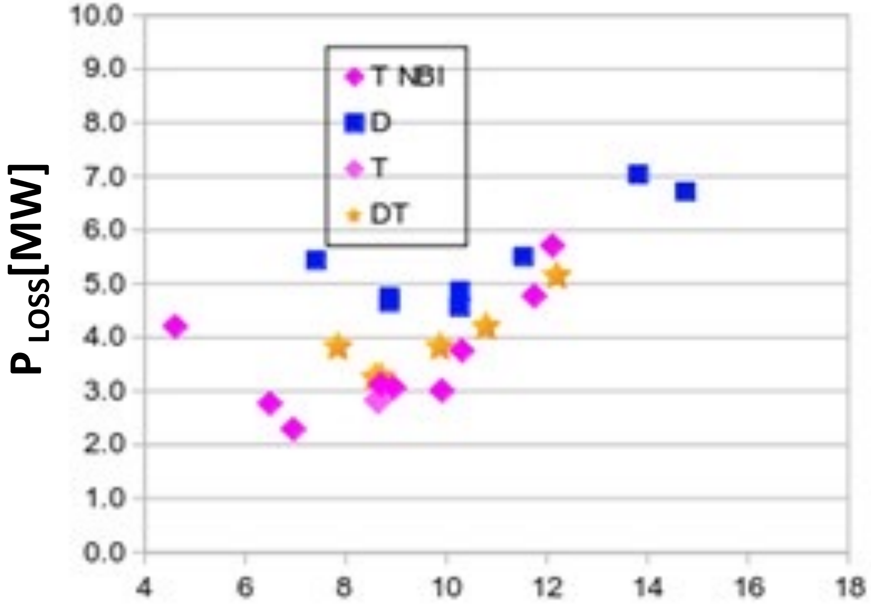
X – deliverables having advanced in readiness level

2 – WP TE successfully completed JET campaign C40B (TT) - C42 in progress

Technical issues (NBI & KL12 camera)

M18-01: Baseline scenario development for DT
M18-14: Isotope effects on L-H transition power threshold
M18-21: Confinement and transport in mixed isotope plasmas
M18-20: Dependence of pedestal structure on fuelling at constant beta
M18-19: Isotope effects on confinement and transport
M18-02: Hybrid scenario development for DT
M18-05 ICRH scenario support in D and T plasmas
M18-18: Determine the W source including ELM, RF and isotope effects
M18-24: Particle transport in pure and mixed isotopes
M18-29: Be erosion and migration to the divertor with isotopic effect
M18-39: Integrated high performance seeded scenario
M18-27: Isotope effects on detachment in L-mode
M18-15: Access to type-I ELMs with reduced torque
Calibration pulse of TIMs for DT analysis
M18-23: Rotation shear effect on ion transport with different isotopes
M18-17: Power width scaling and ELM losses at high current
M18-22: Electron and ion threshold and stiffness in pure and mixed isotopes
M18-50: NBI T power calibration
M18-26: Isotope effect on H-mode detachment and density limit
B18-08: Intrinsic rotation and momentum transport in pure and mixed isotope plasmas

M18-14: Isotope effects on L-H transition power threshold



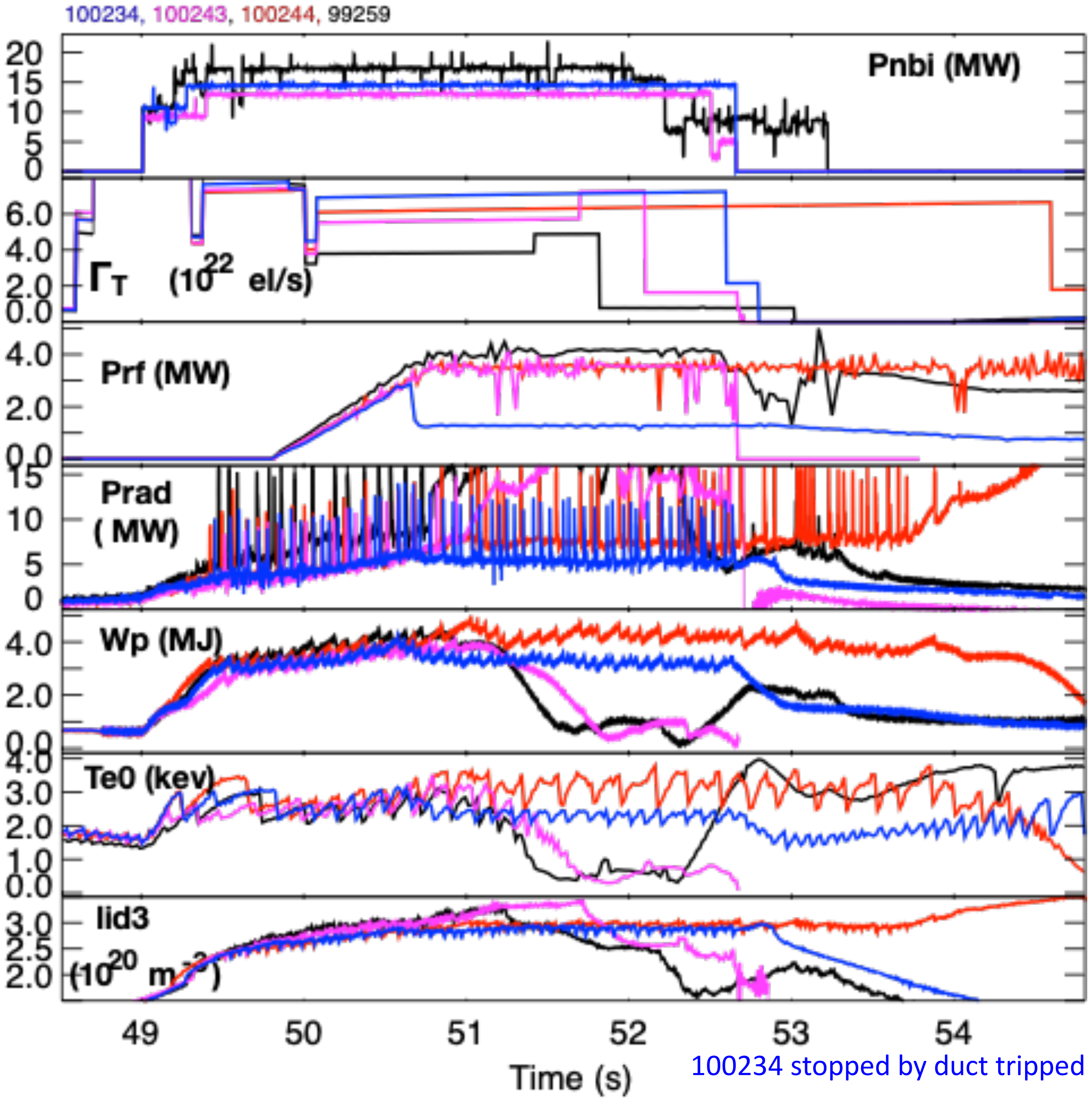
Line average density ($10^{19}m^{-3}$)

(E. Solano)

Completed
Scope changed and completed
Attempted but not completed
Not done

2 – WP TE successfully completed JET campaign C40B (TT) - C42 in progress

4s stationary high-delta plasma achieved at 2.5MA in C40b (TT), data obtained for SOLPS-ITER



100234 stopped by duct tripped

Seeded study in C40a was impaired by ELM-free following LH-transition and rapid W accumulation **(99259)**

Demonstrated in C40b that T-gas rate needs to be at a minimum of 6.5×10^{22} el/s to obtain 4s ELMying plasma w/o excessive accumulation. **(100244)**

Good data obtained of target, SOL and pedestal for SOLPS-ITER modelling.

➔ Ukraine crisis risks SOLPS-ITER modelling: presently done by St. Petersburg group (agreement between ITER, JET, St. Petersburg)

2 – Status of Grant Milestones & Grant Deliverables (previous year)

GA Deliverable No.	Title	Due Date	Status	Details on Status (in case of delays or issues)
D01.01	Successful establishment of Type I ELMy H-mode scenario with dominant electron heating for the first safe operation of ITER.	31/12/2021	Delayed	From experiments in ASDEX Upgrade and TCV, achieving a dominant electron heating scenario has revealed challenging. In ASDEX Upgrade stability issue did not allow the achievement of a scenario at q95=3 with dominant electron heating due to MHD instabilities. In TCV this could not be tested yet because of the lack of electron heating from ECRH. Work continues to achieve the goals of the Grant Deliverable.
D01.02	The effect of total flux expansion and snowflake configurations in environments with intrinsic impurities on power dissipation quantified.	31/12/2021	Achieved	Approved in IDM

GA Milestone No.	Title	Due Date	Status	Details on Status (in case of delays or issues)
n/a				

1 – WP Organization: Changes foreseen for 2022/2023 programme (I): He

2021 → 1st half 2022

	Research Topics	
RT1	ITER Baseline scenarios towards low collisinality and detachment	ITER Scenario
RT2	H-mode entry and pedestal dependence with impurities and isotopes	ITER Scenario
RT3	RF-assisted breakdown and current ramp-up optimization	ITER Scenario
RT4	Disruption avoidance and control for ITER and DEMO	ITER Scenario
RT5	Run-away electron generation and mitigation	ITER Scenario
RT6	ELM mitigation and suppression in ITER/DEMO relevant condition	ITER Scenario
RT7	Negative triangularity scenarios as an alternative for DEMO	DEMO Scenario
RT8	QH-mode and I-mode assessment in view of DEMO	DEMO Scenario
RT9	Extension of EDA and QCE performance towards DEMO	DEMO Scenario
RT12	Development of the steady state scenario	DEMO Scenario
RT10	Fast-ion physics with dominant ICRF heating	Burning plasma
RT11	Impact of MHD activity on fast ion losses and transport	Burning plasma
RT13	X-point radiation and control	Exhaust (PEX)
RT14	Physics of plasma detachment / impurity mix/ heat load patterns	Exhaust (PEX)
RT15	Extrapolation of SOL transport to ITER and DEMO	Exhaust (PEX)
RT18	Alternative divertor configurations	Exhaust (PEX)
RT16	PFC damage evolution under tokamak conditions	PFC (PEX)
RT17	Material migration and fuel retention mechanisms in tokamaks	PFC (PEX)

He Campaign on AUG and JET in 2022

	Research Topics
RT-He-01	*ELMy H-mode operation in He in view of the non-active phase of ITER*
RT-He-02	*Qualifying transport in the core and edge of helium plasmas, in preparation of the non-active phase of ITER*
RT-He-03	*ELM control in helium H-modes for the non-active phase of ITER*
RT05	Runaway electron generation and mitigation, and disruption mitigation in helium plasmas
RT06	ELM mitigation and suppression in ITER/DEMO relevant conditions in helium plasmas
RT-He-04	*Helium plasmas for undestanding detachement physics*
RT17	Fuel retention mechanisms in tokamaks in helium plasmas
RT-He-05	*Assessing plasma wall interactions in He plasmas in view of the non-active phase of ITER*

Extended (with existing SCs) and *new He RTs*

2 – WP Machine time allocation for AUG & JET He Campaign in pulses and sessions

RT	Name	AUG - pulses	JET - sessions
RT-He-01	ELMy H-mode operation in He in view of the non-active phase of ITER	**15**	**22**
RT-He-02	Qualifying transport in the core and edge of helium plasmas, in preparation of the non-active phase of ITER	**12**	**10**
RT-He-03	ELM control in helium H-modes for the non-active phase of ITER	**0**	**6**
RT-He-04	Helium plasmas for undestanding detachement physics	**2**	**2**
RT-He-05	Assessing plasma wall interactions in He plasmas in view of the non-active phase of ITER	**14**	**18**
RT05	Runaway electron generation and mitigation, *including disruption mitigation in He plasmas*	**0**	**2**
RT06	ELM mitigation and suppression in ITER/DEMO relevant conditions, *including RMP in He plasmas*	**12**	**0**
RT17	Material migration and fuel retention mechanisms in tokamaks, *including fuel retention mechanisms in He plasmas*	**0**	**4**
Contingency		**0**	**16**
TOTAL		**55**	**80**

JET: Nb of pulses per session depends on Ar frosting of cryo pump

2 – WP Main Objectives & Milestones (2022 & 2023 as one campaign)

WP TE Milestones 2022/2023

ID	Milestones Table	Date
TE.M.01	Completion of the disruption and run-away mitigation experimental programme with the SPIs.	Dec. 2022
TE.M.02	Access stable operation at low collisionality and high beta	Dec. 2023
TE.M.03	JET scenarios ready for DTE3 operation	Dec. 2023
TE.M.04	High performance reduced/no ELM scenario in a metallic wall operated routinely	Dec. 2023
TE.M.05	H-mode access for the ITER non-activated phase (H, He, H/D) reliably established	Dec. 2023

2 – WP Main Objectives & Milestones (2022 & 2023 as one campaign)

WP TE Grant deliverable for 2022/2023

TE.D.03	High fluence operation on actively cooled divertor at WEST assessed, and documented. (at risk due to WEST delays)	Dec. 2022
TE.D.04	Achievement of ELM control during the transient phases (I_p ramp-up and down, entering and exiting H-mode etc.) integrating ITER operational constraints.	Dec. 2022
TE.D.05	The role of turbulent and MHD driven transport in the vicinity of the separatrix for the stability of the pedestal quantified and the implications for predictions for ITER and DEMO reported.	Dec. 2022
TE.D.06	Achievement of state-observer based control of radiative detachment using multiple diagnostics.	Dec. 2023
TE.D.07	The disruption and run-away electron mitigation efficiency by single and multiple shattered pellet injectors on different sized devices to validate the ITER Strategy assessed and documented.	Dec. 2023
TE.D.08	Balance between gross and net erosion of W under different operational conditions in full-metallic toroidal devices	Dec. 2023
TE.D.09	Establishment and comparison of N and Ne-seeded partially-detached divertor in high-power operations in view of ITER radiative scenario.	Dec. 2023
TE.D.10	The role of electron and ion heat channels and plasma rotation on the access to H-mode for hydrogen, helium and mixed plasmas in view of the ITER non-active phase quantified.	Dec. 2023
TE.D.11	Incorporation of turbulence in multi-fluid calculations using physics-based diffusion coefficients (with TSVV4).	Dec. 2023

In cycle of call for proposal moved from **mixed approach for 2021/22**:

1) establishing priorities for the call & receiving proposals
2) defining Research Topics and Deliverables as a result of the received proposals (Dec. 2020)
3) Extending 2021 programme into 1st half of 2022

Top down approach for 2022/23

Prior to call for proposals:

- Definition of Research Topics
- Definition of Scientific Objectives cross-checked against WP TE GD and MS (no DTE3 preparation)
- Emphasizing integrative aspects (e.g. exhaust and control related objectives combined with ITER and DEMO scenarios)

Proposals expected to implement the scientific objectives into an experimental and modelling context & solicitate TSVValidation

2 – WP Organization: Changes foreseen for 2022/2023 programme (II): D

2021 → 1st half 2022

	Research Topics
RT1	ITER Baseline scenarios towards low collisinality and detachment
RT2	H-mode entry and pedestal dependence with impurities and isotopes
RT3	RF-assisted breakdown and current ramp-up optimization
RT4	Disruption avoidance and control for ITER and DEMO
RT5	Run-away electron generation and mitigation
RT6	ELM mitigation and suppression in ITER/DEMO relevant condition
RT7	Negative triangularity scenarios as an alternative for DEMO
RT8	QH-mode and I-mode assessment in view of DEMO
RT9	Extension of EDA and QCE performance towards DEMO
RT12	Development of the steady state scenario
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RT13	X-point radiation and control
RT14	Physics of plasma detachment / impurity mix/ heat load patterns
RT15	Extrapolation of SOL transport to ITER and DEMO
RT18	Alternative divertor configurations
RT16	PFC damage evolution under tokamak conditions
RT17	Material migration and fuel retention mechanisms in tokamaks

ITER Scenario (RT1–RT6)

DEMO Scenario (RT7, RT8, RT9, RT12)

Burning plasma (RT10, RT11)

Exhaust (RT13, RT14, RT15, RT18)

PFC (RT16, RT17)

PEX (Exhaust + PFC)

2nd half 2022 & 2023

	Research Topics
RT1	Core-Edge-SOL integrated H-mode scenario compatible with exhaust constraints in support of ITER
RT3	Strategies for disruption and run-away mitigation in support of the ITER DMS
RT4	Physics-based machine generic systems for an integrated control of plasma discharge
RT8	Physics and operational basis for high beta long pulse scenarios
RT2	Physics understanding of alternatives to Type-I ELM regime
RT9	Physics understanding of energetics particles confinement and their interplay with thermal plasma
RT5	Physics of divertor detachment and its control for ITER, DEMO and HELIAS operation
RT7	Physics understanding of alternative divertor configurations as risk mitigation for DEMO
RT6	Preparation of efficient Plasma Facing Components (PFC) operation for ITER, DEMO and HELIAS

2 – New WP Organization: To Facilitate physics and control integration of Prgramme

ITER

RT01: Core-Edge-SOL integrated H-mode

DEMO

RT02: Alternative to type-I ELM regimes

Physics & Control integration

RT03: Disruption & RE mitigation strategies

RT04: Machine generic integrated control

RT05: Physics of divertor detachment

RT08: Physics of high β long pulse scenario

RT09: Physics of energetic particles

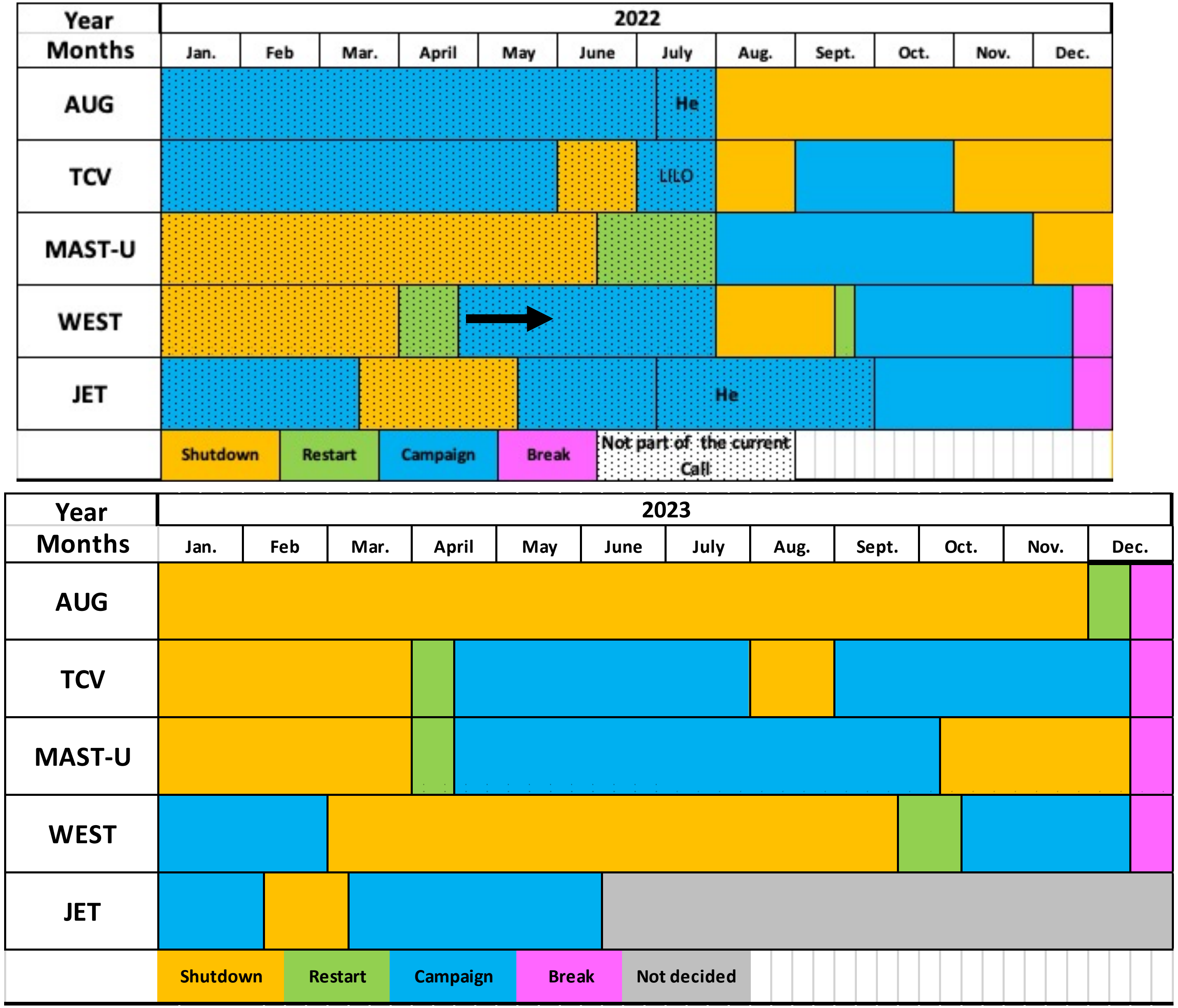
RT06: preparation of efficient PFC operation

RT07: Alternative divertor configuration

PEX

Mission 1	Mission 2

2 – WP Main Objectives & Milestones: Timeline for devices for 2022/2023 call for proposals



JET

- SPI commissioning mid July – mid August 2022
- Commissioning of enhancement of HRTS
- Commissioning of enhanced passive spectroscopy for operation on tile 6

Key uncertainties:

- Existence of budget for operating JET beyond 09/2022
- Decision on DTE3 or TT or extension of programme foreseen in 22/23 beyond April 2023 until shutdown of JET

2 – WP Main Objectives & Milestones (2022 & 2023): organizational timeline

End January 2022: Call for Proposals He Campaign

Early March 2022: He Campaign Programme Meeting

Mid March 2022: Call for Participation to He Campaign

Mid March 2022: Call for Proposals for DD 2022 2023 campaign

May 2022: Call for Participation for late 2022

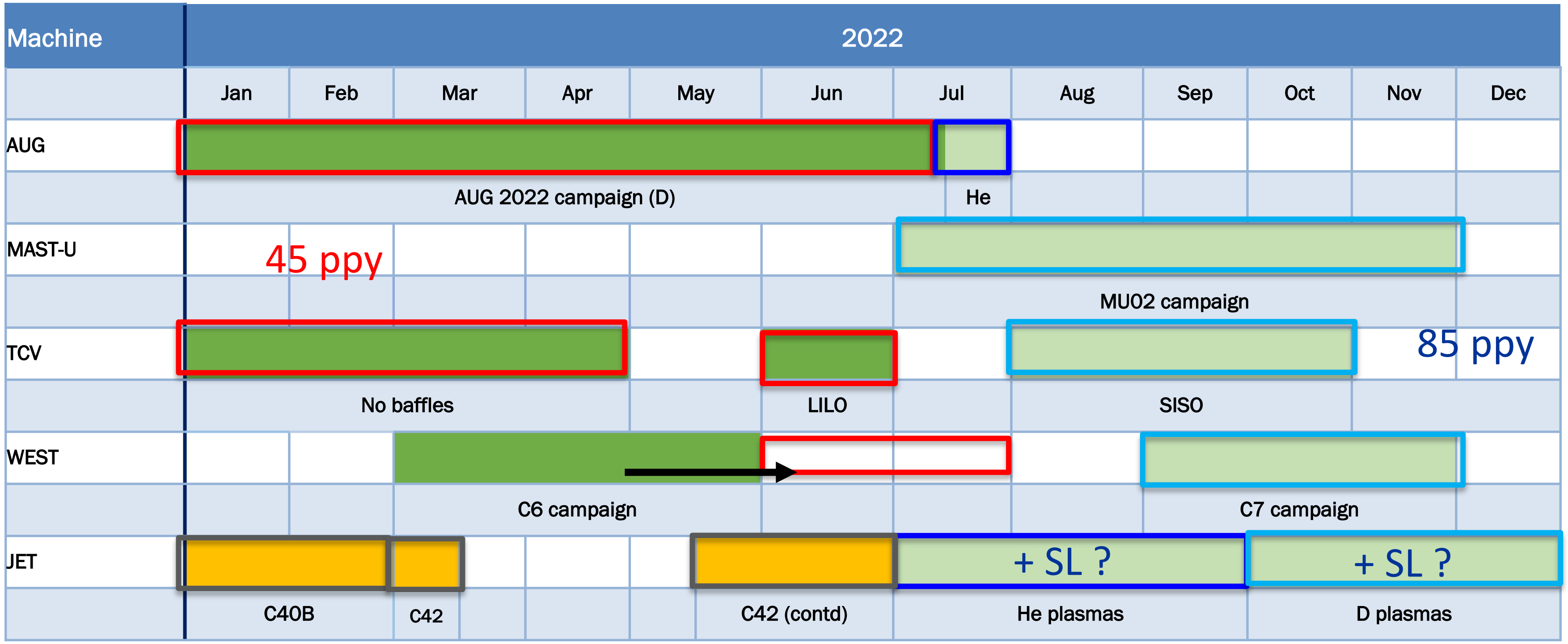
Early June 2022: Call for Analysis of 2021 and early 2022 campaign

Early November 2022: Call for Participation 2023

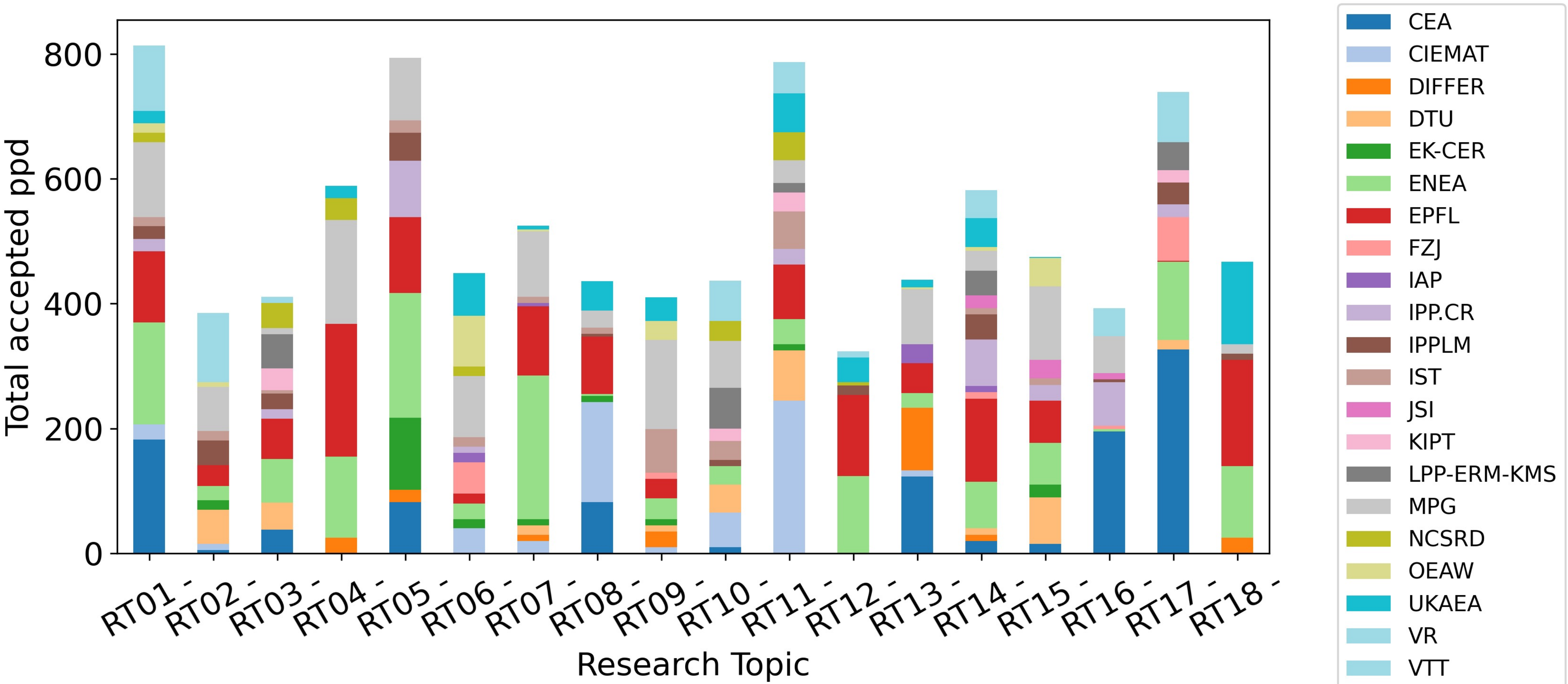
For admin/budget allocation reasons call for participation to be split

2 – WBS level 1 Resource distribution(<u>2022</u>)

- Split 2022 budget in 45 ppy for 1st half of 2022 & 85 ppy for 2nd half of 2022 which inlcudes:
  - He campaigns AUG/JET (with analsis campaign period exceeds 2022 budget period)
  - D campaigns TCV, MAST-U, WEST, JET (campaign period exceeds 2022 budget period)
  - Analysis of 1st half of 2022 & 2021 campaign (analysis might exceed 2022 budget period)



Accepted ppds per Research Topic with highlighted beneficiary contribution



Status January 2022

2 – WBS level 1 Resource distribution(2022): Enhancements

- *JET LIDS-QMS moving ahead if JET continues*
- *AGHS pending as function of possible need in a possible DTE3 campaign end 2023 (UKAEA)*

End 2021 PMU issued call for diagnostic enhancements:

- ASDEX Upgrade - Design and implementation of a divertor Thomson Scattering system for the new upper divertor – *approved, PMP tbd*
- WEST - Design and implementation of a vertical endoscope for the fast IR camera – *approved, PMP tbd*

3 – Risk & Mitigation Register: Current Status

Description of Risk	Severity	Likely hood	Proposed Mitigation Action	Risk materialized?	Mitigating Measures applied?	Comments
Non availability of one or several WP TE devices	H	L	Reprioritization of device usage and amendment of the timeline of the experiment	WEST unavailable. TCV ECRH	Yes	WEST campaign shifted. RT01 experiment with ECRH have high priority in 2022 on TCV
Delay in the PEX Upgrades on the various devices	H	M	Reprioritize PEX experiments and develop international collaboration	No		
SPI experiments are not conclusive in mitigating the disruption loads on tokamaks.	M	L	Find alternative mitigation solution to be developed on tokamaks	No		
Transferability of no/reduced ELM scenario to ITER and DEMO not feasible.	H	L	Increase focus on JT-60SA and the importance of stellarator research	No		
Monitoring of the retention in metallic devices not sufficiently quantifiable	H	M	Develop alternative monitoring methods	No		
JET DT campaign not or partially achieved in 2021	H	M	Review JET extension objectives for DTE3	No		Analysis in Progress
Delay on real time diagnostics deployment for radiation control	M	M	Put more resources on real time control	No		
Fast ion losses found too high in high beta scenarios for viable fusion performance	H	L	Expand the studies to JT-60SA	No		

4 – Project Change Requests & Other Items for Decision/Approval by PB

Decisions on PCRs

PCR Number	PCR Title	PCR Status	Comments
01	Move delivery of GD TE.D.01 to 12/2022	NEW	GD delayed because of unavailability of ECRH X3 on TCV in 2021; now operational
02	Change in RT structure for He and DD campaigns	NEW	Originally foreseen as part of integration of JET after C42

5 – AOB (including lessons learnt)

- Lack of Grant deliverable for He campaign (other than L-H transition in He, considered low priority for ITER in He campaign TE.D.10) but defined as JET focus point in CWP (Table 3.2e)
- No Grant Deliverable in WP TE requires DTE3 (Milestone TE.M.03 exists)
- Discussion required inside FSD of specific content for fulfilment of Grant Deliverables ➔ Review required (July 2022?) – e.g. TE.D.01 formulated generally, but delayed due to TCV X3 gyrotron, though TCV not explicitly mentioned but AUG and TCV implicitly intended
- TE.D.11: “Incorporation of turbulence in multi-fluid calculations using physics-based diffusion coefficients (with TSVV4).”➔ *should be TSVV 3*
- Need to undertake exercise of transferring subjective readiness level of scientific objectives to new RT structure

End of PB-Presentation slides

List of Deliverables of RTs with progress

RT	Deliverable	Description
01	D3	Optimize error field correction in MAST-U by using knowledge from other EU tokamaks (JET, AUG, COMPASS).
03	D1	Develop reliable ECRH and/or ICRH methods for RF assisted breakdown and produce prediction for ITER to determine the required RF power
05	D3	Develop and exploit measurement tools including (e.g., energy spectrum, density) for characterizing run-away electron beams
	D4	Test run-away electron mitigation with alternative methods (e.g., fueling pellets, MHD EC waves). D1. Develop reliable ECRH and/or ICRH methods for RF assisted breakdown and produce prediction for ITER to determine the required RF power
07	D3	Investigate power exhaust and detachment with simulations (2021) and in experiments in AUG and TCV (2022)
08	D1	Develop I-mode and QH-mode and determine existence space
	D2	Extend cross-machine scaling of PL-I threshold
	D3	Compatibility of QH-mode and I-mode with DEMO constraints (including dominant electron heating, low torque, high ne,sep, dissipative divertor)
09	D4	Identify the key parameters for a scaling of the heat loads in both regimes
12	D1	Develop an intrinsically steady state solution at high b_N (>3) in terms of q/pressure profile and stability. Compare it with other existing solutions in view of its application to JT-60SA and DEMO
13	D4	Demonstrate exhaust-compatible ramp-up/-down into detachment (including L-H transition) for at least one device
15	D4	Document associated turbulence properties near the X-point and in divertor region
18	D1	Characterize possible benefits of the snowflake configuration for X-point radiation stability and dissipated power

Definition of subjective scientific readiness levels

Level	
Emerging	Little or no understanding yet on WP TE devices
Exploratory	Physical process is assessed on WP TE devices, transposing to ITER or DEMO is uncertain
Judgemental	Controlling physical processes has been assessed on WP TE devices, but extrapolation to ITER/DEMO requires scalable parameters and further investigation
Mature – needs underpinning	Good understanding of controlling physical processes on WP TE devices, but major uncertainty in view of transposing ITER/DEMO
Mature – needs support	A good understanding has been achieved on WP TE devices, further research exploring ITER or DEMO relevant parameters
Established	Understanding is well developed and can be applied to ITER or DEMO