Centralised Coordinated Control to Protect the JET ITER-like Wall.

*Adam Stephen and JET-EFDA Contributors**

ICALEPCS, 2011.

*See the Appendix of F.Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejeon, Korea.

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The Joint European Torus (JET)

Plasma physics closest to ITER

Torus radius	3.1 m
Vacuum vessel	3.96m high x 2.4m wide
Plasma volume	80 m^3 - 100 m^3
Plasma current	up to 5 MA in present configuration
Main confining field	up to 4 Tesla

Unique technical capabilities :

- Tritium
- Beryllium

⇒ **Optimise the use of JET in support of ITER by making use of its unique capabilities**

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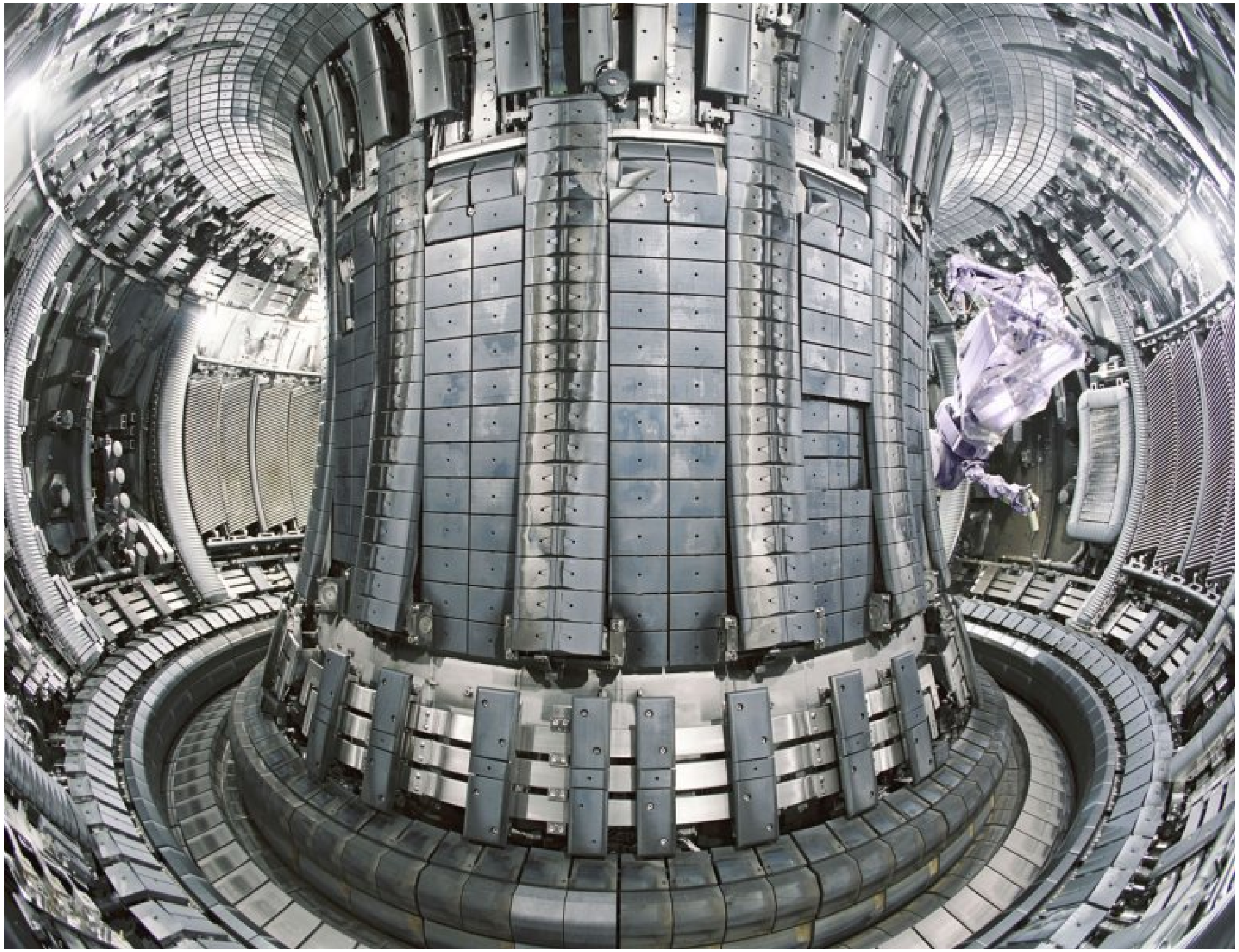
JET vessel 2005



Material for Plasma Facing Components

Carbon Fibre Composite Tiles (CFC)

- ✓ Low atomic number (minimise radiation losses)
- ✓ High power handling capacity (sublimation 4000K)
- ✗ Absorbs deuterium/tritium fuel.

➔ *Design for ITER : all-metal wall with Beryllium*

- ➔ *ITER-like Wall project for JET : 4000 new tiles*

Beryllium Tiles

- ✓ Low atomic number (minimise radiation losses)
- ✗ Reduced power handling capacity (melting pt 1560K)
- ✓ Reduced retention of fuel

Implications for the JET protection systems…

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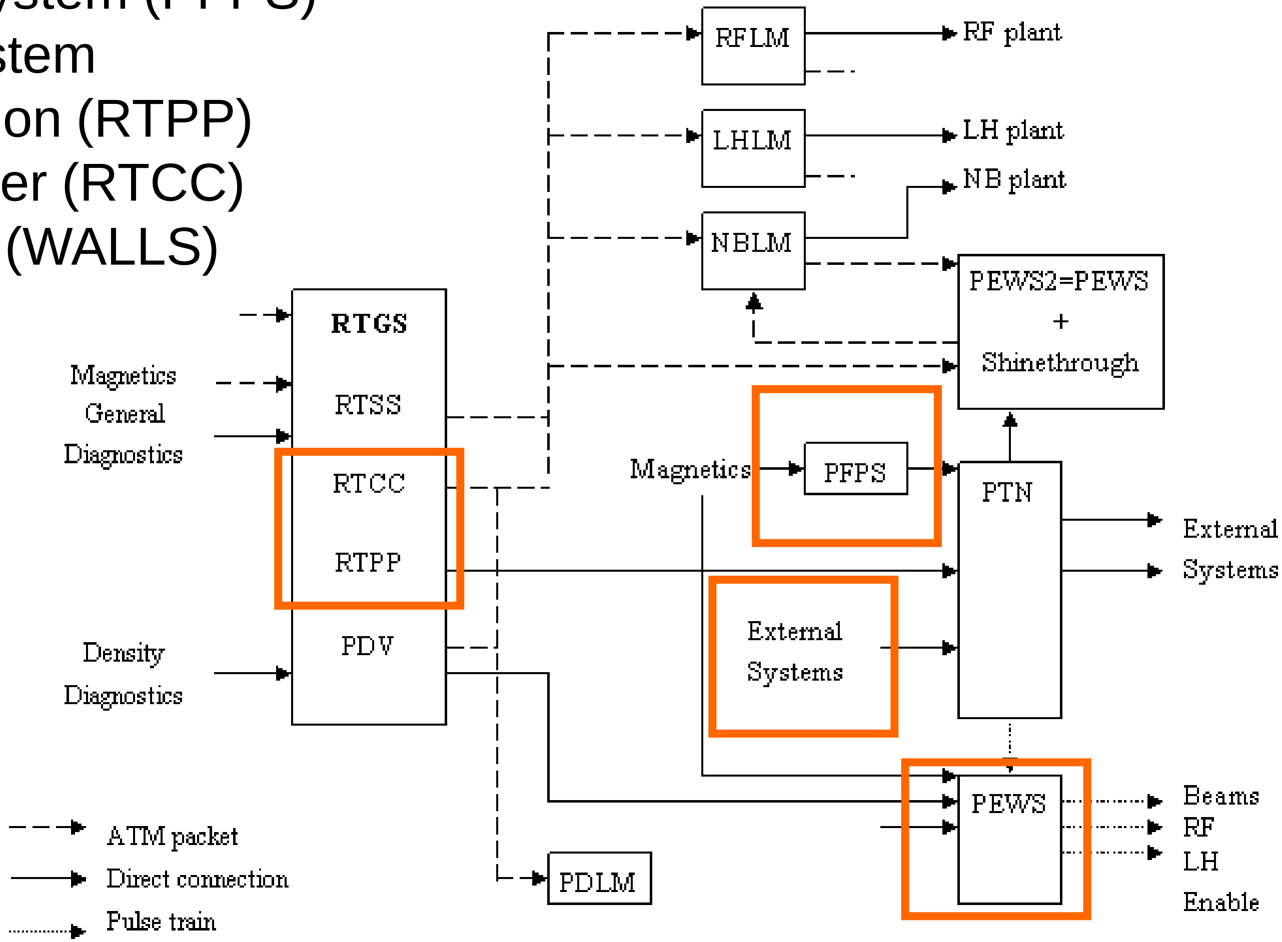
Original Protection Architecture

Detection Systems

- •Plasma Fault Protection System (PFPS)
- •Plant Enable Windows System
- •Real-Time Plasma Protection (RTPP)
- •Real-Time Central Controller (RTCC)
- •Plasma Wall Load System (WALLS)



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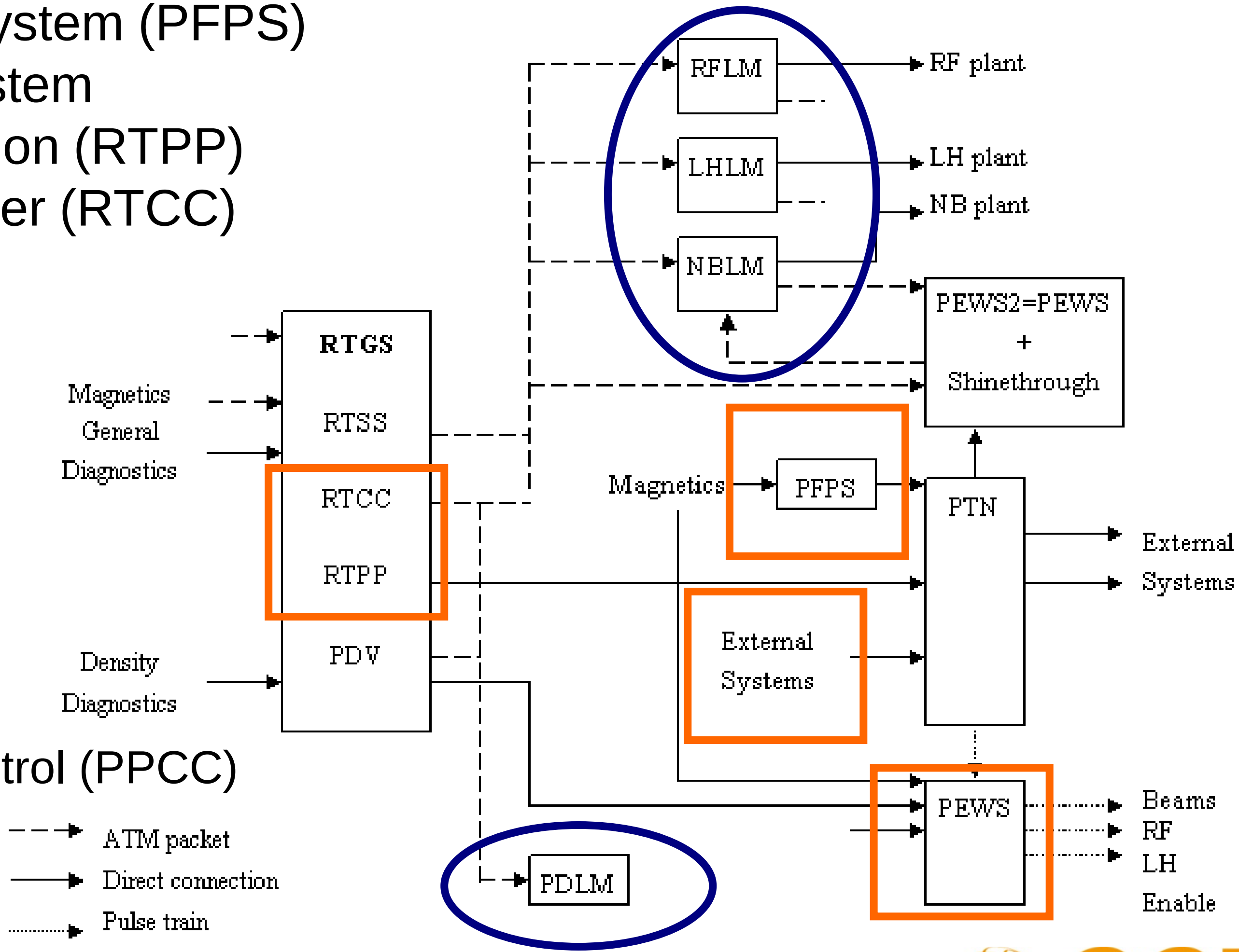
Original Protection Architecture

Detection Systems

- Plasma Fault Protection System (PFPS)
- Plant Enable Windows System
- Real-Time Plasma Protection (RTPP)
- Real-Time Central Controller (RTCC)

Real-time Controllers (local managers)

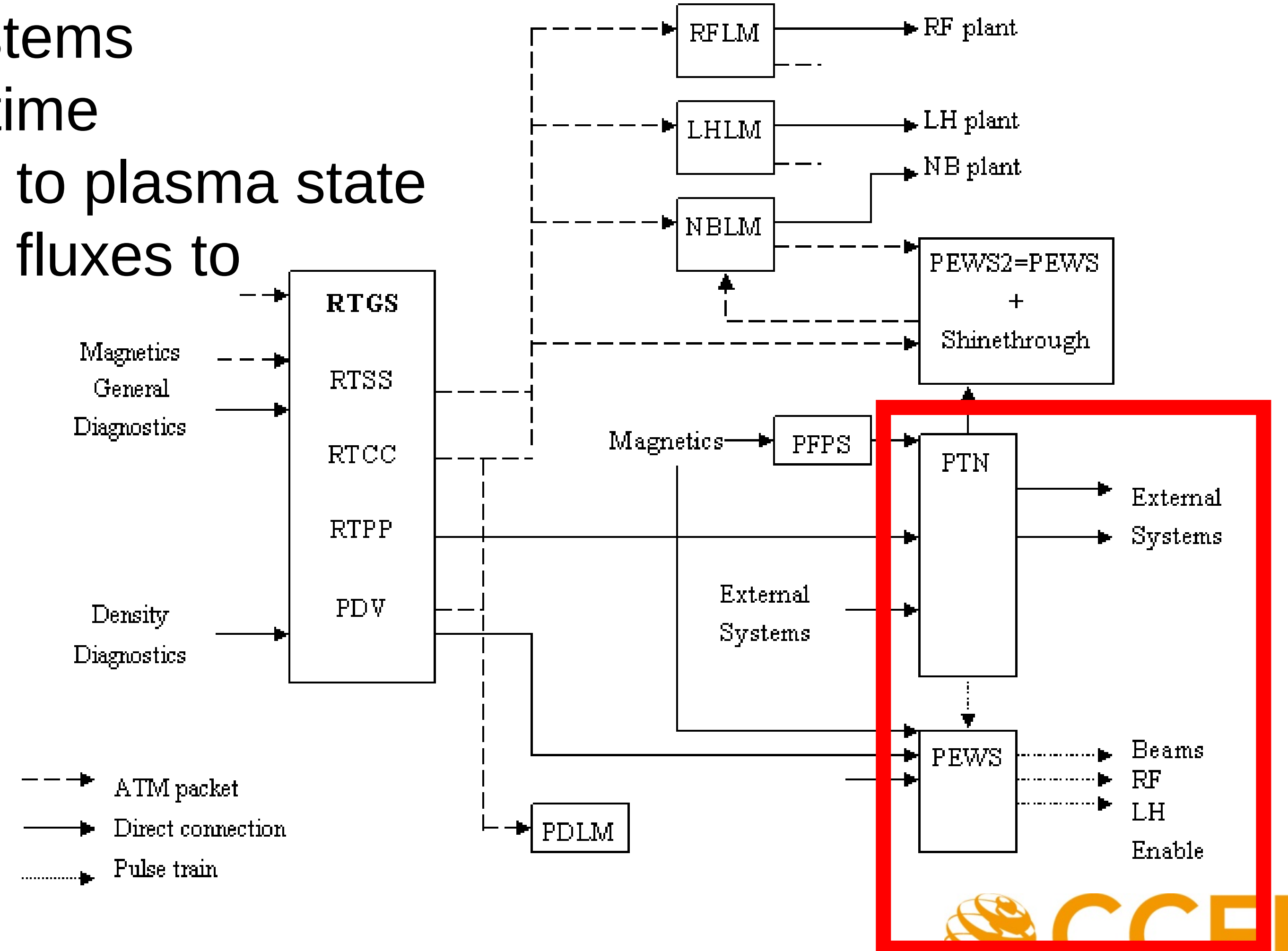
- Fuelling/Density (PDLM)
- Additional Heating
  - Neutral-Beam (NBLM)
  - Radio Frequency (RFLM)
  - Lower-Hybrid (LHLM)
- Plasma Position & Current Control (PPCC)



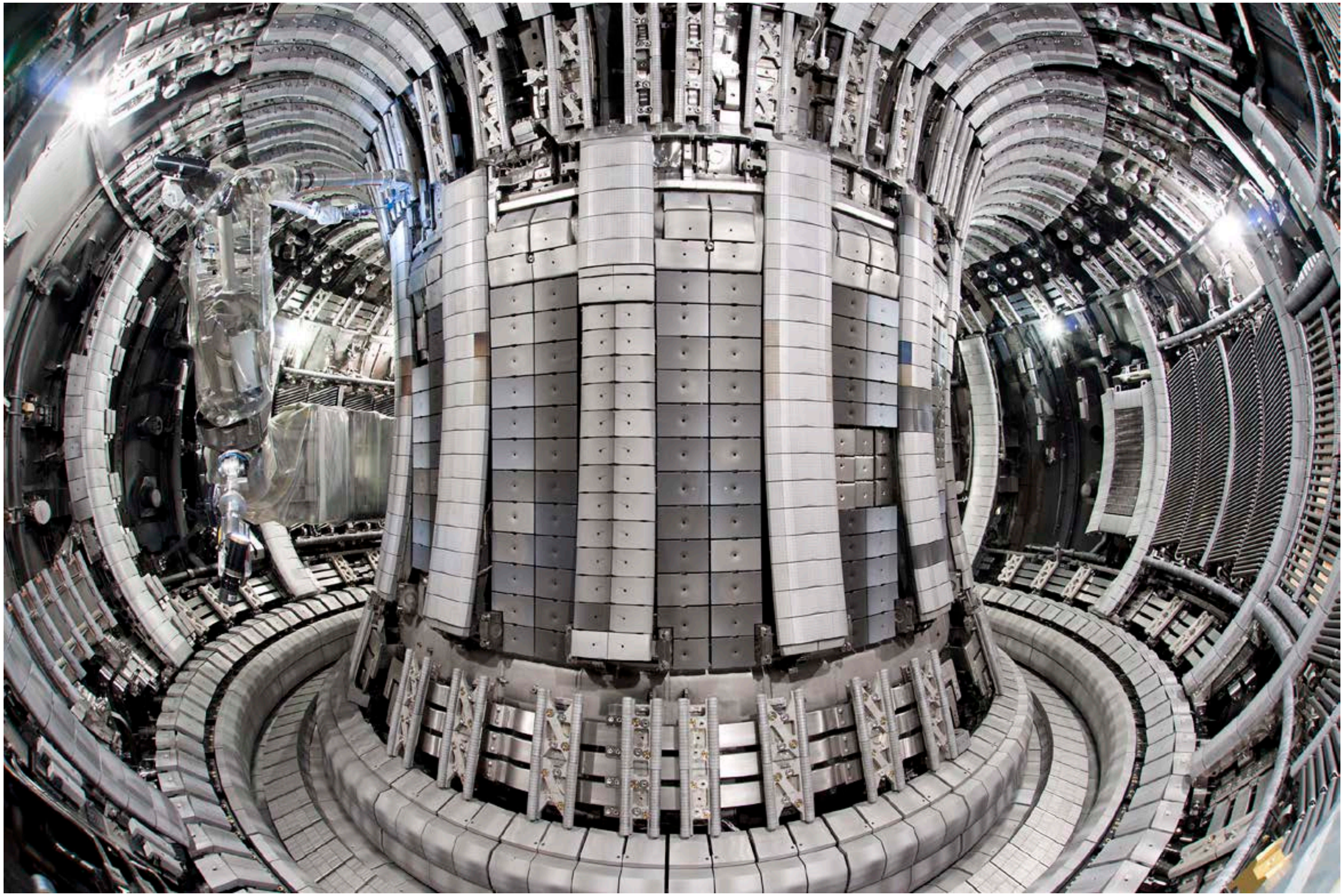
Original Protection Architecture

Protection Response

- •Pulse Termination Network
- •Global STOP to all systems
- •System stops fixed in time
- •No variation according to plasma state
- •Possibility of high heat fluxes to wall components

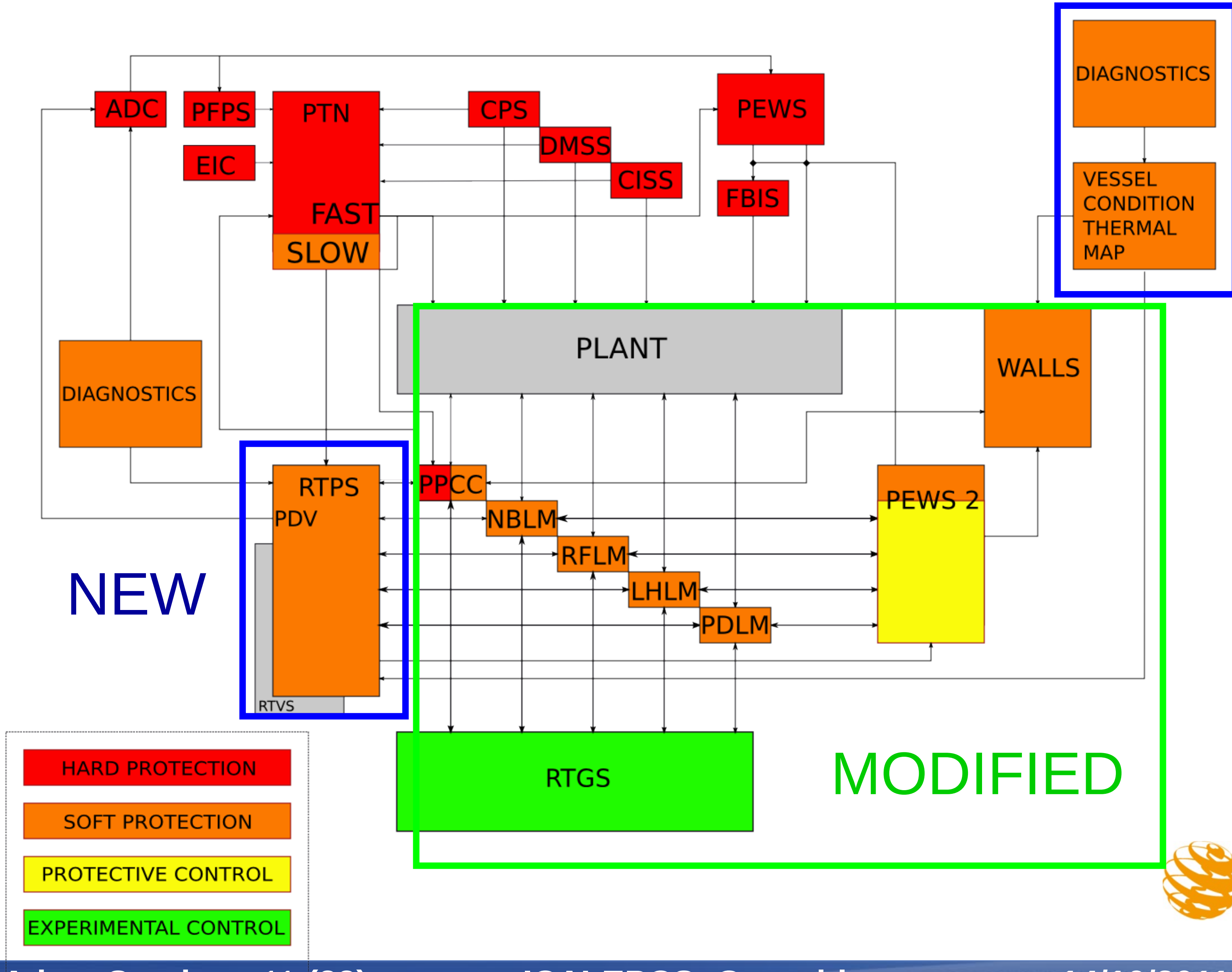


ITER-like Wall 2011



- New Diagnostic Systems to detect faults
  - Pyrometers, IR Cameras + Real-time image processing (*See M.Jouve, WEPMU018, this conference*).
  - Vessel Thermal Map (*See D.Alves, WEPMN014, this conference*)
  - Walls plasma load upgrade
- Update real-time controllers to accept protection override commands, including PPCC (*See A.Neto, MOPMU035, this conference*)
- Real-Time Protection Sequencer (RTPS) – new system to adapt experimental controls to implement hotspot avoidance or else achieve a "soft landing"
- Separation of control (RTCC)/protection(RTPP) diagnostics and related central servers (RTGS E/P)

PIW Protection Architecture 2009



Stop Triggers link to Configurable Stop Responses

- Identify classes of protective response:
  - (A) Overheating (local/walls/divertor/global)
    - Reduce the heating, but avoid turning it off.
    - Move/shrink the plasma.
    - Adjust heating/fuelling `as required'.
  - (B) Magnetohydrodynamic (MHD) Instabilities.
    - Change plasma control scenario to avoid disruption
  - (C) Improved programmable 'Fast' and 'Slow' stops
- Link fault alarms to response actions.
- Allow for local protection, plus two escalated responses.

Local Protection

- Localised overheating ?
- Known culprit ? (1 PINI, 1 Antenna, 1 Klystron)

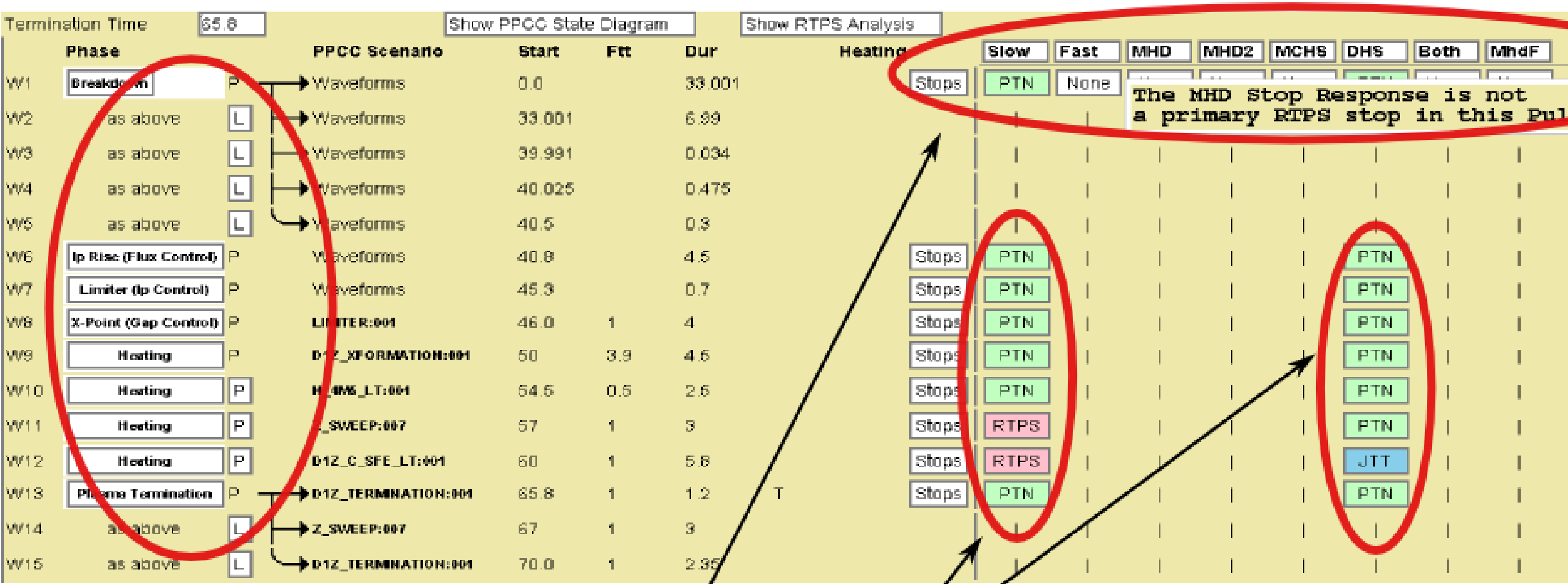
↳ **Inhibit & continue**

Local managers will rebalance the power demand.

If things get worse, stop safely.

Global Stop Response

2. Type of risk



	Phase		PPCC Scenario	Start	Ftt	Dur	Heating		Slow	Fast	MHD	MHD2	MCHS	DHS	Both	MhdF
W1	Breakdown	P	Waveforms	0.0		33.001		Stops	PTN	None						
W2	as above	L	Waveforms	33.001		6.99										
W3	as above	L	Waveforms	39.991		0.034										
W4	as above	L	Waveforms	40.025		0.475										
W5	as above	L	Waveforms	40.5		0.3										
W6	Ip Rise (Flux Control)	P	Waveforms	40.8		4.5		Stops	PTN					PTN		
W7	Limiter (Ip Control)	P	Waveforms	45.3		0.7		Stops	PTN					PTN		
W8	X-Point (Gap Control)	P	LIMITER:001	46.0	1	4		Stops	PTN					PTN		
W9	Heating	P	D1Z_XFORMATION:001	50	3.9	4.5		Stops	PTN					PTN		
W10	Heating	P	H_4M5_LT:001	54.5	0.5	2.5		Stops	PTN					PTN		
W11	Heating	P	Z_SWEEP:007	57	1	3		Stops	RTPS					PTN		
W12	Heating	P	D1Z_C_SFE_LT:001	60	1	5.8		Stops	RTPS					JTT		
W13	Plasma Termination	P	D1Z_TERMINATION:001	65.8	1	1.2	T	Stops	PTN					PTN		
W14	as above	L	Z_SWEEP:007	67	1	3										
W15	as above	L	D1Z_TERMINATION:001	70.0	1	2.35										

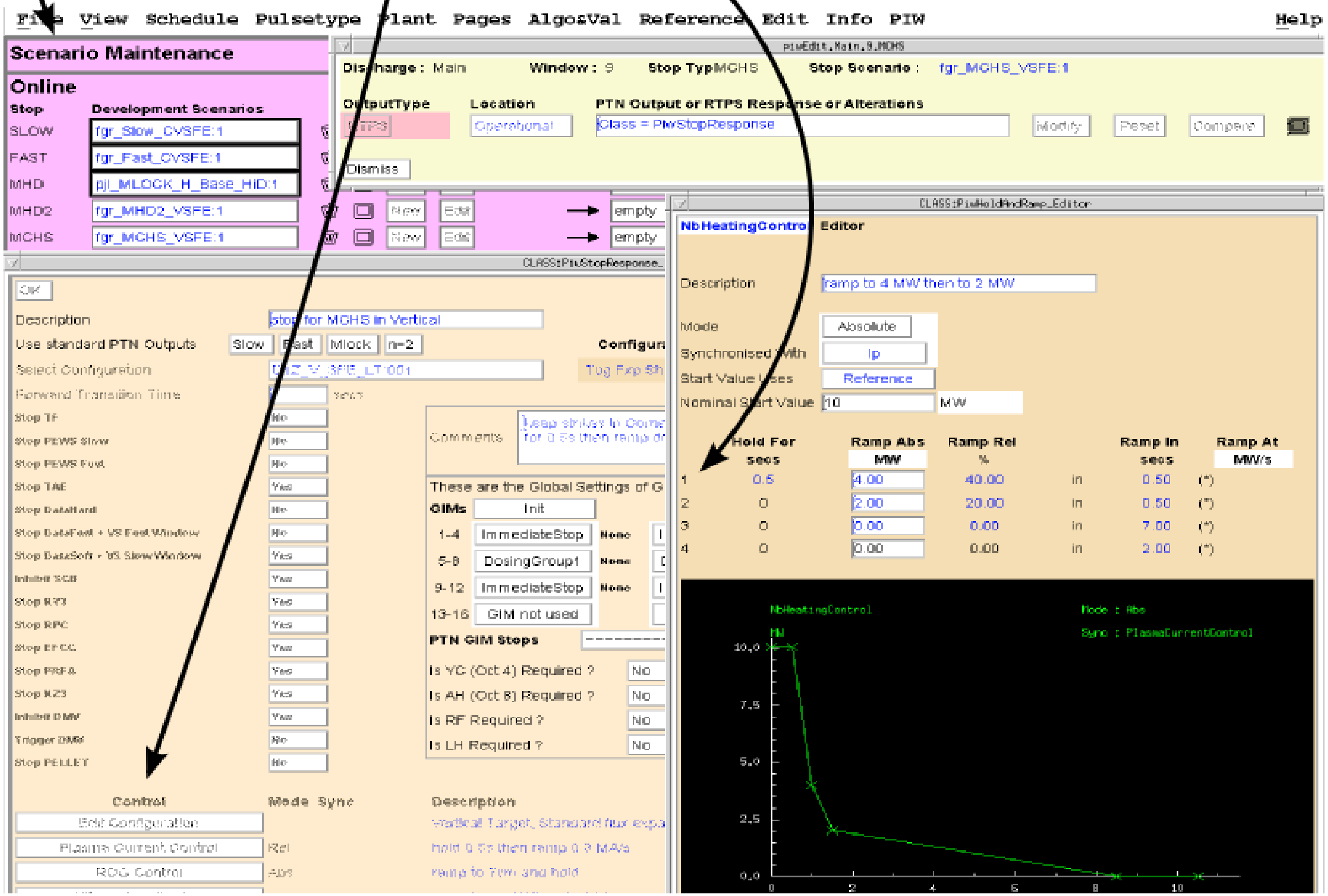
1.Time / phase.

3. Class of response ; PTN/RTPS/JTT

RTPS protection varies according to :

Stop Response Editor

1. Scenarios for each stop type.
2. Stop response = set of controls.
3. Controls define stepped transitions.



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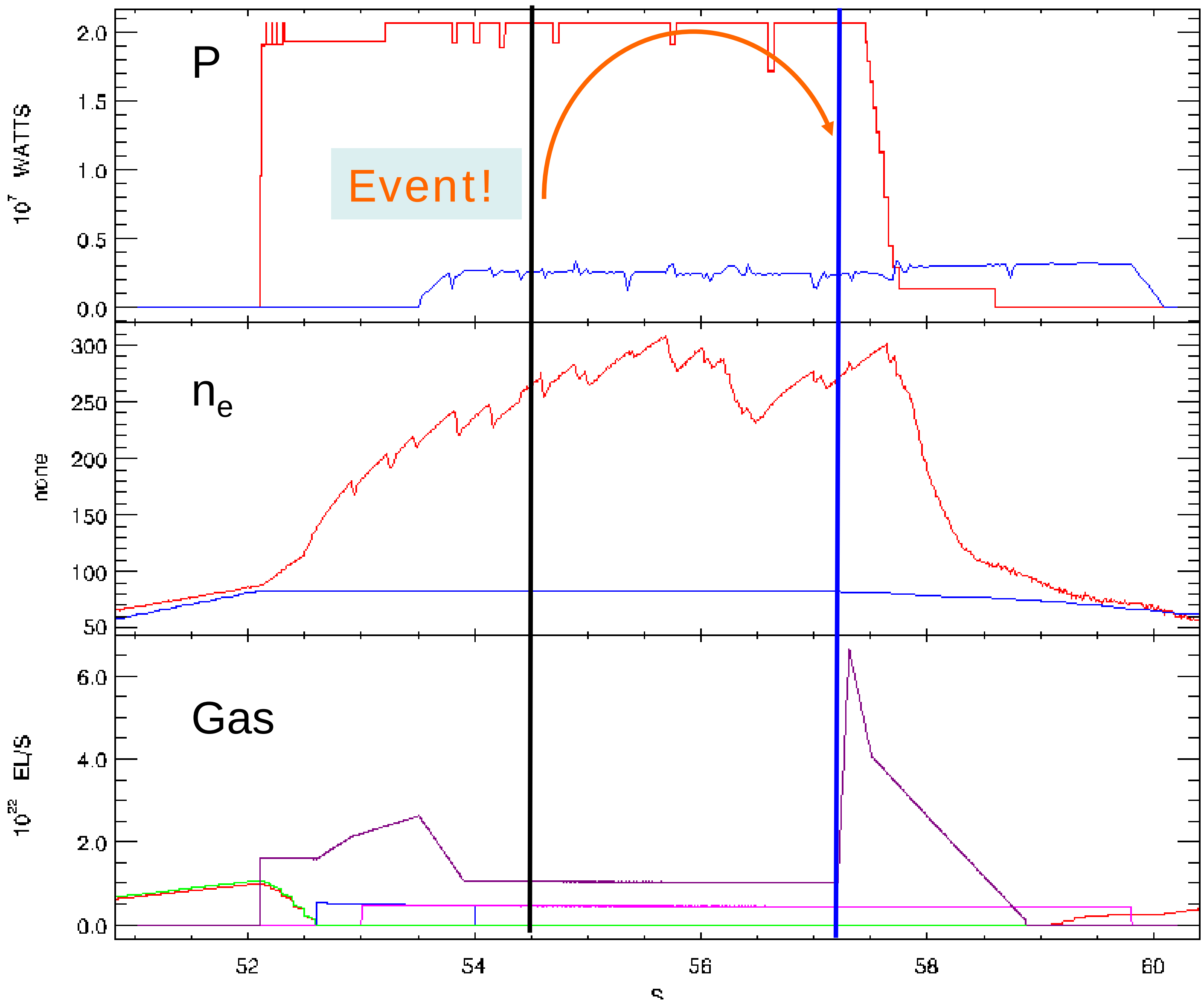
Jump To Termination



Plan:

Steady-state

52.5-57.4

Termination:

57.4-62.0

If event occurs any time in steady-state phase jump to 57.4

Secondary Stop Transitions

Some stops may `accelerate' , others continue to completion.

Table Version = 3.00

	Slow ^	Fast ^	MHD ^	MHD2 ^	MCHS ^	DHS ^	MC+DHS ^	MhdFst ^	JTT ^
Slow >	Slow->Slow Ignore	Slow->Fast RTPS FAST	Slow->MHD RTPS FAST	Slow->MHD2 RTPS FAST	Slow->MCHS RTPS MCHS	Slow->DHS RTPS DHS	Slow->MC+DHS RTPS MC+DHS	Slow->MhdFst Ignore	Slow->JTT Ignore
Fast >	Fast->Slow Ignore	Fast->Fast Ignore	Fast->MHD PTN Fast	Fast->MHD2 PTN Fast	Fast->MCHS PTN Fast	Fast->DHS PTN Fast	Fast->MC+DHS PTN Fast	Fast->MhdFst Ignore	Fast->JTT Ignore
MHD >	MHD->Slow Ignore	MHD->Fast Ignore	MHD->MHD Ignore	MHD->MHD2 Ignore	MHD->MCHS RTPS MhdFst	MHD->DHS RTPS MhdFst	MHD->MC+DHS RTPS MhdFst	MHD->MhdFst Ignore	MHD->JTT Ignore
MHD2 >	MHD2->Slow Ignore	MHD2->Fast Ignore	MHD2->MHD RTPS MHD	MHD2->MHD2 Ignore	MHD2->MCHS RTPS MCHS	MHD2->DHS RTPS DHS	MHD2->MC+DHS RTPS MC+DHS	MHD2->MhdFst Ignore	MHD2->JTT Ignore
MCHS >	MCHS->Slow Ignore	MCHS->Fast Ignore	MCHS->MHD RTPS MhdFst	MCHS->MHD2 Ignore	MCHS->MCHS Ignore	MCHS->DHS RTPS MC+DHS	MCHS->MC+DHS RTPS MC+DHS	MCHS->MhdFst Ignore	MCHS->JTT Ignore
DHS >	DHS->Slow Ignore	DHS->Fast Ignore	DHS->MHD RTPS MhdFst	DHS->MHD2 Ignore	DHS->MCHS RTPS MC+DHS	DHS->DHS Ignore	DHS->MC+DHS RTPS MC+DHS	DHS->MhdFst Ignore	DHS->JTT Ignore
MC+DHS >	MC+DHS->Slow Ignore	MC+DHS->Fast Ignore	MC+DHS->MHD RTPS MhdFst	MC+DHS->MHD2 Ignore	MC+DHS->MCHS Ignore	MC+DHS->DHS Ignore	MC+DHS->MC+DHS Ignore	MC+DHS->MhdFst Ignore	MC+DHS->JTT Ignore
MhdFst >	MhdFst->Slow Ignore	MhdFst->Fast Ignore	MhdFst->MHD Ignore	MhdFst->MHD2 Ignore	MhdFst->MCHS Ignore	MhdFst->DHS Ignore	MhdFst->MC+DHS Ignore	MhdFst->MhdFst Ignore	MhdFst->JTT Ignore
JTT >	JTT->Slow Ignore	JTT->Fast Ignore	JTT->MHD RTPS MHD	JTT->MHD2 Ignore	JTT->MCHS RTPS MCHS	JTT->DHS RTPS DHS	JTT->MC+DHS RTPS MC+DHS	JTT->MhdFst Ignore	JTT->JTT Ignore

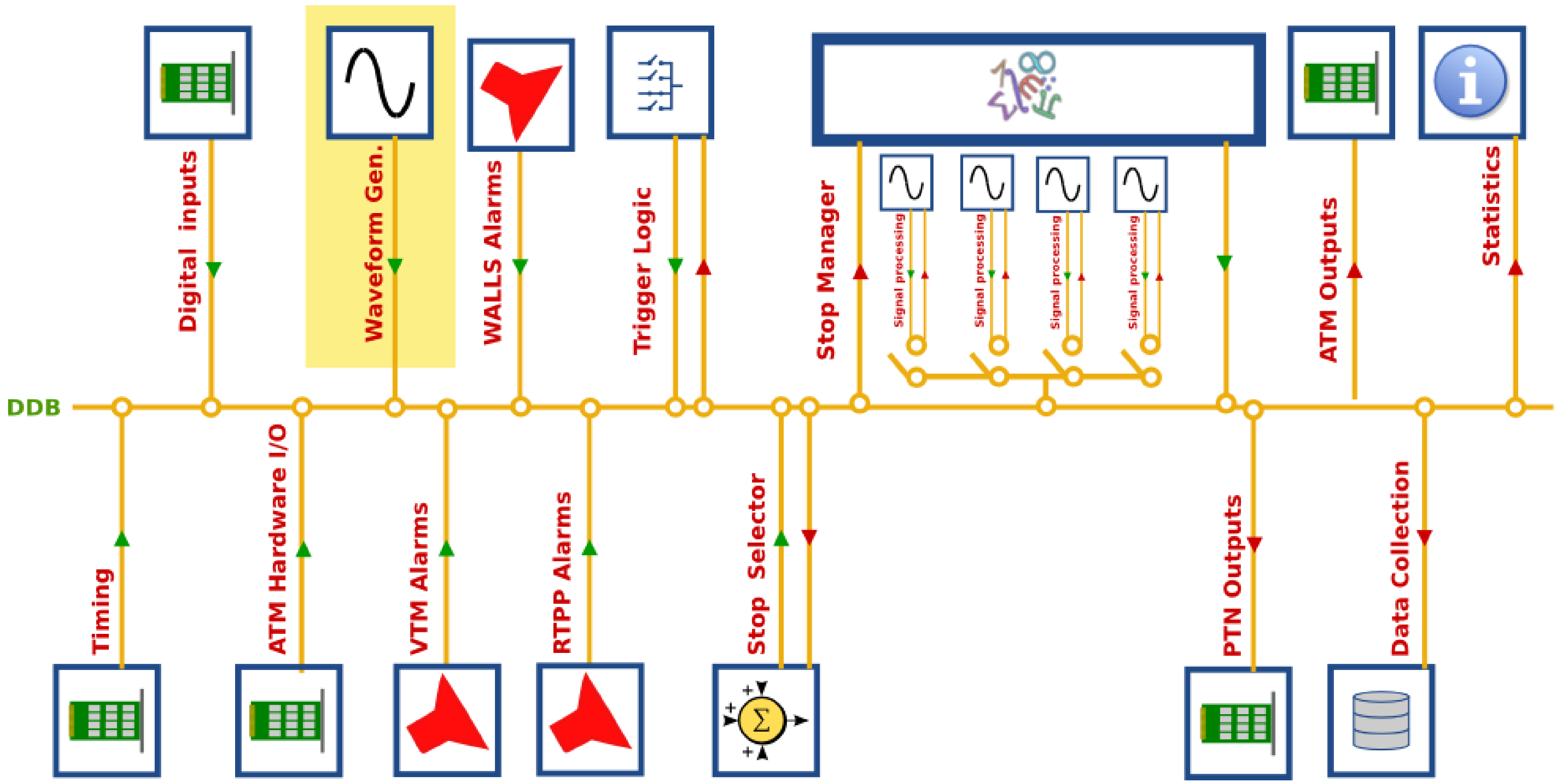
RTPS Software - MARTe

See A. Neto, THDAULT06, this conference.

1. Reusable modules for standard control application (state machine, data collection). Highly data driven application structure. Sophisticated object oriented/component based framework with 10+ years of control system experience.
2. Proven real-time performance.
3. Portable and highly modular : run unit tests on Linux, pluggable simulated inputs, rapidly evolve the design.
4. Strong interface to Level-1 MMI. Decouple compiled code from configuration programming. Strong authorisation and validation checks on changes. Highly visible parameters.

5. Application configuration ➔Documentation
6. Growing community of MARTe experts – a very knowledgeable and helpful group.

RTPS Block Diagram

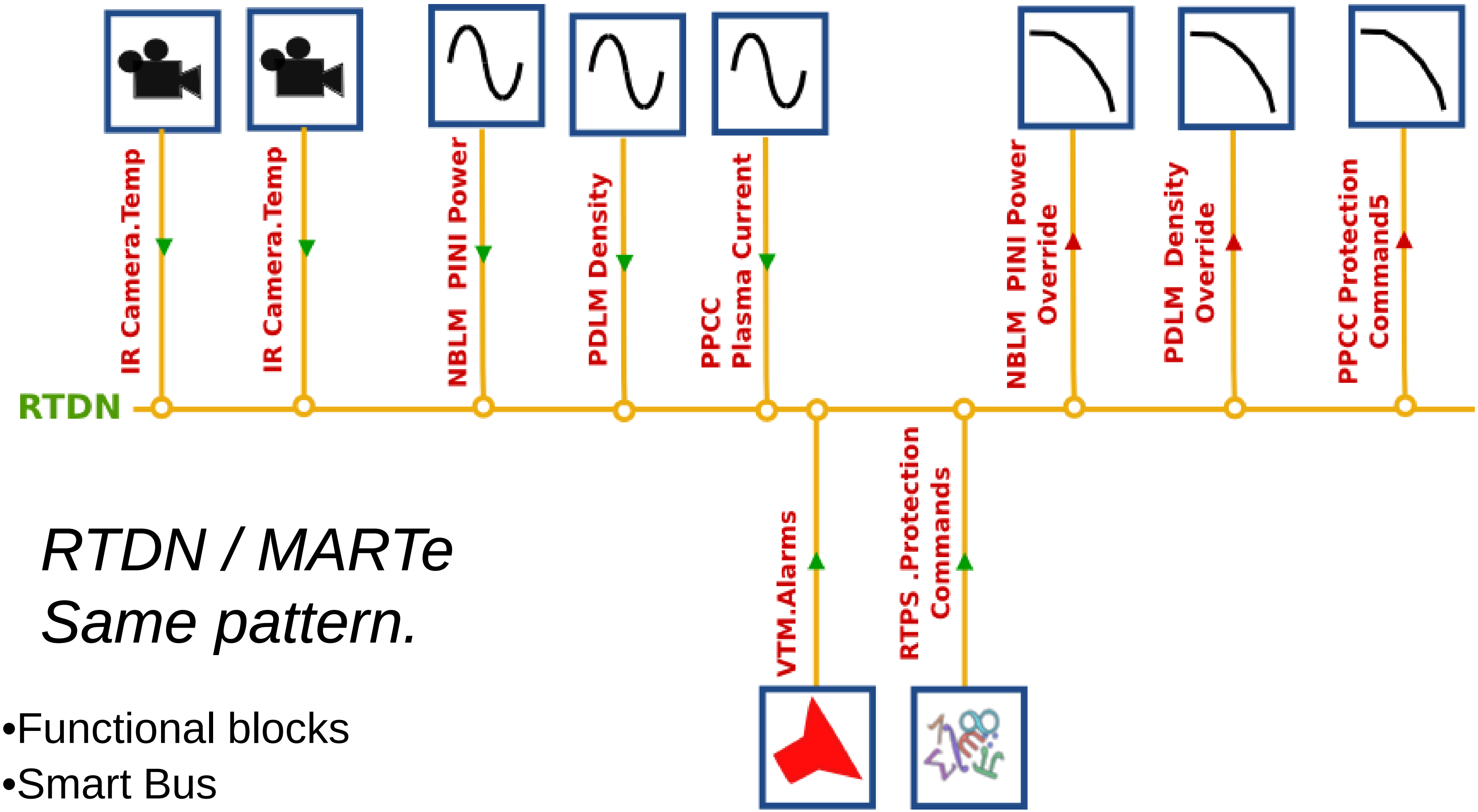


2ms cycle

RTPS Hardware Architecture

- VME system
- MVME5500 1GHz PowerPC 512MB RAM
- Digital IO
- Watchdog monitoring via pulse train
- Ethernet for slow control/data collection
- Real-time communication:
  - ATM segregrated network for RT control
  - Low latency, high reliability
  - Fixed connections (permanent virtual circuits)
  - Fixed size datagrams with controlled version ID.

RTDN

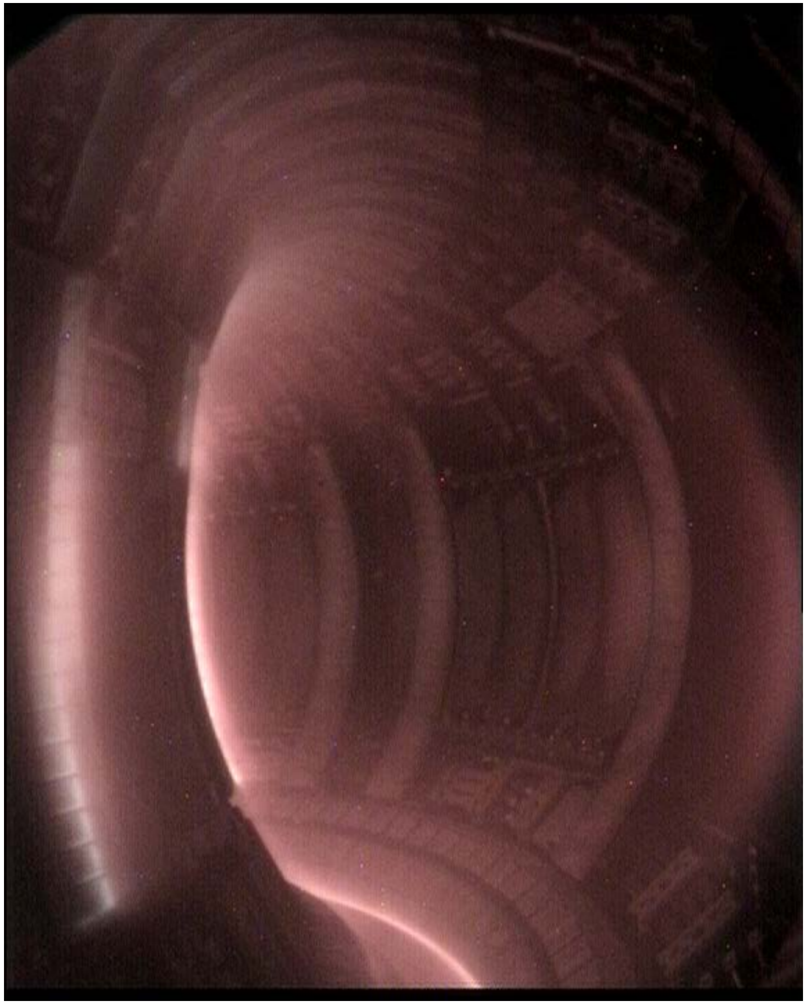


RTDN / MARTe
Same pattern.

- •Functional blocks
- •Smart Bus
    - •Synchronisation
    - •Data Coherency

PIW Commissioning

- Commissioning/Campaigns interleaved.
- Logic tests with dry runs
- Ohmic plasmas
- Plasma light used to simulate high temperatures.
- Vessel Thermal Map alarms checked.
- RTPS stop responses demonstrated.
- Jump To Termination in plasma control JPN 80500.



Future Work

- Full commissioning and calibration of camera systems.
- Integrate control of heating systems.
- Expanded local protection.
- ‘Alternative control’ ?