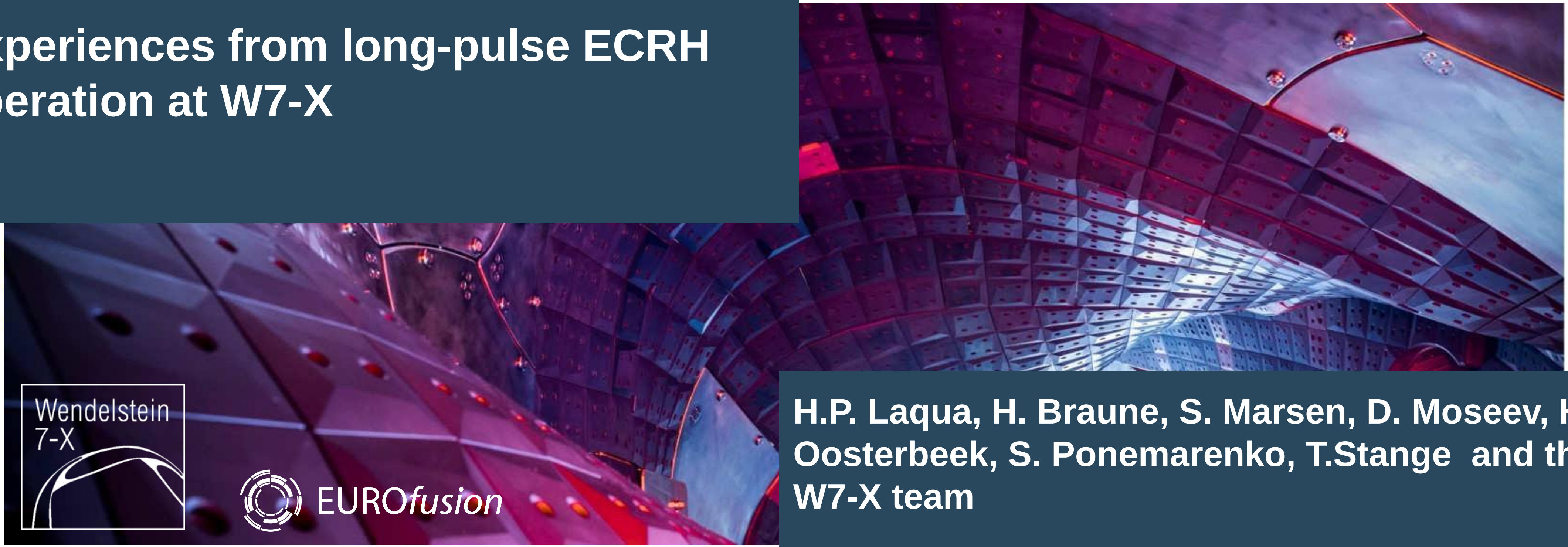
Time lapse

8min in 25 s

MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Experiences from long-pulse ECRH operation at W7-X



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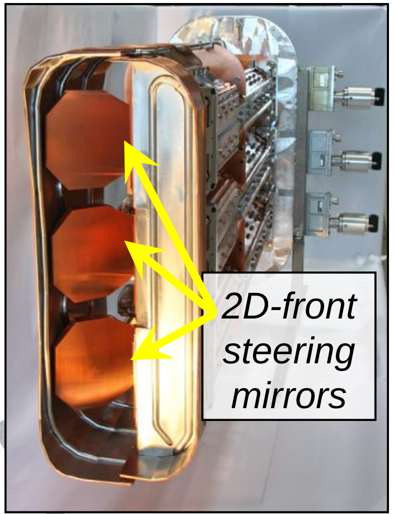
Content

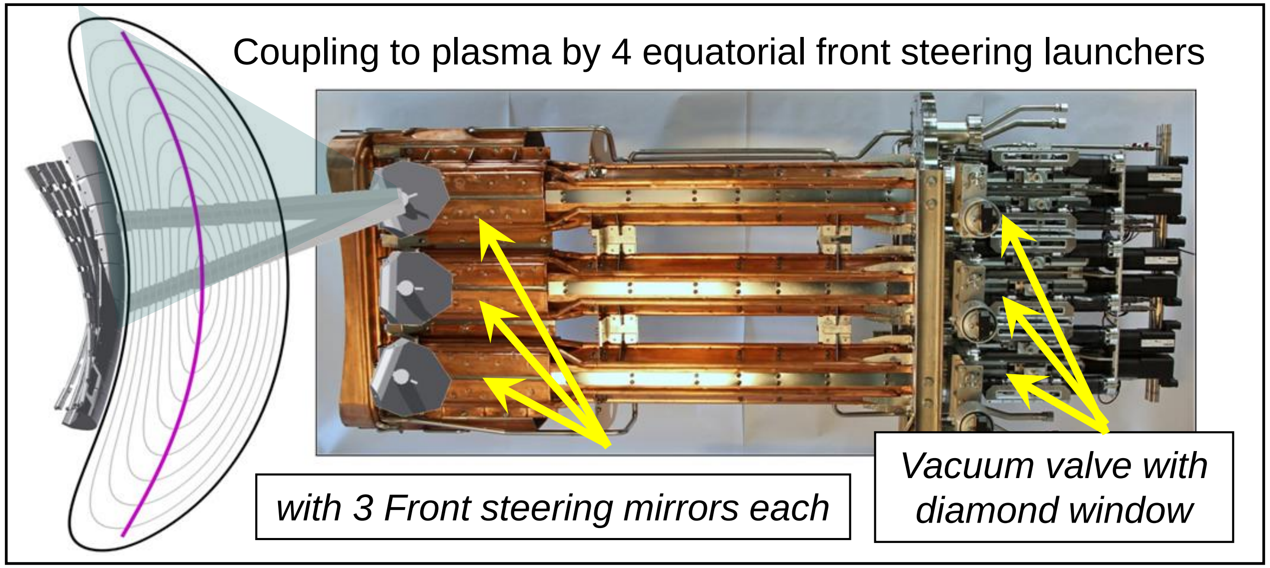
Reliability of the ECRH System

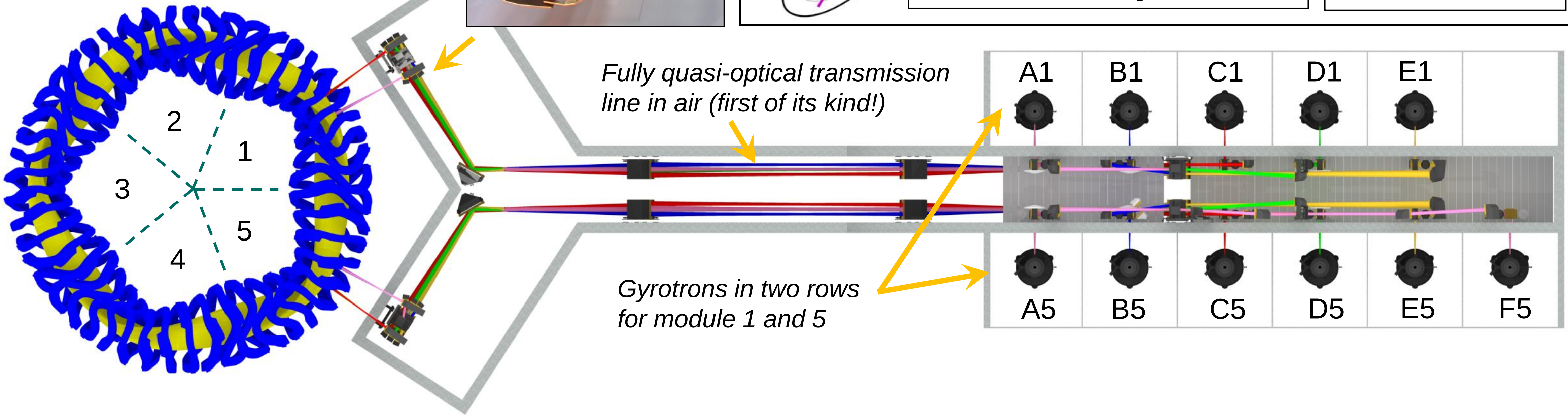
ECRH Stray Radiation Resilience

ECRH Set-Up

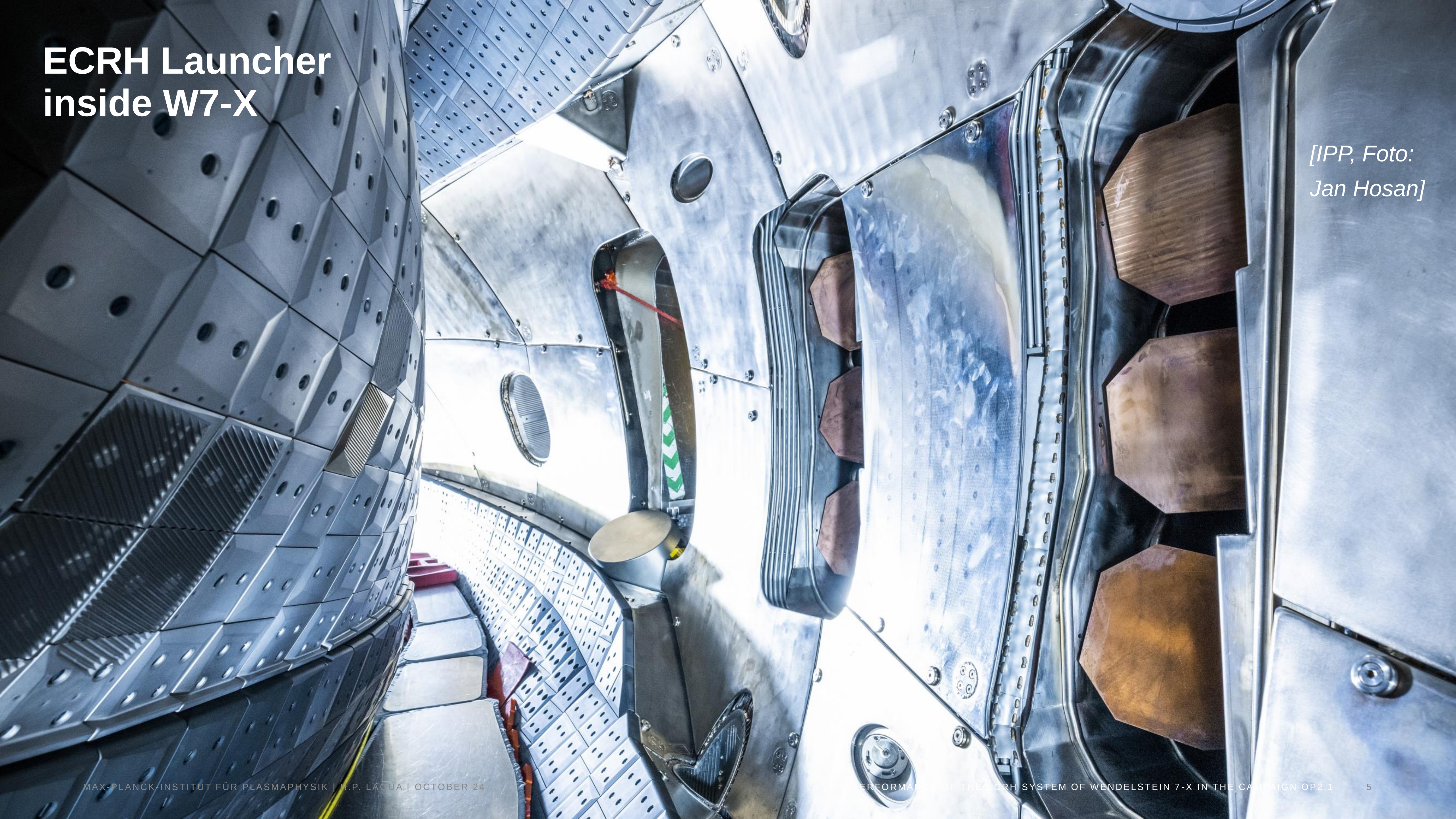
- 94% transmission
- 10 1-MW-class gyrotrons
- (1 1.5-MW-class gyrotron)
  @ 140GHz
- Installed power: 8.3 MW (9.6)
  Injected power: 7.5 MW (8.5)





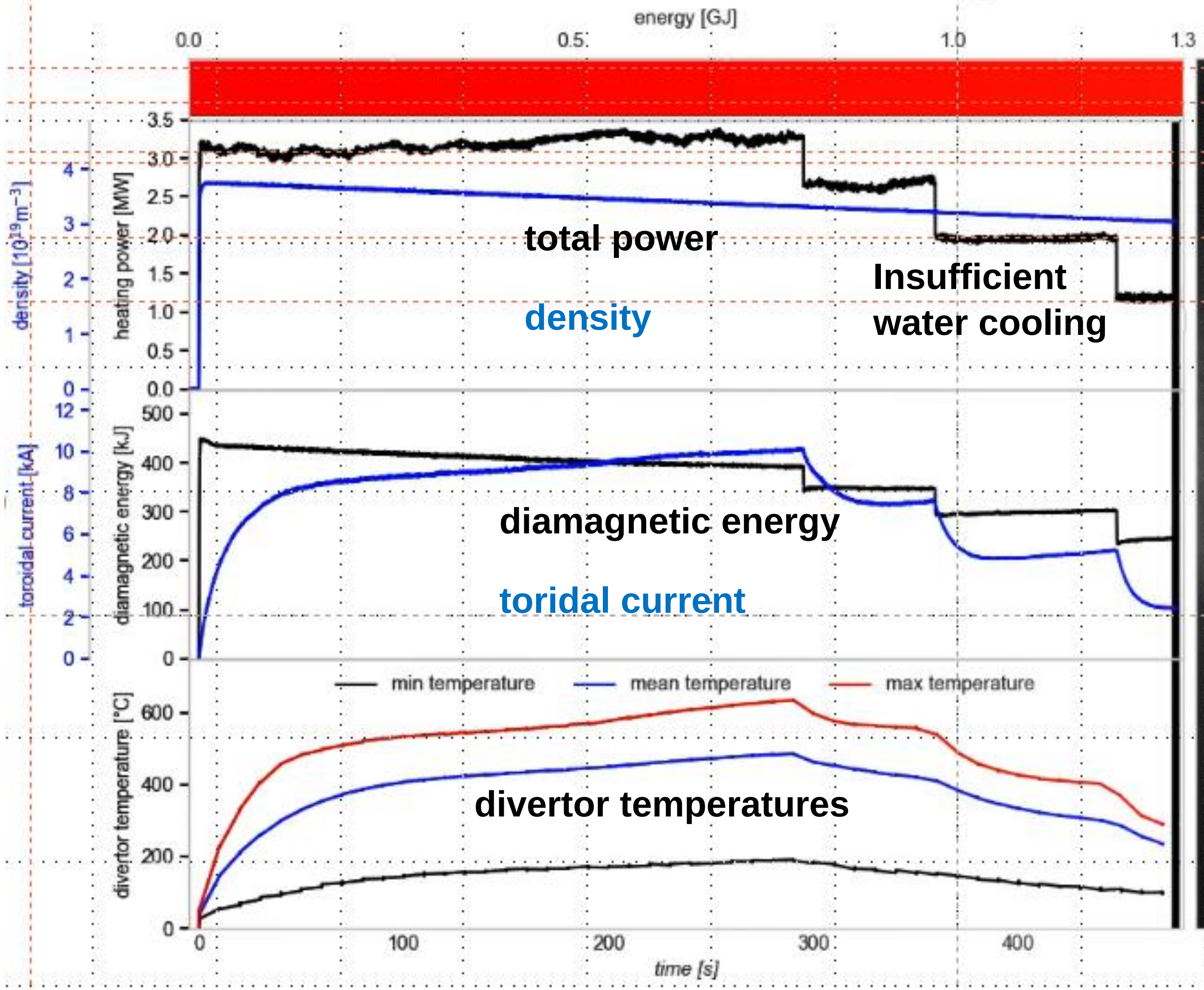


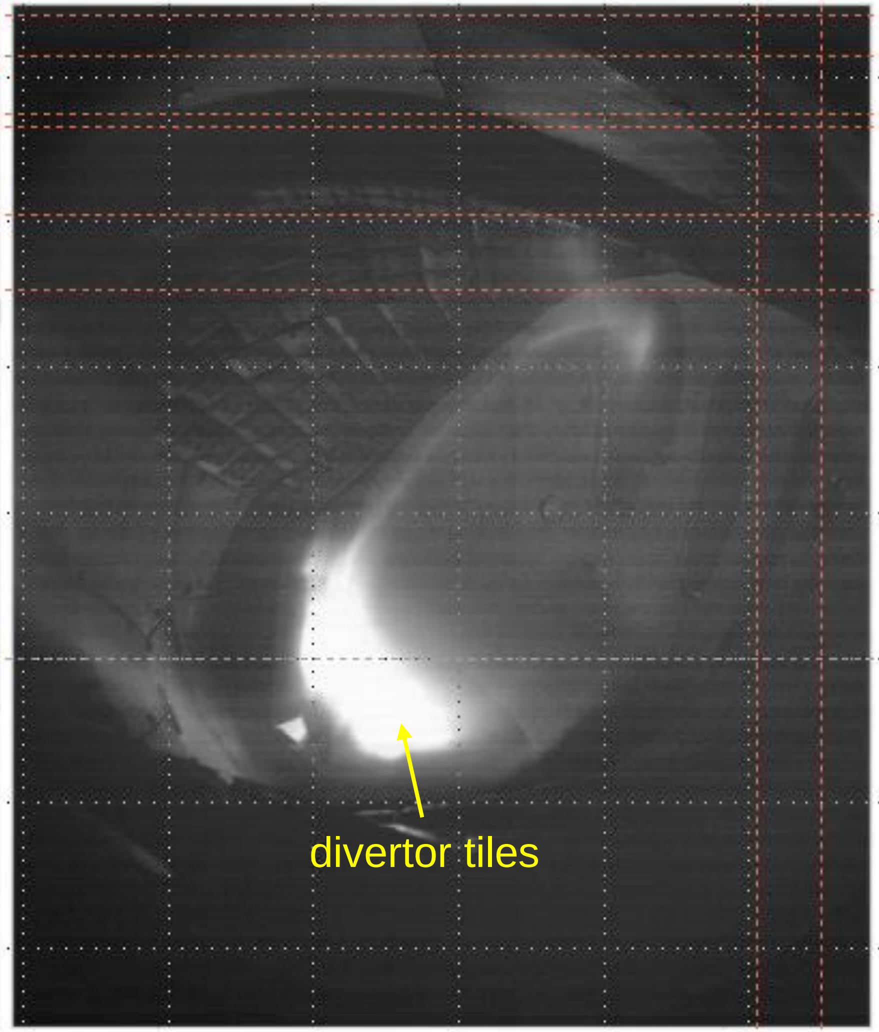
ECRH Launcher inside W7-X



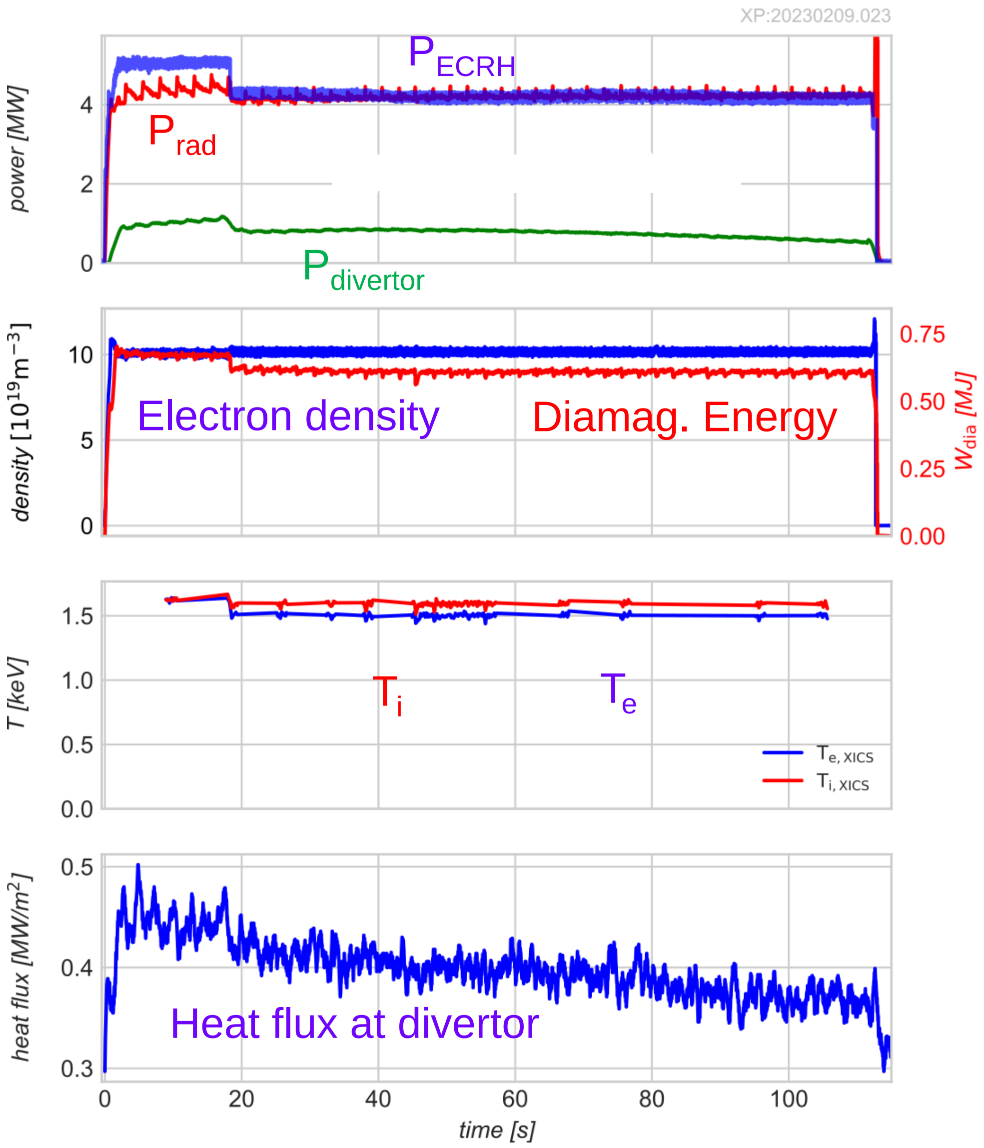
[IPP, Foto: Jan Hosan]

Long Plasma Discharges 1.3 GJ 480s





Long Plasma Discharges with Detachment



- High edge radiation with P_{rad}/P_{heat} >0.8
  - **by high plasma density**
  - **by impurity seeding**
- strongly reduced divertor heat flux at P_{heat}≈1MW/m^2
- promising scenario for long pulse operation (reactor) .

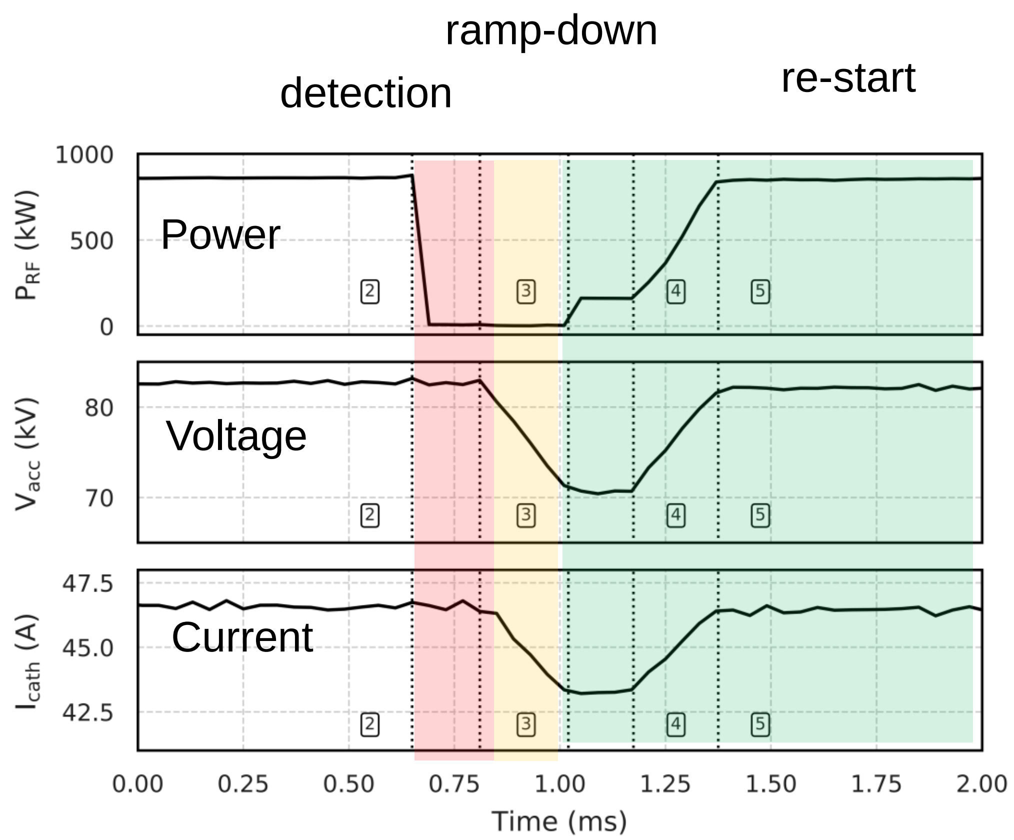
Strong requirements for ECRH

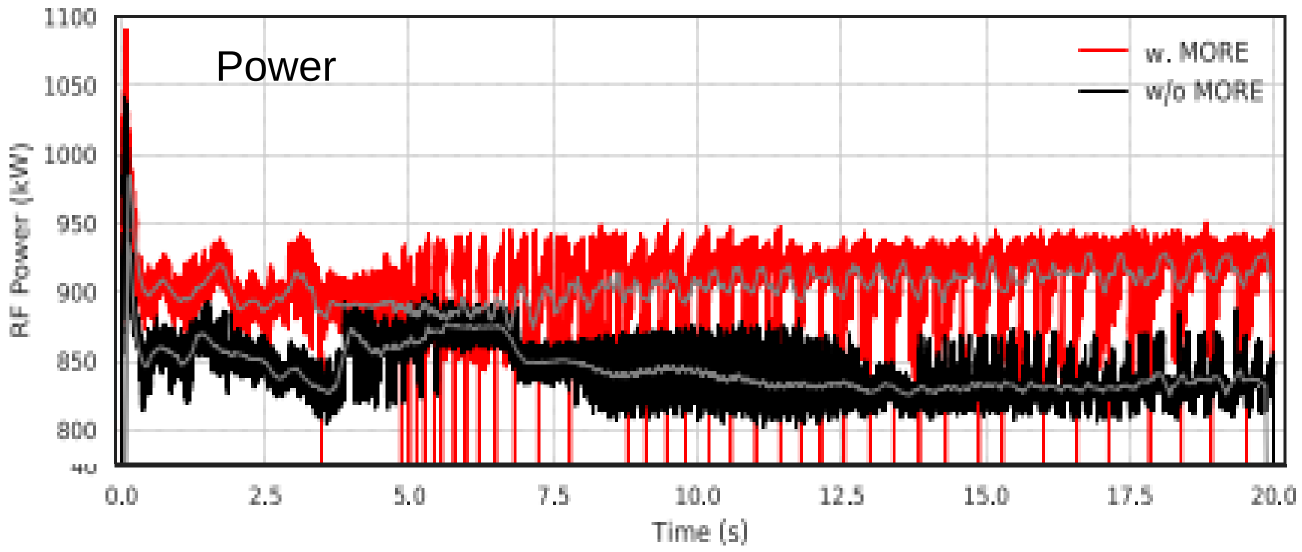
- Very sensitive on P_{rad}/P_{heat} ratio -> high **reliability** demand on the ECRH system
- high density even above X2 cutoff -> **Stray** radiation in O2-scenario

Reliability: Automatic Restarts after Failures

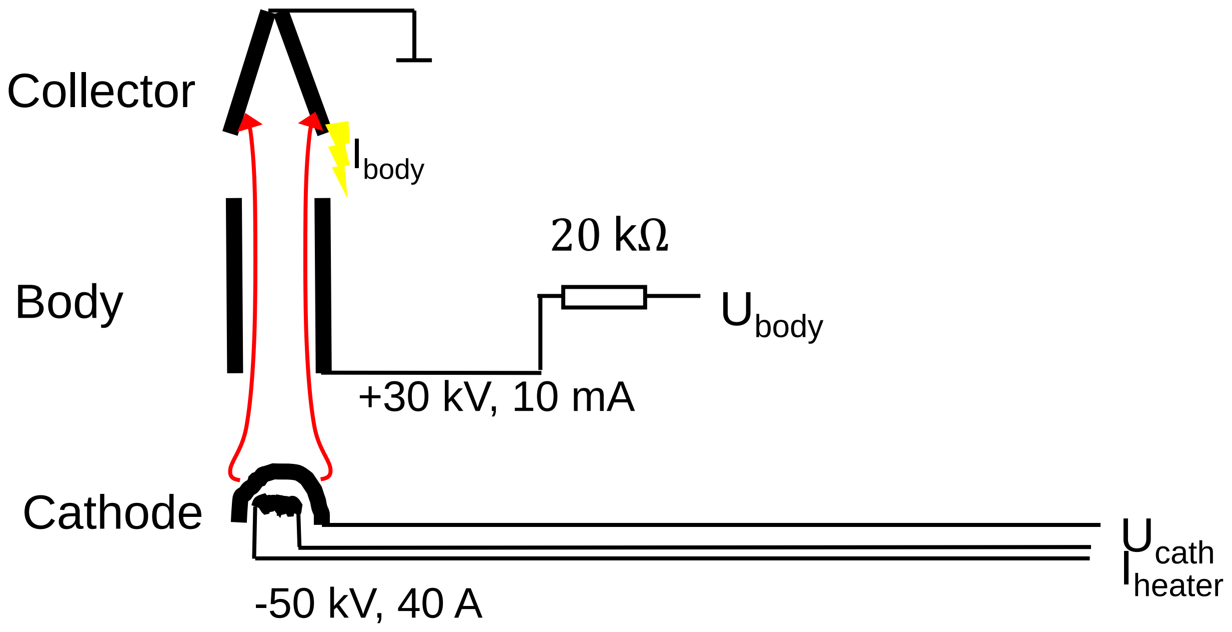
Mode Recovery

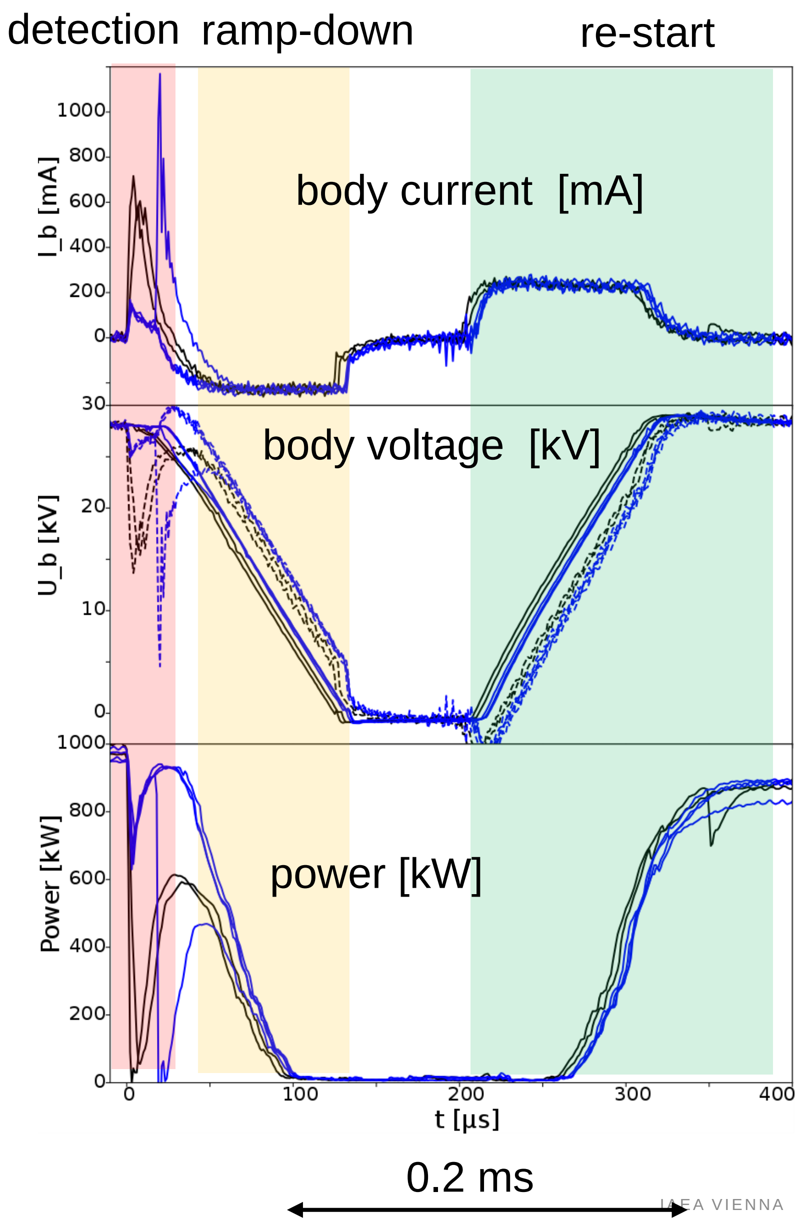
- Mode loss detection
- Ramp down voltage
- Mode is re-excited
- Ramp voltage sligtly below set value
- Slow voltage ramp towards set value



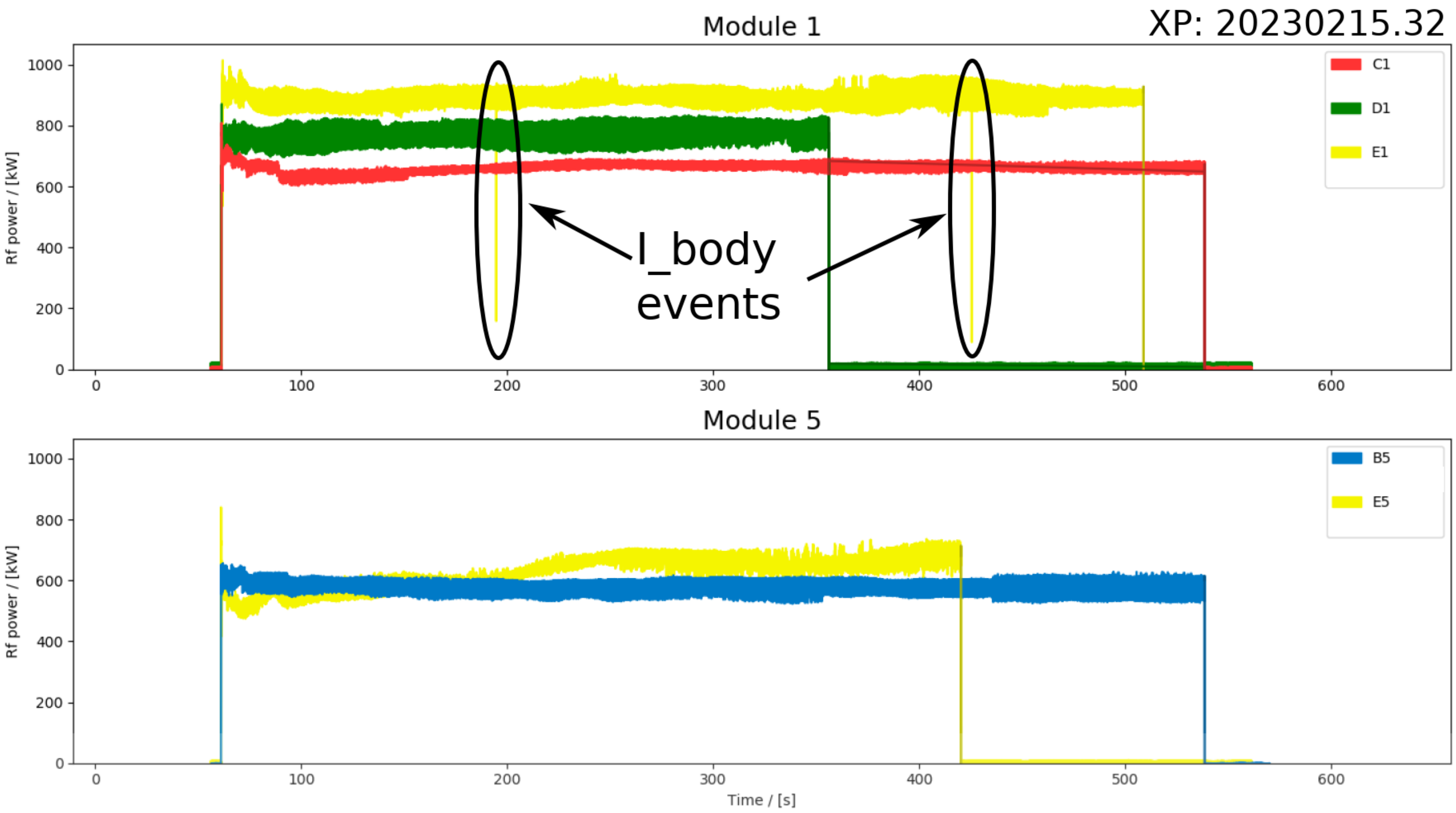


Reliability: Recovery after Internal Gyrotron Arc



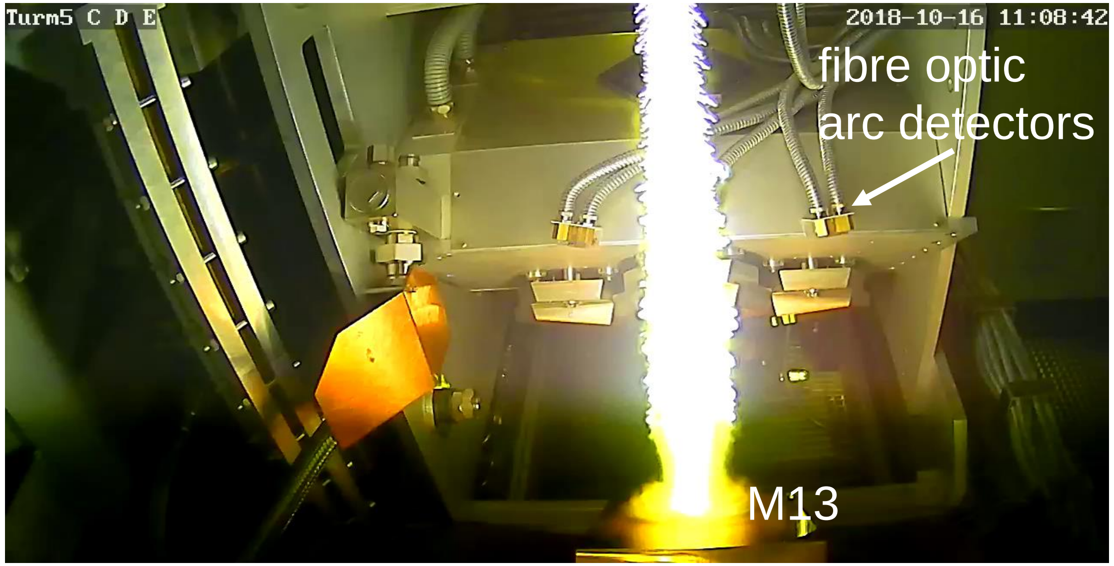


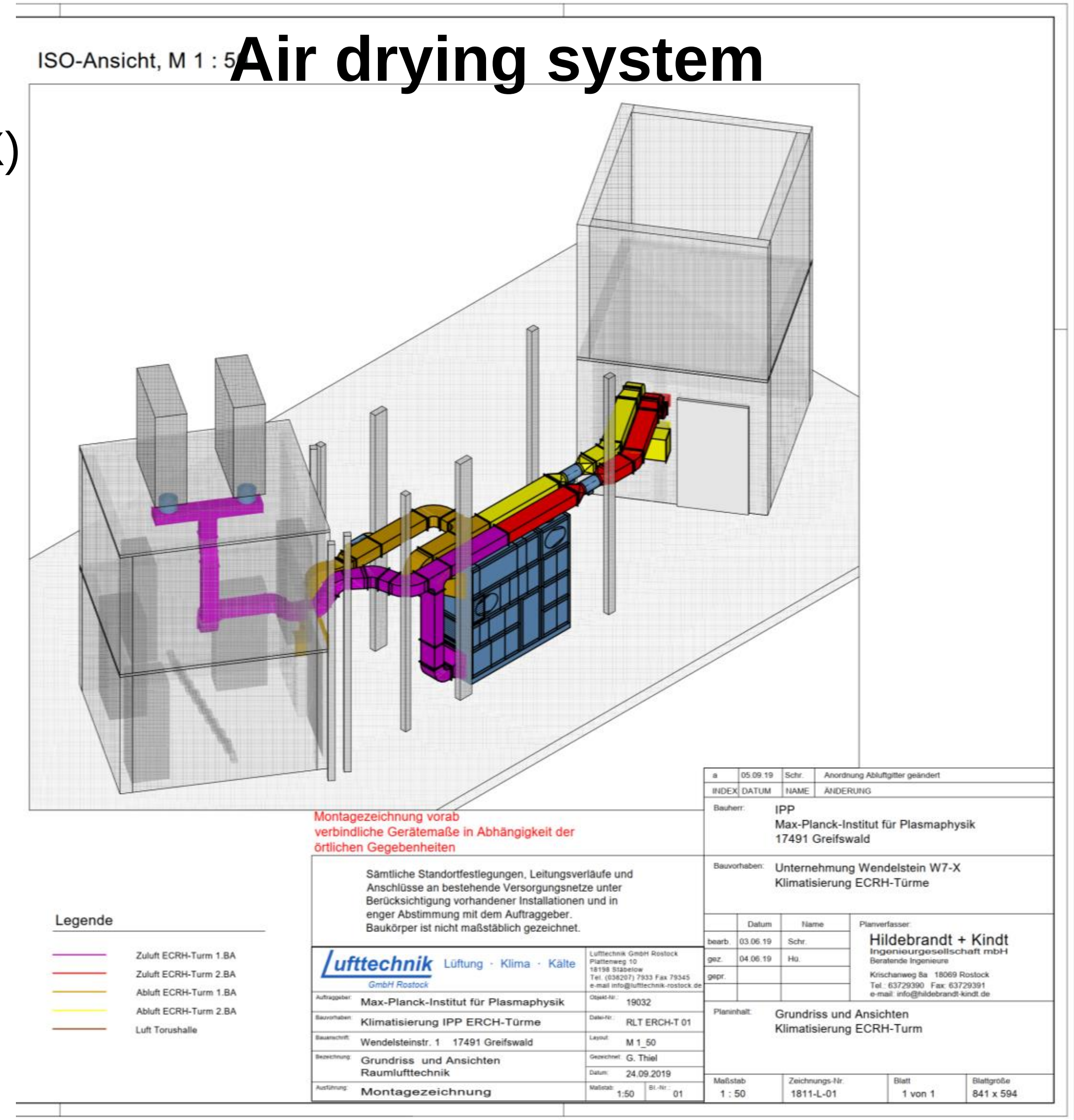
Reliability: Recovery after internal Gyrotron Arc



Arcs in Transmission Line: Air Humidity

Arc between M13 und M14 of D1-Beam (close to W7-X)





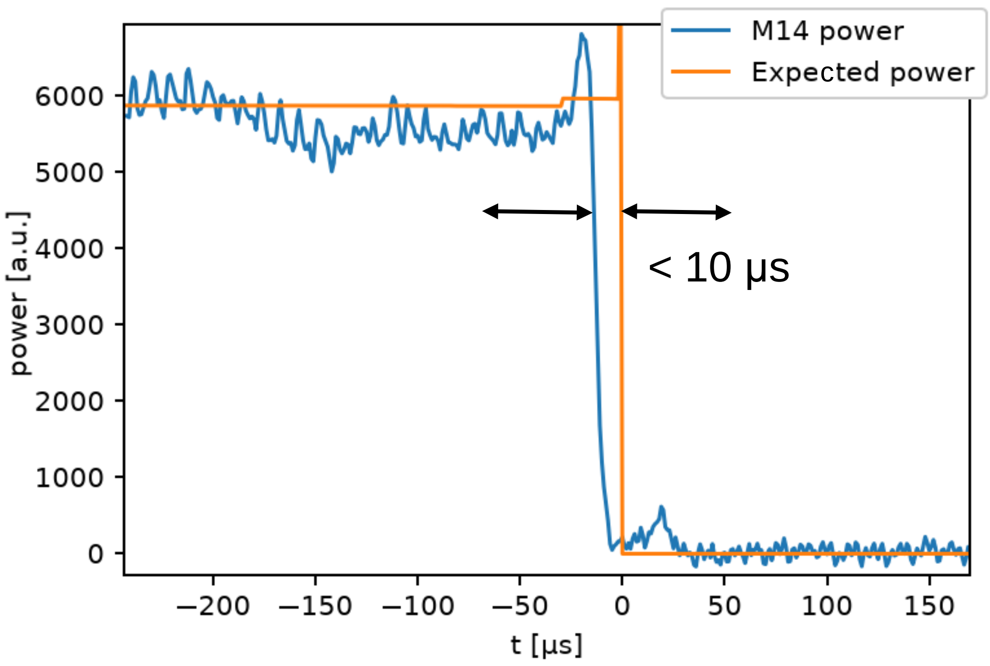
Counter measures by strong air drying system
to achieve relative humiditiy levels <10%

Increased the power level from 0.6 MW to ≤0.9 MW

Reliability: Recovery after Arc in Transmission Line

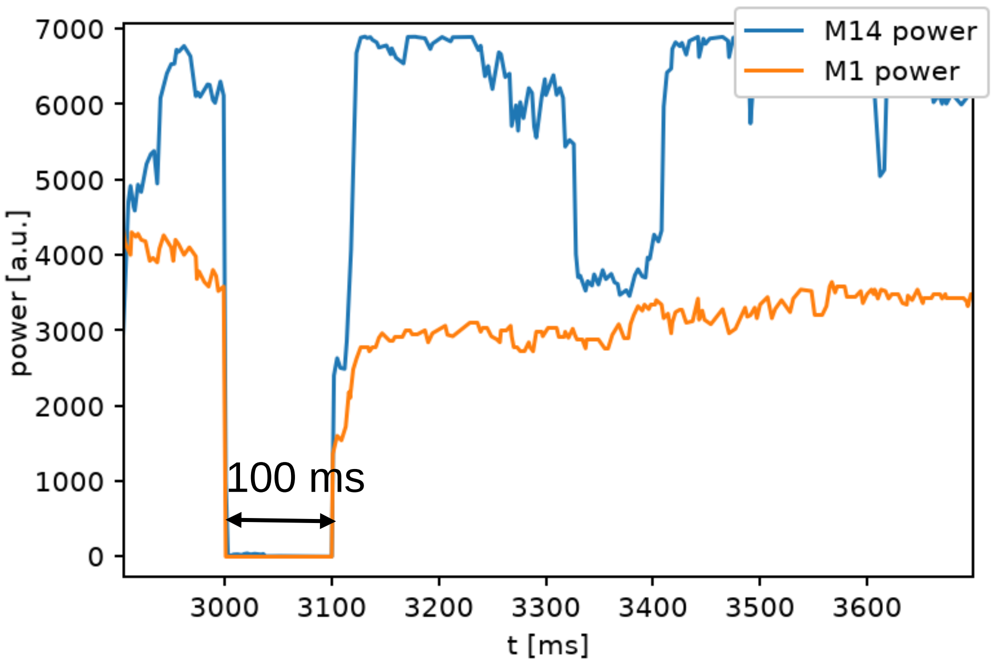
Detection below **10 us** by comparison

of measured microwave power at **first** and **last** mirror. Optical arc detection not fast enough.

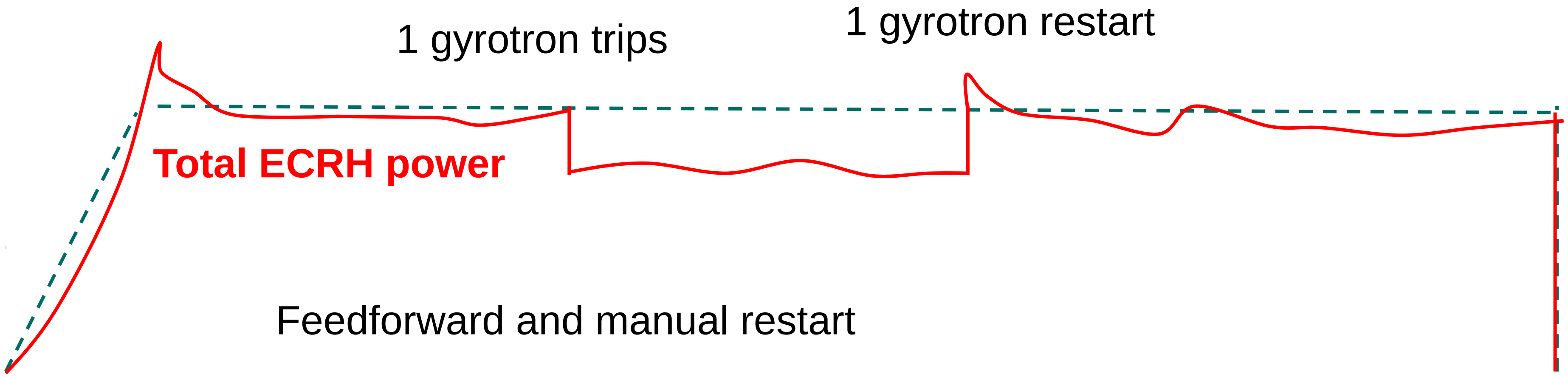


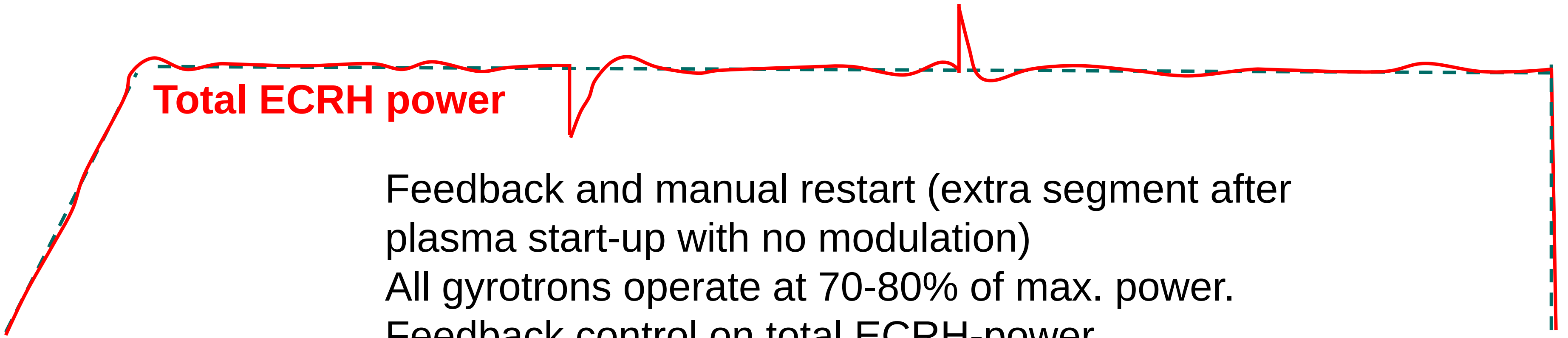
Successful restart after **100 ms**.

Detects all arcs in the transmission line!



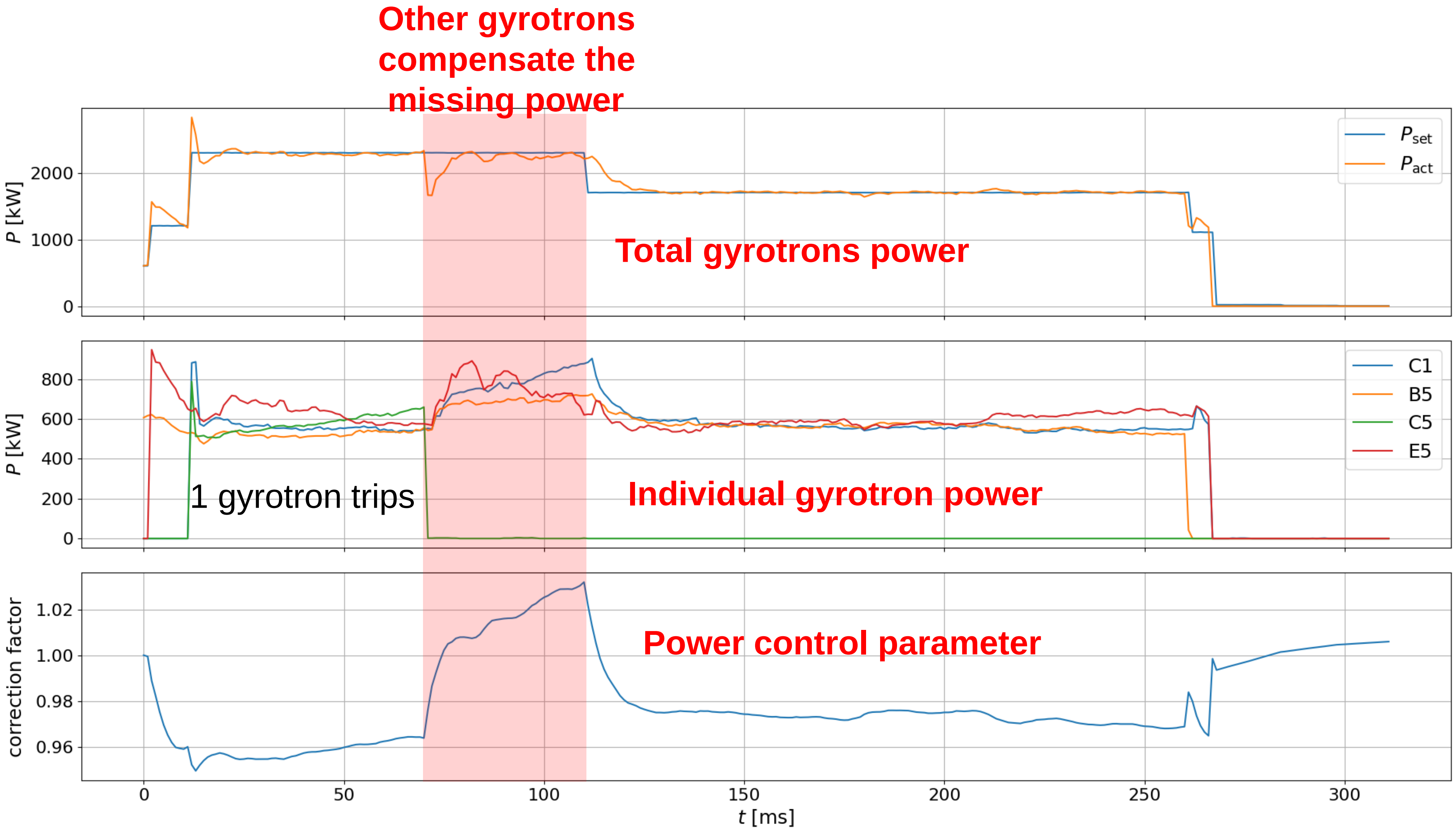
Next Step: Power Feedback and Manual Restart of Gyrotrons





Feedback and manual restart (extra segment after plasma start-up with no modulation)
All gyrotrons operate at 70-80% of max. power.
Feedback control on total ECRH-power
(currently commissioned at W7-X)

Power Feedback Comissioning with 4 Gyrotrons on µW Load



Stray Radiation

Stray radiation due to Incomplete ECRH-absorption in the plasma

Stray radiation in the launcher due to spill-over.

Critical in all kind of long pulse ECRH plasmas scenarios.

This is also an issue for the **ITER upper lateral ECRH-Launcher (ULL)**.

Spill-over by:

- Higher order modes due to an imperfect transmission line
- Misalignment of beams
- Small mirrors due to limited space

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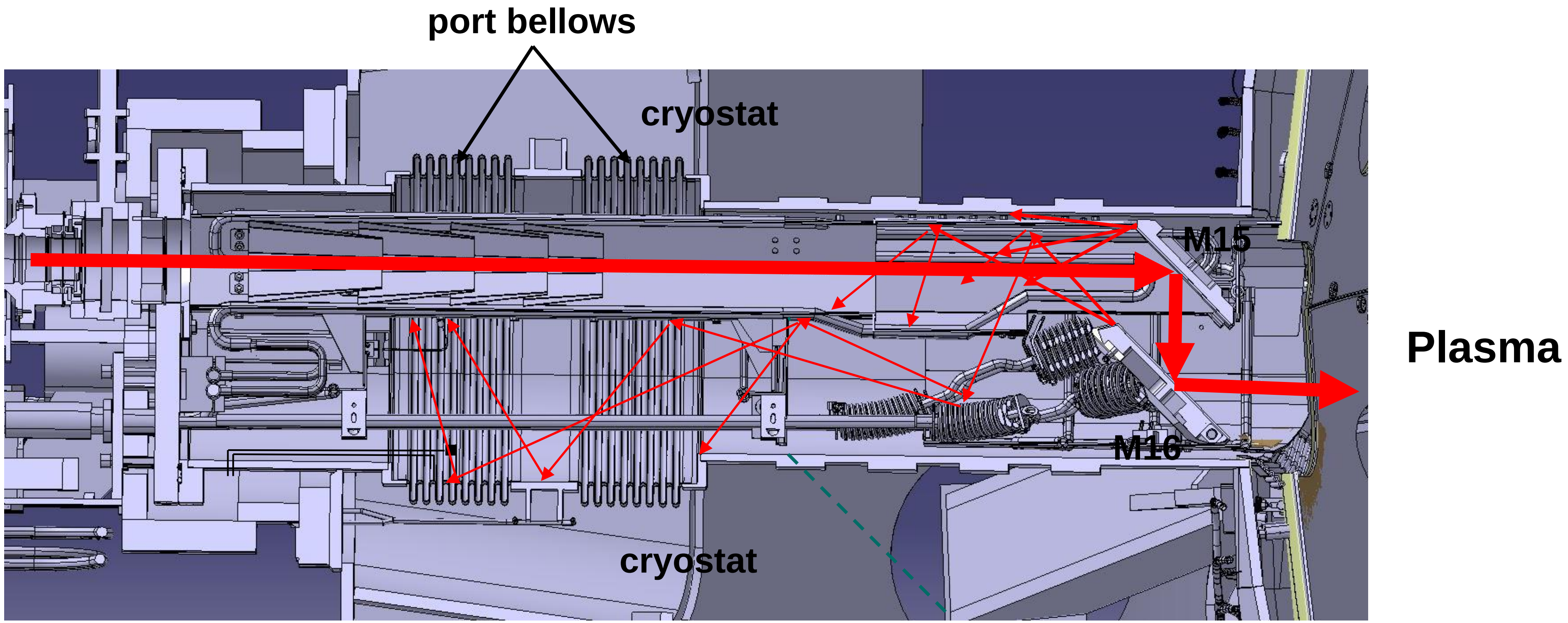
Stray Radiation in the Launcher Port

Stray radiation is generated due to spill over at the internal mirrors due to their size in the limited port space.

The stray radiation filed out the entire port area.

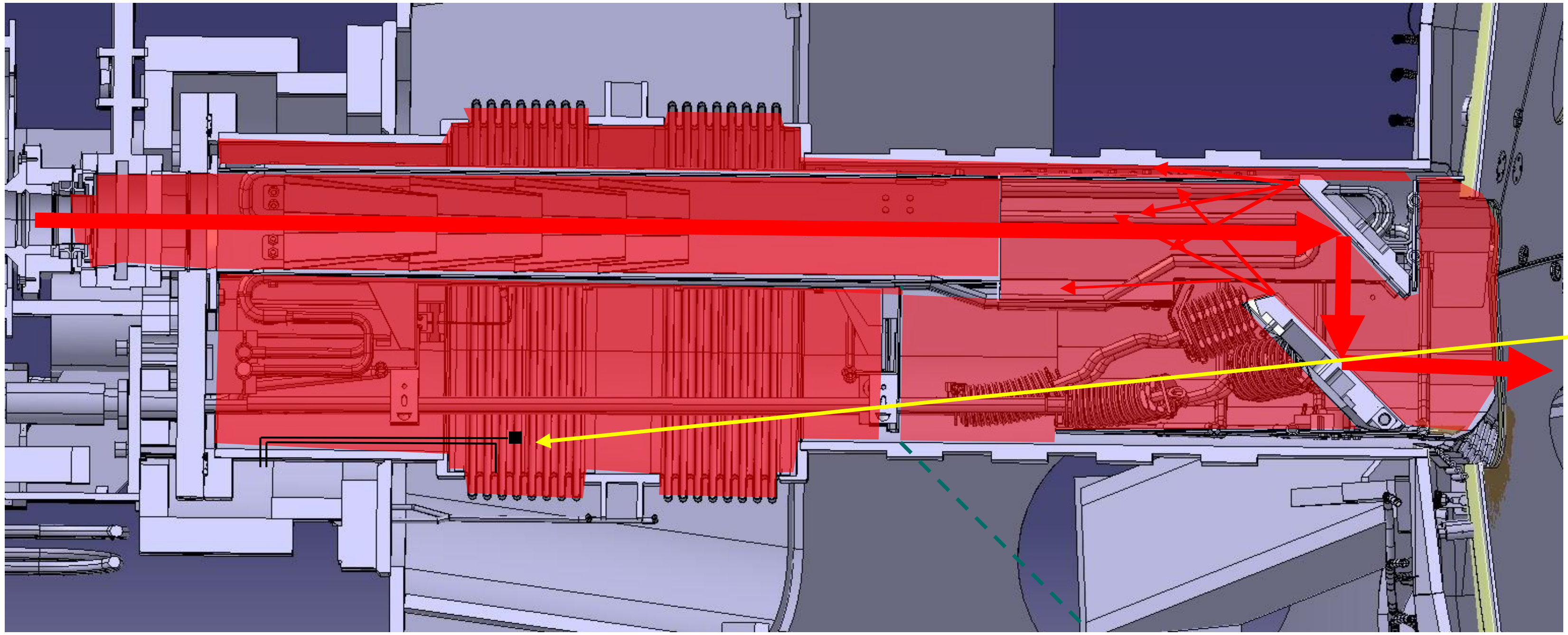


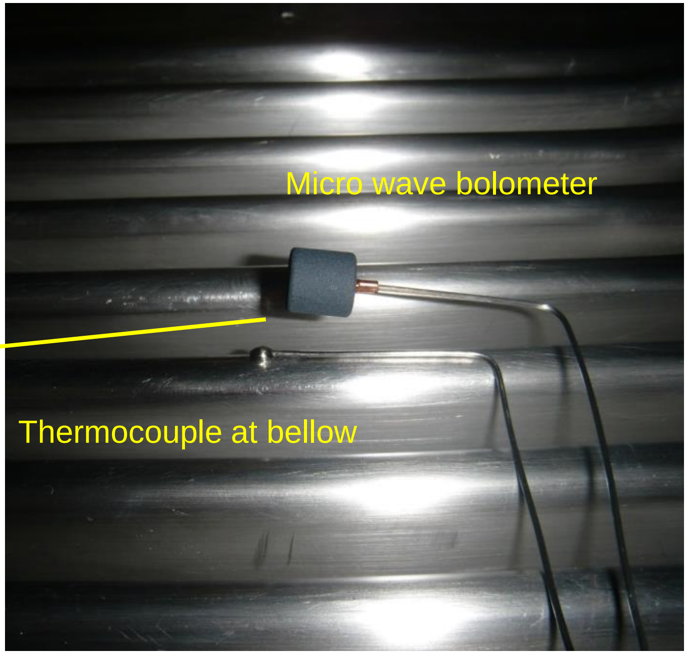
Stray Radiation in the Launcher Port

Critical component: uncooled port bellows as interface between plasma and cryo-vessel.

Maximal temperature of 110 c° limited by allowed thermal loads on SC-coils!

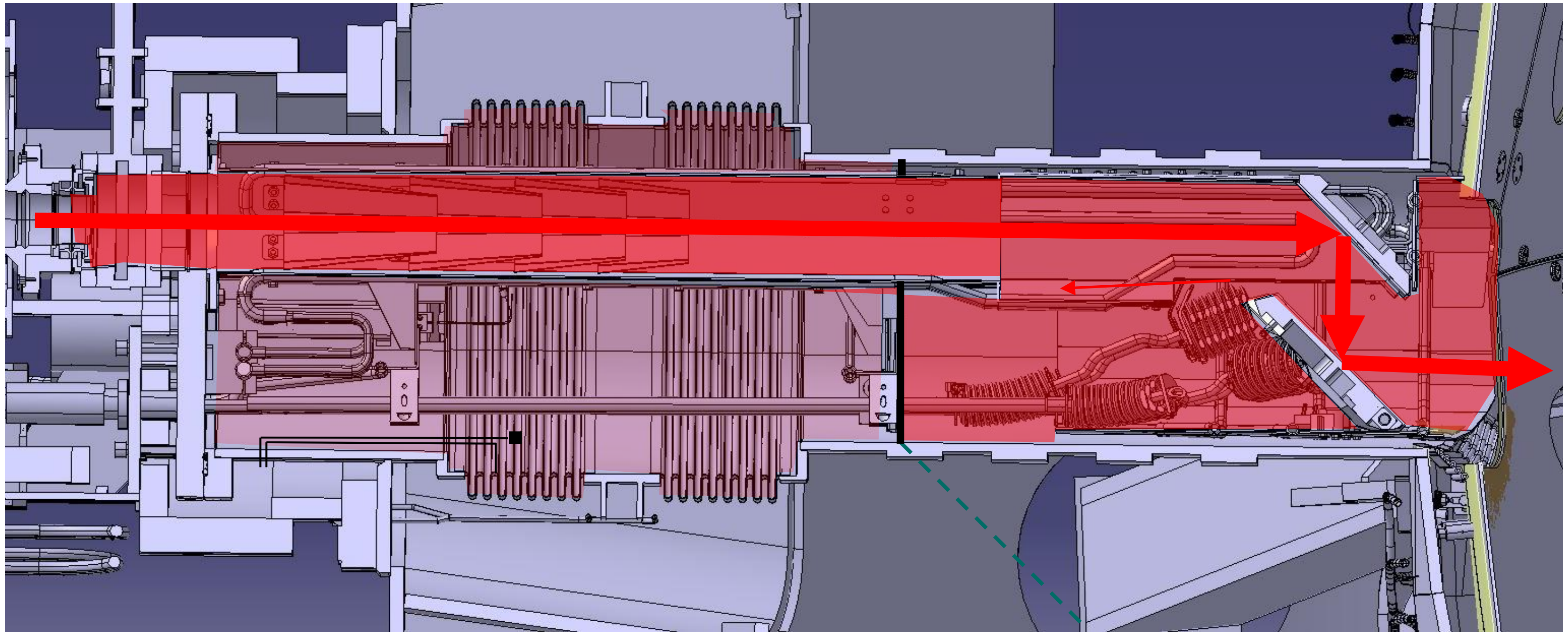
Stray radiation and temperature measurement at below surface.

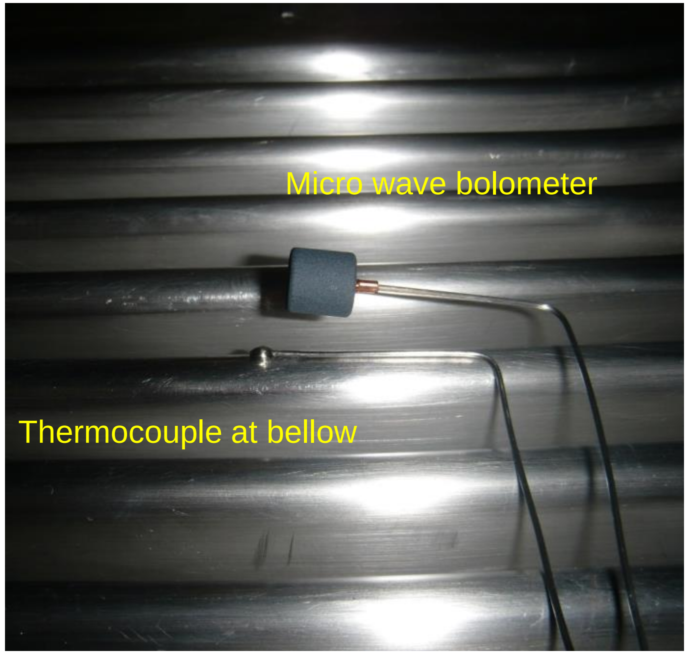




Stray Radiation in the Launcher Port

Additional microwave screening reduced the stray radiation to acceptable value.





Measurement in ECRH Launcher

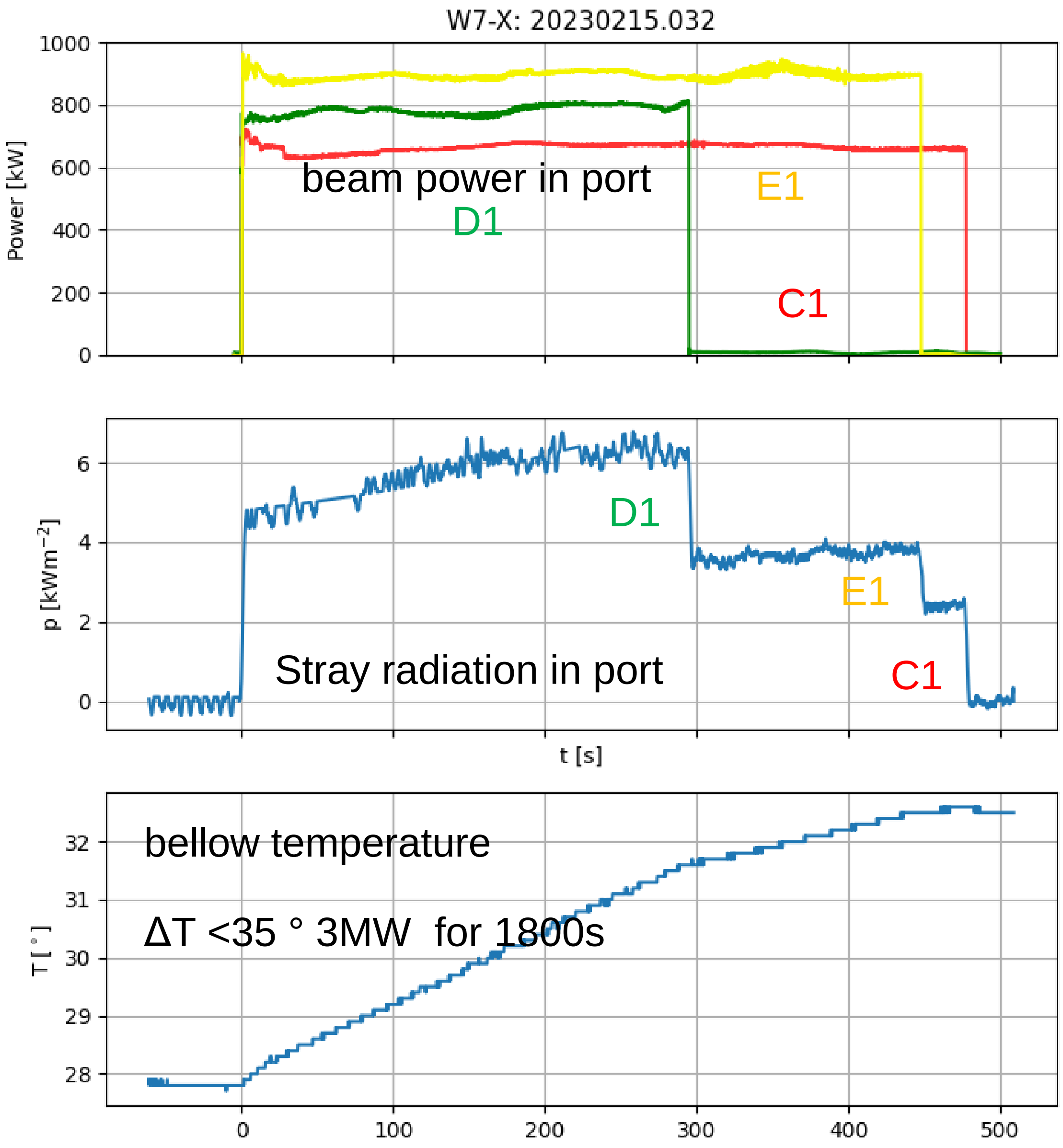
Analysis of the stray radiation steps gives qualitative Information of beam alignement (spill over)

- C1 : 3.46 $kWm^{-2}MW^{-1}$
- D1: 2.75 $kWm^{-2}MW^{-1}$
- E1: 1.89 $kWm^{-2}MW^{-1}$

Extrapolation of bellow Temperature for

30 minutes at 3 MW beam power in Launcher

gives ΔT <35 °. uncritical!



Conclusions

The transition from a short-pulse ECRH system to a long-pulse or CW system requires a change in strategy in the treatment of interlocks.

- Recover after failure.
- Compensate lost power.

In long-pulse operation, the ECRH stray radiation must be considered as an additional load for the plasma vessel components.

- Components, that are even far behind the plasma facing shield, must be adequately protected. In particular stray radiation in the launcher ports must be considered.
    - There are stray radiation tests prepared for the ITER ULL at FALCON (Lausanne) and MISTRAL (Greifswald) facilities.