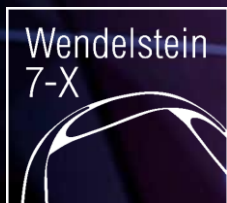
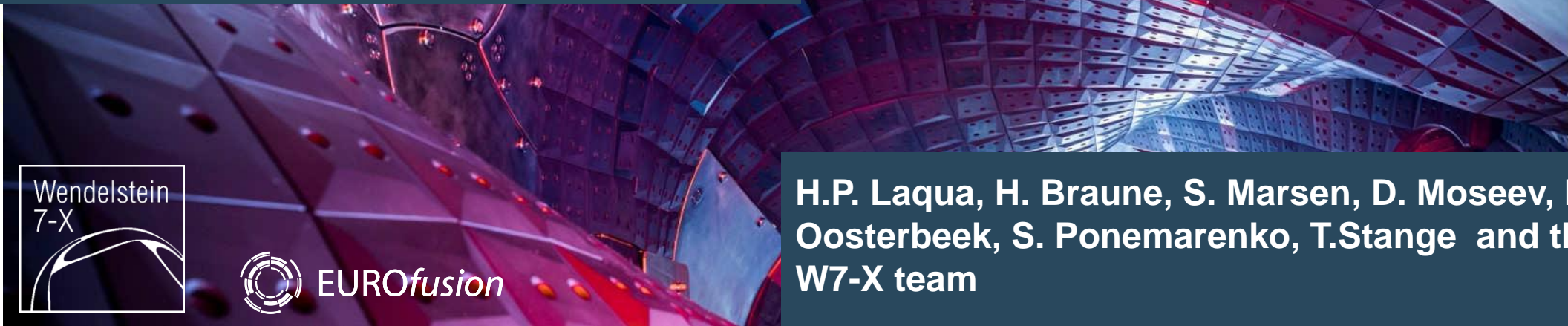


**Time lapse**  
**8min in 25 s**





## Experiences from long-pulse ECRH operation at W7-X



EUROfusion

H.P. Laqua, H. Braune, S. Marsen, D. Moseev, H. Oosterbeek, S. Ponemarenko, T. Stange and the W7-X team

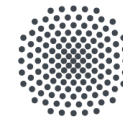


This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

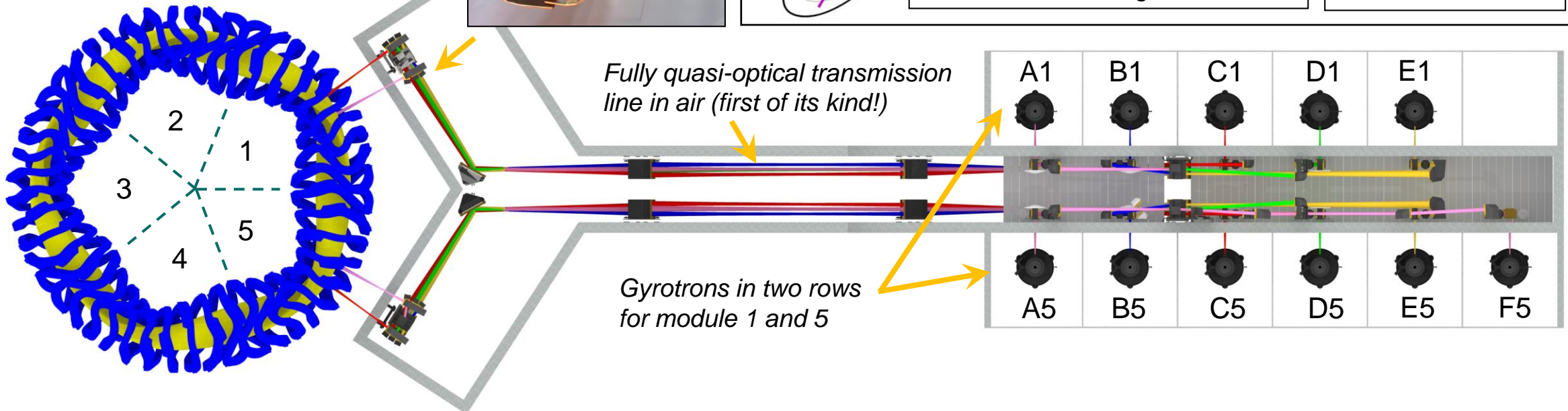
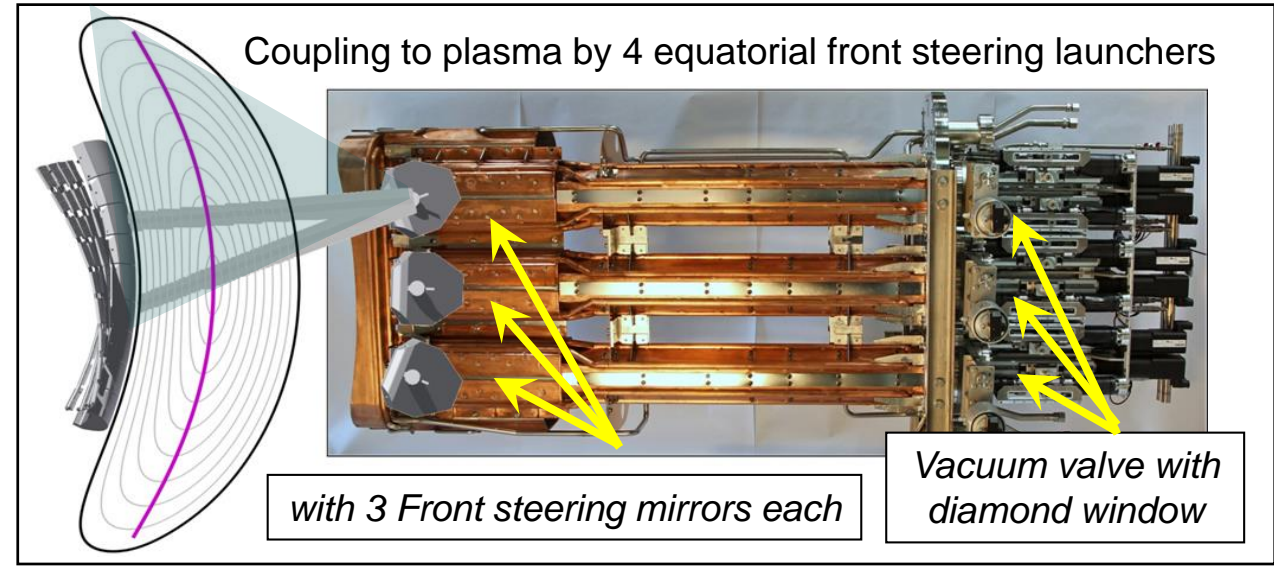
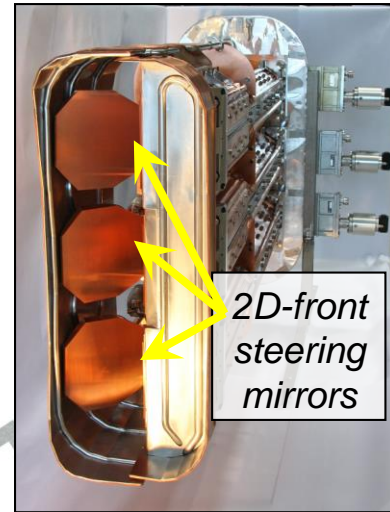
## Reliability of the ECRH System

## 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)



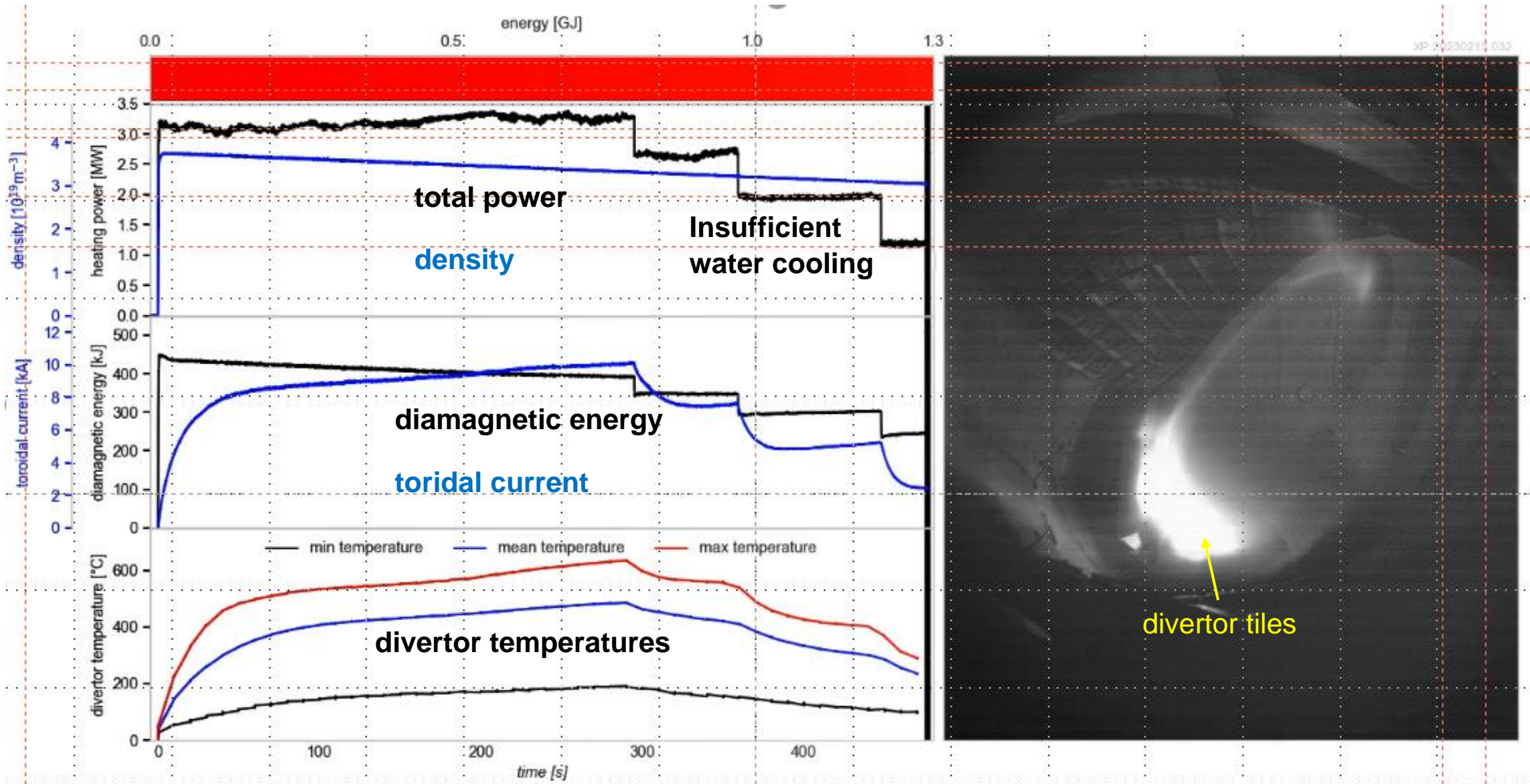


# ECRH Launcher inside W7-X

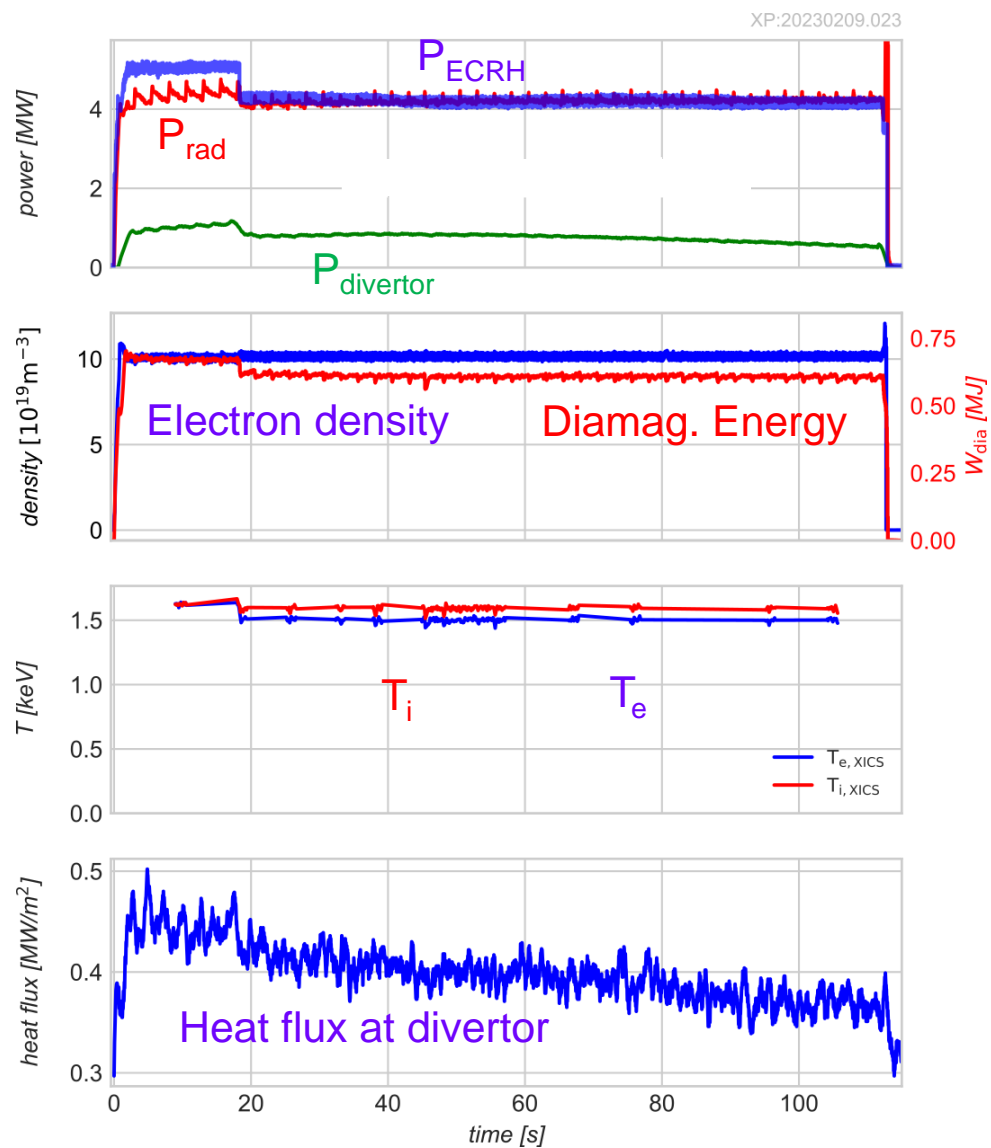
[IPP, Foto:  
Jan Hosan]



# Long Plasma Discharges 1.3 GJ 480s



# Long Plasma Discharges with Detachment



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

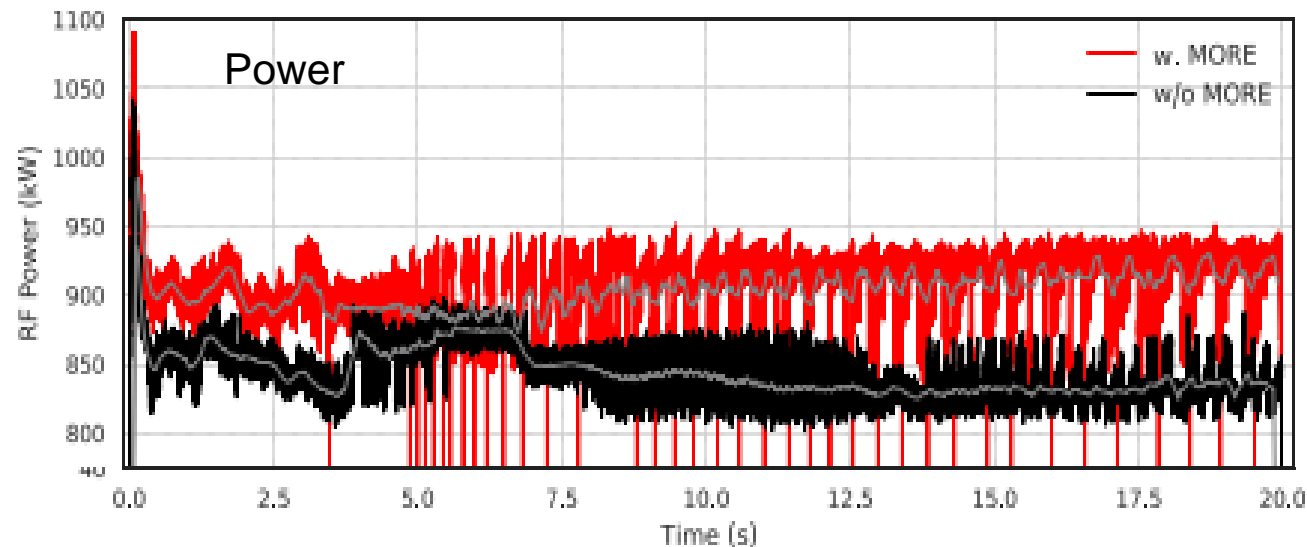
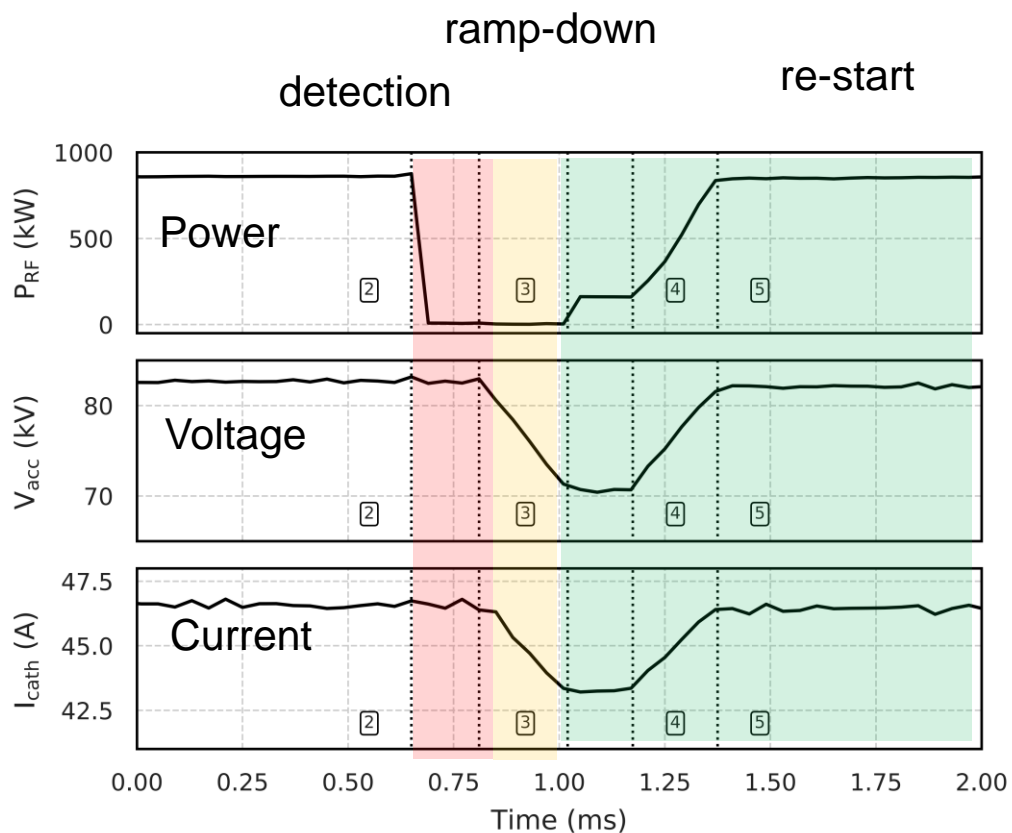
## Strong requirements for ECRH

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

# Reliability: Automatic Restarts after Failures

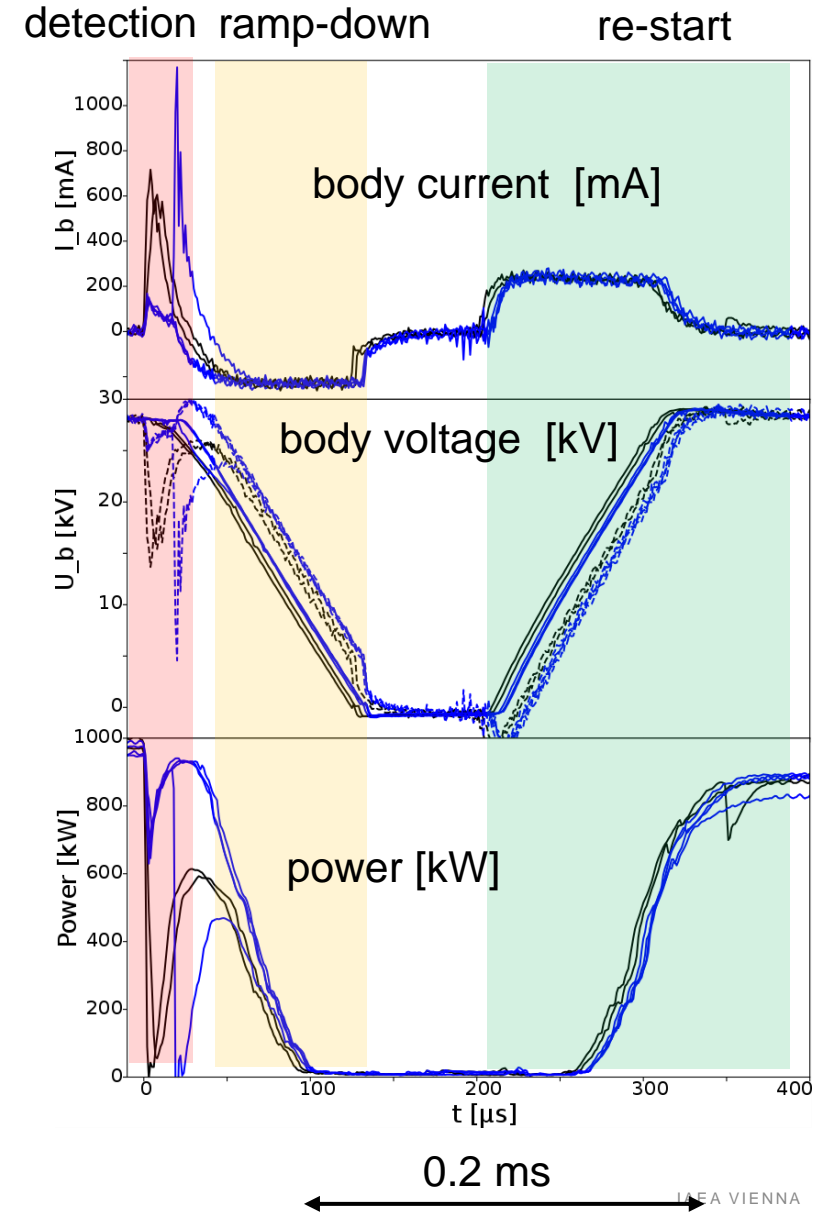
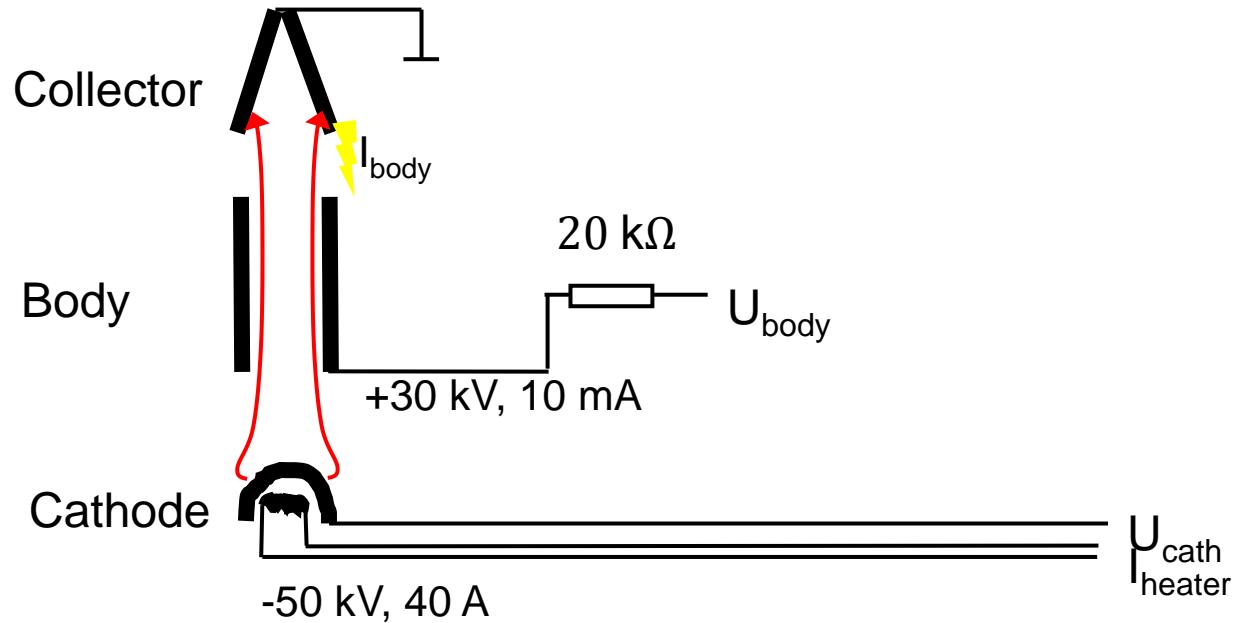
## Mode Recovery

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





# Reliability: Recovery after Internal Gyrotron Arc

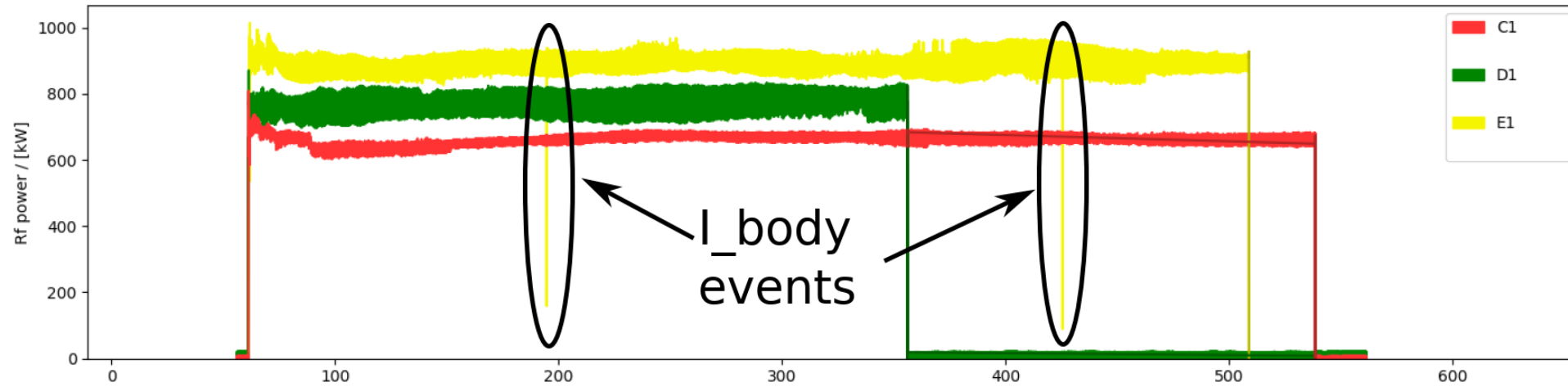


# Reliability: Recovery after internal Gyrotron Arc

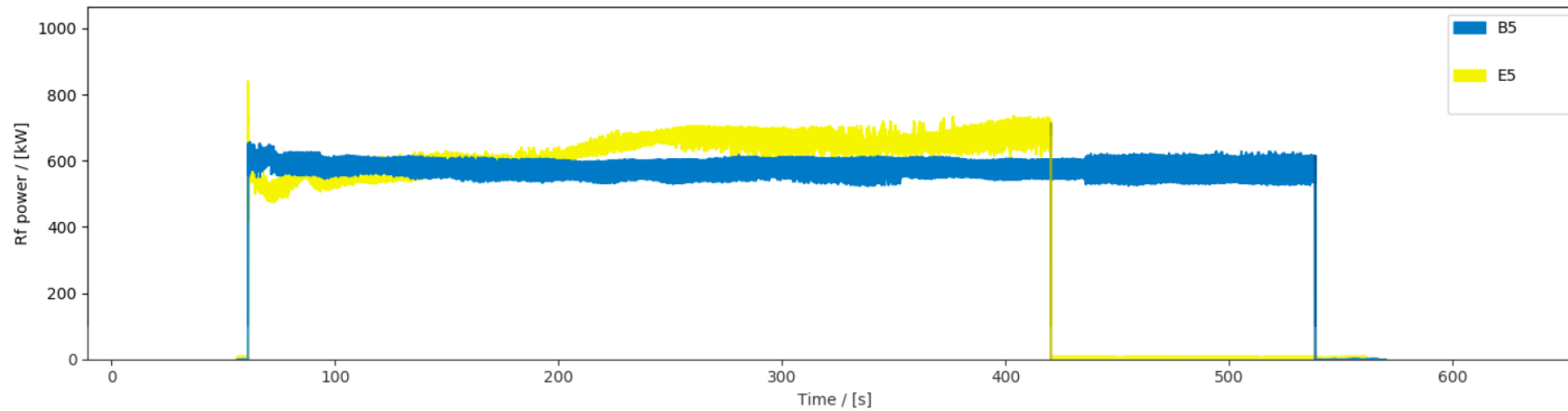


XP: 20230215.32

Module 1



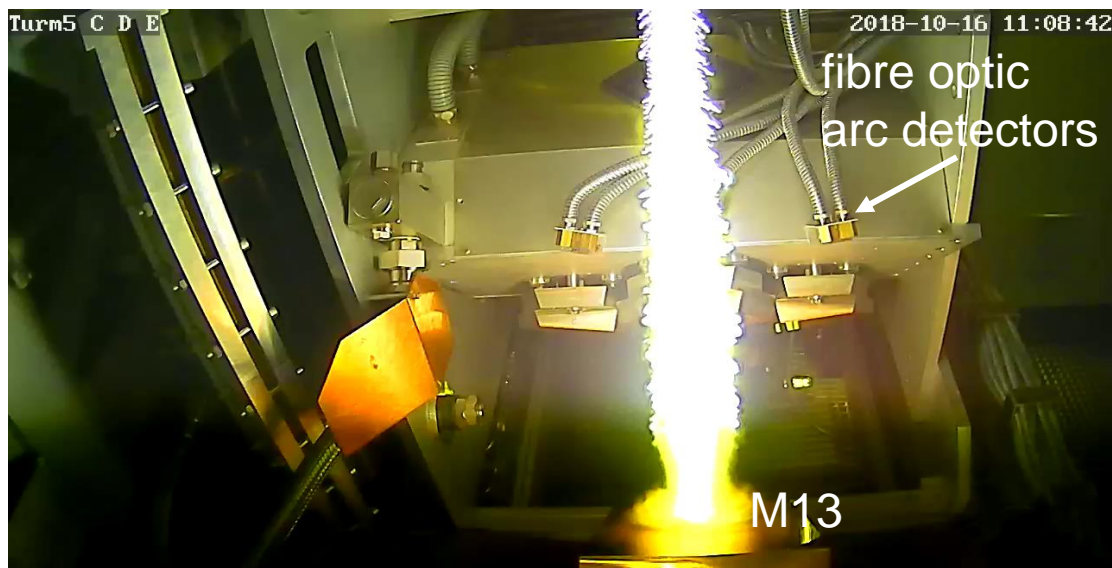
Module 5





# Arcs in Transmission Line: Air Humidity

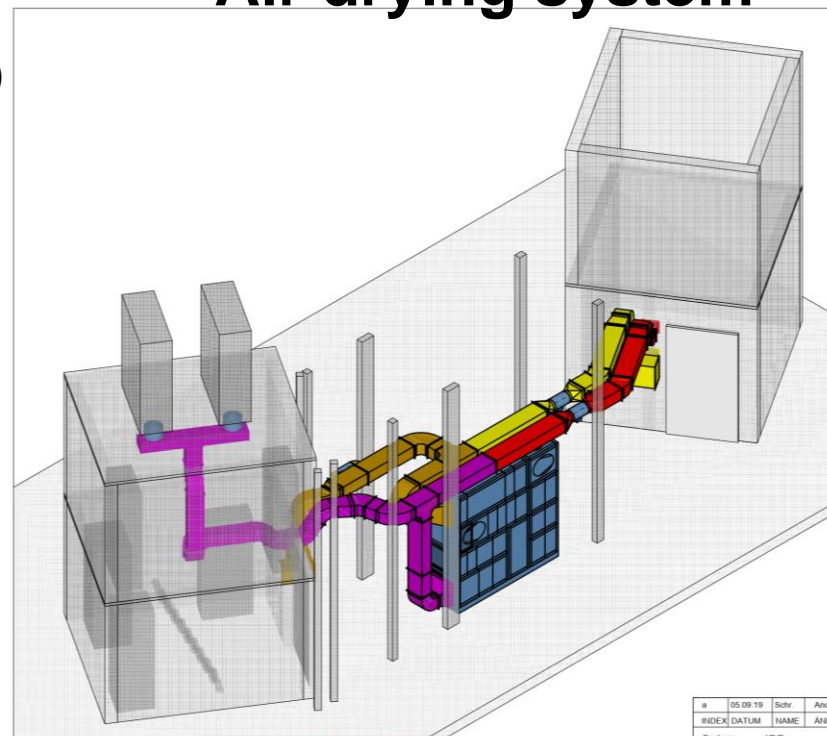
Arc between M13 und M14 of D1-Beam (close to W7-X)



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

Increased the power level from 0.6 MW to  $\leq 0.9$  MW

## ISO-Ansicht, M 1 : 5 **Air drying system**



Montagezeichnung vorab verbindliche Geräte- und Baumaße in Abhängigkeit der örtlichen Gegebenheiten

Sämtliche Standortfestlegungen, Leitungsverläufe und Anschlüsse an bestehende Versorgungsnetze unter Berücksichtigung vorhandener Installationen und in enger Abstimmung mit dem Auftraggeber. Baukörper ist nicht maßstäblich gezeichnet.

### Legende

- Zuluft ECRH-Turm 1.BA
- Zuluft ECRH-Turm 2.BA
- Abluft ECRH-Turm 1.BA
- Abluft ECRH-Turm 2.BA
- Luft Torushalle

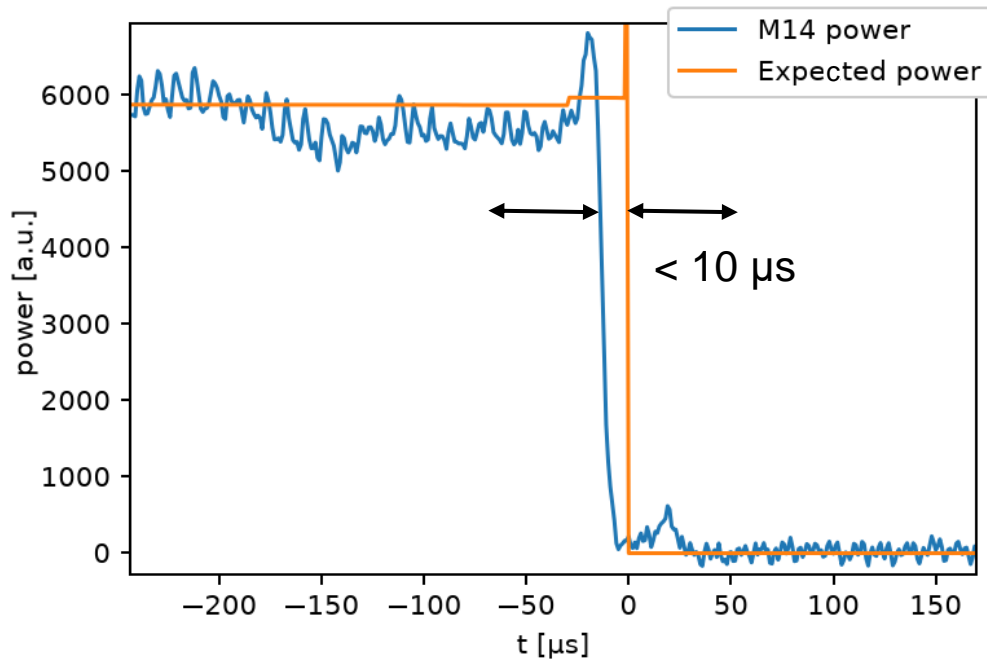
<b>Lufttechnik</b> Lüftung · Klima · Kälte		Lufttechnik GmbH Rostock Platzweg 10 18118 Südbülow Tel. (038207) 7933 Fax 79345 e-mail: info@lufttechnik-rostock.de	
Auftraggeber:	Max-Planck-Institut für Plasmaphysik	Datensatz:	RLT ERCH-T 01
Bauprojekt:	Klimatisierung IPP ERCH-Türme	Lage:	M 1_50
Baustandort:	Wendelsteinstr. 1 17491 Greifswald	Gezeichnet:	G. Thiel
Beschreibung:	Grundriss und Ansichten Raumlufttechnik	Datum:	24.09.2019
Auflösung:	Montagezeichnung	Maßstab:	1:50 Bl.-Nr.: 01

INDEX	05.09.19	Schr.	Anordnung Abluftgitter geändert
DATUM		NAME	ÄNDERUNG
Bauherr:	IPP Max-Planck-Institut für Plasmaphysik 17491 Greifswald		
Bauprojekt:	Unternehmung Wendelstein W7-X Klimatisierung ECRH-Türme		
bearb.	03.06.19	Schr.	
gepr.	04.06.19	Nr.	
gepr.			
Planer/Verfasser:	Hildebrandt + Kindt Ingenieurgesellschaft mbH Beratende Ingenieure Wischchenweg 5a 18069 Rostock Tel. 03729390 Fax 03729391 e-mail: info@hildebrandt-kindt.de		
Planinhalt:	Grundriss und Ansichten Klimatisierung ECRH-Turm		
Maßstab:	1:50	Zeichnungs-Nr.	1811-L-01
Blatt	1 von 1	Blattgröße	841 x 594

# Reliability: Recovery after Arc in Transmission Line

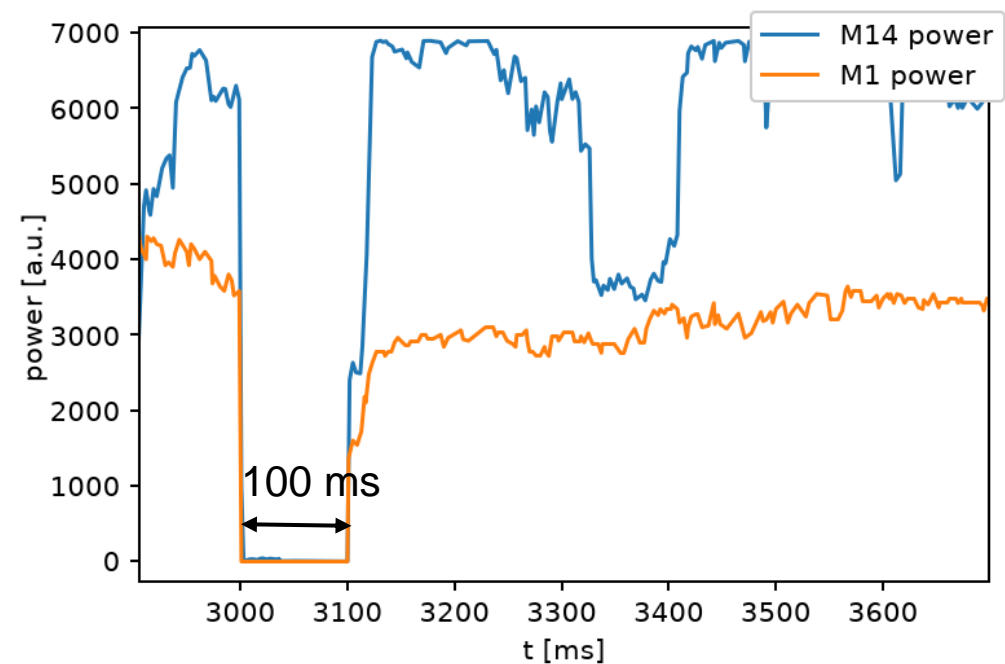


Detection below **10 us** by comparison of measured microwave power at **first** and **last** mirror. Optical arc detection not fast enough.



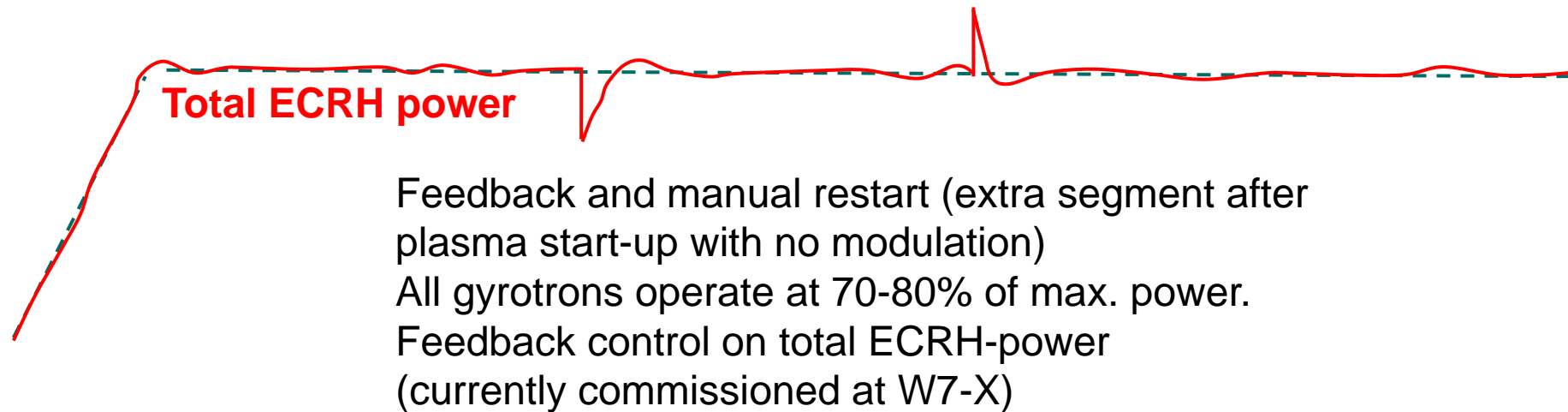
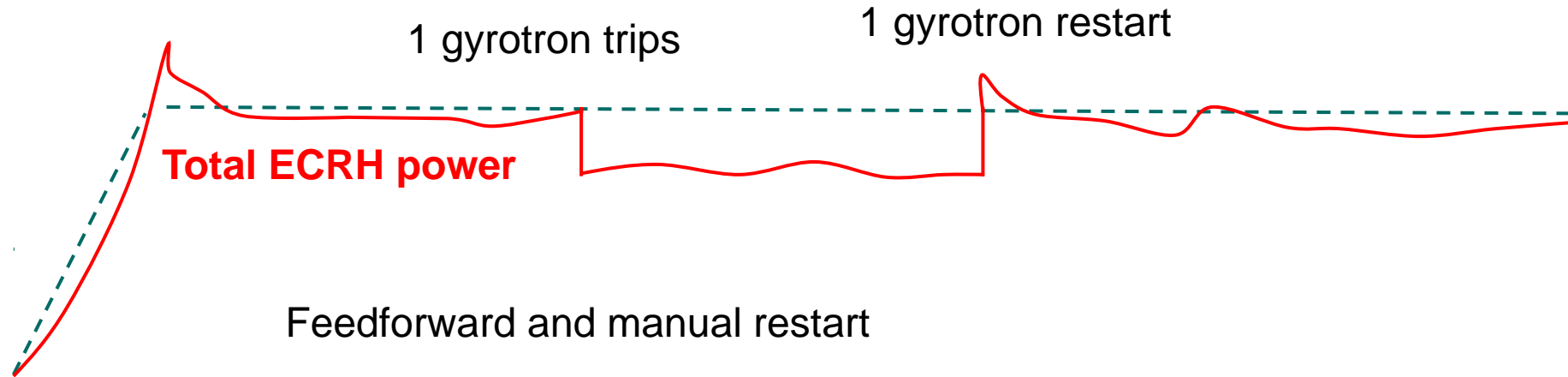
Successful restart after **100 ms**.

Detects all arcs in the transmission line!



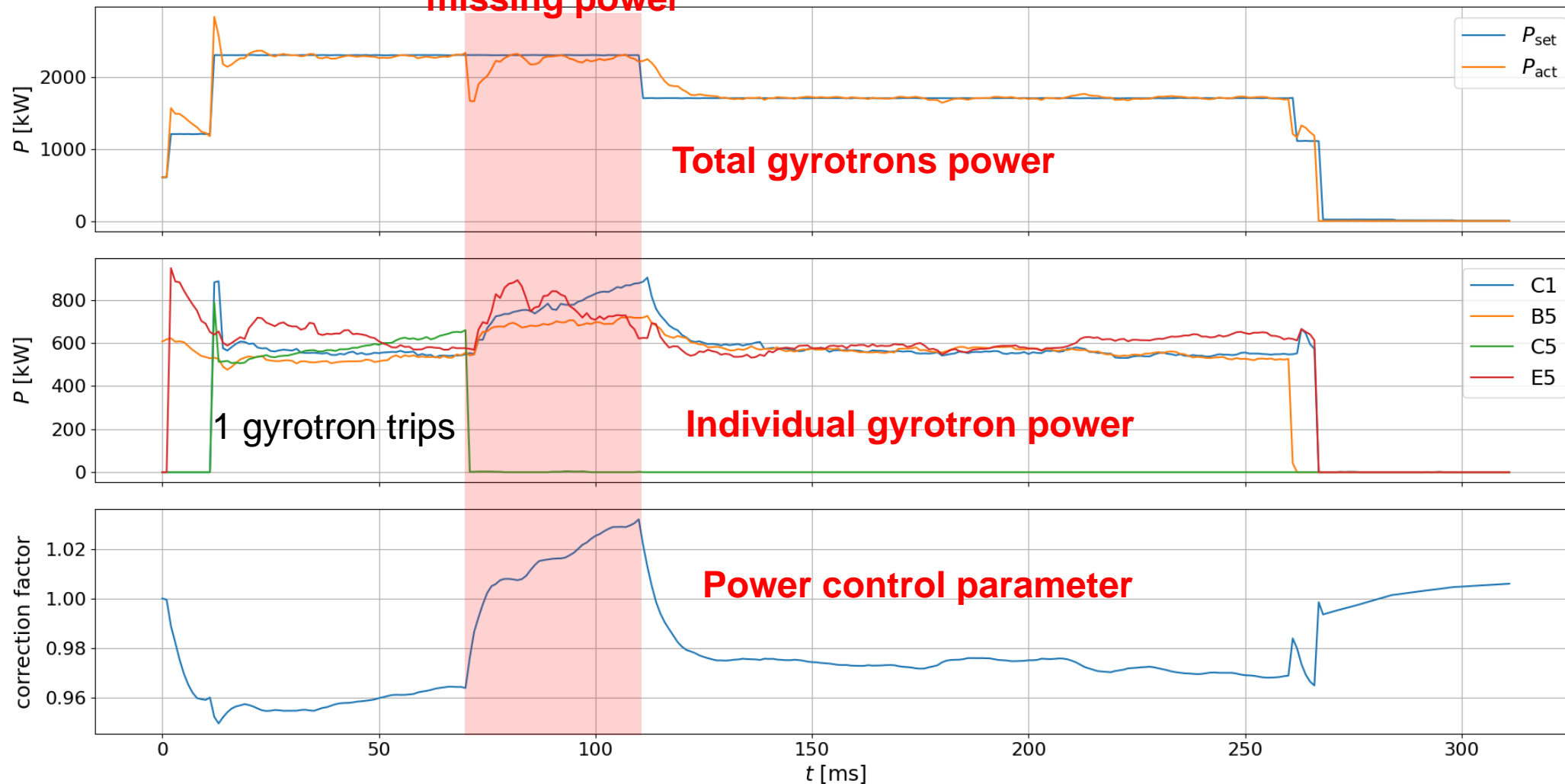


# Next Step: Power Feedback and Manual Restart of Gyrotrons



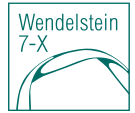
# Power Feedback Commissioning with 4 Gyrotrons on $\mu\text{W}$ Load

Other gyrotrons  
compensate the  
missing power





# 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)**.

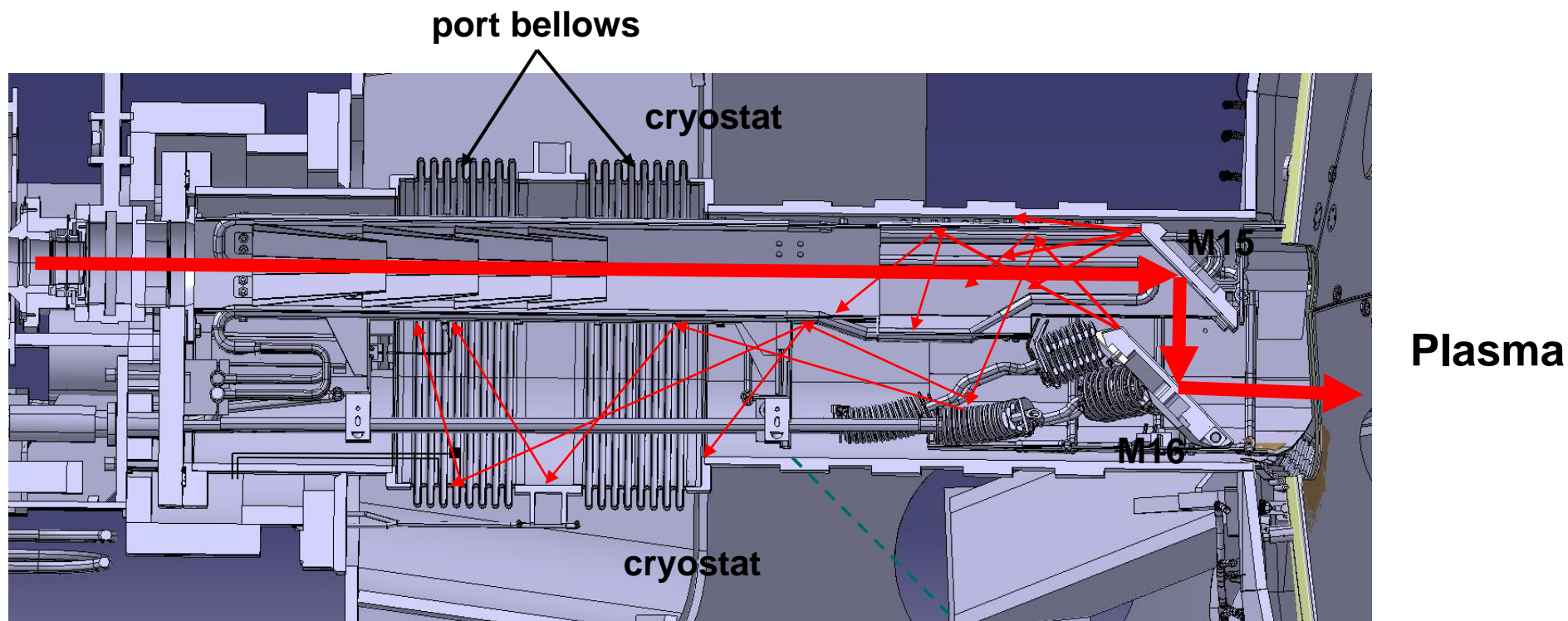
Spill-over by:

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

# 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 filled out the entire port area.

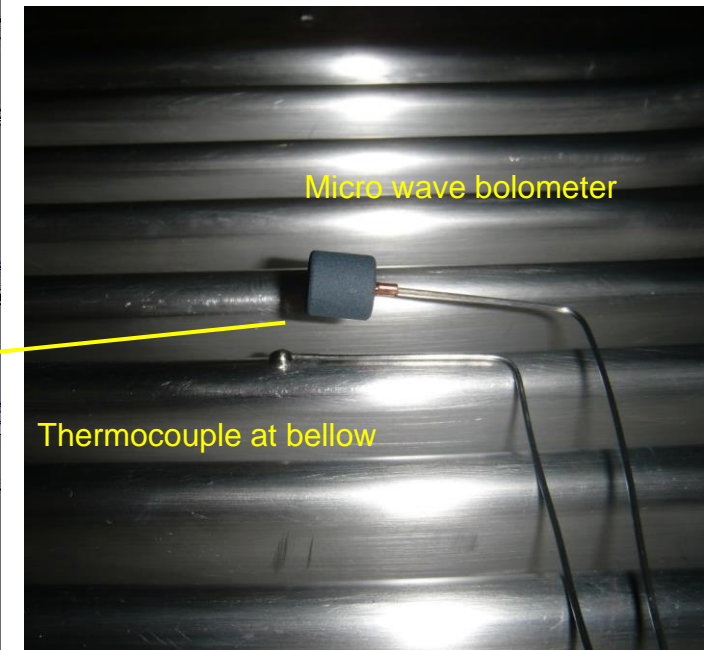
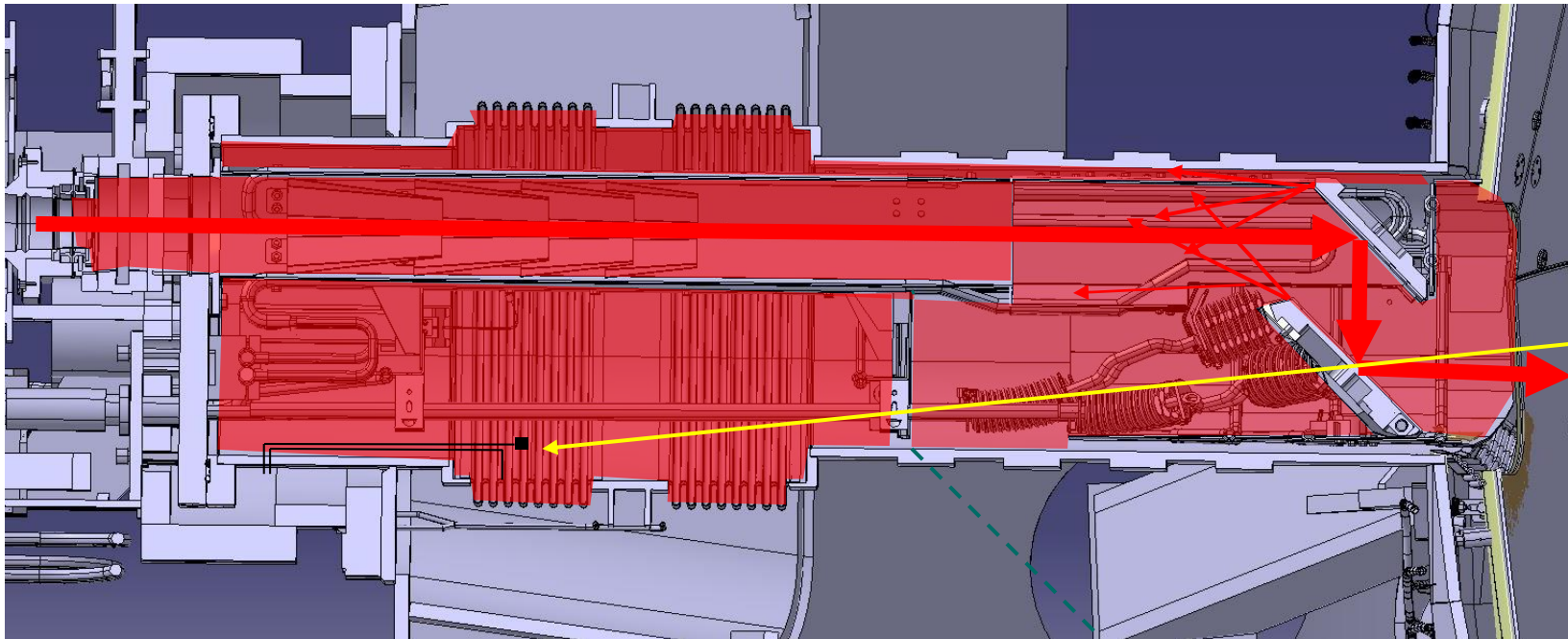


# Stray Radiation in the Launcher Port

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

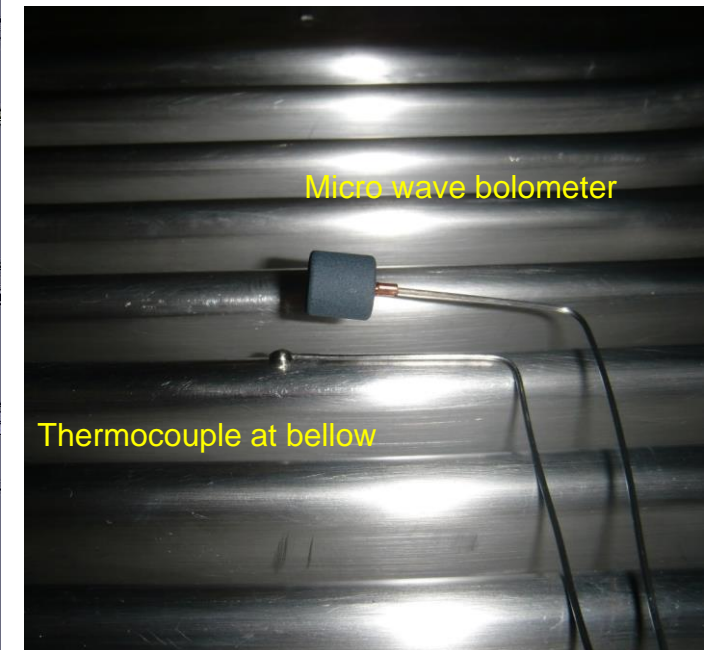
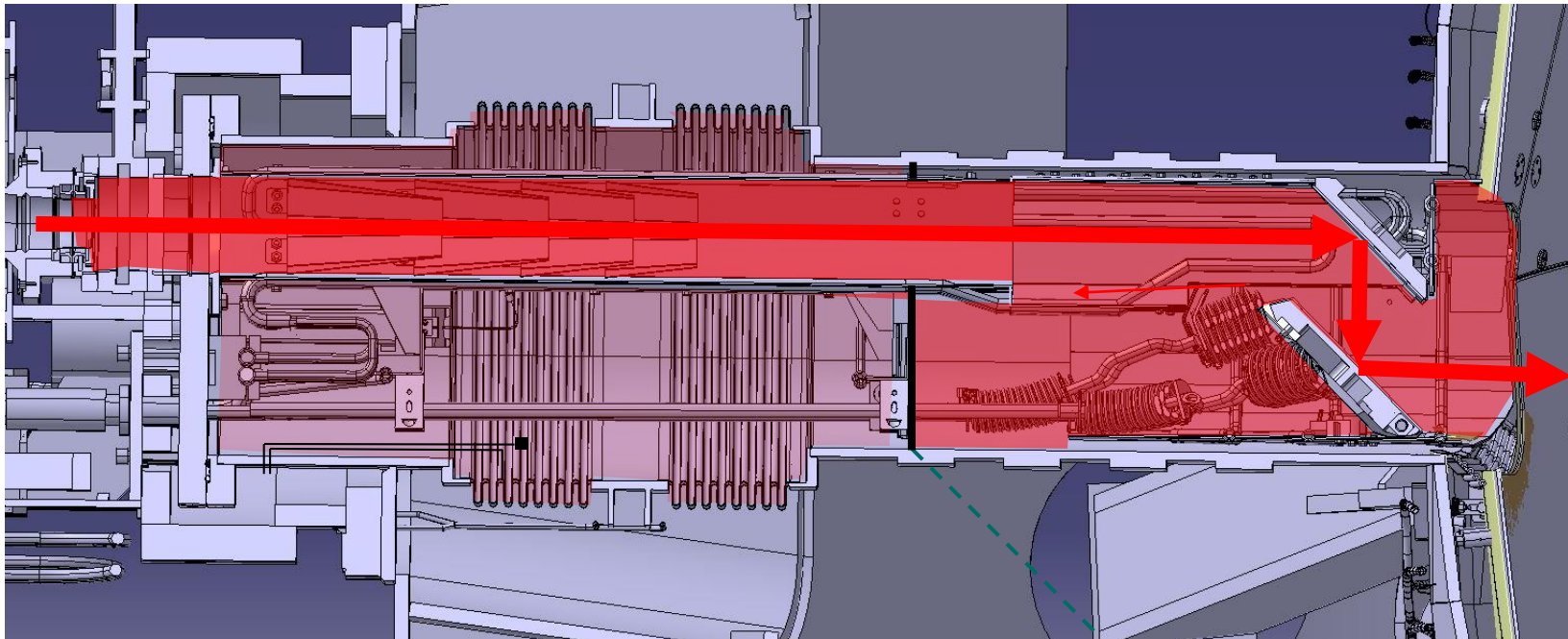
**Maximal temperature of 110 c° limited by allowed thermal loads on SC-coils!**

**Stray radiation and temperature measurement at below surface.**



# Stray Radiation in the Launcher Port

Additional microwave screening reduced the stray radiation to acceptable value.



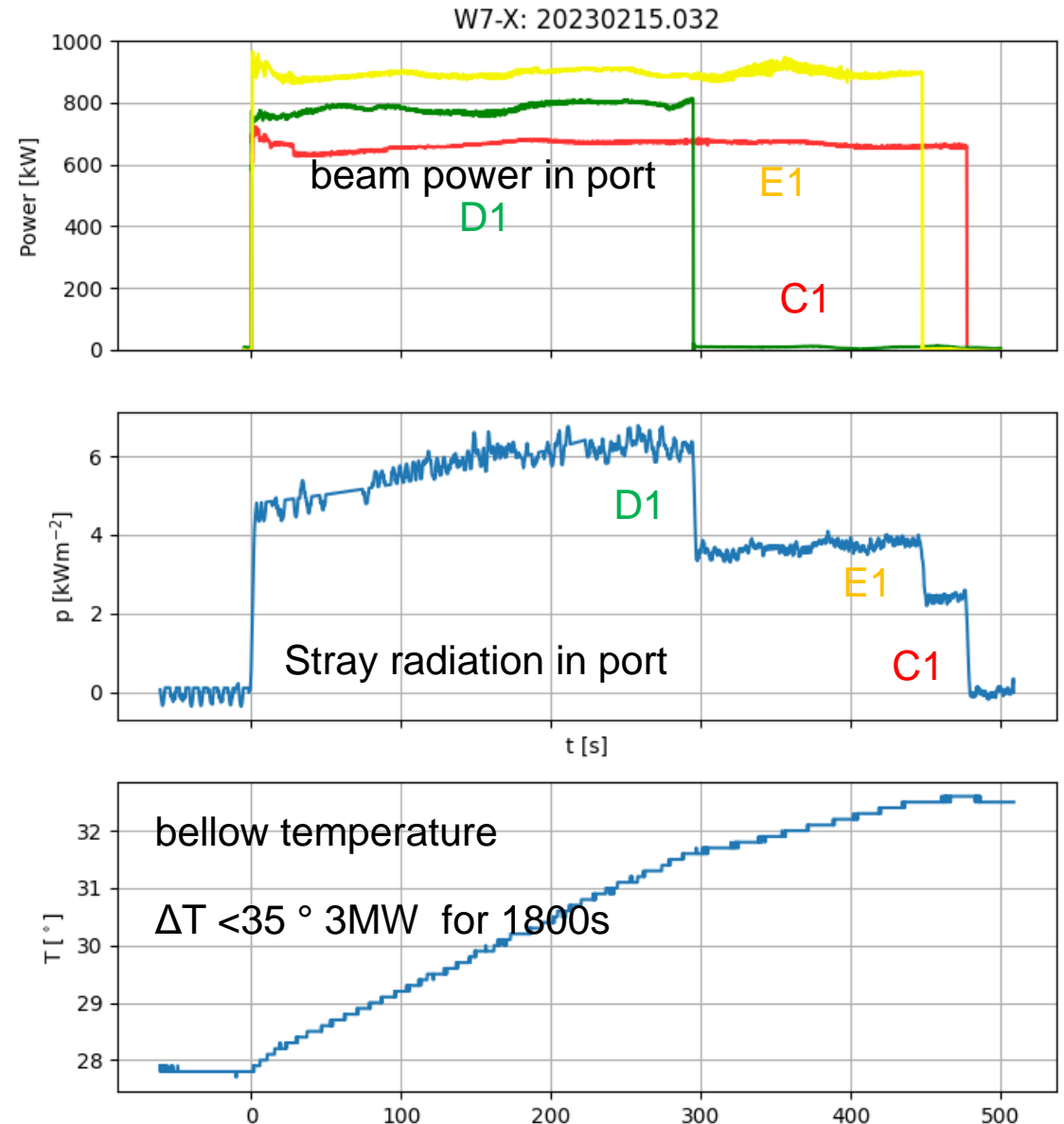


# Measurement in ECRH Launcher

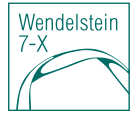
Analysis of the stray radiation steps gives qualitative Information of beam alignment (spill over)

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

Extrapolation of bellow Temperature for 30 minutes at 3 MW beam power in Launcher gives  $\Delta T < 35^\circ$ . 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.**