Mapping of the ASDEX Upgrade Operational Space for Disruption Prediction

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Summary

- ✓ Introduction
- ✓ Self Organizing Map
- ✓ The Database
- ✓ Mapping of AUG operational space
- ✓ Disruption Prediction
- ✓ Conclusions

Introduction

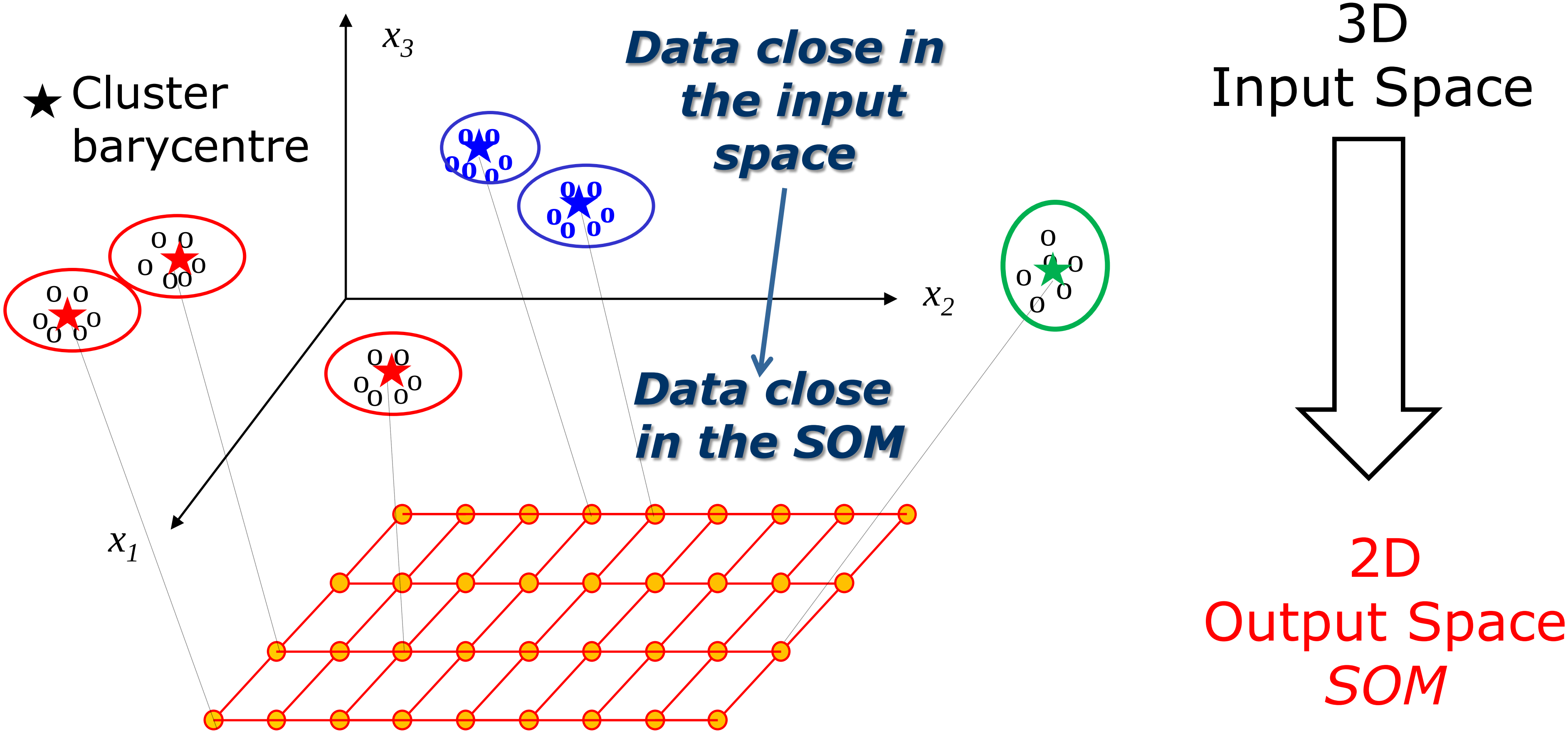
Self Organizing Map as a Tool for:

- ❑ visualization and analysis of the AUG operational space

- ❑ disruption prediction

Self Organizig Map (SOM)

- Mapping from an nD-space to a regular array of neurons (clusters)
- ***Topology preservation***



The Database

DB	discharges		range	Time period	use
	disrupted	safe			
DB1	149	80	16200-19999	2002–2005	Training and Validation
DB2	81	537	20000-22146	2005–2007	Testing of the generalization capability
DB3	118	534	22162-25665	2007–2009	Testing of the aging

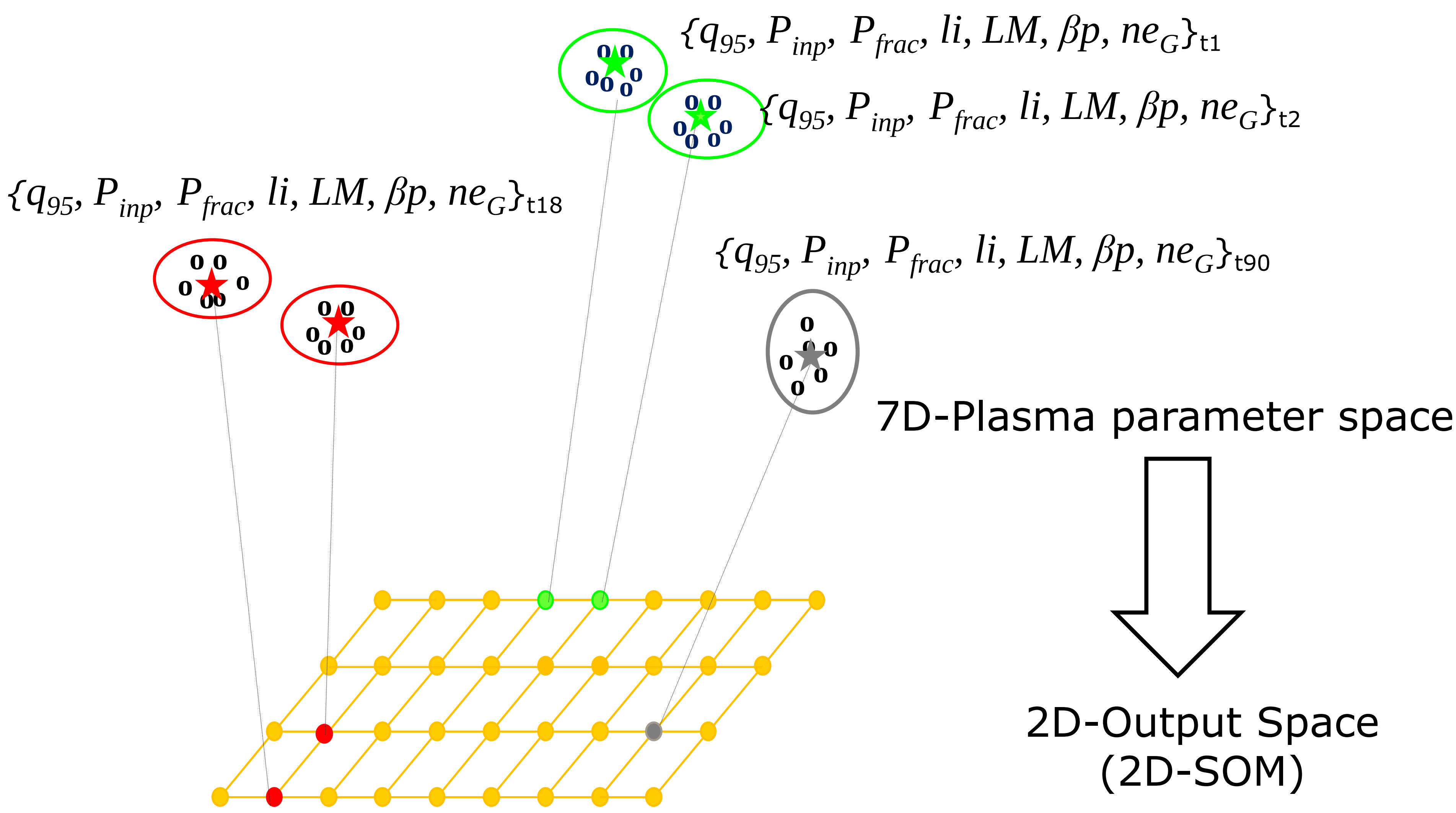
All the disruptions except those:

- in the ramp-up phase
- in the ramp-down phase if $t_D > t_{ramp\text{-}:down} + 100$ ms;
- caused by massive gas injection
- following a VDE

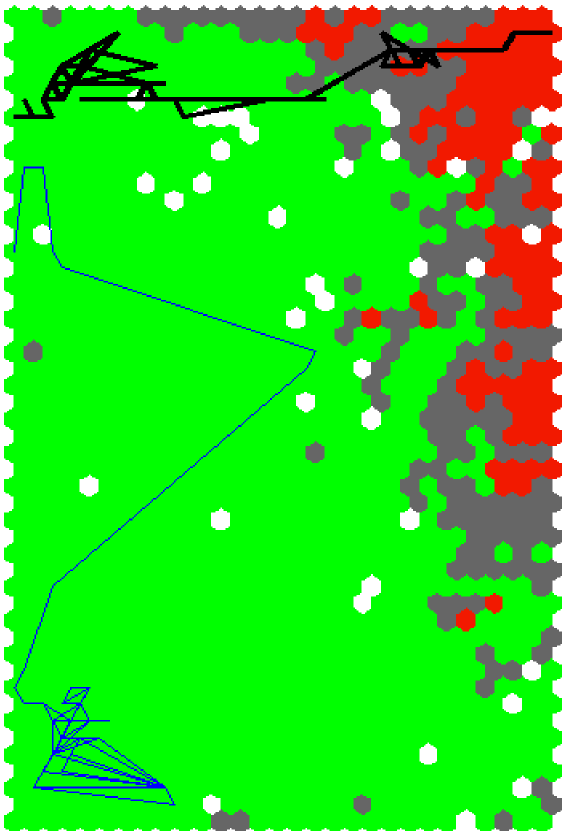
Database

Signal	***Acronym* [unit]**
Plasma current	I_p [A]
Safety factor at 95% of poloidal flux	q_{95}
Input power from Neutral Beam Injection	P_{NBI} [W]
Input power from Electron Cyclotron Radio frequency Heating	P_{ECRH} [W]
Input power from Ion Cyclotron Radio frequency Heating	P_{ICRH} [W]
Ohmic input power	P_{OH} [W]
Total input power	$P_{inp} = 0.9\ P_{NBI} + P_{ECRH} + P_{ICRH} + P_{OH}$ [W]
Locked Mode signal	LM [V]
Radiated power	P_{rad} [W]
Radiated fraction of the input power	$P_{frac=}P_{rad}/P_{inp}$
Plasma density divided by the Greenwald limit	ne_G
Internal inductance	l_i
Poloidal β	b_p
Loop Voltage	U_{loop} [V]

Mapping of AUG 7D-operational space

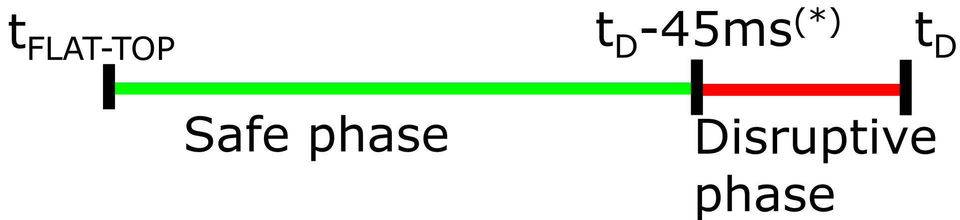


Mapping of AUG 7D-operational space

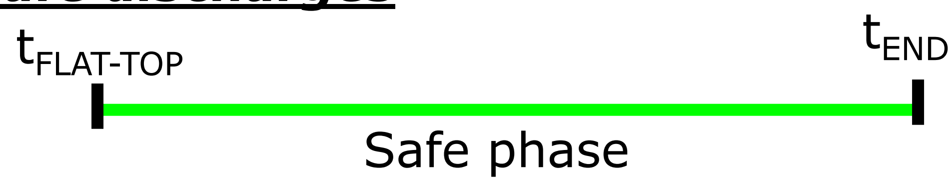


2D mapping colored on the basis of clusters type

Disruptive discharges



Safe discharges



Clusters	safe discharge	Disruptive discharge	
		$t < t_D$-45ms	$t \geq t_D$-45 ms
green	X	X	-
grey	X	X	<85%
red	-	-	≥85%
white	-	-	-

(*) B. Cannas, et al, Nuclear Fusion, vol. 50, 075004 (12pp), 2010.

Disruption Prediction: Performance indexes and results

$$PD = \frac{n° \text{ PrematureDections}}{n° \text{ disruptive shots}} \cdot 100$$

$t_{alarm} < t_D - 160ms$

$$SP = \frac{n° \text{ SuccessfulPredictions}}{n° \text{disruptive (or Safe) shots}} \cdot 100$$

$t_D - 160ms \le t_{alarm} < t_D - 2ms$ or Safe shots predicted as safe

$$TD = \frac{n° \text{ Late Dections}}{n° \text{ disruptive shots}} \cdot 100$$

$t_D - 2ms \le t_{alarm} \le t_D$

$$MA = \frac{n° \text{ Missed Alarms}}{n° \text{ disruptive shots}} \cdot 100$$

$t_{alarm} > t_D$

$$FA = \frac{n° \text{ False Alarms}}{n° \text{ safe shots}} \cdot 100$$

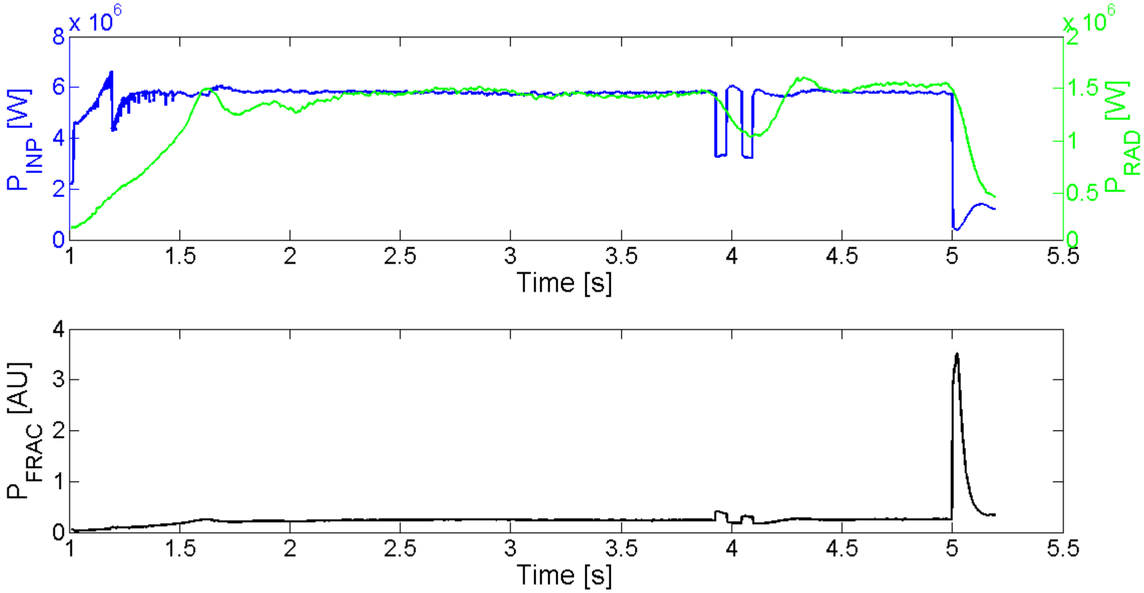
Safe shots predicted as disruptive

Prediction performance:

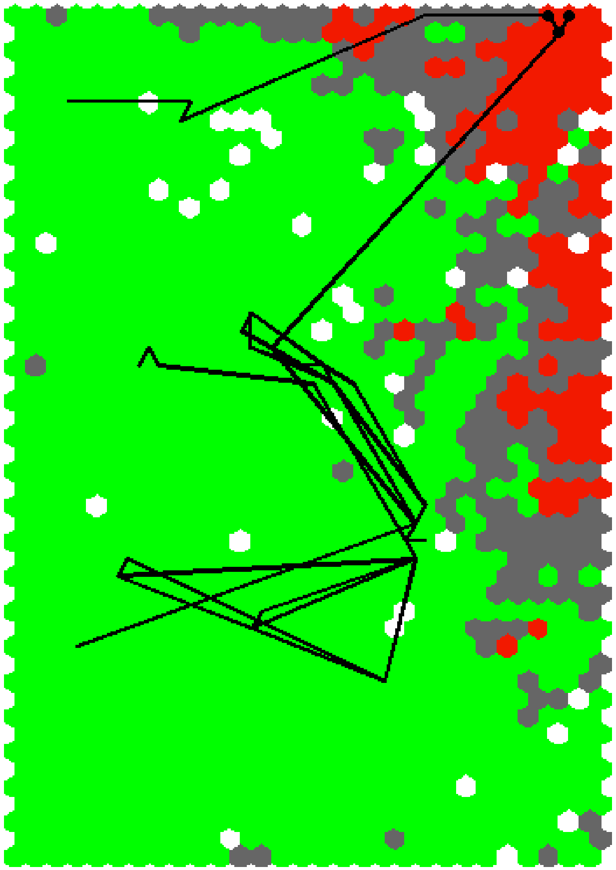
	Disrupted discharges				***Safe discharges***	
	PD[%]	***SP[%]***	***TD[%]***	***MA[%]***	***SP[%]***	***FA[%]***
DB1	9,40	83,89	1,34	5,37	95,00	5,00
DB2	9,88	65,43	4,94	19,75	90,88	9,12
DB3	16,95	56,78	5,08	21,19	85,18	14,82

Disruption Prediction: Analysis of results

- The large majority of correct alarms is triggered in the presence of an increase of P_{rad}
- 73.5% of FAs and 50% of PDs correspond to a peak in the P_{frac} signal due to the shutdown of one or more AHS



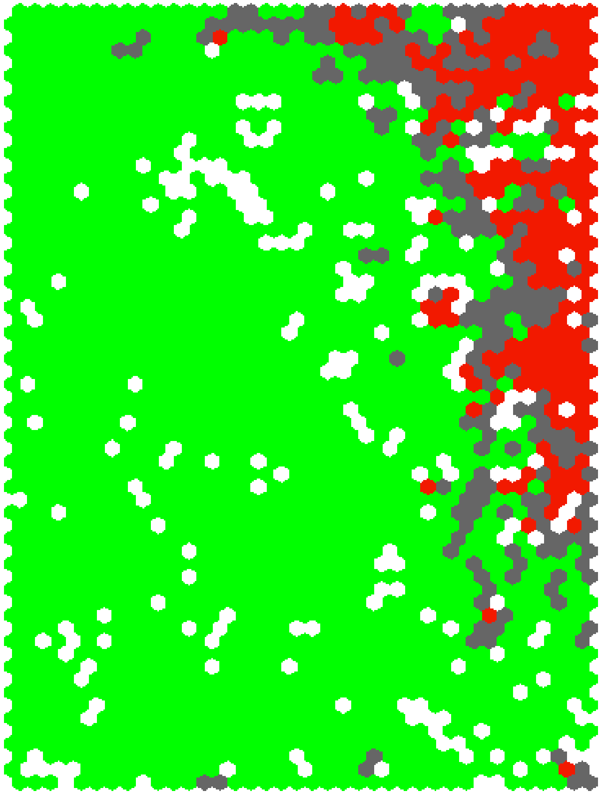
Discharge #21011



Trajectory of the discharge # 21011 on the 2D-SOM

Disruption Prediction: 2D Map of 8D operational space

Inputs : $\{q_{95}, P_{inp}, P_{rad}, P_{frac}, li, LM, \beta p, ne_G\}$



2D map of the 8-D operational space of AUG

Algorithm to limit FAs and PDs

The alarm is inhibited when following conditions are simultaneously satisfied:

1. $$\frac{dP_{inp}}{dt} \leq \frac{dP_{inp}}{dt}\bigg|_{THR}$$ At least once in the 20ms preceding the alarm time
2. $$P_{rad} \leq P_{rad}\big|_{THR}$$
3. $$\frac{dP_{rad}}{dt} < \frac{dP_{rad}}{dt}\bigg|_{THR}$$

Disruption Prediction: 2D Map of 8D-operational space

$$\frac{dP_{inp}}{dt}\Big|_{THR} = -1.2\ \mathrm{GW/ms}$$

Is the minimum value assumed by P_{rad} at the alarm time, for all the correct predictions in the presence of an increase of P_{rad}.

$$P_{rad|THR} = 1.3\ \mathrm{MW}$$

the minimum value assumed by P_{rad} at the alarm time, for all the correct predictions in the presence of an increase of P_{rad}

$$\frac{dP_{rad}}{dt}\Big|_{THR} = 11\ \mathrm{MW/ms}$$

is the minimum value assumed by dP_{rad}/dt at the alarm time, for all the correct predictions in the presence of an increase of P_{rad}.

Prediction performance:

	Disrupted discharges				Safe discharges	
	PD[%]	***SP[%]***	***TD[%]***	***MA[%]***	***SP[%]***	***FA[%]***
DB2	9.88	69.14	6.17	14.81	93,85	6,15
DB3	8,47	69,50	7,63	14,40	87,05	12,95

Conclusions

The SOM of the *8*D-AUG operational space provides:

I. 2D-Map where regions with different risk of disruption can be identified

II. Disruption predictor

Self Organizing Map (SOM)

- The K output neurons are fully connected to the inputs via the weights **w**.

- $O_j = \sum_{i=1}^{n} w_{ji} x_i$ is the output of jth neuron, j=1,.....,K

- A competitive learning rule is used, choosing the winner j^* as the output neuron with weight vector **w** closest to the input **x**:

$$\Delta \mathbf{w}_j = \eta \cdot \Lambda(j, j^*) \cdot (\mathbf{x} - \mathbf{w}_j) \quad j = 1,..K$$

- The neighborhood function Λ is equal to 1 for j=j^*, and decreases with the distance between neurons j and j^* in the output lattice. Thus, neurons close to the winner have their weights updated, while those further away, experience little effect.

Disruption Prediction: Alarm criteria

1. $k = (101.11 - ds_{\%})/0.7 \quad \text{if} \;\; 85 \leq ds_{\%} < 100$

The value *k* is updated only if the trajectory moves into clusters with higher $ds_{\%}$.

2. $k = 2 \quad \text{if} \;\; ds_{\%} = 100$