Max-Planck-Institut
für Plasmaphysik

MAX-PLANCK-GESELLSCHAFT

Actuator management for present and future tokamaks

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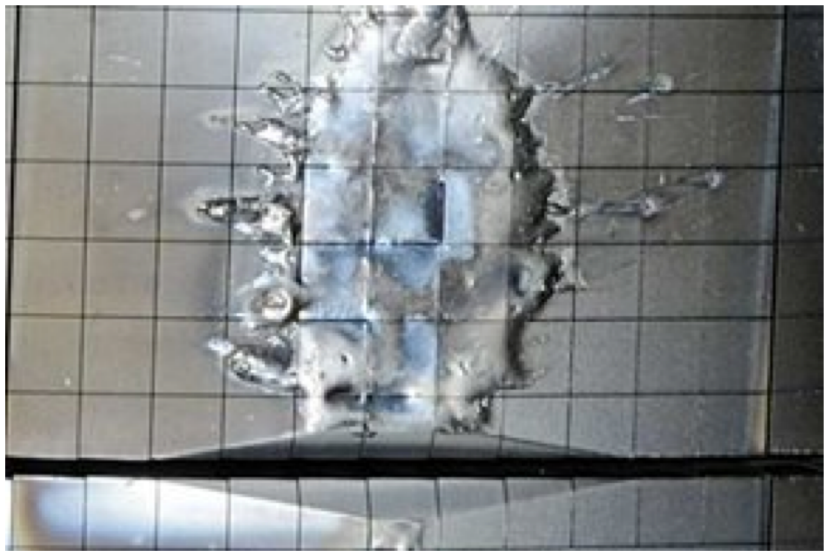
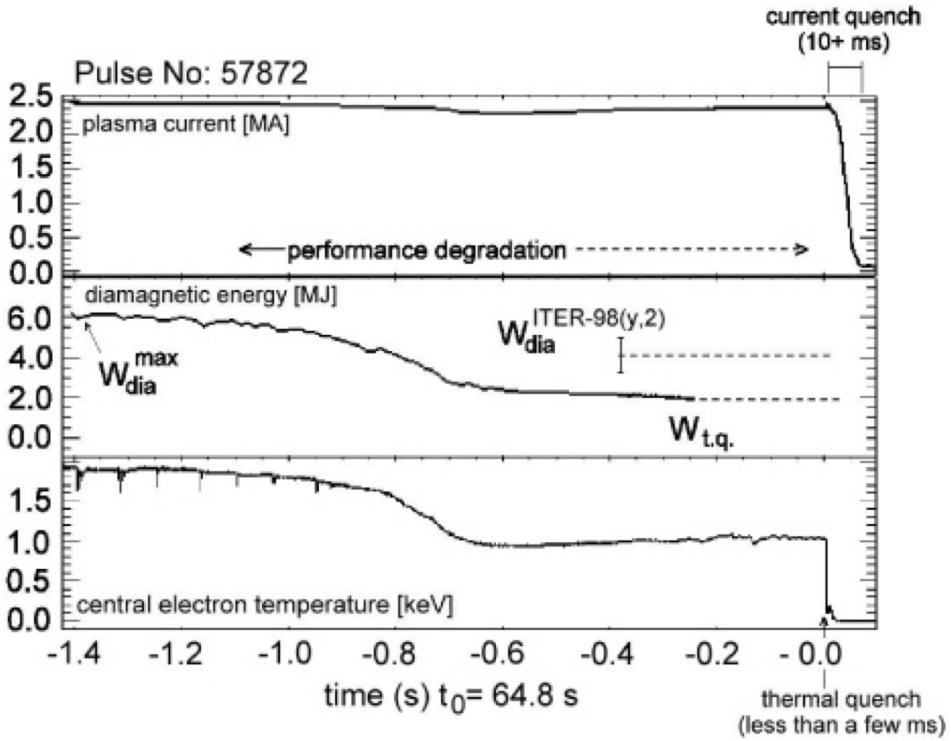
Motivation: why?

- **A lot of problems to handle**:
  - Disruption avoidance: safe the plasma (or the device)
- **Have enough power for control**
  - Current profile + beta
  - Te
- **Have convenient actuators for each task**

What is disruption?

- **Disruption: sudden loss of plasma current and thermal energy**
- **Consequences:**
  - **Thermal damage of the wall due to high heat flux**
  - **Magnetic energy lost: mechanical damage**
  - **Runaway electrons**





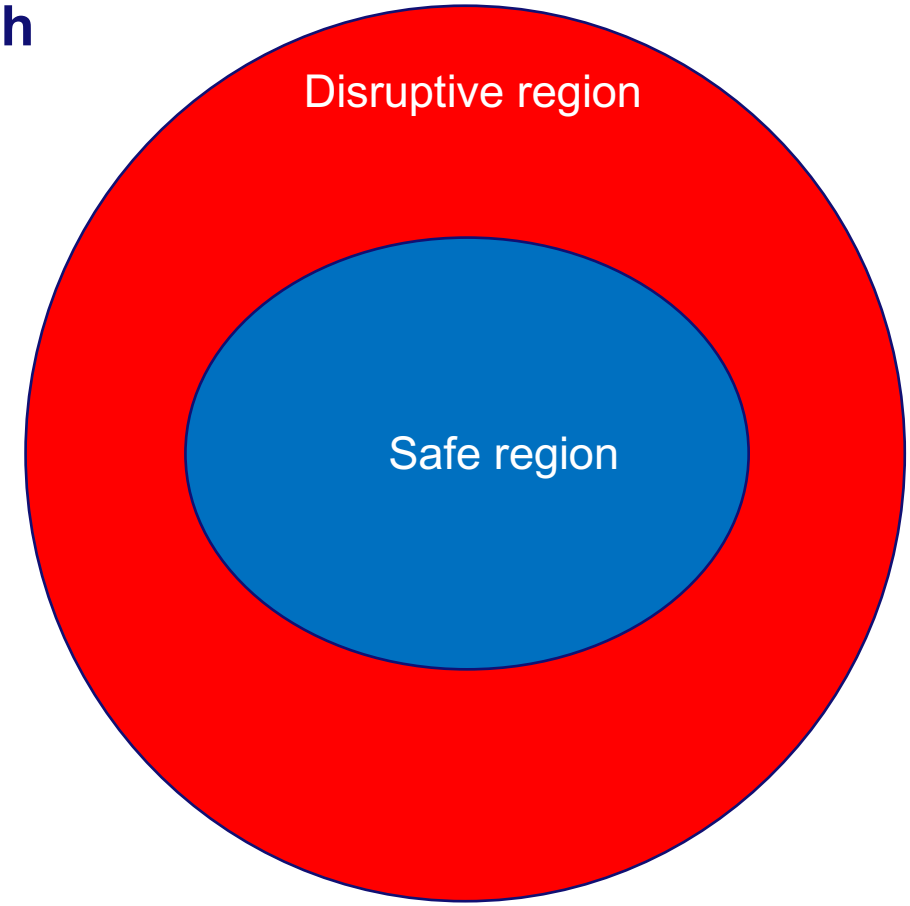
We do not deal with disruptions => we will not build tokamak based power plant!

Disruption: experiment and reactor

- **Experiment goal: Measure good data**
  - **Not much attention paid to discharge end**
- **Reactor goal: Produce energy**
  - **We will push plasma towards stability limits: produced energy ~ β^2**
  - **We will care A LOT about discharge end**
  - **DEMO: no major disruption flat-top request**

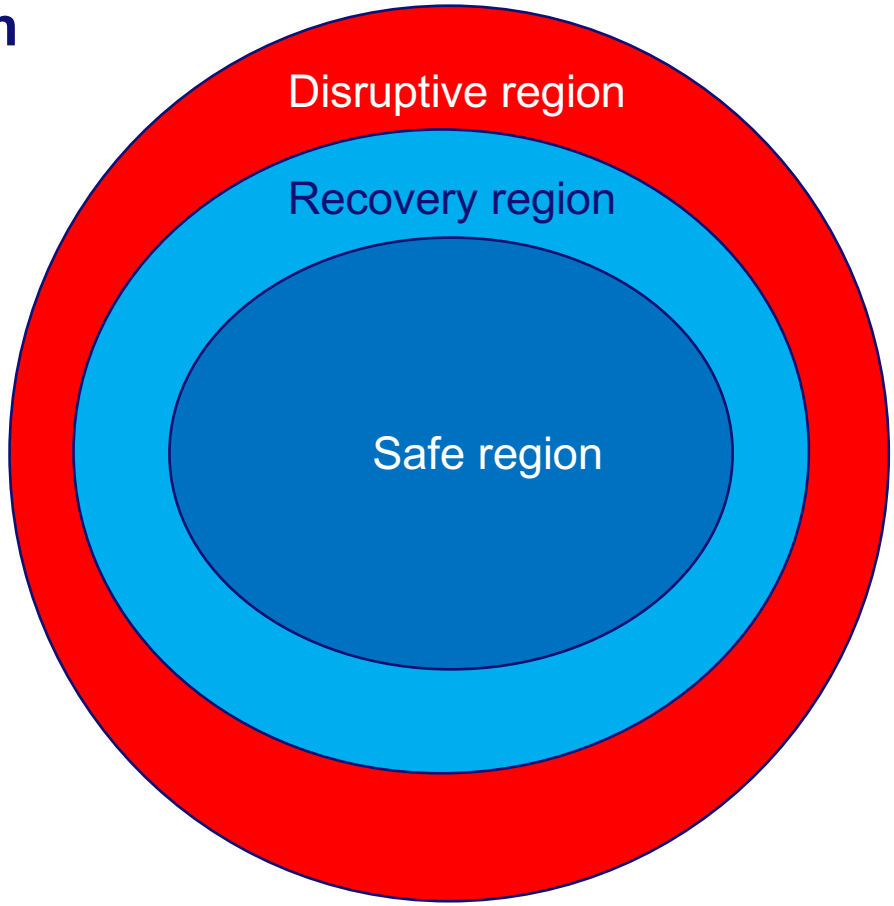
Disruption: experiment and reactor

- **Define boundary between safe and unsafe plasma state: if crossed, switch off**
  - **Machine learning**
  - **Locked mode (NTM that stops rotating)**
  - **…**
- **More “lines of defense” needed**



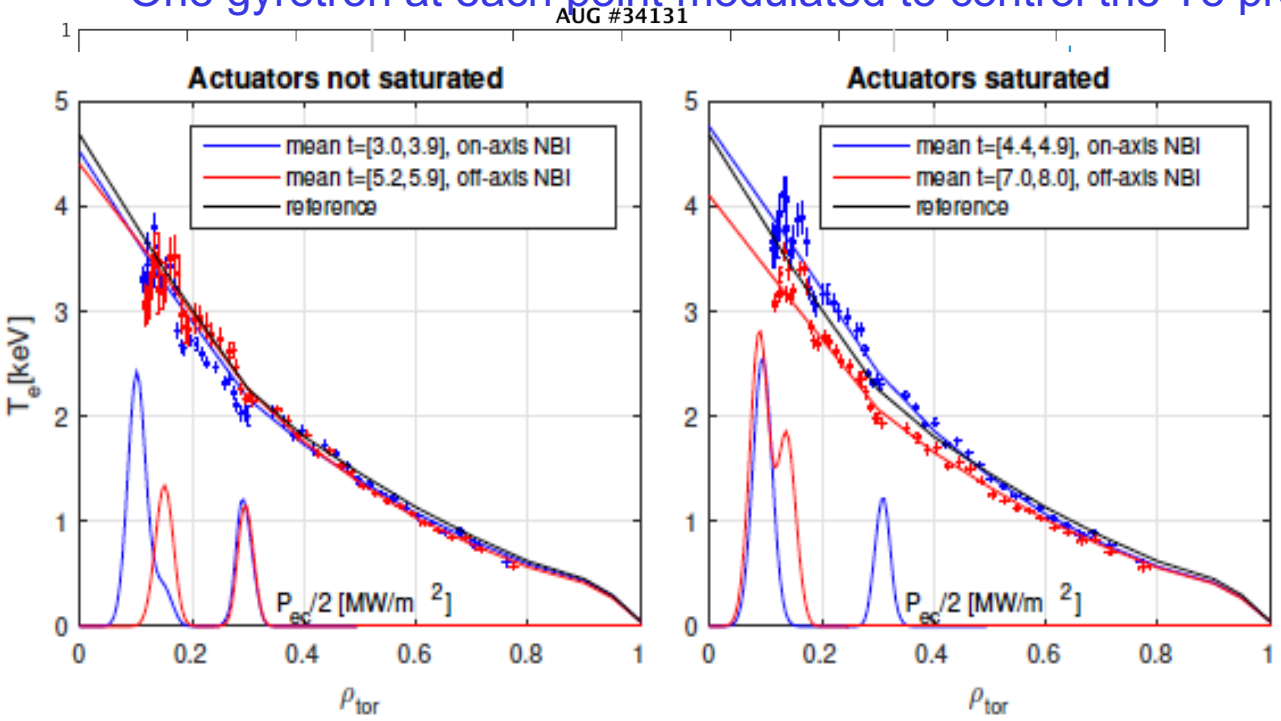
Disruption: experiment and reactor

- Define boundary between safe and unsafe plasma state: if crossed, switch off
  - Machine learning
  - Locked mode (NTM that stops rotating)
  - …
- More “lines of defense” needed
- Developments at AUG:
  - Flight simulator
  - Robust controllers
  - Actuator management & discharge monitor
  - Faster than real time simulations
- Each cause of disruption will have it’s own strategy to deal with



Trigger for us: Te profile control

- Some feedback algorithms require more power sources
- Example: **T_e profile controller**
  - **Swap of NBI** from **on-axis** to **off-axis** (B. Geiger experiment)
  - Controller keeps the **Te profile constant** by **modifying ECRH power** at two points: ρ = 0.15 and ρ = 0.3
  - One gyrotron at each point modulated to control the Te profile

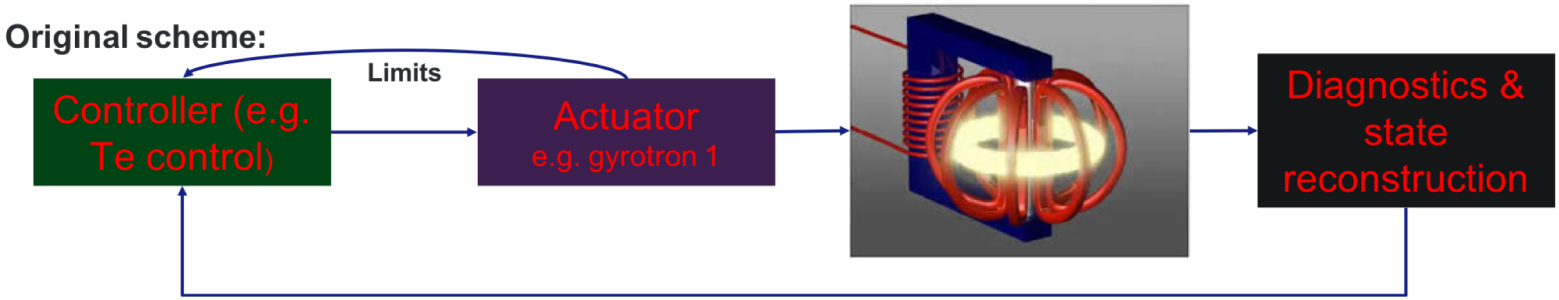


Controller works well as long as the gyrotrons are not at power limit (full/zero)
In this case ~50% of the time Controller was optimized for this scenario!

F. Felici et al, submitted to NF

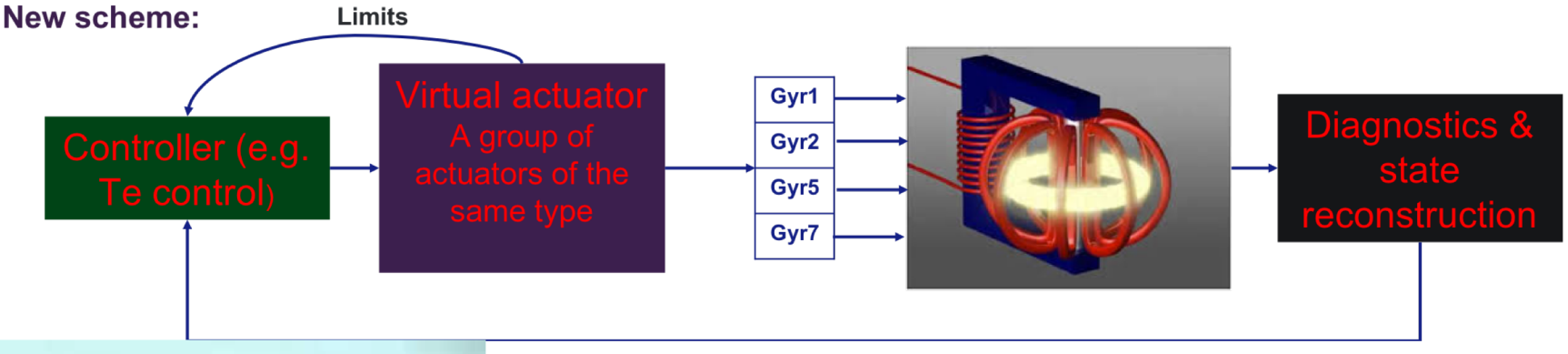
Where is the problem: old system

- Mostly use of a **single power sources for one task** (e.g. β control by ECRH, T_e control)
- **Current version**: 1 actuator (=power source) per control task



What is the change about: new system

- **New version**: more actuators per task available, **virtual actuator**
  - 2 objects of this type exist at AUG: NBI source group and central ECRH heating gyrotrons
  - This scheme has been generalized to allow easier introduction of new virtual actuators and easier communication with controllers

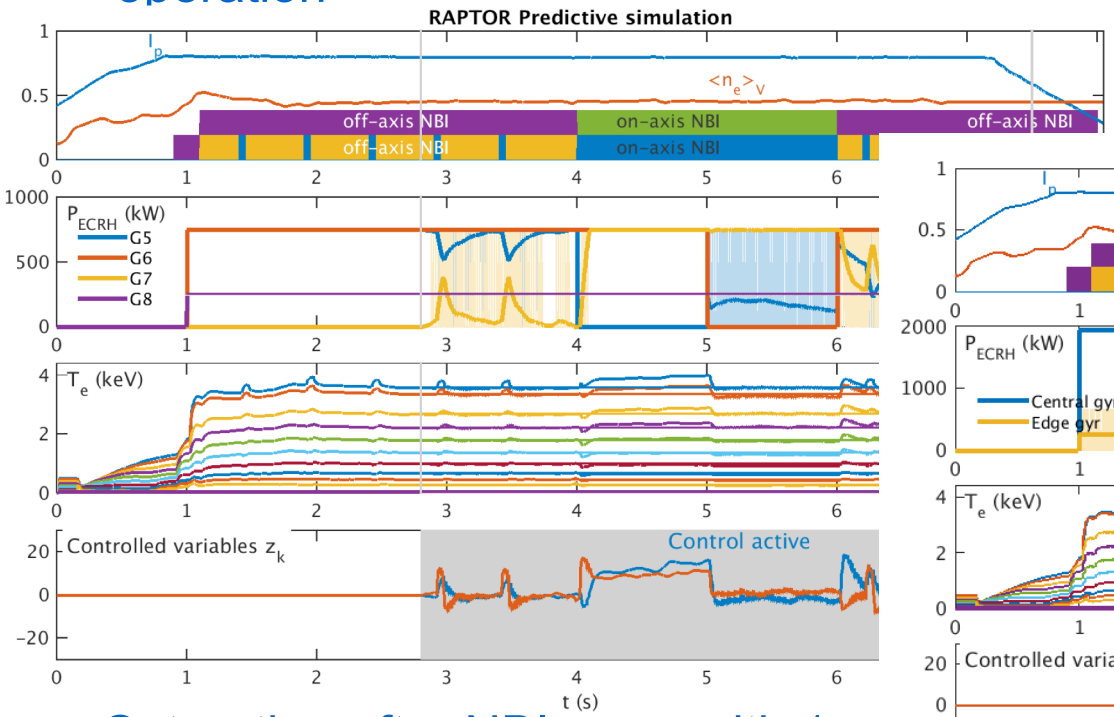


Virtual actuator: what is it and what can it do?

- **A group of actuators of the same impact sorted by priority**
  - We already have this for ECRH central heating group and NBI source group
- Actuator list comes from the discharge program in the priority order
- **Main roles**:
  - **Distribute power** between actuators pointing to the right location
  - **Replacement** of tripped sources
  - Provide **limits** to the connected controller

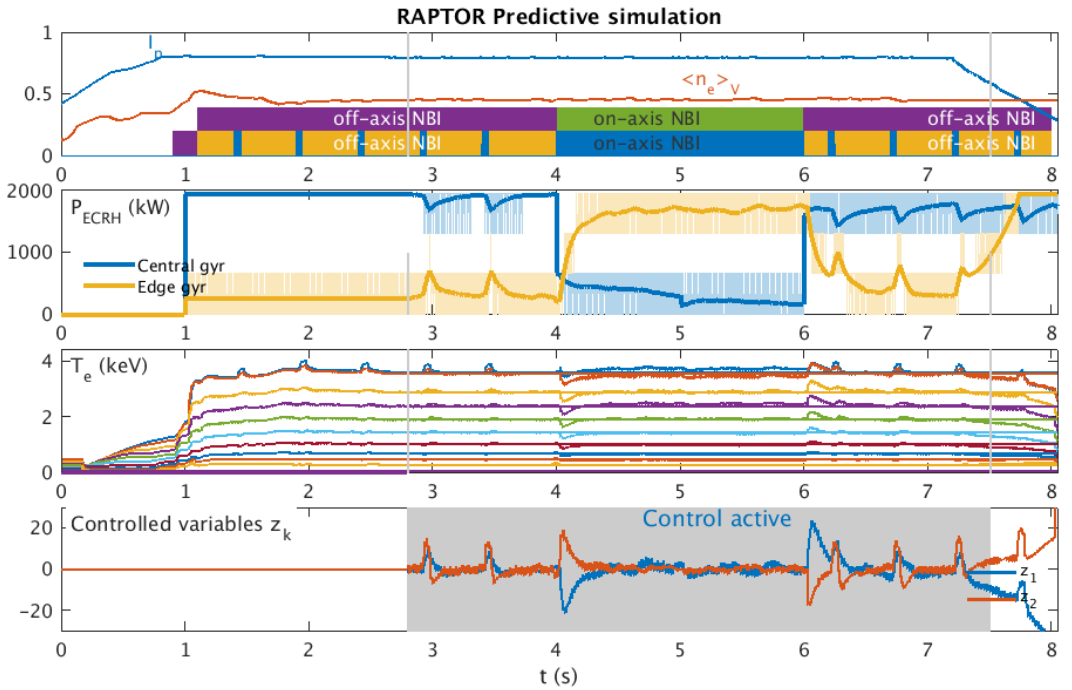
Why do we need that?
What would the AM change?

- **Simulation** result for 33864 (by RAPTOR matched to TRANSP)
- Experiments as soon as we come back to operation



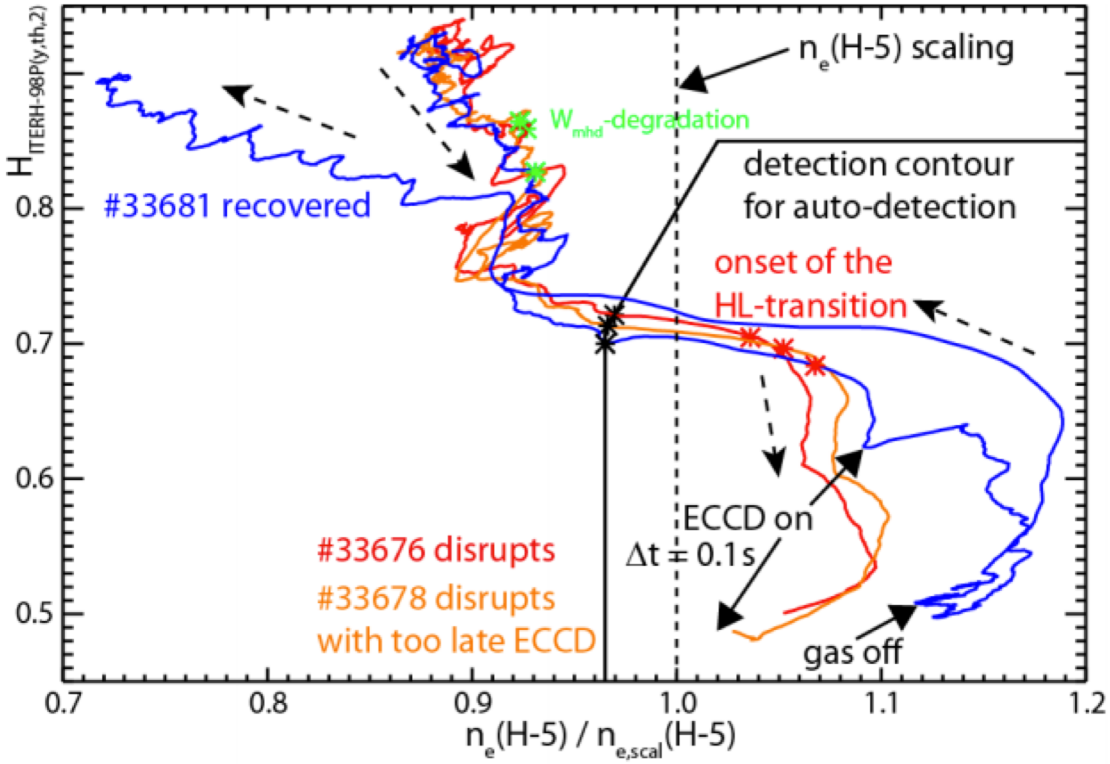
- Saturation after NBI swap with 1 ECRH per channel

- No Saturation after NBI swap with 3 ECRH per channel
- Optimized ECRH heating before the swap



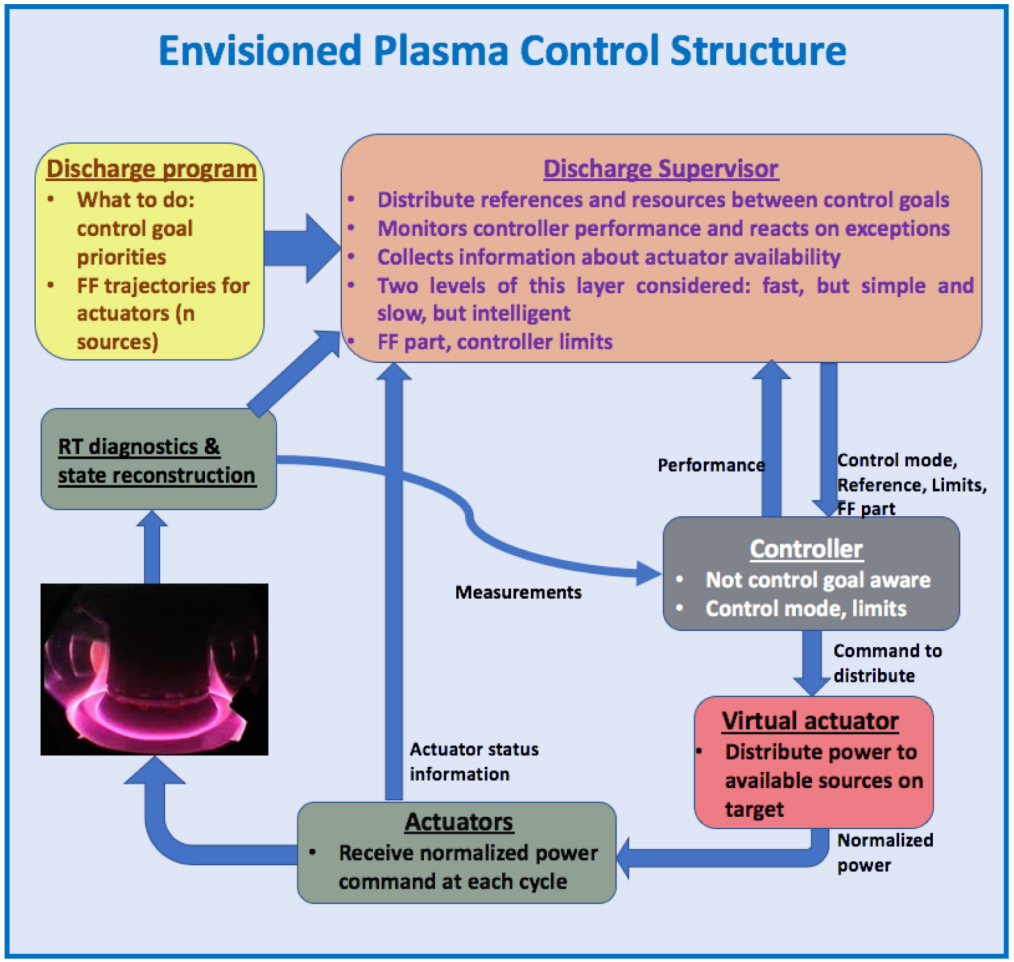
Disruption avoidance: density limit

- Reaction on **off-normal plasma state**
- **Plasma approaches dangerous zone: recovery by EC power** (~100's of ms before disruption)
  - **Ready** as soon as AUG comes back to operation
  - **Virtual actuator** provides more power
- Plans:
  - Further **density limit** studies: gyrotrons aim at the desired location
  - **Work towards more intelligent handling schemes**



M.Maraschek, PPCF 60(2017) 014047

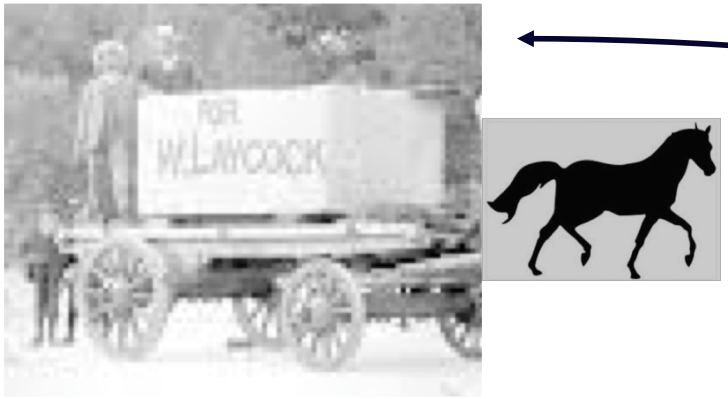
How will the final system look like?



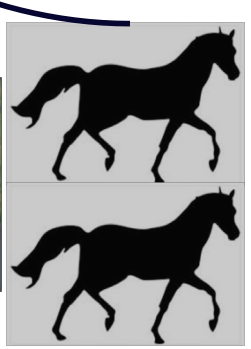
- **Discharge supervisor** does not exist yet, but is essential for long term development of disruption avoidance strategies
- The **use will not be mandatory**: one can use either nothing, or select some parts that will be active (e.g. NTM control), or give the supervisor full freedom

What will the system enable: examples

- Controller does not perform well, other does not need all power**: relocation**
  - Profile control: one task needs more power (saturation)

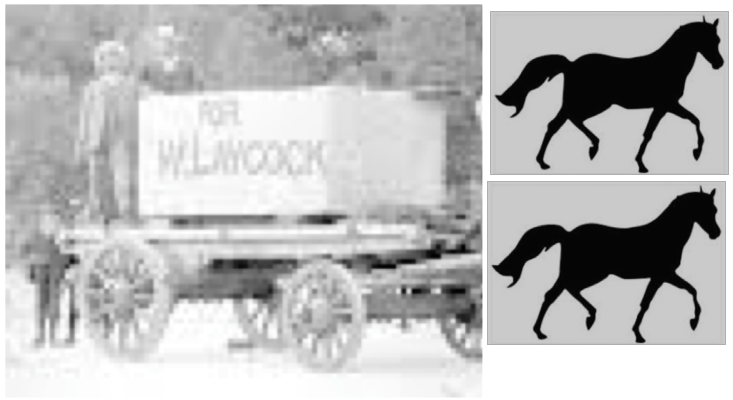


Supervisor:
Relocate
actuator!



What will the system enable: examples

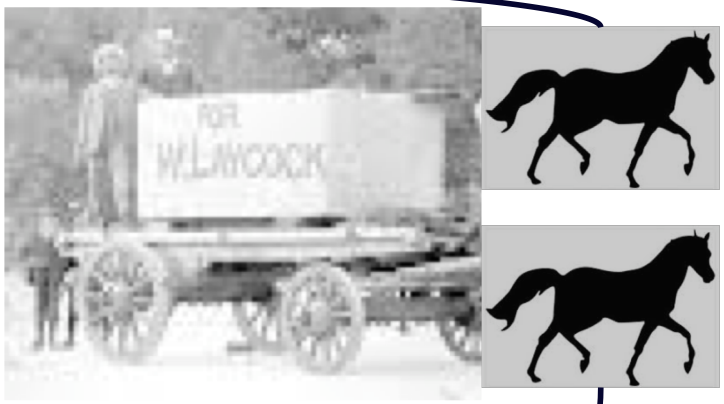
- Controller does not perform well, other does not need all power**: relocation**
  - Profile control: one task needs more power (saturation)
  - No compromise on performance



What will the system enable: examples

- Relocation of actuators where it is needed
  - Profile control: one task needs more power (saturation)
  - Problem recovery: NTM suppression
    - Forget about performance and safe the discharge!

Supervisor: Take all we can to safe situation!



What will the system enable: examples

- Relocation of actuators where it is needed
  - Profile control: one task needs more power (saturation)
  - Problem recovery: NTM suppression
    - Forget about performance and safe the discharge!

Supervisor: After we are safe, return back!

Conclusions

- We have started building a **system which will extend the control opportunities**
- **Combination of more heating sources** to one task. Ready for
  - Te profile control
  - β control by ECRH
  - Density limit handling
- **Outlook**
  - Handle impurity accumulation when it appears
  - Add more power sources when NTM appears
  - Take advantage of the developed tools in current profile control