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Rapid prototyping of advanced control schemes in ASDEX Upgrade

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Overview

- Introduction and strategy for rapid prototyping of advanced control schemes.
- Implementation of runtime expression parsing into the discharge control system (DCS).
- Disruption avoidance testing: H-mode density limit
- Summary

Advanced control schemes in ASDEX Upgrade

Past

- Independent feed back controllers.
- Feed forward for many systems.
- Limited number real time diagnostics.

Present

- Higher degree of coupled controllers.
- Feed back for many systems.
- Exception handling for dedicated (known) scenarios.
- Increasing number of real time diagnostic.

Future

- Objective driven control.
- Decision logic with exception handling.
- Comprehensive plasma state provided by full real time diagnostic coverage.

Switch on heating source X of type Y at time Z

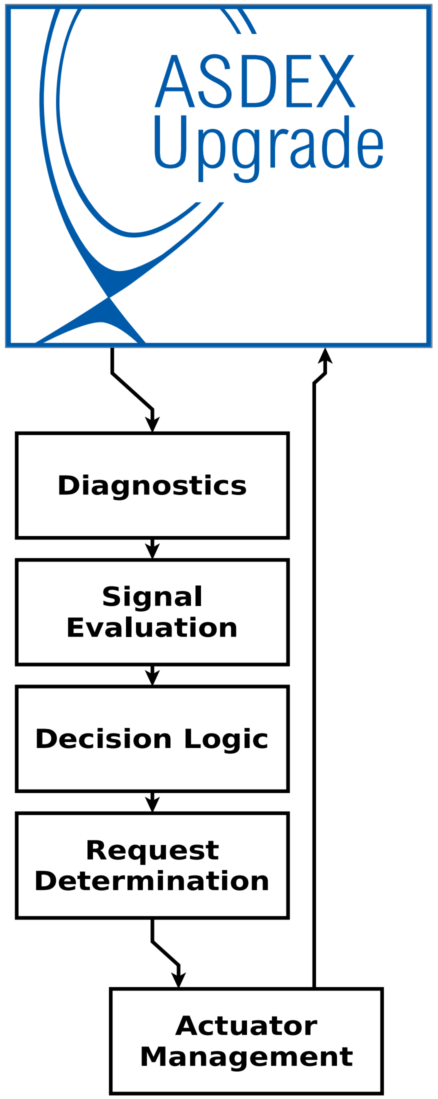
Increasing level of abstraction.

Provide X MW of heating with property Y In case of event Z

Basic Strategy

Overview

- Diagnostics provide data in real time.
- Provided signals are evaluated to determine plasma state.
- Decision logic determines which action has to/can be taken.
- The request (for the different tasks) is determined.
- Actuator management takes the decision which actuators to use and issues the commands accordingly. [O.Kudlacek, P.558]



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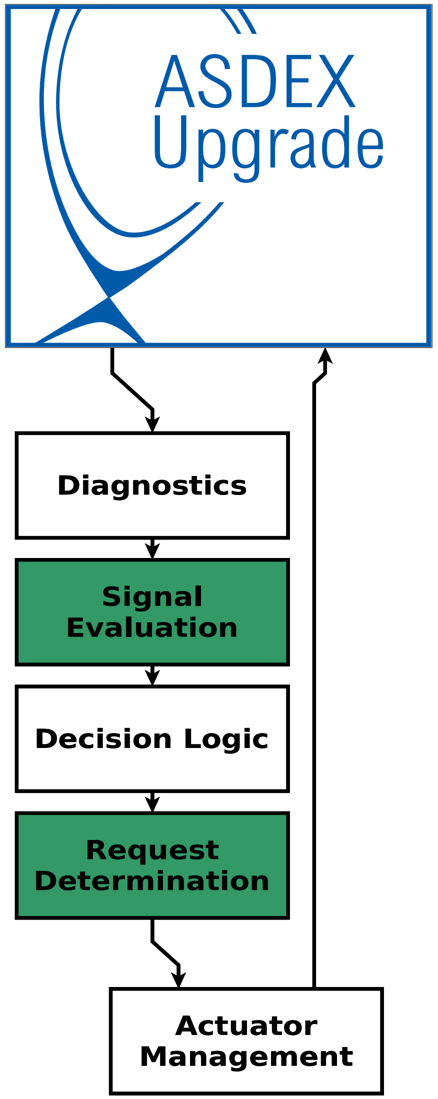
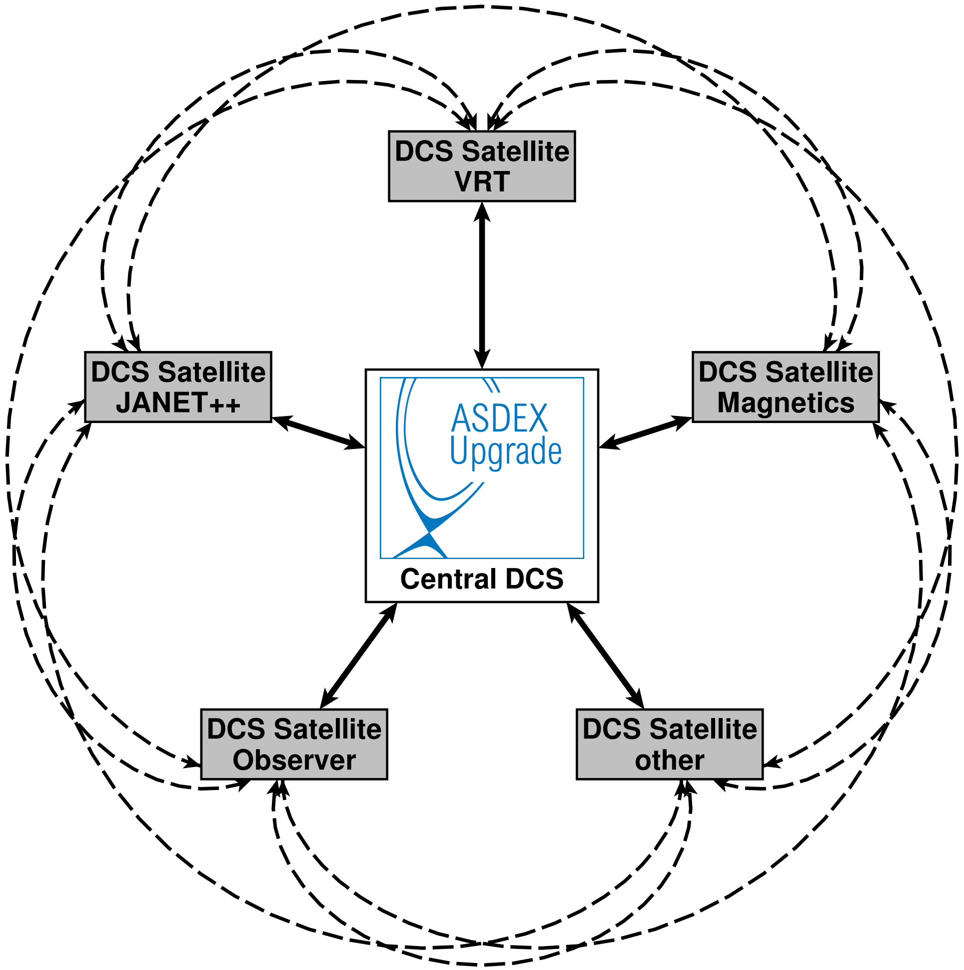
Scope of this talk

- Configuration based
  - signal evaluation for physical quantities.
  - state space observers and request calculation.
- Example:
  - H-mode density limit disruption avoidance in ASDEX Upgrade.



Discharge Control System (DCS)

- The philosophy is to define the control behaviour via configuration.
- DCS satellite concept utilizes the framework to be able to flexibly add, for example, additional diagnostics, actuators or computation nodes.
- The signal evaluation for rapid prototyping is implemented as a so called application process (AP) which can be added to a DCS satellite via configuration.



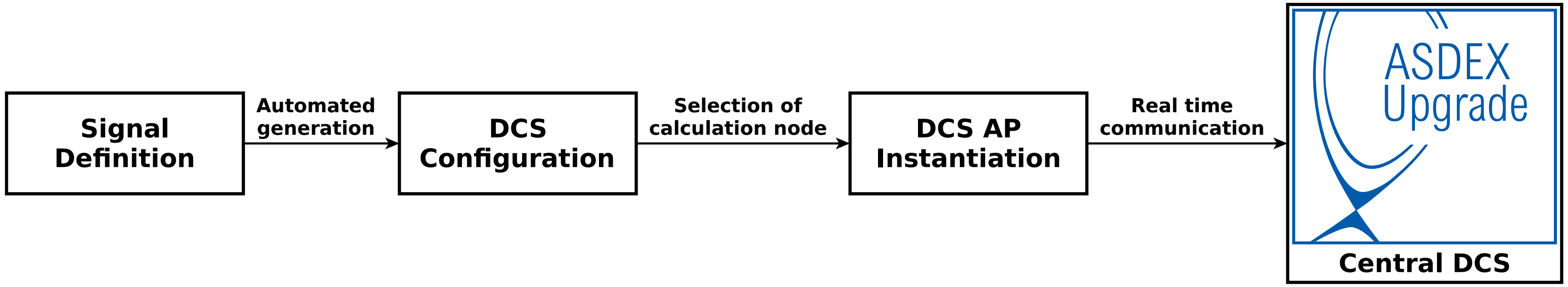
Implementation goals

- Enable to define the computation of an output signal using
  - multiple parameters (e.g. constants).
  - multiple input signals (from e.g. diagnostics or other signal evaluations).
  - an arbitrary mathematical expression for the calculation.

- Exploit possibility of DCS to have automatically scheduled concurrent tasks.

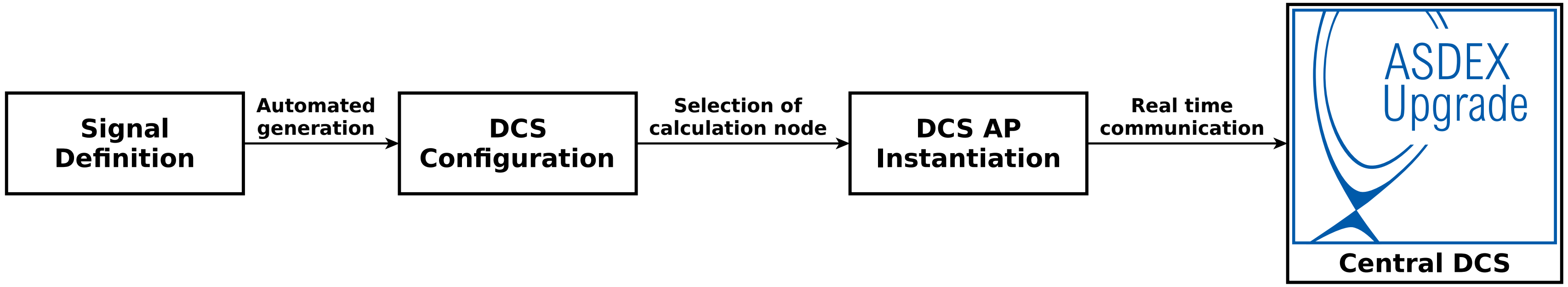
- Ease of use for the experimentalist to define new signals. No expert knowledge of DCS shall be required to define a signal.
  - Deployment to live DCS is done by CODAC operators.

Desired workflow



- The experimentalist should not have to know anything about DCS.
- The definition should be clear and simple.
- Deployment of new signals should be quick and effortless.

Desired workflow



Signal definition is done using YAML (YAML Ain't Markup Language).

$$n_{GW} = 1 \cdot 10^{14} \frac{I_p}{\pi a_{hor}^2} \longrightarrow$$

```yaml
GreenwaldDensity:
    Expression: Prefactor * abs(Ip) / pi / (ahor^2)
    Parameters:
        Prefactor: 1.0e14
    Signals:
        Ip: rts:Dia/FPC/IpiFP.val
        ahor: rts:Dia/FPG/ahor.val
    Output: rts:Dia/OBS/GreenwaldDensity.val
```

Conversion to the DCS configuration XML is done automated.

Implementation

Requirements

- The solution needs to be included into the existing DCS framework (C++).
- Performance needs to be sufficient to handle control cycle times of ~ 1 ms.
    - Evaluation times of a signal « 1 ms

Tools

C++ Mathematical Expression Library (ExprTk)

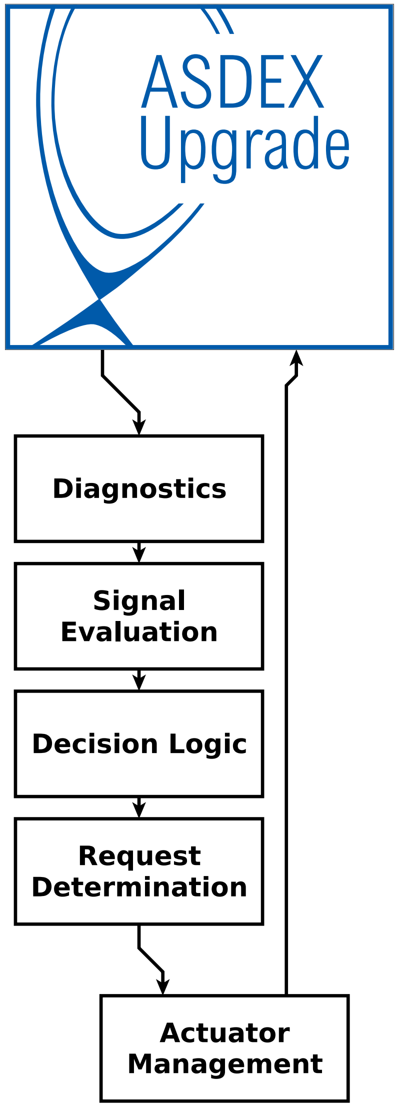
- Developed by Arash Partow. http://partow.net/programming/exprtk/
- Provides extensive expression parsing and evaluation features.
- The library builds an abstract syntax tree (AST) which connects the expression with the C++ variables, which can be configured and evaluated at runtime.
- Has a wide user group.

and more …

Disruption Avoidance

- Disruptions pose a significant risk for the operation fusion experiments and might be intolerable for large devices.

- Disruption avoidance aims at
  - early detection of an off normal behaviour
  - application of the required action to return to the nominal path



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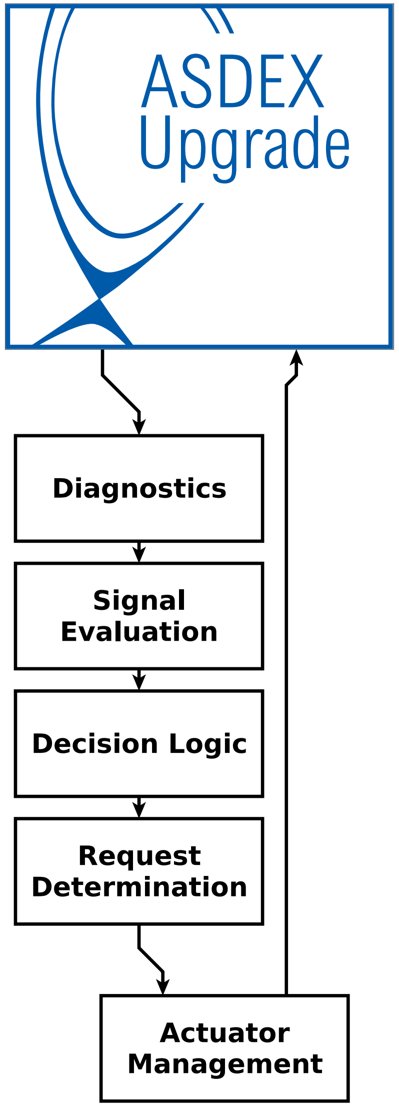
- For each disruption type/path
  - a suitable identifier needs to be defined
  - the required and applicable action needs to be identified



Disruption Avoidance (Testing)

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- For each disruption type/path
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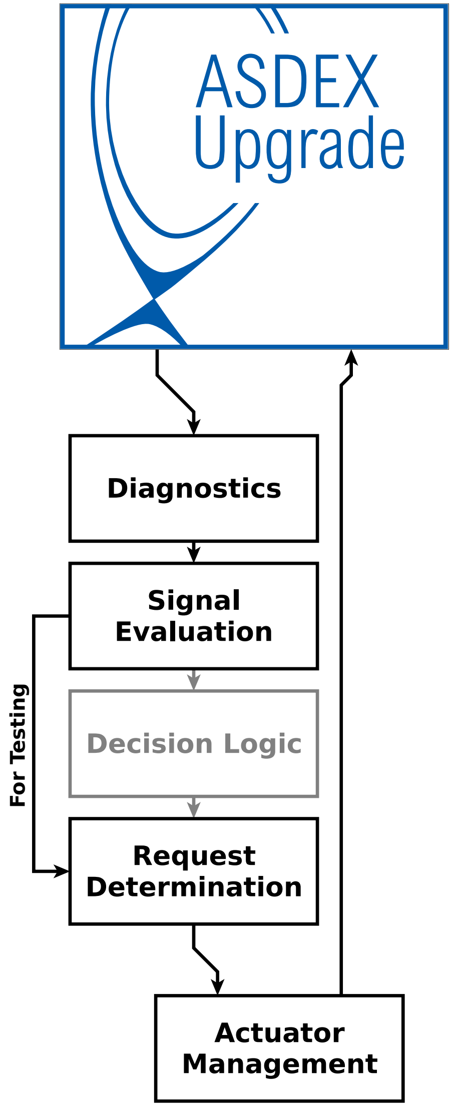
- For testing of a single disruption avoidance scheme the decision logic is not required.

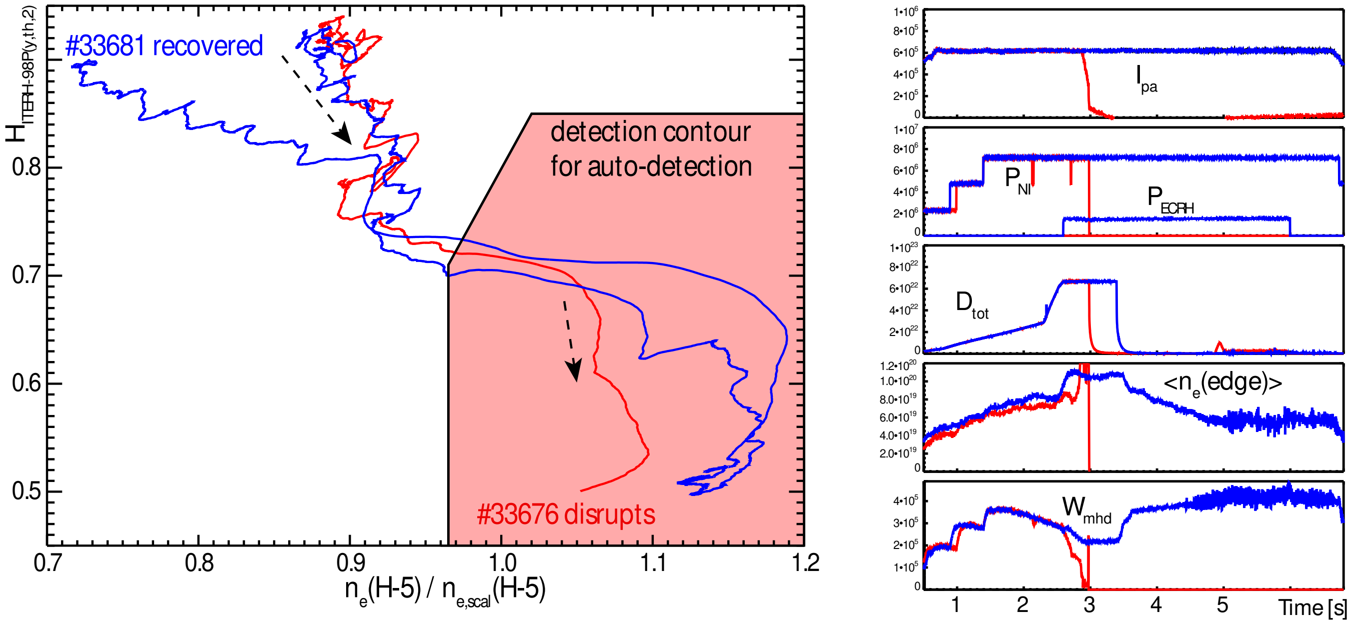


H-Mode Density Limit Disruption

- H-Mode discharges encounter a disruptive state at high densities where the confinement of the discharge is degrading.
- Area of disruptivity defined by an empirical contour in $H_{98,y2}$ and $n_{e,edge}/n_{e,edge,crit}$ diagram.
  - With empirical H-mode density limit, which indicates the start of the H to L transition.

$$n_{e,edge,crit} = 5.06 \cdot 10^{19} P_{tot}^{0.396} \cdot I_p^{0.265} \cdot |q_{95}|^{-0.323}$$

[M.Bernert, PPCF, 2014]

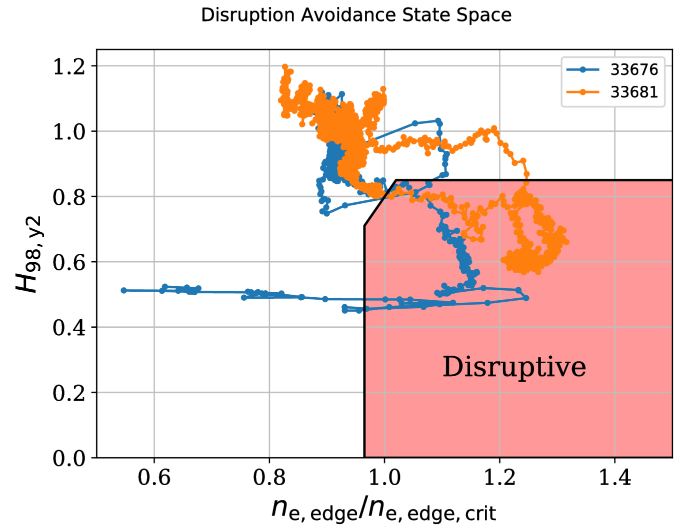


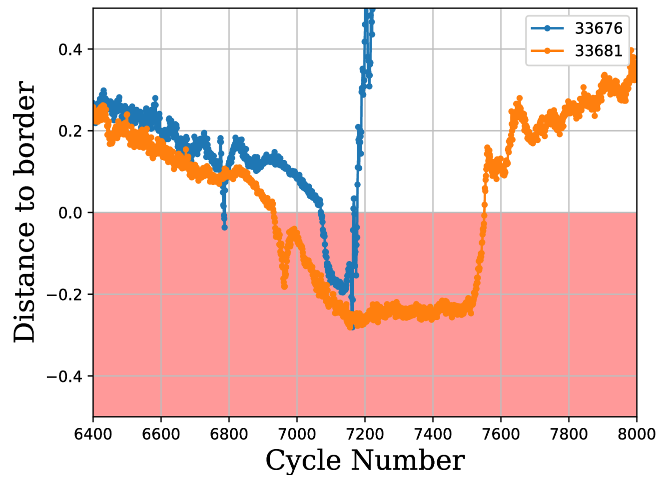
[adapted from,M.Maraschek, PPCF, 2017]

- Identified disruption avoidance scheme:
  - Application of central heating when approaching the disruptive area.

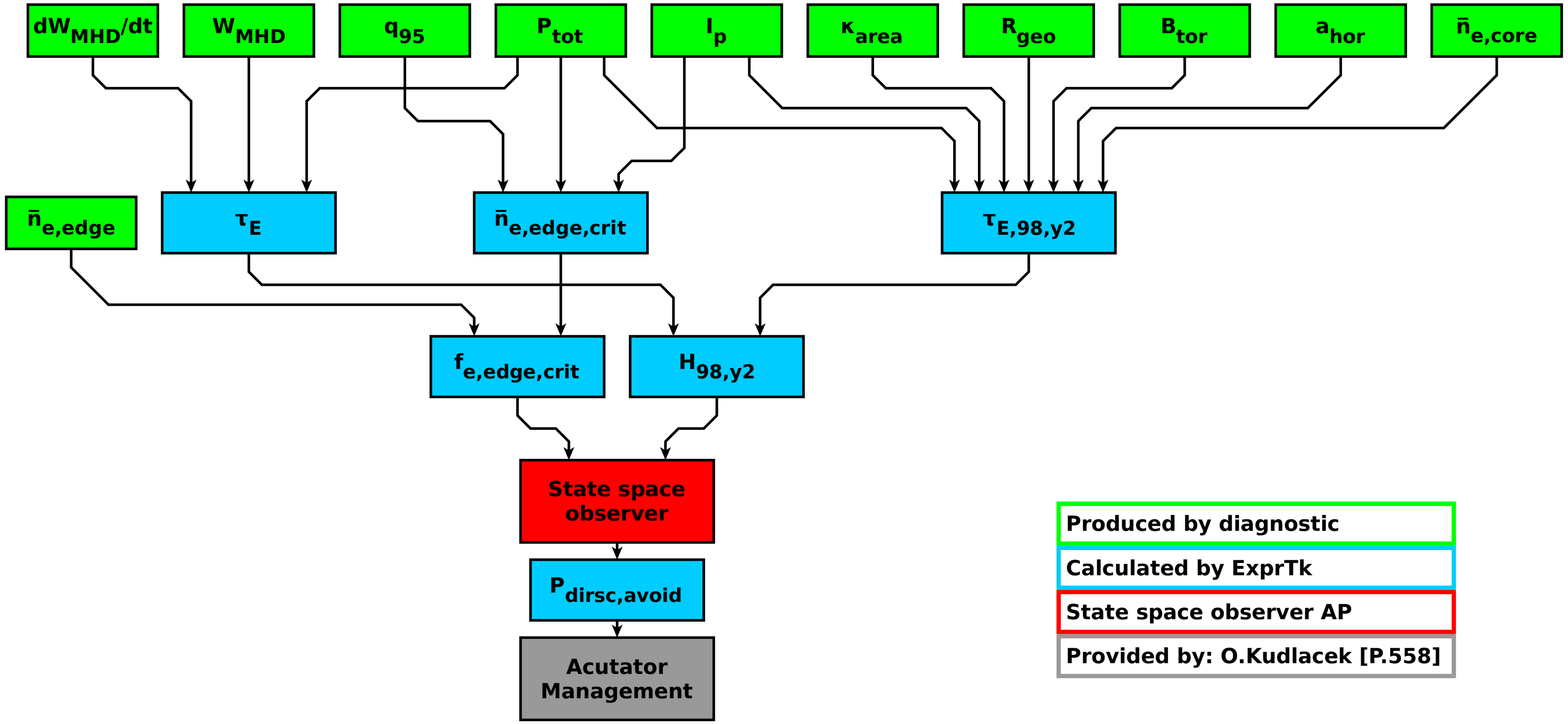
Requirements for avoidance scheme test

- Required signals need to be calculated during the discharge:
  - All required quantities need to be made available to DCS
- Calculation of position in state space needs to be available:
  - DCS AP implemented which calculates the distance to the border of a configurable polygon. (Uses Boost Geometry library.)
    - Distance
      - > 0: Point is outside of polygon
      - < 0: Point is inside of polygon
      - = 0: Point is on the boundary
- Calculated heating power request has to be used as input for the actuator management, which controls the heating systems. [O.Kudlacek, P.558]



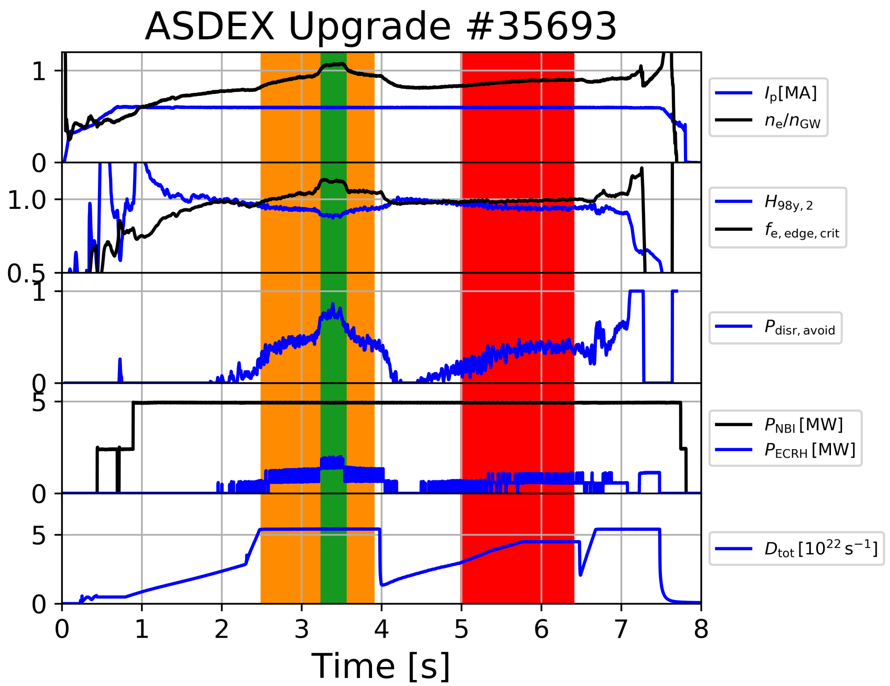


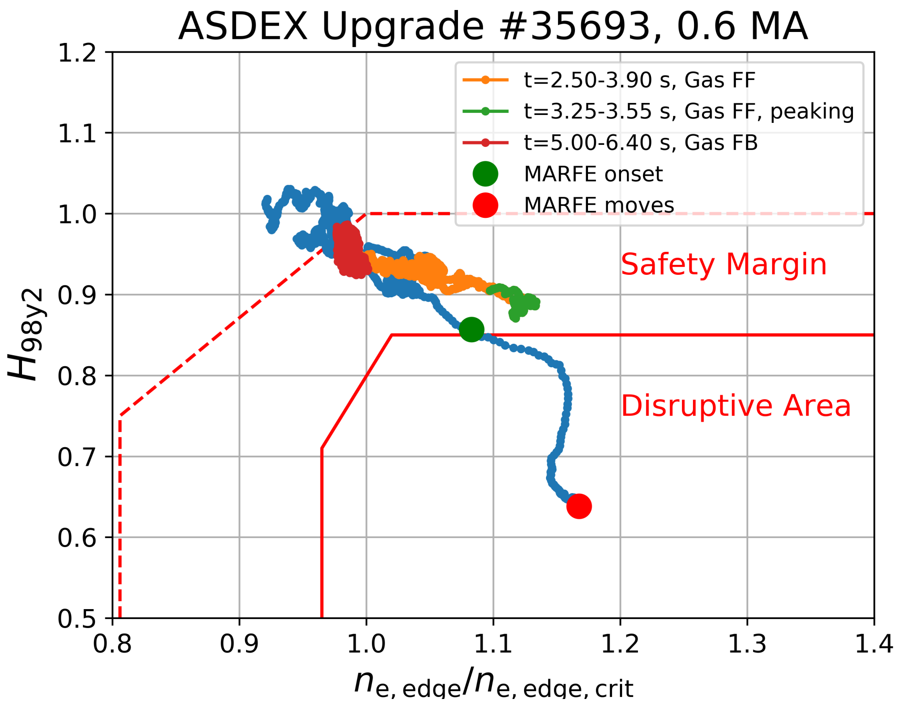
Signal Dependencies for H-Mode density limit



- Required signals have been defined and are included into the DCS calculation.
- State space observer calculates the distance to the disruptive area.
- Actuator management realises the desired heating power request.

Closed loop example





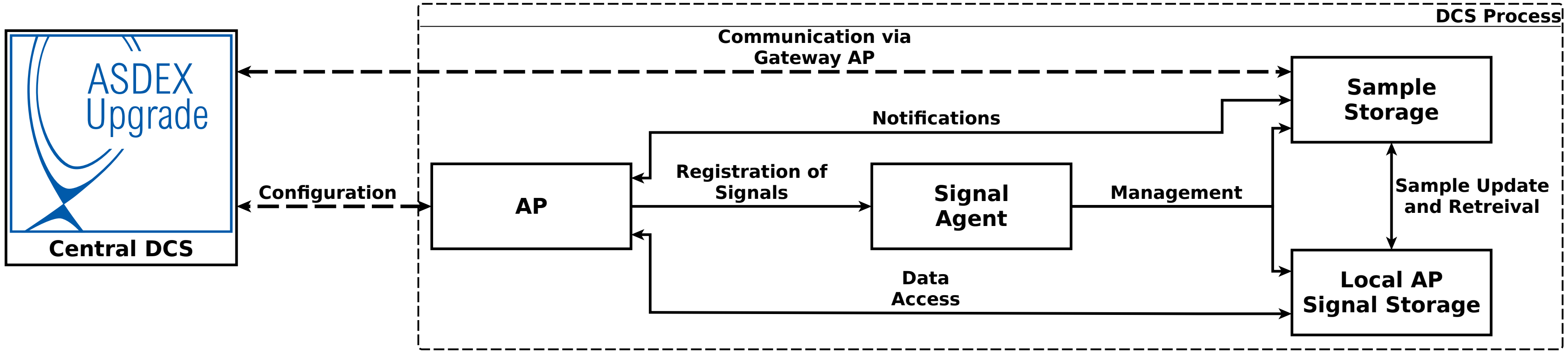
- Used real time calculated disruption avoidance heating power as input for ECRH heating, controlled via actuator management.
- Controlled gas puff is applied which would lead to a disruption if no action is taken.
- Control scheme is able to stabilise the discharge. Disruption only after planed ECRH switch off.

Summary

- A simple and fast way to include new signals into DCS is implemented.
- The signal evaluation is implemented for the H-Mode density limit disruption avoidance.
- Successfull application of the disruption avoidance control scheme has been demonstrated using the new tools.
- Further control schemes will be tested in the future. Validated control schemes are foreseen to be made available to e.g. exception handling.

Backup Slides

Signals within DCS



- Signals are registered before the real time phase.
- During the real time phase the storage location of each signal does not change.
- DCS is handling the update and notification of the signals.
- ExprTk is configured before the real time phase, using the known storage locations of the local process.
- During runtime the evaluation is triggered by DCS once the required signals are available and the result made available for other tasks after the evalution is complete.