Plugging Physics into the W7-X CoDaC Framework
Integrated Software Stack for the Continuous Operation of Wendelstein 7-X

Anett Spring
Wendelstein 7-X CoDaC Software Development Group

Max-Planck-Institut für Plasmaphysik
Greifswald, Germany
Motivation

Wendelstein 7-X
- built to investigate the steady state qualification of a stellarator

W7-X Control and Data Acquisition System
- designed for continuous operation
- and ambitious long running physics experiment programs

Reliably controlled Experiment Programs with duration > 10min during W7-X first operation phase
Prepare and control long running programs

... requires

► assistance for pre-checked experiment planning
► feed back control and event handling for physics driven experiment scheduling
► continuous monitoring of pre-analyzed data

... means to integrate physics knowledge into preparation, control, and monitoring of experiment programs
Plug physics into the experiment planning, control, and monitoring workflow:

1. Physics assisted experiment planning
   - High Level Parameters
   - Component Models

2. Physics driven experiment scheduling
   - Feedback Control
   - Event Handling

3. Physics data live monitoring
   - Online Data Analysis

Physics plug-ins

preparation

control

monitor
Plug physics into the experiment planning, control, and monitoring workflow:

1. Physics assisted experiment planning
   - High Level Parameters
   - Component Models

2. Physics driven experiment scheduling
   - Feedback Control
   - Event Handling

3. Physics data live monitoring
   - Online Data Analysis

Physics plug-ins

preparation

control

monitor
1. Physics assisted experiment program planning

**High Level Parameters (HLP)**

**Objective:** coping with a vast number of technical parameters for configuring W7-X experiment programs

**Concept: parameter abstraction**

- High Level Parameters (on physics abstraction level)
- **Technical parameters**
  - **Physics transformation functions:** mapping, scaling, combining, physics models...
  - **Plug-in** transformation functions: \( f_n(hlp \ldots) \)
Example operative at WEGA (as CoDaC test bed):

- define magnetic field by coils currents (vertices, ramps)

- or by magnetic field properties:
  \( \{B_0, R_{ax}, \iota\} \) or
  \( \{B_0, \text{magnetic shear}, \text{magnetic island positions } r_{is}\} \)

physics model / function parameterization
Framework to assist set-up of complex experiment programs

- built as **generic framework** + component/diagnostic **specific plug-ins**

“knowledge” about parameter dependencies

... persistent set of rules, functions, models etc

... extendable

3 operative W7-X examples
1. Physics assisted Experiment Program Planning

Component Models: Parameter constraints check

**Objective:** check for reasonable parameter values while editing, even for dependent parameters (where limits are not static)

Evaluate rules and dependency functions ➔ for live computation of effective allowed values

- e.g. possible ECRH gyrotron power ranges ➔ depend on technical limits and gyrotron properties:

```
Double limit = upperLimit( uAccValue, gyrotron.getUAccOffset(), gyrotron.getLinScaling() );
```
**Objective**: see what you get …

Configure (single, compound, derived …) parameters to preview

→ plot preview curves over time

**e.g. plot single / total ECRH gyrotron power:**

```java
public XCurve totalPower( XCurve... power ) {
    XCurve total = new XCurve(Interpolation.LINEAR);
    for (XCurve p : power) {
        total = total.add((XCurve) p);
    }
    return total;
}
```
**Objective:** categorizing experiment programs while editing – to assist session planning

Implement parameter evaluation functions

$\Rightarrow$ summarizing prominent experiment program properties

- e.g. automatic experiment program tags:

```java
public Number value(attribute);
public Number maxValue(attribute);
public Number minValue(attribute);
public boolean valueExists(attribute);
... other evaluation functions ...
```
Plug physics into the experiment planning, control, and monitoring workflow:

1. Physics assisted experiment planning
   - High Level Parameters
   - Component Models

2. Physics driven experiment scheduling
   - Feedback Control
   - Event Handling

3. Physics data live monitoring
   - Online Data Analysis
2. Physics driven experiment scheduling

Feedback Control

Physics values in feedback control
e.g. plasma density control
with line-integrated electron density as reference

controller parameters from physics models: particle exchange, recycling, refill efficiency ...

→ research task in next W7-X operation phase
**Objective**: schedule experiment programs dependent on (expected) physics events

**Example**: Over dense heating by mode conversion.

(while investigating ECR heating regimes at WEGA test bed)

**Bernstein mode occurs**

above a certain plasma density

microwave stray radiation drops

---

**Expected event**

**Physics model**

**Plug-in**

**configure event conditions**

= define density and Sniffer signal thresholds

**configure event reaction**

= define heating regime

**Plug-in**

**detect event**

= measure, combine signals and check conditions

**runtime**

**handle event**

= switch to new heating regime
2. Physics driven experiment scheduling

Event Handling Example: OXB transition detection at WEGA

configure event conditions

- Operation mode of 6kW-Magnetron
- Operation mode of 20kW-Magnetron
- 20kW-Magnetron Ramp duration
- 20kW-Magnetron Ramp final value
- Operation mode of 28-GHz Gyrotron
- High Voltage
- Gyrotron HV time nodes
- Gyrotron HV nodes
- Gyrotron magnet time nodes
- Gyrotron magnet nodes

configure event reaction

- WEGA segment duration
- Segment duration
- Stop with error after
- Minimum segment duration
- Stop additional heating after
- Reentry point of WEGA shot?

Event in Bernstein mode

- Window size of online median filter of sniffer probe signal
- Density threshold for OXB transition
- Threshold of a relative decrease of the sniffer probe

Stop segment after OXB Transition

Anett Spring, W7-X CoDaC - 11th IAEA TM on Control, Data Acquisition and Remote Participation, Greifswald 2017
2. Physics driven experiment scheduling
Event Handling Example: OXB transition detection at WEGA

At WEGA, density rises with power

detect event

μWave stray radiation drops in Bernstein wave heating scenario

Combined signal by stray radiation and density

handle event

Segment switch by Plasma state

Magnetron + Gyrotron heating

Gyrotron heating, central deposition only
Plug physics into the experiment planning, control, and monitoring workflow:

1. Physics assisted experiment planning
   - High Level Parameters
   - Component Models

2. Physics driven experiment scheduling
   - Feedback Control
   - Event Handling

3. Physics data live monitoring
   - Online Data Analysis
Objective: live status evaluation at experiment runtime

Framework for continuous processing of experiment live data

Plug in specific analysis functions
- optimized for performance
  e.g. scaling, calibrating, sub-sampling, table lookup ...
- cascadable
- multiple sources
3. Physics data live monitoring

Online data analysis

Physicists have to provide analysis function

```java
interface Function {
    void setParameters(Map<String, ?> parameters);
    Signal process(Signal... signals);
}
```

Plug-in

- set parameters,
- continuously process signals in chunks

Examples:
- ECRH total power → interpolated signal summation
- ECE → electron temperature profiles
- planned: Thomson scattering profiles, diamagnetic energy ...

Intention: offline usage for analysis code verification
- on basis of archived signals

```java
interface Function {
    void setParameters(Map<String, ?> parameters);
    Signal process(Signal... signals);
}
```
Acknowledgement: This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Plug physics into the experiment planning, control, and monitoring workflow

Physics models, component specific rules, analysis functions ...

Framework with plug-ins:
Upgradeable with more knowledge about the machine and with more physics experience at W7-X:
- new rules / dependencies to be defined
- new generators / views to be implemented
- new events to be defined
- new online analysis functions to be implemented

✔ Successfully in operation for program preparation and monitoring.
✔ Controlling by physics events successfully tested → to be established at W7-X with more challenging physics programs.