The Fenix flight simulator as a component of the power plant model for DEMO

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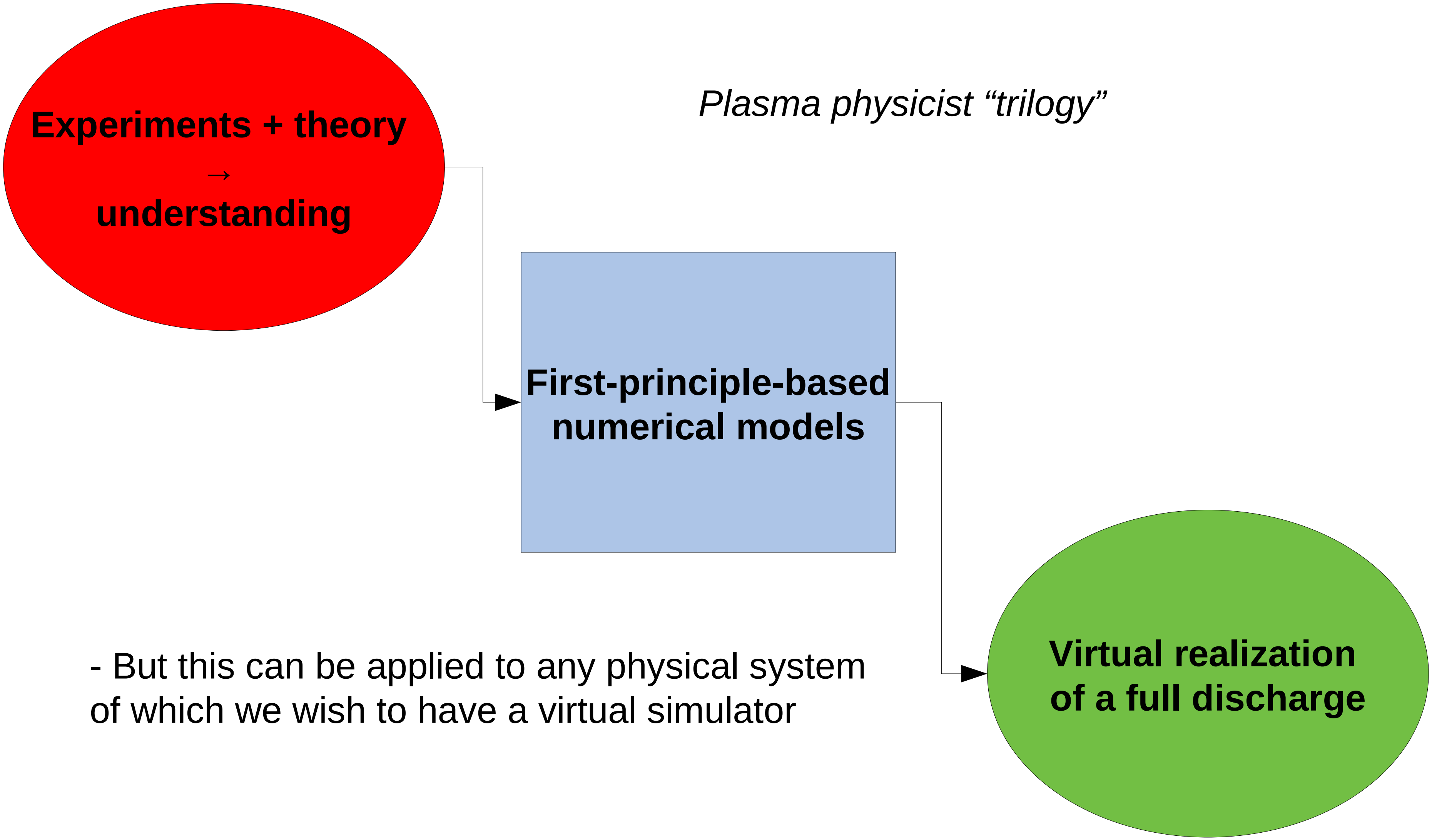
Virtual simulators for fusion

Plasma physicist “trilogy”



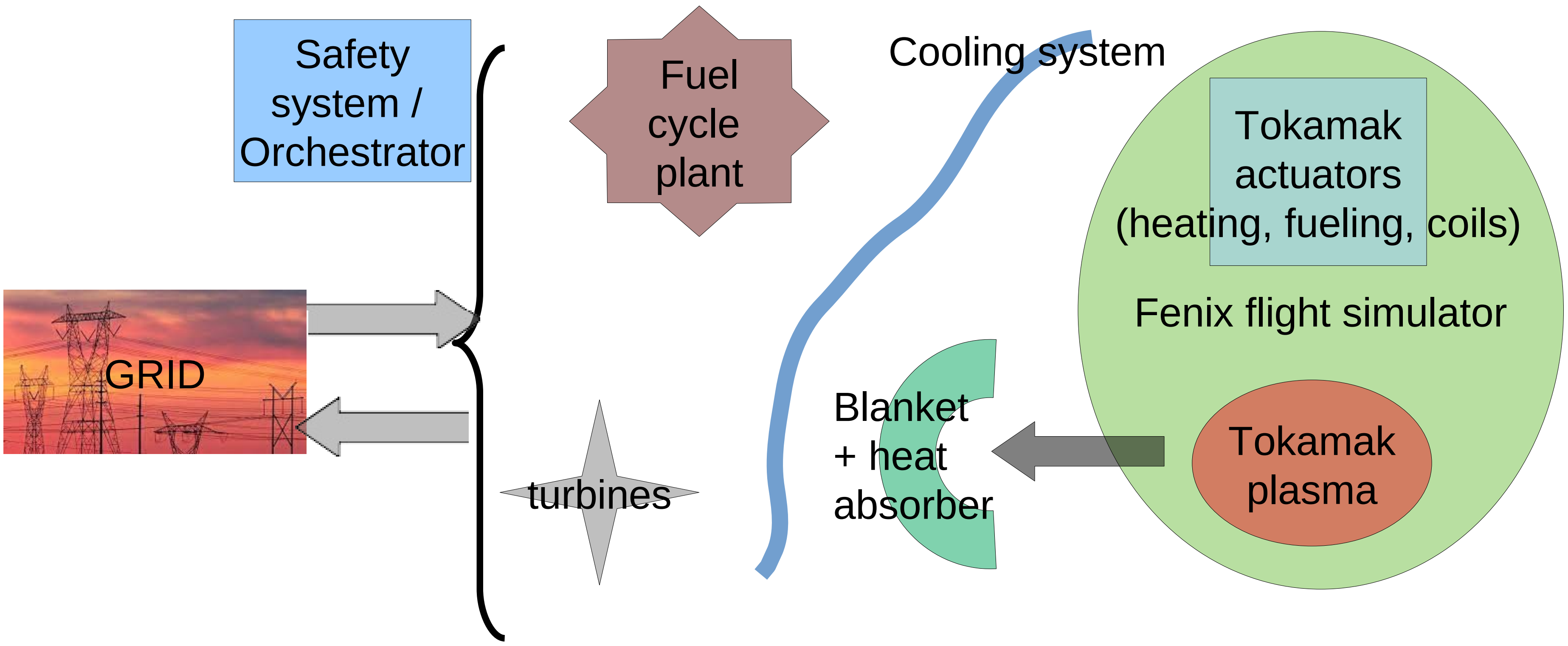
- But this can be applied to any physical system of which we wish to have a virtual simulator

Plant simulator scope

- Larger scope than just a discharge simulator
- Gives OK or NOT to operation, depending on the set-up (input schedule)
- Allows to explore every output trajectory of interest to check for behavior
- Automatic detection of anomalies (trajectories too close to limits, in an unwanted way), crossing of operational or physics limits that could lead to a catastrophic termination of the operation
- Variation of sub-schedule(s): check for impact on resulting sub-system behavior (and eventual impact on related sub-systems)
- Can test virtual operation with added artificial anomalies to check safety/recovery/scram scenarios
- Operator training

Plant elements

- I previously discussed Fenix application to the EU-DEMO transient scenarios
- But how does Fenix enters into the larger scope of a virtual reactor plant?
- Let us have a look first at generic virtual copy of a simplified tokamak-based power plant

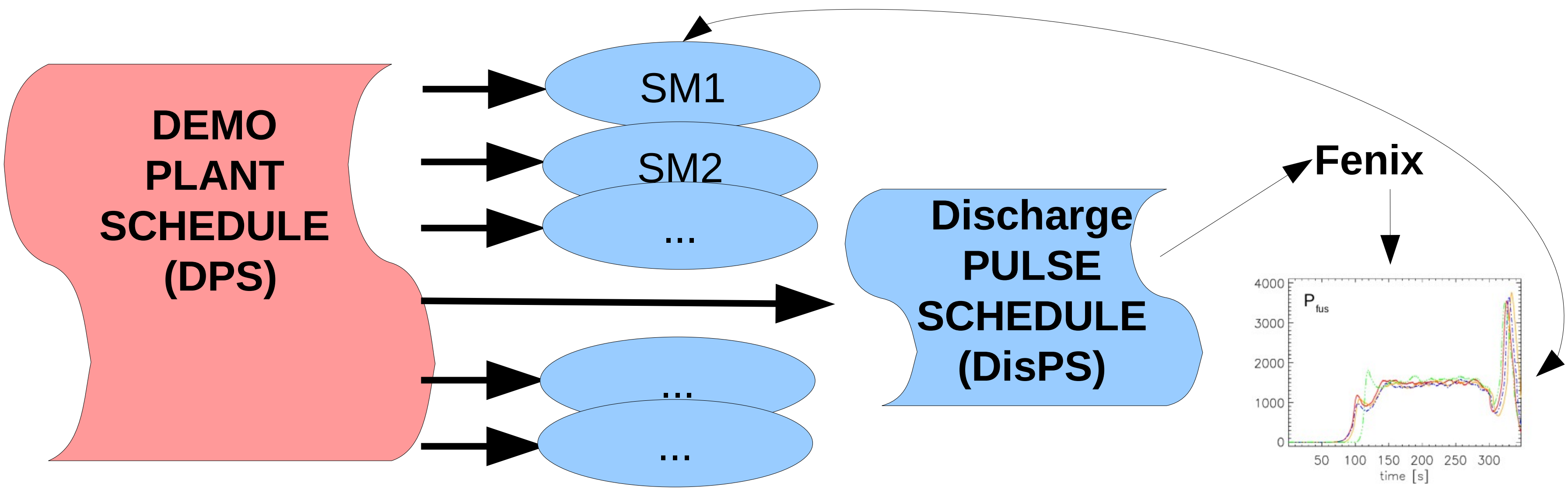


Global vs local pulse schedule(s)

- The plant operation is dictated by a list of actions, reference trajectories, etc.

- The global plant schedule can be thought of as a sum of schedules for the individual elements, where some of the element input are outputs of another element

- This information is needed to inform the surrounding elements on what the needs are to run/sustain the plasma, and inform the operators if the plant trajectories pertaining to the plasma sub-model are correct, operationally speaking

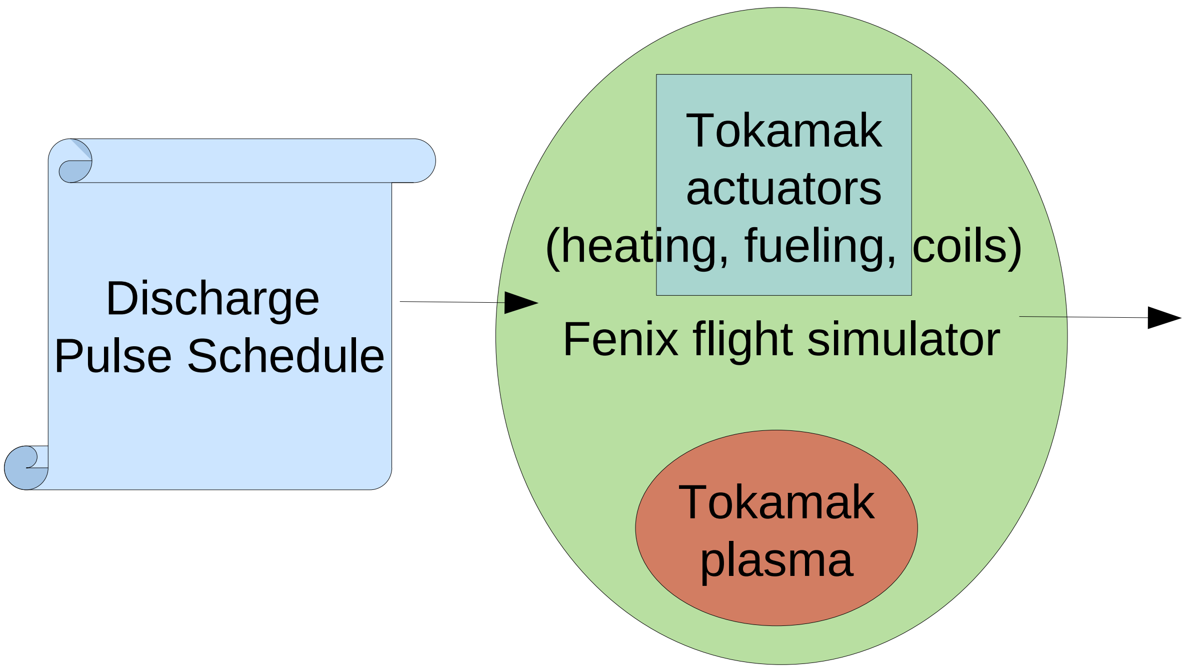


[F. Palermo et al.]

Role of plasma flight simulator

- Fenix I/O in operational terms

Inputs



Outputs

- Actuator requirements:
 * Fuel needed for 1 pulse
 * Electrical power needed to power auxiliary systems like heating, pumps, …
 * Coil currents/forces/ voltages

- Products:
 * Pumped gases not directly recycled
 * Neutron flux to blanket
 * Radiation flux to first wall

- Diagnostics:
 * density, shape, etc...

Tight vs loose time coupling

- Orchestrator (PPSP → Power Plant Simulator Platform):
  - Calls the various sub-models
  - Orchestrates I/O exchange and time synchronisation
  - Select sub-models
  - Detects abnormal output trajectories when constraints / goals / input trajectories are specified
- Tight time coupling: 2 (or more) sub-models interact at almost every time step
- Loose time coupling: sub-models exchange data but no dynamics between them
- Some sub-models (SMs) are actually completely decoupled and can be run in parallel without risks.
- Some sub-models wait for the end of another model(s), or have to be run before another model(s)

Available info worldwide

- Not much can be found on fusion power plant simulators
- Some previous attempts at plasma simulators (but Fenix is the first complete one)
- This work:

"An integrated digital framework for the design, build and operation of fusion power plants" Eann A. Patterson, Sally Purdie, Richard J. Taylor, and Chris Waldon, Published:02 October 2019 https://doi.org/10.1098/rsos.181847

seems to me one good attempt at formulating the problem and proposing how to attack it

- JM Kwon et al.: Virtual K-STAR (this conference)

Discussion

- The Orchestrator + Plant Schedule define the work to be shared and performed between the different sub-models

- Tight vs loose dynamical coupling depending on the actual physical interaction of models and the objective of the simulation

- Tight coupling better be done inside the same numerical framework (but loose coupling can rely on a completely different software, as well as the Orchestrator) → doing both requires dynamic interfacing

- Nested models are allowed (and actually make sense. For example Plasma is nested inside the machine plant model, literally) → Fenix is an example of this

- Critical elements of interaction should have the prominence in defining the logic of the coupling (e.g. fusion power defines the chain of events in case it varies in time too much)

Thank you!