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DINA-CH full tokamak simulator

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8 November 2010

Topics

- What are we trying to do with DINA-CH ?
- Experience coupling with CRONOS ?
- Lessons learned throughout ?

- What are the general issues which are likely to be encountered before getting to where we are now ?
- Try to avoid some of the effort traps we encountered
- We will simply walk you through the components of our full tokamak simulator and point out some issues during the guided tour
- In fact, the overall structuring is part of the lessons (being)learned
- We can handle any detailed points another time, if useful to you

Historical review

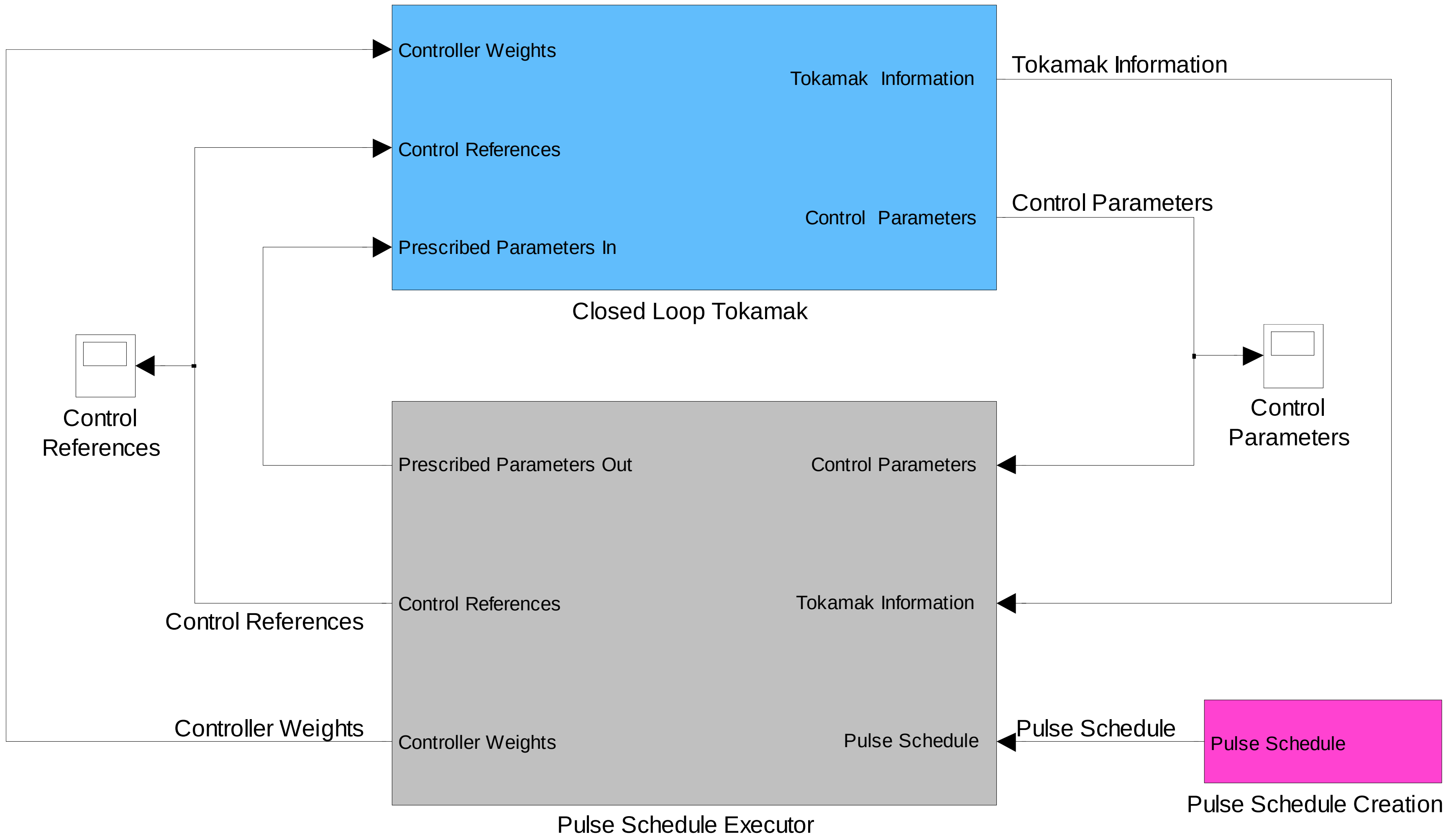
- DINA (1993) was, and still is, a stand-alone FORTRAN solver for heat transport and free-boundary equilibrium evolution
- It is in the class DINA-TSC-CORSICA
- It is a full tokamak simulator, consistent by design

- DINA was validated against TCV PF control experiments under the ITER Expert Group (1998). It was successful but very black-box – controllers, sources, transport all built-in

- DINA-CH (2001) is the “exploded” version of DINA under Simulink, with transport, sources, power supplies, controllers, diagnostics, all external to the solver – just as ITM is targeting
- DINA-CH is being extended to open field-lines for halo-currents

Overview of the full tokamak simulator

DINA-CH : Full Tokamak Simulator Top view of any full tokamak simulator

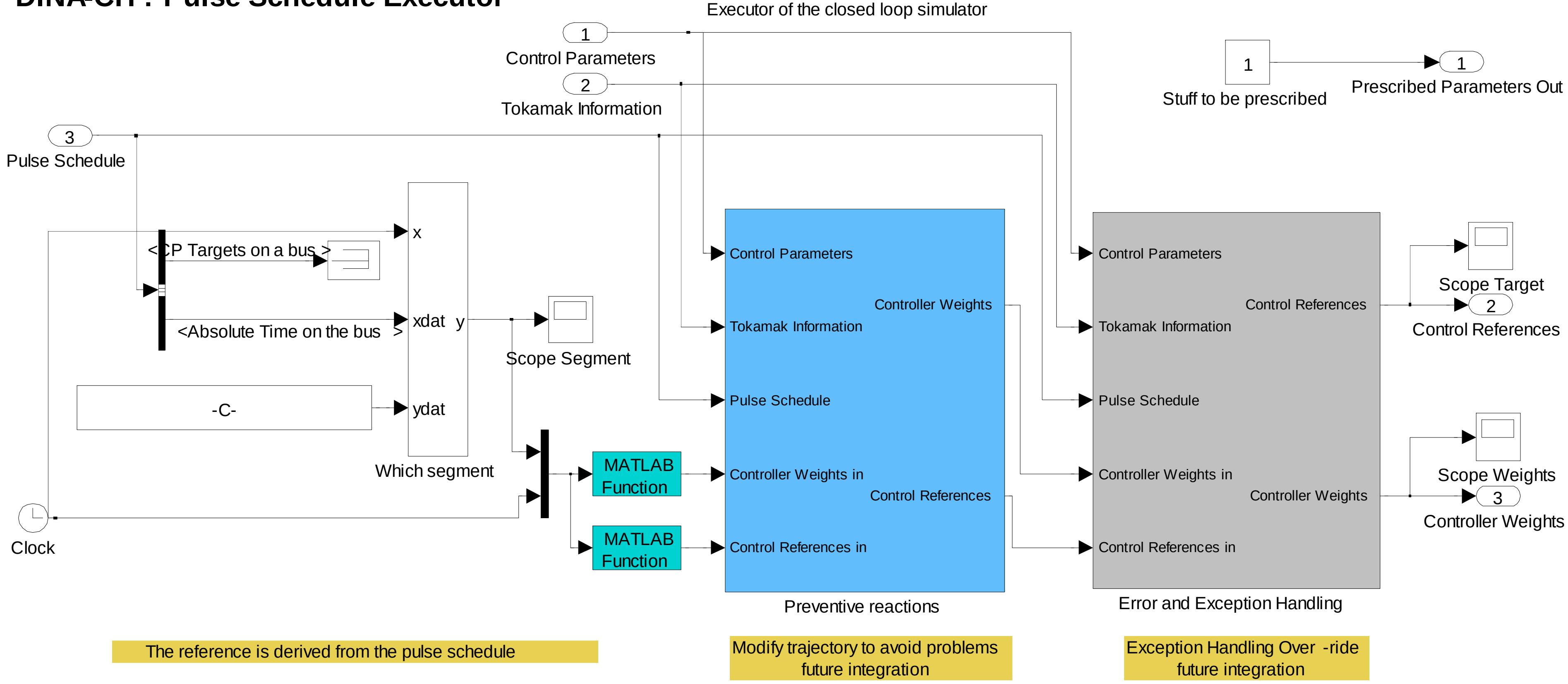


Overview of the full tokamak simulator

- How is the design scenario expressed
  - ITM data structure issue
  - We are currently aiming to adopt an ITER view
- Pulse Schedule Executor takes the design scenario, modifies it if necessary and presents it to the Closed Loop Tokamak Simulator
- The Pulse Schedule Executor creates
  - References (standard)
  - Controller Weights (our design choice today)
  - Prescribed values of any non-evolving physics (e.g. density profiles)

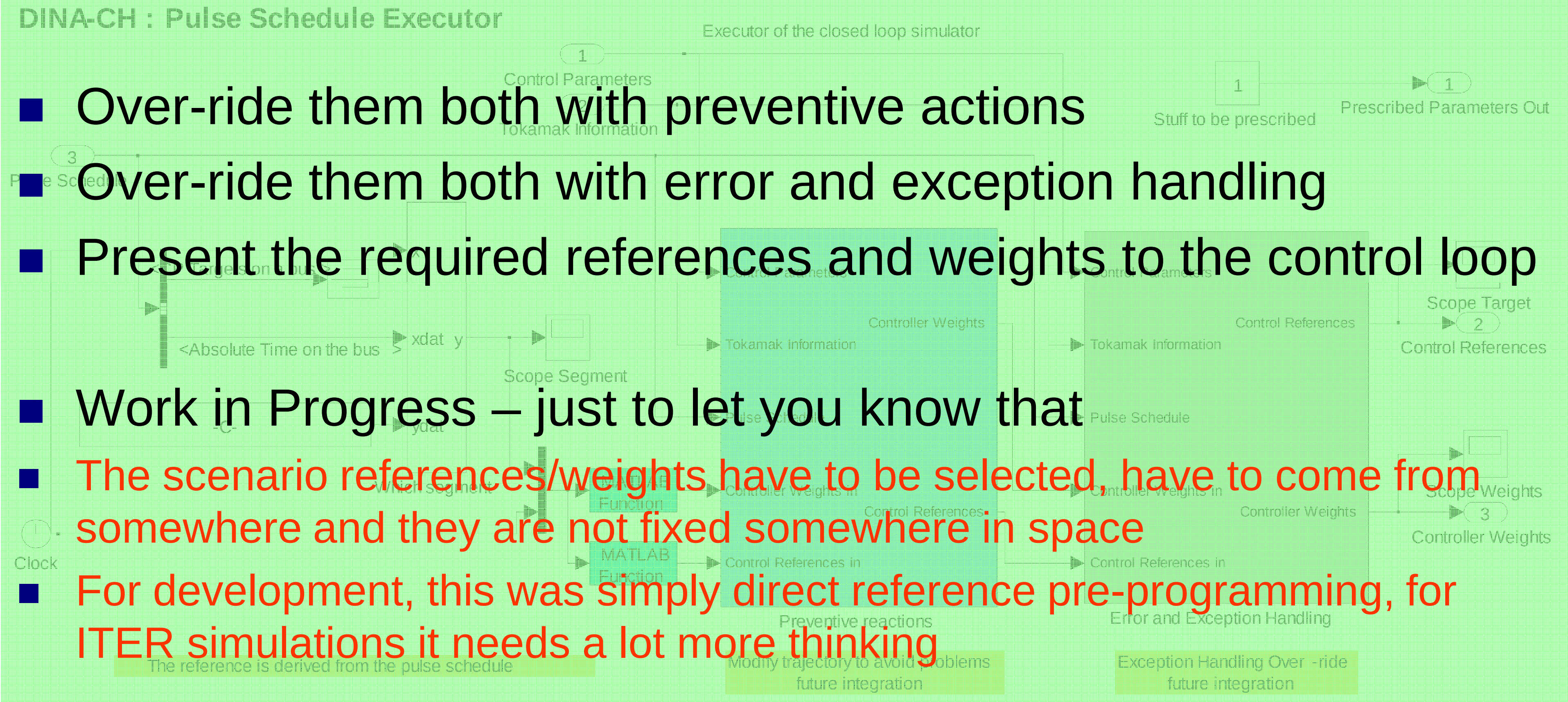
Execute a Pulse Schedule

DINA-CH : Pulse Schedule Executor



Execute a Pulse Schedule

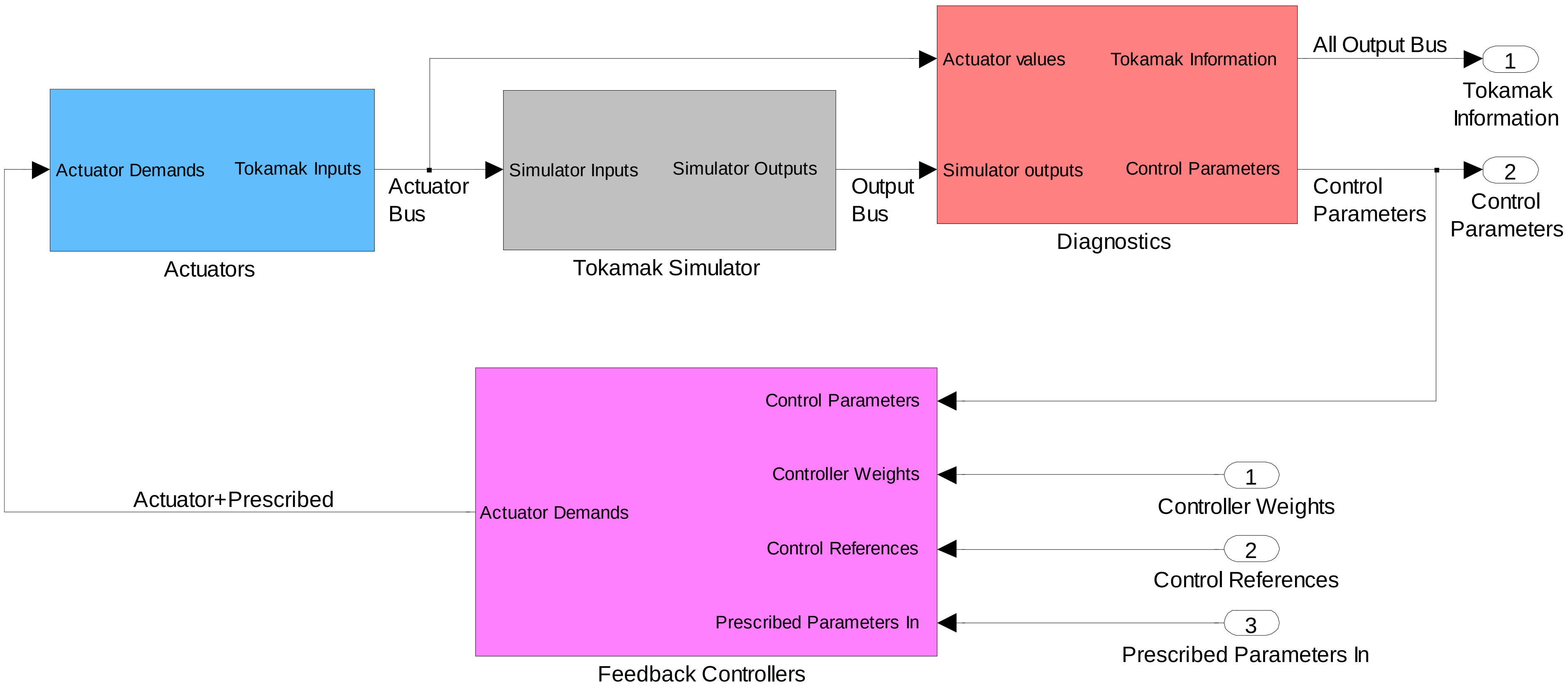
- Take design controller references and design controller weights



- Over-ride them both with preventive actions
- Over-ride them both with error and exception handling
- Present the required references and weights to the control loop
- Work in Progress – just to let you know that
- The scenario references/weights have to be selected, have to come from somewhere and they are not fixed somewhere in space
- For development, this was simply direct reference pre-programming, for ITER simulations it needs a lot more thinking

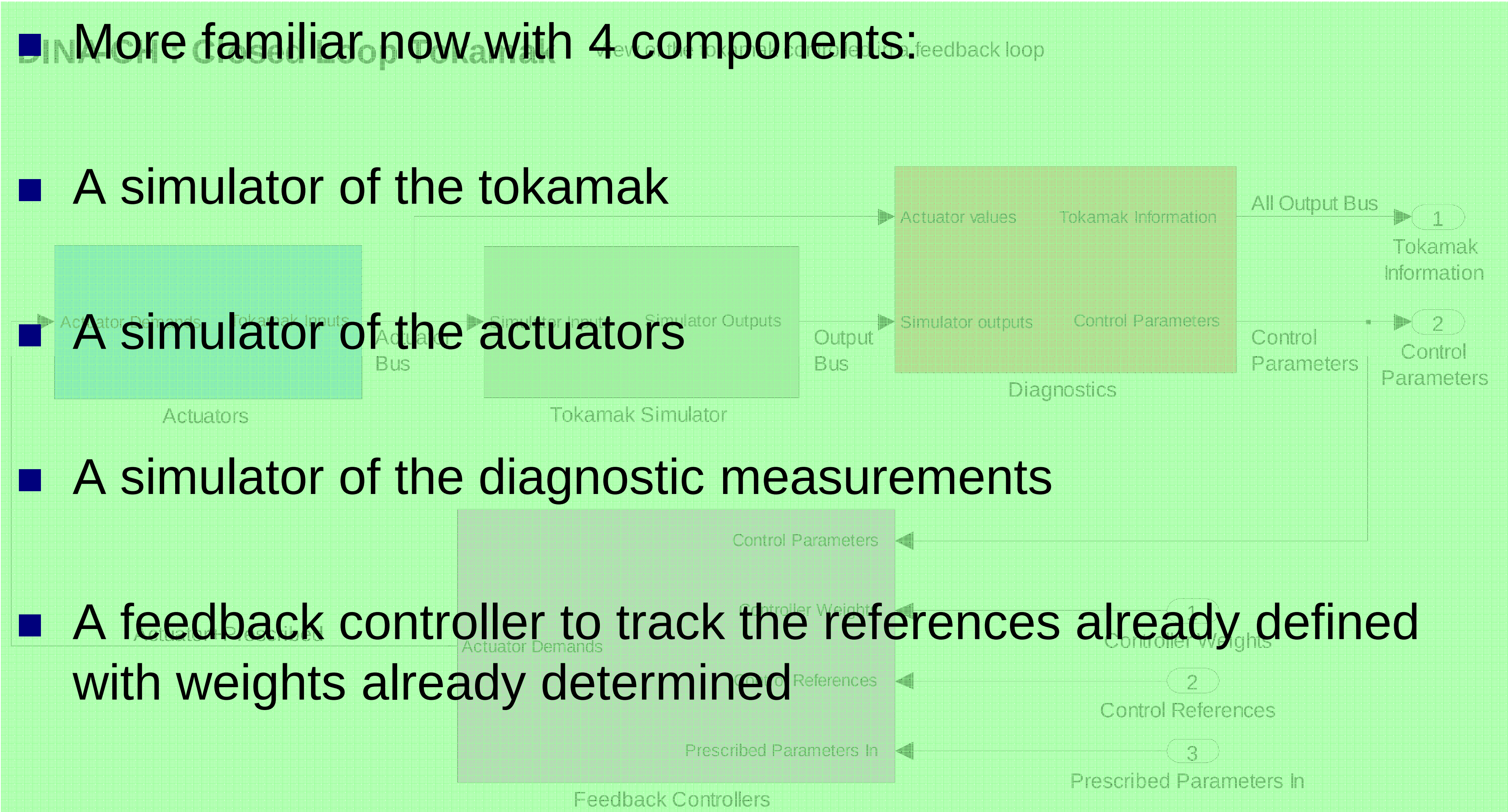
Simulate the Closed Loop

DINA-CH : Closed Loop Tokamak View of the tokamak controlled in a feedback loop



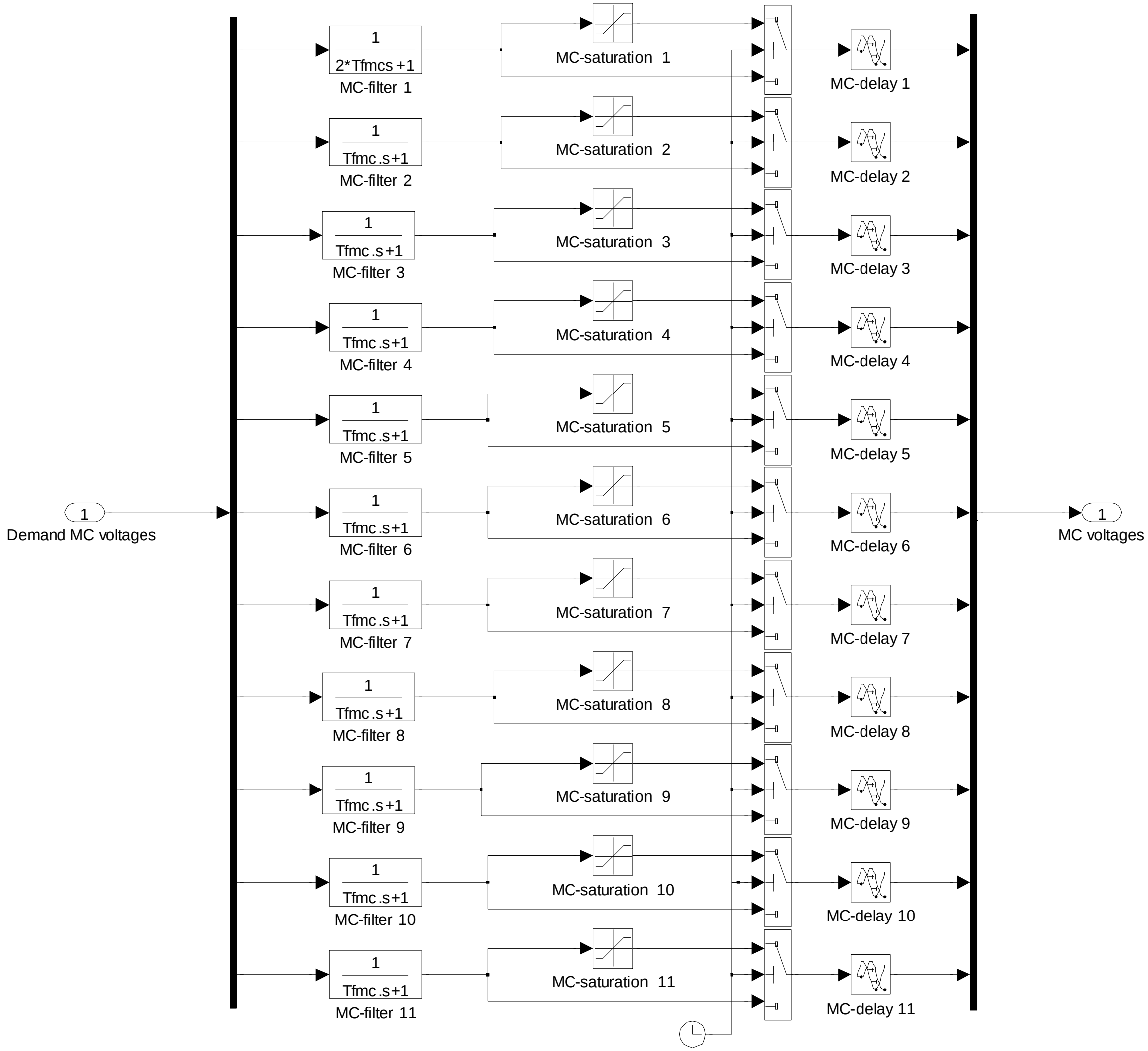
Simulate the Closed Loop

- More familiar now with 4 components:
- A simulator of the tokamak
- A simulator of the actuators
- A simulator of the diagnostic measurements
- A feedback controller to track the references already defined with weights already determined

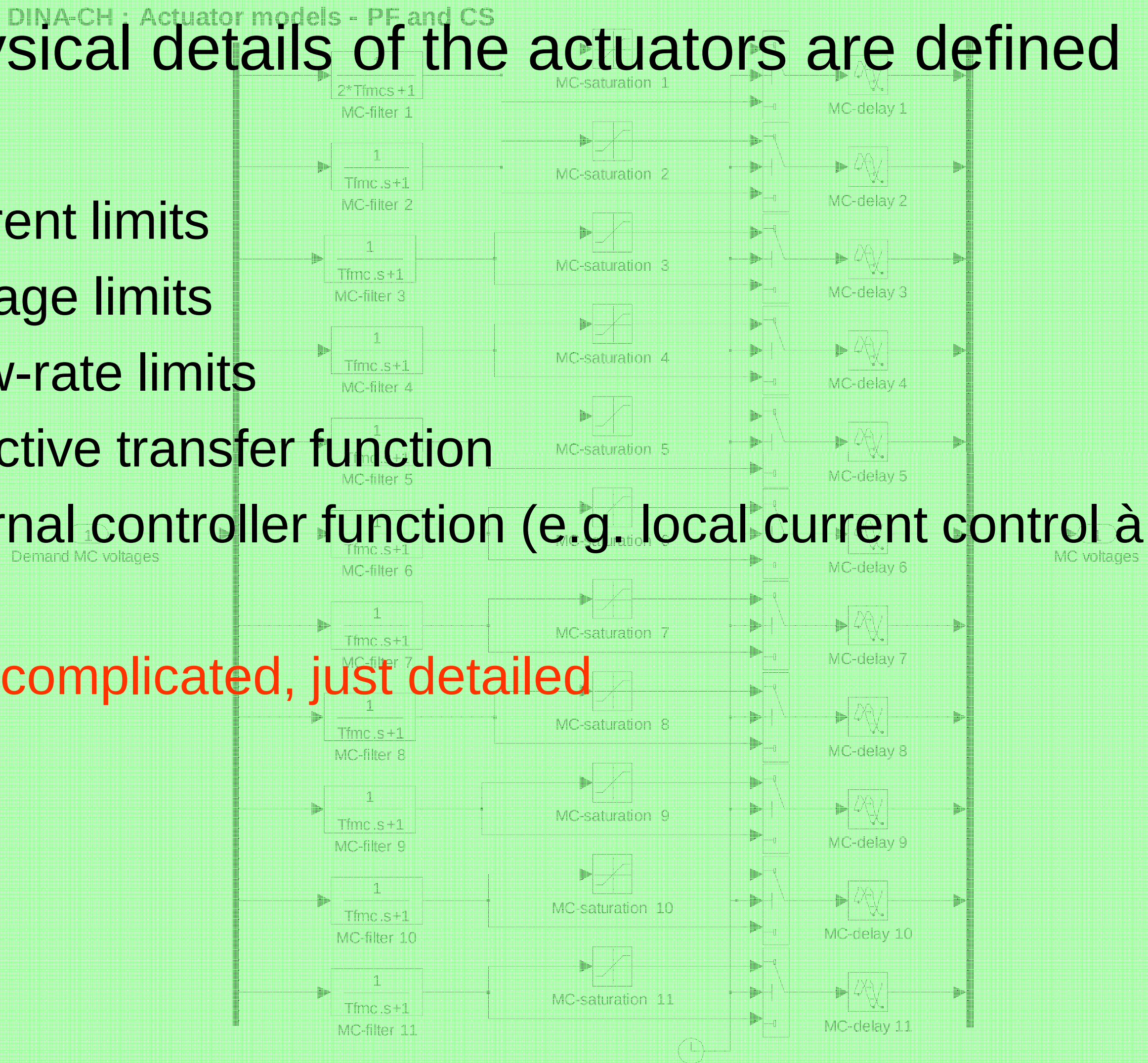


Simulate all the actuators

DINA-CH : Actuator models - PF and CS



Simulate all the actuators

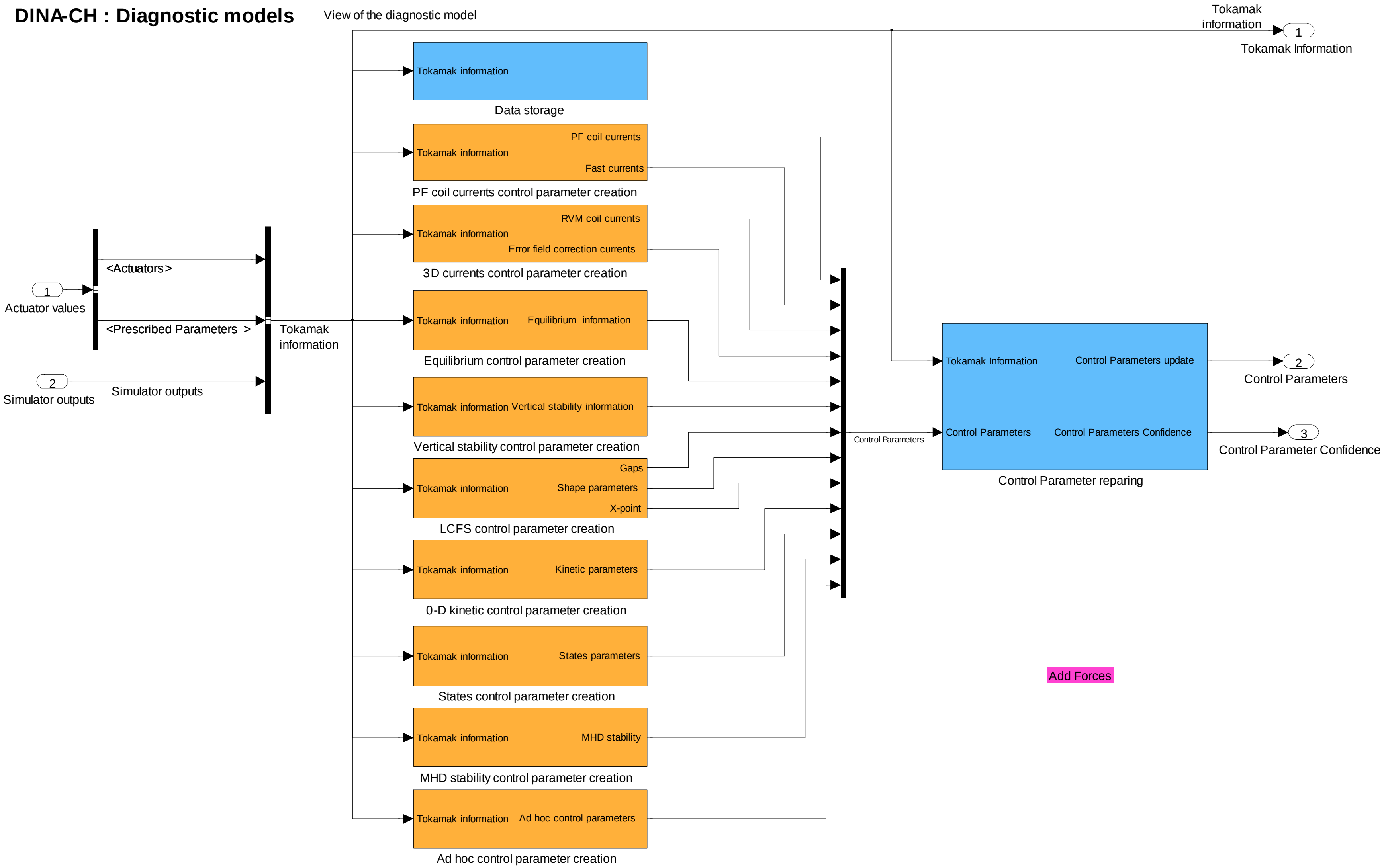


- All physical details of the actuators are defined
  - Current limits
  - Voltage limits
  - Slew-rate limits
  - Effective transfer function
  - Internal controller function (e.g. local current control à la AUG)

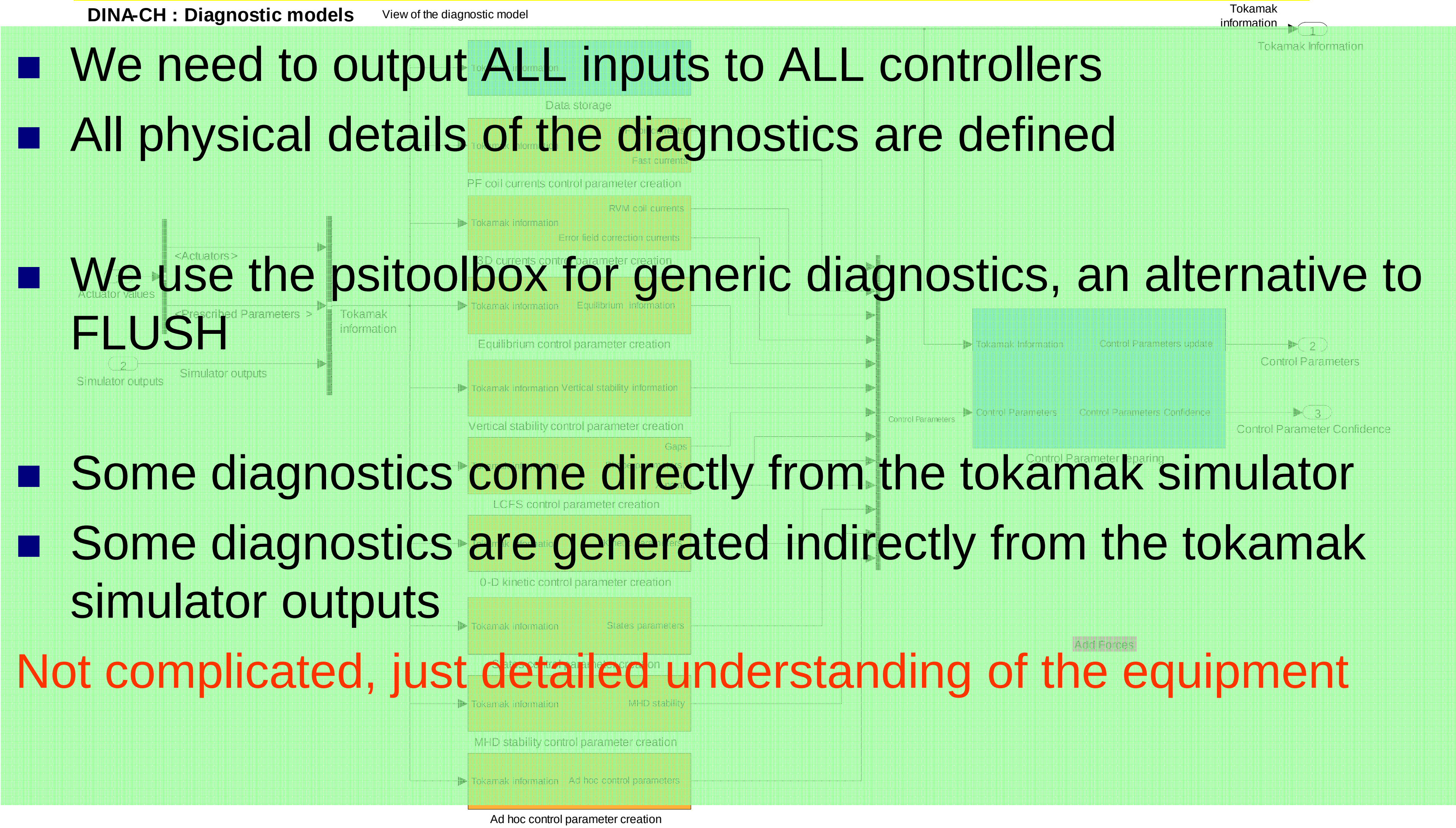
This is not complicated, just detailed

Simulate all the diagnostics

DINA-CH : Diagnostic models



Simulate all the diagnostics

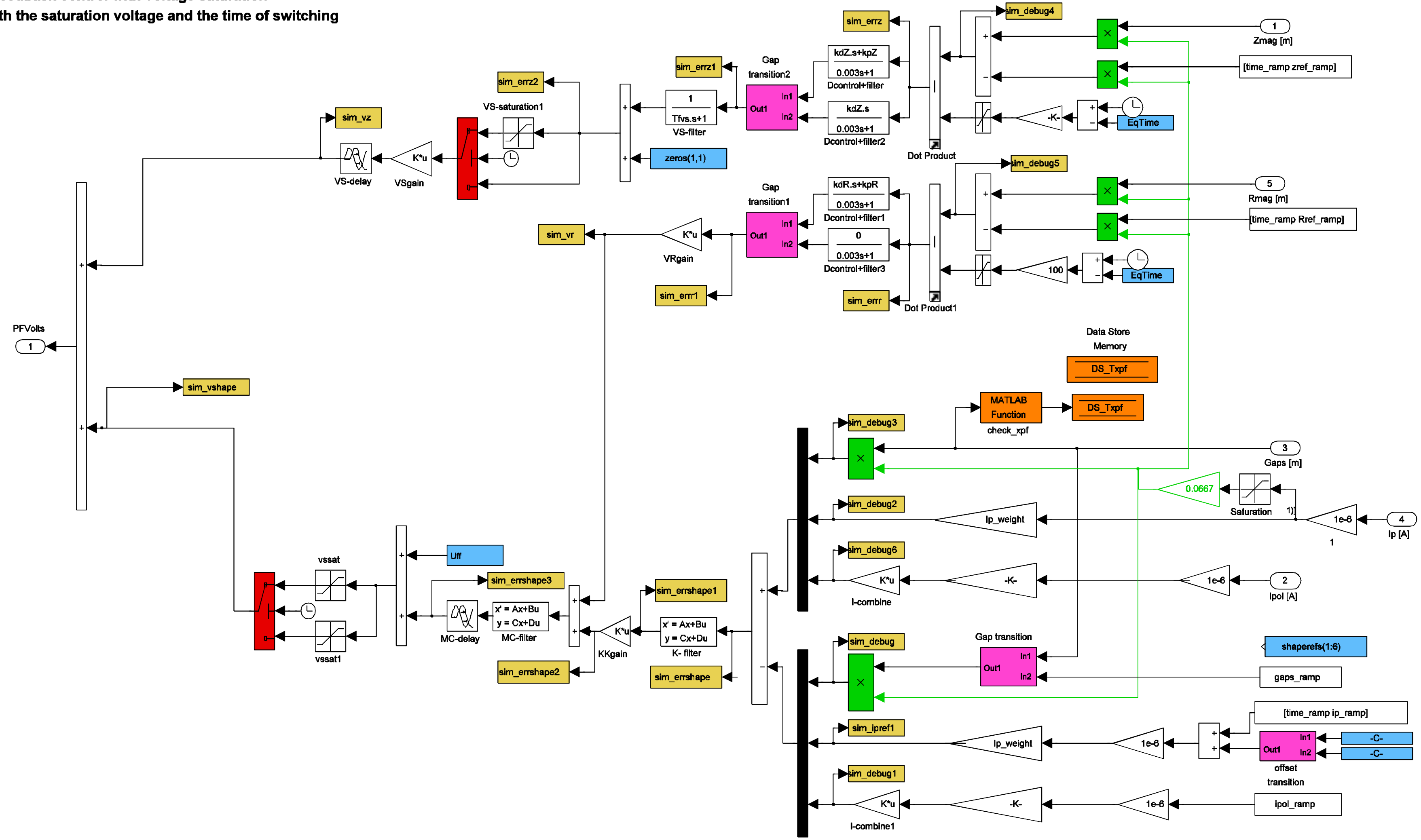


- We need to output ALL inputs to ALL controllers
- All physical details of the diagnostics are defined
- We use the psitoolbox for generic diagnostics, an alternative to FLUSH
- Some diagnostics come directly from the tokamak simulator
- Some diagnostics are generated indirectly from the tokamak simulator outputs

Not complicated, just detailed understanding of the equipment

Simulate all the controllers - 1

Feedback control with voltage saturation
Be careful with the saturation voltage and the time of switching

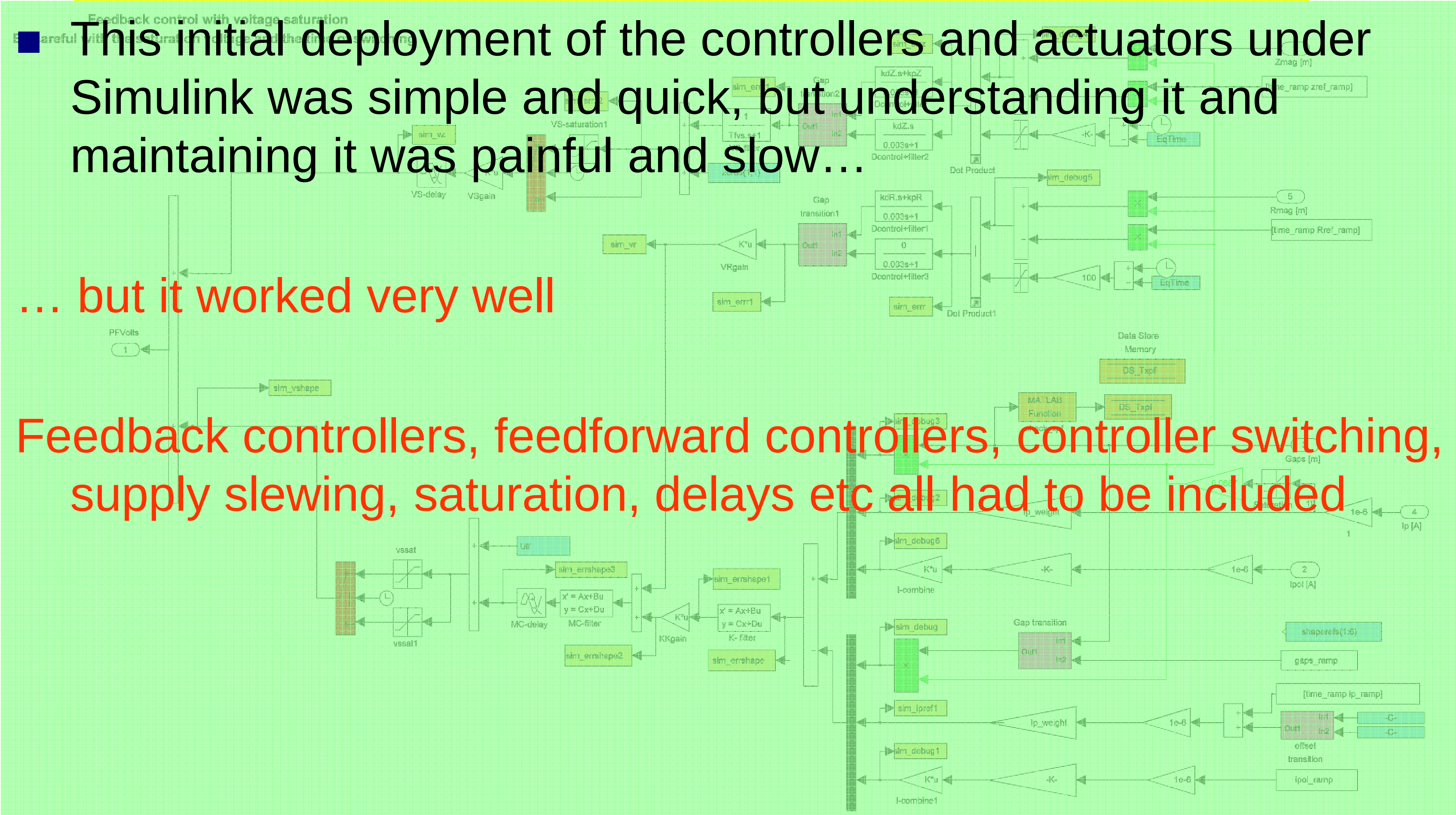


Simulate all the controllers - 1

- This initial deployment of the controllers and actuators under Simulink was simple and quick, but understanding it and maintaining it was painful and slow…

… but it worked very well

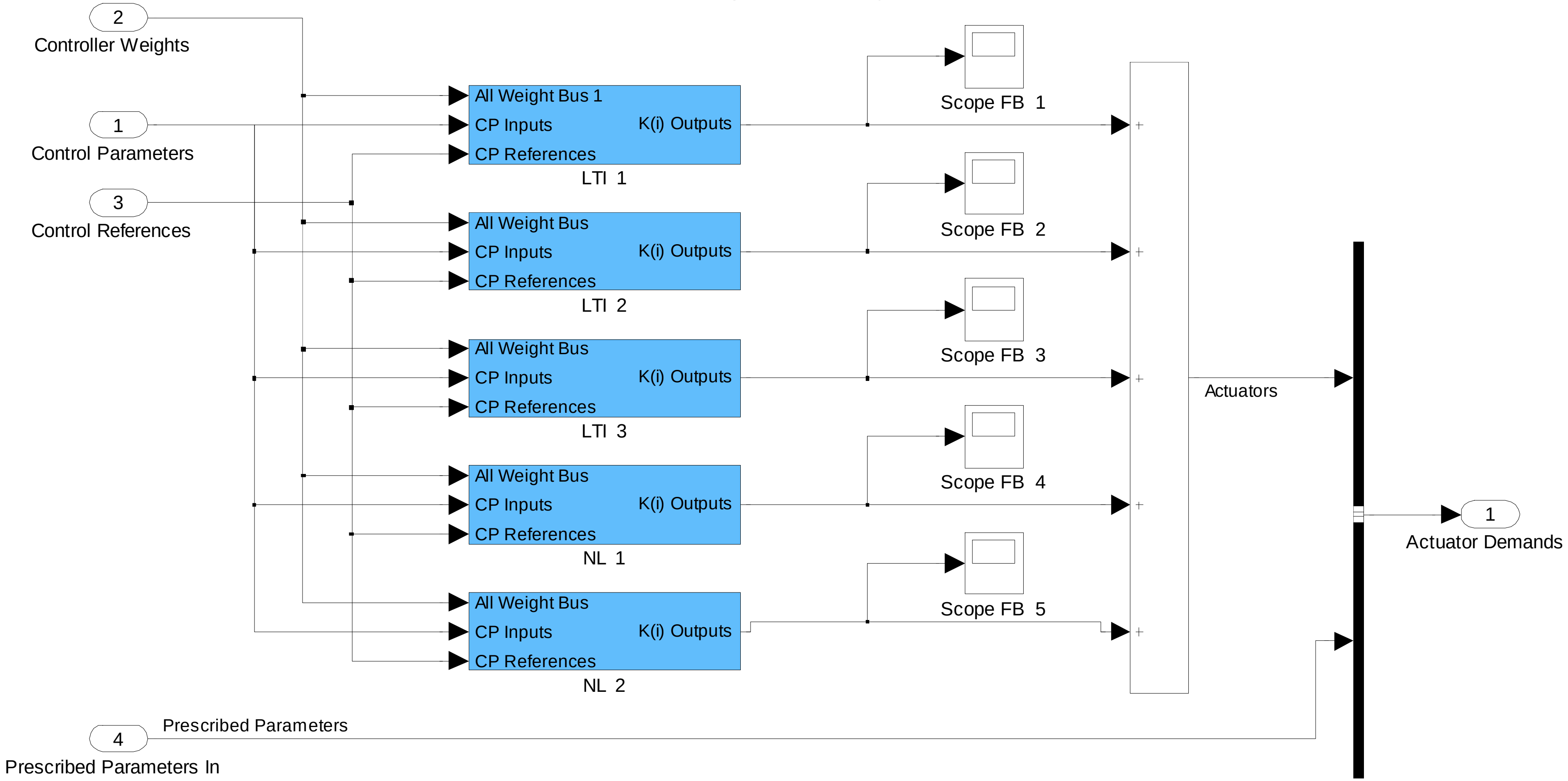
Feedback controllers, feedforward controllers, controller switching, supply slewing, saturation, delays etc all had to be included



Simulate all the controllers - 2

DINA-CH : Feedback Controller set

3 LTI and 2 NL Controllers are all fed with references , current status and a bus of weights
The weights are used for switching controllers
The outputs of all weighted controllers are summed



Simulate all the controllers - 2

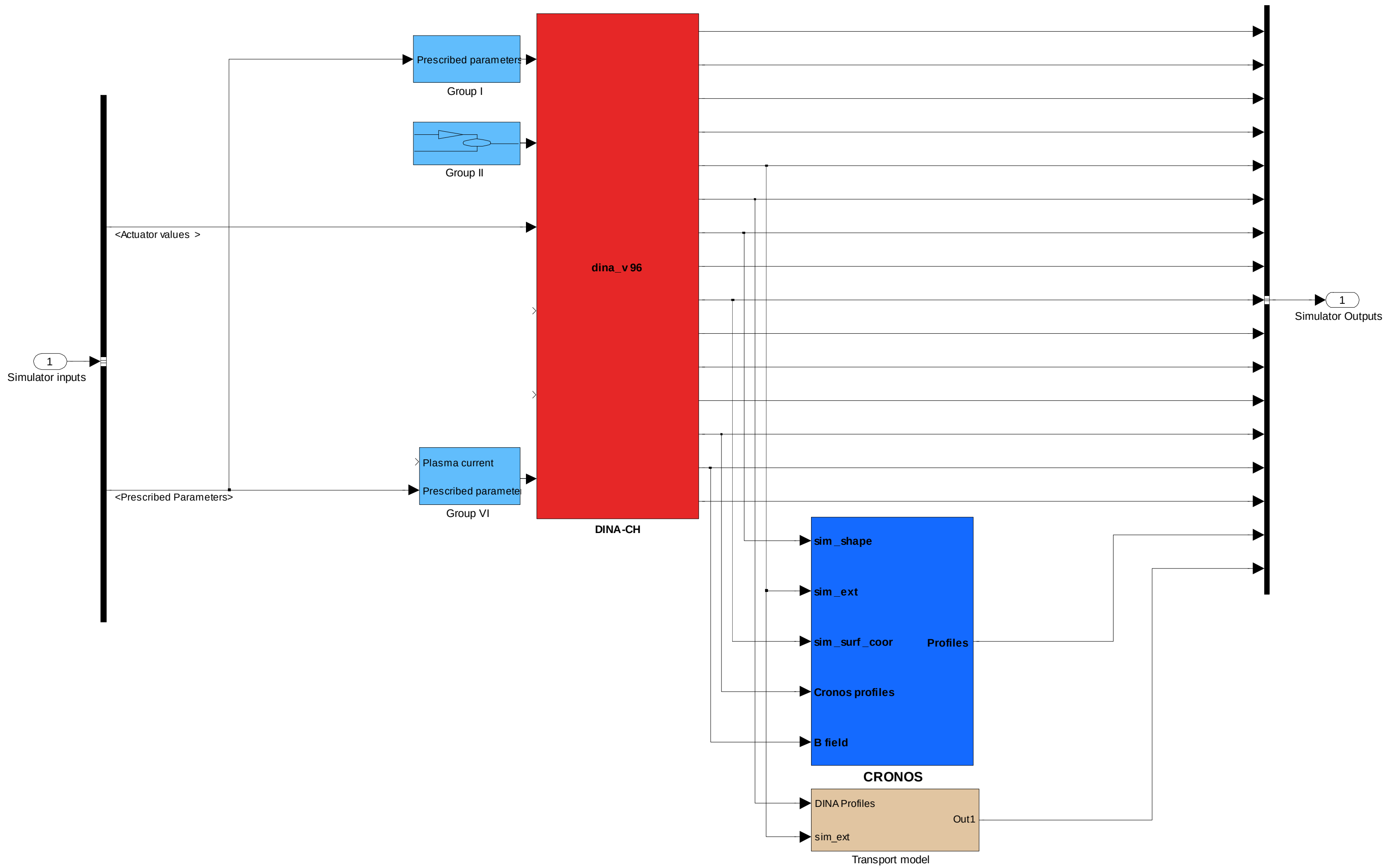
- The re-deployment assumed:
  - Restricted number of F/B and F/F LTI controllers
  - Restricted number of F/B non-linear controllers
  - Externally defined time-dependent weighting of all controllers
- It moves the understanding and all numerical values from the Simulink picture to the LTI Controller creation – easier to maintain
- The Controller is now a big LTI block with its underlying design hidden from the model

Simulate the bare tokamak – the Tokamak Core Solvers

DINA-CH : Full tokamak evolution

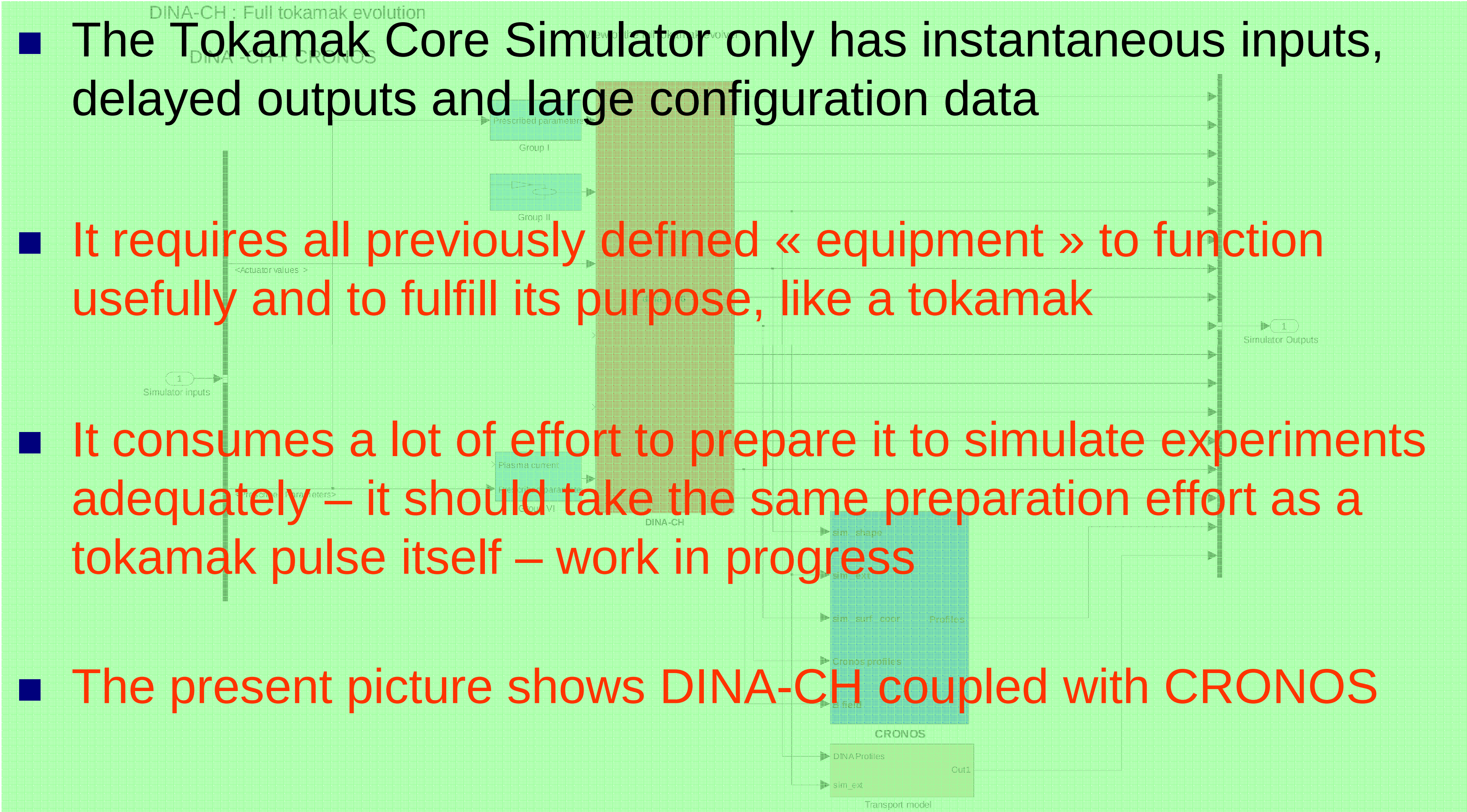
View of the full tokamak evolver

DINA -CH + CRONOS



Simulate the bare tokamak

- The Tokamak Core Simulator only has instantaneous inputs, delayed outputs and large configuration data
- It requires all previously defined « equipment » to function usefully and to fulfill its purpose, like a tokamak
- It consumes a lot of effort to prepare it to simulate experiments adequately – it should take the same preparation effort as a tokamak pulse itself – work in progress
- The present picture shows DINA-CH coupled with CRONOS



What is the solver solving ?

- Electromagnetic equations linking voltages and currents
- Force balance equation linking profiles to vacuum field (GS)
- Deformation and movement of the free-boundary equilibrium creating voltages
- Heat transport equations linking sources and conductivities to temperature changes
- Temperature changes influencing the transport coefficients

So where was the problem ?

- That looked too simple, just create the bits and add the solver
- It was done in 1993, so why is it still a challenge ?

Convergence difficulty

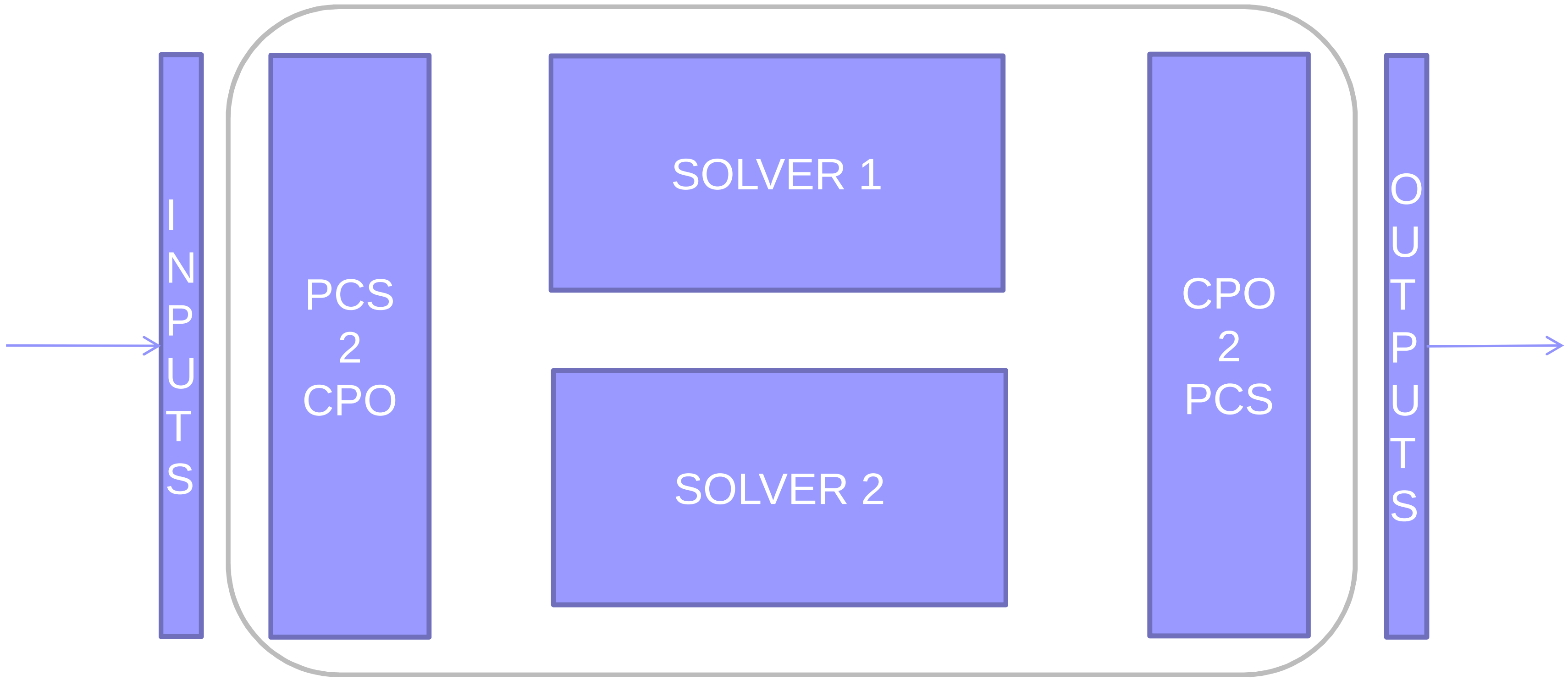
- Converging the EM part and the transport part separately is based on an assumption that thermal evolution is slower than EM evolution
- This is broken with, for example, ELMs and sawtooth crashes
- Convergence of the 2 branches is always a challenge

- Converging heat and current transport is 1-D
- Converging free-boundary induction is 2-D
- 1-D to 2-D mapping is always a challenge and time-consuming
- A pure 2-D solver is a future challenge worth meeting ??
- Does the increased complexity reduce the work to be done ?

Convergence difficulty

- Free boundary evolution moves the target for ECH deposition and moves the LH coupling – just 2 examples
- These modules have to resist rapid changes creating unphysical noise in the deposited power
- The separatrix is mathematical, not physical, since there are no physical discontinuities
- It is difficult to assess what the future difficulties will be with a new solver, we can only illustrate some of the lessons learned

Simulate the bare tokamak – new solver



It might be worth revisiting the PCS and Core Tokamak Solver CPOs early to understand the usage
Do they fit today ??

Lessons learned - Tokamak Core Simulator - 1

- A self-consistent initial startup is a bigger challenge than on the experiment – minimise startup transients
- Obtaining a reliable match between feedforward and startup should be like the experiment
- An intermediate restart is essential due to full pulse execution times – it was quite a job to continuously export enough data to make a perfect restart – this should be built in on Day #1 – not discover it later
- Time-stepping – for ITER simulations, the time-step is 2.5 to 3 msec for PF voltages. Take care that the kinetic updates are not faster

Lessons learned - Tokamak Core Simulator - 2

- DINA-CH and CRONOS were coupled by choice because they were both already implemented under Matlab
- Careful to decide “who does what” and not to have to sort it out afterwards
- Initial coupling required 2-D equilibrium convergence by both codes, and this took forever and was abandoned as not useful
- The solution adopted was to allow
  - CRONOS to step forward the kinetic profiles using the source and transport modules, imposing them on DINA-CH
  - DINA-CH to step forward the current diffusing free-boundary equilibrium, imposing it on CRONOS

Lessons learned - Tokamak Core Simulator - 3

- Manipulating the large data-sets generated requires the same attention as experimental data – but ITM has this view already

Tokamak Core Simulators – are we there yet ?

- Is DINA-CH-CRONOS a perfect black-box solver ??

- Not yet…
  - Initialisation is still a black art
  - Pulse scheduling is under development with ITER
  - Crashes of the core solvers are relatively undiagnosed and therefore hard to track down and time consuming
  - Consistency check on whether the simulation input data are acceptable
  - Generally, how do we reduce the rate of “failed” simulations
  - What is a “failed” simulation

- When we are there, the different core solvers should be able to produce identical results from identical pulse schedules

- This is over the horizon today….