General concepts in control-oriented modeling

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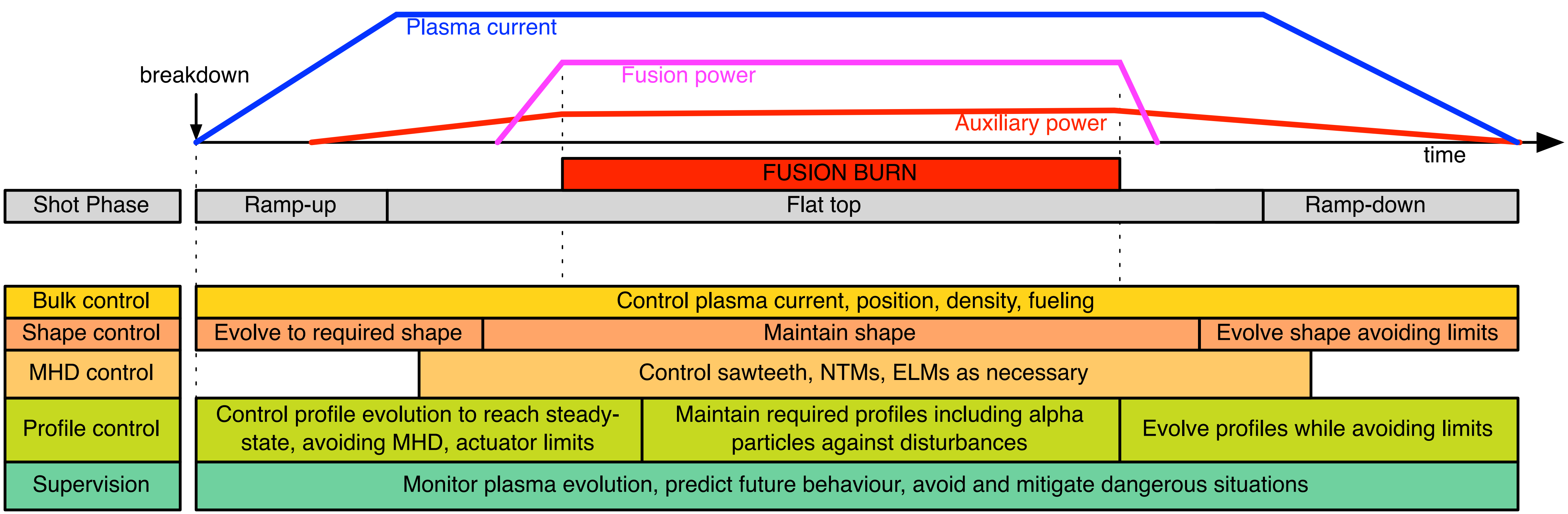
Control problems during a tokamak discharge

- **Tokamaks are pulsed devices.**
  - **We speak about a tokamak ‘shot’ or ‘discharge’**
- **Plasma is started, ramped up, maintained, ramped down.**
- **Different control problems in different parts of a shot**
  - **Do all above at the same time incl. monitoring and supervision**



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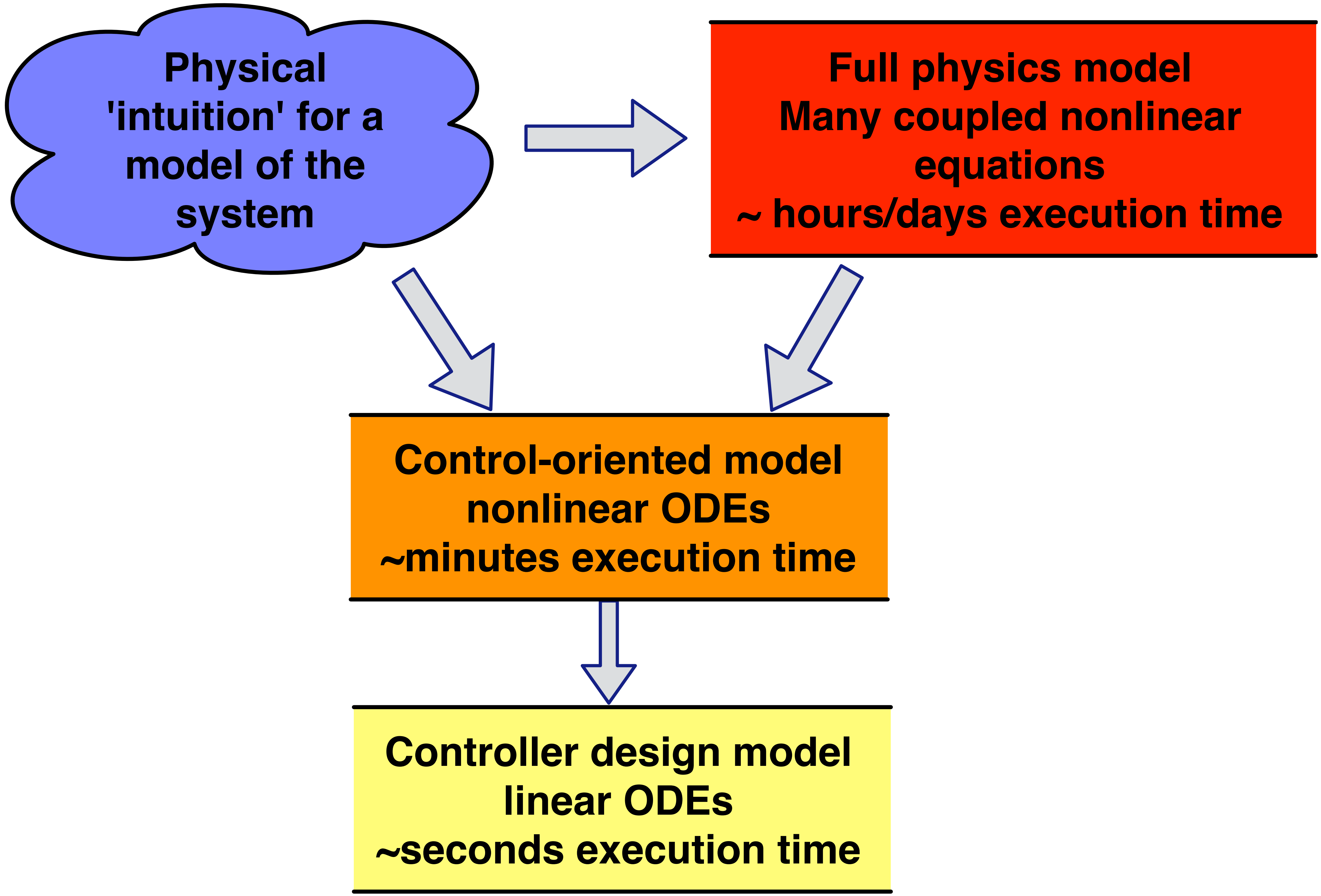
The importance of control-oriented models



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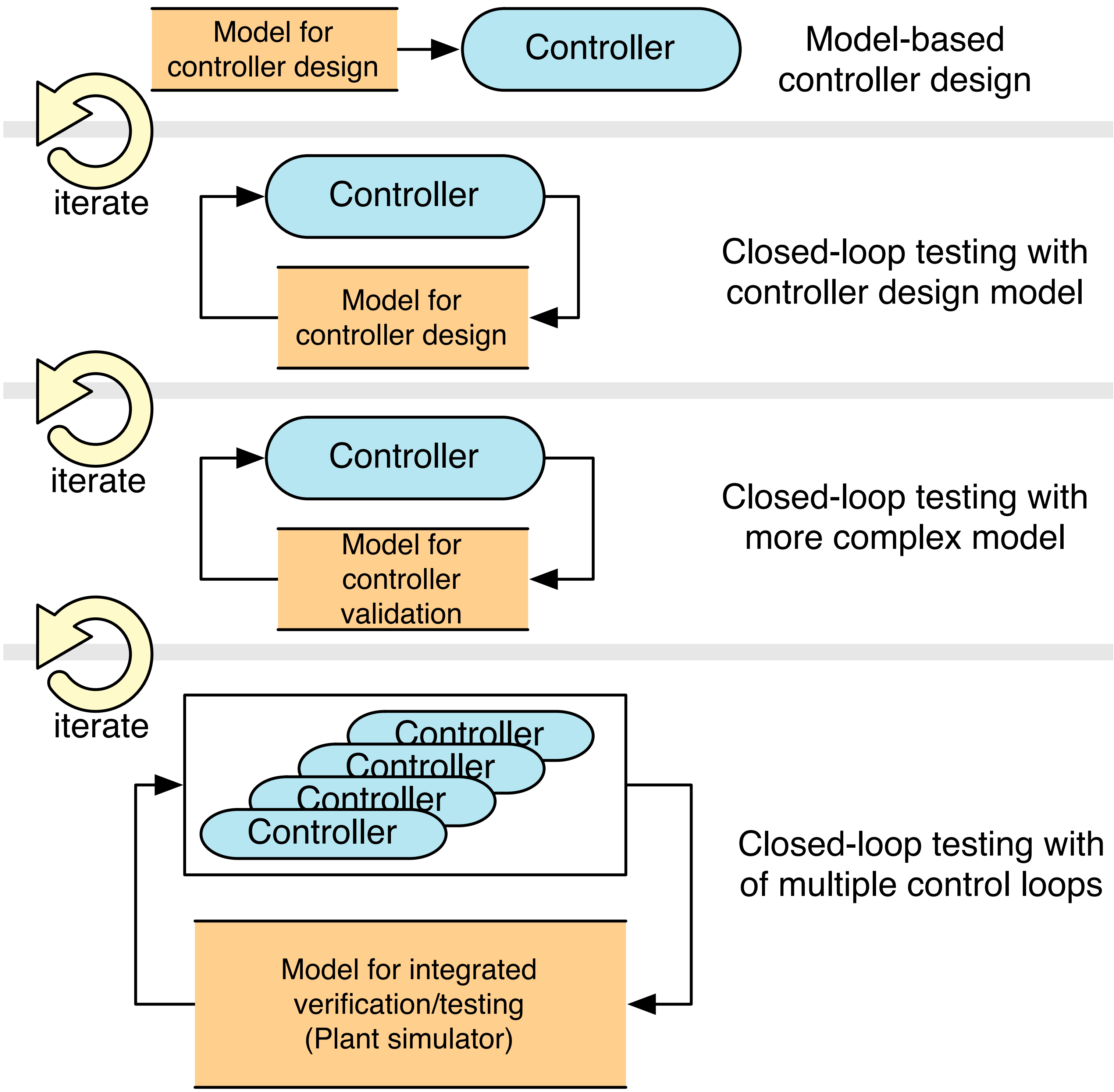
The importance of control-oriented models

- **To design and test controllers, we always use a <u>model</u> of the system.**
  - **Models of varying complexity are used at various stages of design/testing**
  - **Choice of correct model for task is an <u>integral</u> part of the control engineer's task**



The control engineer's toolbox: some examples

PID control
there are three knobs to turn
try until it works

Adaptive control
constantly changes to match
the system controlled

Predictive control
looking into the future
decide what is best

Robust controller
perturbed system? no problem
it works anyway

Learning Controller
what went wrong last time you tried?
do better next time

Requirements for control-oriented models

Role of model	Typical requirements	Typical model structure
Controller design	Tractable form for which controller synthesis tools exist.	Linear time invariant ODEs Linear parameter varying LTI + simple nonlinearity
Controller testing	Fast, so it does not slow down the controller design iterations	Linear/Nonlinear ODEs
Controller validation	Includes key effects which could not be included in the controller design model	Nonlinear ODE or PDE
Integrated verification/ testing	Maximum possible realism	Complex simulator including events + hardware/software interfaces of final plant

Deriving models

- **First-principle, physical modeling**
  - **Derive models from laws of physics governing controlled system.**
- **Mixed empirical + first-principle models**
  - **Derive models from physics, but use empirical formulas ‘difficult’ parts of the model**
- **System identification**
  - **Black-box: derive entire model from data**
  - **Grey-box: derive unknown model parameters from data**
- **A large part of this course was about <u>modeling:</u>**
  - **Derive models of the plasma in a form suitable for controller design**
  - **Awareness of hierarchy in model complexity for various control problems**

Conclusions

- **Operation of tokamaks calls for multiple complex, interconnected control loops**
- **Deriving good controllers is a multidisciplinary problem**
  - **Physical modeling: plasma physics & electromagnetism**
  - **Controller design/testing: Control engineering**
  - **Implementation: hardware/software knowledge**
- **Cutting edge of science and engineering**
  - **Much to do for physicists, control engineers, software engineers, numerical mathematics, machine learning …**