End-to-end in-pulse data analysis at ITER:
from magnetics measurements to live display

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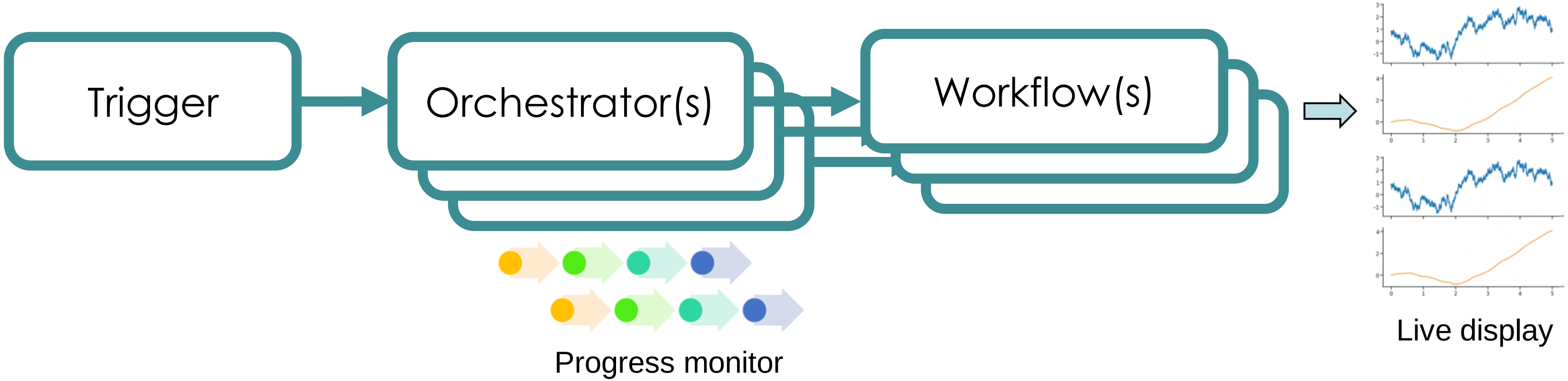
Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

In-pulse data processing

- Provide a consistent **interpretation of the plasma state** (with uncertainties) from the measurements **during** each pulse.

- More specifically to provide **accurate measurement parameters (MP)** in time to prepare the next pulse in the control room.



Outline

- Magnetics synthetic diagnostic
- Data rates, raw data encoding and decoding
- Equilibrium reconstruction
- Performance for data access

Raw diagnostic data without experiments

- Obtain data by:
  - Mapping data from other machines/experiments
  - Synthetic diagnostic modelling

- Test the system with:
  - Realistic data rates
  - Realistic data noise generation

Application of Synthetic Diagnostics

- Synthetic Diagnostics (SD) are used for various types of applications:
  - Design: to optimise the design and performance of the real diagnostic
  - Control: to support the development of control algorithms needed for the design of the Plasma Control System (PCS)
  - Physics: to support the physics interpretation and analysis

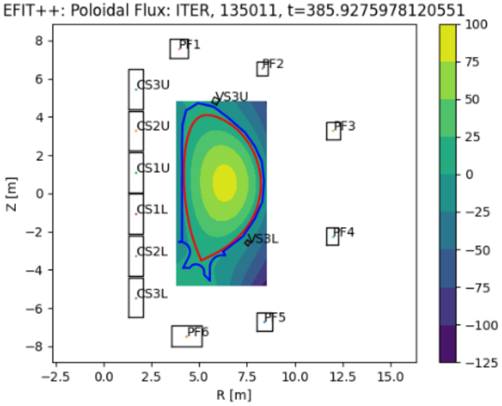
- In all these contexts, ITER uses the IMAS standard and further tools (also planned for the in-pulse analysis) like:
  - Persistent actors (Muscle3)
  - Bayesian frameworks (IDA and Minerva)

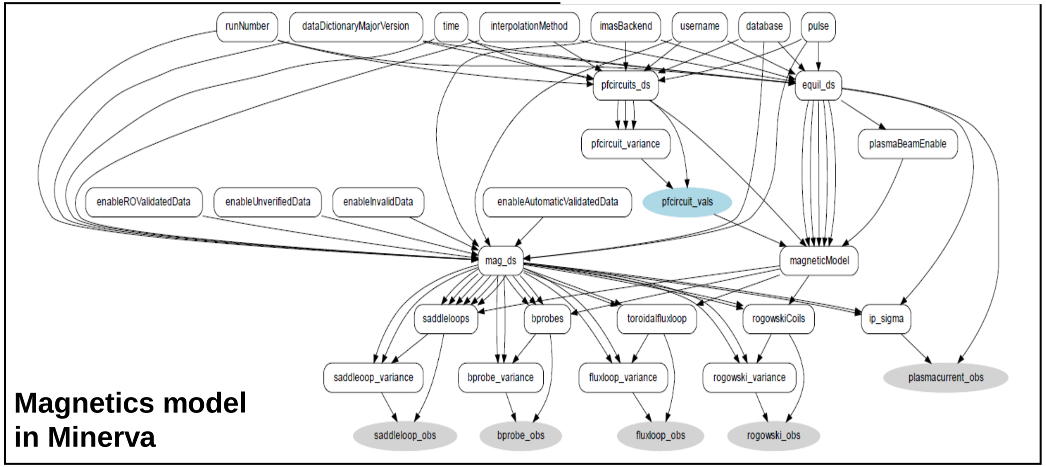
Synthetic diagnostic workflow

- Starting with a discharge scenario (eg, from JINTRAC, ASTRA, DINA, …)
- Go back and re-create the raw diagnostic measurements for that scenario
- The first step is the magnetic measurements
- From there, we can reconstruct a plasma equilibrium
- And from an equilibrium most diagnostics and plasma parameters can be inferred
- And compared with original scenario data

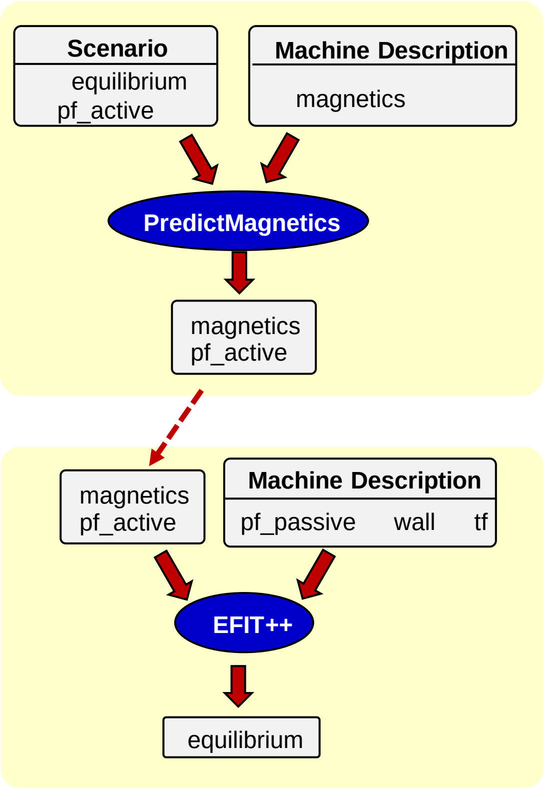
Synthetic Diagnostics for Magnetic Reconstruction

- 55.A* magnetic diagnostics
- PredictMagnetics by L. Appel within the Minerva framework
- EFIT++ actor





Magnetics model in Minerva



M. Schneider @ ITPA TG Diag

List of signals from the magnetic diagnostic

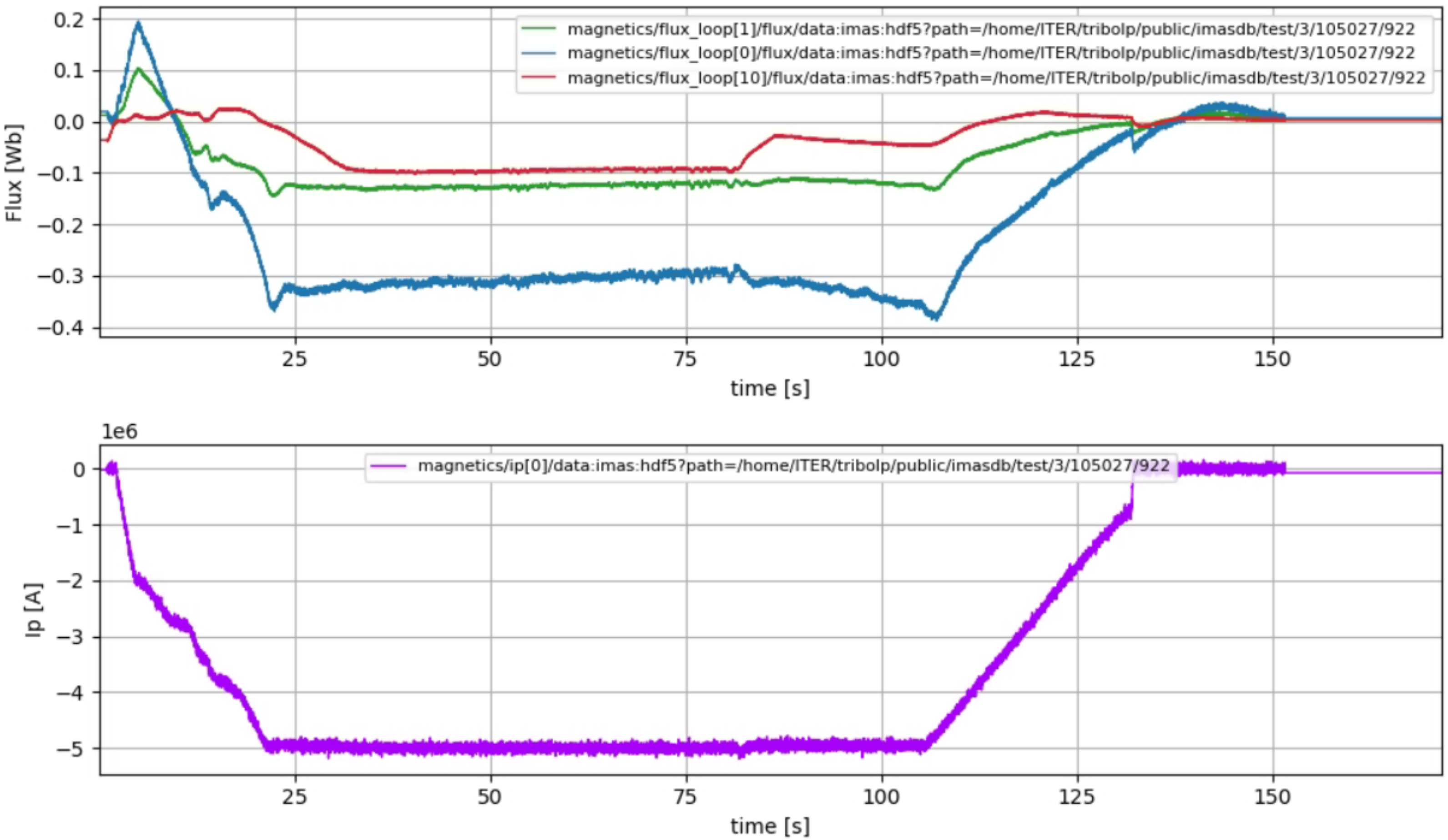
	name	identifier	diagnostic	number	IDS node
AD	Partial Flux Loops	55.AD.00-MSA	saddle	131	flux_loop
AE	Continuous Flux Loops (Inner)	55.AE.00-MCH	saddle	40	flux_loop
AF	Diamagnetic Loop (Main)	55.AF.00-MCL	saddle	3	flux_loop
AH	Diamagnetic Saddles (Inner)	55.AH.00-MSA	saddle	6	flux_loop
AI	MHD Saddles	55.AI.00-MSA	saddle	81	flux_loop
A3	Tangential Coils (Outer)	55.A3.00-MLF	mirnov	180	b_field_pol_probe
A4	Normal Coils (Outer)	55.A4.00-MLF	mirnov	180	b_field_pol_probe
A5	Tangential Steady State Sensors	55.A5.00-MSS	hall	60	b_field_pol_probe
A6	Normal Steady State Sensors	55.A6.00-MSS	hall	60	b_field_pol_probe
AA	Tangential Coils (Inner)	55.AA.00-MLF	mirnov	144	b_field_pol_probe
AB	Normal Coils (Inner)	55.AB.00-MLF	mirnov	72	b_field_pol_probe
AJ	HF Sensors	55.AJ.00-MHF	mirnov	207	b_field_pol_probe
AL	Divertor Equilibrium Sensors	55.AL.00-MLF	mirnov	12	b_field_pol_probe
A9	Diamagnetic Compensation (Outer)	55.A9.00-MLF	mirnov	36	b_field_tor_probe
AC	Toroidal Coils	55.AC.00-MLF	mirnov	9	b_field_tor_probe
AG	Diamagnetic Compensation (Inner)	55.AG.00-MLF	mirnov	6	b_field_tor_probe
AP	Diamagnetic Compensation (Outer)	55.AP.00-MRG	rogowski_coil	358	rogowski_coil

steady state	**120**
integral	**1465**
total	**1585**

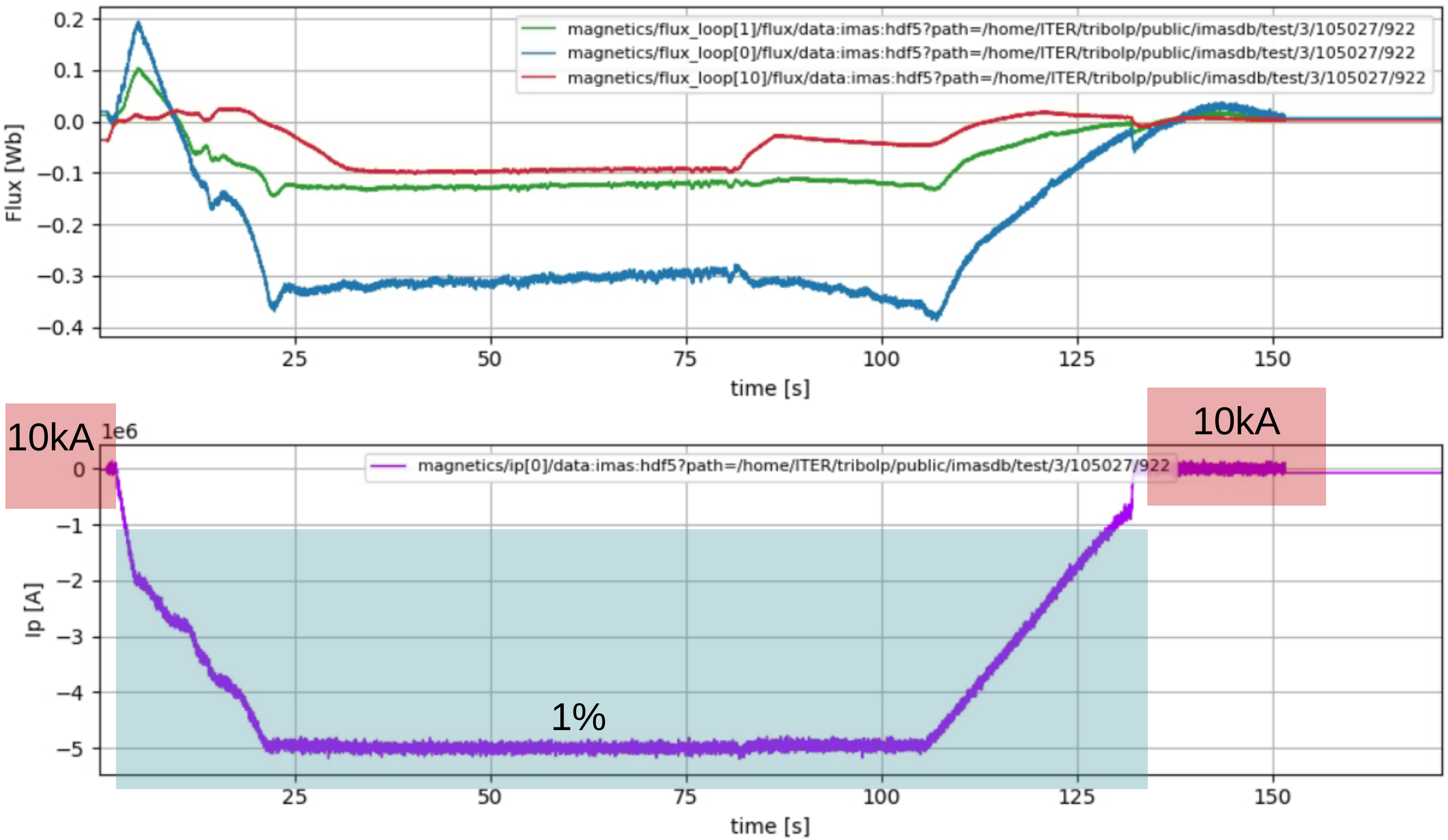
Magnetics Synthetic Diagnostic

- predictMagnetics:
  - read in **pf_active, pf_passive, tf and Ip** to produce a magnetics IDS
  - adds consistent noise:
    - noise with a 1/f spectrum to simulate the effects of signal integrators
    - relative to signal intensity if energized, eg, std. dev. = 1% of average
    - absolute values when not energized, eg, std. dev. = 10kA
  - ready to be use as input for equilibrium reconstruction

Magnetics Synthetic Diagnostic



Magnetics Synthetic Diagnostic



Data rates

- 1585 signals for magnetics
  - 120 are proportional (voltages)
  - 1385 are integral (voltage and flux/field waveforms)
- From 2 MHz to 10 kHz during the pulse
- 2 MHz for 1 min pre- and post- pulse

- Currently testing:

150s @ 1kHz + 2s pre+post @ 2MHz → 10 GB

Encoding/Decoding

- Diagnostic data arrives encoded as a stream of 64-bit unsigned integers.
- To generate synthetic data we encode from floating-point doubles to 64-bit unsigned int.
- Knowing the range, we can decode to floating-point doubles.

$$x_{dec} = (x_{enc} + f_{min}) \times \frac{\Delta f}{\Delta R} = x_{enc} \times \boxed{\frac{\Delta f}{\Delta R}} + \boxed{f_{min} \times \frac{\Delta f}{\Delta R}}$$

Scaling Offset

with:

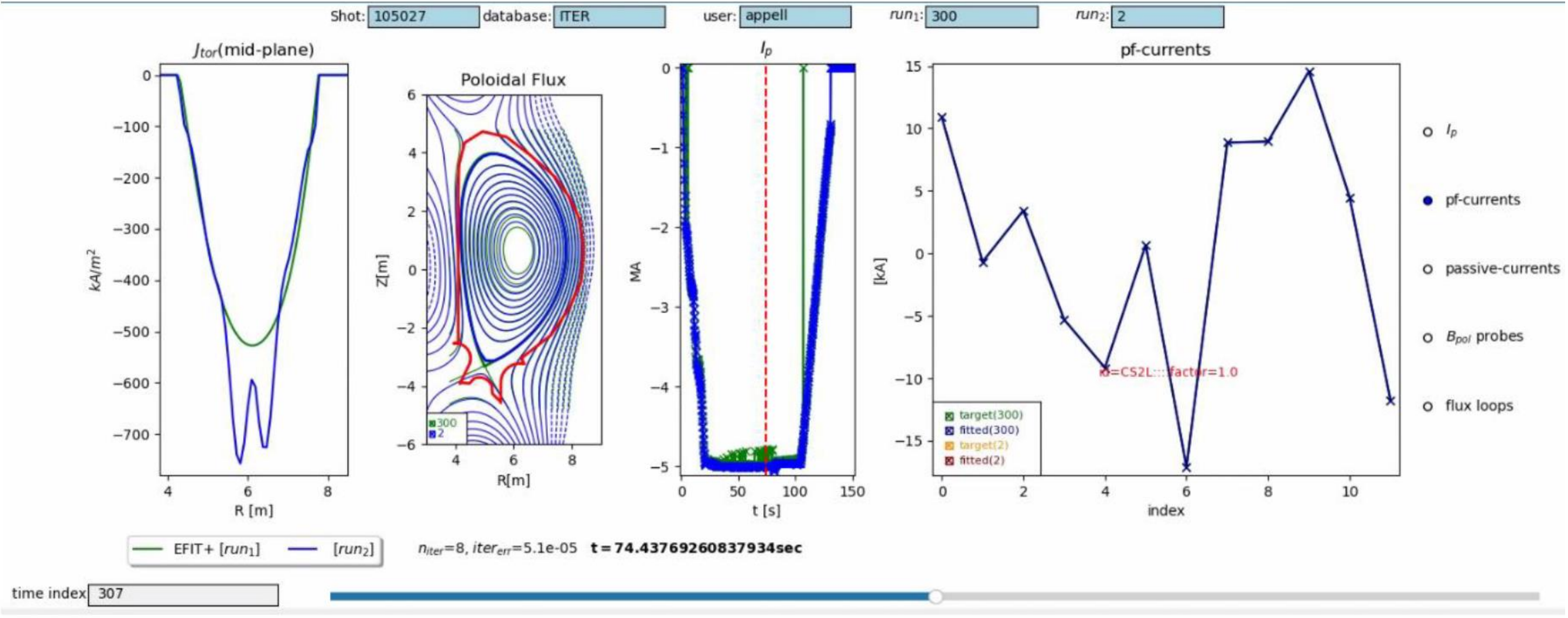
Δf: final range $= f_{max} - f_{min}$

ΔR: DAQ range $= 2^N - 1$

Equilibrium reconstruction

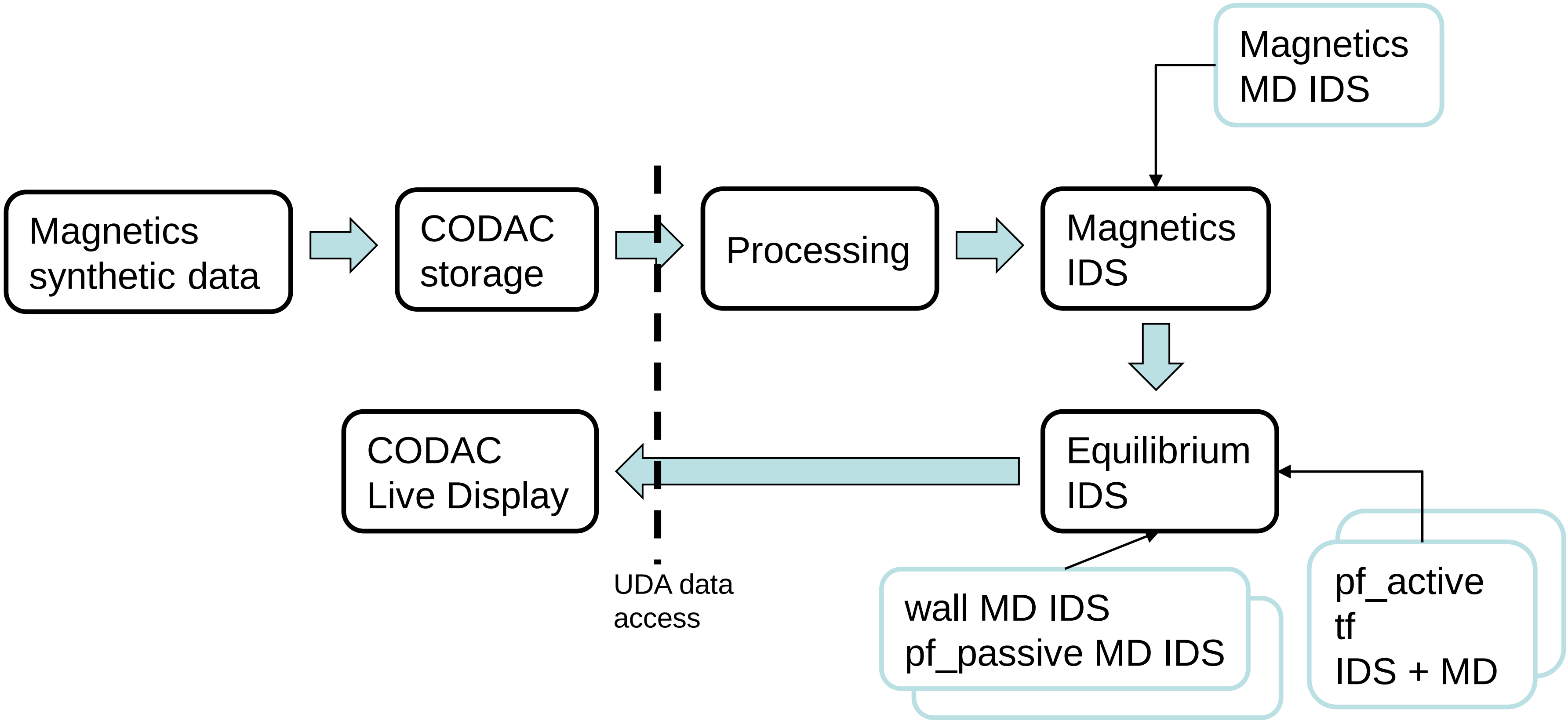
- Using EFIT++.
- Needs:
  - **wall, pf_passive**: static data only, from Machine Description
  - **pf_active, tf, magnetics**: static data (MD) and dynamic data (from scenario simulation).

Equilibrium reconstruction



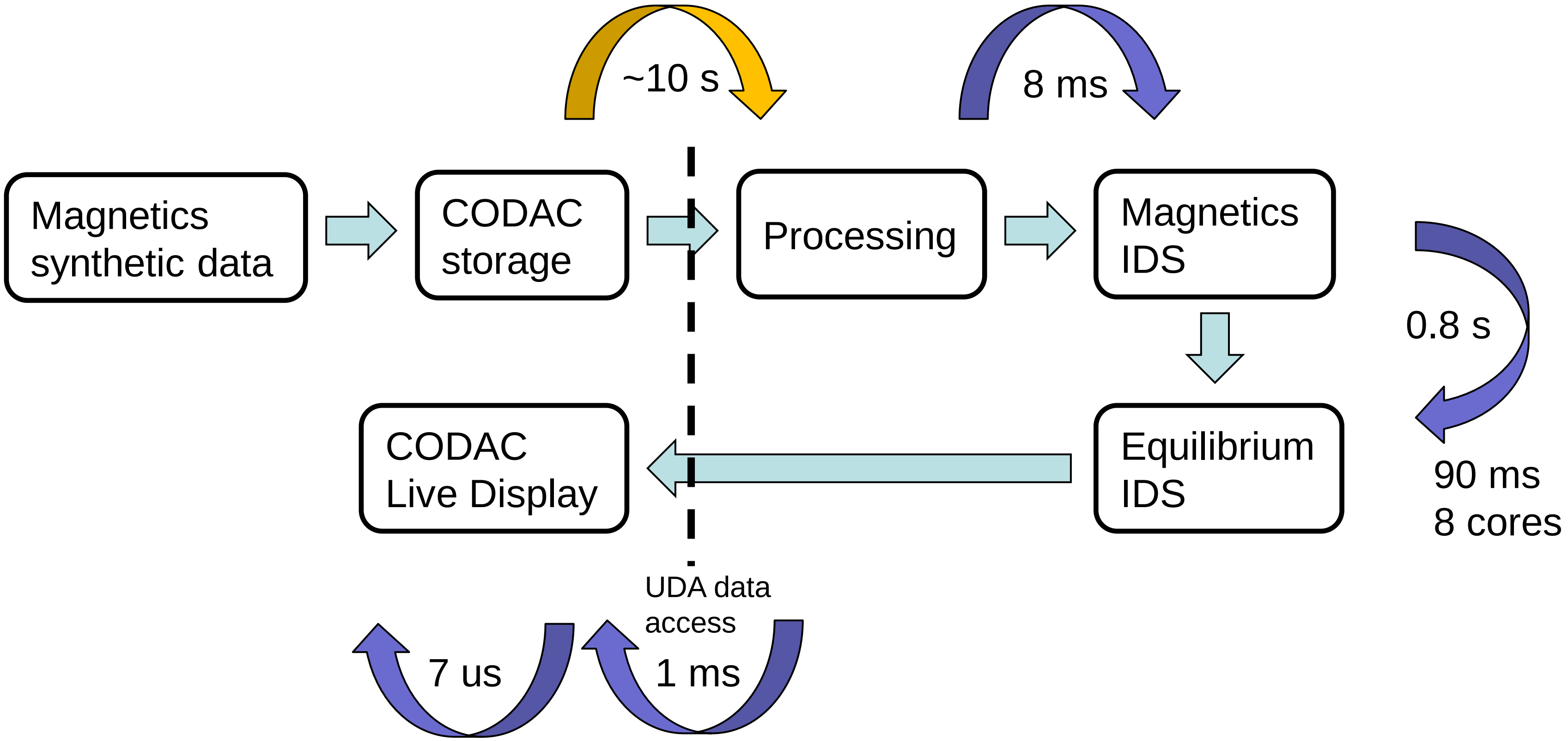
by L Appel @ UKAEA

Data flow



Magnetics
MD IDS
Magnetics
synthetic data
CODAC
storage
Processing
Magnetics
IDS
CODAC
Live Display
Equilibrium
IDS
UDA data
access
wall MD IDS
pf_passive MD IDS
pf_active
tf
IDS + MD

Timings per time point (single core)



Conclusions & future work

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- Workflow created from simulation to synthetic magnetics data to equilibrium.
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Next steps (~1 year):

- UDA+IMAS performance (XPOS ←→ SDCC) needs to improve by ~2 orders of magnitude.
- Need to implement data streaming.
- Thorough comparison with experimental data → experimental data mapping

Thank you!

Questions? Comments?

Reminder on IMAS

***I**ntegrated **M**odelling & **A**nalysis **S**uite is the collection of physics software that will be used to support ITER operations and research as defined in the ITER Integrated Modelling Programme.*

Data Model

- Machine independent data structures
- Can serve as code coupling interface
- Meta-data and provenance

Generic Tools

- Data access, storage, discovery, manipulation, visualization
- Support for simulation, management and exploitation of datasets / databases

Applications

- Independent physics codes
- Complex workflows
- Experimental data processing pipelines
- Multi-machines databases

F. Imbeaux *et al* 2015 *Nucl. Fusion* **55** 123006

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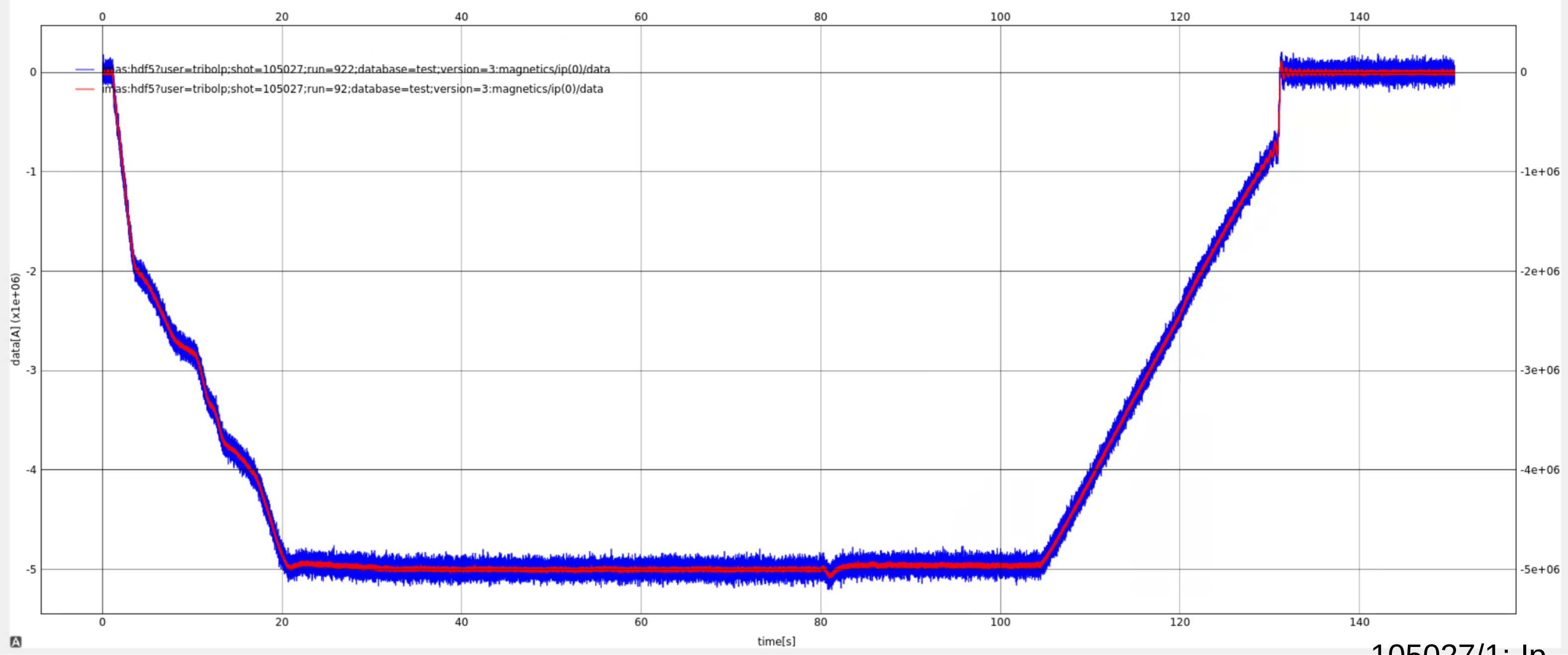

105027/1; Ip

ITER Pulse States during campaigns