WPSA Project Planning Meeting - Integrated Data Analysis and Validation

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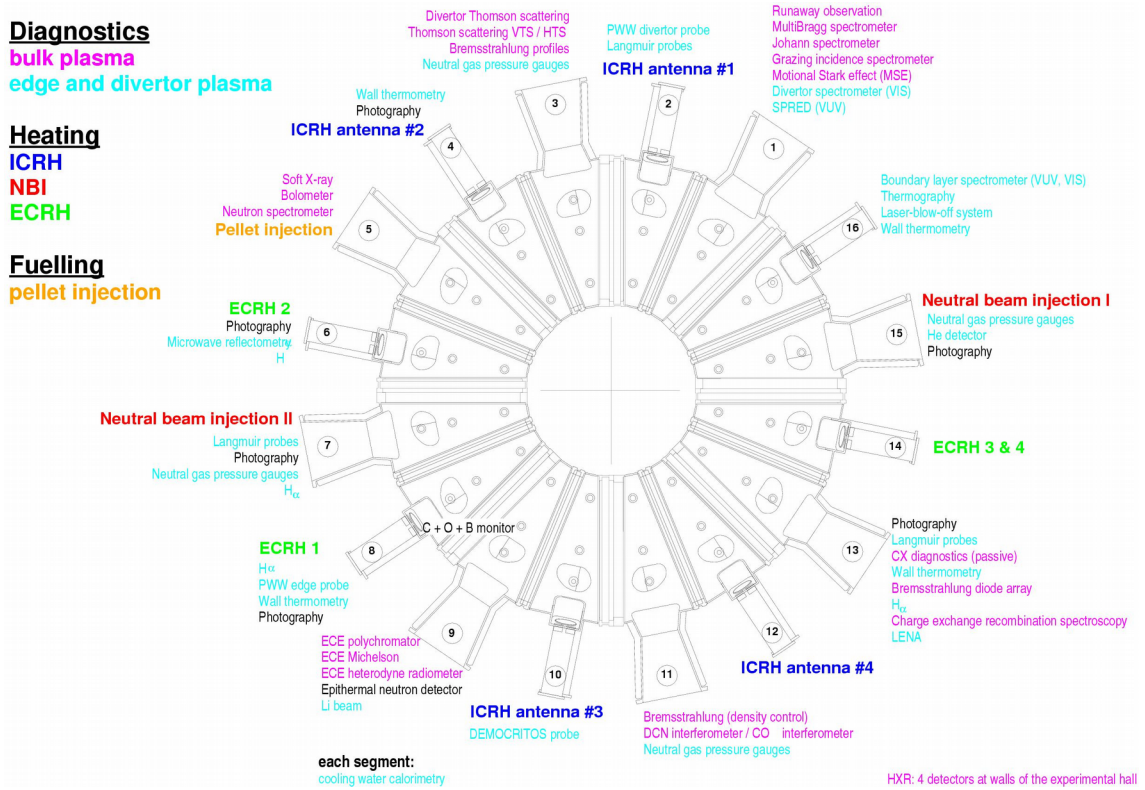
IDA for Nuclear Fusion

Different measurement techniques for the same quantities → redundant and complementary data

Coherent combination of measurements from different diagnostics

Goal:

- replace combination of results from individual diagnostics
- with combination of measured data
  → one-step analysis of pooled data



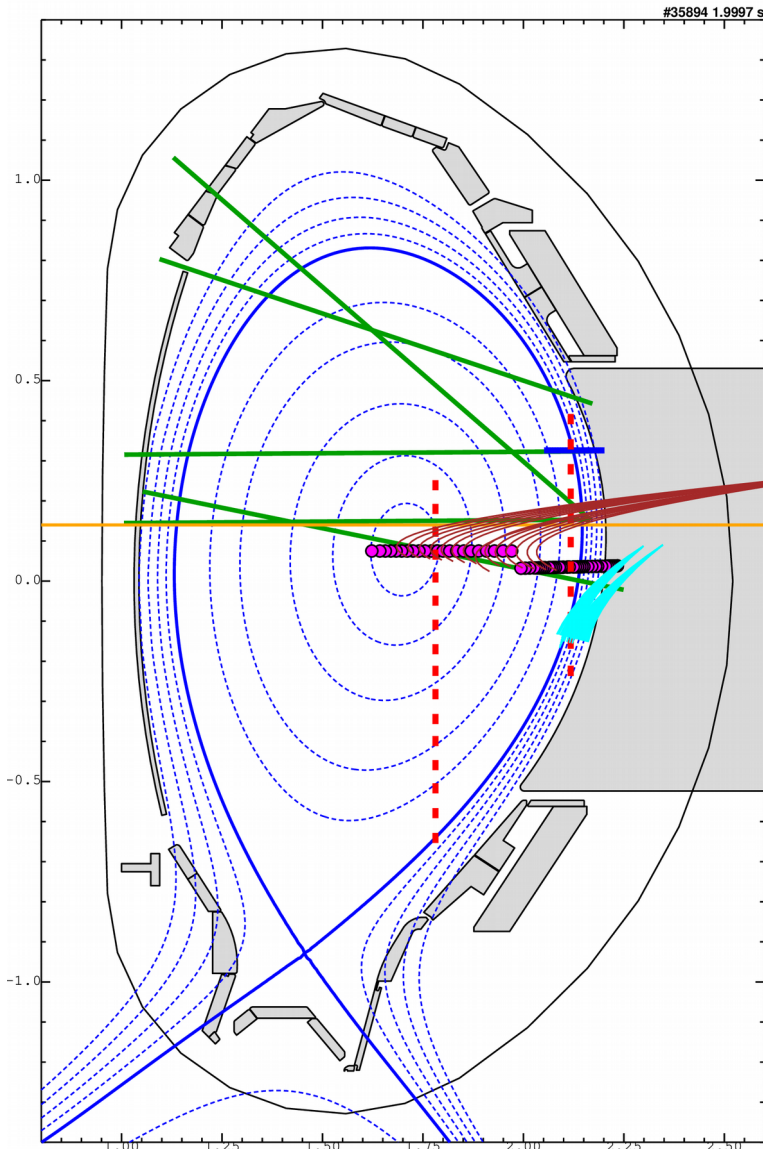
IDA at ASDEX Upgrade

multi-diagnostic profile reconstruction: n_e, T_e

- Lithium beam impact excitation spectroscopy (LIB)
  collisional radiative model → $n_e\,(T_e)$
- Interferometry measurements (DCN) → n_e
- Electron cyclotron emission (ECE)
  ECRad: Electron cyclotron radiation transport → $T_e\,(n_e)$
- Thomson scattering (TS) → n_e, T_e
- Reflectometry → n_e
- Beam emission spectroscopy → $n_e\,(Z_{eff})$
- Thermal Helium beam spectroscopy → n_e, T_e

- Equilibrium reconstructions for diagnostics mapping
  (*IDE*: Grad-Shafranov equation coupled with current diffusion equation)

<u>A lot of dependencies and uncertainties:</u>
<u>We need a probabilistic approach!</u>



IDA: Improved Diagnostic Results

Bring together different diagnostics/diagnosticians with redundant or complementary data

- Redundant data:
  - more reliable results by larger (meta-) data set
    → reduction of estimation uncertainties
  - detect and resolve data inconsistencies (validation for reliable/consistent diagnostics)
    using standardized error/uncertainty treatment

- Complementary data:
  - resolve parametric entanglement
  - resolve complex error propagation (non-Gaussian)
  - synergistic effects (exploiting full probabilistic correlation)
  - automatic *in-situ* and *in-vivo* calibration (transient effects, degradation, …)
  - advanced data analysis technique
    improvements in modelling (e.g. ECE) and diagnostics hardware (e.g. LIB)

ITPA Diagnostic TG: New SWG IDAV

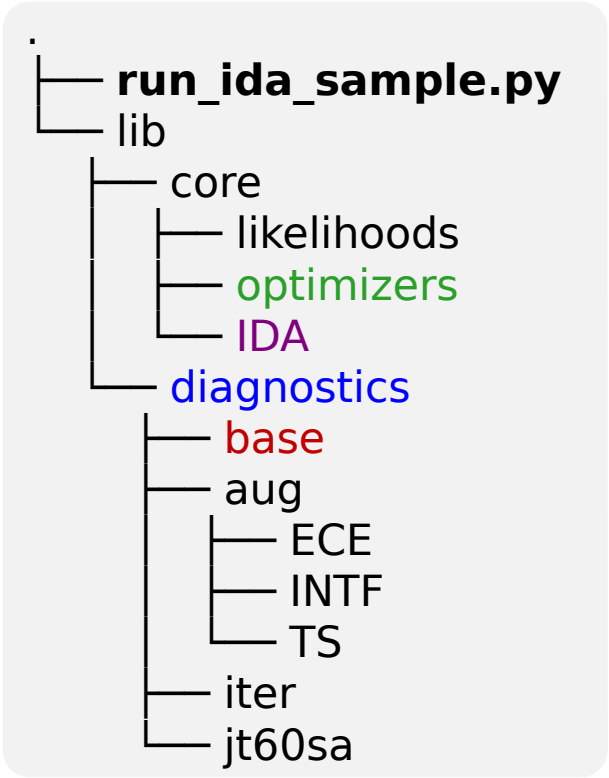
Integrated Data Analysis and Validation (IDAV) specialist working group

- founded: 01.01.2020
- chair: Rainer Fischer (IPP Garching, Germany)
- co-chair: Keisuke Fujii (Kyoto University, Japan)
- IO co-chair: Simon Pinches (IO)
- the IDAV SWG was motivated by (call by Oct 15th 2019):
  - ITER will be dealing with many real-time measurements coming from multiple diagnostics systems and this information will be used for machine control and safety as well as physics studies.
  - It is proposed to create a new SWG working to develop self-consistent data validation procedures (profiles, error bar estimates…) for key ITER measurement parameters (density, ion and electron temperature, current and q-profile, Zeff, wall condition, etc.)
  - The new SWG would deal with integrating all measurements to optimize information available for ITER operations, control and safety.
- now 27 contributors/interested persons

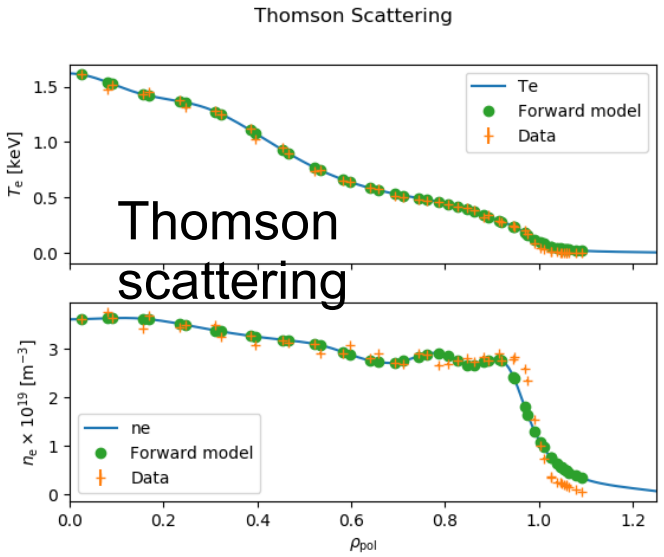
IDA: Basic Implementation for ITER, ...

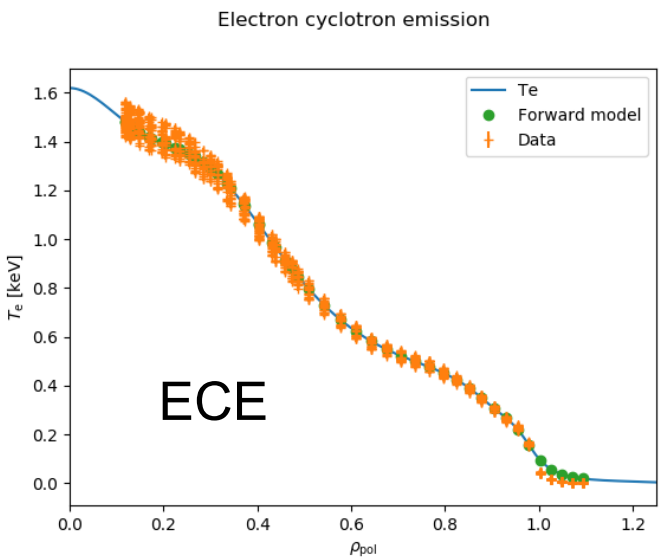
Integrated Data Analysis for ITER: basic implementation in python

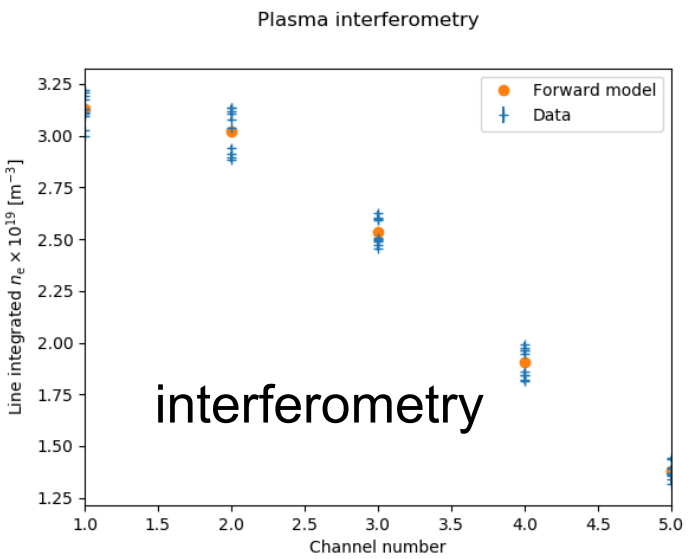
- 1st implementation on https://git.iter.org (July 2020) (S. Denk, MIT)
- open source license (ITER-IPP agreement in preparation)
- 2nd revision coming soon being completely modular (A. Bock, IPP)
  - to be compatible with any fusion device
  - diagnostics: Thomson scattering, ECE and interferometry, ...
  - likelihoods (data uncertainty): Gaussian, Cauchy (outlier robust), …
  - multi-fidelity forward models / synthetic diagnostics
    - ECE: $T_{rad} = T_e$ vs radiation transport modelling $T_{rad}(T_e, n_e)$
    - real-time vs offline analysis
  - flexible parameterisation of, e.g., profiles: splines, GPR, ...
  - priors: curvature, positivity of (T_e, n_e) via exp(spline), ...
  - results and their uncertainties:
    - MAP solution: minimize(method='BFGS'), …
    - MCMC sampling methods (t.b.d.)

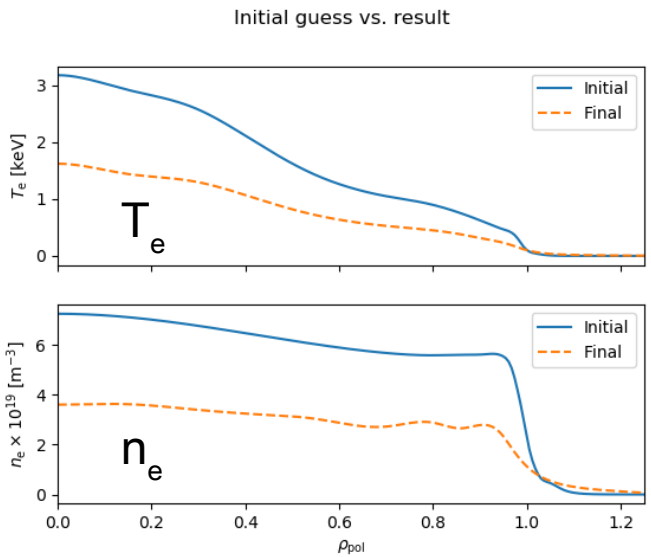


IDA: Basic Implementation Example









IDA for JT-60SA: 2020 Call

EUROfusion

CONSORTIUM WORK PLAN 2021-2025

CALL RESPONSE FORM for the work package

SA –JT-60SA Exploitation

Simulation expert, data analysis tools developer	• Synthetic diagnostics development, including image processing for scientific cameras, particularly but not exclusively for EU-led diagnostics EDICAM, Edge TS, Divertor VUV, FILD • Operation-oriented tools : (equilibrium, control, discharge fast simulator etc.)	12pm/year	Team of Integrated Data Analysis and Validation (IDAV) specialists; based on recent developments in collaboration with ITER and DIII-D it is proposed to prepare IDA tools (e.g. starting with combined ECE, interferometry, Thomson scattering; synthetic diagnostics) for JT-60SA. 20 years of expertise in IDA components comprising forward models (synthetic diagnostics) for all diagnostics being exploited, comprehensive determination and quantification of statistical and systematic measurement and modelling uncertainties, Bayesian probability theory as a framework for the combination of all information from measurements and modelling, and techniques for reliable estimation of physical quantities of interest and their uncertainty quantification. Expertise in magnetic equilibrium reconstruction from magnetic, kinetic and internal current measurements combined with current diffusion modelling. (Fischer) Chair of the Integrated Data Analysis and Validation (IDAV) specialist working group (SWG) within the ITPA Diagnostics TG to develop an IDA code suite for ITER using IMAS.

IDA for JT-60SA

plasma operation and physics exploitation oriented tool:
requirement capture, specifications and to adapt modular IDA (ITER) python code to JT-60SA diagnostics

1st IDAV meeting (10th Dez 2020) prior to the WPSA call: A. Bock (IPP), R. Fischer (IPP), Keisuke Fujii (Kyoto Univ.), D. Nille (IPP), Hiroshi Tojo (QST), C. Sozzi (ENEA ISTP-CNR Milano)

- JT-60SA:
  - start with commissioning diagnostics (PO-1):
    - interferometry → n_e
    - soft-X ray → $T_e(n_e,Z_{eff})$
    - visible spectroscopy → $Z_{eff}(n_e,T_e)$
  - augment with PO-2 synthetic diagnostics:
    - Thomson scattering → n_e,T_e
    - ECE → $T_e(n_e)$
- start: in 2021 (campaign independent)
- goal: IDA for physics exploitation in 2023
- manning (IPP): 12pm/year (postdoc); visits: 1st 2 weeks, 2nd 6 months in 2021/22 (?)
- IMAS at JT-60SA?