EUROfusion

Status of EUROfusion PrIO IMAS related activities: multi-machine databases and synthetic diagnostics

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HIGHLIGTHS of PrIO IMAS related activities

- **EUROfusion multi-machines databases**
  - Disruption and Event analysis framework for FUSion Experiments
  - Pedestal database
  - Confinement database

L Frassinetti et al NF 2021

A Pau IAEA FEC 2023 + NF Jan 2024

E Peluso to be submitted in 2024

- **FOCS synthetic diagnostics ongoing IMASization**
- **ACH support requested for completing IMASization of breakdown workflow, DYON & IR synthetic diagnostics**
- **Advertisement: new PrIO activities in 2024 (pending PB approval & resources)**
  - AI applications to multi-machine DBs and operation DB
  - Integrated data analysis – to be agreed in complement to IO contract(s)

EUROfusion Disruption Database: Status in 2023

DEFUSE

EUROfusion DDB framework

- Implementation and deployment of a new framework , ***DEFUSE*** (Disruption and Event analysis framework for FUSion Experiments).
  A. Pau et al, IAEA FEC2023 (follow-up paper already agreed with NF by January 15th).
- Automated build and testing (under version control, hosted on https://gitlab.epfl.ch/.
- It will be released **open source** under a Collaborative License Agreement (CLA).
- Aligns with **OPEN** and **FAIR** principles
- Implements very efficient and **generic** solutions for automated validation, versioning & Database Management (*JSON* data-libraries & dictionaries, *HDF5* data/metadata, *SQL* relational data model for *IMAS* mapping and *Parquet* tables for data analytics, statistics and AI).

EUROfusion DDB status

- **JET**: ~4000 validated entries (ILW until 2022).
- **TCV**: ~4500 entries with preliminary validation (recent campaigns).
- **AUG**: ~1500 entries with preliminary validation (recent campaigns).
- **MAST(-U)**: integration of data libraries & dictionaries recently started (UKAEA collaborators).
- **WEST:** only preliminary discussion on the integration.
- Validated **multimachine DB** for Density limits and ITER-Baseline for JET, AUG and TCV

EUROfusion Disruption Database: Status in 2023

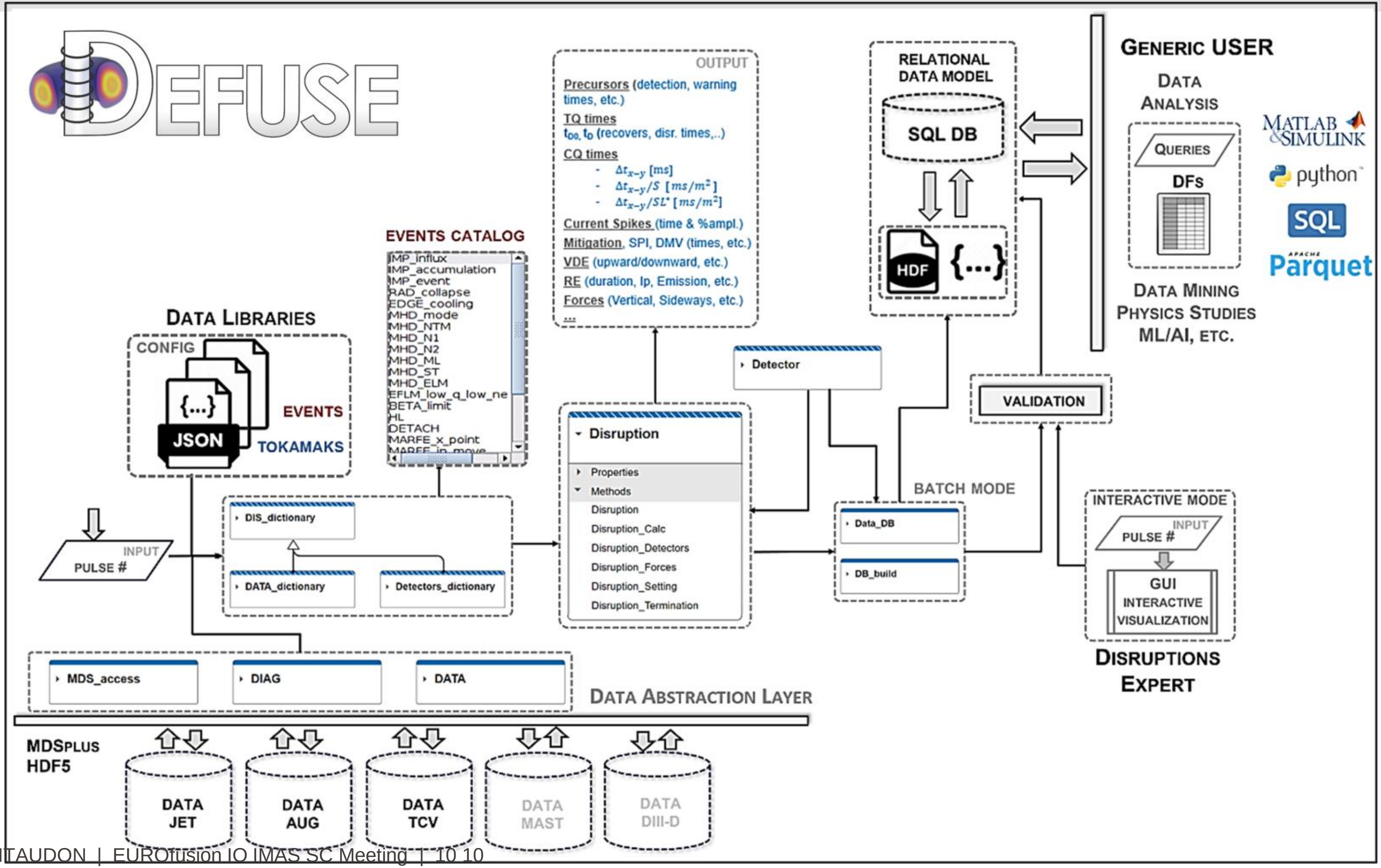
IMAS mapping

- Mapping implemented in the **SQL relational data model**;
- **Interface** to parse the data from validated DB and data sources (docker as a potential solution for **Gateway** or other environments)
- Immediately after IAEA, with the support of F. Imbeaux start the tests to write the **IDS for Disruptions**

2024

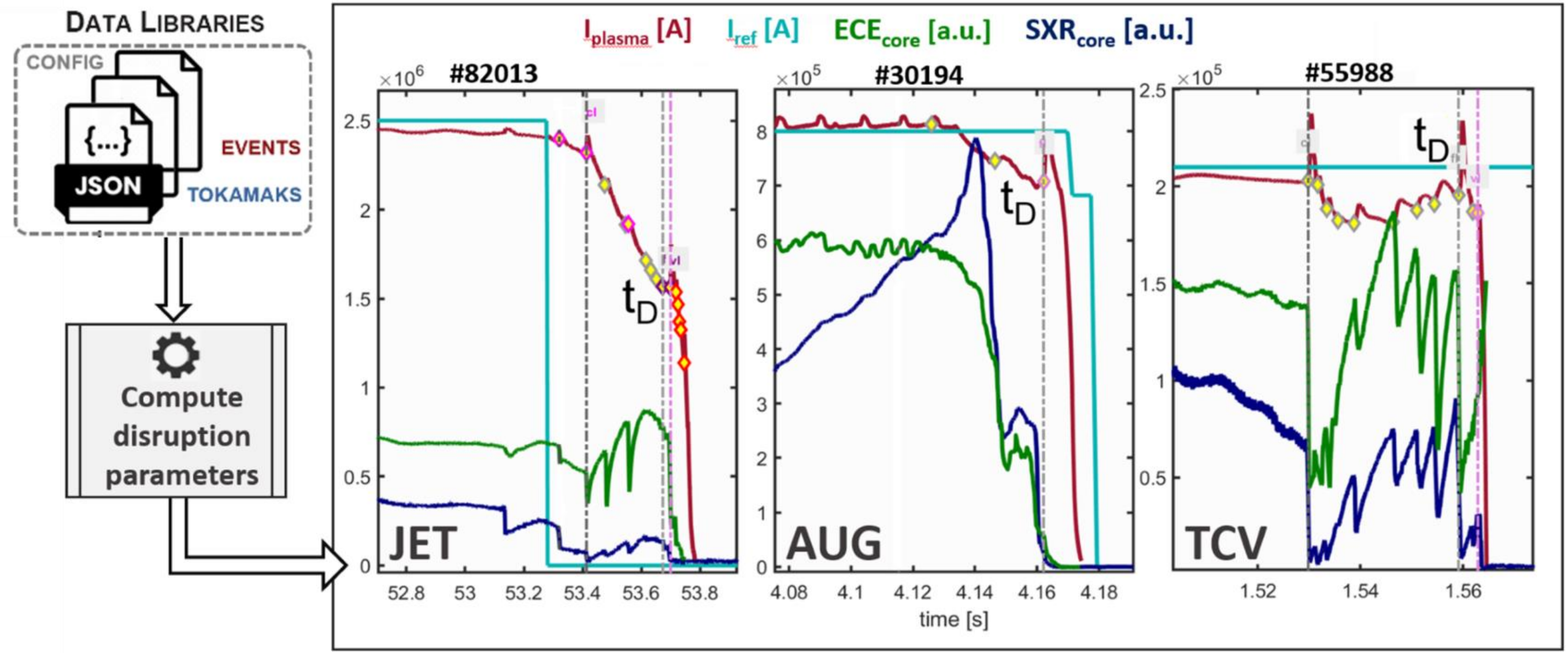
- Finalize validation of AUG and TCV, include MAST, WEST in the DDB, keep JET up to date.
- Finalize **IMAS mapping** and develop a dedicated **web interface** in the Gateway (ACH support requested)

EUROfusion Disruption Database: Highlights



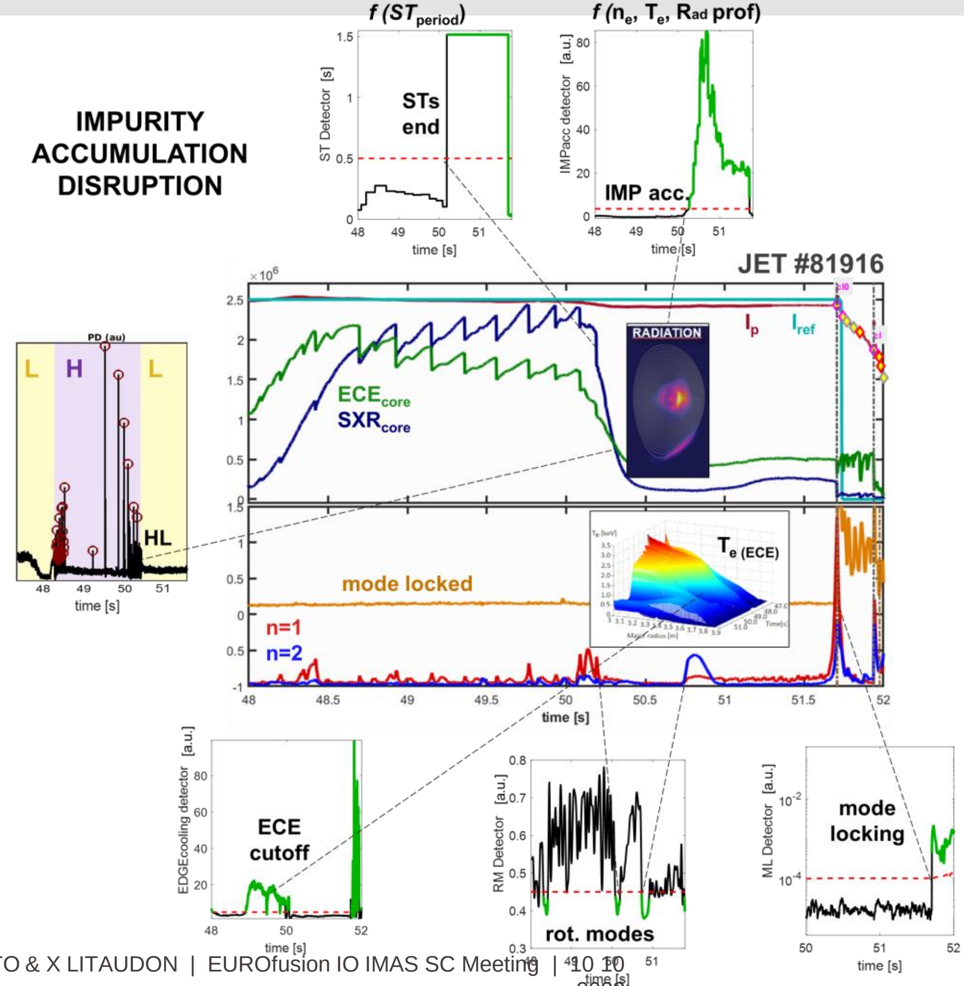
Swiss Plasma Center

EUROfusion Disruption Database: Highlights



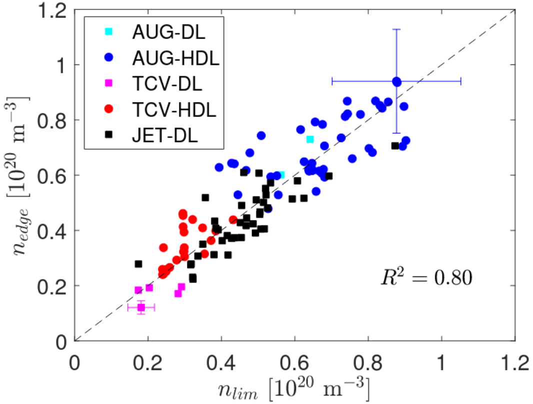
EUROfusion Disruption Database: Highlights

IMPURITY ACCUMULATION DISRUPTION



Density Limit First-Principles Scaling

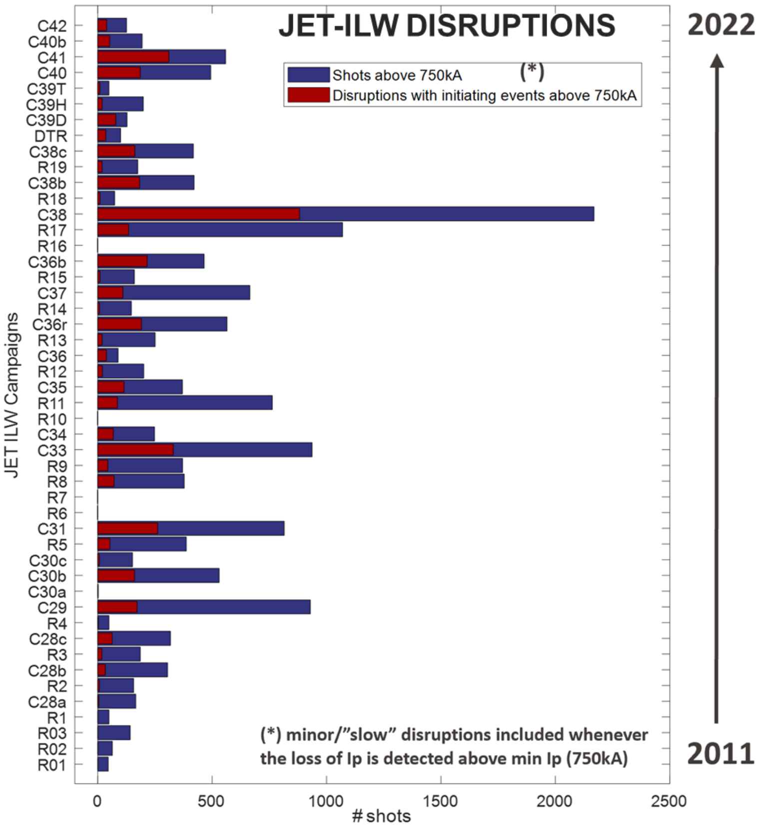
REF: [M. Giacomin et al PRL 2022]



1. P_{SOL} dependence of n_{eLIM}
2. $n_{e_{LIM}}{}^{ITER} \simeq 2 \cdot n_{e_{GW}}{}^{ITER}$

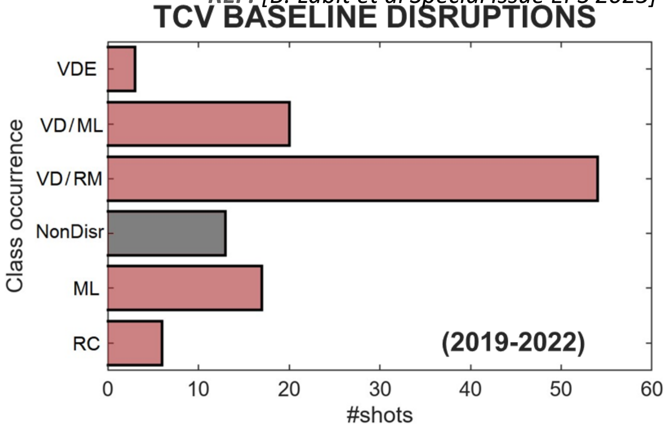
Swiss Plasma Center

EUROfusion Disruption Database: Highlights



REF: [A. Pau et al IAEA-FEC 2023, follow-up paper on NF by January 2024]

REF: [B. Labit et al Special Issue EPS 2023]



VDE: Vertical Displacement Event

VD/ML: Vertical Displacement & Mode Locked

VD/RM: Vertical Displacement & Rotating Mode (2,1)

NonDisr: Regular Termination

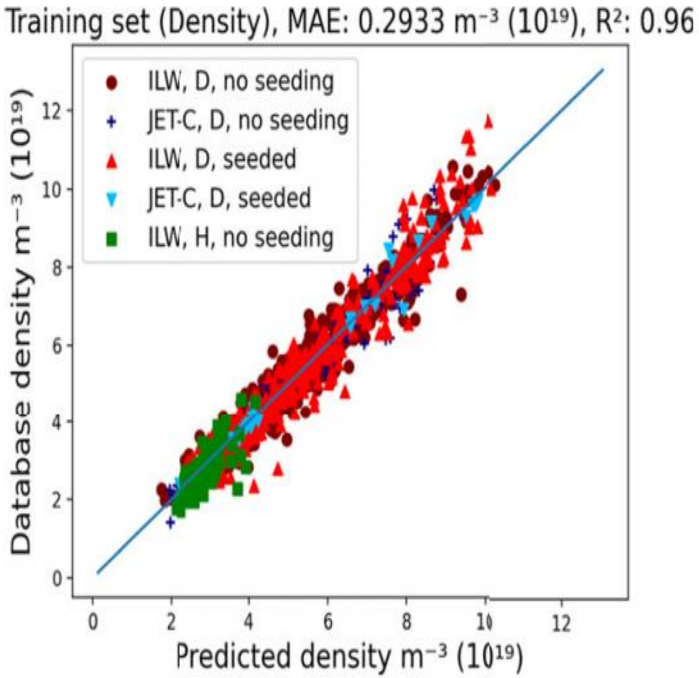
ML: Mode Locked

RC: Radiative Collapse

PEDESTAL multi-machine DB status

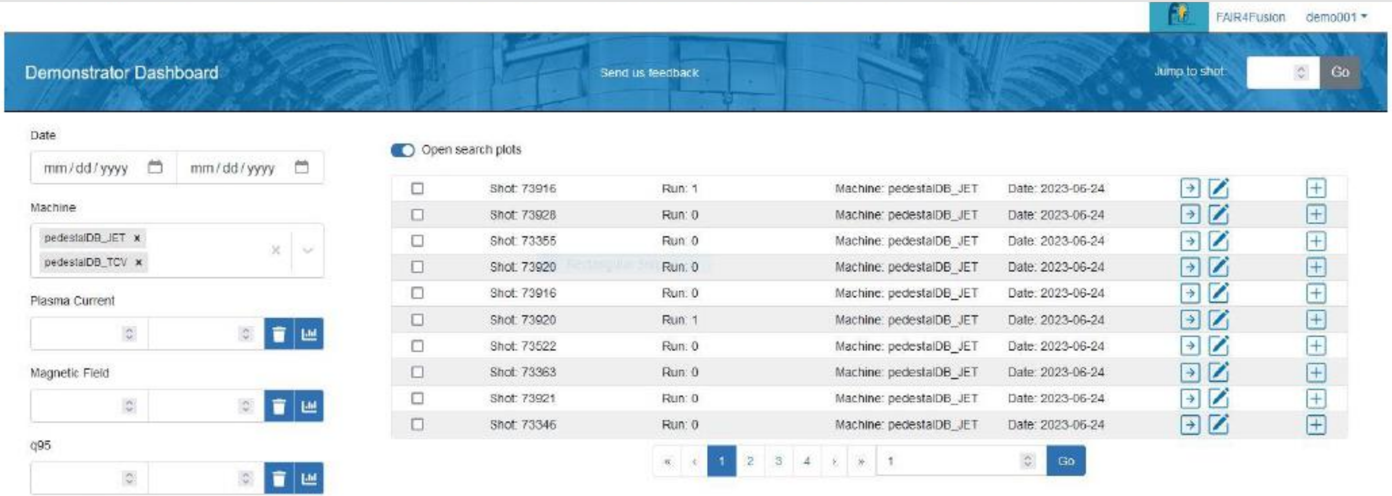
- **Pedestal DB in IMAS on the Gateway since August 2023**
  - JET:
    - 4018 pulses stored in IMAS on the Gateway
    - All JET-C and JET-ILW pulses till the end of DTE2 with validated TS data (including DT and TT pulses)
    - /pfs/work/g2lfrass/imasdb/PedestalDB_JET
  - TCV:
    - 209 pulses stored in IMAS on the Gateway
    - All pulses described in [Labit IAEA 2021]
    - /pfs/work/g2mvan/imasdb/TCV_PedestalDB
  - AUG:
    - All the pulses provided by M. Dunne
    - /pfs/work/g2mvan/imasdb/AUG_PedestalDB

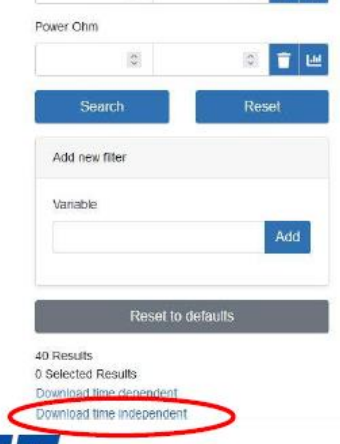
- **Application: deep learning techniques to predict pedestal density (free parameter in E-PED)**
  - Application for integrated modelling



[Gillgren et al., NF 2022 A. Kit et al, PPCF 2023]

WEB INTERFACE TO DOWNLOAD PEDESTAL DB





Example using a small subset of JET database

WEB interface to download the Pedestal DB from the Gateway

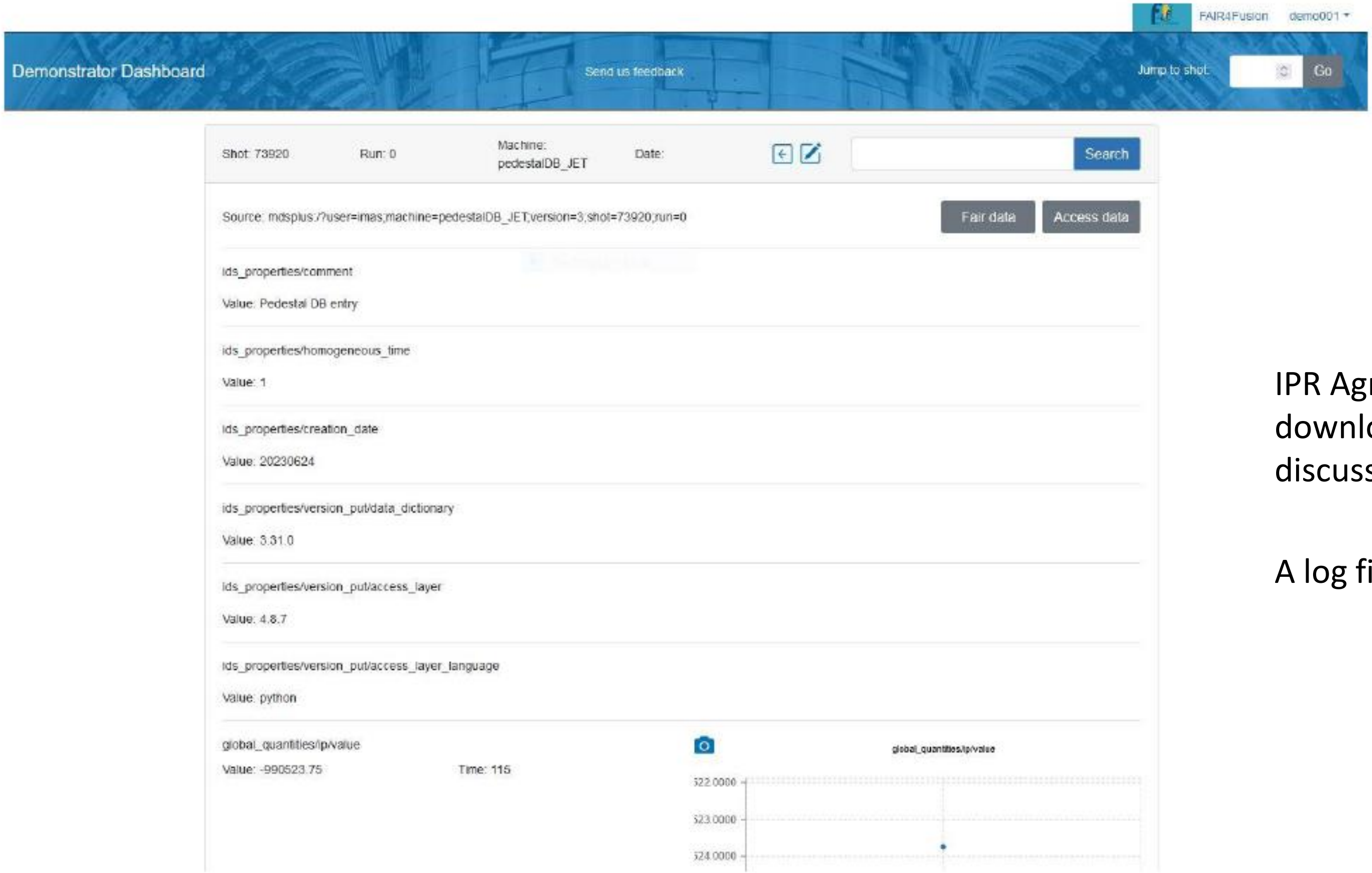
- ✓ requirements agreed: same as Fair4Fusion – usable for other DBs since in IMAS
- ✓ test interface on ACH Poznan server (subset of JET /TCV DBs)

https://chara-47.man.poznan.pl/dashboard/
username: **demo001**
password: **demo001**

- ✓ **to be deployed on new Gateway in 2024**

Frassinetti | 7-sept-2023 | pedestal DB updates | Page 6

WEB INTERFACE TO DOWNLOAD PEDESTAL DB



Example using a small subset of JET database

IPR Agreeement to download the data under discussion not yet agreed

A log file will track the activities

CONFINEMENT MULTI-MACHINE DATABASE STATUS

- **0-D confinement DB contains entries from JET & AUG with full metallic wall in type I ELMs**
  - JET 1699 entries in DT,DD,H,HT,HD,TT up to DTE1
  - AUG 966 entries in DD,H,HD +12 entries in HHe
  - The same rules used for data selection suggested also for WEST.
- Previous JET and AUG data provided to ITPA (v.5.2.3) updated and missing ones added, when possible. e.g. Te0, Ti0 and Te90,Ti90.
- The scientific exploitation of the DB is ongoing focusing on the isotope effect on core confinement

- **1D Profiles Database**
  - Quantities to be included in the profile database identified
  - EX2GK will be used to derive the profiles. Advantage: it can be set to output data in IMAS and run on the entries of the 0D profile.

  ! It has emerged how this database requires interpretative TRANSP runs (eg for a proper estimate of the thermal pressure profile and corresponding energy profile by the dilution of thermal ions, as well as proper deposition power profiles and losses) . TRANSP specialist is required

! Coordinator is ENEA third party and at present cannot access ITER cluster / IMAS

2024 planned DBs activities

- **Pedestal database**
  - Extend by including JET pulses from the 2023 campaign and update with more validated pulses.
  - Extend by including the recent TCV pulses.
  - Final test and deployment of the web interface (pending ACH support)
- **Confinement database**
  - Publication on the exploitation of the 0-D database focusing on the isotope effect on core confinement (H-H, D-D, T-T, D-T) in JET and AUG.
  - Map the 0-D database into IMAS (ACH support may be required)
  - Start adapting the web catalogue and interface for data browsing and visualization (ACH support).

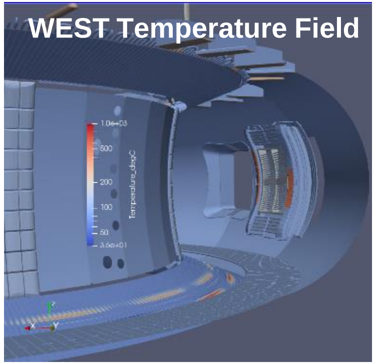
- **Exploit the Pedestal and Disruption databases using AI techniques**

  (pending PB approval & extra resources)

  - for calculating the pedestal parameters
  - for calculating disruption characteristic times in view of application to disruption avoidance

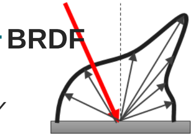
IR synthetic diagnostic

1 **3D Thermal Scene**

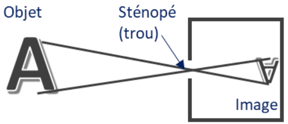


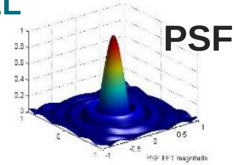
2 **Materials Optical Properties**

Emissivity, Reflectivity



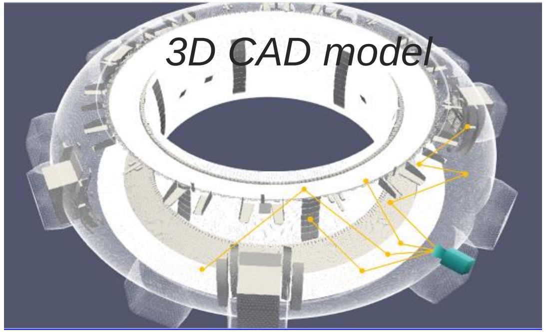
3 **Camera Model**



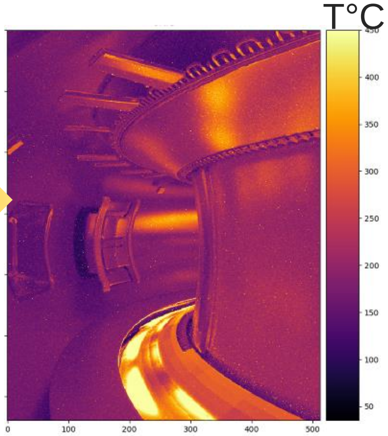


An **end-to-end simulation able** to reproduce with high fidelity IR image, taking into account all physical phenomenon involved in the IR measurement chain: from source to optical response of instrument

4 **Photon Transport Model**



Infrared Synthetic Image



Courtesy Mh Aumeunier

Implementation of IR imaging model: a compromise between speed and precision/generic

❑ IR Imaging model based on Ray Tracing (RT) code

- **Low Fidelity (LF) fast simulation available**
  - ✓ Assuming **diffuse** surface
  - ✓ Assuming **pure specular surface** (acting as mirror)
- **High Fidelity (HF) simulation based on MCRT code**
  - ✓ Complex surface properties (BRDF), complex geometry, **infinite sources**

❑ IR Imaging model based on Precomputed Radiance Transfer (PRT)

- **Low fidelity (LF) fast simulation**
  - ✓ Assuming diffuse surface + simplified geometry
- **Medium fidelity simulation in progress**
  - ✓ Complex brdf, **finite numbers of sources**

❑ A third way: Metamodel (fast with high fidelity) – R&D IN PROGRESS

- ✓ Based on neural network trained from high fidelity simulation

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Implementation of IR imaging model: a compromise between speed and precision/generic

❑ IR Imaging model based on Ray Tracing (RT) code

WALL DESCRIPTION IDS
- surfacic 3d mesh
- T° field
- Materials properties

IR CAMERA IDS
- Detector size
- Field-of-View
- Line-of-Sight
- Filter

IR imaging model - RT

☺ Generic solution
☹ Higher computing time

IR CAMERA IDS
- Apparent_T°_image
- Radiance_image

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❑ IR Imaging model based on Precomputed Radiance Transfer (PRT)

WALL DESCRIPTION IDS
- T° field

IR CAMERA IDS
- ray transfer matrix for fixed geo, camera and brdf

IR imaging model - PRT**

☺ Fast
☹ Geometry, camera and materials dependent

** include projection of input 3d T° field on reduced modal basis (PrIO tasks)

IR CAMERA IDS
- Apparent_T°_image
- Radiance_image

*Solution chosen by V.S. Neverov for VISIBLE camera simulation (easier because of limited number sources in visible)

Extension of IR Camera IDS

Full path name	Description	...es
▸ ids_properties	Interface Data Structure properties. This element identifies the node above as an IDS	
name	Name of the camera {static}	
▸ calibration	Calibration data	
▾ frame(itime)	Set of frames {dynamic}	...ime)/time
surface_temperature(:,:)	Surface temperature image. First dimension : line index (horizontal axis). Second dimension: column index (vertical axis). {dy... 3.34.0	
time	Time {dynamic} [s]	
▸ midplane	Choice of midplane definition for the mapping of measurements on an equilibrium. Introduced after DD version 3.32.1. Availa... identifier structure) :	

Name	Index	Description
magnetic_axis	1	Midplane defined by the height of magnetic axis equilibrium/time_slice/global_quantities/...
dr_dz_zero_sep	2	Midplane defined by the height of the outboard point on the separatrix on which dr/dz = 0 (... separatrix). In case of multiple local maxima, the closest one from z=z_magnetic_axis is ch... equilibrium/time_slice/boundary_separatrix/dr_dz_zero_point/z
z_zero	3	Midplane defined by z = 0
ggd_subset	4	Midplane location is specified by means of the GGD grid subset for the inner and outer mi... from the other available options. If the GGD midplane subset corresponds to one of the oth... option to indicate it

Full path name	Description	...es
▸ frame_analysis(itime)	Quantities deduced from frame analysis for a set of time slices {dynamic}. Introduced after DD version 3.32.1	...nalysis(itime)/time
latency	Upper bound of the delay between physical information received by the detector and data available on the real-time (RT) netw... 3.32.1	
latency_error_upper	Upper error for "latency" {static} [s]. Introduced after DD version 3.32.1	
latency_error_lower	Lower error for "latency" {static} [s]. Introduced after DD version 3.32.1	
latency_error_index	Index in the error_description list for "latency" {constant}	
▸ code	Generic decription of the code-specific parameters for the code that has produced this IDS	
time(:)	Generic time {dynamic} [s]	


```
{
  "position": [
    0.0,
    2.5,
    6.5
  ],
  "direction": [
    0.0,
    0.0,
    -1.0
  ],
  "up": [
    0.0,
    1.0,
    0.0
  ],
  "pixel_size_mm": 0.0015,
  "hfov_deg": 40.0,
  "height_px": 500,
  "width_px": 500,
  "infrared_filter": {
    "lambda_min": 3.8e-06,
    "lambda_max": 4e-06,
    "nb_lambda_subintervals": 10,
    "temperature_celcius_min": -100.0,
    "temperature_celcius_max": 5000.0,
    "nb_temperature_subintervals": 10000,
    "precompute": false
  }
}
```


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Extension of Wall description IDS

Full path name	Description	Data Type
▸ ids_properties	Interface Data Structure properties. This element identifies the node above as an IDS	structure
▸ temperature_reference	Reference temperature for which the machine description data is given in this IDS. Introduced after DD version 3.32.1	structure
first_wall_surface_area	First wall surface area {static} [m^2]	FLT_0D
first_wall_surface_area_error_upper	Upper error for "first_wall_surface_area" {static} [m^2]	FLT_0D
first_wall_surface_area_error_lower	Lower error for "first_wall_surface_area" {static} [m^2]	FLT_0D
first_wall_surface_area_error_index	Index in the error_description list for "first_wall_surface_area" {constant}	INT_0D
▸ first_wall_power_flux_peak	Peak power flux on the first wall [W.m^-2]	
first_wall_enclosed_volume	Volume available to gas or plasma enclosed by the fi	
first_wall_enclosed_volume_error_upper	Upper error for "first_wall_enclosed_volume" {static	
first_wall_enclosed_volume_error_lower	Lower error for "first_wall_enclosed_volume" {static	
first_wall_enclosed_volume_error_index	Index in the error_description list for "first_wall_encl	
▸ global_quantities	Simple 0D description of plasma-wall interaction	
▸ description_2d(i1)	Set of 2D wall descriptions, for each type of possible holes, coarse vs fine representation, single contour lir the toroidal extension of the 2D contours is also prov	_size=3 (limited in MDS+
▾ description_ggd(i1)	Set of 3D wall descriptions, described using the GGD tight vs wall with ports and holes, coarse vs fine repre	_size=3 (limited in MDS+
▸ type	Type of wall: index = 0 for gas tight and 1 for a wall	
▸ grid_ggd(itime)	Wall geometry described using the Generic Grid Des this array of structure must be a subset of the timebase on which physical quantities are described (../ggd structure). Grid_subsets are used to describe various wall components in a modular way. {dynamic}	struct_array
▸ material(itime)	Material of each grid_ggd object, given for each slice of the grid_ggd time base (the material is not supposed to change, but grid_ggd may evolve with time) {dynamic}. Introduced after DD version 3.37.2	struct_array
▸ ggd(itime)	Wall physics quantities represented using the general grid description, for various time slices. {dynamic}	struct_array
▸ code	Generic decription of the code-specific parameters for the code that has produced this IDS	structure
time(:)	Generic time {dynamic} [s]	FLT_1D

Wall IDS extension

- ✓ **Surface temperature** resulting from heat flux computations + thermal computations
- ✓ **Material optical properties** fixed or dynamic by material (W, Be, CFC, Cu, etc)

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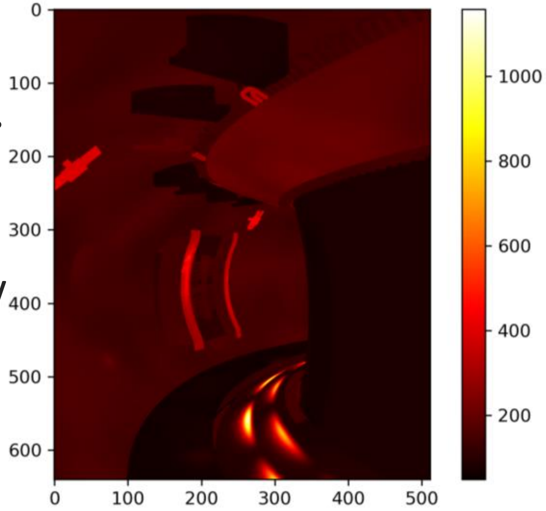
Extension of Wall description IDS

❑ Temperature Field

2 ways to describe spatial T° distribution

- ✓ **3d temperature field T(x,y,z)**
- ✓ **Uniform temperature by component T(component_name)**



❑ Material Optical Properties

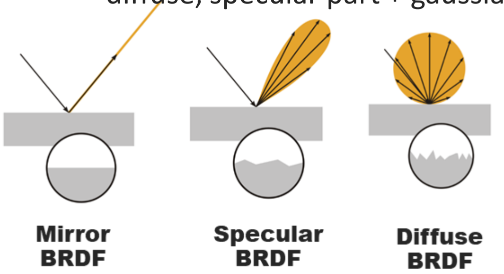
Several models exist to describe photon-wall behavior (Gaussian, Phong, micro-facet, etc)

➔ **Preferred model (for now): Phong reflection model**

- ✓ 4 parameters:
  - ✓ Absolute values of diffuse part + specular part, mirror part + specular Gaussian width

  OR

  - ✓ Normal emissivity + relative values of diffuse, specular part + gaussian width



Possible to upgrade materials for advanced models ?

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IR synthetic diagnostics WorkPlan

- 2023/24: Extension of IDs wall and IR camera for IR imaging model
- 2024: Implementation of fast and Low Fidelity simulation
  - diffuse or specular RT model
  - diffuse PRT model
- 2025: Implementation of High Fidelity simulation
  - RT: slow & High Fidelity,
  - PRT: fast & Medium Fidelity
  - NN: fast & High Fidelity

RT: Ray tracer
PRT: Precomputed Radiance Transfer
NN: Neural Network