# New modelling capabilities to support ITER EC H&CD System optimization and the preparation of plasma operation

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

# Outline

- ITER EC System description
- Zemax OpticStudio Simulations
- EC modelling in IMAS
- Summary

# EC system in the ITER Research Plan

- The ITER Research Plan defines the strategy to achieve its mission goals throughout the scientific and technical exploitation of the tokamak and its ancillary systems.

- It will unfold in four stages:

Link to ITR-18-003


ITER TECHNICAL REPORT
ITER Research Plan within the Staged Approach (Level III – Provisional Version)

## First Plasma

*18 months* **FP**
*IC+FP+EO*
**H plasmas**

ECH – 5.8 MW

Integrated commissioning of tokamak core components

## Pre-Fusion Power Operation 1 and 2

*18 months* **PFPO-1**

**H, $^4$He plasmas**

ECH - 20 MW

- Main plant systems commissioning
- $P_{L\text{-}H}$ determination

*21 months* **PFPO-2**

**H, $^4$He plasmas**

ECH + ICRH + NBI = 73 MW

- Raise current and power
- Increase pulse duration

## Fusion Power Operation

*16 months* **FPO**

**D, DT plasmas**

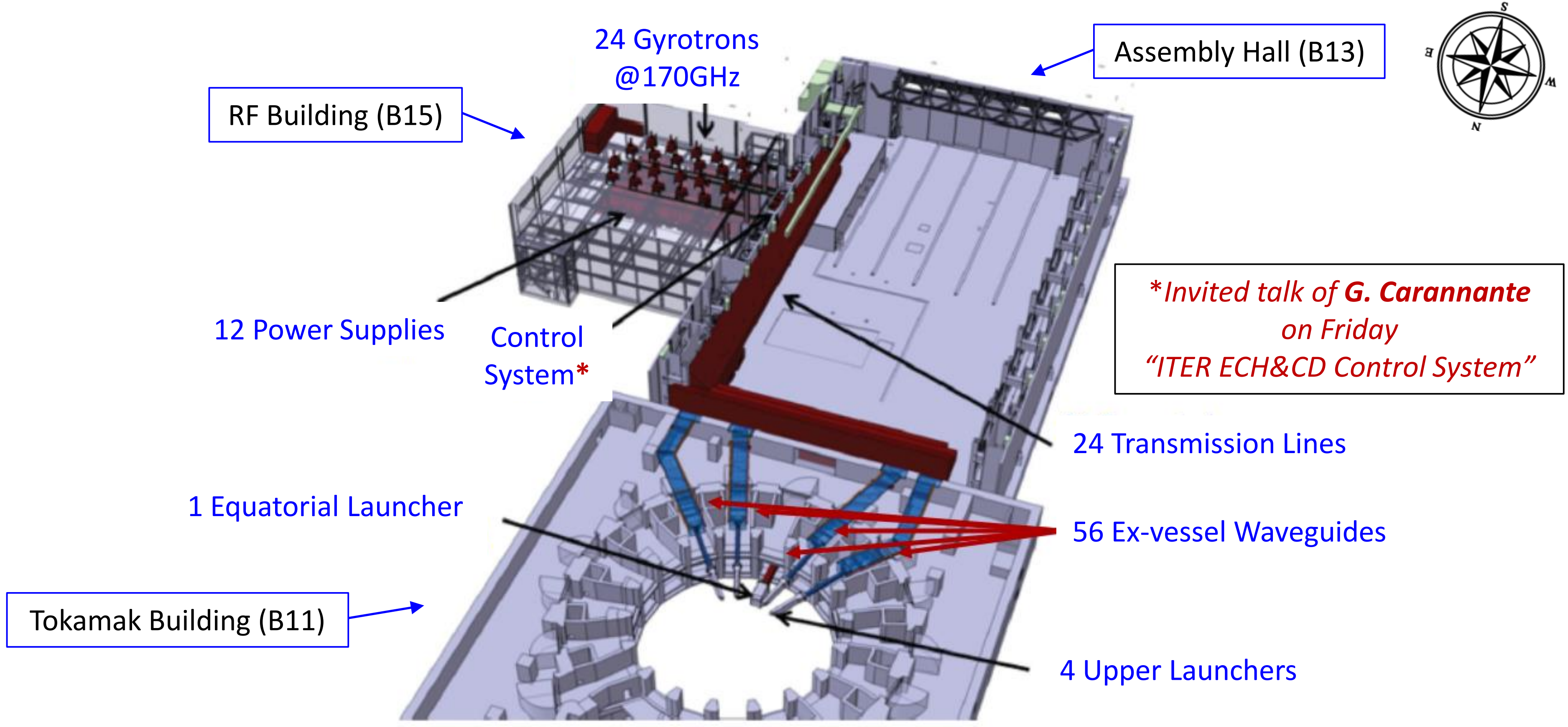
ECH+ICRH+NBI=73 MW + fusion up to 100 MW

- Q=10
- Long pulse operation
- Burning plasmas

Plasma breakdown assist with ECH at 2.65T (and 5.3T in EO if needed after FP)

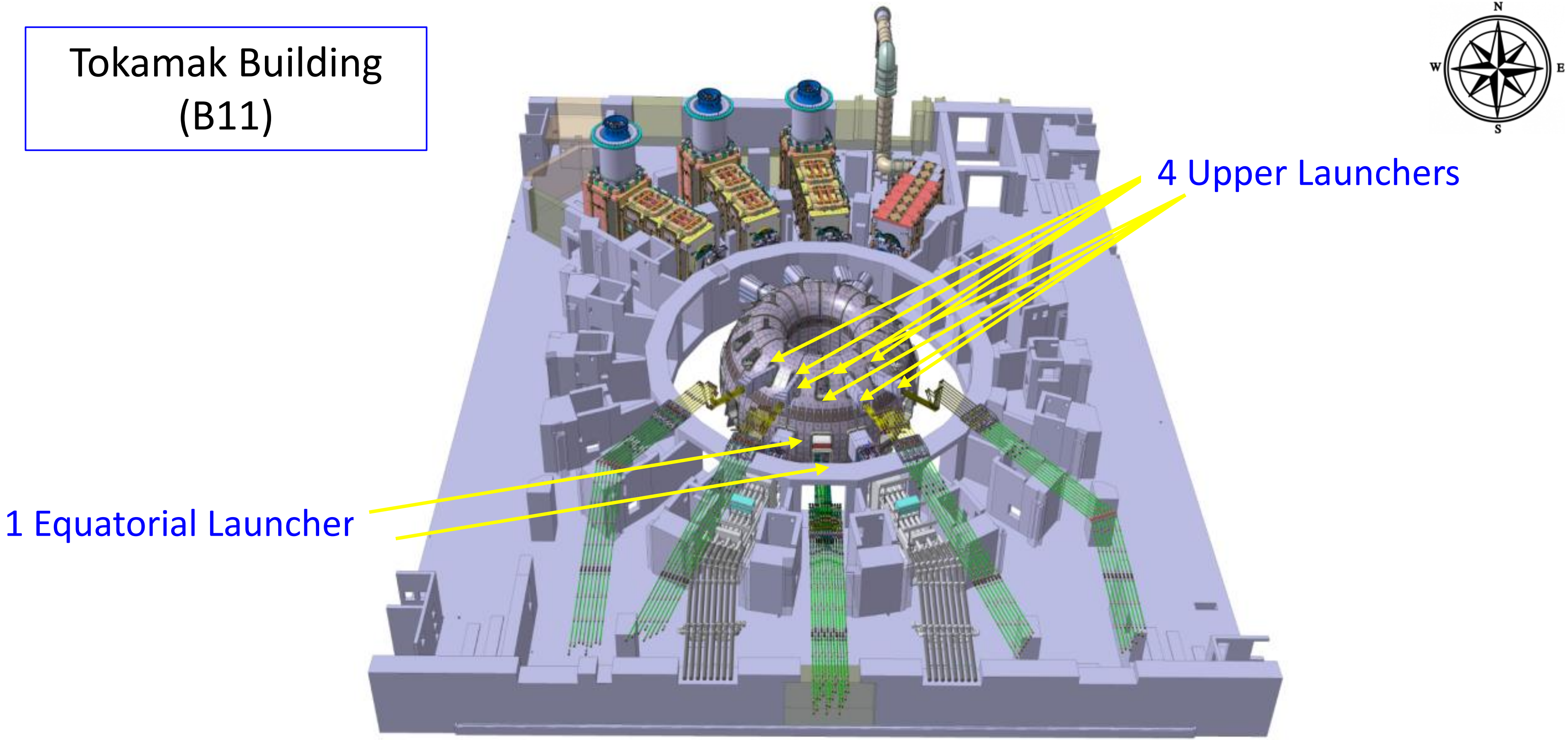
Extension of the pulse length to 3600s

# EC system layout (1/2)



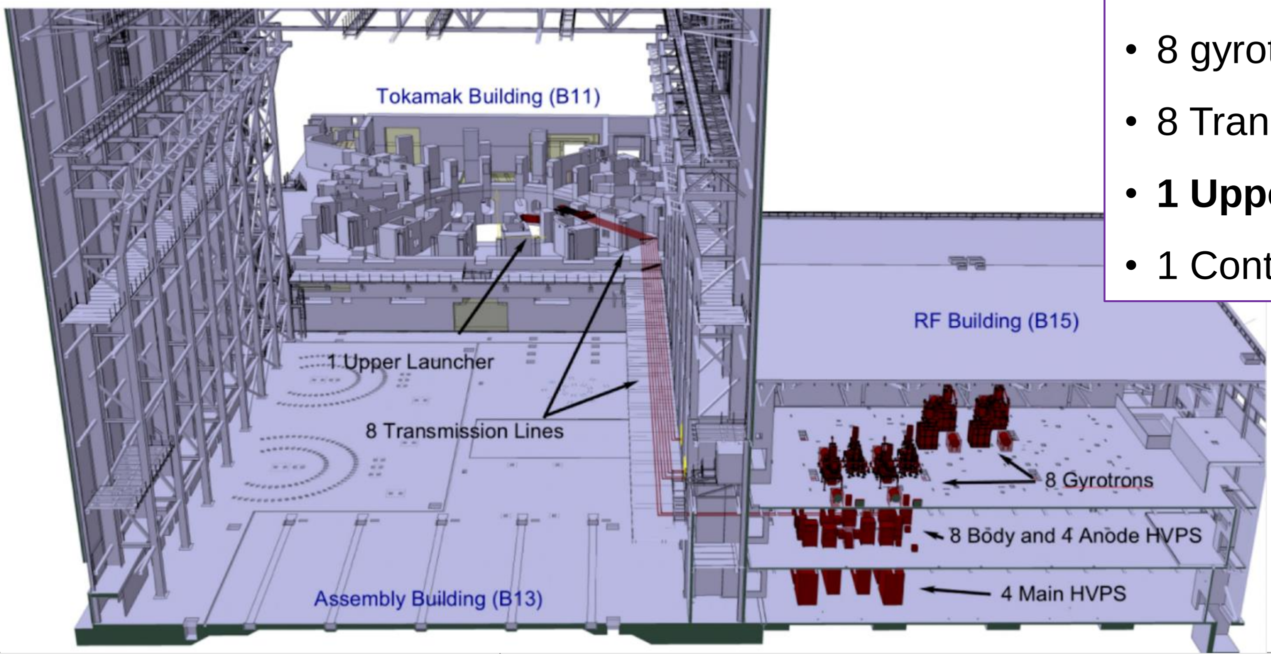
# EC system layout (2/2)

Tokamak Building (B11)



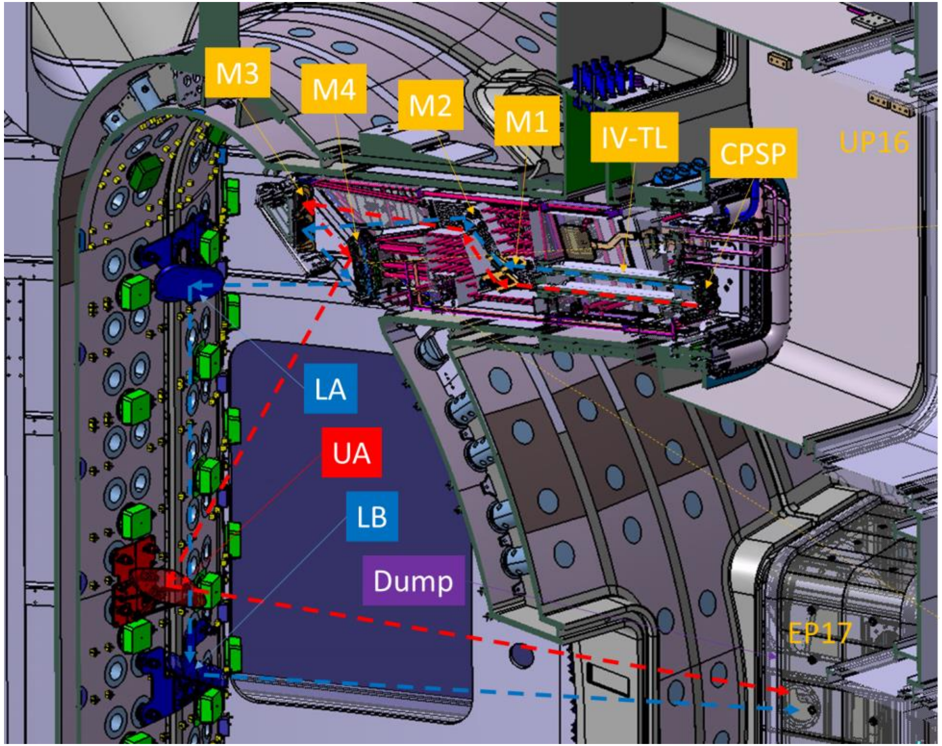
# EC for First Plasma: 8 MW Plant Description

- The EC system will consist of 8 **beamlines of 0.83 MW each, injected into the plasma**
- Currently it is planned to operate with 7 beamlines

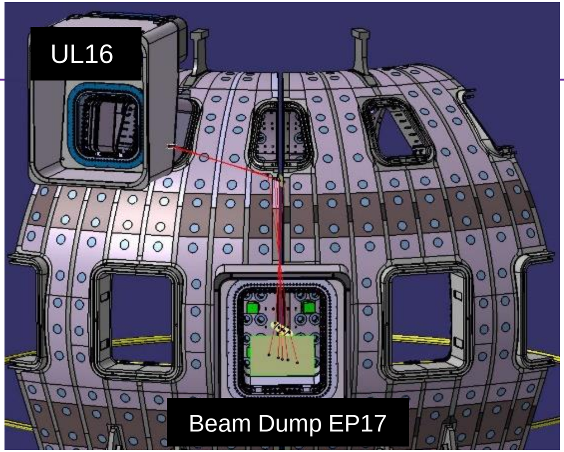



- 4 High Voltage Power Supply sets
- 8 gyrotrons
- 8 Transmission Lines
- **1 Upper Launcher in Upper Port 16**
- 1 Control system

# EC for First Plasma: in-Vessel Optical Design (1/2)

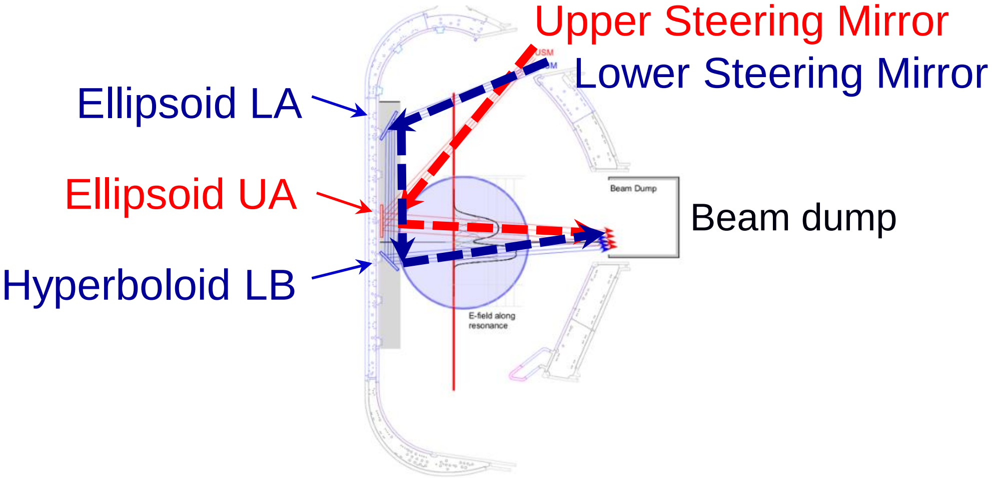


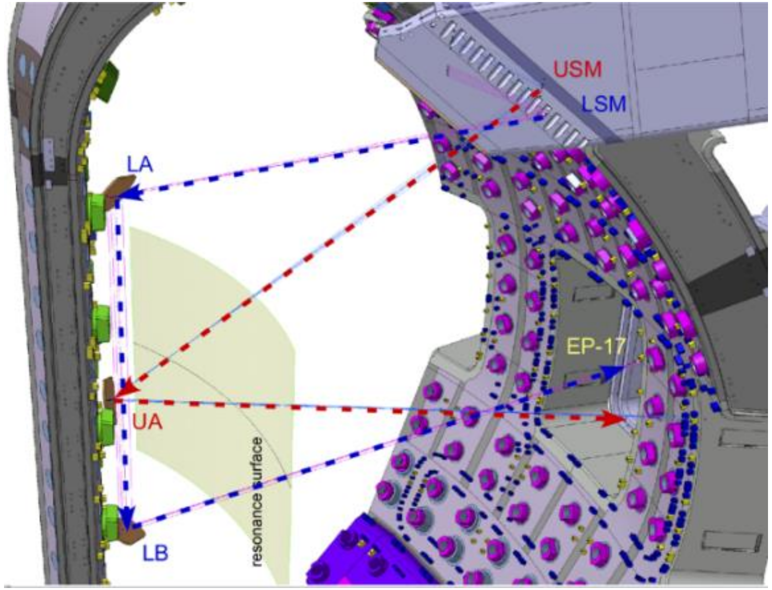

- Adaptation needed on the last **M4** steering mirror
- 2 in-board mirrors **LA & LB** to redirect the L-beams (x4) to the plasma null region
- 1 in-board mirrors **UA** to redirect the U-beams (x3) to the plasma null region
- **Beam dump** in Equatorial Port 17 to absorb the residual power



# EC for First Plasma: in-Vessel Optical Design (2/2)

- In-vessel optical configuration achieves:
  - 3 beams above and 4 beams below magnetic null.
  - Beam size:
    - L-beams: 50 < *w* < 100 mm
    - U-beams: 50 < w < 70 mm.



# Gyrotron distribution of 24MW system / 56 entries

Gyrotrons #1 to #8
Switch between:
- UL12 & UL13
- EL14: top row – Cnt-CD

6.7MW

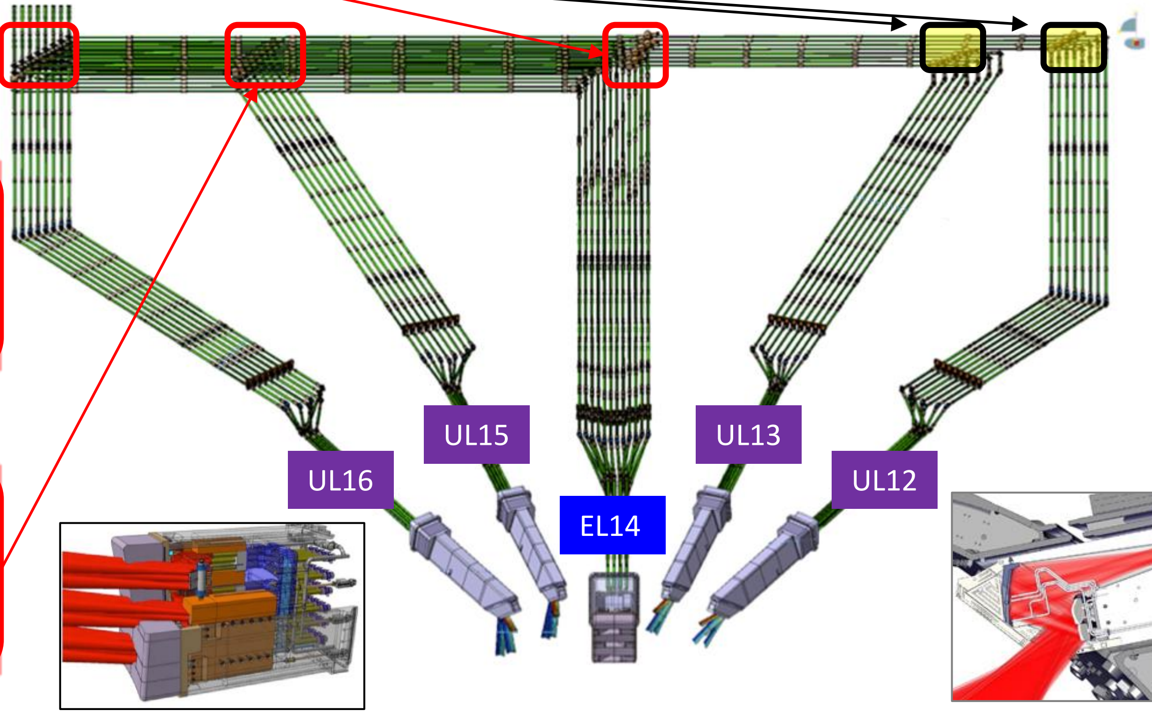
Gyrotrons #17 to #24
Switch between:
- UL16
- EL14: bottom row – Co-CD

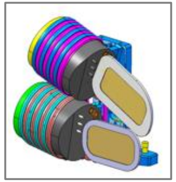
6.7MW

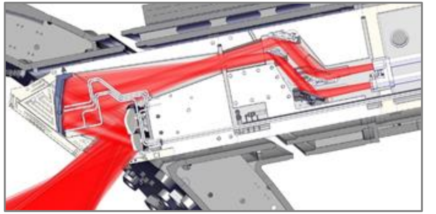
Gyrotrons #9 to #16
Switch between:
- UL15
- EL14: middle row – Co-CD

6.7MW

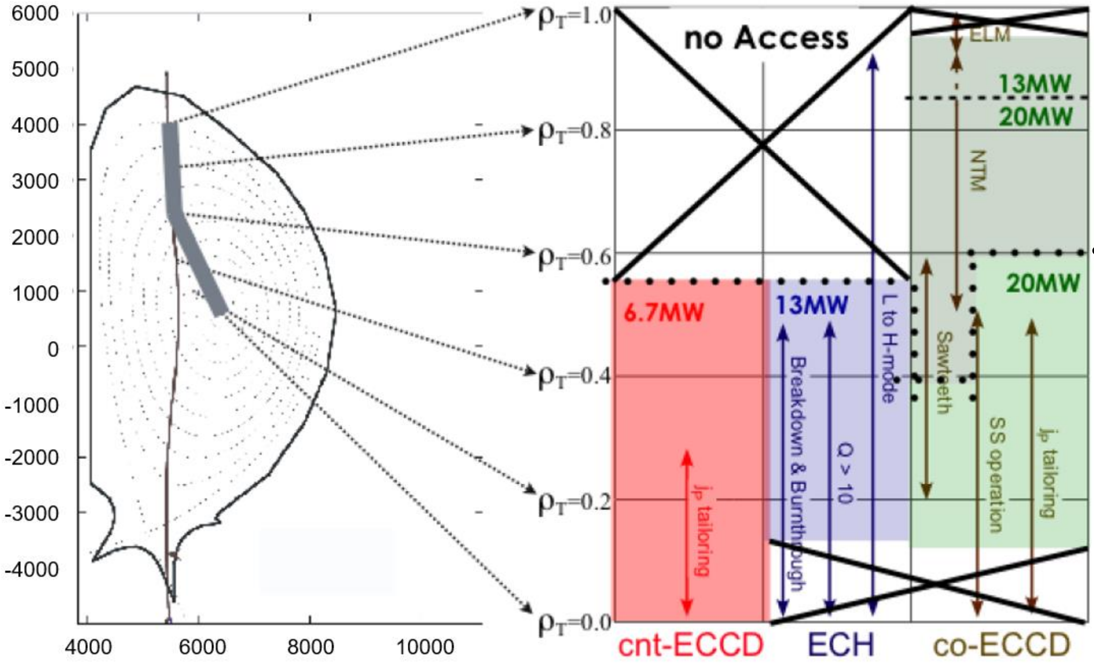

Additional Switches between upper and lower rows of the UL12 & UL13

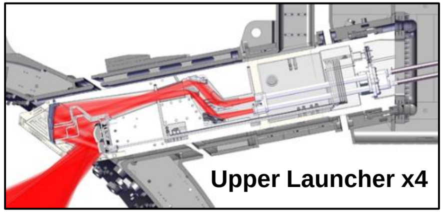


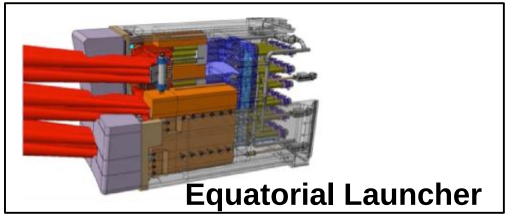



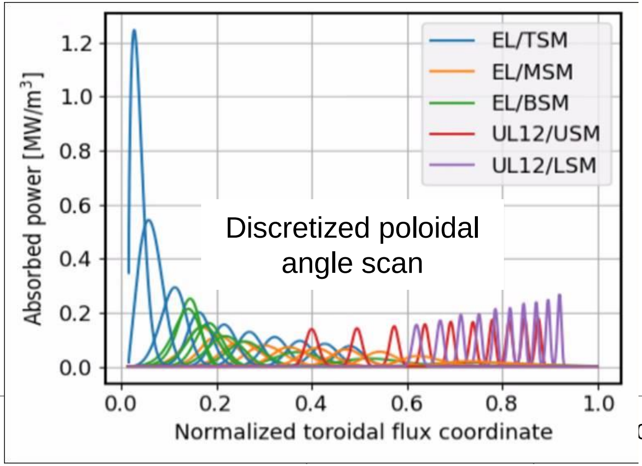


# H&CD capabilities of the EC system




The deposition access of the EL and UL across the plasma cross section and categorized based on driving cnt-ECCD, co-ECCD or pure heating.

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# Zemax OpticStudio

**Zemax OpticStudio** simulations were performed for the first time in IO in the frame of the First Plasma Protection Components design finalization* and validated against PROFUSION**

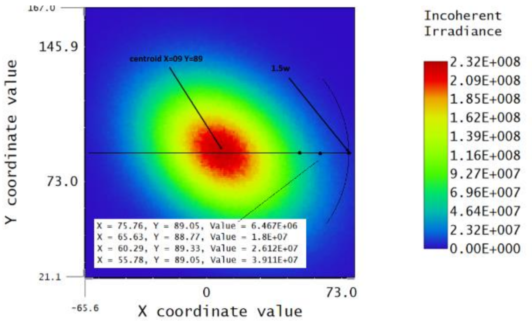
*** Poster 2-6 of **M. CHOE***
*Ray tracing calculations for the First Plasma configuration of ITER ECH system*

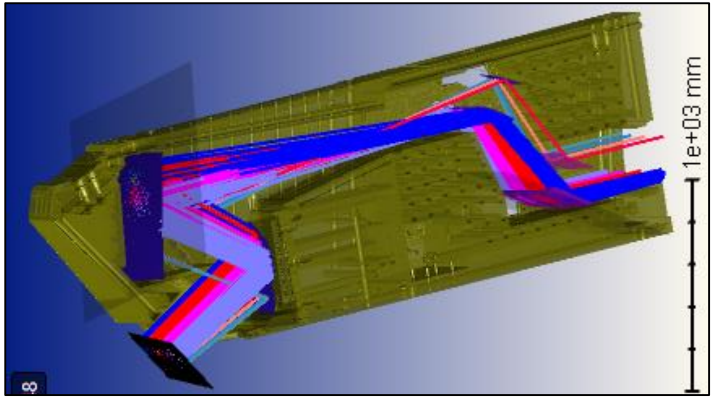
**Talk of **B. Plaum**
"Calculations for the optical system for the first ITER plasma"

Zemax is a complementary tool to existing codes like:

- GRASP (General Reflector Antenna Simulation Package) (CNR)
- PROFUSION (IGVP Stuttgart)

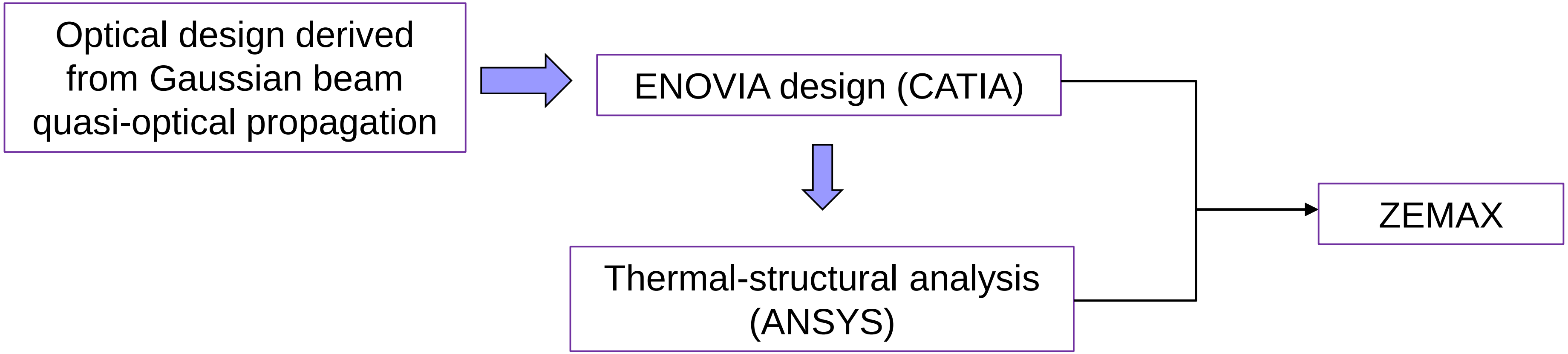
New models developed in the frame of the UL design finalization, in particular to deal with misalignment sources



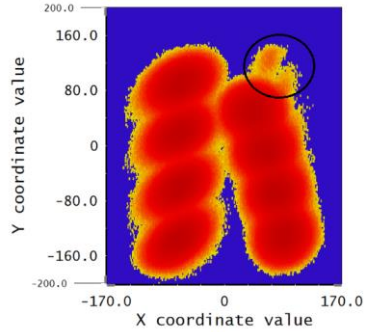
# Zemax OpticStudio

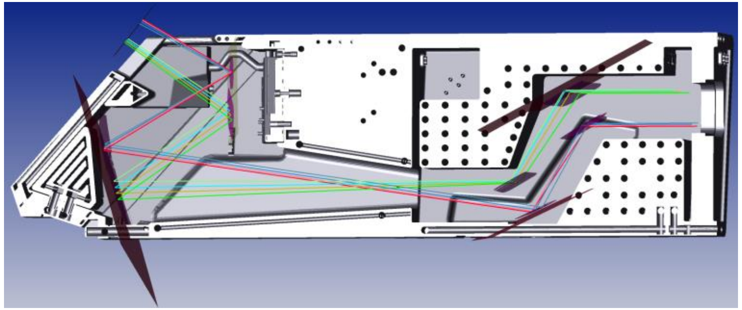
- **Gaussian beams (.dll)** can be described by a bunch or rays (several millions)
- Source of the beam is defined at the aperture of the **IV-WG**
- **Exact geometry** of the mirror surface from ENOVIA model using step files
- All the port plug geometry can be considered
- A **reflective coefficient** can be defined for each component using an arbitrary value or by using an custom coating (that can include polarization and incidence properties)

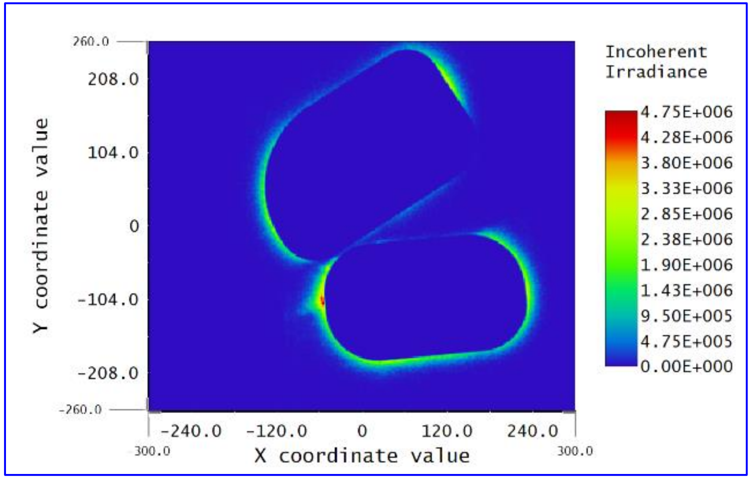


# Zemax OpticStudio

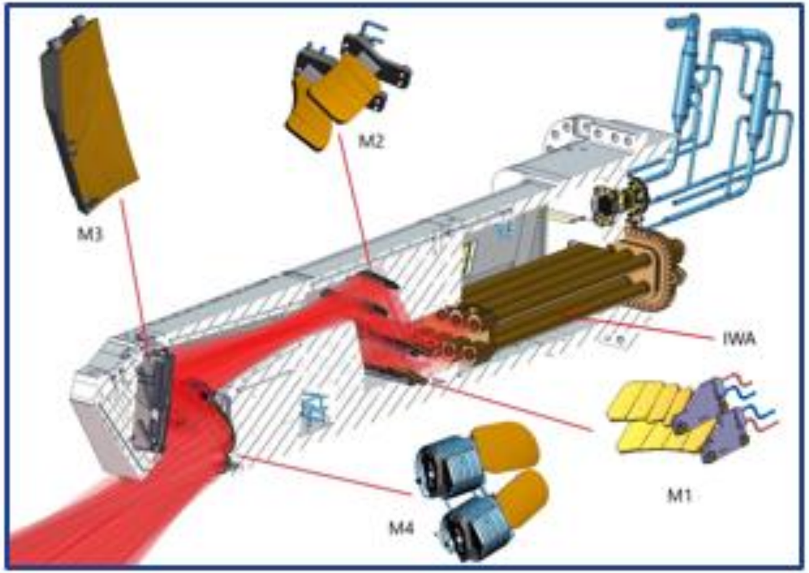
- Full 3D CATIA model can be considered in the model that allows to:
  - Evaluate the propagation losses along beam propagation (launcher):
    - at the mirrors
    - due to the surrounding components (port plug wall, etc)
    - Partial reflection of the beam by surrounding sub-mirrors
  - To characterize power density on sensitive components/area
  - To characterize the potential impact of misalignment sources on:
    - UL survivability
    - UL performances

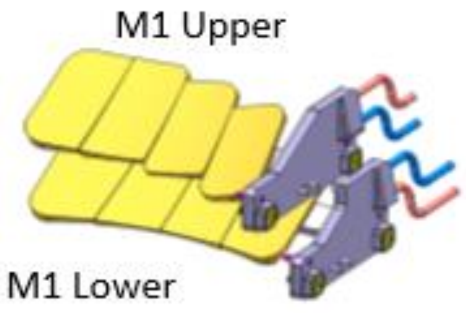


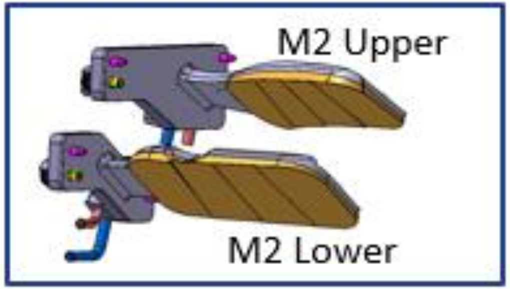



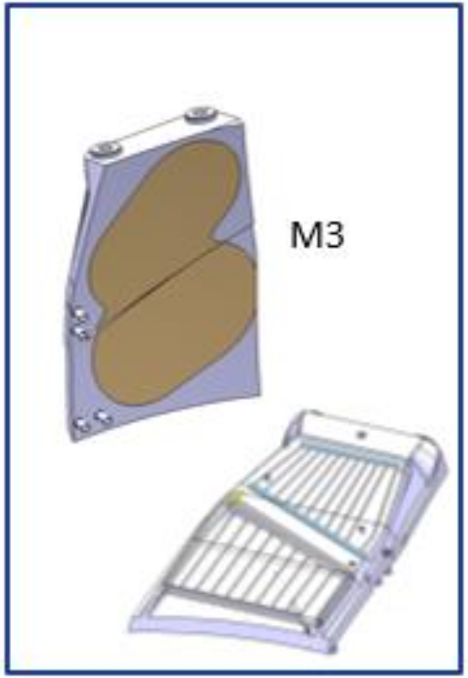


# Upper Launcher overview



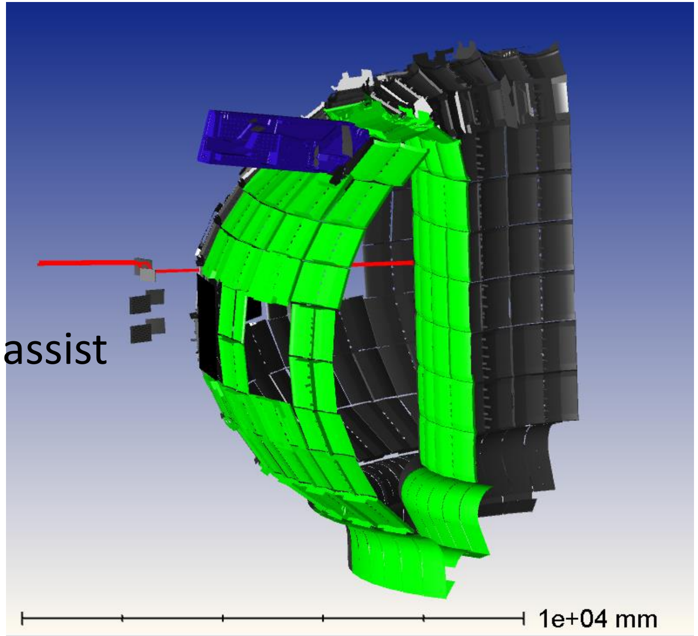
# Equatorial Launcher simulation

A model is being developed with the geometry of the equatorial launcher as well

Currently two goals:

- Complement and assess the stray radiation analysis of the Equatorial launcher performed by JADA

- Develop a tool for plasma operation preparation: definition of operation window of EL for plasma breakdown assist



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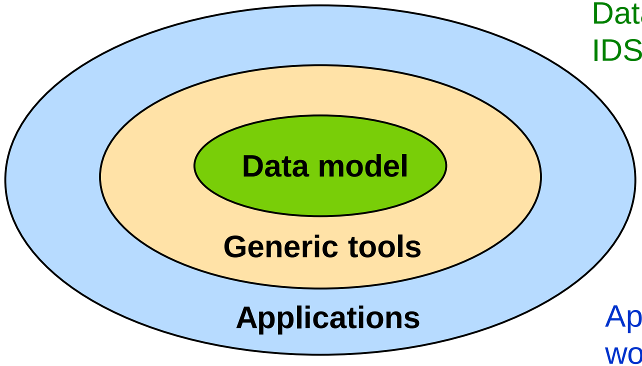
# The ITER Integrated Modelling & Analysis Suite (IMAS)

- **IMAS is the collection of physics software that will be used to support ITER operation and research as defined in the ITER Integrated Modelling Programme**
- It uses standard Interface Data Structures (IDS) to represent experimental and simulated data (defined in collaboration with the ITER Members):
  - IDSs are used to get/put data to storage
  - IDSs are applicable to any fusion device
  - IDSs are passed between IMAS physics models to build up integrated modelling workflows
- IMAS will be capable of high physics-fidelity predictive simulations of ITER plasmas
- IMAS will be used for ITER data processing and analysis




Data model: set of machine-independent IDSs defining the IMAS standard

Generic tools: functions for data access, storage, manipulation, visualization

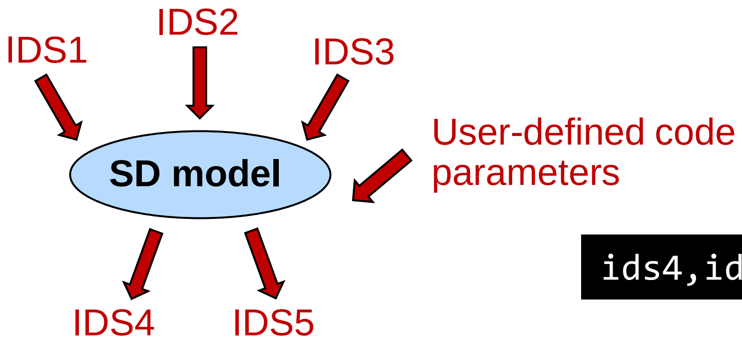
Applications: physics codes, physics workflows, control algorithms

**Databases**
Scenarios
Machine Descr.
Disruption

**Doc & support**
Tutorials
Web documentation
Tracker system

# Models in IMAS

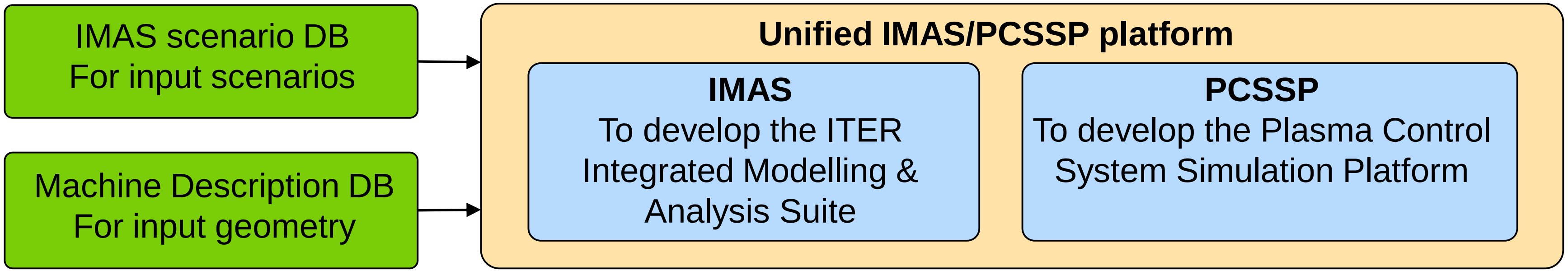
- An IMAS model exchanges IDSs exclusively + optional file for code parameters:




```
ids4,ids5 = sd_model(ids1,ids2,ids3,xml_codeparam)
```

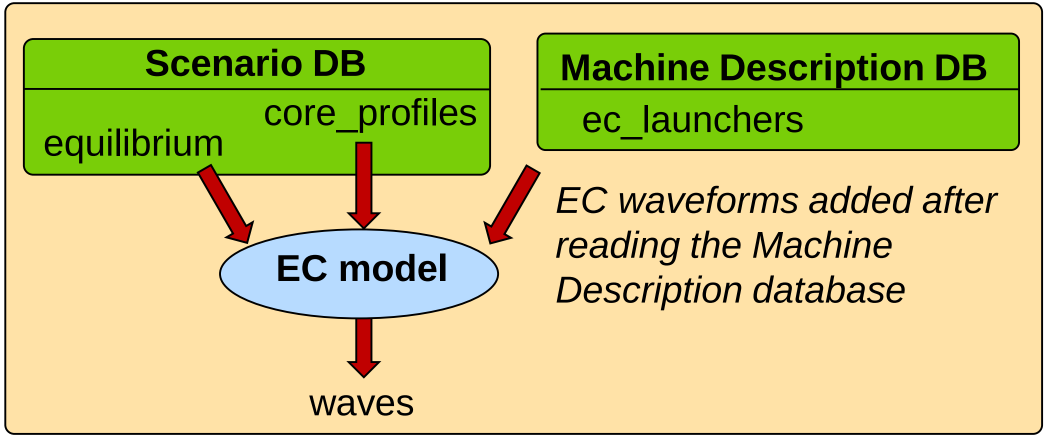
It is a single component that can be integrated into the IMAS framework

- An IMAS model usually takes its input from the Scenario and Machine Description database:



# Running an EC wave code in IMAS

- EC wave codes need the following input:
  - An existing scenario → IMAS Scenario database → *equilibrium*, *core_profiles*
  - The EC geometry → IMAS Machine Description database → *ec_launchers*



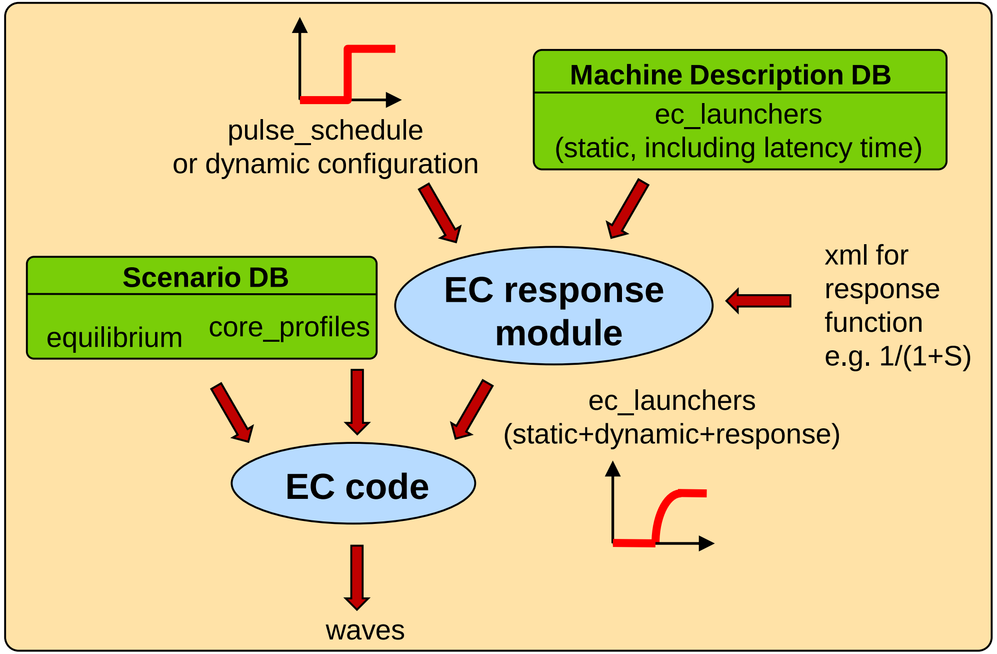

- EC waveforms (power, steering angles, polarization) are configured and added to the *ec_launchers* IDS

- EC wave results are stored in the *waves* IDS.

- All tools and associated documentation are available for this modelling (training material provided on demand)
- Good starting point here: [Getting Started]

# Using pulse_schedule for dynamic data

- We will ultimately provide a waveform editor to use the *pulse_schedule* IDS as input together with a response module to simulate more relastic dynamic data.



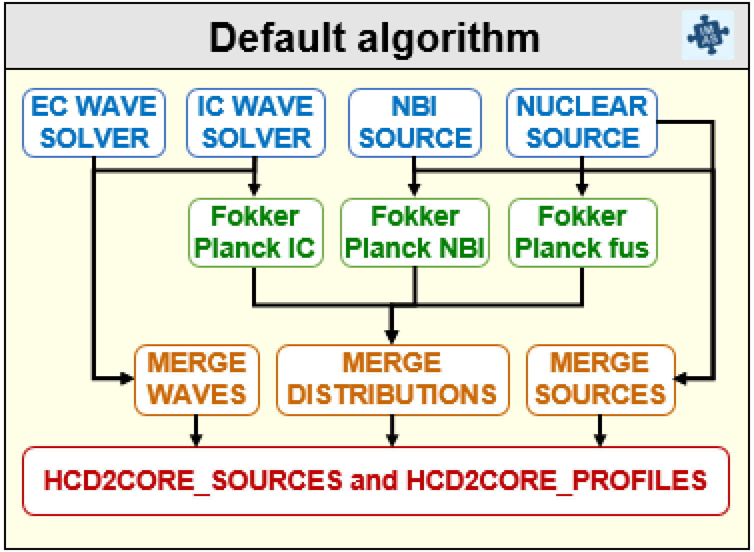

Work in progress!

# Presentation of the H&CD workflow

- Written in plain Python
- Contains IMAS-adapted models to simulate all ITER H&CD sources

|  | ECRH | ICRH | NBI | Nuclear reactions |
|---|---|---|---|---|
| **Wave or source** | GENRAY<br>GRAY<br>GRAYSCALE<br>TORBEAM | CYRANO<br>LION<br>PION<br>TOMCAT | BBNBI<br>NEMO | AFSI<br>SPOT ($\alpha$) |
| **Fokker-Planck** | Ø | FOPLA<br>PION<br>ASCOT<br>SPOT | ASCOT<br>SPOT<br>RISK<br>NBISIM | ASCOT<br>SPOT |

Input from IMAS database or transport solver

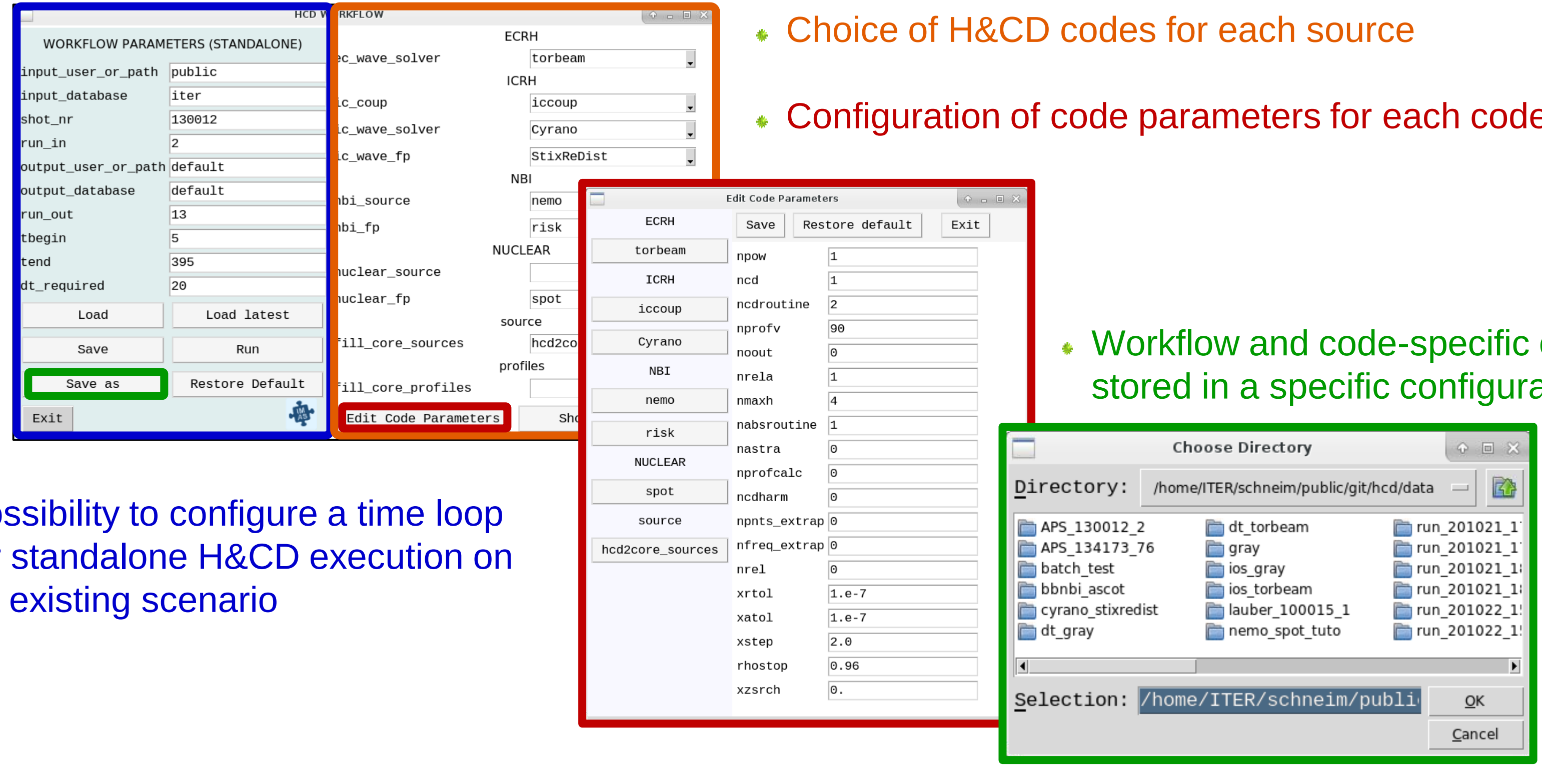



Output to IMAS database or transport solver

- The core of the H&CD workflow has an interface made such that it is easy to plug into other workflows (e.g. transport solvers)
- Includes a graphical interface for standalone H&CD simulation

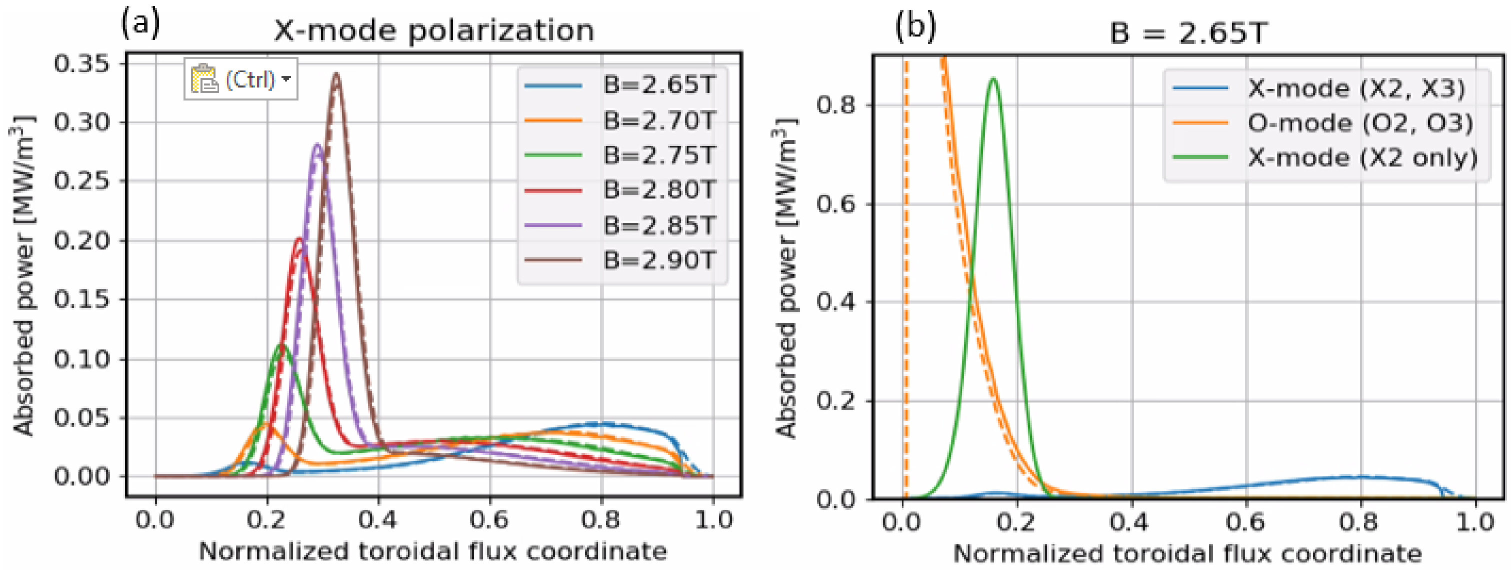
# GUI to configure the H&CD workflow

The graphical interface is dynamically built from code-specific parameters files:




- Choice of H&CD codes for each source
- Configuration of code parameters for each code
- Workflow and code-specific configuration stored in a specific configuration folder
- Possibility to configure a time loop for standalone H&CD execution on an existing scenario

# Study of ECH absorption profiles in 2.65 T / 7.5 MA scenarios




- Switch from TORBEAM to GRAY in the H&CD GUI: one click!
- Since both codes are adapted to IMAS, the exact same input is ensured!
- Excellent agreement between TORBEAM (solid) and GRAY (dashed)

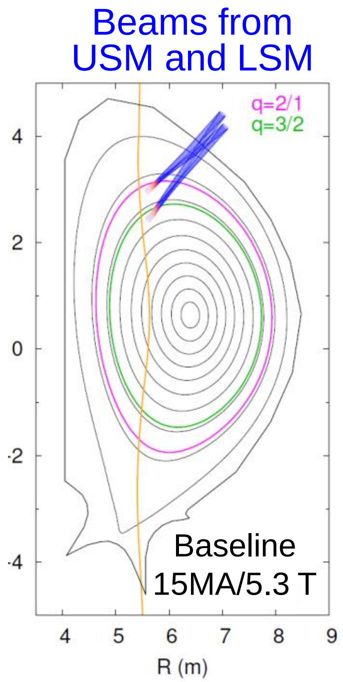
→ IMAS platform suited for Verification and Validation!

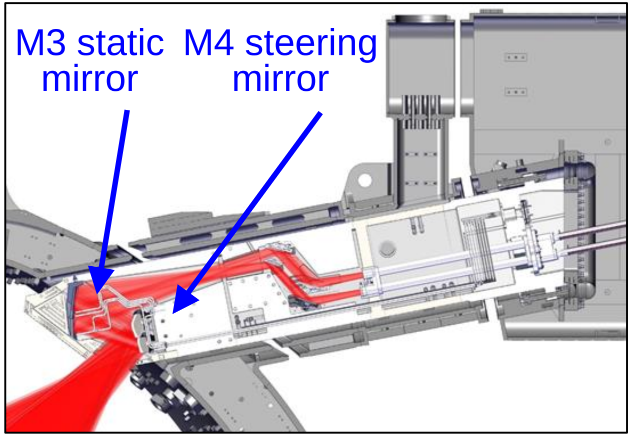
*[M. Schneider et al.,Nucl. Fusion 61 (2021) 126058]*

# EC Machine Description data

Example of the Upper Launchers:

- EC wave codes need the geometry of the beams at the M4 steerable mirror (exit of the launcher)
- The actual static data is at the level of the M3 static mirror




- Right now the ec_launchers IDS contains data coming out of the M4 steering mirror
- The plan is to store M3 static data instead and to develop a tool that computes the characteristics of the beams coming out of M4 on the fly (to be generic if possible)
- So far mirror information was stored but it will be replaced by beam information (56 beams, see IMAS-4244)

Very scenario dependent!
→ List of scenarios recommended by Science Division for performance studies under preparation

→ Work in progress!

# Summary

- Installation of EC system has started (HVPS) but part of it is still under design finalization


- Zemax OpticStudio modelling supports some design finalization activities of the optical design but will be used as well for plasma operation preparation
- IMAS Modelling tools are mature and ready for EC modelling
- EC codes can be run standalone or within the H&CD workflow
- Various activities and significant progress made via the H&CD ITER Scientist Fellow Network (information available here: HCD ISF pages)