ITER Spectroscopic Diagnostics and Atomic Data Needs

Zhifeng CHENG
ITER Organization

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iter
china eu india japan korea russia usa

THE ITER MISSION

To demonstrate the scientific and technological feasibility of fusion power for peaceful purposes at industrial scale

To create a controlled "burning" plasma

To achieve $Q \geq 10$

Overall diagnostics situation

ITER has **26 diagnostic ports** which house about **50 diagnostic systems**.

They are procured through **7 different DAs** (CN, EU, IN, JA, KO, RF and US) and by the **ITER Organization**.

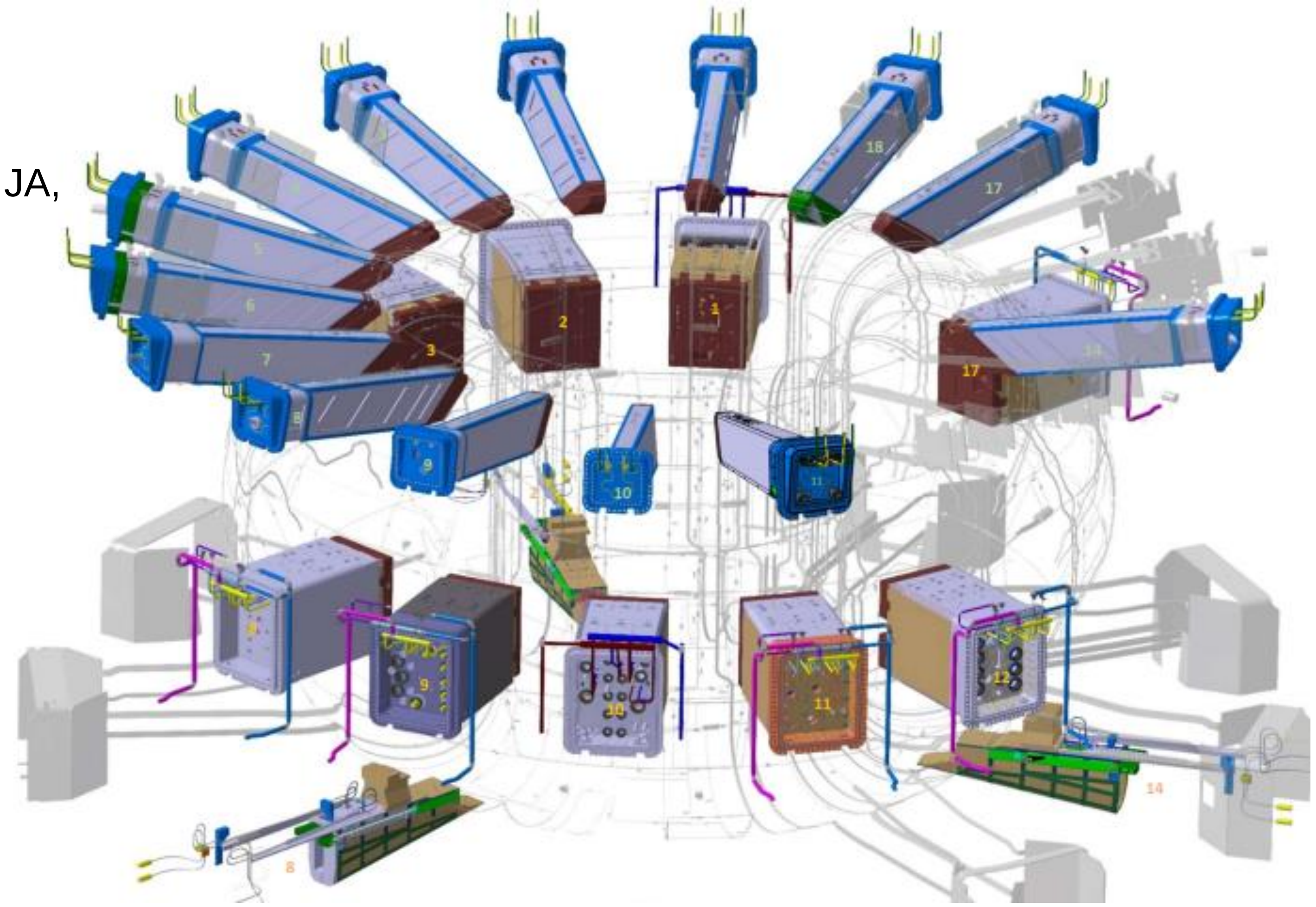
~1/3 are spectroscopic diagnostics:

Visible:
- **H-alpha and Visible Spectroscopy**
- **Divertor Impurity Monitor**
- **Visible Spectroscopy Reference System**

VUV:
- **Vacuum UltraViolet Survey (VUV Survey)**
- **Vacuum UltraViolet Div (VUV Div)**
- **Vacuum UltraViolet Edge (VUV Edge**

X-Ray:
- **X-Ray Crystal Spectroscopy Core (XRCS Core)**
- **X-Ray Crystal Spectroscopy Survey (XRCS Survey)**
- **X-Ray Crystal Spectroscopy Edge (XRCS Edge)**
- **Hard X-Ray Monitor**

Charge Exchange:
- **Charge Exchange Recombination Spectroscopy Core**
- **Charge Exchange Recombination Spectroscopy Edge**
- **Charge Exchange Recombination Spectroscopy Pedestal**

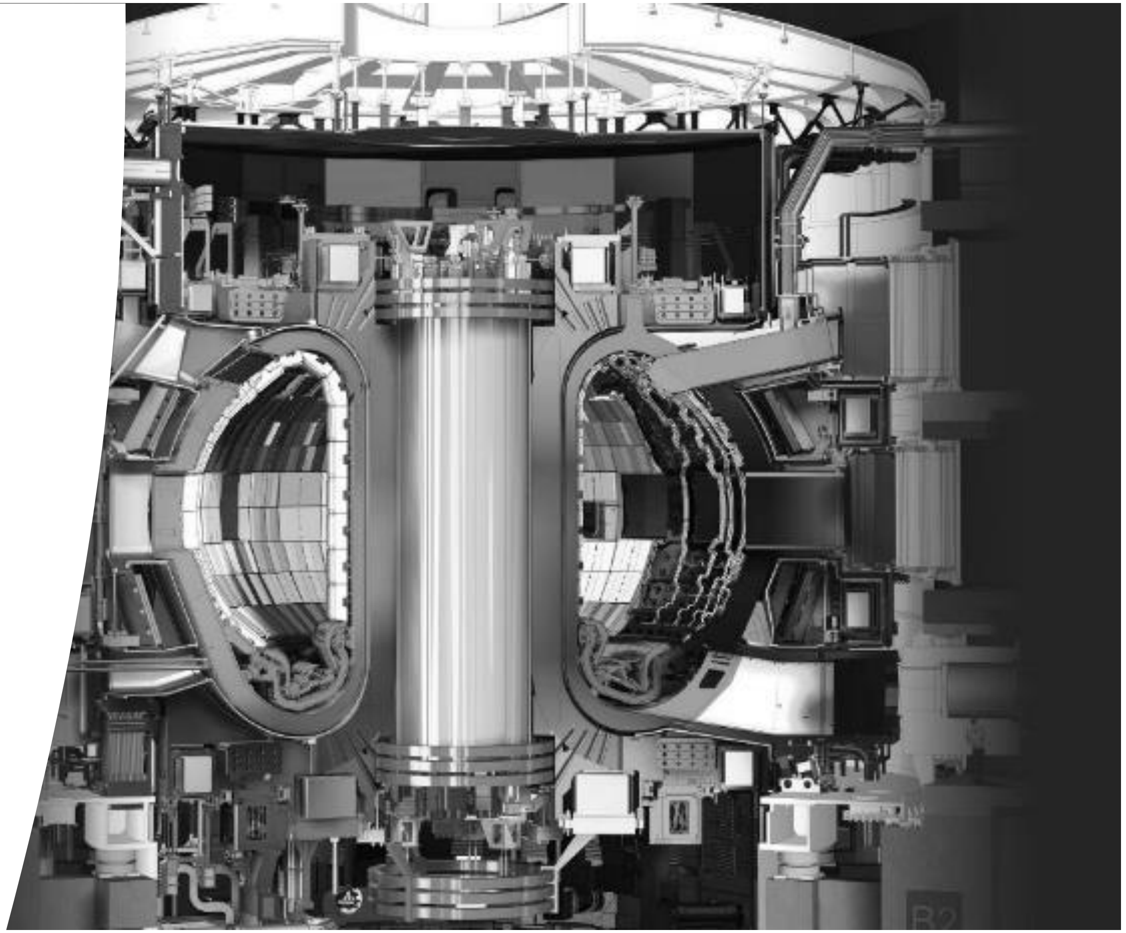


Overview of Diagnostic (port plugs highlighted)

Measurements for Spectroscopic Diagnostics

ITER is being proposed for FULL TUNGSTEN first wall with boronization

- Measurement Parameter 007-009. Prad
- Measurement Parameter 018. Vpol
- Measurement Parameter 019. Vtor
- Measurement Parameter 020. **nT/nD** in Plasma Core
- Measurement Parameter 021. ligh impurities Influx
- Measurement Parameter 022. ligh impurities Relative Concentration
- Measurement Parameter 027. **W Influx**
- Measurement Parameter 028. **W Relative Concentration**
- Measurement Parameter 029. Line-averaged Zeff
- Measurement Parameter 030. ELM radiation bursts
- Measurement Parameter 032. ELM Temperature Transient
- Measurement Parameter 033. **L-H D-alpha** Step
- Measurement Parameter 064. Core Ti
- Measurement Parameter 065. Edge Ti
- Measurement Parameter 073. Fractional Content Z>10
- Measurement Parameter 074. Fractional Content Z≤10
- Measurement Parameter 076. **nT / nD** Edge
- Measurement Parameter 078. Be, C, **W influx** in divertor
- Measurement Parameter 088. **nH / nD** Divertor
- Measurement Parameter 094. **nH / nD** Core
- Measurement Parameter 095. **D /T Influx** in Chamber



New requirement: B is coming while Be will be removed

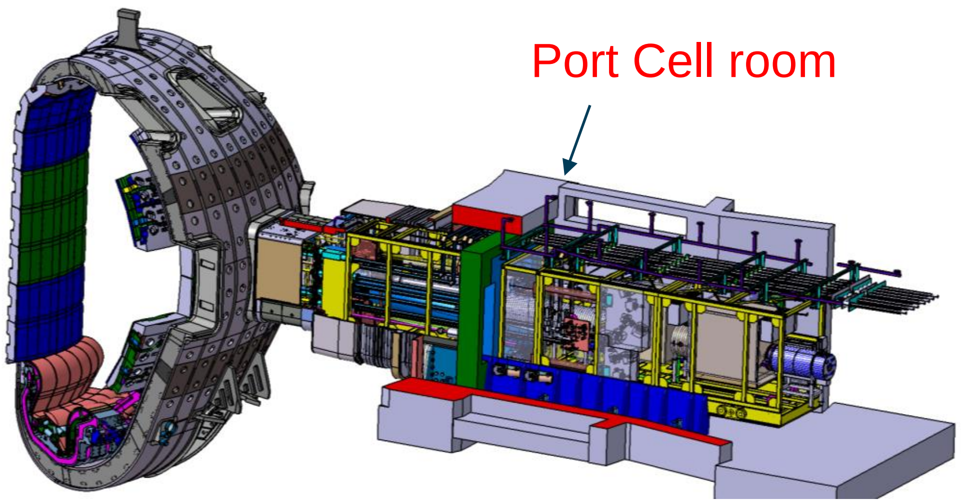
Diagnostic Spectral Ranges

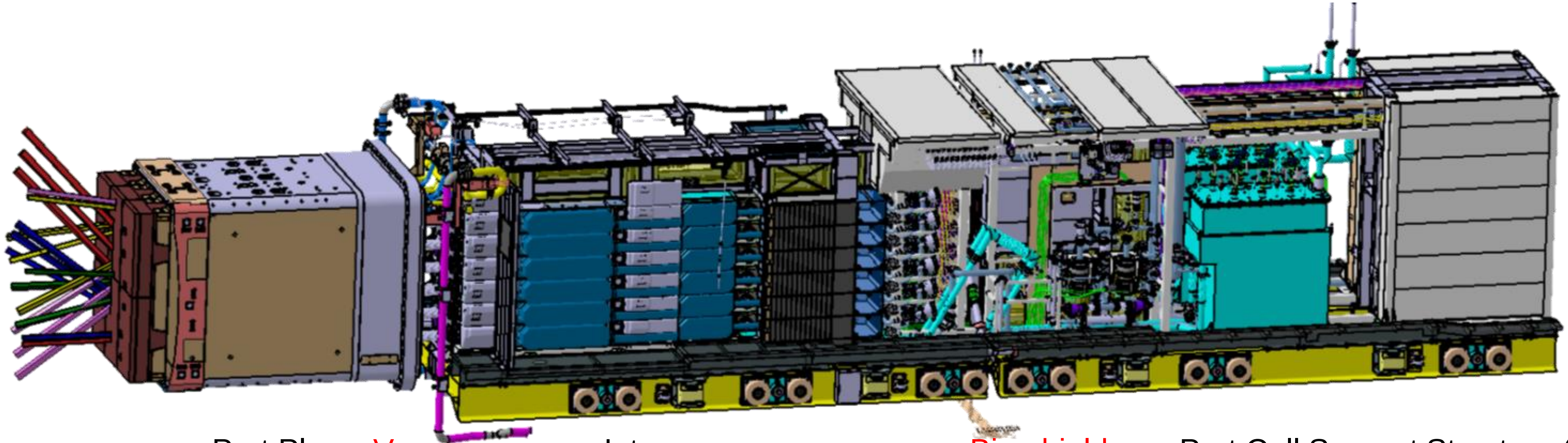
- H-alpha and Visible spectroscopy: 450-700 nm, dedicated channel for H-alpha 656 nm line and for W0 400.9 nm line
- Divertor Impurity Monitor: 200 – 1000 nm, dedicated channel for the W0 400.9 nm line
- VUV Survey: 2.4 – 160 nm range, (W^{46+} 19.6 nm and W^{44+} 132.3 nm)
- VUV Edge: 17 – 32 nm
- VUV Divertor: 15 – 32 nm
- XRCS Survey: 1-100 Å
- XRCS Core: ~1.354 Å (W^{64+}), 2.1899 Å (Xe^{51+}), and 2.555 Å (Xe^{44+} and Xe^{47+})
- XRCS Edge: ~3.95 Å (Ar^{16+}) and ~3.73 Å (Ar^{17+})

Challenges for ITER Diagnostics

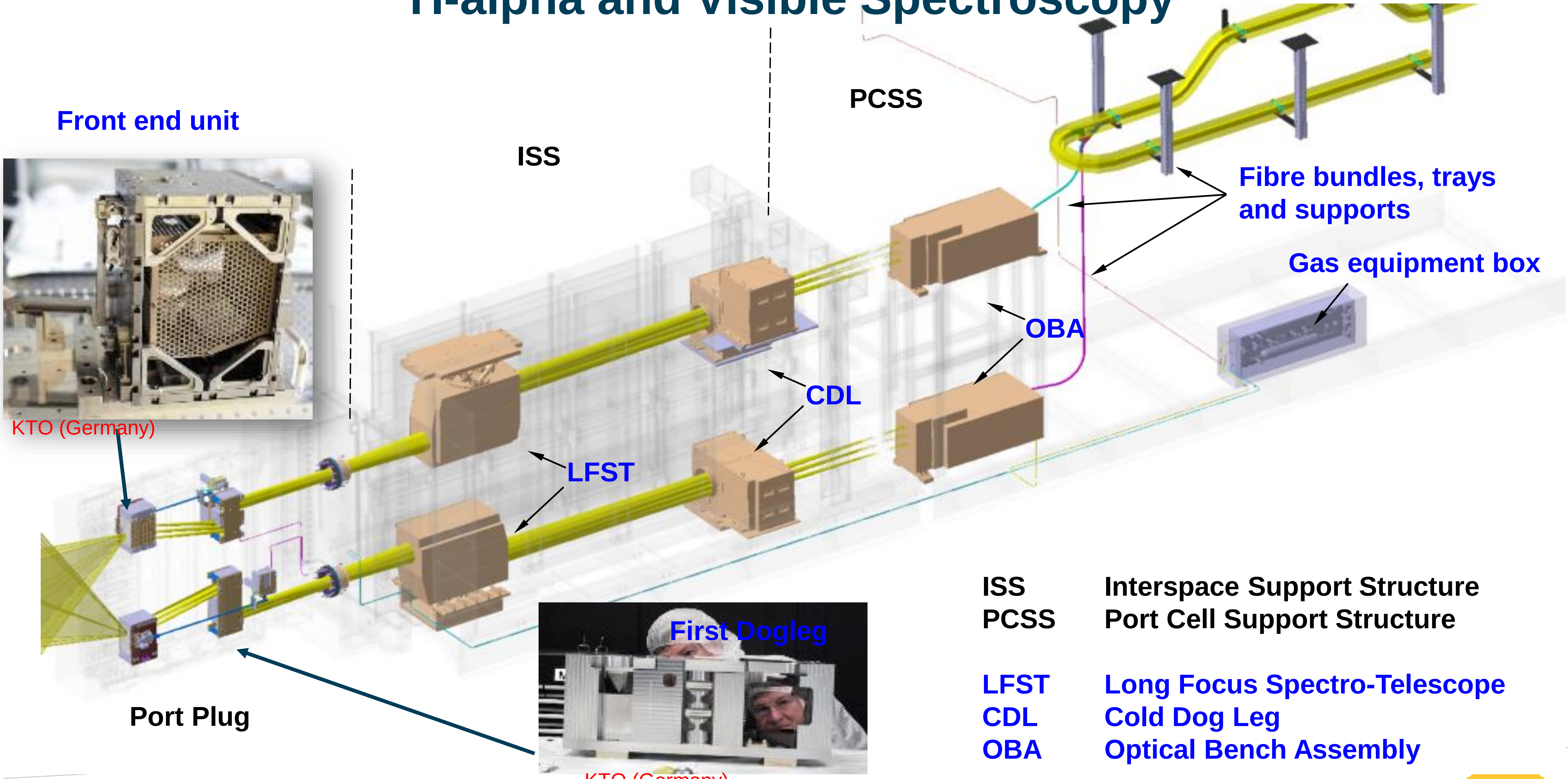
New solutions had to be found in response to the **numerous challenges** posed by ITER to the design of the diagnostic systems

- Constrained space with little accessibility
- Safety concerns
- Harsh radioctive environment





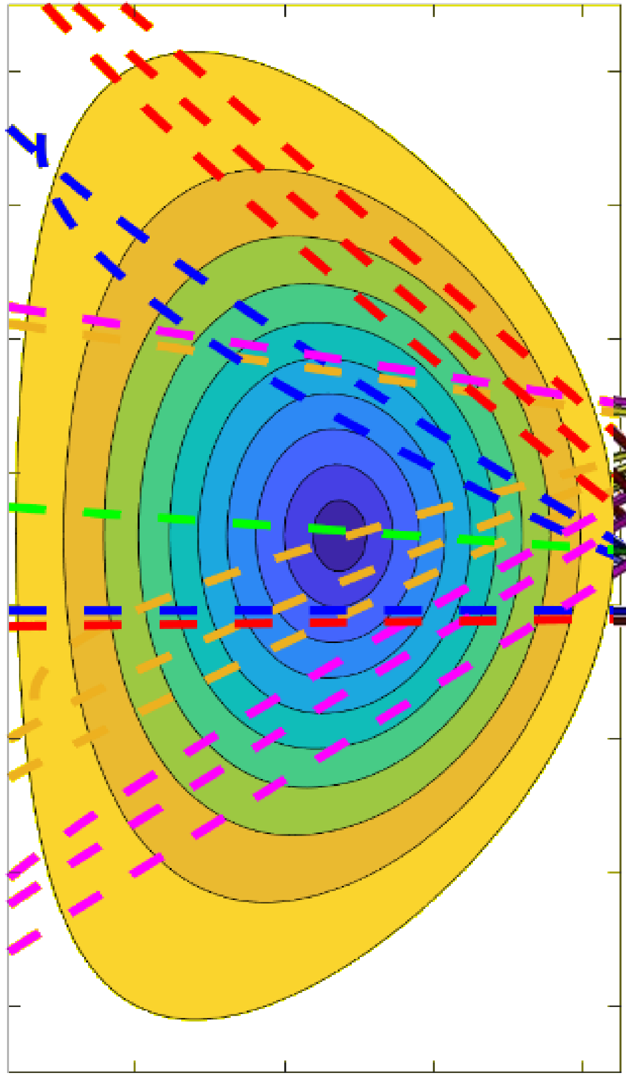
H-alpha and Visible Spectroscopy

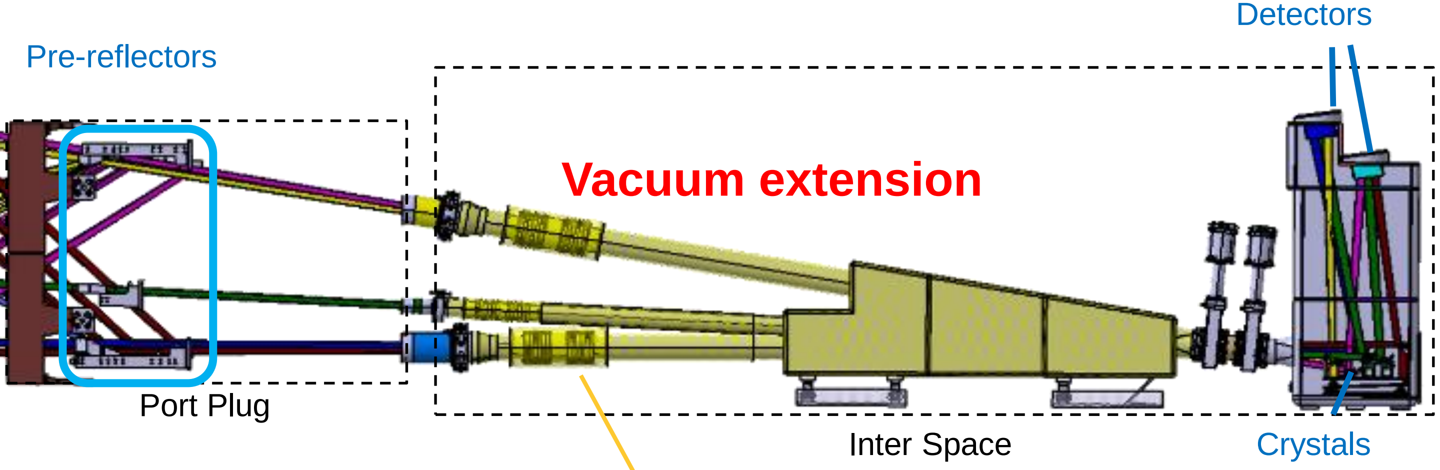


ISS	**Interspace Support Structure**
PCSS	**Port Cell Support Structure**
LFST	**Long Focus Spectro-Telescope**
CDL	**Cold Dog Leg**
OBA	**Optical Bench Assembly**

ITER XRCS Core

- ➢6 spherical crystals (in different colors) are integrated, with each receiving X-ray directly from plasma or deflected by reflectors
- ➢LoSs of XRCS Core are distributed according to possible positions for ions (Xe and W) in ITER plasma
- ➢Bragg reflection on pre-reflector and crystal



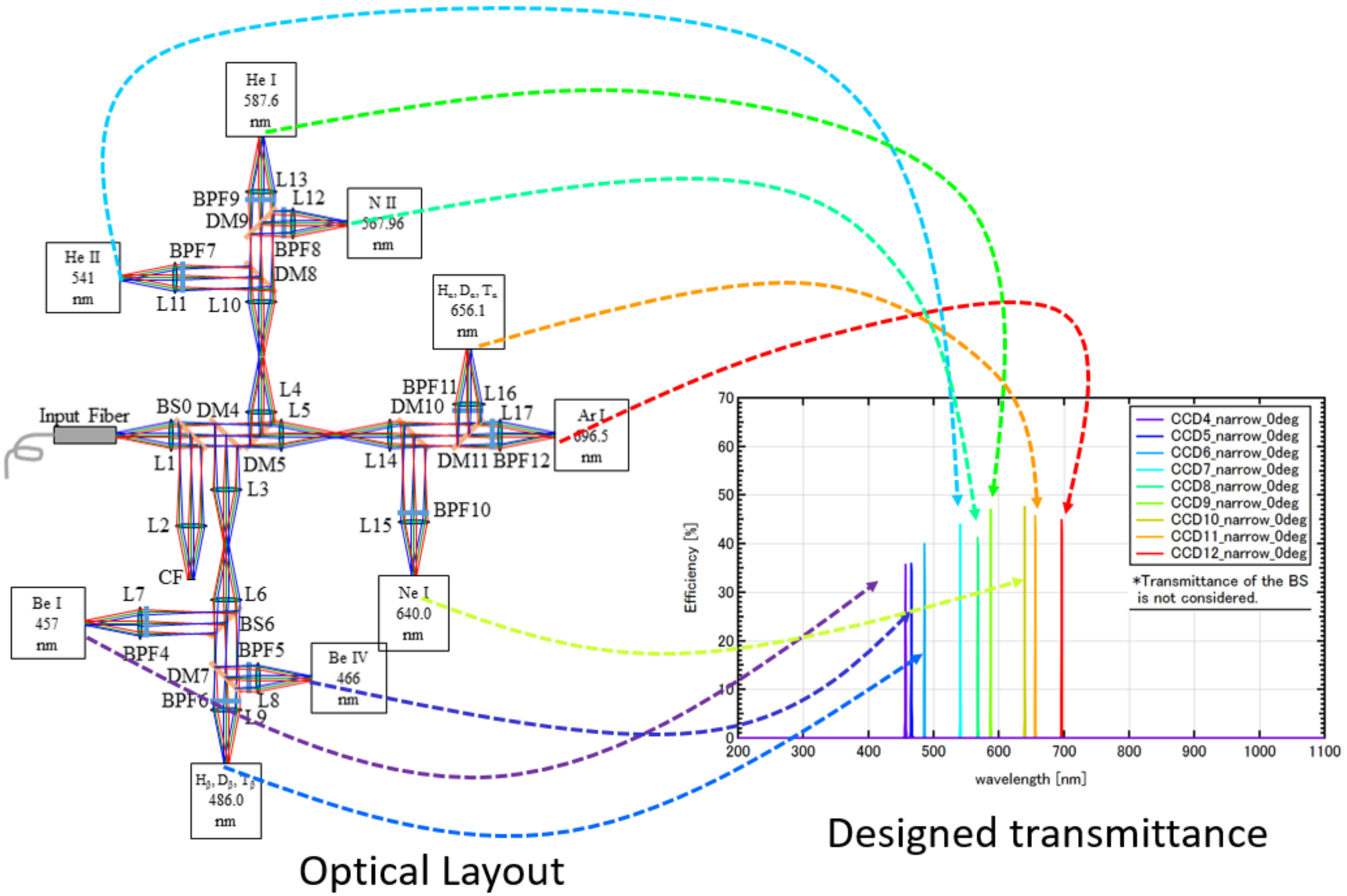


Double wall bellows with interspace monitoring

Roles of atomic data for ITER diagnostics

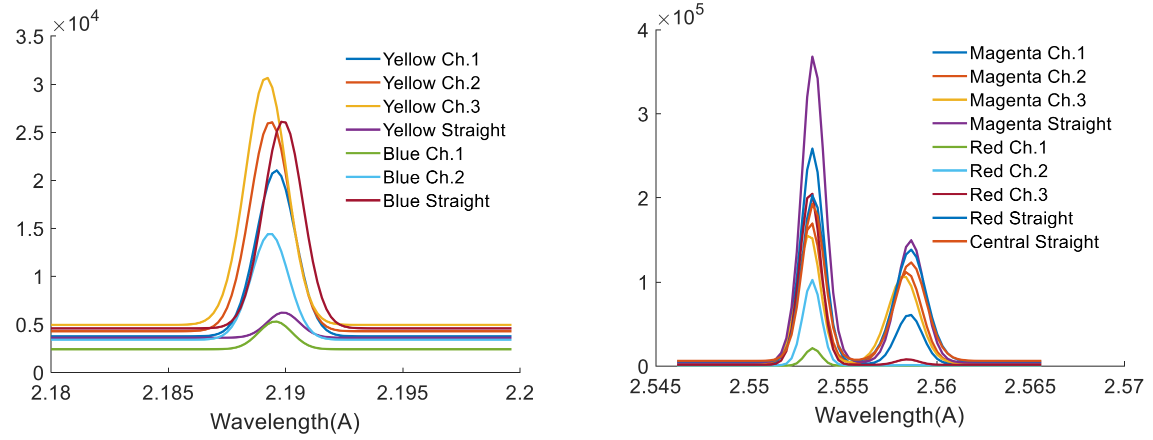
- **Influence diagnostic design**
  - Line wavelengths for optimizing diagnostic configuration

    Possibility of spectral contamination from W lines?
  - Synthetic diagnostic development: Impurity emission modelling
- **Critical for data processing and interpretation**
  - Branching ratio data for cross check among diagnostics
  - S/XB ratio for impurities concentrations
  - Impurity transport model: Impurity emission modelling
  - CX data for evaluating active spectra

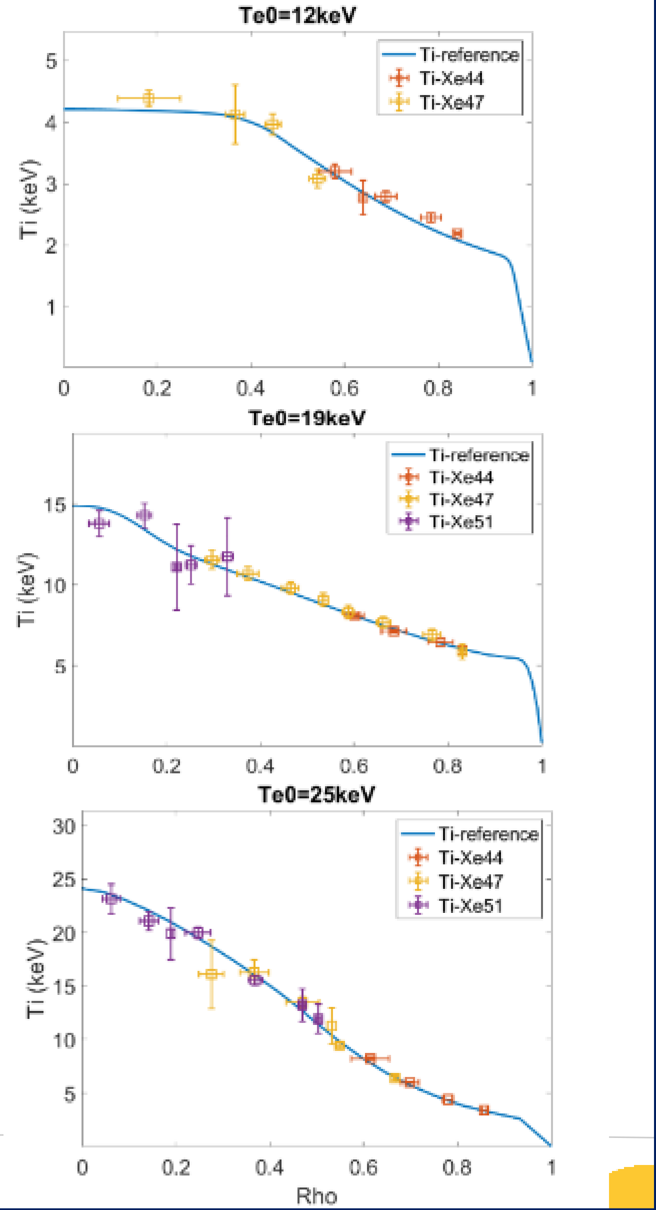


Filter Spectroscopy in visible

Measurements dependance on atomic process



Synthetic diagnostic signals for XRCS Core



- Synthetic diagnostic used to generate signals (Emissivity profiles from ADAS)
- Electron temperature determines measurement accessibility for ion temperature
- Uncertainties about W line contamination of the Xe spectra used for the measurement

Needs for Diagnostics

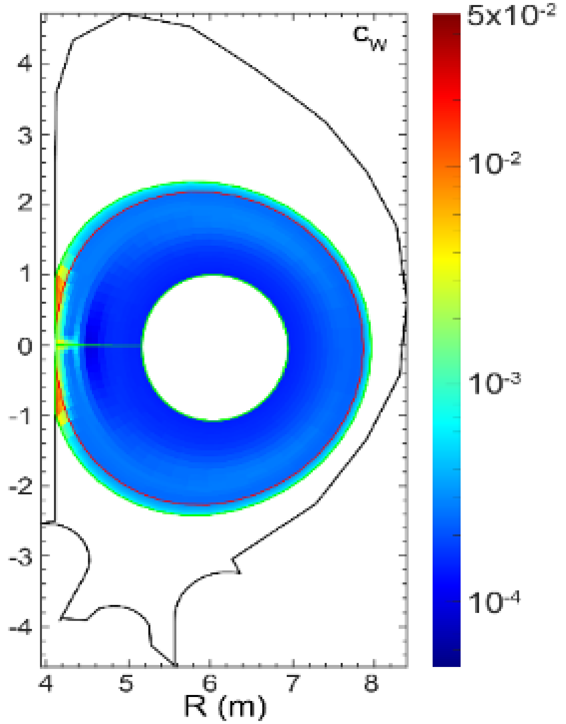
- Improvement of accuracy of ionization, recombination, radiation, and CX rates, now particularly including also boron.
  - CX cross sections (for H^+, He^{2+}, **B^{5+}**, C^{6+}, Ne^{10+}, Ar^{18+}) and thermal cross sections for the same impurities ions
  - ADAS update?
- Improved S/XB ratio accuracies for all spectral lines of interest
  - Critical to estimate W plasma concentration from photon emission rates
  - Need to cover range from W^0 to at least W^{64+}
- Modelling to provide synthetic data to support diagnostic and control system design
  - Detailed full Spectra (including H, **W, B,** Fe, Ne, N, O, Ar) for typical ITER plasma
  - Passive and active spectra for **B^{4+}**

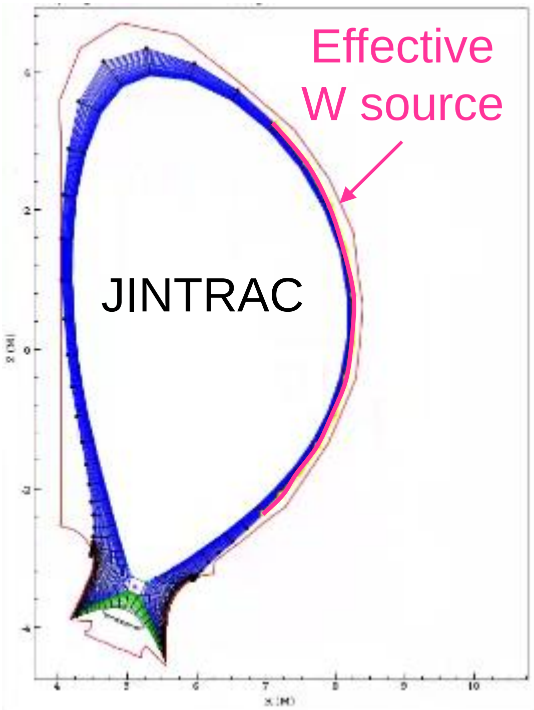
2nd IAEA Technical Meeting on the Collisional-Radiative Properties of Tungsten and Hydrogen in Edge Plasma of Fusion Devices, Nov 28 - Dec 1, 2023

Concerns on ITER operation

Impacts of W first wall plasma facing components for demonstration of Q = 10

- **Operation with W first wall**
  - Limiter operation with W first wall PFCs
  - W wall source in diverted operation
  - Transport of W from the wall to the separatrix
  - Transport of W from the separatrix into the core plasma through the pedestal
  - Transport of W in the core H-mode plasma
- **Boronization process in ITER**
  - Atomic and molecule process with Boron including Diborane
  - Formation of B deposits on W surface
  - Fuel retention in B layers
  - Erosion and lifetime of B layers
  - Transport and migration of B deposits





Use of Atomic data for ITER operation

- **For plasma modelling**
  - Plasma models often require electron cooling rates for energy balance and total ionization/recombination rates for particle balance
    - Ionization/recombination rates of low Argon charge states were recently identified as needing a critical overhaul (ongoing work)
  - Charge state bundling methods used to reduce the number of species to follow
- **For materials modelling, including fuel retention issues:**
  - Nature of hydrogen/helium traps in bulk W
  - Vacancy formation and diffusion rates
  - Blistering, cracking, fatigue, grain boundaries
  - IR emissivity, melting, evaporation

Needs for Operation

- Refinement of particle reflection data at low energies
  - Dependencies on W surface state, incident angle, incident hydrogen isotope, …
- Dissociation, excitation of WD and other molecules
- B deposition and sputtering
- Reliable charge distribution to deduce upstream W migration and core penetration
- Detailed sputtering yields
  - As functions of temperature, surface roughness, other impurities present…
- Fast and reliable prompt redeposition model

- Tokamak experiments on boronization effect, B - W interaction, W transport…

Diagnostician Focuses

- Update of diagnostic configuration with full tungsten first wall
  - Full synthetic spectra (B and W) in **visible range for polychromators**
  - Detailed W spectra at specific X-ray ranges: **2.15 – 2.25 Å (Xe^{51+}), 2.5 – 2.6 Å (Xe^{44+} and Xe^{47+}), 3.85 – 4.05 Å (Ar^{16+}), 3.65 – 3.85 Å (Ar^{17+})**
- Calibration of spectroscopic diagnostics
  - Spectra with **strong lines (W, Xe, Fe, Ar, Ne, B, O, C) from 0.1 nm to 1000 nm** for wavelength calibration of Visible, VUV and X-ray Spectroscopies.
  - Lines data for relative intensity calibration: **Usable ions, wavelength pairs, branching ratios**
  - Continuum spectral distribution for absolute calibration with combination of Bremsstrahlung and Recombination radiation

zhifeng.cheng@iter.org

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External: Robin Barnsley (IO retired), Martin O'Mullane (University of Strathclyde)

Thank you!

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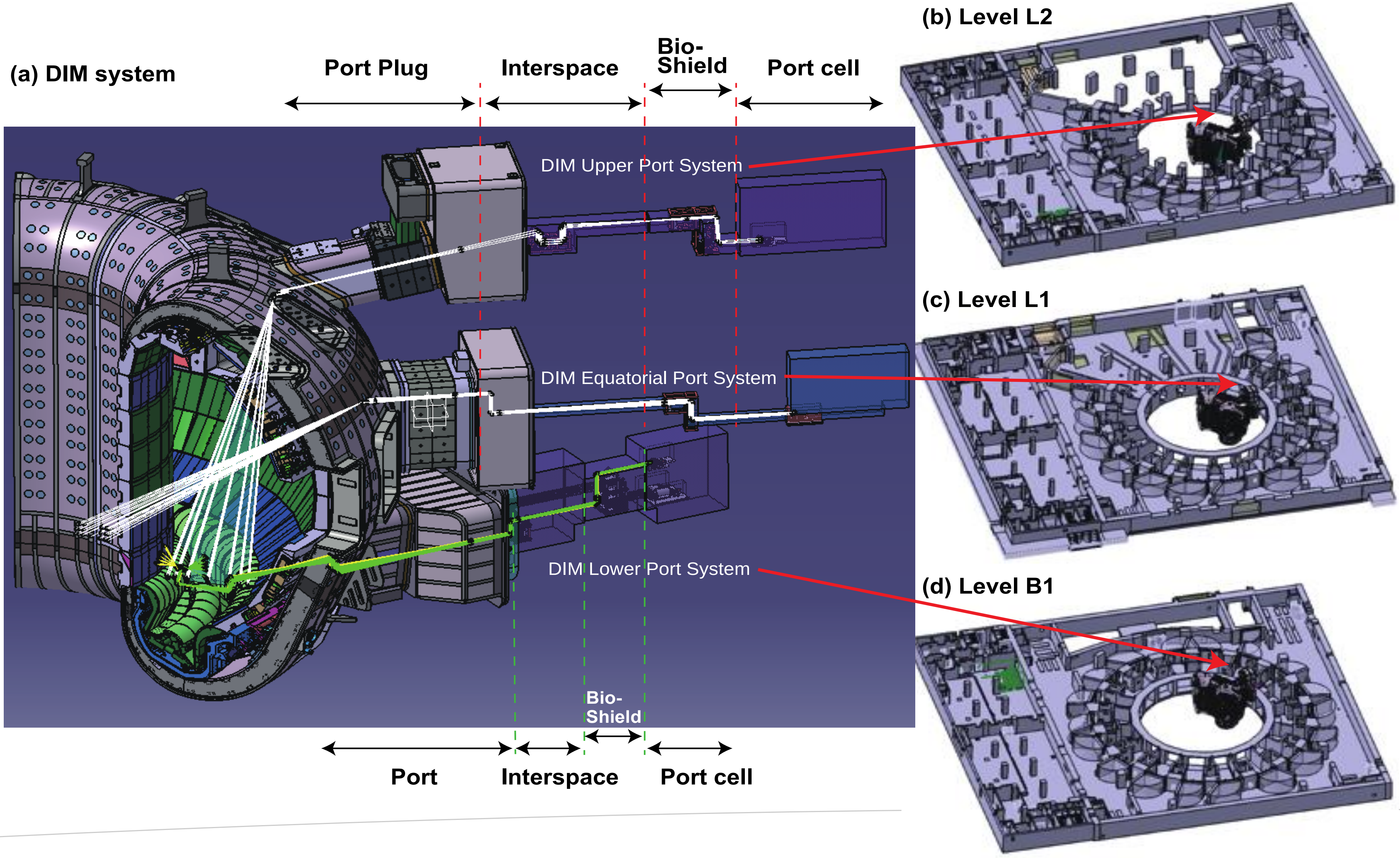
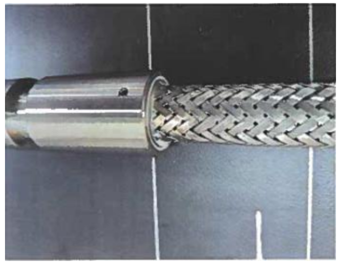
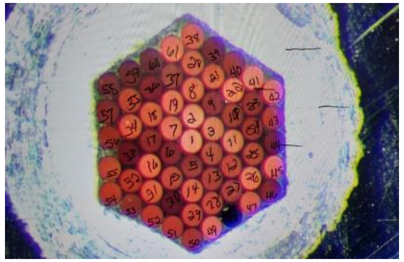
Divertor Impurity Monitor

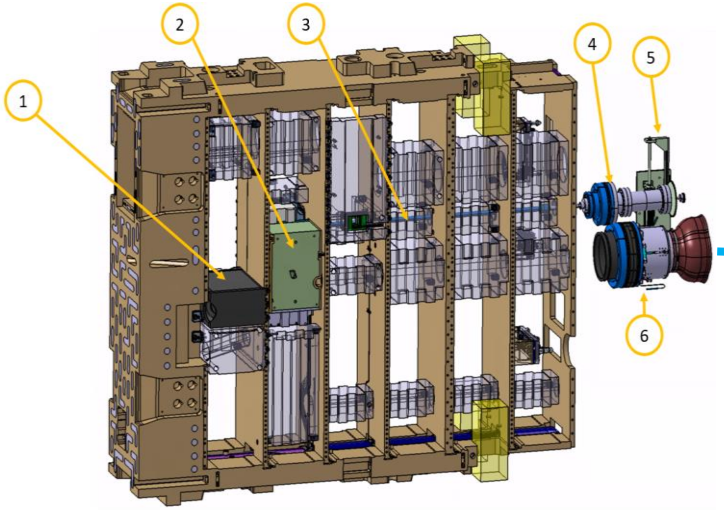


Visible Spectroscopy Reference System

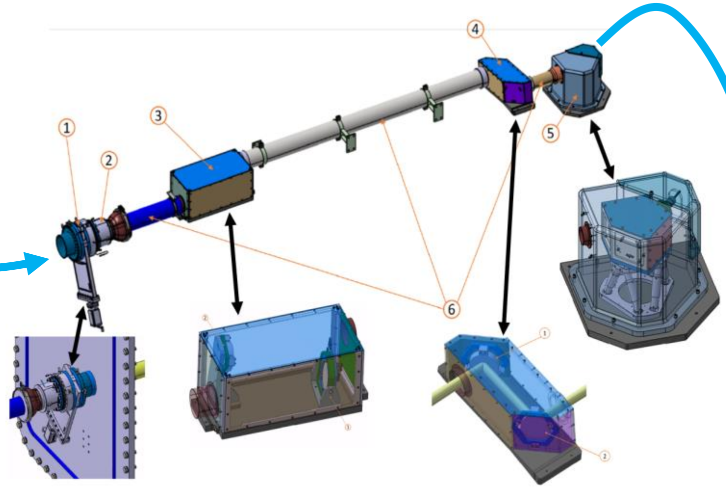




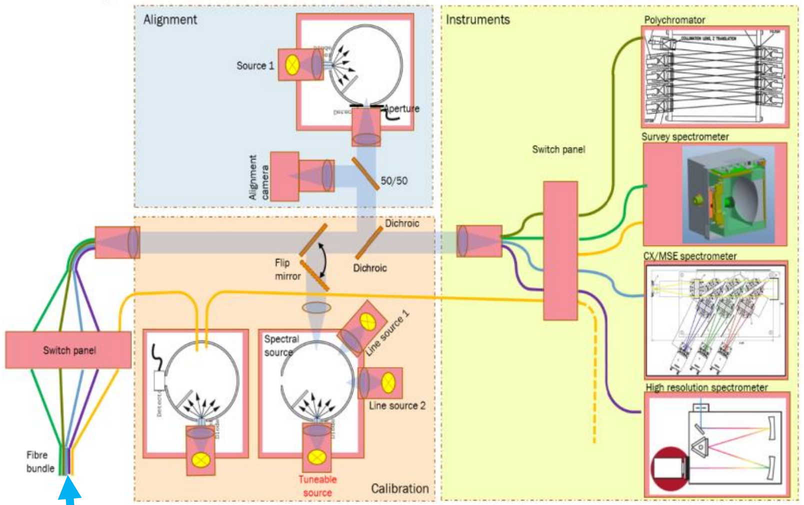
Fibre bundle



Port plug components (2nd plasma)



ISS components (1st plasma)



Diagnostic room components (1st plasma)

2nd IAEA Technical Meeting on the Collisional-Radiative Properties of Tungsten and Hydrogen in Edge Plasma of Fusion Devices, Nov 28 - Dec 1, 2023

XRCS Survey, VUV Survey and Divertor