# Atomic Physics and the ITER Perspective

## ITER Team

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**ITER Organisation**

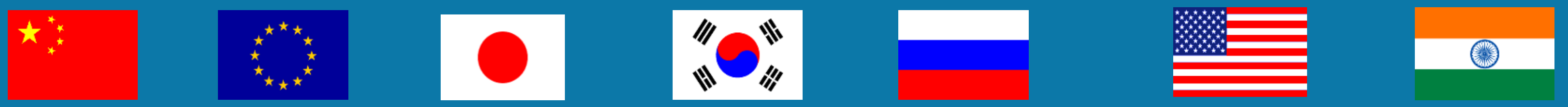
**30/09/2013**

**Ack: Special thanks to all colleagues who provided support and information for this presentation**

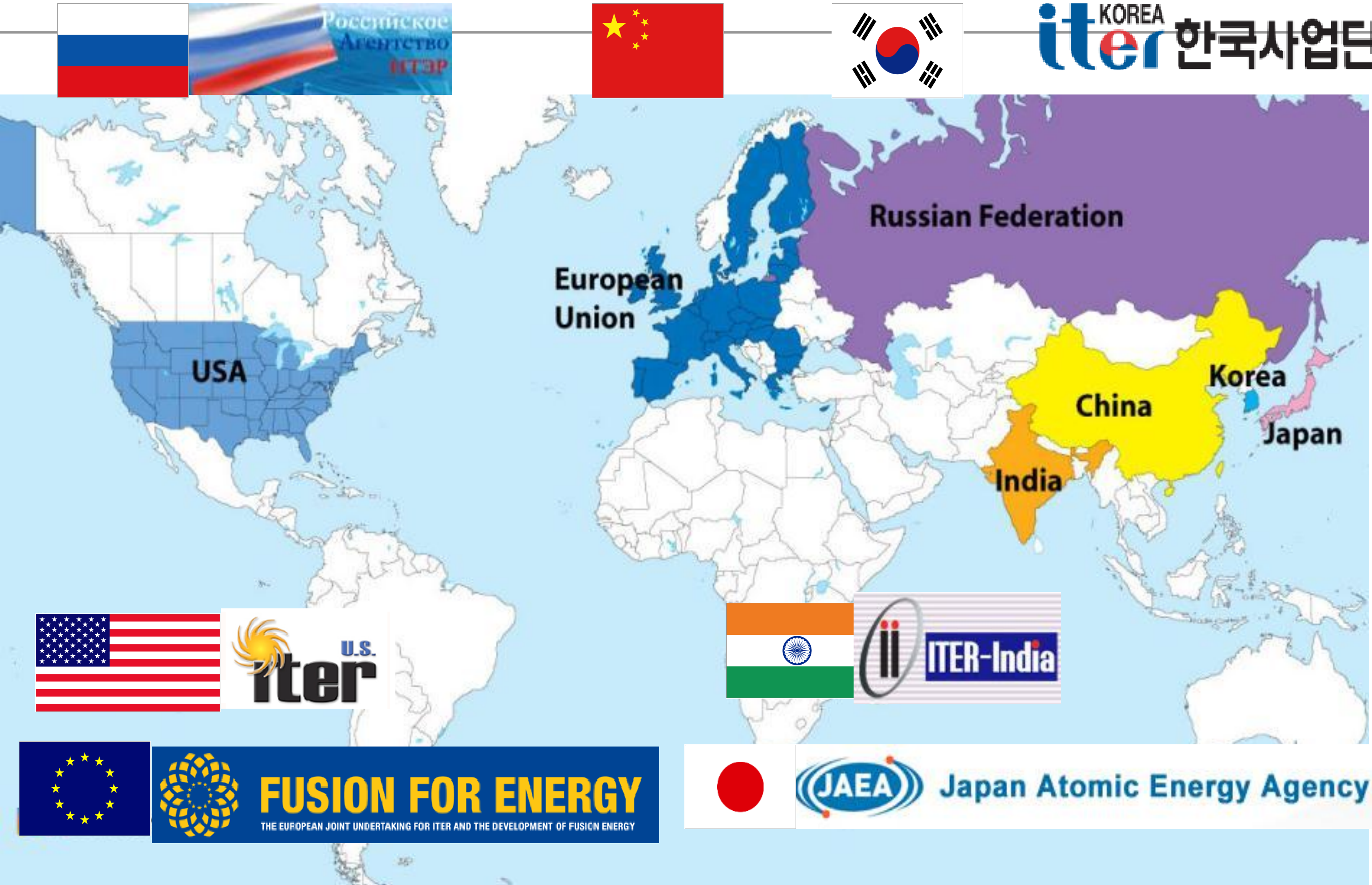
# Outline

- Brief overview of ITER
- General Diagnostics
- Spectroscopic System examples
- Where are we going
- Summary

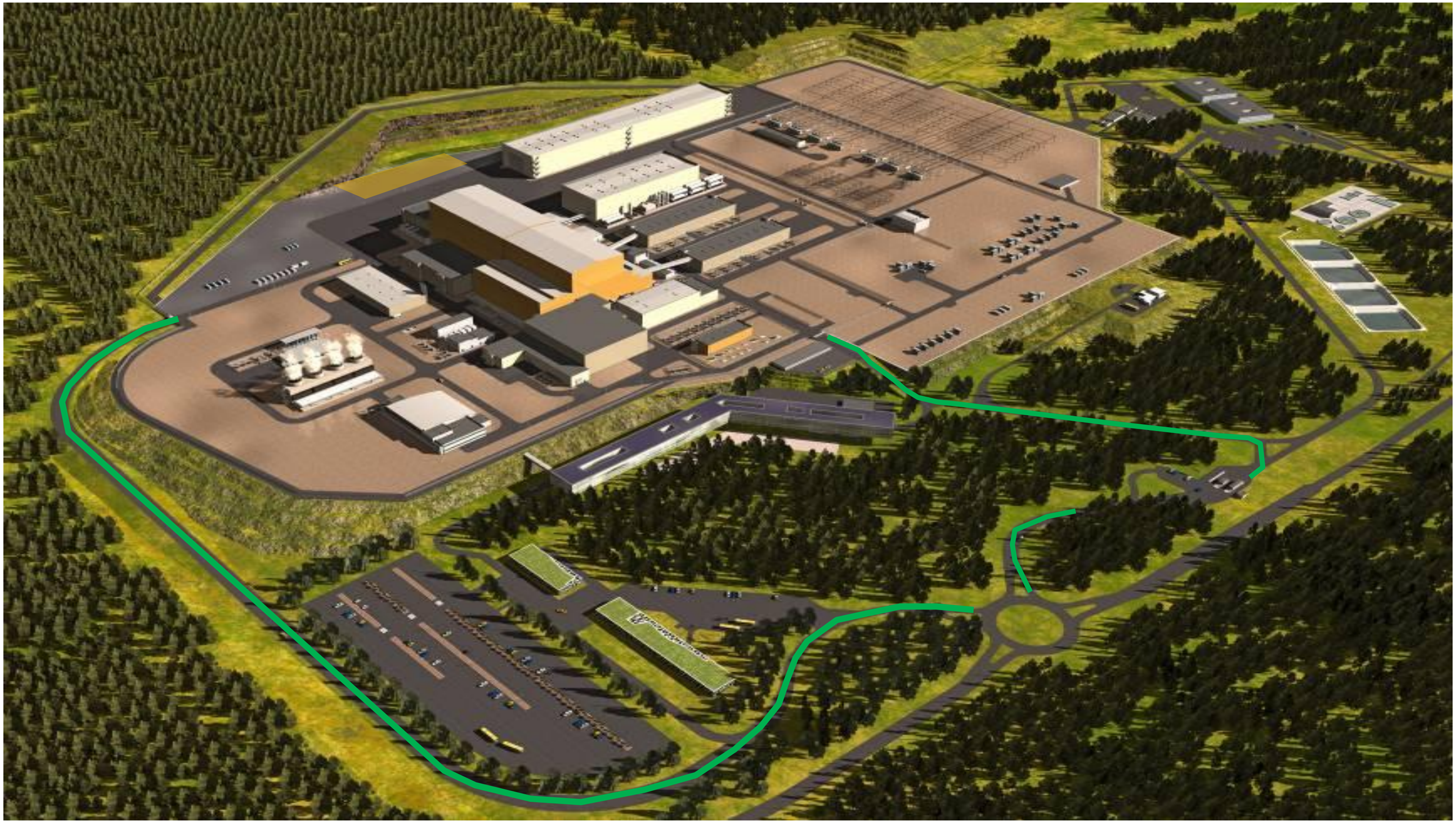
# All ITER Parties and many Institutes and Industries Involved



# *ITER project*



# The Wider View



**ITER Site** consists of 37 buildings each dedicated to a supporting plant system

# Site View now

# Fusion Progress and Records

Huge strides in physics, engineering and technology:

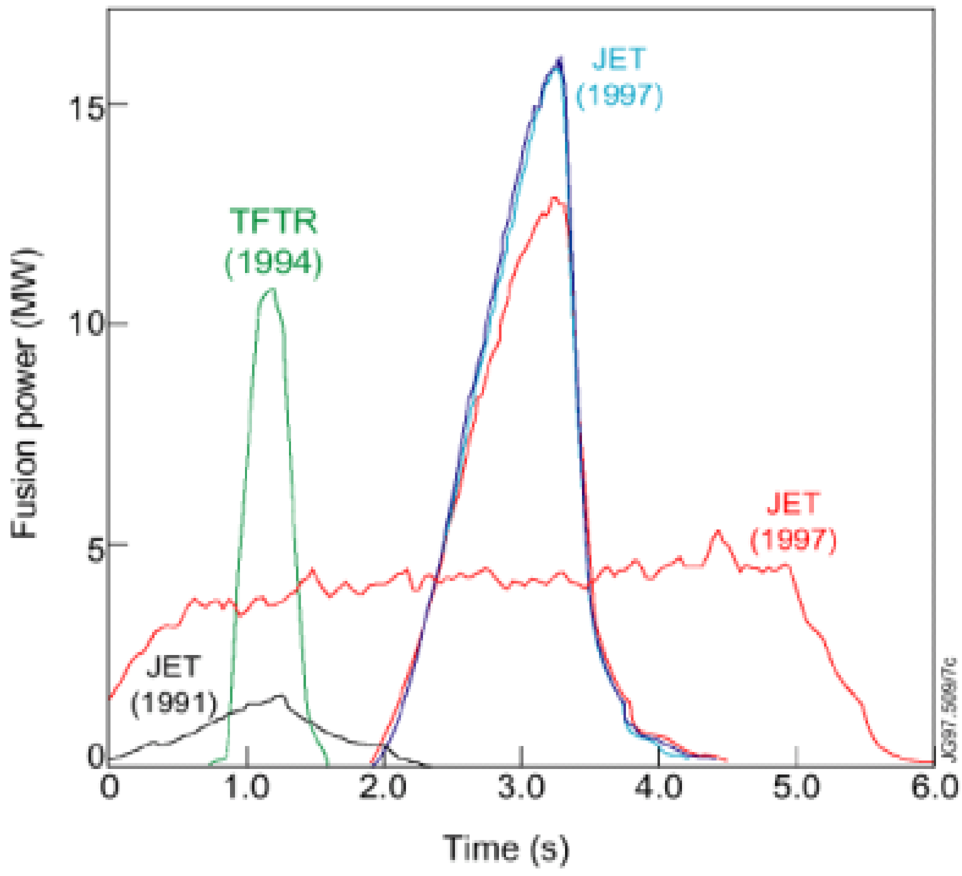
•Temperature (Ti): 10-20 keV

•Density (ni): ~10 × $10^{19}$ m-3

•Energy confinement time (*t*): ~1 sec

•Experiments in JET and TFTR have initiated the study of plasmas with significant fusion power : record fusion power production of 16MW (Q~0.6) at JET

•Use of superconductors : record pulse length 6 minutes 18 sec at Tore Supra



# ITER Scope - Mission Goals

## Physics:

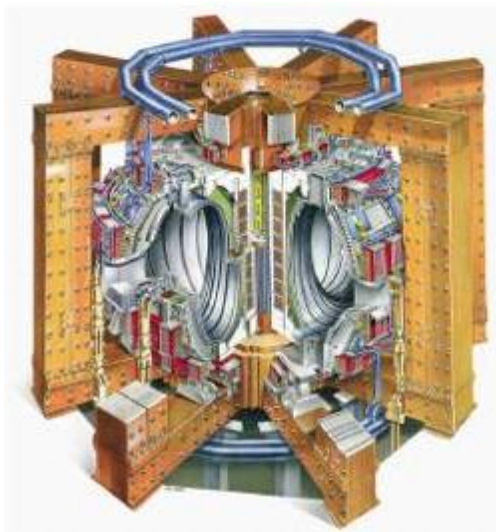
- ITER is designed to produce a plasma dominated by α-particle heating
- produce a significant fusion power amplification factor ($Q \geq 10$) in long-pulse operation (300 – 500 s)
- aim to achieve steady-state operation of a tokamak ($Q \geq 5$/ $\leq 3000$ s)
- retain the possibility of exploring 'controlled ignition' ($Q \geq 30$)

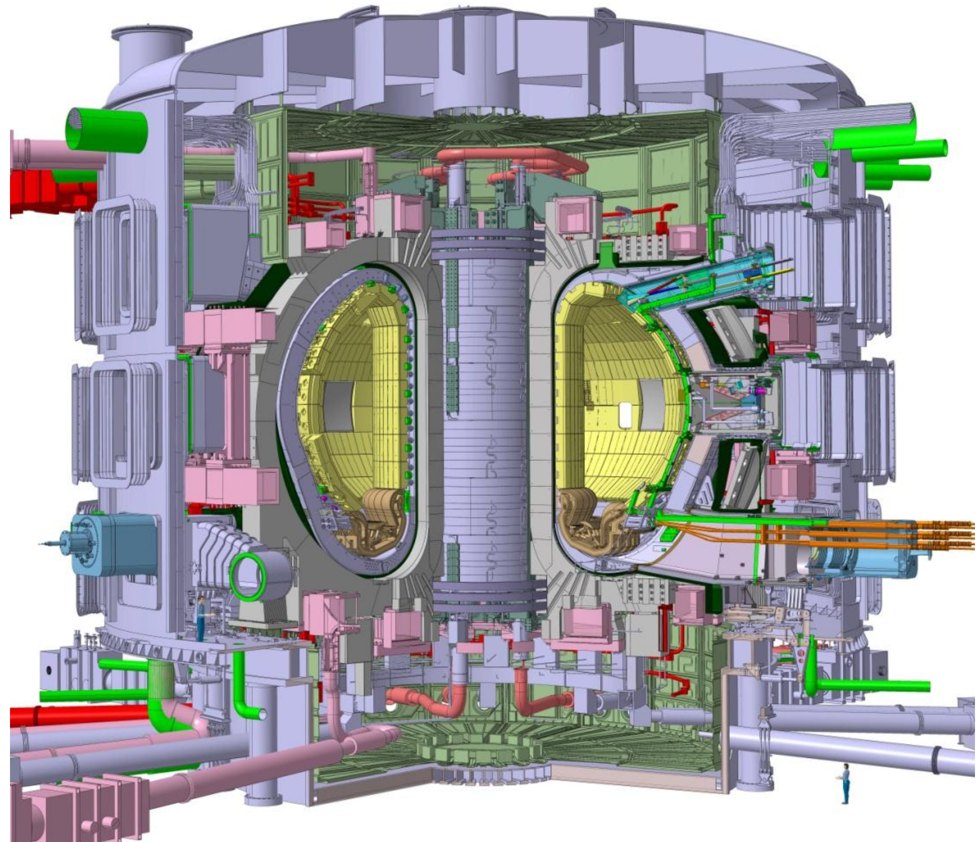
## Technology:

- demonstrate integrated operation of technologies for a fusion power plant
- test components required for a fusion power plant
- test concepts for a tritium breeding module

# Is ITER different?

## ITER is twice as large as our largest existing experiments





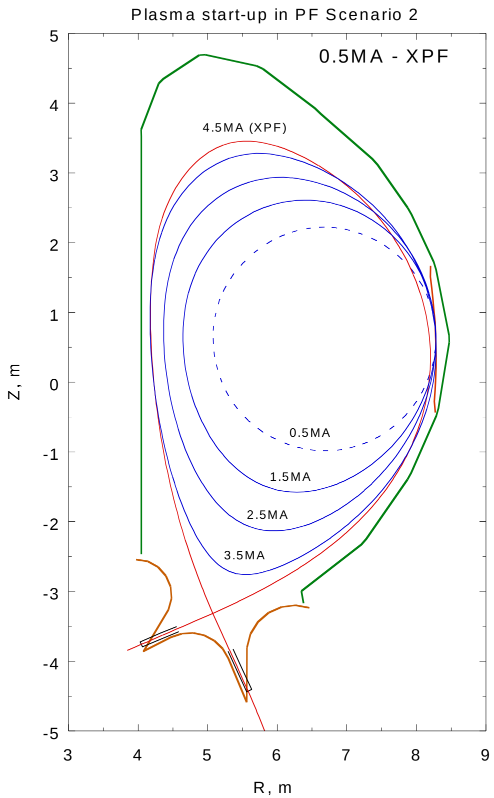
| | JET | ITER |
|---|---|---|
| $V_{plasma}$ | $80\ m^3$ | $830\ m^3$ |
| $P_{fusion}$ | ~16 MW 2s | ~500 MW 500s |
| $t_{plasma}$ | ~30 s | ~400 s |

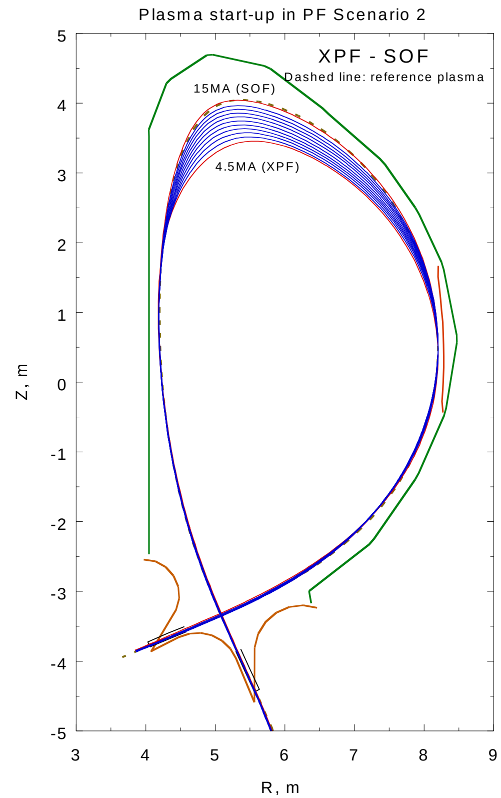
# What do we need to see and measure?

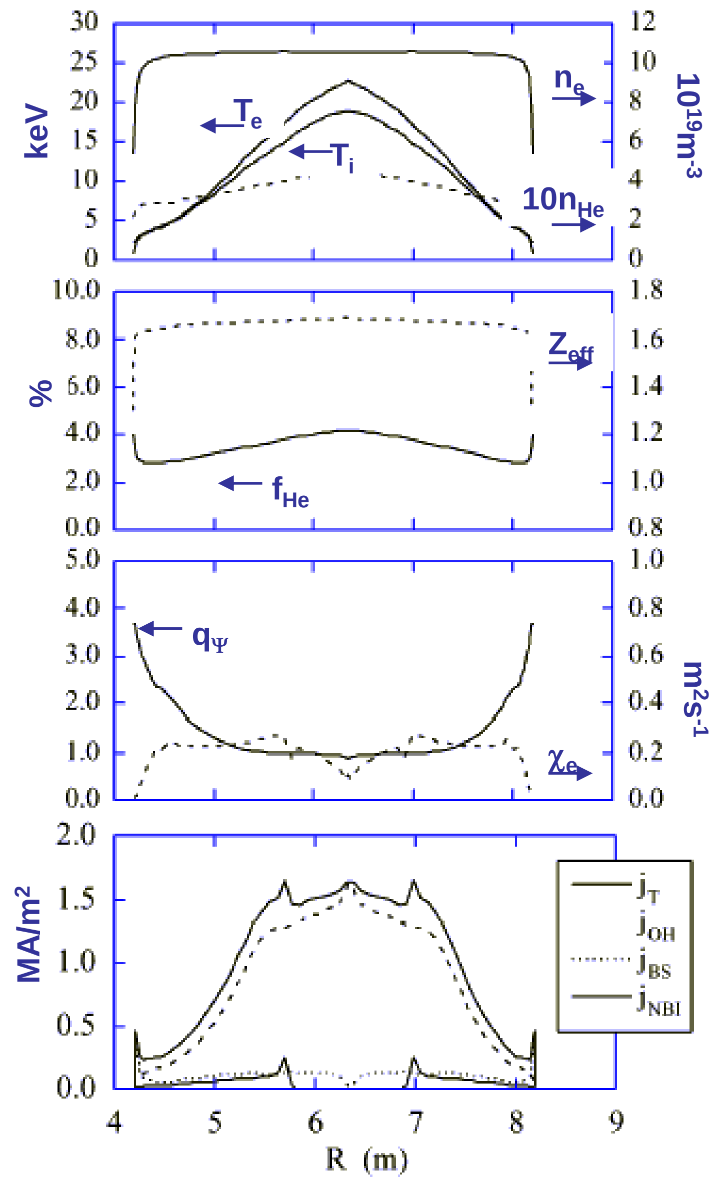
# ITER Plasma Scenario - Example end result

## A Q=10 scenario with (ELMy H-mode ):

**$I_p$=15MA, $P_{aux}$=40MW, $H_{98(y,2)}$=1**




**Current Ramp-up Phase**

# Types of Systems Used

About 45 different diagnostic identified for different measurement roles

**A- Magnetics systems**
**B- Neutrons systems**
**C- Optical systems**
**D- Bolometry systems**
**E- Spectroscopy systems**
**F- Microwave systems**
**G- Operational systems**
**N- Electrical Services**

**All integrated directly in to machine or in the port plugs**

# How diagnostic functionality is grouped?

1) for machine protection or basic control

2) for advanced performance control, and

3) evaluating the plasma performance and understanding important physical phenomena

# Measurement Requirements

Developed by International Teams based around ITPA

Now part of the ITER High Level Project Requirements

Next slide has some relating to Spectroscopy
Require good atomic data to predict physics phenomena and signal intensities

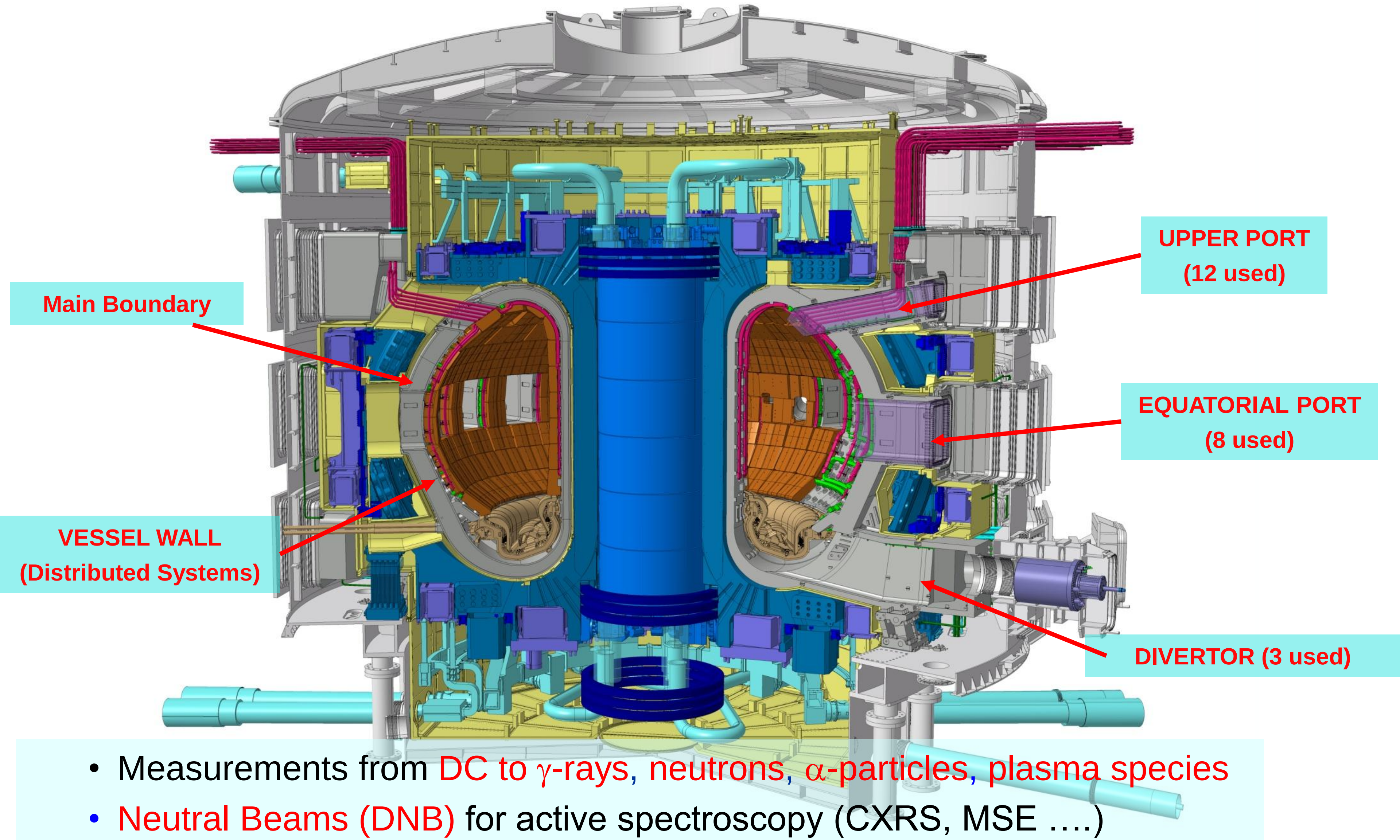
# Spectroscopy Diagnostics Measurements Requirements

| MEASUREMENT | PARAMETER | CONDITION | RANGE or COVERAGE | RESOLUTION | | ACCURACY |
|---|---|---|---|---|---|---|
| **10. Plasma Rotation** | $V_{TOR}$ | | 1-200 km/s | 10 ms | a/30 | 30 % |
| | $V_{POL}$ | | 1-50 km/s | 10 ms | a/30 | 30 % |
| **12. Impurity Species Monitoring** | Be, C rel. conc. | | $1x10^{-4}$-$5x10^{-2}$ | 10 ms | Integral | 10 % (rel.) |
| | Be, C influx | | $4x10^{16}$-$2x10^{19}$ /s | 10 ms | Integral | 10 % (rel.) |
| | Cu rel. conc. | | $1x10^{-5}$-$5x10^{-3}$ | 10 ms | Integral | 10 % (rel.) |
| | Cu influx | | $4x10^{15}$-$2x10^{18}$ /s | 10 ms | Integral | 10 % (rel.) |
| | W rel. conc. | | $1x10^{-6}$-$5x10^{-4}$ | 10 ms | Integral | 10 % (rel.) |
| | W influx | | $4x10^{14}$-$2x10^{17}$ /s | 10 ms | Integral | 10 % (rel.) |
| | Extrinsic (Ne, Ar, Kr) rel. conc. | | $1x10^{-4}$-$2x10^{-2}$ | 10 ms | Integral | 10 % (rel.) |
| | Extrinsic (Ne, Ar, Kr) influx | | $4x10^{16}$-$8x10^{18}$ /s | 10 ms | Integral | 10 % (rel.) |
| **28. Ion Temperature Profile** | Core Ti | r/a < 0.9 | 0.5 - 40 keV | 100 ms | a/10 | 10 % |
| | Edge Ti | r/a > 0.9 | 0.05 - 10 keV | 100 ms | 50 mm | 10 % |
| **32. Impurity Density Profile** | Fractional content, Z<=10 | r/a < 0.9 | 0.5 - 20 % | 100 ms | a/10 | 20 % |
| | | r/a > 0.9 | 0.5 - 20 % | 100 ms | 50 mm | 20 % |
| | Fractional content, Z>10 | r/a < 0.9 | 0.01 - 0.3 % | 100 ms | a/10 | 20 % |
| | | r/a > 0.9 | 0.01 - 0.3 % | 100 ms | 50 mm | 20 % |

# When these are expanded to systems

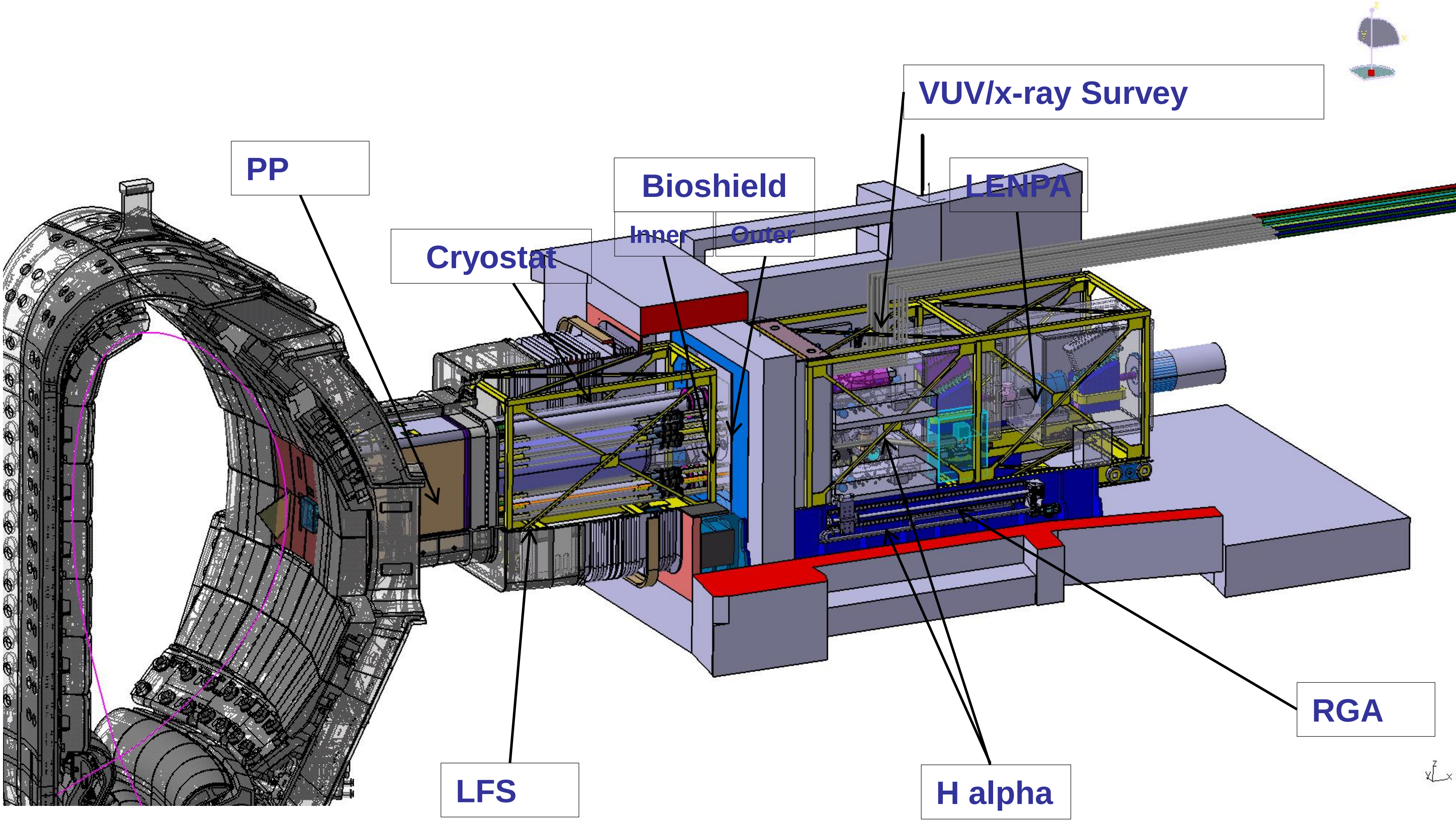
| PBS | System | Wavelength/ Energy range | Function | Status |
|---|---|---|---|---|
| 55E4 | Divertor impurity monitor | 200 – 1000 nm | Impurity species and influx, divertor He density, ionisation front position, $T_i$. | PA signed |
| 55E2 | Hα system | Visible region | ELMs, L/H mode indicator, $n_T/n_D$ and $n_H/n_D$ at edge and in divertor. | CDR closed |
| 55E3 | VUV spectroscopy - main | 2.3 – 160 nm | Impurity species identification. | PA signed |
| 55EG | VUV spectroscopy - divertor | 15 – 40 nm | Divertor impurity influxes, particularly Tungsten | PA signed |
| 55EH | VUV spectroscopy - edge | 15-40 nm | Edge impurity profiles | PA signed |
| 55ED | X-ray spectroscopy – survey | 0.1 – 10 nm | Impurity species identification | PA signed |
| 55EI | X-ray spectrometer - edge | 0.4 – 0.6 nm | Impurity species identification, plasma rotation, $T_i$. | PA signed |
| 55E5 | X-ray spectroscopy-core | 0.1 – 0.5 nm | Impurity species identification, plasma rotation, $T_i$. | CDR Jun 2013 |
| 55E7 | Radial x-ray camera | 1 – 200 keV | MHD, Impurity influxes, Te | PA signed |
| 55EB | MSE | Visible region | q (r), internal magnetic structure | CDR Jan 2013 |
| 55E1 | Core CXRS | Visible region | $T_i$ (r), He ash density, impurity density profile, plasma rotation, alphas. | CDR Mid 2014 |
| 55EC | Edge CXRS | Visible region | $T_i$ (r), He ash density, impurity density profile, plasma rotation, alphas. | CDR Oct 2012 |
| 55EF | BES | Visible region | Beam-attenuation and fluctuations. | CDR Oct 2012 |
| 55E8 | NPA | 10 keV,- 4 MeV) | $n_T/n_D$ and $n_H/n_D$ at edge and core. Fast alphas. | PA signed |
| 55EA | Laser-induced fluorescence | Visible | Divertor neutrals | Pre- CDR held |
| 55E | Hard X-ray Monitor | 100keV – 20MeV | Runaway electron detection | CDR Early 2014 |

# General Diagnostic Locations

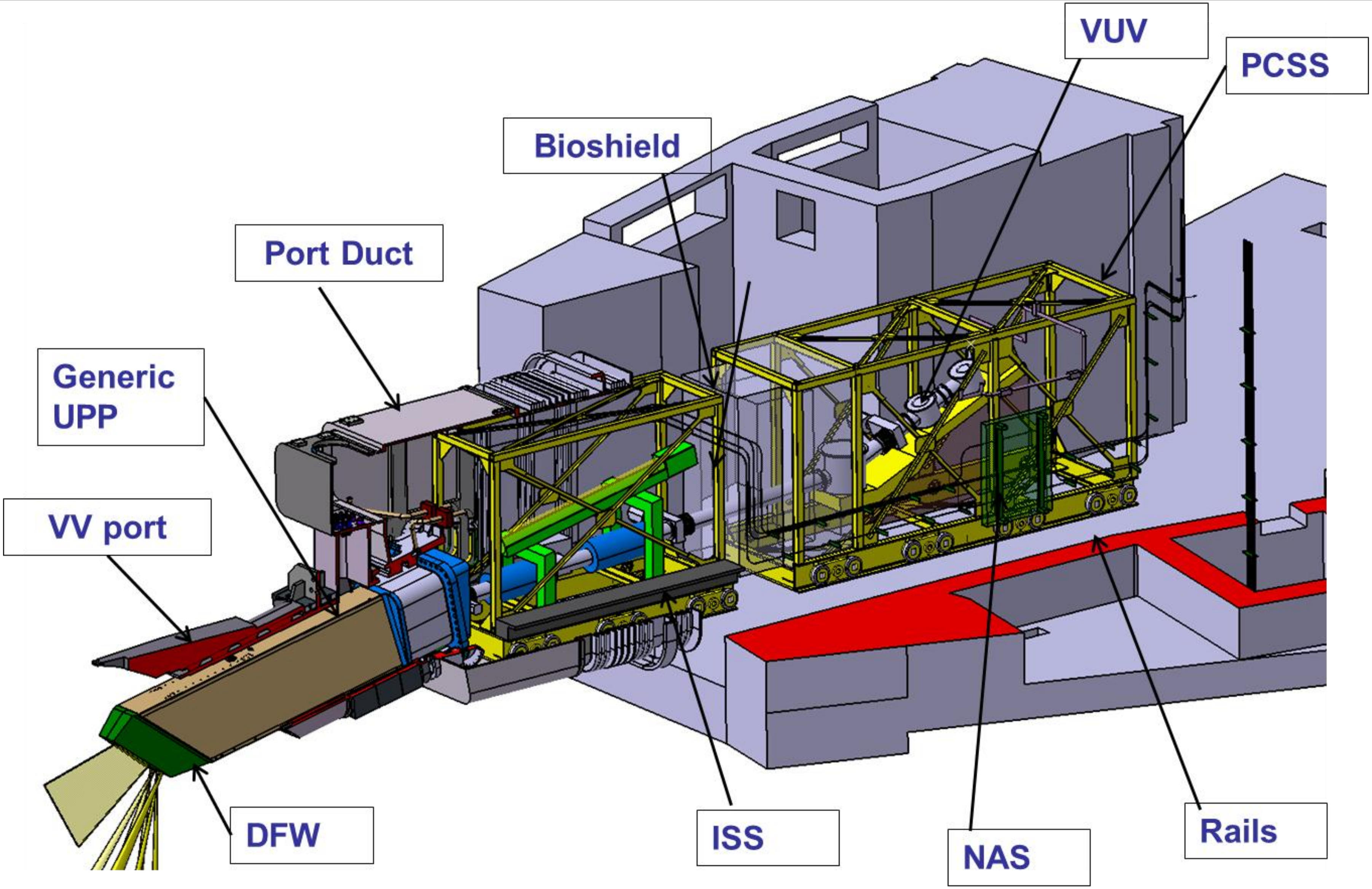



- Measurements from DC to γ-rays, neutrons, α-particles, plasma species
- Neutral Beams (DNB) for active spectroscopy (CXRS, MSE ….)

# General overview of a Hardware system on ITER

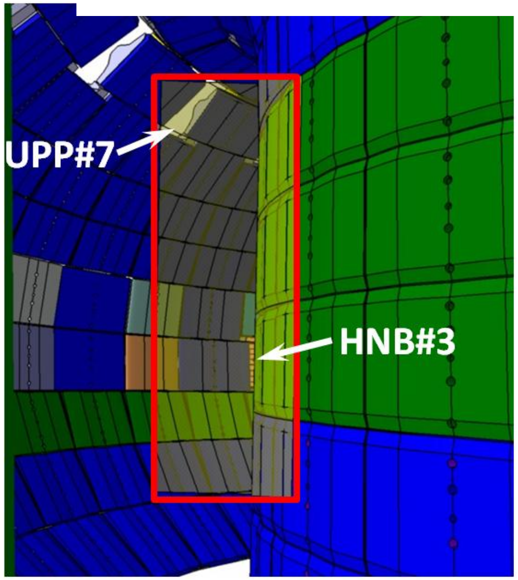


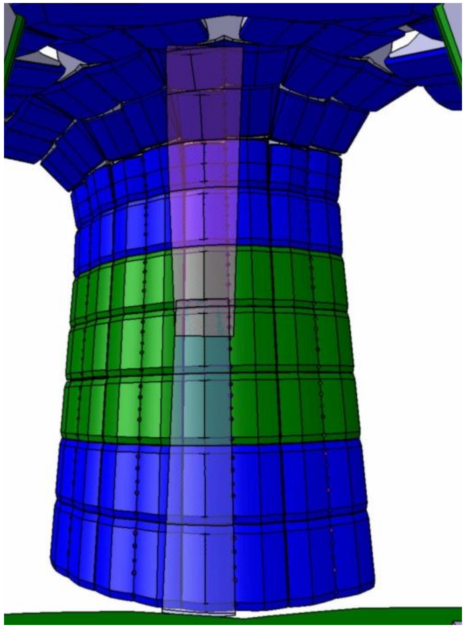
# Integrated Upper Port #18

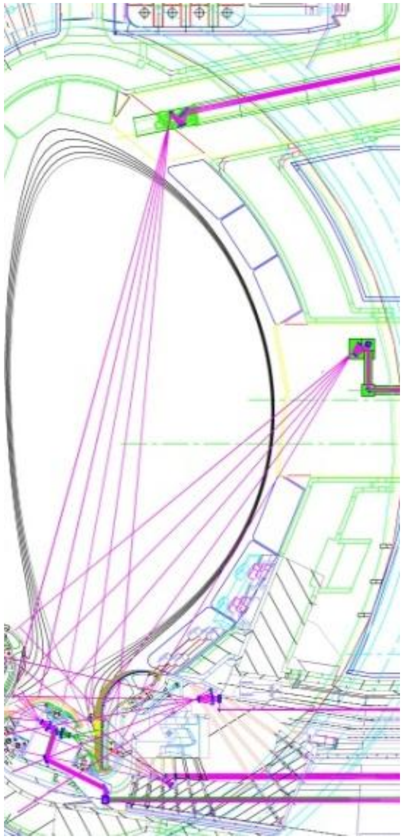


# UV/Visible Spectroscopy

**Ha and Vis has 4 views** **DIM has 3 views**





- Ha and Vis - Can see inner and outer wall
- Divertor can be bright
- Significant Reflection analysis carried out
- Various mitigation techniques – effort needed
- E.g. dumps and zeeman techniques etc

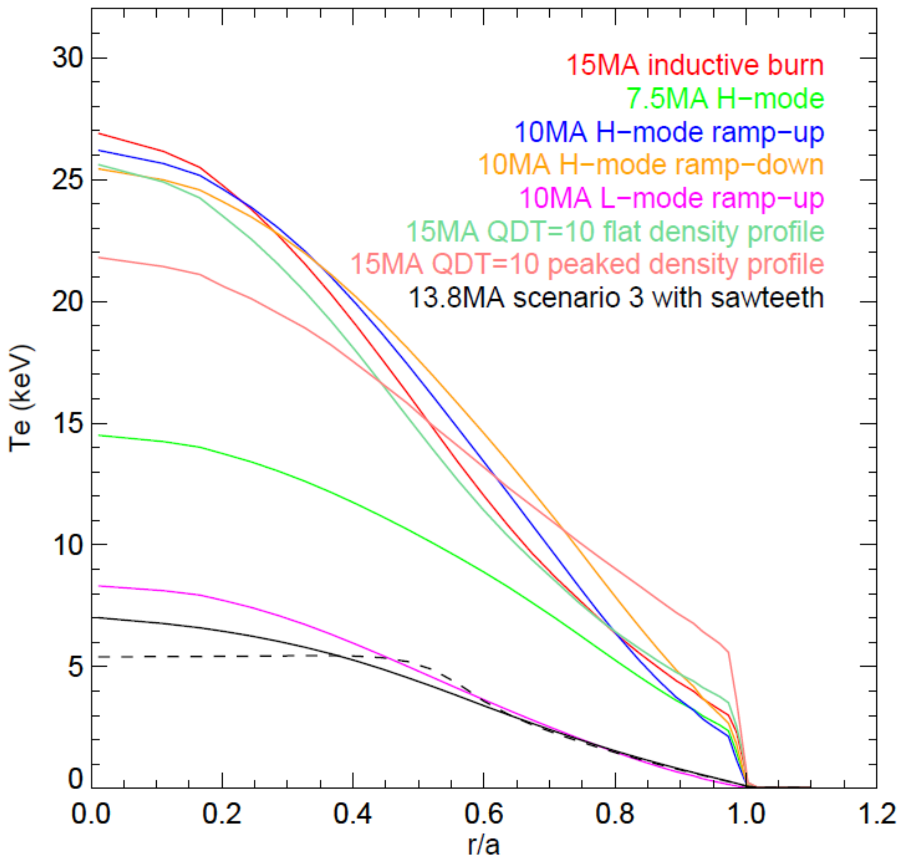
# ITER Plasma emission modelling with ADAS-SANCO

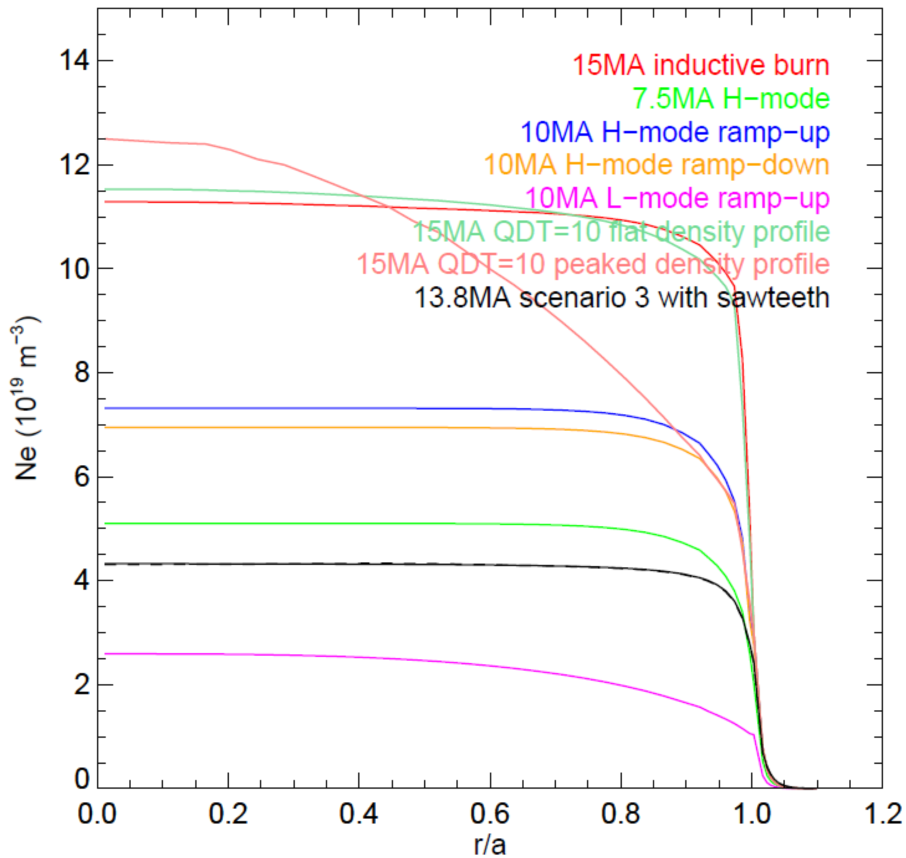
ADAS has been part of plasma emission modelling for ITER diagnostic design studies since 1995.

Increasingly developed during the recent round of Conceptual Design Studies 2010-2013

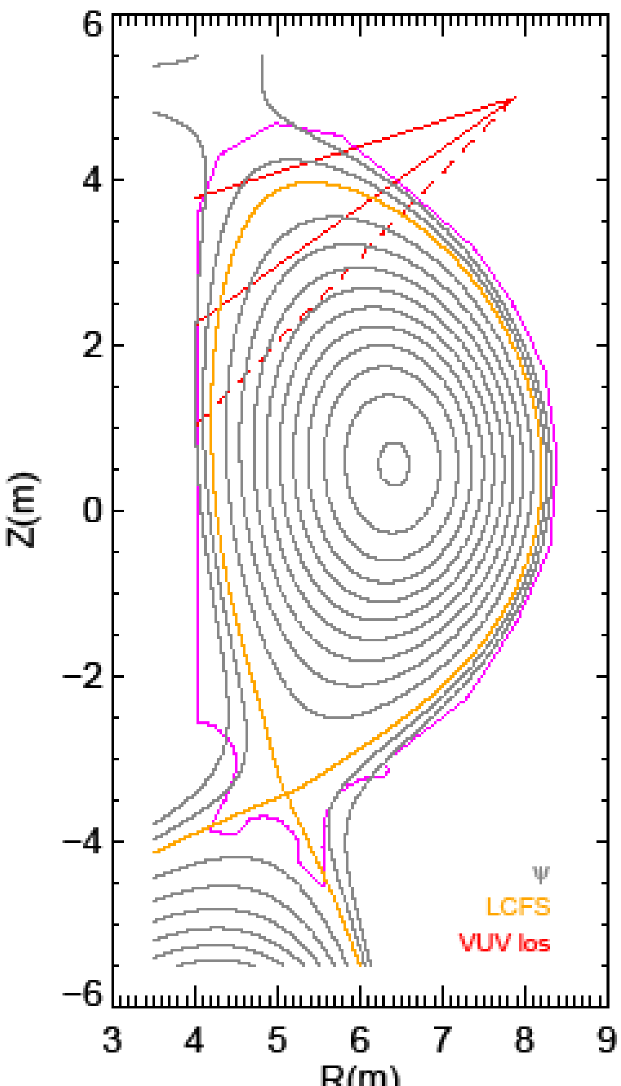
- Wide range of ITER plasma scenarios – start-up low current etc
- Wide spectrum now modelled – Visible > UV > VUV > X-ray
- Can include instrumental effects in modelled spectra
- Lines of sight and fan-views can be set up to suit actual diagnostic design
- Whole new area opening up with ITER

# Wide range of plasma scenarios for ADAS-SANCO modelling

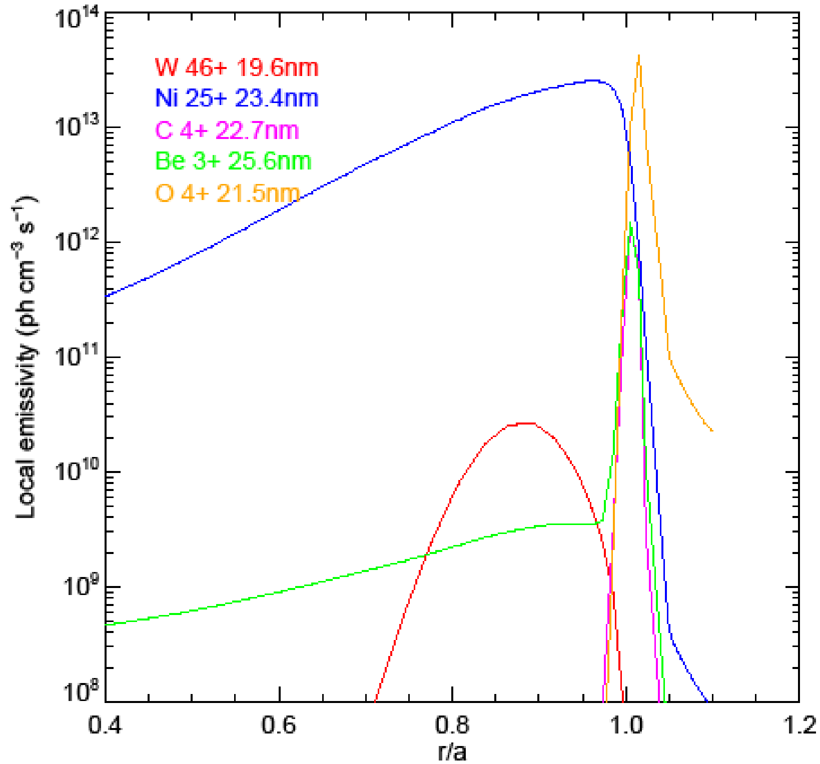


# ADAS/SANCO Modelled emission of VUV spectral lines

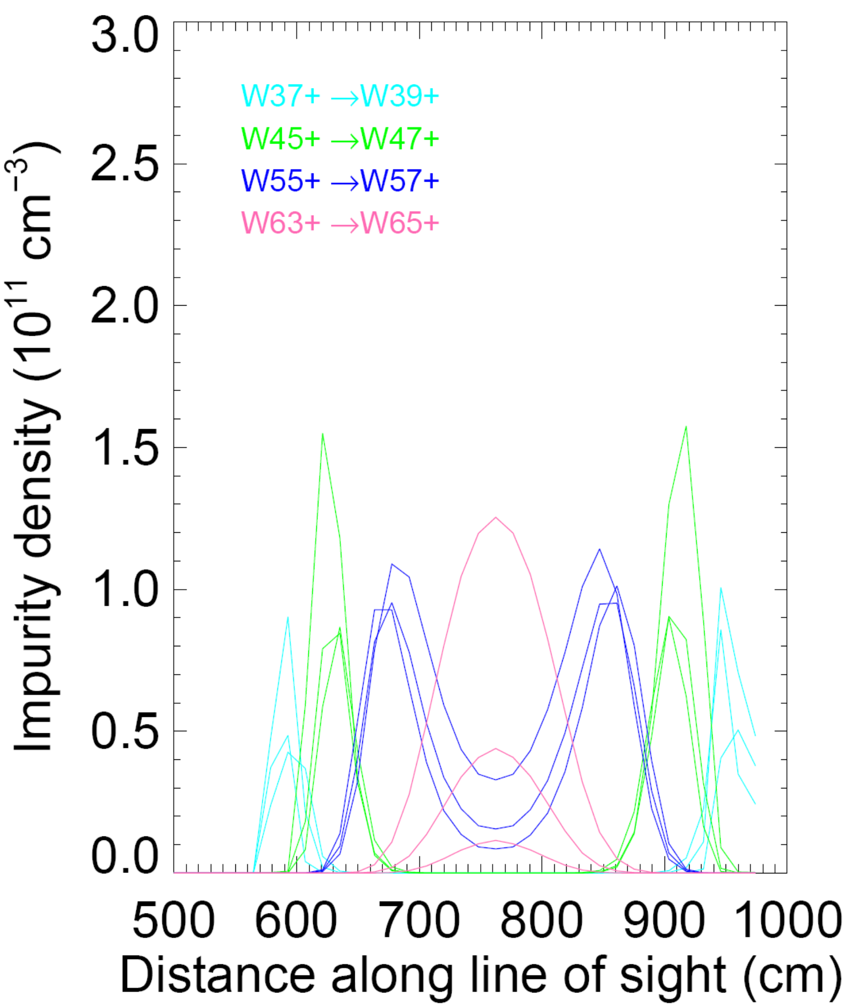


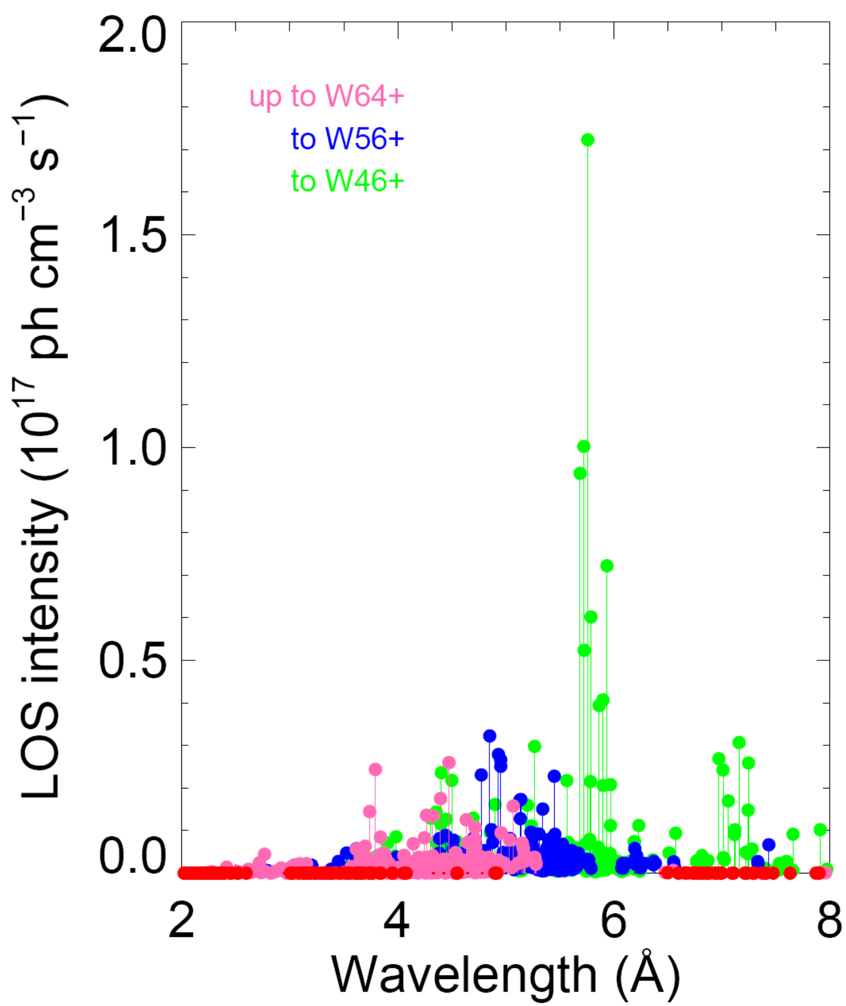

SANCO post-processing lines of sight for imaging VUV spectrometer




VUV lines 10 – 100 nm mostly in the outer plasma

# W chordal profiles for various ionization stages & synthetic soft x-ray spectrum



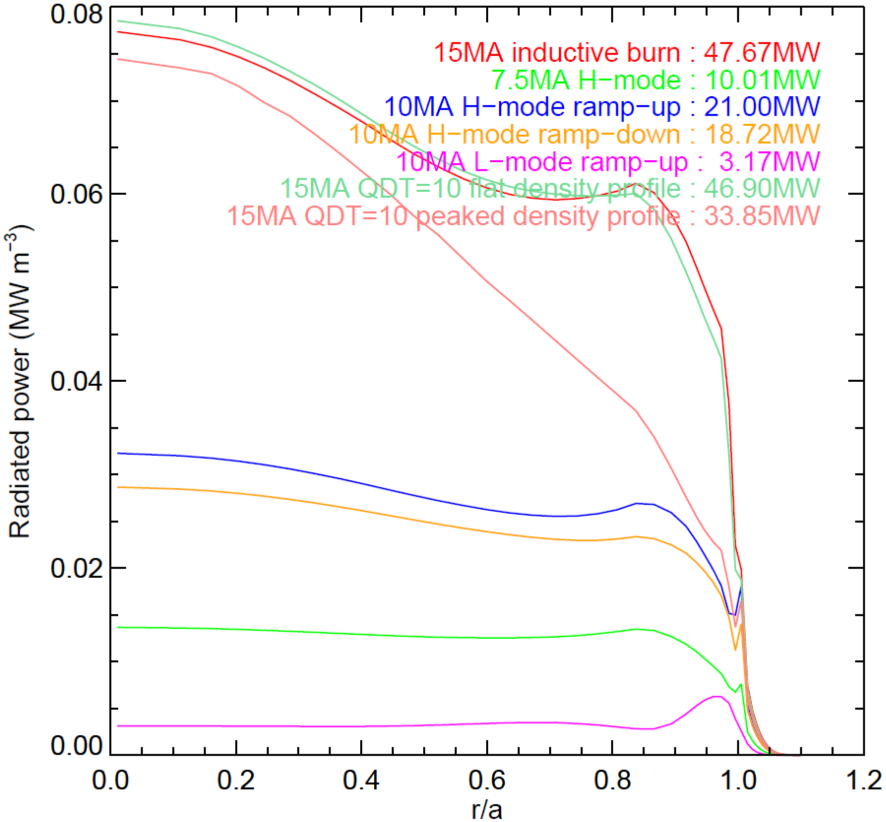



# Total core radiated power is around 50 MW – mostly x-rays

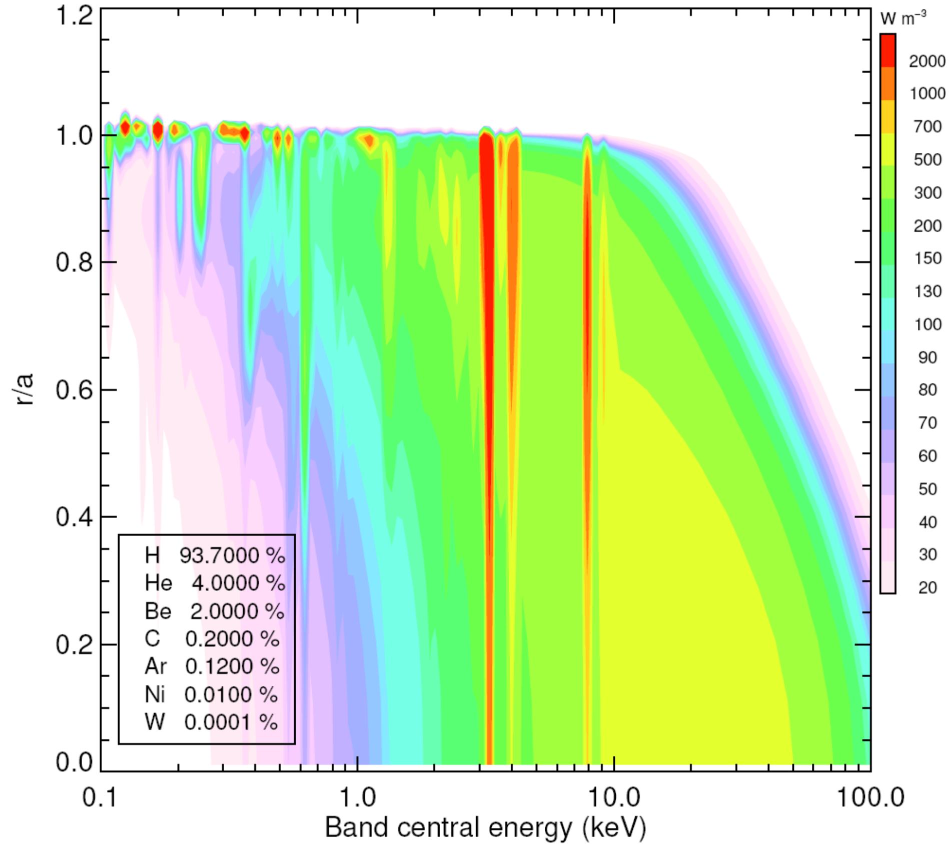
This is a strong test of atomic data and plasma modelling

– Requires all excitation phenomena to be handled

- electron impact, recombination, continuum etc.

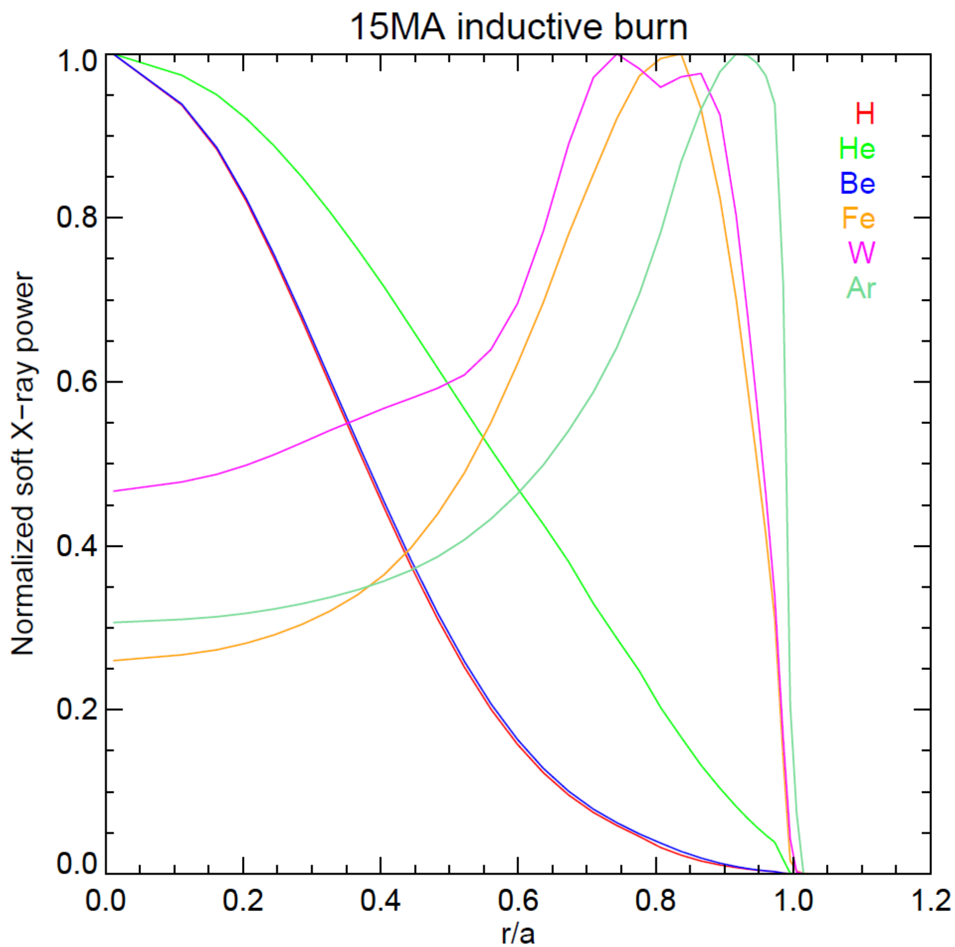



Total radiated power profiles for a range of plasma scenarios

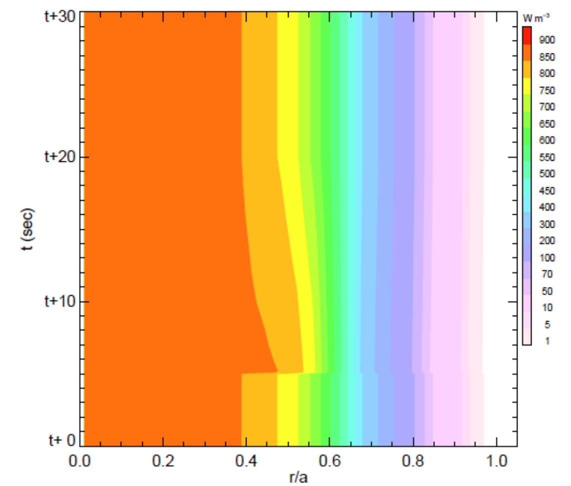



X-ray profile resolved into 5% energy bands

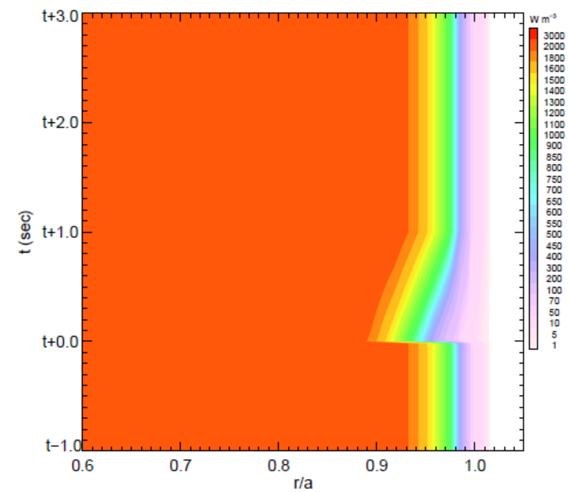
# Characteristic impurity radiated power profiles




SXR emission during a sawtooth event




SXR response to uncontrolled ELMs



# Active Spectroscopy

# ITER Active Beam Spectroscopy

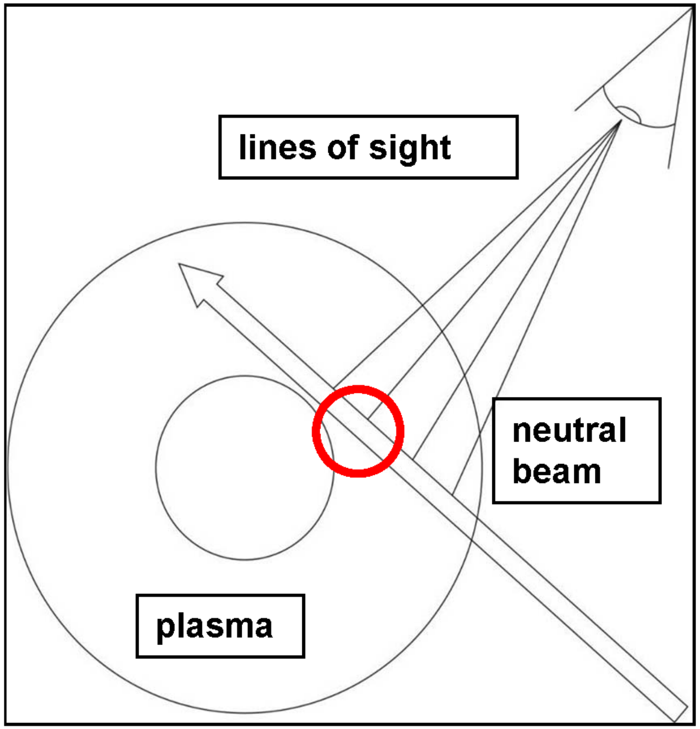
## CXRS principle:

Emission of spectral lines $\hbar\omega$ excited by charge exchange collision:

$$A^{Z+} + H \rightarrow A^{(Z-1)+}(nl)^* + H^+$$
$$A^{(Z-1)+}(nl)^* \rightarrow A^{(Z-1)+} + \hbar\omega$$

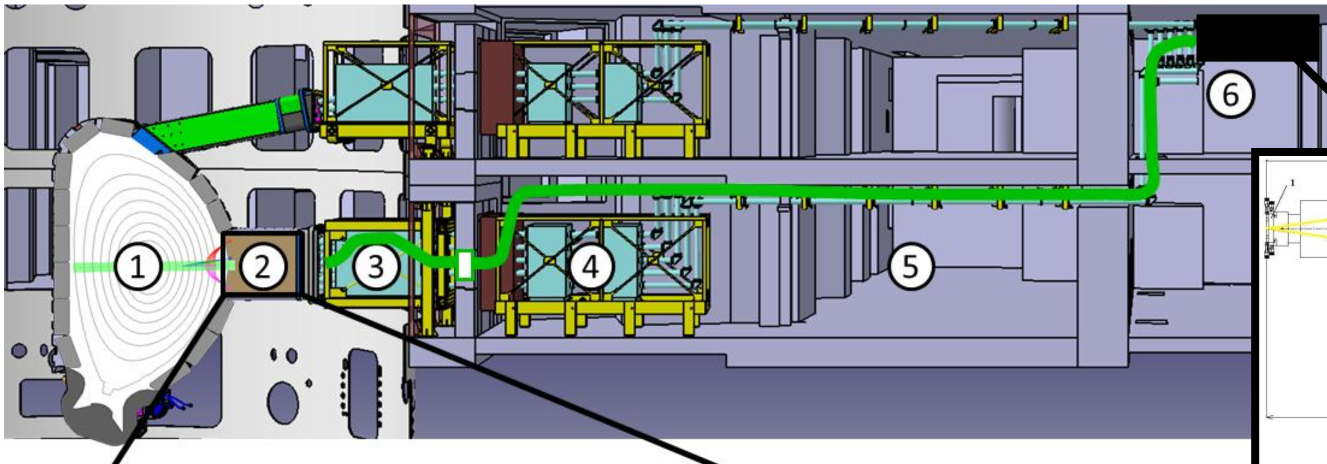
From spectrum analysis, ion density, temperature and velocity are obtained.

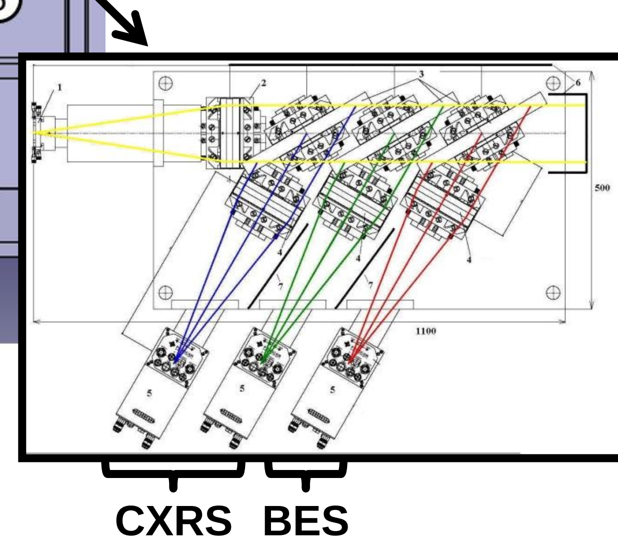
Also BES and MSE

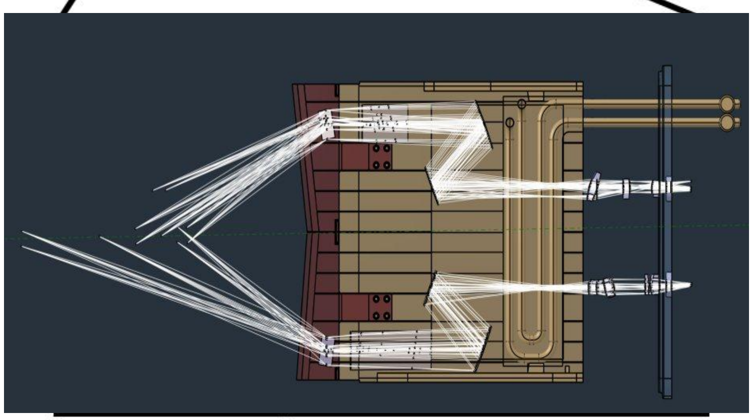


# Outline Design for Edge CXRS in Eq3

- Measures the outer half of the plasma – key parameters



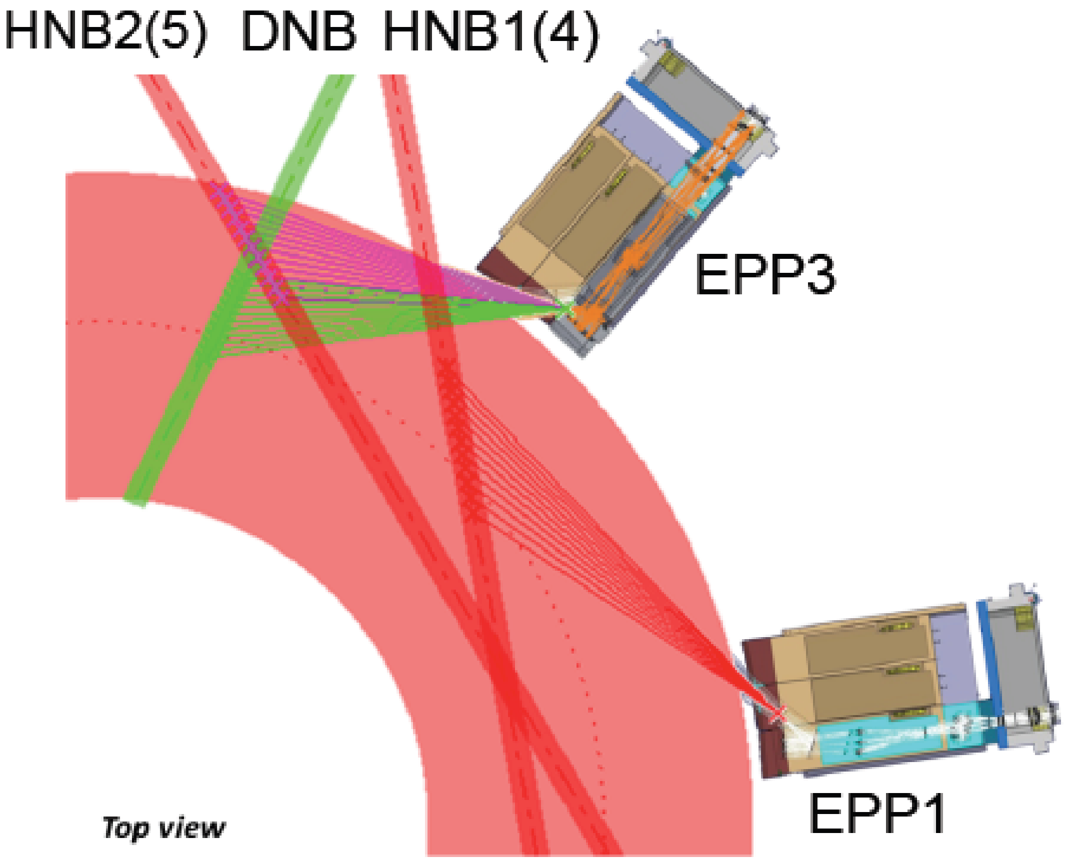



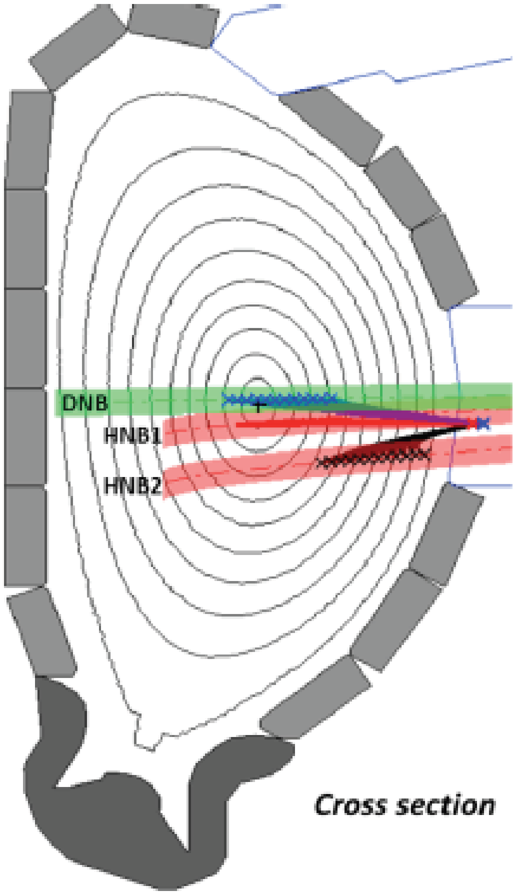



**(1) Plasma**
**(2) Port plug**
**(3) Interspace**
**(4) Port Cell**
**(5) Gallery**
**(6) Diagnostic area in building 14**

Get profiles of:
- Ion Temperature
- Rotation
- etc

# Overview of MSE



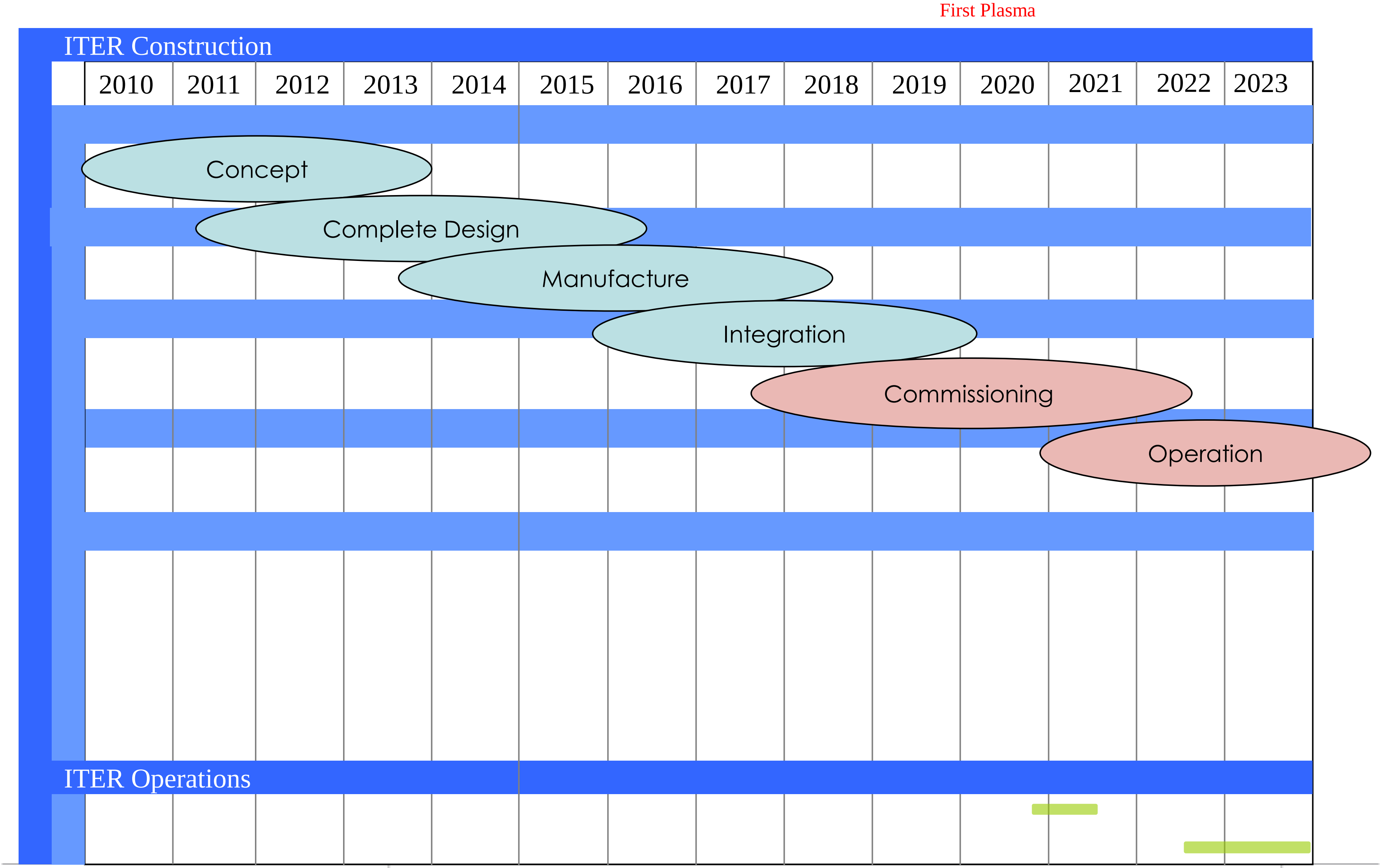

**(from GLB7UC – MSE CDR- Levington)**

Heating beams may be on or off axis

Line Splitting versus Line Polarisation now an important discussion

# Where are we?

# Present planning for ITER Diagnostics



# Summary

- Conceptual design and integration of ITER spectroscopy is almost complete.
- Now entering Preliminary Design phase, in collaboration with international teams.
- ADAS has been essential input to diagnostic designs:
  - Management of huge atomic data archive
  - Availability of applications to retrieve and process atomic data
  - Availability of ADAS experts to model and interpret plasma emission
- Next steps
  - More detailed analysis to support the advanced design stages
  - Validation of system designs
  - Update plasma emission modelling with new atomic data as available
  - Prepare for operation and data analysis phase
  - Please help us to tackle the new challenges