Overview of ITER's EP diagnostics:

fast ions (NPA, FICX, lost alphas, ICE, HF magnetics, neutrons, etc)

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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

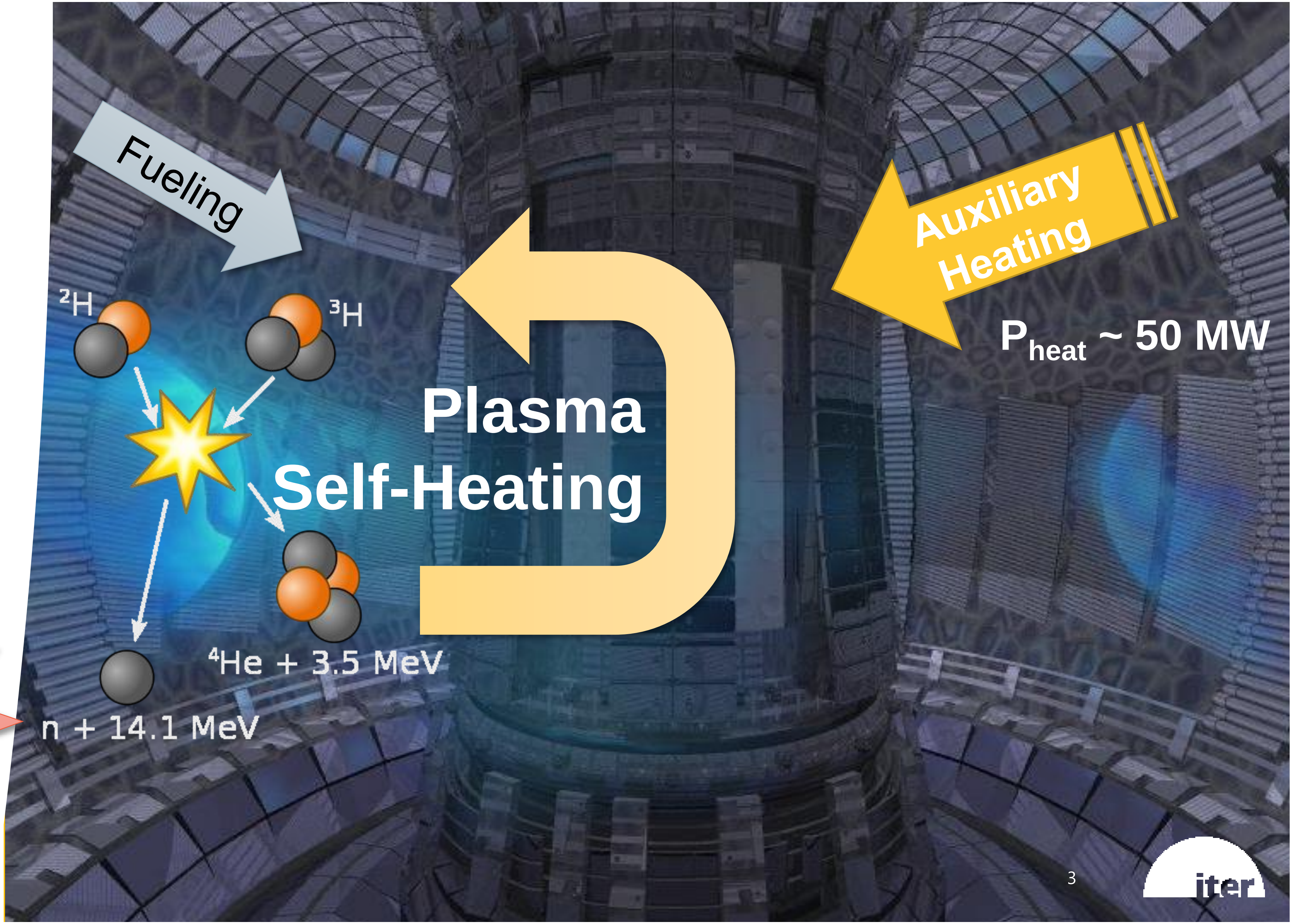
To create a controlled "burning" plasma

To achieve Q ≥ 10

FUSION ON EARTH

Magnetic confinement fusion

- Deuterium + Tritium produces Helium + a neutron
- Requires a precisely shaped and controlled magnetic field.
- Temperature: ~150 million C
- Desired outcome: a ”burning” (largely self-heating) plasma

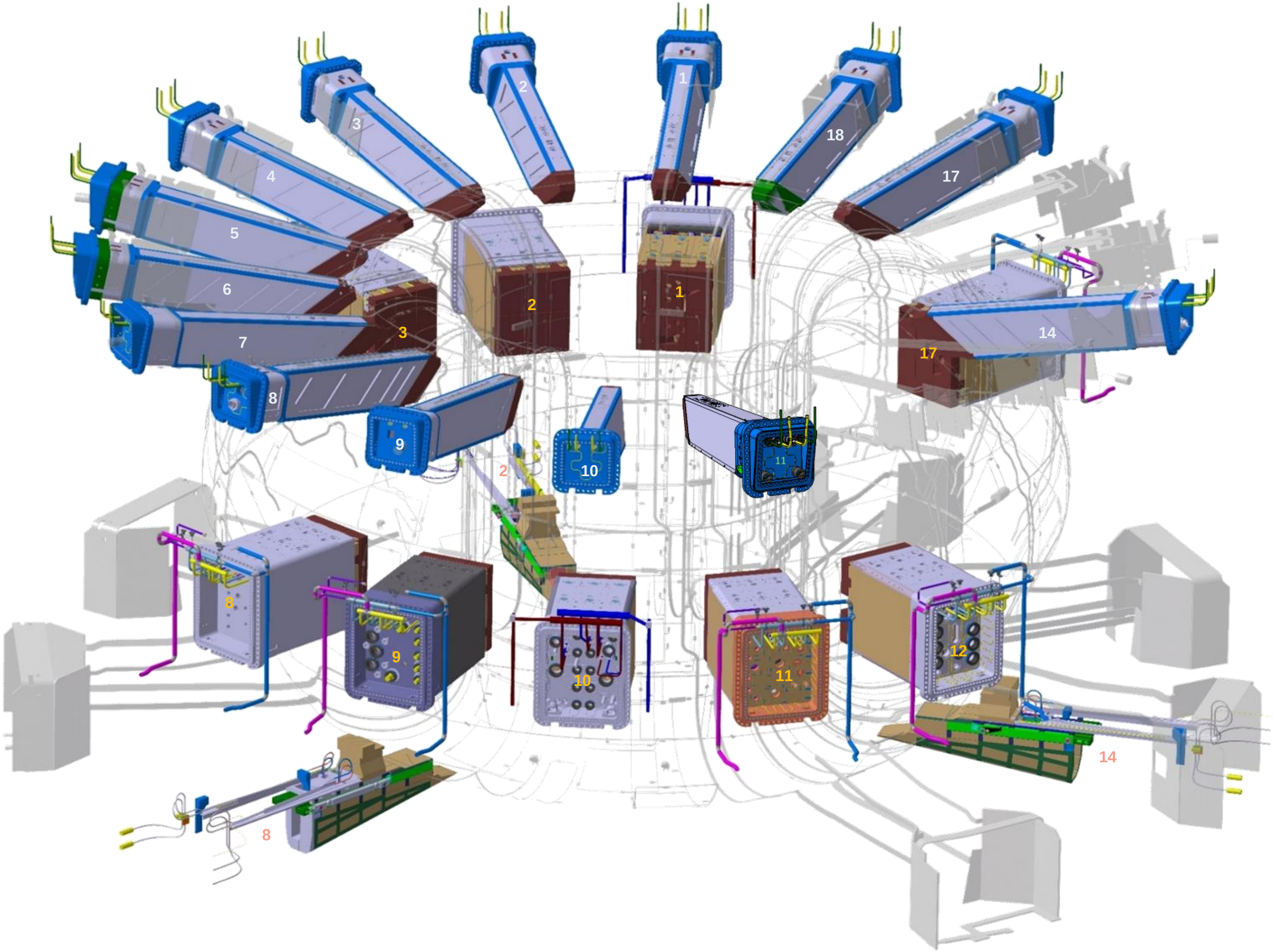


ITER has more than 50 diagnostic systems distributed in 26 ports for

- Machine protection
- Basic control
- Advance control
- Physics studies

Manufacturing has started for many of these systems

Some of the first parts have already been installed.



Challenges with Designing Diagnostics for ITER

Harsh environment

- Nuclear heating, Radiations, Magnetic field, Fire loads consideration, interferences,…

Port integration

- Multiple systems in confined spaces
- Multiple interfaces

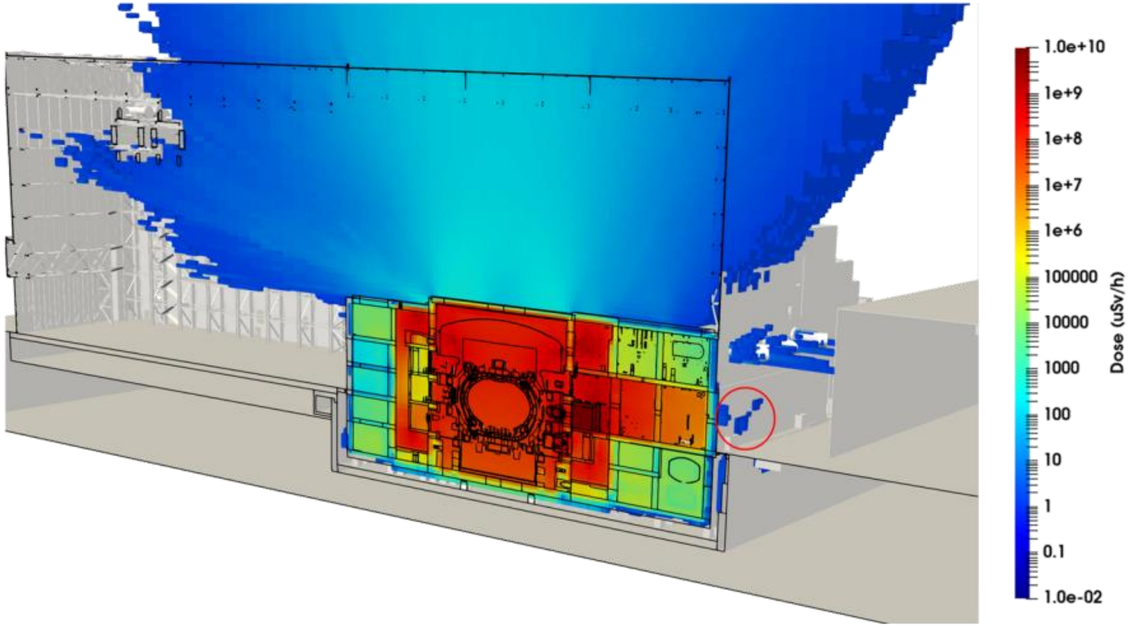
Reliability and robustness

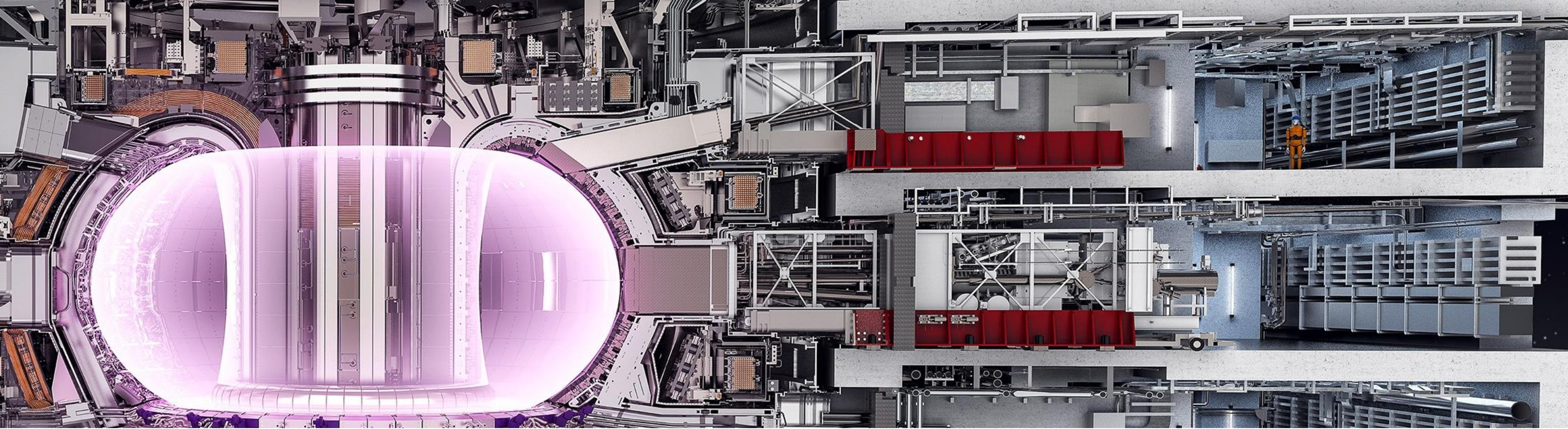
- Maximizing machine runtime
- Minimizing maintenance downtime

Maintenance planning

- Safe human access
- Remote handling compatibility

…into a nuclear reactor environment

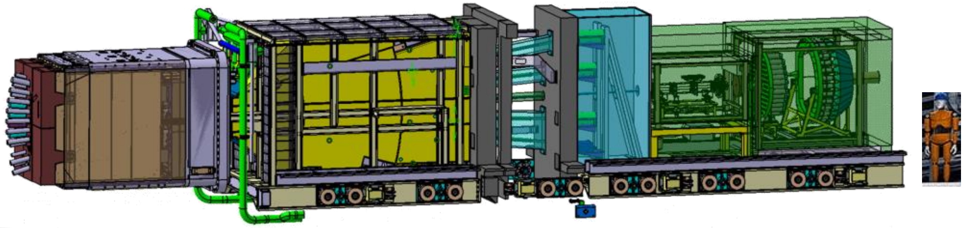




Neutron fluxes during plasma operation [n/cm^2/s]: 10^{14} → 10^{9} → 10^{6} → 10^{3}

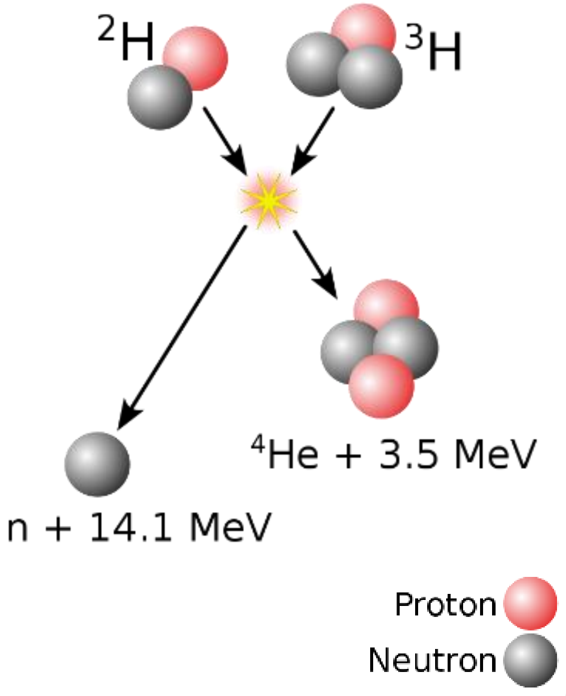
Bioshield

Port Plug | **Interspace** | **Port Cell** | **Gallery**



Modular design to address challenges with different level of accessibility, reliability, maintainanability

Why fast ions are important?



1. Fueling ratio (e.g. T/D) in the plasma?

2. Is the plasma well heated?

   Fast alpha population

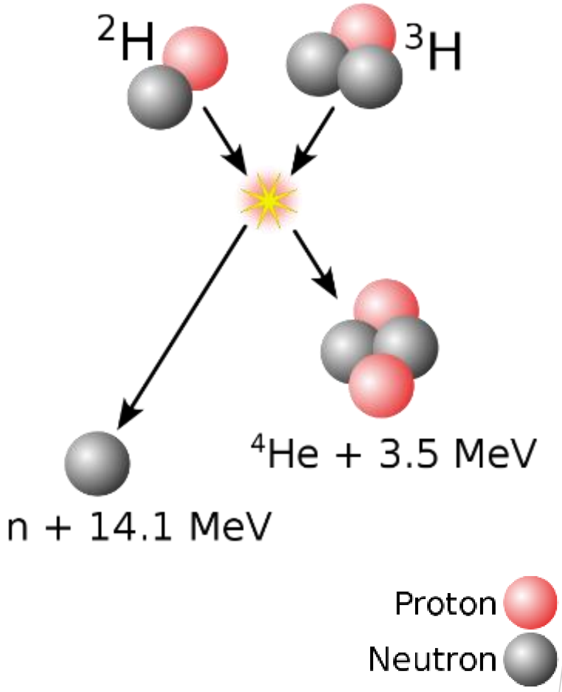
   Fast beam population

   ICRH population

3. How good is the alpha and fast ion confinement?

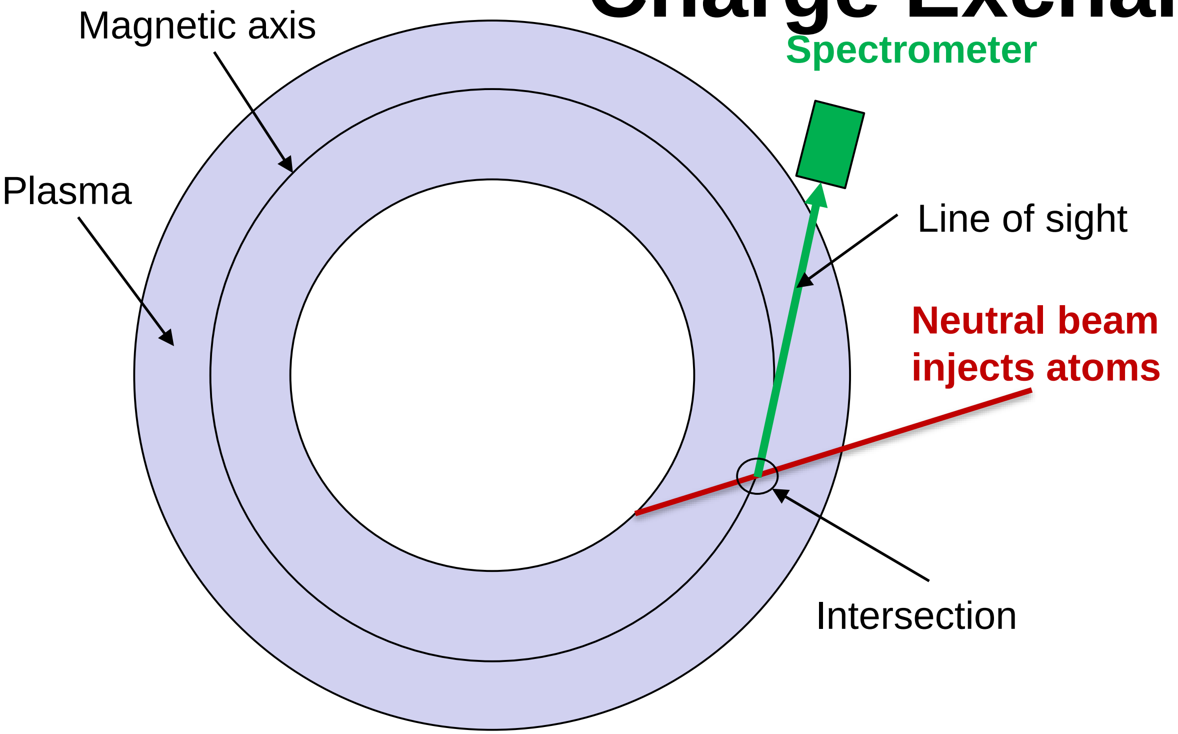
4. How much fusion power is being produced?

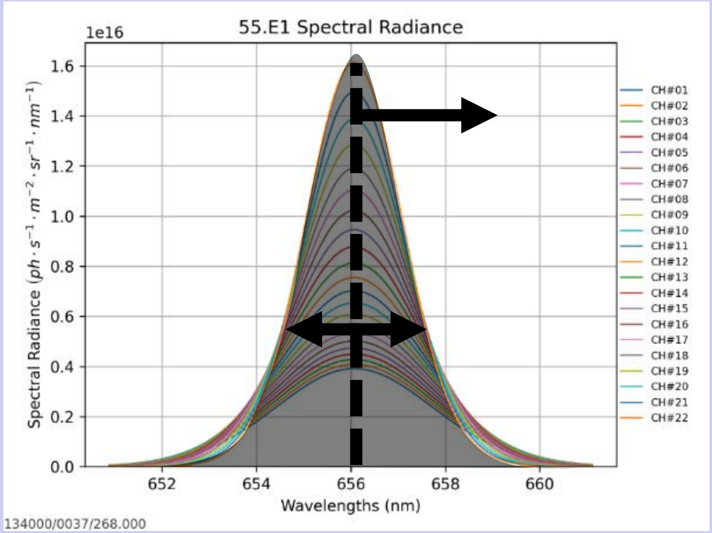
How to get information on fast ions?

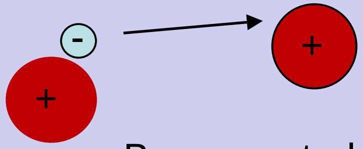


• Ions	➢ Probe near plasma boundary (Fast Ion loss Detector – FILD)
• Neutral Particles	➢ Neutral Particle Analyzer
• Light	➢ Inject fast neutrals and detect light from charge exchange
• Waves	➢ Excite particles at certain frequency and detect feedback
• Neutrons	➢ Neutron diagnostics

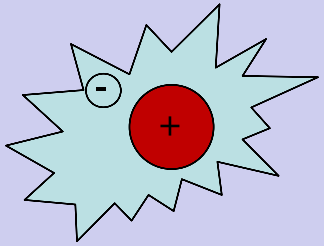
Charge Exchange principle







Beam neutral **atom exchanges electron** with plasma ion



New plasma ion in **excited state** emits **line emission** picked up by **spectrometer**

Line emission shape reveals:

Doppler width	⇔ ion velocity distribution
	(~ion temp. if Maxwellian)
Doppler shift	⇔ bulk ion velocity
	(~ plasma rotation)
Intensity	⇔ ion density

“Active Spectroscopy” approach to fast ion measurements

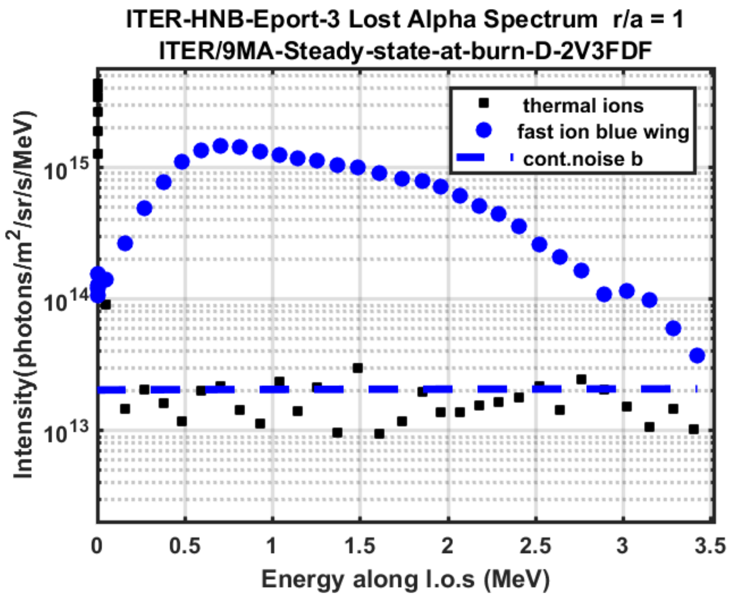
Fast Ion Charge eXchange (FICX)

- Charge exchange does not only happen with thermal ions, but also with fast (energetic) ones:

  ⇔ leads to asymmetric spectrum: information on fast particle energy and density

  – Signal of FICX (Fast Ion Charge eXchange) is low

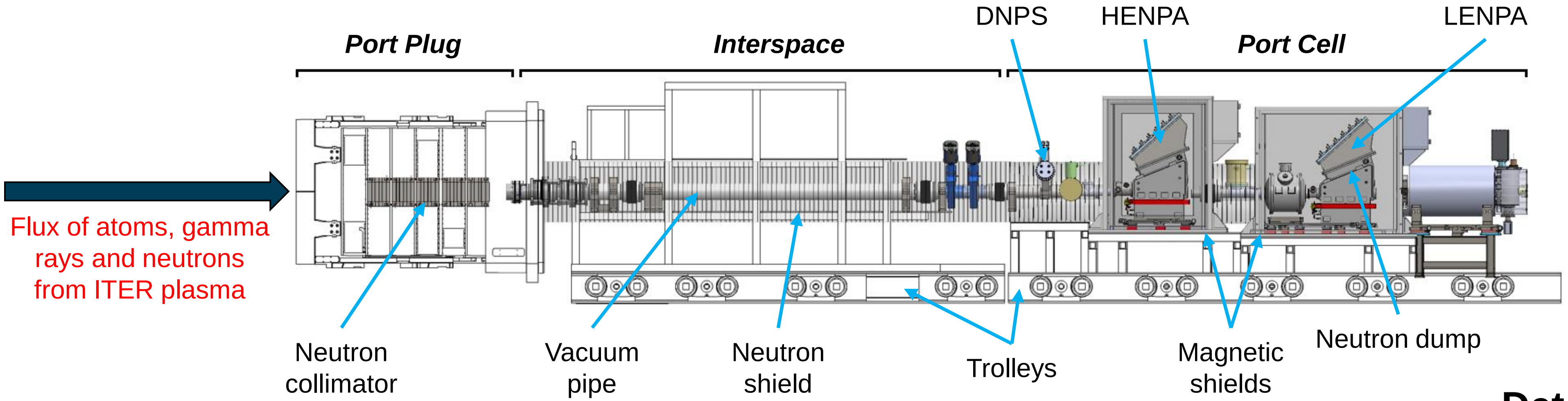
    ⇔ long integration times



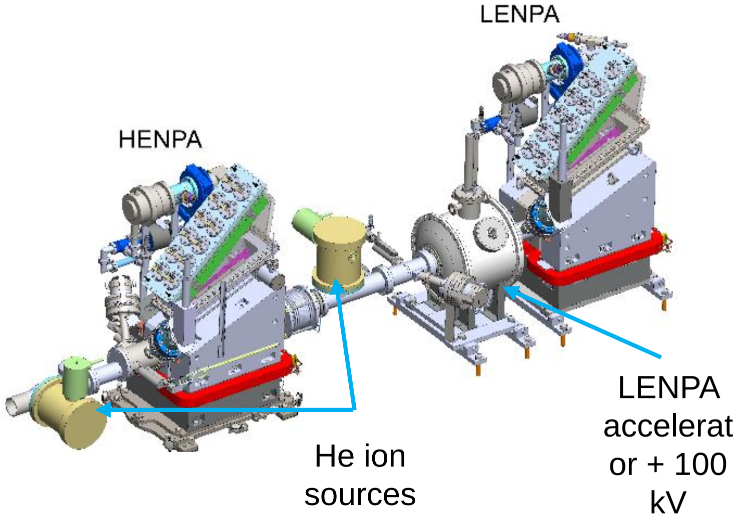
E.g. for ITER: only blue shifted part of fast ion spectrum above noise floor

  – Fast Ions can come from:
    - Fusion (He4) ➔ Info on fusion products and escaping α's
    - Minority heated ICRH (He3) ➔ Info on slowing down and heating efficiency
    - Fast beam ions (a.k.a. FIDA) ➔ Info on slowing down and heating efficiency

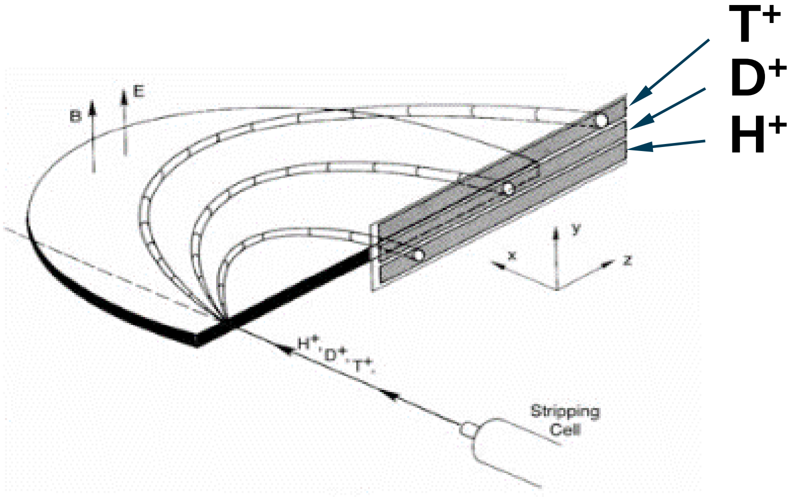
Measurements are limited to edge plasma in ITER



Flux of atoms, gamma rays and neutrons from ITER plasma



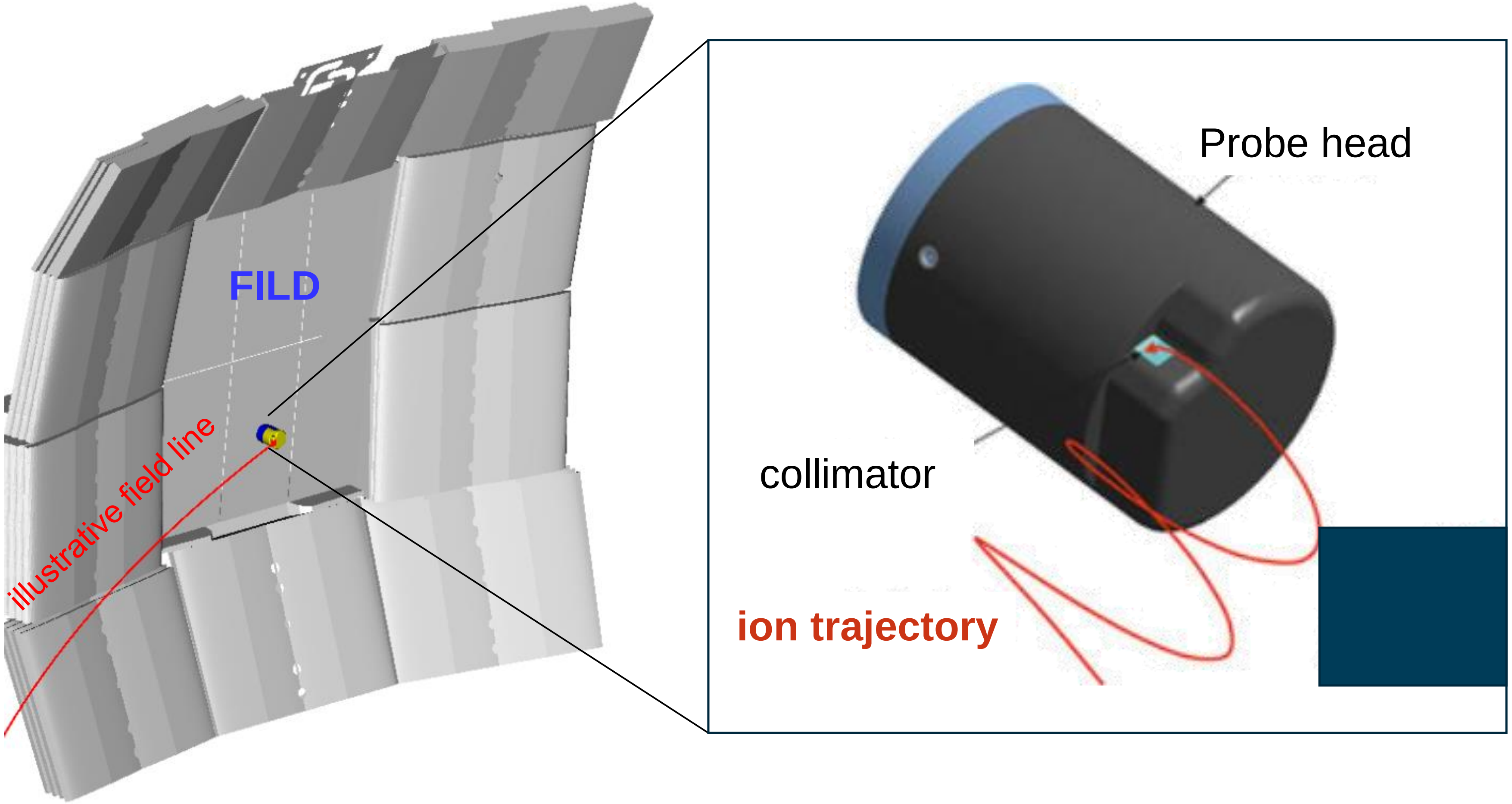
Detector array with



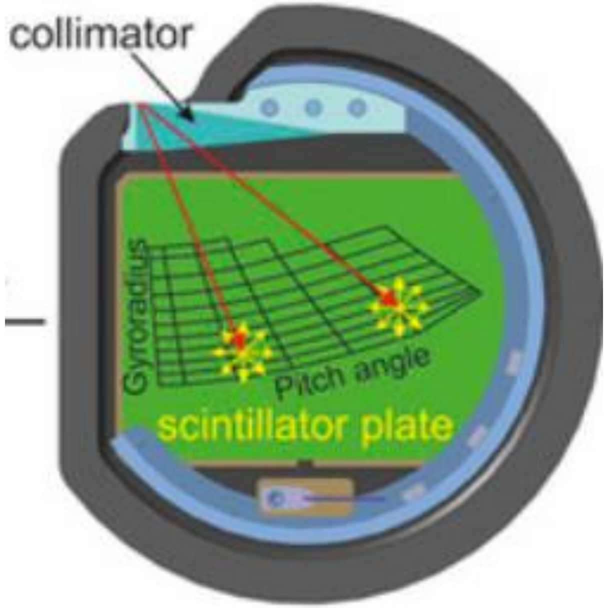
Neutral Particle Analyzer can provide high-dynamic range fueling ratio measurements with 20% accuracy

Equatorial Port Plug area

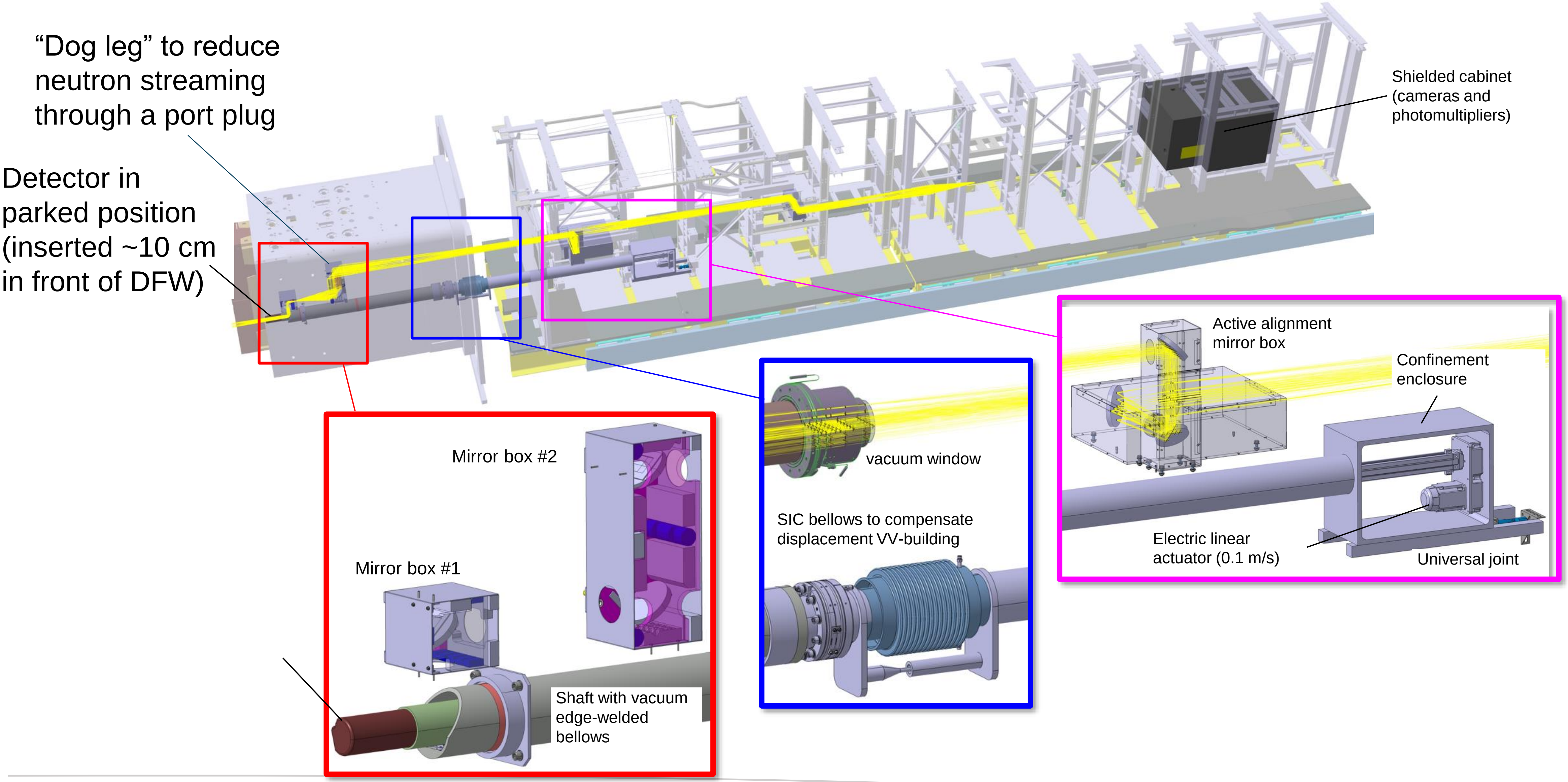
Due to plasma instabilities, fast ions escape the plasma and ultimately hit plasma facing components.



The position of the light on the scintillator tells us the energy and velocity of the ions

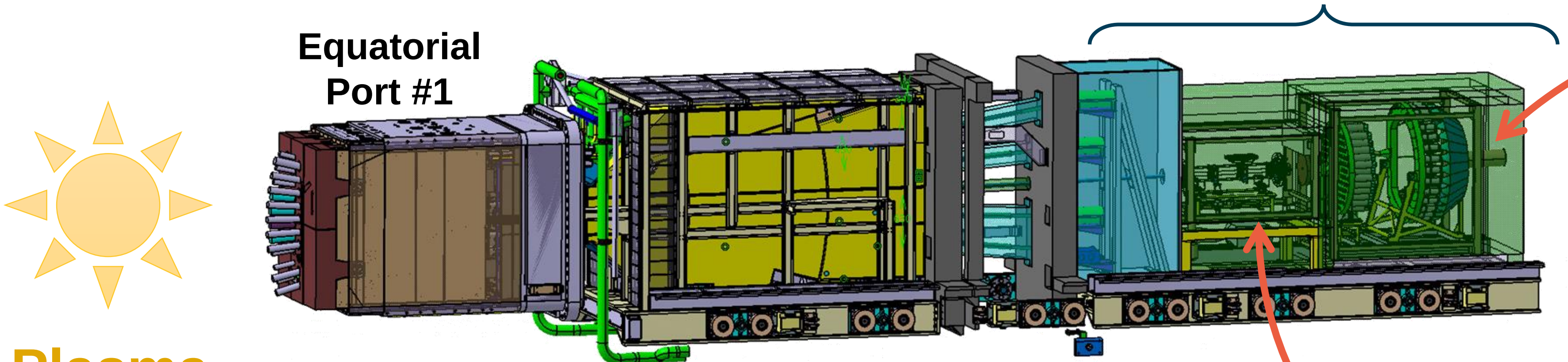


Fast Ion Loss Detector (FILD) captures alphas and other fast ions as they escape the plasma



FILD is based on reciprocating probe to minimize probe exposure to plasma loads

High-Resolution Neutron Spectrometer


Equatorial Port #1

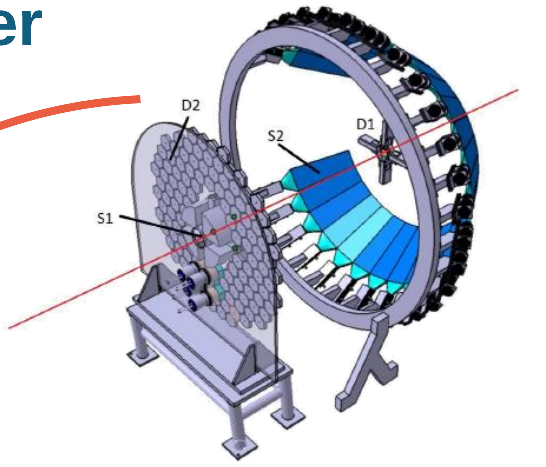
Plasma

Port Plug

Interspace

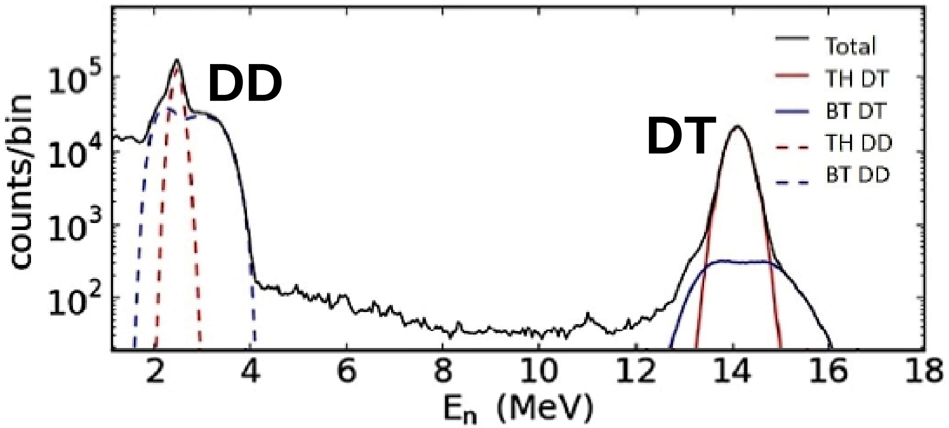
Bioshield

Port Cell



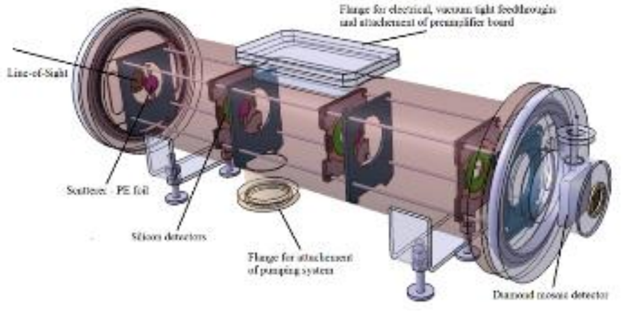
Time-of-Flight Spectrometers

Neutron Energy Spectra



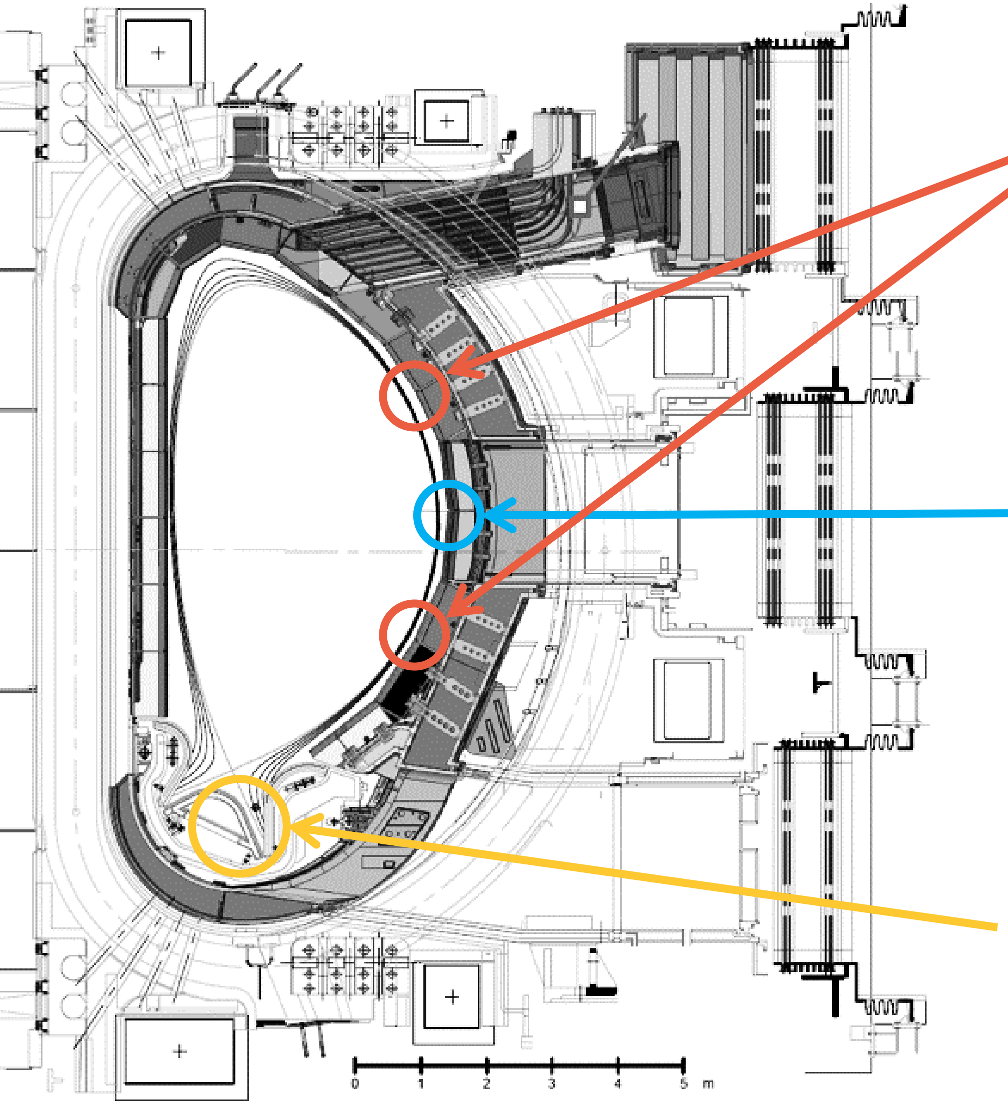
Dynamic range:

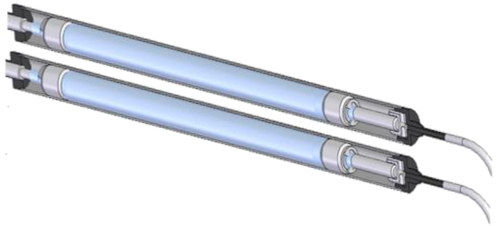
$n_T/n_D \sim 0.01$ to 10



Thin-Foil Proton Recoil
+ Neutron Diamond Detector

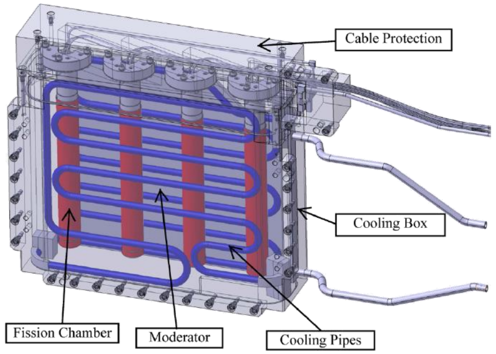
Neutron spectrometers can provide high-dynamic range fueling ratio measurements with 20% accuracy





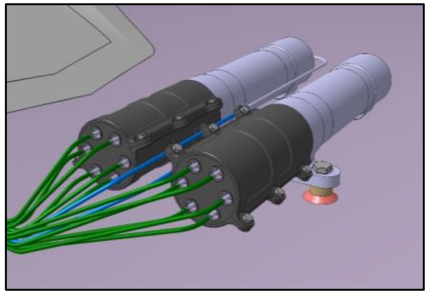
Micro Fission Chambers

^{235}U Fission Chambers
(Japan)



Neutron Flux Monitors

^{235}U Fission Chambers
(China)



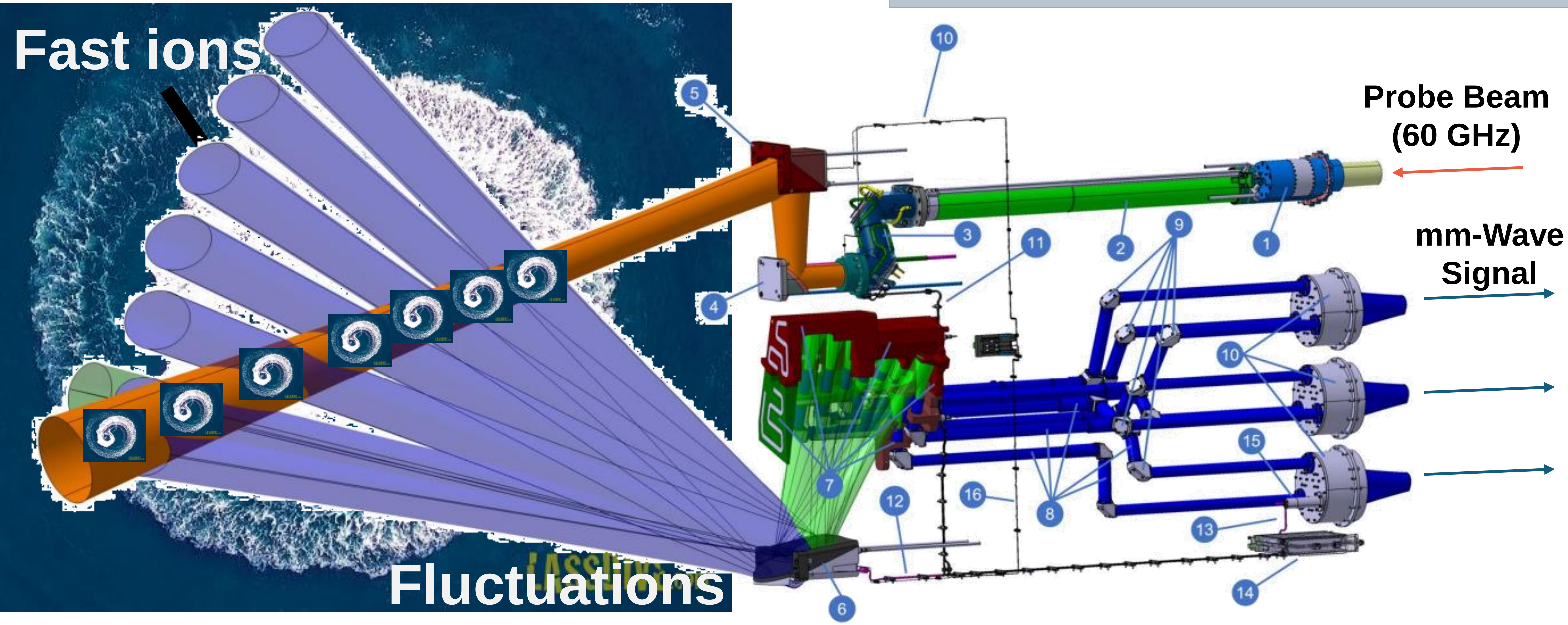
Divertor Neutron Flux Monitors

^{235}U & ^{238}U Fission Chambers
(Russia)

Neutron flux monitors can “count” the fusion power with 10% accuracy and 1 ms time resolution

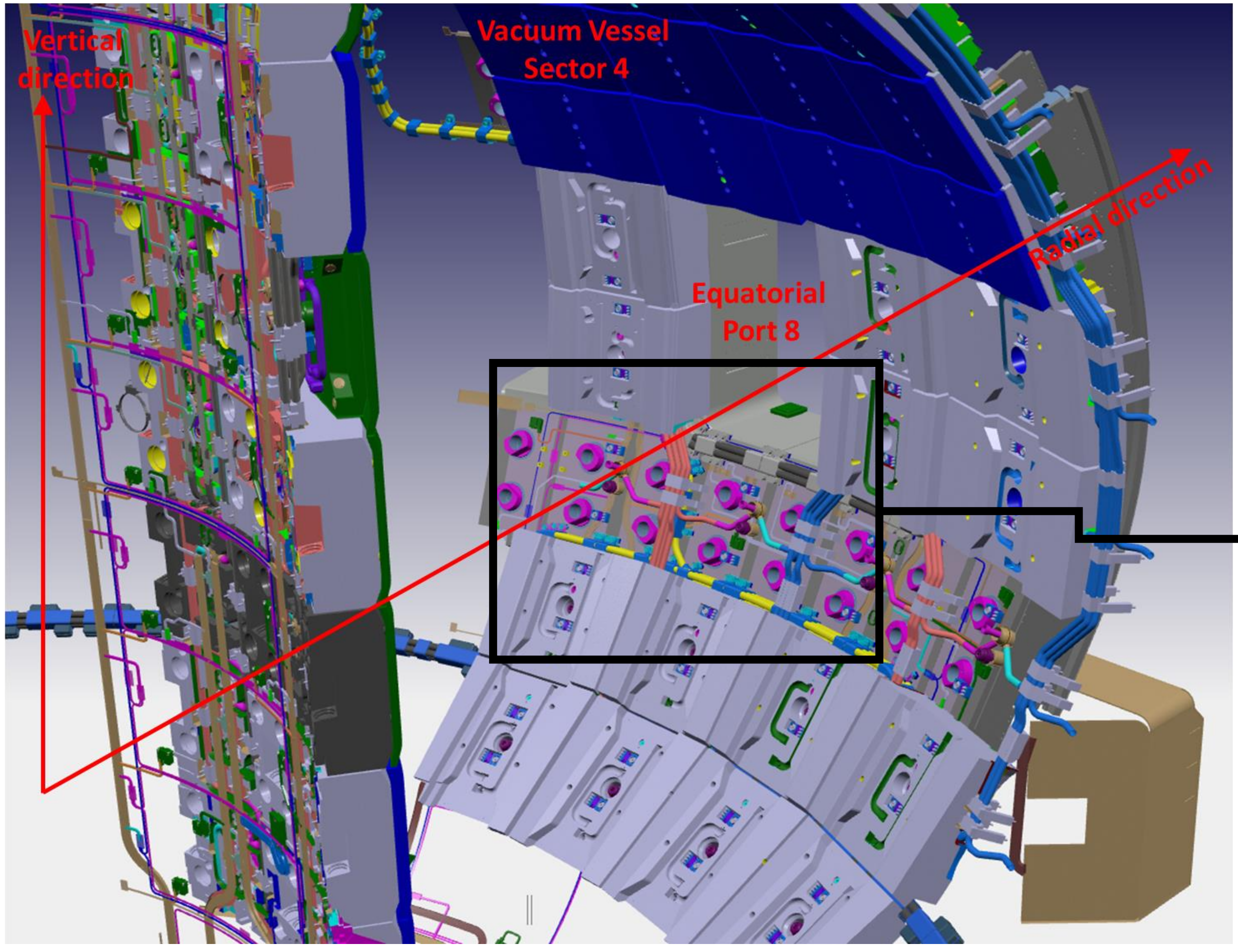
Collective Thomson Scattering

Microwave reflectors and waveguides are resilient to ITER environment

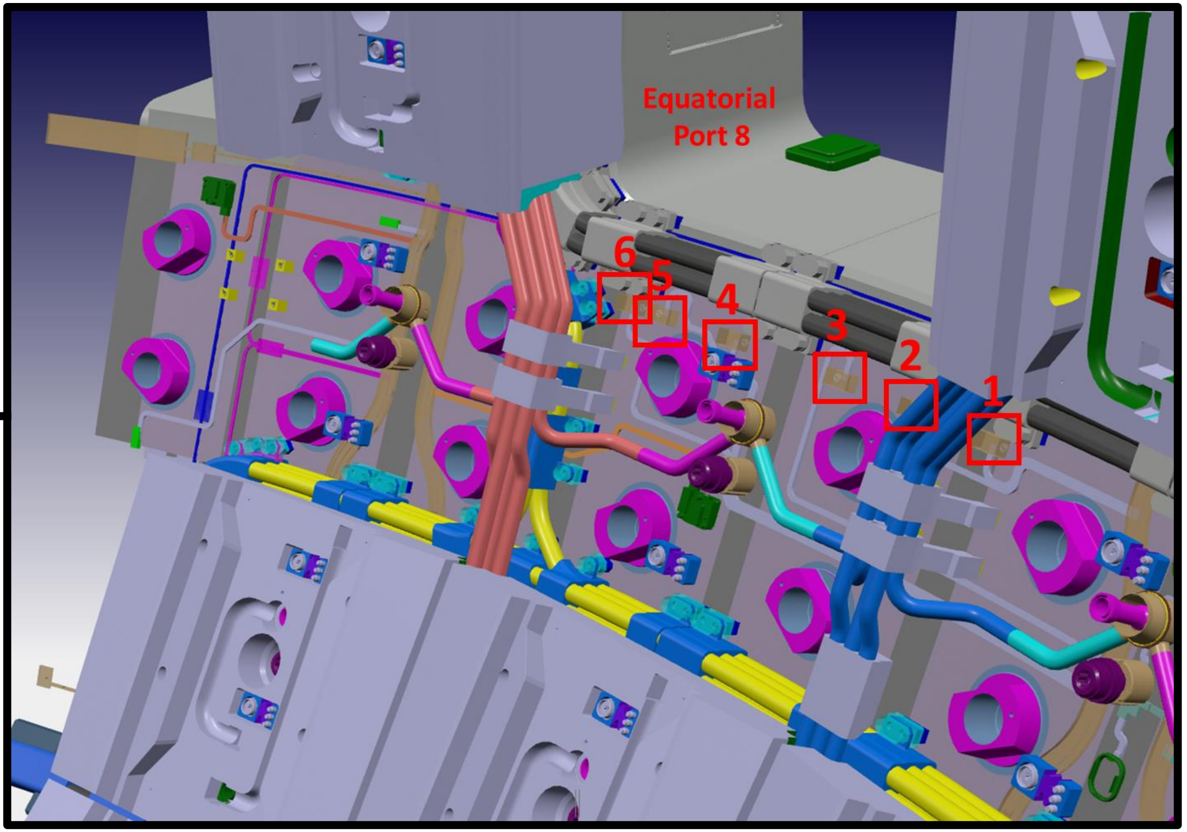


Quantifying the Alpha density profile with 20% accuracy using Collective Thomson Scattering (CTS)

RADAR system retrofitting from existing components



Candidate positions for MHz antennas

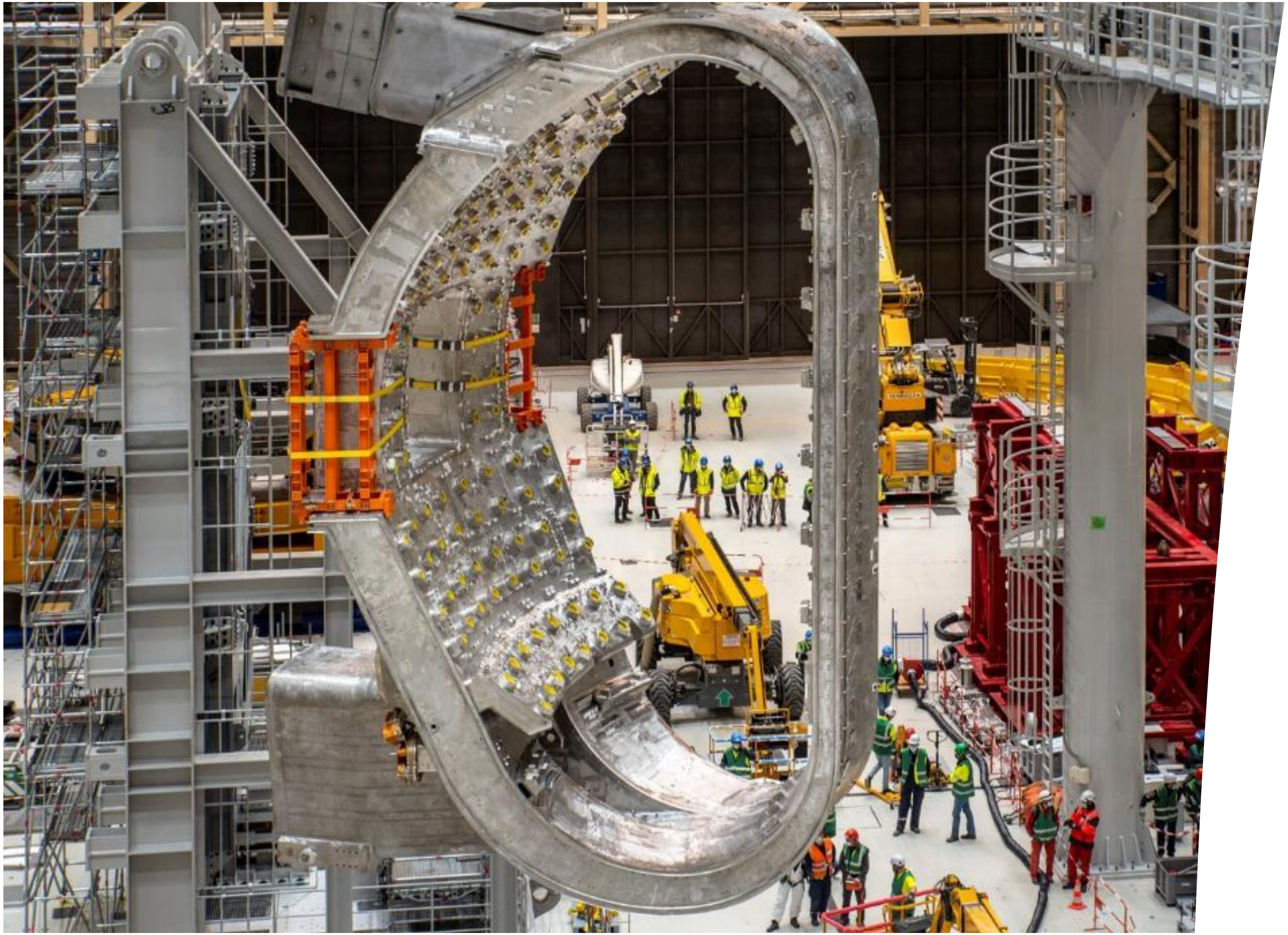


On-going discussion to implement a Fast Wave Reflectometer for Ion Cyclotron Emission (ICE) in 10-100 MHz range

Thank you!

iter

china eu india japan korea russia usa



FIRST SECTOR SUBASSEMBLY

Vacuum Vessel Sector 6 placed on the Sector Sub-Assembly Tool

May-June 2021

Back-ups

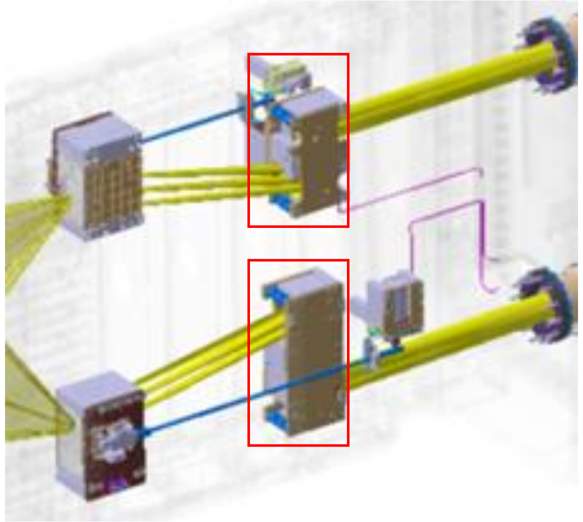
china eu india japan korea russia usa

Strategies for reducing radiations are paramount

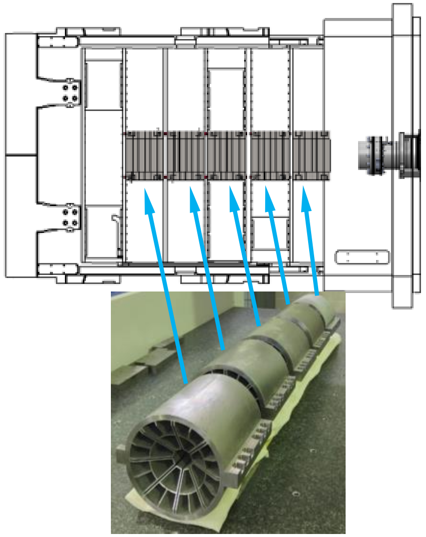
First, not letting the neutrons in

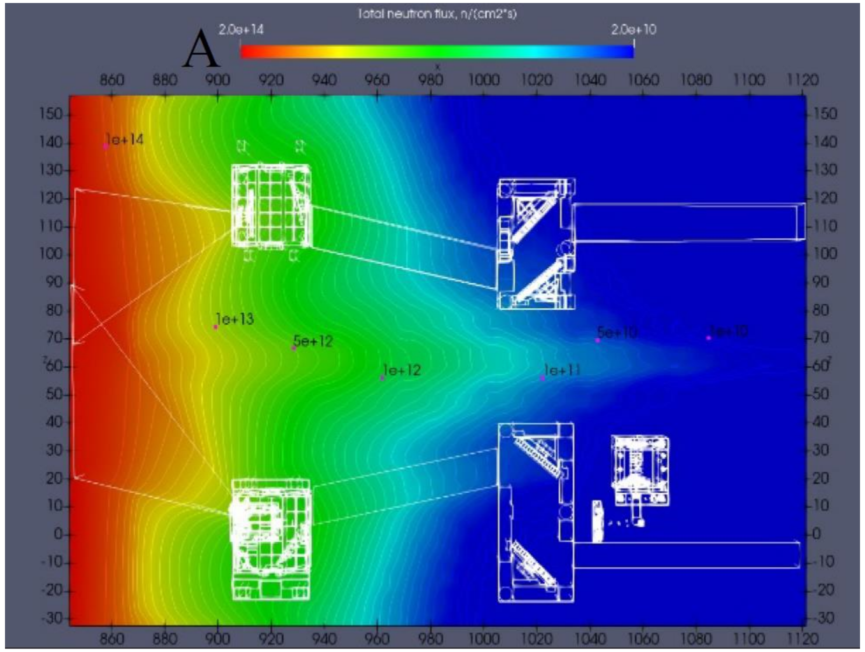
Dog-legs in optical systems and **collimators** in line-of-sight

Dog-Legs



Collimators





Strategies for reducing radiations are paramount

First, not letting the neutrons in

Dog-legs in optical systems and **collimators** in line-of-sight

Local and integrated **shielding**