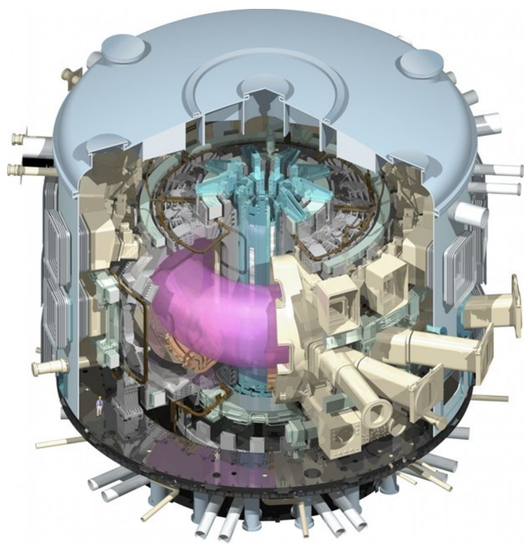
Measuring Density in the ITER Fusion Plasma

The ITER Experiment

ITER is a large-scale scientific experiment that aims to demonstrate that it is possible to produce commercial energy from fusion.

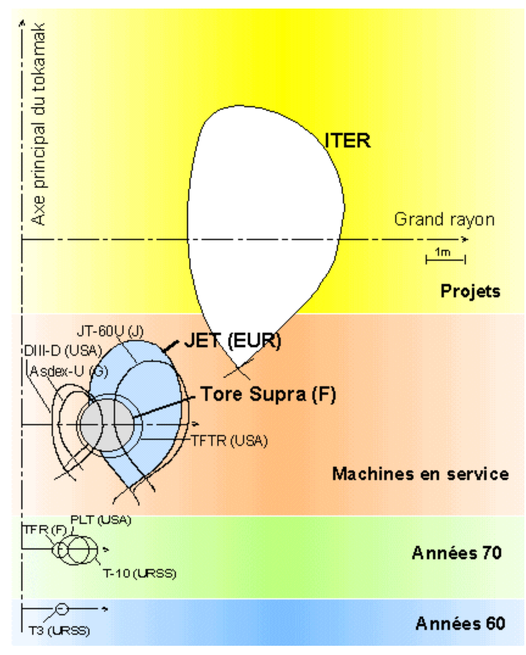


ITER Tokamak

ITER Headquarters building with Experiment Platform in the background

Common Challenges for ITER Diagnostics

- Iter is significantly larger than previous experiments
  - ~10x plasma volume of previous experiments
- Much hotter
  - 40 keV
- Burning fusion plasma
  - Large neutron fluxes
  - High EM radiation loads
  - Large mechanical stresses (Disruptions)



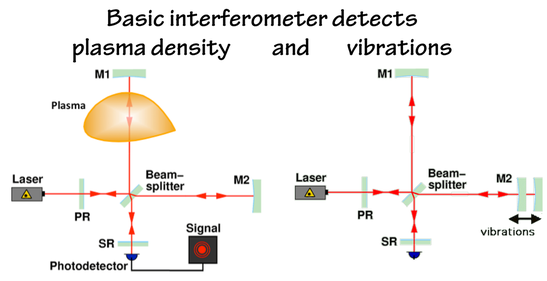
Scaling of ITER relative to previous devices

Line Integrated: 10^{18} – 5x10^{20} m^{-3}

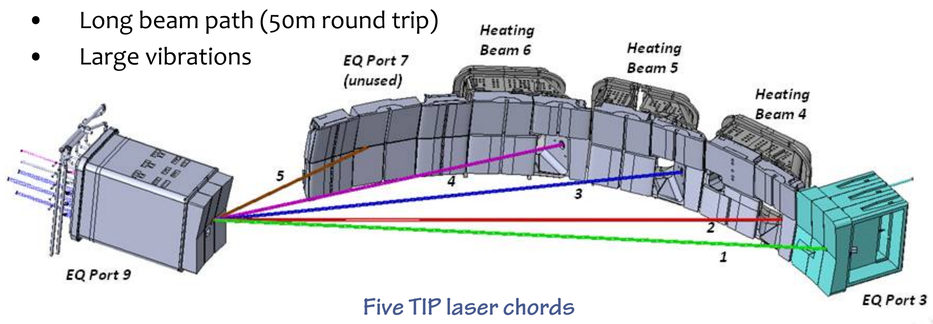
<u>TIP (Toroidal Interferometer-Polarimeter)</u>

- Principle
  - IR interferometer
  - 2nd interferometer for vibration compensation
  - Polarimeter for fringe skips (see PolPo below)
- Design Features
  - CO_2 laser, 10.6 µm; CO laser, 5.7 µm
  - Cu Corner cube retroreflector (CCR) in blankets
- Particular Challenges
  - CCR thermal distortion
  - Alignment issues
    - Long beam path (50m round trip)
    - Large vibrations

Basic interferometer detects plasma density and vibrations



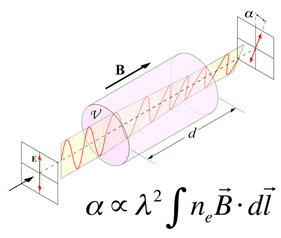
$$\Delta\phi = \frac{e^2\lambda}{4\pi\varepsilon_0 m_e c^2}\int n_e dl$$



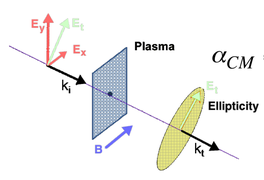
Five TIP laser chords

<u>PolPo (Poloidal Polarimeter)</u>

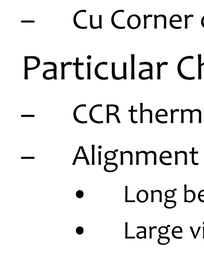
- Principle
  - Faraday rotation changes polarization
  - Cotton Mouton effect changes ellipticity
- Design Features
  - Laser 57 µm; 48 µm
  - Cu CCR behind blankets
- Particular Challenges
  - CCR thermal distortion
  - Cooling of CCR
  - Low signal-to-noise



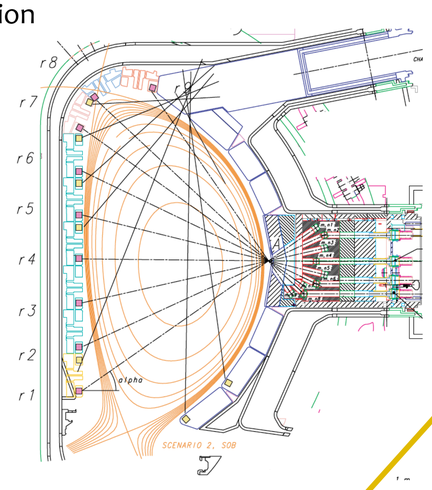
$$\alpha \propto \lambda^2 \int n_e \vec{B}\cdot d\vec{l}$$



$$\alpha_{CM} \approx \frac{C}{\omega^3}\int n_e(\vec{B}\times\hat{k})^2\, ds$$



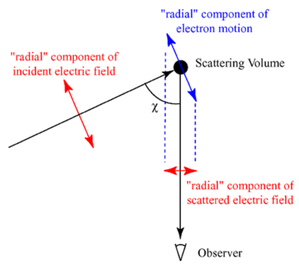
Retroreflector design

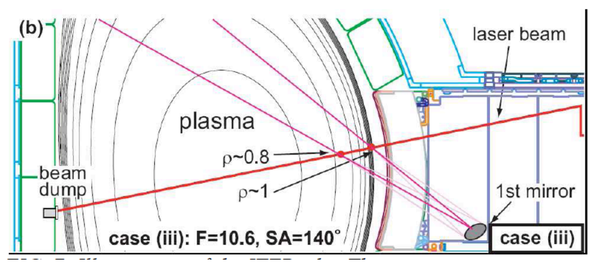


Edge: 10^{18} – 10^{20} m^{-3}

<u>Edge Thomson Scattering</u>

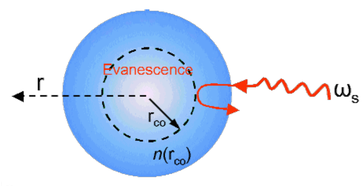
- Principle
  - Imaging Thomson scattering
  - Multi-point detection along laser beam
- Design Features
  - Nd-YAG laser: 5J, 30ns, 100Hz
  - Located in single equatorial port
- Particular Challenges
  - Viewing optics

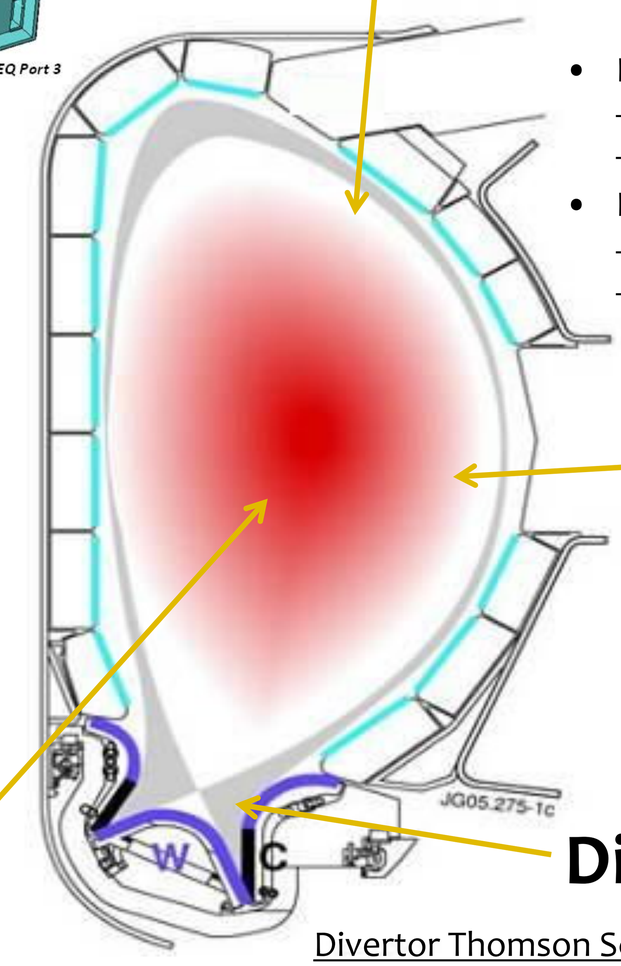




<u>Reflectometry (Low field side)</u>

- Principle
  - Microwave RADAR
    - Amplitude and phase detection
- Design Features
  - multi-antenna system: O and X mode
  - Measures: profiles, fluctuations and flows
- Particular Challenges
  - Design of core antennas to cope with plasma height variations
  - Performance for large density fluctuation





Pedestal: 10^{18} – 10^{20} m^{-3}

<u>TIP (Toroidal Interferometer-Polarimeter)</u>

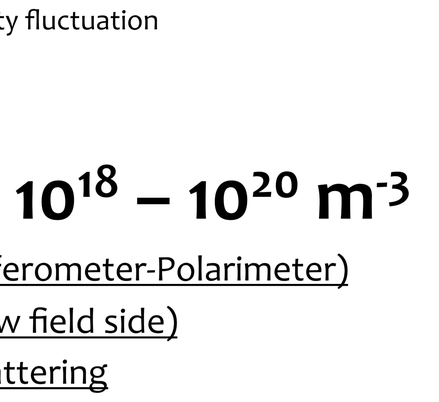
<u>Reflectometry (Low field side)</u>

<u>Edge Thomson Scattering</u>

Divertor: 10^{18} – 10^{22} m^{-3}

<u>Divertor Thomson Scattering</u>

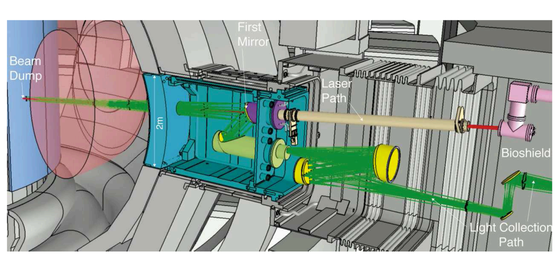
- Principle
  - Thomson scattering from electrons
- Design Features
  - Nd-YAG laser: 2J, 3 ns, 100Hz
  - SiO_2 coated, silver 1st mirror
  - Complex real-time alignment system
  - Highly dispersive triple-grating polychrometer
- Particular Challenges
  - Very tight space constraints
  - Steep density gradients
  - High nuclear environment
  - Low temperatures ➜ narrow line width
  - High background light
  - C and Be dust in cassette region
  - High etendu vs. deposition protection



Core: 10^{19} – 5x10^{20} m^{-3}

<u>Core Thomson Scattering</u>

- Principle
  - LIDAR Thomson scattering
  - Time-resolved detection of backscattered radiation
- Design Features
  - 7 x ND-YAG lasers: 5J, 250ps, 15Hz
  - UV (300nm) detection
- Particular Challenges
  - Very high time resolution requirements
  - Highly efficient beam dump required
  - Wide spectral range requirement for mirrors



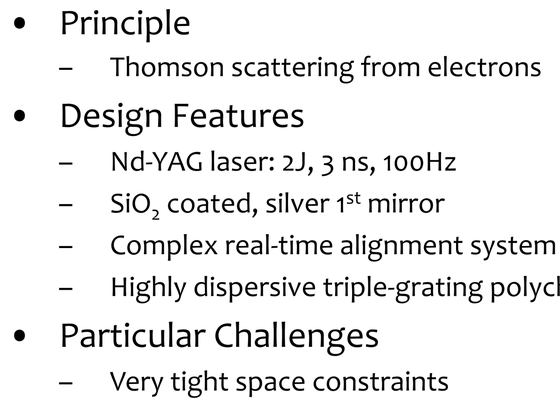
<u>Reflectometry (High field side)</u>

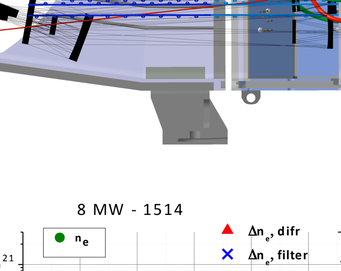
- Principle
  - Microwave RADAR
    - Amplitude and phase detection
    - X & O mode detection
- Design Features
  - X-mode observation 10-98 GHz
  - O-mode observations 15-155 GHz
- Particular Challenges
  - Integration of in-vessel waveguides and antennas
  - Performance with large density fluctuation

Reflectometry horn behind blanket

<u>Langmuir Probes</u>

- Principle
  - Swept Langmuir probe or triple probe
- Design Feature
  - Attached to cooled divertor support
  - Tapered design to distribute heat load
  - Designed to erode in sync with divertor
- Particular Challenges
  - Steady-state radiative heat load
    - operating temperatures ~2600° C
    - design of heat shield
  - Erosion issues
    - Distorted probe characteristic
    - Uncertain probe area
  - Long cable lengths
  - Strong magnetic fields





Heat loads to the Langmuir probes