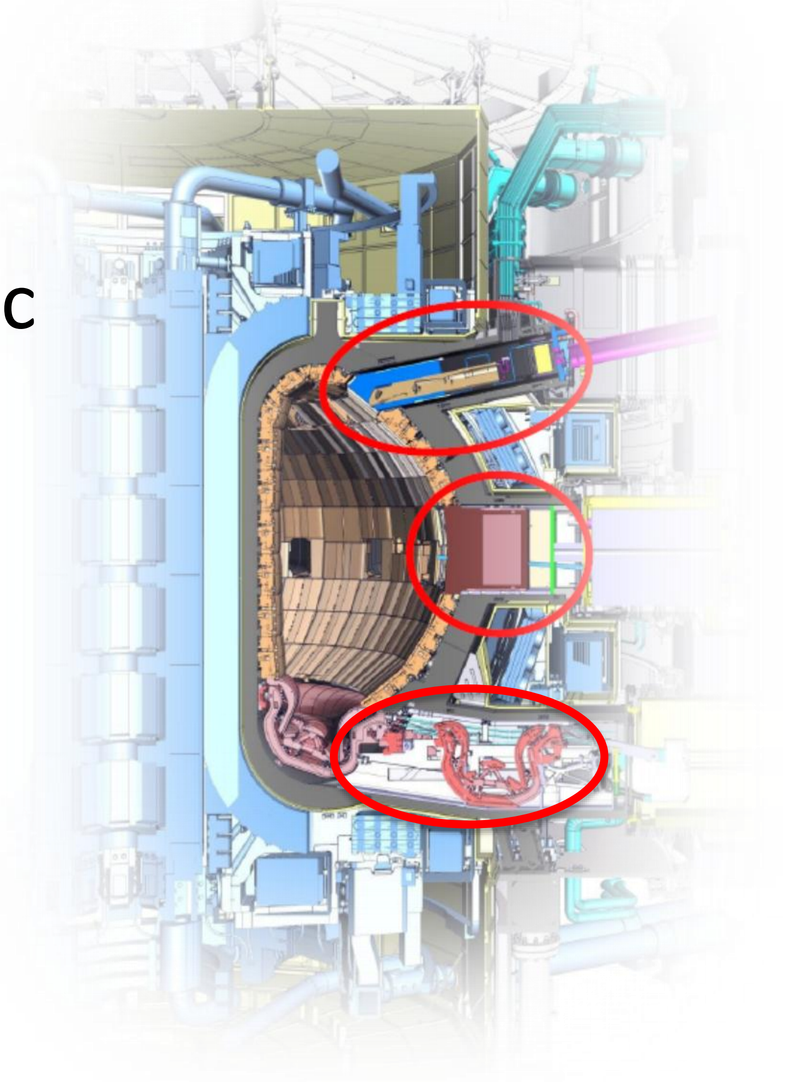
Status of US ITER Diagnostic Development

D. Johnson - PPPL



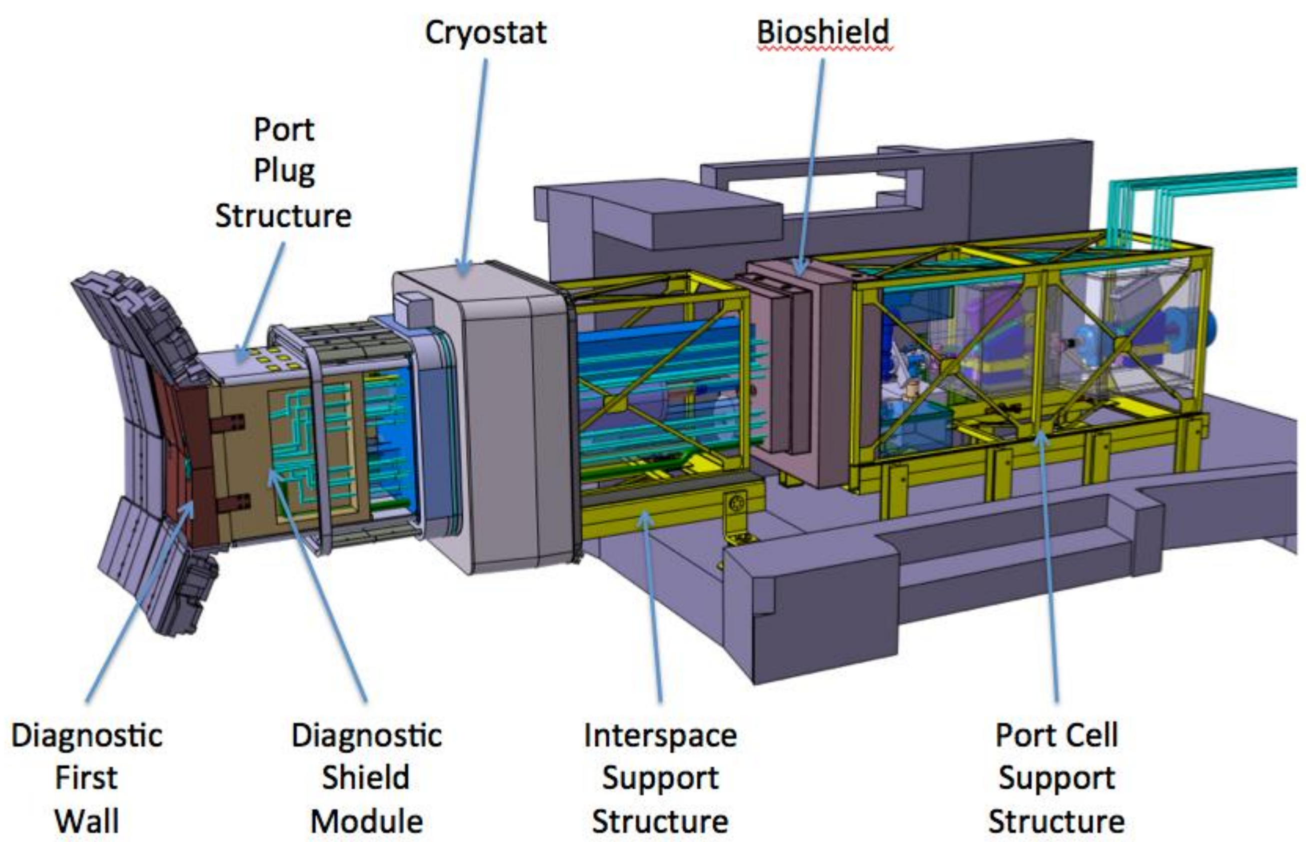
Outline

- What is different about developing diagnostics for ITER?
  - Removing heat at the front-end
  - Tolerating disruptions
  - Providing adequate shielding
  - Tolerating thermal excursions and motions
- ITER diagnostic system development status
- US systems and development status
  - Getting involved in US ITER diagnostics
- For each US diagnostic
  - Brief description of current design
    - emphasis on front-end
  - Main technical challenges and R&D topics
- Summary

Diagnostic Integration Challenges

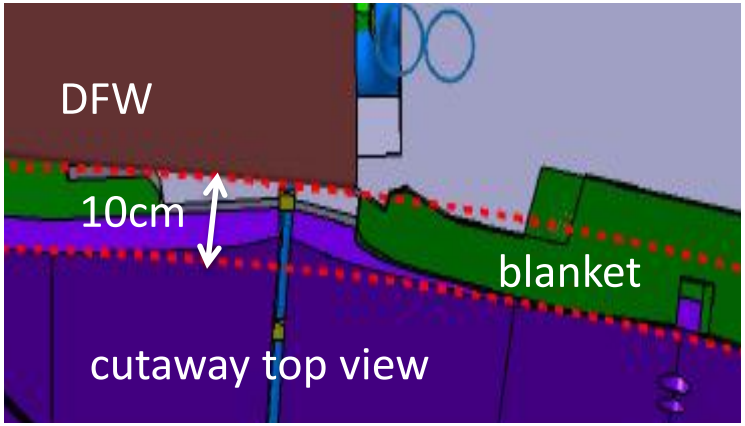
Unique ITER Environment
[relative to Joint European Torus (JET)]

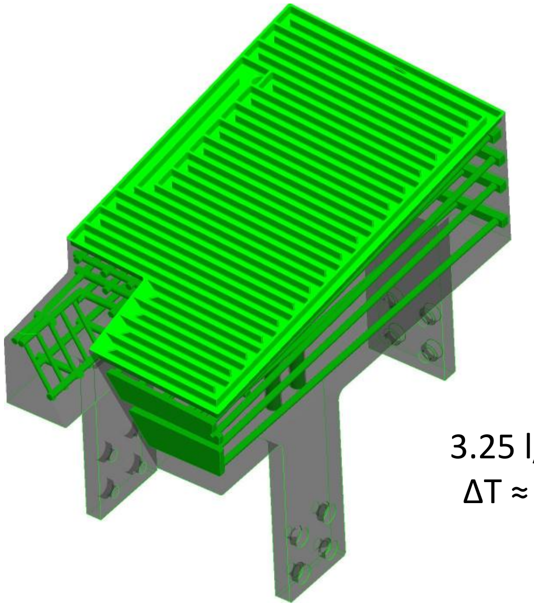
- Neutron and gamma fluxes (up to x10)
- Pulse length (up to x100)
- Neutron fluence ($>10^6$)
- Neutron heating ($1 MW/m^2$) (essentially 0 on JET)
- Charge exchanger (CX) neutral particles (up to x5)



Heat Removal - Diagnostic First Wall

- DFW is set back 10 cm, allowing stainless steel plasma-facing surface.
- Peak heating is ≈ 0.5 MW for 1 panel
  - Max surface heat load is 35 W/cm^2
  - Max nuclear heating is 8 ➔ 1 W/cm^3
- For surface heat removal, coolant channels are milled into DFW front surface, before bonding a 5 mm thick stainless plate.
- Gun-drilled holes in the bulk of the panel are used to remove nuclear heat.
- Bolted tabs attach DFW to the diagnostic shield module with bolts protected at a distance from plasma.
- Apertures require custom cooling designs.
- DFW in preliminary design and R&D phase.

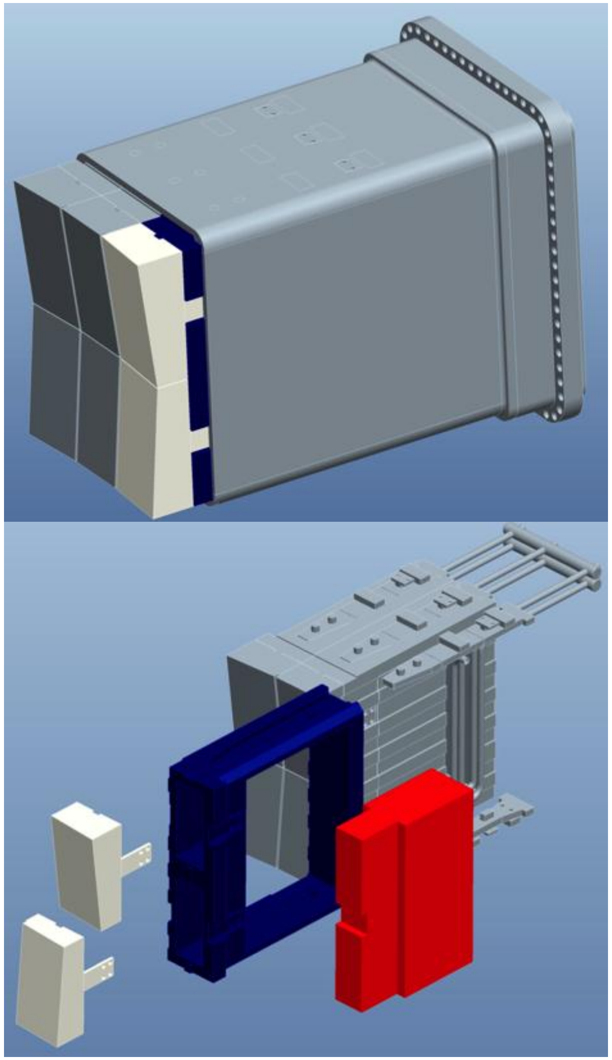




3.25 l/s for
ΔT ≈ 50°C

diagnostic first wall panel
(5 mm plate removed)

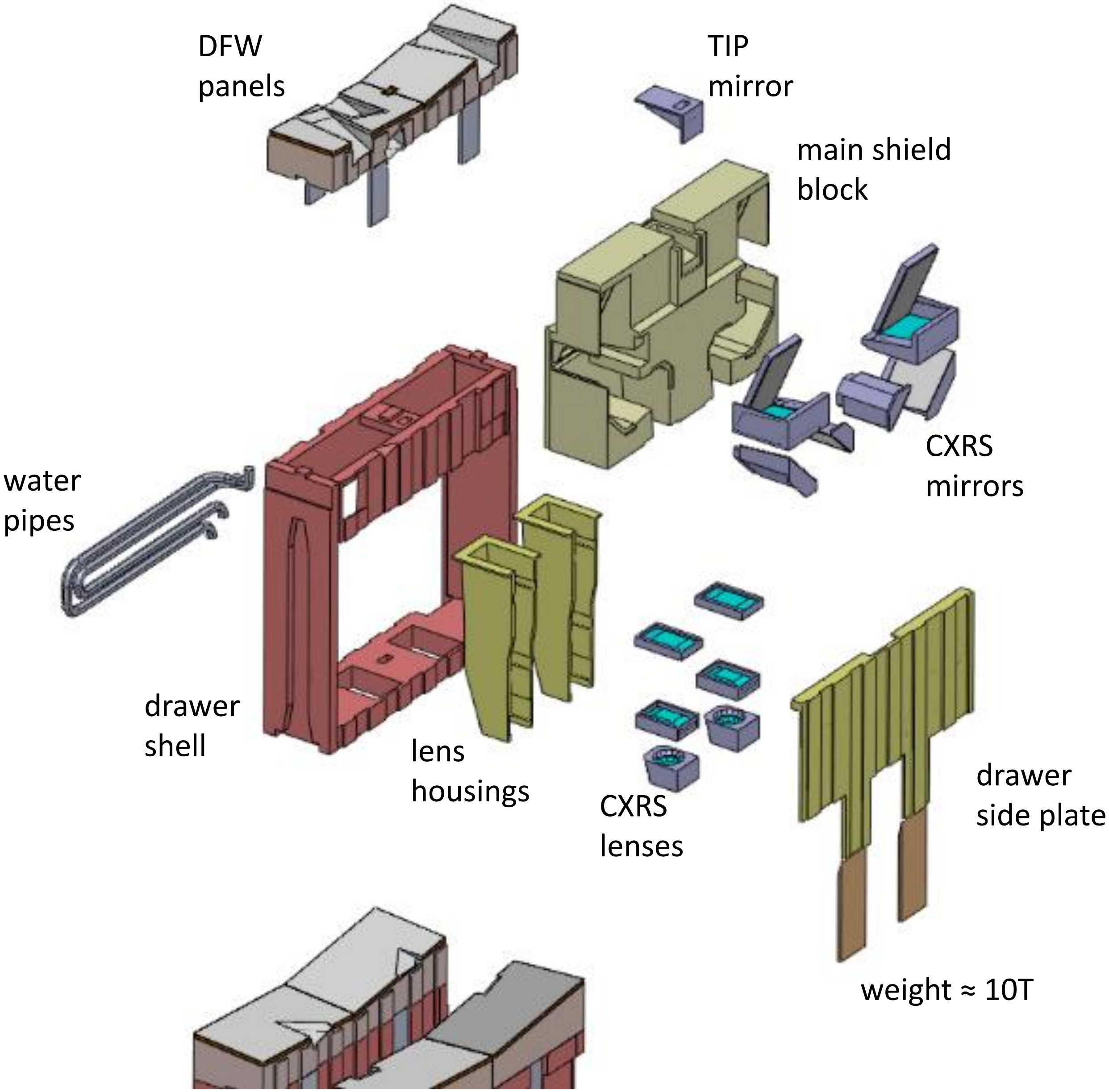
Modular Approach to Packaging Also Reduces Disruption Forces



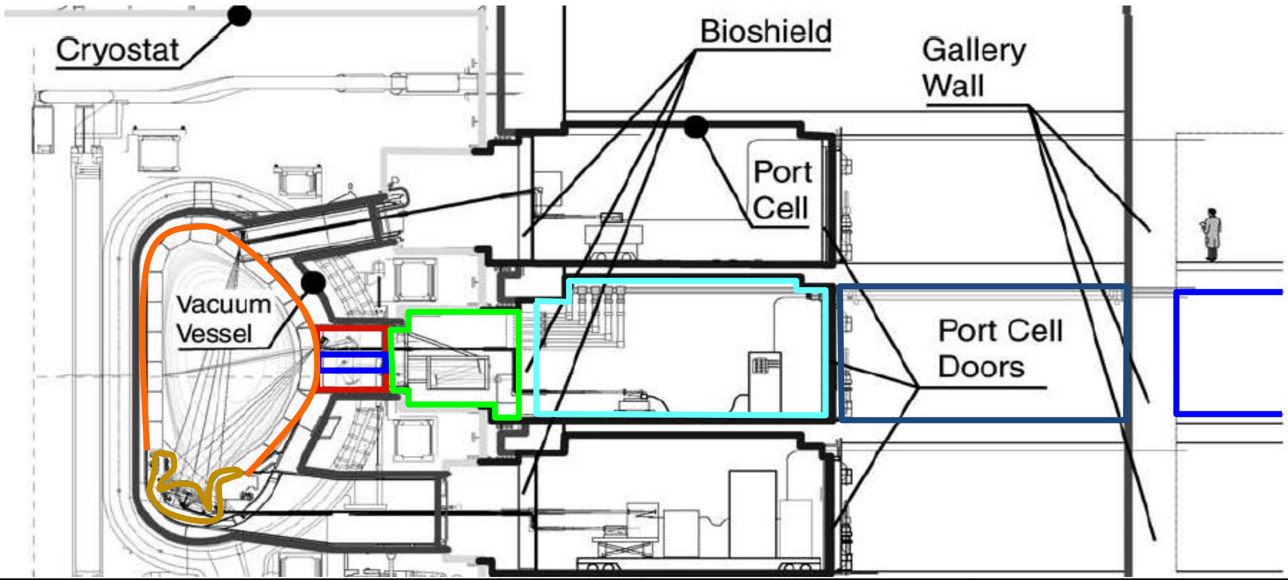
S. Pitcher, ITER

- Vertical shield modules are inserted along radial rails from the plasma side of the box.
- Configuration provides vertical electrical breaks, needed to reduce eddy-current forces.
- Multiple diagnostics, often supplied by different DAs, are housed in each equatorial plug.
- Modular approach results in considerable simplification of interfaces, permitting parallel design, assembly, and qualification efforts to proceed efficiently.
- Module standardization also simplifies remote handling of the diagnostics.
  - Standardized hot cell tooling can be designed to extract and position the modules for robotic maintenance and repair operations.

Example E3 Plug, Central Drawer (CXRS)



Diagnostic Components are Distributed Across ITER Confinement Zones

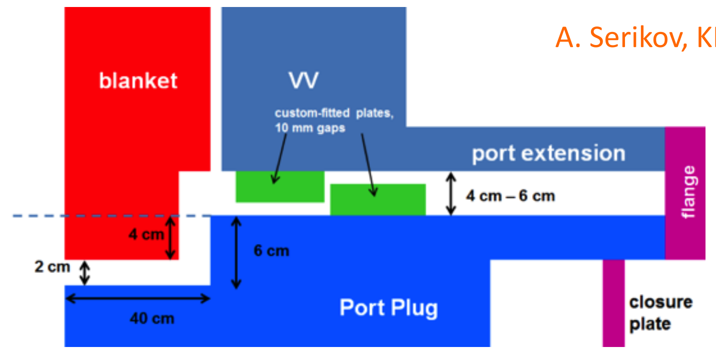


Zone	In-vessel, Divertor, Cassette, Port Plug	Interspace	Port Cell	Gallery	Diagnostic Hall
Access	RH only	12 days after DT run	1 day after DT run	restricted	unlimited
Maint. Int.	several years	several months	weeks/month	days/week	unlimited
Hazards of Environment	ultra-high vacuum, nuclear heating, thermal excursions, vibrations, radiation-induced damage & signal contamination for in-vessel sensors, erosion and deposition on optical surfaces, high B	radiation-induced noise in detectors, thermal excursions $0.1<B<0.5T$	periodic radiation exposure due to RH transfers, $B<0.1T$	periodic radiation exposure due to RH transfers	low hazards, similar to existing facilities

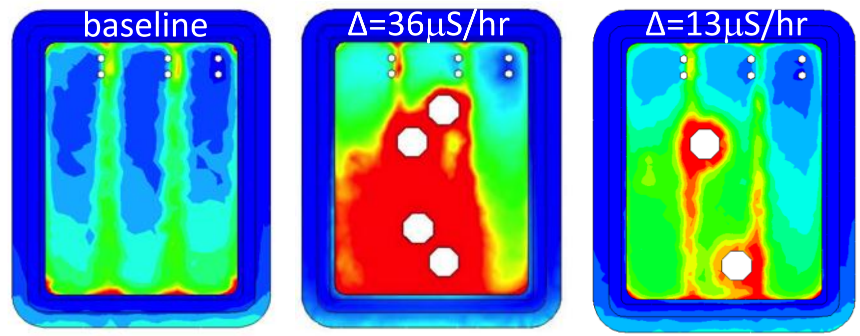
Shielding Challenges

- Only recently has the effectiveness of shielding labyrinths begun to be assessed.
- Streaming down the gaps between the plug and the vacuum vessel has been reduced with multiple dog-legs.
- Even so, steaming down gaps accounts for ≈ 1/2 of maximum dose rate of 100 μS/hr in interspace region.
- Comparison of cases with/without labyrinths permit diagnostic contributions to be assessed relative to targets.
- Shown is a study used to optimize the configuration of the ECE diagnostic.
  - Calibration sources will have to be within the shield module to reach dose-rate target of 17μS/hr.

A. Serikov, KIT

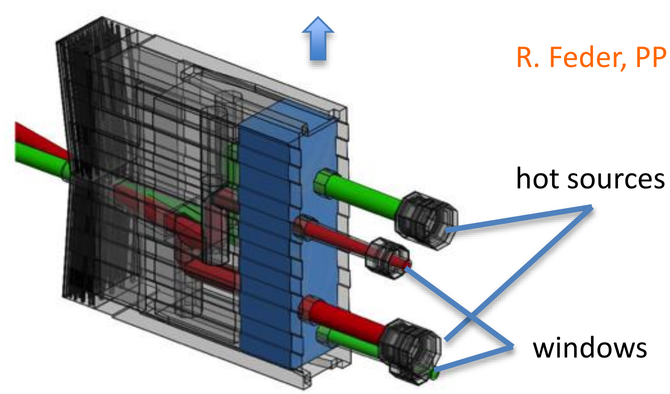


neutron streaming contours



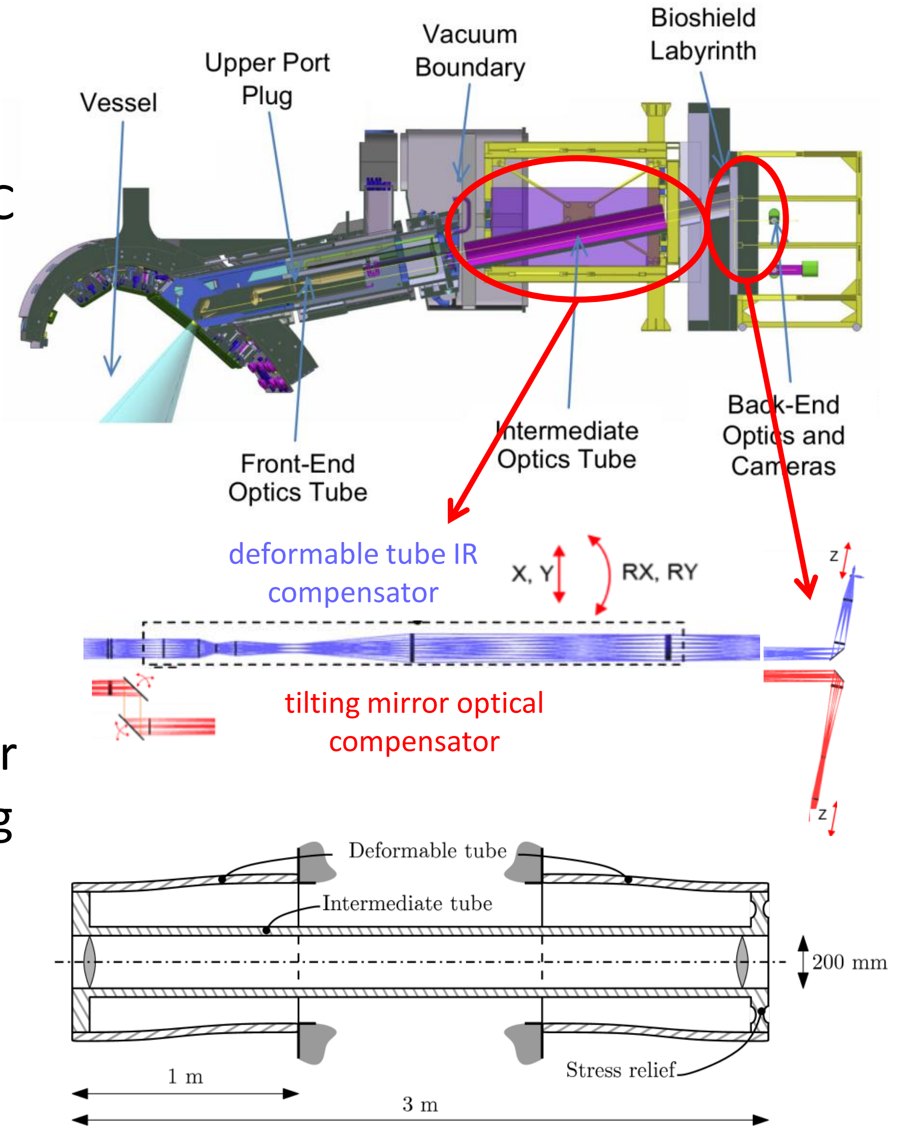
solid drawers no labyrinths | labyrinths for ECE views & calibration sources | labyrinths for views only

R. Feder, PPPL

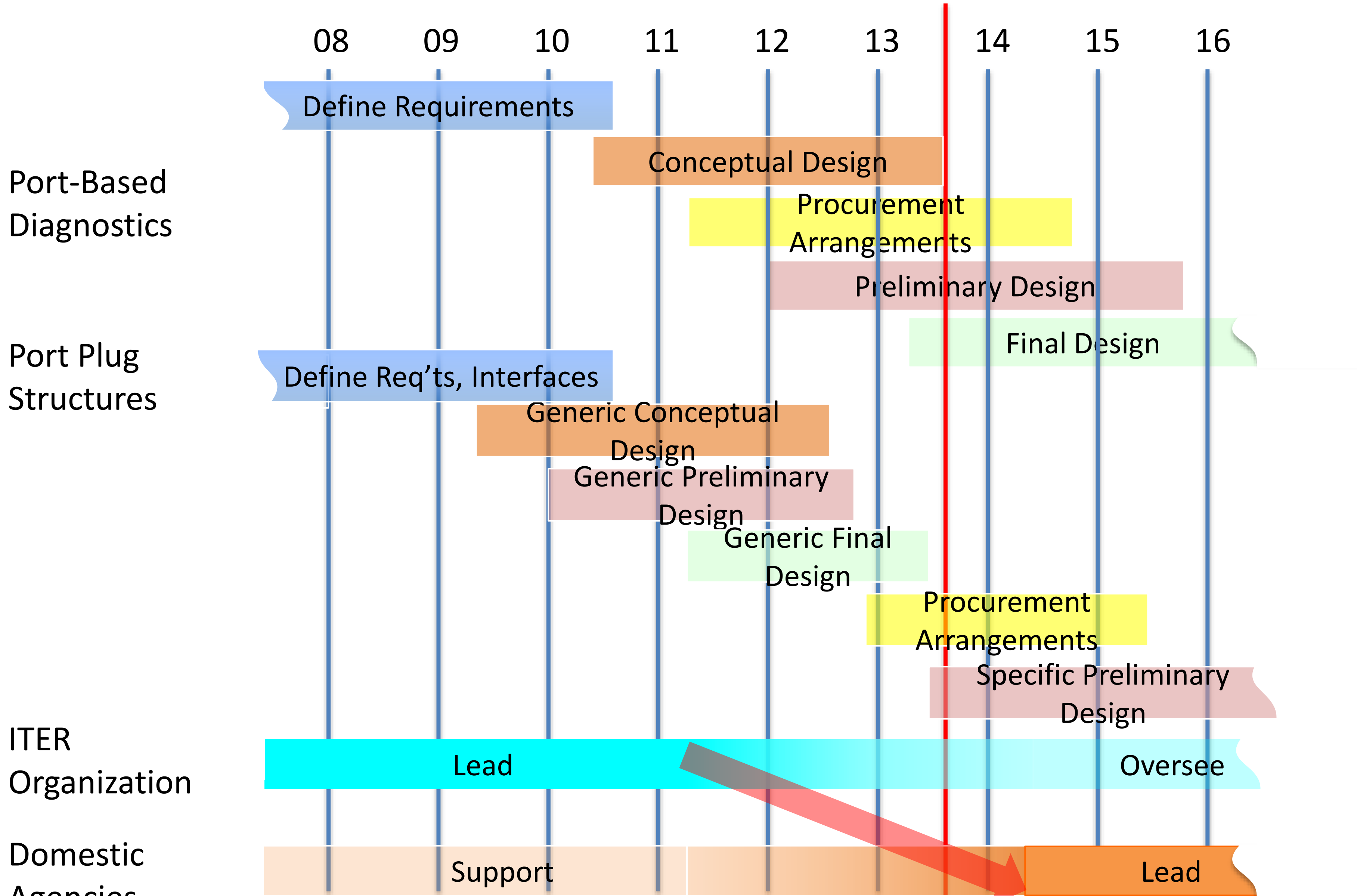


Compensating for Vessel Motion

- Compared to room temperature, a point on the back of the equatorial plug will move outward and upward ~ 1 cm at 70°C and ~ 3 cm at bakeout (240°C) relative to the building.
- Toroidal motions of ~ 1 cm are expected during disruptions, and shot-to-shot changes of a few mm are expected.
- Vacuum extensions must be compliant to this motion.
- Diagnostics such as imaging systems, laser systems, waveguide systems, are planning feedback systems to maintain alignment.
- A recent manufacturing study of the upper camera diagnostic suggested compensators in the optical and IR relays



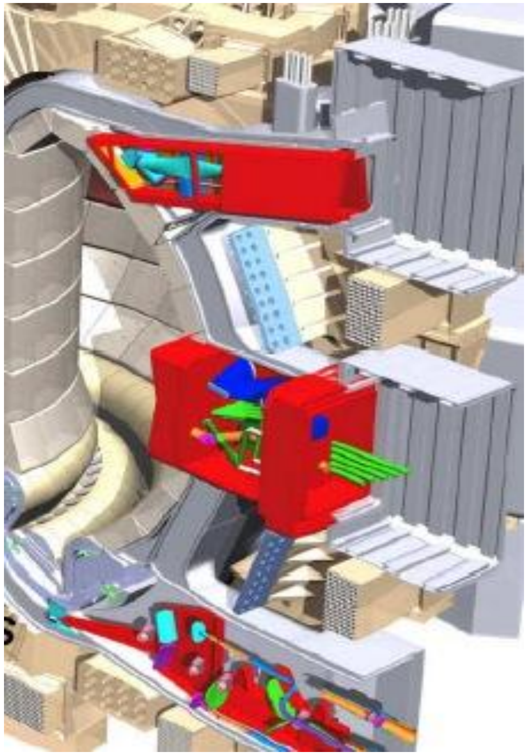
ITER Diagnostic Development



Diagnostics – US Scope and Status

U.S. will provide 14% of ITER diagnostics - indicates 1st plasma diagnostic

Port Plugs	CDR or SIR	PA	PDR	Contract Award Targets
Upper Port 11	x	x	Nov-14	
Upper Port 14	x	x	Nov-14	
Equatorial Port E3	x	Jan-14	Aug-15	
Equatorial Port E9	x	x	Jun-14	
Diagnostics				
Residual Gas Analyzer	x	x	x	
Low Field Side Reflectometry	x	x	Dec-14	Sept-13
Electron Cyclotron Emission	x	x	Aug-15	Jan-14
Toroidal Interferometer/Polarimeter	x	x	Aug-15	Jan-14
Upper IR/Visible Cameras	x	x	Sep-15	Jan-14
Motional Stark Effect	x	Jan-14	Jul-15	Jul-14
Core Imaging X-ray Spectrometer	x	Jan-14	Jun-15	



Getting Involved with US ITER Diagnostics

- Watch for 'sources sought' notification for:
  - Upper Cameras
  - ECE
  - TIP

  } www.princeton.gov or www.fbo.gov

- Planned to be phased contracts with optional Phase 2

  Phase 1 – R&D and Design – cost or cost + fixed fee

  Option - Phase 2 - Fab, procure, assemble, test, ship – fixed price

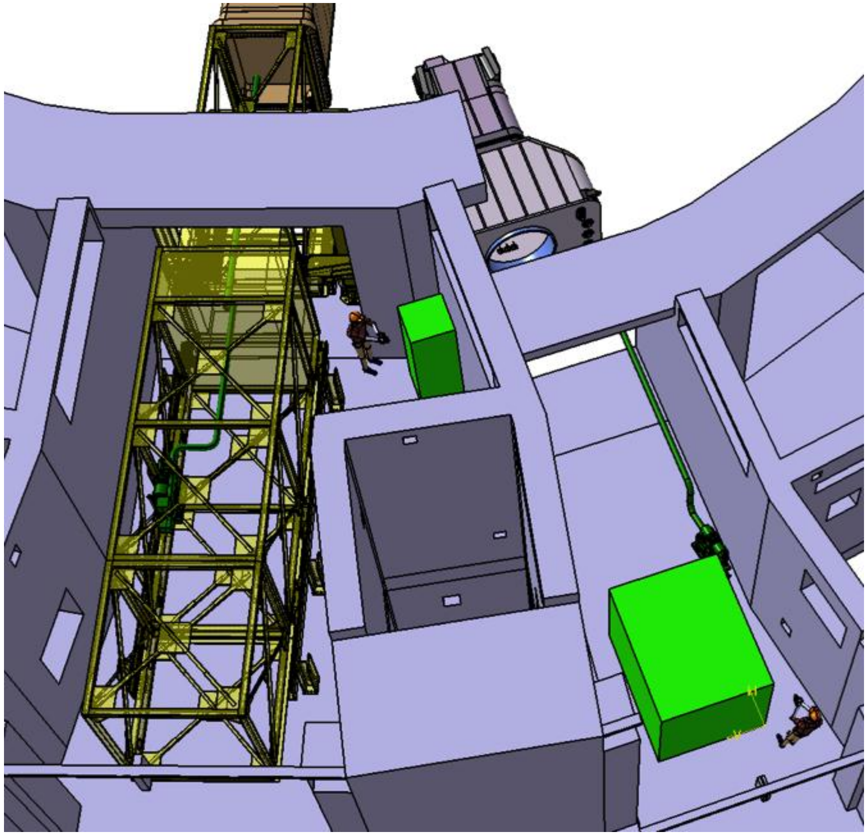
- Strong proposals would have evidence of
  - Relevant technical expertise – perhaps through teaming
  - Strong quality program
  - Project management experience

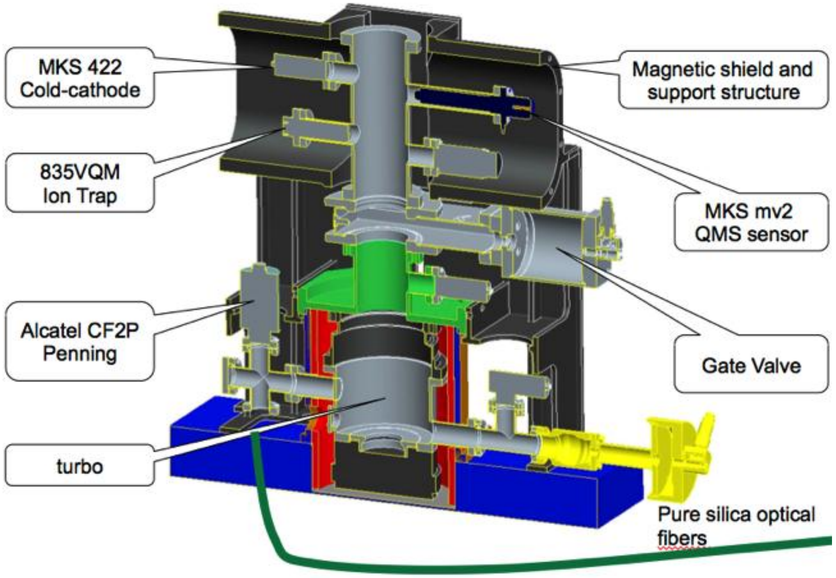
- If you wish to become involved on voluntary basis, contact USBPO (M. Reinke or D. Brower)

Residual Gas Analyzer (RGA)

R&D Issues

- Qualification of ion trap sensor
- Validation of pressure range for optical Penning Gauge





Technical Challenges

- Survivability of sensor electronics during DT
- Tolerating vessel motion
- Accommodating tritium line breaks for maintenance

Experience from the First ITER Diagnostic PDR

- Two-day review held in Cadarache
- Review Panel consisted of:
  - external experts
  - reps for interfacing systems
  - ITER physics rep
  - quality, safety, CODAC, machine ass'y
  - many on panel not at CDR
- Very helpful in highlighting interface issues
- Large document burden →
- Dry-run by web-meeting very helpful
- Panel seemed to revisit many issues that arose at CDR
  - measurement requirements
  - number of systems
  - avoidable with a recap at start of PDR
- PDR resulted in slowing of US efforts in some areas, while we wait for important interfaces to be better defined.

- 2012.04_PA_R&D_Plan_5.5.P1.US.01_55.G4_RGA (ITER_D_7GH226 v1.0)
- 2013.03_PA_Risk and Mitigation Plan_5.5.P1.US.01.55.G4_RGA (ITER_D_DVVK6X v1.0)
- Aperture Replacement Strategy Report (ITER_D_D3ZT7C v1.0)
- Assessment of Penning OGA operation with the Penning tube mounted between stages of Turbo Pump (ITER_D_DW3FGU v1.0)
- Chit_tracking_table_5.5.P1.US.01_55.G4_RGA (ITER_D_CUMGSG v0.0)
- DDD for PD stage of diagnostic RGA (ITER_D_EH6N29 v1.0)
- Design Compliance Matrix (ITER_D_F92TXM v1.0)
- Diagrams and Drawings
- DRGA I&C Integration Plan (FAT and SAT Scenarios) (ITER_D_FZTHXJ v1.0)
- DRGA I&C Software Design Description (ITER_D_F933J9 v1.0)
- DRGA Software Requirement Specification (ITER_D_F84LHC v1.0)
- Electrical Power and Grounding Requirements (ITER_D_DWYMQY v1.0)
- Electromagnetic Forces Analysis Report (ITER_D_EAUDY4 v1.0)
- Interface documents
- Ion-trap mass spectrometer testing for the ITER DRGA (ITER_D_DCNXTY v1.0)
- ITER DRGA Calibration Procedure (ITER_D_DX8JZM v1.0)
- Load Specification for PDR (ITER_D_EAYTDW v1.0)
- Report on Magnetic Shielding Calculation for the ITER DRGA (ITER_D_DWYUUL v1.0)
- Report on Radiation Shielding Calculation for the ITER DRGA (ITER_D_DHXJDM v1.0)
- Seismic Response Analysis (ITER_D_EAWR34 v1.0)
- Structural Integrity Report (ITER_D_EAXVST v1.0)

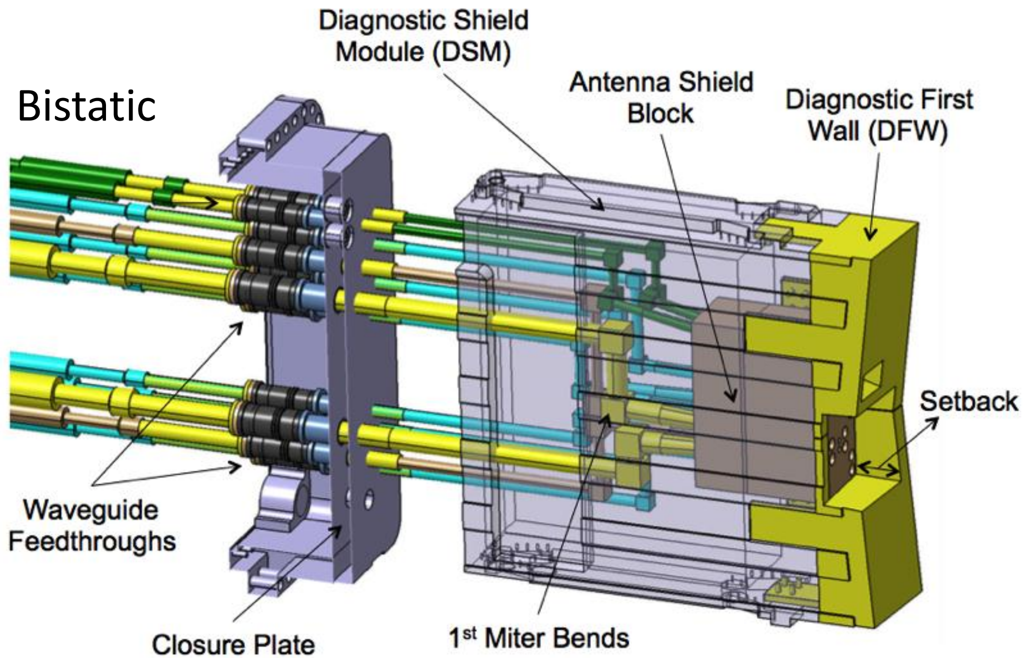
No. of Records : 21

Low Field Side Reflectometer (LFSR)

R&D Issues

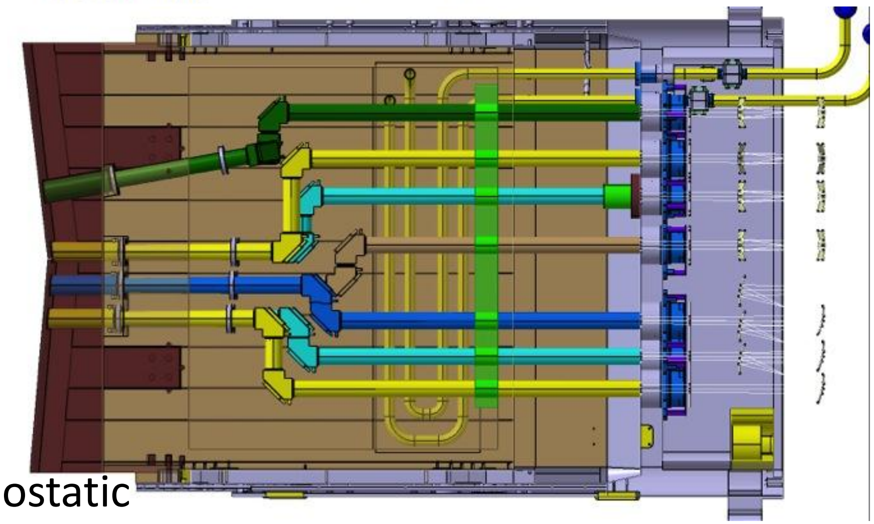
- Qualification of corrugation design
- Mitigation of window reflections
- FPGA – based data acquisition/analysis
- Mitigation of damage from stray m-wave radiation

Bistatic



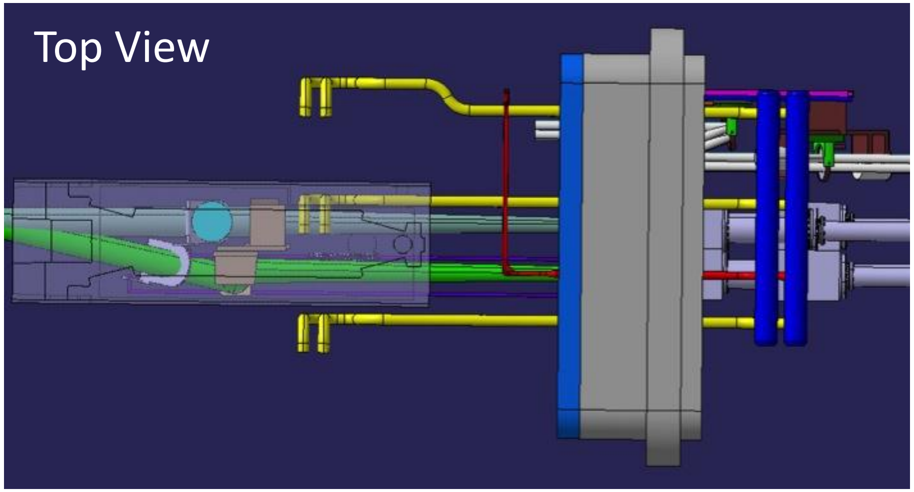
Technical Challenges

- Tight spatial constraints
- Optimization of antenna geometry to maximize capability
- Propagation across vacuum boundary



Monostatic

Electron Cyclotron Emission (ECE)

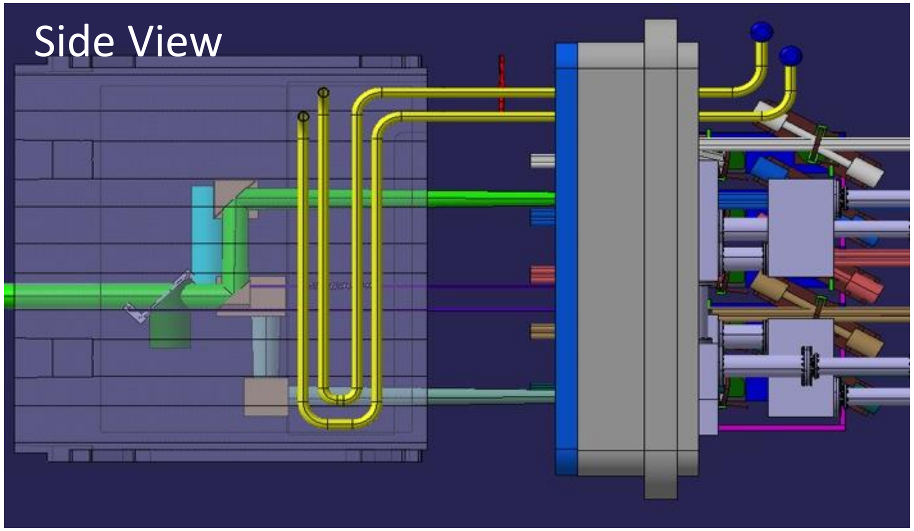


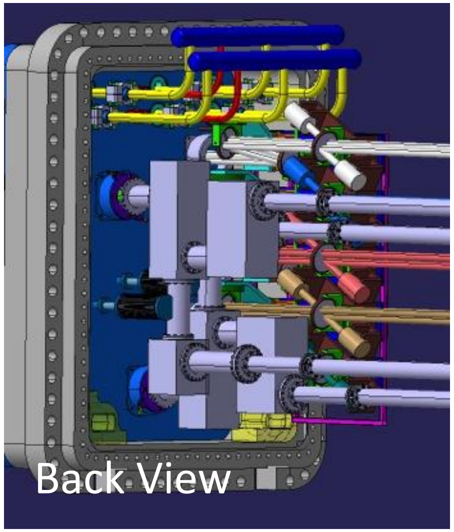
R&D Issues

- Qualification of hot calibration source
- Shutter qualification
- Qualification of vacuum windows (IO)
- Mitigation of damage from stray m-wave radiation
- Qualification of TL for wide bandwidth (IN)
- Qualification of Michelson (IN)

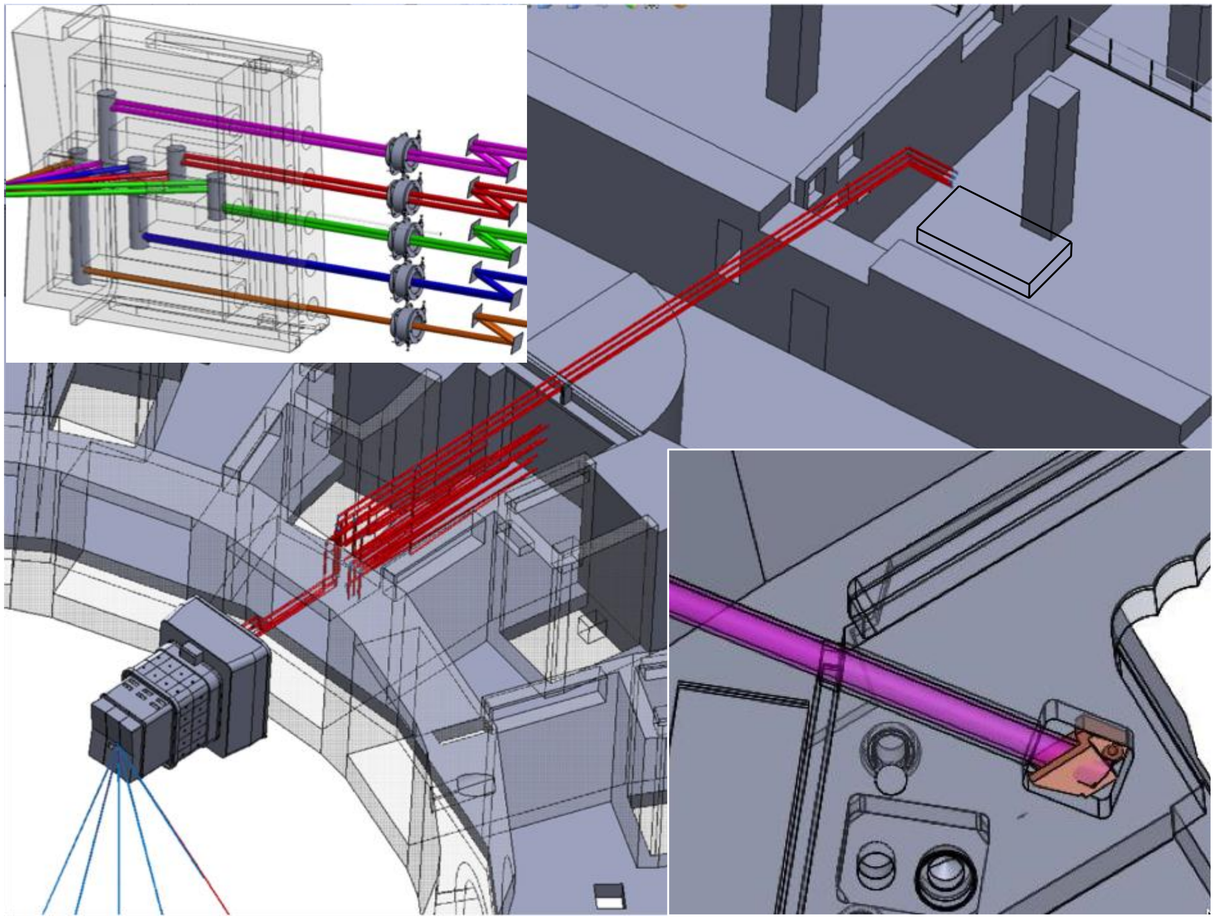
Technical Challenges

- Tight spatial constraints
- Compensation for vessel motion





Toroidal Interferometer Polarimeter (TIP)



R&D Issues

- Finite-offset vs zero-offset beams
- Window development (IO)
- Prototype real-time alignment
- Prototype retroreflectors

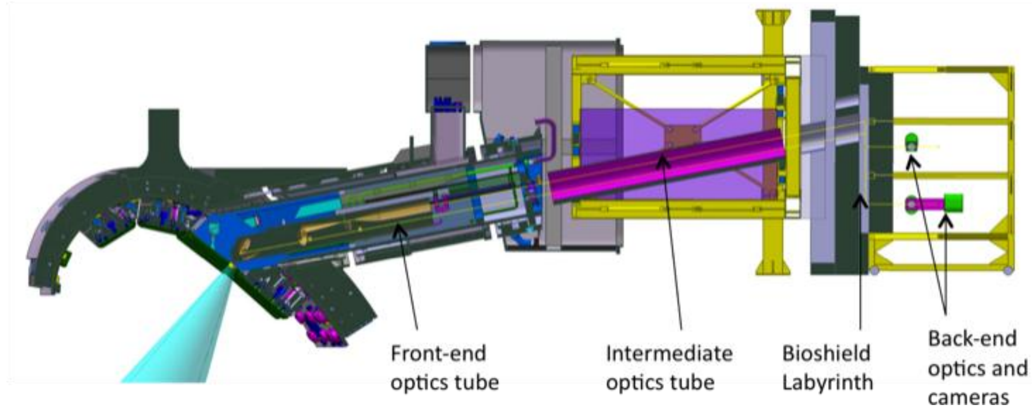
Technical Challenges

- Minimizing optical distortion for plasma-facing optics
- Complex interfaces with blankets for retros
- Tight spatial constraints at closure plate
- Meeting high reliability needed for machine control

Upper Visible/IR Cameras (UpCam)

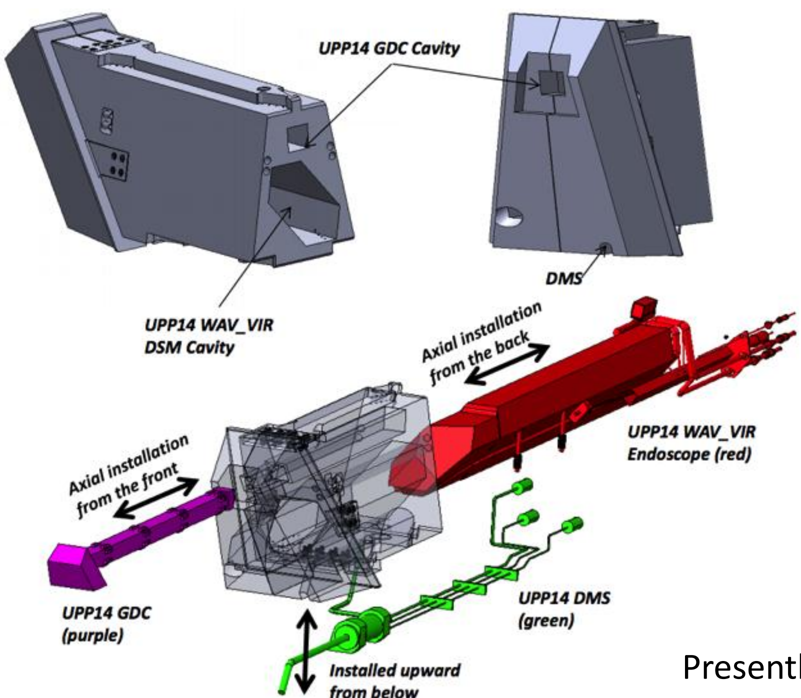
R&D Issues

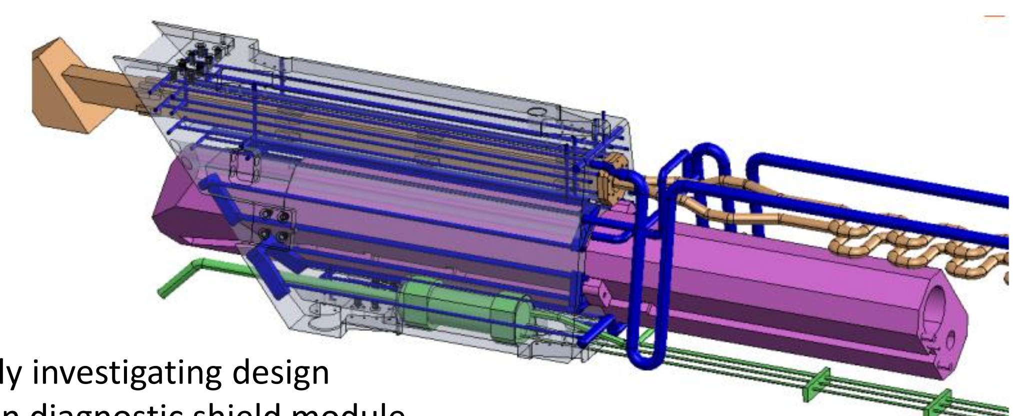
- Mirror cleaning
- Shutter prototyping
- In-situ calibration
- Development of real-time image analysis capability
- Sensor development



Technical Challenges

- Tight spatial constraints in plug and at closure plate
- Compensation for vessel motion
- Shielding of sensors and associated electronics





Presently investigating design constraints on diagnostic shield module

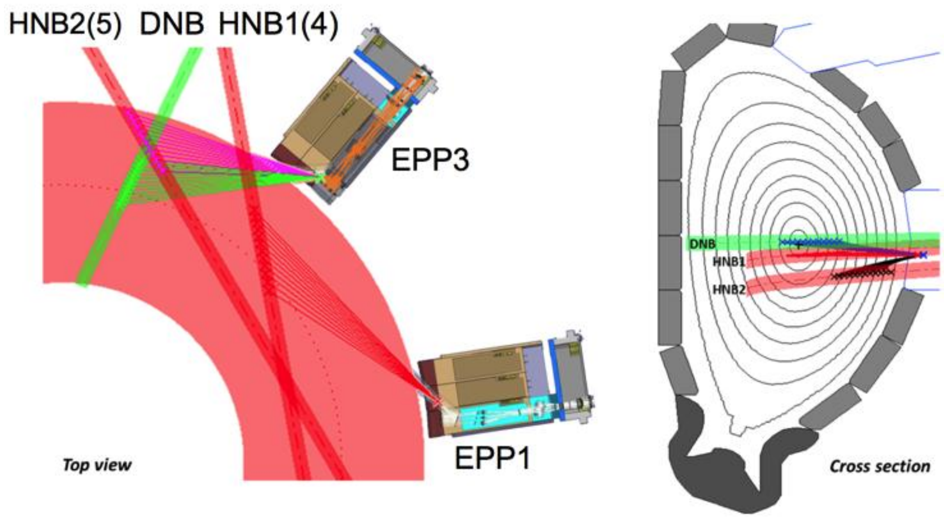
Motional Stark Effect (MSE)

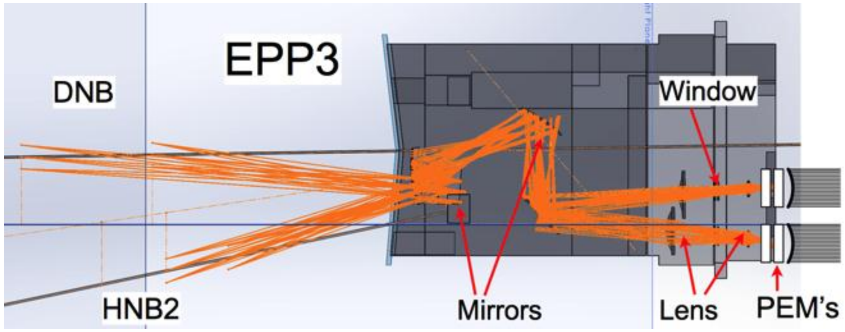
R&D Issues

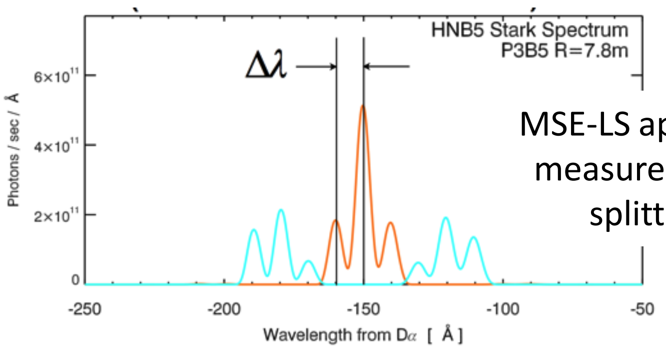
- Mirror cleaning
- In-situ polarimetry calibration
- Shutter prototyping
- High-throughput spectrometer development
- Qualification of MSE-LS approach on existing device (JET?)

Technical Challenges

- High stray background emission
- Complex optical implementation
- Tight spatial constraints in port plug
- Uncertainty regarding drifts in energy distribution of beamlets

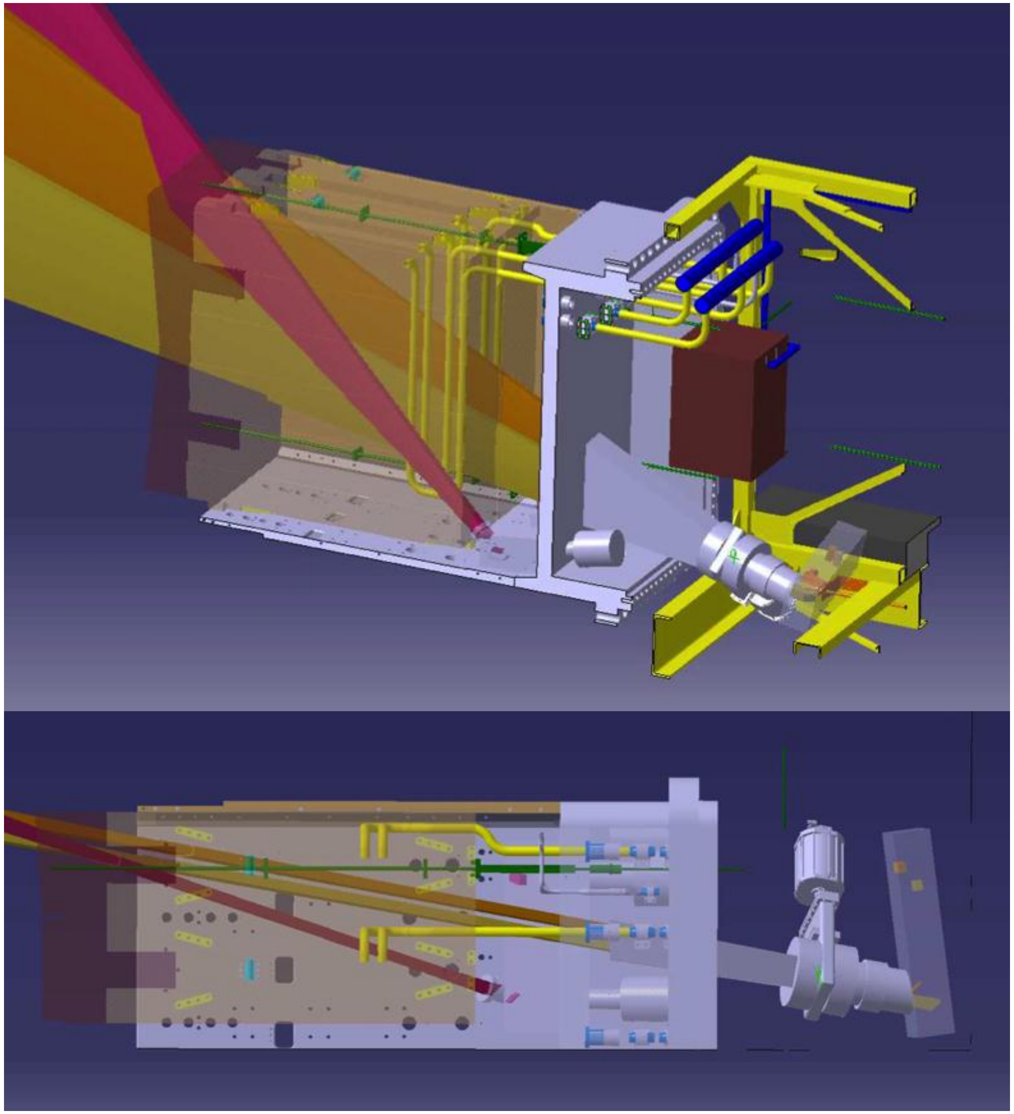






MSE-LS approach measures Stark splitting

Core Imaging X-ray Spectrometer (CIXS)



R&D Issues

- Radiation hardened detectors
- Be window development (IO)
- In-situ calibration source

Technical Challenges

- Survivability of internal detector
- Maintainability of system (IO?)
- Uncertainty of intrinsic impurity levels
- Temperature control of crystals

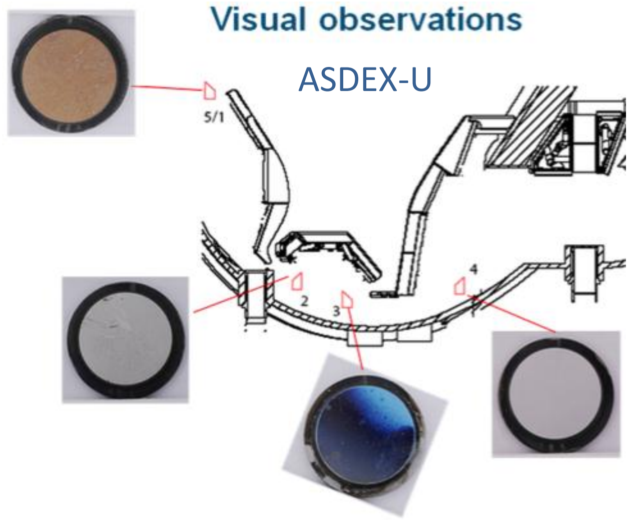
Summary

- ITER poses interesting new challenges for diagnostic developers, which are being identified and addressed.
  - heat removal, disruption loads, shielding, thermal expansion
- The ITER Organization and the Domestic Agencies have been working together to provide a framework for coherent diagnostic development.
- Standardized, modular approach to diagnostic packaging
  - has helped to define the roles of host and tenants in the plugs
  - will permit parallel designs at the DAs to proceed efficiently
  - will facilitate the use of common tools for installation and maintenance.
- With the completion of Procurement Arrangements, we are entering a new phase of diagnostic development on ITER.
  - Design leadership is being passed to design teams in the DAs to carry out R&D and complete designs, and then to build the diagnostics.
- In the US, we are in the process of selecting the expert teams to complete the designs.
  - Will not succeed without very close coordination between IO, US-DA, and expert teams

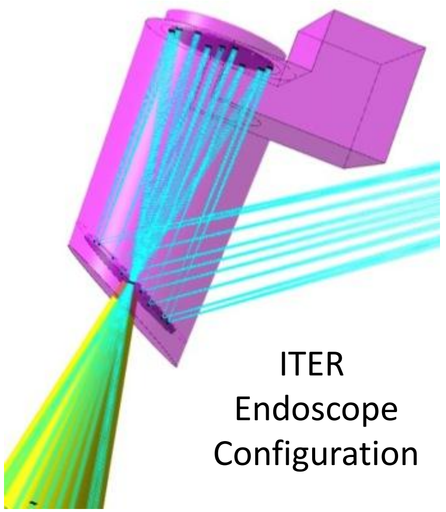
Backup

Lifetime of Diagnostic Mirrors

- Diagnostic mirrors are subjected to deposition from sputtered material (mainly Be).
  - Modeling of deposition and mirror exposure experiments on present devices both indicate a risk that some mirror lifetimes could be short.
  - Lifetime estimate uncertainties are very large.
- Concepts for protecting and cleaning mirrors have been under investigation, coordinated by ITPA WG.
  - Ideas include protection by gas curtain, cleaning by laser ablation, and cleaning by sputtering of the deposited layer by energetic ions produced in DC, RF, or microwave plasmas.
  - Solution that is compatible with ITER environment and realistic diagnostic mirror configurations has not yet been demonstrated.
- A new mirror cleaning working group has been organized by the IO to coordinate effort in this area.



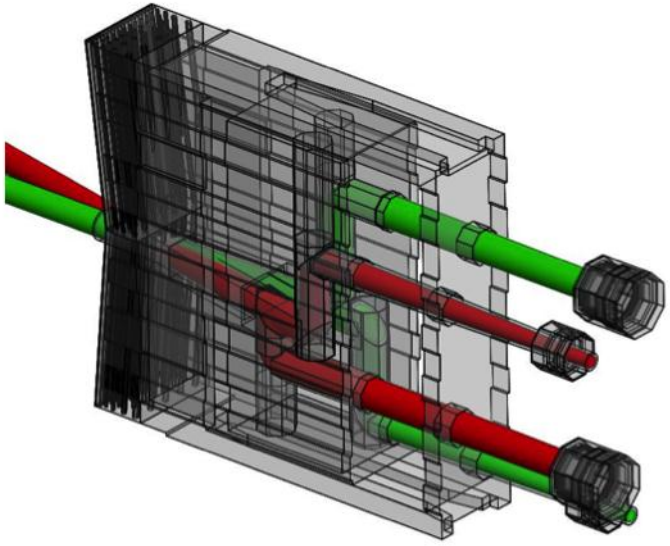
A. Litnovsky, IPP

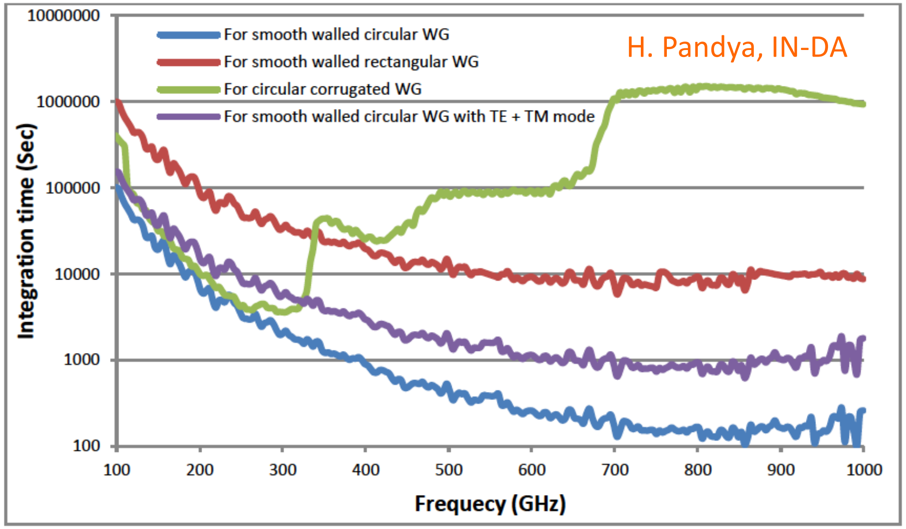


ITER Endoscope Configuration

ECE Measurement Strategy

- T_e measurements at $6 \le T_e \le 13$ keV on TFTR and JET gave evidence of a non-Maxwelian electron distribution.
- With T_e up to ~ 40 keV expected on ITER, the design concept for the ITER ECE radiometer has features to probe for such distortions.
- Radial and oblique (~13°) views are planned with capability to make O- and X-mode, calibrated measurements of several harmonics to I THz.
- Recent measurements indicate losses with circular, corrugated waveguide are too high at high frequency.
- For reasonable calibration time periods, present design features smooth-walled circular waveguide and a high-throughput Michelson interferometer.
- R&D is planned to confirm these design choices.





Impacts of High Electron Temperatures

- At the high temperatures expected for ITER, relativistic effects are important.
  - at T_e=25 keV, $T_e/(m_e c^2) \approx .05$
- For the poloidal and toroidal interferometer/polarimeter diagnostics, T_e along the sightline will be needed for high precision.
  - will complicate real-time density control
- Relativistic effects severely impact the X-mode cutoff contours for the low-field-side reflectometer.
  - Complicates strategy to obtain robust reflected signal
  - Also complicates data interpretation

Two-Color Interferometer/Polarimete

Phase

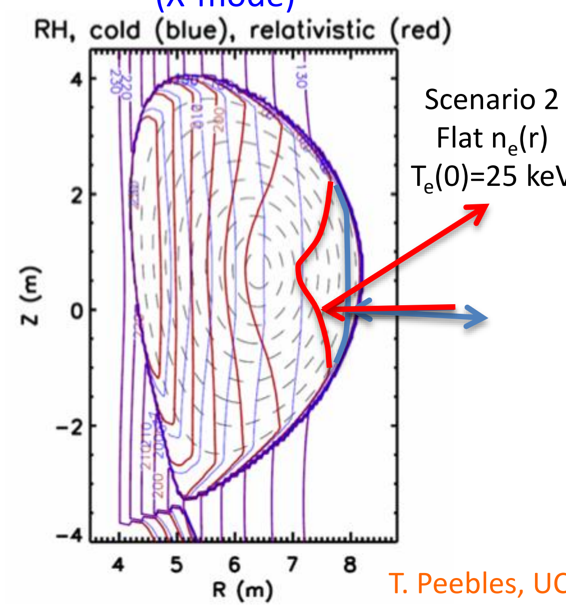
$$\phi_1 = r_e \lambda_1 \int \left(1 - \frac{3T_e}{2m_e c^2}\right) n_e dL + \frac{2\pi V}{\lambda_1}$$

$$\phi_2 = r_e \lambda_2 \int \left(1 - \frac{3T_e}{2m_e c^2}\right) n_e dL + \frac{2\pi V}{\lambda_2}$$

$$\alpha = 2C_p \lambda_2^2 \int \left(1 - \frac{2T_e}{m_e c^2}\right) n_e \vec{B} \bullet d\vec{L}$$

Faraday Rotation

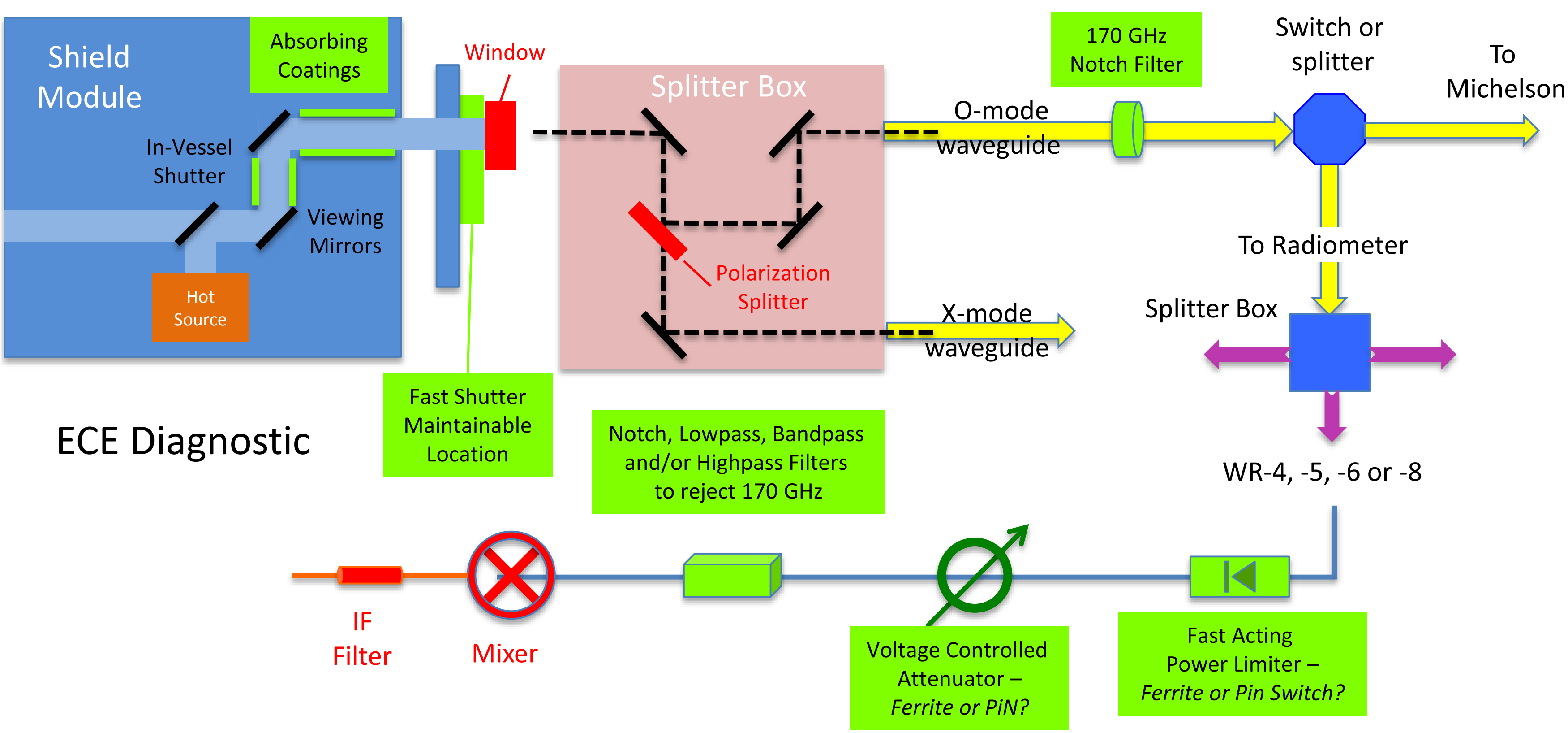
LFS Reflectometer (X-mode)



T. Peebles, UCLA

Damage from Stray Microwave Power

- Stray microwave power from ECH heating (170GHz, 10s of MW), CTS (60 GHz, 2 MW) and fast electron transients (ELMs, etc.) pose a threat to components.
  - Reflected ECH power is a particular hazard at plasma startup.
- Passive and active mitigation measures are planned.
  - Development of reliable triggers for active mitigation also needed.



G. Hanson, ORNL