Diagnostic Challenges and Opportunities on ITER

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Savannah APS DPP
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Outline

- **Diagnostics in the ITER environment**
  - new implementation challenges
  - diagnostics currently being designed into ITER ports
  - ‘uncredited’ systems

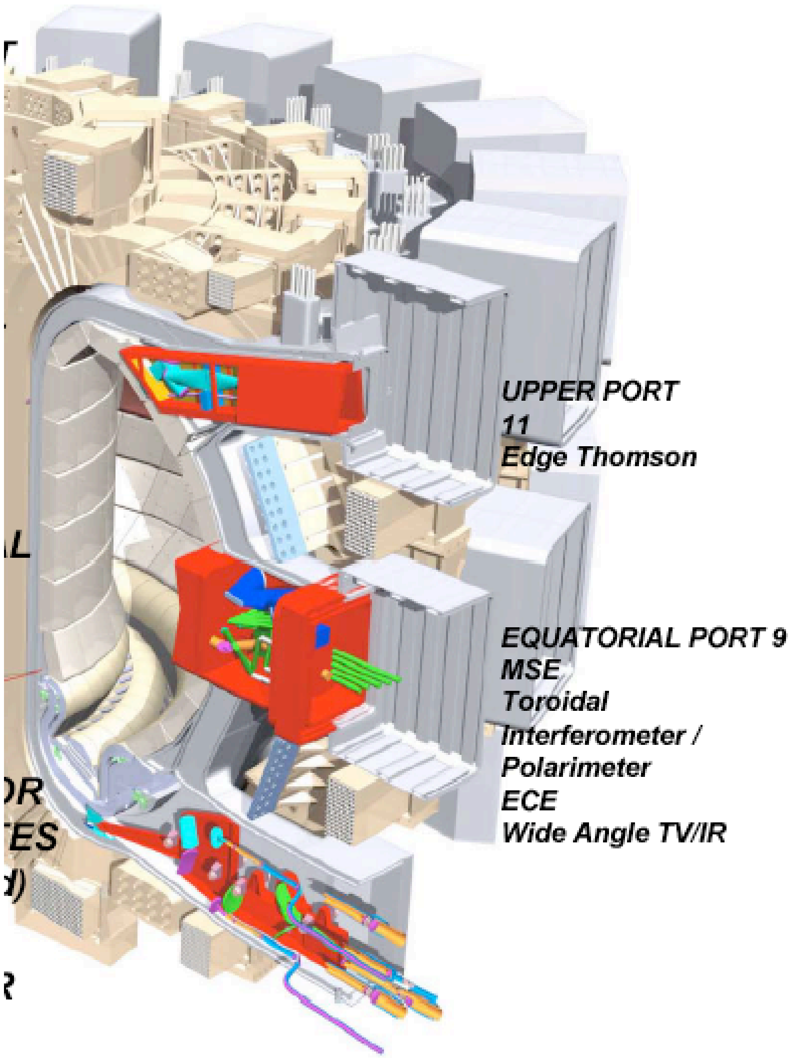
- **US role in ITER diagnostics**
  - specific diagnostic systems presently allocated to the US
  - R&D needs
  - present US participation in ITER diagnostics

- **My view of the next couple of years**

ITER environment

Relative to existing machines, on ITER, front end diagnostic components will be exposed to **(relative to JET)**

- –high neutron and gamma fluxes (up to x10)
- –neutron heating (zero on JET)
- –high fluxes of energetic charge exchange neutrals (up to x5)
- –long pulse lengths (up to x100)
- –high neutron fluence (? x10^6)



‘Front ends’ will be very different on ITER

- **A host of radiation effects on cables and insulators**
- **Thermal control through conduction to actively cooled surfaces**
  - UV and x-ray surface heating of ~ 5-10 watts/cm^2
  - volume nuclear heating in the range of ~ 0.1-1 watt/cm^3
- **Diagnostic access will be through complex labyrinths to reduce neutron streaming**
- **Refractive optics can only be used at the outside of these labyrinths**
  - Need to rely on metal mirrors
- **First mirrors will be subject to degradation due to erosion by neutral particles and due to deposition**
  - In-situ calibration techniques need to be developed
- **Long path lengths and relative motion of massive components**
  - development of real time alignment techniques
- **Components need to be very reliable and compatible with remote handling.**

ITER diagnostics being integrated into port designs

(currently 'uncredited')

Magnetic Diagnostics	**Spectroscopic and NPA Systems**
Vessel Magnetics	CXRS Active Spectr. (based on DNB)
In-Vessel Magnetics	H Alpha Spectroscopy
Divertor Coils	VUV Impurity Monitoring (Main Plasma)
Continuous Rogowski Coils	Visible & UV Impurity Monitoring (Div)
Diamagnetic Loop	X-Ray Crystal Spectrometers
Halo Current Sensors	Visible Continuum Array
Neutron Diagnostics	Soft X-Ray Array
Radial Neutron Camera	Neutral Particle Analysers
Vertical Neutron Camera	Laser Induced Fluorescence (N/C)
Microfission Chambers (In-Vessel) (N/C)	MSE based on heating beam
Neutron Flux Monitors (Ex-Vessel)	**Microwave Diagnostics**
Gamma-Ray Spectrometers	ECE Diagnostics for Main Plasma
Neutron Activation System	Reflectometers for Main Plasma
Lost Alpha Detectors (N/C)	Reflectometers for Plasma Position
Knock-on Tail Neutron Spectrom. (N/C)	Reflectometers for Divertor Plasma
Optical Systems	Fast Wave Reflectometry (N/C)
Thomson Scattering (Core)	**Plasma-Facing Comps and Operational Diag**
Thomson Scattering (Edge)	IR Cameras, visible/IR TV
Thomson Scattering (Divertor region)	Thermocouples
Toroidal Interferom./Polarimetric System	Pressure Gauges
Polarimetric System (Pol. Field Meas)	Residual Gas Analyzers
Interferometers for Divertor Plasma	IR Thermography Divertor
Collective Scattering System	Langmuir Probes
Bolometric Systems	Erosion and dust monitors
Bolometric Arrays for Main Plasma & Divertor	**Diagnostic Neutral Beam**

US to provide 16% of ITER diagnostic effort

- **Includes 5 ‘Port Plugs’ - supporting structures and shielding**

1.	2 upper ports	preliminary
2.	2 equatorial ports	preliminary
3.	1 divertor port	preliminary

- **Includes 7 diagnostic systems integrated into these and other ports**

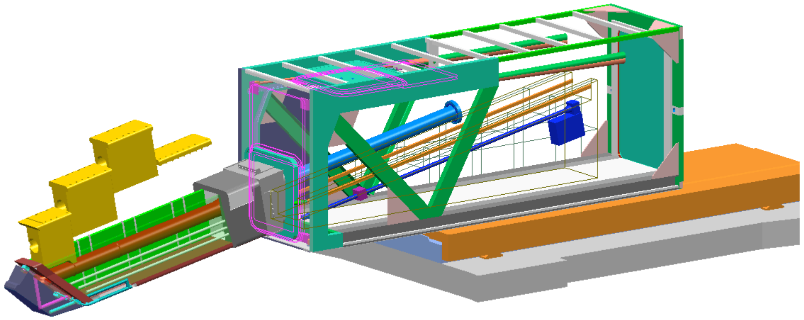
4.	Visible/IR cameras	preliminary
5.	Electron cyclotron emission	preliminary
6.	LFS reflectometer	preliminary
7.	Toroidal interferometer/polarimeter	conc./prel.
8.	Motional Stark effect on heating beam	conceptual
9.	Divertor interferometer	pre-conceptual
10.	Residual gas analyzers	pre-conceptual

level
of
design

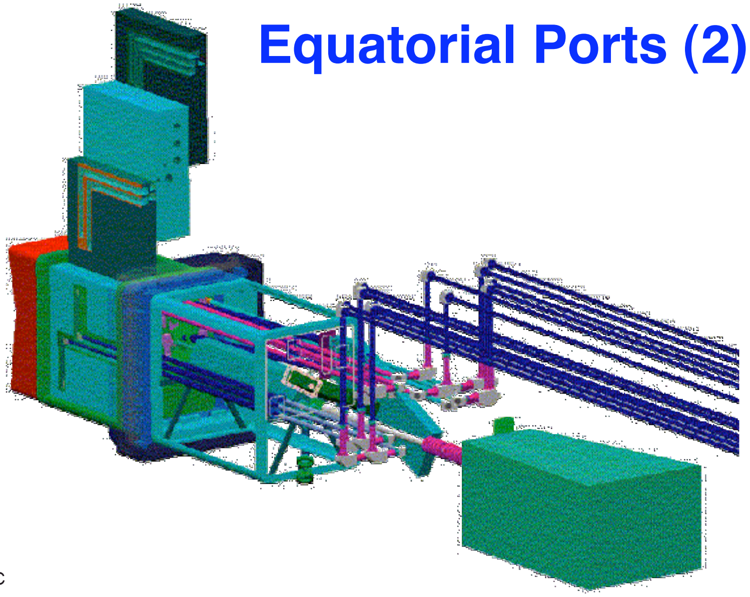
- **Proposed US WBS organization has these 10 elements**

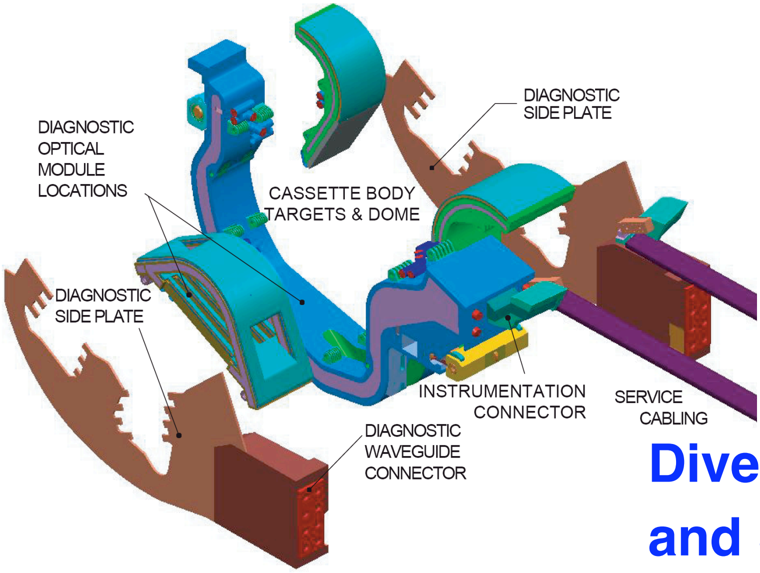
Diagnostic packages include port support structures

Upper Ports (2)



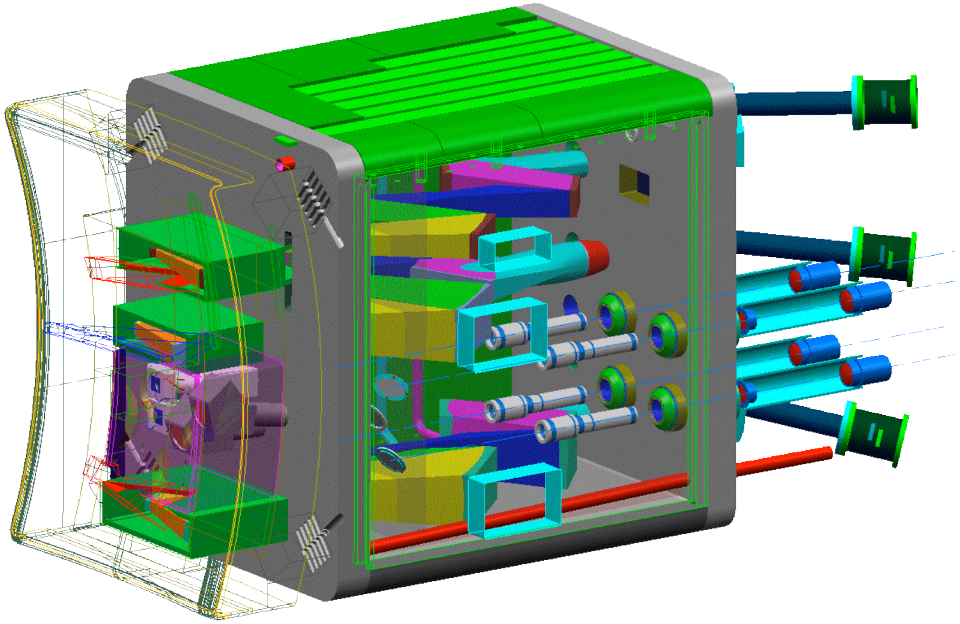
Equatorial Ports (2)





Divertor Side Panels and Support Structures (1)

Numerous systems must be integrated into each port



- **Design constraints**
  - Intermingling of numerous labyrinths, many with precision optics
  - Provide access while limiting neutron streaming
  - Provide attachments and cooling to blanket shield modules

- **Example - Port 3 is a US responsibility**
  - US will provide the MSE system as the ‘lead diagnostic’
    - Edge MSE view in port 3 (US) and core view in port 1 (EU)
  - US is also responsible for integrating the following into port 3
    - Visible/IR camera view (EU)
    - Two edge CXRS views (RF)
    - H_α arrays (RF)

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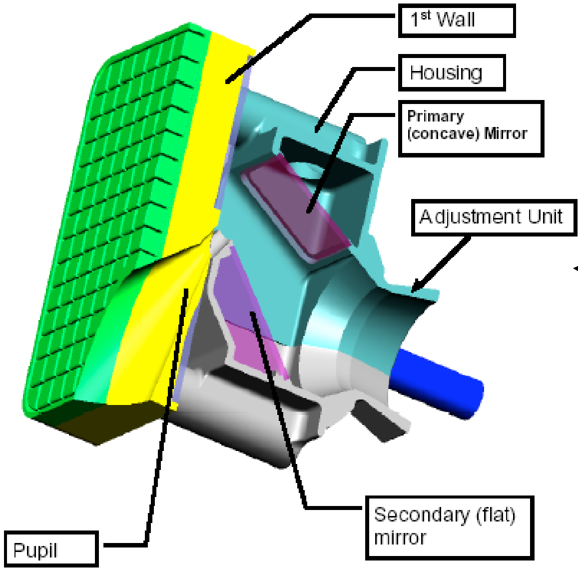
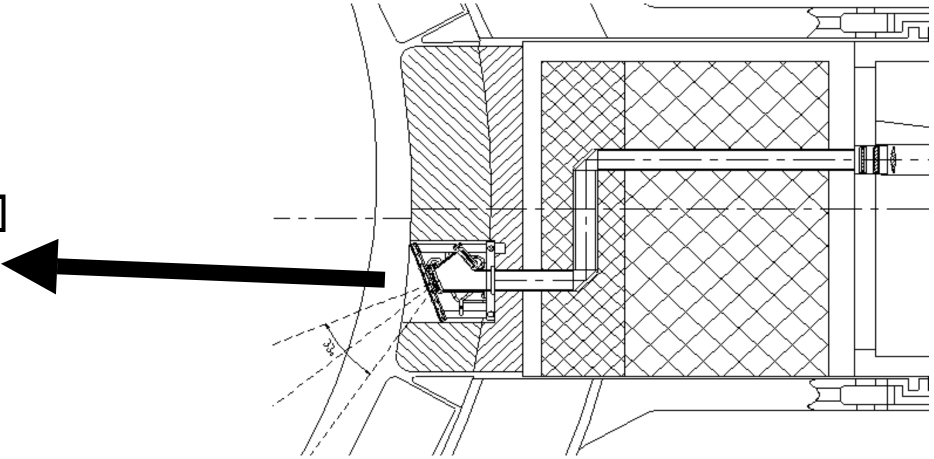
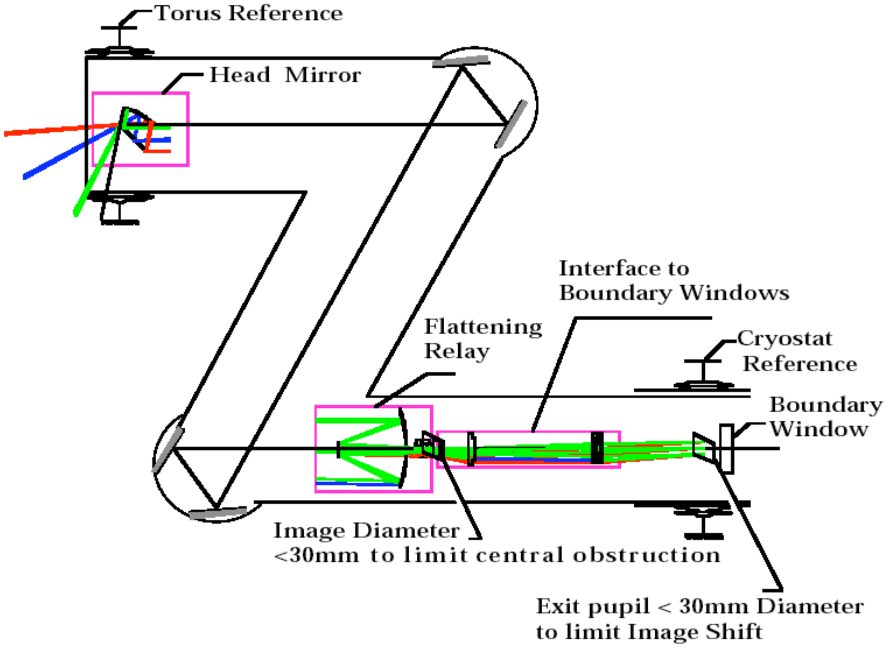
Upper Visible/IR Cameras

(6 cameras in upper ports)



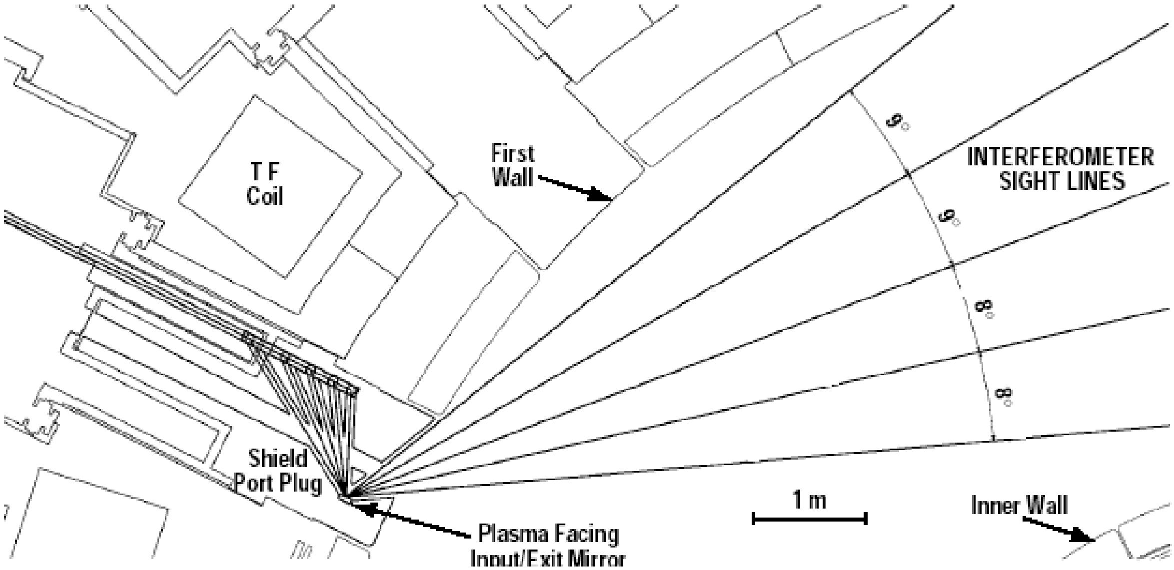


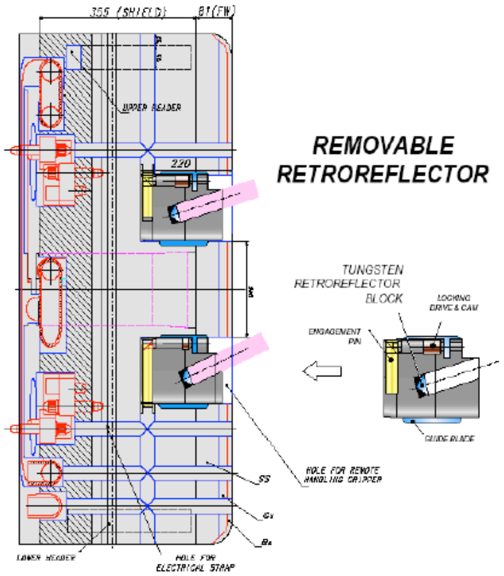


- **Essential diagnostic for operations and machine protection**
- **Provides wide angle view of:**
  - plasma in visible light
  - wall and target temperature in IR
- **Presently being prototyped on JET**
- **R&D issues**
  - survivability of first mirror, shutter
  - in-situ calibration of sensitivity

Toroidal Interferometer/Polarimeter

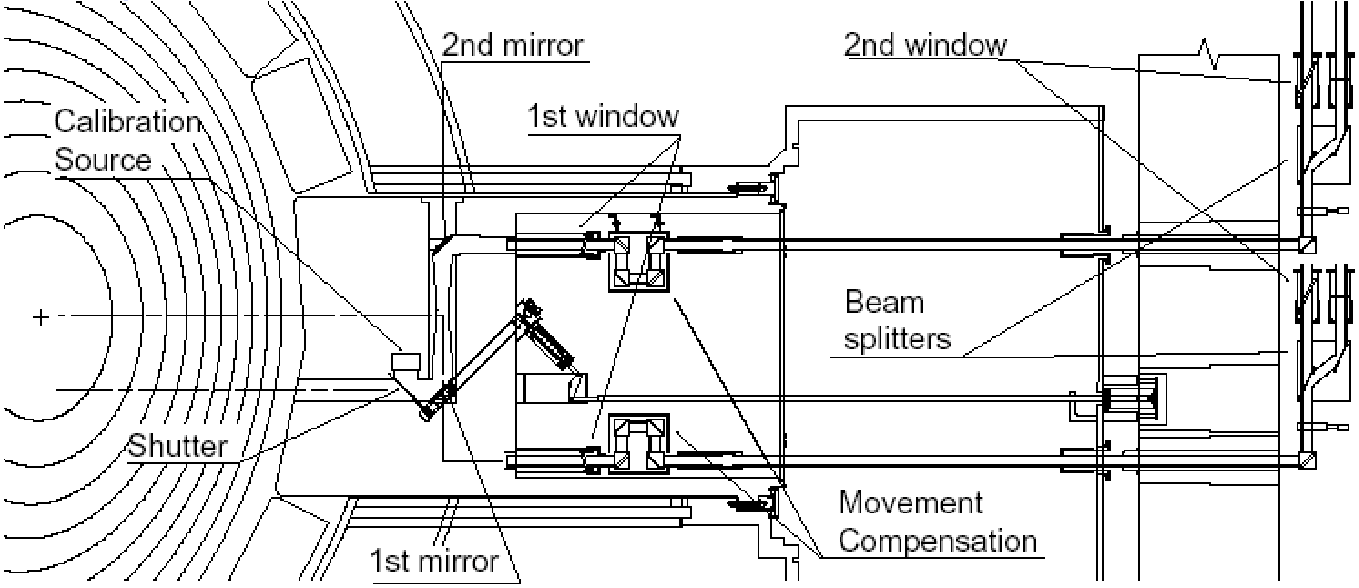
- **Expected to provide high reliability and good time resolution necessary for density feedback control**
- **Five tangential sightlines with retro-reflectors located in outer blanket shield modules**
- **Two color (5.3μ and 10.6μ) interferometry for vibration compensation**
- **Polarimetry signal (10.6μ) will provide check against fringe jumps**
- **R&D issues**
  - survivability of first mirror, retro-reflectors, shutter
  - feedback stabilized alignment





Electron Cyclotron Emission

- For T_e profile control and detection and control of low (m,n) MHD modes, locked modes, disruption precursors.
- Employs two Gaussian collection antennas staggered above and below midplane to access core for variety of plasma shapes.
- A shutter can be actuated to bring hot source into view for in-situ calibration.
- Miter bends provide compensation for machine movement.
- R&D issue
  - development of radiation hardened hot source



R&D Needs

- **Generic**
  - Survivability of mirrors
    - understanding the deposition process, both at outer wall and in divertor region
    - mitigation techniques: shutters, screening, in-situ cleaning
  - Prototyping of in-situ calibration and alignment techniques
  - Prototyping of waveguide runs
  - Better definition of the limits of where fiber optics can be used and possible use of new fiber technologies

- **Specific needs but currently uncredited and unassigned**
  - Dust and erosion detectors
  - Long-pulse magnetic sensors
  - ITER compatible lost-alpha detectors, SXR detectors, knock-on tail neutron spectrometers

Identifying US Diagnostic Teams

- **Ideal team members**
  - strong mechanical engineering group for port integration and front-end design tasks
  - diagnostic group which is expert in instrumentation
  - modeling experts able to simulate performance to aid in design and to prepare data analysis tools
  - component experts for specific R&D tasks
  - ties with existing devices for prototyping ideas

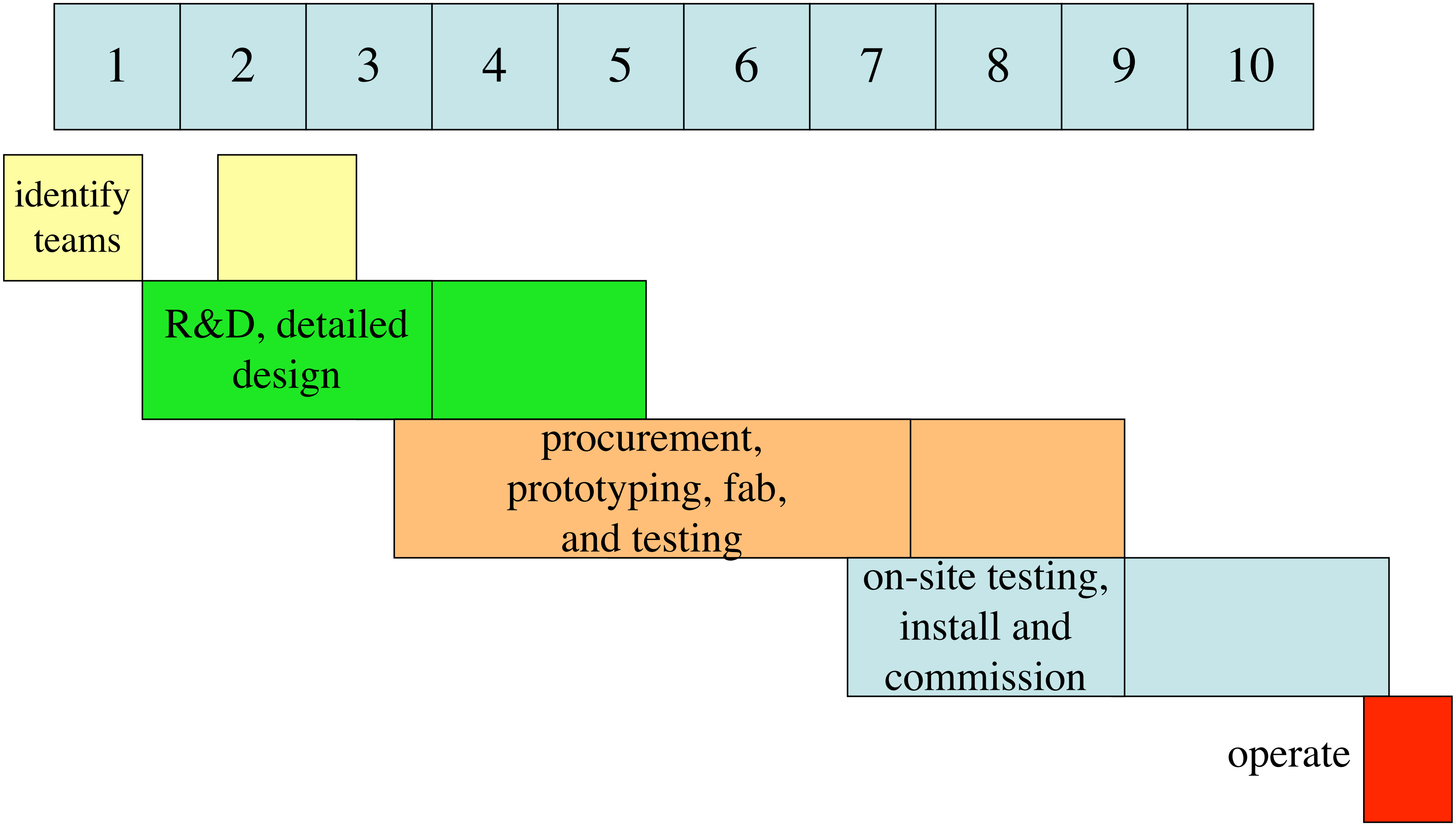
- **Envision two solicitations**
  - expressions of interest - to identify interested parties and motivate teaming, to clarify roles for university, industry, and labs.
  - full proposals - subject to competitive review process

- **Timing**
  - EOI solicitation in 3-6 months
  - full proposals in 6-18 months

Present US participation

- **The US is lagging behind the other major diagnostic providers (EU, JP, RF) as they actively pursue more detailed ITER designs.**
- **Effort in other parties is now being focused on their allocated systems, however, they are also pursuing ‘uncredited’ systems.**
- **The US needs to get experts involved soon in diagnostic design for US systems and for uncredited systems, in order to be able to effectively**
  - compete for port space as these designs are being integrated into ports
  - meet the proposed ITER delivery schedule.

Schedule for development for a major ITER diagnostic



1 2 3 4 5 6 7 8 9 10

identify teams

R&D, detailed design

procurement, prototyping, fab, and testing

on-site testing, install and commission

operate

Summary

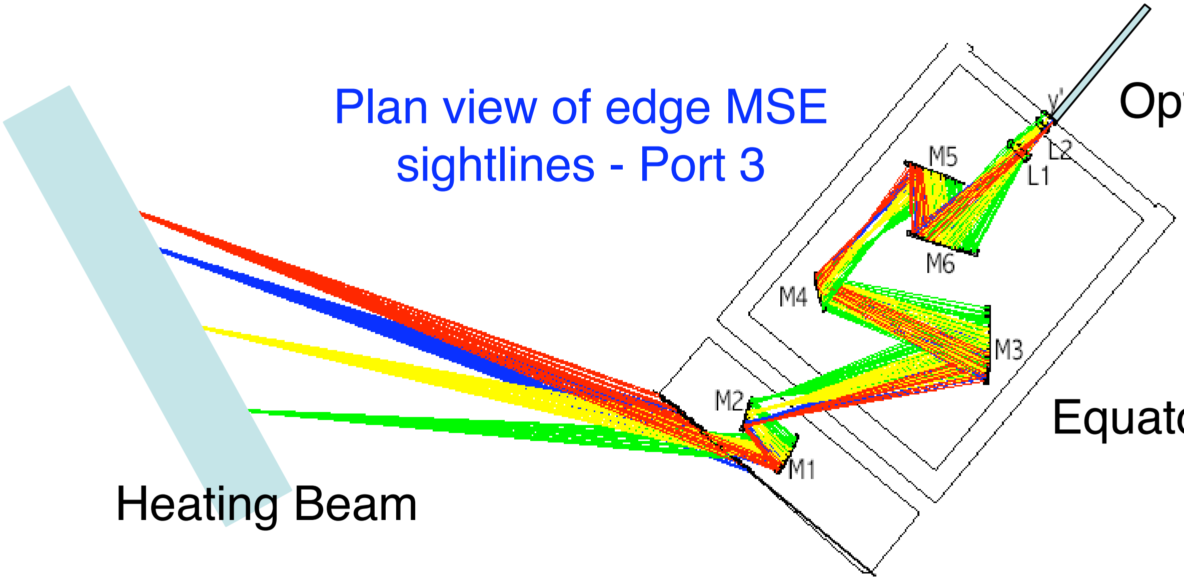
- Diagnostic implementation on ITER faces significant technical challenges due to the harsh ITER environment, and the need for high reliability and remote handling.
- Negotiating for a strong physics role in ITER, the US made a strong bid for diagnostics, and will provide 16% of the diagnostic systems.
- Today there is no ITER diagnostic design activity in the US. This needs to change soon if the US is to keep pace with the other major providers and meet IT delivery schedule.
- To begin the design effort, US teams need to be identified.
- Proposed that solicitations for ‘expressions of interest’ will occur in the near future.
- The US University Fusion Community must play a significant role in providing ITER diagnostics.

ITER Port-Based Packages

Package	**Level**	**Group**	**Lead Diagnostic**	**credit % (less installation)**	**Other diagnostics in port [uncredited in parenthesis]**	**includes components in ports**
3	Upper	1a	**Vis./IR Cameras (Upper only)**	1.8%	N2 activation(P4-KO), VNC(P23-RF)	U2(P5-RF), U5(P3-US), U8(P8-JA), U11(P9-JA), U14(P1-EU), U17(P10-US)
10	Upper	1b	**Reflectometer (LFS Main Plasma)**	2.5%	x-ray crystal(P7-Flex), vis/IR cameras(P3-US), bolometers (P21-Flex), [SXR array]	E11(P15-RF)
12	Equat.	1b	**MSE based on heating beam**	2.4%	vis/IR cameras(P11-EU), CXRS(P2-EU), H-alpha(P5-RF)	E1(P11-EU), E3(P12-US)
13	Equat.	1a	**ECE** **Toroidal Interferometer/Polarimeter**	4.6%	[SXR array, FW Reflectometer]	E9(P13-US)
18	Lower	1a	**Interferometer (Divertor)**	2.5%	[LIF], magnetics(P22-Host), bolometers & gauges(P21-Flex)	L8(P18-US), L14(P20-Fund)
28	Distr.	1a	**Residual Gas Analyzers**	2.1%		?
				16.0%		

Motional Stark Effect Polarimeter

- **Highly desirable for optimizing plasma performance using magnetic shear.**
- **Utilizes the 1 MeV ITER heating beams.**
- **Two viewing systems of two beams provide good spatial resolution for edge and core regions.**
- **R&D issues**
  - survivability of first mirror and other mirrors, considering sensitivity of polarization characteristics to deposition
  - in-situ calibration techniques



Plan view of edge MSE sightlines - Port 3

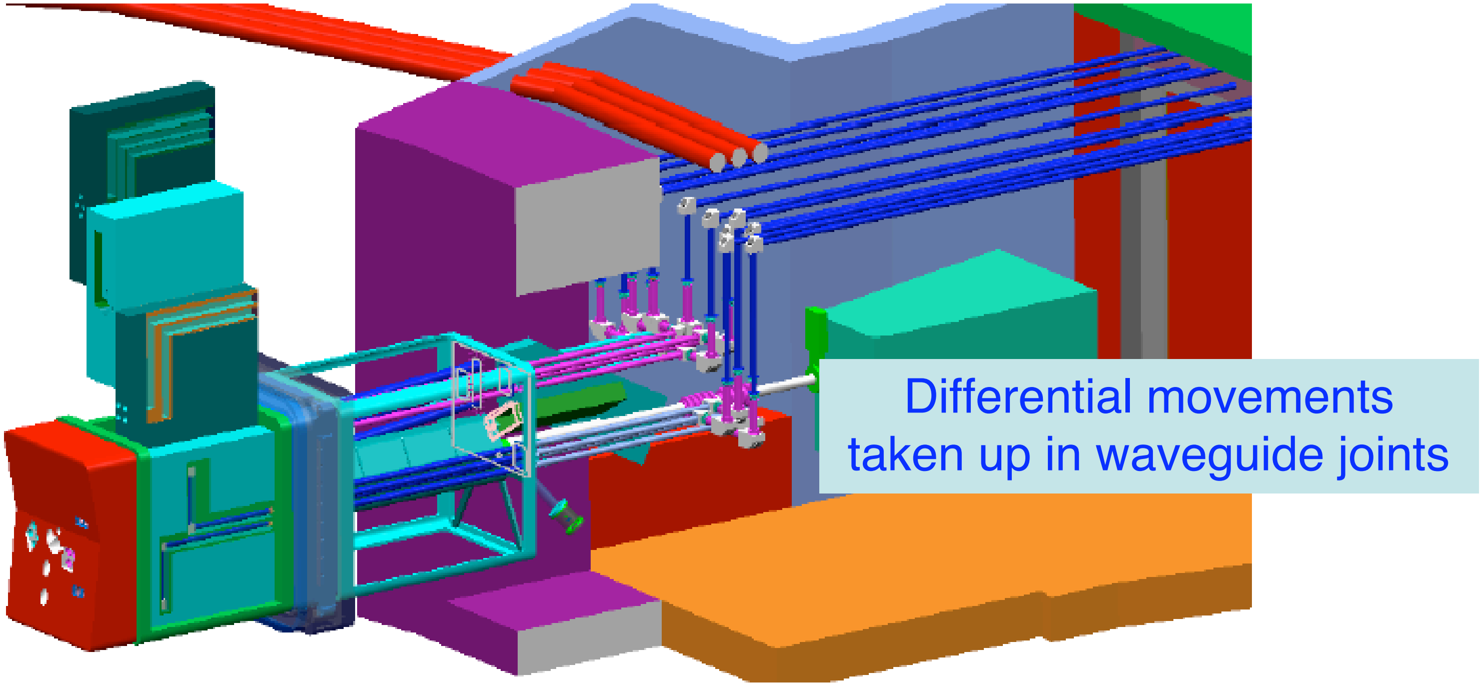
Optical Fibers

Equatorial Port 3

Heating Beam

Main Plasma Reflectometer (LFS)

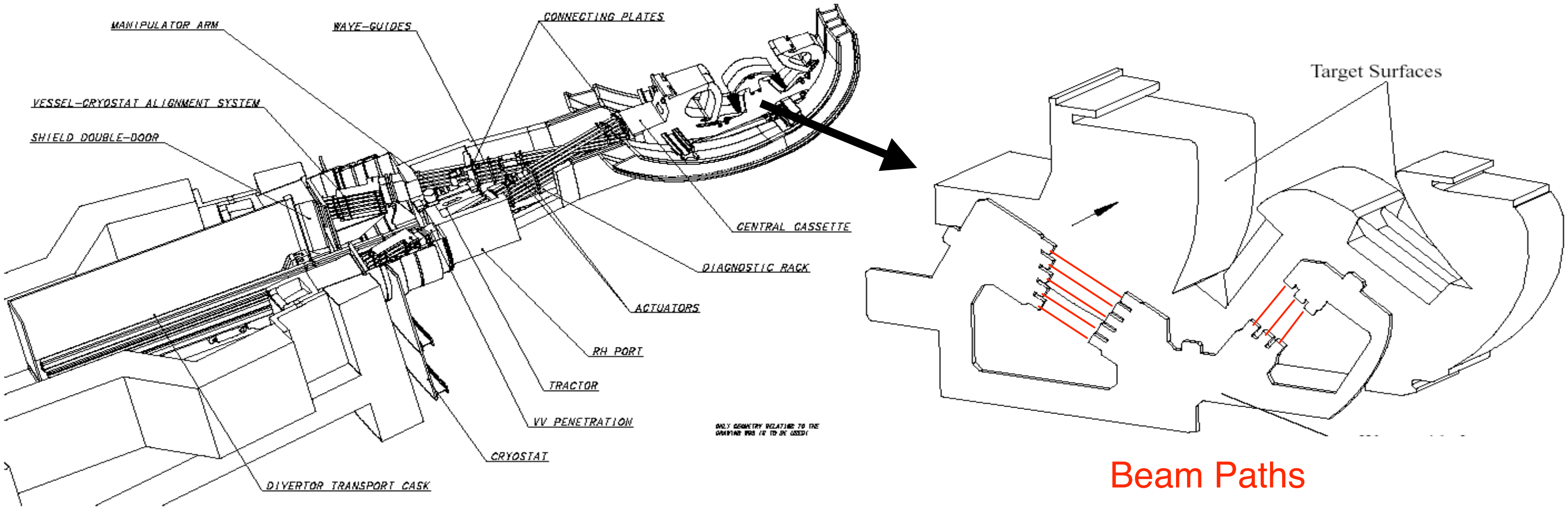
- **Provides density profile, MHD, and fluctuation information in the gradient, edge, and SOL regions.**
- **Both X and O mode employed using several launch/receive pairs.**
- **Miter bends provide compensation for machine movement.**
- **R&D issues**
  - prototyping of waveguide runs needed to assess losses



Differential movements taken up in waveguide joints

Divertor Interferometer

- **This system was originally designed as a microwave system, but high divertor densities and density gradients preclude this approach.**
- **Design needs to be revisited at a conceptual level to see if a CO_2 laser based interferometer is feasible considering the tight spatial constraints.**
- **R&D issues**
  - survivability of optics which see the divertor throat region
  - feedback stabilized alignment concepts



Assessment of Measurement Capability

GROUP 1a Measurements For Machine Protection and Basic Control	GROUP 1b Measurements for Advanced Control	GROUP 2 Additional Measurements for Performance Eval. and Physics
Plasma shape and position, separatrix- wall gaps, gap between separatrixes Plasma current, q(a), q(95%) Loop voltage Fusion power $\beta_N = \beta_{tor}(aB/I)$ Line-averaged electron density Impurity and D,T influx (divertor, & main plasma) Surface temp. (div. & upper plates) Surface temperature (first wall) Runaway electrons 'Halo' currents Radiated power (main pla, X-pt & div). Divertor detachment indicator (J_{sat}, n_e, T_e at divertor plate) Disruption precursors (locked modes,m=2) H/L mode indicator Z_{eff} (line-averaged) n_T/n_D in plasma core ELMs Gas pressure (divertor & duct) Gas composition (divertor & duct) Dust	Neutron and α-source profile Helium density profile (core) Plasma rot. (tor and pol) Current density profile (q-profile) Electron temperature profile (core) Electron den profile (core and edge) Ion temperature profile (core) Radiation power profile (core, X-point & divertor) Z_{eff} profile Helium density (divertor) Heat deposition profile (divertor) Ionization front position in divertor Impurity density profiles Neutral density between plasma and first wall n_e of divertor plasma T_e of divertor plasma Alpha-particle loss Low m/n MHD activity Sawteeth Net erosion (divertor plate) Neutron fluence	Confined α-particles TAE Modes, fishbones T_e profile (edge) n_e, T_e profiles (X-point) T_i in divertor Plasma flow (divertor) $n_T/n_D/n_H$ (edge) $n_T/n_D/n_H$ (divertor) T_e fluctuations n_e fluctuations Radial electric field and field fluctuations Edge turbulence MHD activity in plasma core

Expect to meet meas. reqs; maybe/maybe not; expect not to meet meas reqs.