ITPA R&D Activities in Support of Optimizing ITER Diagnostic Performance

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and the topical group and specialist working group members

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- High Priority topics
  - **Develop methods of measuring the energy and density distribution of escaping a-particles**
  - **Determination of the life-time of plasma facing mirrors used in optical systems**
  - **The assessment of impacts of in-vessel wall reflections on diagnostics**
  - **Plasma control system measurement requirements**
  - **Cross validation of Ti and toroidal/poloidal rotation**
- Others
  - **Stray ECH power**
  - **Status of Joint Experiments**

Mission and high priority research tasks

- **Identify and develop solutions for diagnostic techniques, which are necessary for the fulfilment of ITER scientific goals while remaining compatible with its predicted harsh environment.**

- **HP#1 Develop methods of measuring the energy and density distribution of escaping α-particles**
- **HP#2 Determination of the life-time of plasma facing mirrors used in optical systems**
- **HP#3 The assessment of impacts of in-vessel wall reflections on diagnostics**
- **HP#4 Plasma control system measurement requirements**
- **HP#5 Plasma control system measurement requirements (CER Vs. X-ray crystal spectroscopy)**

Topical Group Membership and Specialist Working Group Chairmanship (2010-12)

CN: Fan, T., Hu, L., Yang, Q. , Zhao, J., Zhong, G.

EU: Beurskens, M., Donne, T. , Ingesson, C., Koenig, R., Murari, A., Serra, F., Weisen, H., Zoletnik, S., A. Litnovsky

IN: Pathak, S.K., Rao, CVS , Vasu, P.

JA: Itami, K., Kawahata, K., Kawano, Y., Mase, A., Sasao, M., Peterson, B., Kusama, Y.

KO: Lee, H.G., Lee, J.H., Lee, S.G., Nam, Y.U., Park, H.

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US: Allen, S., Boivin, R., Brower. D., Hillis, D., Johnson, D., Stratton, B., Terry, J.

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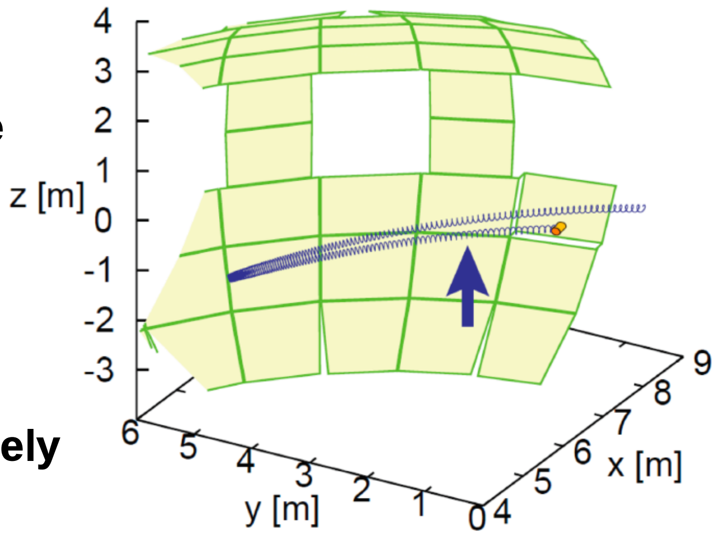
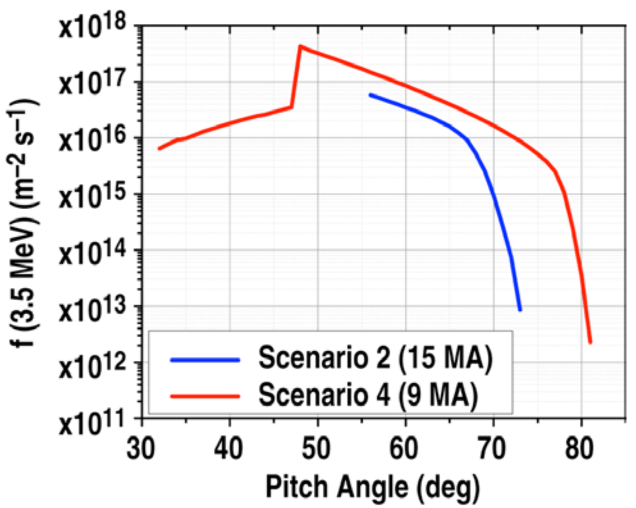
SWG	Chair	Co-Chair	IO Co-chair
Active Spectroscopy	N. Hawkes	S. Tugarinov	M. Von Hellermann
First Mirrors	A. Litnovsky	V. Voitsenya	R. Reichle
First Walls	C. Skinner	D. Rudakov	R. Reichle
Laser Aided	M. Beurskens	J. Irby	G. Vayakis
Microwave	G. Conway	M. Austin	V. Udintsev
Neutrons	S. Popovichev	D. Darrow	L. Bertalot
Passive Spectroscopy	B. Stratton	W. Biel	R. Barnsley
Radiation effects	B. Brichard	T. Nishitani	R. Reichle

HP#1: Develop methods of measuring the energy and density distribution of escaping α-particles

- **Present day techniques do NOT extrapolate to ITER**
- **Inherently a lost alpha detector needs to be in close proximity to the first wall.**
  - Aperture within a gyroradius (~5 cm)
  - Detector within 1-2 cm!!!
  - Requires a significant trench/opening in BM and/or a prominent probe
- **A detector within 1-2 cm of the FW would be extremely difficult to integrate**
  - $\alpha/(n+\gamma)$ ratio is not favorable
  - Active cooling, protective Aperture protected, etc.
- **IR viewing cameras will indicate the impact locations**
  - Little information, no energy or pitch angle
  - Activation may be another alternative (no time resolution)
- **Losses of fast ions are strongly dependent on plasma conditions, and vary widely with plasma parameters such as shape, current, beta and toroidal field (to name a few…)**
  - Due to coverage and ripple trapped particle , not impossible to detect ($v_{||}$~0)



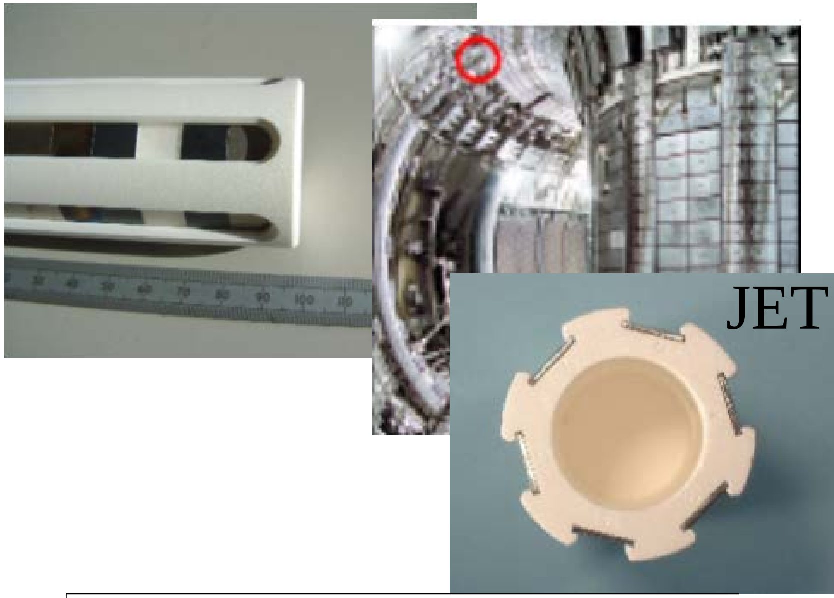


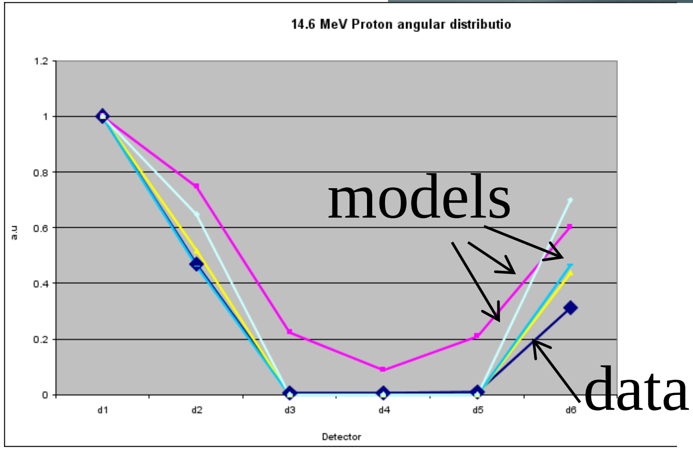
The final answer requires many contributions

1. **Evaluate the expected signal level**
   - **Amount of losses expected at the first wall, (vs pitch angle ($v_{||}/v$)).**
   - **Evaluate Detection efficiency**
     - **Include aperture (gyro phase selection)**
     - **Include overall probe/detector dimensions (self-shadowing)**
     - **Include a full 3D description of the first wall**
   - **Evaluate Optical efficiency (or equivalent for non-optical system)**
     - **Include scintillation efficiency (photons/ion)**
     - **Include scintillation degradation with temperature and radiation damage**
2. **Evaluate the noise (background) levels**
   - **Detector response to neutrons, gammas and secondary electrons**
   - **Evaluate background (MCNP + full angular dependence of the radiation)**
3. **Evaluate technical feasibility**
   - **Evaluate expected heat flux to the probe and its aperture.**
     - **Evaluate required opening in the first wall for particle detection**

Activation probes can be use to detect lost αs

- **Loss of MeV ions can be detected through relevant activation process**
  - JET D/T exp in 2016?
  - 6 different pitch angle ranges
  - $^{48}Ti(p,n)^{48}V$ for $E_p > 4.9$ MeV
- **Losses consistent with first orbit losses**
- **Can be absolutely calibrated**
- **Very low noise levels – clear gamma decay lines**
- **ITER: no time resolution**
- **ITER: requires a retrieval system**





Lost/confined α detector: current options

- **IR/visible camera system** (base option)
  - Global and local measurements but no energy/particle discrimination
- **activation probes** (option I) waiting for JET test (2016)
  - Some pitch-angle resolution, no time resolution
  - Energy threshold (Activation)
  - More engineering assessement
- **Reciprocating probe for lost αs** (option II)
  - Active cooling –need engineering study
  - No sufficient time resolution
- **NPA system for the confined αs**(option II)
  - measurement of neutralized knock-on D^+/T^+
  - Confinement time of fusion αs

HP #2: Determination of life-time of plasma facing mirrors used in optical systems

Work Plan to Address Issues

A. Evaluate performance under erosion-and deposition-conditions: material choice

B. Develop predictive modeling of mirror performance in ITER: Under particle and neutron flux

C. Develop mitigation techniques of deposition
   - Preventive and corrective techniques
   - Cleaning of deposited layers on the mirror - surface recovery

D. Tests under neutron, gamma and X-ray environment

E. Engineering and manufacturing of ITER first mirrors

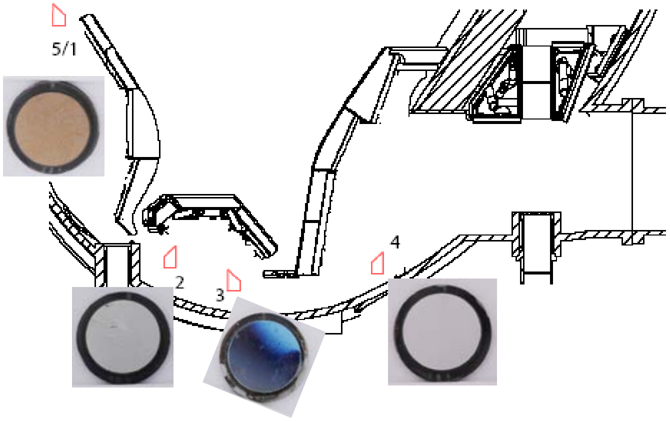
Results of Mo and Cu mirrors under the all metal wall in AUG and simulation

A. **Dominant deposition on the dome mirror facing and the tungsten coating is uniform for all tested mirrors**

B. **Reflectivity of all exposed mirrors degraded and mirrors far away from plasma almost preserved the reflectivity**

Simulation results

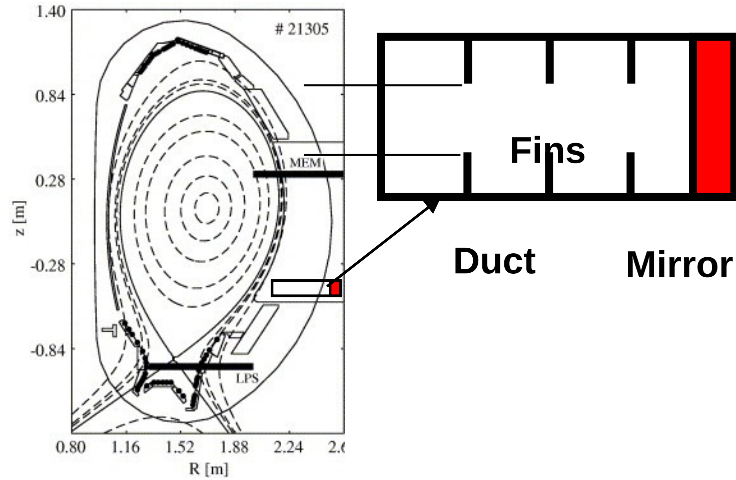
- **Different thickness and elemental composition of deposits on all the mirrors depending on location of exposure**
- **Boron and carbon are primarily found in divertor**



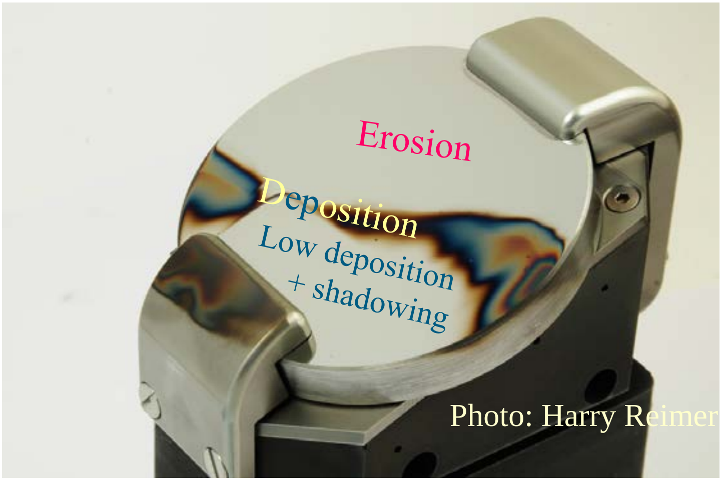
- **W is found on all mirrors**
- **Initial oxidation of the mirrors observed by SIMS clearly correlated with results of reflectivity measurements**

Summary and future direction

- First mirror test in the tokamak with all-metal PFCs is now finished and mirrors must be cleaned
    - Test results from AUG and Aditya tokamaks
- Majority of activities are on mirror surface recovery (MSR)
    - Preliminary test results from laser cleaning on C and Be are promising
- Joint tokamak experiments to be study the predicted mitigation of deposition on mirrors are started
    - Concept of duct with fins is under test
- Industrial manufacturing and multi-machine testing of mirrors is underway
    - Test of large single crystal Mo mirror under erosion conditions



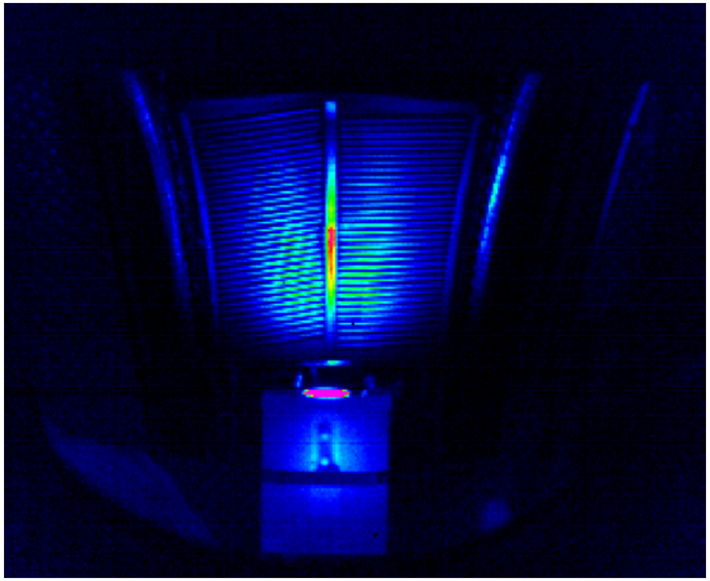
Mirrors in the ducts with fins



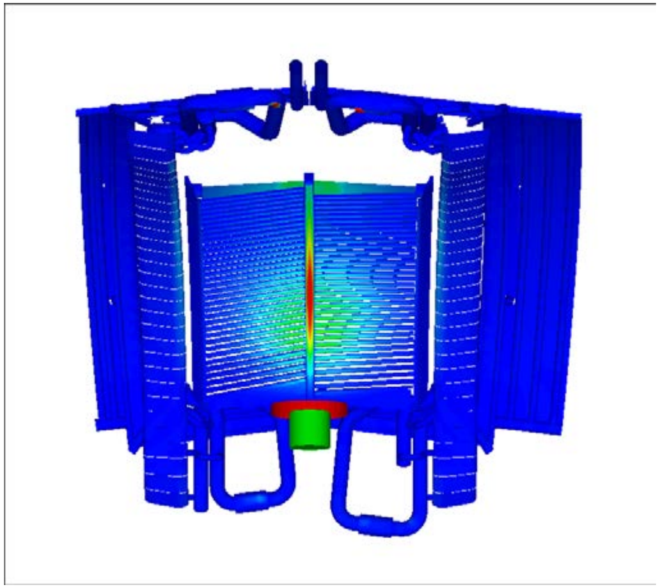
Large SC Mo mirror after exposure in TEXTOR (June 2011)

HP #3: Assessment of impacts of in-vessel wall reflections on diagnostics

- **ITER's metallic walls will result in increased wall reflections**
- **Experience on Tore-Supra shows that this effect can be significant**
  - IR, MSE, etc



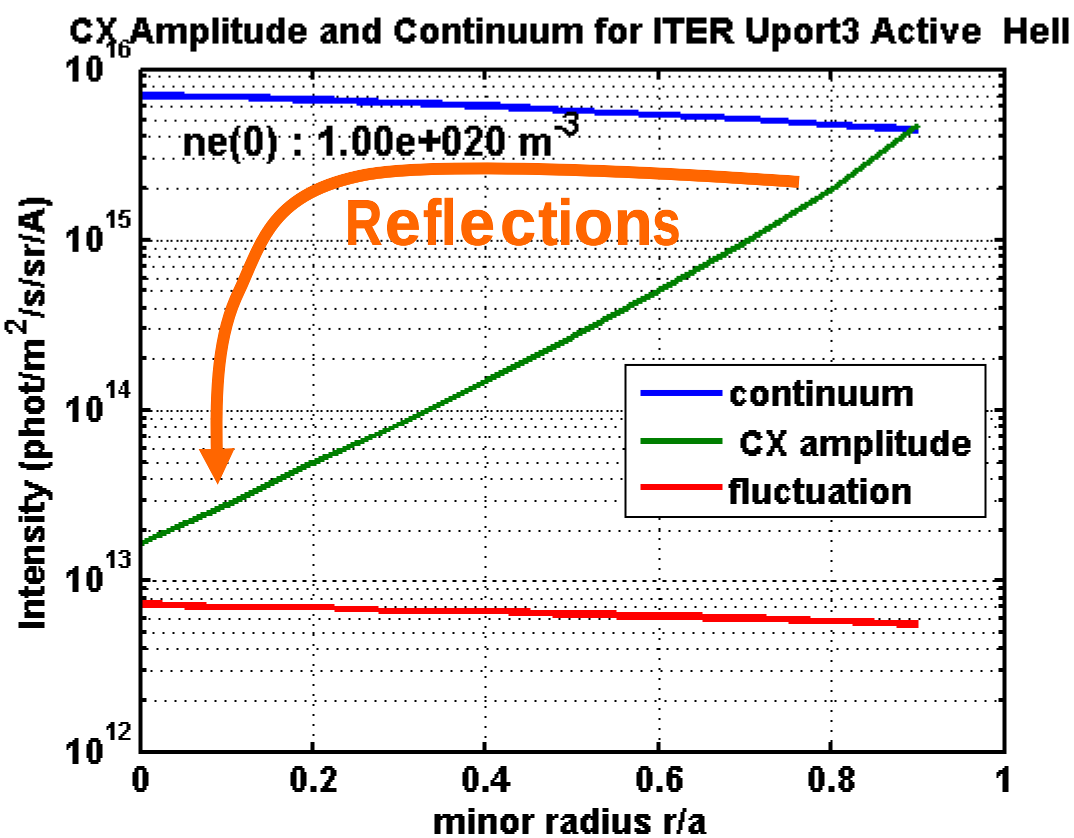
IR measurements in situ

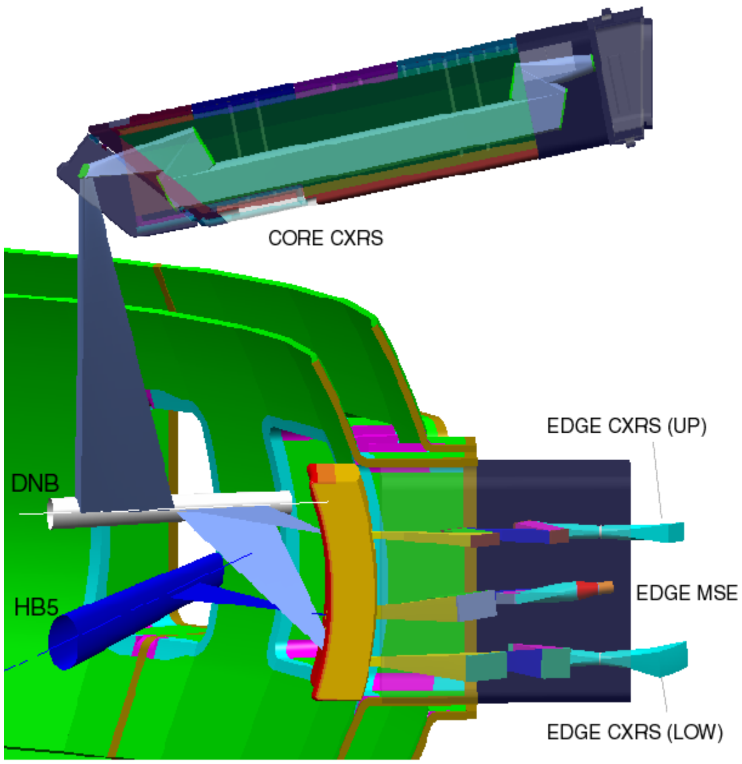


Simulation using COSMOS code and measured reflection coefficients

CXRS measurements are challenging in the core

- **How much of the edge light gets reflected into the core view?**



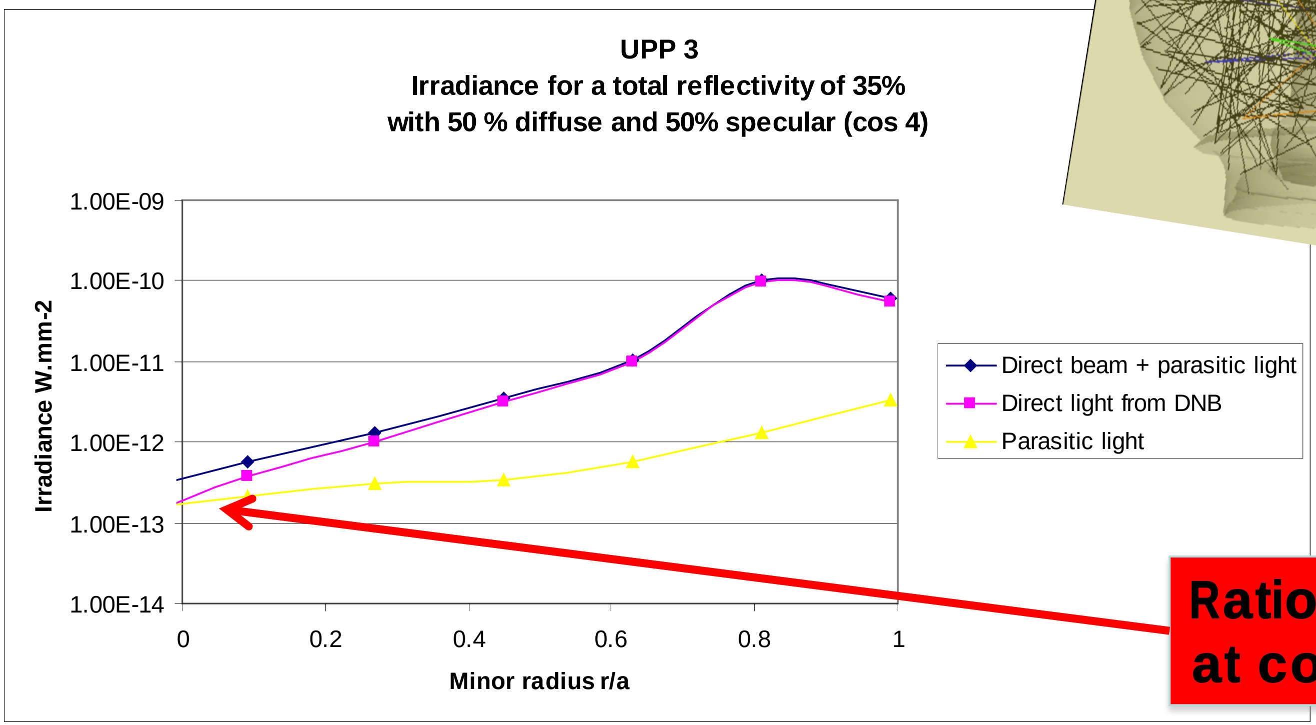


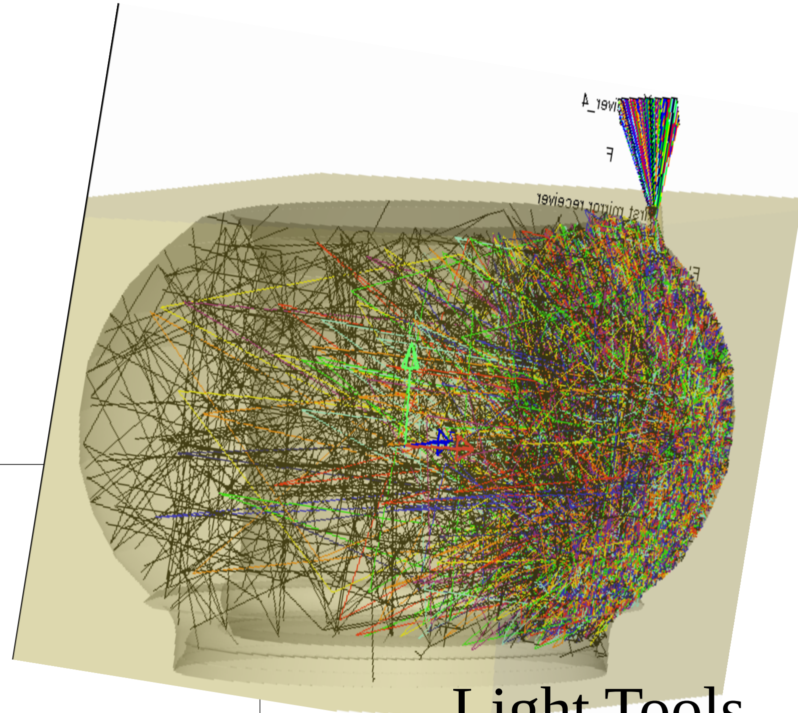
ECH stray power will introduce new issues to diagnostic components

- **ECH Stray/Reflected power may pollute measurements**
- **ECH stray power will be a major concern for potential diagnostic (and in general internal) damage**
  - Breakdown assist being a major concern
  - Initial concerns: microwave diagnostics
    - Reflectometers, ECE, CTS
- **The plan incorporates 3 key aspects:**
  - Understand and predict stray power deposition
  - Characterize impact of stray power on diagnostic components
    - For example: direct interaction, thermal effects and arcing
  - Devise simple mechanisms for protection
    - Shutters, filters, absorbers, etc
- **Much work is also being done at W7-X to understand and quantify these effects**

Software tool can help in calculating ratio of direct to reflected (parasitic) light

- **Modelling requires**
  - Large photon statistics
  - Reflection coefficients
    - material/surface dependent
  - Full 3D (import from Catia)



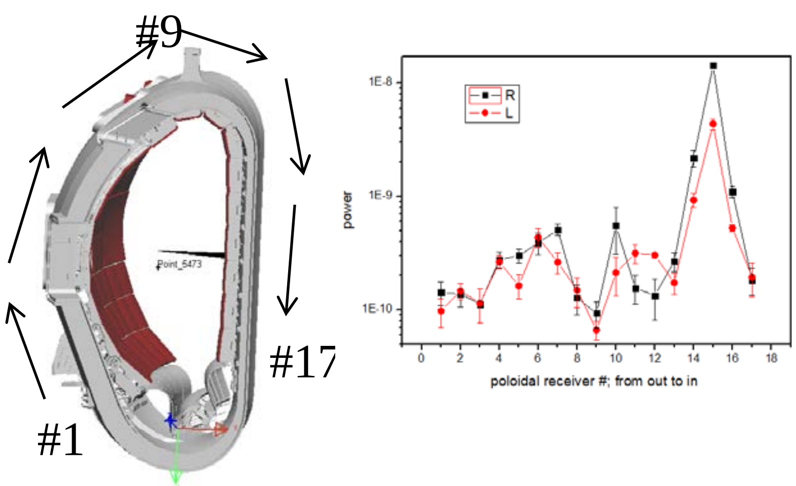


Light Tools

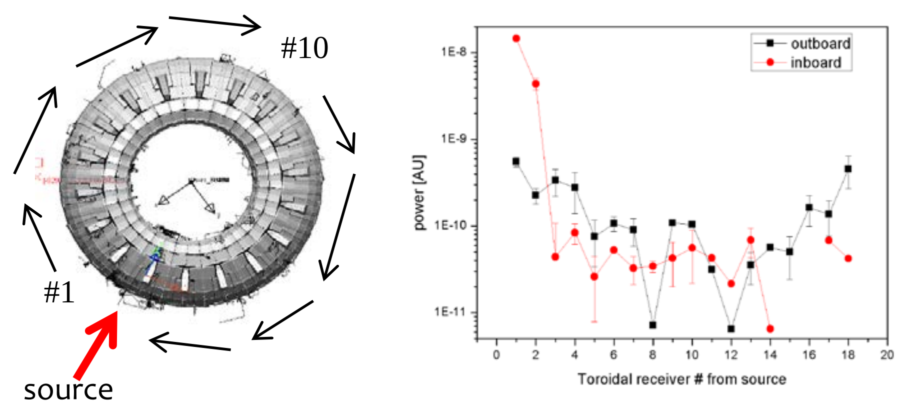
Ratio approaching 1 at core for this model!

Modeling Stray ECH in ITER

- **Ray tracing for simplified tokamak to mimic ECH stray radiation**
- **General results robust (though not details)**
  - Asymmetric distribution
  - Long-distance propagation behind blankets
- **Limitations**
  - Port plugs have not been included
  - Neutral beam ducts ignored in symmetric (duplicated) sector model



Poloidal power distribution



Toroidal power distribution

Risks associated with the stray ECH

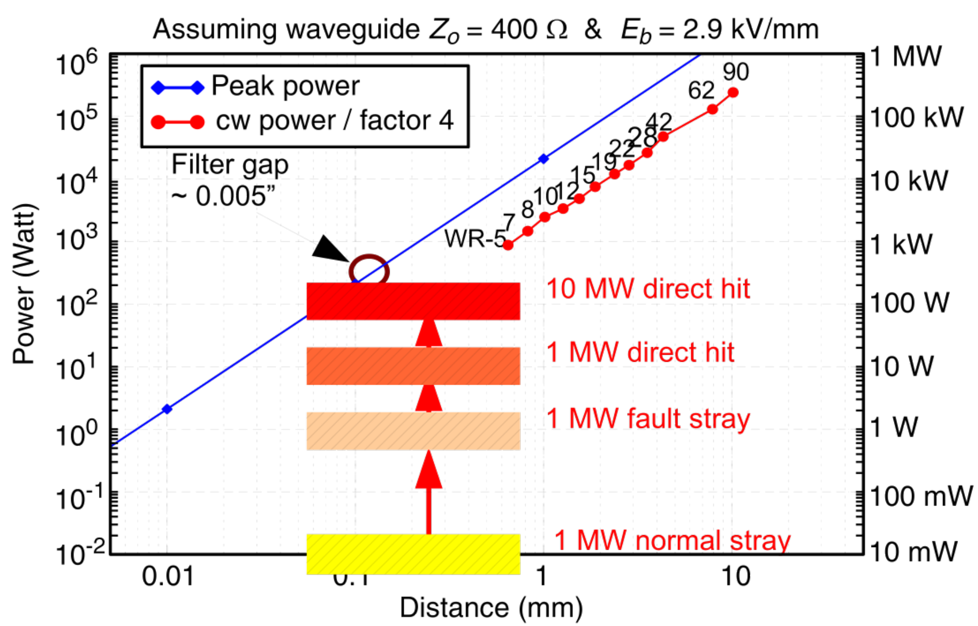
- **Direct interaction**
  - Microwave and FIR : Reflectometry, ECE, Interferometry / Polarimetry (fast detectors, mixers, pin-switches, windows, ferrite isolators, circulators, filters, ...)
- **Thermal effects**
  - Bolometry (foils), SXR cameras (detectors, foils) & IR detectors
  - Spectroscopy, VUV & Optical diagnostics (windows, lenses, fiber-optics {heating changes optical properties}, CCD, Channeltrons, ...)
- **Cavity resonances in small gaps -> arcing**
  - Microwave : Polarizer & Combiner/splitter grids etc. as well as in-vessel components
  - Probes : Langmuir & magnetic (dielectric insulation breakdown, cables, etc.

Continue

- **In current devices, (with plasma), normal stray radiation levels for 1 MW launched microwave power are typically several milliwatts at the diagnostic detector.**
- **Under fault (no plasma) conditions this can rise by a factor of 100 to 1000, or more for a direct hit on a diagnostic antenna by a microwave beam.**
- **The 24 MW heating system planned for ITER may easily overwhelm the protection components with sub-mm dimensions**

Conway et al. "Stray radiation protection of ITER microwave based diagnostics" (2009)

ITER_D_33PKHG (ref: RWG-55F-0901)



Present Joint Experiment

- Diag-2: First Mirror testing (see HP#3)
- Diag-3: TS-ECE discrepancy at high T_e
  - No conclusion –DIII-D where, Ti>>Te
- Diag-4: Micro-balance test
  - 2 being installed on KSTAR
  - Also being installed on AUG
- Diag-5: Activation probe
  - AUG (in progress)