# Progress in physics and system integration of ITER Core X-Ray Crystal Spectrometer

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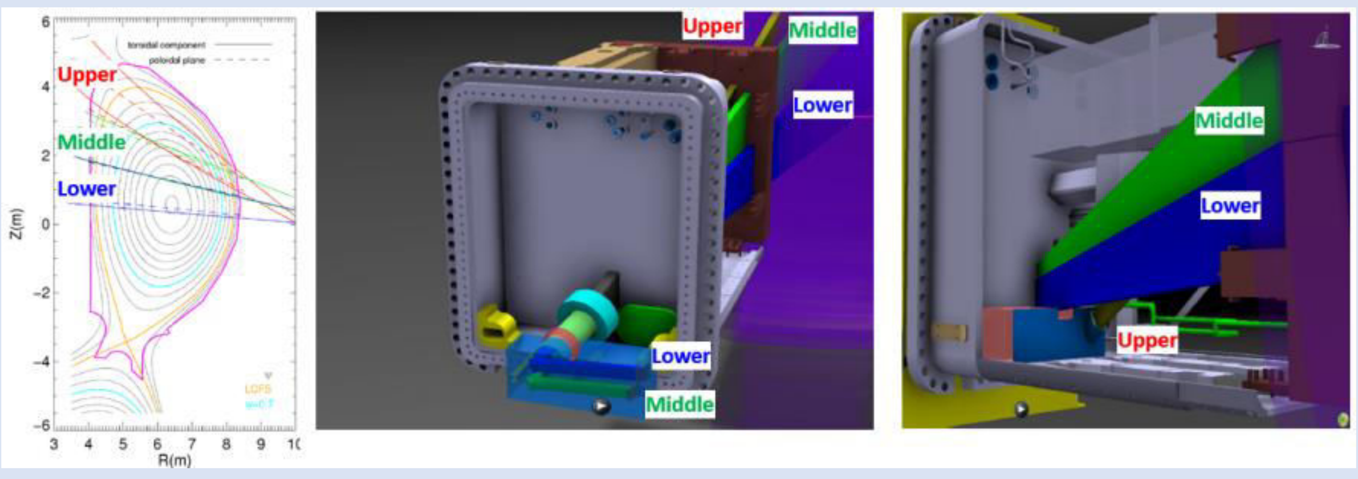
## ROLE OF ITER CORE XRCS

- **Measuring line emission from highly ionized heavy element (impurity)**
- **Measurement**
  - Ion temperature, Plasma rotation
  - Doppler shift and broadening
- **Spatial coverage: 0-0.85a**
- **Purpose**
  - To support advanced plasma control and improve understanding of plasma transport in burning plasma
  - Categorized as EE (Essential for execution of the IRP experimental programme)

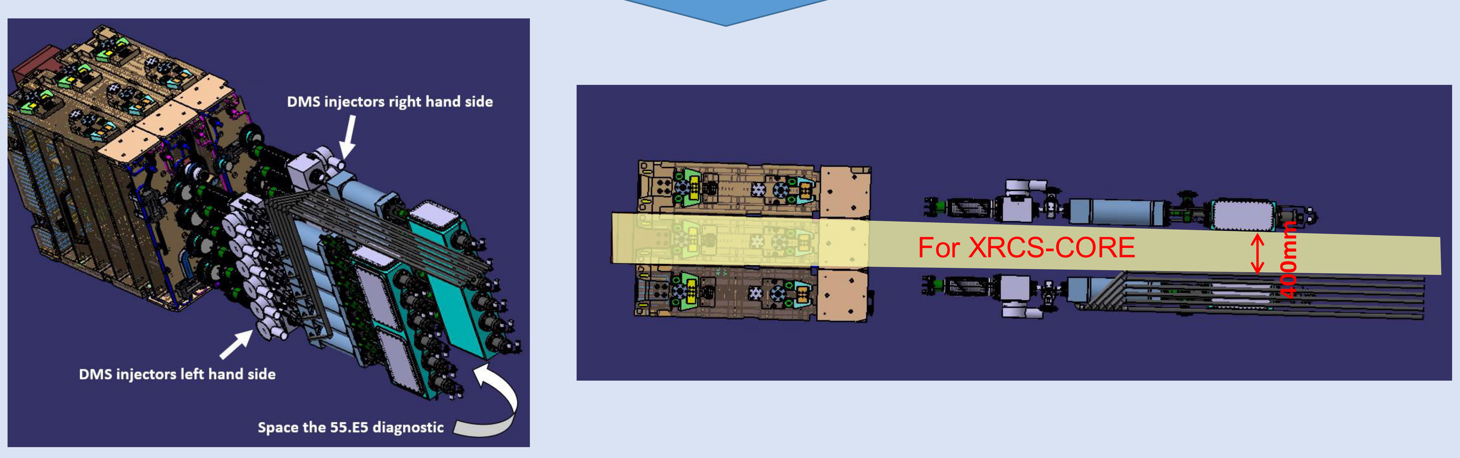
## BACKGROUND

- **Original location and layout at EP#17**
  - Imaging concept with 3 continuous views in predominantly poloidal plane
  - Spectral diffraction in toroidal direction at closure plate location
- **Present location at EP#2**
  - Sandwiched by two DMS units. Narrow but enough space toroidally
  - Previous layout no longer fits the space in EP02. A radial layout is now assumed (see right)

➢ **EP#17**



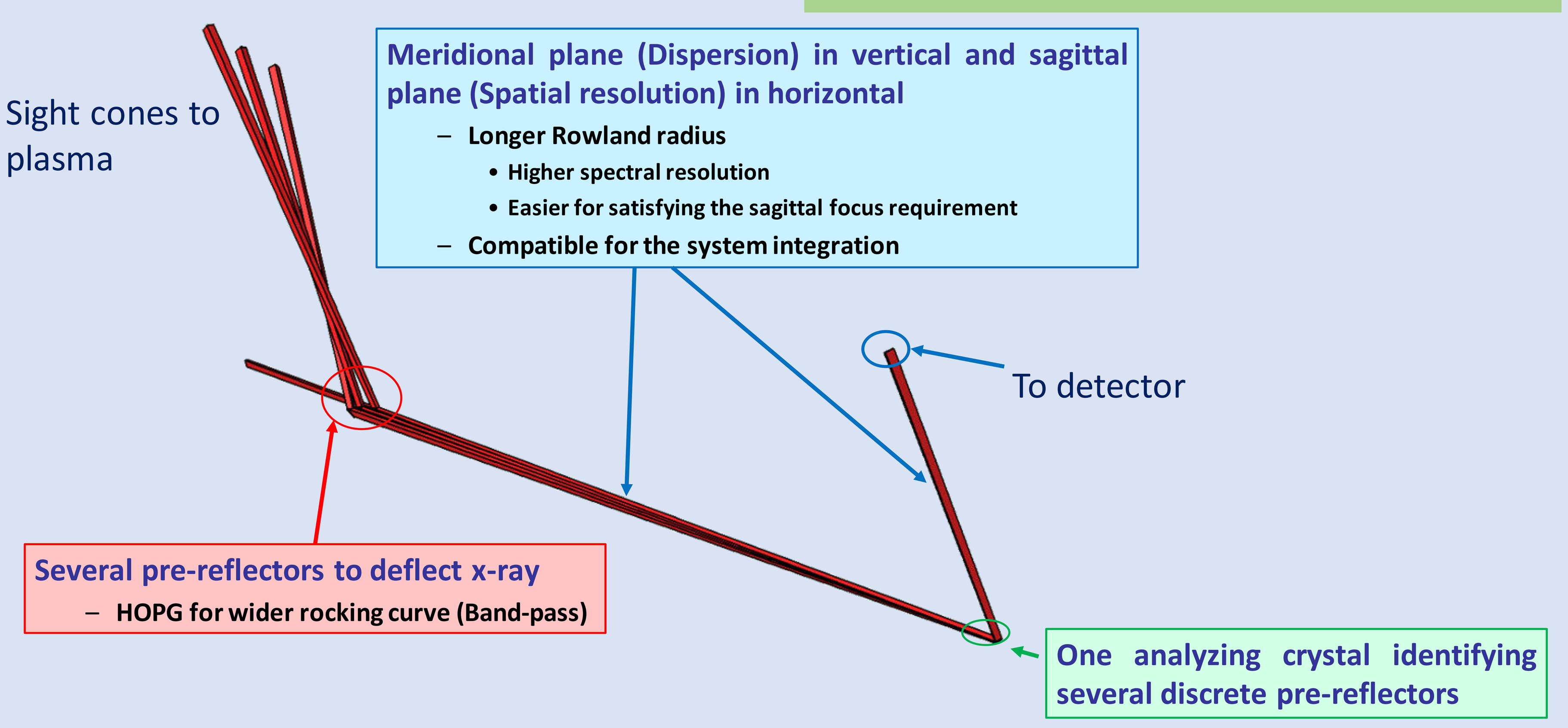

➢ **EP#2**




## CHALLENGES & SOLUTION

- **High neutron dosage in port plug**
- **No space for horizontal spectral dispersion**

- **Pre-reflectors ➔ Space allocation and viewing coverage**
- **Johann spectrometer ➔ Imaging ➔ More compact**



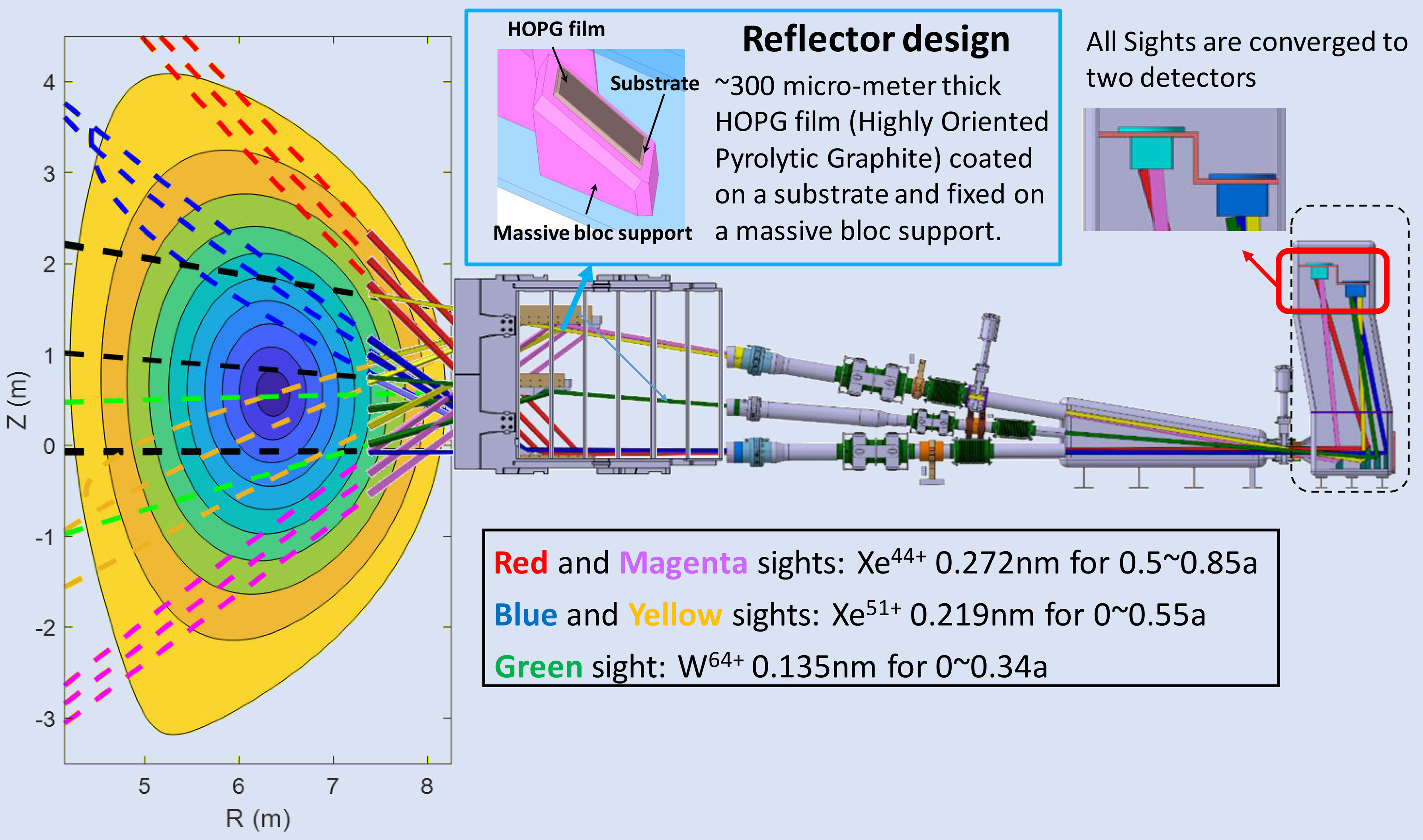

## LINE AND CRYSTAL SELECTION

- **Bragg Angle of Pre-reflector in the range of 10° (to view central region) to 35° (to view outer region) according to ITER Port Plug dimension**
- **Bragg Angle of crystal ~50° for better spatial resolution**
- **Germanium crystals are chosen due to relatively wide rocking curve**

| Impurity /ionization | Lines | | Effective region | Reflector Features (HOPG 0.4°) | | Crystal Features | |
|---|---|---|---|---|---|---|---|
| | Energy (keV) | Wavelength (nm) | | Bragg Angle (degrees) | $R_p$; FWHM µrad (from XOP) | Bragg Angle (degrees) | $R_p$; FWHM µrad |
| Fe 24+ (He-like) | 6.70 | 0.18503 | 0.5a<r<0.95a | 16.041 (0 0 2) | 0.37; 9192 | 50.57 Qtz (2 2 -4 1) | 0.7; 5.92 |
| Fe 25+ (H-like) | 6.95 | 0.1784 | r<0.9a | 15.45 (0 0 2)<br>32.2 (0 0 4) | 0.38; 9240<br>0.14; 7747 | 50.57 Ge (2 2 4) | 0.9; 40.16 |
| Kr 34+ (He-like) | 13.11 | 0.0946 | r<0.9a | 8.12 (0 0 2)<br>16.4 (0 0 4)<br>25.08 (0 0 6) | 0.48; 10040<br>0.2; 8094<br>0.09; 7463 | 49.61 Ge (3 5 7)<br>51.65 Ge (4 6 6)<br>55 Ge (4 4 8) | 1; 3.69<br>0.6; 5<br>0.6; 4.8 |
| Kr 35+ (H-like) | 13.43 | 0.0923 | r<0.6a (0.4a) | 7.92 (0 0 2) | 0.48; 10070 | 49.92 Ge (4 6 6) | 0.6; 4.8 |
| **Xe 44+ (Ne-like)** | **4.56** | **0.272** | **0.6a<r<0.9a** | **23.97 (0 0 2)** | **0.31; 8765** | **52.88 Ge (1 1 3)** | **0.78; 90.3** |
| **Xe 51+ (Li-like)** | **5.67** | **0.219** | **r<0.6a** | **19.05 (0 0 2)** | **0.34; 8990** | **50.6 Ge (0 0 4 )** | **0.93; 71.7** |
| W 46+ (Ni-like) | 2.19 | 0.567 | 0.75a<r<0.95a | 57.86 (0 0 2) | 0.28; 8581 | 48.85 ADP (0 2 0) | 0.6; 100.74 |
| **W 64+ (Ne-like)** | **9.16** | **0.1354** | **r<0.6a (0.5a)** | **11.67 (0 0 2)** | **0.42; 9597** | **51.69 Ge (3 3 5)** | **0.86; 11.4** |

## SYSTEM DESIGN AND LAYOUT

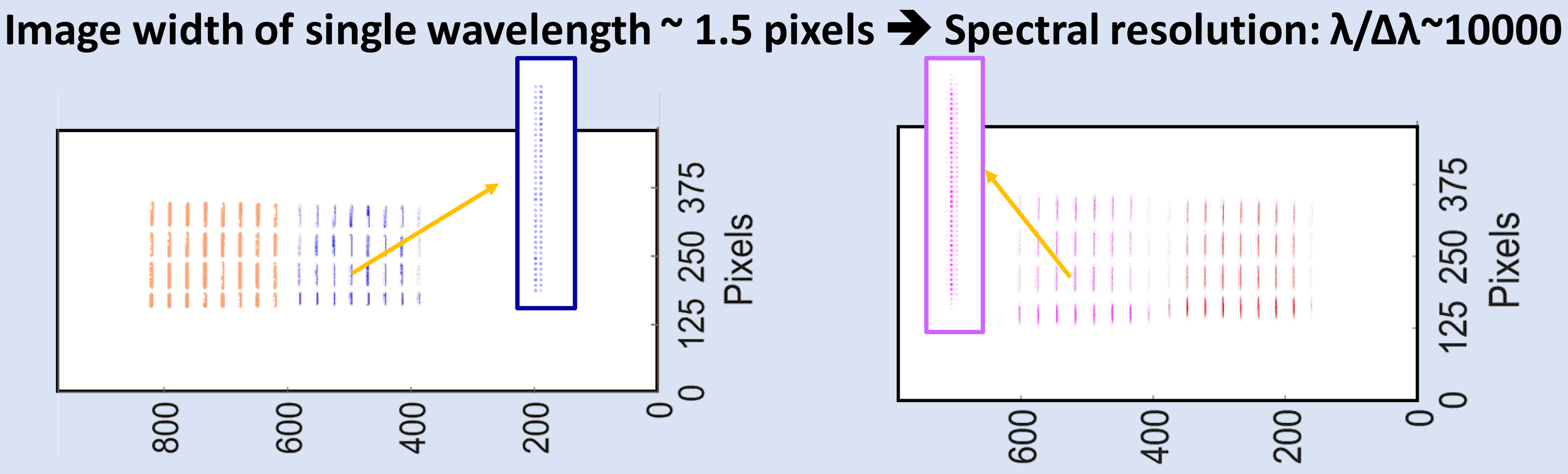
- **Pre-reflectors in PP near to DFW, and analysing crystals in rear of ISS behind Bio-shield**
- **4 sets * 4 sight lines ($Xe^{44+}$ and $Xe^{51+}$) + 1 set * 3 sight lines ($W^{64+}$)**
  - Each set composed with 3 pre-reflectors (or 2 for $W^{64+}$) and one straight as reference/flex channel
  - $Xe^{44+}$ and $Xe^{51+}$ sets follow same path after pre-reflection $\Leftrightarrow$ only 3 vacuum extensions
  - Sight lines 'converge' in DFW to minimize and simplify cut-out



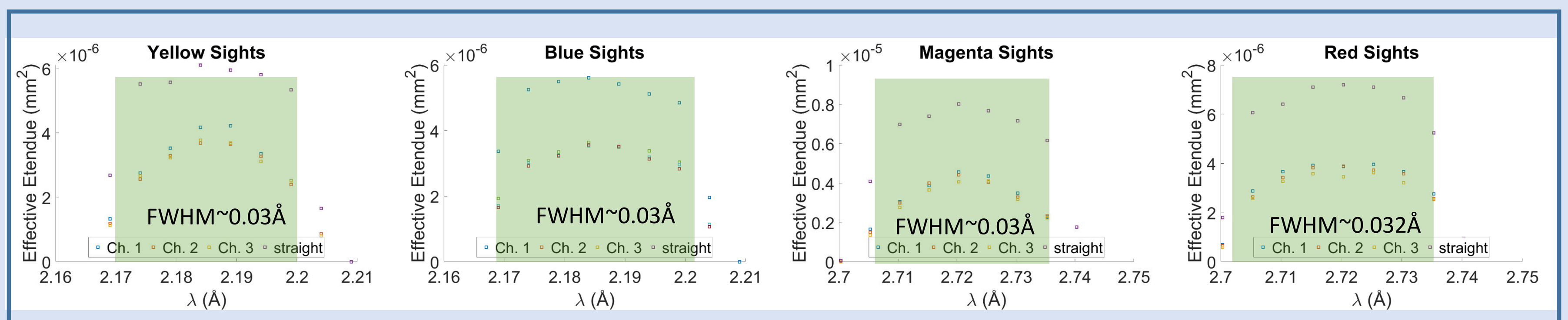

## PERFORMANCE ASSESSMENT

- **Analytical-raytracing mixed code XRSA developed to evaluate double-reflection x-ray spectral system; Validated with full raytracing code XICSRT**
- **Real coordinates adopted**
- **Images on PILATUS detector is simulated, which are used to evaluate the band pass and spectral resolution evaluation**

**Image width of single wavelength ~ 1.5 pixels ➔ Spectral resolution: λ/Δλ~10000**




**Discrete wavelengths' image on detector with real pixel size**




**Effective etendue for each sight**

**Band pass FWHM ~ 0.03Å; Efficiency of straight sights is ~ 1.5 times higher**

## SUMMARY

- ✓ **ITER XRCS Core has been redesigned by introducing pre-reflectors to fit the present space allocation**
- ✓ **X-ray spectrometers are moved to the back part of interspace structure behind bio-shield, with pre-reflector in port plug**
- ✓ **Lines from $Xe^{51+}$ and $Xe^{44+}$ are chosen for the measurement, available at core and outer region respectively**
- ✓ **Analytical-raytracing mixed code XRSA is developed aiding design optimization and performance assessment**
- ✓ **System band pass and spectral resolution are evaluated using XRSA**

## REFERENCES


- Beiersdorfer, P., Clementson, J., Dunn, J., Gu, M.F., Morris, K., Podpaly, Y., Wang, E., Bitter, M., Feder, R., Hill, K.W. and Johnson, D., 2010. The ITER core imaging x-ray spectrometer. *Journal of Physics B: Atomic, Molecular and Optical Physics*, *43*(14), p.144008.
- Yakusevich, Y., Pablant, N., Kring, J., Cheng, Z. and DeBock, M., 2020. Simulated Validation of the ITER XRCS Core using Ray-Tracing Algorithm. *Bulletin of the American Physical Society*.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