Some additions to liquid lithium divertor spectroscopy in FY 2010: LADA and DIMS

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Lithium Research FY2011 NSTX Research Milestone

The plasma facing components (PFC) of fusion devices play a key role in determining the performance of the fusion plasma edge and core by providing particle pumping and fueling and acting as a source of plasma impurities. On NSTX, coating the divertor carbon PFCs with evaporated lithium has resulted in transient particle pumping, increased energy confinement, and suppression of edge localized modes (ELMs). To extend the duration of particle pumping, and to investigate the impact of liquid lithium on plasma performance, a liquid lithium divertor (LLD) will be installed in FY2010, and the relationship between lithiated surface conditions and edge and core plasma conditions will be determined. To understand pumping, D retention will be studied as a function of surface conditions such as lithium coverage and LLD surface temperature, and plasma exhaust parameters such as divertor electron density and temperature, strike-point location, and flux expansion. The temperature evolution of the LLD surface will be measured to understand the heat transfer properties of the LLD, to determine the allowable peak flux onto the LLD, and to relate the LLD surface temperature to the measured influx of lithium and hydrogenic species. Recycling and retention on the divertor carbon and LLD surfaces are particularly important, so **a Lyman-α AXUV diode array will be utilized for deuterium recycling measurements in the presence of the highly-reflective liquid lithium surface**. Further, an in-situ materials analysis particle probe placed near the LLD will provide measurements of retention and surface composition in the outer divertor region for selected shots. These retention measurements will be compared to dynamic retention measurements and to retention models. Finally, **D, Li, and C sources from the divertor and Li transport from the plasma edge to the core will be measured**. This research will provide the scientific understanding of LLD operation necessary to begin to comprehensively assess liquid lithium as a possible PFC solution for NSTX and next-step ST facilities.

Some additions to LLD spectroscopy diagnostics in FY 2010: LADA diagnostic

- LADA – Lyman Alpha (Ly_{α}) Diode Array
  - 20-channel AXUV-20EL diode array from IRD Inc.
  - Narrow bandpass filter with central wavelength at λ=121.6 nm from Acton Research Corp.
  - 20-channel trans-impedance amplifier from Clear-Pulse, Inc. (Japan)
  - cm-scale resolution in lower divertor, 3-5 channels on LLD
  - 10-20 kHz time response
  - D-tacq data acquisition module transfers data directly to MDS Plus data server after every shot
  - In-vessel installation is required to avoid absorption of vacuum ultraviolet (VUV) emission by air
  - Active cooling of in-vessel filter holder is required by air or water to avoid permanent filter transmission loss occurring

    at $T > 50\text{-}70^{O}$ C

LADA will provide absolute measurements of divertor recycling profiles in the presence of highly-reflective LLD surface

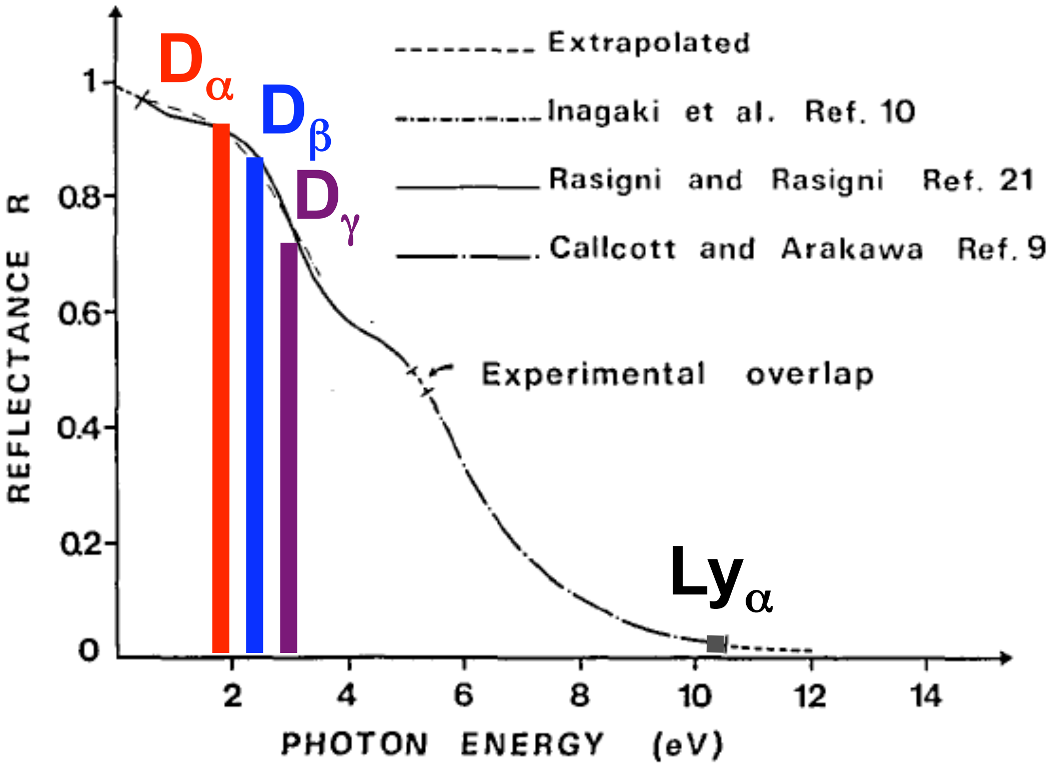
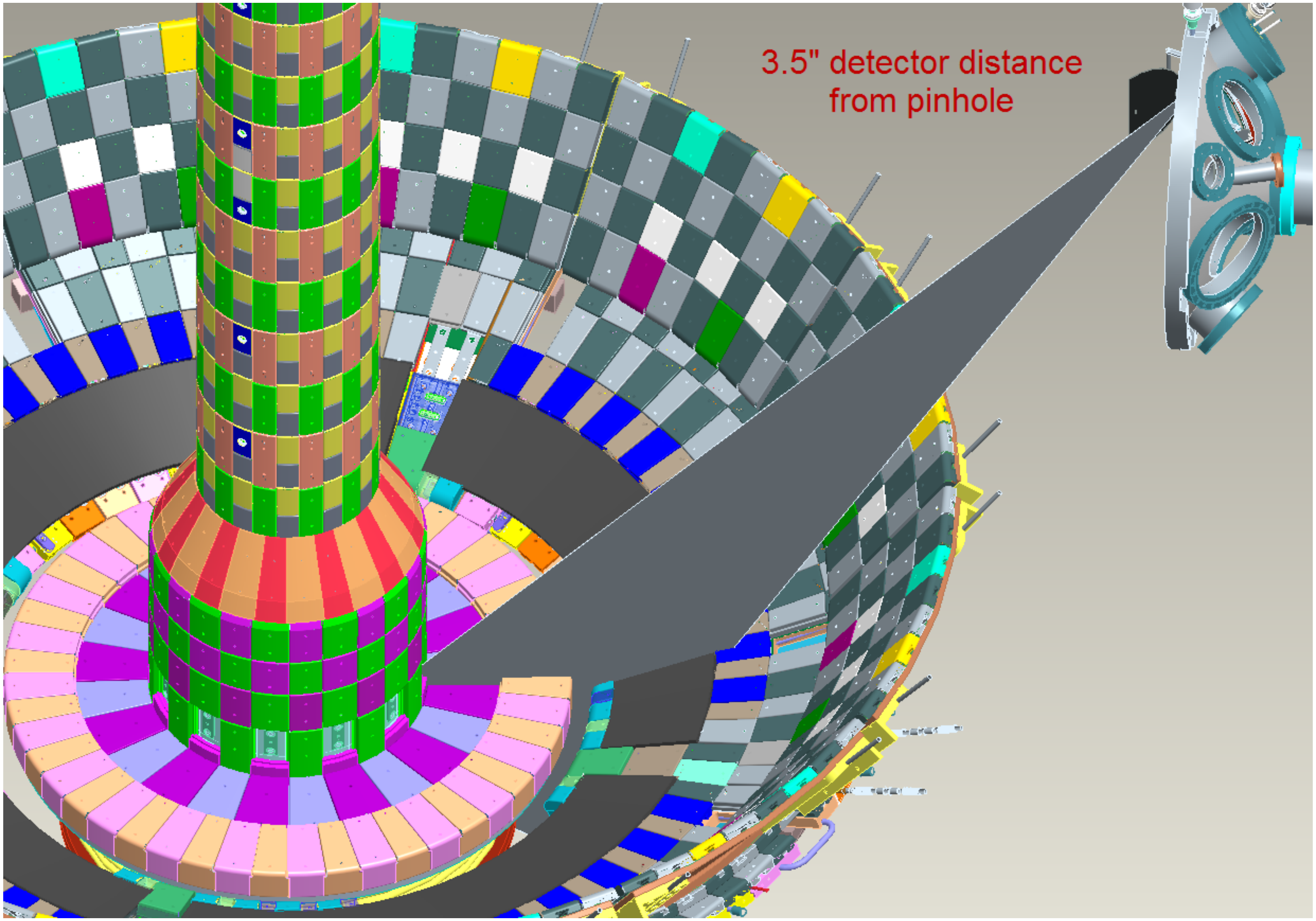


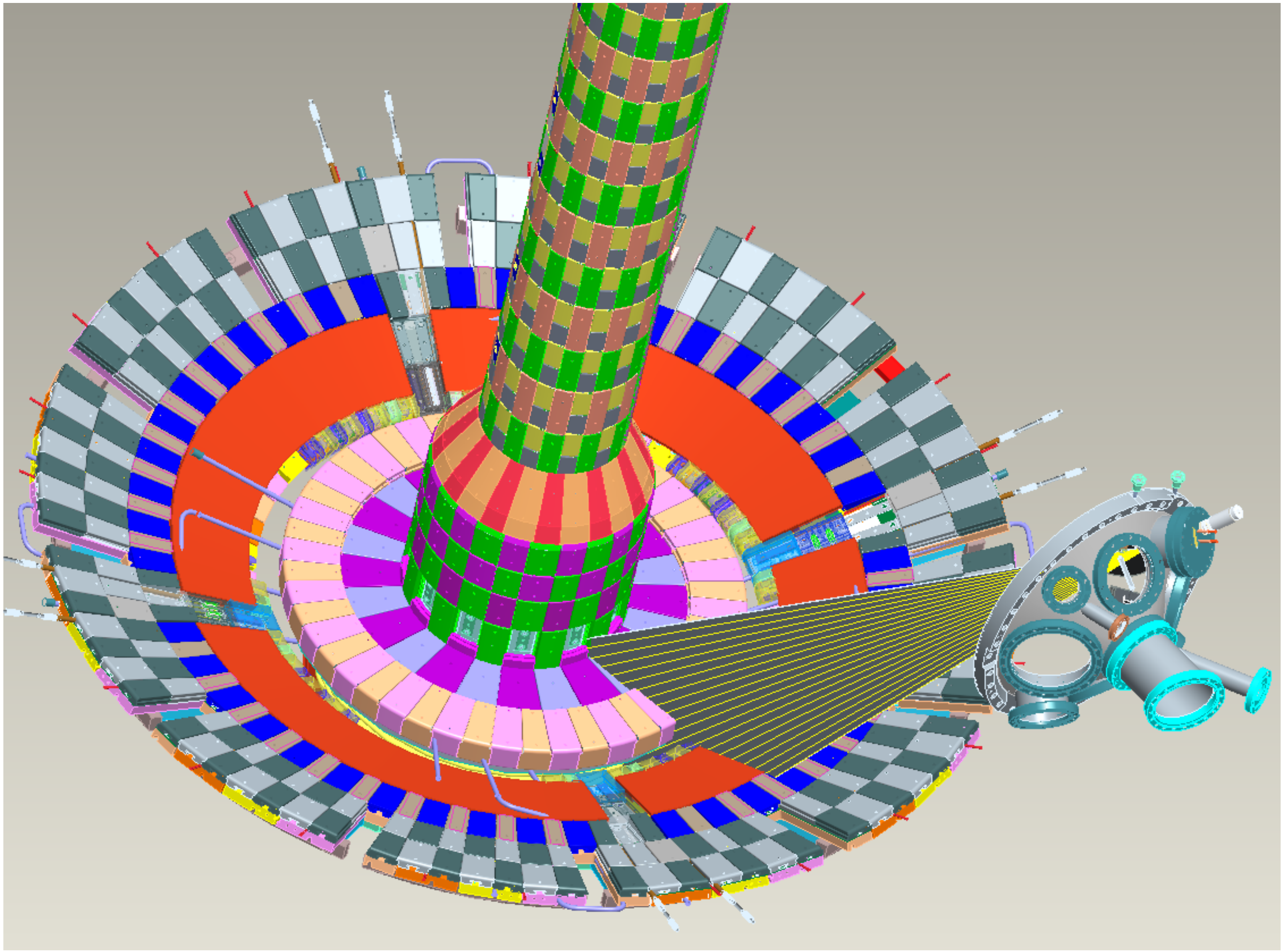
FIG. 1. Normal incidence reflectance data of lithium.

- Figure from M. Rosigni et al., JOSA 67, 54 (1977)
- Reflections for the Balmer α, β, γ lines in the visible range are much higher than for the Lyman α line λ=121.6 nm in the far UV range

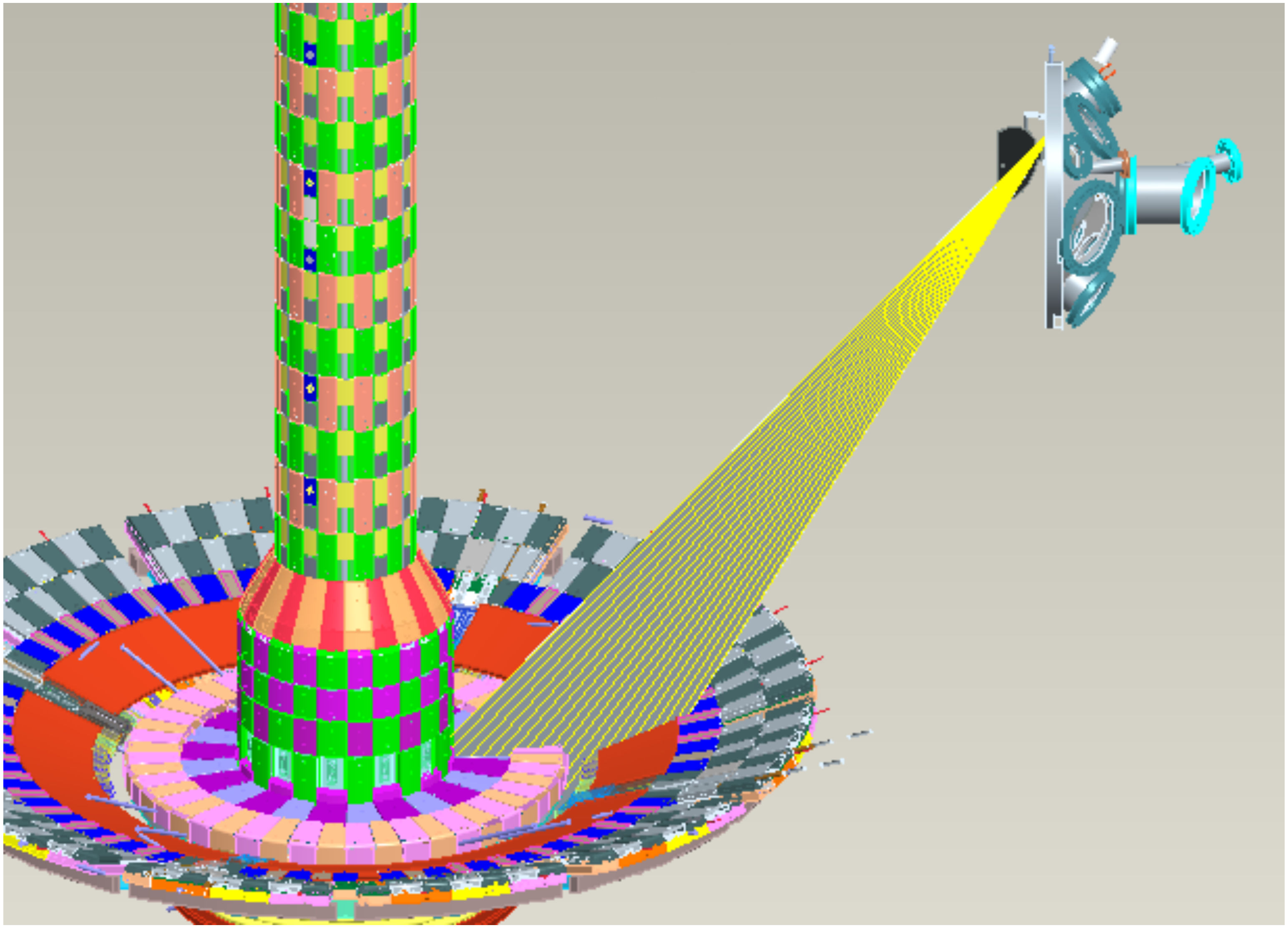
LADA diagnostic placement



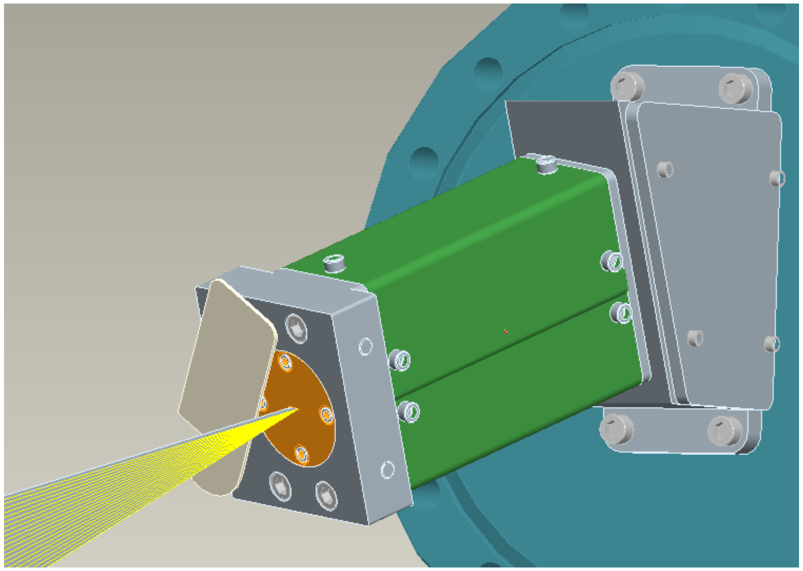
LADA diagnostic placement

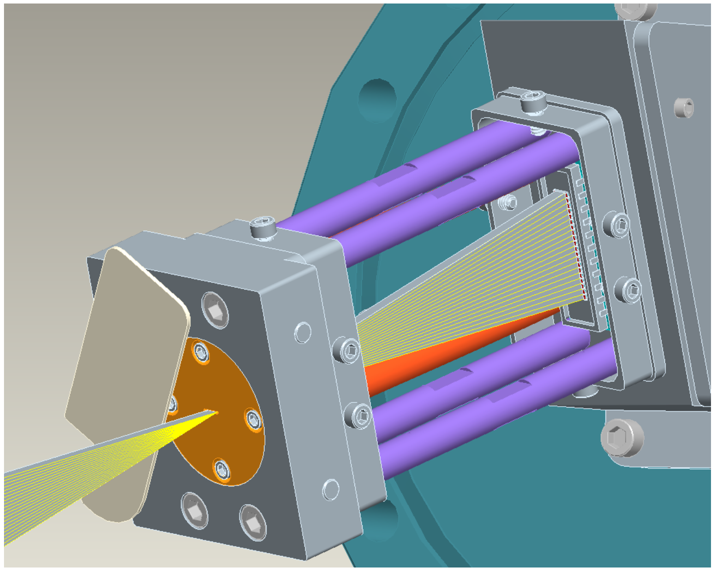


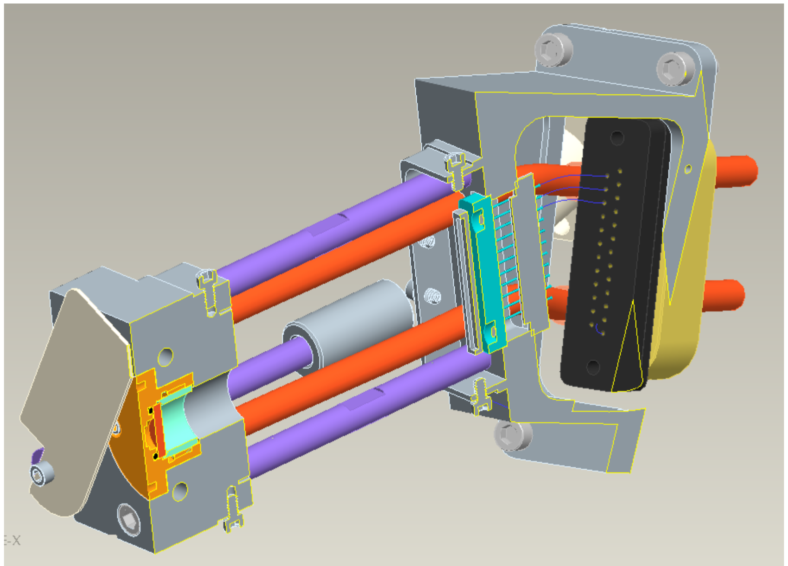
LADA diagnostic placement



LADA in-vessel installation and cross-sections







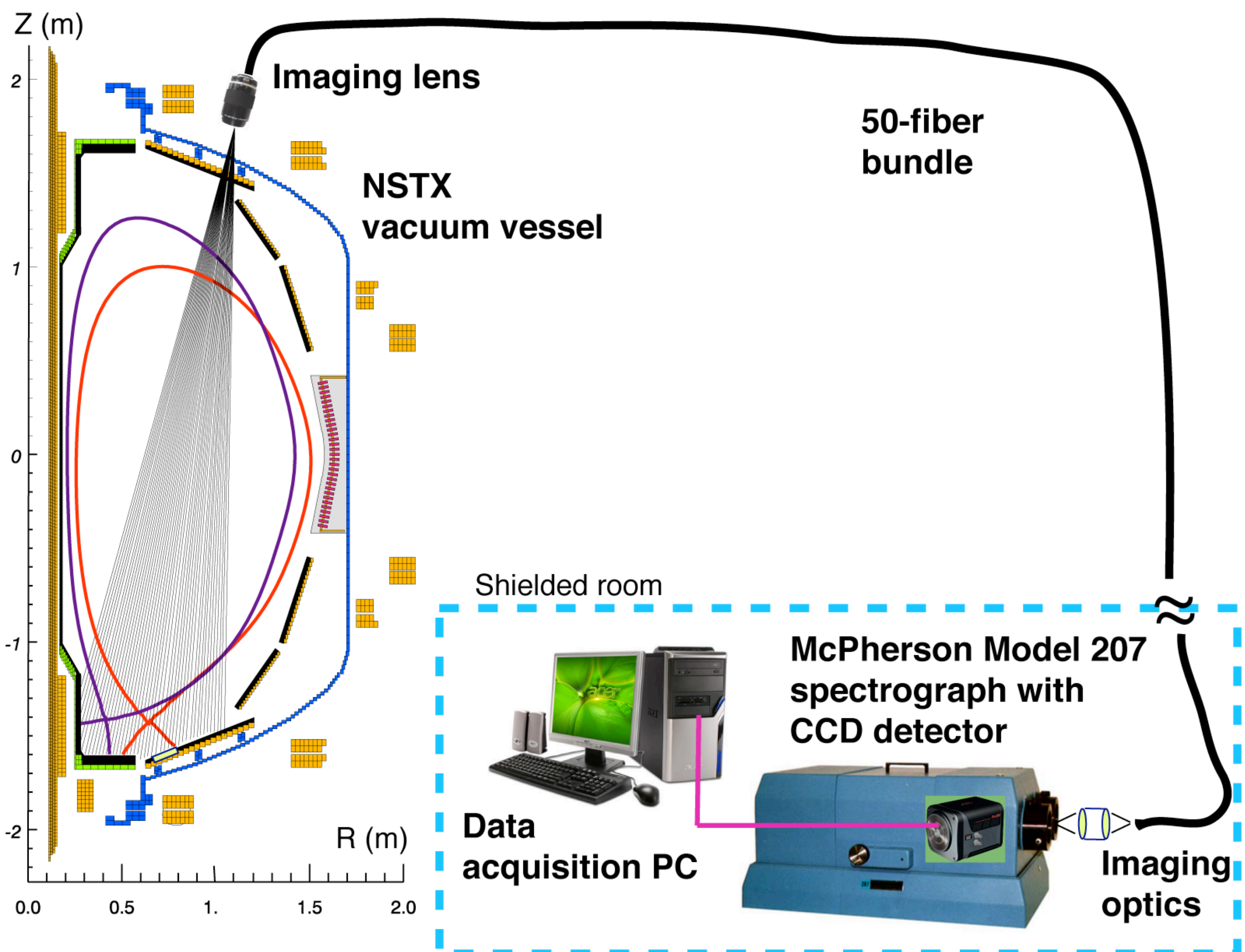
Some additions to LLD spectroscopy diagnostics in FY 2010: DIMS diagnostic

- DIMS – Divertor Imaging Spectrometer
  - Optimized for ultraviolet, visible, and near-infrared high-resolution imaging spectroscopy from 250 nm to 1100 nm
  - Tochigi Nikon UV 105mm f/4.5 imaging lens
  - 50-fiber optical relay bundle, 400-um FBP400 broadband fibers from Polymicro, Inc.
  - Two acromatic triplet lenses as input optics
  - McPherson Model 207 R=0.67 m f/4.7 spectrograph with aberration-corrected imaging optics
  - Three gratings (3600, 2400, 1800 lines/mm) for ultraviolet, visible, and near-infrared line spectra
  - Princeton Instruments Pro EM 512 CCD camera
  - Expect 17-point divertor profiles with 1 cm spatial resolution, 1-10 ms time resolution

DIMS will address high-priority measurements for NSTX Lithium and Boundary Physics research

- Divertor physical and chemical sputtering sources
  - Atomic D, Li, C, metal influx **profile measurements in divertor**
  - Molecular sources (D_2, LiD, BD, CD_4, …)
- Divertor ion sink characterization
  - Electron-ion recombination patterns in divertor (D, He, Li)
  - High-*n* Balmer (and Paschen) series lines for n_e, T_e estimates
- **Ion temperature** measurements in divertor (based on Doppler broadening) for ion heat transport analysis
- Various applications
  - Divertor and edge measurements in HHFW-heated plasmas
  - Near-infrared spectroscopy for ITER
  - Possibly, SOL flow measurements and helium line ratios

DIMS will provide divertor impurity profiles



NSTX VIPS-2 10-channel divertor imaging spectrometer served as DIMS prototype and collected important edge data

022501-8 Soukhanovskii *et al.*

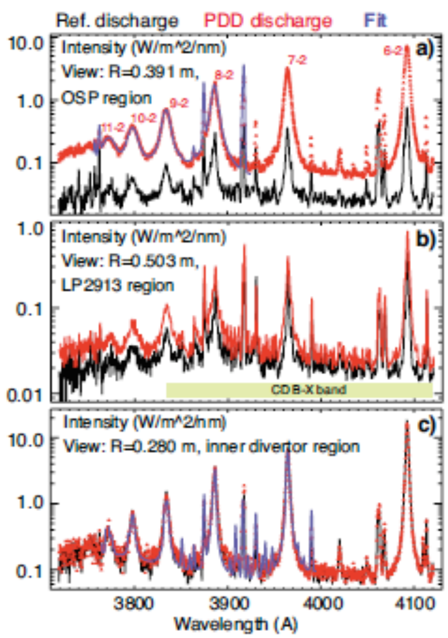


FIG. 9. (Color online) Divertor deuterium Balmer spectra recorded at three lines of sight shown in Fig. 1 in the reference 1.0 MA, 6 MW NBI discharge and the discharge with a partially detached OSP.

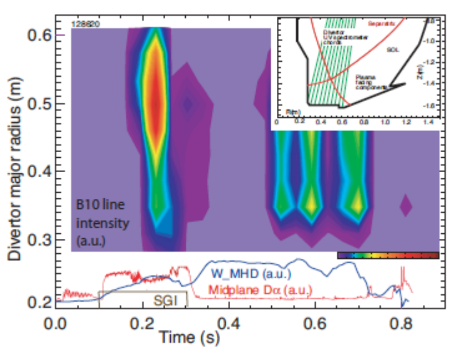


Figure 4: Spectroscopic evidence of X-point MARFE formation during SGI-U gas pulse.

Divertor Heat Flux Mitigation in NSTX High-Performance H-mode discharges 14

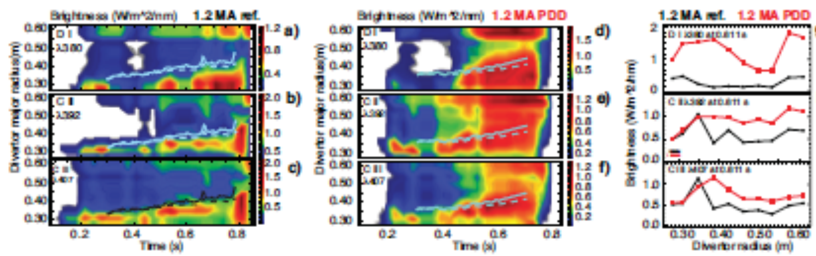


Figure 9. *Time histories of divertor line brightnesses and divertor emission profiles. In the 1.2 MA reference discharge: (a) - Deuterium λ380 nm B10 line, (b) - CII λ = 392 nm line, (c) - C III λ = 407 nm line; In the 1.2 MA PDD discharge: (d) - Deuterium λ380 nm B10 line, (e) - CII λ = 392 nm line, (f) - C III λ = 407 nm line. Panels (g), (h), (i) - Brightness profiles of B10, C II and C III emission in the reference and PDD discharges at 0.611 s. Solid lines show time histories of the OSP major radius. Dashed lines show a projection of the X-point major radius on the divertor along the spectrometer viewing chords.*

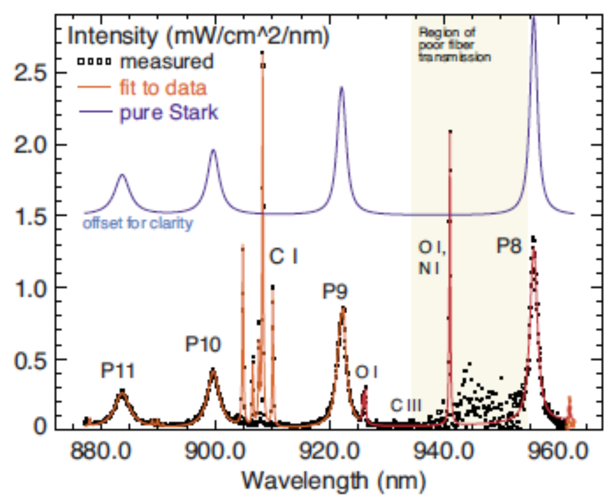


FIG. 3. (Color online) Stark broadening of P8–P11 Paschen series lines in the recombining (detached) divertor.

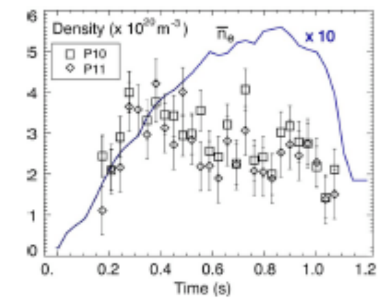


FIG. 5. Comparison of the detached divertor density inferred from the P10 and P11 lines.

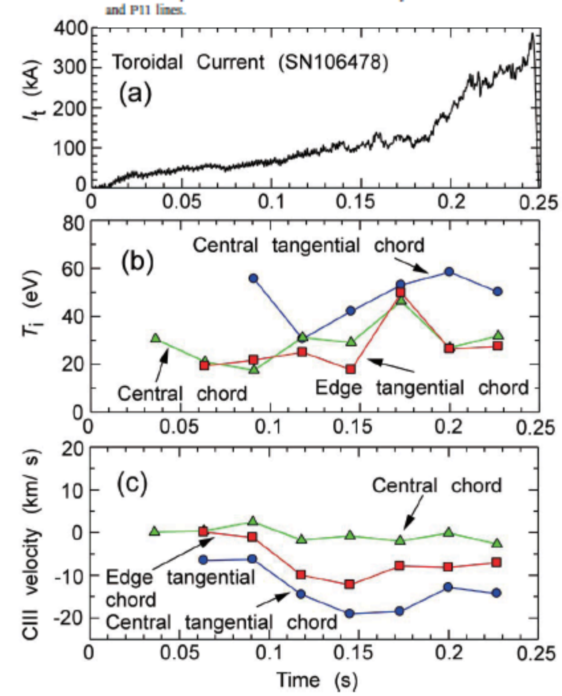


Fig. 3 Time evolution of the toroidal current I_t (a), Doppler ion temperature $T_{i,D}$ (b) and CIII ion flow velocity (c).