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Development of rugged hydrogen sensors for first wall charge-exchange neutral flux measurement

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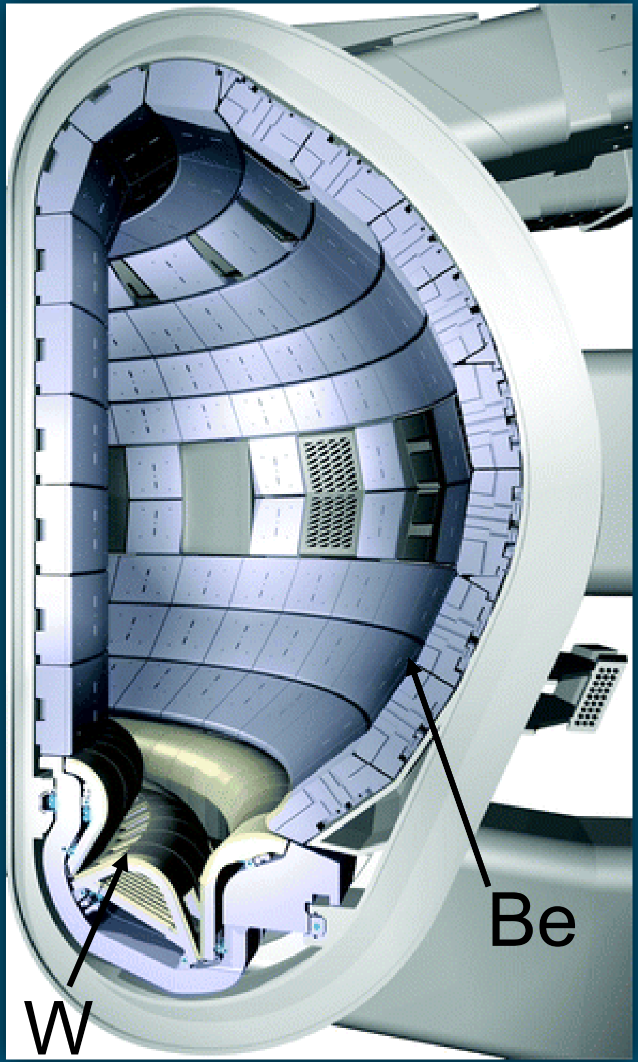
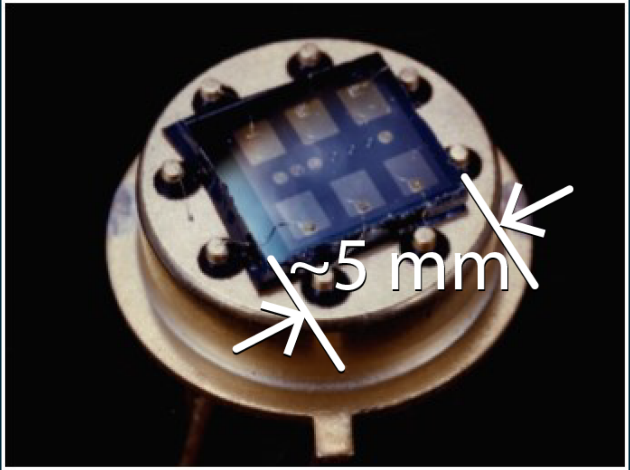
Plasma facing materials will be a significant challenge for future tokamaks



Exposure conditions:

- High-flux D-T plasmas
- High-energy fusion products (14 MeV n, helium ash)
- Impurities
- Charge-exchange neutrals
  - Diagnostics are presently lacking on US Tokamaks
  - In past, low energy neutral analyzers and carbon resistance probes have been used
  - Pd-MIS style sensors may be better choice – compact and can be regenerated [1]



6 element Pd-MIS sensor

[1] R. Bastasz, B.L. Cain, T.E. Cayton, R.C. Hughes, and D.N. Ruzic, J. Nucl. Mater. 162-164 (1989) 587

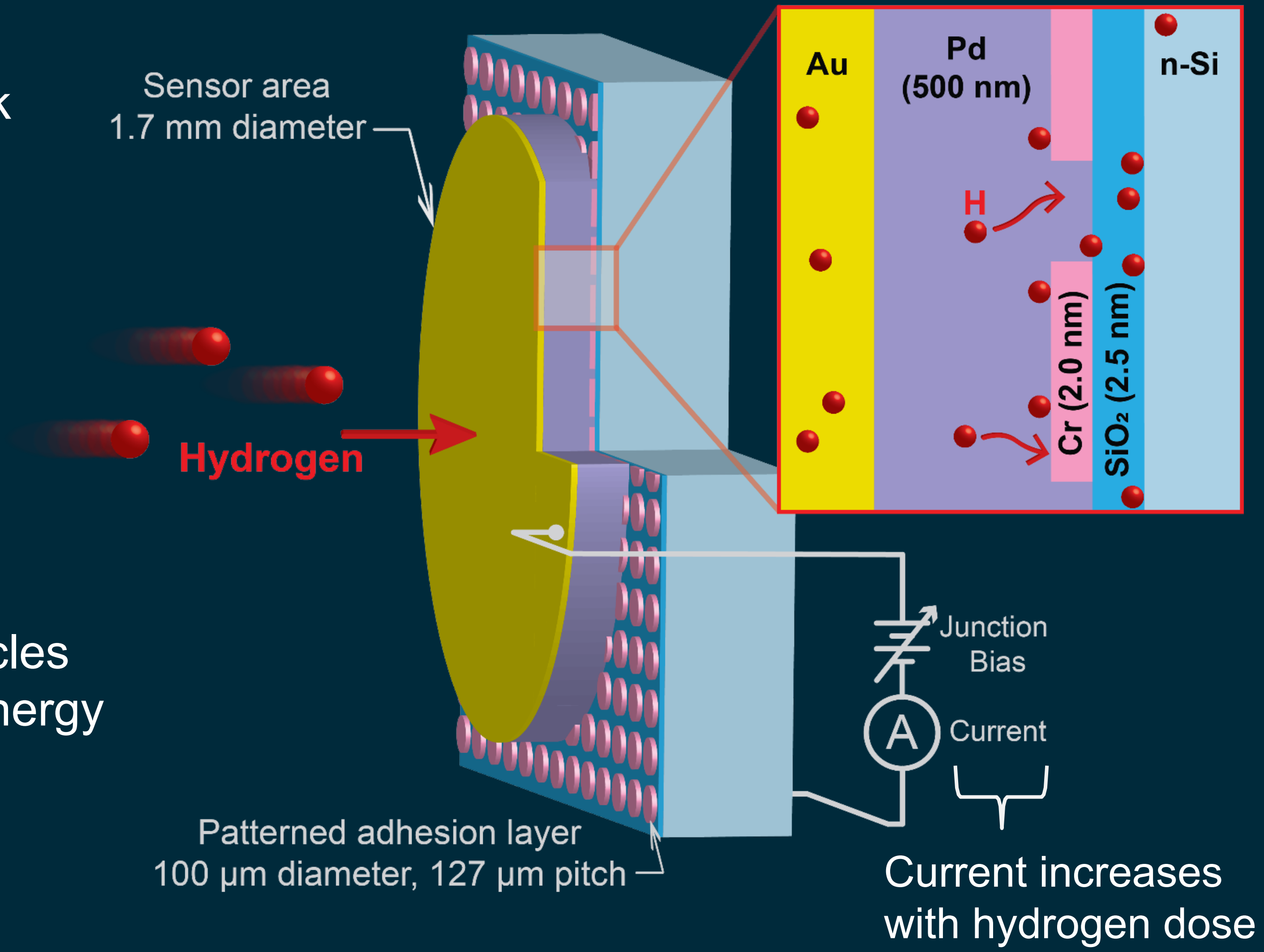
Changes to Pd-MIS sensor construction aim to improve performance

Patterned adhesion layer enables thick protective Pd layer while maintaining hydrogen sensitivity

Good compromise

	No adhesion layer	Patterned Cr layer	Continuous Cr layer
H Sensitivity	Great	Very Good	Poor
Film Adhesion	Poor	Good	Very Good

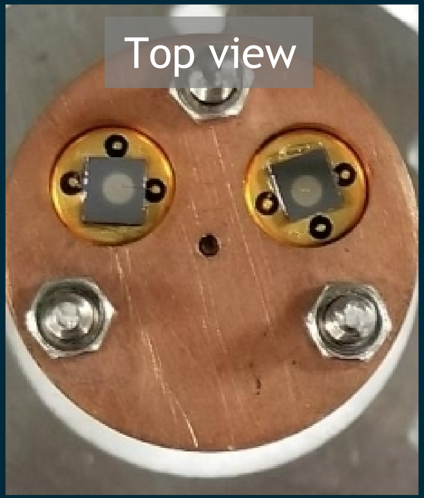
Gold overlayer blocks low energy particles (will be used in future experiments for energy resolution)

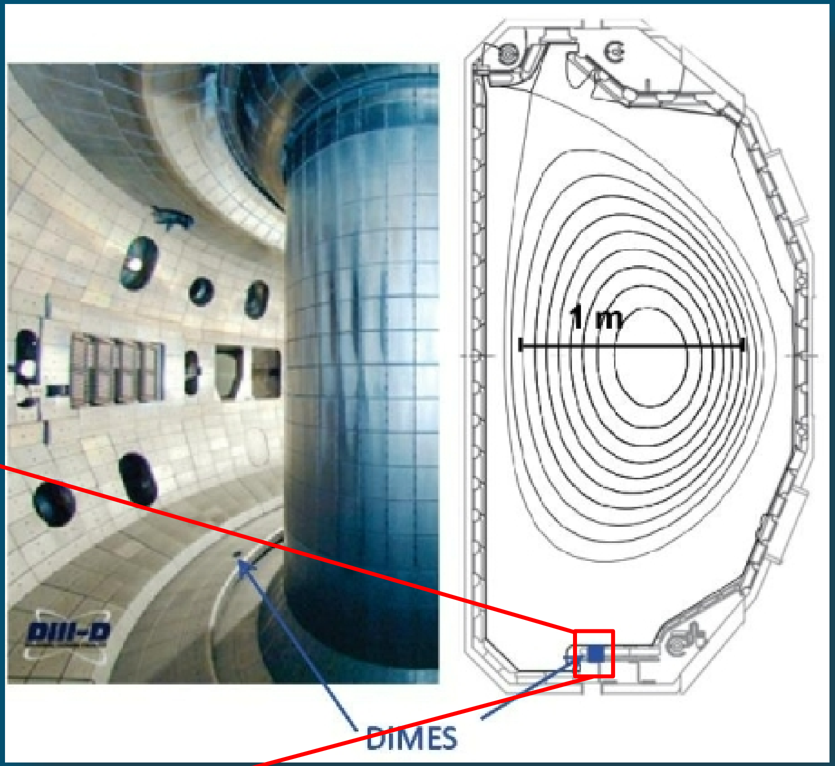


Sensors were tested at DIII-D tokamak in piggyback experiments (June 2021)

Sensors were mounted in Divertor Material Evaluation System (DiMES) and tested over several days

- Test of sensors and data collection system in the tokamak environment
- Same gold thickness on each sensor (7 nm Au)





Adapted from:
Rudakov D., et al., Fusion Eng. Des., 124 (2017), pp. 196-201

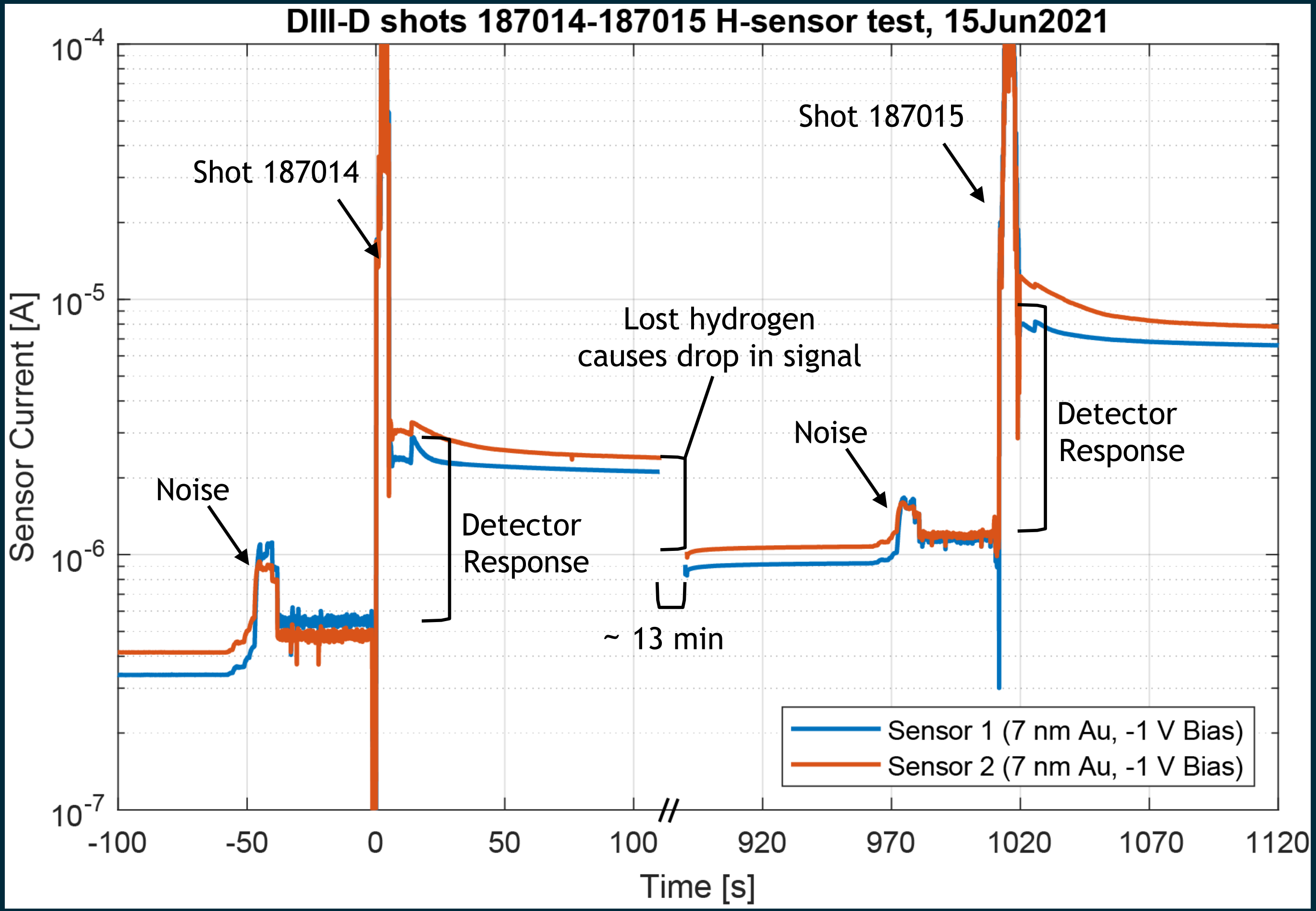
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Sensors were successfully demonstrated in tokamak environment

Sensors exposed to ~ 27 plasma shots over 2 days*

- Saturation after ~ 3 H-mode shots in USN configuration – strong signal!
- Demonstrated sensor regeneration with thermal cycling
- Nearly identical response from pair of sensors in USN configuration before saturation

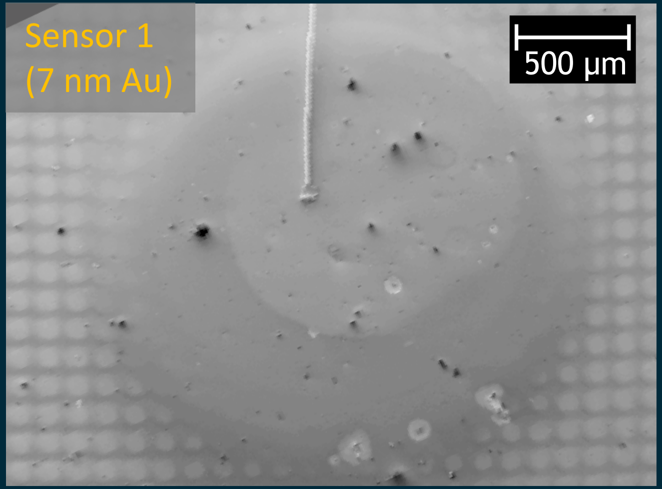
If we assume 500 eV thermal c-x particles: ~ 5 x 10^{14} D/cm^2 s

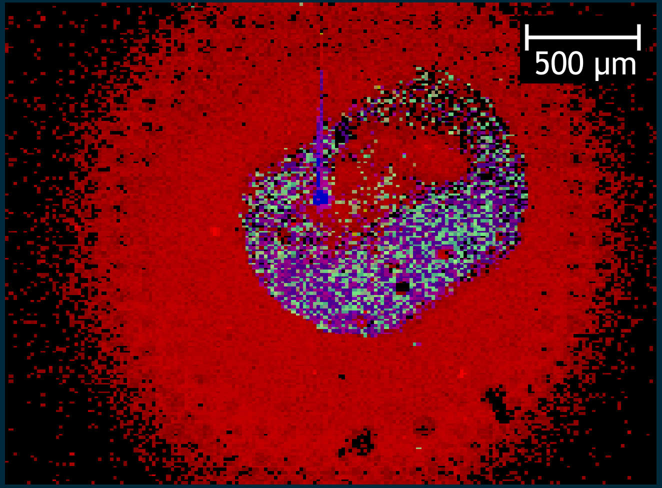


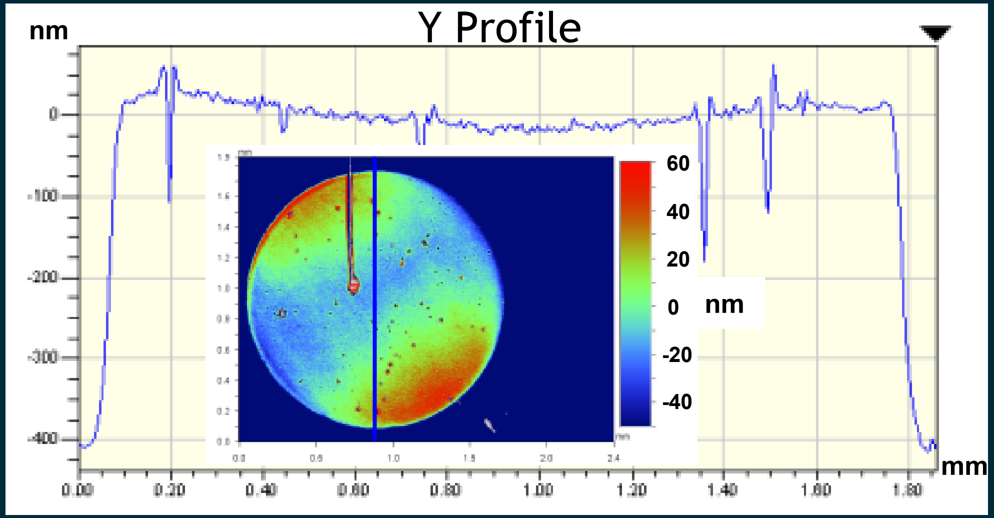
H-sensor data from consecutive USN plasma shots in DiMES, starting from regenerated state

* Special thanks to Huiqian Wang for allowing us to piggyback during his experiment

Post-exposure analysis shows signs of deposition/re-erosion



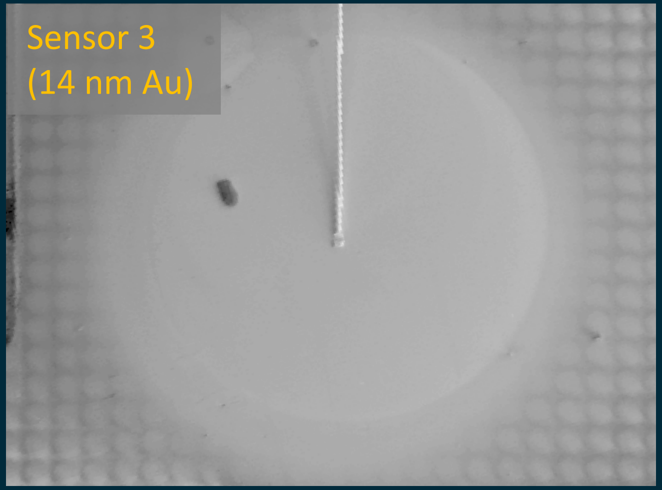


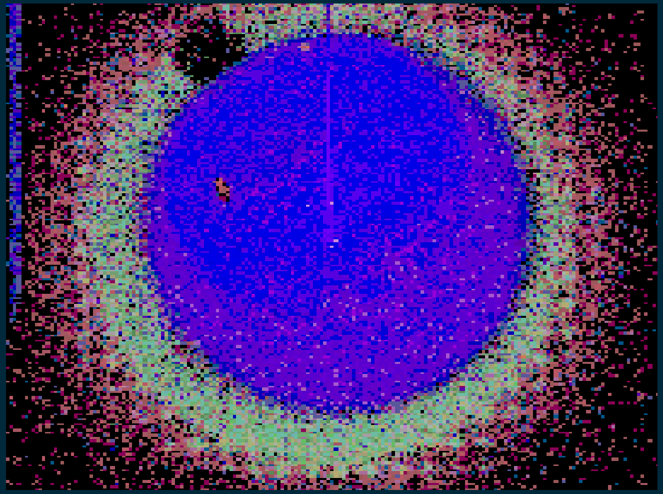


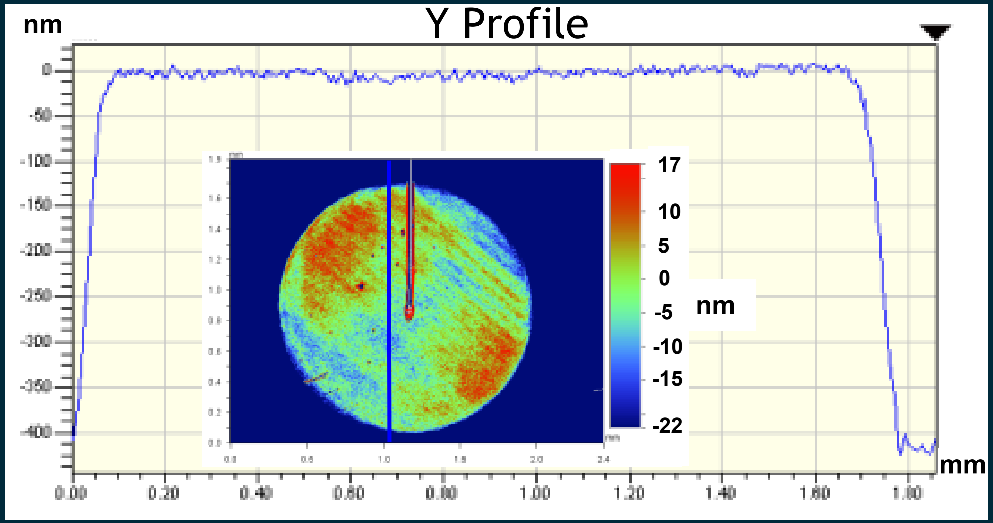
Scanning electron microscopy

Auger microscopy (**Carbon** **Palladium** **Gold**)

Optical profilometry







Conclusions

Successful demonstration at DIII-D paves way for future development and testing

H-sensor summary

- Ruggedized H-sensors have been developed for resilience to high energy particles
- Sensors were demonstrated in DiMES at the DIII-D Tokamak withstanding ~27 plasma shots

Future H-sensor work

- Explore optimization of adhesion layer
- Continue laboratory testing of sensors
- Further testing at DIII-D
  - Measurements of shot-to-shot energy distribution and fluence
  - Resolve poloidal distribution of CX flux
  - Integration into WITS station
  - Integration into wall tiles

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