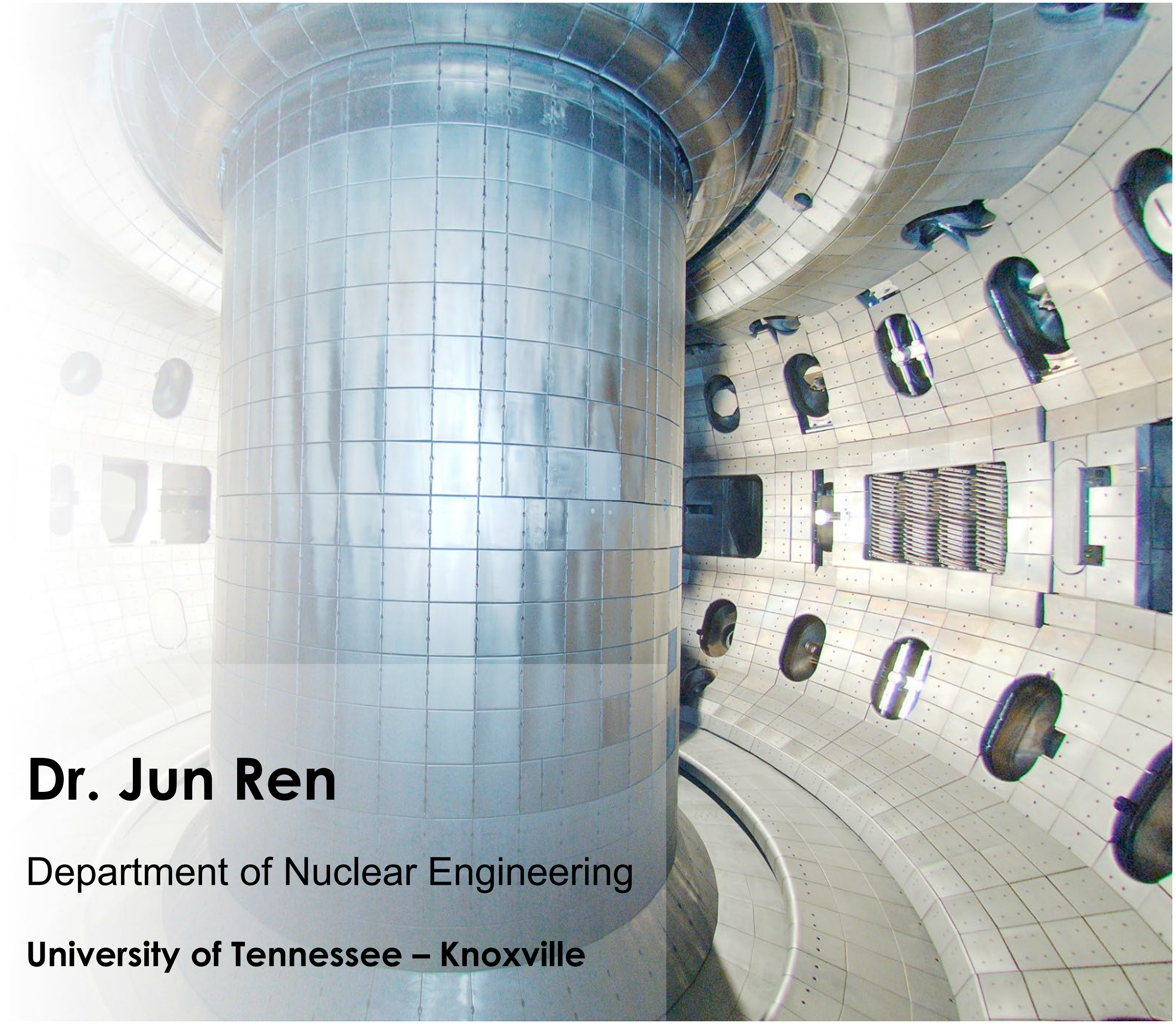
Advancing self-renewing high temperature sensor for fusion applications



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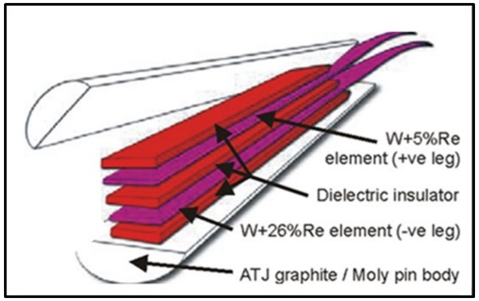
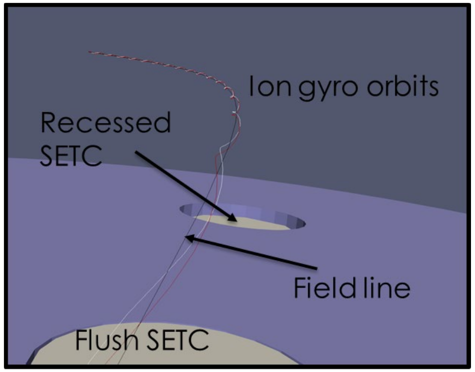
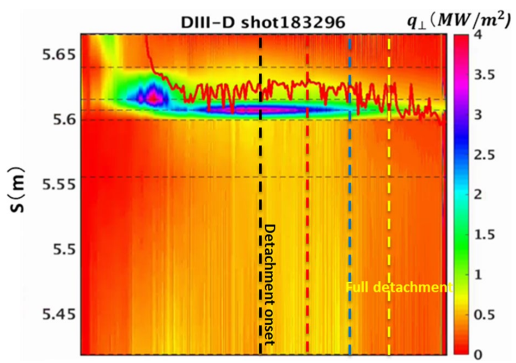
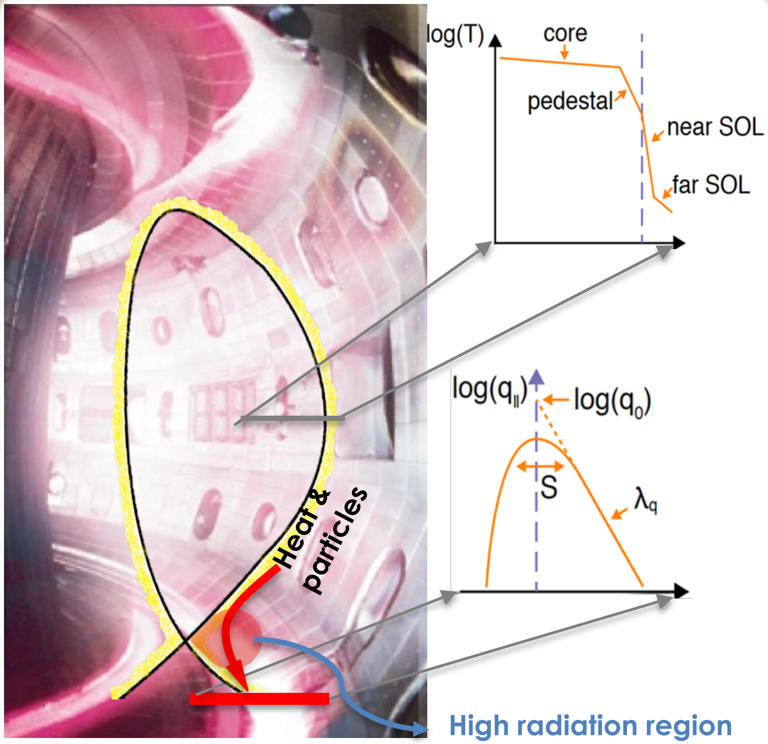
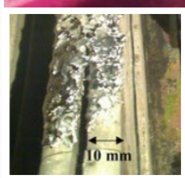






Surface Eroding Thermocouple is a reliable thermal sensor for fusion industry and beyond

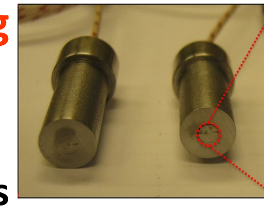


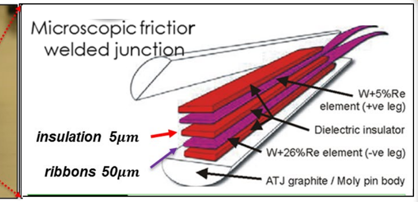


Melt damages and erosion of tungsten in fusion device

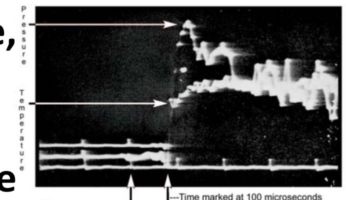
Needs: Reliable diagnostics is important to ensure device security and optimize heat flux management in the fusion device

The Surface Eroding Thermocouples SETCs

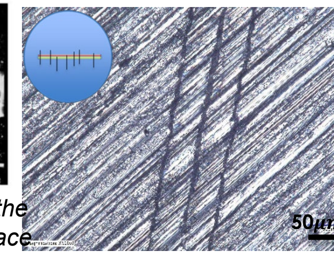




-The thermojunction is directly on the surface, fast response



oscilloscope screen shot of the pressure and temperature trace



-Self-renewing surface is resistant to highly eroding environments

Collaboration with NANMAC Corporation (Foremost in Temperature Measurement™)

Commonly used in igniters, internal combustion engines, rocket and aerospace systems, and manufacturing processes, this technology is now finding new applications in the fusion industry

SETC has been used for multiple applications in DIII-D

- *Machine Security*
- *Heat flux characterization*
- *Divertor Detachment*
- *Feedback control*

✓ Standard Type-C junction

✓ High temperature : up to 2320℃

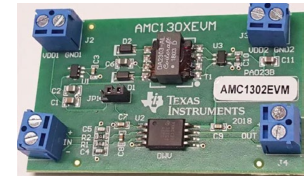
✓ Fast thermal response : < few ms

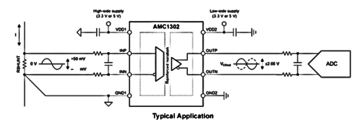
✓ High spatial resolution : < 1 *mm*

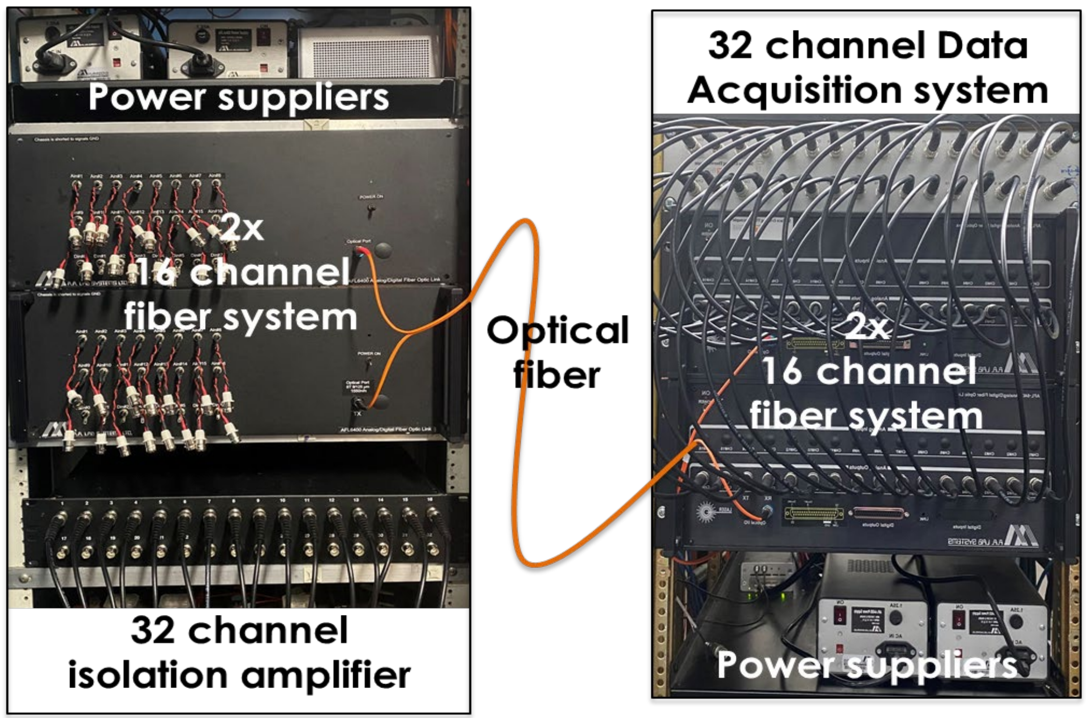
The newly developed SETC measurement and processing system have been established in DIII-D

Example of SETCs installed in the DIII-D

- **Identify mounting tile design and simplified mounting mechanism**
- **Analog fiber optic link signals at 200kHz sampling rate and 25kHz bandwidth**
- **isolation amplifier system with low error and drift**

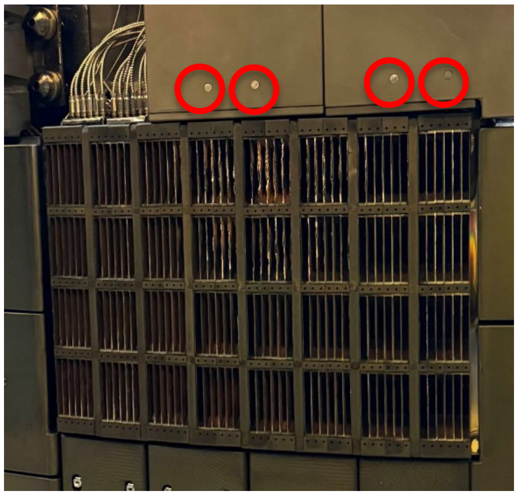




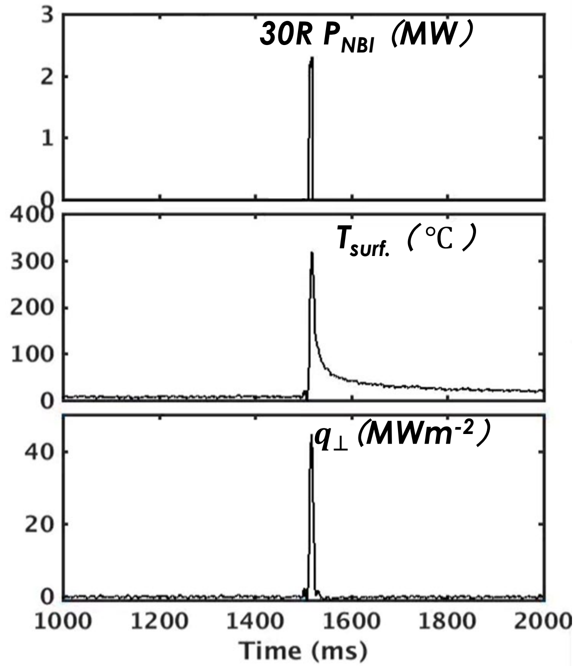


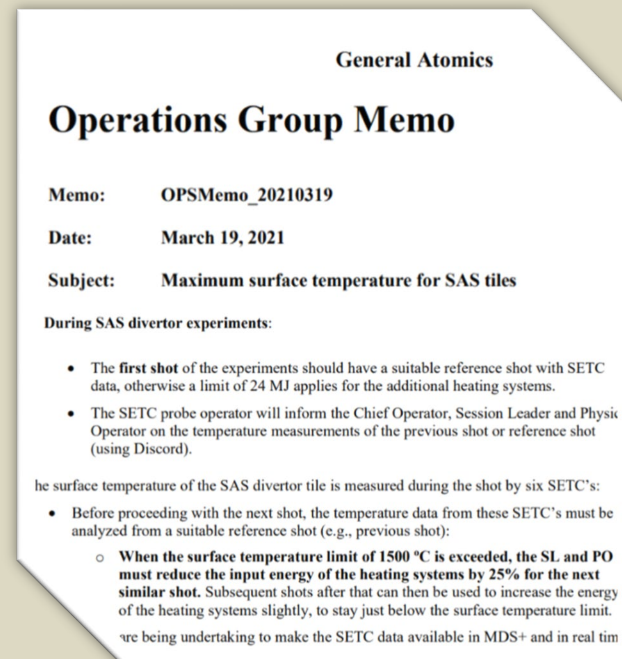
Enables direct quantification of surface temperature and heat flux, which is critical for maintaining machine integrity and operational

●Fast response time ● High maximum temperature capability ● Reliable performance in harsh environments



The SETCs installed on the LHCD tile





General Atomics

Operations Group Memo

Memo: OPSMemo_20210319

Date: March 19, 2021

Subject: Maximum surface temperature for SAS tiles

During SAS divertor experiments:

- The **first shot** of the experiments should have a suitable reference shot with SETC data, otherwise a limit of 24 MJ applies for the additional heating systems.
- The SETC probe operator will inform the Chief Operator, Session Leader and Physic Operator on the temperature measurements of the previous shot or reference shot (using Discord).

he surface temperature of the SAS divertor tile is measured during the shot by six SETC's:

- Before proceeding with the next shot, the temperature data from these SETC's must be analyzed from a suitable reference shot (e.g., previous shot):
  - **When the surface temperature limit of 1500 °C is exceeded, the SL and PO must reduce the input energy of the heating systems by 25% for the next similar shot.** Subsequent shots after that can then be used to increase the energy of the heating systems slightly, to stay just below the surface temperature limit.

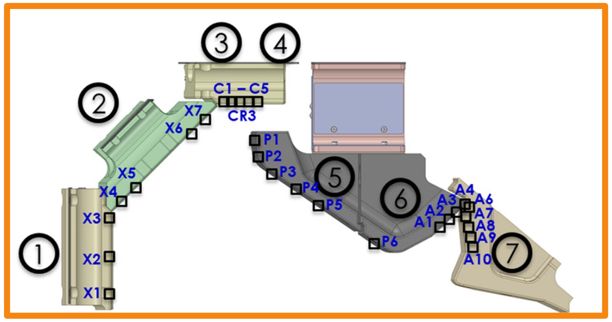
are being undertaking to make the SETC data available in MDS+ and in real tim

SETCs are essential for ensuring machine safety during DIII-D operations by preventing plasma-induced thermal damage and mechanical failure due to thermal stress.

- **Successfully captured the shine-through heat flux from the 30R NBI based on the temperature measured by SETC.**
  Over 300 ℃ temperature increase in few millisecond
- **Provide valuable insight into power deposition management**
  - *Strong dependence on the plasma density*
  - *Extreme heat flux within gas shot*

Multiple measuring point array provide detailed temperature map at important locations

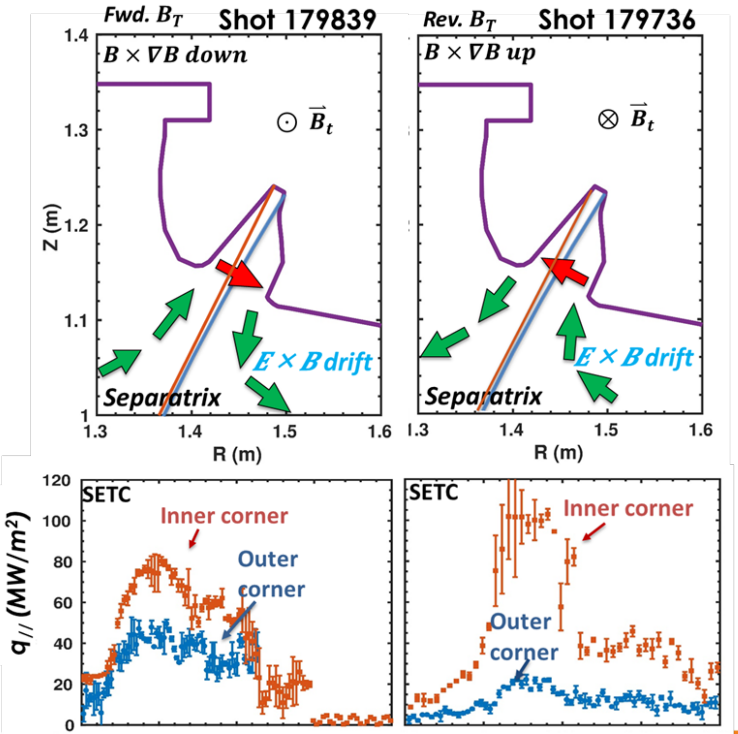
High-density, high-spatial-resolution SETC array resolves surface temperature and heat flux profiles for analysis and physics studies.



Example of heat flux profile in DIII-D divertor surface :

- $B \times \nabla B$ away from SAS
- $\boldsymbol{E} \times \boldsymbol{B}$ drift enhances neutral build-up near the outer corner of SAS divertor
- Peak heat flux near outer corner is 50%~100% lower than that at inner corner

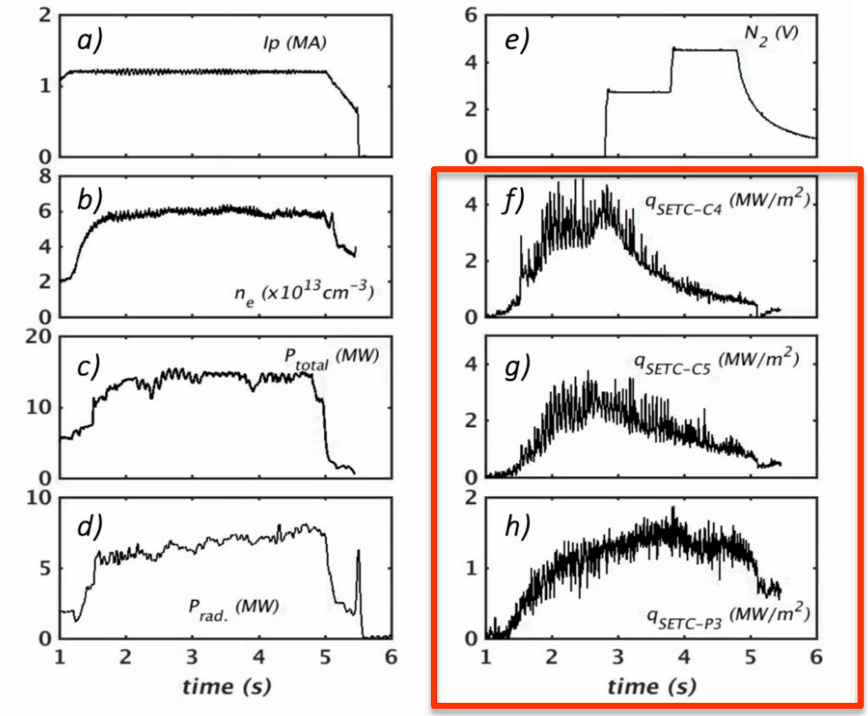
- $B \times \nabla B$ towards to SAS
- $\boldsymbol{E} \times \boldsymbol{B}$ drift drives the particles away from vertical target, SAS geometry further limits the incoming particles
- Extremely low heat flux at outer corner, higher heat flux near inner corner due to the drift



Fast-response SETCs enabling the study of rapid physical processes

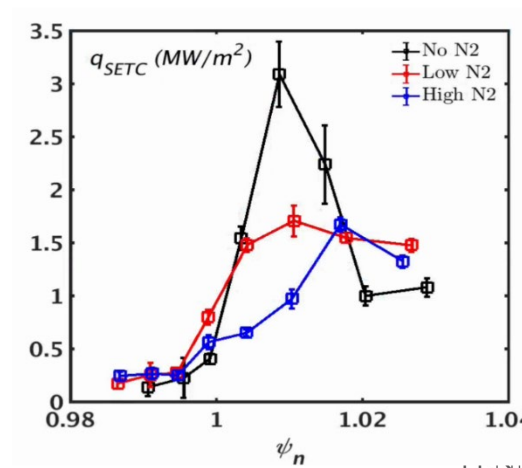
The high-temporal-resolution SETC array records the evolution of critical temperature and heat flux, which is essential for understanding the mechanisms of rapid physical or industrial processes.

$I_p = 1.2$ MA, $n_e = 6 \times 10^{13}$ cm^{-3}, $P_{total} = 14.5$ MW



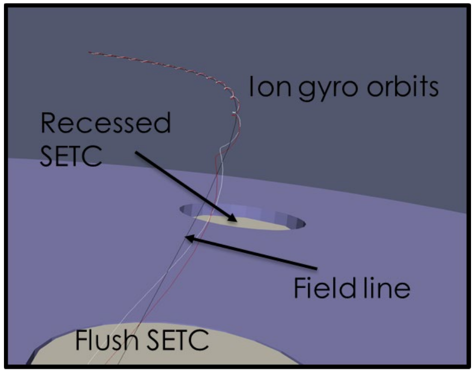
Example of heat flux evolution in DIII-D during the divertor detachment:

- **Two step Nitrogen puffing induced detachment**
- **Heat flux at near SOL began to decrease at the first stage N_2 puffing**
- **Heat flux at the far SOL, did not decrease until the stage 2 puffing(SETC-P3)**
- **Peak hear flux 80% reduction at OSP (SETC-C4)**

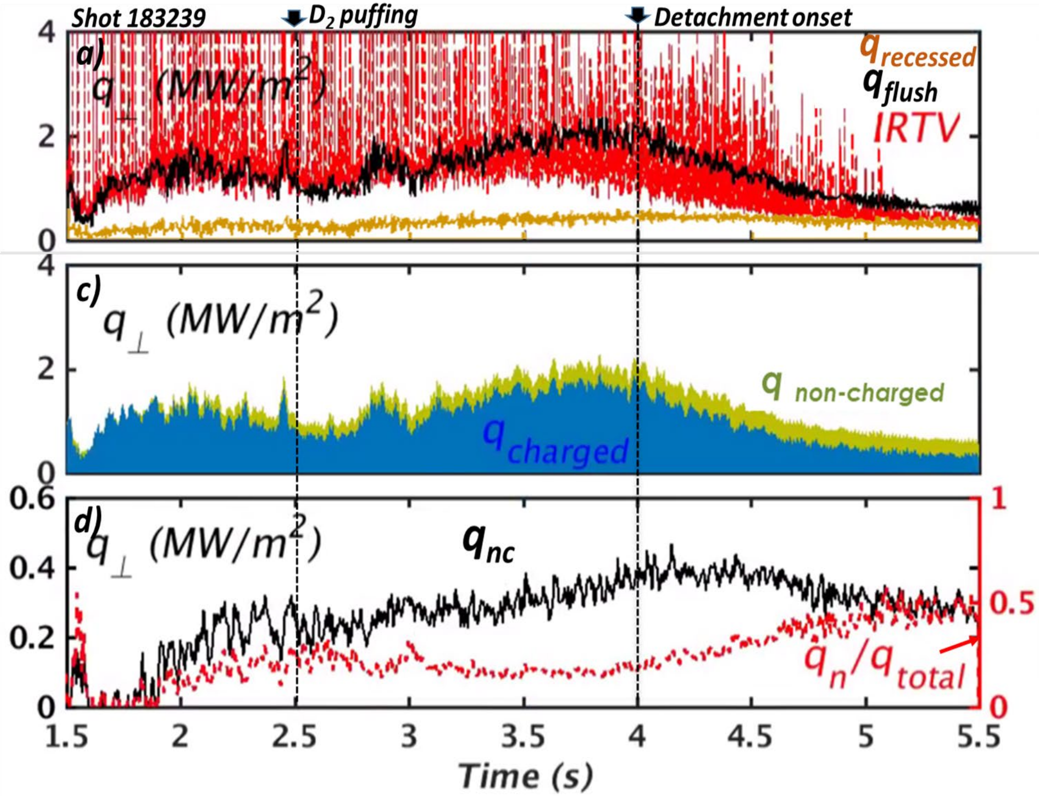


The novel application of SETCs in DIII-D enables estimation of heat flux derived from radiated power

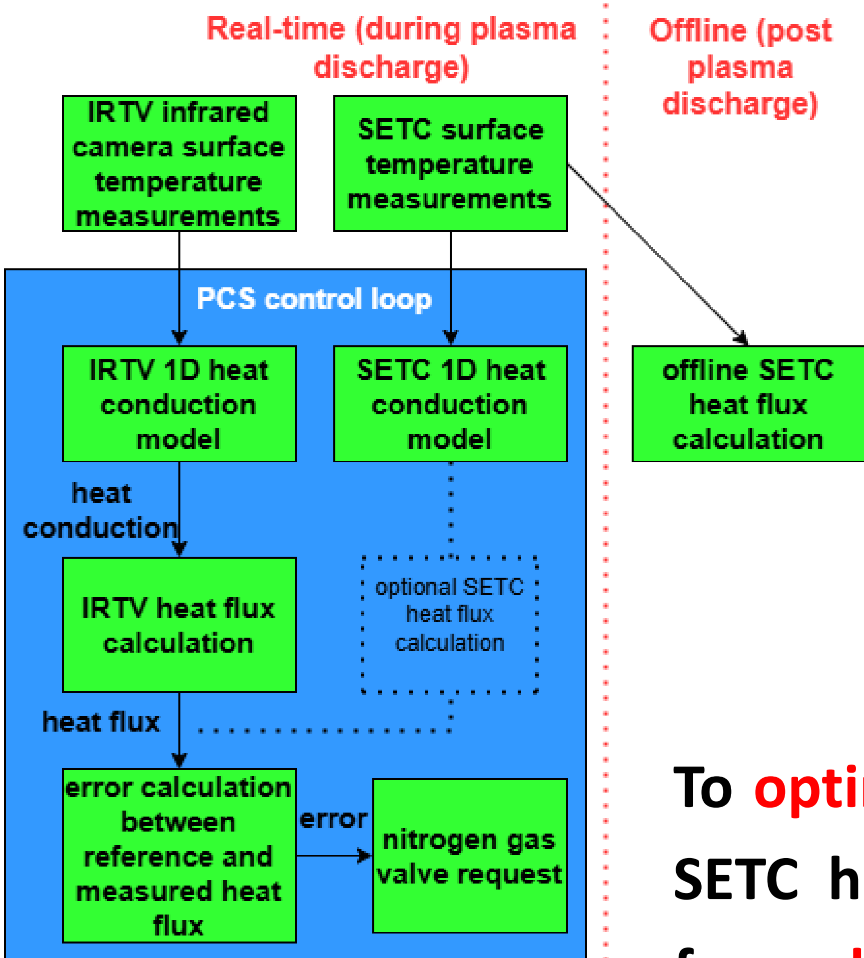
The combination of recessed and flush SETCs at specific locations can distinguish the heat flux carried by neutral particles from that by charged particles.

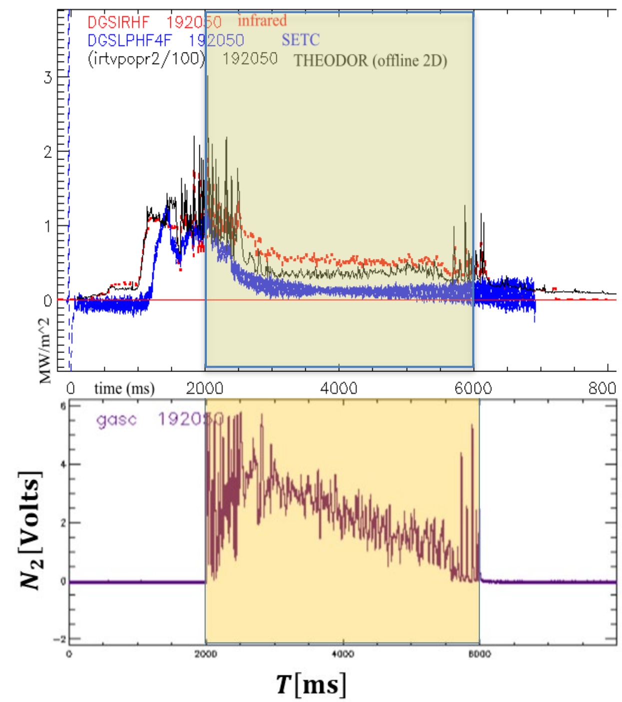


- ❑ The recessed SETC significantly reduced the direct line-of-sight exposure of the sensor to the magnetic field lines
- ❑ The volumetric radiation and kinetic neutrals are close to isotropy in divertor region
- ❑ The fraction of heat flux from non-charged particles significantly increase after detachment onsite.



SETC has been developed for real time feedback control





To **optimize heat flux management**, the SETC has been developed as a sensor for **real-time control**.

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Outlook

Advancing fusion technology readiness

- Offers a practical diagnostic solution adaptable for reactor-grade divertor and first-wall modules
- Bridges experimental research and reactor engineering through robust, high-temperature instrumentation
- Suitable for training AI based modeling, digital twin and predictive control

Material qualification and lifetime assessment

Quantify surface temperature response and erosion behavior for plasma-facing materials under transient and steady-state conditions.

Liner machine, plasma source ,laser induced damage

Other High-temperature industrial applications

Thanks!

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