3rd IAEA Technical Meeting on Plasma Disruptions and their Mitigation

Characterization of transient heat flux induced damages of tungsten PFCs during plasma disruption in EAST

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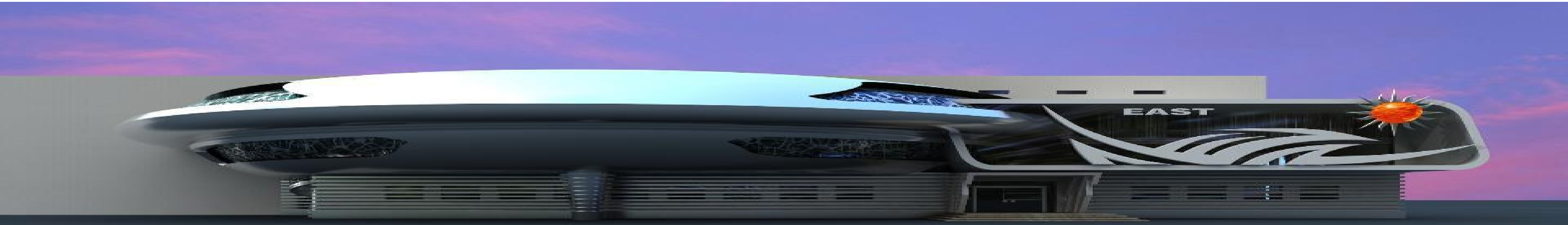

3-6 Sept 2024, IO Headquarters

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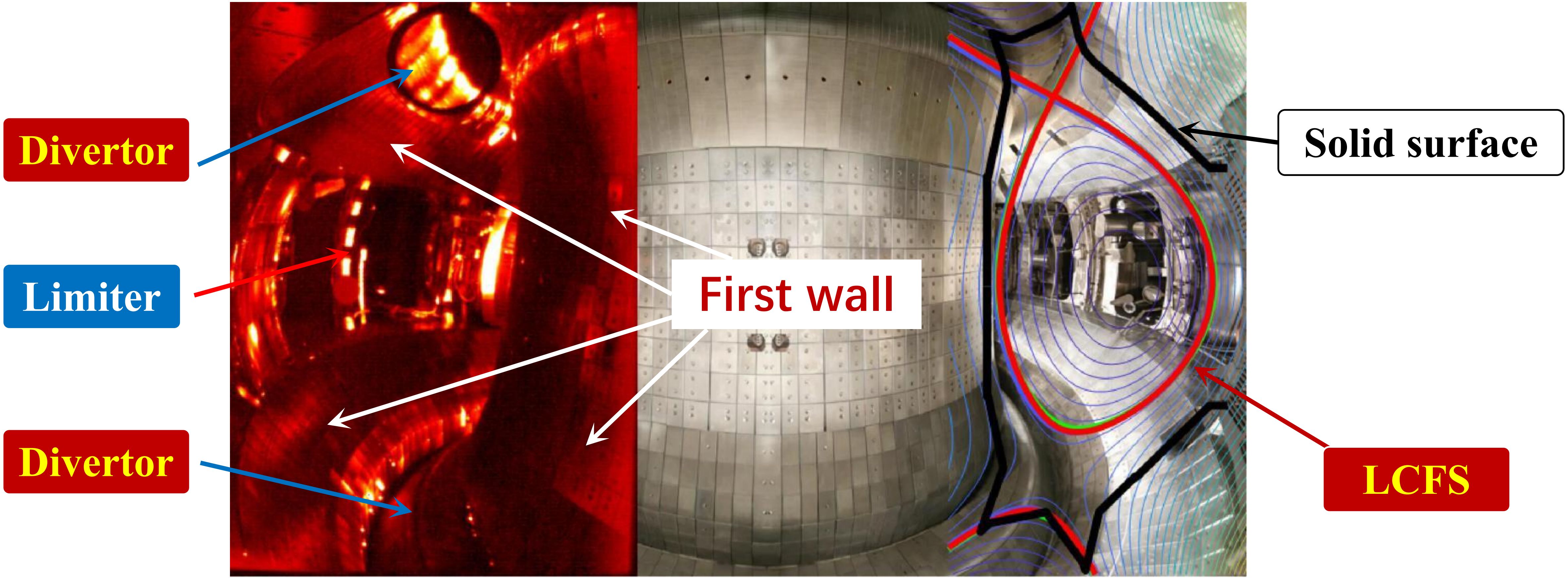
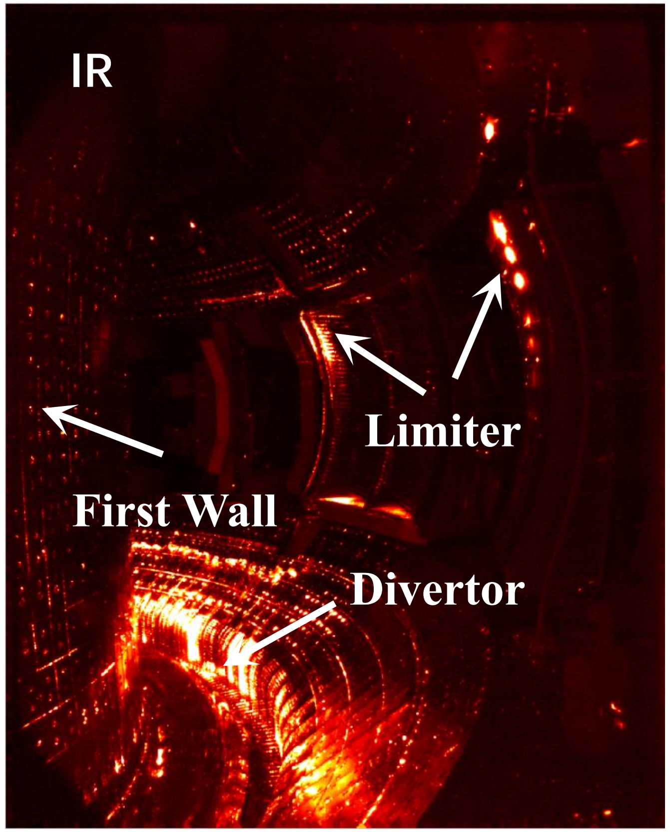
Plasma facing components in fusion devices



- Plasma facing components (PFCs, including divertor, limiter and first wall) directly face the plasma
- PFCs are subjected to the strong irradiation (heat loads, particle fluxes, neutrons)

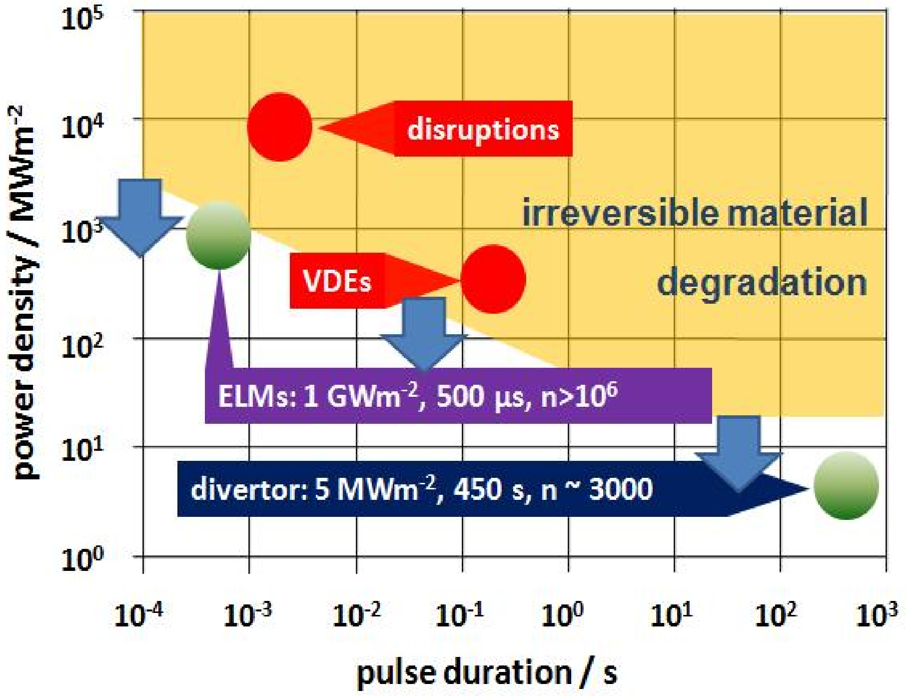
High heat loads on PFCs

normal



off-normal

◆ Steady-state heat flux ◆ Transient heat flux

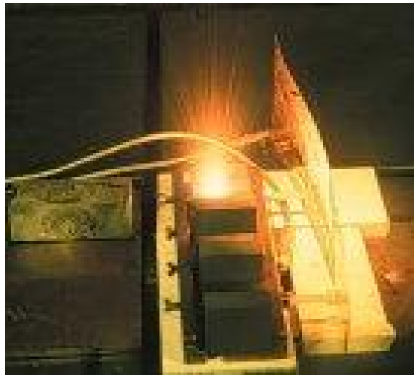


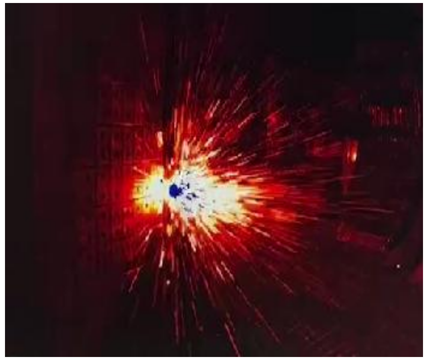
J. Linke, ITPA Div/SOL meeting, Jülich, 16-19. 01. 2012

PFCs are subjected to extremely high heat loads in fusion devices

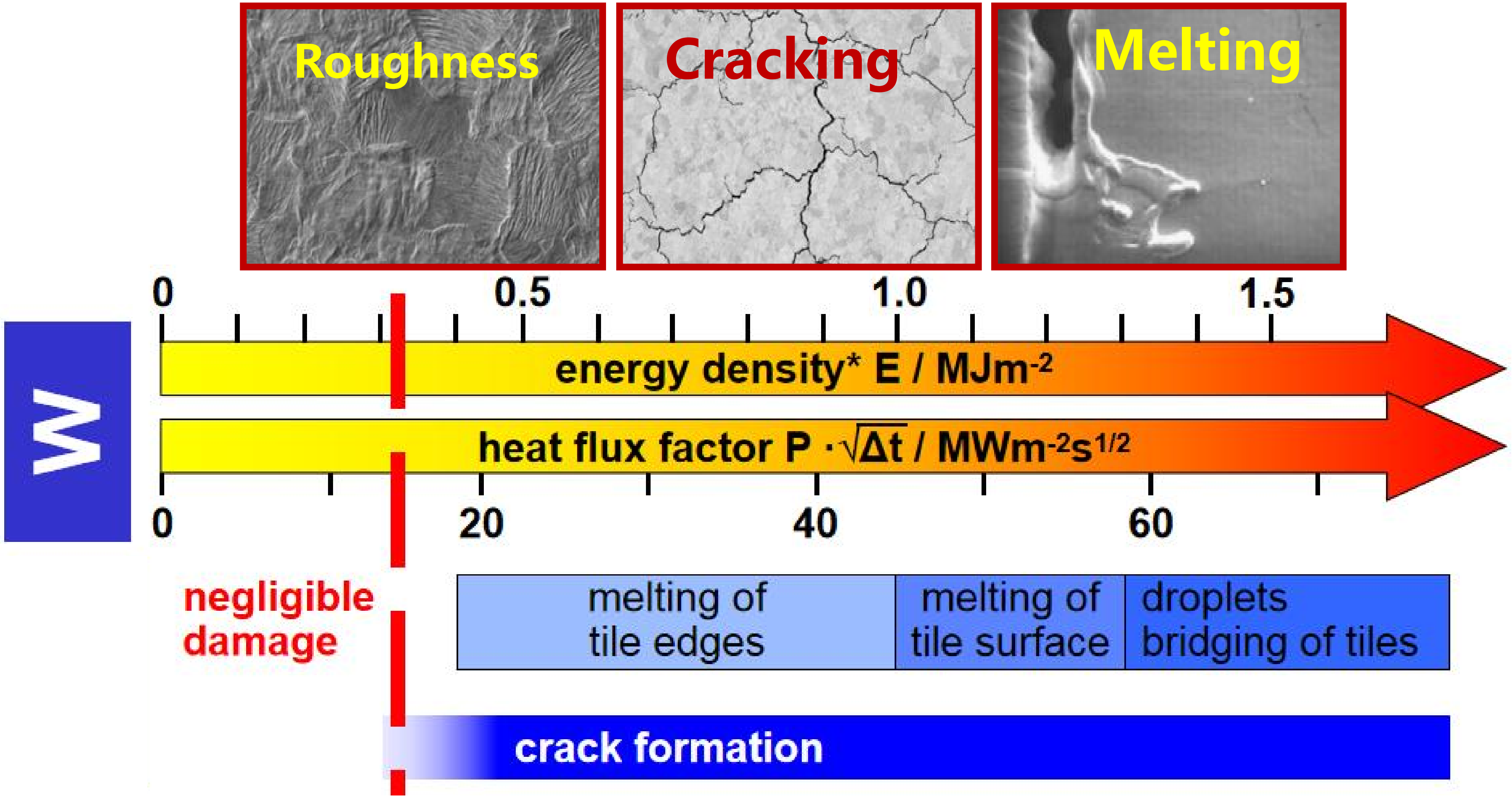
Transient heat flux induced damages

E-beam test





Tokamak event



J. Linke, 16thICFRM, Beijing, China, 20-26. 10. 2013

PFCs are expected to occur roughness, cracking and melting under extremely transient heat loads in fusion devices

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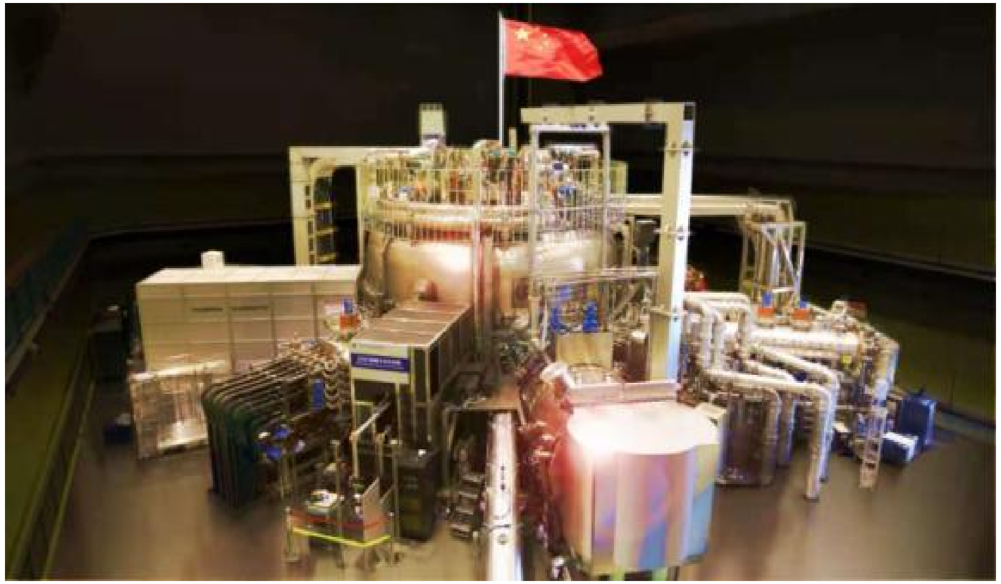
EAST fully superconducting Tokamak

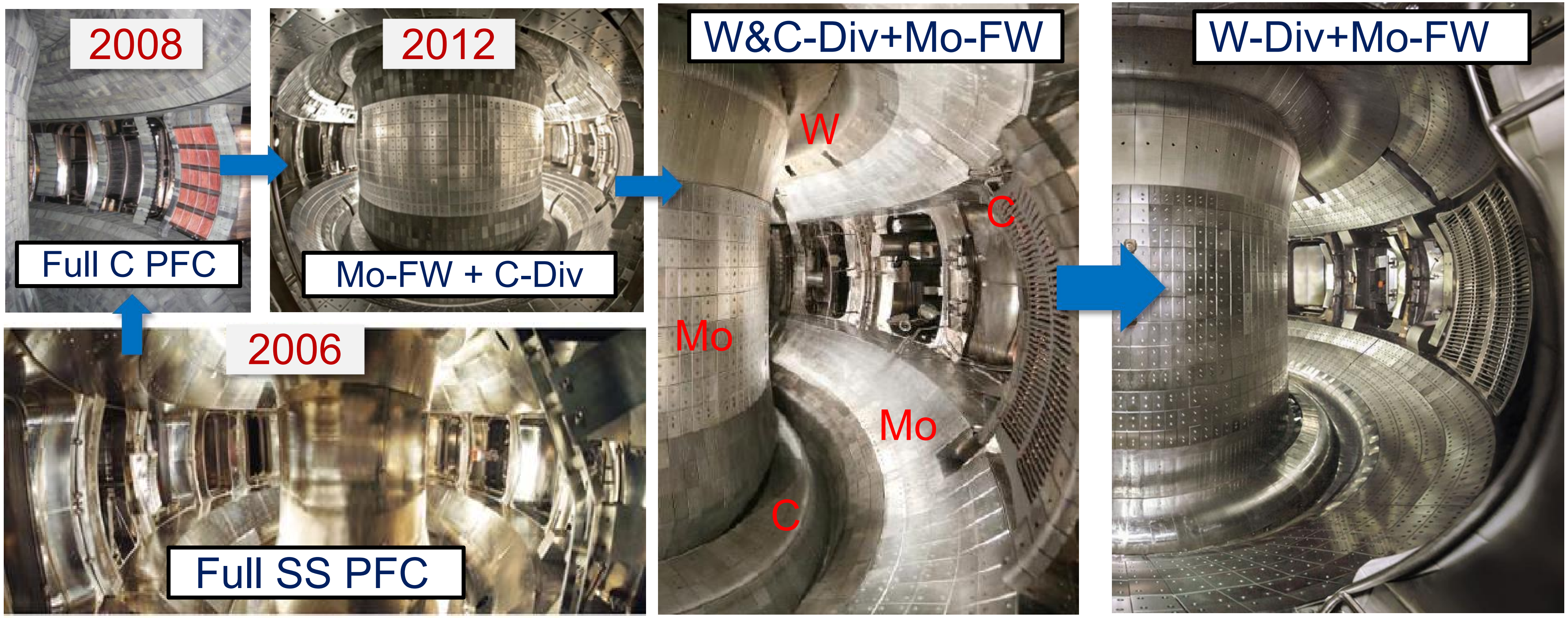


To realize the advanced long pulse steady-state operation (SSO) and provide scientific basis for the design, construction and experimental operation of ITER, BEST and CFETR

➔ An **open platform for steady-state** high performance plasma operation

PFCs in EAST

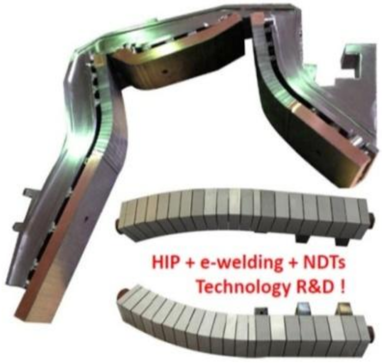
The PFCs in EAST were upgraded several times. Now, it has the ITER-like metal wall.



1st plasma **2014** **Now**

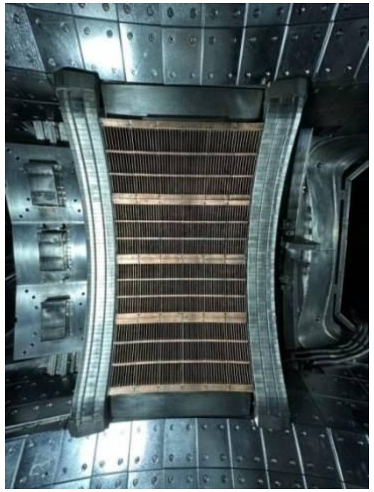
Metal PFCs in EAST

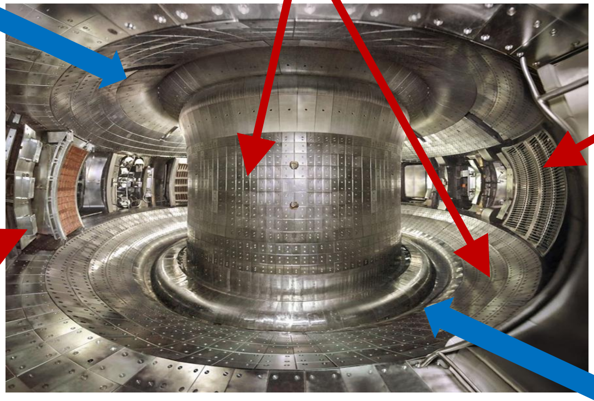
Upper W cassette module



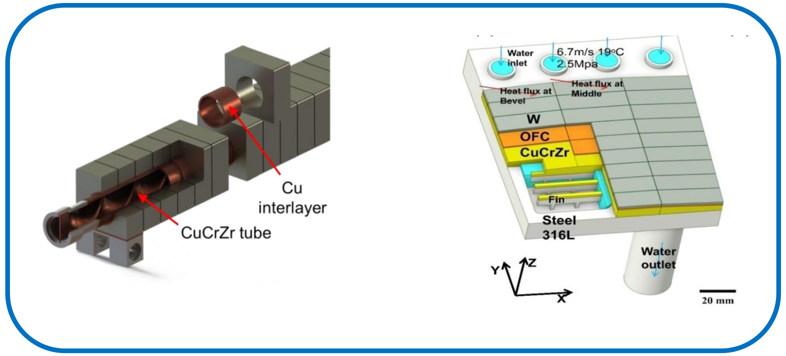
TZM tile for first wall

Guard W limiter

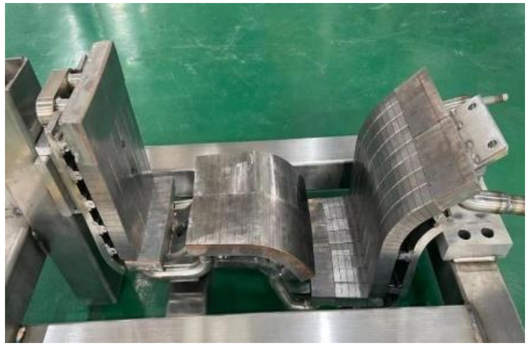




Main W limiter



Lower W cassette module



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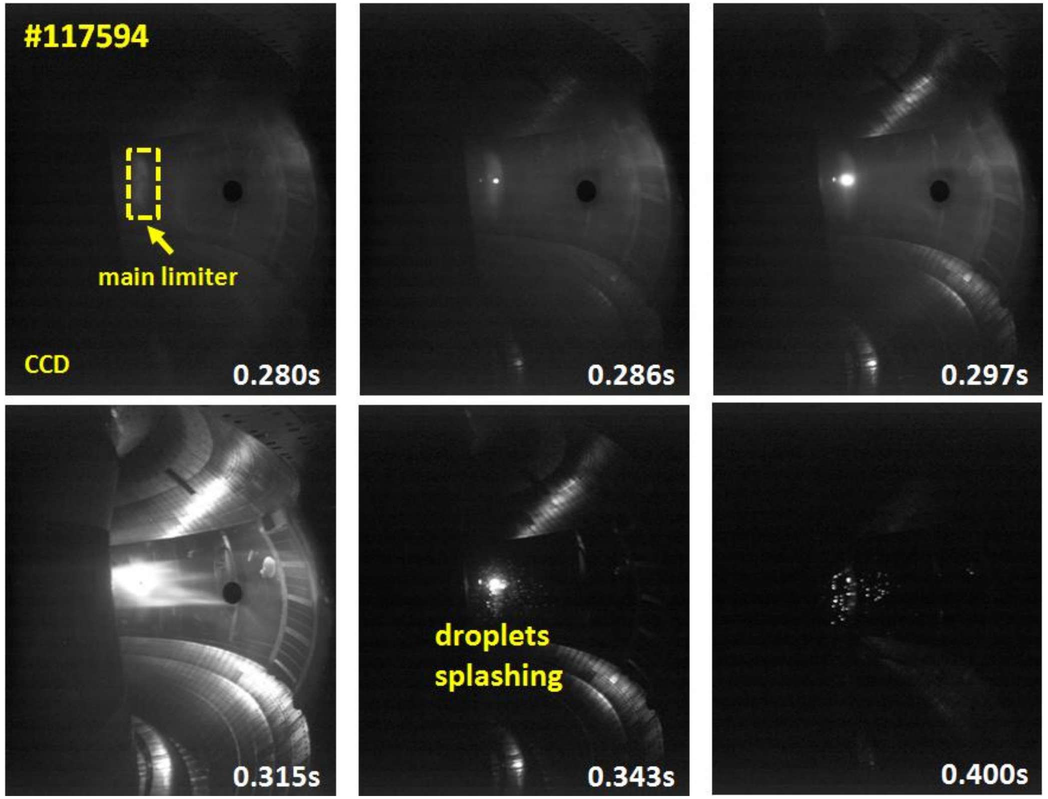
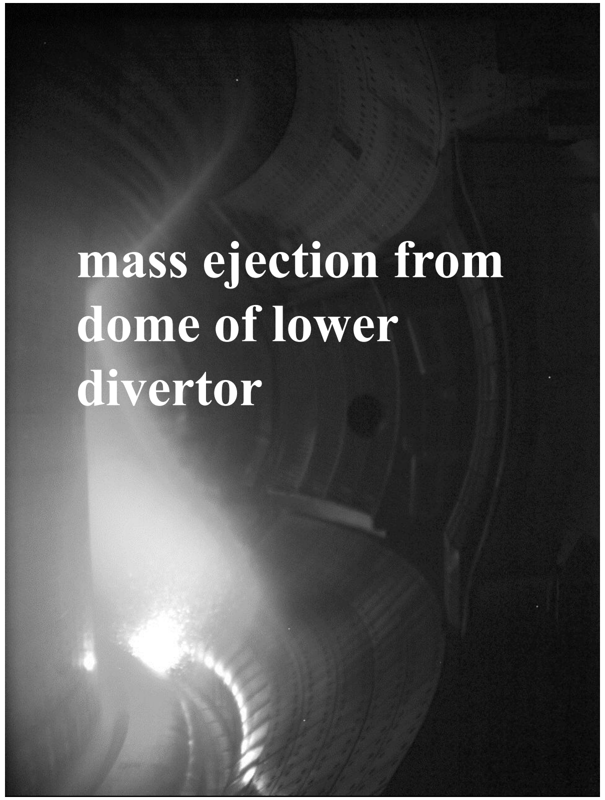
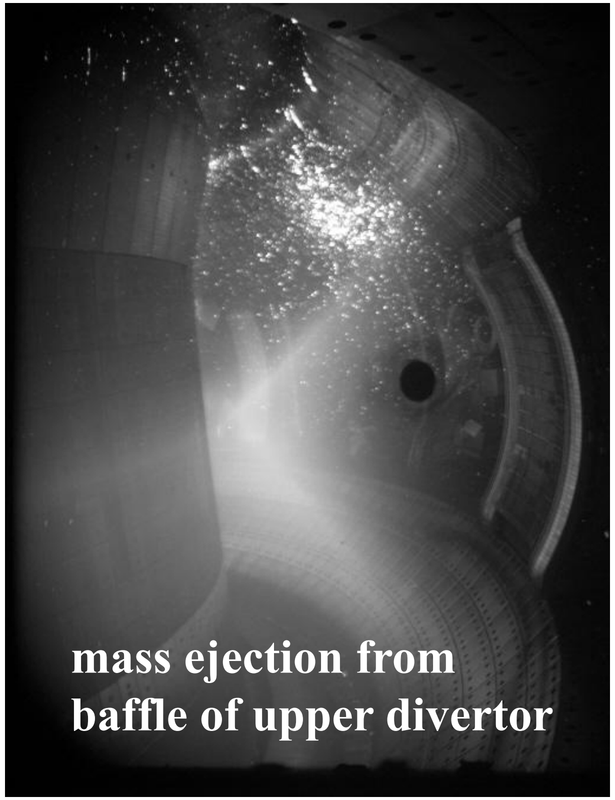
Observation of disruption induced splashing of PFC



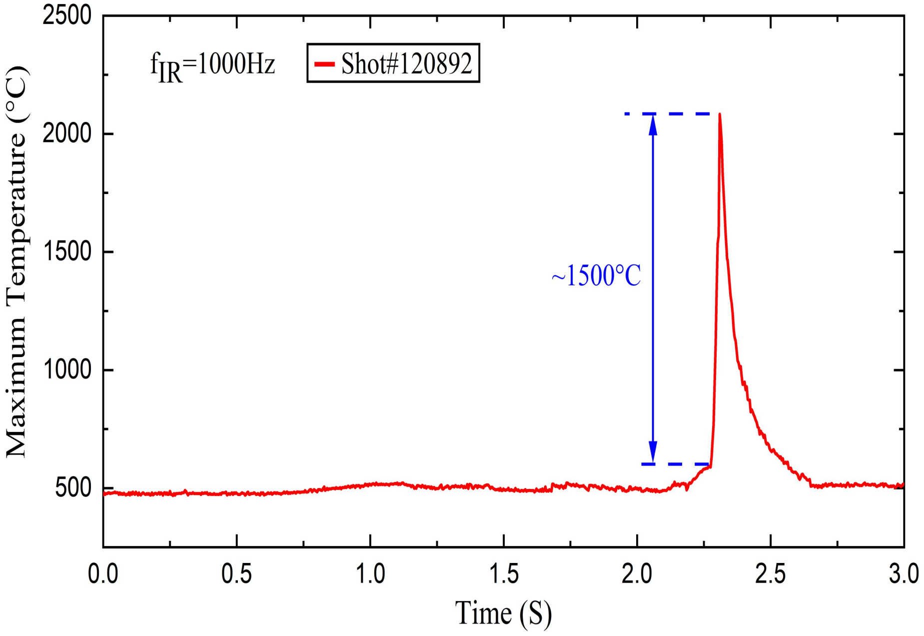




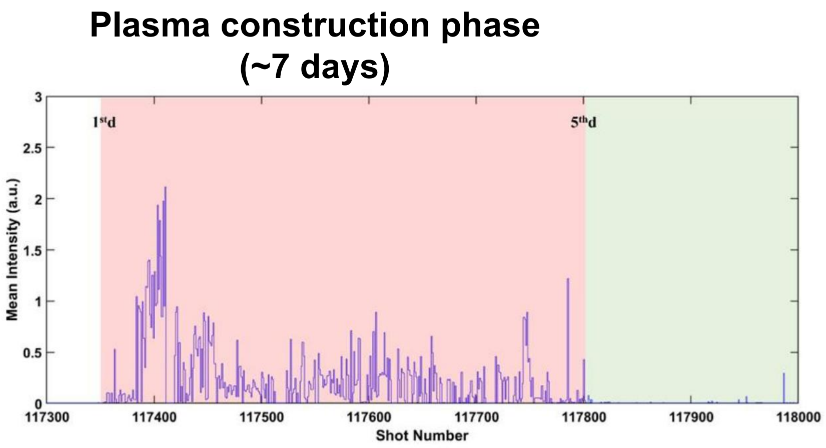
- **Mass ejection/Splashing** from main limiter when disruption events occurred was repeatedly monitored by CCD camera during plasma startup phase in each plasma campaign
- Same phenomena were also found on the dome and baffle of divertor, and the first wall

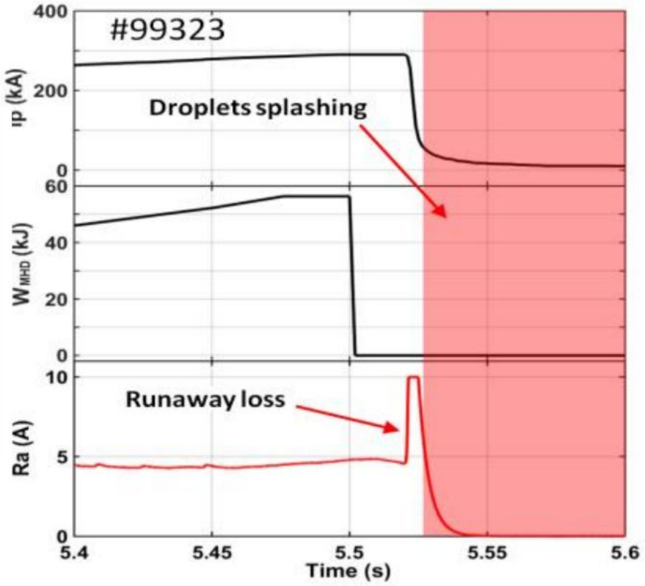
Analysis and confirmation of such transient events

IR temperature evolution



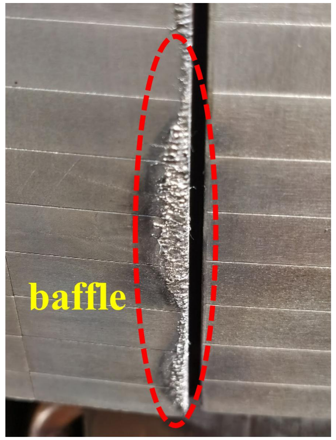
Runaway electron behaviors

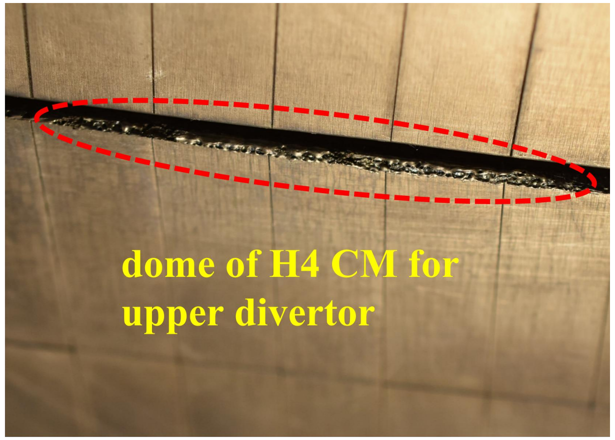


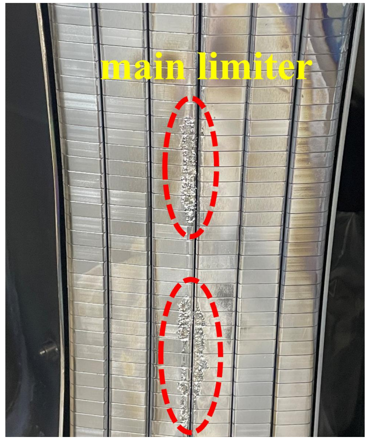


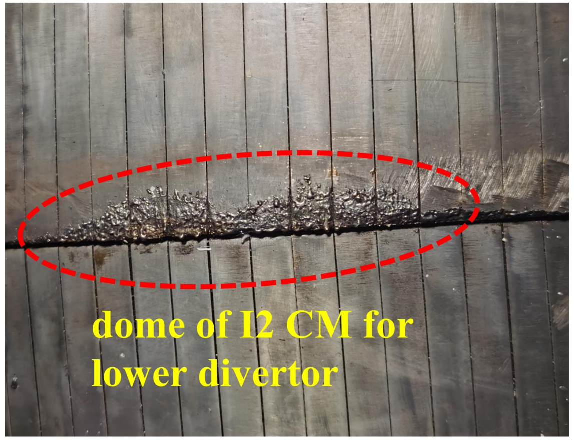
- IR temperature evoluation confirmed it was **a transient heat loading effect**
- The time of runaway electron loss mathchs well with the time when the splashing occured
- **Multiple runaway electron loss events** often occurred at the initial phase with plasma construction

Post mortem inspection of transient heat flux induced damages





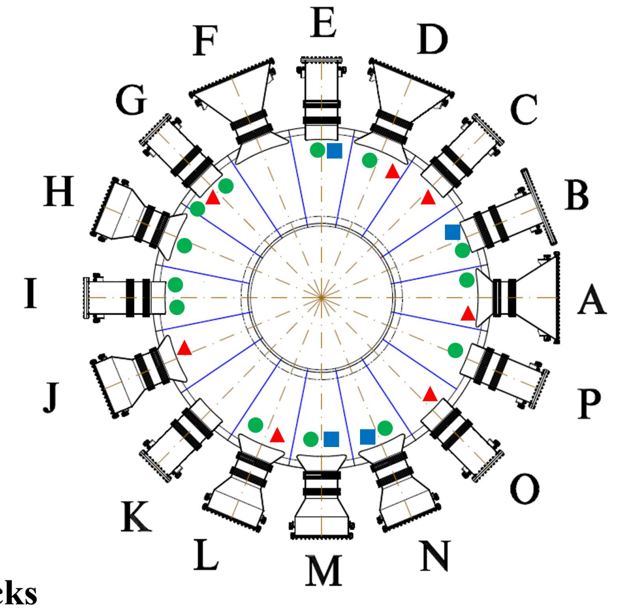




● PFCs which melted

■ PFCs with macrocracks

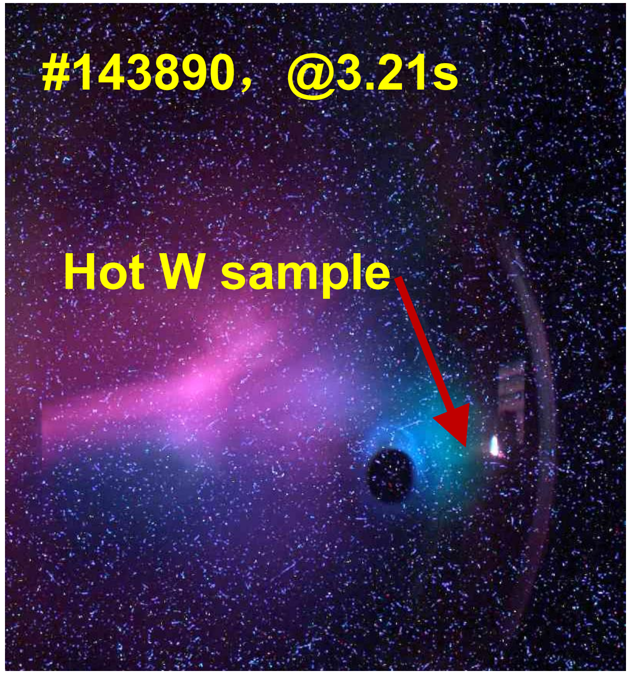
▲ Melted PFCs with macrocracks

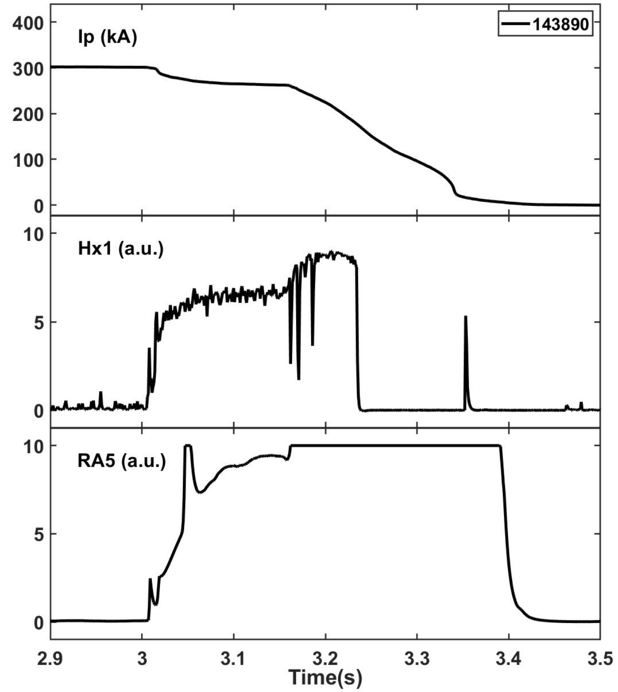


- Multiple PFCs transient heat flux induced damage, including melting and cracking were found universally
- Damages often occur on the leading edge area, and the protruded part

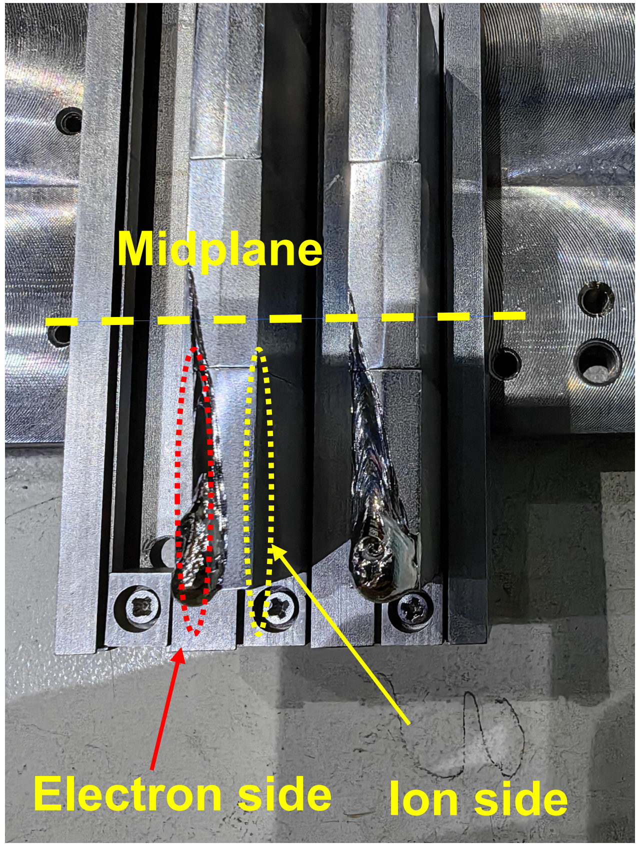
Actively-induced melting experiments

REs in MGI-triggered disruption





REs plateau(~300ms)



- **Actively-induced melting by REs during MGI-triggered disruption was successfully performed using MAPES during 2024 EAST spring experimental campaign**

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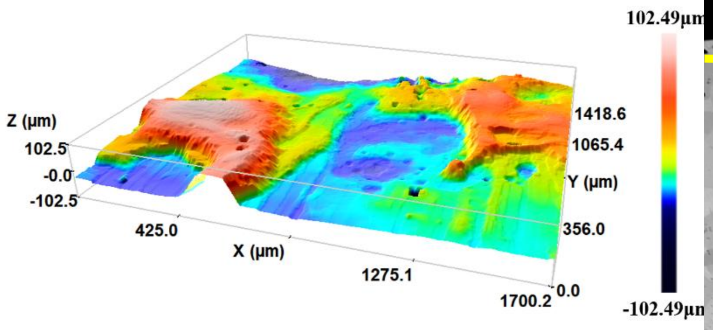
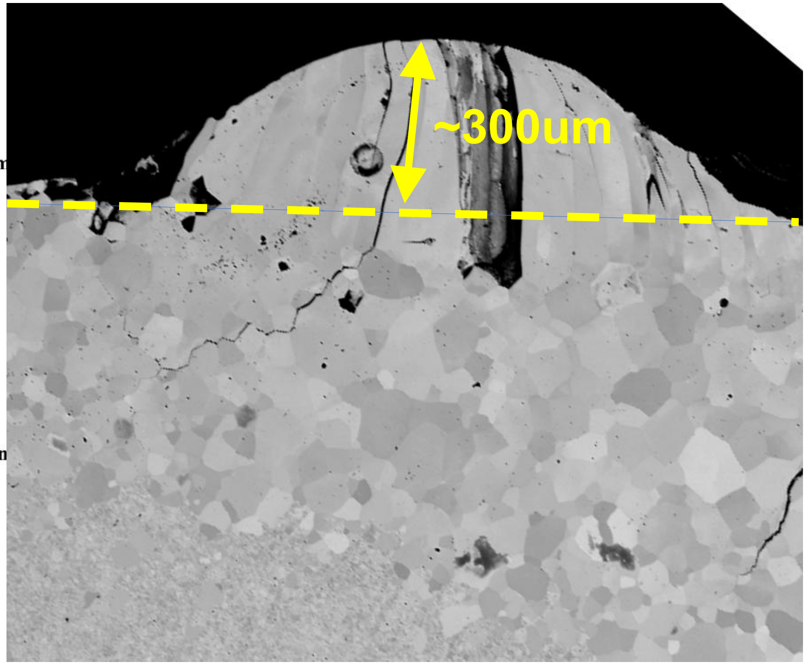
4.1 Rough surface morphology

Rough surface

Dome **Limiter**

3D profile

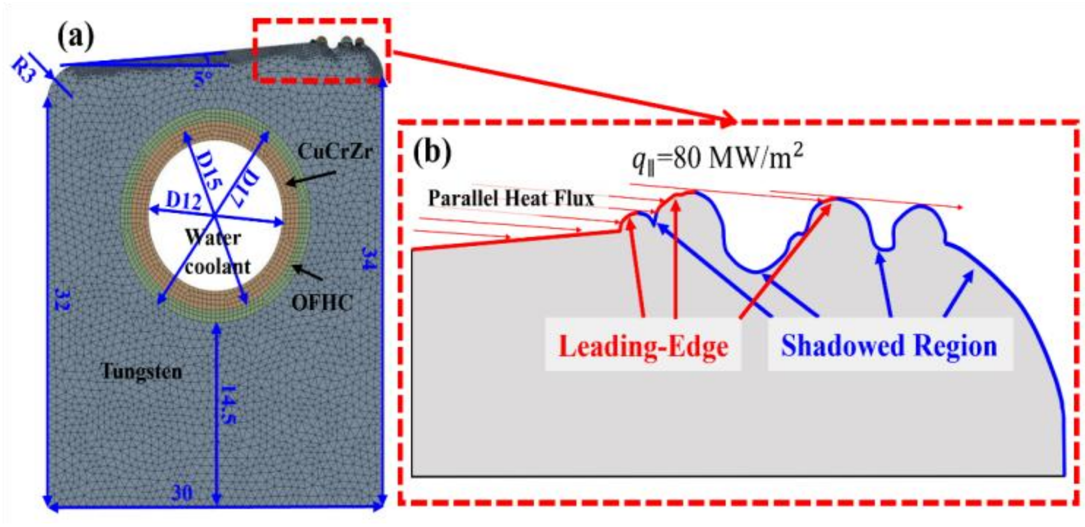




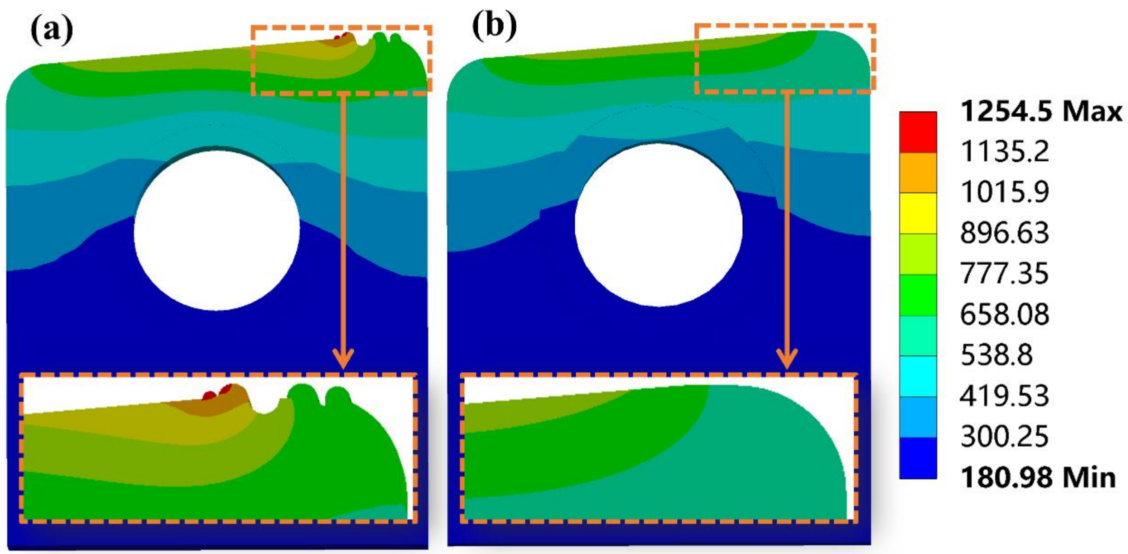
- Transient heat flux induced melting often leaves a rough (wave) surface
- Typical particles were protruded with a height 0.2 mm~0.5 mm

Rough morphology imposed leading edge issue

Rough surface & parallel heat flux



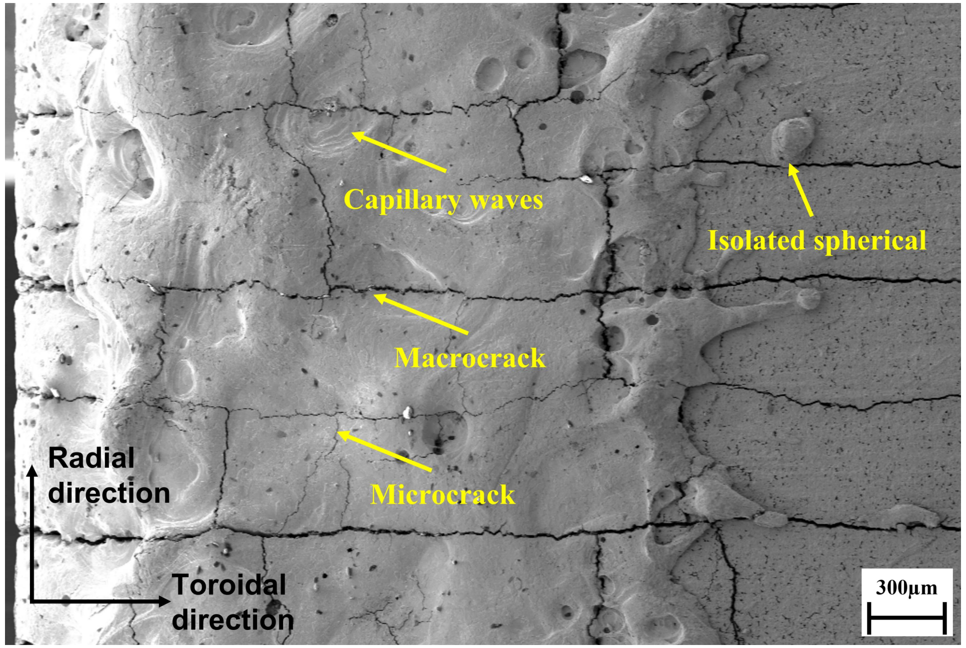
After **Before**



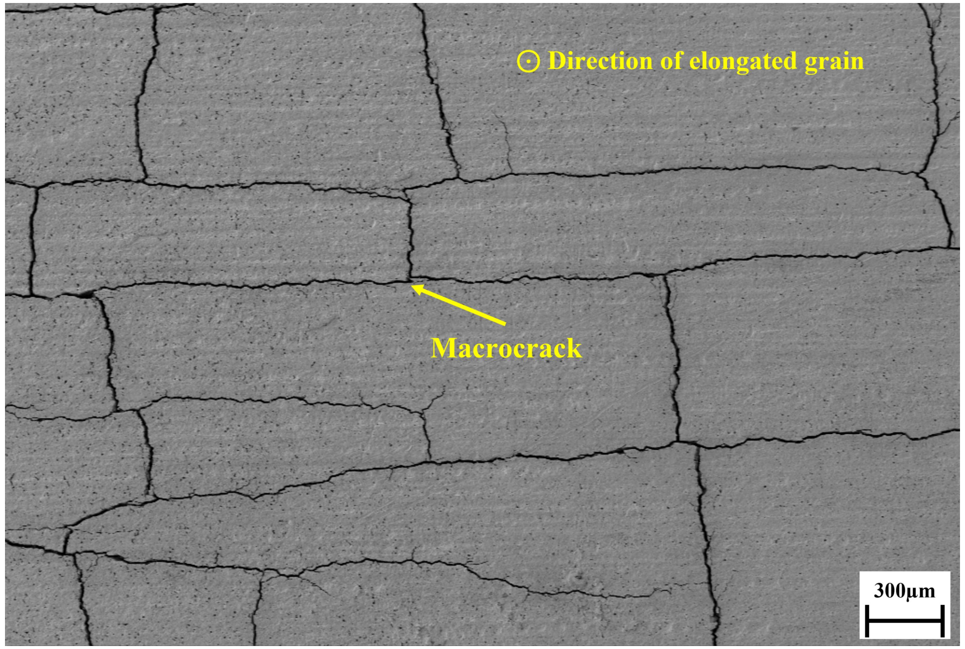
- Rough（wave，±0.5 mm）surface forms new **leading edge induced thermal effect** in tokamak conditons
- Thermal analysis shows that such wave surface seems to have neighble influence on lower area, but leads to obvious temperature increasing on the near melting area, **decreasing the heat exhaust capacity of steady state heat load**

4.2 Net-like cracks on surfrace

Melting zone

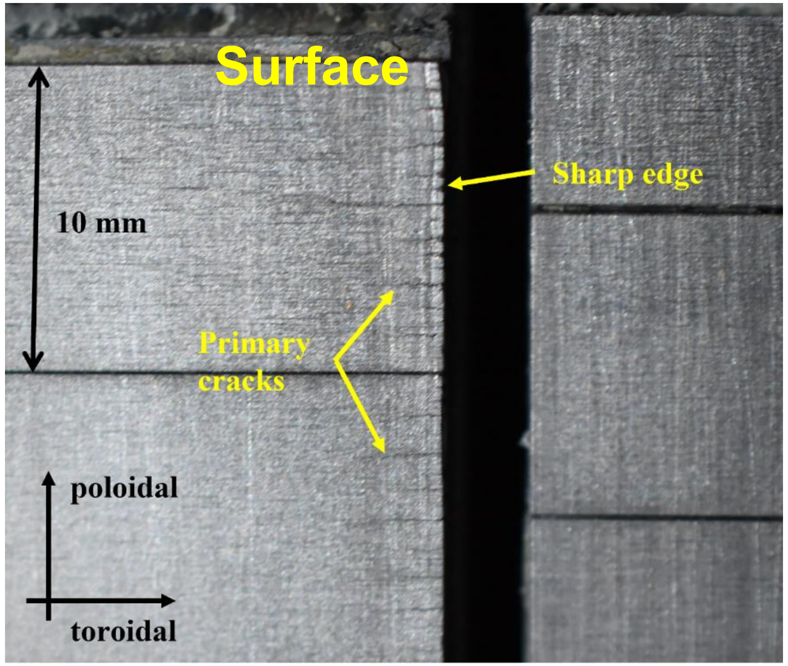


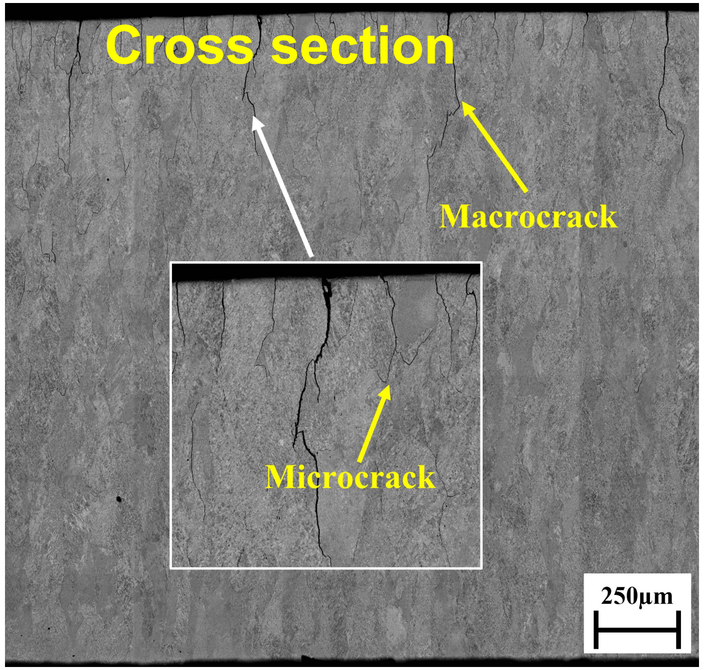
Wihtout melting zone

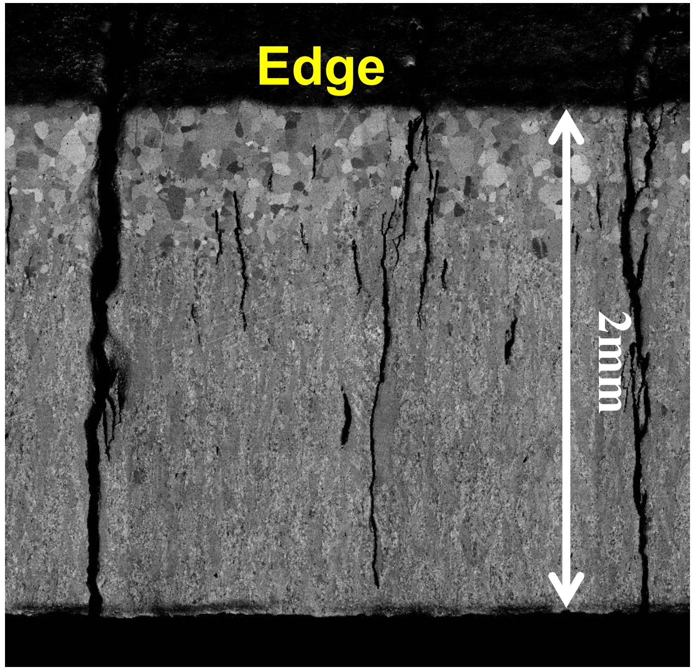


- **Net-like (~0.3mm*~1mm) cracks** are observed on melting region on tungsten surface and can extend along toroidal direction up to 1~2 cm

4.3 Dense cracks at leading edges

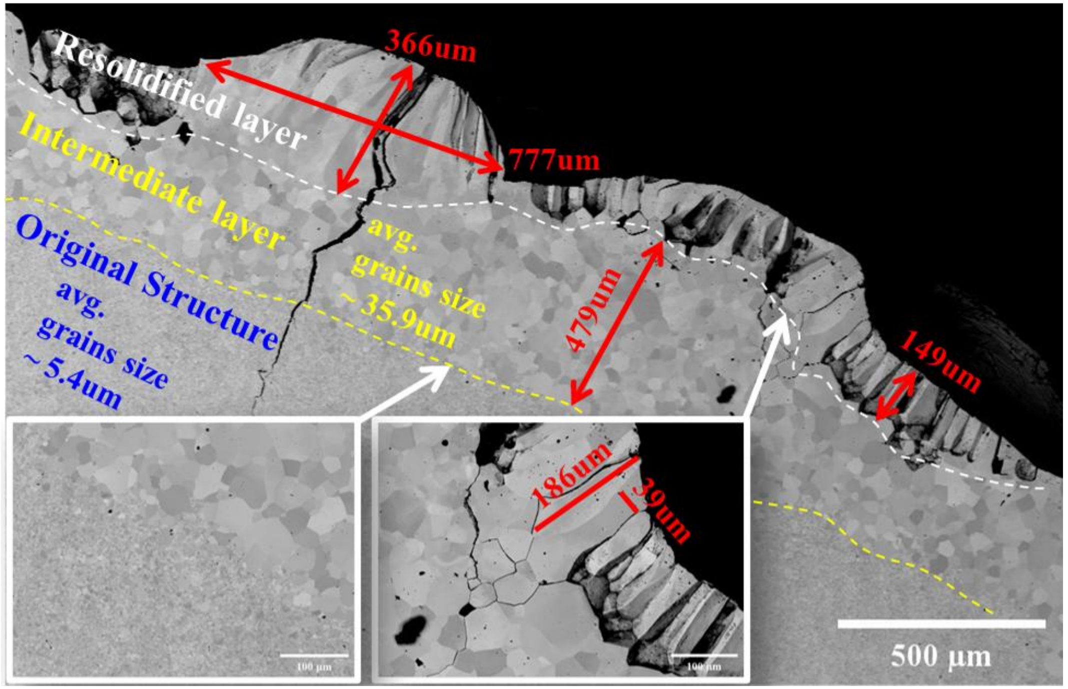






- Macrocracks and microcracks are observed on melting region and macrocracks can extend along toroidal direction up to 1~2 mm
- Macrocracks at leading edges on melting regin can extend to the W/Cu joint (W thickness ~2mm)
- Microcracks can be observed on cross-section inside W plate

4.4 Material degradation by recrystallization



Cross-section of melted area

- **Three layers of grain crystal:**

  (1) Columnar grain (100-300 µm, recrystallization → brittle),

  (2) Equiaxed grain (300-500µm, recrystallization → brittle)

  (3) Original grain (deeper zone, large temperature gradient from 3410^{o}C to ~1200^{o}C further confirm transient event)

- **Cracks often accompany with the such transient melting, the depth of cracks can reach up to 400~600 µm, propagating into the original grains**

- **Some columnar grains exfoliated from the material, indicating the serious cracking of tungsten**

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Conclusions

- ✓ Transient heat flux induced damges, i.e. melting and cracking during disruption were uniformly found on W divertor and limiter region in EAST
- ✓ Melting morphology was similar with melting waves and capillary waves, imposing leading edge induced thermal issue.
- ✓ Three layers of grains from the surface to deep region, columnar grain (100-300 μm), equiaxed grain (recrystallization region) and original grain respectively, resluting material degradation even cracking.
- ✓ Net-like cracks were generally formed on surface and can extend along toroidal direction up to 1~2 cm
- ✓ Whether W melting occurred or not, dense cracks on leading edges can be generated.

THANKS FOR YOUR ATTENTION!