First campaign with Alternative Divertor Configurations in ASDEX Upgrade

T.Lunt[1] on behalf of the ASDEX Upgrade and EUROfusion teams

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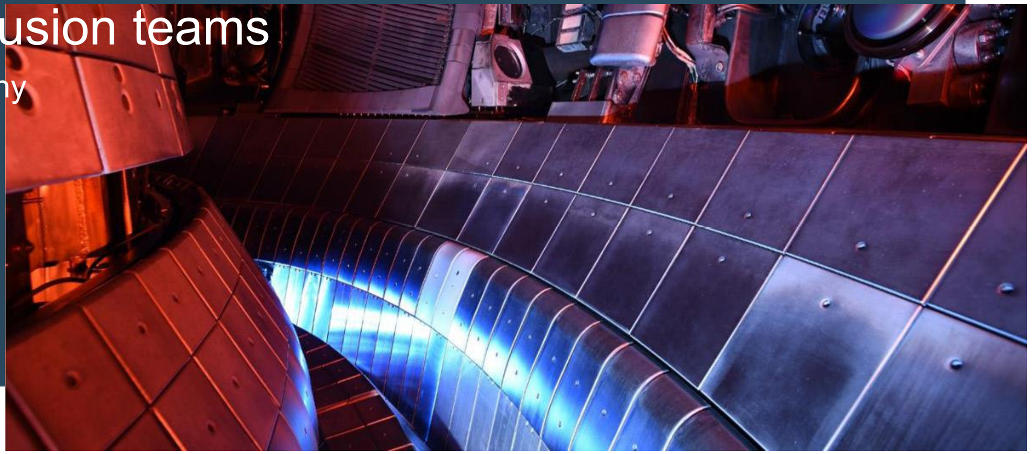
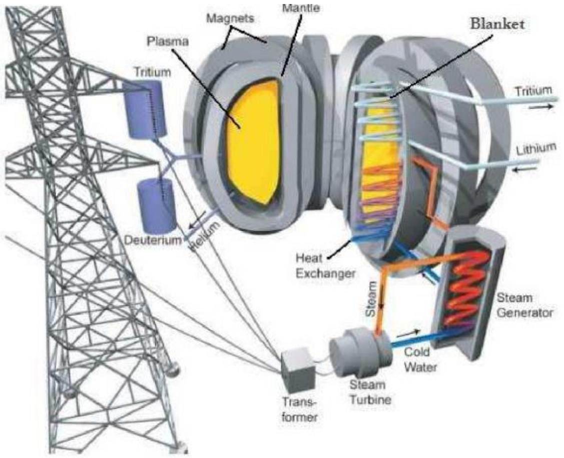
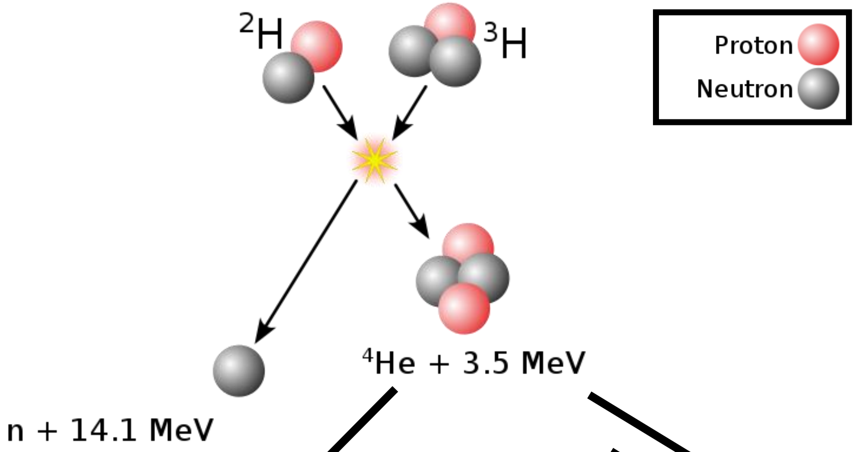


Outline:
- Introduction
- New upper divertor of ASDEX Upgrade
- Overview experimental campaign 2025
- First results
- Summary

Introduction: Power and He exhaust challenge





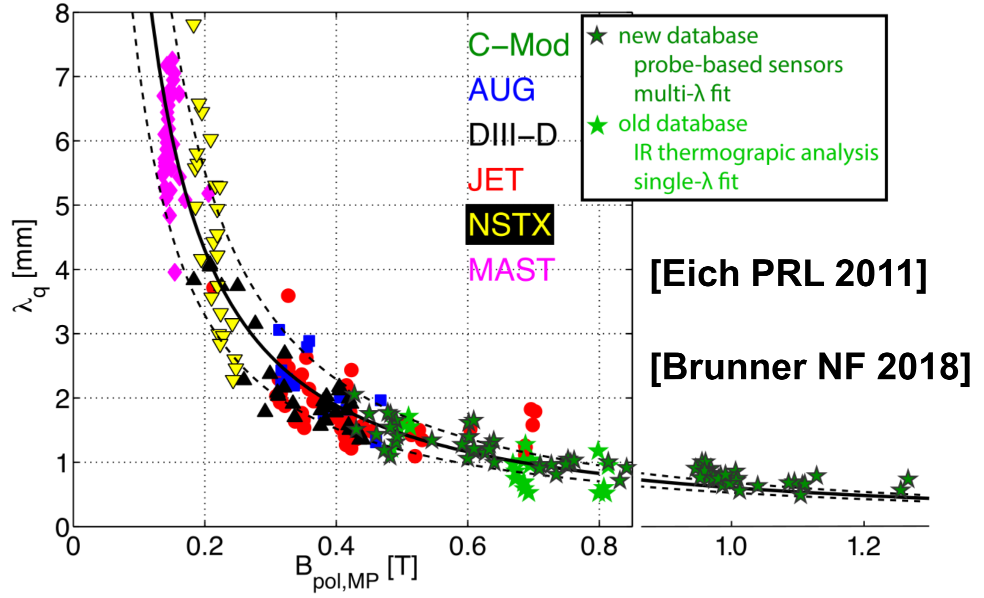
$$Q = \frac{P_{DT}}{P_{aux}} \gg 1$$

$$P_{DT} = 2\ \mathrm{GW}$$

$\Phi_{He} = 7\mathrm{x}10^{20}$ 1/s

P_α =400 MW

$+P_{aux}$



[Eich PRL 2011]

[Brunner NF 2018]

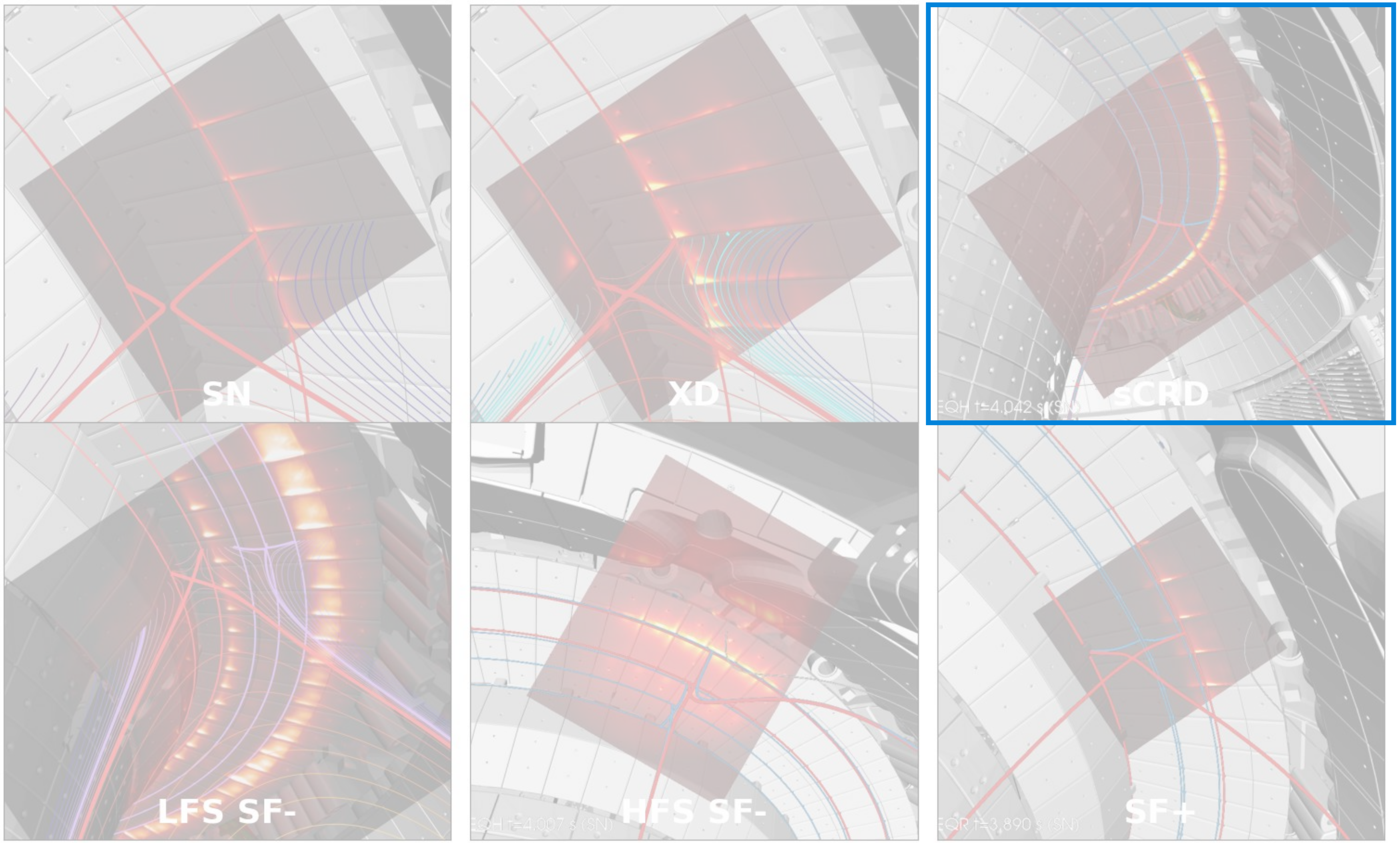
$\Phi_{He} = S_{pump}\ n_{He,pump}$

High neutral He densities (pressures) in subdivertor volume mandatory for reactor to remove He ‚ash‘

$A_{wet} = 2\ \pi\ R\ f_x\ \lambda_q$

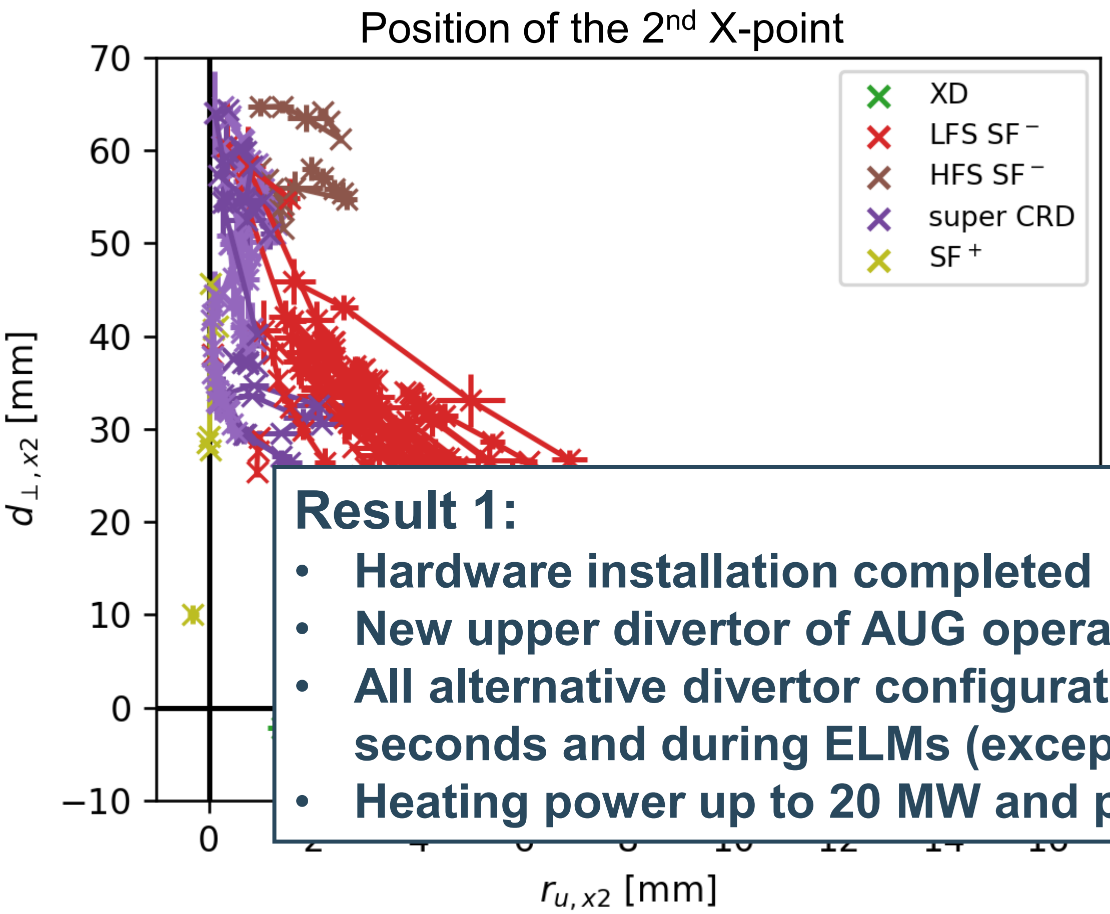
$$\lambda_q\ (\mathrm{mm}) = (0.63 \pm 0.08) \times (B_p\ (\mathrm{T}))^{-1.19 \pm 0.08}$$

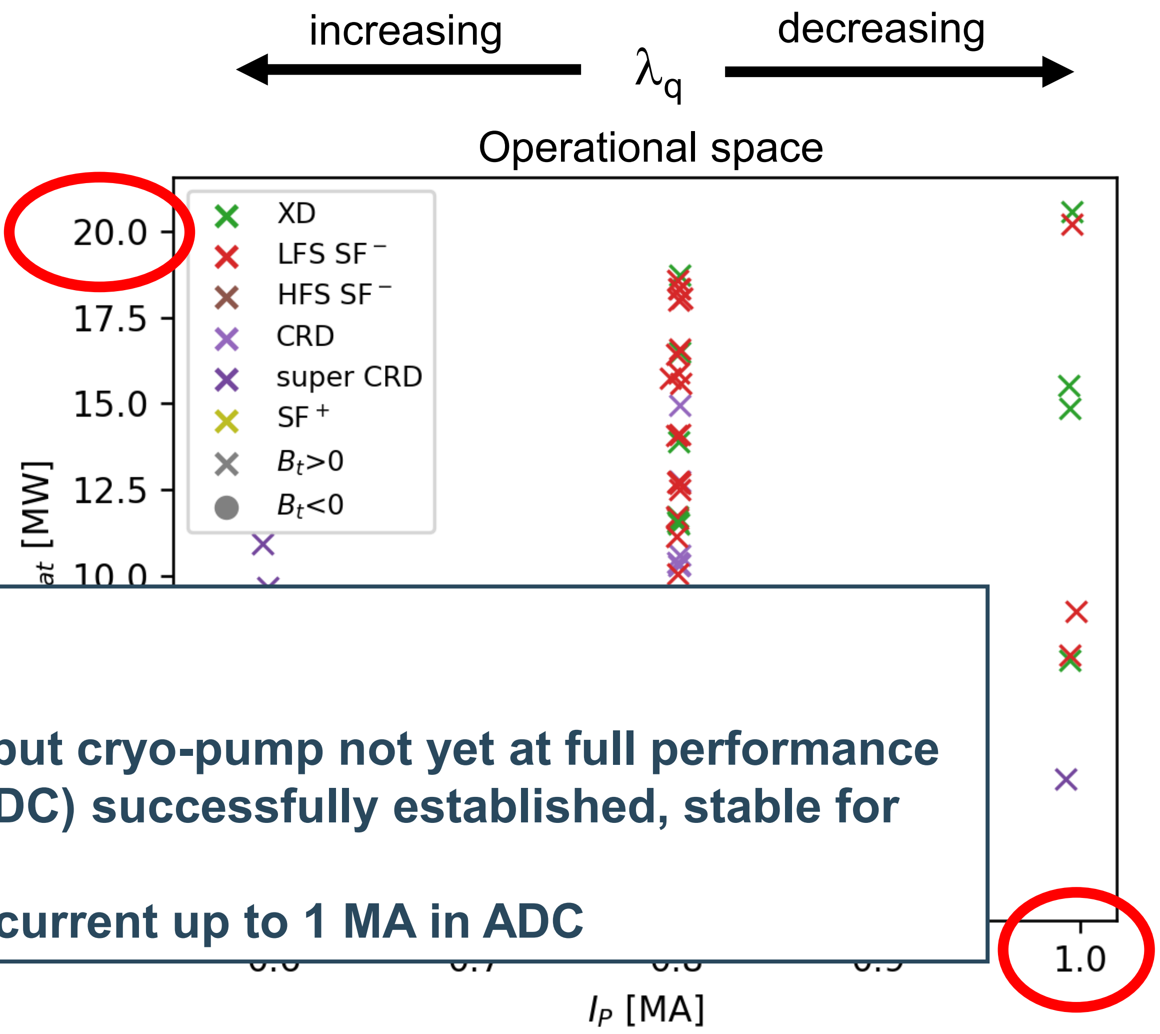
New Upper Divertor of ASDEX Upgrade: Configurations



[Lunt et al. PRL 2023]

Overview experimental campaign 2025





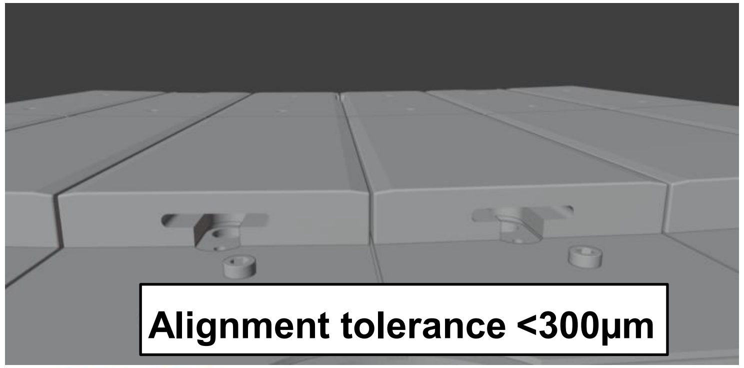
Result 1:

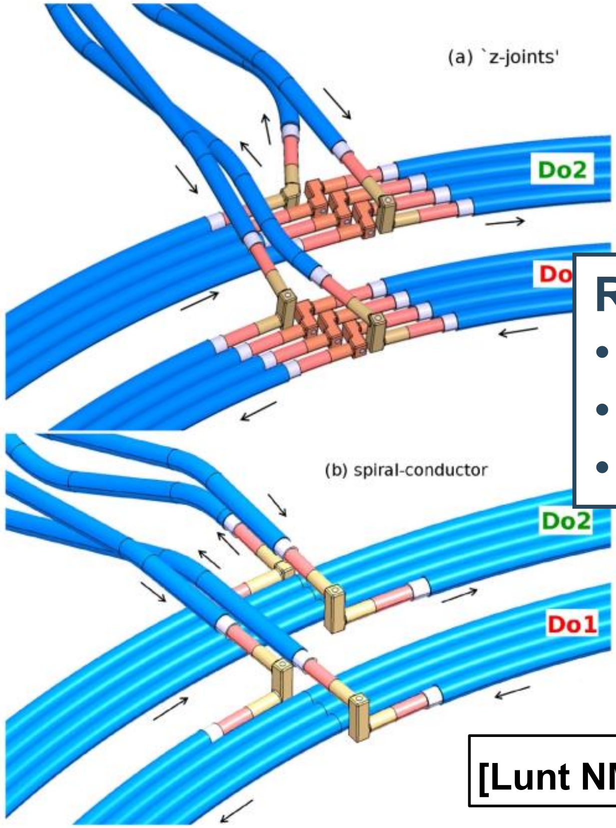
- **Hardware installation completed**
- **New upper divertor of AUG operational, but cryo-pump not yet at full performance**
- **All alternative divertor configurations (ADC) successfully established, stable for seconds and during ELMs (except SF+)**
- **Heating power up to 20 MW and plasma current up to 1 MA in ADC**

Database of >100 discharges in stable ADC

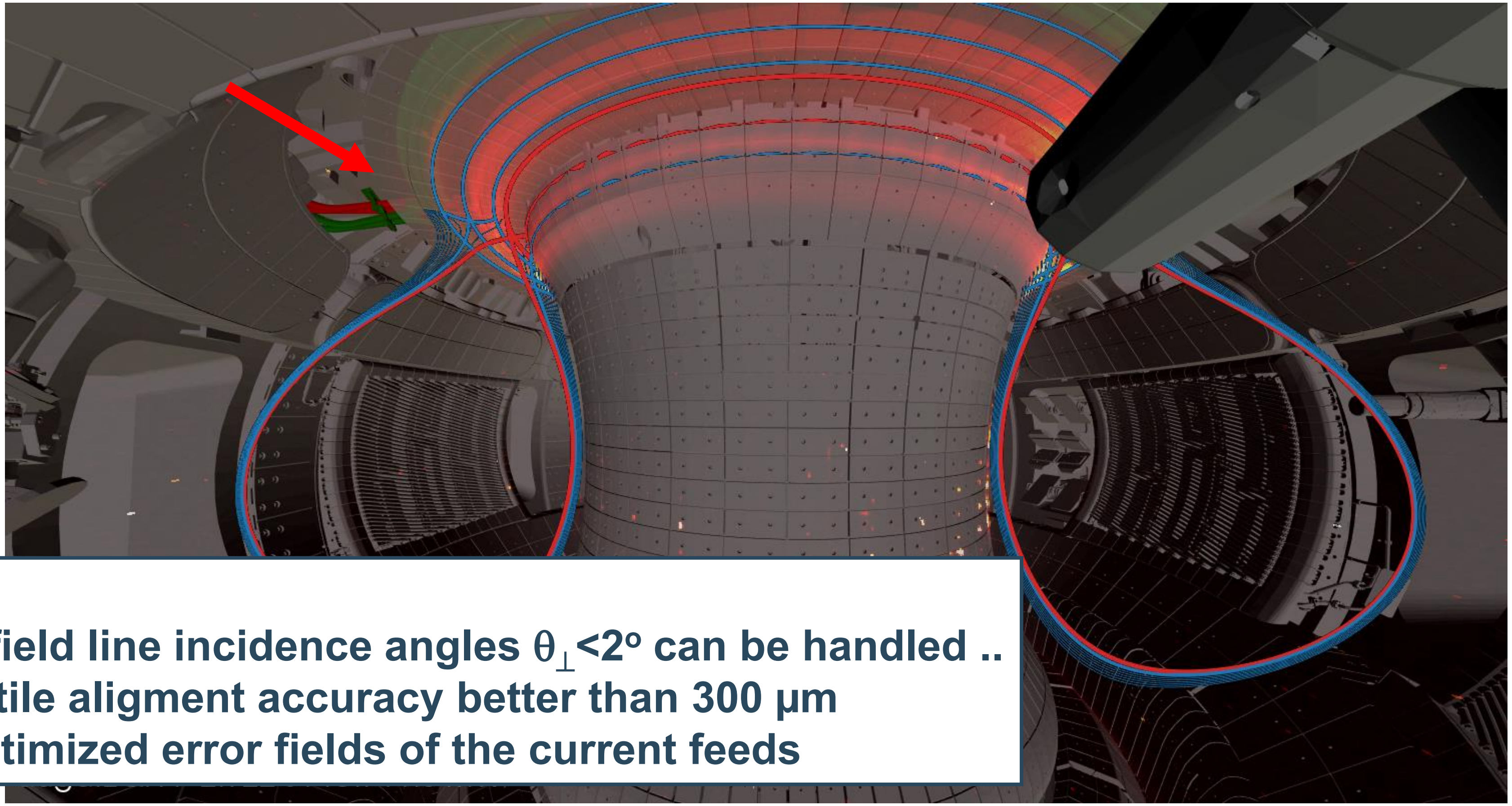
f_x=flux expansion

Small field line incidence angles $\theta_\perp$<2° can be handled



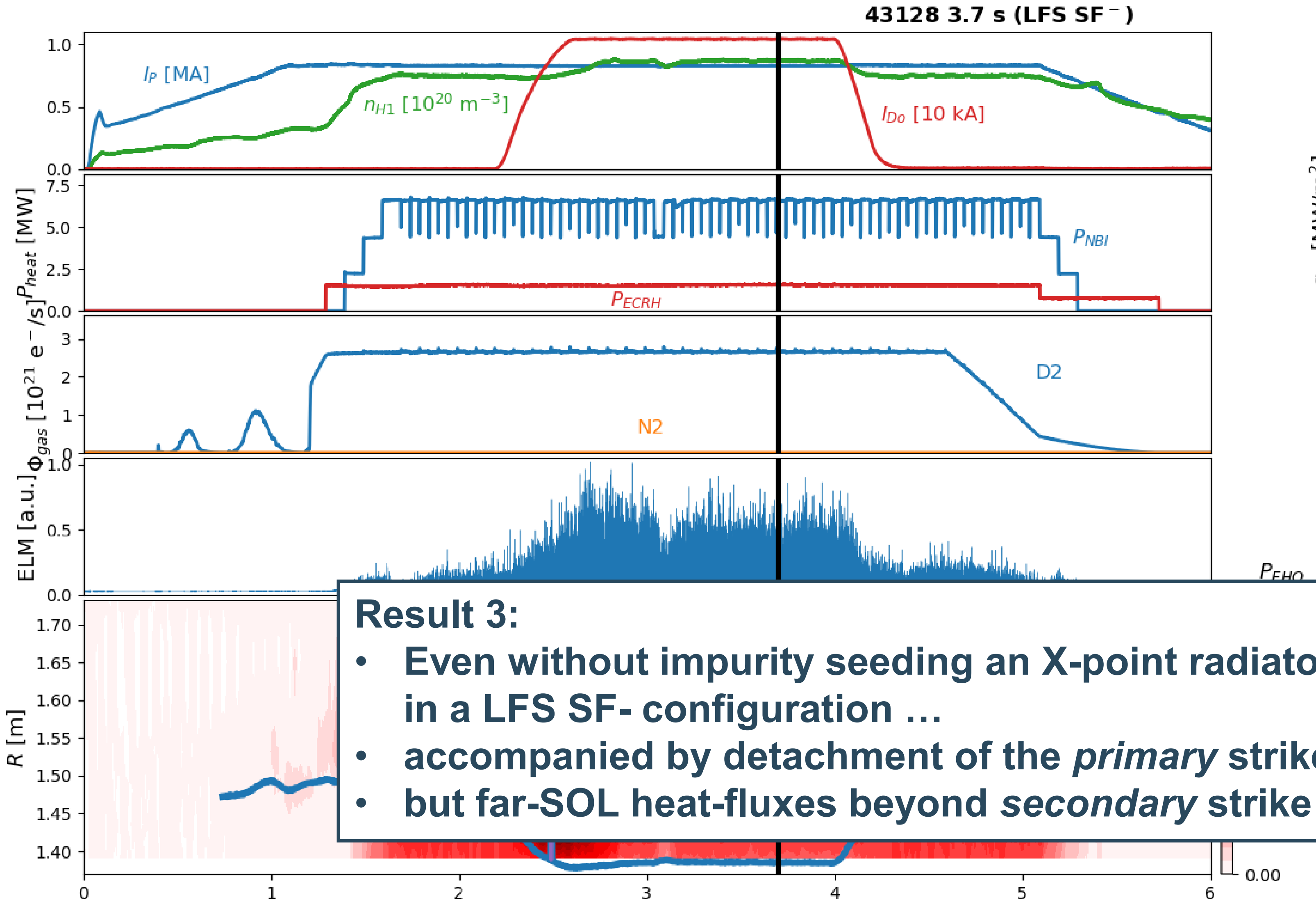


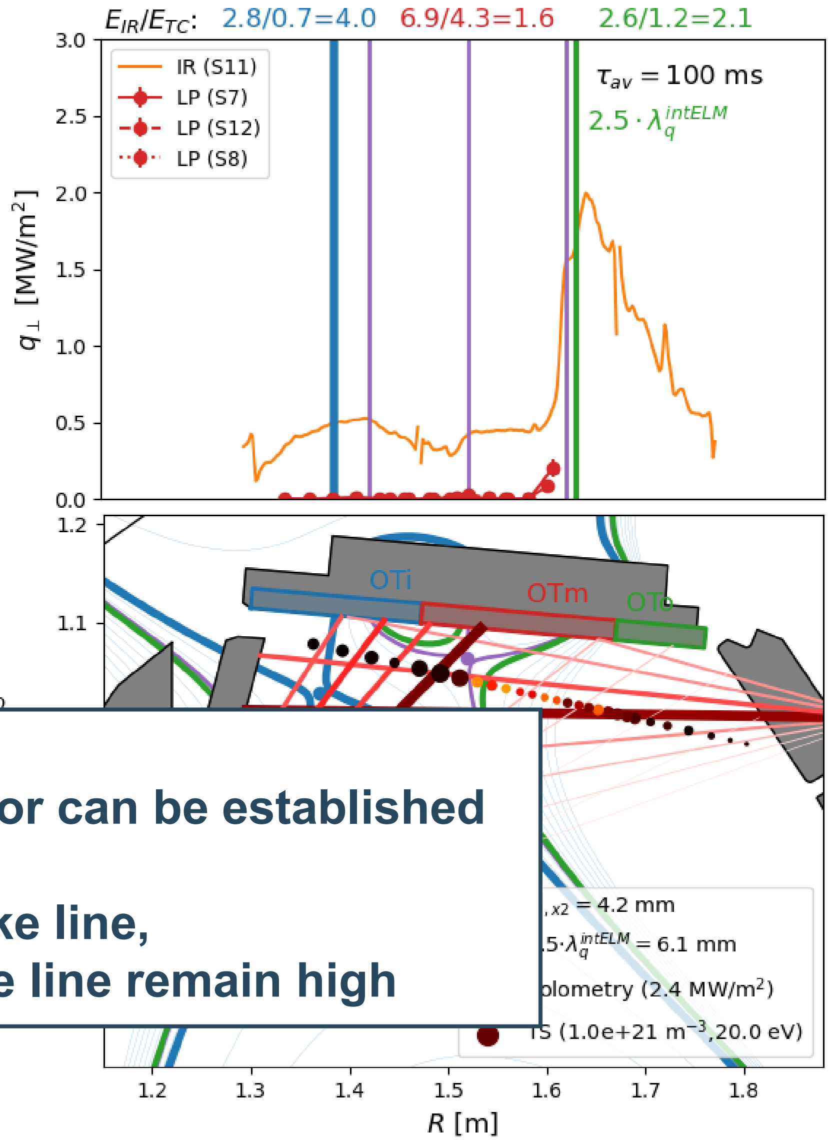
[Lunt NME 2019]



Result 2:
- Small field line incidence angles $\theta_\perp$<2° can be handled ..
- with a tile aligment accuracy better than 300 µm
- and optimized error fields of the current feeds

X-point radiator w/o impurity seeding in 800kA H-mode



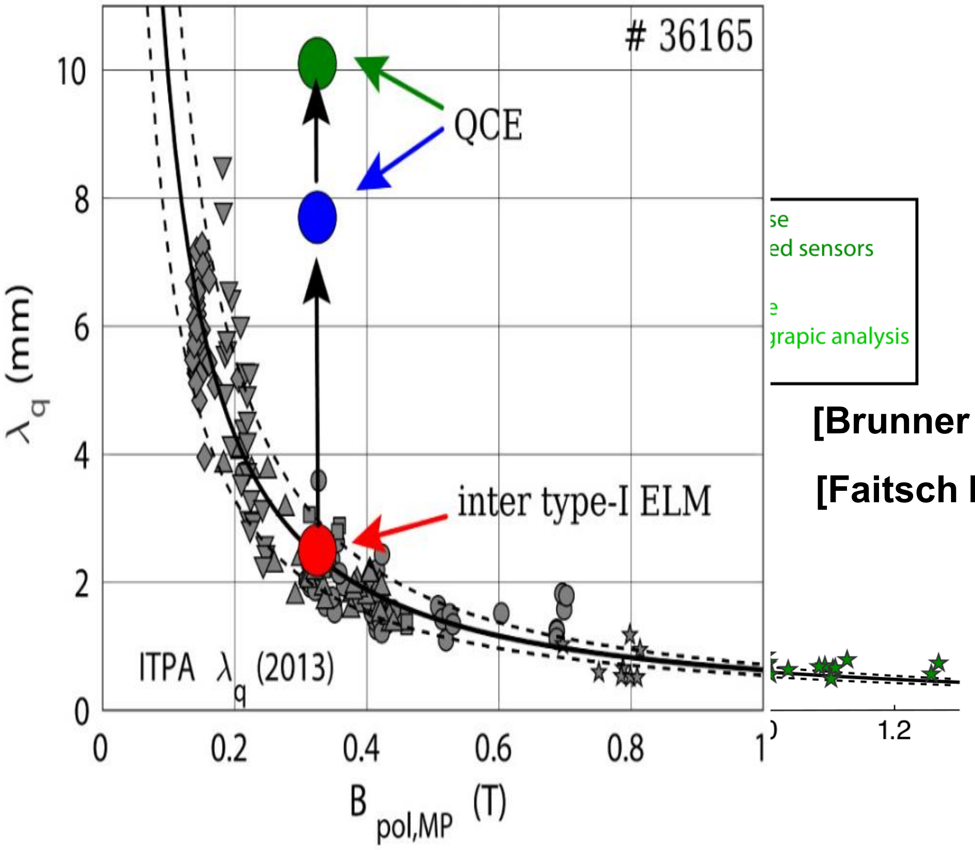


Result 3:

- Even without impurity seeding an X-point radiator can be established in a LFS SF- configuration …
- accompanied by detachment of the *primary* strike line,
- but far-SOL heat-fluxes beyond *secondary* strike line remain high

[Bernert NF 2021], [Stroth NF 2022]

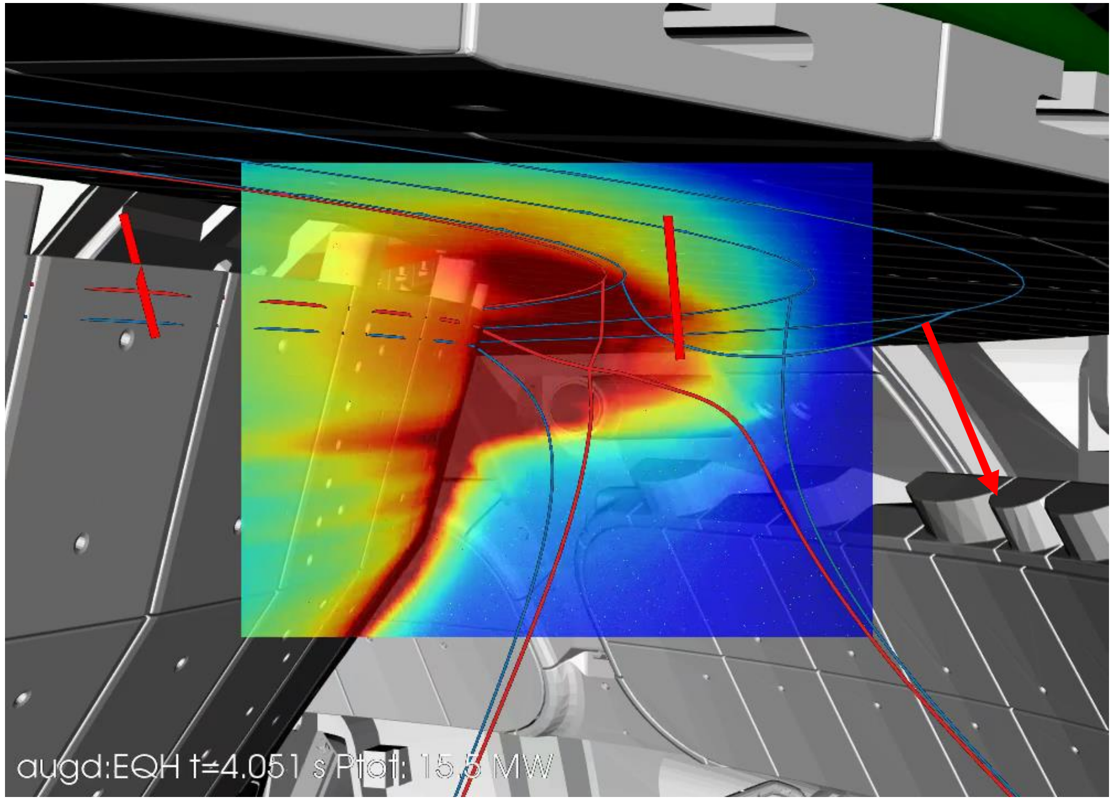
Small-ELM regime (QCE?)



[Brunner NF 2018]

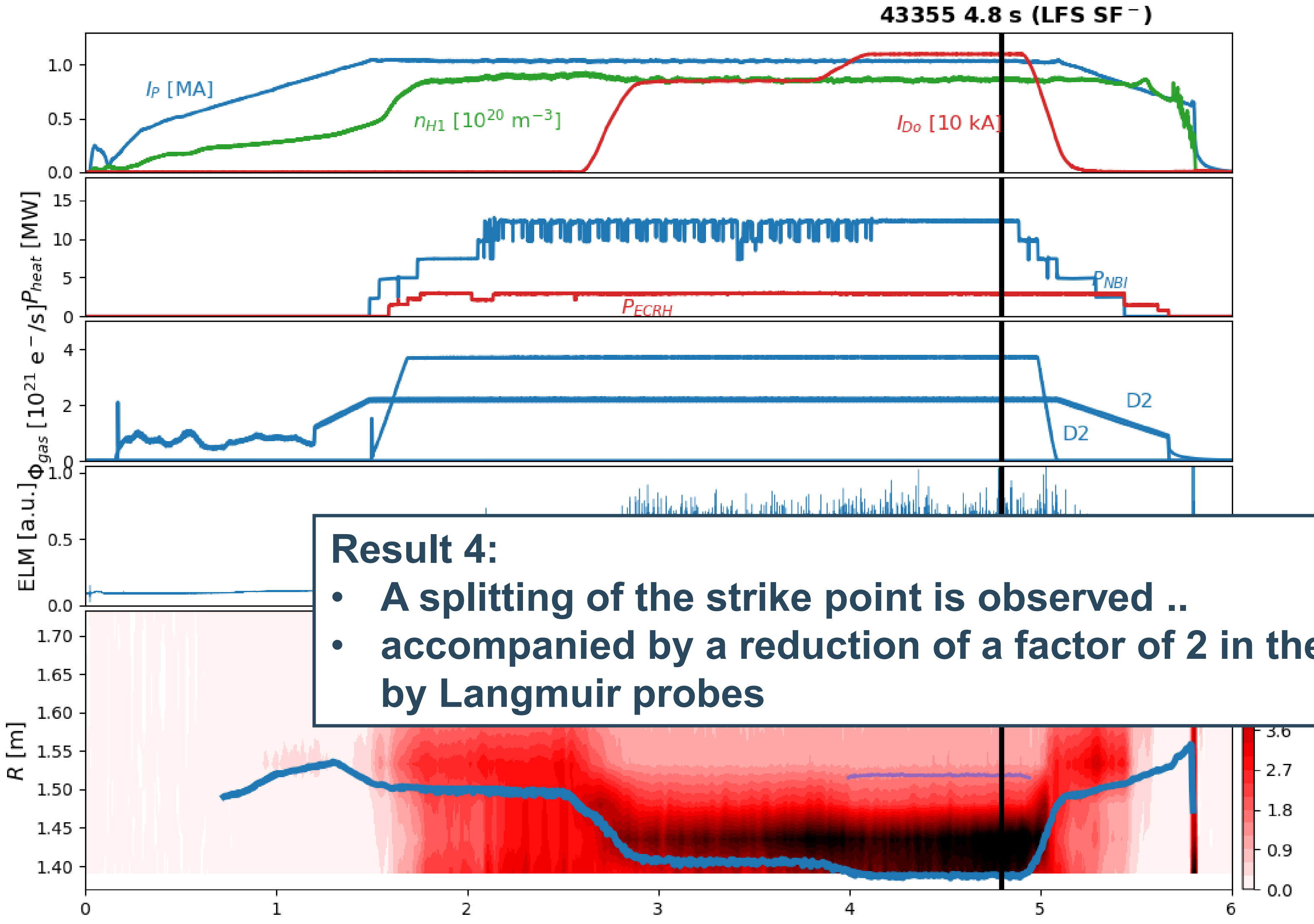
[Faitsch NME 2021]

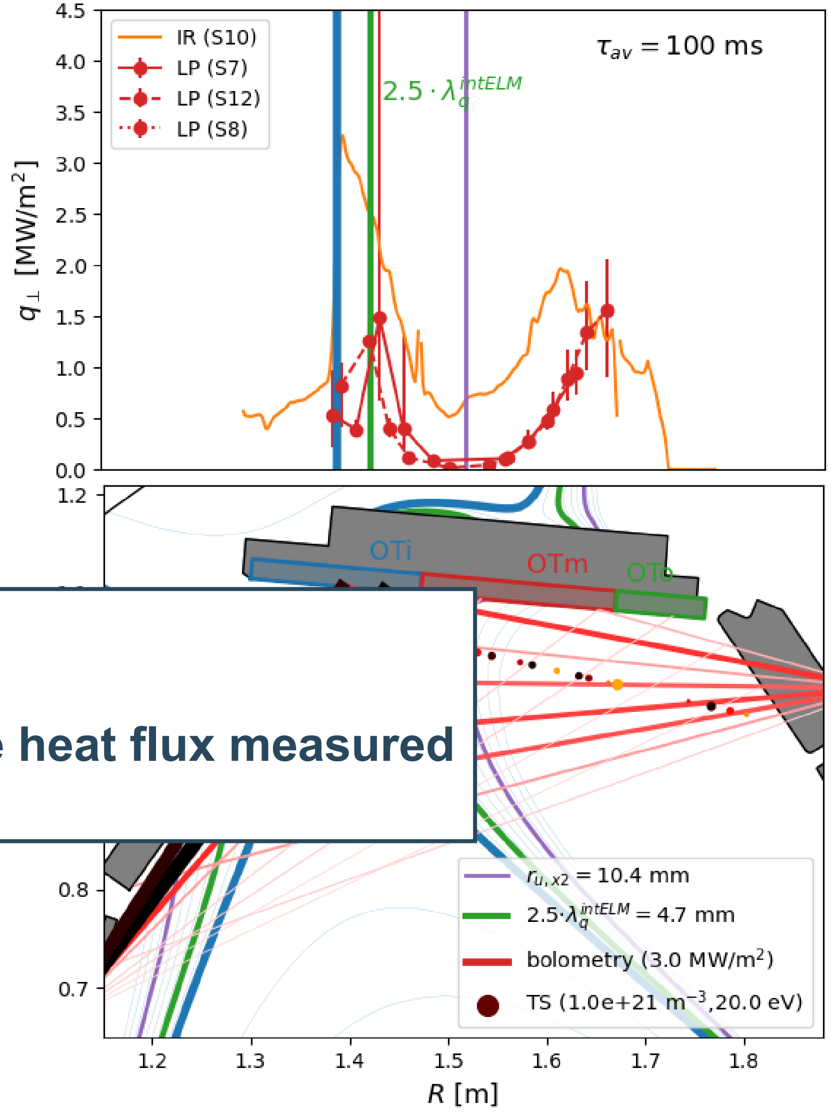
$$\lambda_q\ (\mathrm{mm}) = (0.63 \pm 0.08) \times (B_p\ (\mathrm{T}))^{-1.19\pm0.08}$$



$$\Phi_{\mathrm{mc,USN}}/\Phi_{\mathrm{mc,LSN}} \sim 7$$

Strike point splitting in 1MA H-mode





Result 4:

- **A splitting of the strike point is observed ..**
- **accompanied by a reduction of a factor of 2 in the heat flux measured by Langmuir probes**

[Lunt NME 2017], [Pan PPCF 2018]

Summary

First results:

1. Hardware installation of a pair of in-vessel coils, a charcoal coated cryo-pump and new divertor targets completed

   All alternative divertor configurations (ADC) successfully established, stable for seconds and during ELMs (except SF+)

   Heating power up to 20 MW and plasma current up to 1 MA in ADC
2. Even at high heating powers field line incidence angles can be made arbitrarily small – or even negative – due to outstanding target alignment accuracy and small magnetic error fields
3. X-point radiator forms in a LFS SF- configuration even without impurity seeding, where the primary strike point is fully detached, but far-SOL heat fluxes still high → far-SOL fluxes irrelevant at a reactor-like power fall-off lengths λ_q?
4. Splitting of the outer strike point observed, accompanied by reduction of the peak heat flux of a factor of ~2 in 1 MA LFS SF^- discharges measured by Langmuir probes

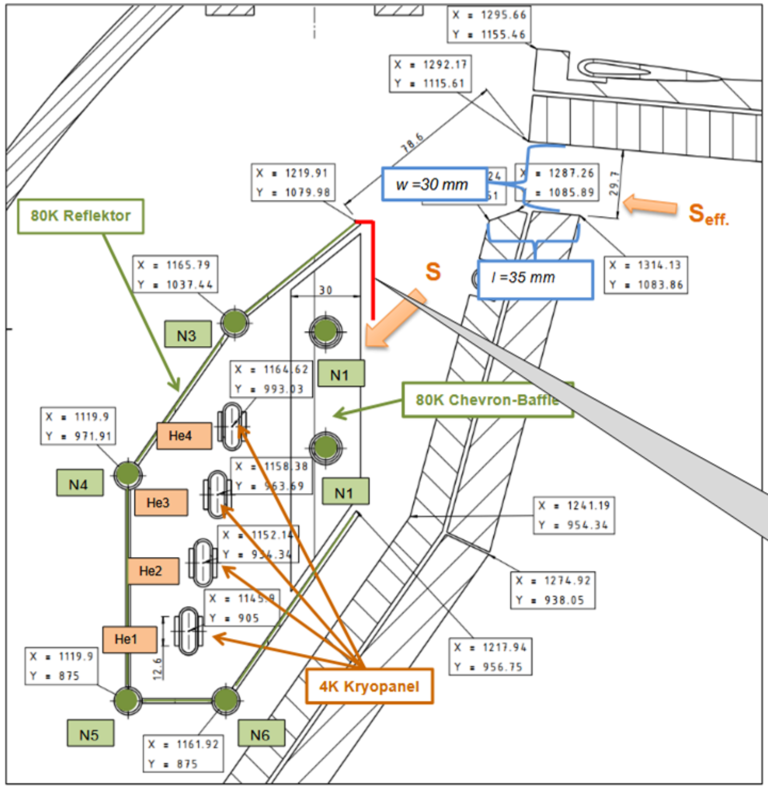
Outlook

Upcoming campaign

- Install protection plates on cryo-pump
- Try other seeding gases to reduce far-SOL heat fluxes
- Carry out 1 MA discharges in (s)CRD configuration

Long term

- Install baffles



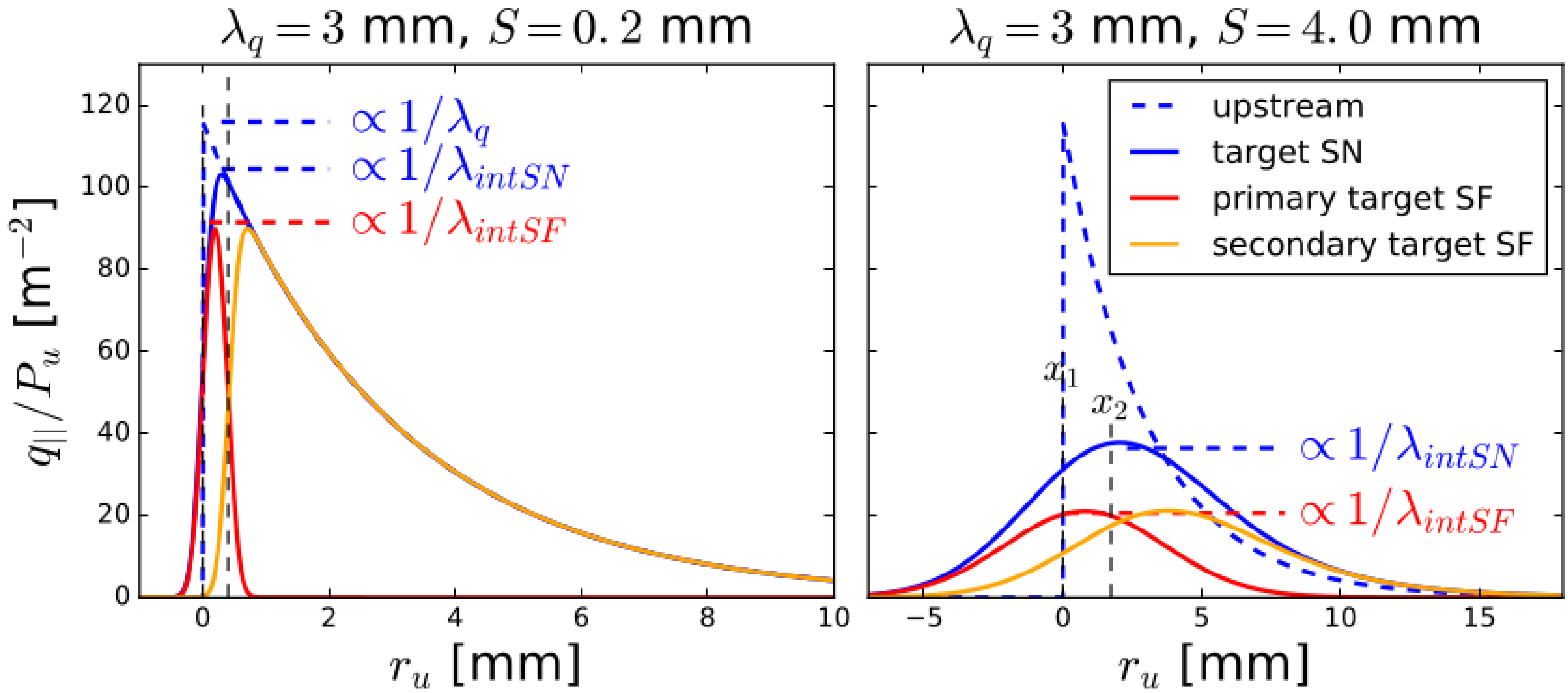
Protective panel:

- ➢ Reduction of ECRH stray radiation (Coated inside with Al_2O_3/TiO_2)
- ➢ Reduction of radiation (0 … 2000 nm)

Protective panel:
Length 35 mm
Reduces S_{eff} 20 %

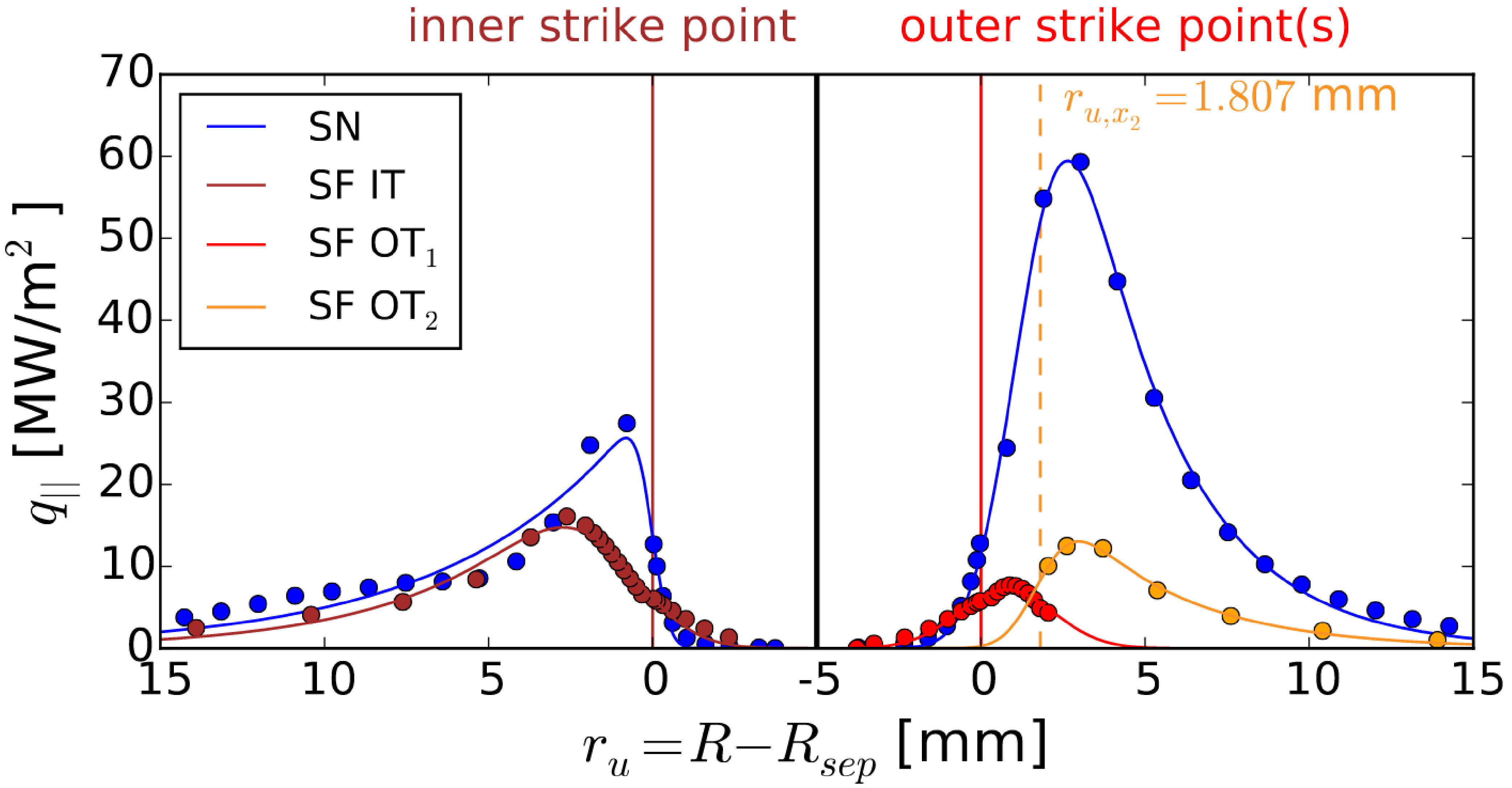
Backup slides

SOL splitting



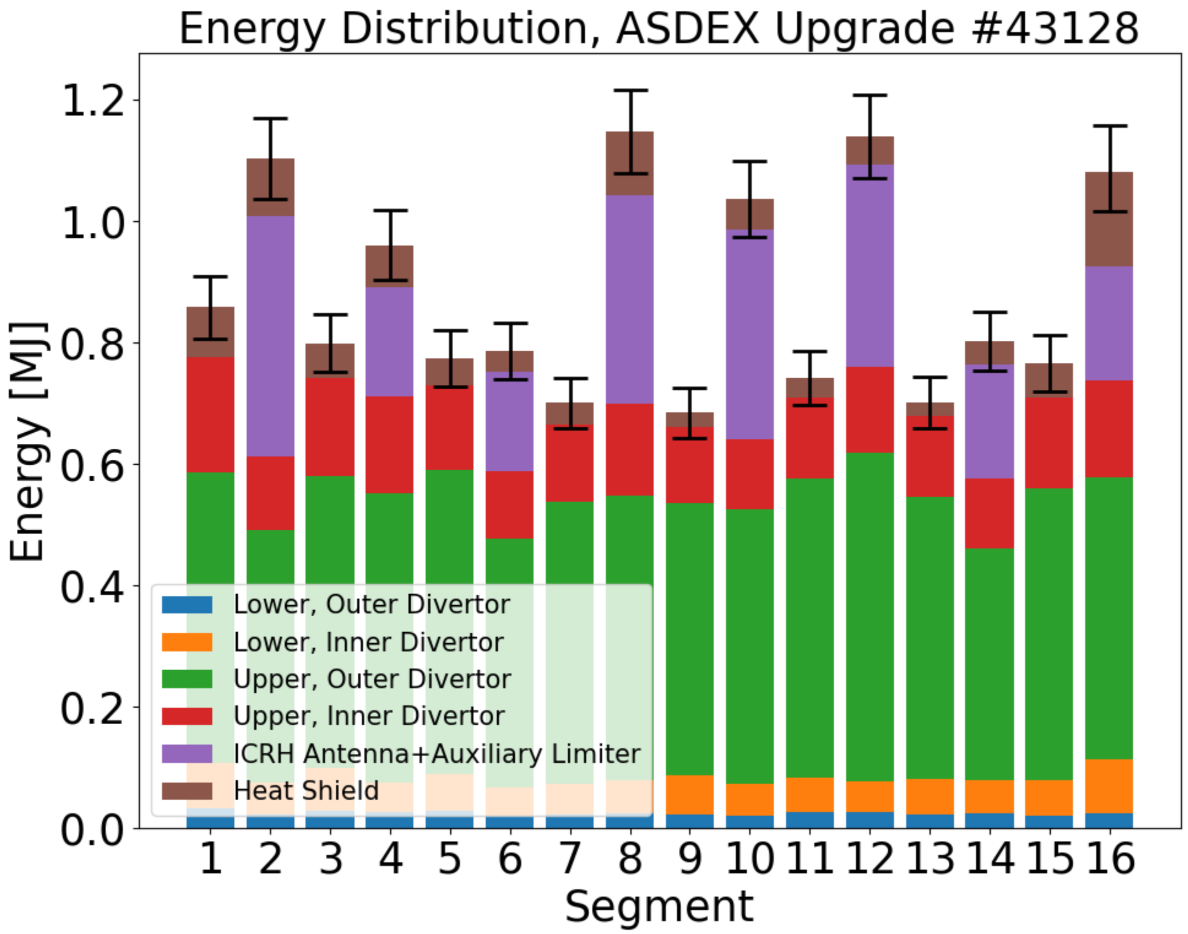
[Lunt NME 2017]

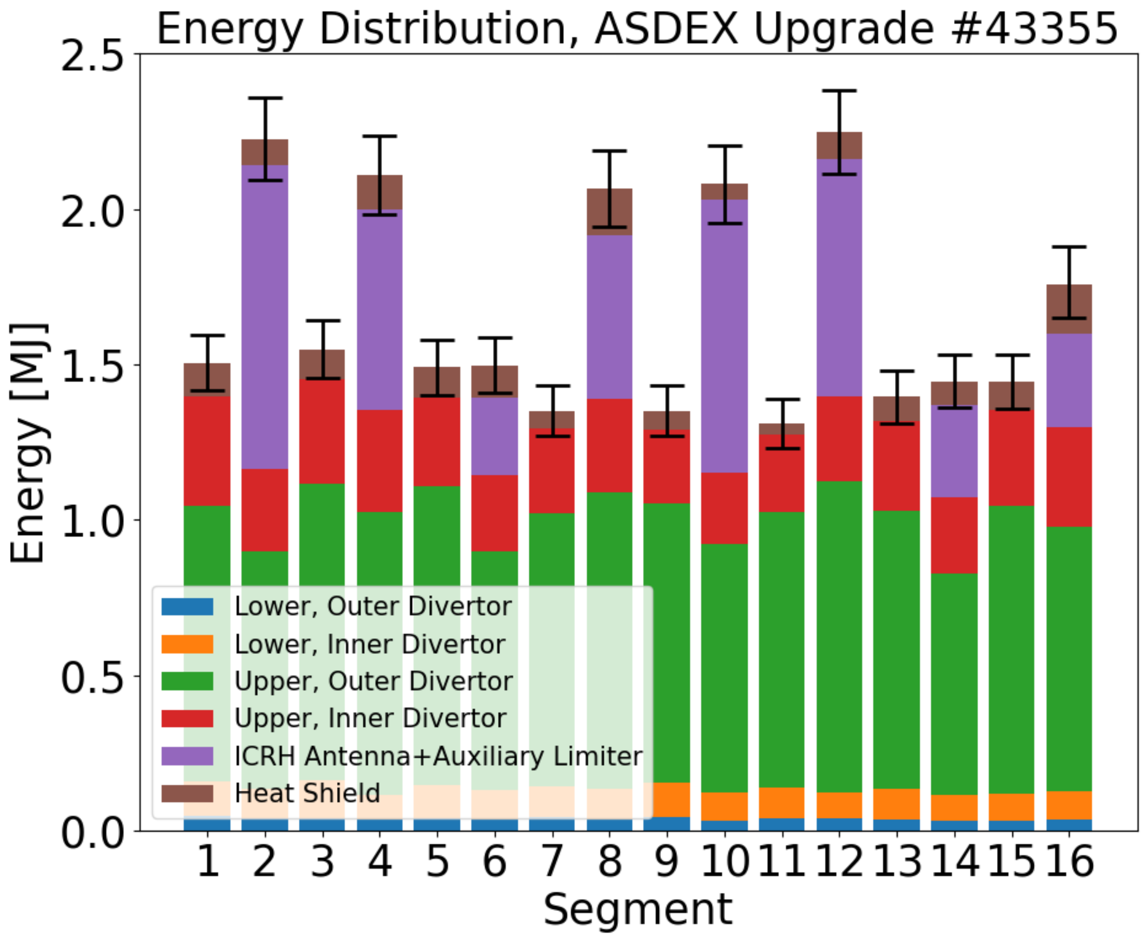
SOL splitting



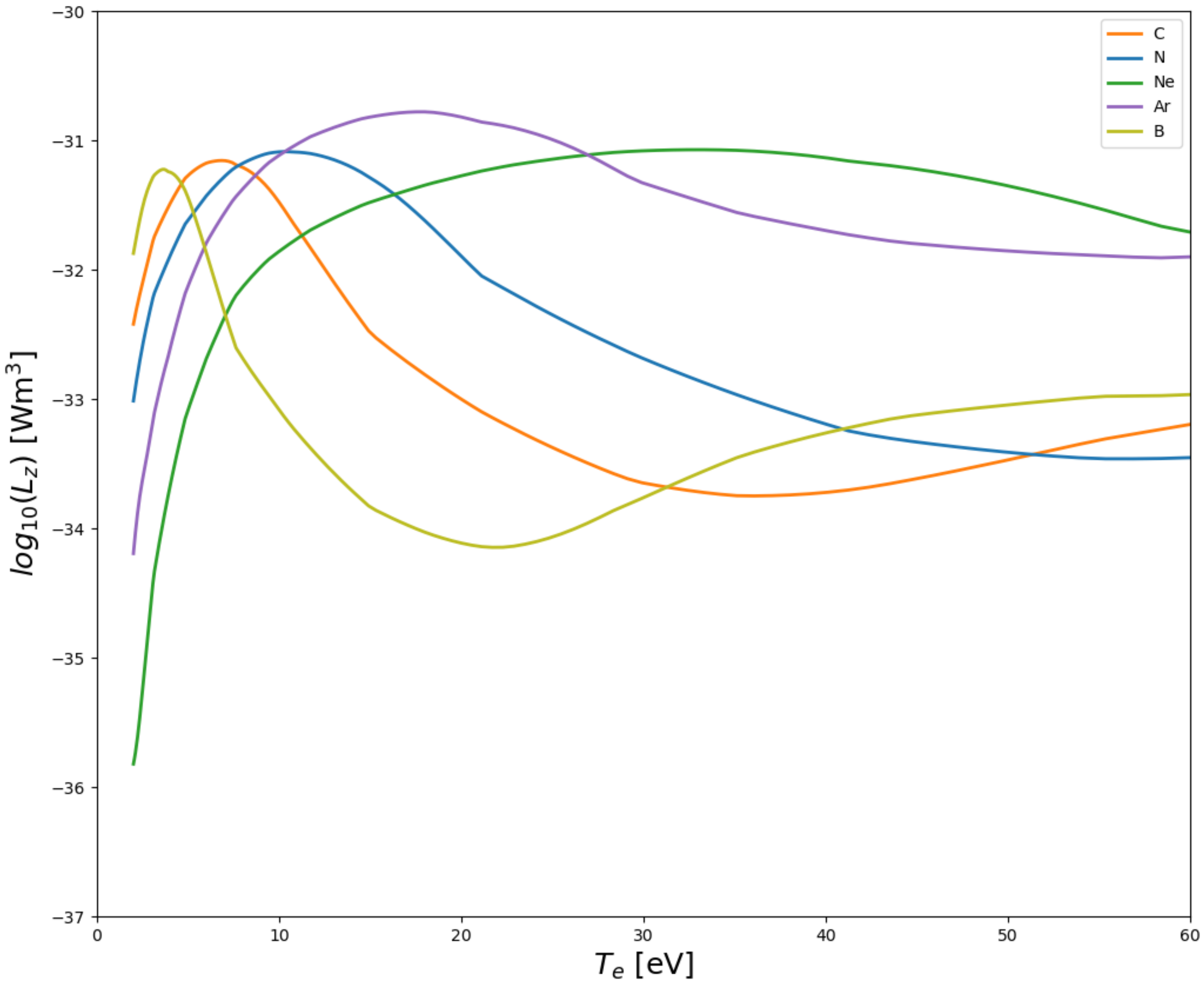
[Pan PPCF 2018]

Energy Balance

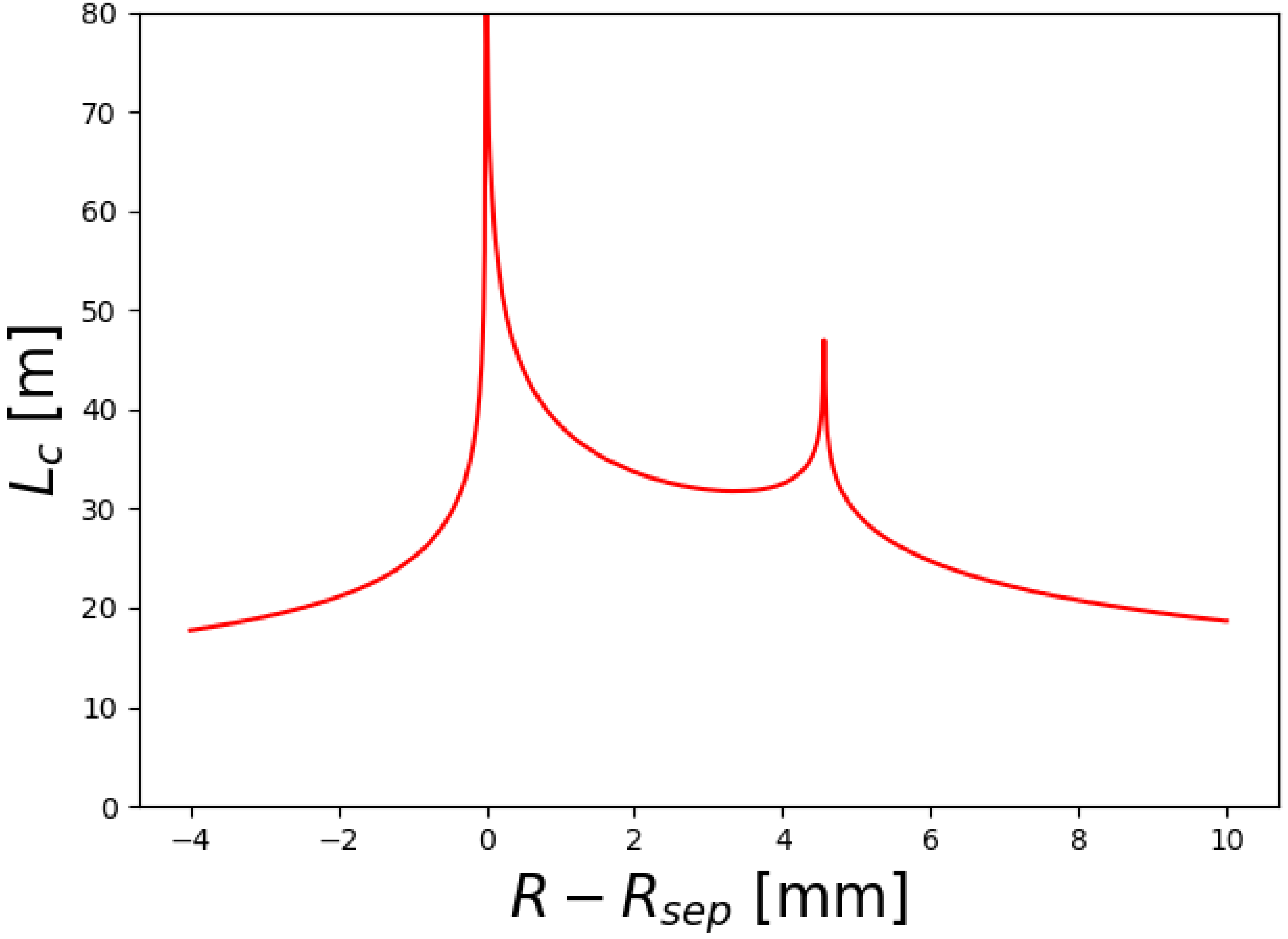




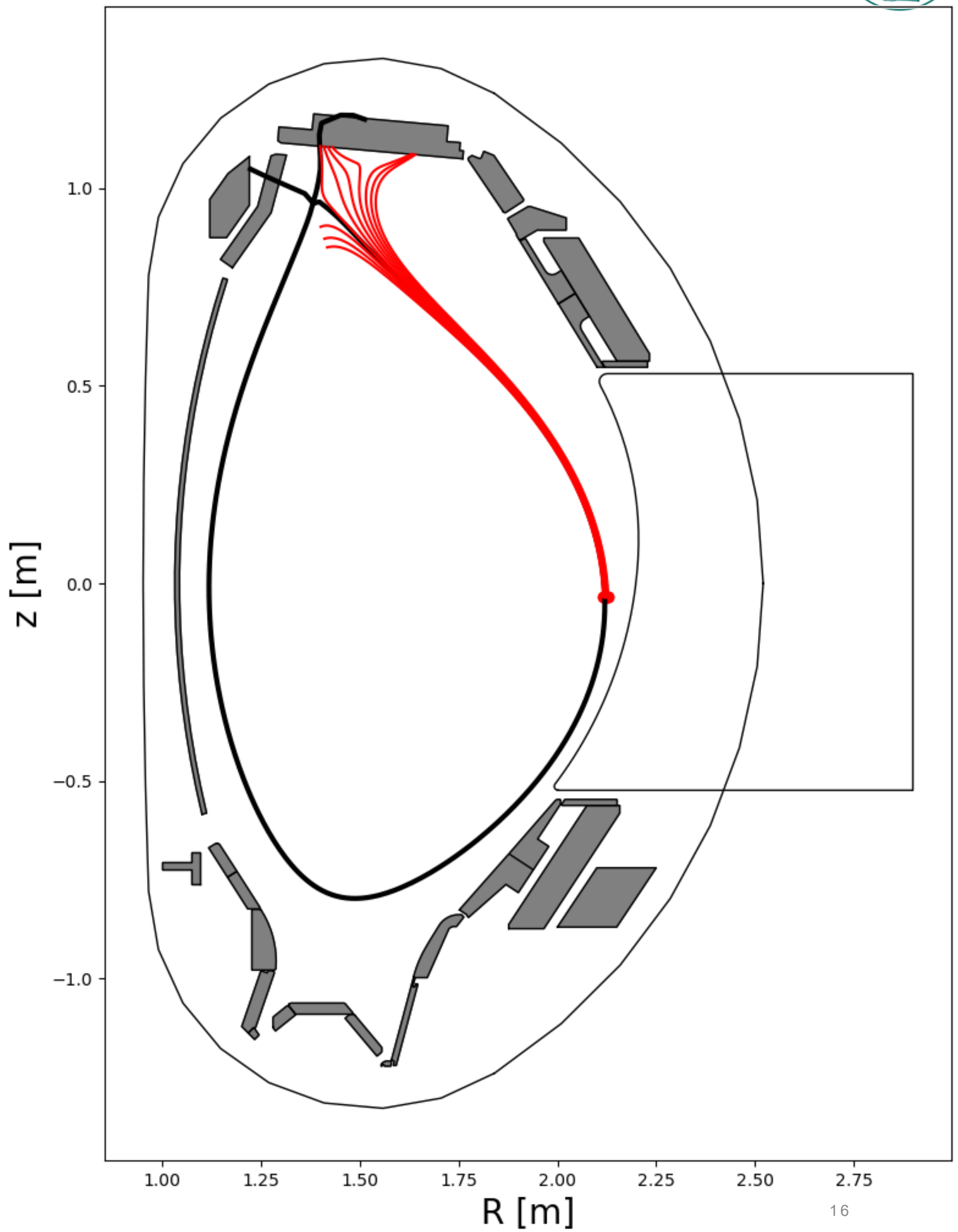
Radiative cooling



Effect on Lc

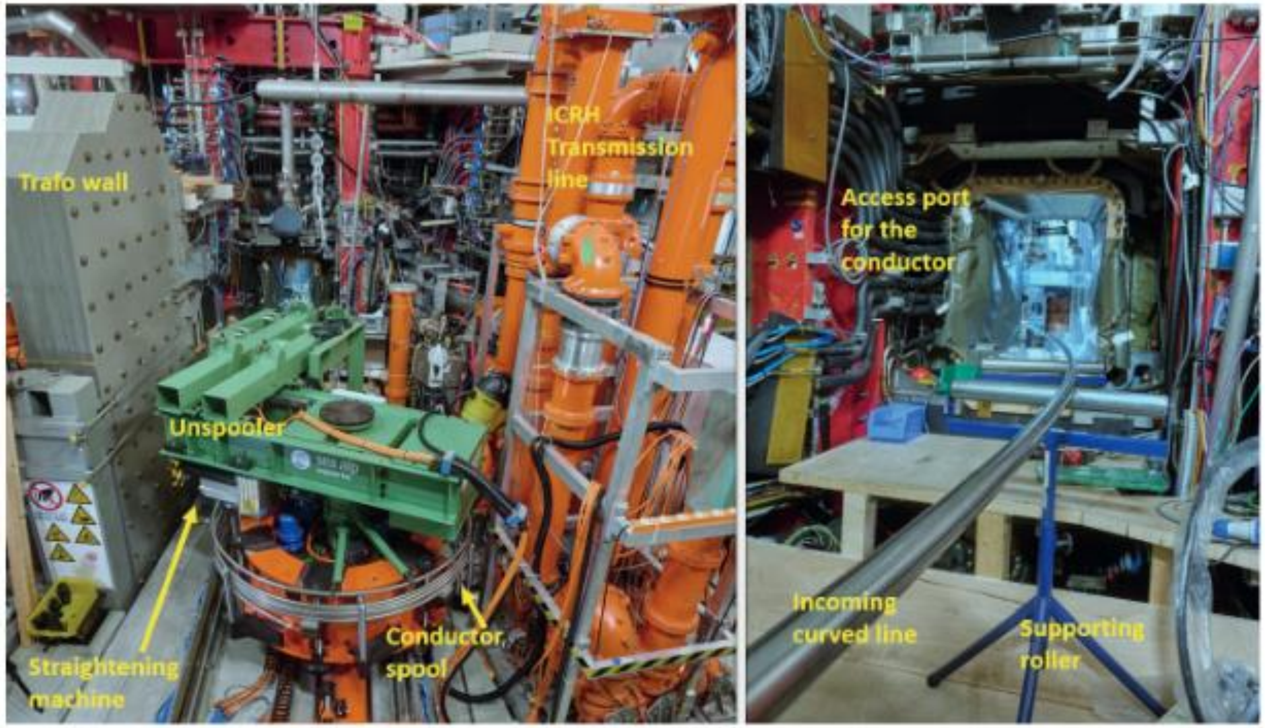


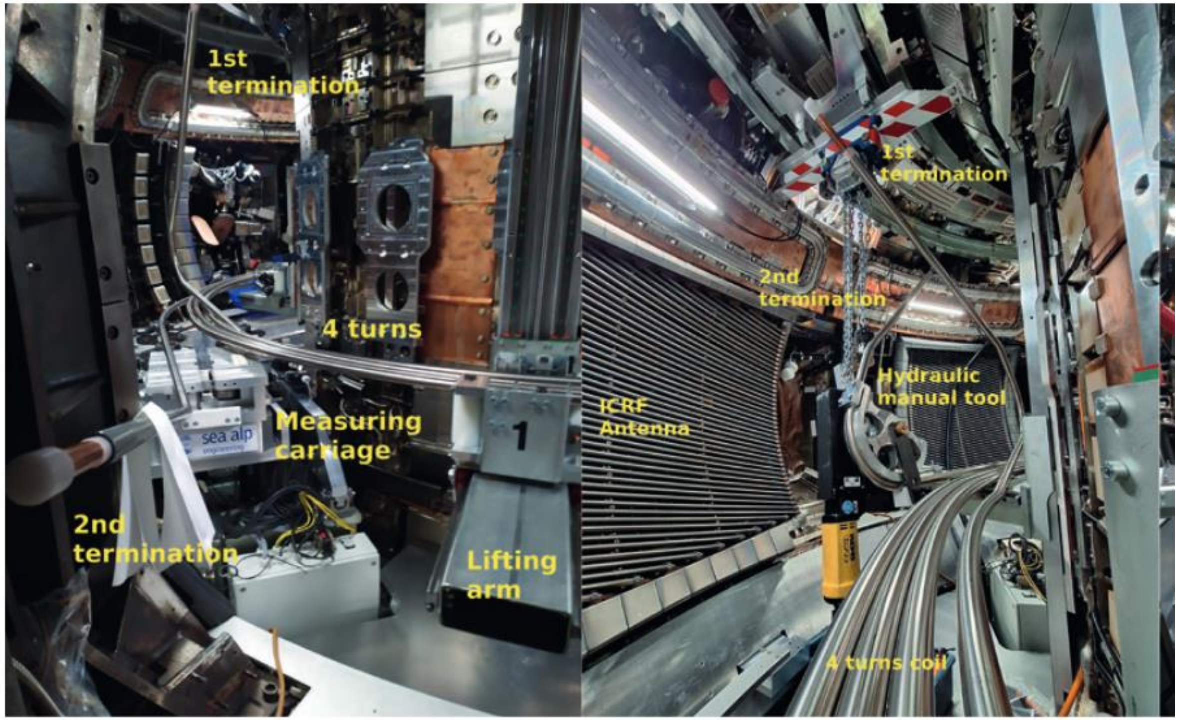
80
70
60
50
40
30
20
10
0
L_c [m]
−4
−2
0
2
4
6
8
10
$R - R_{sep}$ [mm]



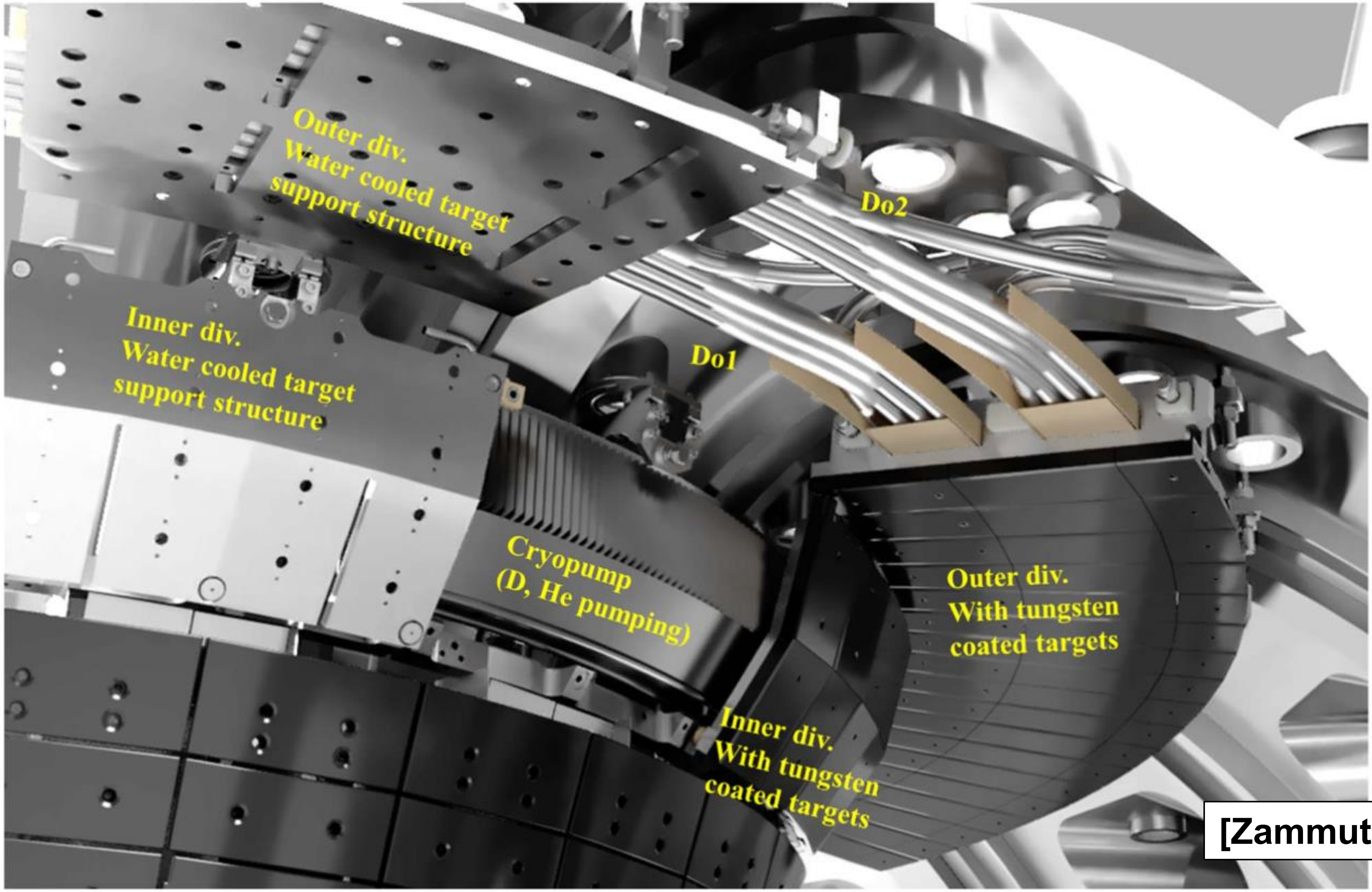
1.0
0.5
0.0
−0.5
−1.0
z [m]
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
R [m]

New upper divertor hardware



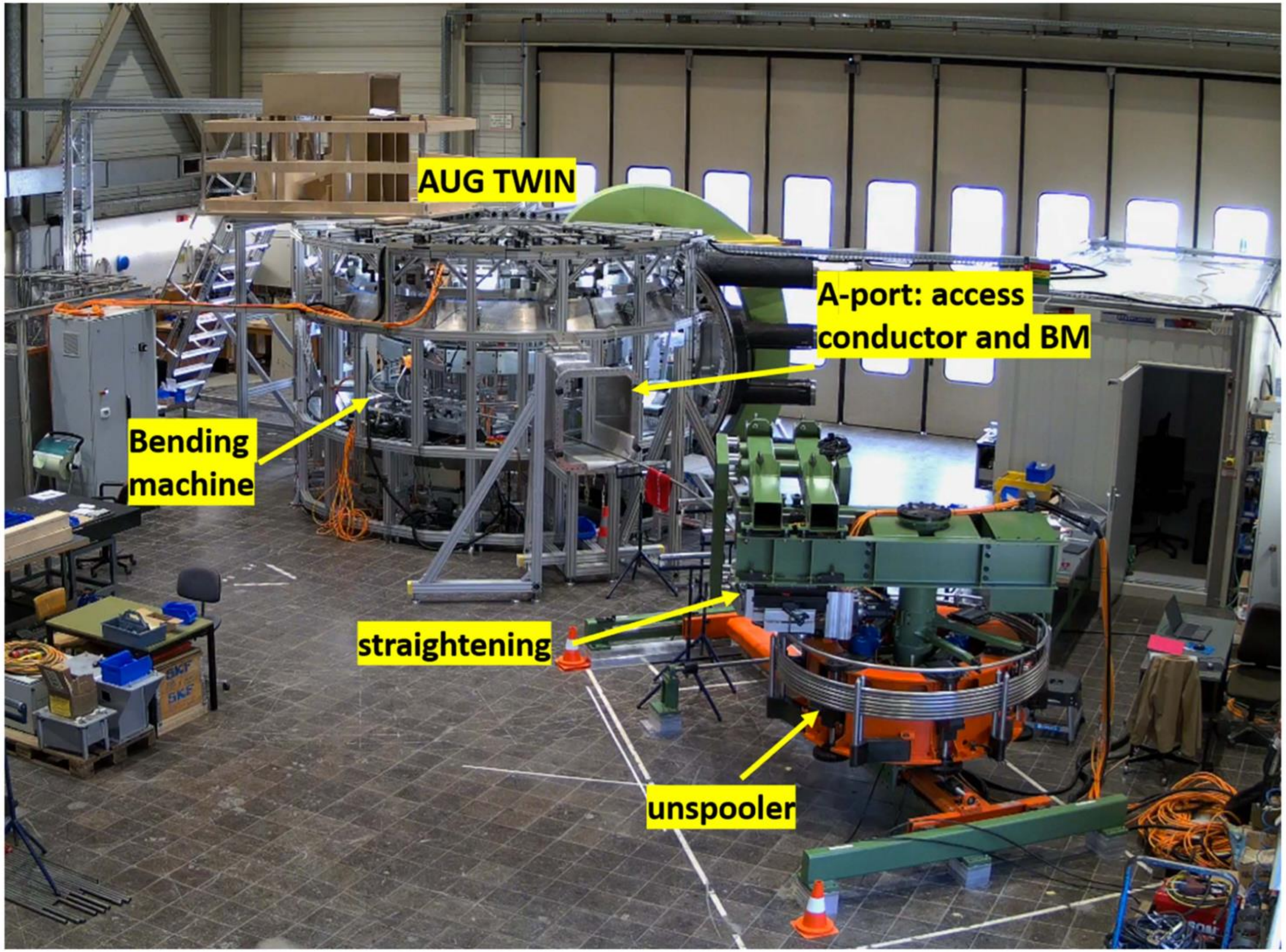


New upper divertor hardware



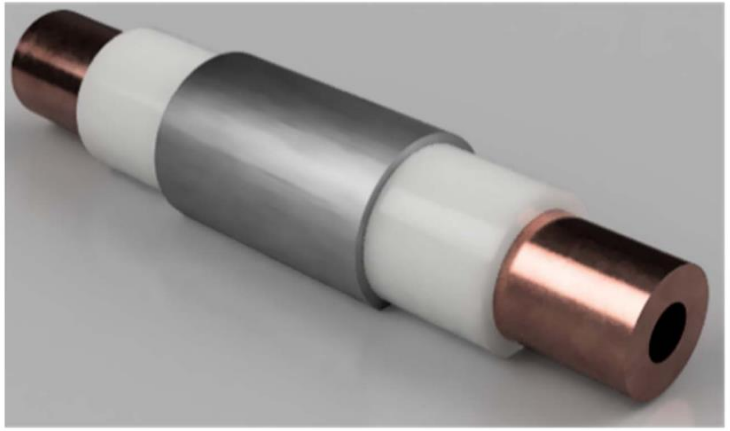
[Zammuto IEEE 2024]

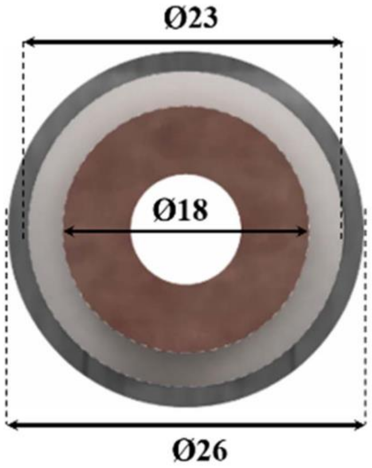
AUG mechanical twin

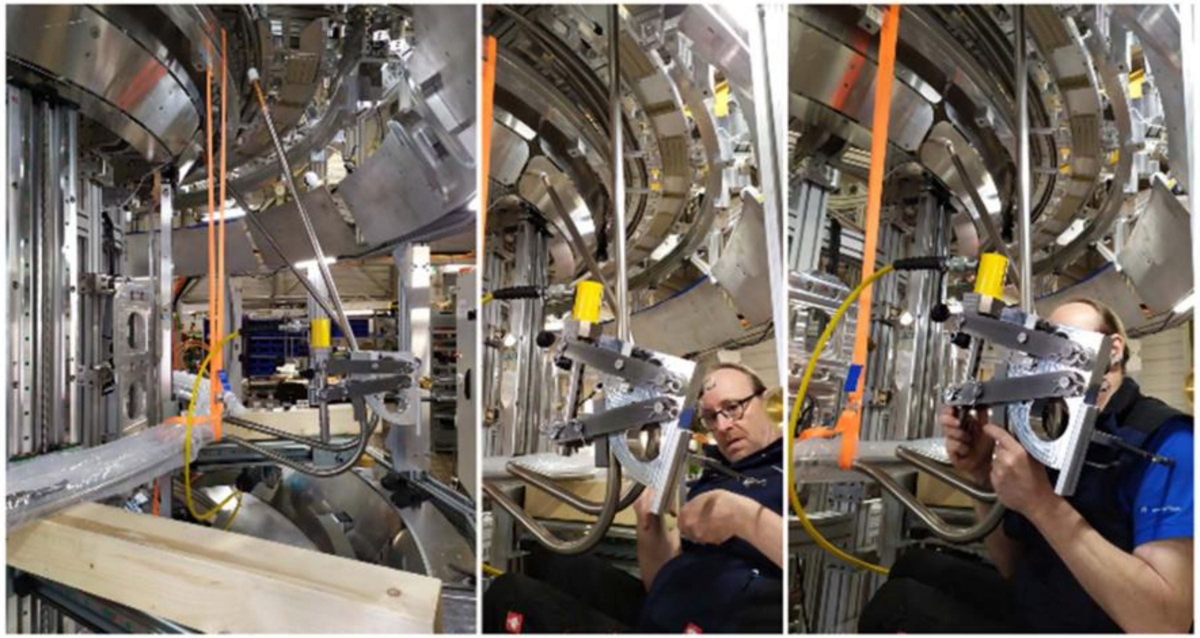


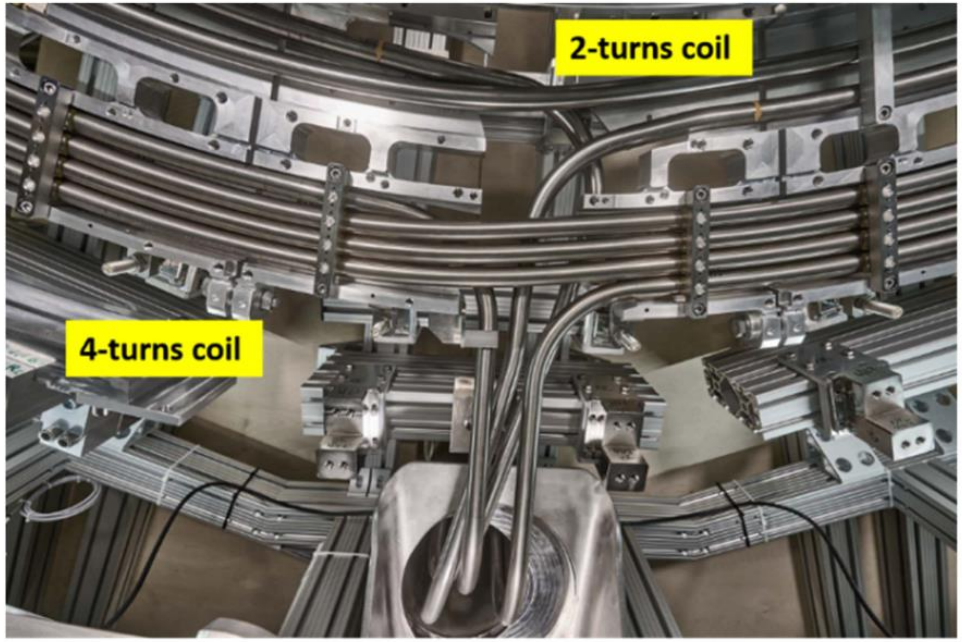
[Zammuto IEEE 2024]

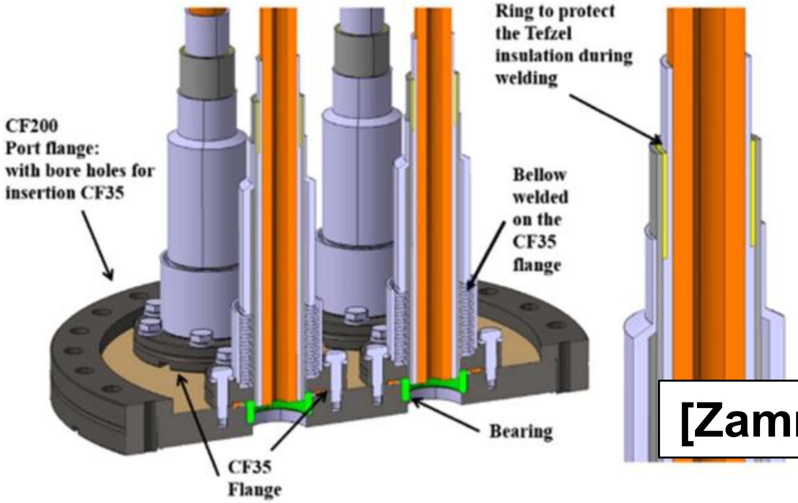
New upper divertor hardware

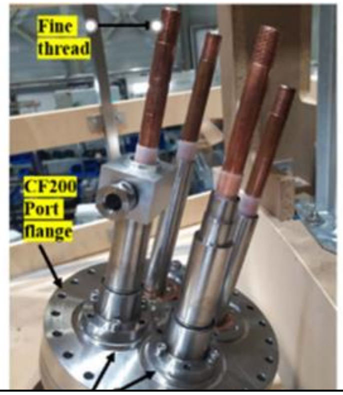






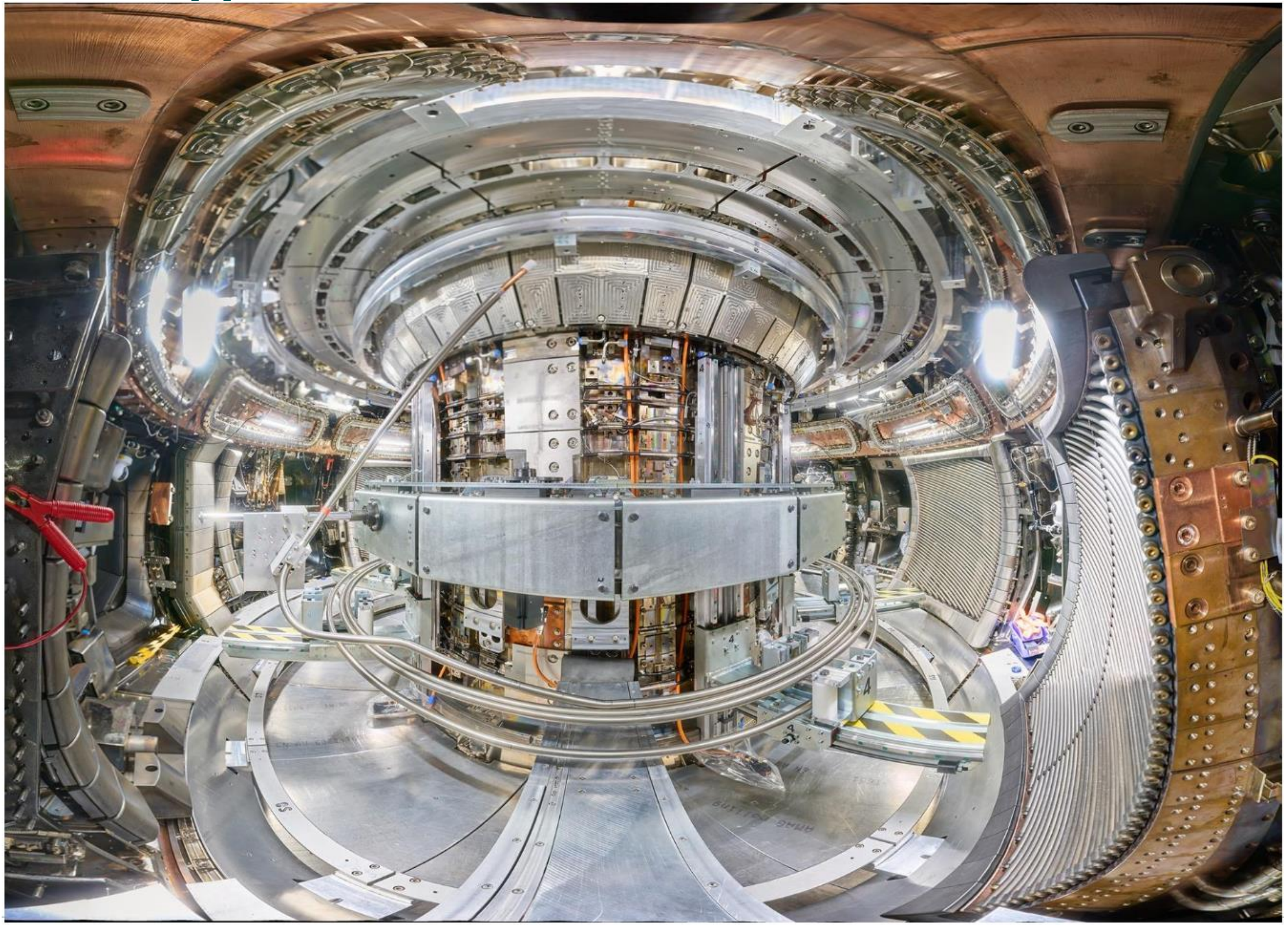


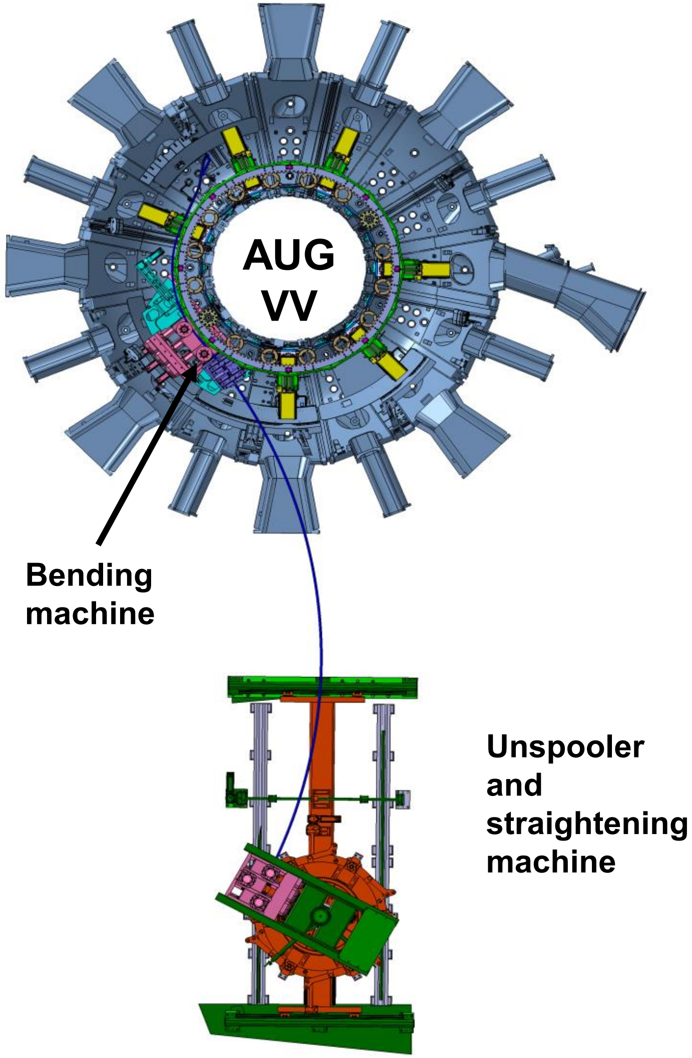




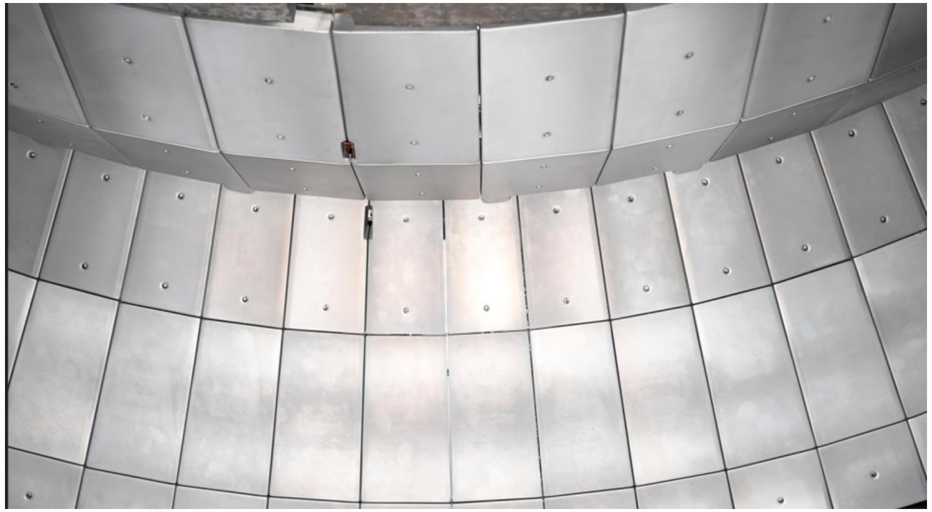
[Zammuto IEEE 2024]

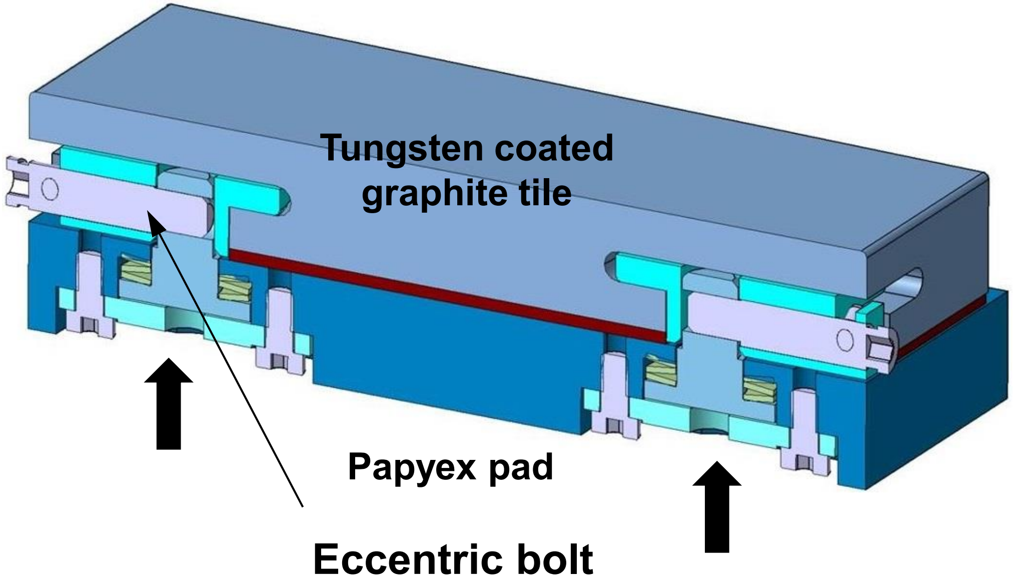
New upper divertor hardware

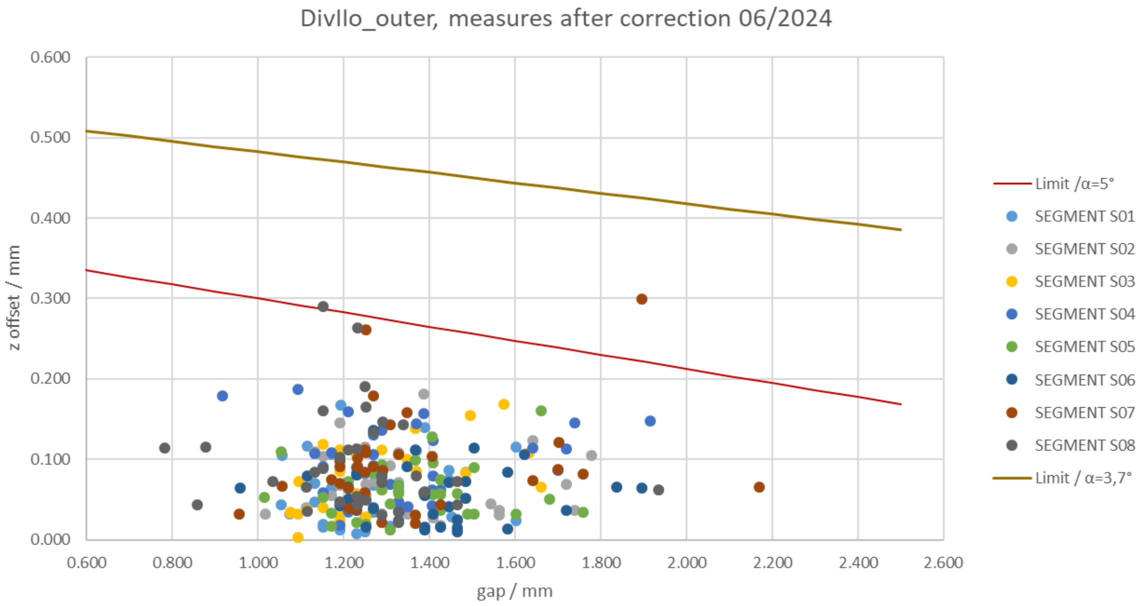




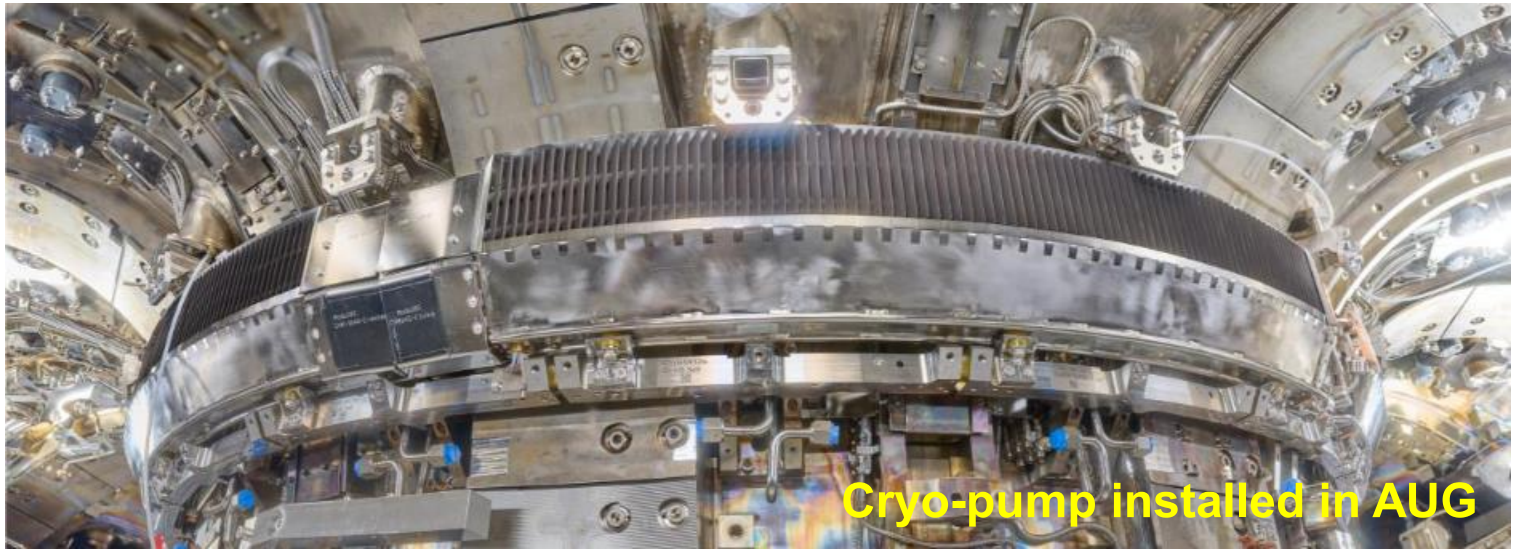
New upper divertor hardware

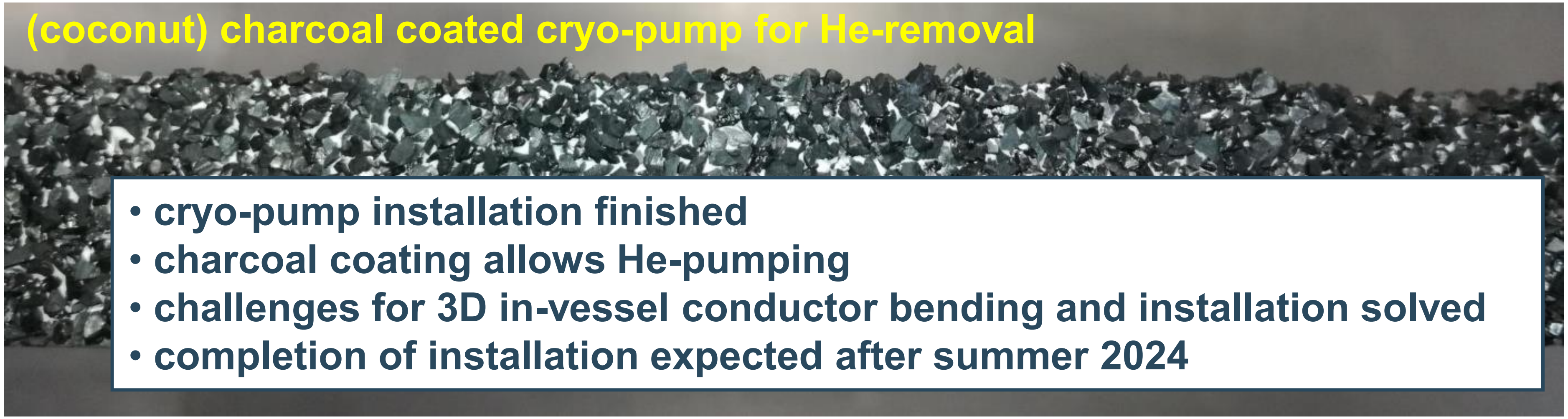






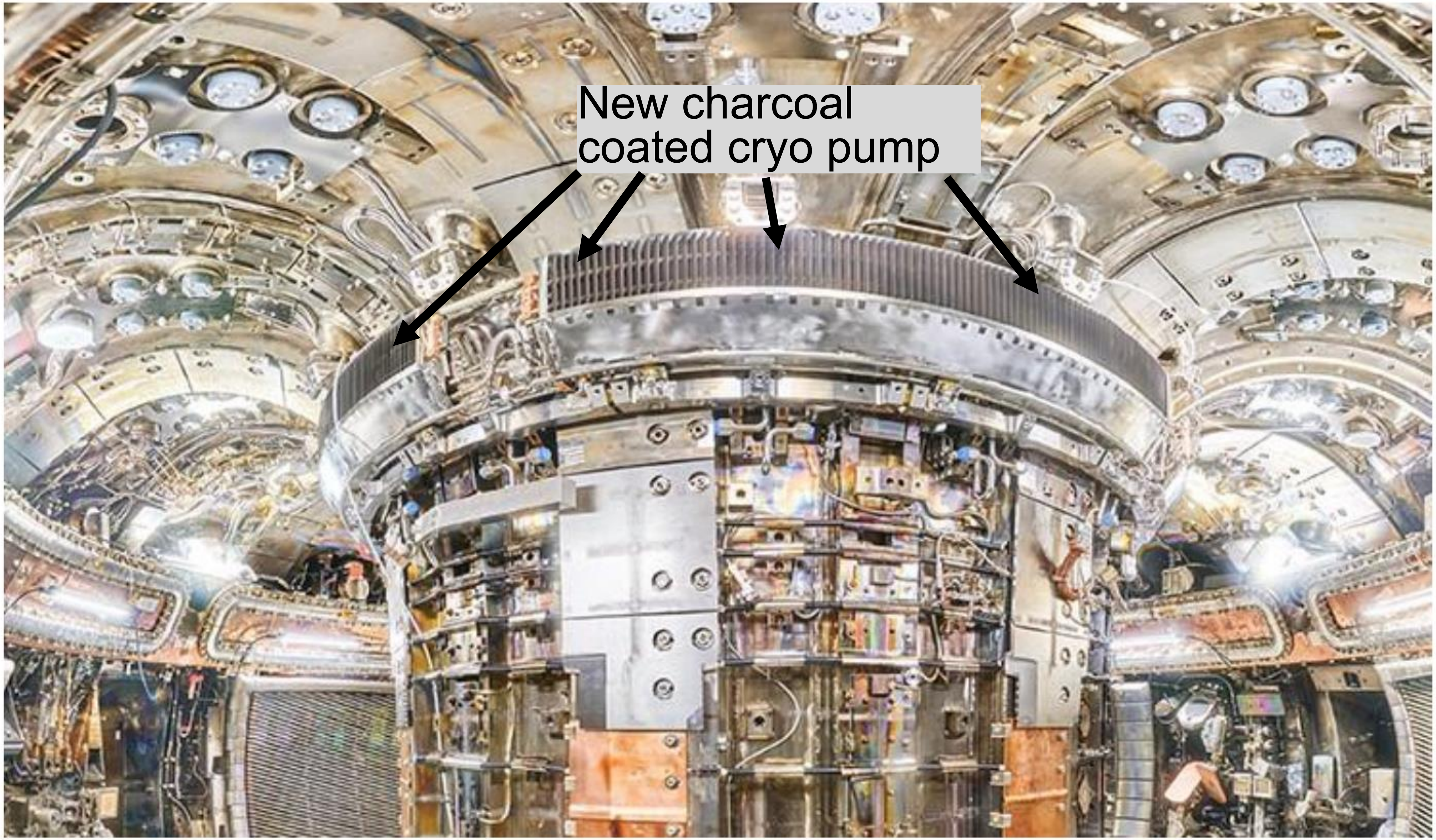
New upper divertor hardware





- cryo-pump installation finished
- charcoal coating allows He-pumping
- challenges for 3D in-vessel conductor bending and installation solved
- completion of installation expected after summer 2024

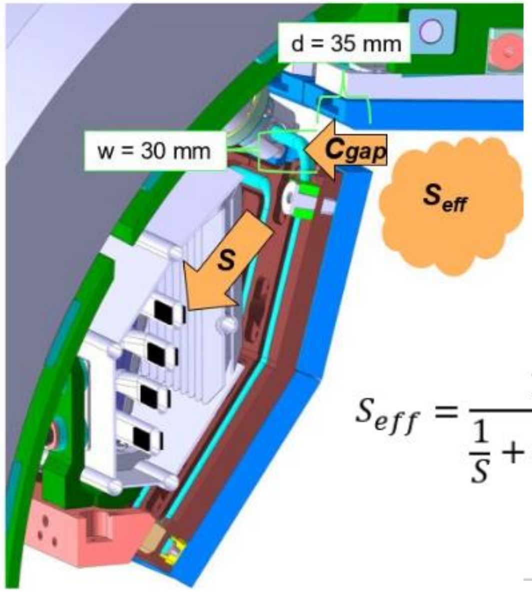
New upper divertor hardware



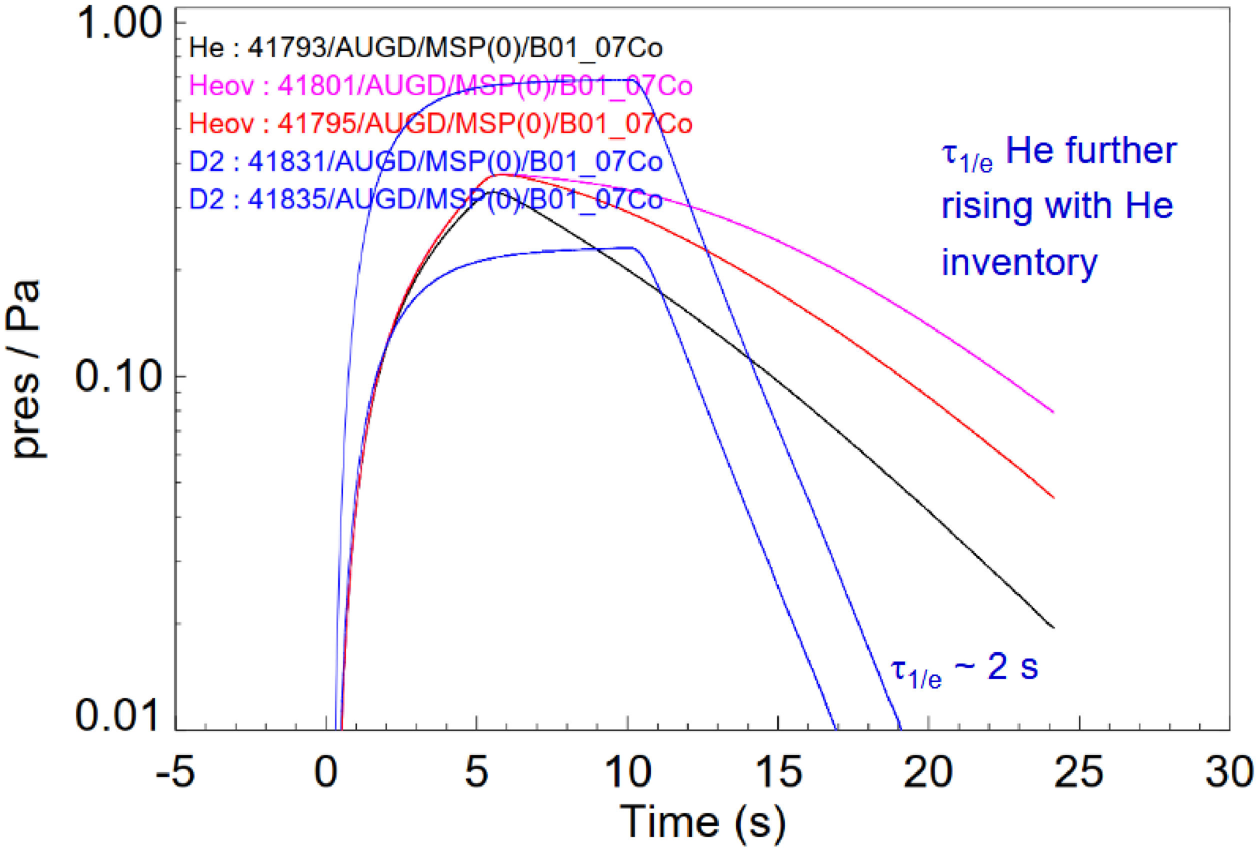
New upper divertor hardware

D_2 pumping speed regular and as expected

$S_{eff} = V / \tau \sim 20\text{-}25\ m^3/s$, $S_{gap} \sim 37\ m^3/s$

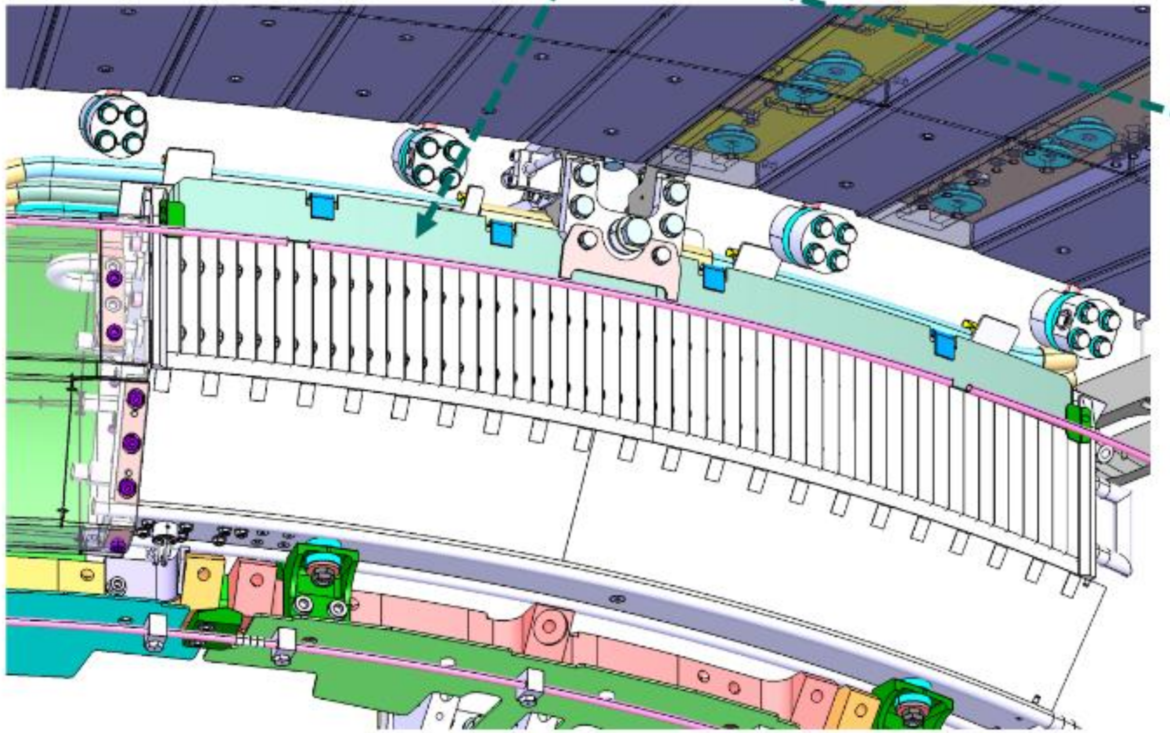


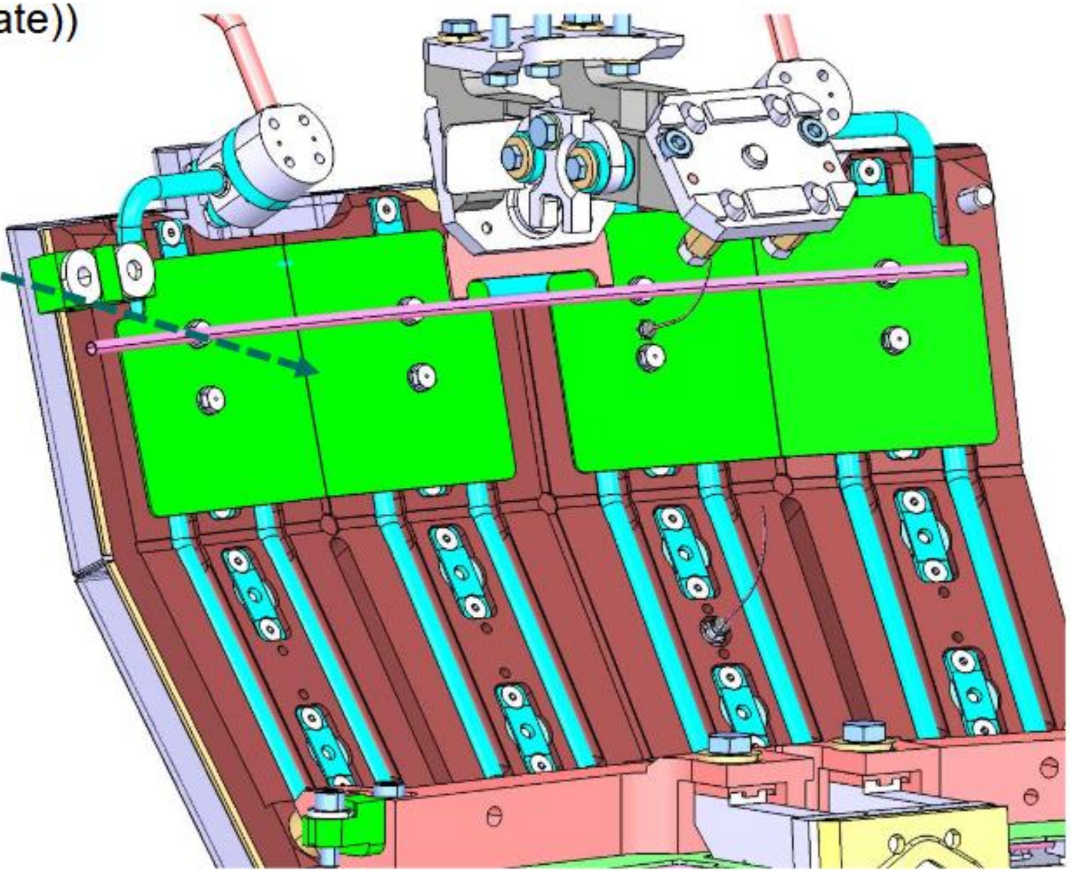
$$S_{eff} = \frac{1}{\frac{1}{S} + \frac{1}{C_{gap}}}$$



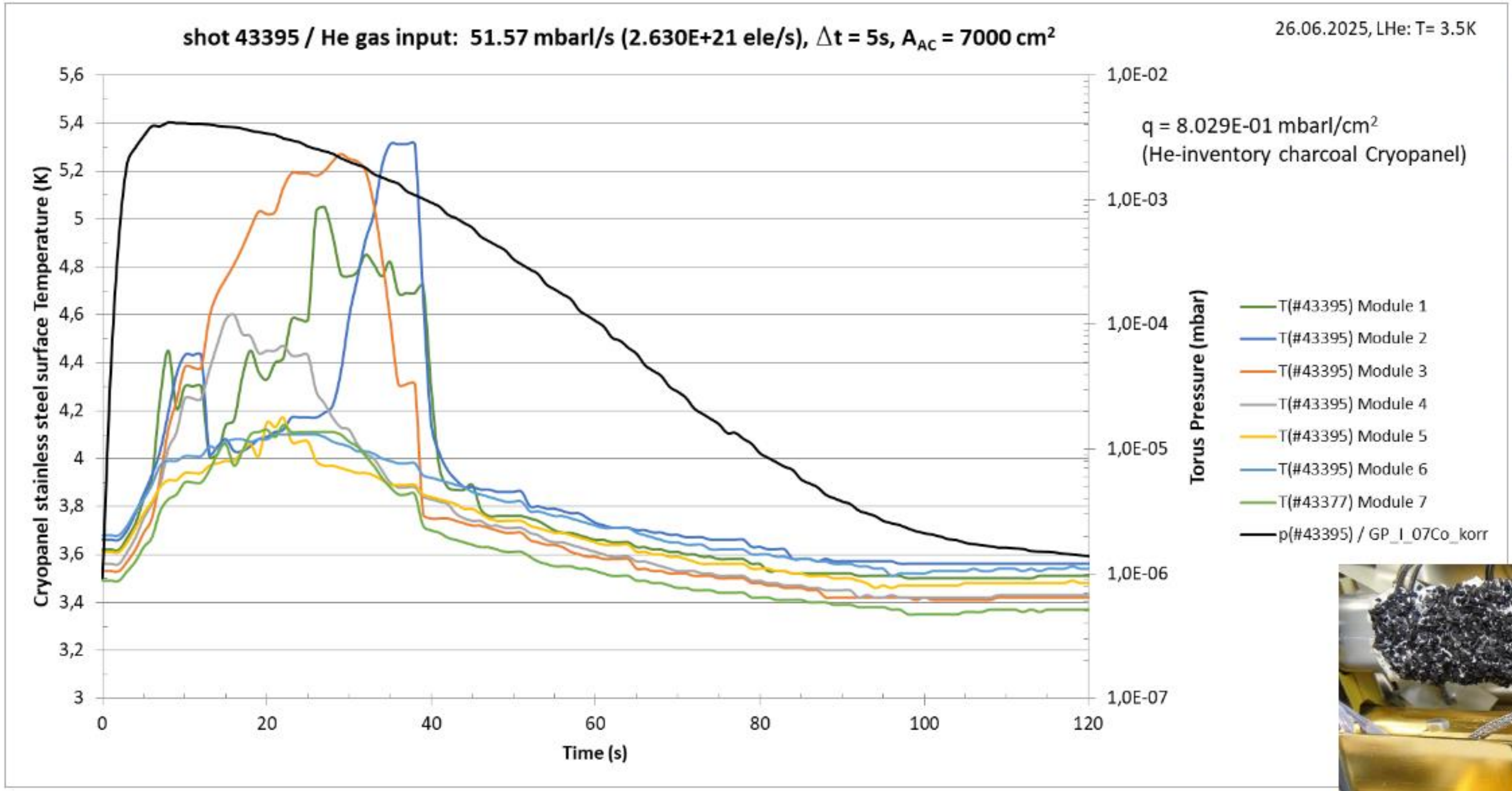
New upper divertor hardware

Proposal:
- Reduce the direct view on the He panel
- Add some ECRH absorber (TiO-AlO coating (160-180 mu on a SS plate))





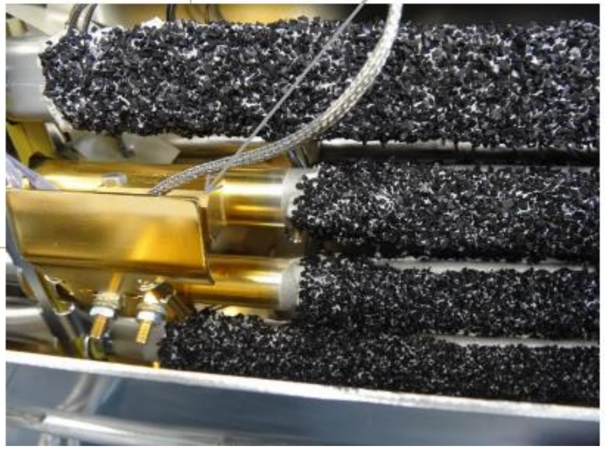
Cryopanel Temperature on stainless steel surface



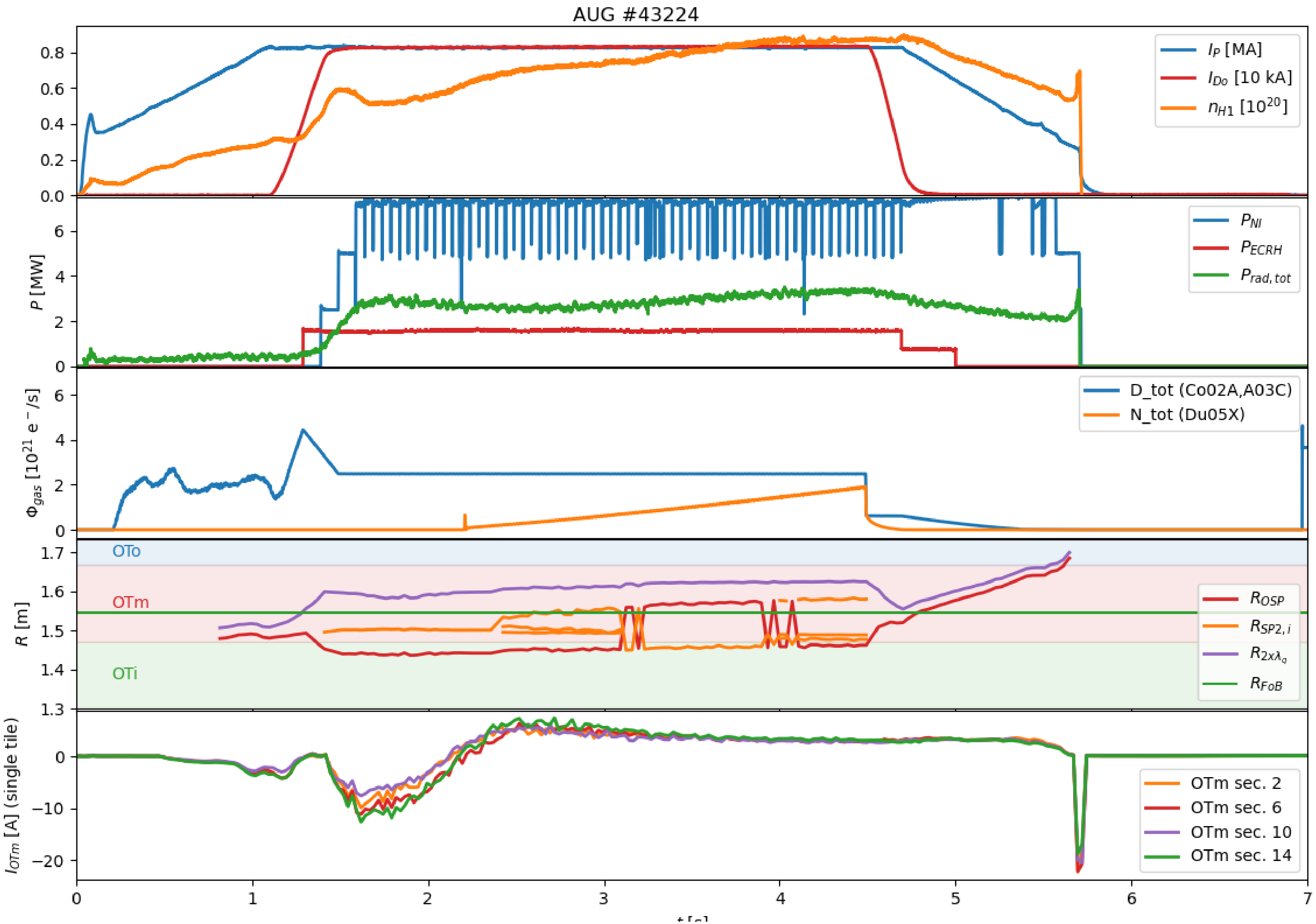
Coolant in the cryopanels:

Saturated Helium

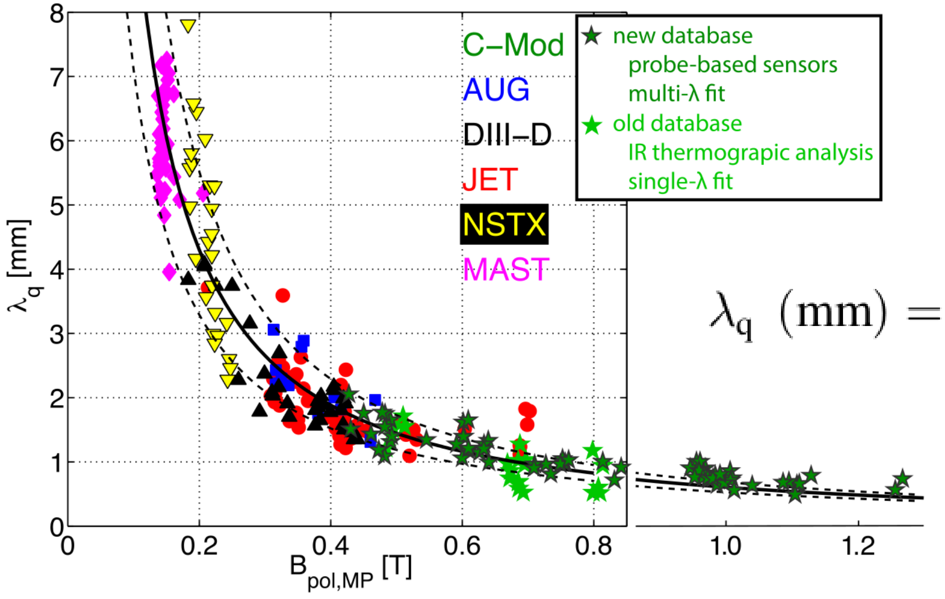
LHe sensor



Backup: 3D asymmetries (detachment?)

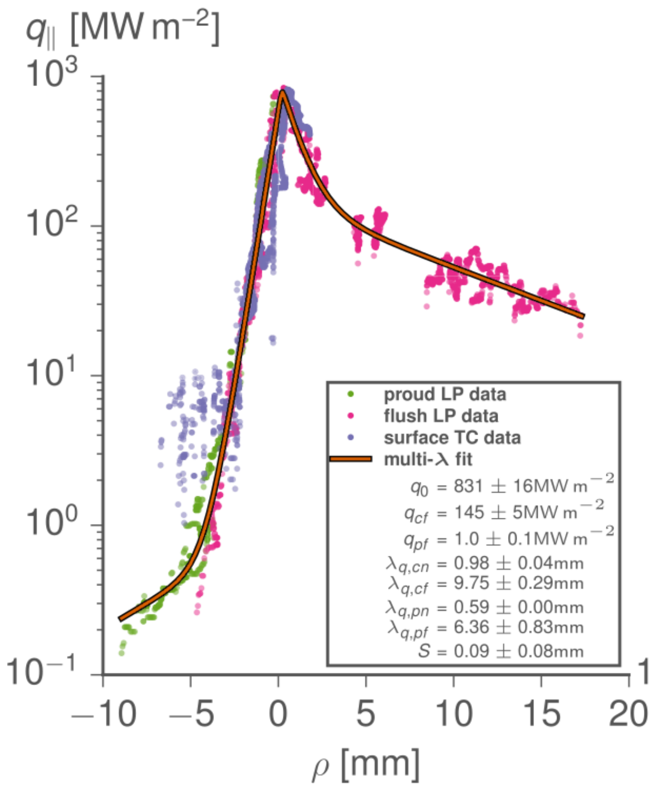


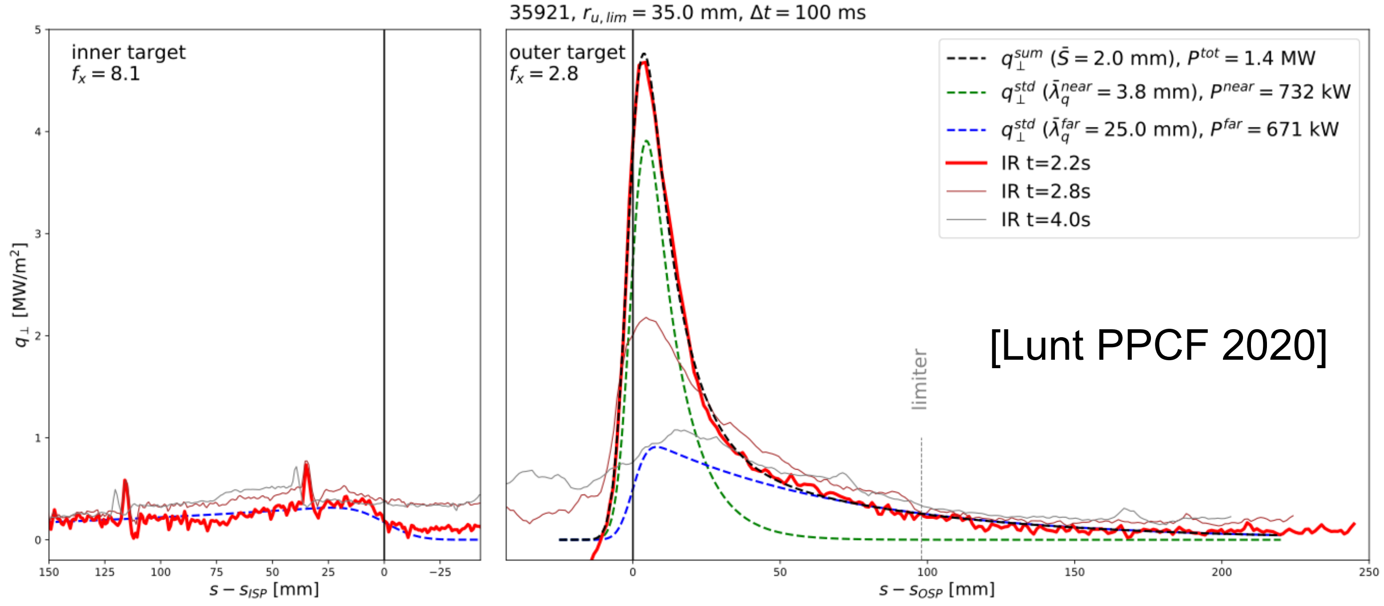
Near/Far-SOL fall-off length



$$\lambda_q \ (\mathrm{mm}) = (0.63 \pm 0.08) \times (B_p \ (\mathrm{T}))^{-1.19 \pm 0.08}$$

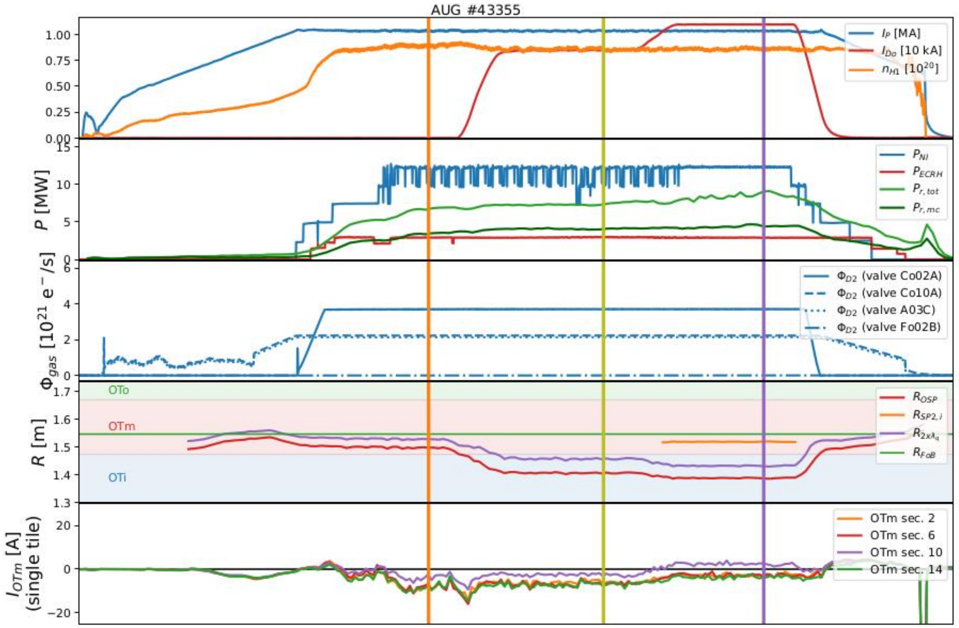
[Brunner NF 2018]

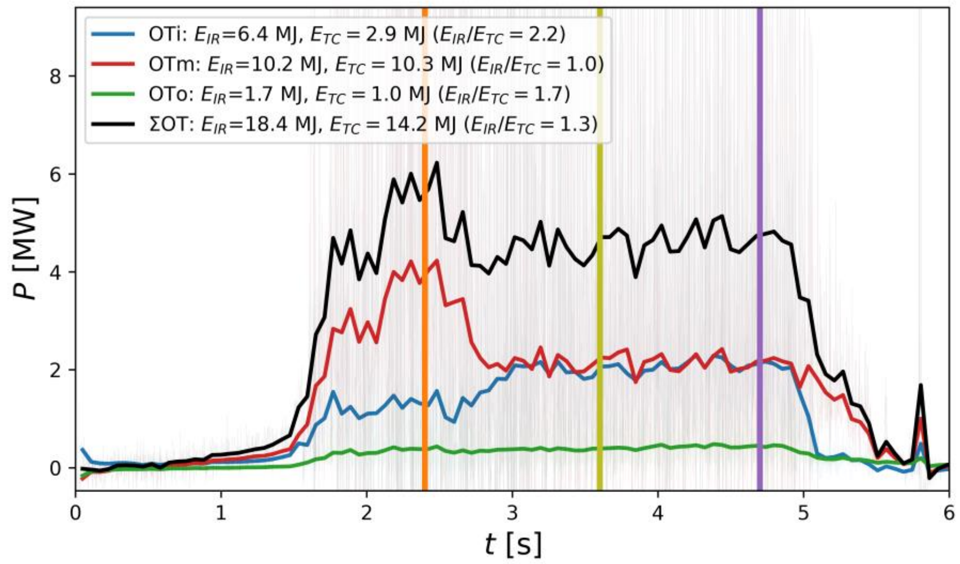




[Lunt PPCF 2020]

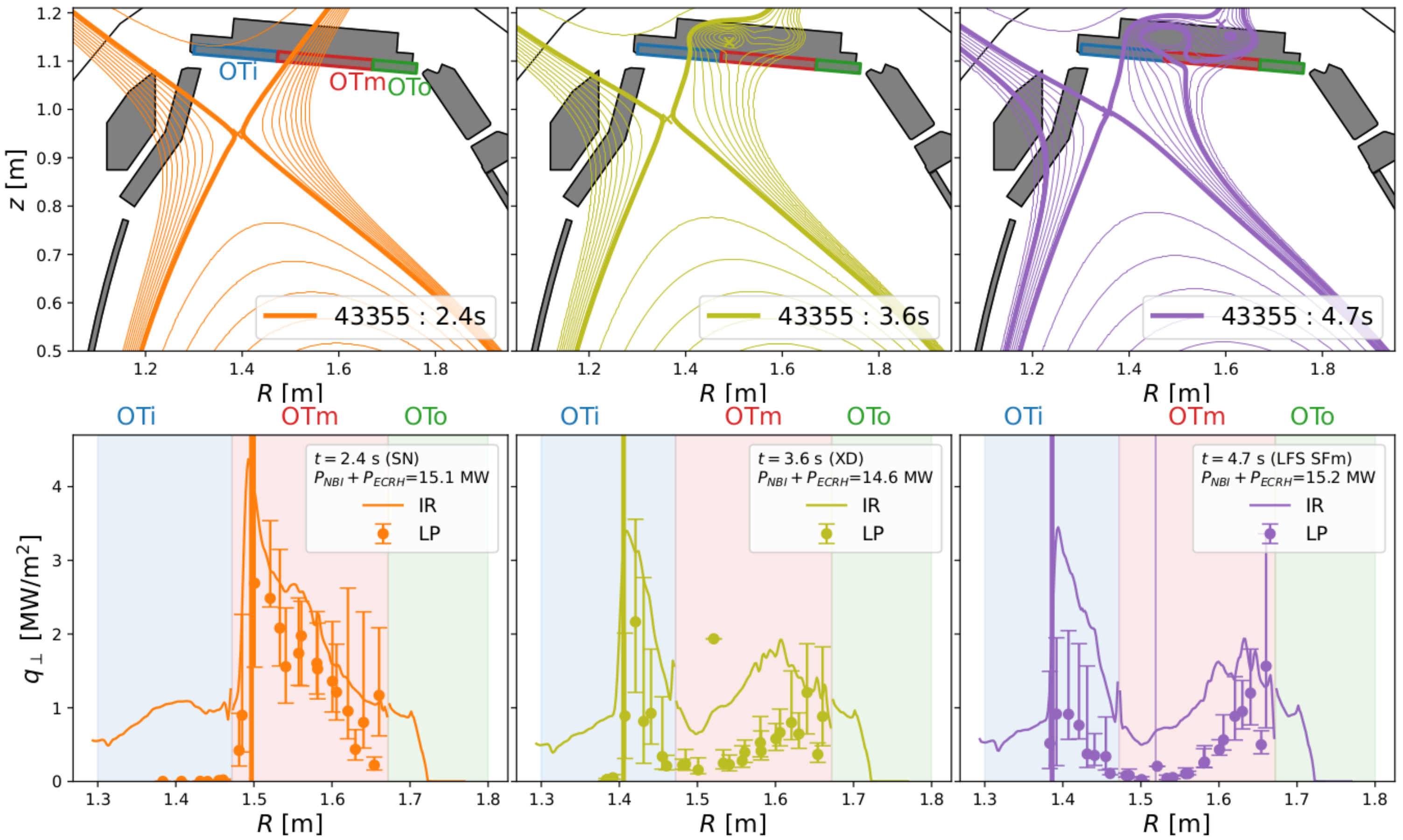
1 MA H-mode



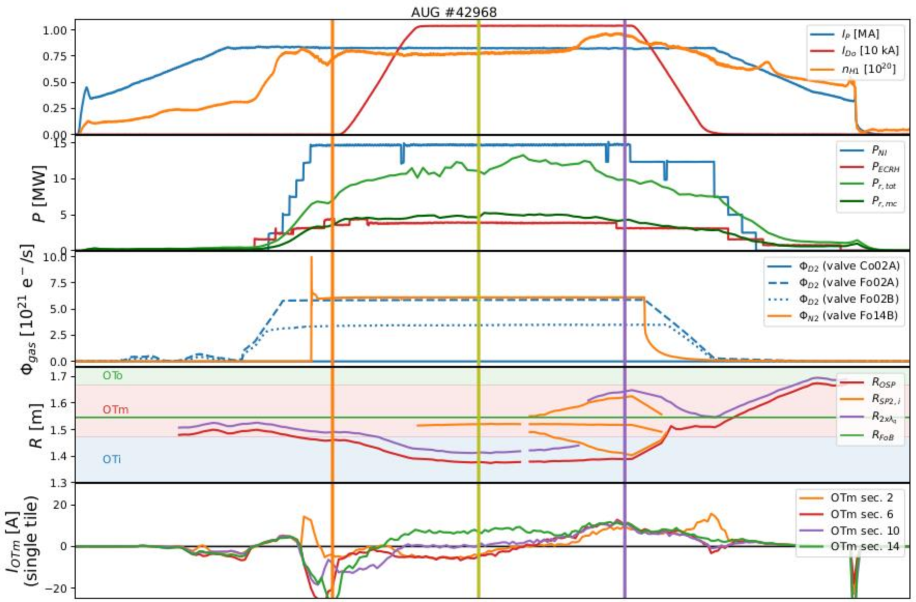


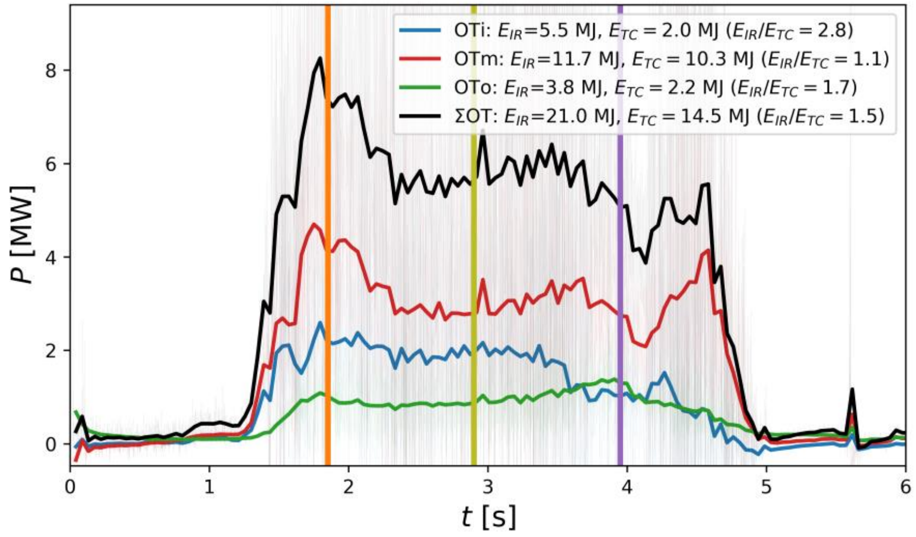
$\lambda_{q,Eich/Brunner}$=1.9 mm

$\Delta r_{u,x2}$=10.8 mm



800 kA H-mode strong gas puff

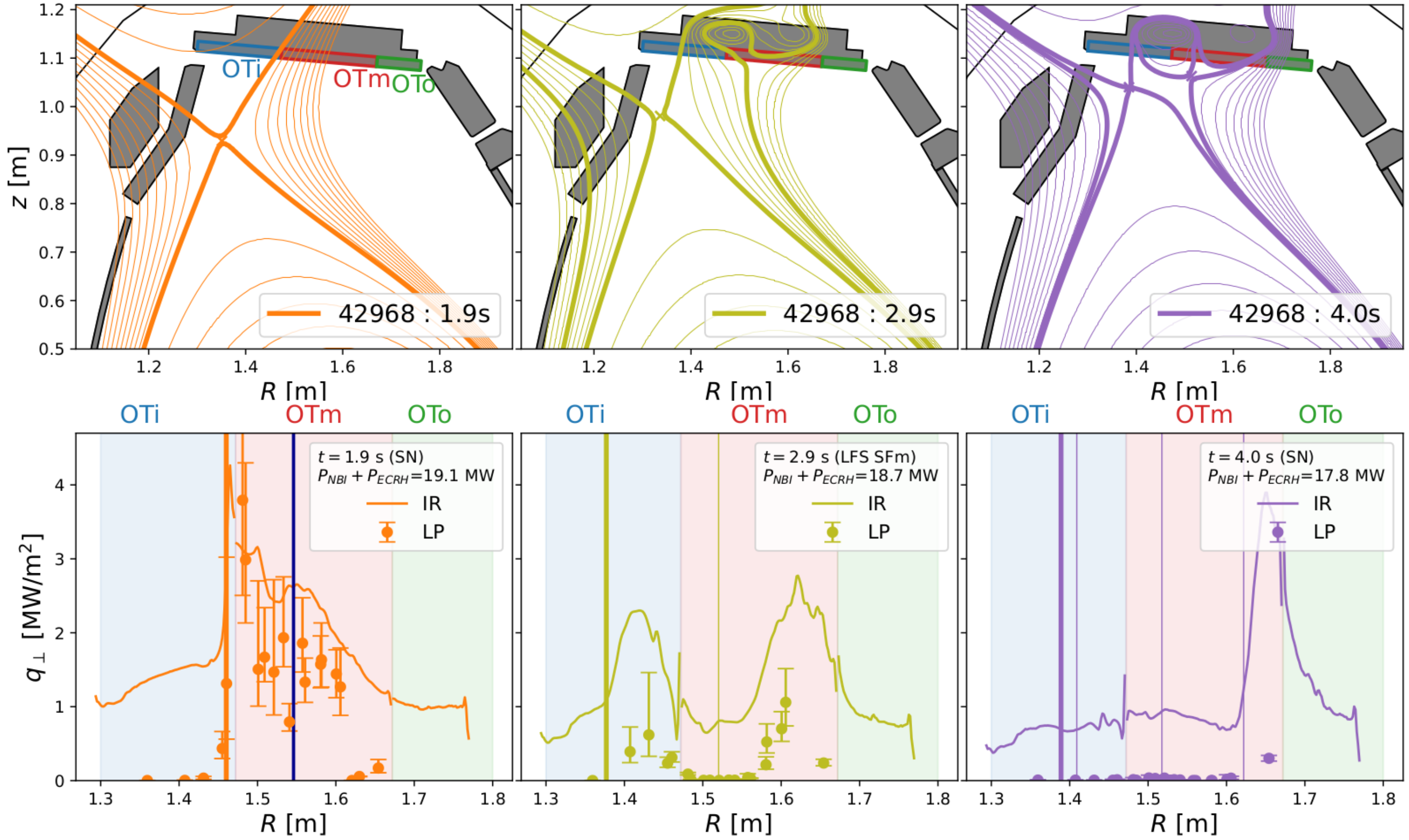




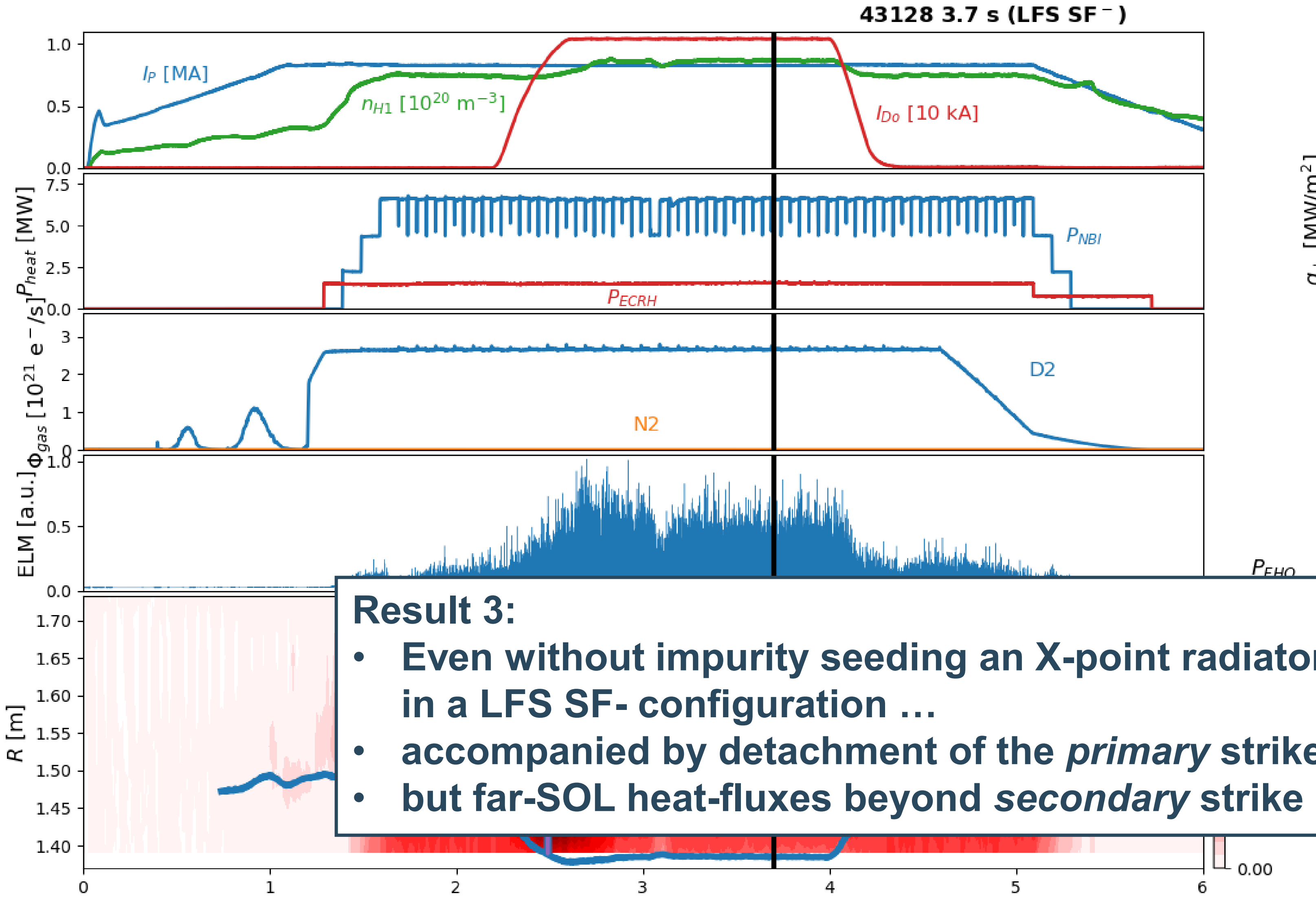
$\lambda_{q,Eich/Brunner}$=2.1 mm

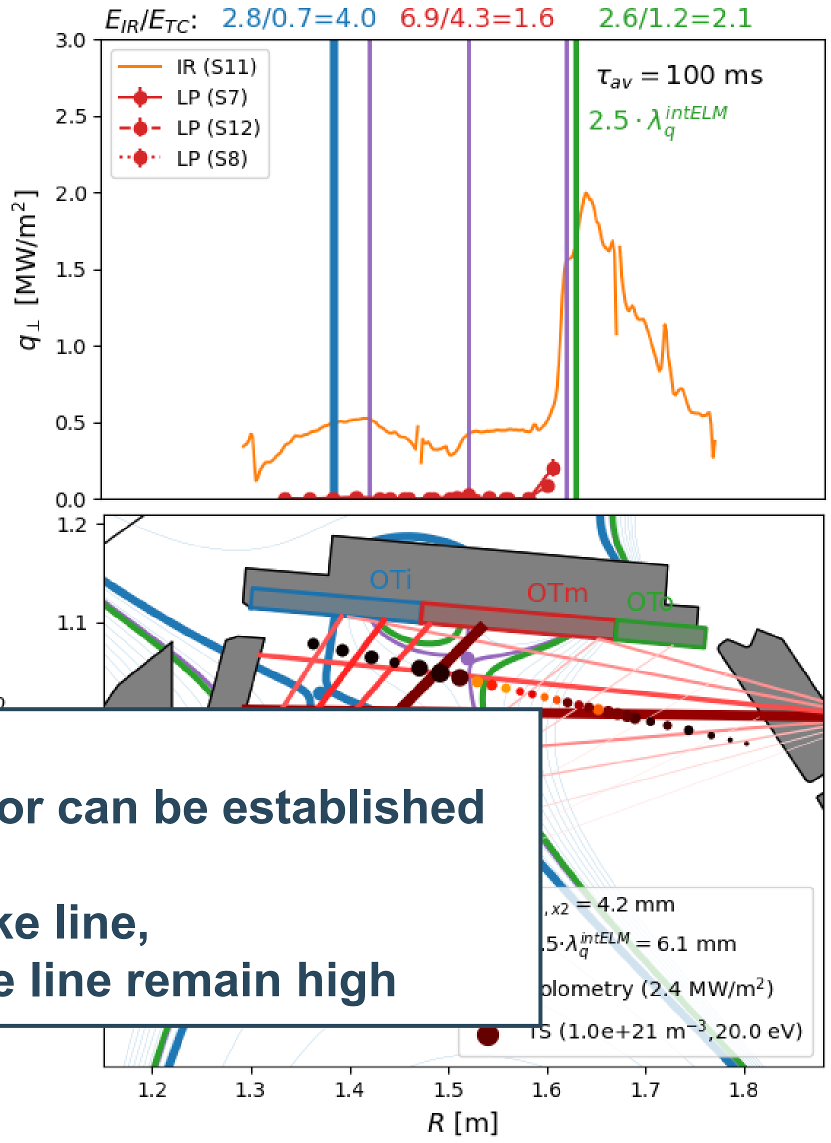
$\Delta r_{u,x2}$=11.8 mm

$\Delta r_{u,x2}$=1.2 mm



X-point radiator w/o impurity seeding in 800kA H-mode





Result 3:

- Even without impurity seeding an X-point radiator can be established in a LFS SF- configuration …
- accompanied by detachment of the *primary* strike line,
- but far-SOL heat-fluxes beyond *secondary* strike line remain high