NSTX-U

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Relation of pedestal stability regime to the behavior of ELM heat flux footprints in NSTX-U and DIII-D

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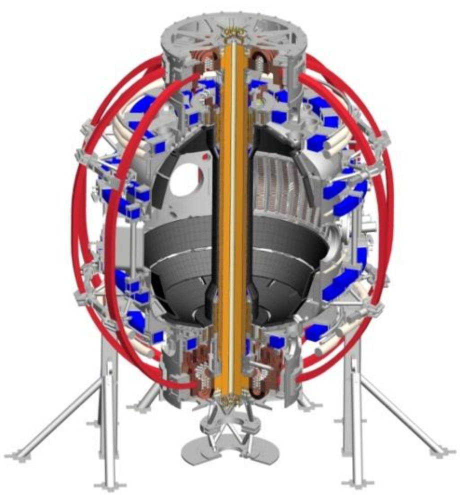

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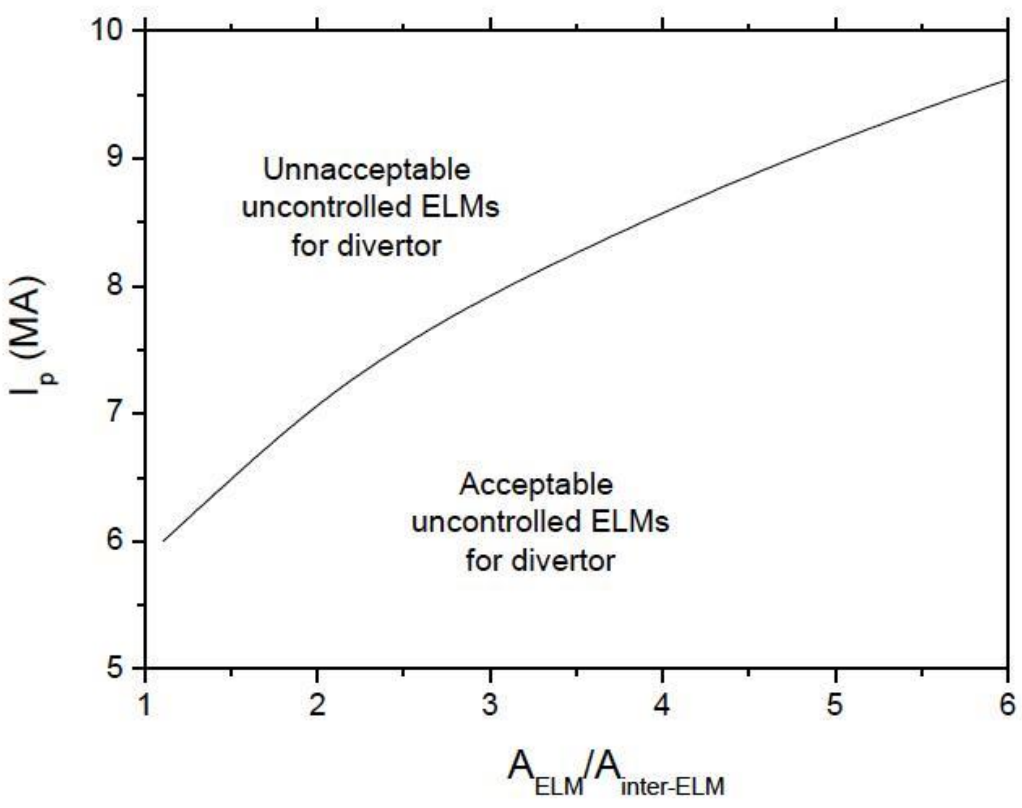
Motivation

- ELM heat flux characterization is important to determine requirement of ELM control system performance in future machines
- Relationship of wetted area (A_{wet}) to the size of ELM energy loss directly impacts peak heat flux (q_{peak})
- Larger A_{wet} allows larger total ELM energy loss (ΔE_{ELM}) to be acceptable, however uncertainty on A_{wet} remains unresolved yet
- Relation of ELM stability regime with different toroidal mode number to A_{wet} behavior

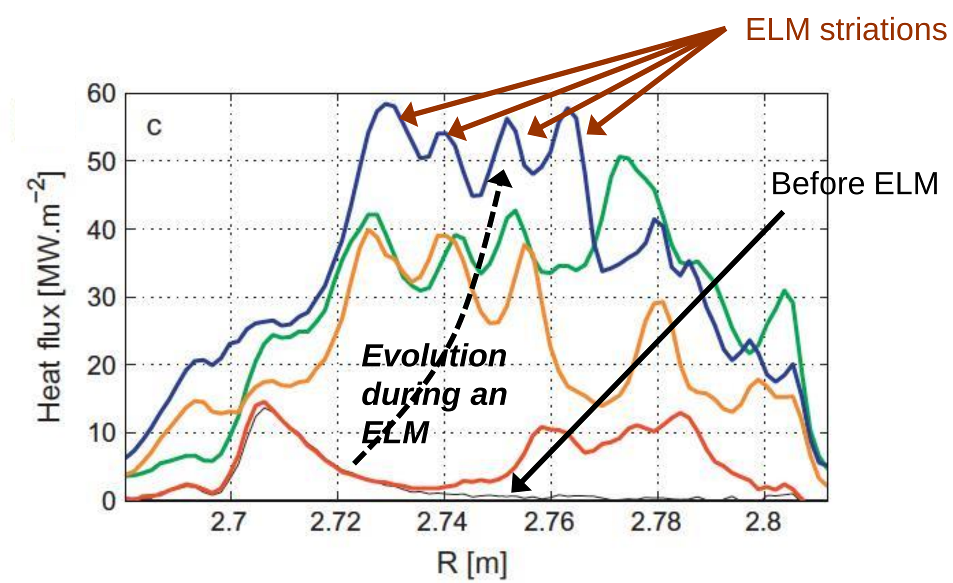
Acceptable ELMs for various I_p for ITER are predicted



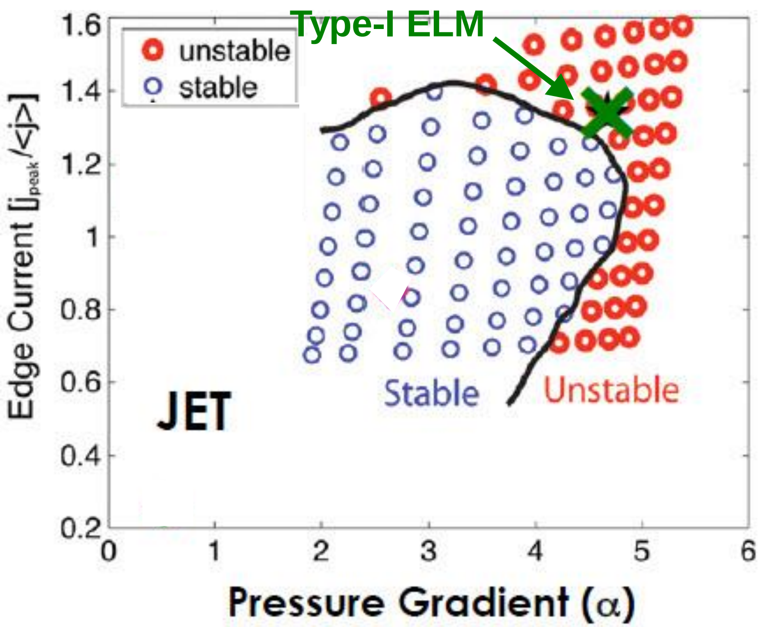
A. Loarte, NF 2014

- A_{wet} increase by up to a factor of 6 has been observed in JET
- I_p is key parameter for pedestal pressure, therefore ELM energy loss
- Necessary A_{wet} increase for a range of I_p to avoid divertor damage by ELMs

Example of ELM striations to broaden heat flux profile in JET



S. Devaux, JNM 2011



S. Saarelma (PPCF 2009)

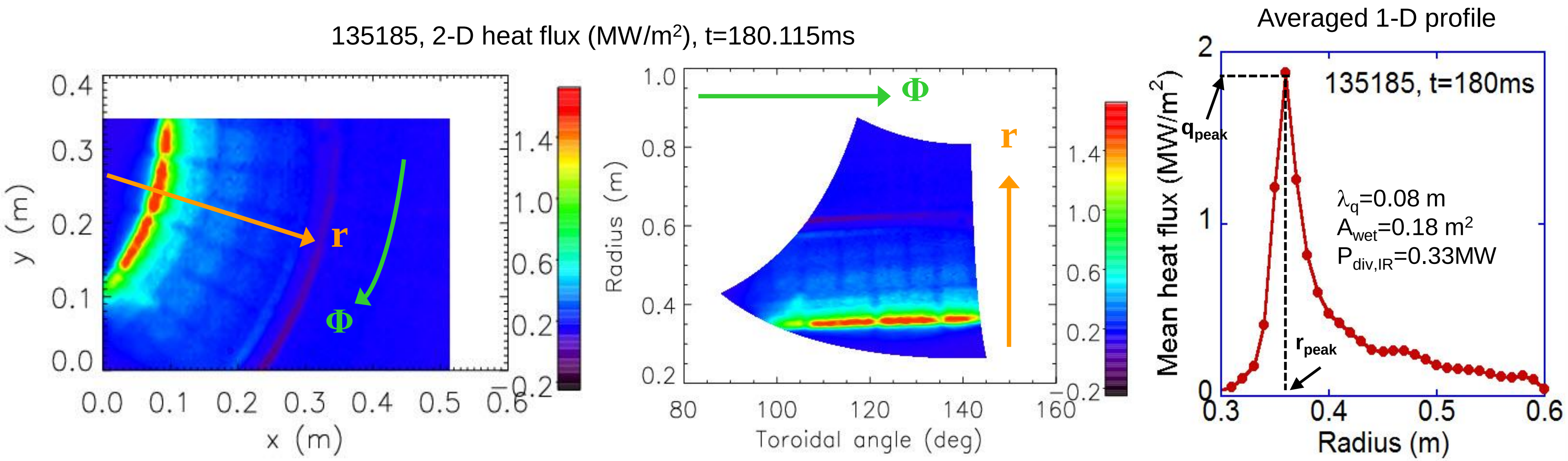
- Number of striations, i.e. ELM filaments, observed on the outer divertor target increases from 3 – 5 to 10 – 15 during the ELM rise time → consistent with peeling-ballooning ELMs with n~15 from stability analysis

- A_{wet} significantly increases compared to inter-ELM value, by 3-4x

NSTX data

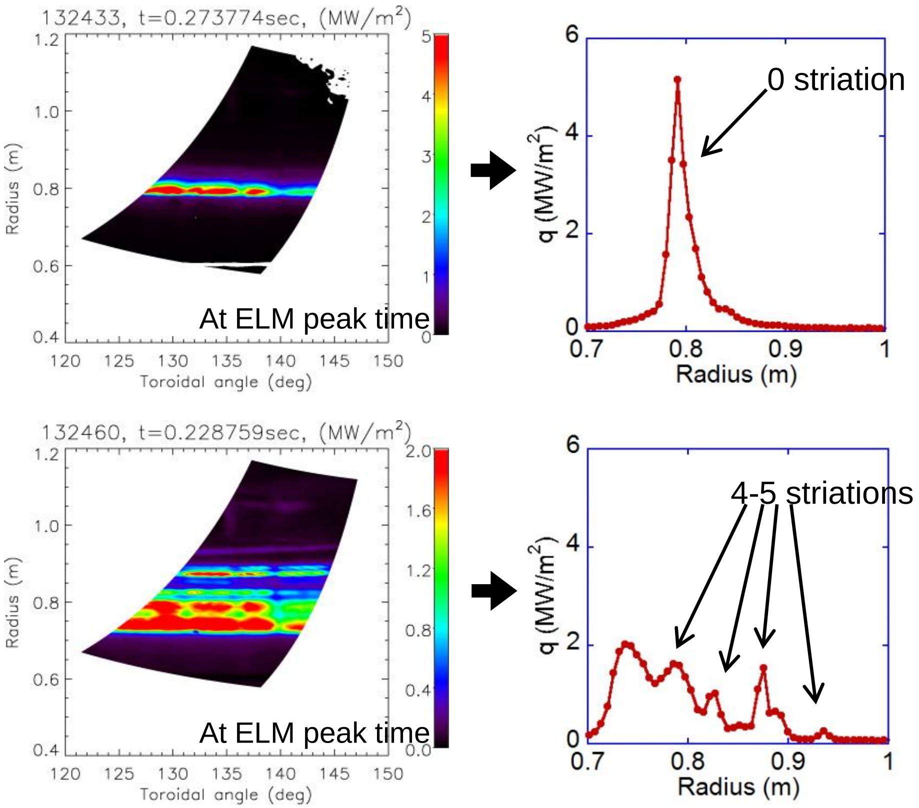
Definition of heat flux footprint parameters

Outer divertor in LSN

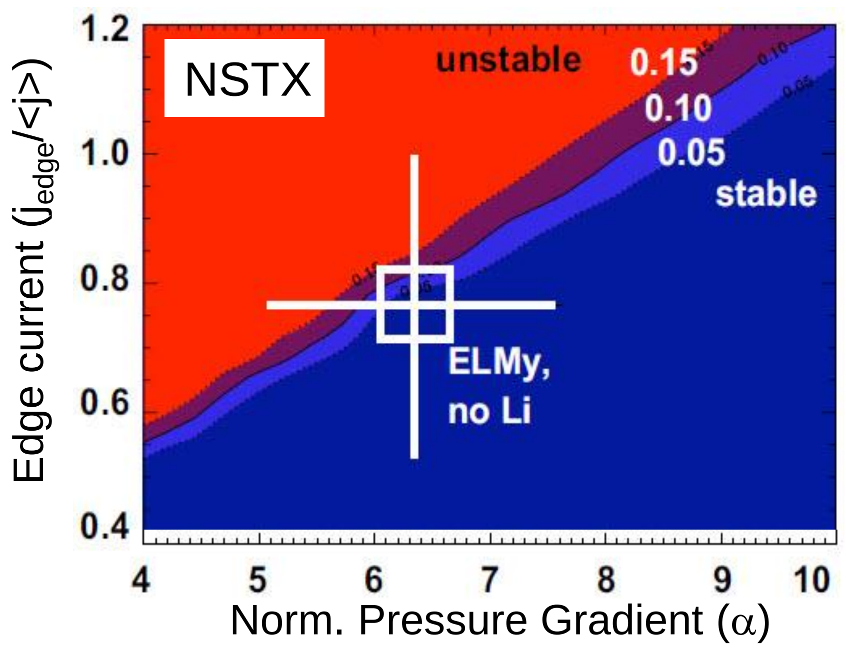


- 2-D heat flux is averaged out to produce 1-D profile
- Total deposited power to divertor $P_{div,IR} = \int 2\pi r \bar{q}_{tor}(r)dr$
- Wetted area $A_{wet} = P_{div,IR} / \bar{q}_{peak,tor}$
- Integral heat flux width $\bar{\lambda}^{int}_{q,tor} = P_{div,IR} / 2\pi r_{peak} \bar{q}_{peak,tor} = A_{wet} / 2\pi r_{peak}$
- Total deposited energy to divertor $W_{div,IR} = \int P_{div,IR} dt$

Example of heat flux profiles with 0 and 4-5 ELM striations show opposite heat deposition pattern in NSTX



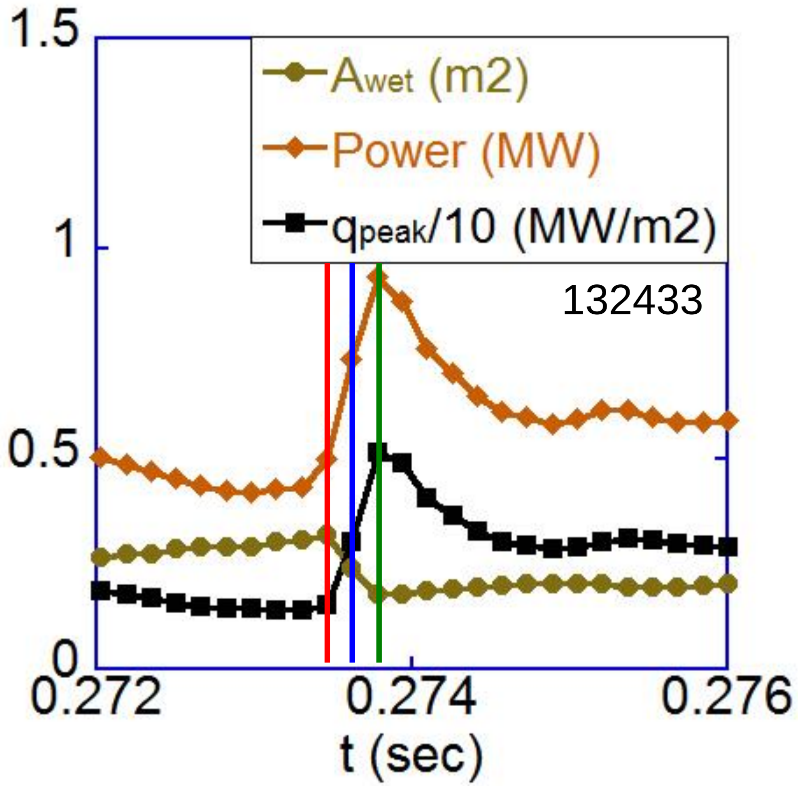
J-W. Ahn, NF 2014

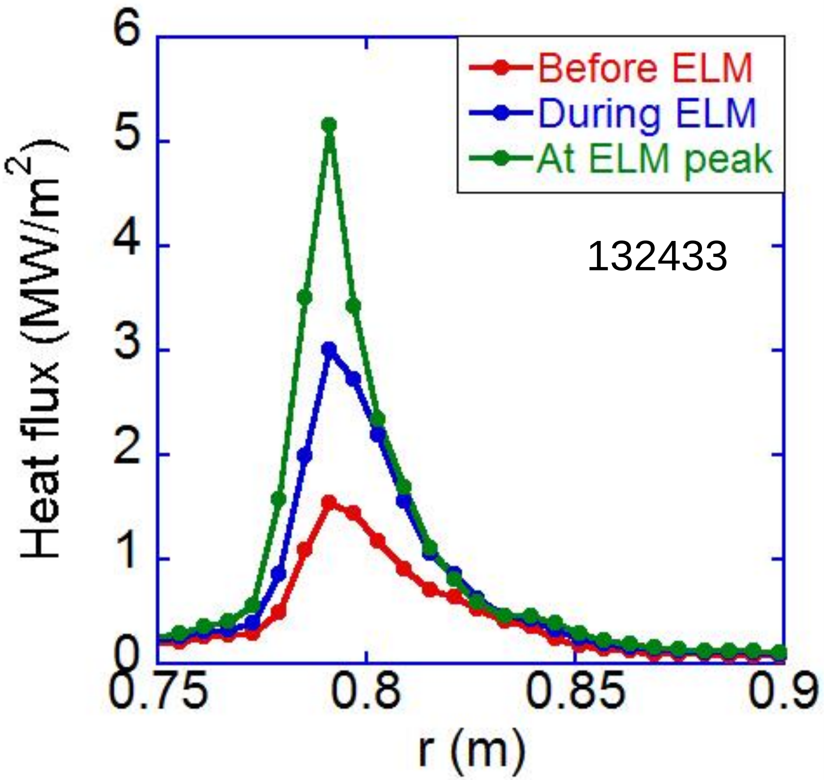


R. Maingi (PRL 2009), D.P. Boyle (PPCF 2011)

- An ELM with no striations → peaked heat flux profile with high q_{peak} (> 5MW/m²)
- 4-5 ELM striations spread heat over a larger area, reducing q_{peak} (~ 2MW/m²)
- NSTX ELMs lie against peeling side with n=1 – 5

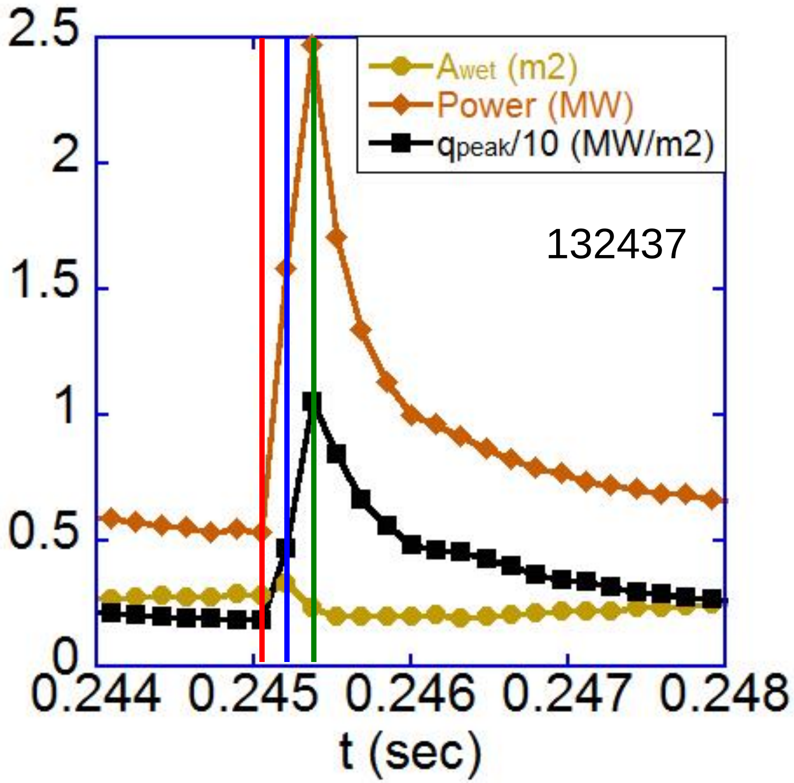
ELM heat flux profile with 0 striation – A_{wet} decreases most significantly

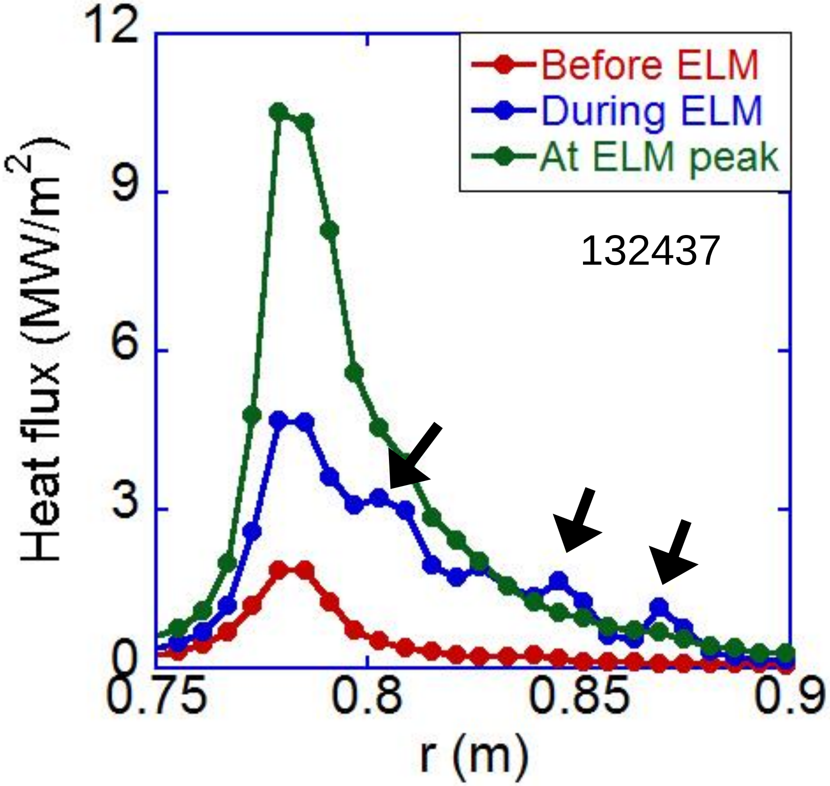




- No striation seen during the whole ELM rise time
- A_{wet} decrease is generally largest, up to ~40 – 50%
- q_{peak} keeps rising, A_{wet} continues to decrease during the ELM rise time

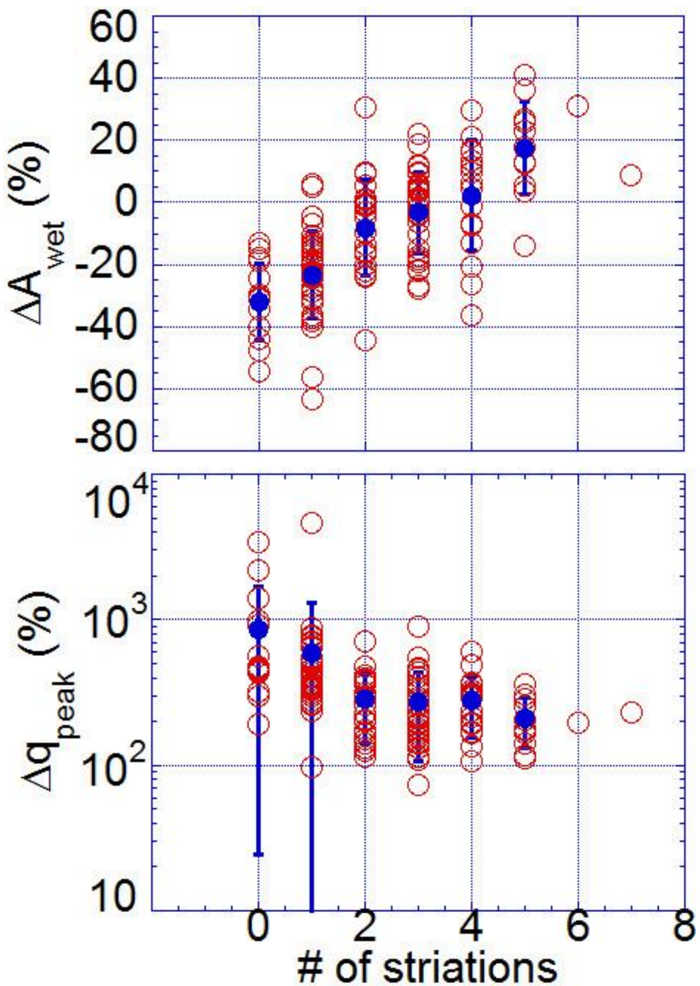
ELM heat flux profile with 3 striations – A_{wet} begins to rise





- 3 – 4 filaments slightly raises A_{wet} but at a later stage striations disappear and A_{wet} decreases while power goes up
- Generally, A_{wet} can either increase or decrease for 3 striations

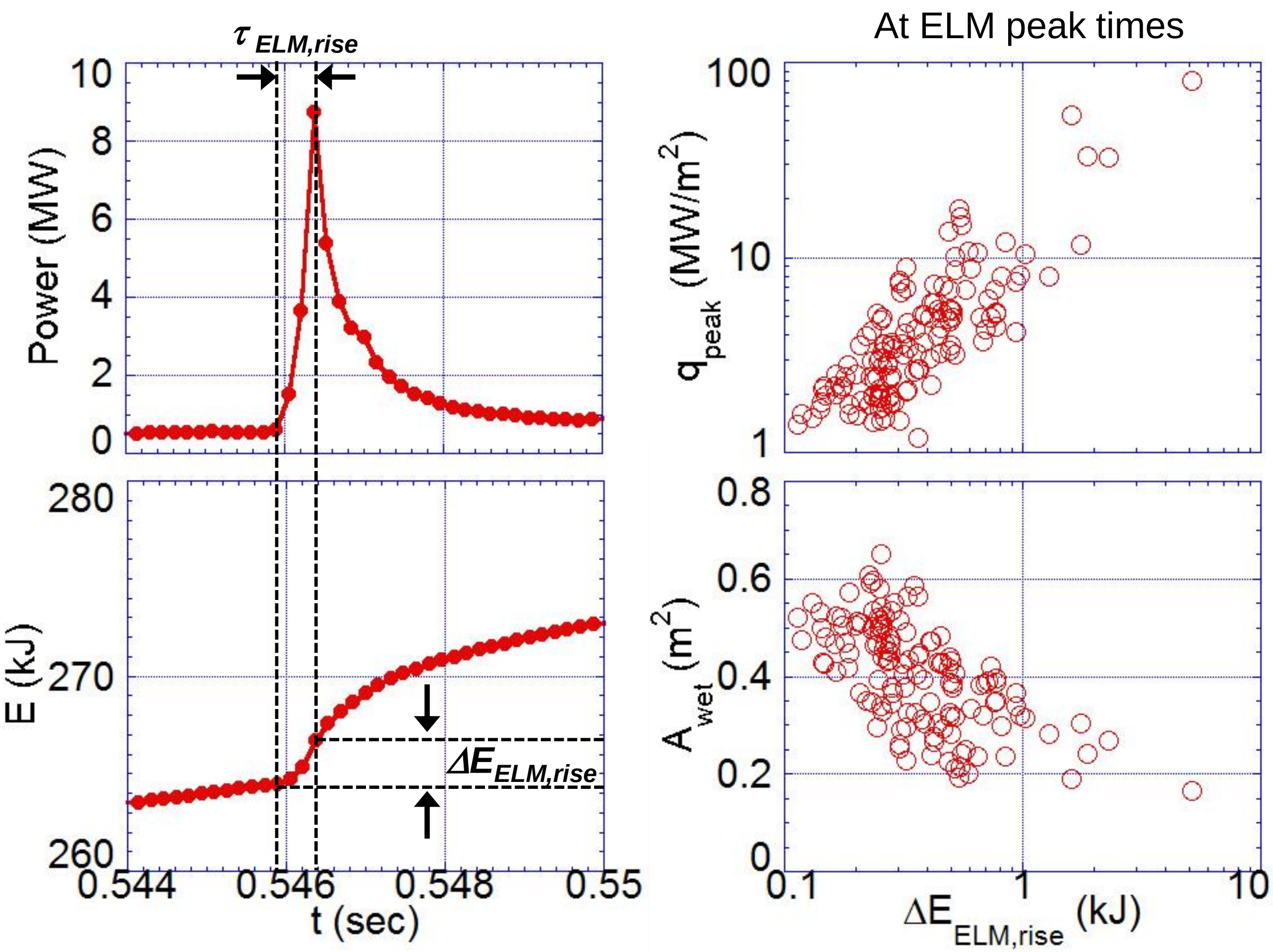
A_{wet} increases and q_{peak} decreases with the number of observed ELM striations



J-W. Ahn, NF 2014

- Data for a total of 135 ELMs from a weaker plasma shape (κ~1.9, δ~0.5)
- Each data point for ELM peak time. ΔA_{wet} and Δq_{peak} for changes w.r.t. inter-ELM value
- A_{wet} increases and q_{peak} decreases with the # of striations
- Even for the broadening case, spreading of heat is not sufficient

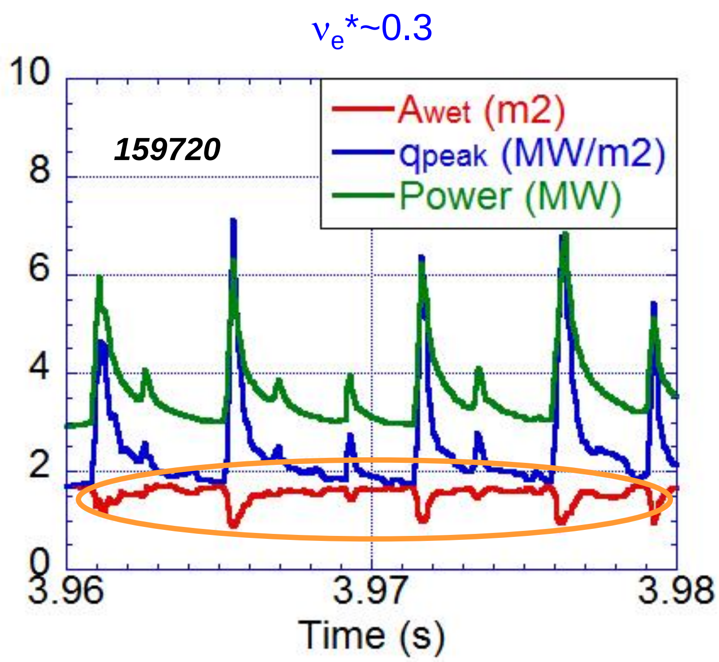
A_{wet} and q_{peak} change with the ELM size is unfavorable for NSTX ELMs

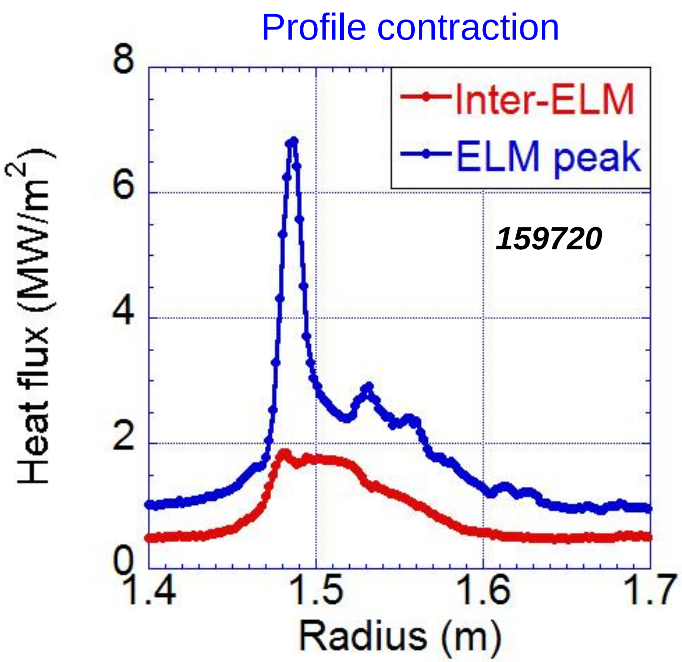


- Measured ELM energy loss by IR camera during the ELM rise time ($\Delta E_{ELM,rise}$) is used as a metric for ELM size
- A_{wet} decreases and q_{peak} clearly increases with increasing ELM size → Sharp contrast to JET and AUG

DIII-D data

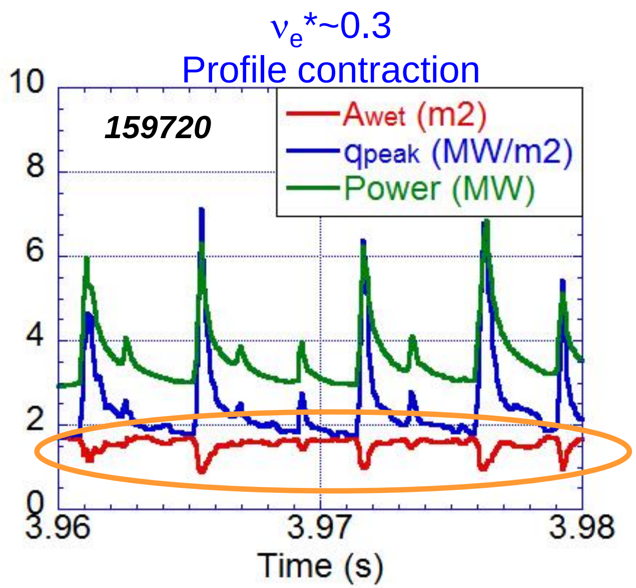
A_{wet} drops significantly during ELM for low collisionality: similar to NSTX

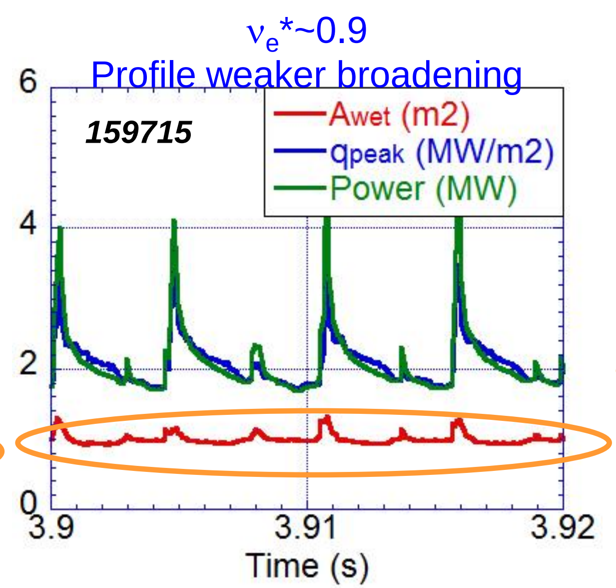


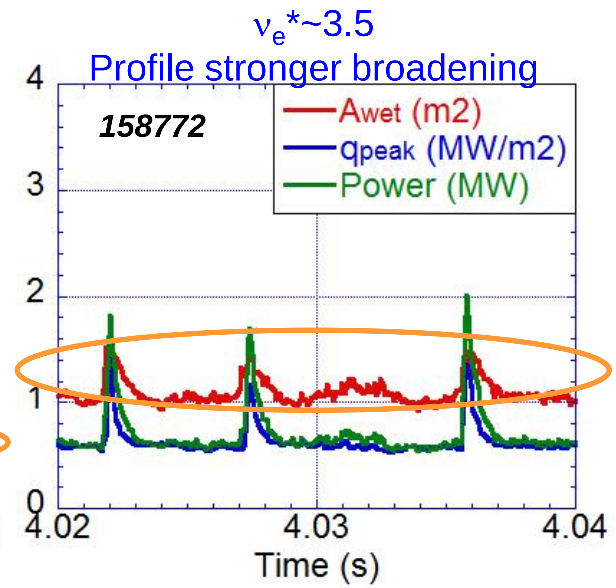


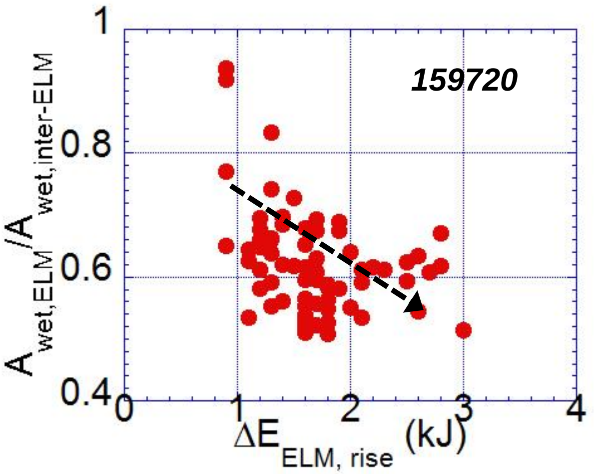
- Only a few ELM filaments observed in the heat flux profile for low ν_e*
- Profile narrows significantly during the ELM by ~30 – 40%
- Increase of peak heat flux is severe (x3-4)

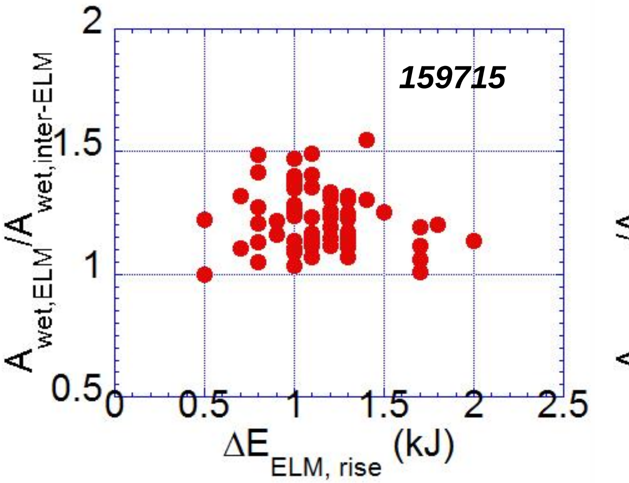
A_{wet} behavior with ELM size becomes more favorable with increasing collisionality

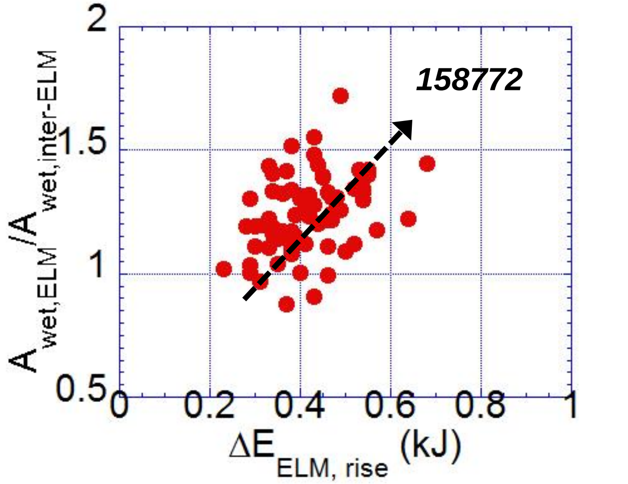






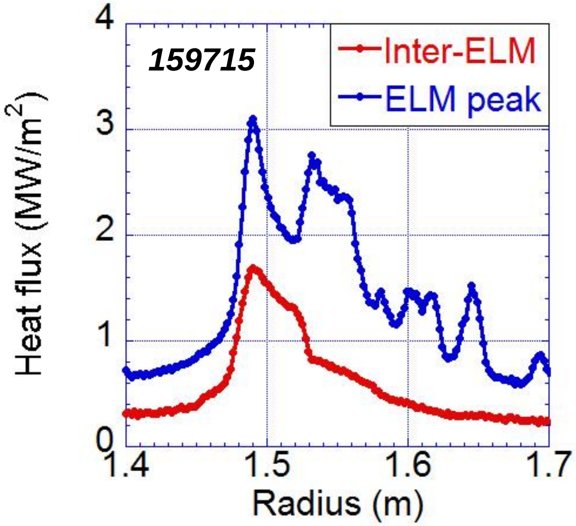




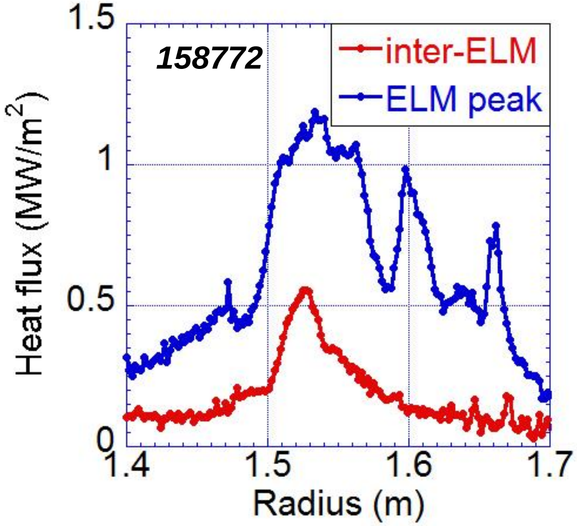


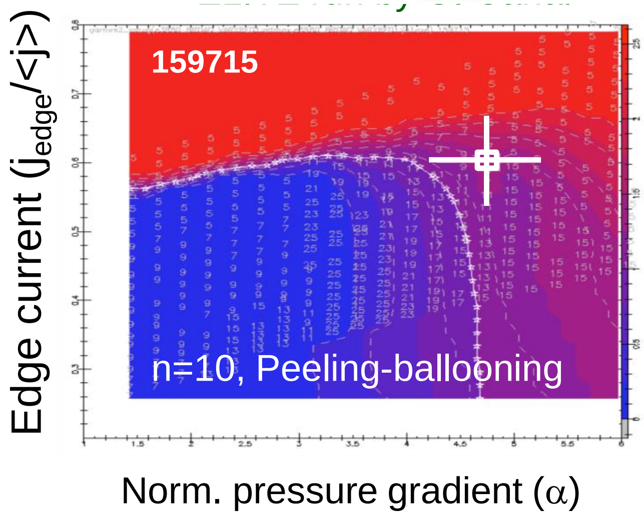
n=10 peeling-ballooning ELMs show weaker broadening and n=25 ballooning ELMs show stronger broadening of heat flux

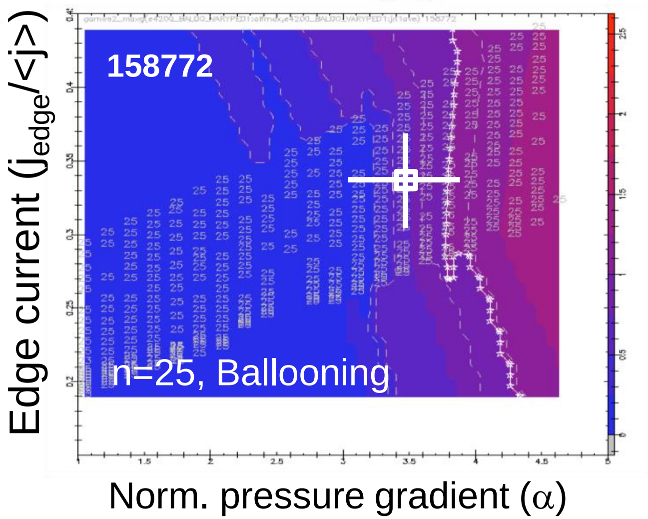
ν_e*~0.9
Profile weaker broadening



ν_e*~3.5
Profile stronger broadening



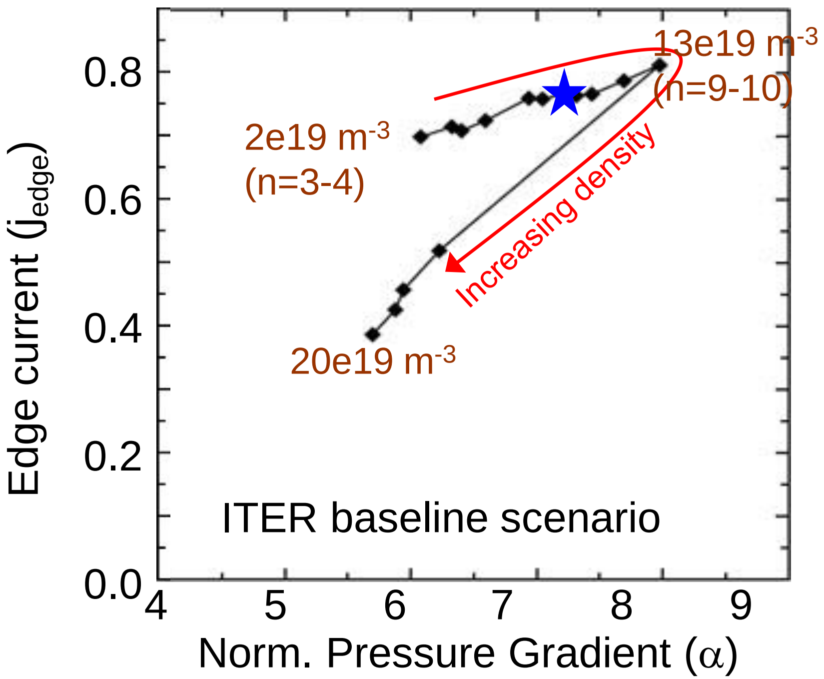




- Stability analysis shows n=10 most unstable, peeling-ballooning, for ν_e*~0.9 → weaker broadening of ELM heat flux footprints
- High density led to ν_e*~3.5 with n=25 most unstable, ballooning regime → stronger broadening
- Work in progress for low ν_e* case

EPED model predicts ITER ELMs to be against peeling boundary with low n-number like in NSTX

EPED modeling as a function of $n_{e,ped}$



- Stability analysis shows that ITER pedestal will be against current-driven kink/peeling modes due to low collisionality and shaping
- Predicted n~3 – 10, closer to NSTX → ELM profile broadening might not be as effective as in JET

Conclusions

- ELM filament structure determines A_{wet} change and the # of striations can be used as a good metric for toroidal mode number of an ELM → More ELM filaments broaden heat flux profile more effectively

- ELM heat flux from peeling ELMs are concentrated near the strike point, leading to reduced A_{wet}. Bigger ELMs reduce A_{wet}

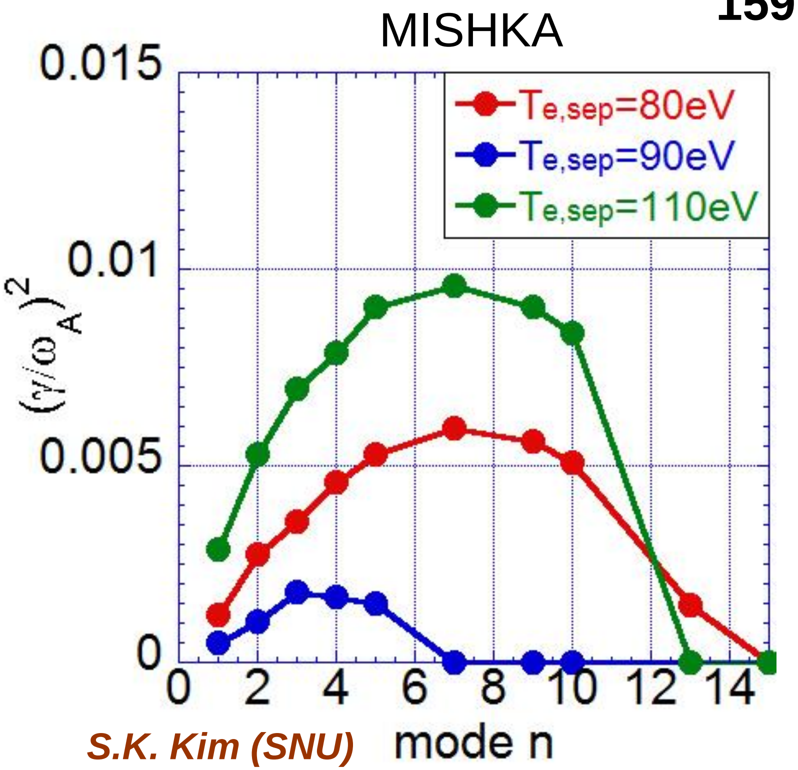
- Increase of collisionality (ν_e*) raises toroidal mode number of ELMs, moves plasma toward ballooning side and increases profile broadening, leading to A_{wet} increase and q_{peak} decrease

- ITER is predicted to be in low ν_e* regime, therefore low n ELMs could produce unfavorable trend → Need detailed study of stability analysis and the requirements for ELM mitigation

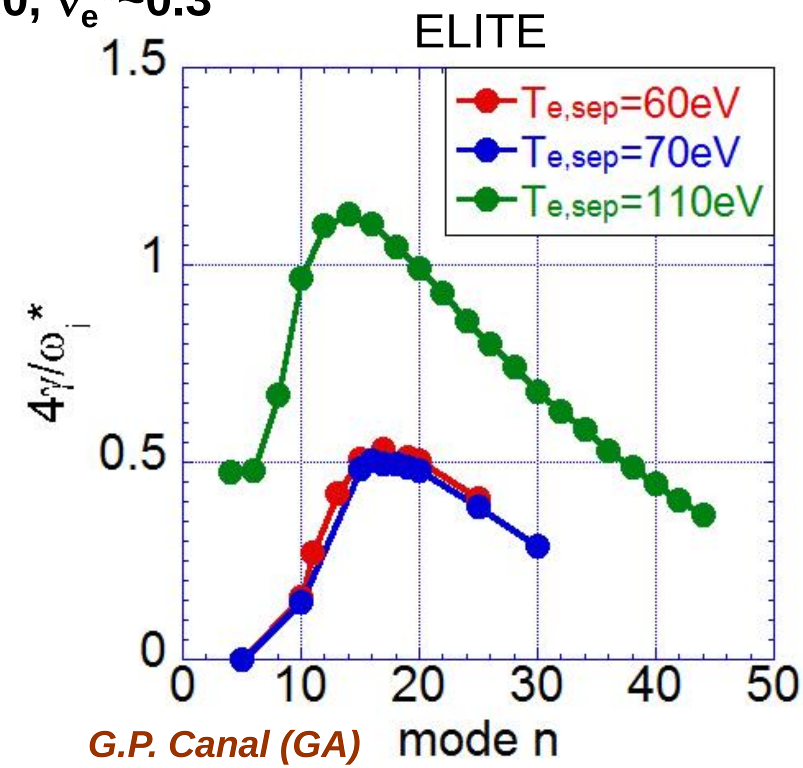
Backup slides

Ideal MHD modeling for low ν_e* ELMs – MISHKA and ELITE show different n for dominant unstable mode

159720, ν_e*~0.3



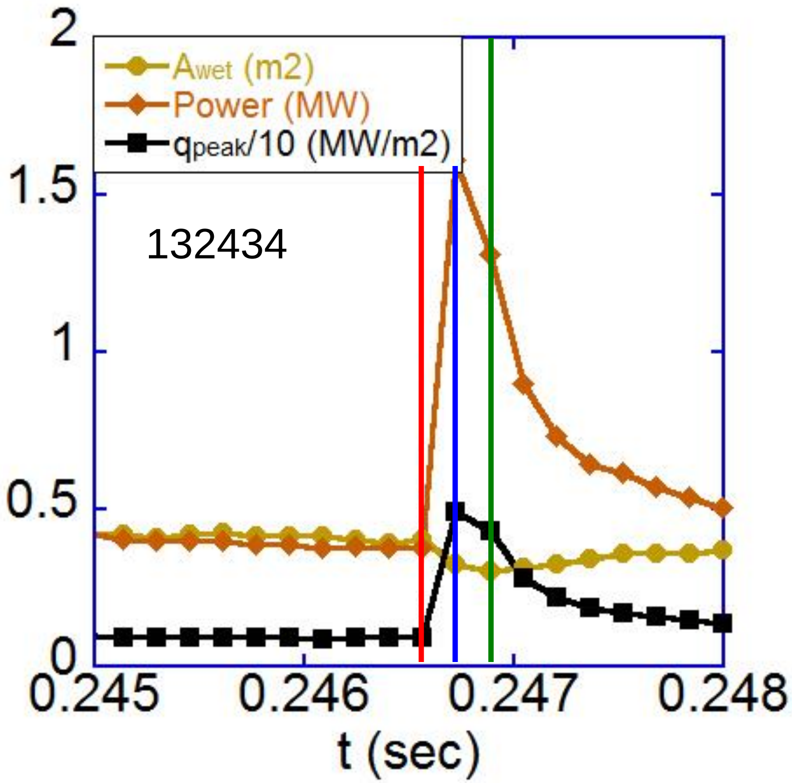
S.K. Kim (SNU)

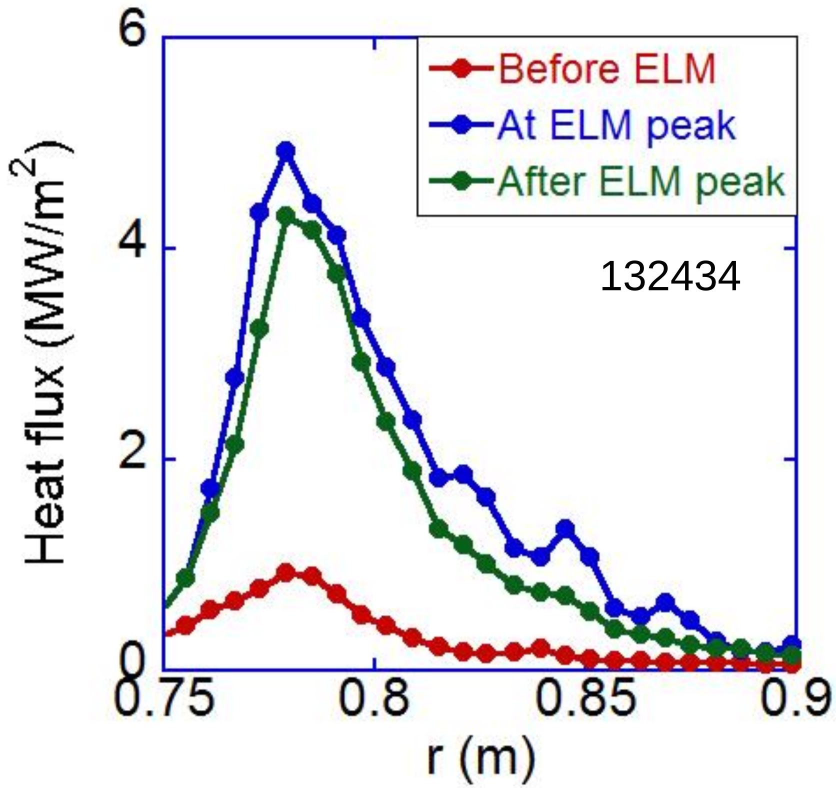


G.P. Canal (GA)

- $T_{e,sep}$ scan was carried out to investigate trend
- MISHKA indicates that maximum growth rate of unstable mode occurs at n=3 – 7 → peeling side
- ELITE shows n~15 for maximum growth rate → peeling-ballooning?

ELM heat flux profile with 3 striations that reduces A_{wet}





- Three filaments are observed but A_{wet} decreases in this case → q_{peak} remains rather constant after peak power deposition