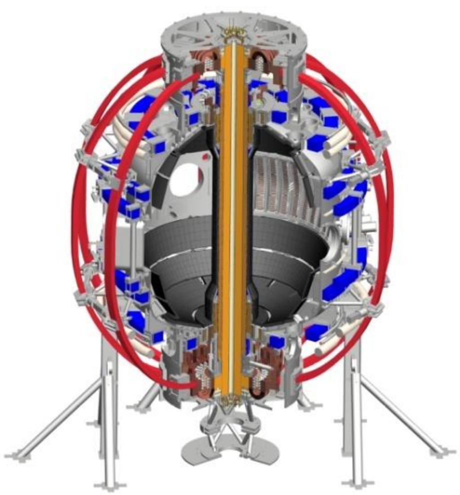
ELM heat flux study in NSTX

J-W Ahn[1] Oak Ridge National Laboratory

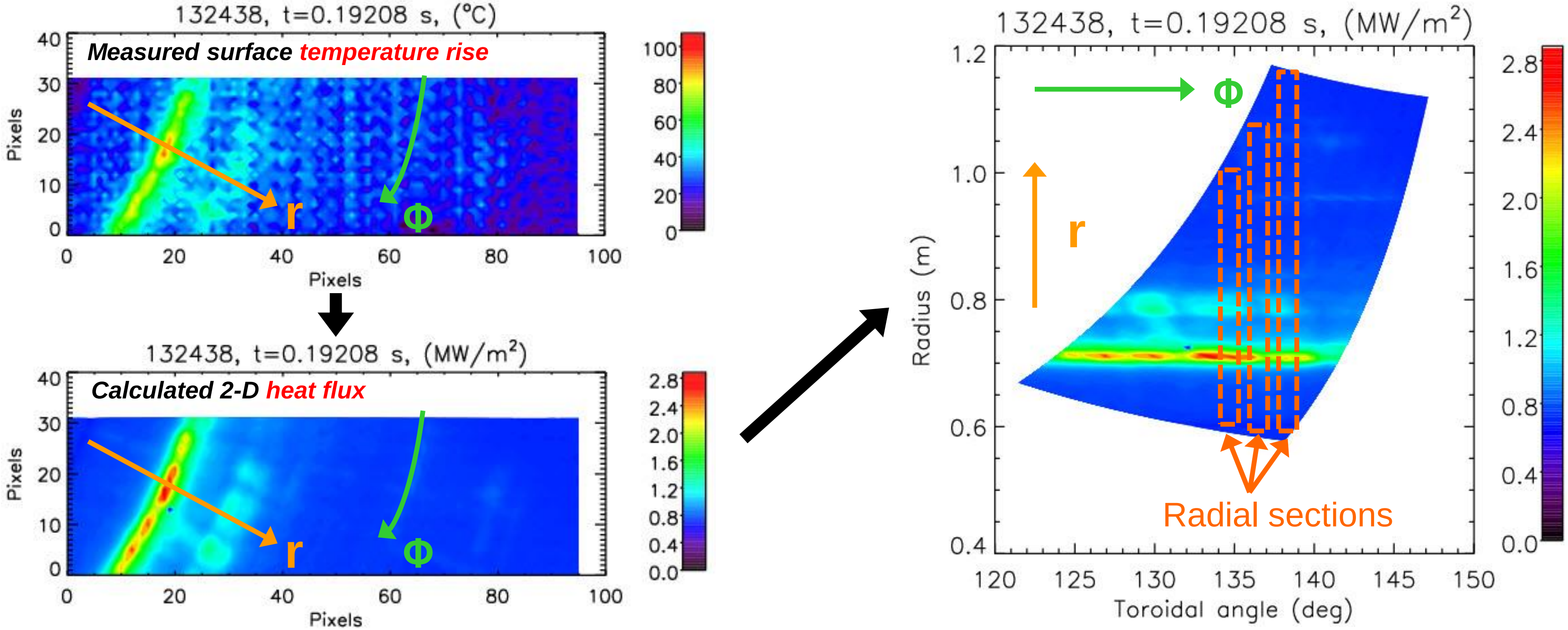
K.F. Gan[2], R. Maingi[3], T.K. Gray[1], A.G. McLean[4],J.M. Canik[1], J.D. Lore[1], V.A. Soukhanovskii[4], and the NSTX Research Team

[1]ORNL, [2]ASIPP, [3]PPPL, [4]LLNL

APS-DPP - Denver, CO
Nov 11 – 15, 2013



Multiple radial heat flux profiles are averaged for data analysis

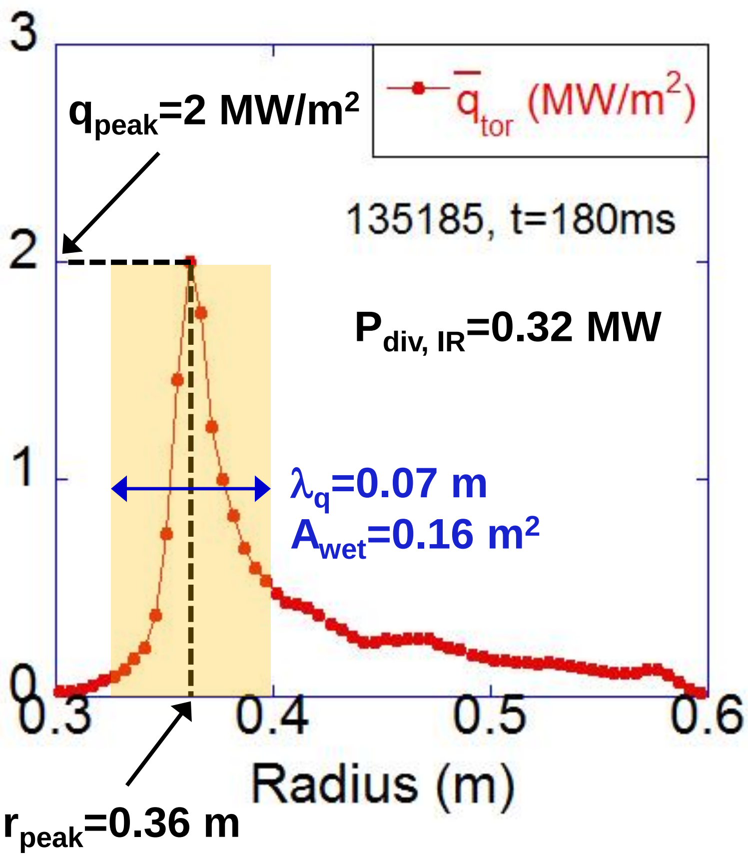


- 2-D surface temperature data from IR camera are used for heat flux calc.
- Heat flux data in (x, y) plane is re-mapped to the (r, Φ) plane and all radial heat flux profiles are combined to create an average profile

$$\bar{q}_{peak,tor} = \sum \left(q_{peak,rad} \right) / N_{rad} \qquad \bar{\lambda}_{q,tor} = \sum \left(\lambda_{q,rad} \right) / N_{rad}$$

Peak heat flux and heat flux width are determined by total power and wetted area

Average radial heat flux profile



- Total deposited power to divertor:

$$P_{div,IR} = \int 2\pi r \overline{q}_{tor}(r)dr$$

- Wetted area

$$A_{wet} = P_{div,IR} / \overline{q}_{peak,tor}$$

- Integral heat flux width

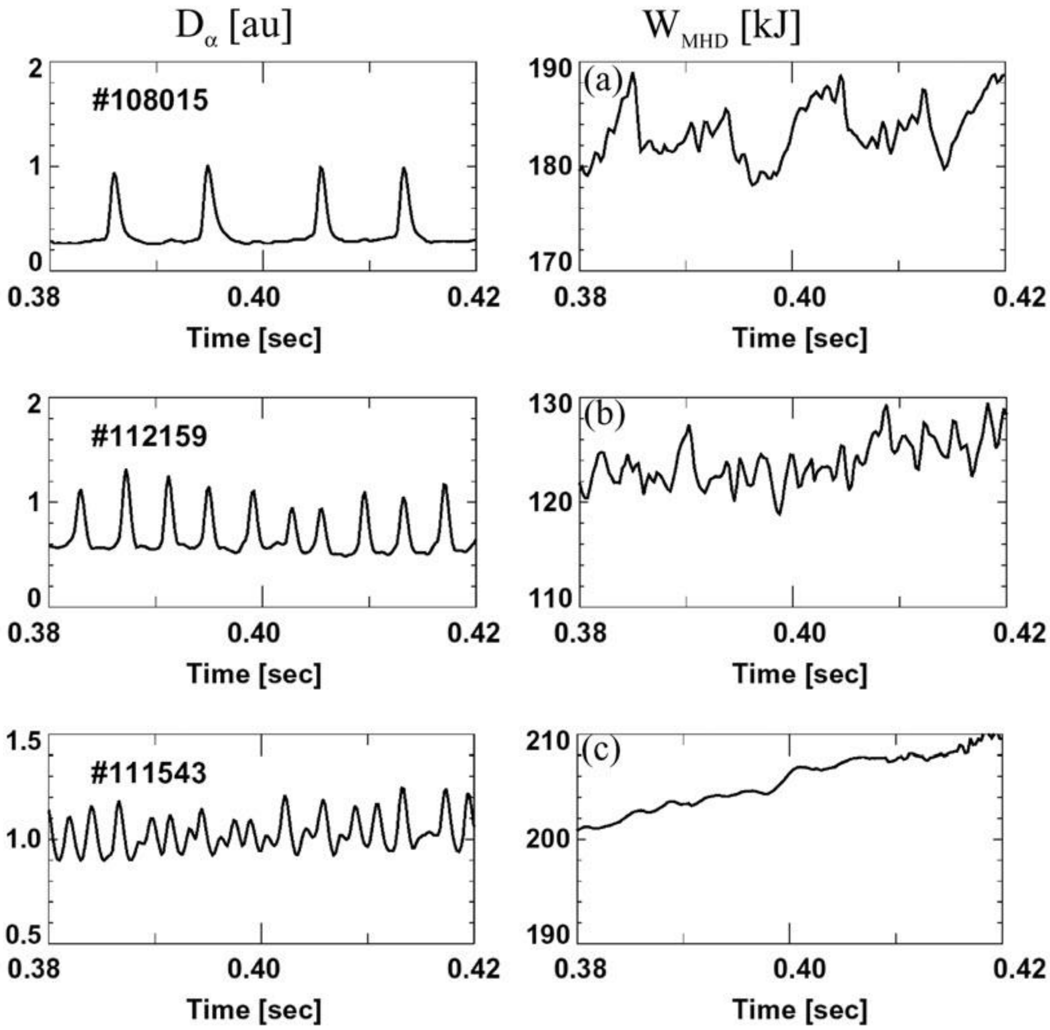
$$\overline{\lambda}^{\text{int}}_{q,tor} = P_{div,IR} / 2\pi r_{peak} \overline{q}_{peak,tor}$$
$$= A_{wet} / 2\pi r_{peak}$$

- Total deposited energy to divertor

$$W_{div,IR} = \int P_{div,IR} dt$$

Temporal evolution and dependence on the ELM size of $P_{div,IR}$ and A_{wet}

Characteristics of several ELM types in NSTX

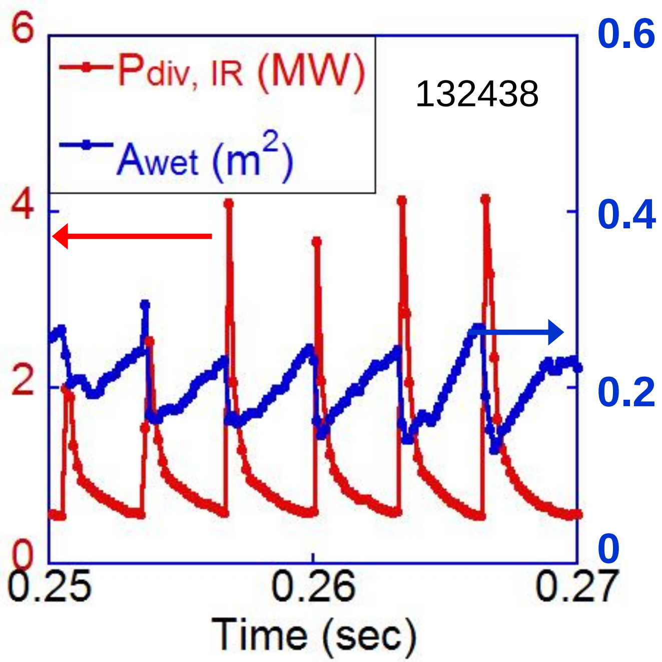


R. Maingi, NF 2005

- Type-I ELMs:
  → Large ELM size, good confinement, high heating power
- Type-III ELMs:
  → Medium size, poorer confinement, lower heating power
- Type-V ELMs:
  → A small ELM regime in NSTX, good confinement, n = 1 – 2, indiscernible individual D_α peaks, IR and GPI data

Wetted area decreases for type-I and III, and increases for type-V during the ELM

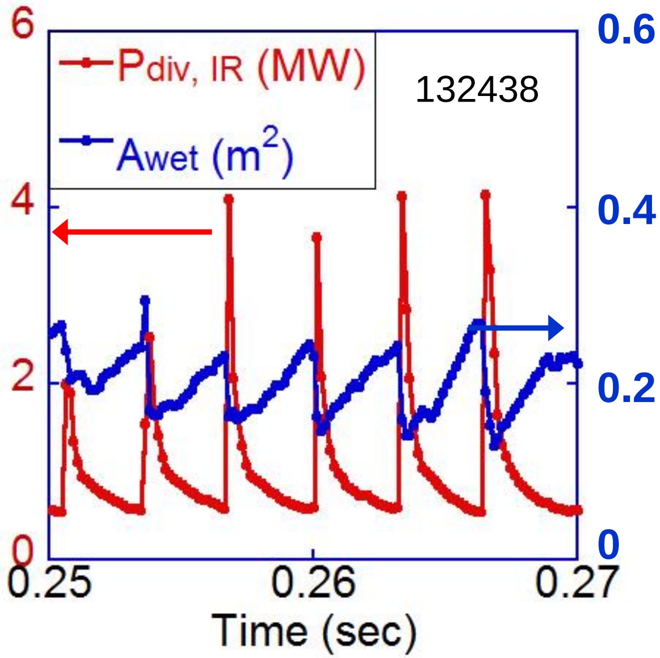
Type-I ELMs



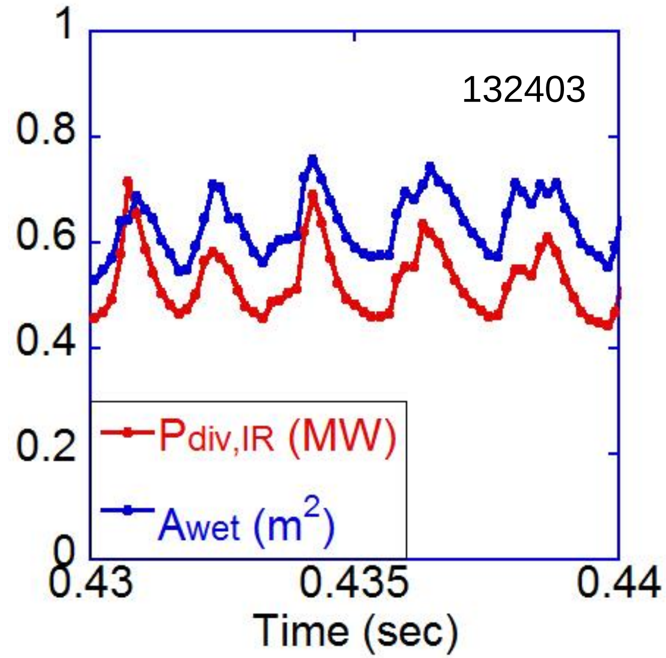
- Wetted area (A_{wet}) and heat flux width (λ_q) **decrease** during the ELM
  - → Significant A_{wet} reduction, 20 - 50%
  - → Inverse relation between λ_q and q_{peak}
  - → Same trend for type-III ELMs
  - → Contrary to results from other tokamaks

Wetted area decreases for type-I and III, and increases for type-V during the ELM

Type-I ELMs



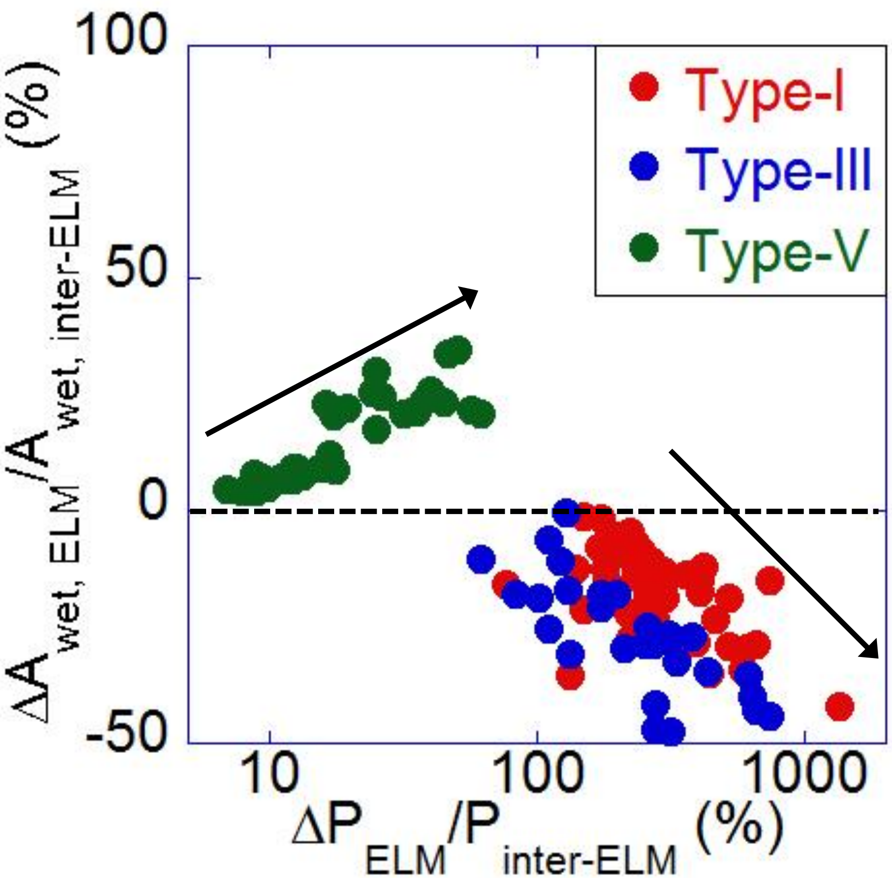
Type-V ELMs



- Wetted area (A_{wet}) and heat flux width (λ_q) **decrease** during the ELM
  - → Significant A_{wet} reduction, 20 - 50%
  - → Inverse relation between λ_q and q_{peak}
  - → Same trend for type-III ELMs
  - → Contrary to results from other tokamaks

- Clear **increase** of A_{wet} and λ_q during ELM
  - → Contrary to type-I and type-III ELMs
  - → Only modest q_{peak} rise (~20 - 30%) due to A_{wet} increase

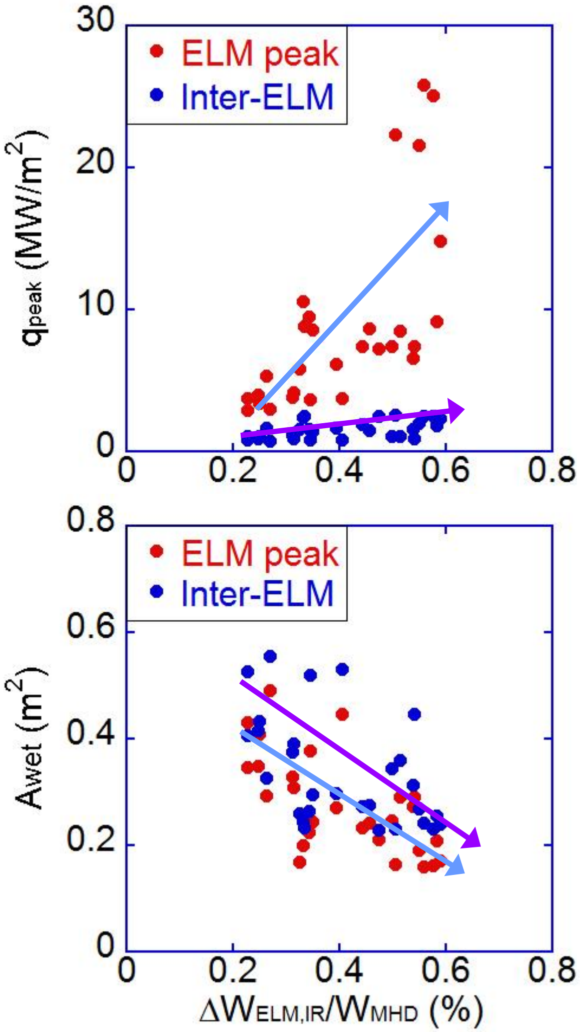
Dependence of A_{wet} on ELM size shows unfavorable trend for type-I and III ELMs and favorable trend for type-V



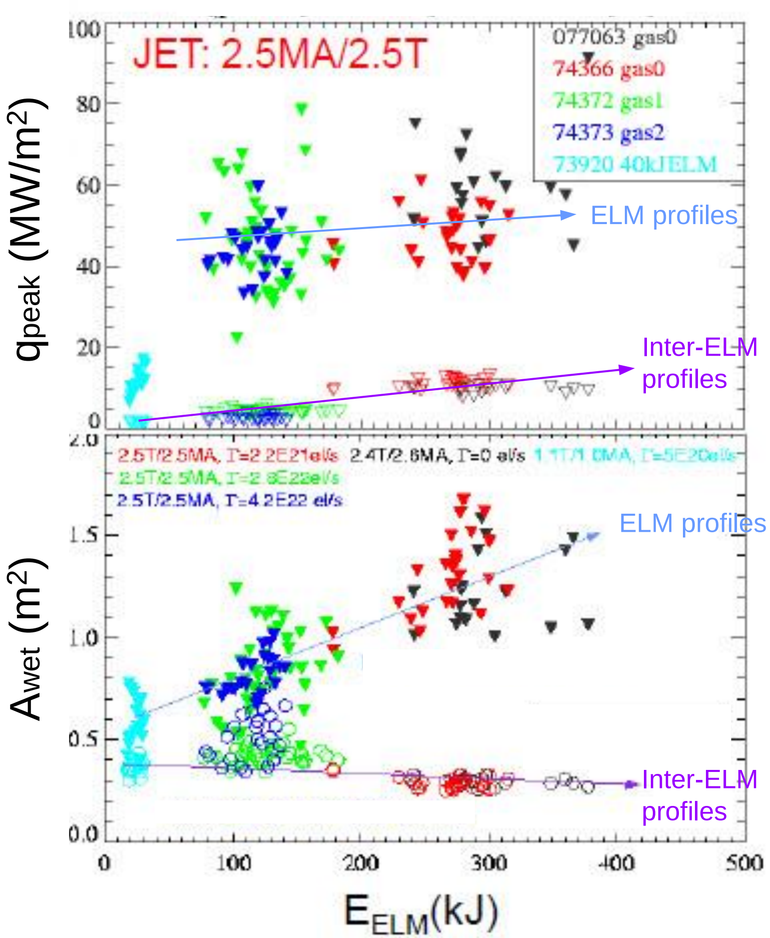
- Type-I and type-III ELMs show similar trend:
  - A_{wet} (therefore λ_q) decreases during the ELM
  - The size of decrease becomes bigger with the size of ELM power → λ_q decrease worse for larger ELMs
- Type-V ELMs:
  - Shows favorable trend of A_{wet} (λ_q) increase and the size of increase is proportional to the ELM size
- Larger ELM size gives bigger impact on expansion and contraction of A_{wet}

A_{wet} decrease leads to q_{peak} increase with increasing ELM energy loss for type-I ELMs in NSTX

NSTX, type-I



JET, type-I



- NSTX: A_{wet} decreases with ELM energy loss → q_{peak} increases
- JET [1]: A_{wet} increases with ELM energy loss → q_{peak} constant
- Both machines show A_{wet} ↓ and q_{peak} ↑ for inter-ELM profiles

[1] T. Eich, PFMC 2013

Conclusions

- Wetted area (A_{wet}) determines heat flux width (λ_q) → decreases during type-I and III ELMs and increases during type-V ELMs

- The size of A_{wet} change is proportional to the size of ELM for both increase and decrease cases

- Contrary to data from conventional tokamaks, eg JET and AUG, A_{wet} decrease leads to q_{peak} increase with increase of ELM energy loss in NSTX → ELM heat flux mitigation technique necessary (eg, Snowflake divertor, ELM control by 3-D fields, etc. for NSTX-U)

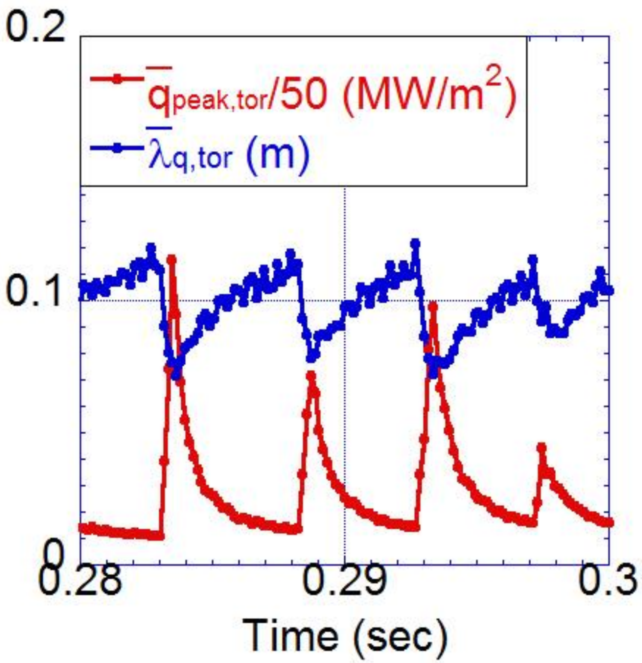
Future work:

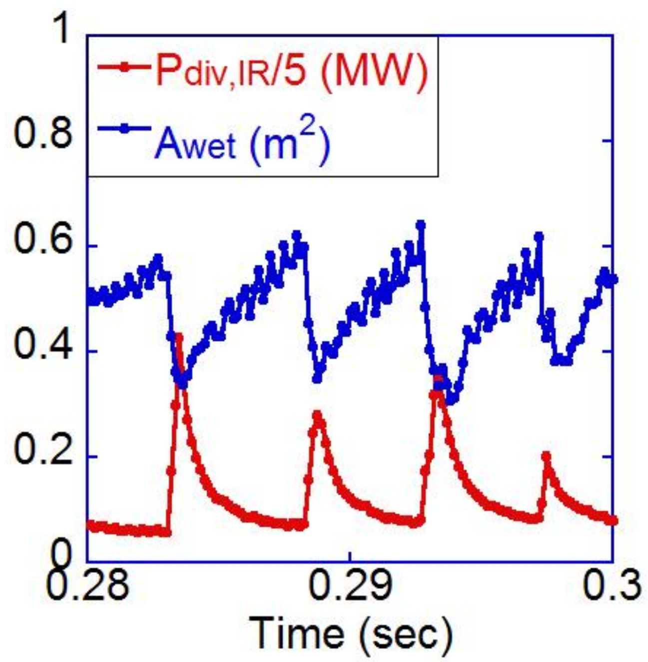
- Relation of A_{wet} to pedestal pressure in wider parameter range
- Understanding of the transport processes for A_{wet} contraction

Back-up Slides

Type-III ELMs: Similar behavior to type-I ELMs

132403, type-III ELMs with high W_{tot}, P_{NBI}=3.5MW



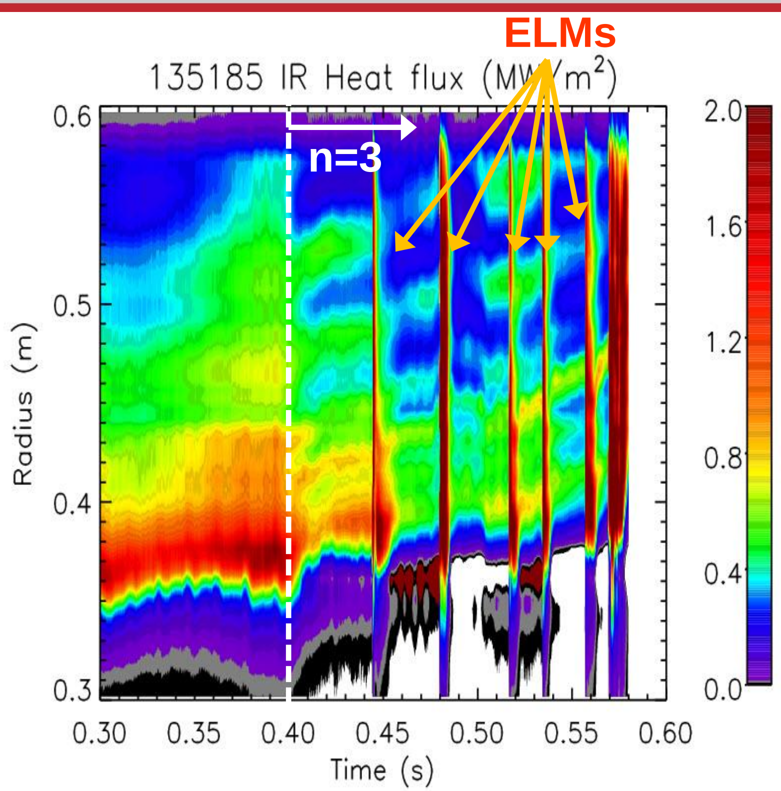


- Similar behaviors to type-I ELMs are observed

  → A_{wet} ↓ and λ_q ↓ during ELM rise

  → Inverse relation between λ_q and q_{peak} at ELM

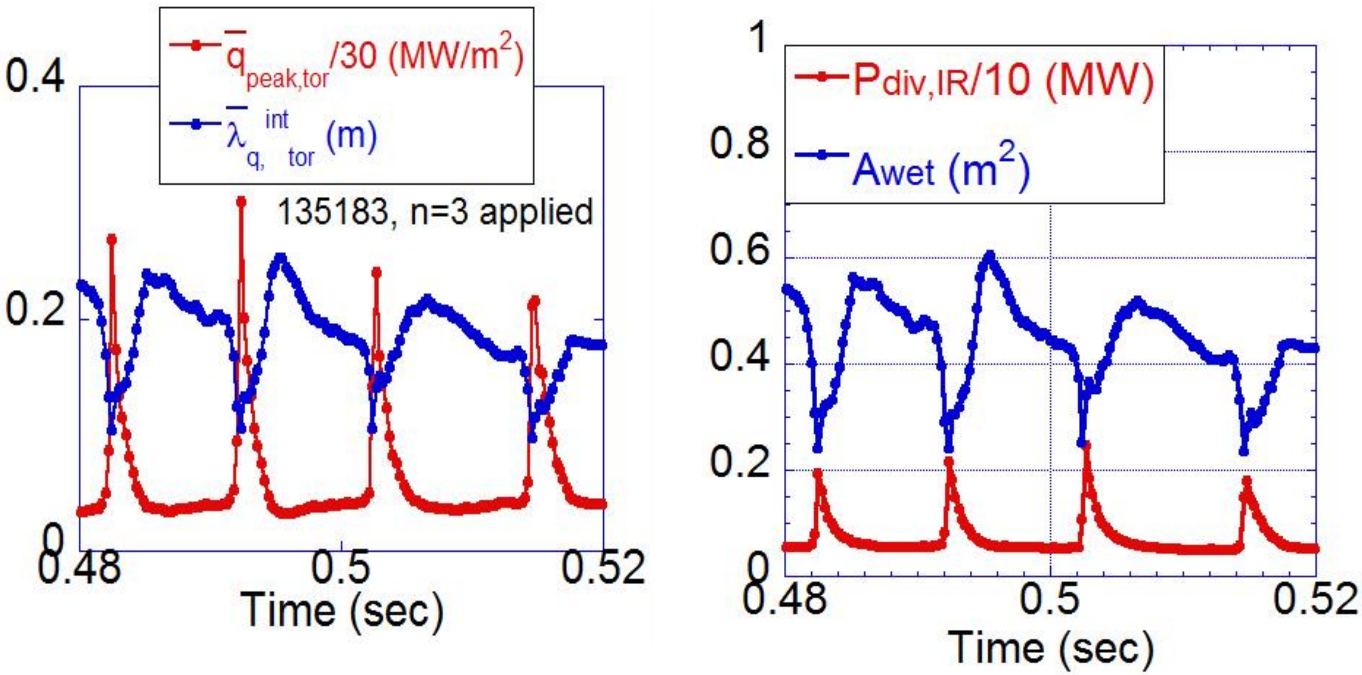
3-D field triggered ELMs: similar to type-I ELMs



- ELMs are triggered by applied 3-D fields, e.g. n=3 [1]

[1] J.M Canik, PRL **104** (2010), 045001

3-D field triggered ELMs: similar to type-I ELMs



- ELMs are triggered by applied 3-D fields, e.g. n=3 [1]
- Again, ELMs reduce A_{wet} and therefore λ_q , similar to type-I ELMs

[1] J.M Canik, PRL **104** (2010), 045001

Toroidal asymmetry of peak heat flux and heat flux width is quantified

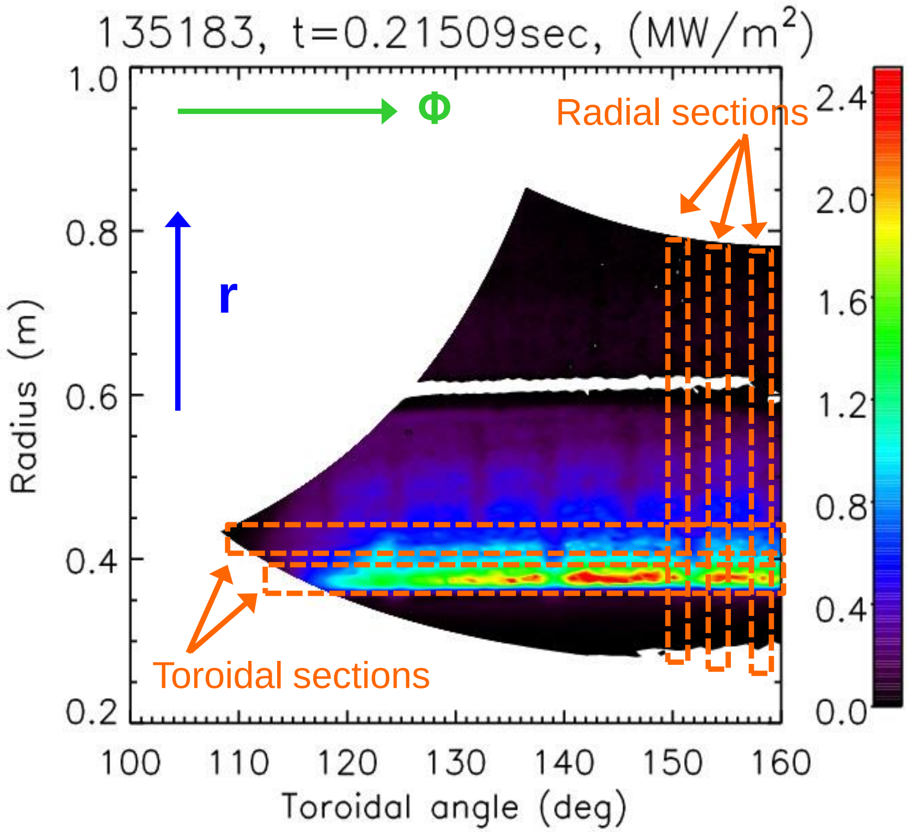
- Toroidal asymmetry (ε_{DA}) of peak heat flux (q_{peak}) and heat flux width (λ_q) is defined:

$$\varepsilon_{DA}(q_{peak}) = \sigma_{qpeak} / \bar{q}_{peak,tor}$$

$$\varepsilon_{DA}(\lambda_q) = \sigma_{\lambda q} / \bar{\lambda}_{q,tor}$$

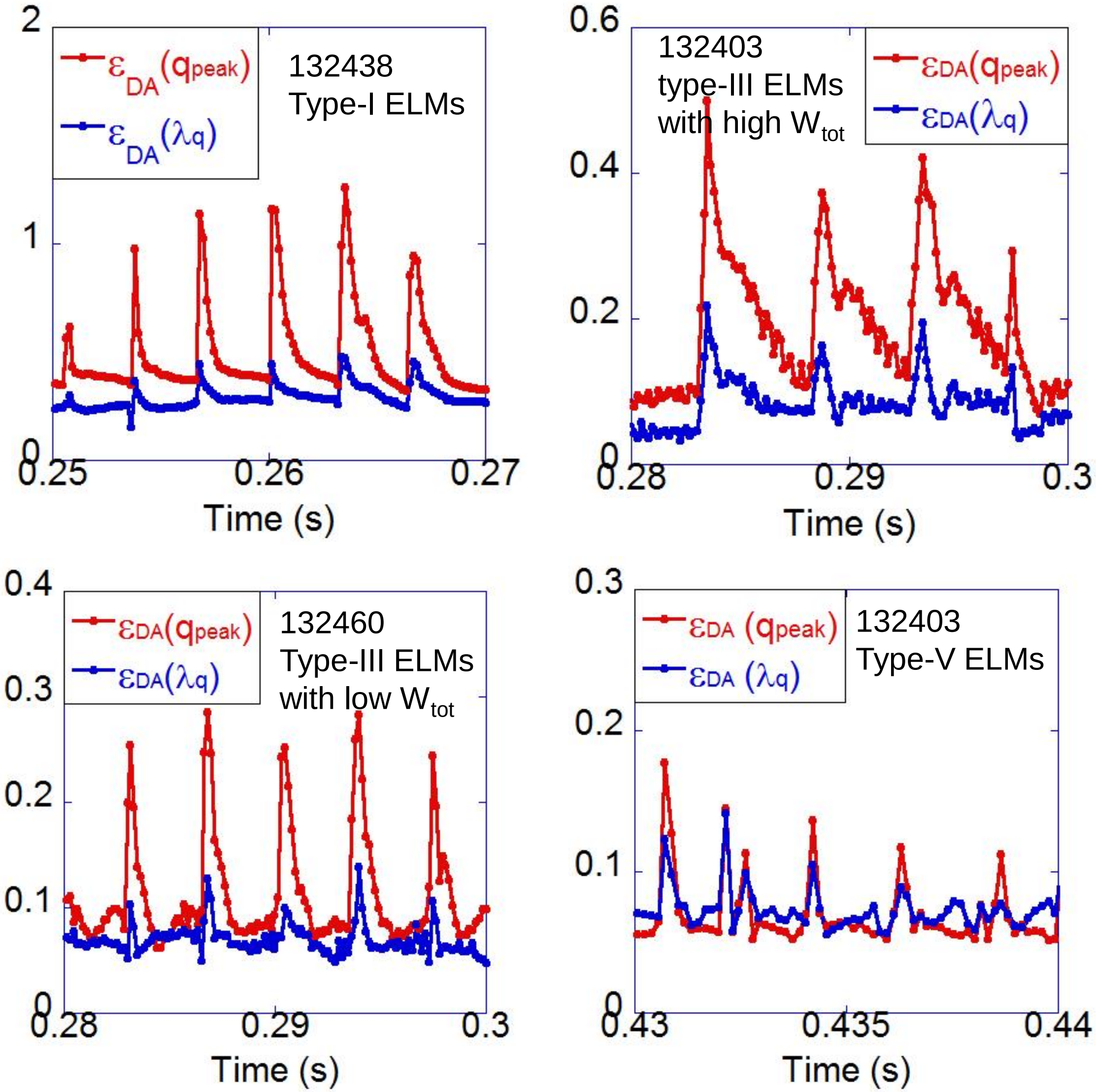
- σ_{peak} and $\sigma_{\lambda q}$ are the standard deviation of q_{peak} and λ_q over the data in the toroidal direction

- σ_{peak} and $\sigma_{\lambda q}$ are normalized to the toroidal mean values of q_{peak} and λ_q



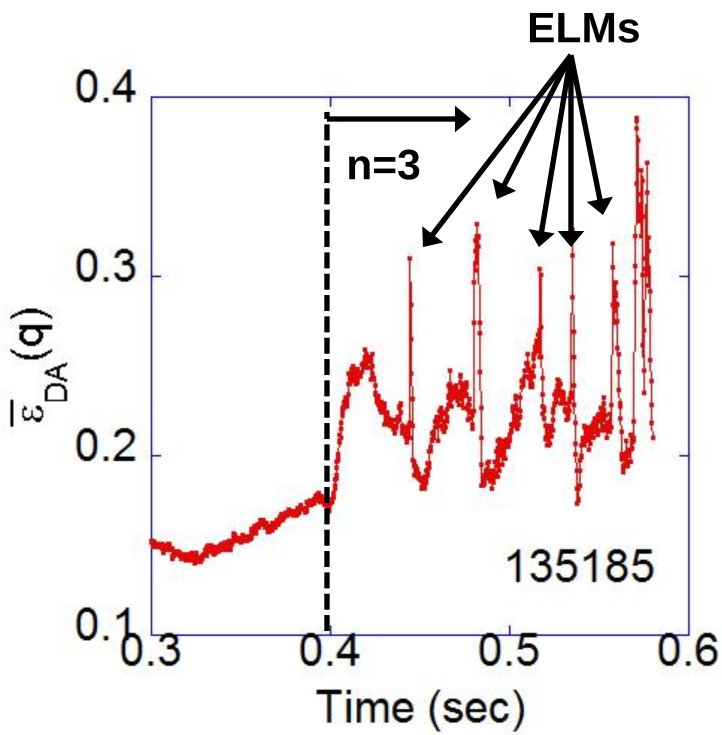
J-W. Ahn, JNM **438** (2013), S317

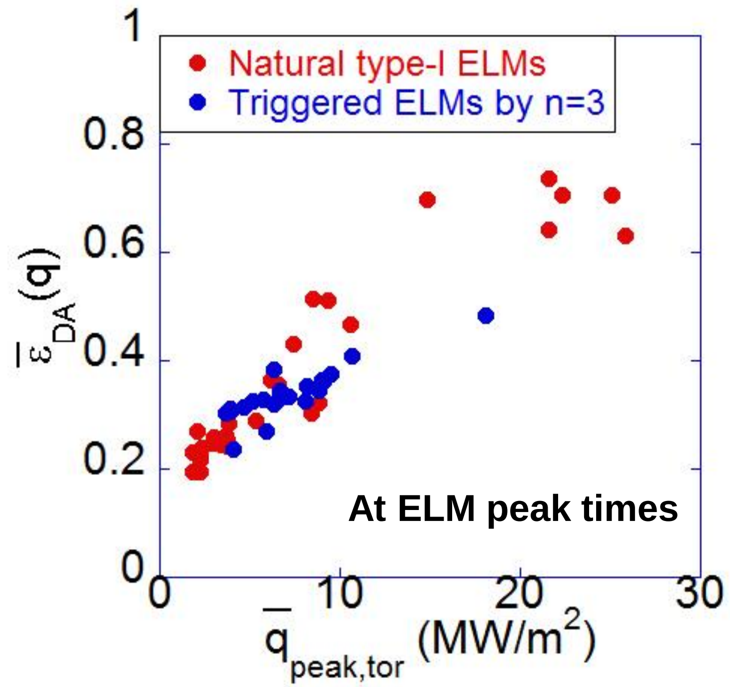
Toroidal asymmetry of peak heat flux and λ_q increases during ELM for all ELM types



- Asymmetry of both q_{peak} and λ_q increases during ELM for all ELM types
- Generally appears to be proportional to peak heat flux
- $\varepsilon_{DA}(q_{peak})$ is larger than $\varepsilon_{DA}(\lambda_q)$ except type-V ELMs, $\varepsilon_{DA}(q_{peak}) \sim \varepsilon_{DA}(\lambda_q)$

Heat flux asymmetry for triggered ELMs follows similar trend to natural type-I ELMs





- Toroidal asymmetry immediately increases with 3-D field application
- Data for triggered ELMs at ELM peak times well aligned with those for naturally occurring type-I ELMs