NSTX

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Comparison of Small ELM regimes in Alcator C-Mod, MAST, and NSTX

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UKAEA Fusion Working in Europe

IAEA 2008 Fusion Energy Conference
Geneva, SZ
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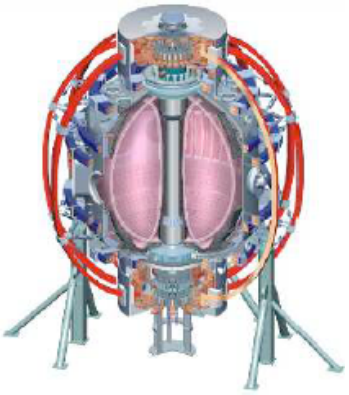
Alcator C-Mod



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Summary: Small ELMs with certain similarities observed in Alcator C-Mod, MAST, and NSTX

- Coordinated small ELM comparison experiments conducted in C-Mod, MAST, and NSTX
- In near double-null operation with matched poloidal cross-sections and q_{95}, small ELMs observed in all three devices
  - Differs from more common NSTX Type V regime
- Common β_{ped}^{pol} ~ 15% threshold for small ELMs, but details between machines differ widely
  - Flux-surface average poloidal field at separatrix used in definition
  - Upper limit for small ELMs in MAST, lower limit in C-Mod and NSTX
  - β_{ped}^{tot} (normalized to total magnetic field at outer midplane) range much broader across machines
    - Not an ordering parameter across machines
- Edge stability analysis with kinetic EFITs commencing

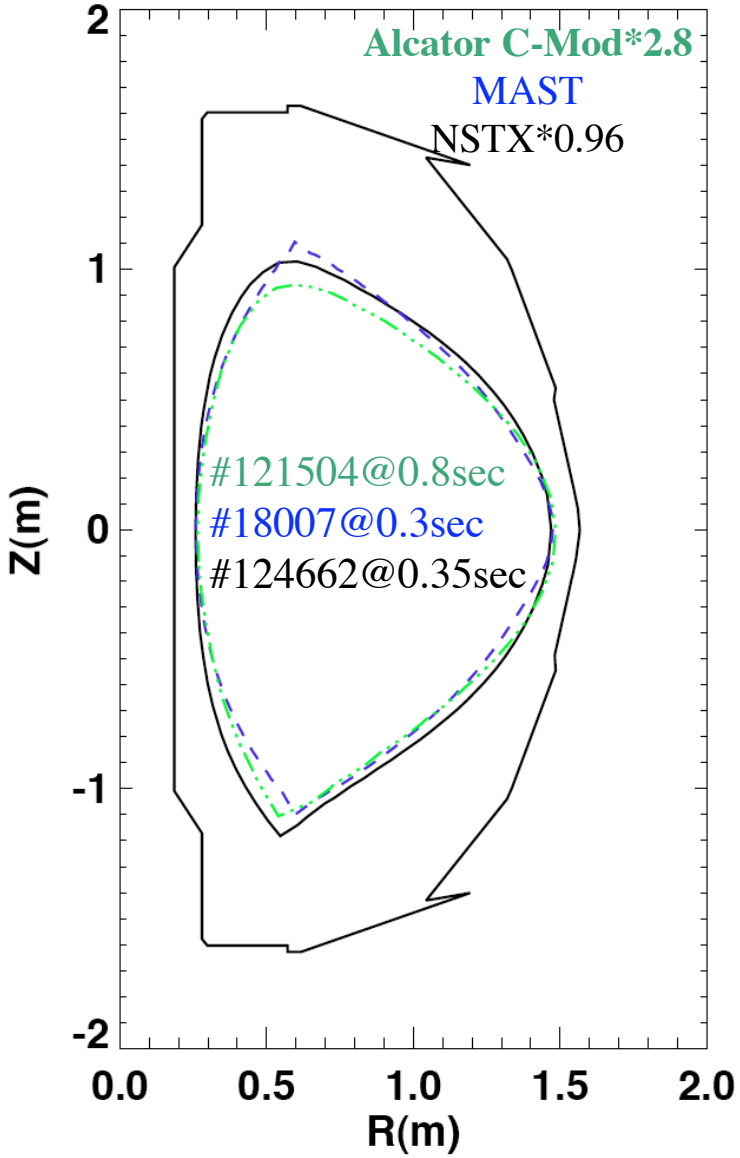
Motivation: looking for commonality in small ELM regimes to better assess extrapolability to ITER

- Many different small ELM regimes reported in literature
  - type-II, type-V, HRS, EDA at high β, QH-mode, etc.
  - Most regimes are observed at high ν^*_{ped}
- Previous comparison between CMOD and JFT-2M showed that EDA and HRS mode access is similar with respect to q_{95} and ν^*_{ped}
  - Experiments executed through ITPA PEP group
- MAST and NSTX also show small (and large) ELM regimes
  - MAST small ELMs in double-null
  - NSTX type-V ELMs mostly in lower-single null
- Key questions for *ITPA PEP-16* multi-machine comparison:
  - Are there common access conditions?
  - Are the ELM filamentary characteristics comparable?
  - Can any of the small ELM regimes be extended to low ν^*_{ped} ?

Dedicated experiments conducted on C-Mod, MAST, and NSTX

- Common near double-null shape was chosen
  - e.g. type-II ELMs are observed close to DN
  - Lower single-null discharges also in NSTX for Type V ELM data
- Discharges with similar $\delta_L \sim 0.5$ and $\kappa \sim 1.8$ selected
- Goal was to match q_{95} perform a power scan in each machine to get a range of β_{ped} and ν^*_{ped}
  - Power scan in each machine
- ELM characteristics and small ELM access conditions compared between the devices
  - Small ELM existence window
  - Filament structure
  - Pedestal structure

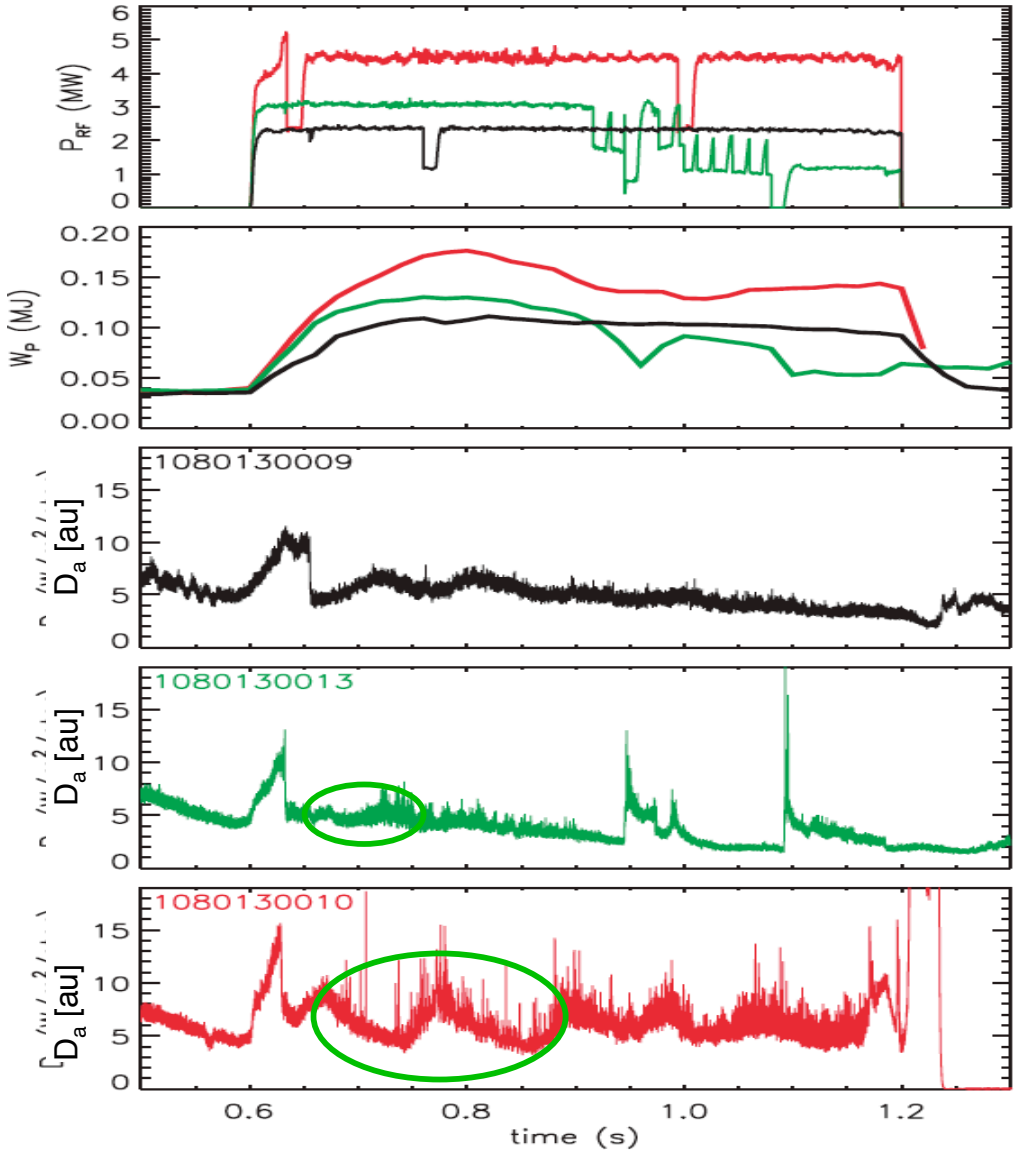
Good scaled poloidal cross-section shape match achieved in near double-null discharges



- C-Mod shape scaled by 2.8 and shifted inward by 0.19 m
- $\delta_L \sim 0.5$, $\kappa \sim 1.8$
- Near double-null in all machines
  - Additional NSTX Type V ELM data in lower single-null
- q95 ~ 5.5 in all machines

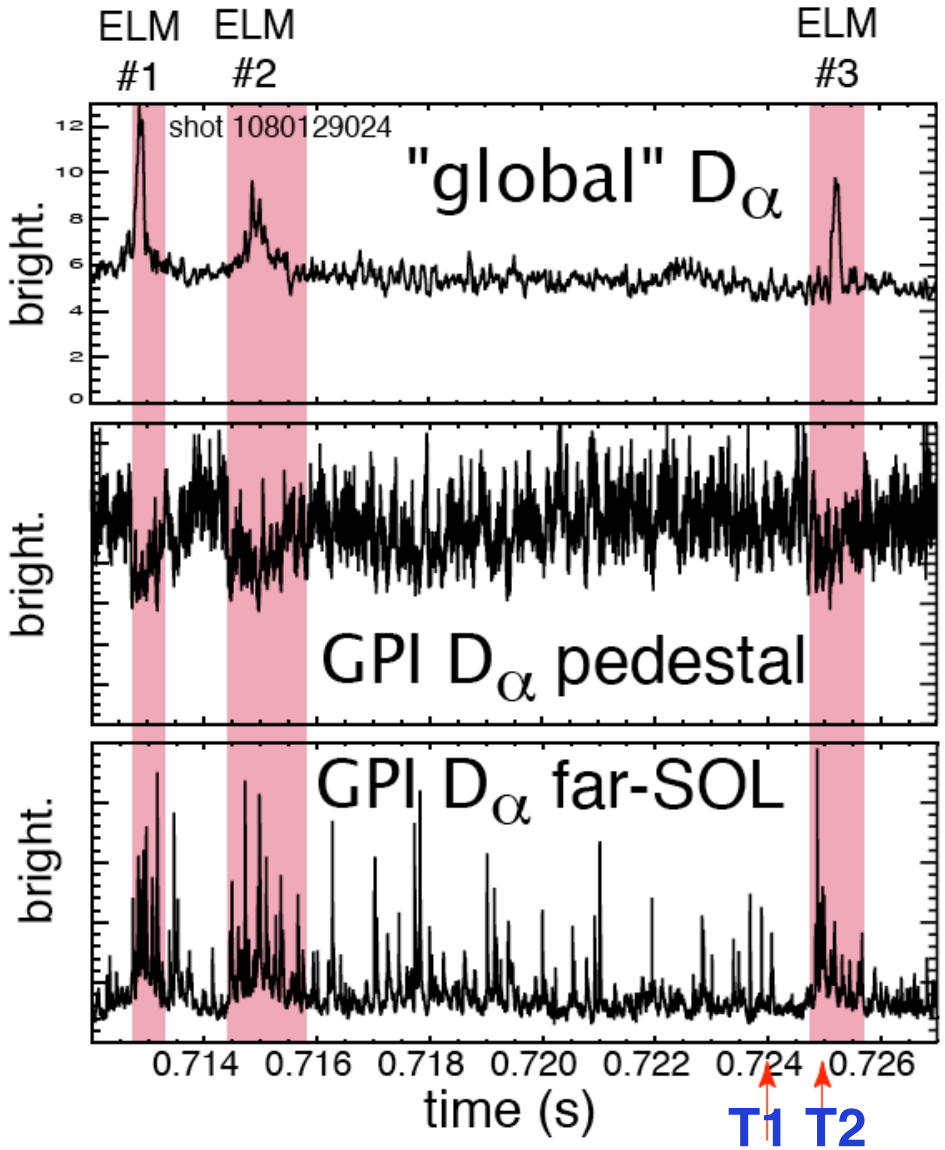
C-Mod

Small ELMs observed above ~ 3 MW ICRF in Alcator C-Mod

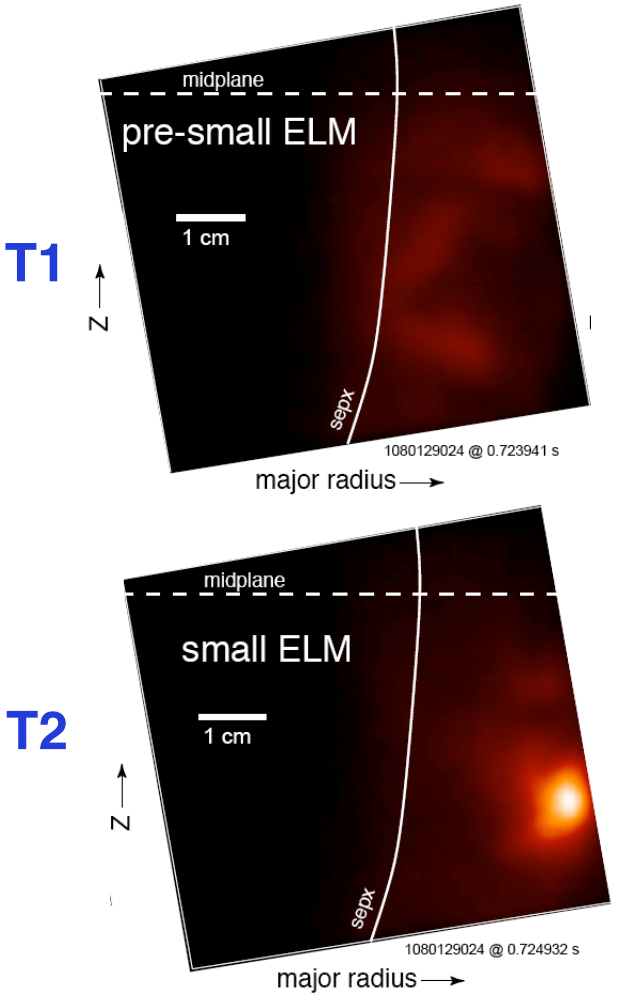


- ICRF power scan
  - $P_{ICRF}^{max} \leq 4.7MW$
- Stored energy
- Pure EDA H-mode
- Small ELMs on top of EDA
- Small ELMs on top of EDA

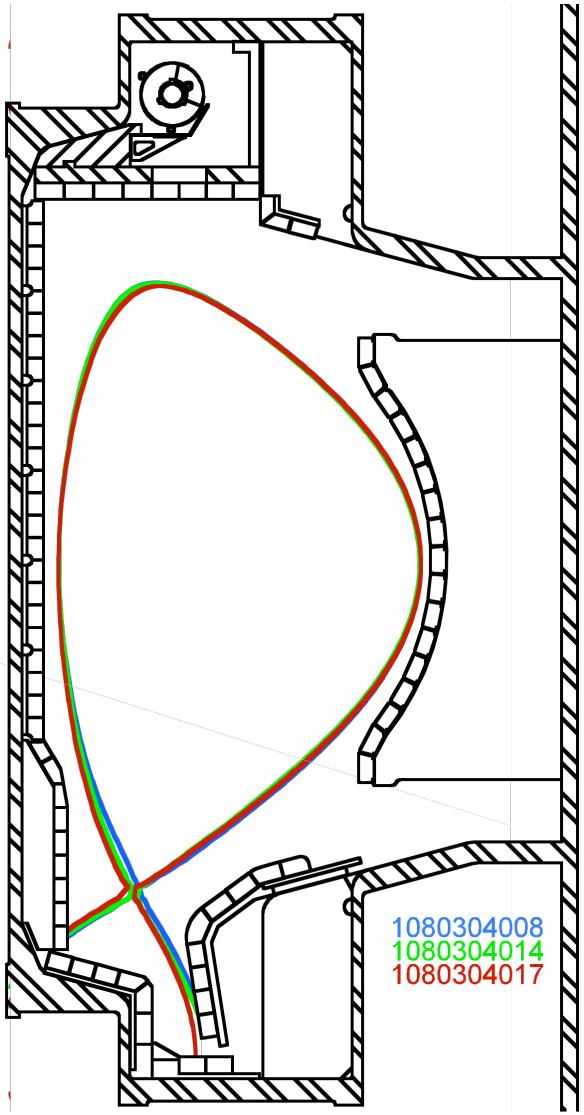
Small ELMs appear as groups of detaching filaments; Pedestal top D_α affected in Alcator C-Mod

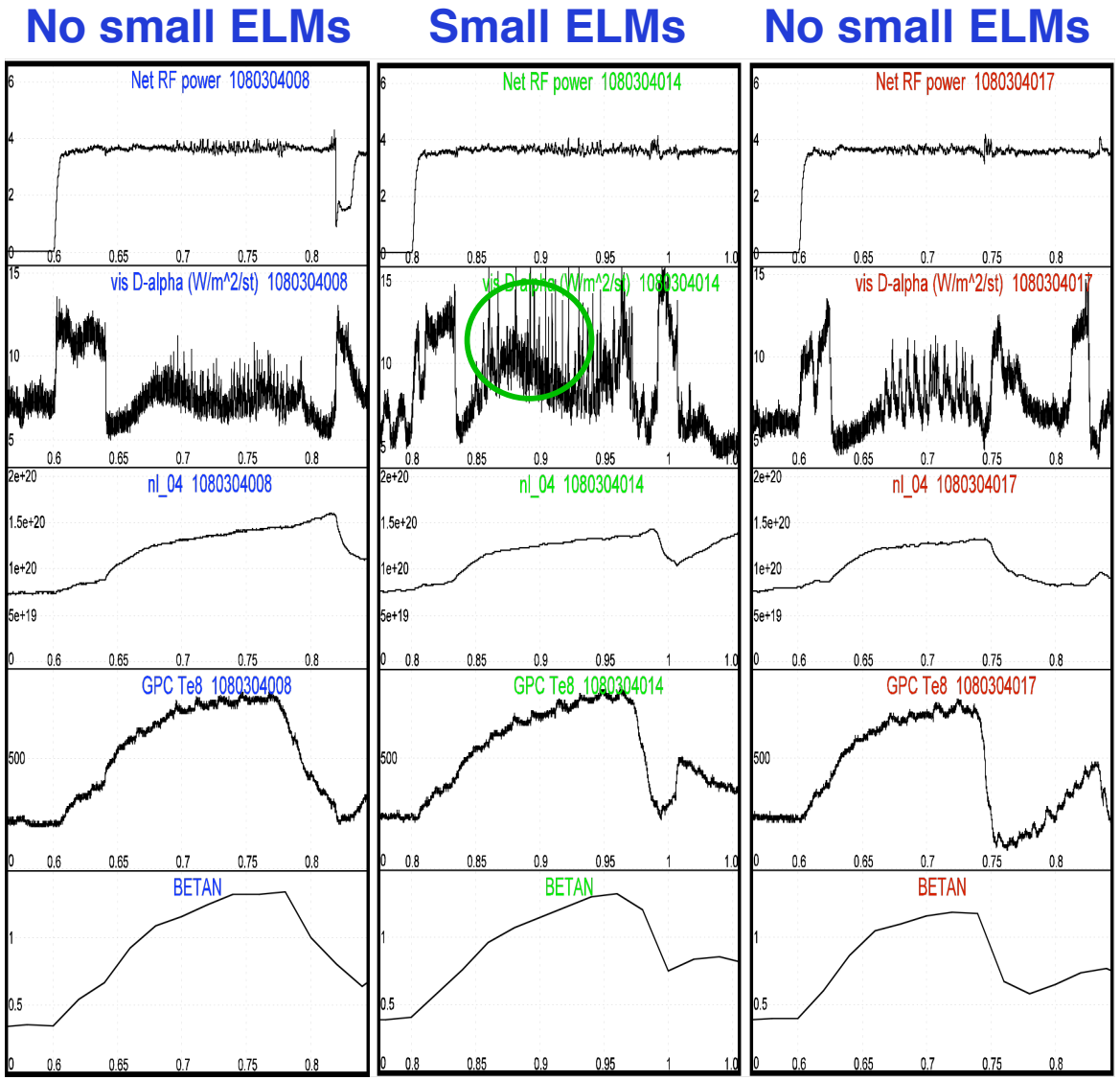


Gas Puff Imaging Diagnostic

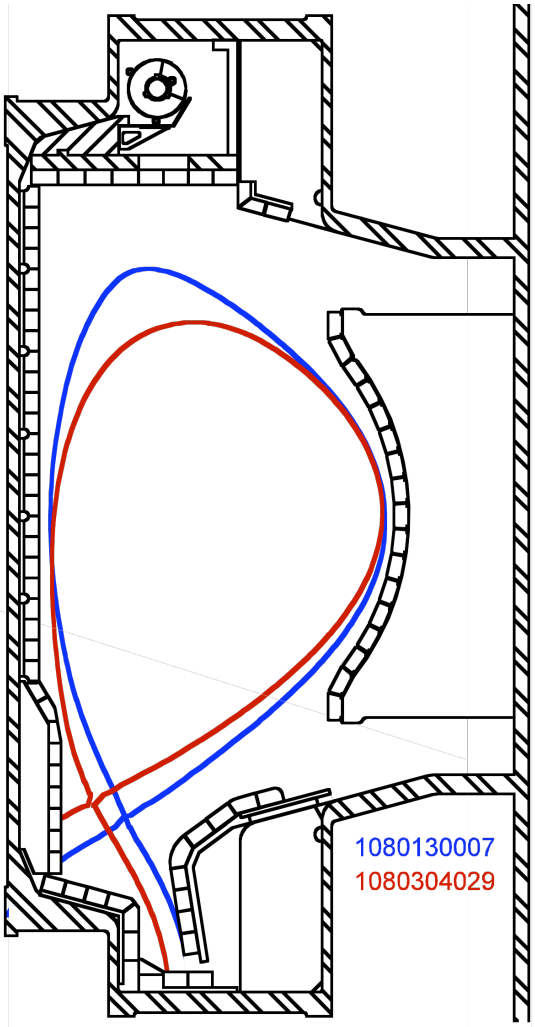


Modest changes to lower (and upper) triangularity changed signature of small ELMs in C-Mod

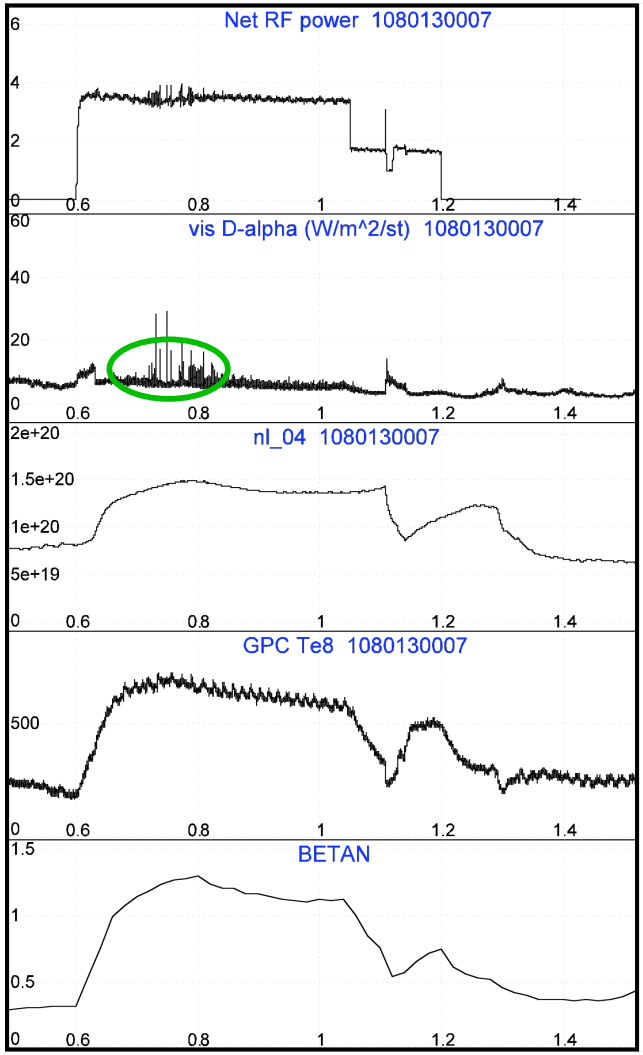




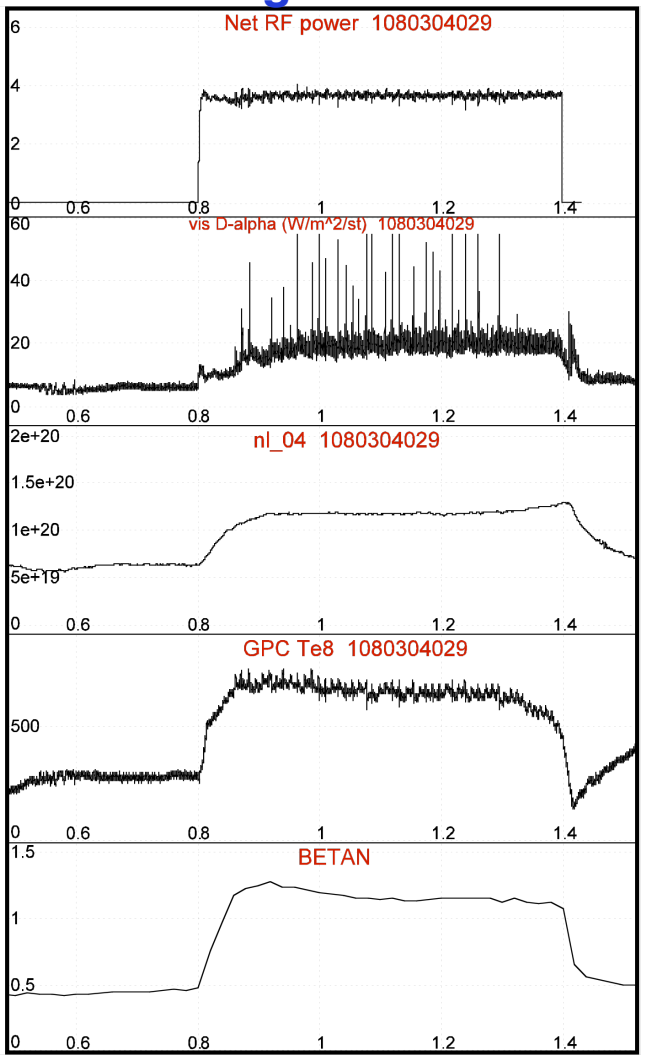
Larger change in triangularity (δ_L higher, δ_L lower) correlated with appearance of large ELMs in C-Mod



Small ELMs

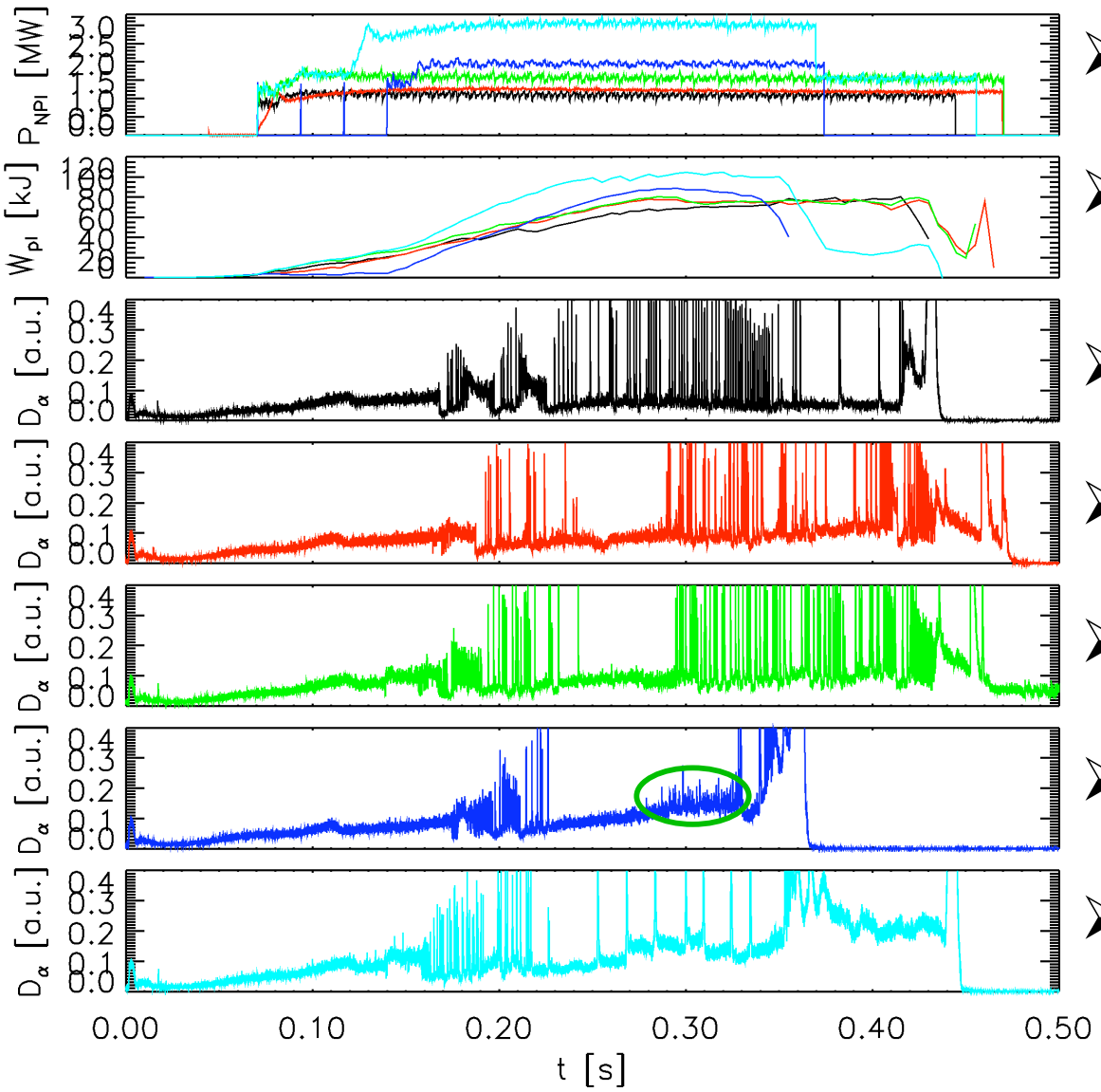


Large ELMs



MAST

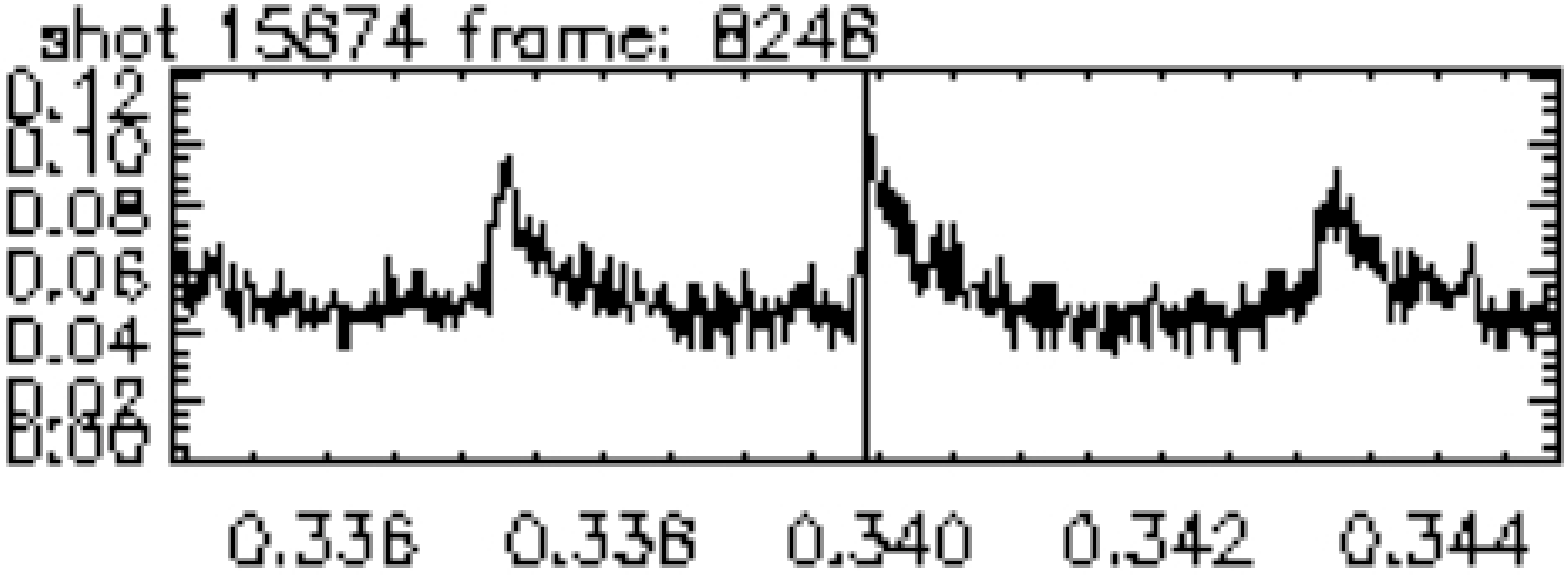
Small ELMs present over wide heating power range in MAST

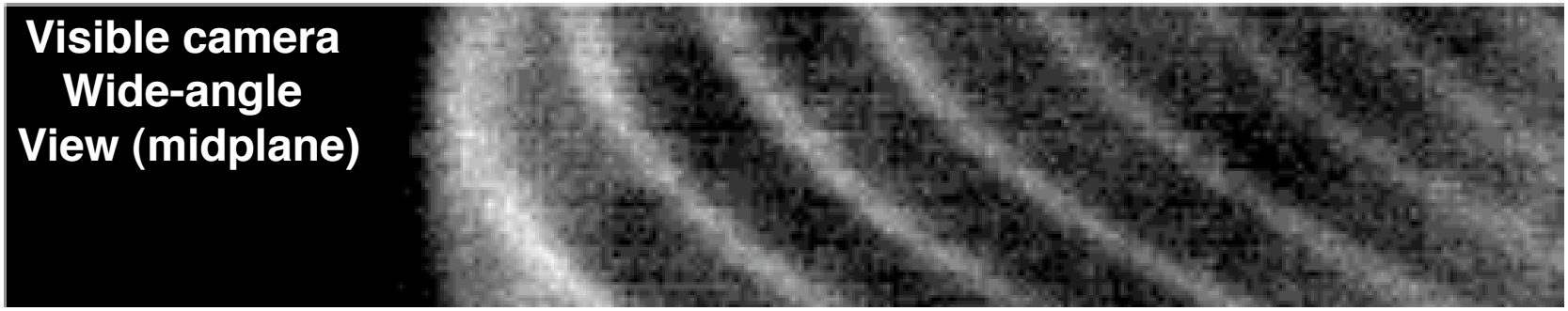


- Fine NBI power scan
- Stored energy
- Small ELMs + Type III
- Small ELMs + Type III
- Small ELMs + Type III
- Small ELMs only
- Type I ELMs only

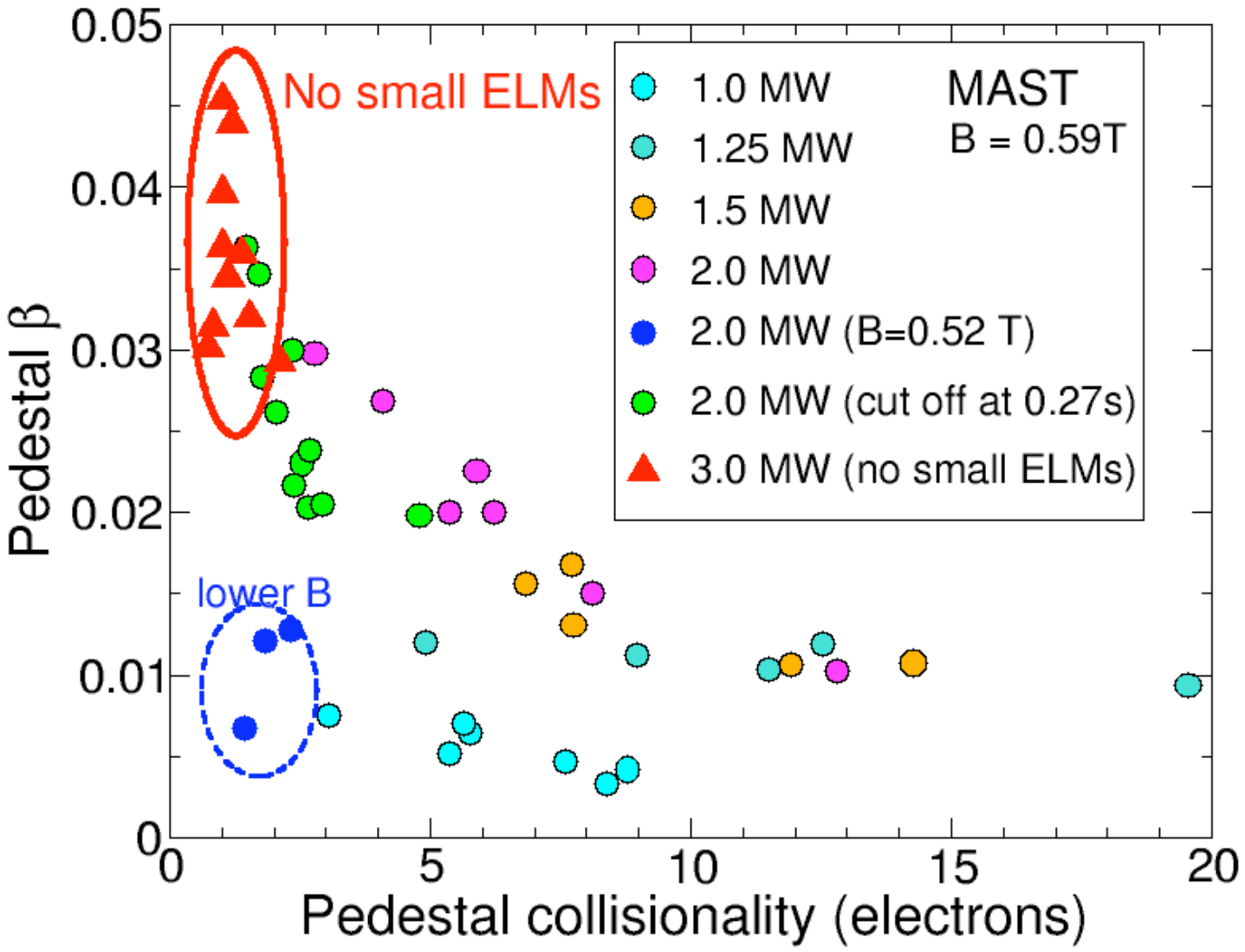
Small ELMs in MAST consist of large number of filaments

- About twice as many filaments as compared with larger ELMs
- Most of the filaments do not detach, but rather dissipate





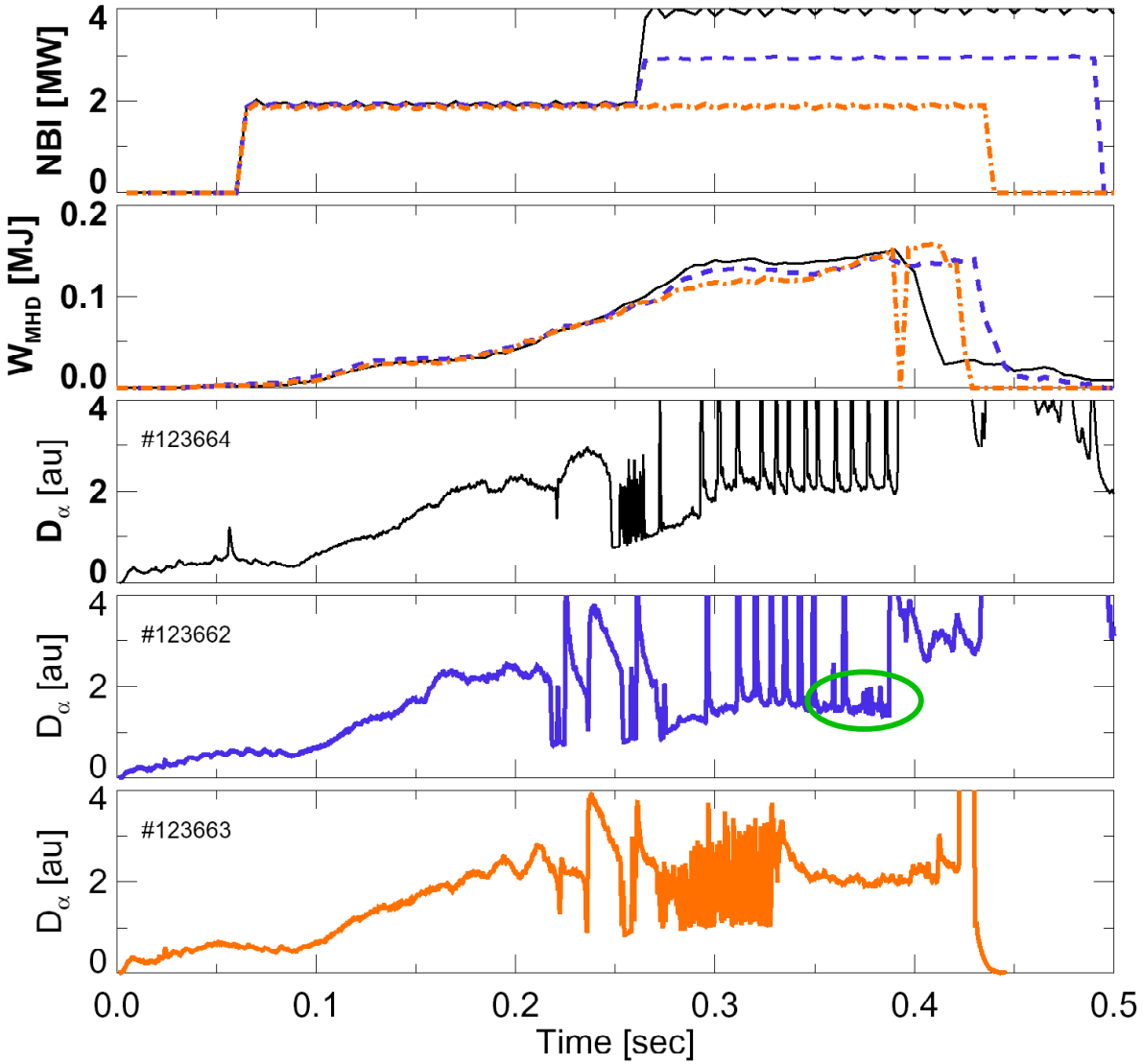
Small ELMs in MAST exist over a wide β_{ped}, ν_e window*



- At low P_{NBI}, small ELMs inter-mixed with Type III ELMs
- At high P_{NBI}, small ELMs disappear

NSTX

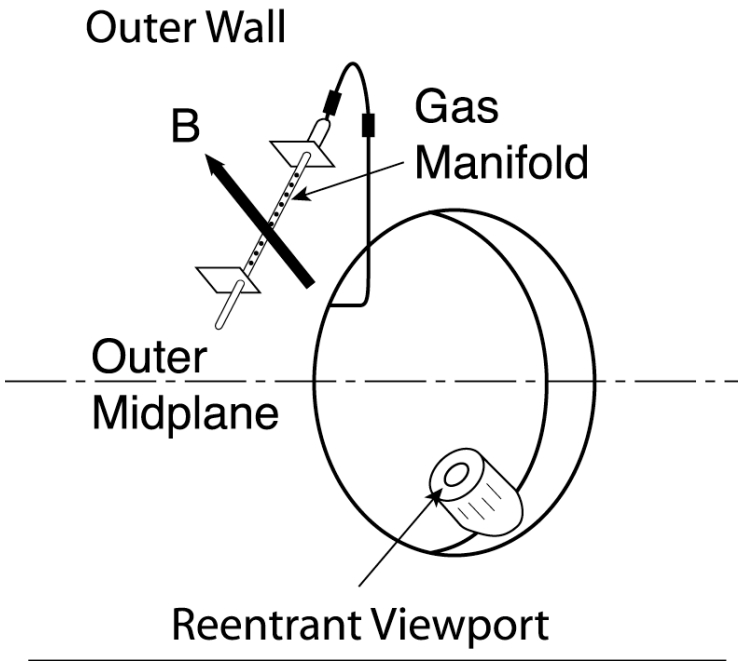
Small ELMs in narrow heating power range close to DN

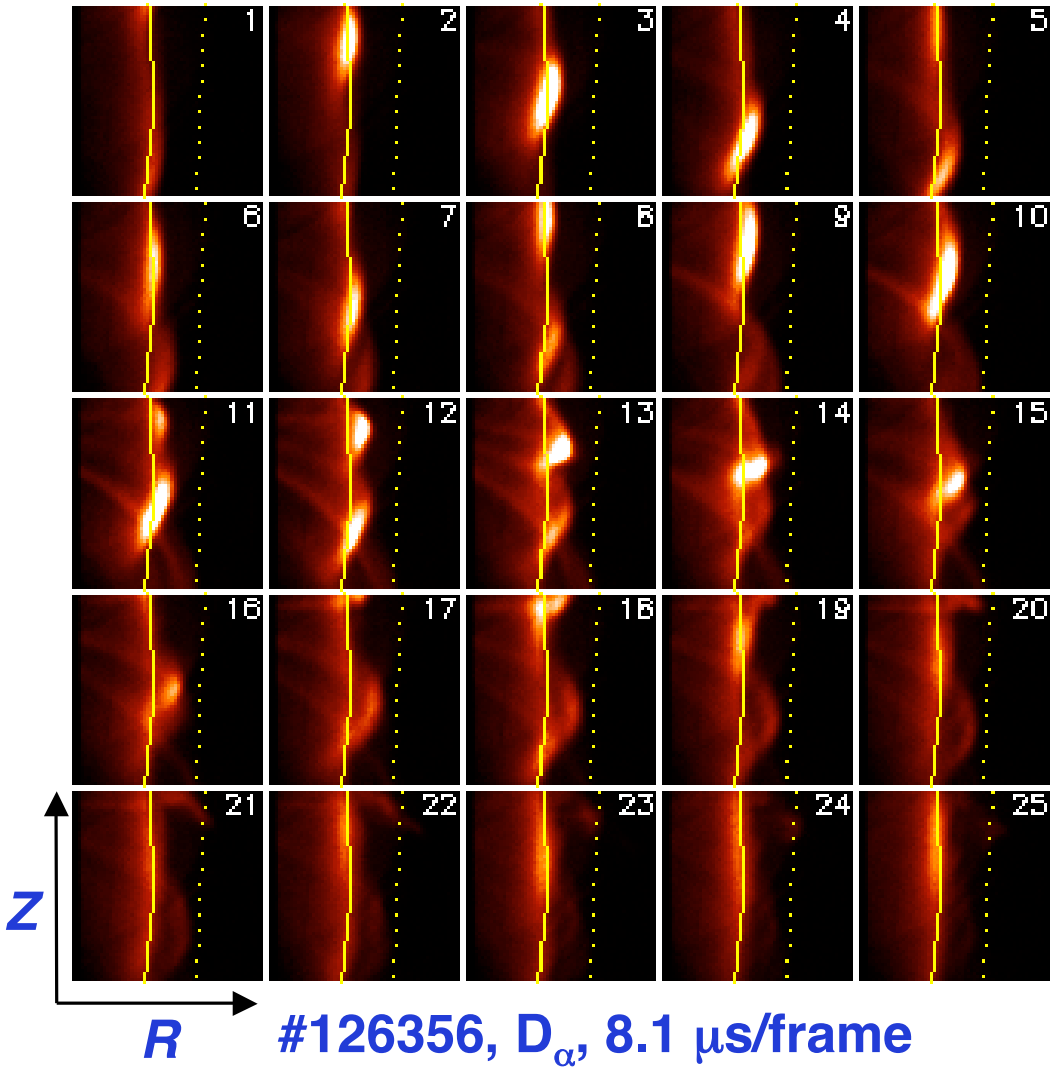


- NBI power scan
- Stored energy
- Type I only
- Small ELMs for only brief time
- Type III ELMS only

Small ELM has multiple filaments and propagates downward in NSTX near double-null discharges

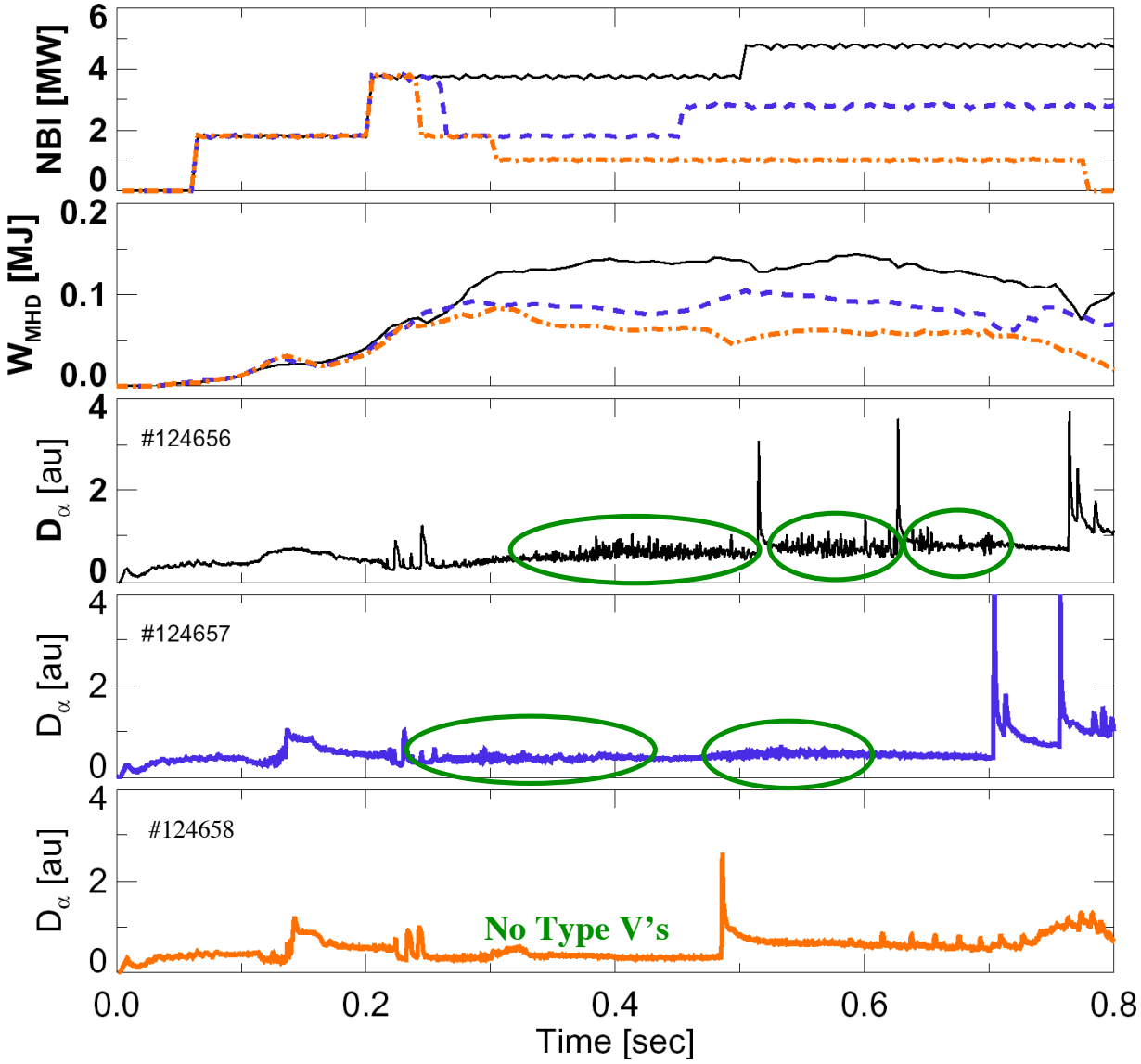
Gas Puff Imaging Diagnostic
23 cm x 23 cm field of view





#126356, D_α, 8.1 μs/frame

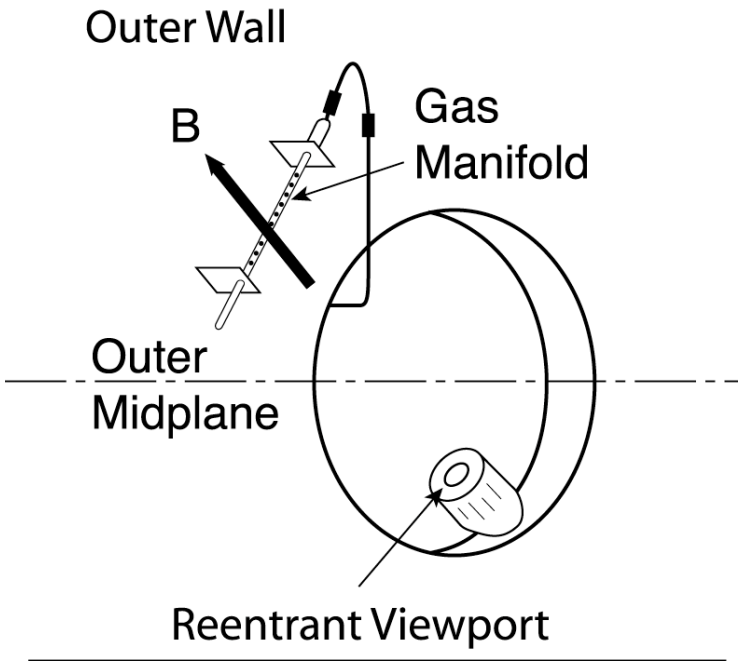
Type V ELMs in wide heating power range in NSTX lower-single null discharges

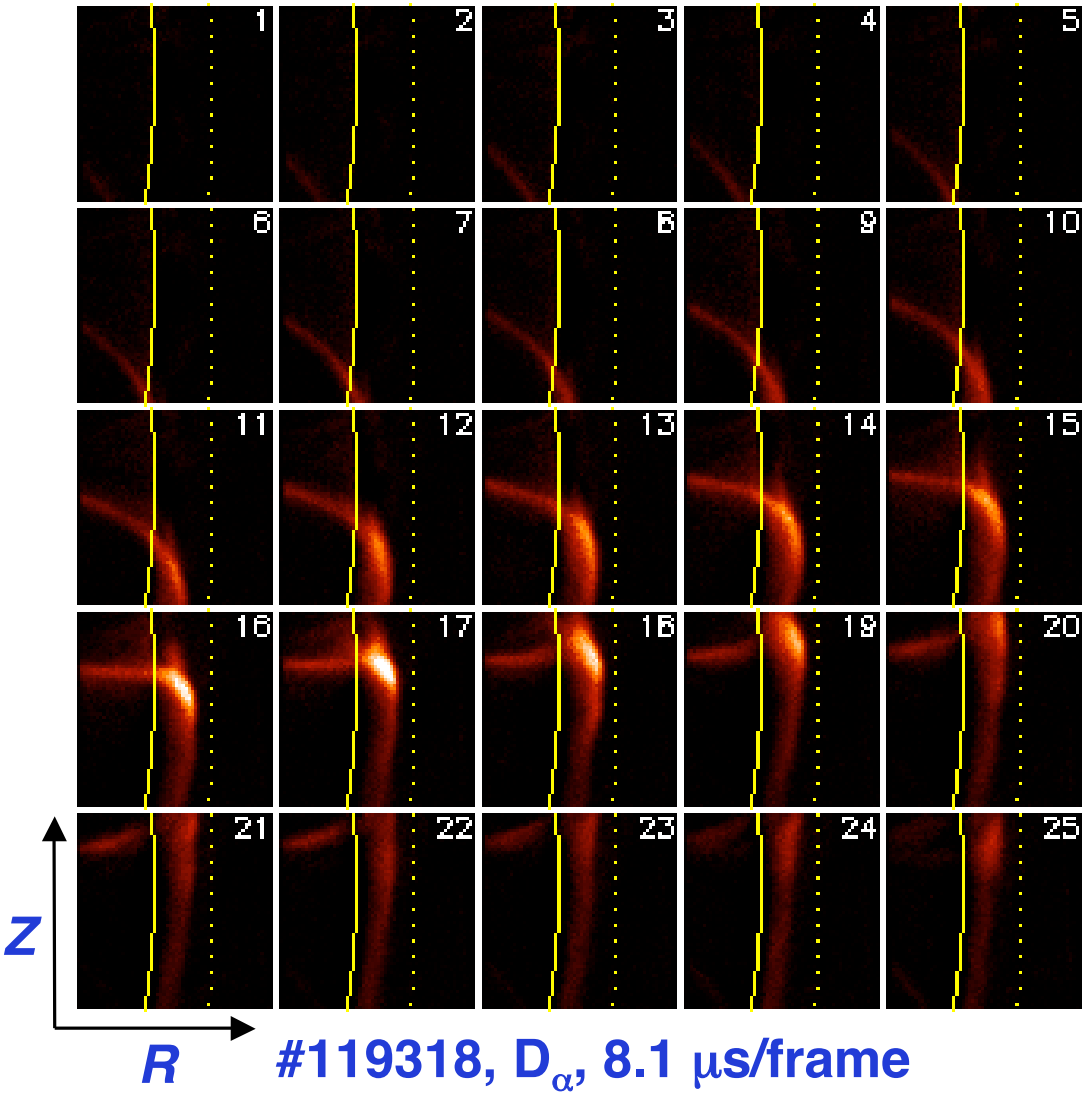


- NBI power scan
- Stored energy
- Type I and Type V ELMs
- Type V only
- Mostly ELM-free

Type V ELM has single filament and propagates upward in NSTX lower single-null discharges

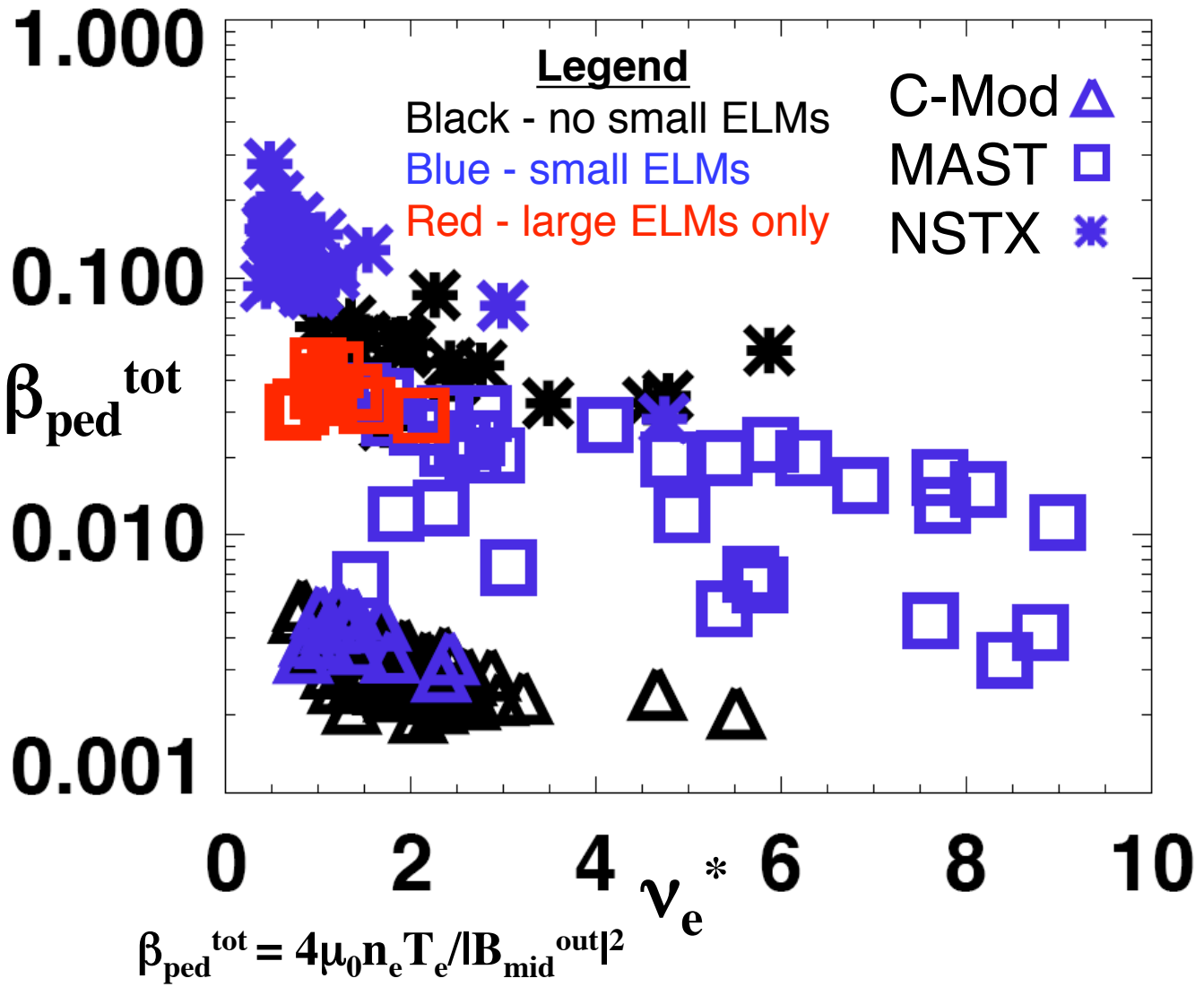
Gas Puff Imaging Diagnostic
23 cm x 23 cm field of view





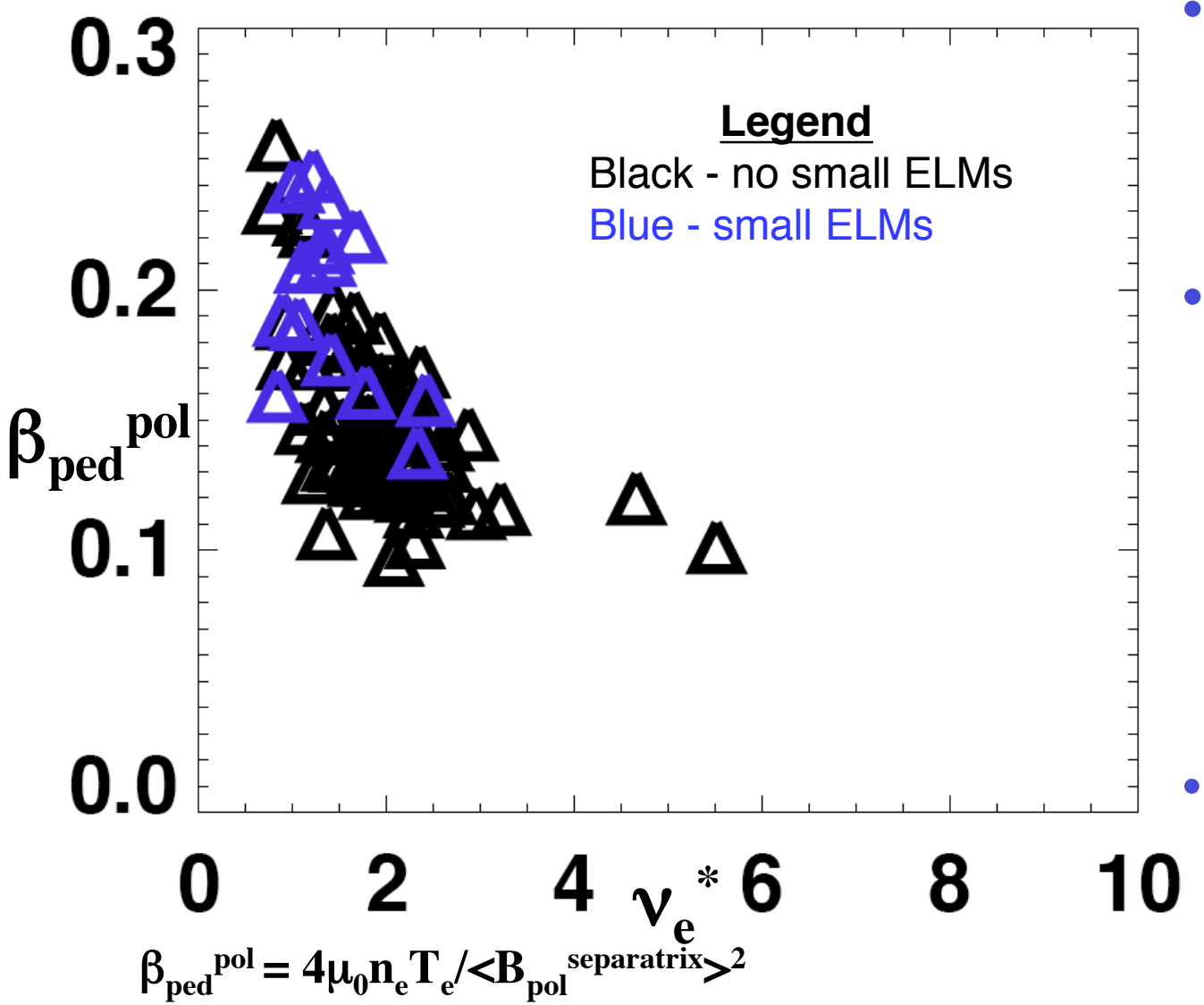
#119318, D_α, 8.1 μs/frame

Pedestal β normalized to outer midplane B_{tot} not a good ordering parameter across machines for small ELM access window



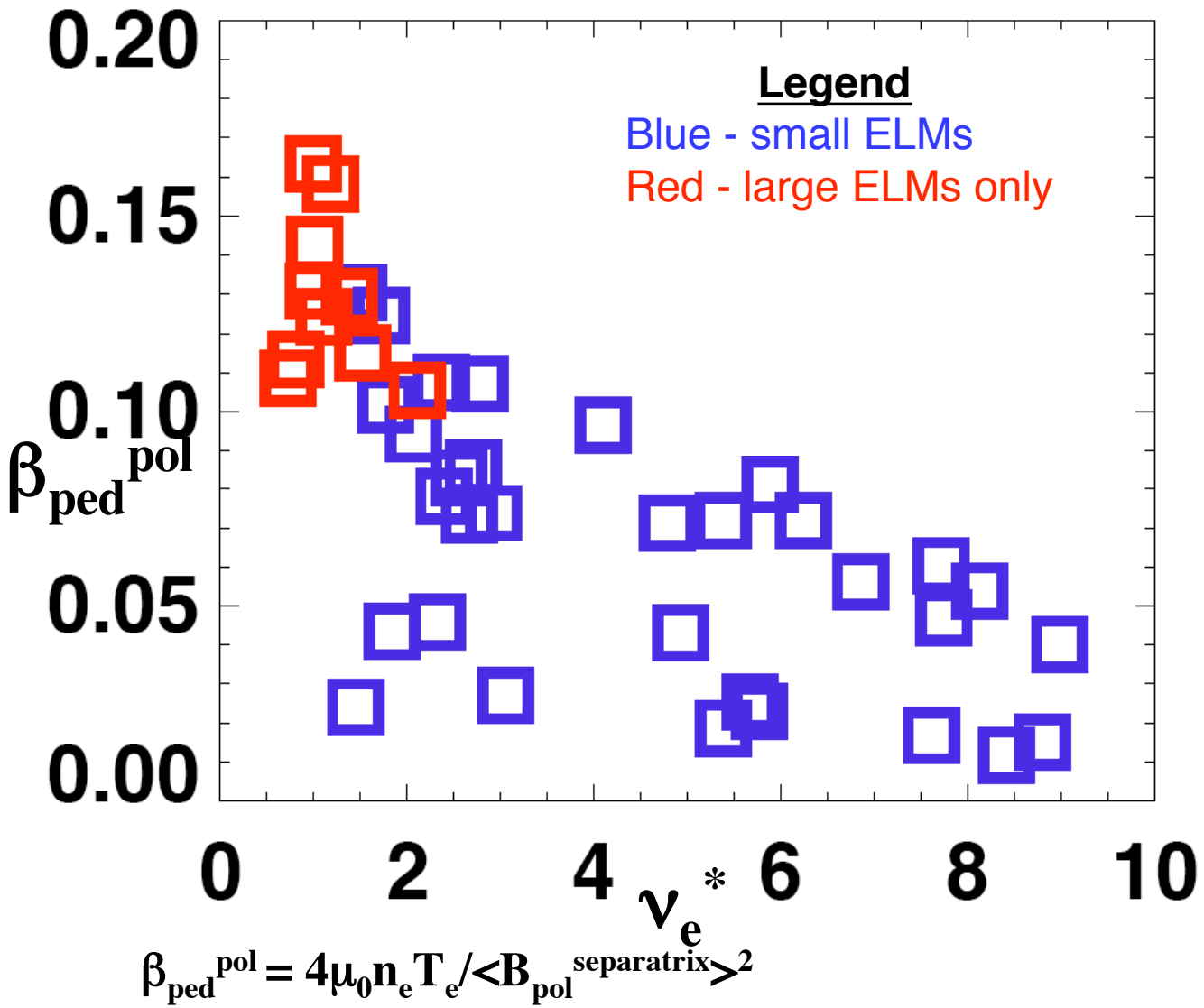
- **Small ELMs appear in C-Mod when $\beta_{ped}^{tot} \geq 0.3\%$**
- **Small ELMs in MAST exist at β_{ped}^{tot} down to 0.3% and *vanish* when $\beta_{ped}^{tot} \geq 3\%$,**
- **Type V ELMs appear in NSTX when $\beta_{ped}^{tot} \geq 6\%$**
- **'Type II' ELMs in NSTX DN shape also appear when $\beta_{ped}^{tot} \sim 6\%$**

Lowest β_{ped}^{pol} is ~ 15% for access to small ELMs in C-Mod



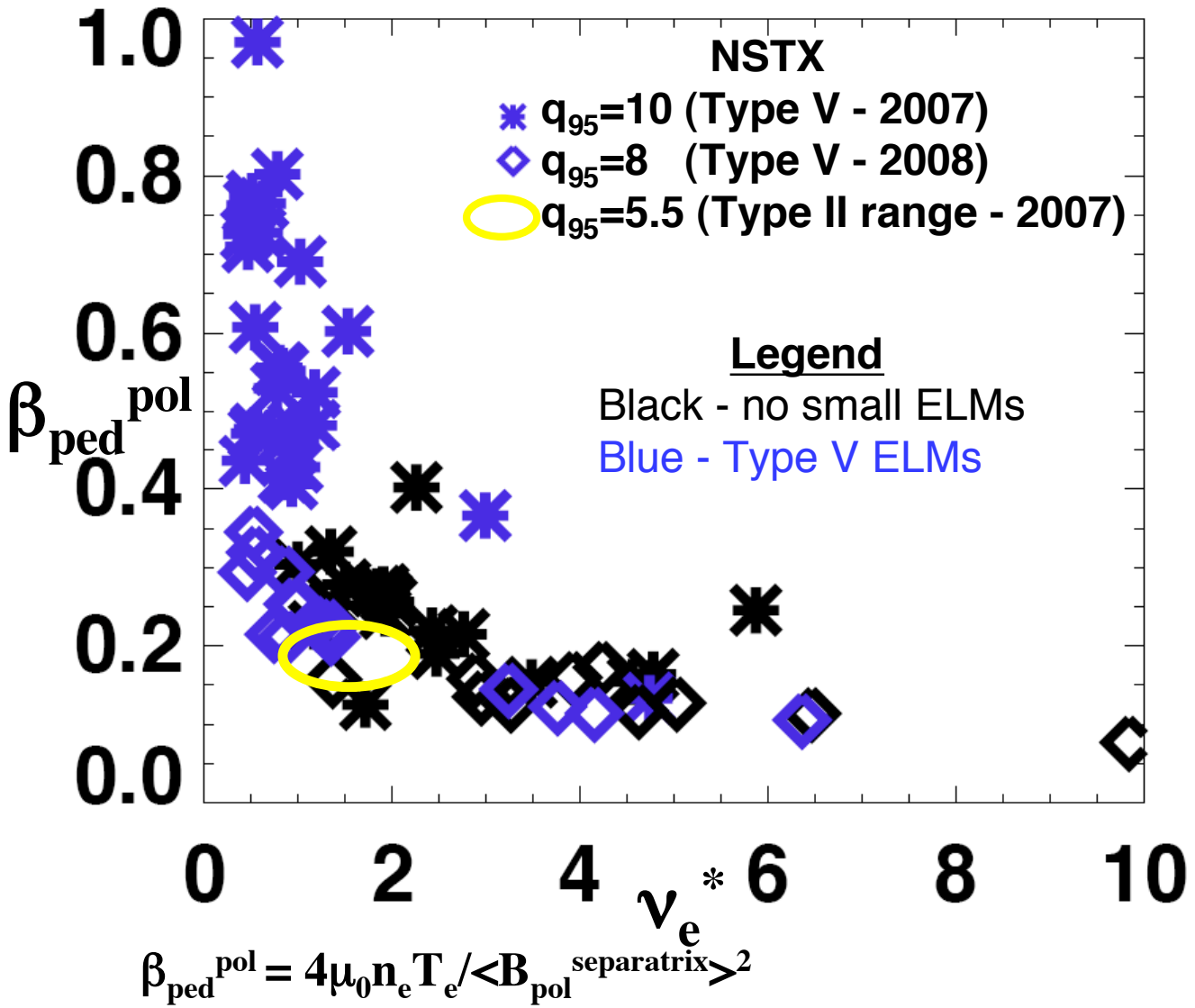
- **Baseline discharges are ELM-free EDA H-modes**
- **Small ELMs appear on top of EDA at high heating power, consistent with previous experiments**
- **Small ELMs may be Type II - proximity to double-null shape**

Highest β_{ped}^{pol} is ~ 15% for access to small ELMs in MAST



- **Small ELMs can be distinguished at the lowest heating power between Type III ELMs**
- **At highest heating power, small ELMs vanish, with only Large Type I ELMs left**
- **Small ELMs may be Type II - proximity to double-null shape**

Lowest β_{ped}^{pol} is ~ 15% for access to small ELMs in NSTX



$\beta_{ped}^{pol} = 4\mu_0 n_e T_e / \langle B_{pol}^{separatrix} \rangle^2$

- Lowest q_{95} was with I_p=0.9 MA, B_t=0.42 T, in near DN shape
  - 'Type II' ELMs
- Higher q_{95} was with I_p=0.6-0.8 MA, B_t=0.44 T in lower single-null shape
- Although β_{ped}^{pol} aligns NSTX data with C-Mod and MAST, it does not order the NSTX data as well as β_{ped}^{tot}

Summary, Conclusions, and Near Term Work

- C-Mod: small ELMs observed on top of EDA H-mode
  - Sensitive to shape (triangularity, proximity to double-null)
  - Apparent power threshold: $P_{ICRF} \geq 3$ MW
  - Appear as bursts of turbulence filaments in Gas-puff imaging
- MAST: small ELMs observed to co-exist with Type III ELMs
  - Apparent upper power limit: $1.8 \text{ MW} \leq P_{NBI} \leq 3 \text{ MW}$
  - Large number of rotating filaments, most of which do not detach
- NSTX: small ELMs observed both near double-null ("Type II") and also in lower-single null (Type V)
  - Type II ELMs observed in narrow heating power window
  - Type V ELMs observed in wide heating power window
  - Type II ELMs propagate downward poloidally, Type V upward
- Common $\beta_{ped}^{pol} \sim 15\%$ threshold for small ELMs
  - However it's a lower limit in Cmod, NSTX; upper limit in MAST
  - β_{tot}^{ped} range much broader across machines
    - not the correct ordering parameter across machines
- Edge stability analysis with kinetic EFITs commencing

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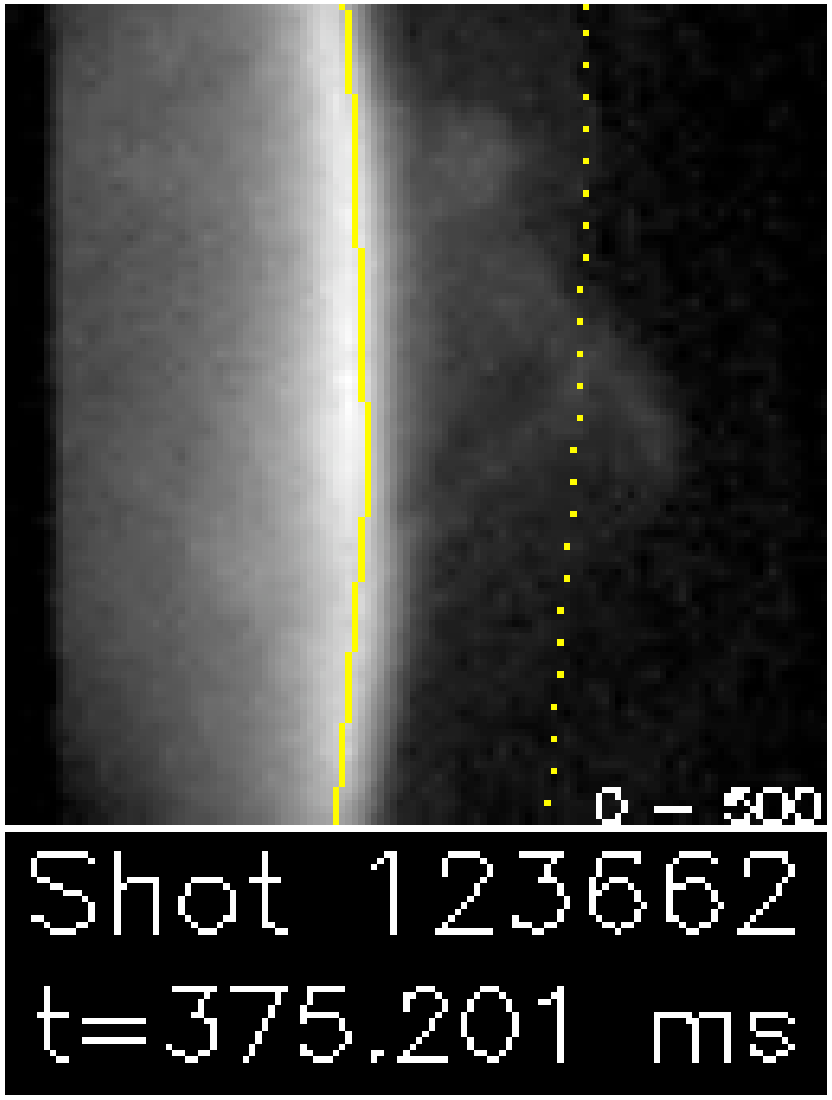
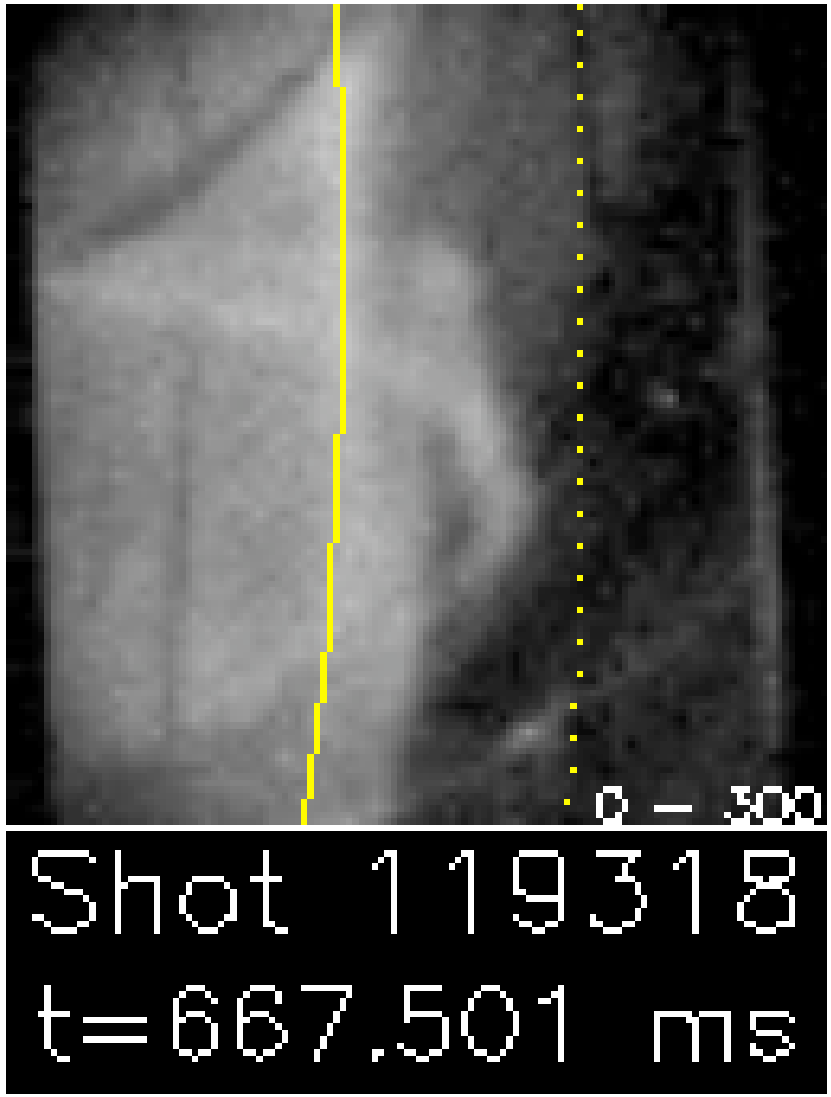
Small ELMs and Type V ELMs propagate in opposite poloidal directions

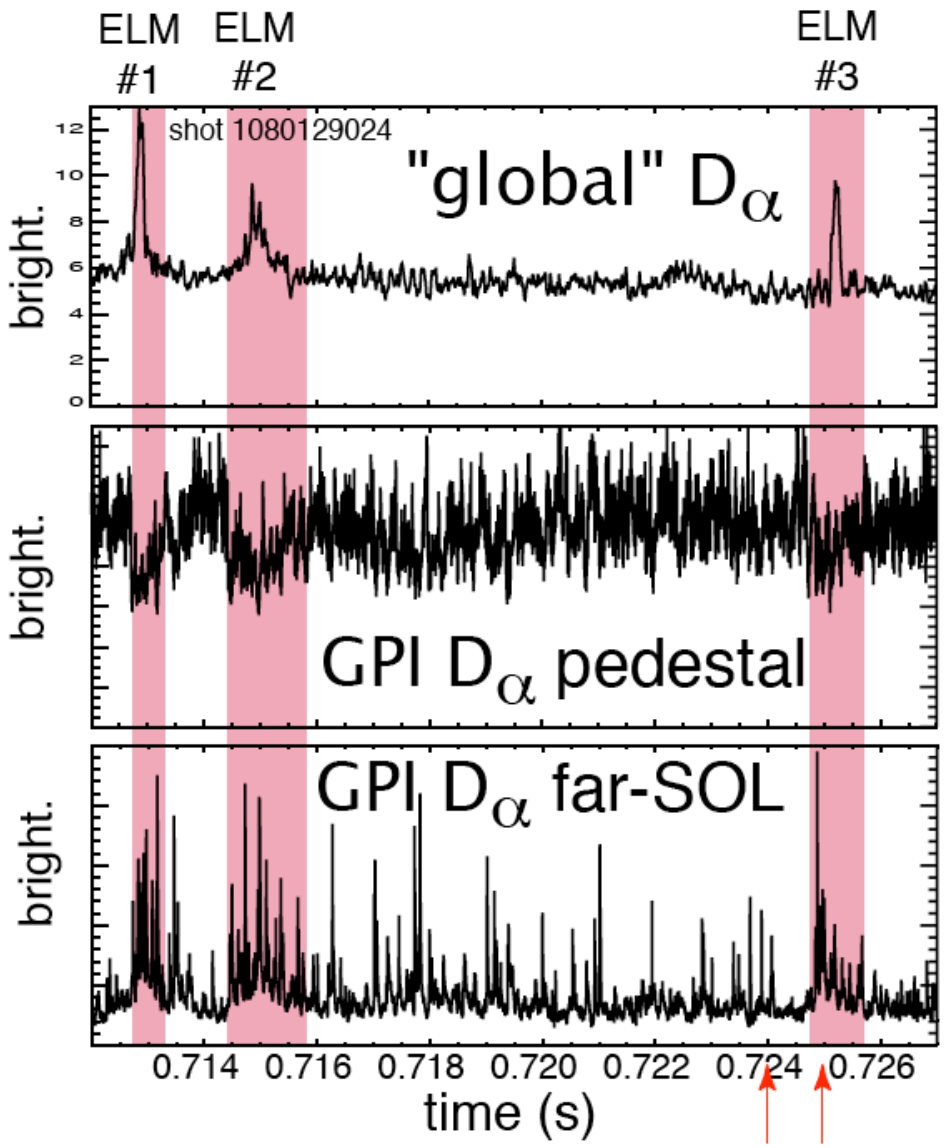
Small ELM near double-null



Type V ELM in lower single-null



Small ELMs appear as groups of detaching filaments; Pedestal top D_α affected in Alcator C-Mod



Gas Puff Imaging Diagnostic