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Effects of low-Z powders on high-confinement plasmas in DIII-D

Florian Effenberg, Alessandro Bortolon, Livia Casali, Igor Bykov, Filippo Scotti, Huiqian Q. Wang, Robert Lunsford, Federico Nespoli, Florian M. Laggner, Brian A. Grierson, et al.

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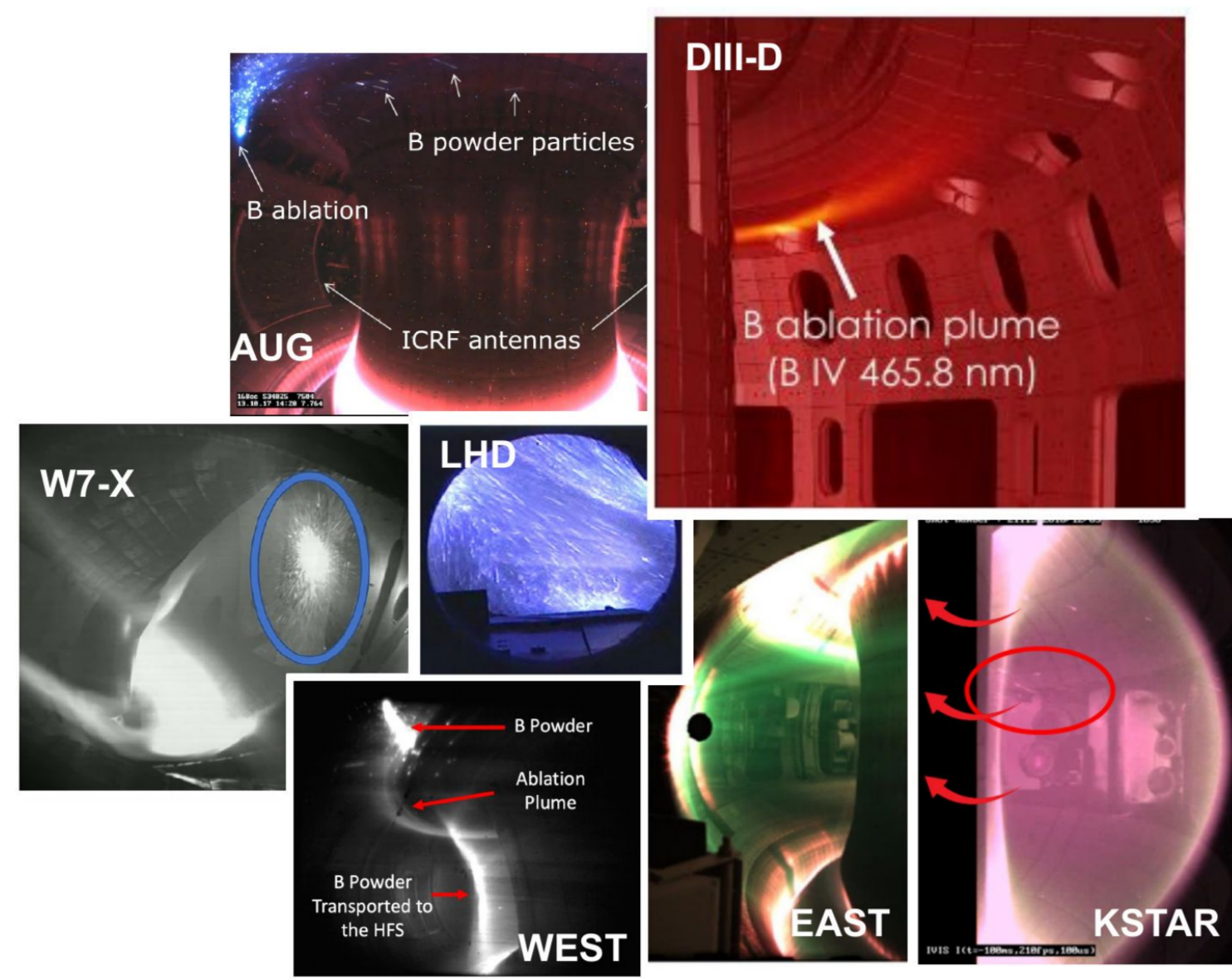
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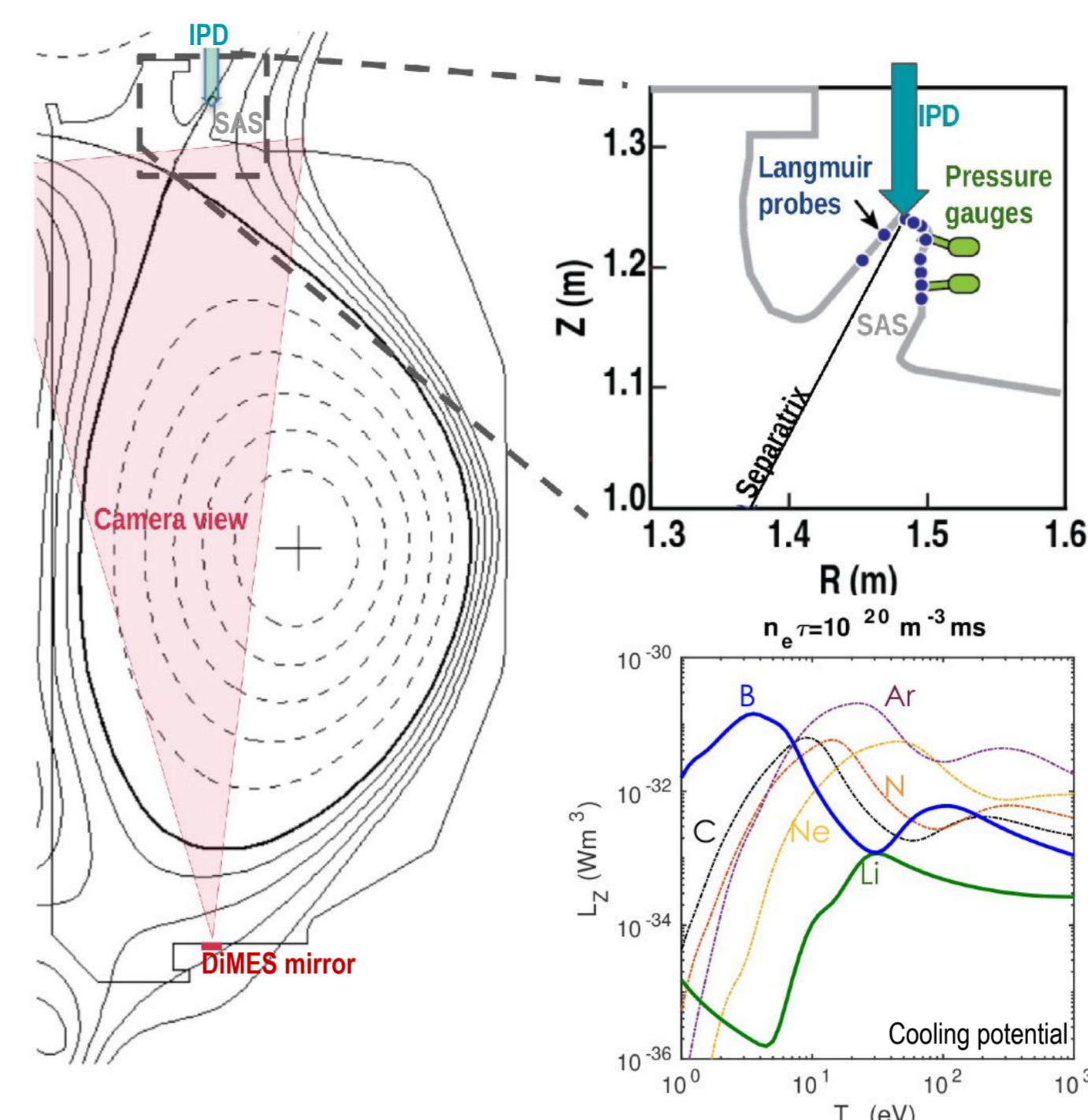
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Materials are injected in powder form to control plasma-material interactions and pedestal at DIII-D and other devices

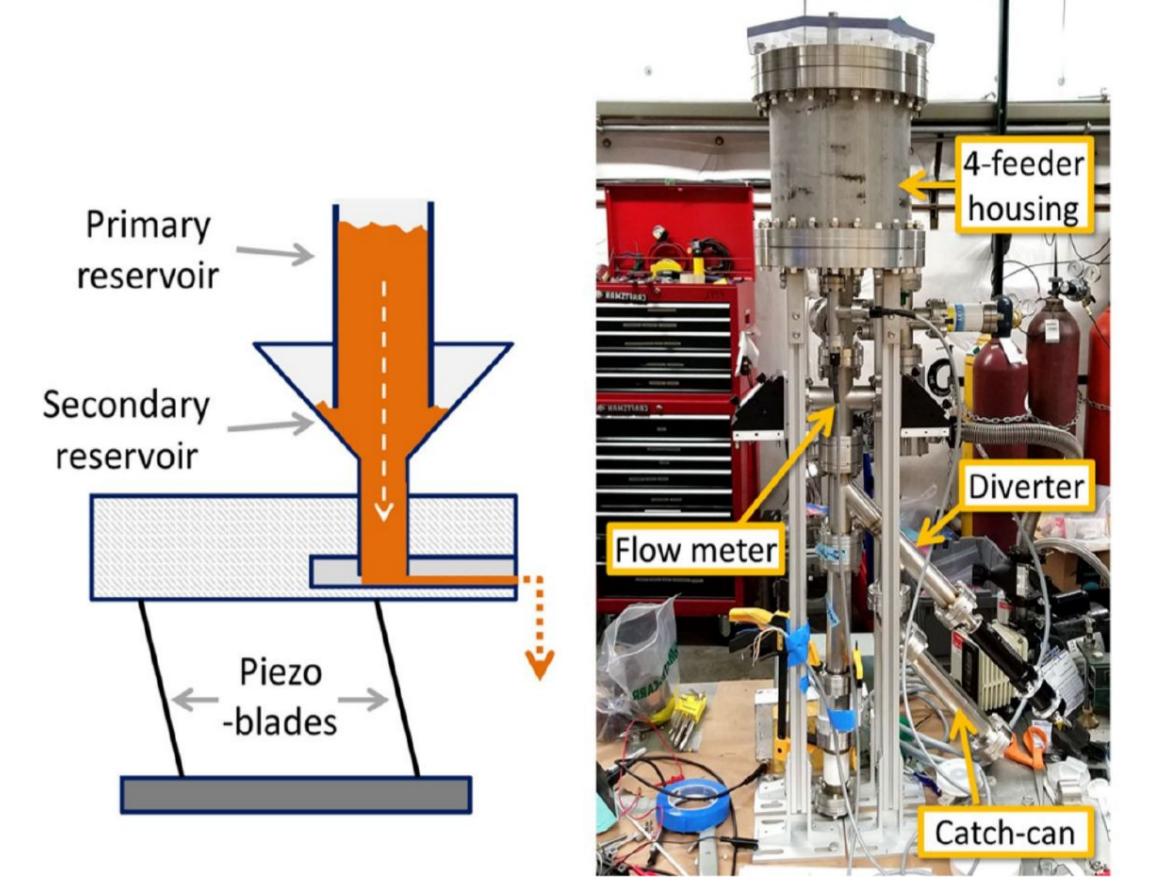
- Recent applications: ELM & pedestal control, real-time wall conditioning, impurity transport
- This work: low-Z powders injection into C and W divertor dissipate power and improve wall conditions during H-mode
- BN, Li are more efficient than B for divertor power exhaust; BN most suitable for detachment
- EMC3-EIRENE & DIS show Li & BN ablate in divertor, less retention for B



Lithium, boron, and boron nitride powders were injected into the small angle slot (SAS) divertor in DIII-D H-mode

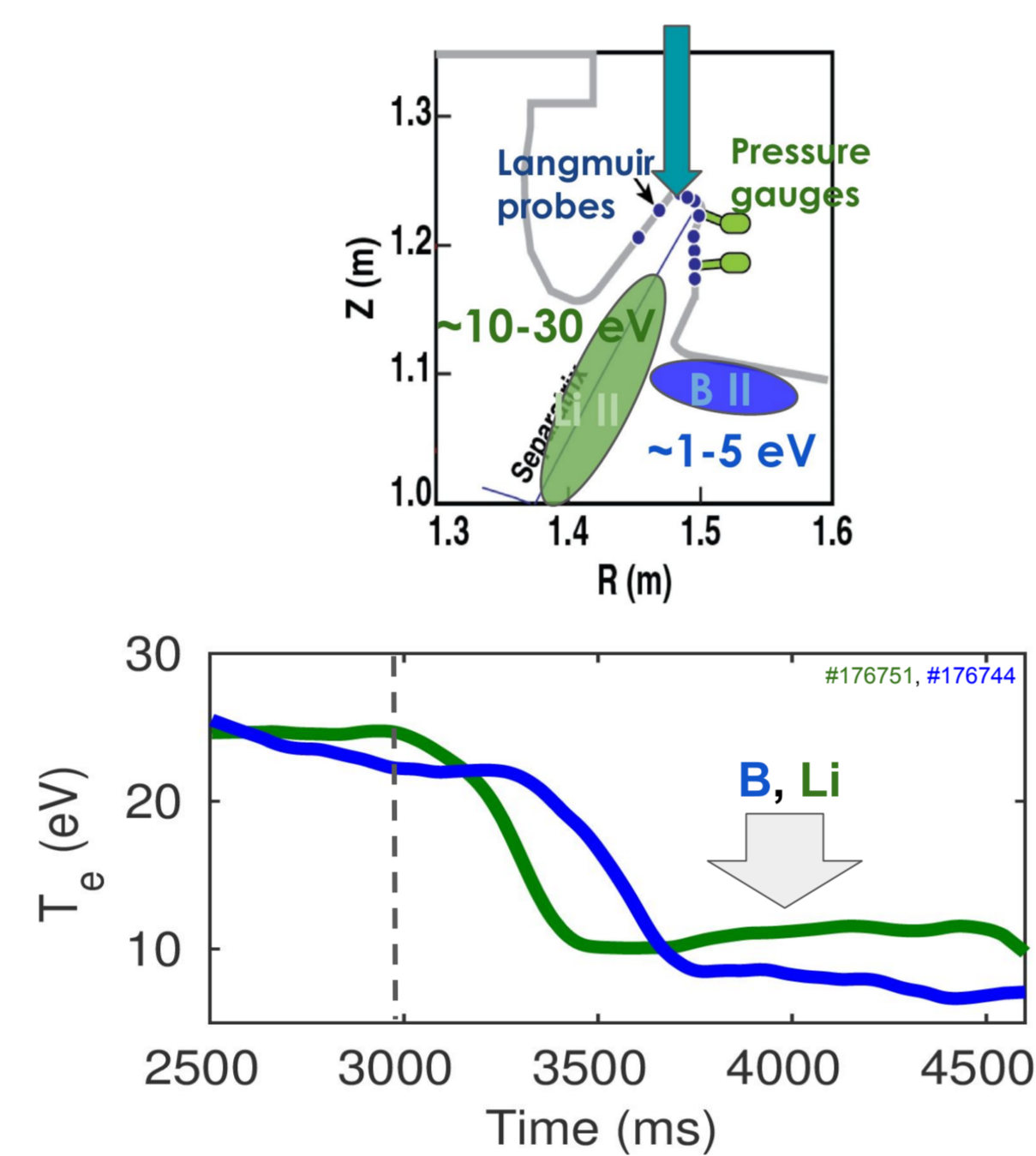
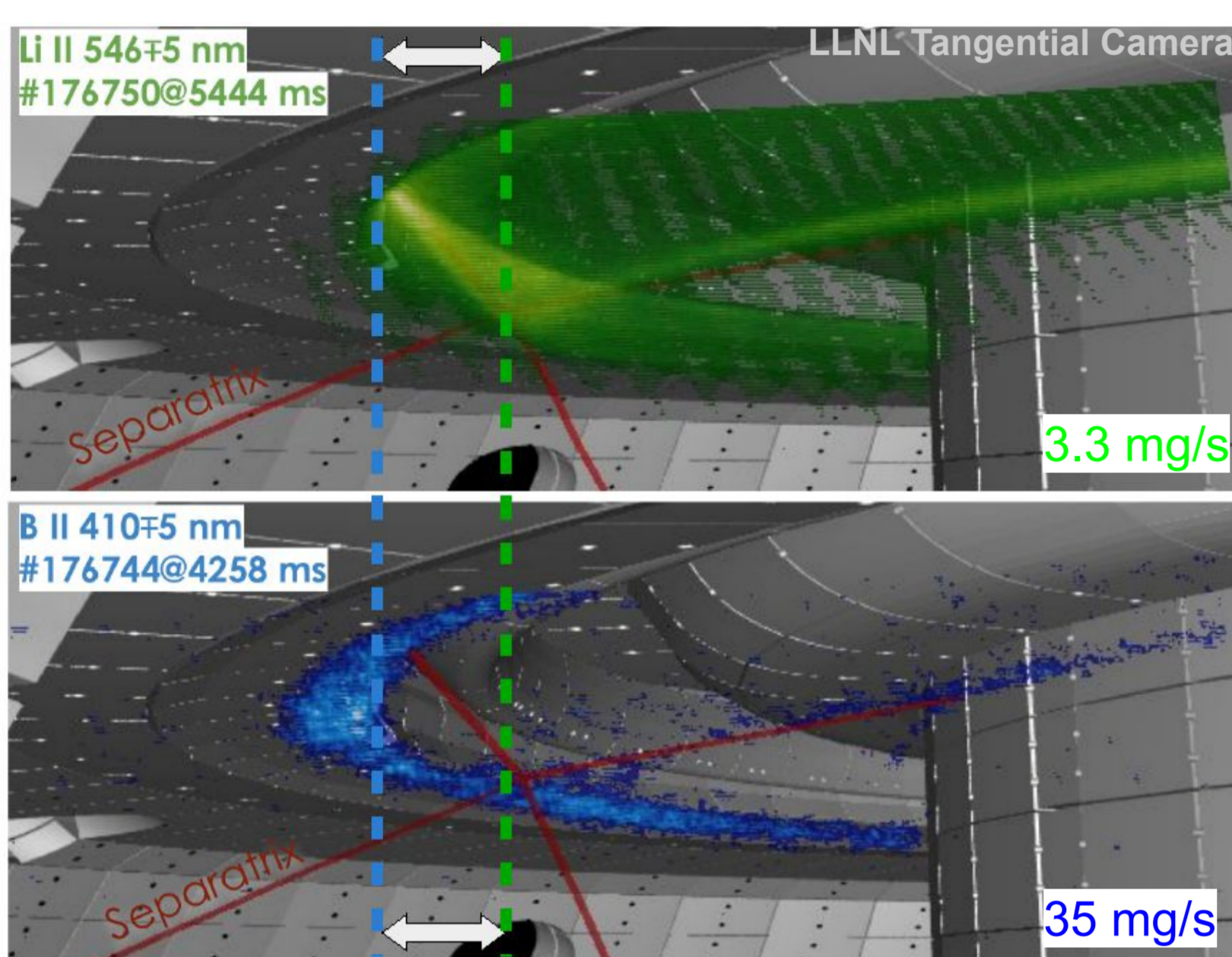


- ### PPPL Impurity Powder Dropper
- Li, B, BN powders (40-150 μm)
 - flow rates 3-200 mg/s, atomic rates 10^{20} - 10^{22} atoms/s, (1-300 Torr-l/s), particle speed: 5-6 m/s

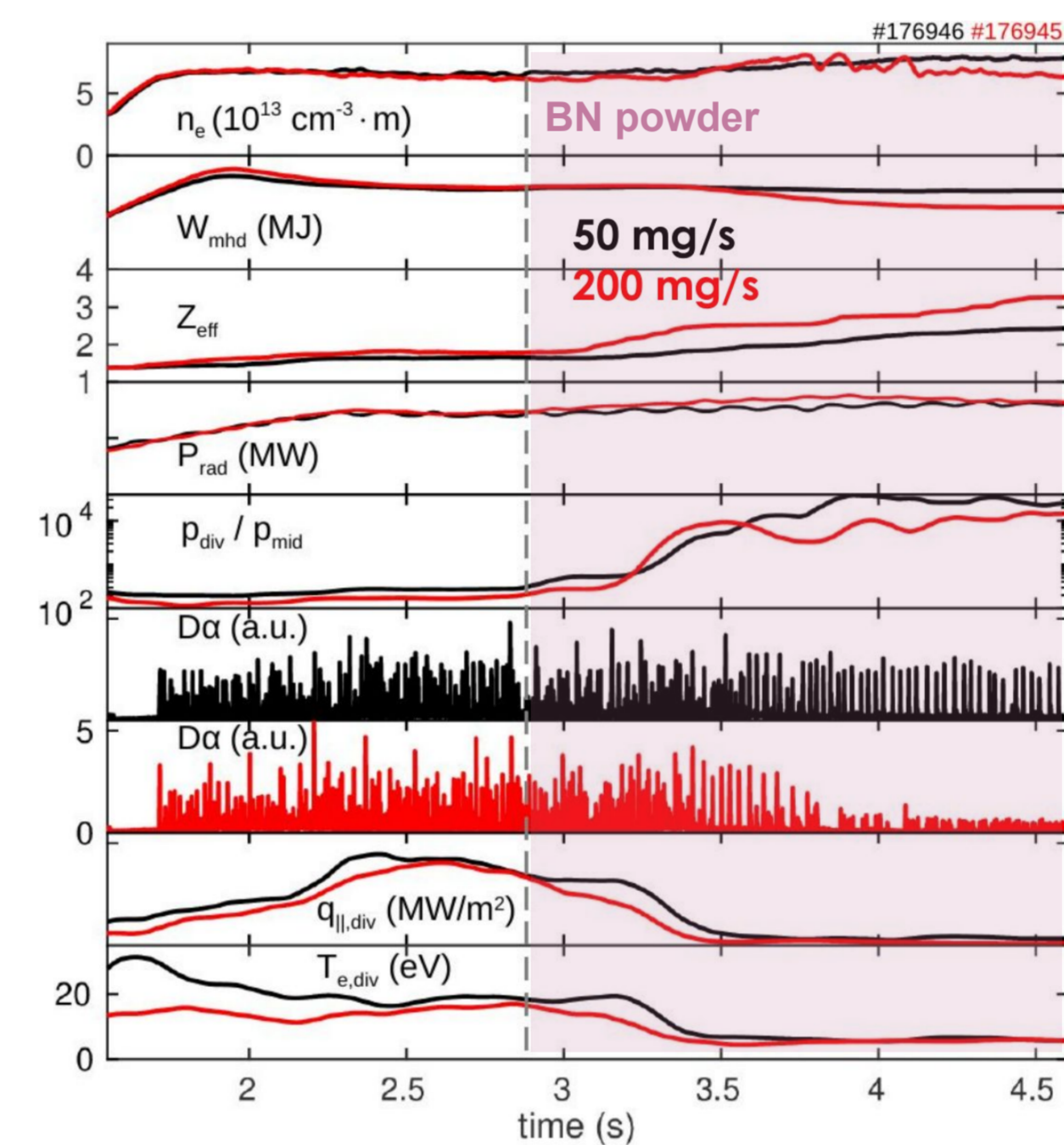


A. Nagy et al, Rev. Sci. Instrum., 2018 89, 10K121
A. Bortolon et al 2020 Nucl. Fusion 60 126010

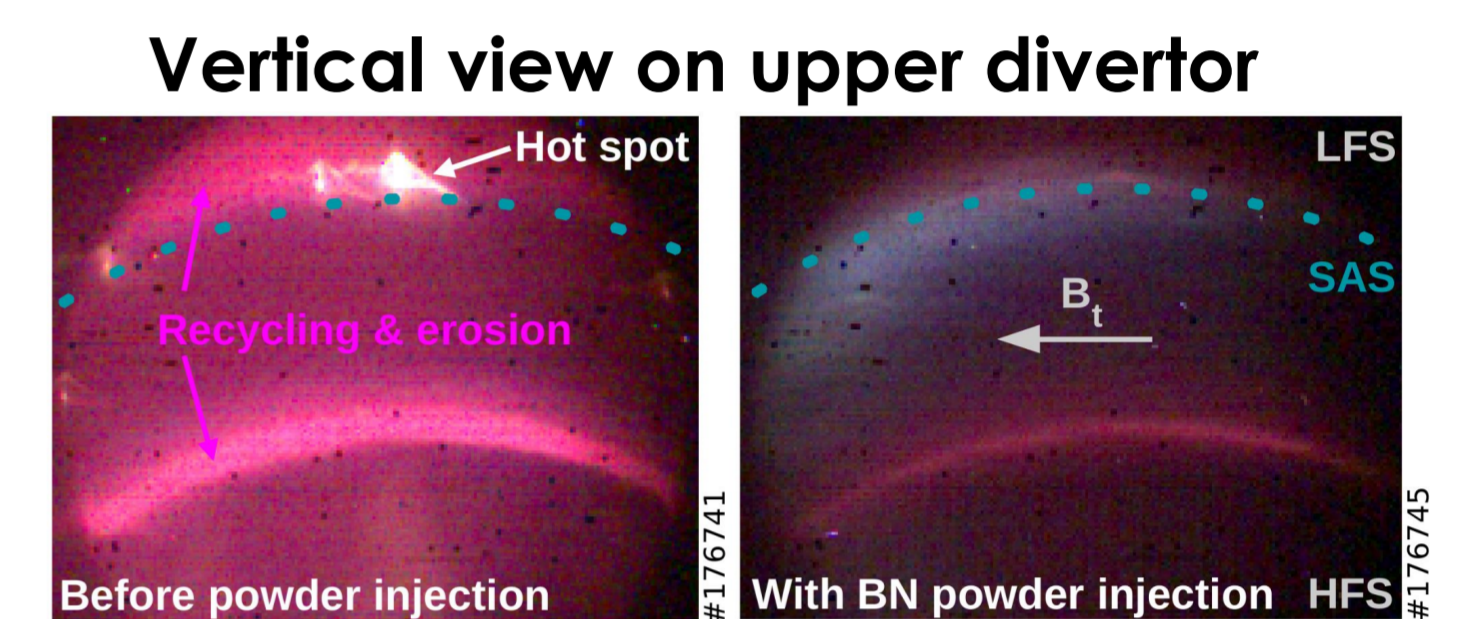
Boron is an effective radiator in colder far scrape-off layer, while lithium radiates close to separatrix



Boron nitride powder detaches the divertor and reduces ELM fluxes to the divertor targets

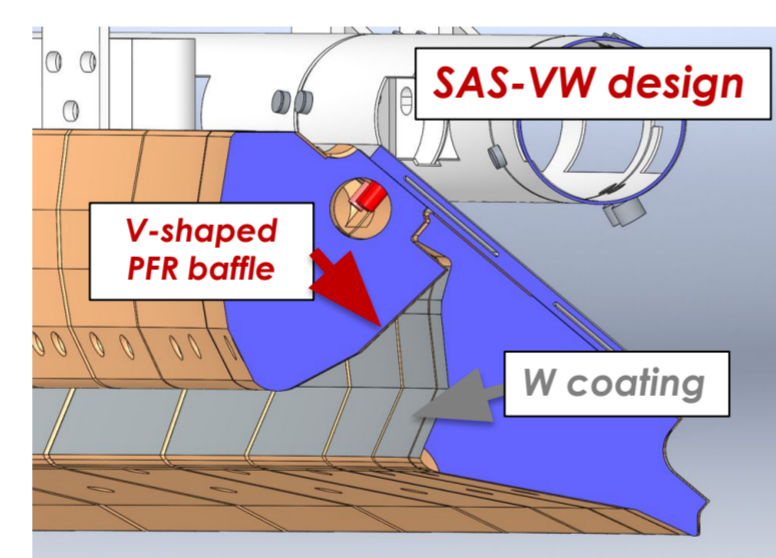
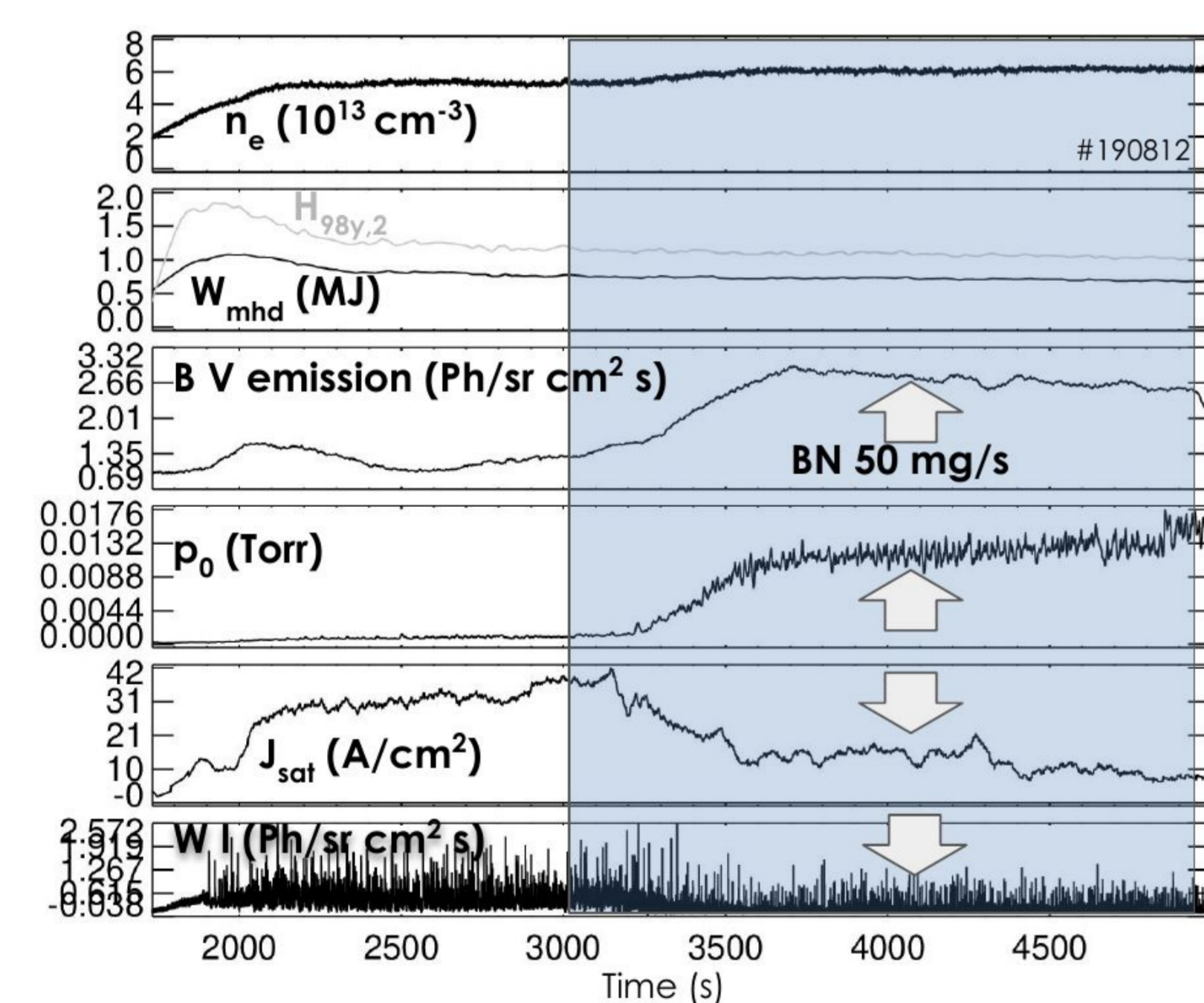


F. Effenberg et al 2022 Nucl. Fusion 62 106015



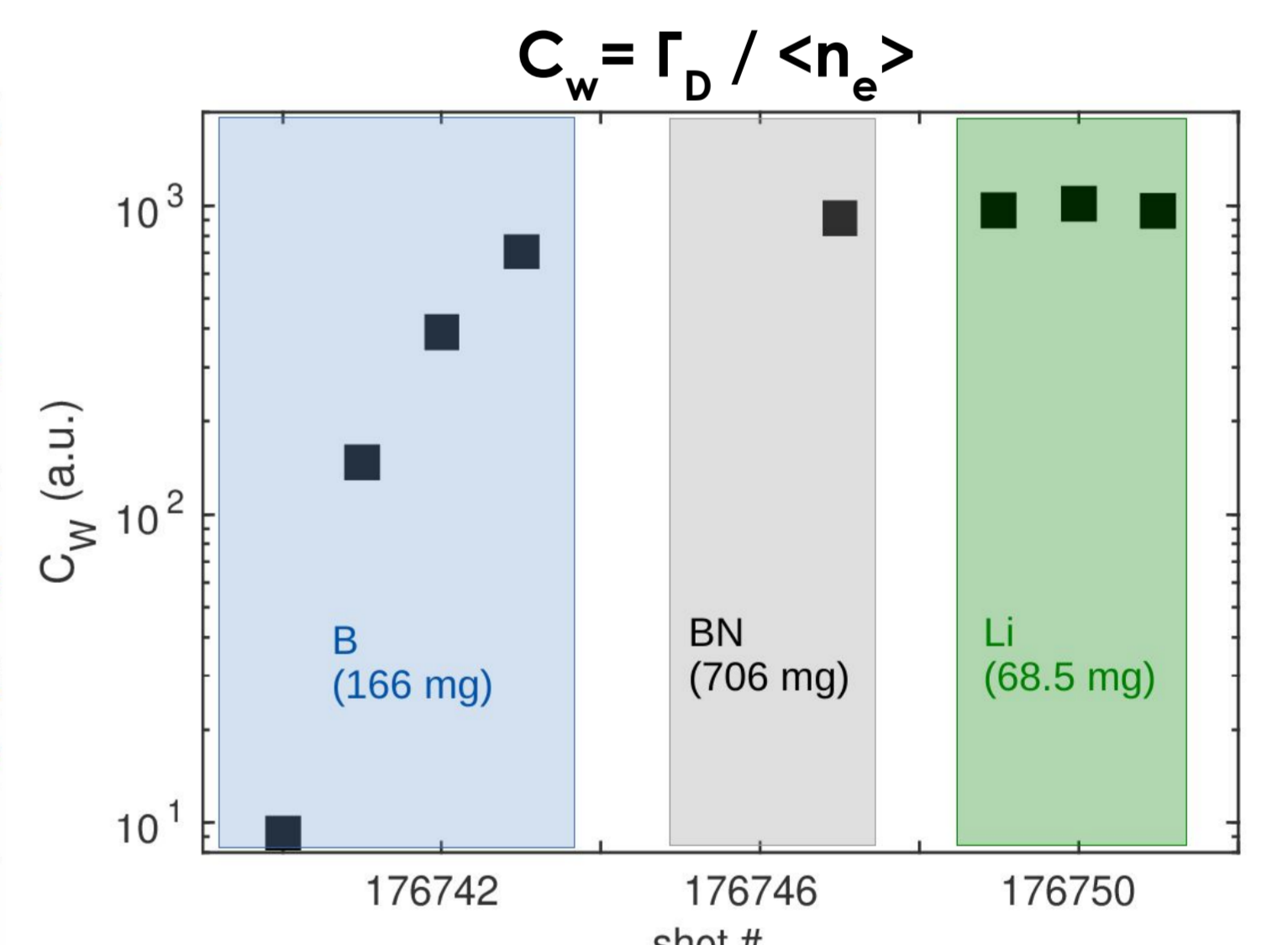
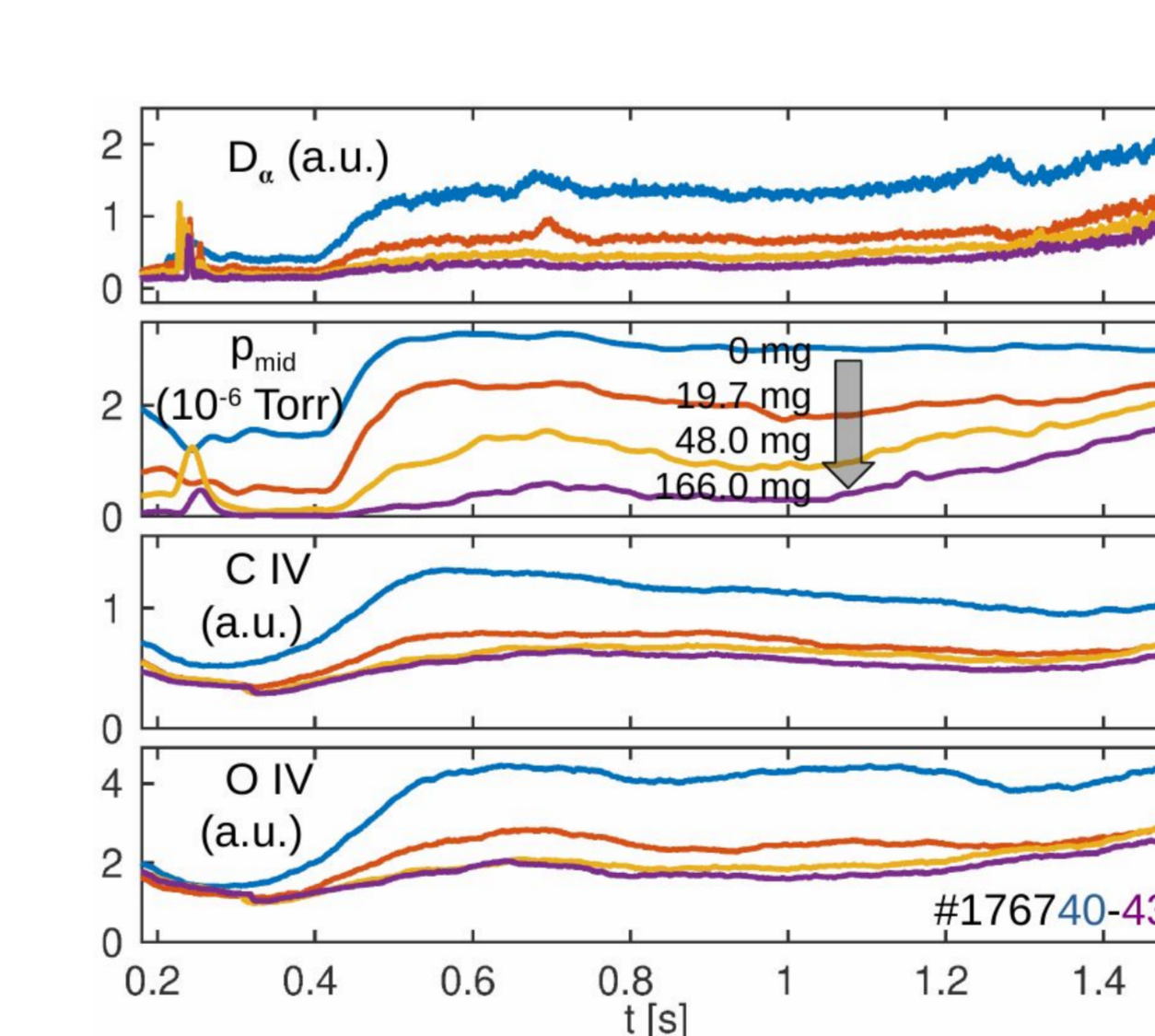
- ### BN at moderate-high rates
- 65 μm BN injected at ~50-200 mg/s
 - Sustained detachment
 - ELM frequency and amplitude reduce at the target

New experiments in closed tungsten divertor (SAS-VW) demonstrate suppression of W source and detachment



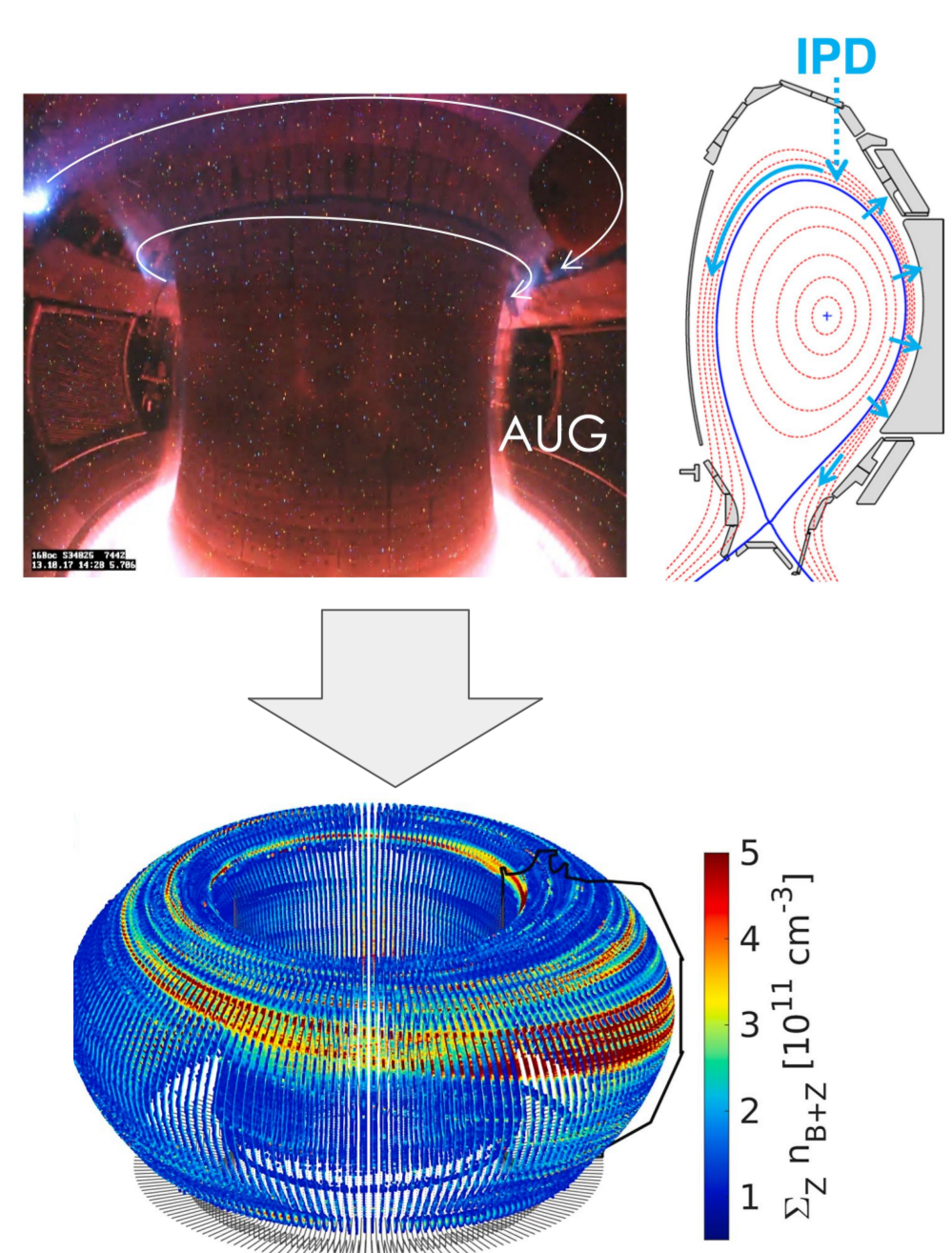
- ### Outer strike point located on W coated files
- 65 μm BN injected at ~50 mg/s
 - Sustained detachment
 - W source (W I) reduces

Powders also reduce recycling and intrinsic impurities, allowing access to lower collisionality plasmas



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The Dust Injection Simulator was coupled to EMC3-EIRENE to enable full-torus treatment of powder & impurity transport



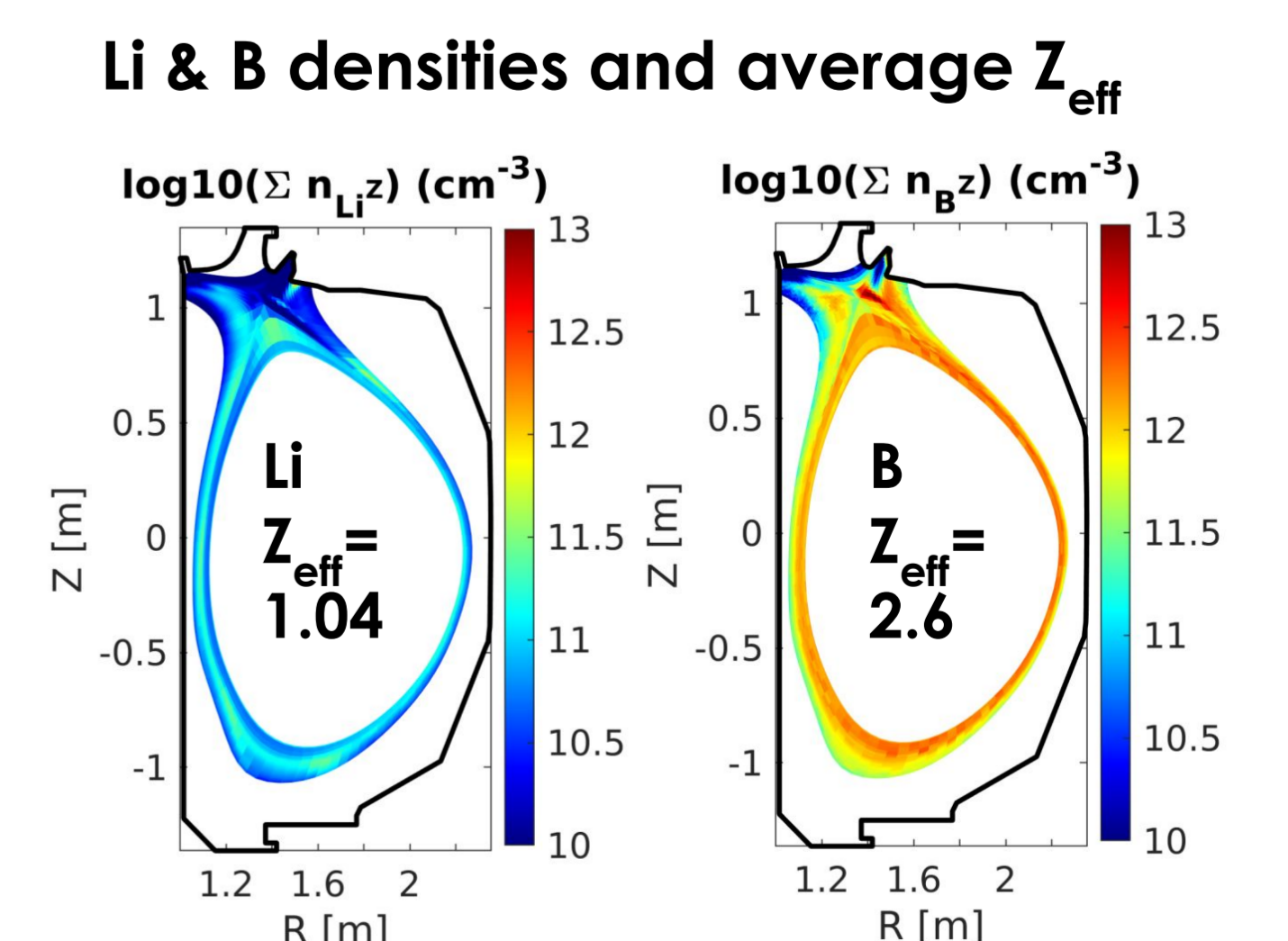
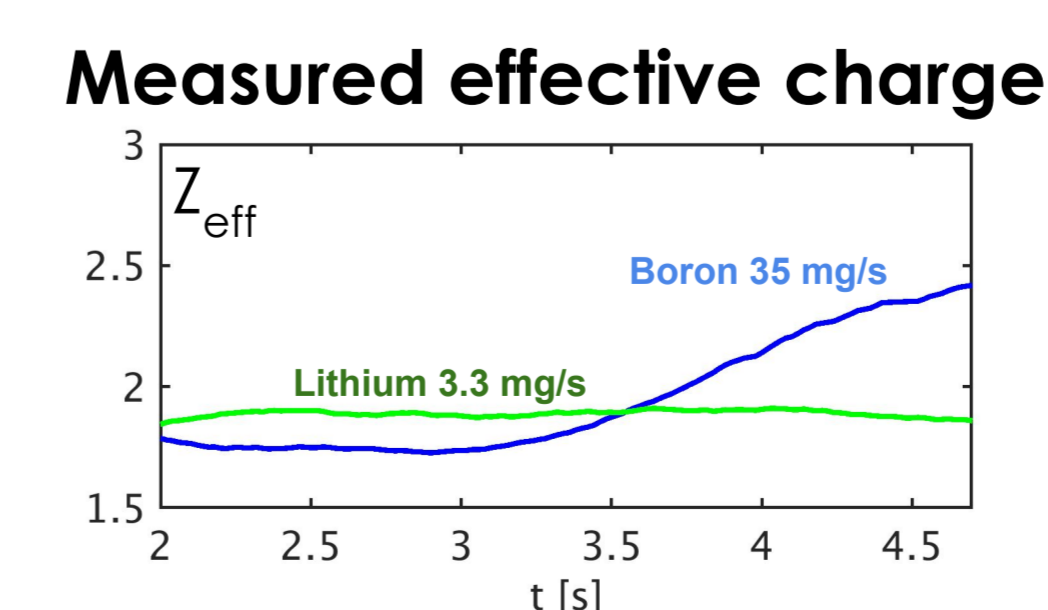
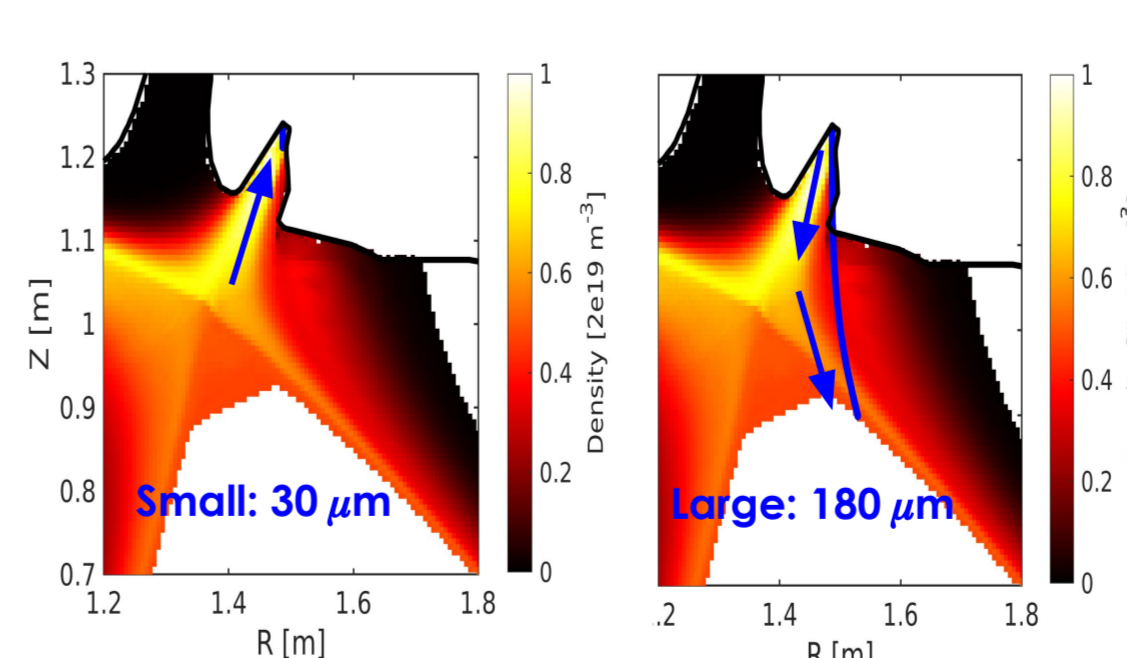
- EMC3:** 3D edge transport Monte Carlo code
 - Braginski plasma-fluid model for D, T, H
 - Trace impurity fluid model
- EIRENE:** kinetic neutral transport code

- Dust Injection Simulator (DIS):**

$$R_f = \sum F_{\text{drag},nZ} + F_{\text{drag},n0} + F_E + F_{\text{grav}} + F_{\text{centr.}}$$

F. Effenberg et al 2021 Nucl. Mat. and Energy 26 100900
Y. Feng et al, Contrib. Plasma Phys. 54 (4-6) 2014
F. Nespoli et al, PoP 28, 073704 2021

Modeling shows more substantial dilution by boron compared to lithium, boron nitride powders similar to the experiment



- ### Next steps:
- Compare effects in different configurations (USN, LSN, DN)
 - Effects on profiles & pedestal