Observations from recent experiments of wall conditioning by means of boron powder injection in AUG and DIII-D

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Introduction

- Deposition of B coatings allows density-controlled, high-purity plasmas
  - Reduced wall fueling, impurities sources
  - Fresh boronization is key to access low density / low collisionality regimes

- In present-day tokamaks (e.g. AUG, DIII-D) boronization consists in glow discharge enriched with borane gas (D_2B_6)
  - Hazardous gas → costly infrastructure/procedures
  - Effect lasts until the coatings are eroded (typically 100-200 shots)
  - Expected to be not effective for larger scale, steady-state devices

- Recent data from AUG and DIII-D indicate that injection of B powder in fusion plasmas can improve wall conditions

Outline

- Impurity powder dropper (IPD)
- Wall conditioning effects on ASDEX-Upgrade
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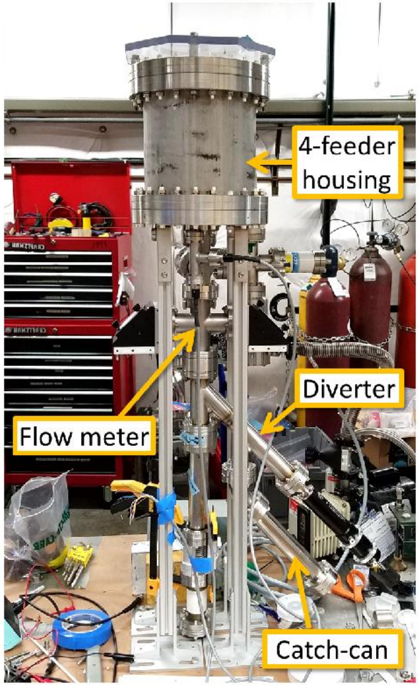
Multi Impurity Powder Dropper (IPD)

- Developed by PPPL team at General Atomics
- Successfully drops different materials in powder form
  - B, BN, Li, Si, SiC, Sn…
  - particle size 5-100 µm
  - calibrated rates 2-200 mg/s
- Presently installed on DIII-D, AUG, EAST and KSTAR

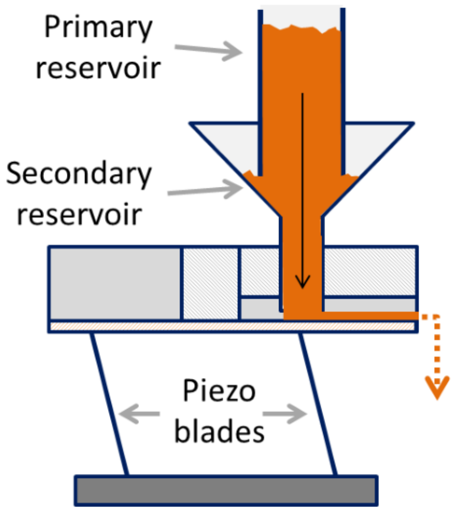


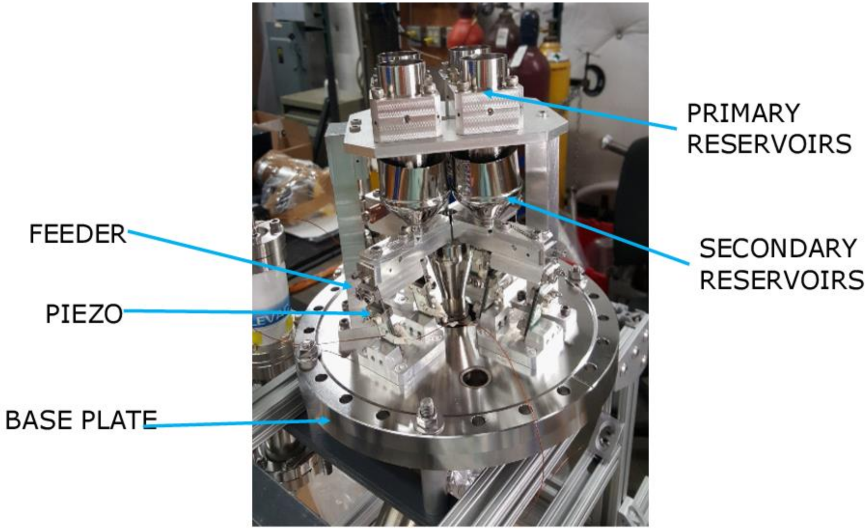
In the lab

On DIII-D

Nagy RSI submitted

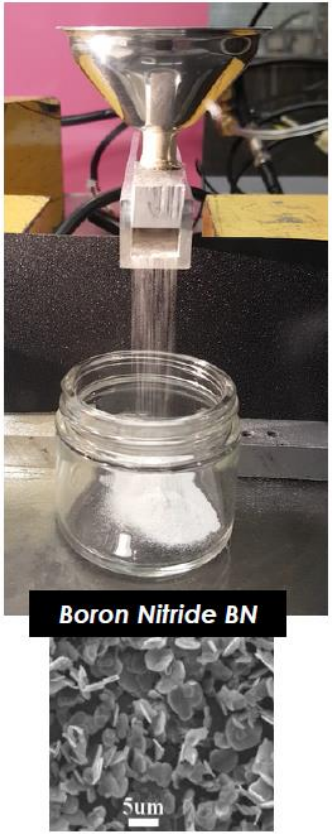
IPD based on linear powder feeder



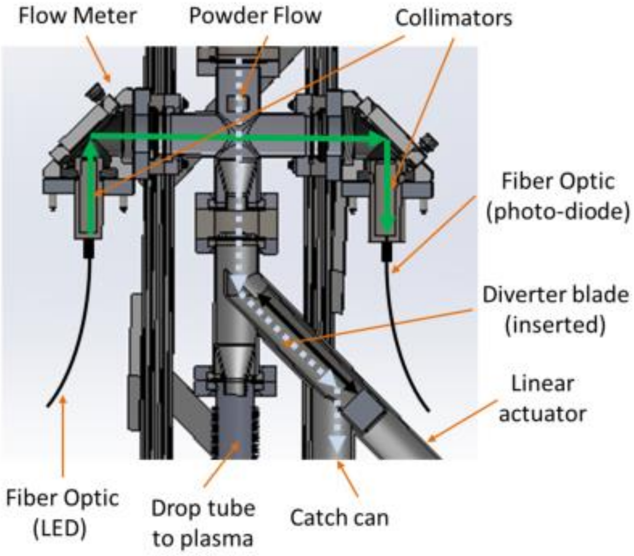


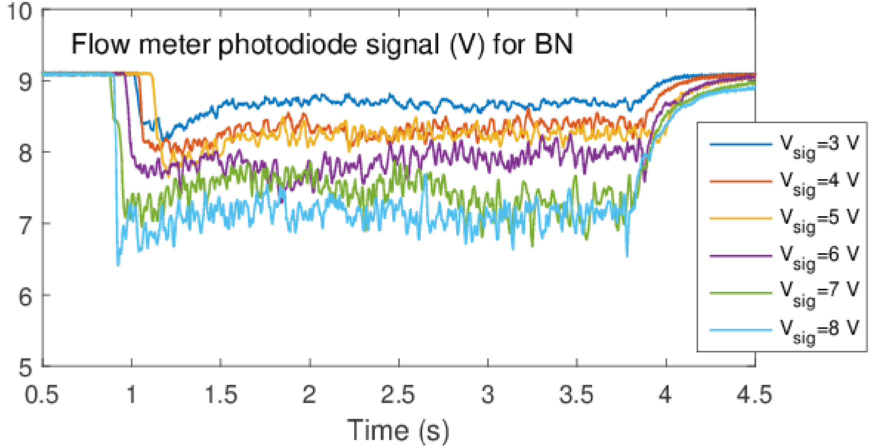
- Drop rate proportional to voltage applied to piezo-blades
- 4 linear feeders drop through same drop tube

Examples of tests with materials of different form



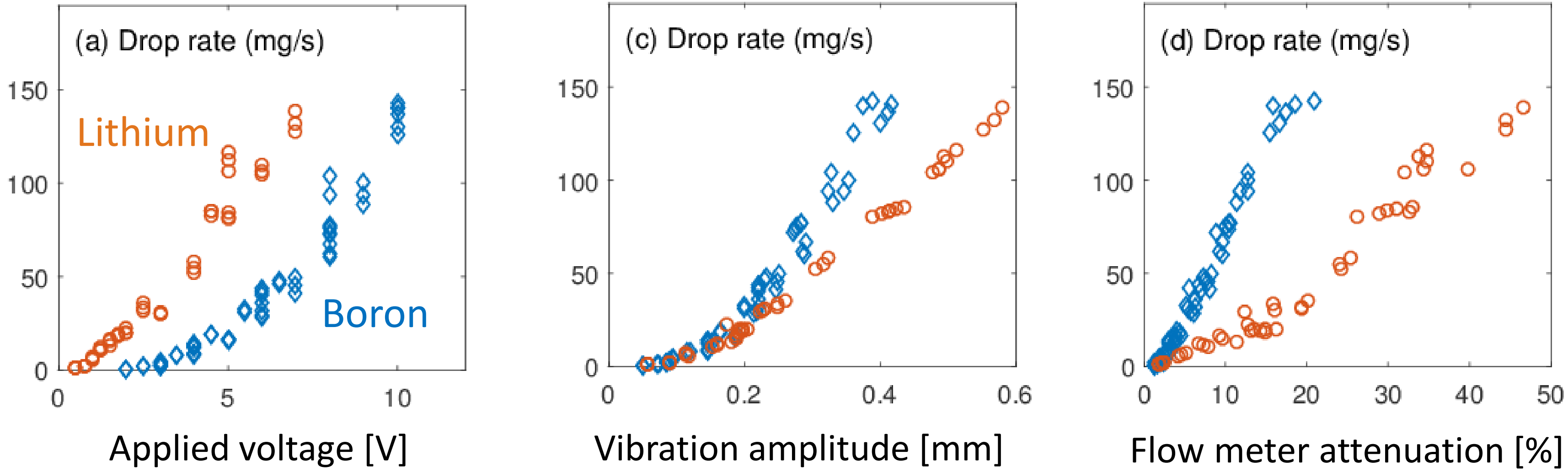
Powder mass delivery rate measured by “flow meter”





- A diverter tube can be inserted for testing when installed
  - Powder used for tests is collected in catch can

Flow rate is calibrated in the lab with dedicated unit



- Calibration rates used in programming operation

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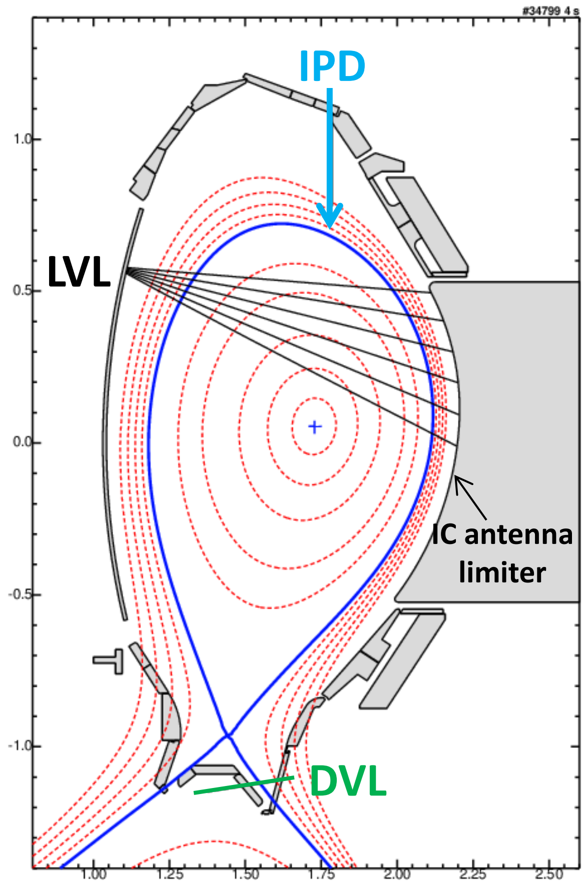
In AUG, B powder injection tested to coat W limiters

- ICRH antenna limiter is major source of W
  - Gas puff used to mitigate accumulation
  - Limits operation at low ne/nustar

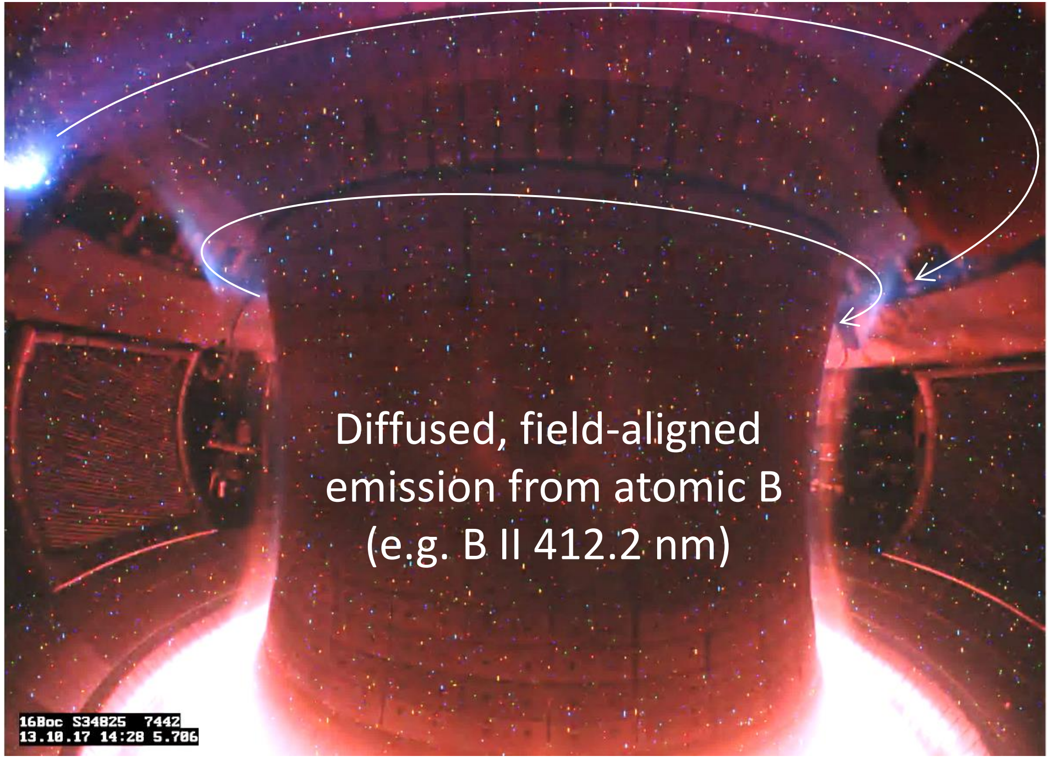
- B and BN powder injection applied in sequence of 8 plasmas with co-formal shape
- Test shots without boron injection repeated to evaluate wall conditions

- Total ~220 mg of B introduced in AUG
  - For a D2B6 boronization ~ 8 g



Bortolon PSI 2018

Ablated B atoms are transported by SOL flows



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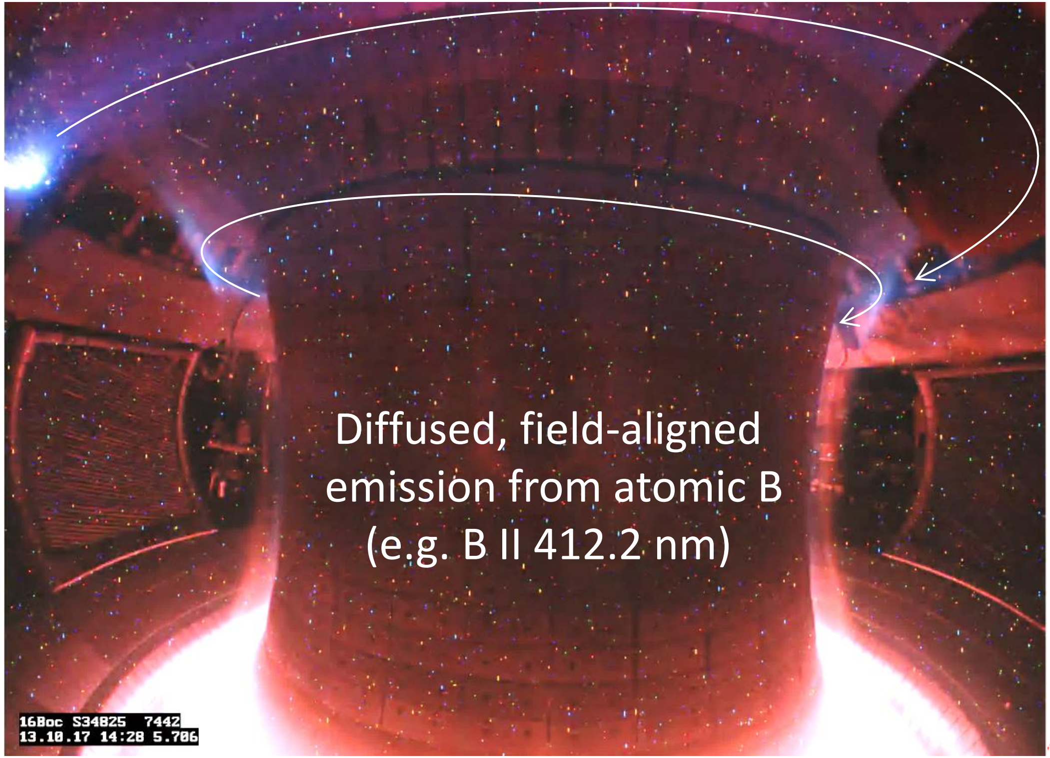
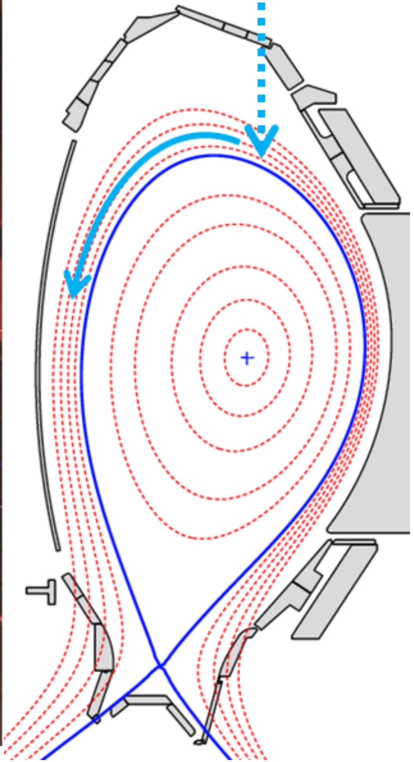
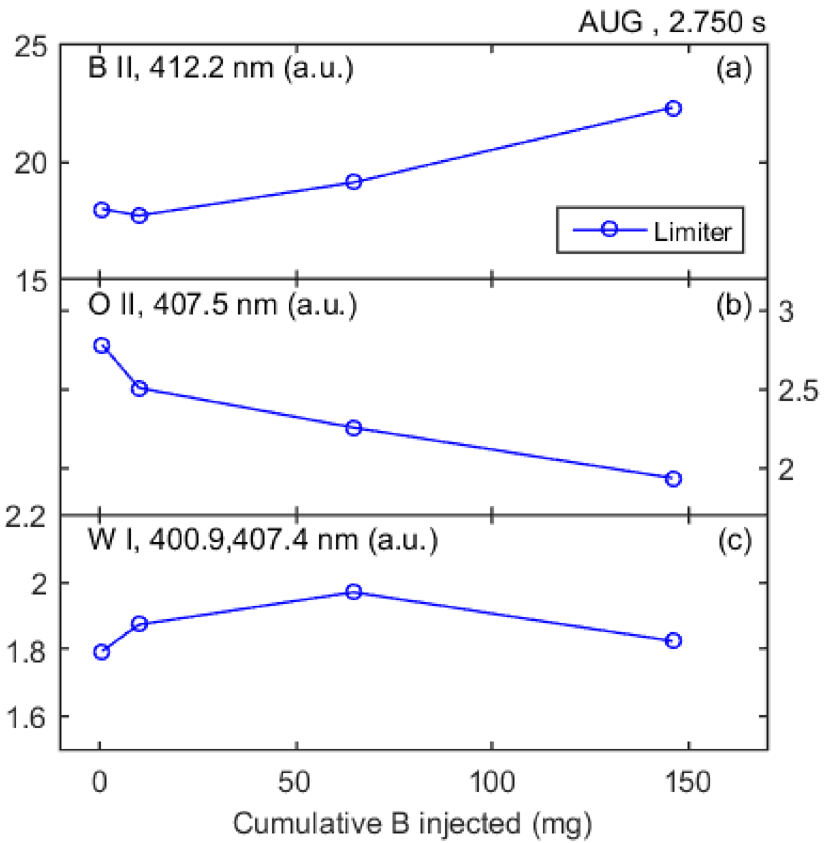




Wall condition observables improve during test-shot series

- Estimate impurity source from time-average of line emission
  - BII, OII and WI

- B from limiter increases → B coating
- O from limiter decrease → O getting
- W source decreases for >100 mg B



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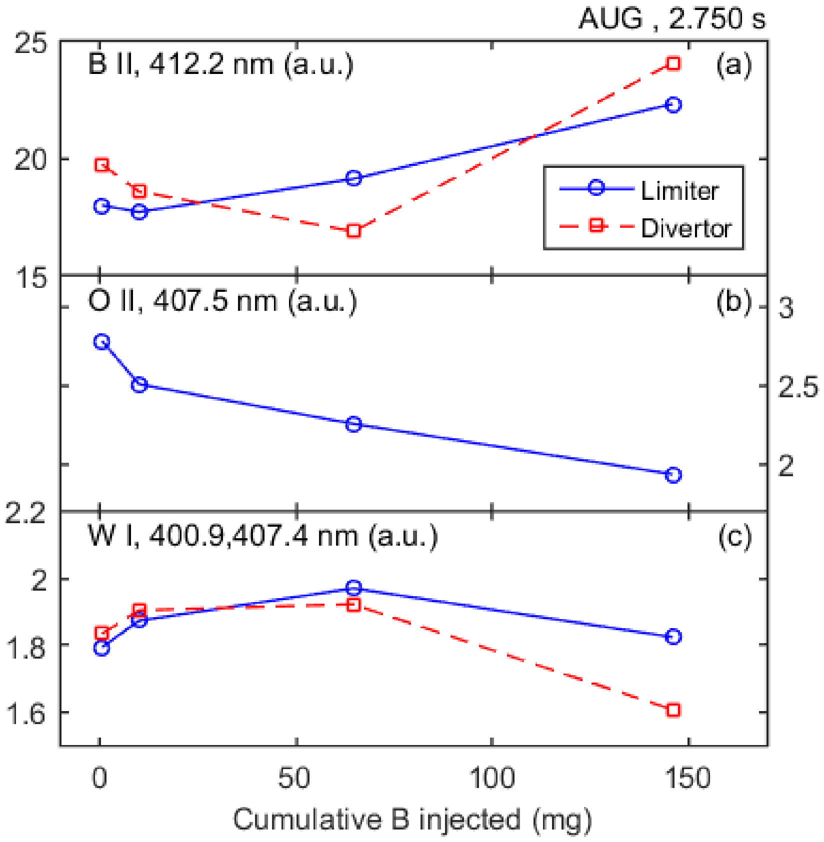
- Similar trends observed in divertor

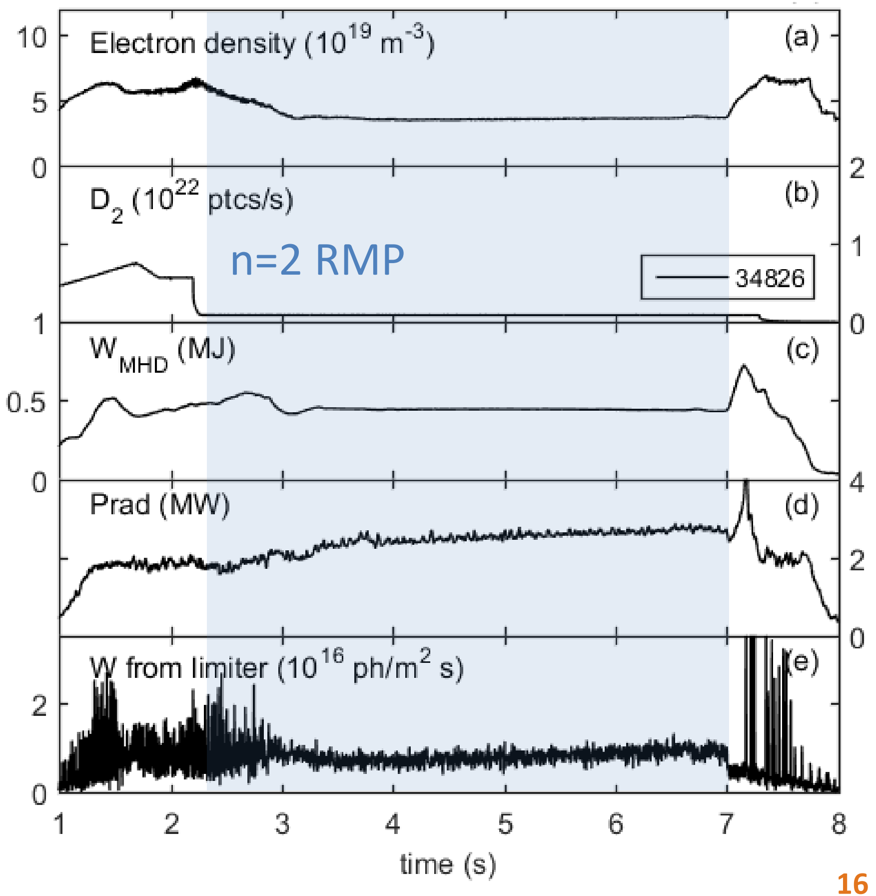


ELM-suppression test indicates access to low collisionality

1. Conditioning shot with B injection
   – 73 mg (220 mg cumulative)
2. Attempt ELM-suppression with n=2 RMP

- Full-shot ELM suppression achieved
  – Sufficient n_e pump-out maintained
  – 3 consecutive discharges

- Slow increase in P_{rad} and W radiation
  – Impurity sources recovering on discharge time-scales



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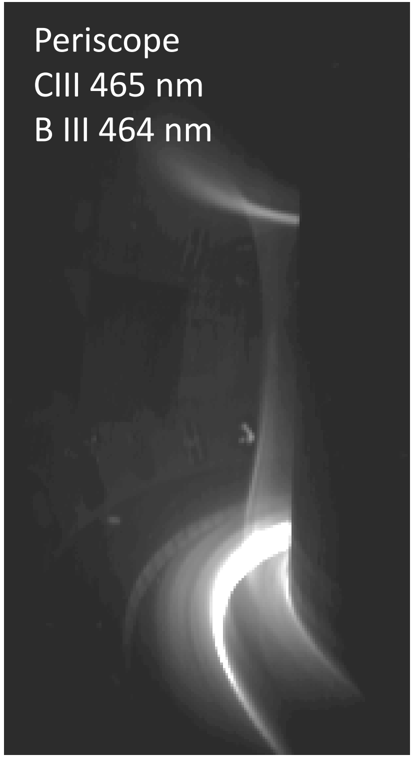
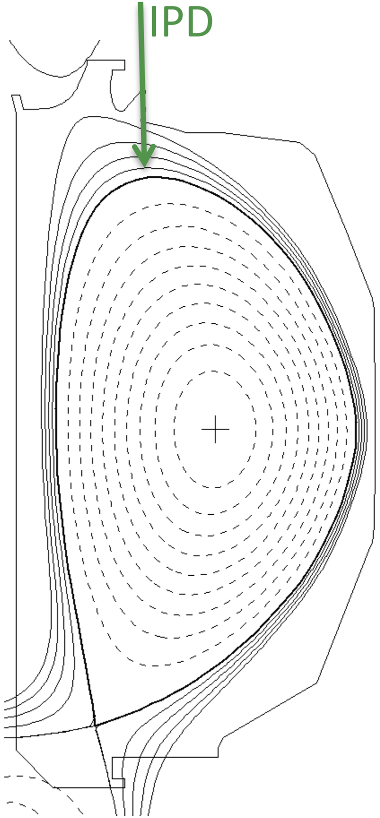
Wall conditioning with B injection tested after short vent

- Boron powder applied during a sequence of 5 repeated shots
  - 2 without B injection
  - 3 with B injection during I_p flat top

- Increasing injected amounts
  - 30 mg → 90 mg → 120 mg

- Wall conditions assessed from discharge formation (t<0.5s)



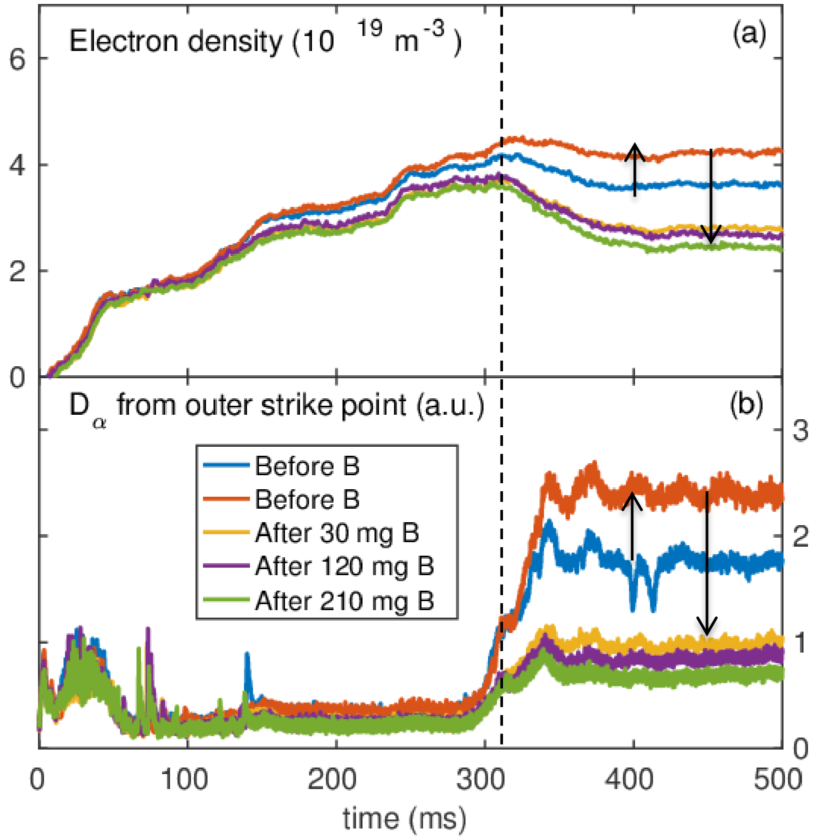


After boron injection stepwise change in recycling

- Step-wise change in flat-top density with B injection

- Before B: $n_e \sim 4\times10^{19}\ m^{-3}$
- After B: $n_e < 3\times10^{19}\ m^{-3}$

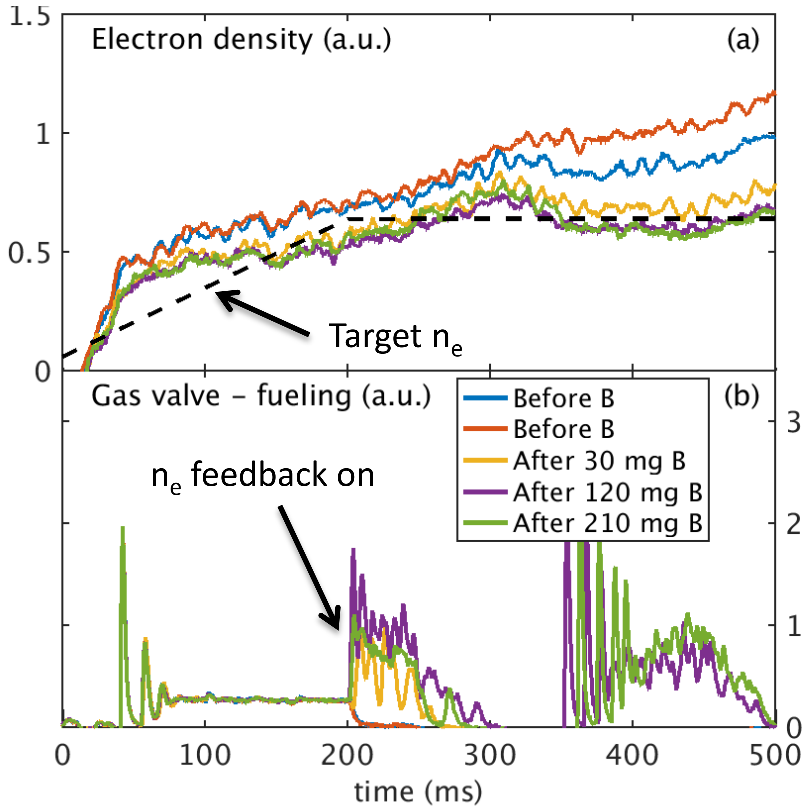
- Strong reduction of D_α from strike point



Density feedback indicates reduction of wall source

- For t<200 ms, gas fueling is programmed
- For t>200 ms, gas valve operated by density feedback

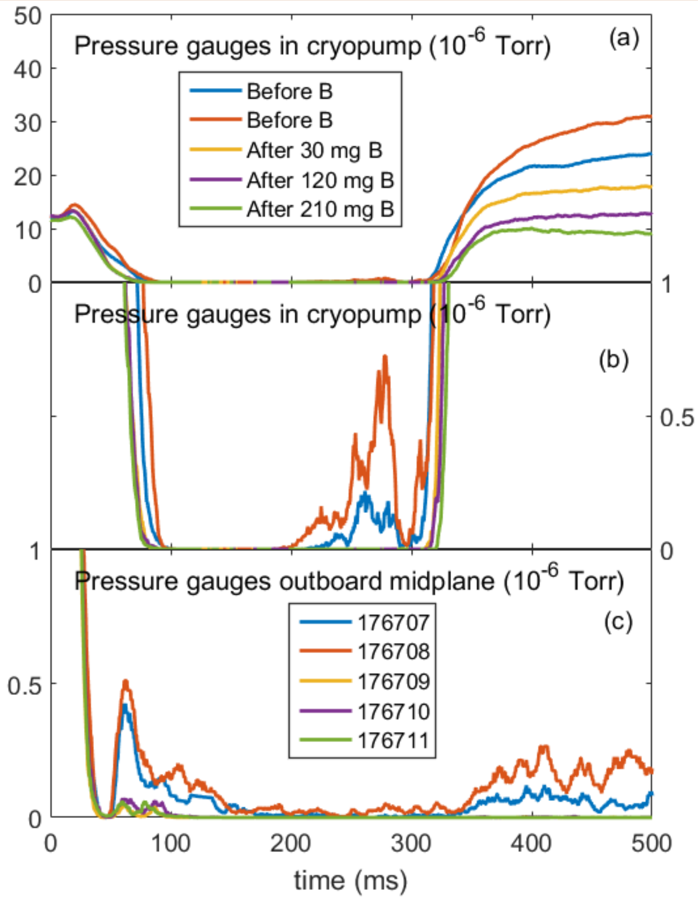
- After B injection the density request is met
- Gas fueling needed to compensates reduced wall source



Pressure gauges indicate reduction of neutral pressure

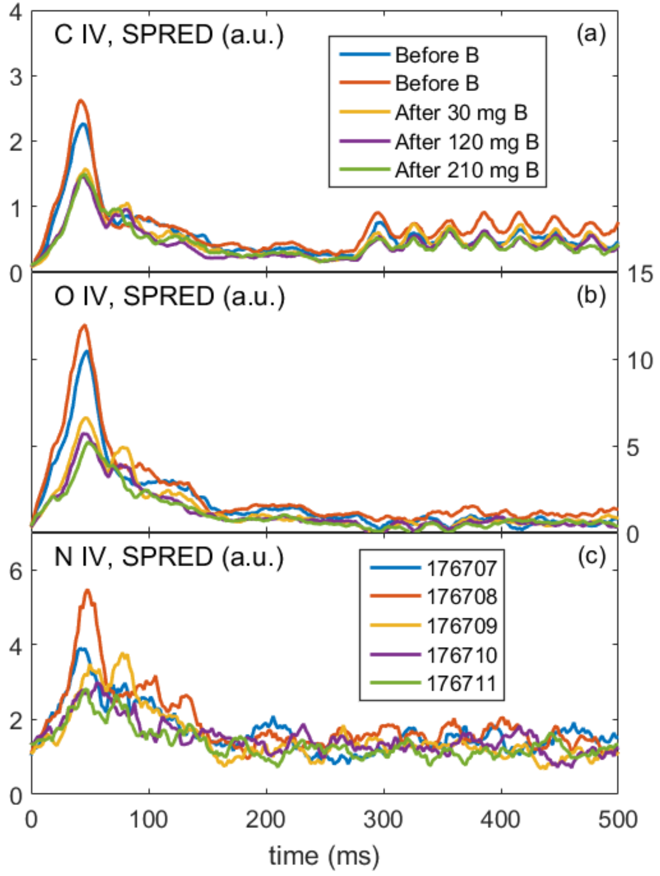
- Pressure gauges location
  - Plenum of lower divertor cryo-pump
  - Outboard midplane

- Stepwise reduction observed in early phase (t<250 ms), when density is only slightly reduced



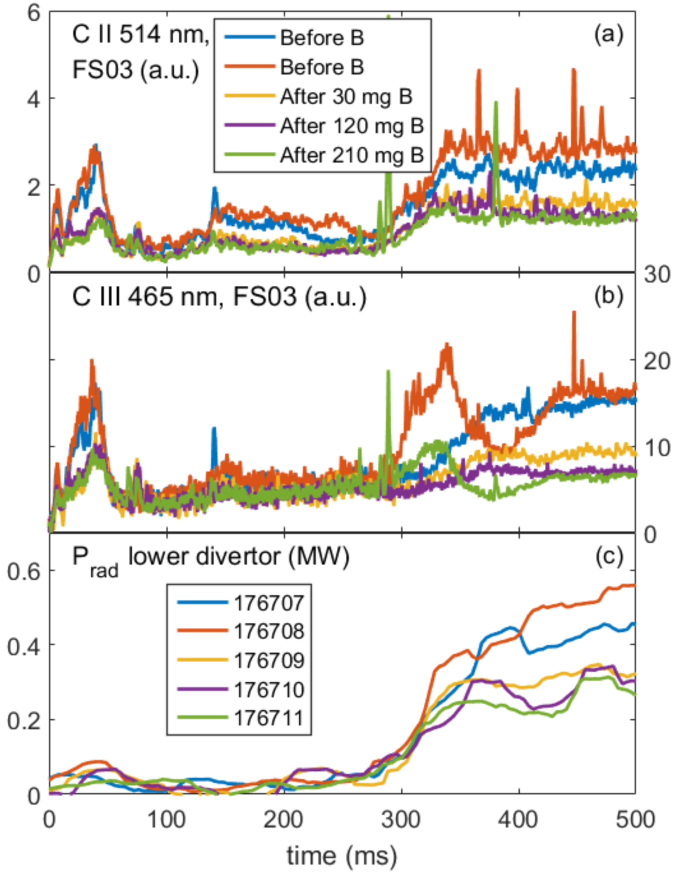
Reduction of impurity emission at breakdown

- Amplitude of line impurity emission at breakdown used as monitor of wall cleanness
- Stepwise reduction observed after exposure to boron
  - Carbon, oxygen, nitrogen
  - Peak emission reduced by ~50%



Carbon emission from OSP reduced

- For t<320ms FS03 filterscope observes the limited plasma during ramp-up
- Reduction of emission from low charge states of carbon
  - At breakdown
  - During ramp-up
- For t>320ms FS03 observes the OSP in front of the pump
  - Reduced emission from CII-III
- Radiative losses also strongly reduced
  - Density effect?



Modeling initiated to understand boron transport and deposition

- Open questions
  - How much B powder is actually ablated?
  - Where is the ablated material deposited?
  - What is the expected lifetime of the deposited coating?

- Modeling will attempt to combine several aspects of the problem
  - B transport in SOL, including impurity source from injected particles (UEDGE + DUSTT, Umanski LLNL, Smirnov UCDS)
  - Distribution function of particles through the sheath (hPIC, Curreli, Drobny, U-C)
  - Dynamics of the surface layer of the substrate material and the deposited B (Fractal-Tridyn, Currely, Drobny, U-C)

- DiMES and MiMES samples have been exposed to B injection
  - Substrates to be analyzed at UTK (Ren, Donovan)

Conclusions

- The new impurity powder dropper allows continuous, long timescale delivery of a variety impurity powder

- Recent experiments on AUG and DIII-D indicate that injection of solid B dust can reduce source of impurity and particles
  - No hazardous materials
  - Potentially opens opportunity for long timescale plasma operation

- These findings might be confirmed and extended in upcoming experiments in AUG, KSTAR and W7-X