Overview + Preliminary results from EAST experiments studying relative particle pumping of lithium and cryo-pumping

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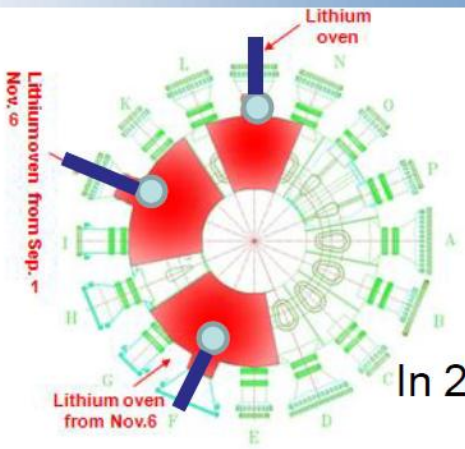
2 EAST experiments proposed by J. Menard, M. Jaworski

- JM: “Particle control comparison between lithium & cryo-pumping”
  - Goal: characterize the separate contributions of Li wall conditioning and cryos
  - Assess the persistence of deuterium pumping from lithium
- MJ: “Evaporated lithium coating lifetimes on EAST Tokamak”
  - Goal: study the evolution of divertor conditions during long-pulse experiments on EAST
  - Langmuir Probes, filter-scopes to monitor local conditions over time, correlate with performance
- Our experiments above were combined, and shot-plan further combined with another experiment studying H and L-mode access (and pumping) vs. strike-point position by Qingsheng Hu (ASIPP) and Zhenfing Ding (Dalian University of Technology)
- Got ~80 shots over 2 days
  - Day 1 was from ~12PM to 1AM, Day 2 from ~12PM to ~5PM

Methods of Lithium Coatings

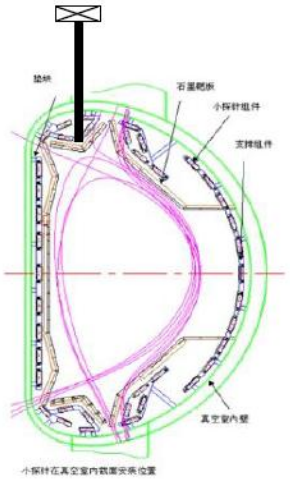
EAST

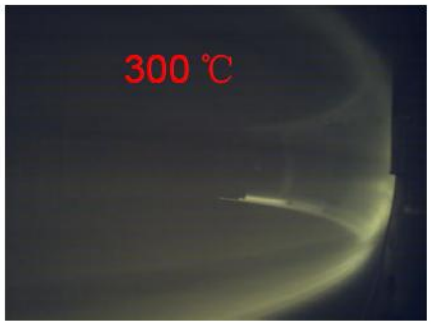
- **Li Oven Coatings :**
  - ✓ by evaporation, ionized by GDC or ICRF discharge
- **Real-time Li Coating:**
  - ✓ Lithium powder dropper used during plasma discharge



In 2010

dropper





ICRF lithium coating

- **ICRF Li coatings seem better than GDC or evaporation only:**
  - ✓ More Li atoms were ionized by ICRF plasma with larger symmetric flux of energetic ions than that by GDC or Li evaporation only
  - ✓ More uniform Li distribution along toroidal direction

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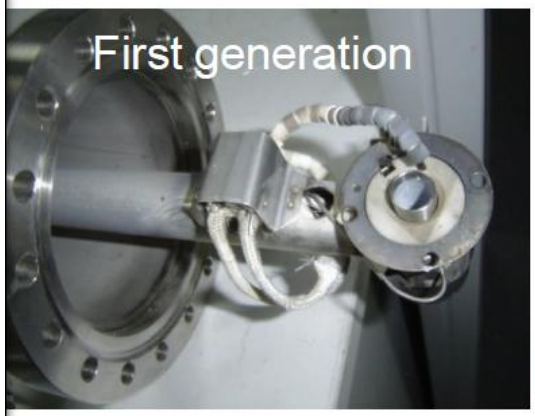
From G. Z. Zuo – "Lithium Coating for H-Mode and High Performance Plasmas on EAST in ASIPP" – PSI2012

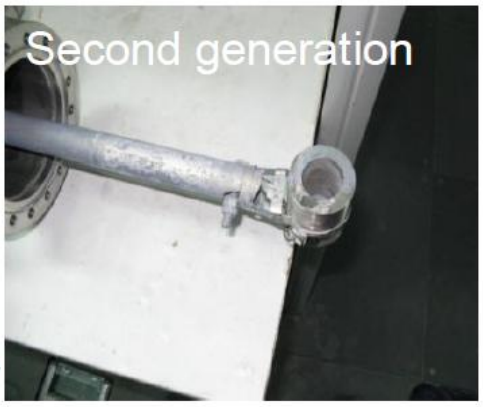
Development of Inserted Li Ovens for Increasingly Uniform (Top and Bottom) Coverage on EAST

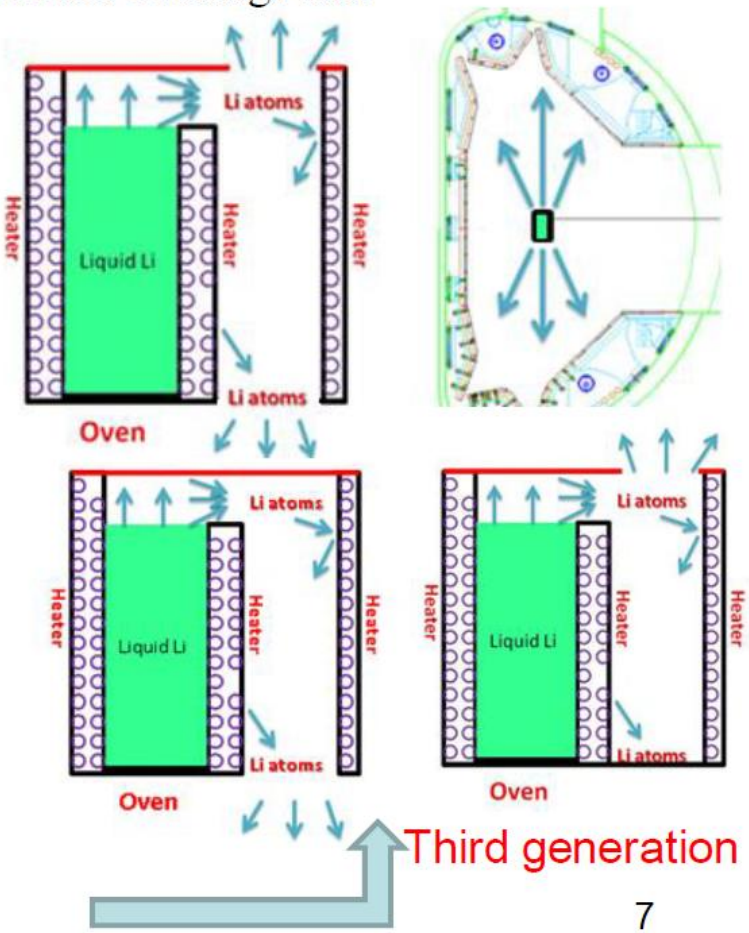
EAST

- Three generation of ovens were developed, each upgraded step-by-step.
- Using third generation ovens, Li deposition can be controlled on required areas.
- Multiple ovens and deeper radial insertion have allowed better coatings and better plasmas.

Run Year	Oven location(s)	Position in VV R (m)	Oven Capacity (g)
2009	Bay D	~2.7	~3g
2010 Spring	Bays M+D	~2.7	~15
2010 Autumn	Bays M+F (or J)	~2.7/2.3	~15
2012	Bays M+J+D	~2.3/1.9/1.9	~15



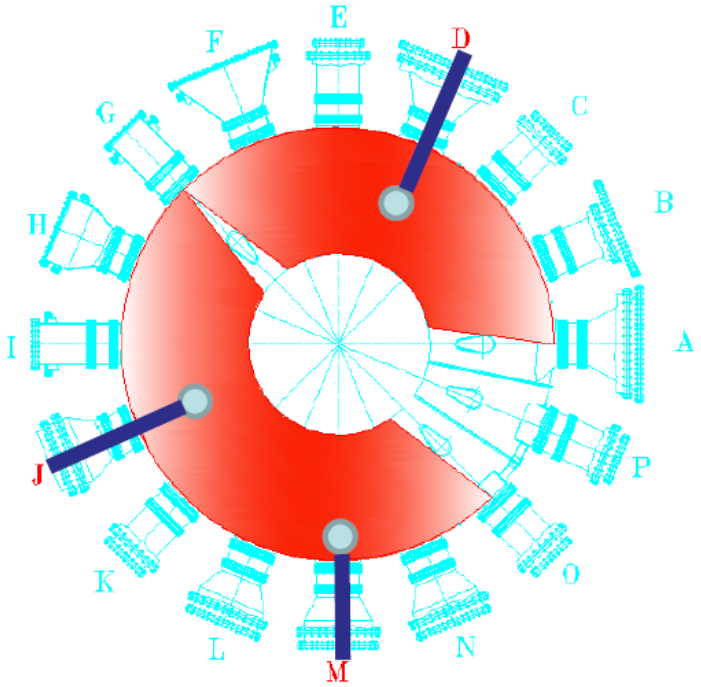


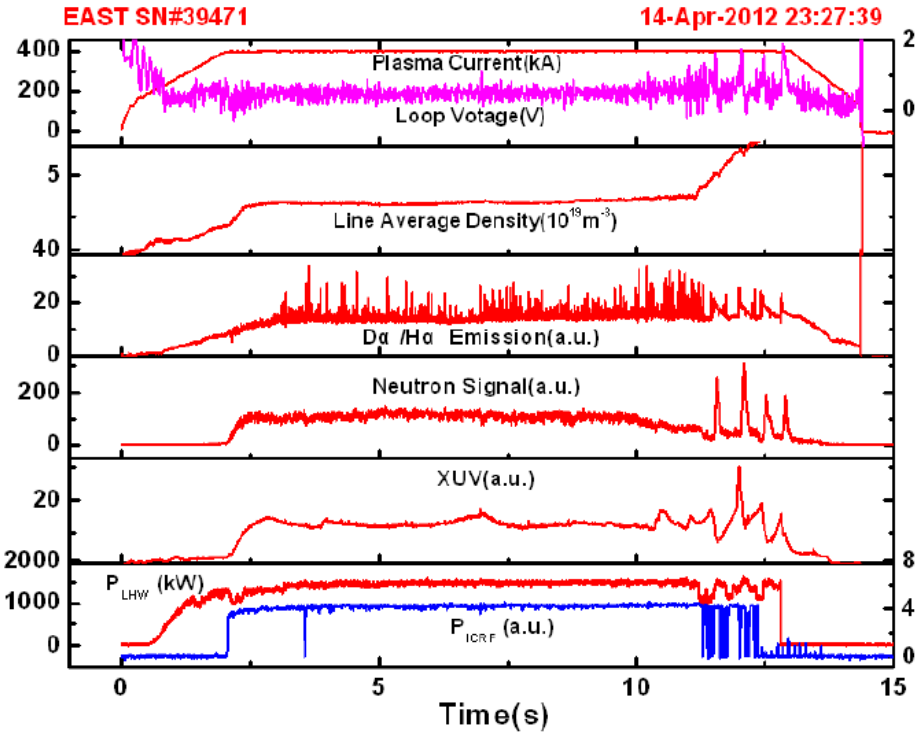


From G. Z. Zuo – "Lithium Coating for H-Mode and High Performance Plasmas on EAST in ASIPP" – PSI2012

First Results of Li Coating in 2012

EAST





With 3 deeply inserted ovens, 45g/Li coating:

- Lithium coating are more uniform than in 2010
- Lower recycling and remarkable low H/(H+D) **~2.5%** were obtained
- H mode plasmas were easily achieved, and **10s long H mode** has been obtained.

From G. Z. Zuo – "Lithium Coating for H-Mode and High Performance Plasmas on EAST in ASIPP" – PSI2012

SMBI results from HL2-A show high fueling efficiency even with large distance between injector and plasma

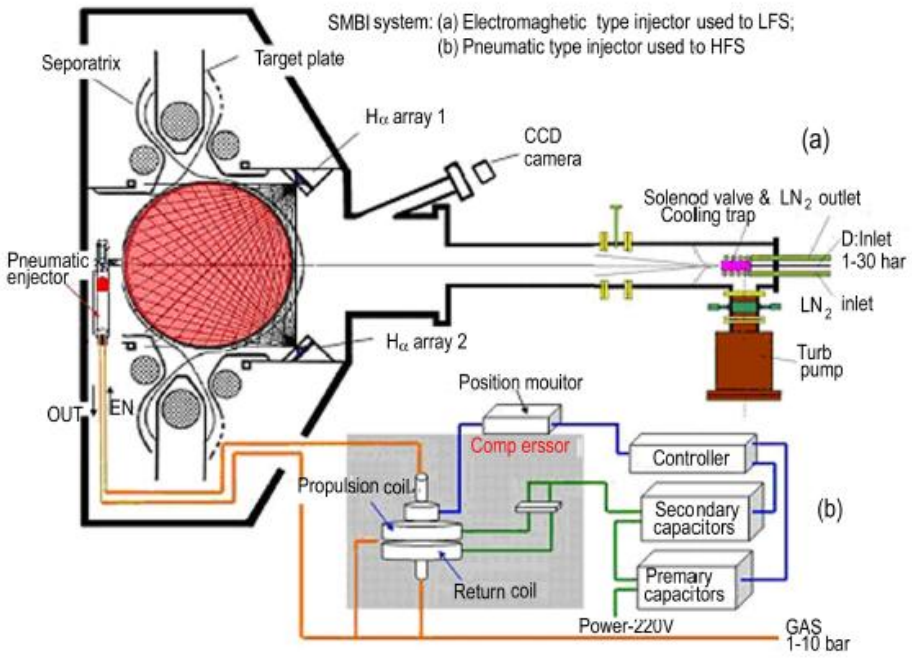


Fig.2 Experimental set-up of the SMBI system in HL-2A

HL-2A: R=1.65m, a=0.4m,
I_P = 160–480 kA, B_T = 1-3T, ECRH heated

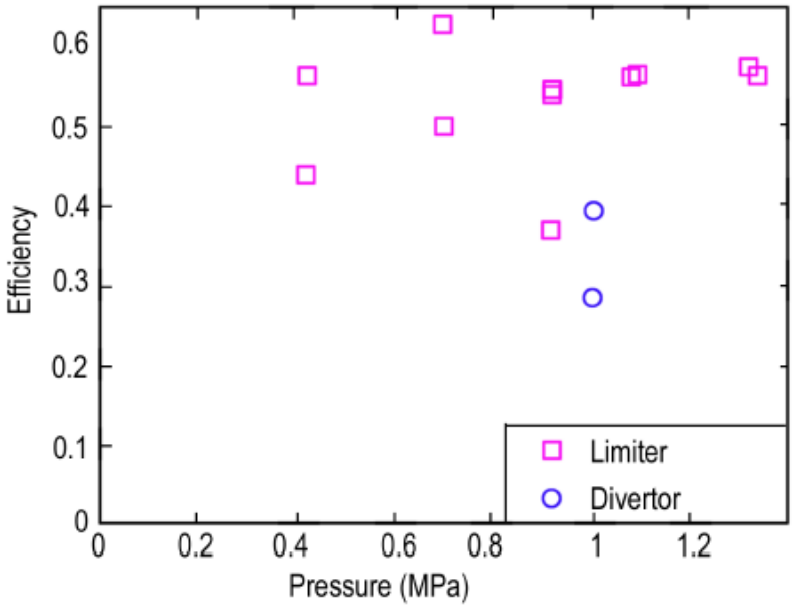
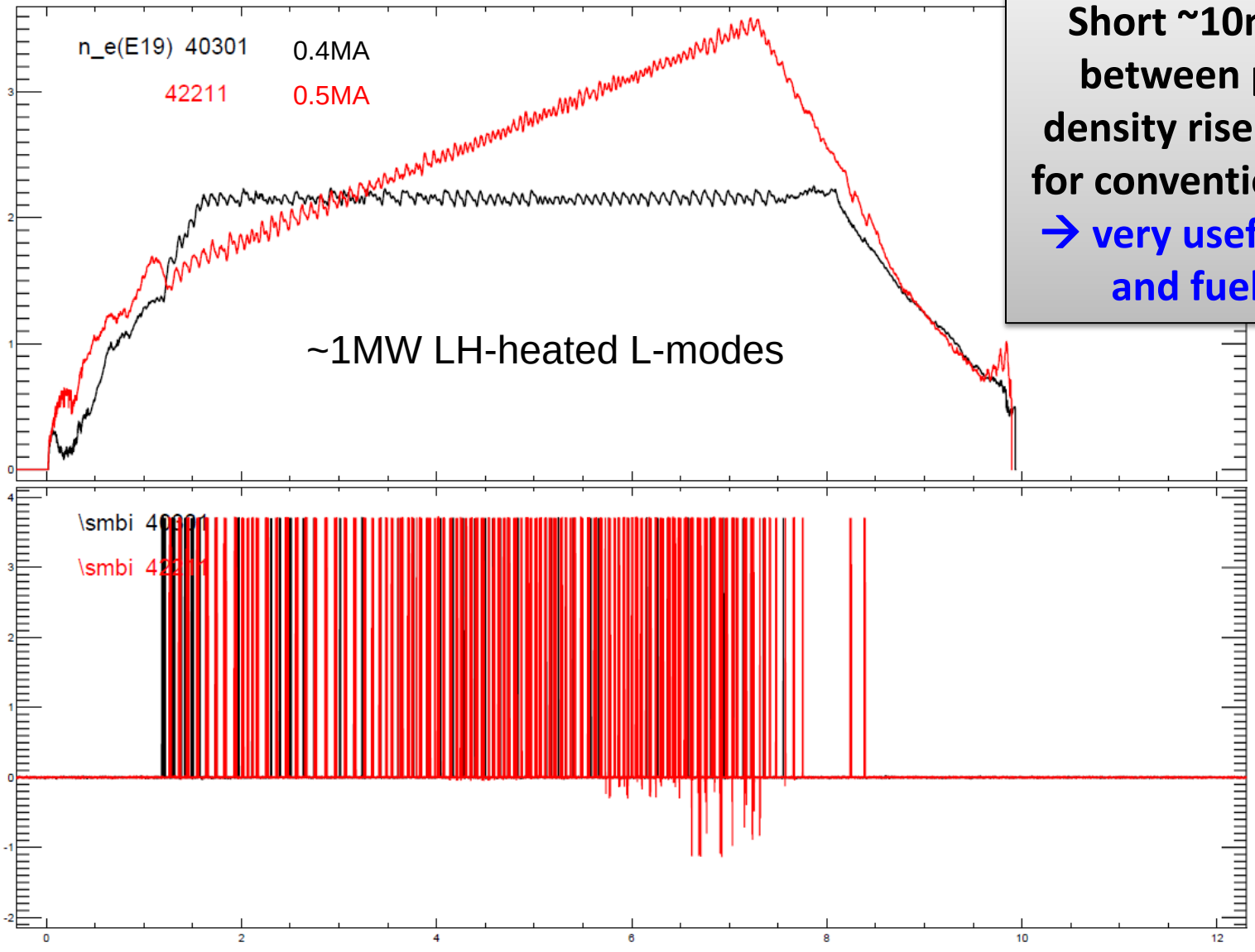


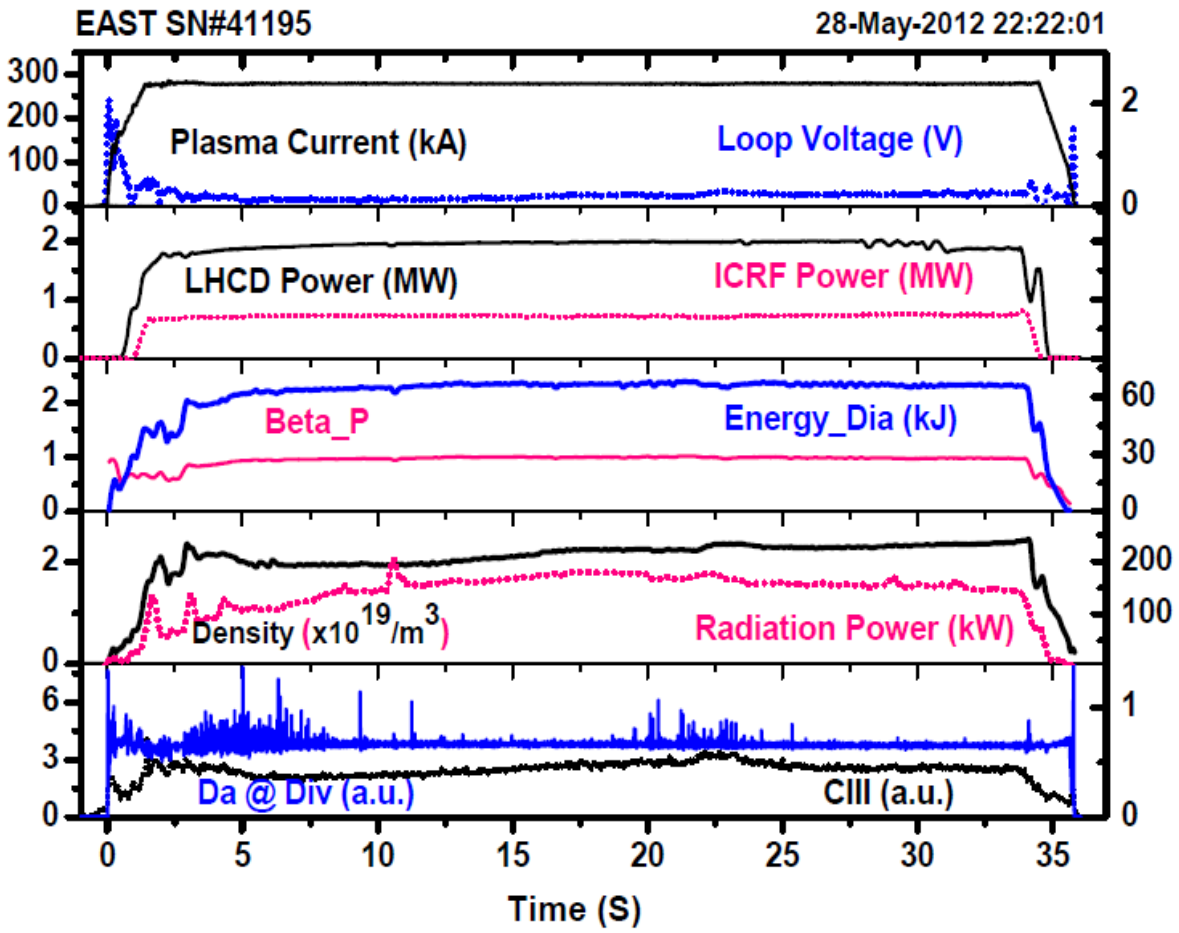
Fig.9 Fueling efficiency of SMBI from LFS in limiter and divertor discharges. Shots from 9925 to 9934 (square) are limiter discharges with, $I_p = 170$ kA, $B_t = 1.3 \sim 1.4$ T and $n_e = 0.7 \sim 1.3 \times 10^{19}$ m^{-3}. Shots 10476 and 10477 (circle) are divertor discharges with, $I_p = 165$ kA, $B_t = 1.3$ T and $n_e = 1.3 \times 10^{19}$ m^{-3}

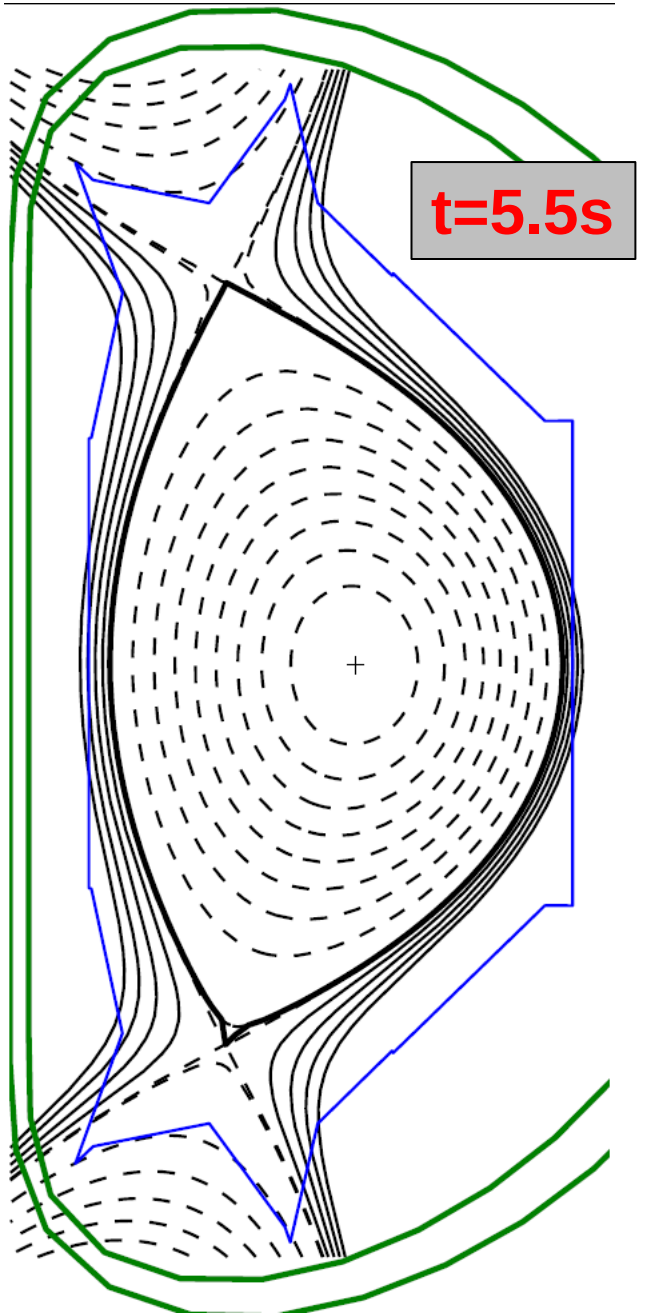
SMBI density control recently developed for EAST
(still need to get details on EAST system…)



Short ~10ms delay time between puff-end and density rise vs. 100-200ms for conventional gas fueling
→ very useful for pumping and fueling studies

Reference plasma shape for long-pulse H-mode (30s) and this experiment

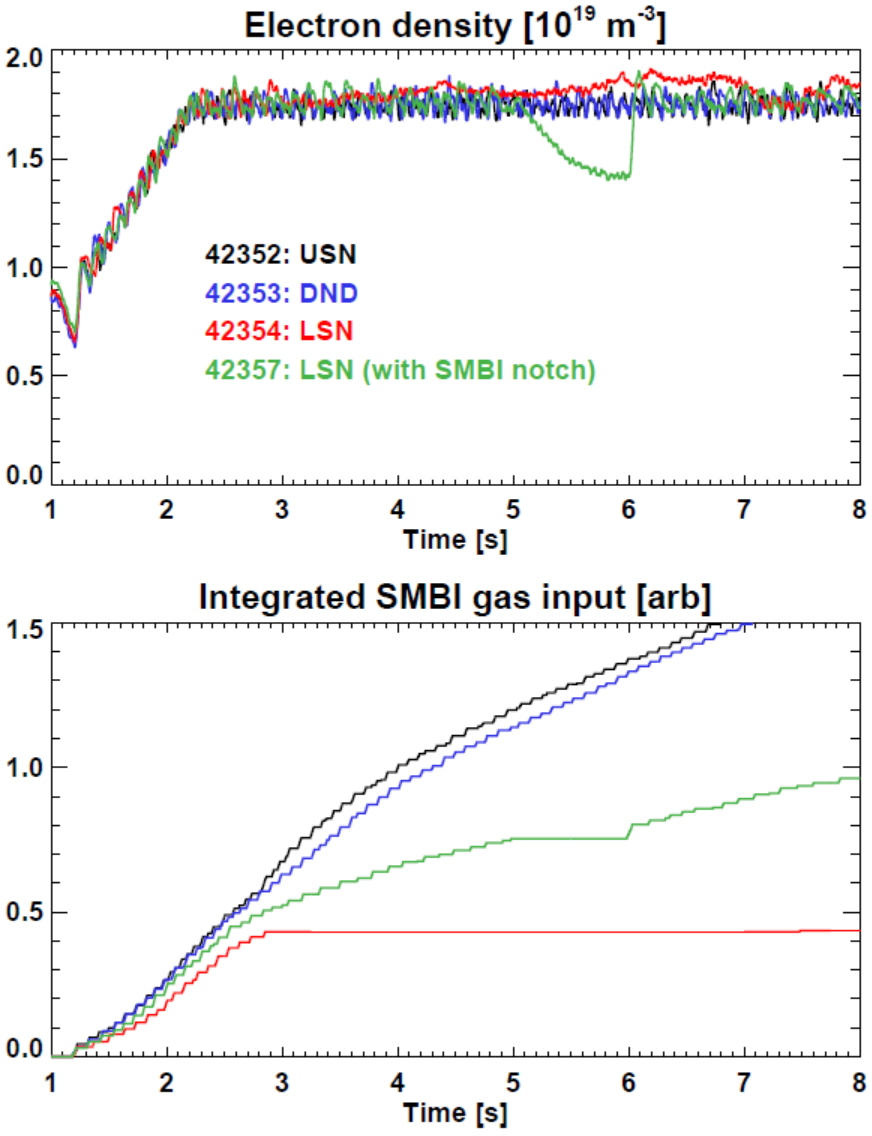




Day 1 - Initial comparison of Li vs. cryo-pumping

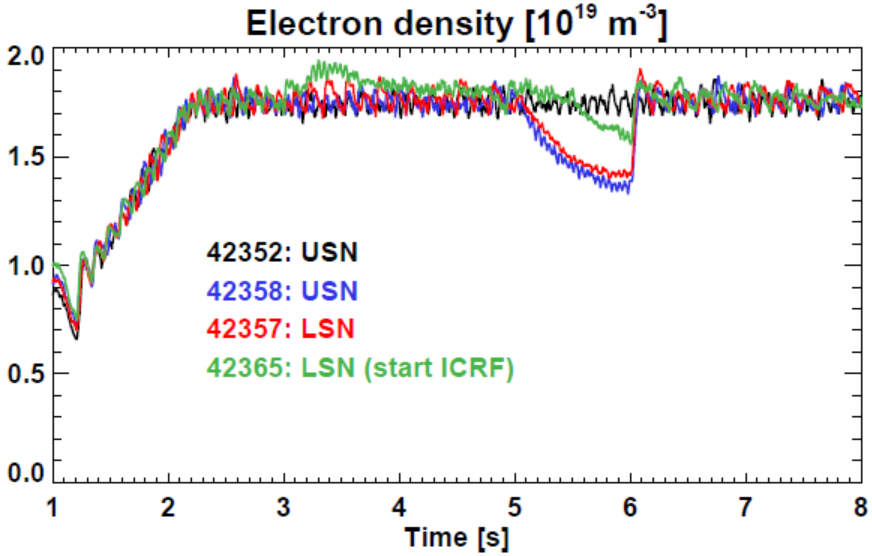
- 400kA, 2T, 1MW LH (+ some ICRF), mostly L-mode
- Used SMBI for density feedback control
  - Turn-off SMBI notch for global particle pump-out calculation
- Scans (Li + cryos on):
  - DRSEP
  - LSN delta-Z
  - Measured degradation of Li pumping
  - Used LH + ICRF to access H-mode (no H-mode for dZ = -4cm)
- Scans (No Li, no cryos - RF He GDC + regen to 40K cryos)
  - DRSEP scan
  - dZ scan (-4 to +4cm)
- Still would like to have Li + cryos off (T=40K) case

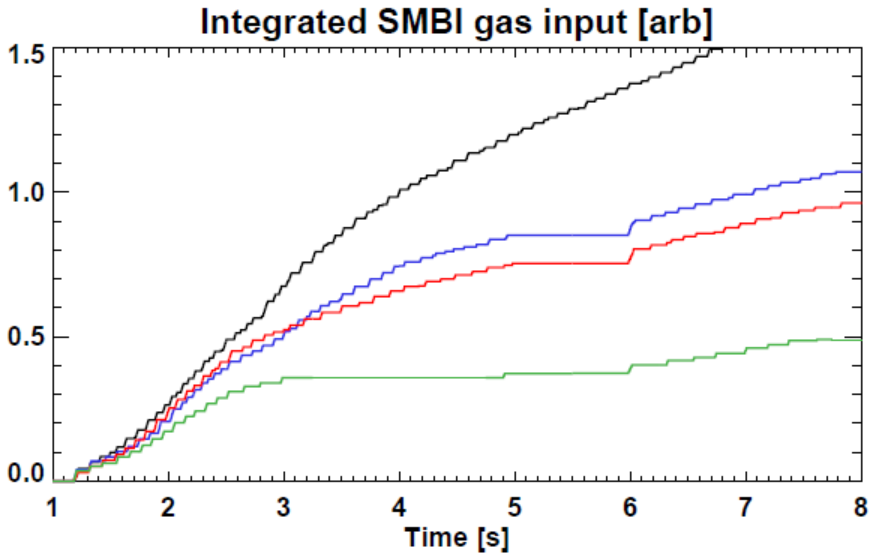
Results of early DRSEP scan with fresh Lithium



- USN and DND have strongest pump-out as evidenced by higher integrated SMBI gas required to maintain density
- LSN has less pumping
  - Counter-intuitive given cryo-pumping is on bottom of machine
  - Possible role of drifts?
  - Or up/down asymmetries in Li?
- Have asked for reversed B_T
  - Due to small remaining run-time this year, likely won't get…

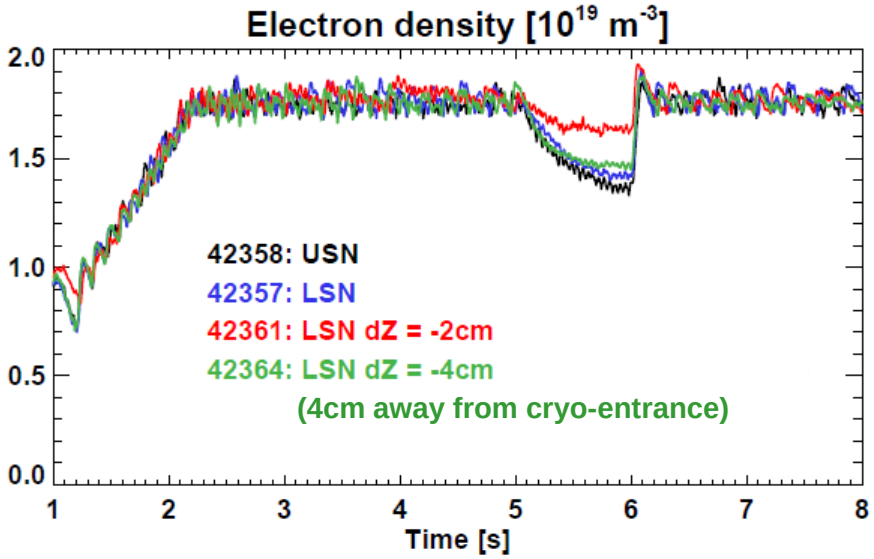
Degradation of strong Li pumping observed

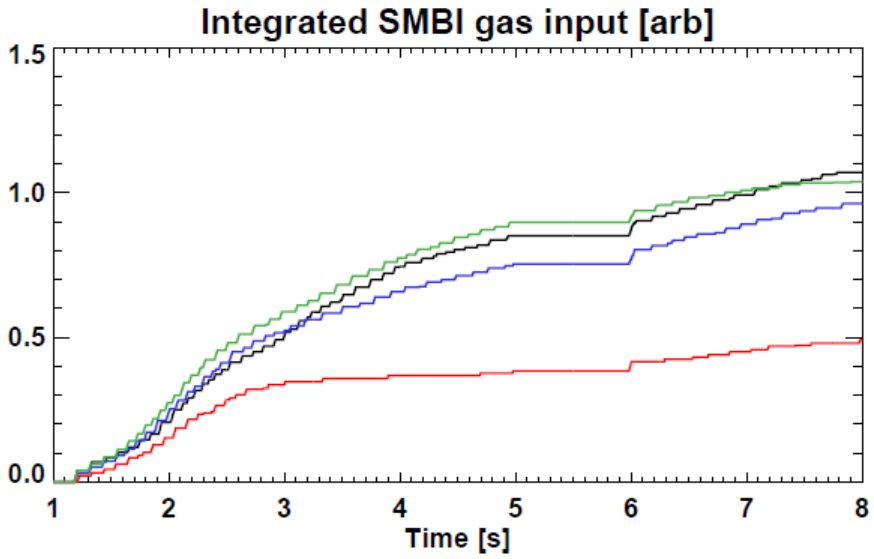




- Compare shots with same magnetic balance but similar increment in shot number
- Observe 30-50% reduction in pumping after 6-8 shots
- Each shot ~10s → 60-80 shot seconds of strong Li pumping

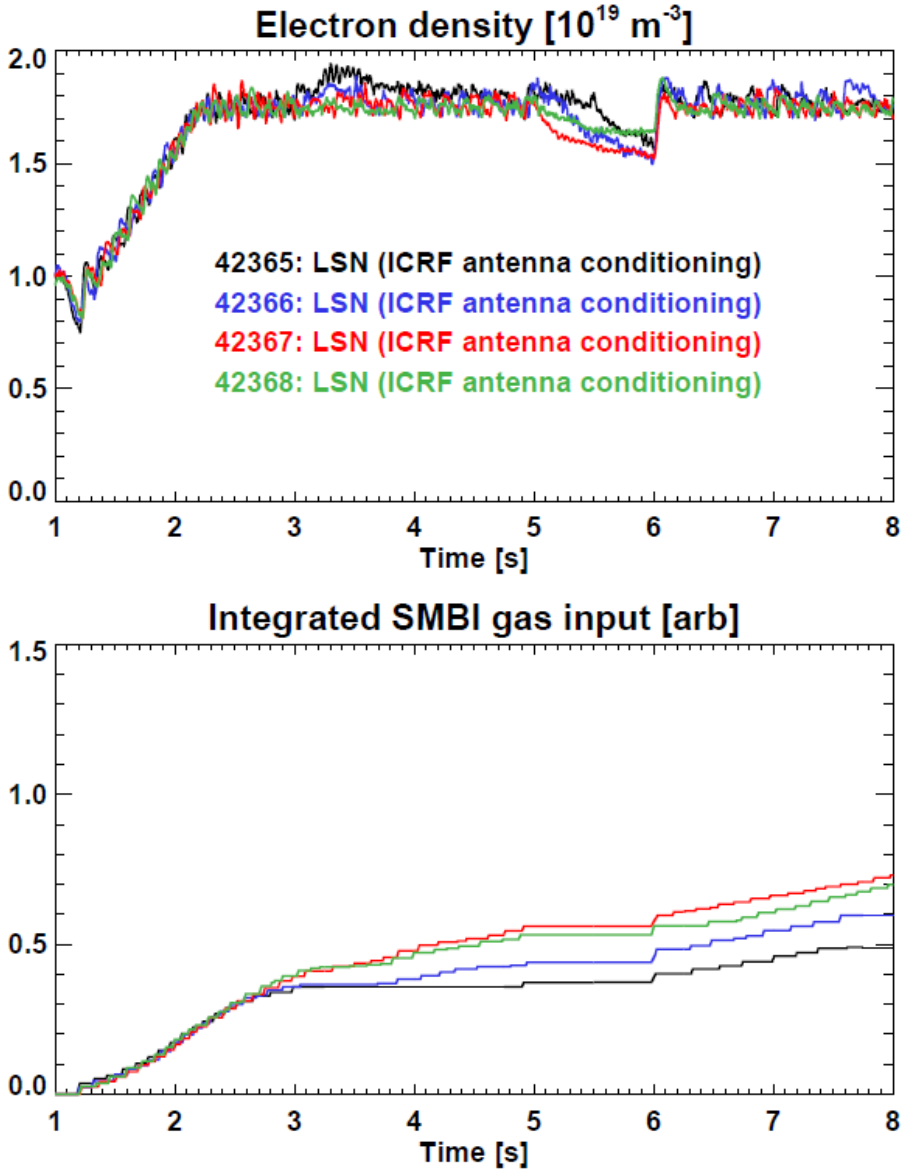
USN vs. LSN, scan of LSN strike-point



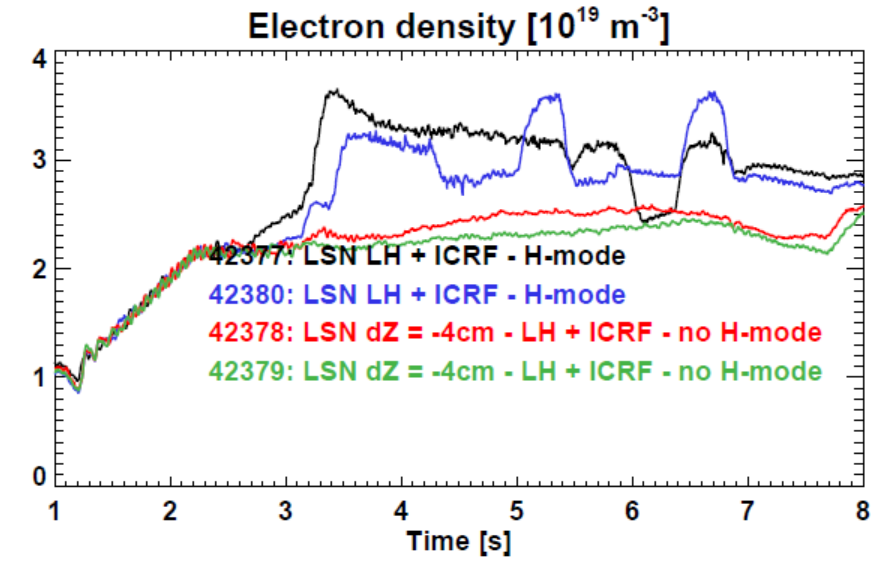


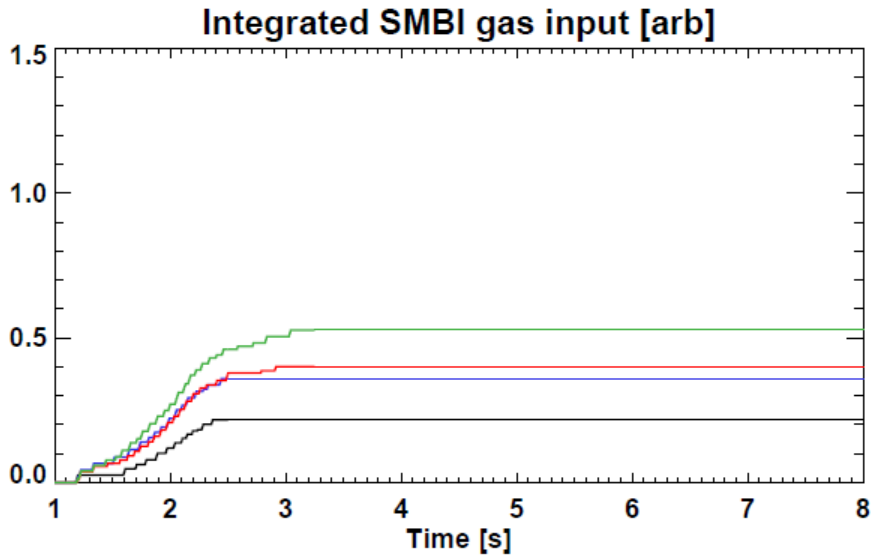
- Pump-out is quite sensitive to exact location of strike-point
- After upper lithium pumping has degraded, USN and LSN reference are similar
- -2cm shift = weakest pumping
  - Li and D accumulation in private flux region?
- -4cm strongest
  - Reason unclear – possible role of proximity to cryo? (see later part of talk)

ICRF initially acts as modest particle source, but is conditioned after 3-4 shots



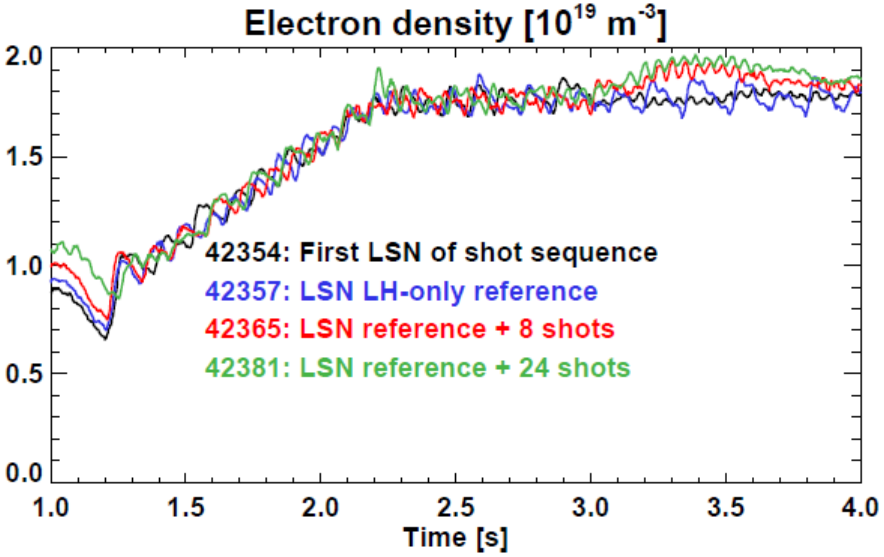
LH+ICRF H-mode with nominal LSN strike-point

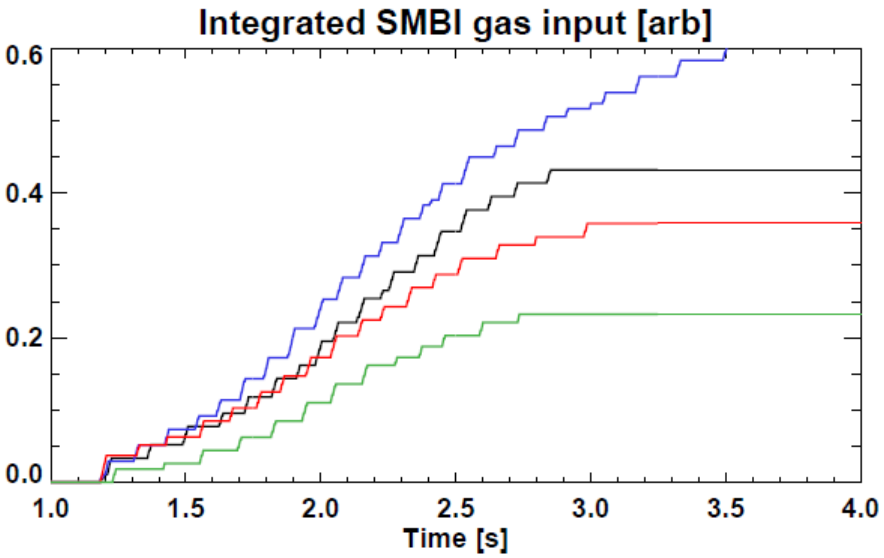




- Pumping insufficient for very low density H-mode
  - Density increases ~50% above requested control value
- Could not obtain H-mode with -4cm shift
- Did not spend much time to increase coupling + power
- Remaining shots done only in L-mode

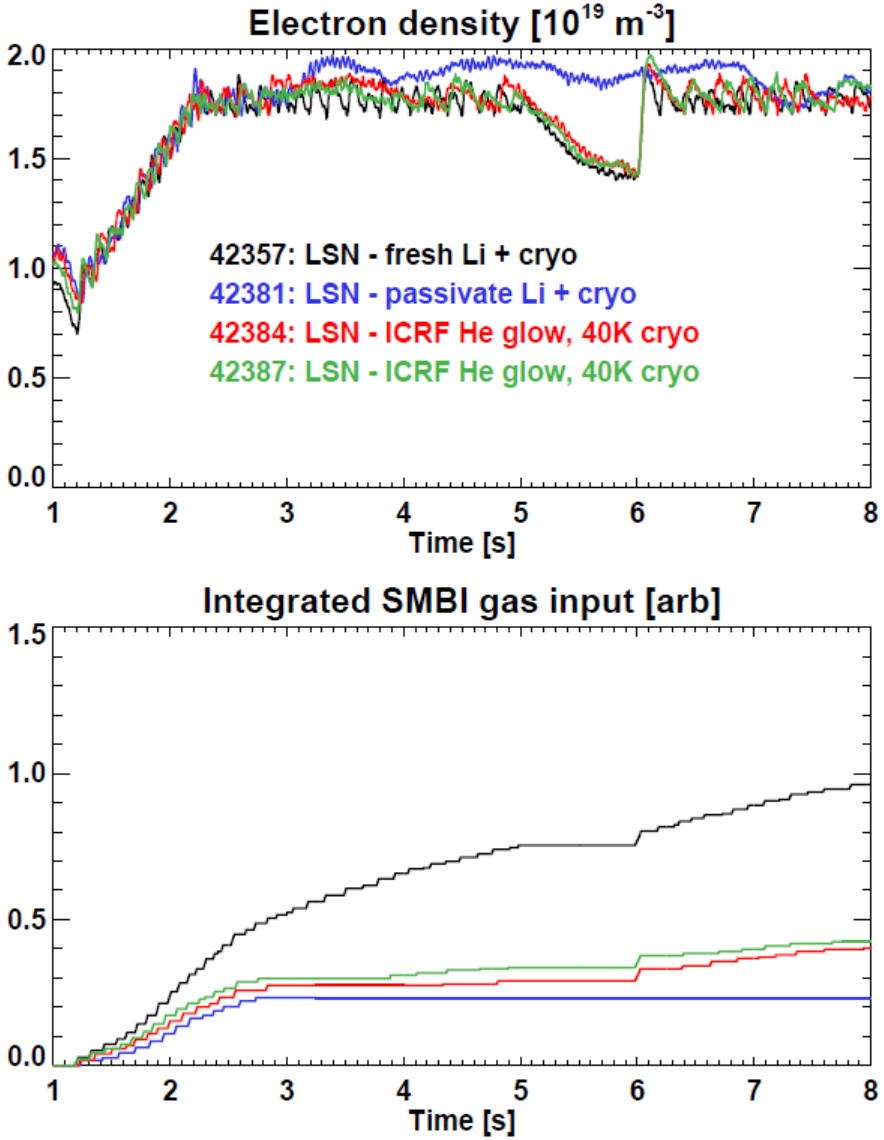
Long-term Li pumping reduction trend vs shot





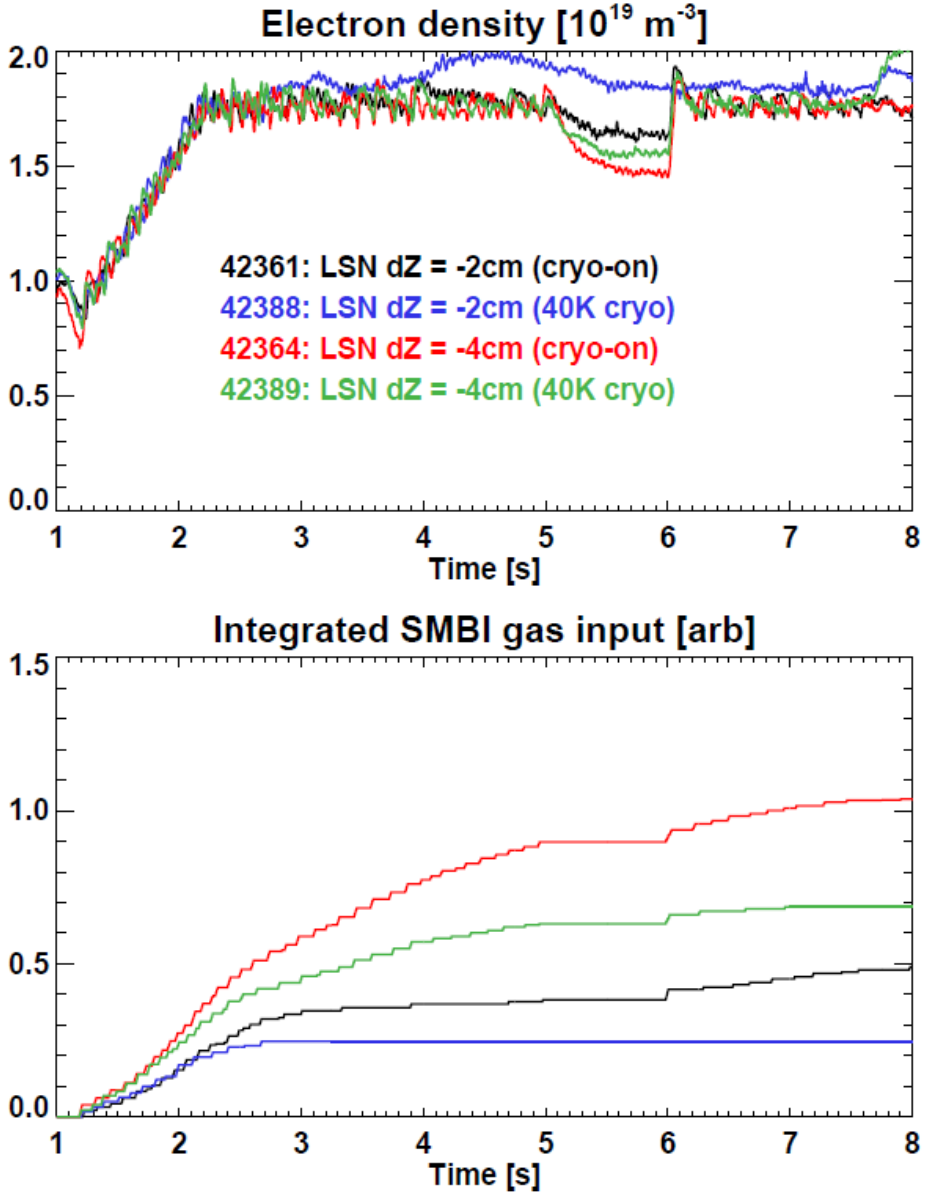
- Pumping decreased factor of 2 after 20-25 shots
  - 200-250 shot seconds
- Suggests significant passivation of fresh Li
- Li pumping largely saturated (see next slides)

Reference LSN pumping - weakly dependent on cryo

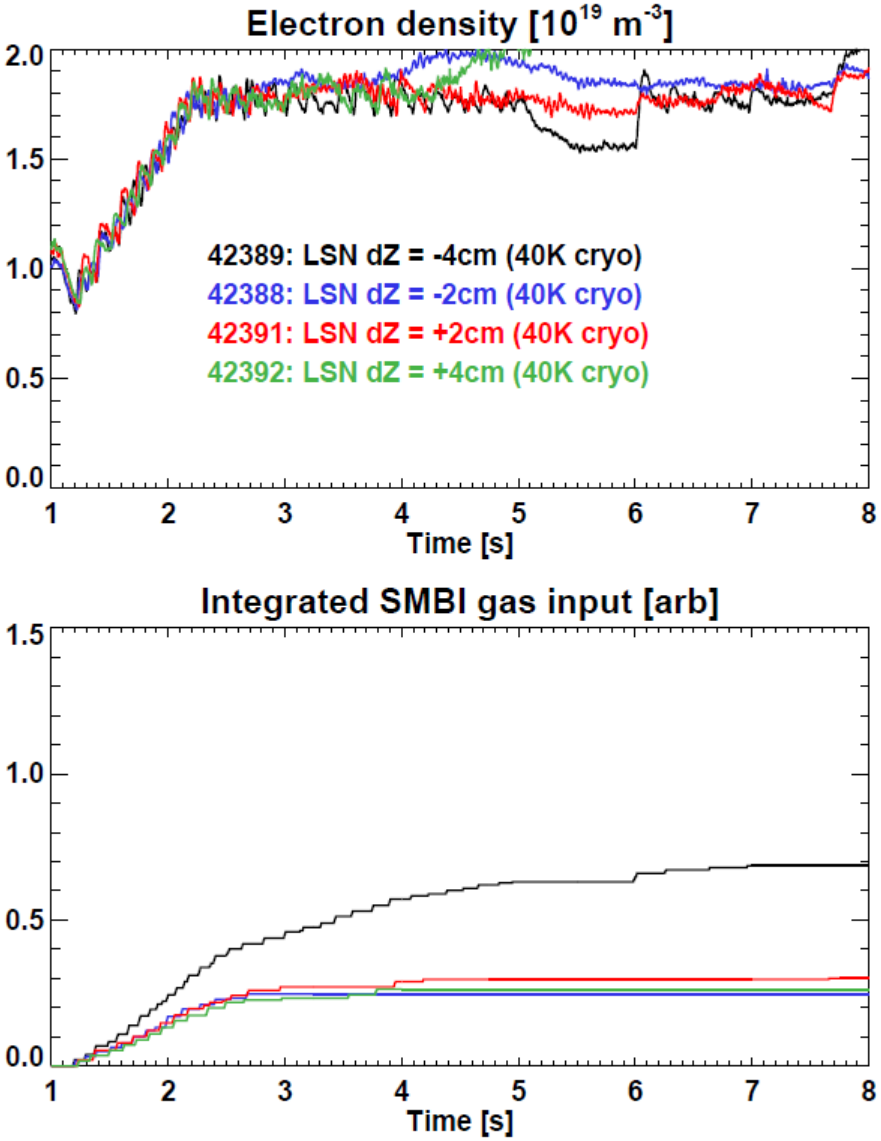


- Pumping of passivated Li + cryo similar to pumping from ICRF He-glow and warmed (40K) cryo
- Pump-out during SMBI notch stronger after ICRF He-glow conditioning
  - Possible that ICRF He-glow detraps D?
  - Some re-activation of Li?

Pumping with -2cm shift with fresh Li + cryo weaker than -4cm with passivated Li and warm cryo – why?



Pumping sensitive to strike-point location



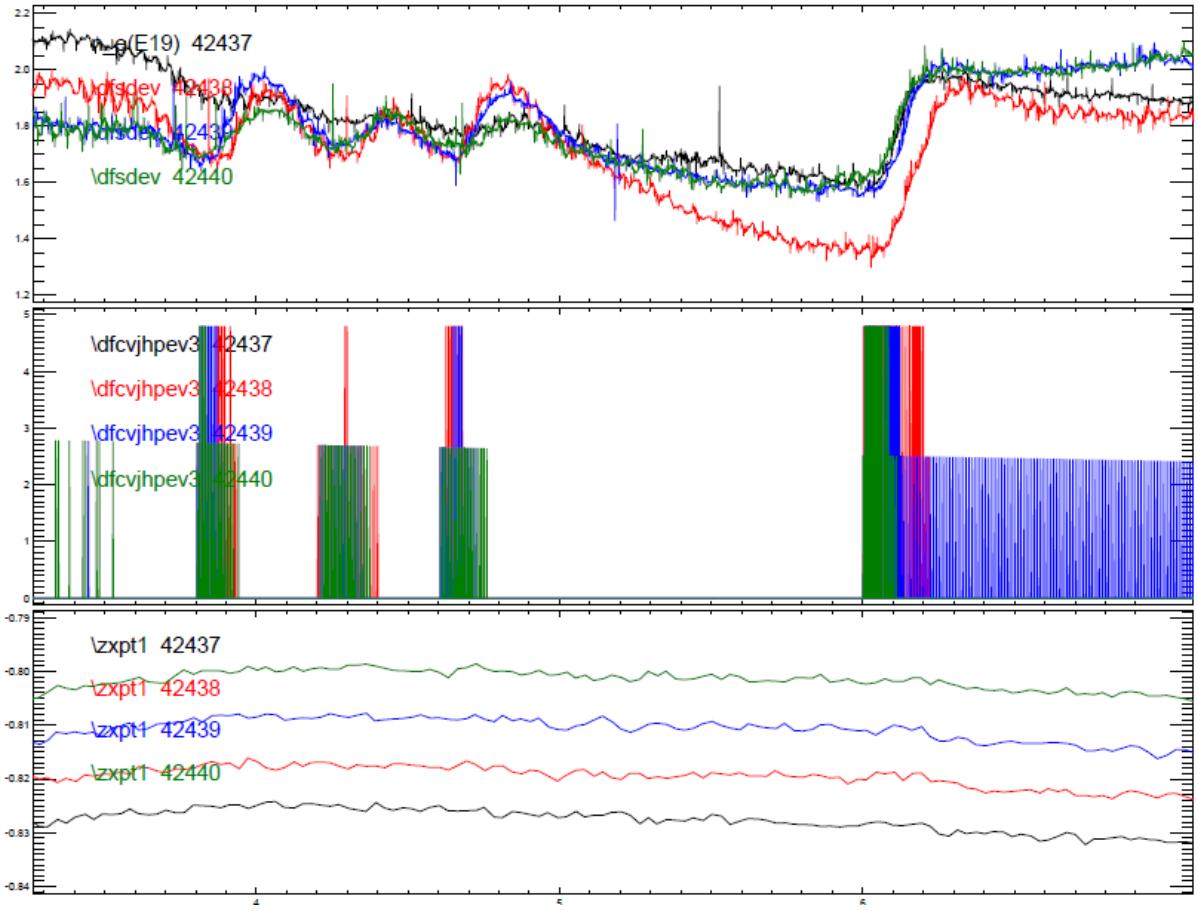
- After Li passivation, and cryos partially warmed, pumping independent of strike-point position except for -4cm
- Still unclear why -4cm has better pumping

Day 2 - role of Li vs. cryo-pumping

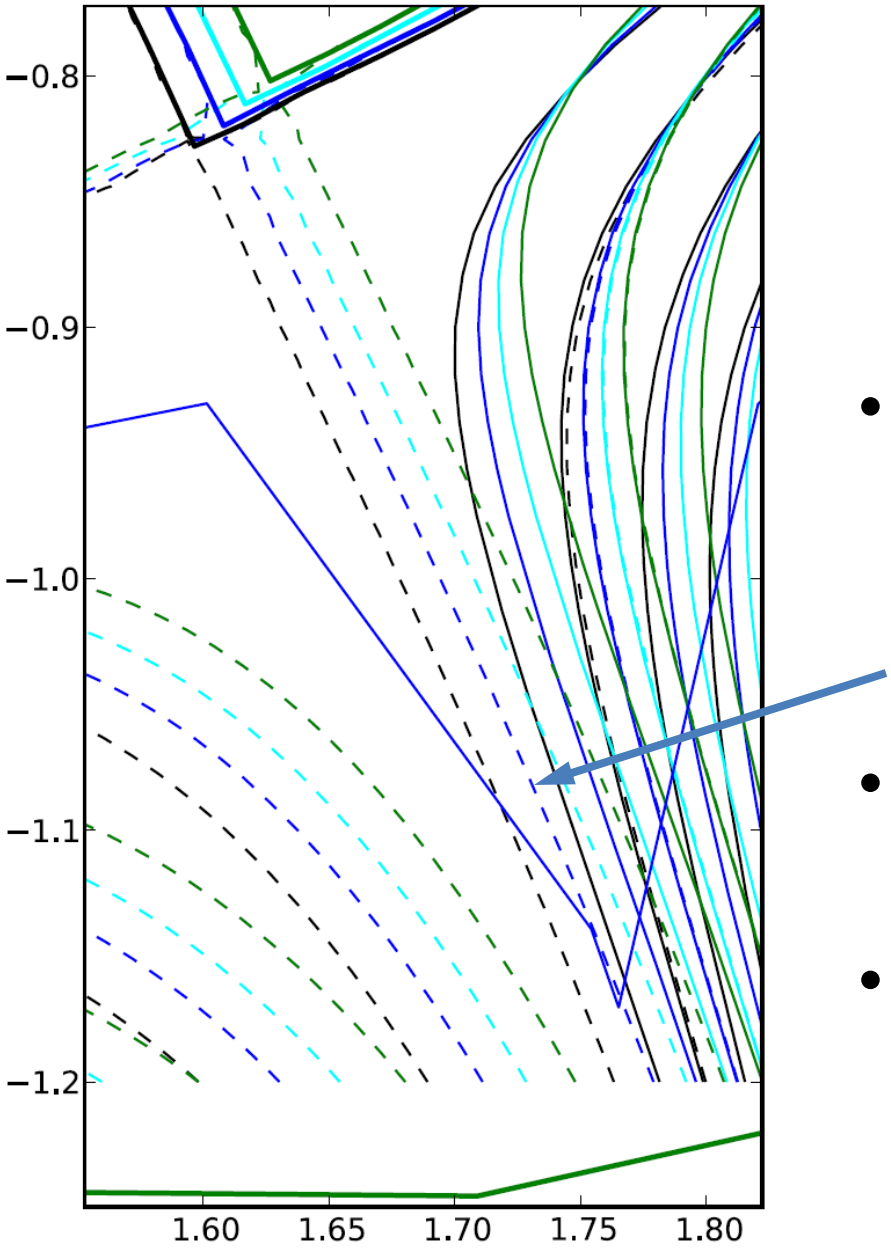
- 400kA, 2T, 1MW LH – no ICRF, stay in L-mode
- This time with fresh lithium, no cryo-pumping (T=40K)
- SMBI not available for density feedback control
- Spent ~10 shots optimizing waveform for low-field-side gas fueling including increased integral gains for density feedback control, improved DRSEP transition
- Achieved good control of gas and electron density:
  - square-wave and impulse (turn-off) pumping response
- Li trends = similar results as previous day:
  - USN and DND have more rapid pump-out than LSN
  - Observed reduction in Li pumping by 8-10 shots
  - Stationary pumping conditions by ~20 shots

Day 2 – optimization of cryo-pumping

- Performed X-point height scan with cryo cold (8K)
  - Tried shifts relative to reference LSN: -2, -4, -6, -8, -10cm
- Only -8cm case exhibited increased particle pumping



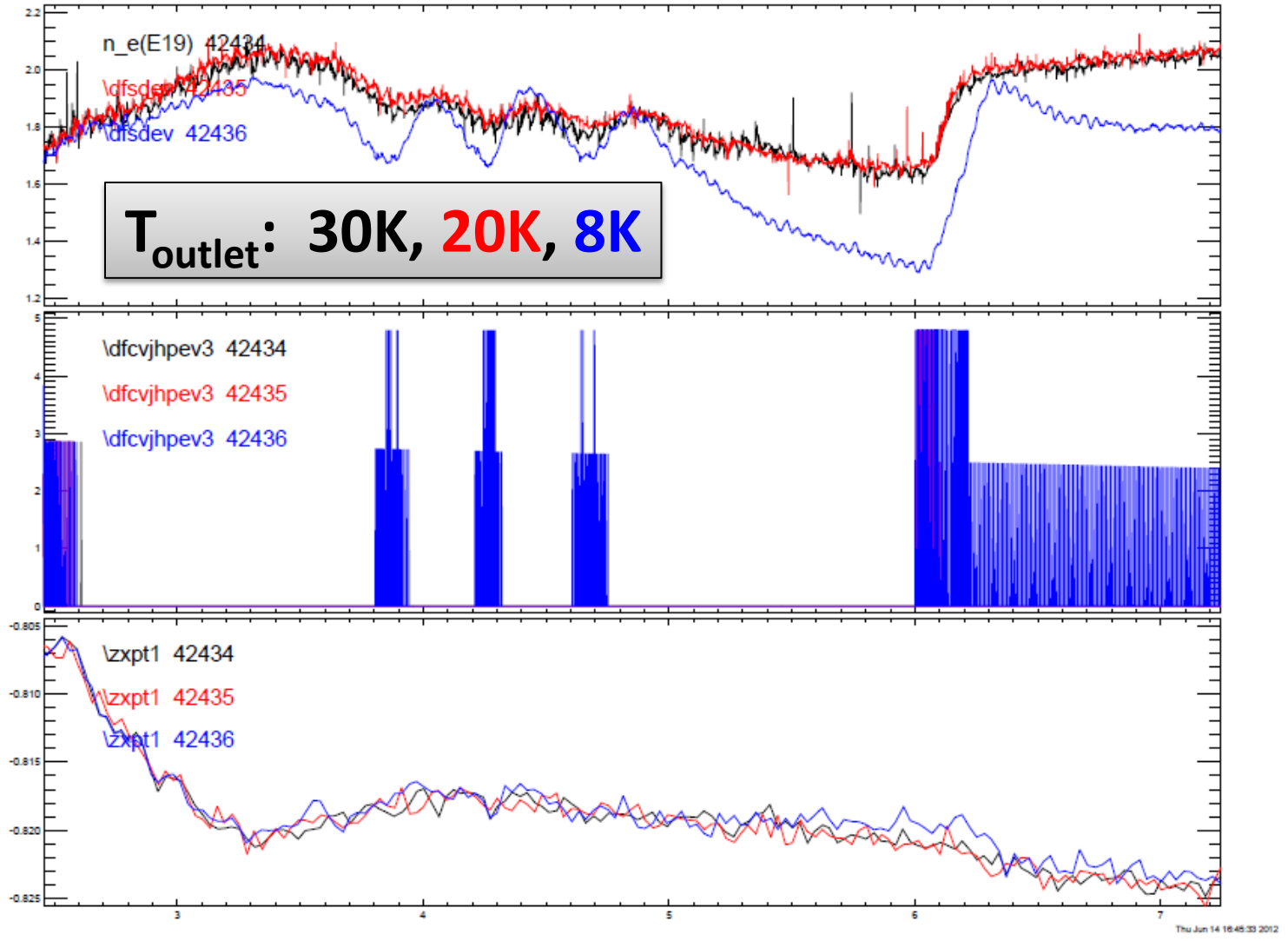
Cryo-pumping sensitive to strike-pt position



- Case with increased density pump-out places strike-point directly at divertor corner (plenum entrance)
- Other nearby shapes do not show significant pumping
- Implies precise strike-point control likely needed for particle control with cryo

Clear dependence on cryo temperature

- As expected, pump only effective below 20K (D_2 freezing)



Summary conclusions from experiment

- Pumping from Li dominates reference LSN, since reference LSN has little/no cryo-pumping
- Li pumping degraded by 30-50% after ~6-8 10s shots
- Li pumping conditions saturated at factor of 2-3 lower pumping (relative to fresh Li) after ~20 10s shots
- Results may be different for different plasma conditions!
- Cryo-pumping appears to only be effective with strike-point directly at corner of divertor = plenum entrance
- If very long-pulse H-modes saturate Li, will need very good strike-point control for cryo-pumping for D control
- Achieved H-mode for reference LSN, but not for -4cm shift, and did not try -8cm → future work (not for me!)