The effect of lithium conditioning approaches for plasma-facing surfaces on the edge and core temperature and density profiles

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LTX-β

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Outline

LTX-β

- Introduction
  - LTX and LTX-β
- Progress in the elimination of core plasma temperature gradients - *solid lithium walls*
- Core impurity levels during tokamak operation with full *solid* or *liquid* lithium walls
- Implications of a low collisionality scrape-off layer
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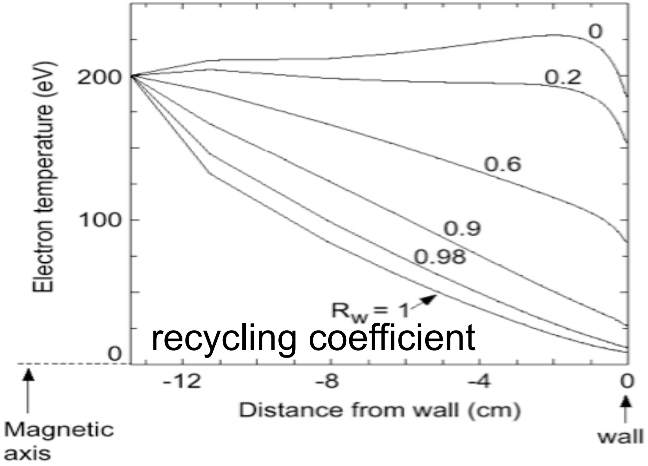
Nonrecycling walls simplify the tokamak

LTX-β

- Robustly flat ion, electron temperature profiles predicted
- No ∇T driven effects
  - No ion heat conduction losses
    - » Approaches thermal equilibrium in a confined plasma
  - No drive for the ITG, ETG
  - Bootstrap current driven only by ∇n
  - Particles transport heat. $\tau_E = \tau_p$
- Edge power deposition profile strongly broadened
  - Hotter ions – broader orbits
  - E×B convection, drifts ⇒ more broadening

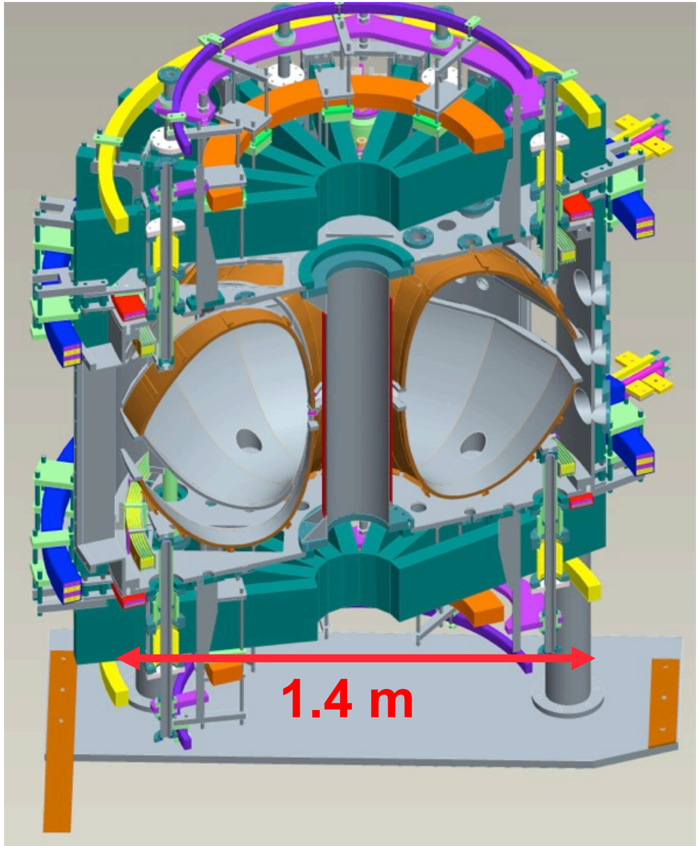


- Effect of recycling on edge temperature predicted by UEDGE modeling
  - ➢ LLNL will study LTX-β SOL

LTX and LTX-β

LTX-β

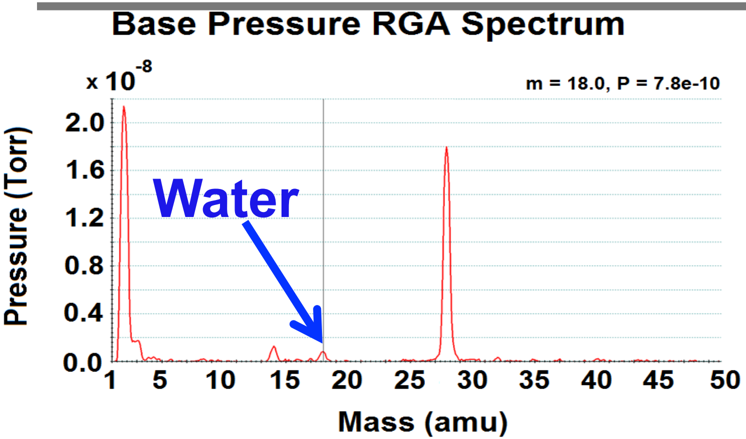
	LTX	LTX-β
A	1.6	1.6
R_0	40 cm	40 cm
a	26 cm	26 cm
B_T	<1.7 kG	<3.4 kG
I_p	<100 kA	<200 kA
P_{aux}	0	700 kW
Pulse length	<50 msec	<100 msec

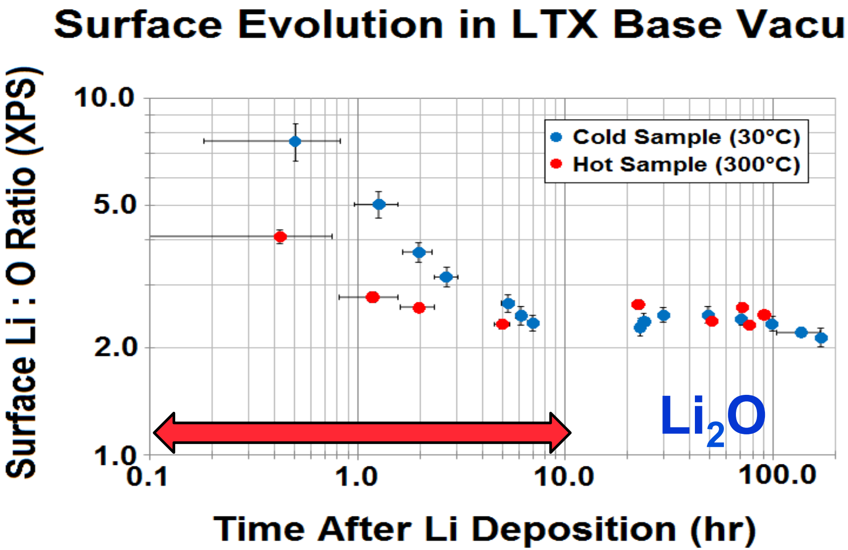


- High field-side limited by a conformal, high-Z wall
  - Not diverted
- Operated in hydrogen (gas puffing)
  - LTX: Fueled from the high field side midplane
  - LTX-β: 35A neutral beam fueling, improved HFS puffing, topside SGI

Very low partial pressure of water achieved in LTX

➪clean, metallic lithium PFCs





LTX-β

(UIUC MAPP probe)

- Background water 5-9 × 10^{-10} Torr in LTX
  - ➢ Pumping speed doubled on LTX-β to 7,800 L/s
  - ➢ Bakeout system upgraded

- X-ray Photoelectron Spectroscopy (XPS)
- Oxygen only impurity on lithium coating
- Li:O ratio initially high; asymptotes to 2:1 (Li_2O)
  - ➢ Expanded surface analysis on LTX-β – Princeton U. collaboration, U. Tennessee

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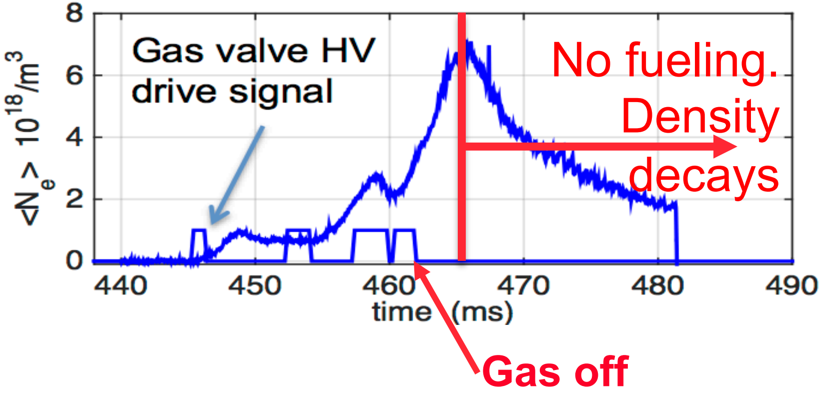
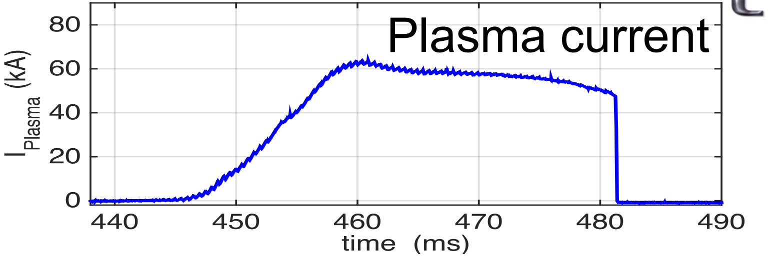
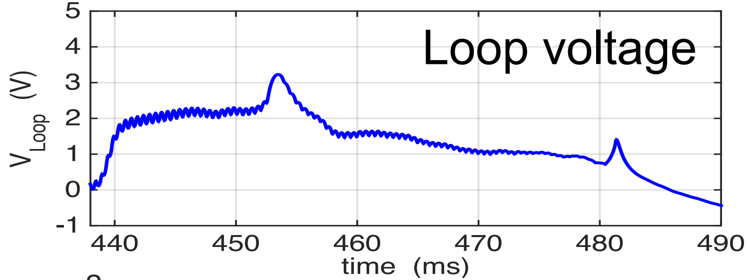
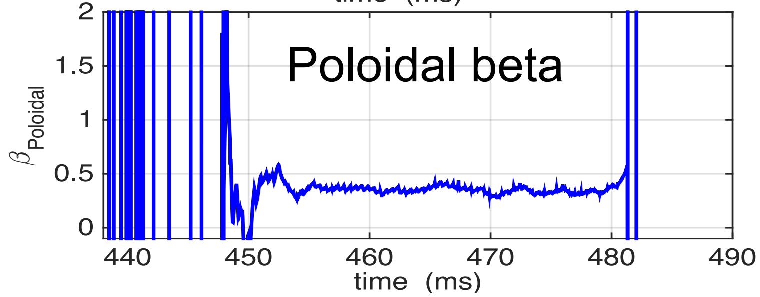
Transient experiments eliminate edge neutral cooling



- Centerstack gas terminates at 462 ms
  ~3-4 ms to clear gas from nozzle
- Monitor T_e evolution
- Thomson scattering time is stepped through the discharge
  - Dataset of 55 identical discharges
  - Average ~ 5 discharges/time

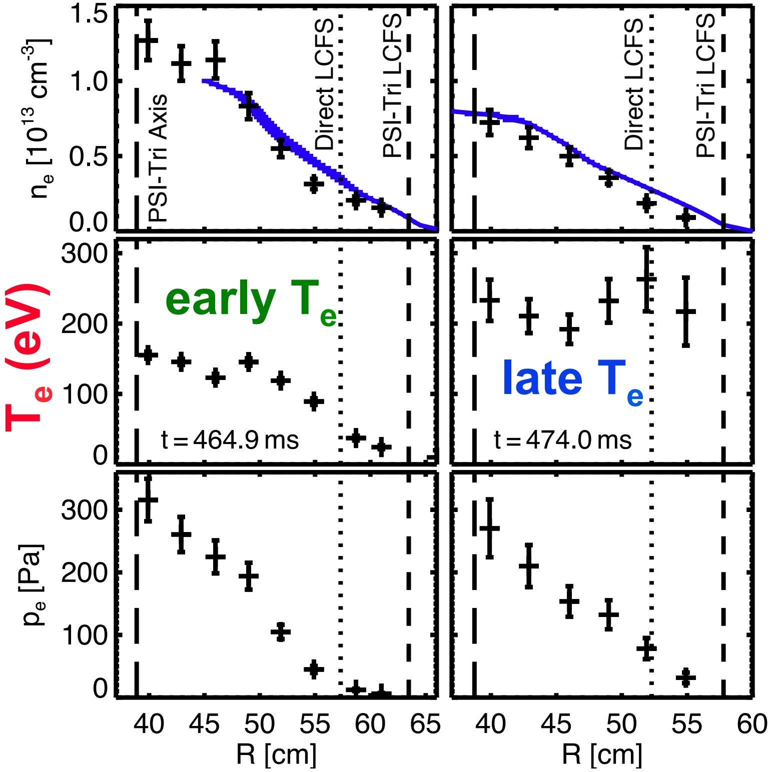






Control of recycling provides control over the **temperature** profile

- Very low recycling allows completely flat temperature profiles to develop

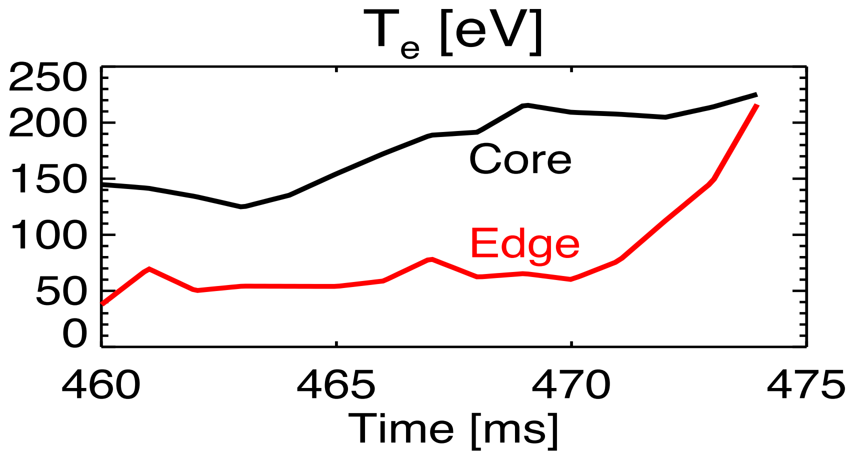


t=464.9 ms

t=474 ms

- Gas puffing early in discharge

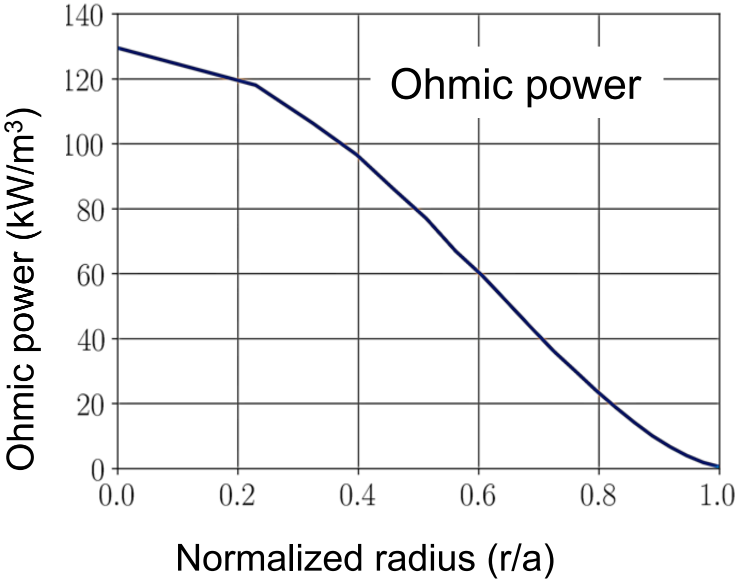
- Late in discharge:
  - Lithium suppresses recycling
  - No gas from puffing

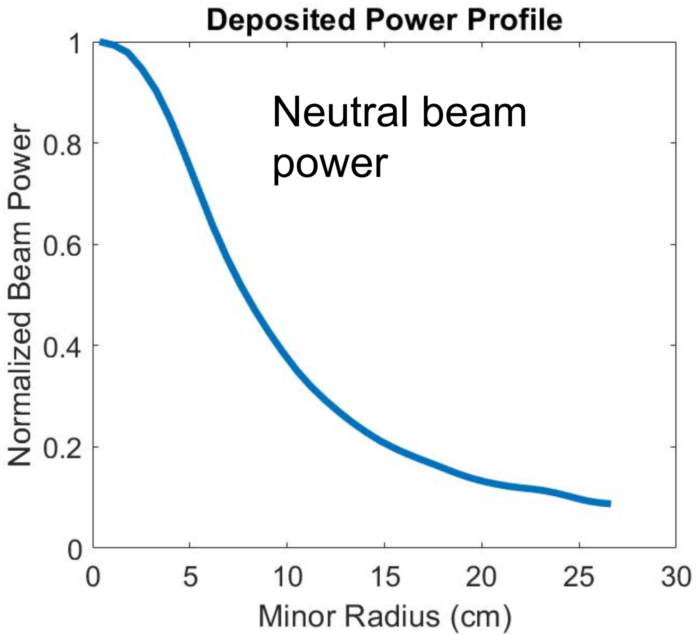


- PSI-TRI equilibrium (U. Washington).
- New equilibrium modeling from LiFusion
- Thomson upgrades on LTX-β

LTX-β

Flat T_e profile develops with peaked Ohmic power deposition





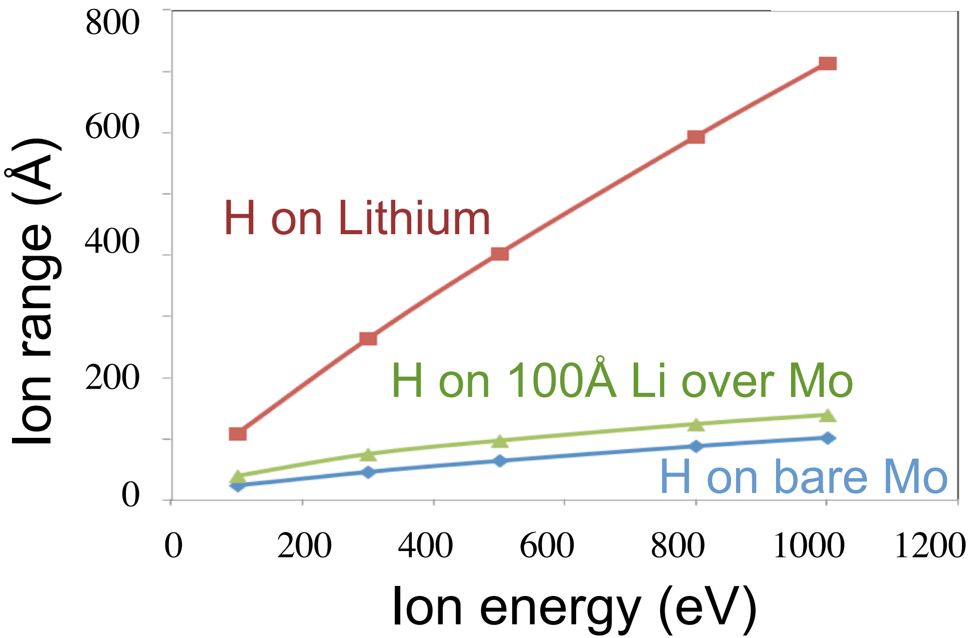
LTX-β

- T_e profile is much broader than Ohmic power deposition profile
  - NBI in LTX-β will test T profiles with ion heating

- Neutral beam heating profile will be more peaked
  - E_{beam}>$E_{critical}$
  - Electron and ion heating from NBI

Recycling reduction robust with high edge T_e

- Proton will penetrate 10's to 100 monolayers deep in metallic lithium coating
  - Buried in the solid
  - Recycling less dependent on near-surface conditions
  - Differs from NSTX case
- Large hydrogen inventory can be stored in the lithium wall
- Diffusivity of hydrogen, other impurities in *liquid* lithium will modify impurity profile



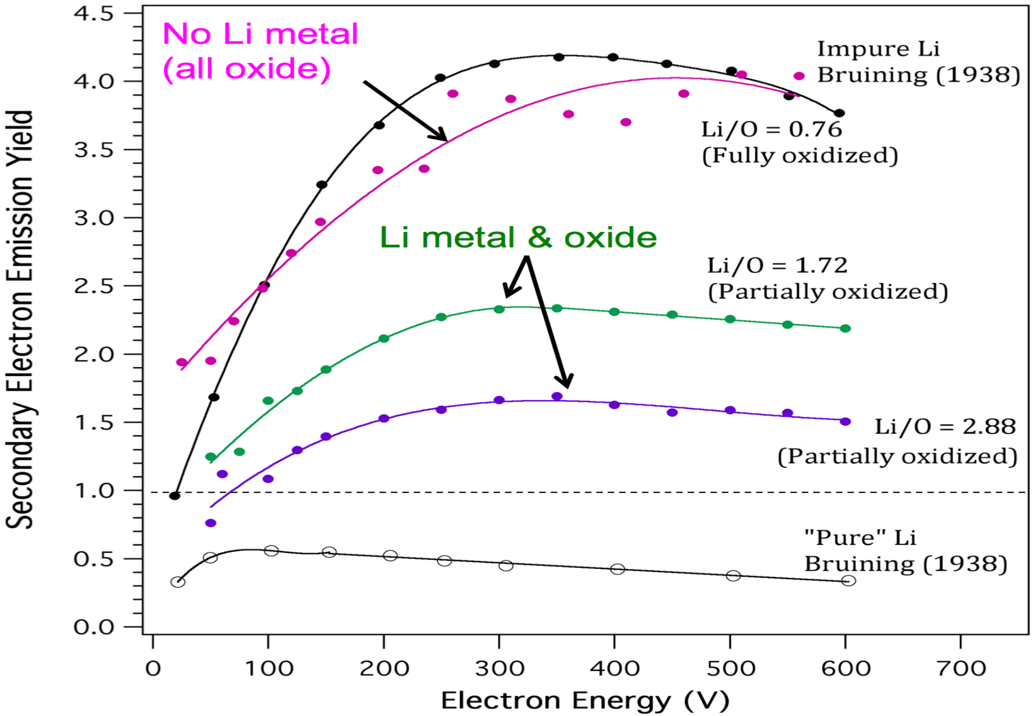
TRIM modeling by
L. Buzi, Princeton U.

Surface conditions still determine electron "recycling"

- Electrons are also "recycled" via secondary electron emission
  - Secondaries cool the edge. Simple estimate:

$$q_{pe} = (2kT_e + e\varphi_0)\frac{0.6n_e c_s}{(1-\gamma_e)} - e\varphi_0\gamma_e\frac{0.6n_e c_s}{(1-\gamma_e)}$$

- Metallic lithium has low secondary electron emission
- SEE higher for contaminated lithium
  - LTX-β surface science will be studied by Princeton U., U. Tennessee
  - New lithium deposition systems – between-shots coatings



A. Capece, M. Patino, Y. Raitses, B. Koel, *Bull. Am. Phys. Soc., 2015.DPP.NO6.4*

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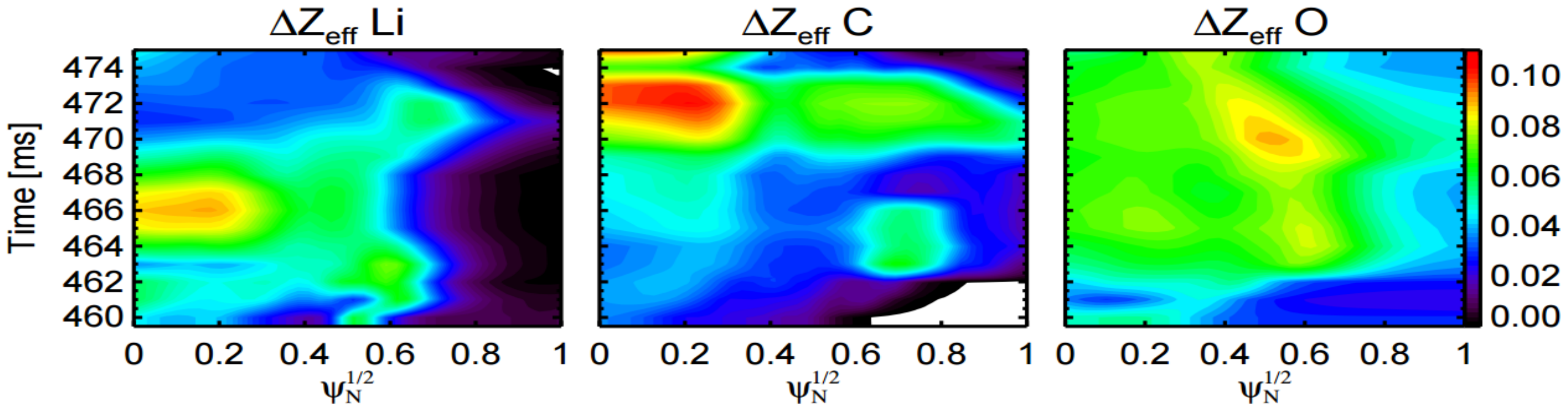
Low impurities -- Lithium does not significantly dilute core plasma



- Lithium impurity <2-3%
  - $Z_{effective}$ remains below 1.2
  - Carbon remains a contributor to $Z_{effective}$
- ***Solid*** lithium PFCs

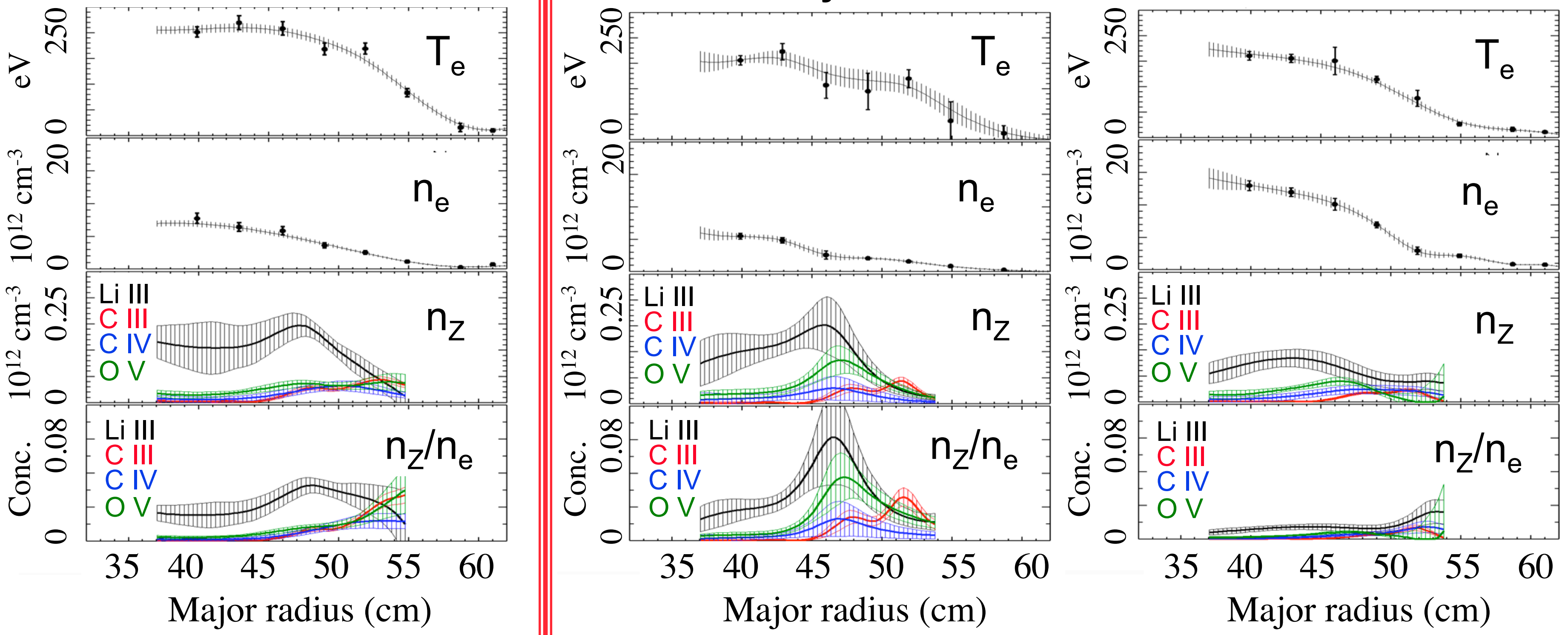
LTX-β

Lithium, other impurities modest with *liquid* walls

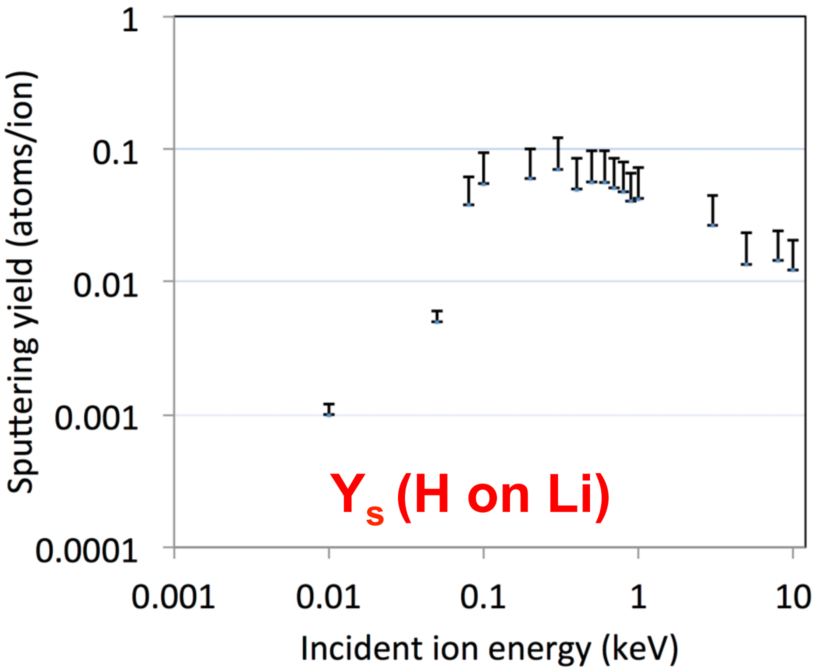
Solid lithium walls - decaying density. 0.47 sec

Liquid lithium walls - 260°C - low density. 0.464 sec

Liquid lithium walls - 260°C - higher density. 0.467 sec



Lithium impurity influx will be further reduced at higher edge temperatures



TRIM modeling by
L. Buzi, Princeton U.

LTX-β

- Hot edge during low recycling operation in LTX produced incident ion energies near the peak in the sputtering yield for H on lithium
  - Very low density edge
  - Ion *flux* very low
- Colder edge ions during liquid lithium operation ➪ lower yield
  - Higher edge density
  - Ion flux higher

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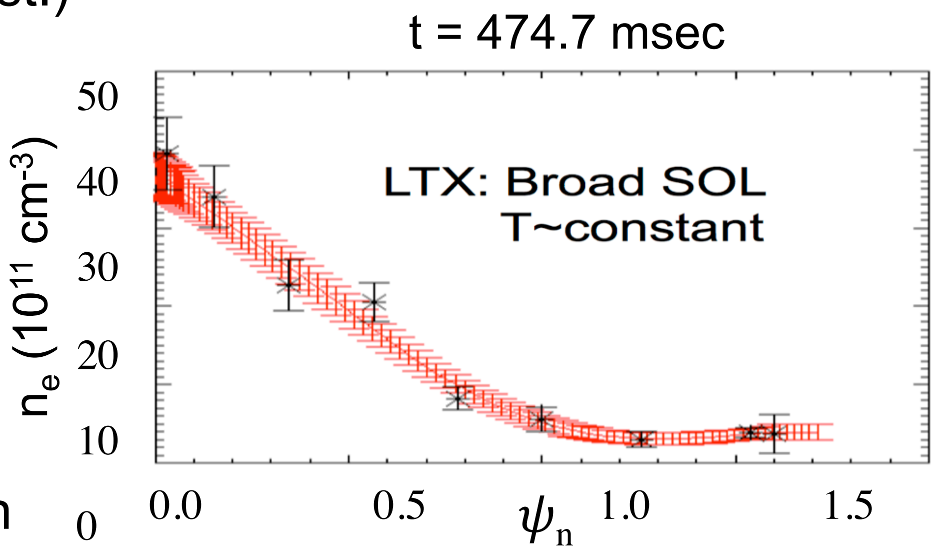
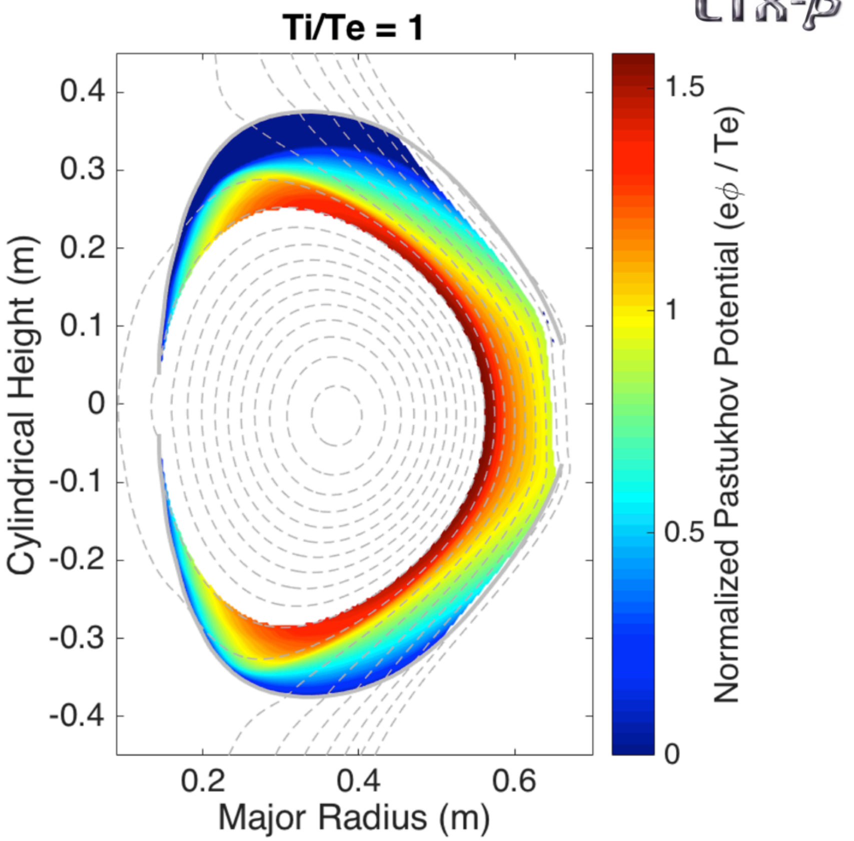
Very low collisionality in LTX SOL

- Edge T_e ~200 eV, T_i ~40 – 70 eV (est.)
  - n_e ~ **2-3 × 10^{17} m^{-3} (H)**
- L_{conn} ~5 - 10 m ($q_a \geq 5$)
- Neutral pressure < 10^{-5} Torr
  - λ_{CX} ~ 1-2 km
- τ_{ee} ~ 400 μsec, τ_{ii} ~ 1-2 msec
  - L_{con}/C_s ~ 60 μsec ≪ τ_{ii}
- ST: large trapped particle population
- Mirror ratio, LFS → HFS ~ 4
  - **80-90% SOL particles trapped**



SOL electric fields not confined to sheaths

- Loss rate along SOL determined by ion-ion pitch angle scattering
  - SOL plasma mirror confined
- Pastukhov potential will develop [Nucl. Fusion 14 (1974)3]
  - φ_p~0.6 – 0.8 kT_e for LTX parameters
  - SOL electric field should strongly eject sputtered impurities
  - SOL diagnostics in LTX-β will include energy analyzers, langmuir and emissive probes
  - LLNL, LiFusion will provide modeling support for LTX-β



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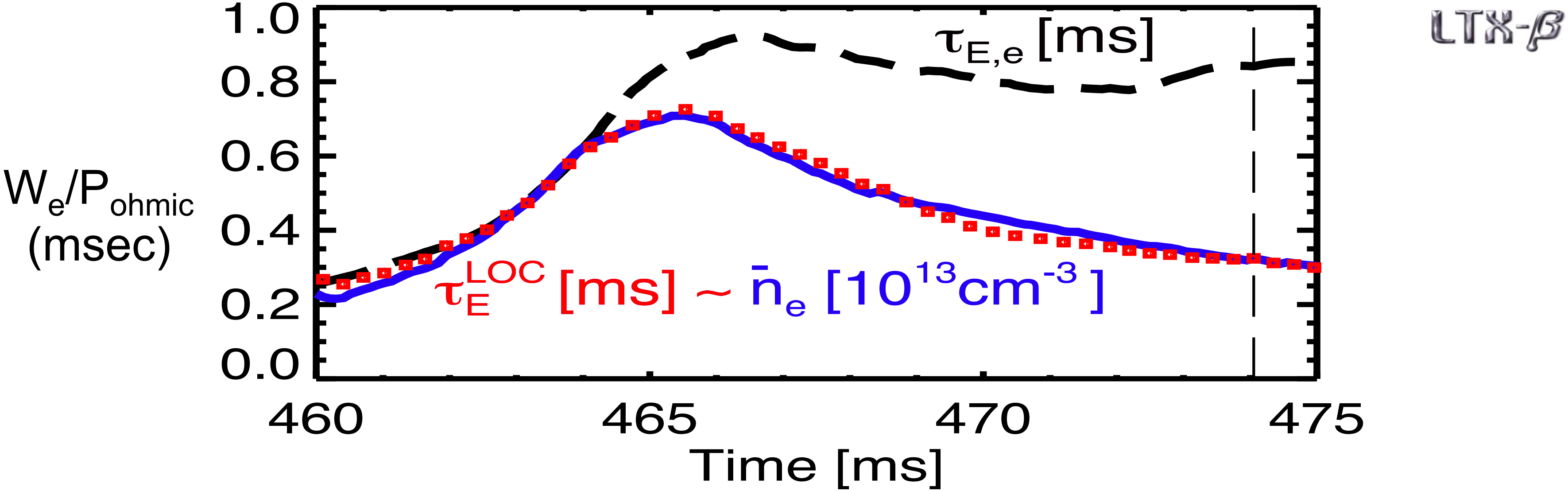
Low recycling plasma confinement exceeds neo-Alcator scaling



- Comparison is with neo-Alcator Linear Ohmic Confinement scaling
  - Appropriate for small tokamaks without auxiliary heating, like LTX
- Confinement time for LTX neglects ion stored energy; core T_i uncertain
- Core transport and turbulence not diagnosed in LTX
- Kinetic measurements of stored energy emphasized in LTX-β

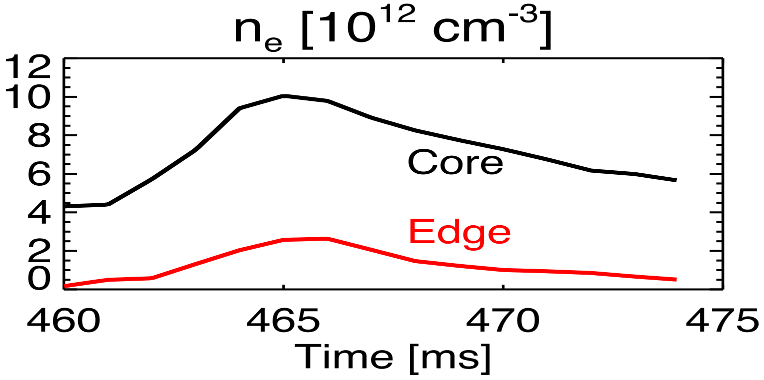
Core particle confinement

LTX-β

- Core density decays with e-folding time of 15 – 20 msec
  - Edge density e-folding ~ 4.8 msec
- By comparison, $\tau_{i\text{-}e}$ ~5-10 msec
  - Core electrons, ions expected to equilibrate
- Require core ion temperature measurement, local transport for accurate confinement estimates

➢ ORNL has installed CHERs diagnostic on LTX-β

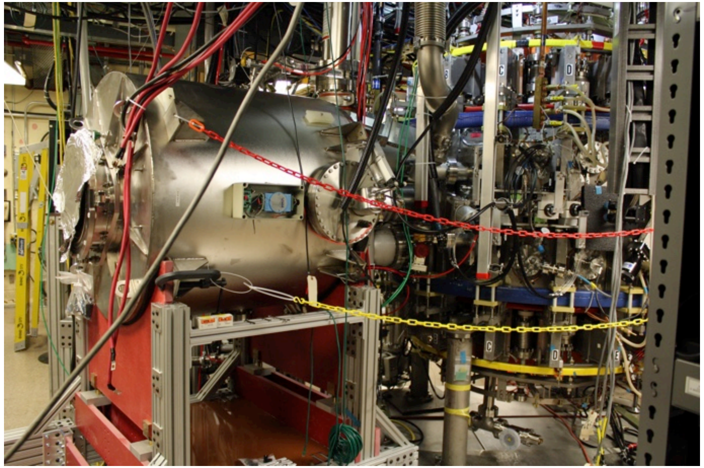
➢ UCLA will contribute core fluctuation measurements (reflectometry)

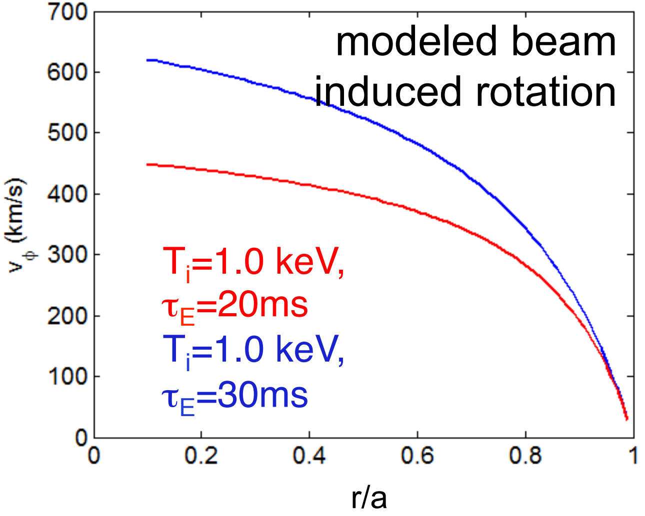


Evolution of edge and core n_e in LTX

LTX-β will combine gradient-free temperature profiles with sheared flow

- Two neutral beam injectors on loan from Tri - Alpha Technologies
  - One injector installed on LTX-β
  - 17-23 keV, 35A, hydrogen, R_{tan} = 23 cm
  - 5-8 msec pulse, upgrade to ~30 msec





- NBI support, fast ion physics: U. Wisconsin
- Momentum transport (& CHERs): ORNL

Summary

LTX-β

- Liquid metal PFCs require engineering, physics development
- Effects of lithium PFCs on transport, equilibrium, SOL not well understood
- Major effect on equilibrium - $\nabla T = 0$ – demonstrated on LTX
  - Simplifies neoclassical transport in the tokamak
  - Effect on anomalous transport TBD
  - Extensibility to auxiliary heated systems TBD
- Impurity levels benign for T < 260 °C – *liquid* lithium
- SOL changes may be as significant as the core modifications
- LTX-β will examine a much broader parameter space than was accessible in LTX