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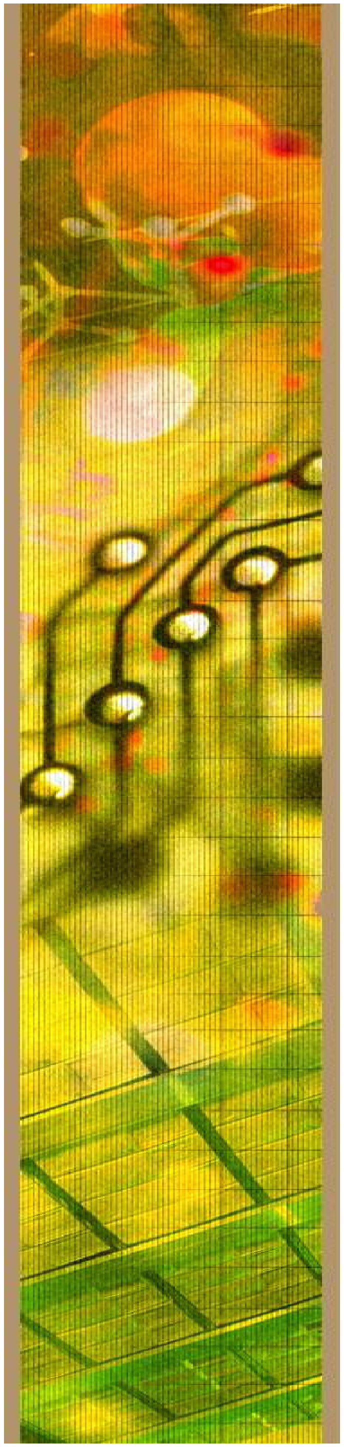

Erosion/redeposition analysis of NSTX Liquid Lithium Divertor (LLD)

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REDEP/WBC NSTX LLD Analysis

GOALS
--Determine:

- *Surface temperature limit set by lithium sputtering/runaway and/or evaporation*

- *Lithium ion density in edge/SOL*

- *Core plasma Li contamination potential*

- *Flux of sputtered lithium to carbon surfaces and D-pumping capability.*

REDEP/WBC Analysis

- REDEP/WBC code simulation of NSTX Liquid Lithium Divertor (LLD). Full kinetic, sub-gyro-orbit analysis. (100,000 sputtered histories/simulation).

- Plasma parameters from UEDGE/DEGAS solution, “0.65 D^+ reflection coefficient”, D. Stotler, R. Maingi, et al. (2008). Includes supplied LLD surface temperature profile, at t = 2.01020 seconds (L. Zakharov). (Max temp = 281° C). Near-surface grid UEDGE used, extends ~20 cm from surface. Parameters used: Ne, Te, Ti, magnetic field vector **B**, Vd (plasma fluid flow speed), and electric field along net magnetic field.

- Incident particles: D^+ ions, Li ions. Incident D^+ flux computed based on supplied fluid velocity at divertor, density at divertor, space-dependent net magnetic field angle with divertor surface. No D^0 charge exchange sputtering used (can be added if supplied).

- Energy-dependent and surface-temperature-dependent sputter yields for D, Li, incidence, from TRIM-SP code runs (J.P. Allain), for pure Li; 45° incidence. (Note: incidence angles likely to be somewhat less oblique, due to sheath structure, per below; but probably not major difference to results).

- **Charged/neutral lithum sputtered fraction model (Allain) used (~2/3 charged, ~1/3 neutral). Reference WBC model used for recycle/re-sputter of sputtered Li^+ (net atomic Li sputtered ~ ½ of total gross (charged + neutral).**

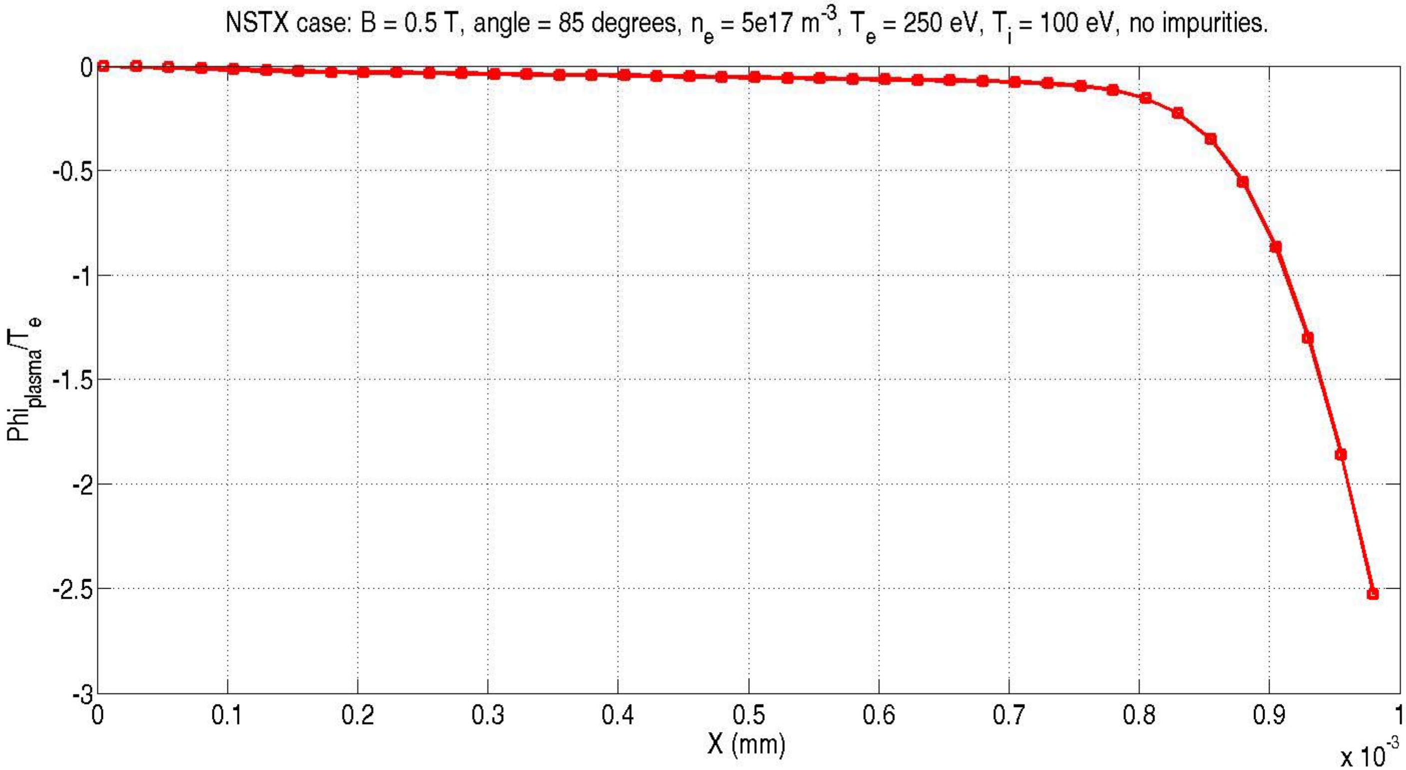
REDEP/WBC Analysis continued

- Sputtered Li atom energy distribution functions used in WBC per representative TRIM-SP results (note: some refining of the distribution model can be done-but we do not expect big difference). "Cosine" elevation angle and uniform azimuthal angle distributions used.

- LiI density-dependent and Te-dependent electron impact ionization rate coefficients from ADAS, S.D. Loch et al., Atomic Data and Nuclear Data Tables 92(2006)813. Te-dependent rates used for LiII-LiIV from previous supplied ADAS data (note: little higher-state ionization takes place, in this low-recycle/low-density regime).

- **Sheath: BPHI-3D code run for NSTX conditions (Brooks/Ochuockov) Dual-structure (Debye sheath + magnetic sheath) found *not* to be present (due to weaker magnetic field, less oblique B-field incidence, viz. 5-10° NSTX vs. 1-2°. for ITER, CMOD, etc.). Debye-sheath-only model therefore used in WBC. Locally-varying sheath potential eϕ = 3kTe.**

BPHI-3D Code- NSTX Sheath Analysis at Liquid Lithium Divertor

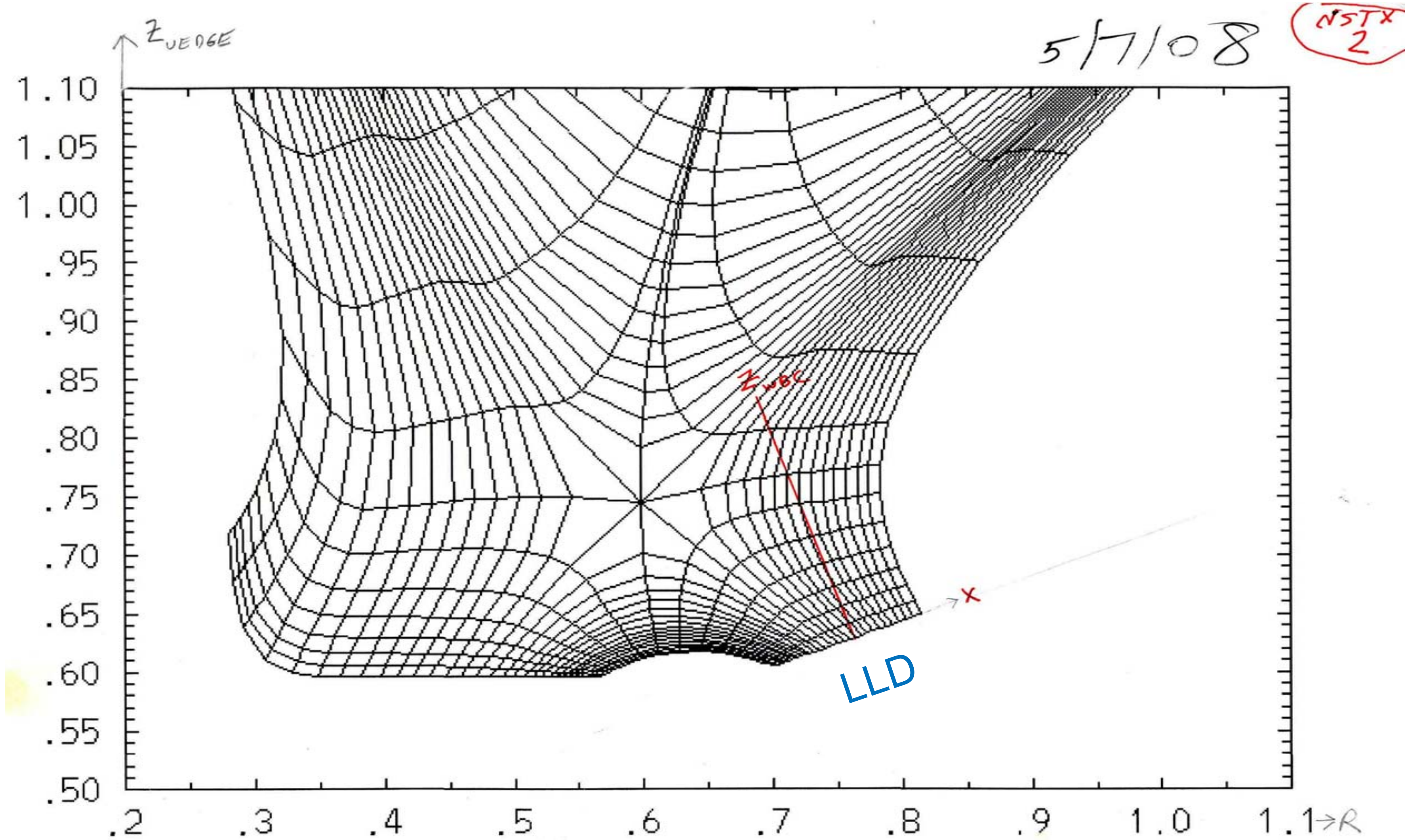


- No magnetic sheath predicted; Debye sheath only

REDEP/WBC code package--computation of sputtered particle transport

3-D, fully kinetic, Monte Carlo, treats multiple (~100) processes:

- Sputtering of plasma facing surface from D-T, He, self-sputtering, etc.
- Atom launched with given energy, azimuthal angle, elevation angle
- Elastic collisions between atom and near-surface plasma
- Electron impact ionization of atom→impurity ion
- Ionization of impurity ion to higher charge states
- Charge-exchange of ion with D^0 etc.
- Recombination (usually low)
- q(**E** +**V**x**B)** Lorentz force motion of impurity ion
- Ion collisions with plasma
- Anomalous diffusion (e.g., Bohm)
- Convective force motion of ion
- Transport of atom/ion to core plasma, and/or to surfaces
- Upon hitting surface: redeposited ion can stick, reflect, or self-sputter
- Tritium co-deposition at surface, with redeposited material
- Chemical sputtering of carbon; atomic & hydrocarbon A&M processes



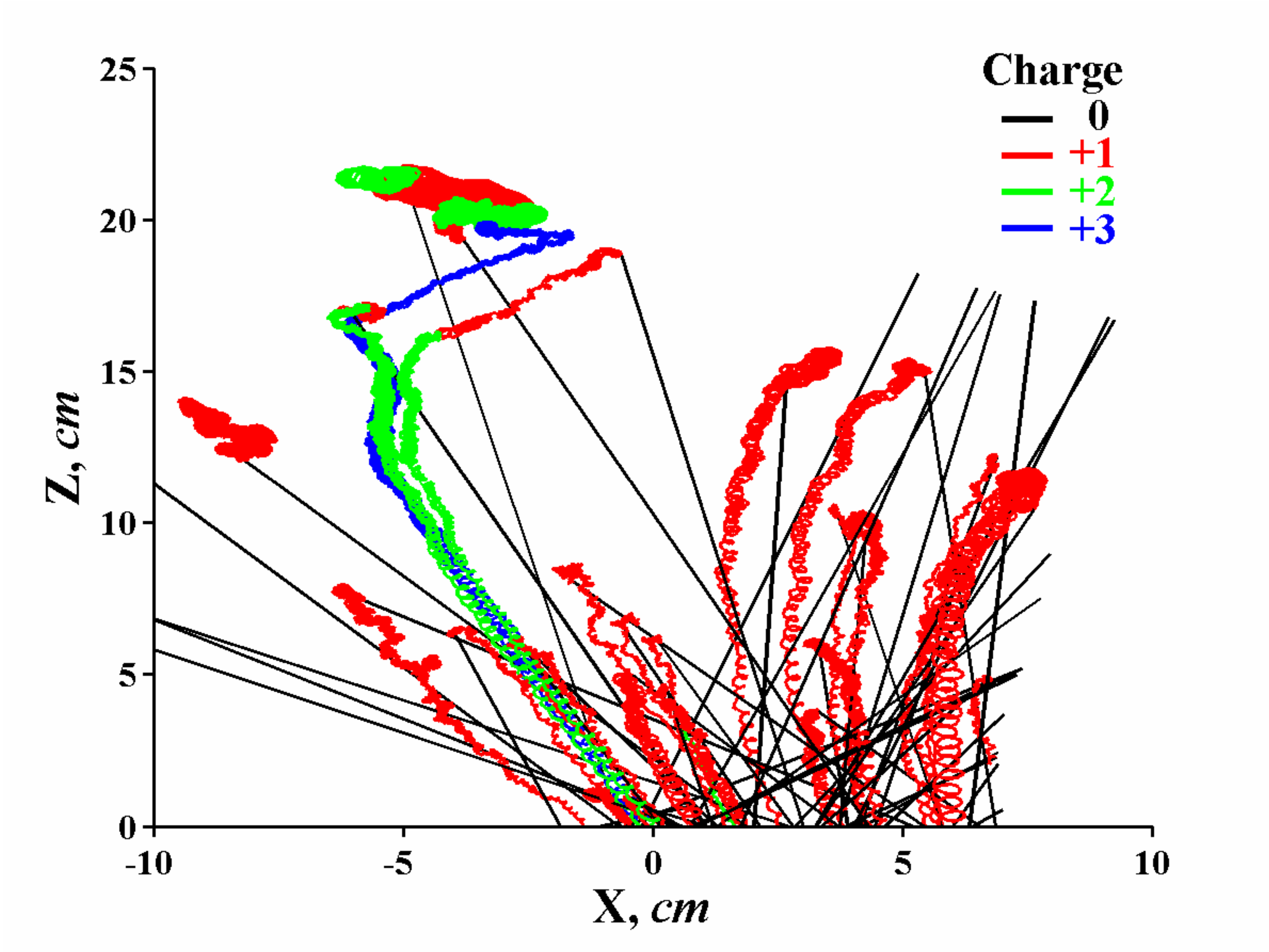
UEDGE/NSTX GRID

Some interesting erosion/redeposition physics for sputtered lithium in the NSTX plasma regime studied

- Large sputtered-atom ionization mean free path, order of 10 cm
- Large Li^{+1} gyroradius (~5 mm), due to relatively low B field
- Low collisionality, due to high T_e, low N_e
- $\Rightarrow$ Kinetic, sub-gyro orbit analysis required (i.e. WBC code)

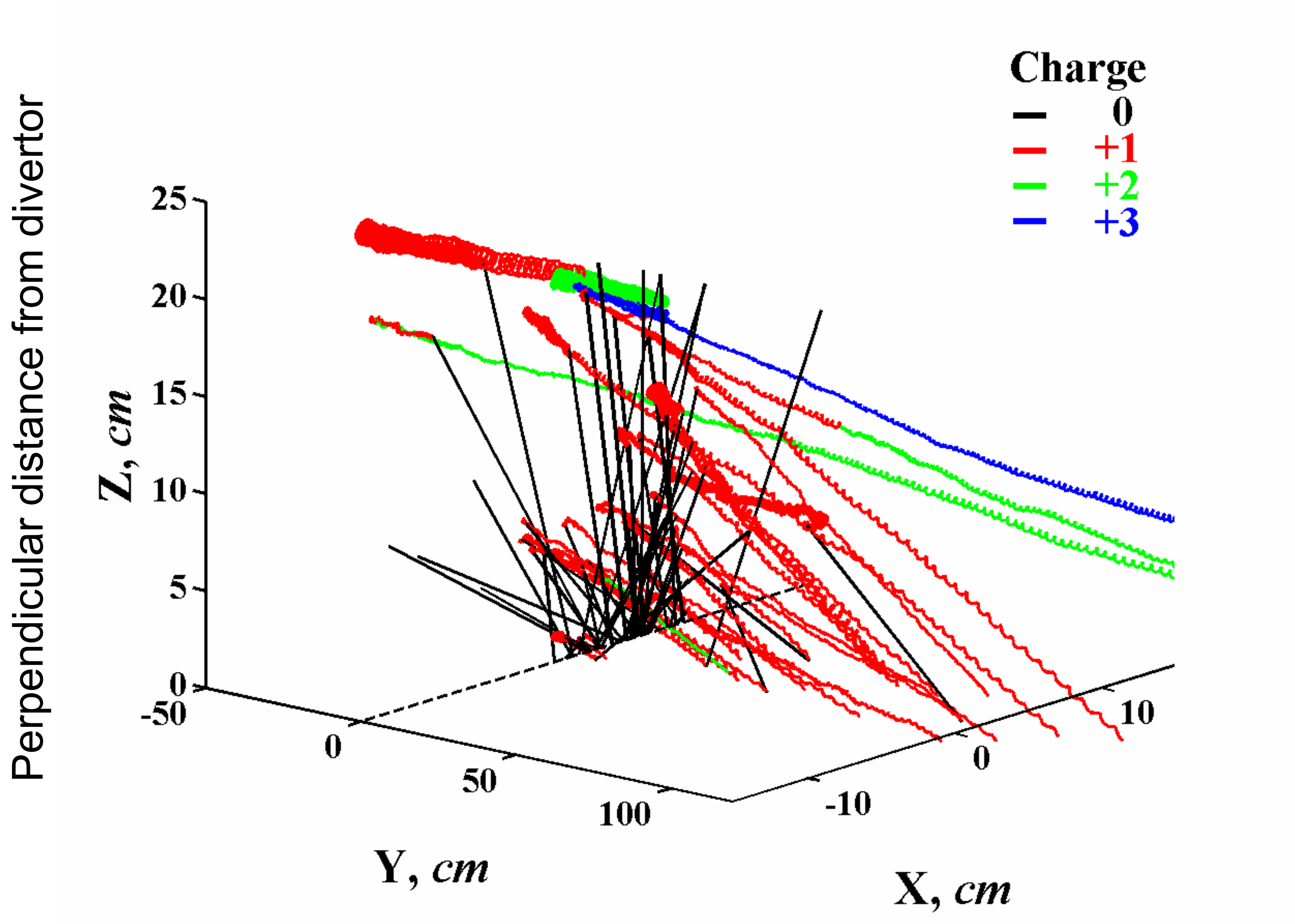
WBC Simulation of LLD sputtered lithium transport: 50 trajectories shown;
2-D view

Perpendicular distance from divertor



Distance along divertor (strike point at zero)

WBC Simulation of LLD sputtered lithium transport: 50 trajectories shown;
3-D view



x = distance along divertor (strike point at zero), y=distance along toroidal field

<u>Transport Results</u>

<u>Results, run of 5/5/09 (PRELIMINARY)</u>

1. Sputtering is “OK”. Gross and net lithium erosion profiles: Fairly broad profiles-to be plotted. Peak gross rate = 10.3 nm/s, peak net rate = 5.7 nm/s. Average effective D^+ sputter yield = 0.07

2. 50.3% of sputtered (neutral) lithium is ionized within the computation zone (LLD and associated near-surface grid). 49.7% of sputtered lithium “escapes”.

3. Of the zone-ionized material, 91% is redeposited on LLD, 9% escapes.

4. Fate of escaping lithium: ~13% (of total sputtered) goes towards core plasma (not followed further), ~24% goes to outside (higher major radius) of LLD, ~17% goes to inside of LLD. Thus, roughly 50% of sputtered Li would likely impinge on the various carbon surfaces.

5. Total sputtered Li atom current = 1.38 $\times 10^{20}$ s^{-1}. About 9% is from self-sputtering, rest from D^+ sputtering.

LLD redeposited lithium ion parameters

Parameter (average across divertor)	Value
Charge state	1.083
Energy	429 eV
Transit time	41 μs
Angle (to surface normal)	21 deg

Ongoing Work

- Several model enhancements to present case
- Higher temperature case analysis, at ~5.0 seconds
- LI/C effects?
- Higher power case-need UEDGE analysis