IMPACT OF NEUTRAL PARTICLES ON BEAM-ION LOSSES IN EAST TOKAMAK

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Motivation

- **Controlling fast particle losses is key to high-performance operation in future fusion devices**
  - Steady-state high-performance operation → High density & temperature

$n_i \cdot \tau_E \cdot T \geq 5\times10^{21}\ m^{-3}\cdot s\cdot keV$

Fueling — Auxiliary heating

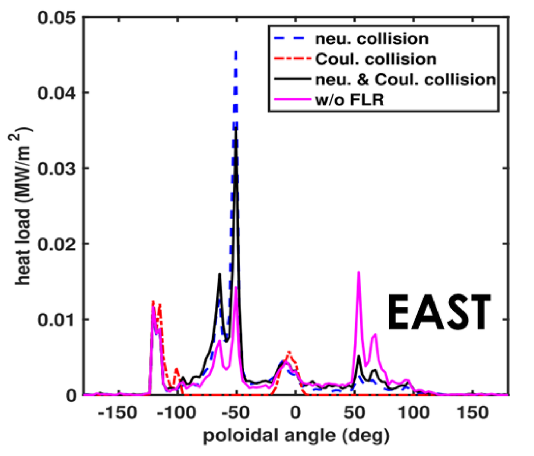
  - Charge exchange (CX) between fast ions & neutrals

↓

Enhanced fast-particle losses

✓ Lower heating efficiency

✓ Higher first wall load



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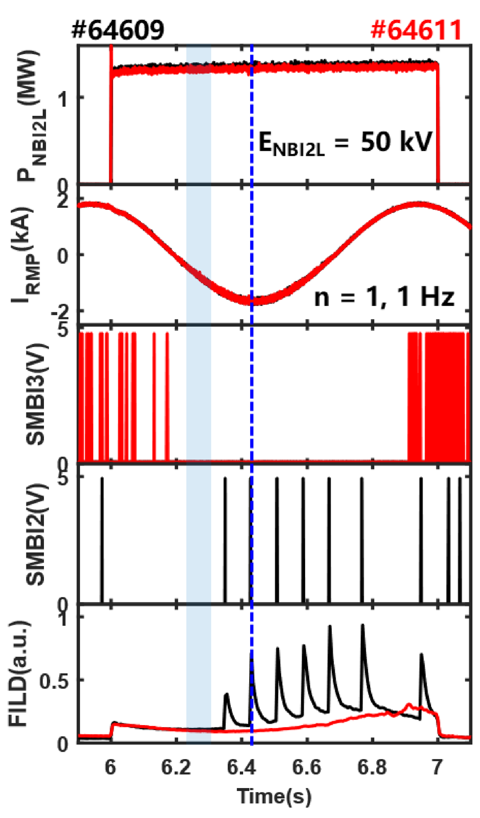
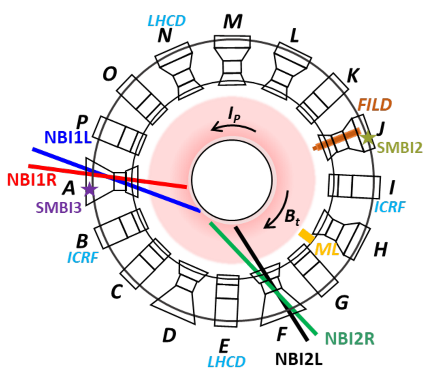
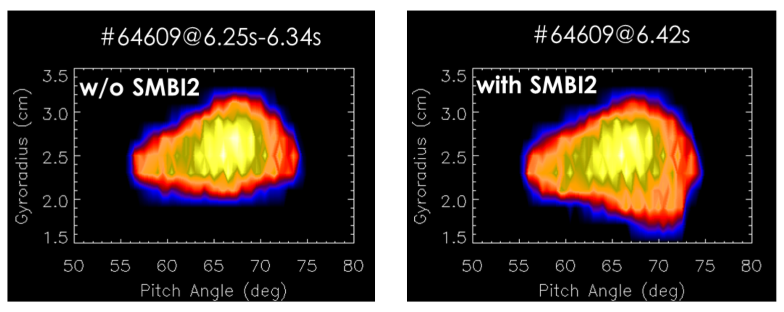
Increased local neutral density leads to enhanced beam-ion losses



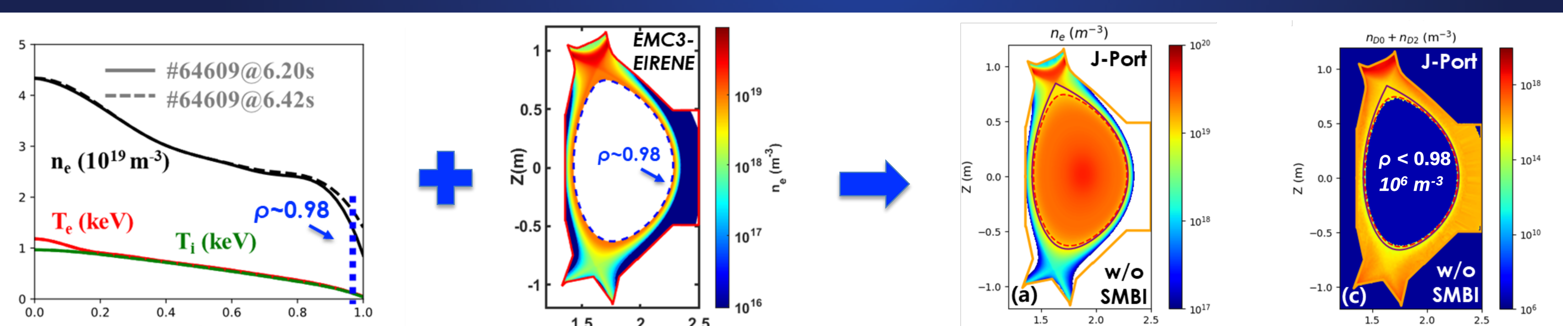




- **SMBI2 enhances beam ion loss, while SMBI3 does not**
- **Rotating RMP modulates the intensity of beam-ion losses**
  - RMP (n=1, 1Hz) alters the orbits of edge fast ions
  - A synergistic loss effect is observed between SMBI2 & RMP
- **The velocity-space distribution of lost beam ions is broadened**
  - There is observed loss of slowed-down beam ions (pitch ~ 70°, gyro ~ 2 cm)

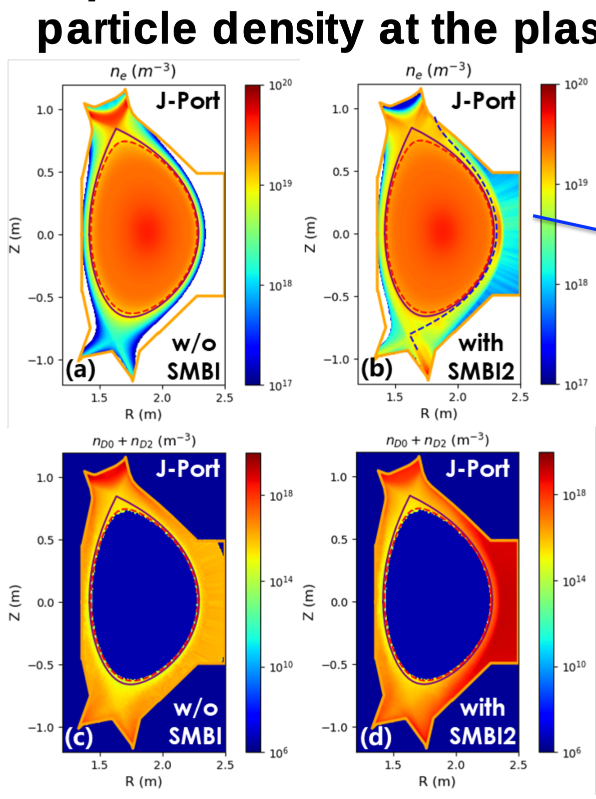
The experimental results are further explained by simulations (ASCOT, BBNBI, EMC3-EIRENE)

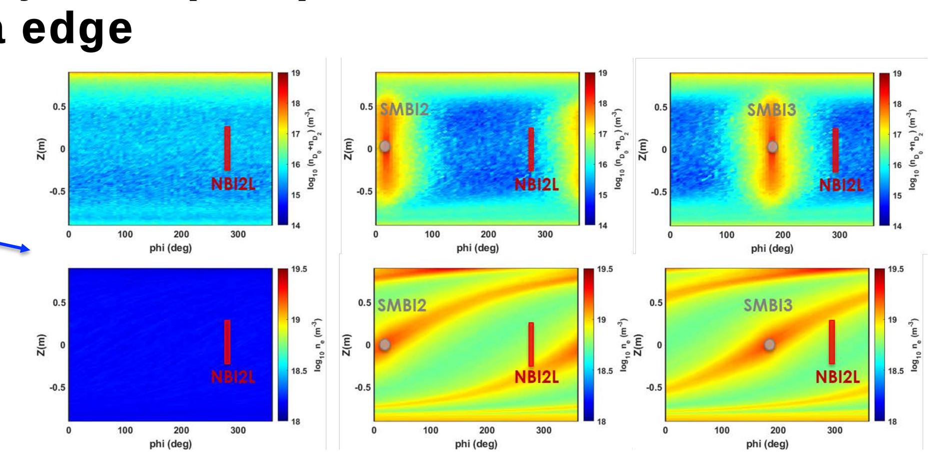
3D Electron & Neutral Density from Integrated Experiment/Simulation



- **1D core plasma profiles (ρ < 0.98) are obtained from diagnostics**
  - ✓ n_e (POINT, REF), T_e (TS,ECE), T_i (CXRS)
  - ✓ Data fitting with OMFIT & stored energy calculation with ONETWO show good agreement (~5% error) with experiment
- **3D edge background parameters (ρ > 0.98) are provided by EMC3-EIRENE**
  - ✓ w/o SMBI : n_{up} = 1.1×10^{19}m^{-3} , $D_\perp$ = 0.15 m^2·s^{-1}
  - ✓ with SMBI : n_{up} = 1.46×10^{19}m^{-3}, $D_\perp$ = 0.2 m^2·s^{-1} ,R_{inj} = 4.682×10^{21} s^{-1}
- **3D background parameters (charged & neutral particles) serve as input for ASCOT5**

- **Supersonic Molecular Beam Injection (SMBI) results in an enhanced background particle density at the plasma edge**





- **SMBI increases the background particle density in the SOL**
  - ✓ ne: w/o SMBI → ~10^{17} m^{-3}, with SMBI → ~10^{19} m^{-3}
  - ✓ $n_{D_0}+n_{D_2}$: w/o SMBI → ~10^{16} m^{-3}, with SMBI → ~10^{19} m^{-3}
- **Localized neutral density peak at fueling location**
  - ✓ SMBI2 → J port (phi~22.5°), SMBI3 → A port (phi~180°)
- **Toroidal electron density rise from parallel electron transport**

A Two-Stage Simulation Scheme for Achieving High-Fidelity FILD Signal Modeling with Enhanced Resolution

- **Step1: Marker tracking is stopped if the marker is lost, neutralized, or reaches T_{lim}**
  - ***SMBI causes increased prompt loss of beam ions deposited in the SOL***

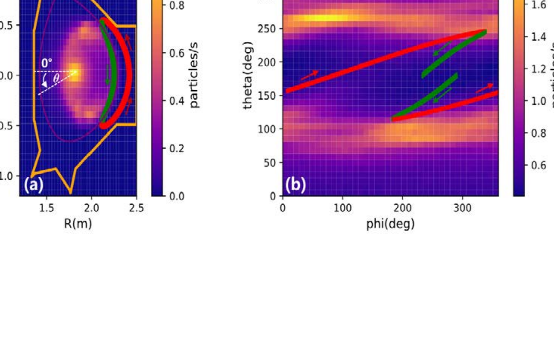
✓ Most markers are located in the core and "banana-tip" regions

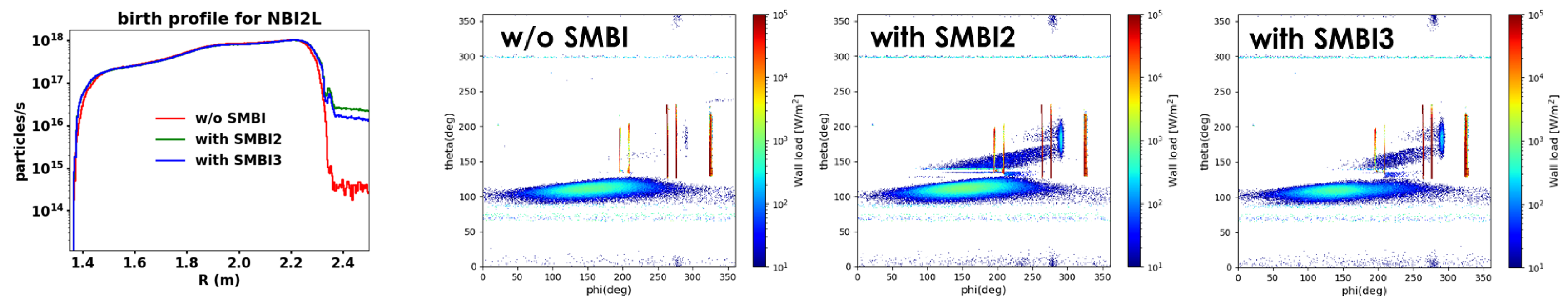
➢ Trapped particles ($v_\parallel$↓, $v_\perp$↑) dwell longer at "banana tips" than passing particles in the core

➢ Dominant fast-ion loss to pfcs at "banana tips"

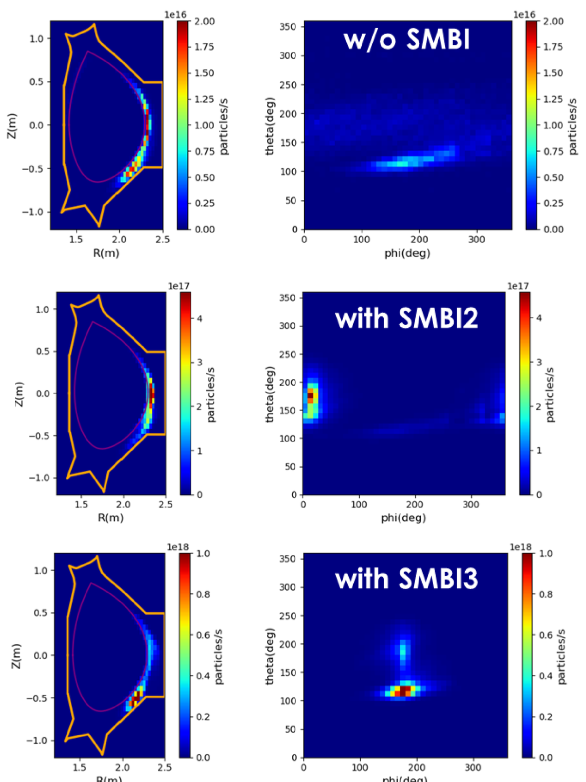
✓ SMBI increases the wall load near the beamline

➢ SMBI2 & 3 increase the electron density near the beamline (F-port), thereby raising the initial deposition fraction in the SOL





- ***Fast-neutrals peak is determined by the fueling location & beam ion distribution***



✓ Beam ion CX process involves both background D & D_2

$$D^+ + D_2 \to D + D_2^+$$
$$D^+ + D \to D + D^+$$

$$P(\delta t) = 1 - \prod_j \exp(-n_j\langle\sigma_j v\rangle\delta t)$$

✓ Fast neutrals production rate: $R_{w/o\ SMBI} < R_{SMBI2} < R_{SMBI3}$

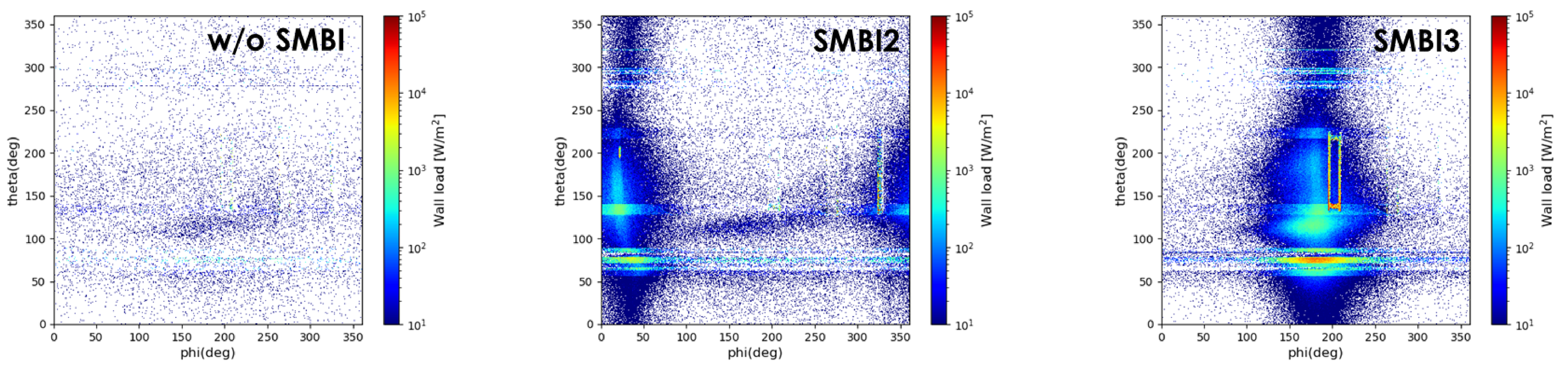
✓ Fast neutrals yield is peaked at the fueling location

➢ The outer leg of beam ion orbits intersects the SMBI2 location, causing additional neutralization there

➢ Toroidal location of SMBI3 is closer to the "banana tips", where most beam ions are neutralized.

- **Step2: Resample neutralized markers & continue the simulation (t<Tlim)**
  - ***a significant portion of fast neutrals is lost near the fueling location***

Wall loads of fast neutrals



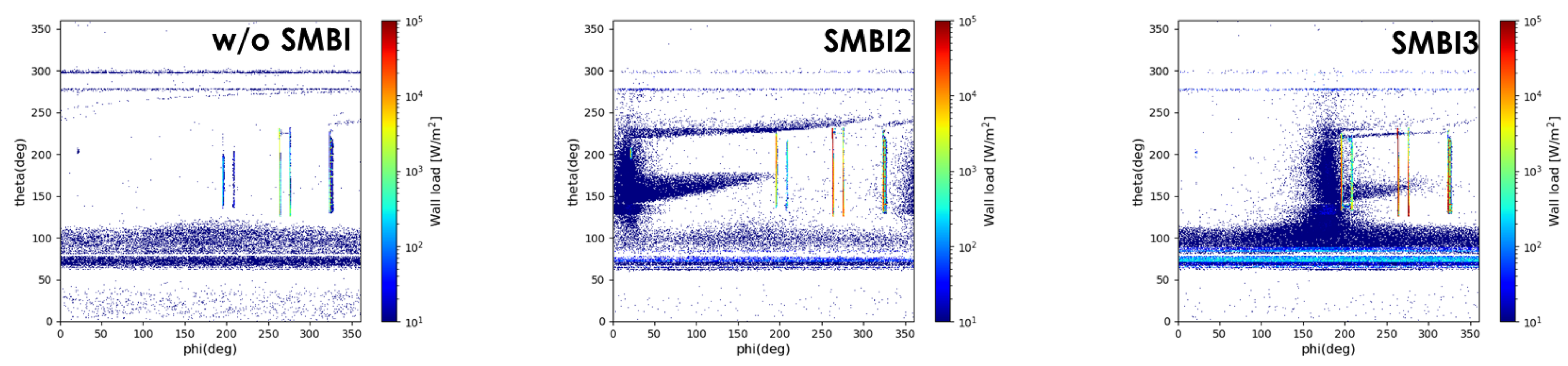
✓ Fast neutrals, unaffected by magnetic fields, are directly lost to the PFCs

✓ The peak location of fast neutral loss coincides with that of its production

✓ Compared to the w/o SMBI, SMBI increases the local peak wall load by two orders of magnitude(~10^2 W/m^2→~10^4 W/m^2)

- ***the loss distribution of re-ionized beam ions is linked to the electron density***

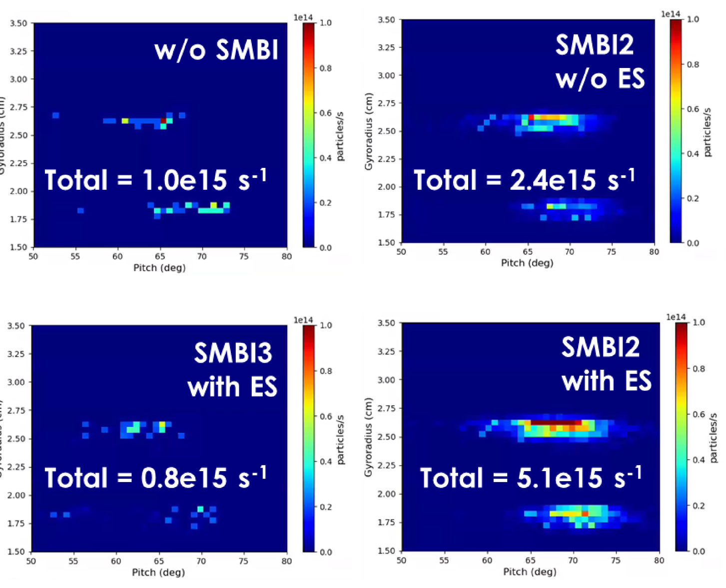
Wall loads of beam ions



✓ The wall load on the limiter from re-ionized beam ions is significantly lower than the damage to local PFCs caused by fast neutrals

Reionization by background neutrals is the dominant mechanism for enhanced beam-ion losses

velocity space distribution at FILD (ASCOT)



- Collection and weighting of FILD loss markers per step
- Beam ion reionization comprises BMS (involving plasma) and ES (involving neutrals)

$$D + D_2 \to D^+ + D_2 + e$$
$$D + D \to D^+ + D + e$$

Electron Stripping

- Experiment-Simulation Agreement with ES Reionization Included
  - ✓ SMBI2 causes a 500% increase in beam ion loss detected by FILD, while SMBI3 does not
  - ✓ The velocity-space distribution of the lost beam ions is broadened, particularly in the region with pitch ~70° & gyro ~2 cm

Summary & outlook

- Combining experiment with simulation provides the 3D distributions of electron and neutral density
  - 1D (Diagnostic) & 3D (EMC3-EIRENE) Plasma Parameters
  - The obtained 3D background parameters (charged & neutral particles) serve as input for ASCOT5 simulations
- Enhanced beam ion loss from increased local neutral density
  - Reionization by background neutrals is the dominant mechanism for enhanced beam-ion losses
- Simulation Study of the Synergistic Loss Effect between RMP & SMBI
- Further investigation into methods for reducing CX loss (e.g., RMP, different beam sources, fueling rate & techniques...)

Acknowledgements

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