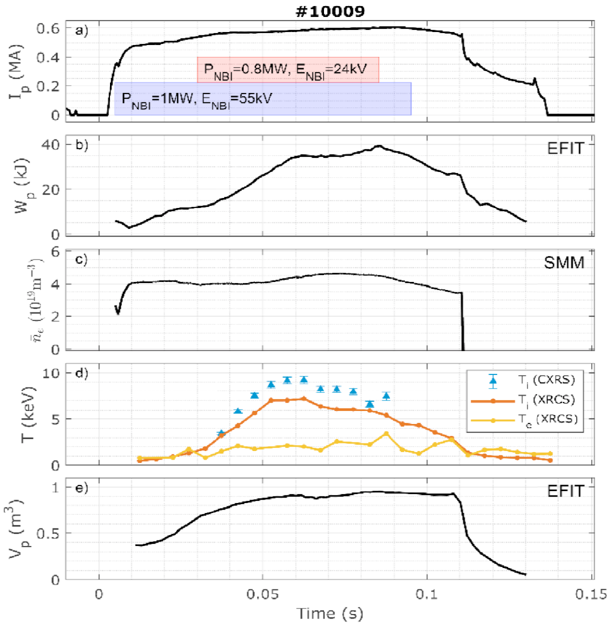
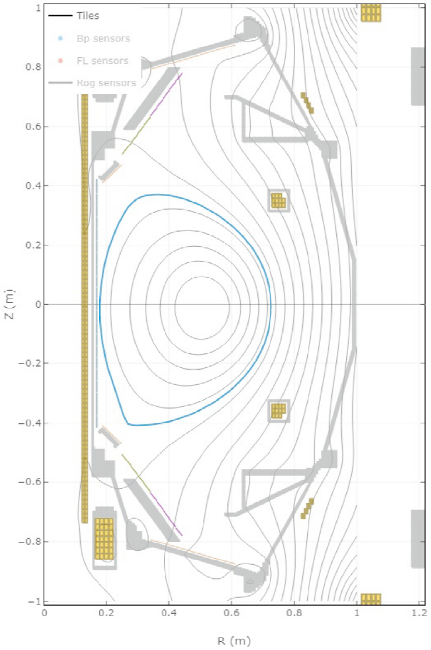
Transport Analysis of High Performance ST40 plasmas

S. Kaye, Jan. 18, 2023

ST40 Business Milestone: Achieve 100M C plasmas

- Do this in hot ion mode plasma ($T_i >> T_e$)
- Develop scenarios starting in H-H, then D-H, then D-D





R(23-1): Transport characteristics of high performance, high temperature ST40 discharges

- High T_i discharge parameters (“hot ion mode” with $T_i >> T_e$)

Shot	9520	9539	9780	10009
Time of interest (s)	0.09	0.07	0.085	0.06
Type	$H^0 \rightarrow H^+$	$H^0 \rightarrow H^+$	$D^0 \rightarrow H^+$	$D^0 \rightarrow D^+$
a (m)	0.25	0.26	0.26	0.28
R (m)	0.42	0.44	0.47	0.49
I_p (kA)	507	537	544	580
B_T (T)	1.72	1.95	1.98	1.89
κ	1.46	1.44	1.36	1.42
n_e (m^{-3})	4.4×10^{19}	3.5×10^{19}	5.0×10^{19}	4.4×10^{19}
P_{inj} (MW)	1.51	1.48	1.80	1.60

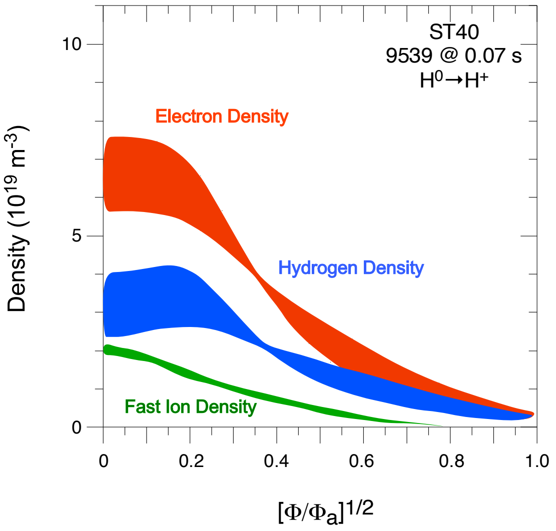
TRANSP used to determine hydrogenic temperature and transport coefficients; study isotope scaling of confinement/transport

- Measured T_i and inferred profiles based on impurity measurements
  - TRANSP determines hydrogenic temperature from power balance
- Use different sets of consistent profiles inferred from Integrated Data Analysis workflow to determine hydrogenic temperatures, power flows, transport coefficients, confinement times
- Use EFIT outer boundary and internal equilibria
  - Compared to TRANSP calculation of internal equilibrium – little impact on calculated hydrogenic temperatures
- Assume Z_{eff} = 2.1 – 2.3 (flat profile), consistent with preliminary measurements
  - Also tested by inputting inferred carbon and argon profiles – little impact on results
- Use inferred rotation profile for all cases
  - 10s% variations in rotation has little impact on results

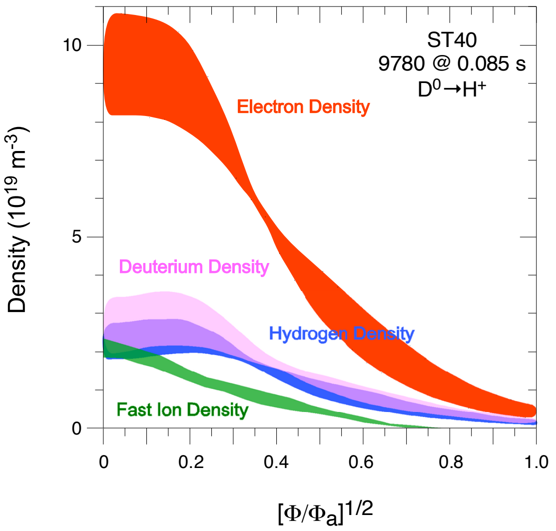
Density profiles

- Use range of density, temperature profiles that are consistent with experimental constraints in IDA workflow
  - Reflects uncertainties in results

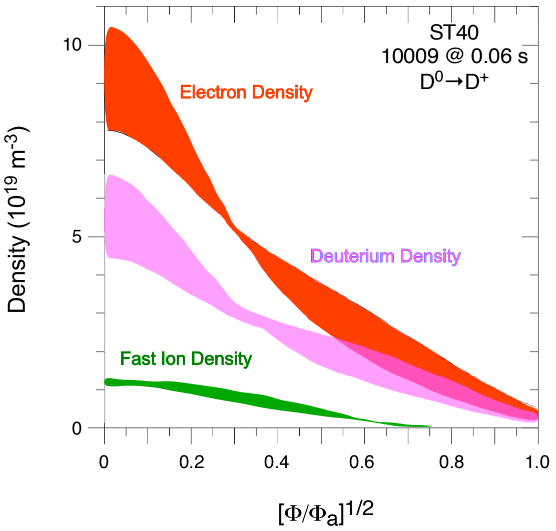
$H^0 \rightarrow H^+$



$D^0 \rightarrow H^+$



$D^0 \rightarrow D^+$

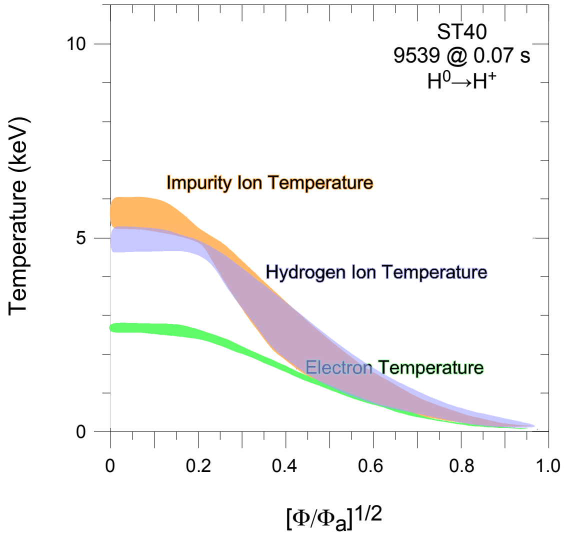


Hydrogenic temperatures slightly lower than impurity temperatures

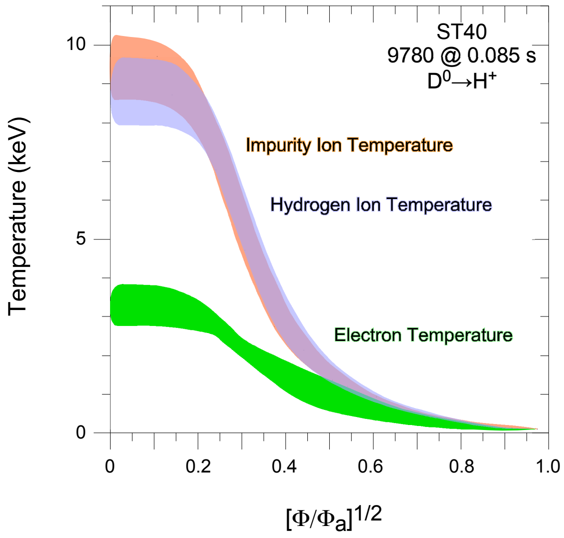
- 100M C (~8.4 keV) exceeded in D^0-D^+ discharge
- Similar results for other high T_i D^0-D^+ discharges (T_i ~0.5 keV lower in 10014)

Increase of T_i seen with increasing isotopic mass

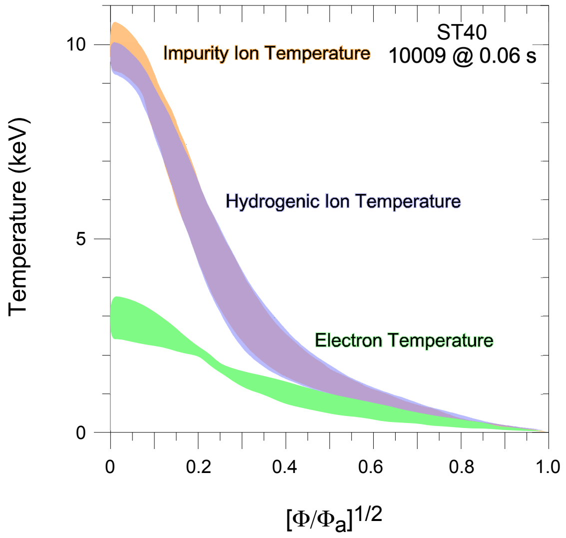
$H^0 \rightarrow H^+$



$D^0 \rightarrow H^+$

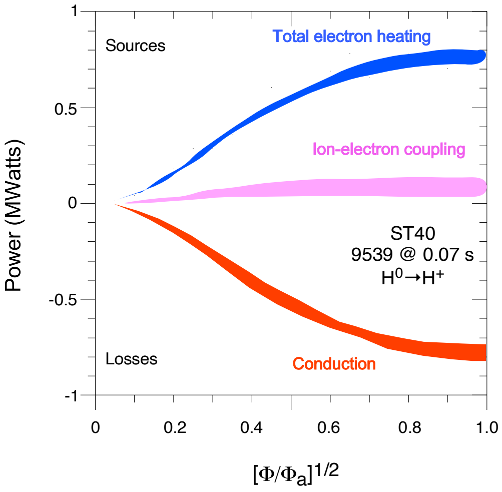


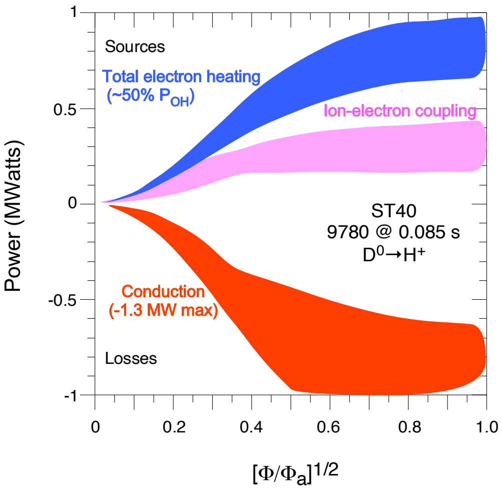
$D^0 \rightarrow D^+$

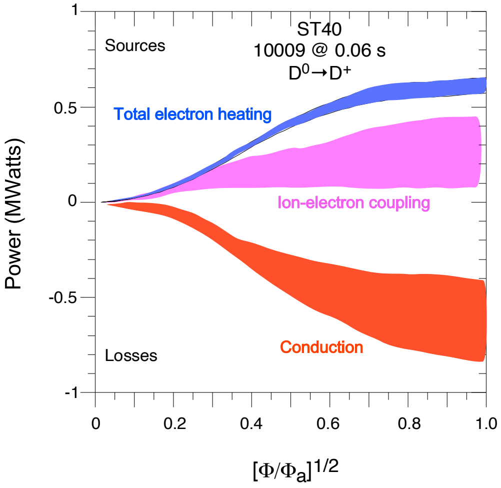


Volume-integrated electron power balance

- Thermal conduction dominant loss channel
- Ion-electron coupling (source) increases with difference in $T_i - T_e$

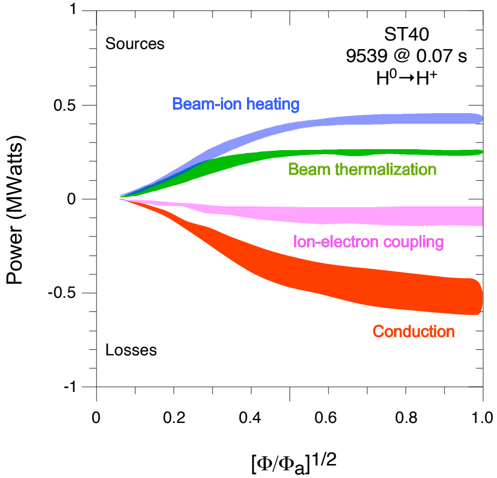


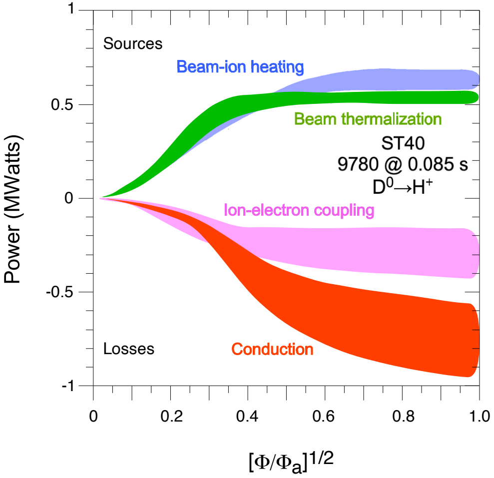


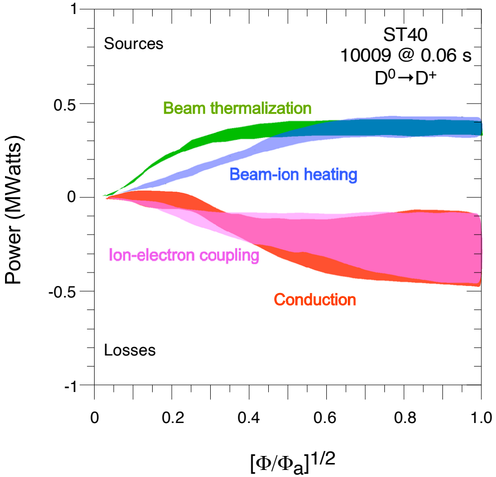


Volume-integrated ion power balance

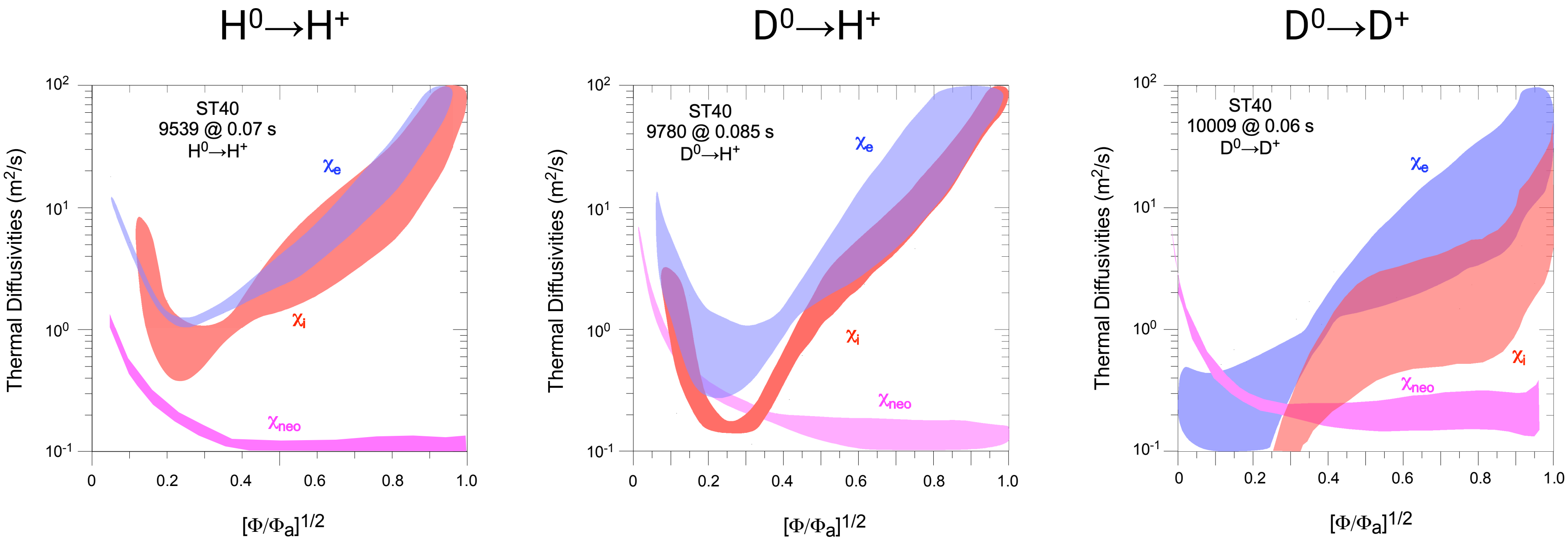
- Thermal conduction dominant loss channel
- Ion-electron coupling (loss) rivals conduction loss only in D-D plasma
- Process limiting T_i mostly through conduction loss (coupling helps)







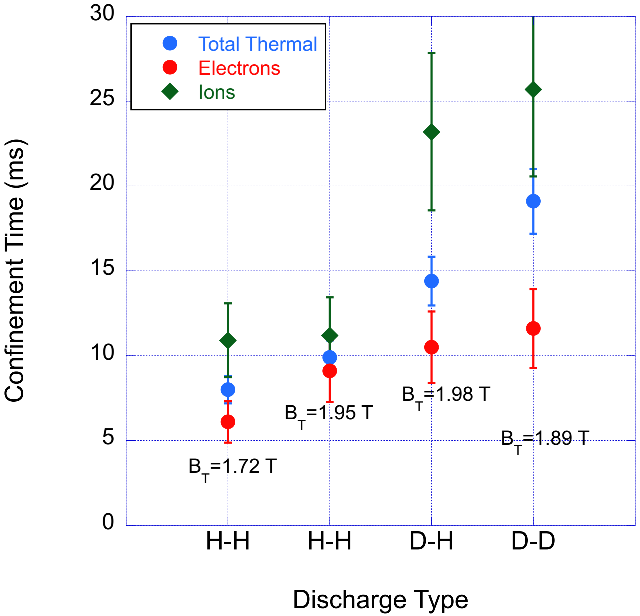
Clear reduction in ion thermal diffusivity with increasing isotopic mass



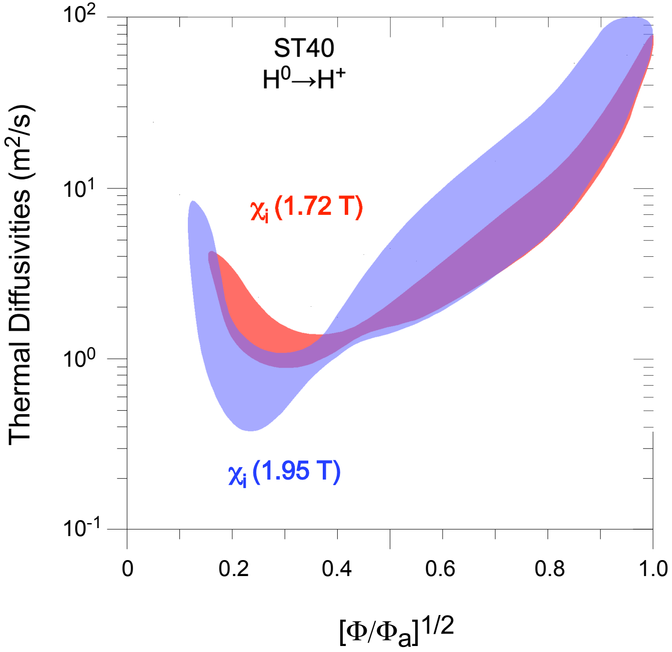
- $\chi_e \geq \chi_i$, $\chi_i \gg \chi_{neoclassical}$
- Decrease in χ_i going from H-H to D-H to D-D; slower reduction going from D-H to D-D
  - D-H contains significant thermal deuterium ion density; more similar to D-D discharge
- Reduced central transport appears to account for higher T_i for higher isotopic mass
  - Reduced transport overcompensates for increased ion-electron coupling loss

Confinement increase/transport reduction may account for higher T_i with increasing isotopic mass, and with higher B_T (for H-H discharges)

- Increase in confinement time in all channels with isotopic mass, B_T



- Reduced core ion thermal transport at higher B_T



Submitted as NF Letter

Plans for next ST40 run campaign

- Experimental proposal on I_p, B_T, collisionality, isotope scans in hot-ion and H-mode plasmas (several run days) submitted and accepted
    - Getting good signal from TS, so hope is to have ”full” kinetic profiles
    - Hot-ion portion slated to run this run campaign, if high performance plasmas recovered
        - ST40 presently assessing fix for leak at two locations of outer TF leg support pins (mid-April start?)
    - H-mode portion during Campaign 2
- Exploring options for augmenting CRADA with research in this and additional areas
    - Important for coverage during Recovery period
    - Additional funding can support this work
    - We welcome ideas from staff on how they can contribute to ST40 effort