NSTX Results and Theory Review meeting
December 1, 2010 – PPPL

Comparison Study of Divertor Heat Fluxes in Alcator C-Mod, DIII-D, and NSTX tokamaks

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Neoclassical Scaling of Divertor Heat Load

- **Heat load width scaling on the tokamak divertor plates is studied**
  - In realistic diverted edge geometry
  - With realistic heating power at core-edge boundary
  - In pure neoclassical plasma and with the addition of anomalous transport modeling
  - Effect of neutral collisions has been investigated
- **Four DIII-D, one Alcator C-Mod and one NSTX discharges have been considered**
- **In order to mimic the Ip scan, B_p has been scaled by factors from 0.33 to 2 for each discharge in XGC0 code, while B_T has been left kept fixed**

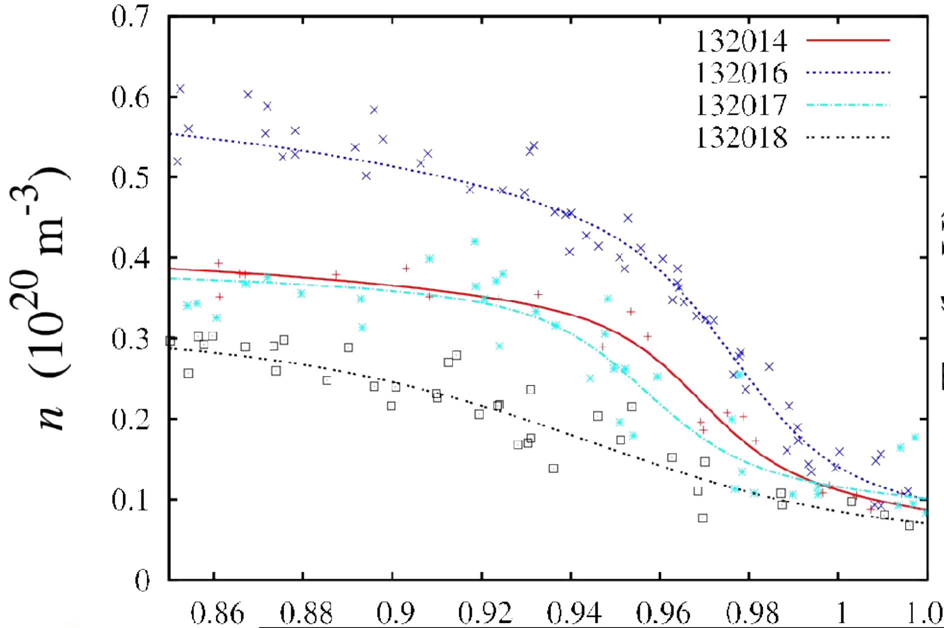
XGC0 Kinetic Edge Code

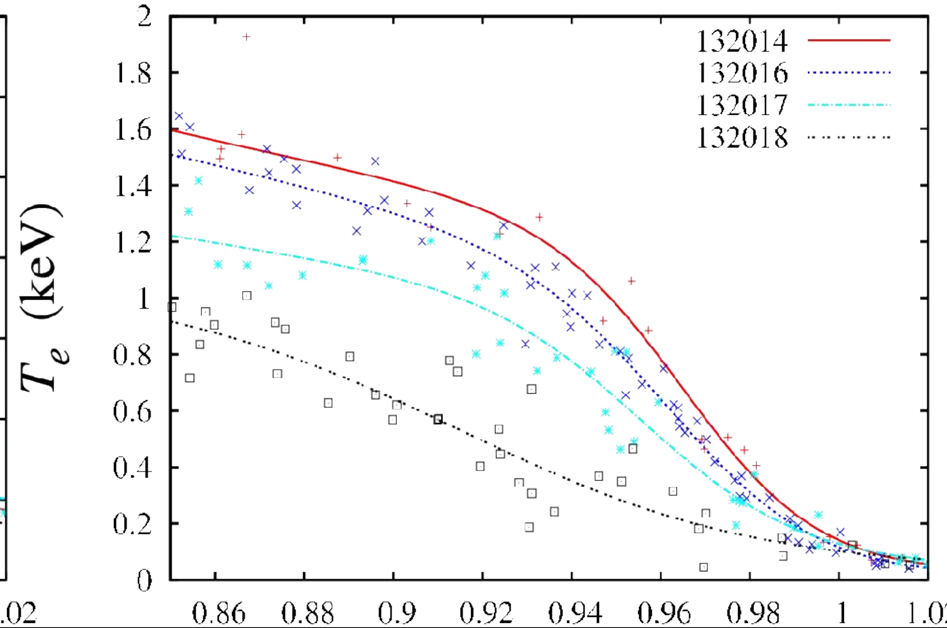
- XGC0 code is developed for long time simulation of kinetic equilibrium and transport
  - 5D Lagrangian guiding center dynamics
  - Axisymmetric solution for radial electric field *Er*
  - Ion/electron/neutral, full-f
  - Zeff in the version version used for this study
  - Momentum-energy-particle conserving Monte-Carlo collisions
  - $\Phi(\psi)$ electric potential solver
  - XGC0 is being integrated with all the other physics components
  - XGC0 evaluates kinetic bootstrap current, and reconstruct the Grad-Shafranov equilibrium
- EFFIS (End-to-end Framework for Fusion Integrated Simulation) framework for automatic coupling of XGC0-ELITE-M3D(NIMROD) is established for pedestal-ELM cycle, and of XGC0-GEM for edge E&M turbulence scoping.
- Integration of DEGAS2 into XGC0 is producing higher fidelity kinetic, edge plasma-neutral code

Experimental Current Scan on DIII-D

- Four reference DIII-D discharges with four different plasma currents (0.51-1.5MA)
- [Snyder *et al.*, PoP 16 (2008) 056118; Groebner *et al.*, NF 49 (2009) 085037]
  - The discharges have about the same
    - toroidal magnetic field (2.1 T)
    - plasma shape (average triangularity 0.55)
    - normalized toroidal beta (β_n ~ 2.1-2.4)

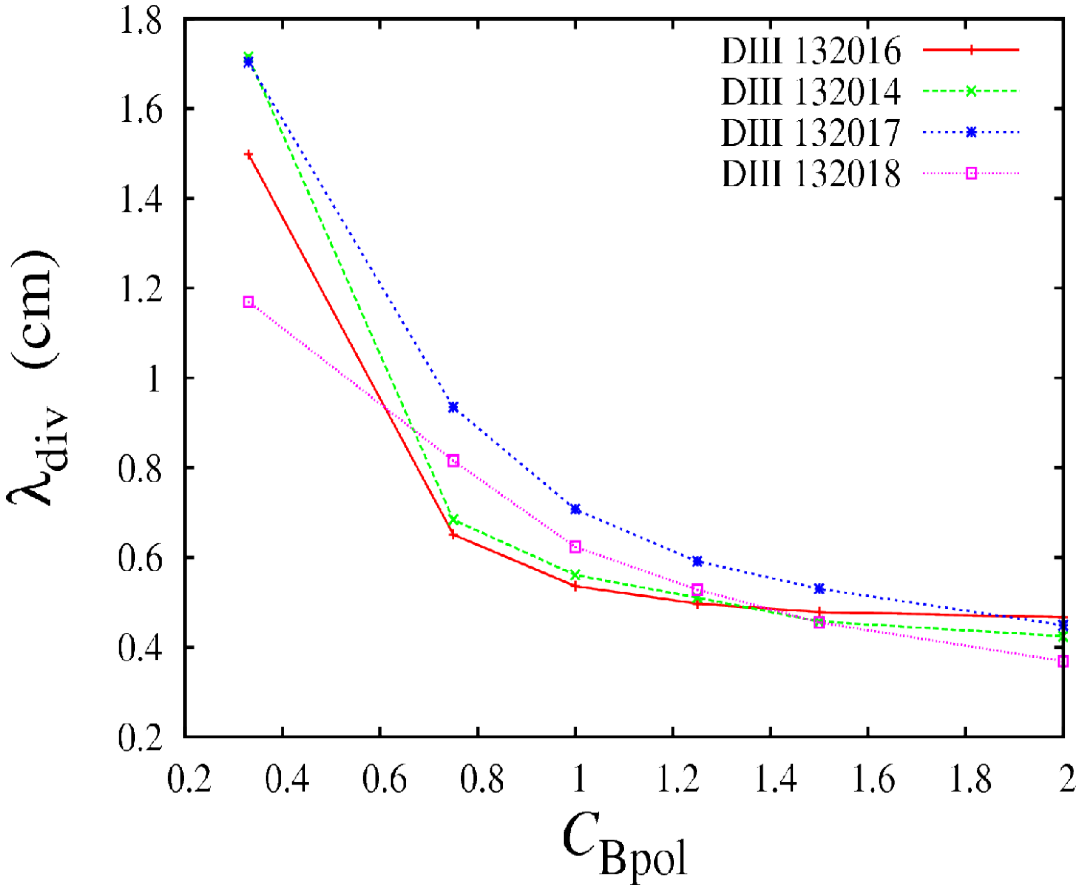
Discharge	132016	132014	132017	132018
Time, msec	3023	3023	2998	1948
I_p, MA	1.50	1.17	0.85	0.51

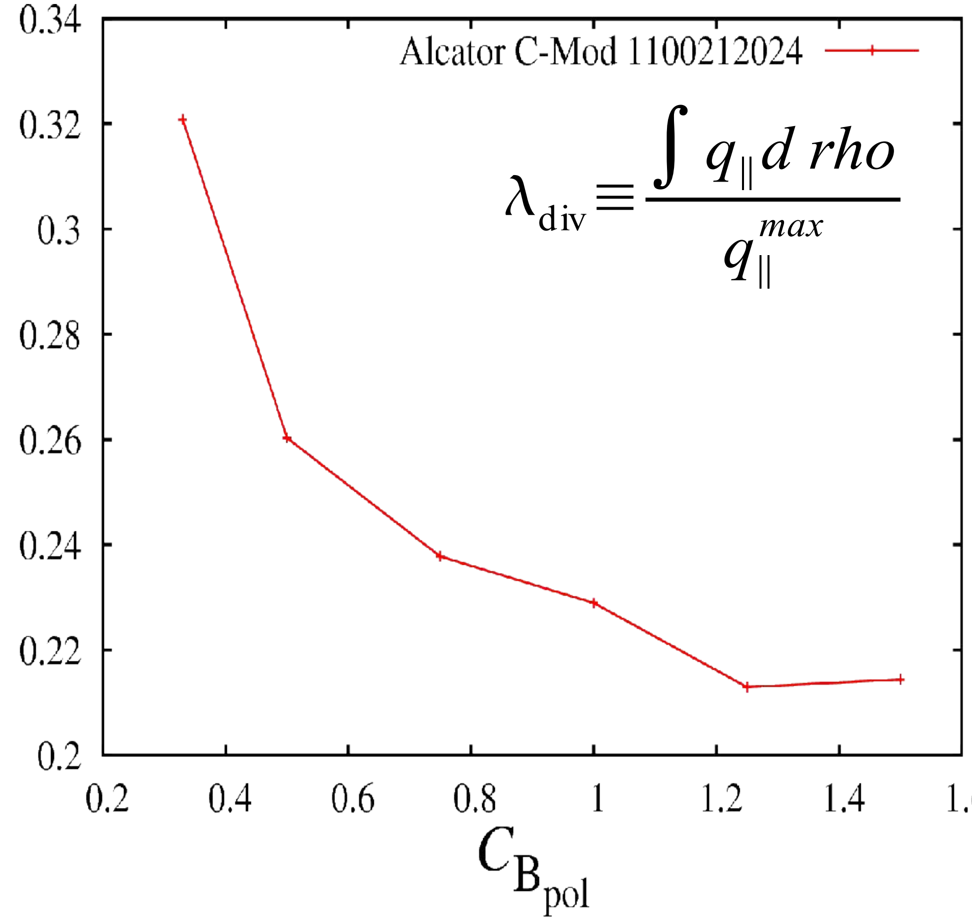




XGC0 evaluated Neoclassical Heat Load Width is Broader at Smaller Plasma Currents

Four DIII-D discharges and one Alcator C-Mod discharge 1100212024 that was a part of Alcator C-Mod/DIII-D similarity campaign analyzed → $\lambda_{div} \propto I_P^{-0.8}$ for DIII-D

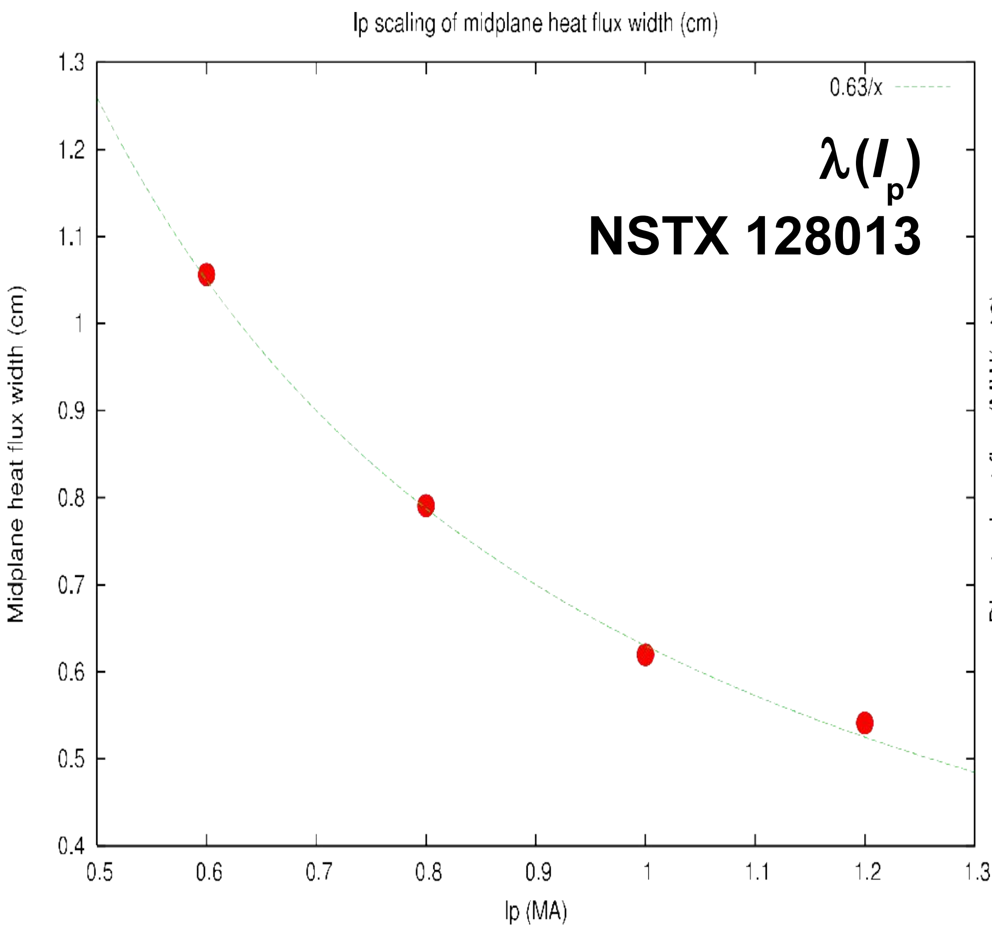


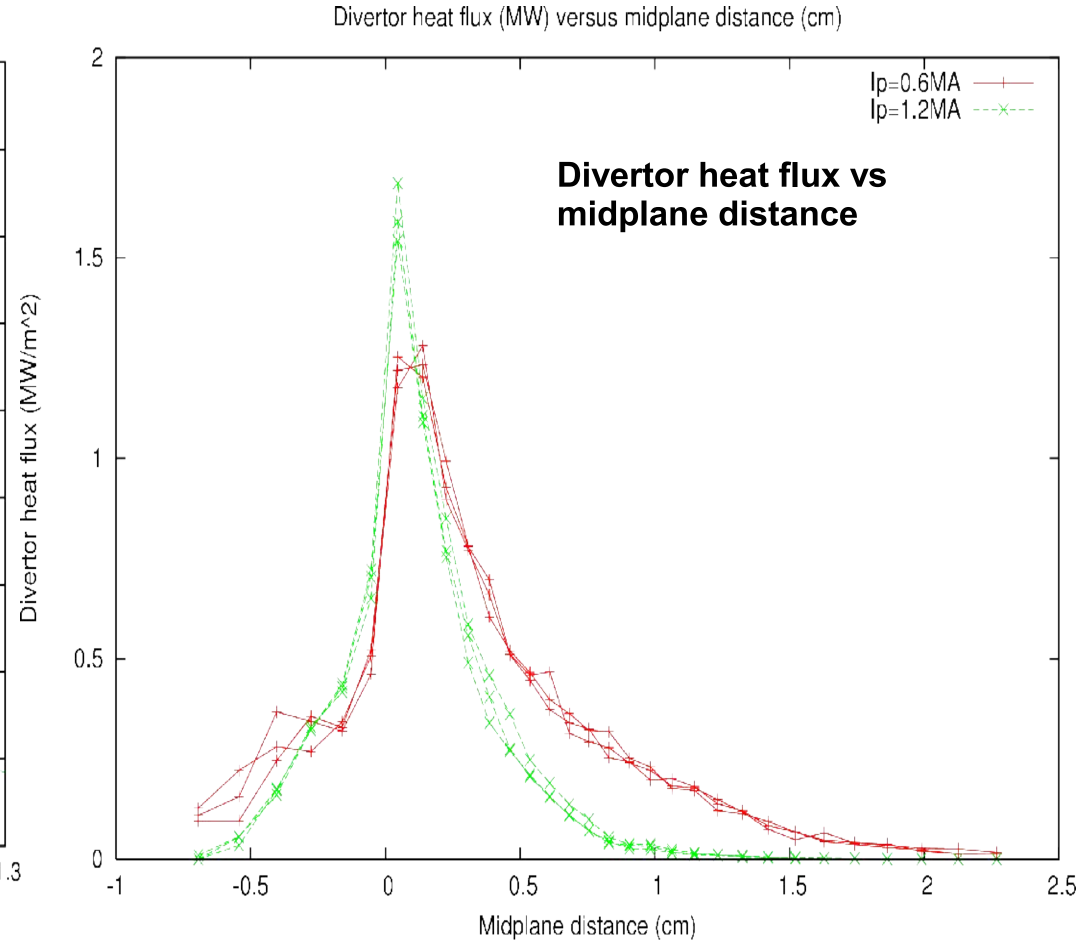


C_{Bpol} is a scaling factor in XGC0 for poloidal flux, hence plasma current

XGC0: Neoclassical Heat Load Width is Broader at Smaller Plasma Currents

Heat load width in the divertor area decreases with the plasma current $\lambda_{div} \propto I_P^{-\alpha}$, with $\alpha \approx 0.8$ for DIII-D discharges, $\alpha \approx 0.3$ for Alcator C-Mod discharges, and $\alpha \approx 1.0$ for NSTX discharges

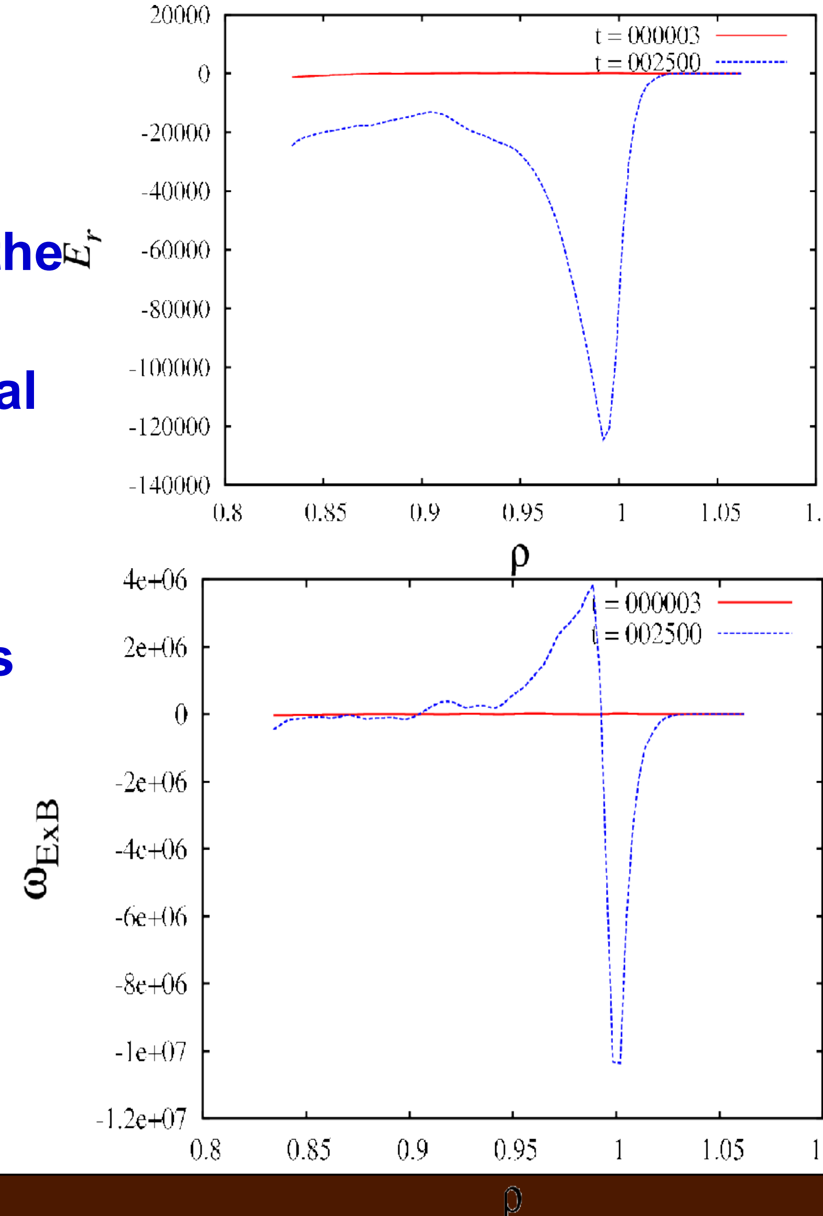




Anomalous Transport Effects in Kinetic XGC0 Code

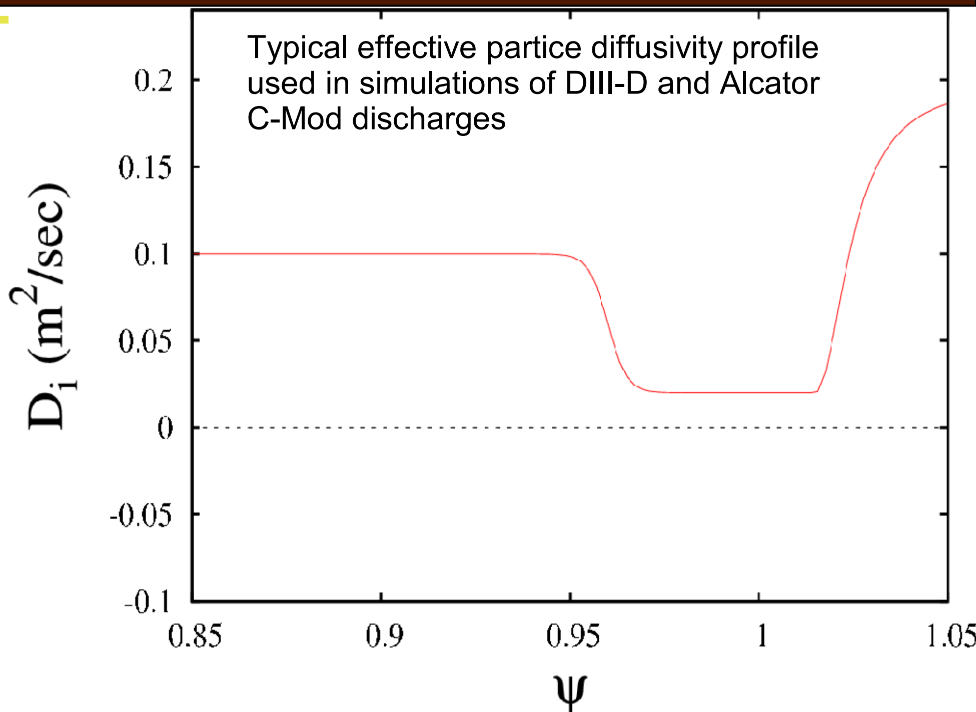
- **There are two ways to investigate the role of anomalous transport in XGC-0**
- **Using reduced models (MMM95 and GLF23)**
- **Using effective diffusivities obtained in analysis mode**
- **The effect of ExB flow shear is important in the pedestal region**
- **The flow shear rates are estimated from radial electric field computed using XGC-0**
- **Strongly sheared radial electric field in the separatrix region is typical result of kinetic XGC-0 modeling of H-mode DIII-D discharges**
  - **Flow shear rates are found in the range from at the top of the pedestal to up to near the separatrix**
- **ExB flow shear strongly reduces the anomalous transport at the top of H-mode pedestal and almost completely eliminates anomalous transport at the pedestal bottom**

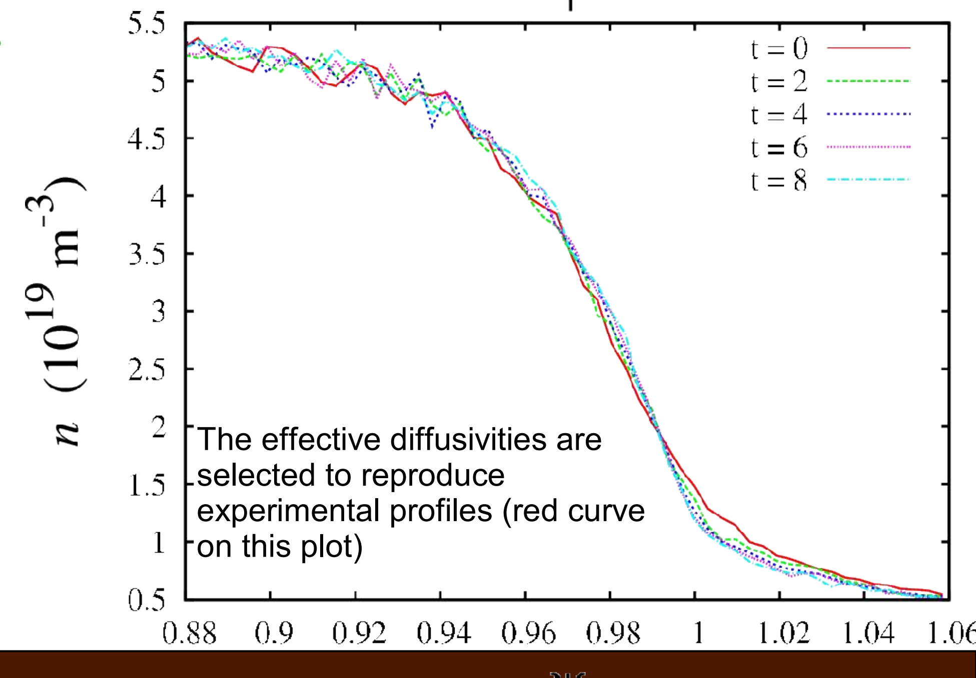
Radial electric field and flow shear profiles for DIII-D discharge 132014



Anomalous transport found from XGC0 analysis

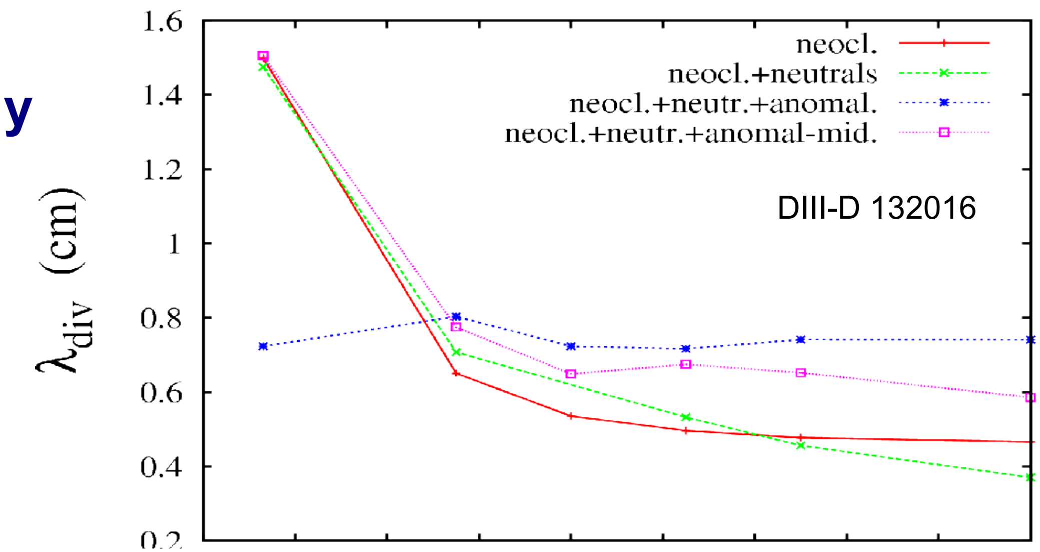
- **While the reduced-theory-based models for anomalous transport in XGC0 are available, in these heat load studies the XGC0 simulations use anomalous effective diffusivities that are intended to reproduce experimental profiles**
  - **Alcator C-Mod, DIII-D and NSTX discharges were analyzed**
  - **It has been found that strong pinches in all channels of anomalous transport were necessary to reproduce experimental profiles**
- **To begin with, anomalous diffusivity profiles are kept fixed and assume to be poloidally uniform for each discharge in all the I_p scans**

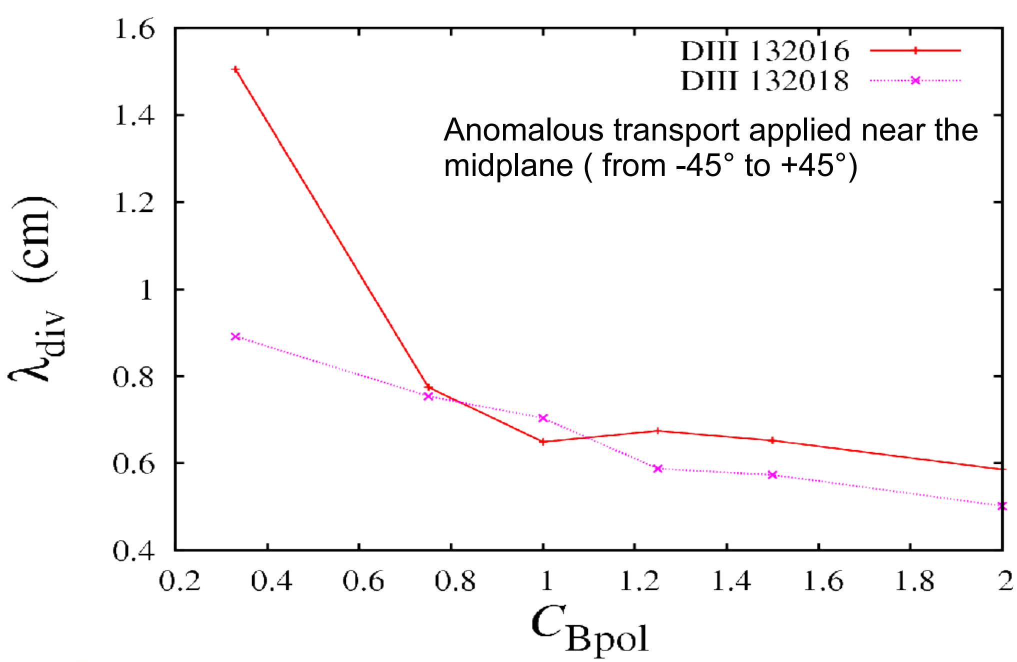


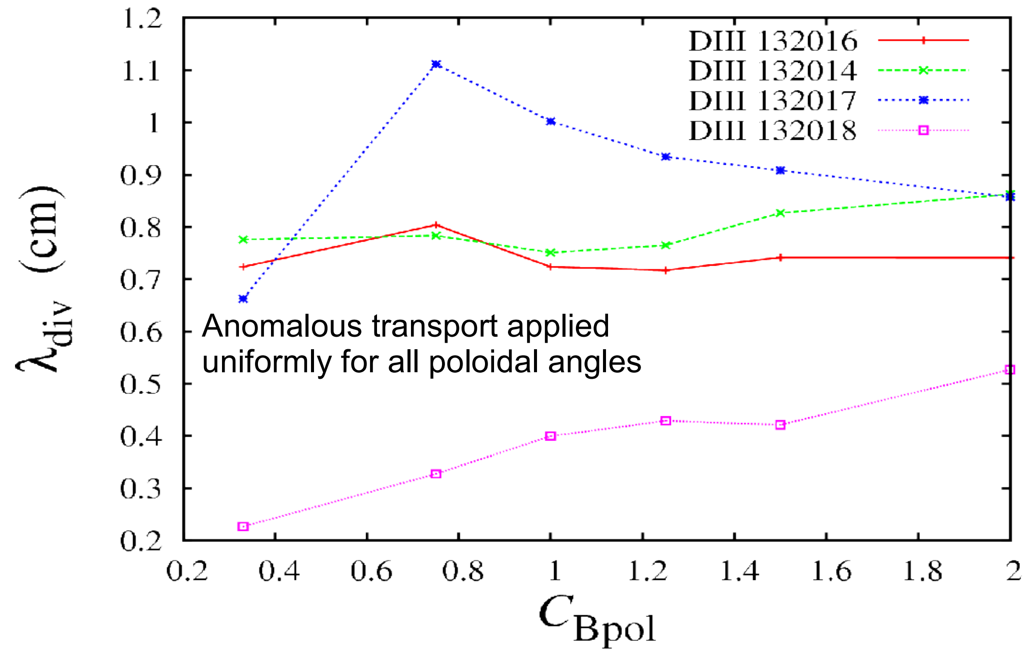


Effects of Neutral Collisions and Poloidally Uniform Anomalous Transport on divertor heat-load width in XGC0

- **Effect of neutral collisions on heat fluxes in the divertor area is relatively weak especially at lower plasma currents where neoclassical effects are strong**
- **Poloidally uniform and plasma current independent anomalous transport can completely mask the neoclassical scaling.**



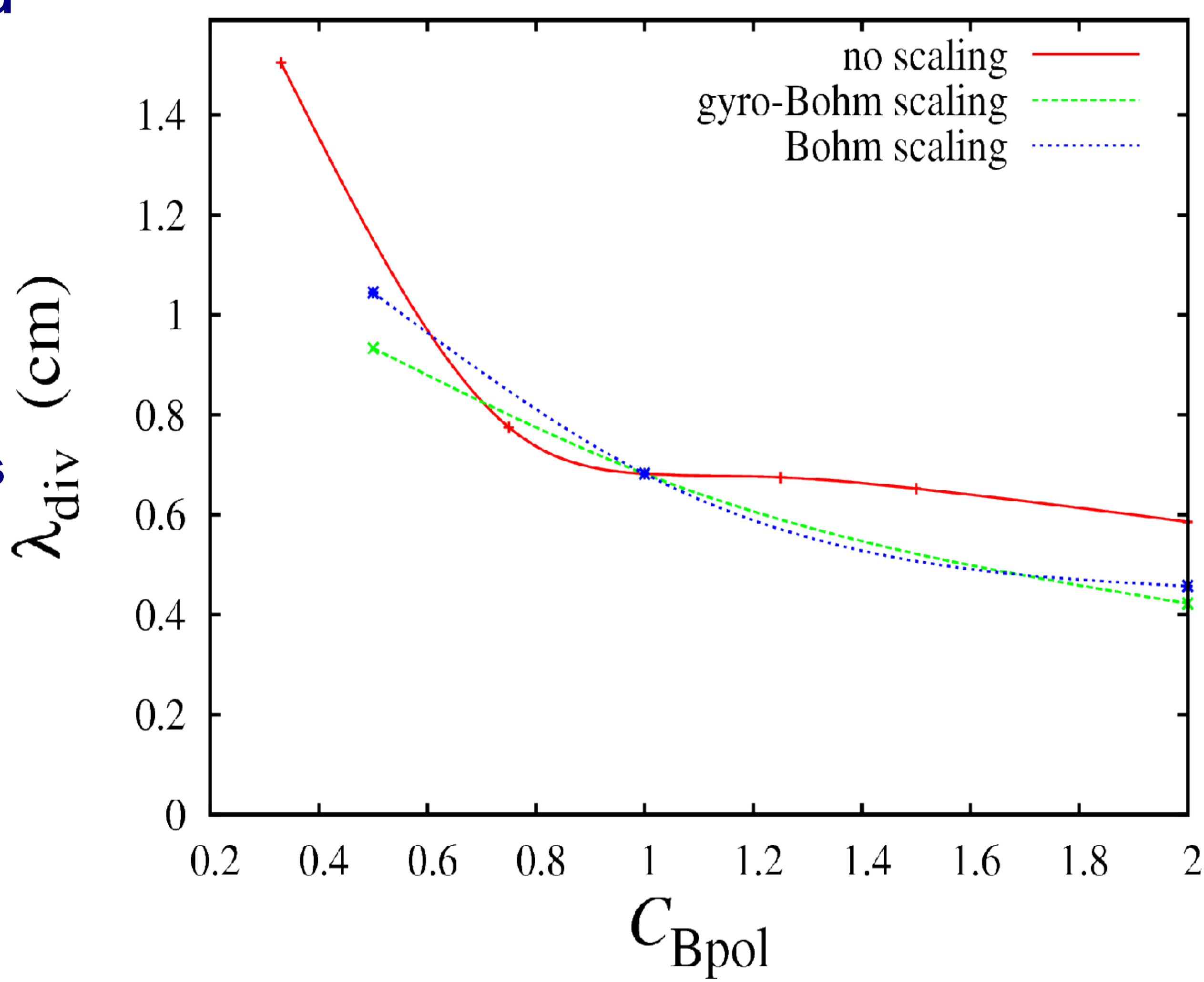




B-dependent anomalous transport also recovers $I_P^{-\alpha}$

- **The gyro-Bohm ($\chi \sim 1/B^2$) and Bohm scalings ($\chi \sim 1/B$) for anomalous have been implemented in XGC0**
- **Both gyro-Bohm and Bohm scalings result in narrower widths at larger plasma currents and broader widths for smaller plasma currents**
- **This effect is stronger for anomalous transport with gyro-Bohm scaling**

DIII-D 132016



Summary

Progress in understanding divertor heat load width is presented using XGC0 particle code

- Neoclassical divertor heat load width is found to be broader for smaller plasma currents $\propto I_P^{-0.8}$ in DIII-D
- Alcator C-Mod discharge has weaker scaling of the divertor heat load width with plasma current compared to four DIII-D discharges analyzed in this study
- Neutral collisions have rather weak effect on the neoclassical divertor heat load width.
- A poloidally uniform, Ip-independent anomalous transport can destroy the neoclassical Ip scaling behavior.
- However, Ip-independent anomalous transport that has ballooning nature can recover the neoclassical behavior $\propto I_P^{-0.6}$
- Gyro-Bohm ($\chi \propto 1/B^2$) and Bohm scalings ($\chi \propto 1/B$) for anomalous transport yields neoclassical type scaling with plasma current $\propto I_P^{-\alpha}$ with α ranging from 0.54 for gyro-Bohm scaling to 0.6 for Bohm scaling