Pedestal Modeling with XGC0 and XGC1*

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Outline

1. Introduction to XGC0, XGC1 and EFFIS
   – Kinetic particle codes in magnetic **separatrix** geometry
2. Radial E_r, rotation and pedestal structure (XGC0)
   – Baseline neoclassical during pedestal growth and at linear ELM stability boundary
   – What is the kinetically analyzed anomalous transport in H-mode pedestal and how does it affect E_r profile?
3. Anisotropic ion distribution function (XGC0/1)
4. Effect of neutral fueling on pedestal structure under self-consistent E_r and kinetic physics (XGC0)
5. Neoclassical-consistent turbulence effect on pedestal, E_r and rotation (XGC1)

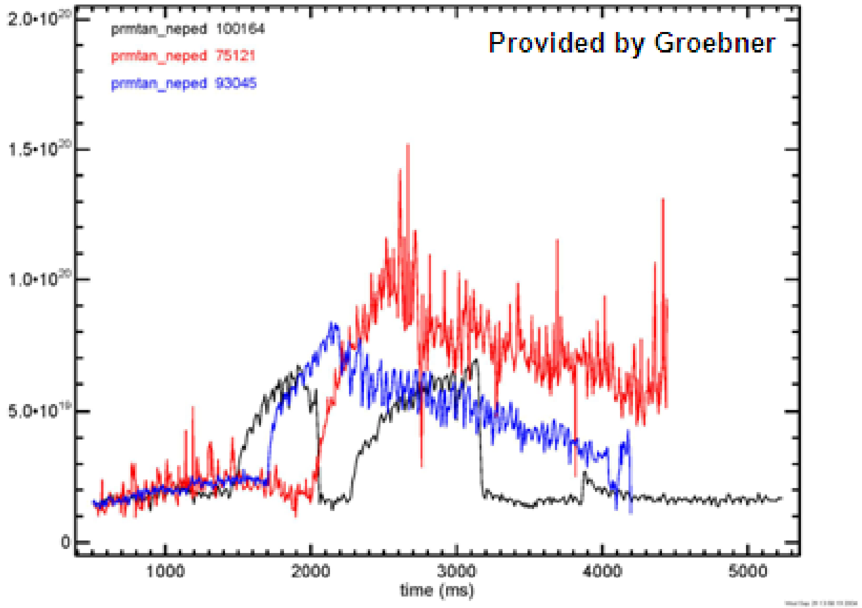
1. Introduction to XGC0, XGC1 and EFFIS

- **XGC1** is a full-f gyrokinetic particle code in realistic edge geometry (separatrix and wall) with heat flux. Multiscale: turbulence and neoclassical.
- **XGC0** is a simplified version of XGC1 for axisymmetric background physics, with additional multiscale capabilities such as
  - Kinetic ions, electrons and neutrals
  - DEGAS2 or simplified neutral Monte-Carlo transport
  - 1D $\Phi(\psi)$ and logical 2D sheath, presently
  - Wall-recycling and gas puff
  - Impurity and radiation
  - Anomalous transport modeling, or turbulence code coupling in **EFFIS**
  - 3D magnetic perturbation and fluid-coupled RMP penetration
  - ELM linear stability and nonlinear ELM crash, coupled in **EFFIS**
- **EFFIS** is a high performance framework for integrated simulation
  - Automated provenance storage/search
  - Dashboard analyses of simulation data (real time or stored)
  - MDS+ interface for experimental collaboration
  - Keep independence of each codes/compilers, using ADIOS I/O

2. Radial E_r, rotation and pedestal structure (XGC0)

- What does the purely neoclassical physics say?
- What anomalous transport is needed to bring the kinetic neoclassical pedestal closer to experimental pedestal?

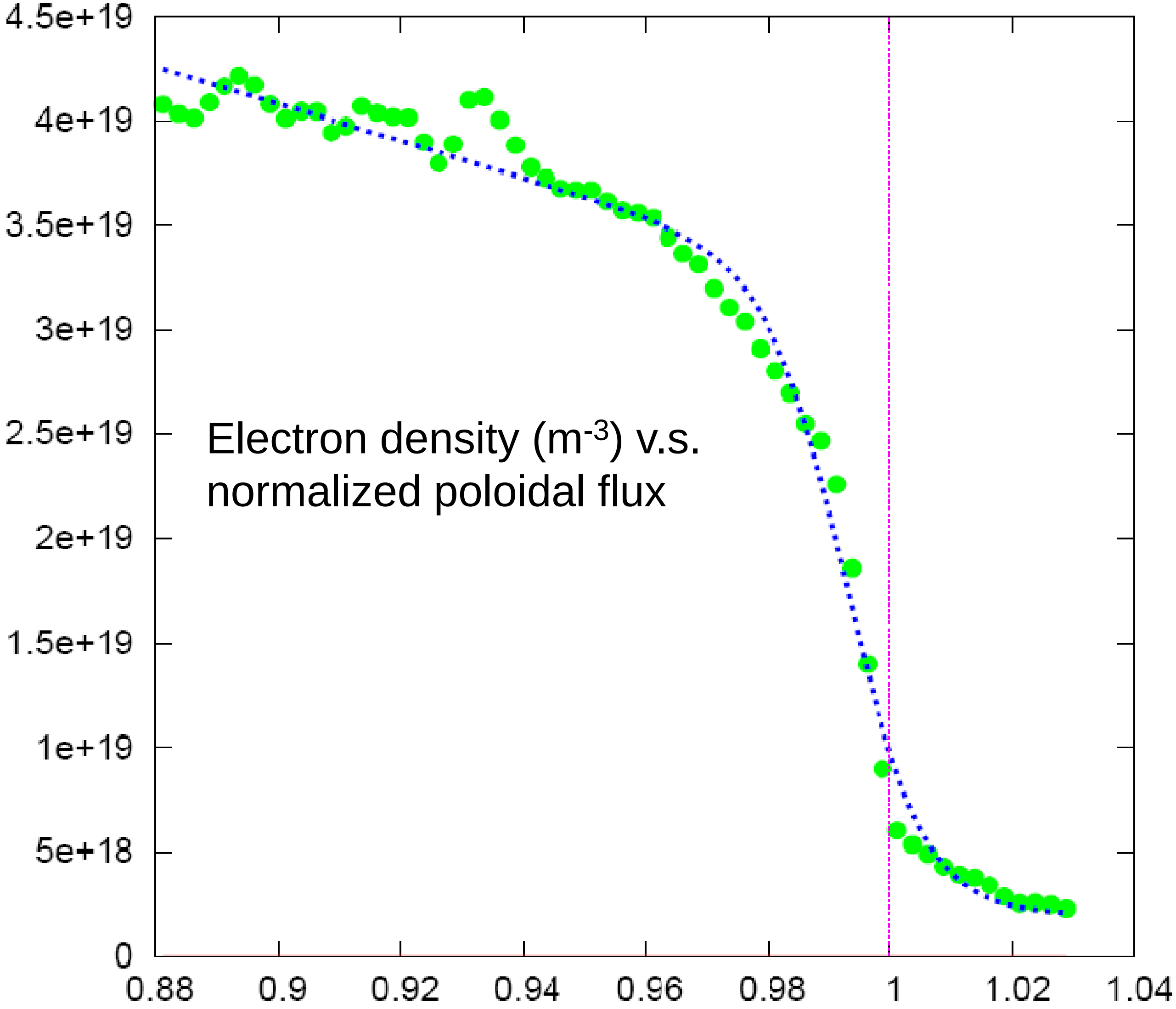
DIII-D experimental data on N_e(ped) vs time



Data needed from experimentalists

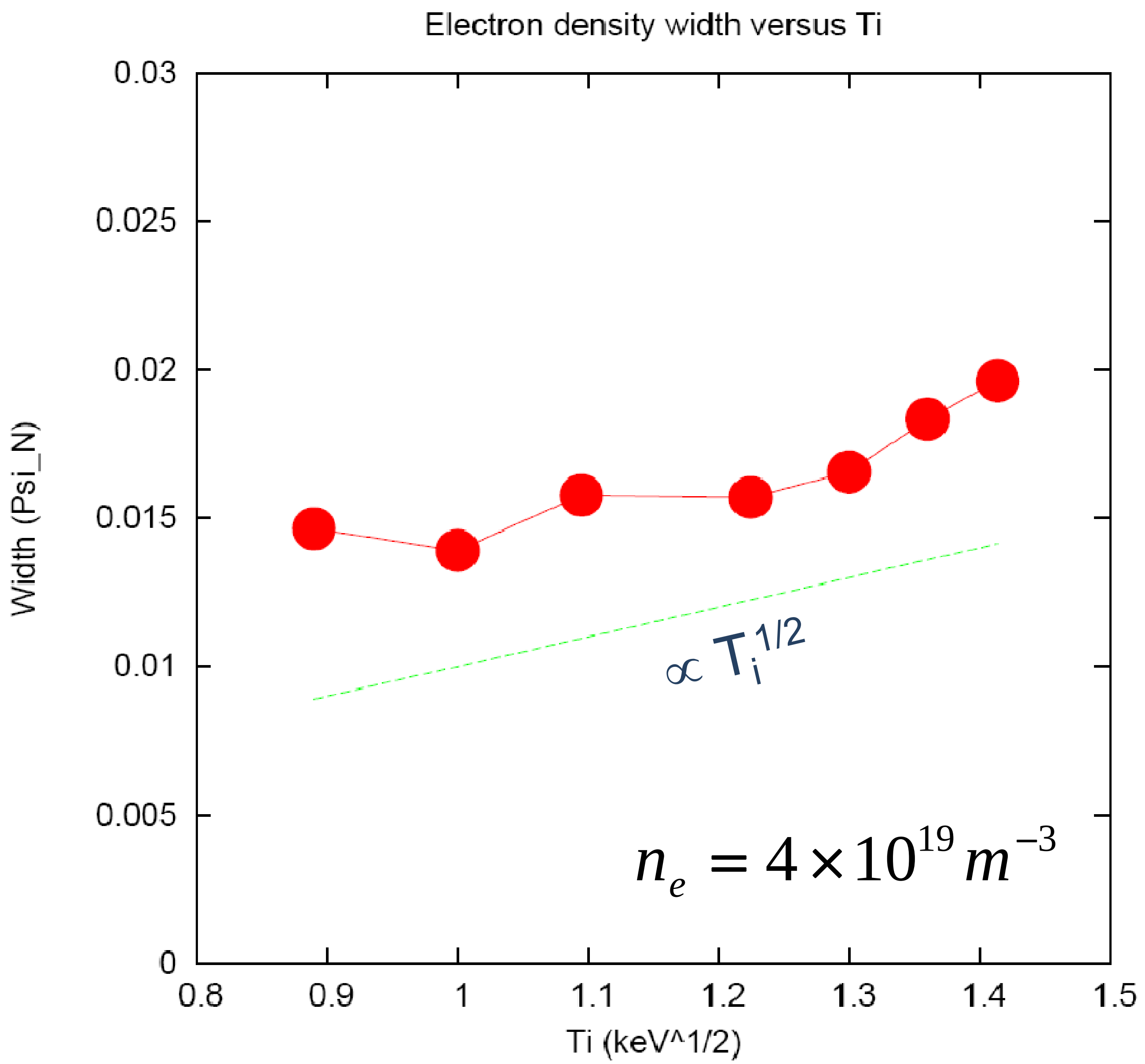
- Statistically meaningful length of ELM-free growth phase, eventually limited by ELMs
- Measured radial profiles, with Tanh width, Er, and rotation at various Ip, density, T, geometry, power, and B.

Radial pedestal profile from XGC is good for "modified tanh" fitting. T_i width is wider.

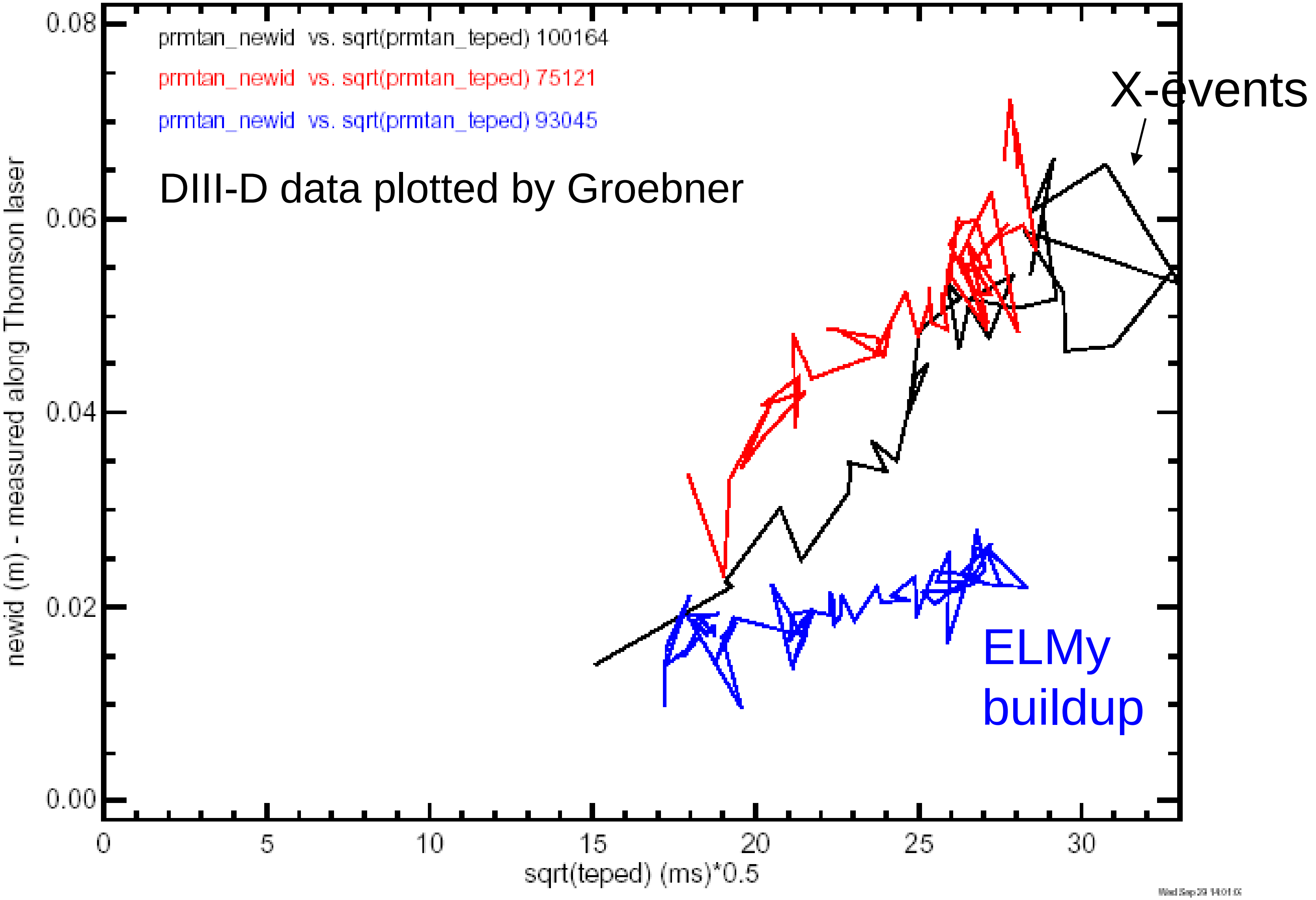


Data-fitting software provided by R. Groebner.

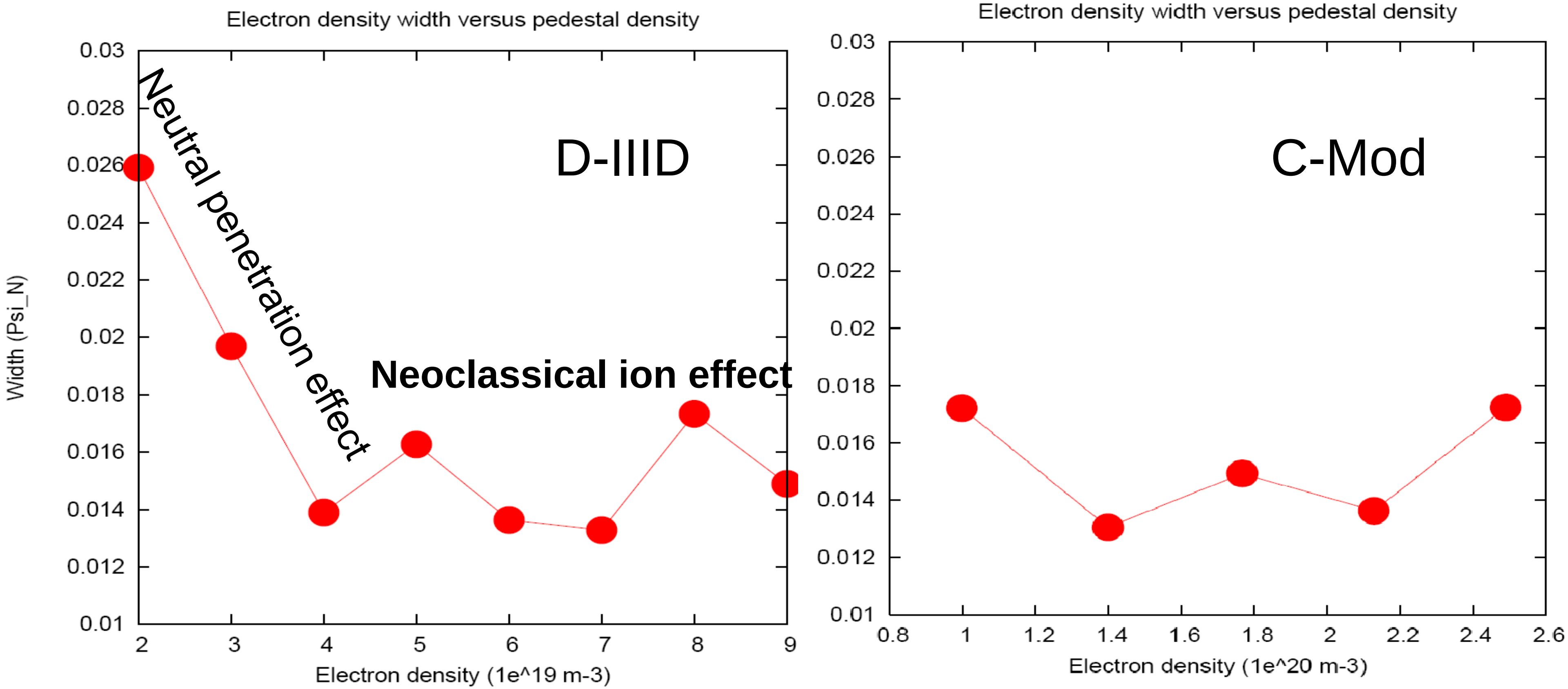
Neoclassical density pedestal width versus T_i(ped) in DIII-D



Experiments:
Δ_n increases with Sqrt($T_{e,ped}$) during buildup

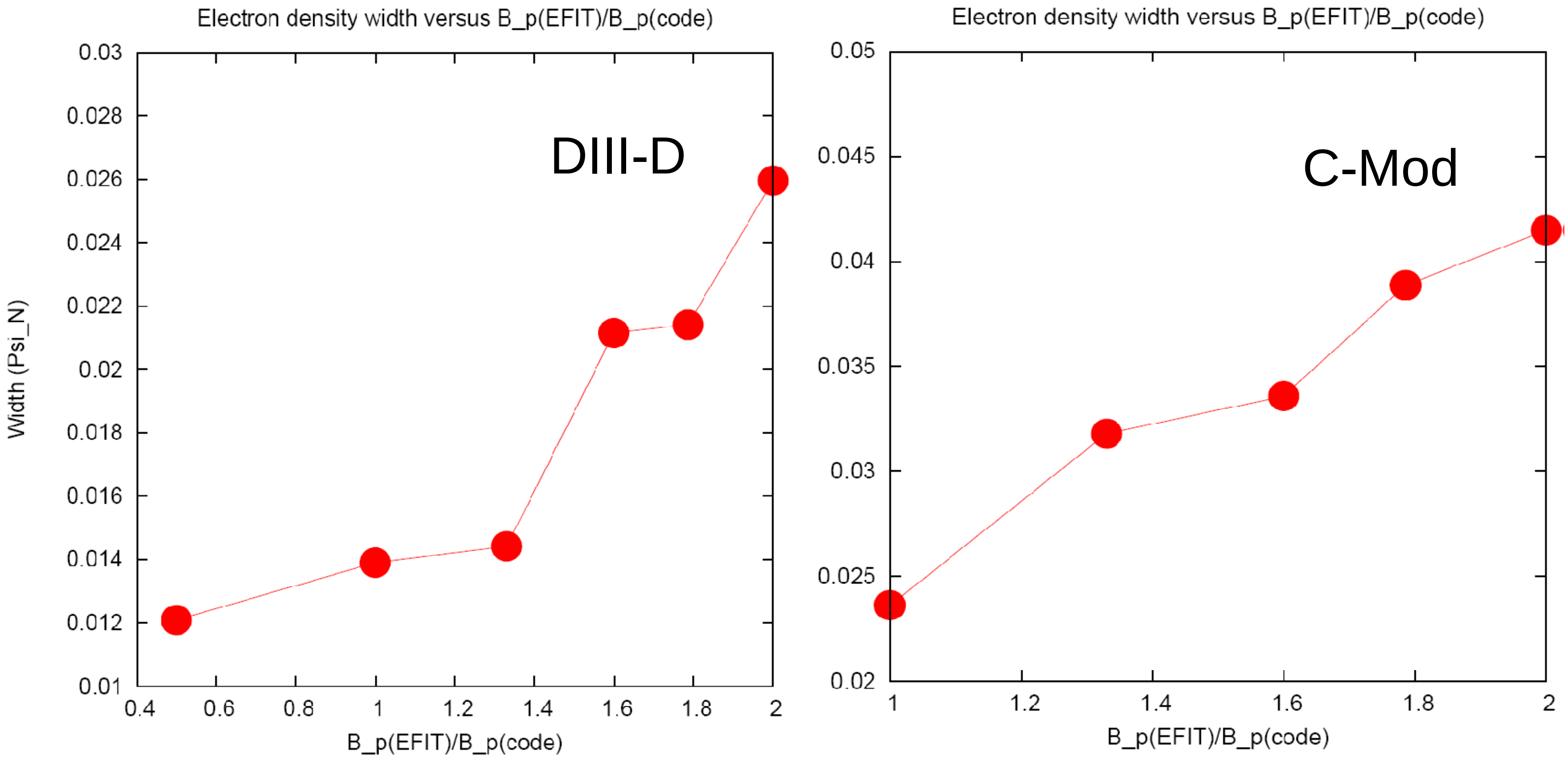


Comparison of neoclassical pedestal width versus n_e(ped) between DIII-D and C-Mod tokamaks



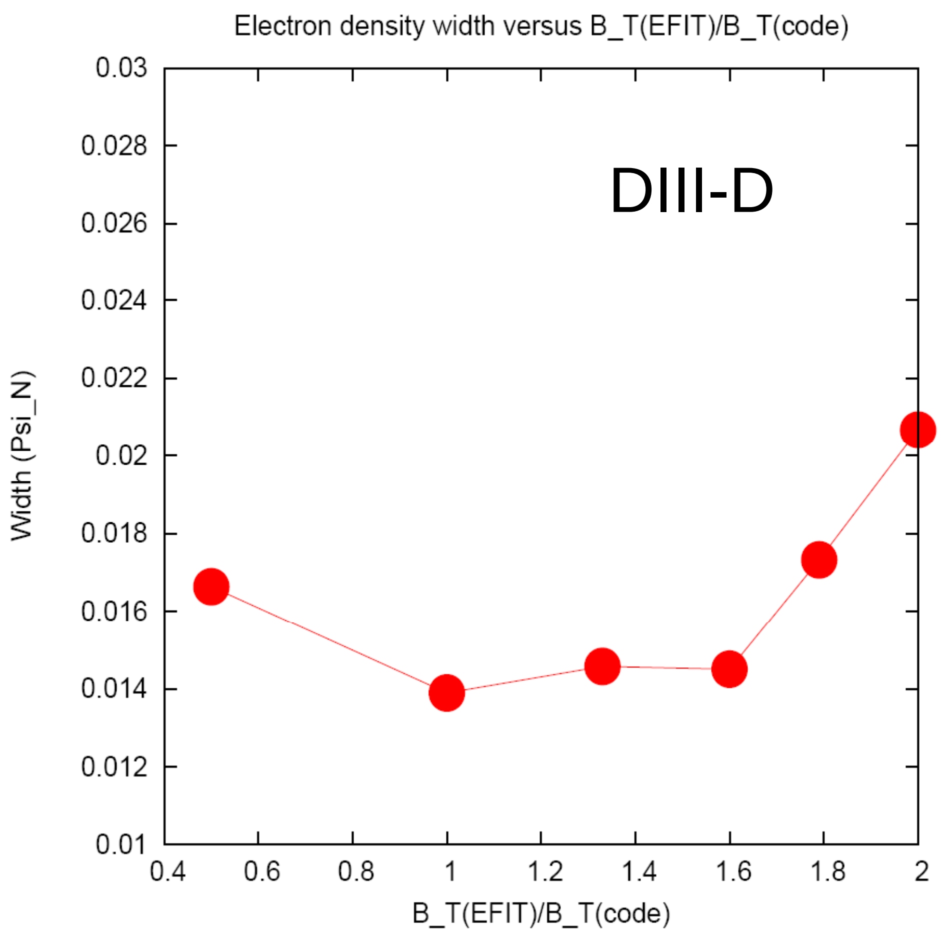
DIII-D shows neutral penetration effect at low n_e only. In C-MOD, density pedestal width is independent of density pedestal value

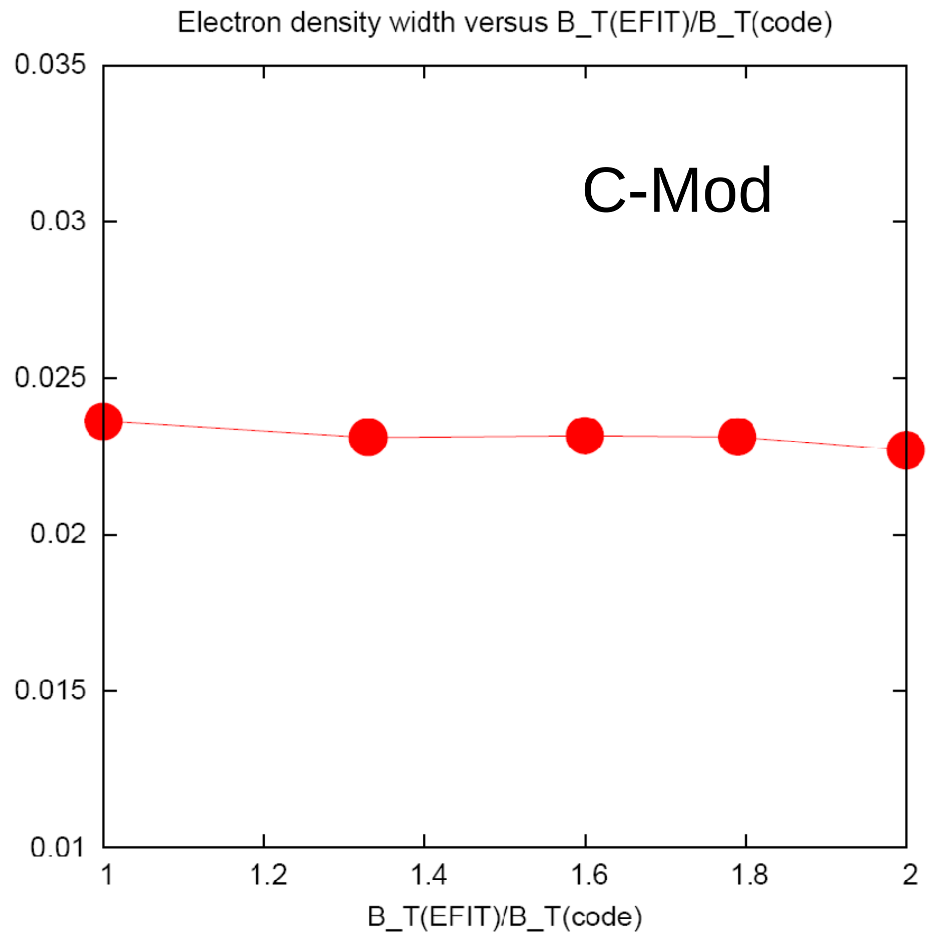
Pedestal width versus $1/B_p$ in DIIID and C-Mod



Pedestal density width is close to $\propto 1/B_p$, more pronounced in C-Mod

Comparison of pedestal width versus $1/B_T$ between DIII-D and C-Mod tokamaks



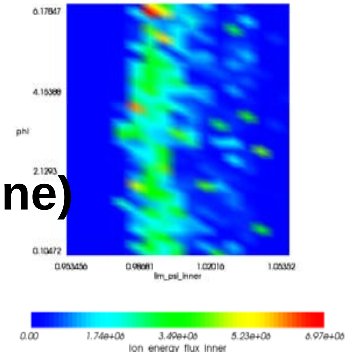


Pedestal density width does not show dependence on B_T in C-Mod and shows dependence in DIII-D at low B_T

Coupled simulation of XGC0-M3Domp-Elite-M3Dmpp for pedestal-ELM cycle in automated EFFIS framework

Linear stability check (Binary **Elite**) -file coupling

Divertor Heat Load
(2010 OFES Milestone)



B-reconstruction and mesh interpolation by **M3D-OMP** (file coupling)

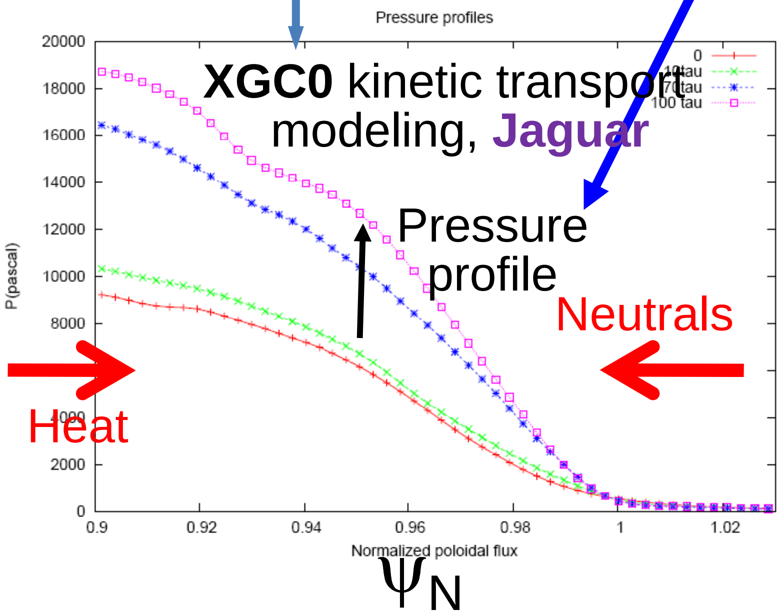
ELM crash in extended **M3D-MPP, Jaguar**

XGC0 kinetic transport modeling, **Jaguar**

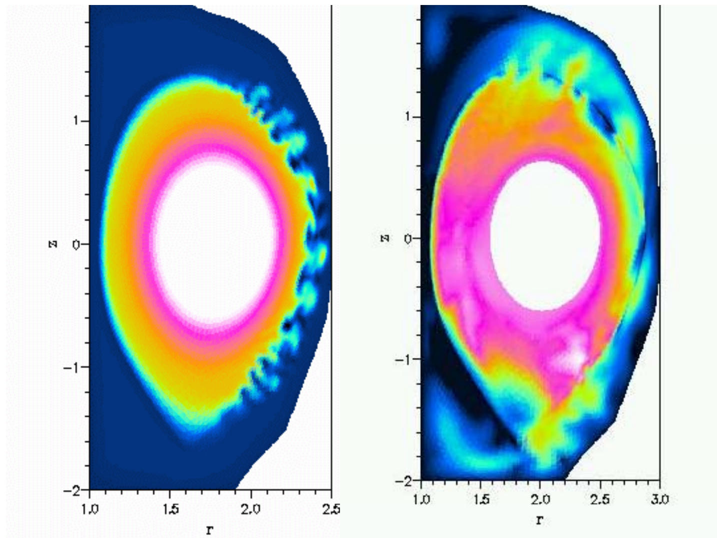
Pressure profile

Heat

Neutrals



Memory coupling

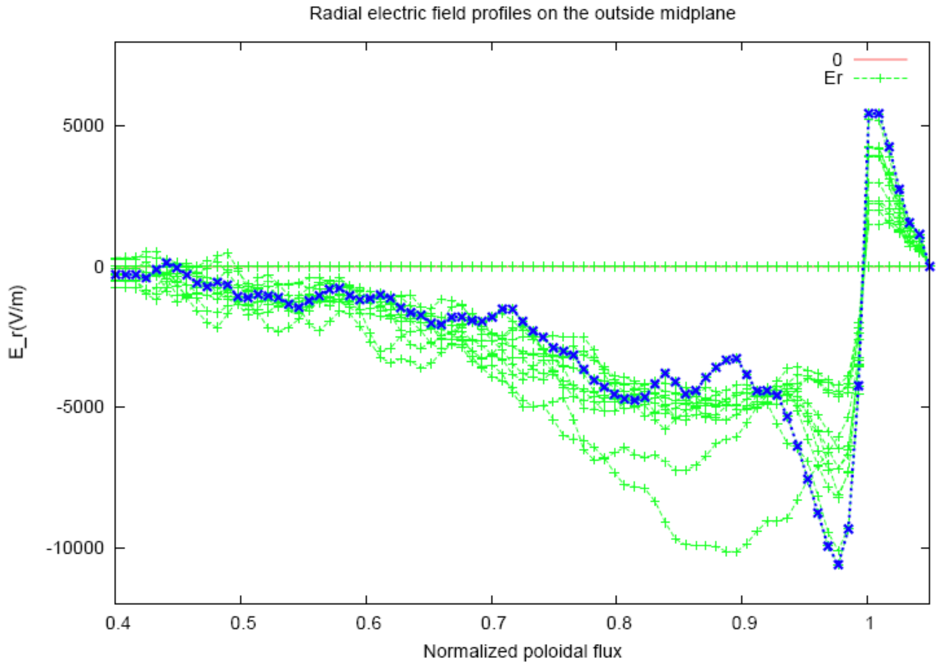


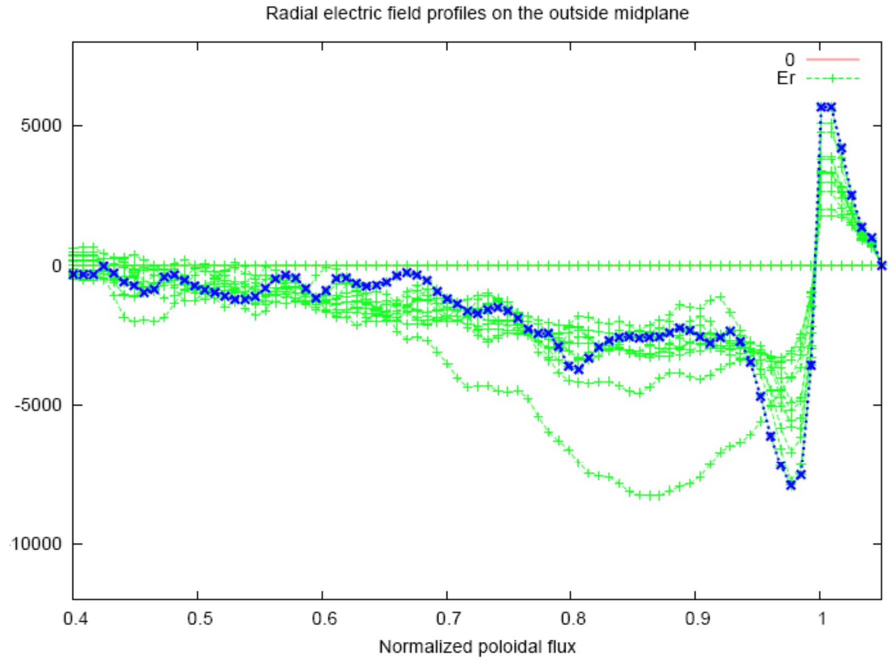
T=76 saturation

T = 496 relaxation

- **Impurities affect the E_r-well depth (thus, the pedestal structure).**

E_r-well depth at n_C/n_e=10% is weaker than at 5% ($m^{-1/2}$ vs Z^{-1} in X-loss)



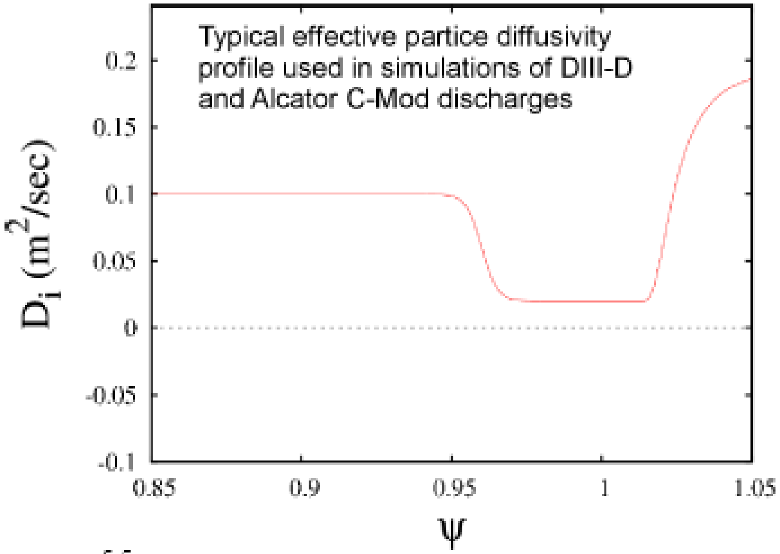


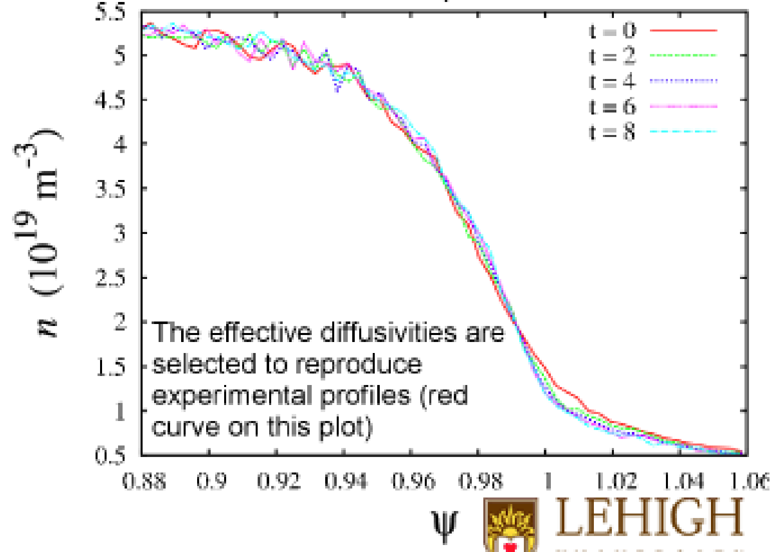
- **Anomalous transport weakens E_r well depth and widens pedestal width.**

Effective diffusivities deduced from experimental pedestal profile (Pankin)

Anomalous transport in XGC0 code

- While reduced theory-based models for anomalous transport in XGC0 are available, these heat load studies uses anomalous effective diffusivities obtained in analysis XGC0 simulation intended to reproduce experimental profiles
    - Alcator C-Mod and DIII-D discharges were analyzed
        - NSTX discharge will be analyzed in near future
    - It has been found that strong pinches in all channels of anomalous transport were necessary to reproduce experimental profiles
- Anomalous diffusivity profiles are kept fixed for each discharge in all I_p scans
- The gyro-Bohm ($\chi \sim 1/B^2$) and Bohm scalings ($\chi \sim 1/B$) for anomalous have been implemented in XGC0 and will be tested in near future





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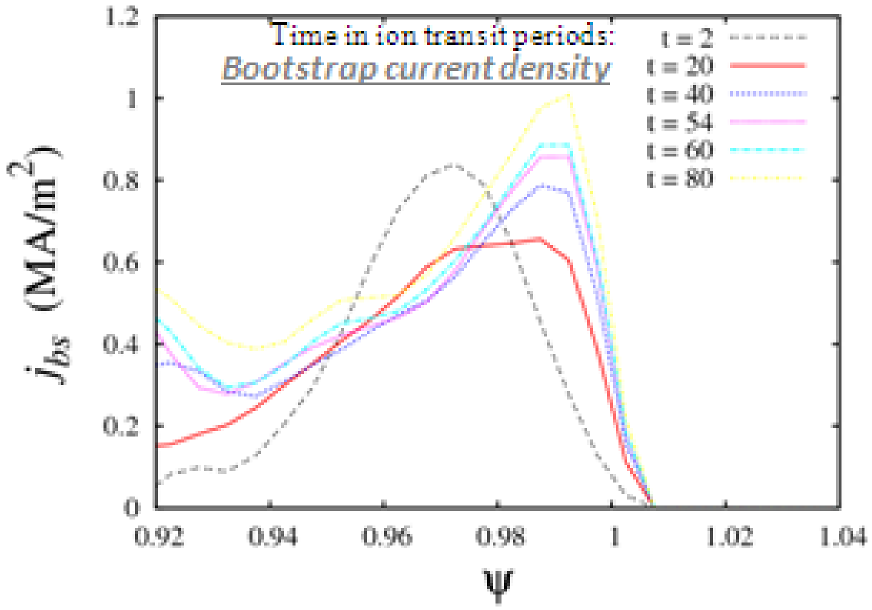
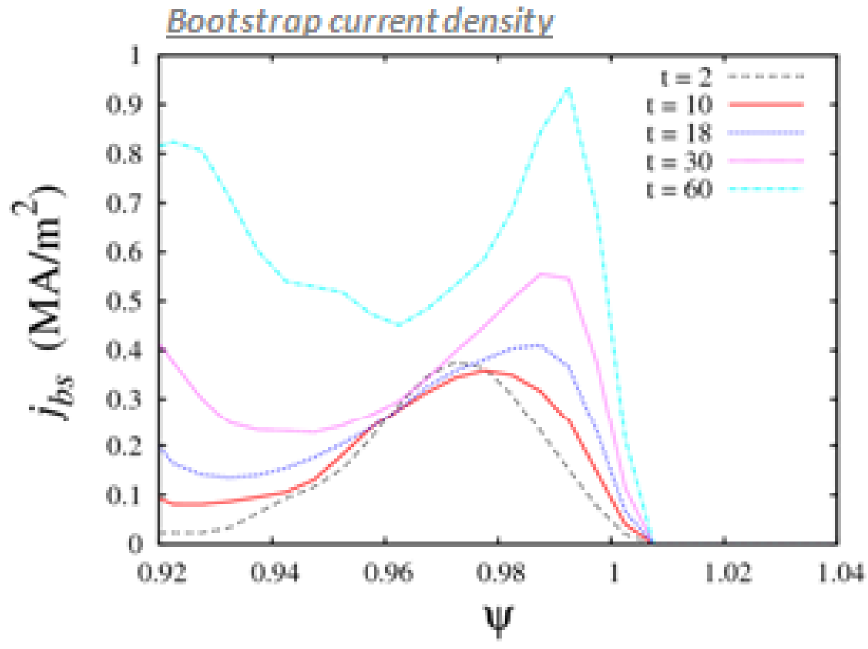
XGC0 finds radial profiles of bootstrap current



High triangularity
DIII-D 136674

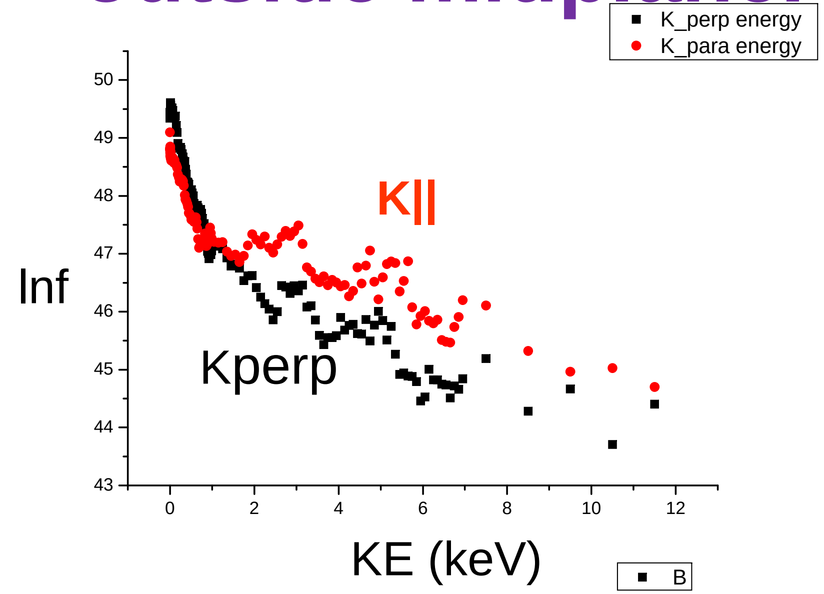


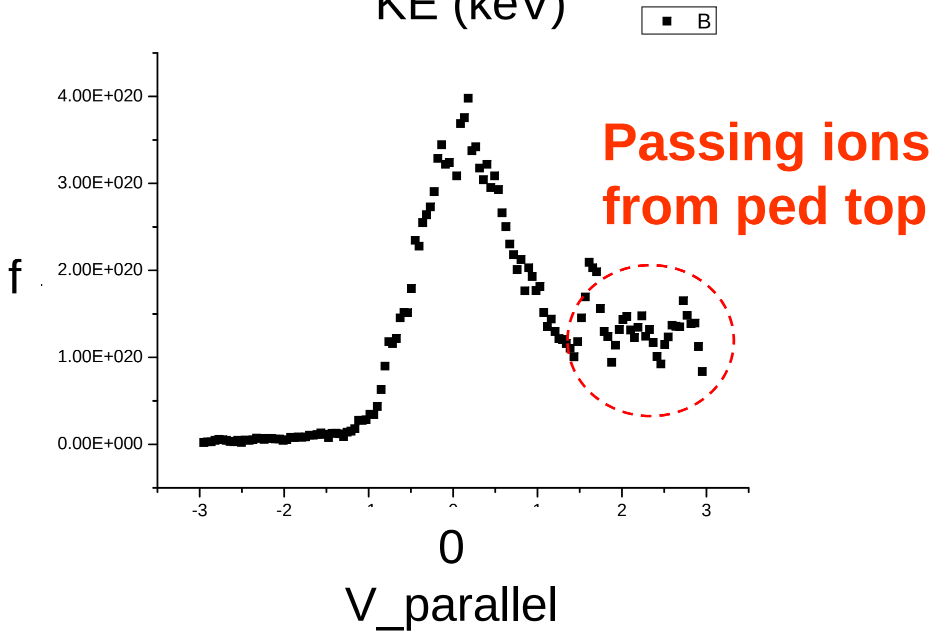
Low triangularity
DIII-D 136693

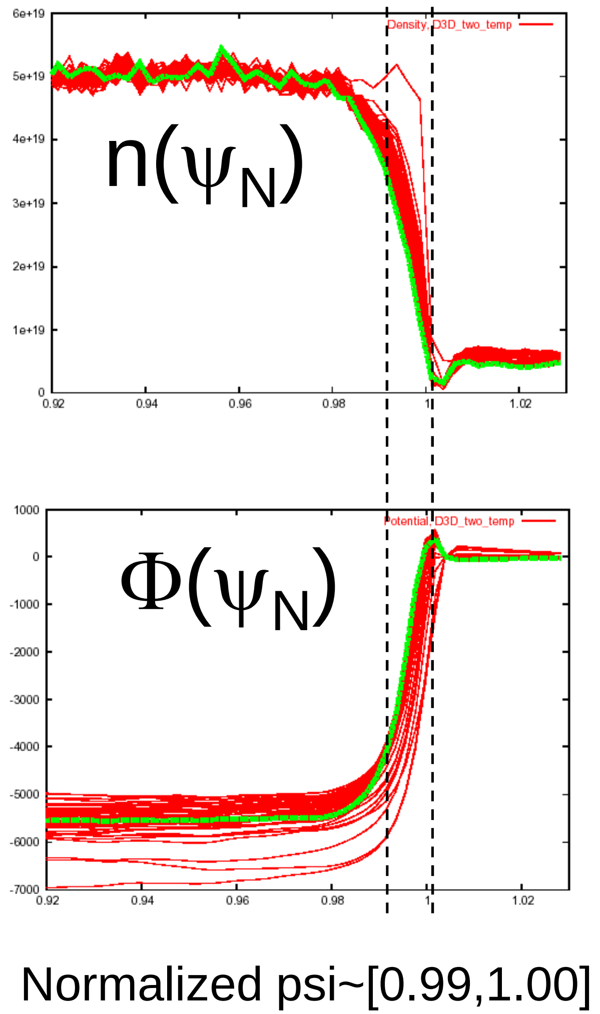
Inward pinch of cold ions

- XGC0 shows inward pinch of cold ions in the pedestal, in the absence of turbulence, driven by neoclassical effect
- GEM shows inward pinch of cold ions driven by turbulence
- Coupled GEM-XGC0 simulation is planned to nail-down the inward pinch of cold ions, driven by neoclassical and turbulence physics.

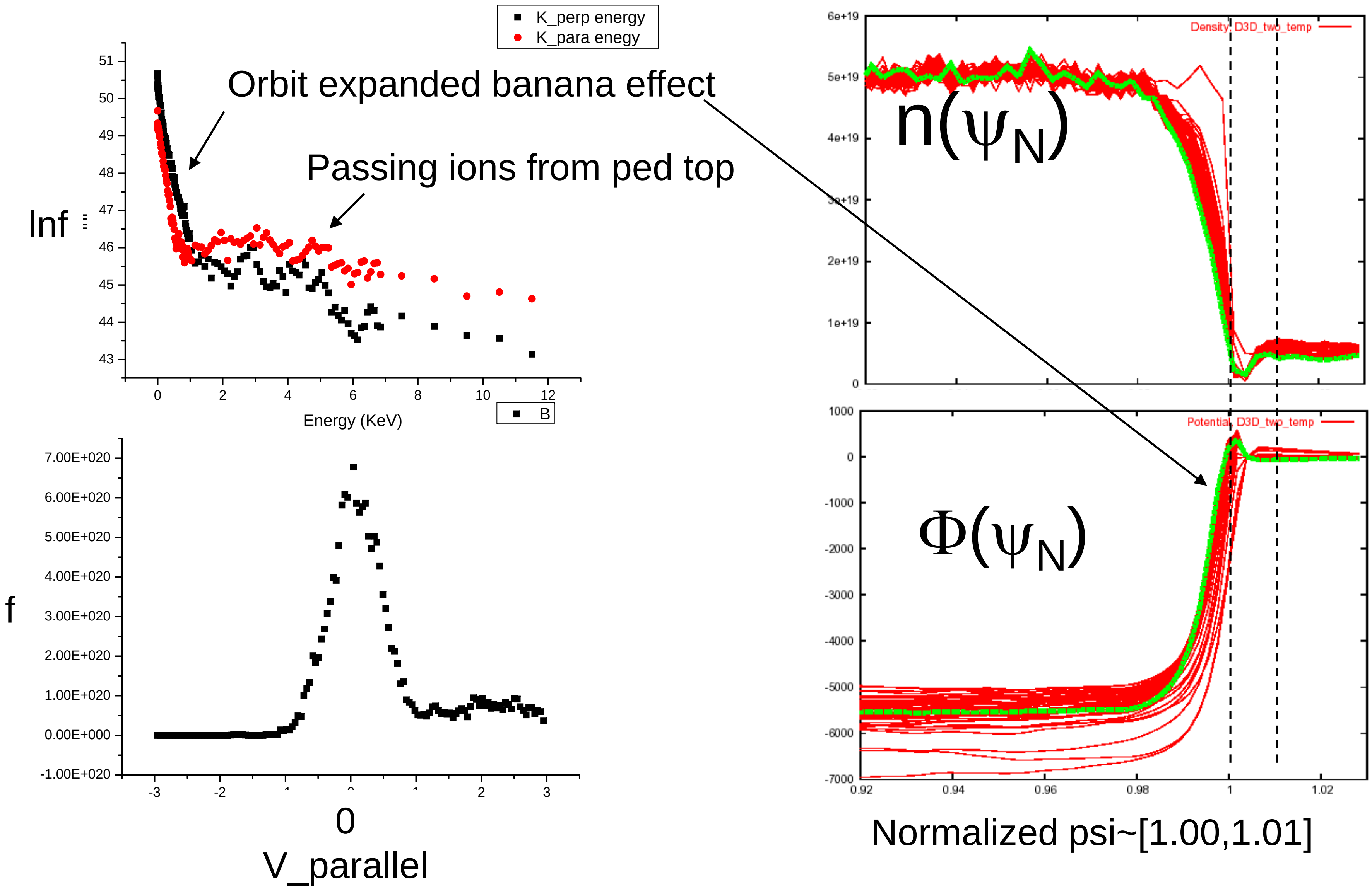
3. f_{i0} is non-Maxwellian in the pedestal at outside midplane. $K_{||} > K_{\perp}$







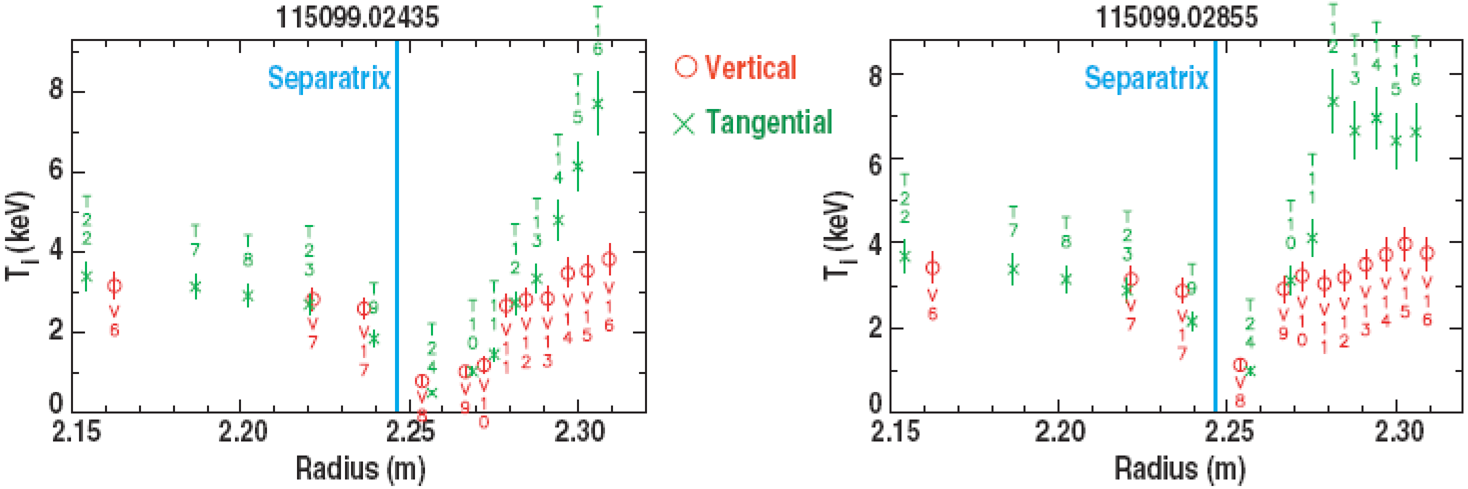
Outside the separatrix: better separation of hot and cold species

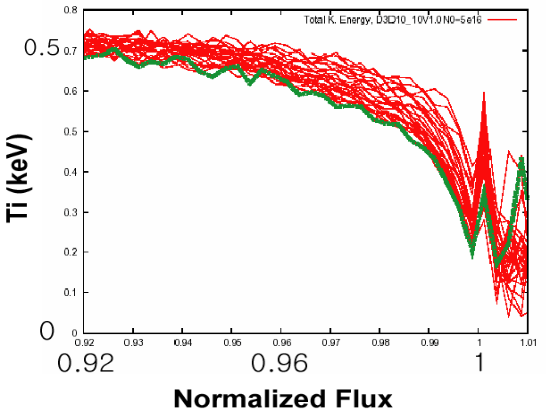


DIII-D results by K. Burrell finds $K_{\|} > K_{\perp}$. Radial profile is similar, too.

ANISOTROPIC SOL CVI ION TEMPERATURES

- Region of anisotropy broadens during triangularity change





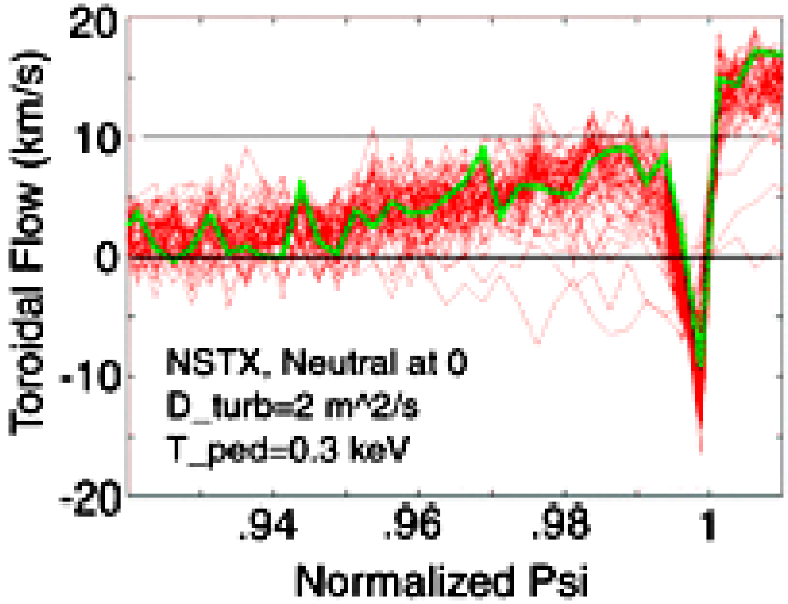
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

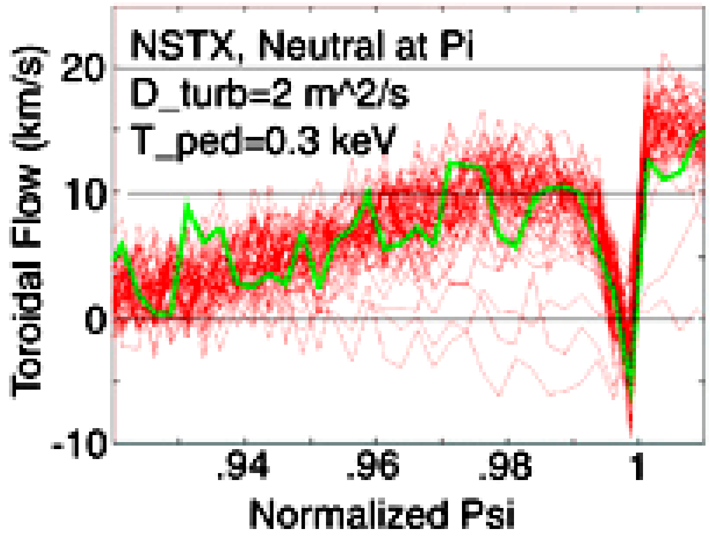
199-03/KB/rs

4. Fueling effect on pedestal

E.g., Inside fueling gives ~50% higher $\langle V_{||} \rangle$ in NSTX

Outside fueling | **Inside fueling**





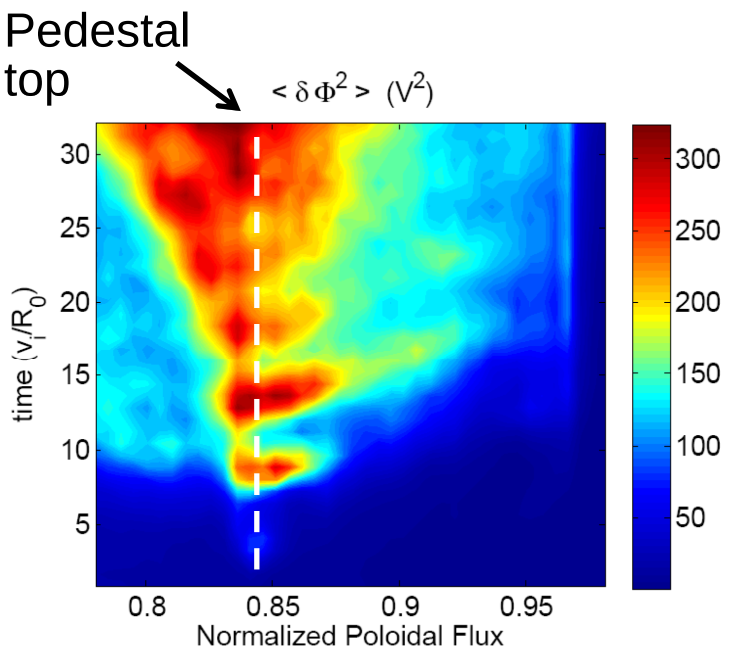
Maingi, Chang, et al, Plasma Phys. Control. Fusion **46** (2004) A305–A313

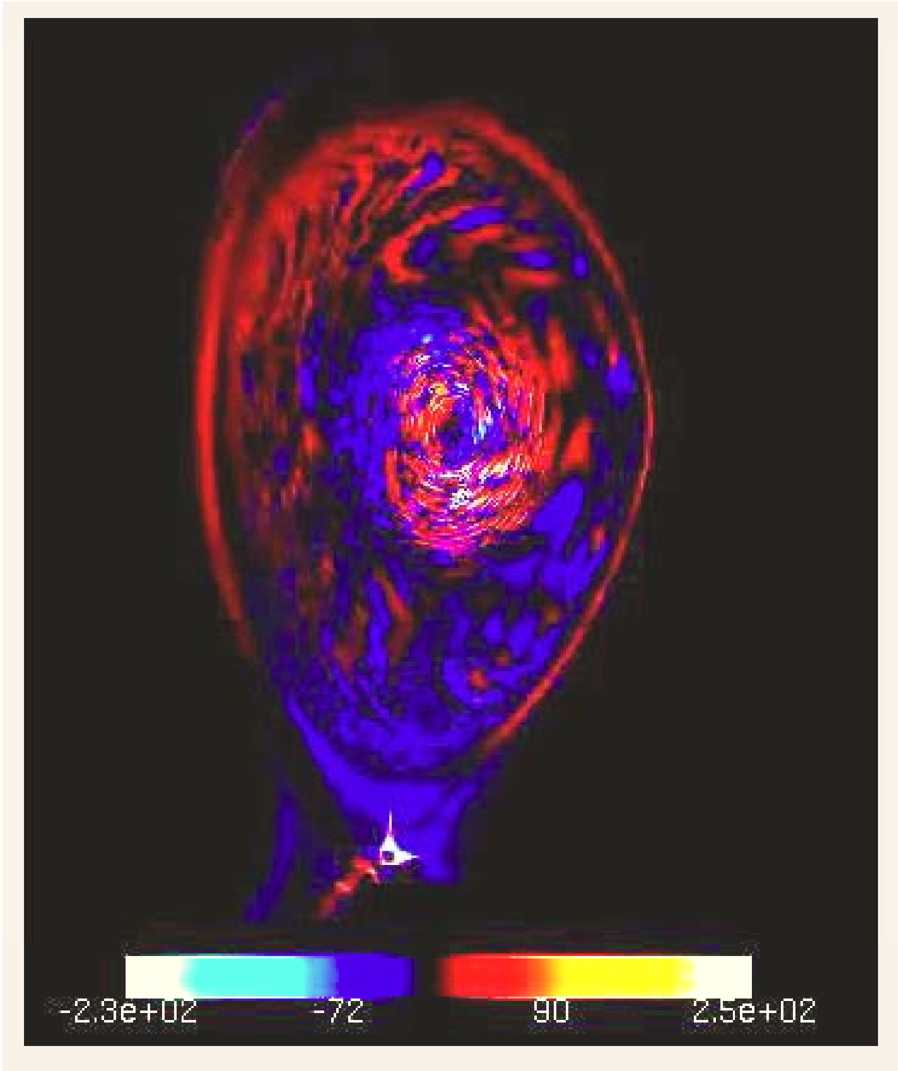
Pedestal structure and E_r also respond to fueling.

We will study the fueling effect on the pedestal structure, Er and V.

5. Neoclassical-consistent turbulence effect on pedestal, E_r and rotation in separatrix geometry (XGC1)

- **Currently ITG with adiabatic electrons**
- **Electromagnetic turbulence is under development**
- **Spontaneous V_T source in edge**

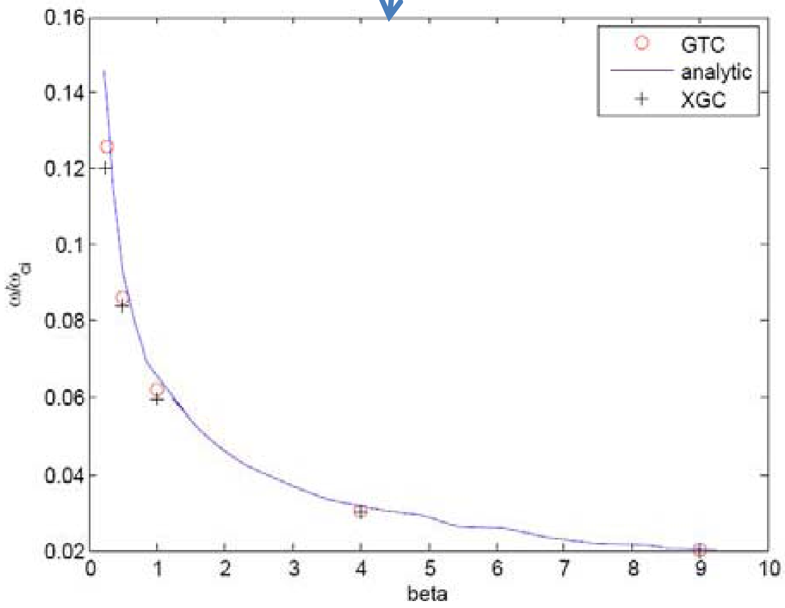




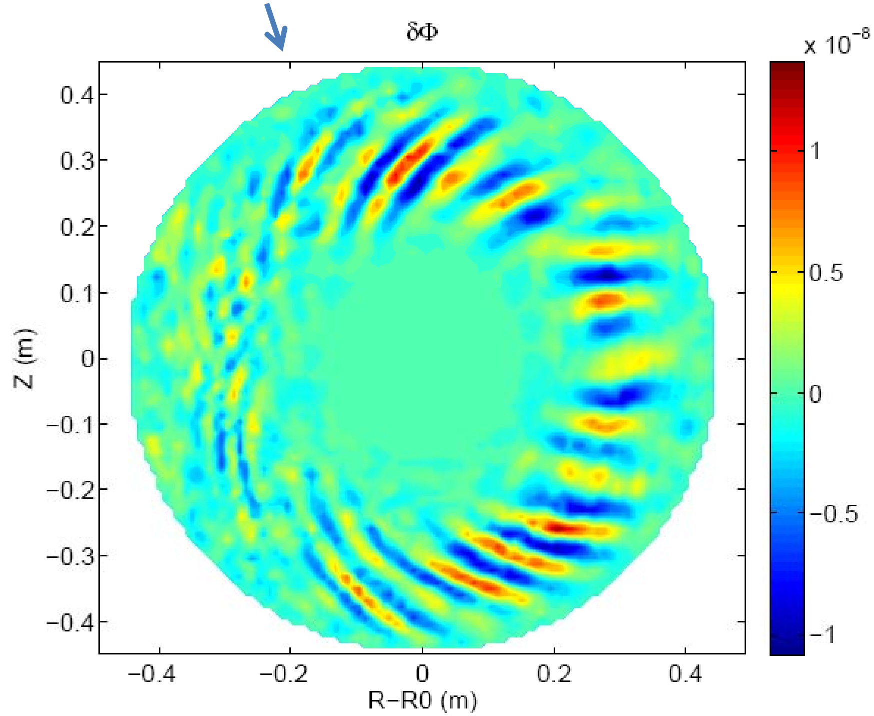
Moving Forward: Electromagnetic turbulence capability is under development in XGC1

Fluid-kinetic hybrid electron scheme (imported from GTC)

Split-weight electron scheme (imported from GEM)



XGC1 verification of Shear Alfven wave. The line is from an analytic calculation, the “o” data points are from GTC and the “+” data points are from XGC1.



Split-weight-electron simulation of electromagnetic turbulence in XGC1 at low electron beta.

Experimental data needed for Kinetic modeling at CPES

- N, Te, Ti, V, and Er profile for different q, I_p and geometry
- Pedestal width in n, Ti, Te under different pedestal height.
- How does the pedestal structure, rotation, and the widths change under gas puff?
- Ion distribution function measurement in parallel and perpendicular direction
- Toroidal and poloidal rotations under different plasma and geometrical conditions.
- Fluctuation data for density and temperature for r>0.5a, across the separatrix and into SOL, together with the plasma profiles.
- Time evolution of these data during L→H