Daniel Told et al.
IPP Garching/Greifswald

What sets the residual electron heat transport in an edge transport barrier?

Told et al., PoP 2008
Jenko et al., PoP 2009
Told & Jenko, PoP 2010

Workshop on Gyrokinetics, Cambridge, 27 July 2010

Background

Physics of H-mode barriers

- Strong ExB shear flows thought to suppress long-wavelength turbulence
- Ion heat transport close to neoclassical, but other transport channels remain anomalous
- What sets the residual electron heat transport?

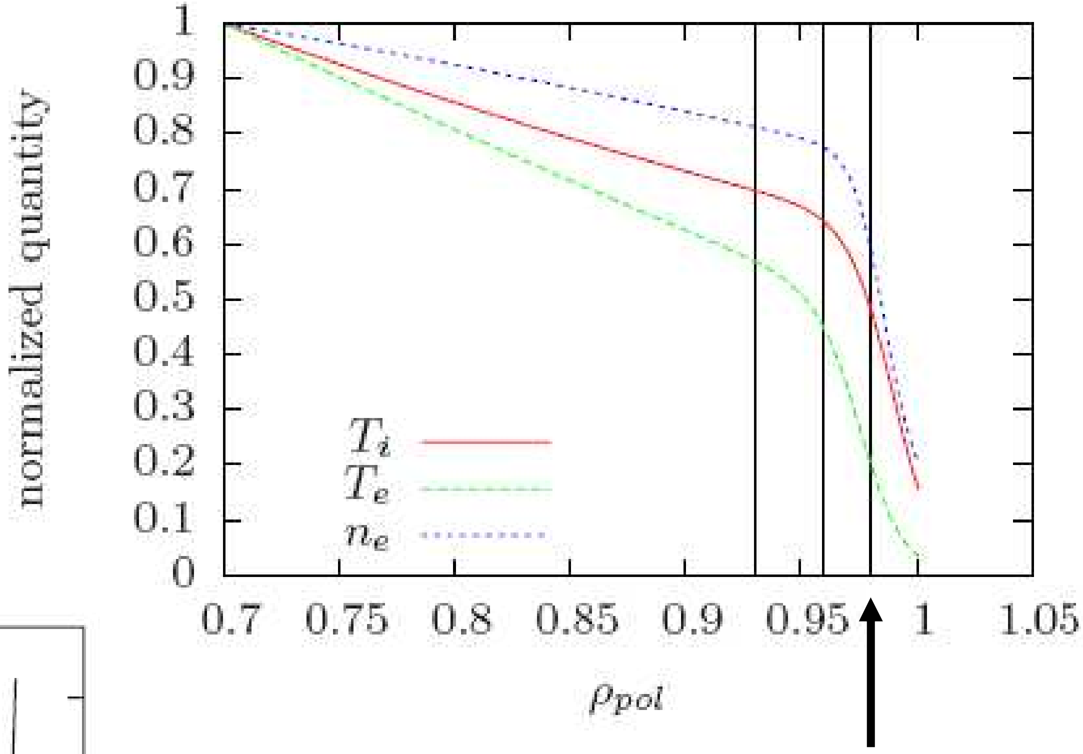
Some candidates for setting the residual electron heat transport

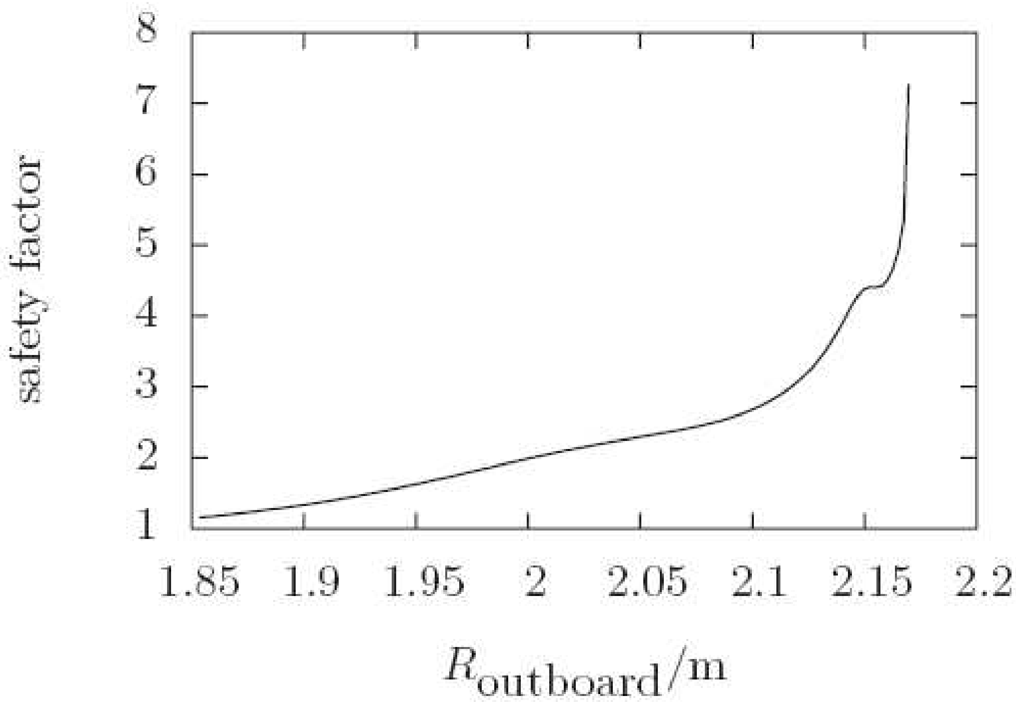
- Paleoclassical transport (theoretical foundations are disputed)
- Residual long-wavelength turbulence (not ITG)
- High-wavenumber turbulence (e.g., ETG)

  This possibility is investigated by means of GENE simulations…

ASDEX Upgrade #20431 at t=1.82s
(H-mode discharge)

Density and temperature profiles





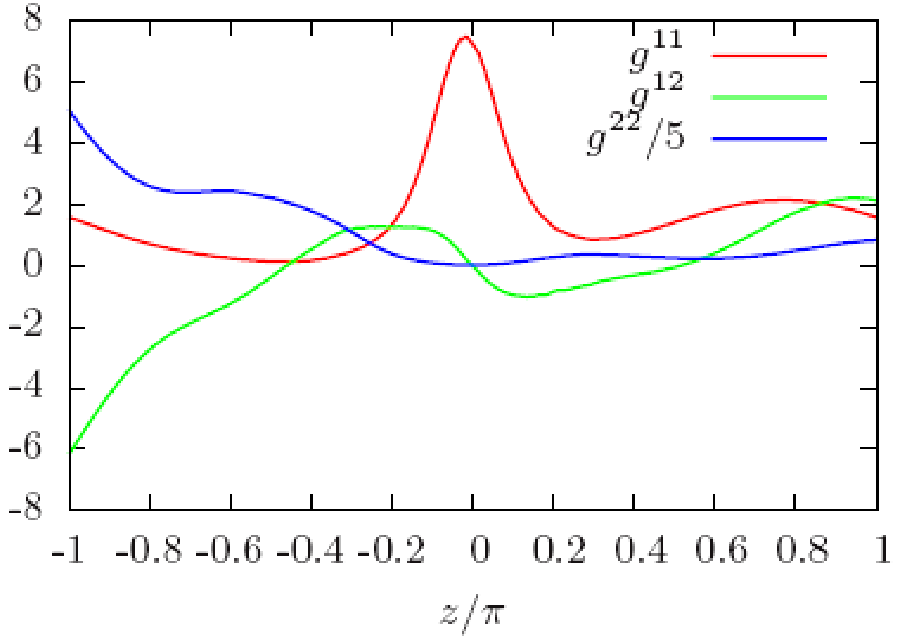
Safety factor profile

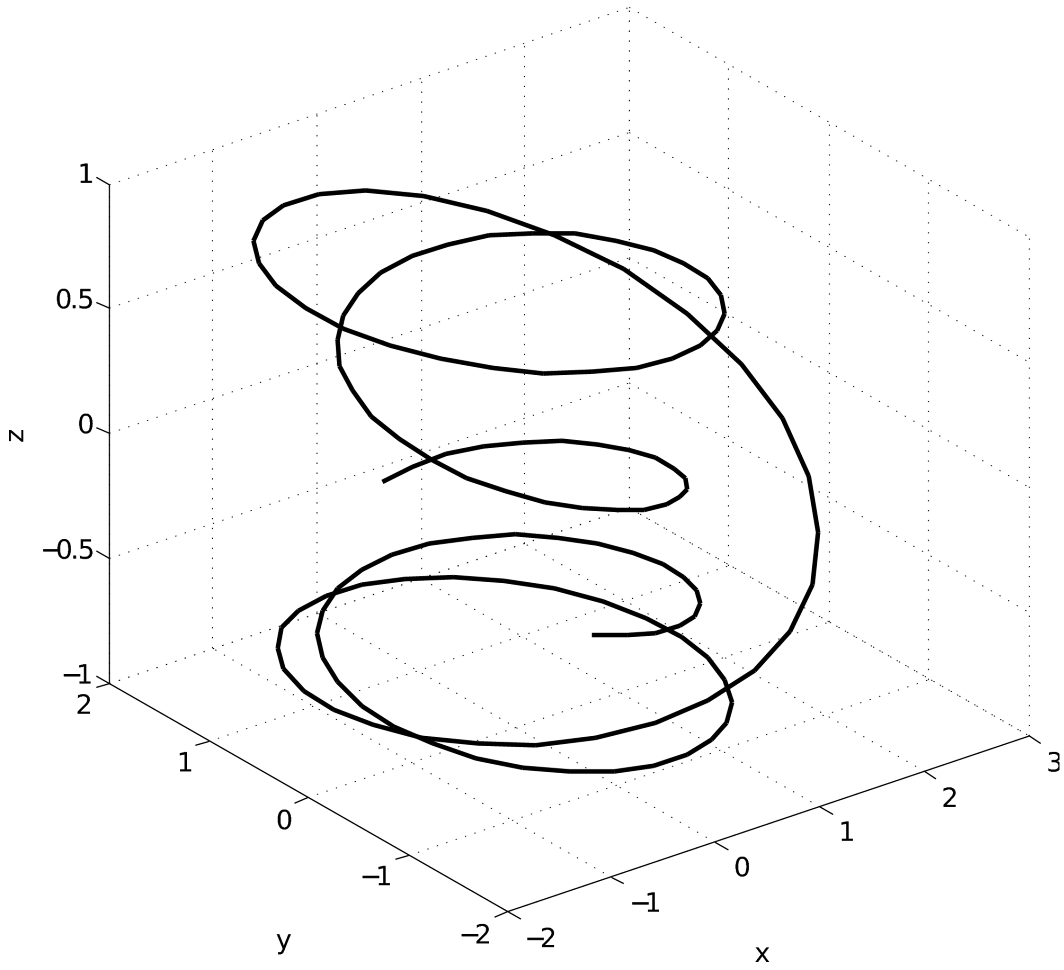
Metric generated via field-line tracing method

Field-line tracing method

- Implemented in TRACER/GIST[a]
- Yields field-aligned coordinates

[a]P. Xanthopoulos et al. (2006, 2009)

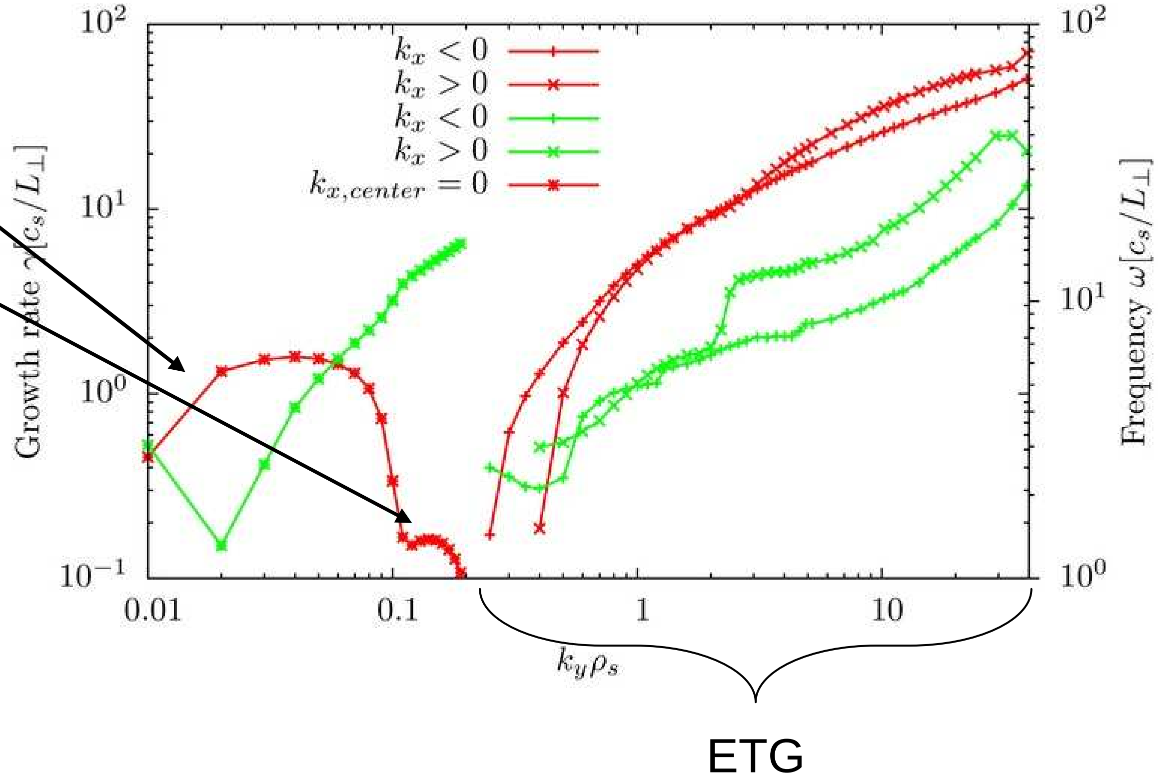




Linear GENE simulations for AUG edge

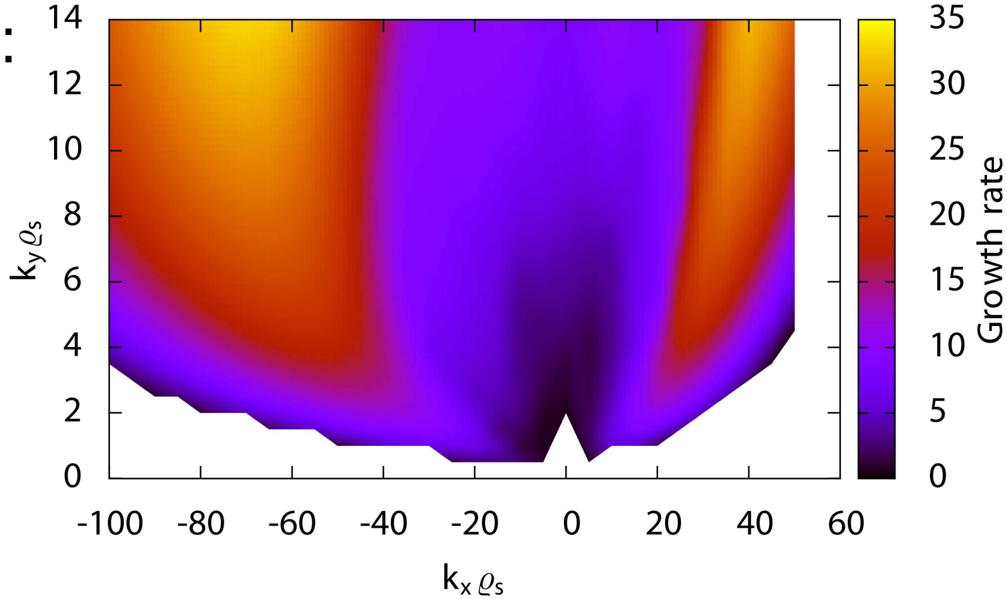
Low *k*: ITG/KBM mode
Microtearing

Spectrum largely dominated by ETG mode



Linear characteristics of ETG mode:

- critical $\eta_e = L_n / L_{Te} \approx 1.2$
- AUG H-modes: usually $\eta_e > 1.5$
- weak dependence on collisions ion dynamics
- Pronounced peak at finite radial wavenumbers



ETG turbulence as candidate for edge heat flux

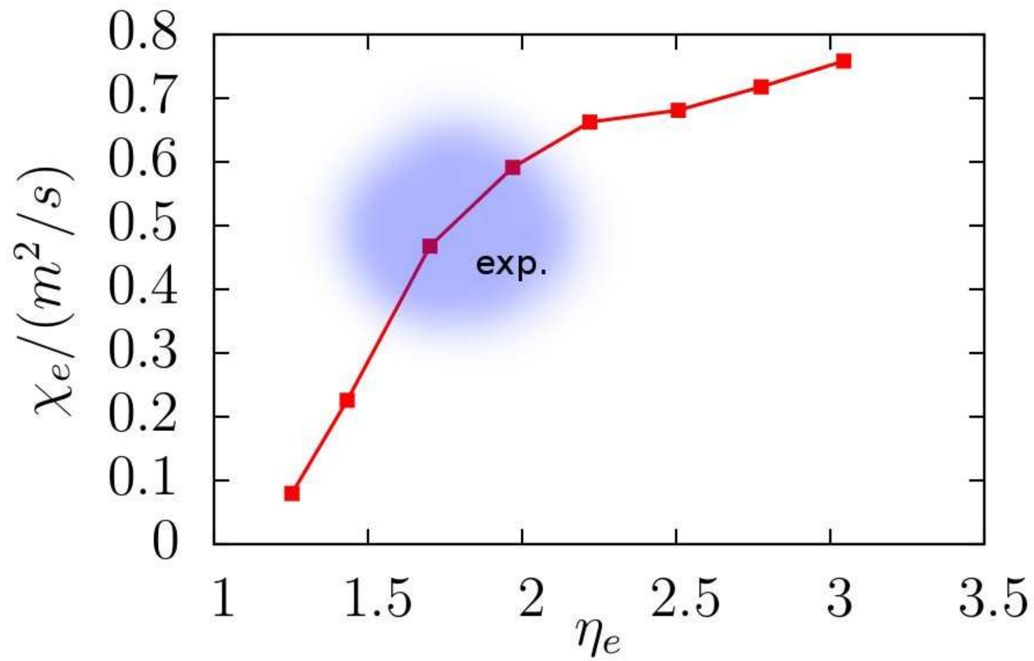
Common scenario for ETB:

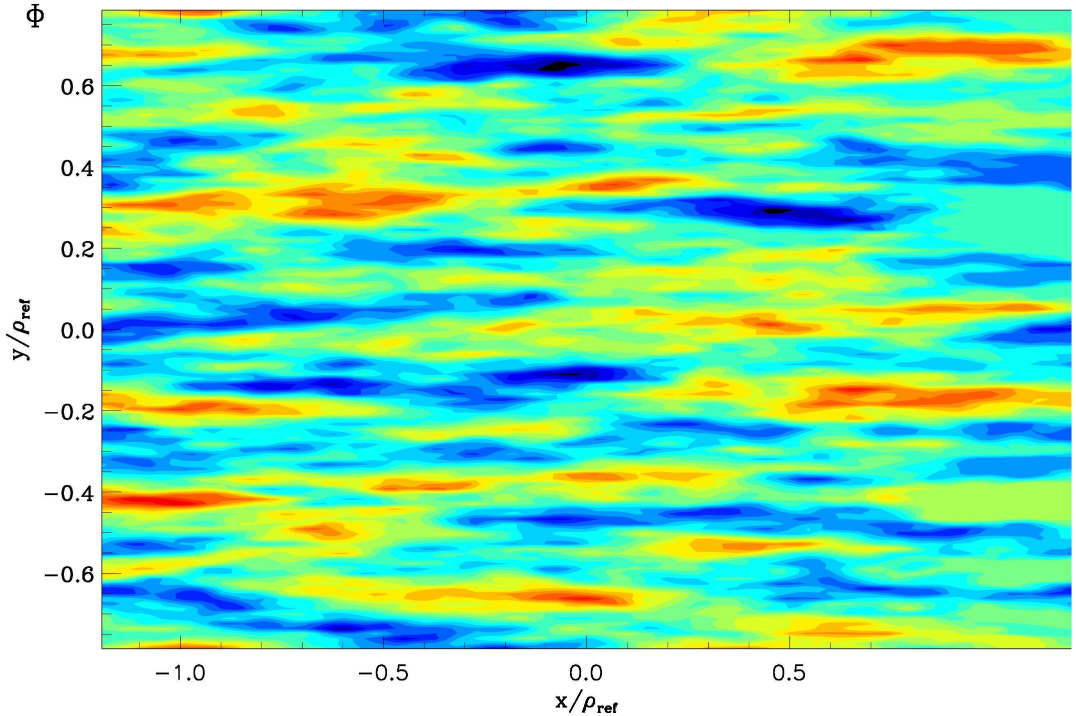
- Strong ExB flows suppress low-*k* turbulence
- Residual heat flux influences pedestal height

→Examine ETG transport in gyrokinetic simulations

Nonlinear GENE runs:

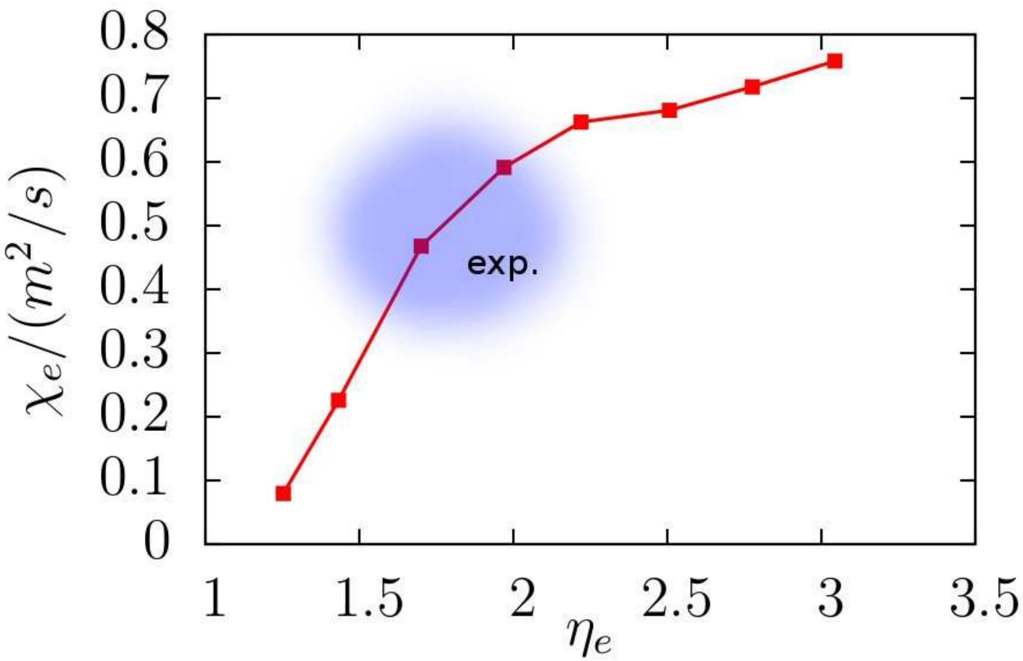
- Scan over R/L_{Te} for ρ=0.98
- Realistic edge geometry
- Grid 96x96x32x24x8
- Diffusivities comparable to edge transport modeling
- Nominal value: Q_e≈8MW≈P_{input}



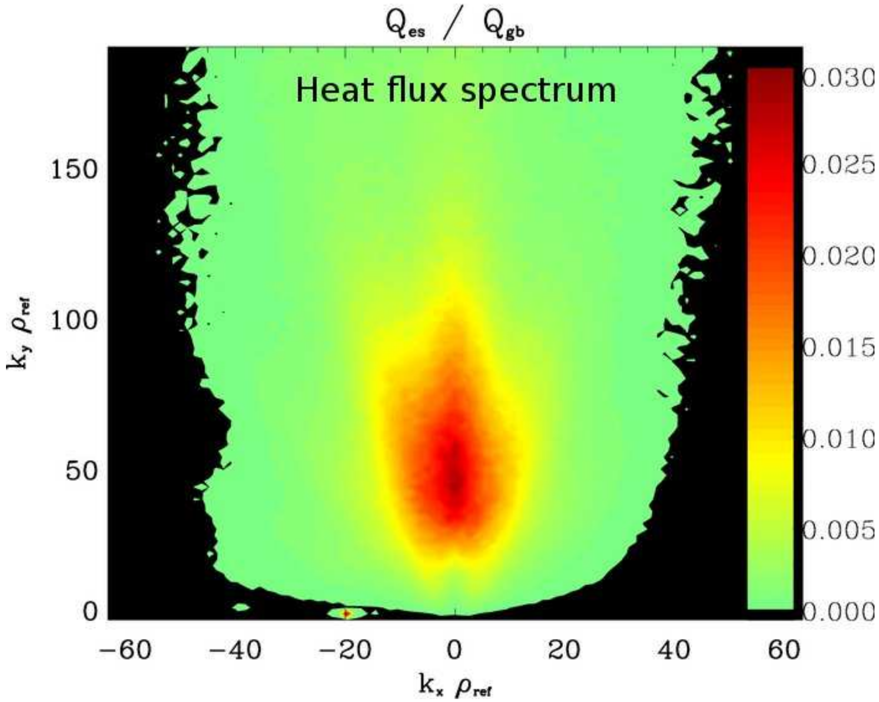


Further edge ETG characteristics

- Linear threshold $\eta_e = 1.2$ confirmed nonlinearly
- AUG H-mode edge should be unstable to ETG turbulence



- Linear finite k_x peaking does not carry over to nonlinear regime



So far, so good.
But: Three questions

Are you able to treat the
complicated edge geometry correctly?

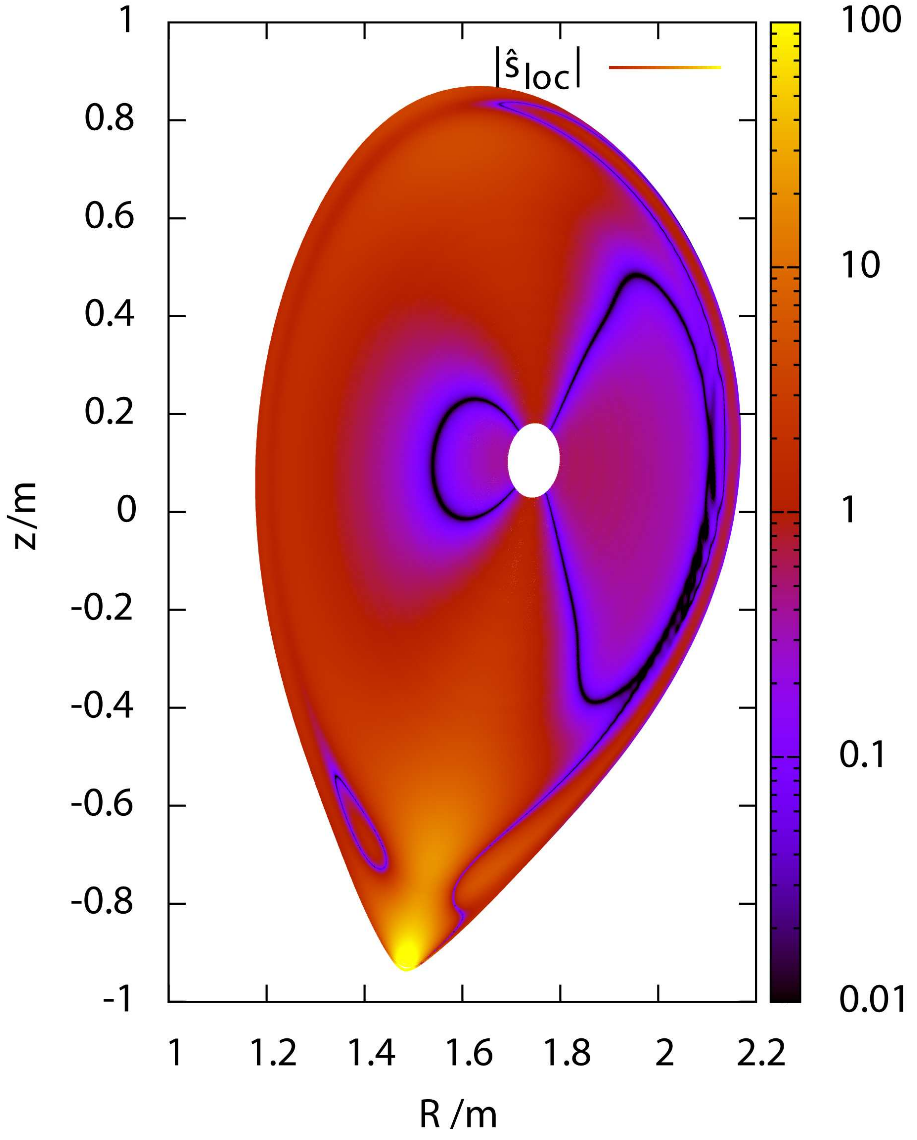
Near-separatrix geometry

Similarity to s-α model?

- Plot shows absolute value of local magnetic shear
- Negative shear even in the core, though global values positive
- Effect of plasma shaping

Behavior near separatrix

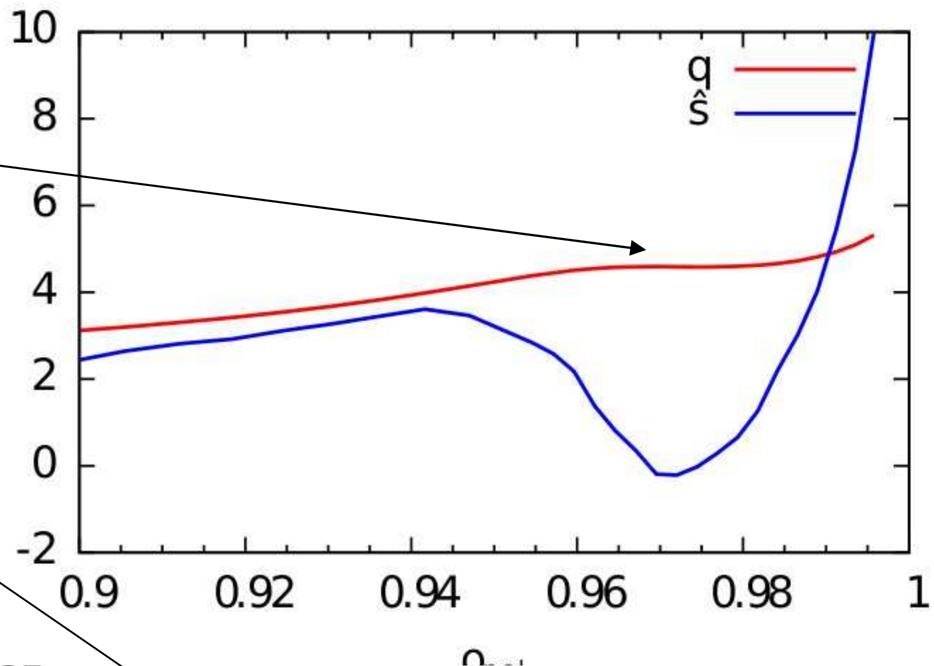
- Metric coefficients have complex parallel structure (e.g. distance between flux surfaces varies strongly)
- Strong up-down asymmetry
- Strong local shear near X-point(s)
- Safety factor + magnetic shear diverge



Edge: Safety factor and shear diverge

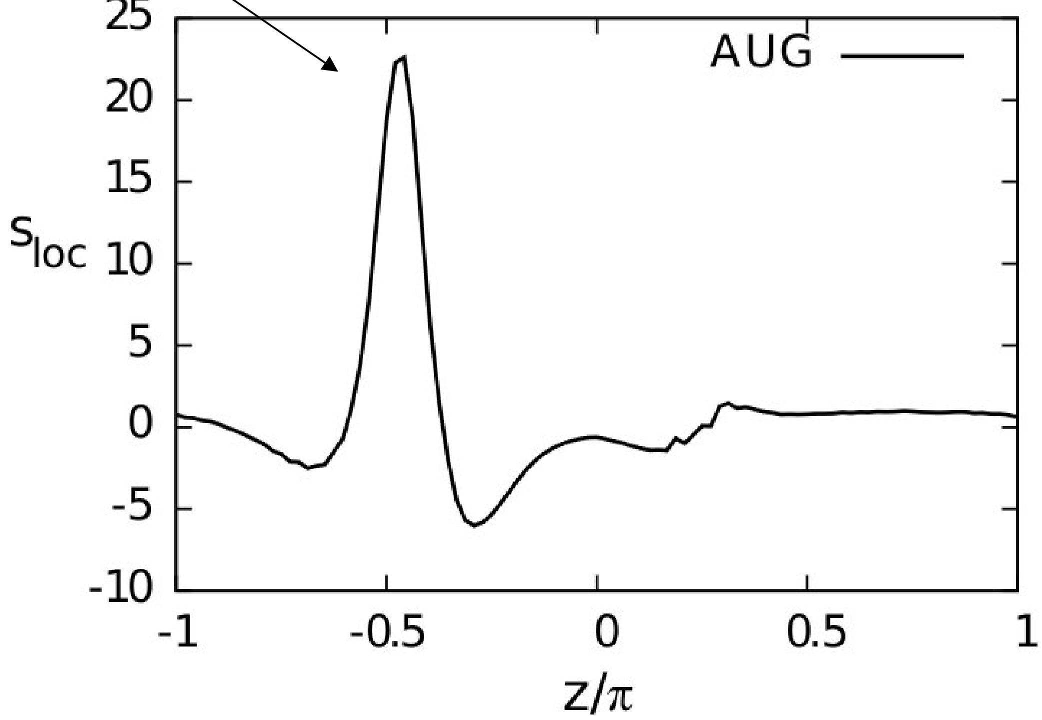
Magnetic shear in the edge:

- Bootstrap current leads to local flattening of q-profile
- Strong parallel dependence of local shear remains



Toroidal geometry:

- Ballooning of modes may alleviate resolution problems



But how to discern real from spurious ballooning?

Large shear requires increased radial resolution

Sheared slab: Lo-res can lead to artificial ballooning (Scott 2001)

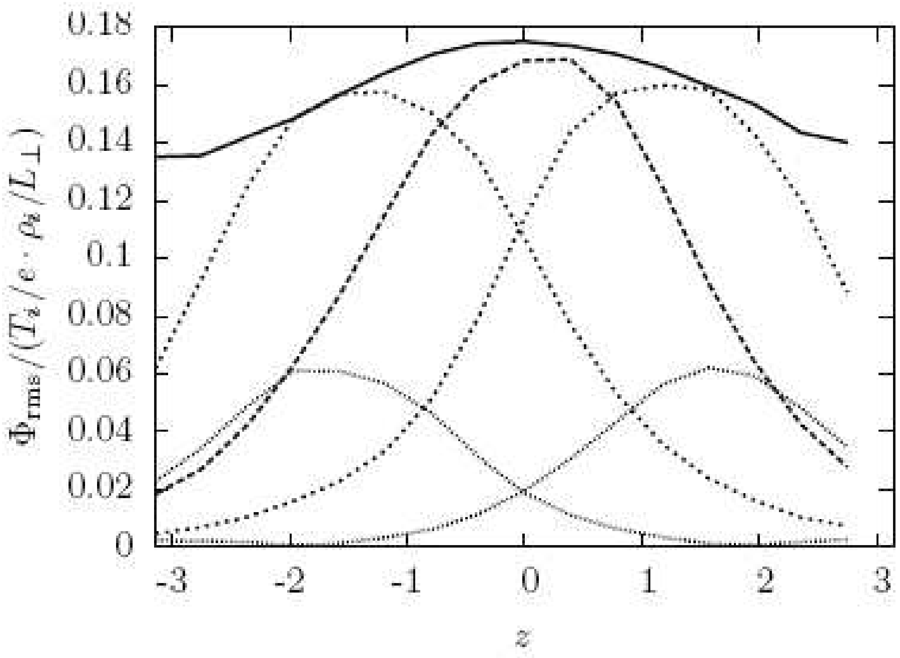
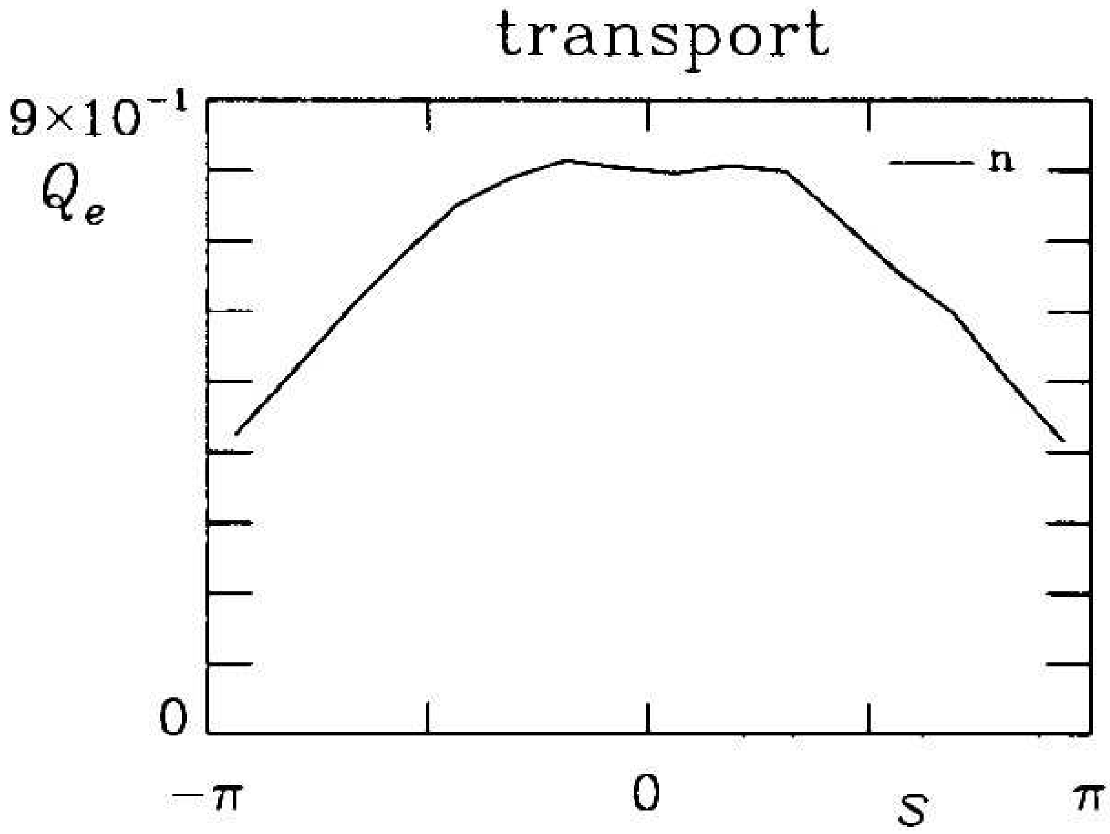


FIG. 9. Time-averaged electrostatic potential for $k_y\varrho_s=0.75$ and $k_x\varrho_s=0$ (dashed), $k_x\varrho_s=\pm 0.942$ (shorter dashes), and $k_x\varrho_s=\pm 1.885$ (dotted) for a nonlinear simulation with $\epsilon_x=10$. The solid line shows the rescaled overall heat transport which exhibits unphysical ballooning.



Shifted metric approach (Scott 2001)

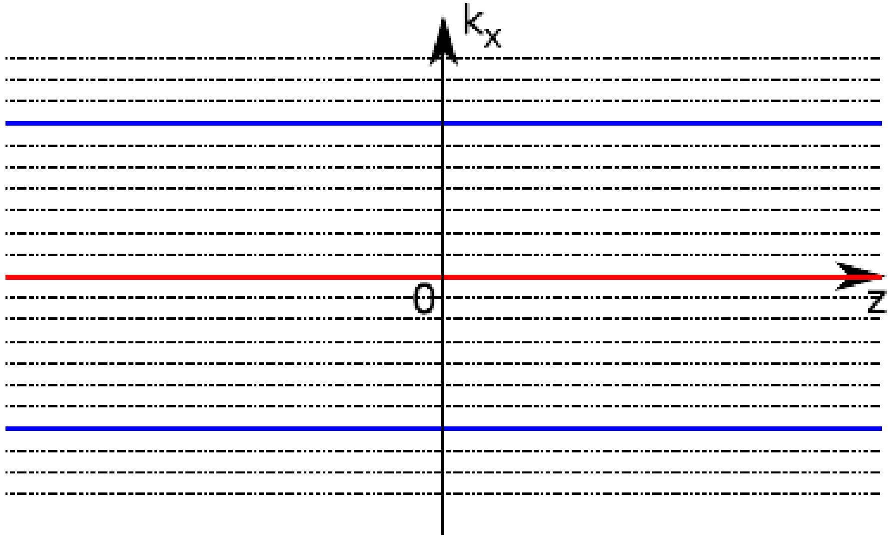


FIG. 13. (Color online) With straight metric, parallel derivatives follow the sheared magnetic field automatically when using the same k_x mode, and a large shift has to be applied at the ends of the z domain in order to connect to beyond the flux tube end.

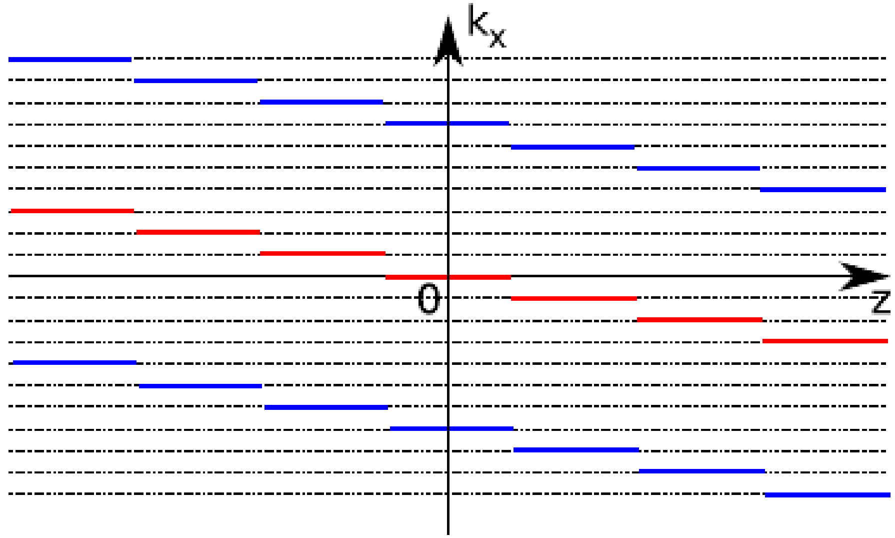
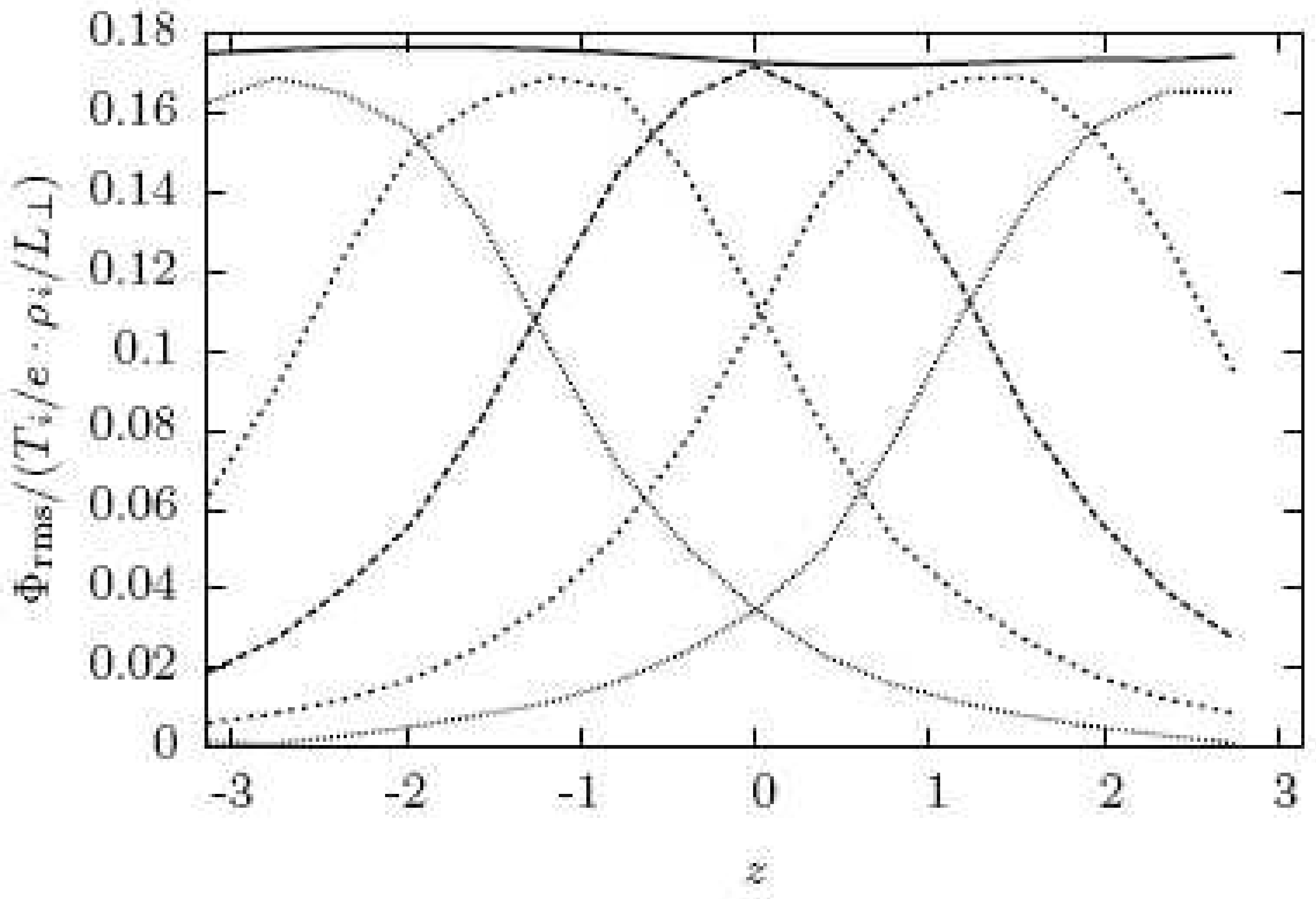
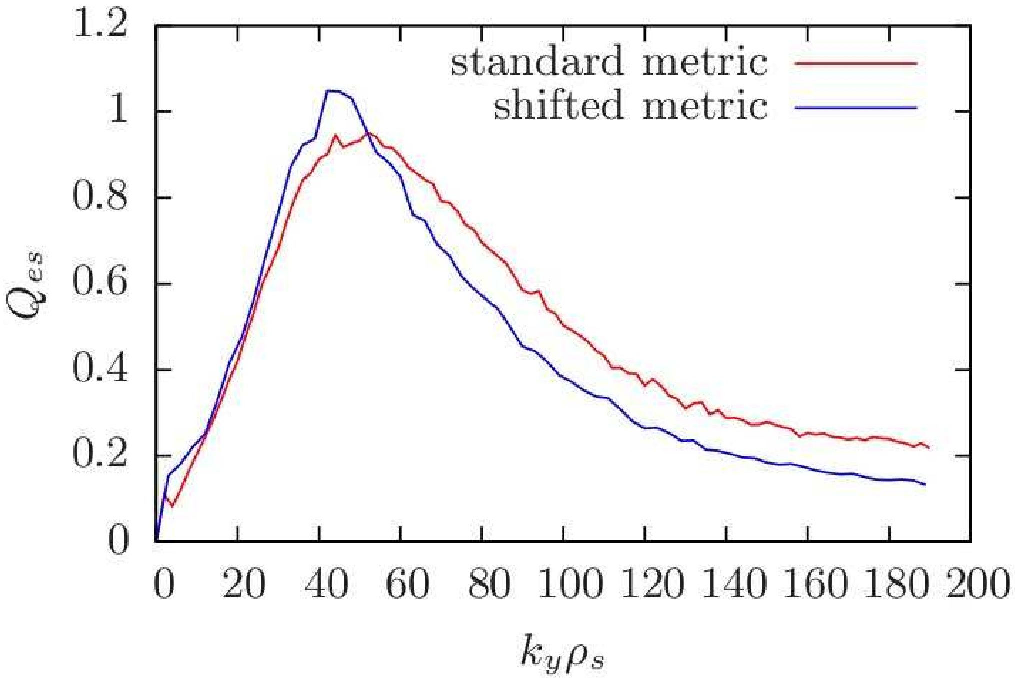


FIG. 14. (Color online) With shifted metric, a small k_x shift has to be applied from each parallel position to the next in order to follow the sheared magnetic field and periodic boundary conditions suffice to connect to the next flux tube. In straight metric, the mode drawn in the picture would correspond to $k_x=0$ all along the flux tube.

Shifted metric in action



Comparison shifted metric/standard metric

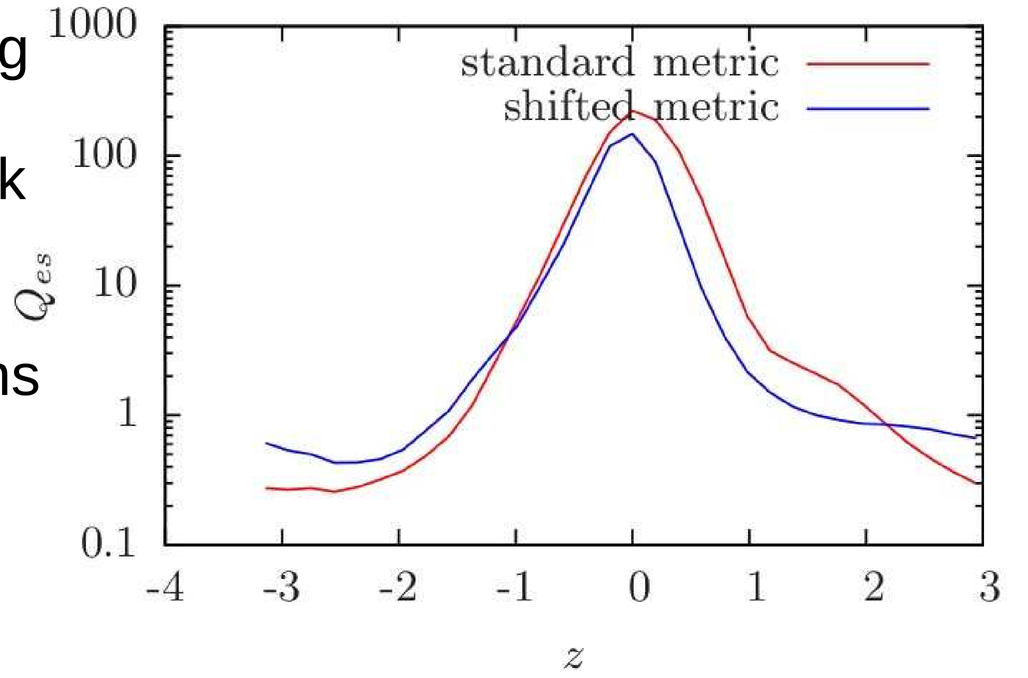


Differences in treatment:

- Shifted metric violates periodic boundaries
- Use Dirichlet with damping zone

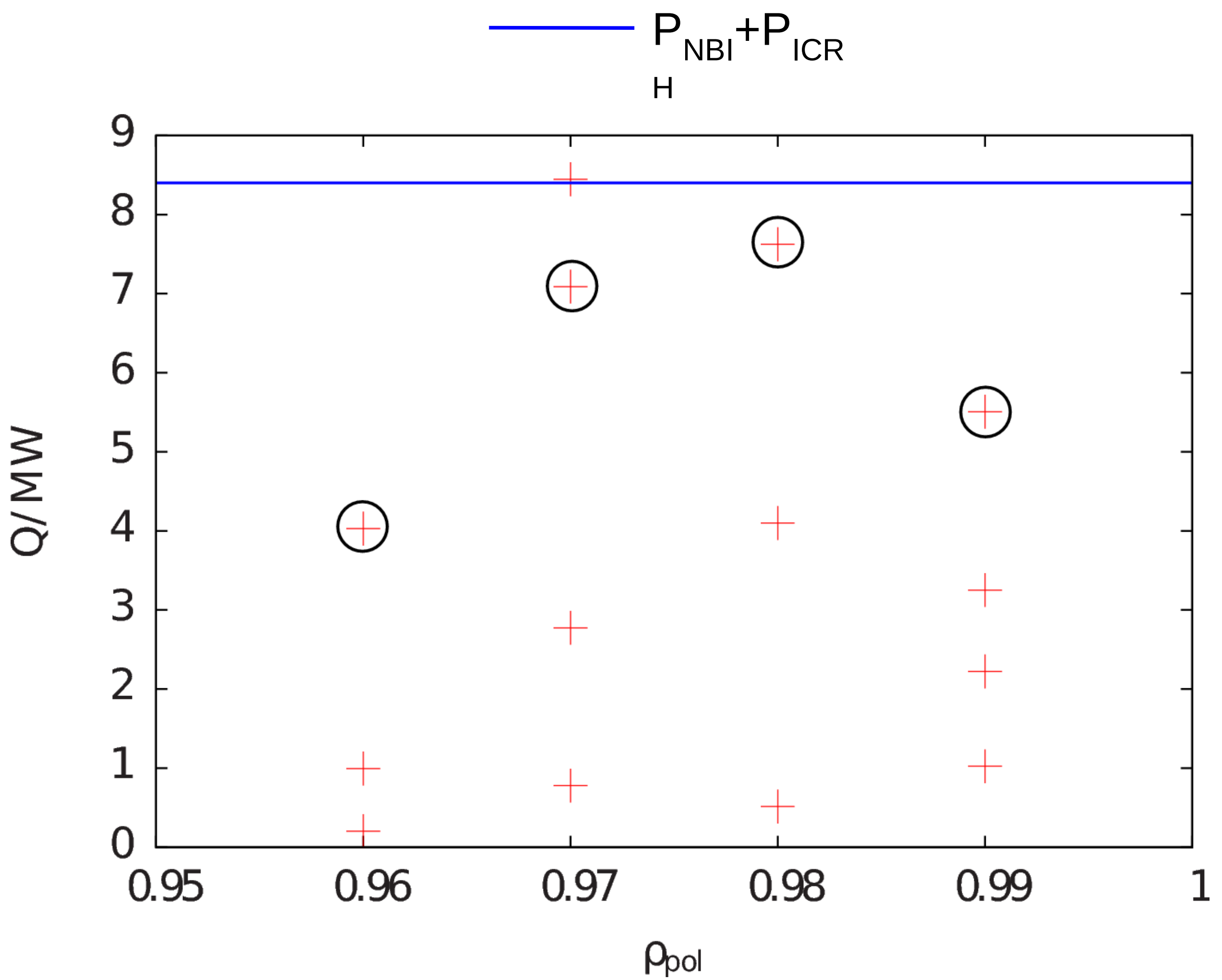
Results of comparison:

- Average heat flux (including damping zones) ~20% lower
- Heat flux spectrum very similar, peak at $k_\perp \rho_s \approx 15$
- Parallel localization of heat flux appears in *both* geometry descriptions



Do you obtain strong ETG turbulence throughout the whole pedestal region?

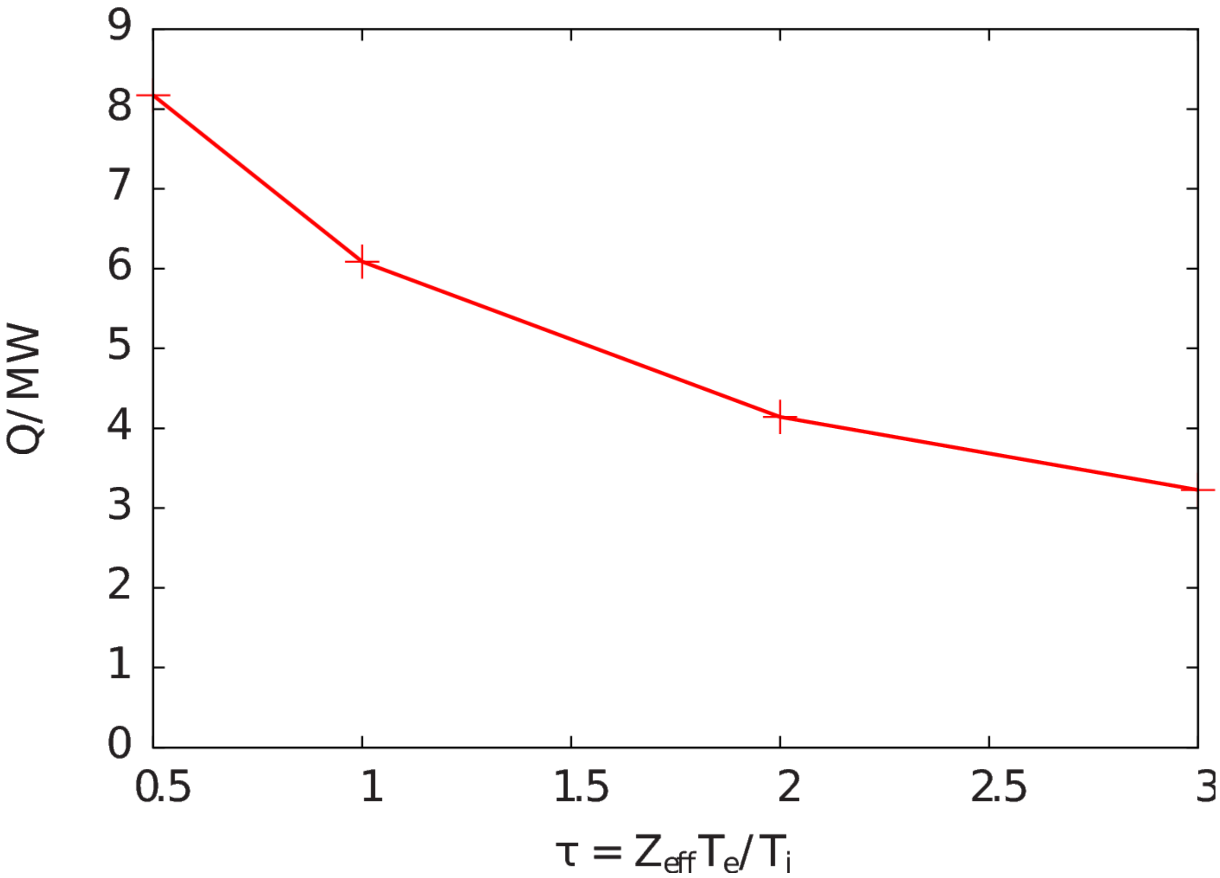
Investigation of radial ETG heat flux dependence



- ➔Circles: nominal gradients
- ➔ETGs can generate almost entire experimental flux
- ➔Pedestal knee (ρ=0.96): Transition to core turbulence?
- ➔Outermost position: Slight reduction of heat flux

Might ETG modes be removed via Zeff or Te/Ti?

Effect of impurities and temperature ratio on edge ETGs



- ➔Expectation: no dependence of critical R/L_{Te} on τ (Jenko et al., PoP 2001)
- ➔Perform nonlinear ETG runs for ρ=0.98
- ➔Introduce parameter $\tau = Z_{eff}\, T_e/T_i$ into adiabatic ion field solver
- ➔AUG edge: Z_{eff}~2-3, but usually $T_i > T_e$
- ➔Result: moderate dependence, roughly $Q \sim 1/\tau^{0.5}$

Conclusions:

ETG turbulence remains a strong candidate for setting the residual electron heat flux in edge transport barriers

If this is confirmed, future simulations of L-H transitions must include sub-ion-scale dynamics