

# Passing particle pinch effects in core ITG, TEM and ETG turbulence

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- **Importance of particle balance**
- **Pinch theories**
- **Numerical gyrokinetic study of ITG+TEM pinch effect**
- **“ ETG pinch effect**

# Importance of particle balance

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- particle transport small compared to heat transport in hot plasmas
- despite this: density profile extremely important for confinement / fusion performance
  - controls  $\eta_i/\eta_e$  / ITG/ETG stability
  - at given  $T$  determines  $\beta$
  - peaking of  $n$  in core reduces heat conductivity outside
- Seems to play a role in transport barrier formation
  - fast steepening of density in internal barrier in TFTR, C-Mod
  - extreme drop of  $D_\alpha$  light at L-H transition  $\rightarrow$  particle transport goes through zero.
- In more collisionless hot burning plasmas: expect stronger **anomalous** pinch, enough time for relaxation  $\rightarrow$  ***should be purposefully controlled***

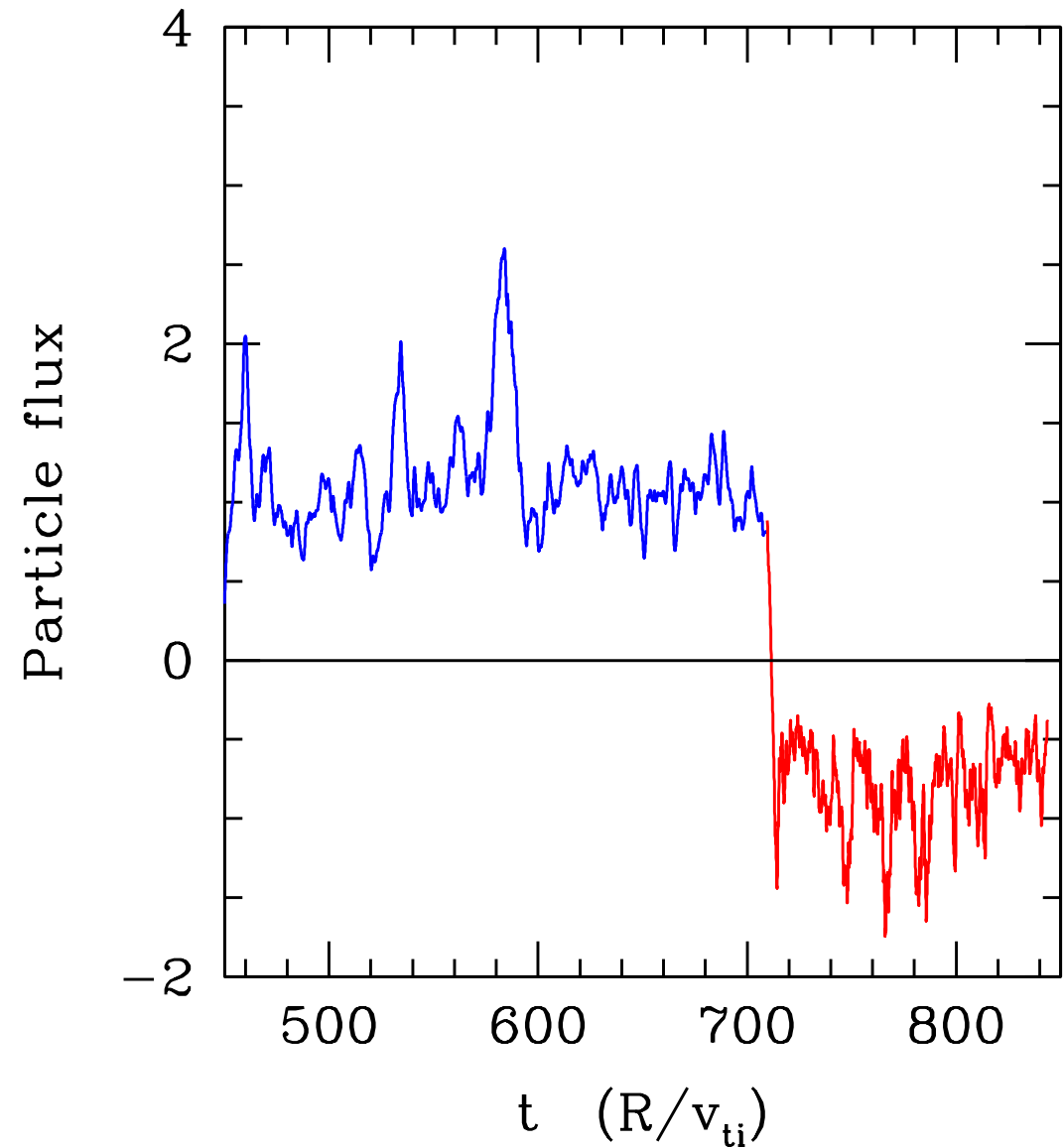
# Some anomalous pinch theories

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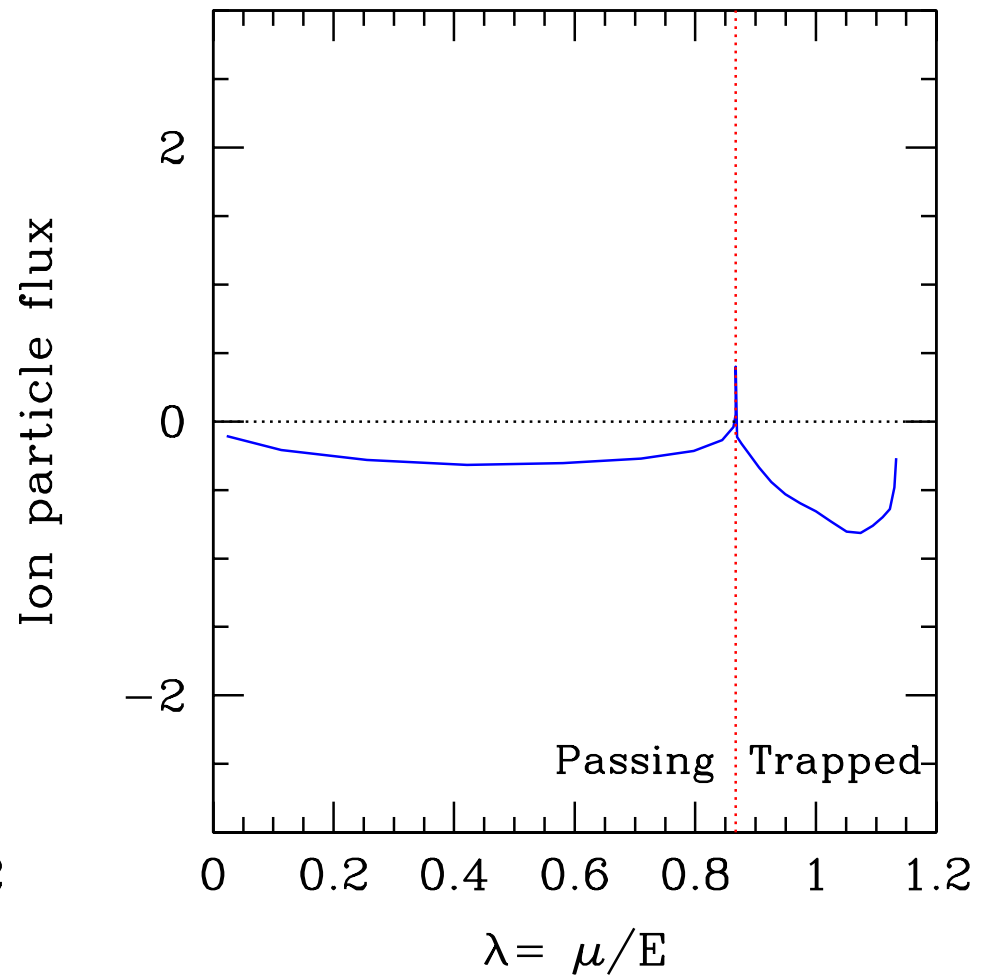
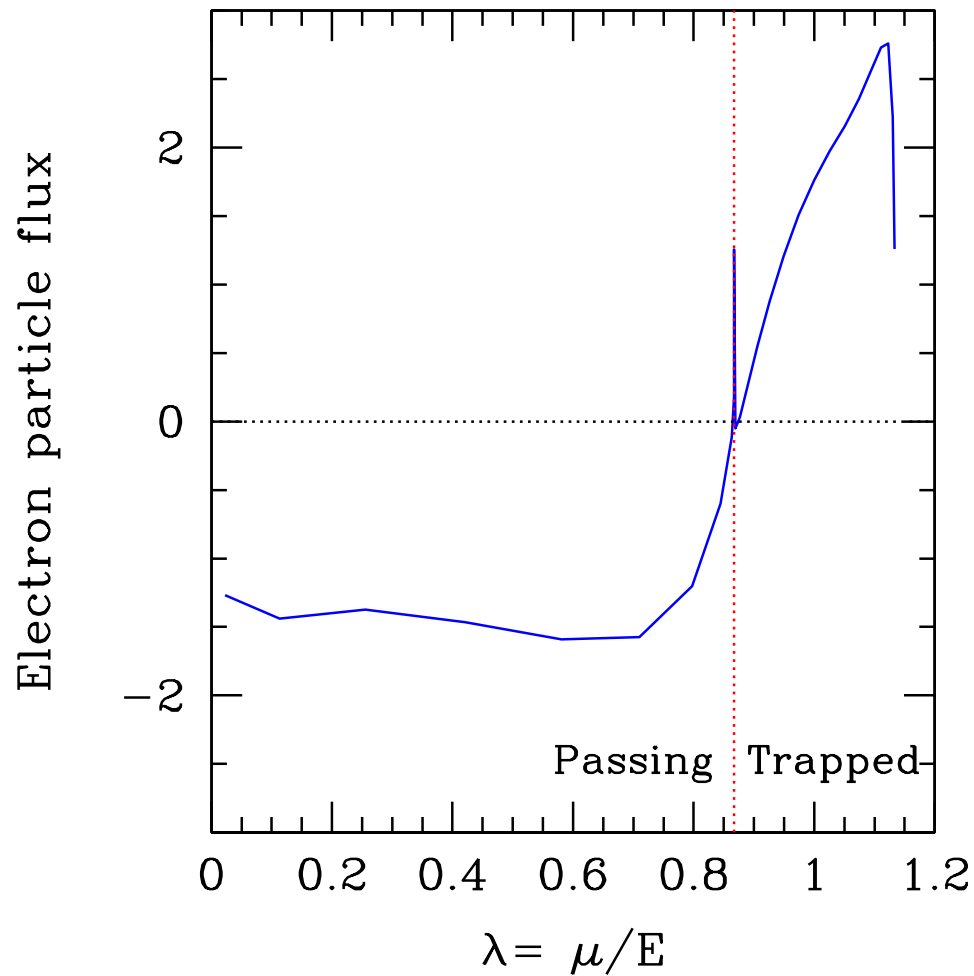
- **nearly adiabatic collisional electron response, Ion mixing mode [Coppi78]**  
collisional electrons; assume electrons to be nearly adiabatic, not affecting the dispersion of an ion mode; small deviation from adiabaticity creates negative particle flux
- **nearly adiabatic trapped electron response [Lee86,Terry89]**  
nearly adiabatic electrons, only trapped electron response dominates in higher temperature plasmas, passing particles assumed not to contribute because of short electron transit time and mode localization
- **radial equipartition of trapped electrons [Isichenko94,Nycander95,Baker98]**  
assumed passive advection of trapped electrons leads to compression in the tokamak center; problem: self consistency with ions

# Gyrokinetic result— TEM

- GS2 computation
- $\epsilon = 0.13, q = 1.8, \hat{s} = 0.5$   
 $T_i/T_e = 0.65, \nu_e^* = 0.13,$   
 $R/L_n = 3.4, \eta_e = 3$
- $\eta_i = 0.7 \rightarrow 1.5$ :  
particle flux changes sign
- temperature dependence  
→ equipartitioning ruled out.
- $Q_e = 18 \rightarrow 12,$   
 $Q_i = 1.5 \rightarrow 5$



# Gyrokinetic result— TEM

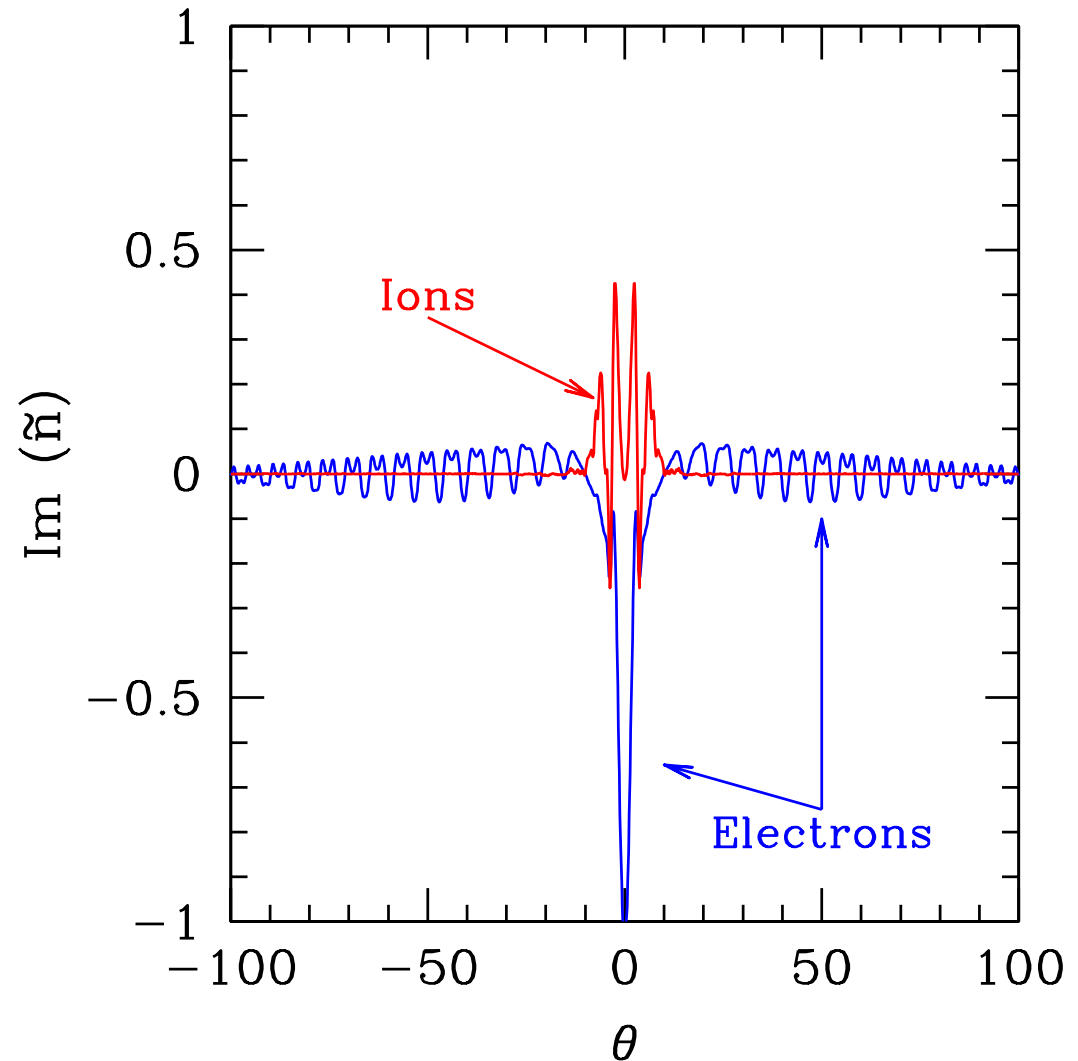


- ion trapping unimportant (too long bounce time)
- passing electrons carry pinch

# Gyrokinetic result— TEM

## dominant linear eigenfunction:

- density moment of perturbations
- ions: perturbation in narrow region around  $\theta = 0$   
→ source region of instability
- electrons: perturbation apart from narrow peak:  
very long scale component along the magnetic field lines



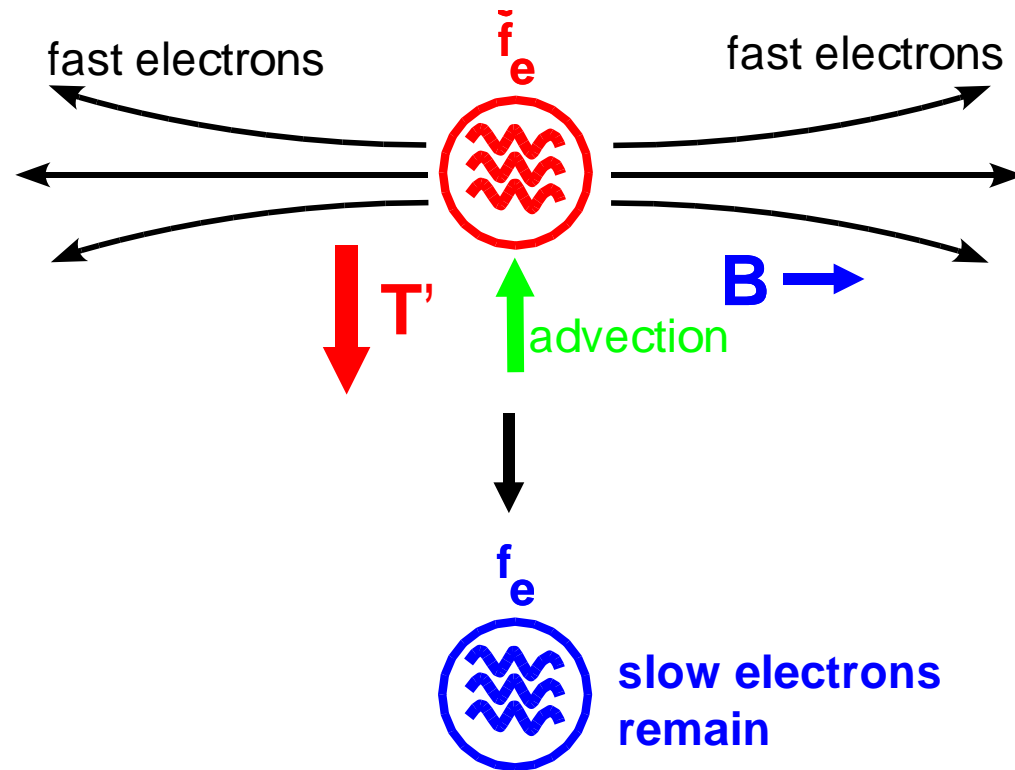
# Principle — Passing electron pinch

## Passing electron response:

$$k_{\parallel} v_{th,e} \gg \omega \quad |T'_e| \gg |n'|$$

## Nearly adiabatic electrons

- $\tilde{\phi}/T_e \approx \tilde{n}$ , deviation controlled by “stiff” electron response. ( $\rightarrow \tilde{n}$  out of phase with  $v_r = \partial_y \phi$ ) ion response is flexible (it strongly depends on  $\omega$ ).
- advection of hotter plasma onto fieldline  $\rightarrow$  perturbation in  $v_{\parallel} \sim v_{e,th}$  electrons quickly travels away
- negative perturbation of slow electrons remains (in phase with original  $v_r$ ) and is advected outward
- essential: cut off mechanism for fast electrons



# Principle — Passing electron pinch

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- radial gradient of background distribution (dimensionless units):

$$F'(v_{\parallel}) = (n' + T'(\frac{1}{2}v_{\parallel}^2 - \frac{1}{2}))F(v_{\parallel})$$

$T'$  sufficiently strong  $\rightarrow$  slow electron density gradient reversed.

## Why previously considered small?

- small factor  $\frac{\omega}{k_{\parallel} v_{th,e}} \sim 1/700$  in estimate for low gradient ITG turbulence
- However: mode structure not sinusoidal but gaussian  $\rightarrow$  continuous  $k_{\parallel}$  spectrum up to  $k_{\parallel} = 0 \rightarrow$  dominant singular contribution ( $\rightarrow$  long electron tails in the eigenfunctions)

# Principle — Passing electron pinch

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- Estimate of quasilinear flux due to deviation from adiabaticity ( $\gamma \sim \omega$ ):

$$\begin{aligned}\Gamma &= \int \frac{\gamma F'(v_{\parallel}) |v_x(k_{\parallel})|^2}{(\omega + v_{\parallel} k_{\parallel})^2 + \gamma^2} dk_{\parallel} dv_{\parallel} \\ &\approx \int_{v_{cutoff}}^{\infty} dv_{\parallel} \int dk_{\parallel} F'(v_{\parallel}) |v_x(k_{\parallel})|^2 \frac{\pi}{v_{\parallel}} \delta(\omega/v_{\parallel} + k_{\parallel}) \\ &\approx \int_{v_{cutoff}}^{\infty} F'(v_{\parallel}) |v_x(0)|^2 \frac{\pi}{v_{\parallel}} dv_{\parallel} \\ &\sim \pi F'(0) |v_x(0)|^2 \ln(v_{e,th}/v_{cutoff})\end{aligned}$$

$v_{cutoff} \approx \omega/\Delta k_{\parallel}$  ( $\Delta k_{\parallel}$ : spectral width of velocity  $v_x(k_{\parallel})$ )

- typically  $v_{cutoff} \sim 1$ ,  $v_{e,th} \sim 60 - 70$ , enhancement factor  $\ln(70) \sim 4$ . Furthermore higher gradients than assumed in trapped electron estimates.

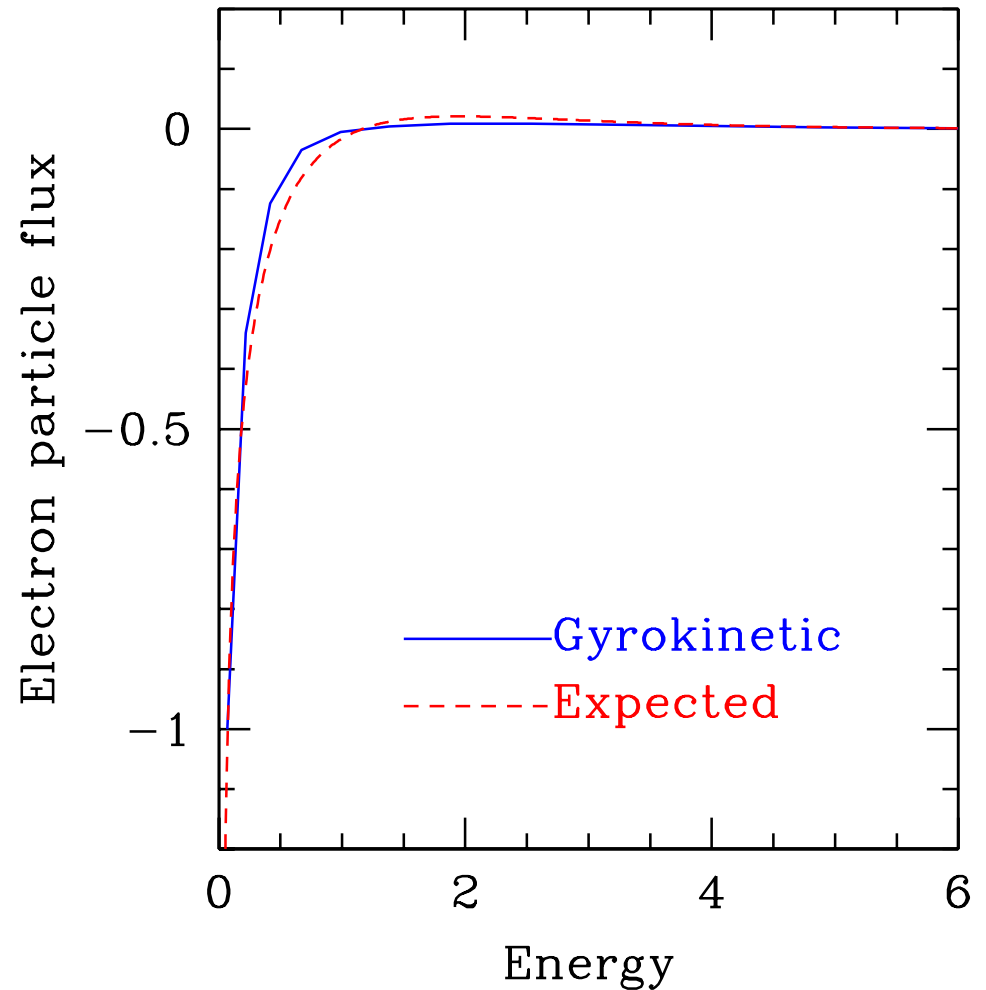
# Gyrokinetic result— TEM

## Detail of passing electron flux:

- radial flux of electrons with  $\mu/E = 0.2$  versus  $E$

- estimate

$$\propto F'(v) |v_x(0)|^2 \frac{\pi}{v_{\parallel}}$$
$$= \frac{(3.34 + 10(E - 3/2)) \exp(-E)}{v_{\parallel}}$$



# Principle — ETG pinch

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## Nearly adiabatic ions:

- $k_{\perp} \rho_i \sim 1$  and very high  $\omega \rightarrow$  parallel electron motion sluggish
- ions can move quickly within one ion gyro radius
- $\rightarrow$  stiff ion response producing  $\phi/T_i \sim -\tilde{n}_i$  (sufficiently small perp. scales), flexible electron response

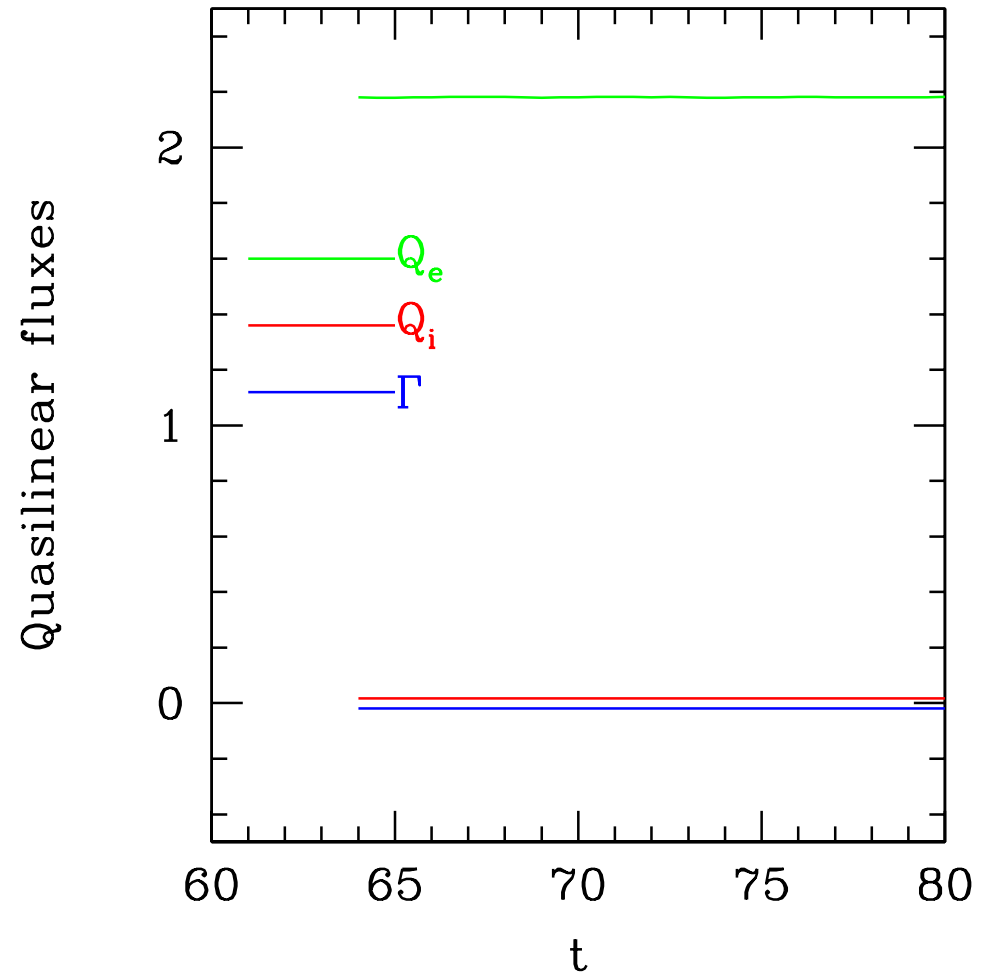
## Pinch mechanism (analogous):

- sufficiently strong ion temperature gradient
- perp. advection perturbs distribution function
- ion perturbation at high  $v_{\perp}$  smeared out over ion gyroradius ( $J_0$  filtering)
- perturbation near  $v_{\perp} = 0$  remain correlated with original advective velocity
- high enough temperature gradient creates negative radial phase space density gradient near  $v_{\perp} = 0$

# Gyrokinetic result— ETG

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- very high pedestal gradients
- high resolution of ion perp. velocity space



# Conclusions

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- Significant pinch effects have been found in gyrokinetic turbulence simulations in the core and in the edge in TEM and ITG turbulence
- Different from expectations the passing electrons can play a major role
- The passing particle pinch effect seems to be well described by a simple analytic model and involves very small parallel wavenumbers
- A novel pinch effect in the case of ETG modes has been found
- The pinch effects observed in collisional edge turbulence simulations involve electrons far from adiabaticity