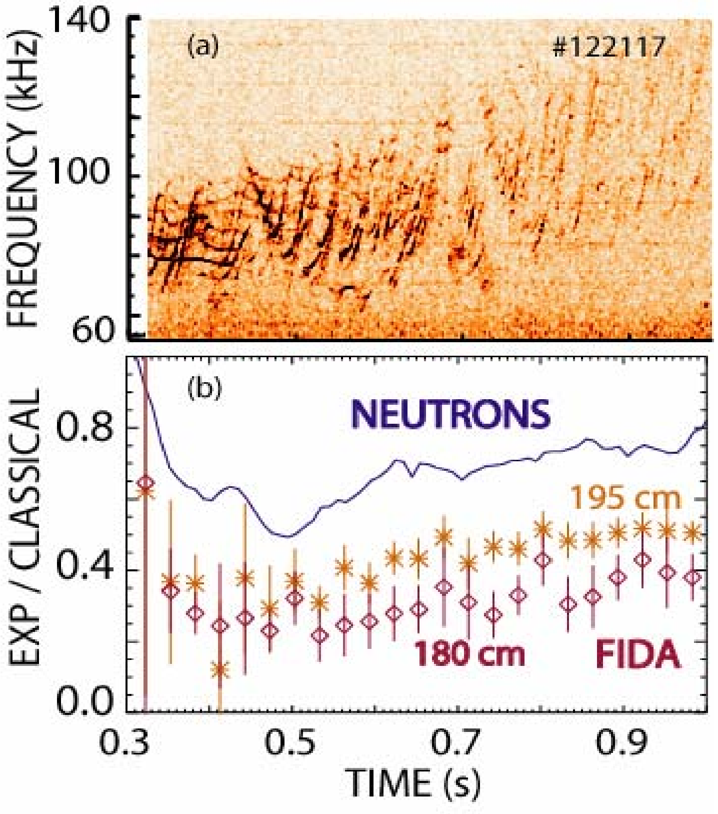
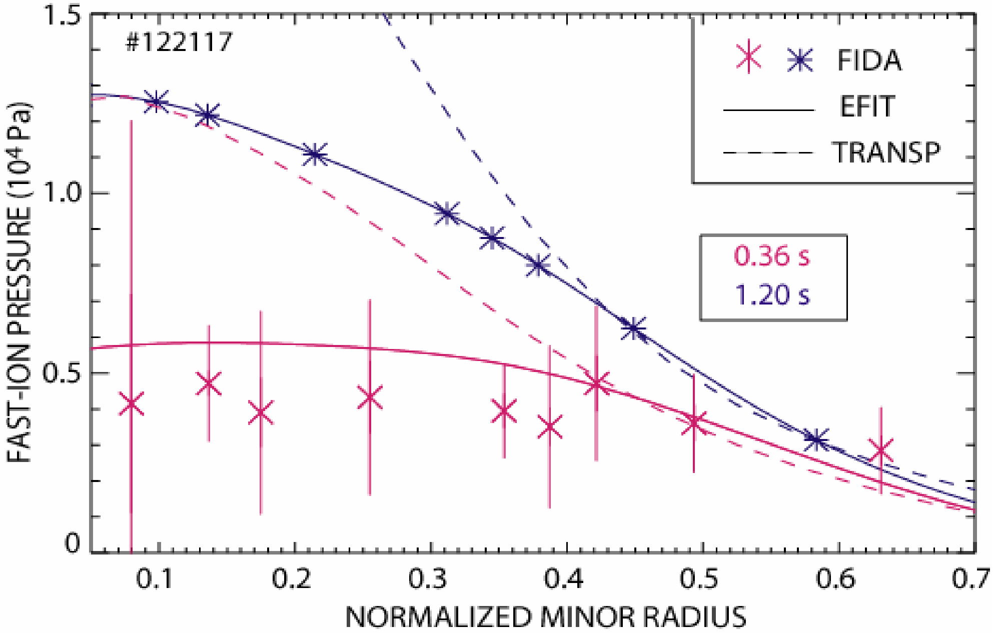
Severe Flattening of Fast-ion Profile Measured during Alfven Eigenmodes

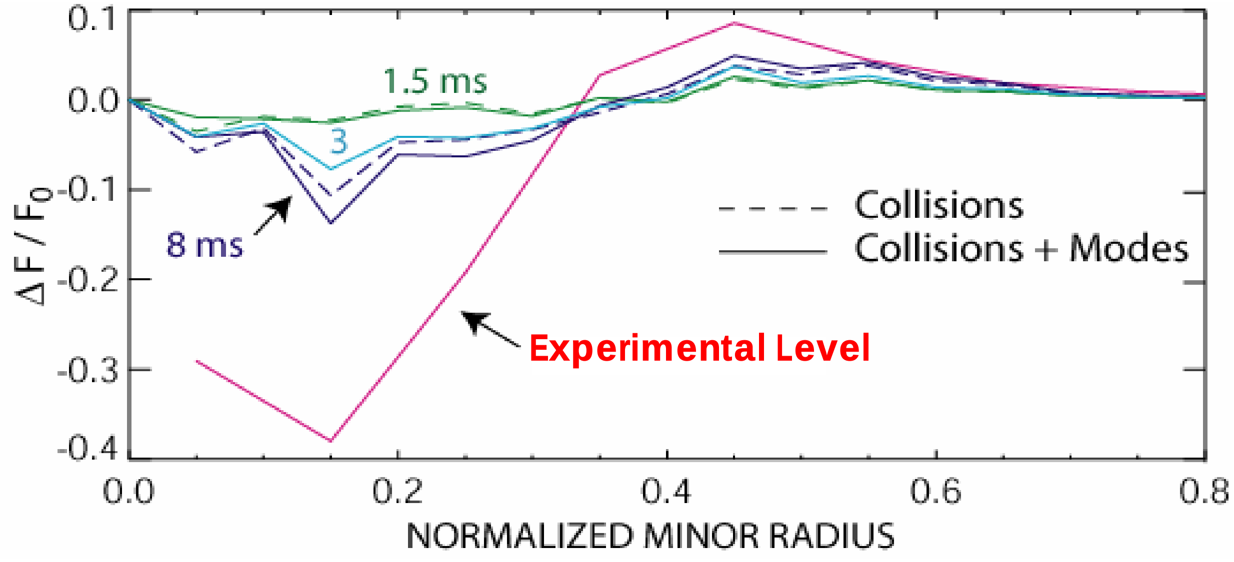


- **Lots of constantly changing modes**
- **Modeling is performed for a time short compared to τ_s**
- **Measured distribution function is fully evolved**



Heidbrink, PRL 99 (2007) 245002; NF 48 (2008) 084001.

The first (crude) comparison showed theory was an order of magnitude too small

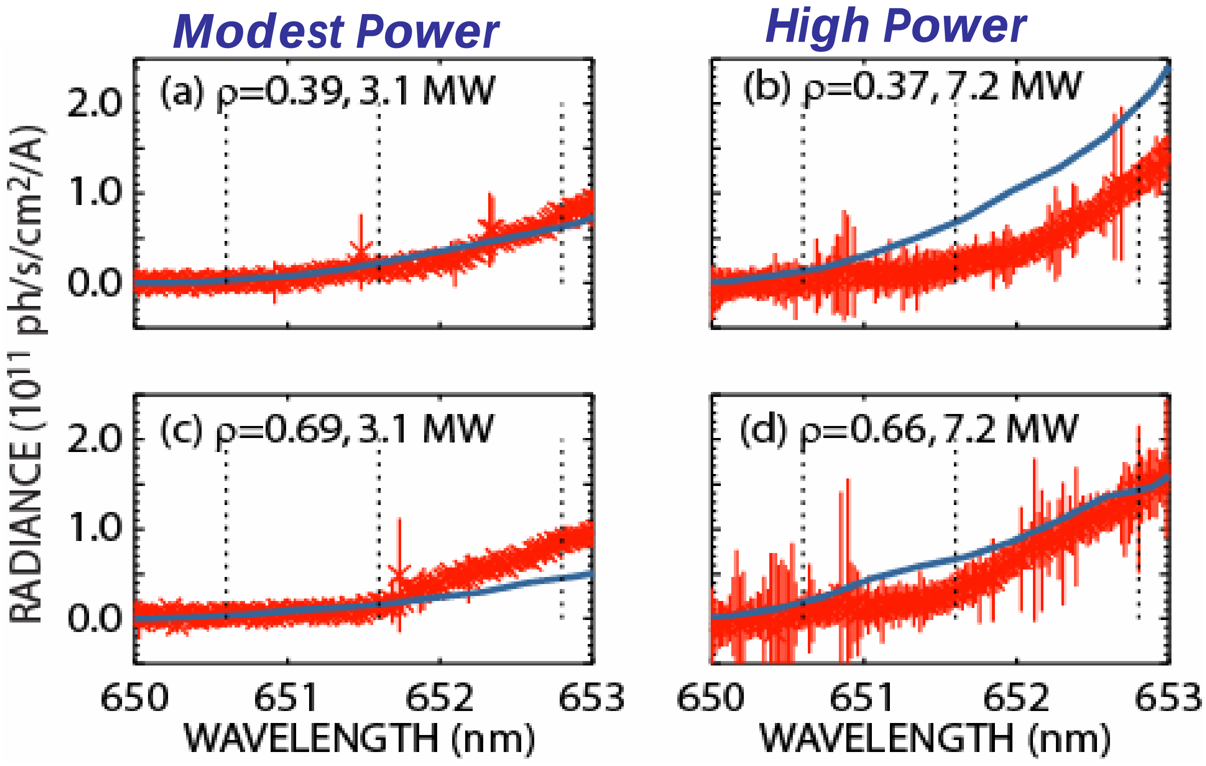


- The normalized change in the distribution function in the co-passing part of phase space is shown for ORBIT runs of varying duration.

- The red curve is the change observed in the TRANSP runs with *ad hoc* D_B in ~ 8 ms. *(This was a rough estimate.)*

- Now that theory is the right order of magnitude, how do we make a more accurate comparison?

Recent Evidence that Microturbulence causes Fast-ion Transport



Line: Classical Theory

- Spectral shape deviates from classical theory when temperature is large, Doppler shift is small; more pronounced at larger minor radius
- Steady-state transport; measure fully-evolved distribution function

Heidbrink PRL 102 (2009) submitted.

Theoretical Explanation for Small Diffusion: Large Orbits Phase Average

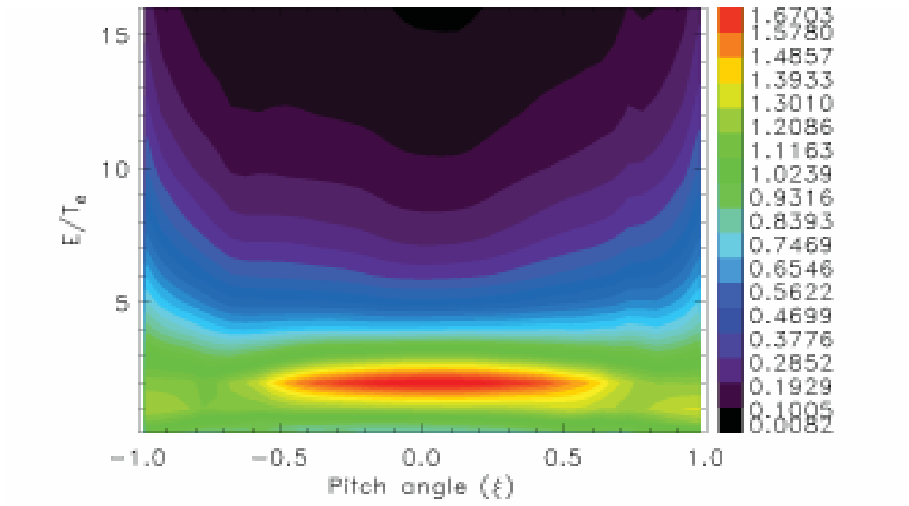
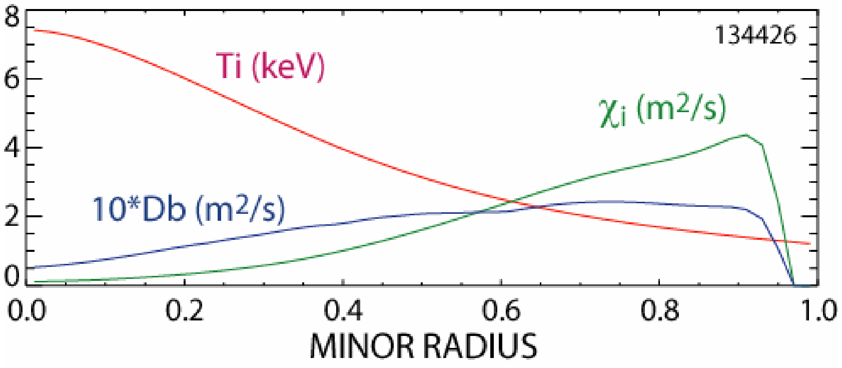


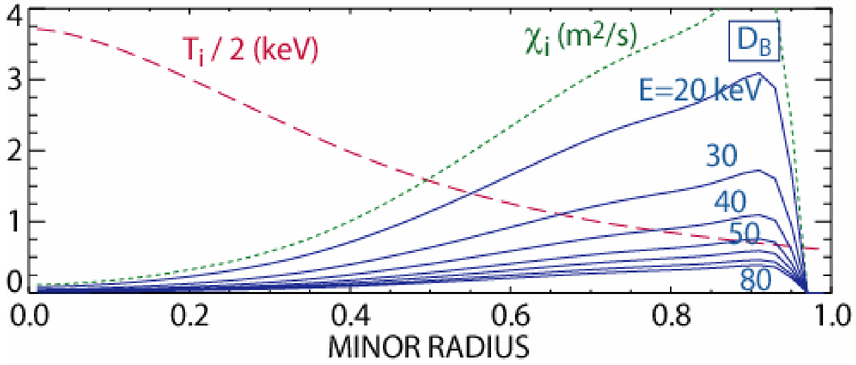
FIG. 3 (color). Diffusivity $D = D_I$ as a function of particle energy $E = T_e$ and pitch angle ξ.

W. Zhang, Phys. Rev. Lett. 101 (2008) 095001.

- **Transport scales with E/T (fast-ion energy/temperature)**
- **$D_B(r) = c[E/T(r)]\, D_i(r)$**

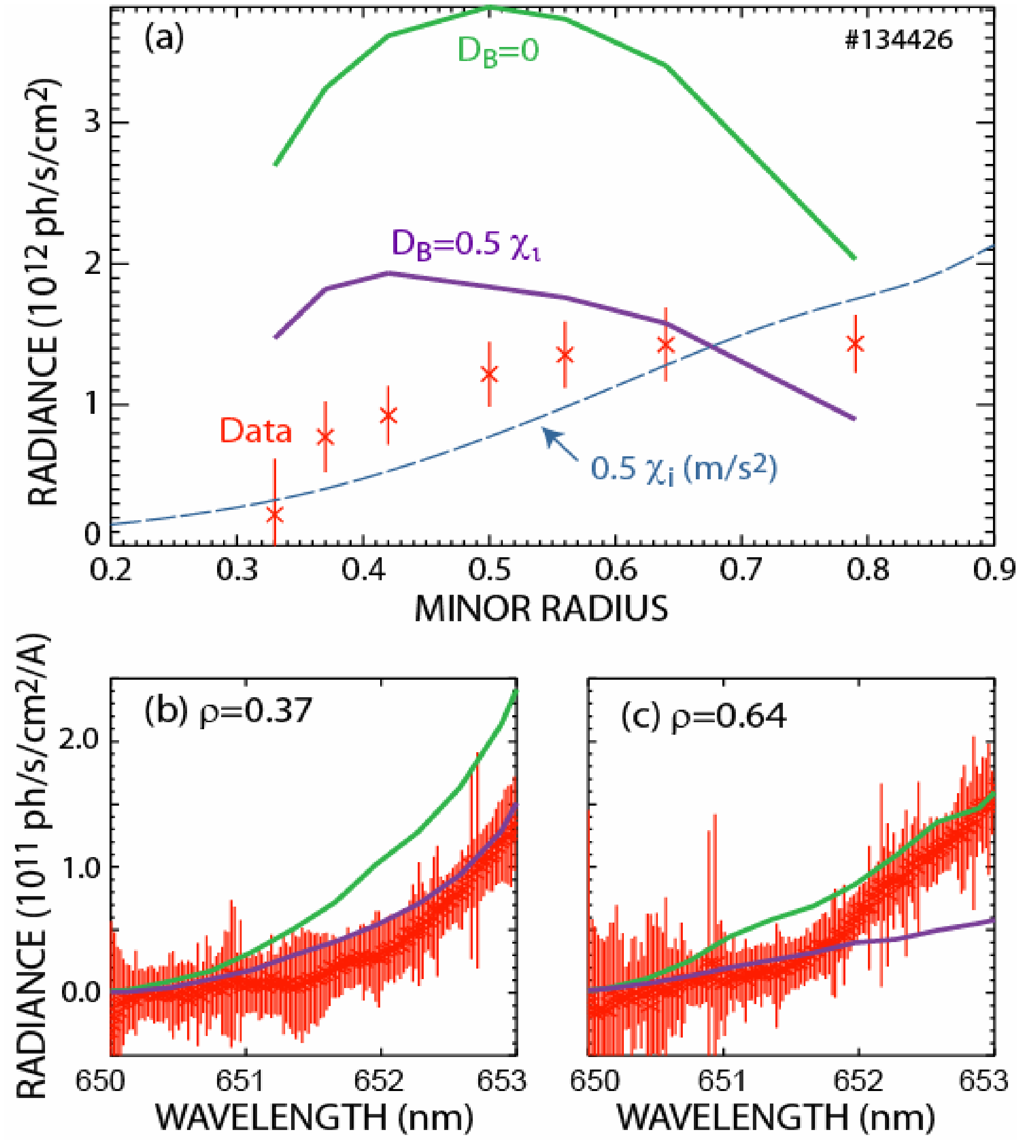
Use TRANSP D_B for quantitative estimate of expected effect





- **Want to model**
  $D_B(r)=c[E/T(r)]\ D_i(r)$
- **NUBEAM assumes separable dependence: $D_B=g(E)h(r)$**
- **First try: Use experimental value of E/T_i to estimate magnitude of transport, then multiply by χ_i**
- **Second try: Use $D_B(E)$ for a particular T_i, multiply by χ_i**
- **Both give right magnitude but neither reproduce FIDA spectra or profile**

The predicted transport is the right order of magnitude but the details are wrong



- This example from first modeling attempt
- The second approach yields something similar
- TRANSP produces a fully-evolved f →suitable input for forward modeling
- Current NUBEAM can’t get phase-space details right

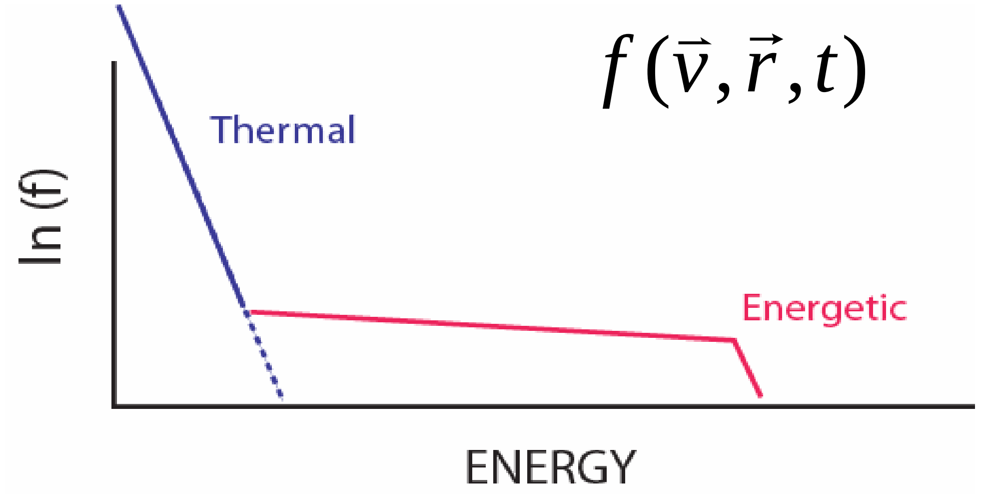
Why is quasi-steady transport hard to model?

- Theory computes a flux (Δf)
- Experiment requires the evolved f

Important simplification*:** **Although the forward modeling to simulate the diagnostic signals is complicated, it is linear → can concentrate on finding *f

Combine TRANSP with physics-based instability transport

- **Source: *S***
- **Collisions: *C***
- **Waves: *Q***
- **Losses: *L***



$$\boxed{\partial f / \partial t = S + C + Q + L}$$

- **TRANSP accurately treats source, collisions, and losses**
- **Derive D_B (and convective flux) from simulations → insert into TRANSP**

Bottom Line

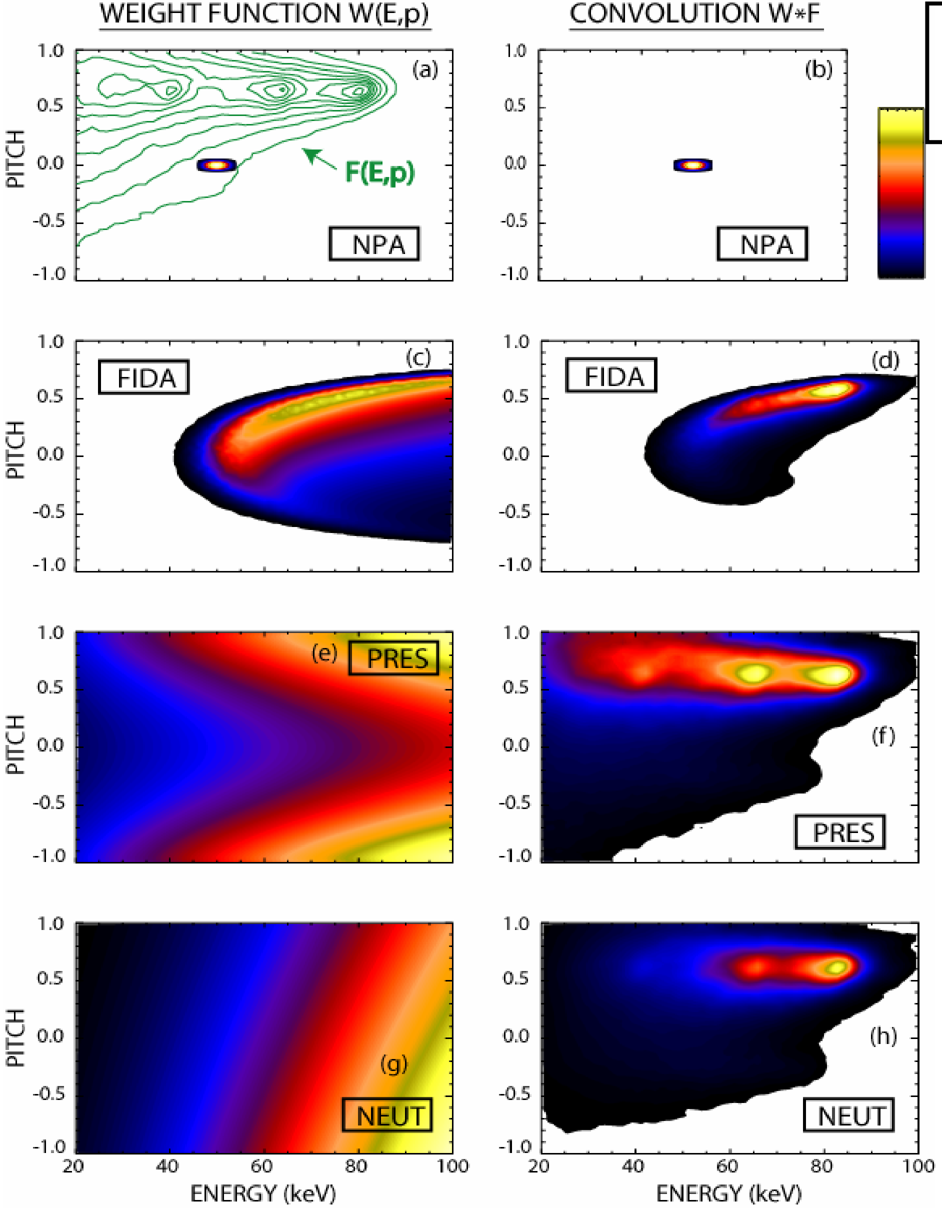
- Need to decide required form of D_B and Γ_B to describe relevant wave-particle interactions

- This capability needs to be incorporated into TRANSP

→ enables quantitative validation of theory

Backup Slide

How do the diagnostic measurements relate to the fast-ion distribution function?



$$Signal = \iint (W \times F)\, dE\, dPitch$$

- Define a “weight function” in velocity space
- Like an “instrument function” for spectroscopy
- Sharp “W” best for physics mechanism; broad “W” best for average properties

Heidbrink, PPCF 49 (2007) 1457