Particle acceleration at the discontinuous flow boundary of collimated cylindrical jets

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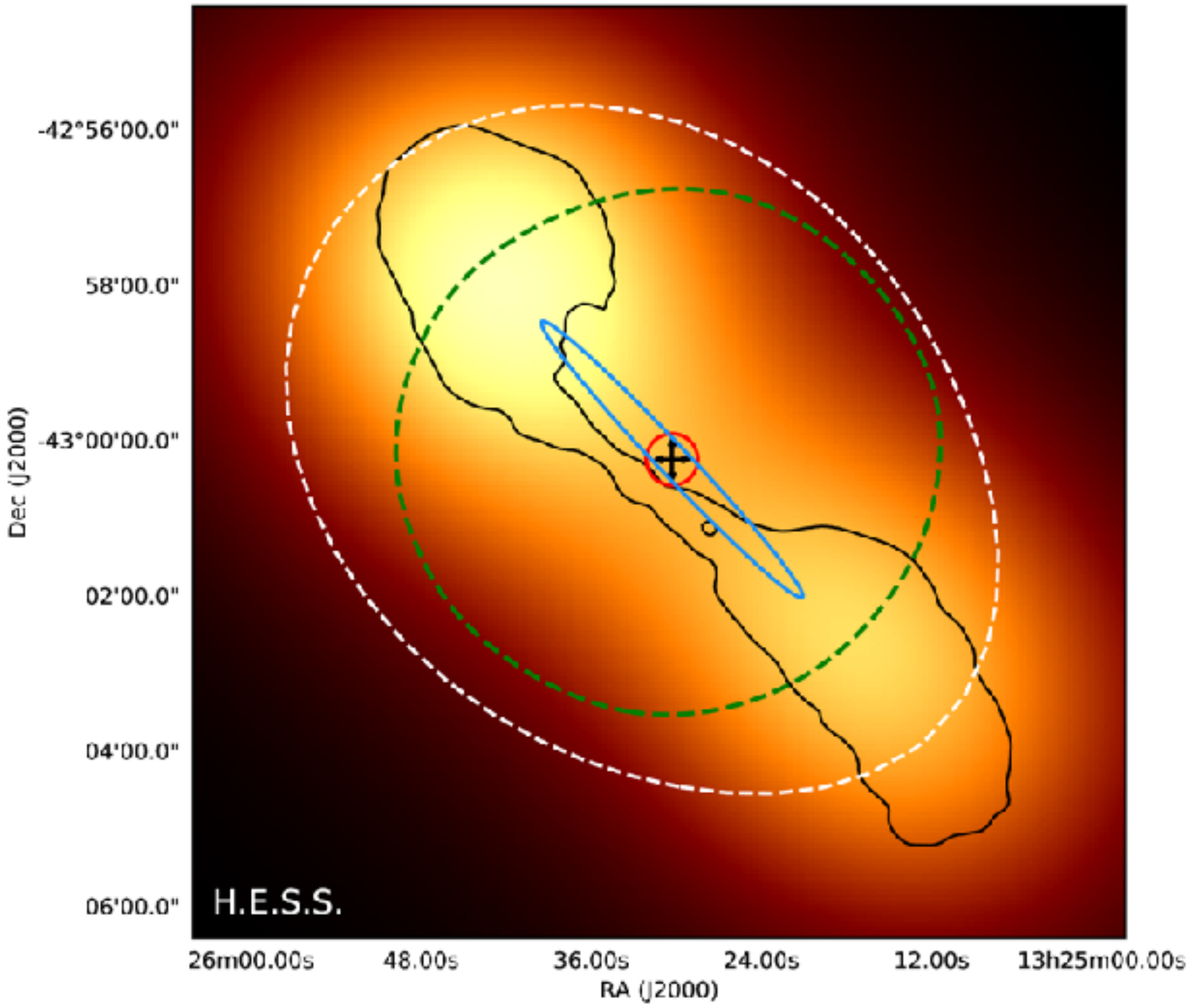
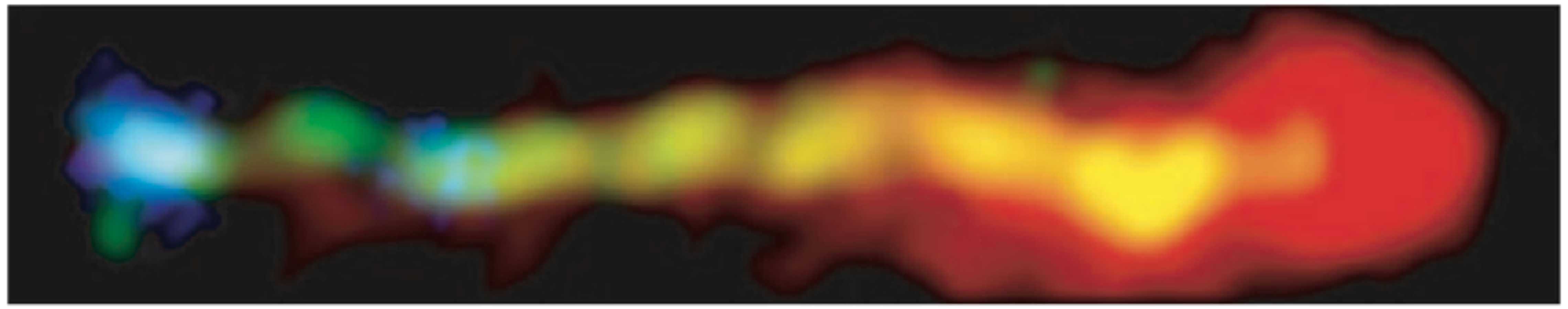
Continuous Acceleration in kpc jets - Shearly You're Joking.....

[Cen A - HESS Collaboration, Nature 2020]

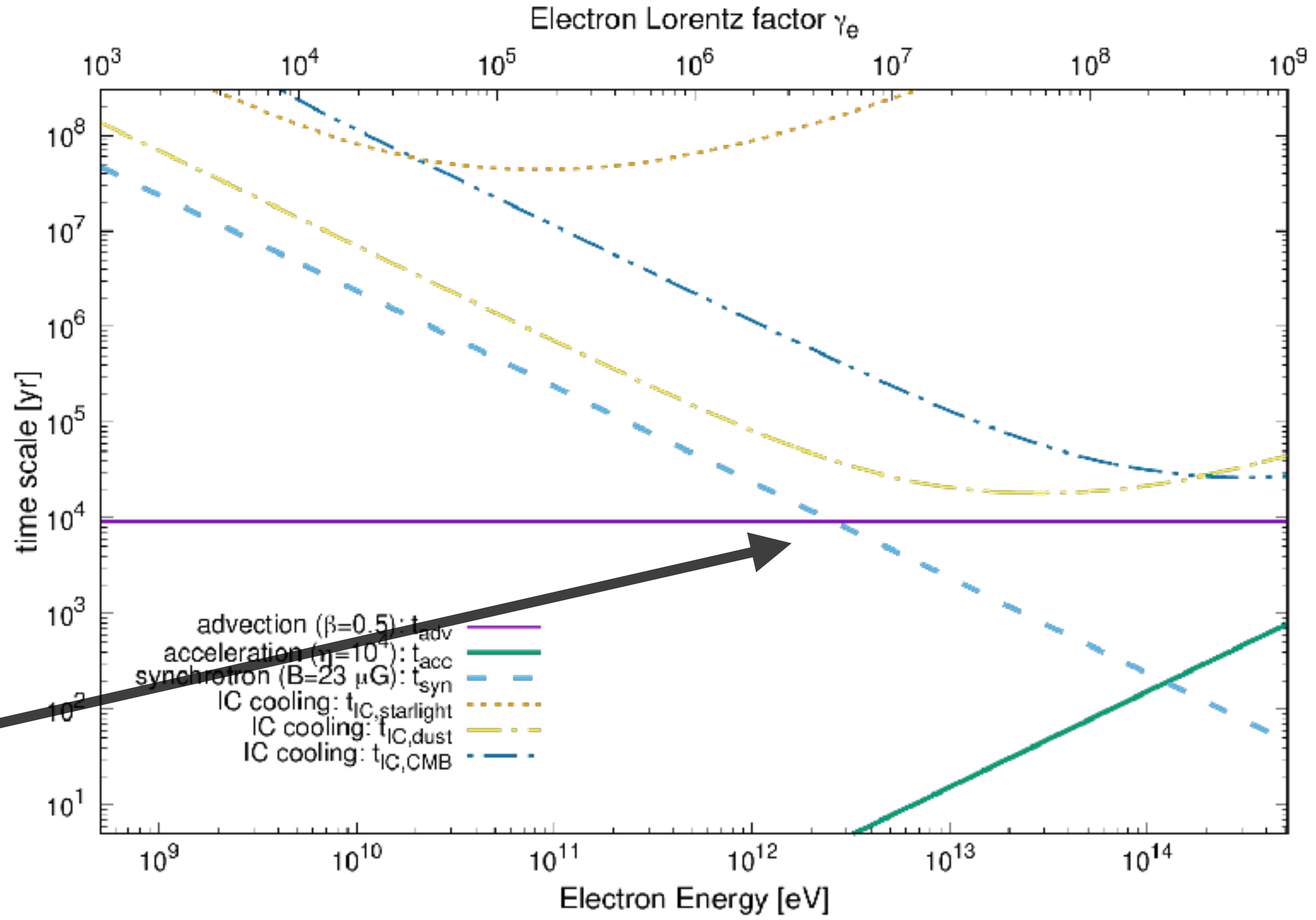




Chandra
HST
VLA

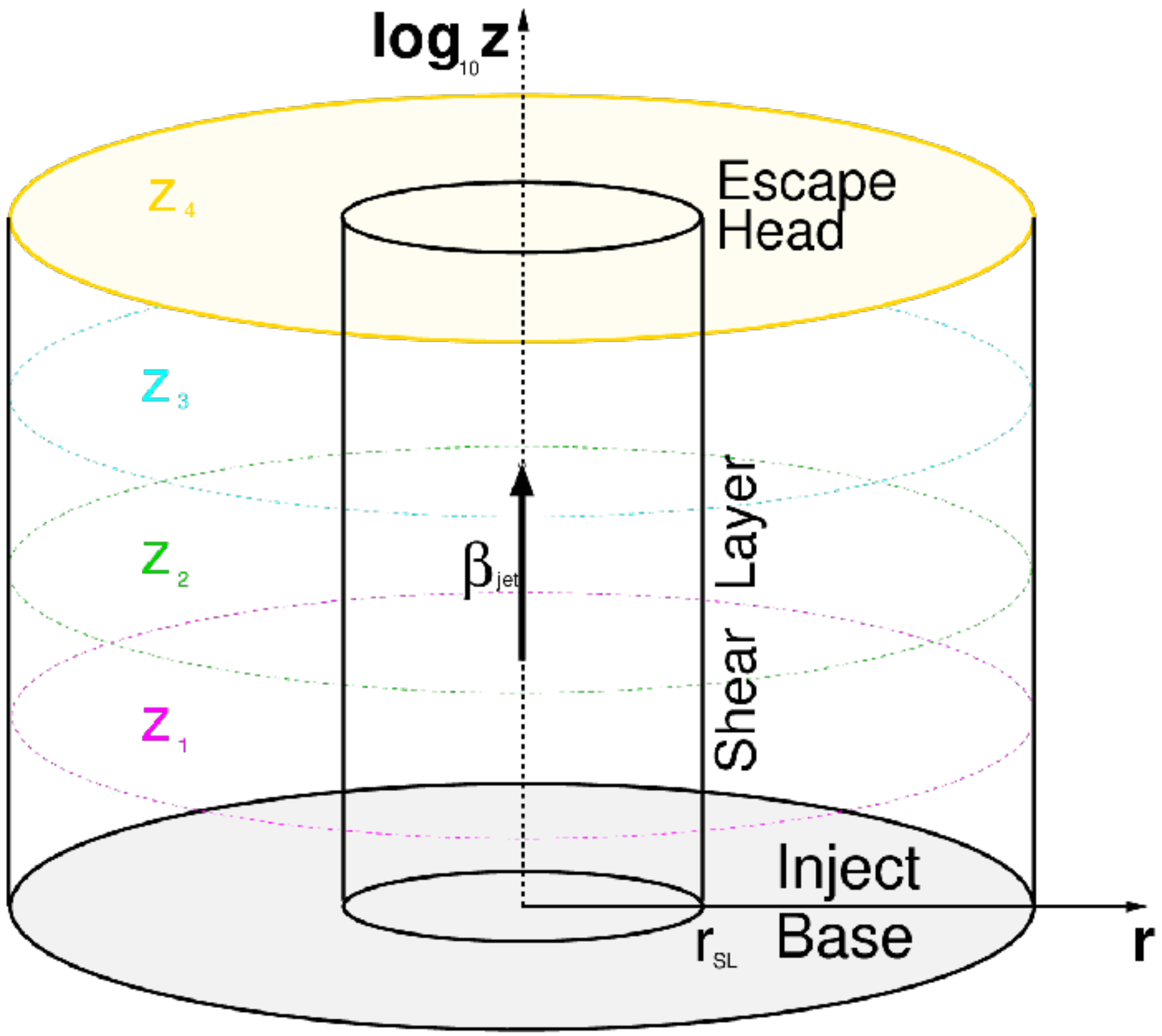
[3c 273 Jester et al., ApJ 2006]

Radiating electrons must be accelerated in situ along the jet



Cooling time becomes shorter than advection time

Shear Action - Shear simplicity



Easy to employ a simple toy model of *non-gradual shear in relativistic jets* (e.g. Ostrowski '90, Rieger Duffy '04, Caprioli '15):

- Top-hat jet profile (Here we adopt $\Gamma_j = 10$)
- Random isotropic scattering in local frame (Here Kolmogorov)

Define $\rho = r_g / r_{jet}$

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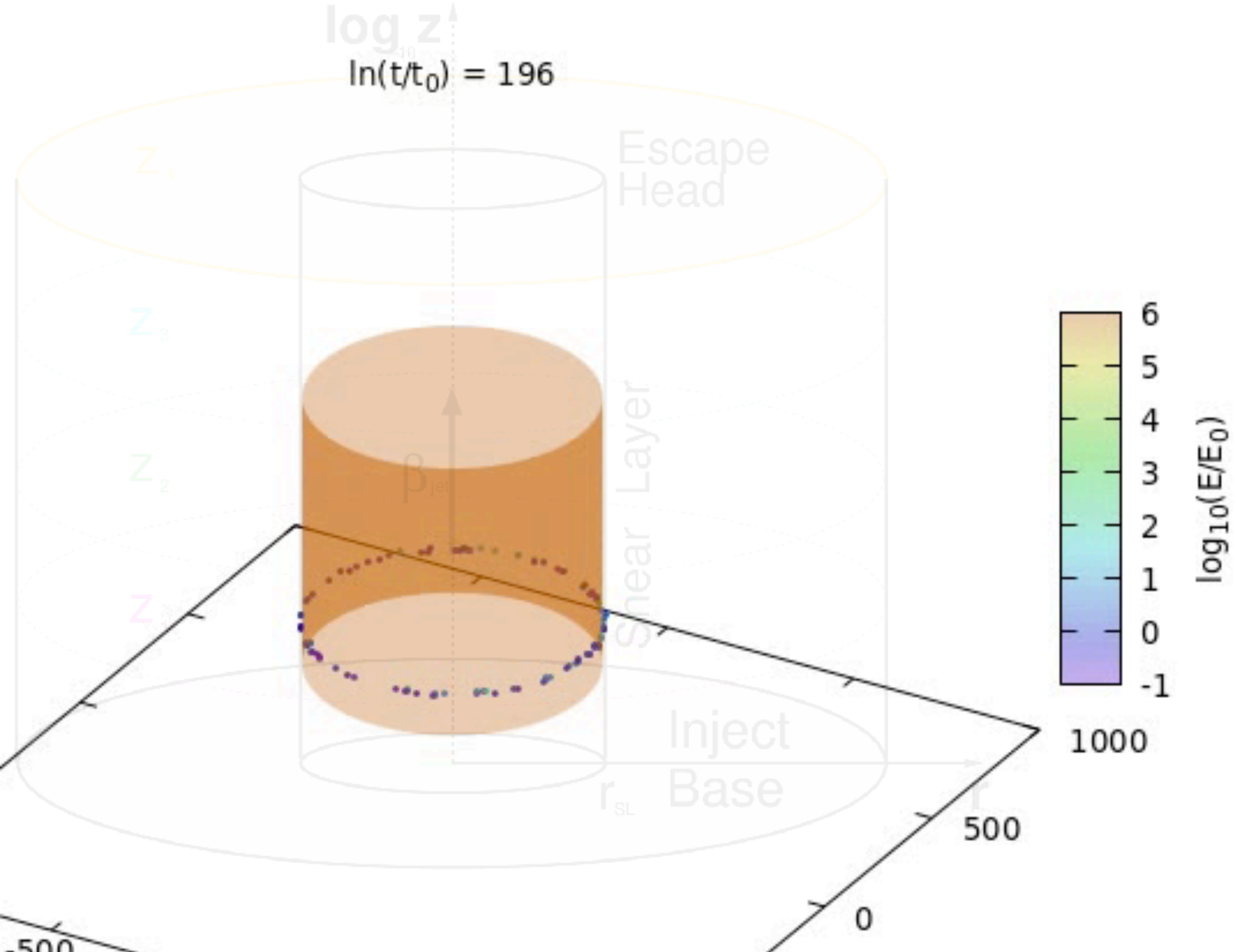

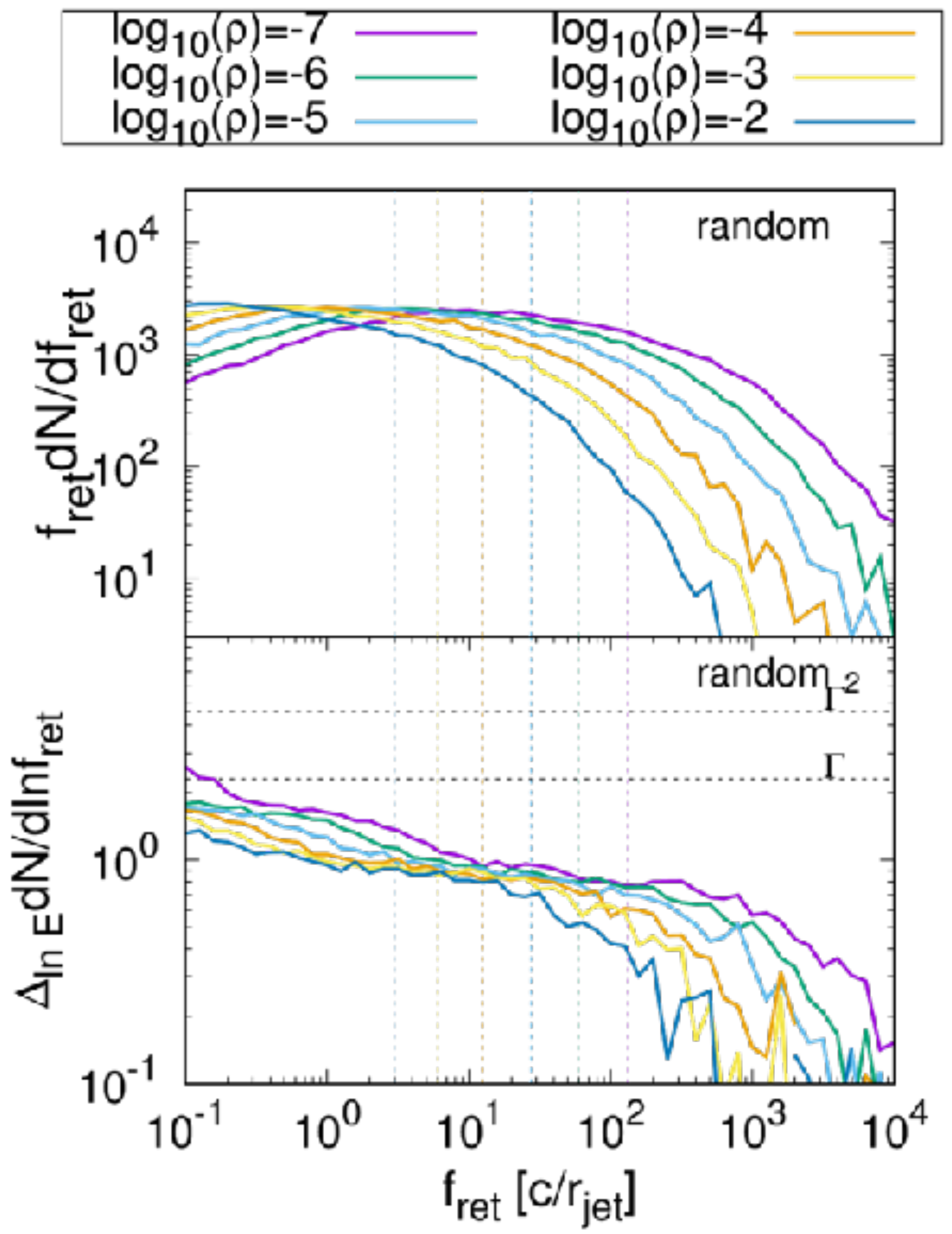

Return time distribution

Energy boost distribution

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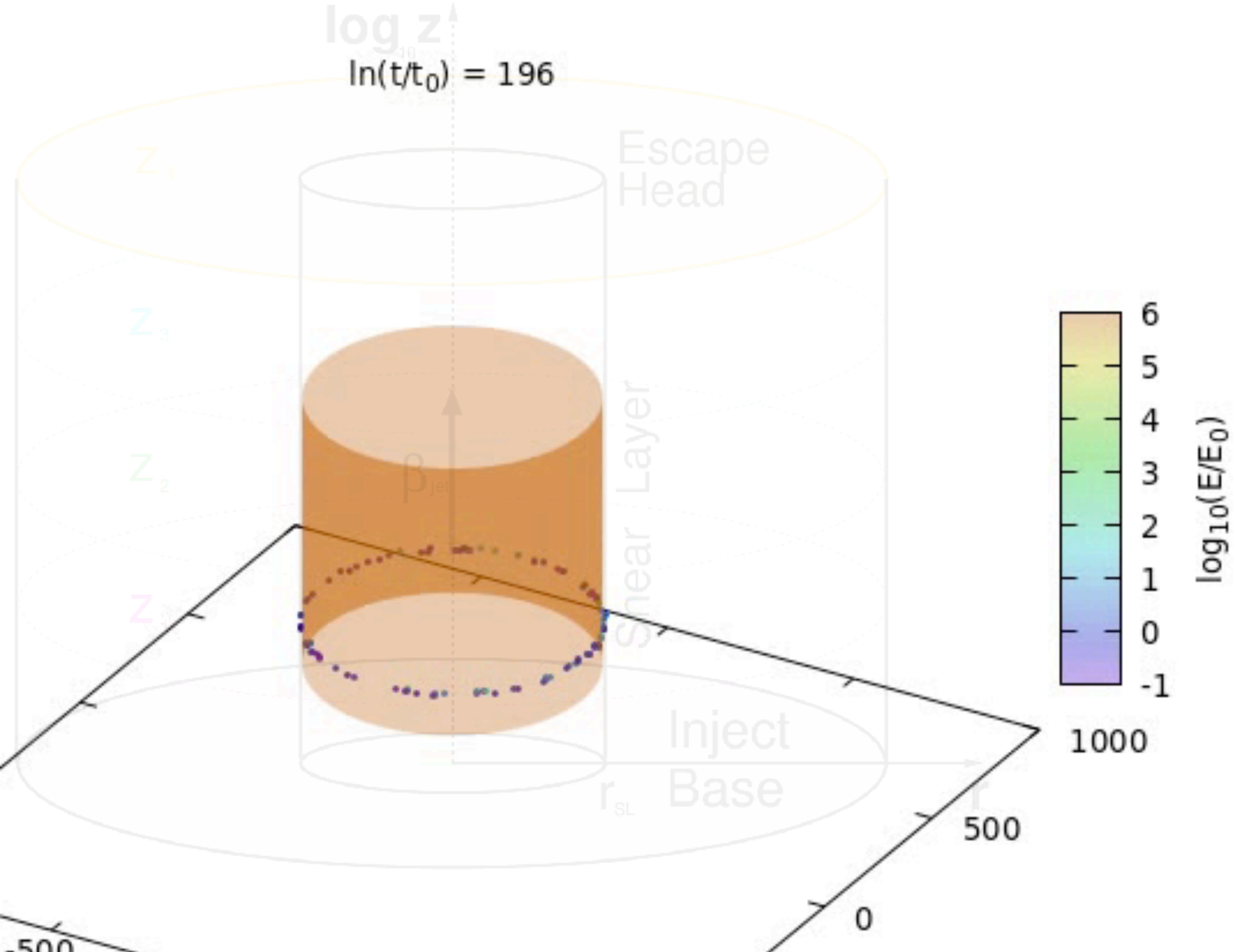

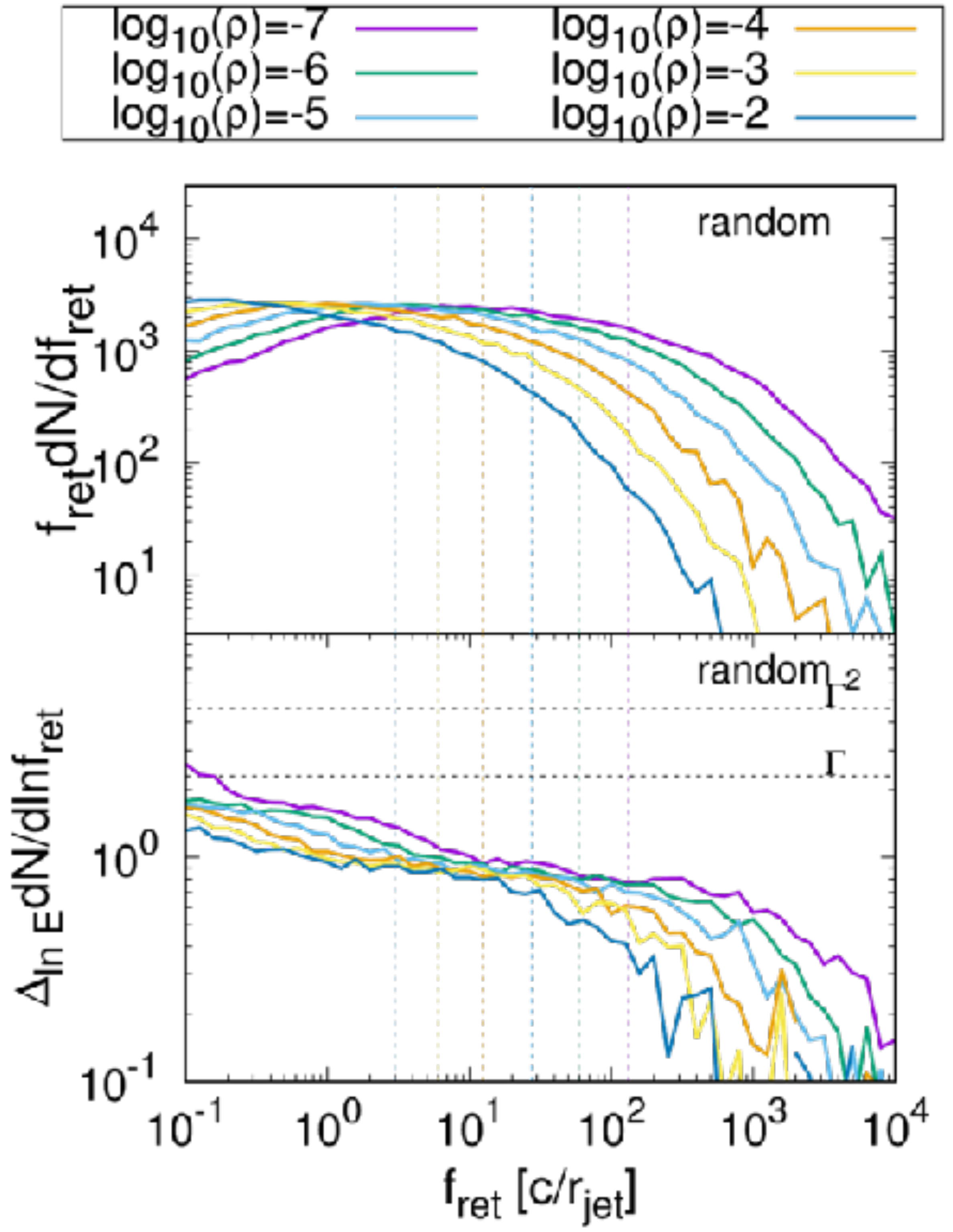

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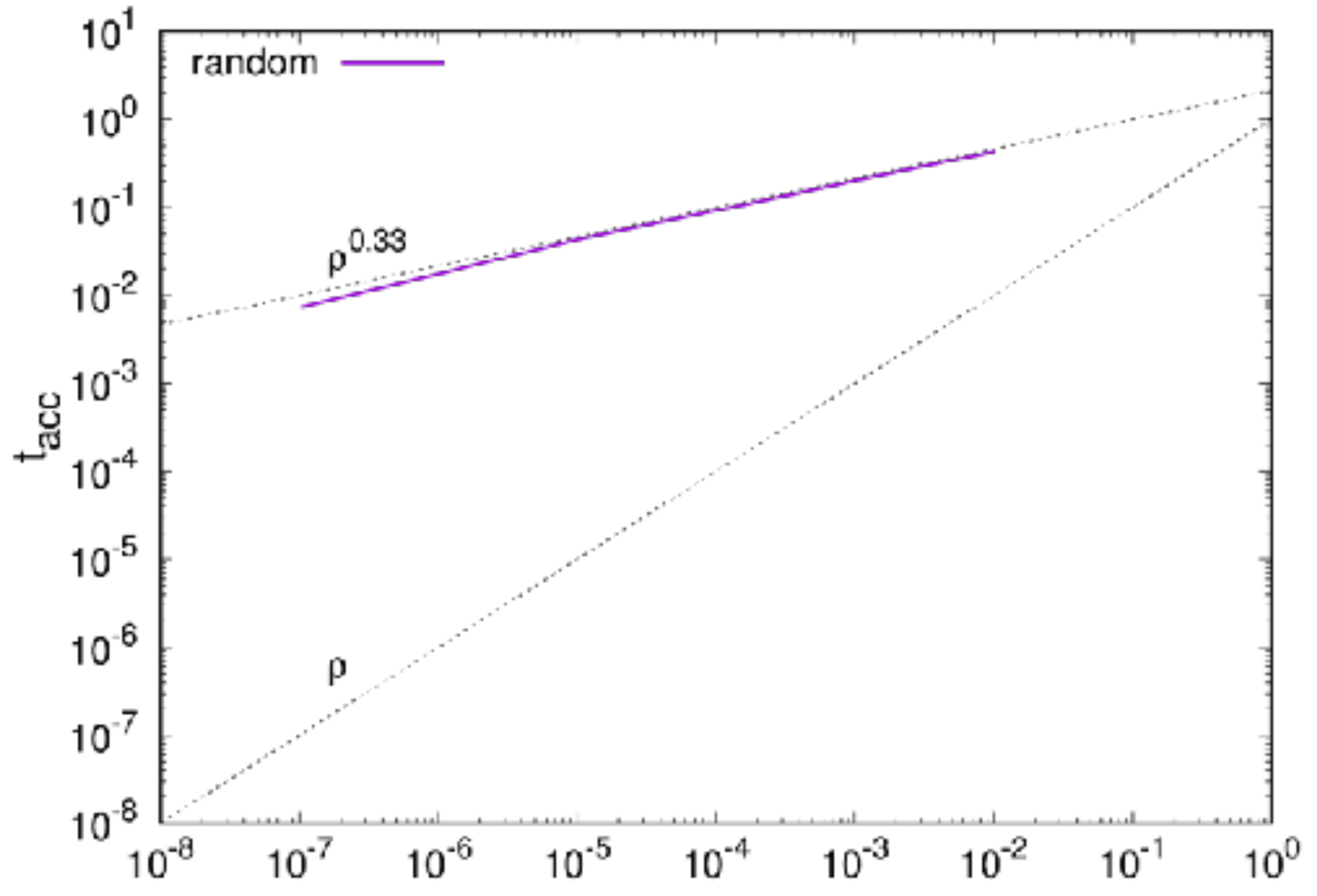
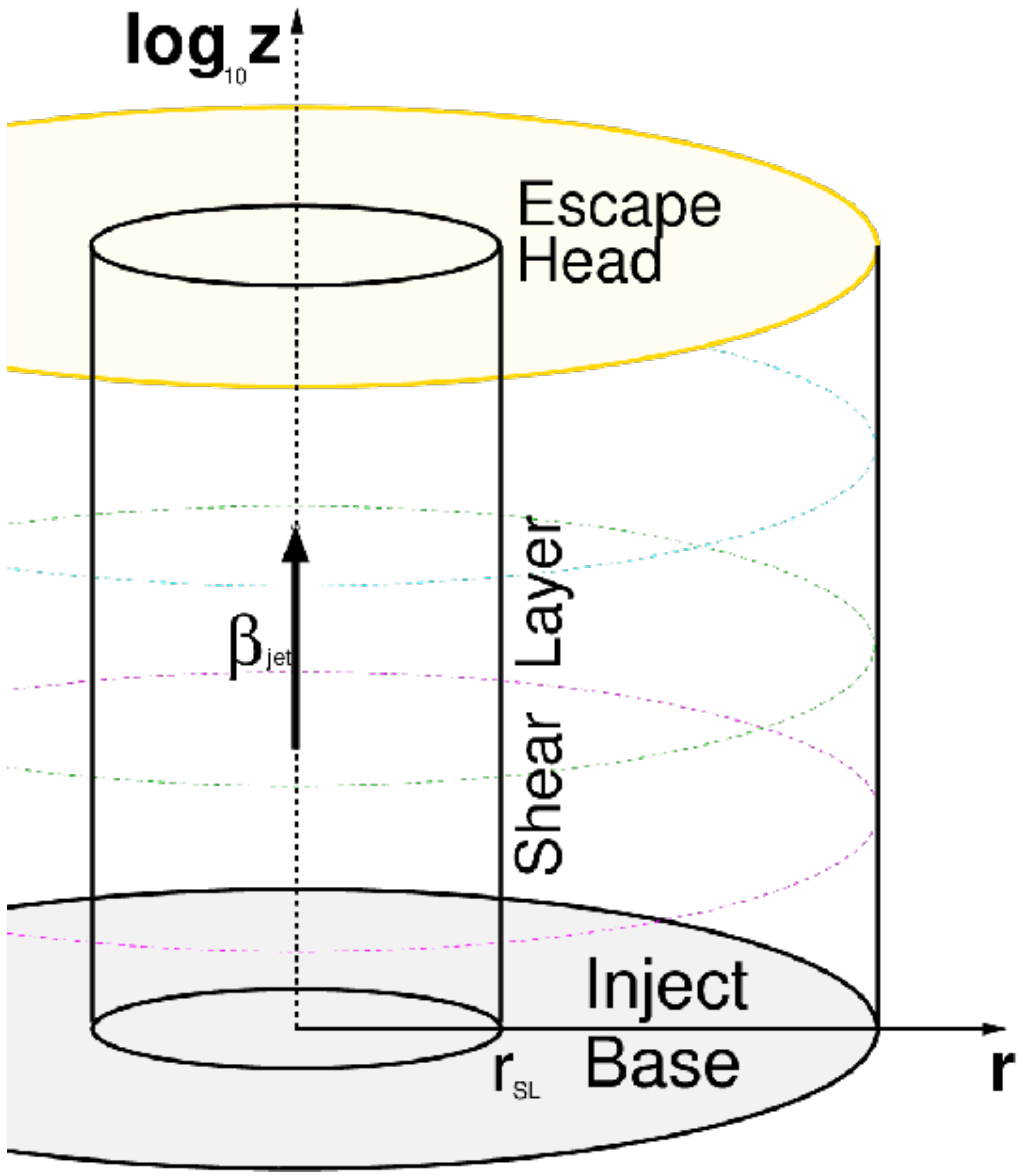


$\rho = r_g / r_{jet}$

Kolmogorov scattering $t_{sc} \propto E^{1/3}$
Since only one timescale in problem, unsurprisingly $t_{acc} \propto E^{1/3}$

Shear Action - Shear simplicity

Steady-state spectrum
for continuous injection
at base of jet



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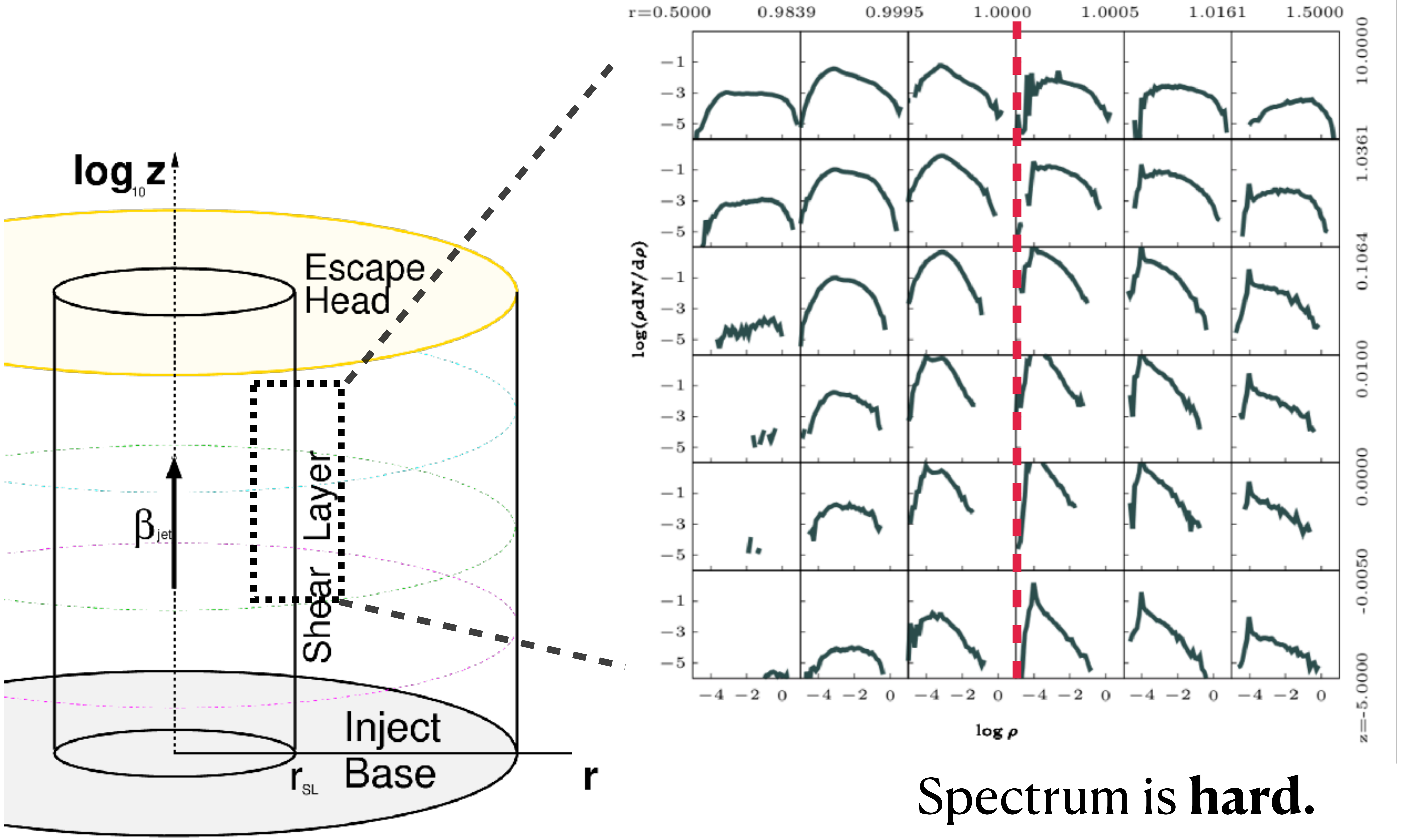
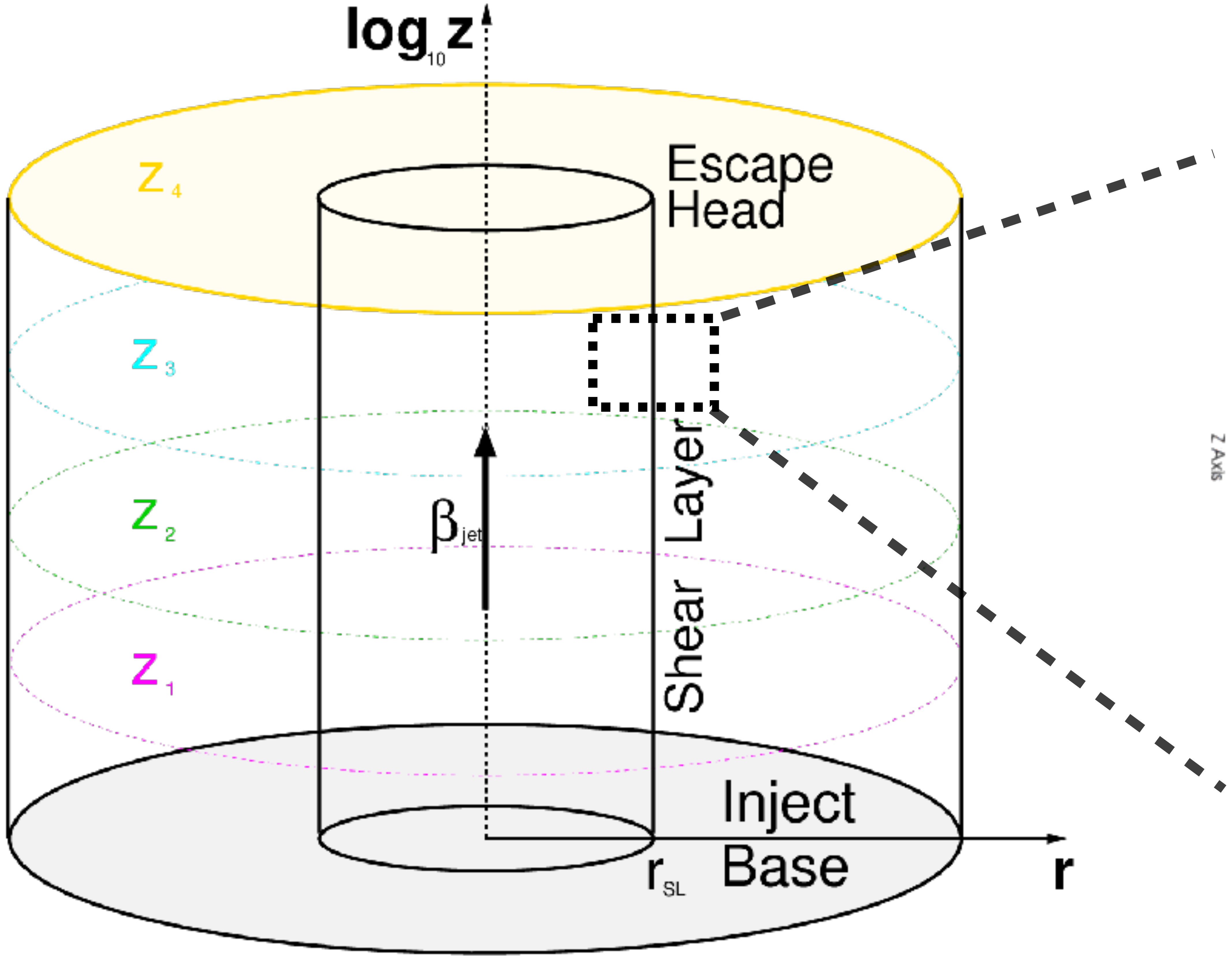
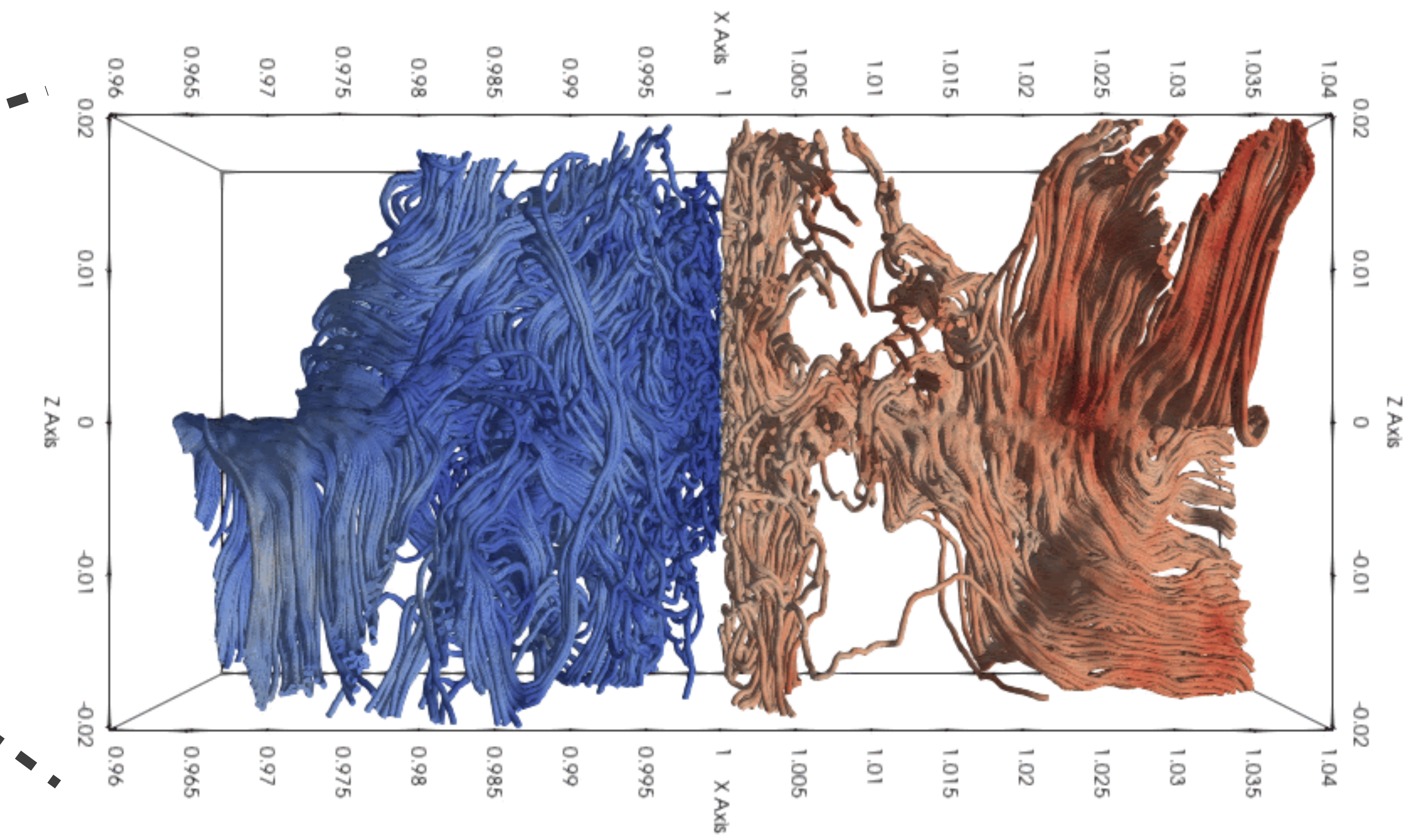


Spectrum is **hard.**
Highest energy particles
accumulate at “head” of jet

Shear Action - Shear simplicity

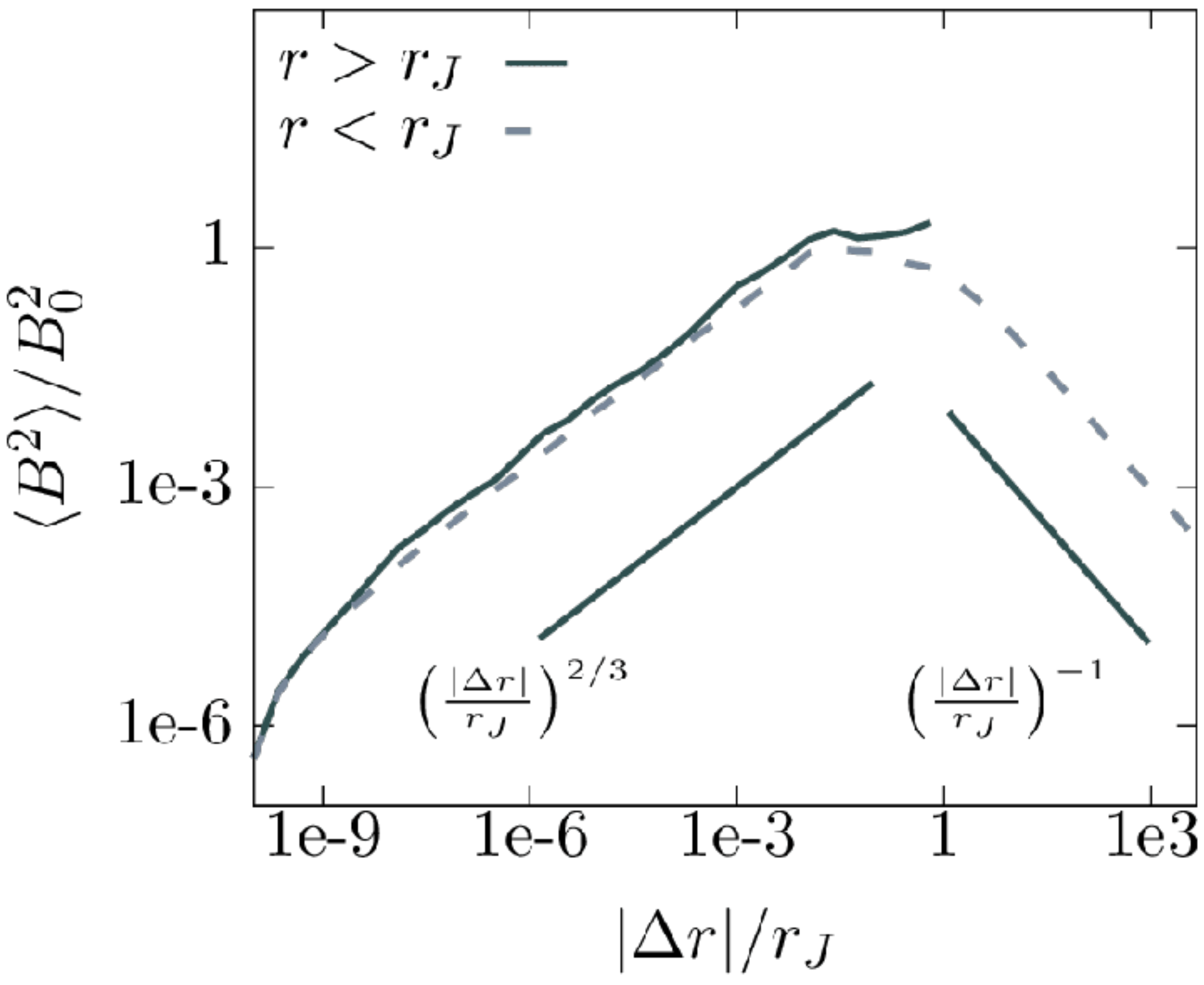
Trying to move beyond the simple toy model instantly reveals the issue





Field lines should **not** thread the boundary

Geometric constraints - a shear cliff



$(\Delta r = r - r_\mathrm{J})$

Adopting a physically motivated Ansatz

$$l_c(r) \sim \begin{cases} |\Delta r|, & |\Delta r| < l_c^0, \\ l_c^0, & |\Delta r| \geq l_c^0, \end{cases}$$

Magnetic field power falls as $|\Delta r|^{q-1}$ **as the shear boundary layer is approached.**

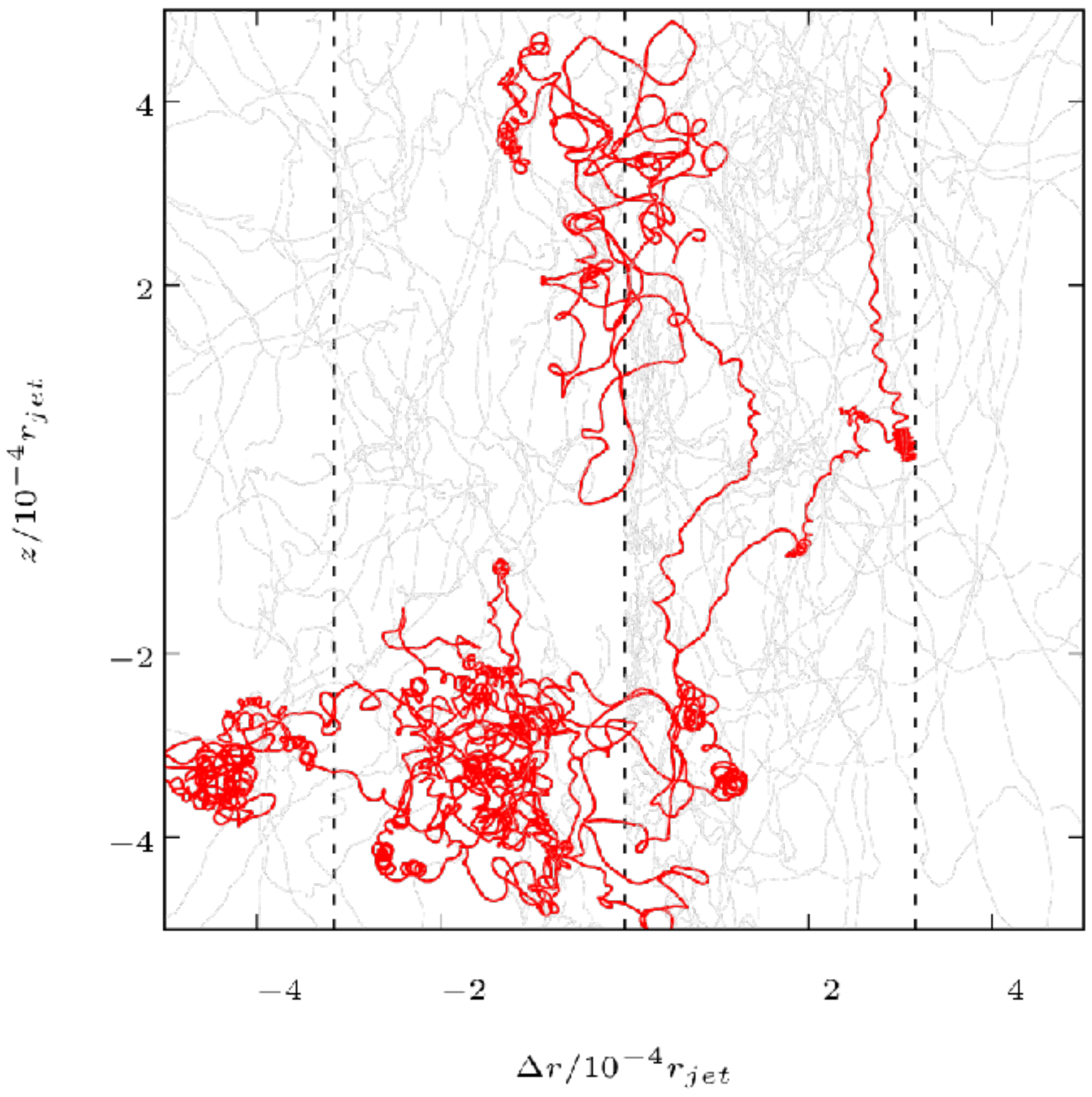
l_c^0 **is the reference correlation scale of the field**

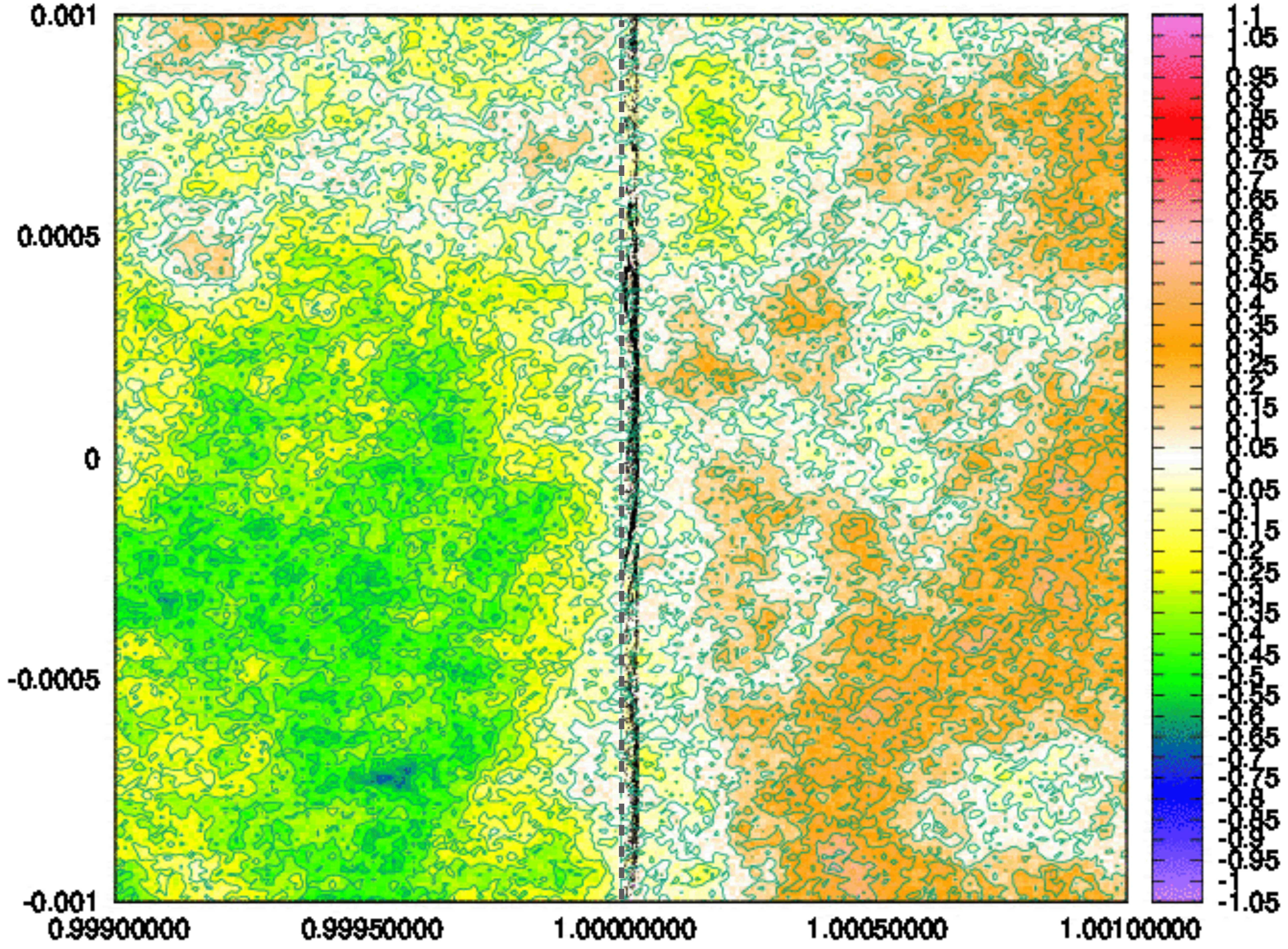
q **is the index of the magnetic power spectrum**

This detail turns out to be the determining factor for explaining the acceleration rate

Shearing through the islands

Swarm Plots 1 - sample trajectories in reduced field model - region with **larger** field patches





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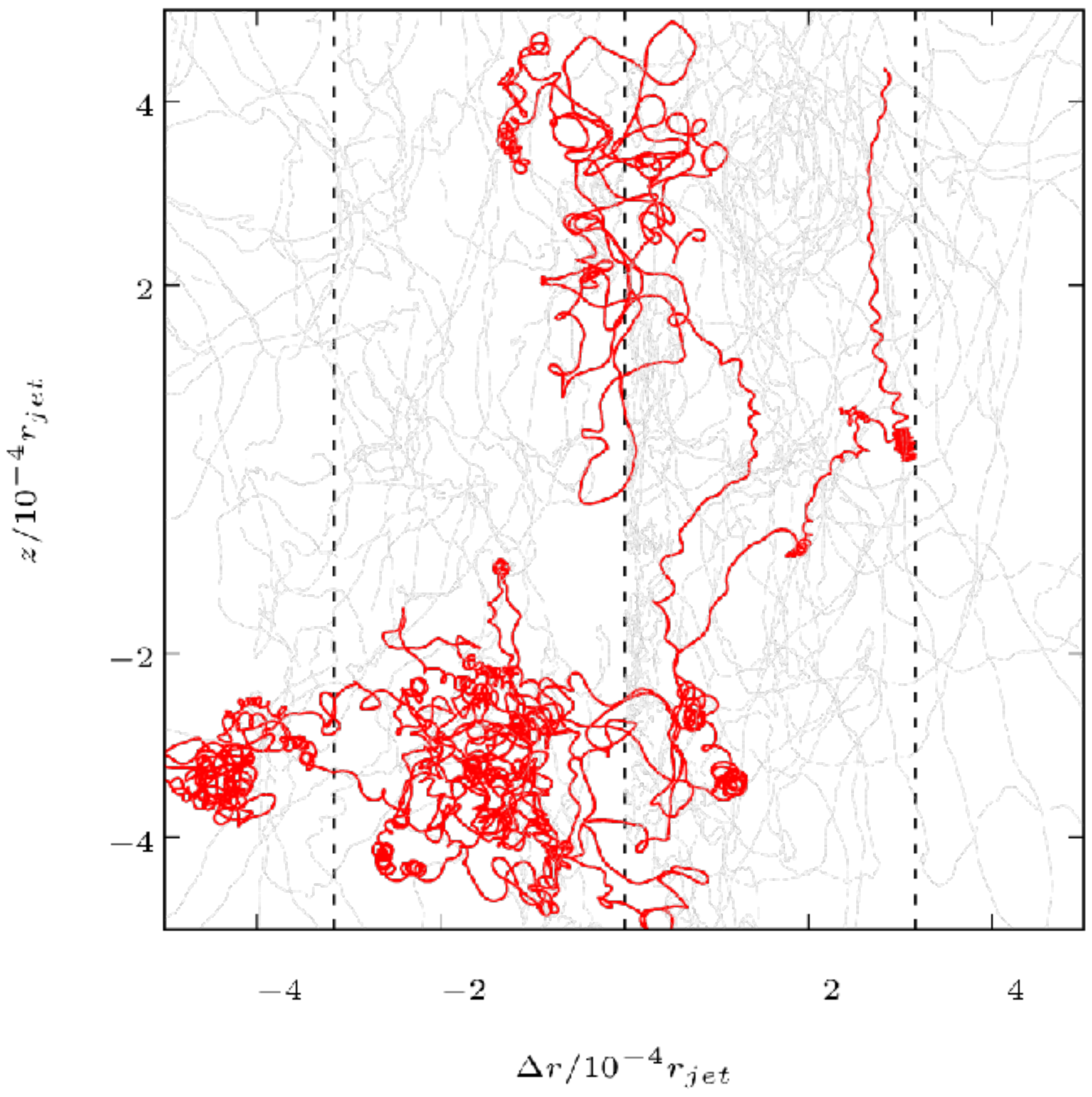
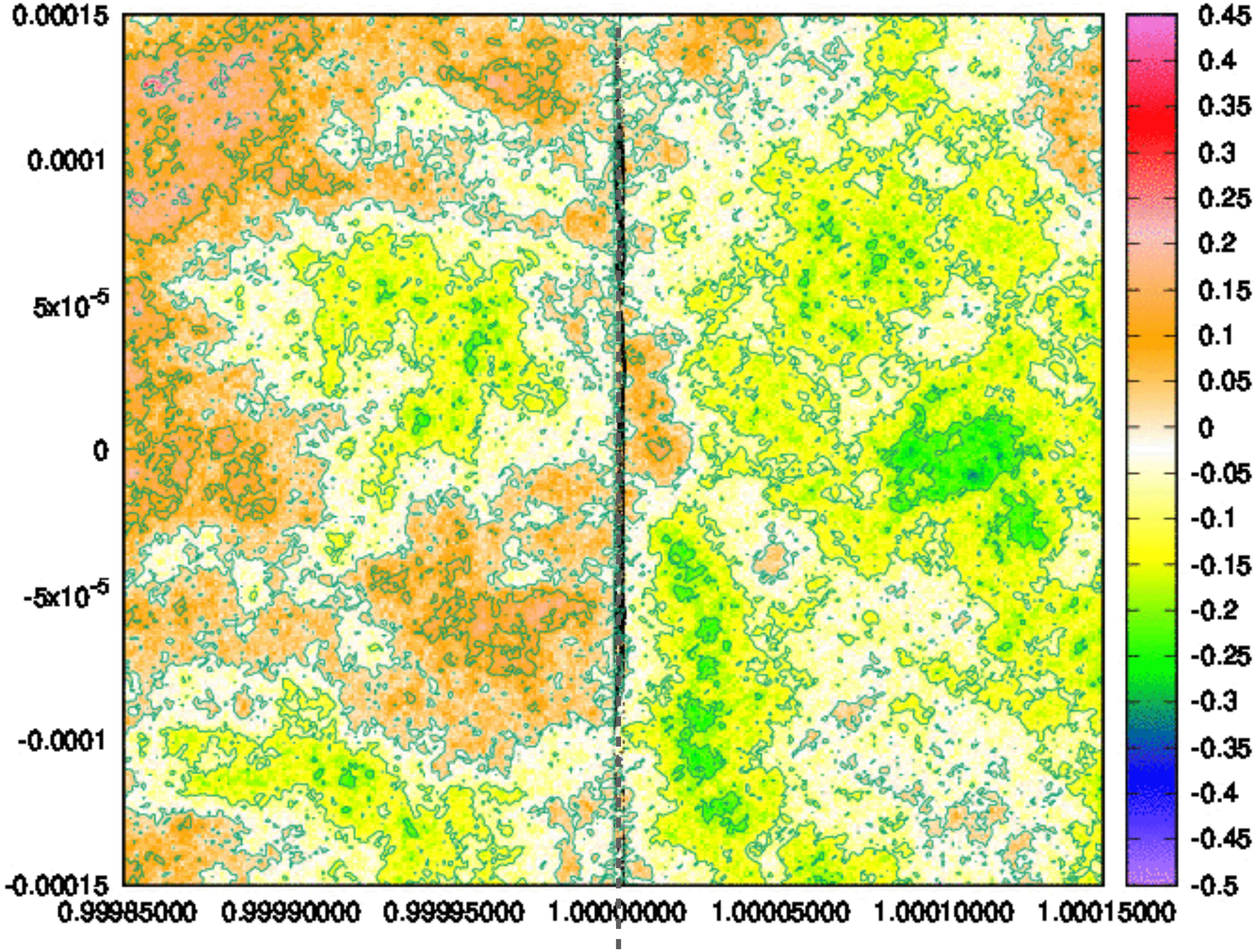
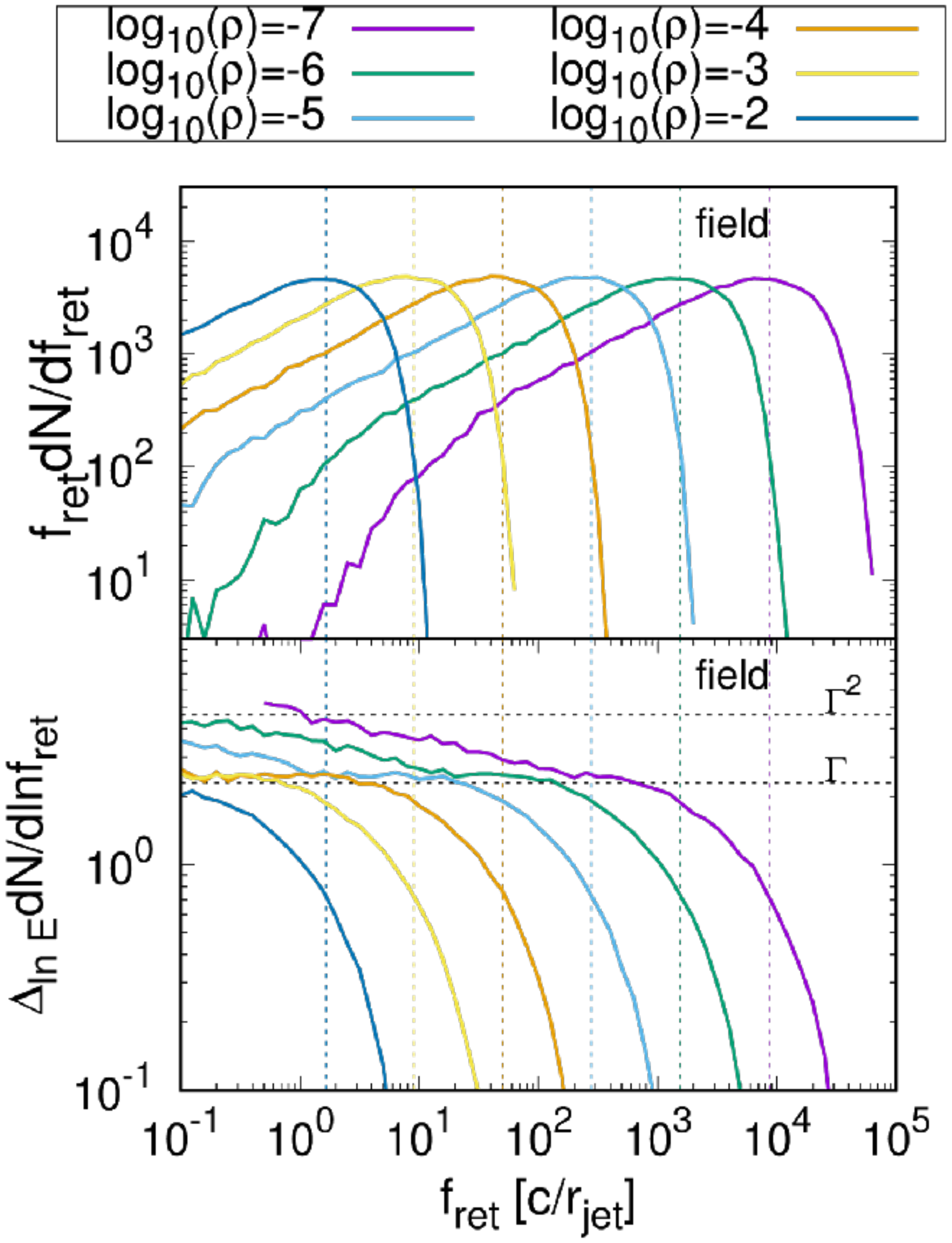


Swarm Plots 2 - sample trajectories in reduced field model - region with **smaller** field patches



No more excuses for shear ignorance



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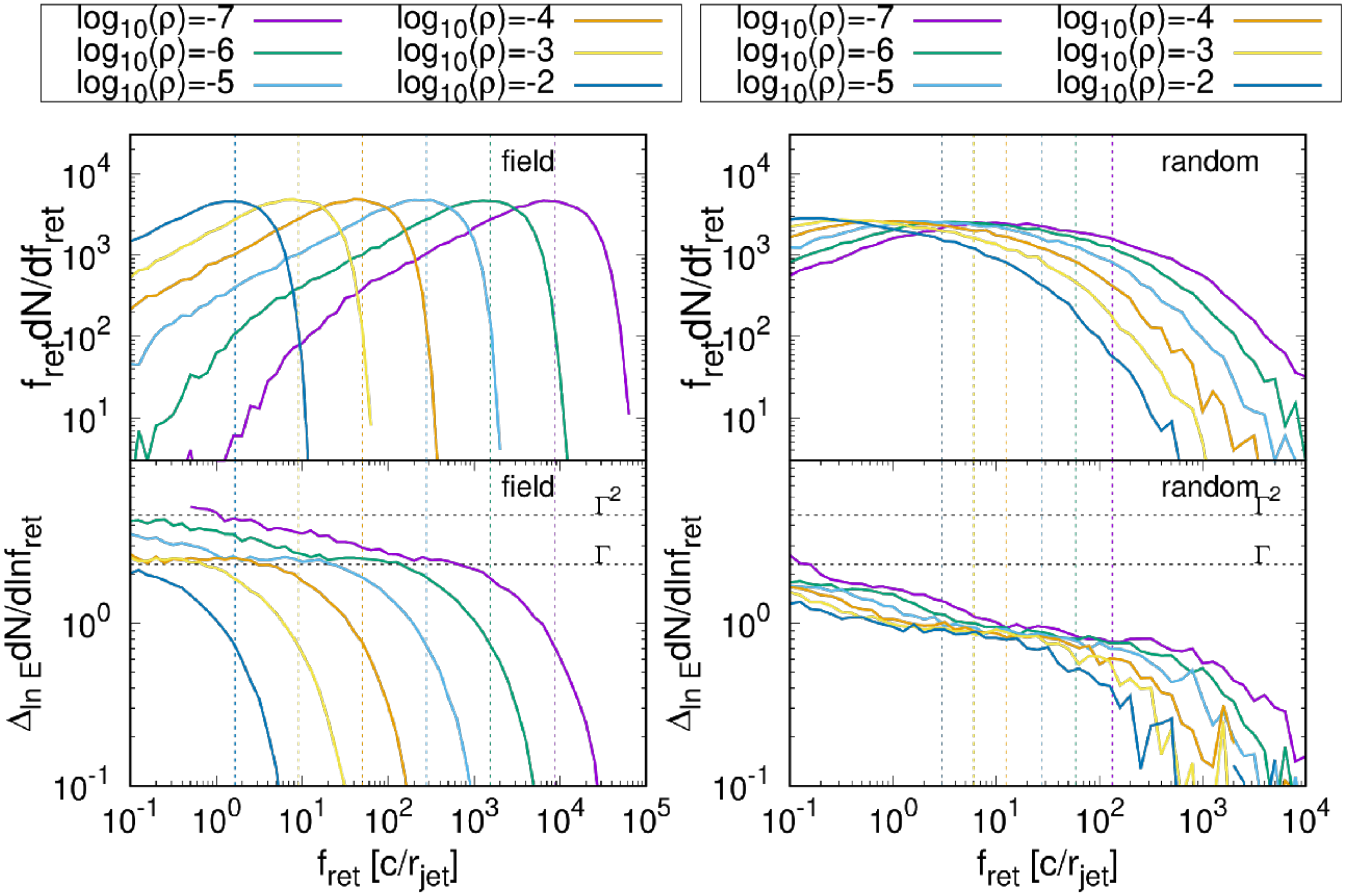

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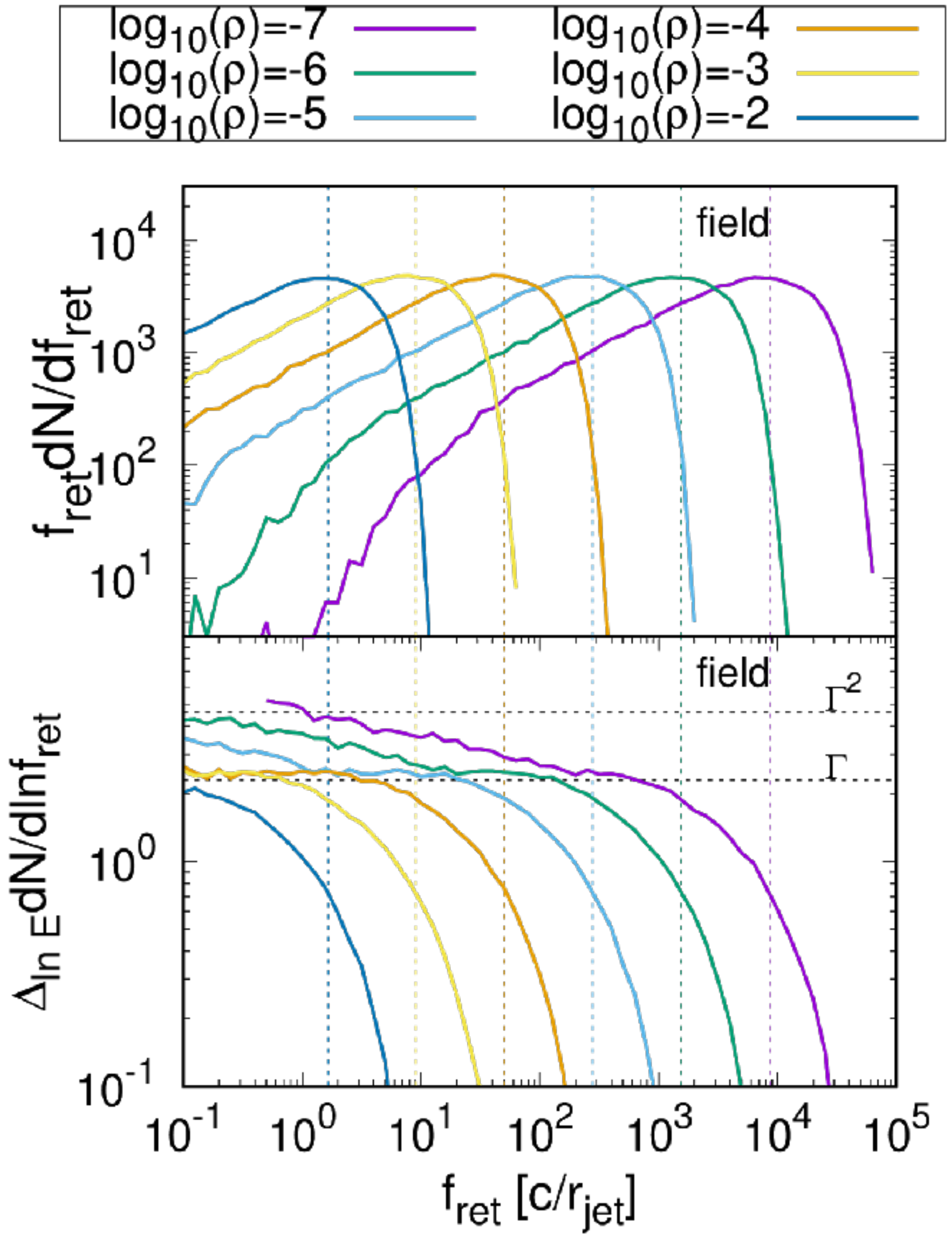

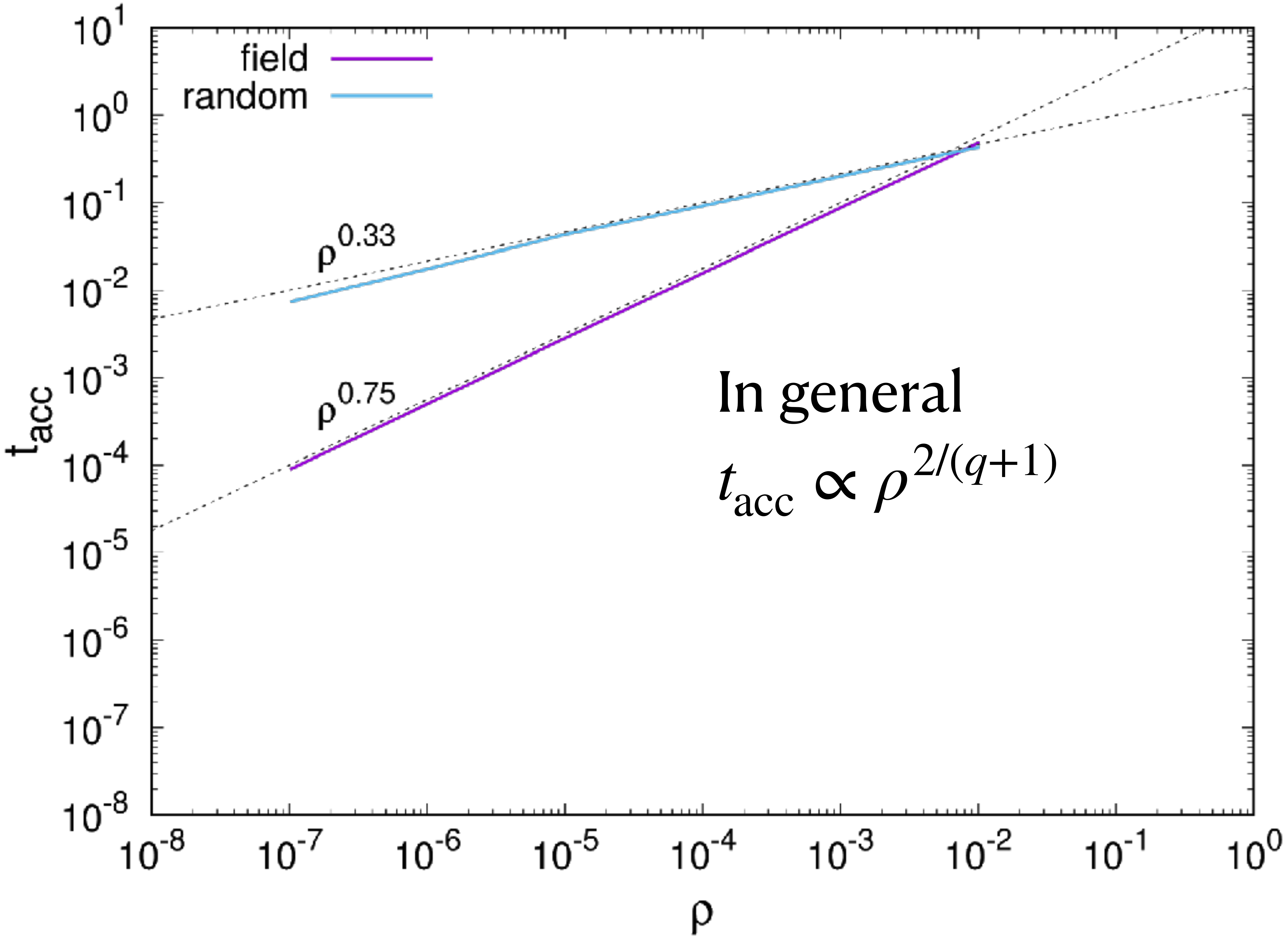

In general
$t_{\mathrm{acc}} \propto \rho^{2/(q+1)}$

Acceleration rate enhanced relative to simple random scattering model

Conclusion - Shear Class

- With observational evidence motivating the operation of effective in situ acceleration along the jet, going beyond toy model for particle acceleration in shear flows is motivated.

- The (Monte Carlo) prescription commonly used in previous studies, adopting a scattering function for the particles, can only be considered as a physics-lite description.

- The actual field configuration adopted at the shear flow can (will?) imprint itself on the particle acceleration rate, particularly for low rigidity particles which probe the region very local to the shear boundary.

- Shear Acceleration remains a viable candidate for UHECR production, and may underlie the non-thermal emission from many jets

Thank-you for your attention