The electrostatic instability for realistic pair distributions in blazar/EBL cascades

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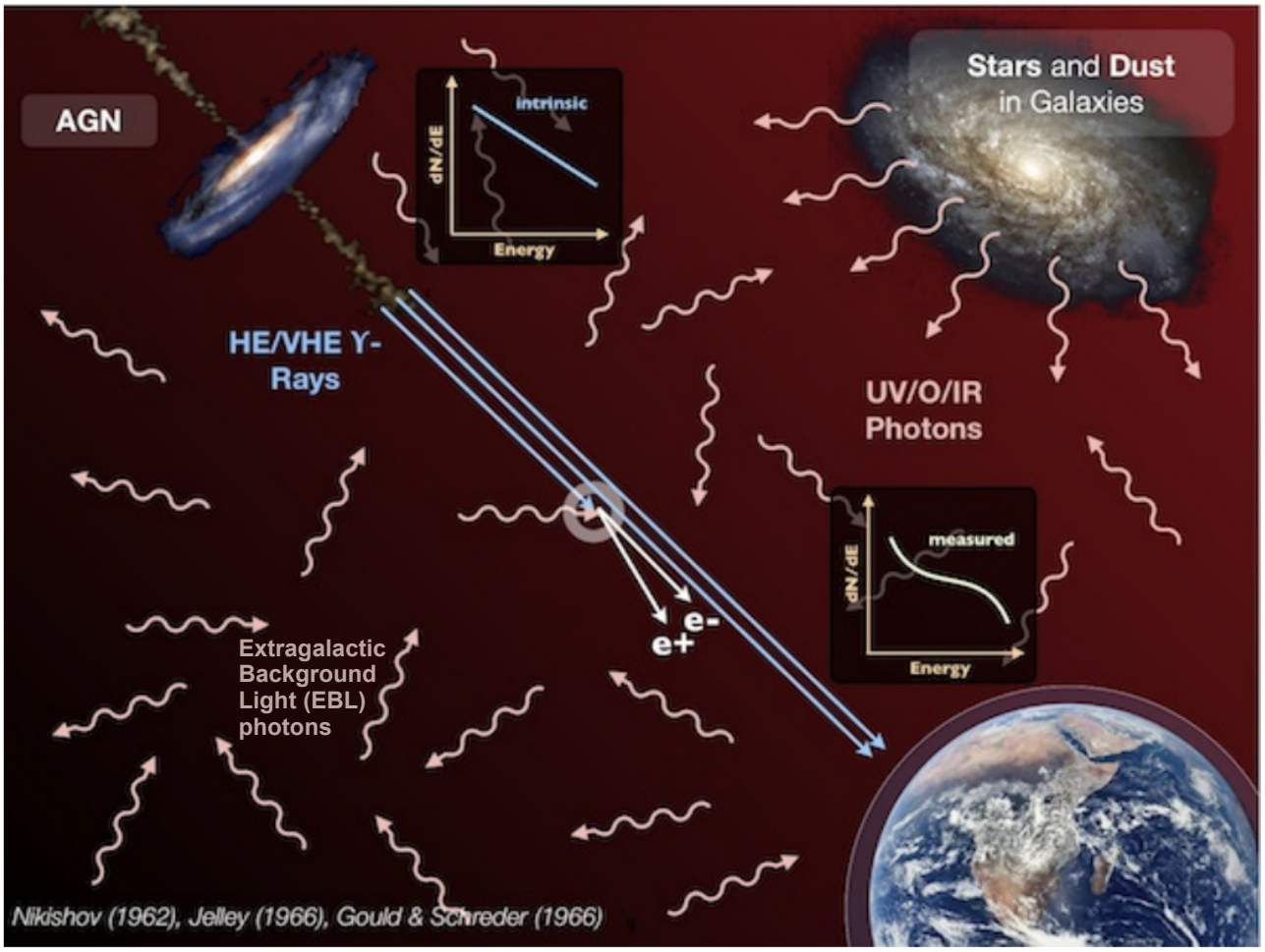
Introduction



Very high energy gamma-ray get attenuated by interactions with the EBL. (Credit: Martin Raue 2011)

$$\gamma + \gamma_g \rightarrow e^+ + e^-$$

$$e + \gamma_g \rightarrow e' + \gamma'$$

Pairs are affected by:

1. inverse Compton scattering
2. magnetic field deflection
3. beam-plasma instabilities

Observations

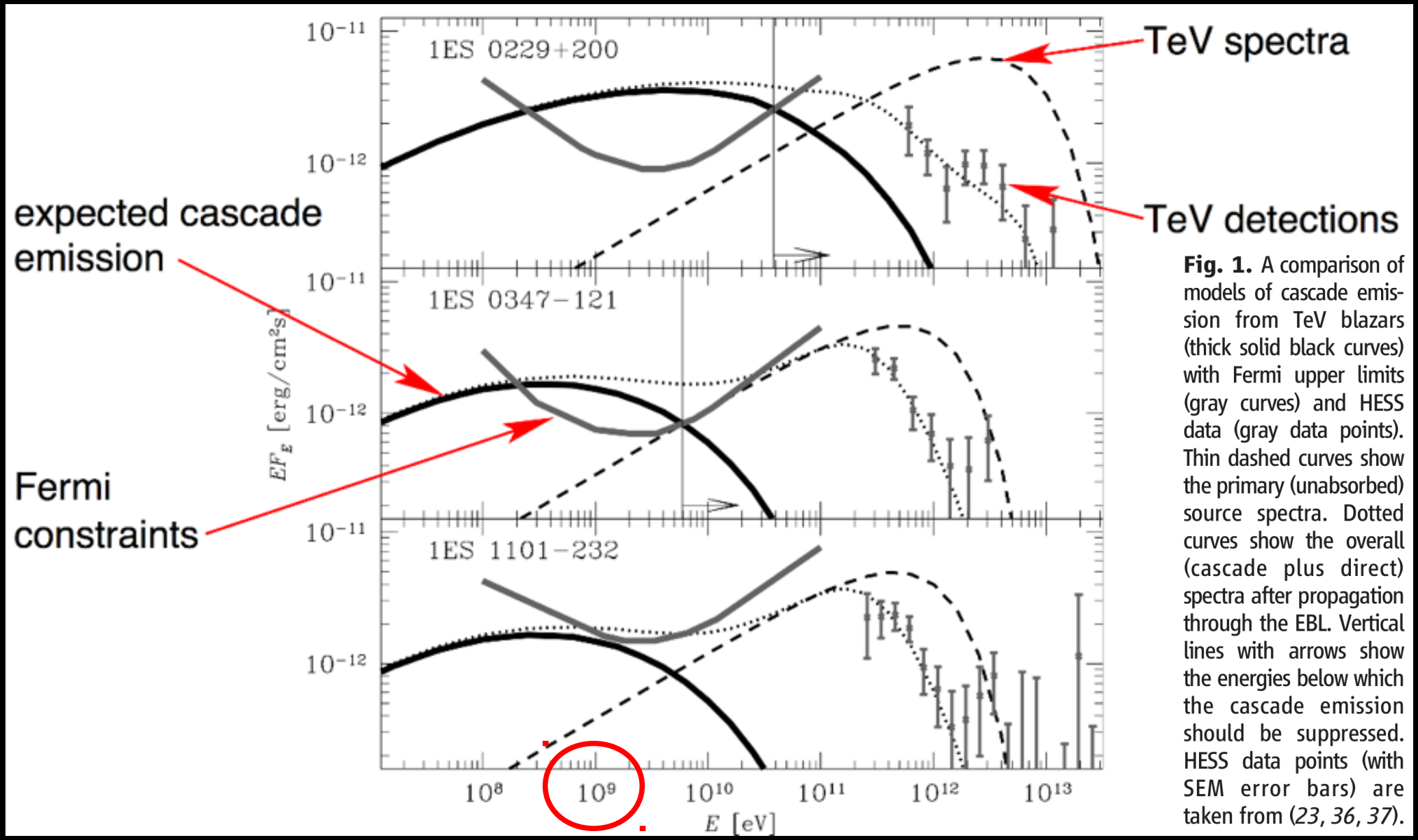
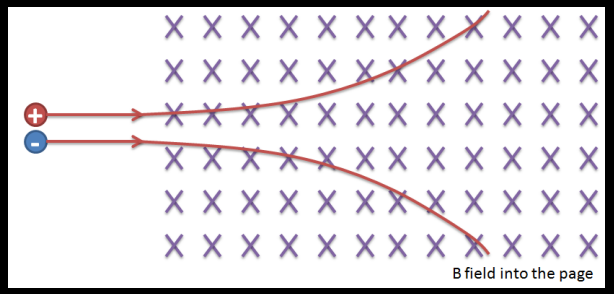


Fig. 1. A comparison of models of cascade emission from TeV blazars (thick solid black curves) with Fermi upper limits (gray curves) and HESS data (gray data points). Thin dashed curves show the primary (unabsorbed) source spectra. Dotted curves show the overall (cascade plus direct) spectra after propagation through the EBL. Vertical lines with arrows show the energies below which the cascade emission should be suppressed. HESS data points (with SEM error bars) are taken from (*23*, *36*, *37*).

Neronov & Vovk (2010); Giannios (2014)

Explanation

Deflection by the IGM magnetic field



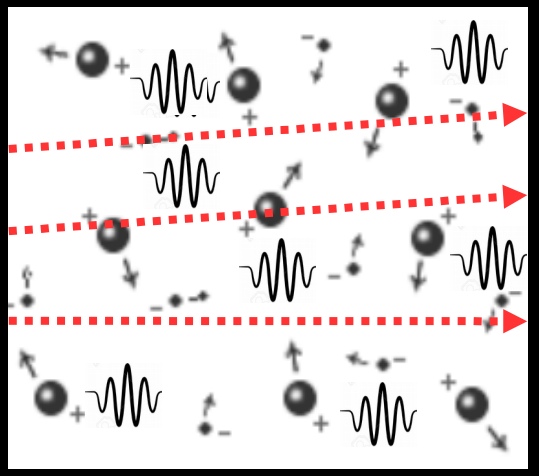
$$B \geq 3 \times 10^{-16} \text{ gauss}$$

Effect of plasma instabilities is neglected

Neronov & Vovk (2010)
Taylor et al. (2011)

Electrostatic instability

B=0 **NO MAGNETIC FIELD**



$$\frac{\omega_p}{k_{||}} = c$$

→ Electrostatic instability

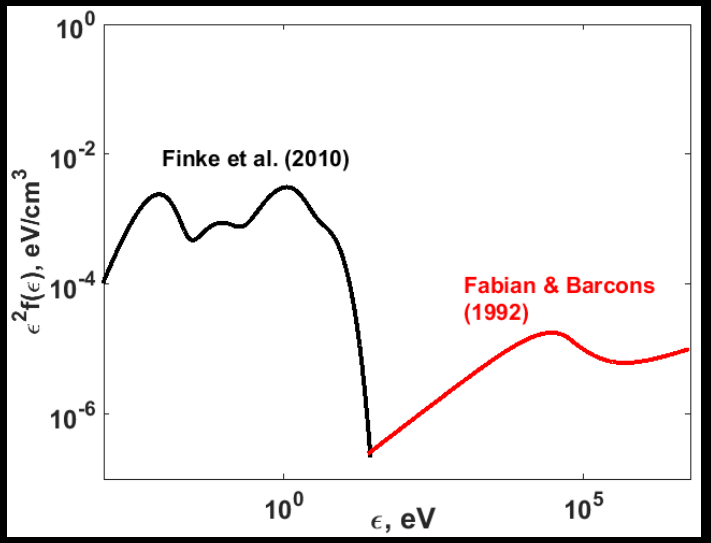
Broderick et al. (2012)

Pair distribution

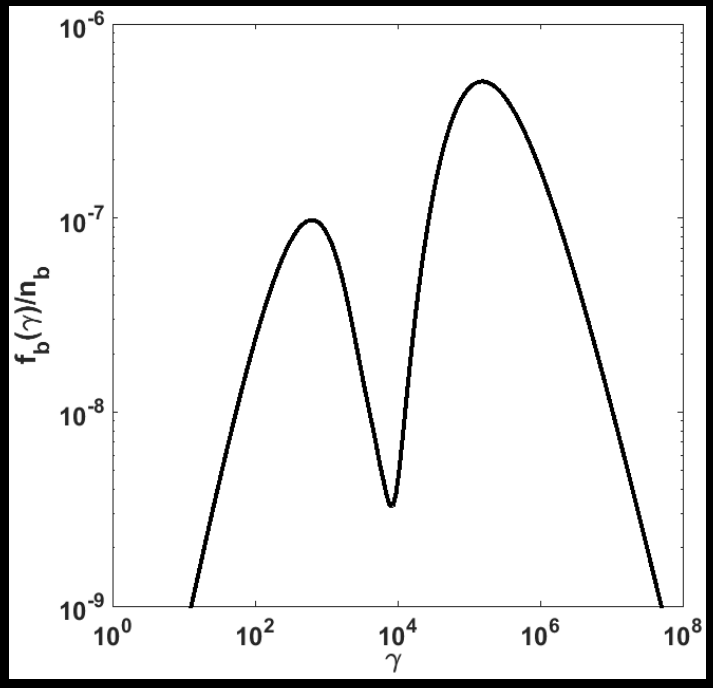
Primary VHE gamma-rays:

$dN/dE \sim E^{-1.8}$

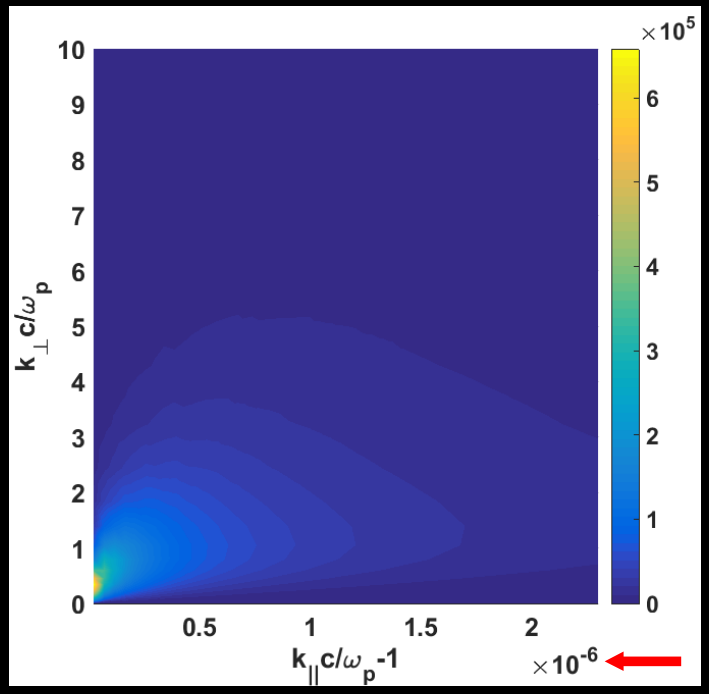
EBL:



Pair spectrum at 50 Mpc from the sample source



Growth rate of electrostatic instability



In contrast to Miniati & Elyiv (2013), we neglect IC scattering !!!

The peak growth rate of electrostatic instability is 10 times larger compared to Miniati & Elyiv (2013)

Lower limit of relaxation time for blazar-induced pair beams

Non-linear Landau (NL) damping: $\omega_{\text{max. growth}} = \omega_{NL}(W_E^{NL})$

vs.

Modulation instability (MI): $\omega_{\text{max. growth}} = \omega_{MI}(W_E^{MI})$

$W_E^{MI} < W_E^{NL}$ **Modulation instability provides a smaller saturation energy!**

$dW_E^{inst}/dt = \int \omega_{growth} W(k) dk$ $\quad$ $\mathbf{t_{rel} = W_b / (dW_E^{inst}/dt)}$

$$\frac{\tau_{\text{loss}}}{\tau_{\text{IC}}} \simeq 2.2 \times 10^{-4} \frac{\gamma_6^{7/3}}{T_4} \left(\frac{n_{e7}}{n_{b20}}\right)^{1/3} (1+z)^5$$
$$\simeq 0.02(1+z)^5,$$

Electrostatic instability can dominate inverse Compton scattering!

Vafin et al. (2018)

Particle-In-Cell (PIC) method - EPOCH code

$$10^{-12} < \alpha = n_b/n_{IGM} < 10^{-18}$$

No simulation possible!

Important physics of the realistic pair beams:

- Beam/plasma energy density ratio:

$$\epsilon = n_b \langle \Gamma \rangle m_e c^2/(n k_B T) \approx 10^{-10} - 10^{-1}$$

- The fastest electrostatic mode develops in slightly oblique direction to the beam (only 2D or 3D simulation)
- No Weibel instability

Some published studies on this topic do not consider all of these conditions together

Summary

1. There is a lack of cascade emission in GeV band

2. It can be explained by pair deflection in the IGM magnetic field, but neglecting plasma effects.

3. The role of plasma effects:

    a. Analytical study: the electrostatic instability can act faster then the inverse Compton scattering

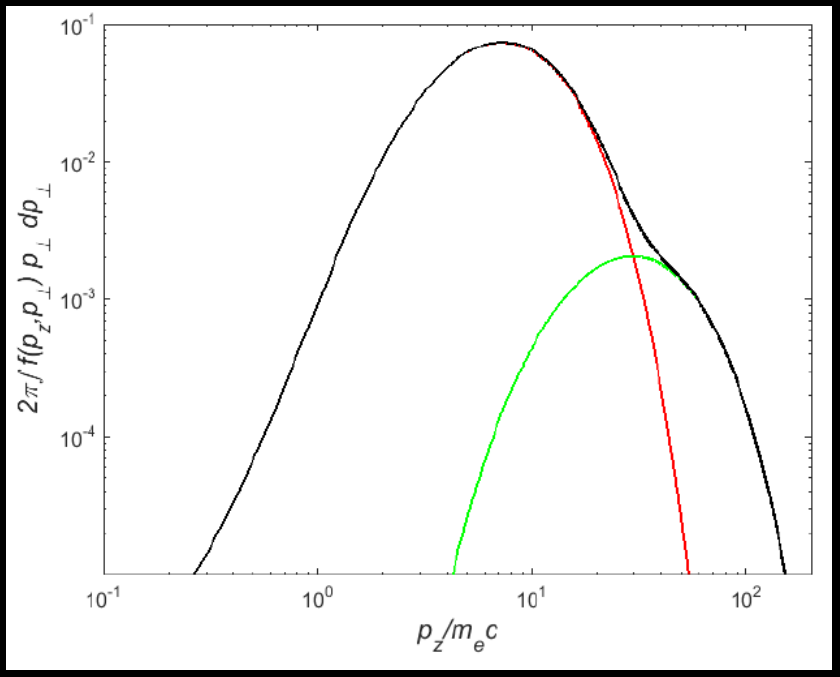
    b. PIC simulations: for the first time, we mimic a pair beam which satisfies all three criteria of realistic blazar-induced pair beams

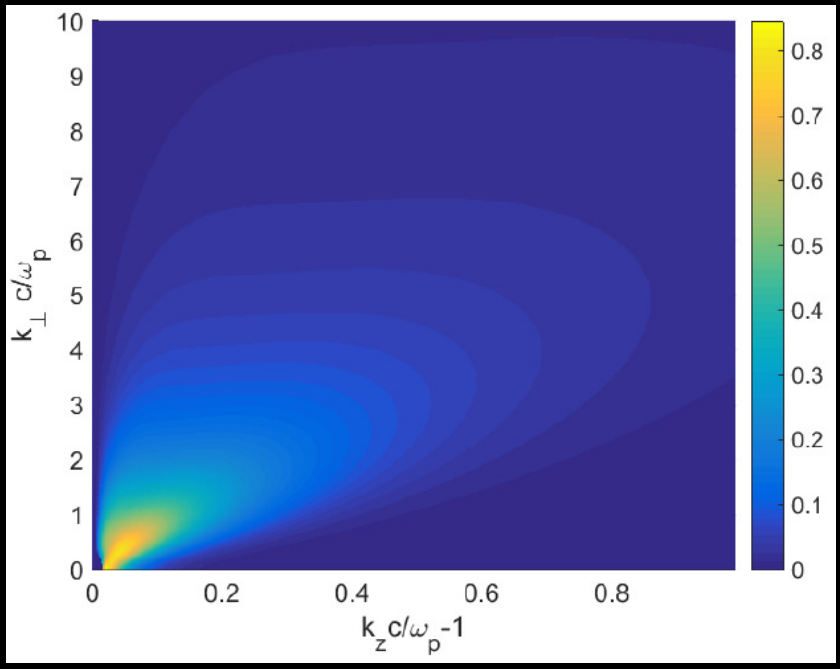
For more information visit the talk by Martin Pohl (Thursday, 30 Aug)

PIC simulations

Table 1. Simulation parameters for composite beams with $\Gamma_1 = 5$ and $\Gamma_2 = 20$.

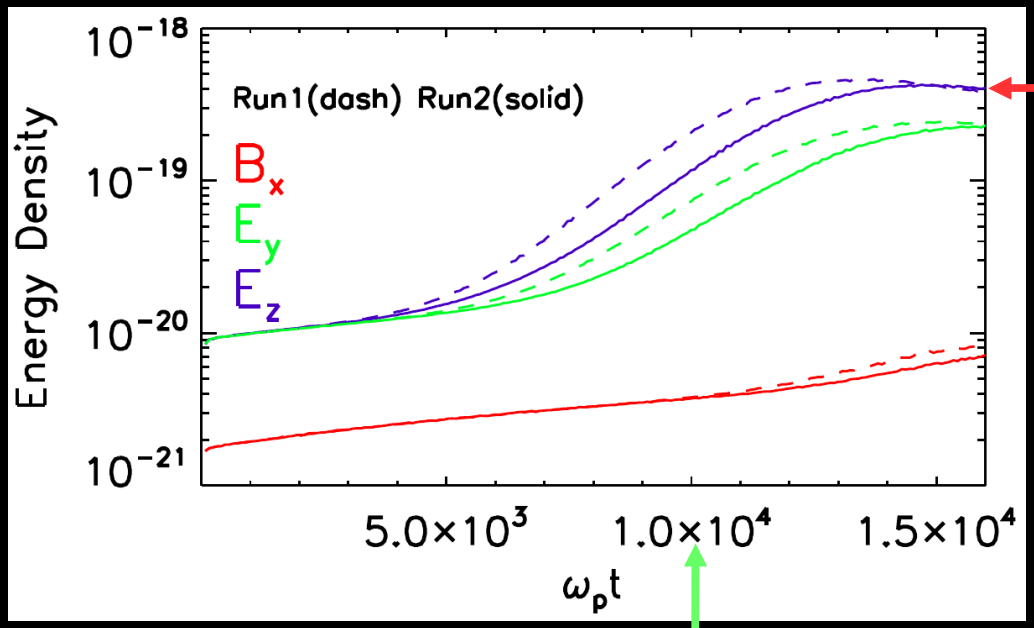
Parameter		run 1	run 2
Density ratio	α	2×10^{-4}	2×10^{-4}
Plasma temperature	T_p	2 keV	2 keV
Beam temperature	T_b	200 keV	200 keV
Weight for beam 1	w_1	1	0.9
Weight for beam 2	w_2	0	0.1
Energy density ratio	ϵ	0.5	0.66





Simulation results

Time evolution of E- and B-energy



$E_{elect.\ field} \sim 10^{-2} E_{beam}$

Saturation by the modulation instability

$$\tau_{loss} \approx 5 \times 10^5 / \omega_p$$

Fourier plot of electric field E II k