

QU Kick-off

Beam instabilities in astroparticle physics and in the laboratory

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Hamburg, Mar 20, 2019

Cosmic plasma is collisionless

→ Interactions via collective electromagnetic fields

Decisive question:

→ How are magnetic fluctuations efficiently produced?

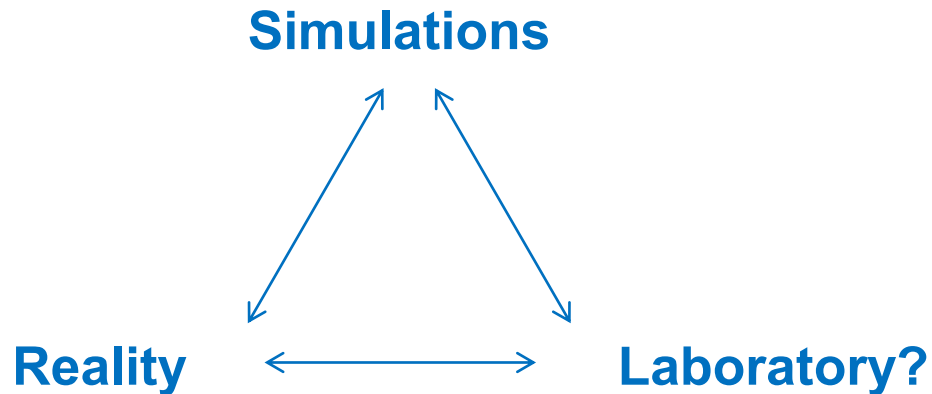
Simulations vs. reality

Testing in the laboratory

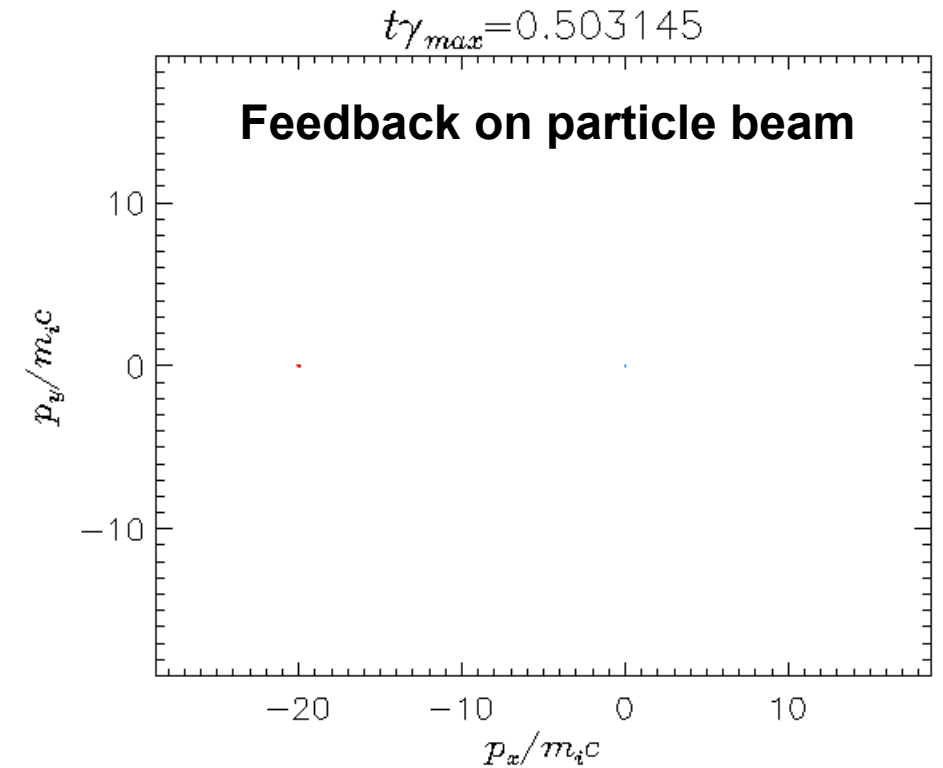
We use extensive simulations to model turbulence

Parameters are far from realistic.

Can we verify the simulations?



Can we test simulations in the laboratory?



Simulations vs. reality

Testing in the laboratory

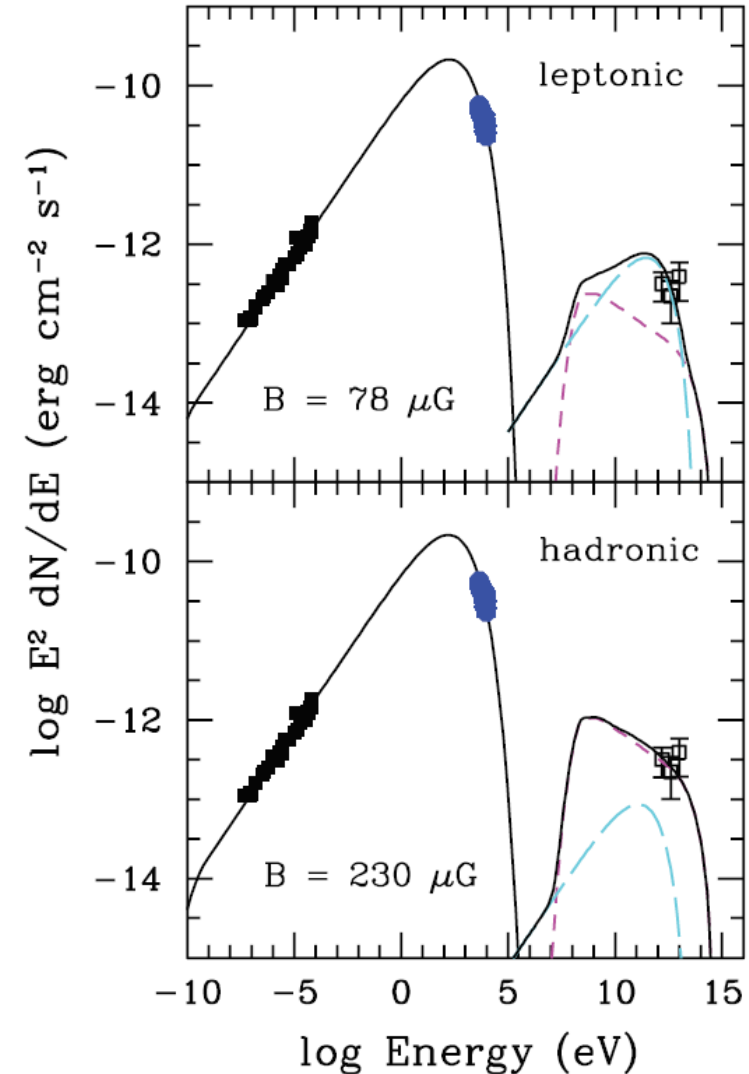
Two examples:

- **Bell's instability**
- **Oblique instability of TeV pair beams**

Motivation

**Turbulent magnetic-field
amplification required,
here for a supernova
remnant**

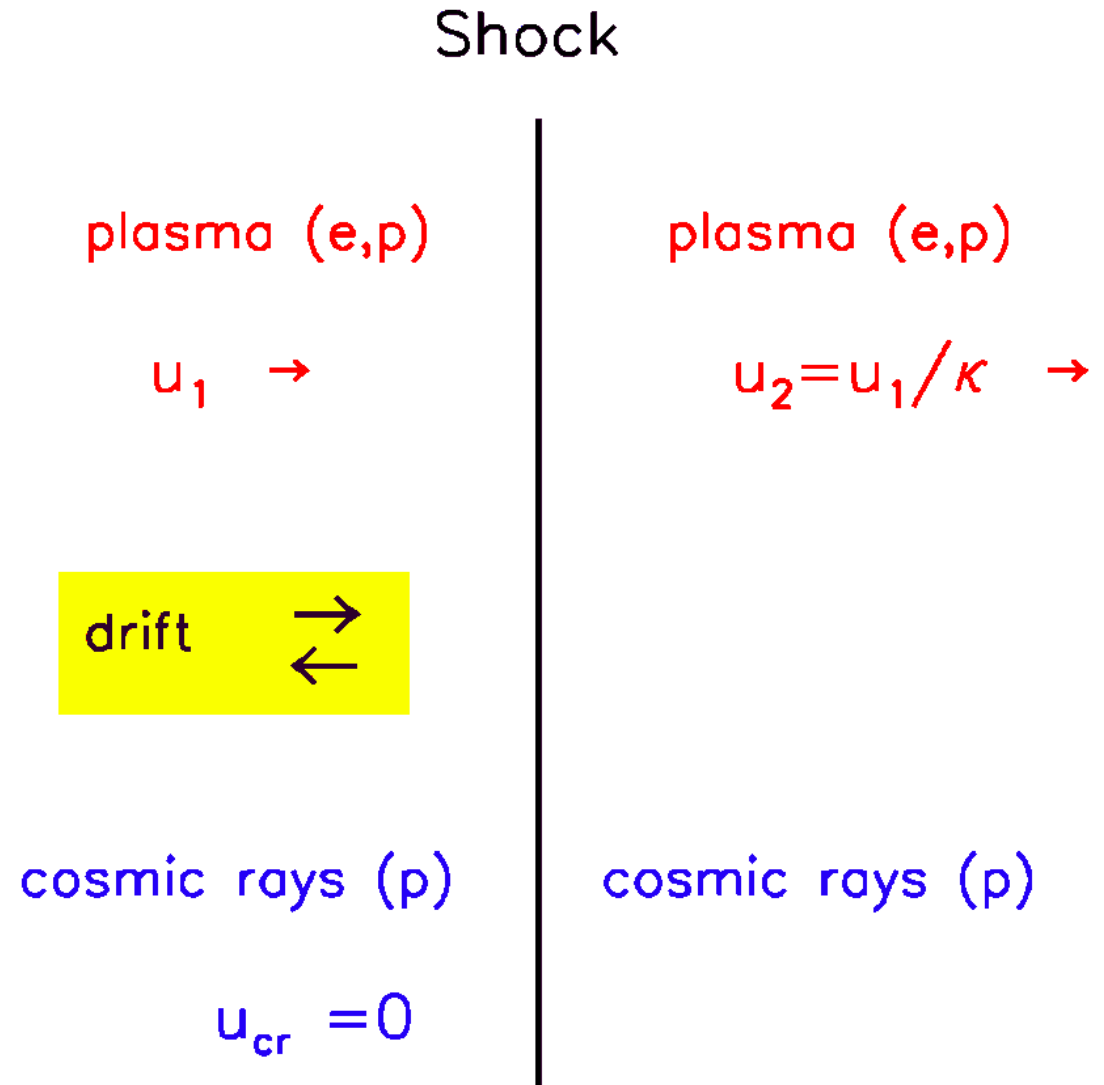
How to get to $\delta B \gg B_0$?



Motivation

Energy source:

**Drifts,
anisotropy,
currents**

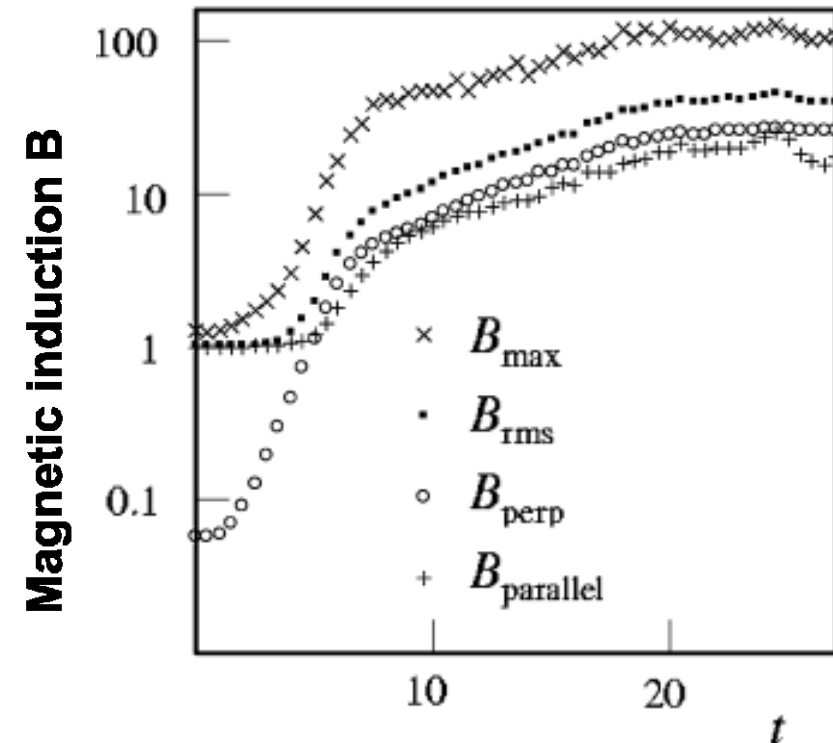


Bell's instability

Analytic theory for waves parallel to large-scale magnetic field

- Streaming cosmic rays generate aperiodic magnetic fluctuations
- Wave vector parallel to streaming

In MHD: $\delta B \gg B_0$

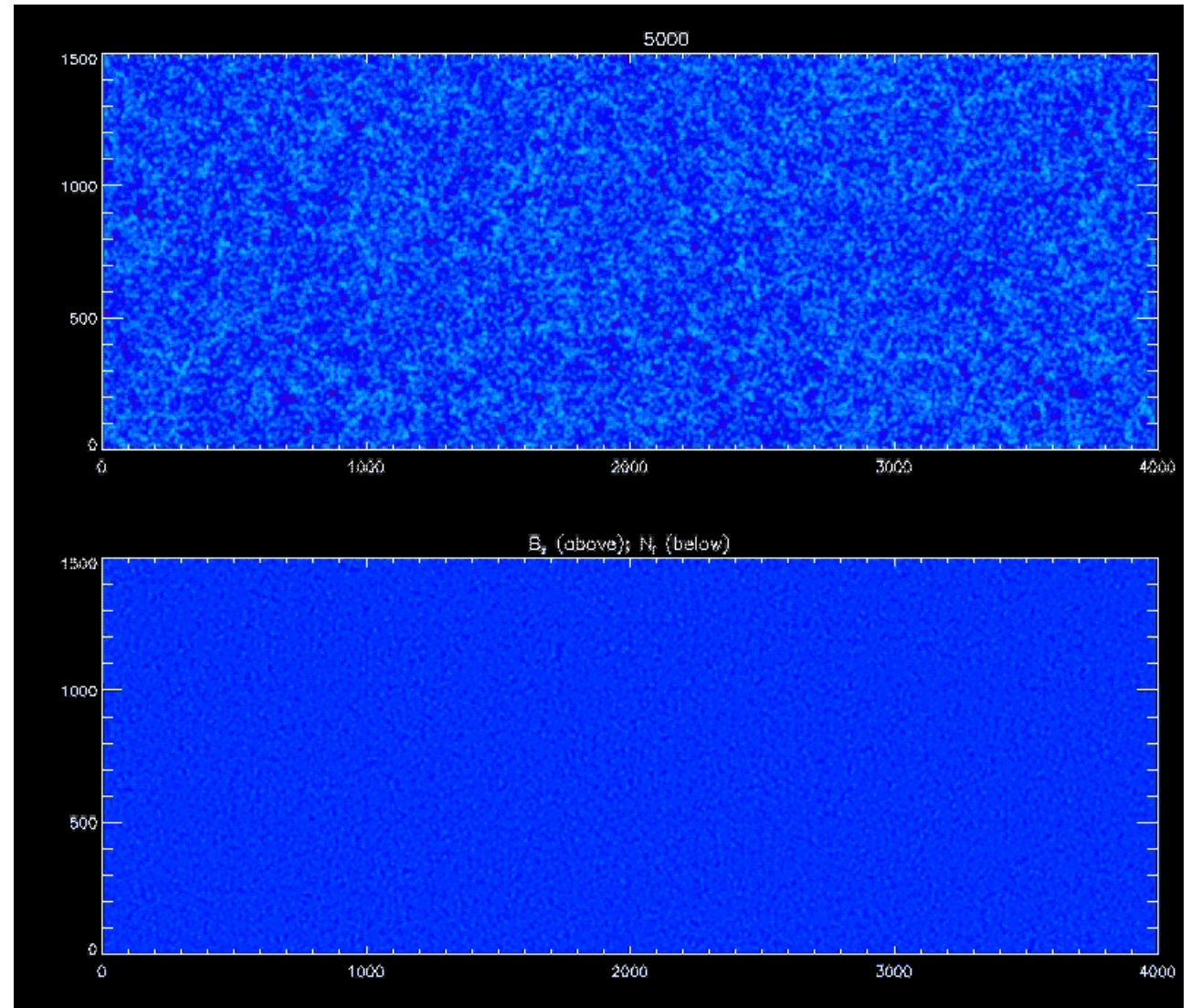


Bell's instability

Kinetic simulations

Periodic box

Magnetic
field



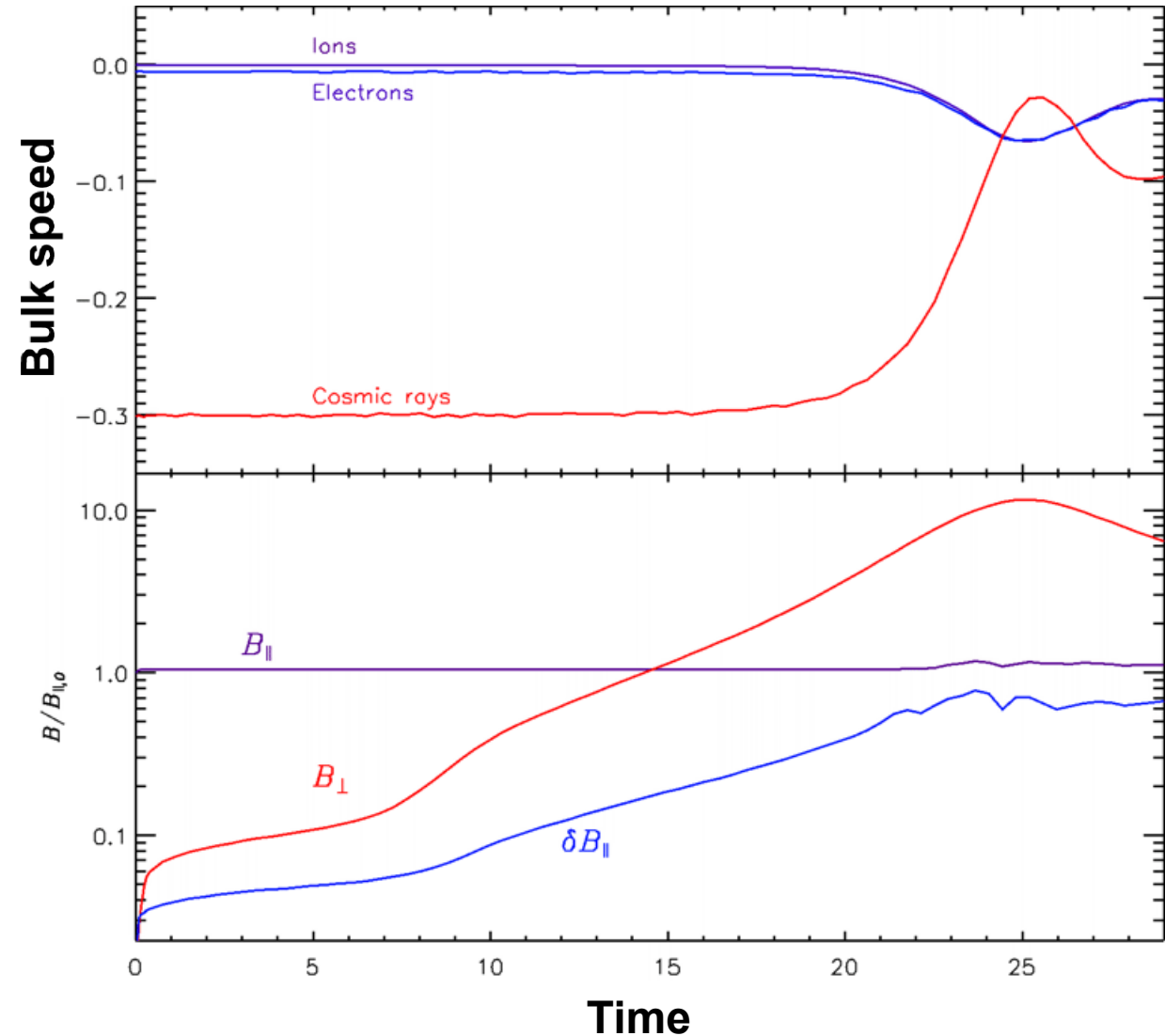
Ion
density

Stroman et al. 2010

Bell's instability

Energy source:
Streaming

Amplification:
Moderate



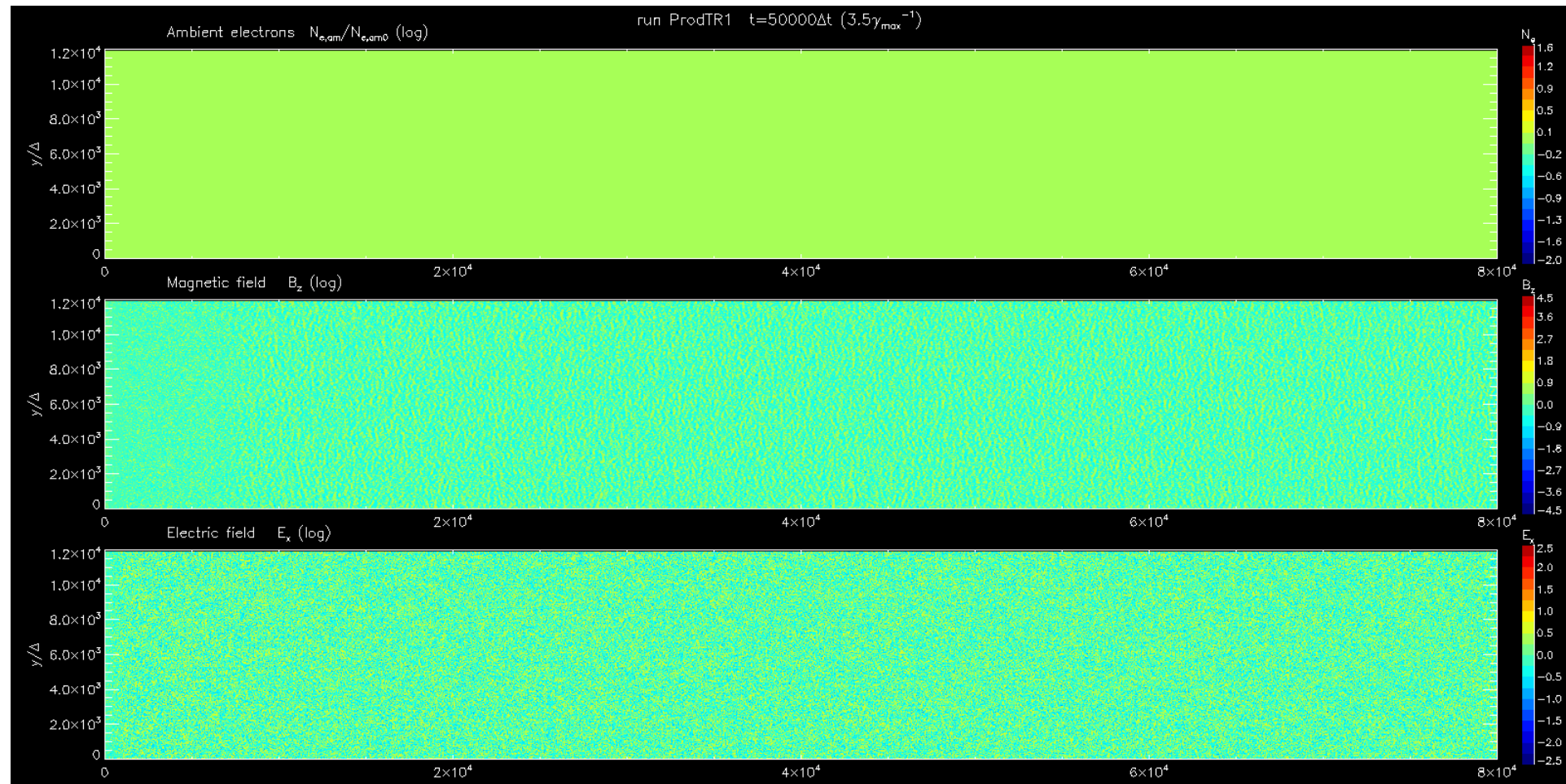
Bell's instability

Also with open boundaries

Electron
density

Magnetic field

Electric field



Kobzar et al. 2017

Earlier activities

Bell's instability in the laboratory

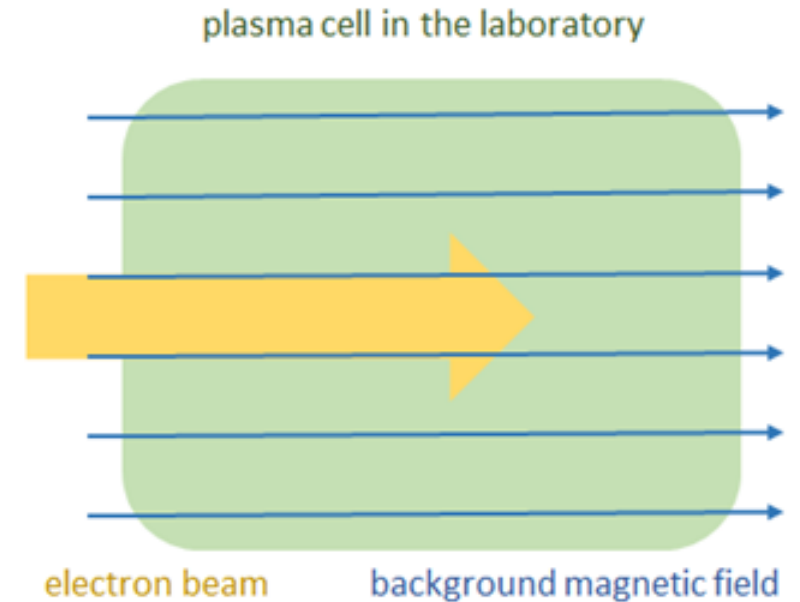
**Cooperation between astroparticle theory,
the PITZ accelerator group, and the plasma-wakefield accelerator group.**

**The charge: Explore the feasibility of experiments
with Bell's mode with existing hardware**

PITZ electron gun

PITZ or Hamburg plasma cell

PIC simulations of the system

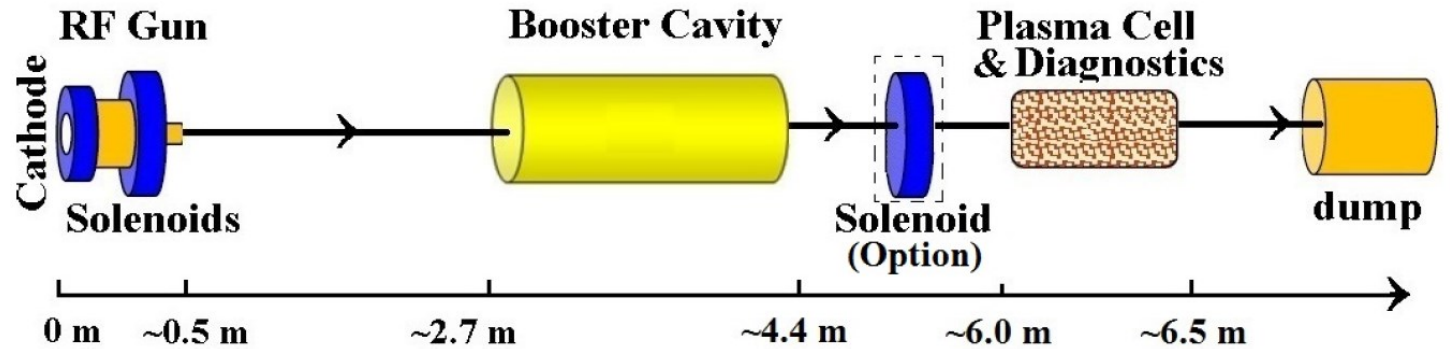


PITZ hardware

Beam instabilities in the laboratory

Setup at PITZ

Beam current and energy fluctuating on GHz scale



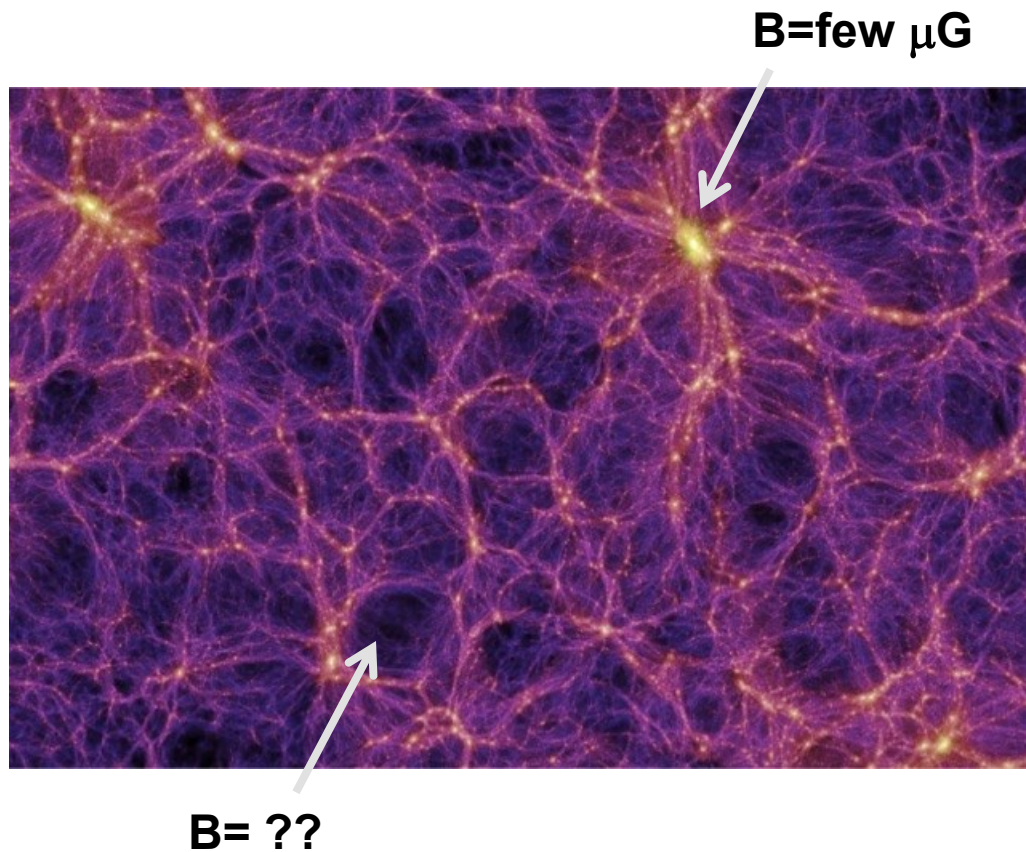
Electrostatic instability can destroy the beam or at least change the conditions

We need to kinetically simulate the behavior, but
for the PITZ hardware the growth time of Bell's mode is 10^6 plasma times,
too large for simulations

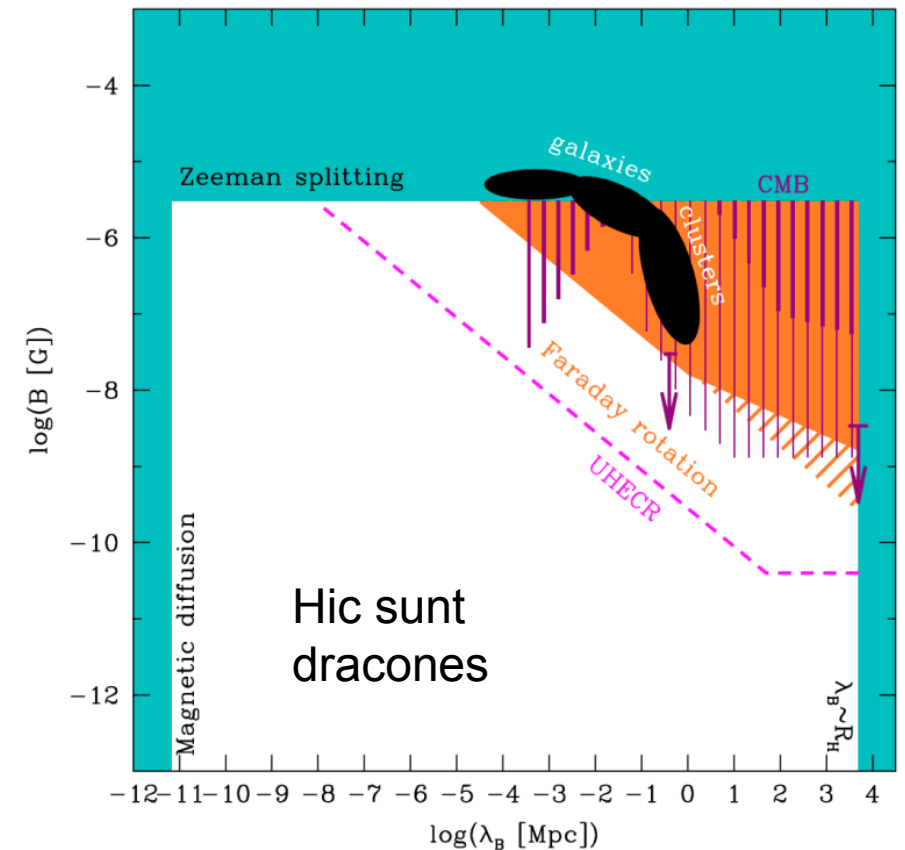
TeV pair beams

Beam instabilities in the laboratory

Second example: TeV pair beams



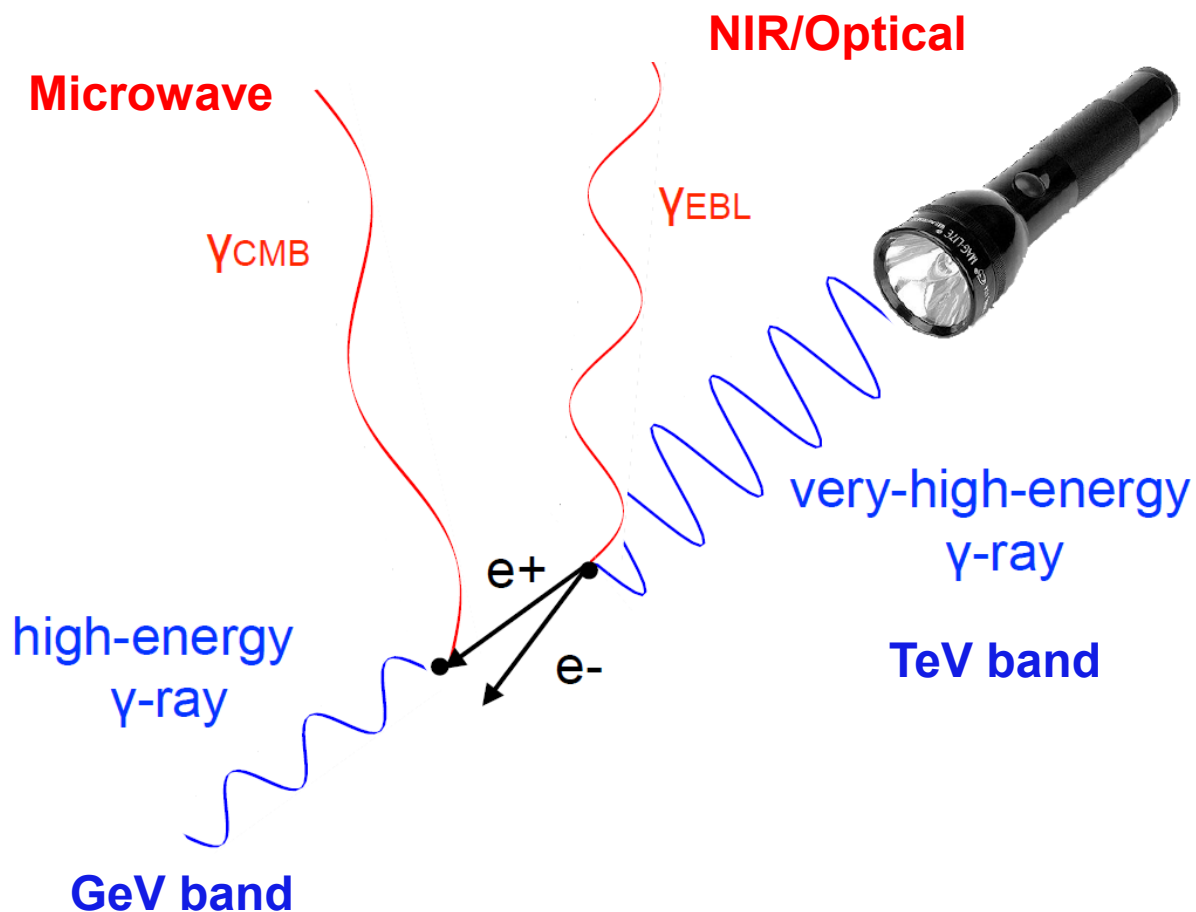
Millennium simulation



Neronov 2009

TeV pair beams

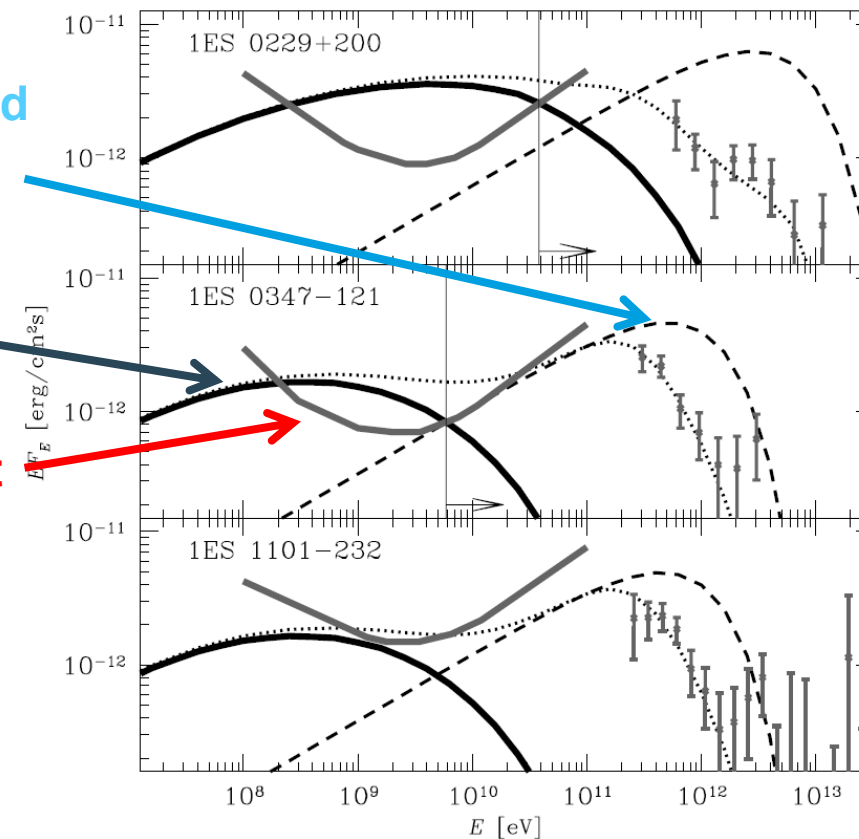
Beam instabilities in the laboratory



Deabsorbed
emission

Cascade
emission

Upper limit

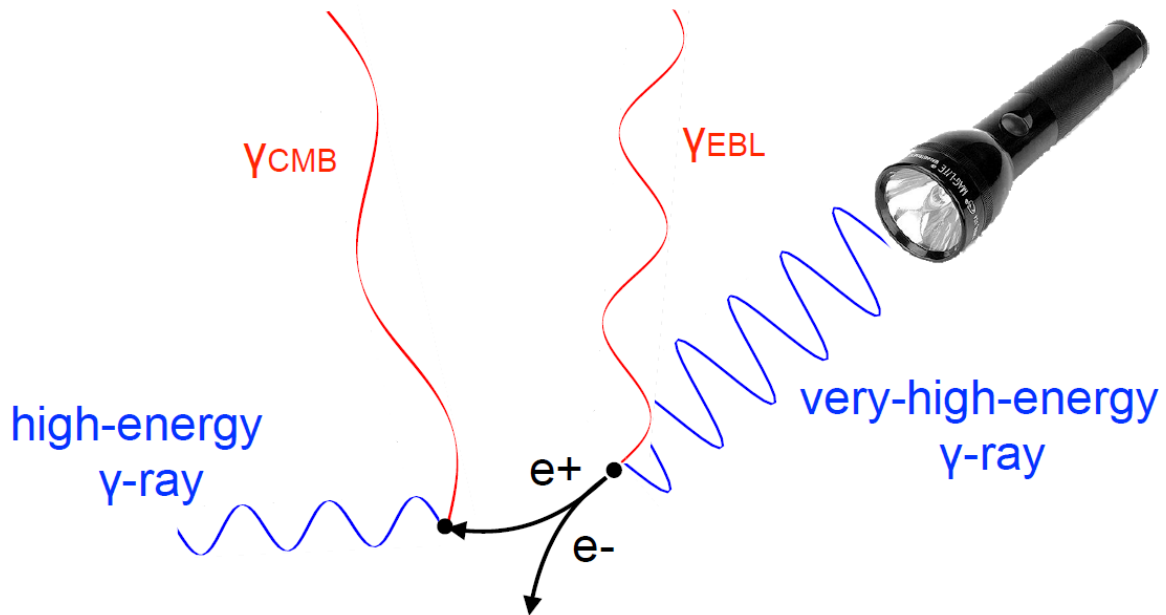


TeV pair beams

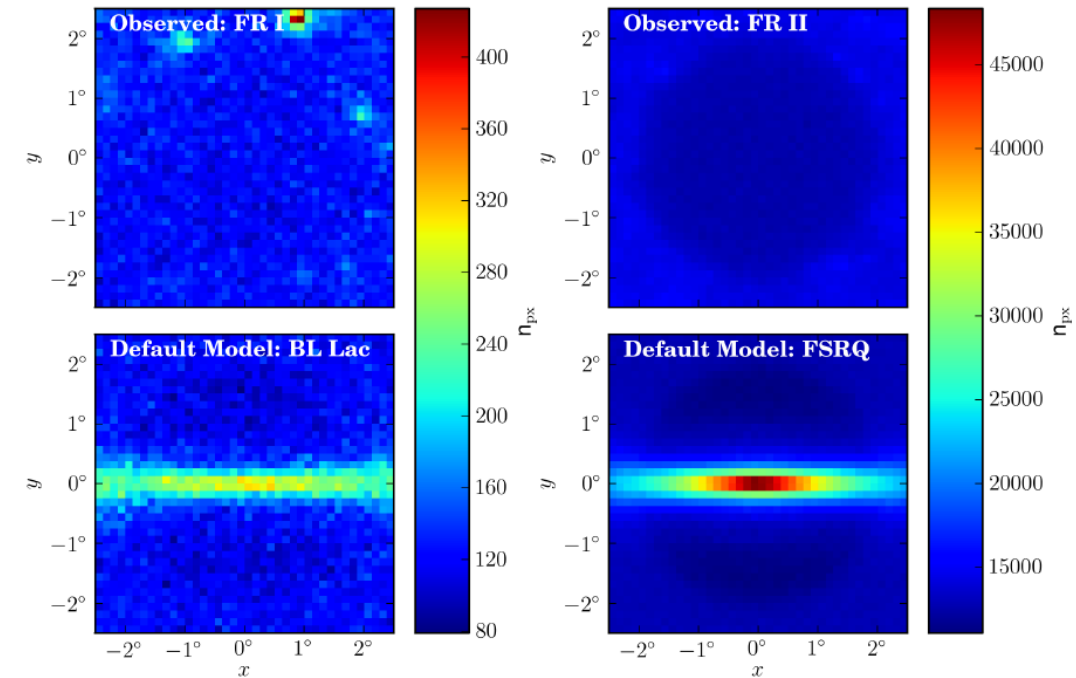
Beam instabilities in the laboratory

Now what?

Magnetic deflection → fG fields required



No deflected signal

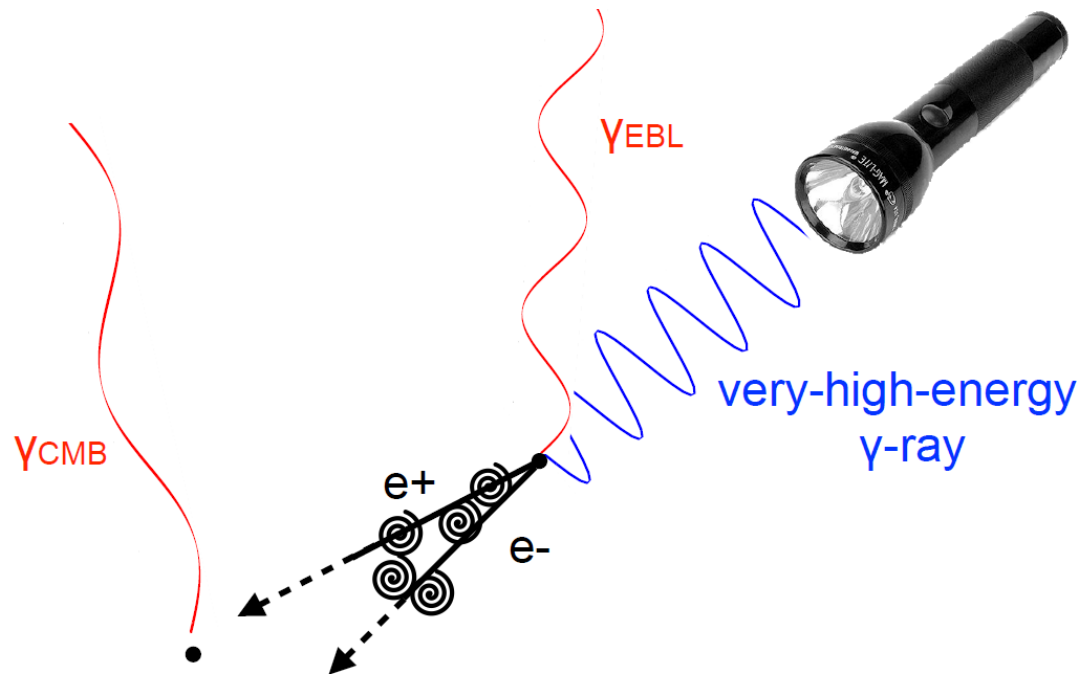


Broderick et al. 2018

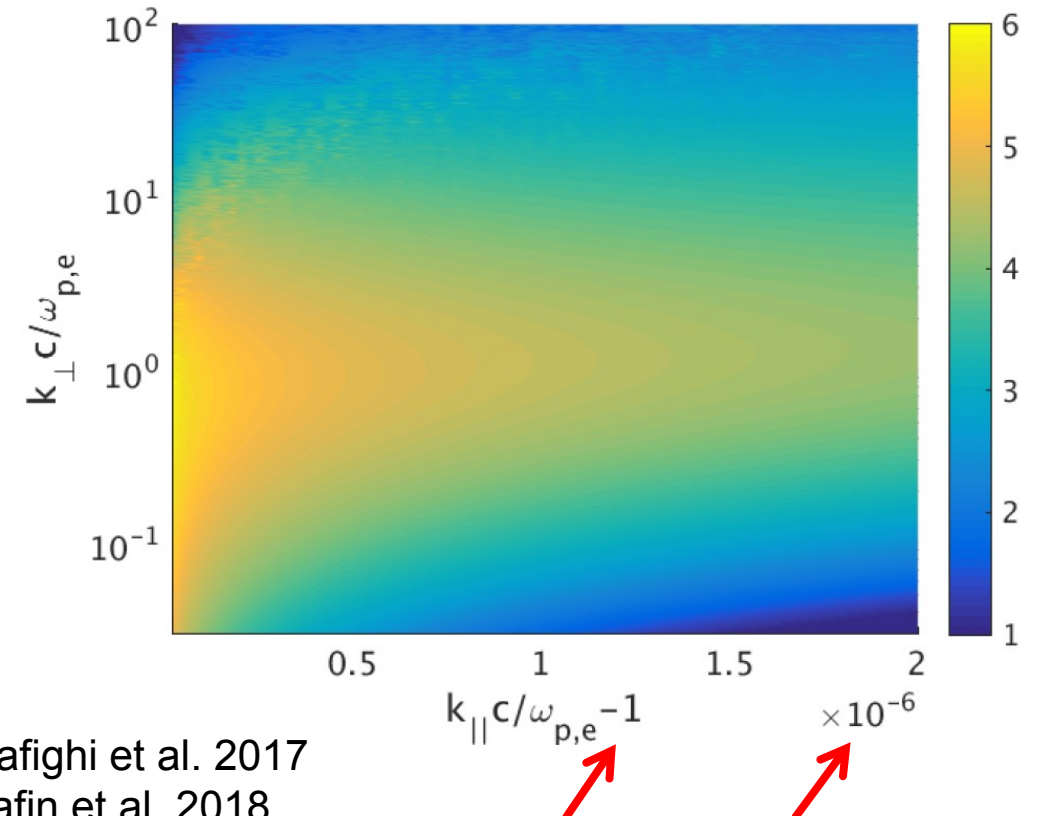
TeV pair beams

Beam instabilities in the laboratory

Energy losses through plasma instabilities?



Linear growth rate
Real parameters



Rafighi et al. 2017
Vafin et al. 2018

Extrapolation to reality

Beam instabilities in the laboratory

Simulation possible only for tuned parameters

Simulation too short to capture energy loss

Understanding of saturation allows scaling to real pair beams

Saturation level W_k reflects equilibrium between driving and damping

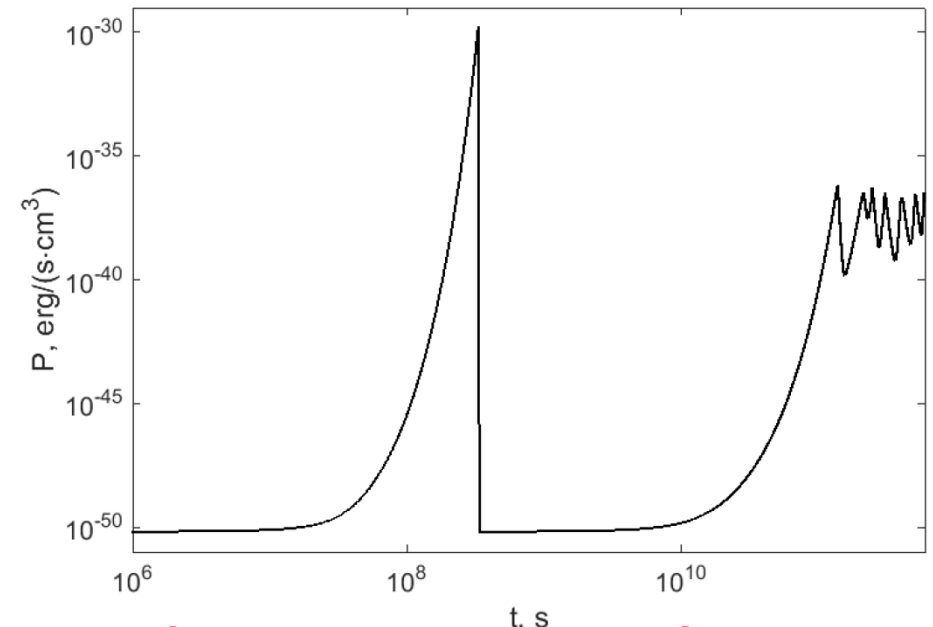
Can calculate energy loss rate $\propto \int d^3k \omega_I W_k$

Analytical scaling: plasma instabilities are ten times faster than Compton scattering

Numerical handling

Vafin et al. 2019

→ no constant saturation level



→ no constant energy loss rate

Subdominant processes matter!

What else do we miss??

Conclusions and outlook

Beam instabilities in the laboratory

- Numerous plasma instabilities are relevant in astrophysics
- Simulations are often not possible with real parameters
- We should study relevant processes in the lab
- There is no easy option for laboratory astroparticle physics
- Which instabilities are possible with existing hardware?

What can we do within Quantum Universe?