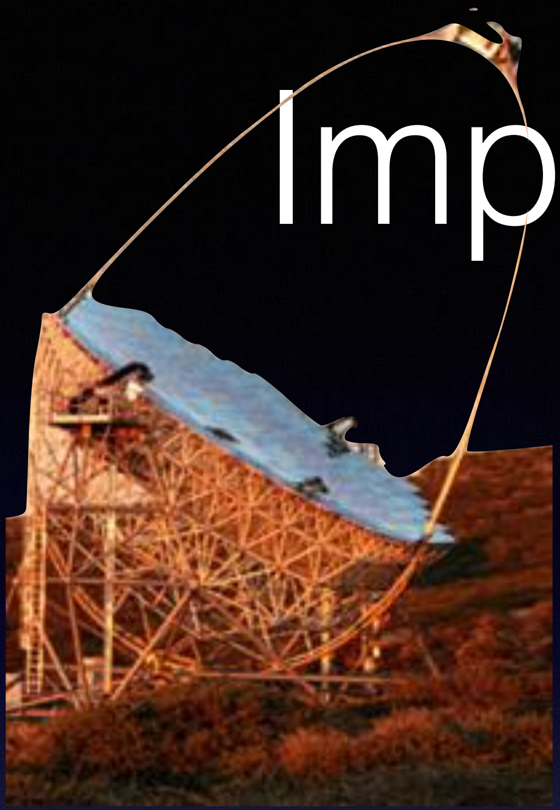

Implications of the sub-TeV emission from GRB 190114C

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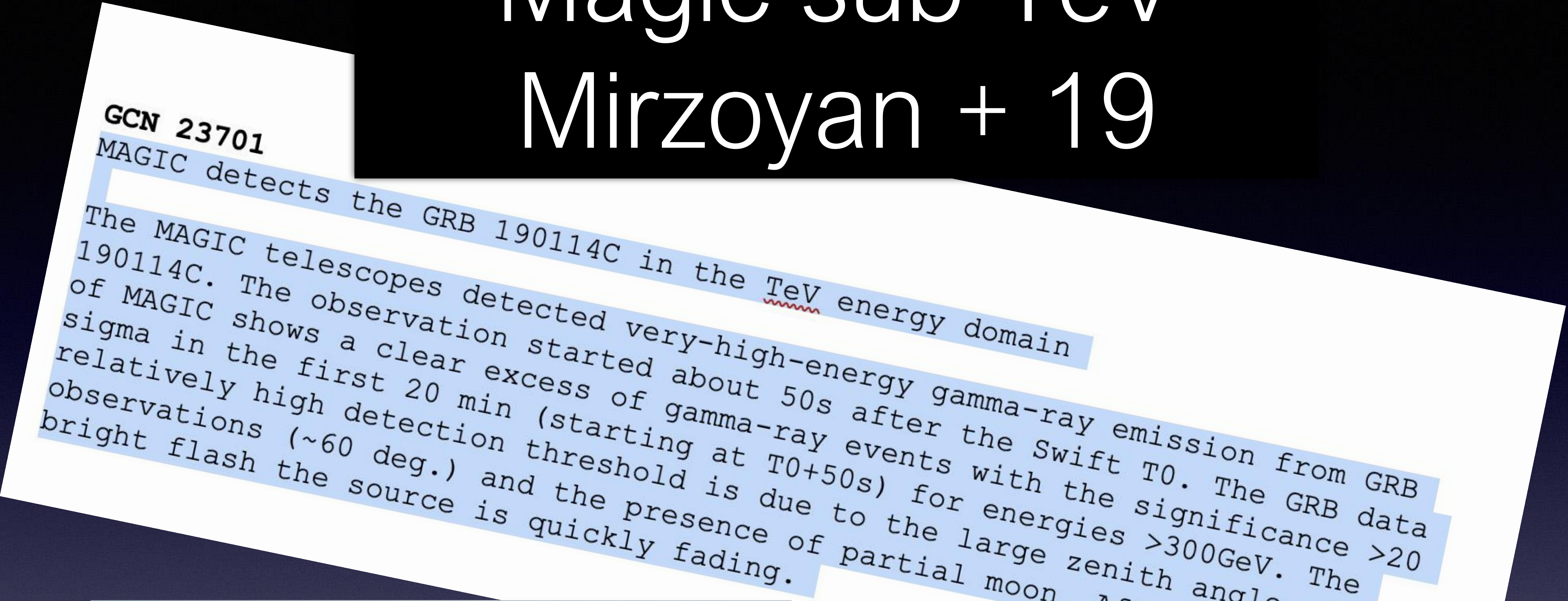
St Petersburg, Russia

Magic sub-TeV
Mirzoyan + 19

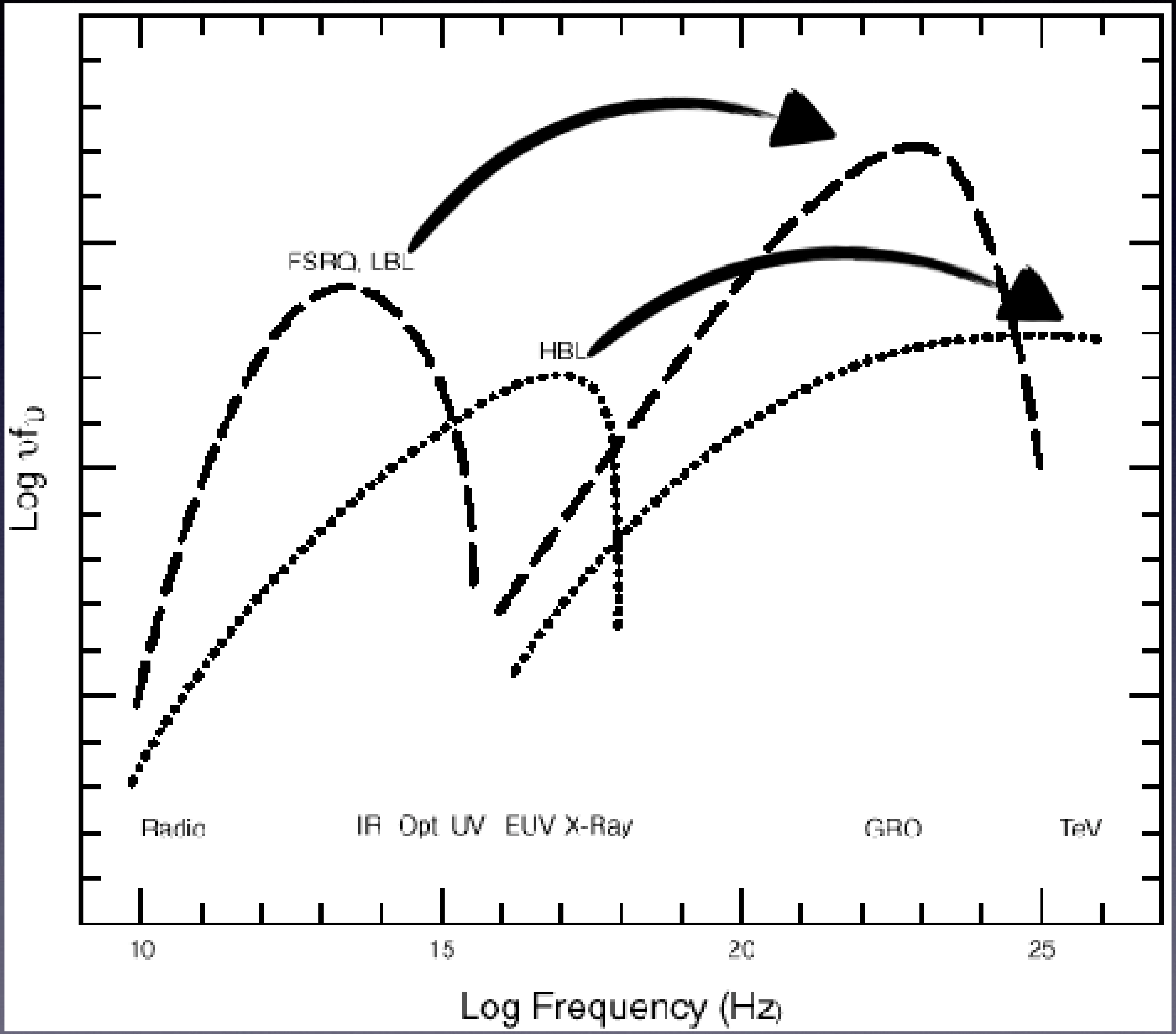


GCN 23701

MAGIC detects the GRB 190114C in the TeV energy domain

The MAGIC telescopes detected very-high-energy gamma-ray emission from GRB 190114C. The observation started about 50s after the Swift T0. The GRB data of MAGIC shows a clear excess of gamma-ray events with the significance >20 sigma in the first 20 min (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (~60 deg.) and the presence of partial moon. After the first bright flash the source is quickly fading.

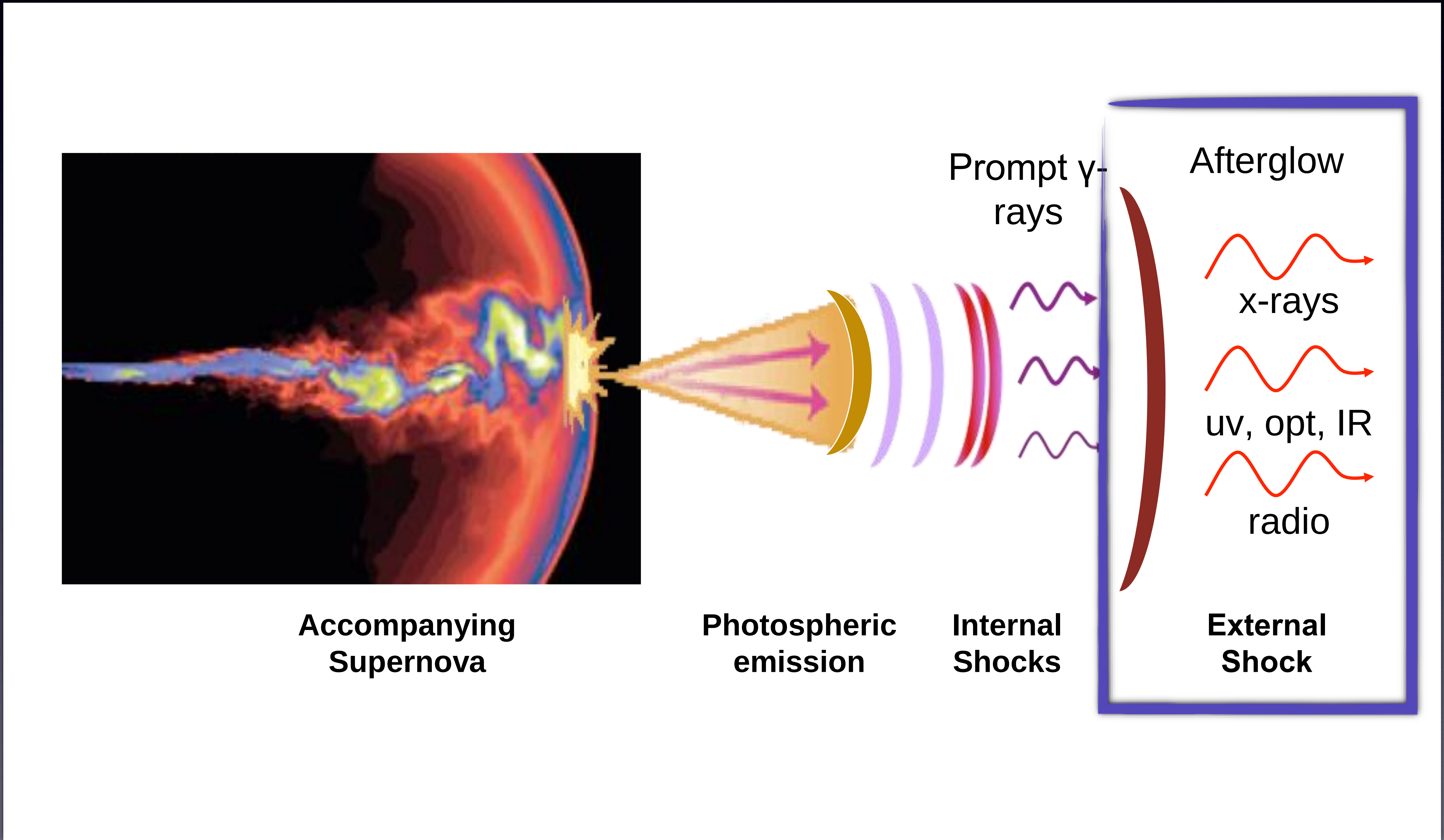
Blazars


FSRQ, LBL
HBL
Log νf_ν
Radio
IR
Opt
UV
EUV
X-Ray
GRO
TeV
10
15
20
25
Log Frequency (Hz)

Observations

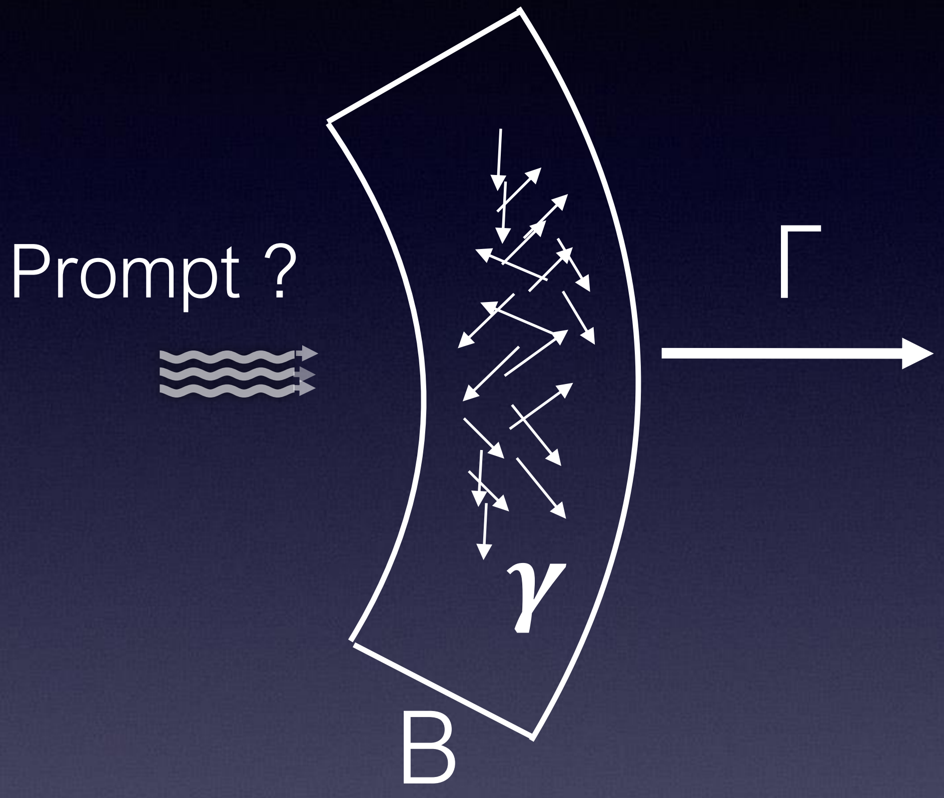
- Z=0.4245 (Some TeV absorption)
- $L_{peak}^{Iso} \simeq 1.6 \text{ x}10^{53}$ erg/sec ; $E^{Iso} \simeq 3\text{x}10^{53}$erg
- @ 70 sec $L_x^{Iso} \simeq 6 \text{ x}10^{49}$erg/sec
- $E_{sub\text{-}TeV} \simeq 350$ GeV
- $y=L_{Tev}^{Iso}/L_x^{Iso} \simeq 0.25$

A Gamma-Ray Burst Model



The Model

- Blast wave into wind or ISM
- Single Zone
- Single energy electrons*



Parameters: Γ, n, t,
ε_e, ε_B that can be replaced by y,t_{dyn}/t_{cool},ε_R

Origin of Sub-TeV?

- Synchrotron burn-off limit
  (Acc. time $\simeq$ cooling time)
  $E_{\text{burn-off}} = \Gamma\, m_e c^2 / \boldsymbol{\alpha} \simeq \Gamma$ 100 MeV too low .

- Bypass burn-off limit: acceleration in a weak field and emission in a strong one (e.g. Kumar & Barniol-Duran 09) or “converter” acceleration.

- => Inverse Compton

The Lorentz Factors

- $\boldsymbol{\gamma}\Gamma\ m_e c^2 > E_{IC} \Rightarrow \boldsymbol{\gamma}\Gamma \simeq 10^6$

- @ 70 sec and longer Γ cannot be too large $\Rightarrow \boldsymbol{\gamma} \gtrsim 10^4$

- Not unreasonable in an external shock with $\boldsymbol{\gamma} \simeq f(m_p/m_e)\Gamma$

- => Sub Tev is Inverse Compton of X-rays (Consistent with a comparable X-ray luminosity)

Opacity

- The optical depth for pair production $\tau_{IC,x} < 1$
  The usual opacity estimates for GRBs with L_x
  as the source of absorbing photons

=> Γ > 170

$$\Gamma > 170 \left(\eta_a \frac{L^{\rm iso}_{X,51}}{t_2} \right)^{1/6}$$

- Somewhat different analysis if the X-rays are from “prompt” origin.

- Even this Γ requires low external density (e.g. $n_{ISM} < 10^{-2}$) =>
  cannot expect much larger Γ =>
  cannot expect much lower **γ** (**γ** $\Gamma > 10^6$)

The Optical Depth

- The low density (e.g. $n_{ISM} < 10^{-2}$) may be the reason why sub-TeV observations are not common.
- Other events are typically self-absorbed (See also - Vrum & Beloborodov 2017).

What kind of IC?
To KN or not to KN

The usual Comptonisation energy is $\boldsymbol{\gamma}^2 E_{seed}$

If $\boldsymbol{\gamma}^2 E_{seed} > \boldsymbol{\gamma} m_e c^2$ we are in the Klein Nishina (KN) regime:
$E_{IC} = \boldsymbol{\gamma} m_e c^2$

What kind of IC?

The SSC Klein Nishina Energy

$$E_{\rm IC}^{\rm cr} = \Gamma \gamma_{\rm cr} m_e c^2 = \Gamma \left(\frac{B_{\rm cr}}{B} \right)^{1/3} m_e c^2$$

KN for Γ<

$$\Gamma_{\rm KN} \simeq 86 \, \frac{(L_{51}^{\rm iso})^{1/12}}{t_2^{1/6}}$$

=> With the opacity limit (Γ>100) the system is close to KN but in regular Comptonization

The electron’s Lorentz factor

Combining the Opacity and KN limits:

$$\gamma_{e,\mathrm{min}} \simeq \frac{E_{\mathrm{IC}}}{\Gamma m_e c^2} = \frac{10^6}{\Gamma}$$

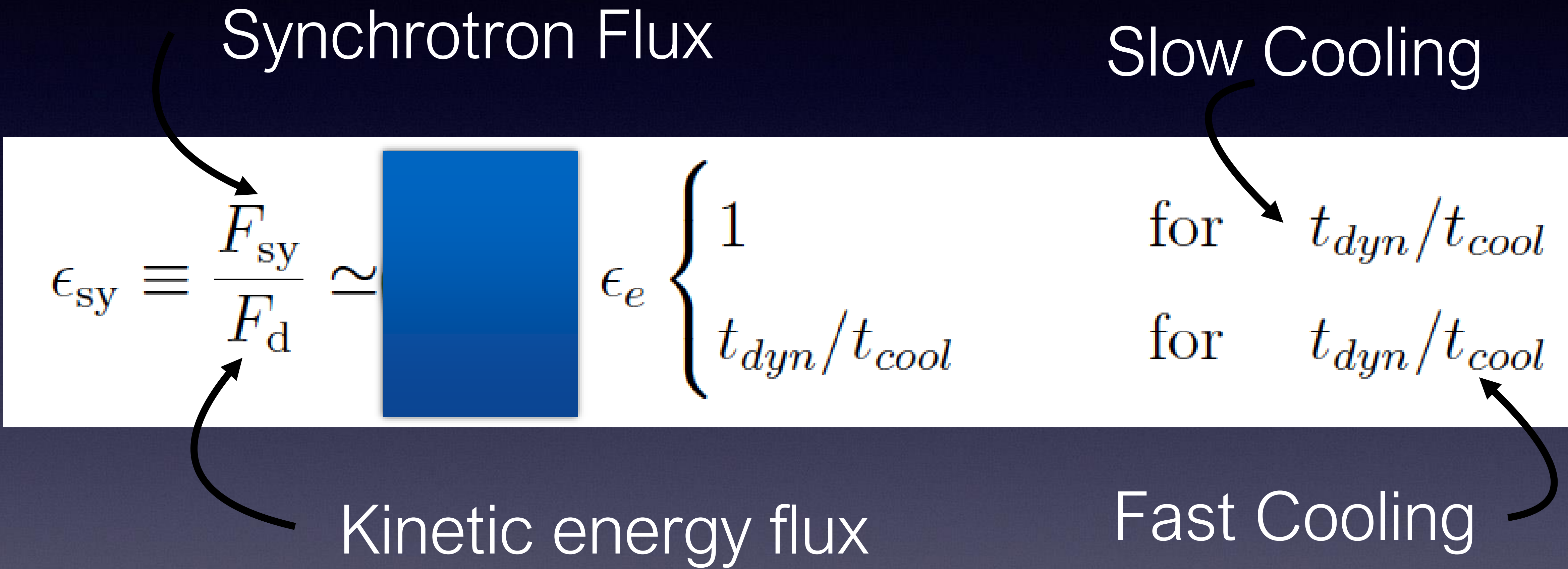
>170

$\simeq 90$

$$\gamma_{e,\mathrm{max}} \simeq \left(\frac{\Gamma}{\Gamma_{\mathrm{KN}}}\right)^{3/2} \gamma_{e,\mathrm{min}}$$

$$\boxed{\gamma_e \simeq \gamma_{e,\mathrm{max}} \simeq 1.5 \times 10^4}$$

Efficiency



Synchrotron Flux

Slow Cooling

$$\epsilon_{\rm sy} \equiv \frac{F_{\rm sy}}{F_{\rm d}} \simeq \text{[redacted]}\ \epsilon_e \begin{cases} 1 & \text{for} \quad t_{dyn}/t_{cool} > 1 \\ t_{dyn}/t_{cool} & \text{for} \quad t_{dyn}/t_{cool} < 1 \end{cases}$$

Kinetic energy flux

Fast Cooling

(See also Sari, Narayan & TP 96)

Efficiency

$E_X^{Iso} \simeq 10^{52}$ erg.

$E_{tot}^{iso} = E_X^{Iso} / \boldsymbol{\varepsilon}_{sy}$

But $\boldsymbol{\varepsilon}_{sy} = y\ \boldsymbol{\varepsilon}_B \simeq 0.25 \boldsymbol{\varepsilon}_B$

=> $E_{tot}^{iso} \simeq 5\mathrm{x}10^{52}$ erg $/ \boldsymbol{\varepsilon}_B$

=> $\boldsymbol{\varepsilon}_B > 0.005\ (E_{tot,max}^{iso} / 10^{55})$

Caveats

- $L_{sub\text{-}TeV}$ is underestimated because of self absorption => y is larger, maybe even > 1. => $\boldsymbol{\varepsilon}_e > \boldsymbol{\varepsilon}_B$ and $\boldsymbol{\varepsilon}_B$ can be smaller (but not tiny).

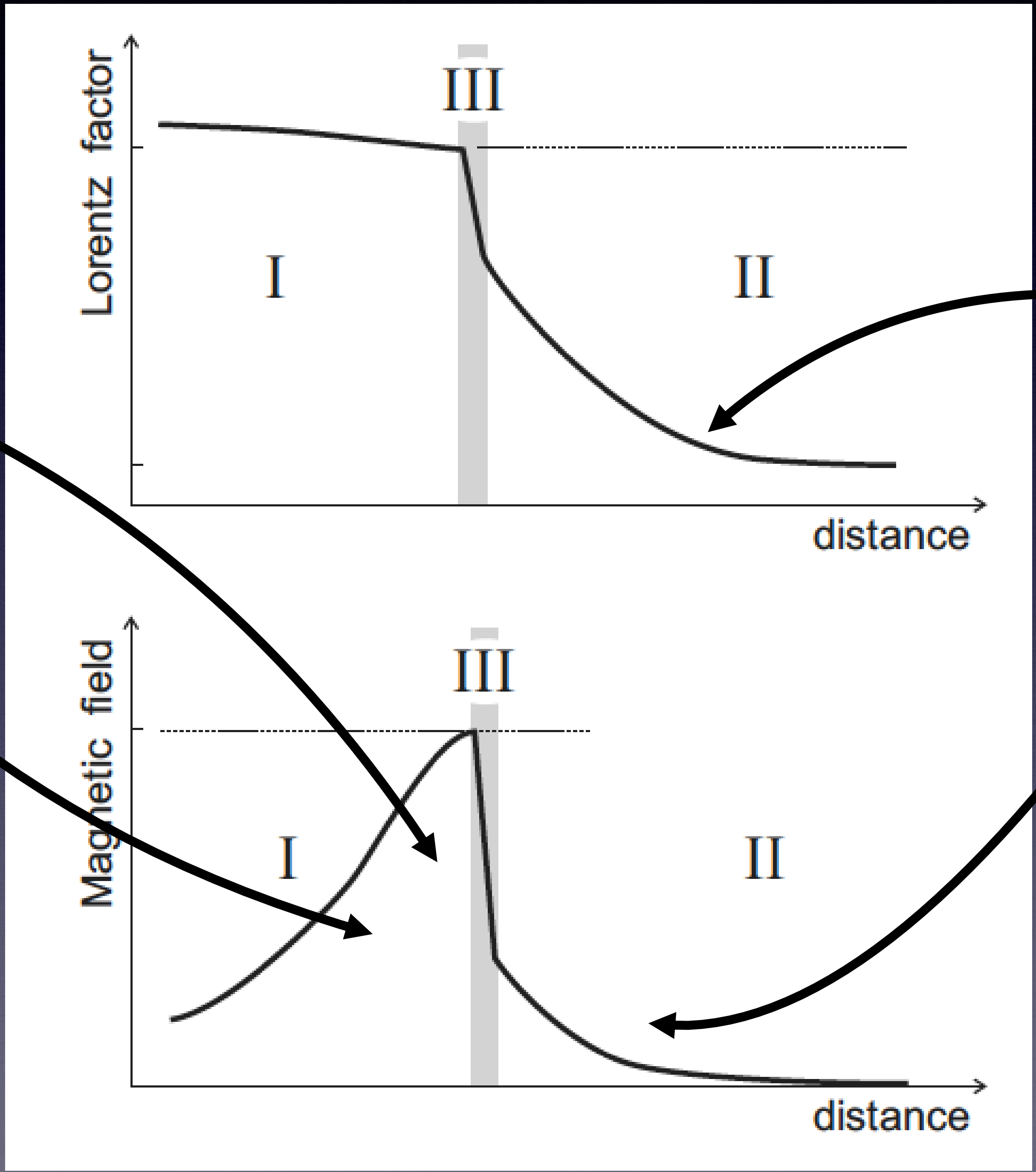
- A fraction of L_X arises from the "prompt component". This relaxes somewhat the efficiency problem but since y is unchanged the condition $\boldsymbol{\varepsilon}_B > \boldsymbol{\varepsilon}_e$ remains.

Partial Summary

- The electron's Lorentz factor ~10^4
- The bulk Lorentz factor @100 sec ~ 100
- Low external density enables the sub-TeV photons to escape
- Relatively large magnetization $\varepsilon_B > 0.005$ and $\varepsilon_B > \varepsilon_e$
- IC slightly below the Klein Nishina regime

Coincidence?

Pair Balance Model



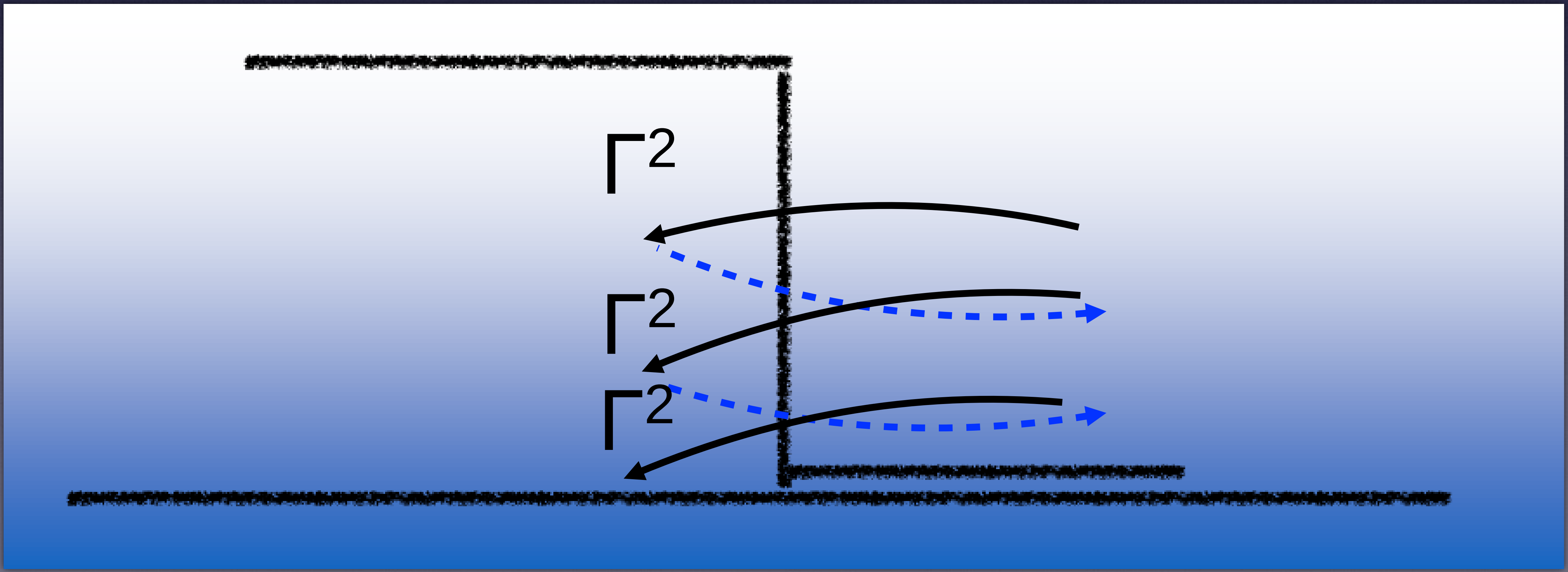
1) Very strong magnetic field
2) Pair loading; saturation around the Klein Nishina threshold

1) Pre acceleration
2) Magnetic field build up

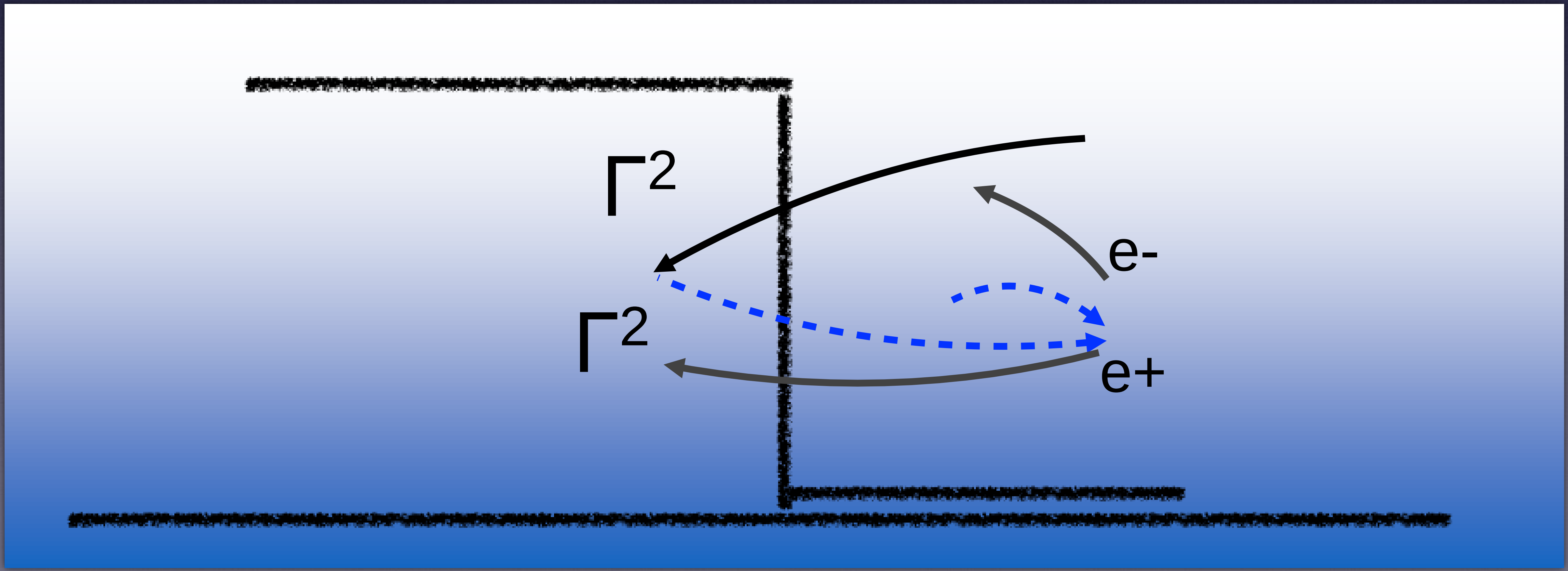
Derishev & TP 16

Converter acceleration

Derishev et al. (2003); Stern (2003)

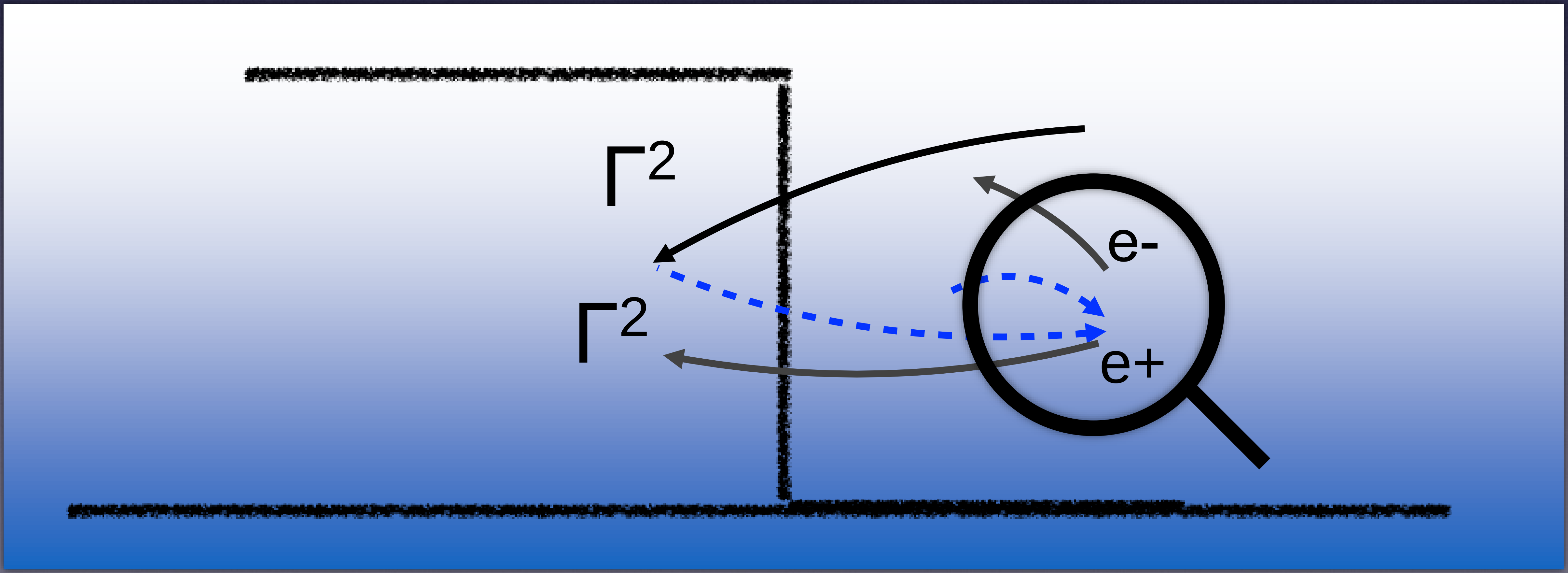


Converter acceleration via high energy (IC) photons

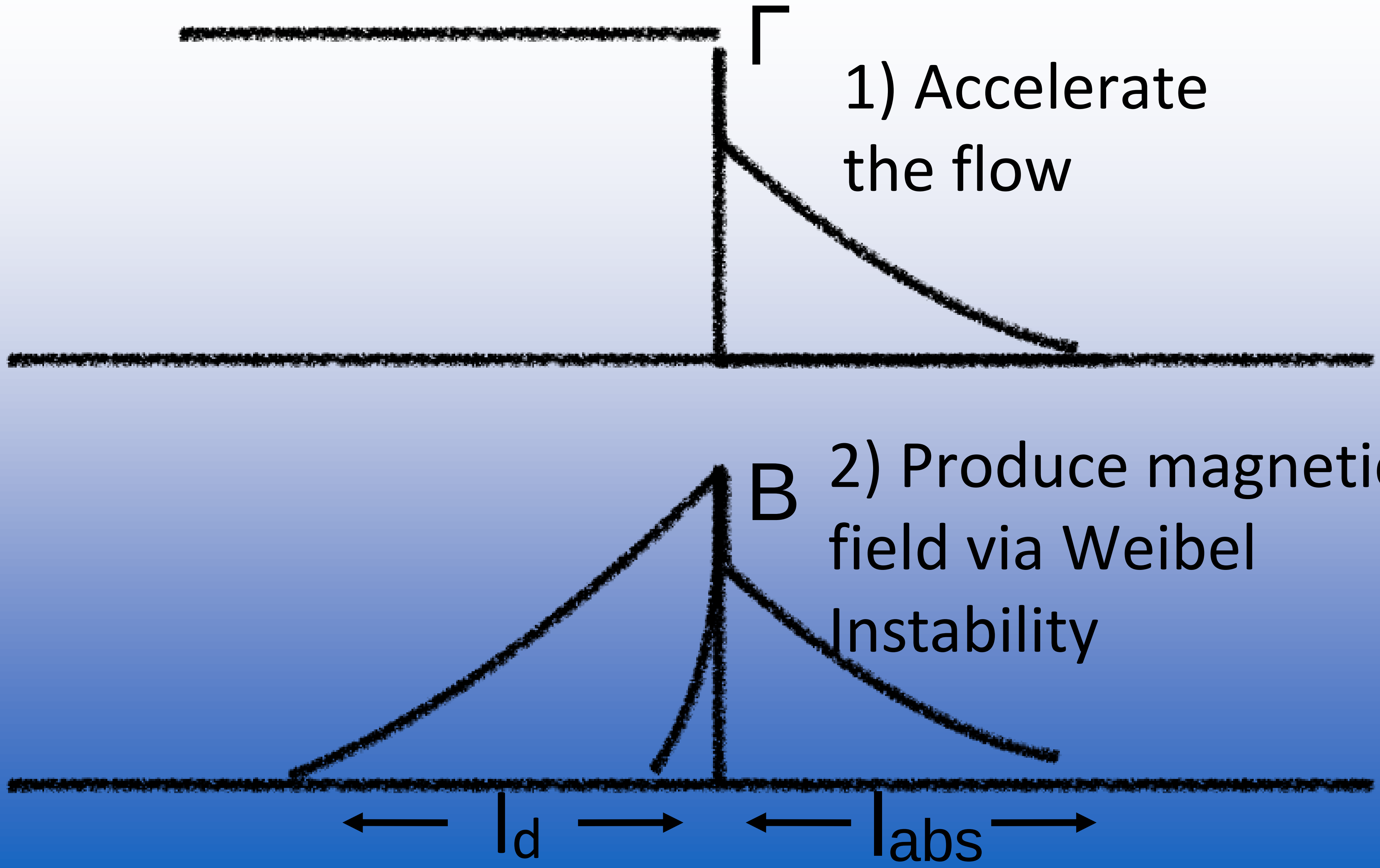


1) Accelerate the flow

2) Produce magnetic field via Weibel Instability



Modified structure



1) Accelerate the flow

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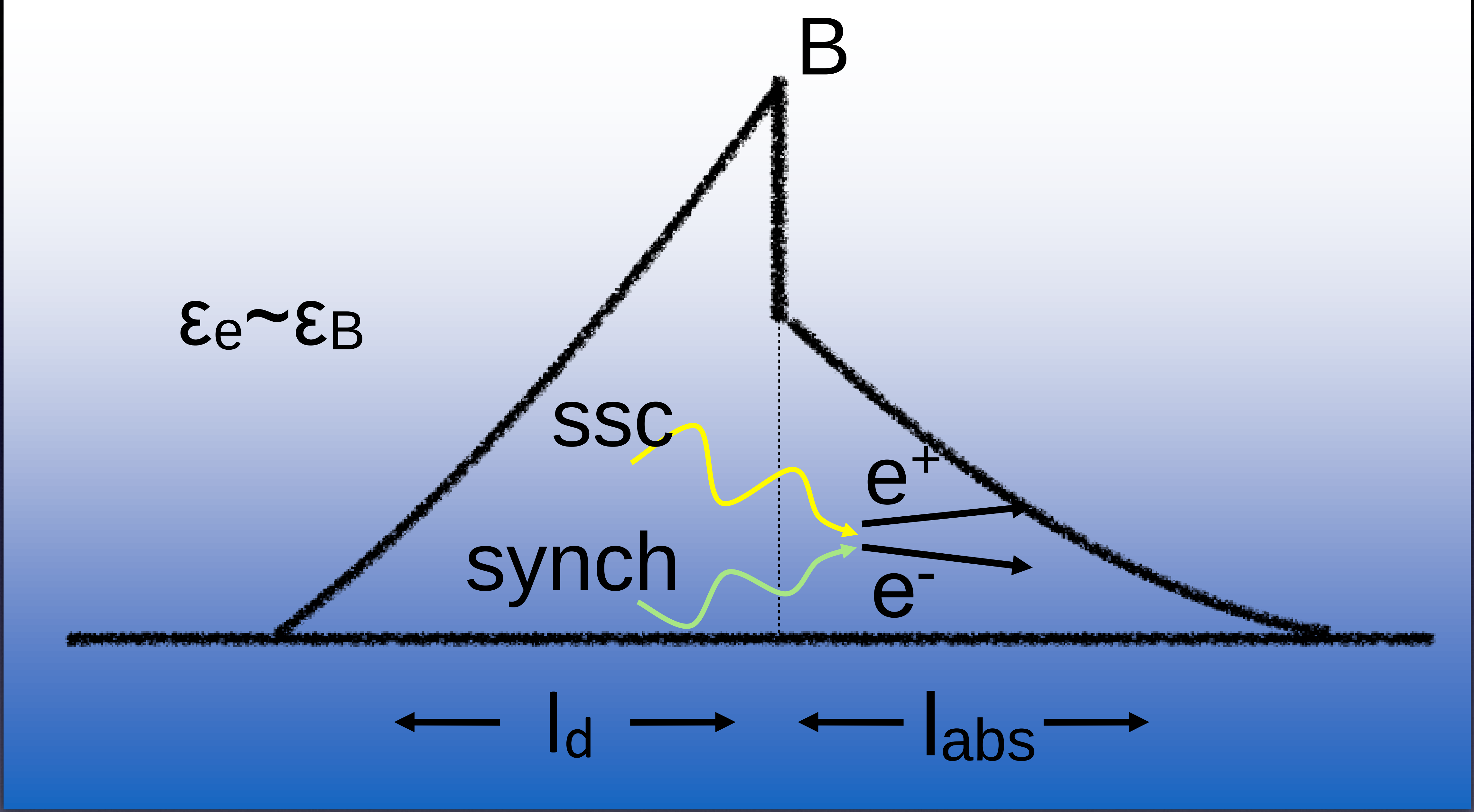
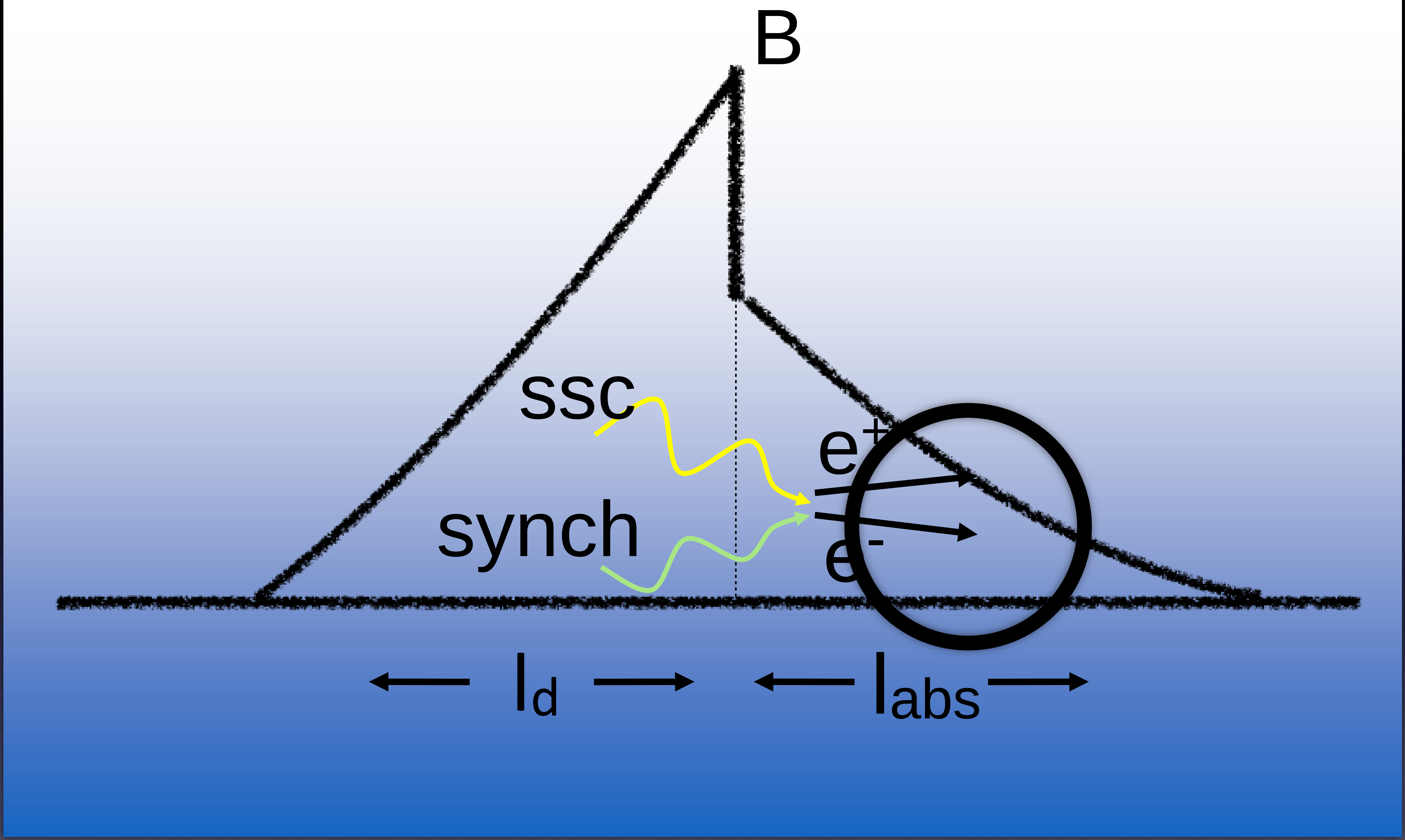
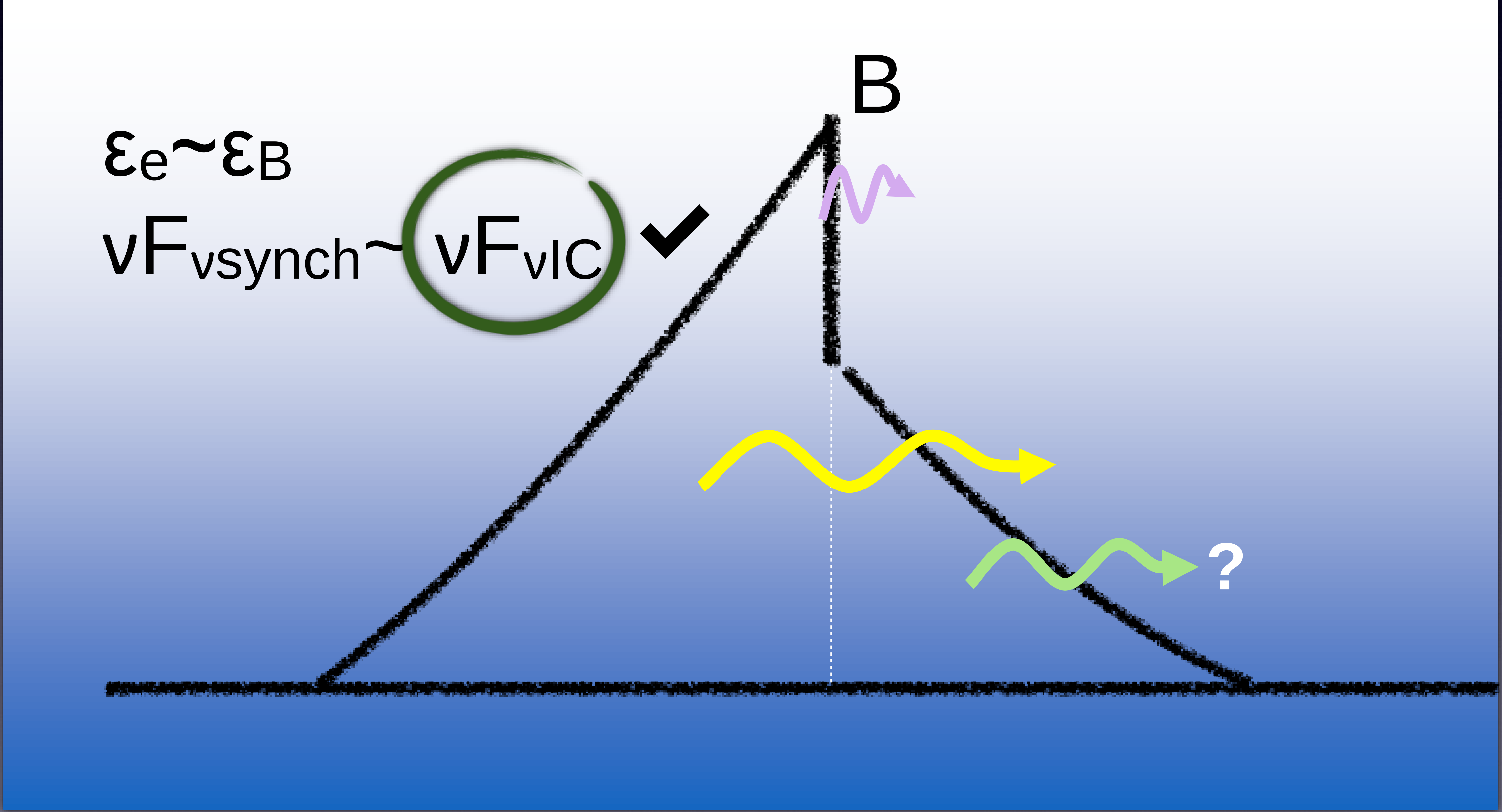


gnetic field, in the downstream, accelera



e upstream increase the multiplicity of the

Three emission components



$\varepsilon_e \sim \varepsilon_B$

$\nu F_{\nu \mathrm{synch}} \sim \nu F_{\nu \mathrm{IC}}$ ✓

Summary

- The electron’s Lorentz factor ~10^4
- The bulk Lorentz factor @100 sec ~ 100
- Low external density enables the sub-TeV photons to escape escape
- Relatively large magnetization $\boldsymbol{\varepsilon}_B > 0.005$ and $\boldsymbol{\varepsilon}_B > \boldsymbol{\varepsilon}_e$
- IC slightly below the Klein Nishina regime
- The configuration is consistent with the pair balance model (Derishev & TP 2016).