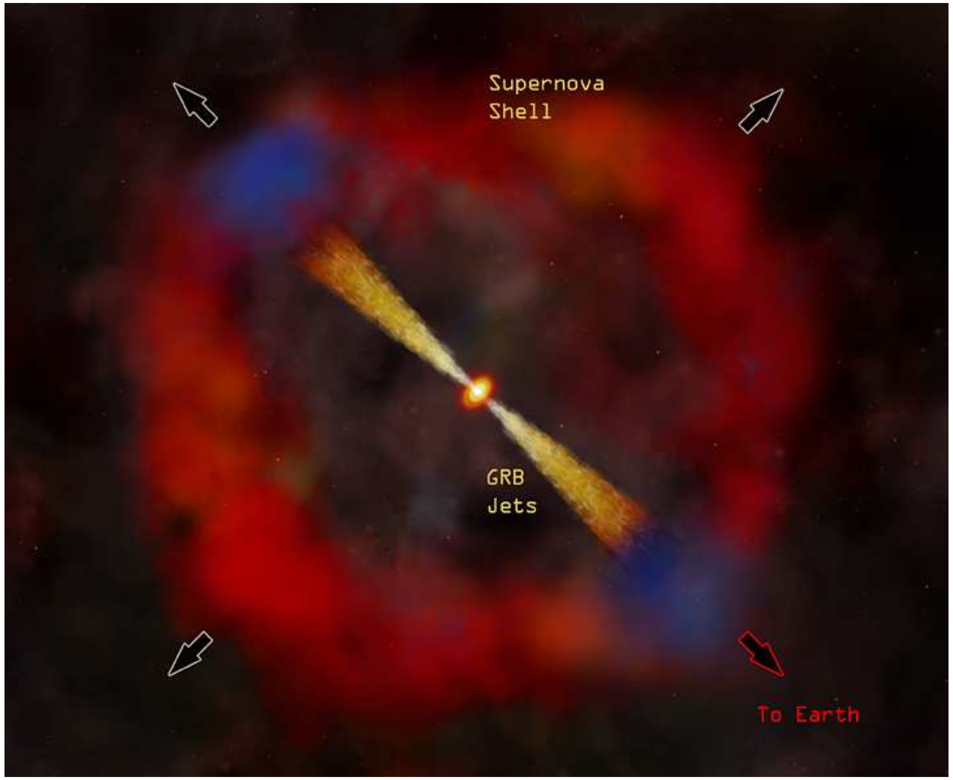
# Relativistic interaction of a high intensity photon beam with a plasma: a possible GRB emission mechanism

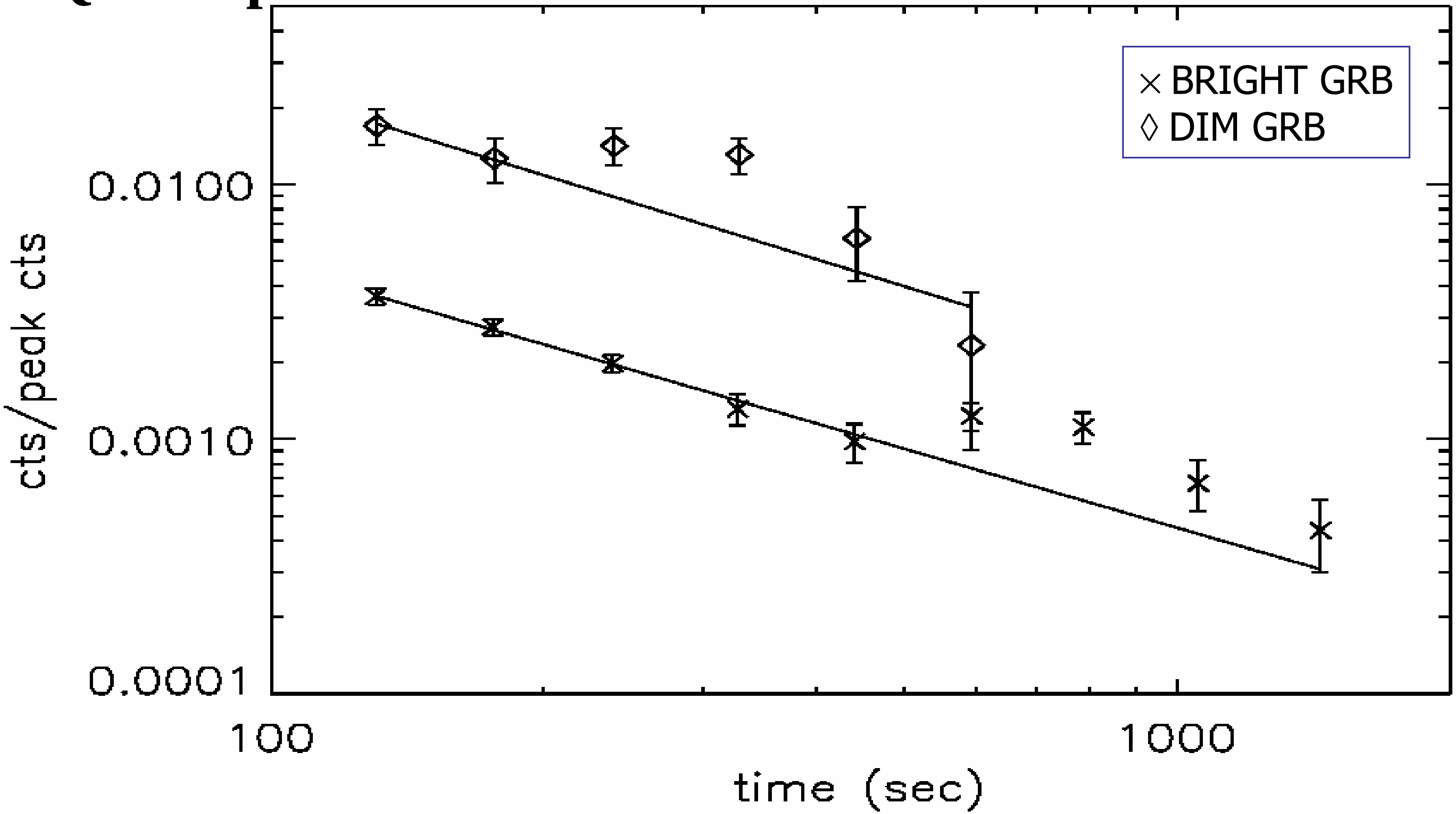



L. Amati, G. Barbiellini, A Celotti, A. Galli, R. Landi,
F. Longo, N. Omodei, M. Tavani

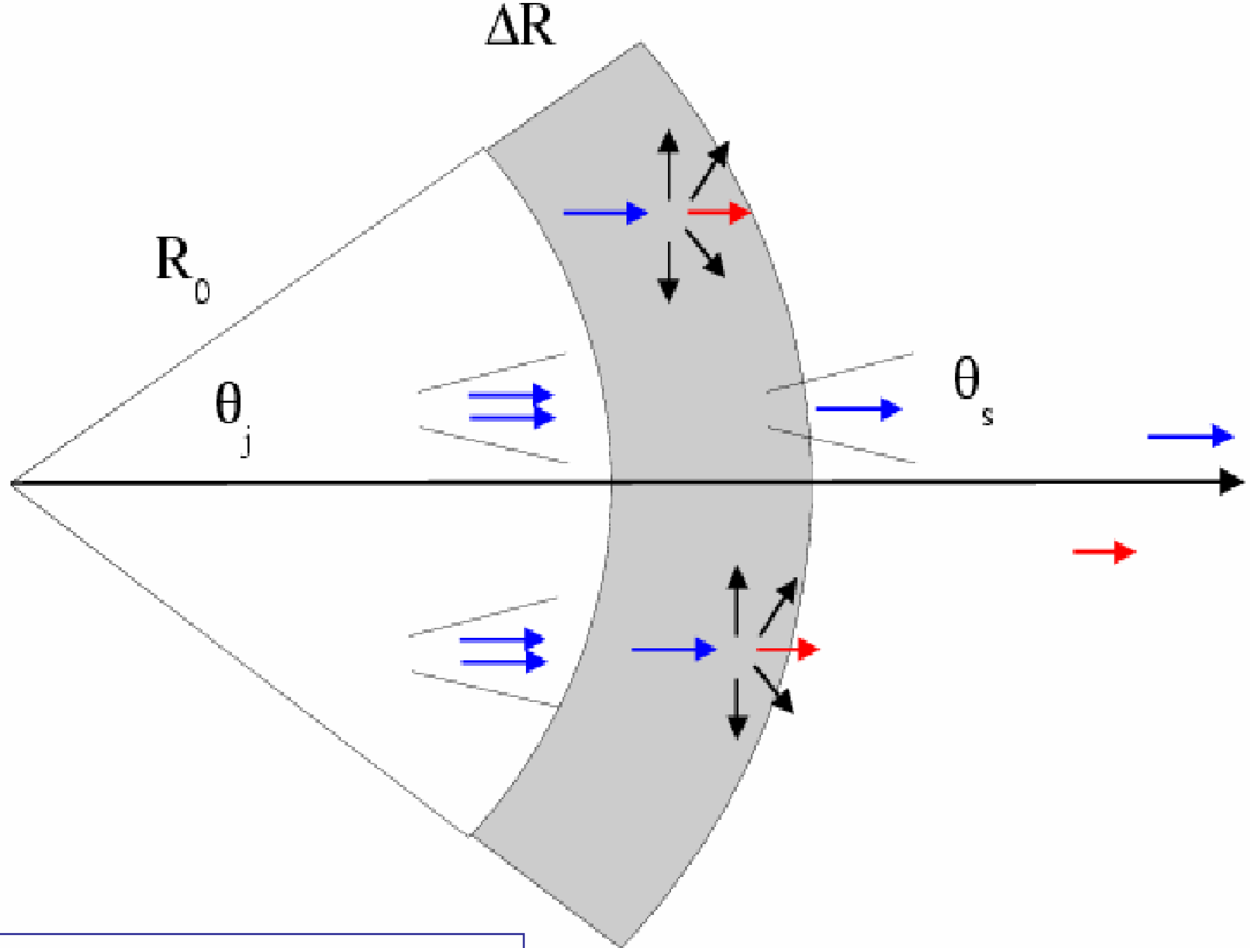
# Bright and Dim GRB

(Connaughton 2002)

**Q = cts/peak cts**



# The Compton Tail




Barbiellini et al. (2004) MNRAS 350, L5

# Bright and Dim Bursts

- Bright bursts (tail at 800 s)
  - Peak counts >1.5 $cm^{-2}$ $s^{-1}$
  - Mean Fluence 1.5 $\times$ $10^{-5}$ erg $cm^{-2}$
  - Q = 4.0 $\pm$ 0.8 $10^{-4}$ (5 $\sigma$) fit over PL
  - $\tau$ = 1.3

$R = 10^{15}$ cm
$\Delta R \sim R$
$\theta \sim 0.1$

- Dim bursts (tail at 300s)
  - peak counts < 0.75 $cm^{-2}$ $s^{-1}$
  - Mean fluence 1.3 $\times$ $10^{-6}$ erg $cm^{-2}$
  - Q = 5.6 $\pm$ 1.4 $10^{-3}$ (4 $\sigma$) fit over PL
  - $\tau$ =2.8
- Mean fluence ratio = 11
- "Compton" correction $E = e^{\tau} E_{\rm obs}$
- Corrected fluence ratio = 2.8

# GRB tails

- Connaughton (2002), ApJ 567, 1028
- Search for Post Burst emission in prompt GRB energy band
- Looking for high energy afterglow (overlapping with prompt emission) for constraining Internal/External Shock Model
- Sum of Background Subtracted Burst Light Curves
- Tails out to hundreds of seconds decaying as temporal power law $\delta = 0.6 \pm 0.1$
- Common feature for long GRB
- Not related to presence of low energy afterglow

# The Compton tail

- "Prompt" luminosity

$$\langle L_{\rm s}\rangle = \langle \frac{dn_{\rm s}}{d\Omega\ dt}\rangle \simeq \frac{n_{\rm p}\ e^{-\tau}}{\pi\theta_{\rm s}^2\ t_{\rm grb}} \cdot \frac{\theta_{\rm s}^2}{\theta_{\rm j}^2}$$

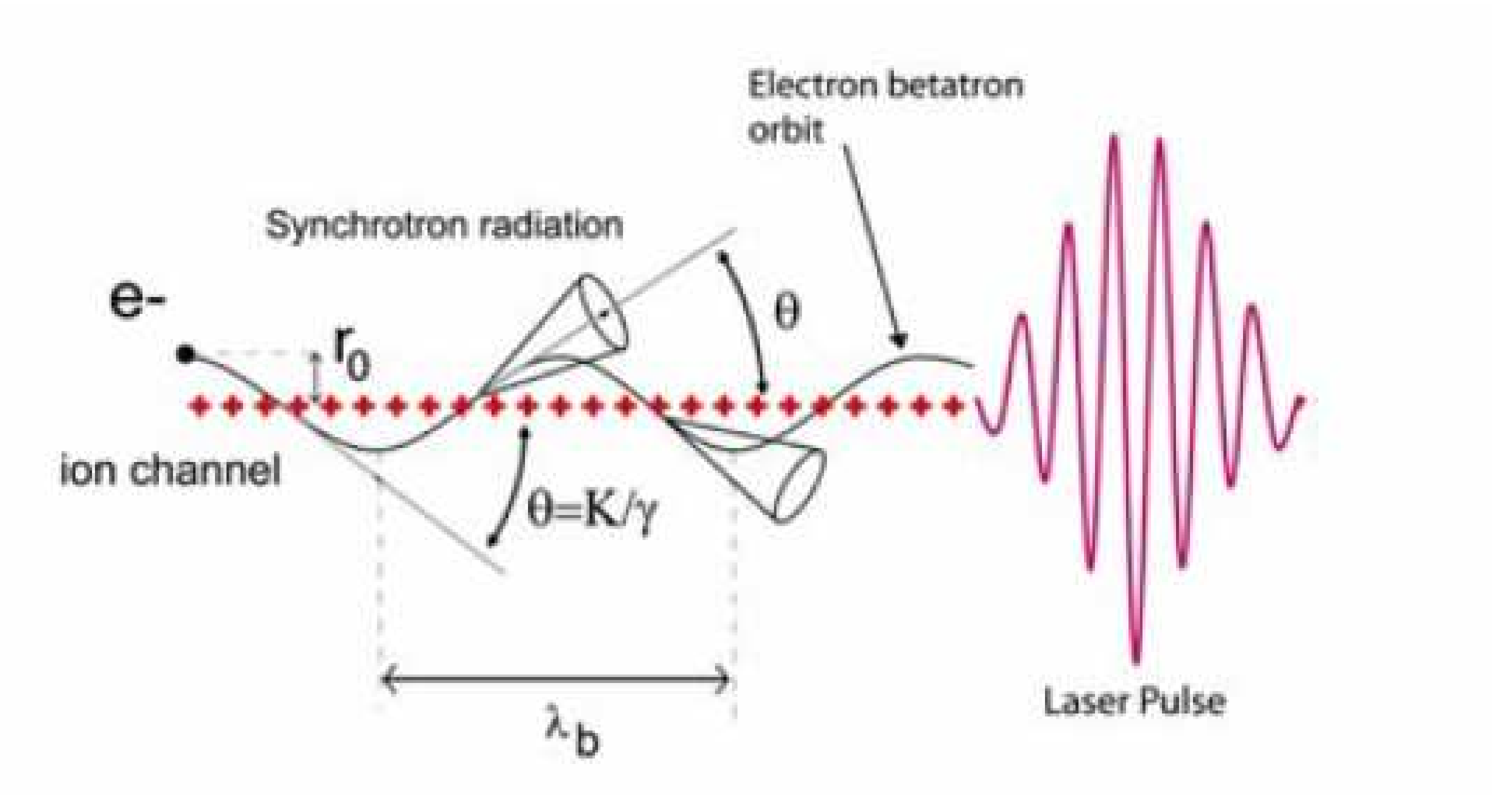
- Compton "Reprocessed" luminosity

$$\langle L_{\rm c}\rangle = \frac{n_{\rm p}\ (1-e^{-\tau})}{2\pi\ t_{\rm geom}} \qquad t_{\rm geom} \sim \frac{(R_0+\Delta R)\theta_{\rm j}^2}{c}$$

- "Q" ratio

$$\boxed{Q = \frac{\langle L_{\rm c}\rangle}{\langle L_{\rm s}\rangle} = (e^{\tau}-1)\cdot\frac{c\ t_{\rm grb}}{(R_0+\Delta R)}}$$

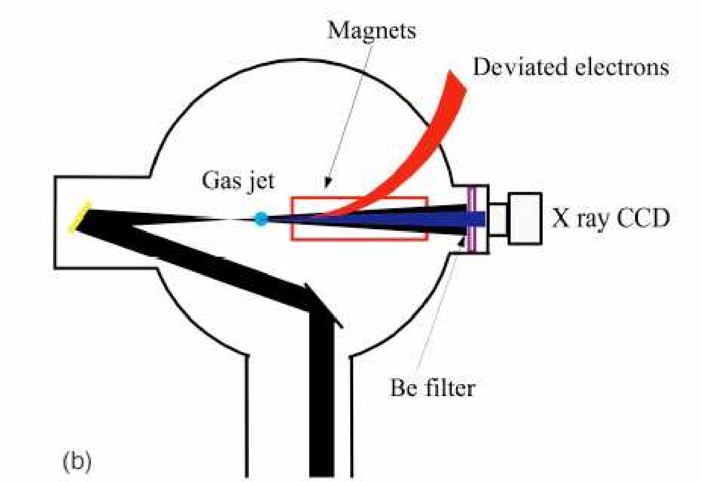
# WakeField Acceleration

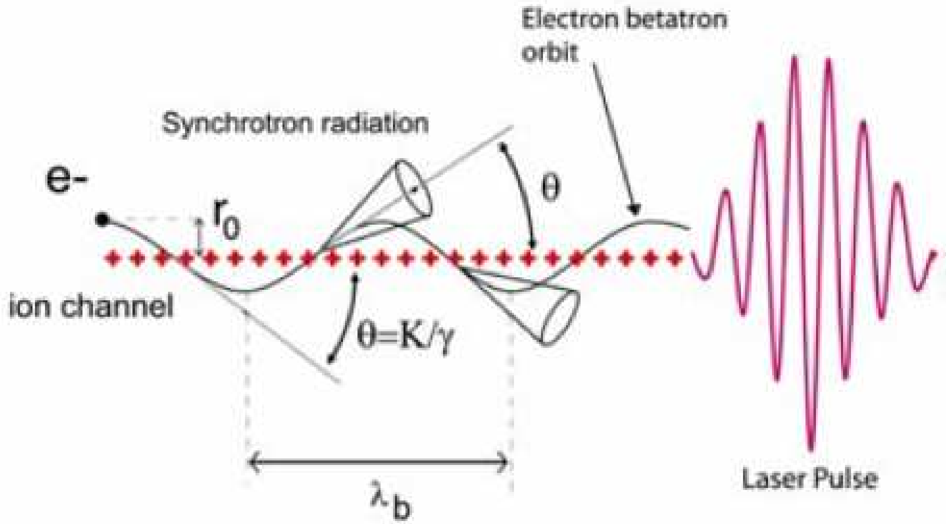



(Ta Phuoc et al. 2005)

# WakeField Acceleration

(Ta Phuoc et al. 2005)

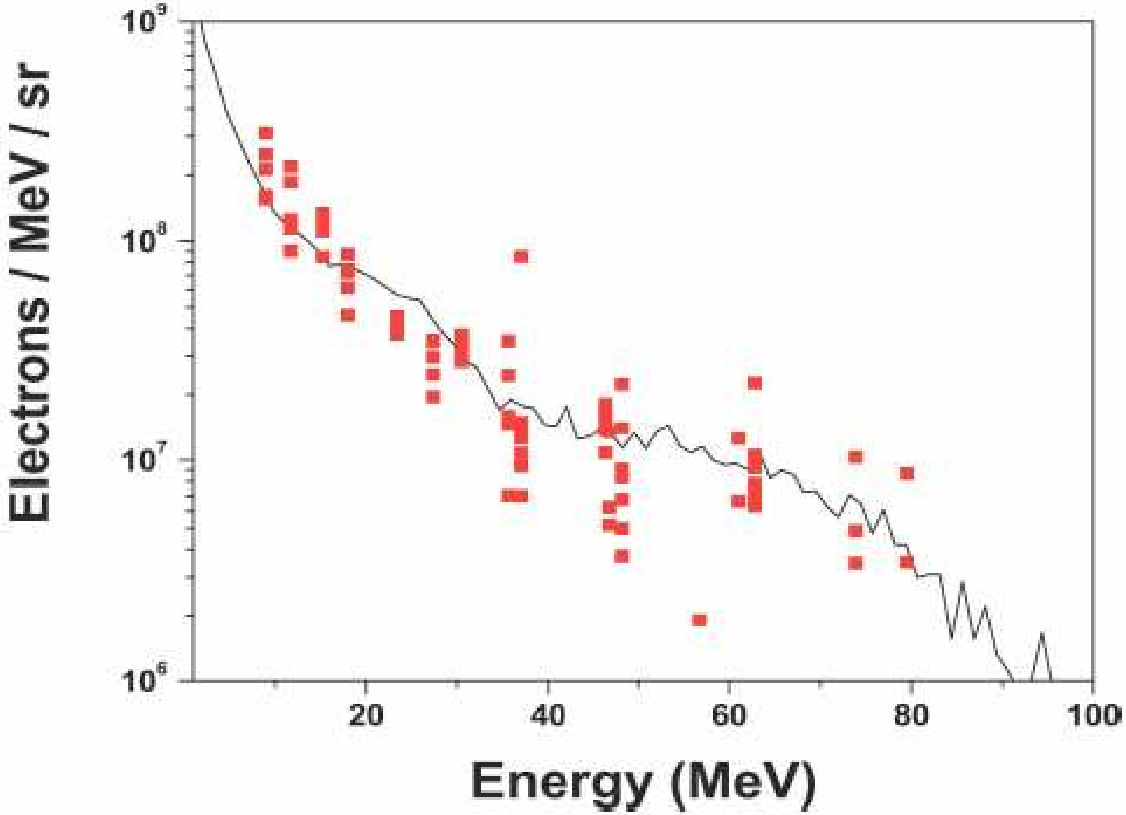



Laser Pulse $t_{laser} = 3\ 10^{-14}$ s
Laser Energy = 1 Joule
Gas Surface = 0.01 mm$^2$
Gas Volume Density = $10^{19}$ cm$^3$
Power Surface Density $\sigma_W = 3\ 10^{18}$ W cm$^{-2}$

# WakeField Acceleration

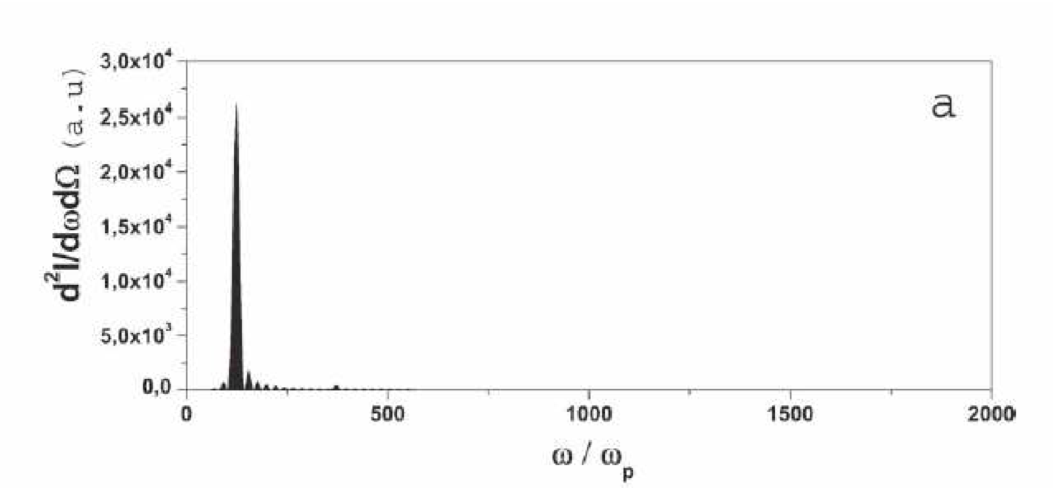
(Ta Phuoc et al. 2005)

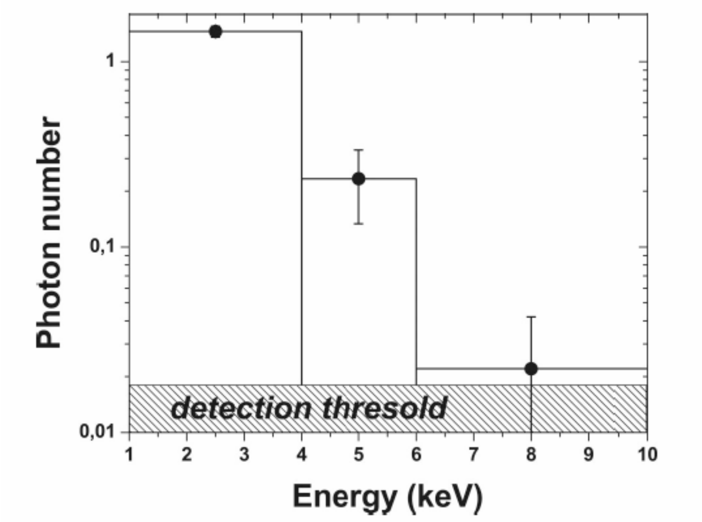


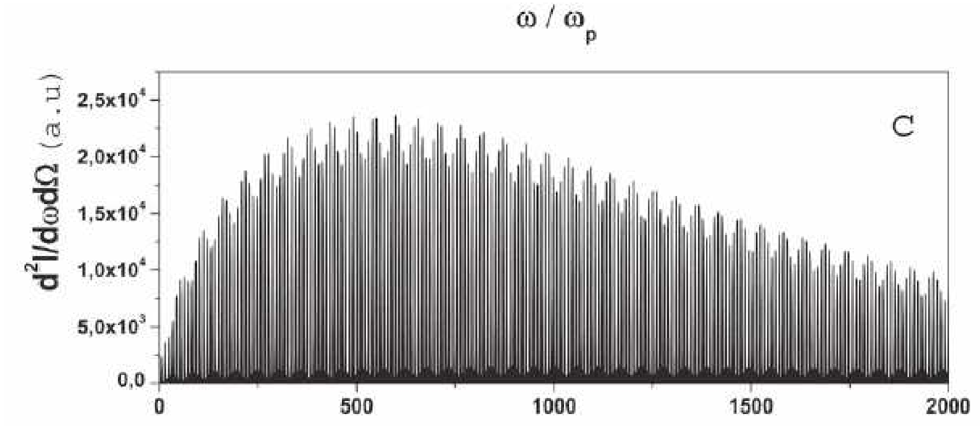

Electron Spectrum

# WakeField Acceleration

(Ta Phuoc et al. 2005)

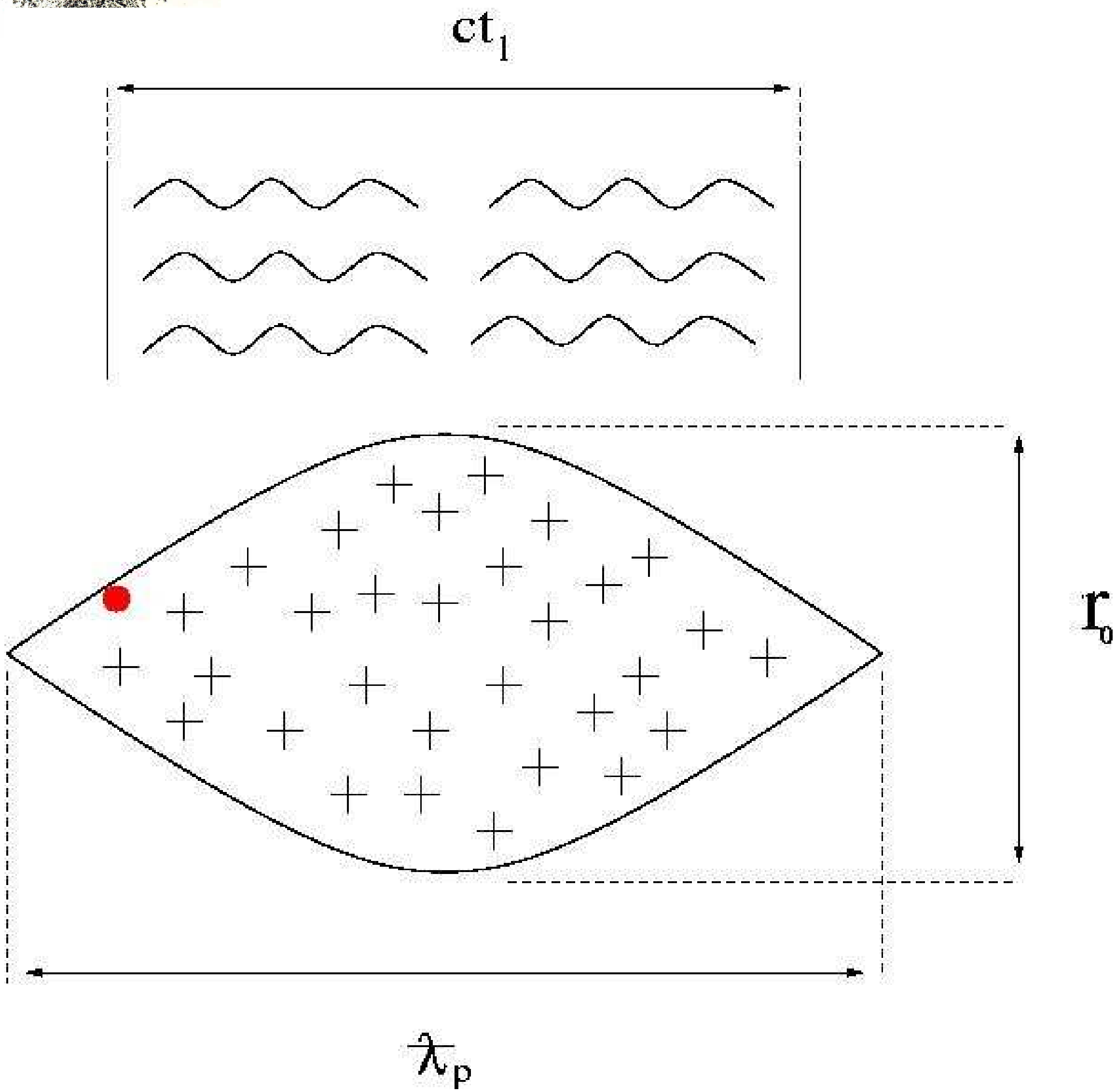



Emitted Photon Spectrum

# Scaling relations

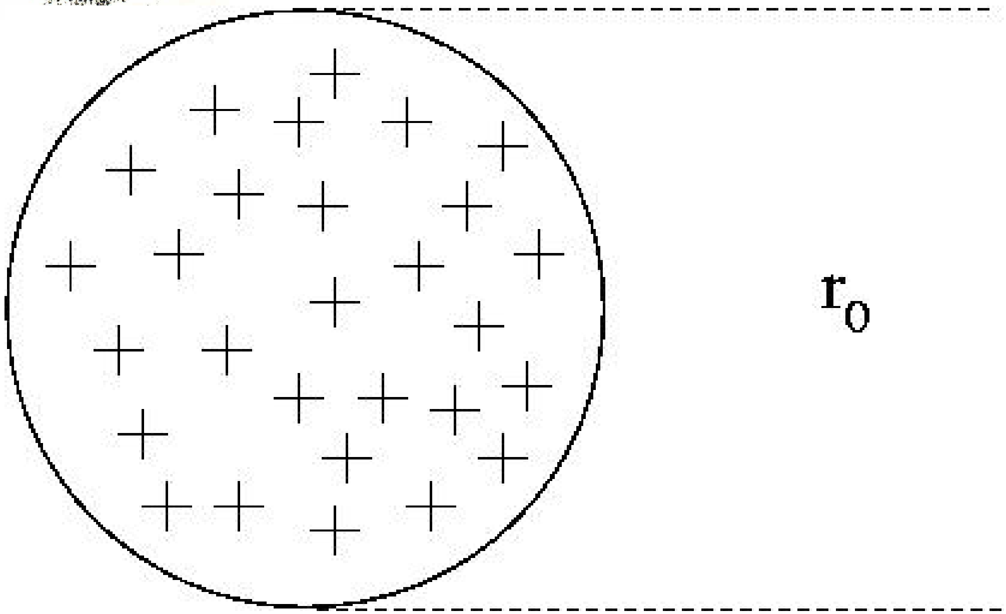



$\lambda_p \sim n^{-1/2}$

$\lambda_b \sim n^{-1/2}\gamma^{1/2}$

$r_0 \sim n^{-1/3}\ \gamma^{-1/2}$

# Scaling relations




$$V \sim r_0^3 \sim n^{-1}$$
$$Q_+ = e n r_0^3 \sim n^0$$

$\gamma(10^{19}) \sim 10^2$

$\gamma(10^{9}) \sim 2\text{x}10^5$

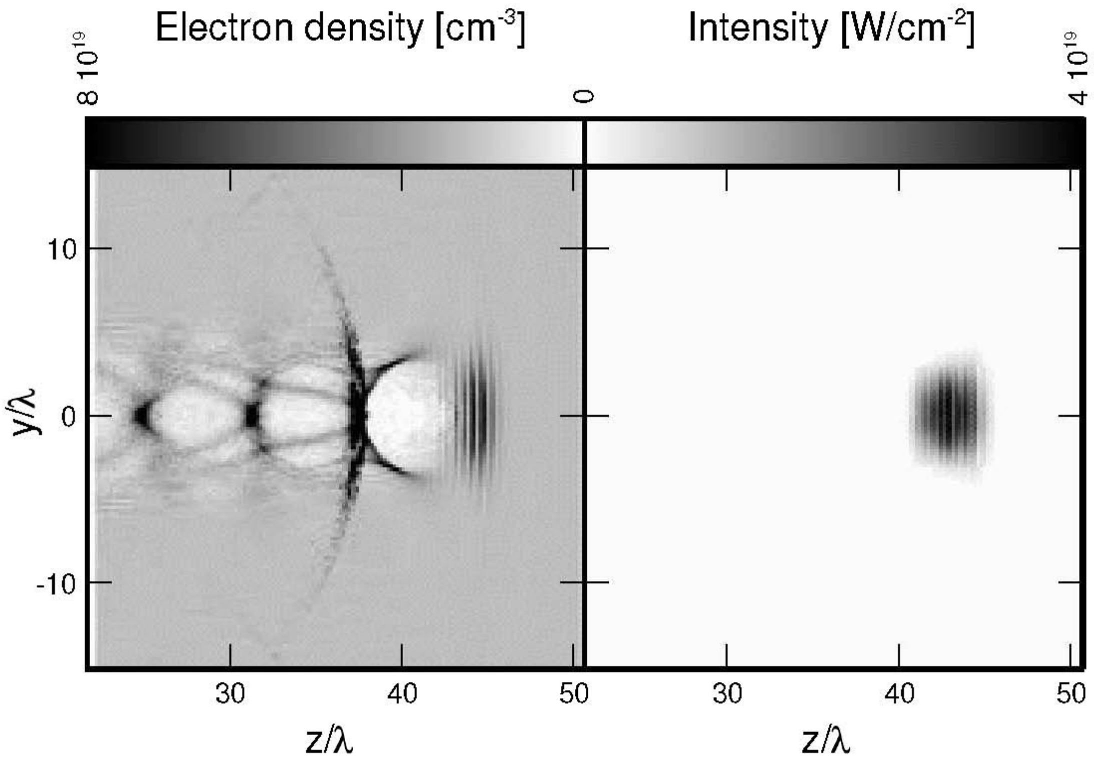
$\gamma(10^{2}) \sim 2\text{x}10^8$

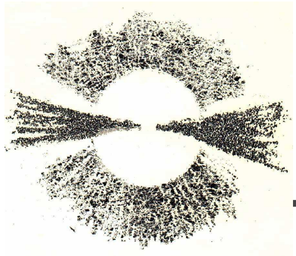
$\gamma \sim n^{-1/3}$

$E_p = 3/4\ hc\gamma^2\ r_0/\lambda_p^{\ 2}$

# 3D PIC Simulation

- PhD Thesis Marco Galimberti  2003  Pisa





# GRB Gamma Emission in the stochastic wake field acceleration regime

$$\theta_i = \frac{r_o}{\lambda_b}$$

$$R_\theta \frac{r_0^2}{\lambda_p^3}(2\gamma)^{-1.5} \leq \theta_j^2$$

$$\theta_{eff}^2 = (\frac{R}{\lambda_b})\theta_i^2$$

$$R_\theta(\gamma) = 2\sqrt{2}\lambda_p \theta_j^2 \gamma^{5/2}$$

From the equation of the electron energy loss we derive

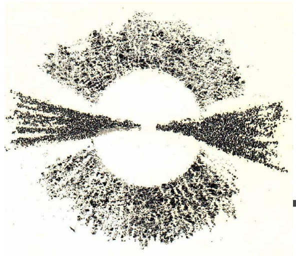
$$R_e \sim 4.1\lambda_p (\frac{\lambda_p}{r_e})^{2/3}\gamma^{1/6}$$

Imposing $R_e = R_0$, we link the jet angle to an energy threshold $\gamma_t$

$$\gamma_t = 1.2(\frac{\lambda_p}{r_e})^{2/7}\theta_j^{-6/7}$$

The previous relations allow the prediction of the typical energy emission

$$< E_{peak} >_{eff} \approx 25\frac{n}{10^9}\theta_j^{-8/7} keV \approx 350 keV$$



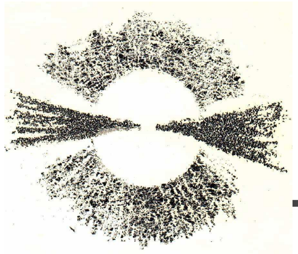
# Condition for the realization of the SWFA regime

$$\frac{N_\gamma(R)\sigma\lambda\sqrt{2}\Gamma}{ct_p R^2\theta^2} > 1$$

$$N_\gamma(R) = \left(\frac{E_\gamma(R)}{E_p}\right)_{prec}$$

$$E_\gamma(R) = E_\gamma(R_0)F(R)$$

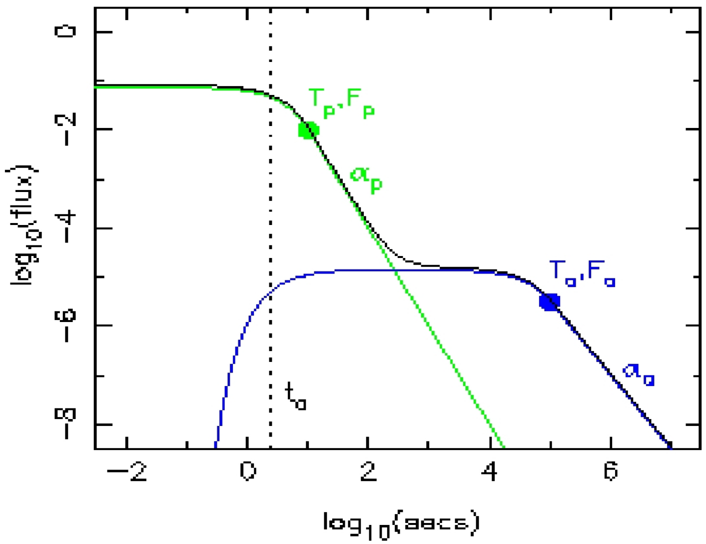
$$F(R) = \frac{e^{\sigma n_0 R_0\left(1-\frac{R\lambda_0}{R_0\lambda(R)}\right)}}{R_0^2\left(1+\frac{R\lambda_0}{R_0\lambda(R)}\right)^2}$$

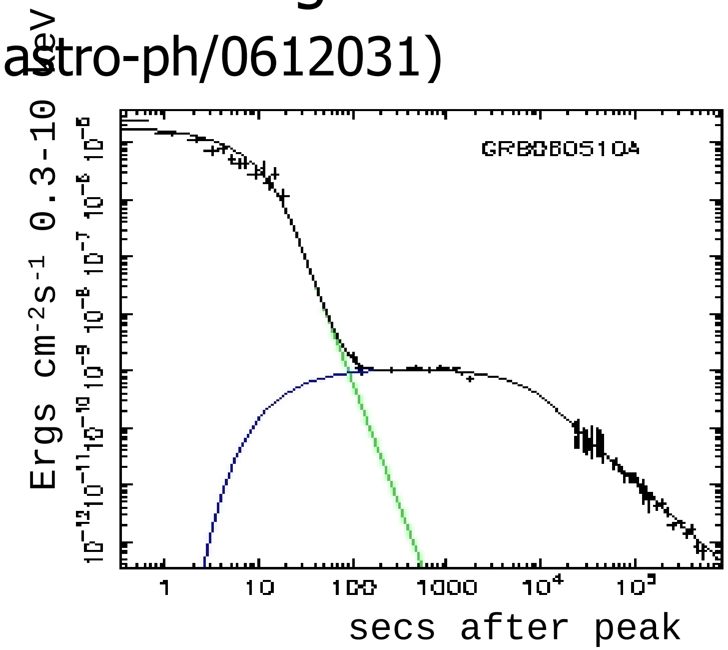


# Prediction (1)

- X-ray light curve for prompt and after-glow emission

(R. Willingale astro-ph/0612031)




i) $\alpha_p = n_0 R_0 \sigma_T \qquad \alpha_a = \frac{1}{2}\alpha_p \qquad T_p = \frac{R_0\theta^2}{24c} \qquad \frac{T_a}{T_p} = \sqrt{\frac{\mathrm{n_0(R_0)}}{\mathrm{n(R_a)}}}$

ii) $n_0 = 1.6\times 10^{14}\alpha_p^2 m^{-3} \qquad R_0 = 6\times 10^{13}\alpha_p^{-1} m \qquad \theta^2 = 10^{-4}\frac{T_p\alpha_p}{1+z}$

# Prediction (2)

- Spectral geometrical correlation:

$$E_p \propto \left(\frac{T\alpha}{1+z}\right)^{\frac{4}{7}} \qquad\qquad E_{iso} \propto \left(\frac{T\alpha}{1+z}\right)^{\frac{27}{28}}$$

- Spectral-Energy correlation:

$$\frac{E_{iso}^{0.59}}{E_p} \propto \cos t$$

(Amati relation: $\frac{E_{iso}^{0.58}}{E_p} \propto \cos t$)

(L. Amati *Il Nuovo Cimento*)

# Amati “corrected” relation

-- Not corrected

-- Absorption corrected

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

# Conclusions

- Jetted structure of GRB
- Presence of Material around GRB
- Compton tail measurement
- Plasma acceleration mechanism
- Laboratory vs Astrophysics
- Cosmology with Spectral – Energy correlations?