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Hadronic Models in type IIn Supernovae

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HELLENIC ASTRONOMICAL SOCIETY

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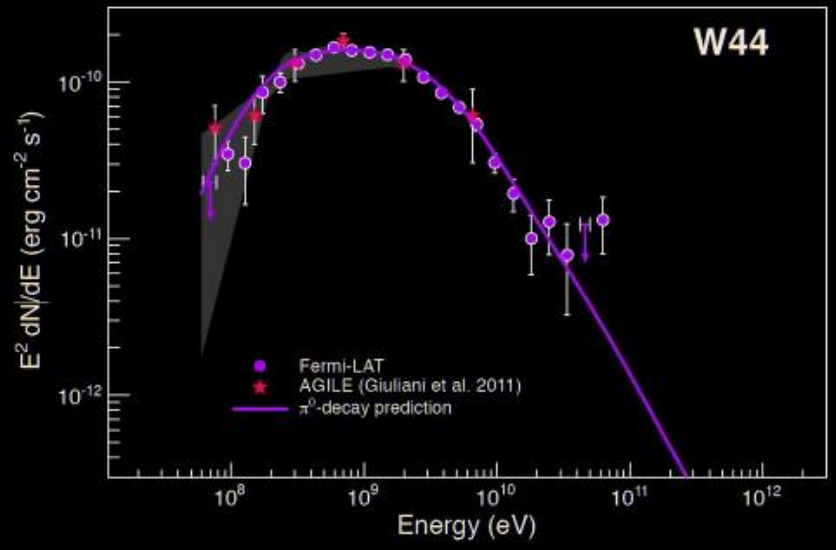
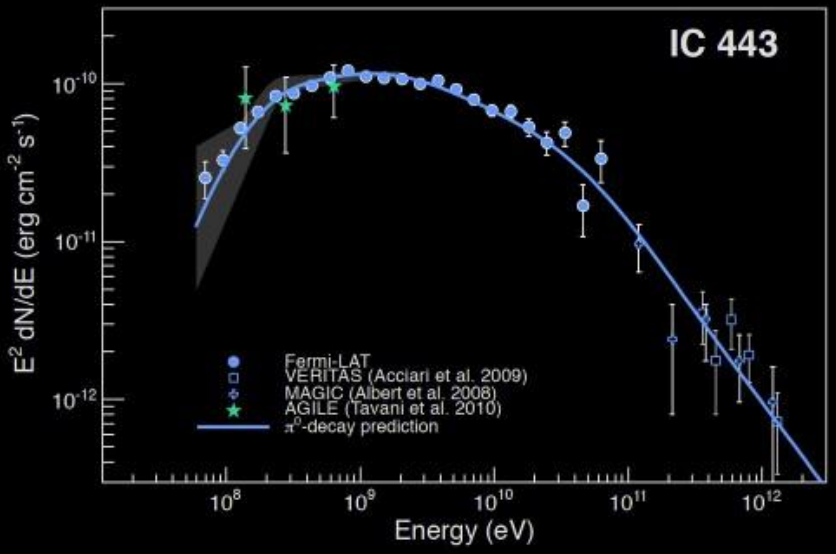
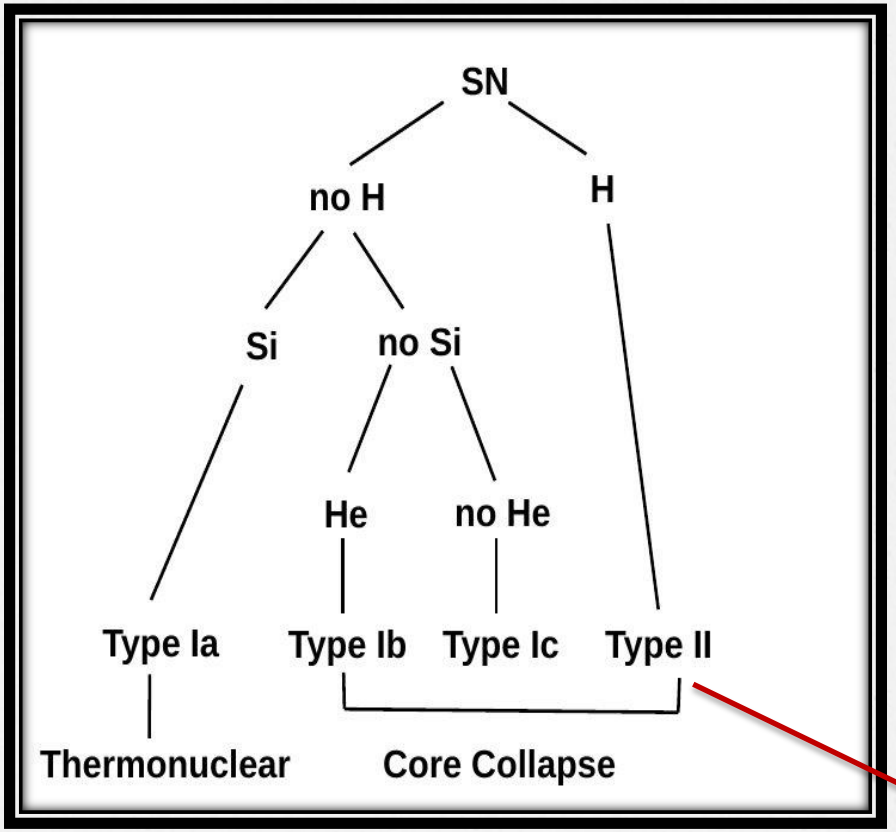
Supernova W44 & IC 443 Neutral Pion Decay Spectral Fit

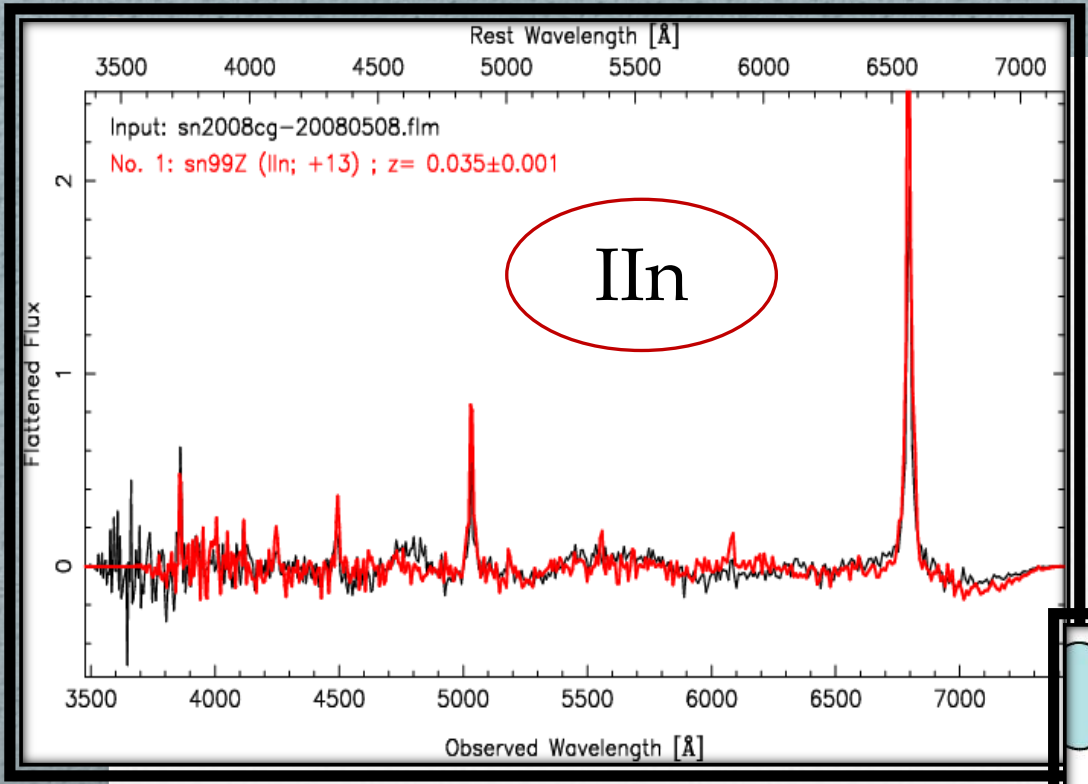




Supernovae (SNe)



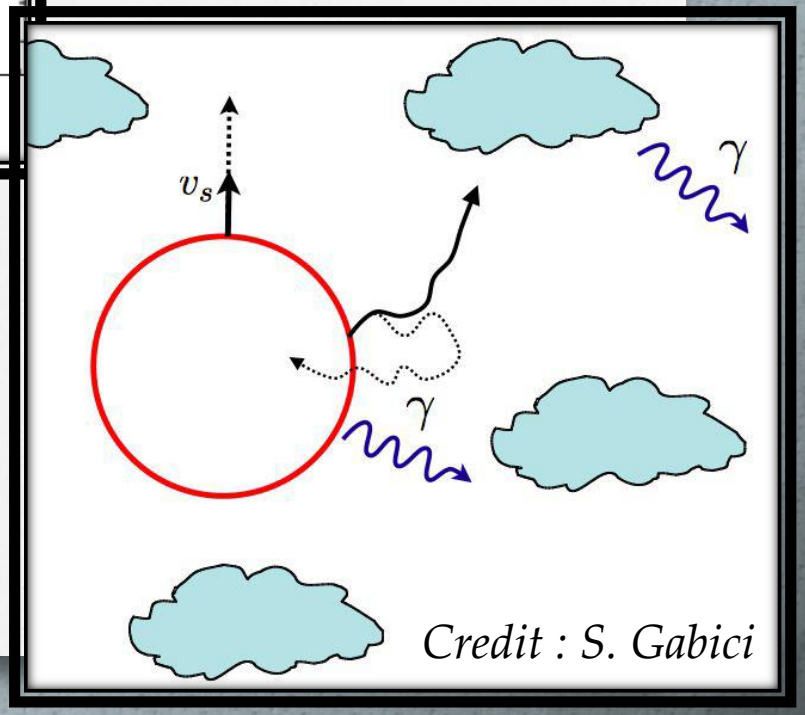
IIn



https://www.cfa.harvard.edu/supernova/spectra/sn2008cg_comp.gif

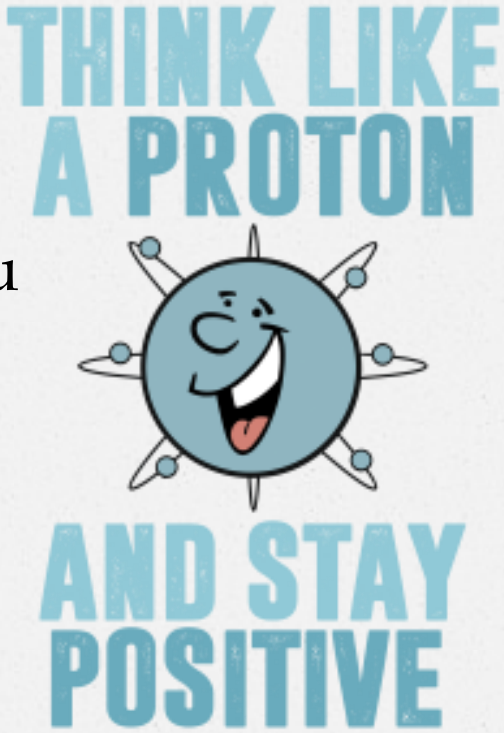
$n \sim 10^{7} - 10^{12}\ cm^{-3}$

(Kiewe et al., 2012)



Leptonic Model

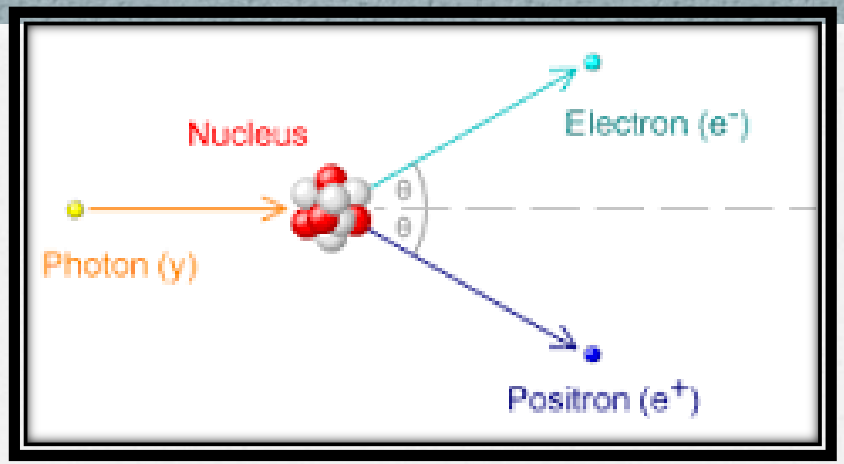
- electrons
- ICS
- low B
- see talk of M. Petropoulou and S. Dimitrakoudis …

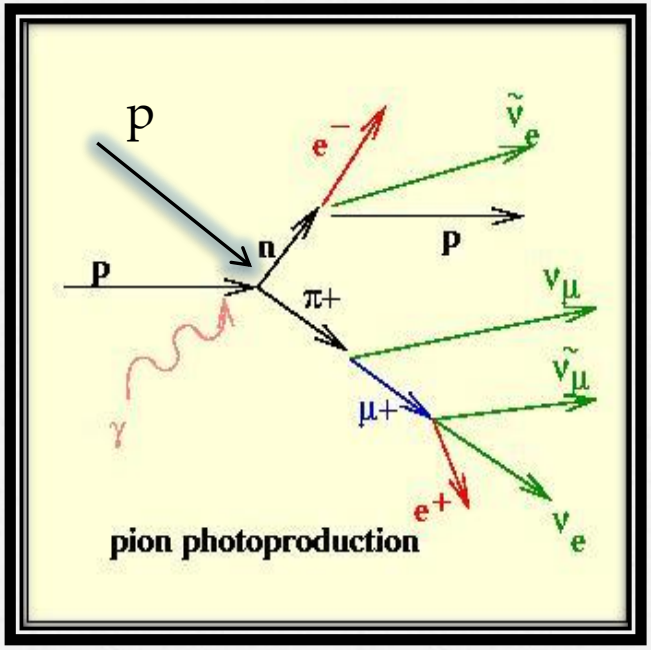


Hadronic Model

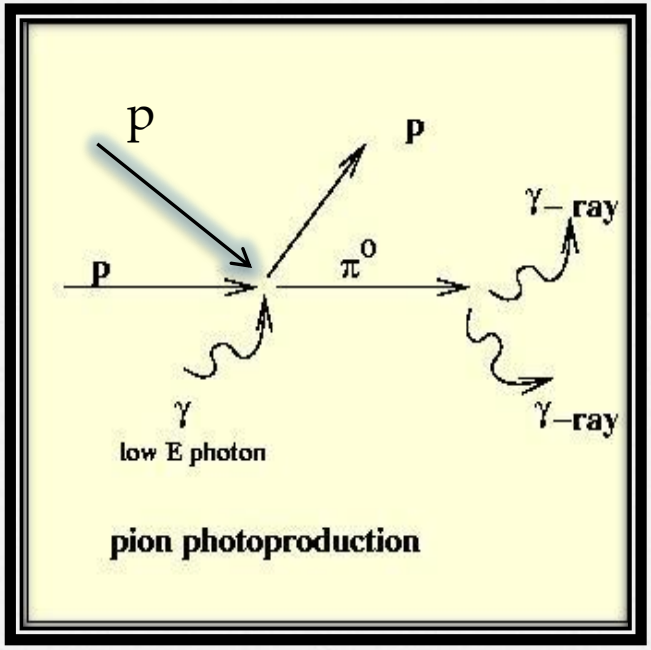
- protons/nuclei
- π^0 decay
- high B – amplification (Vink 2006 - Bell 2004)
- CR acceleration (>0)
- high energy (<0)
- neutrinos (…)

https://astronomicamens.wordpress.com/2015/08/05/icecube-vede-il-neutrino-piu-energetico-mai-rivelato/





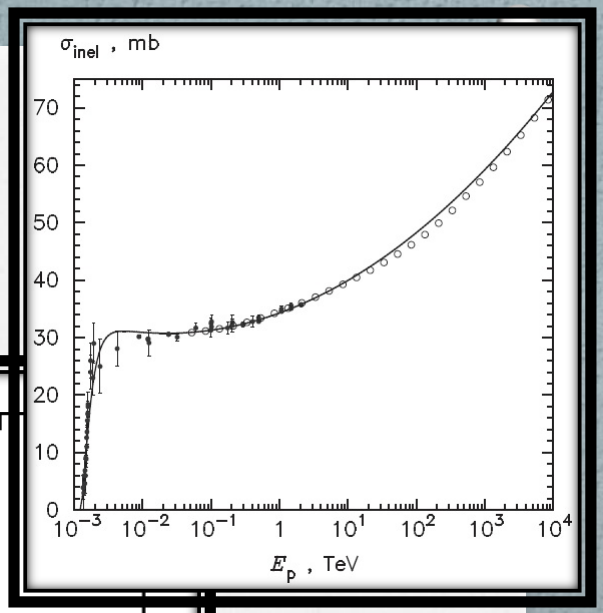
2.6×10^{-8} sec & 2.2×10^{-6} *sec*

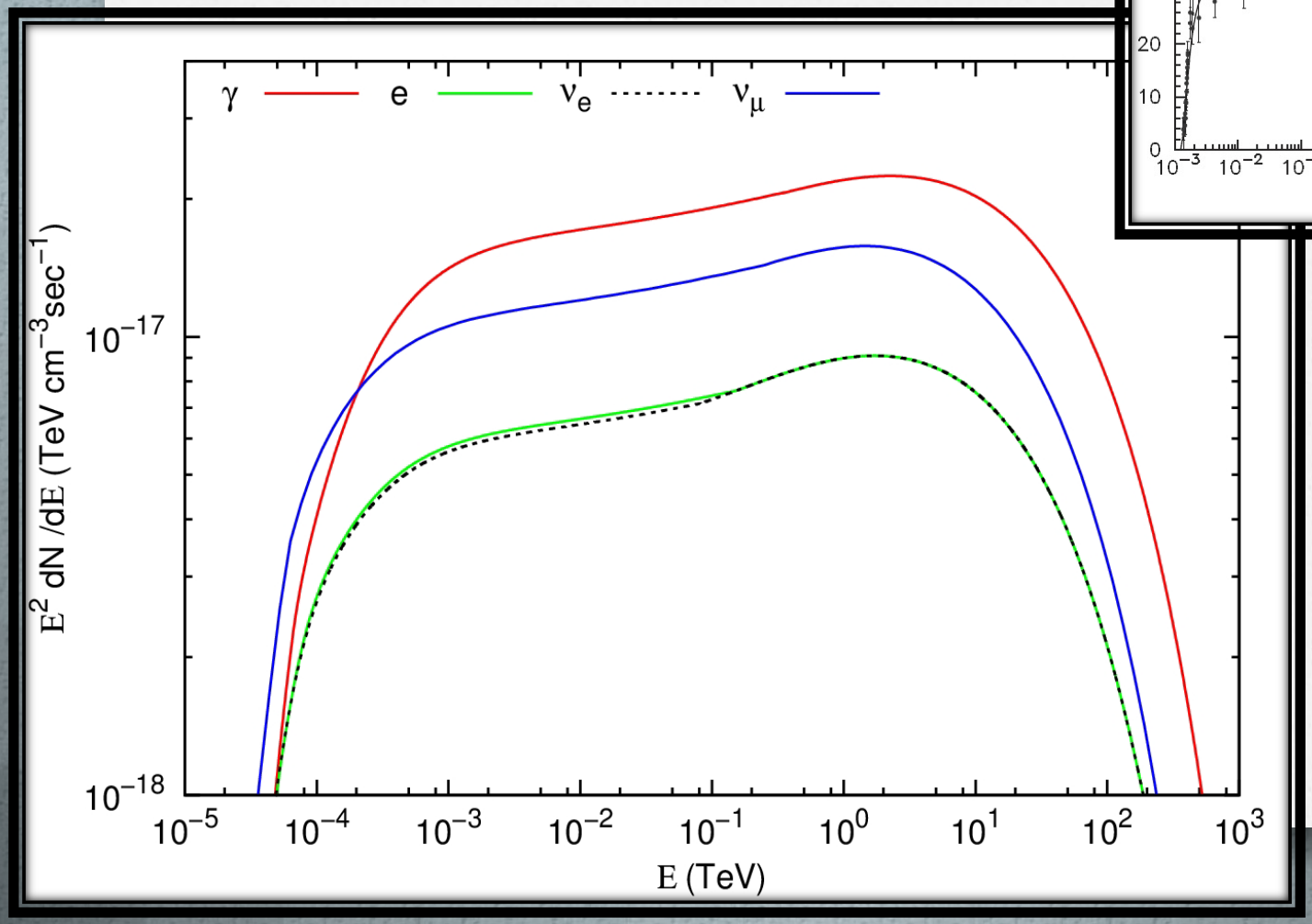


9×10^{-17} *sec*

http://homepage.uibk.ac.at/~c705282/intro.html http://www.hardhack.org.au/book/export/html/76

pp collisions





Kelner et al., 2006

The kinetic equation approach

Protons:

$$\frac{\partial n_{\rm p}}{\partial t} + L_{\rm p}^{\rm BH} + L_{\rm p}^{\rm photopion} + L_{p}^{\rm psyn} + L_{p}^{pp} + \frac{n_{\rm p}}{t_{\rm p,esc}} = Q_{\rm p}^{\rm inj} + Q_{\rm p}^{\rm photopion}$$

Electrons:

$$\frac{\partial n_{\rm e}}{\partial t} + L_{\rm e}^{\rm syn} + L_{\rm e}^{\rm ics} + L_{\rm e}^{\rm ann} + L_{\rm e}^{\rm tpp} + \frac{n_{\rm e}}{t_{\rm e,esc}} = Q_{\rm e}^{\rm ext} + Q_{\rm e}^{\rm BH} + Q_{\rm e}^{\gamma\gamma} + Q_{\rm e}^{\rm photopion} + Q_{\rm e}^{\rm tpp} + Q_{e}^{pp}$$

Photons:

$$\frac{\partial n_{\gamma}}{\partial t} + \frac{n_{\gamma}}{t_{\gamma,\rm esc}} + L_{\gamma}^{\gamma\gamma} + L_{\gamma}^{\rm ssa} = Q_{\gamma}^{\rm syn} + Q_{\gamma}^{\rm psyn} + Q_{\gamma}^{\rm ics} + Q_{\gamma}^{\rm ann} + Q_{\gamma}^{\rm photopion} + Q_{\gamma}^{pp}$$

Neutrinos:

$$\frac{\partial n_{\nu}}{\partial t} + \frac{n_{\nu}}{t_{\rm esc}} = Q_{\nu}^{\rm photopion} + Q_{\nu}^{pp}$$

Neutrons:

$$\frac{\partial n_{n}}{\partial t} + L_{n}^{\rm photopion} + \frac{n_{n}}{t_{\rm esc}} = Q_{n}^{\rm photopion} + Q_{n}^{pp}$$

injection

pp — Bethe-Heitler

ssa — proton synchrotron

γγ — synchrotron

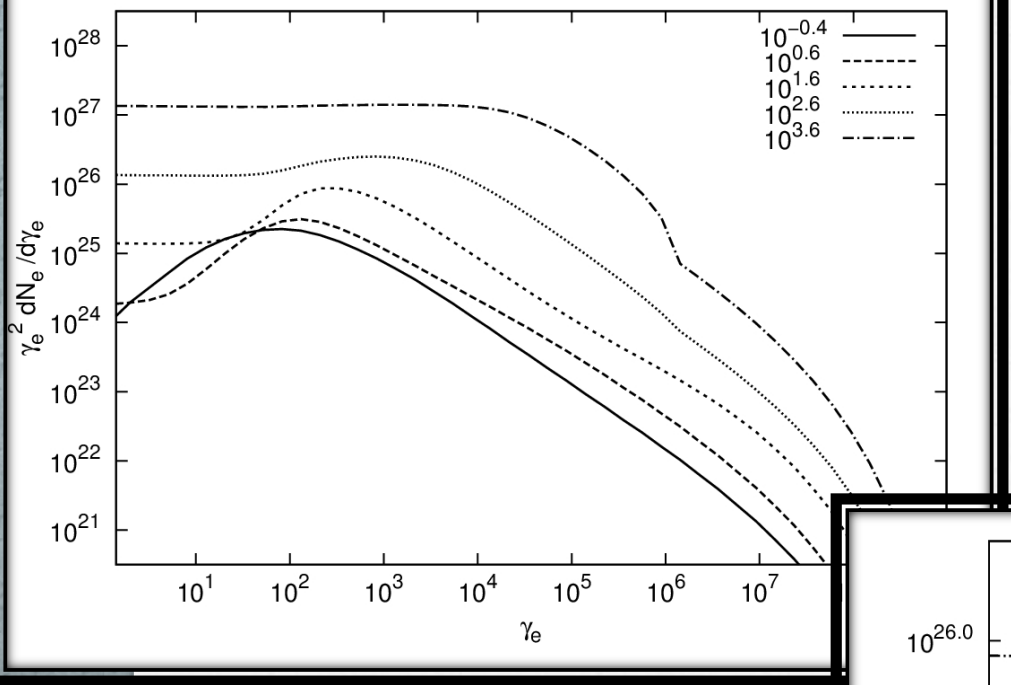
photopion — annihilation — triplet pair production

Mastichiadis & Kirk, 1995

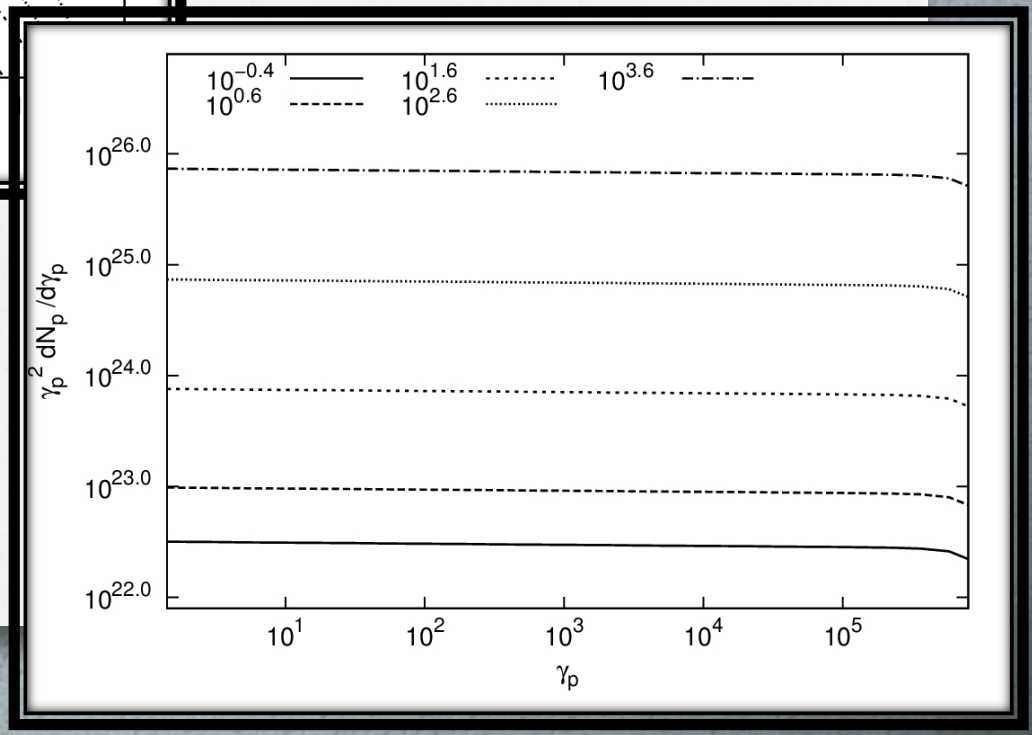
Dimitrakoudis et al., 2012 +

Application to SNe IIn

- $n(R) = n_0 \left(\frac{R_0}{R}\right)^2$
- $n_0 \approx 2 \times 10^{12} \left(\frac{R_0}{10^{14}\ cm}\right)^{-1} \left(\frac{v_s}{0.03\ c}\right)^{-1} cm^{-3}$
- $B(R) = B_0 \left(\frac{R_0}{R}\right)^{a_B}$
- $B_0 \approx 460 \left(\frac{\varepsilon_B}{0.01}\right)^{1/2} \left(\frac{v_s}{0.03\ c}\right)^{1/2} \left(\frac{R_0}{10^{14}\ cm}\right)^{-1/2}$ G



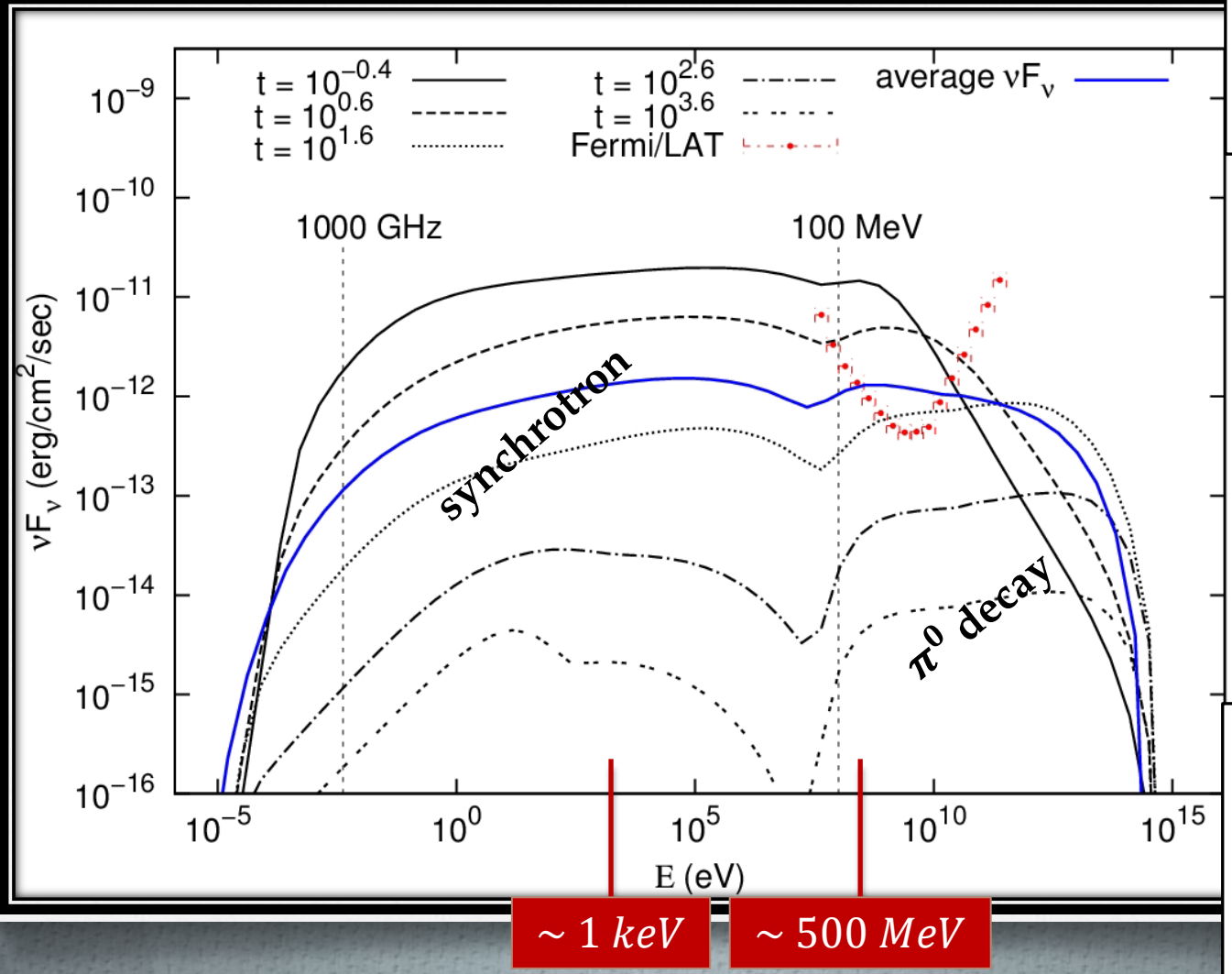
$$R_0 = 10^{14}\ cm$$
$$p = 2$$
$$L_p = 10^{41}\ erg/s$$
$$L_e = 0.01\, L_p$$
$$[t] = days$$



TIE fighter

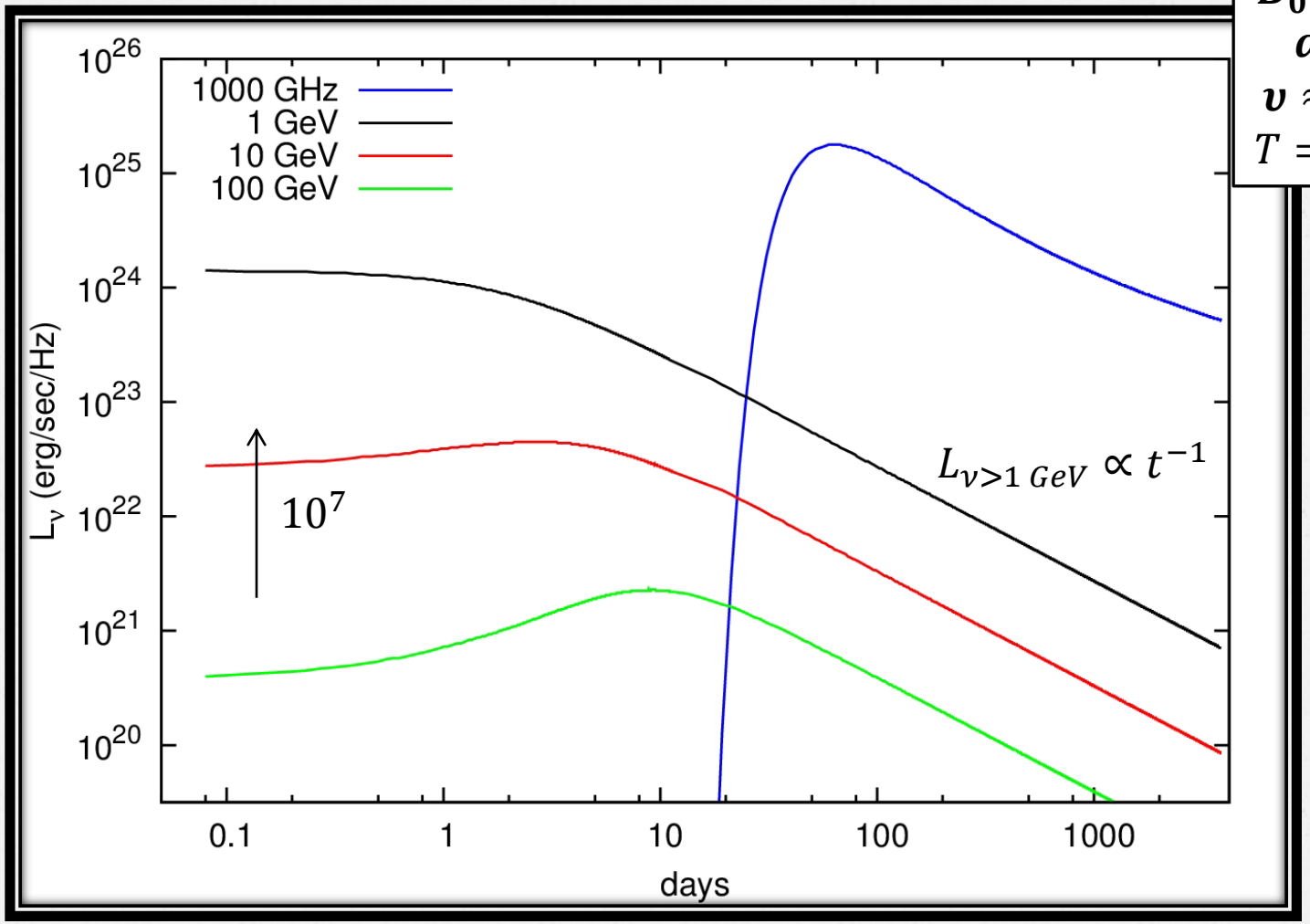
Fermi/LAT

$B_0 = 46\ G$
$\alpha_B = 1$
$v \approx 0.03c$
$d = 5\ Mpc$



$\sim 1\ keV$ $\sim 500\ MeV$

$R_0 = 10^{14}\ cm$
$p = 2$
$L_p = 10^{41}\ erg/s$
$L_e = 0.01\ L_p$
$[t] = days$



$B_0 = 46\ G$
$\alpha_B = 1$
$v \approx 0.03c$
$T = 10^5\ K$

Take Home Note

- pp → γ-rays, e & ν
- photon – photon absorption
- $d < 10\ Mpc$ or $n_0 > 10^{10} cm^{-3}$

+

- thermal & relativistic bremsstrahlung

+

- optical light

ΚΑΛΟ ΚΑΛΟΚΑΙΡΙ!!!