A heavy jet for Cen A

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Outline

- WHY …
- WHAT …
- SO WHAT …

WHY

Why

- Association of multiple Auger UHE events with Cen A
  - possible particle acceleration sites?
- Cen A is a relatively local extragalactic object with:
  - Radio lobes, relativistic jet → diffusive shock acceleration
  - Supermassive Black Hole → voltage drop created by spin
  - Less deviation by extragalactic fields
  - Wide observed SED
- Jet composition still unknown
- Some indications of "needed" heavy component

(Celotti & Ghisellini 2008).

WHAT

What we know

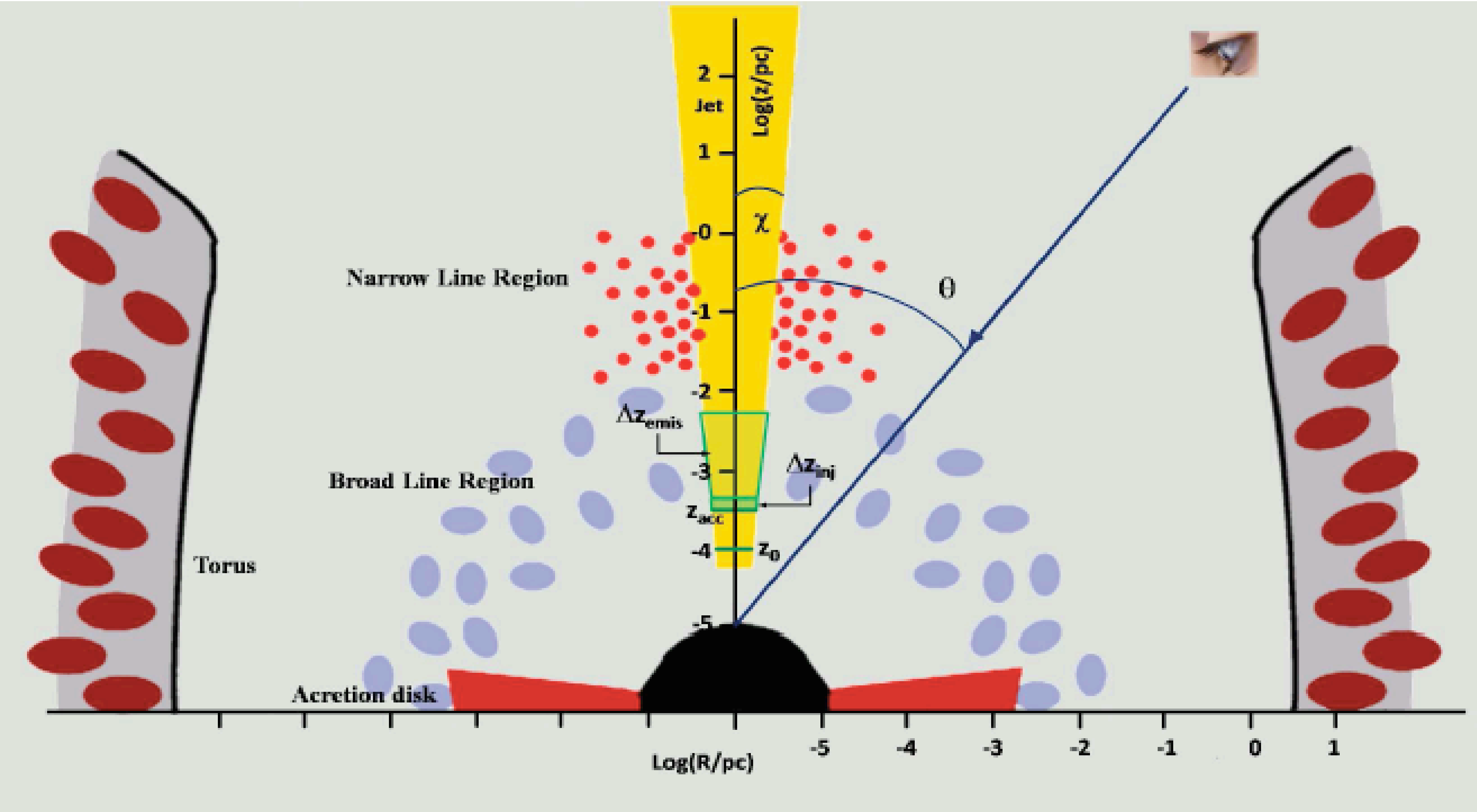
- $d = 3.8$ Mpc
- $M = (0.5-2)\times10^{8} M_\odot$
- $\dot{M} = 6\times10^{-4} M_\odot/y$
- $L_X = 4\times10^{42}$ erg/s (40–1200 keV, 10^{43} erg s^{-1} for the intermediate state (Bond et al. 1996))
- Jet viewing angle between 15° and 80°
- HESS detection at VHE associated with the nuclear part (excluding radio lobes)
- Fermi detection at HE (pc-scale core, jet, and kpc-scale jet, excluding radio lobes, Cheung & Fukazawa 2009).

What we assume

- Radiation produced by accelerated particles in the jet
- Jet launched by a dissipationless accretion disk
  - Transforms gravitational energy into energy of jet-like outflows with a high efficiency.(Bogovalov & Kelner 2005,2009; Blandford & Begelman 1999)
- Jet content: thermal plasma with a mildly relativistic bulk Lorentz factor $\Gamma = 3$
- Few % of the jet power is carried by relativistic particles
- The jet expands in a conical way.

What we assume

- Plasma initially in equipartition with a tangled magnetic field at the Alfvén surface (50 Rg from BH)
- $B(z) \propto 1/z^m$, with $m \in [1, 2]$.
- Shock acceleration -> magnetic energy density in sub-partition with the jet kinetic energy density
- Diffusive acceleration process efficiency ~0.01
- Proportion electrons and protons power variable
- Extended emission zone



Jet
Log(z/pc)
2
1
0
-1
-2
-3
-4
-5
χ
θ
Narrow Line Region
Broad Line Region
Torus
Acretion disk
Δz_{emis}
Δz_{inj}
z_{acc}
z_0
Log(R/pc)
-5
-4
-3
-2
-1
0
1

What we do

Primary Particles Distributions Np(z, E) & Ne(z,E) :

Stationary state equation (1 D)

$$v\frac{\partial N(E,z)}{\partial z} + \frac{\partial\left(b(E,z)N(E,z)\right)}{\partial E} = Q(E,z)$$

Convection

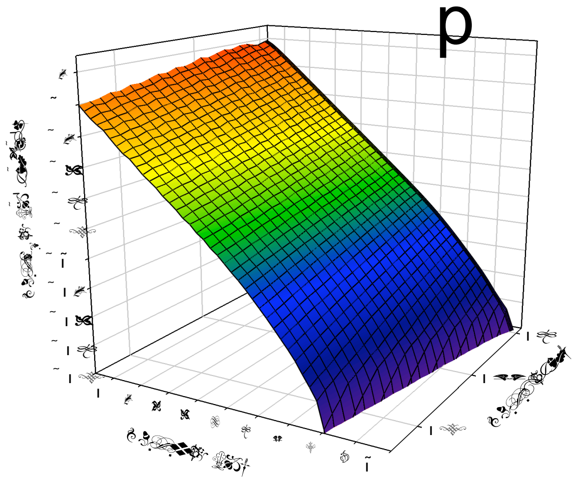
$v = flux\ velocity$

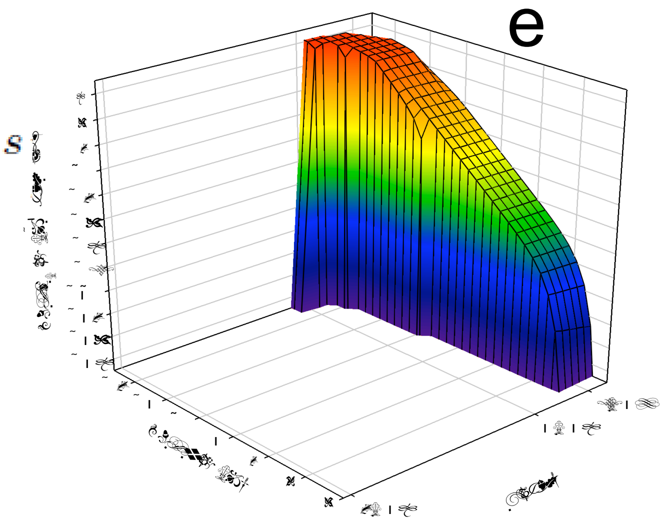
$b(E,z) = \frac{dE}{dt}$

Injection

$Q(E',z) \propto \left(\frac{z_0}{z}\right)^2 E'^{-s}$

+ High Energy cut-off





What we do

- Radiative Processes :
- Synchrotron
  - primary protons and electrons
  - secondary $e^{\pm}$, πs,μs
- Inverse Compton Scattering
  - primary e^{-} and secondary $e^{\pm}$
- Proton - proton interactions
- Proton - γ interactions

What we do

- Maximum Energy attained by the particles

$$t_{\rm acc}^{-1}(E^{(\rm max)}) = t_{\rm loss}^{-1}(E^{(\rm max)})$$

$$t_{\rm acc}^{-1} = \eta \frac{ceB(z)}{E}$$

$$t_{loss}^{-1} = t_{syn}^{-1} + t_{ad}^{-1} + t_{IC}^{-1} \quad \text{Electrons}$$

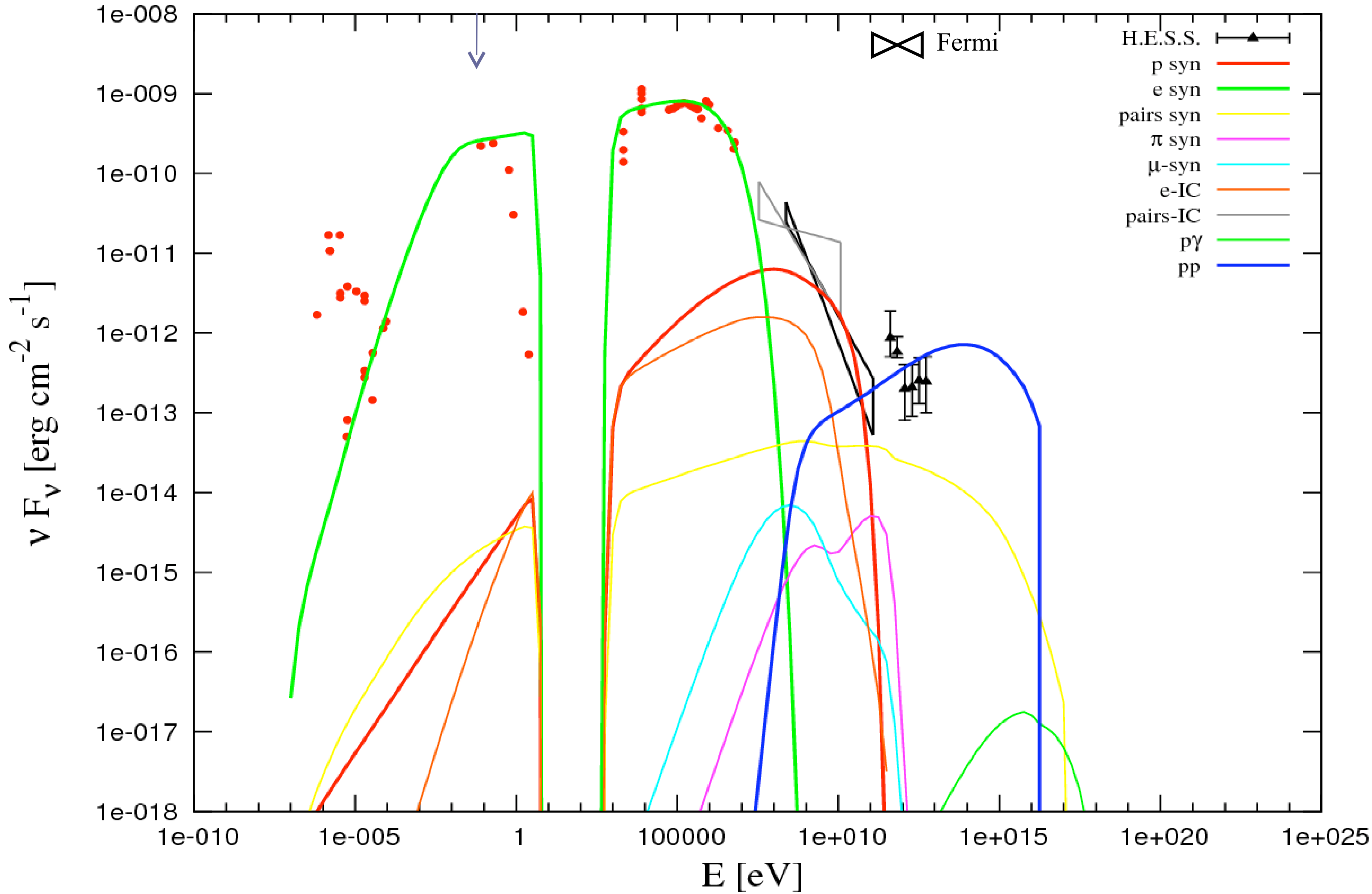
$$t_{loss}^{-1} = t_{syn}^{-1} + t_{ad}^{-1} + t_{p\gamma}^{-1} + t_{pp}^{-1} \quad \text{Protons}$$

Hillas Criterion fulfilled

- Photon absorption:
  - Internal absorption ($\gamma - \gamma$ annihilation within the jet)
  - External photons and absorption with dust material ($N_H = 10^{23} cm^{-2}$, Morganti et al.)

SO WHAT?

Application to Cen A SED



Fermi
H.E.S.S.
p syn
e syn
pairs syn
π syn
μ-syn
e-IC
pairs-IC
pγ
pp
ν F_ν [erg cm^-2 s^-1]
E [eV]
1e-008
1e-009
1e-010
1e-011
1e-012
1e-013
1e-014
1e-015
1e-016
1e-017
1e-018
1e-010
1e-005
1
100000
1e+010
1e+015
1e+020
1e+025

Discussion

- Measurements composing the SED of CenA
  - inhomogeneous in time and angular resolution
- lack of a good spatial resolution
  - impossible to distinguish the emission components (jet, nucleus or other radiation sources)
- Nevertheless, spectral energy distribution which is basically consistent with the multi-λ emission from Cen A.
- VHE emission : p − p interactions.
- hard X-ray peak : electron synchrotron radiation
- Soft γ : proton synchrotron and IC emission

- Photoionization interactions in the surrounding dust:
  - Drastic modulation in the electron synchrotron spectrum (broadband range 10^{-5} – 10^{7}eV)
  - Electrons efficiently accelerated (η= 0.01) to high energies with a flat spectrum (s = 1.8).
- The maximum proton energy obtained in this scenario is about 3.5 $\times 10^{18}$ eV.
  - Other mechanisms for UHECR observed by Auger in the direction of Cen A :
    - Shear acceleration along the jet (Rieger et Aharonian,2009)
    - Production of neutrons by accelerated protons in the jet which decay in protons near radio lobes (re-acceleration)
    - Shock acceleration in outer lobes (Romero et al. 1996).

- Controversial Parameters ?

Parameter	Value
M_{bh}: black hole mass	$10^8 M_\odot$
Γ_b: jet Lorentz factor	3
L_k: jet power	2×10^{45} erg s^{-1}
q_{rel}: fraction of power in rel. part.	0.1
a: proton to electron power ratio	0.4
m: magnetic field index	1.5
z_0: jet launching site	$50R_g = 7.4 \times 10^{14}$cm
z_{acc}: particle acceleration site	7.4×10^{15}cm
ξ: jet half-oppening angle	5°
θ: viewing angle	25°

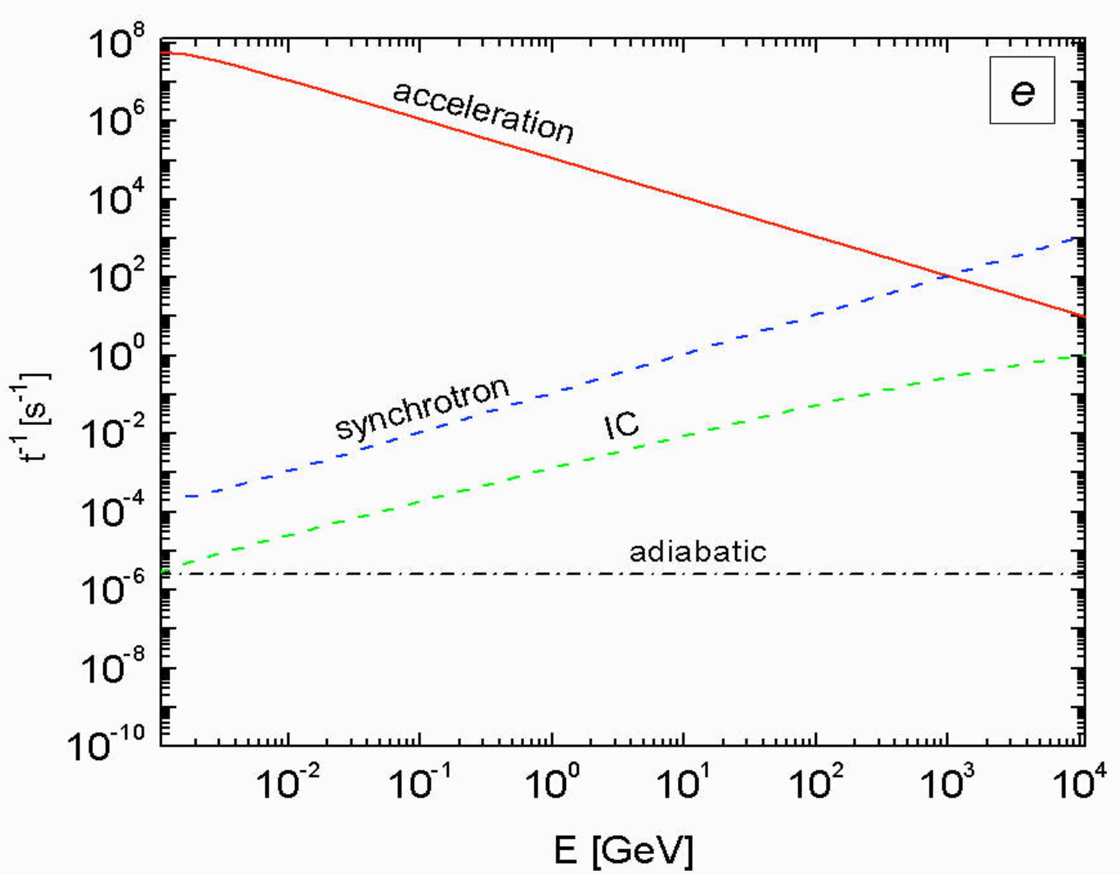
$B_0 \sim 10^4$ G (base of the jet)

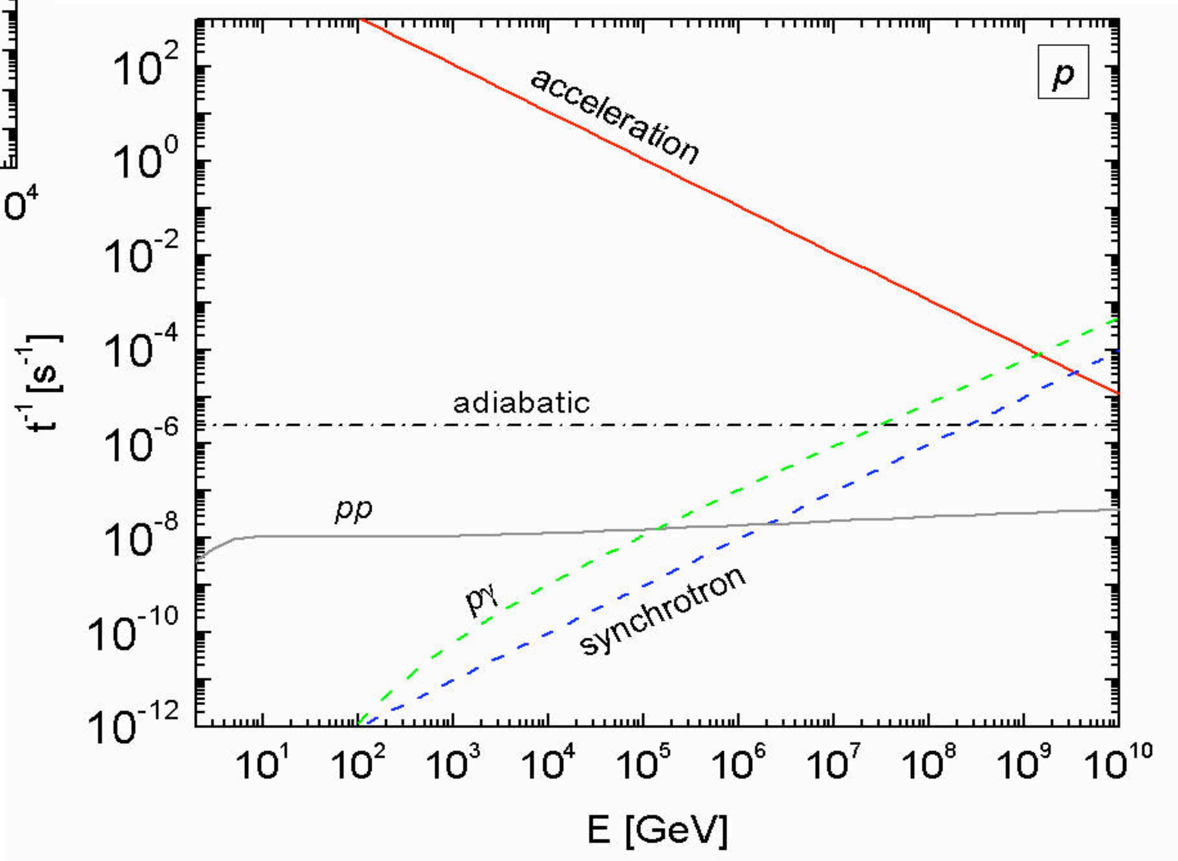
$B_{acc} \sim 200$ G (acceleration zone)

$$B_0 = \sqrt{\frac{8L_k}{[r_j(z_0)]^2 v_b}}$$

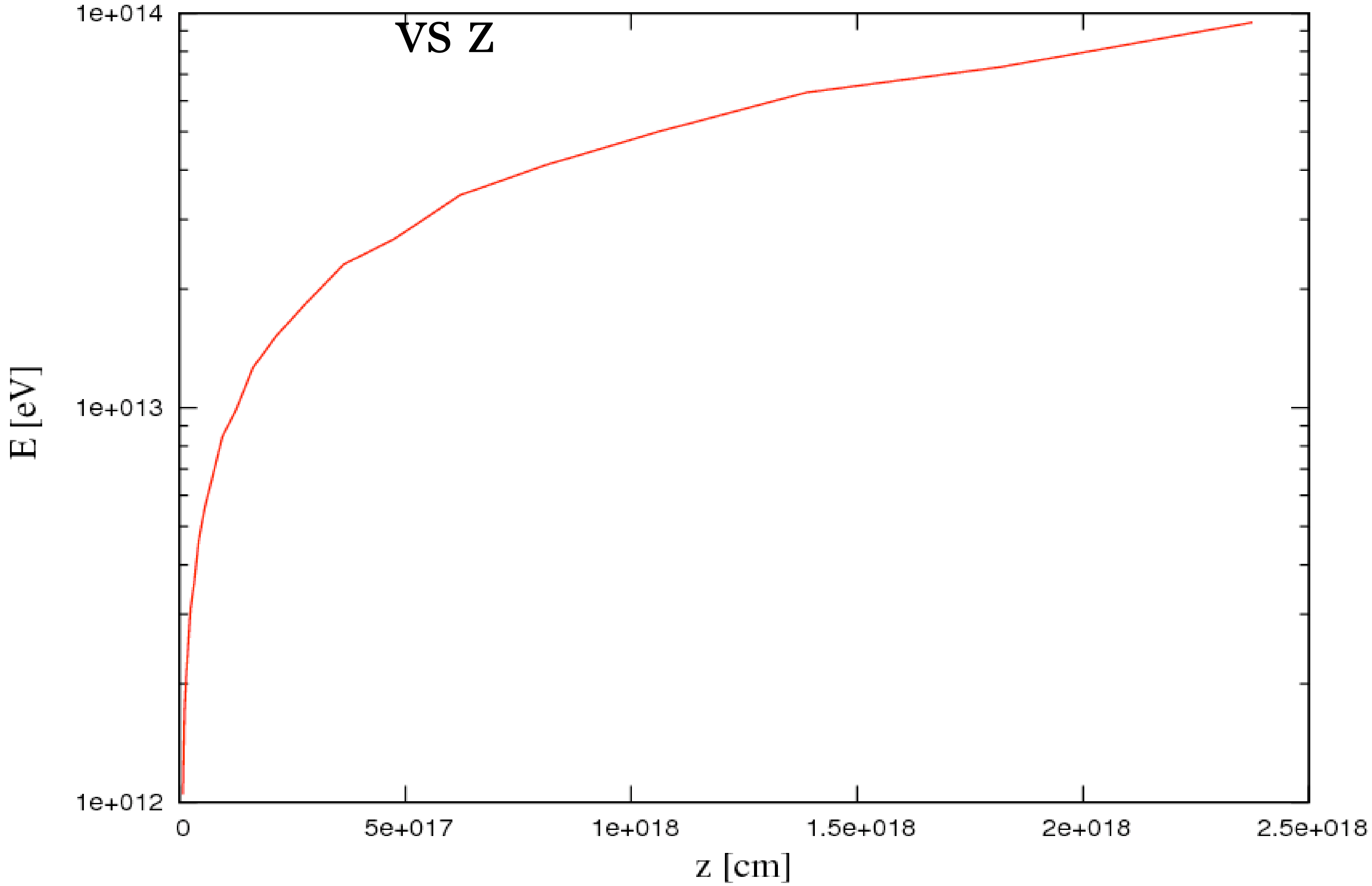
Perspectives

- Neutrinos production (see Matías Reynoso talk)
- Application to other sources
- Time dependent injection function
- Wait for HESS II, CTA and KM3Net.


e
acceleration
synchrotron
IC
adiabatic
t^{-1} [s^{-1}]
E [GeV]


p
acceleration
adiabatic
pp
pγ
synchrotron
t^{-1} [s^{-1}]
E [GeV]

Maximum electron energy vs z



Maximum proton energy vs z