Heavy jet for radiogalaxies

M. C. Medina, M. Reynoso & G. E. Romero

TeVPa 2010

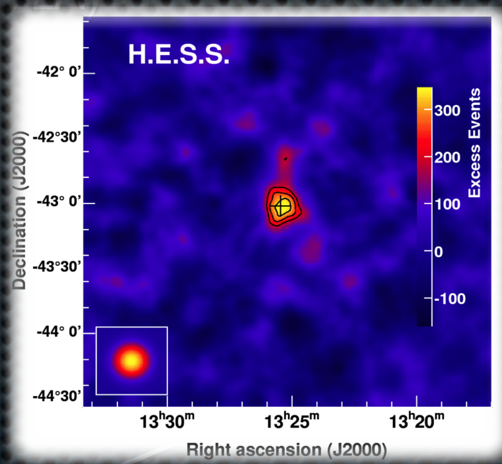
irfu
cea
saclay
Universidad Nacional de Mar del Plata

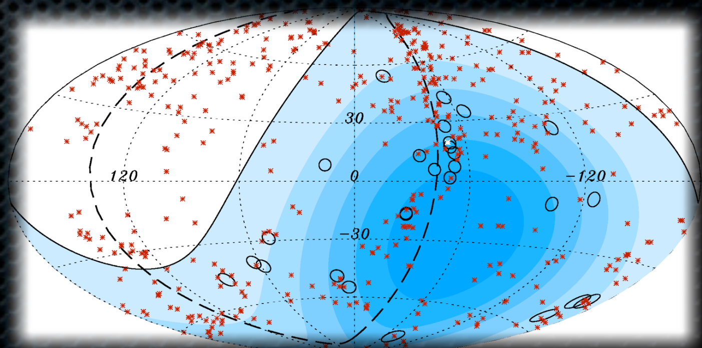
Outline

- Cen A: a radiogalaxy as UHECR and TeV γ-Rays source
- Basic scenario
- Model Assumptions
- Cen A case
- M87 case
- Final comments

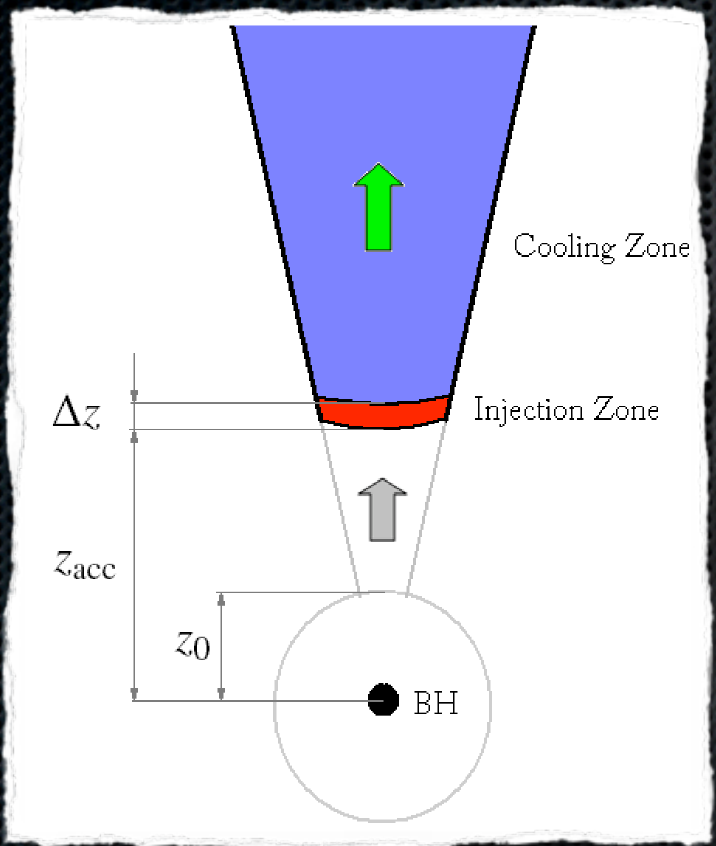
Centaurus A

- FR I radiogalaxy - non blazar
  - Distance ~ 3.4 Mpc
  - Central Black Hole Mass 10^8 $M_\odot$
- TeV γ-Rays source
  - HESS detection (100h)
    - Emission up to 5 TeV
    - relatively hard spectrum (photon index 2.7)
    - non-variability
- UHE Cosmic Rays source?
  - Apparent clustering of arrival directions
    - up to 4 of 27 Auger events





Basic Scenario

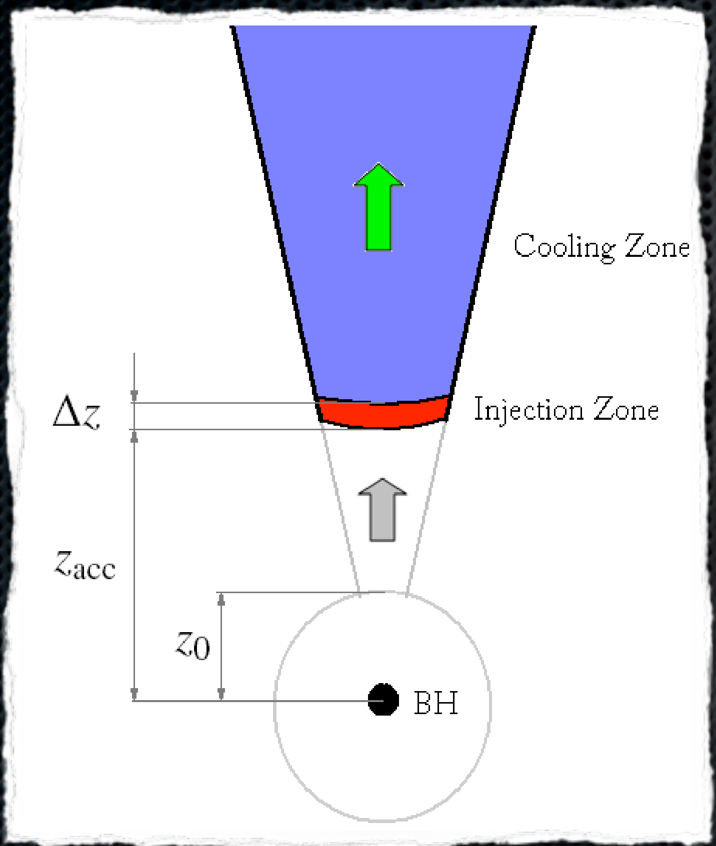


- Particle acceleration by shocks in the jet
- Jet kinetic power $L_k = q_j L_{Edd}$; $q_j \ll 1$
- Jet content : thermal plasma middly relativistic.
- Few % of jet power carried by relativistic particles:

$$L_e + L_p = q_{rel} L_k \quad ; \quad L_p = a L_e$$

- Plasma at equipartion with a tangled magnetic field at the jet base ($z_0 = 50\ R_g$)

Basic Scenario



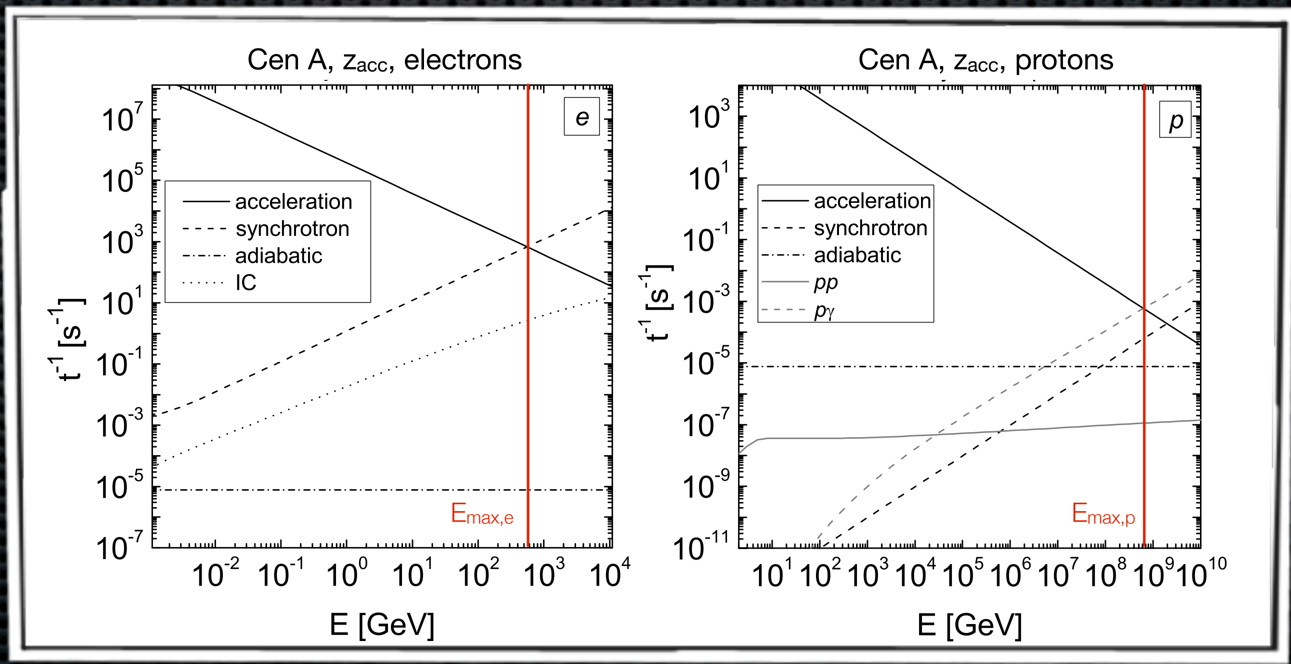
- $B(z) = B_0 \left(\frac{z_0}{z}\right)^m \quad ; \; m \in [1, 2]$
- Primary protons & electrons injected at z_{acc} $(\rho_m \ll \rho_k)$
- Injection:

$$Q_i(E, z) = K_i \left(\frac{z_{\rm acc}}{z}\right)^2 E^{-s} \exp\left[-\left(\frac{E}{E_i^{(\rm max)}}\right)^2\right]$$

- Photon absorption :
  - γγ anhilation within the jet
  - External photons + dust column (N_H)

Primary relativistic particles

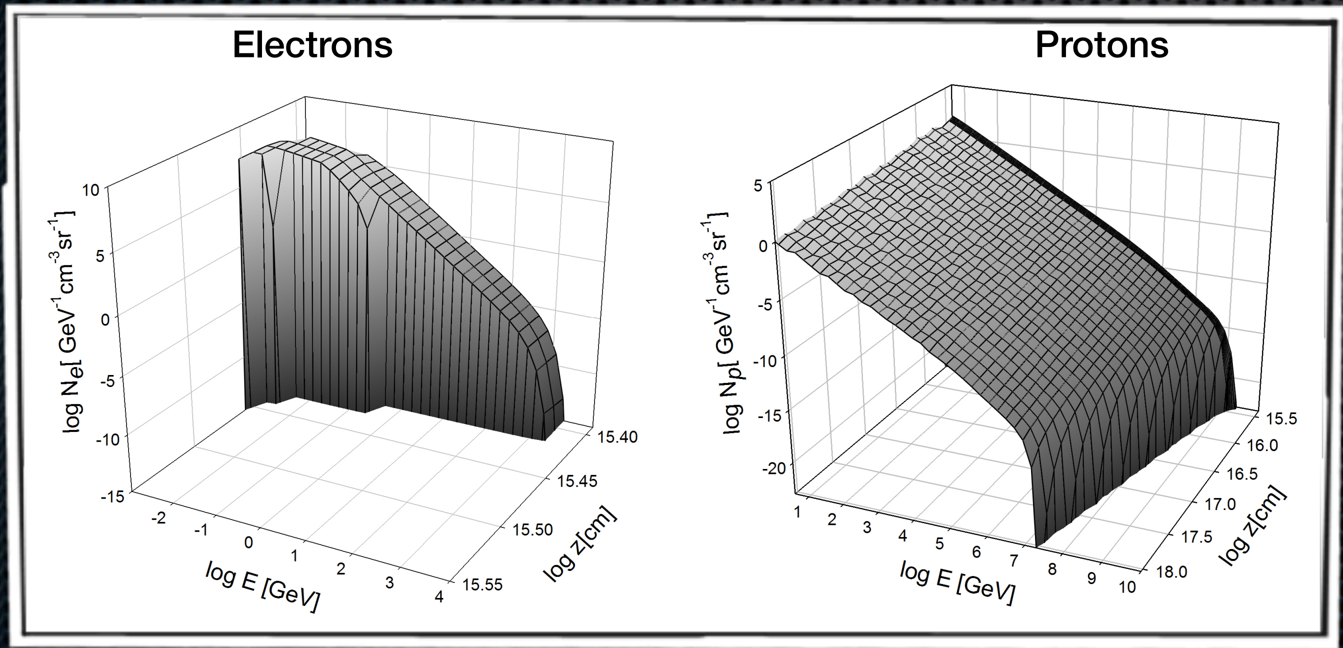
- Acceleration rate $$t_{\rm acc}^{-1}(E,z) = \eta \frac{ceB(z)}{E}$$
- Energy loss rates $$t^{-1}_{\rm (loss,e)} = t^{-1}_{\rm syn} + t^{-1}_{\rm ad} + t^{-1}_{\rm IC}$$
$$t^{-1}_{\rm (loss,p)} = t^{-1}_{\rm syn} + t^{-1}_{\rm ad} + t^{-1}_{p\gamma} + t^{-1}_{pp}$$



Primary particles distributions

- Resolution of 1D Steady state equation

$$v\frac{\partial N(E,z)}{\partial z} + \frac{\partial\left[b(E,z)N(E,z)\right]}{\partial E} = Q(E,z) \qquad b(E,z) = \frac{dE}{dt}$$



Method of characteristics

$$\frac{dz}{v_b} = \frac{dE}{b(E,z)} = \frac{dN(E,z)}{Q(E,z) - \frac{\delta b(E,z)}{\delta E}N(E,z)}$$

Secondary particles in the jet

- Pion production

$$p + \gamma \longrightarrow p + n\pi^0 + m(\pi^+ + \pi^-) \quad n, m = 0, 1, 2...$$

Atoyan & Delmer 2003

$$p + \gamma \longrightarrow \Delta^+ \longrightarrow p + \pi^0$$

$$p + \gamma \longrightarrow \Delta^+ \longrightarrow n + \pi^0$$

Kelner et al. 2006

$$p + p \longrightarrow p + p + a\pi^0 + b(\pi^+ + \pi^-)$$

$$p + p \longrightarrow p + n + \pi^+ + a\pi^0 + b(\pi^+ + \pi^-)$$

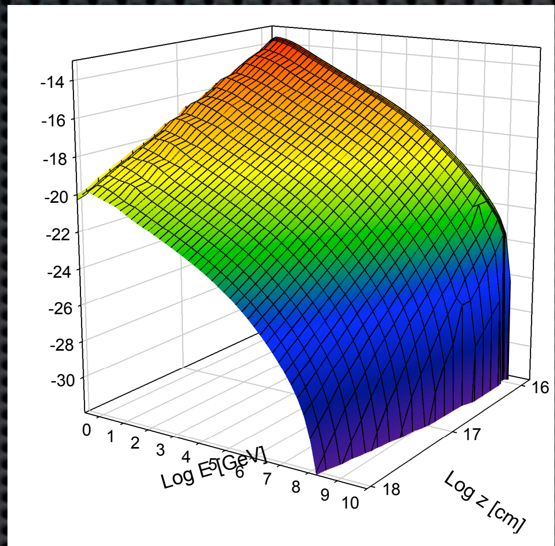
$$p + p \longrightarrow n + n + 2\pi^+ + a\pi^0 + b(\pi^+ + \pi^-)$$

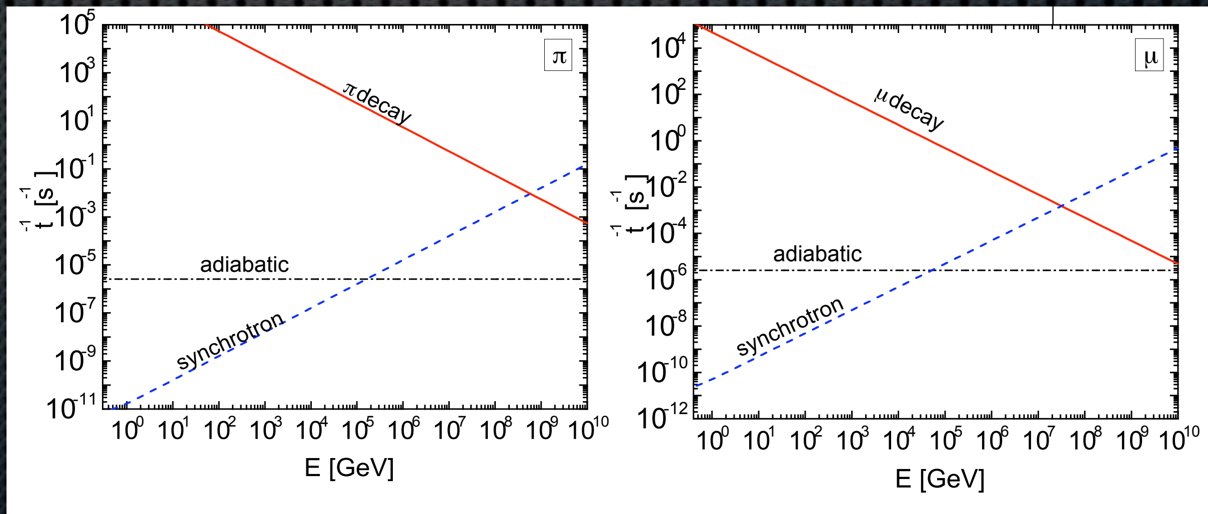
- Pion decay $\pi^\pm \longrightarrow 2\mu^\pm + \bar{\nu}_\mu(\nu_\mu)$ Lipari et al. 2007

$$v\frac{\partial N(E,z)}{\partial z} + \frac{\partial\left[b(E,z)N(E,z)\right]}{\partial E} + \frac{N(E,z)}{T_{\rm dec}(E)} = Q(E,z)$$

Secondary particles in the jet

pions from pp interactions

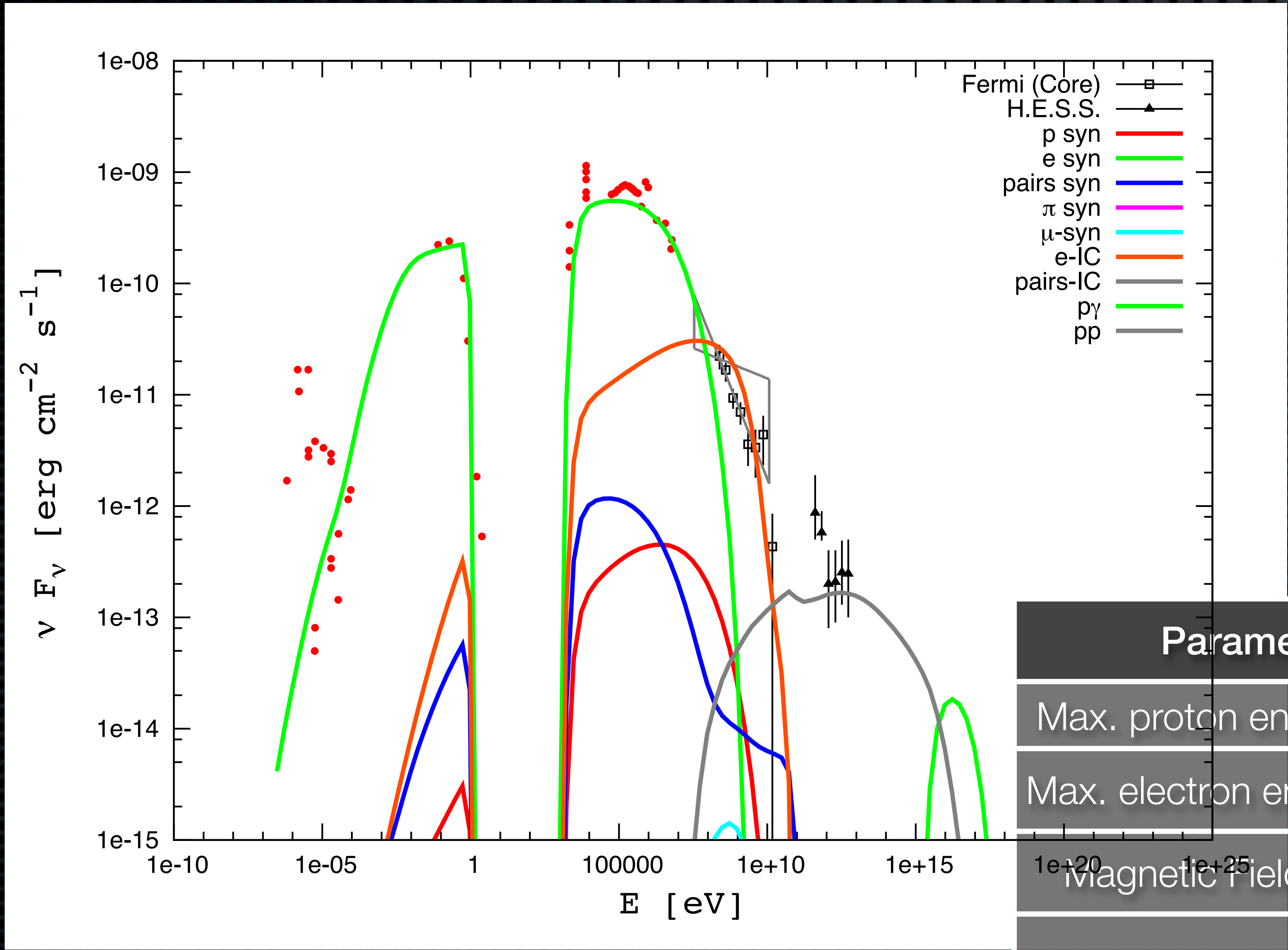




Cen A case

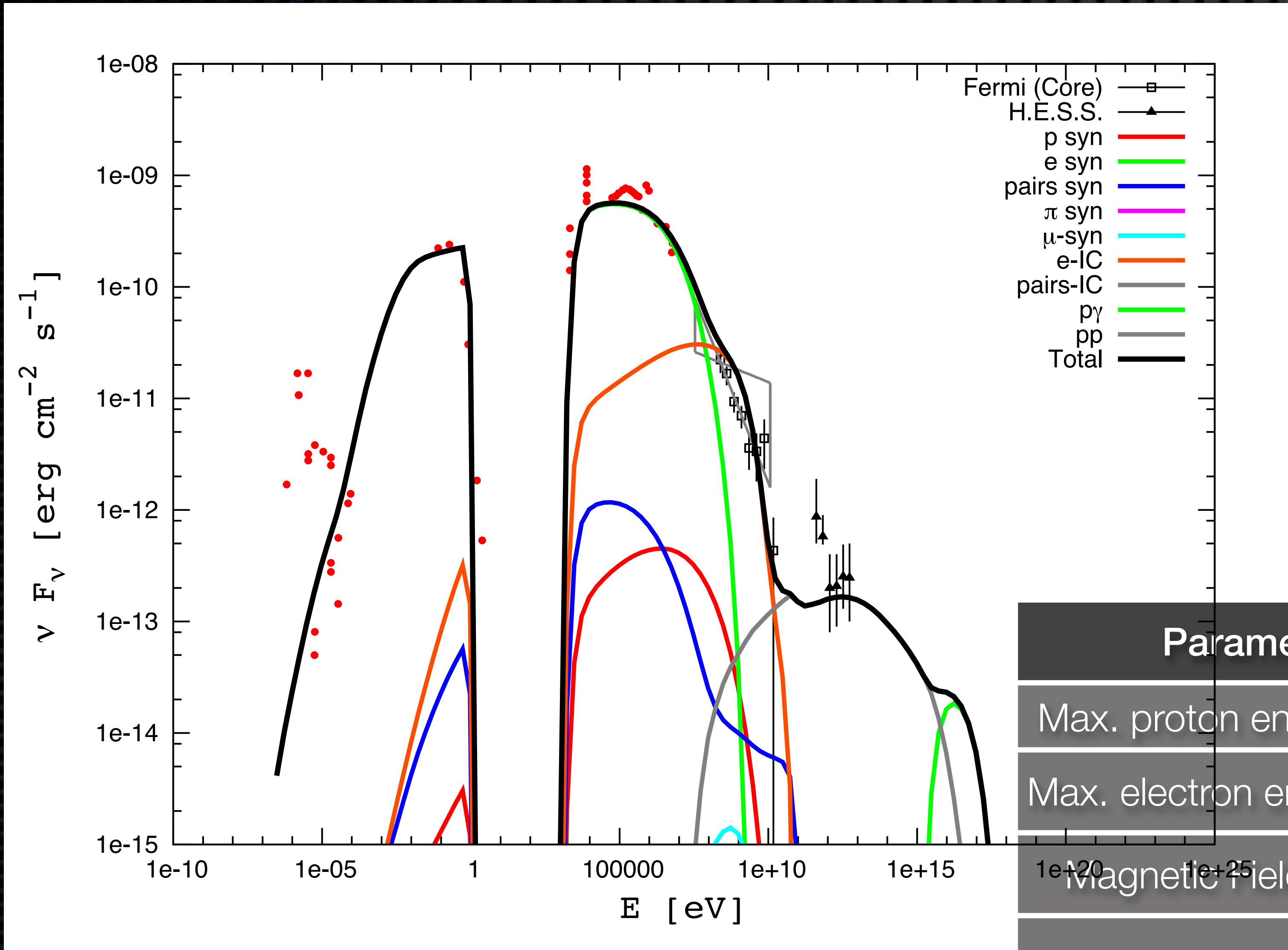
Parameter	Value
Mass BH $\mathbf{M_{BH}}$	10^8 $M_\odot$
Lorentz factor Γ	3
Jet kinetic power $\mathbf{L_k}$	1,25 x 10^{45} erg s^{-1}
fraction of power in relativistic particles $\mathbf{q_{rel}}$	0,1
proton to electron ratio **a**	0,1
jet launching position $\mathbf{z_0}$	50 R_g = 7,38 x 10^{14} cm
particle acceleration position $\mathbf{z_{acc}}$	250 R_g = 3,69 x 10^{15} cm
jet opening angle ξ	5°
viewing angle θ	25°
acceleration efficiency η	0,01
spectral index injection **s**	1,8
dust column density $\mathbf{N_H}$	1x10^{23} cm^{-2}

Cen A radiative output



Parameter	Value
Max. proton energy $\mathbf{E_{max,p}}$	2,7x10^8 GeV
Max. electron energy $\mathbf{E_{max,z}}$	800 GeV
Magnetic Field at z_0 $\mathbf{B_0}$	9234 G
Magnetic Field at z_{acc} $\mathbf{B_{acc}}$	826 G

Cen A radiative output

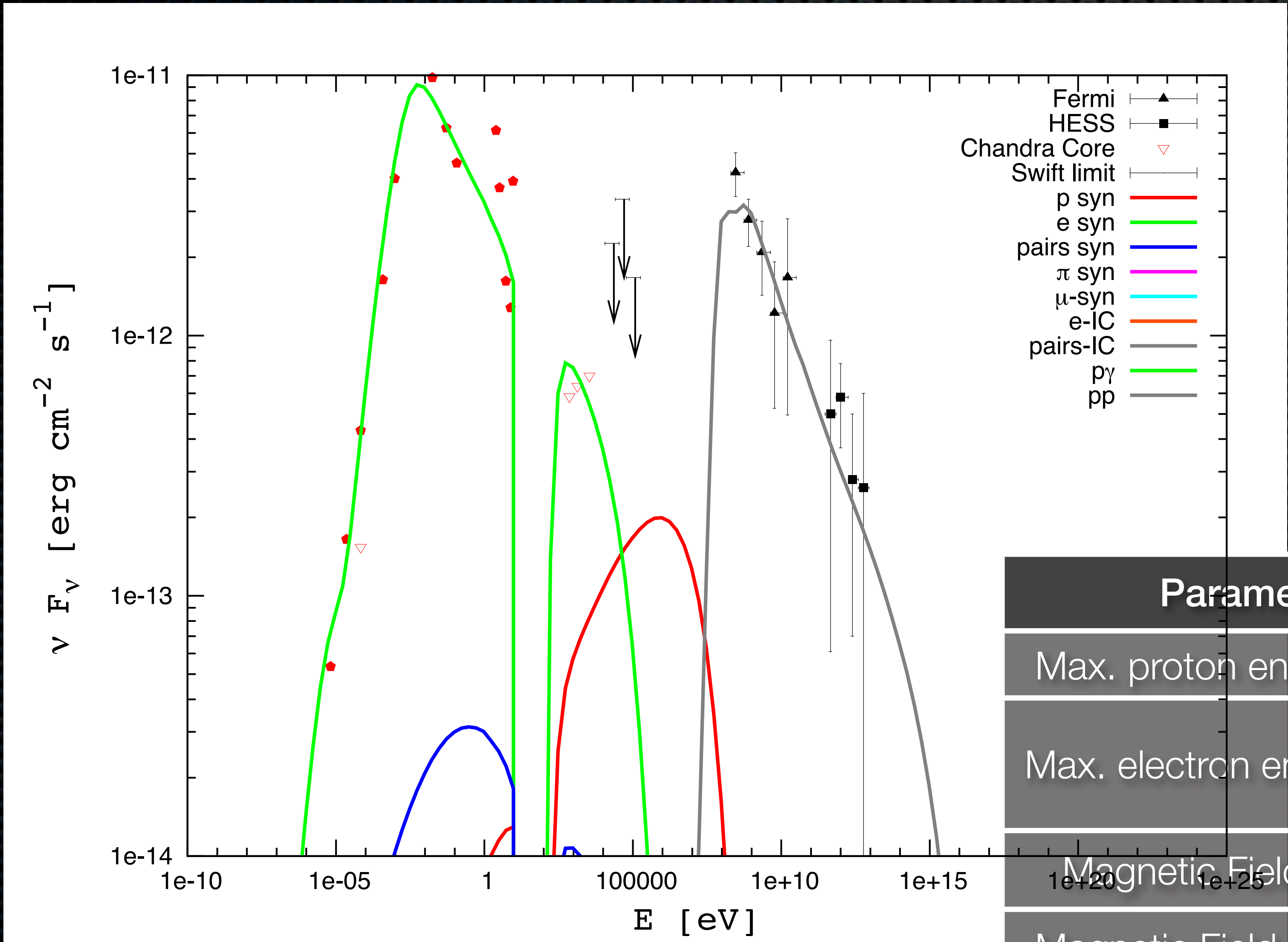


Parameter	Value
Max. proton energy $\mathbf{E_{max,p}}$	2,7x10^8 GeV
Max. electron energy $\mathbf{E_{max,z}}$	800 GeV
Magnetic Field at z_0 $\mathbf{B_0}$	9234 G
Magnetic Field at z_{acc} $\mathbf{B_{acc}}$	826 G

M87 case:

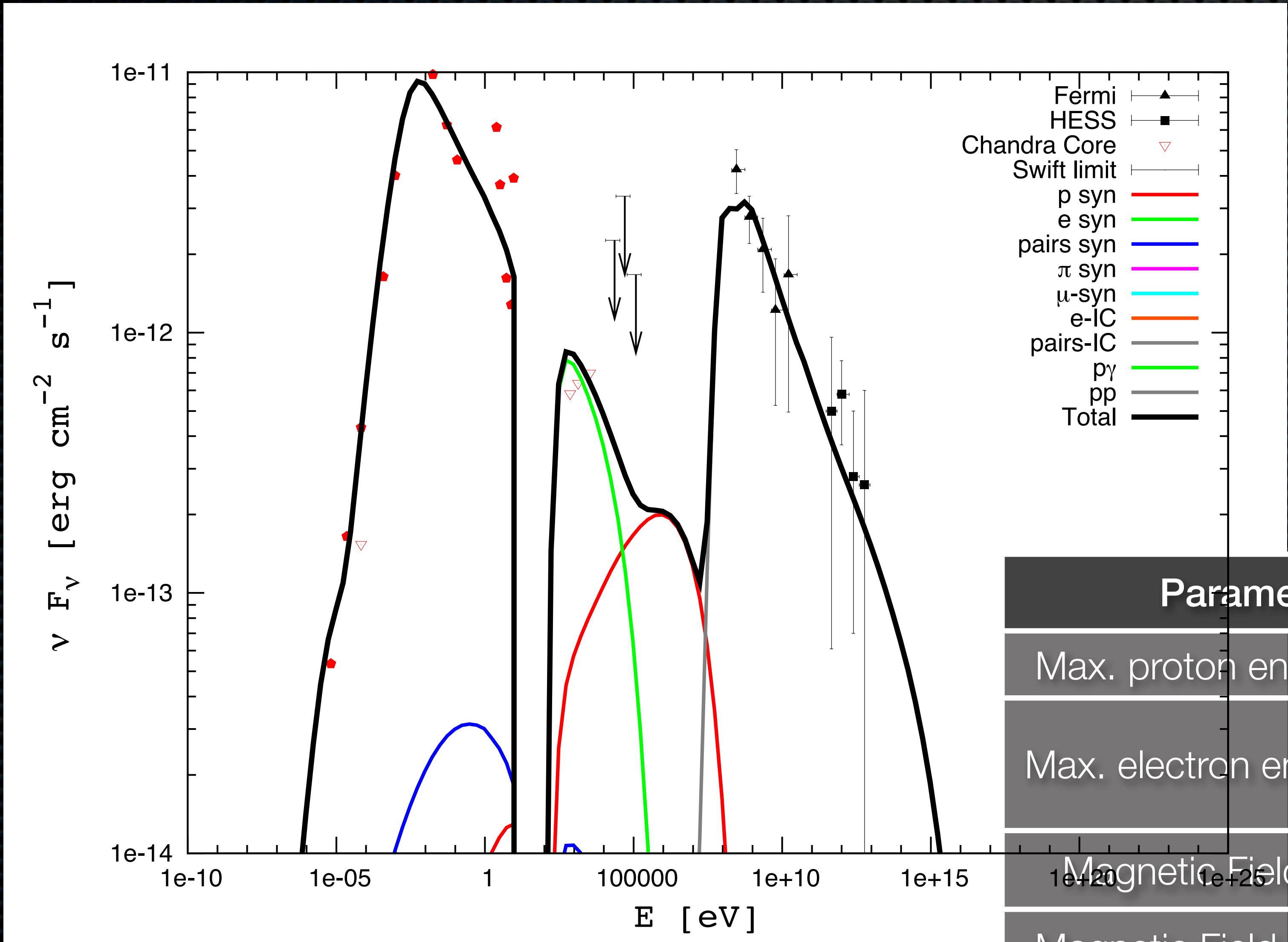
Parameter	Value
Mass BH M_{BH}	$6 \times 10^9\ M_\odot$
Lorentz factor Γ	5
Jet kinetic power L_k	$6{,}78 \times 10^{46}$ erg s^{-1}
fraction of power in relativistic particles q_{rel}	0,1
proton to electron ratio **a**	80
jet launching position z_0	$50\ R_g = 4{,}42 \times 10^{16}$ cm
particle acceleration position z_{acc}	$250\ R_g = 2{,}21 \times 10^{17}$ cm
jet opening angle ξ	1,5°
viewing angle θ	20°
acceleration efficiency η	0,0001
spectral index injection **s**	2,4
dust column density N_H	$2{,}5 \times 10^{20}$ cm^{-2}

M87 radiative output



Parameter	Value
Max. proton energy $\mathbf{E_{max,p}}$	3,6 x10^8 GeV
Max. electron energy $\mathbf{E_{max,z}}$	175 GeV
Magnetic Field at z_0 $\mathbf{B_0}$	3706 G
Magnetic Field at z_{acc} $\mathbf{B_{acc}}$	331 G

M87 radiative output



Parameter	Value
Max. proton energy $\mathbf{E}_{\mathbf{max,p}}$	3,6 x10^8 GeV
Max. electron energy $\mathbf{E}_{\mathbf{max,z}}$	175 GeV
Magnetic Field at z_0 $\mathbf{B}_\mathbf{0}$	3706 G
Magnetic Field at z_{acc} $\mathbf{B}_{\mathbf{acc}}$	331 G

Final comments

- Cen A SED:
  - inhomogeneous in time, angular & spatial resolution
- Nevertheless, spectral energy distribution basically consistent with the multi-λ emission from Cen A.
- **VHE emission** : p – p interactions.
- **Hard X-ray peak** : electron synchrotron radiation
- **Soft γ** : mainly IC emission

Final comments

- Photoionization interactions in the surrounding dust:
  - Drastic modulation in the electron synchrotron spectrum (broadband range 10^{-5} – 10^{7}eV)
- Maximum proton energy obtained: ~ 3 $\times 10^{17}$ eV.
  - Other mechanisms for UHECR observed by Auger:
  - Shear acceleration along the jet (Rieger et Aharonian,2009)
  - Production of neutrons in the jet which decay in protons near radio lobes (re-acceleration)

Final comments

- M87 case:
  - Model compatible with stationary SED.
  - **VHE emission & Soft** γ: p – p interactions.
  - Steeper injection (spectral index of 2.4)
  - Bigger proportion of protons
  - Challenge : flux variability

Neutrino production