On the production of neutrinos in the jet of Centaurus A

Matías M. Reynoso (IFIMAR-CONICET, Argentina)

María C. Medina (LUTH-OBSPM, France)

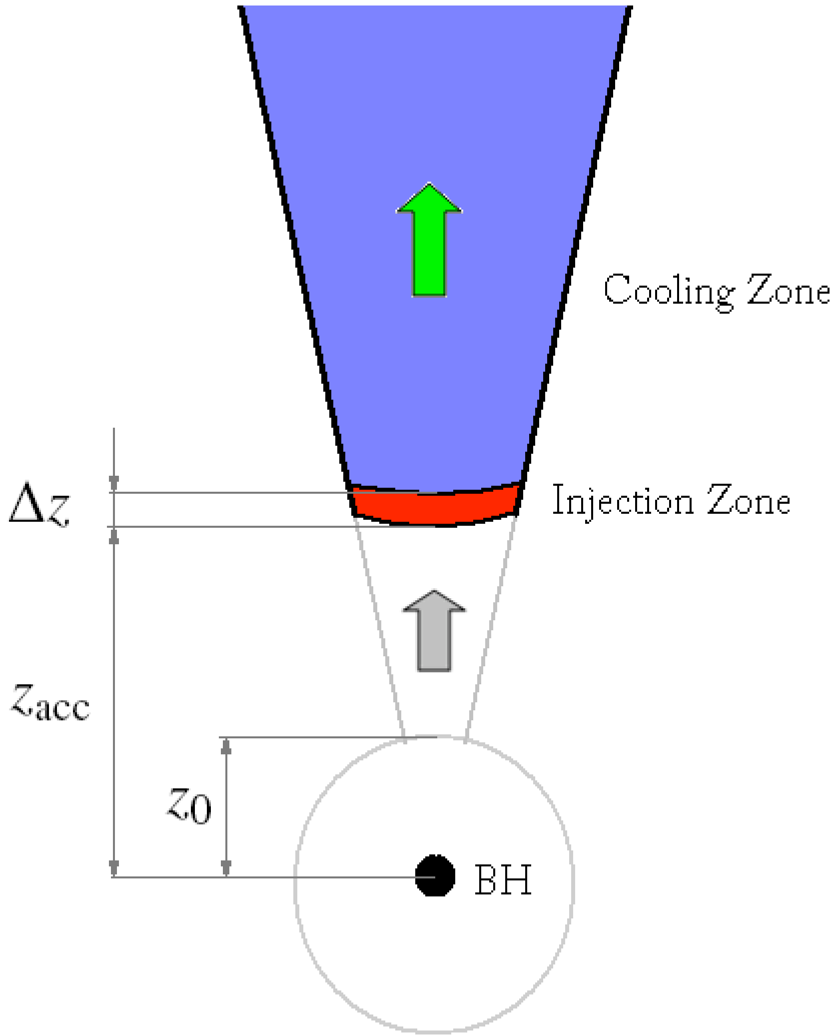
Gustavo E. Romero (IAR-CONICET, Argentina)

Plan

- Basic scenario
- Primary relativistic particles in the jet
- Secondary relativistic particles in the jet
- VHE neutrinos
- Final comments

Basic scenario

Scheme:



Basic scenario

- Jet kinetic luminosity: $L_{\rm k} = \frac{q_{\rm k}}{2} L_{\rm Edd}$
- Magnetic field in the jet: $B(z) = B_0 \left(\frac{z_0}{z}\right)^m$

  Equipartition at jet base $z_0 = 50 R_g$

- Primary relativistic *e*'s and *p*'s

  Injected at $z_{\rm acc}$; $\rho_{\rm m} = 0.1 \rho_{\rm k}$

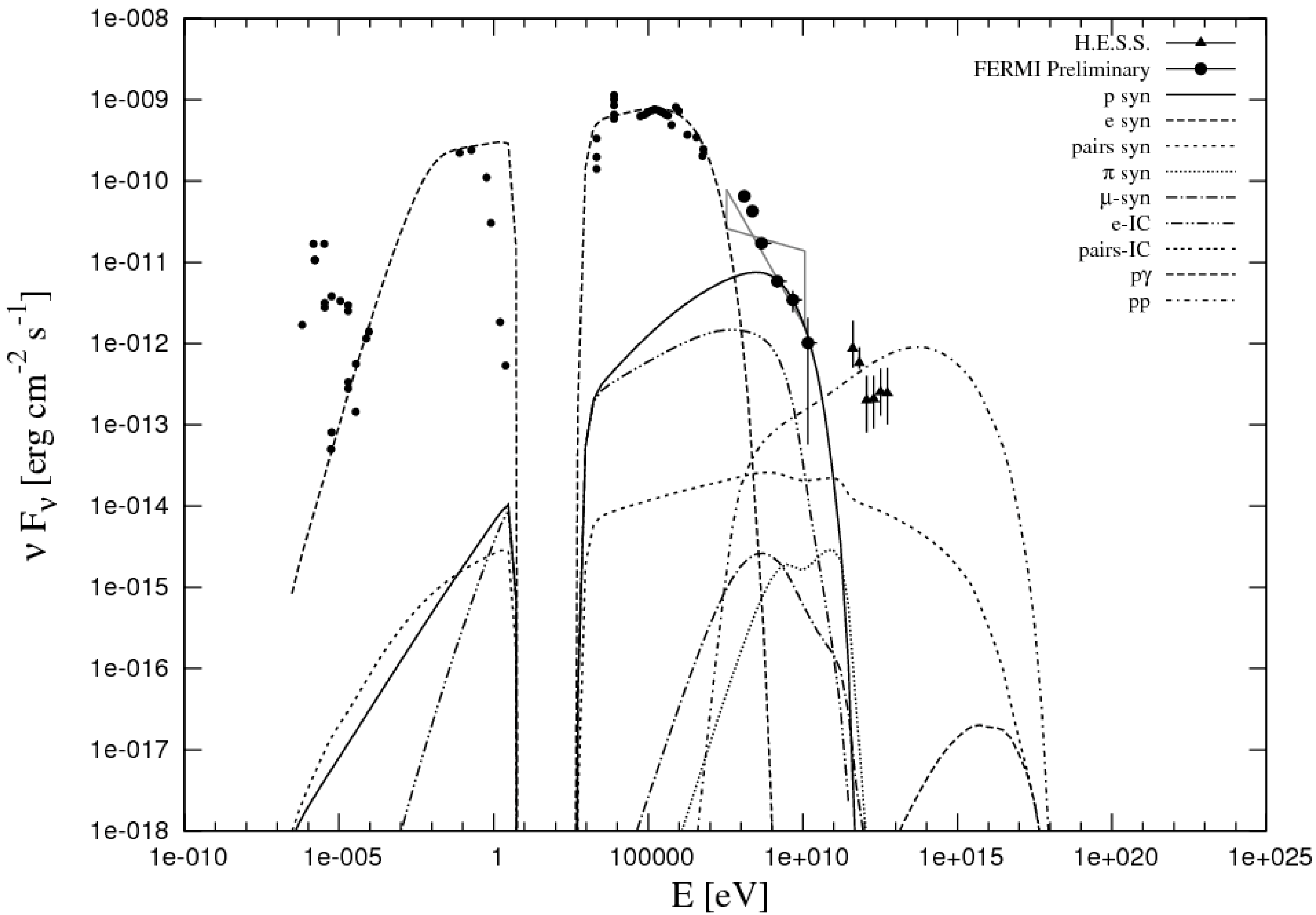
Injection: $Q_{\{e,p\}}(E,z) = K_{\{e,p\}} \left(\frac{z_0}{z}\right)^2 E^{-s} \exp\left(\frac{E}{E_{\rm max}}\right)^2$

Power: $L_e + L_p = q_{\rm rel} L_{\rm k}$ $\qquad L_p = a\, L_e$

Parameters used for Cen A

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°

Model output of photons:

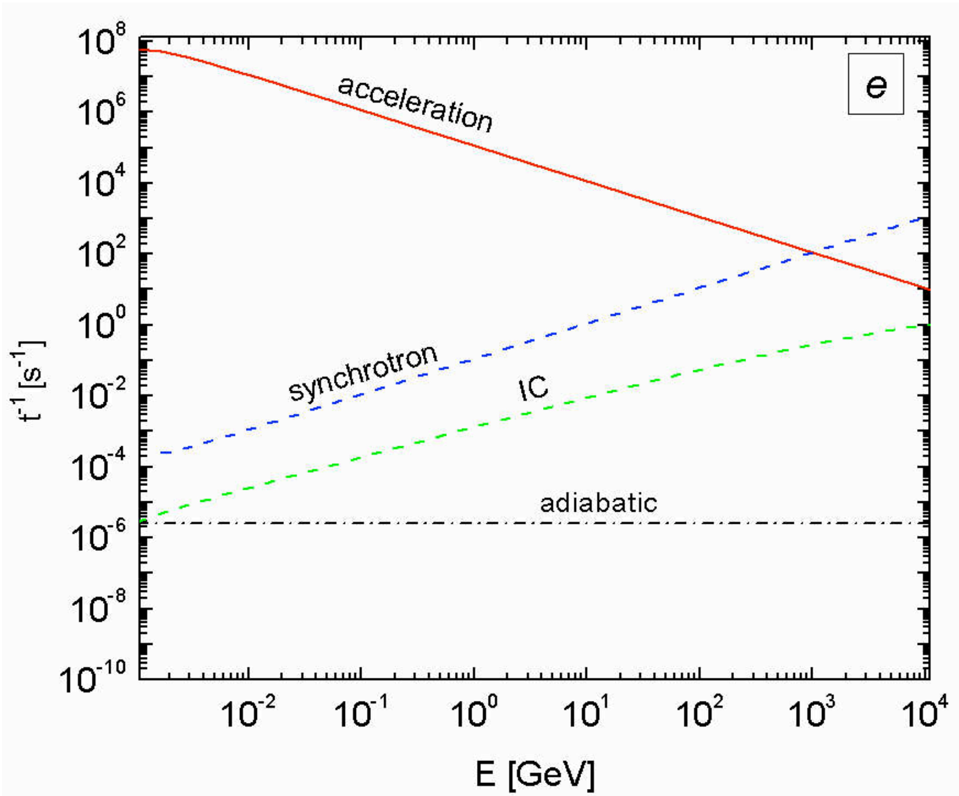


Primary relativistic *e*'s and *p*'s in the jet

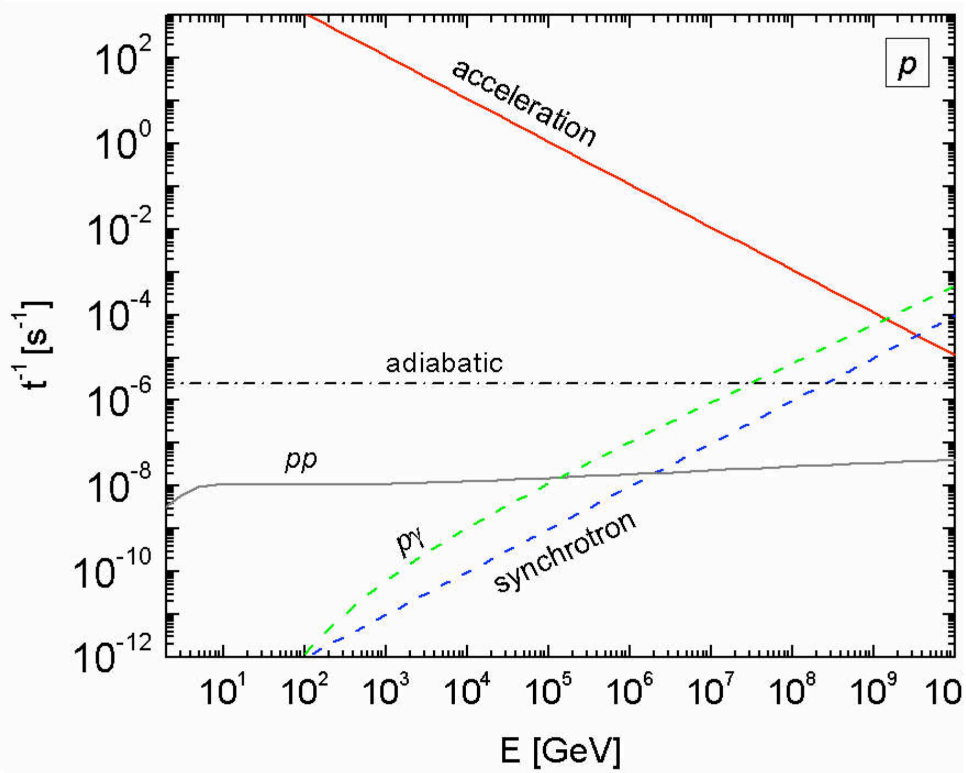
Acceleration rate: $$t_{\mathrm{acc}}^{-1} = \eta \frac{ceB(z)}{E}$$

Cooling processes:

e: synchrotron + adiabatic + IC



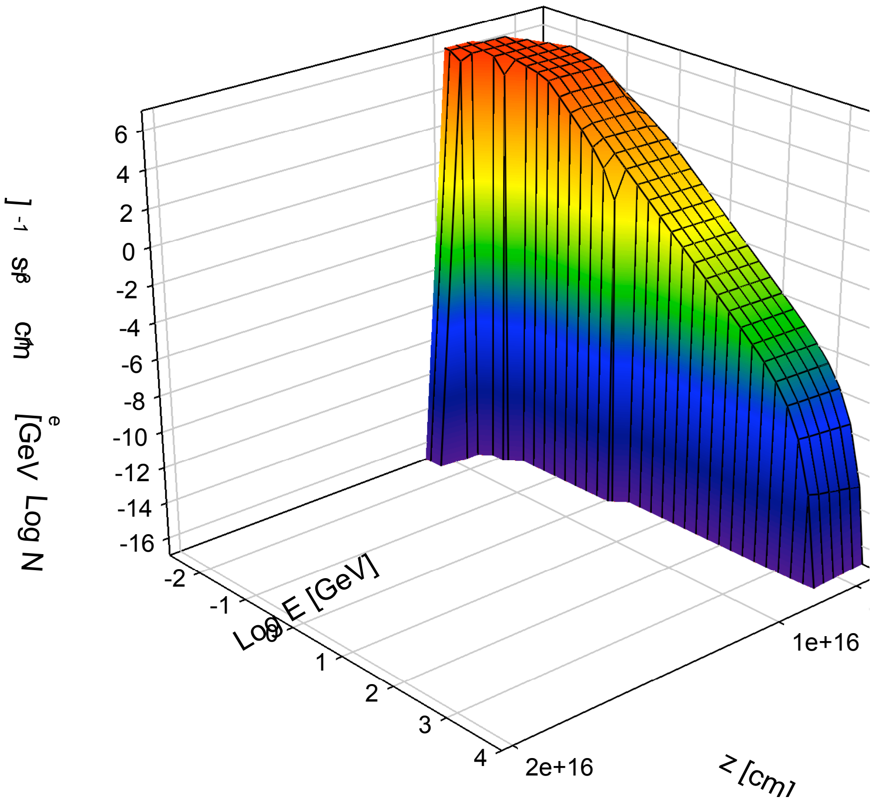
p: synchrotron + adiabatic + *p_* + *pp*

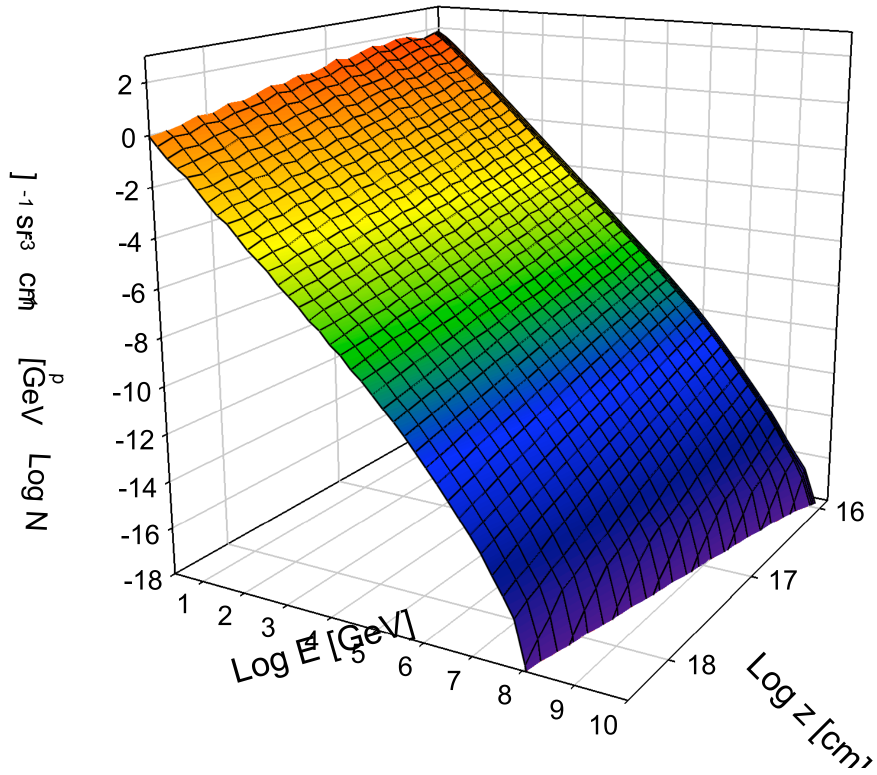


Energy distributions of *e*'s and *p*'s

- 1D steady transport equation:

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





Secondary particles in the jet

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

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

Atoyan & Dermer 2003

Injection of pions:

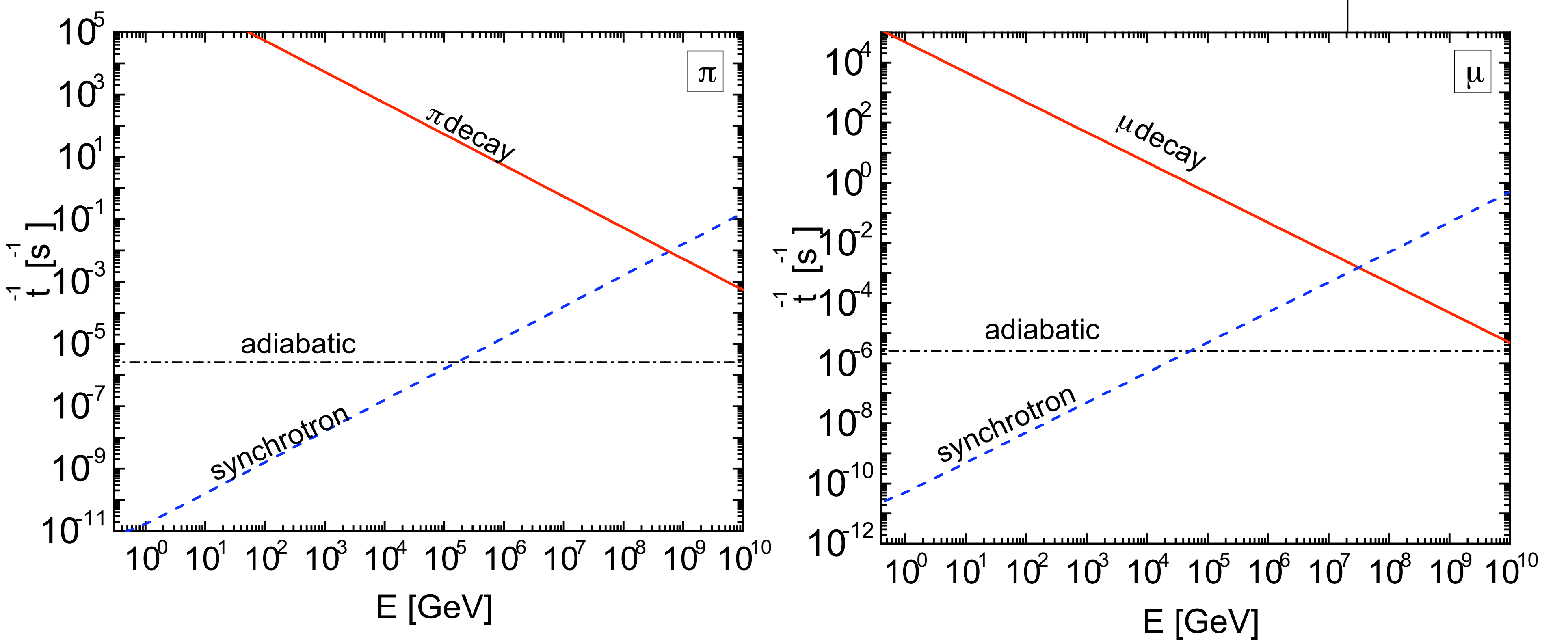
$$p + p \longrightarrow p + p + a\pi^0 + b(\pi^+ + \pi^-)$$
$$p + p \longrightarrow p + n + \pi^+ + a\pi^0 + b(\pi^+ + \pi^-)$$
$$p + p \longrightarrow n + n + 2\pi^+ + a\pi^0 + b(\pi^+ + \pi^-)$$

Kelner et al 2006

Injection of muons: $\pi^\pm \longrightarrow \mu^\pm + \bar{\nu}_\mu(\nu_\mu)$ Lipari et al 2007

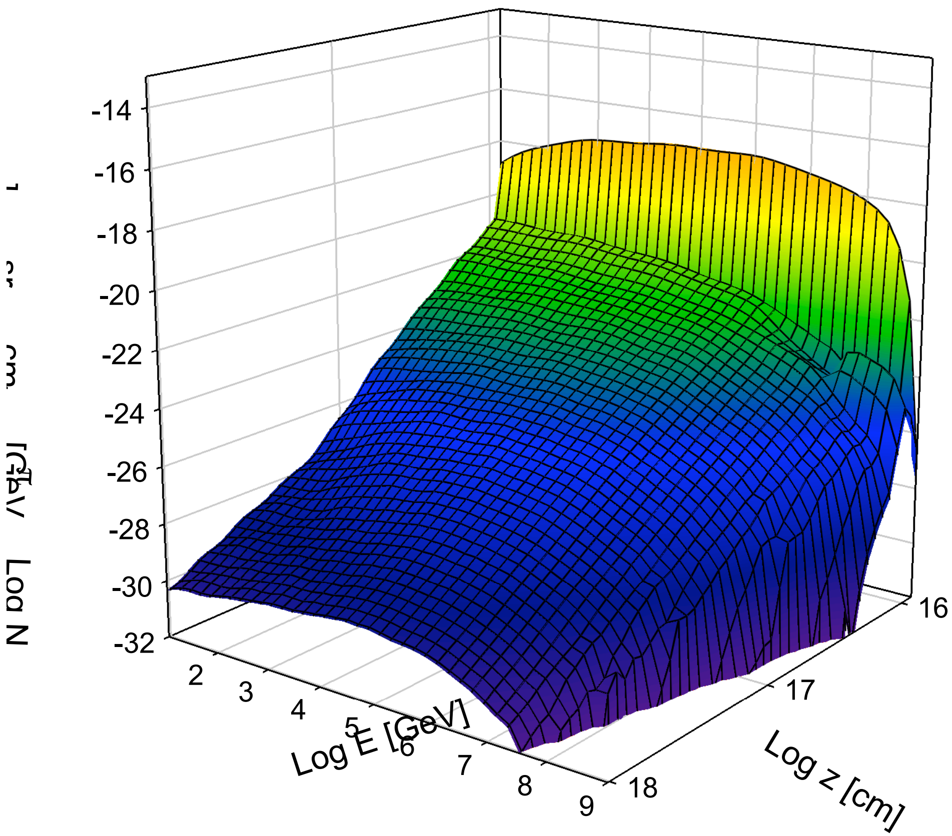
$$v\frac{\partial N(E,z)}{\partial z} + \frac{\partial\left[b(E,z)N(E,z)\right]}{\partial E} + \frac{N(E,z)}{T_{\rm dec}} = Q(E,z)$$

Pion cooling and decay rates:

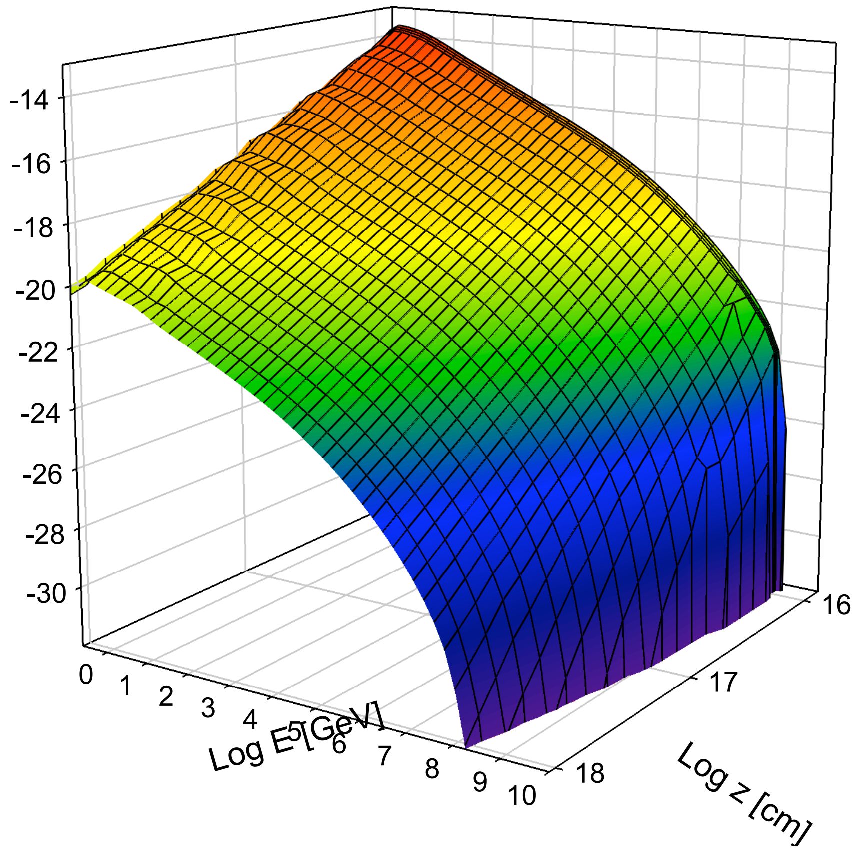


High energy pions in the jet

pions from *p_* intereactions



pions from *pp* intereactions



Neutrinos from pion & muon decays

$$Q_{\pi\to\nu_\mu}(E,z) = \int_E dE_\pi t^{-1}_{\pi,\mathrm{dec}}(E_\pi) N_\pi(E_\pi,z) \frac{\Theta(1-r_\pi-x)}{E_\pi(1-r_\pi)} \qquad x = \frac{E}{E_\pi}$$

$$Q_{\mu\to\nu_\mu}(E,z) = \sum_{i=1}^{4} \int_E \frac{dE_\mu}{E_\mu} t^{-1}_{\mu,\mathrm{dec}}(E_\mu) N_{\mu_i}(E_\mu,z) \left[\frac{5}{3} - 3x^2 + \frac{4}{3}x^3 + \left(3x^2 - \frac{1}{3} - \frac{8x^3}{3}\right) h_i\right]$$

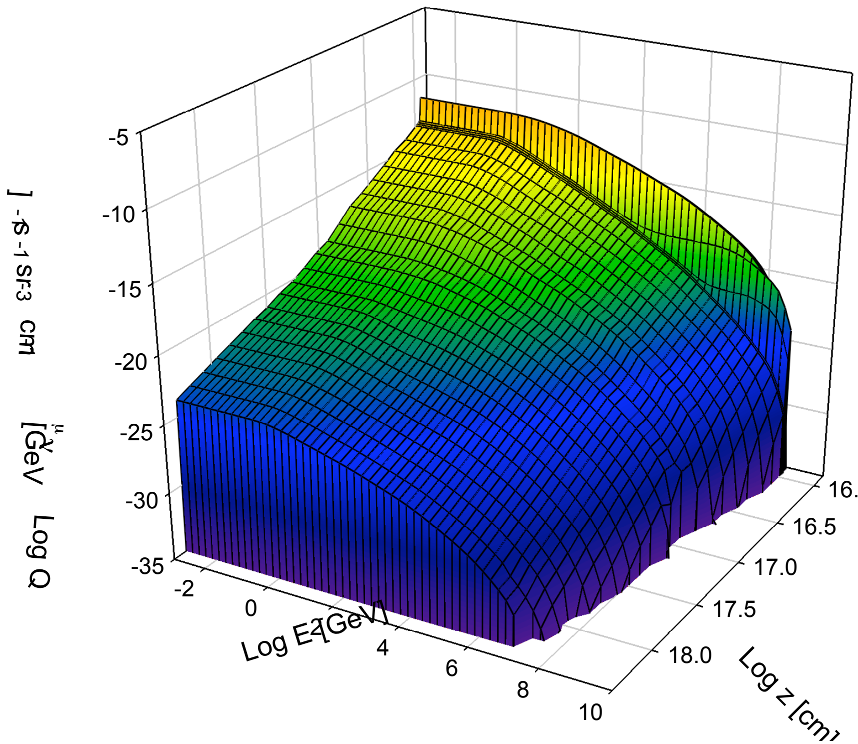
$$Q_{\mu\to\nu_e}(E,z) = \sum_{i-1}^{4} \int_E \frac{dE_\mu}{E_\mu} t^{-1}_{\mu,\mathrm{dec}}(E_\mu) N_{\mu_i}(E_\mu,z) \left[2 - 6x^2 + 4x^3 + \left(2 - 12x + 18x^2 - 8x^3\right) h_i\right]$$

$$x = \frac{E}{E_\mu}$$

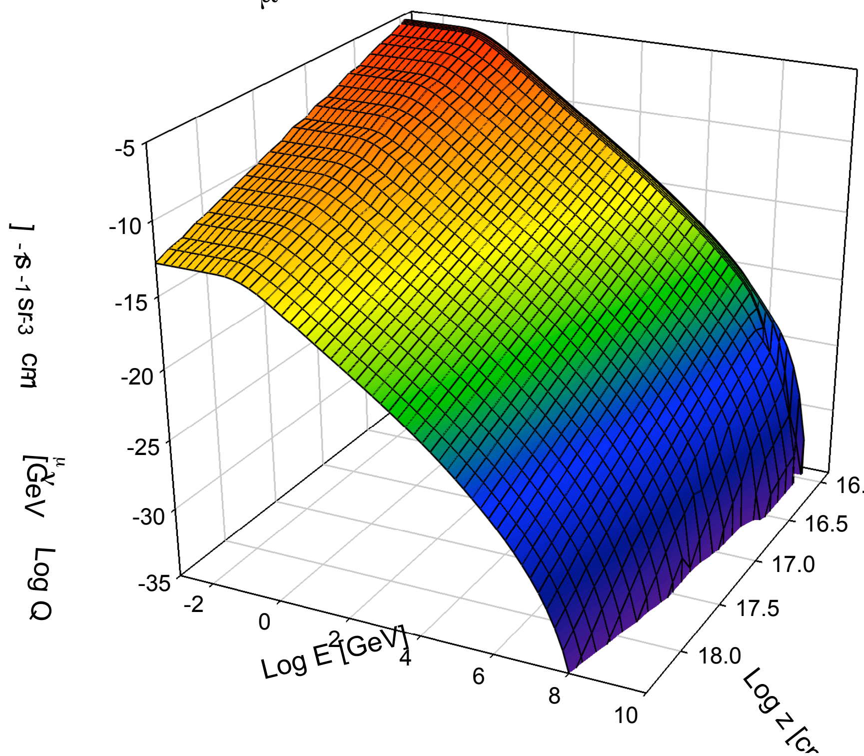
Lipari et al 2007

Neutrino Emissivities

ν_μ's from *p_* interactions



ν_μ's from *pp* interactions



Neutrino Flux at the Earth

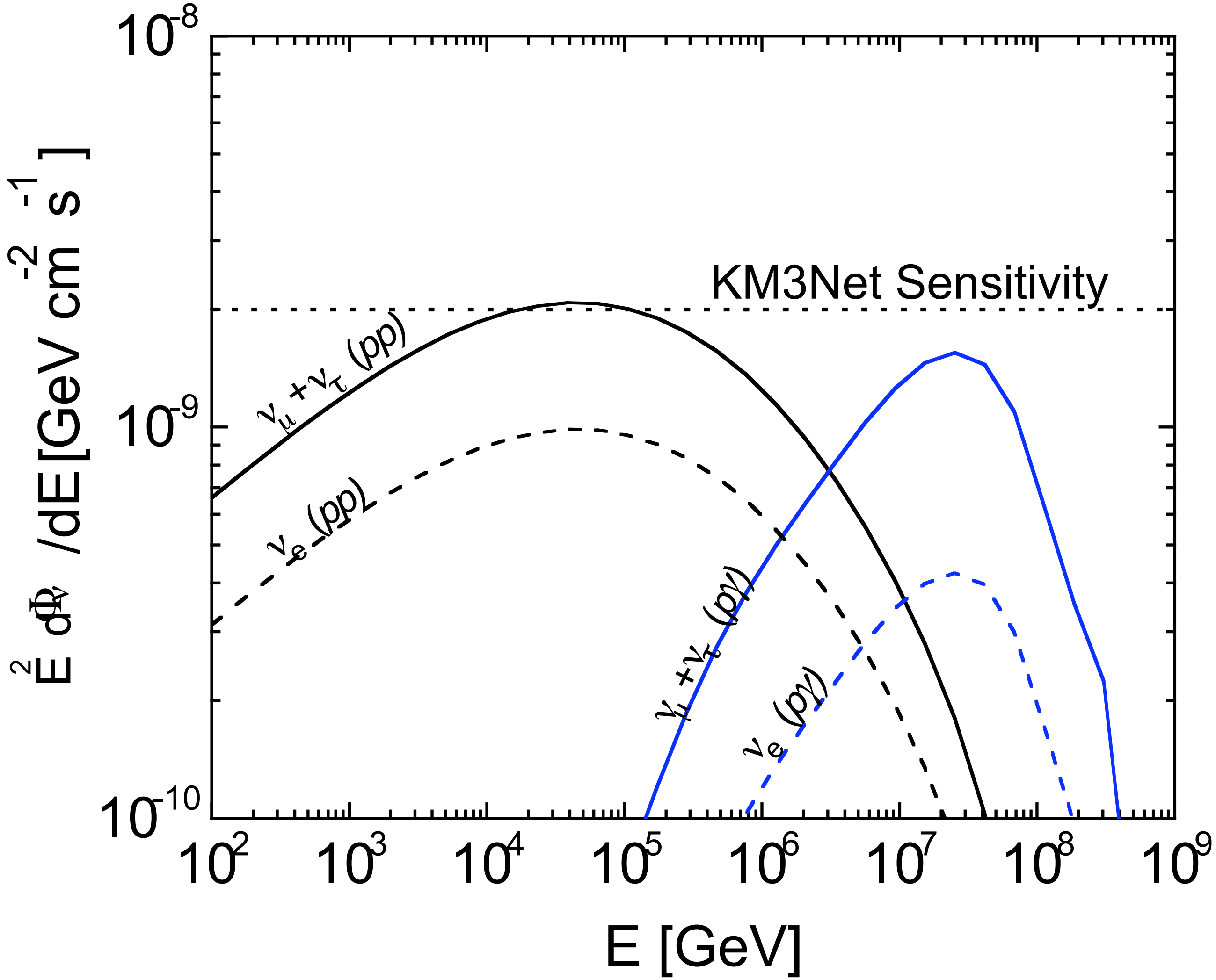
Taking into account oscillation effects:

$$\frac{d\Phi_{\nu_\mu}}{dE} = \frac{1}{d^2}\int_V dV\left[Q_{\nu_\mu}(E,z)P_{\nu_\mu\to\nu_\mu} + Q_{\nu_e}(E,z)P_{\nu_\mu\to\nu_e}\right]$$

$$\frac{d\Phi_{\nu_e}}{dE} = \frac{1}{d^2}\int_V dV\left[Q_{\nu_\mu}(E,z)P_{\nu_\mu\to\nu_e} + Q_{\nu_e}(E,z)P_{\nu_e\to\nu_e}\right]$$

$$\frac{d\Phi_{\nu_\tau}}{dE} = \frac{1}{d^2}\int_V dV\left[Q_{\nu_\mu}(E,z)P_{\nu_\mu\to\nu_\tau} + Q_{\nu_e}(E,z)P_{\nu_e\to\nu_\tau}\right]$$

Neutrino Flux



Final comments

- If *pp* interactions at the inner jet can account for VHE _-ray emission at the level detected, an accompanying neutrino flux is produced. Detection with KM3net could be possible.
- Auger correlated UHECR events are to be produced elsewhere (not at the inner jet). Hence, other neutrino signal might be expected.