UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

POLITECNICO DI BARI

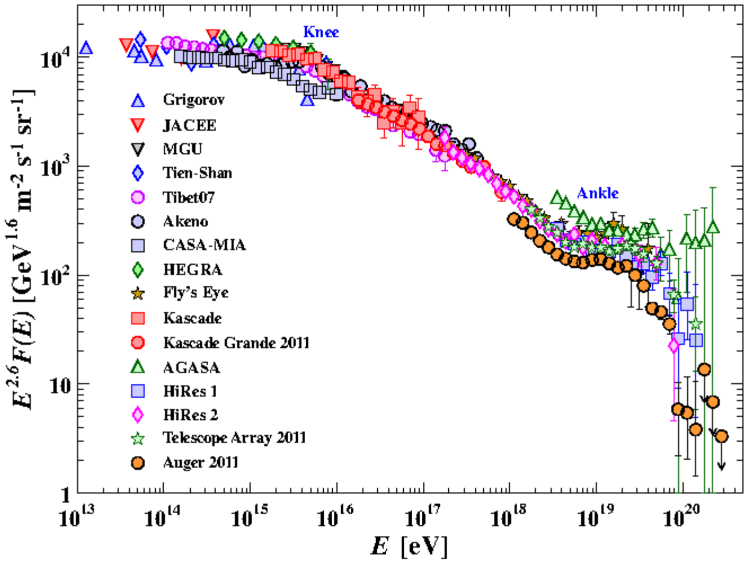
DOTTORATO DI RICERCA XXX CICLO

Inferring the Cosmic Ray spectra and interaction mechanisms by means of the study of gamma-ray emissions

Dottorando:

Leonardo Di Venere

Cosmic Rays

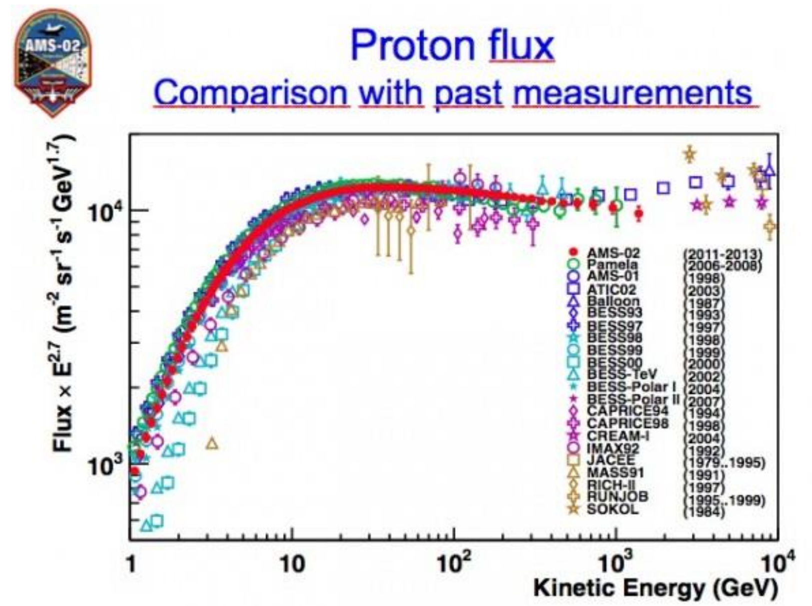


J. Beringer et al. (Particle Data Group), and 2013 update for the 2014 edition (http://pdg.lbl.gov), Phys. Rev. D86, 010001 (2012)

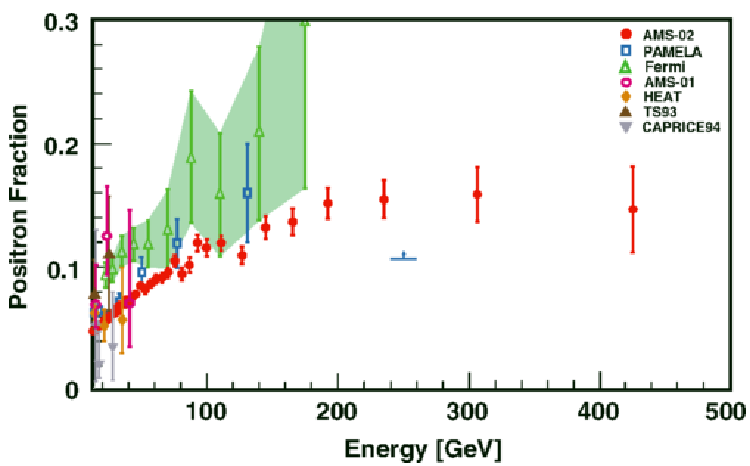
$$\frac{dN}{dE} \propto E^{-\alpha}$$

Two main features:

- Below the 'knee' $\alpha = 2.7$
- Below the 'ankle' $\alpha = 3$



AMS-02 Collaboration, ICRC 2013

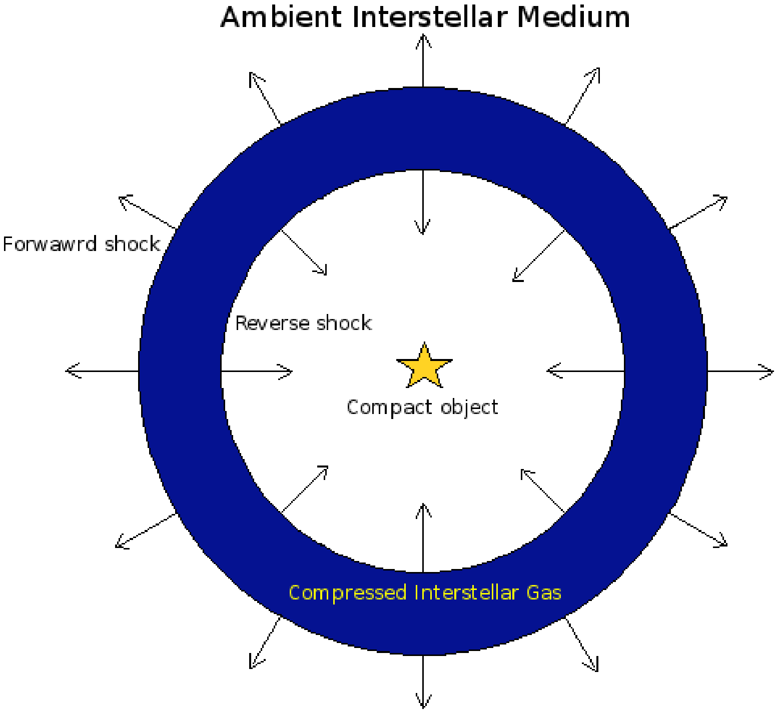


L. Accardo et al. (AMS Collaboration), Phys. Rev. Lett. 113, 121101 (2014)

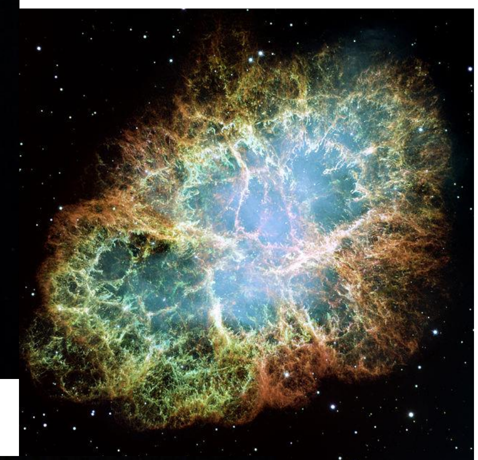
COMPOSITION

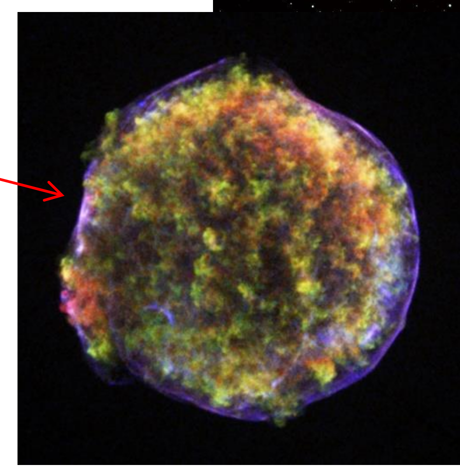
- 98% protons and nuclei
- 2% electrons

Supernova Remnants




Kepler SNR


Crab Nebula


Tycho SNR

SNR shock

Energetics of SNRs

- SN explosion energy E_{SN}~10^{51} erg
- Rate of explosion in the Galaxy R_{SN}~3 SN/century
- Confinement time of cosmic rays τ_e~10 Myr
- Cosmic-ray energy density ρ_{CR}~1 eV cm^{-3}

$$\rho_{CR} = R_{SN}\, E_{SN}\, \tau_e\, \epsilon$$

γ-ray observations

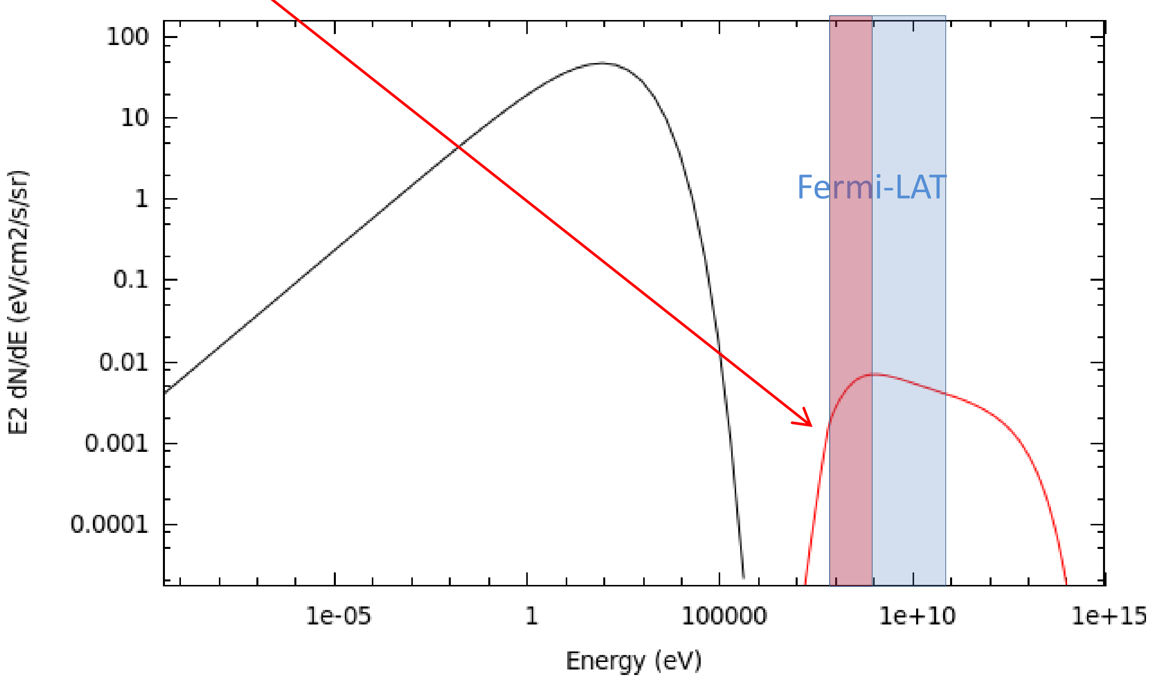
Hadronic interaction

$$Q_\gamma(E_\gamma) = \int \frac{4\pi}{\beta c} n_H \frac{dN_p}{dE_p} \frac{1}{E_\gamma} \frac{d\sigma(E_p/E_\gamma)}{dlog(E_\gamma)} dE_p$$

Parametrisation from T. Kamae et al.
Astrop. Jour. 647 (2006), p. 692.

$$p + p \rightarrow \pi^0 + X$$

$$\pi^0 \rightarrow \gamma + \gamma$$



γ-ray observations

Hadronic interaction

$$Q_\gamma(E_\gamma) = \int \frac{4\pi}{\beta c} n_H \frac{dN_p}{dE_p} \frac{1}{E_\gamma} \frac{d\sigma(E_p/\,E_\gamma)}{dlog(E_\gamma)} dE_p$$

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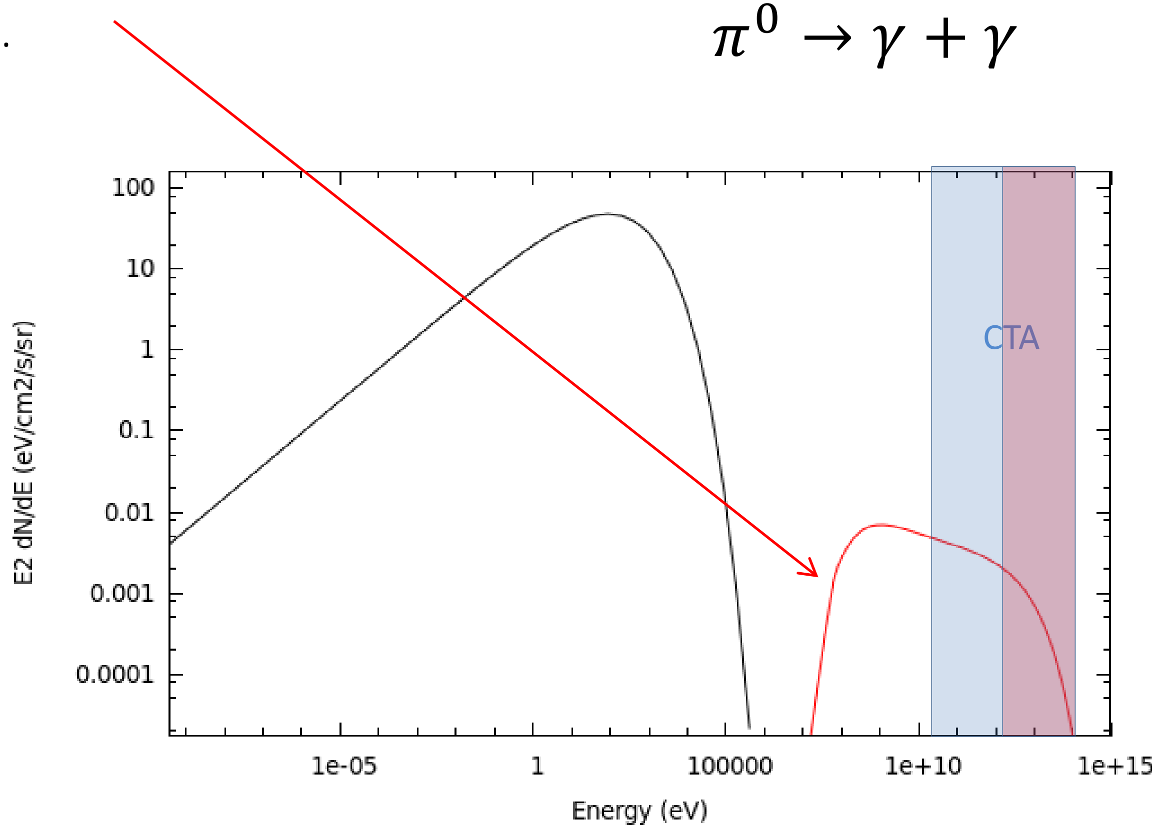
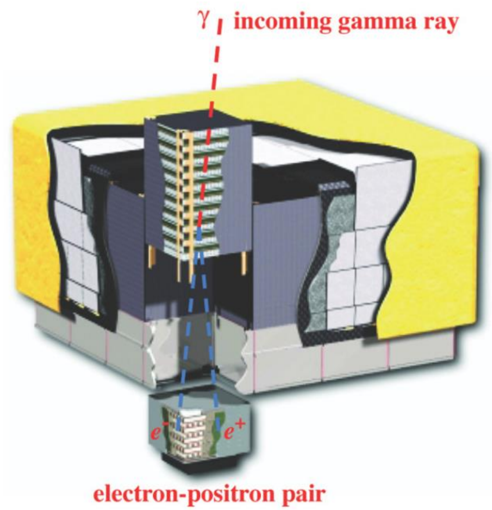
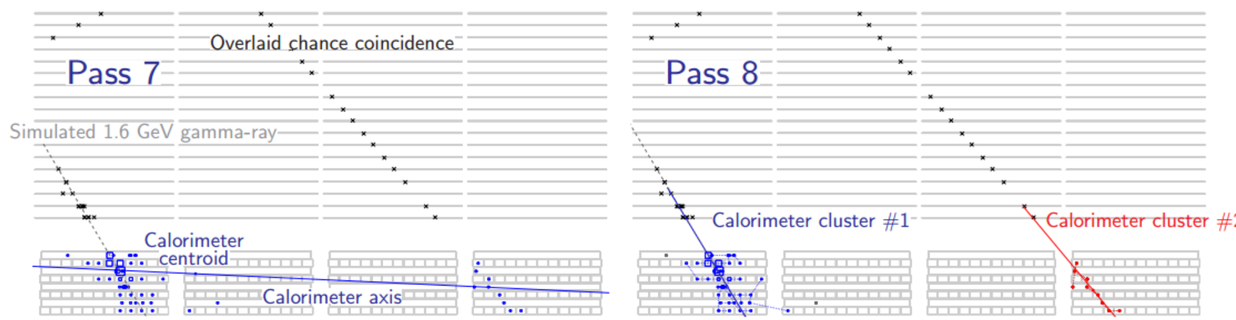
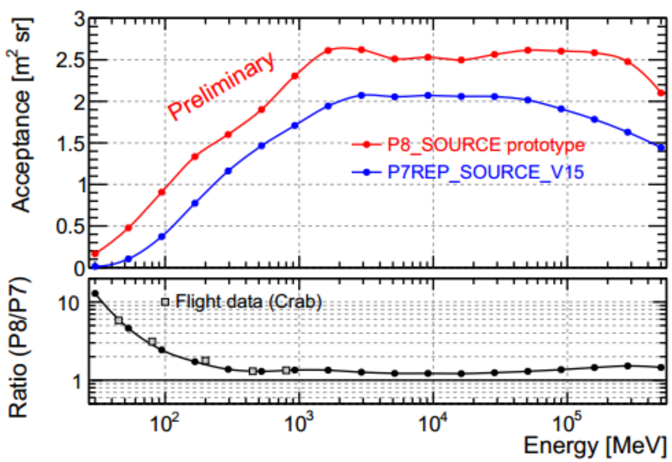


FERMI-LAT experiment



New reconstruction method: Pass 8



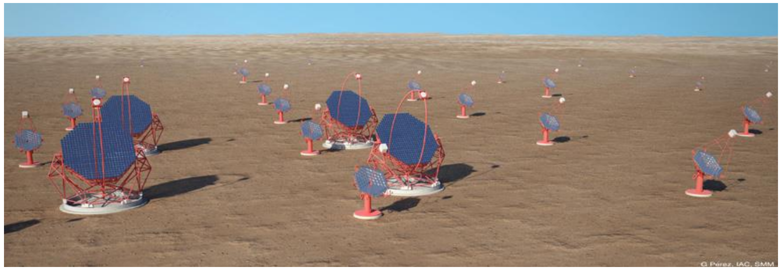


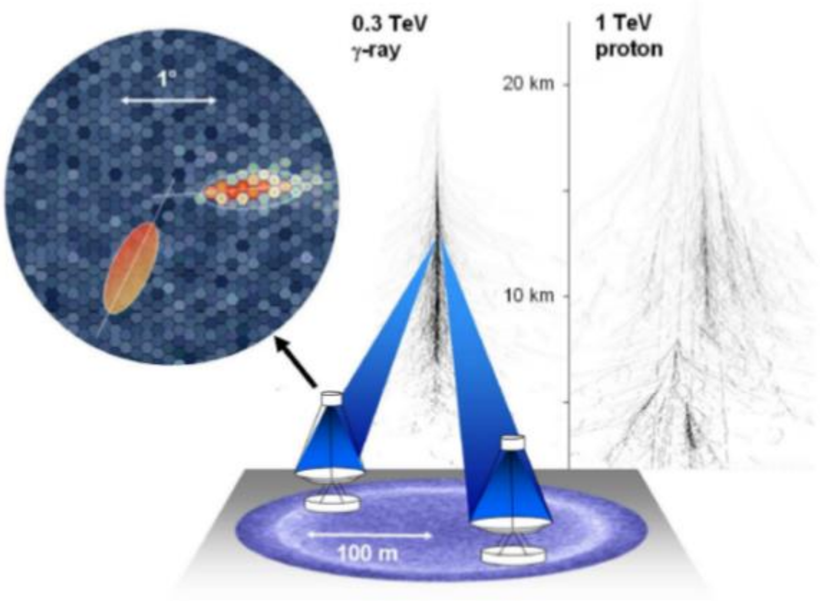
Increment in acceptance:

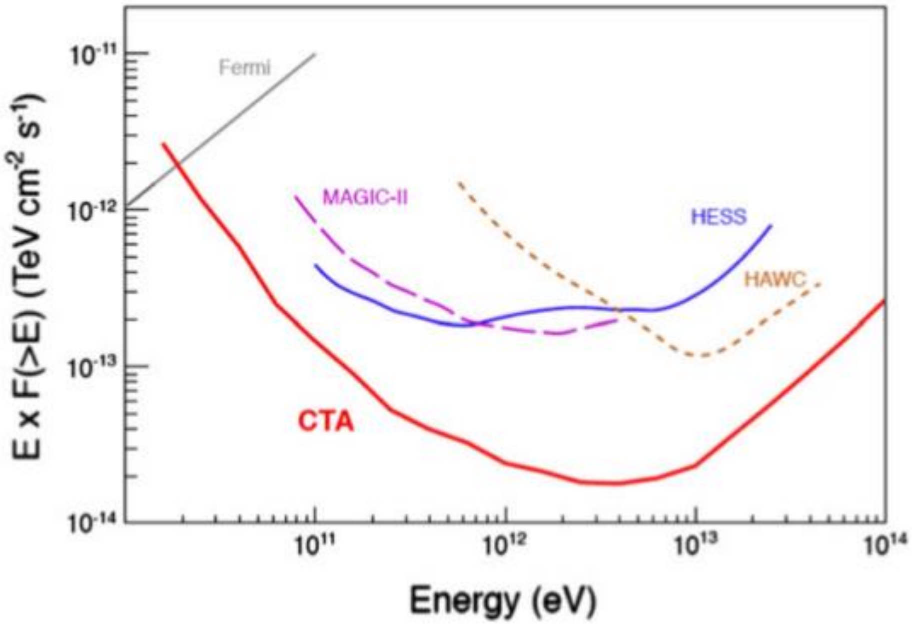
- 25% for energy above 1 GeV
- 300% @ 100 MeV!!

Pass 8 event reconstruction is still a prototype

CTA experiment







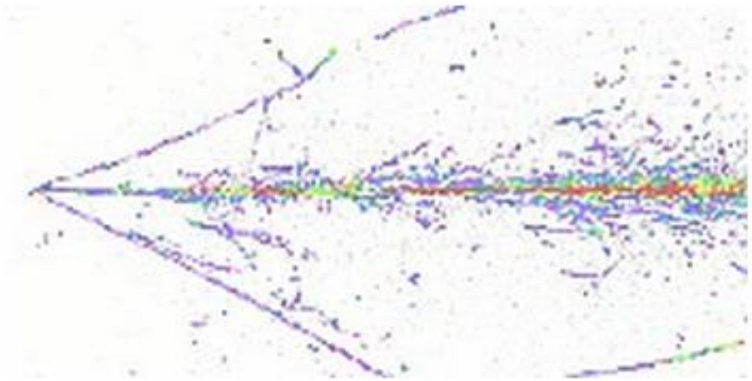
B.S. Acharya et al. (CTA Consortium), Astrop. Phys. 43, (2013), p.3-18

- Improved sensitivity
- Broaden energy range (20 GeV – 100 TeV)
- Improve angular resolution (2 arc min)

FLUKA Simulation Tool

- Interaction of high energy particles
- Complex geometry of targets
- Cross-section calculation for low density targets

Reliable simulations allow discovery of new physics

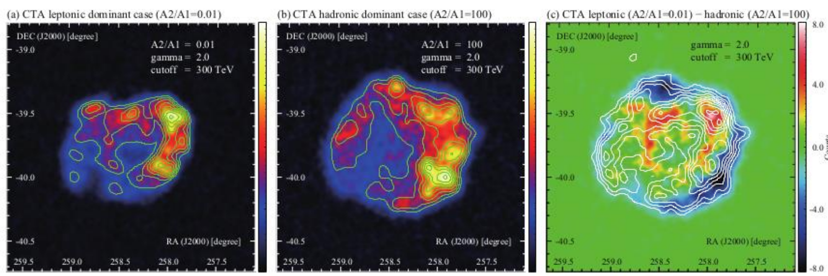


Project Goals

- Fermi-LAT data analysis focusing on some issues of the new reconstruction method (energy dispersion, diffuse model)
- Study of simulation codes (such as FLUKA) to predict gamma-ray spectra for astrophysical objects

Project Goals

- Simulations for TeV gamma-ray experiments (CTA)



- Detailed study of the diffuse component issues for source analysis

Ph.D. Tutor

- Dott. Francesco Giordano
- Dott. Mario Nicola Mazziotta

- Upcoming submission of the project for a cotutelle PhD program with Germany (DAAD call)
- Collaboration with Prof. Stefan Funk at University of Erlangen

BACKUP SLIDES

γ-RAY OBSERVATIONS OF SNRs

Cosmic rays are deflected by Galactic magnetic field

↓

Neutral particles, such as γ-rays and ν, allow source pointings

Synchrotron radiation

$$Q_\gamma(\omega) = \frac{\sqrt{3}\,B\,e^3}{2\pi\,m_e c^2}\int \frac{4\pi}{\beta c}\frac{dN_e}{dE_e} R\left(\frac{\omega}{\omega_c}\right) dE_e$$

G. R. Blumenthal and R. J. Gould., Rev. Mod. Phys. 42 (1970), p. 237.

Inverse Compton scattering

$$Q_\gamma(E_\gamma) = \int \frac{dN_e}{dE_e} dE_e \int n(E_s)\sigma_{K-N}(E_s, E_e, E_\gamma) dE_s$$

G. R. Blumenthal and R. J. Gould., Rev. Mod. Phys. 42 (1970), p. 237.

Bremsstrahlung radiation

$$Q_\gamma(\epsilon) = 4\pi\, n_H \int \frac{dN_e}{dE_e}\frac{d\sigma_{B-H}}{d\epsilon} dE_e$$

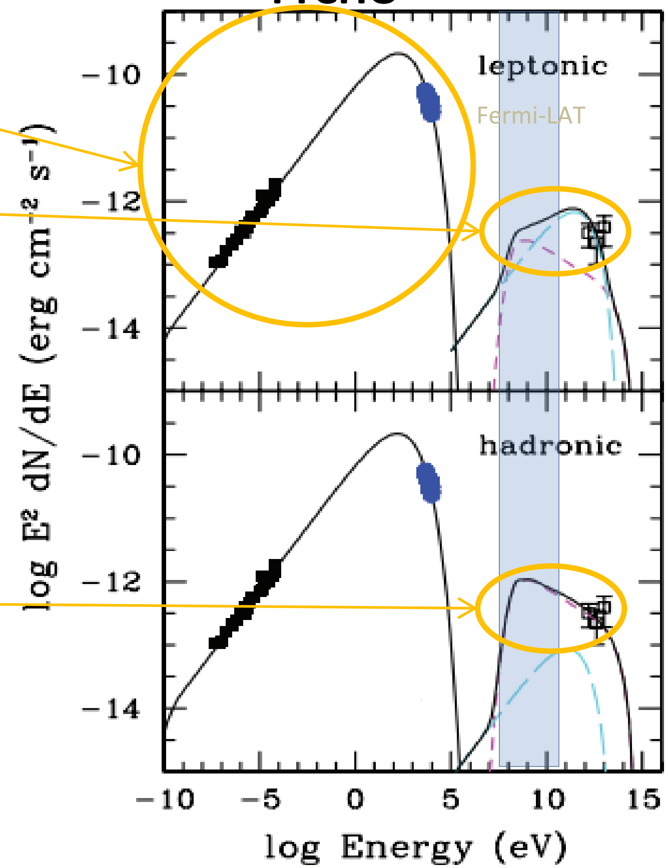
M. G. Baring et al., Astrop. Jour. 513 (1999), p. 311.

Hadronic interaction $p + p \rightarrow \pi^0 + X,\ \ \pi^0 \rightarrow \gamma + \gamma$

$$Q_\gamma(E_\gamma) = \int \frac{4\pi}{\beta c} n_H \frac{dN_p}{dE_p}\frac{1}{E_\gamma}\frac{d\sigma(E_p/\,E_\gamma)}{d\log(E_\gamma)} dE_p$$

Parametrisation from T. Kamae et al. Astrop. Jour. 647 (2006), p. 692.

TYCHO



V. A. Acciari et al. In: Astrophys. Journ. 730 (2011), p. L20.

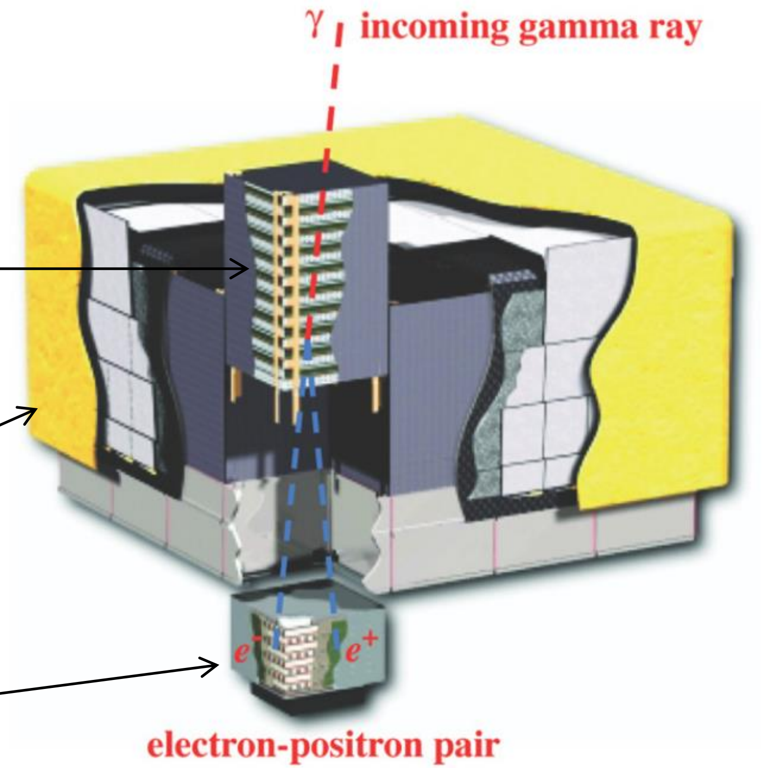
FERMI-LAT EXPERIMENT

- 4x4 array of towers

Converter-tracker
(angular resolution:
0.6° @ 1GeV; 0.1° above 10 GeV)

Anticoincidence detector

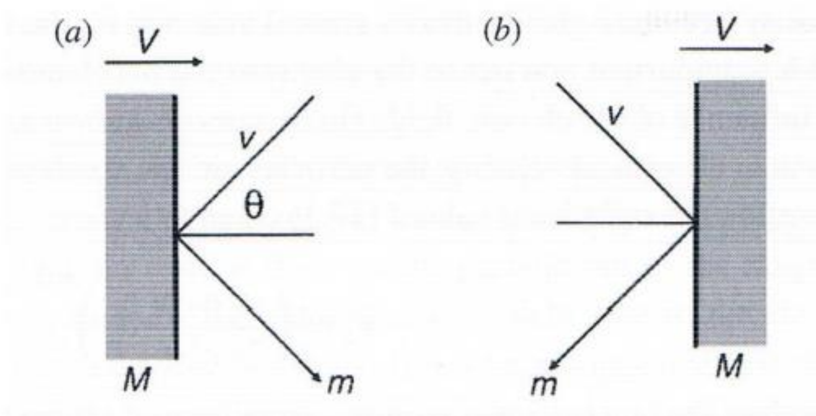
Calorimeter
(energy resolution: ≤ 10% above 1 GeV)



W. B. Atwood et al. In: Astrophys. Journ. 697 (2009), p. 1071.

ACCELERATION MECHANISMS

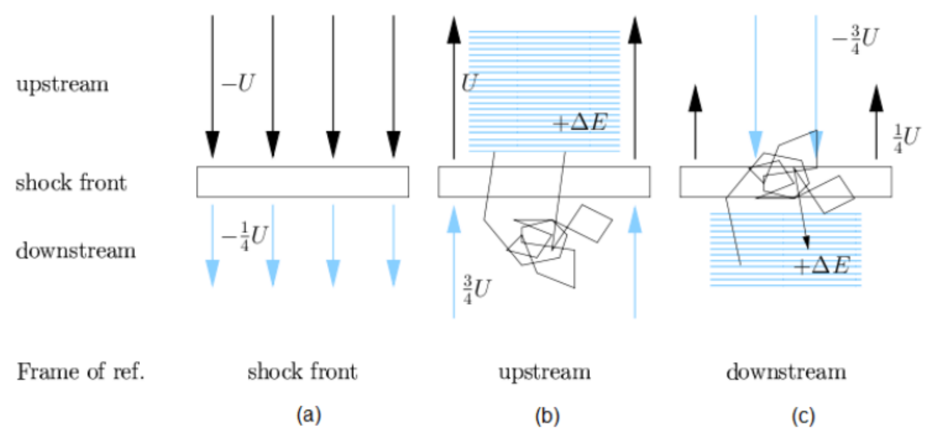
Second-order Fermi mechanism



$$\frac{\Delta E}{E} \propto \beta^2$$

Low energy gain requires acceleration times of ~10^9 years: INEFFICIENT!

First-order Fermi mechanism



$$\frac{\Delta E}{E} \propto \beta \qquad \frac{dN}{dE} \propto E^{-\gamma-1} \qquad \gamma = 1$$

Predicts a power-law spectrum with index **-2** with the only requirements:

- Supersonic shock wave
- Isotropic distribution of shocked particles

SUPERNOVAE are ideal candidates!

Interacting SNRs