Parametrized Model for Secondary Particle Spectra and Angular Distribution of Proton-ISM Interaction

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1. Description of Simulation and Parameterization Procedure
2. Parameterization of Inclusive Cross-sections for γ, $e^{+/-}$, and ν
3. Angular Distribution of γ-rays
4. Parameterization of γ-rays Angular Distribution
5. Future Plans

Introduction

Gamma rays

- **Need an accurate model to detect "anomalies" and to determine the contributions from the following 3 major mechanisms.**
  - π^0 decay
  - Inverse Compton
  - Bremsstrahlung
- **Focus on *pp* $\rightarrow \pi^0$**
  - Include diffraction process
  - Include scaling violation
  - Rising cross section

Other secondary particles

- **New experiments starting to detect high energy neutrinos and >100GeV electrons.**
  - Ice Cube
  - PAMELA (Electron up to 2TeV)

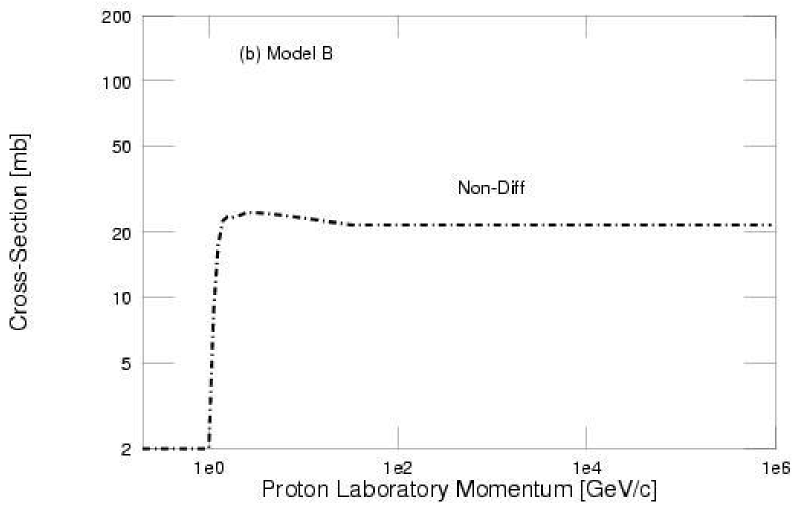
Simulating pp interactions

- **Break down the inelastic cross-section into two parts**
  - **Non-diffractive** inelastic
  - **Diffractive** inelastic
- **Simulate these independently**
  - **Non-diffractive**: Pythia and parameterization by Blattnig et al.
    - Pythia: 62.5 GeV $\leq T_p \leq$ 512 TeV
    - Blattnig et al.: 0.488 GeV $\leq T_p <$ 62.5 GeV
  - **Diffractive**: Kamae's MC (based on formulae by Goulianos)
    - 1.95 GeV $\leq T_p \leq$ 512 TeV
  - Force unstable particles to decay instantly
- **For neutrinos**, use (quasi) V-A matrix element implemented in Geant4

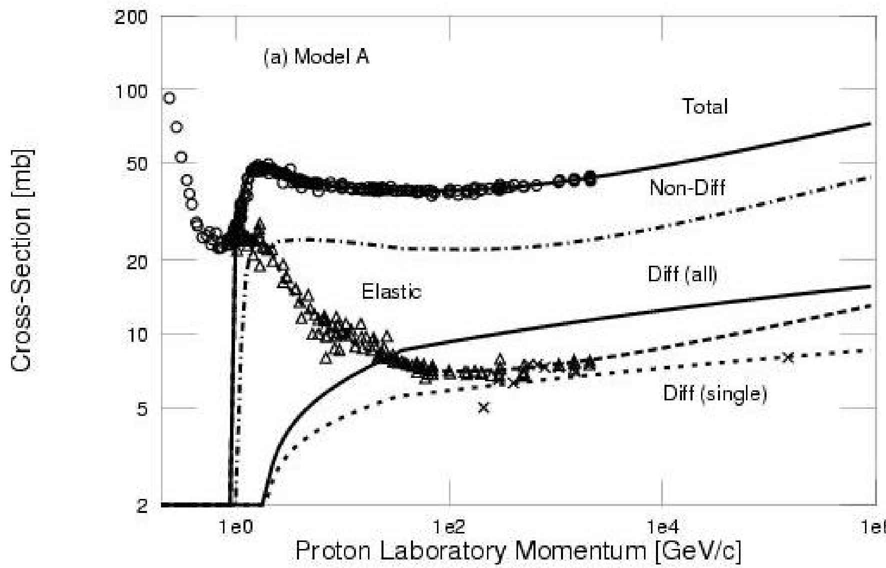
to decay charged pions for diffractive part and low energy part

PP Cross-section

Model B – no diffraction and non-rising cross section (used as reference only)



Model A – diffractive process, rising cross section and scaling violation



Blattnig et al.: Parameterization for $\pi^{+,0,-}$ for Proton Kinetic Energy < 50GeV

- **Parameterizations of pion spectral distributions and total cross sections as functions of T_p and T_π**
  - For charged and neutral pions
  - Parameter formulae of Stephen and Badhwar
  - **Fitted to experimental data available as of ~1995**
  - No theoretical model assumed other than the SB parameterization

Why yet another parameterization model?

- To cover wider energy range from 10MeV to 100TeV
- Include diffraction dissociation, scaling violation and the rising cross section at higher energies
- Robust formula that can be used in higher level simulators, such as GALPROP
- To model angular distribution
- To include other secondary particles: electrons, positrons, and neutrinos

Our parameterization model

1. **Simulate events for mono-energetic protons from 0.488GeV to 512TeV**
2. **Fit secondary particle spectra for mono-energetic protons**
   - **Non-diffractive**:

$$\left(\frac{d\sigma}{d\log E}\right)_{incl} = a_0 \exp\left(-a_1\left(x-a_3+a_2(x-a_3)^2\right)^2\right)+a_4 \exp\left(-a_5\left(x-a_8+a_6(x-a_8)^2+a_7(x-a_8)^3\right)^2\right)$$

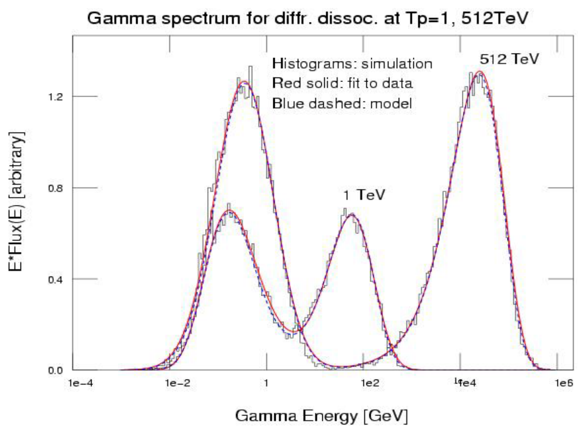
   - **Diffractive**:

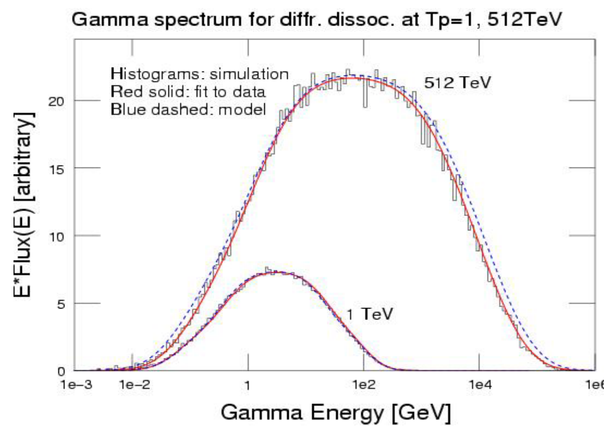
$$\left(\frac{d\sigma}{d\log E}\right)_{incl} = b_0 \exp\left(-b_1\left(\frac{x-b_2}{1+b_3(x-b_2)}\right)^2\right)+b_4 \exp\left(-b_5\left(\frac{x-b_6}{1+b_7(x-b_6)}\right)^2\right)$$

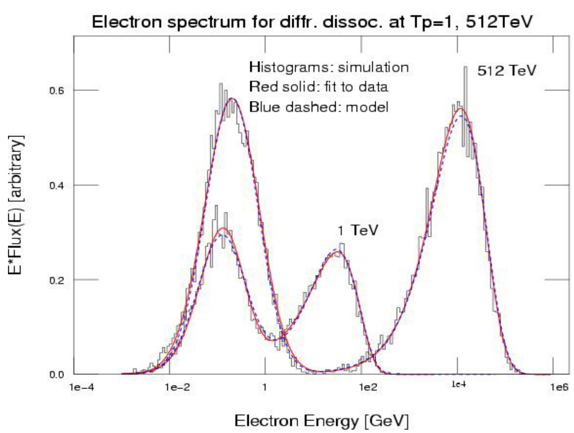
$$x=\log_{10}\left(T_p\right)$$

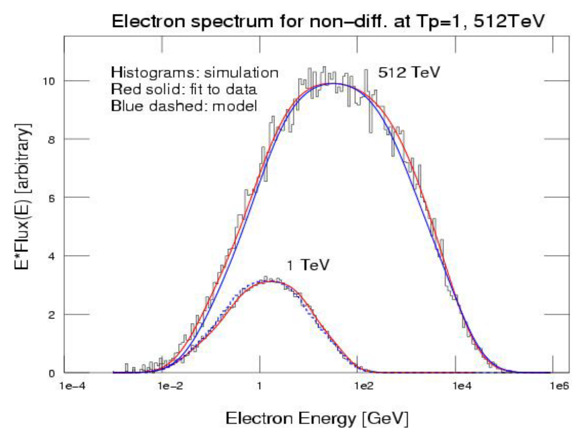
3. **Fit proton kinetic energy dependency of parameters a_0-a_8 and b_0-b_7**
4. **Force a simple energy-momentum conservation**
5. **Can calculate secondary spectra for any continuum proton spectra: power-law with breaks and cut-off**

Parameterized cross-section





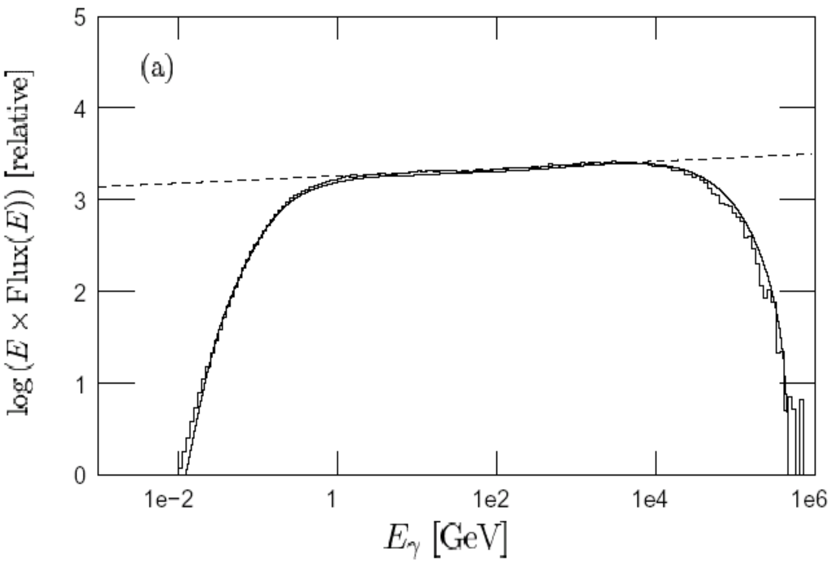




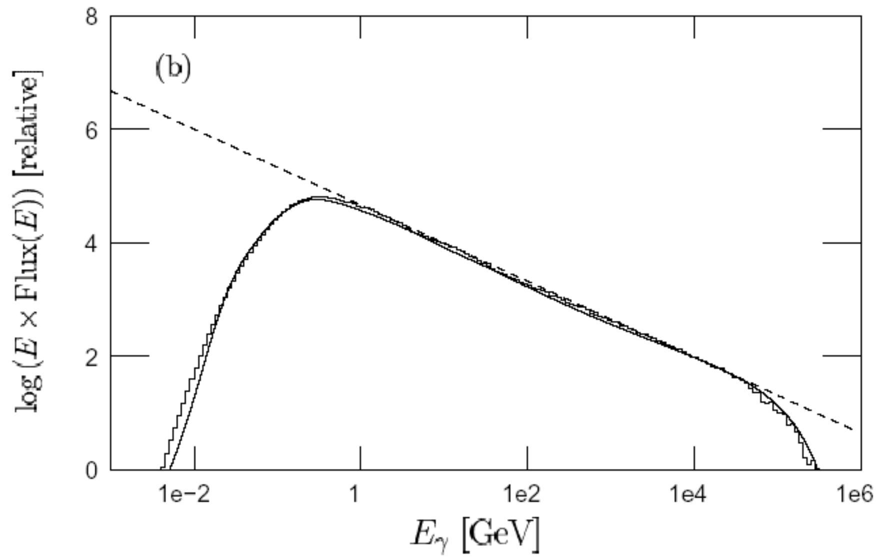
Gamma-ray Spectrum for Power-Law Protons

We calculated the gamma ray spectrum using our model for power law protons of index=2 (preliminary results)

Gamma: Index=2



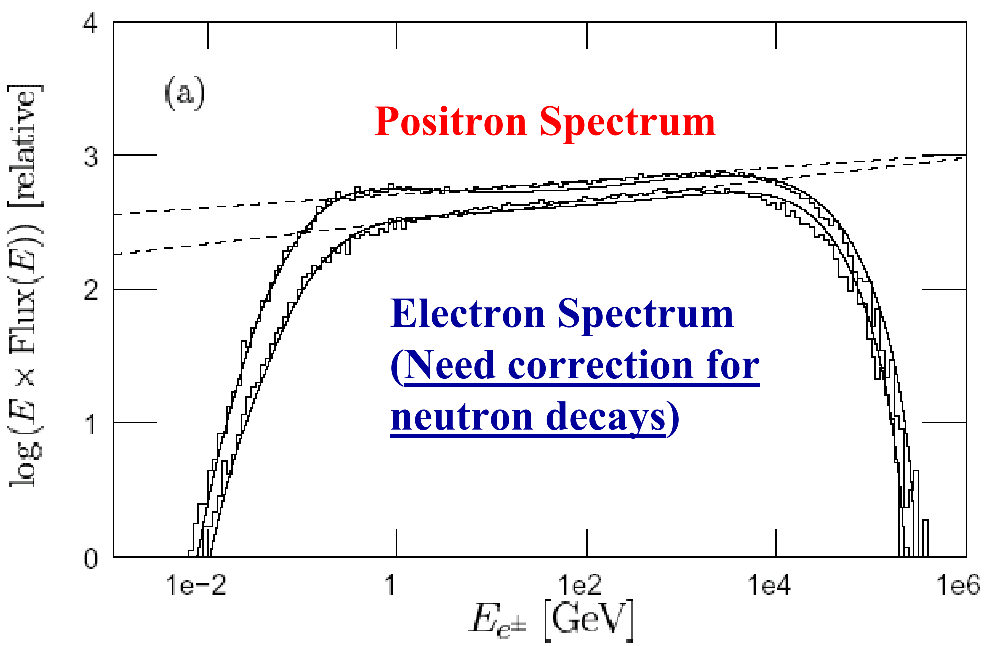
Gamma: Index=2.7



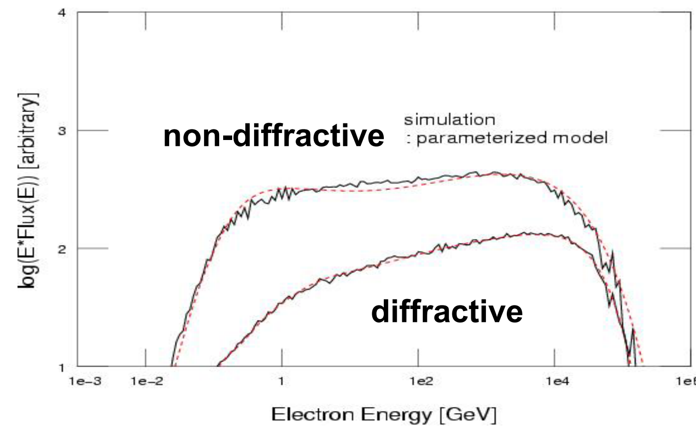
Secondary e^- and e^+ spectra

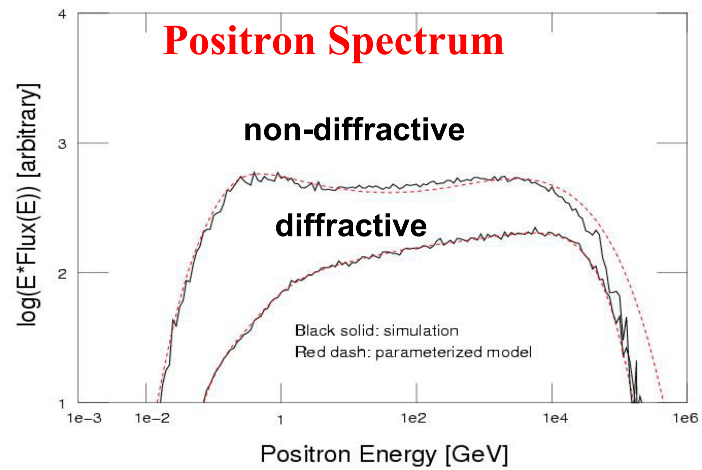
We also calculated the $e^{-/+}$ spectra using our model for power law protons of index=2

Note: more positrons than electrons due to charge conservations, more apparent at low energies

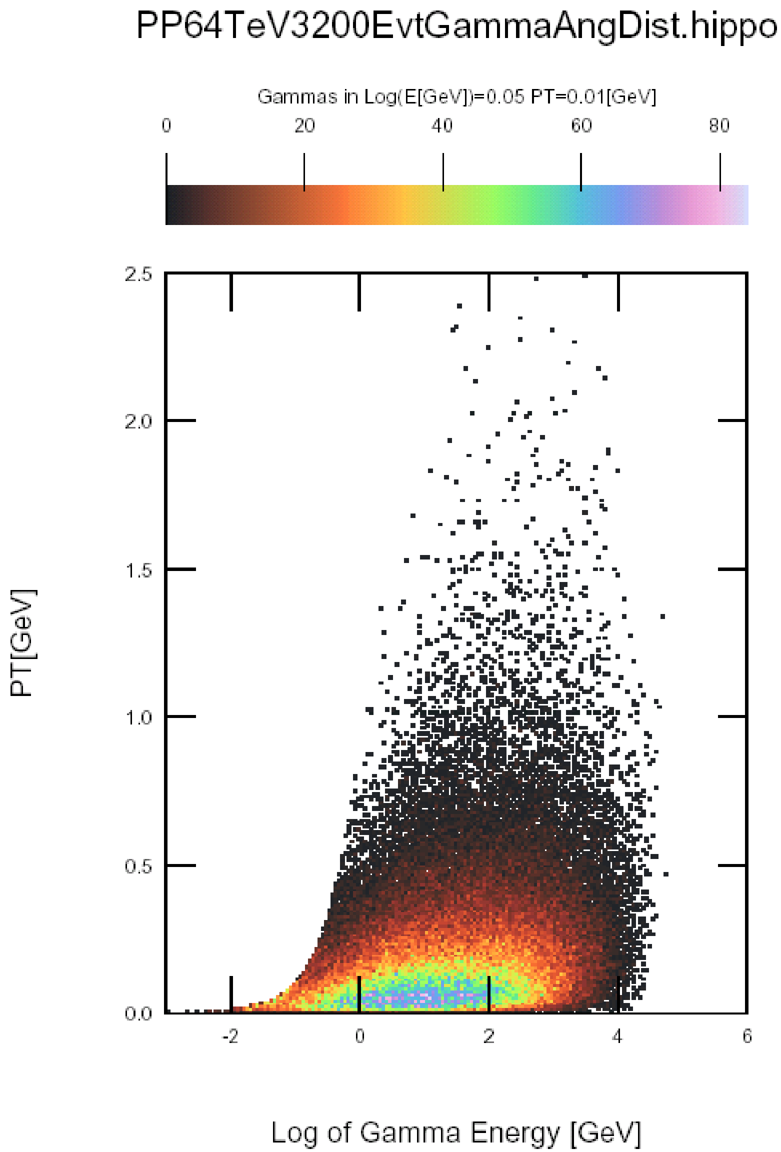


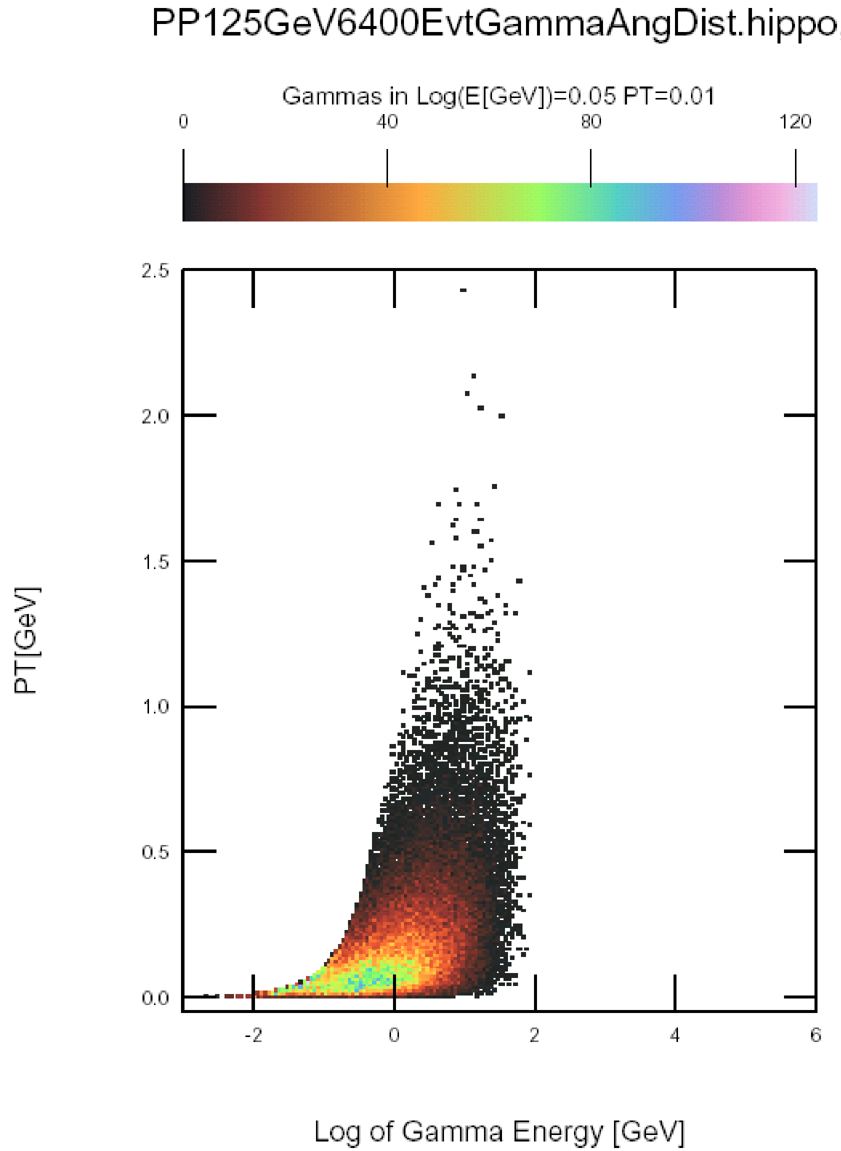
Electron Spectrum
(Need corr. for neutron decays)





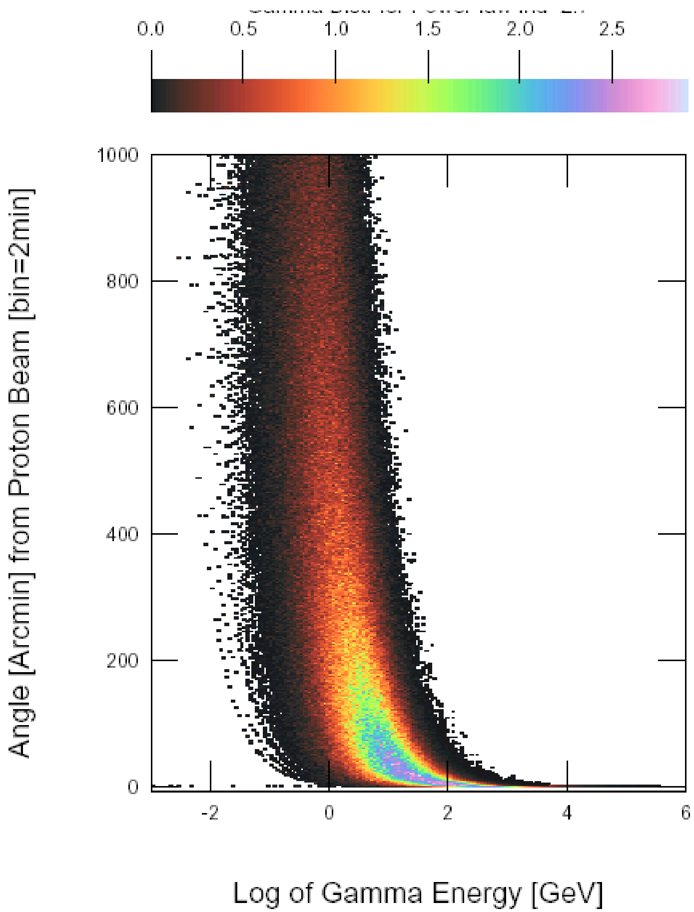
Angular Distr. of γ-ray: PT Distribution (1/2)



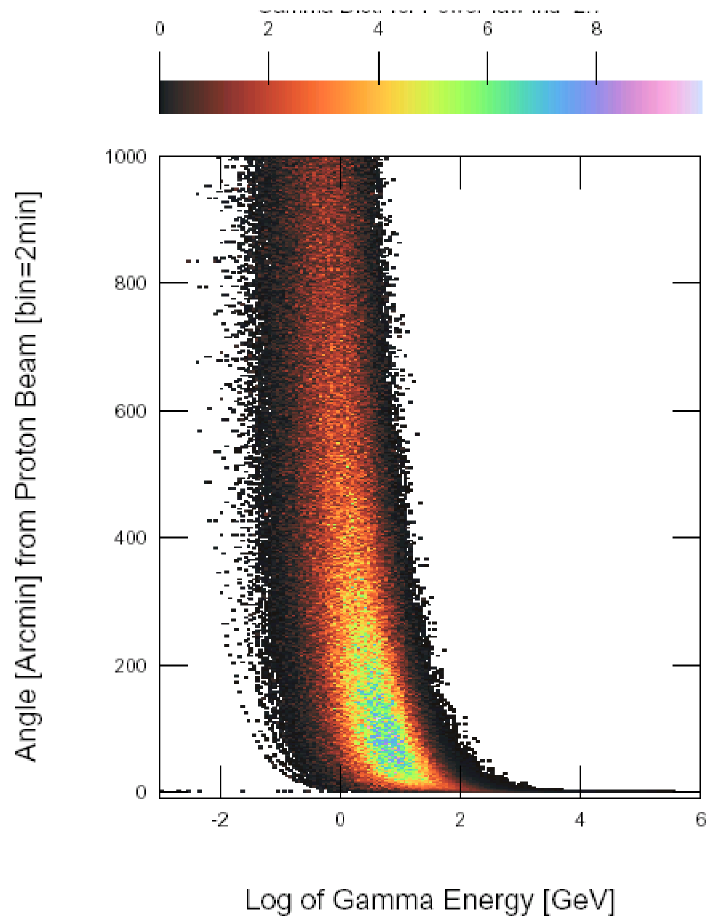


Angular Distr. of γ-ray: PT Distribution (2/2)

Power-law index 2.0 (Pythia)

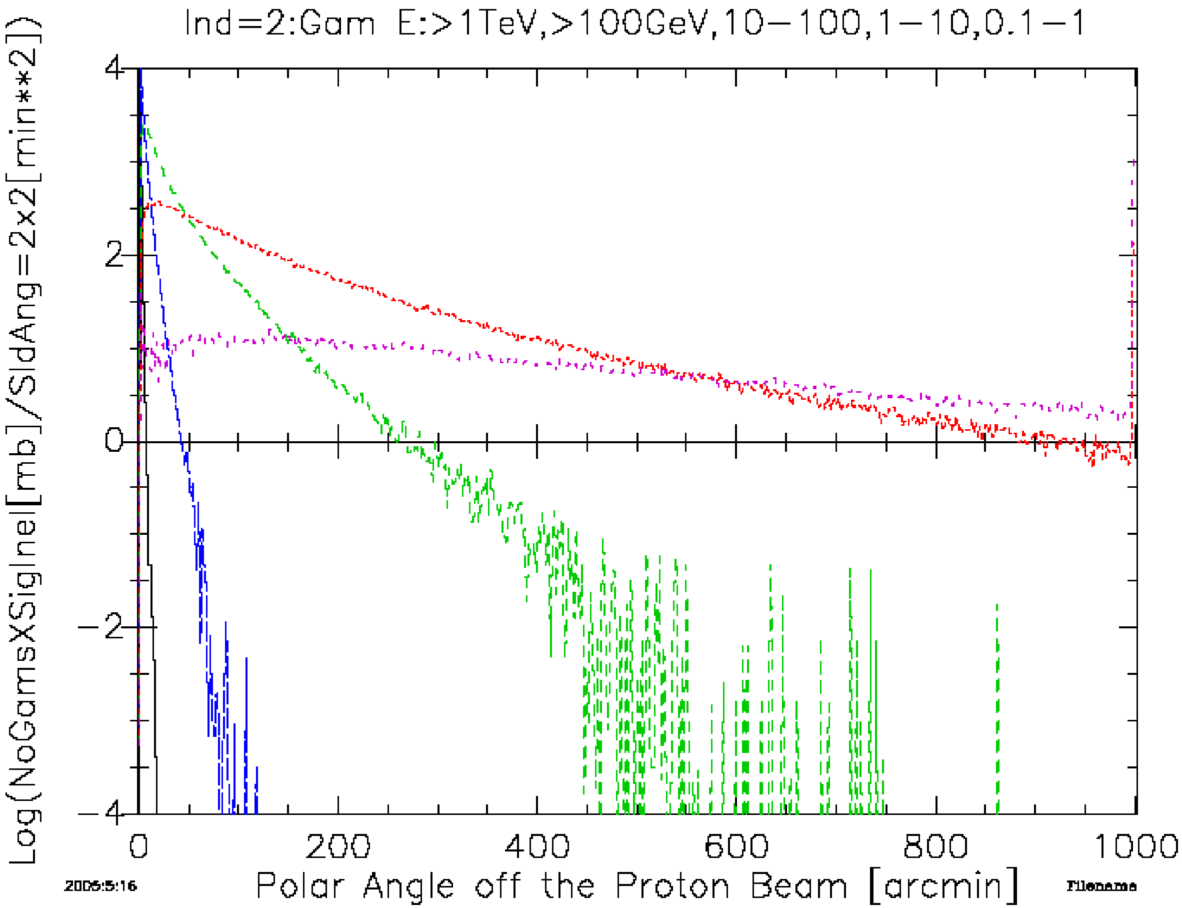


Power-law index 2.7 (Pythia)



Angular Distr. of γ-ray: Polar Angle (1/2)

Power-law with index=2.0: Tp>62.5GeV: Flux(θ)/2x2 min² for different E bands



Angular Distr. of γ-ray: Polar Angle (2/2)

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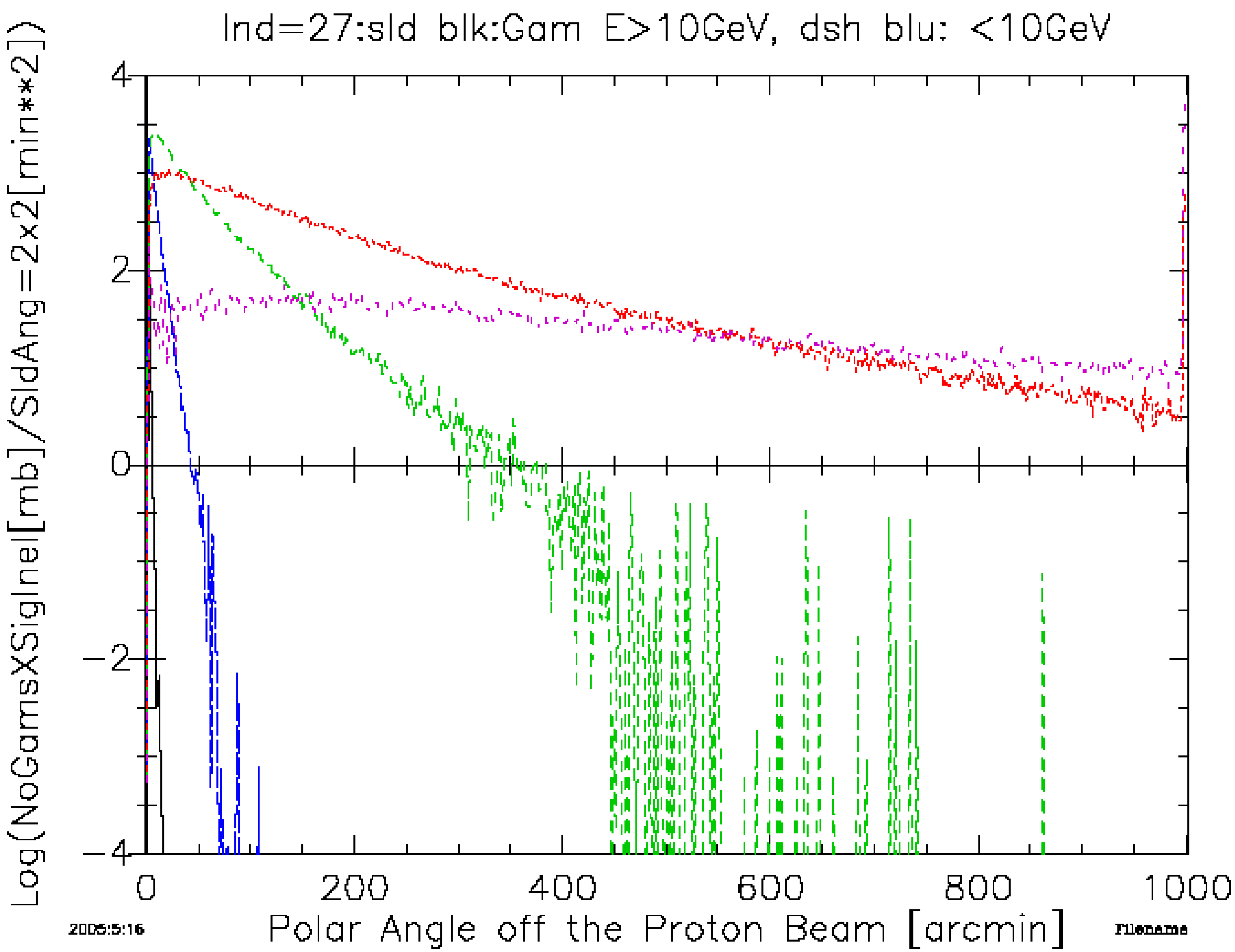
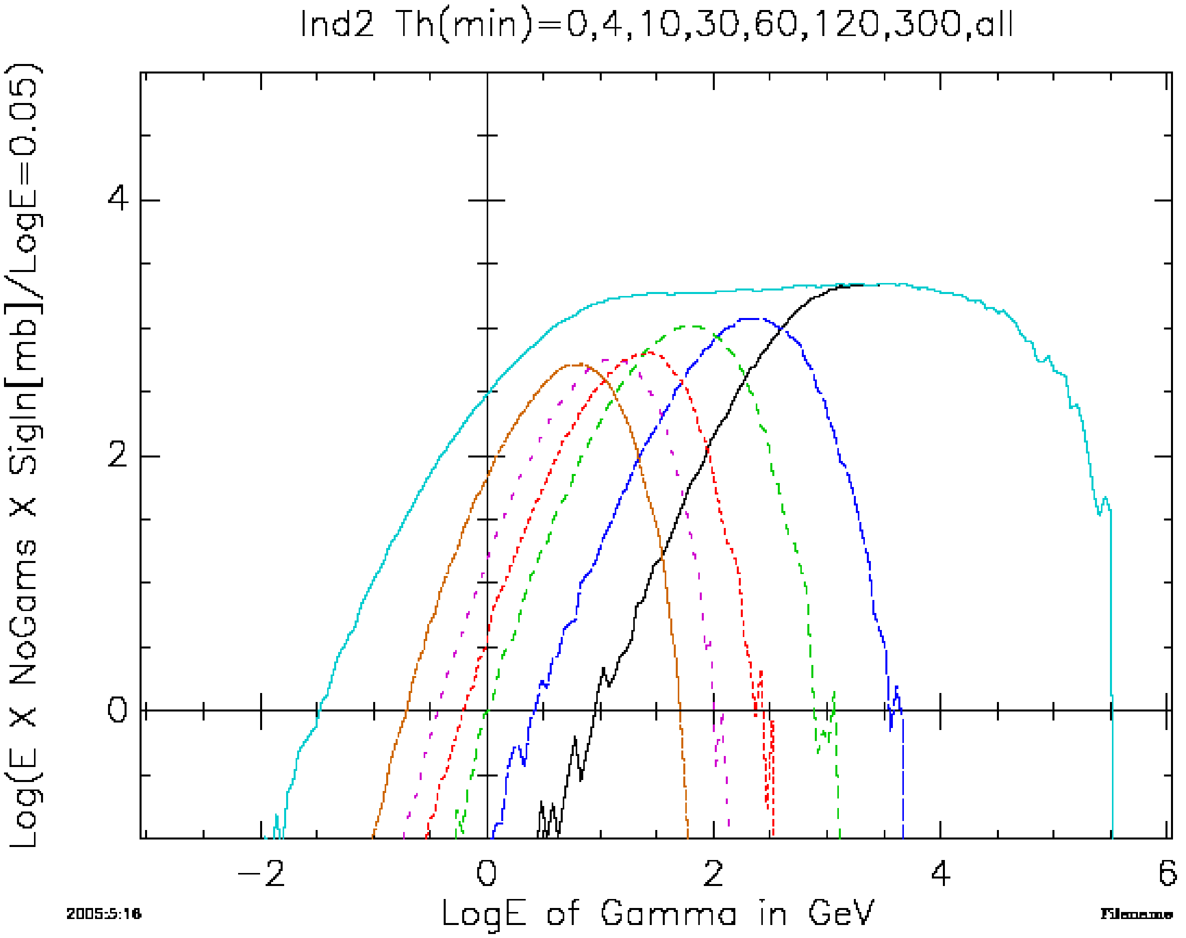


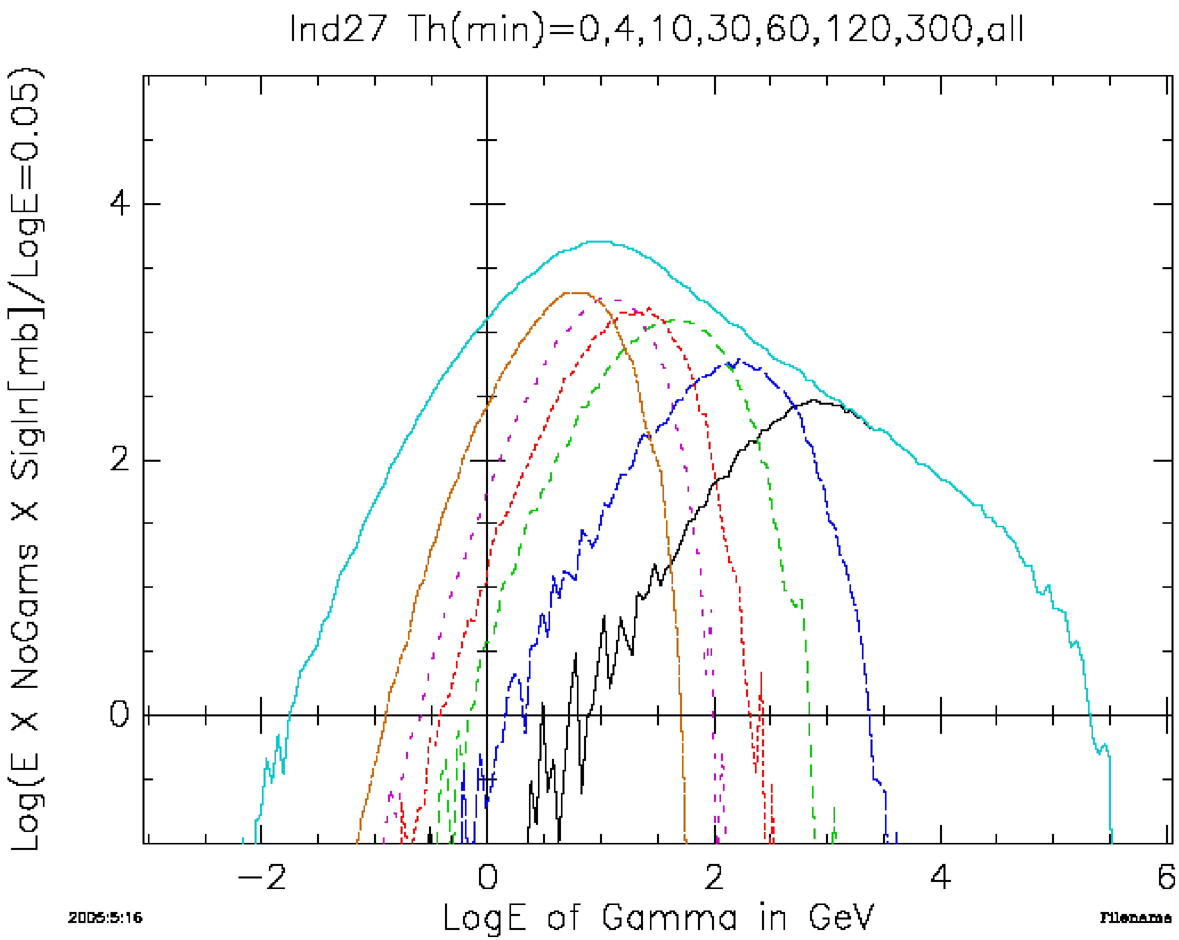
Spectrum of γ-ray: Viewing Angle (1/2)

Power-law with index=2.0: Tp>62.5GeV: $E^2F_\gamma(E)$ for different angular regions



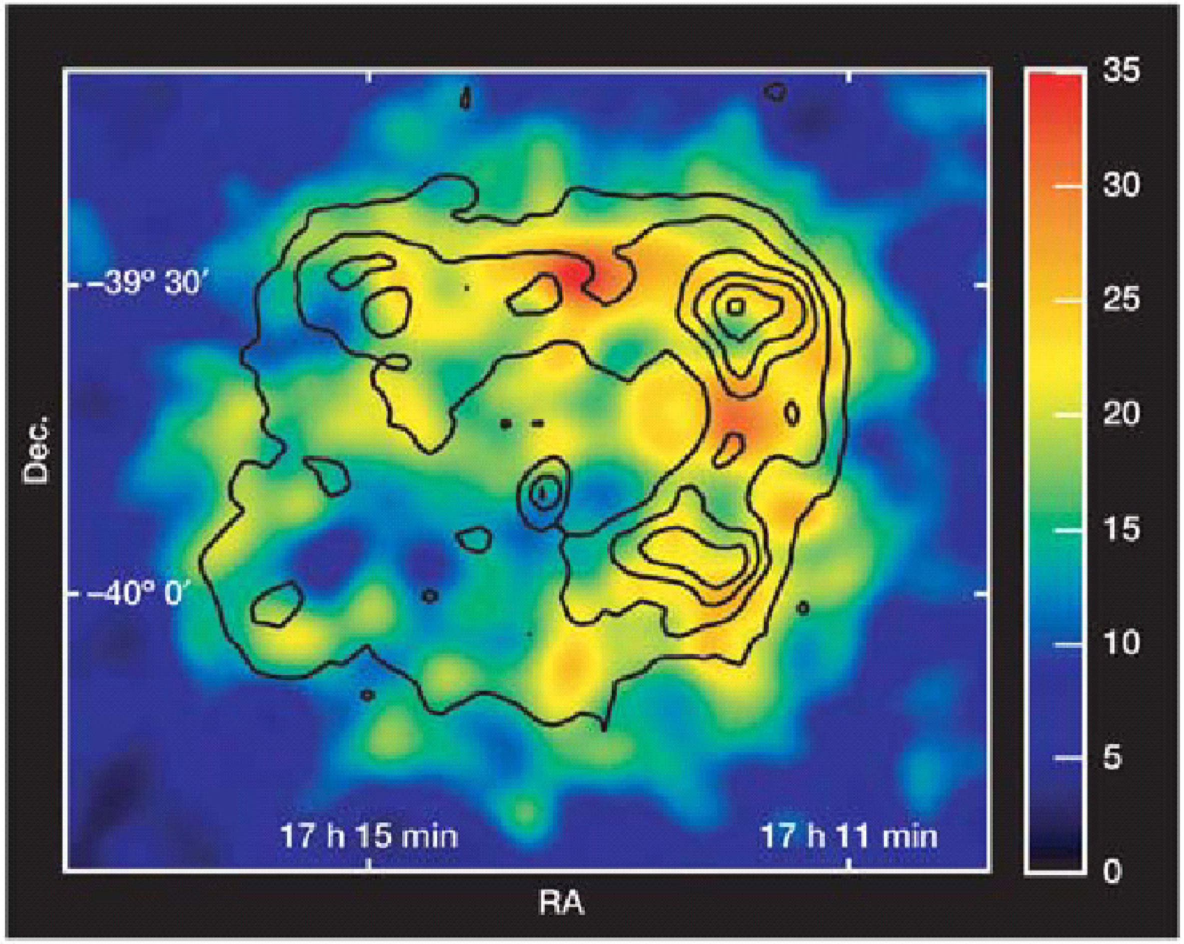
Spectrum of γ-ray: Viewing Angle (2/2)

Power-law with index=2.7: Tp>62.5GeV: $E^2F_\gamma(E)$ for different angular regions



RX J1713

High-energy particle acceleration in the shell of a supernova remnant
F. A. Aharonian, et al. (HESS)
Nature, Vol.432, p.75-77 (2004) 4 November



Future Plans

- **Gamma, $e^{-/+}$ and neutrino spectra param.: ApJ paper being drafted**
- **Angular distr. of gamma: Mono-energetic parameterization in progress**
- **Application to GALPROP: Waiting for the final parameterization**
- **Study of SNR images and spectra (X-ray to HESS): Just beginning**