Up-to-date pp-interaction model + galprop as a tool to study galactic diffuse gammas

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History of Changes:
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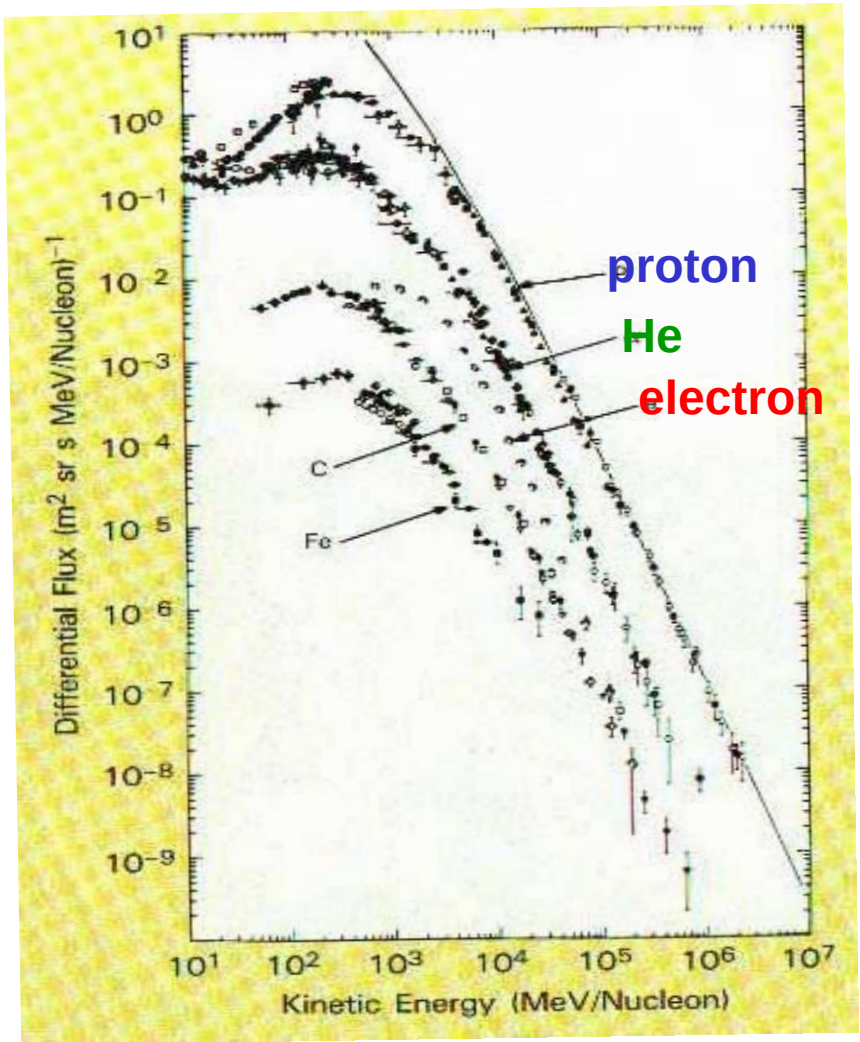
Introduction: Cosmic Rays



- Since the discovery by HESS in 1912, origin and nature of Cosmic Rays (CRs) are one of the biggest topics in astrophysics.
- Proton is the major component of CRs (~90%).
- Spectral break around 10^{15} eV ("knee")
  - E<Eknee: Galactic origin
  - E>Eknee: extragalactic

Question:

- Where were they accelerated to such a high energy?
- How do they distribute in our Galaxy?

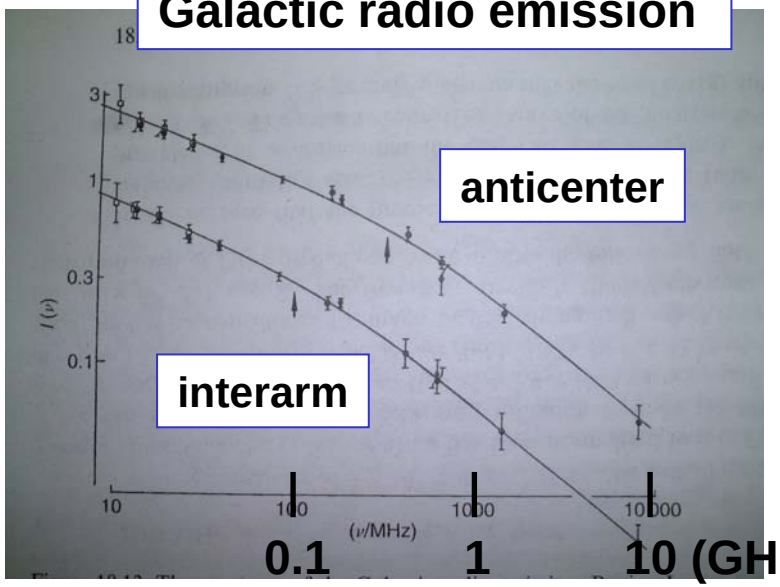
- X-ray/Gamma-ray observation can tell!

CR Electrons

CR electrons emit photons via synchrotron radiation:

$$\nu \approx 28\,\gamma^2 \left(\frac{B}{1\mathrm{T}}\right)\mathrm{GHz}$$ **(High Energy Astrophysics, Longair 1992)**

The spectrum of the Galactic radio emission

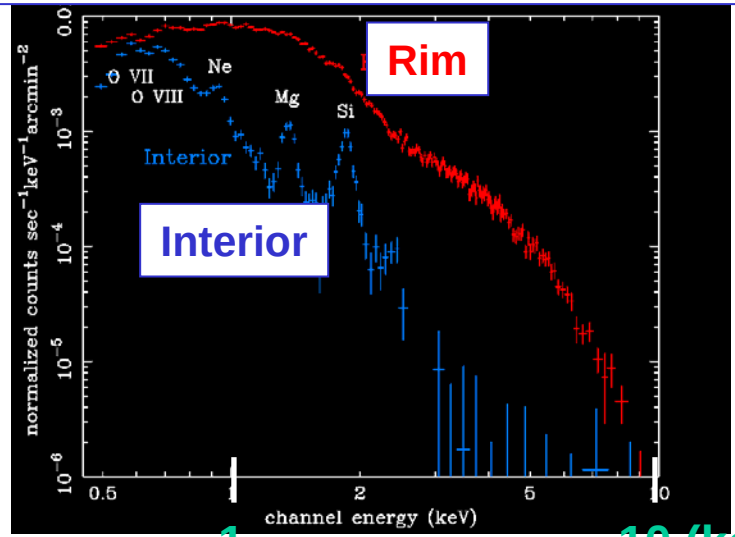


0.1 1 10 (GHz)

$$\nu \approx 1.07 \times \left(\frac{E_{electron}}{10\mathrm{GeV}}\right)^2 \times \left(\frac{B}{1\mathrm{uG}}\right)\mathrm{GHz}$$

electrons of 10-100GeV

X-ray spectrum of a SNR, SN1006 (Koyama et al. 1995, Nature)



1 10 (keV)

$$E \approx 0.44 \times \left(\frac{E_{electron}}{100\mathrm{TeV}}\right)^2 \times \left(\frac{B}{1\mathrm{uG}}\right)\mathrm{keV}$$

electrons of >=100TeV (“knee”)

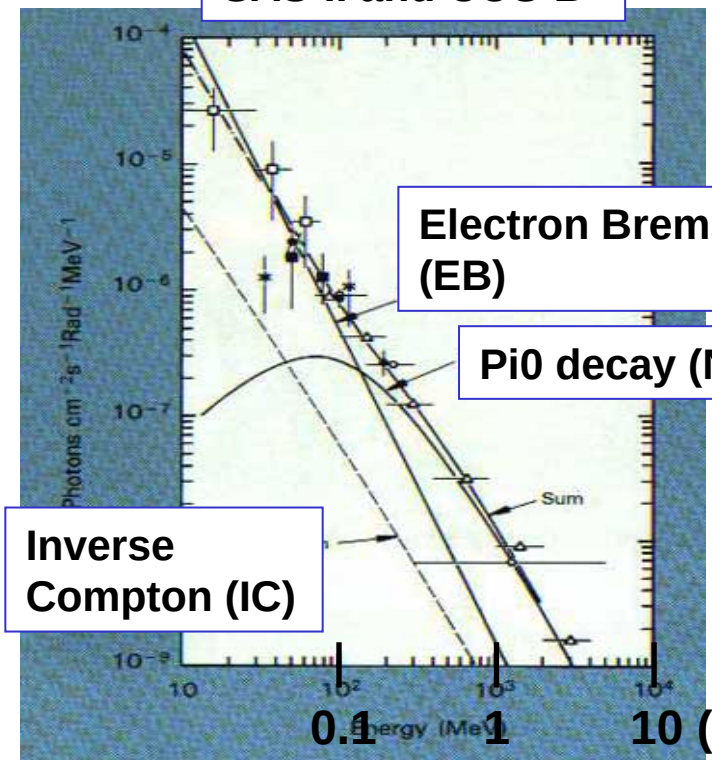
➡ **What about protons?**

CR Protons

CR protons emit photons via pi0 production: $pp \rightarrow \pi^0 + X$

Gamma-ray spectrum from the Galactic Center

SAS-II and COS-B



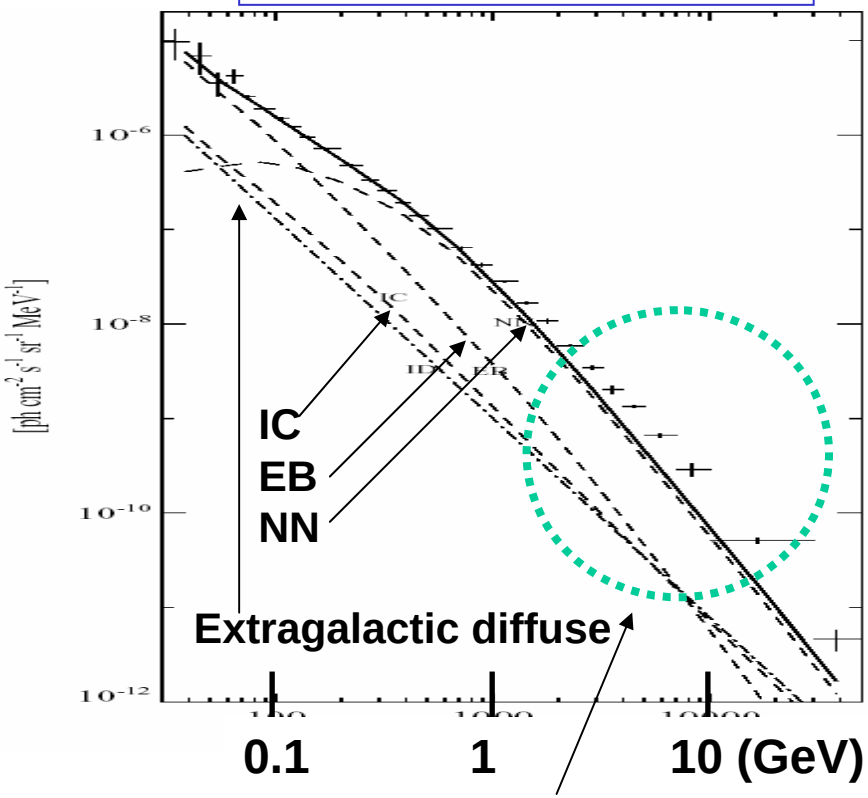
Electron Bremss. (EB)

Pi0 decay (NN)

Inverse Compton (IC)

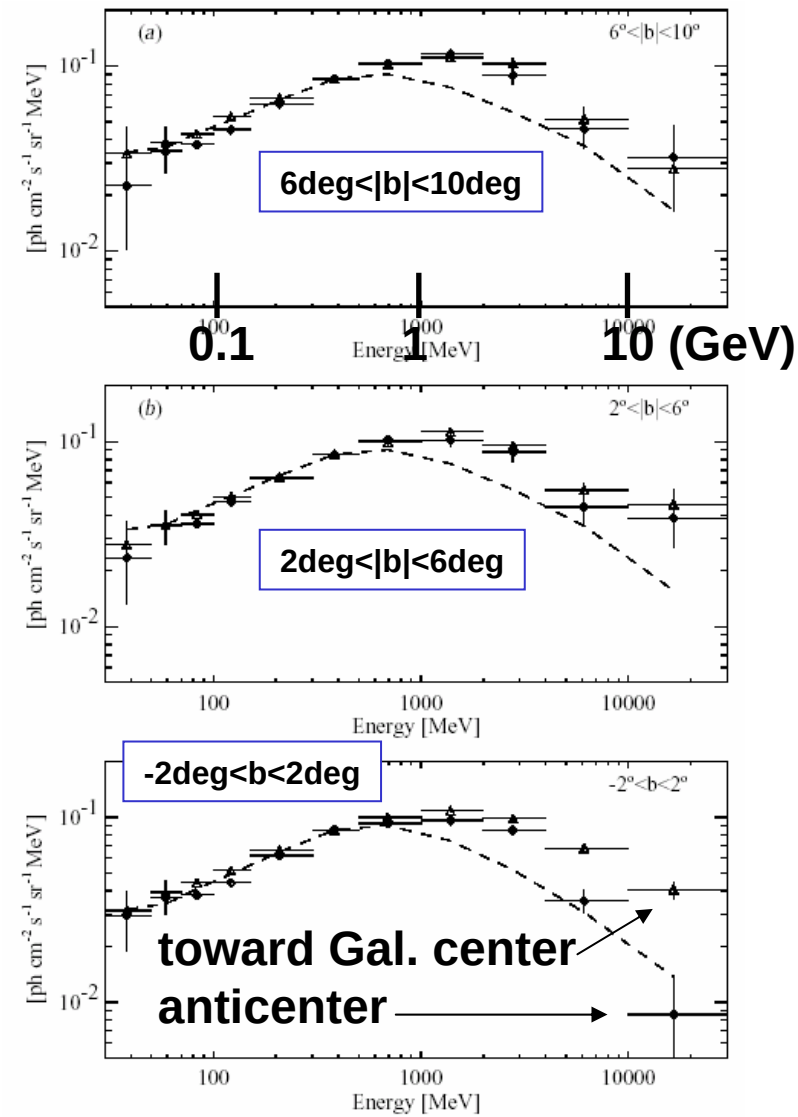
0.1 1 10 (GeV)

EGRET(Hunter et al. 1997)



So called "GeV excess" was found by EGRET (Hunter et al. 1997, ApJ)

More about GeV excess



- GeV excess is observed from the outer Galaxy as well as the inner Galaxy regardless of galactic latitude.

Possible Solutions:

- harder proton spectrum
- pp-interaction model
- contribution of electron radiation
- etc.

- We need tools to study GeV excess/diffuse emission

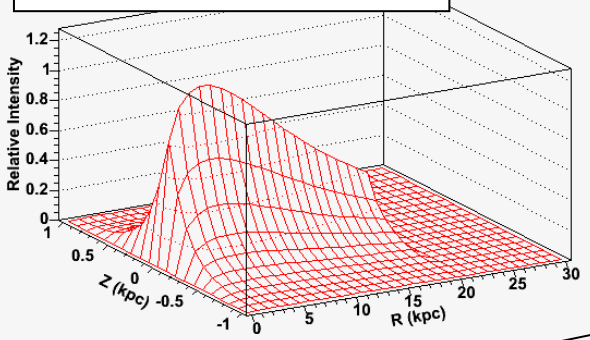
- galprop + up-to-date pp-interaction model

galprop

•galprop is a framework to predict CR propagation and gamma-ray emission in Galaxy, developed by I. Moskalenko and A. Strong (see Igor's talks)

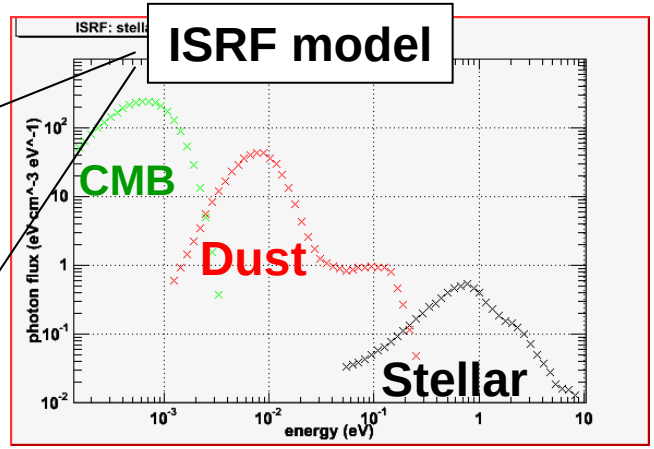
source of CRs

CR source model



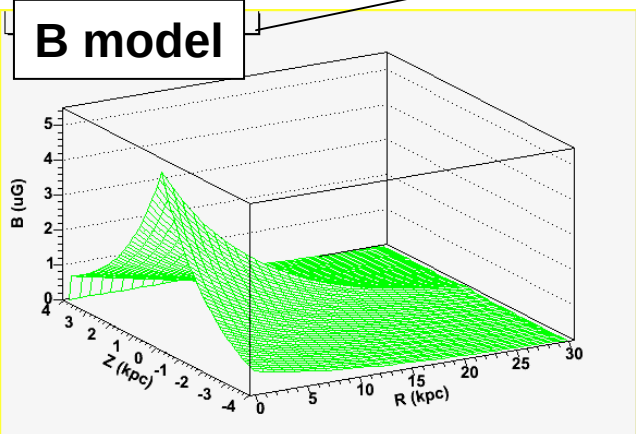
Propagation of CRs
- Diffusion
- Diffusive reacceleration
- Energy loss
- Fragmentation

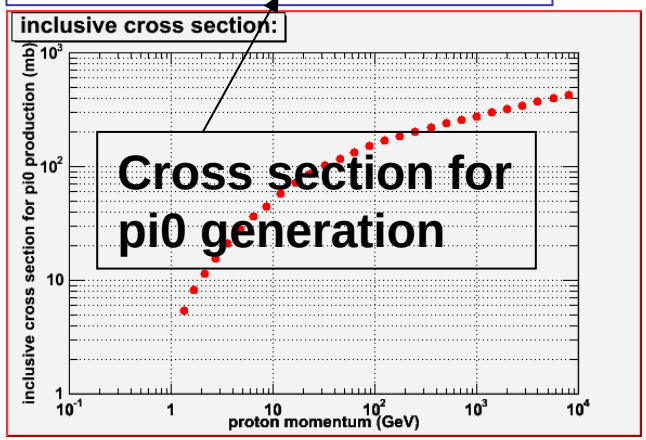
ISRF model



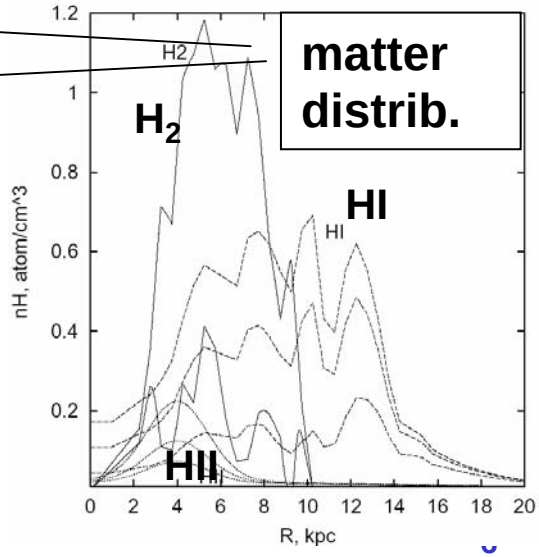
Emission of gamma-rays
- Synchrotron radiation (e-)
- Bremsstrahlung (e-)
- Inverse Compton (e-)
- Pi0 production (p)

B model





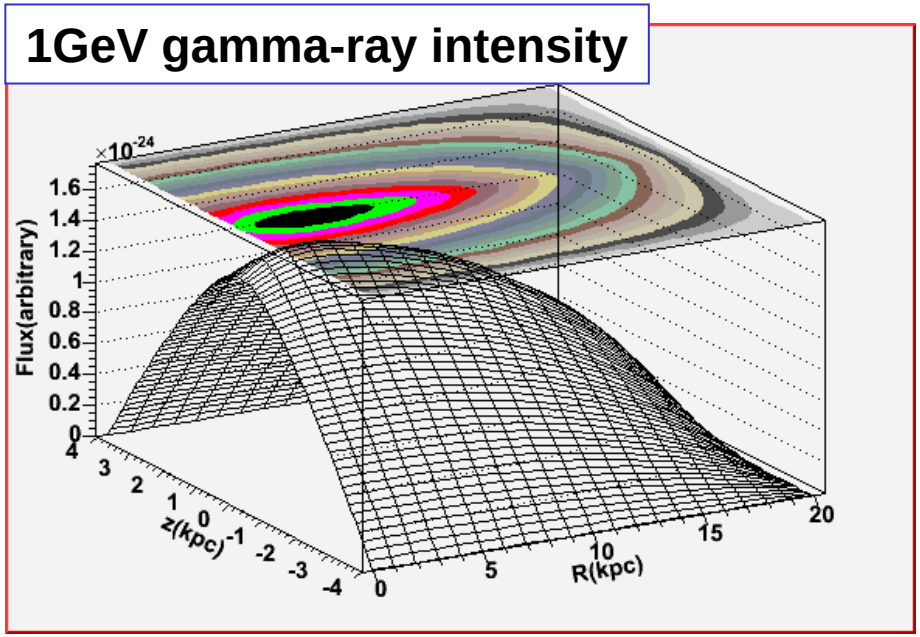
matter distrib.



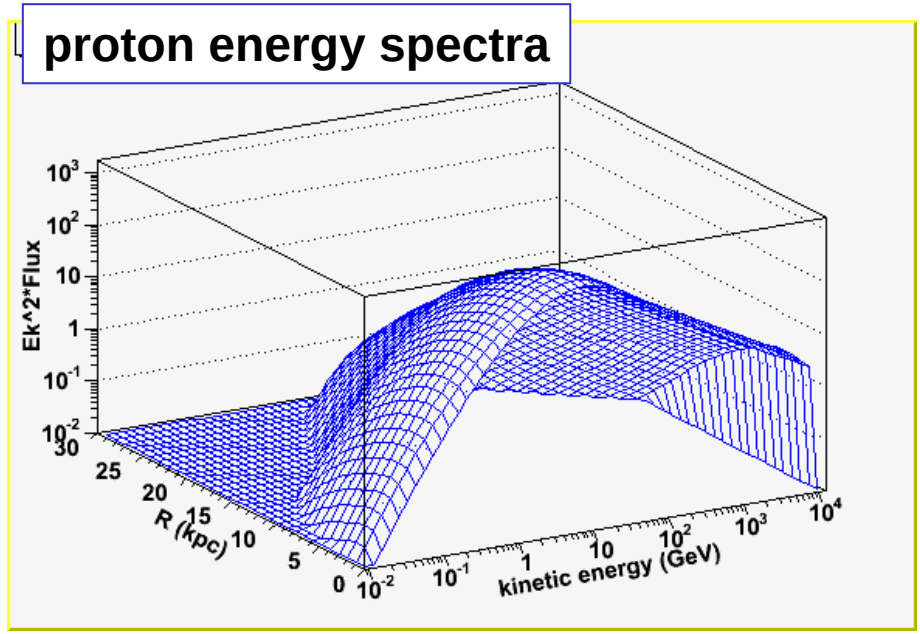
galprop (Contd.)

- Most of parameters (e.g., CR source model, inject spectrum, diffusion coefficient) can be specified by galdef file.
  - ⇒ user can play with them
- Not all, but most of the codes are written in C++.
  - ⇒ user can replace (upgrade) galprop
- Output in FITS format.
  - ⇒ standard in astrophysics. Lots of tools to read/plot

1GeV gamma-ray intensity



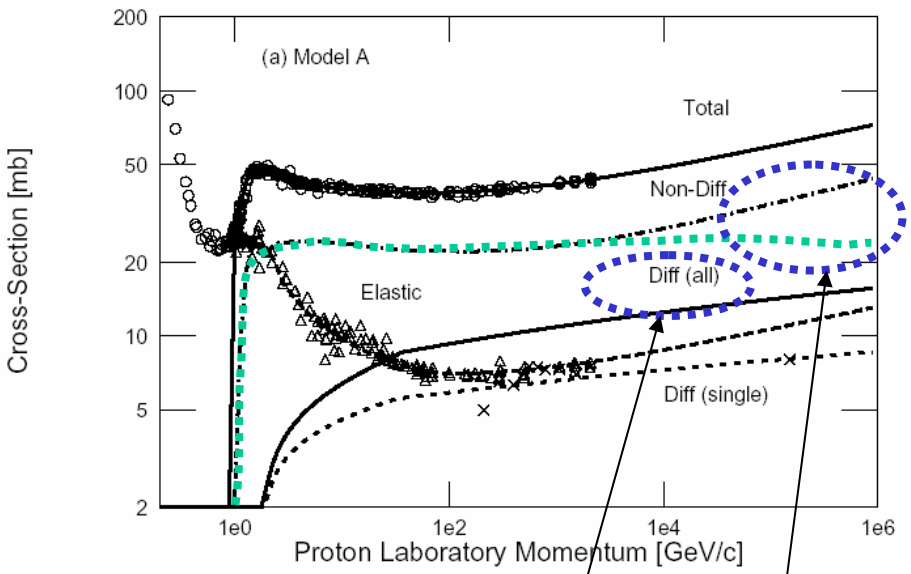
proton energy spectra



PP-interaction model

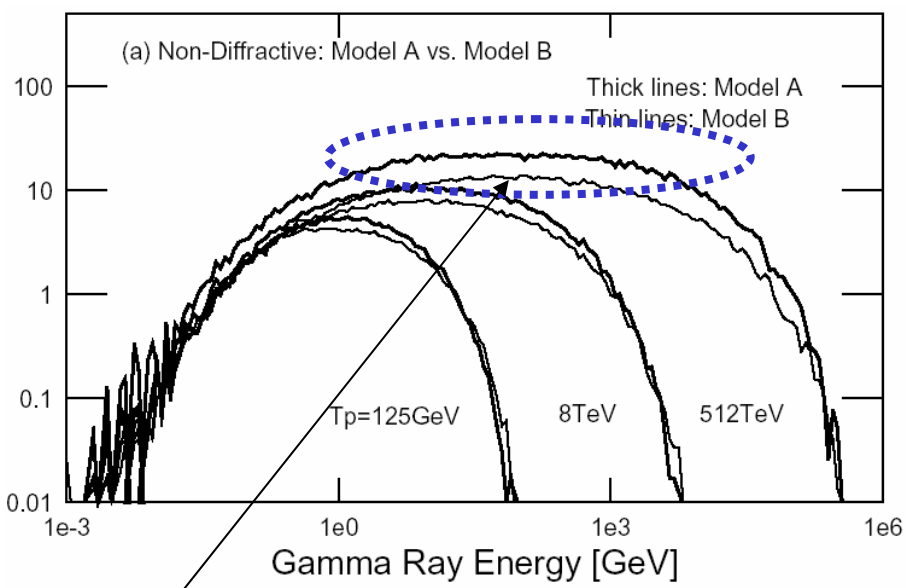
- Based on up-to-date knowledge, pp-interaction model update was proposed by Kamae et al. (2005 ApJ). This model was intended to be used to calculate gamma-ray emission (galactic diffuse, AGN, SNR, GRB, etc.) without uncertainty. Hereafter we call this "TK model"
- Thee features; rising cross section, diffractive dissociation and scaling violation

pp-interaction cross section



- Rising cross section in high energy
- Add diffractive dissociation process

Spectrum of generated gamma-rays

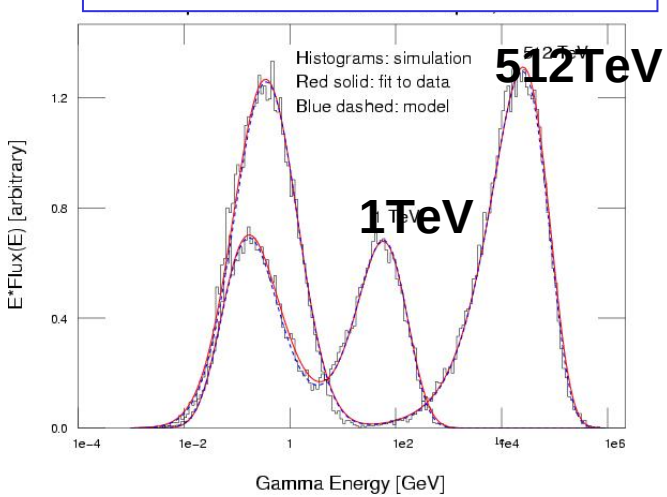


- Scaling violation

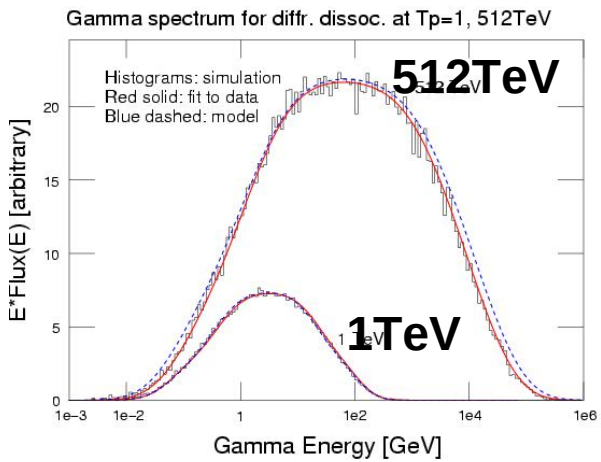
Parameterization of pp-interaction

- Under development by N. Kerlsson and T. Kamae (see Niklas's lunch talk) to replace time-consuming Monte Carlo simulations.
- One update; add the Delta resonance (1232) and the other resonance (1600) to reproduce pp-interaction cross section and inclusive pi0 cross section in lower energies.
- Immediate application: incorporate into galprop!

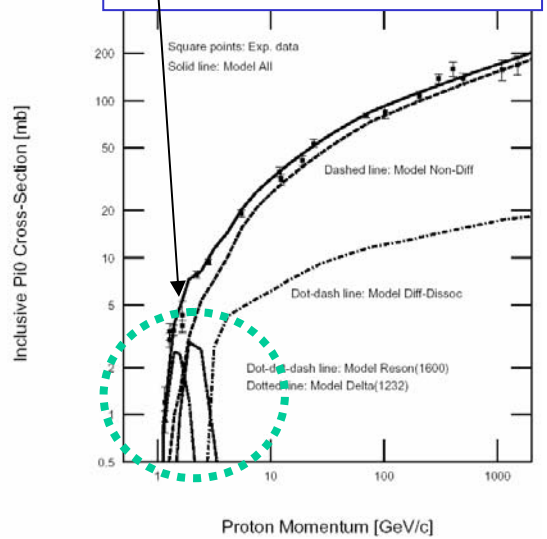
Gamma Spectrum for diffractive dissociation



Gamma Spectrum for non-diffractive dissoc.

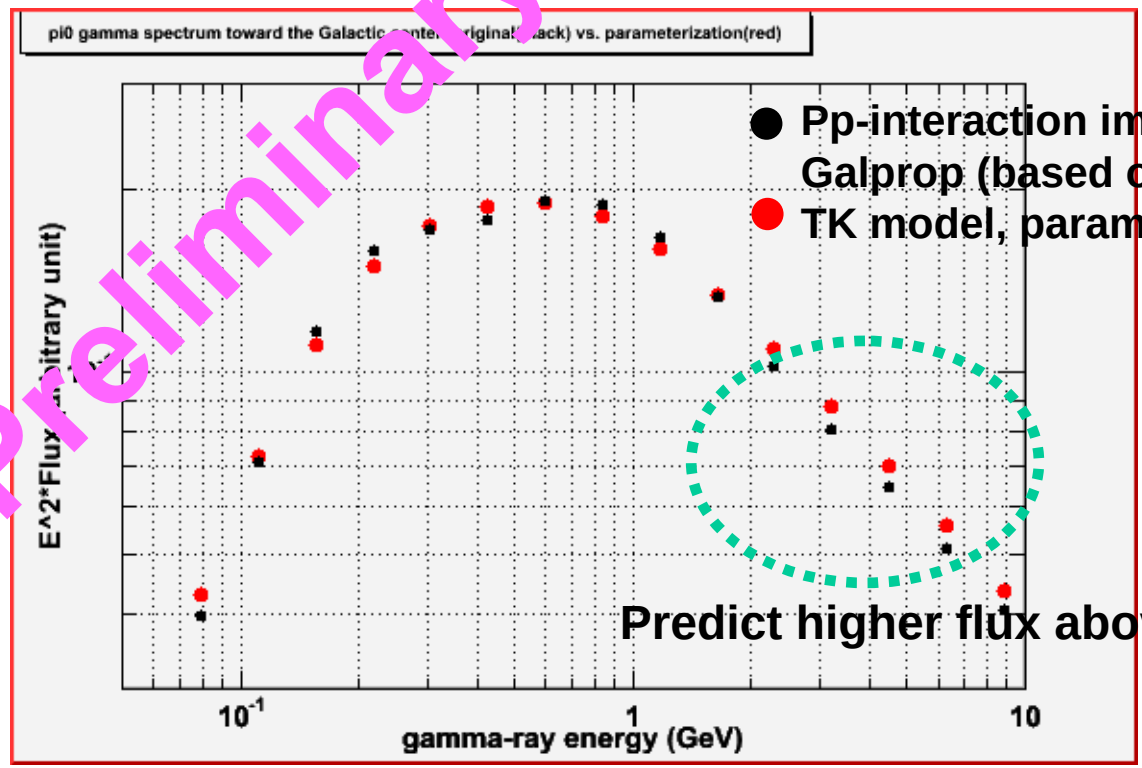


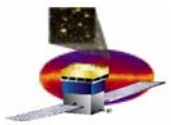
Inclusive Pi0 cross section



Prediction of gammas by galprop with updated pp-interaction model

- Comparison of gamma spectra toward galactic center, predicted by conventional interaction model and updated one (TK model; parameterized)
- Work in progress; parameterization is yet to be tuned to reproduce the MC.





Summary and Future plan

Summary

•Galactic diffuse gammas are strong tool to study CRs.
•Galprop is a flexible framework to study CR propagation and gamma-ray emission.
•Up-to-date of pp-interaction model leaves less (or no) uncertainty in pi0 production calculation and can be used for variety of data (e.g., GLAST, EGRET, HESS and Suzaku).
•We incorporated a (preliminary) parameterization of up-to-date pp-interaction model in galprop.

Future Plan

•Complete the parameterization
•Comparison with EGRET data; energy and spatial distribution of diffuse gammas
•Prepare for GLAST; develop 3D-model calculation (need 3D model of matter distribution)
•Apply pp-interaction model to SNR/AGN/GRB/etc.