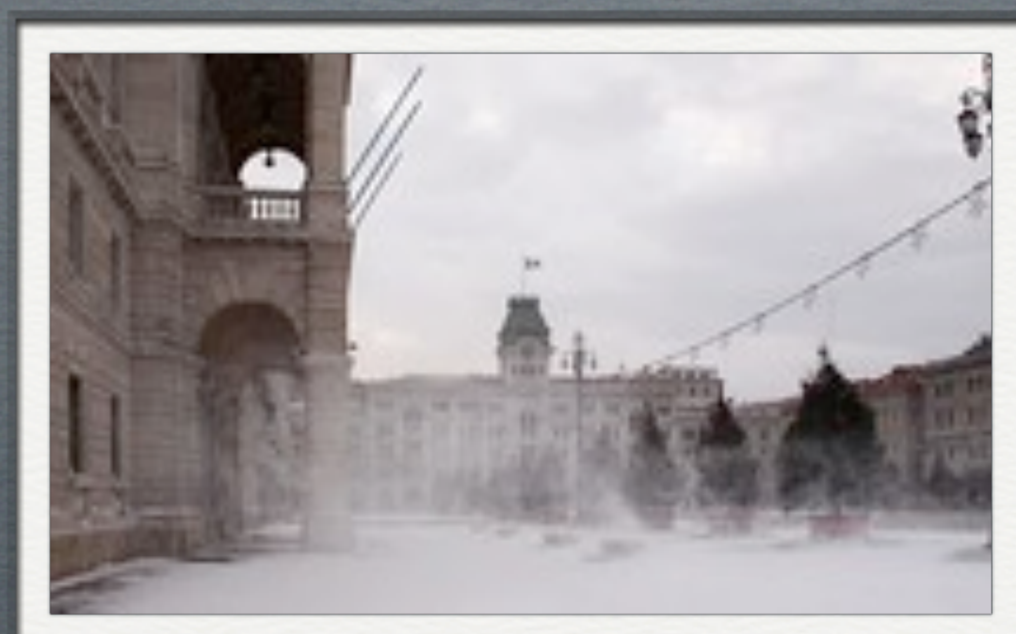
UNDERSTANDING CR PROPAGATION

Scineghe,
Trieste, 9th of September



Carmelo Evoli (SISSA, Trieste)

In collaboration with...

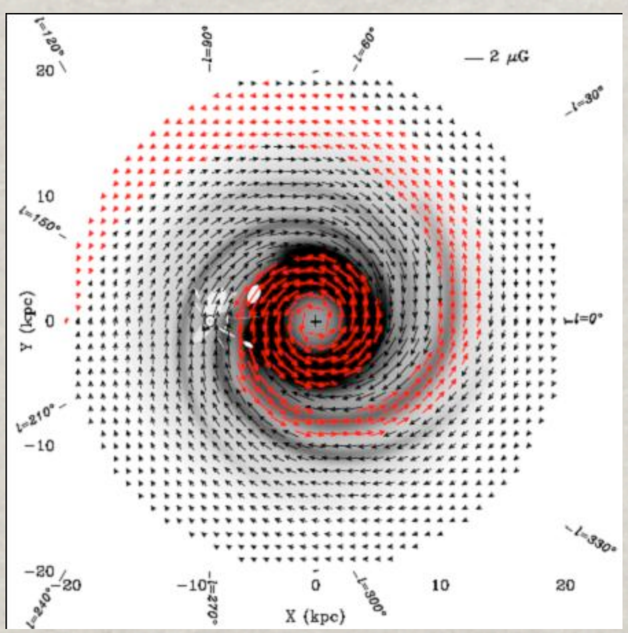
- *The **DRAGON** **(CR propagation code)** Team:*
  Luca Maccione (DESY, Hamburg)
  Dario Grasso (INFN, Pisa)
  Daniele Gaggero (INFN, Pisa)
  Giuseppe Di Bernardo (University of Pisa)

- *Other collaborators:*
  Riccardo Catena (MPI, Heidelberg)
  Maryam Tavakoli (SISSA, Trieste)
  Piero Ullio (SISSA, Trieste)

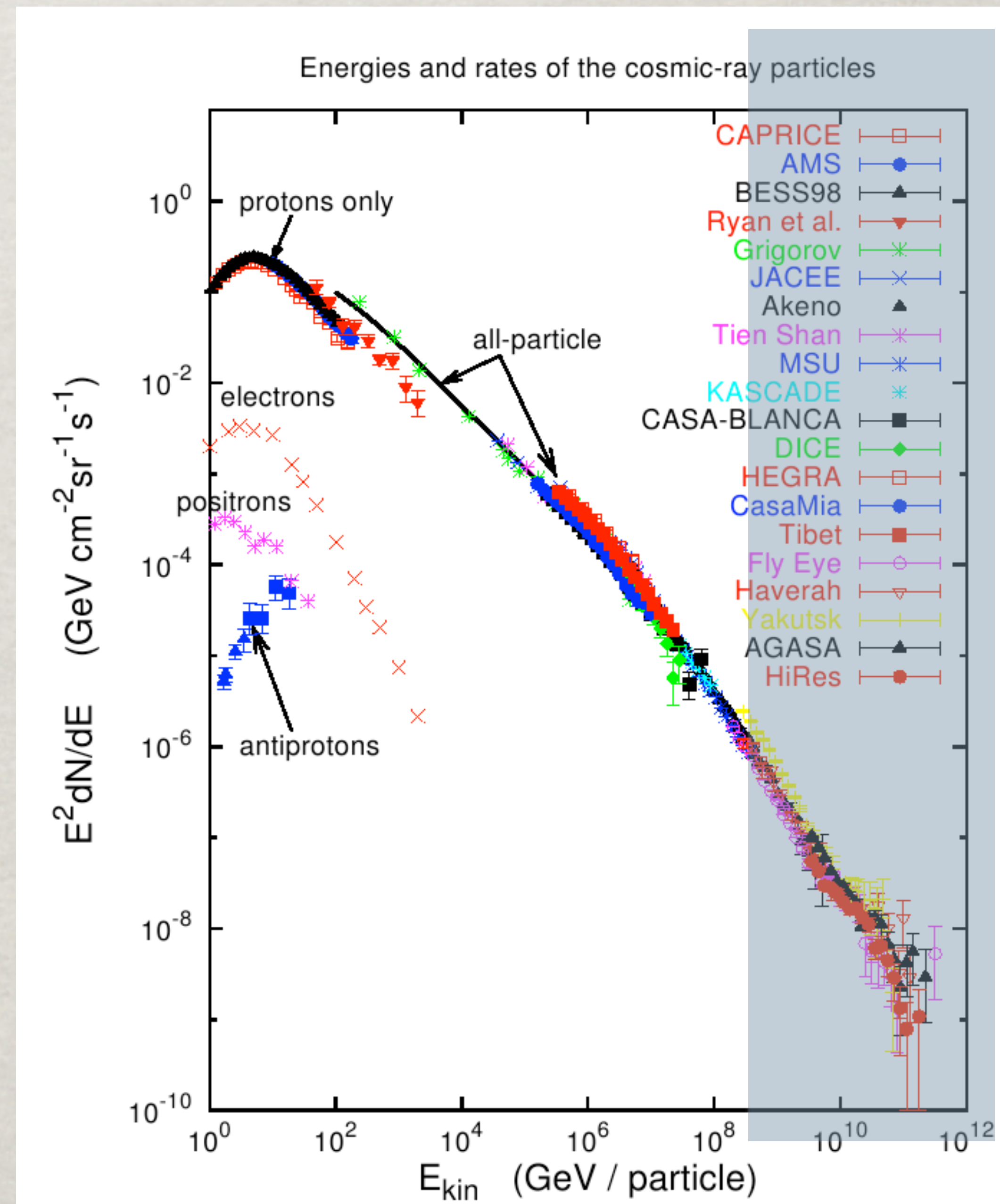
CR Diffusion in the MW

See the first slide of the previous talk!

Galactic SNR as sources...



... and Galactic MF



(Hillas 2006, arXiv:astro-ph/0607109)

CR Diffusion in the MW

CRs obey essentially a diffusion equation:
(Ginzburg & Syrovatsky, 1964)

Diffusion tensor
$D(E) = D_0\,(\rho/\rho_0)^\delta$
$\rho = \text{rigidity} \sim p/Z$

Convection term

Energy loss

Reacceleration
$D_{pp} \propto \frac{p^2 v_A^2}{D}$

$$\frac{\partial N^i}{\partial t} - \nabla\cdot(D\,\nabla - v_c)N^i + \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla\cdot v_c\right)N^i - \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{N^i}{p^2} =$$
$$= Q^i(p,r,z) + \sum_{j>i} c\beta n_{\rm gas}(r,z)\sigma_{ji}N^j - c\beta n_{\rm gas}\sigma_{\rm in}(E_k)N^i$$

SN source term.
We assume everywhere
a power law energy spectrum

Spallation cross section. Appearance of nucleus i due to spallation of nucleus j

Total inelastic cross section.
Disappearance of nucleus i

$$D = D_0 E^{\delta} \exp(z/z_t)$$

SOLVING THE DIFFUSION EQUATION

- **leaky-box models**

  Back of the envelope approach with many useful predictions.

- **semi-analytic models**

  Assume simplified distributions for sources and gas, and try to solve the diffusion equation analytically

  (see Maurin, Salati, Donato et al.)

- **numerical models (GALPROP)**

  use more realistic distribution

  (see Igor Moskalenko's talk)

- a new numerical model: **DRAGON** (Diffusion of cosmic RAys in the Galaxy modelizatiON). See Evoli et al. 2008.

UNDERSTANDING CR PROPAGATION

- Understanding **propagation** it is extremely important to infer the properties of the galactic environment...

- ...and to determine/constrain the properties of any other **extra** component.

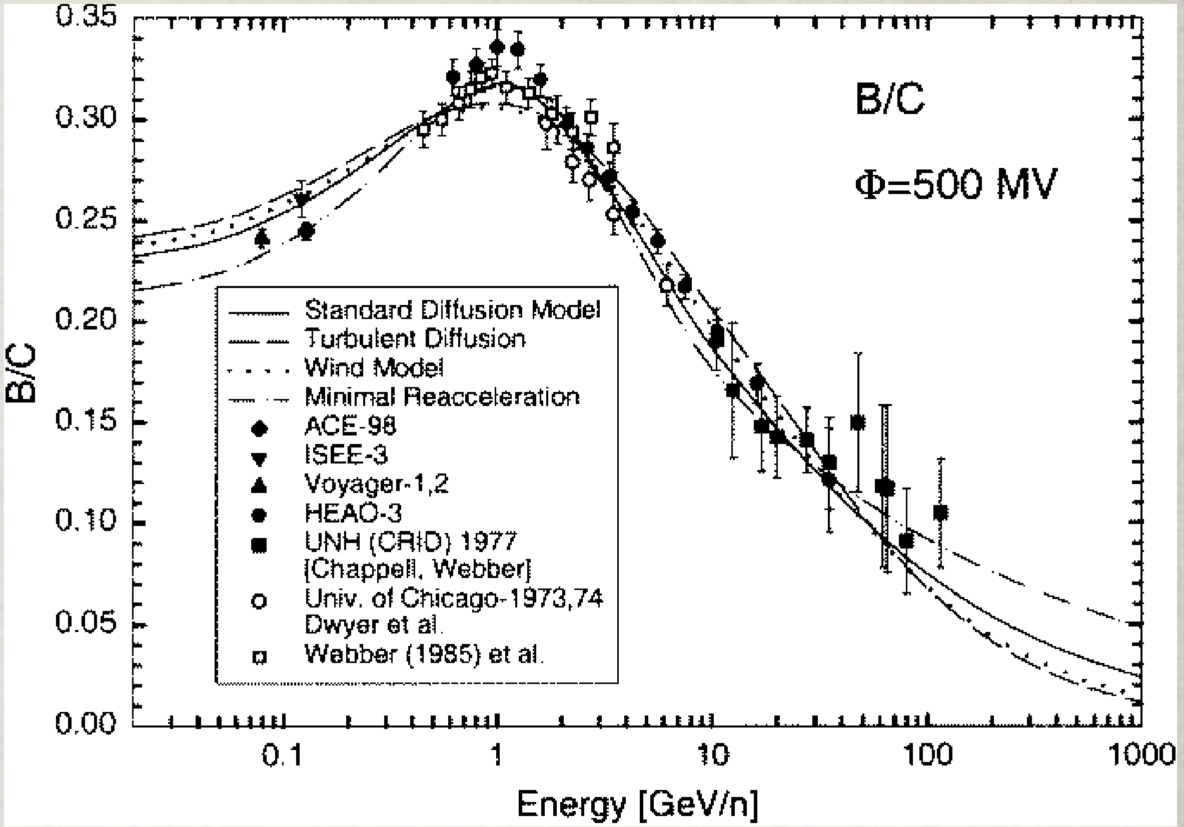
- But, the diffusion equation depends on many **free parameters**...

- ...we can determine them by comparing **model predictions** with observational data.

Our Strategy

- We want to focus on the most important propagation parameters: **D_0 (o z_t), δ**.
- Standard wisdom: **high energy** spectra are just the result of diffusion and possibly spallation.
- At low energy other processes (reacceleration, convection, energy losses, change of diffusion regime at low energy) are relevant and may mask the effects of diffusion.
- **High energy** data now available (**CREAM**, **PAMELA**).

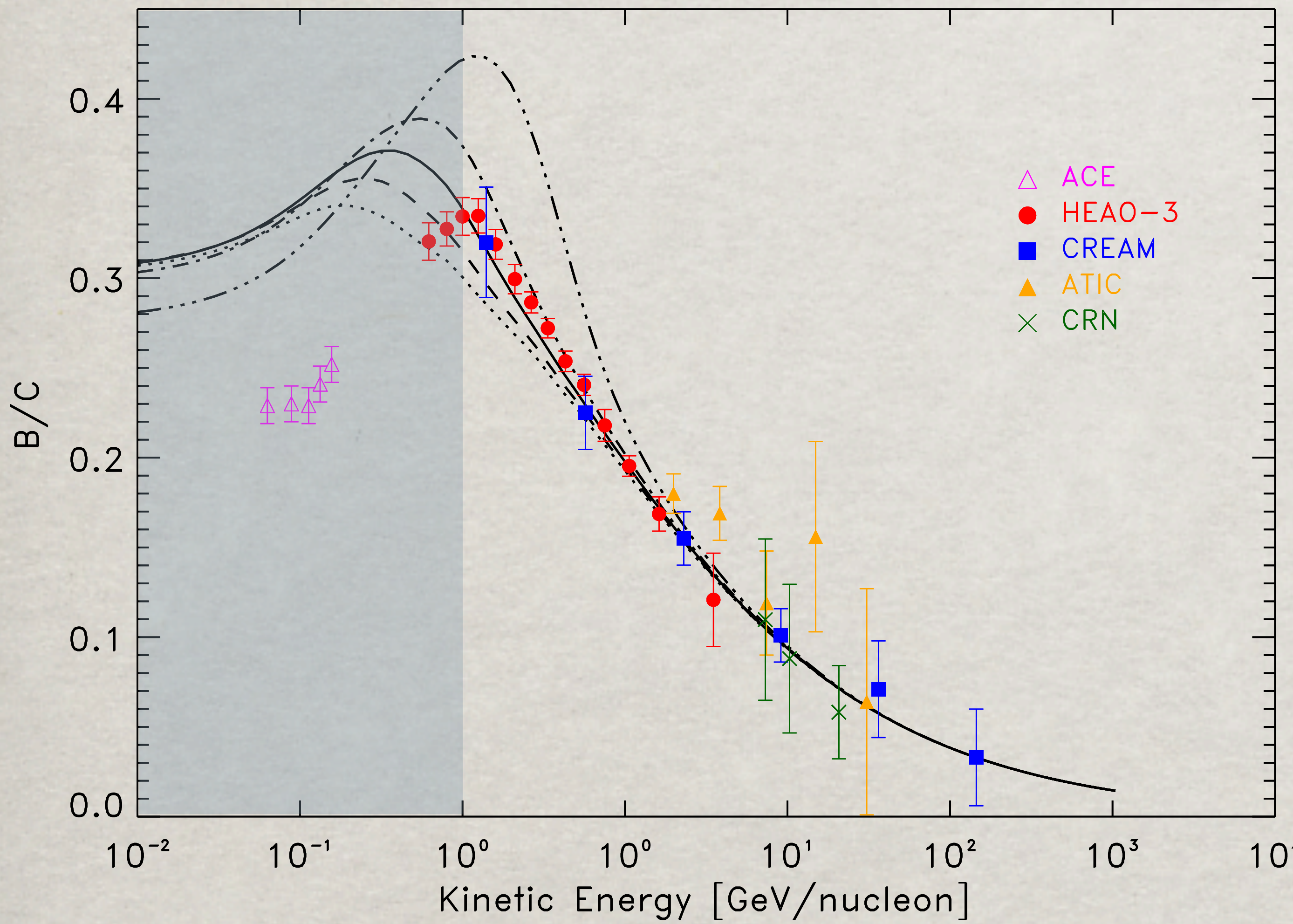
Boron only secondary!

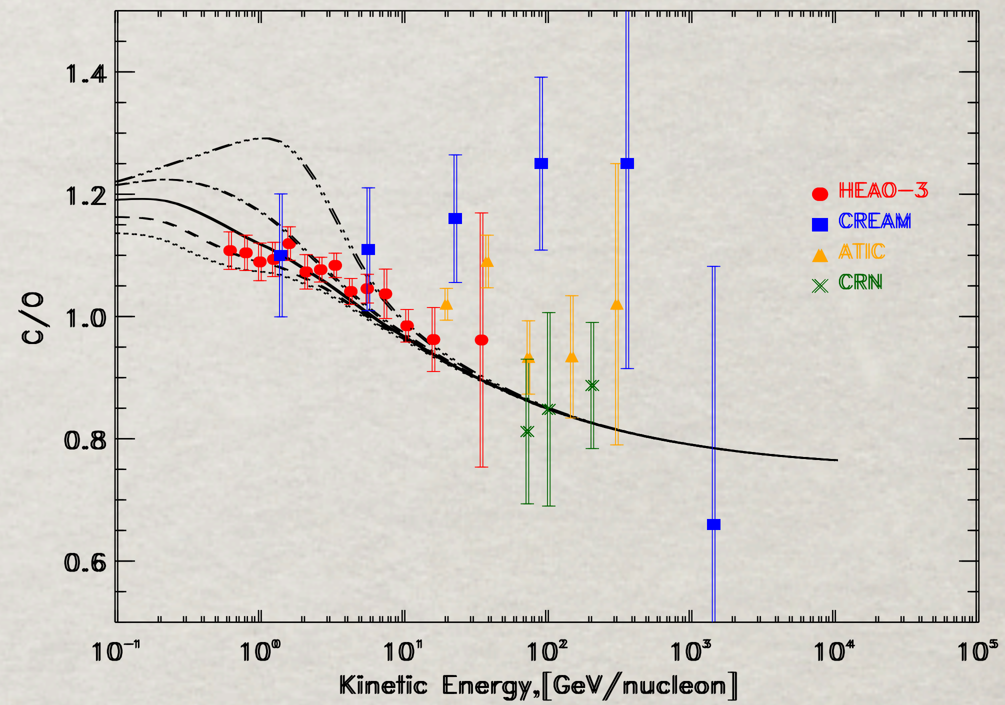


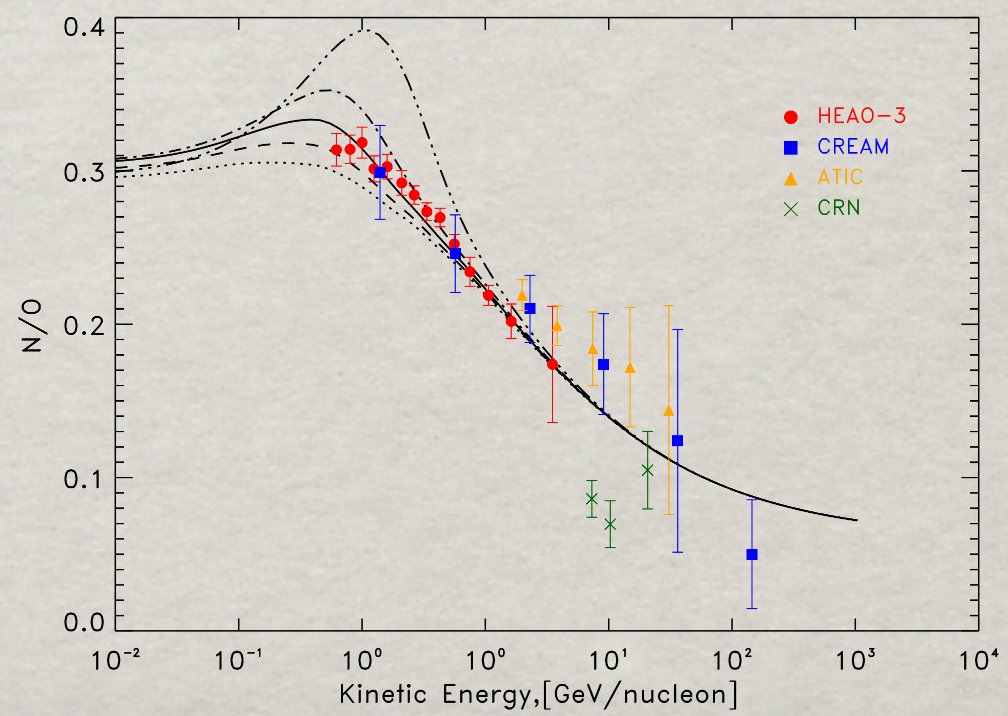
Ref. http://galprop.stanford.edu/

- See also e.g. **Maurin et al, 1001.0553 & 1001.0551, Ptuskin et al, ApJ 642, 2006**

Secondary/Primary

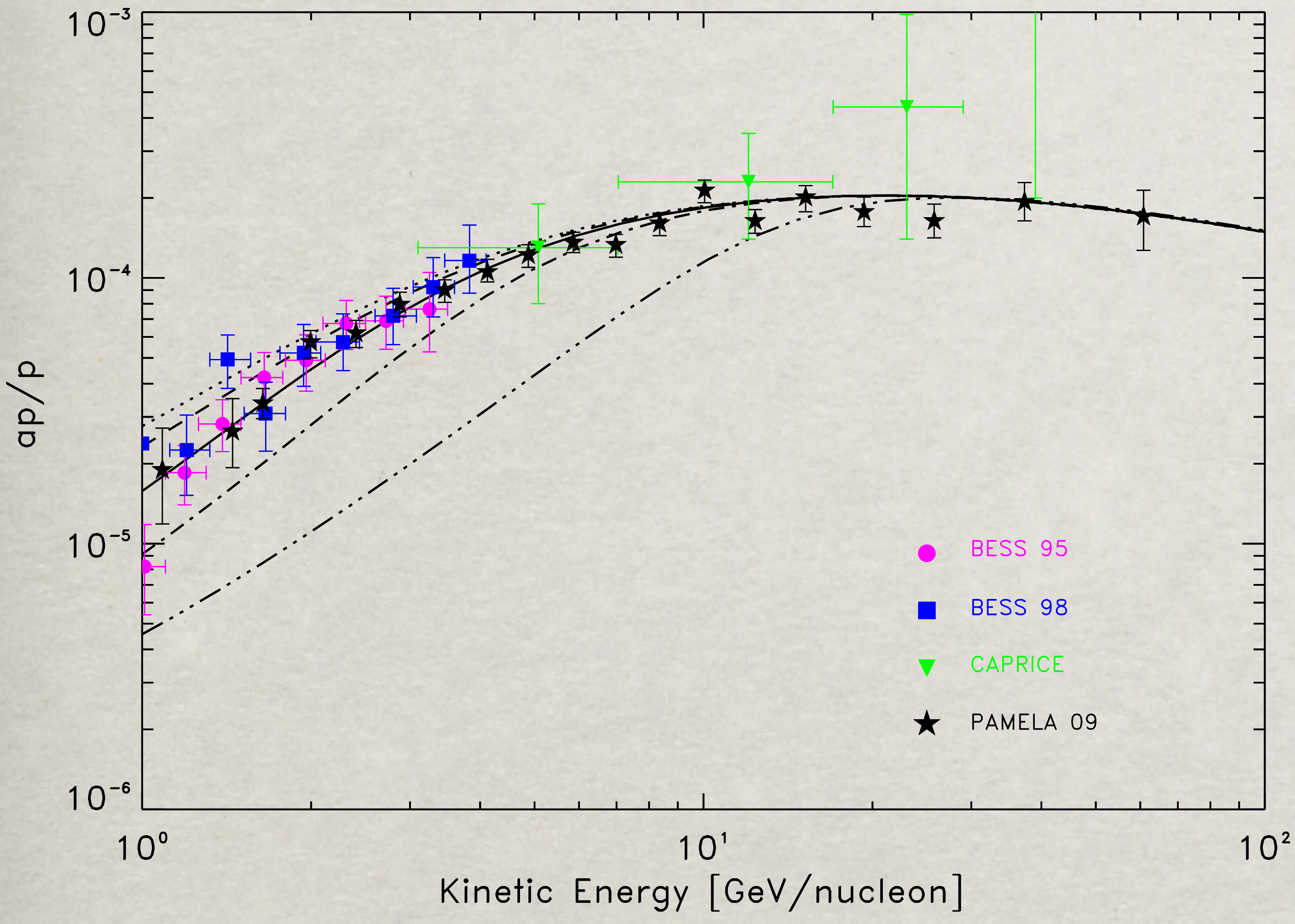


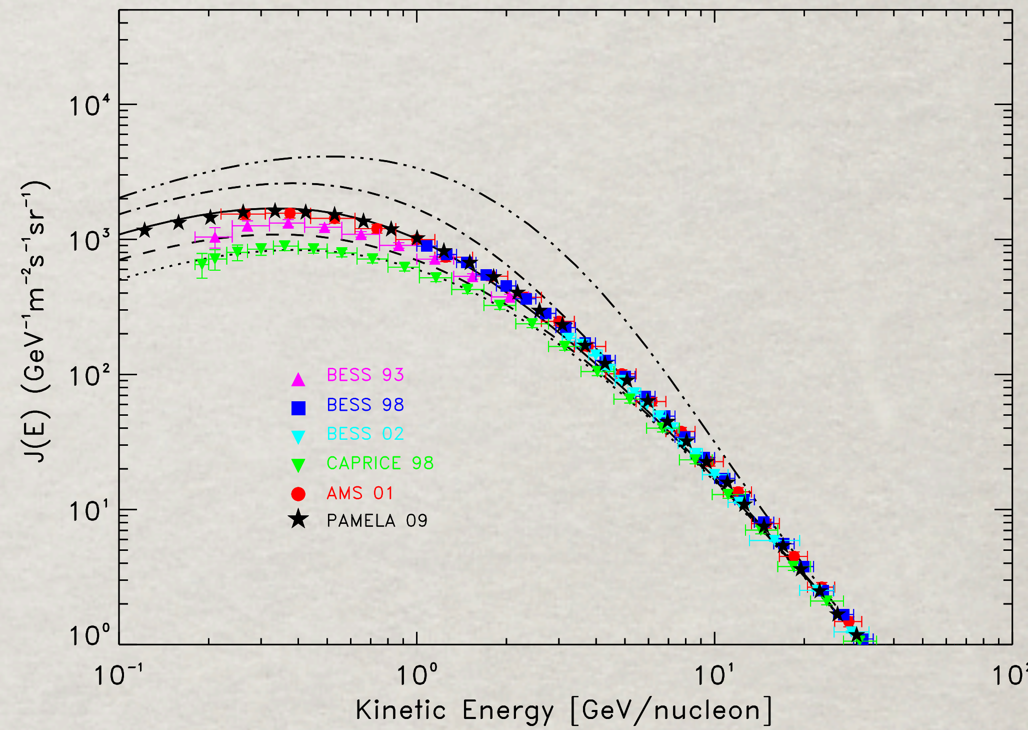


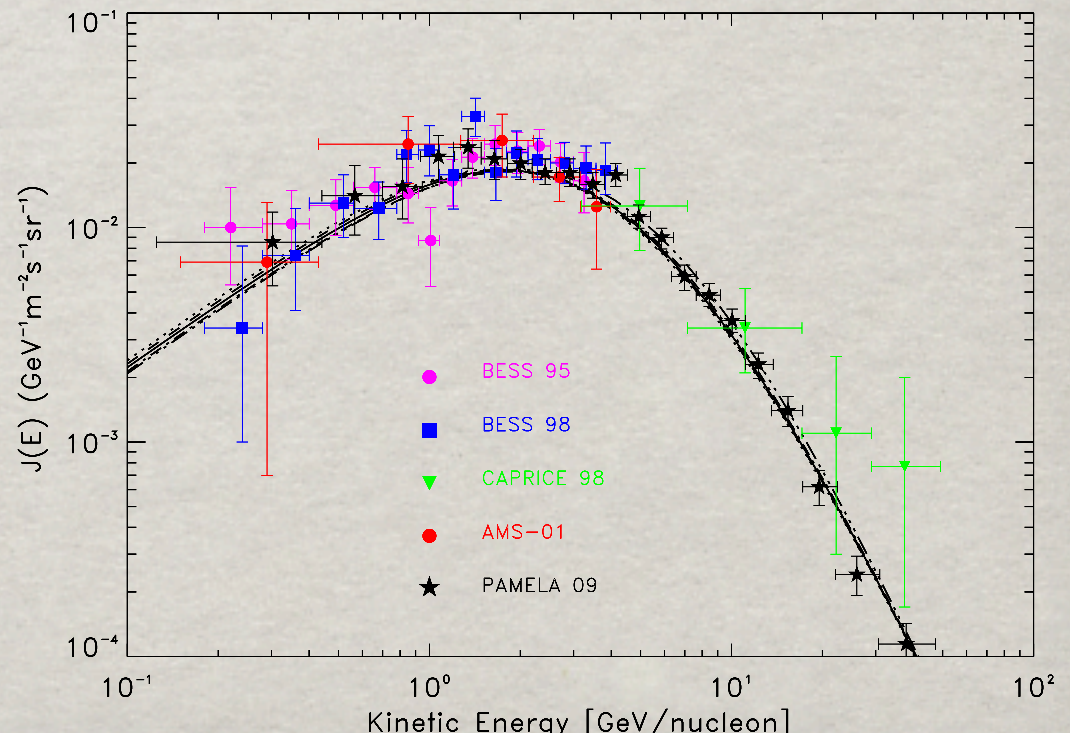


Dependence of secondary/primary ratios on the **reacceleration** level in the "best fit" case. **Modulation potential** fixed by requiring to reproduce the proton spectrum

Antiproton/Protons







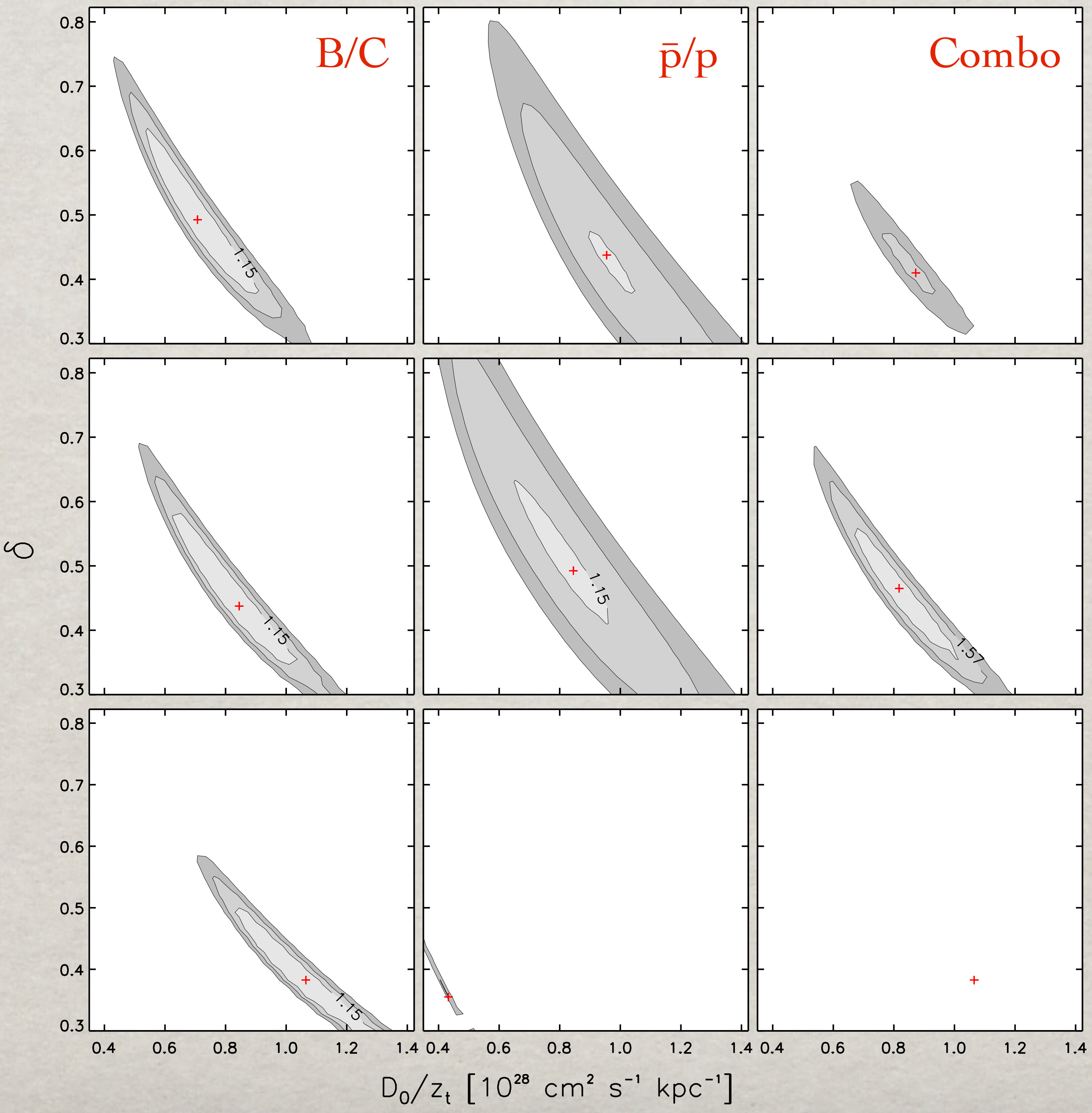
Large effects of **reacceleration** on the proton spectrum: can it constrain v_A?
Interesting feature: the antiproton flux is less affected by reacceleration.

Results

$v_A \sim 10$

$v_A \sim 20$

$v_A \sim 30$



$E_{\rm min} = 5$ GeV/n

No spectrum **breaks** here!

Results

		B/C analysis			joint analysis		
v_A [km/s]	$E_{\rm min}$ [GeV/n]	δ	D_0/z_t	χ^2	δ	D_0/z_t	χ^2
	1	0.57	0.60	0.38	0.47	0.74	3.25
0	5	0.52	0.65	0.33	**0.41**	**0.85**	**2.04**
	10	0.46	0.76	0.19	0.44	0.82	1.57
	1	0.52	0.68	0.32	0.49	0.71	1.47
10	5	0.49	0.71	0.28	**0.41**	**0.85**	**1.69**
	10	0.44	0.82	0.20	0.44	0.82	0.12
	1	0.46	0.76	0.33	0.47	0.76	0.94
15	5	0.49	0.73	0.26	**0.44**	**0.82**	**0.12**
	10	0.44	0.84	0.18	0.41	0.98	0.16
	1	0.41	0.90	0.47	0.47	0.79	2.28
20	5	0.44	0.84	0.22	**0.44**	**0.84**	**0.85**
	10	0.44	0.87	0.20	0.44	0.85	0.98
	1	0.33	1.20	0.40	0.33	1.20	5.84
30	5	0.38	1.06	0.20	**0.36**	**1.09**	**2.47**
	10	0.41	0.98	0.16	0.38	1.04	1.61

What we learn from this analysis is:

@95% C.L.
$0.2 < \delta < 0.7$
$v_A < 30$ km/s

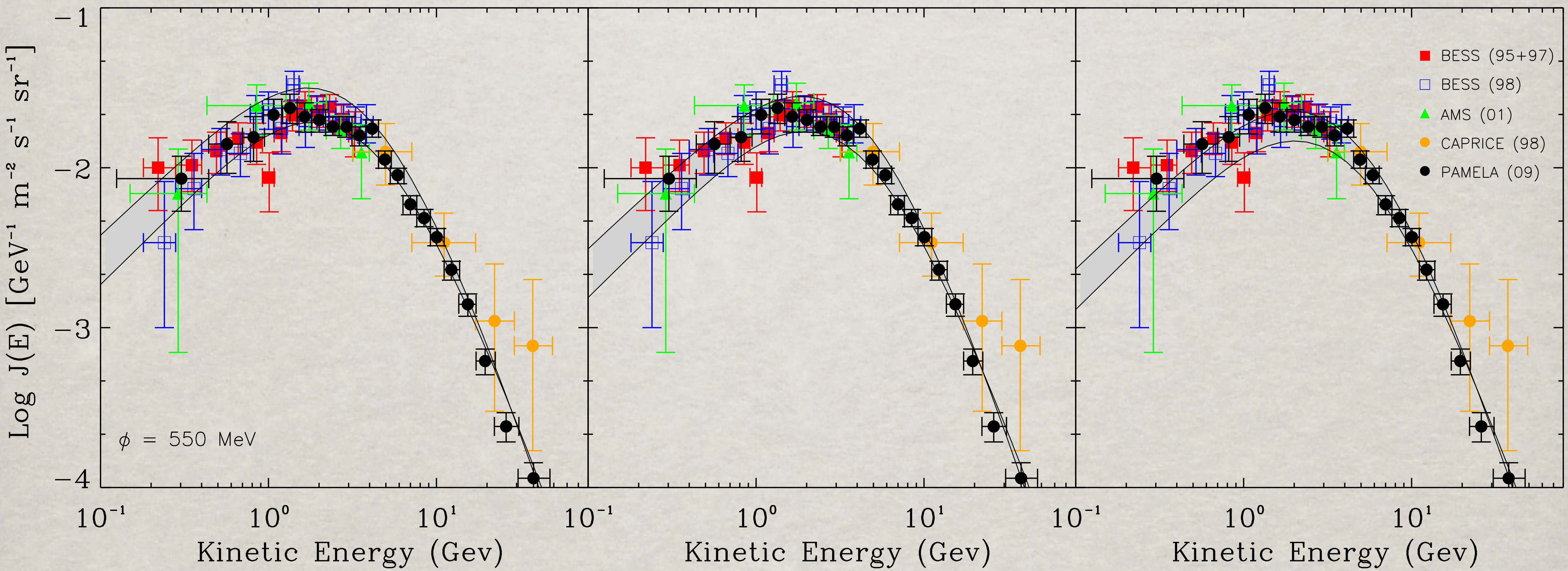
@best-fit:
$\delta = 0.45$
$v_A = 15$ km/s

Kraichnan turbulence in the ISM?

Di Bernardo et al., 2010, Astroparticle Physics

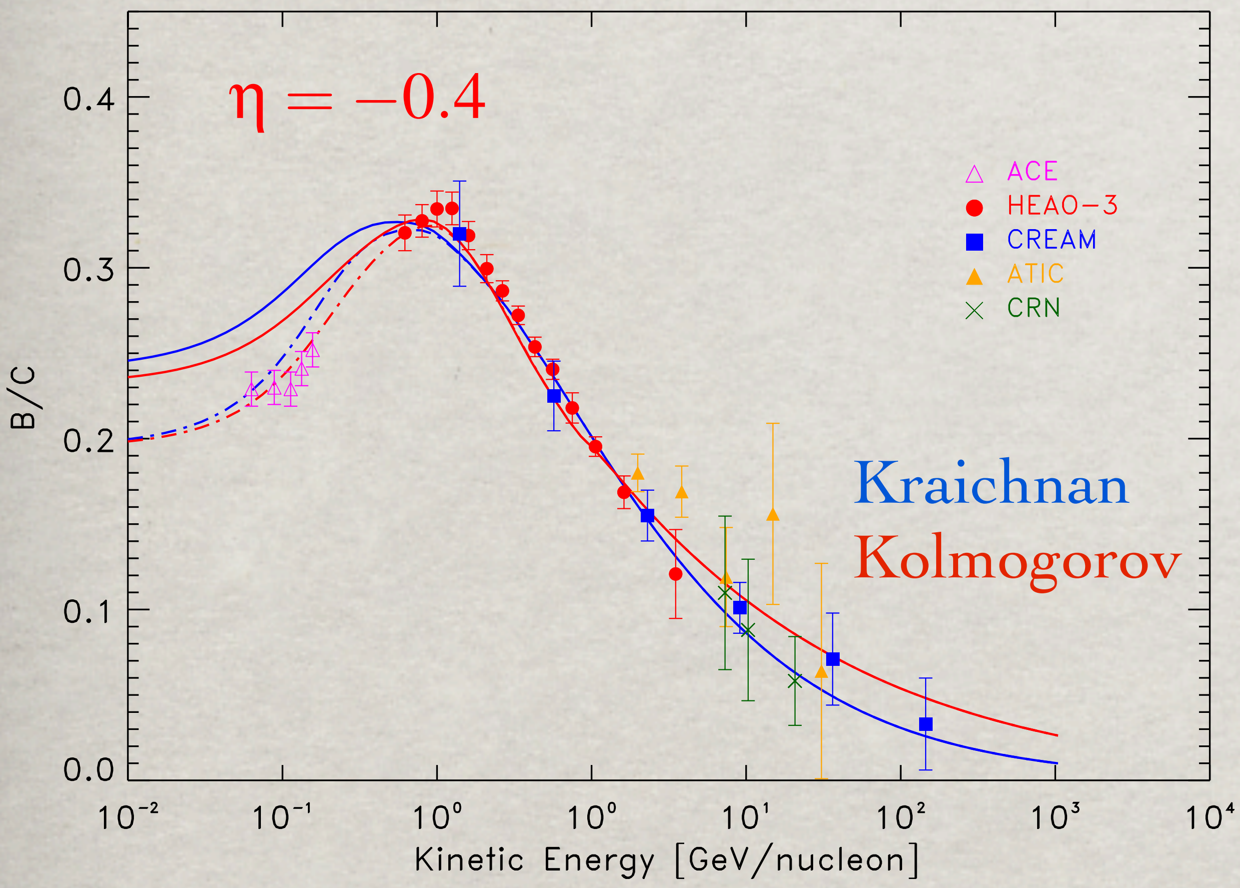
Results

Antiproton minimum and maximum flux:



Di Bernardo et al., 2010, Astroparticle Physics

Fixing Low Energy



Low energy physics can be parametrized as

$$D \propto \beta^{\eta} (\rho/\rho_0)^{\delta}$$

$\eta < 0$ might correspond to scenarios of magnetic wave dissipation (Ptuskin et al, ApJ, 642, 2006)

The diffusion parameters fitted at high energy with the energy dependent analysis are robust against low energy physics effects.

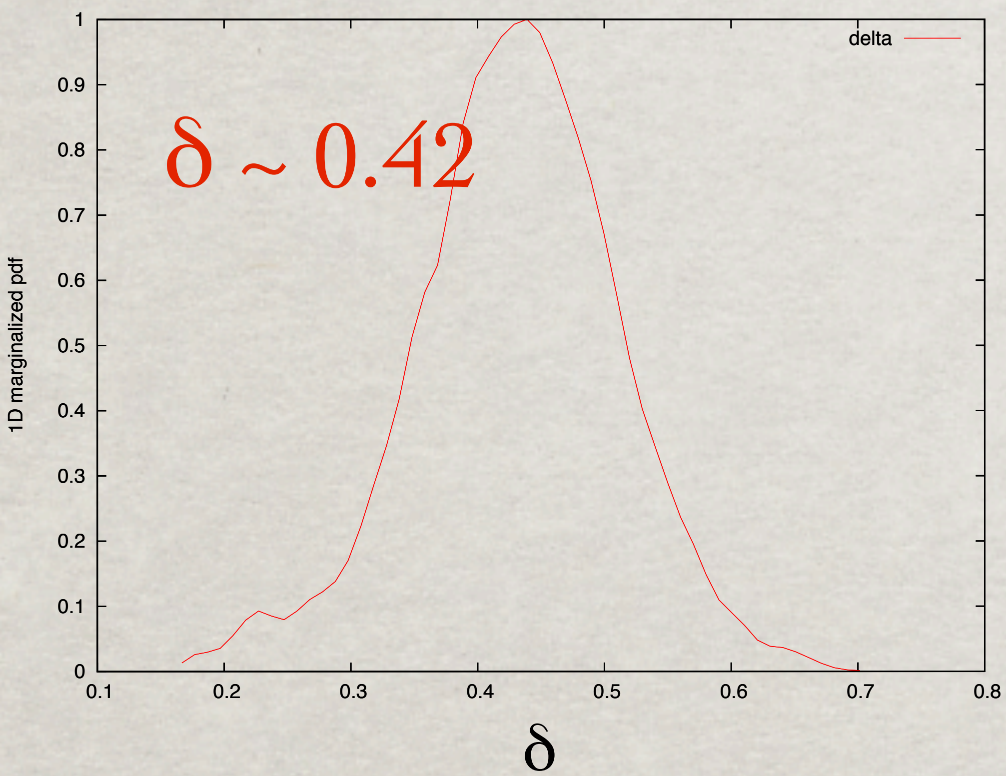
See also *Maurin et al., 1001.0553* where several sources of uncertainties are discussed.

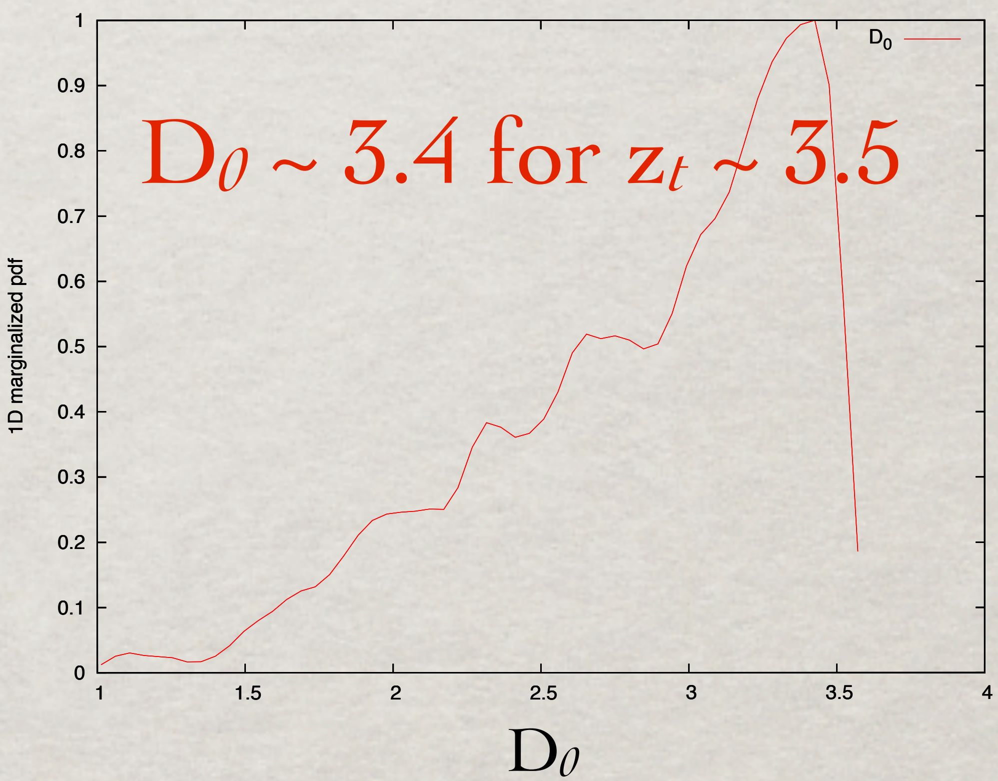
Likelihood Analysis

PRELIMINARY RESULTS!

MCMC to improve efficiency and number of parameters:

PDF





The analysis has been performed using the available data in the entire energy range $0.1 < E < 10^3$ GeV/n.

Parameters in the fit: $\delta, D_0, z_t, q_C, q_N, v_A, \eta$

Catena et al., *in preparation*

The Leptonic Sector

The situation before 2008:

- Above few GeV the e+p spectrum was fitted (large uncertainty) by a power-law:

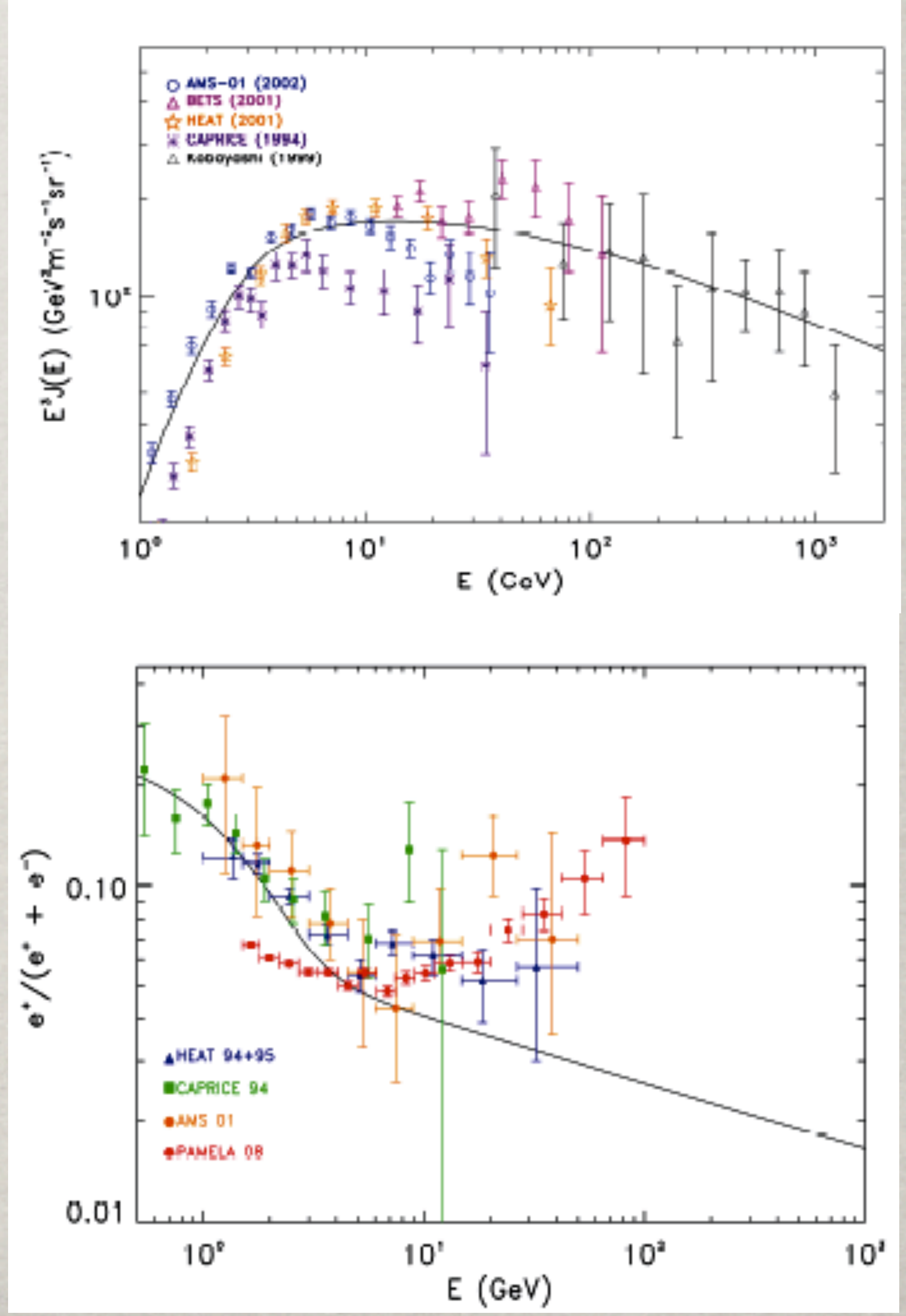
$$\sim E^{-3.2}$$

- **GALPROP** model:

$$\delta = 0.33\ ,\ \gamma_0 = 2.54$$

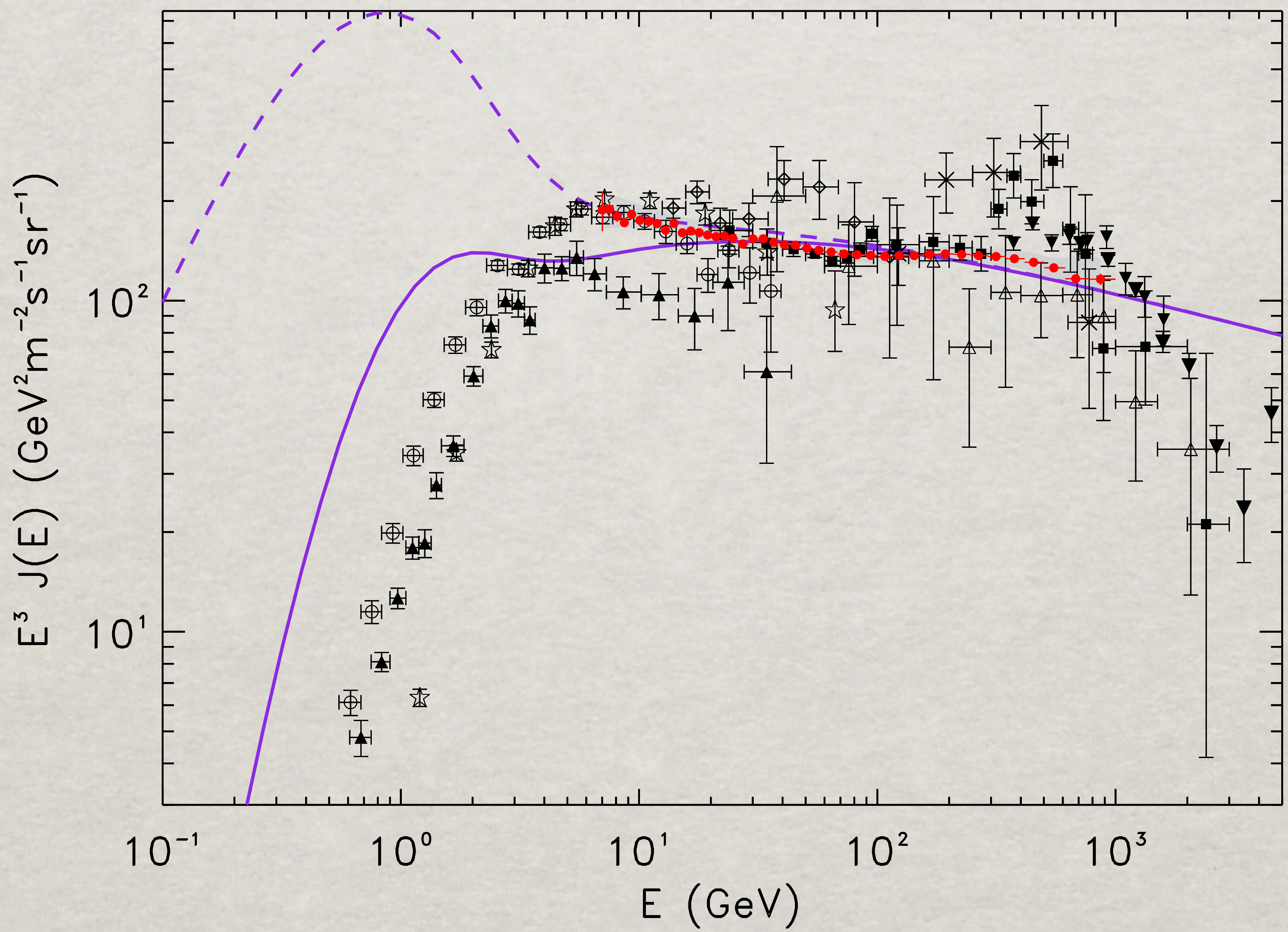
(va = 30 km/s, no convection)

- but! The “conventional model” is in disagreement with the PAMELA rise of the positron fraction.



The FERMI-LAT + HESS CRE spectrum

The e+p spectrum based on 12 months data, down to 7 GeV:

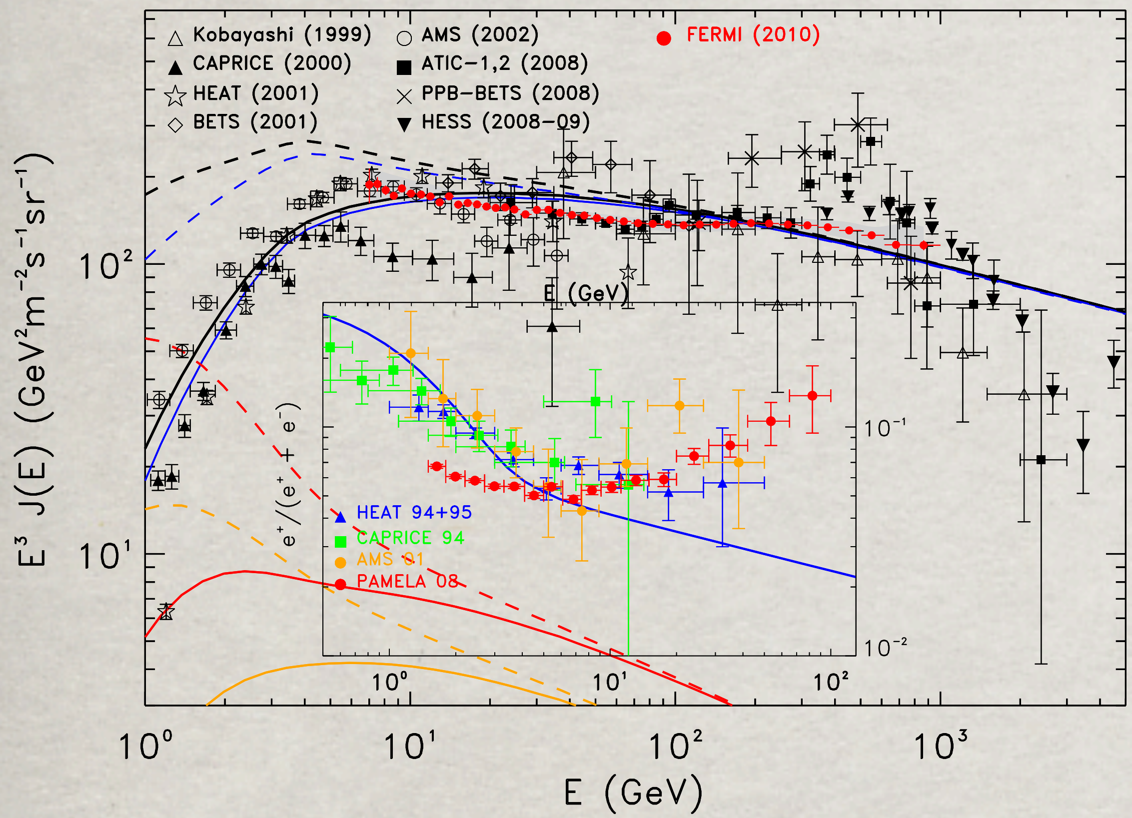


hardening at around 100 GeV

steepening above 500 GeV

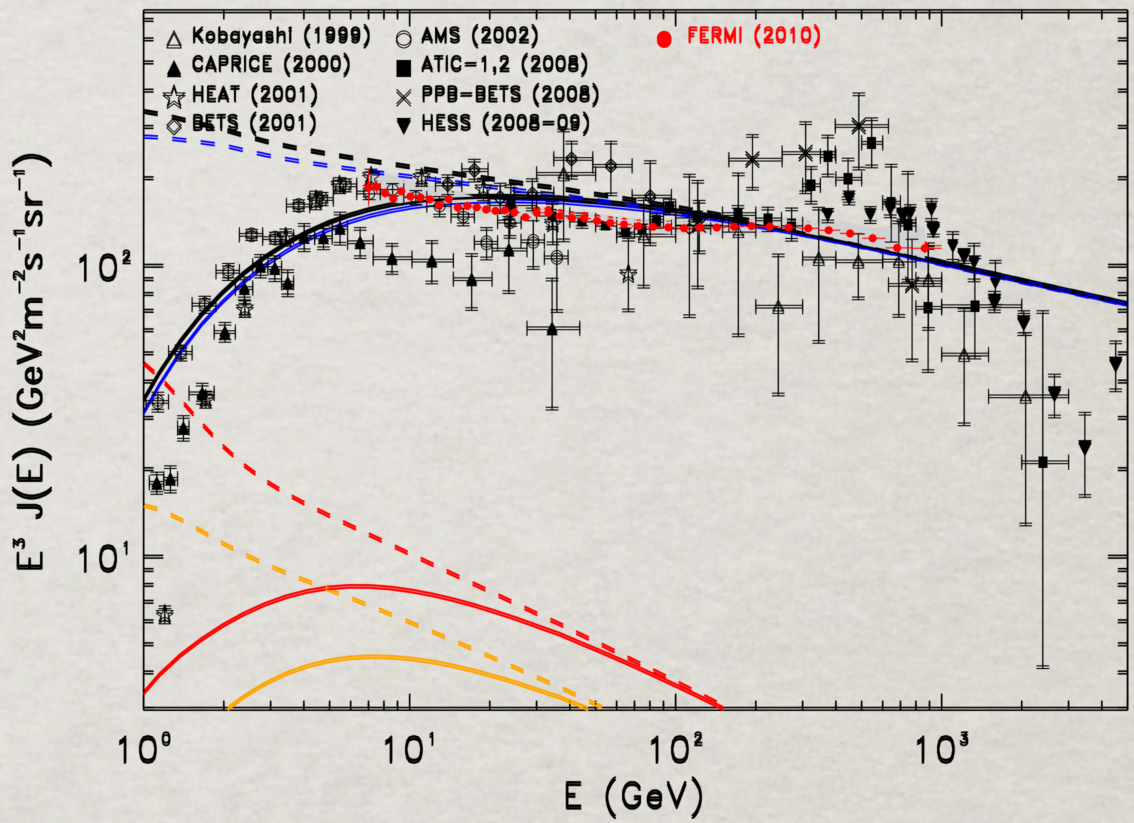
Power-law with slope 3.06

A conservative interpretation



Kolmogorov

$\gamma_e = 1.6/2.5 \quad below/above\, 4\, GeV$



Kraichnan

$\gamma_e = 2.0/2.43 \quad below/above\, 2\, GeV$

Under the hypothesis:

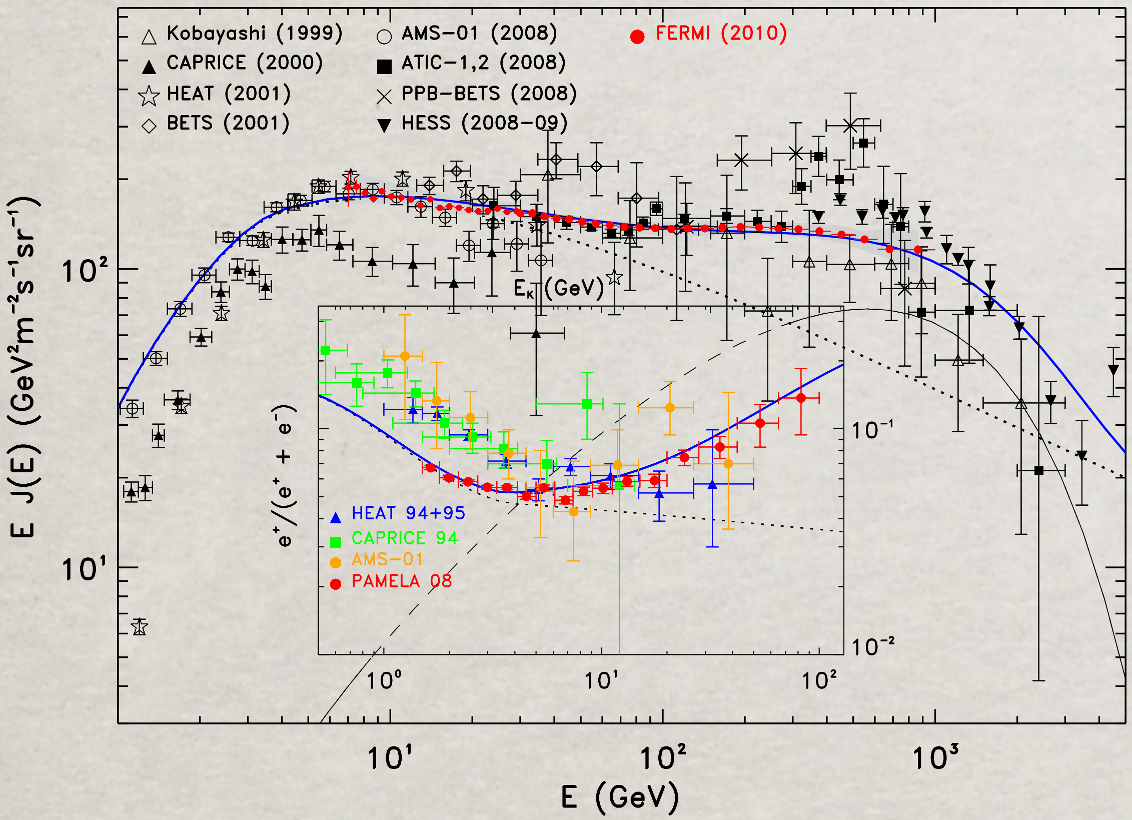
1. electrons comes from SNR
2. positrons are secondary only

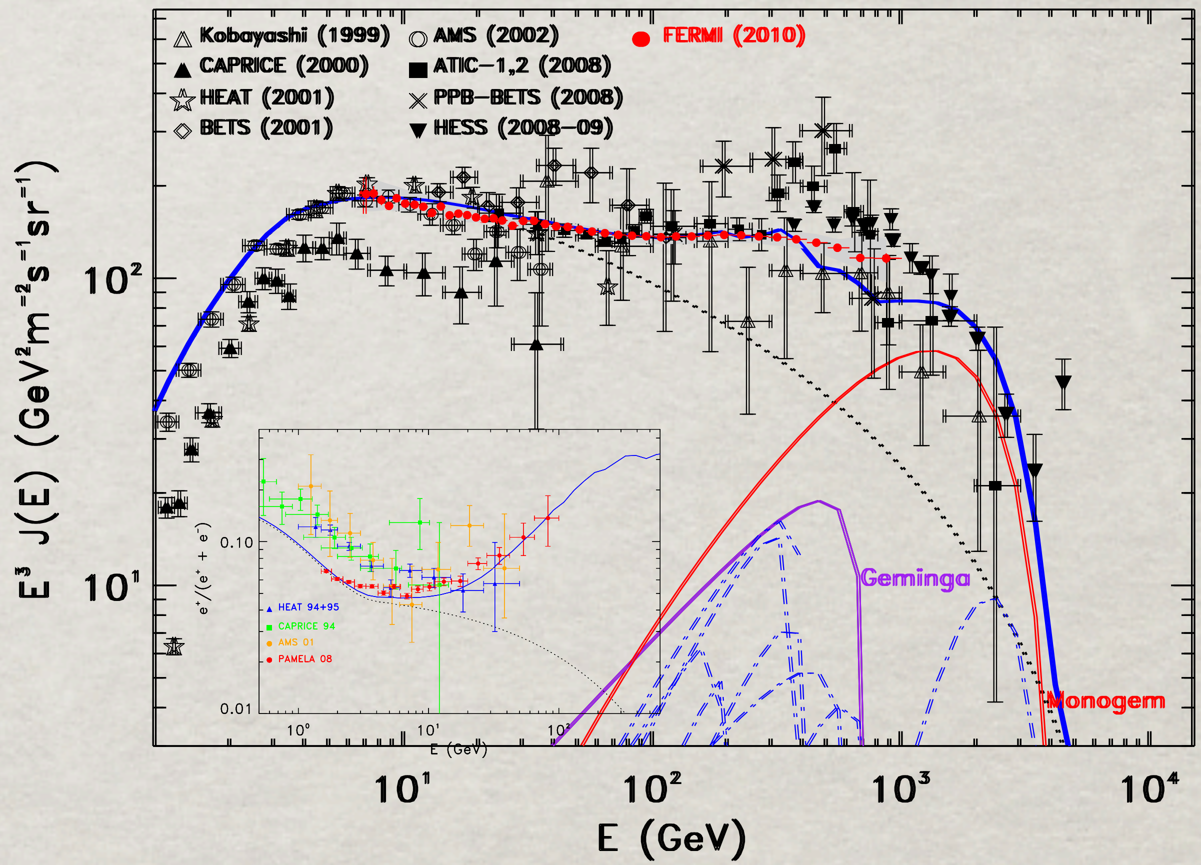
do not match PAMELA data!

do not match HESS data!

Two Galactic Components?

$\gamma_0 = 2.0/2.65 \ , \ \delta = 0.46$





Toy model:

$$N_{extra} \propto E^{-1.5} \exp(-E/1TeV)$$

galactic component that follows the pulsar distribution

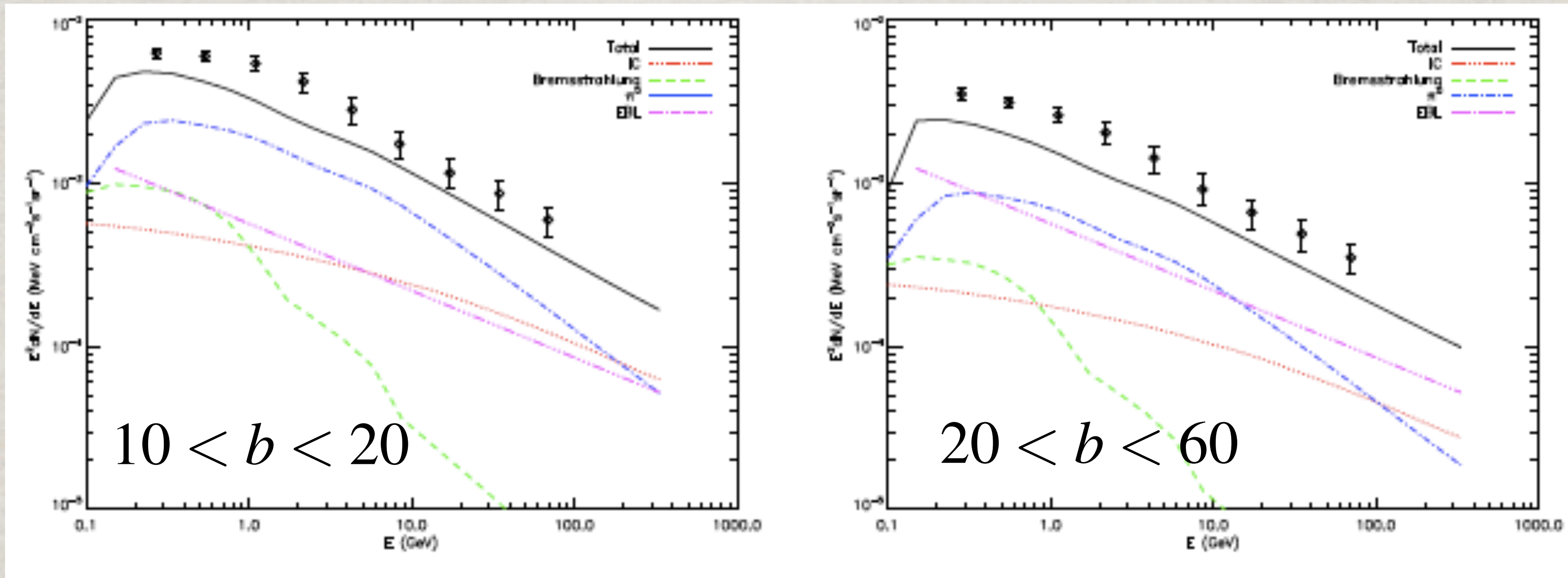
Point-sources model:

$$\gamma_e = 1.4 \ , \ E_{cut} = 2TeV \ ,$$
$$t_0 = 75kyr \ , \ \eta_p = 0.35$$

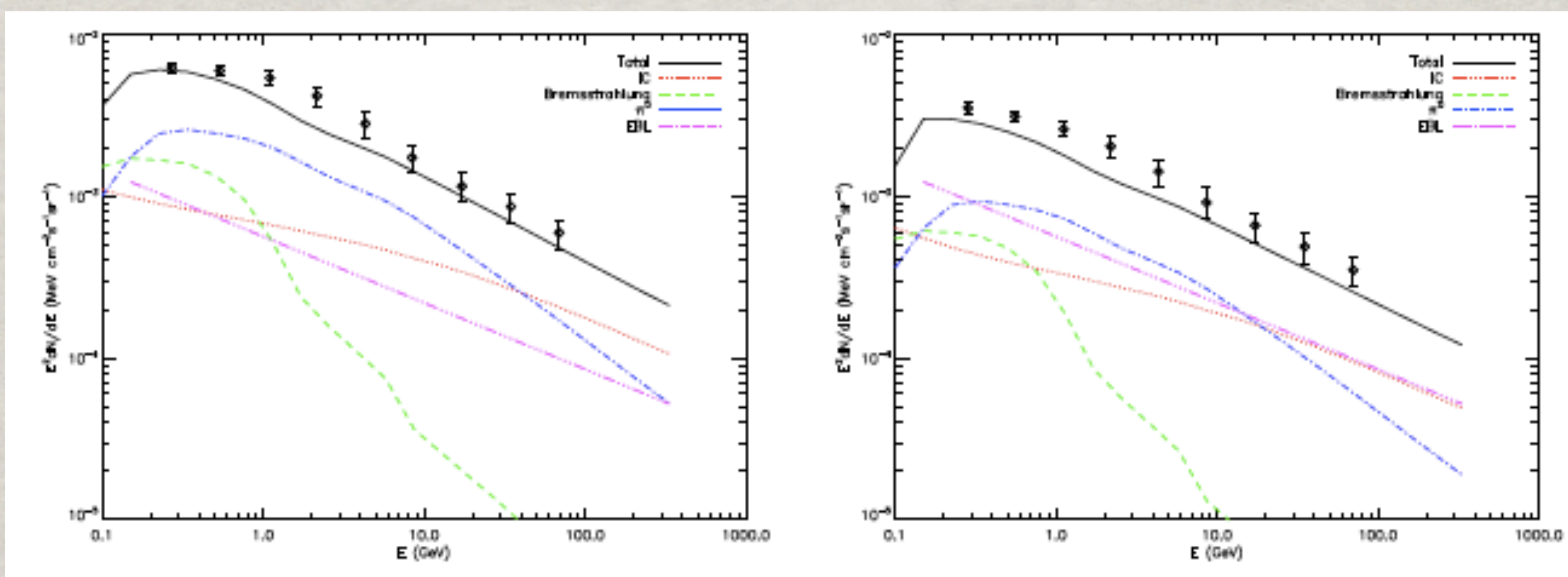
contribution from nearby pulsars (<2kpc) taken from the ATFN catalogue

What about DIFFUSE emission?

PRELIMINARY RESULTS!



Standard model with $z_t \sim$ ***2-4*** kpc



Thick halo model with $z_t \sim$ ***8-10*** kpc

Data from
Abdo et al. 2010

Tavakoli et al., *in preparation*

CONCLUSIONS

We use nuclei and anti-proton recent measurements to constrain the diffusion parameter range.

We present a “two-component” (SNR + PSR) interpretation of the electron/positron spectrum.

Our “multi-messenger” model is still not able to reproduce the diffuse γ emission. Work in progress!