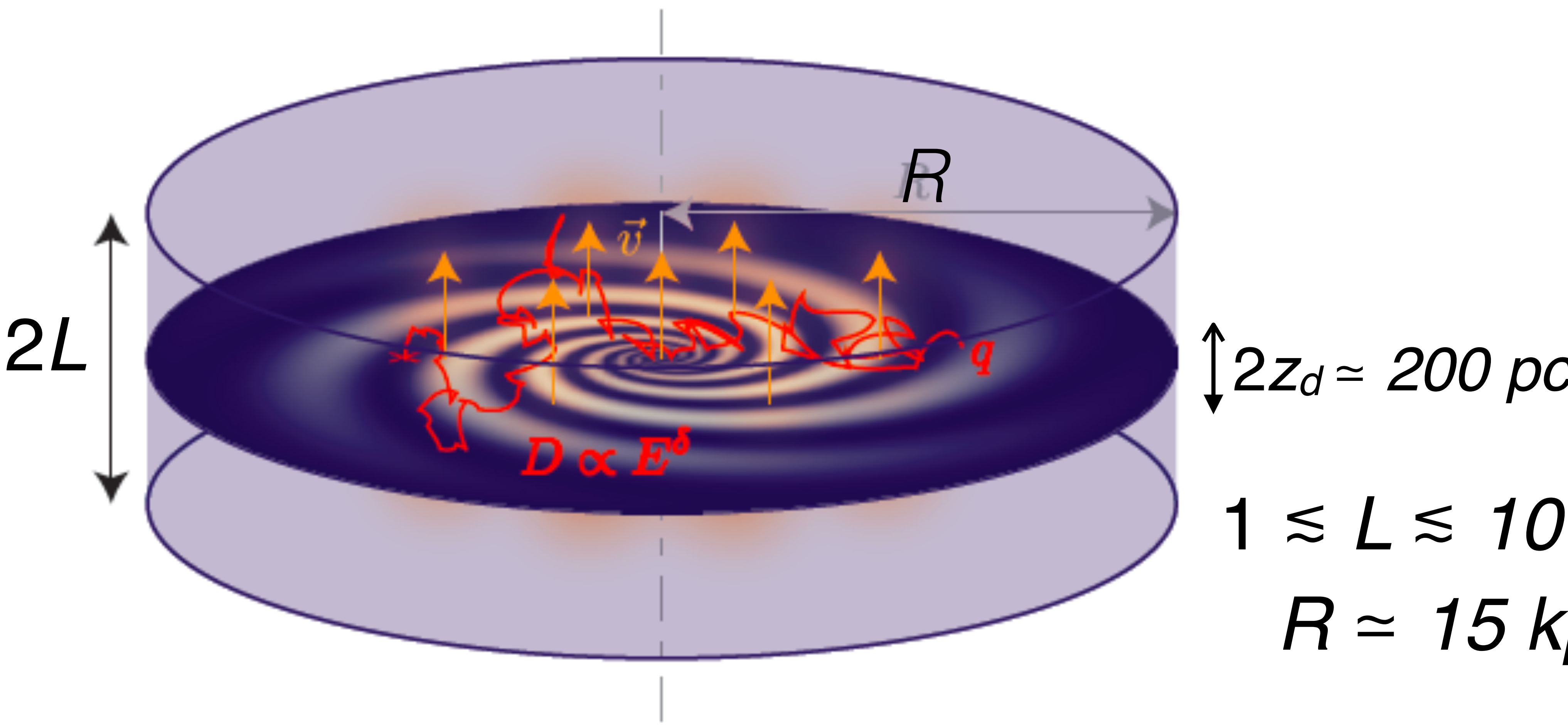
Cosmic ray propagation with DRAGON

few recipes to cook good models

D. GRASSO (INFN, Pisa)

CASPAR school, DESY 15-19 Sep. 2014

Geometry of the galactic CR pool



$1 \lesssim L \lesssim 10$ kpc

$R \simeq 15$ kpc

Our position: $R \simeq 8.3$ kpc $\quad z \simeq 0$

CR nuclei

The transport equation (2d)

(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

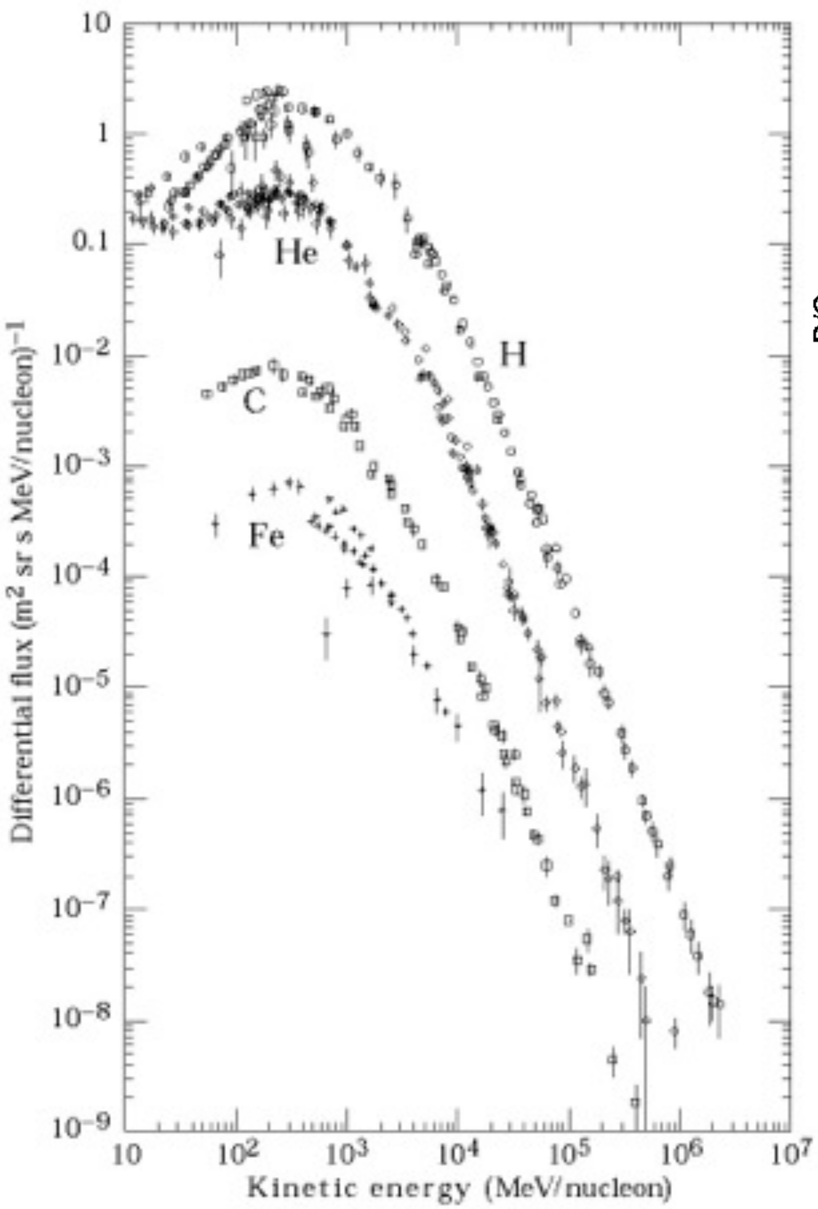
Spallation cross
section. Appearance
of nucleus i due to
spallation of nucleus j

Total inelastic cros
section.
Disappearance of
nucleus i

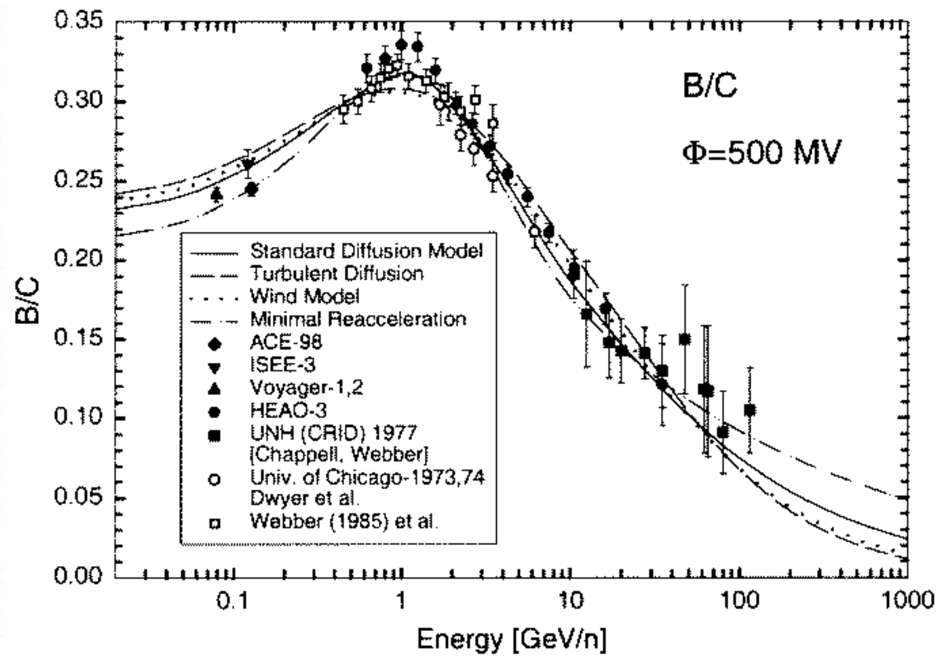
boundary condition: $N^i(r, z) = 0$ either for r = R or I z I = L

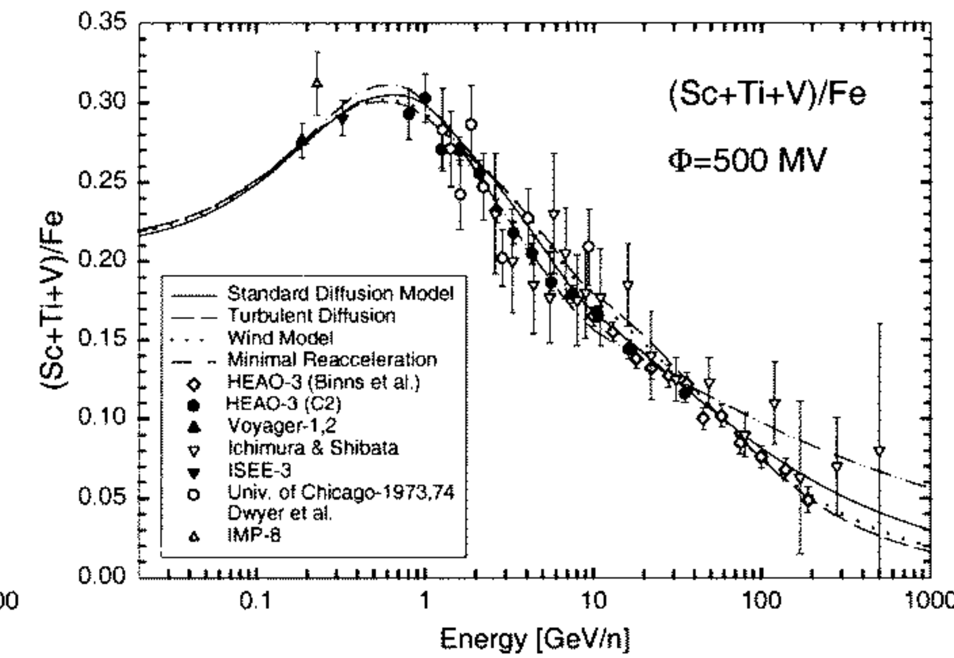
A large number of parameters to be fixed against multichannel CR data !

CR nuclei data

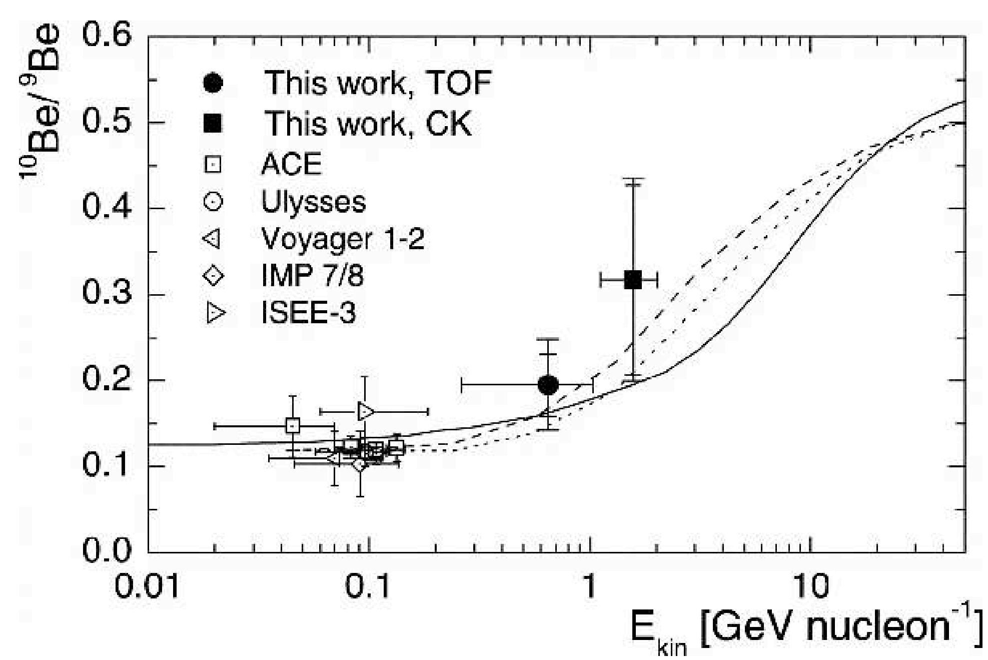


primary spectra





primary/secondary ratio of stable nuclei



primary/secondary ratio of unstable nuclei

Source term

- **Spatial dependence**

  we assume sources trace SNRs

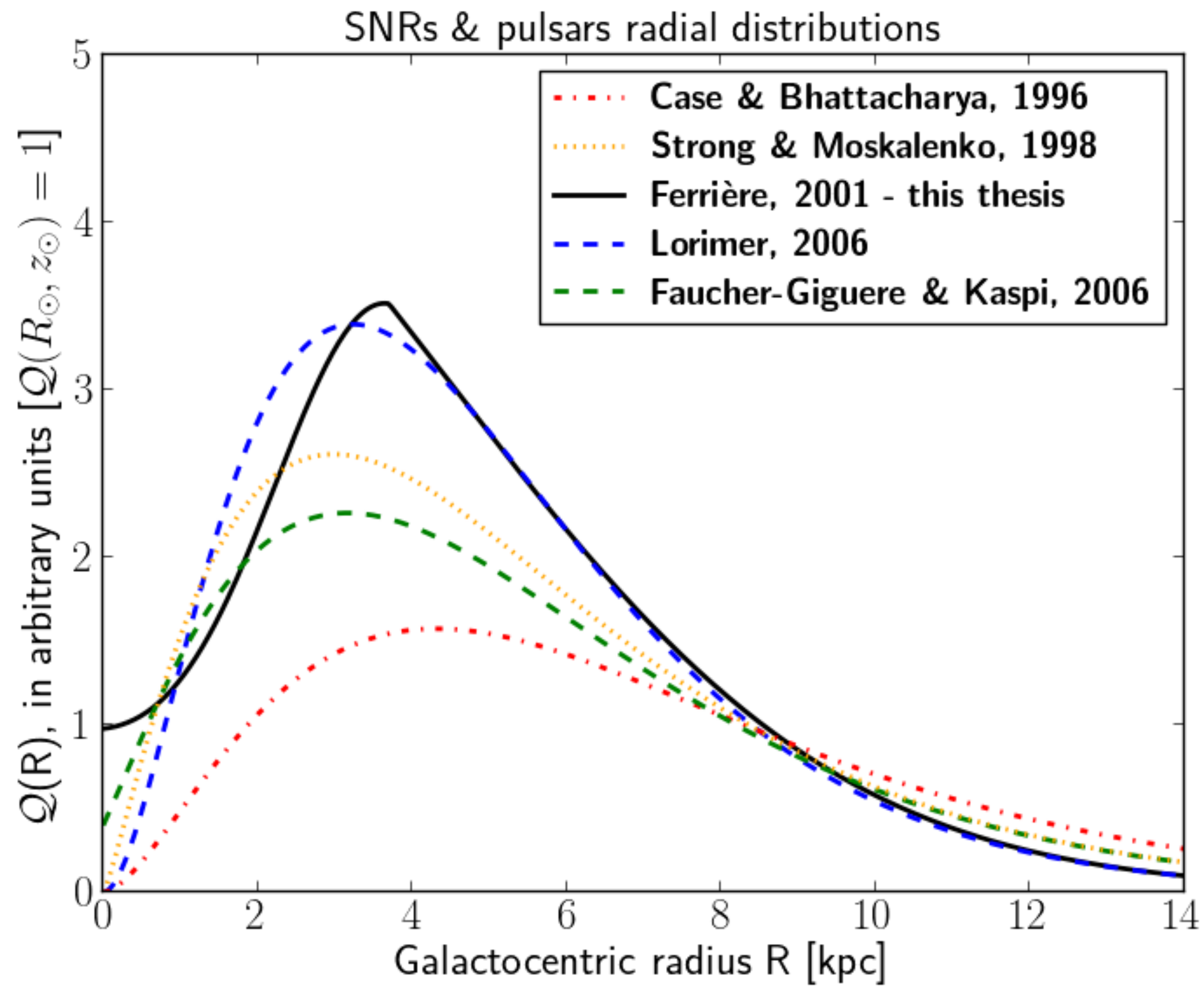
  distributions implemented in DRAGON: Galprop, Ferriere

  in DRAGON 3D we can also account for spiral arms

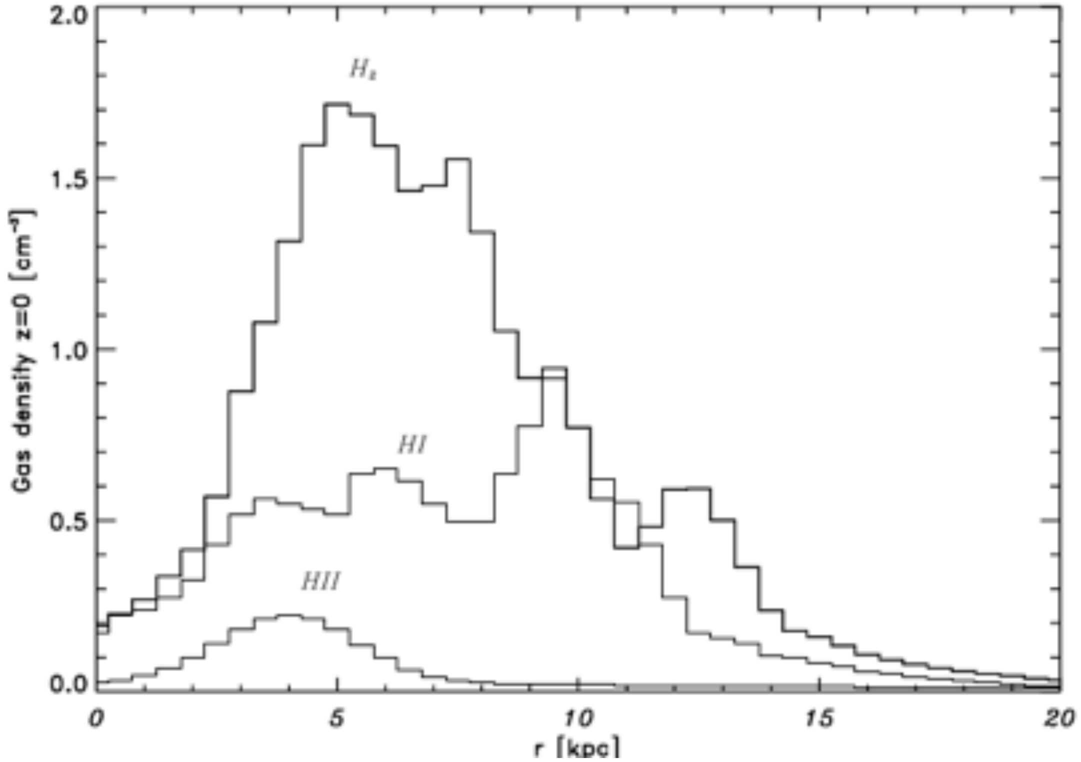
- **Rigidity dependence**

$$Q(\mathbf{x}, \rho) = Q_0(\mathbf{x}) \left(\frac{\rho}{\rho_0}\right)^{-\gamma}$$

we allow for several spectral breaks (3 in the present version)



Gas distribution



$$n_{\mathrm{H_I}}(R,z) = \frac{1}{n_{\mathrm{GB}}} Y(R) \times \begin{cases} \sum_{i=1,2} A_i e^{-ln2\ (z^2/z_i^2)} + A_3 e^{-|z|/z_3}, & R \leq \ 8\mathrm{kpc} \\ \text{interpolato}, & 8 < R < 10\mathrm{kpc} \\ n_{\mathrm{DL}} \exp\left(-z^2 e^{-0.22R}/z_4^2\right), & R \geq 10\mathrm{kpc} \end{cases}$$

Gordon & Burton 1976

$$n_{\mathrm{H_2}}(R,z) = 3.24 \times 10^{-22} X Q_{\mathrm{co}}(R) \exp\left(-\ln 2 \left[\frac{(z-z_0)^2}{z_{1/2}^2}\right]\right)$$

Bronfman, 1998

$$X \equiv \frac{n_{\mathrm{H2}}}{Q_{\mathrm{co}}} = 1.9 \times 10^{20} \mathrm{moli\ cm^{-2}/(K\ km\ s^{-1})},$$

see Ferriere review, 2001

Diffusion equation

Particle flux, 1-dim. $J = nv - D\frac{\partial n}{\partial x_i}$ $\Rightarrow$ 3-dim. $J_i = nv_i - \sum_{j=1}^{3} D_{ij}\frac{\partial n}{\partial x_i}$

Particle number conservation $\Rightarrow$ $\frac{\partial n}{\partial t} = -\frac{\partial J_i}{\partial x_i}$

$$\boxed{\frac{\partial n}{\partial t} + \frac{\partial}{\partial x_i}(nv_i) + \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial n}{\partial x_j}\right) = q(\vec{x}, t)}$$

$q(\vec{x}, t)$: source term

In the presence of a regular magnetic field one expects isotropy to be broken and

$$D_{ij}(\vec{x}) = (D_{||}(\vec{x}) - D_{\perp}(\vec{x}))b_i(\vec{x})b_j(\vec{x}) + D_{\perp}(\vec{x})\ \delta_{ij}$$: diffusion tensor

$b_i(\vec{x})$: regular magnetic field versor

$[D_{ij}] =$: lenght^2 / time

Diffusion equation

for uniform and isotropic diffusion $D_{ij}(\mathbf{x}) = D\ \delta_{ij}$

and a bursting source $q(E, \vec{x}, t) = q(E)\delta(\vec{x};\ t)$

$$N(E, r, t) = \frac{q(E)}{\pi^{3/2} R_{\rm diff}^3} \exp\left(-\frac{r^2}{R_{\rm diff}^2}\right)$$

$$R_{\rm diff}(t) = 2\sqrt{Dt}$$: diffusion length

$$t_{\rm diff}(L) \simeq \frac{L^2}{D}$$: diffusion time on a length L

smaller/larger D $\Rightarrow$ slower/faster diffusion out of the source region

Diffusion coefficient

Here we assume isotropic diffusion
note that for azimuthal symmetry only one component ($D_\perp$) is relevant anyhow

We assume $D(\mathbf{x}, \rho) = D_o(\mathbf{x})\ (\rho/\rho_0)^\delta$

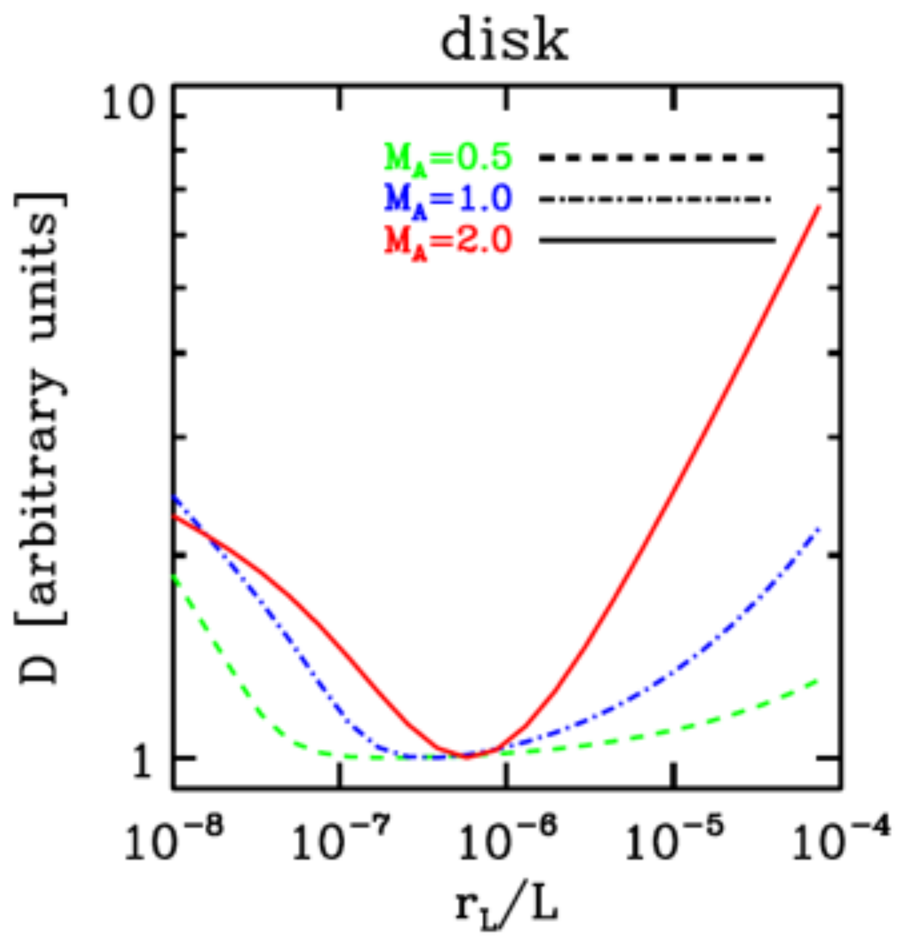
where $\rho = p/Ze$: magnetic rigidity

At low energy dissipation of MHD turbulence may come in (see e.g. Ptuskin et al. ApJ 2006; Evoli & Yan 2013) giving rise to faster CR escape

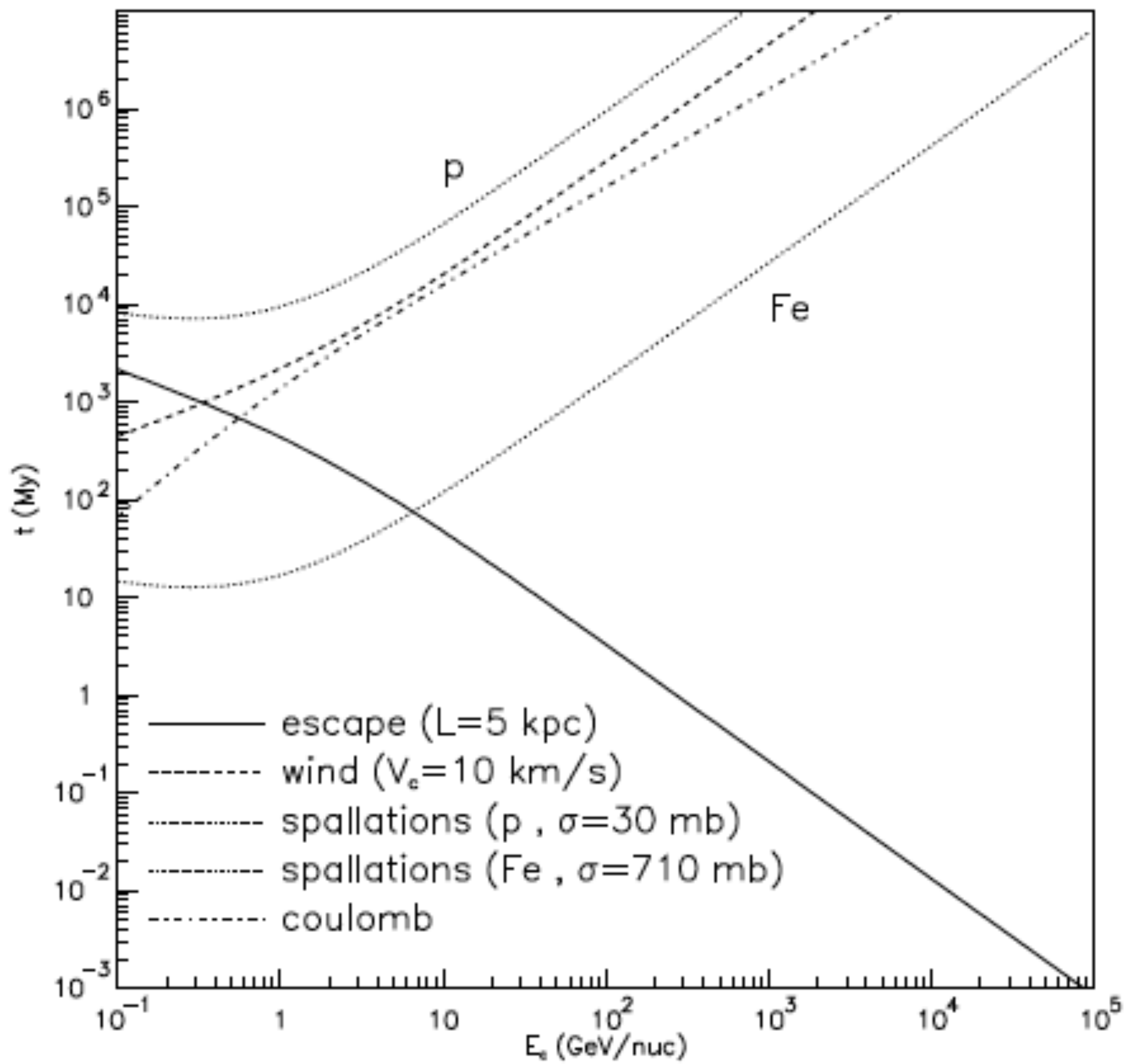
This is often parametrized introducing

$$D(\mathbf{x}, \rho) = D_o(\mathbf{x})\ (\rho/\rho_0)^\delta\ \beta^\eta$$

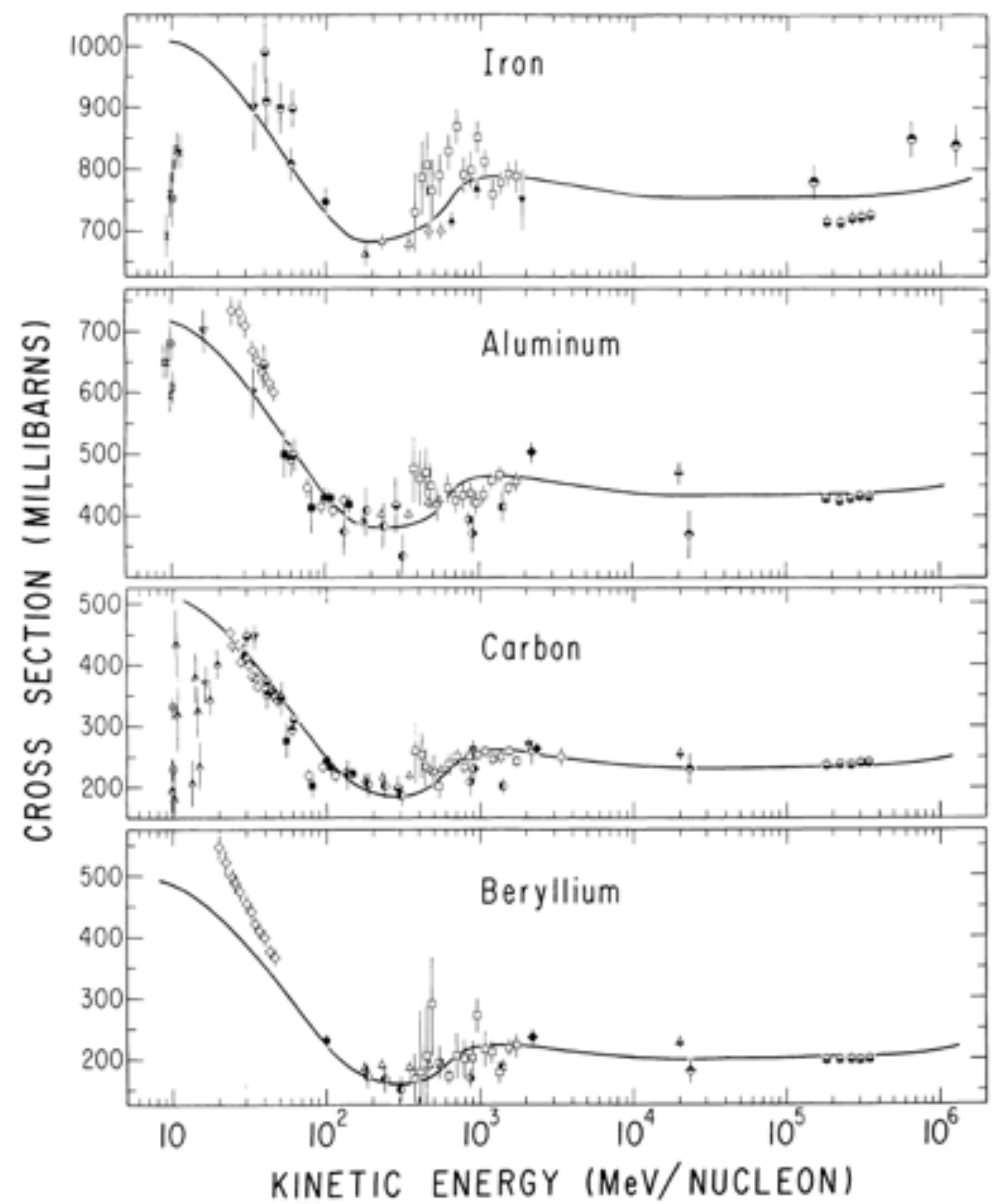
where $\eta < 0$ $\quad \beta = v/c$



Nuclei losses



some spallation cross sections



for $E_k \geq 2$ GeV/n $\sigma^{in}_{tot} = 45\, A^{0.7}\; [\, 1 + 0.016 \sin (5.3 - 2.63 \ln A)\,]$ mb Letaw at al. '83

see also Tang & Ng 1983

Nuclei losses

Castellina & Donato 2005

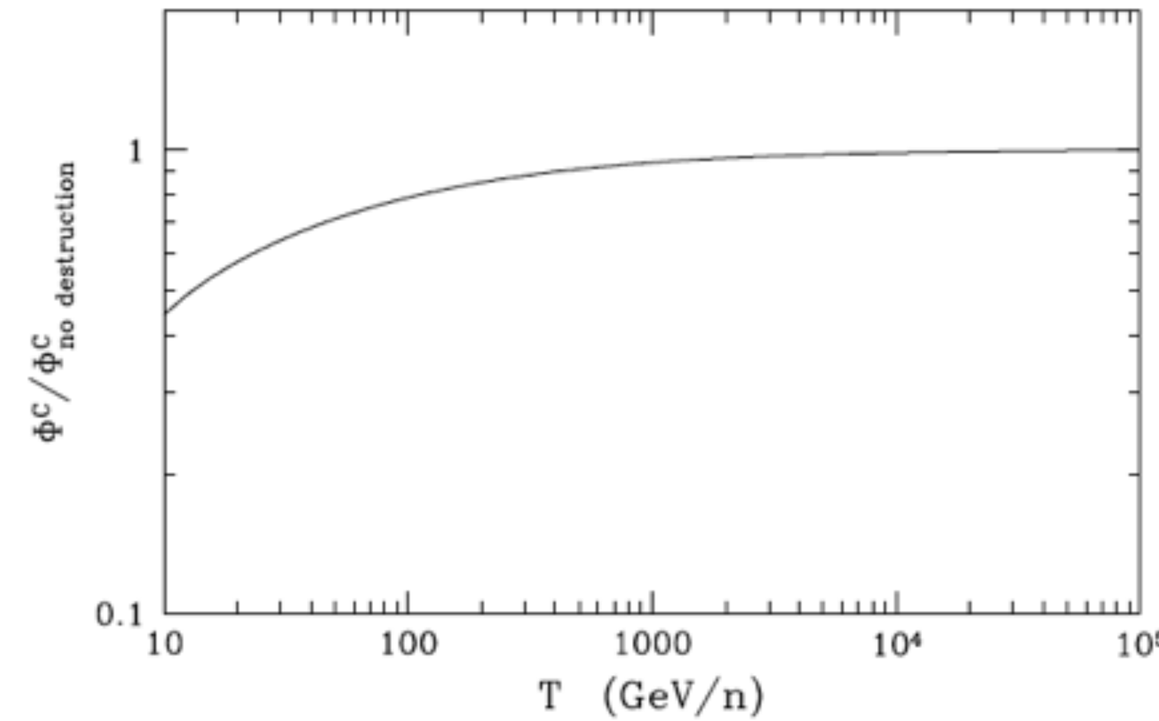


Fig. 4. *Ratio of calculated carbon fluxes from the same propagation model, where nuclear destructions have been turned off at the denominator.*

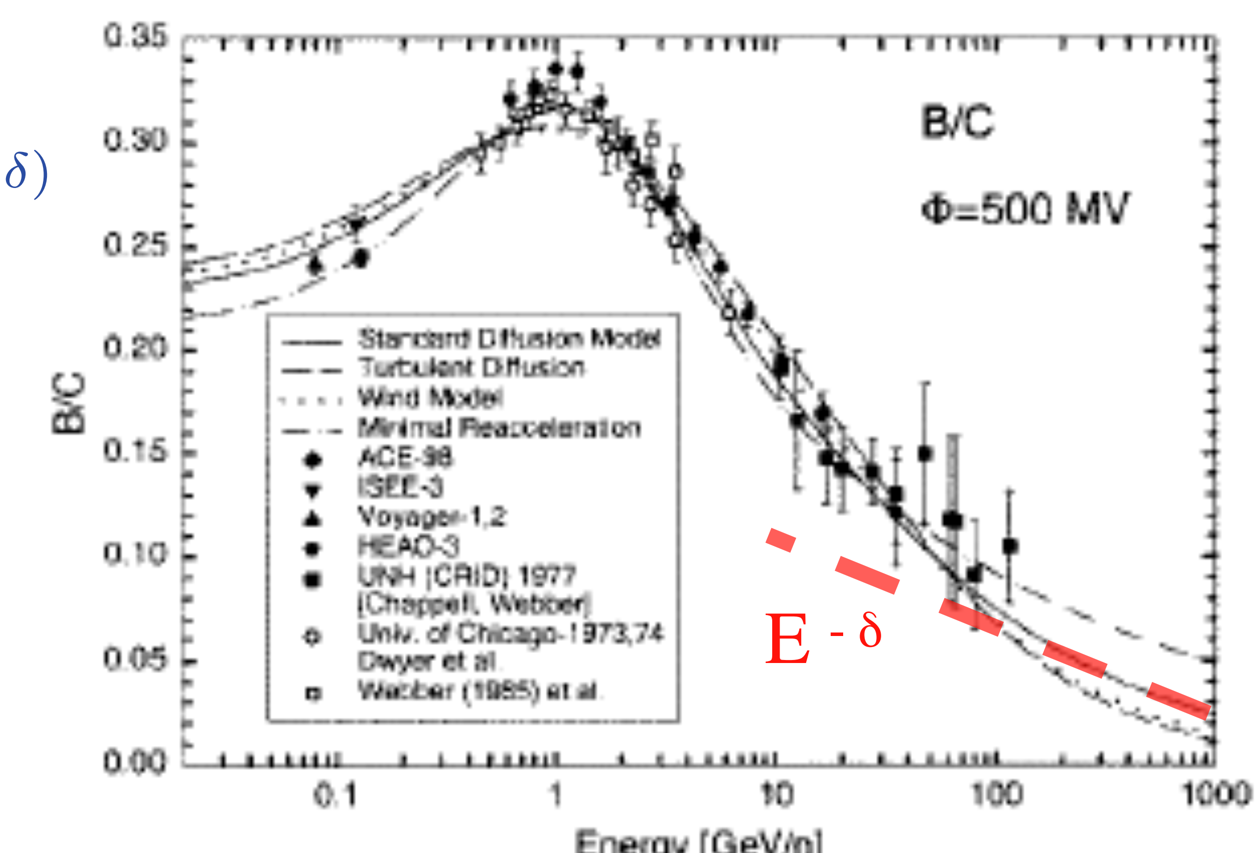
above ~ 100 GeV/n
energy losses become energy independent (other effect are also negligible at those energies, see below), hence CR spectra are determined by diffusion. Hence from a simple leaky box model

for primary nuclei spectra

$$N_i(E) \equiv \frac{dN_i}{dE} \propto Q_i(E)\ \tau_{\rm esc}(E) \propto E^{-(\alpha_i+\delta)}$$

for primary/secondary ratio

$$\frac{N_p(E)}{N_s(E)} \propto E^{-\delta}$$



Reacceleration and convection

- <u>Reacceleration</u>

due to stochastic scattering onto MHD waves (Fermi 2nd order acc.)
For a given detection energy it increases the residence time respect to the no reaccelerating case (more secondaries)

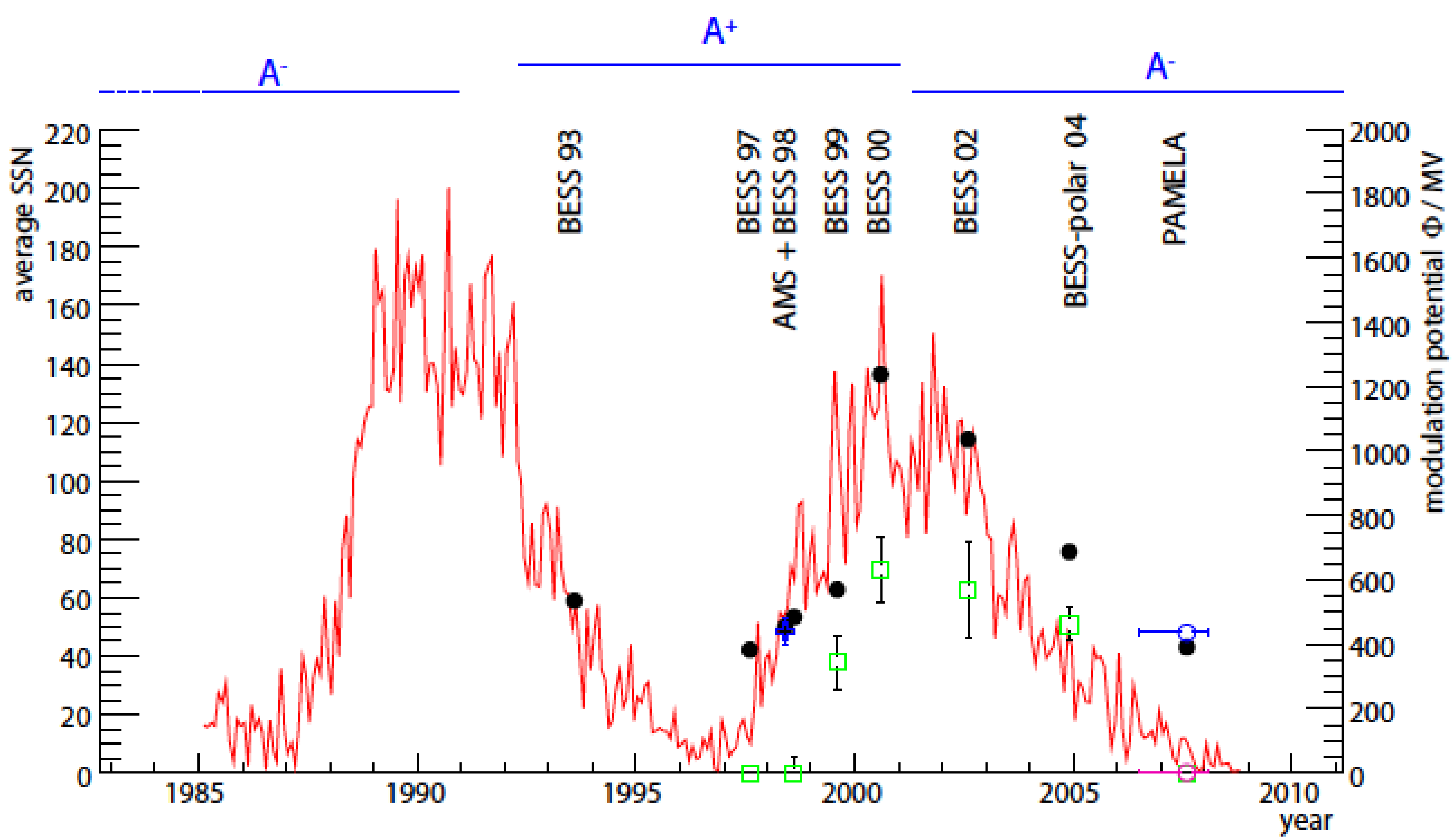
in the quasi-linear theory $D_{pp} = p^2 V_A^2 / (9\,D)$
$V_A = B^2 / (4\pi\,\rho_{plasma}) \simeq 10\ km^2/s$ in the ISM (large uncertainty)
Berezinsky et al. 1990, Schlickeiser 2002

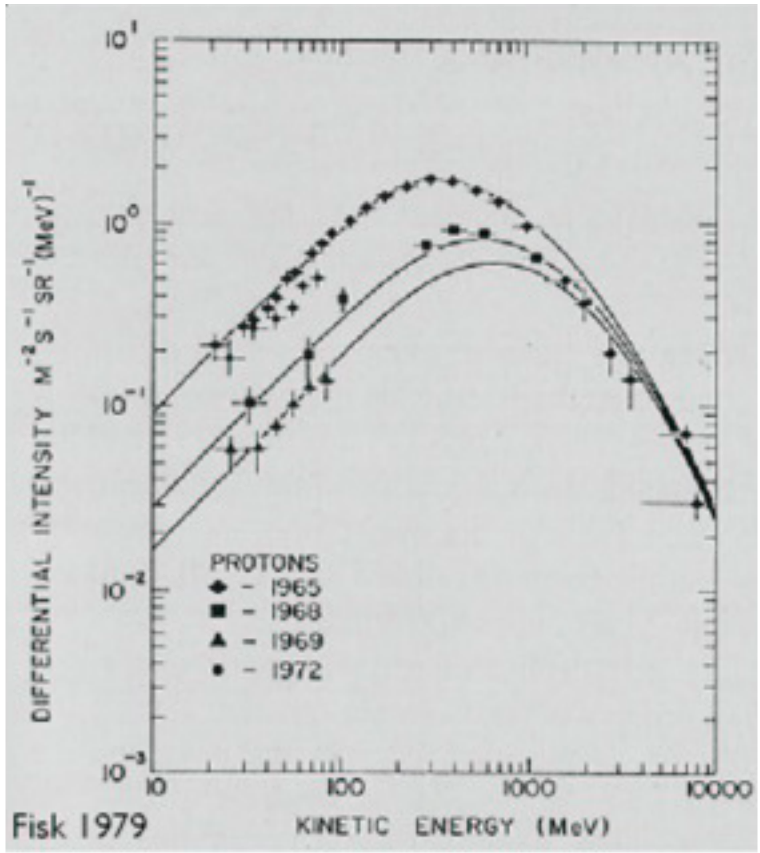
- <u>Convection</u>

$$\frac{dE}{dt} = -\frac{2}{3}\frac{nV}{N}E(\boldsymbol{\nabla}\cdot\boldsymbol{v}) = -\frac{2}{3}(\boldsymbol{\nabla}\cdot\boldsymbol{v})E$$

evidence of winds are observed with speed as high as 100 km/s
They should transport and induce adiabatic cooling of low energy CR
Take in mind that V_C may also depend on R

Solar modulation





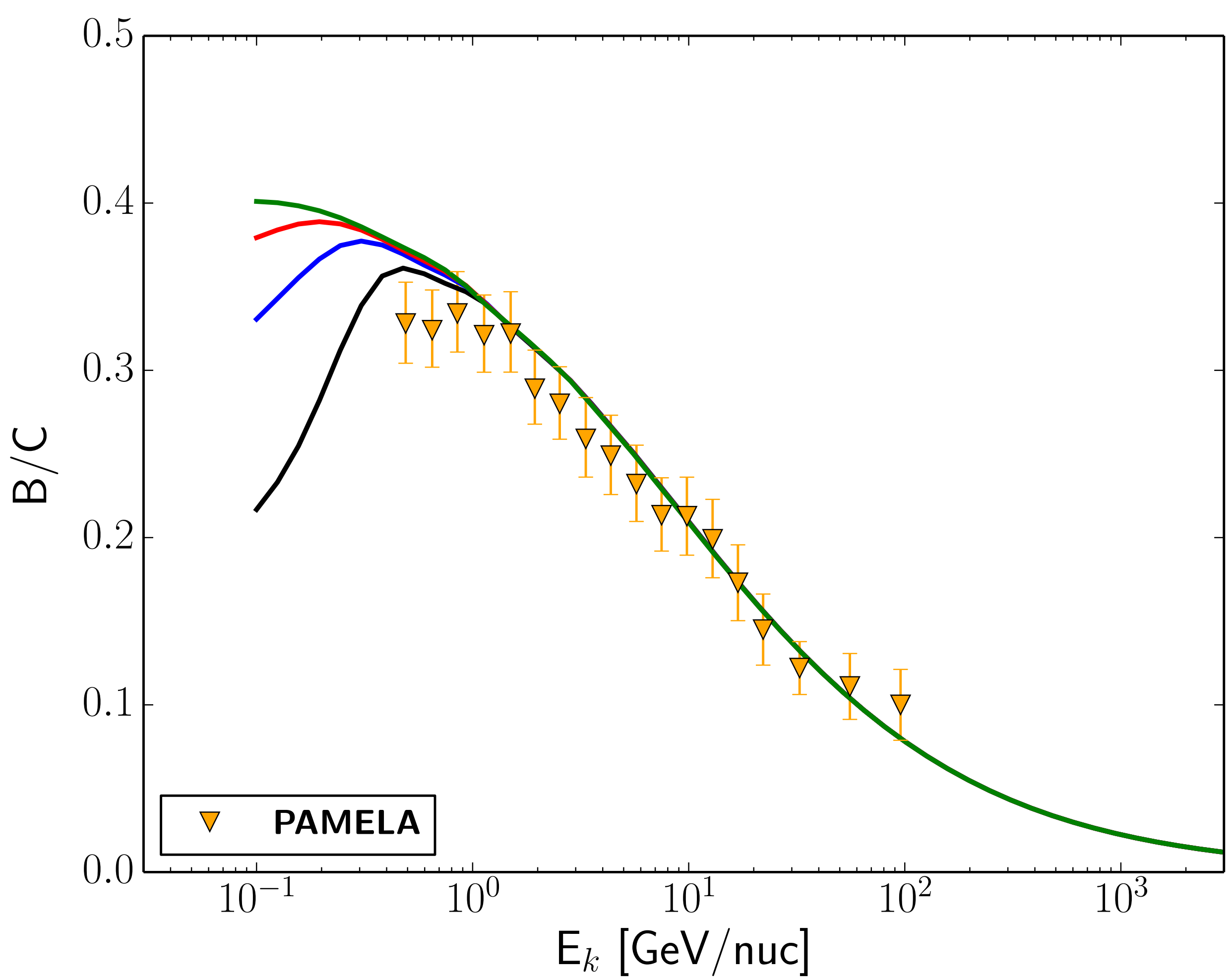
Solar modulation (force field approximation)

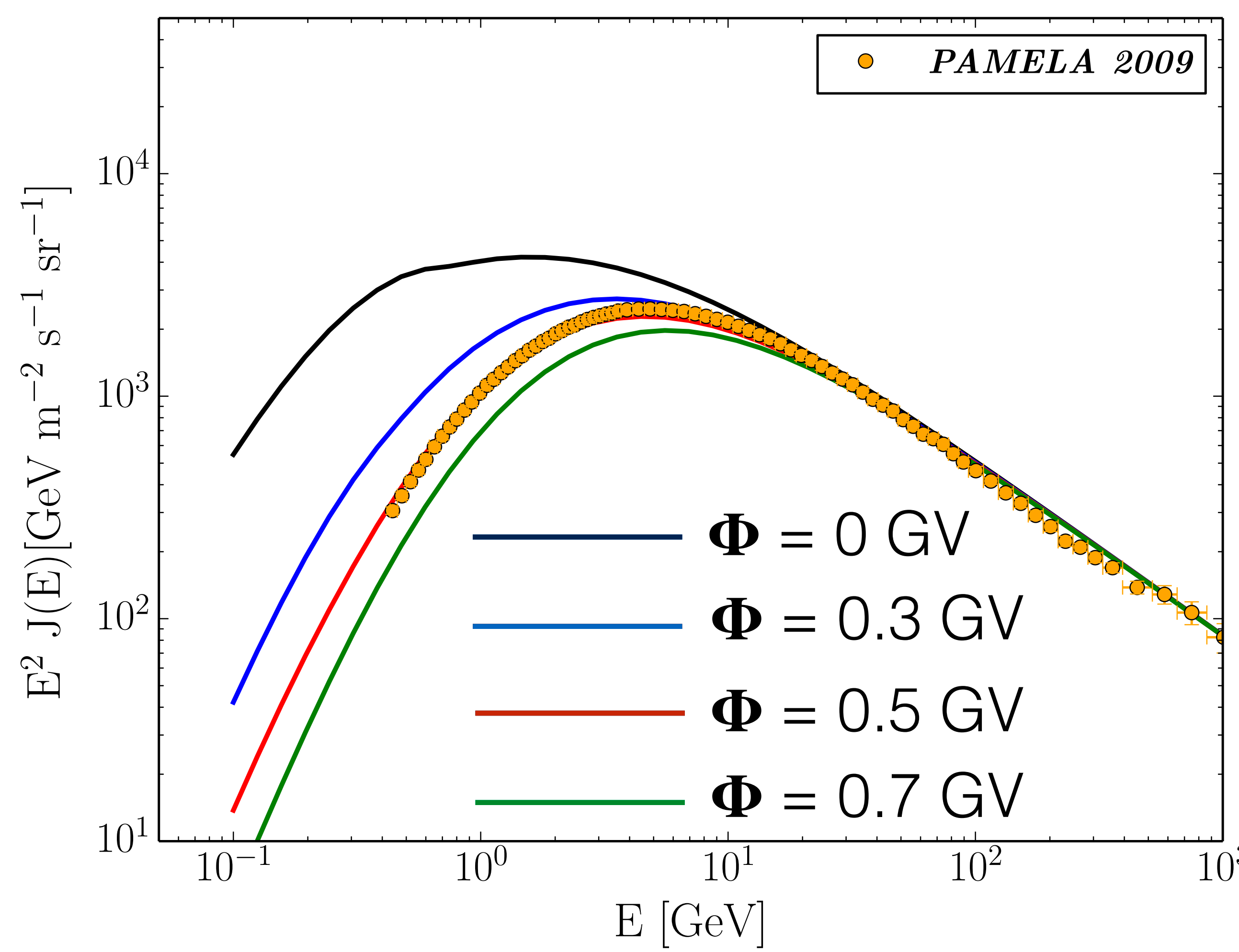
Gleeson & Axforfd 1968

$$J(E_k, Z, A) = \frac{(E_k + m)^2 - m^2}{\left(E_k + m + \frac{Z|e|}{A}\Phi\right)^2 - m^2} J_{\text{LIS}}(E_k + \frac{Z|e|}{A}\Phi, Z, A)$$

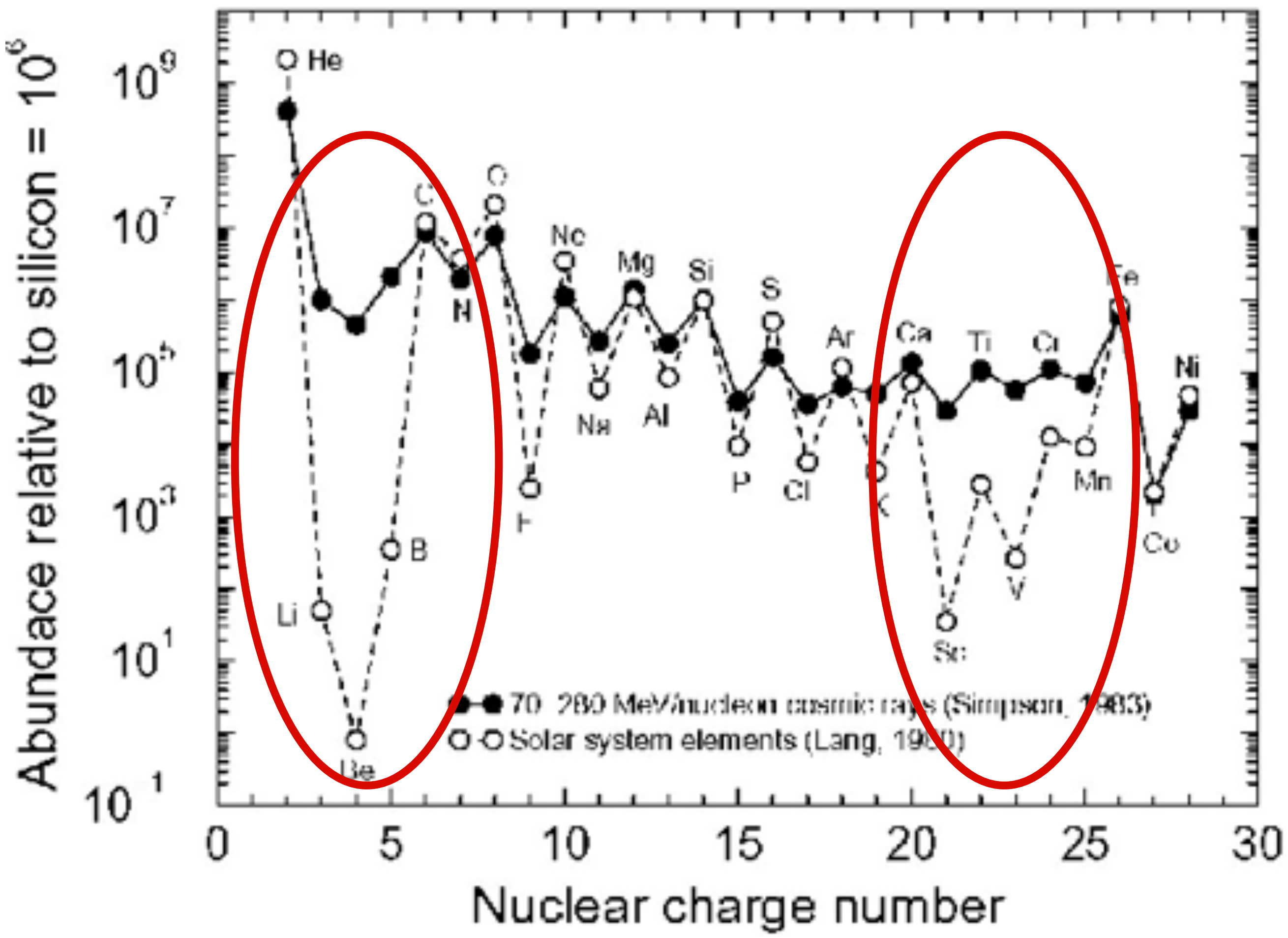
modulated spectrum

DRAGON output





Diffusion parameters from secondary-primary ratio



J.A. Simpson, Ann. Rev. Nucl. Part. Sci. 33 (1983) 323

In order to reproduce the measured abundances of stable nuclei, CRs should have traversed: ~**10 g cm²** of material:

Primary species are present in sources (CNO, Fe). Produced by stellar nucleosynthesis. Acceleration in SN shocks (≥10^4 yr).

Secondary species are absent of sources (LiBeB, SubFe). Produced during propagation of primaries.

Plain diffusion - uniform D

D - *L* are **almost** degenerate

(for spherical symmetry $\tau_{esc} \propto \dfrac{R^2}{D}$)

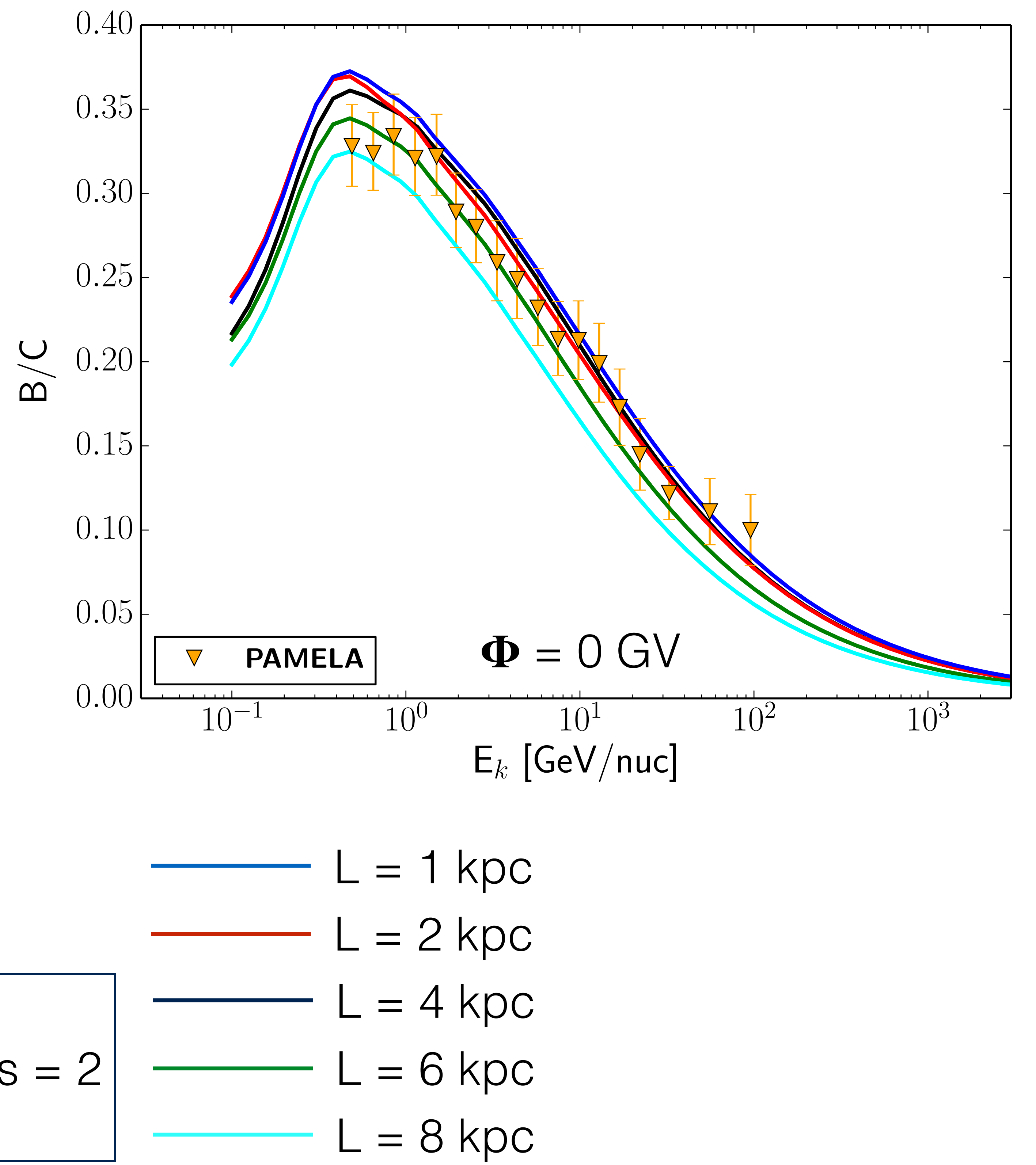
In the plot $D_0 / L = 0.675 =$ **const**

where D_0 is in units of 10^{28} cm^2/s and
L " " of kpc

good degeneracy only for low L !

(Z_{max} = 14 is enough for modeling B/C)

for the models in the plot
$\delta = 0.6$, $v_A = 0$, $v_C = 0$, $\eta = 1$; dimensions = 2
$\Phi = 0$



Plain diffusion - uniform D

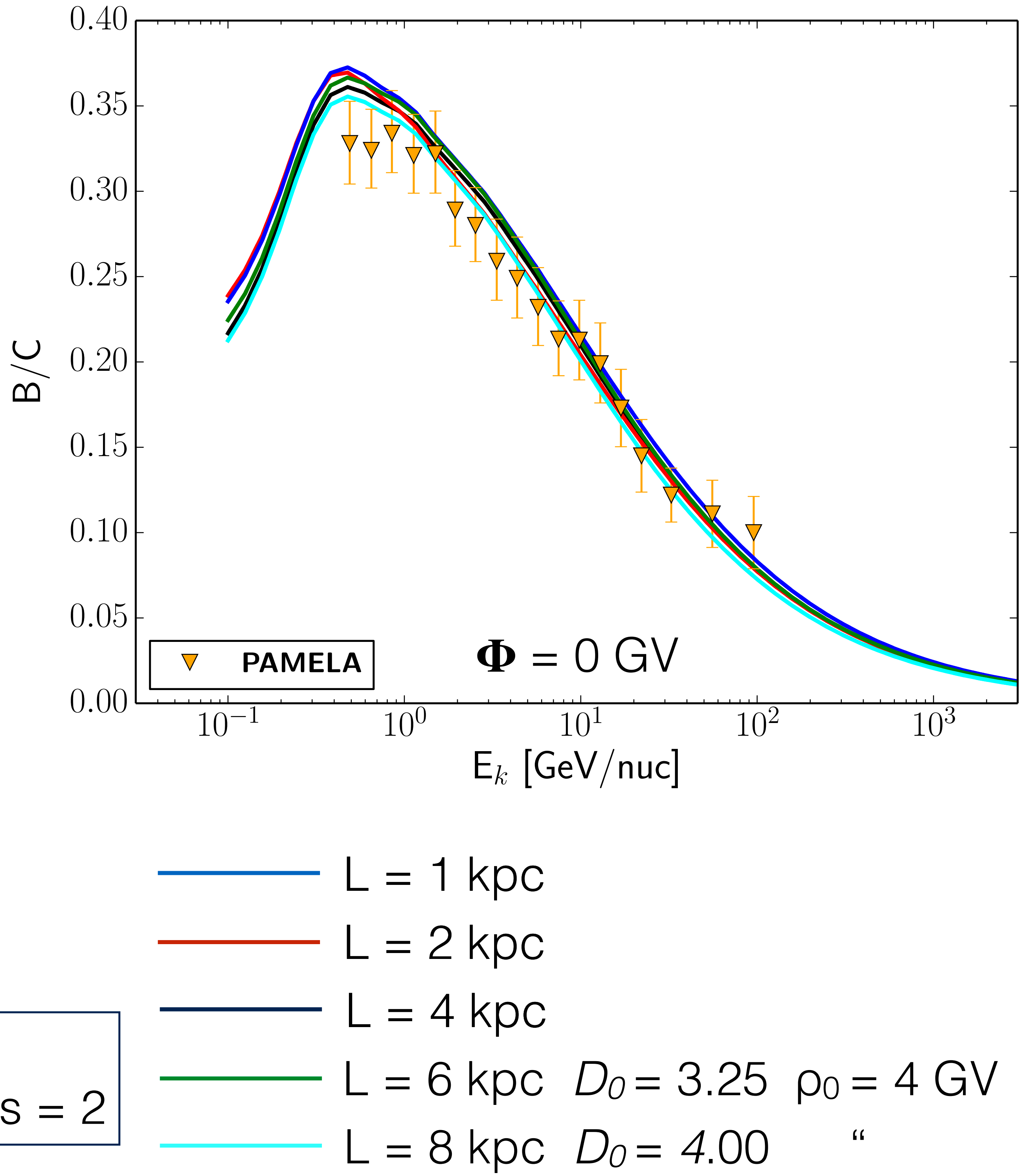
D - *L* are **almost** degenerate

(for spherical symmetry $\tau_{esc} \propto \frac{R^2}{D}$)

In the plot $D_0 / L = 0.675$
only for L = 1, 2, 4 kpc

where D_0 is in units of 10^{28} cm^2/s and
L " " of kpc

degeneracy is restored after rescaling D_0, ➜ we cannot use the B/C to constrain L !



for the models in the plot
$\delta = 0.6$, $v_A = 0$, $v_C = 0$, $\eta = 1$; dimensions = 2

Plain diffusion - uniform D

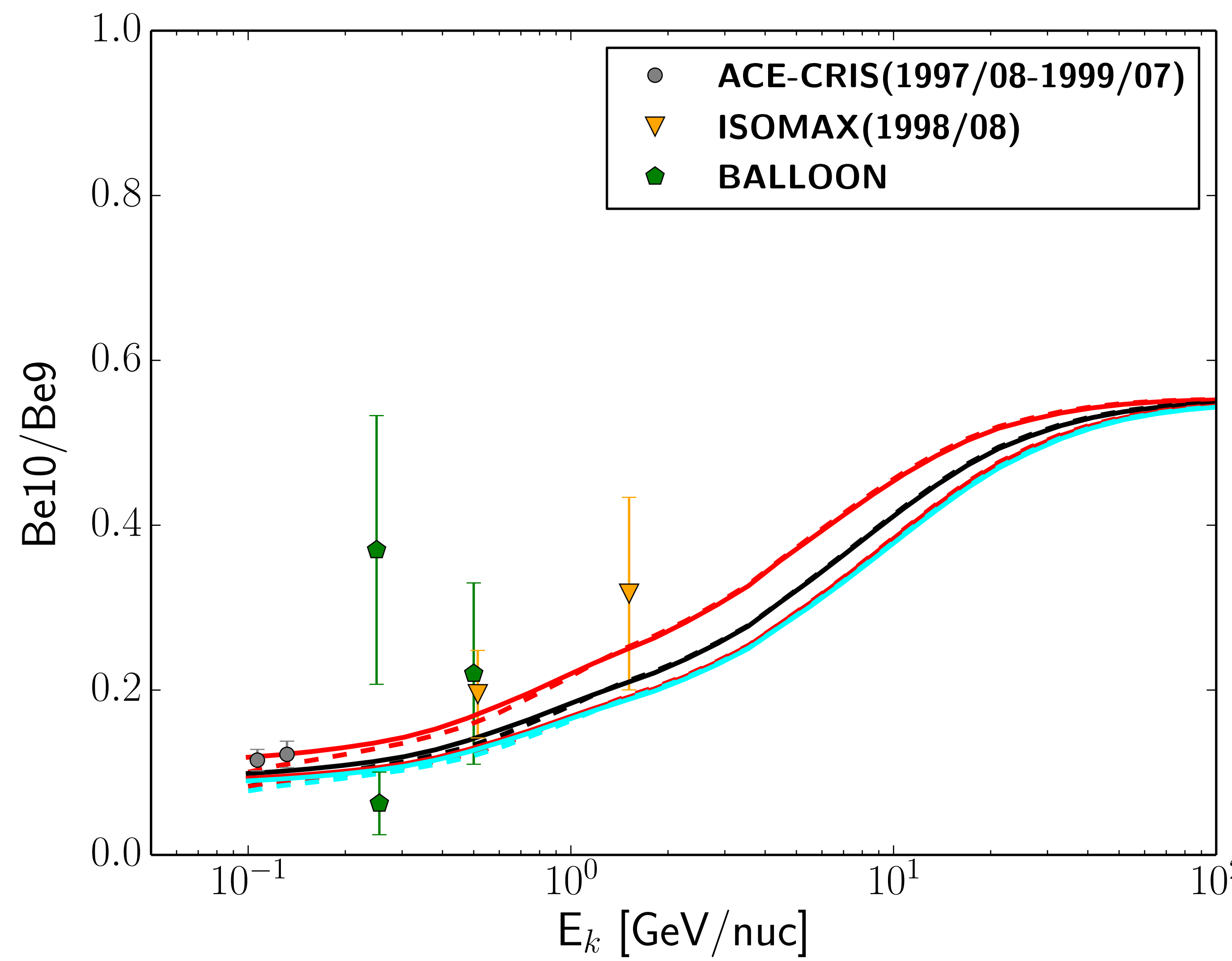
D - L   are **almost** degenerate

(for spherical symmetry $\tau_{esc} \propto \frac{R^2}{D}$)

In the plot $D_0 / L = 0.675$
only for L = 1, 2, 4 kpc

where D_0 is in units of 10^{28} cm²/s and
L   "   "   of   kpc

degeneracy is restored after rescaling D_0, ➜ we cannot use the B/C to constrain L !



L = 2 kpc
L = 4 kpc
L = 6 kpc $D_0 = 3.25$ $\rho_0 = 4$ GV
L = 8 kpc $D_0 = 4.00$ "

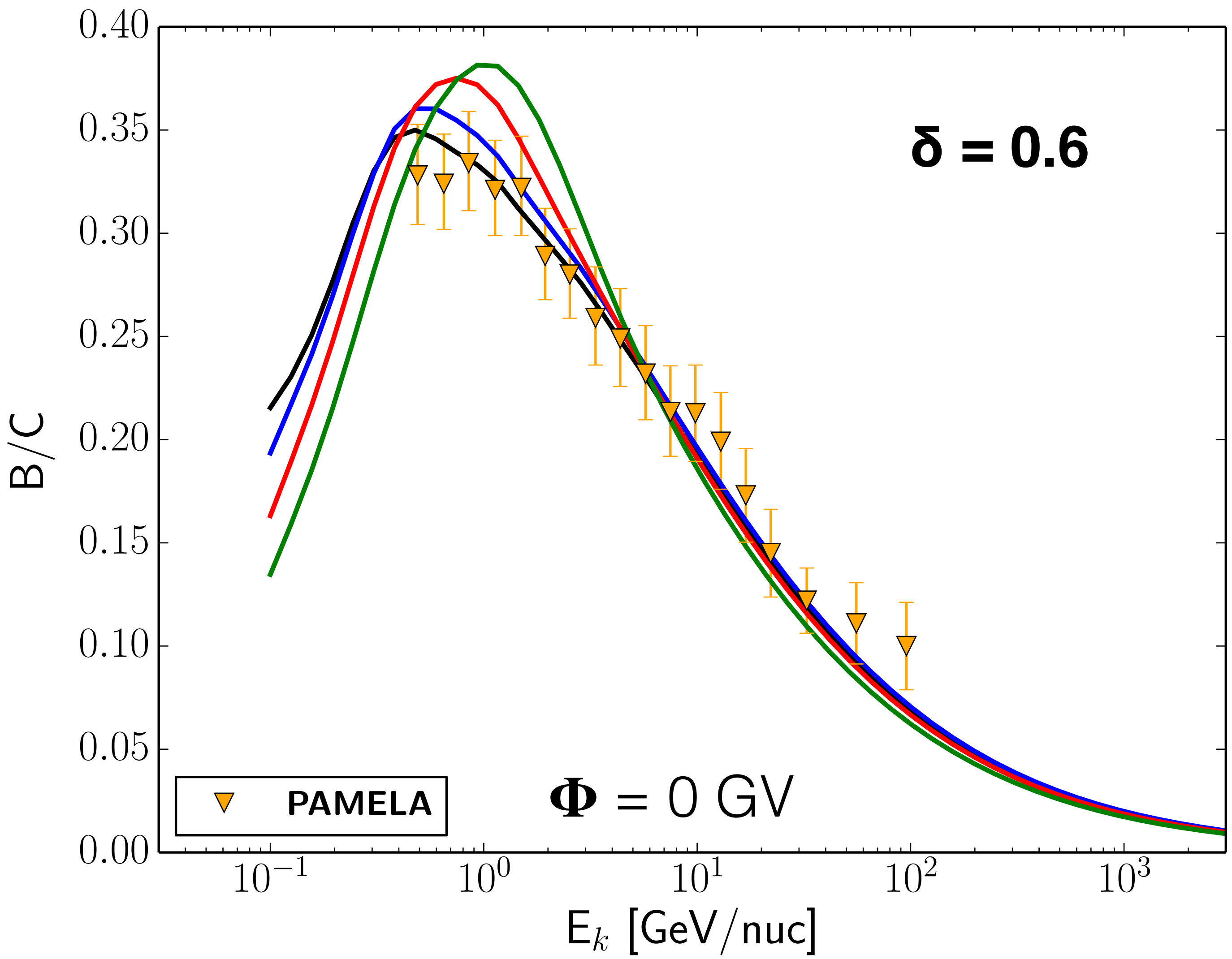
for the models in the plot
$\delta = 0.6$, $v_A = 0$, $v_C = 0$, $\eta = 1$;   dimensions = 2

The effect of reacceleration

Generally this is parametrized in terms of V_A entering in D_{pp}

increasing $V_{A,}$ particles detected at a given E have spent some time at lower energy, hence they had a larger residence time with respect to the case with $V_A = 0$ → more secondaries !

When changing V_A , D_0 has to be rescaled to reproduce the B/C above 10 GeV/n <u>(above that energy the effects of reacceleration are negligible for realistic V_A)</u>



V_A = 0 km/s D_0 = 2.5

V_A = 10 km/s D_0 = 2.8

V_A = 20 km/s D_0 = 3.0

V_A = 30 km/s D_0 = 3.25

for the models in the following plots
δ = 0.6, L = 4 kpc , $v_C = 0$, η = 1 ; dimensions = 2
D(z) <u>exponential</u>;

The effect of reacceleration

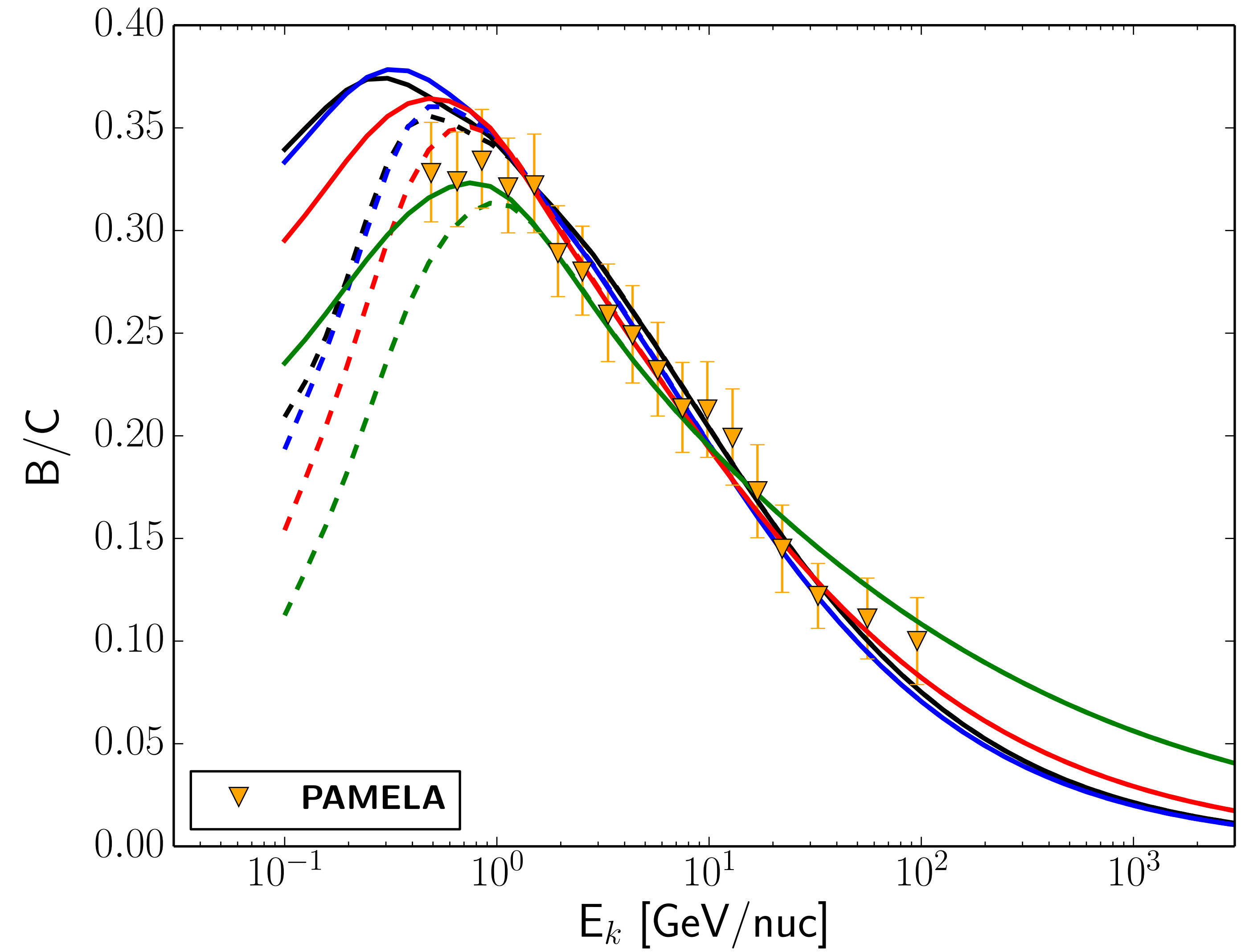
when increasing V_A the diffusion coefficient rigidity dependence (δ) has to be changed !

<u>note that the source spectral index has to be changed so to leave $\alpha_i + \delta$ constant</u>

in the literature high values of V_A were introduced to match the B/C below 1 GeV/n

α_i : source spectral index of nuclei

Φ = 0 GV - - - **Φ = 0.4 GV** ———



δ = 0.6 V_A = 0 km/s D_0 = 2.6 ρ_0 = 4 GV

δ = 0.6 V_A = 10 km/s D_0 = 2.8 "

δ = 0.5 V_A = 20 km/s D_0 = 3.5 "

δ = 0.33 V_A = 30 km/s D_0 = 5.0 "

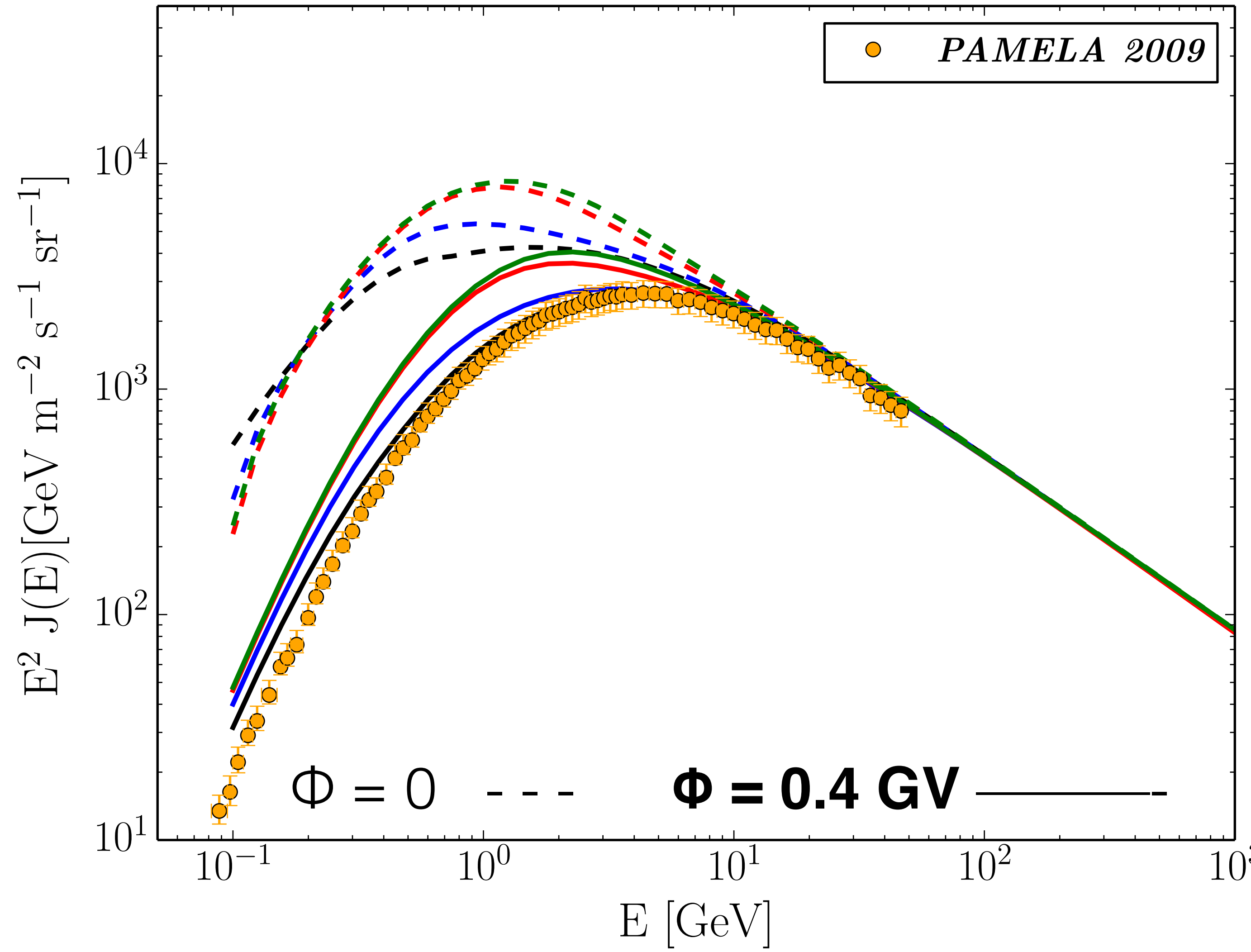
The effect of reacceleration (proton spectrum)

when increasing V_A the diffusion coefficient rigidity dependence (δ) has to be changed !

<u>note that the source spectral index has to be change so to leave $\alpha_i + \delta$ constant</u>

in the literature high values of V_A were introduced to match the B/C below 1 GeV/n

large V_A result in more peaked spectra at about 1 GeV/n



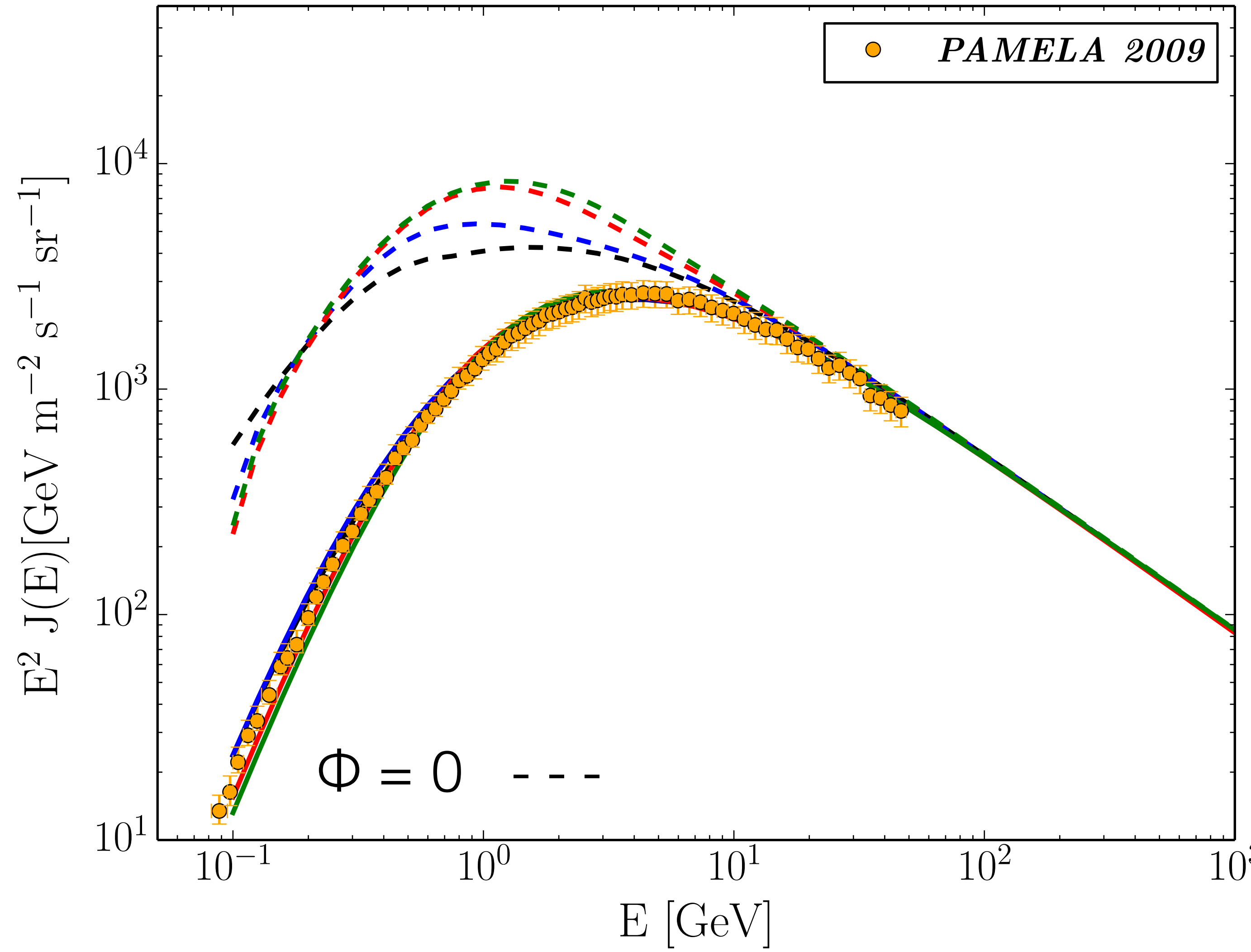
(dark blue line)	δ = 0.6	V_A = 0 km/s	D_0 = 2.6	Φ = 0.35 GV	α = 2.2
(blue line)	δ = 0.6	V_A = 10 km/s	D_0 = 2.8	Φ = 0.35 GV	α = 2.2
(red line)	δ = 0.5	V_A = 20 km/s	D_0 = 3.5	Φ = 0.35 GV	α = 2.3
(green line)	δ = 0.33	V_A = 30 km/s	D_0 = 5.0	Φ = 0.35 GV	α = 2.47

The effect of reacceleration (proton spectrum)

larger V_A result in more peaked spectra at about 1 GeV/n

this may be compensated increasing the modulation potential

⇒ degeneration V_A - Φ !



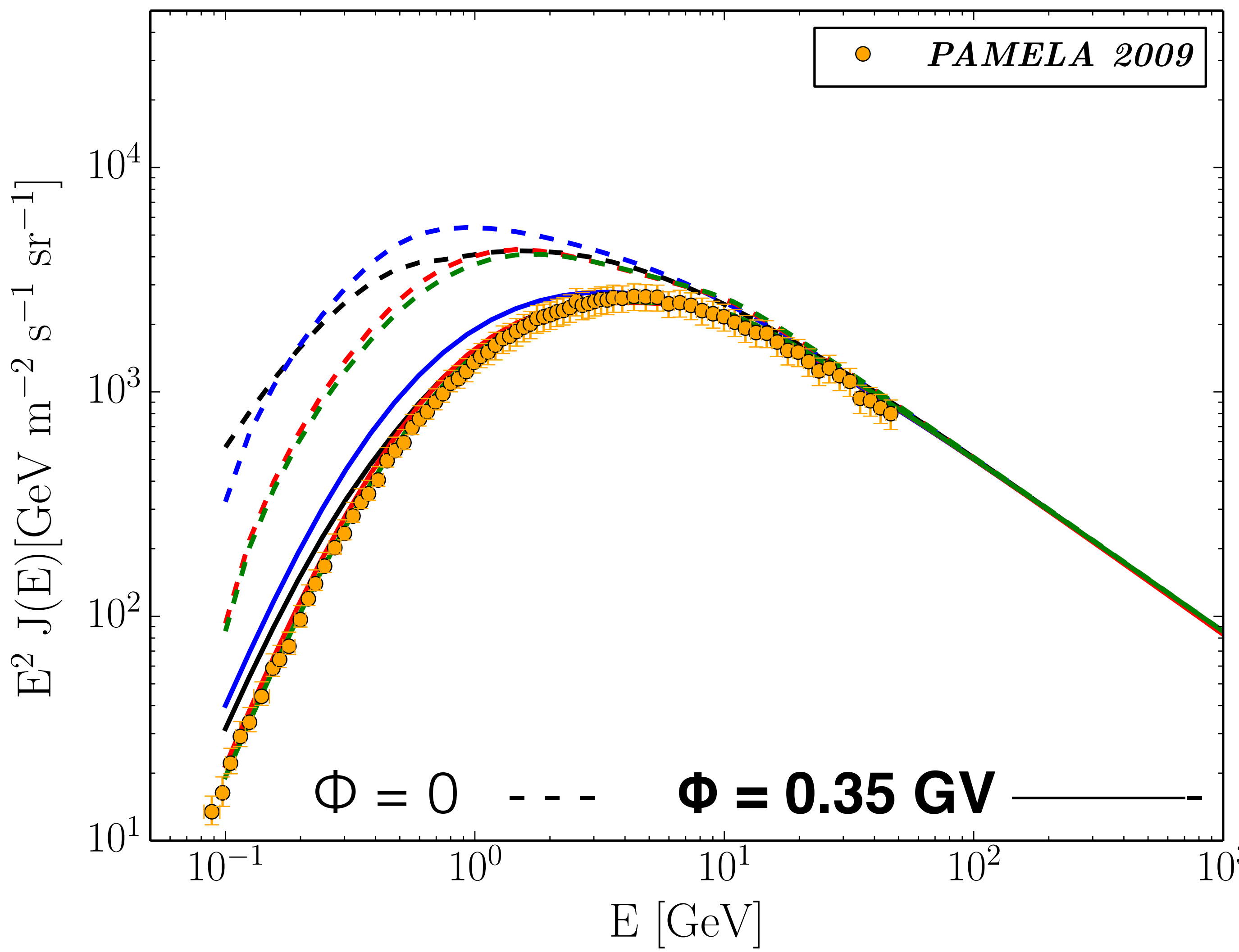
(dark blue line)	$\delta = 0.6$	$V_A = 0$ km/s	$D_0 = 2.6$	**Φ = 0.4 GV**
(blue line)	$\delta = 0.6$	$V_A = 10$ km/s	$D_0 = 2.8$	Φ = 0.45 GV
(red line)	$\delta = 0.5$	$V_A = 20$ km/s	$D_0 = 3.5$	Φ = 0.60 GV
(green line)	$\delta = 0.33$	$V_A = 30$ km/s	$D_0 = 5.0$	Φ = 0.65 GV

The effect of reacceleration (proton spectrum)

large V_A result in more peaked spectra at about 1 GeV/n

this may be compensated increasing the modulation potential

or introducing a break in the p source spectrum at ~ 10 GeV
(marginal effect on the B/C)



dark blue line	δ = 0.6	V_A = 0 km/s	D_0 = 2.6	Φ = 0.35 GV	α = 2.2
blue line	δ = 0.6	V_A = 10 km/s	D_0 = 2.8	Φ = 0.35 GV	α = 2.2
red line	δ = 0.5	V_A = 20 km/s	D_0 = 3.5	Φ = 0.35 GV	α = 2.0/2.3 b/a 11 GeV
green line	δ = 0.33	V_A = 30 km/s	D_0 = 5.0	Φ = 0.35 GV	α = 2.1/2.45 b/a 11 GeV

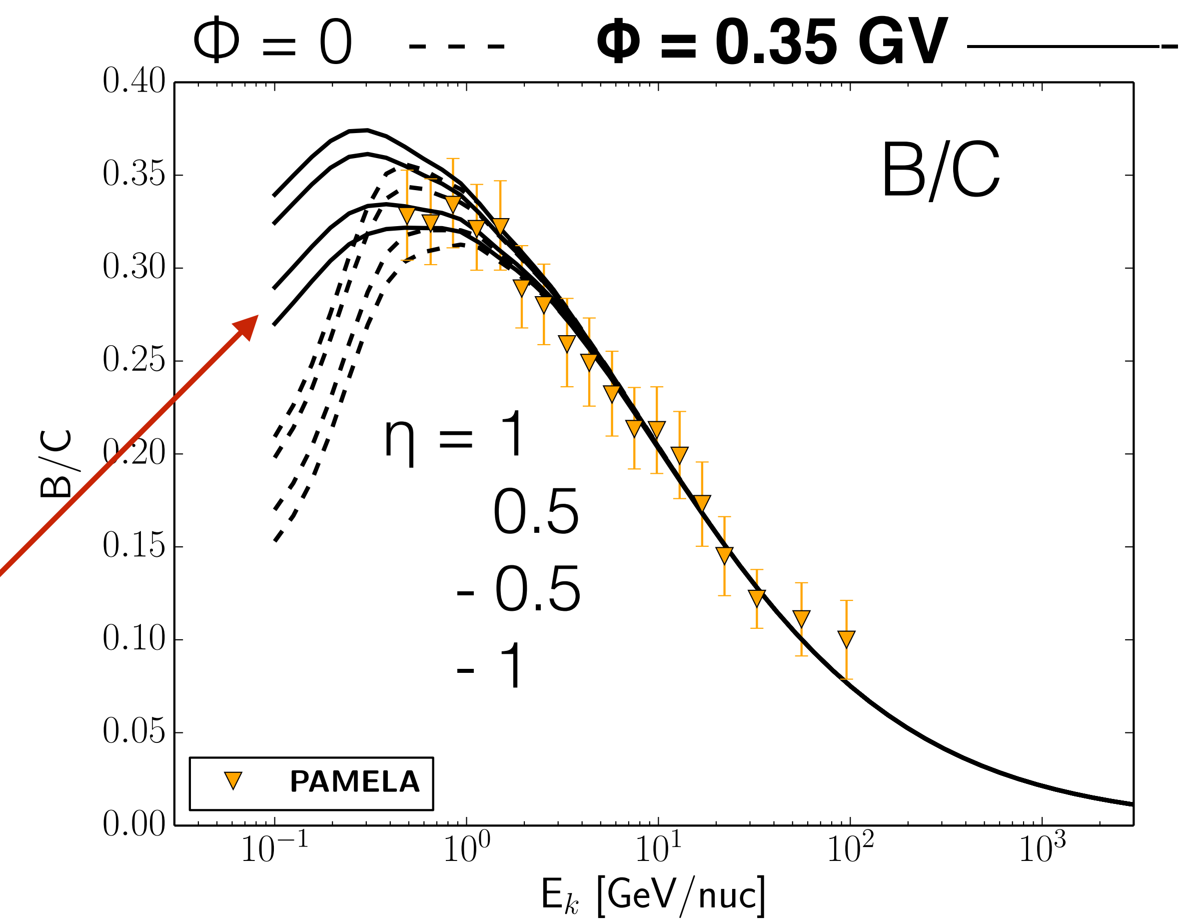
The effect of changing D(E) at low energy

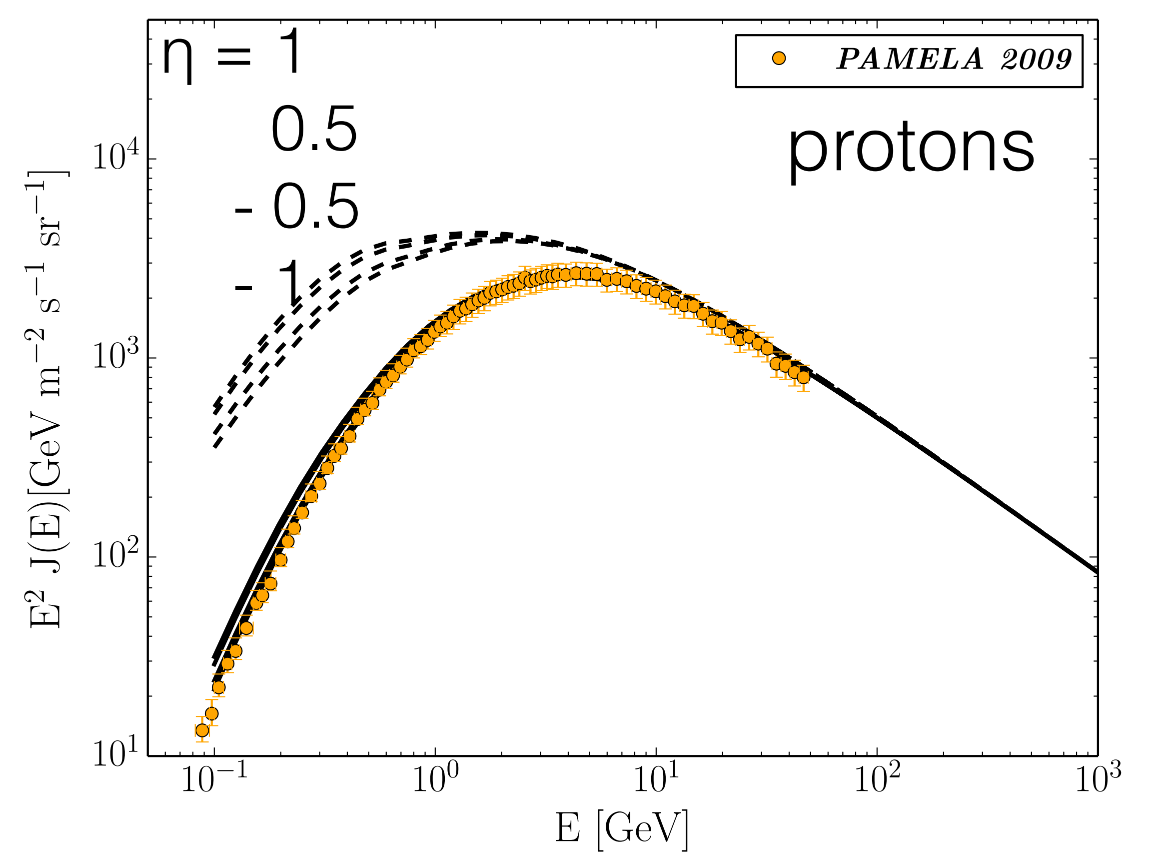
This may be parameterized in the form

$$D(\rho) = D_0\ \beta^\eta \left(\frac{\rho}{\rho_o}\right)^\delta$$

The effect may help to reproduce the B/C below 1 GeV for low reacceleration models

the effect on the proton spectrum is small and almost degenerate with solar modulation





models in the plots
δ = 0.6, v_{C} = 0; D_0 = 2.6 z_t = 4 kpc

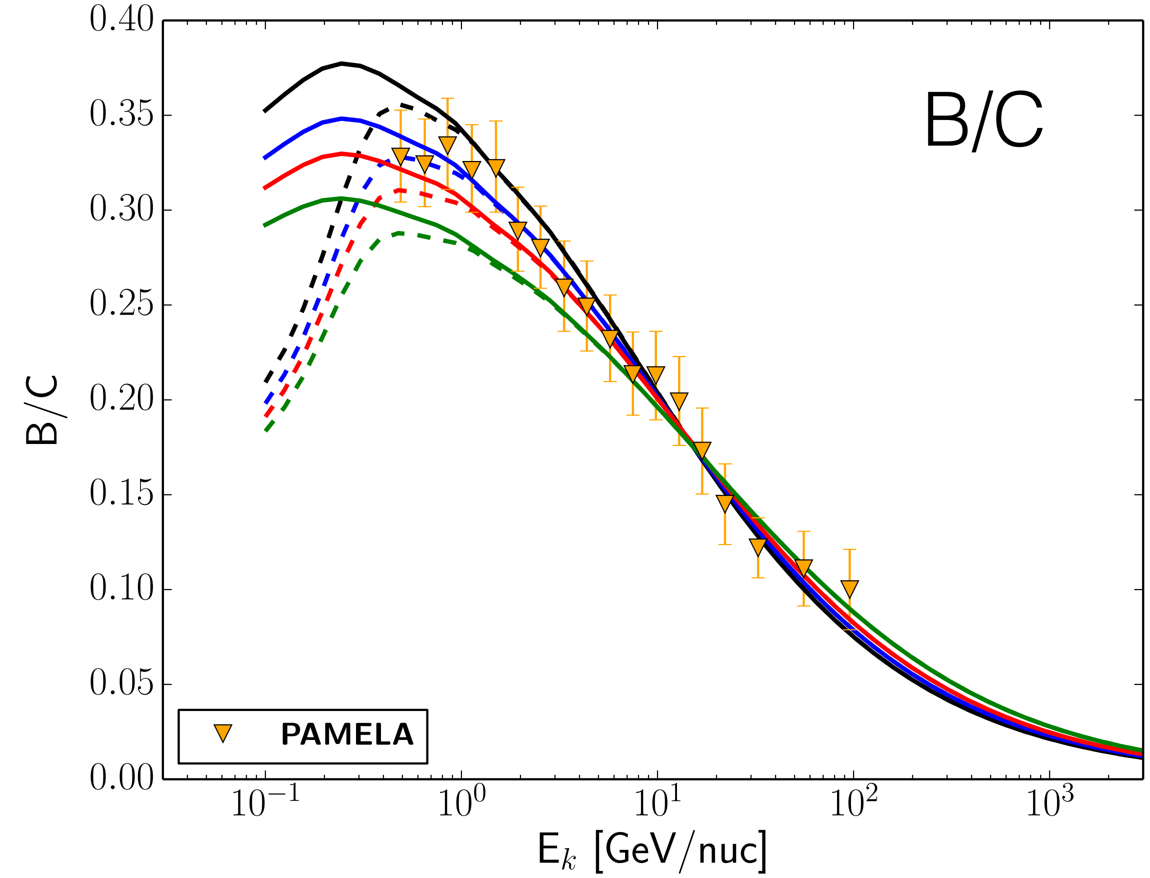
The effects of convection

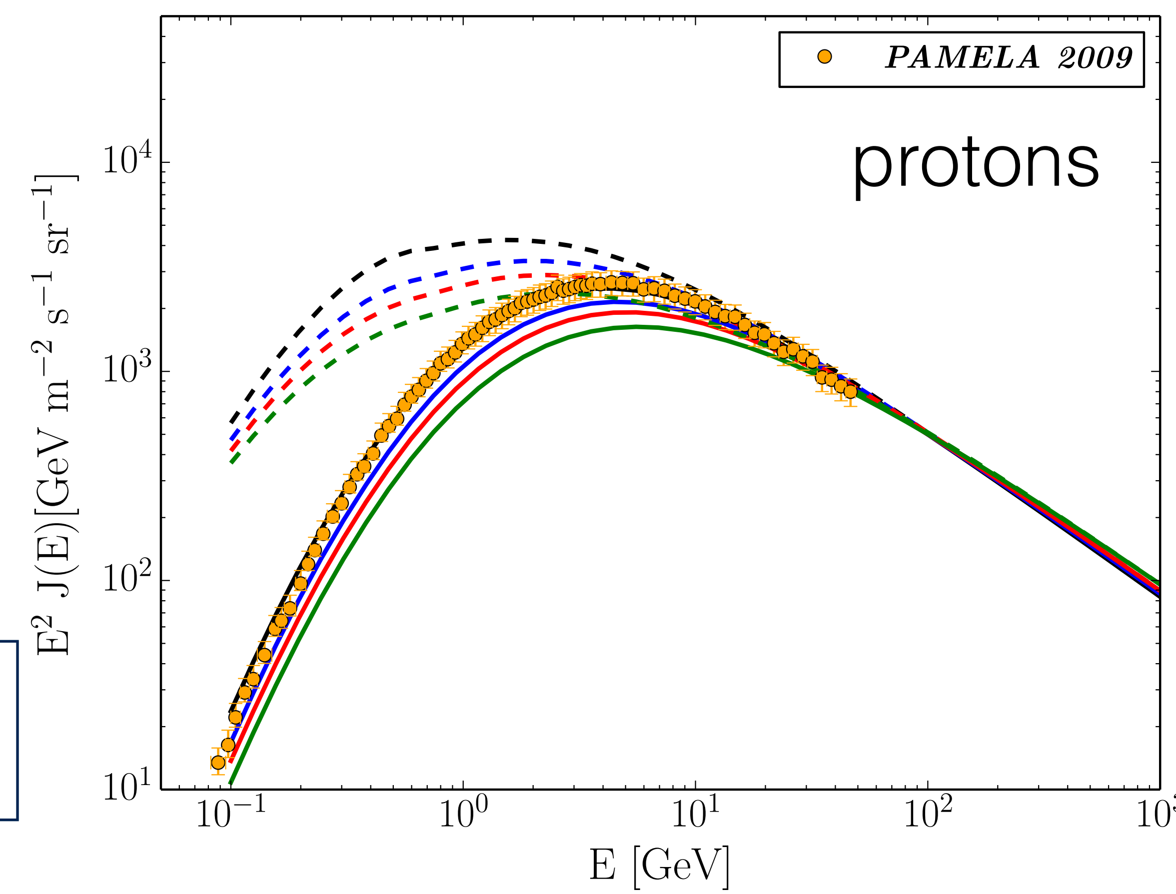
We assume $V_c = 0$ at $z = 0$ and it grows specularly with z with constant dV_c/dz

The effect is negligible above ~ 20 GeV/n

D_0 has to be rescaled when changing dV_c/dz

$\Phi = 0$ - - - **Φ = 0.4 GV** ———



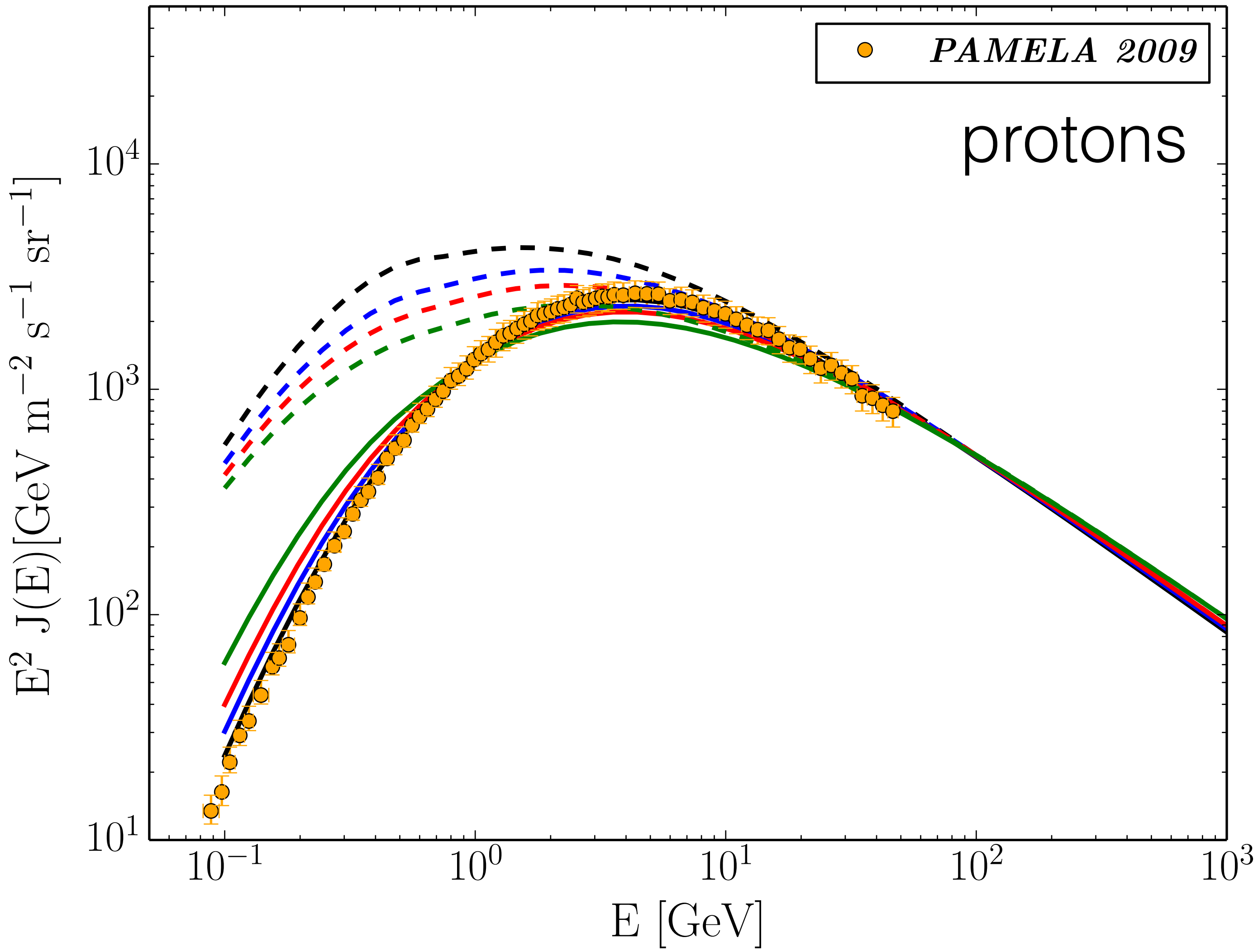


- dV_c/dz = 0 km/s/kpc D_0 = 2.6
- dV_c/dz = 5 km/s/kpc D_0 = 2.4
- dV_c/dz = 10 km/s/kpc D_0 = 2.2
- dV_c/dz = 20 km/s/kpc D_0 = 1.8

for all models in these plots
δ = 0.6, $V_A = 0$; z_t = 4 kpc

The effects of convection

proton data can hardly be matched lowering the modulation potential and only for small values of dV_c/dz



dV_c/dz = 0 km/s/kpc D_0 = 2.6 Φ = 0.4 GV

dV_c/dz = 5 km/s/kpc D_0 = 2.4 Φ = 0.3 GV

dV_c/dz = 10 km/s/kpc D_0 = 2.2 Φ = 0.23 GV

dV_c/dz = 20 km/s/kpc D_0 = 1.8 Φ = 0.15 GV !!

for all models in these plots
δ = 0.6, $V_A = 0$; z_t = 4 kpc

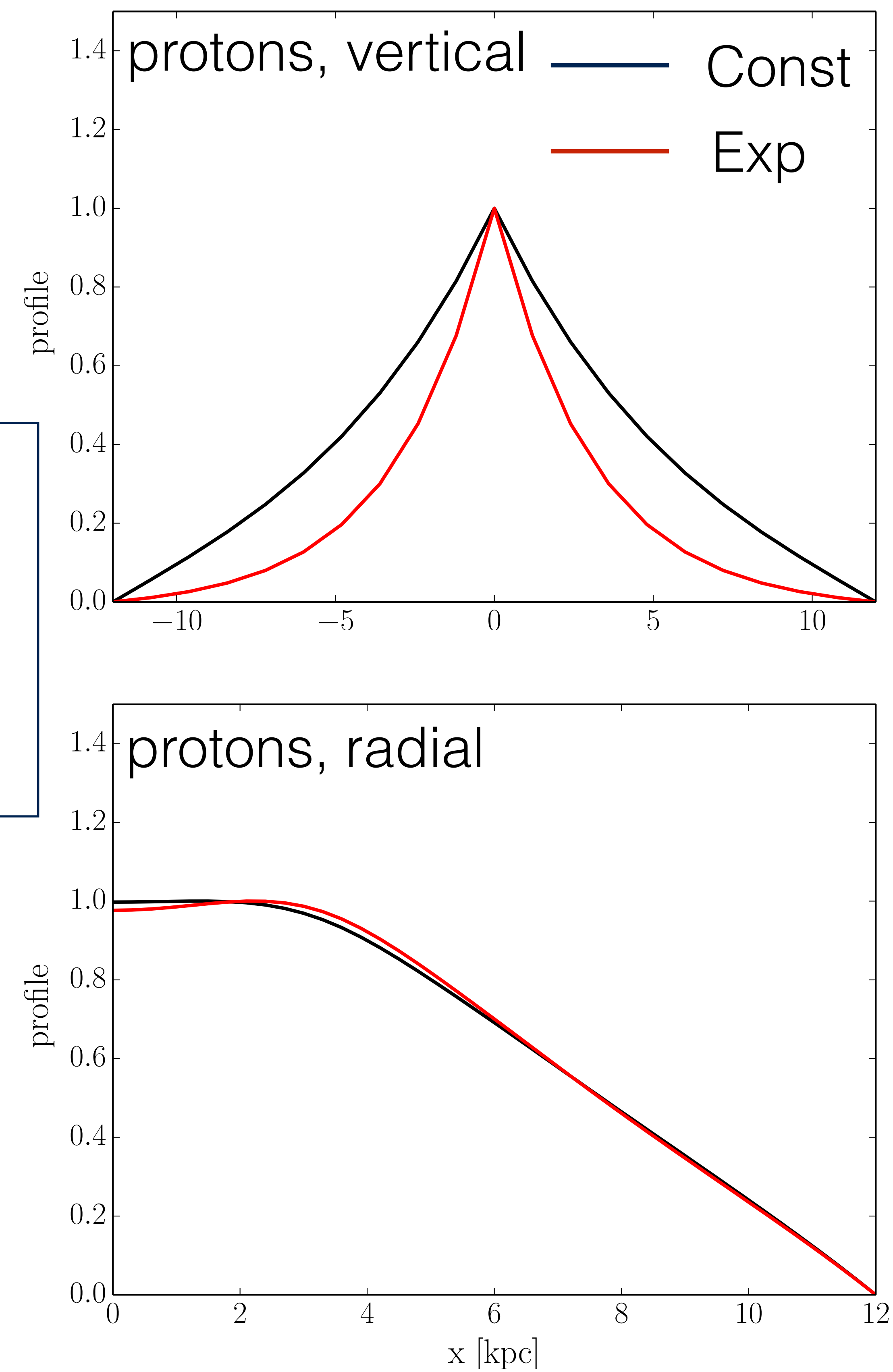
The CR spatial distribution (Constant vs Exp)

Const: $$D(z) = const$$

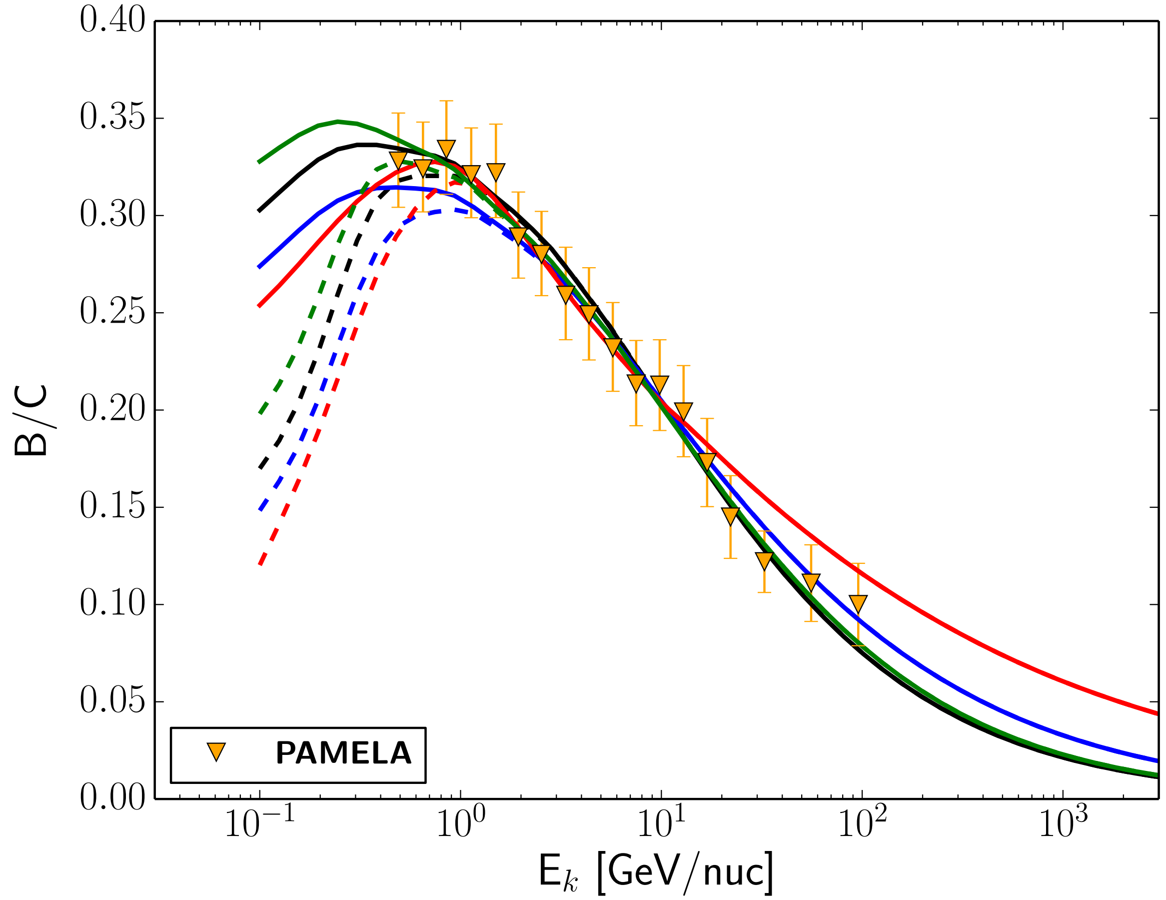
Exp: $$D(z) \propto \exp\left(\frac{z}{z_t}\right)$$

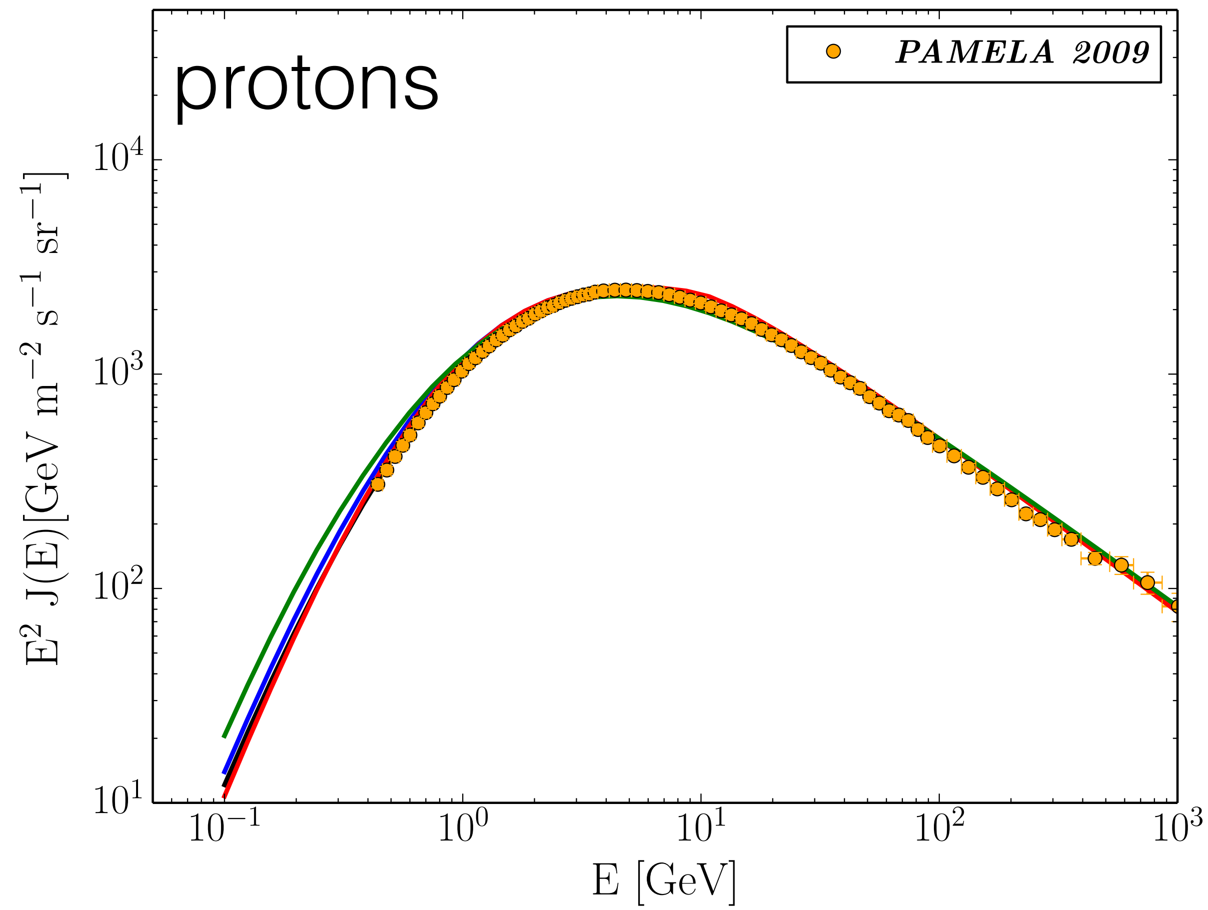
in these plots
$D_0 =$ 2.6, **z_t = 4 kpc**

E = 1 GeV
almost coincident for higher energies as proton energy losses are almost energy independent



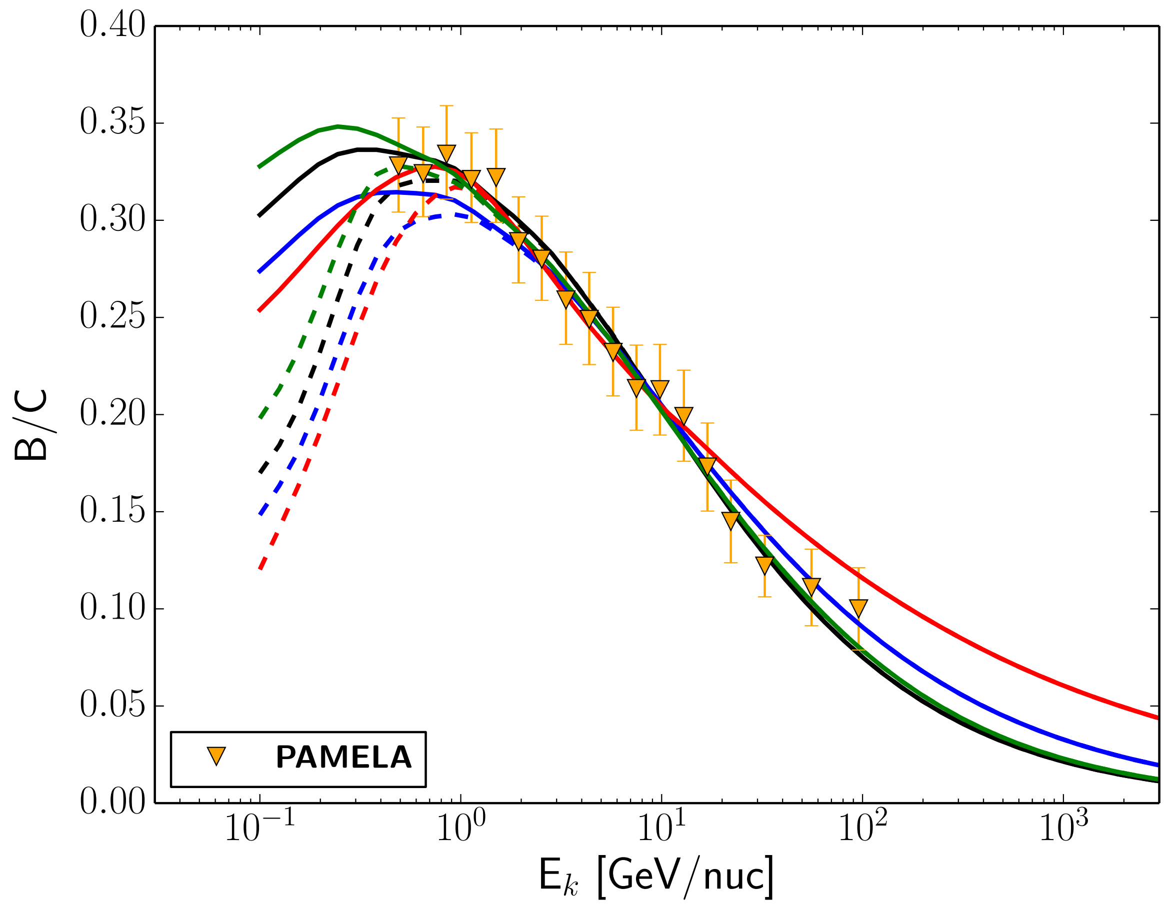
The “fantastic” four

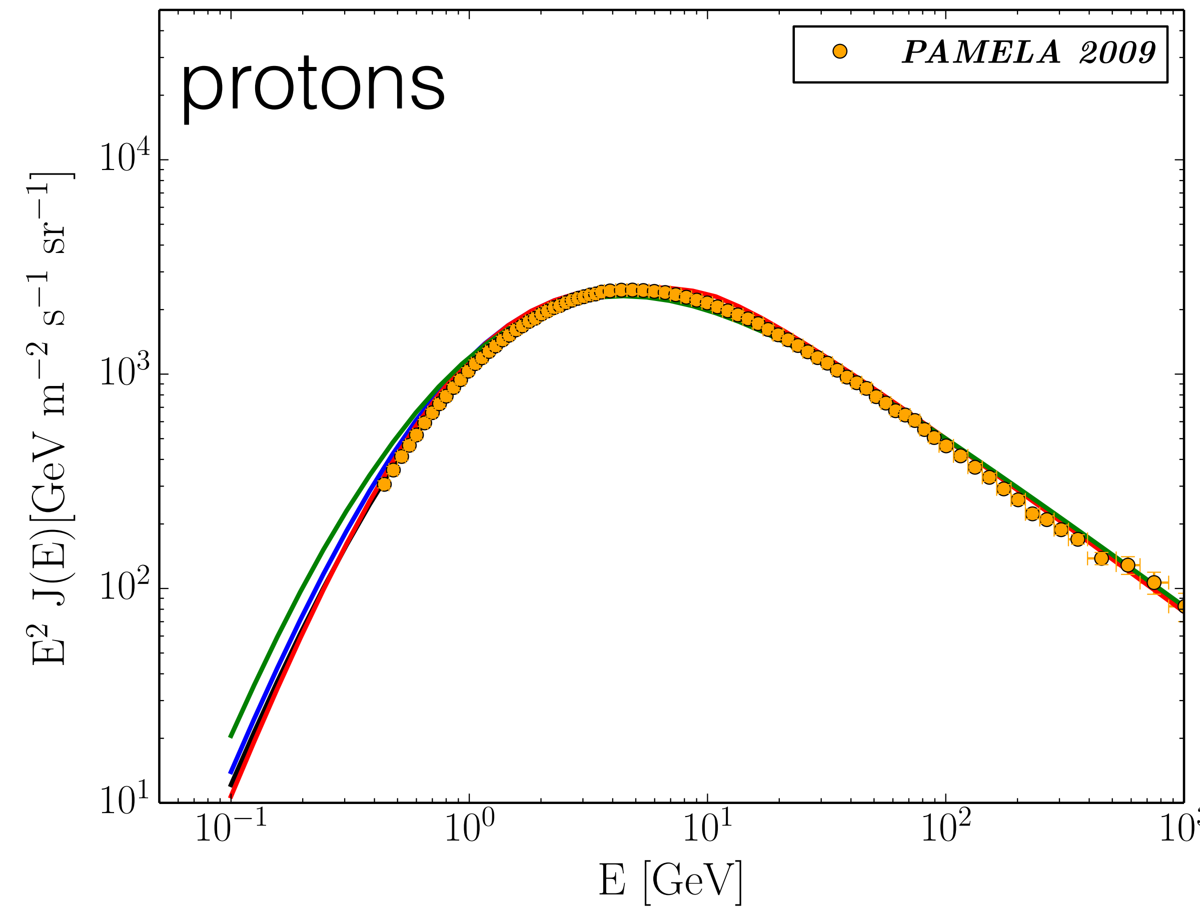




(black line)	δ = 0.6 V_A = 0 km/s D_0 = 2.6 η = -0.5 α = 2.22 dV_c/dz = 0 Φ = 0.5	PD
(blue line)	δ = 0.5 V_A = 10 km/s D_0 = 3.1 η = -0.5 α = 2.32 dV_c/dz = 0 Φ = 0.65	KRA
(red line)	δ = 0.33 V_A = 30 km/s D_0 = 4.6 η = 1 α = 2.1/2.49 dV_c/dz = 0 Φ = 0.5	KOL
(green line)	δ = 0.6 V_A = 0 km/s D_0 = 2.4 η = 1 α = 2.22 dV_c/dz = 5 Φ = 0.5	CONV

The “fantastic” four





$\delta = 0.6$ $V_A = 0$ km/s $D_0 = 2.6$ $\eta = -0.5$ $\alpha = 2.22$ $dV_c/dz = 0$ $\Phi = 0.5$ PD

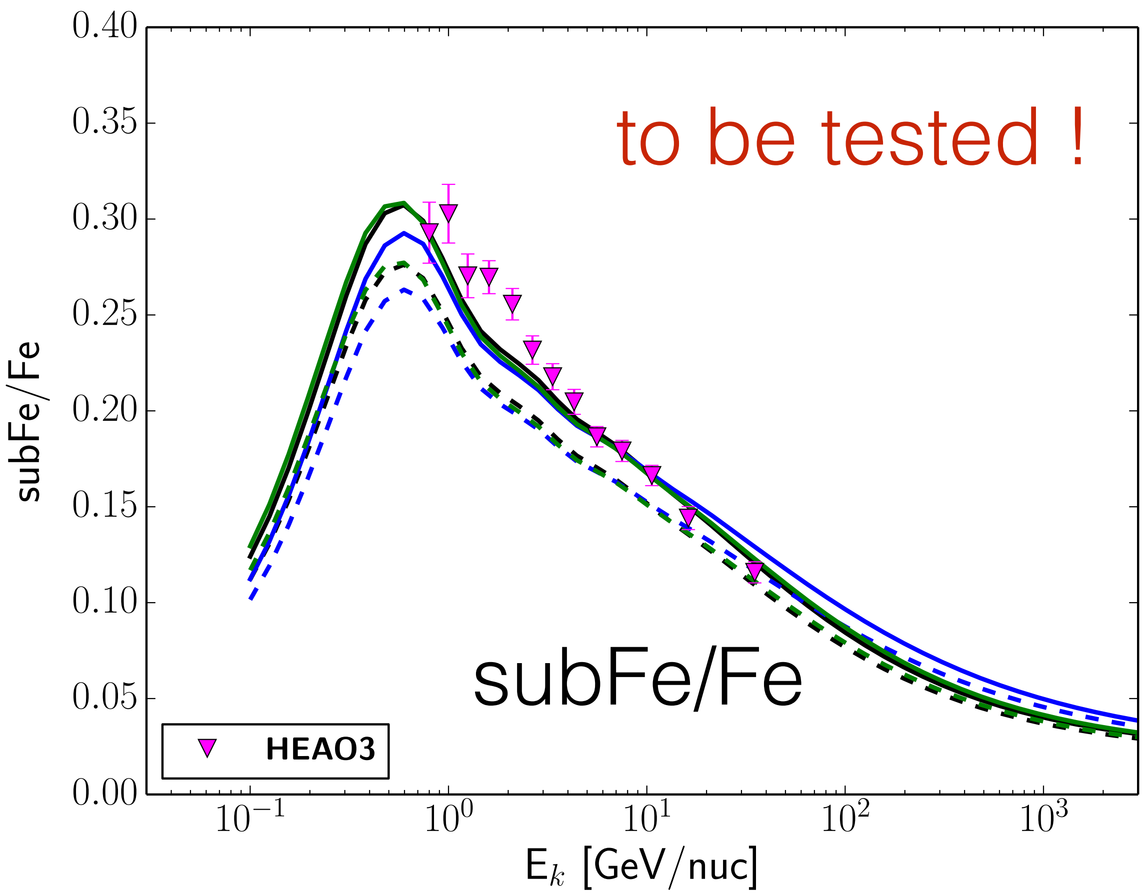
$\delta = 0.5$ $V_A = 10$ km/s $D_0 = 3.1$ $\eta = -0.5$ $\alpha = 2.32$ $dV_c/dz = 0$ $\Phi = 0.65$ KRA

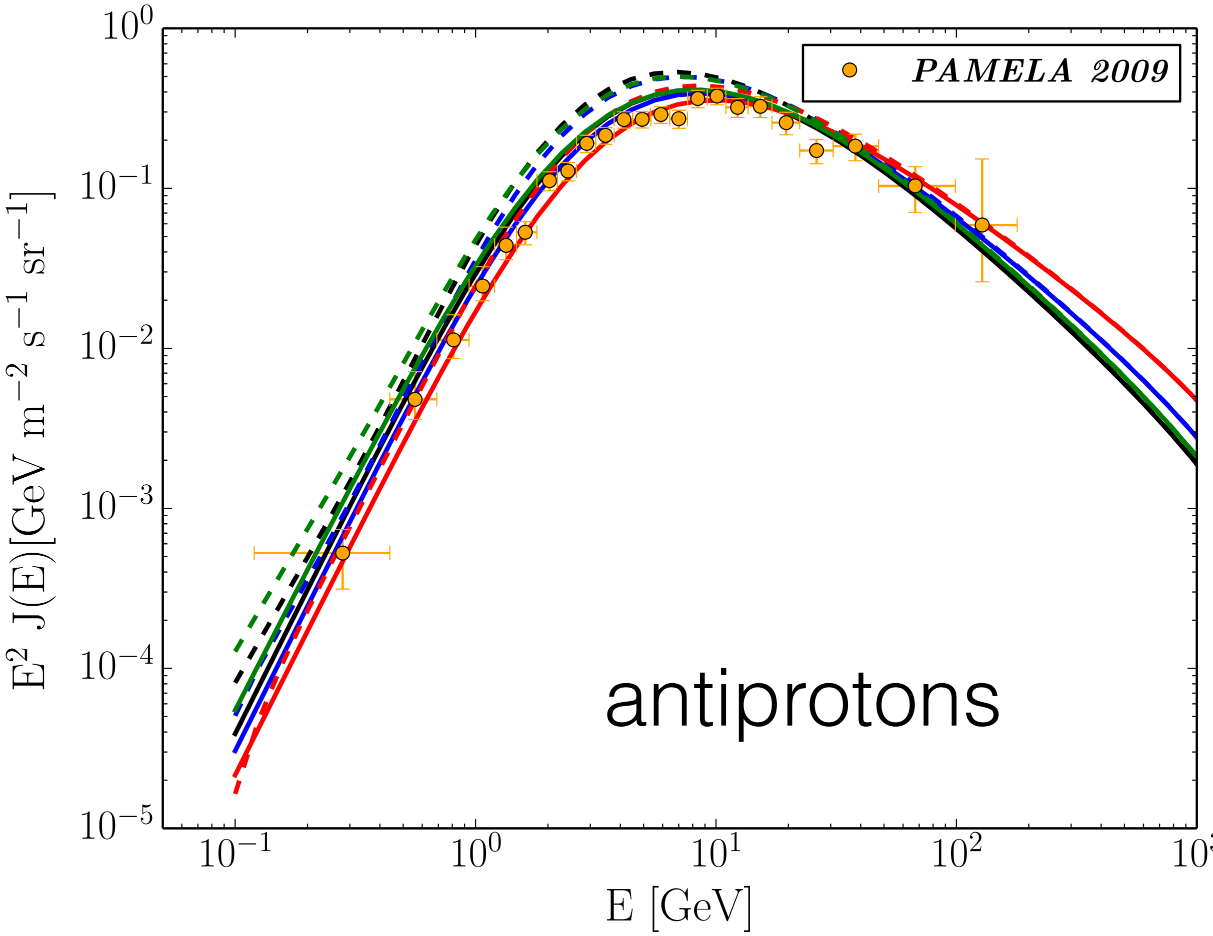
$\delta = 0.33$ $V_A = 30$ km/s $D_0 = 4.6$ $\eta = 1$ $\alpha = 2.1/2.49$ $dV_c/dz = 0$ $\Phi = 0.5$ KOL

$\delta = 0.6$ $V_A = 0$ km/s $D_0 = 2.4$ $\eta = 1$ $\alpha = 2.22$ $dV_c/dz = 5$ $\Phi = 0.5$ CONV

which one is ?

The “fantastic” four





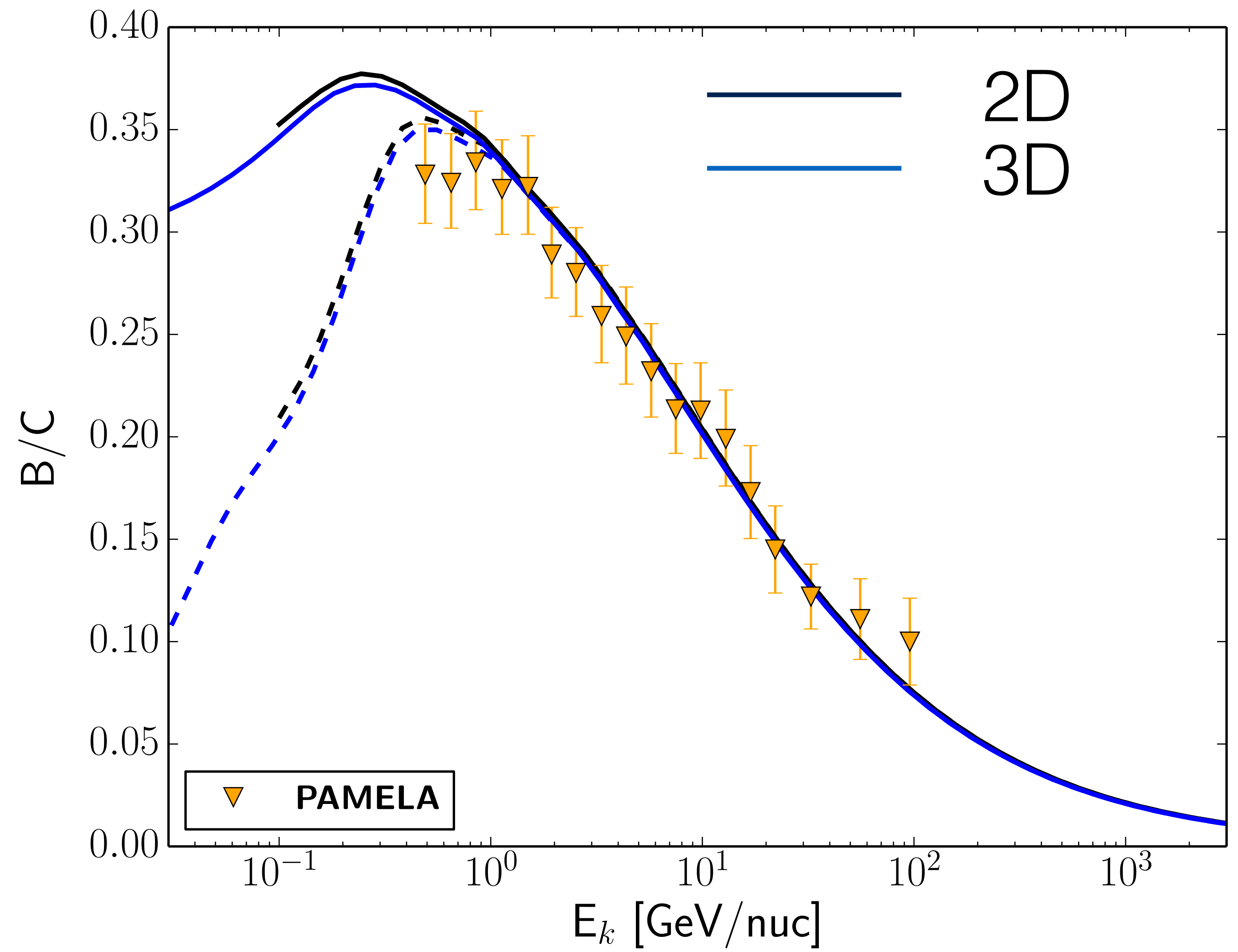
—	$\delta = 0.6$ $V_A = 0$ km/s $D_0 = 2.6$ $\eta = -0.5$ $\alpha = 2.22$ $dV_c/dz = 0$ $\Phi = 0.5$	PD
—	$\delta = 0.5$ $V_A = 10$ km/s $D_0 = 3.1$ $\eta = -0.5$ $\alpha = 2.32$ $dV_c/dz = 0$ $\Phi = 0.65$	KRA
—	$\delta = 0.33$ $V_A = 30$ km/s $D_0 = 4.6$ $\eta = 1$ $\alpha = 2.1/2.49$ $dV_c/dz = 0$ $\Phi = 0.5$	KOL
—	$\delta = 0.6$ $V_A = 0$ km/s $D_0 = 2.4$ $\eta = 1$ $\alpha = 2.22$ $dV_c/dz = 5$ $\Phi = 0.5$	CONV

(Note that $Z_{max} > 32$ for correctly modeling sub Fe/Fe
sub Fe = Sc + V + Ti)

Cosmic rays in 3D

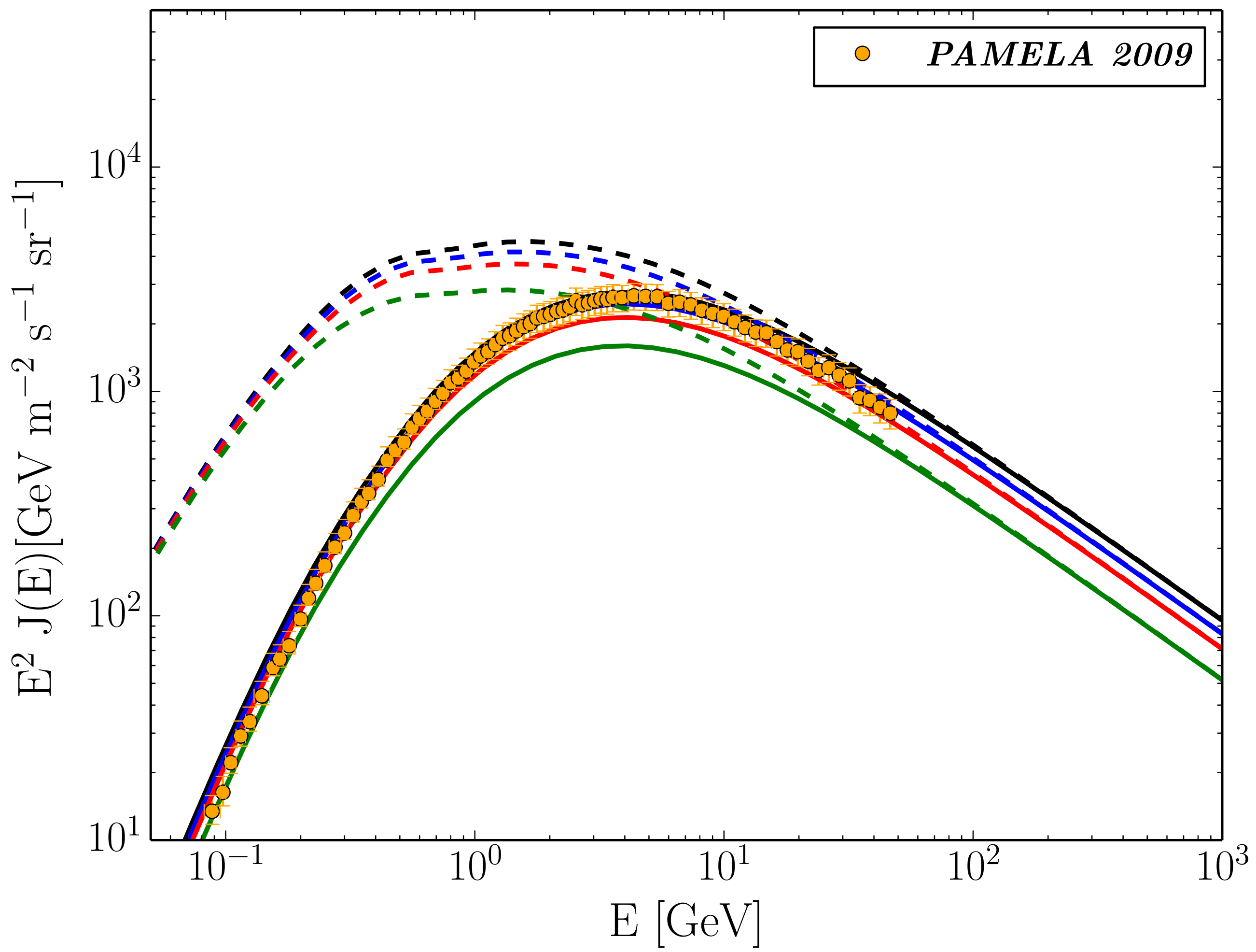
We consider a 3D grid (x,y,z)

If the same source, gas, MF, distributions are adopted
same results !



for the models in the plot
δ = 0.6, L = 4 kpc , $V_A = V_C = 0$, η = 1 ; $D_0 =$ 2.6
D(z) exponential;

Where the primary and secondary CR reaching the Earth are produced ?



z_t = 4 kpc

sources only within d < R_{cut}

$R_{cut} = R_{max}$

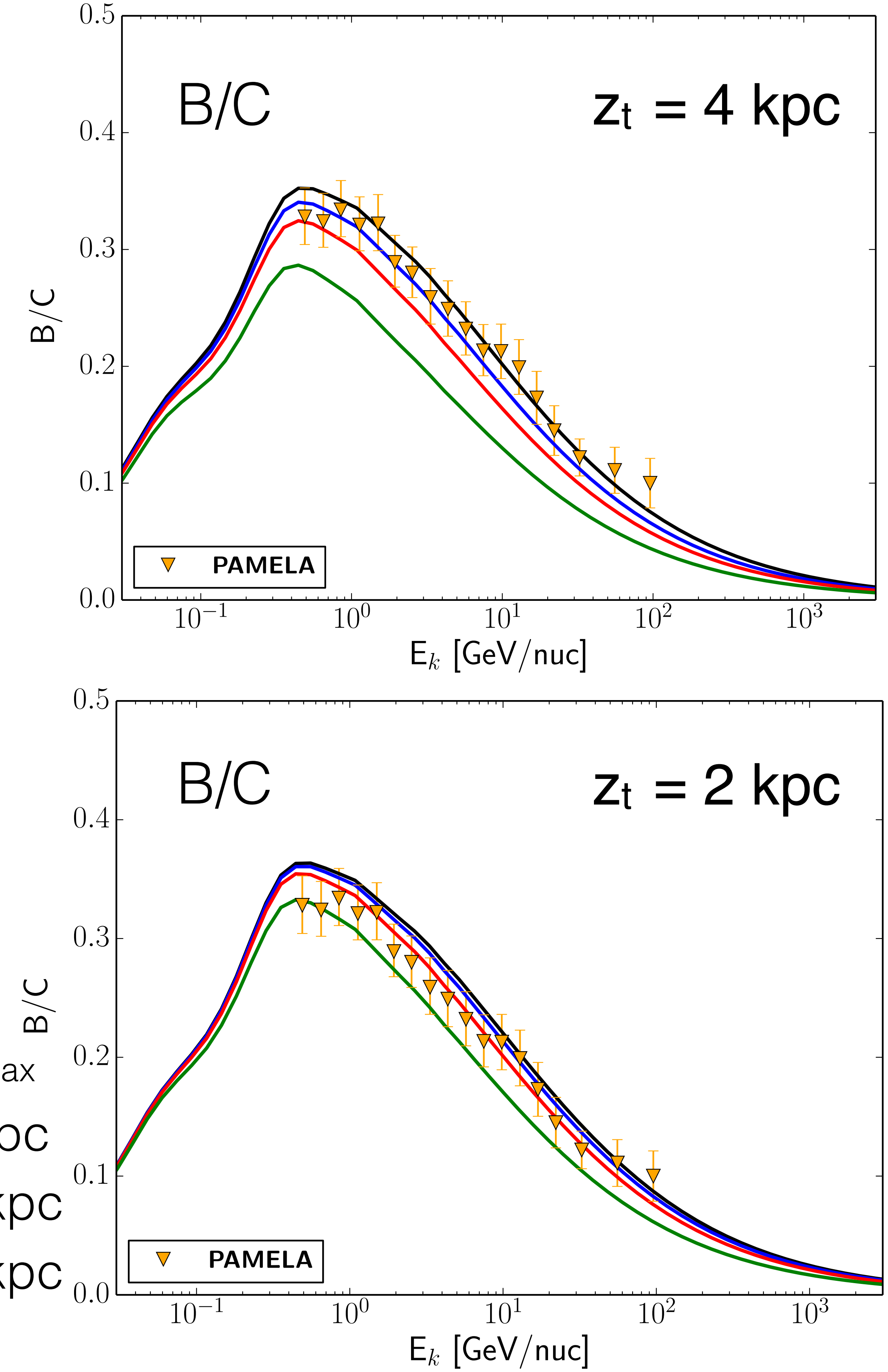
R_{cut}= 7 kpc

R_{cut} = 5 kpc

R_{cut} = 3 kpc

Where the primary and secondary CR reaching the Earth are produced ?

Light secondary stable nuclei are produced in a region of size slightly larger than $\mathbf{z_t}$



sources only within d < R_{cut}

R_{cut} = R_{max}

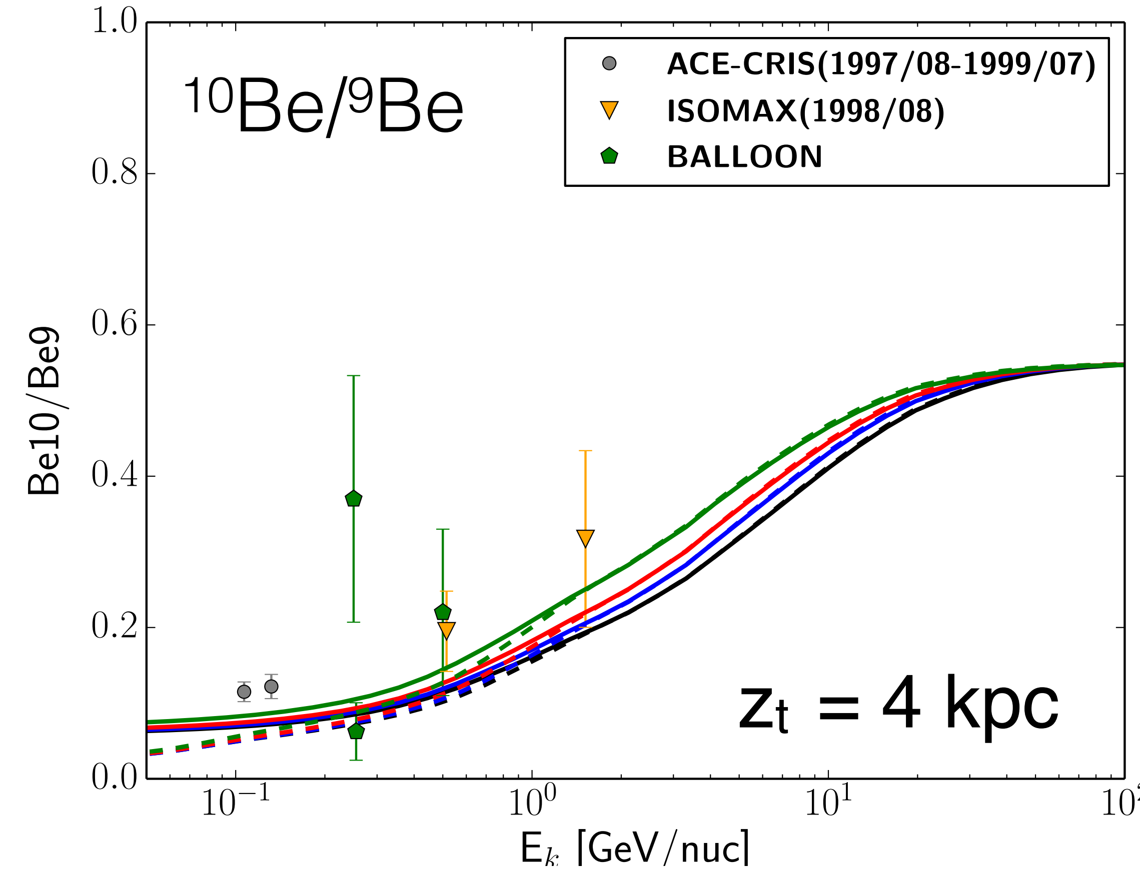
R_{cut}= 7 kpc

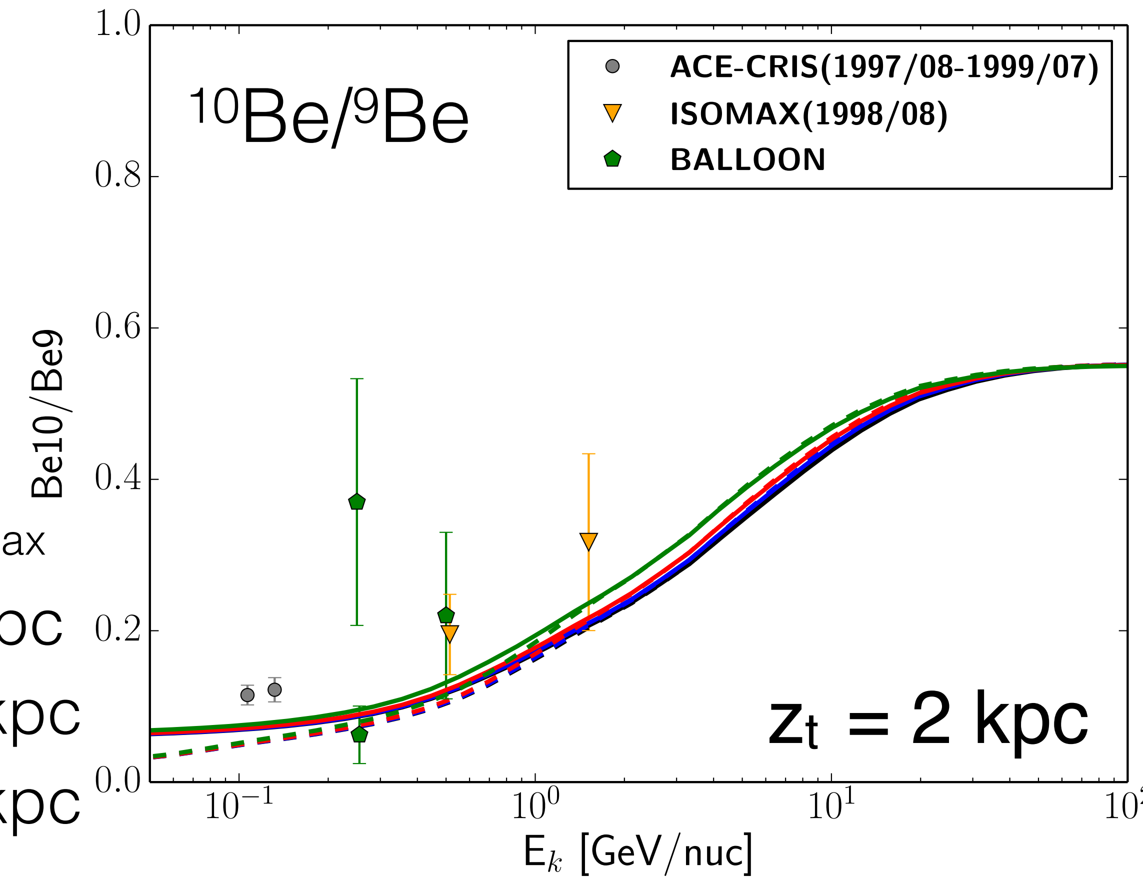
R_{cut} = 5 kpc

R_{cut} = 3 kpc

Where the primary and secondary CR reaching the Earth are produced ?

the ^{10}Be is produce almost locally, hence it is almost independent on $R_{cut,}$ while ^{9}Be decreases increasing R_{cut} up to $\mathbf{z}_t$





sources only within $d < R_{cut}$

$R_{cut} = R_{max}$

R_{cut}= 7 kpc

R_{cut} = 5 kpc

R_{cut} = 3 kpc

Short summary

- D and L are almost degenerate. The value of L does not affect the secondary/primary ratios (after D rescaling). When relevant (e.g. for DM) L should be determined from other measurments.
- strong reacceleration need string (ad hoc ?) breaks in the source spectral index
- low reacceleration models may need a change in the low energy dependence of D (modulation may also do the job)
- exponential D(z) give more physically reasonable CR profiles, still this is not necessary for what concerns only nuclei

Electrons and positrons

e± energy losses and transport equation

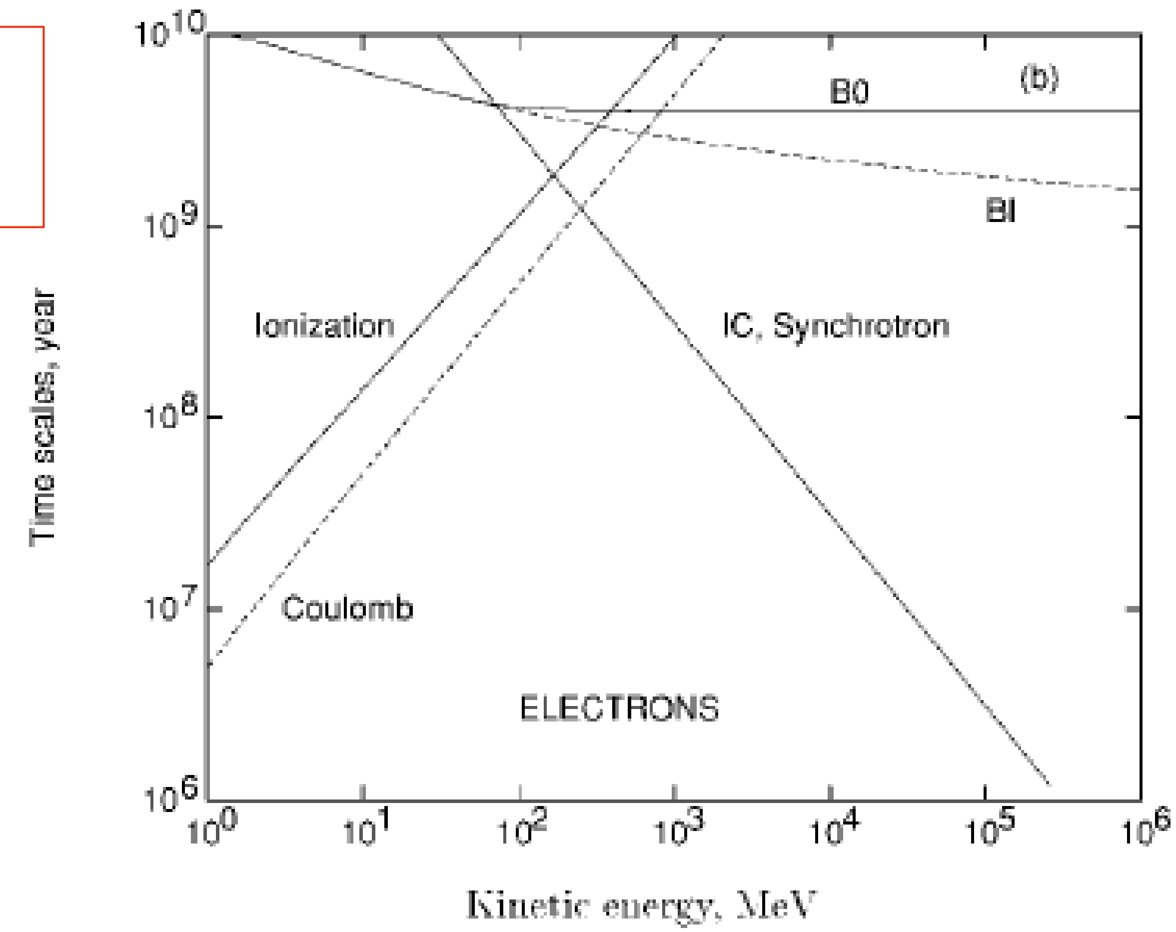
$$\boxed{\frac{d}{dt}N_e(E) = D(E)\nabla^2 N_e + \frac{\partial}{\partial N}\left(b(E)N_e(E)\right) + Q(E)}$$

above 1 GeV

$$b \equiv -\frac{dE}{dt} = \beta E^2 = \frac{4}{3}\frac{\sigma_T\, c}{(m\,c^2)^2}\left(\frac{\mathrm{B}}{8\pi^2} + \rho_{\mathrm{rad}}\right)E^2$$

synchro IC

at the solar system $\quad b \cong 1 \times 10^{-16}\ \mathrm{GeV}^{-1}\ \mathrm{s}^{-1}$



below 0.1 GeV

$$\tau_{loss}^{ion} = \left(-\frac{1}{\mathrm{E}}\frac{dE}{dt}\right)^{-1} = 10^8\left(\frac{\mathrm{E}}{1\ \mathrm{GeV}}\right)\left(\frac{\mathrm{n_{gas}}}{1\ cm^{-3}}\right)^{-1}\ \mathrm{yr}$$

ionization losses

$\tau_{\mathrm{loss}}(1\ \mathrm{GeV}) \sim 10^8\ \mathrm{yr}\ ; \quad \tau_{\mathrm{loss}}(100\ \mathrm{GeV}) \sim 10^6\ \mathrm{yr}$

The effects of energy losses

Bulanov & Dogel 74, Berezinsky et al. 1990

Diffusive loss length

$$\lambda_{\rm loss}(E) = \left(\int_0^{\tau_{\rm loss}(E)} D(E')dE'\right)^2 = \left(\int_0^E \frac{D(E')}{b(E')}dE'\right)^2$$

This has to be compared with the halo scale height $\boldsymbol{z_t}$

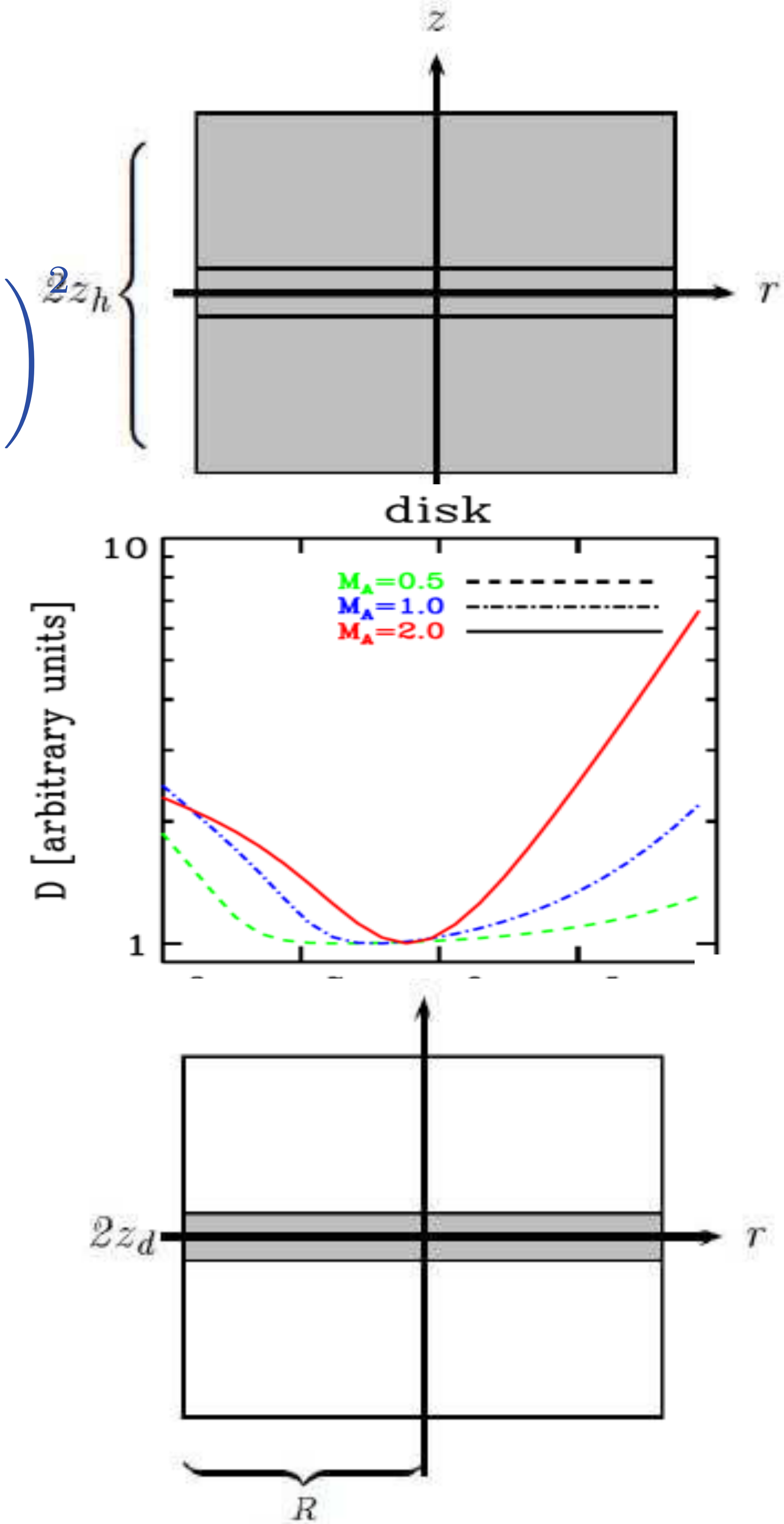
$\lambda_{\rm loss}$ become smaller than $\boldsymbol{z_t}$ for

$$E > E_* \simeq \frac{10}{1-\delta} \left(\frac{D_0}{10^{28}\ {\rm cm^2/s}}\right) \left(\frac{z_t}{1\ {\rm kpc}}\right)^{-2} \ {\rm GeV}$$

this few GeV for the models considered.

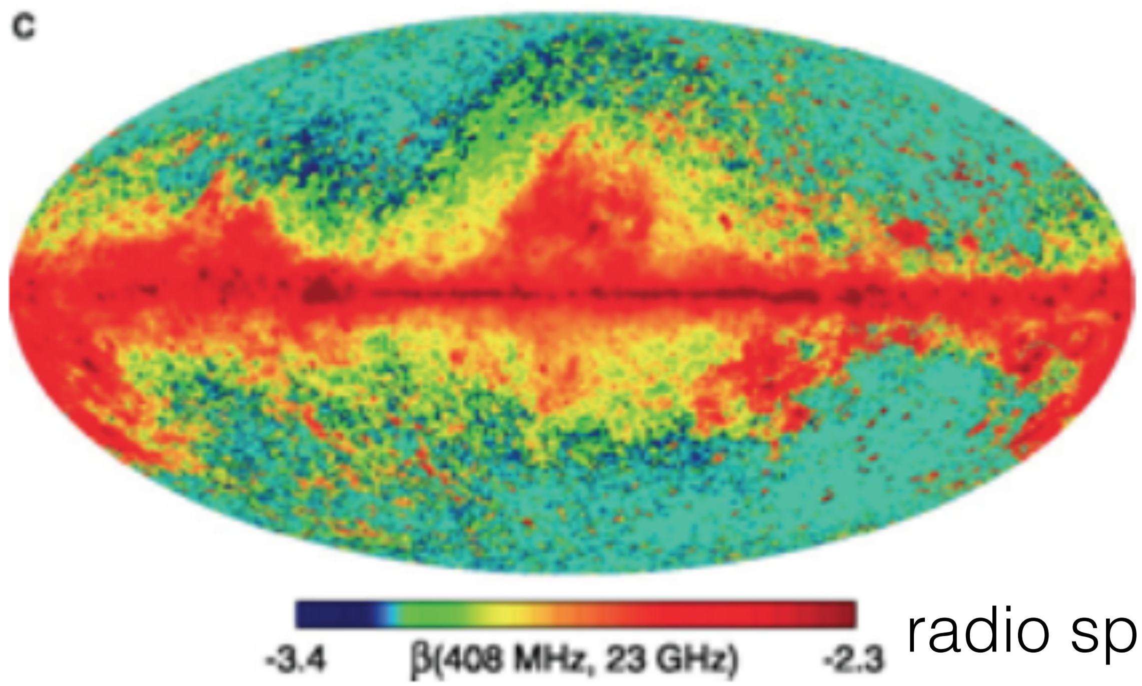
Electrons do not escape the disk ($z_d \sim$ 100 pc) only above several TeV.

Note that $\boldsymbol{z_d} \simeq$ mean separation between SNRs

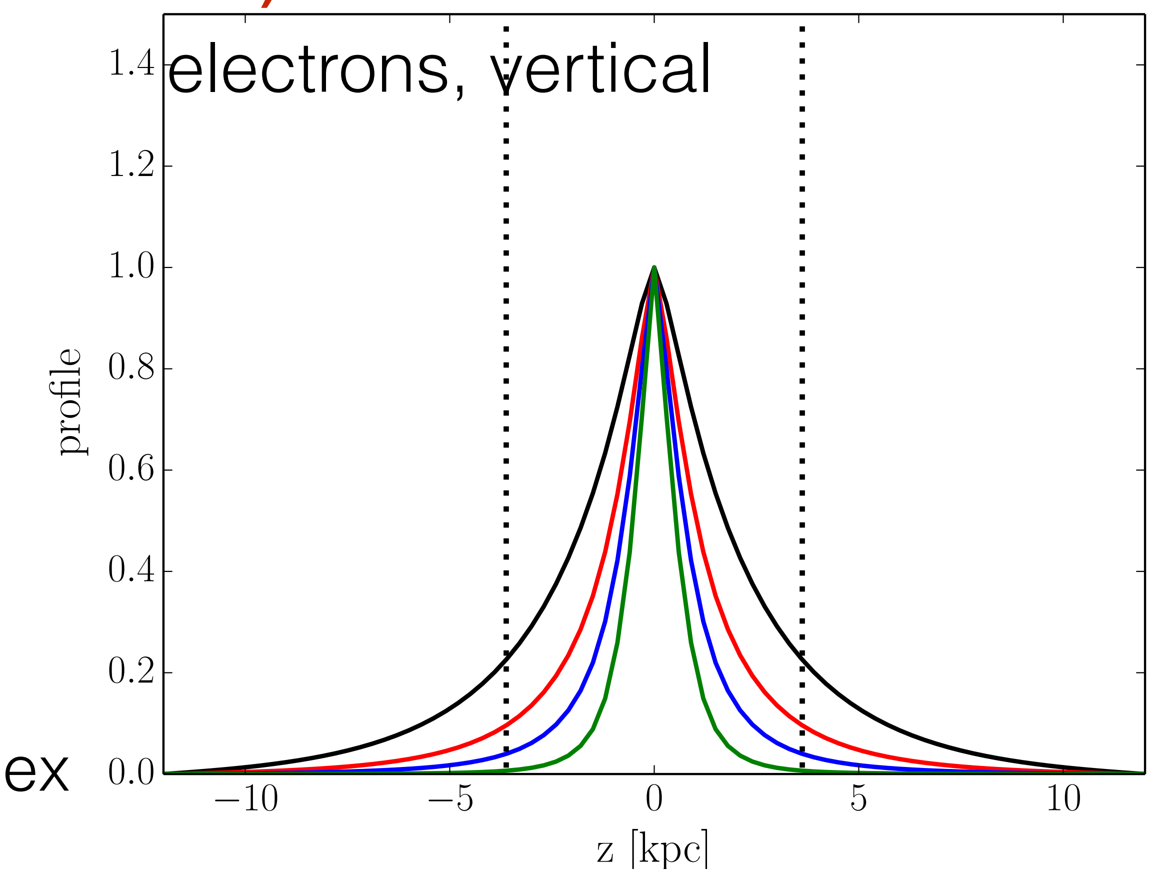


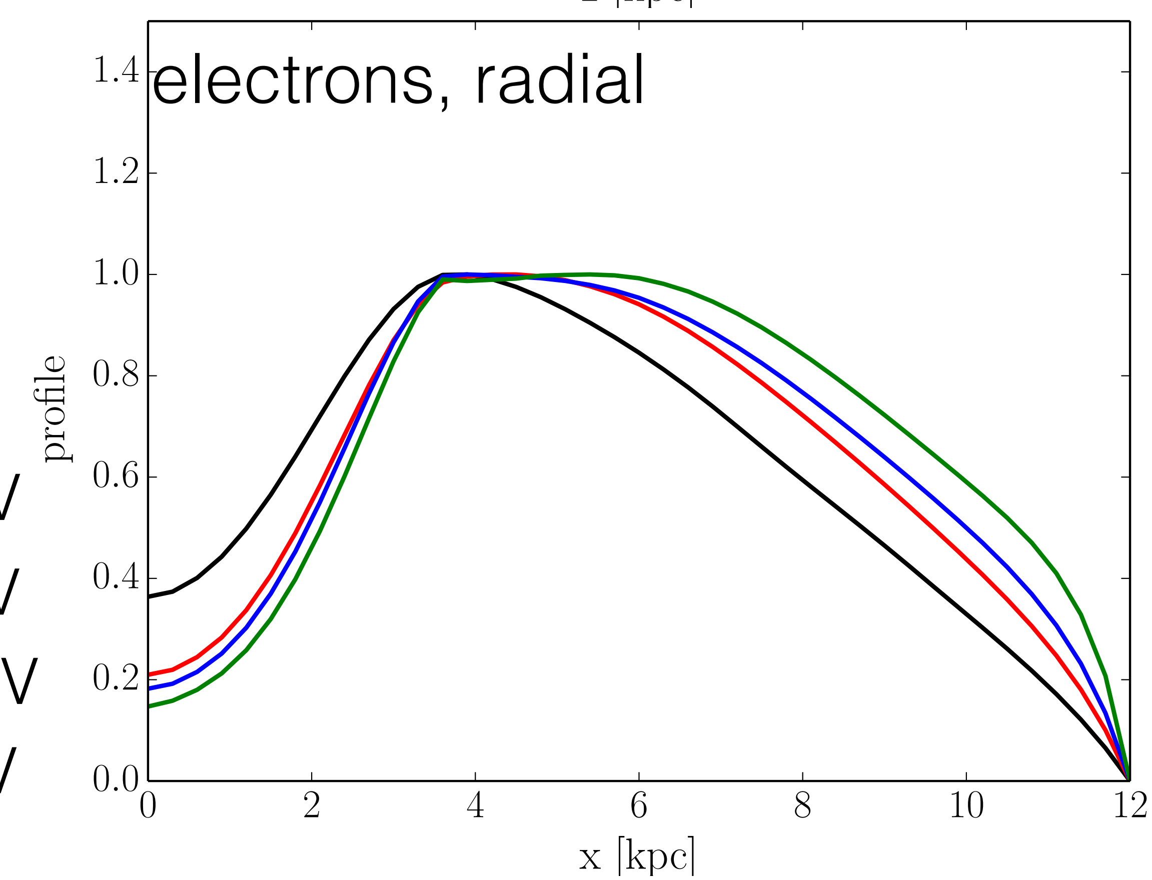
The effect of energy losses
(no arms case)

WMAP 2003



radio sp. index





in these plots
D_0 = 2.6, $\mathbf{z_t}$ **= 4 kpc**
plain diffusion

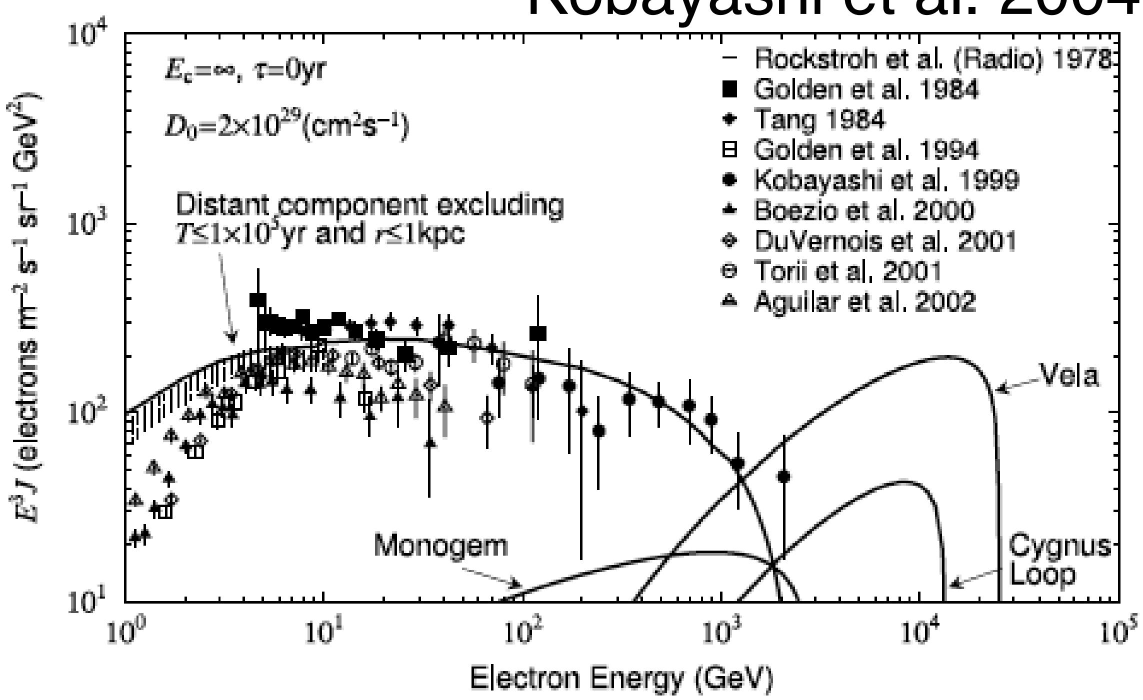
E = 1 GeV
E = 10 GeV
E = 100 GeV
E = 1 TeV

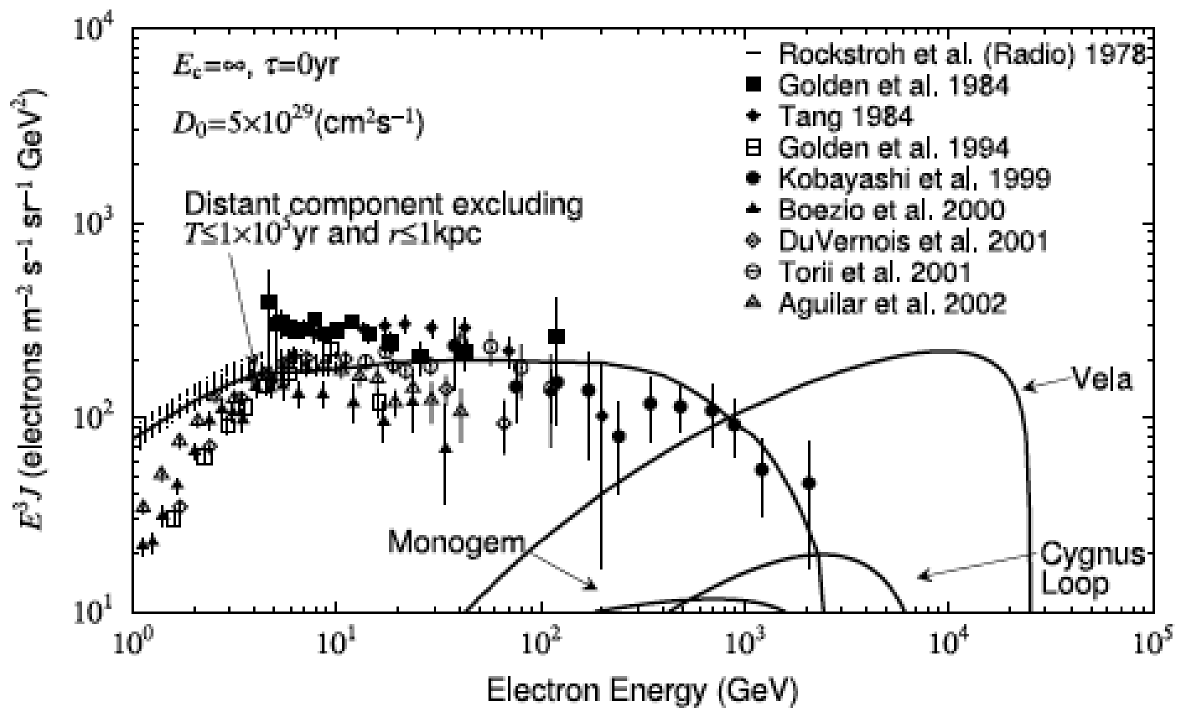
The effect of energy losses (source stochasticity)

Above/near the TeV only a few prominent sources may contribute to the e∓ flux reaching the Earth

therefore above/near that energy to assume a continuous source distribution may be inadequate !

Kobayashi et al. 2004





Primary and secondary e±

This is assuming that e^+ are only secondary products of CR interaction with the ISM

In this plots the e^- source spectral index is

$\alpha(e^-)$ = 1.6/2.3 a/b 4 GeV

plain diffusion model which match light nuclei with L = 4 kpc

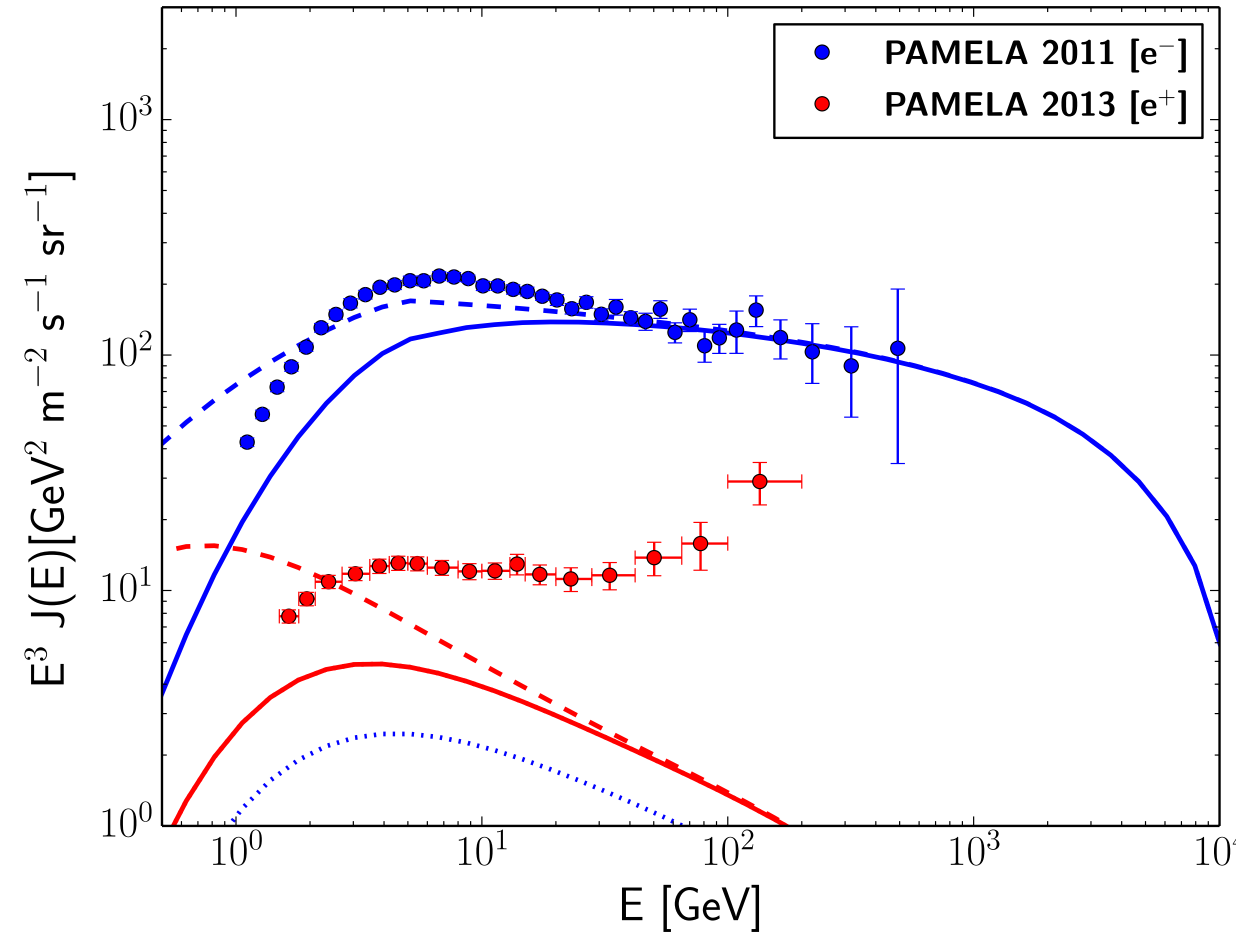
total modulated e^-

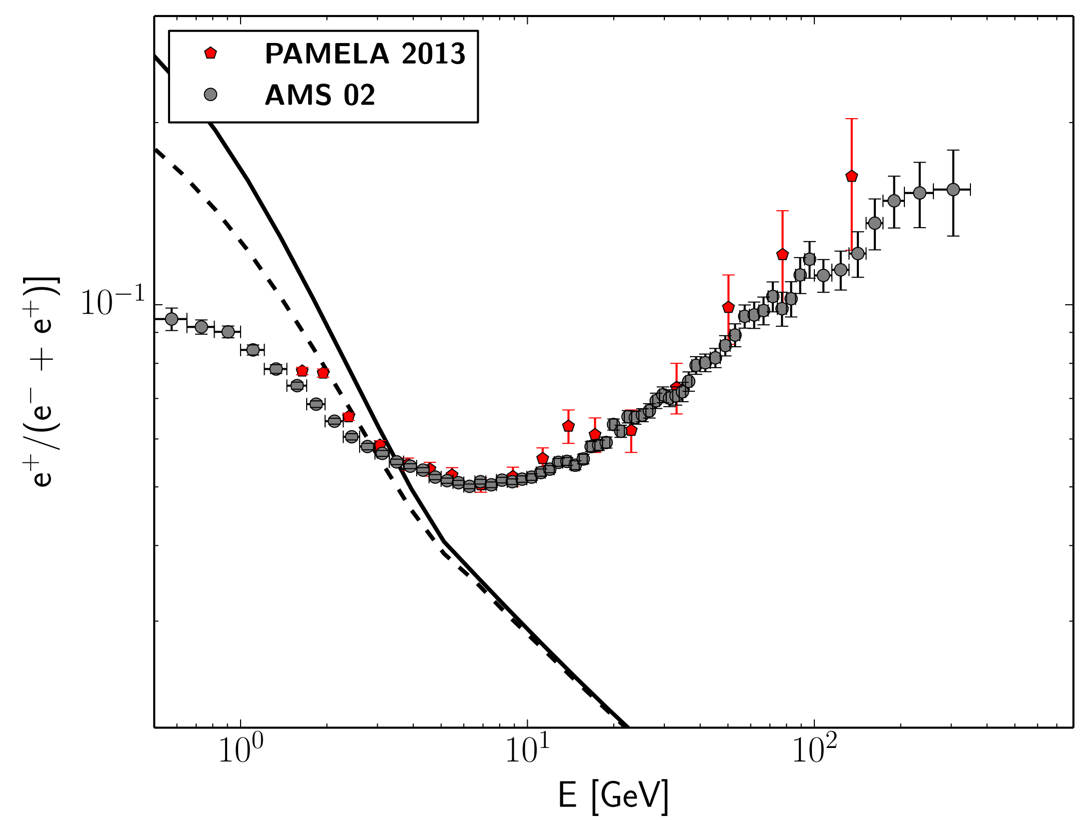
total unmodulated e^-

secondary e^-

secondary = total e^+

Φ = 0.4 GV





Primary and secondary e±

This is assuming that e^+ are only secondary products of CR interaction with the ISM

In this plots the e^- source spectral index is

$\alpha(e^-)$ = 1.6/2.5 a/b 4 GeV

plain diffusion model which match light nuclei with L = 4 kpc

total modulated e^-

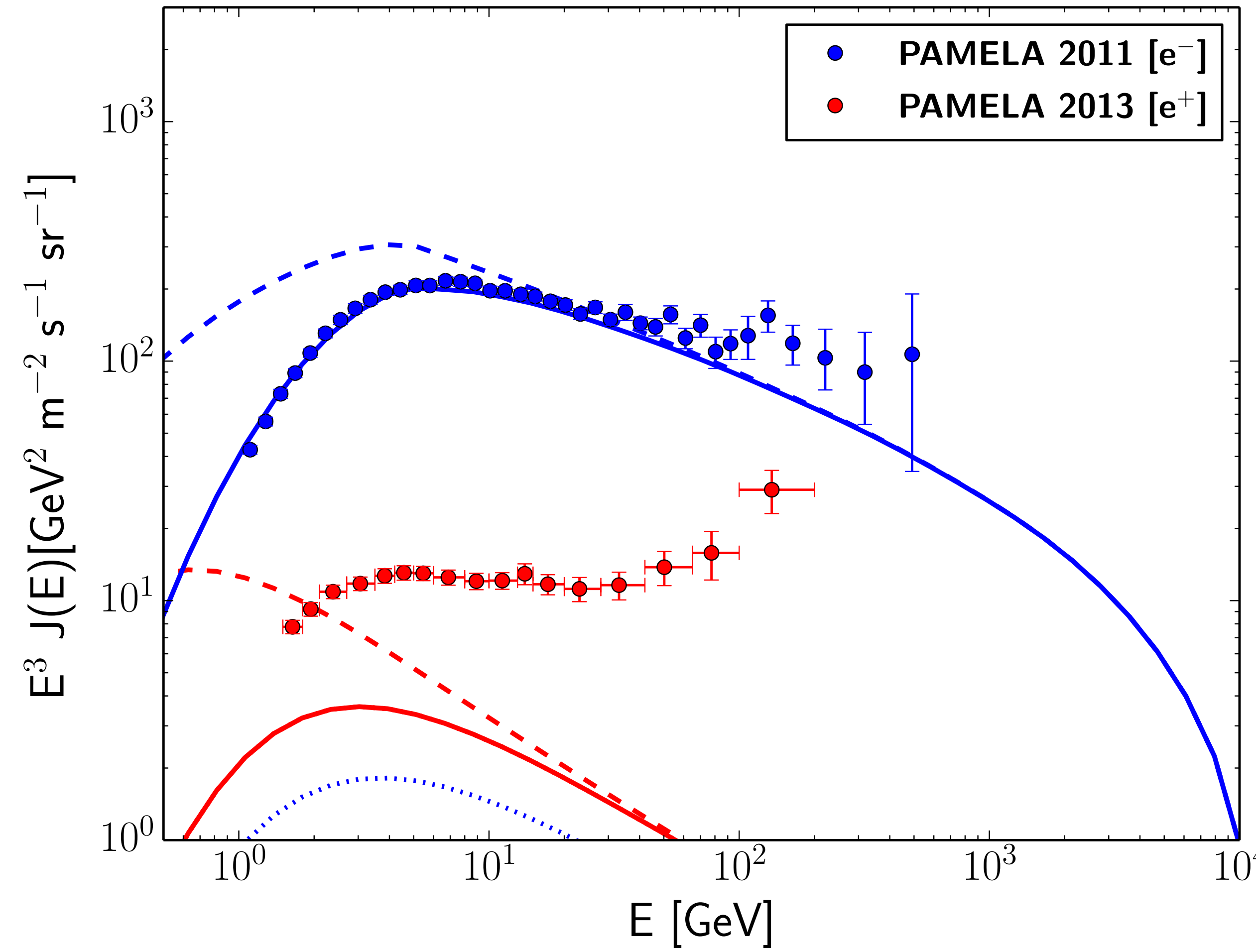
total unmodulated e^-

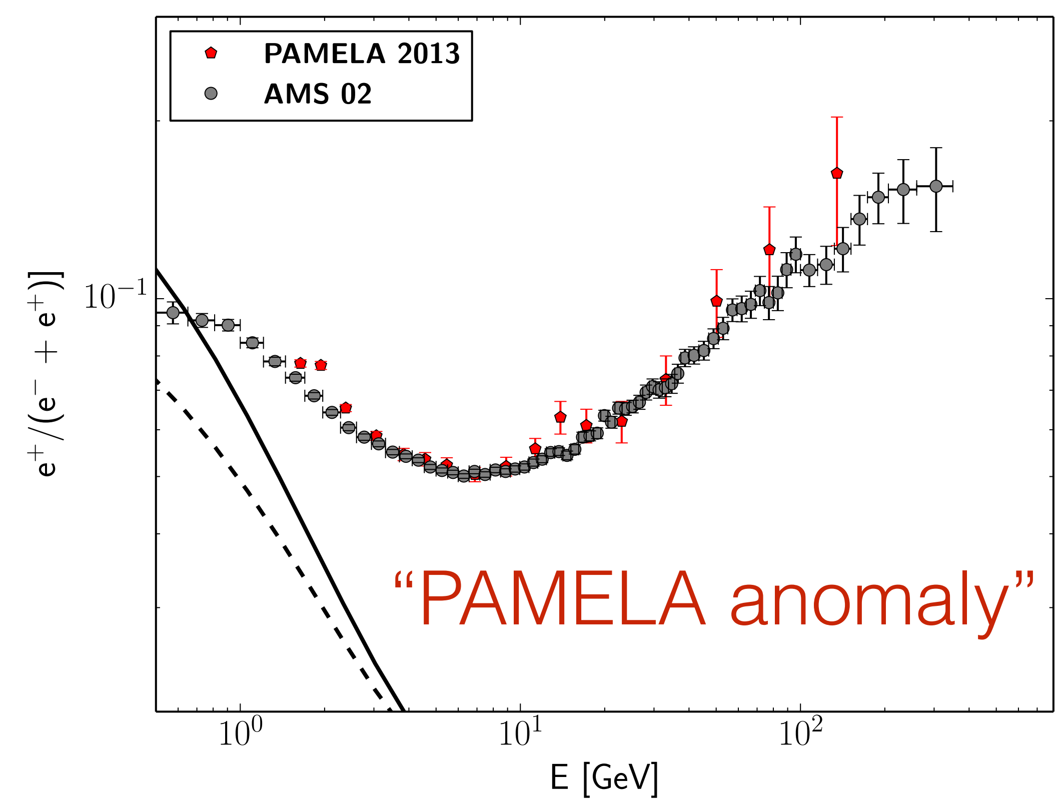
secondary e^-

secondary = total e^+

unmodulated " e^+

Φ = 0.4 GV





Primary and secondary e±

for several propagation setups

This is assuming that e^+ are only secondary products of CR interaction with the ISM

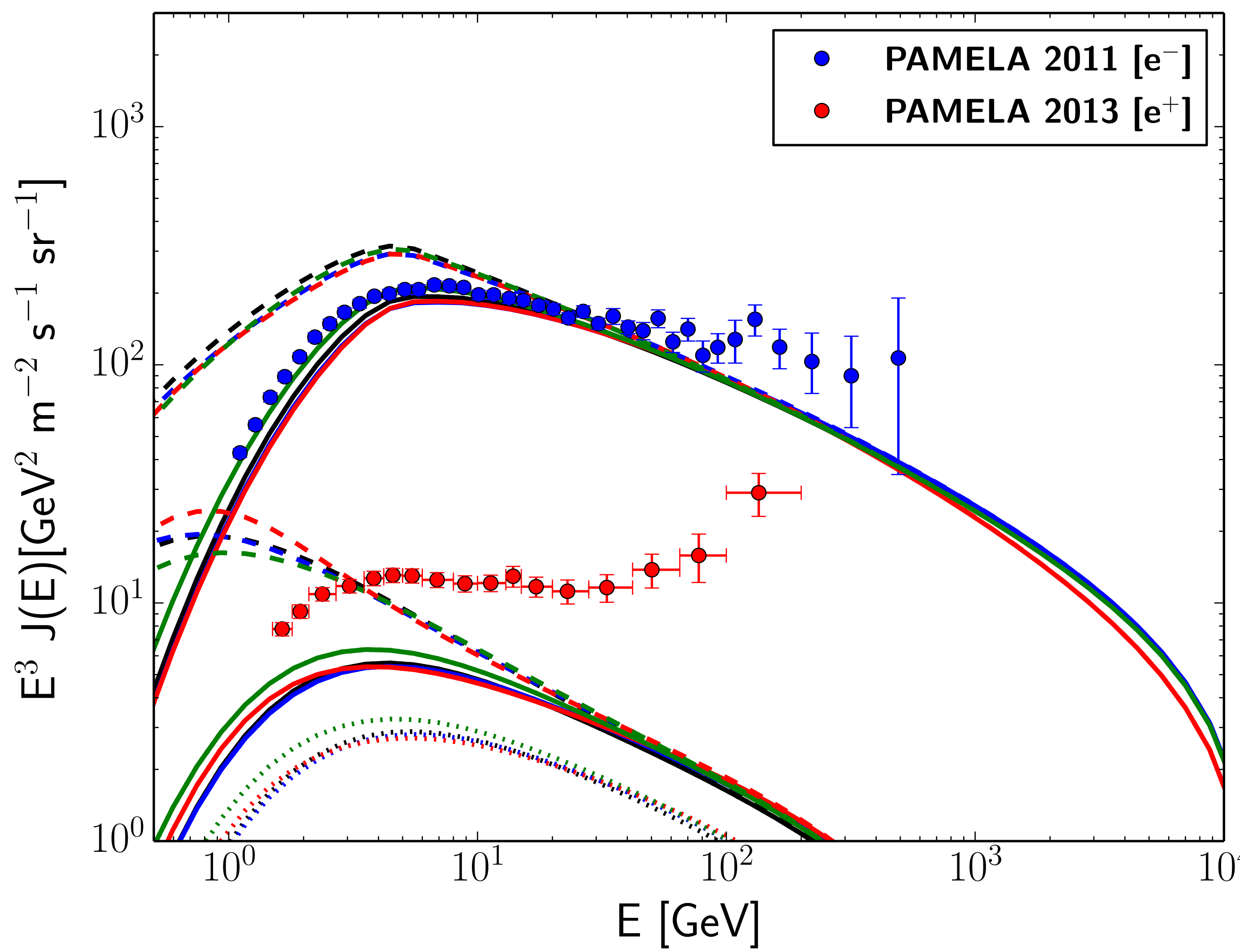
Propagation setups in this plots

PD4 ($\alpha(e^-)$ = 1.6/2.65)

KRA4 ($\alpha(e^-)$ = 1.6/2.65)

KOL4 ($\alpha(e^-)$ = 1.6/2.65)

CONV4 ($\alpha(e^-)$ = 1.6/2.7)



total modulated e^-

total unmodulated e^-

secondary mod. e^-

secondary = total e^+

(for all these models Exp profile for D with **z_t = 4 kpc**)

PAMELA anomaly is independent on the choice of the propagation setup !

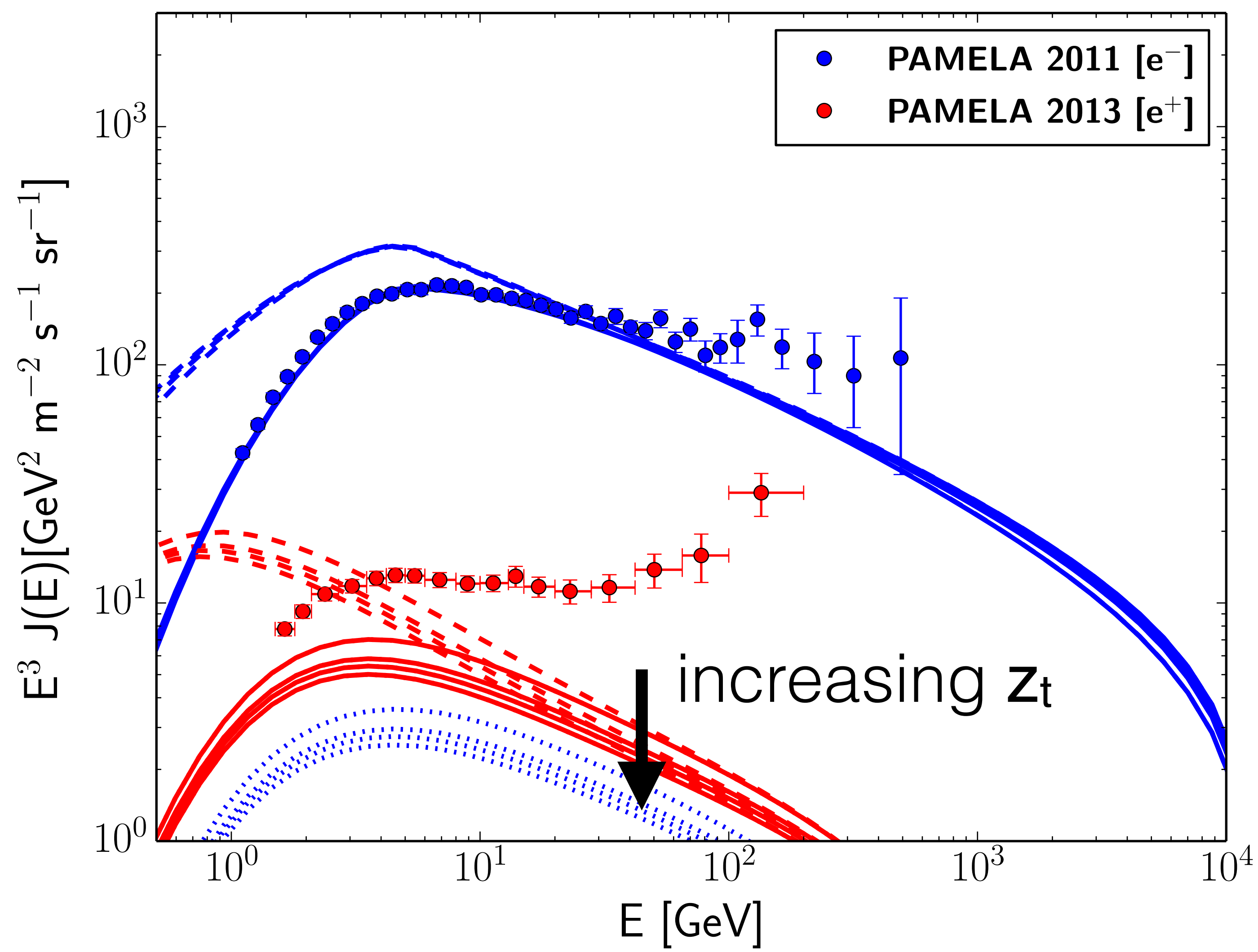
Primary and secondary e±

the effect of changing the halo height

This is assuming that e^+ are only secondary products of CR interaction with the ISM

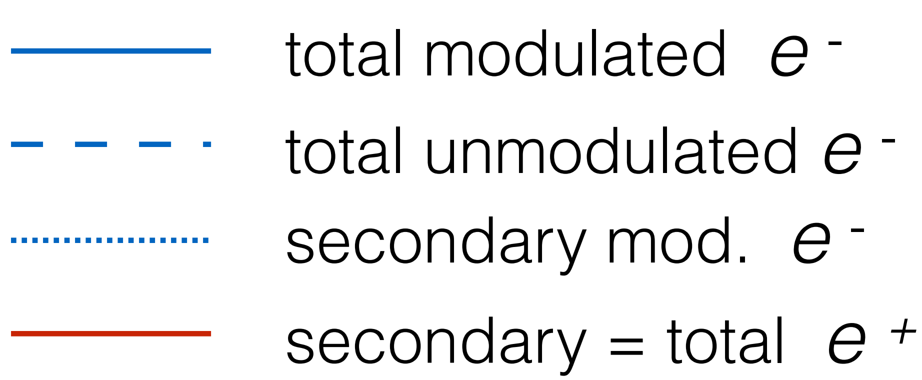
Propagation setups in this plots

PD2
PD4
PD6
PD8



Φ = 0.4 GV

(for all these models Exp profile match B/C)



The extra component paradigm

This is assuming a charge symmetric e± extra component with a continuos source distribution tracing SNR (pulsar) (no arms) and source spectrum

$$J(e^{\pm}) \propto E^{-\alpha_{\rm extra}} \; \exp\left(-E/E_{\rm cut}\right)$$

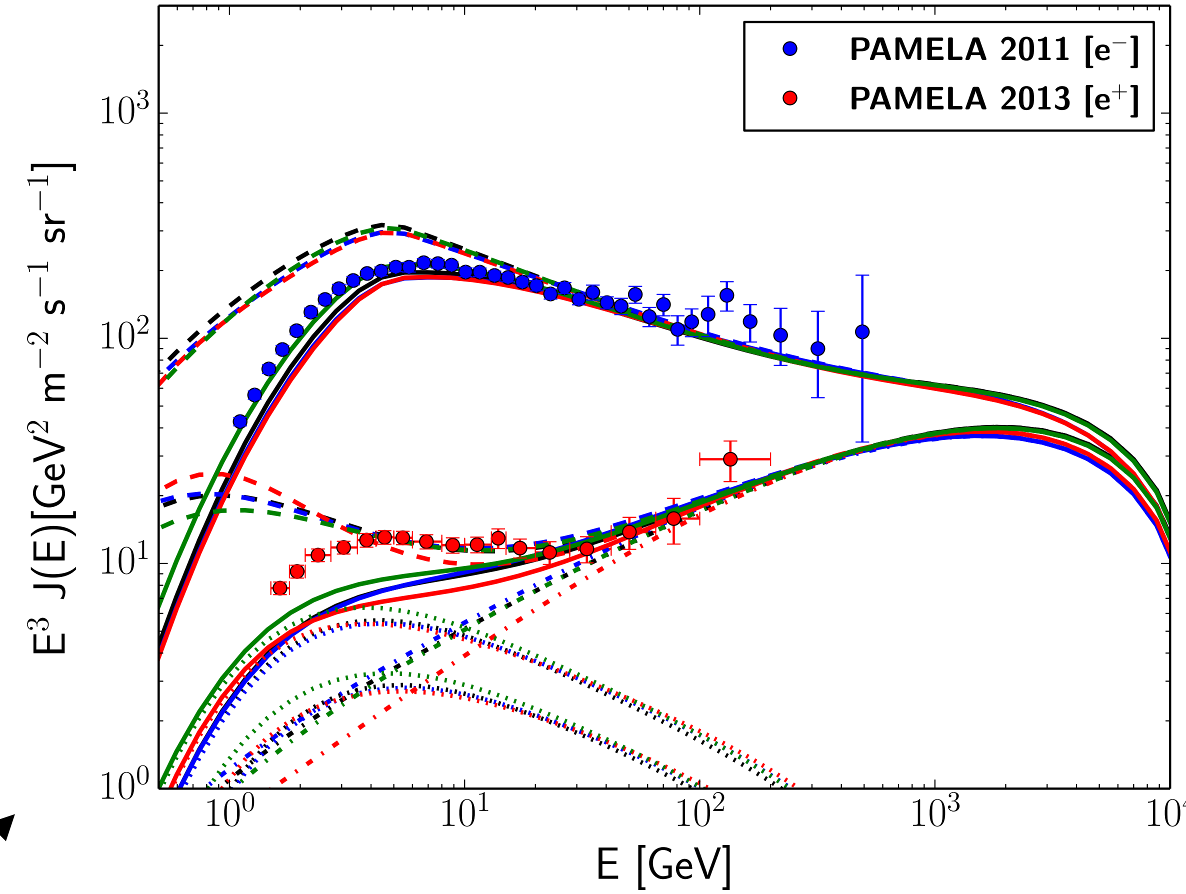
here $\alpha_{\rm extra} = 1.7$ $E_{\rm cut} = 1$ TeV

total modulated e^-

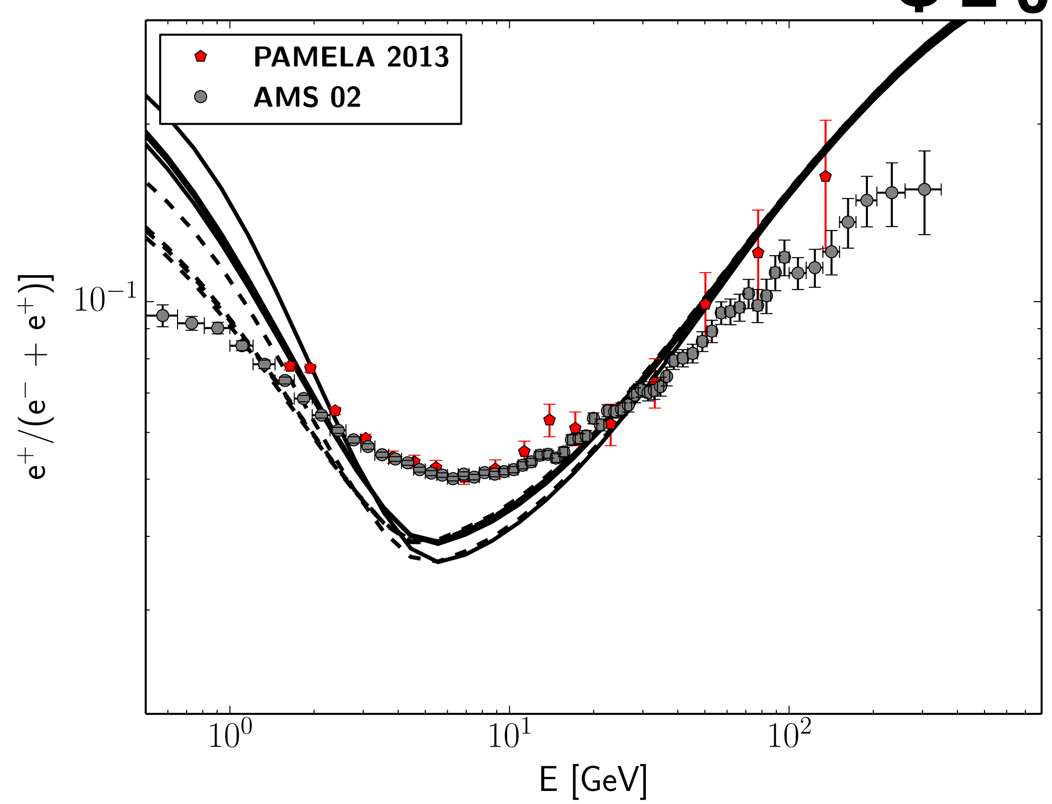
total unmodulated e^-

secondary $e^{\pm}$

$e^{\pm}$ extra component



Φ = 0.4 GV



The effect of spiral arms

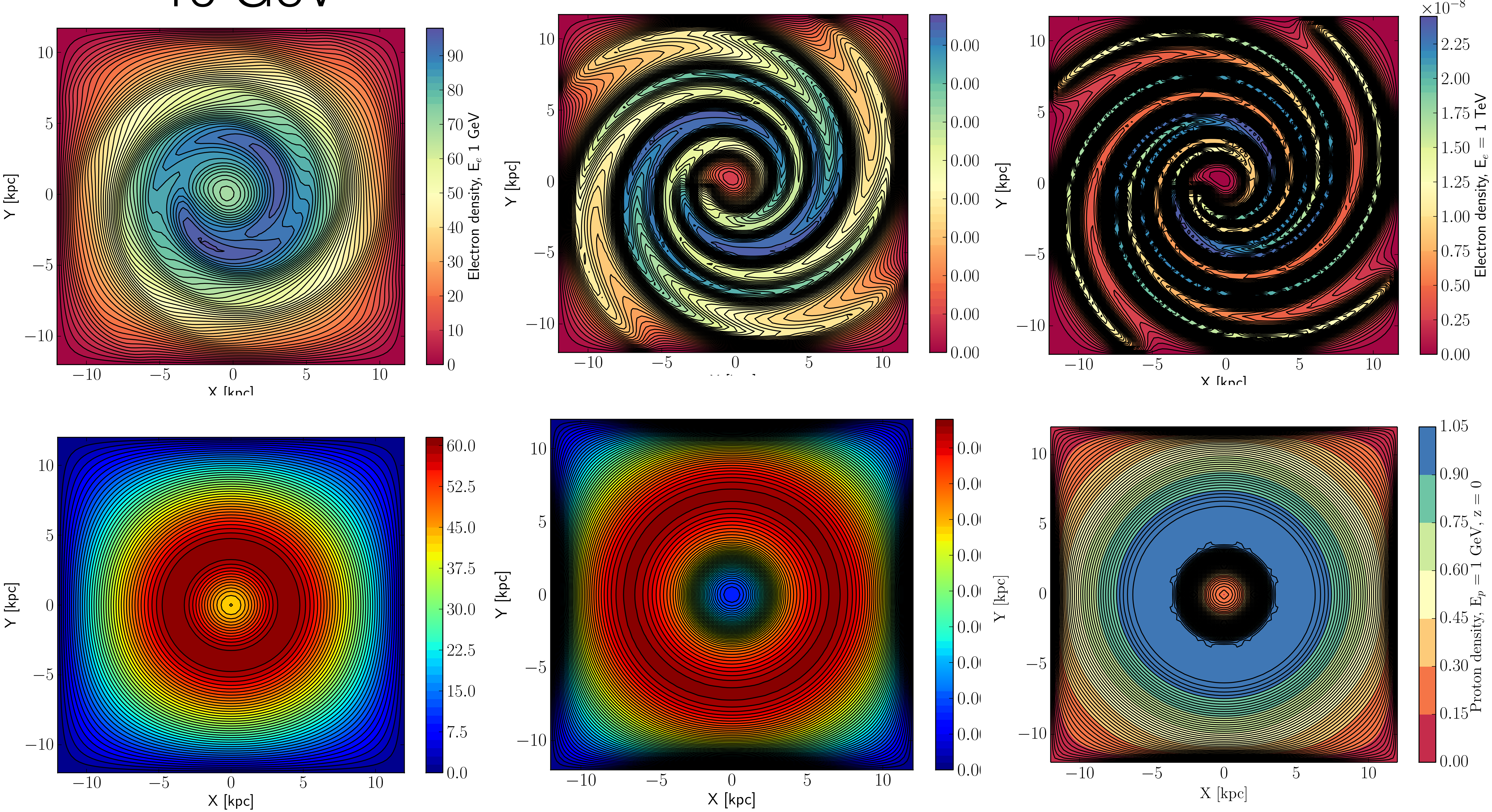
Star formation take place mainly in spiral arms

distance between arms
$\simeq$ 1 kpc

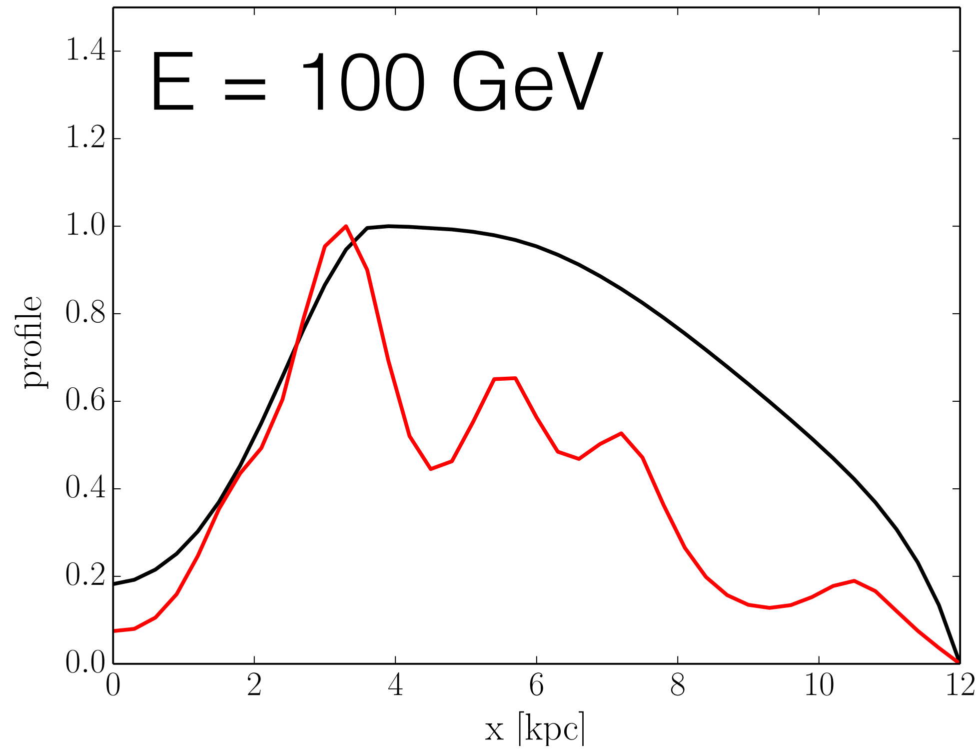
we are in a low density region between two arms

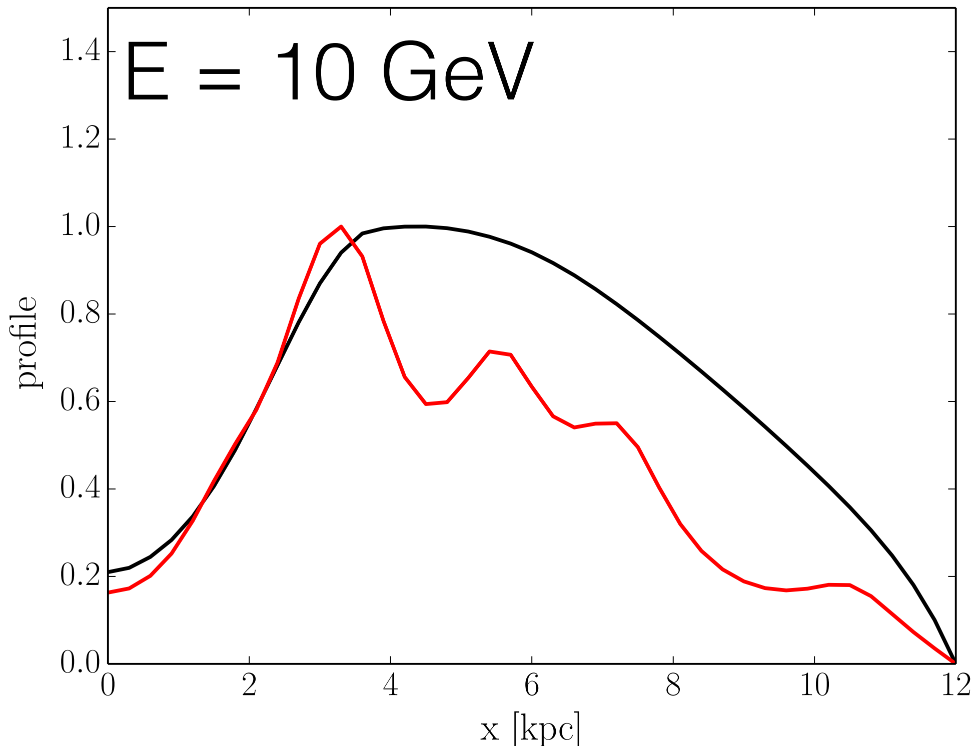
arms make the difference !

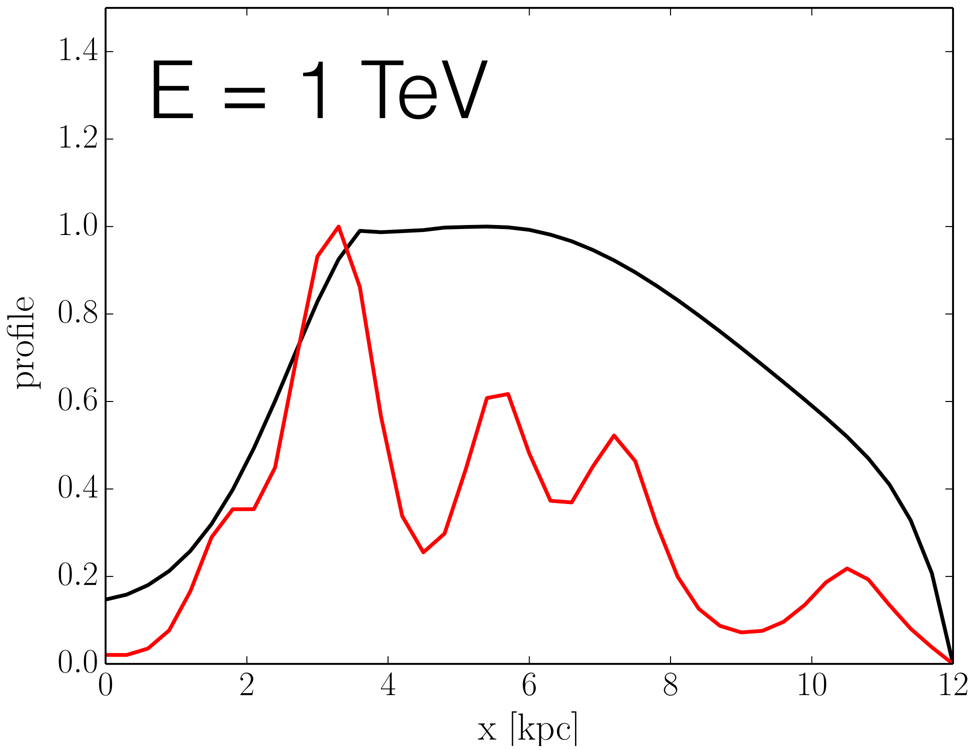
10 GeV | 100 GeV | 1 TeV



Arms make the difference !
(radial profile)

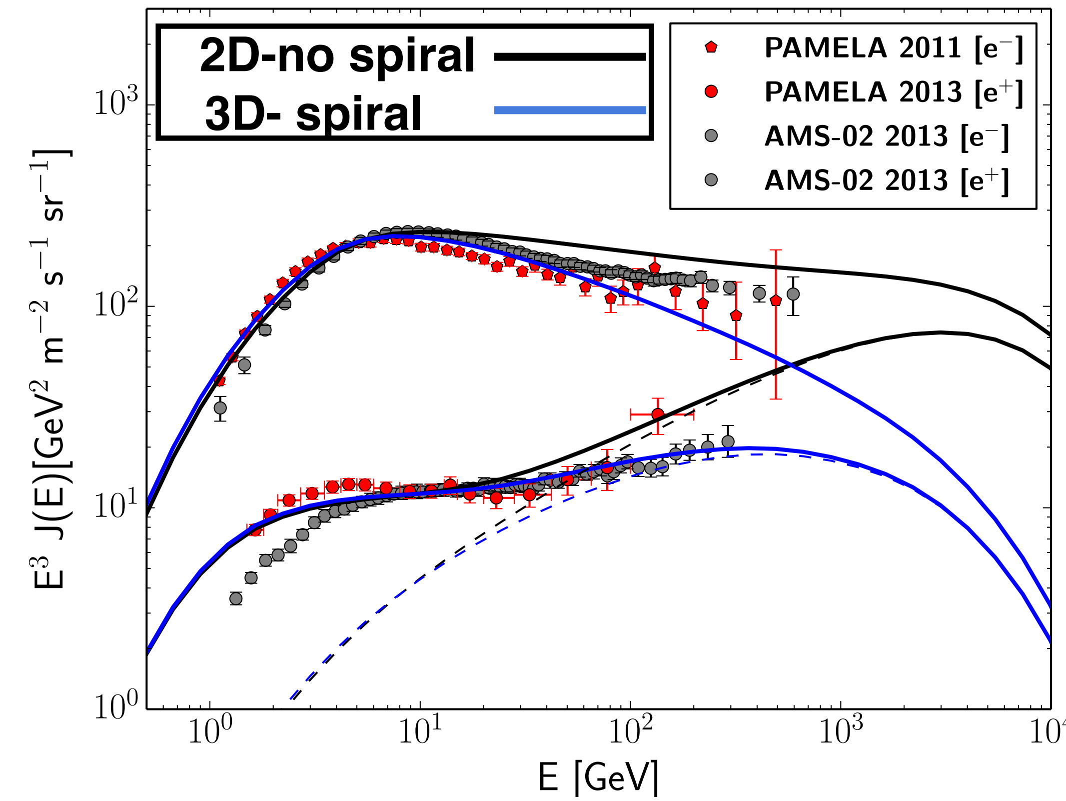


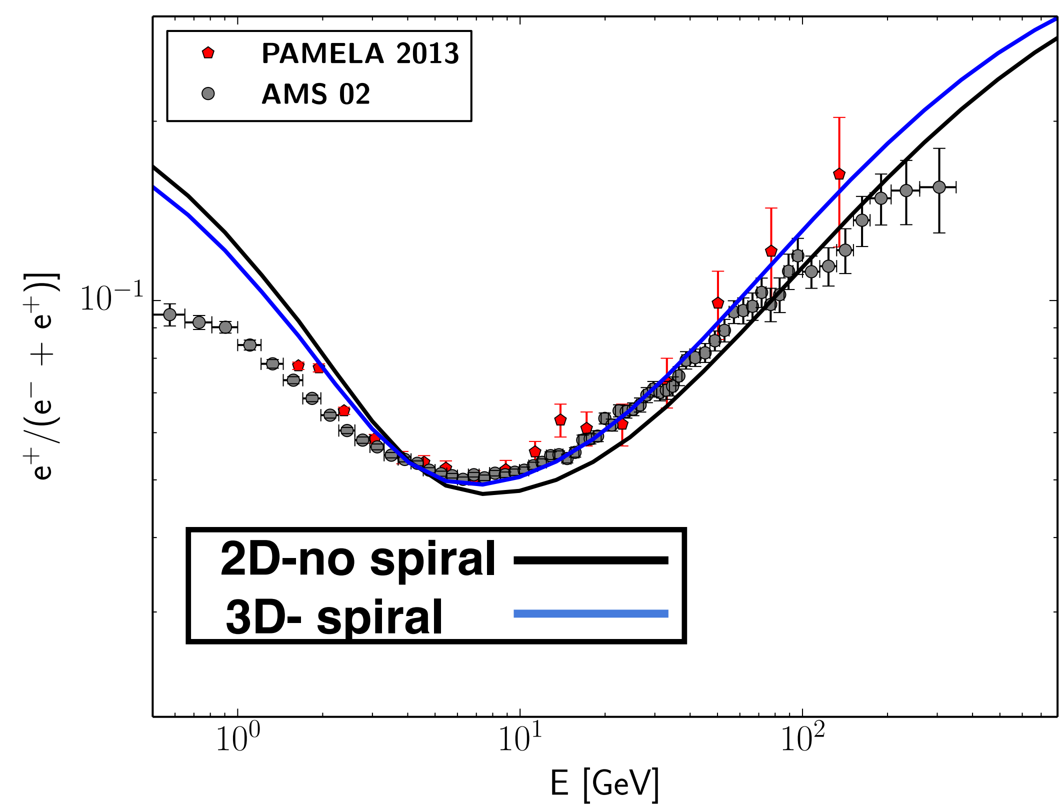




The effect of the spiral arms on the lepton spectra

- Energy losses in the inter-arm region change dramatically the e^- and e^+ spectra above 20 GeV
- the effect is almost absent in the positron fraction (PAMELA pf and FERMI $e^- + e^+$ were reproduced in 2D)
- even if the extra-component is due to DM (not affected by arms), the e^- background computed in 2D is unrealistic





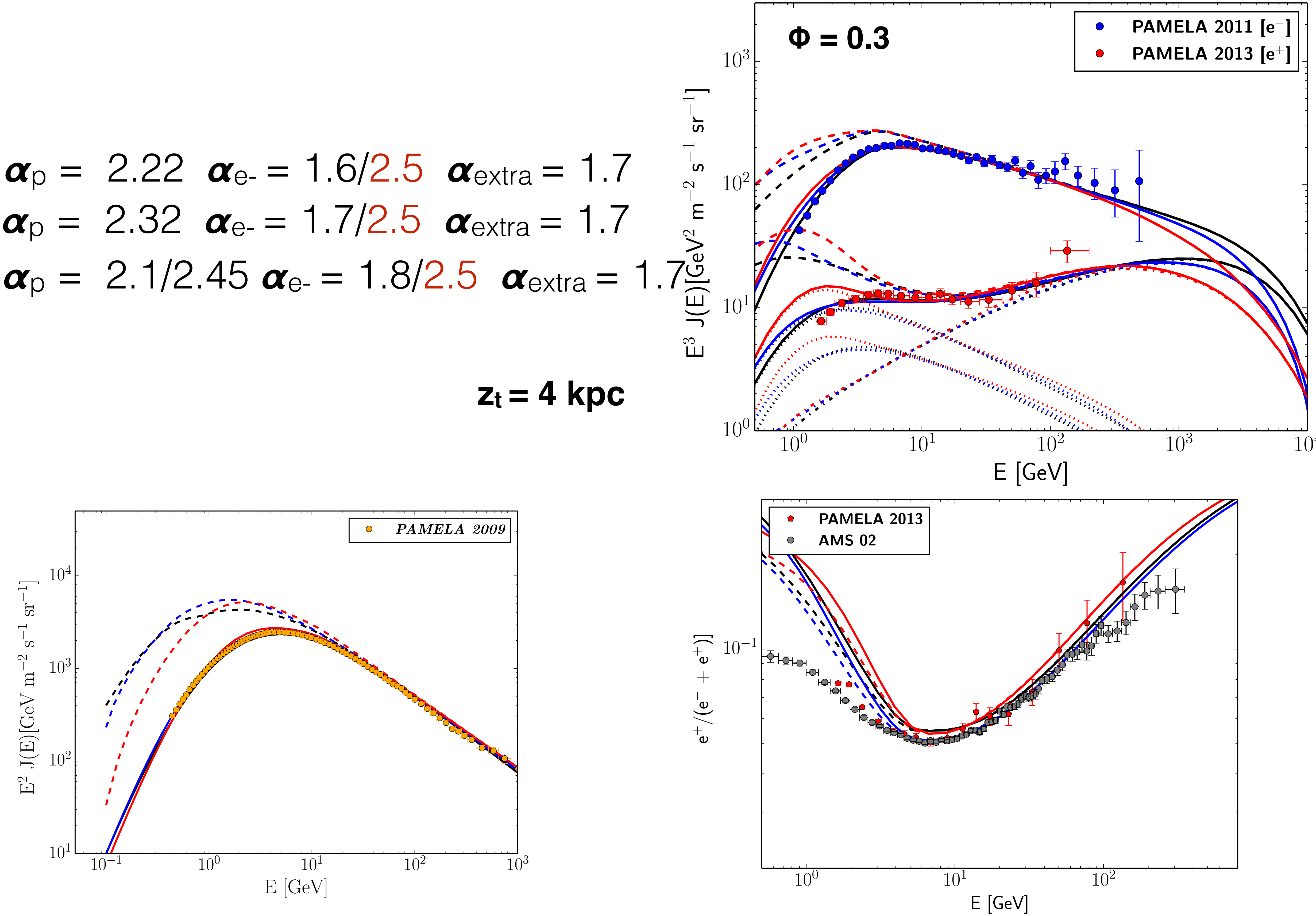
3 (almost) good models in 3D

PD α_p = 2.22 α_{e-} = 1.6/2.5 α_{extra} = 1.7

KRA α_p = 2.32 α_{e-} = 1.7/2.5 α_{extra} = 1.7

KOL α_p = 2.1/2.45 α_{e-} = 1.8/2.5 α_{extra} = 1.7

z_t = 4 kpc



The possible effect of nearby sources

So far we modeled local source contributions adding to DRAGON output the analytical solution of diffusion/loss equation (using the same parameters we have in DRAGON in the local region).

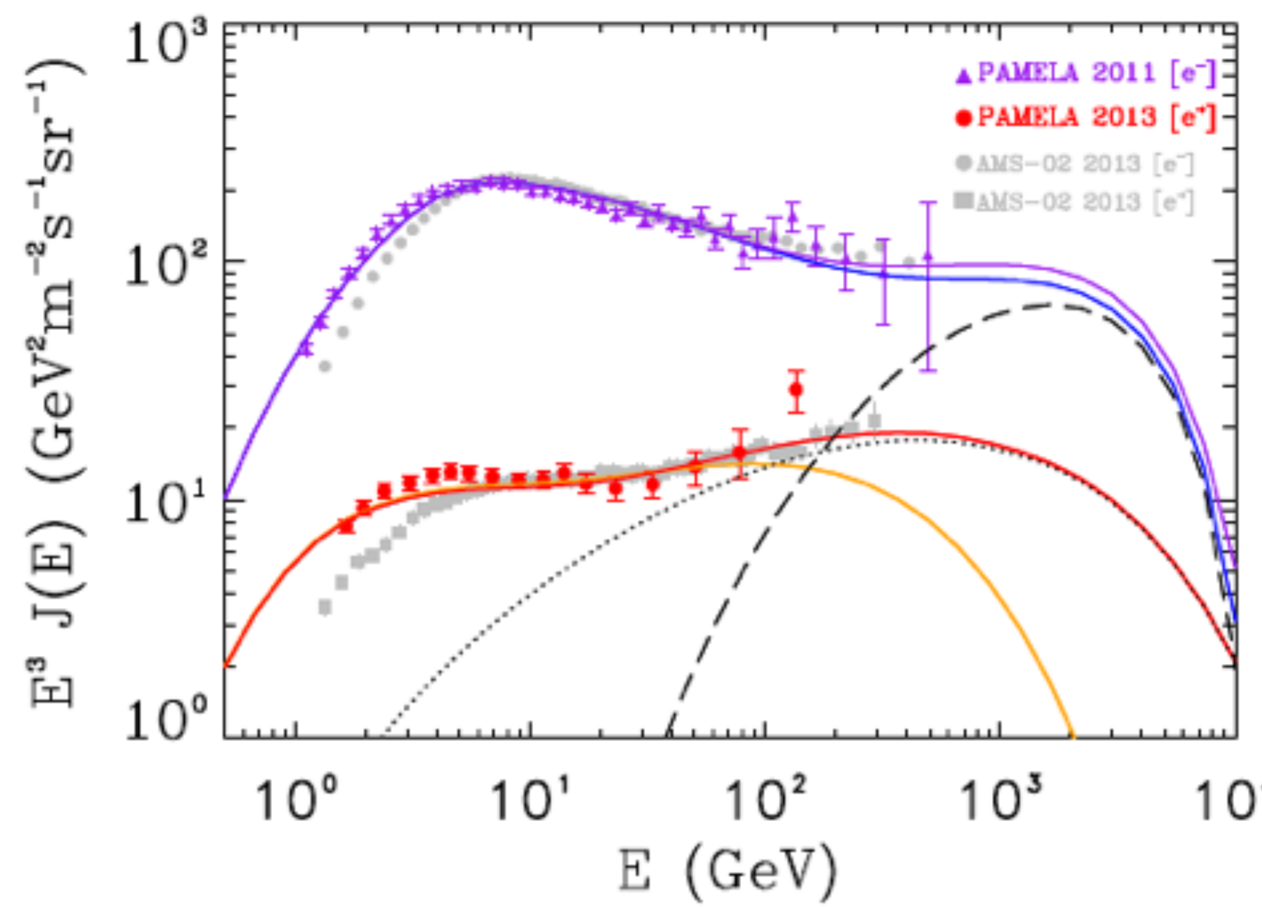
This is done with IDL/Python routines

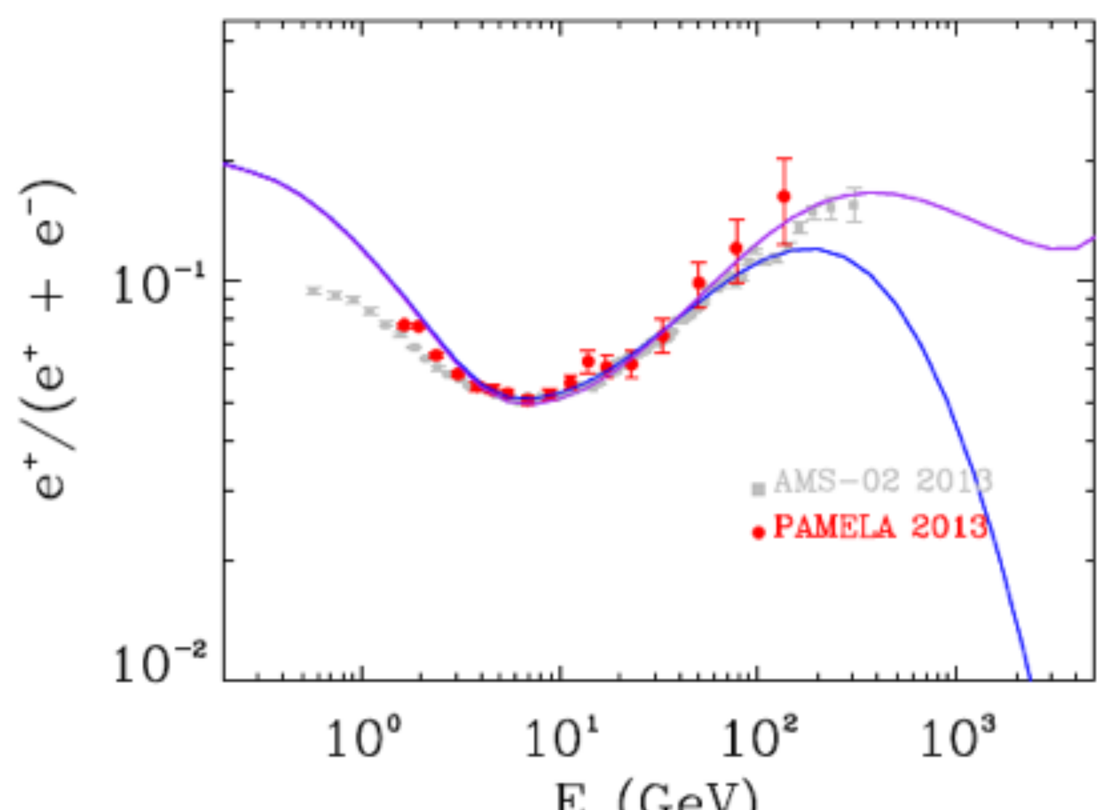
In these figures:

Vela SNR, d = 300 pc, T = 10^4 yrs

$\gamma_{SNR}(e^-) = 2.4$ $E_{cut}(SNR) = 5$ TeV

$E_{SNR}(e^-) = 2\ 10^{48}$ erg

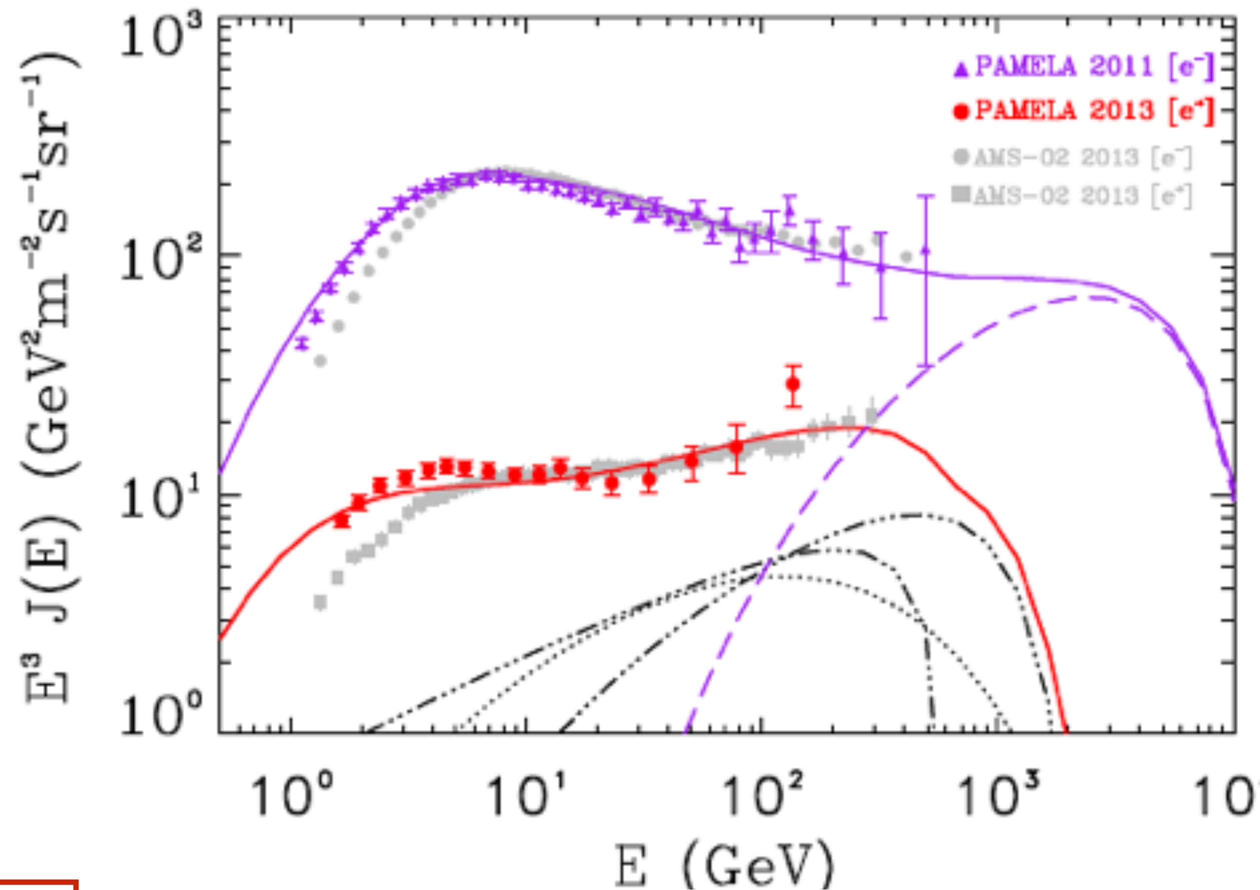




The possible effect of nearby sources

So far we modeled local source contributions adding to DRAGON output the analytical solution of diffusion/loss equation (using the same parameters we have in DRAGON in the local region).

This is done with IDL/Python routine



In these figures: Vela SNR +

Monogem pulsar d = 280 pc, T = 10^5 yrs +
Geminga pulsar d = 160 pc, T = 3 10^5 yrs

for both we assume 15% $e^{\pm}$ conversion effic.

$\gamma_{pulsars}(e^{\pm}) = 1.9$ E_{cut} = 1 TeV