A quantitative study of AMS-02 $e^{\pm}$ data. What can we learn about DM?

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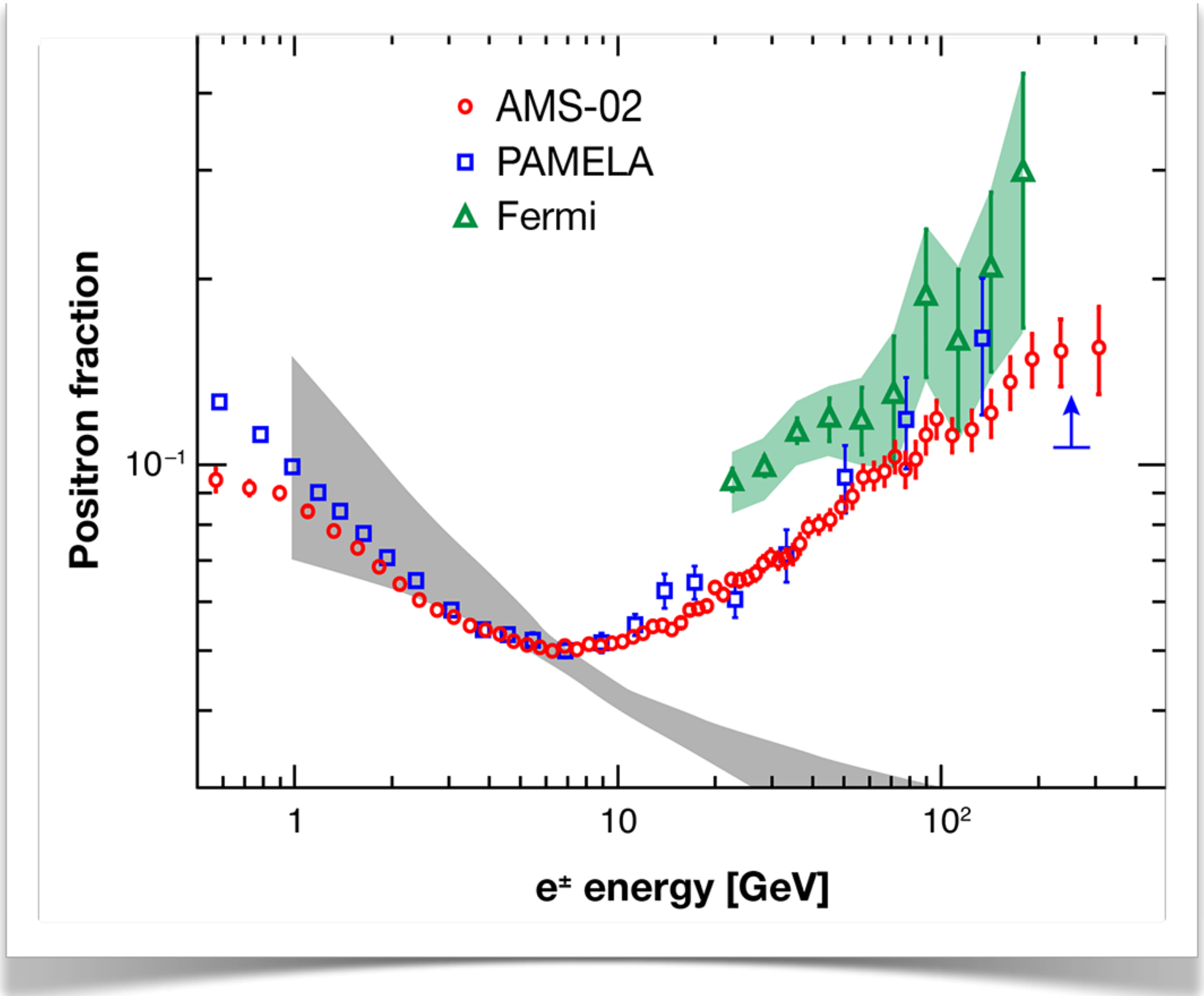
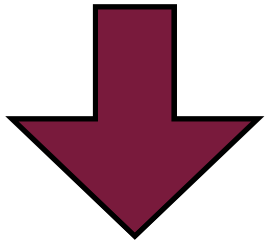
Motivations

A steep **increase** in the energy spectrum of the **positron fraction** has been firstly measured by **PAMELA** and then confirmed by **Fermi-LAT** and, most recently, by **AMS-02**



The rise is **not compatible** with the hypothesis that all positrons have a **secondary origin**



It implies the existence of additional **sources of primary e⁺**

In principle, these high-energy positrons can be generated by **astrophysical sources** or by the **annihilation/decay of WIMPs**

Outline

This talk is composed by **two parts**:

- **Part 1** will be devoted to the **study of the astrophysical sources** of primary and secondary $e^{\pm}$:

  We will **investigate the properties** of these sources by performing a **global fit** of the measurements performed by **AMS02**

  > ***Interpretation of AMS02 electrons and positrons data***
  > *M. Di Mauro, F. Donato, N.Fornengo, R.Lineros, AV, JCAP 04 (2014) 003, arXiv:1401.4017*

- In **part 2** we will derive **constraints on Dark Matter properties** within a **realistic** model for the $e^{\pm}$ astrophysical background

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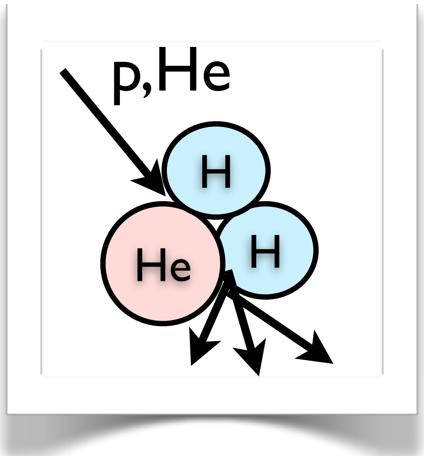
e± from astrophysical sources

- Electrons



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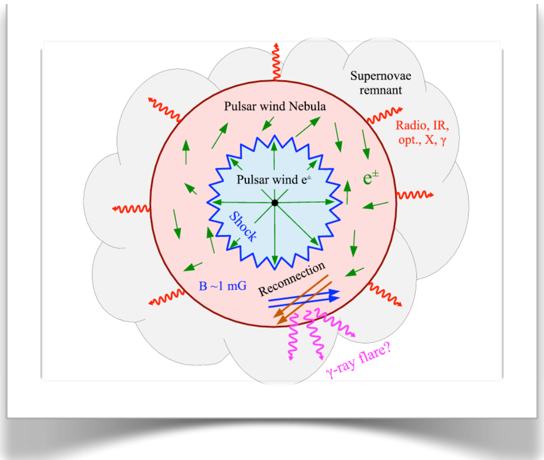
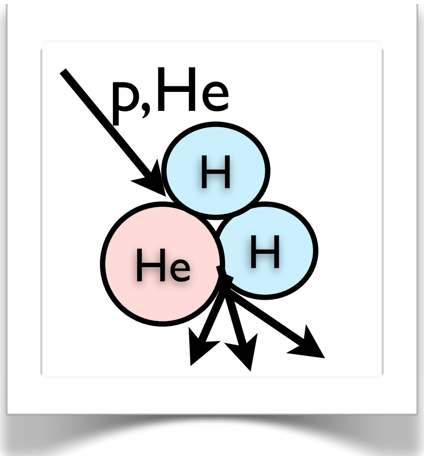


secondaries SNRs PWNe

- Positrons



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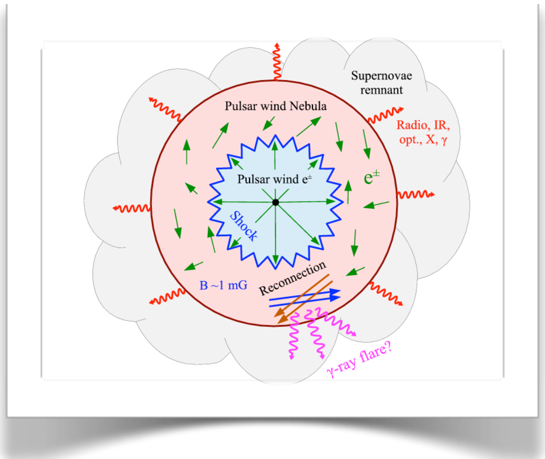


secondaries PWNe

Secondary e$^\pm$

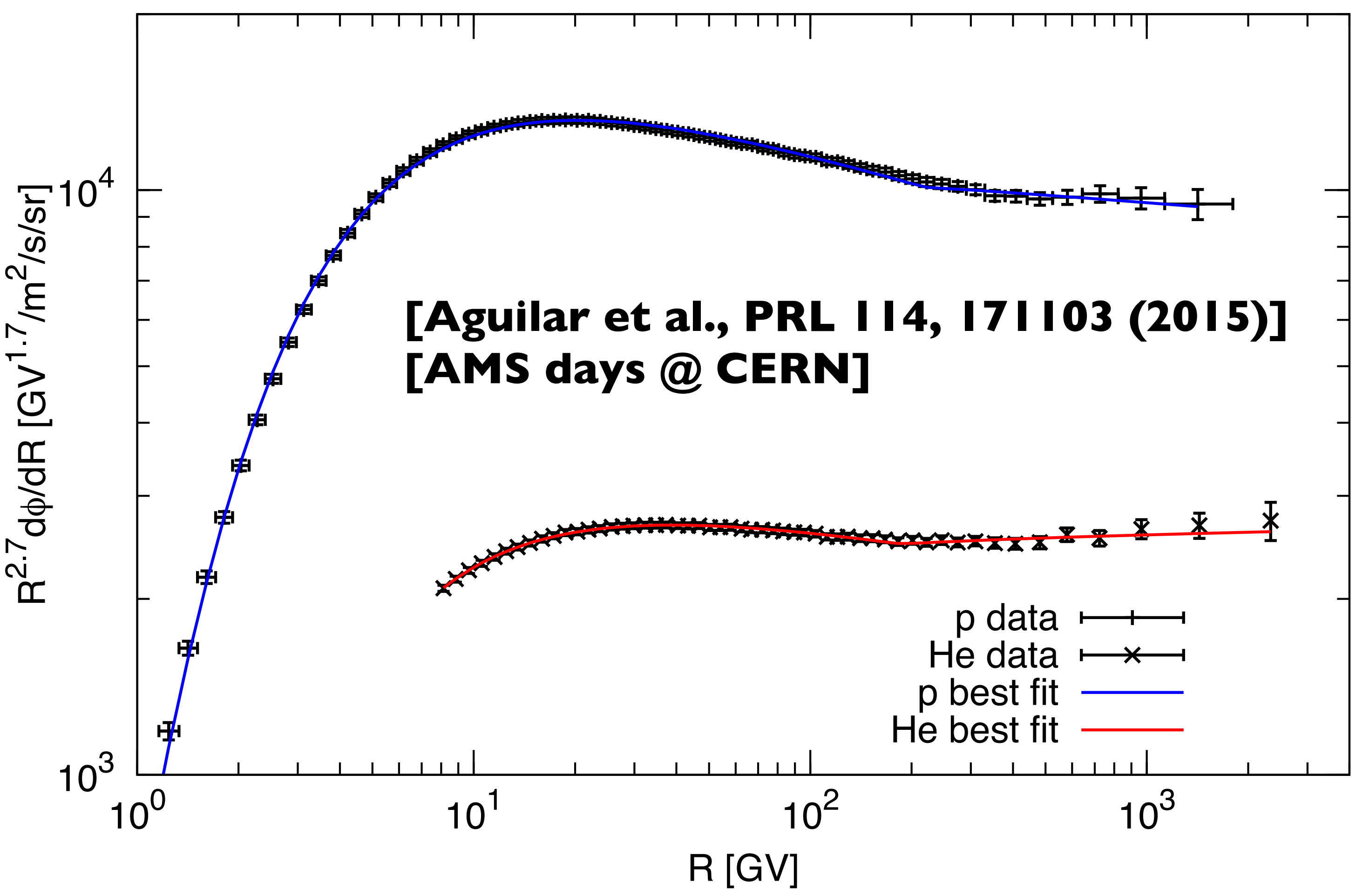
$$q_{e^\pm}(\mathbf{x},E_e) = 4\pi \boxed{n_{\rm ISM}(\mathbf{x})} \int dE_{\rm CR} \boxed{\Phi_{\rm CR}(\mathbf{x},E_{\rm CR})} \boxed{\frac{d\sigma}{dE_e}(E_{\rm CR},E_e)}$$

gas density in the ISM

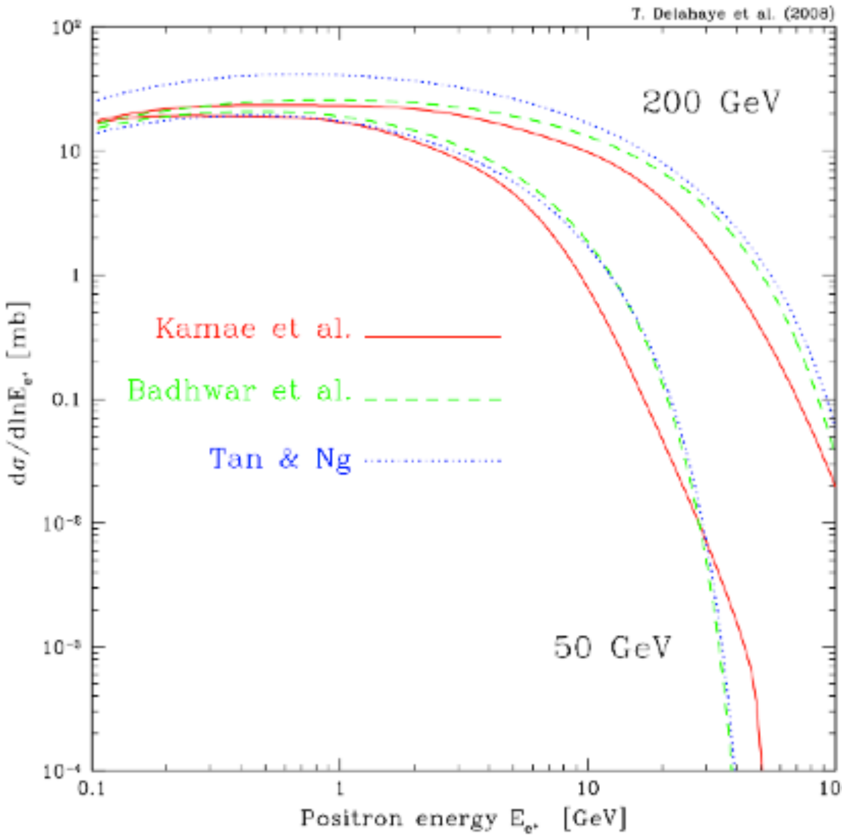
primary CR fluxes

e$^\pm$ production cross-section (Kamae parameterization)

Fit to AMS-02 p and He data



[Aguilar et al., PRL 114, 171103 (2015)]
[AMS days @ CERN]



T. Delahaye et al, 2008

In our fit we will allow for a **free normalization** of the secondary flux

Supernova Remnants (SNRs)

They accelerate electrons through the **shock acceleration mechanism**. The spectrum is:

$$\boxed{Q(E) = Q_0 \left(\frac{E}{1\ \mathrm{GeV}}\right)^{-\gamma} \exp\left(-\frac{E}{E_c}\right)}$$

The cut-off energy is **E_c = 2 TeV**

The value of Q_0 can be derived from radio data:

radio flux

$$Q_0 = 1.2 \cdot 10^{47} (0.79)^{\gamma} \left[\frac{d}{\mathrm{kpc}}\right]^2 \left[\frac{\nu}{\mathrm{GHz}}\right]^{(\gamma-1)/2} \left[\frac{B}{100\mu\mathrm{G}}\right]^{-(\gamma+1)/2} \left[\frac{B_r^{\nu}}{\mathrm{Jy}}\right]$$

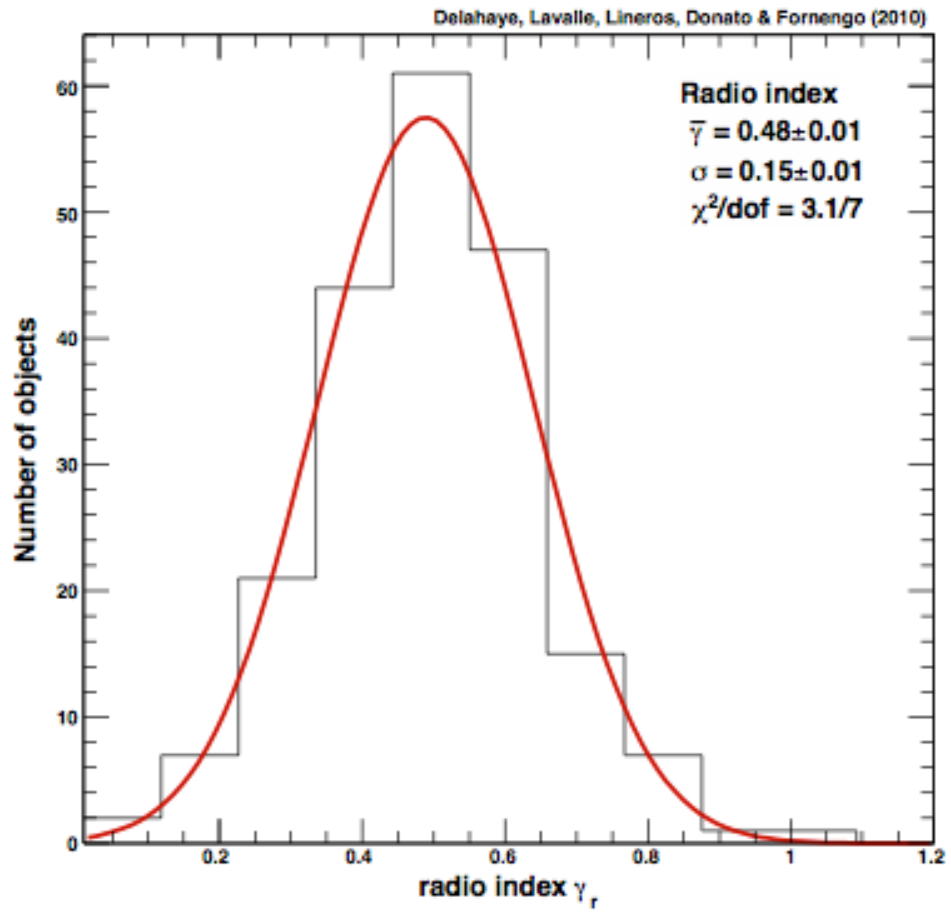
distance from the observer

magnetic field

Supernova Remnants (SNRs)

The **Green catalogue** is the most complete **SNR catalog** (265 sources)

$$\boxed{\langle\gamma\rangle = 2.0 \pm 0.3}$$

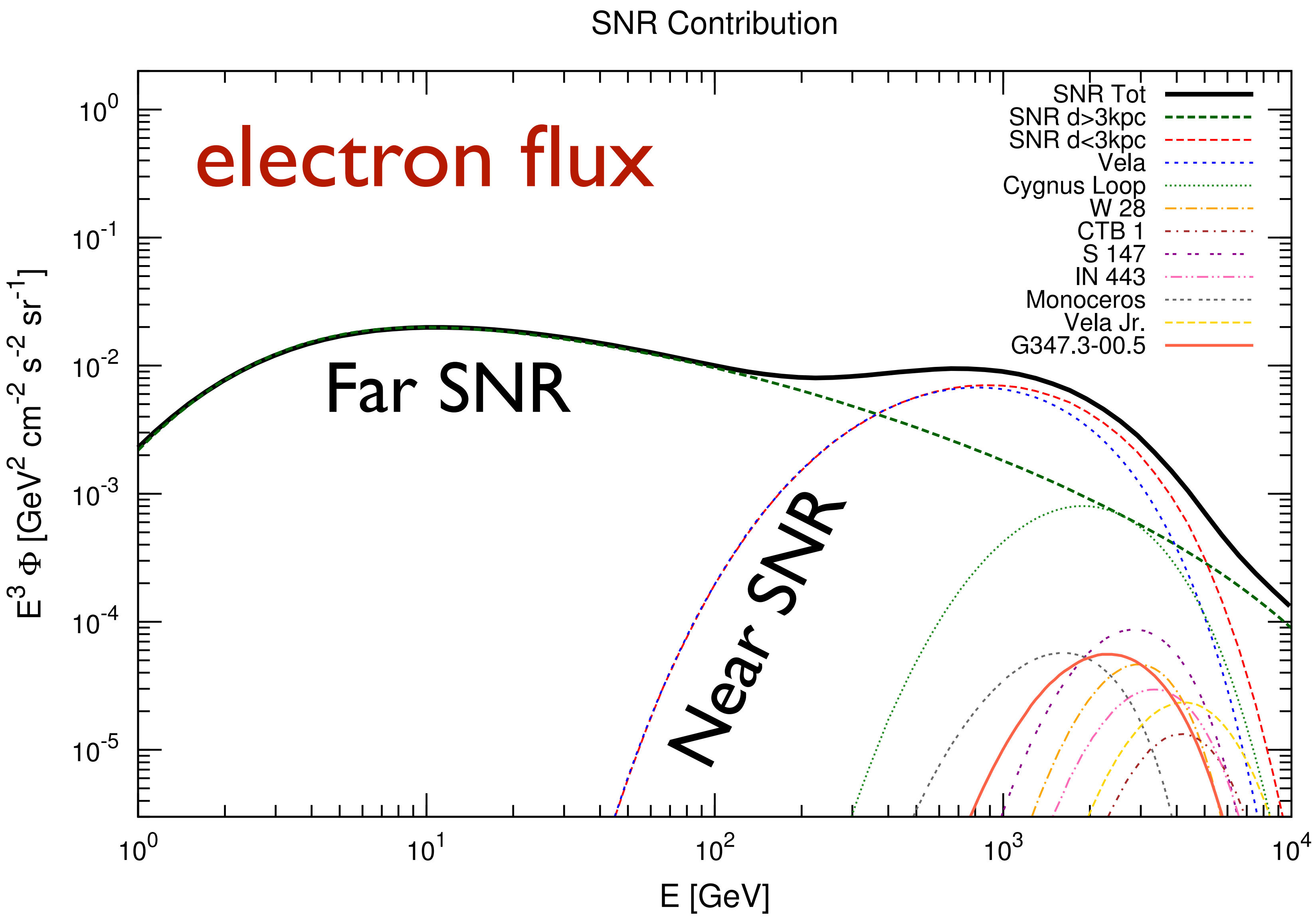


Delahaye, Lavalle, Lineros, Donato & Fornengo (2010)

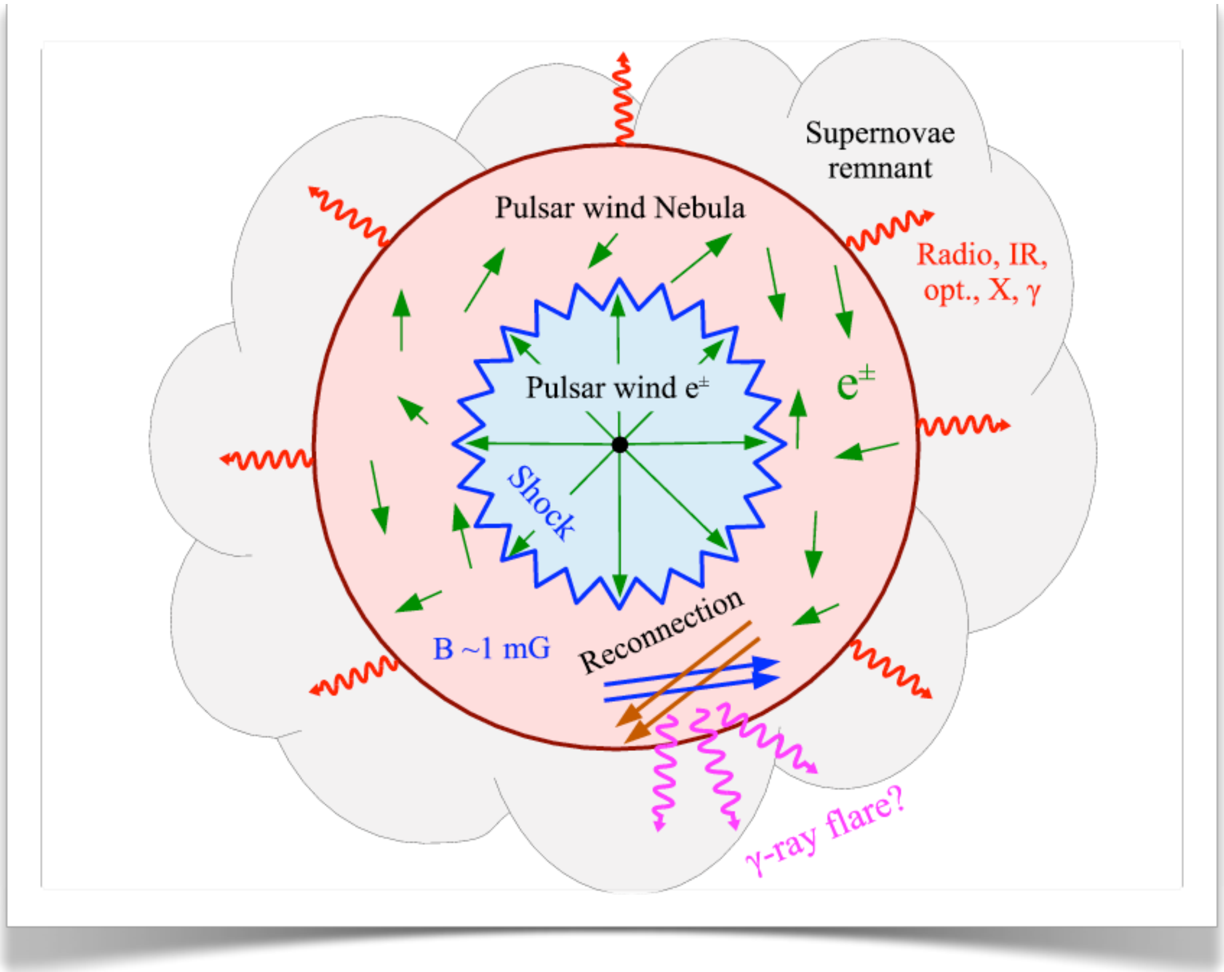
For our analysis, we **divide** the SNRs population in **two classes**:

- **Near SNRs** (d ≤ 3 kpc): their distances and ages are **fixed** to the values of the Green catalogue, we allow a free normalization
- **Far SNRs** (d > 3kpc): treated as an **average population** (which follows a Lorimer radial profile) they share common values for Q_0 and γ, which are **free parameters** of the fit

Supernova Remnants (SNRs)



Pulsar Wind Nebulae (PWNe)



The rotating magnetic field of a pulsar can be so strong to tear particle away from the surface of the star. These particles are **trapped in a nebula**, accelerated (through shock diffusion mechanisms) and **then released in the ISM** (after ~50 kyr).

$$\boxed{Q(E) = Q_0 \left(\frac{E}{1\ \mathrm{GeV}}\right)^{-\gamma} \exp\left(-\frac{E}{E_c}\right)}$$

The cut-off energy is **E_c = 2 TeV**

$$\boxed{Q_0 = \eta W_0}$$

$\eta \in [0,1]$

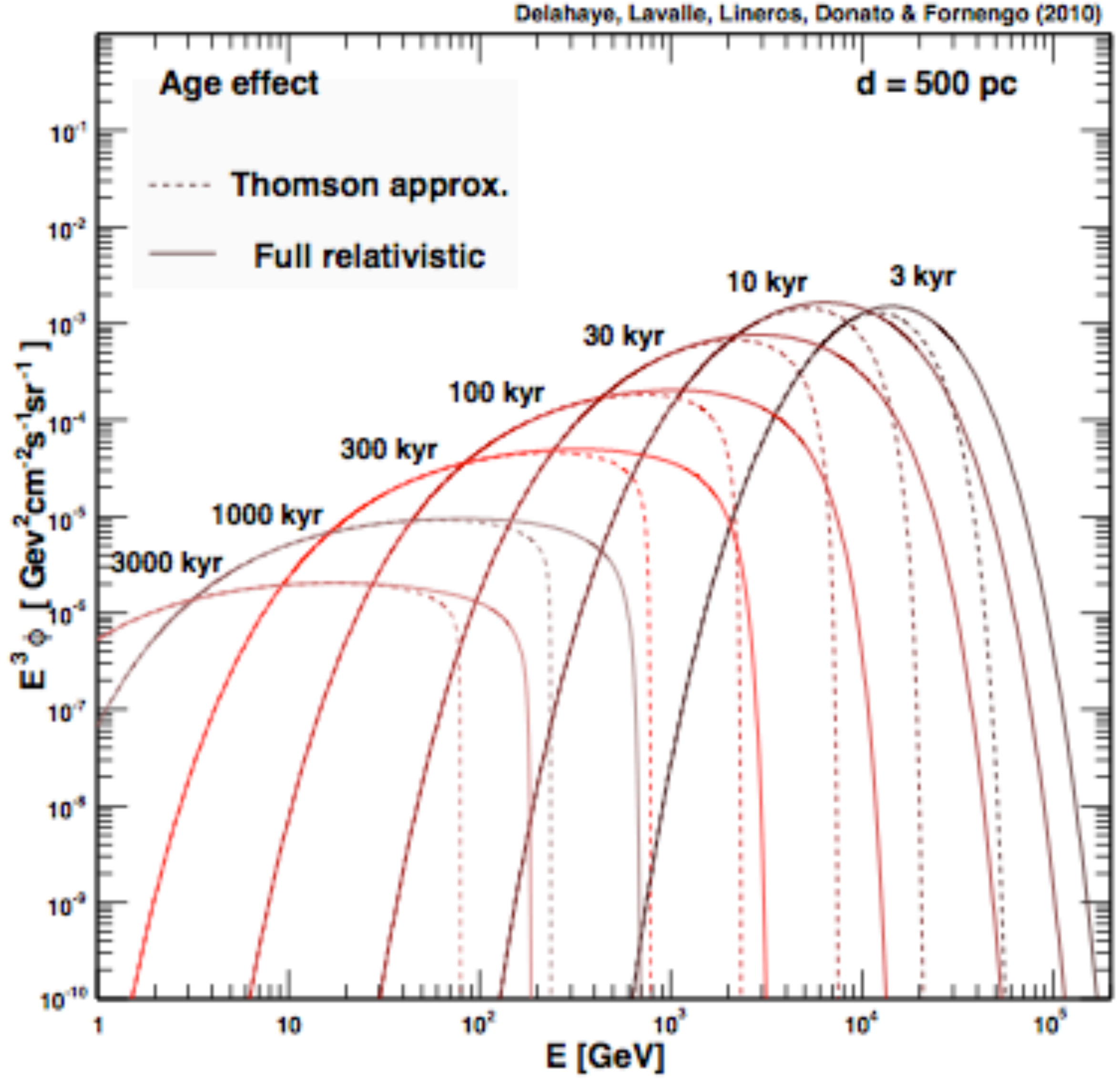
where

$$\boxed{W_0 \approx \tau_0 \dot{E} \left(1 + \frac{t_\star}{\tau_0}\right)}$$

pulsar spin-down energy
(energy emitted by the pulsar as it slows down)
[ATNF catalogue]

In our fit, pulsars are characterised by **2 free parameters**: γ and η

Pulsar Wind Nebulae (PWNe)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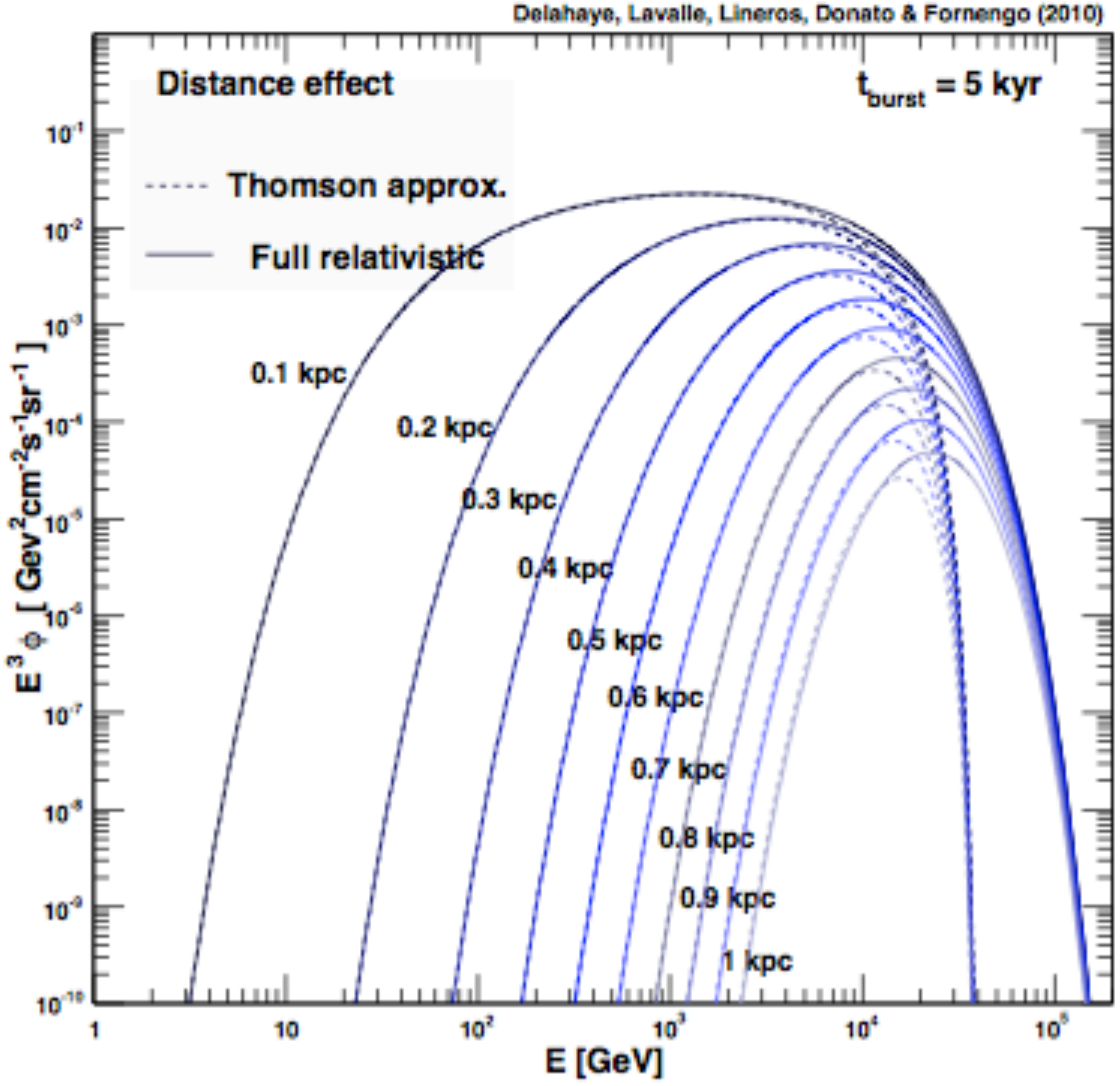
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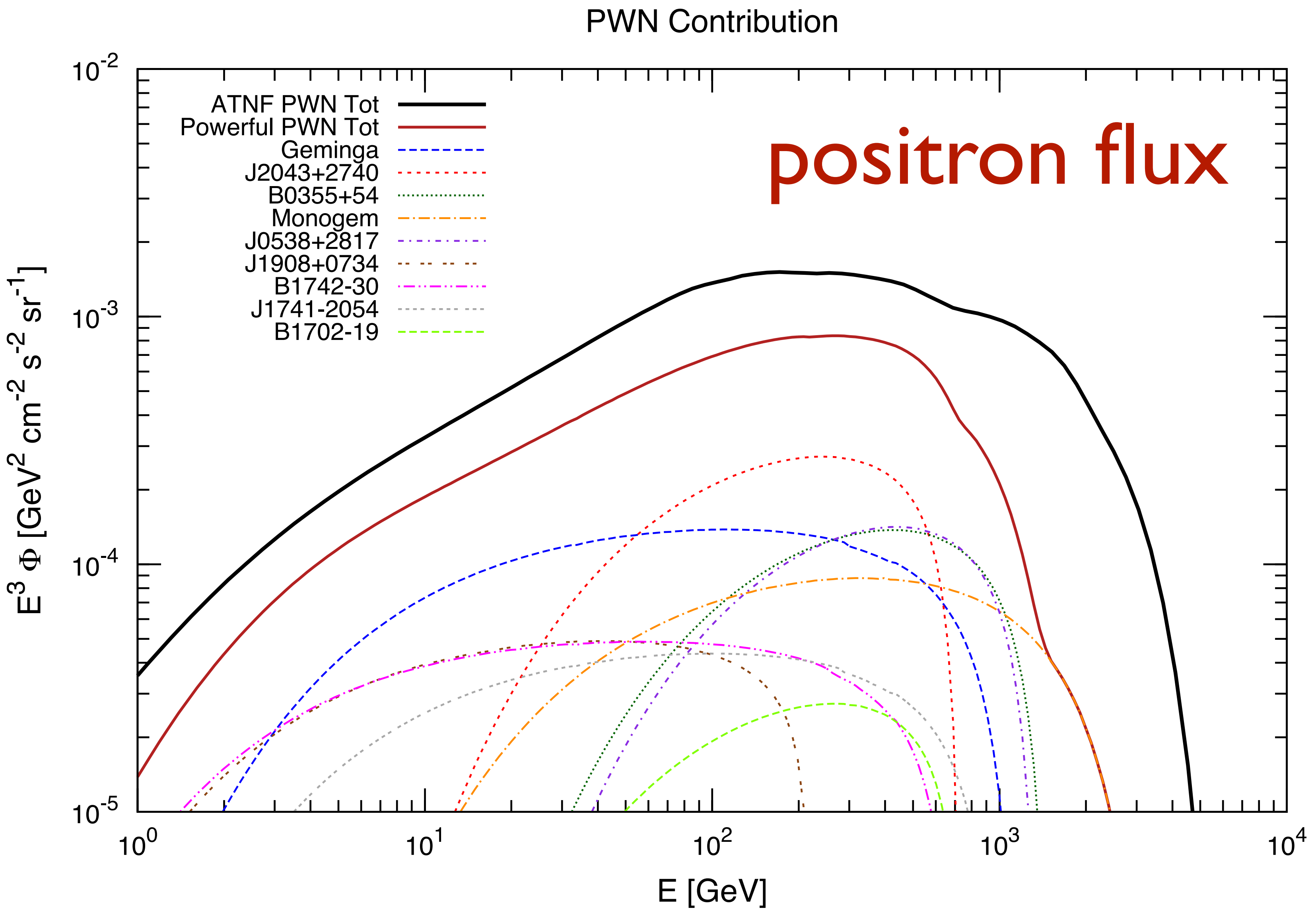
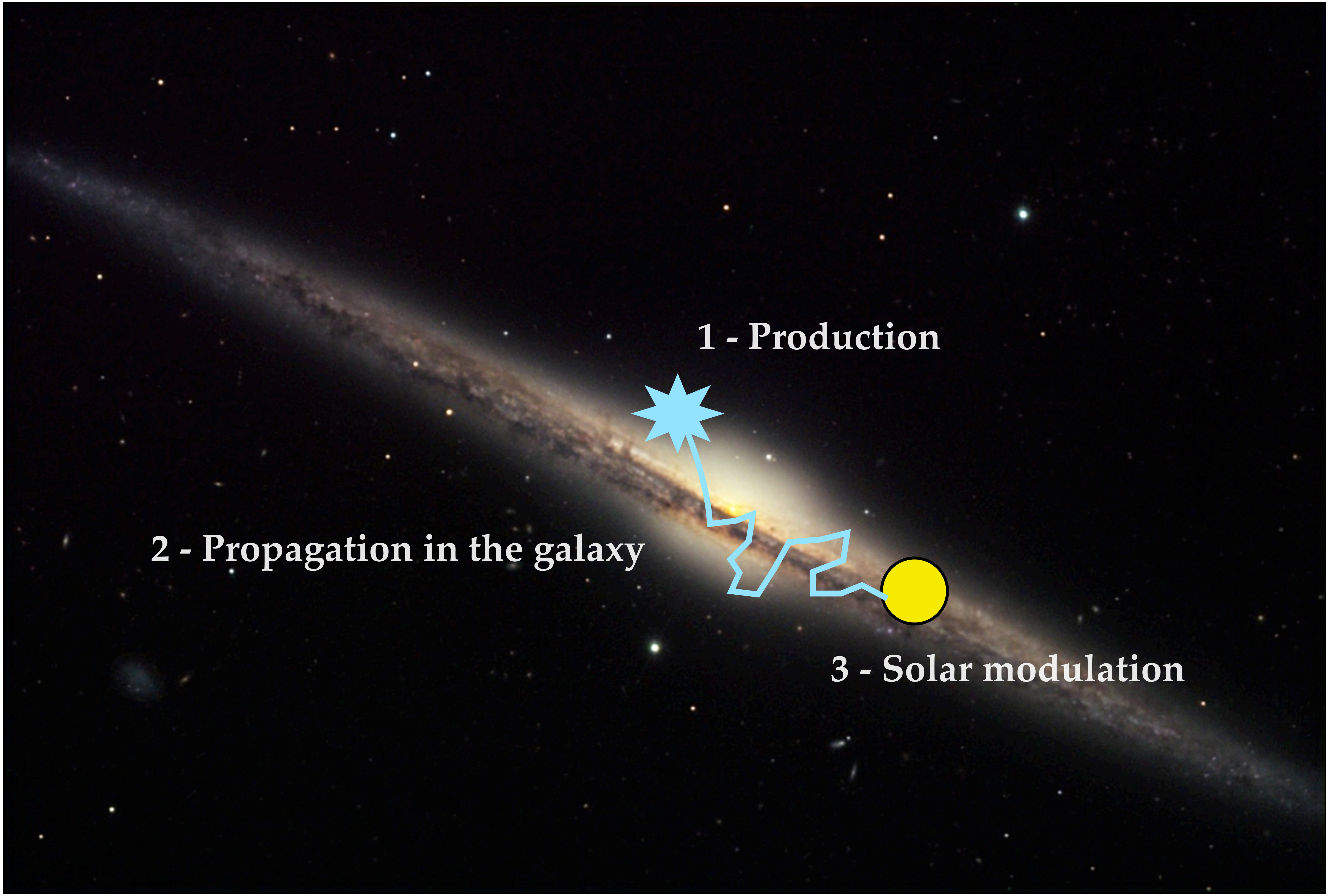


$e^{\pm}$ propagation



1 - Production

2 - Propagation in the galaxy

3 - Solar modulation

$e^{\pm}$ propagation

$$\partial_t \mathcal{N} - \vec{\nabla}\cdot\left\{K(E)\vec{\nabla}\mathcal{N}\right\} + \partial_E\left\{\frac{dE}{dt}\mathcal{N}\right\} = \mathcal{Q}(E,\vec{x},t)$$

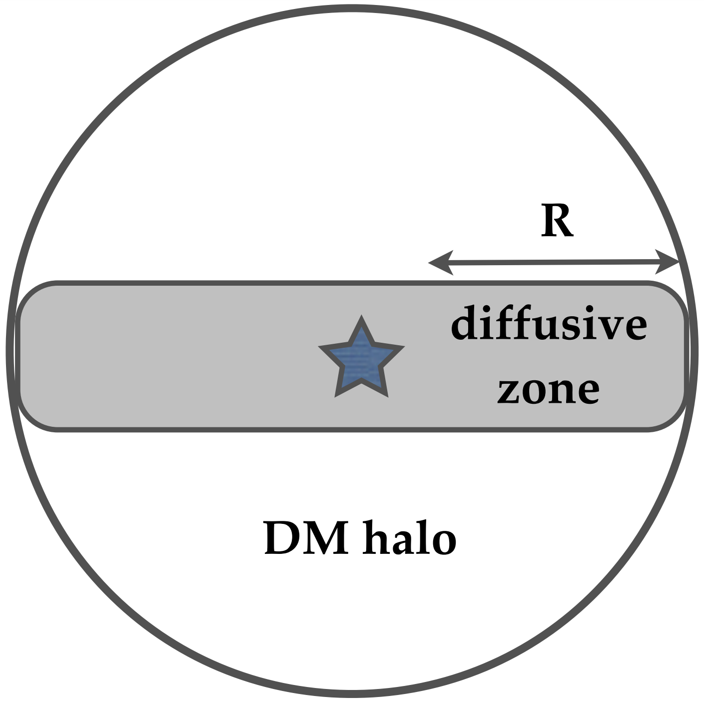
(≠0 if burst-like injection)

Spatial diffusion

Energy losses (synchrotron and inverse Compton)

Source term

Two-zone diffusion model



$$K(r,z,E) = \beta K_0\left(\frac{\mathcal{R}}{1\ \mathrm{GV}}\right)^{\delta}$$

Propagation data are constrained by the B/C data

	δ	K_0 (kpc^2/Myr)	L (kpc)
MIN	0.85	0.0016	1
MED	0.70	0.0112	4
MAX	0.46	0.0765	15

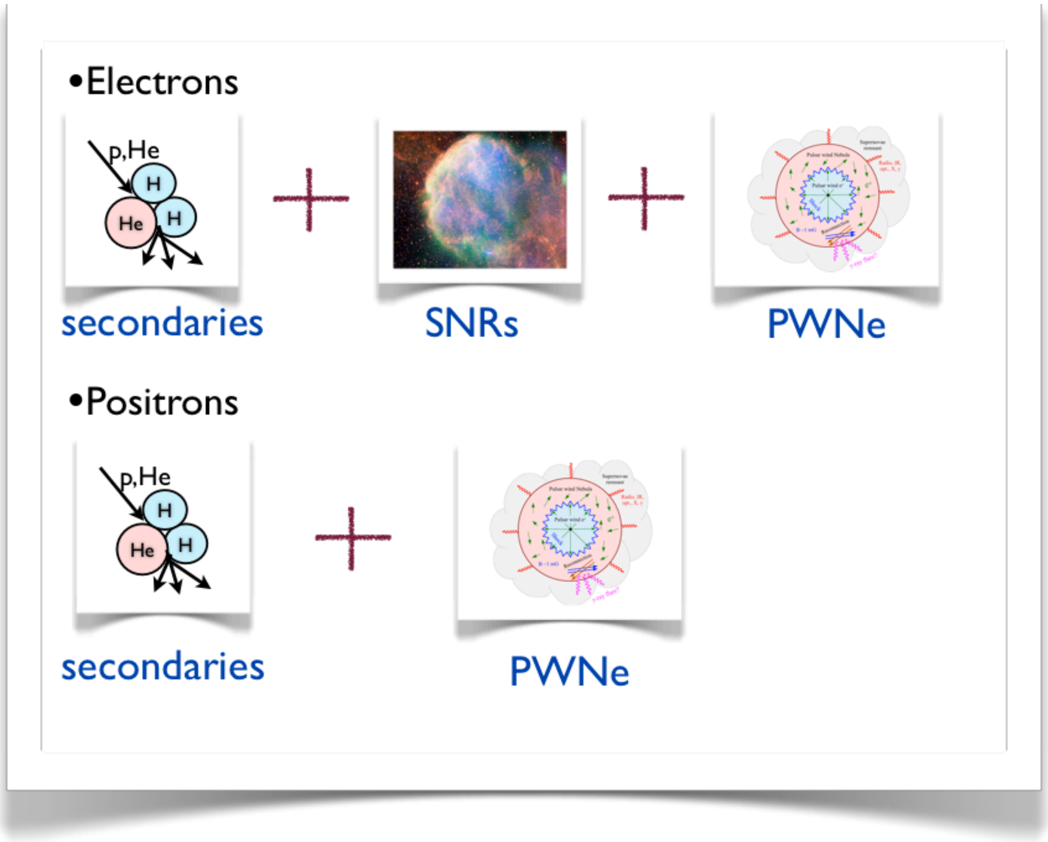
Solar modulation

$$\Phi_{\mathrm{TOA}}(T_{\mathrm{TOA}}) = \frac{T_{\mathrm{TOA}}(T_{\mathrm{TOA}}+2m)}{T_{\mathrm{IS}}(T_{\mathrm{IS}}+2m)}\Phi_{\mathrm{IS}}(T_{\mathrm{IS}})$$

$$T_{\mathrm{TOA}} = T_{\mathrm{IS}} - \varphi$$

fit to AMS-02 data

We will now **constrain the properties** of our model by performing a **global fit** to the observables measured by **AMS-02**



- Electrons

secondaries + SNRs + PWNe

- Positrons

secondaries + PWNe

We fit the **four observables**:

- e^+ flux
- e^- flux
- $e^+/(e^++e^-)$
- e^++e^- flux

We have **6 free parameters**:

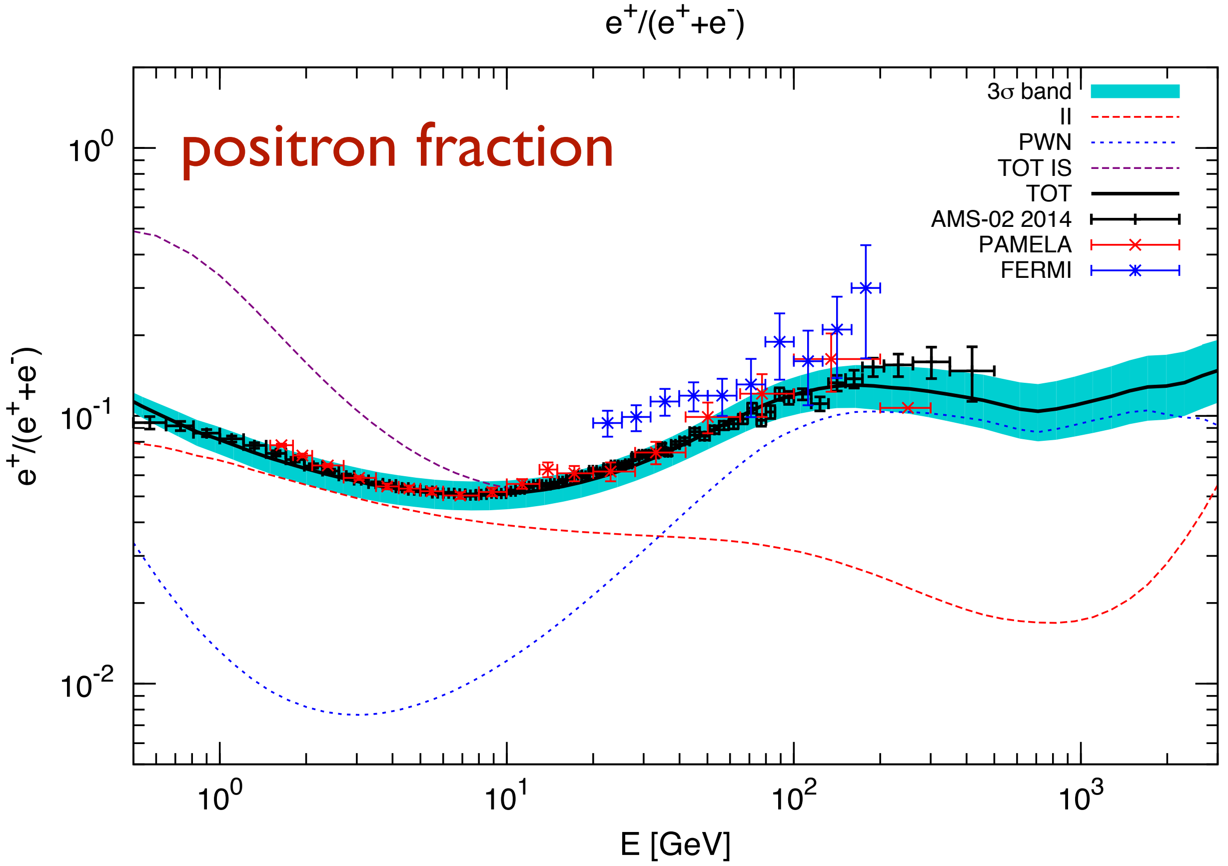
PWNe:
- γ
- η

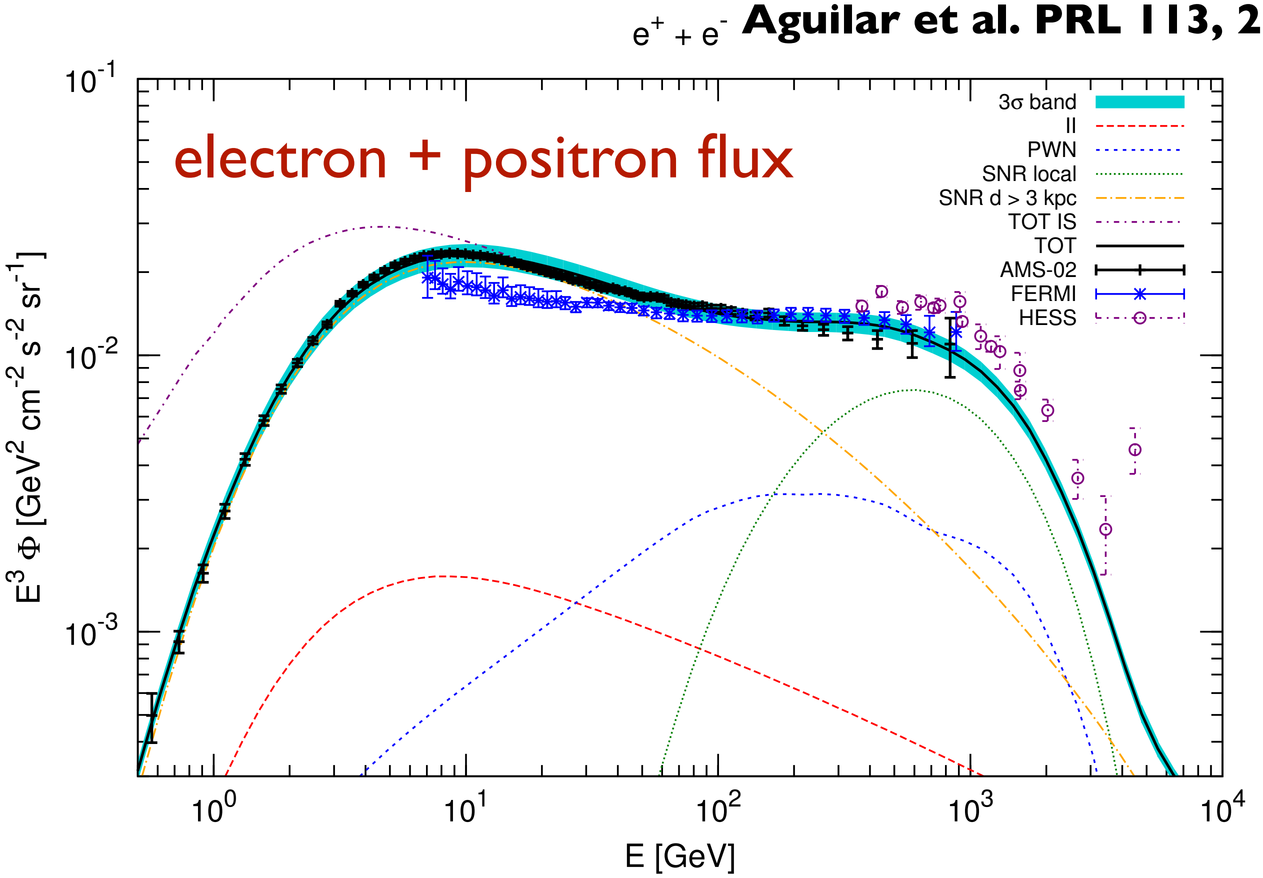
Far SNRs:
- Q_0
- γ_{SNR}

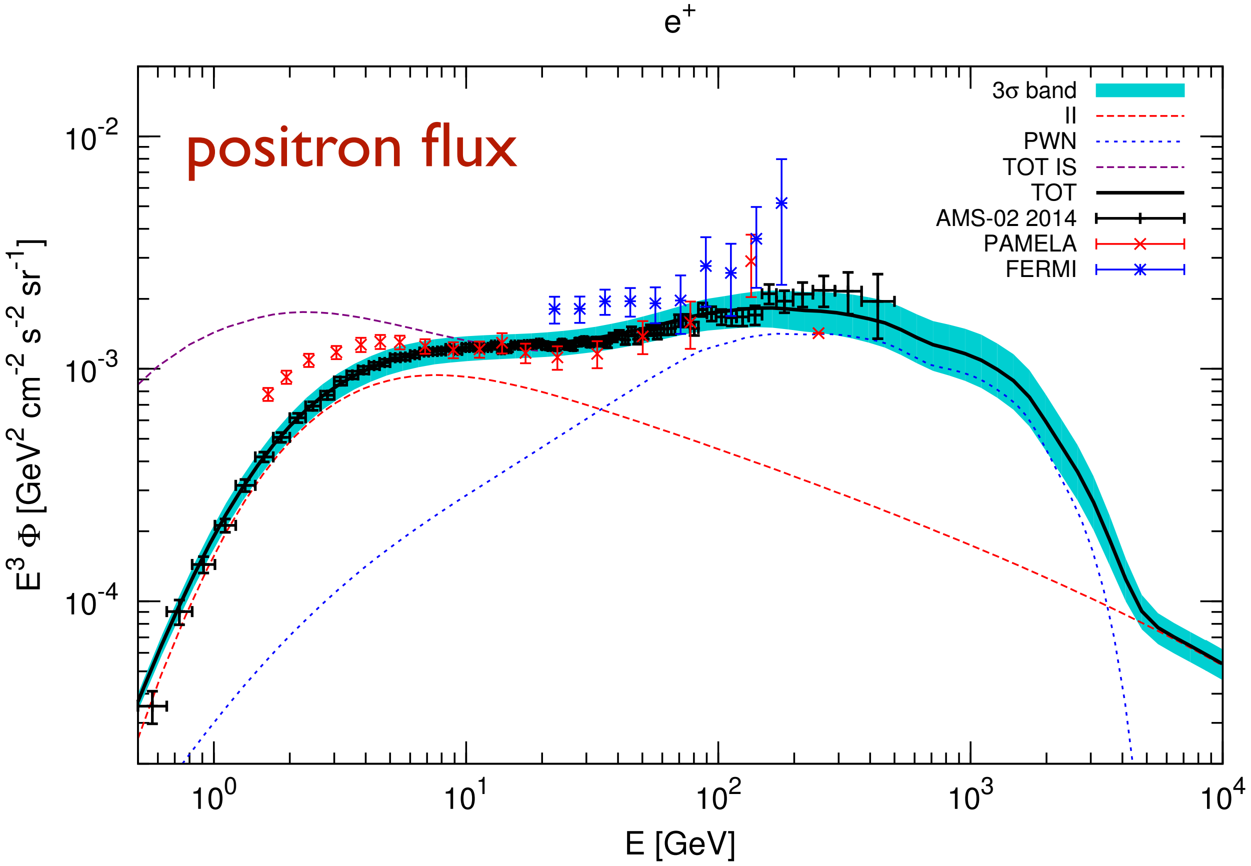
- φ Fisk potential
- Q_{sec} Normalization of secondaries

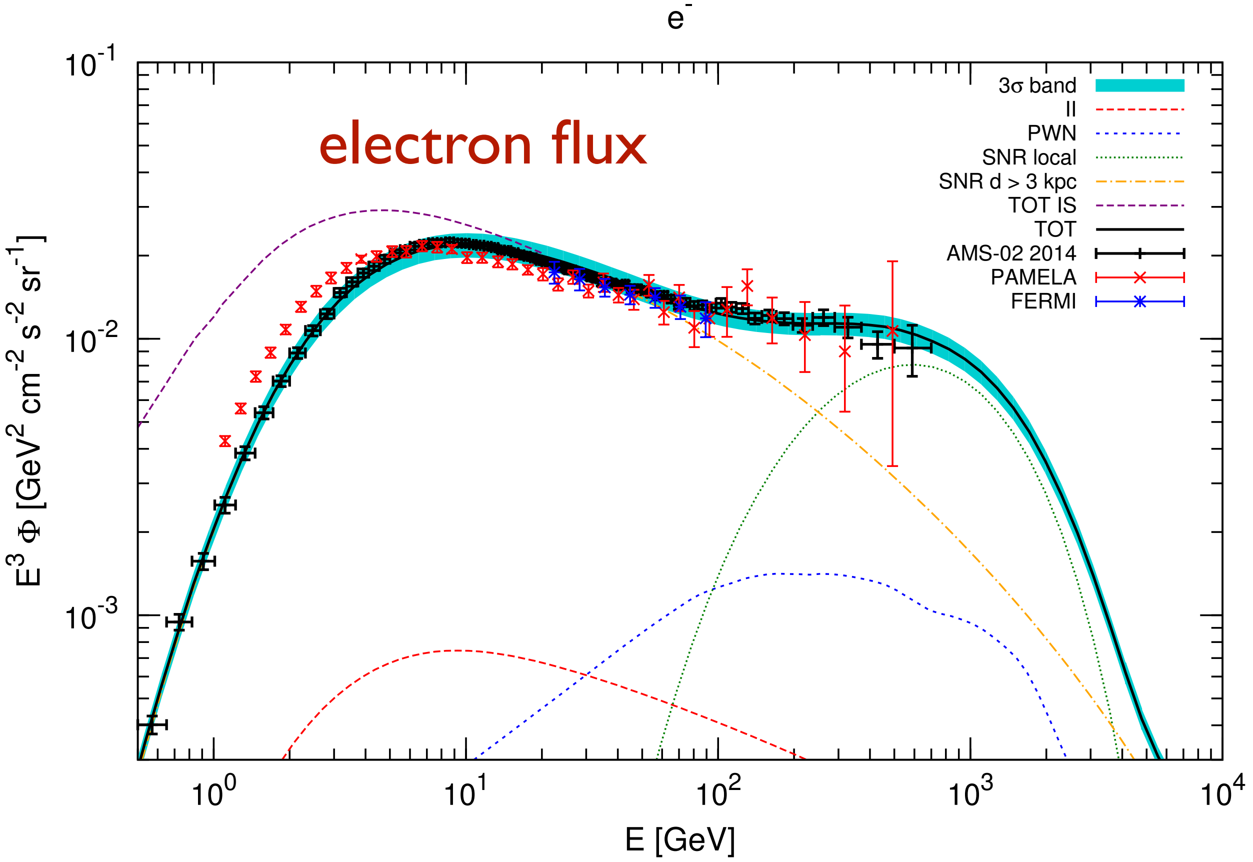
fit to AMS-02 data

Accardo et al. PRL 113, 2014
Aguilar et al. PRL 113, 2014









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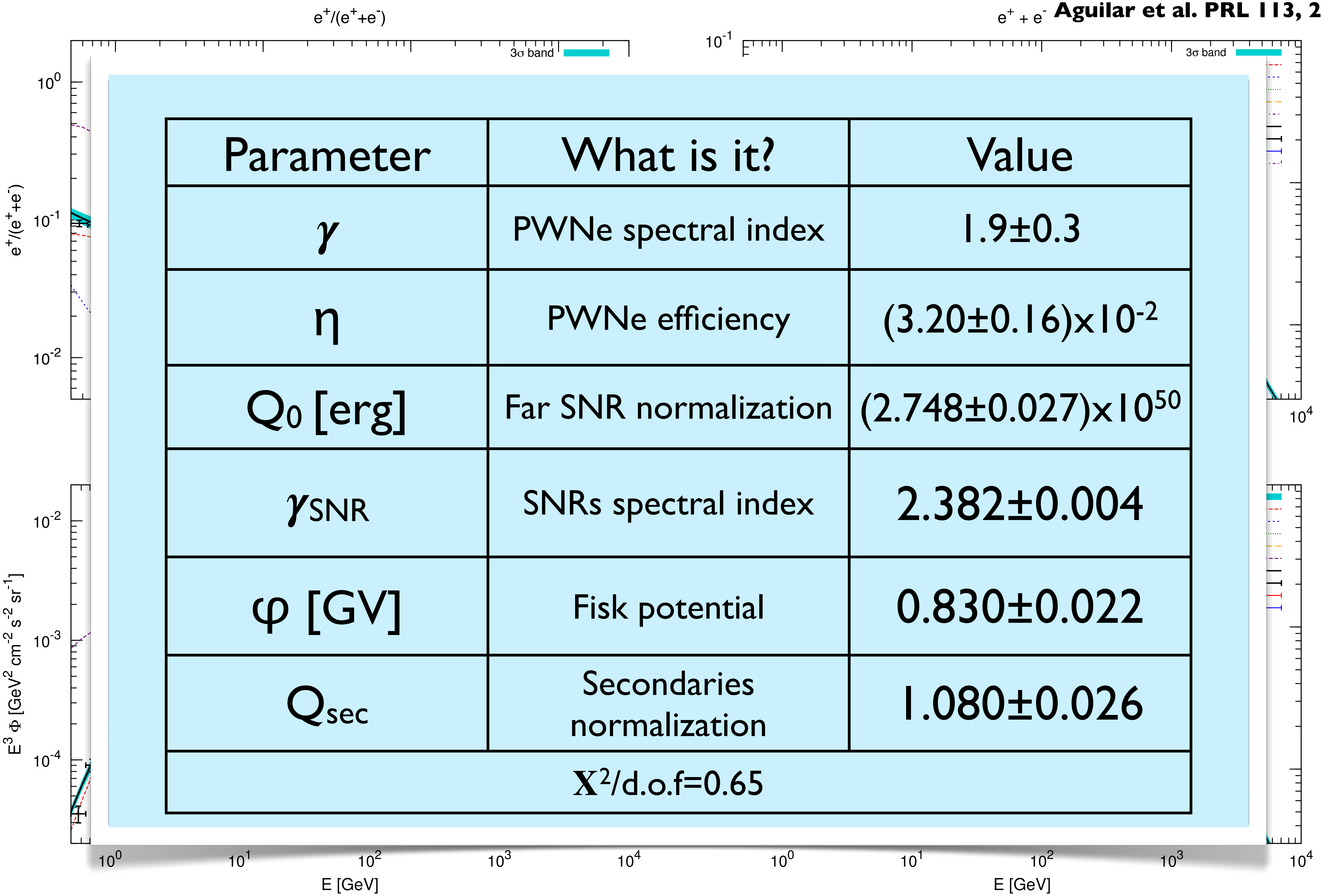

Parameter	What is it?	Value
γ	PWNe spectral index	1.9±0.3
η	PWNe efficiency	$(3.20\pm0.16)\times10^{-2}$
Q_0 [erg]	Far SNR normalization	$(2.748\pm0.027)\times10^{50}$
γ_{SNR}	SNRs spectral index	2.382±0.004
φ [GV]	Fisk potential	0.830±0.022
Q_{sec}	Secondaries normalization	1.080±0.026
χ^2/d.o.f=0.65		

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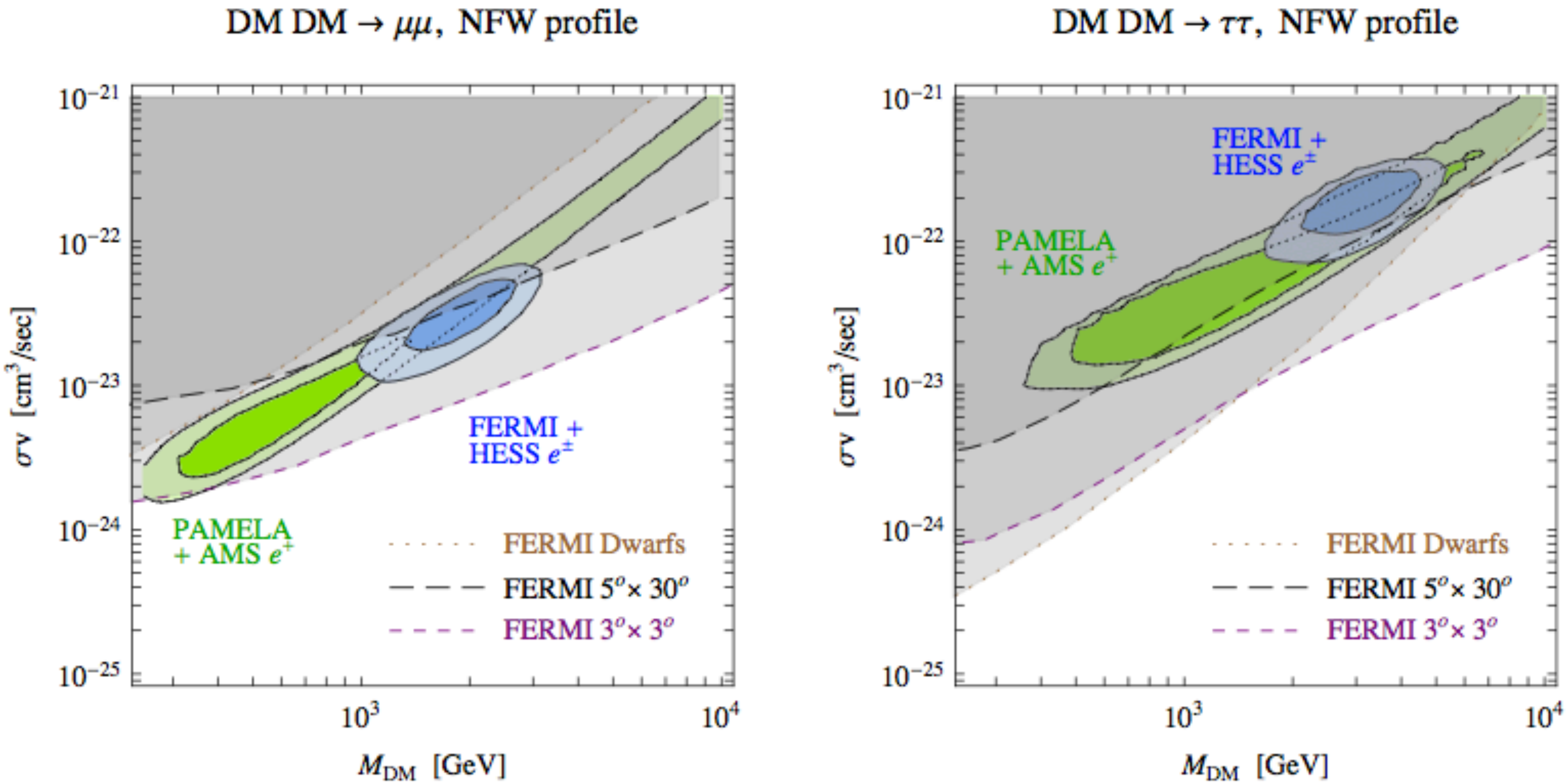
Constraints on DM

It is known that a pure **DM interpretation** of the positron fraction rise is in **tension** with bounds coming from **other channels**

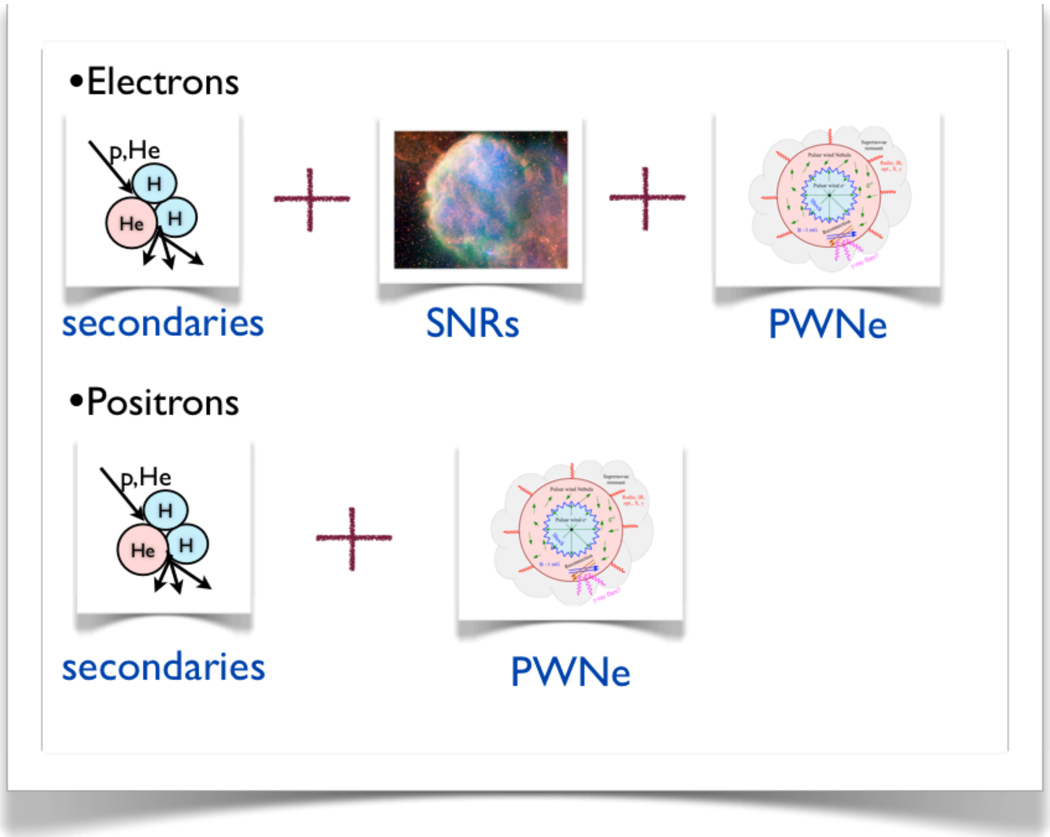


Cirelli et al. Nucl.Phys. B813 (2009) 1-21

What if we consider an astrophysical background that takes into account emission from primary sources?

Constraints on DM

Our model is now composed by **astrophysical** primary and secondary sources **and Dark Matter**



- Electrons

secondaries + SNRs + PWNe

- Positrons

secondaries + PWNe

+ DM

We fit the **four observables**:

- e^+ flux
- e^- flux
- $e^+/(e^++e^-)$
- e^++e^- flux

We have **8 parameters**: 7 are free, 1 is fixed

PWNe:
- γ
- η

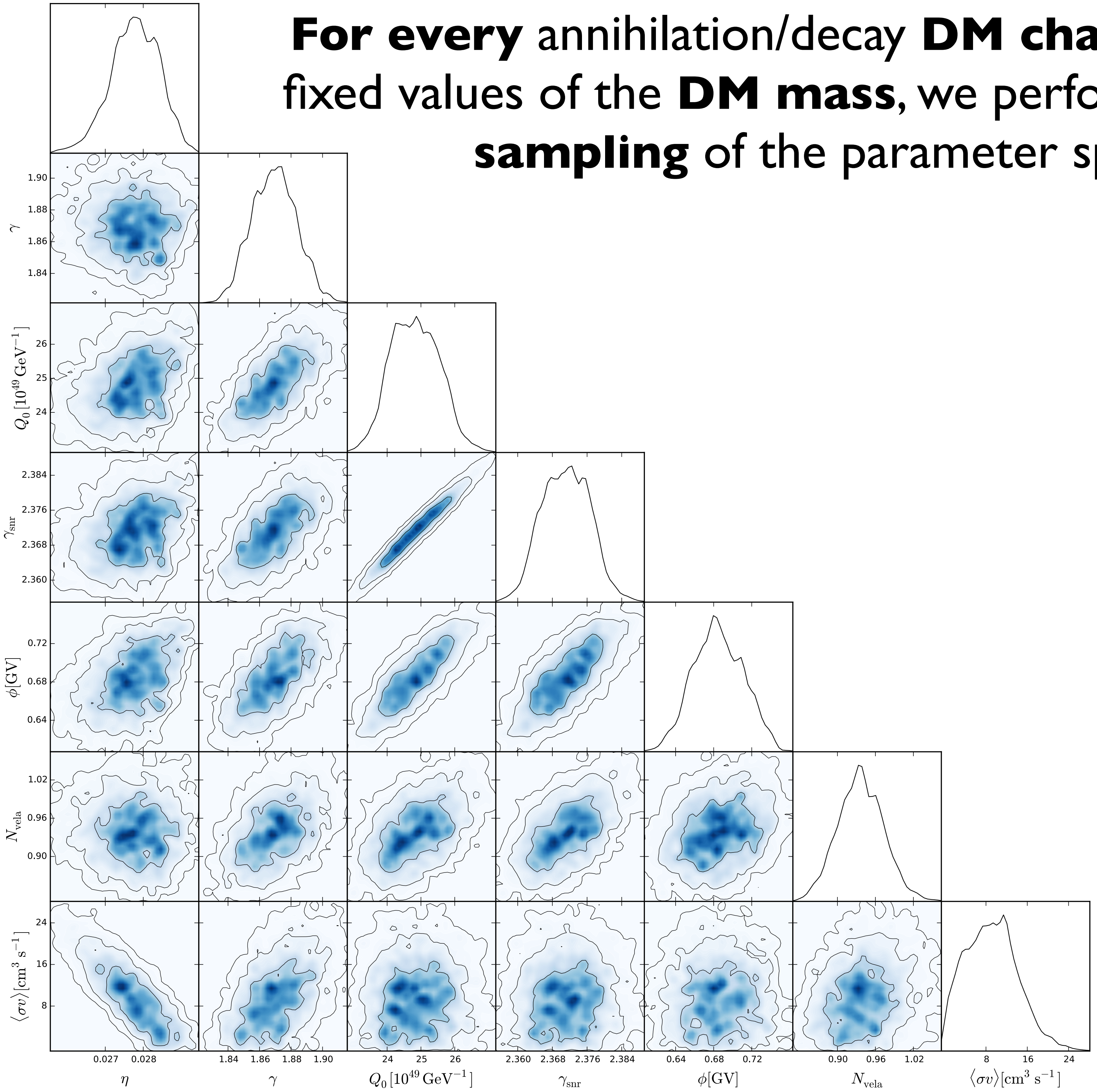
Far SNRs:
- $Q0$
- γ_{SNR}

DM:
- $<\sigma v>$
- mDM → We keep it fixed

- φ Fisk potential
- Nvela Normalization of Vela flux

Constraints on DM

For every annihilation/decay **DM channel** and for fixed values of the **DM mass**, we perform a **MCMC sampling** of the parameter space



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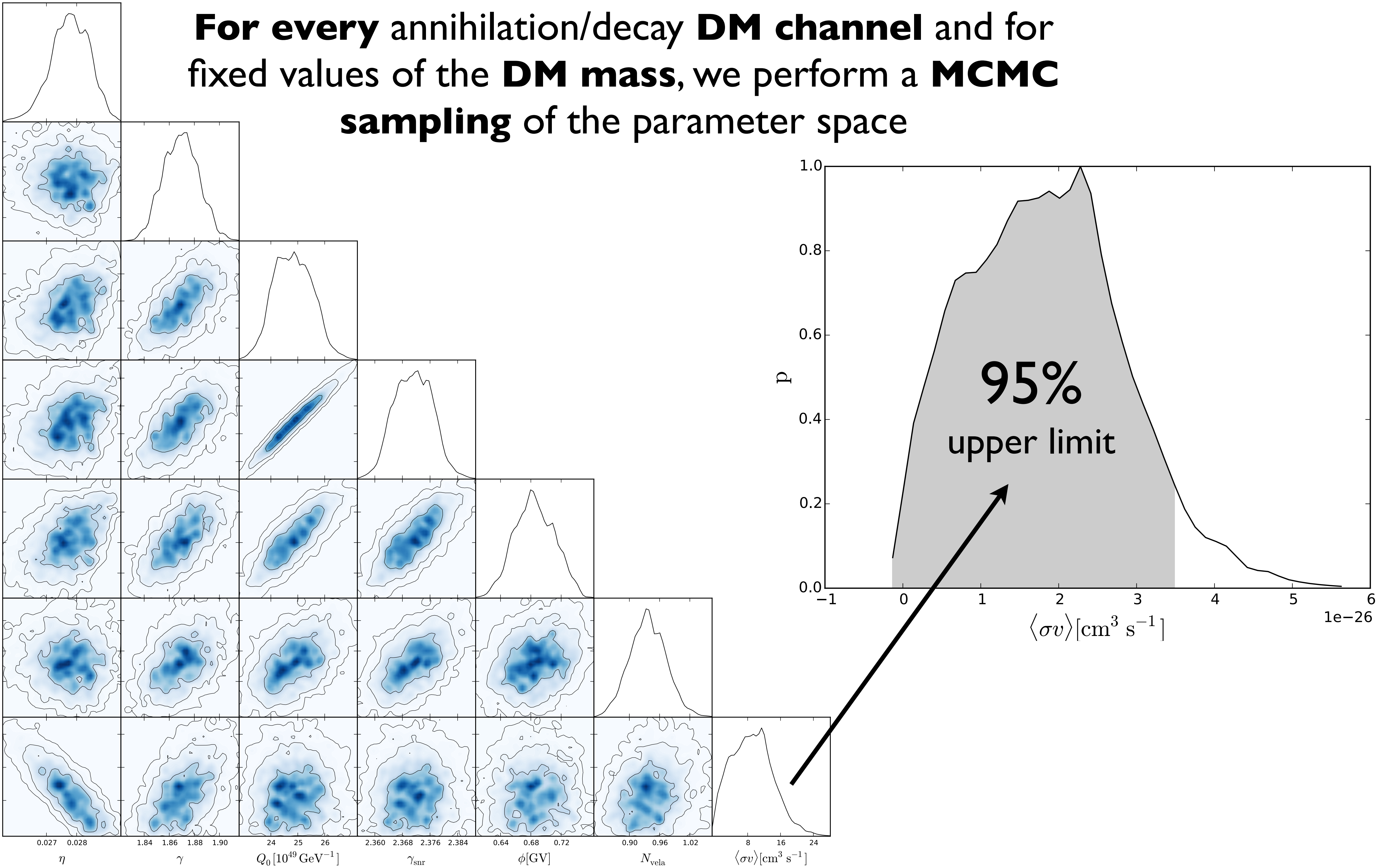
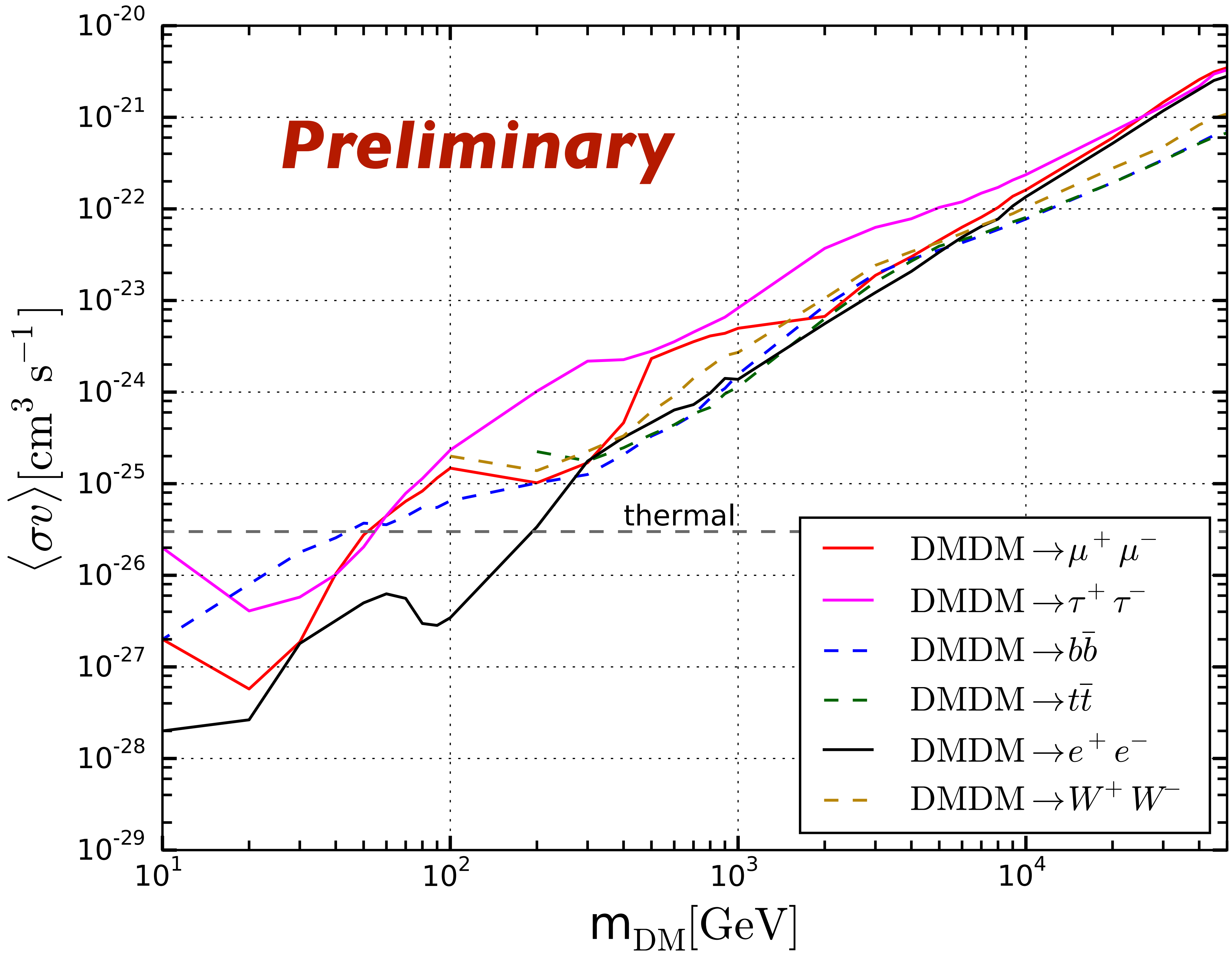


95%
upper limit

Constraints on DM



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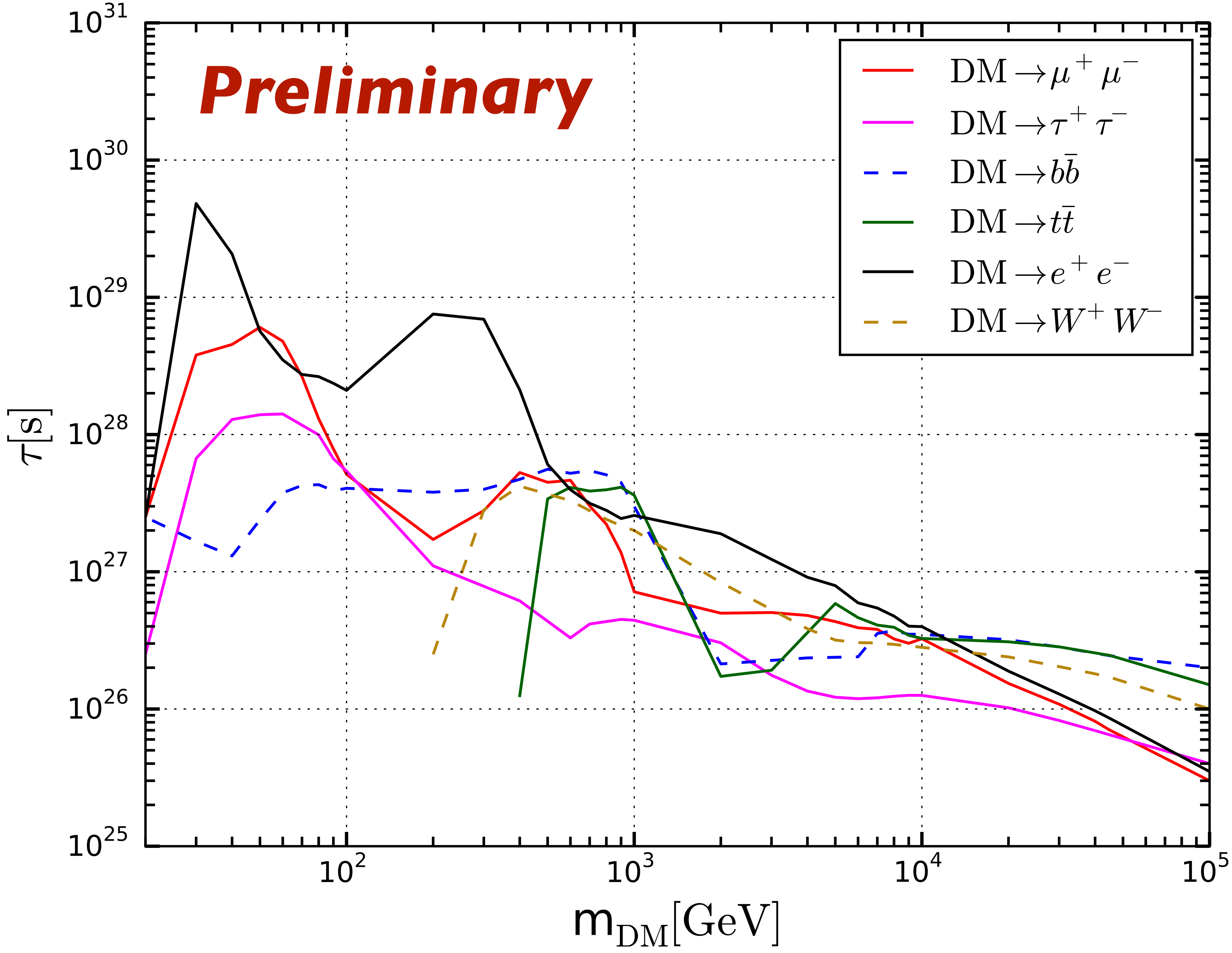


Conclusions

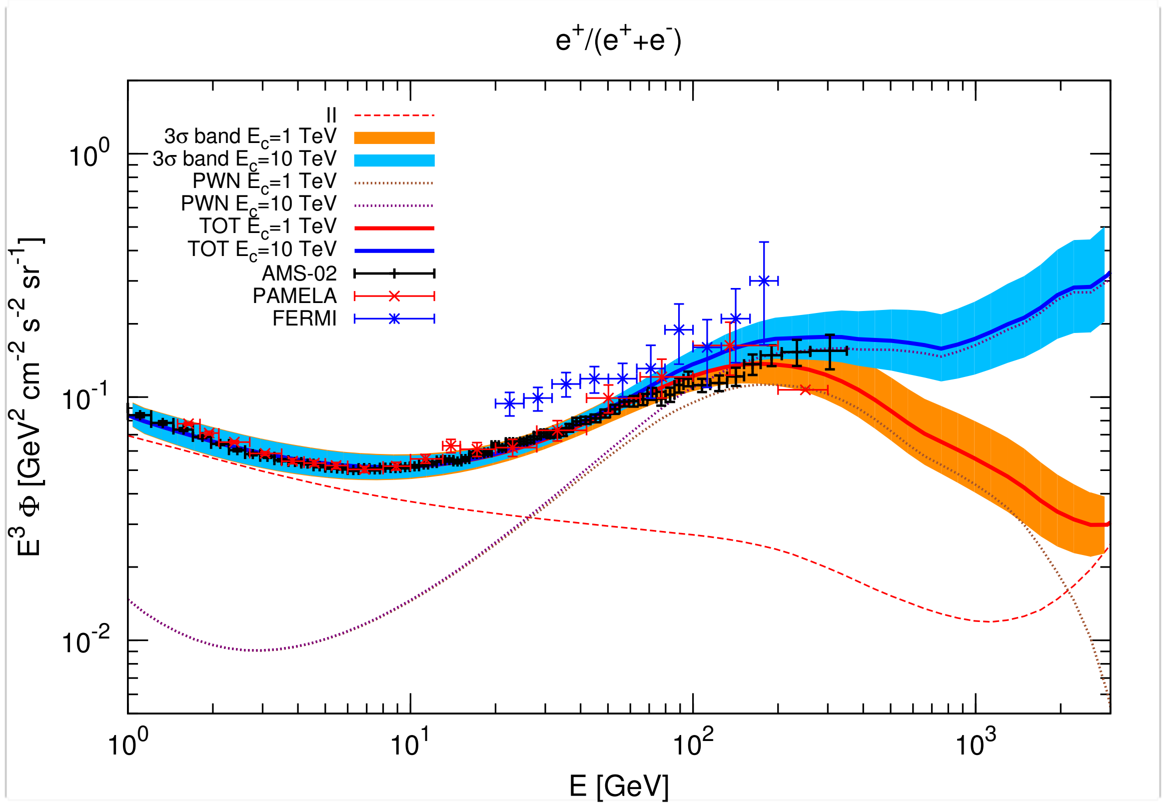
- We have seen that the **electron flux** can be interpreted as the sum of the emission of **distant and local SNRs**, while the flux of **positrons** can be modeled as the result of a **secondary emission** plus a contribution from **PWNe**

- If we add **Dark Matter** to the picture, we are able to impose **strong constraints** on its properties. In particular, we can set bounds on the annihilation/decay rate into leptons that are **comparable or even stronger** to the ones that can be obtained from **other channels**

- The unprecedented **accuracy** of AMS-02 measurements has thus made us able to **explore** configurations of the DM **parameters that are crucial for cold WIMPs**

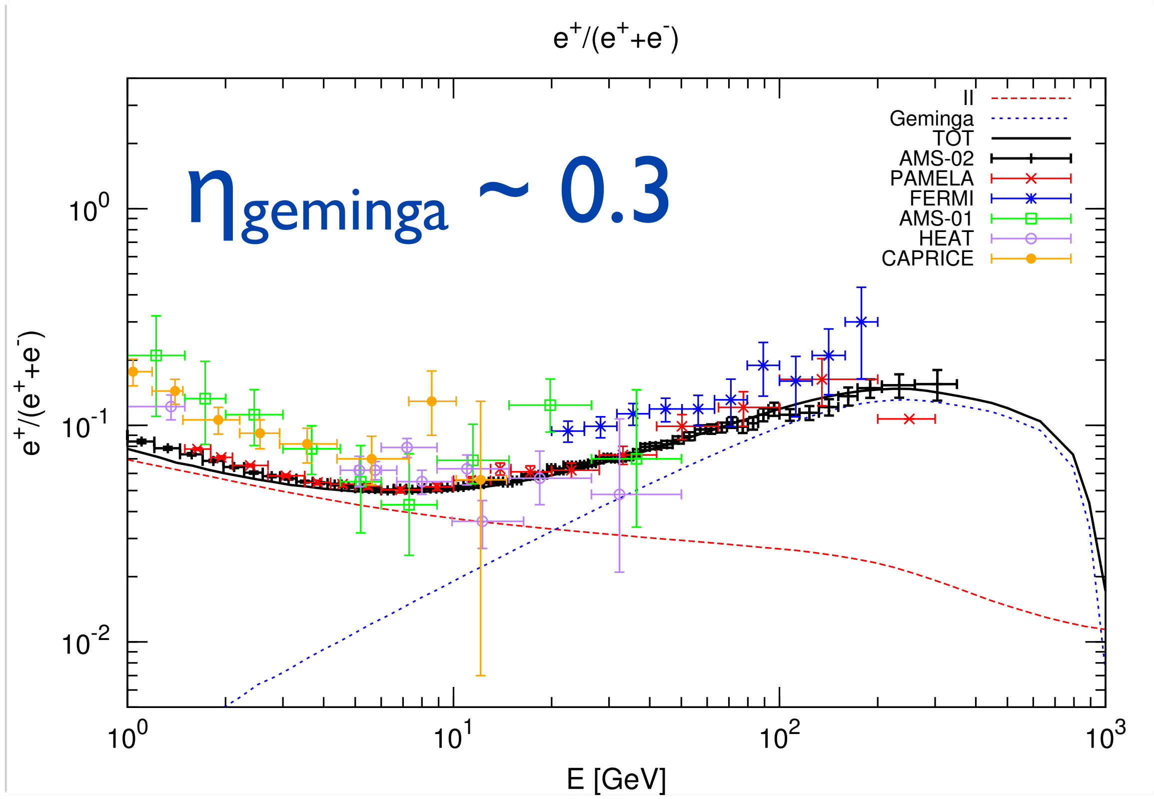
- In any case, in order to fully exploit these highly precise data, a **deeper knowledge** of the astrophysical background **is mandatory**.

fit to AMS-02 data



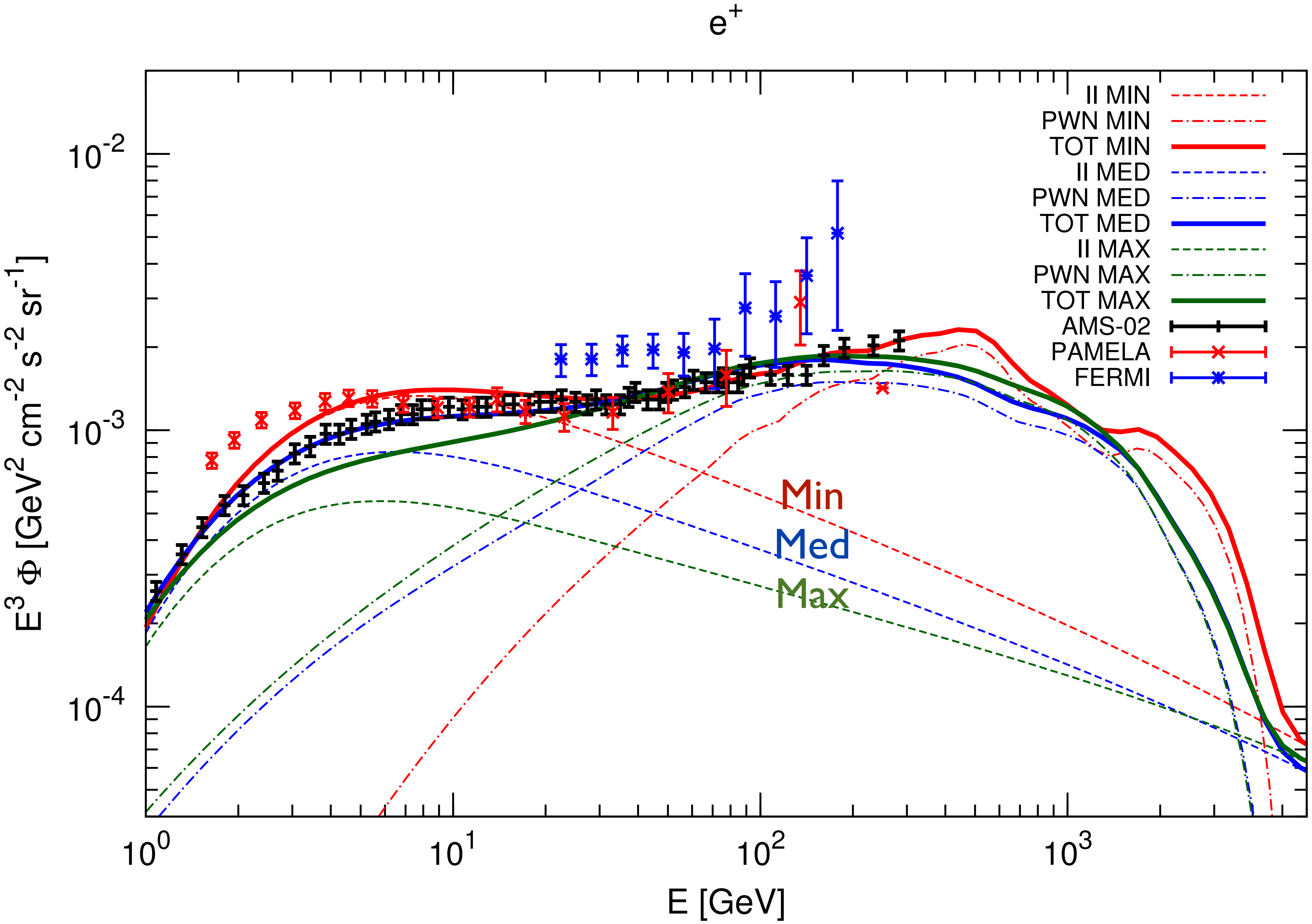
- **Results** have been obtained with a **cut-off E_c = 2 TeV** in the spectrum of $e^\pm$ emitted by PWNe.
- **Changing this value** can **affect** the shape of **the positron fraction** at high energies to **a large extent**.
- Only **a sudden drop would appear not compatible with PWNe emission**

- In our analysis, we have also checked that **our model does not require the full set of PWNe to emit positrons**.
- In the case shown here, **the whole amount** of positrons is **emitted by Geminga**.



$\eta_{geminga} \sim 0.3$

Can we disfavor the Min and Max propagation models?



Q_{sec} = 0.72(Min) , 1.78(Max)