Possible interpretations to AMS-02 electron and positron data

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Outline

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

•<u>Part 1</u> 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**

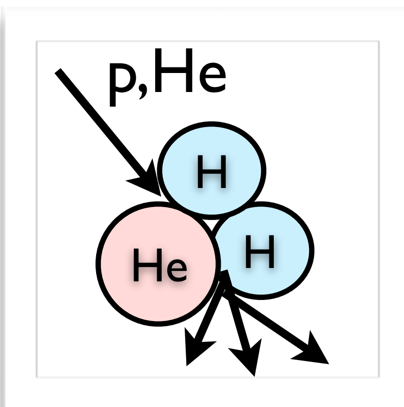
Interpretation of AMS02 electrons and positrons data
M. Di Mauro, F. Donato, N.Fornengo, R.Lineros, A.Vittino, JCAP 04 (2014) 003, arXiv:1401.401

•In <u>part 2</u> we will derive **informations on Dark Matter properties** within a **realistic** model for the $e^{\pm}$ astrophysical background

Dark matter vs. astrophysics in the interpretation of AMS-02 electron and positron data
M. Di Mauro, F. Donato, N.Fornengo, A.Vittino, JCAP 1605 (2016) 031, arXiv:1507.07001[astro-ph.HE]

$e^{\pm}$ from astrophysical sources

- Electrons



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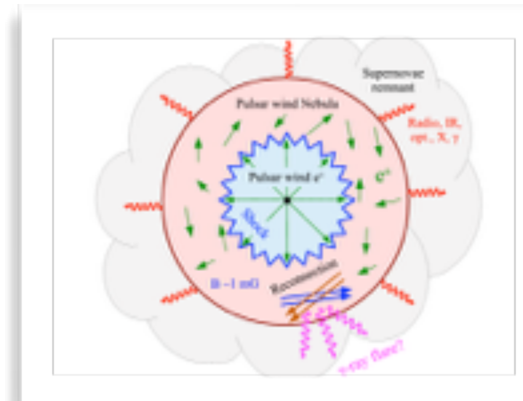
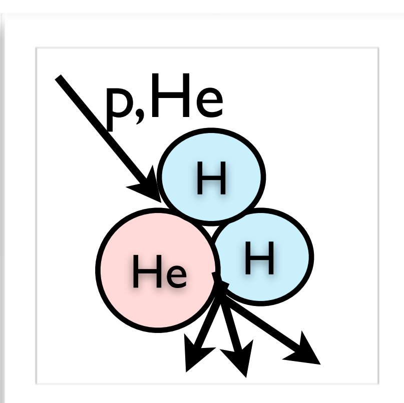


secondaries SNRs PWNe

- Positrons



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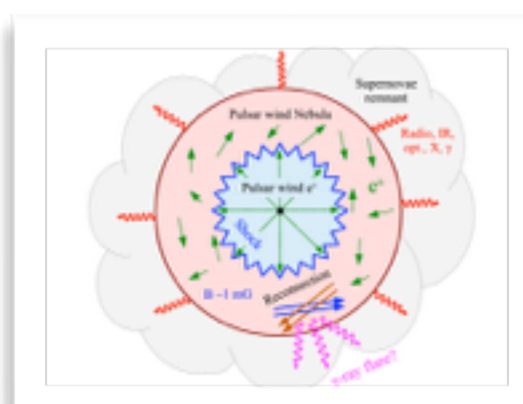


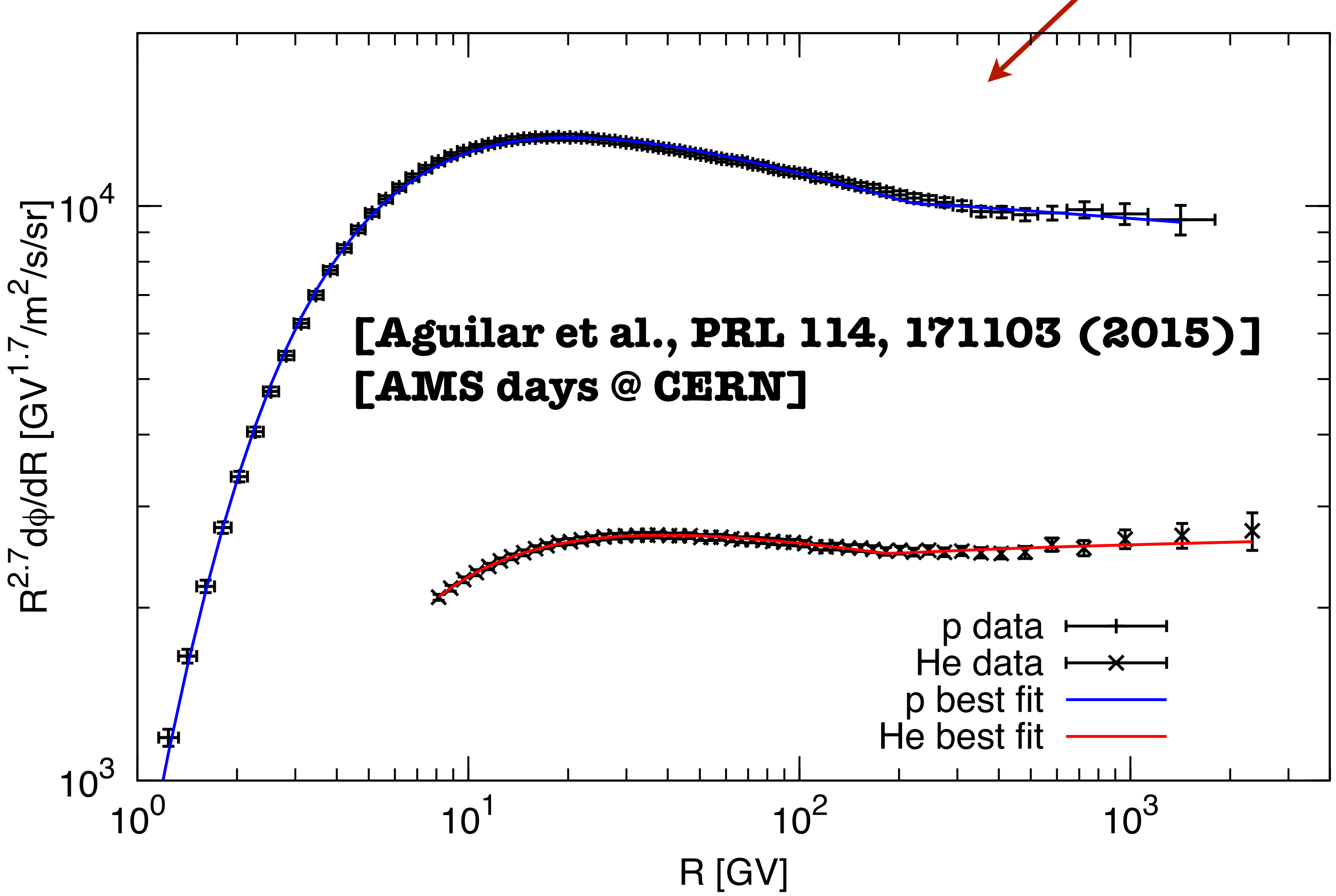
secondaries PWNe

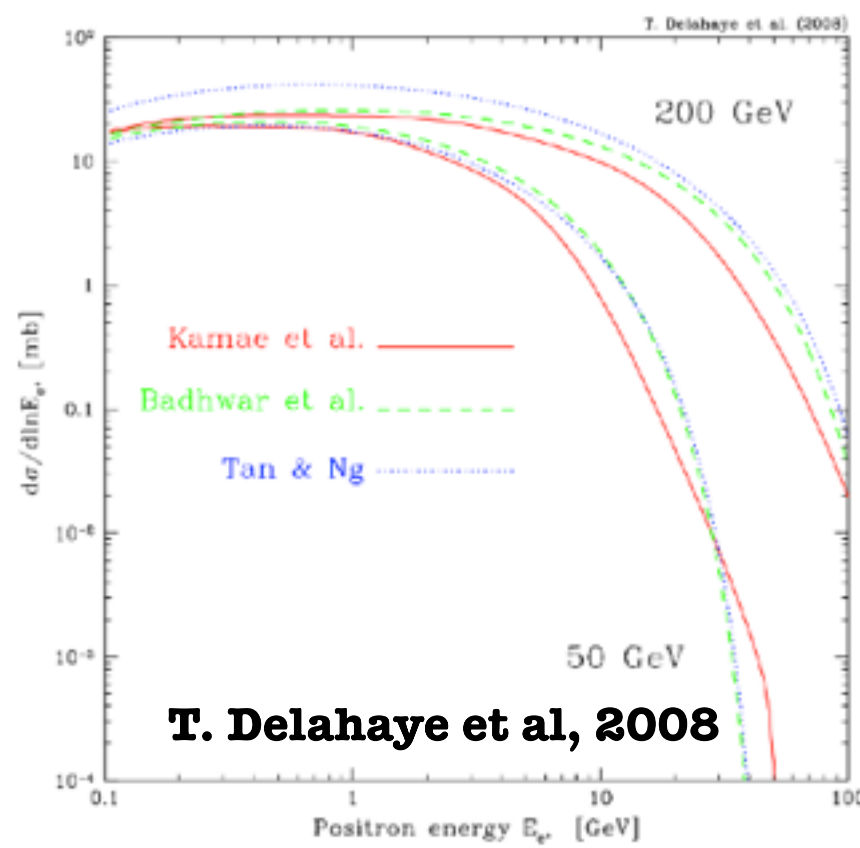
Secondary e$^\pm$

Secondary emission is the one associated to the **spallation** of primary cosmic rays impinging on the interstellar medium

$$q_{e^\pm}(\mathbf{x},E_e) = 4\pi \underbrace{\boxed{n_{\rm ISM}(\mathbf{x})}}_{\text{gas density in the ISM}} \int dE_{\rm CR} \underbrace{\boxed{\Phi_{\rm CR}(\mathbf{x},E_{\rm CR})}}_{\text{primary CR fluxes}} \underbrace{\boxed{\frac{d\sigma}{dE_e}(E_{\rm CR},E_e)}}_{e^\pm \text{ production cross-section (Kamae parameterization)}}$$

Fit to AMS-02 p and He data





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

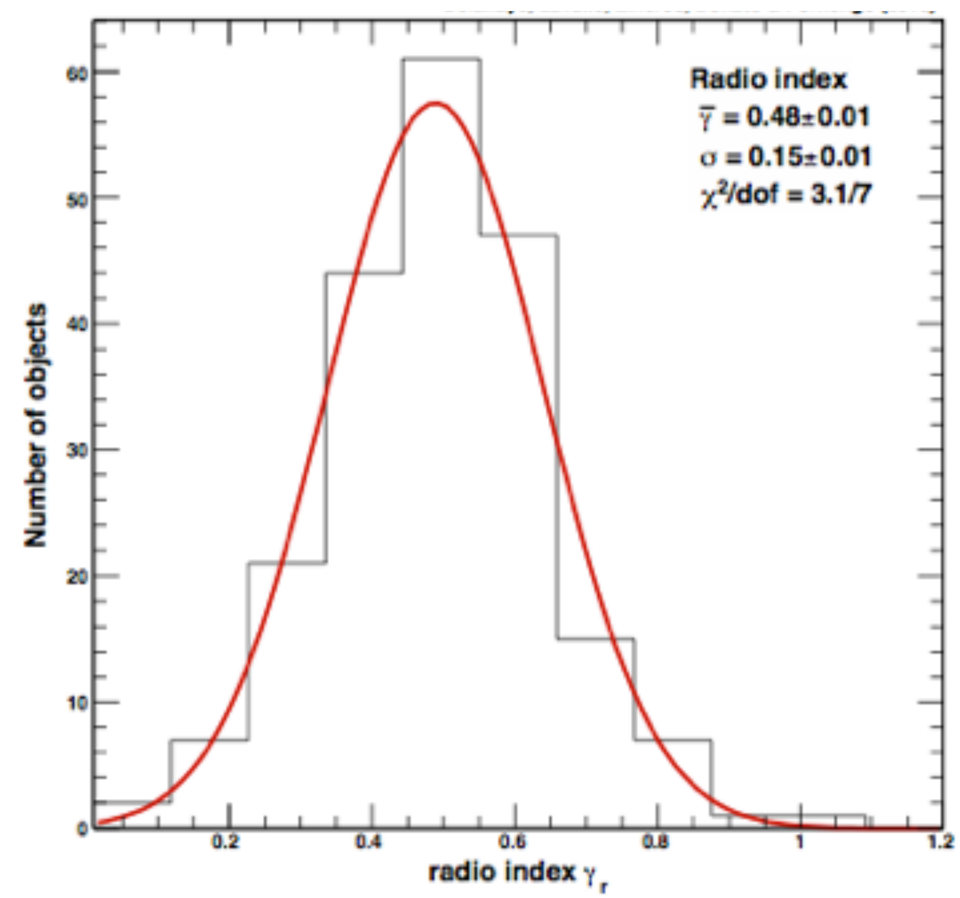
$$Q_0 = 1.2 \cdot 10^{47} (0.79)^{\gamma} \left[\frac{d}{\mathrm{kpc}}\right]^2 \left[\frac{\nu}{\mathrm{GHz}}\right]^{(\gamma-1)/2} \left[\frac{B}{100\mu\mathrm{G}}\right]^{-(\gamma+1)/2} \left[\frac{B_r^{\nu}}{\mathrm{Jy}}\right]$$

distance from the observer

magnetic field

Supernova Remnants (SNRs)

T. Delahaye et al, 2010



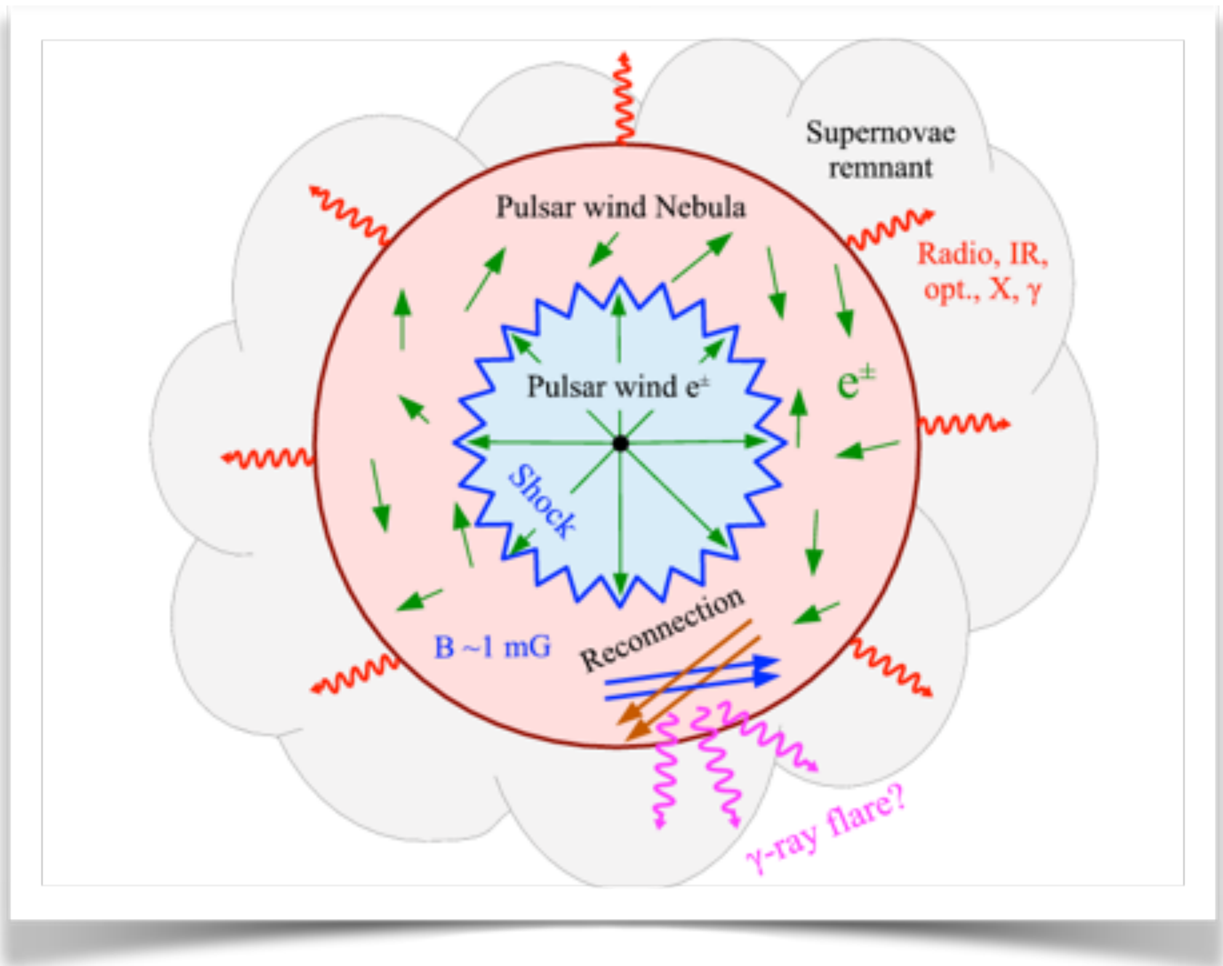
The **Green catalogue** is the most complete **SNR catalog** (265 sources)

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

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

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**

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

$\eta \in [0,1]$

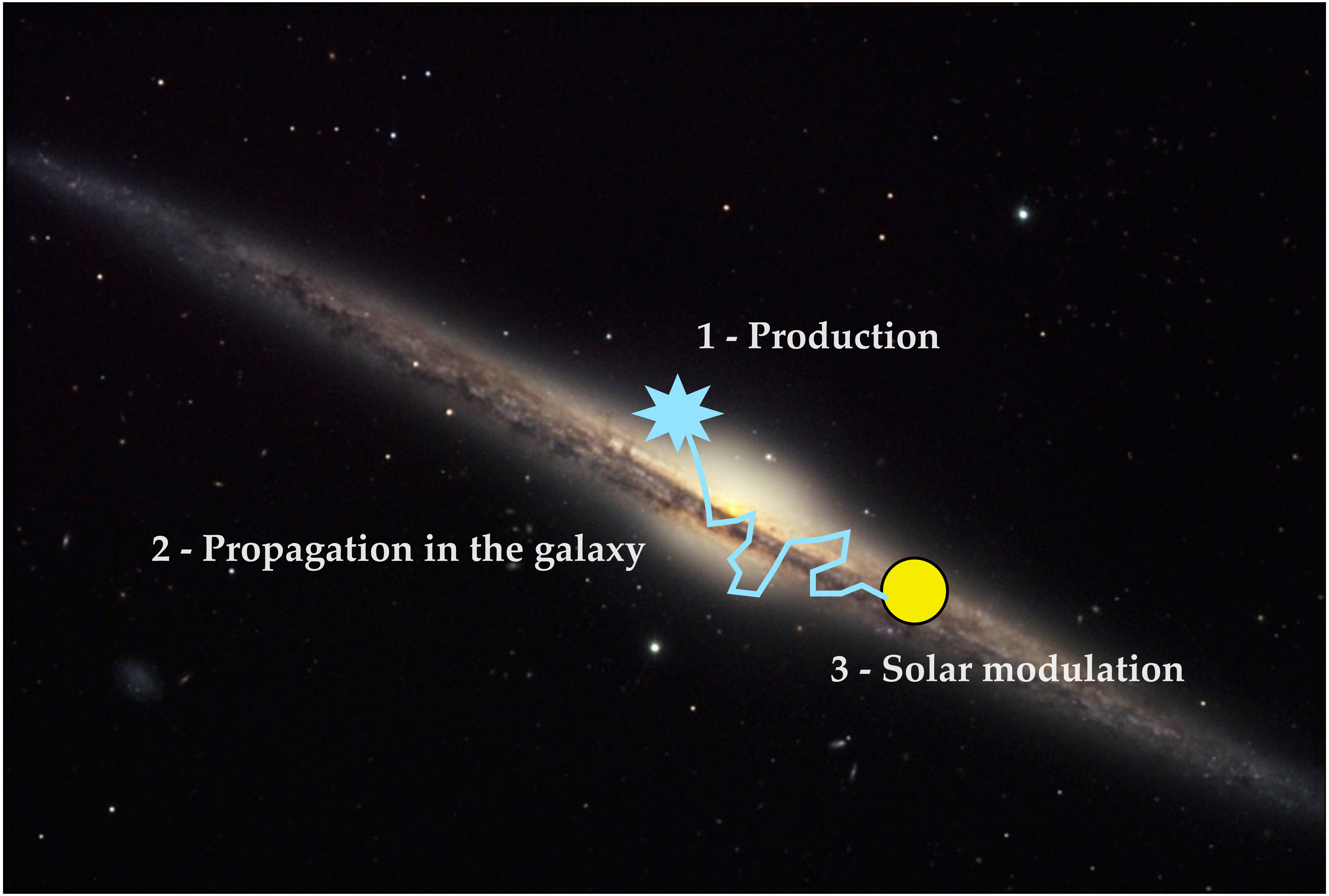
where

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

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

In our fit, pulsars are characterized by **2 free parameters:** γ and η which are assumed to be the **same for all the PWNe** of the ATNF catalogue

$e^{\pm}$ propagation



$e^{\pm}$ propagation

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

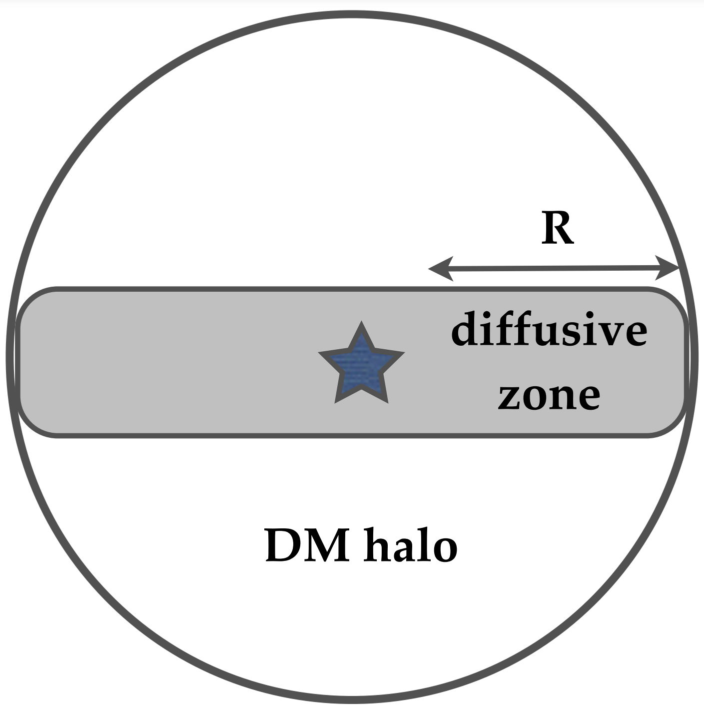
($\neq$0 if burst-like injection)

Spatial diffusion

Energy losses (synchrotron and inverse Compton)

Source term

Two-zone diffusion model



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

Maurin et al., 2001

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

Donato et al., 2004

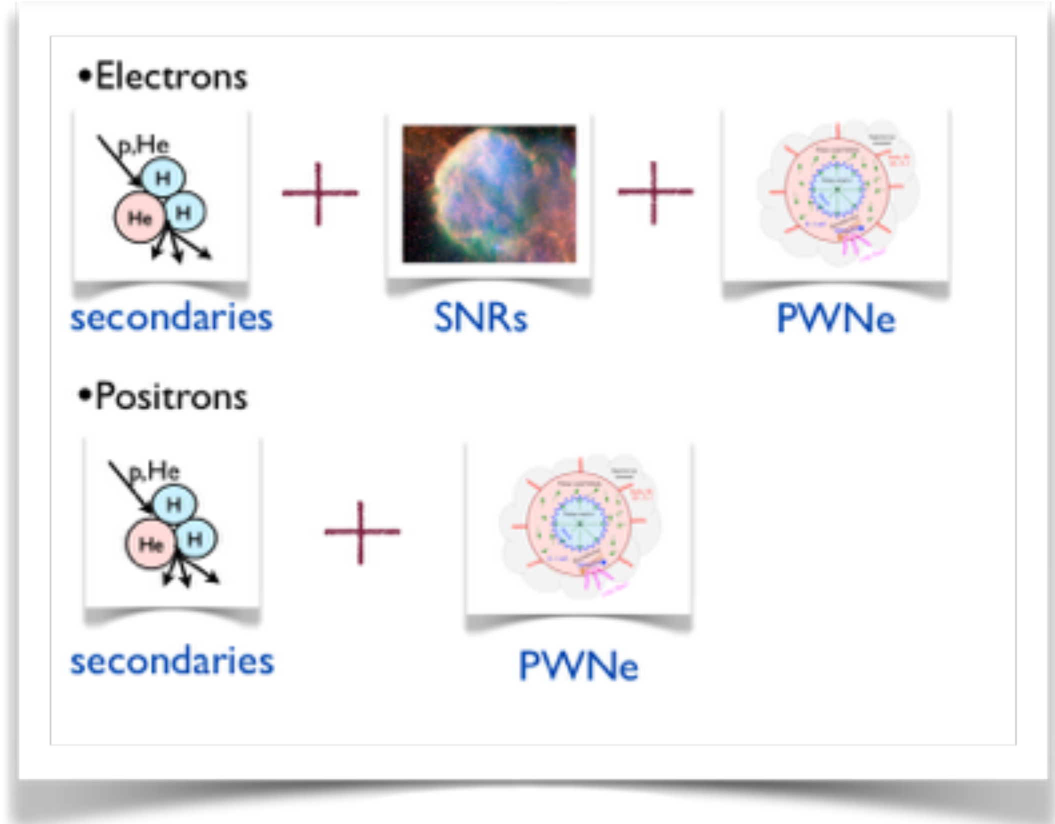
Solar modulation

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

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

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.**
We use the MED model of propagation.



We fit the **four observables:**

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

We have **5 free parameters:**

- γ
- η

PWNe

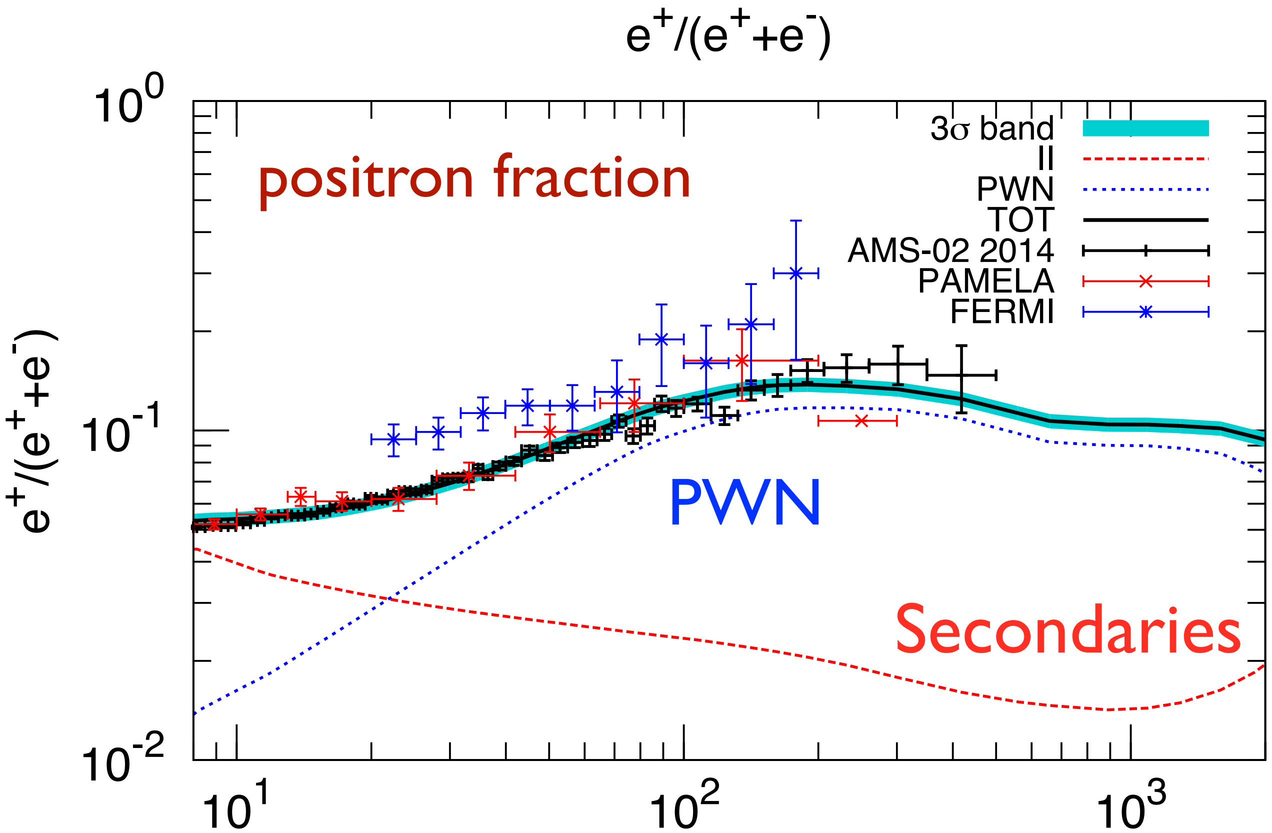
- Q_0
- γ_{SNR}

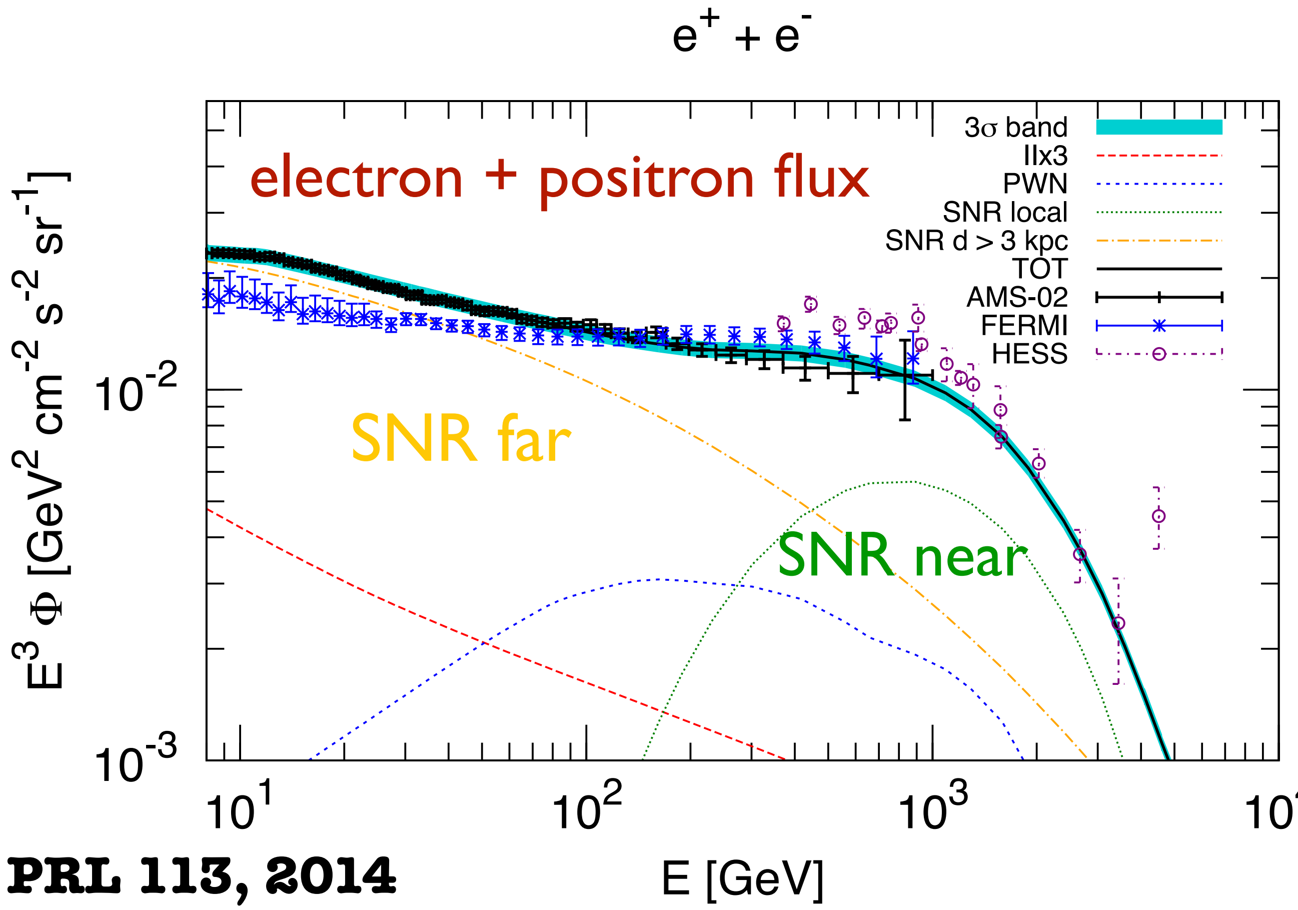
Far SNRs

- N_{vela}

Near SNRs (normalization)

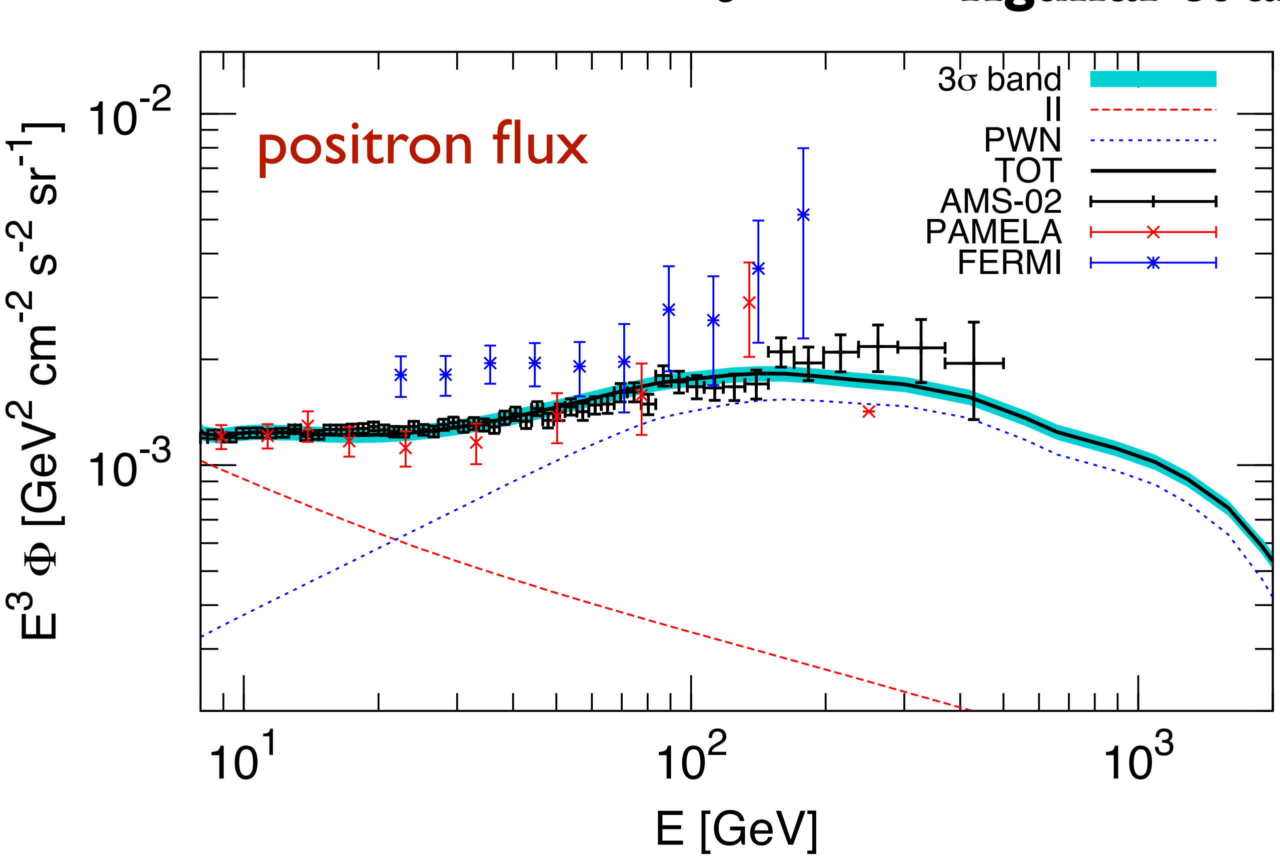
fit to AMS-02 data

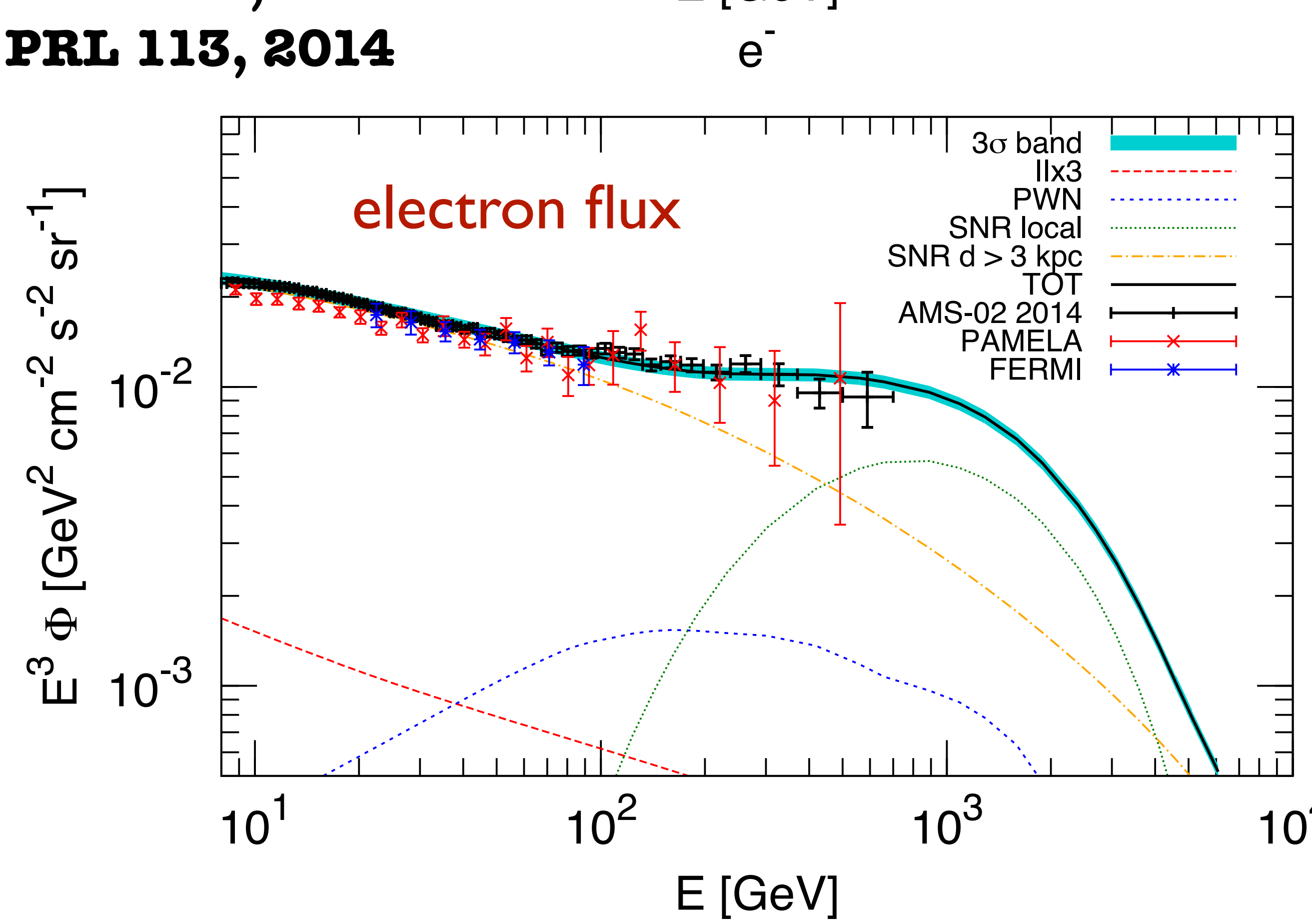




Accardo et al. PRL 113, 2014

Aguilar et al. PRL 113, 2014





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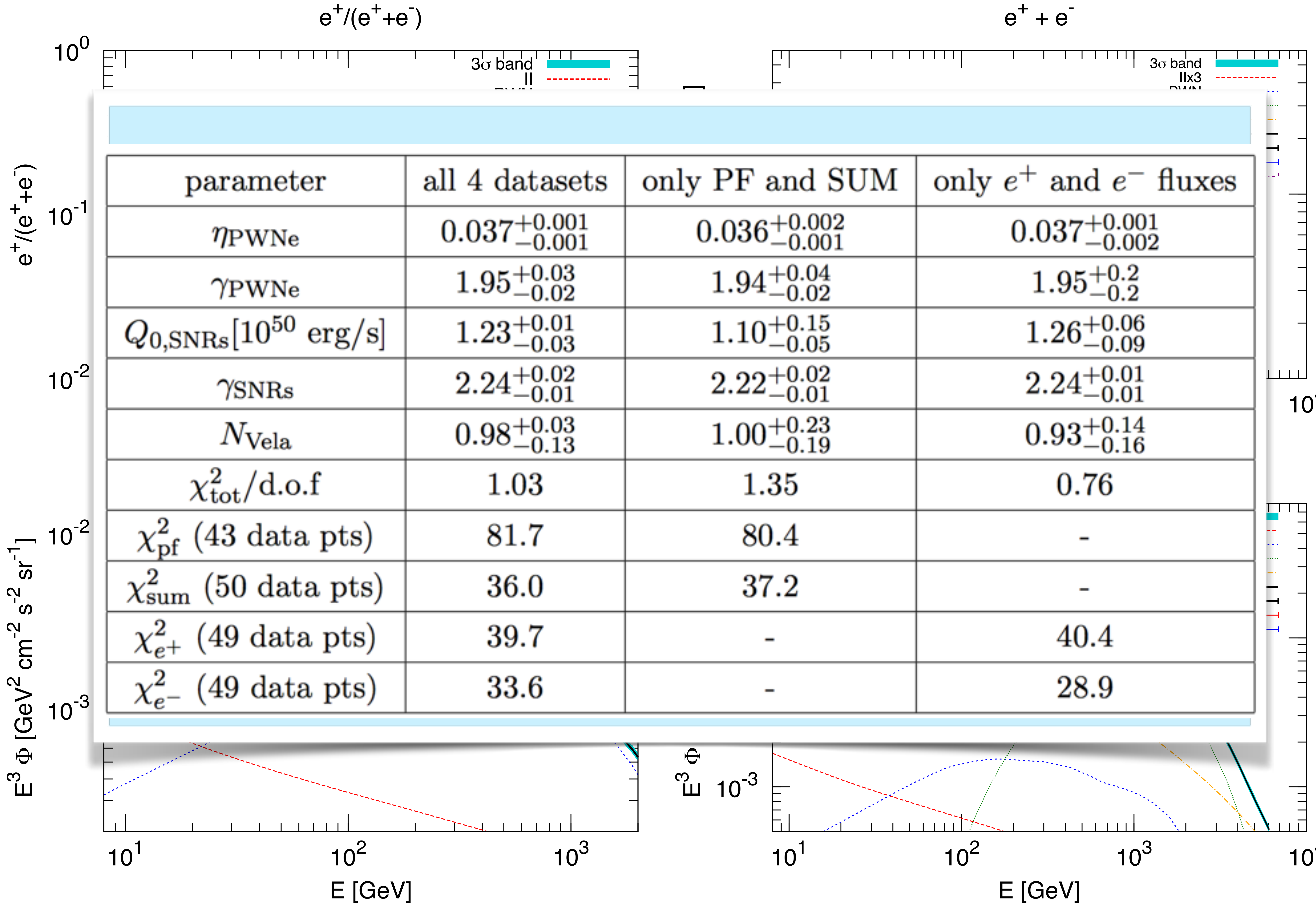
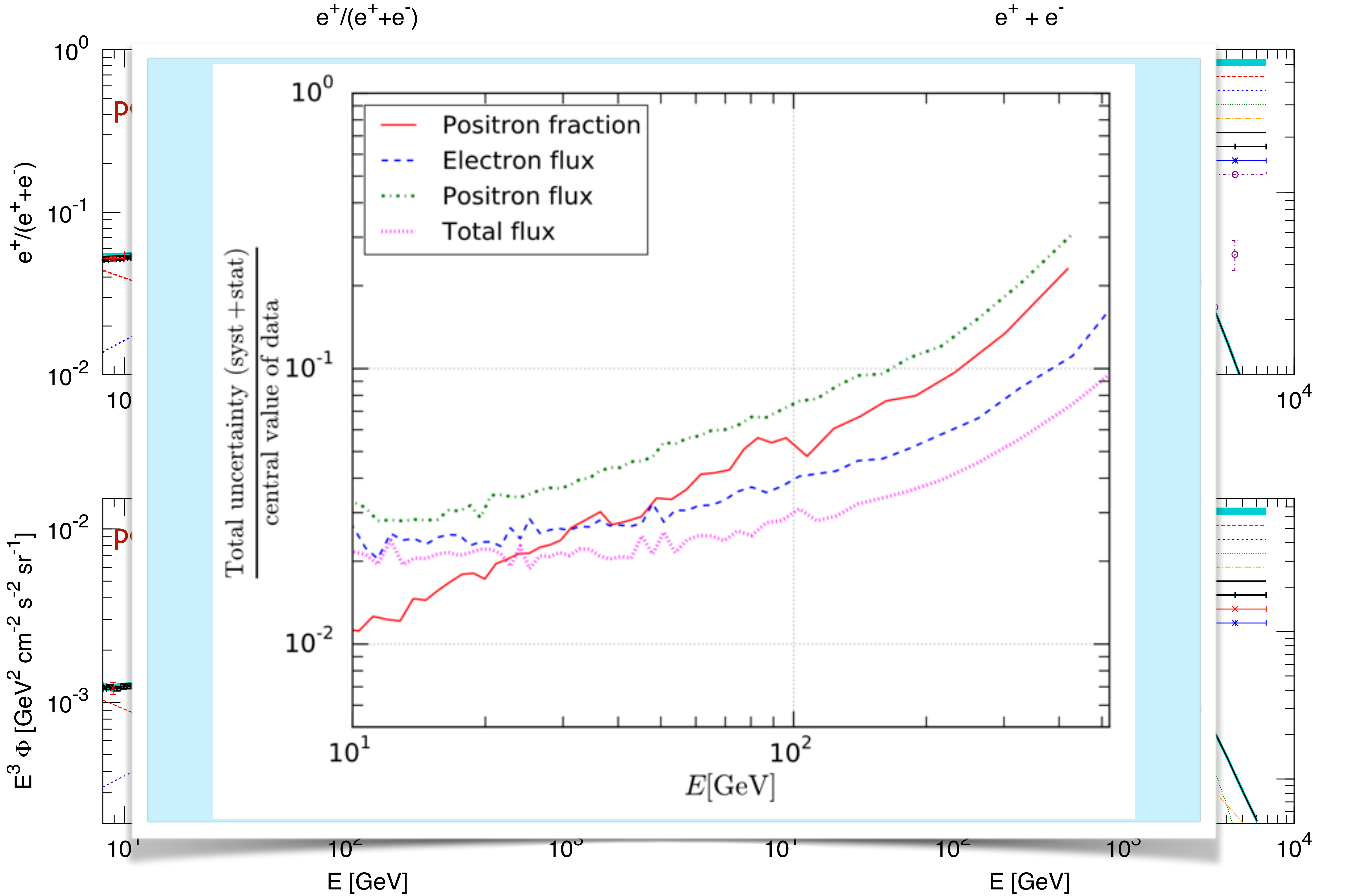
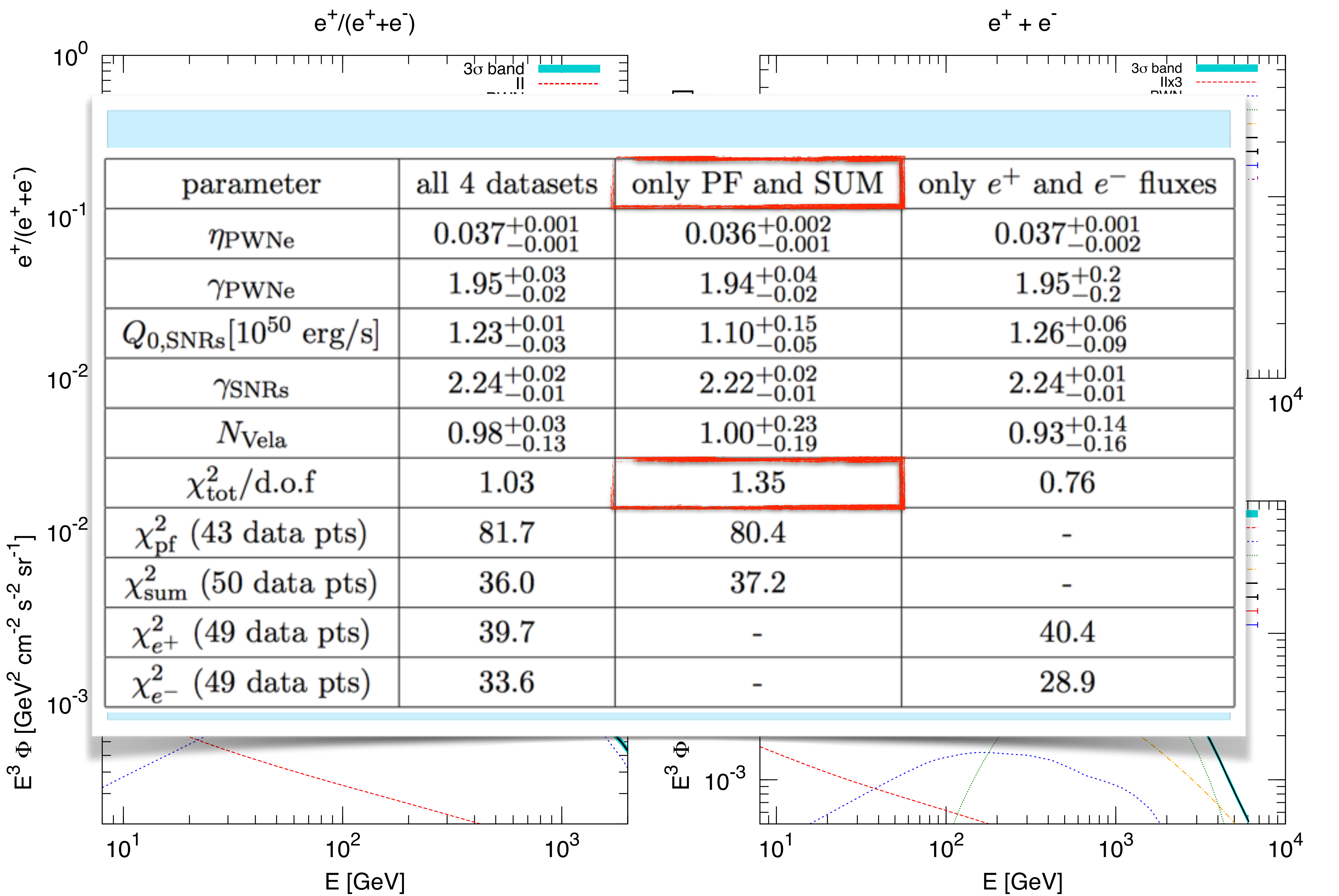


parameter	all 4 datasets	only PF and SUM	only e^+ and e^- fluxes
η_{PWNe}	$0.037^{+0.001}_{-0.001}$	$0.036^{+0.002}_{-0.001}$	$0.037^{+0.001}_{-0.002}$
γ_{PWNe}	$1.95^{+0.03}_{-0.02}$	$1.94^{+0.04}_{-0.02}$	$1.95^{+0.2}_{-0.2}$
$Q_{0,\mathrm{SNRs}}[10^{50}\ \mathrm{erg/s}]$	$1.23^{+0.01}_{-0.03}$	$1.10^{+0.15}_{-0.05}$	$1.26^{+0.06}_{-0.09}$
γ_{SNRs}	$2.24^{+0.02}_{-0.01}$	$2.22^{+0.02}_{-0.01}$	$2.24^{+0.01}_{-0.01}$
N_{Vela}	$0.98^{+0.03}_{-0.13}$	$1.00^{+0.23}_{-0.19}$	$0.93^{+0.14}_{-0.16}$
$\chi^2_{\mathrm{tot}}/\mathrm{d.o.f}$	1.03	1.35	0.76
χ^2_{pf} (43 data pts)	81.7	80.4	-
χ^2_{sum} (50 data pts)	36.0	37.2	-
χ^2_{e+} (49 data pts)	39.7	-	40.4
χ^2_{e-} (49 data pts)	33.6	-	28.9

fit to AMS-02 data



fit to AMS-02 data



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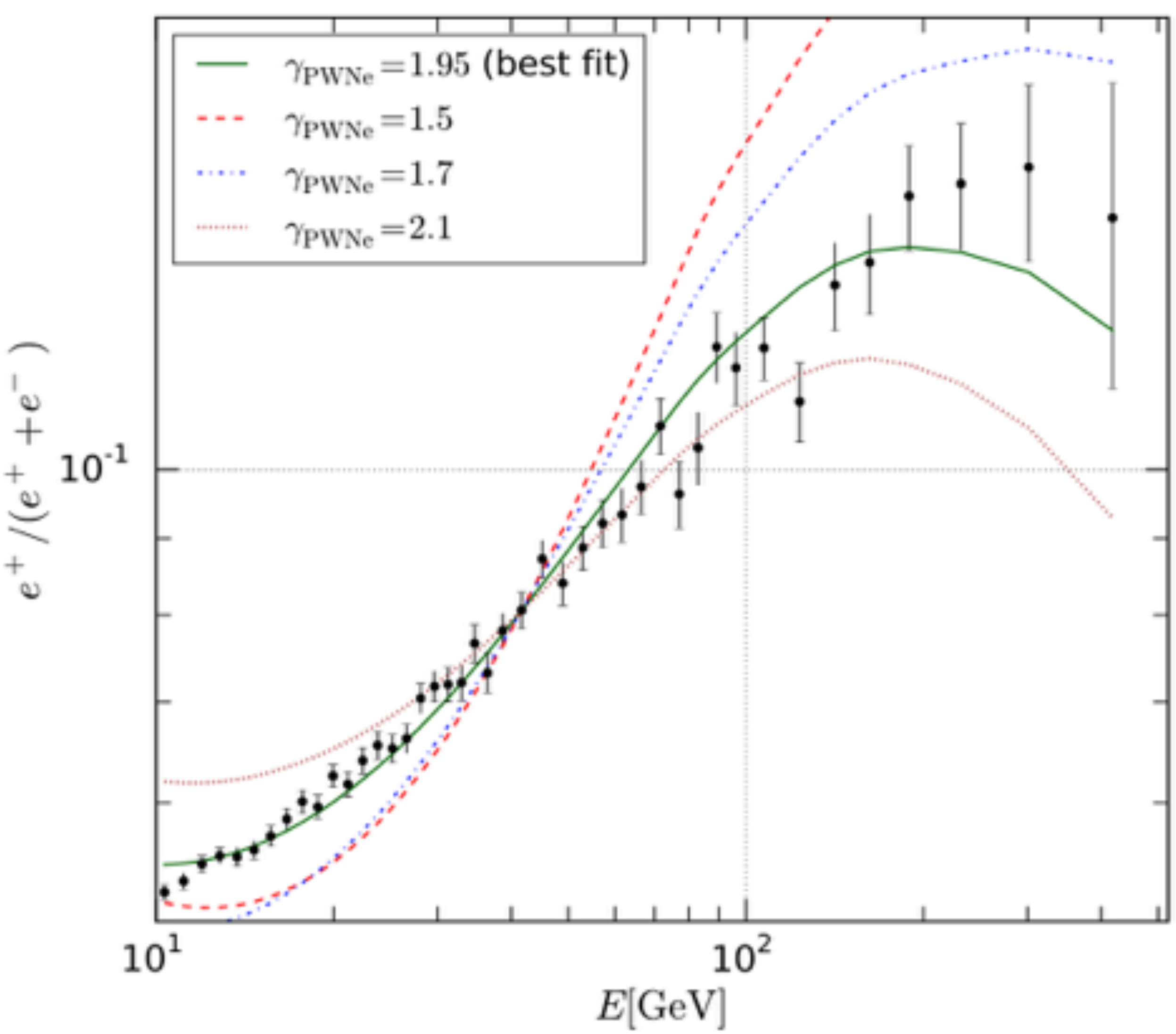
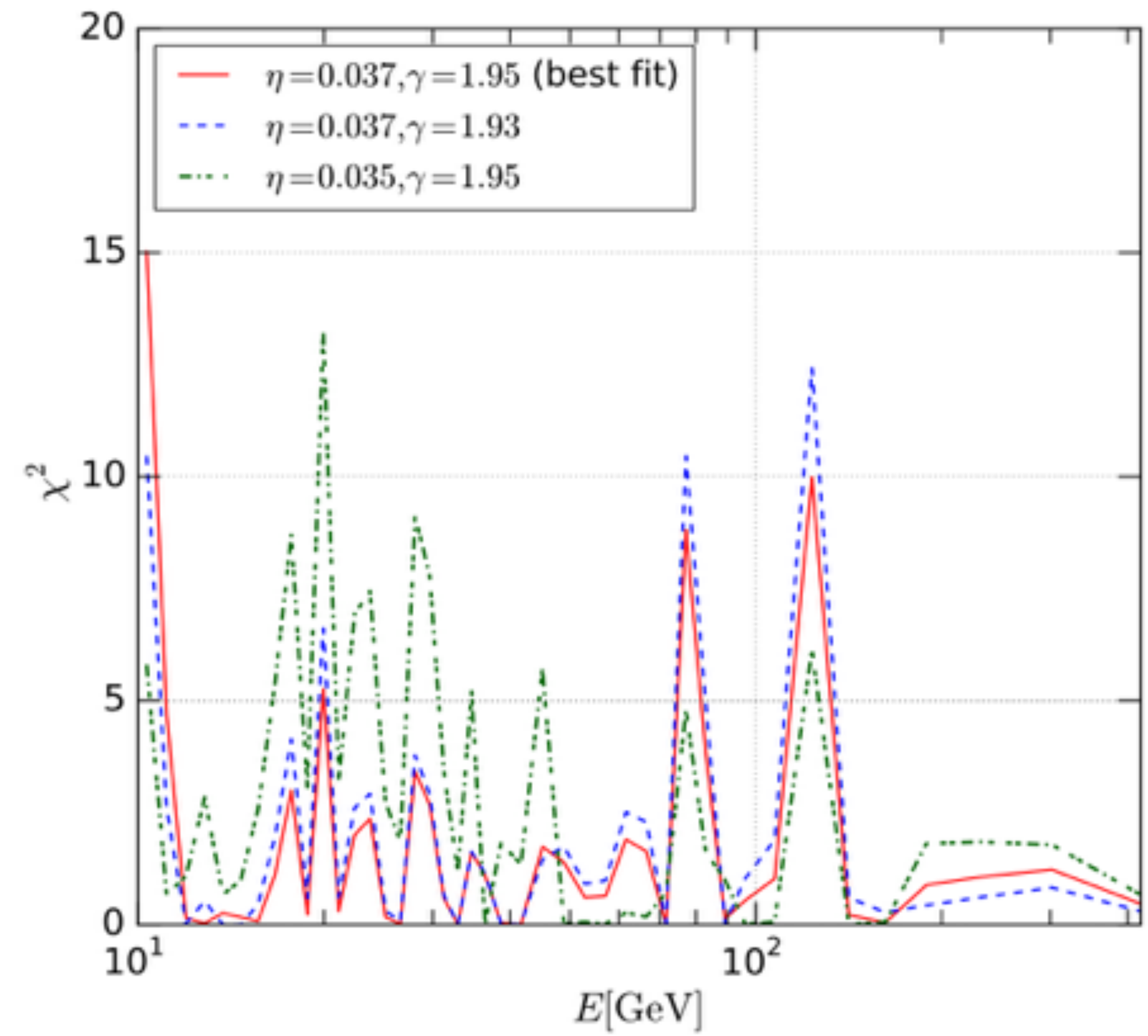
fit to AMS-02 data (PF)

- As it can be seen, the data points giving the maximal contribution to the total chi-square are the two at the lowest energies and the two at 77.1 GeV and 123.31 GeV.
- this arises from the wiggly features that the positron fraction possesses at these energies.
- Every change of parameters that goes in the direction of lowering the chi-square at low energies has the effect of augmenting the chi-square at high energies.





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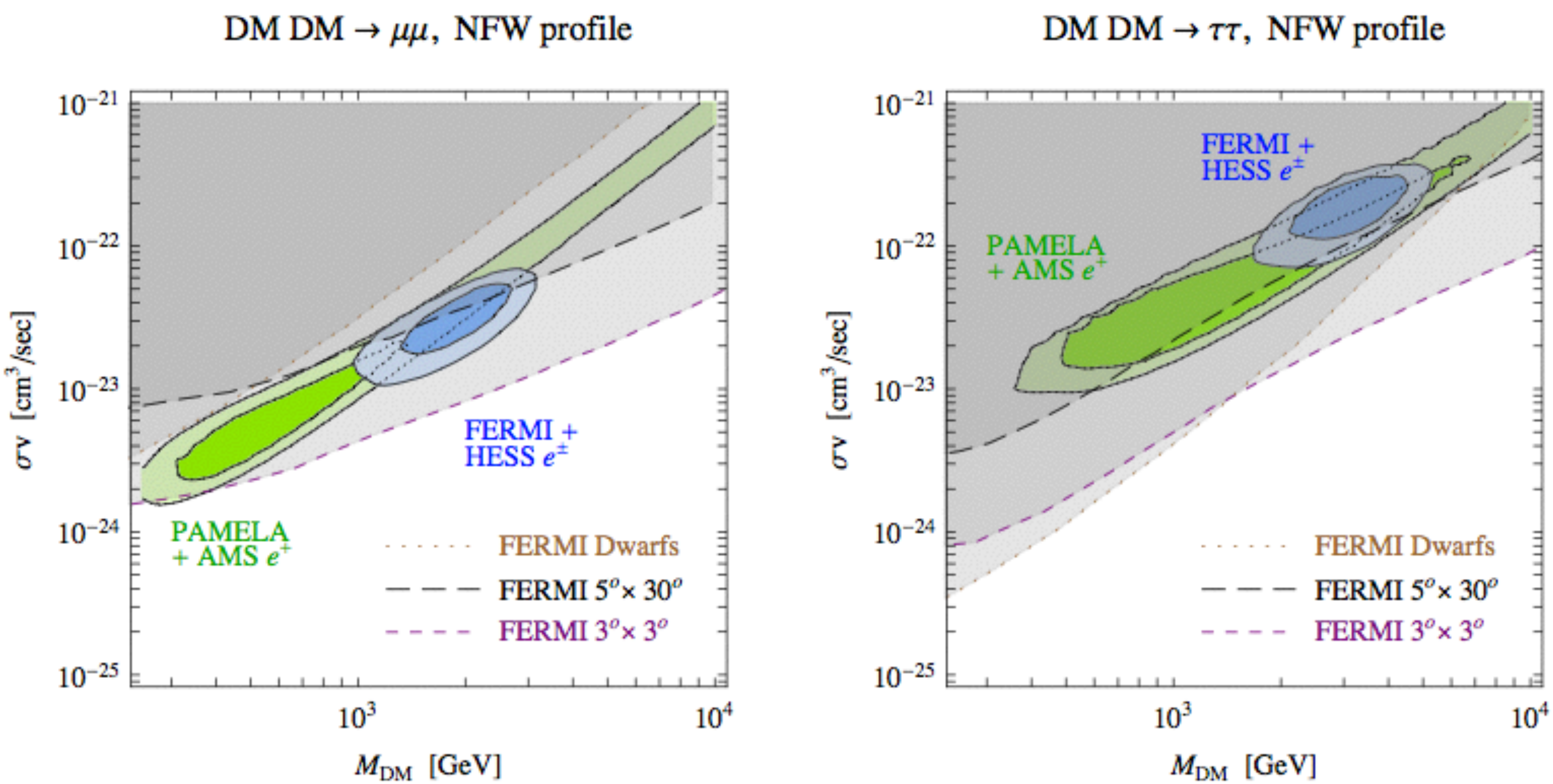
M. Di Mauro, F. Donato, N.Fornengo, AV, arXiv:1507.07001 [astro-ph.HE]

Adding DM

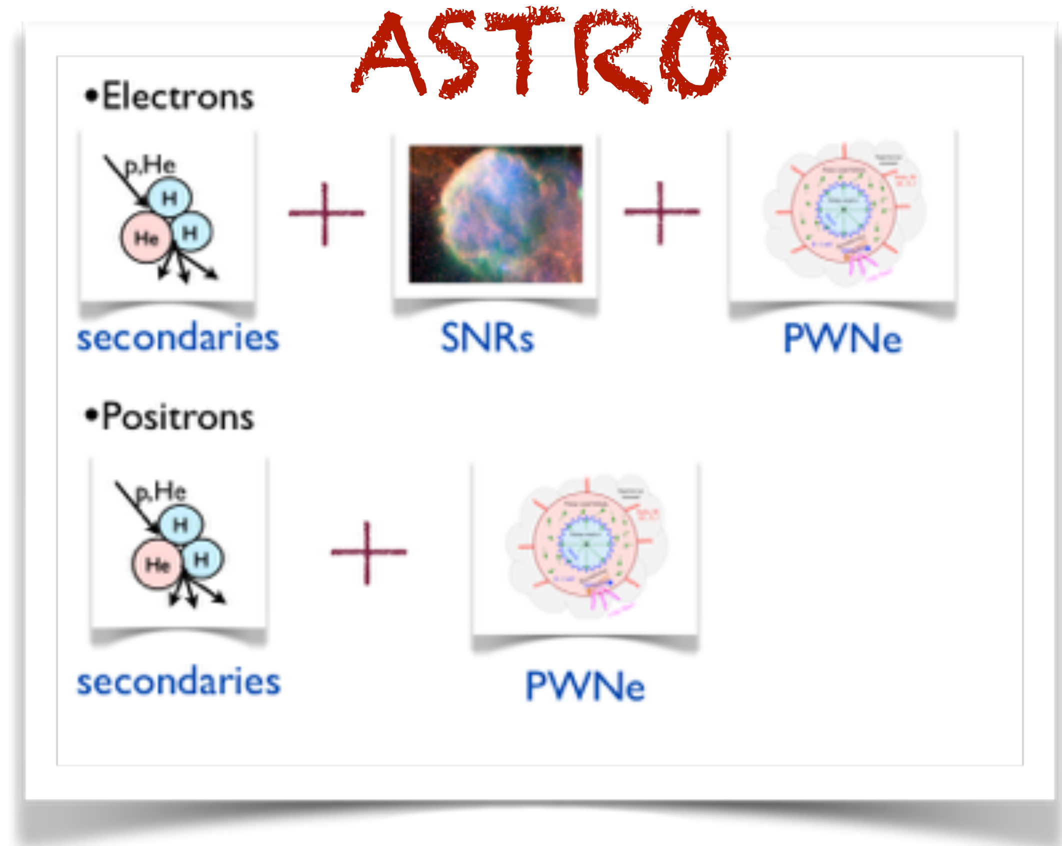
It is known that a pure **DM interpretation** of the positron fraction rise is in **tension** with bounds coming from **other channels**



Cirelli et al. 2009

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

Adding DM



+ DM

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

We fit the two **observables (chi-square astro = 1.35):**

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

We have **7 parameters:**

- γ
- η

PWNe

- Q0
- γ_{SNR}

Far SNRs

- $\langle\sigma v\rangle$
- mDM

DM

- Nvela

Near SNRs

Best fit regions

Annihilating DM					
Parameter	$\mathbf{e^+e^-}$	$\mu^+\mu^-$	$\tau^+\tau^-$	$b\bar{b}$	W^+W^-
η_{PWNe}	$0.032^{+0.002}_{-0.002}$	$0.028^{+0.002}_{-0.005}$	$0.011^{+0.005}_{-0.001}$	$0.006^{+0.015}_{-0.001}$	$0.006^{+0.011}_{-0.001}$
γ_{PWNe}	$1.87^{+0.05}_{-0.05}$	$1.76^{+0.09}_{-0.20}$	$1.23^{+0.33}_{-0.23}$	$1.77^{+0.19}_{-0.69}$	$1.72^{+0.27}_{-0.68}$
$Q_{0,SNRs}[10^{50}$ erg/s]	$1.13^{+0.12}_{-0.09}$	$1.24^{+0.10}_{-0.18}$	$1.16^{+0.14}_{-0.05}$	$1.40^{+0.11}_{-0.14}$	$1.33^{+0.12}_{-0.11}$
γ_{SNRs}	$2.22^{+0.02}_{-0.01}$	$2.24^{+0.01}_{-0.03}$	$2.23^{+0.02}_{-0.01}$	$2.26^{+0.01}_{-0.02}$	$2.25^{+0.02}_{-0.01}$
N_{Vela}	$0.80^{+0.19}_{-0.17}$	$0.74^{+0.24}_{-0.20}$	$0.88^{+0.14}_{-0.20}$	$0.84^{+0.22}_{-0.15}$	$0.81^{+0.22}_{-0.17}$
m_{DM} [GeV]	50^{+1}_{-4}	88^{+31}_{-9}	635^{+73}_{-195}	39572^{+10351}_{-28792}	24759^{+22964}_{-14907}
$\langle\sigma v\rangle$ [cm^{3}s^{-1}]	$5.6^{+2.2}_{-2.6}\times10^{-27}$	$7.9^{+12.6}_{-3.4}\times10^{-26}$	$7.2^{+1.4}_{-3.5}\times10^{-24}$	$9.5^{+0.5}_{-8.4}\times10^{-22}$	$7.2^{+11.5}_{-5.7}\times10^{-22}$
χ^2/85 d.o.f.	1.13	0.98	1.05	1.24	1.18

Astro-model χ^2 /d.o.f. = 1.35

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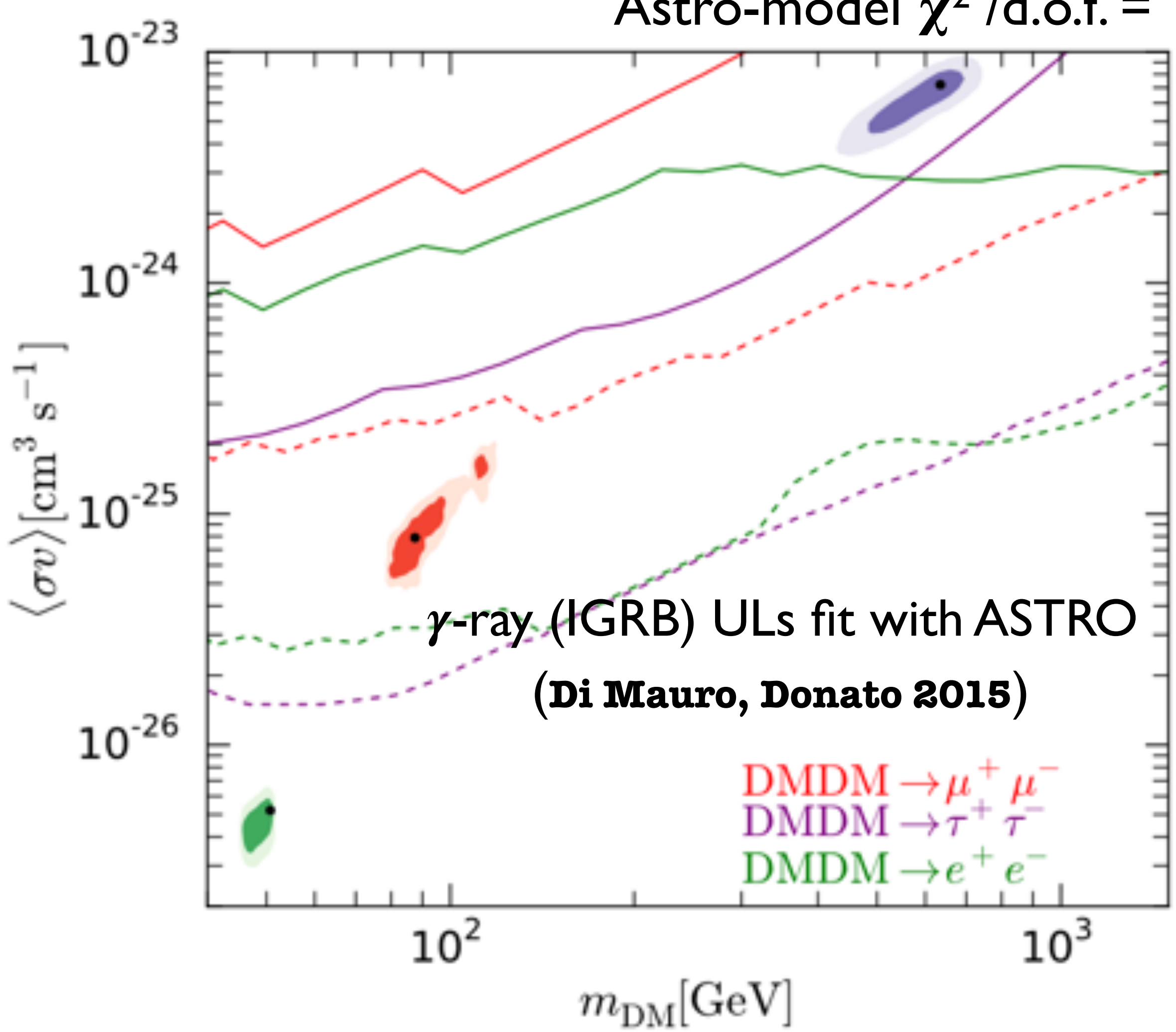
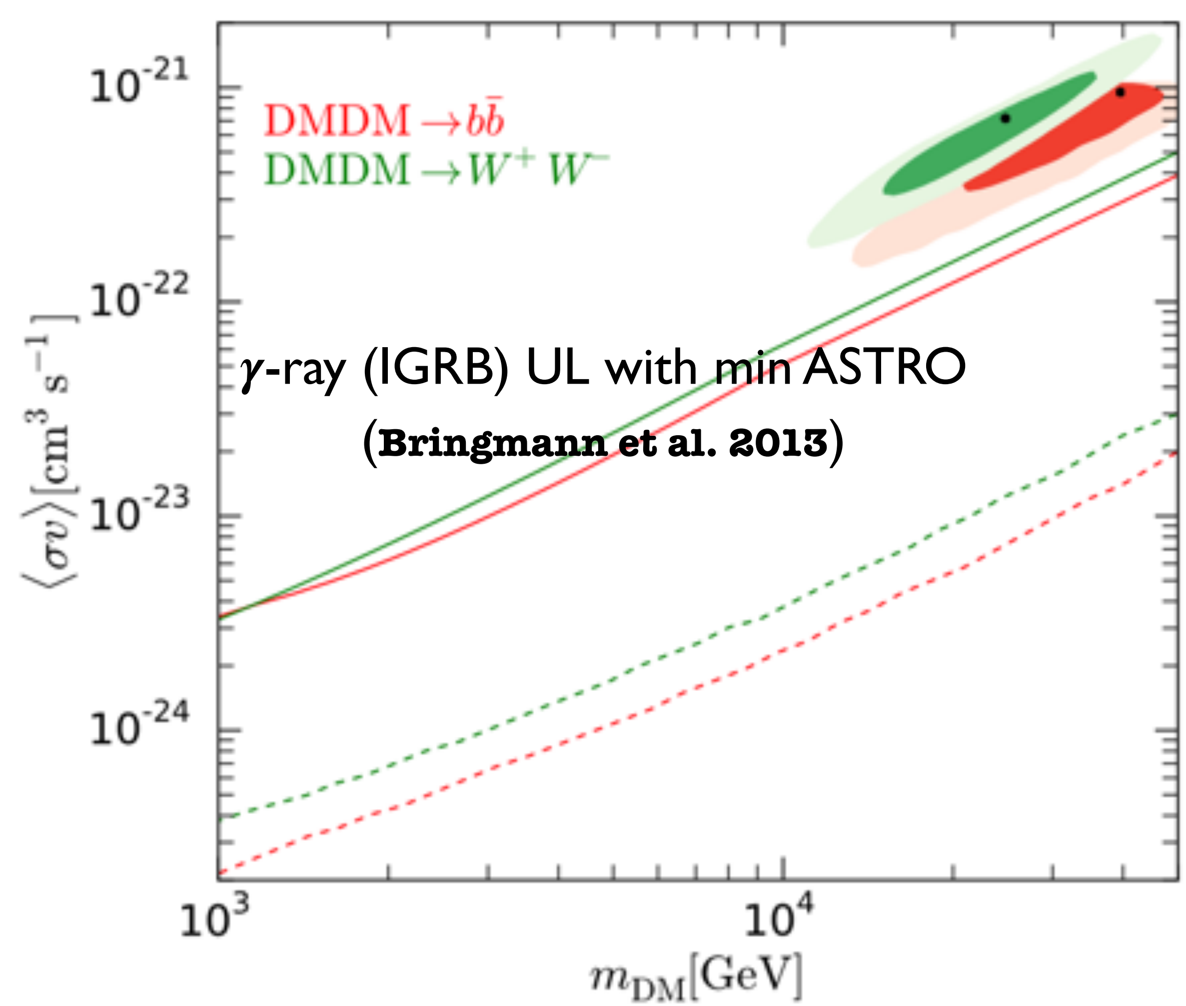


γ-ray (IGRB) ULs fit with ASTRO

(**Di Mauro, Donato 2015**)



γ-ray (IGRB) UL with min ASTRO

(**Bringmann et al. 2013**)

Best fit regions

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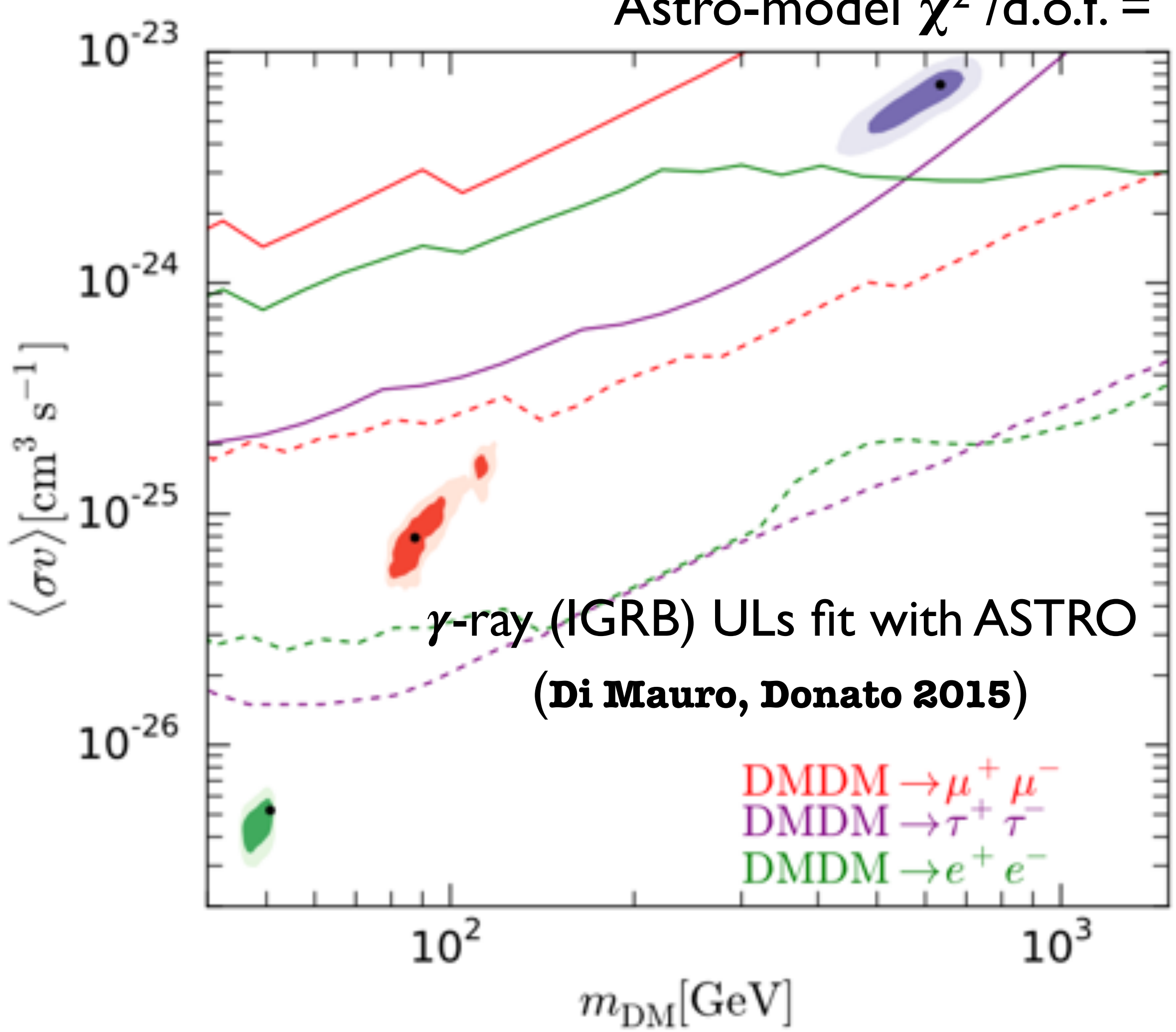
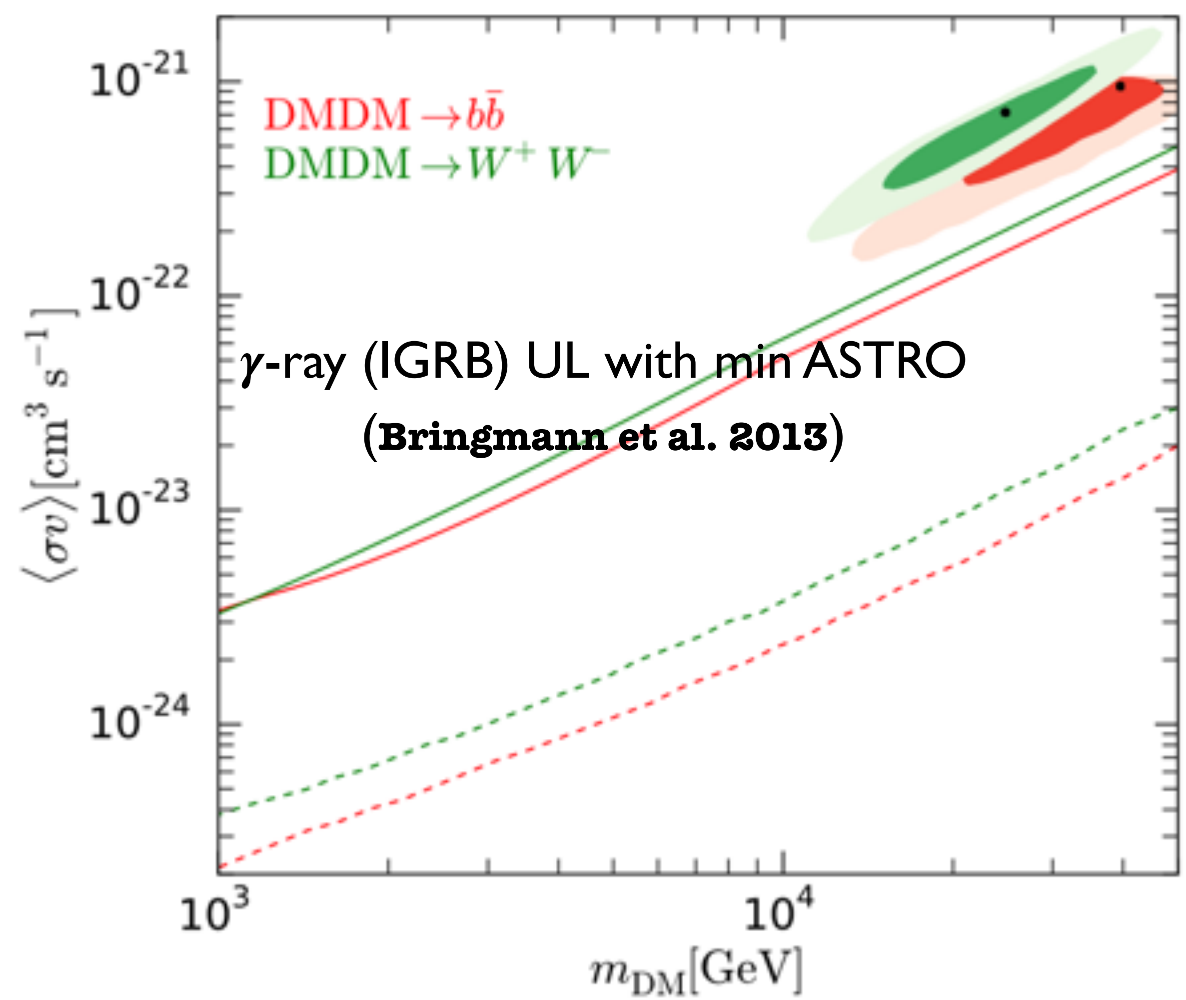
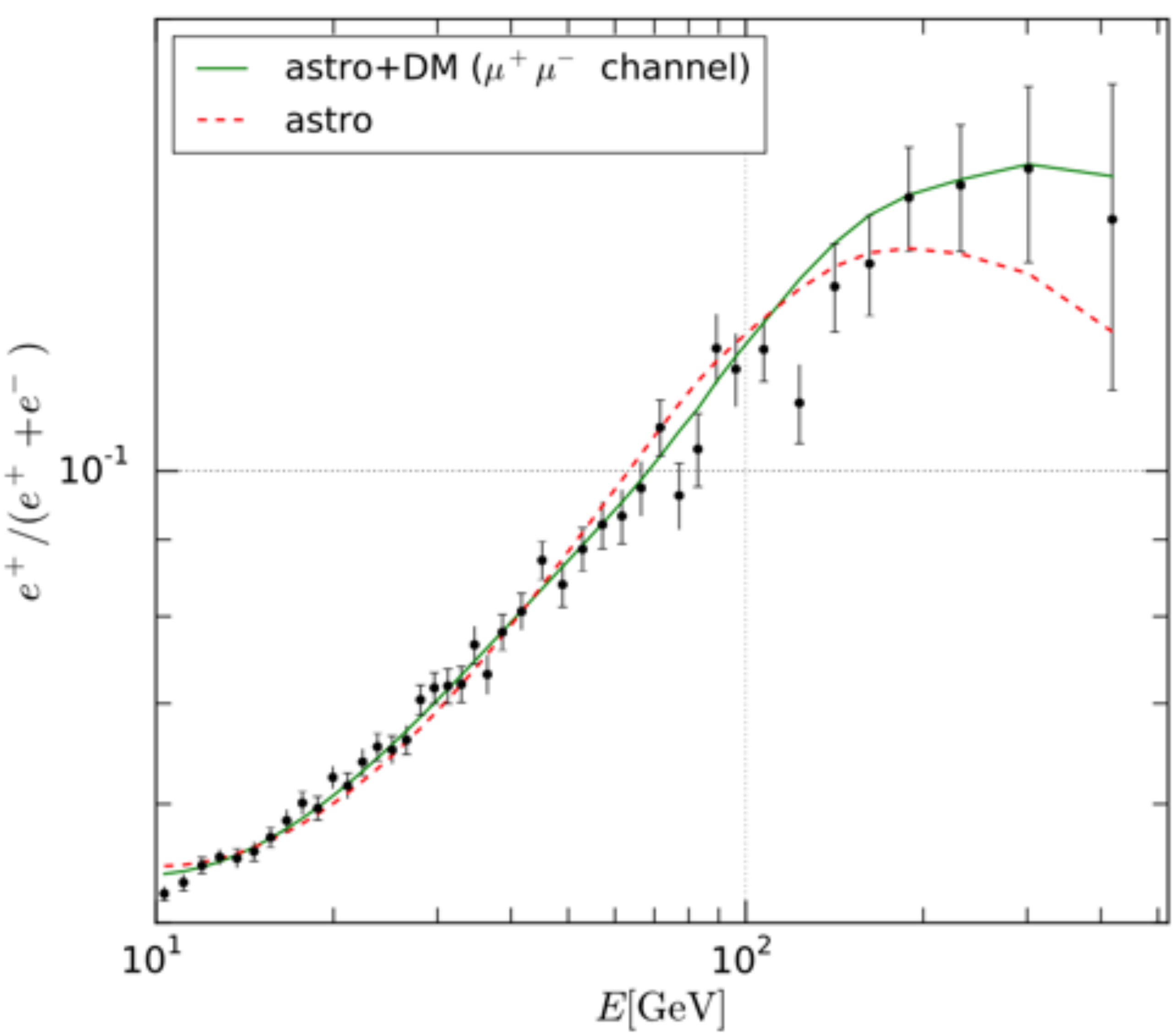
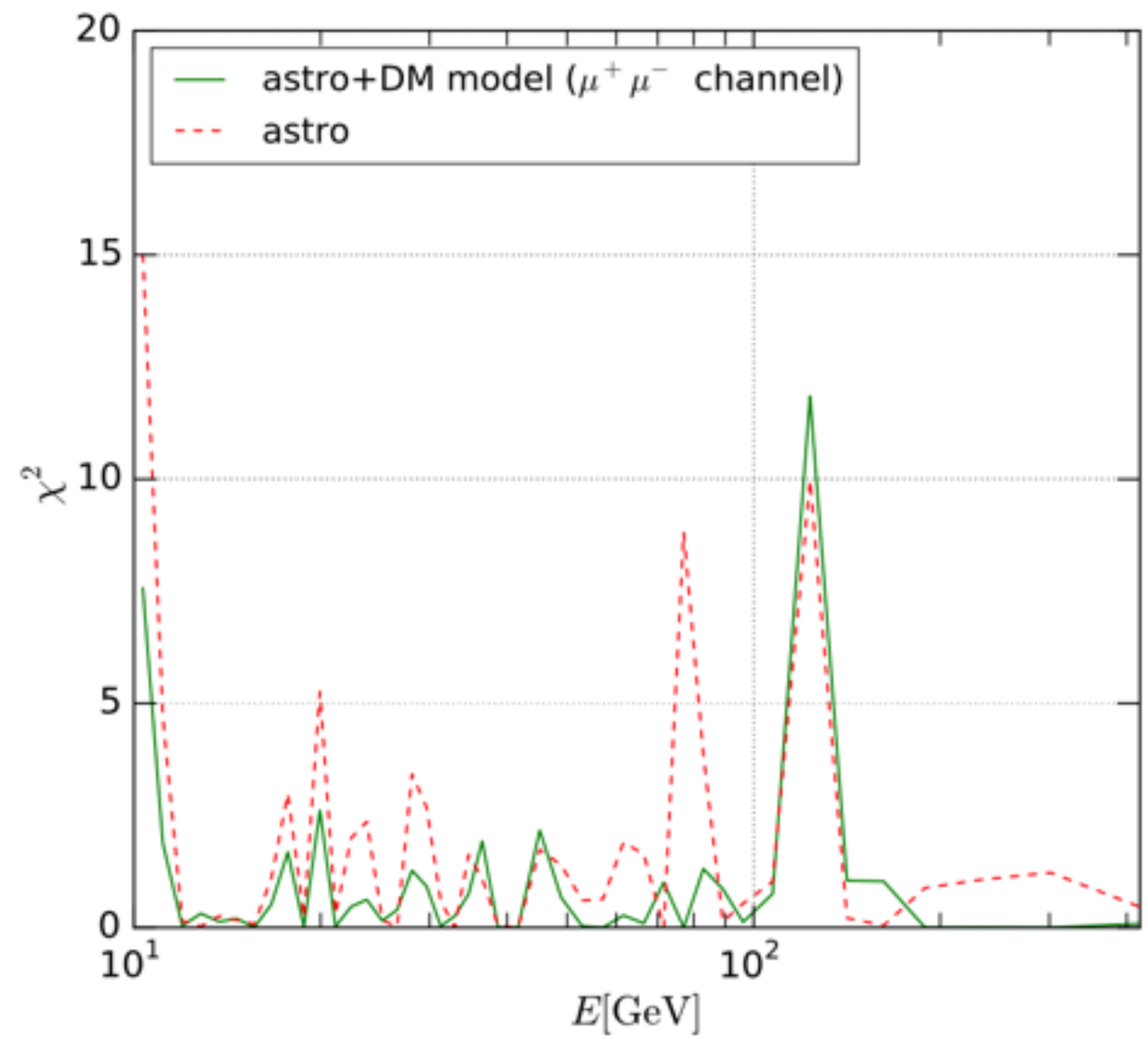




Astro model vs DM

- The astro + DM model has a better agreement with AMS-02 data than the pure astro model. This is especially true for $\mu^+\mu^-$ and $\tau^+\tau^-$ annihilation/decay channels, for which the reduced χ^2 drops to values around 1 (for the astro model we had χ^2/d.o.f = 1.35).
- The addition of the DM contribution brings a significant improvement of the fit that is not confined to the low-energy data points, but extends over all the energy range of AMS-02 measurements.





Best fit regions

PWNe
- γ
- η

Far SNRs
- Q_0
- γ_{SNR}

DM
- $\langle\sigma v\rangle$
- m_{DM}

Near SNRs
- N_{vela}

We want to study the **significance** of this DM interpretation of AMS-02 data within a **more refined model**

PWNe
- γ
- η

Far SNRs
- Q_0
- γ_{SNR}

DM
- $\langle\sigma v\rangle$
- m_{DM}

Near SNRs
- N_{vela}

- $\eta_1, \eta_2, \eta_3, \eta_4, \eta_5$ — Efficiencies (normalizations) of the 5 most powerful PWNe

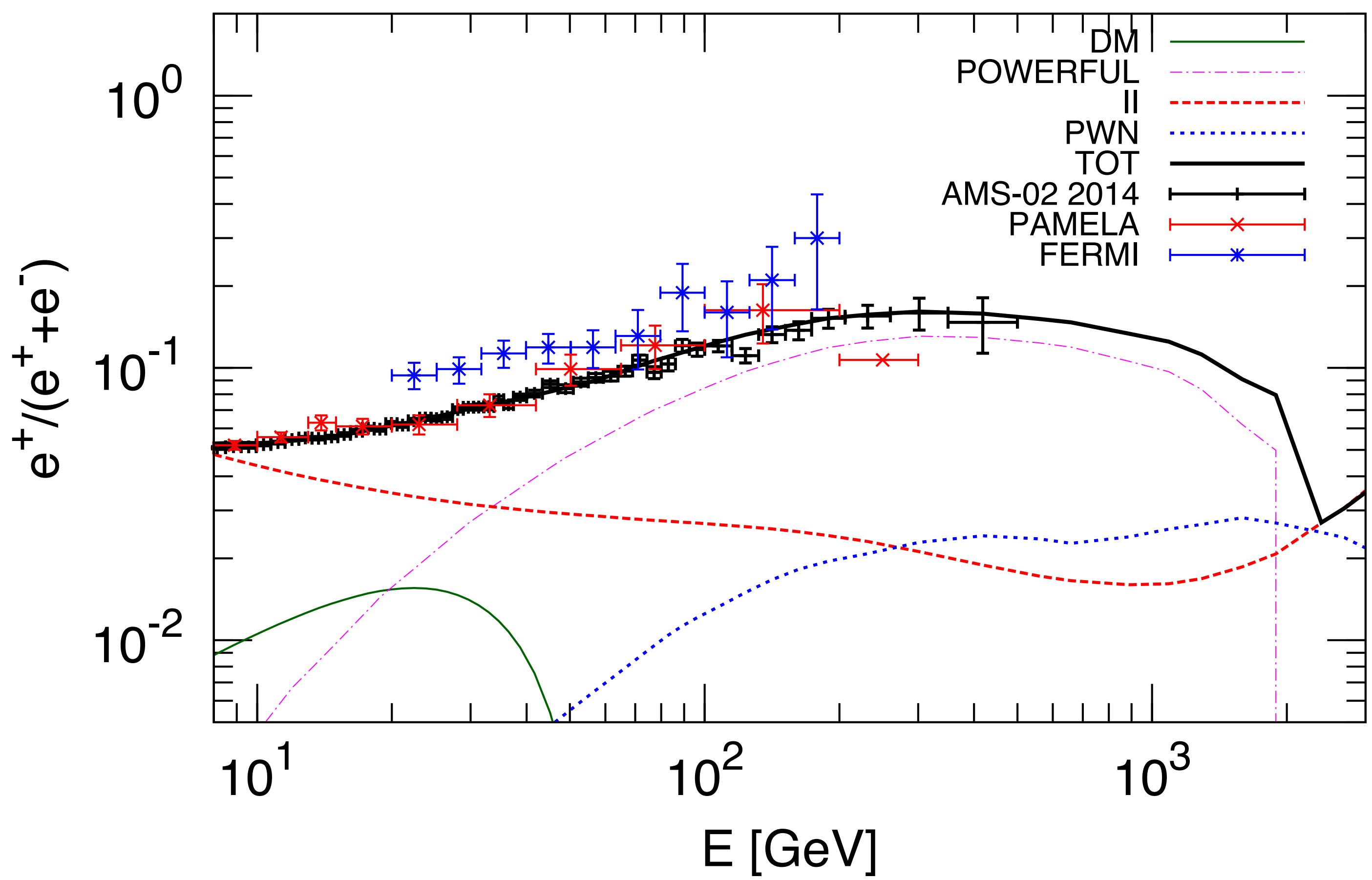
We thus allow for a **free normalization** of the $e^{\pm}$ flux emitted by the **5 most powerful PWNe** of the ATNF catalogue

Best fit regions

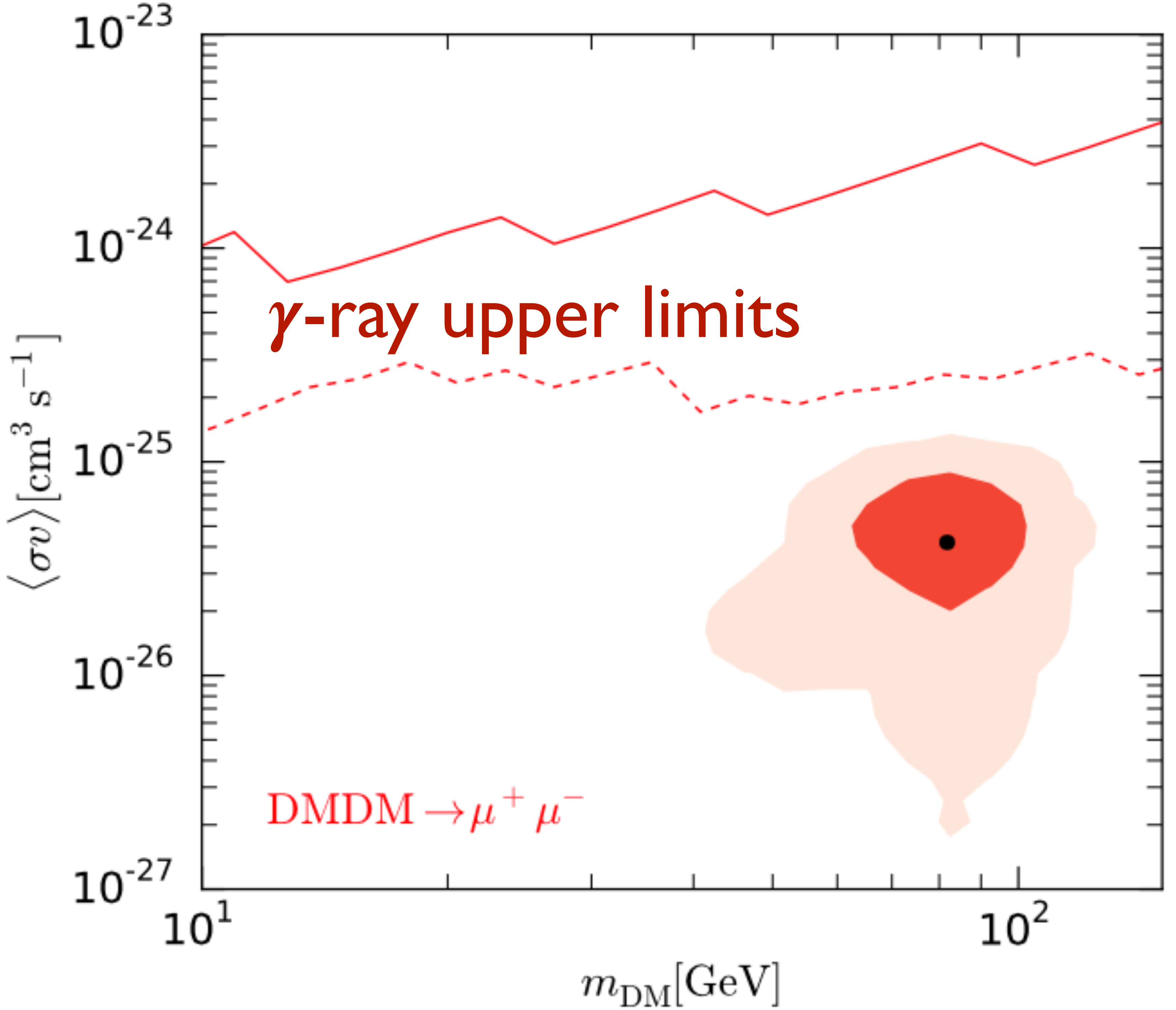
Annihilating DM			
Parameter	astro	e^+e^-	$\mu^+\mu^-$
η_{PWNe}	$19.7^{+90.5}_{-9.7} \times 10^{-4}$	$18.27^{+94.25}_{-17.25} \times 10^{-4}$	$31.7^{+112.5}_{-30.7} \times 10^{-4}$
γ_{PWNe}	$1.64^{+0.76}_{-0.70}$	$1.70^{+0.50}_{-0.25}$	$1.69^{+0.51}_{-0.24}$
η_1	$0.104^{+0.035}_{-0.071}$	$0.089^{+0.041}_{-0.080}$	$0.054^{+0.064}_{-0.053}$
η_2	$0.005^{+0.027}_{-0.004}$	$0.011^{+0.032}_{-0.010}$	$0.001^{+0.077}_{-0.001}$
η_3	$0.023^{+0.066}_{-0.022}$	$0.005^{+0.089}_{-0.005}$	$0.023^{+0.068}_{-0.022}$
η_4	$0.297^{+0.056}_{-0.131}$	$0.299^{+0.063}_{-0.137}$	$0.338^{+0.096}_{-0.171}$
η_5	$0.006^{+0.185}_{-0.005}$	$0.014^{+0.206}_{-0.014}$	$0.027^{+0.168}_{-0.026}$
$Q_{0,SNRs}[10^{50}$ erg/s]	$1.12^{+0.17}_{-0.05}$	$1.08^{+0.18}_{-0.03}$	$1.10^{+0.10}_{-0.05}$
γ_{SNRs}	$2.22^{+0.03}_{-0.01}$	$2.21^{+0.03}_{-0.01}$	$2.22^{+0.01}_{-0.02}$
N_{Vela}	$0.79^{+0.19}_{-0.21}$	$0.89^{+0.41}_{-0.04}$	$0.65^{+0.25}_{-0.11}$
m_{DM} [GeV]	-	34^{+130}_{-14}	$82^{+108.}_{-44.}$
$\langle\sigma v\rangle$ [cm^{3}s^{-1}]	-	$1.34^{+14.3}_{-1.2} \times 10^{-27}$	$4.2^{+4.3}_{-4.2} \times 10^{-26}$
χ^2/d.o.f.	1.00	0.97	0.93

Previous astro-model χ^2 /d.o.f. = 1.35

$e^+/(e^++e^-)$ POWERFUL PWN + DMDM --> $\mu^+\mu^-$



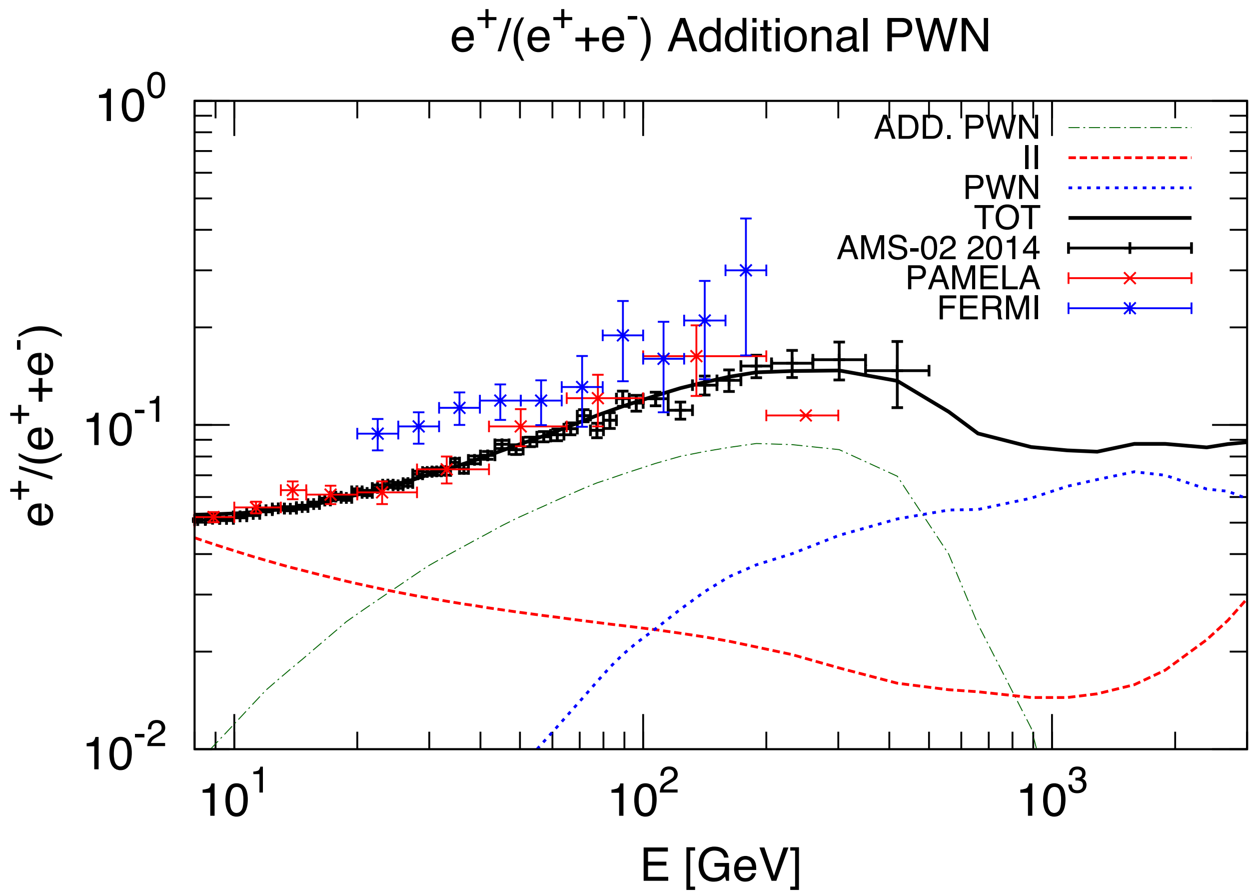
Best fit regions

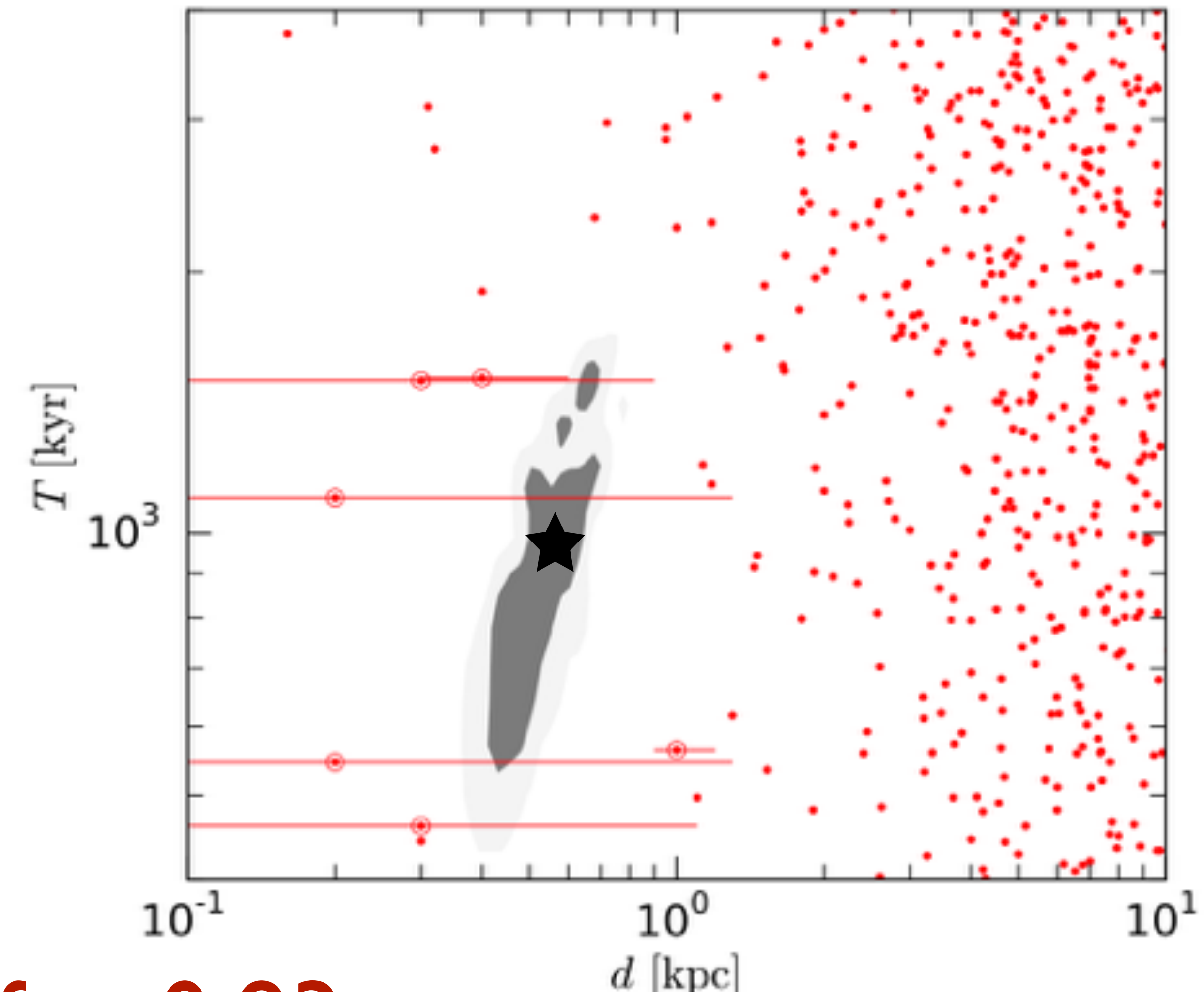


A word of caution

DM **can** fit AMS-02 data, but **it is not** the **only possibility** out there:

For example, an **additional PWN** (in addition to the ones of the ATNF catalogue) can provide fits that are **comparably good**

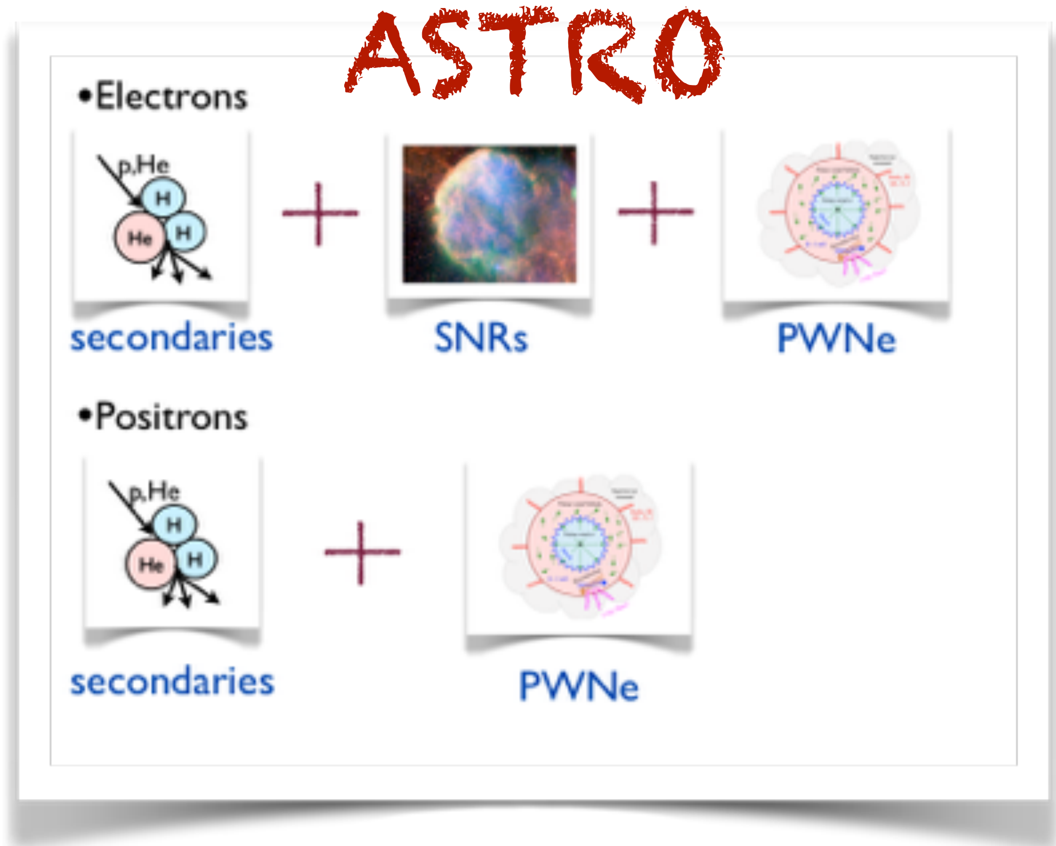




χ^2 /d.o.f. = 0.93

Adding DM - constraints

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



+ DM

We fit the **four observables:**

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

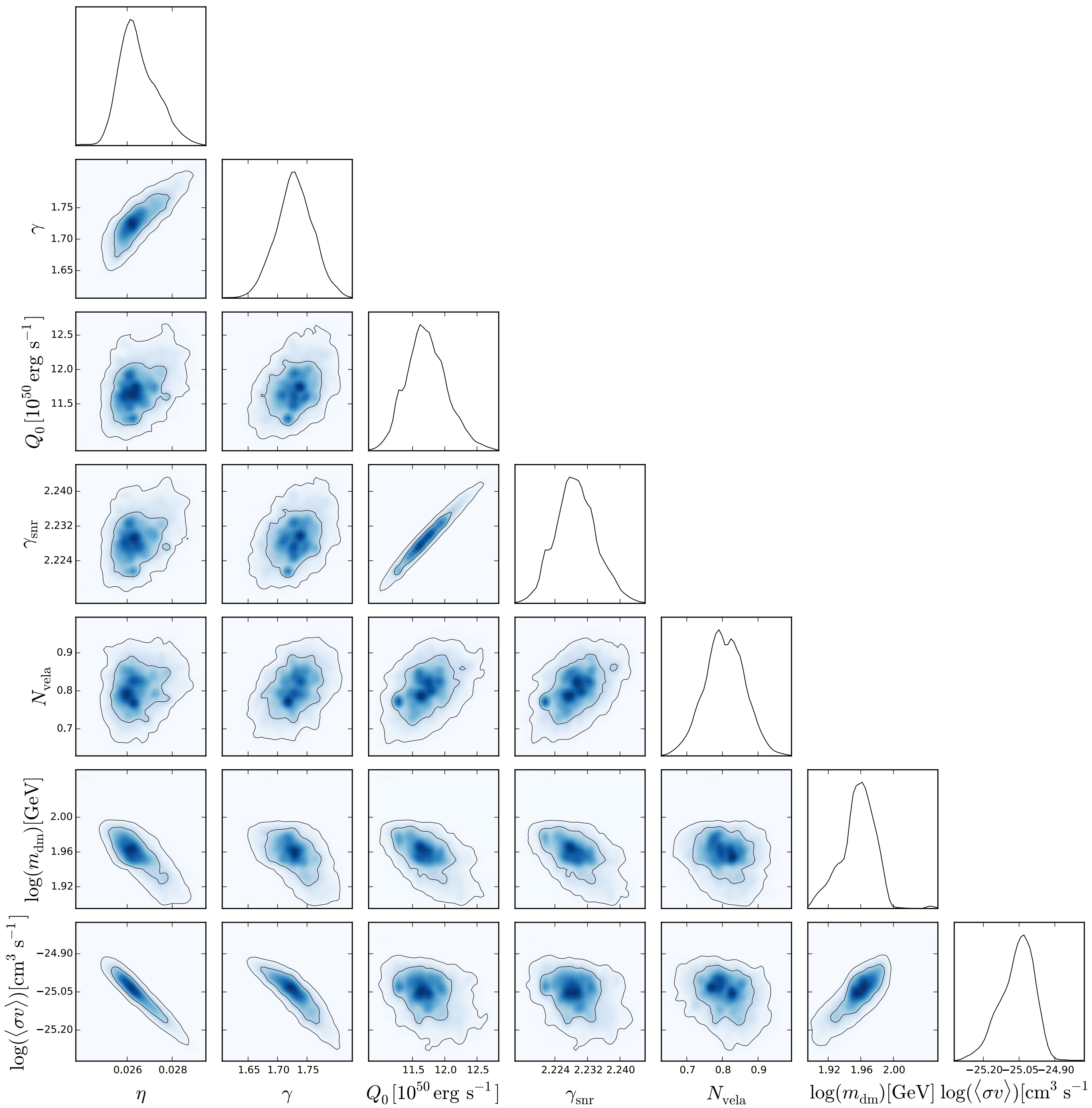
We have **7 parameters:** 6 free + 1 fixed

PWNe	Far SNRs	DM	Near SNRs
•γ •η	•Q0 •γ_{SNR}	•$<\sigma v>$ •mDM	•Nvela

We keep it fixed

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



We use the cosmoMC package
Lewis, Bridle 2002

Constraints on DM

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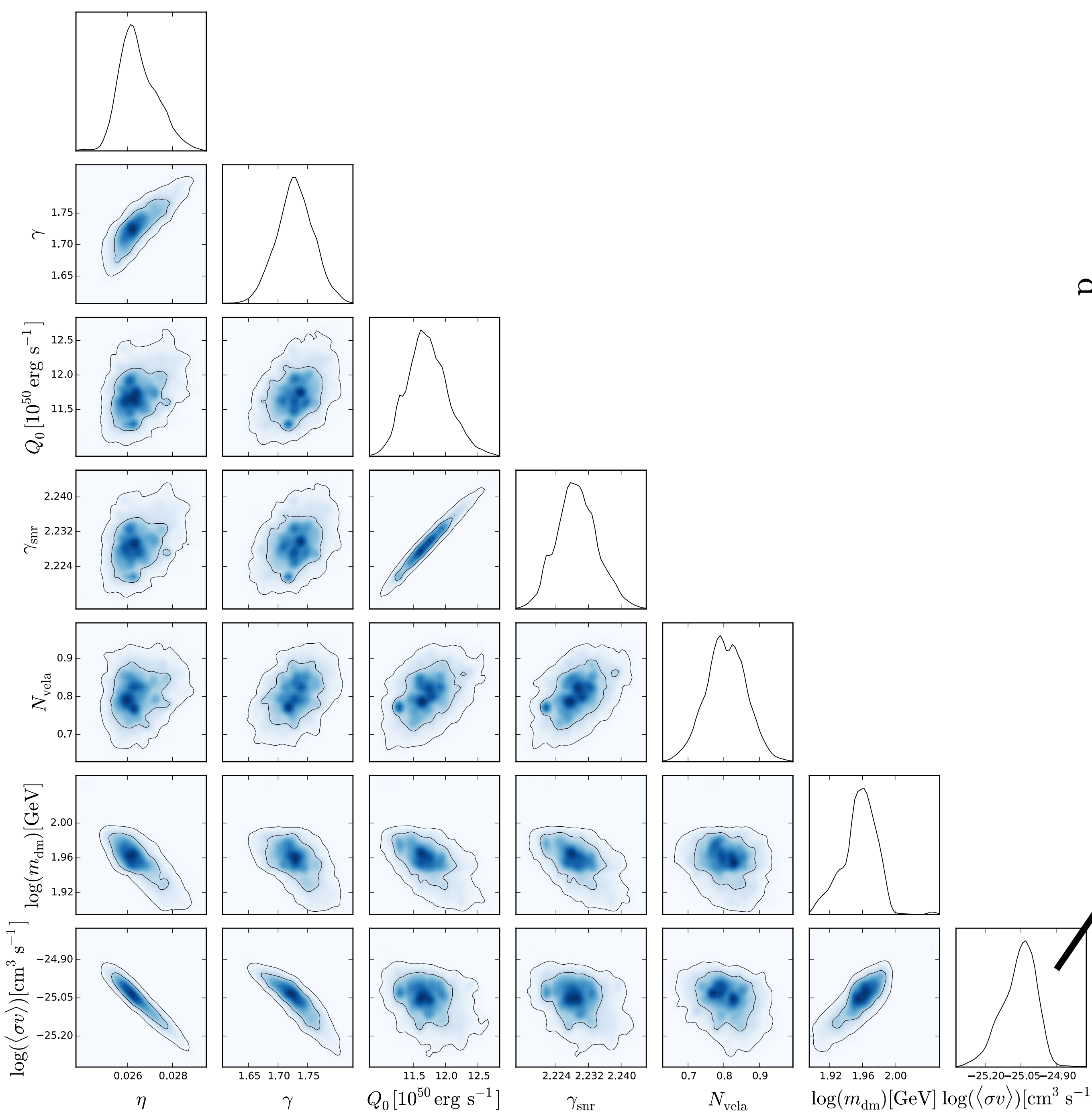

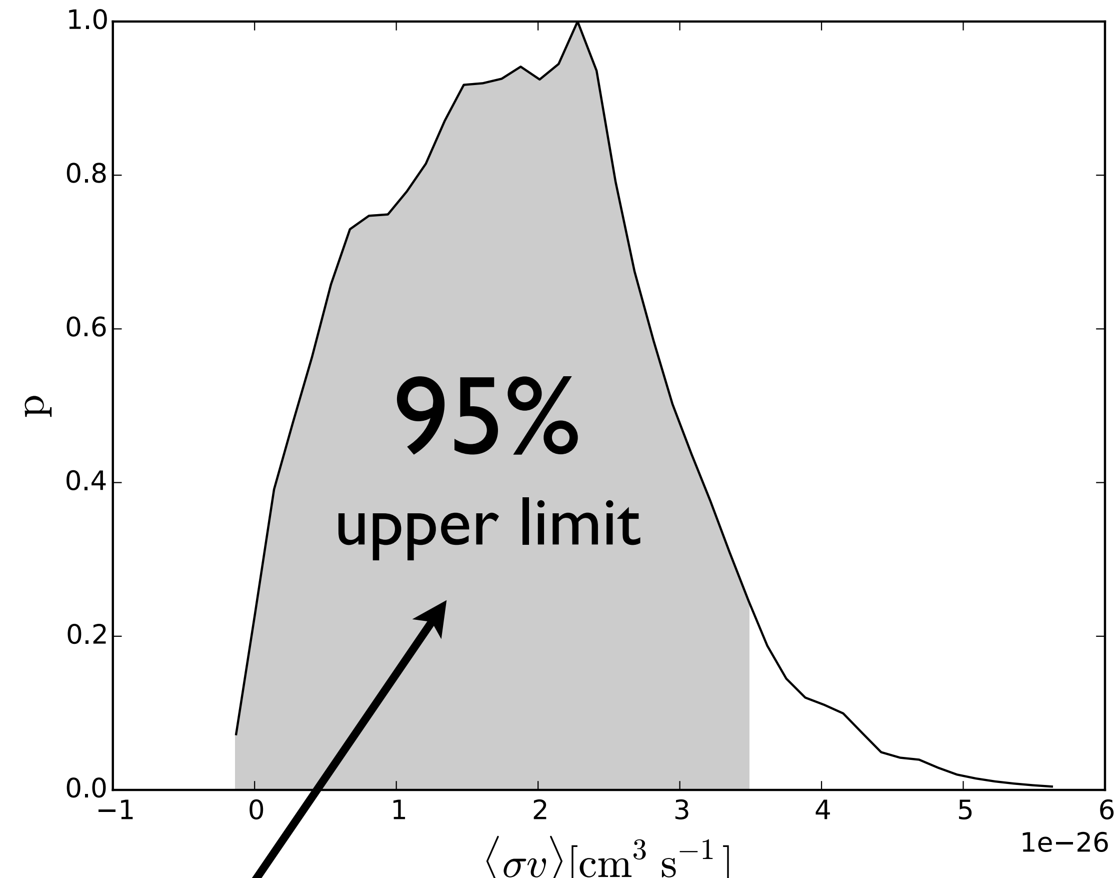

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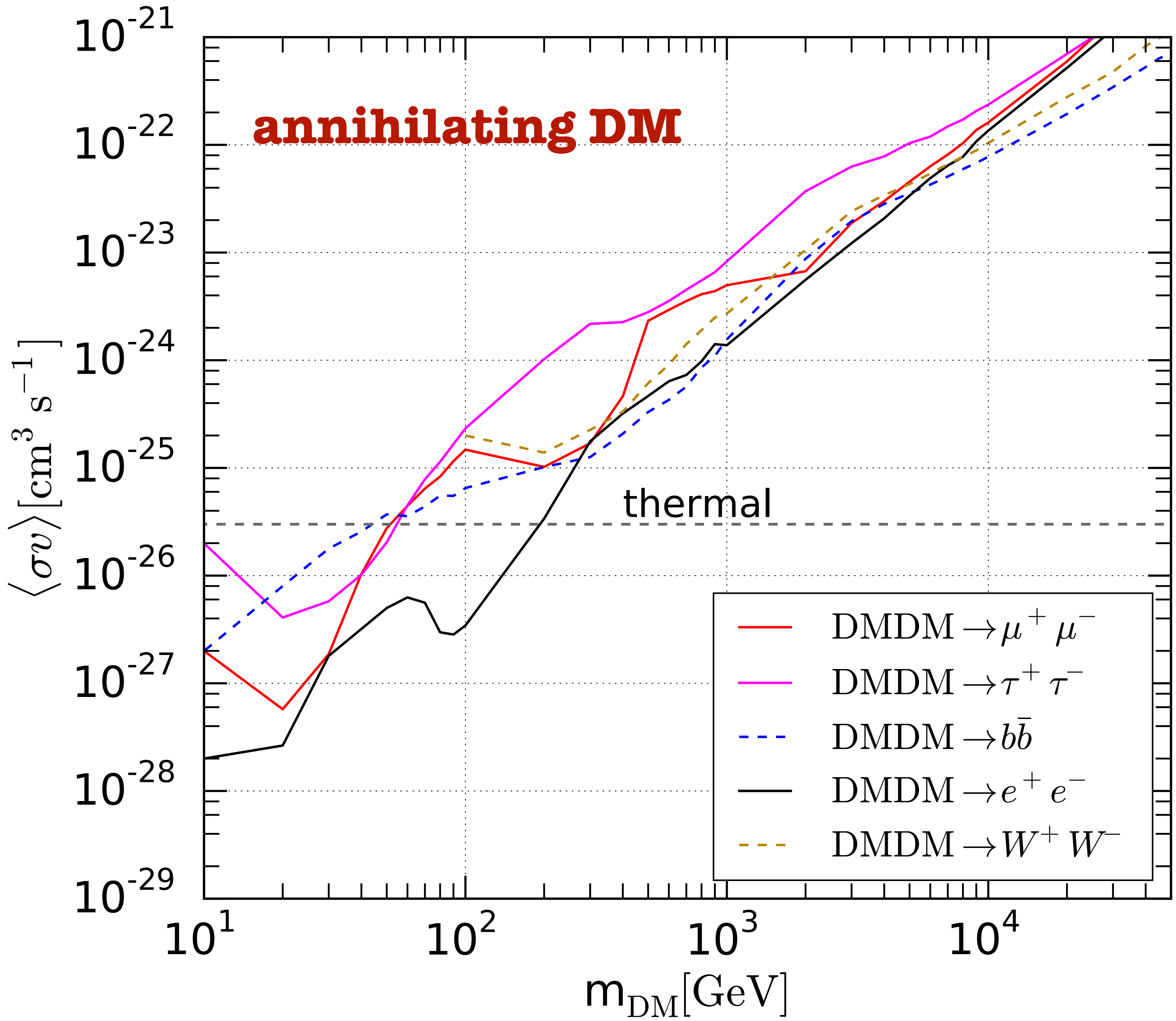
Lewis, Bridle 2002

Constraints on DM



Similar results found by **Bergstrom et al., 2013** and **Ibarra et al., 2013** by employing different techniques

Conclusions

AMS-02 data can be **fitted remarkably well** both:

- within **purely astrophysical** models (SNRs + PWNe)
- within models in which $e^{\pm}$ are emitted by **both DM and astrophysical sources**

In particular, the best fit is given by a **WIMP with $m_{DM} \approx$ 50 GeV and $\langle\sigma v\rangle$ close to the thermal value** that annihilates in the **$\mu^+\mu^-$ channel**.

Such a candidate **does not seem to be in tension** with bounds coming from **other indirect detection channels**

However, **without** a clear understanding of the astrophysical background, **one cannot seriously claim for a DM hint or, eventually, a detection**

In any case, despite this uncertainty, **one can effectively use $e^{\pm}$ data to put robust constraints on DM annihilation cross section**

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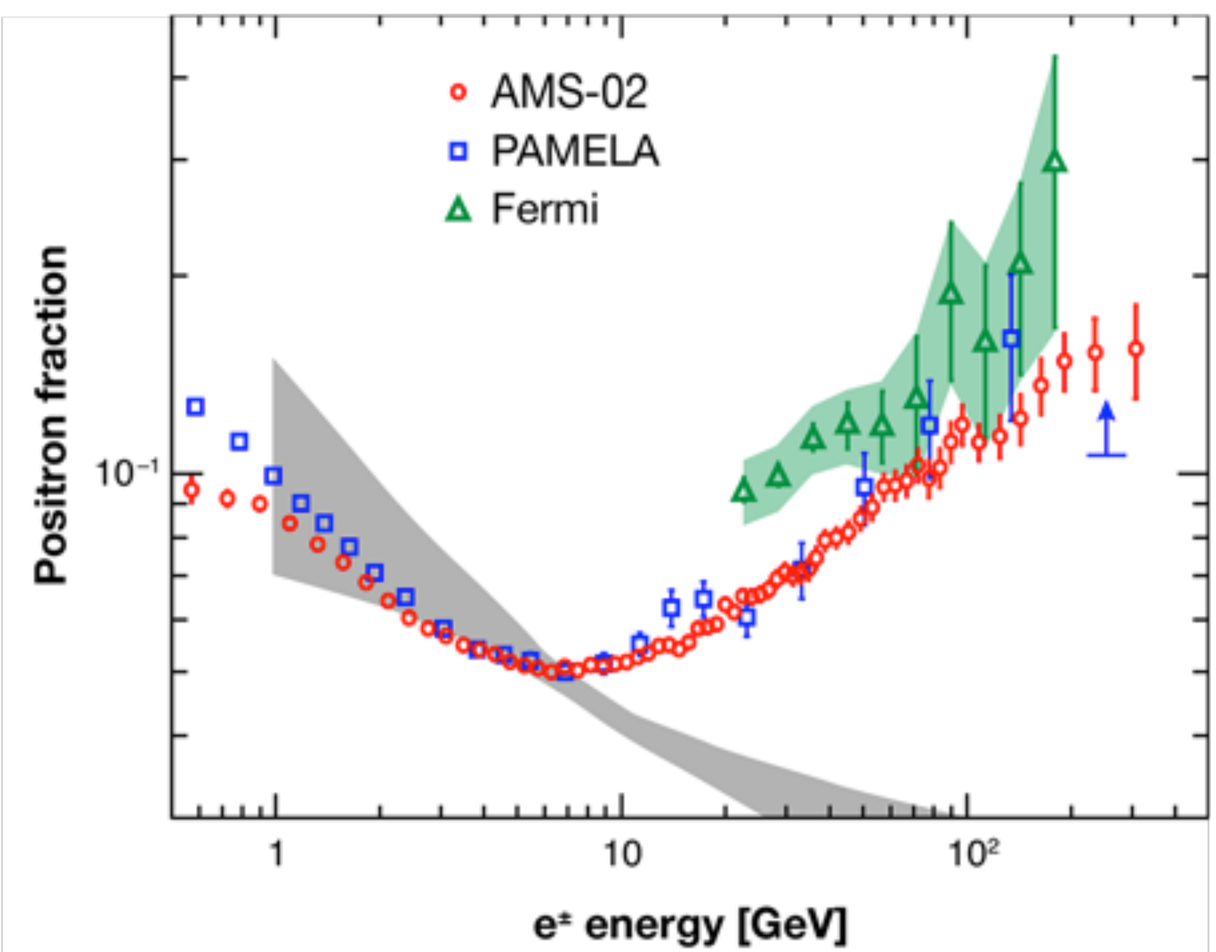
In any case, despite this uncertainty, **one can effectively use $e^{\pm}$ data to put robust constraints on DM annihilation cross section**

thank you!

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**

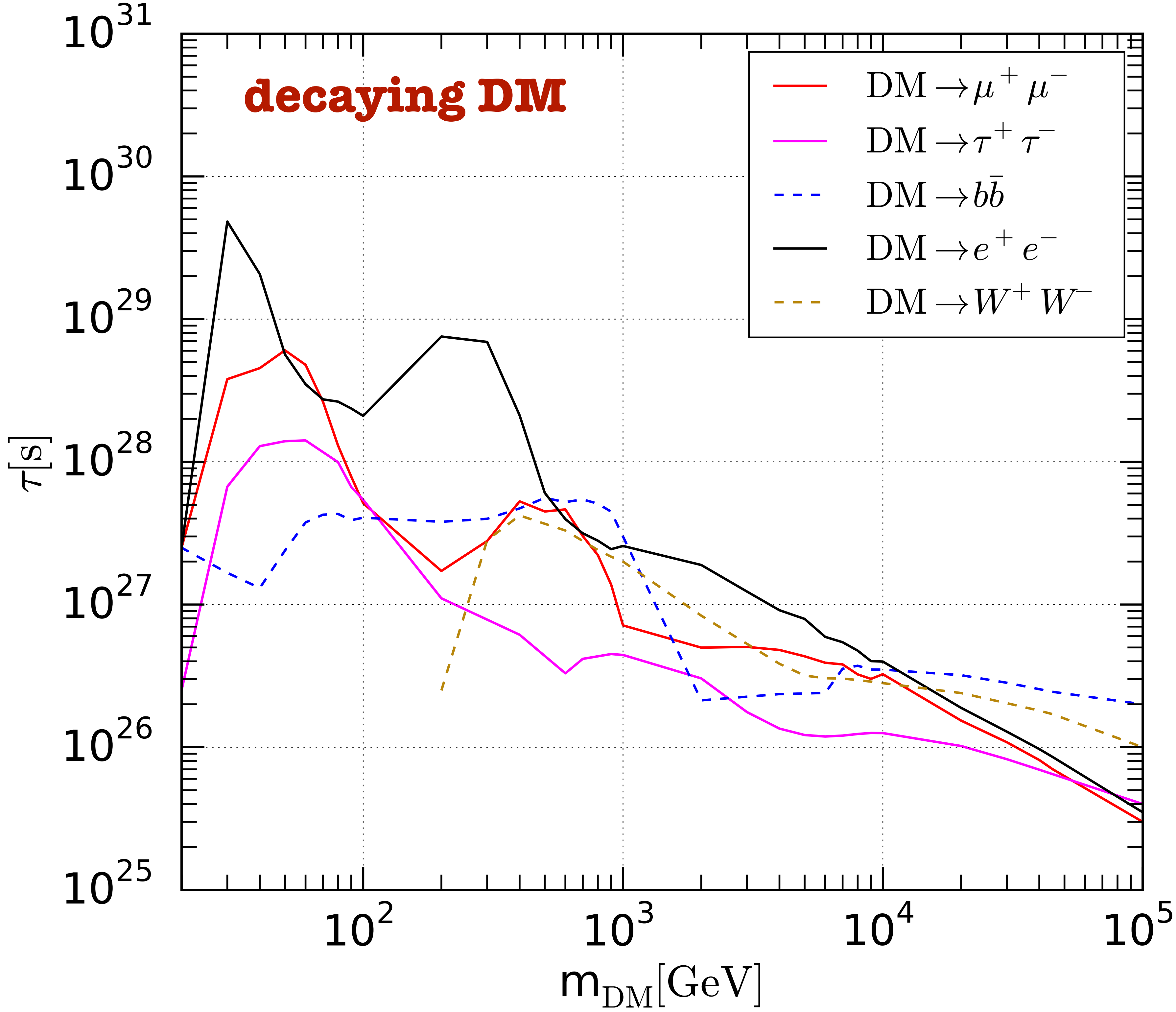


The rise is **not compatible** with the hypothesis that all positrons have a **secondary origin**

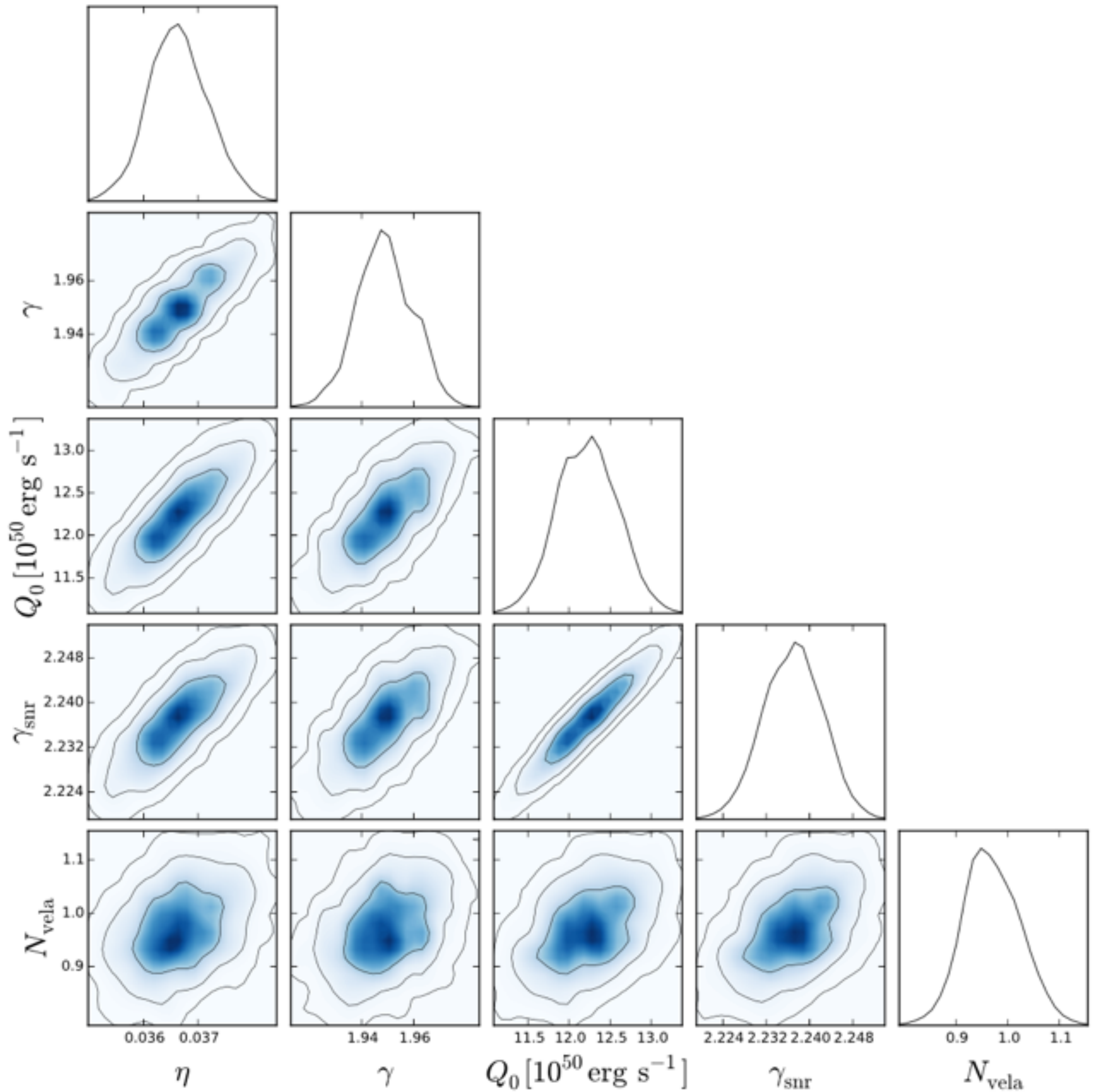
It implies the existence of additional **sources of primary e^+**

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

Constraints on DM

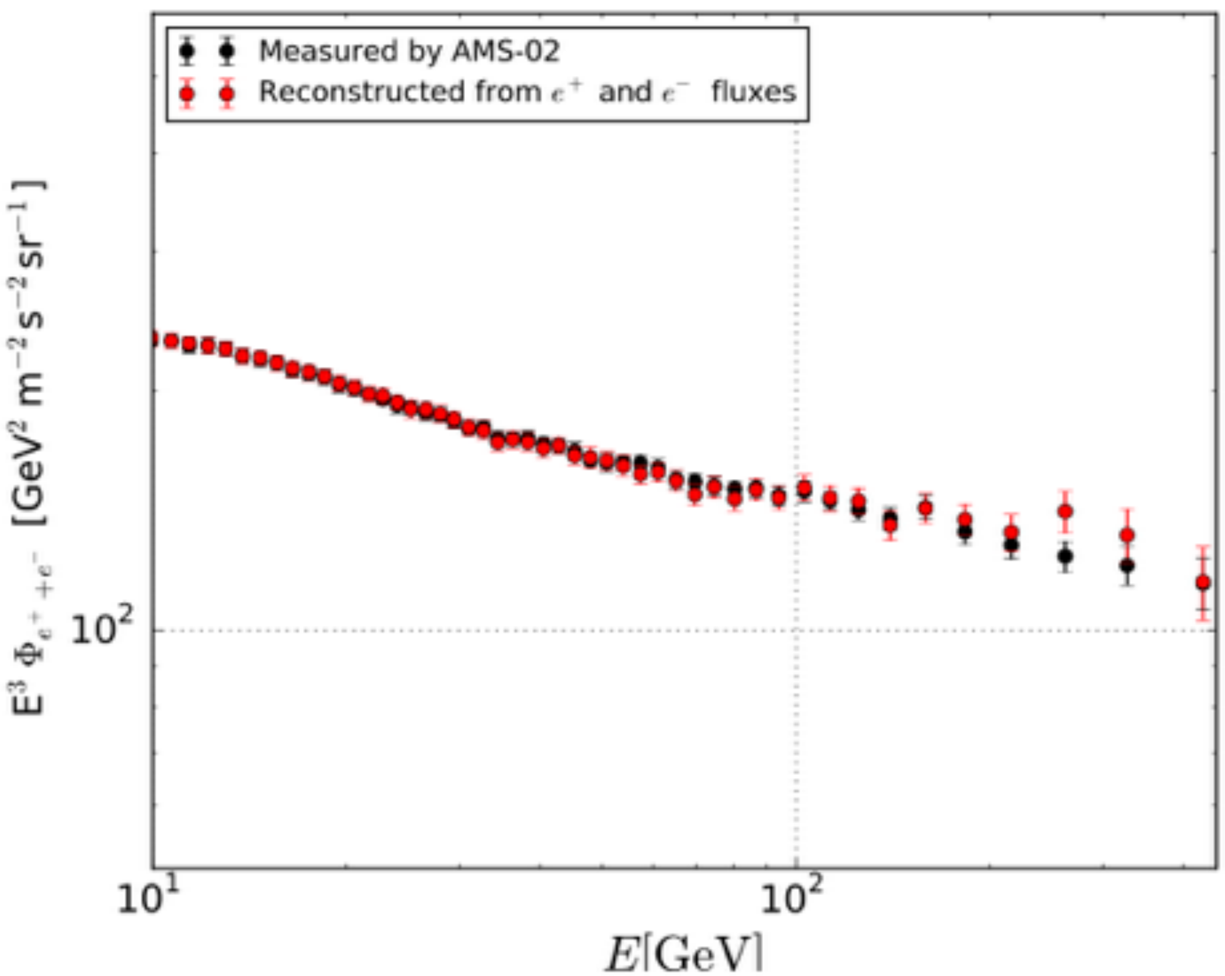


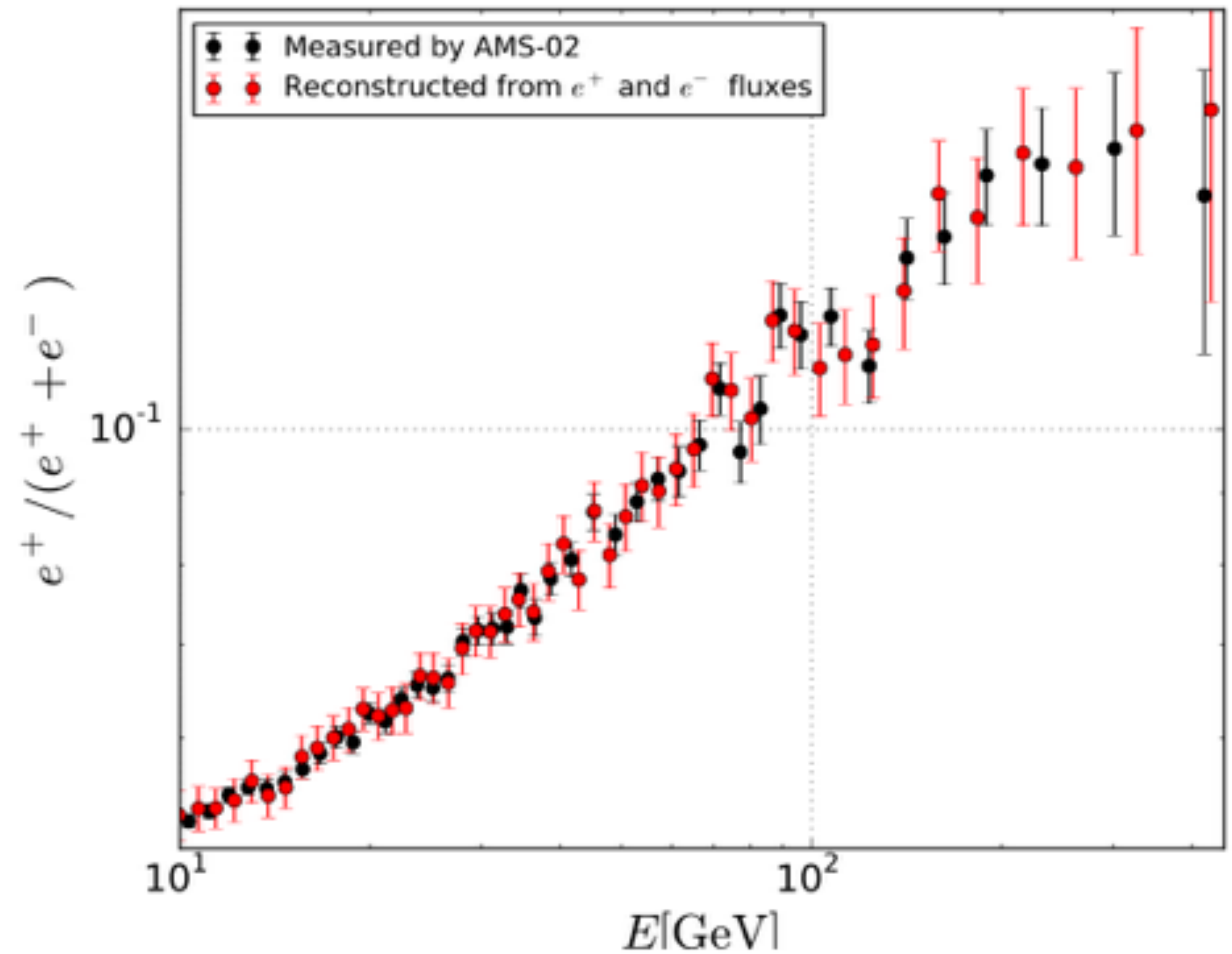
COSMOMC



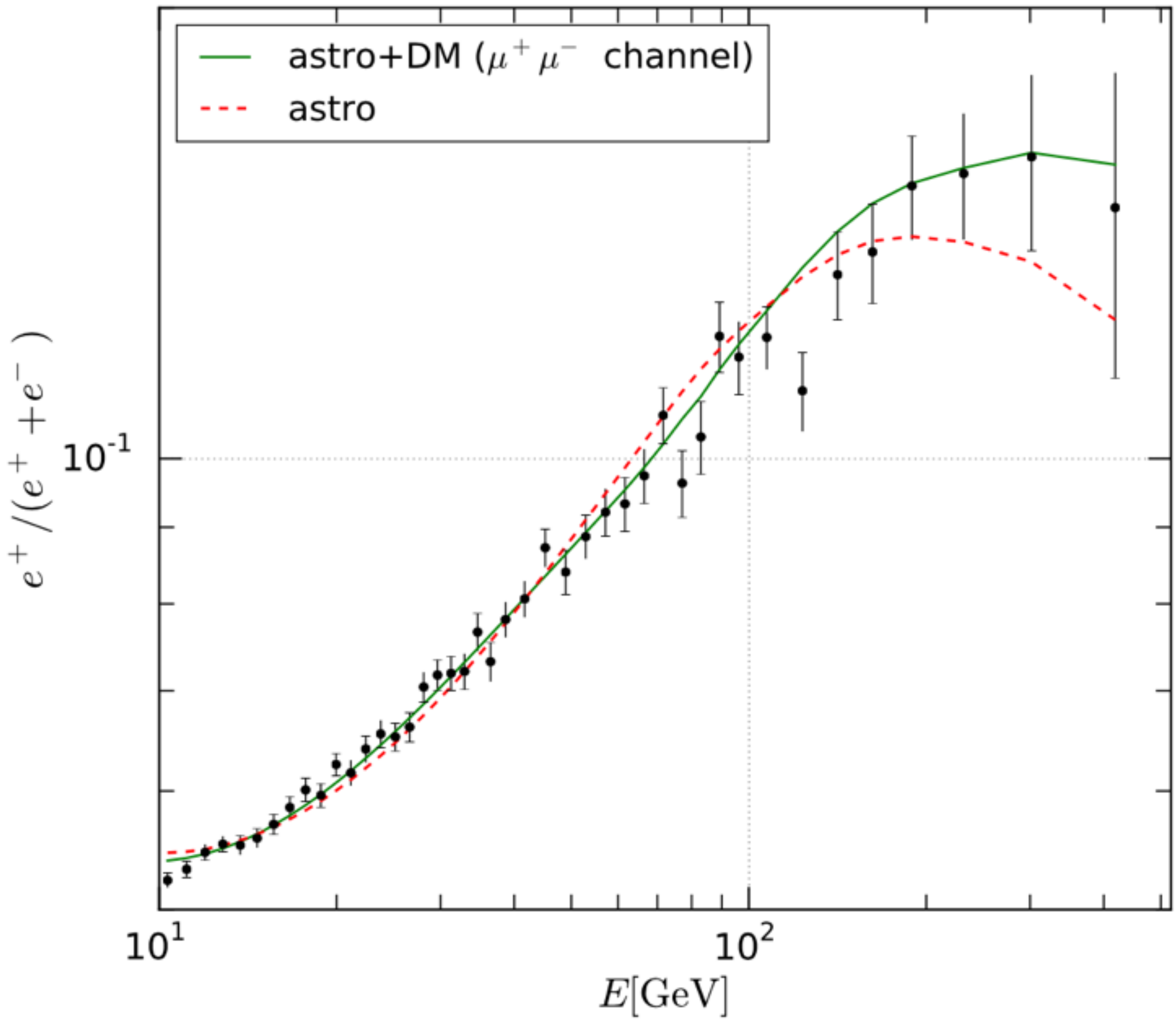
1.96
1.94
γ
13.0
12.5
12.0
11.5
$Q_0\,[10^{50}\,\mathrm{erg\ s^{-1}}]$
2.248
2.240
2.232
2.224
$\gamma_{\rm snr}$
1.1
1.0
0.9
$N_{\rm vela}$
0.036 0.037
η
1.94 1.96
γ
11.5 12.0 12.5 13.0
$Q_0\,[10^{50}\,\mathrm{erg\ s^{-1}}]$
2.224 2.232 2.240 2.248
$\gamma_{\rm snr}$
0.9 1.0 1.1
$N_{\rm vela}$

AMS DATASETS

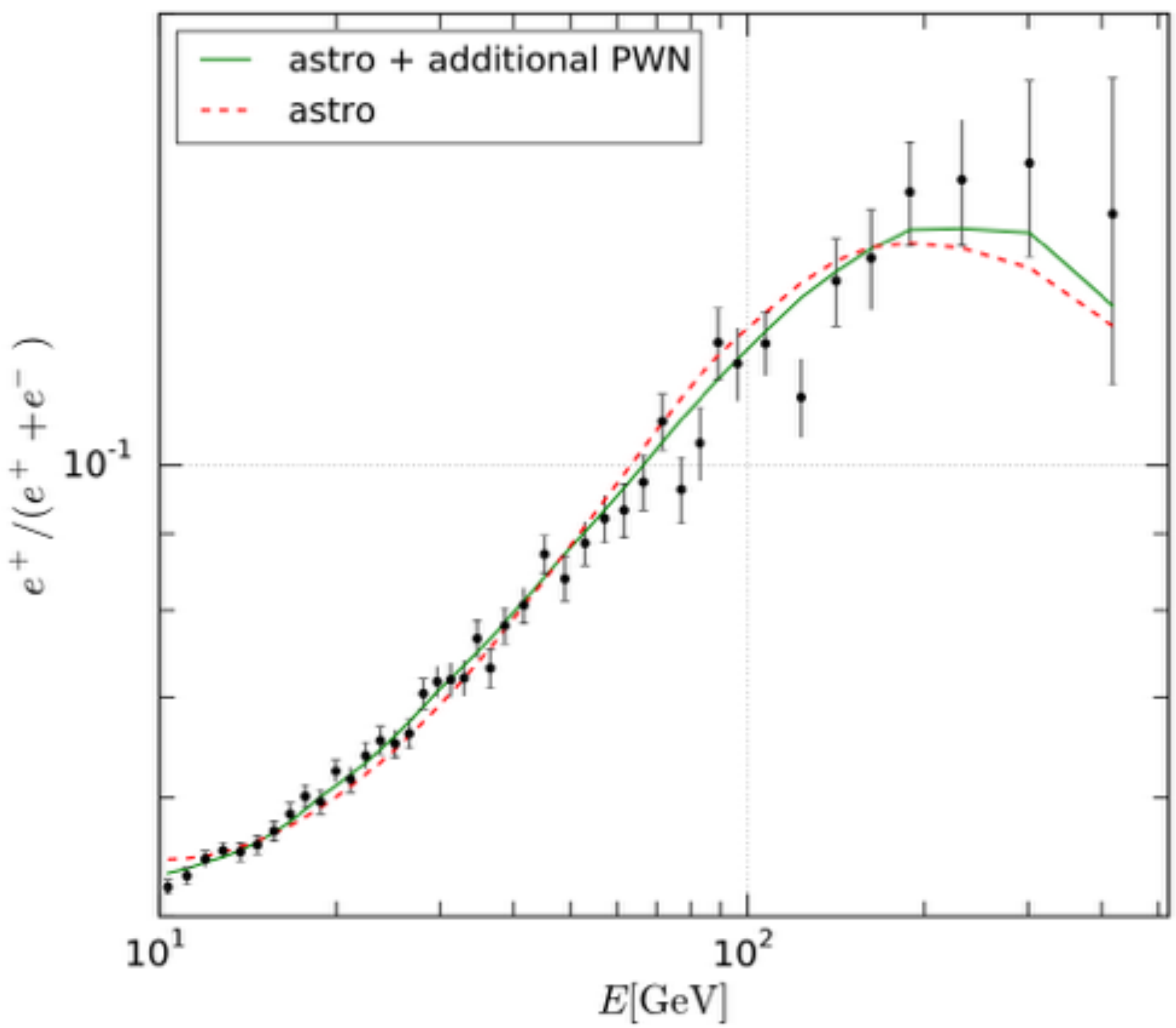


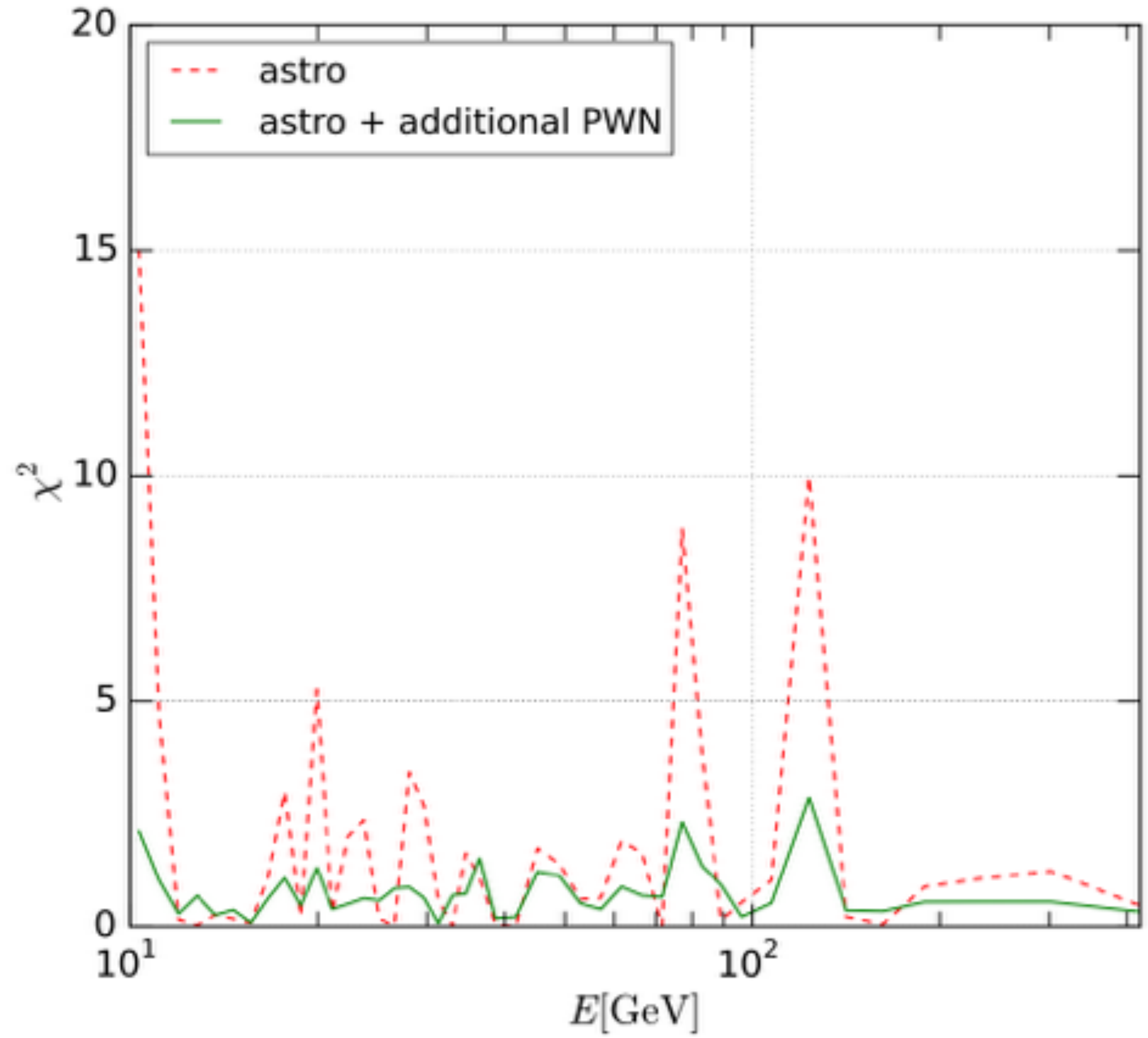


ASTRO VS DM

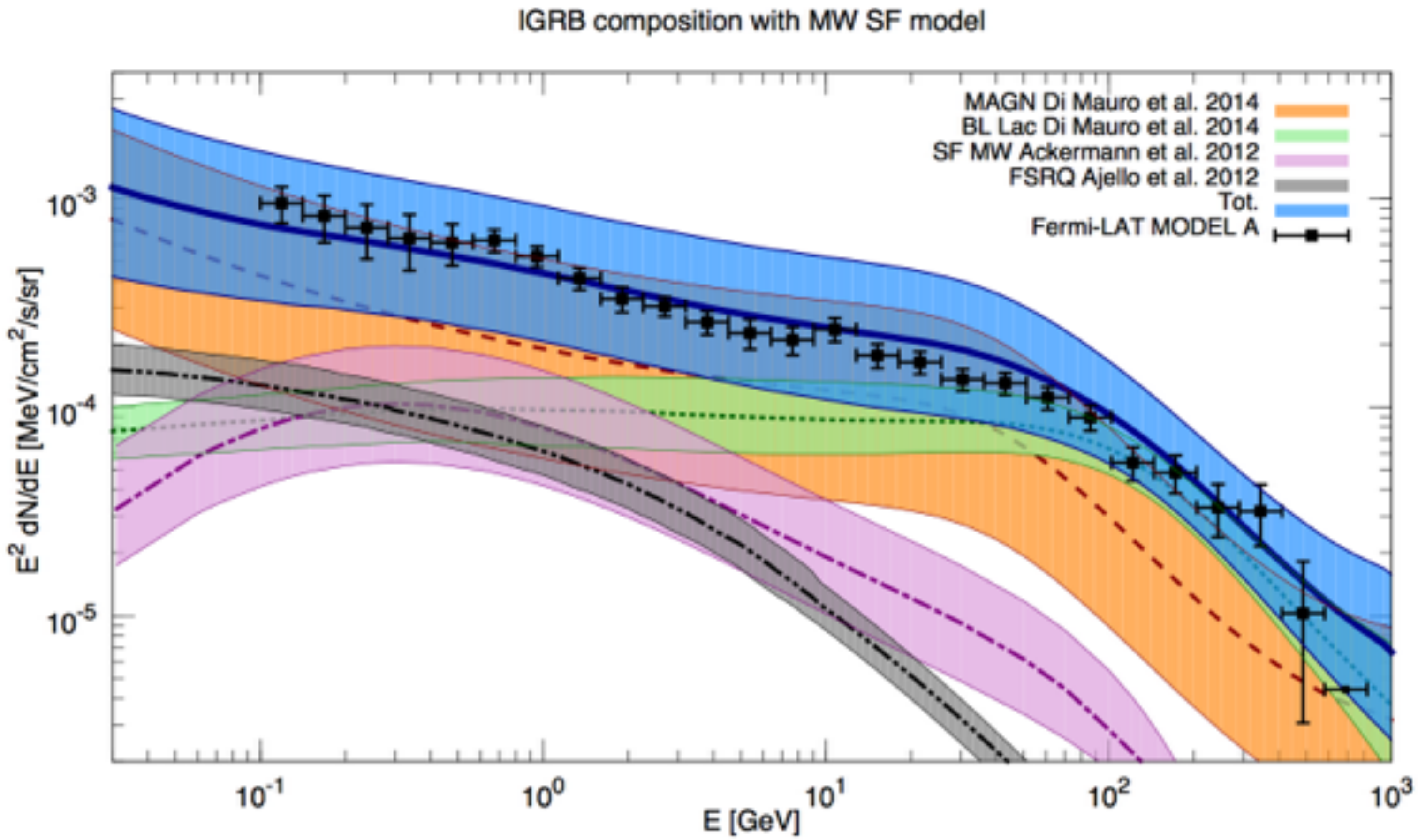


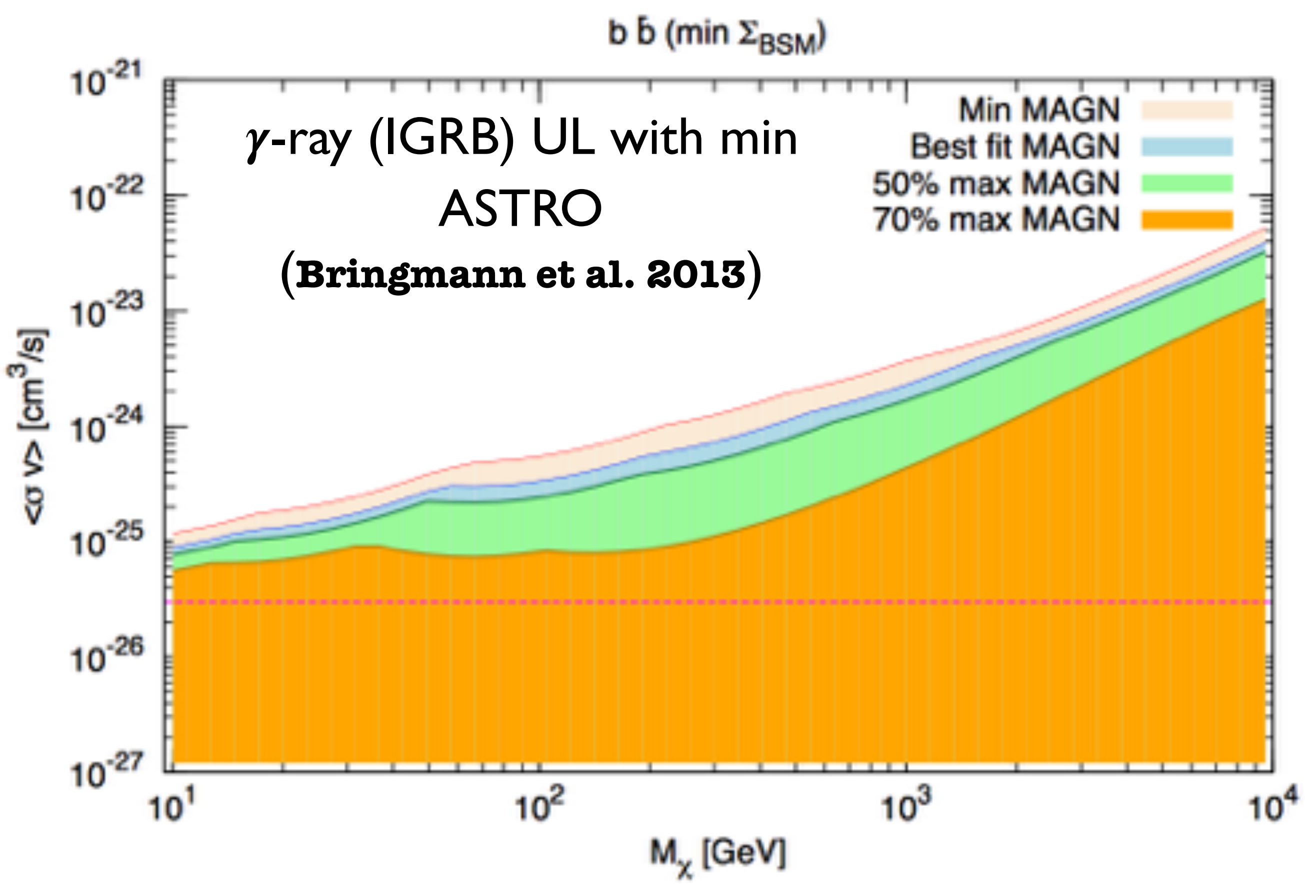
ADDITIONAL PWN

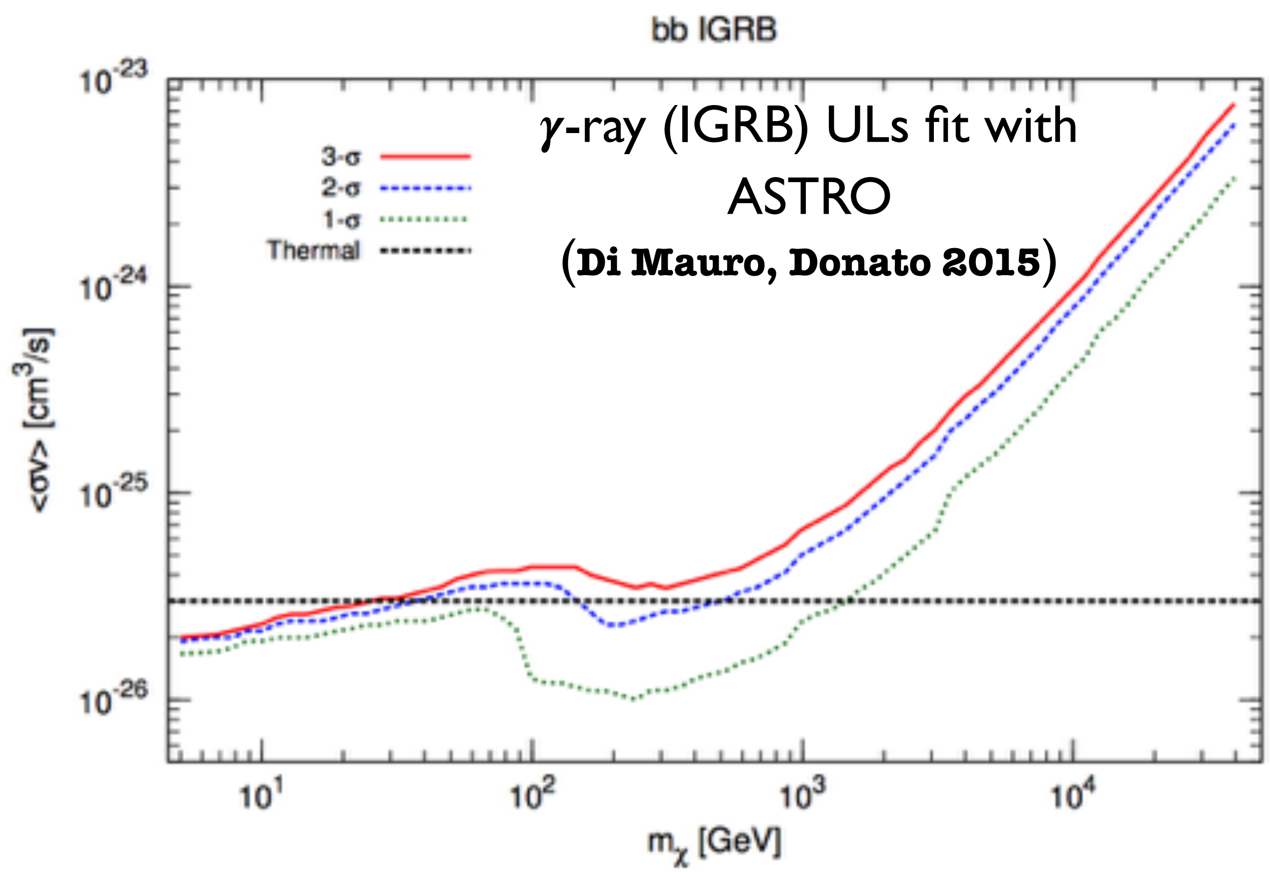




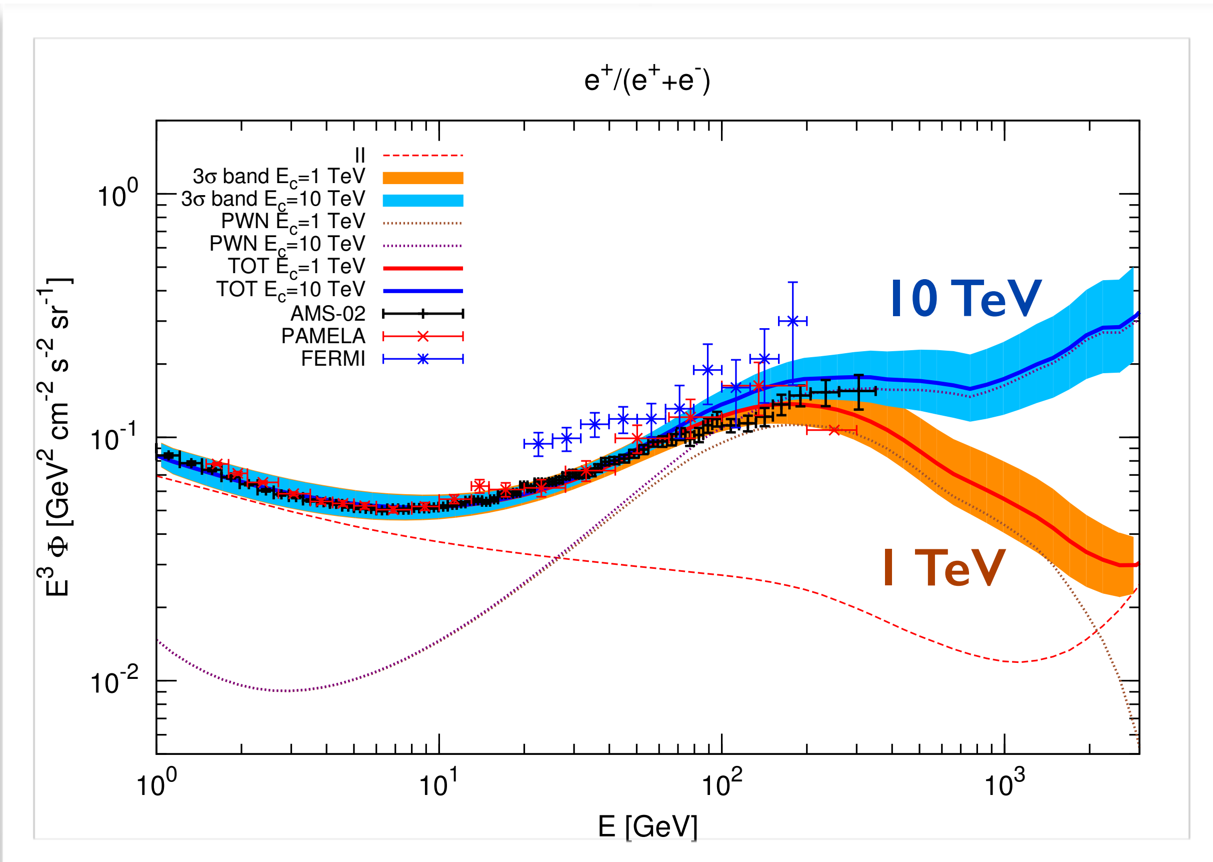
GAMMA-RAY ULs





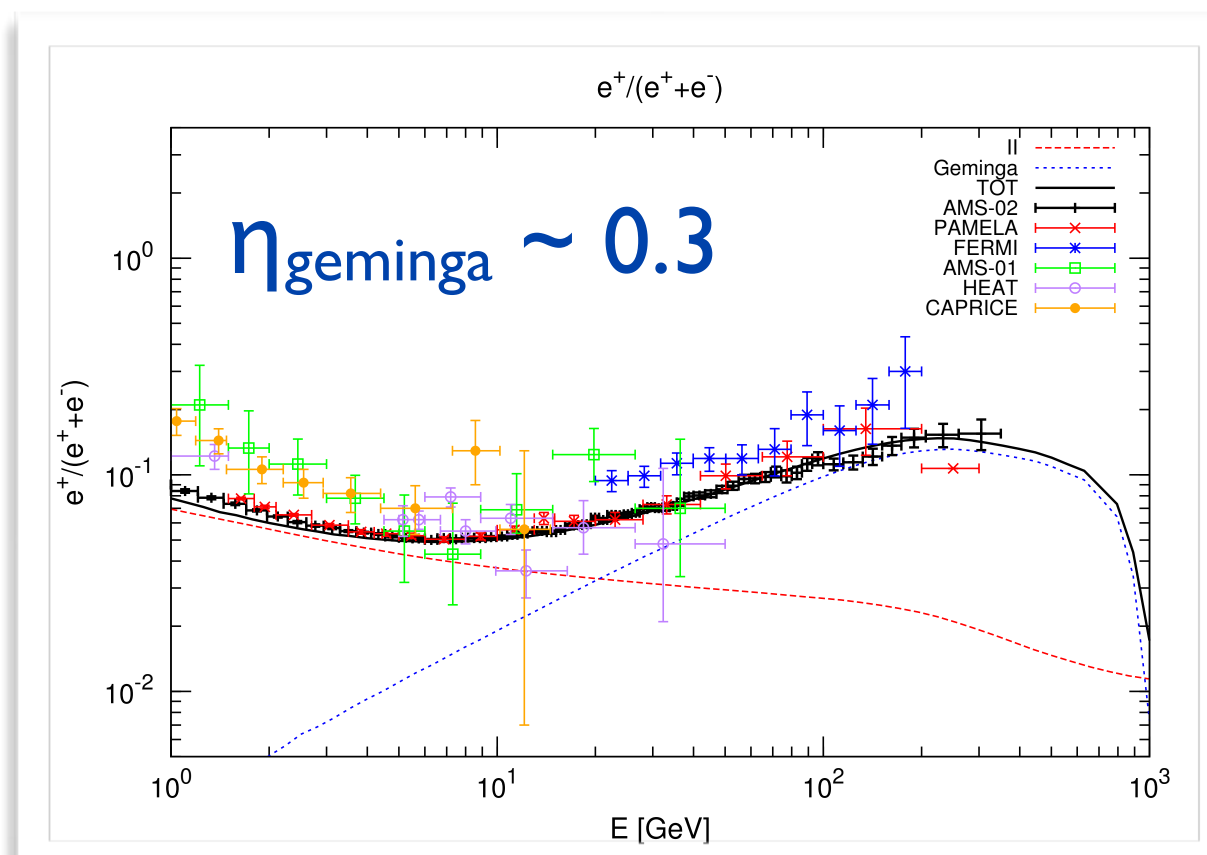


fit to AMS-02 data

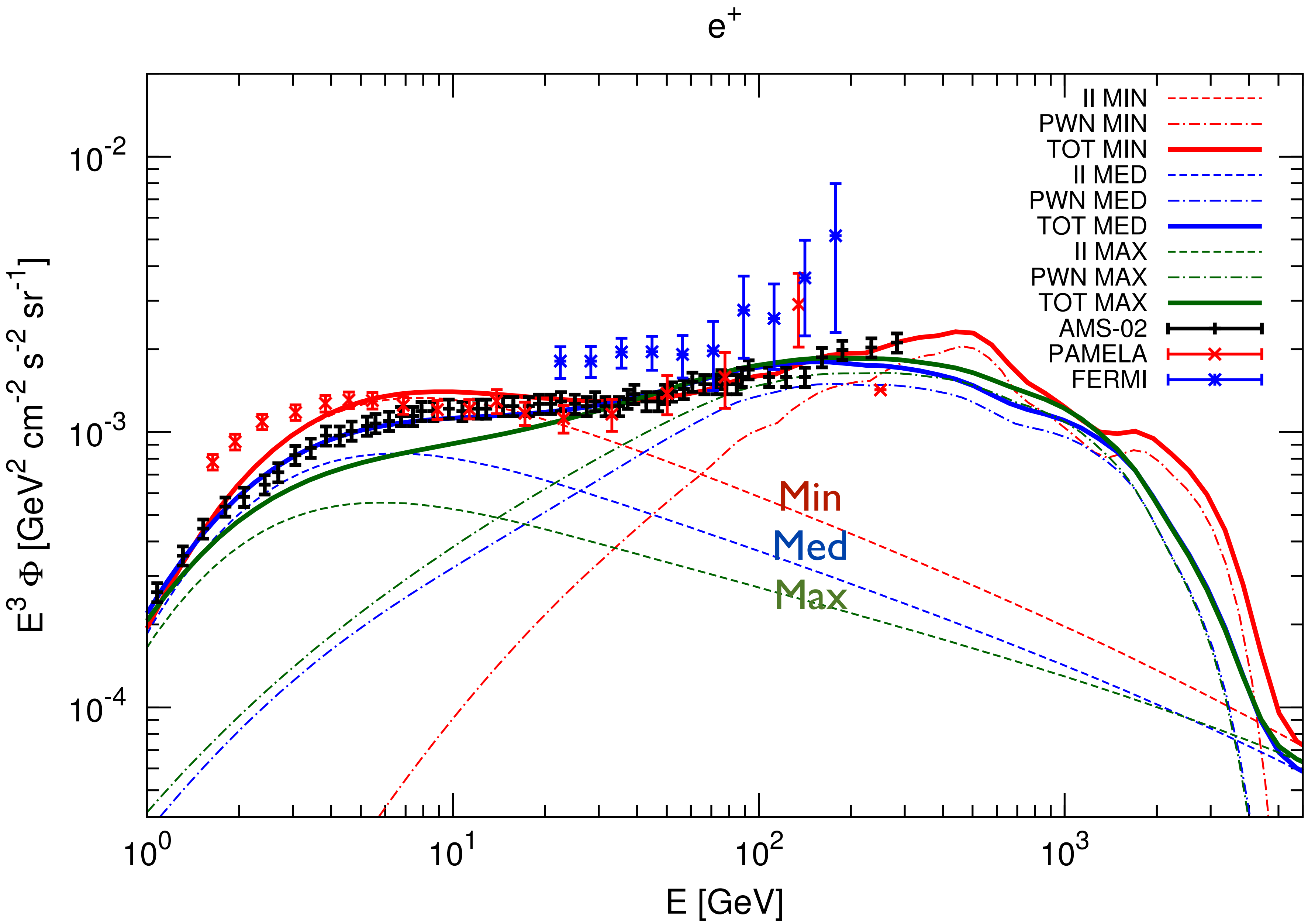


- **Results** have been obtained with a **cut-off E_c = 2 TeV** in the spectrum of $e^{\pm}$ emitted by PWNe.
- **Changing this value can affect** the shape of **the positron fraction** at high energies **to a large extent.**
- Only **a sudden drop would appear not compatible with PWNe emission**

- 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.**

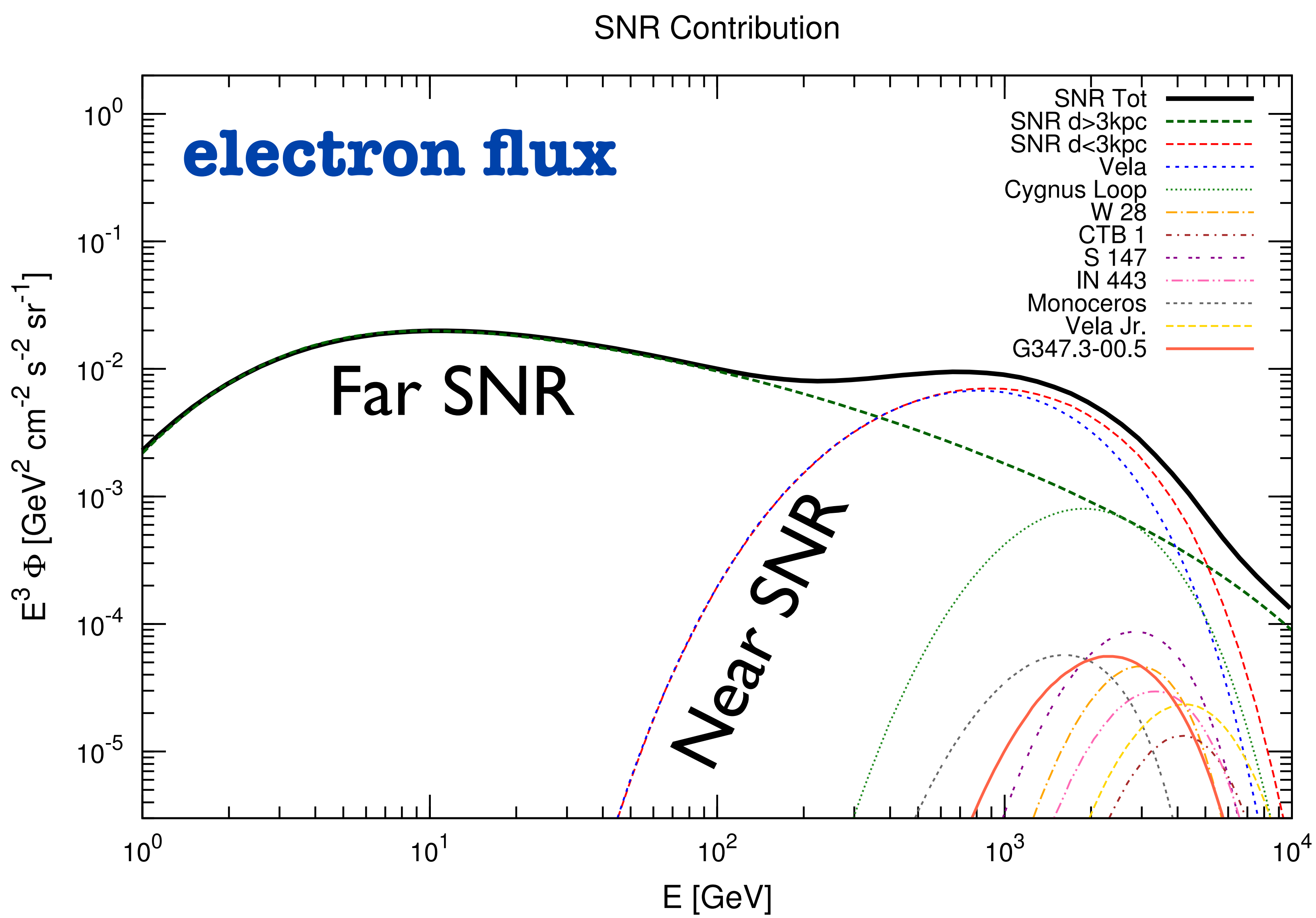


Can we disfavor the Min and Max propagation models?



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

Supernova Remnants (SNRs)



Pulsar Wind Nebulae (PWNe)