

# A new look at the cosmic ray positron fraction

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*LAPTh - Annecy, France*

International Cosmic Ray Conference

*The Hague, The Netherlands*

August 1 2015

**Cosmic Ray Alpine Collaboration**

(M.B, S.Caroff, A.Putze, Y.Genolini, S.Aupetit, G.Belanger, C.Goy, V.Poireau,  
V.Poulin, S.Rosier, P.Salati, L.Tao and M.Vecchi)

*Based on A&A 575,A67(2015)*

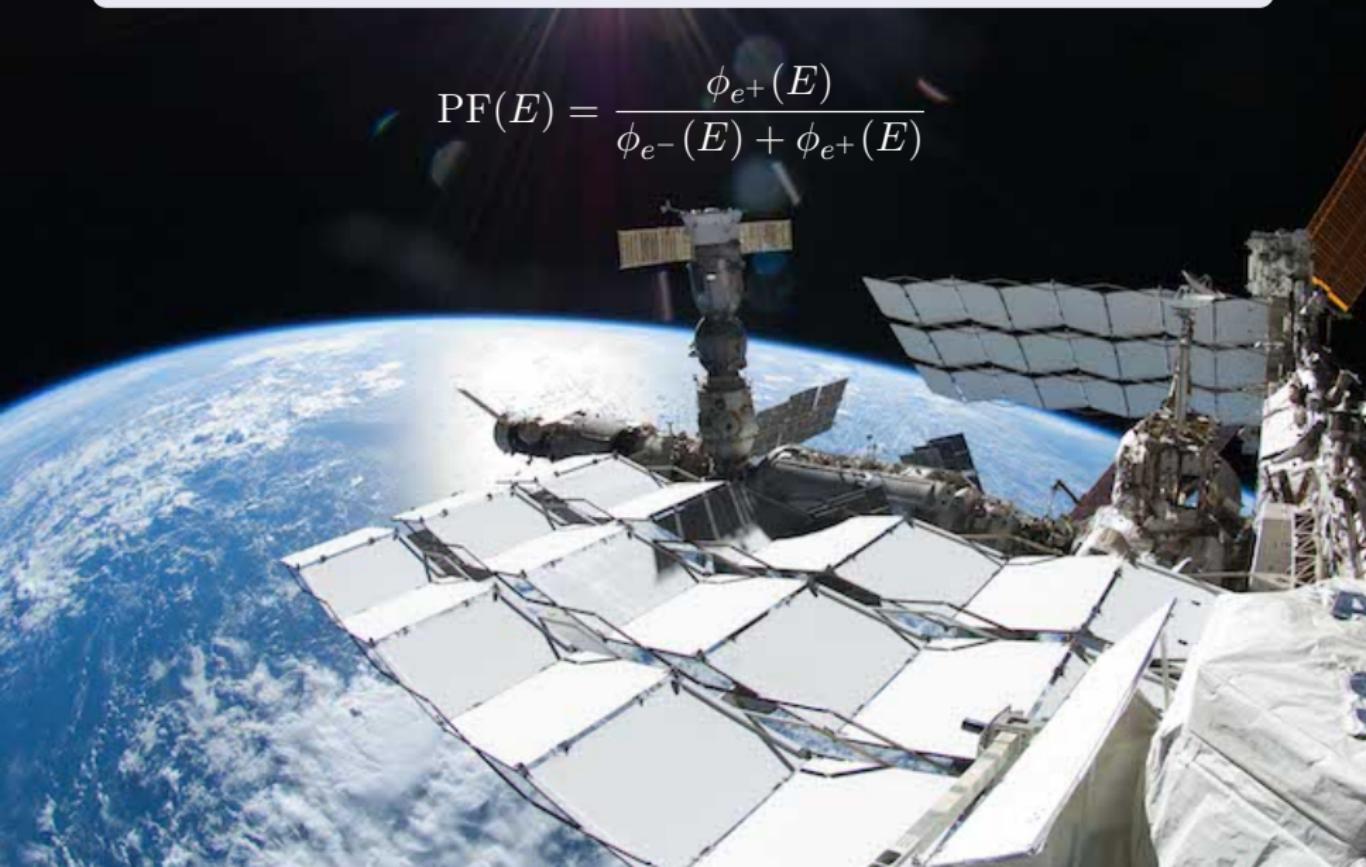


AMS-02 measured the positron fraction (PF) with an unprecedent high accuracy from 0.5 up to 500 GeV.



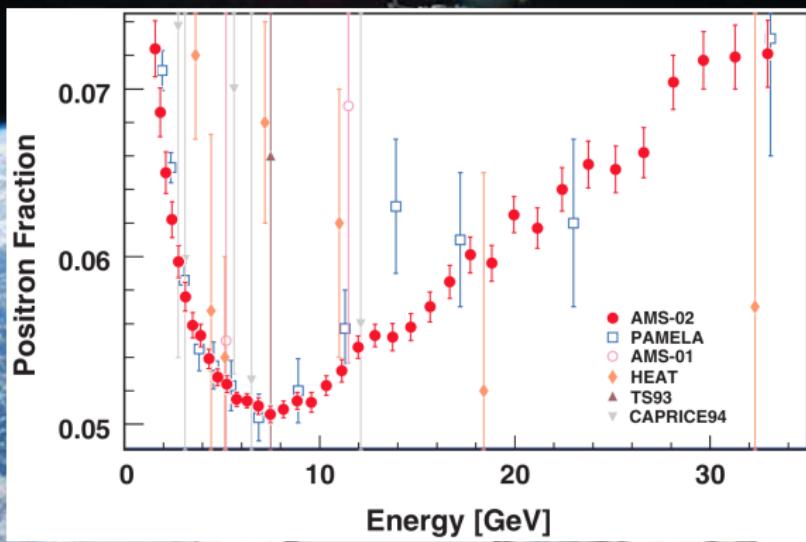
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$$\text{PF}(E) = \frac{\phi_{e^+}(E)}{\phi_{e^-}(E) + \phi_{e^+}(E)}$$



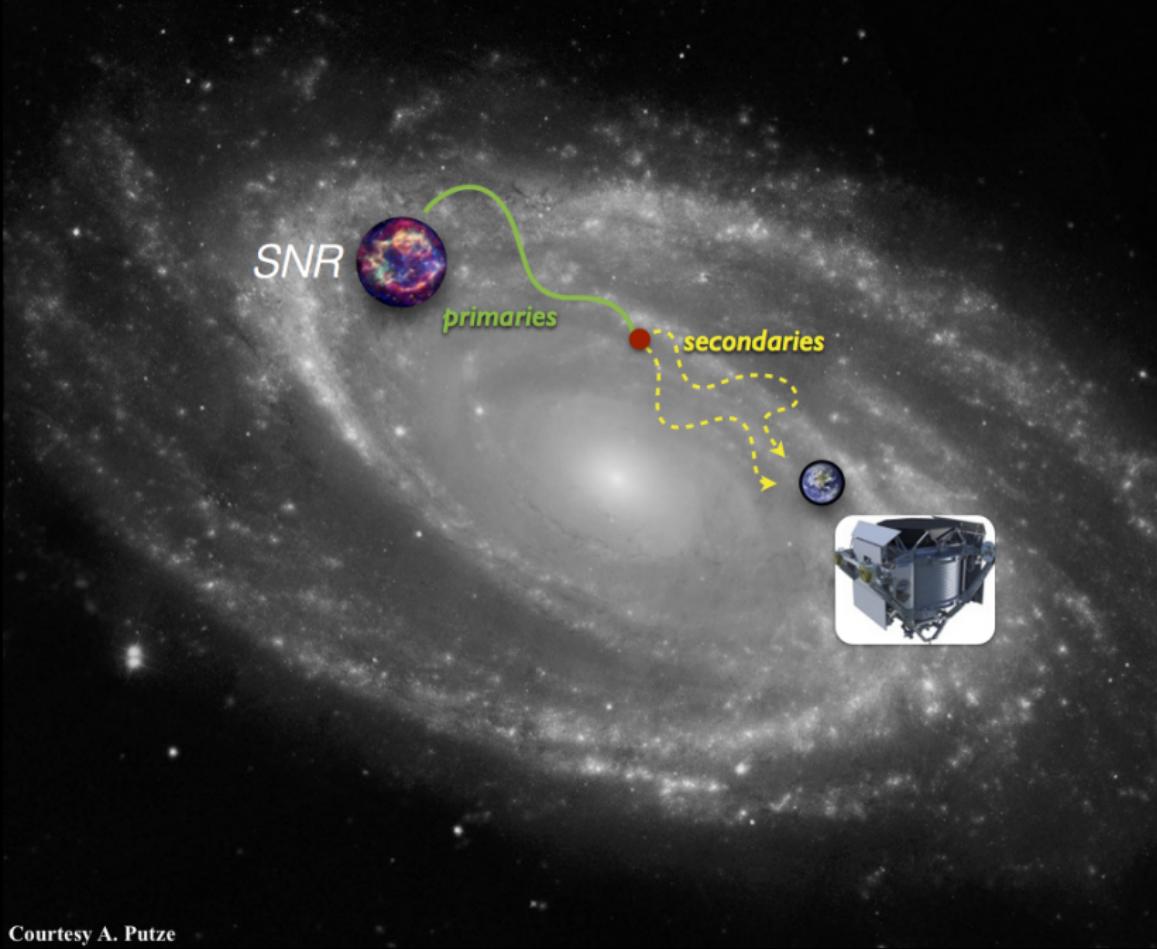
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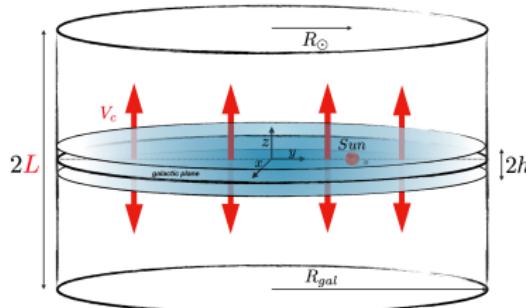
The data confirm the '*positron anomaly*'.

*What is the positron anomaly?*



Courtesy A. Putze

## Two-zone model and semi-analytic method



$$1 < \textcolor{red}{L} < 15 \text{ kpc}$$

$$K(E) = \textcolor{red}{K}_0 \beta \left( \frac{R}{R_0} \right)^{\delta}$$

$$\vec{V}_c = \textcolor{red}{V}_c \operatorname{sign}(z) \vec{e}_z$$

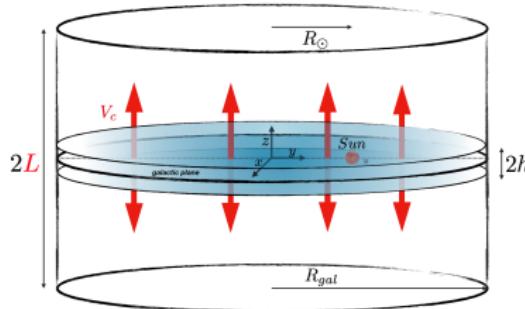
$$K_{EE}(E) = \frac{2}{9} \textcolor{red}{V}_a^2 \frac{E^2 \beta^2}{K(E)}$$

### Cosmic rays transport equation

$$\partial_t \psi - K(E) \nabla^2 \psi + \partial_z [V_c \operatorname{sign}(z) \psi] + \partial_E [b(E, \vec{x}) \psi - K_{EE}(E, \vec{x}) \partial_E \psi] = Q(E, t, \vec{x})$$

$$Q(E, t, \vec{x}) = Q^{source}(E, t, \vec{x}) - Q^{sink}(E, \vec{x})$$

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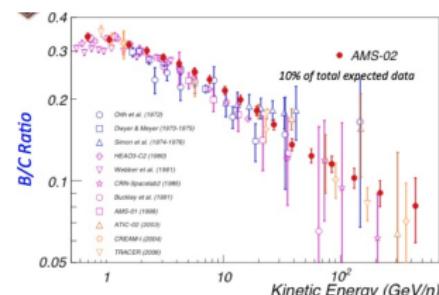
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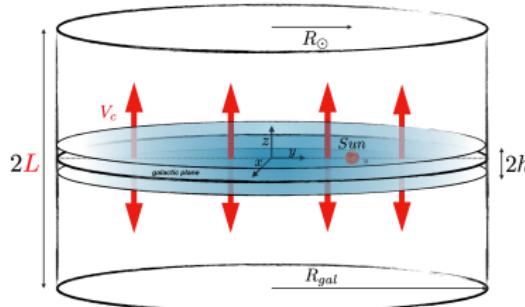


$\Rightarrow$   
 (Maurin *et al.* 2001)  
 (Donato *et al.* 2003)

Case	$\delta$	$K_0 [\text{kpc}^2/\text{Myr}]$	$L [\text{kpc}]$	$V_c [\text{km/s}]$	$V_a [\text{km/s}]$
MIN	0.85	0.0016	1	13.5	22.4
MED	0.70	0.0112	4	12	52.9
MAX	0.46	0.0765	15	5	117.6

LAPTh

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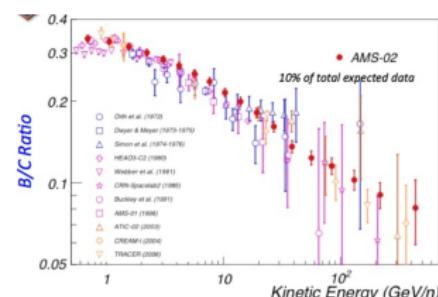
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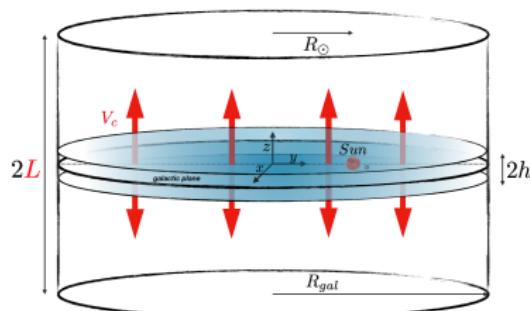
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HE positrons  $E_{e^+} \geq 10\text{GeV}$

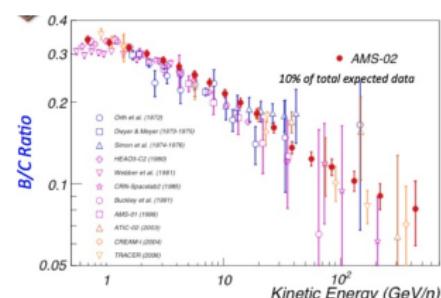


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$$Q_{e+}^{\text{sec}}(E, \vec{x}) = 4\pi \sum_{i=p,\alpha} \sum_{j=H,He} n_j \int_{E_0}^{+\infty} dE_i \phi_i(E_i, \vec{x}) \frac{d\sigma}{dE_i}(E_j \rightarrow E) \quad \begin{cases} i = \text{projectile} \\ j = \text{target} \end{cases}$$

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$(\phi_{e-} + \phi_{e+})^{\text{exp}}$  : AMS-02 data

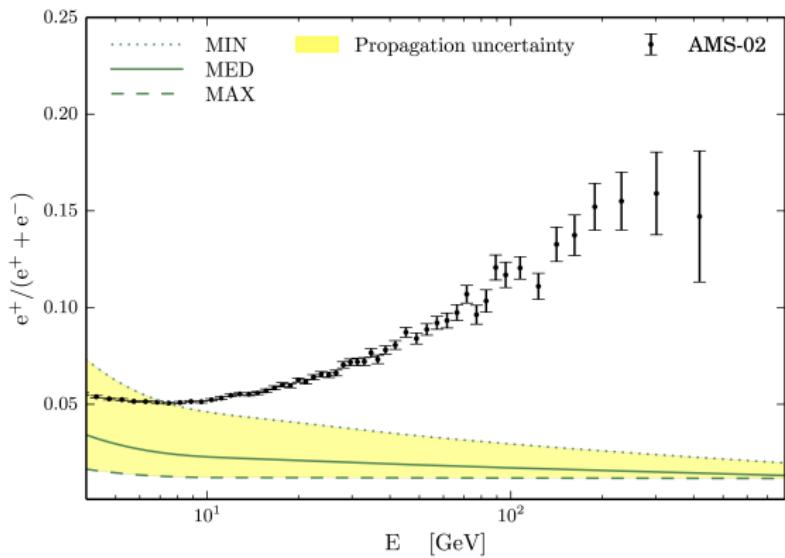
(PRL 113,221102(2014))

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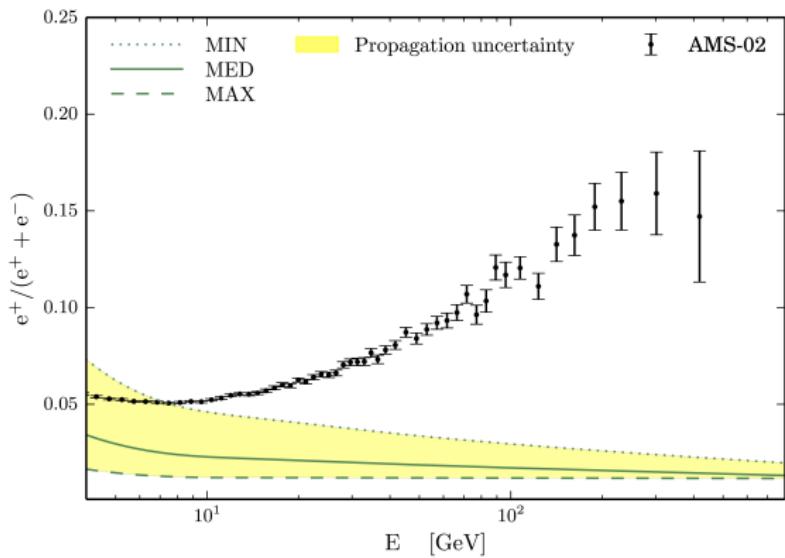


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This is the positron anomaly !

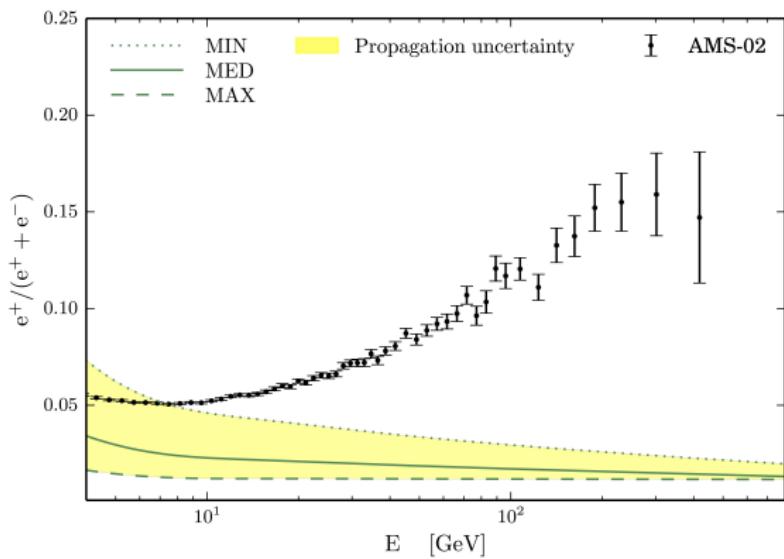
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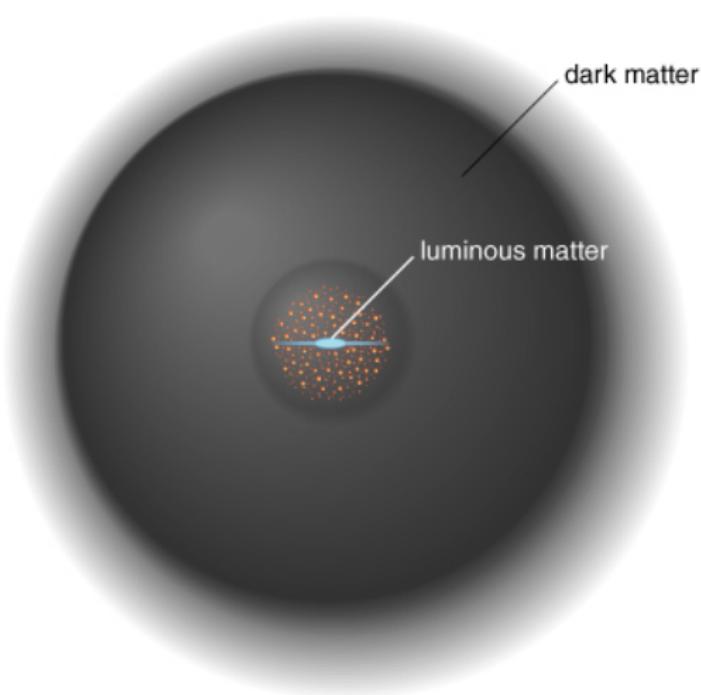
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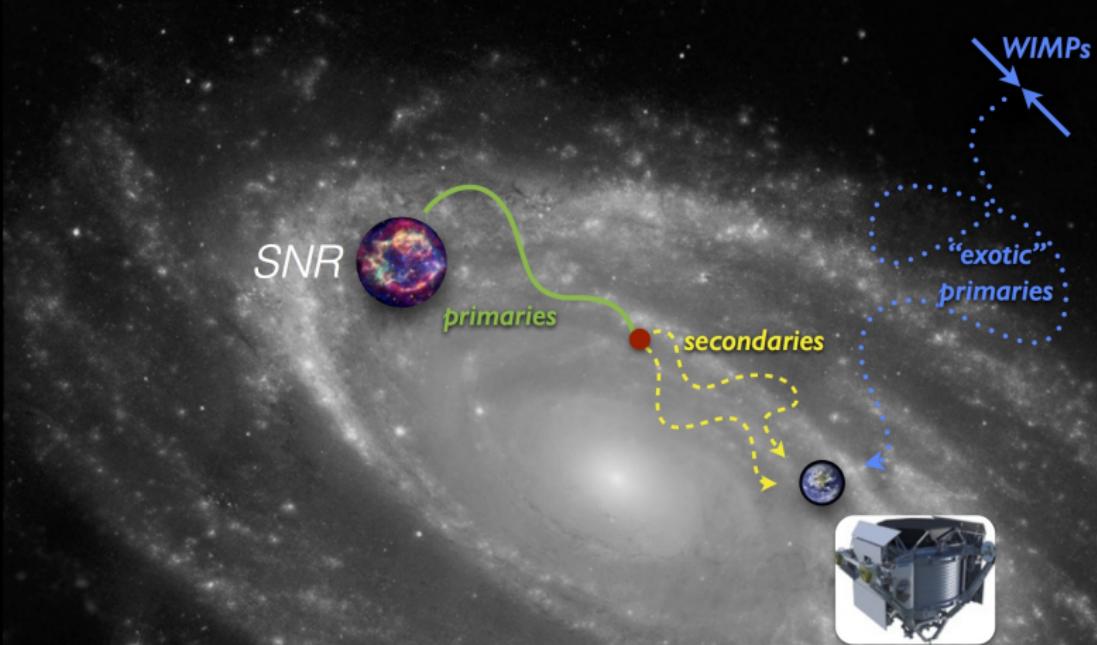
We need another component to explain the data !

## *The Dark Matter scenario*

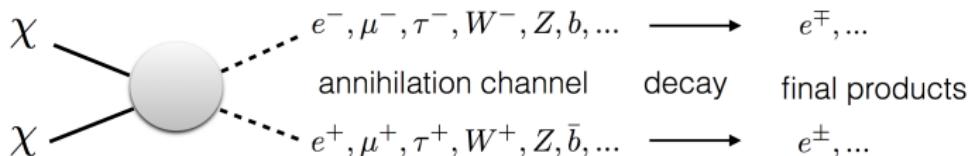


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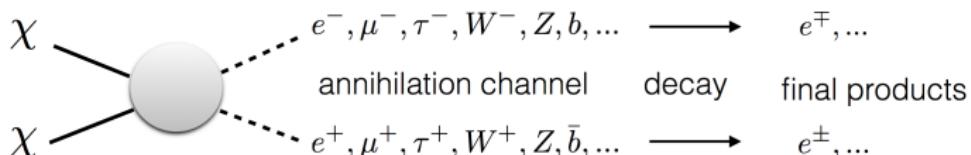


Courtesy A.Putze



### The DM source term

$$Q_{e^+}^{\text{DM}}(E, \vec{x}) = \underbrace{\left( \frac{\rho(\vec{x})}{m_\chi} \right)^2}_{\text{astrophysics}} \times \underbrace{\frac{1}{2} \sum_i \langle \sigma v \rangle_i \frac{dN(E)}{dE}}_{\text{particle physics}}$$

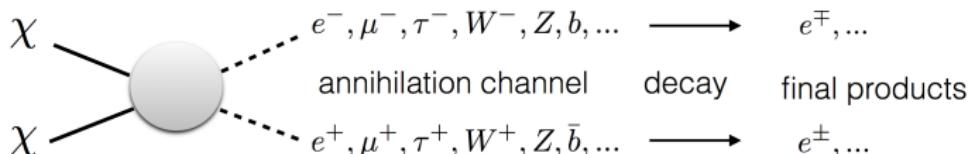


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$\rho(\vec{x})$ : DM density profile

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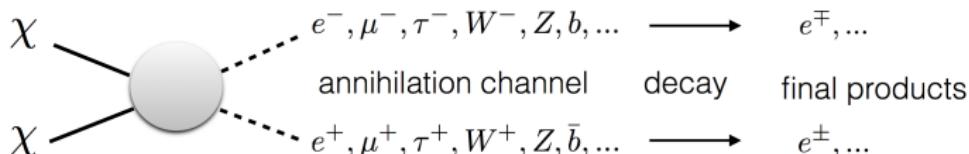
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MicrOMEGAs 3.6



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2 free parameters:

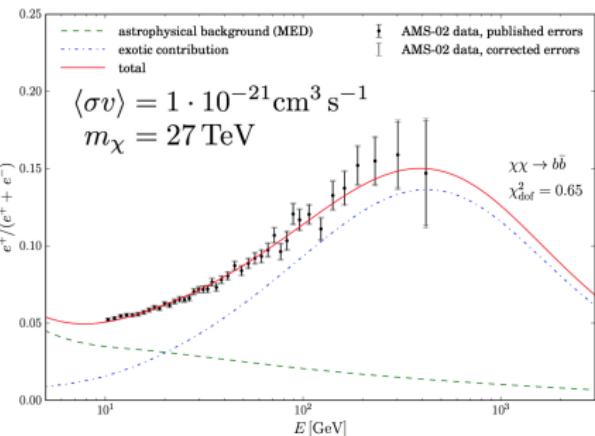
$m_\chi$ : DM mass

$\langle \sigma v \rangle_i$ : average annihilation cross-section

Scan over  $m_\chi$  and  $\langle \sigma v \rangle_i$  to fit the AMS-02 data using MINUIT C++ package.

## Single annihilation channel analysis

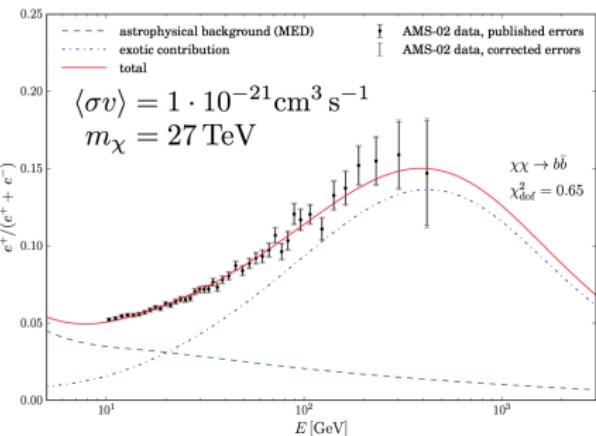
e.g.  $\chi\chi \rightarrow b\bar{b} \rightarrow e^+e^- + \dots$



Channel	$m_\chi$ [TeV]	$\langle\sigma v\rangle$ [ $\text{cm}^3 \text{ s}^{-1}$ ]	$\chi^2$	$\chi^2_{\text{dof}}$	$p$
e	$0.350 \pm 0.004$	$(2.31 \pm 0.02) \cdot 10^{-24}$	1489	37.2	0
$\mu$	$0.350 \pm 0.003$	$(3.40 \pm 0.03) \cdot 10^{-24}$	346	8.44	0
$\tau$	$0.894 \pm 0.040$	$(2.25 \pm 0.15) \cdot 10^{-23}$	93.0	2.27	$4.2 \cdot 10^{-6}$
$u$	$31.5 \pm 2.9$	$(1.43 \pm 0.20) \cdot 10^{-21}$	25.2	0.61	0.97
$b$	$27.0 \pm 2.2$	$(1.00 \pm 0.12) \cdot 10^{-21}$	26.5	0.65	0.95
$t$	$42.5 \pm 3.3$	$(1.81 \pm 0.21) \cdot 10^{-21}$	29.4	0.72	0.89
Z	$14.2 \pm 0.9$	$(6.02 \pm 0.58) \cdot 10^{-22}$	43.8	1.07	0.31
W	$12.2 \pm 0.08$	$(5.10 \pm 0.48) \cdot 10^{-22}$	41.1	1.00	0.42
H	$23.2 \pm 1.5$	$(8.17 \pm 0.77) \cdot 10^{-22}$	39.1	0.95	0.51
$\phi \rightarrow e$	$0.350 \pm 0.0008$	$(1.56 \pm 0.01) \cdot 10^{-24}$	534	13.0	0
$\phi \rightarrow \mu$	$0.590 \pm 0.022$	$(5.87 \pm 0.36) \cdot 10^{-24}$	175	4.27	0
$\phi \rightarrow \tau$	$1.76 \pm 0.08$	$(4.51 \pm 0.32) \cdot 10^{-23}$	83.5	2.04	$7.7 \cdot 10^{-5}$

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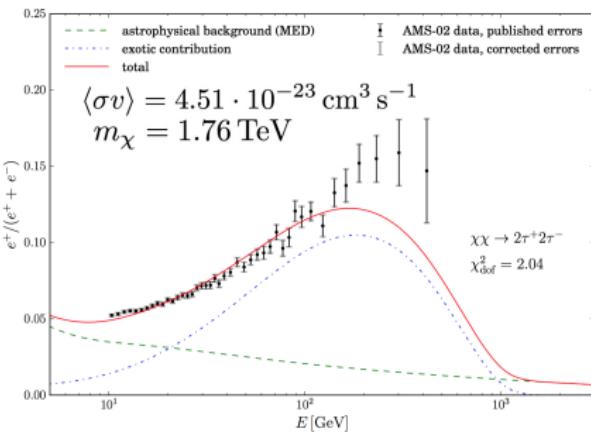


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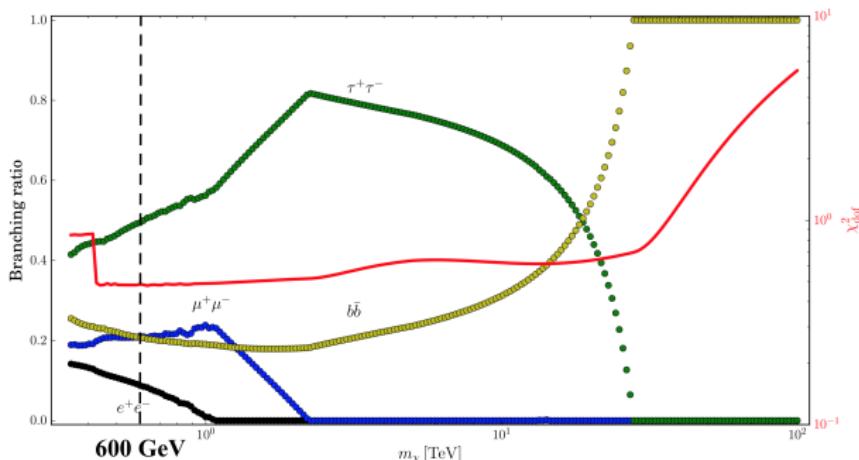
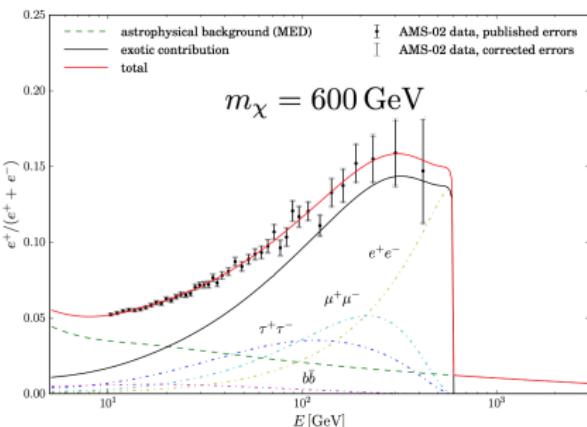
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- The agreement is excellent for quark, gauge boson and Higgs boson pairs.
- Individual annihilation channels disfavor leptons as the final state.

## Channels combination analysis

$$\chi\chi \rightarrow B_e e^+e^- + B_\mu \mu^+\mu^- + B_\tau \tau^+\tau^- + B_b b\bar{b}$$

What is the best values for the branching ratios  $B_i$ ?

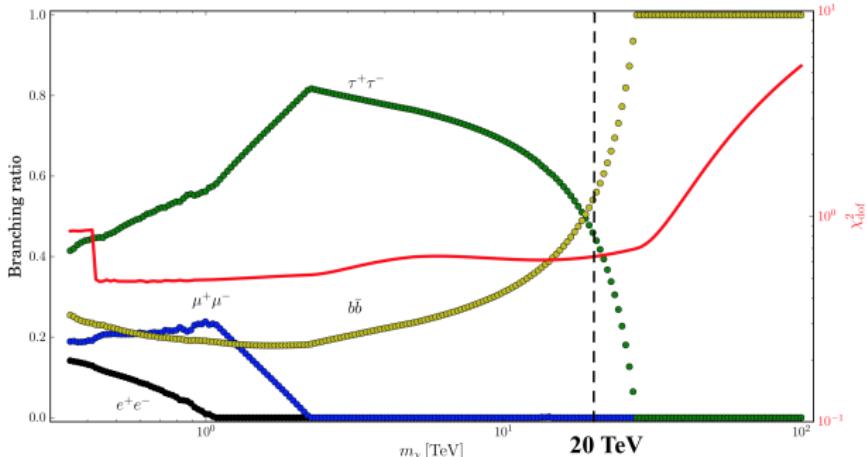
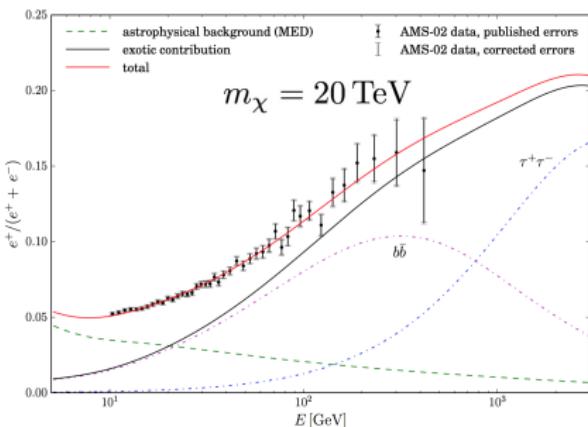


LAPTh

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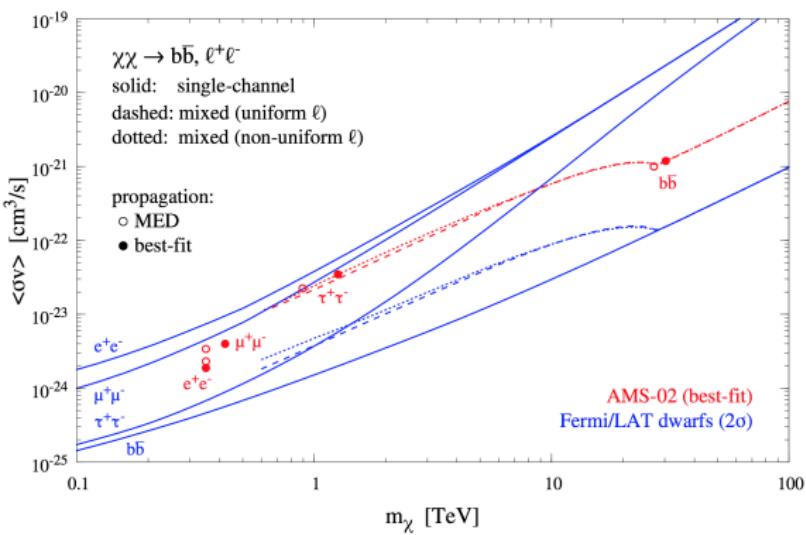
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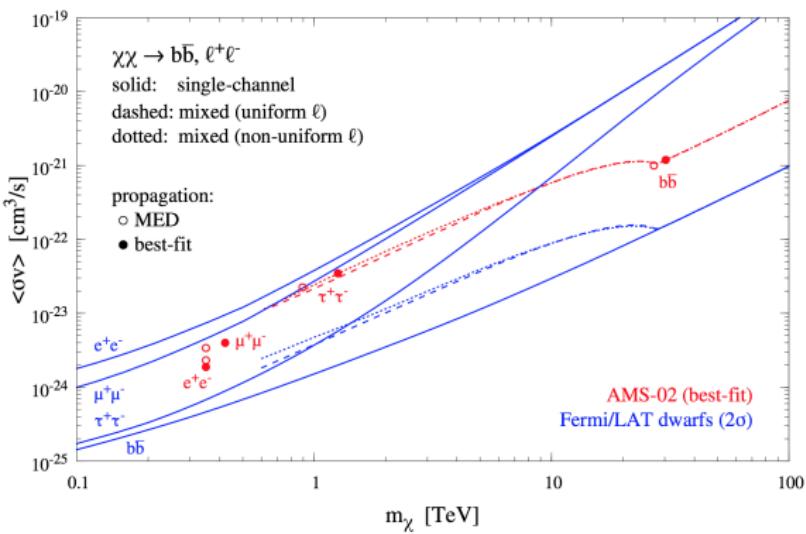
FERMI data analysis by A. Lopez *et al.*  
**arXiv:1501.01618v1**



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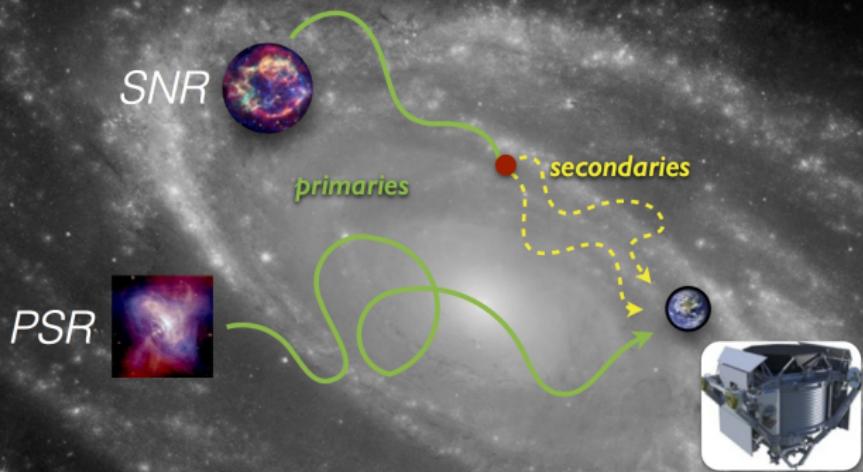
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All best fit  $\langle\sigma v\rangle$  values are excluded at  $2\sigma$  CL !

*The pulsar scenario*





Courtesy A.Putze

## The PSR source term

$$Q_{e+}^{PSR}(E, t, \vec{x}) = \delta(t - t_*)\delta(\vec{x} - \vec{x}_*)Q_0 \left(\frac{E}{E_0}\right)^{-\gamma} \exp\left(-\frac{E}{E_C}\right)$$

Total energy released by the pulsar through positrons:

$$\int_0^{+\infty} dE E Q_0 \left(\frac{E}{E_0}\right)^{-\gamma} \exp\left(-\frac{E}{E_C}\right) = f W_0$$



LAPTh

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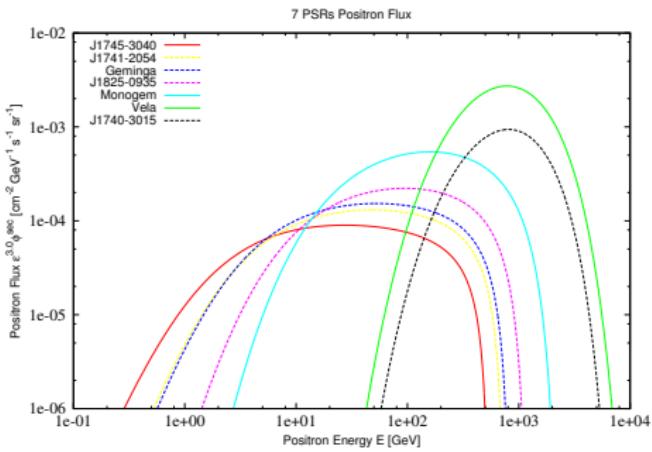
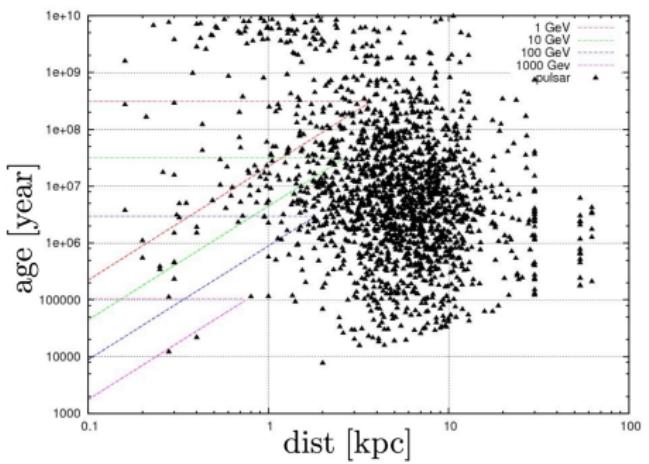
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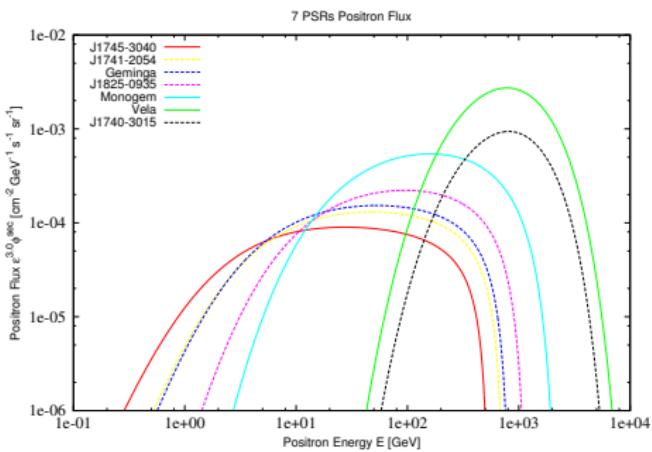
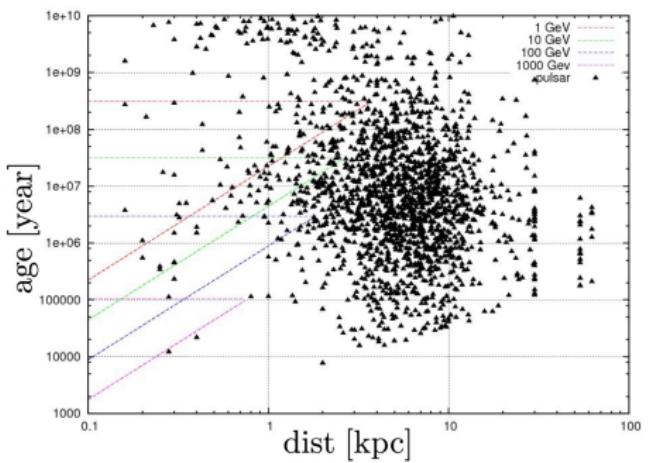
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- Fixed parameter
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## Observed PSR's from the Australian Telescope National Facility catalogue



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Only few young and nearby PSRs contribute to the positron flux for  $E \geq 10 \text{ GeV}$  !

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*Since there is only an **upper limit** on the **injection normalisation**  $fW_0$ , if the **single pulsar hypothesis** is viable, a combination of **pulsars** is capable of reproducing the experimental data.*

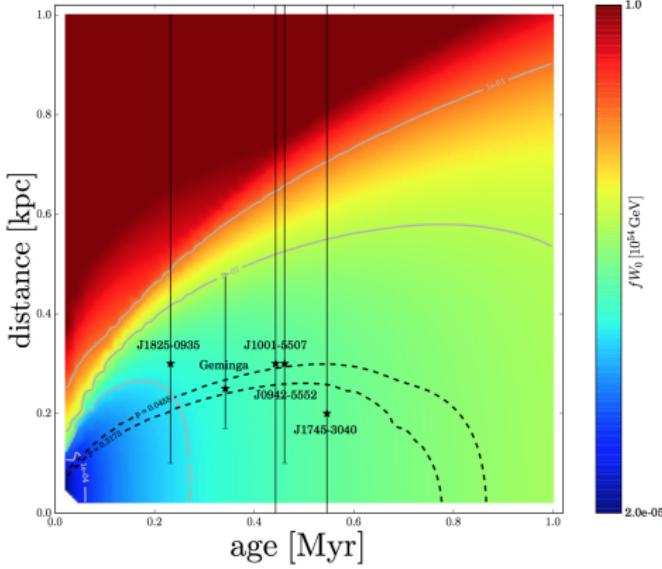
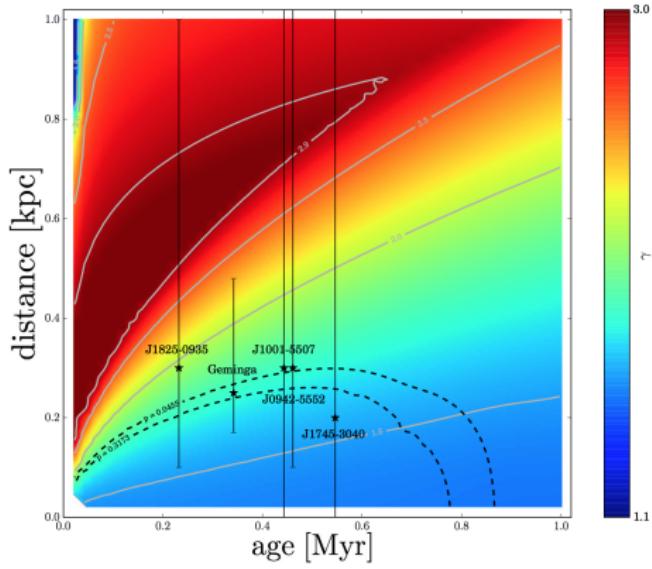
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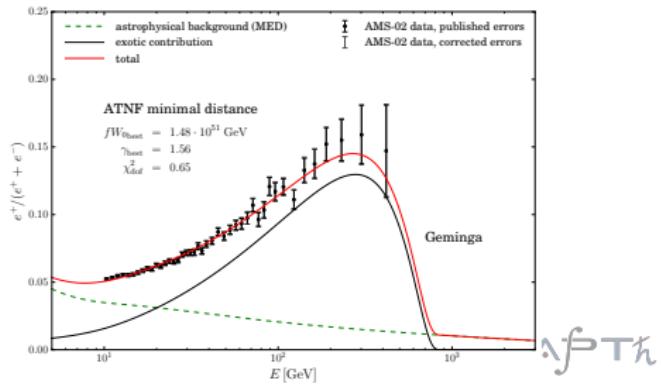
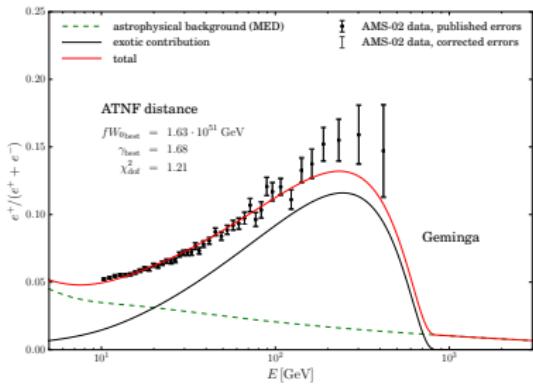
Can we explain the positron fraction with the contribution of **one single pulsar**?

**YES !**



## The 5 survivor PSR's from the ATNF catalog

Name	Age [kyr]	Distance [kpc]	$fW_0 [10^{54} \text{ GeV}]$	$\gamma$	$\chi^2$	$\chi^2_{\text{dof}}$	p
J1745-3040	546	0	$(2.95 \pm 0.07) \cdot 10^{-3}$	$1.45 \pm 0.02$	23.4	0.57	0.99
		<b>0.20</b>	$(3.03 \pm 0.06) \cdot 10^{-3}$	<b><math>1.54 \pm 0.02</math></b>	<b>33.6</b>	<b>0.82</b>	<b>0.79</b>
		1.3	1	2.54	9902	241	0
J0633+1746 <i>Geminga</i>	342	0.17	$(1.48 \pm 0.03) \cdot 10^{-3}$	$1.56 \pm 0.02$	26.8	0.65	0.96
		<b>0.25</b>	$(1.63 \pm 0.02) \cdot 10^{-3}$	<b><math>1.68 \pm 0.02</math></b>	<b>49.6</b>	<b>1.21</b>	<b>0.17</b>
		0.48	$(1.01 \pm 0.06) \cdot 10^{-2}$	2.29 $\pm$ 0.02	332	8.10	0
J0942-5552	461	0.10	$(2.28 \pm 0.05) \cdot 10^{-3}$	$1.48 \pm 0.02$	21.7	0.53	0.99
		<b>0.30</b>	$(2.61 \pm 0.04) \cdot 10^{-3}$	<b><math>1.69 \pm 0.02</math></b>	<b>61.0</b>	<b>1.49</b>	<b>0.02</b>
		1.1	1	2.65	7747	189	0
J1001-5507	443	0	$(2.13 \pm 0.05) \cdot 10^{-3}$	$1.46 \pm 0.02$	19.8	0.48	0.99
		<b>0.30</b>	$(2.49 \pm 0.03) \cdot 10^{-3}$	<b><math>1.70 \pm 0.02</math></b>	<b>62.4</b>	<b>1.52</b>	<b>0.02</b>
		1.4	1	2.46	13202	322	0
J1825-0935	232	0.1	$(0.80 \pm 0.02) \cdot 10^{-3}$	$1.52 \pm 0.02$	21.0	0.51	0.99
		<b>0.30</b>	$(1.45 \pm 0.03) \cdot 10^{-3}$	<b><math>1.94 \pm 0.02</math></b>	<b>126</b>	<b>3.07</b>	<b>0</b>
		1.0	1	2.64	12776	312	0



## Conclusion and prospects

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The single PSR scenario provides good fits to AMS-02 PF data for 5 observed PSR's.

## Conclusion and prospects

### Outlook

- Constrain the propagation parameters (see Y. Genolini posters)
  - B/C ratio analysis as soon as the AMS-02 collaboration will release data
  - Radioactive nuclei analysis
- Refine energy losses processes:
  - Better estimation of the ISRF (IC scattering)
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*Thank you for your attention !*