

A new look at the cosmic ray positron fraction

Mathieu Boudaud

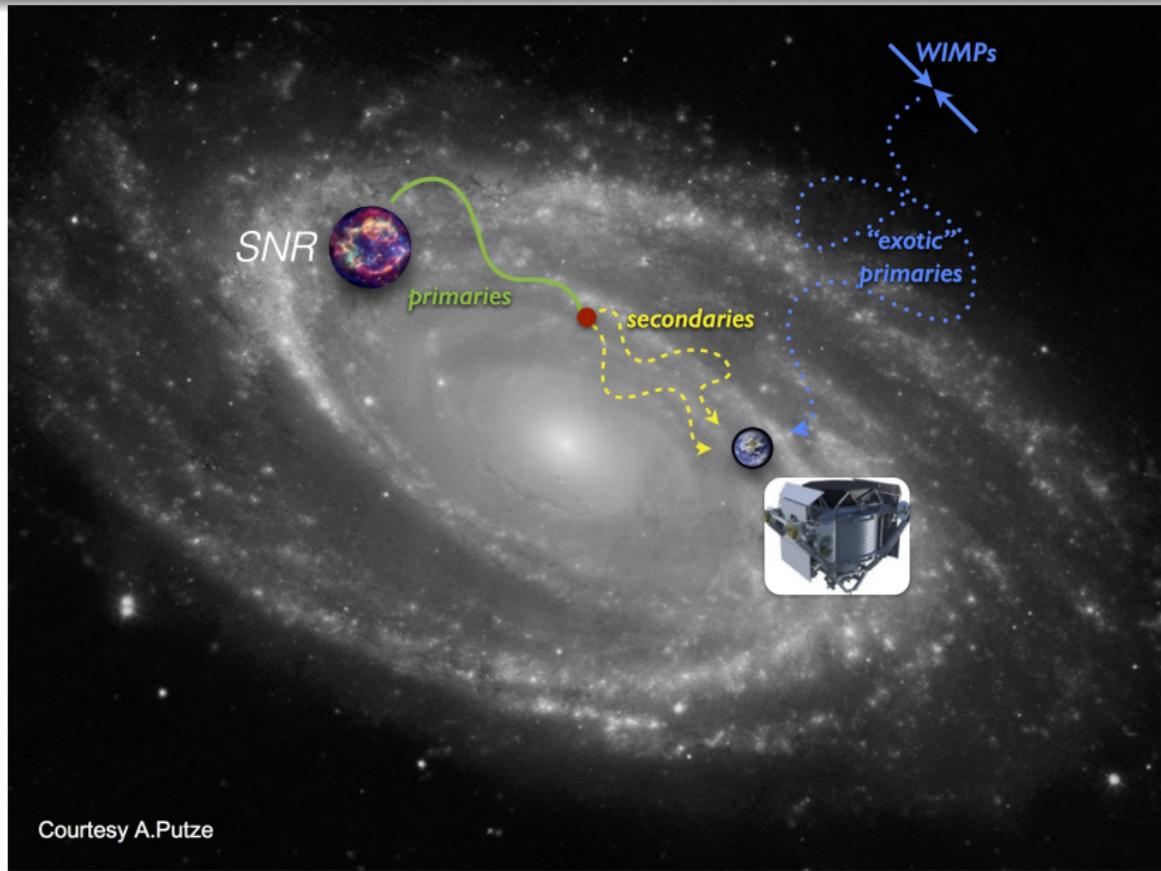
LAPTh

Rencontre de Physique des Particules
Institut Henri Poincaré
16 Janvier 2015

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

arXiv :1410.3799

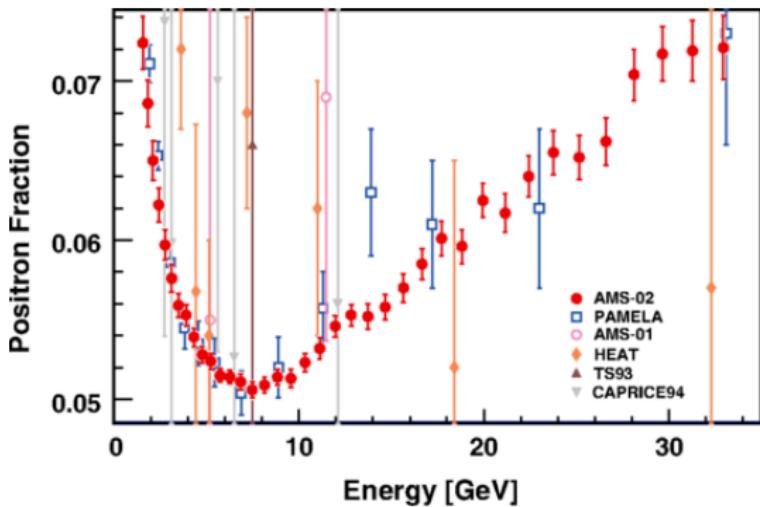




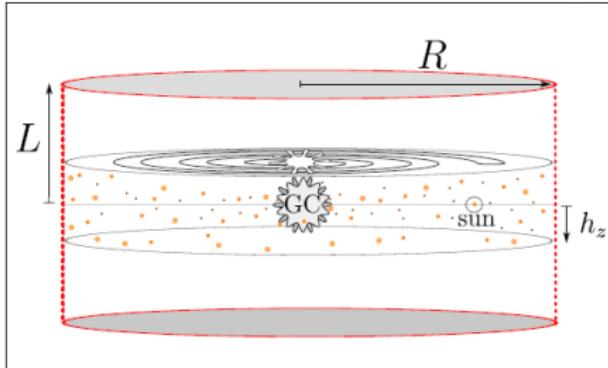
Courtesy A.Putze



$$P.F = \frac{\phi_{e^+}}{\phi_{e^-} + \phi_{e^+}}$$



Lineros' PhD thesis (2008)



$$\begin{aligned} R &= 20 \text{kpc} \\ h_z &= 100 \text{pc} \\ 1 < L < 15 \text{kpc} \\ R_\odot &= 8.5 \text{kpc} \end{aligned}$$

Positron transport equation

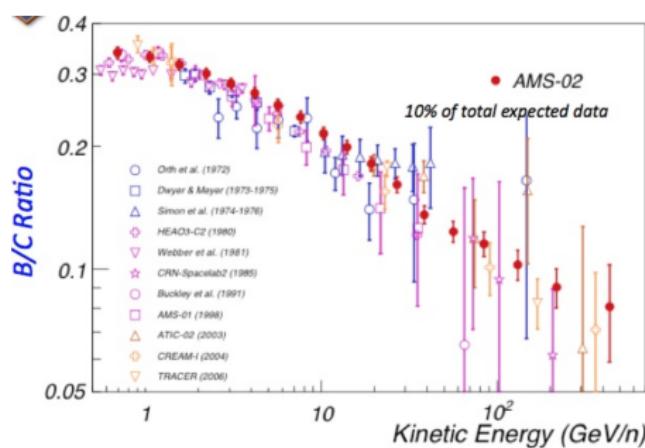
$$\psi(E, t, \mathbf{x}) = \frac{d^4 N(E, t, \mathbf{x})}{d^3 \mathbf{x} dE}$$

$$\partial_t \psi - K(E) \Delta \psi - \partial_E [b(E) \psi] = q(E, t, \mathbf{x})$$

$$K(E) = K_0 \beta \left(\frac{R}{R_0} \right)^\delta$$

Propagation parameters constrained by the B/C ratio

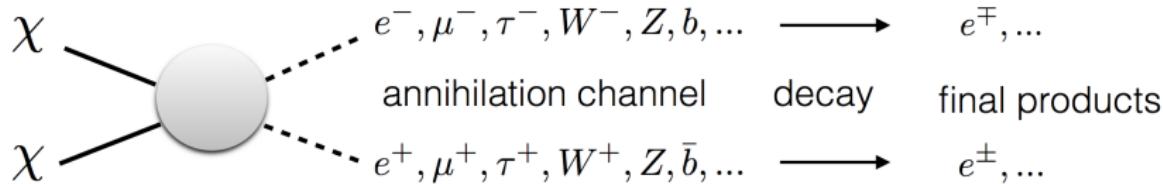
Case	δ	K_0 [kpc 2 /Myr]	L [kpc]	V_C [km/s]	V_a [km/s]
MIN	0.85	0.0016	1	13.5	22.4
MED	0.70	0.0112	4	12	52.9
MAX	0.46	0.0765	15	5	117.6



The next B/C results from AMS-02 will considerably reduce the parameter space !

DM source term

$$q_{DM}(E, \mathbf{x}) = \frac{1}{2} \langle \sigma v \rangle \left(\frac{\rho(\mathbf{x})}{m_\chi} \right)^2 g(E)$$



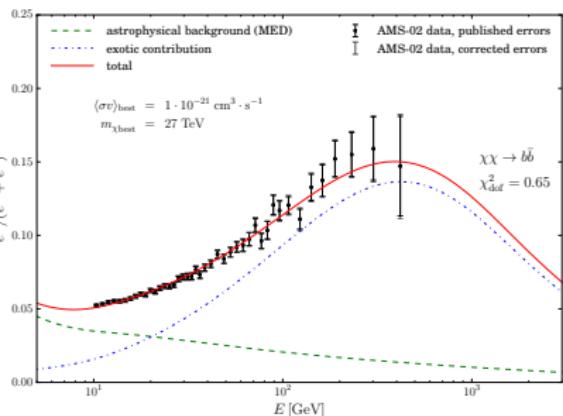
$\rho(\mathbf{x})$: DM density (**NFW** profile)

$g(E) = \frac{dN(E)}{dE}$ (**MicrOMEGAs**)



Single annihilation channel

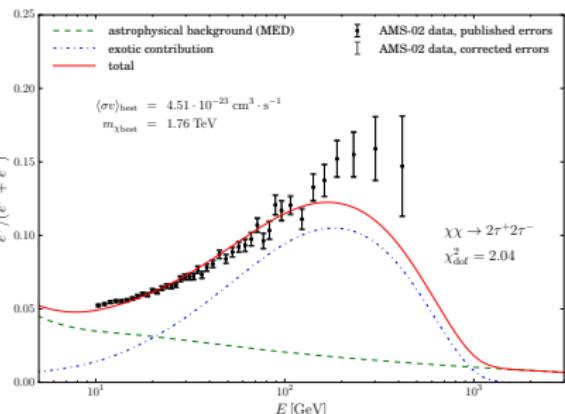
Channel	m_χ [TeV]	$\langle\sigma v\rangle$ [$\text{cm}^3 \text{s}^{-1}$]	χ^2	χ^2_{dof}	p
e	0.350 ± 0.004	$(2.31 \pm 0.02) \cdot 10^{-24}$	1489	37.2	0
μ	0.350 ± 0.003	$(3.40 \pm 0.03) \cdot 10^{-24}$	346	8.44	0
τ	0.894 ± 0.040	$(2.25 \pm 0.15) \cdot 10^{-23}$	93.0	2.27	$4.2 \cdot 10^{-6}$
u	31.5 ± 2.9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



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

Single annihilation channel

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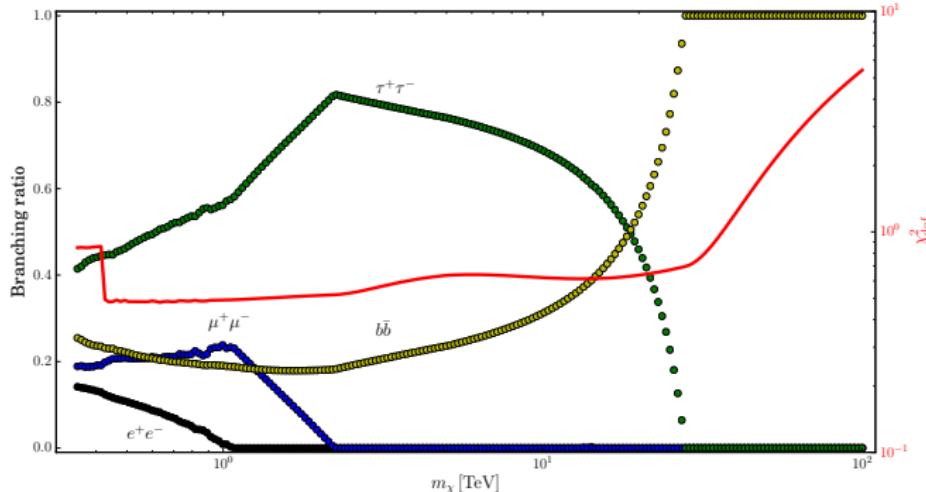
- The agreement is excellent for quark, gauge boson and Higgs boson pairs.
- Individual annihilation channels disfavors leptons as the final state.

Combination of channels

Leptons + quark channels

$$\chi\chi \rightarrow B(e)e^+e^- + B(\mu)\mu^+\mu^- + B(\tau)\tau^+\tau^- + B(b)\bar{b}b$$

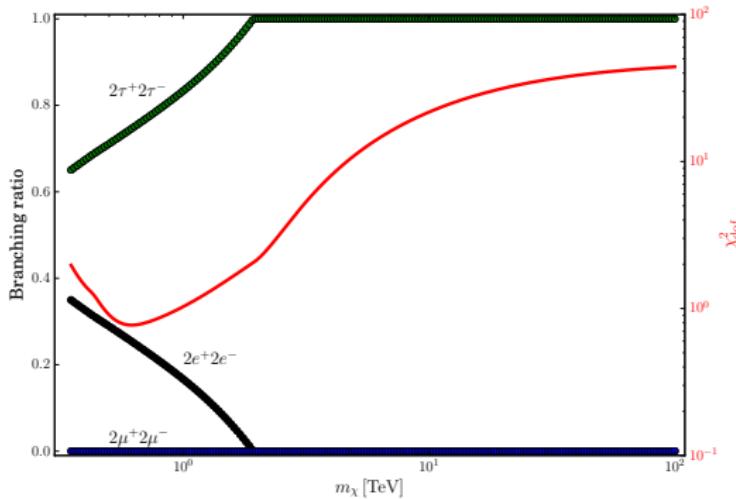
What is the best values for the branching ratios ?



4-leptons channels

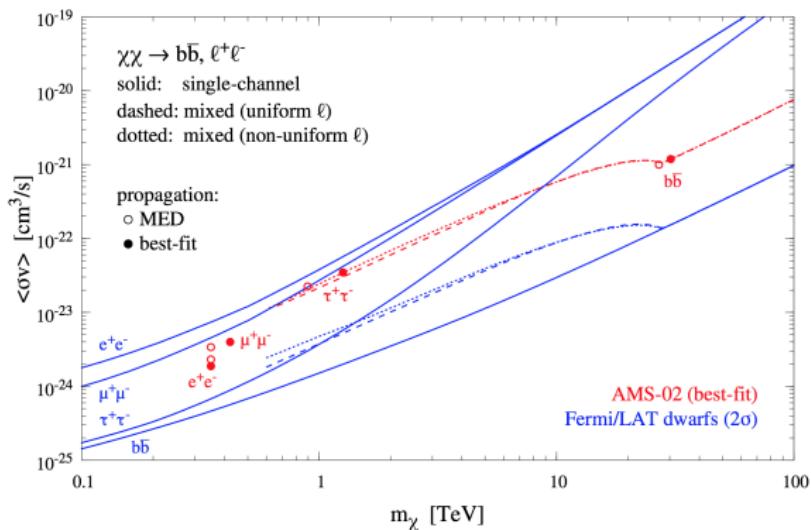
$$\chi\chi \rightarrow \phi\phi \rightarrow 2B(e)e^+e^- + 2B(\mu)\mu^+\mu^- + 2B(\tau)\tau^+\tau^-$$

What is the best values for the branching ratios ?



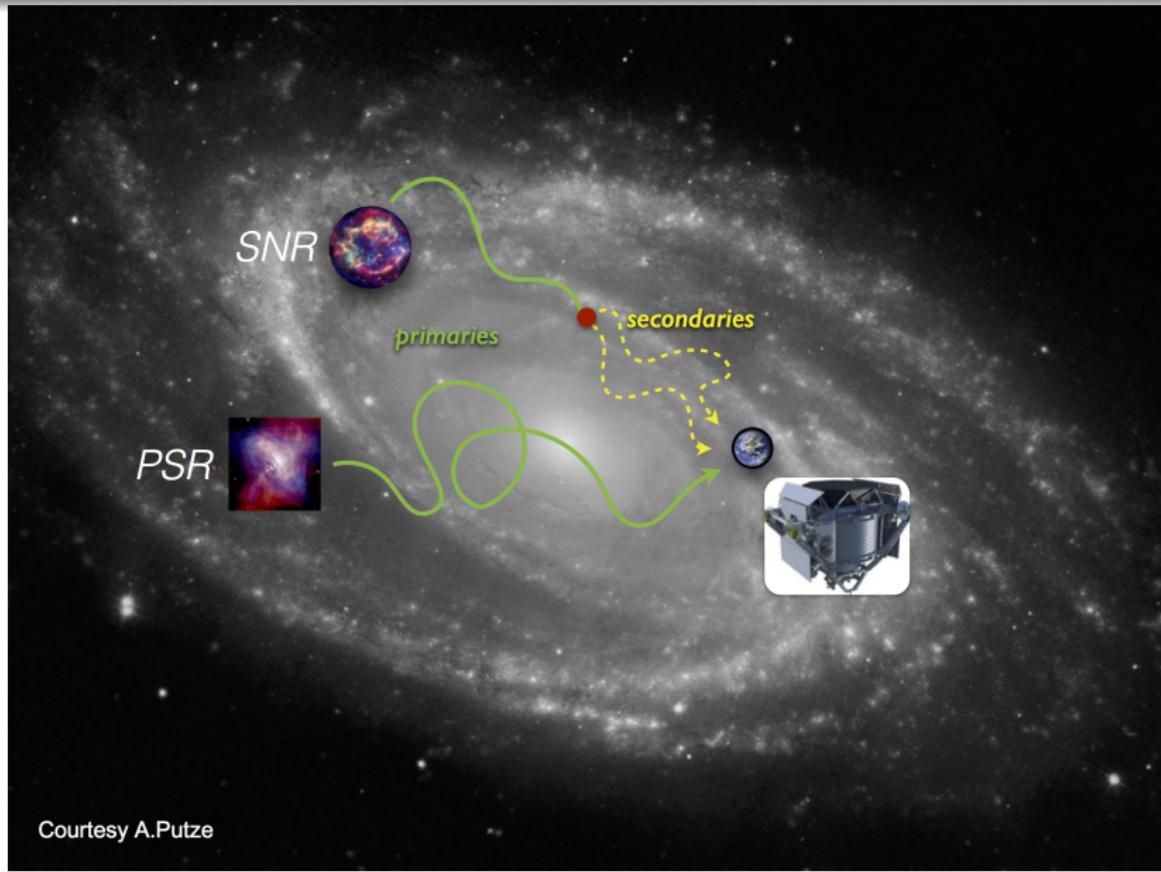
Constraints on dark matter annihilating cross-section $\langle\sigma v\rangle$

- Gamma-ray (Fermi/LAT, VERITAS, MAGIC, HESS)
- CMB (WMAP, PLANCK)
- Antiprotons (PAMELA)



Dwarf galaxies Fermi/LAT constraints : arXiv :1501.01618v1

Almost all best fit $\langle\sigma v\rangle$ values are excluded (2 σ CL)!



Courtesy A.Putze

PSR source term

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

$$\int_0^{+\infty} dE E Q_0 \left(\frac{E}{E_0}\right)^{-\gamma} \exp\left(-\frac{E}{E_C}\right) = fW_0$$

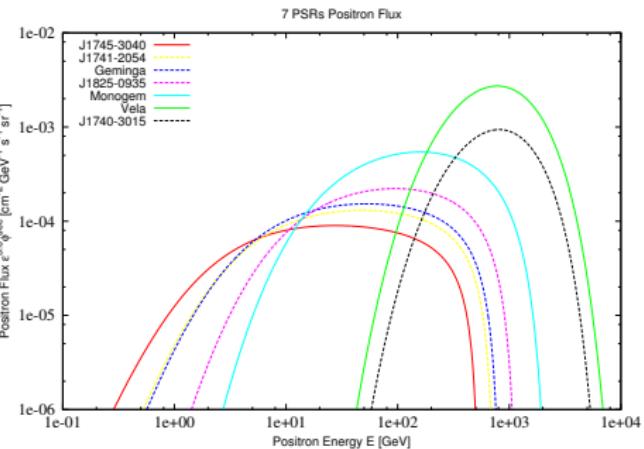
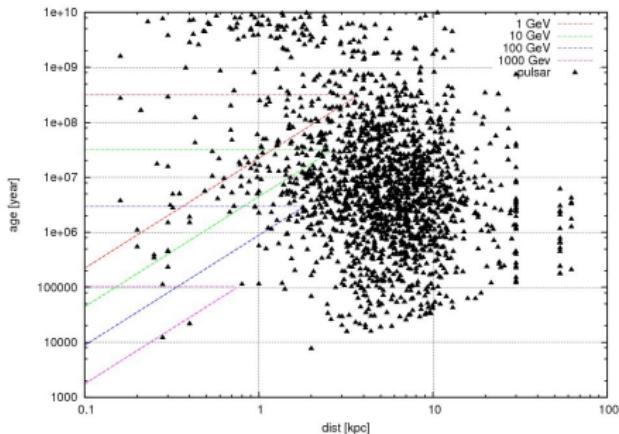


$E_C \sim 1 \text{ TeV}$

$1.5 < \gamma < 2.5$

$fW_0 < 10^{54} [\text{GeV}]$

PSRs from the ATNF catalog

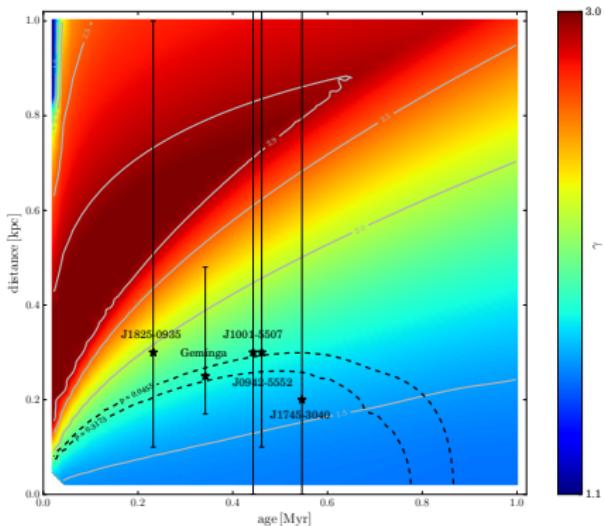


Only few young and nearby PSRs contribute to the positron flux for $E > 10\text{GeV}$.

Single PSR hypothesis

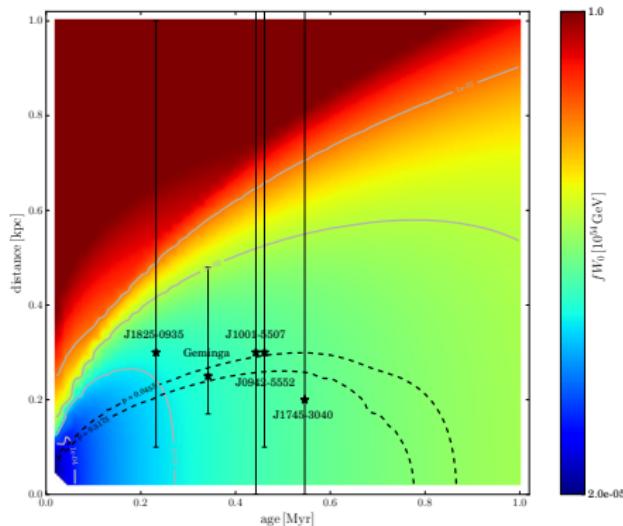
Can we explain the positron fraction with the contribution of one single pulsar ?

YES !



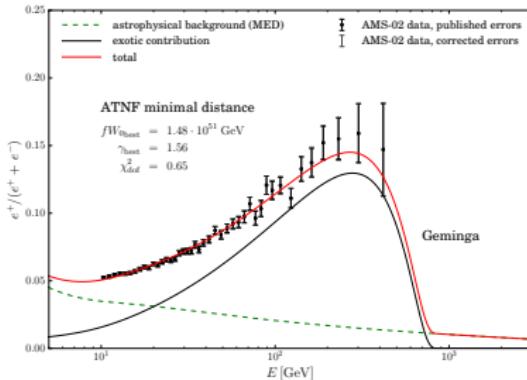
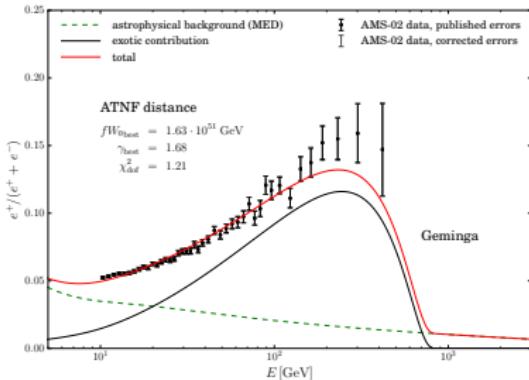
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Five survivors from the ATNF catalog

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



Conclusions

The DM scenario cannot both provide a good fit to AMS-02 and avoid the 2σ constraints from Fermi/LAT.

The single PSR scenario provides good fits to AMS-02 using five PSR from the ATNF catalog.

Outlook

- Use the released positron flux (**PRL 113, 121102 (2014)**).
- Use more realistic energy losses.
- Assess the systematics coming from :
 - propagation parameters
 - energy losses
 - spallation cross sections

Thank you for your attention !

Simplification for high energy positrons

$E > 10\text{ GeV}$

$$\partial_t \psi + \nabla [V_E(z)\bar{\psi} - K(E)\nabla\psi] + \partial_E [b(E)\psi + K_{EE}\partial_E\bar{\psi}] = q(E, t, \mathbf{x})$$

$$\partial_t \psi - K(E)\Delta\psi - \partial_E [b(E)\psi] = q(E, t, \mathbf{x})$$

Spatial diffusion

$$K(E) = K_0 \beta \left(\frac{R}{R_0} \right)^\delta$$

Energy losses

$$b(E) = -\langle \frac{dE}{dt} \rangle$$

Simplification for high energy positrons

$E > 10 \text{ GeV}$

$\tau_D(E) \ll \tau_C(E)$ and $\tau_I(E) \ll \tau_{DR}(E)$

$$\partial_t \psi(E, t, \mathbf{x}) - K(E) \Delta \psi(E, t, \mathbf{x}) - \partial_E [b(E) \psi(E, t, \mathbf{x})] = q(E, t, \mathbf{x})$$

Boundary conditions

$$\psi(r = R, z) = 0 \quad \psi(r, z = L) = 0$$

Positron horizon sphere radius

$$\lambda^2(E, E_S) = -4 \int_{ES}^E dE' \frac{K(E')}{b(E')}$$

Green functions

Dynamical solution :

$$\psi(E, t, \mathbf{x}) = \int_0^{+\infty} dt_S \int_E^{+\infty} dE_S \int_{DH} d^3\mathbf{x}_S G_t(E, t, \mathbf{x} \leftarrow E_S, t_S, \mathbf{x}_S) q(E_S, t_S, \mathbf{x}_S)$$

Stationary solution :

$$\psi(E, \mathbf{x}) = \int_E^{+\infty} dE_S \int_{DH} d^3\mathbf{x}_S G(E, \mathbf{x} \leftarrow E_S, \mathbf{x}_S) q(E_S, \mathbf{x}_S)$$

$$G_t(E, t, \mathbf{x} \leftarrow E_S, t_S, \mathbf{x}_S) = \delta(E_S - E_*) b(E_*) G(E, \mathbf{x} \leftarrow E_S, \mathbf{x}_S)$$

$$G(E, \mathbf{x} \leftarrow E_S, \mathbf{x}_S) = \frac{1}{b(E)\pi\lambda^2} \exp\left[-\frac{r^2}{\lambda^2}\right] \tilde{V}(E, z \leftarrow E_S, z_S)$$

$$r^2 = (x - x_s)^2 + (y - y_s)^2$$

Bessel expansions

Stationary solution :

$$\psi(E, \mathbf{x}) = \sum_{i=1}^{+\infty} \sum_{n=1}^{+\infty} J_0\left(\frac{\alpha_i r}{R}\right) \varphi_n(z) P_{i,n}(E)$$

$$P_{i,n}(E) = \frac{E_0 \tau_E}{E^2} \int_E^{+\infty} dE_S Q_{i,n}(E_S) \exp[-\tilde{C}_{i,n}(\lambda^2)]$$

$$\tilde{C}_{i,n}(\lambda^2) = \left[\left(\frac{n\pi}{2L} \right)^2 + \left(\frac{\alpha_i}{R} \right)^2 \right] \frac{\lambda^2}{4}$$

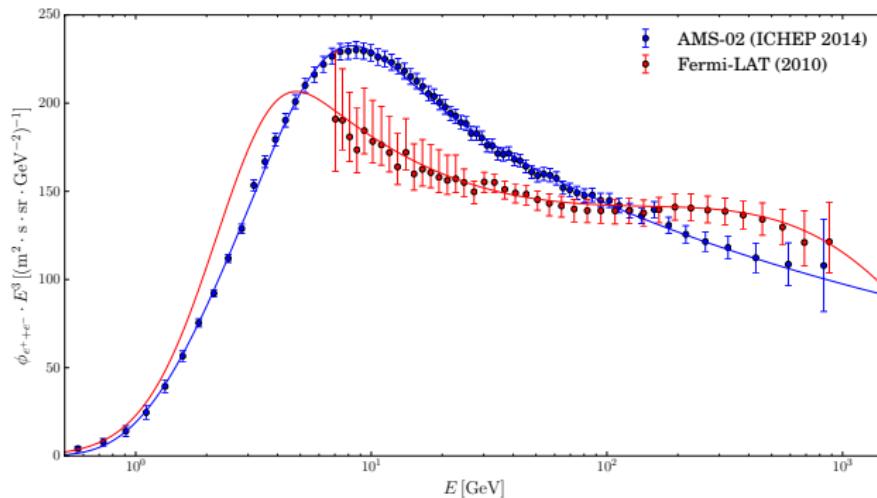
$$P.F = \frac{\phi_{e^+}^{th}}{[\phi_{e^-} + \phi_{e^+}]^{exp}}$$

$\phi_{e^+}^{th}$

Given by the Green functions and Bessel expansion methods.

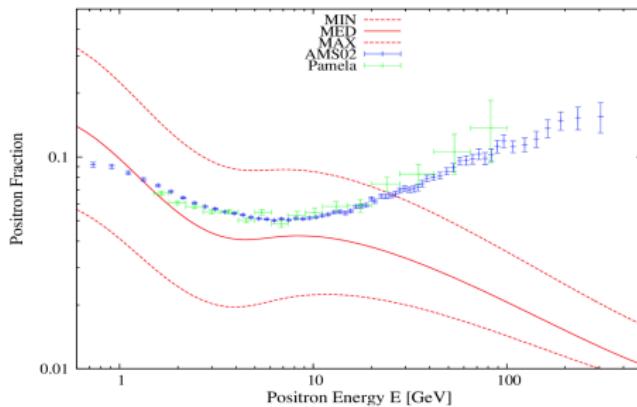
$[\phi_{e^-} + \phi_{e^+}]^{exp}$

Borrowed from available measurements.



Secondary positrons from spallation

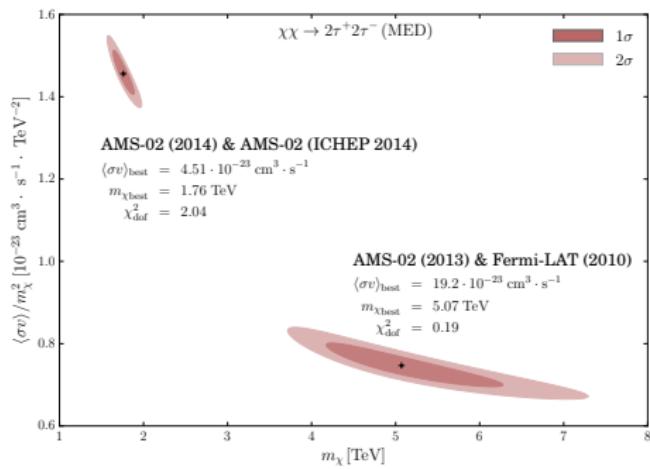
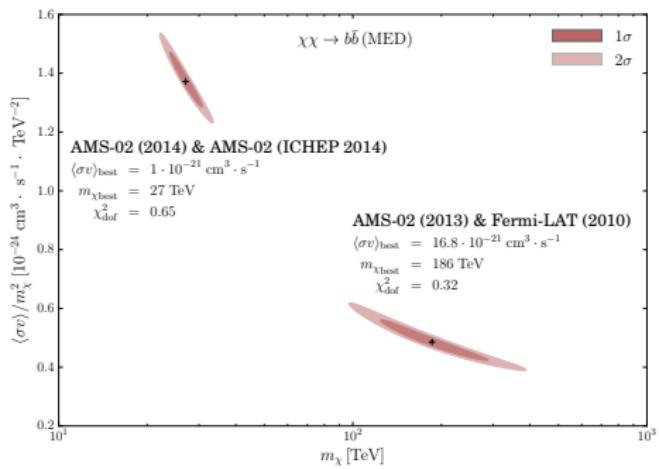
$$q_{e+}^{sec}(E, \mathbf{x}) = 4\pi \sum_{proj=p,\alpha} \sum_{target=H,He} n_{targ} \int_{E_0}^{+\infty} dE_{proj} \phi_{proj}(E_{proj} \mathbf{x}) \frac{d\sigma}{dE_{proj}} (E_{proj} \rightarrow E)$$



We need a primary component to explain the positron fraction at HE!

Dependance on the lepton flux data

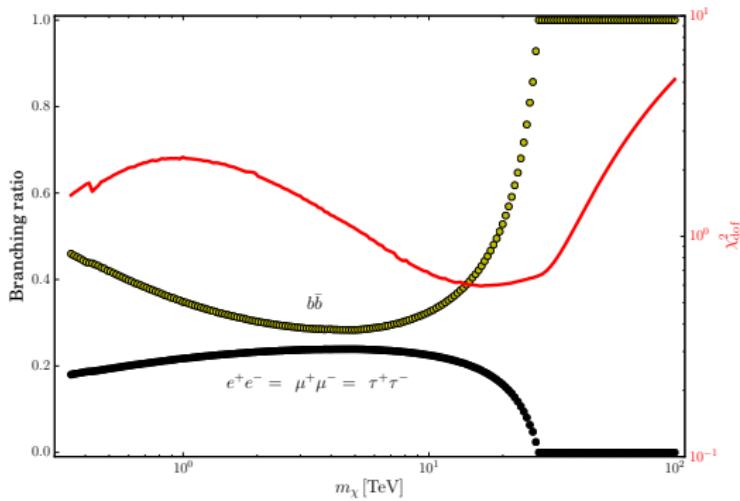
Taking into account the new results from AMS-02 for the lepton flux change radically the results of the analysis !



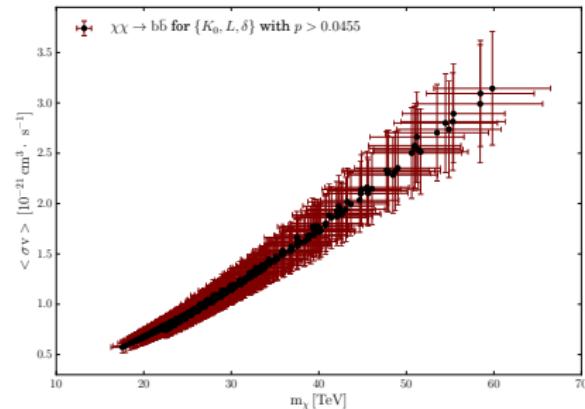
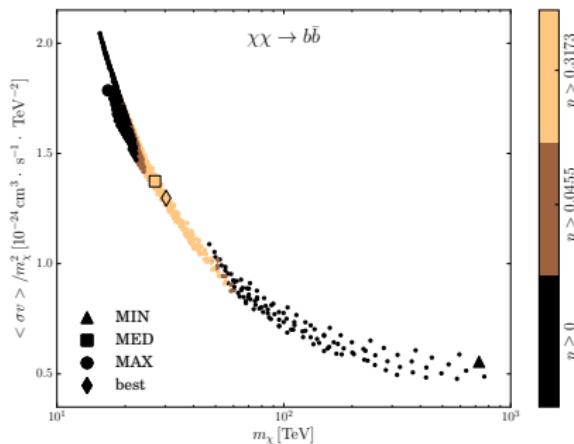
UED Dark Matter

$$\chi\chi \rightarrow B(I) [e^+ e^- + \mu^+ \mu^- + \tau^+ \tau^-] + B(b)b\bar{b}$$

What is the best values for the branching ratios ?



Propagation uncertainties

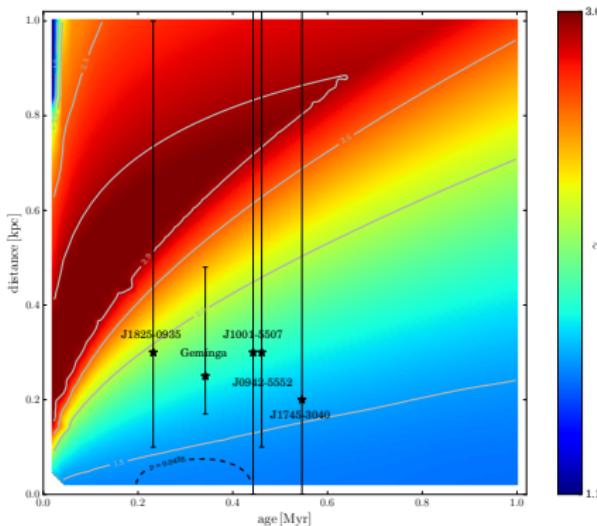


Systematic uncertainties from the propagation parameters is much larger than statistical uncertainties from AMS-02 results !

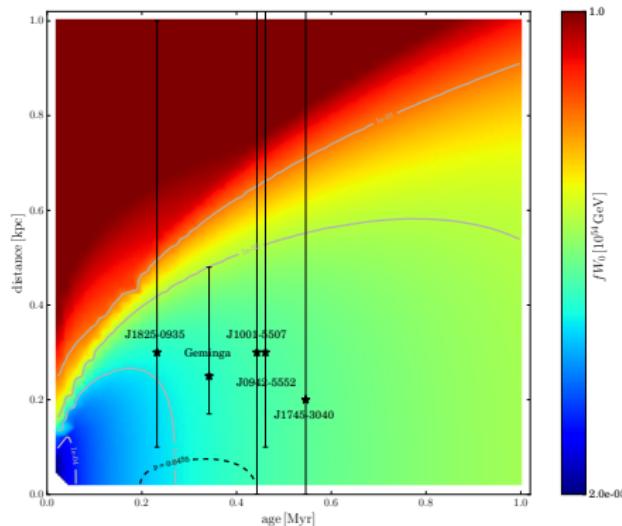
AMS-02 : 10 years of data

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

NO !

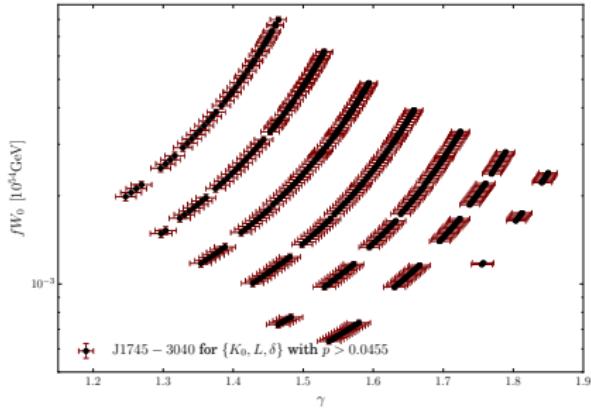
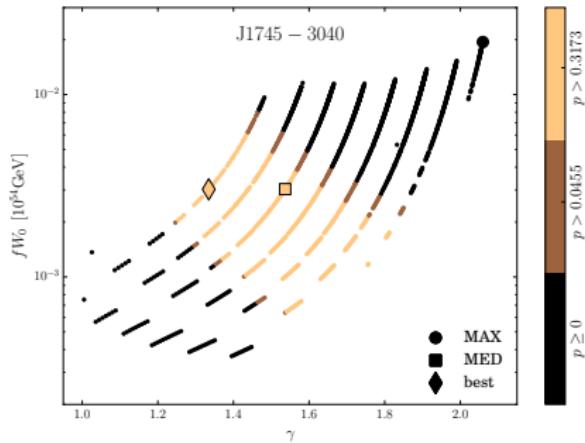


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Propagation uncertainties



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