Cosmic ray positrons and antiprotons: implications for Dark Matter

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LAPTh - Annecy, France

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Geneva, Switzerland

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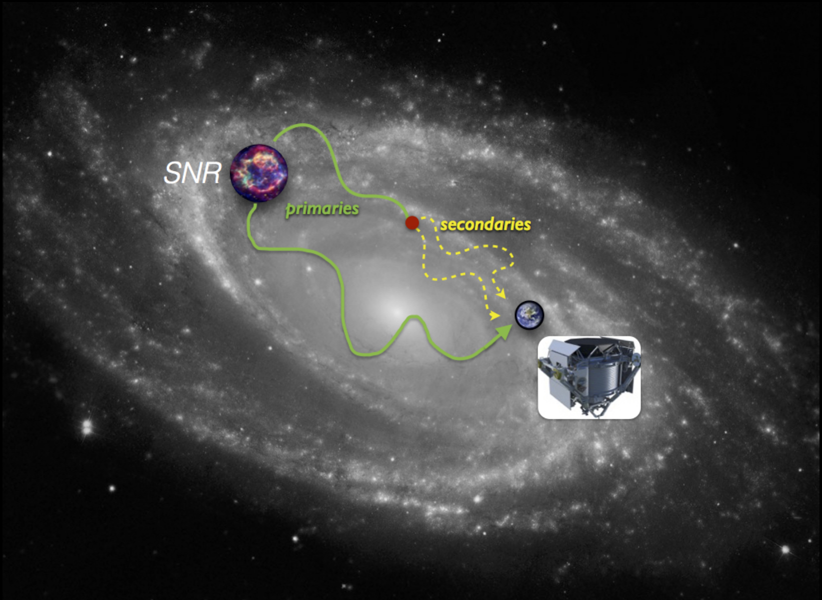
Based on:

A&A 575 (2015) A67
JCAP 1505 (2015) 013
JCAP 1509 (2015) 023

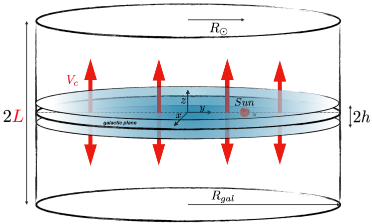
Contents

Propagation of cosmic rays in the Galaxy



Courtesy A. Putze

Two-zone model and semi-analytic method



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

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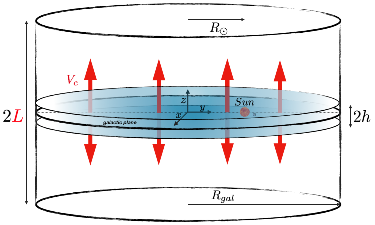

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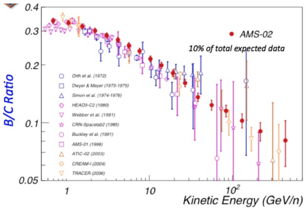

Maurin et al. (2001)
Donato et al. (2003)
$\Rightarrow$

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

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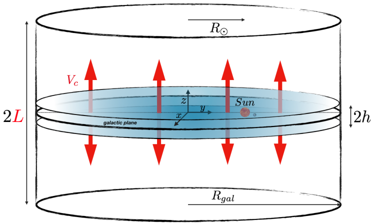

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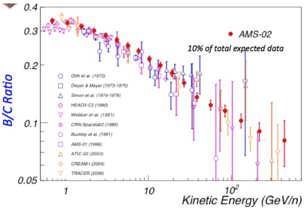

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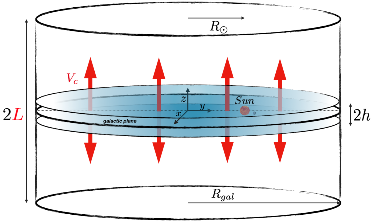

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The transport equation can be solved using Bessel expansions or Green functions.

Cosmic ray positrons

Cosmic **R**ay **A**lpine **C**ollaboration
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 Collaboration - PRL 113,121101(2014)

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

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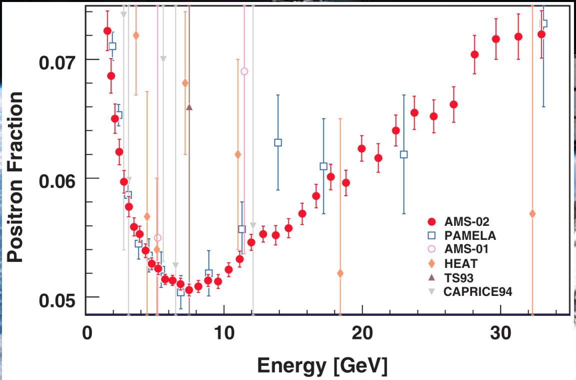
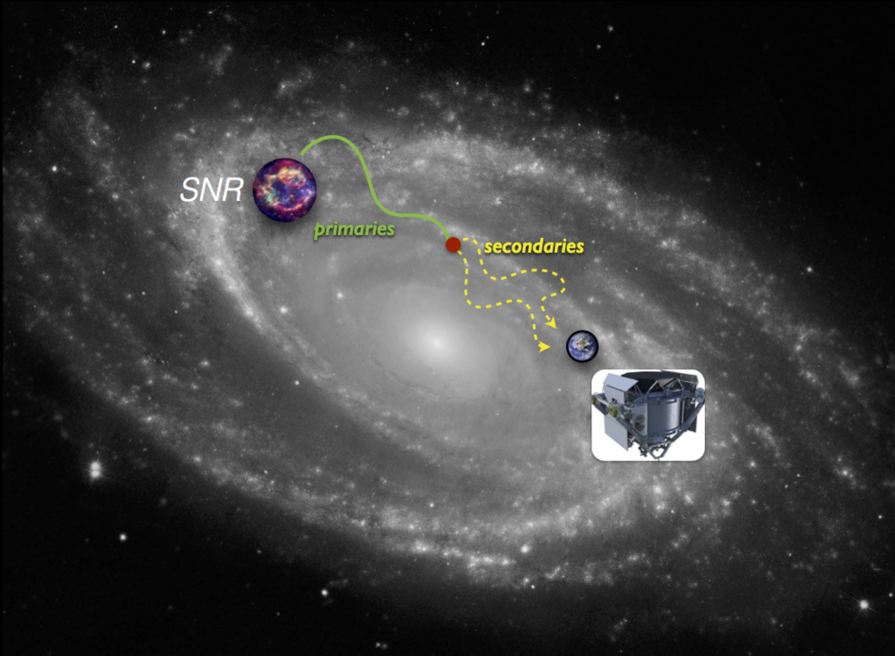


The data confirm the '*positron anomaly*'.



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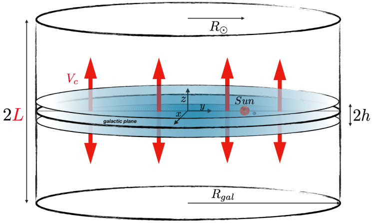
HE positrons $E_{e^+} \geq 10\text{GeV}$



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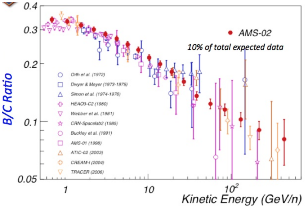

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(PRL 113,221102(2014))

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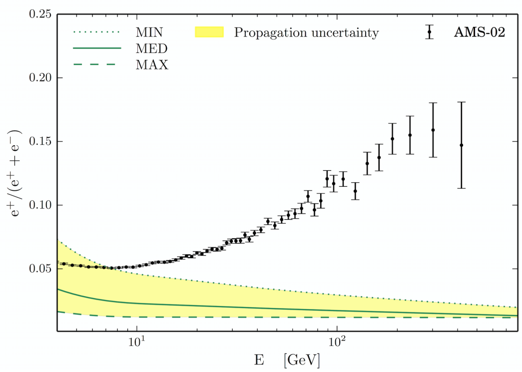

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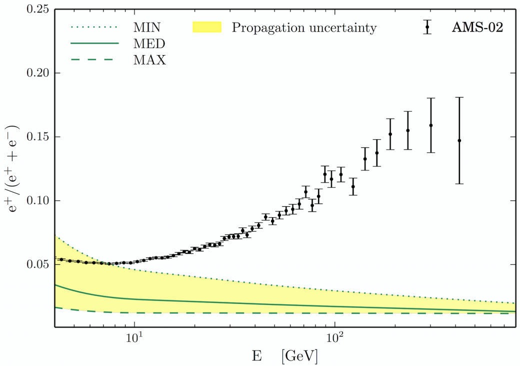

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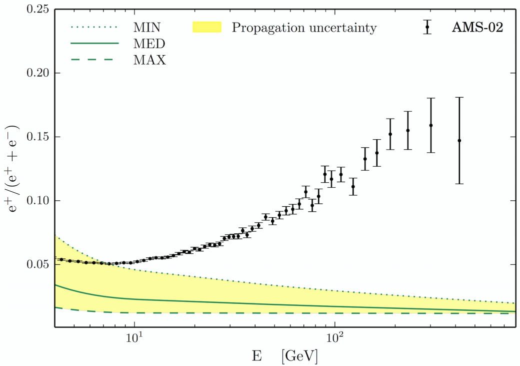
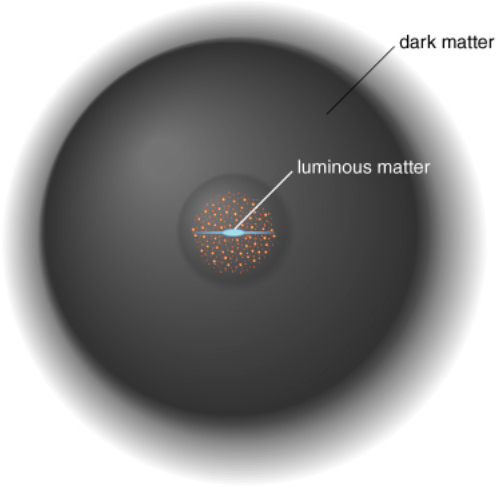
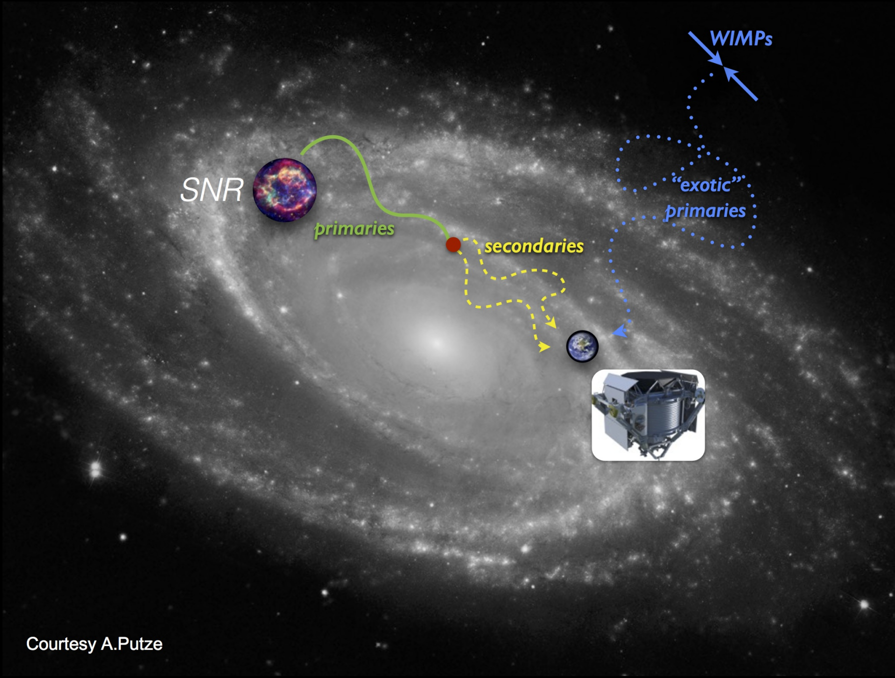


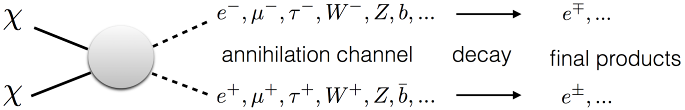
This is the positron anomaly !

We need another component to explain the data !

The Dark Matter scenario

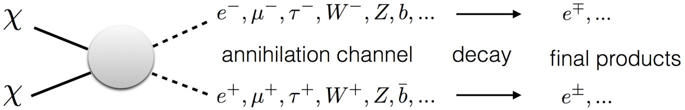



WIMPs
SNR
primaries
secondaries
"exotic"
primaries
Courtesy A.Putze



The DM source term

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



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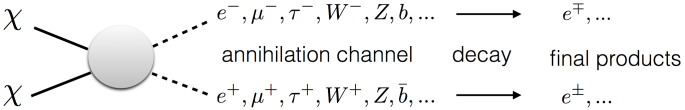
$\rho(\vec{x})$: DM density profile

NFW



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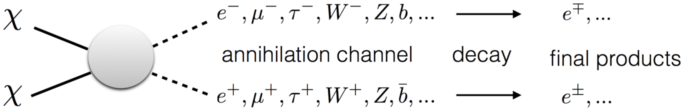
MicrOMEGAs_3.6



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MicrOMEGAs_3.6

2 free parameters:

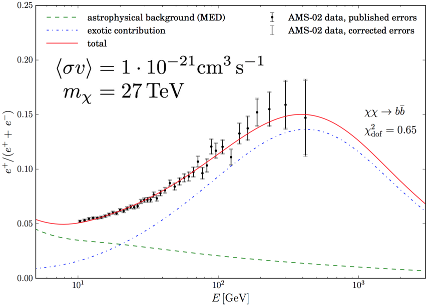
m_χ: DM mass

$<\sigma v>_i$: average annihilation cross-section

Scan over m_χ and $<\sigma v>_i$ to fit the AMS-02 data using MINUIT C++ package.

Single annihilation channel analysis

$$e.g \qquad \chi\chi \to b\bar{b} \to e^+e^- + \ldots$$



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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	$4.2 \cdot 10^{-6}$
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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
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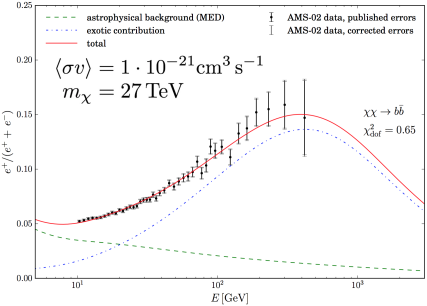

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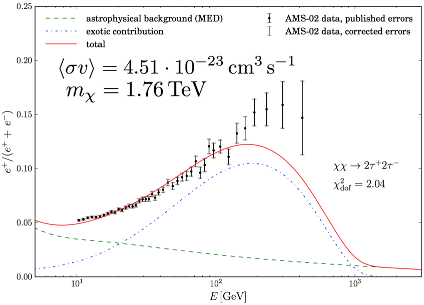

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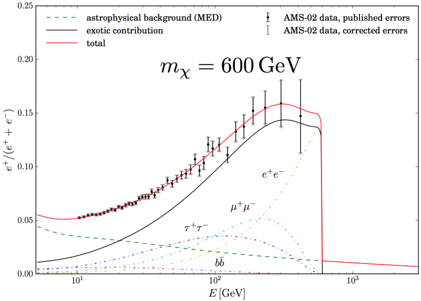
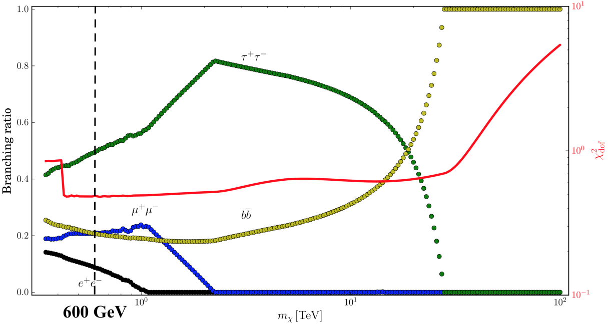
- Individual annihilation channels disfavor leptons as the final state.

Channels combination analysis



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

What is the best values for the branching ratios B_i?



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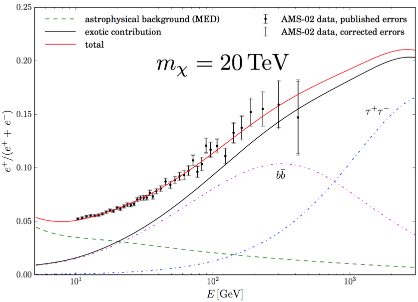
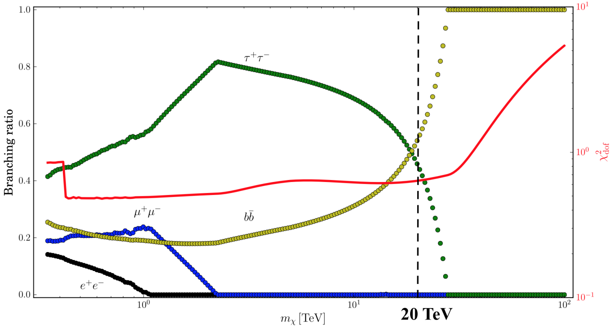
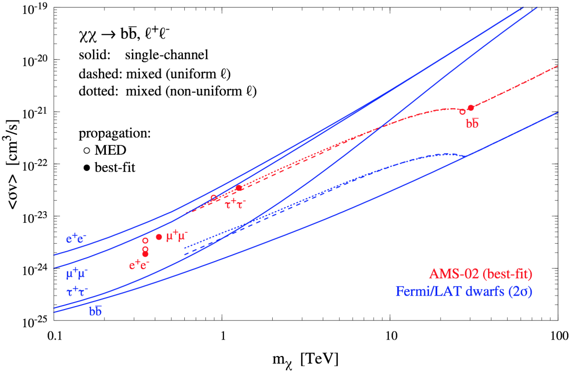




Constraints on dark matter annihilation cross-section $\langle \sigma v \rangle$

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

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



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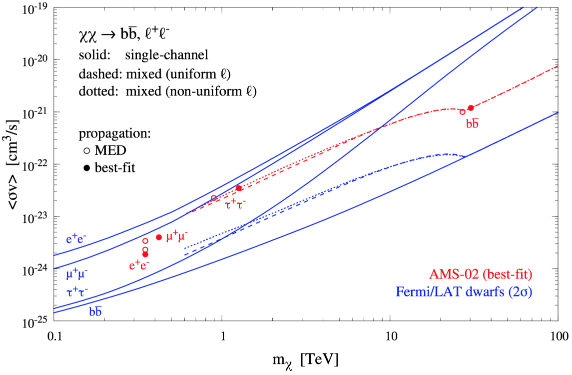
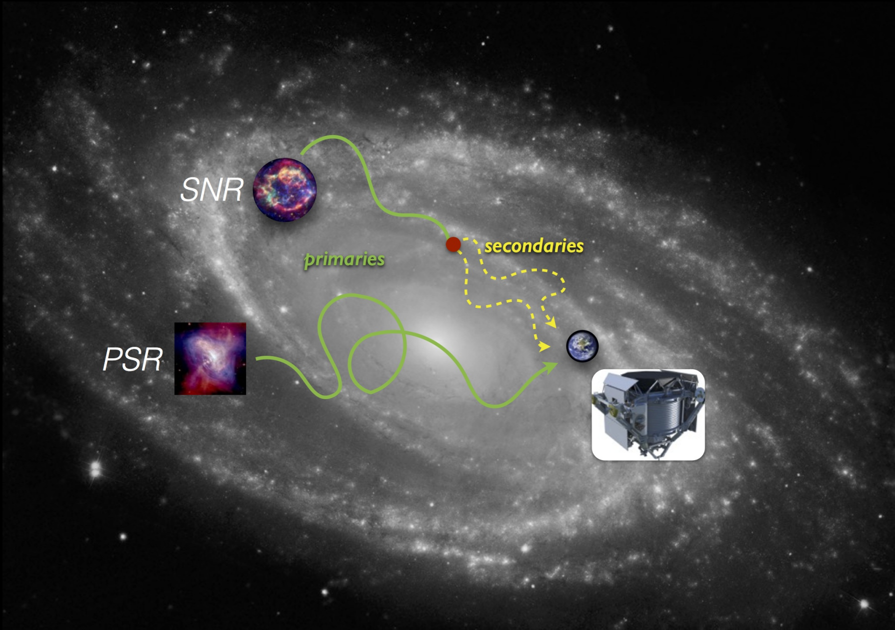


All best fit $\langle \sigma v \rangle$ values are excluded at 2σ CL !

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:

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

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  - $E_C \simeq 1\text{TeV}$

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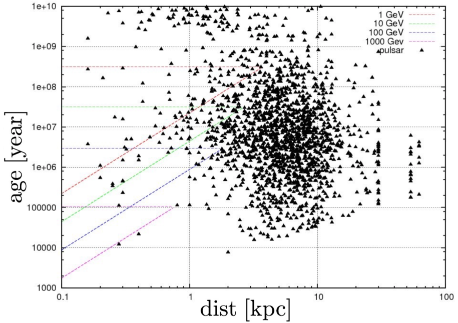
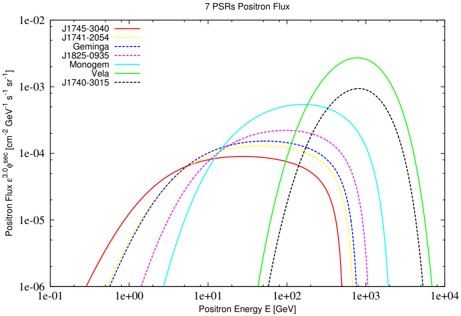
- Fixed parameter
  - $E_C \simeq 1\text{TeV}$
- Free parameters
  - $1.5 < \gamma < 2.5$
  - $fW_0 < 10^{54}\text{GeV}$

Observed PSR's from the Australian Telescope National Facility catalogue





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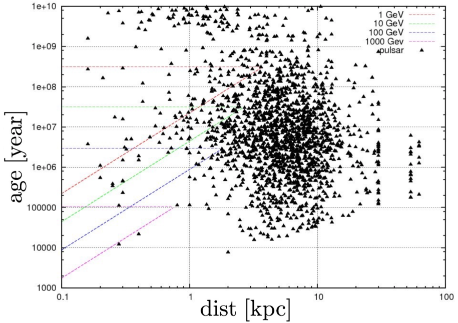

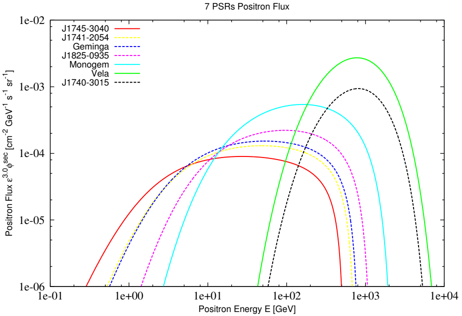

Only few young and nearby PSRs contribute to the positron flux for $E \geq 10\,\text{GeV}$!

Demonstrating that the positron fraction data can be explained by a ***unique pulsar*** *contribution provides with a* ***valid alternative*** *to the DM explanation of the positron anomaly.*

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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.*

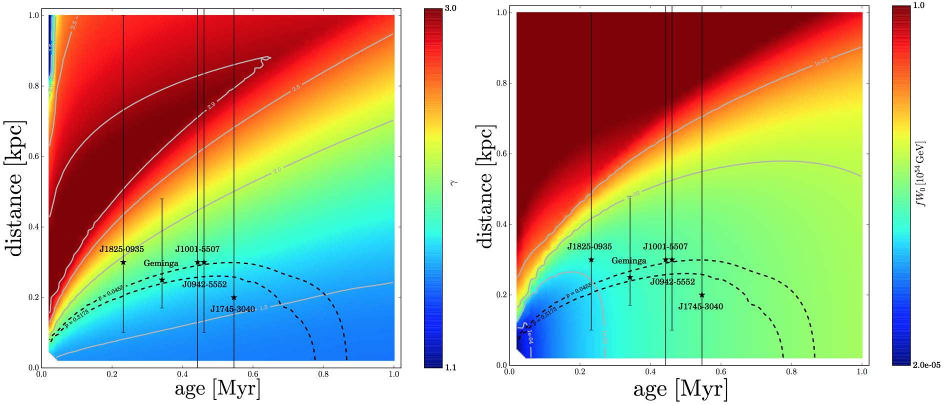
The single PSR hypothesis

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

The single PSR hypothesis

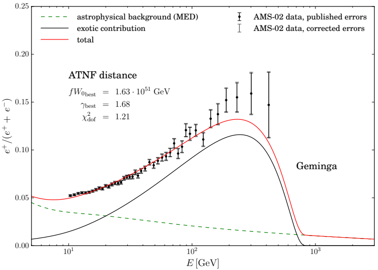
Can we explain the positron fraction with the contribution of **one single** pulsar?

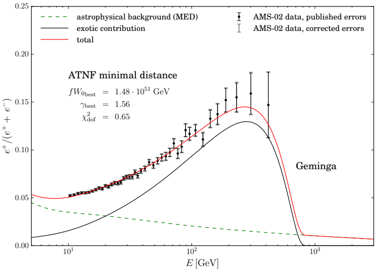
YES !



The 5 survivor PSR's from the ATNF catalog

Name	Age [kyr]	Distance [kpc]	fW_0 [10^{54} GeV]	γ	χ^2	$\chi^2_{\rm dof}$	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	$\mathbf{(3.03 \pm 0.06) \cdot 10^{-3}}$	$\mathbf{1.54 \pm 0.02}$	**33.6**	**0.82**	**0.79**
		1.3	1	2.54	9902	241	0
J0633+1746 *Geminga*	342	0.17	$(1.48 \pm 0.03) \cdot 10^{-3}$	1.56 ± 0.02	26.8	0.65	0.96
		0.25	$\mathbf{(1.63 \pm 0.02) \cdot 10^{-3}}$	$\mathbf{1.68 \pm 0.02}$	**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	$\mathbf{(2.61 \pm 0.04) \cdot 10^{-3}}$	$\mathbf{1.69 \pm 0.02}$	**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	$\mathbf{(2.49 \pm 0.03) \cdot 10^{-3}}$	$\mathbf{1.70 \pm 0.02}$	**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	$\mathbf{(1.45 \pm 0.03) \cdot 10^{-3}}$	$\mathbf{1.94 \pm 0.02}$	**126**	**3.07**	**0**
		1.0	1	2.64	12776	312	0





Conclusion

The DM scenario cannot both:

- provide a good fit of AMS-02 PF data.
- avoid the constraints on $\langle\sigma v\rangle$ from Fermi/LAT, HESS, PLANCK and PAMELA $\bar{p}$.

The single PSR scenario provides a valid explanation for AMS-02 PF data for 5 observed PSR's.

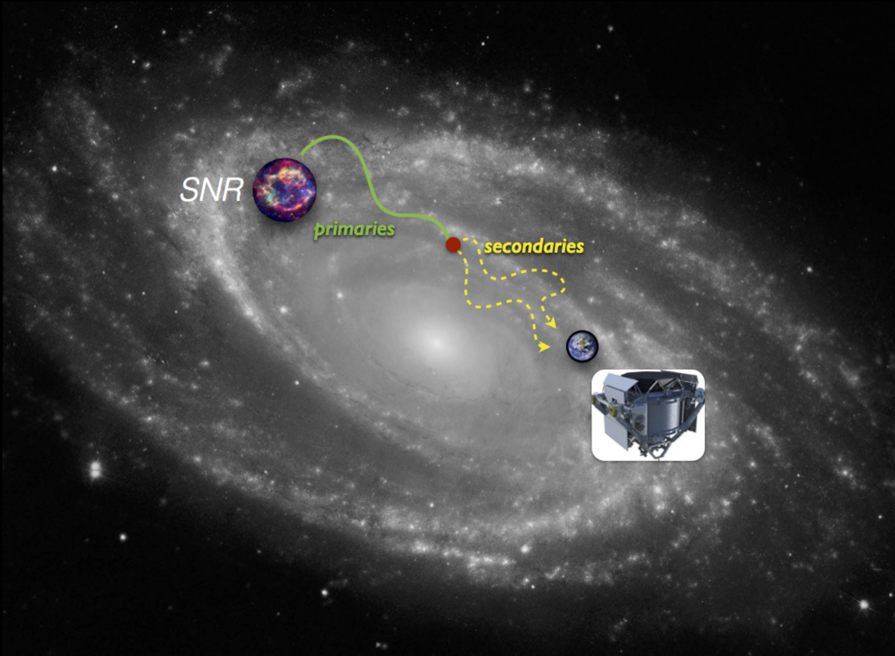
Cosmic ray antiprotons

M.B, M.Cirelli, Y.Genolini, G.Giesen, V.Poulin, P.Salati and P.D.Serpico

Based on:

JCAP 1505 (2015) 013

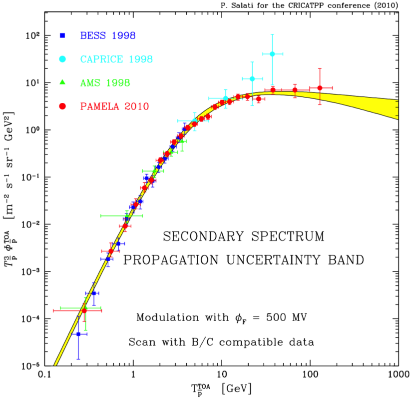
JCAP 1509 (2015) 023

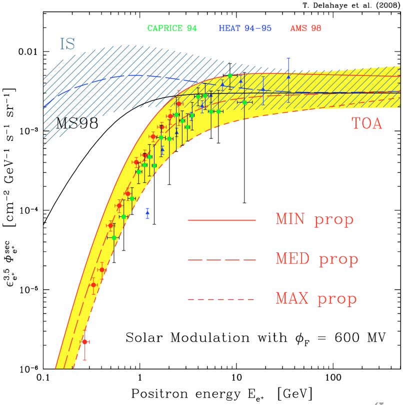


Courtesy A. Putze

$\bar{p}$ astrophysical background relatively under control compared to other channels ($e^+, \gamma, ...$).

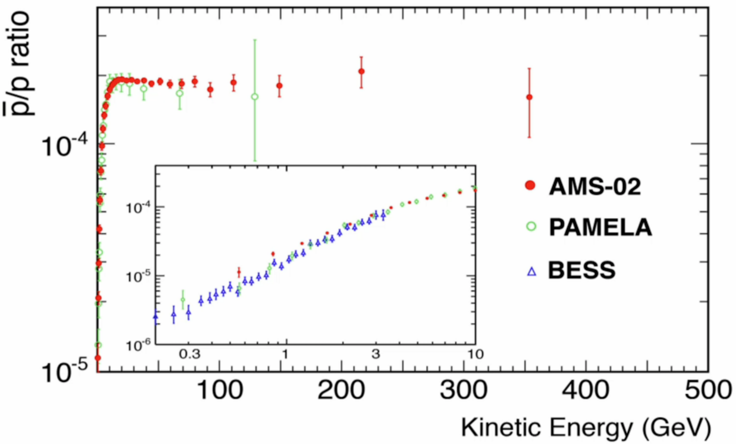
- No astrophysical primary component
- Propagation uncertainty is rather small





Preliminary $\bar{p}/p$ ratio from AMS-02

AMS-02 collaboration presented for the first time the measured $\bar{p}/p$ ratio from $\sim$ 1GeV to $\sim$ 500GeV.



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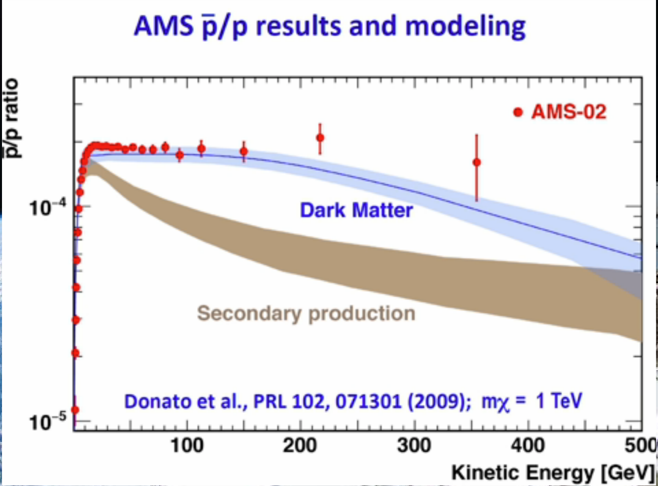

AMS-02 has suggested an antiproton excess with respect to the astrophysical background!

Is this the discovery of dark matter?

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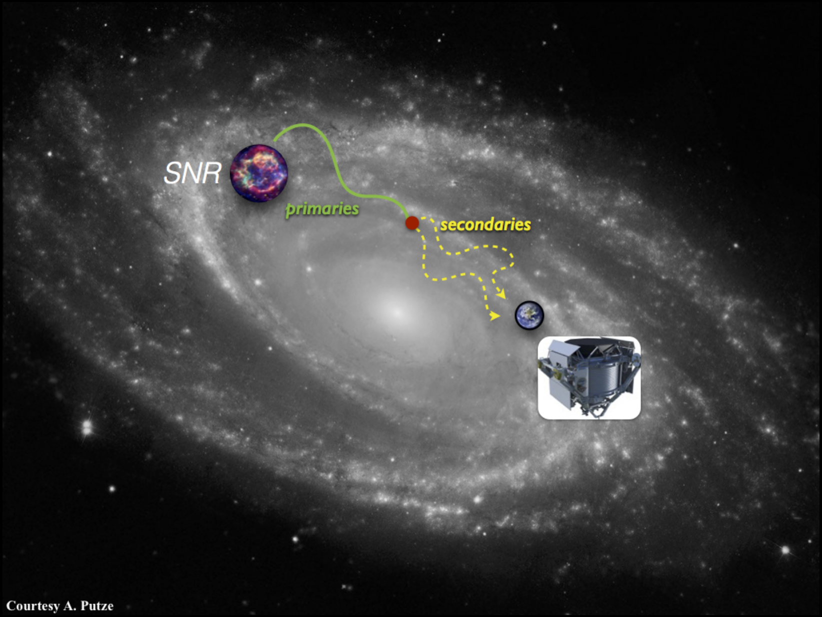
Let's compute the systematic uncertainties for the astrophysical antiprotons background


SNR
primaries
secondaries
Courtesy A. Putze

Secondary astrophysical $\bar{p}$ source term

$$\begin{cases} p + H \to \bar{p} + X & \sim 70\% \\ \alpha + H \to \bar{p} + X & \sim 25\% \\ p + He \to \bar{p} + X & \sim 4\% \\ \alpha + He \to \bar{p} + X & \sim 1\% \end{cases}$$

$$Q_{\bar{p}}^{sec}(E, \mathbf{x}) = 4\pi \sum_{i=p,\alpha} \sum_{j=H,He} \int_{E_i^0}^{+\infty} dE_i \frac{d\sigma_{ij\to\bar{p}X}}{dE}(E_i \to E)\phi_i(E_i, \mathbf{x})n_j(\mathbf{x})$$

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  → Supernova and pulsar distribution (*Yusifov et al. 2004*)

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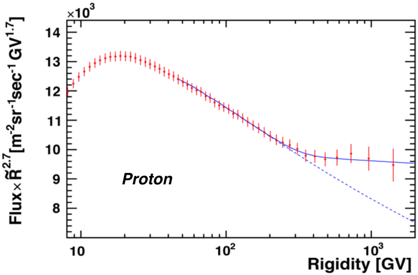
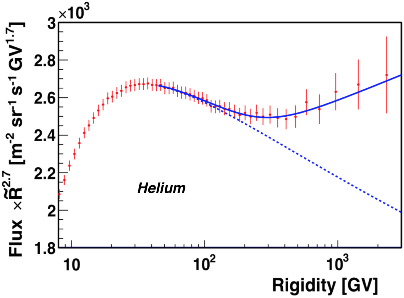
  $\to$ NA49 data parameterization/extrapolation (*Di Mauro et al. 2014)*

Primary flux slope parametrization uncertainties

AMS-02 p and α fluxes presented during the AMS days.





$$\Phi(R) \sim R^{\gamma} \left[1 + \left(\frac{R}{R_0} \right)^{\Delta\gamma} \right]$$

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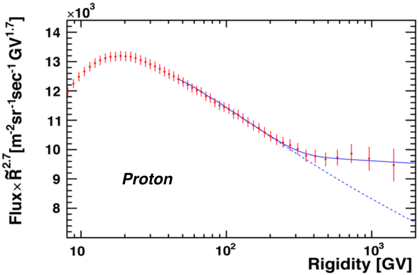

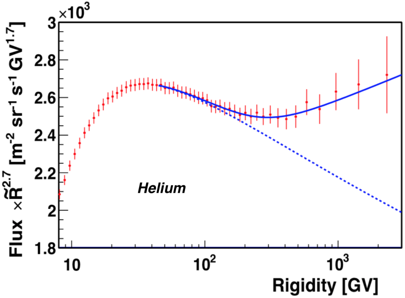

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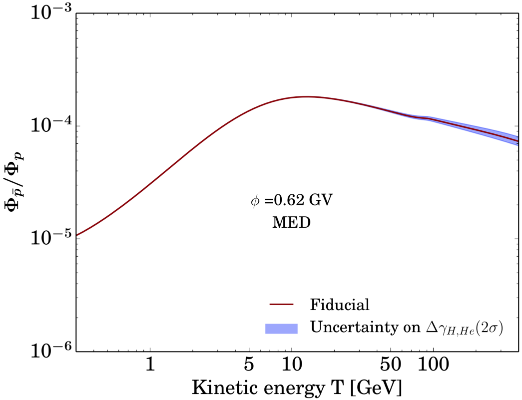

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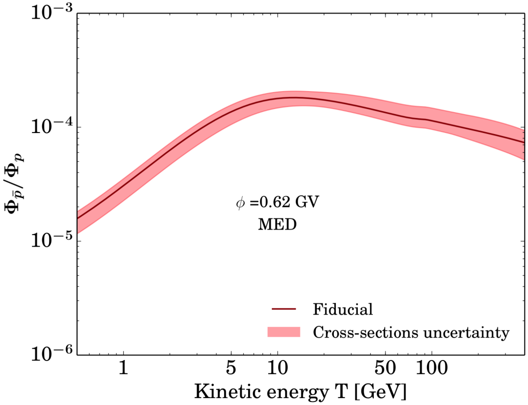
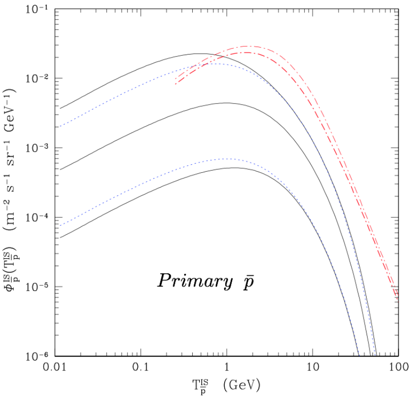


Propagation uncertainties



5 parameters constrained using the B/C.

Maurin et al. (2001)
Donato et al. (2003)

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

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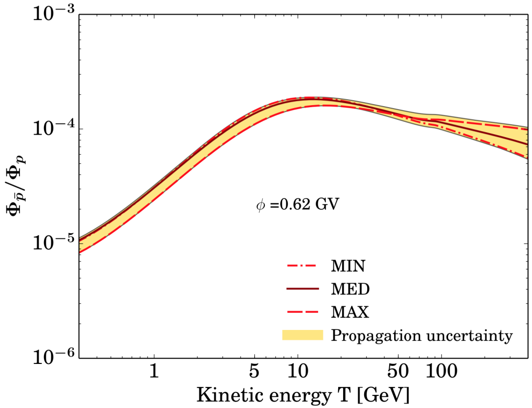

Solar modulation uncertainties

Force Field Approximation : $\varphi_F^{\bar{p}} = [0.3, 1.0]$ GV $\simeq \varphi_F^{p} \pm 50\%$ *Cirelli et al. (2014)*

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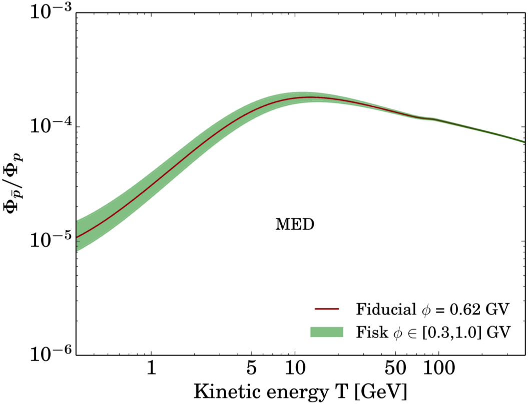
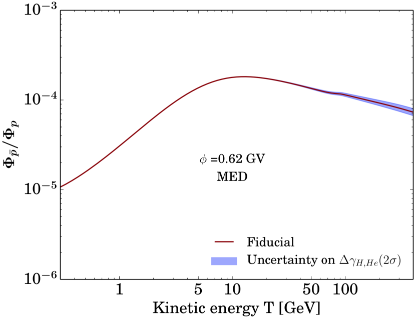
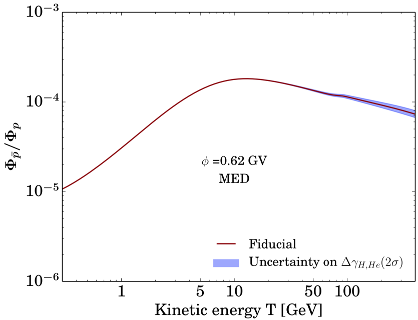




10^{-3}
10^{-4}
10^{-5}
10^{-6}
$\Phi_{\bar{p}}/\Phi_p$
ϕ =0.62 GV
MED
Fiducial
Uncertainty on $\Delta\gamma_{H,He}(2\sigma)$
1
5
10
50
100
Kinetic energy T [GeV]



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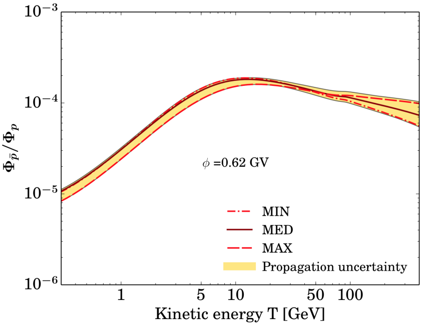

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MAX
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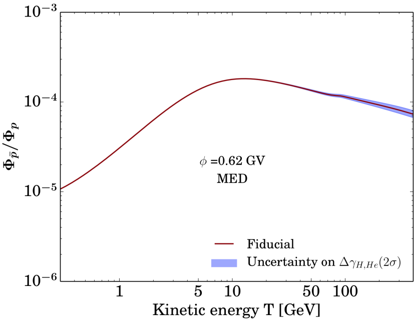
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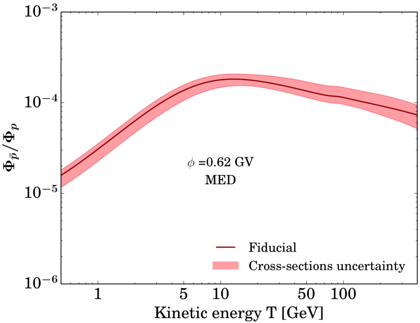
$\Phi_{\bar{p}}/\Phi_p$
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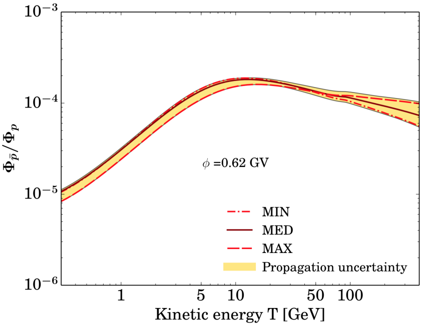
MED
Fiducial
Cross-sections uncertainty
Kinetic energy T [GeV]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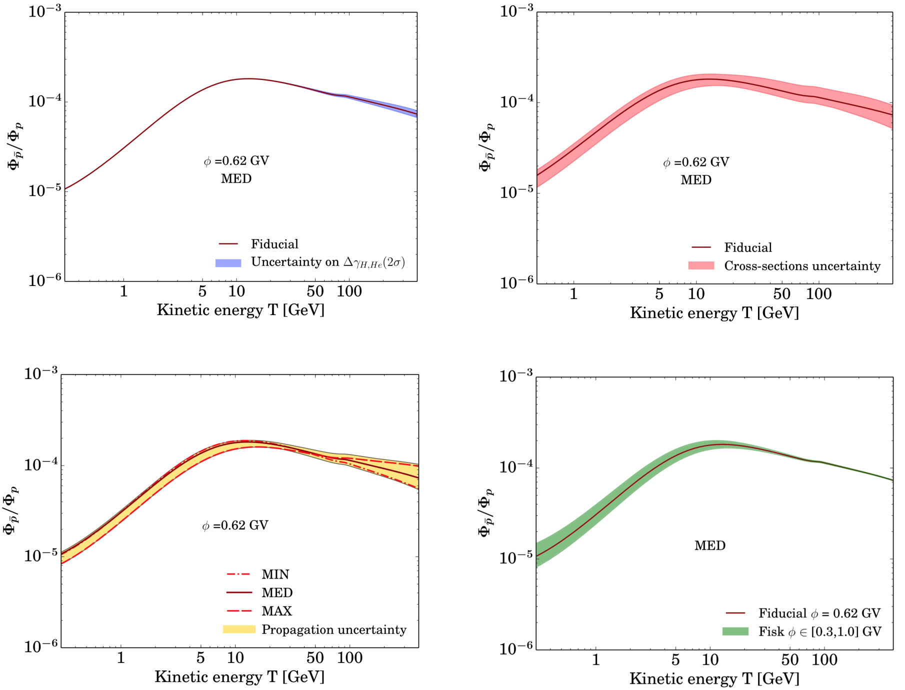
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Kinetic energy T [GeV]
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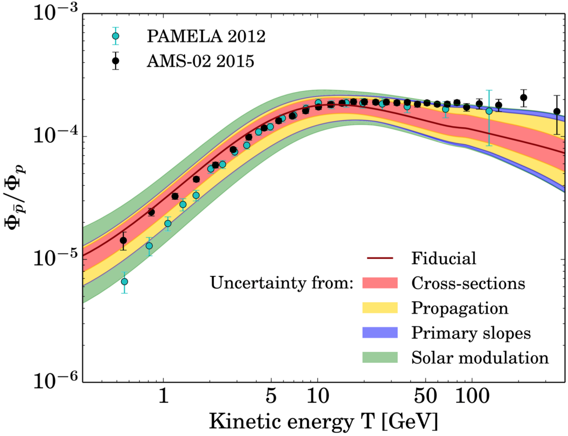
Fisk $\phi \in$ [0.3,1.0] GV

Astrophysical background uncertainties



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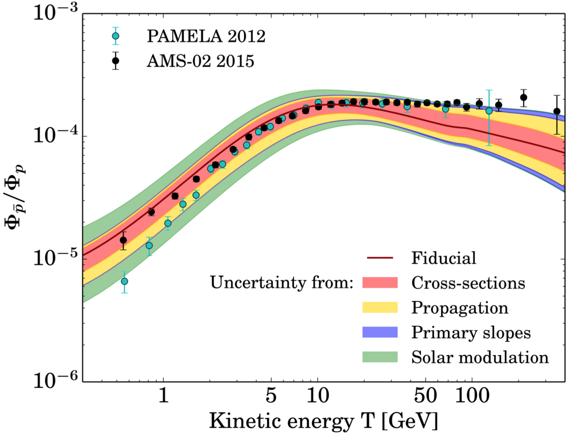

AMS-02 data are consistent with the astrophysical background.

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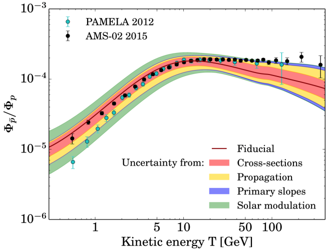
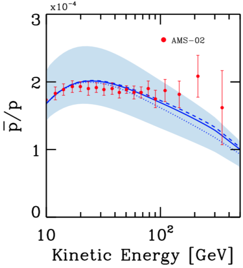
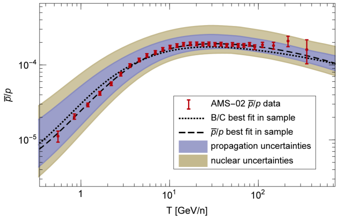


Similar conclusion from independent analysis:

Evoli, Gaggero and Grasso, arXiv:1504.05175



Kappl, Reinert and Winkler, arXiv:1506.04145



Updated dark matter constraints

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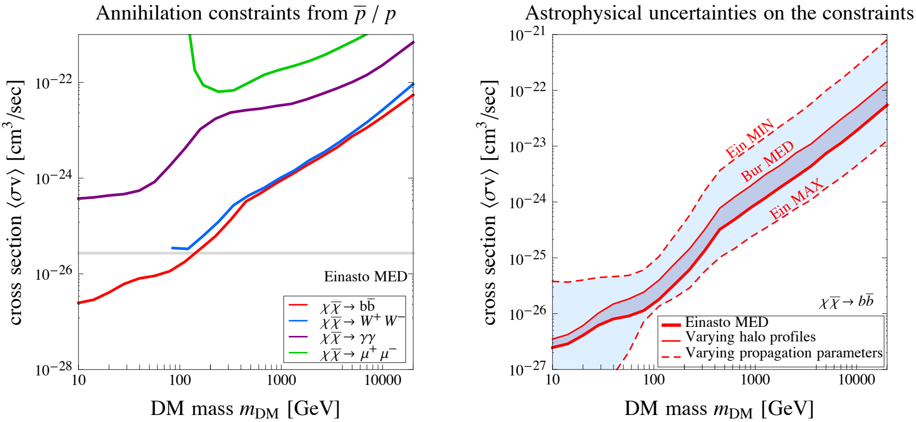

Conclusion

- There is no clear antiproton excess.

- Stronger bounds on DM annihilation X-section or decay life-time.
- Data seem to prefer a relatively mild energy dependence of the diffusion coefficient at high energies (such as MAX model).

Ongoing works - ***preliminary***

New cosmic ray positron analysis with:

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- AMS-02 positron flux PRL 113.121102(2015)

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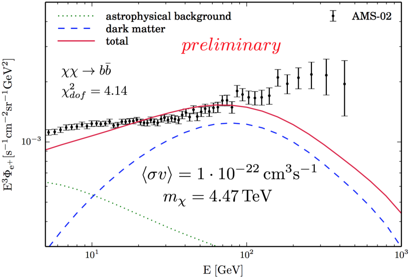
Single annihilation channel analysis

$$e.g \qquad \chi\chi \to b\bar{b} \to e^+e^- + \ldots$$

Channel	m_χ [TeV]	$\langle\sigma v\rangle$ [cm^3 s^{-1}]	χ^2	$\chi^2_{\rm dof}$	p
e	0.500 (*limit*)	$(3.39 \pm 0.04) \cdot 10^{-24}$	4560	95.0	0
μ	0.500 (*limit*)	$(5.84 \pm 0.06) \cdot 10^{-24}$	2356	50	0
τ	0.500 (*limit*)	$(1.07 \pm 0.09) \cdot 10^{-23}$	573	12.0	$5.1 \cdot 10^{-91}$
u	4.20 ± 0.26	$(1.14 \pm 0.08) \cdot 10^{-22}$	166	3.45	$6.6 \cdot 10^{-15}$
b	4.47 ± 0.30	$(1.05 \pm 0.08) \cdot 10^{-22}$	199	4.14	$2.7 \cdot 10^{-20}$
t	6.14 ± 0.44	$(1.63 \pm 0.12) \cdot 10^{-22}$	159	3.31	$8.2 \cdot 10^{-14}$
Z	2.58 ± 0.15	$(7.35 \pm 0.48) \cdot 10^{-23}$	162	3.37	$2.8 \cdot 10^{-14}$
W	1.58 ± 0.26	$(4.25 \pm 0.75) \cdot 10^{-23}$	114	2.37	$2.7 \cdot 10^{-6}$



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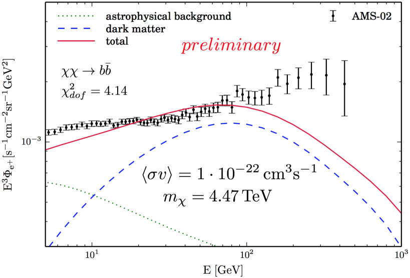

All single annihilation channel explanations are excluded!

Thanks for your attention!

Backup