Some anomalies in cosmic ray fluxes ?

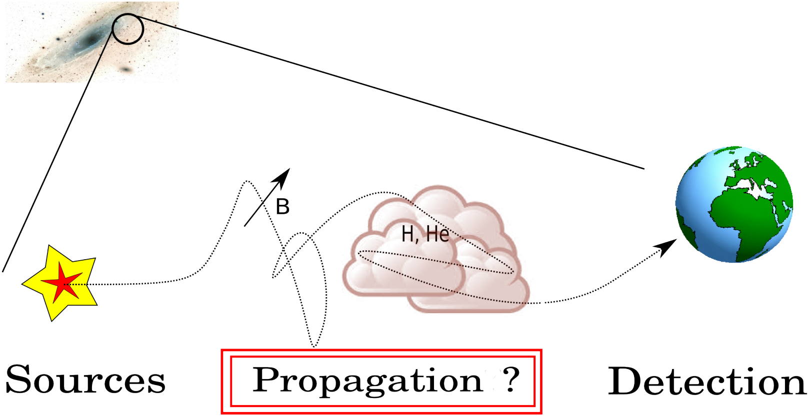
Yoann Génolini

December 14th, 2015

LAPTh

Outline

We don't measure directly the sources !



The model has to take into account :

- Sources spectra :
  $\rightarrow Q\left(E_k\right) \propto R^{-\alpha}$, with $R(E_k) = p/(Ze)$ and $\alpha \in [2.0, 2.5]$
- Transport (In the case of a weak electromagnetic turbulence) :
  $\rightarrow$ Diffusion in phase space $(\boldsymbol{x}, \boldsymbol{p})$ $D_x = D_0.\beta.R^\delta$
  $\rightarrow$ Convective wind $\boldsymbol{V_c}$.
- Interaction with the ISM :
  $\rightarrow$Energy losses
  $\rightarrow$Spallation $(\sigma_\alpha, \sigma_{\alpha\rightarrow\beta})$

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Simplified propagation equation :

$$\frac{\partial f_a}{\partial t} + \boldsymbol{V_c}.\nabla_{\boldsymbol{x}} f_a - \frac{1}{3}(\nabla_{\boldsymbol{x}}.\boldsymbol{V_c}) p \frac{\partial f_a}{\partial p} + \nabla_{\boldsymbol{p}}(b(\boldsymbol{p}) f_a) + \sigma_a v_a n_{ISM} f_a +$$

$$\frac{f_a}{\tau_a} - \nabla_{\boldsymbol{x}}.(D_x \nabla_{\boldsymbol{x}} f_a) - \nabla_{\boldsymbol{p}}.(D_p \nabla_{\boldsymbol{p}} f_a) =$$

$$q_a + \sum_{Z_b \geqslant Z_a}^{Z_{max}} \sigma_{b \to a} v_b n_{ISM} f_b + \frac{f_b}{\tau_b}$$

Simplifying the equation :

Ek>10GeV/nuc

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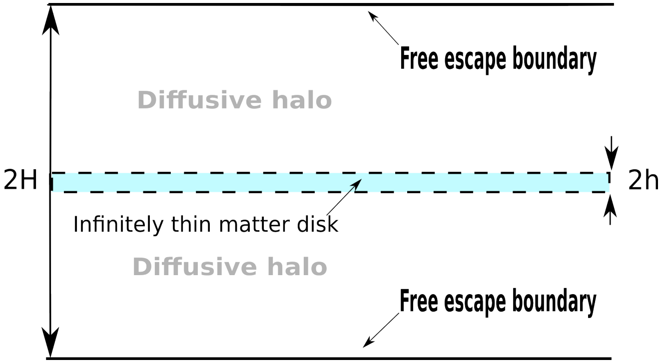
Galaxy model :



Surface density of the disc $\mu = 2.4 \text{ mg.cm}^{-2}$.

Analytical resolution of the propagation equation :

For a stable nucleus :

$$\mathcal{J}_a(E_k) = \left\{ Q_a + \sum_{Z_b \geqslant Z_a}^{Z_{max}} \sigma_{b\to a}\, \mathcal{J}_b \right\} / \left\{ \sigma^{\text{diff}} + \sigma_a \right\} \quad (1)$$

Primary and secondary source terms.

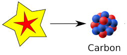
$$\text{Where : } \sigma^{\text{diff}} = \frac{2D\, m_{\text{ISM}}}{\mu v H} .$$

$$\text{and } Q_a = \frac{1}{4\pi} \frac{q_a}{n_{ISM}} \equiv N_a \left(\frac{\mathcal{R}}{1\,\text{GV}} \right)^{\alpha} .$$

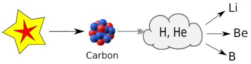
High energy behaviour of fluxes :

Ek>10GeV/nuc

Hadrons :

Primary species : 

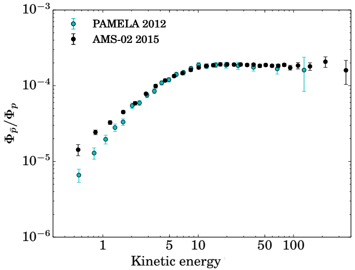
$\Rightarrow \mathcal{J}_C \propto \mathcal{R}^{-(\alpha+\delta)}$

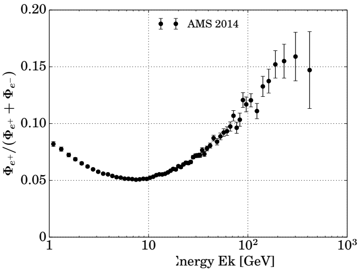
Secondary species : 

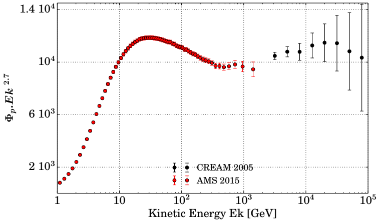
$\Rightarrow \mathcal{J}_B \propto \mathcal{R}^{-(\alpha+2\delta)}$

Secondary leptons : $\Rightarrow \mathcal{J}_{e^+,e^-} \propto \mathcal{R}^{-(\alpha+\delta+1)}$
(Thomson energy losses)

Some measurements which challenge this models :







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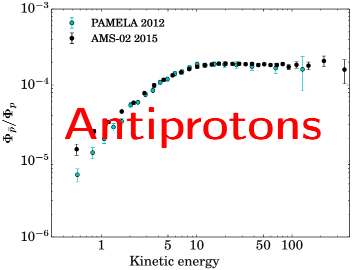

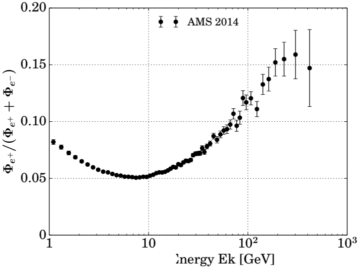

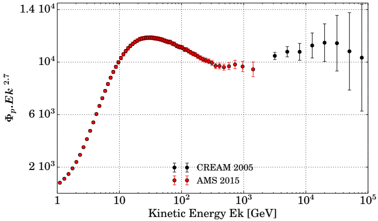

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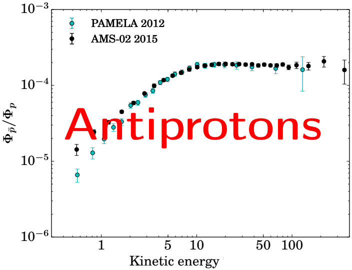

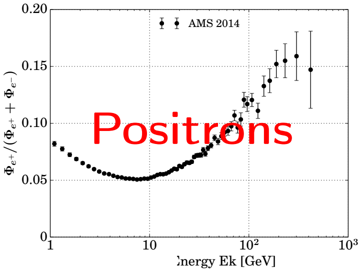

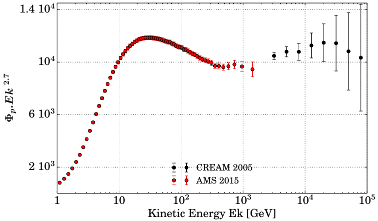

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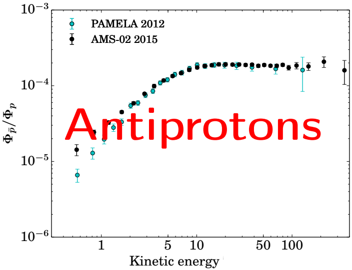

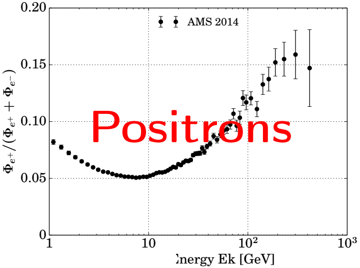

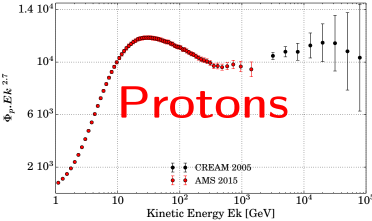

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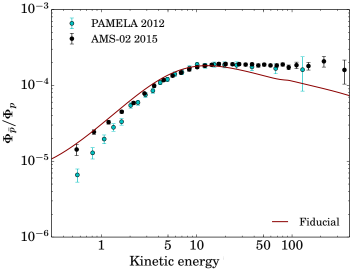

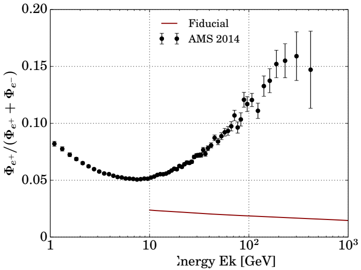

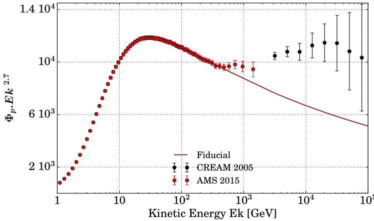

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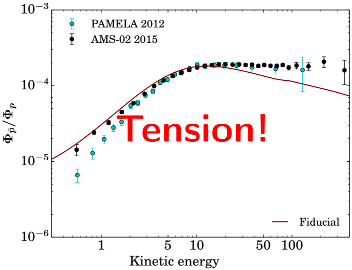

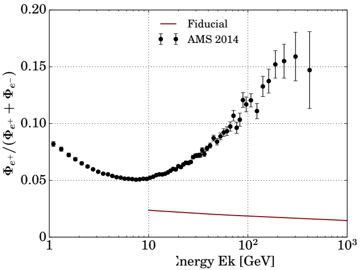

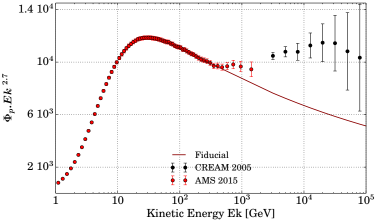

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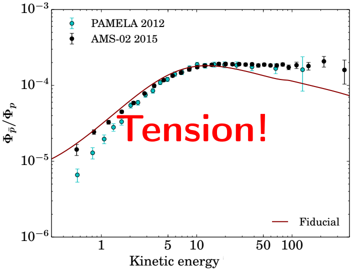

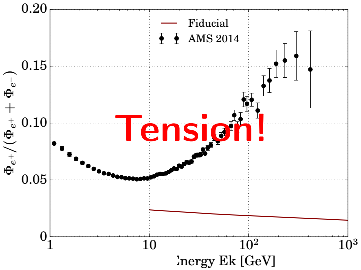

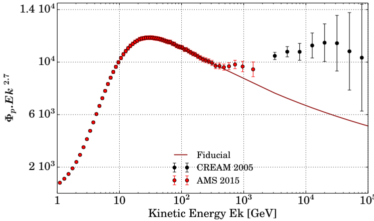

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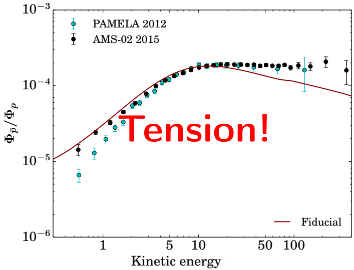

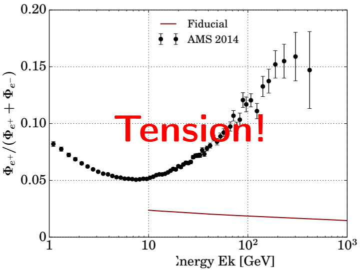

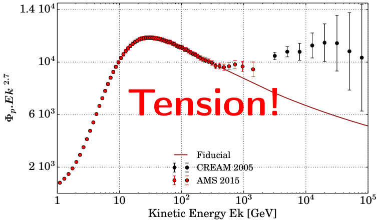

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Outline

1. Modeling the high energy CRs fluxes

2. Propagation paradigm
   - ⇒ State of the art
   - ⇒ Positrons
   - ⇒ Antiprotons

3. *Theoretical* uncertainties on propagation

4. Conclusion

Outline

2. Propagation paradigm
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How do we constrain the propagation ?

$$\frac{\partial f_a}{\partial t} + \boldsymbol{V_c}.\nabla_{\boldsymbol{x}} f_a - \frac{1}{3}(\nabla_{\boldsymbol{x}}.\boldsymbol{V_c})p\frac{\partial f_a}{\partial p}\nabla_{\boldsymbol{p}}(b(\boldsymbol{p})f_a) + \sigma_a v_a n_{ISM} f_a +$$

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- Characteristics of the Galaxy
- Based on nuclear data

How do we constrain the propagation ?

We are need to determine these parameters :

$$V_c, b(p), n_{ISM}, D_x, D_p, H$$

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$$V_c, \quad D_x = D_0.\mathcal{R}^{\delta}, \quad D_p = \frac{{V_A}^2}{9D_x}p^2, \quad H$$

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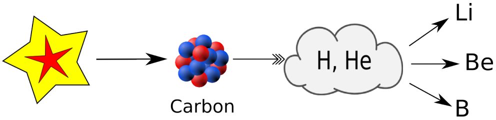
Measuring the propagation parameters :



Li, B, Be are said secondary.

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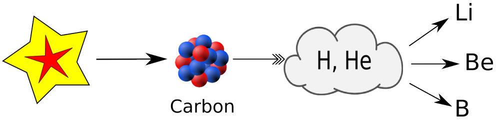

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Secondary/primary ratio :

$$\mathcal{J}_B(E_k) = \left\{ Q_B + \sum_{Z_b \geqslant Z_B}^{Z_{max}} \sigma_{b \to B} \, \mathcal{J}_b \right\} / \left\{ \sigma^{\text{diff}} + \sigma_B \right\} \quad (2)$$

Hypothesis :

- $Q_B = 0$
- Double nuclei system (B,C)

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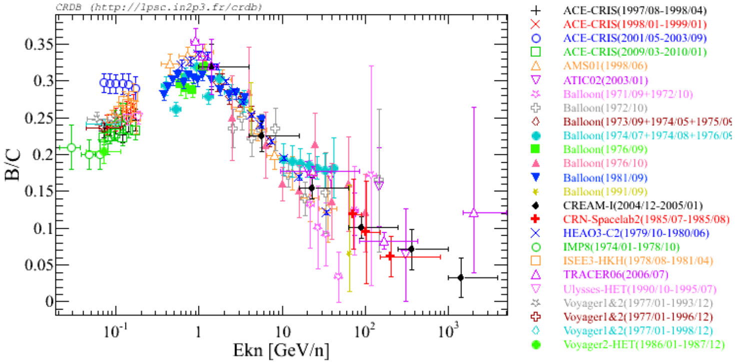
$$\frac{\mathcal{J}_B(E_k)}{\mathcal{J}_C(E_k)} = \sigma_{C\to B}/\left\{\sigma^{\mathrm{diff}} + \sigma_B\right\}.$$

When : $\sigma_B << \sigma^{diff} \Rightarrow \boxed{\frac{\mathcal{J}_B}{\mathcal{J}_C} \propto R^{-\delta}}$

Experimental data :



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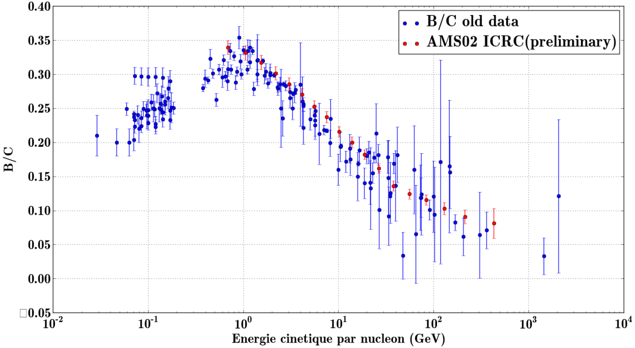
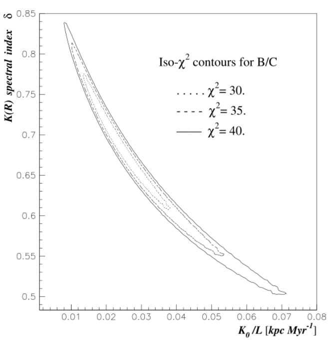
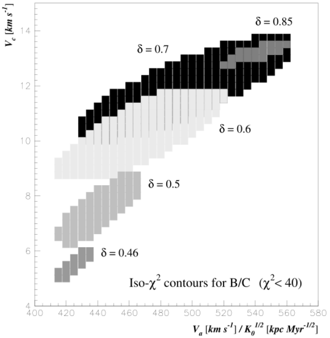


New data with AMS02 !..and soon CALET !

Analysis currently used :

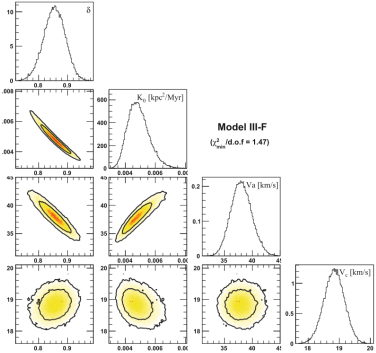
[Maurin 2001] ⇒ 1623(3σ) sets are found to be consistent with B/C.

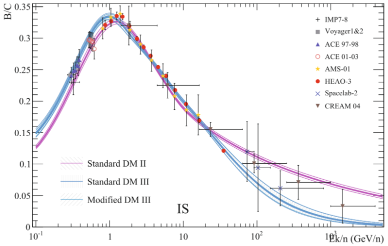




Other analysis :

[Putze 2010] ⇒ More comprhensive study(Including $^{10}Be/^{9}Be$).

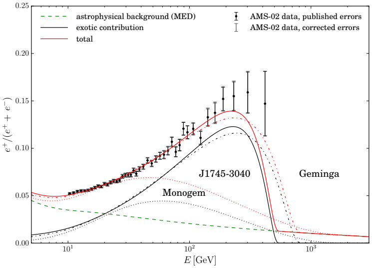




Outline

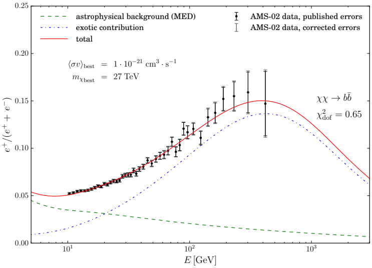
Typical fits of the positron fraction : $\Phi_{e+} = \Phi_{e+}^{\text{secondary}} + \Phi_{e+}^{\text{primary}}$

Pulsar explanation ?



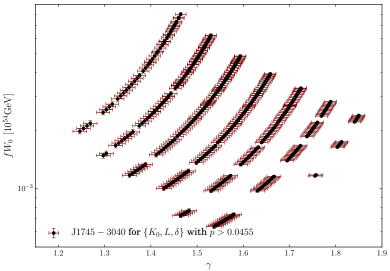
Fit of $\{fW_0, \gamma\}$

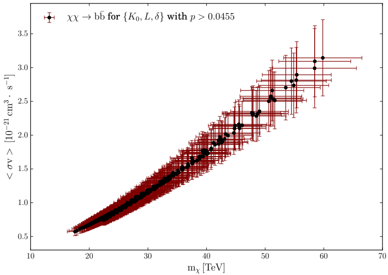
Dark matter explanation ?



Fit of $\{< \sigma v >, m_\chi\}$

Systematic vs statistical uncertainties :





⇒ **The systematics on propagation dominate completely their determination.**

[Boudaud 2014] : Carefull analysis of the positron fraction.

Boudaud 2014 → arxiv[1410.3799]

Astronomy & Astrophysics manuscript no. CRAC_paper_1
January 22, 2015

A new look at the cosmic ray positron fraction

M. Boudaud[1], S. Aupetit[1], S. Caroff[2], A. Putze[1,2], G. Belanger[1], Y. Genolini[1], C. Goy[2], V. Poireau[2], V. Poulin[1], S. Rosier[2], P. Salati[1], L. Tao[2], and M. Vecchi[2,3,⋆,⋆⋆]

[1] LAPTh, Université de Savoie & CNRS, 9 Chemin de Bellevue, B.P.110 Annecy-le-Vieux, F-74941, France

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[3] Instituto de Fisica de São Carlos - Av. Trabalhador são-carlense, 400 CEP: 13566-590 - São Carlos (SP), Brazil

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Preprint numbers : LAPTH-224/14

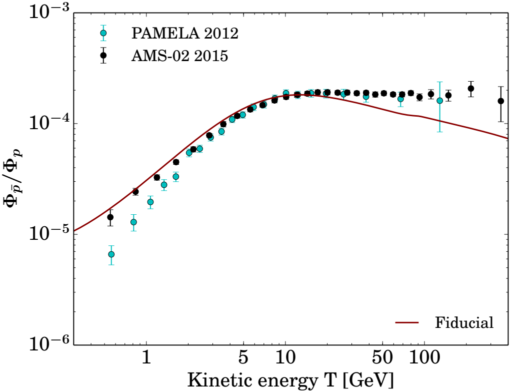
ABSTRACT

Context. The positron fraction in cosmic rays has recently been measured with improved accuracy up to 500 GeV, and it was found to be a steadily increasing function of energy above ∼ 10 GeV. This behaviour contrasts with standard astrophysical mechanisms, in which positrons are secondary particles, produced in the interactions of primary cosmic rays during their propagation in the interstellar

Outline

2 Propagation paradigm
- ⇒ State of the art
- ⇒ Positrons
- ⇒ Antiprotons

Revaluation of the astrophysical background :



Tension with the fiducial model !

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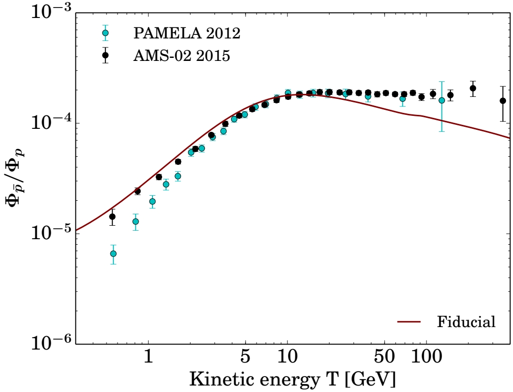

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Revaluation of the astrophysical background.

Equation in steady state :

$$\partial_z(V_C\psi) - D_x\Delta\psi + \partial_E\{b^{loss}(E)\psi - D_{EE}(E)\partial_E\psi\} = Q$$

With : $Q(\psi_p, \psi_{He}, \sigma_{pH\to\bar{p}}(E), ..)$

- Propagation → [Maurin 2001]
- Primary fluxes → [AMS02 2015]
- Production cross-section → [di Mauro 2014]

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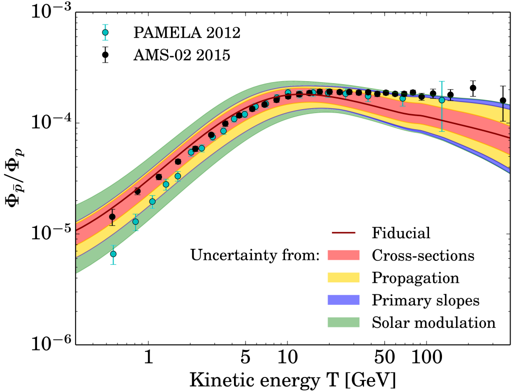

→ Published in [Guisen 2015]

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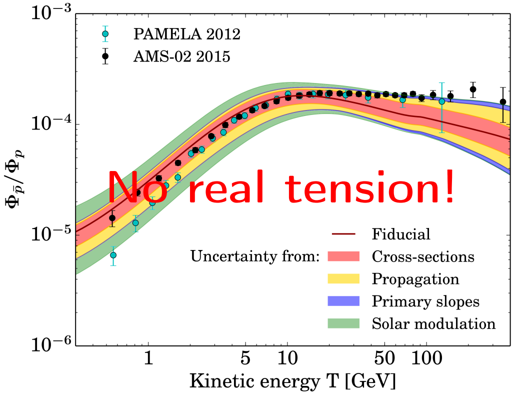

→ Published in [Guisen 2015]

Guisen 2015 → arxiv[1504.0427]

AMS-02 antiprotons, at last!

Secondary astrophysical component and immediate implications for Dark Matter

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Abstract

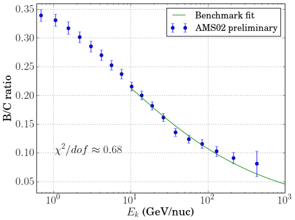
Using the updated proton and helium fluxes just released by the AMS-

Outline

Benchmark model :

The goal is to minimize :

$$\chi^2_{\mathrm{B/C}} = \sum_i \left\{ \frac{\mathcal{F}_i^{\mathrm{exp}} - \mathcal{F}_i^{\mathrm{th}}(Parameters..)}{\sigma_i} \right\}^2$$



Reference parameter values	
D_0 [kpc^2/Myr]	$(5.8 \pm 0.7) \cdot 10^{-2}$
δ	0.44 ± 0.03
$\chi^2_{\mathrm{B/C}}/\mathrm{dof}$	$5.4/8 \approx 0.68$
$\gamma = \alpha - \delta$ (fixed)	-2.78

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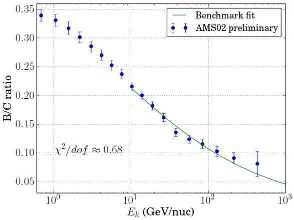

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Any assumptions ? :

$$\mathcal{F}^{\text{th}} = \frac{\mathcal{J}_{\mathsf{B}}(E_k)}{\mathcal{J}_{\mathsf{C}}(E_k)} = \frac{Q_{\mathsf{B}}}{\sigma^{\mathsf{diff}} + \sigma_B} / \mathcal{J}_{\mathsf{C}} + \sum_{Z_b \geqslant Z_{\mathsf{C}}}^{Z_{\mathsf{max}}} \frac{\sigma_{b \to \mathsf{B}}}{\sigma^{\mathsf{diff}} + \sigma_{\mathsf{B}}} \frac{\mathcal{J}_b}{\mathcal{J}_{\mathsf{C}}}$$

- Primary boron contribution
- Production cross-section uncertainties
- Destruction cross-section uncertainties
- Geometry framework

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Primary boron ?

[Bla09], [BS09], [MS09], [MS14]

→ **Secondary species may be formed at sources !**

- Confinement inside a SNR at TeV/nuc :

$$X_{SNR} \approx 0.17 \text{ g cm}^{-2} \frac{n_{ISM}}{\text{cm}^{-3}} \frac{T_{SNR}}{2.10^4 \text{ yr}}$$

- Galactic diffusion at TeV/nuc :

$$X_{Diff} \approx 1.2 \text{ g cm}^{-2}$$

⇒ **Order of 10% !**

Primary boron ?

At high energy...

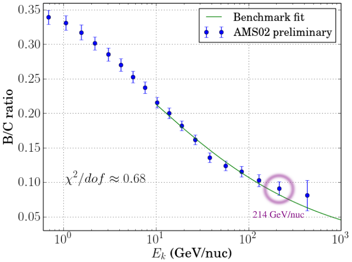
$$\frac{\mathcal{J}_B(E_k)}{\mathcal{J}_C(E_k)} = \left\{ \frac{Q_B}{\mathcal{J}_C} + \sigma_{C\to B} + \sum_{Z_b > Z_C}^{Z_{max}} \sigma_{b\to B} \frac{\mathcal{J}_b}{\mathcal{J}_C} \right\} / \left\{ \sigma^{\text{diff}} + \sigma_B \right\}$$

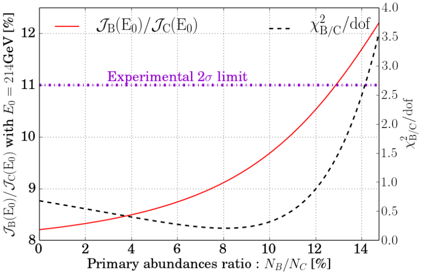
$$\underset{HE}{\propto} \frac{N_B}{N_C}$$

...it leads to a plateau.

Primary boron ?

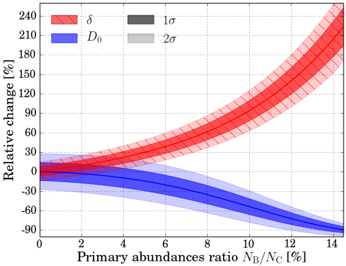
Constraining $\frac{N_B}{N_C}$:

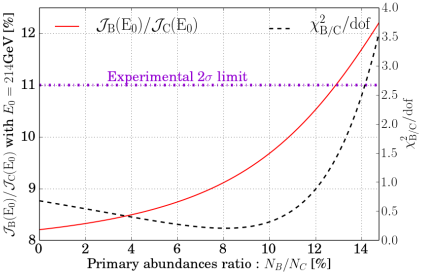




Primary boron ?

Scan on $\frac{N_B}{N_C}$:





→ Huge impact on the determination of delta !

Primary boron ?

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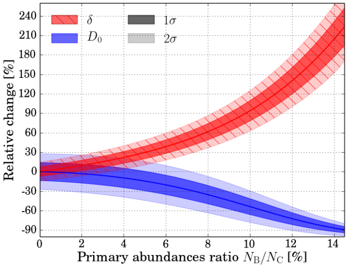

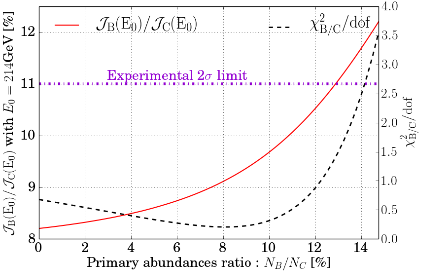

→ Huge impact on the determination of delta !

Summary of the main systematics :

	Wind	1D/2D geometry	Cross-sections	Primary boron
$\Delta D_0/D_0$	-40%	-2 to -13%	$\pm 60\%$	0 to -90%
$\Delta\delta/\delta$	$+15\%$	0 to $+1\%$	$\pm 20\%$	0 to $+100\%$

Prospects, what we need at zero order :

1. Find a way to quantify primary boron contribution.
2. New precise measurements of nuclear cross-sections.

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Génolini 2015 → arxiv[1504.03134]

Astronomy & Astrophysics manuscript no. draft4
July 22, 2015

Theoretical uncertainties in extracting cosmic-ray diffusion parameters: the boron-to-carbon ratio

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Preprint numbers : LAPTH-018/15

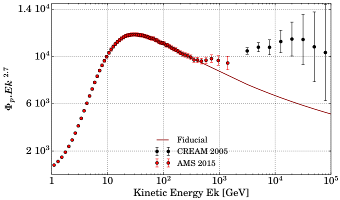
ABSTRACT

Context. PAMELA and, more recently, AMS-02, are ushering us into a new era of greatly reduced statistical uncertainties in experimental measurements of cosmic-ray fluxes. In particular, new determinations of traditional diagnostic tools such as the boron-to-carbon ratio (B/C) are expected to significantly reduce errors on cosmic-ray diffusion parameters, with important implications for astroparticle physics, ranging from inferring primary source spectra to indirect dark matter searches.

Outline

Future projects :

- Discretness of sources :
  With Pasquale Serpico, Pierre Salati and Richard Taillet.
- Revaluation of secondary positon propagation uncertainties :
  With Antje Putze for an updated analysis.
- An updated analysis of the B/C ratio..



Thanks for listening

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- Pasquale Blasi and Pasquale D. Serpico, *High-energy antiprotons from old supernova remnants*, Phys.Rev.Lett. **103** (2009), 081103.
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- P. Mertsch and S. Sarkar, *AMS-02 data confront acceleration of cosmic ray secondaries in nearby sources*, Prd **90** (2014), no. 6, 061301.