

# Some anomalies in cosmic ray fluxes ?

Yoann Génolini

January 25th, 2016

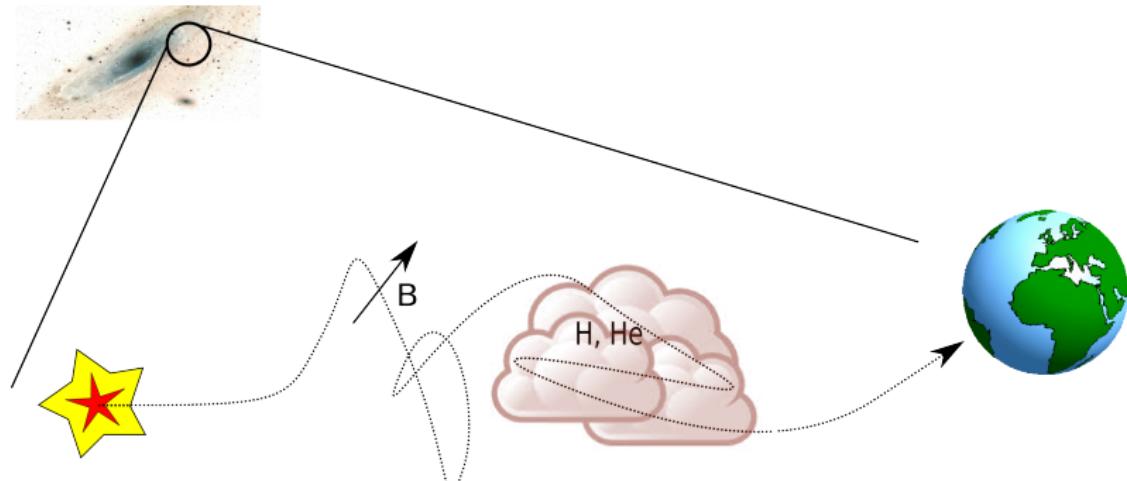
LAPTh

- ① Modeling the high energy CRs fluxes
- ② Propagation paradigm
- ③ *Theoretical uncertainties on propagation*
- ④ Conclusion

# Outline

- ① Modeling the high energy CRs fluxes
- ② Propagation paradigm
- ③ *Theoretical uncertainties on propagation*
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# We don't measure directly the sources !



Sources

Propagation ?

Detection

## The model has to take into account :

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

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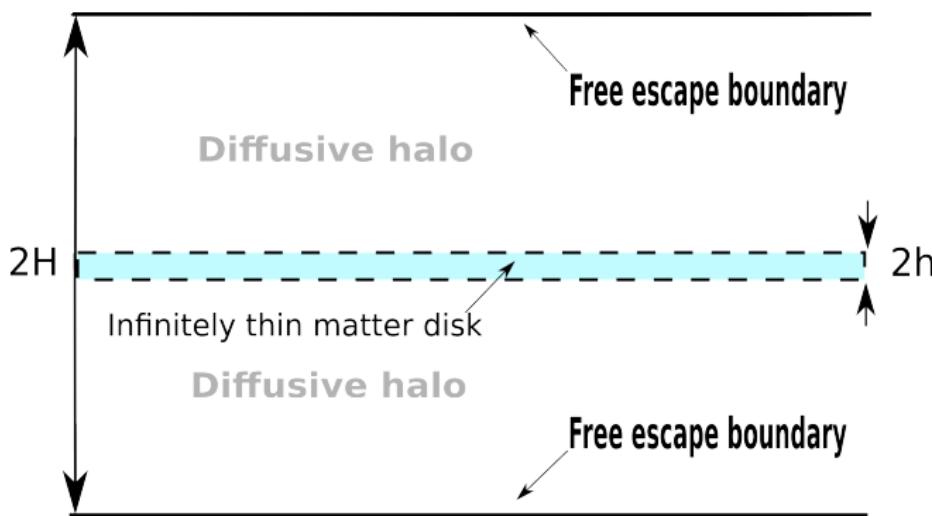
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# Propagation equation for a nucleus $a$ simplified version at high energy :

E $\text{k}>10\text{GeV/nuc}$

$$\frac{\partial f_a}{\partial t} + \sigma_a v_a n_{ISM} f_a + \frac{f_a}{\tau_a} - \nabla_x \cdot (D_x \nabla_x f_a) = q_a + \sum_{Z_b \geq Z_a}^{Z_{max}} \sigma_{b \rightarrow a} v_b n_{ISM} f_b + \frac{f_b}{\tau_b}$$

# Galaxy model :



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

# Analytical resolution of the propagation equation :

For a stable nucleus :

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

Primary and secondary source terms.

Where :  $\sigma^{\text{diff}} = \frac{2D m_{\text{ISM}}}{\mu v H} \propto \mathcal{R}^\delta$  and

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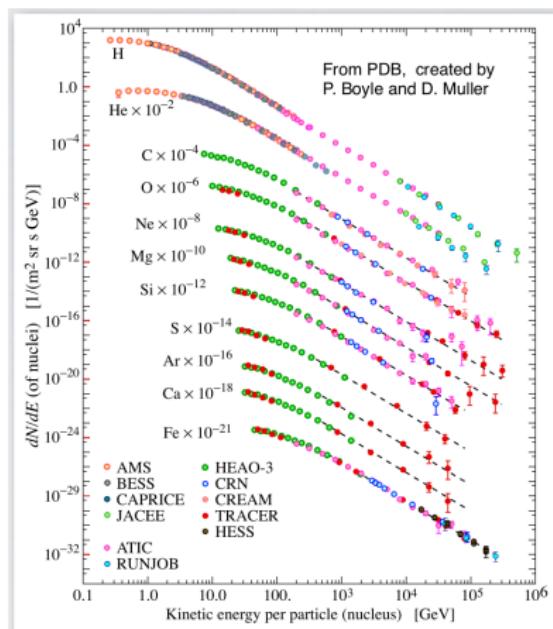
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Primary species :  $\Rightarrow \mathcal{J}_C \propto \mathcal{R}^{-(\alpha+\delta)}$

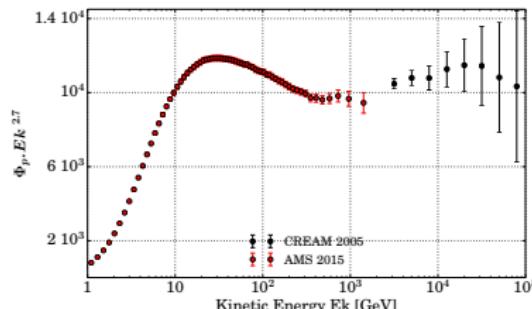
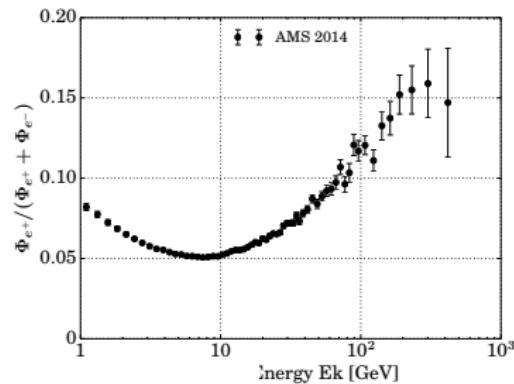
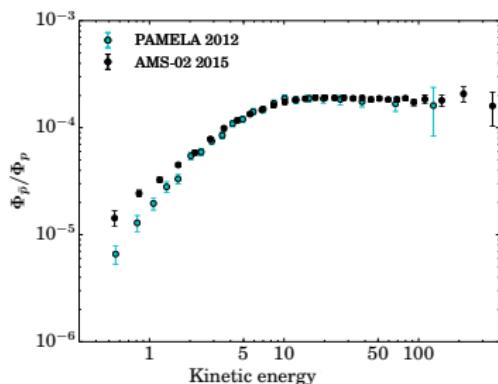
Secondary species :  $\Rightarrow \mathcal{J}_B \propto \mathcal{R}^{-(\alpha+2\delta)}$

# Measurements are in **agreement** with this model !

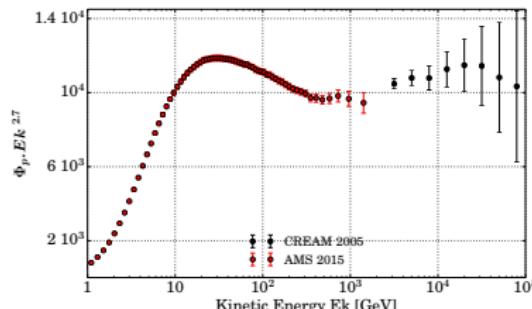
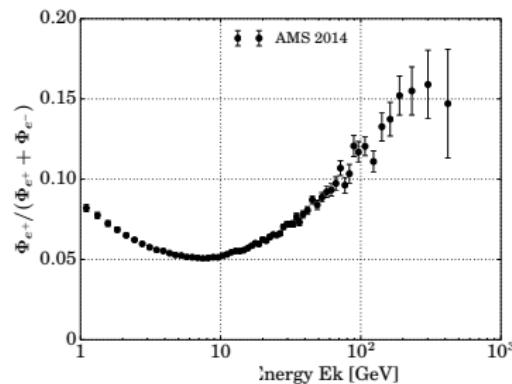
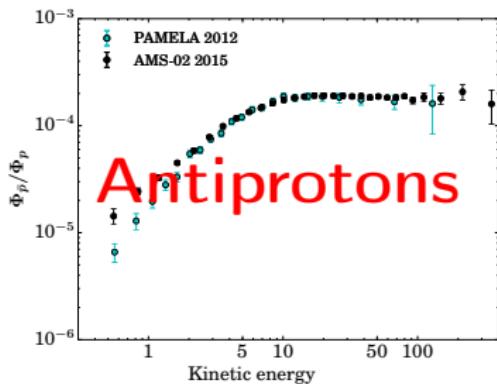
At zero order we find a featureless and universal power-law spectrum.



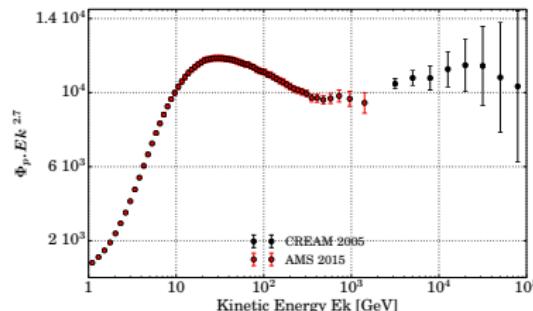
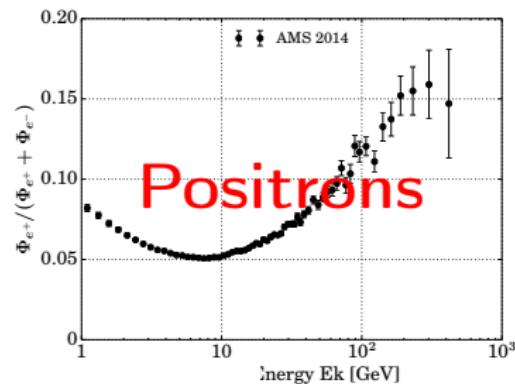
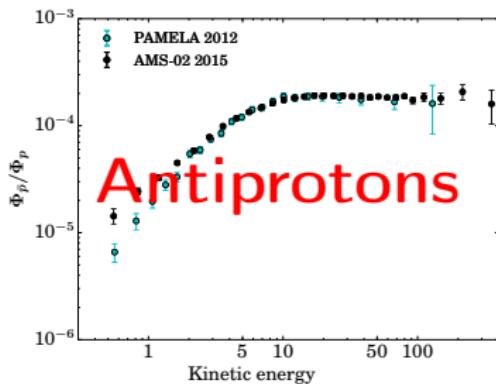
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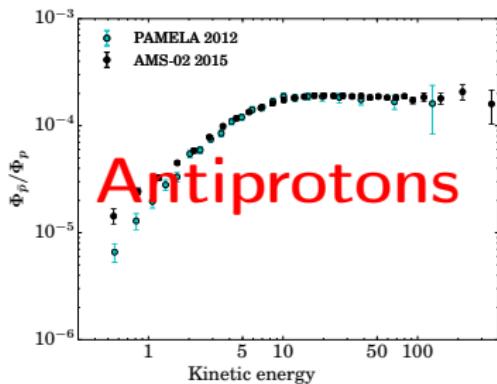
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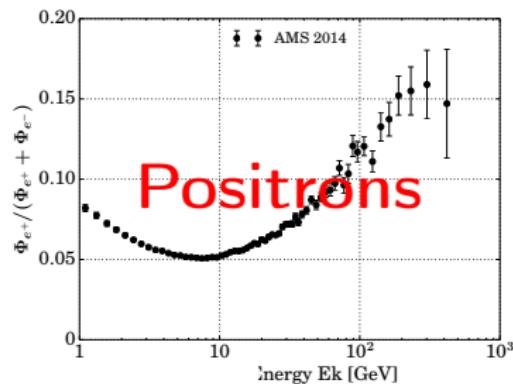
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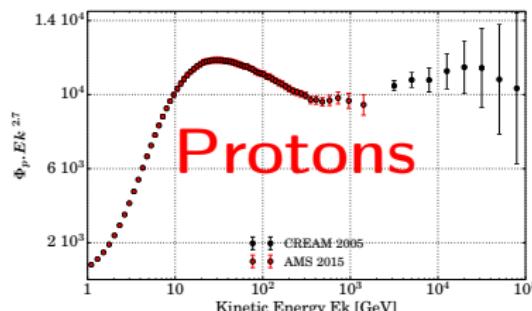
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**Antiprotons**

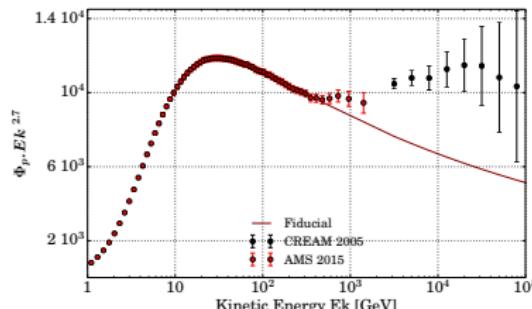
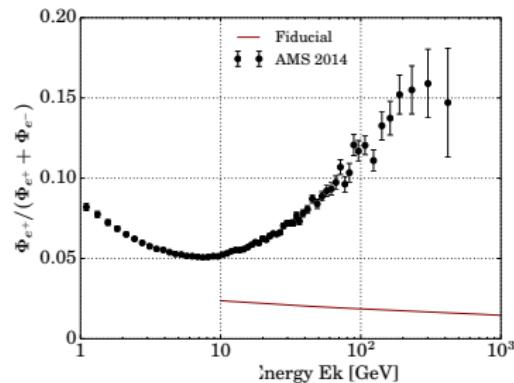
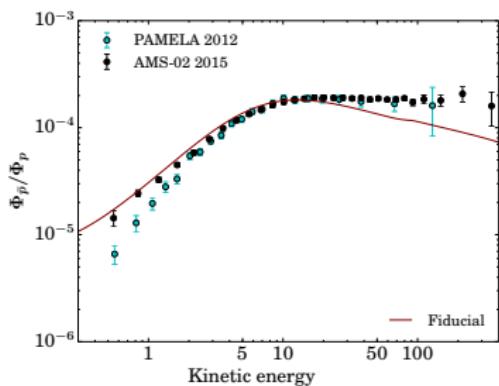


**Positrons**

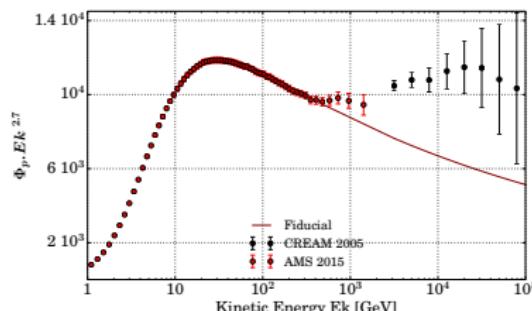
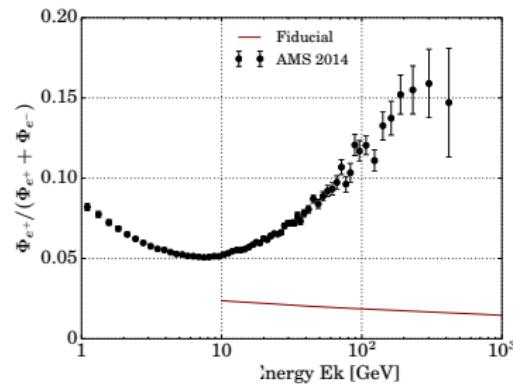
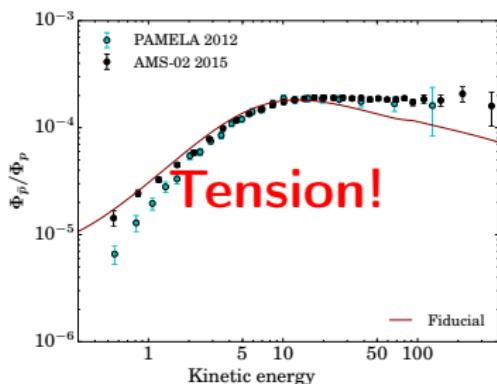


**Protons**

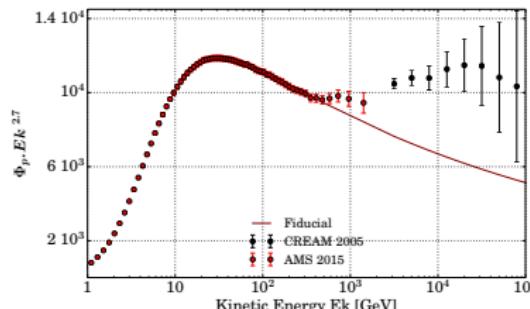
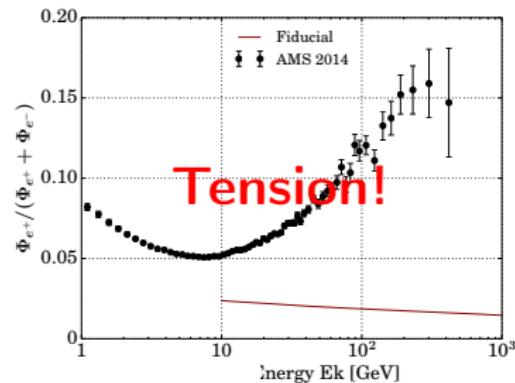
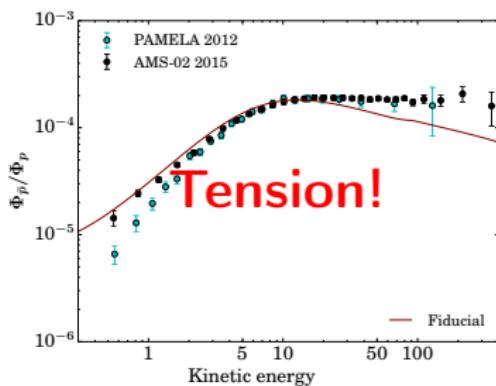
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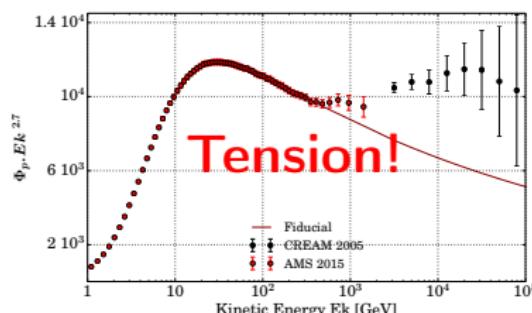
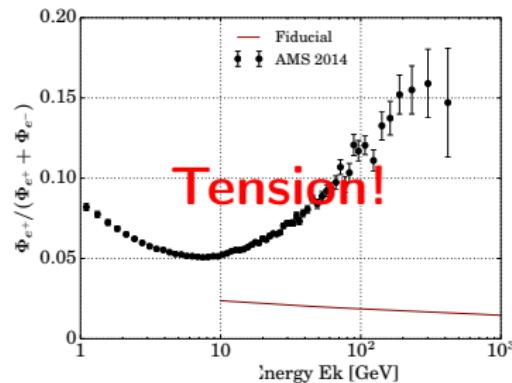
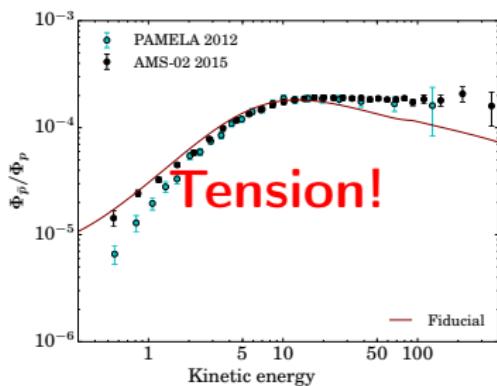
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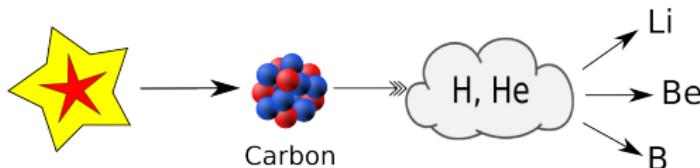
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# How do we constrain the propagation ?

We need to determine these parameters :

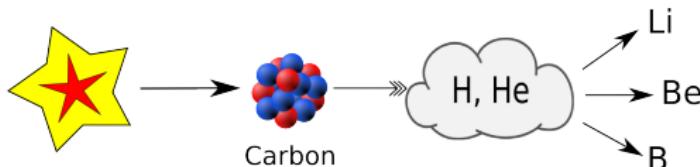
$$V_c, \quad D_x = D_0 \cdot \mathcal{R}^\delta, \quad D_p = \frac{V_A^2}{9D_x} p^2, \quad H$$

# Measuring the propagation parameters :



Li, B, Be are said secondary.

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

## Hypothesis :

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

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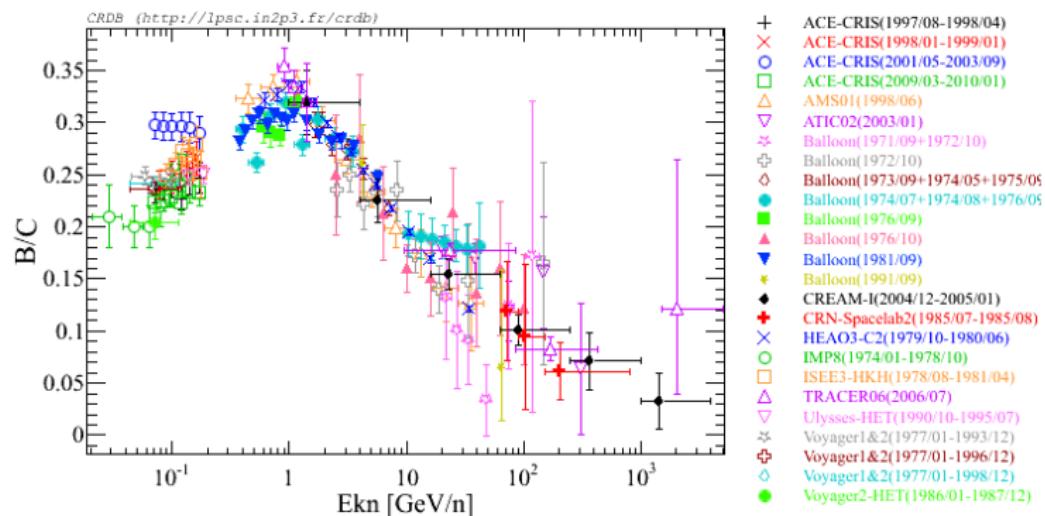
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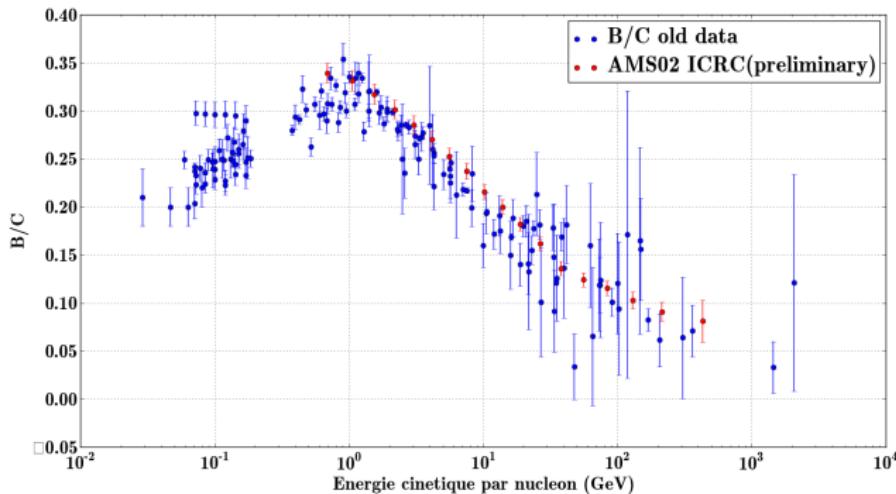
When :  $\sigma_B \ll \sigma^{\text{diff}}$   $\Rightarrow$

$$\boxed{\frac{\mathcal{J}_B}{\mathcal{J}_C} \propto R^{-\delta}}$$

# Experimental data :



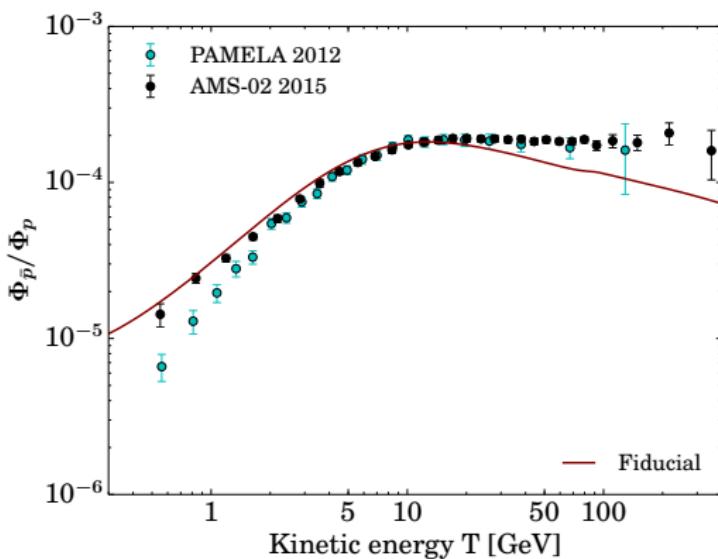
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New data with AMS02 !..and soon CALET !

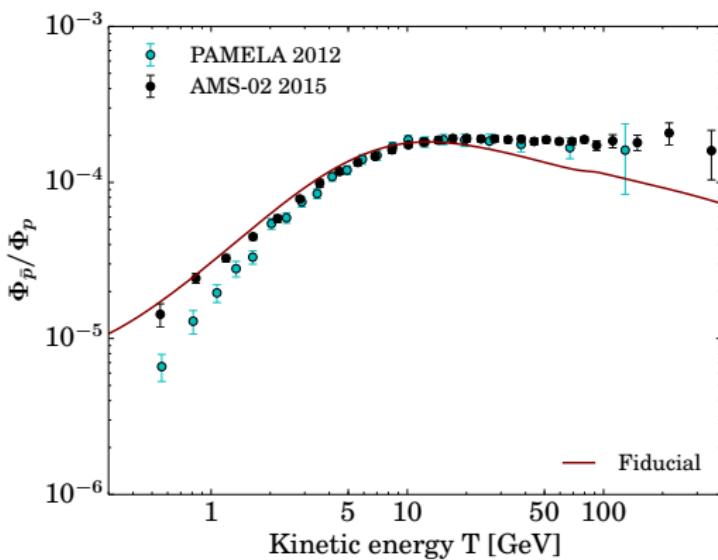
## Application to antiprotons !

# Revaluation of the astrophysical background :



Tension with the fiducial model !

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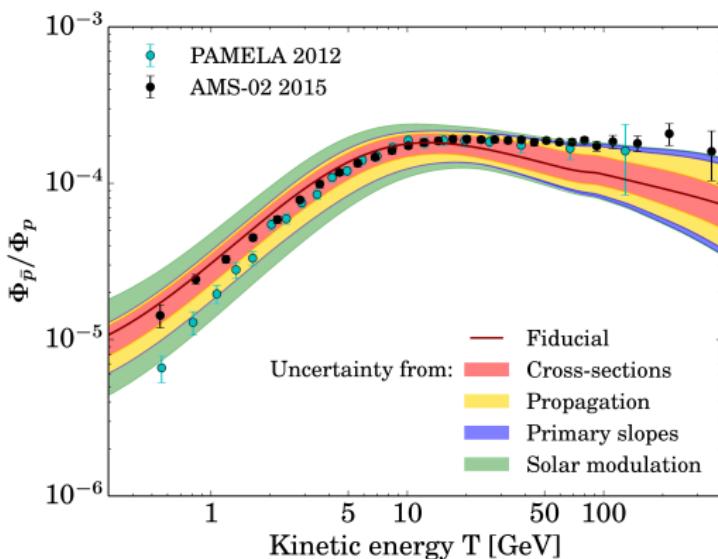
Equation in steady state :

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

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

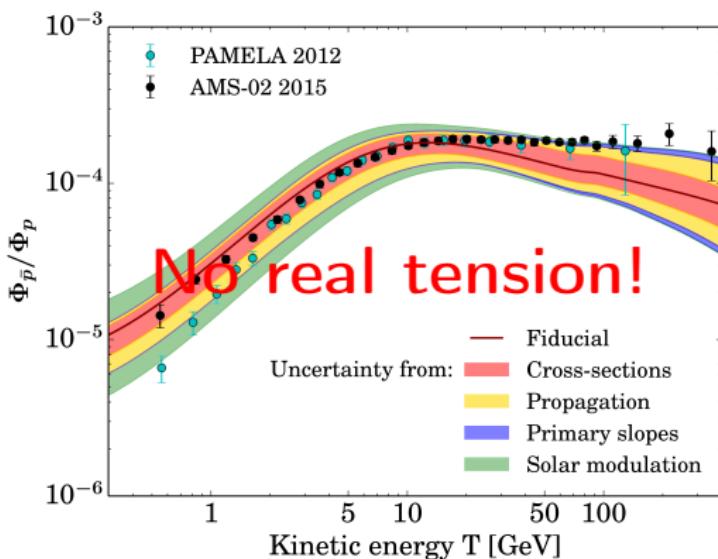
- Propagation → [Maurin 2001]
- Primary fluxes → [AMS02 2015]
- Production cross-section → [di Mauro 2014]

# Revaluation of the astrophysical background :



→ Published in [Giesen 2015]

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Giesen 2015 → arxiv[1504.0427]

# AMS-02 antiprotons, at last!

## Secondary astrophysical component and immediate implications for Dark Matter

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Marco Cirelli<sup>a</sup>, Pierre Salati<sup>b</sup>, Pasquale D. Serpico<sup>b</sup>

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<sup>b</sup> *LAPTh, Université Savoie Mont Blanc, CNRS,  
F-74941 Annecy-le-Vieux, France*

<sup>c</sup> *Institute for Theoretical Particle Physics and Cosmology (TTK),  
RWTH Aachen University, D-52056 Aachen, Germany.*

### Abstract

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

Yoann Génolini

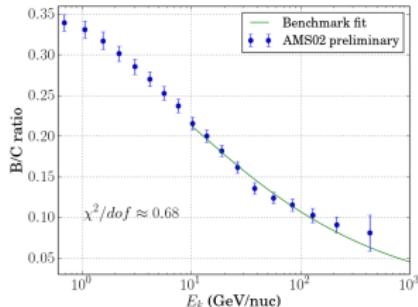
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# Benchmark model :

The goal is to minimize :

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

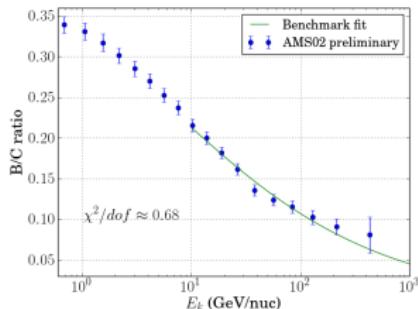


Reference parameter values	
$D_0$ [kpc <sup>2</sup> /Myr]	$(5.8 \pm 0.7) \cdot 10^{-2}$
$\delta$	$0.44 \pm 0.03$
$\chi_{\text{B/C}}^2/\text{dof}$	$5.4/8 \approx 0.68$
$\gamma = \alpha - \delta$ (fixed)	-2.78

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

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*1D/2D geometry?*

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# Primary boron ?

[Blasi 2009], [Blasi Serpico 2009], [Mertsch Sarkar 2009-14]  
→ Secondary species may be formed at sources !

- Confinement inside a SNR at TeV/nuc :

$$X_{SNR} \approx 0.17 \text{ g cm}^{-2} \frac{n_{ISM}}{\text{cm}^{-3}} \frac{T_{SNR}}{2 \cdot 10^4 \text{ yr}}$$

- Galactic diffusion at TeV/nuc :

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

⇒ Order of 10% !

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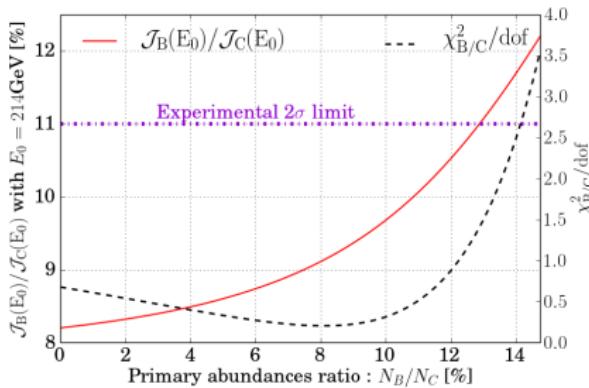
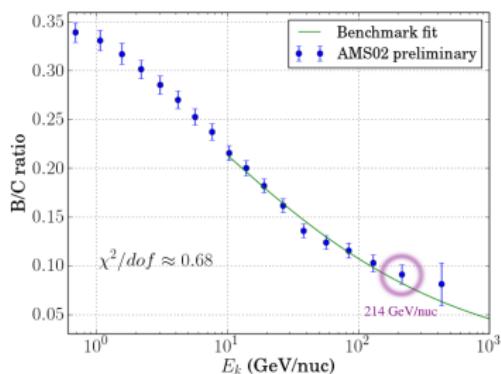
At high energy...

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

...it leads to a plateau.

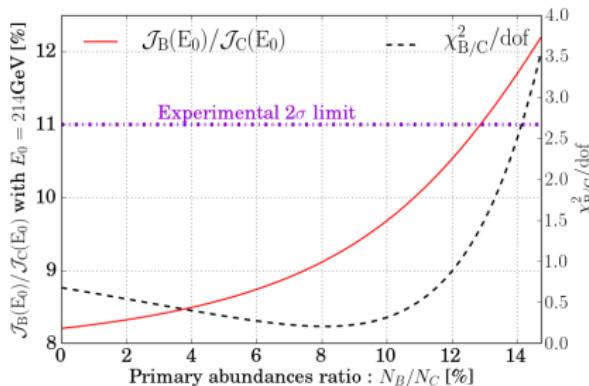
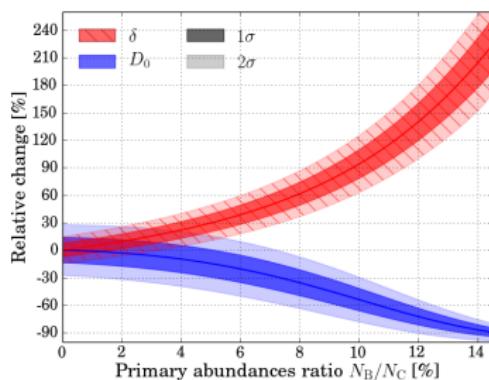
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Constraining  $\frac{N_B}{N_C}$  :



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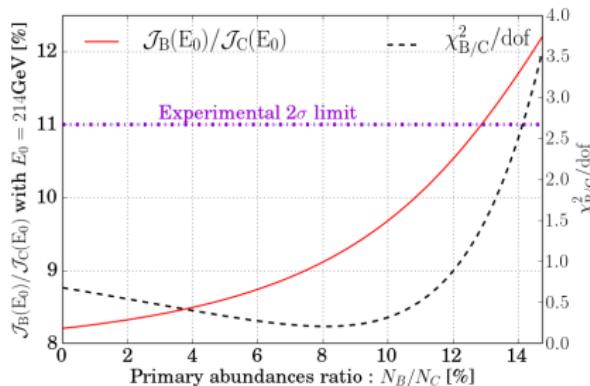
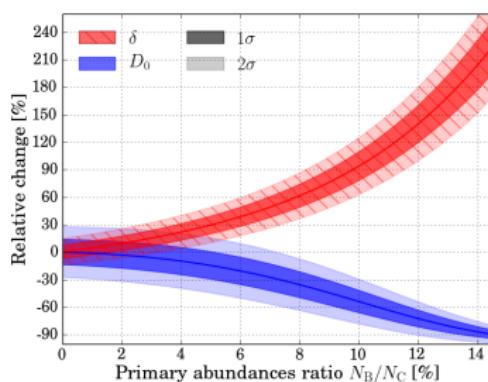
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## Summary of the main systematics :

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

## 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.

# Génolini 2015 → arxiv[1504.03134]

Astronomy & Astrophysics manuscript no. draft4  
July 22, 2015

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

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Received; accepted

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

- ① Modeling the high energy CRs fluxes
- ② Propagation paradigm
- ③ *Theoretical uncertainties on propagation*
- ④ Conclusion

## Main conclusions :

- Propagation is still very poorly known.
- Many results are inferred from simplified hypotheses.
- We hope that some spectral features will reveal generic properties of propagation and help to disentangle between different models.

**New experimental results and updated analysis will come soon !**

Thanks for listening

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