(Possible physics scenarios behind) cosmic ray "anomalies"

DISCLAIMER:

I won't talk about "Anomalous Cosmic Rays"

(most likely neutral atoms in the interstellar space leaking into heliosphere, get ionized, picked up by solar wind and accelerated e.g. at the termination shock, drifting and diffusing back in the inner heliosphere as cosmic rays**)**

Pasquale Dario Serpico

ICRC 2015 The Hague

THE SUBJECT OF MY TALK

<u>Anomaly</u>: something that is unusual or unexpected
From Latin *anomalia* & Greek ἀνωμαλία: “not the same, uneven, irregular”

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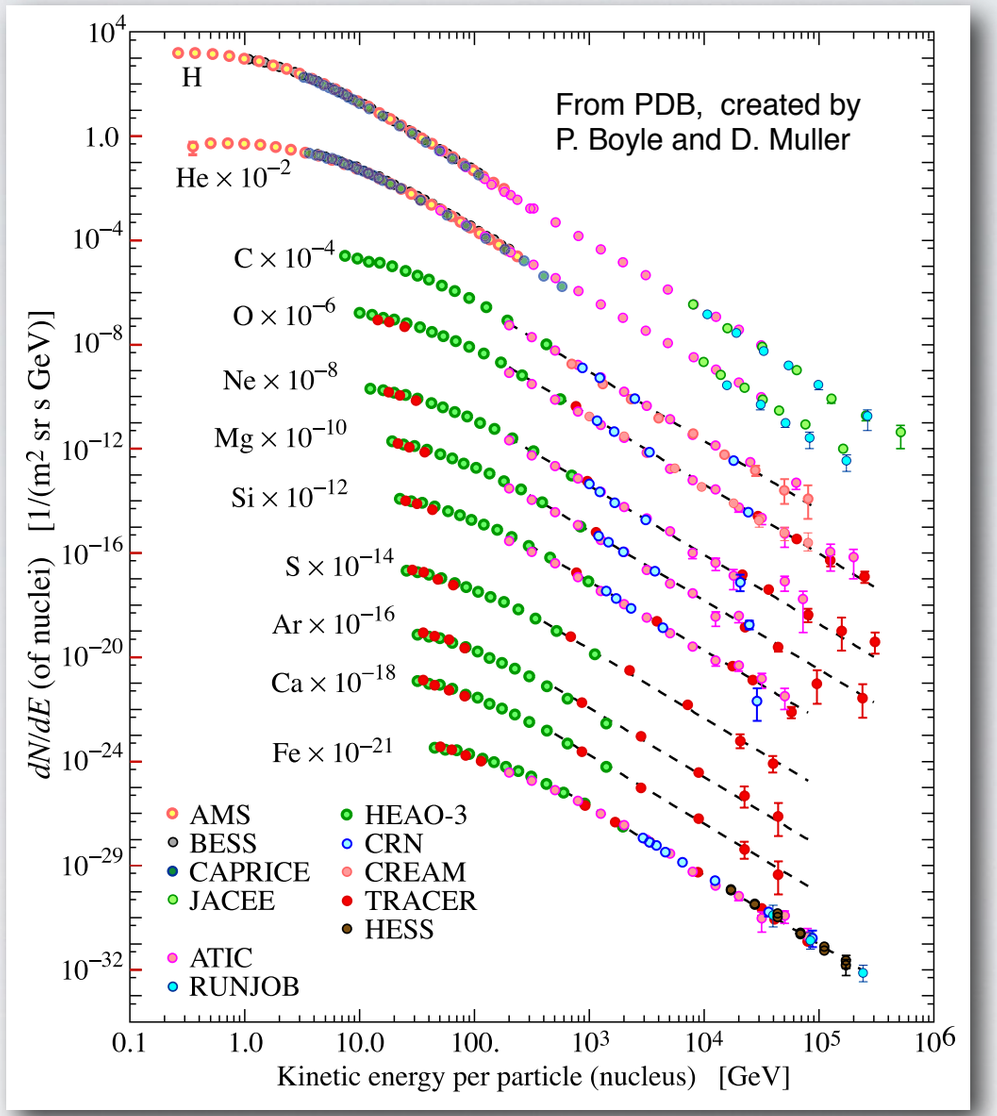
Put otherwise, remembering my PhD times in Munich, I should talk about the CR counterpart of the

I will deal with observations which seem to defy expectations about (Galactic) cosmic rays, focusing on direct detection range (rather than EAS/UHECRs) and on charged particles only (neutrinos & photons out of my talk), notably the ones emerged with clarity since past ICRC

Of course, what one's expectations are is to large extent subjective.
Bear this caveat in mind. I do acknowledge that yours might be different.

BACK TO BASICS

Probably the most obvious *expectation* about cosmic rays (0th order picture we teach in CR 101) is that, above a few GeV, they have a **"featureless & universal power-law energy spectra"**



Lots of work rely on/predict e.g. self-similarity (e.g. Fermi Theory, Kolmogorov spectrum...)

Important to test for departures from basic features: may provide clues on ***specific scales & phenomena*** shedding light on non-universal features of *injection, acceleration, escape, propagation*

HISTORICAL ANALOGY (AND A HOMAGE)

"Perfect" Gas (Clayperon, 1834) $$p\,V = n\,R\,T$$

Universal: valid for low pressure and "warm" gas, no detail of "atomic scales" enters

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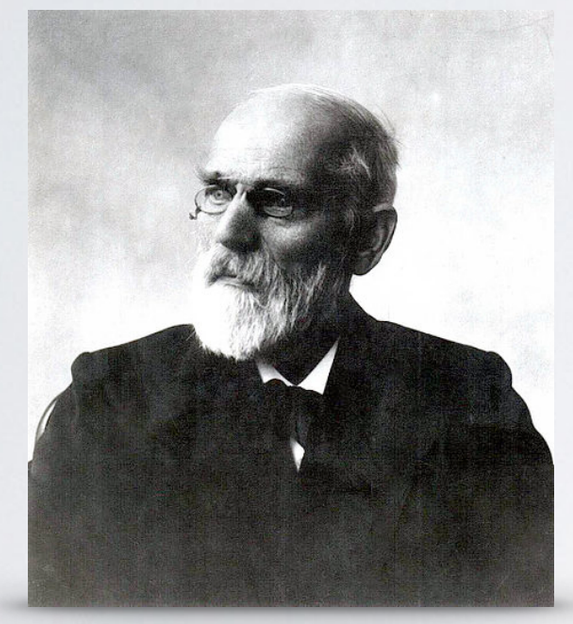
$$\left(p + \frac{n^2 a}{V^2}\right)(V - n\,b) = n\,R\,T$$

correction for *intermolecular forces*

"Atomic" scales!

correction for *finite molecular size*



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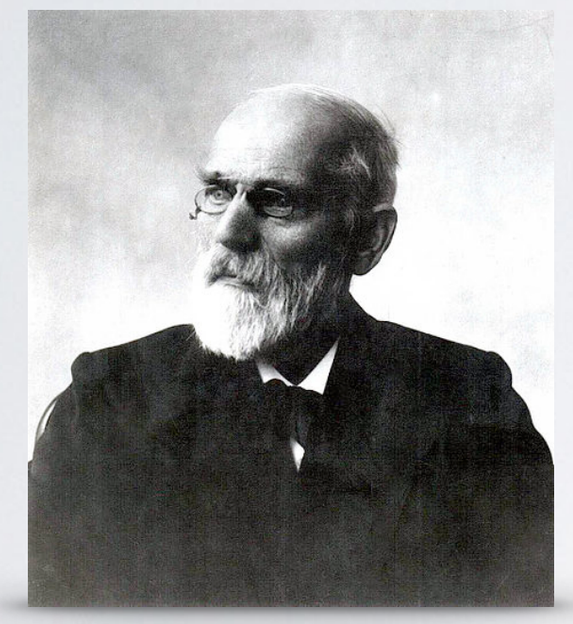

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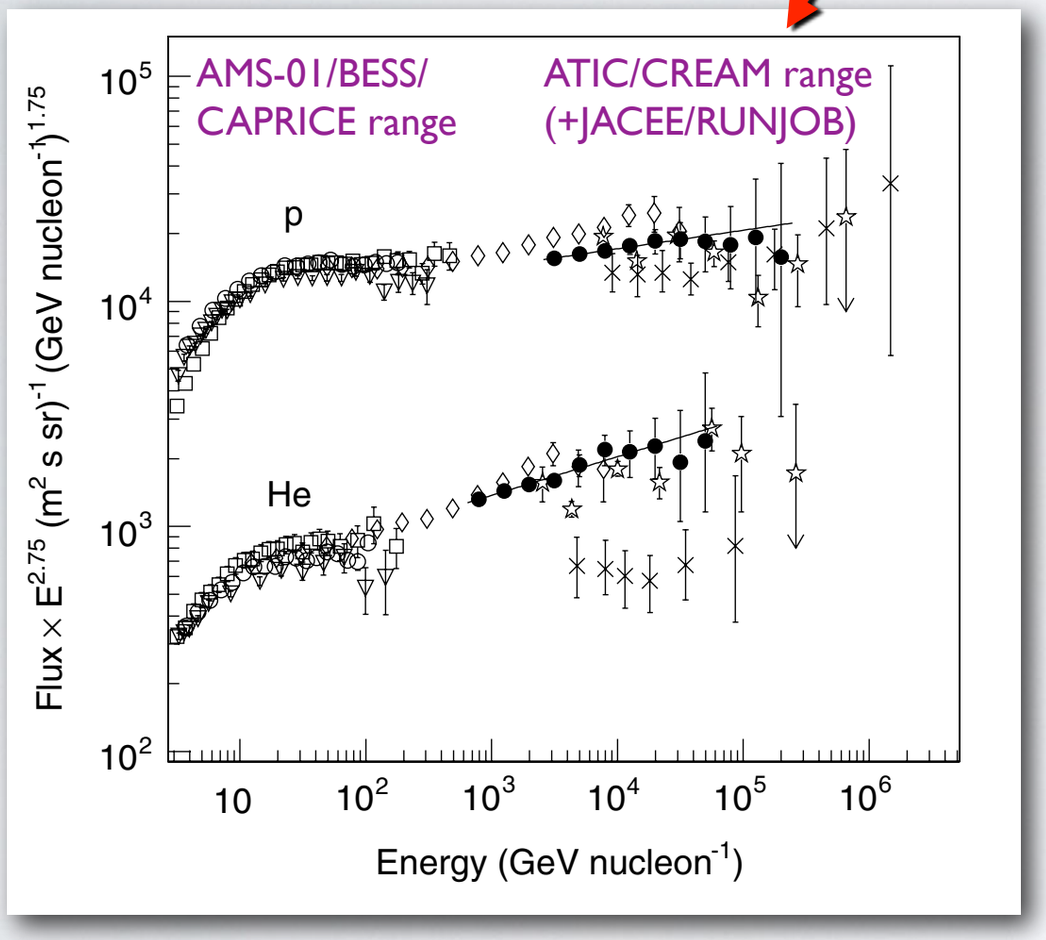
[…] It does not seem to me superfluous, perhaps <u>it is even necessary, to make a general observation</u> […] in all my studies I was quite convinced of the real existence of molecules, that I never regarded them as a figment of my imagination […] When I began my studies I had the feeling that I was almost alone in holding that view […] <u>now I do not think it any exaggeration to state that the real existence of molecules is universally assumed</u> by physicists. Many of those who opposed it most have ultimately been won over, and <u>my theory may have been a contributory factor. And precisely this, I feel, is a step forward</u>

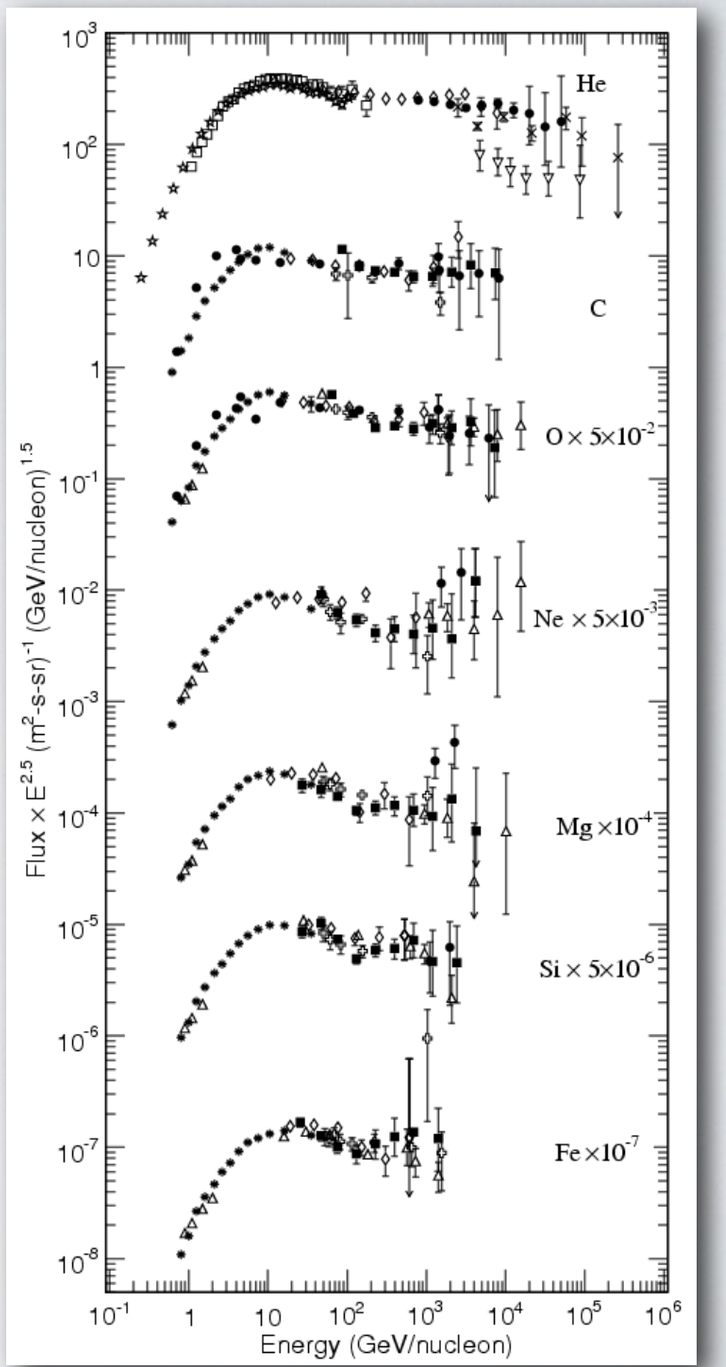
not "mere improvement in fits", but conceptual "step forward"!

HINTS OF POSSIBLE SURPRISES

When the TeV/n range became to be explored with sufficient precision-notably with ATIC-2 (*A. Panov et al 2009, Bull. Russ. Acad. Sci. Phys, 73, 564*) & CREAM (*Y. S. Yoon et al 2011 ApJ 728 122*)- hints of possible departures from extrapolations of lower energies spectra clearly emerging in *p*, He... but also seen in nuclei!



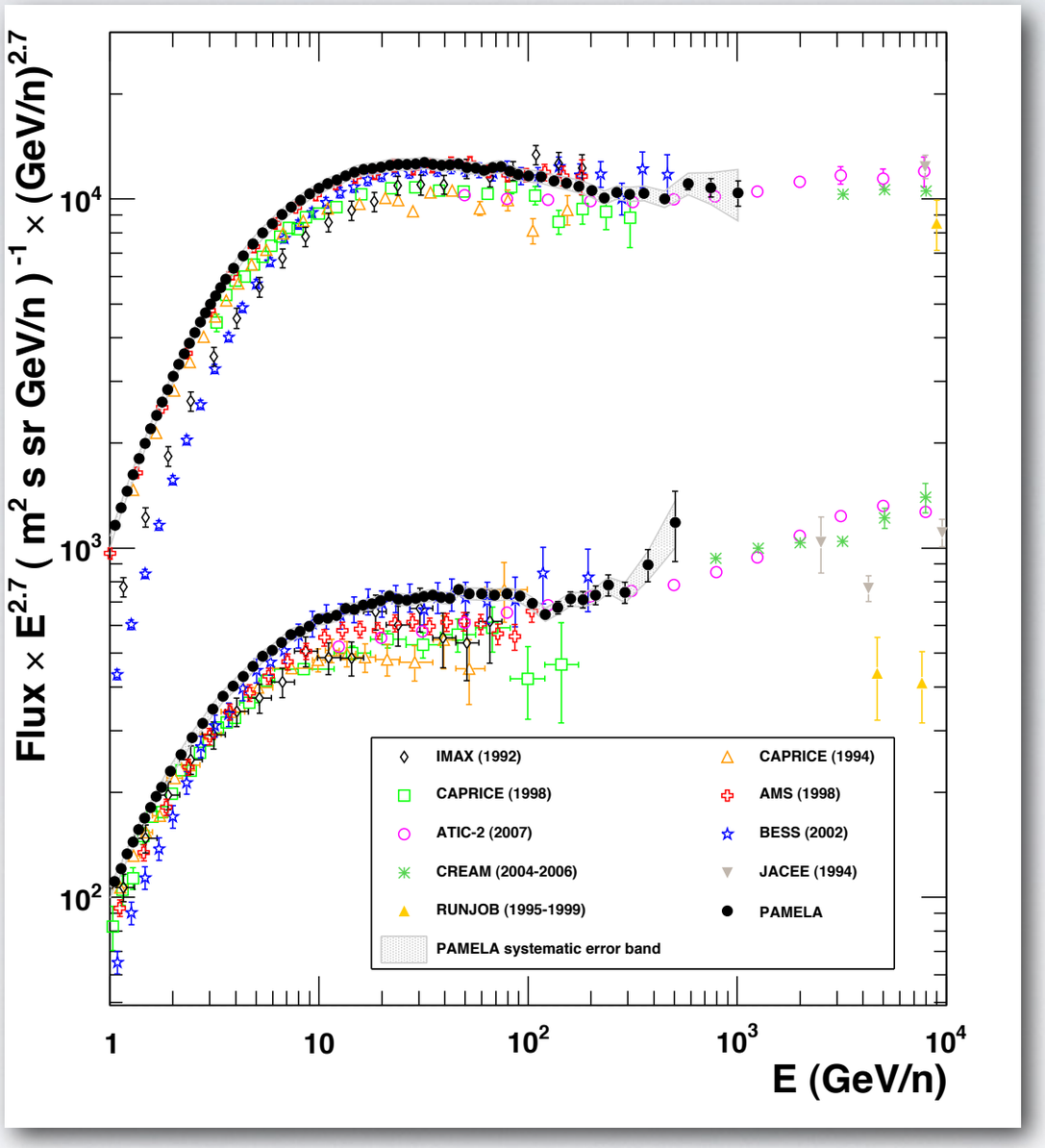
H. S. Ahn et al,
ApJ 714 (2010) L89-L93



Yet, conceivable concerns: systematics, possibly related to different experimental technologies?

1ST ANOMALY: BROKEN PL'S BELOW KNEE!

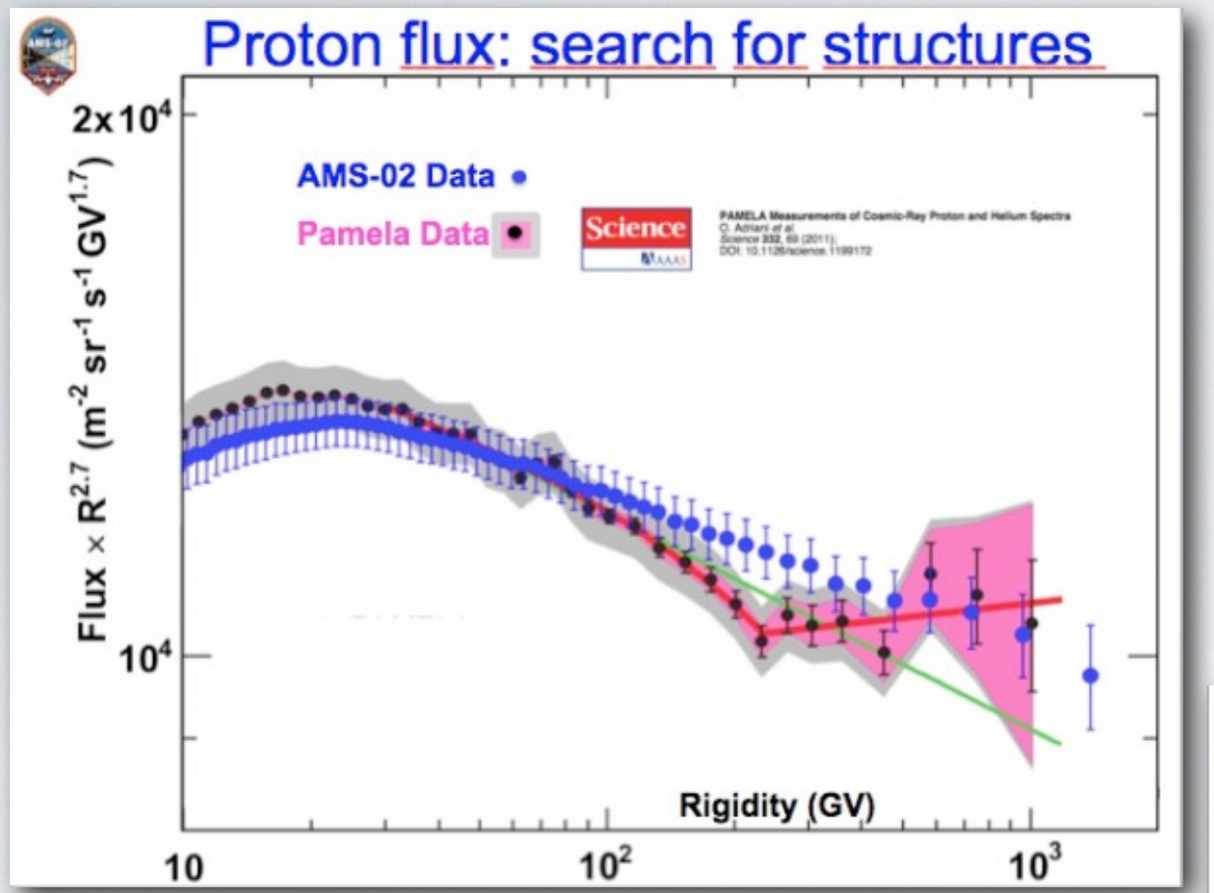
Soon after, PAMELA seemed for the first time to have a glimpse ***at the transition in p & He***



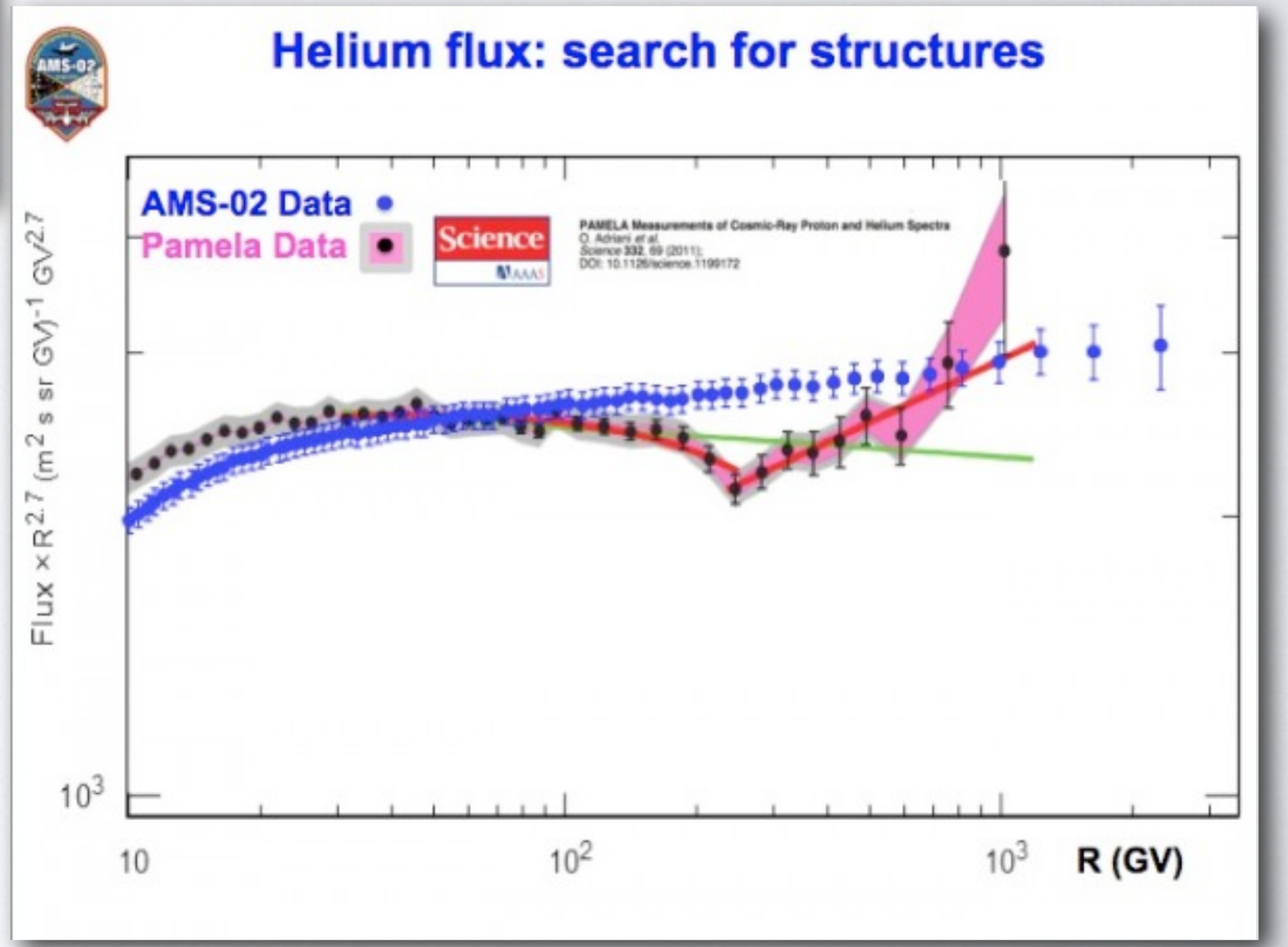
Evidence in a single instrument seemed to settle the issue!

O. Adriani et al., "PAMELA Measurements of Cosmic-ray Proton and Helium Spectra," Science 332, 69 (2011) [arXiv:1103.4055]

NOT YET! LIKE IN A GOOD THRILLER...



Preliminary results by AMS-02 @ ICRC 2013 did not confirm the picture!!!



How to make sense of the situation?

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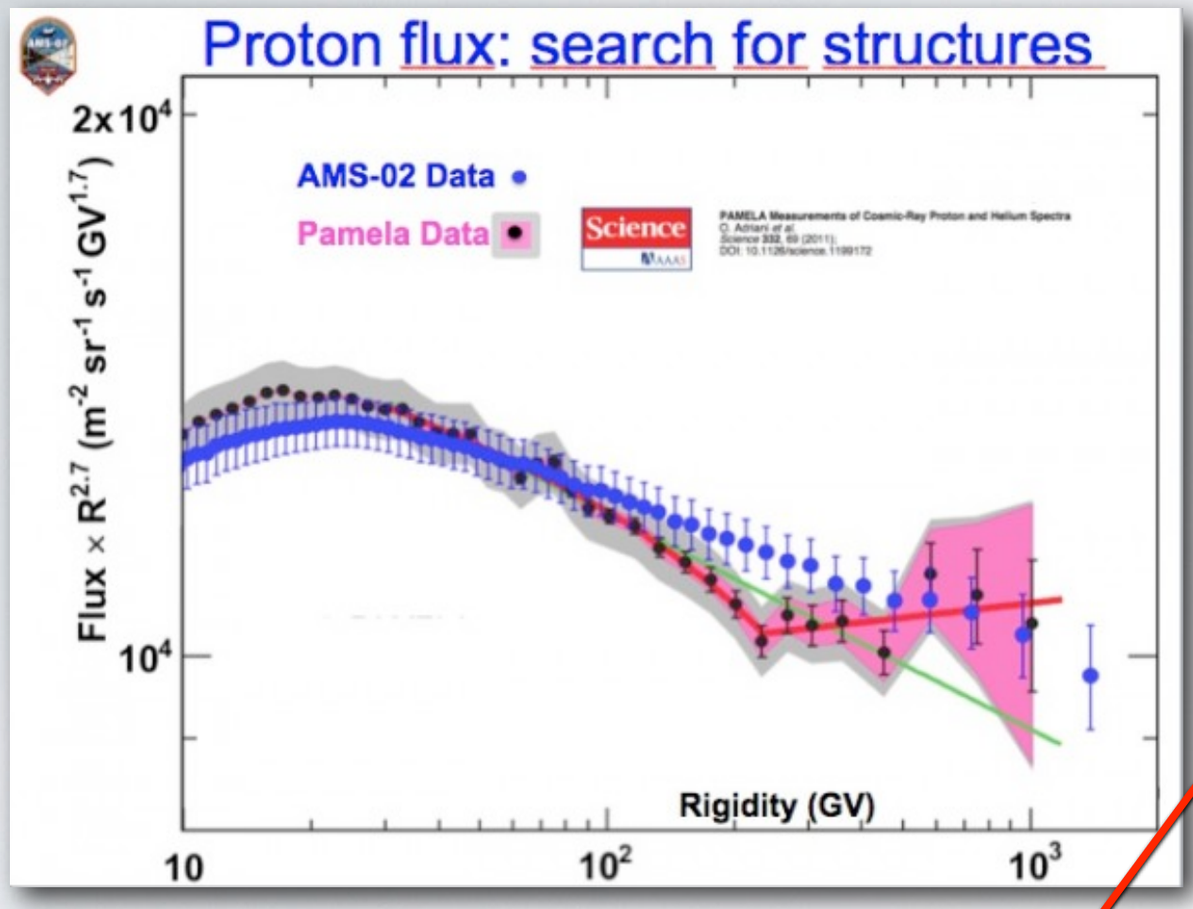

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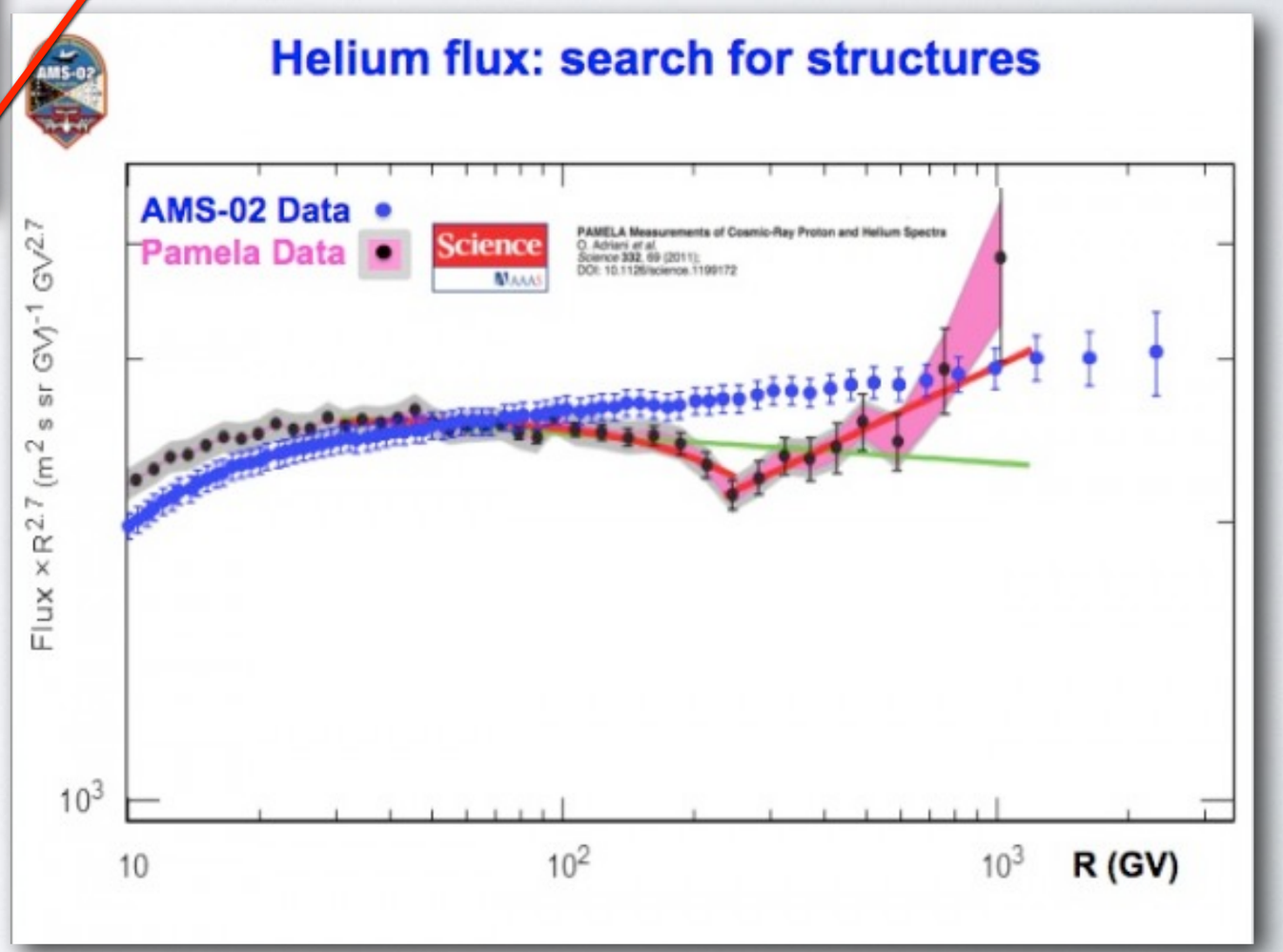

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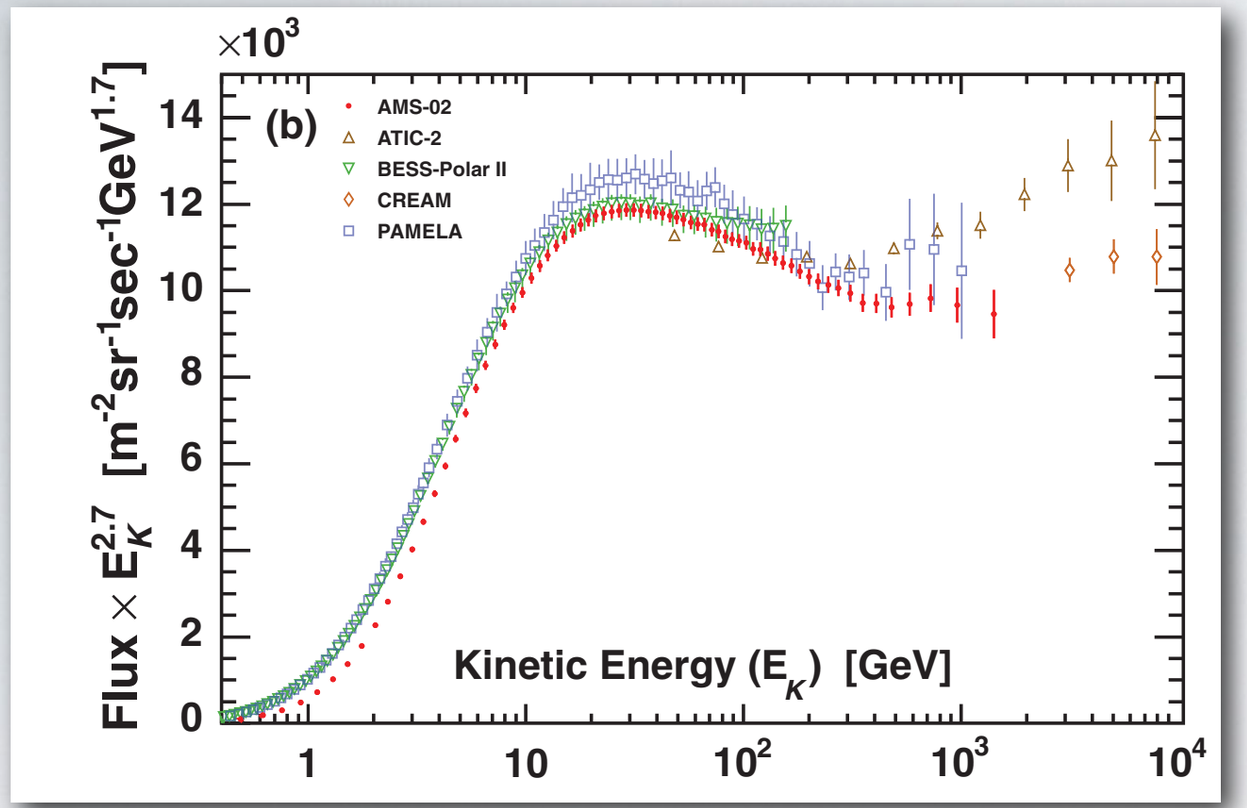
FINALLY, HAPPY ENDING



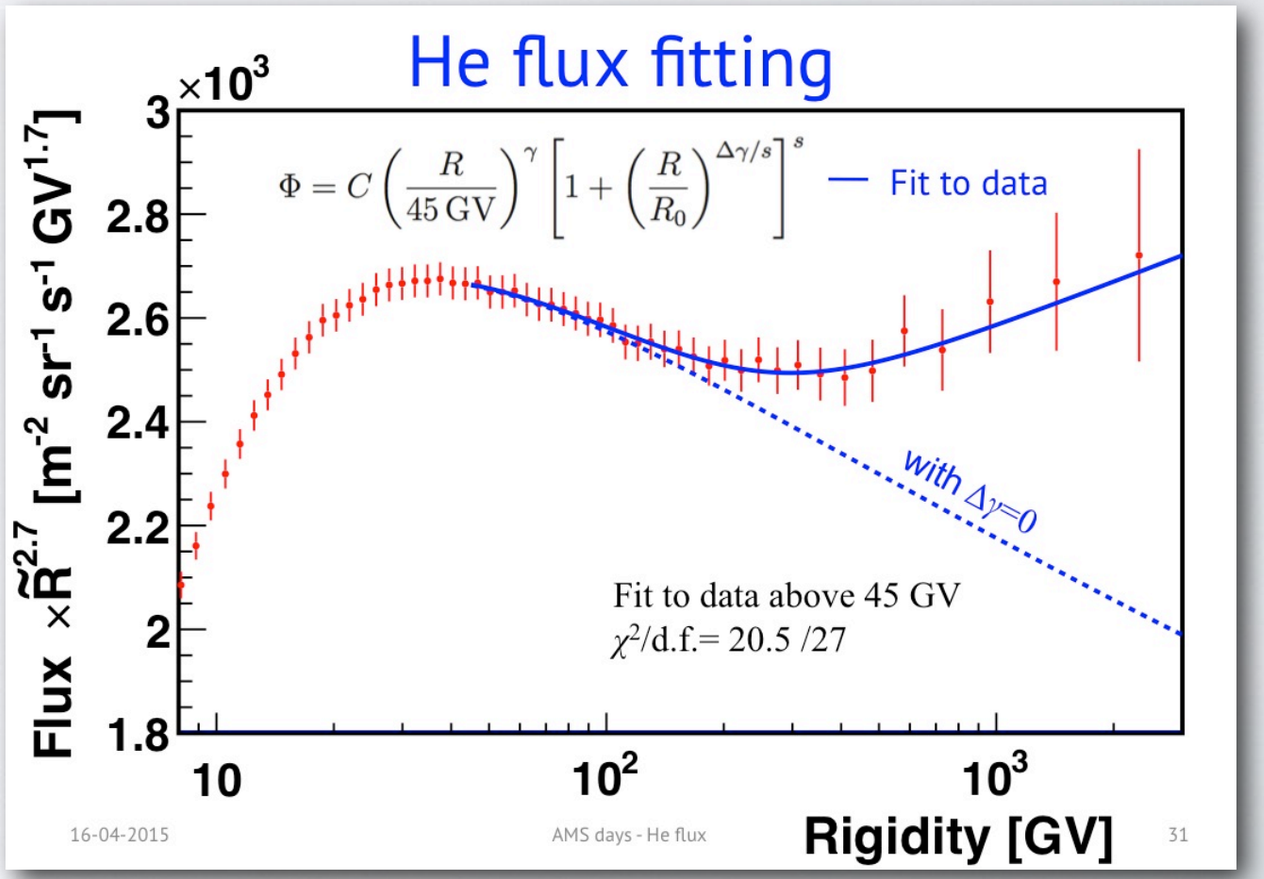
M. Aguilar et al. (AMS Collaboration)
Phys. Rev. Lett. 114, 171103 (2015)

For *p*, agreement among AMS-02, PAMELA, CREAM (to some extent also quantitatively)

Exp. hardening (AMS)=0.13(~±0.05, sys. dom)

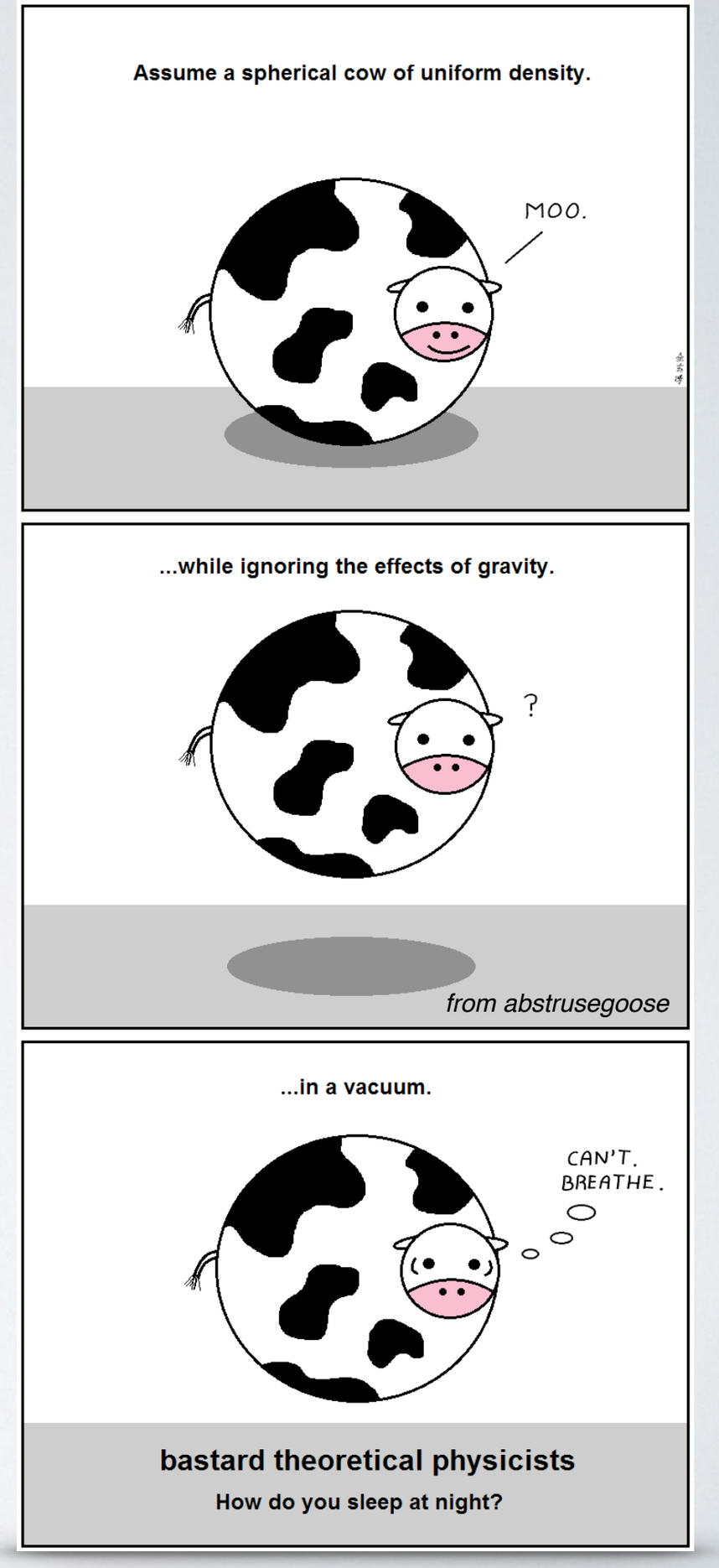
For He, updated preliminary analysis agrees at least qualitatively on the presence of a change of spectral slope *(although less prominent than PAMELA reports)*, at a rigidity ~300 GV comparable to the *p* one

S. Haino, AMS days @ CERN (AMS Collaboration)



The ball is in the theorists' court!


WARNING
THIS AREA MAY CONTAIN
TRACES OF NUTS


Assume a spherical cow of uniform density.
MOO.
...while ignoring the effects of gravity.
?
from abstrusegoose
...in a vacuum.
CAN'T.
BREATHE.
bastard theoretical physicists
How do you sleep at night?

I. PROPAGATION

Power-law injection, feature reflects corresponding one in the diffusion coefficient, ***K*** **(naturally account for universality in rigidity)**. Different models differ in what causes the feature in ***K***, **e.g.**

K not separable into energy and space variables:

N. Tomassetti, Astrophys. J. 752, L13 (2012) [arXiv:1204.4492].

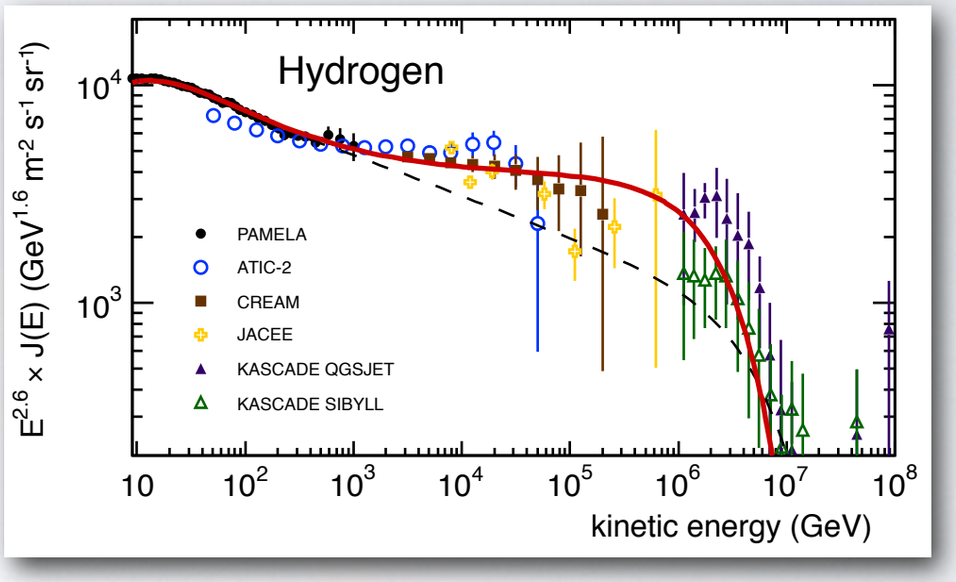
Qualitatively reflecting the fact that that turbulence in the halo (mostly CR-driven) should be different than close to the disk (mostly SNR driven)

$$K(z,\rho) = \begin{cases} k_0 \beta \rho^{\delta} & for\ |z| < \xi L\ (inner\ halo) \\ k_0 \beta \rho^{\delta+\Delta} & for\ |z| > \xi L\ (outer\ halo) \end{cases}$$

~.55

ξ~0.1

L~5 kpc



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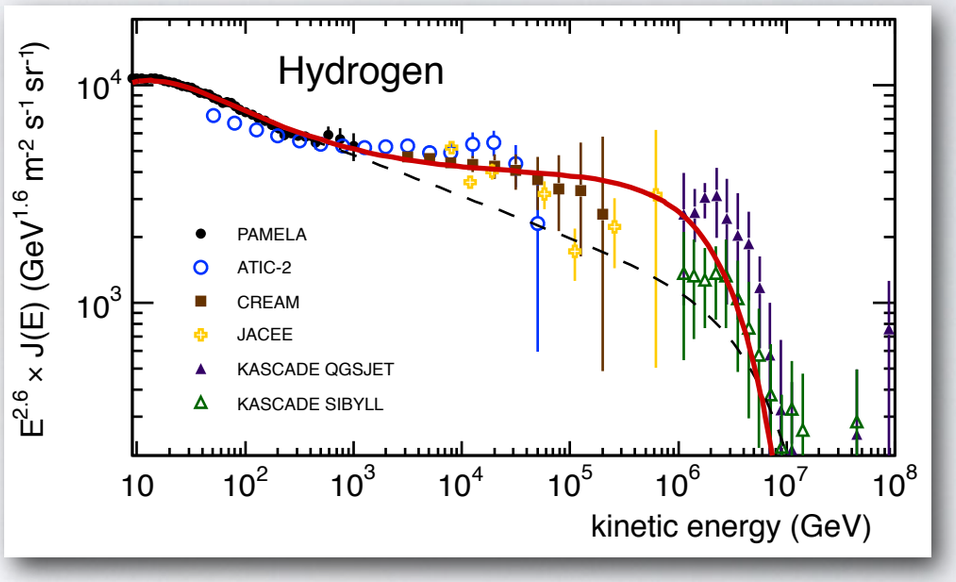
$\Delta \sim .55$

$\xi \sim 0.1$

$L \sim 5$ kpc



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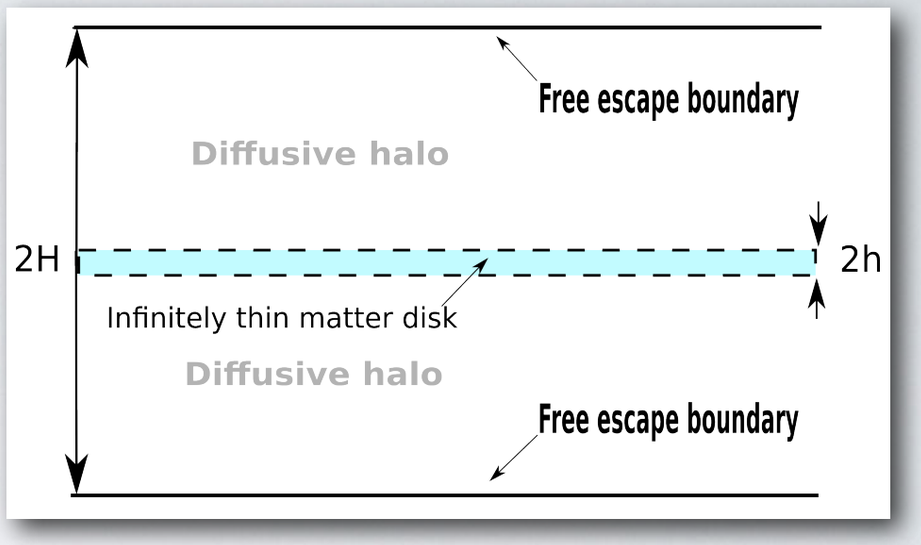
Non-linear coupling of CRs with K:

CR below the break diffuse on waves generated by CRs themselves, above the break onto external turbulence.

P. Blasi, E. Amato, PDS, Phys. Rev. Lett. 109, 061101 (2012) [arXiv:1207.3706].

NON-LINEAR COUPLING: TOY MODEL

"Infinite layer", diffusive halo height ***H***, Galactic-matter disk of infinitesimal thickness, advective wind velocity $v_c \sim v_A$ outgoing.



$$-\frac{\partial}{\partial z}\left[D\frac{\partial f}{\partial z}\right] + v_{\rm A}\frac{\partial f}{\partial z} - \frac{dv_{\rm A}}{dz}\frac{p}{3}\frac{\partial f}{\partial p} = q_{\rm CR}(z,p)$$

Remembering that

$$D(p) = \frac{1}{3} r_L(p) v(p) \left.\frac{1}{k\ W(k)}\right|_{k=qB_0/pc} \qquad \int_{k_0}^{\infty} dk\ W(k) = \eta_B = \frac{\delta B^2}{B_0^2},$$

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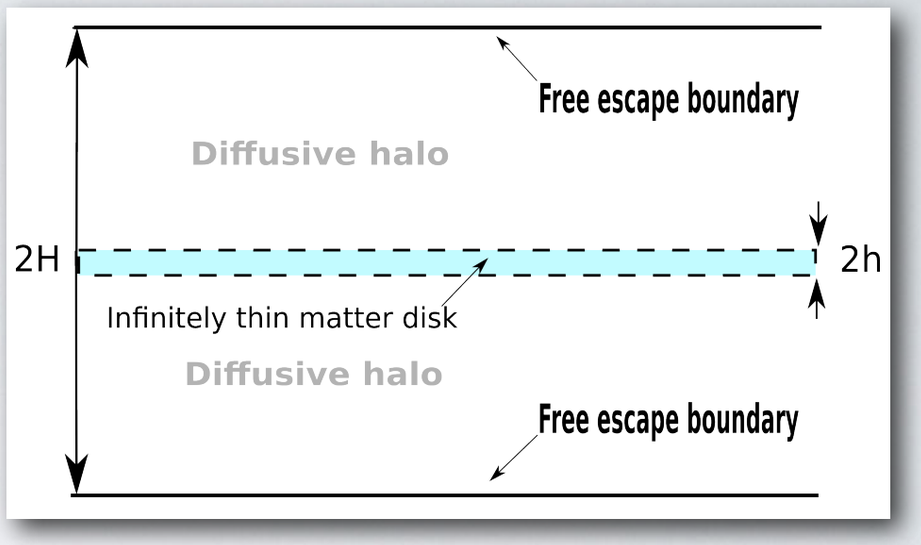

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CR transport eq. solved iteratively with the following one for the waves to which it is coupled

$$\frac{\partial}{\partial k}\left[D_{kk}\frac{\partial W}{\partial k}\right] + \Gamma_{\rm CR} W = q_W(k).$$

External power injected at large scale, e.g. SNRs at ~1/50 pc

$$q_W \propto \delta(k - k_0)$$

Non-linear "wave-wave" coupling → cascade

$$D_{kk} = C_{\rm K} v_{\rm A} k^{7/2} W(k)^{1/2}$$

Streaming instability rate (coupling with CR)

$$\Gamma_{\rm CR}(k) = \frac{16\pi^2}{3}\frac{v_{\rm A}}{k\,W(k)B_0^2}\left[p^4 v(p)\frac{\partial f}{\partial z}\right]_{p=qB_0/kc}$$

SANITY CHECK

In absence of CR coupling, one finds the well-known Kolmogorov spectrum

$$W_{\rm ext}(k) = (2\eta_B/3k_0)\ (k/k_0)^{-5/3}\ \Theta(k-k_0)$$

the input spectrum of CRs $f_0(p) = A_p(p/m\,c)^{-\gamma_p}$ implies that the NLLD diffusion rate (Γ_{NL}~D_{kk}/k^2) equals the CR instability growth rate (i.e. CR driven waves saturation condition) at

The right transition energy scale $$E_{\rm tr} = 228\ {\rm GeV}\left(\frac{R_{d,10}^2 H_3^{-1/3}}{\xi_{0.1} E_{51} \mathcal{R}_{30}}\right)^{\frac{3}{2(\gamma_p-4)}} B_{0,\mu}^{\frac{2\gamma_p-5}{2(\gamma_p-4)}}$$

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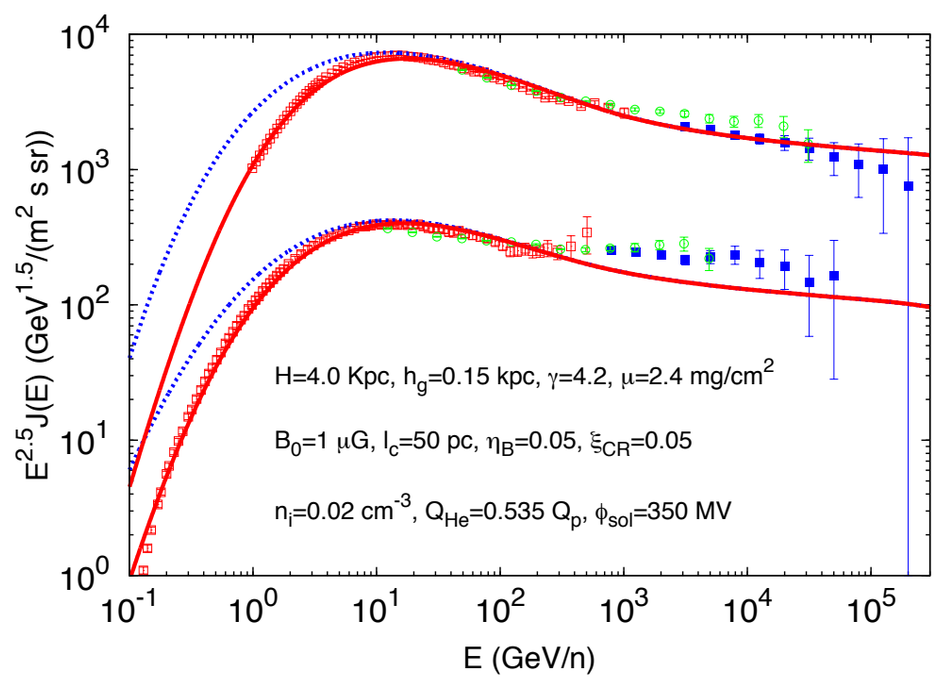
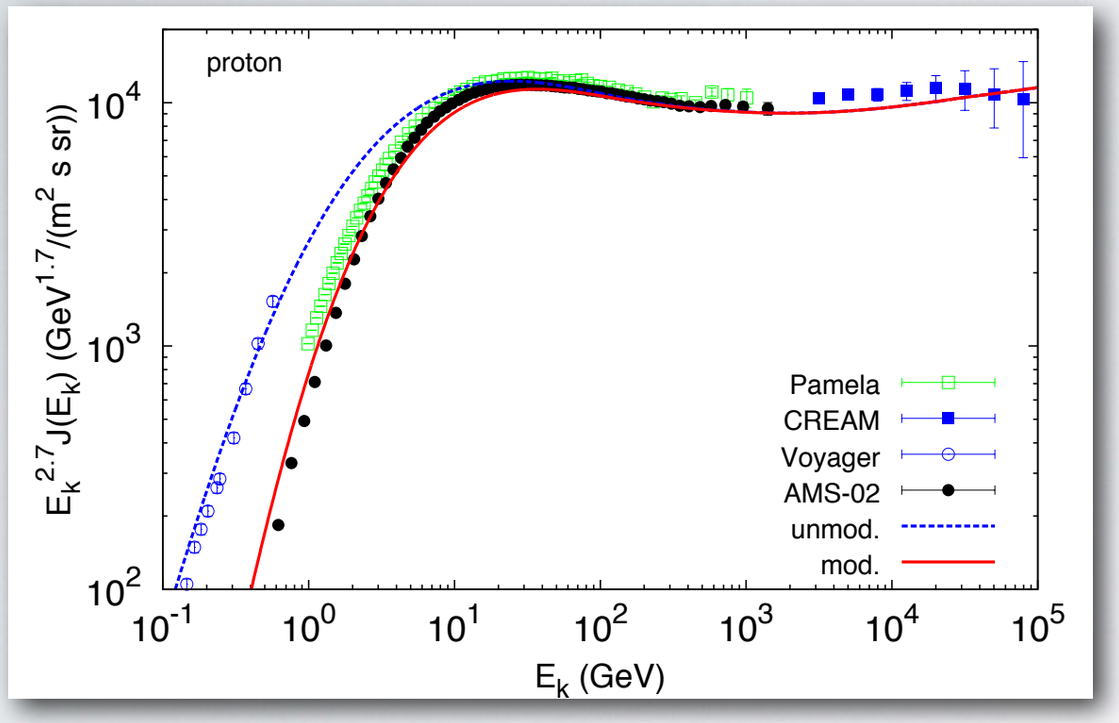
Pheno consequences already worked out a couple of years ago and overall a remarkable agreement with data

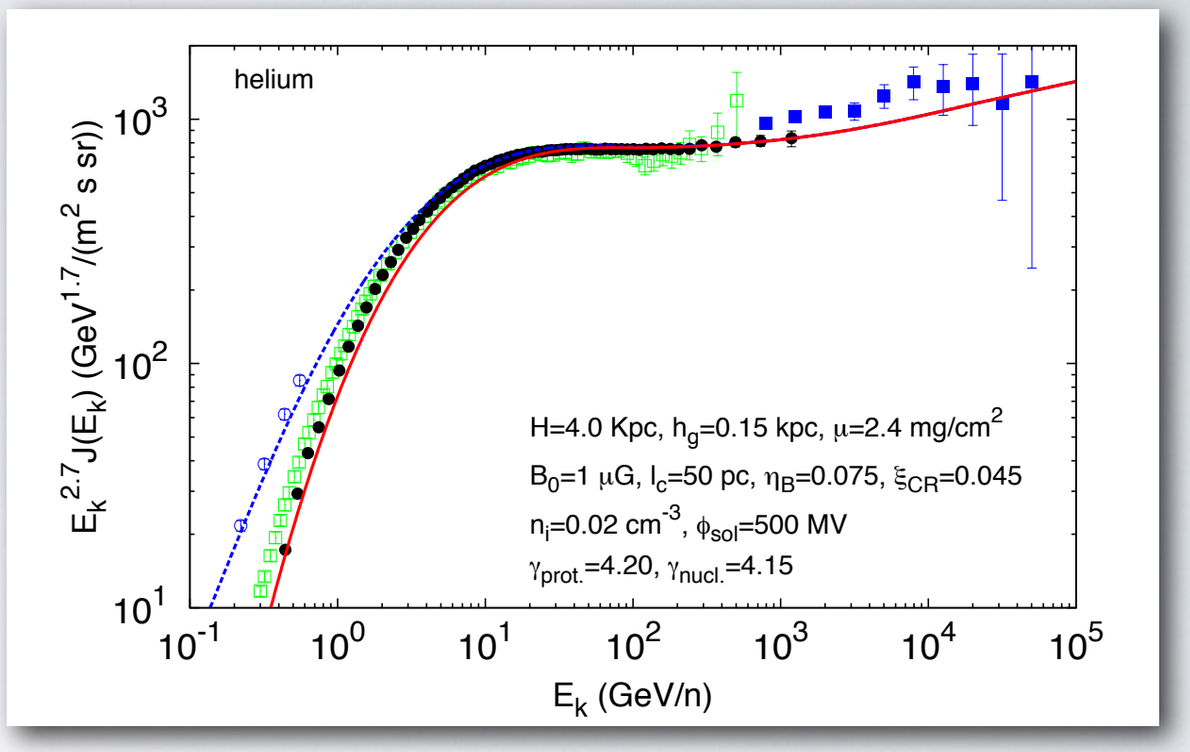
R. Aloisio and P. Blasi, JCAP 1307, 001 (2013) [arXiv:1306.2018]

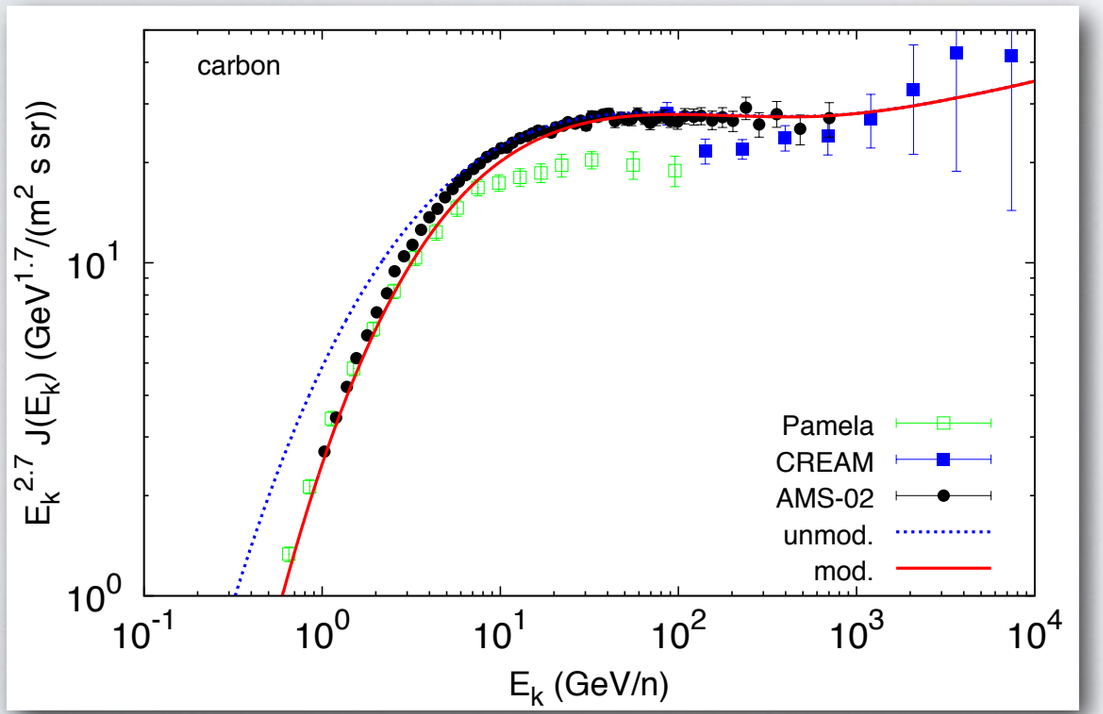


REVISITING THE MODEL

in the light of AMS-02 and Voyager (*E. C. Stone et al.. Science, 341 (2013) 150*) data







despite its simplicity & the low number of free parameters, remarkable level of agreement over 6 decades of energy!

(notably even with the "unmodulated" data at low-E, where transport is essentially advective)

R. Aloisio, P. Blasi and PS,
"Non-linear cosmic ray Galactic transport in the light of AMS-02 and Voyager data," arXiv:1507.00594

II. AT ACCELERATION SITE

One can play with acceleration population(s), acceleration mechanisms, or escape. For instance:

- ***"Natural" evolution of Mach number, $\mathcal{M}$,*** **within DSA**

High-E CR accelerated/escape early on when $\mathcal{M}>>1$, spectral index α~2, while low-E later when $\mathcal{M}$ is relatively low, α steeper, remembering

$$\alpha = 2\frac{\mathcal{M}^2+1}{\mathcal{M}^2-1}$$

- ***Multiple sources/sites***

E.g. harder high-E component involving OB associations - Superbubbles, explosion of stars into magnetized winds (like Wolf-Rayet), as proposed in the past, e.g.

T. Stanev, P. L. Biermann & T. K. Gaisser, A&A 274, 902 (1993)

E. Parizot et al. A&A 424, 747 (2004)

- ***"Natural" consequence of non-linear DSA***

concavity of spectrum resulting from the nonlinear nature of DSA (but why reflected in escaping particles? Why universality?)

V. Ptuskin, V. Zirakashvili, E. S. Seo, ApJ 763, 47 (2013)

- ***(Weak) reacceleration***

In the sense of *E. Seo & V. Ptuskin, ApJ 431, 705 (1994)*

Associated to the volume of ISM occupied by SNR shocks (mostly old, low $\mathcal{M}$), parameters too extreme? (e.g. p & He spectrum too steep)

S. Thoudam and J. R. Hörandel, A&A. 567, A33 (2014)

Key (common) questions:

how easily reproduce the observed spectral shapes? How universal is the mechanism?

III. DUE TO EFFECT OF LOCAL SOURCES

I.e. hardening due to CR released from local young CR sources, but typically needs fast diffusion and low SN rate, in tension with other observations

G. Bernard, T. Delahaye, P. Salati & R. Taillet, A&A 544, A92 (2012) [arXiv:1204.6289]

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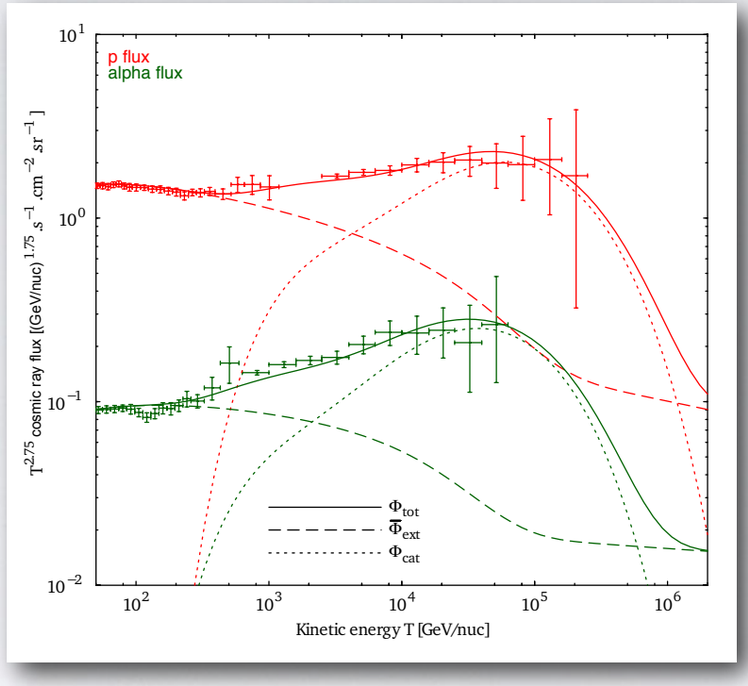
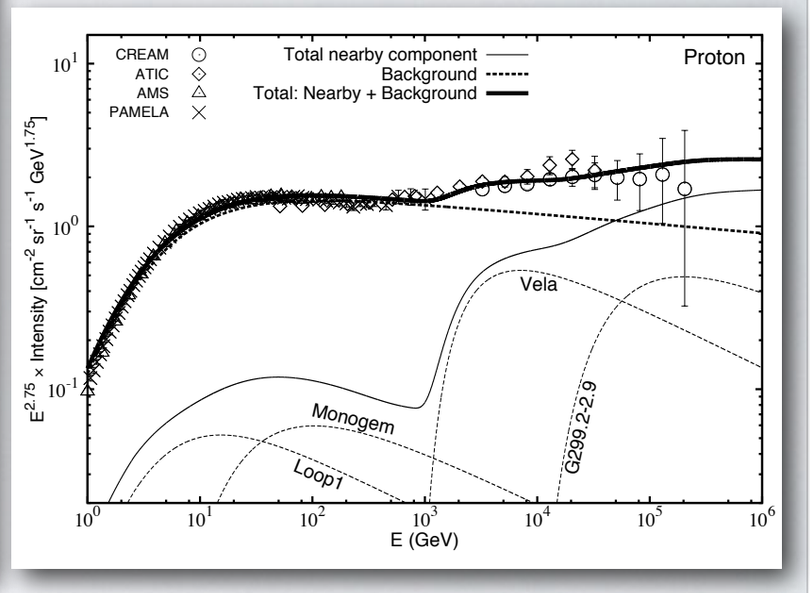


S. Thoudam and J. R. Horandel, MNRAS 421, 1209 (2012) [1112.3020] MNRAS 435, 2532 (2013) [1304.1400]



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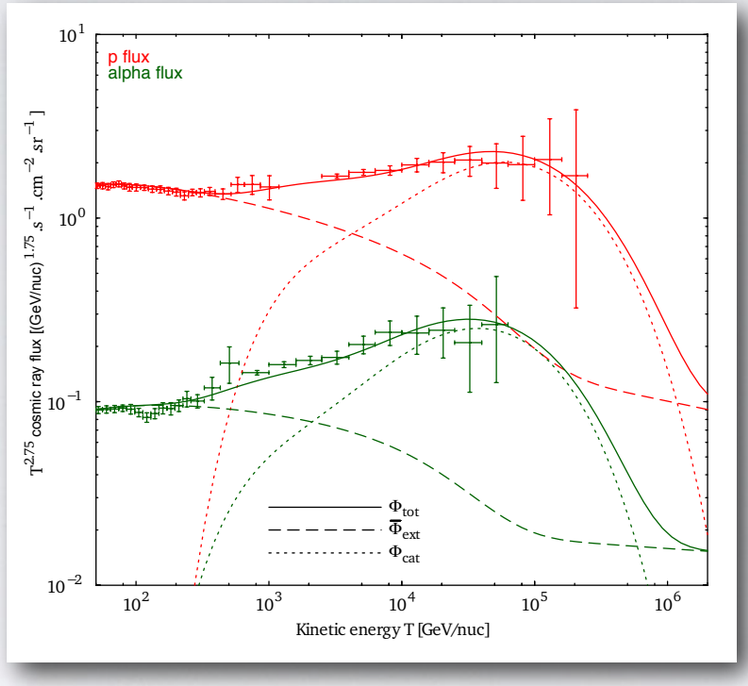

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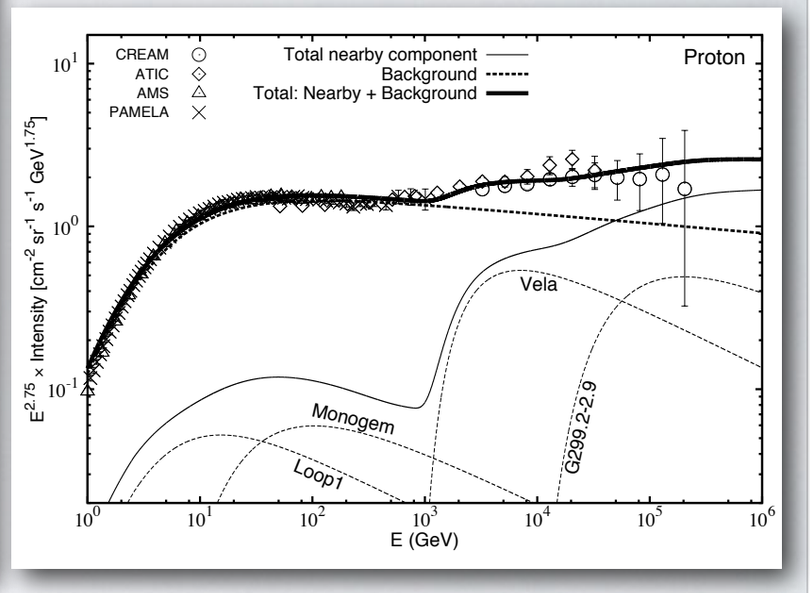
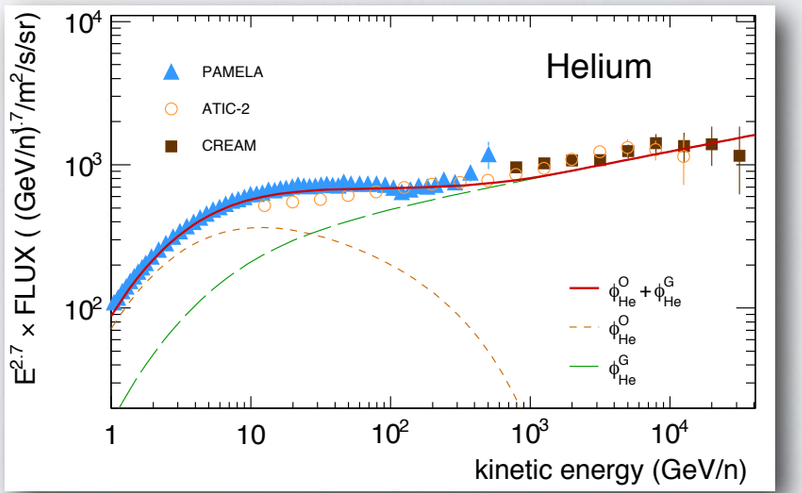


As another example, it has also been proposed that some "local/old" source contributes at low-E, & overall contribution of young and further away ones dominates at high-E

+ Easily allows for a hadronic origin of the e^+ excess
- "breaking" a link, loses predictivity

N. Tomassetti and F. Donato, ApJ 803, 2, L15 (2015) [arXiv:1502.06150]



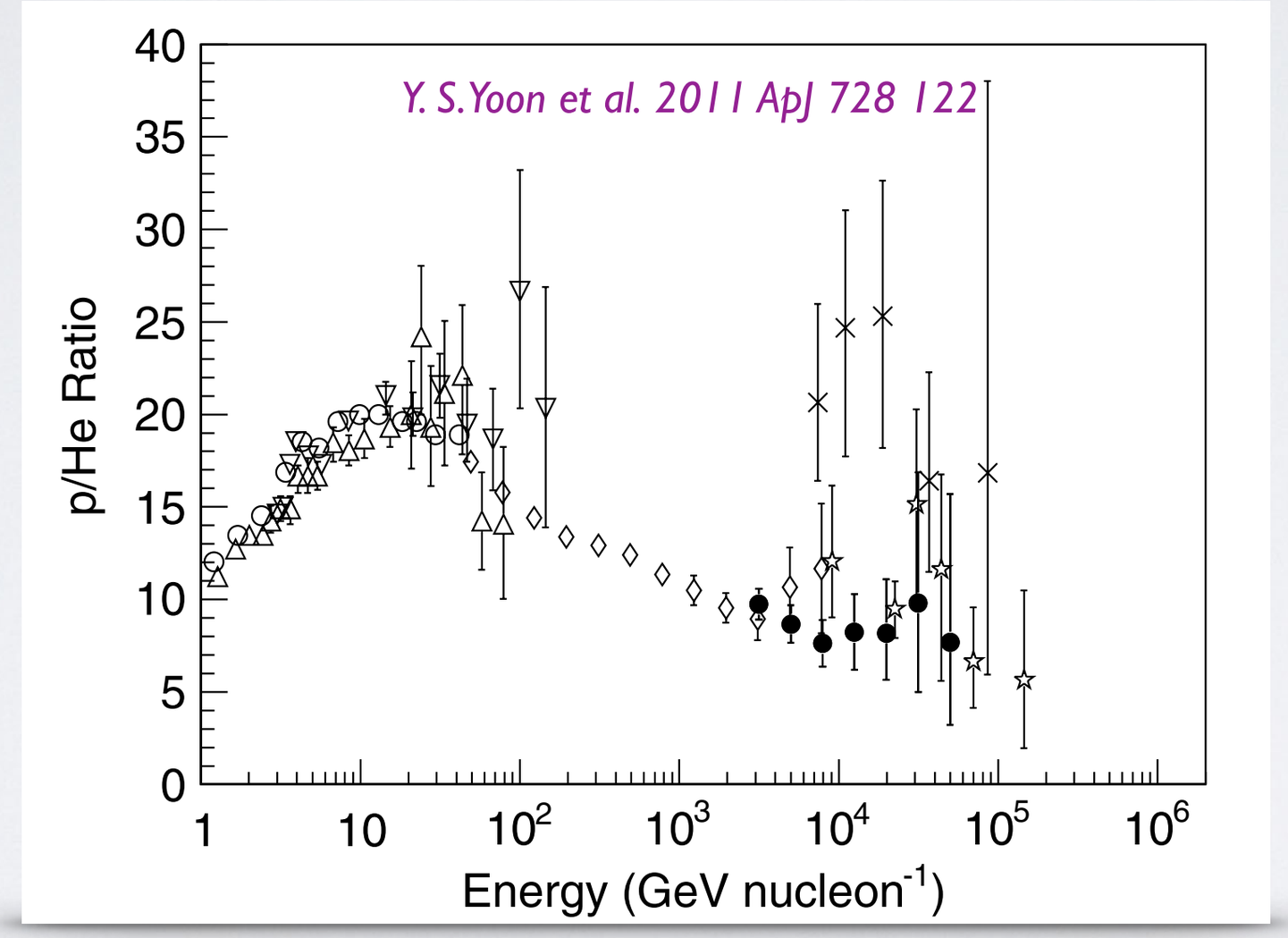
LET ME PAUSE A BIT, IT'S TIME TO INTRODUCE ANOTHER "ANOMALY"...

2ND ANOMALY: NON-UNIVERSALITY

Above O(10) GeV/n, He spectrum ~0.1 harder than the *p* one

ATIC-2 (*Panov, A. D., et al. 2009, Bull. Russ. Acad. Sci. Phys, 73, 564*) and CREAM (*Y. S. Yoon et al. 2011 ApJ 728 122*)

as well older experiments already offering strong indications in that sense...

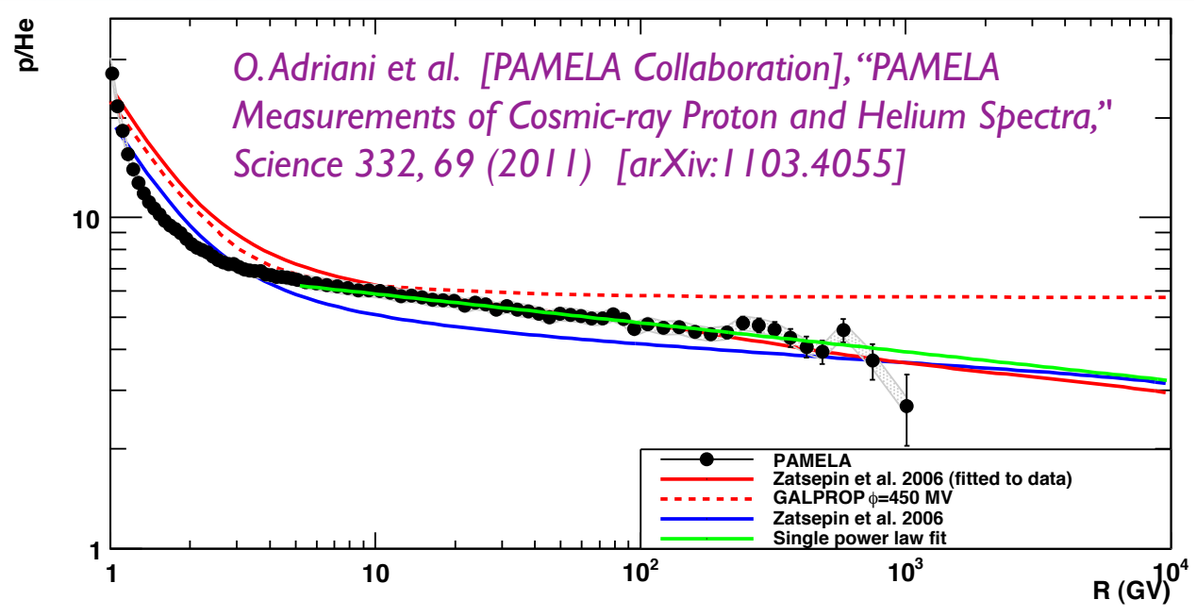


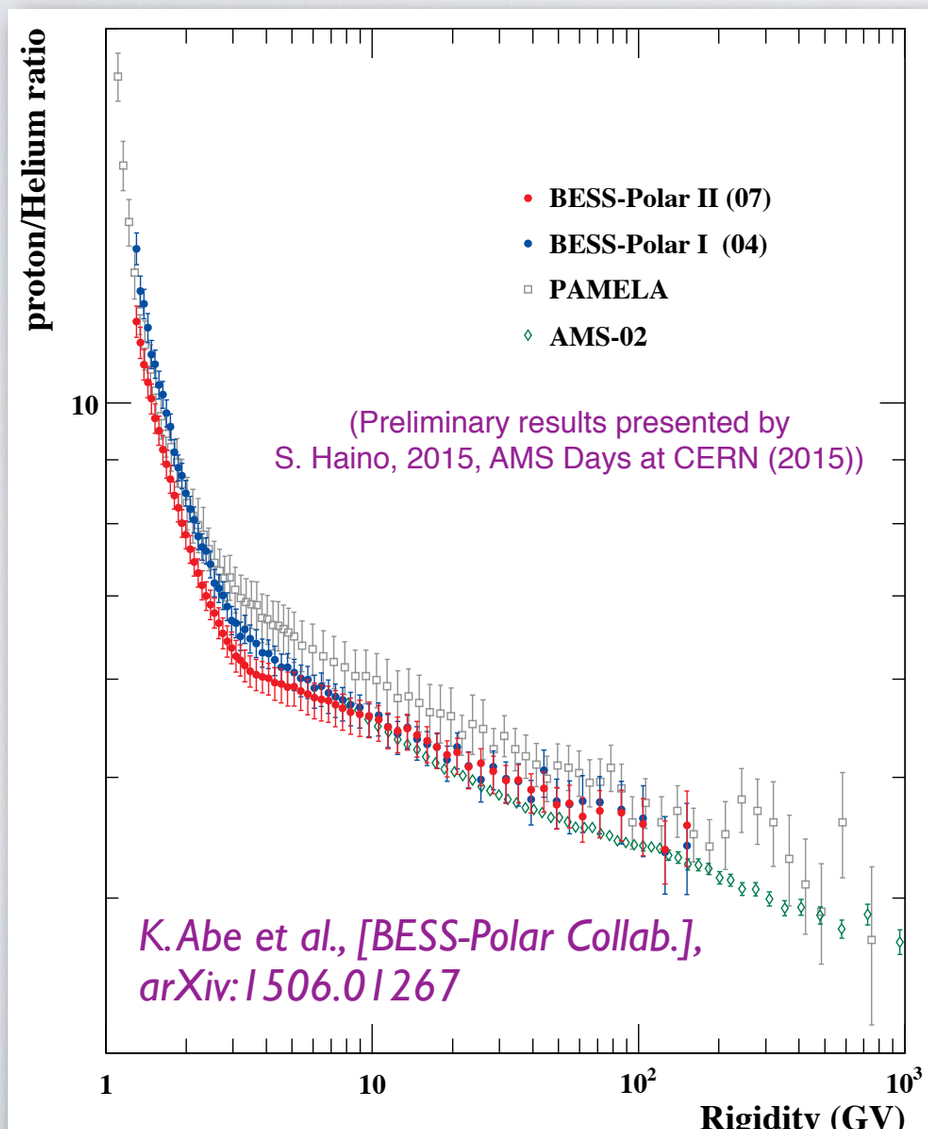
CREAM (filled circles), ATIC-2 (diamonds), CAPRICE94 (upward triangles), CAPRICE98 (downward triangles), LEAP (open circles), JACEE (stars), and RUNJOB (crosses)

NON-UNIVERSALITY, CONT'D

Confidence grew stronger after PAMELA.
By now, conclusively established:

Almost uncontroversial, several experiments in agreement!





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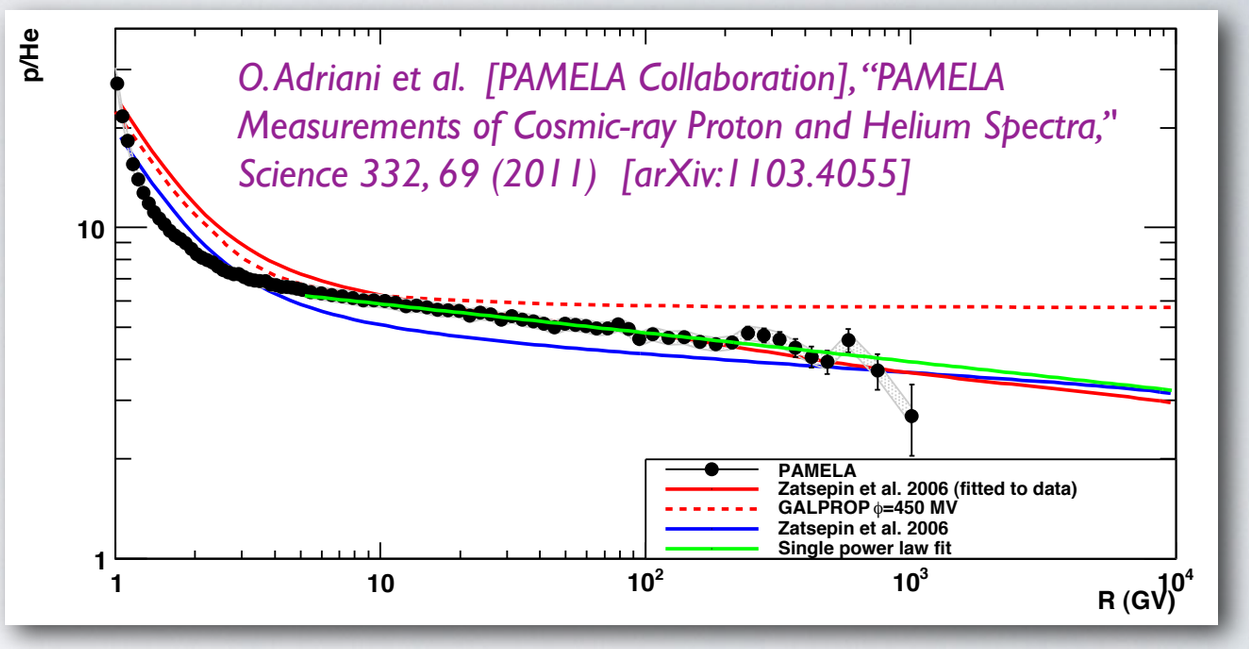
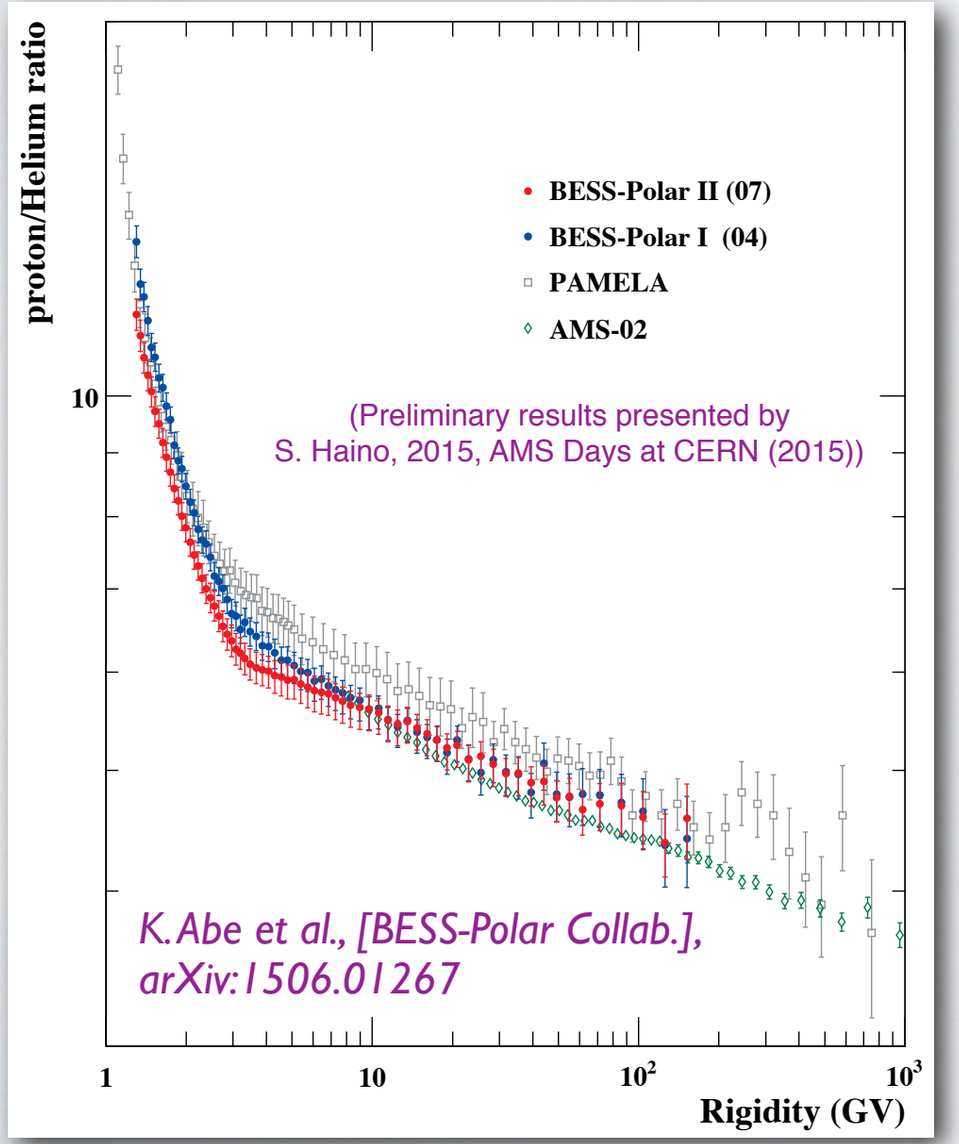
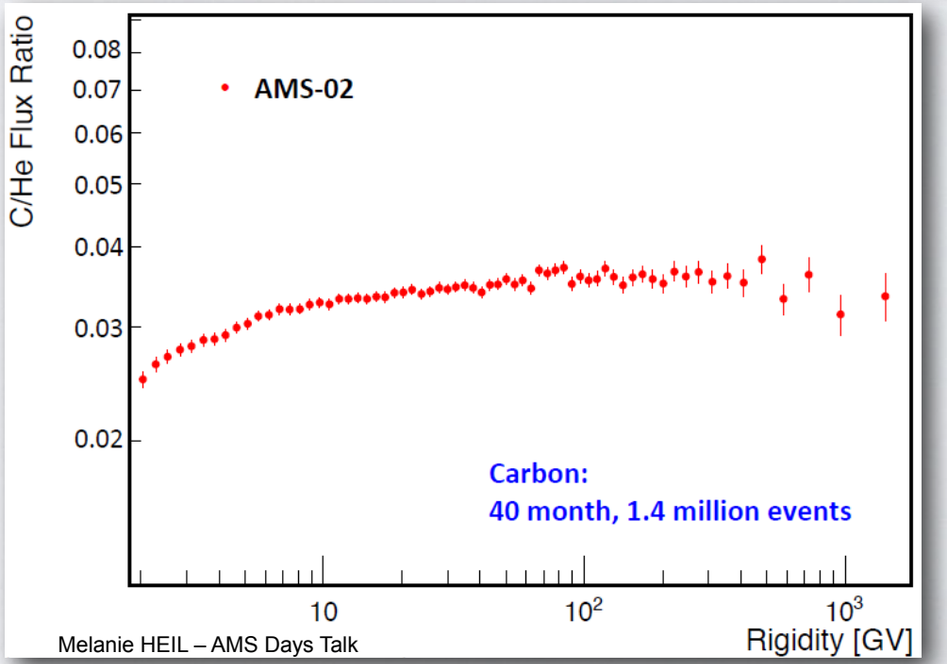




at high-E, harder He spectrum seems to be shared by heavier nuclei (strong hints e.g. from CREAM, being confirmed by AMS-02?)



THE PUZZLE & POSSIBLE SOLUTIONS

Usual acceleration & diffusive propagation mechanisms respond to **rigidity**: should be composition-blind in the *ultra-relativistic regime*

$$\frac{1}{c}\frac{d\vec{\mathscr{R}}}{dt} = \mathbf{E}(\mathbf{r},t) + \frac{\vec{\mathscr{R}} \times \mathbf{B}(\mathbf{r},t)}{\sqrt{\mathscr{R}_0^2 + \mathscr{R}^2}} \qquad \mathscr{R}_0 = Am_p c^2/Ze$$

$$\frac{1}{c}\frac{d\mathbf{r}}{dt} = \frac{\vec{\mathscr{R}}}{\sqrt{\mathscr{R}_0^2 + \mathscr{R}^2}}. \qquad \vec{\mathscr{R}} = \mathbf{p}c/eZ$$

Some solutions proposed (and a few challenges!)

- ***Non-e.m. effects in propagation (spallation?)*** *P. Blasi, E. Amato, JCAP 1201, 010 (2012)*

  Does not seem consistent with parameters for B/C or anti-*p* *A. E. Vladimirov et al. ApJ 752, 68 (2012)*

- ***Different sources/sites***

  Requires special conditions (e.g. break should be propagation-induced to explain universality, in He/metals accelerators need to suppress *p* one & vice versa...) *V. I. Zatsepin, N.V. Sokolskaya, A&A 458, 1 (2006)*

- ***Linked to the "Natural" evolution of Mach number, $\mathscr{M}$,*** **within DSA:**

  For <u>some reason</u>, He mostly accelerated "early on" ($\mathscr{M}$>>1) *p*'s "later" ($\mathscr{M}$ is relatively low)

  what is this reason?

PREFERENTIAL "LATE" P ACCELERATION

(Some) possible reasons

- ***Related to the efficiency of injection in the acceleration cycle***

Alfven waves ~ frozen with the shock, dominated by *p*. At same Vs (Mach velocity) He^{++} have twice the *p* gyroradius, more likely to return upstream, more efficiently accelerated. Both *p* and He efficiency declines with *M*, but faster decline for p. expected ⇒ softer spectrum

M. A. Malkov, P. H. Diamond, R. Z. Sagdeev, PRL 108, 081104 (2012)

No "standard theory" for this, further complications due to role of partially ionized atoms (see e.g. G. Morlino, MNRAS 412, 2333–2344 (2011)), and role of grains of dust (D. Ellison, L. Drury and J. Meyer, ApJ 487, 197 (1997) …

- ***Variable (ionized) He/p concentration in medium swept by shocks***

caused by time-dependent ionization state?

older/weaker shocks propagate in medium where more He is neutral than in strongly ionized environment of young remnant

L. O. Drury, MNRAS 415, 1807 (2011)

"just" reflecting the chemical environment in the sources?

e.g. argued to match environment in superbubbles

Y. Ohira and K. Ioka, ApJ 729, L13 (2011)

Y. Ohira, N. Kawanaka and K. Ioka, arXiv:1506.01196

"spatial" segregation of He vs p

p tend to be in % more abundant "far away" (attained later by the shock)

A. D. Erlykin and A. W. Wolfendale, J. Phys. G 42 (2015) 7, 075201

TESTING BREAK MODELS

Main diagnostics: from secondaries, notably (but not exclusively!) B/C

In short:

1) Source origin for the break: no feature expected in secondaries/primaries

2) Propagation origin for the break: should reflect in probes of propagation as B/C (i.e. secondary spectra should show a more pronounced break than primary ones)

3) Local models like the "myriad" one may even obtain a softening of sec/primary, since secondaries are ~ sourced by the "unbroken" average spectrum

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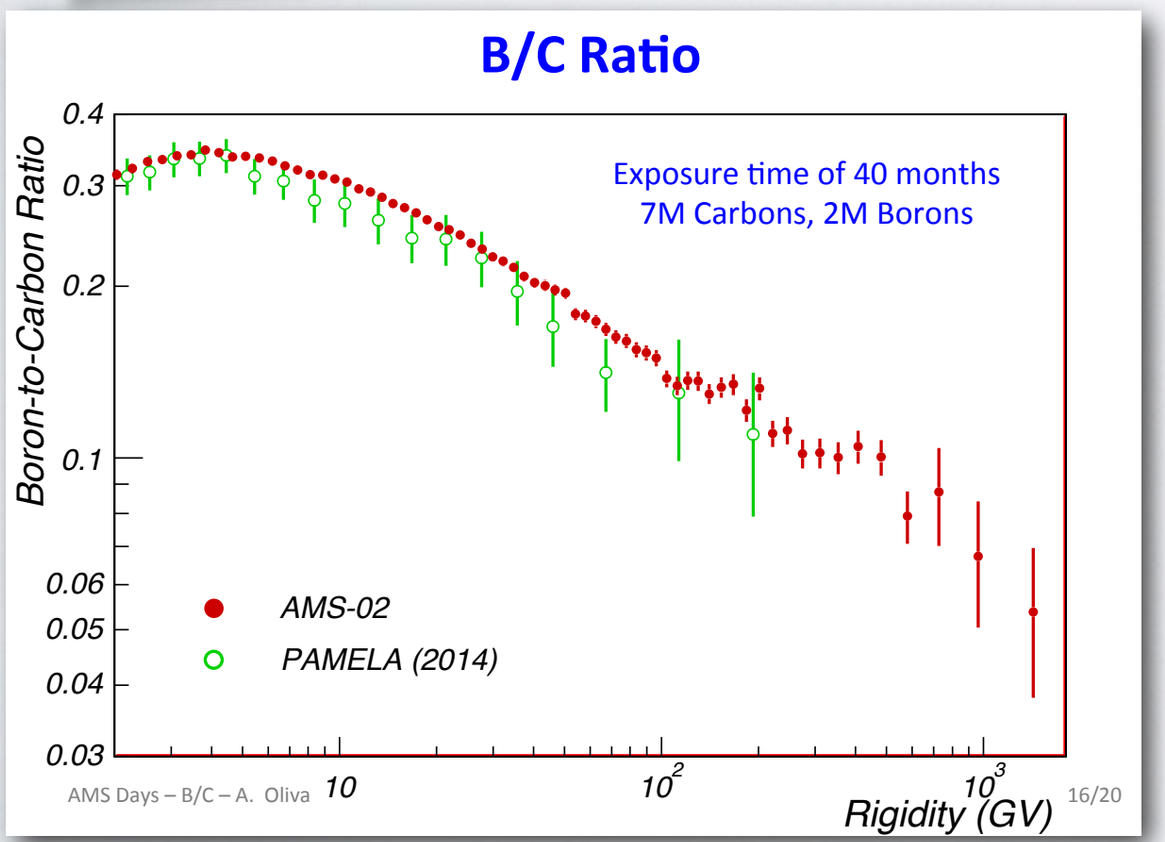
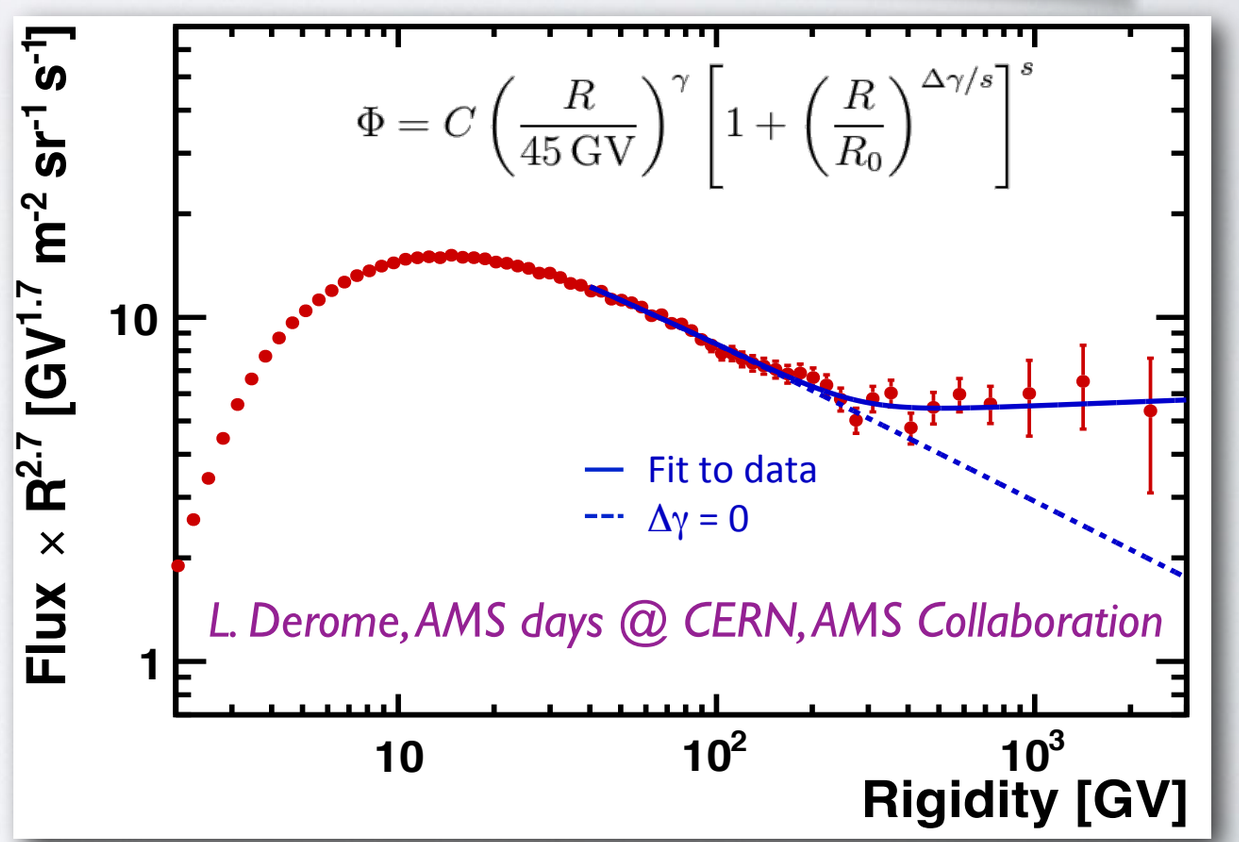


B/C preliminary results do not seem to favour 3), surely inconclusive for 1) vs 2)



Qualitative hints for 2) from AMS Lithium?

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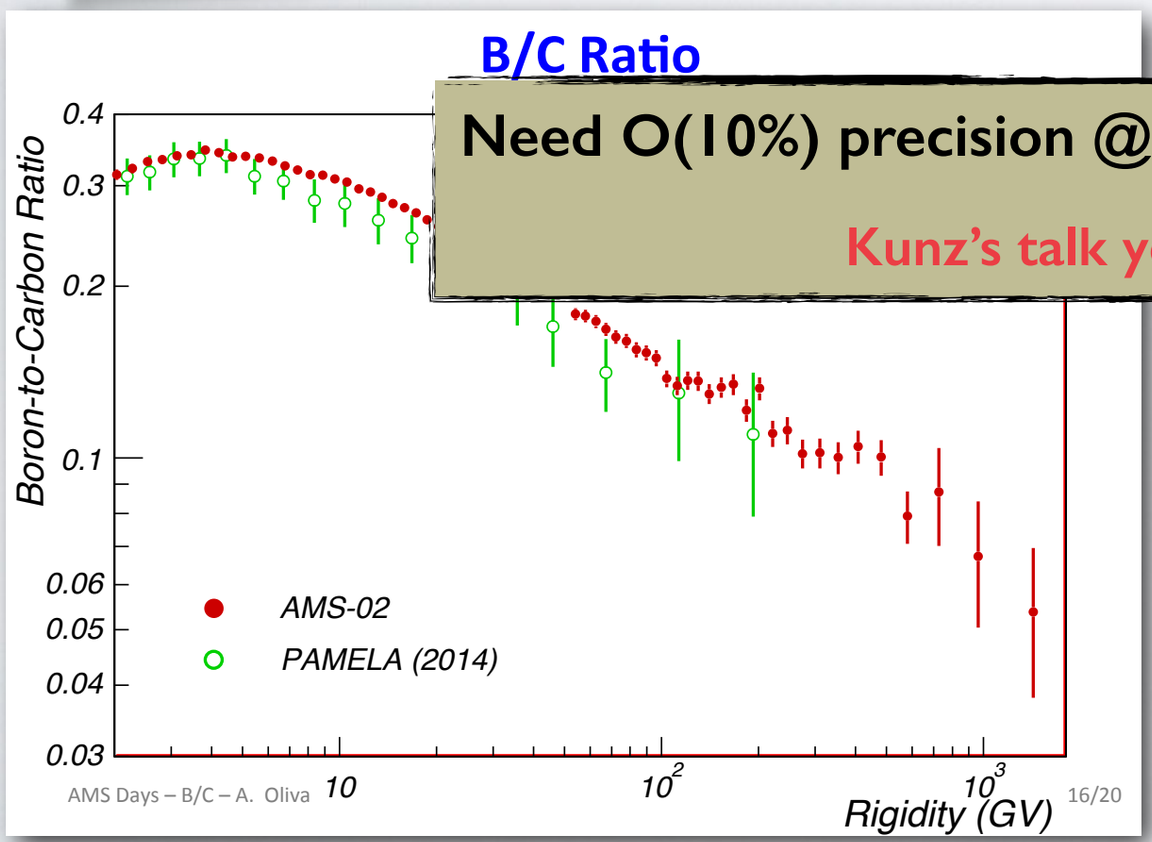
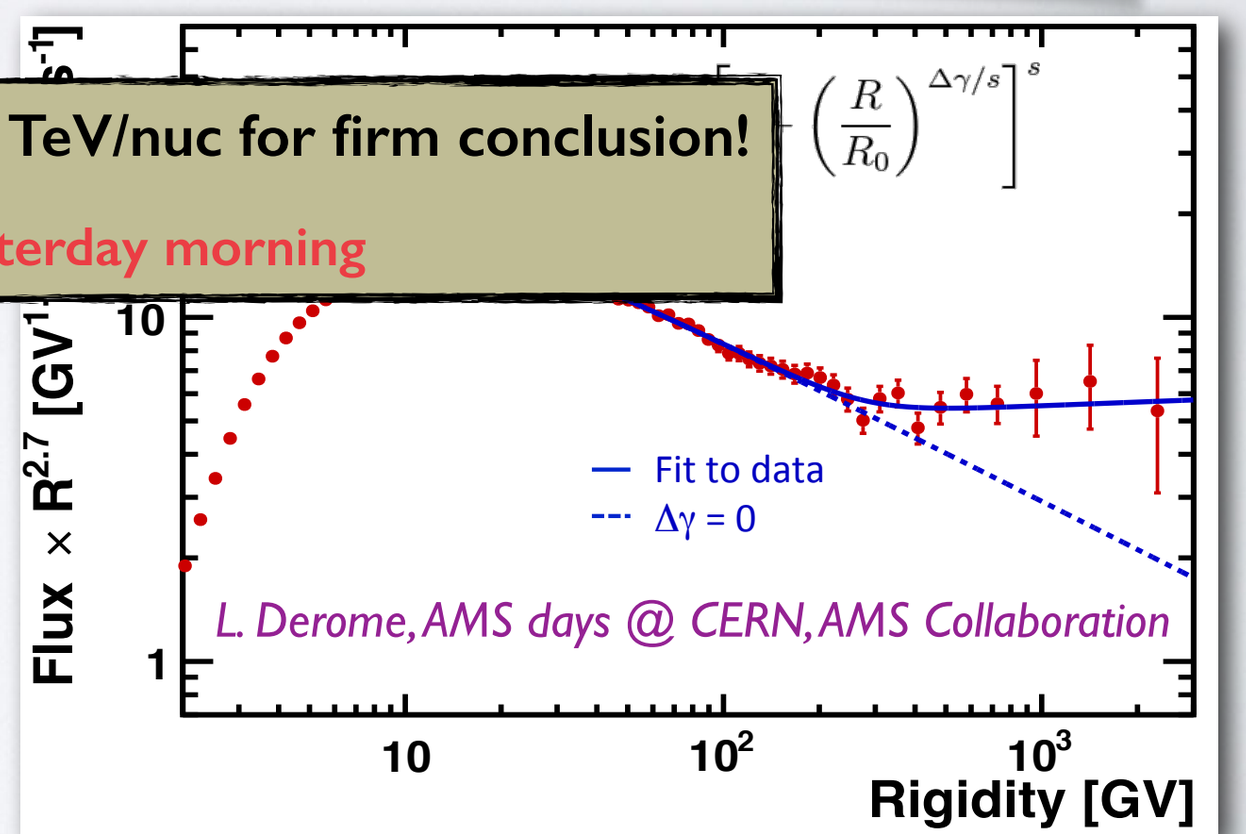


Need O(10%) precision @ 1 TeV/nuc for firm conclusion!

Kunz's talk yesterday morning

B/C preliminary results do not seem to favour 3), surely inconclusive for 1) vs 2)



Qualitative hints for 2) from AMS Lithium?

SOME DIFFICULTIES

➡ *Models within the same class (source/propagation) largely degenerate within foreseeable sensitivity*

Obvious, yet true: Possibility to reduce degeneracies in models where links with additional observables are present (multi-messenger approach)

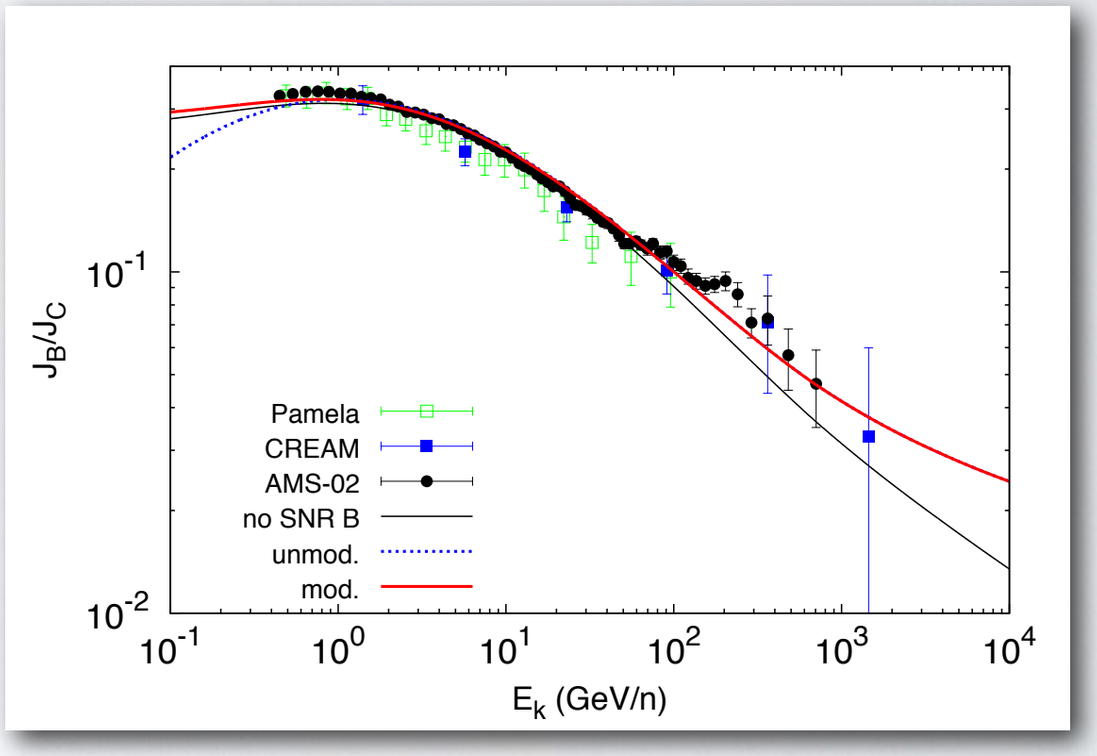
➡ *"Secondary" production at sources become a major concern (must be taken into account)*

High precision data on secondaries (or sec/prim.) in E~0.1-1 TeV/nuc. needed to test source vs. propagation scenarios.

However, easy to estimate than in the same range we expect sizable "secondary" production at the source

$$X_{\rm SNR} \approx 1.4 r_s m_p n_{\rm ISM} c T_{\rm SNR} \approx 0.17\,{\rm g\,cm^{-2}} \frac{n_{\rm ISM}}{{\rm cm^{-3}}} \frac{T_{\rm SNR}}{2\times 10^4 {\rm yr}}$$

R. Aloisio, P. Blasi and PS, arXiv:1507.00594 [astro-ph.HE]



This is a generic conclusion on "theoretical" limitation in extracting propagation parameters from B/C

Y. Genolini's poster, based on A&A 580, A9 (2015) [arXiv:1504.03134]

TESTS OF NON-UNIVERSAL. MODELS?

One important diagnostics is the dependence of the feature on the nuclei

Are the spectra of the "metals" the same as He and among themselves?

Good News: AMS should provide some new data soon.

Bad News: Problem may be related to understanding of relative abundances of species of different chemical composition, either poorly understood aspects of injection or of source astrophysics may be involved.

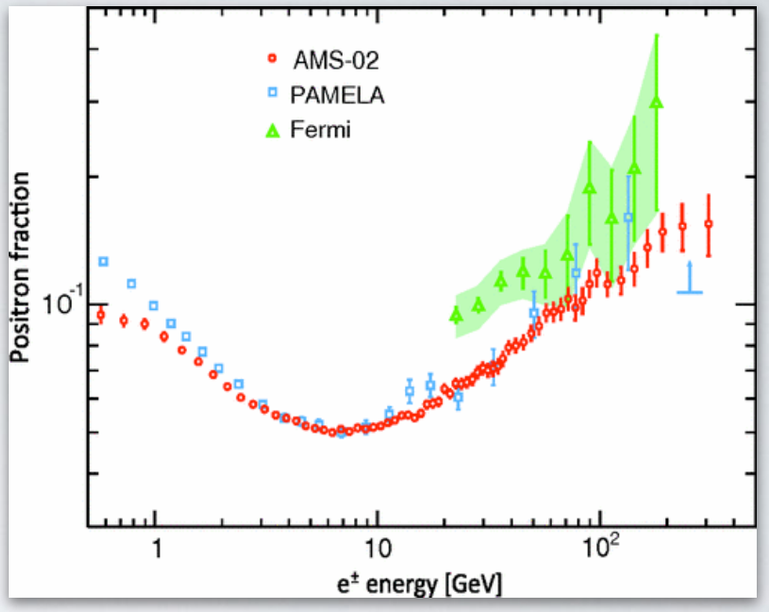
Do not despair, yet! Keep hoping in the future...

Example of futuristic handle: inferring and comparing the "grammage at source" experienced by protons & nuclei (e.g. antiprotons wrt secondary nuclei) could indicate if the main culprit is some environmental condition at accelerator site (as opposed to injection)

THE (BY NOW OLD) POSITRON "EXCESS"

Interesting example of <u>misnomer</u> (or "sociological aspect of the word anomaly"): not the too large number of e^+, rather their energy spectrum that requires an explanation *(if one aims at a coherent modeling of CR fluxes, of course)*

P.S. PRD 79, 021302 (2009)



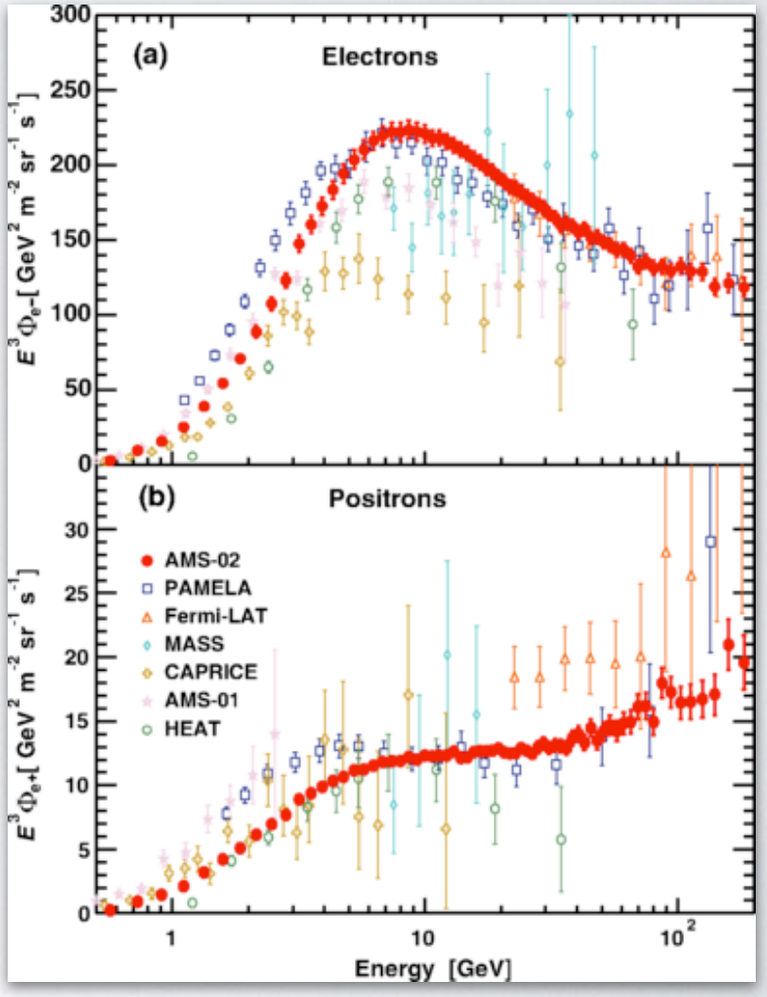
Latest results in this field: AMS-02 publication of fraction (2013), and of both fraction and absolute fluxes of e^+ and e^- (2014), preliminary updated results announced at CERN in 2015

M. Aguilar et al. [AMS Collaboration], PRL 110, 141102 (2013) (e^+ fraction)

L. Accardo et al. [AMS Collaboration], PRL 113, 121101 (2014) (e^+ fraction update)

M. Aguilar et al. [AMS Collaboration], PRL 113, 121102 (2014) (separate e^+ and e^-)

M. Aguilar et al. [AMS Collaboration], PRL113, 221102 (2014) ($e^+ + e^-$)



Since a few years, I consider the (main) **case closed**: there is *no consistent model* (i.e. compatible with B/C, diffuse gamma-rays, etc.) *which does not require some primary* source of e+

STATUS AND EXPECTATIONS

On Primary source(s): **(talks by M. Di Mauro, M. Boudaud)**

- must be mostly *astrophysical rather than DM* (to pass multi-messenger constraints, notably from γ's).
- *PWNe are natural candidates* ($e^{\pm}$ producers & accelerators, spectrum at termination shock hard as needed, energetics Ok), but other sources (e.g. SNRs) possible, at least as sub-leading component.
- Local, discrete sources more and more important with E; O(0.1%) anisotropy @ O(100) GeV likely

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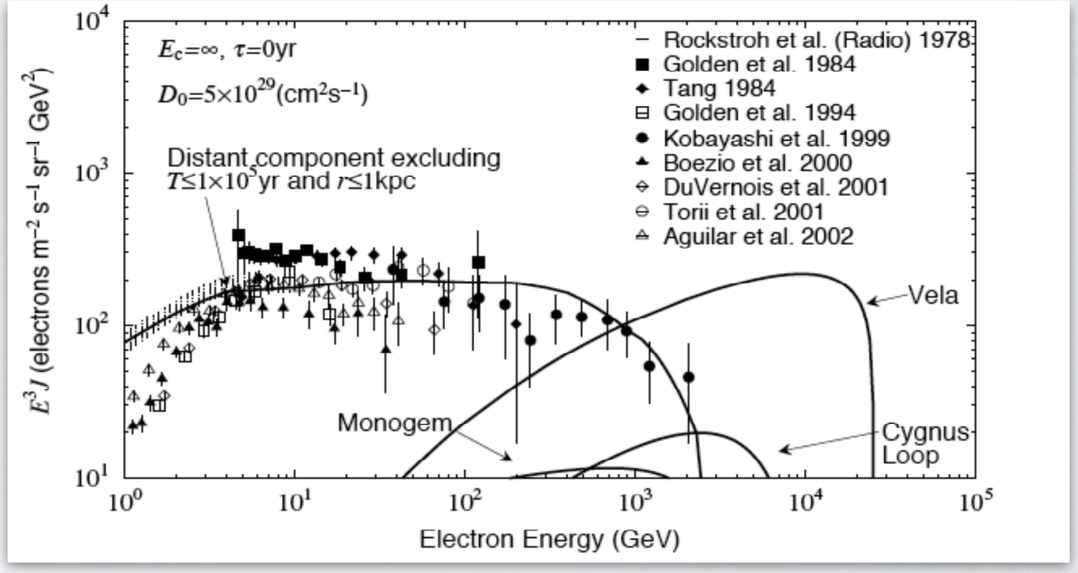
NOTE

several of these aspects already clear well before "good modern data" came in! E.g.

A. M. Atoyan, F. A. Aharonian, and H. J. Völk PRD 52 (1995) 3265

[…] separating the contribution of the local (discrete) source(s) from the contribution of distant sources, it is possible to explain all the locally observed features of the energy spectrum of cosmic ray electrons from sub-GeV to TeV energies. In addition, assuming that the local source produces electrons and positrons in equal amounts, the model allows us to explain also the reported increase of the positron content in the flux above 10 GeV […]

Kobayashi, Komori, Yoshida, Nishimura, ApJ 601, 340 (2004)

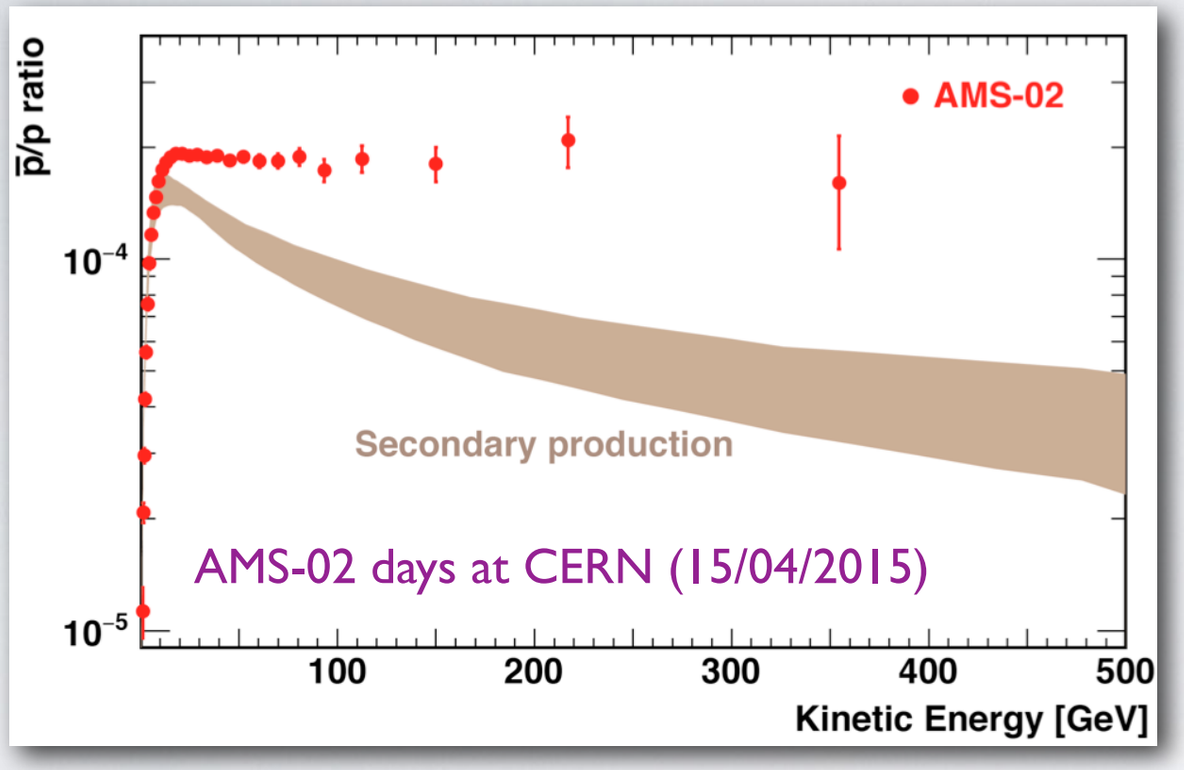


here the **anomaly** would be featureless power-laws! We ***expect*** lepton CR spectra to be "bumpy" at high-energy. (Some indication by HESS?) e^+ fraction determined by e.g. relative PWN to SNR contribution in the range, turning points expected when exceeding single PWN E_{max}

Detecting these features would confirm the standard understanding of CR, not disprove it!

preliminary!

AN ANOMALY IN AMS-02 ✔ ANTI-P?



By glancing at such a plot, one would naively conclude so!

However: Old predictions cannot be consistently overlapped with points!

preliminary!

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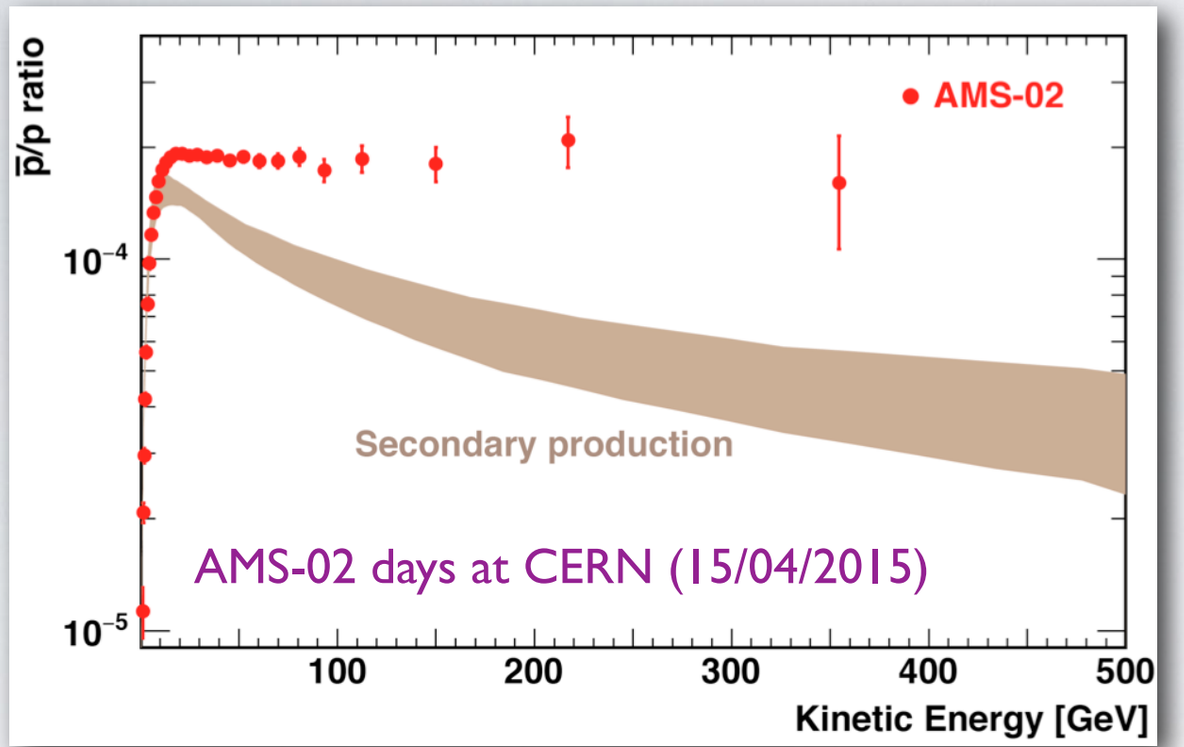

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However: Old predictions cannot be consistently overlapped with points!

For instance, they do not take into account harder *p* and He fluxes at high-E (recently found)

M. di Mauro, F. Donato, A. Goudelis and PS, PRD 90, 085017 (2014)

Newer data on anti-p production cross section could/should be taken into account

R. Kappl and M.W. Winkler, JCAP1409, 051 (2014)

notably both account for data of NA49 exp. @ CERN

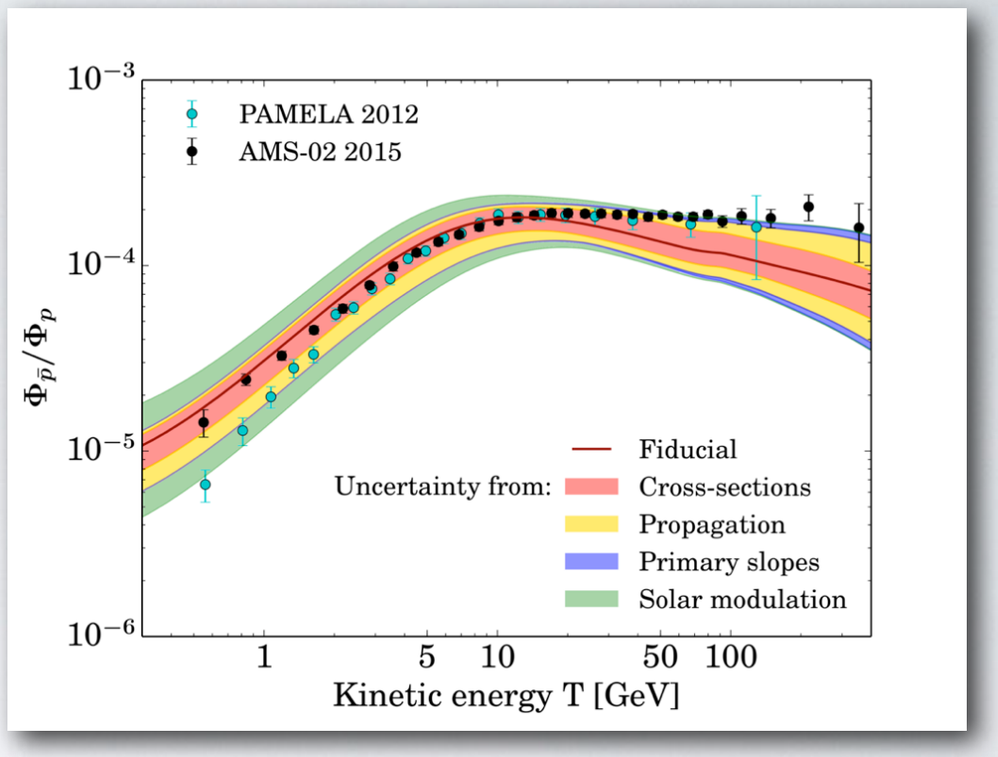
MORE REALISTIC COMPARISONS

G. Giesen et al. JCAP, in press [arXiv:1504.04276]

(M. Boudaud's poster)

Even within *old propagation models*, once update is performed of these inputs and realistic account of uncertainties is done... *"anomaly" is at most marginal*: cannot be unambiguously established.

Models with milder dependence of diffusion coefficient wrt rigidity (like "MAX") preferred



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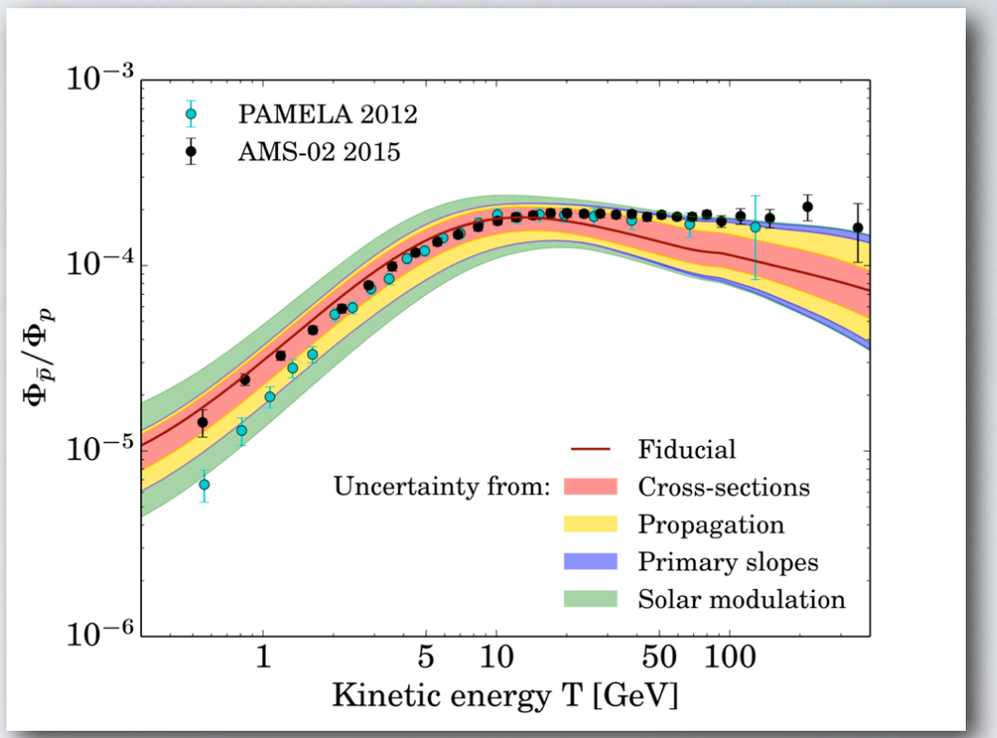
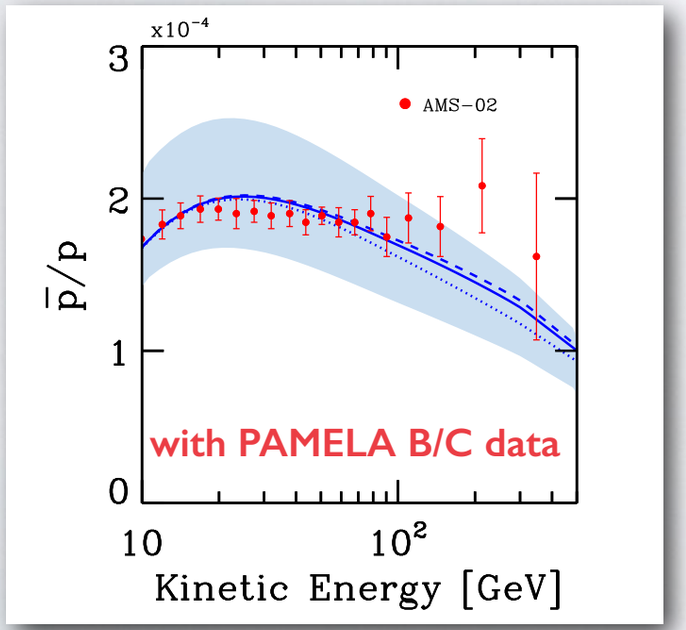
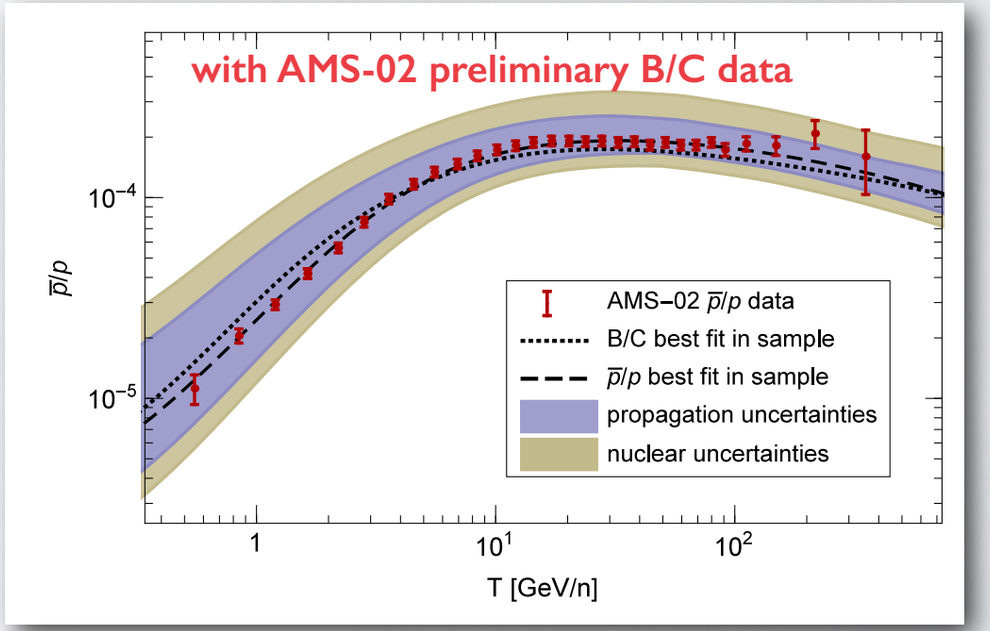


First attempts when updating propagation models reach similar conclusions:

C. Evoli, D. Gaggero and D. Grasso, arXiv:1504.05175



R. Kappl, A. Reinert and M.W. Winkler, arXiv:1506.04145



Extremely important for Dark Matter constraints! (*Cirelli's talk*) Without doubt, to be continued!

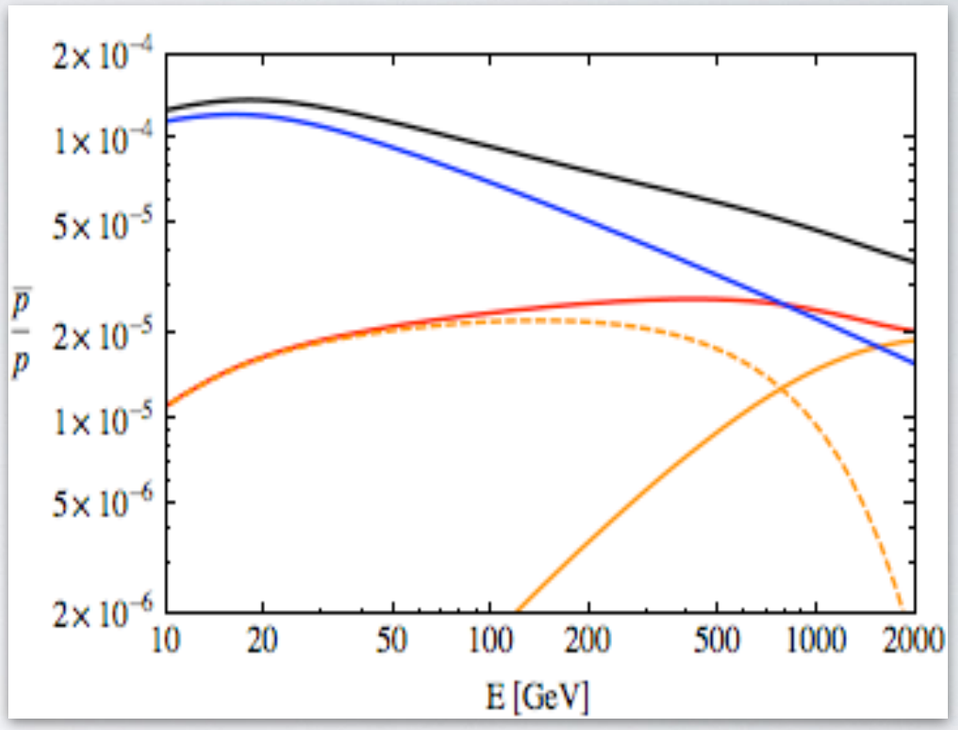
ANOTHER CAVEAT

Just as B/C at high-E could be significantly affected by production at sources, so could anti-p!

Already noted in the past (well before any suspect of anomaly in p-bar was even raised!) e.g.

P. Blasi and PS,
"High-energy antiprotons from old supernova remnants,"
PRL 103, 081103 (2009) [arXiv:0904.0871]

"The good news is that the high-energy range of the antiproton spectrum may reveal important constraints on the physics of the CR acceleration sites. The bad news is that it is not straightforward to infer from high energy p̄/p -data the propagation parameters […] our results may change dramatically the perspectives for the detection of DM An "excess" in the high-energy range of antip̄/p could not be interpreted anymore uniquely as manifestation of new physics […]"



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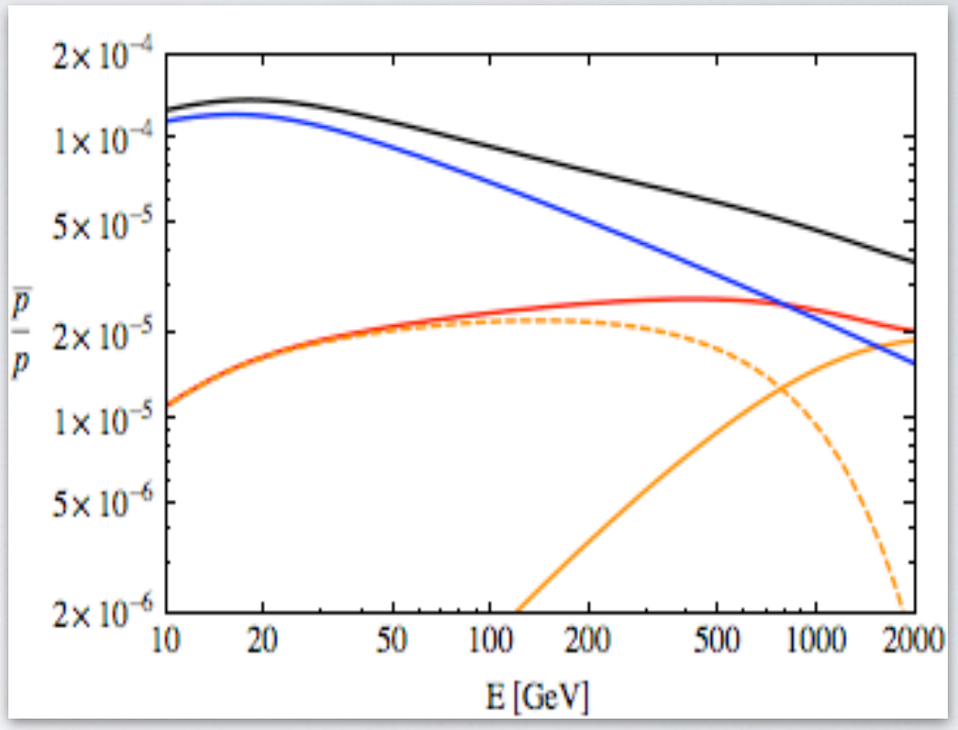
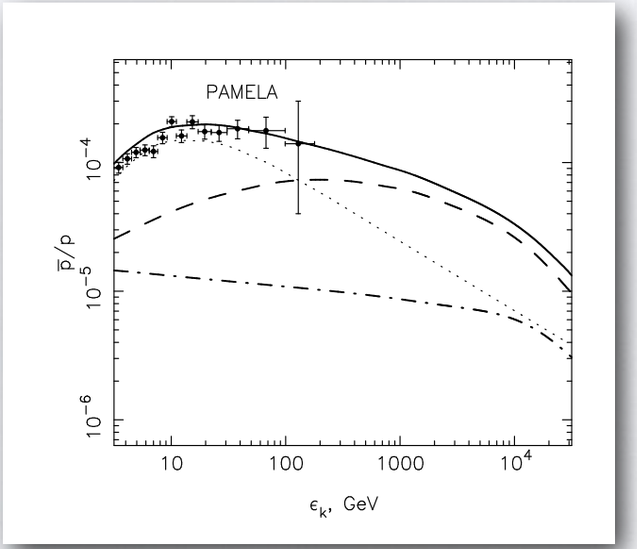


Newer calculation further stresses this point

E.G. Berezhko and L.T. Ksenofontov, ApJ 791, L22 (2014) [arXiv:1405.5281]

More details in Ksenofontov's talk later today



Important implications for DM confirmed in

V. Pettorino et al.
"Can AMS-02 discriminate the origin of an anti-proton signal?,"
JCAP 1410, 078 (2014) [arXiv:1406.5377]

"We investigate the two signals from different dark models and different supernova remnant parameters, as forecasted for the AMS-02, and show that they present a significant degeneracy."

OTHER ANOMALIES (& PROBES)

Almost all of what I said pertains to locally observed CR fluxes!

If CR in the Galaxy were homogeneously distributed, same fluxes should also apply globally.

But neither CR source distribution nor diffusive propagation expected to be homogeneous!

More difficult & less constrained questions to address, but 2 handles on non-local CR population

Gamma ray flux morphology $\phi_\gamma \propto \int_{\mathrm{l.o.s.}} \phi_{\mathrm{CR}}\, n_{\mathrm{gas}} \mathrm{d}s$

Anisotropy $\mathrm{CR\,(dip.)\,anisotropy} \propto \nabla \phi_{\mathrm{CR}}$

Perhaps not surprisingly (since linked to things we know relatively little about!)
both associated to long-standing "problems":

gamma-ray gradient problem & anisotropy problem(s)

whose nature & related subjects have lately been investigated a lot.

They have been touched upon e.g. in

Gaggero's talk (Mon highlight), Grasso's and Mertsch's talks (Tue parallel)

to which I address for further details

SOME CONCLUSIONS

Provided that the precision of modern experiments is not illusory *(i.e. systematics are not underestimated)* what is happening in CR physics is a sign of **normal progress** in experimental science, where with higher precision one expects to see "cracks" in the simplest models.

Violation of species **universality and energy-invariant** spectra may be such signs.

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Let me emphasize that this "healthy" progress is rare & extraordinary, for CR physics! When studying CR, I quickly learned an important fact:

"Sec.1.2: Is progress in the cosmic ray field slow?"
It certainly looks like that.

From T. Stanev's "High Energy Cosmic Rays" textbook

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Most pressing issue, in my opinion: to understand how many of these "cracks" are telling us something ***generic*** about CR sources/propagation, and what is instead ***"accidental"*** (e.g. specific position and time of the Galaxy we happen to live at): remember Van der Waals' lesson!

SOME CONCLUSIONS, CONT'D

For sure, more data will help, notably nuclei (both "primary" and "secondary" ones). Understanding the main class in which the solution falls (e.g. source vs. propagation) is probably within reach, but discriminating different models is much more challenging

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For that, achievable improvement in the precision of data probably not enough. We need theoretical progress + combined pheno approaches (Caprioli's talk)

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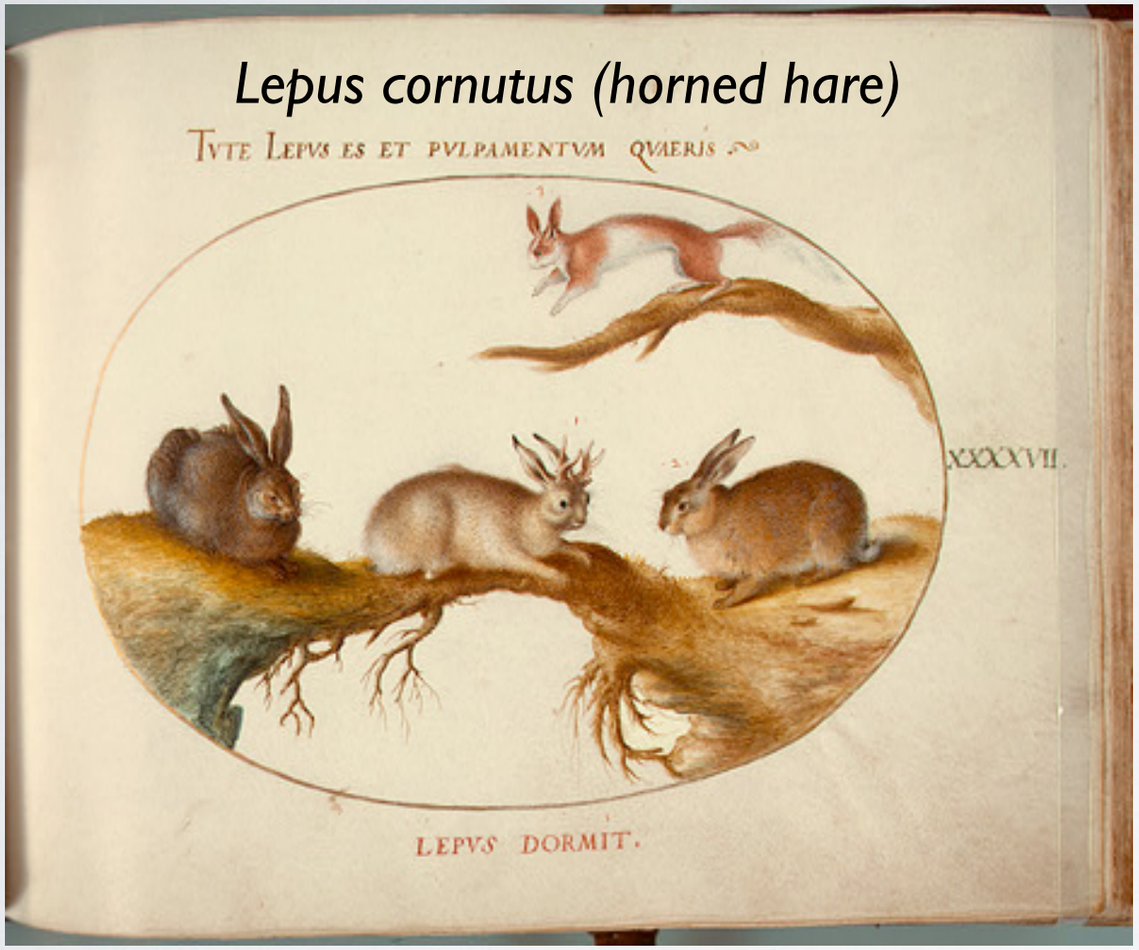
Antimatter in CR provides extra diagnostic potential (also for DM):

while the one of e^+ is saturating (probably more interesting to see spectral features at high-E in the overall $e^+ + e^-$) for anti-p significant room for improvement is certainly there, but meaningful studies should wait for release of nuclear data (and, for DM, should seriously account about many sources of uncertainties and astrophysics)

APPROPRIATE LOCATION FOR THIS TOPIC: "ANOMALIES" HAVE ALWAYS FASCINATED ARTISTS IN THE LOW COUNTRIES!

Joris Hoefnagel (1542-1601)

illustrator of natural history subjects, topographical views, etc.



"Animalia Qvadrvpedia et Reptilia (Terra)" ca. 1575

APPROPRIATE LOCATION FOR THIS TOPIC: "ANOMALIES" HAVE ALWAYS FASCINATED ARTISTS IN THE LOW COUNTRIES!

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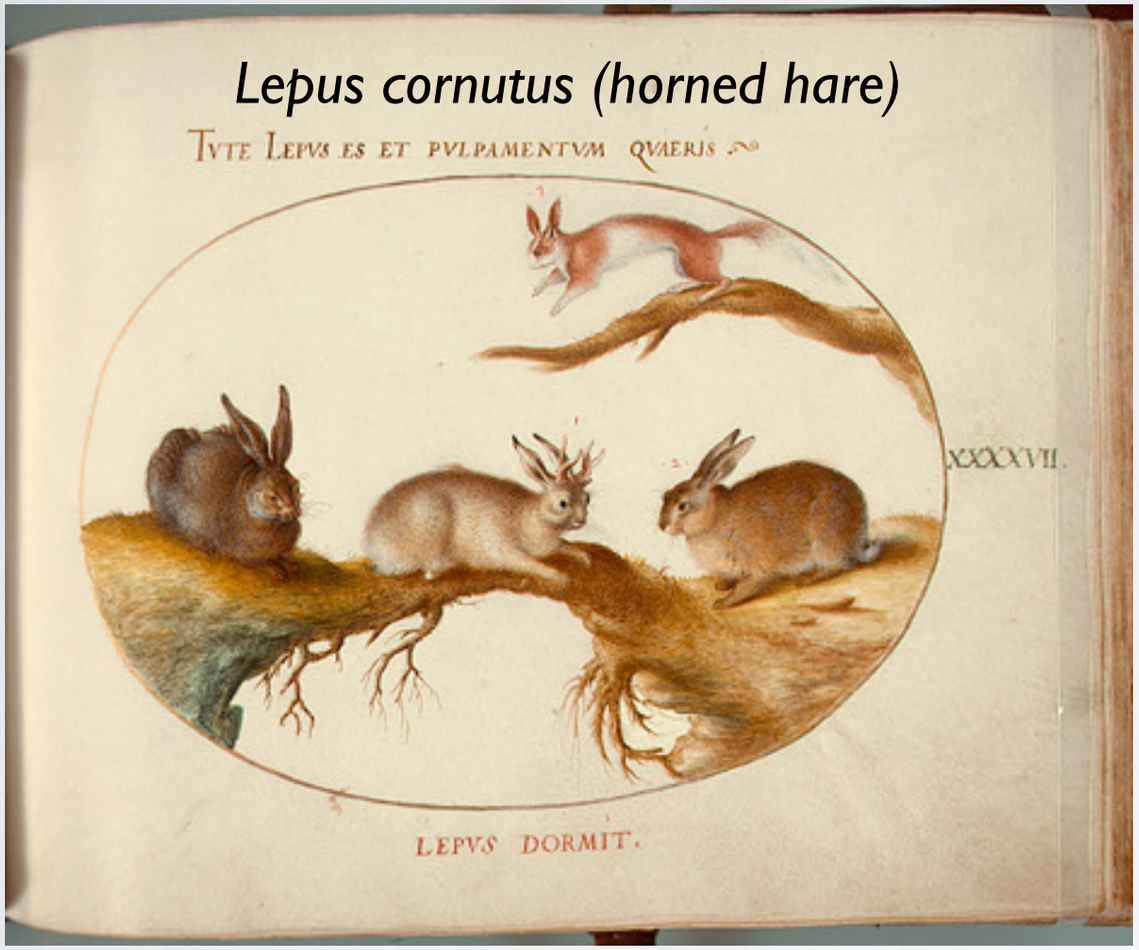

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Virgin and Child Surrounded by Flowers and Fruit

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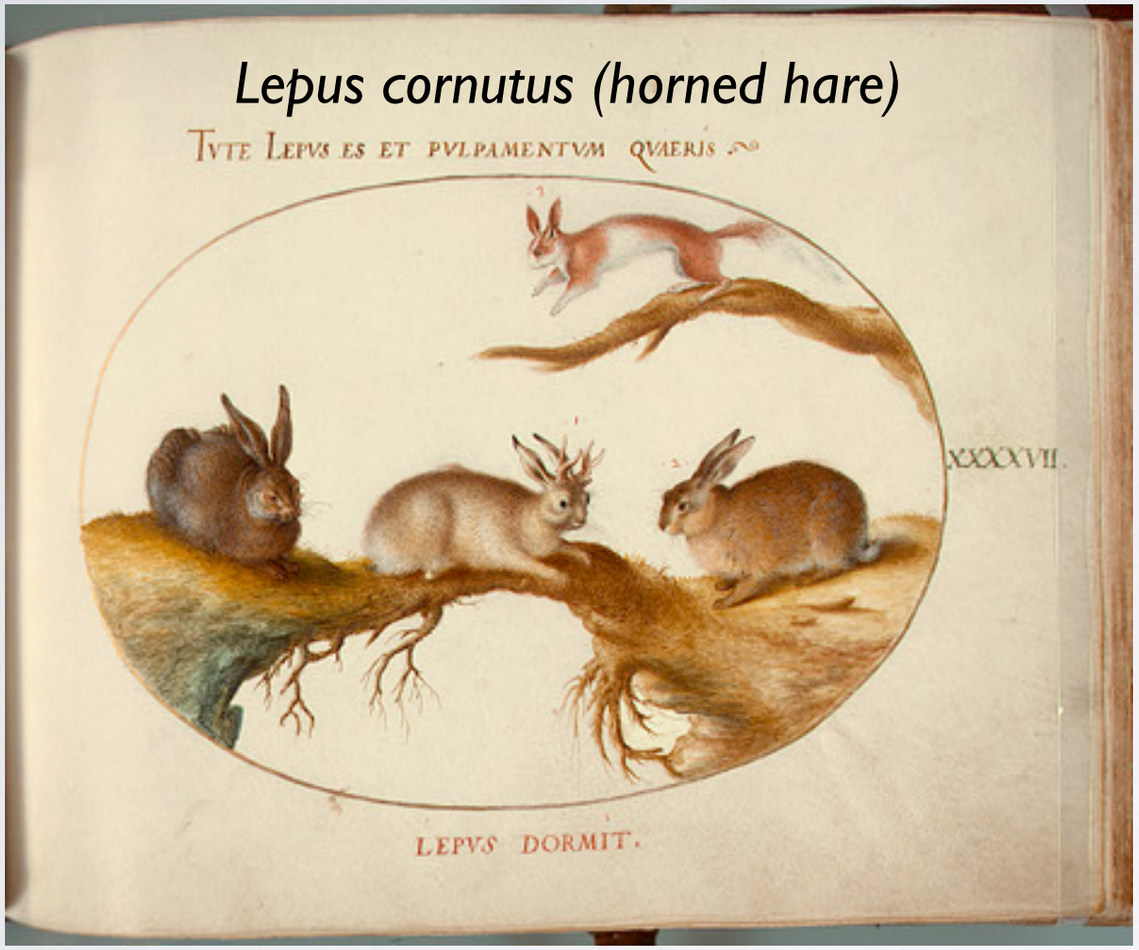

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Dank je!