# The AMS-02 leptons and nuclei measurements interpretation: implications and perspectives for dark matter indirect search


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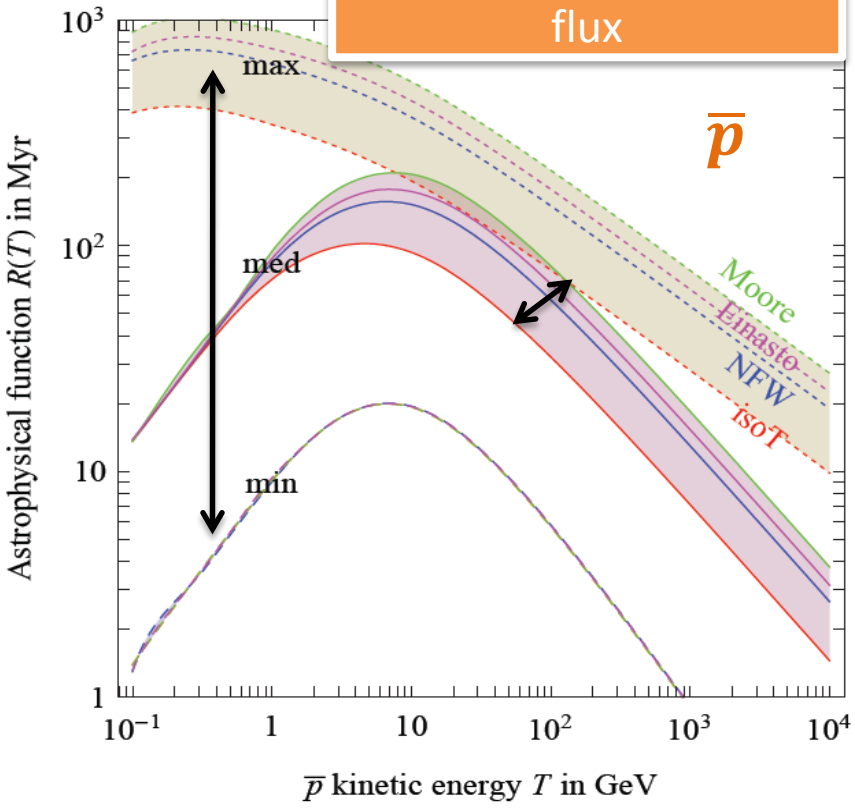
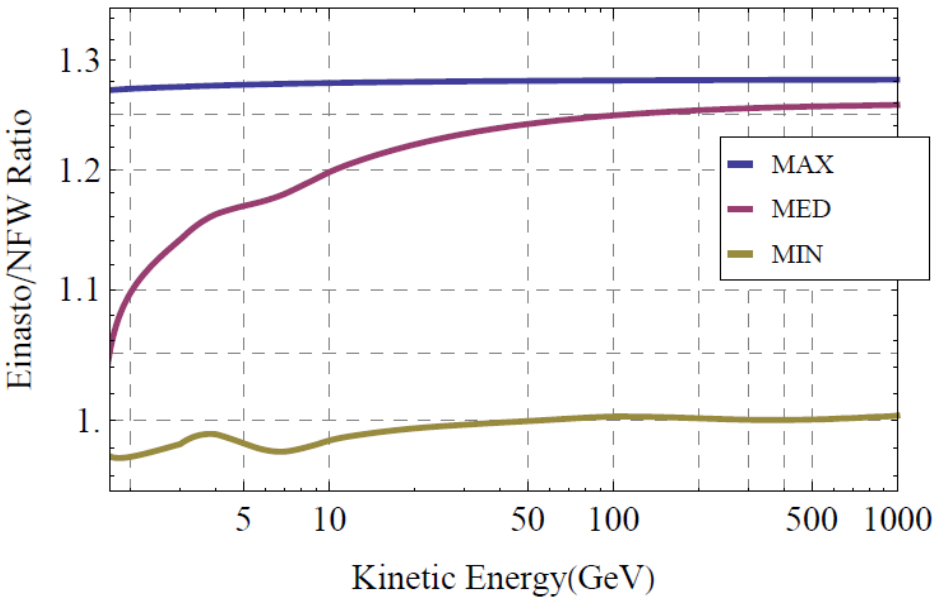
# Theoretical Uncertainties: background for indirect DM searches

# Fluxes uncertainties: astrophysics vs dark halo

Rescaled antiproton flux

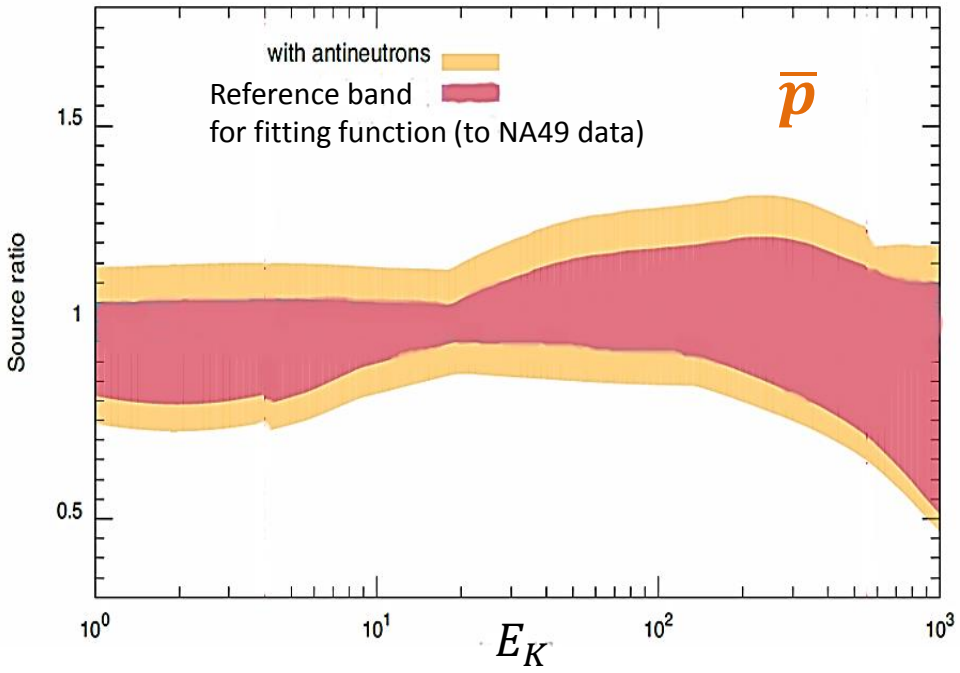


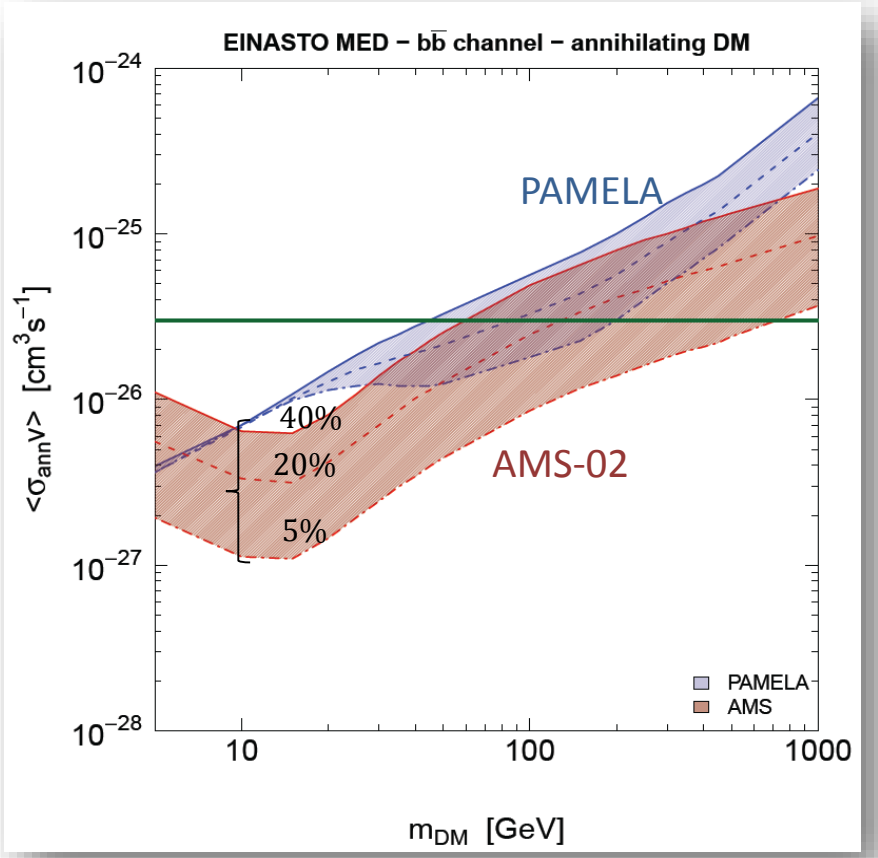

DM halo ratio: Einasto vs NFW




1. **Propagation models**: almost two orders of magnitude, one above one below the MED set
2. **Radial distribution of the halo:** modulates spectra in a less significant way, even if *higher DM density regions* in the inner Galaxy or the introduction of a *cohorotating Dark Disk* could induce a greater annihilation cross section

# Nuclear Uncertainties:
## DM annihilation cross section constraints from PAMELA and an AMS-02 data projection



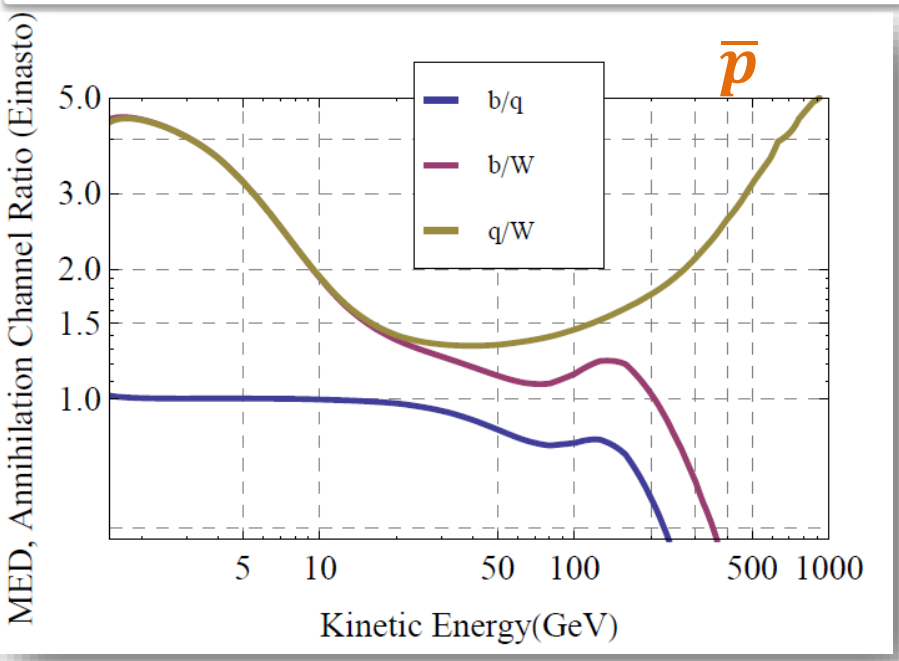




$$p + ISM \rightarrow \bar{p} \ldots \quad \begin{cases} p + p \rightarrow \bar{p} \ldots \\ p + He \rightarrow \bar{p} \ldots \end{cases}$$

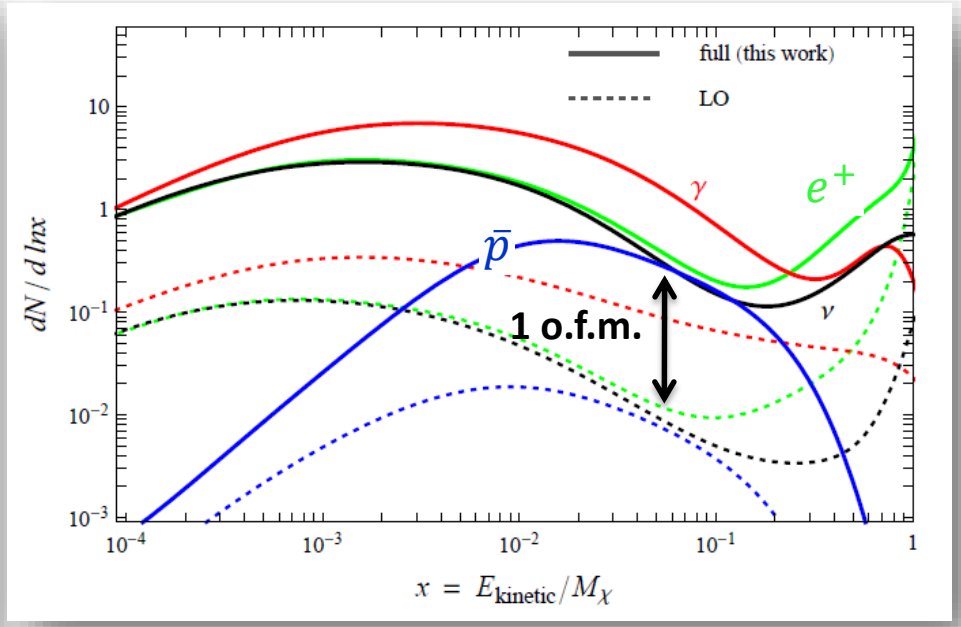
20% uncertainty => $\frac{\Phi_{\bar{p}}^{max}}{\Phi_{\bar{p}}^{min}} \approx 1.5$

# Flux uncertainty for $\bar{p}$ from the dark sector physics

Annihilation channels ratio:
bottom (b) vs up/down (q) vs vector boson (W)




NLO corrections to the primary DM flux



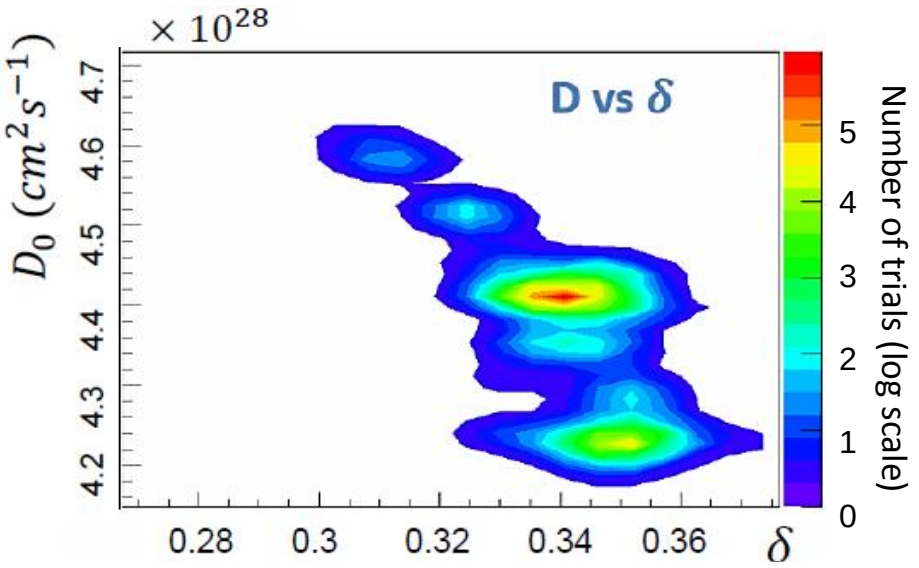

***Simulazions based on PPPC 4 DM ID (Cirelli, Kadastik, Strumia et al.)***

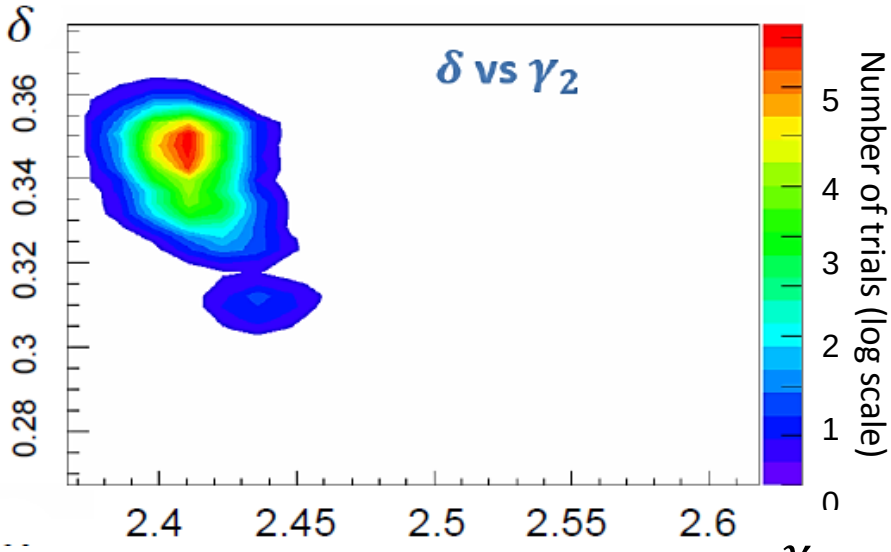
**Uncertainties linked to DM physics are hard to be removed**, but they are still lower than the fundamental uncertainty which afflicts the cosmic rays propagation physics

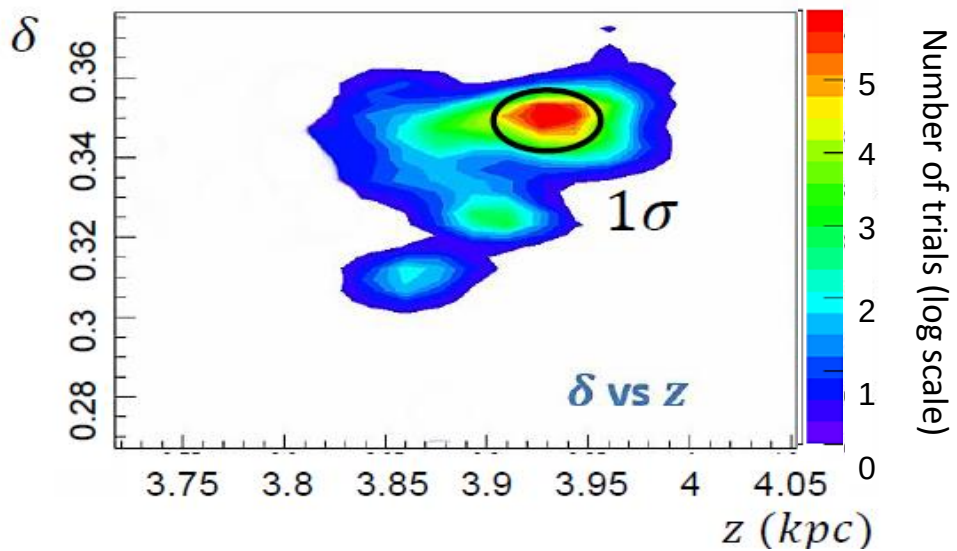
# MonteCarlo Markov Chain Approach:
# full parameters scan with
# AMS multiple constraints from CRs

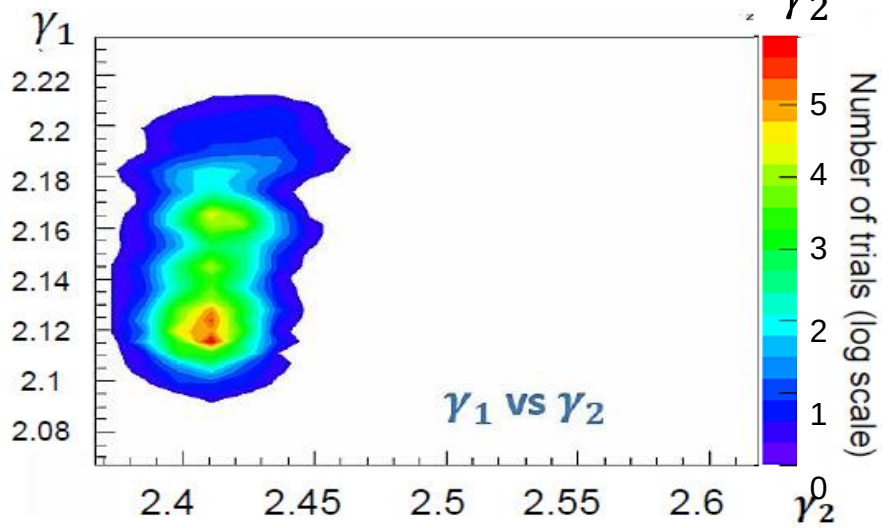
***What we are doing in Bologna…***

With p, He, B/C, and preliminary Boron, Carbon, Oxygen spectra from AMS-02 we can easily constrain, for the first time, the fundamental parameters that describe the CR propagation and the galactic physics



# CR Physics Improvements

## Before AMS-02

| | Unit | Error (%) |
|---|---|---|
| $z$ | kpc | 54% |
| $D_0/10\text{^}28$ | $\mathrm{cm^2 s^{-1}}$ | 96% |
| $\delta_{1,2}$ | | 57% |
| $V_{Alfven}$ | $\mathrm{km\ s^{-1}}$ | 89% |
| $V_{0conv}$ | $\mathrm{km\ s^{-1}}$ | 100% |
| $dV_C/dz$ | $\mathrm{km\ s^{-1} kpc^{-1}}$ | 100% |

## After AMS-02

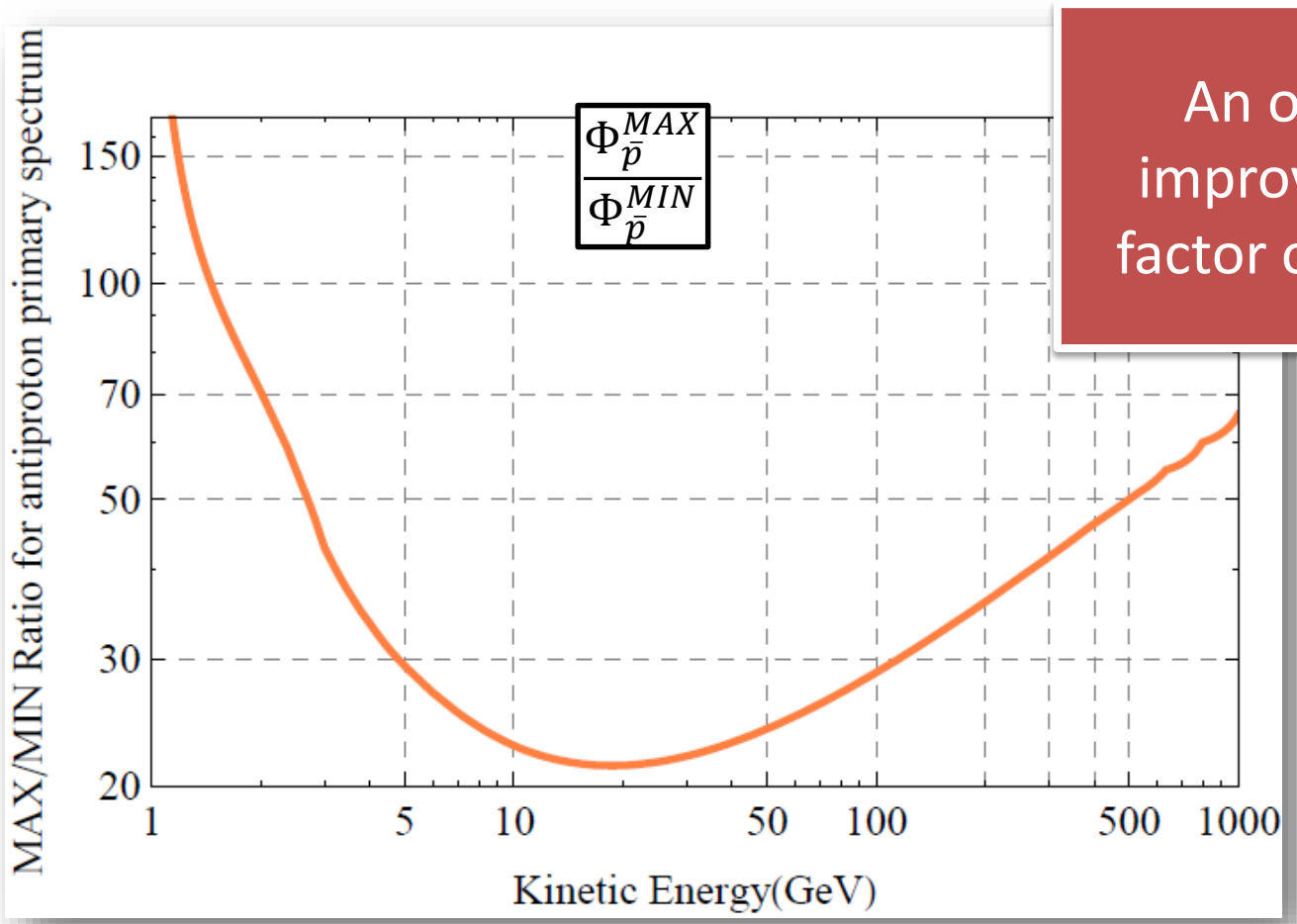
| Error (%) | Improvement factor $\varepsilon_{before}/\varepsilon_{after}$ |
|---|---|
| 4% | 14 |
| 6% | 16 |
| 5% | 11 |
| 11% | 8 |
| 10% | 10 |
| 10% | 10 |

- Past experiments were not able to fix the CR propagation physics: **the parameters lied in very wide ranges**.
- With AMS-02 data is finally possible to achive a consistent best fit: the **errors associated to the fundamental propagation parameters z, $D_{0xx}$, $\delta_{1,2}$ are greatly reduced**
- We still have **some degeneracies/uncertainties which afflict secondaries predictions**

A factor 10 (or greater) of improvement for fundamental parameters

# Reduction of primary $\bar{p}$ flux astrophysical uncertainties after AMS

**MAX/MIN Dark Matter $\bar{p}$ Flux Ratio: removing the astrophysical background**



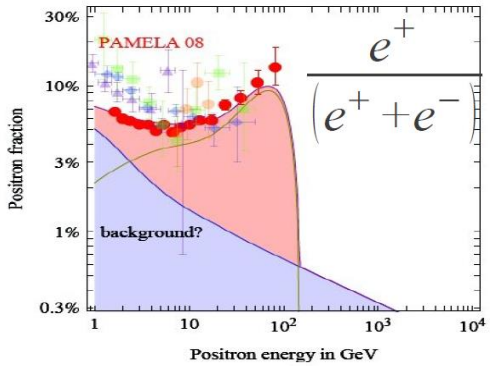

An overall improvement factor of 20÷50

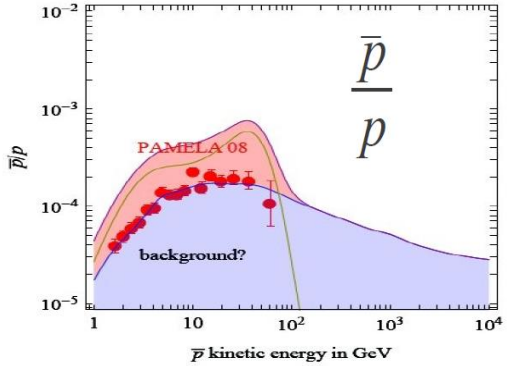
# DM Candidates for AMS

Inadequate production for <1÷2 TeV WIMP: to grant PAMELA and AMS-02 results we need heavier candidates and high Boost Factors for the annihilation cross section

→ **new antiproton physics for AMS-02 in the 150 GeV - 2 TeV range for $M_{DM} \lesssim 10$ TeV**

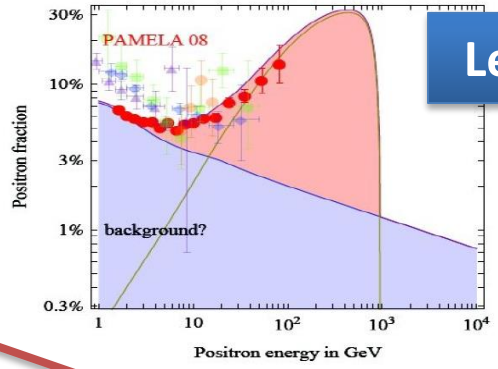
## DM with mass 150 GeV that annihilates into $W^+W^-$

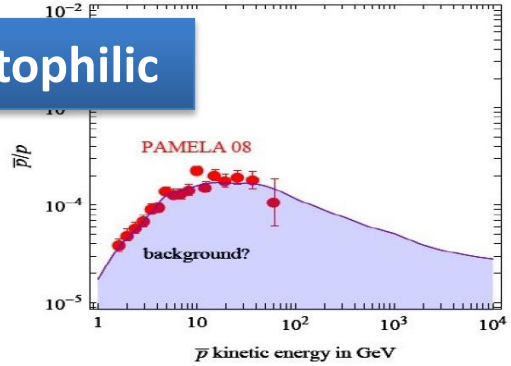


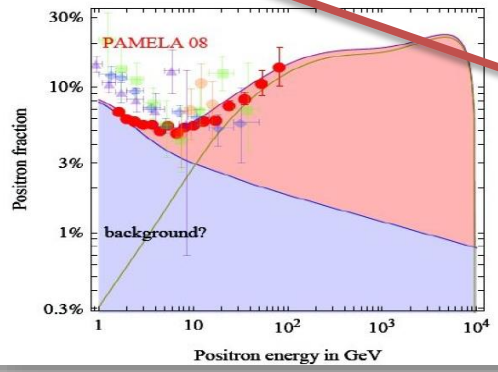

## DM with mass 1 TeV that annihilates into $\mu^+\mu^-$

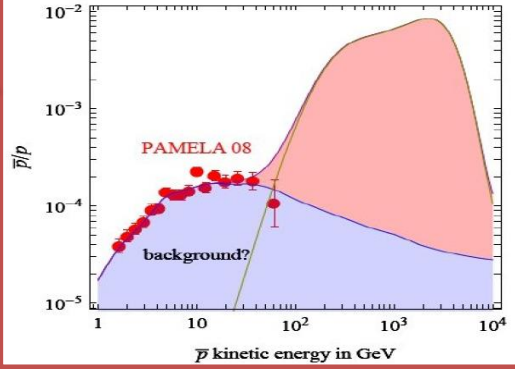
**Leptophilic**



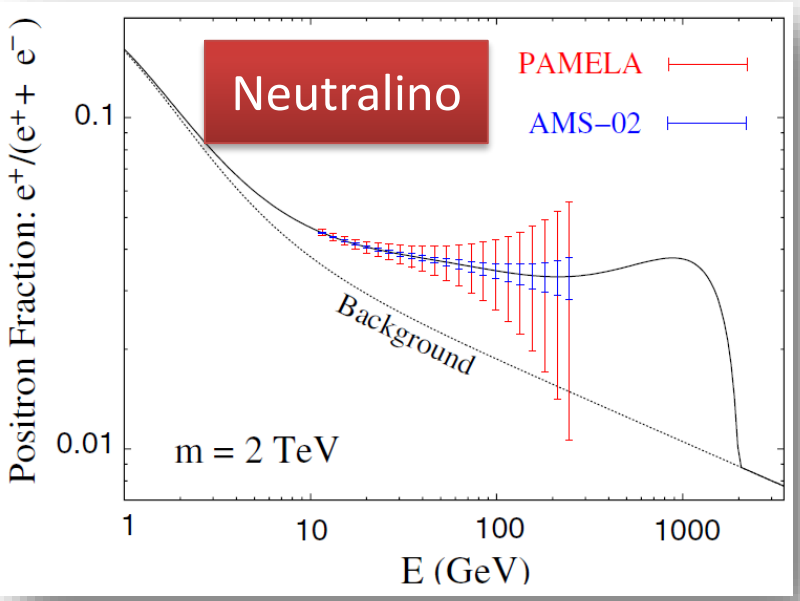



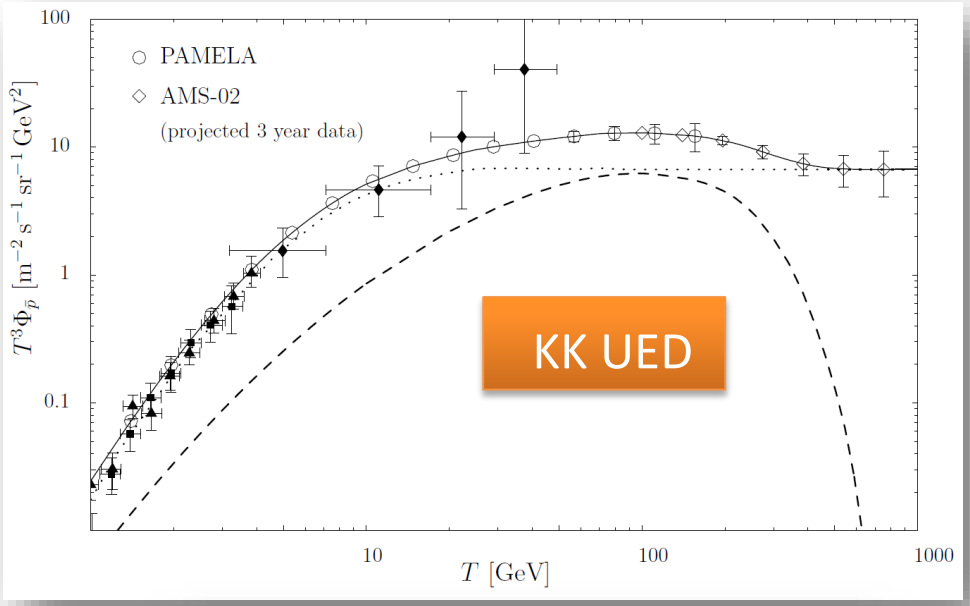

## DM with mass 10 TeV that annihilates into $W^+W^-$



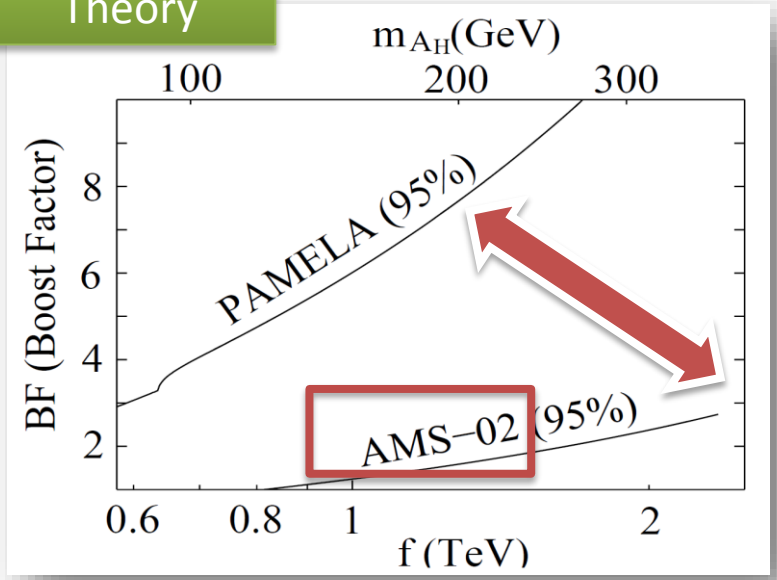



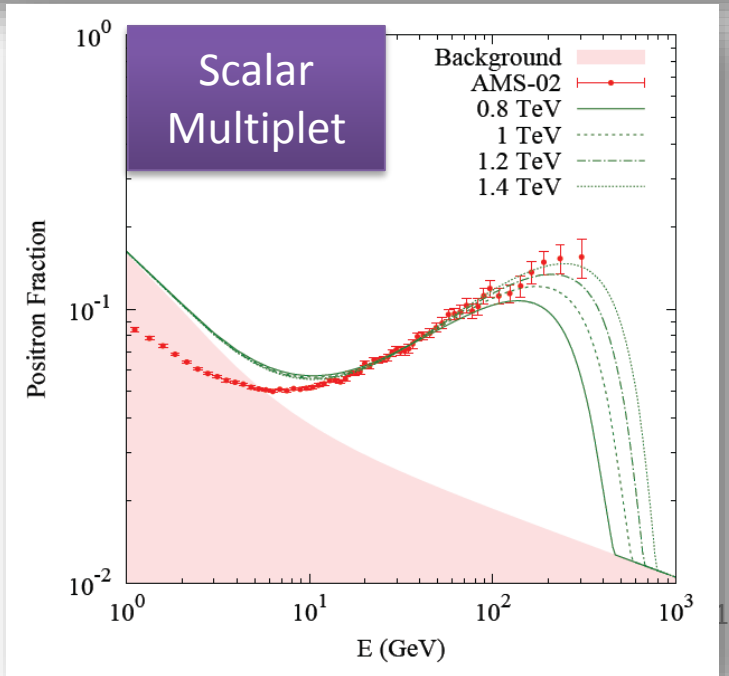
# Heavy Candidates for AMS-02



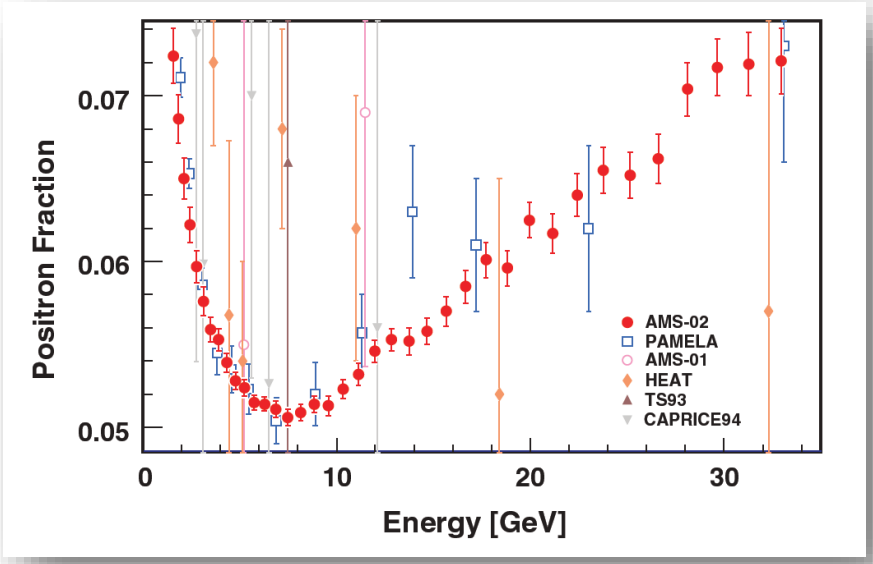

Little Higgs Theory



# AMS-02 recent results: how can we read them?

# Positron Fraction (0.5-500 GeV) Interpretation



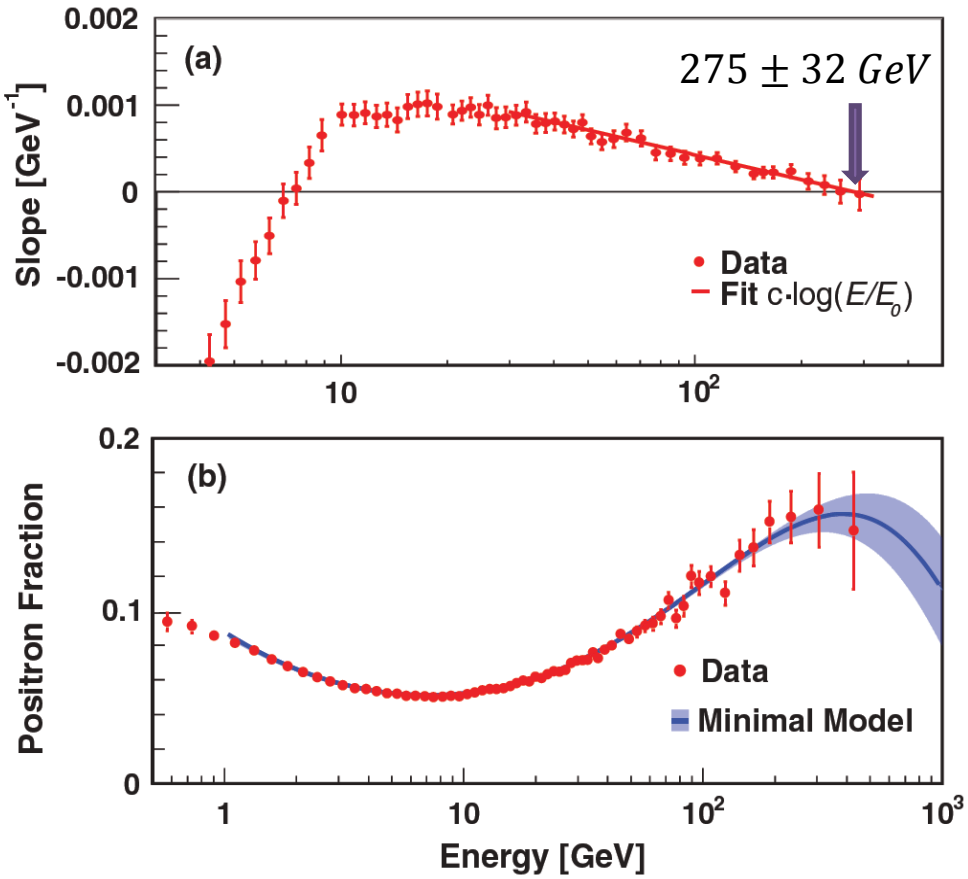

1. Sum of a diffuse spectrum and a **single power law source**

2. The proportion between the **DM mass** and the positron fraction maximum can be worth up to 3 : 1, whereas for $\bar{p}/p$ up to 5 : 1

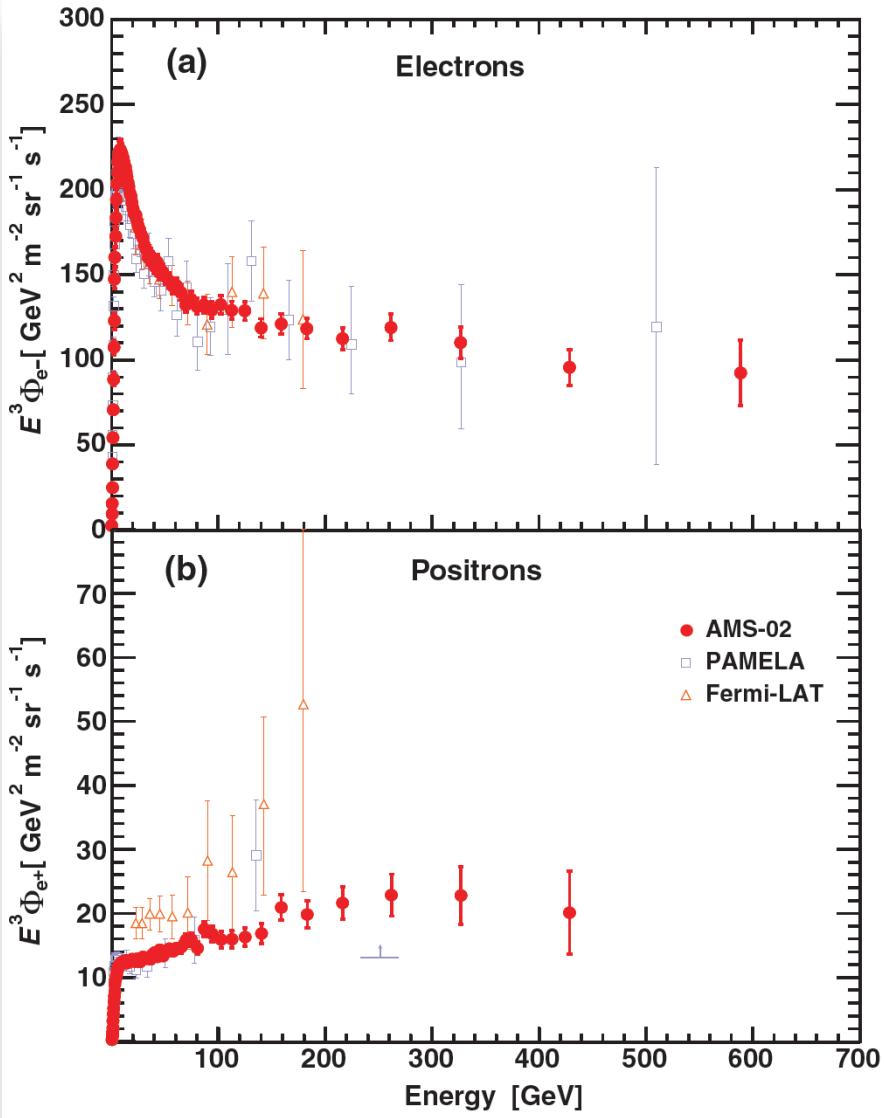
3. **No** clear sign of **substructures**

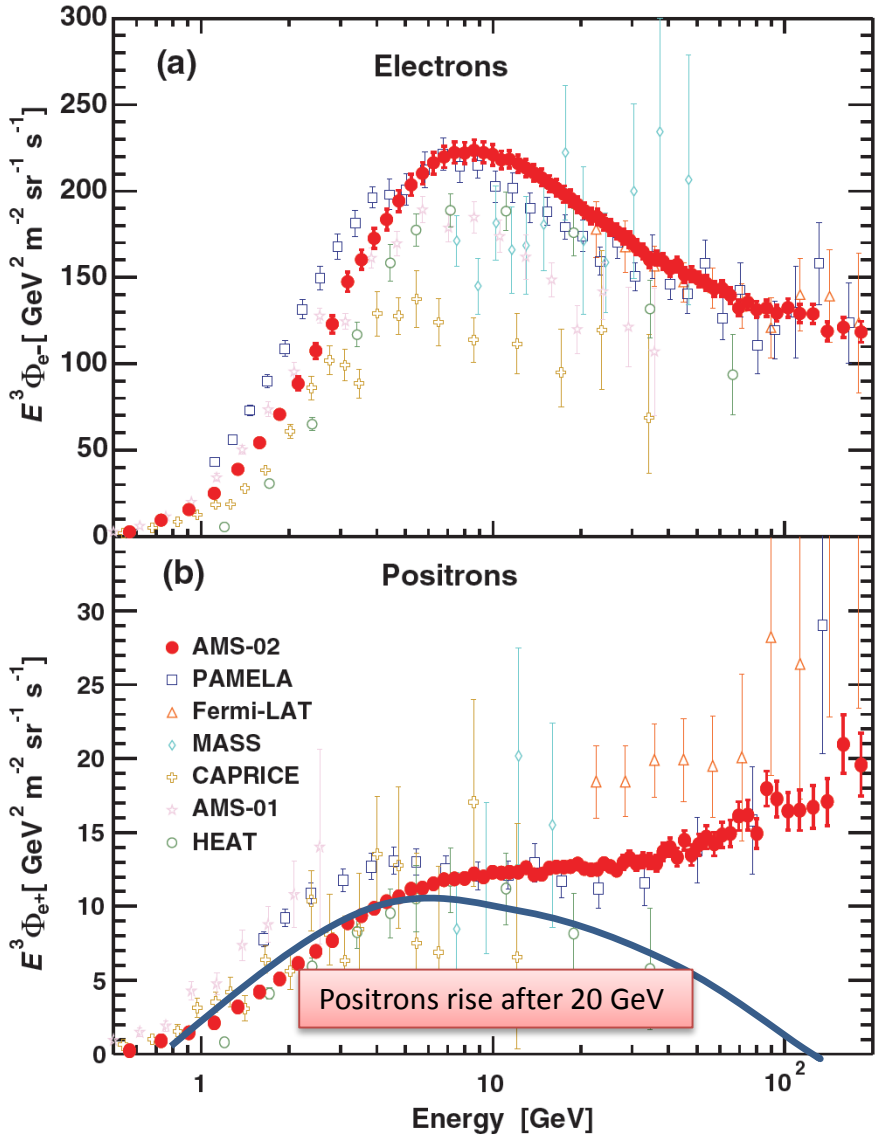
4. **Isotropy:** $\delta \leq 0.030$ – Pulsar Scenario not excluded

5. **Above** $\sim 250\ GeV$ the positron fraction no longer exhibits a remarkable increase with energy

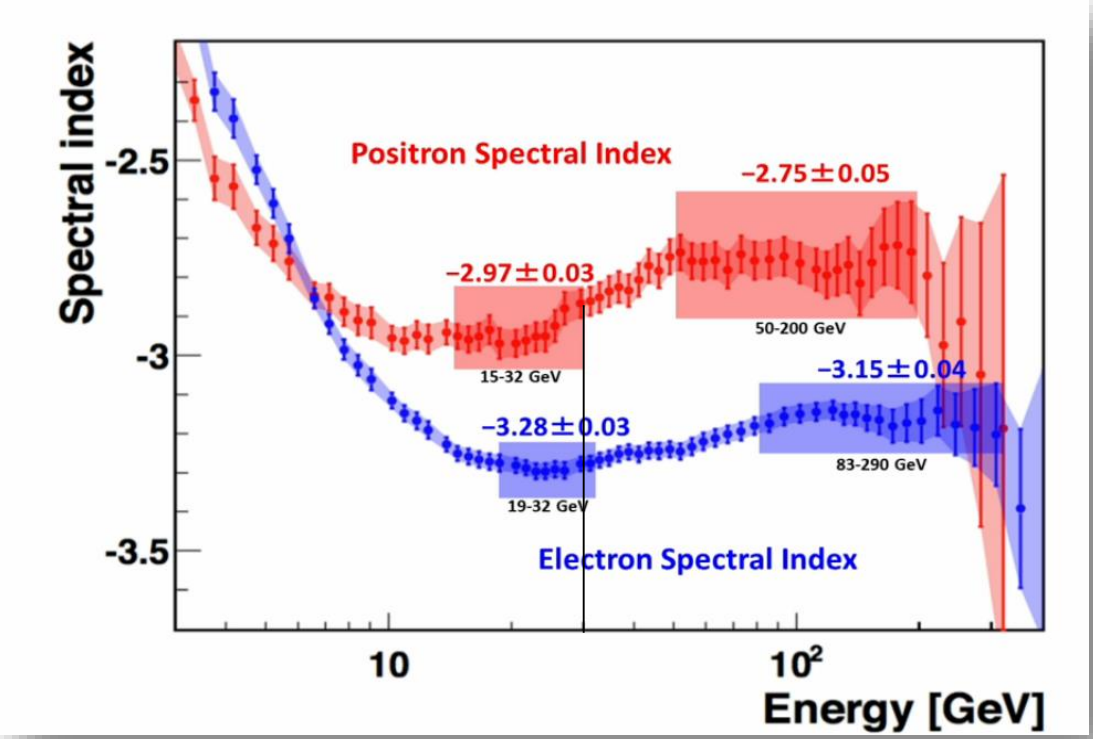


# Electrons (0.5÷700 GeV) and Positrons (0.5÷500 GeV) fluxes



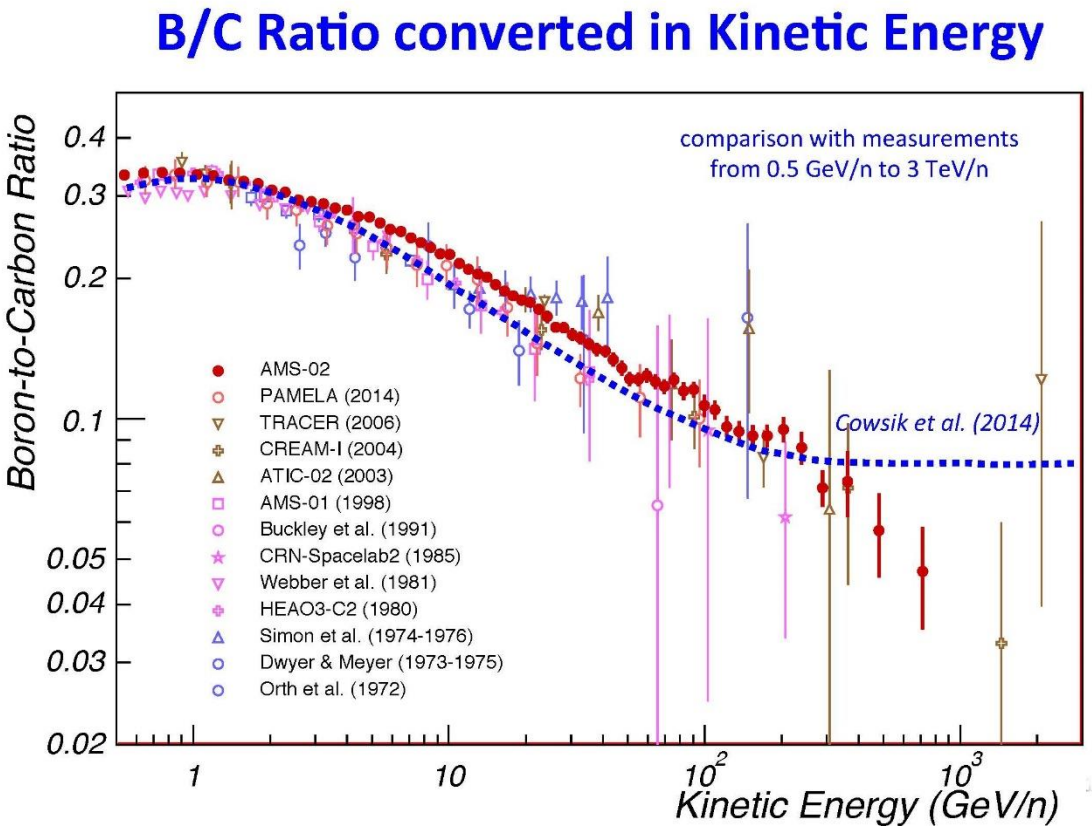



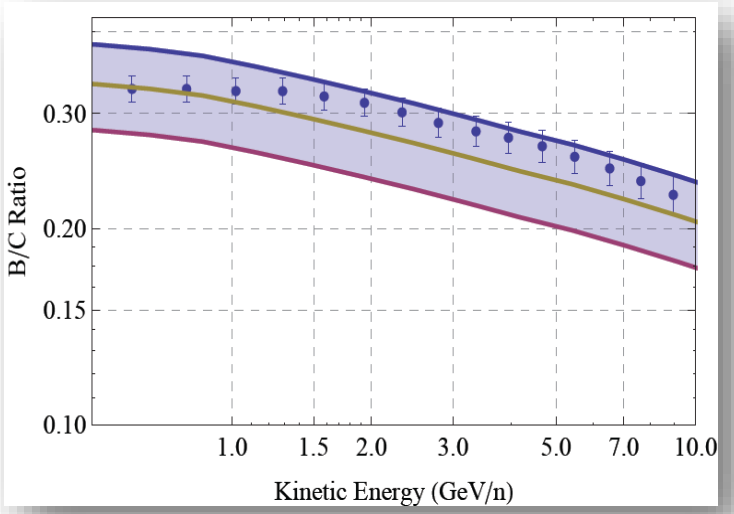
# Changes in the spectral indices of leptons fluxes: what is missing?




- Standard simulations with pure secondaries are not capable of reproducing positrons, without introducing primary DM or/and astrophysical components
- Positrons (and electrons) spectra hardening above 30 GeV is not expected within the standard paradigms
- The change of slope is very similar for electrons and positrons, with an approximately conserved $\Delta\gamma_{e^+-e^-}$

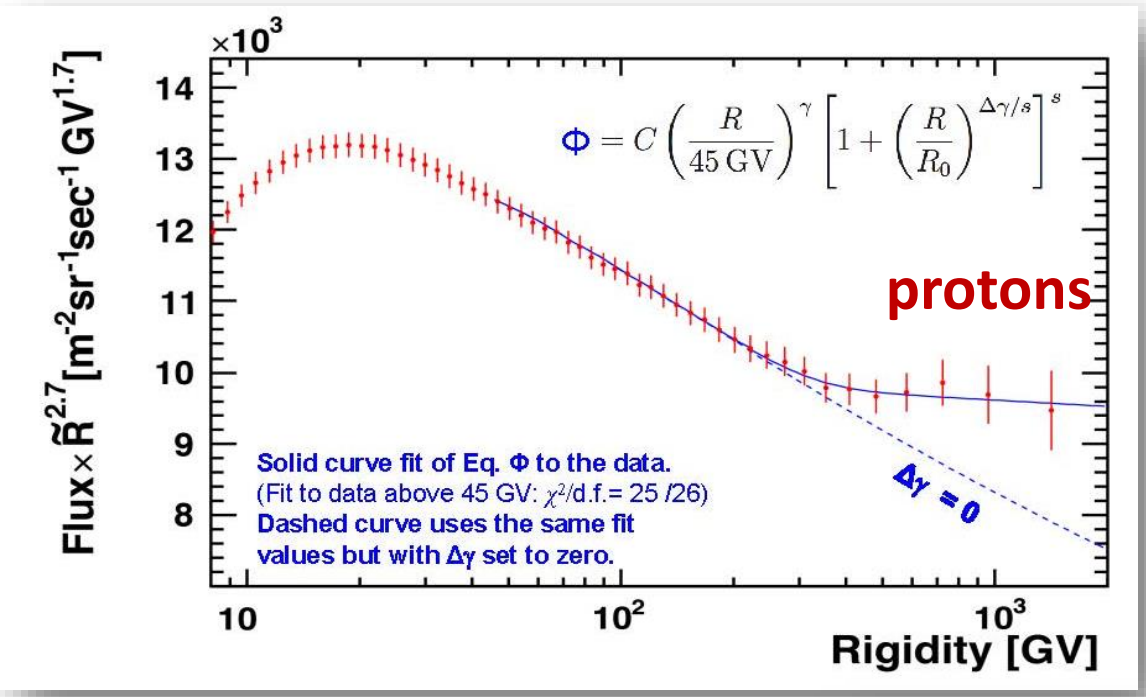
# B/C: preliminary hints



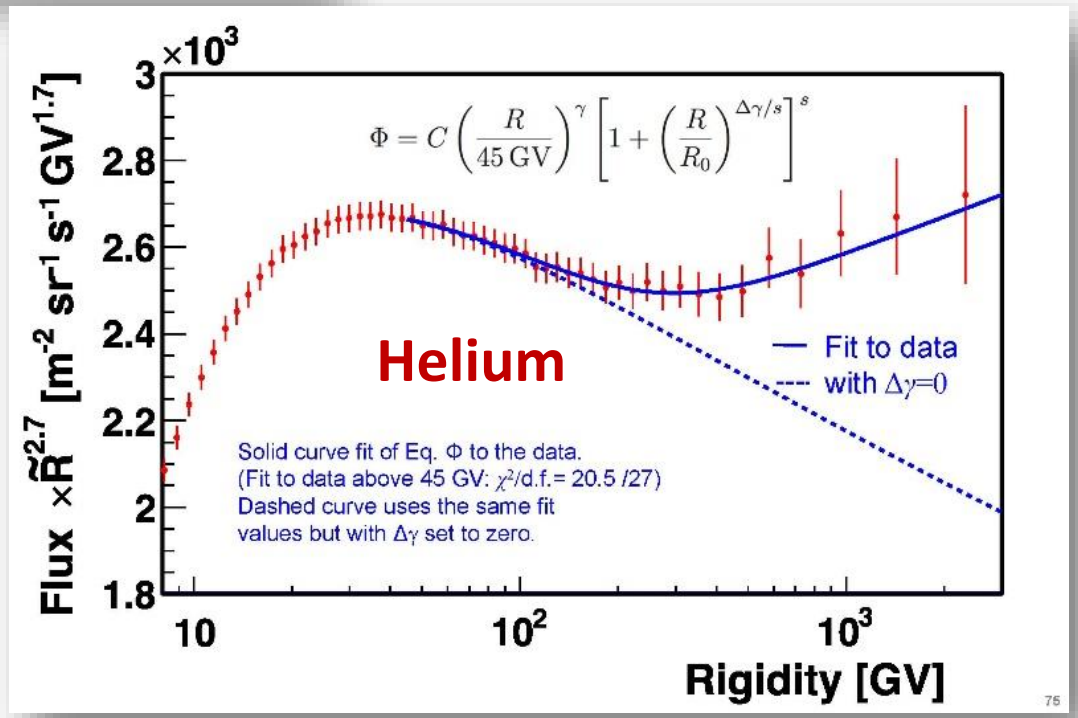



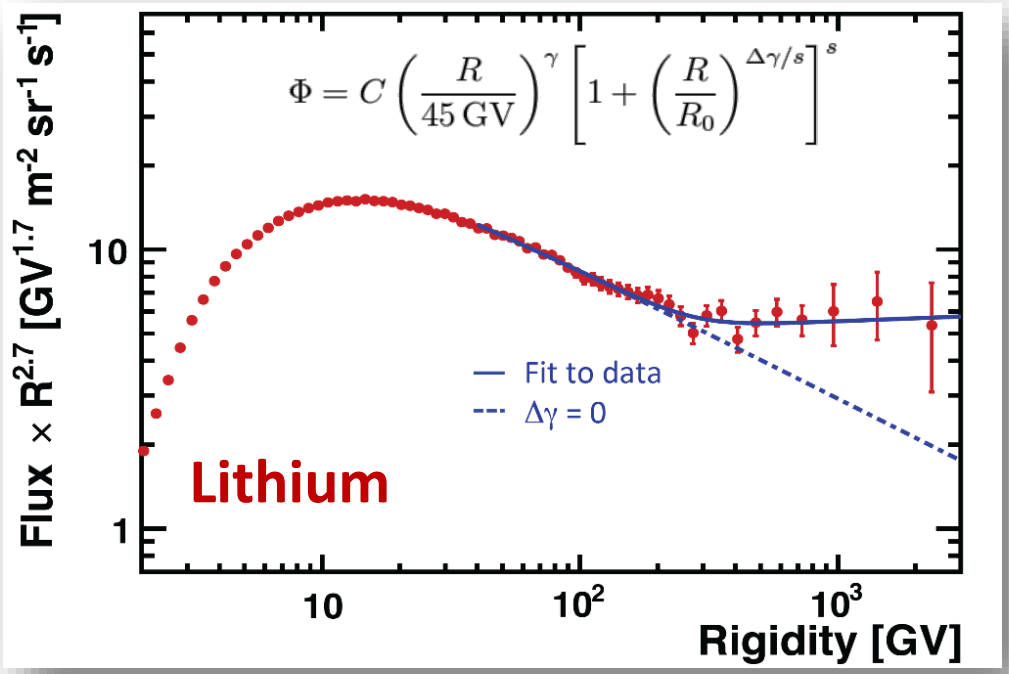

15% uncertainty band from nuclear physics, solar modulation and abundances estimation: greater than experimental errors

- The B/C ratio does not rise at high energies, up to about 700 GeV/n: **SNRs reacceleration models are ill-favored**
- The quite slow decreasing of the B/C ratio above 50 GeV/n seems to allow us to **exclude the anisotropic CR propagation models and long galactic permanence models**, such as Cowsik's.

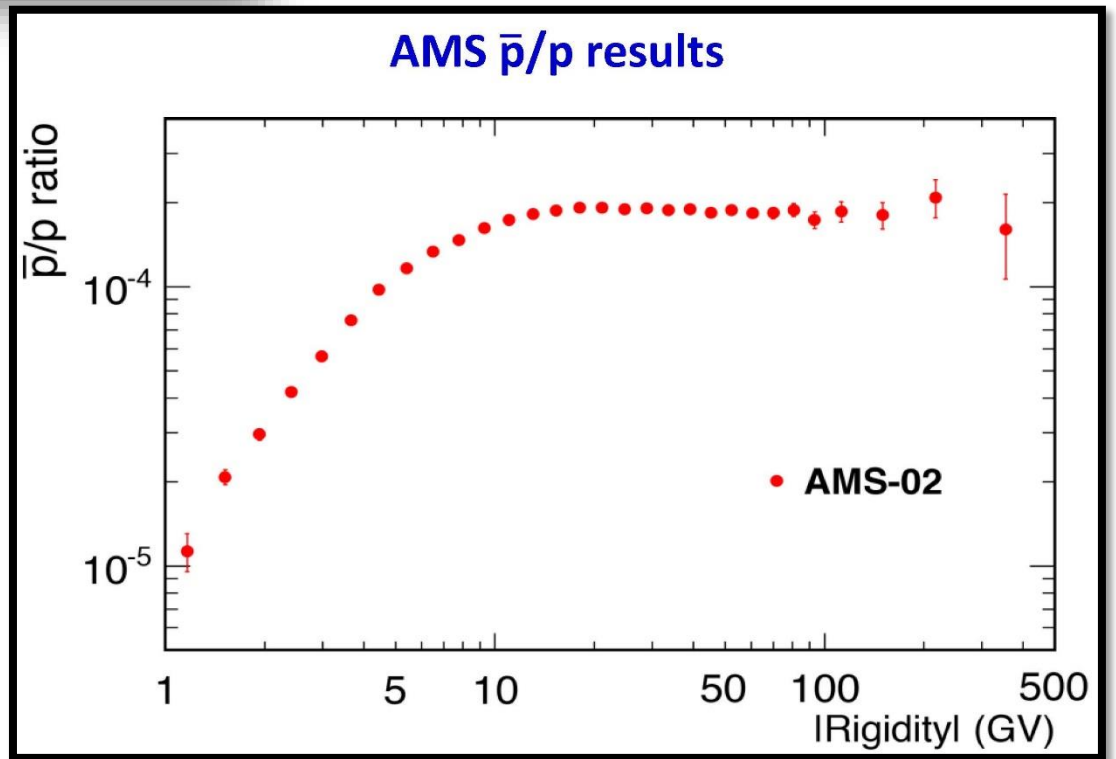



Change of slopes




$\Phi = C\left(\frac{R}{45\,\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$
Flux × R^2.7 [GV^1.7 m^-2 sr^-1 s^-1]
10
1
Fit to data
Δγ = 0
Lithium
10
10^2
10^3
Rigidity [GV]

Anomalies?


AMS p̄/p results
p̄/p ratio
10^-4
10^-5
AMS-02
1
5
10
50
100
500
|Rigidityl (GV)

# Other anomalies w.r.t the Standard Model

**Hadrons**

- Change of slope ($\Delta\gamma \sim 0.1$) after 300 GeV/n for protons and Helia (diffusive $\delta_2 \neq \delta_3$ effects, shock model, composite galactic SNe with $\gamma_2 \neq \gamma_{2'}$ or nearby high energy sources?)

- Differences in gamma indices ($\Delta\gamma_{p-He} \sim 0.1$) between p and He, which seems to remain constant at all energies (source origin)

- A break or a change of slope?

- Unexpected rise of the pure secondary Lithium spectrum: this could change the orthodoxy!

- Is there a flattening of the antiproton over proton ratio?

# Conclusions

1. AMS-02 showed an **excellent capability and versatility in doing the described dark matter researches**, granting the opportunity to measure CR antiparticle to particle ratios with unprecedented precision and guiding the community in the interpretation of CR physics
2. To say something conclusive about DM indirect detection we have to face the **astrophysical uncertainties:** it will be possible to determine an almost univocal propagation using multiple constraints from nuclei and fundamental particles spectra
3. Astrophysical and LHC observations suggest that **DM must be very massive:** some candidates are more viable than others
4. The determination of the differing behavior of the leptons spectral indices versus energy is a new observation and provides **important information on the origins and propagation mechanisms of cosmic-ray electrons and positrons,** to shed light on the positron fraction conundrum
5. The research for **an antiproton signal** related to heavy DM particles is going to be published up to 500 GeV: an antiproton anomaly would be very difficult be explained without dark matter, in particular after the incoming AMS-02 B/C ratio results
6. If the antiproton/proton ratio won't show a decreasing nor an increasing behavior, it will be necessary to study the implications of **the flattening** in details, to determine the compatibility with a secondary spectrum
7. **Theoretical uncertainties are greater than AMS-02 experimental errors** (20÷40% vs few %): a joint effort of the fundamental interactions physicists is mandatory to fully exploit the information contained in AMS data.