Cosmic-ray propagation models and their impact on indirect dark-matter searches

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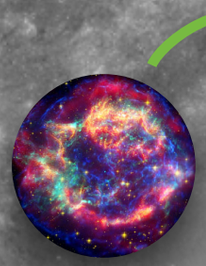
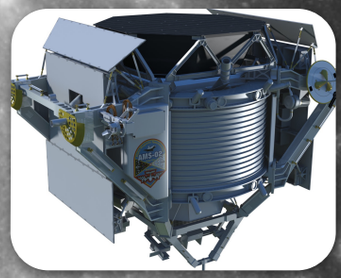
LAPTh
DMAstroLHC (ANR-12-BS05-0006)

GDR Terascale 2015
IPhT Saclay



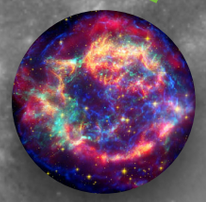
secondaries

primaries



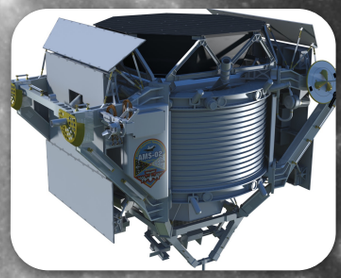
I. Sources & Acceleration

diffusive shock acceleration



secondaries

primaries

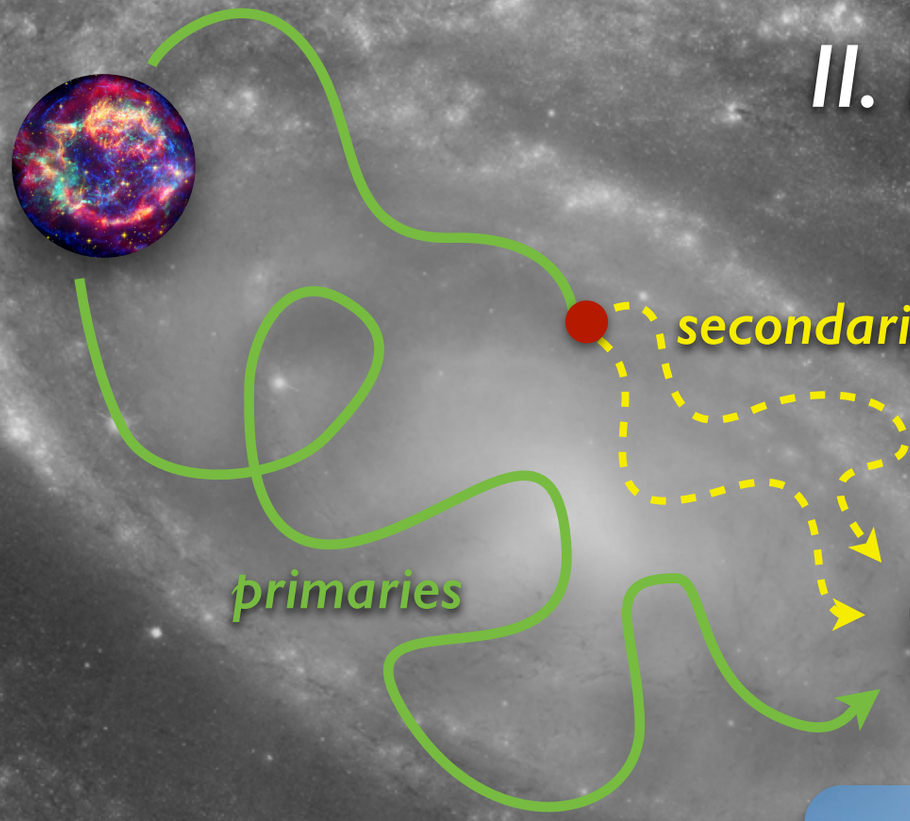


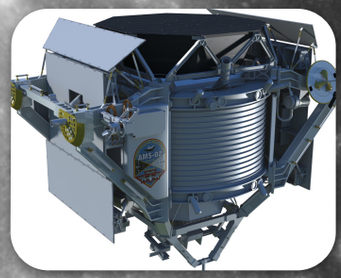
I. Sources & Acceleration

diffusive shock acceleration

II. Propagation in the ISM

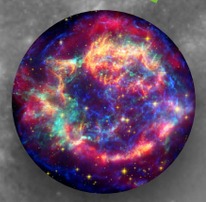
diffusion, convection, re-acceleration





I. Sources & Acceleration

diffusive shock acceleration



II. Propagation in the ISM

diffusion, convection, re-acceleration

secondaries

primaries

III. Solar System & Detection

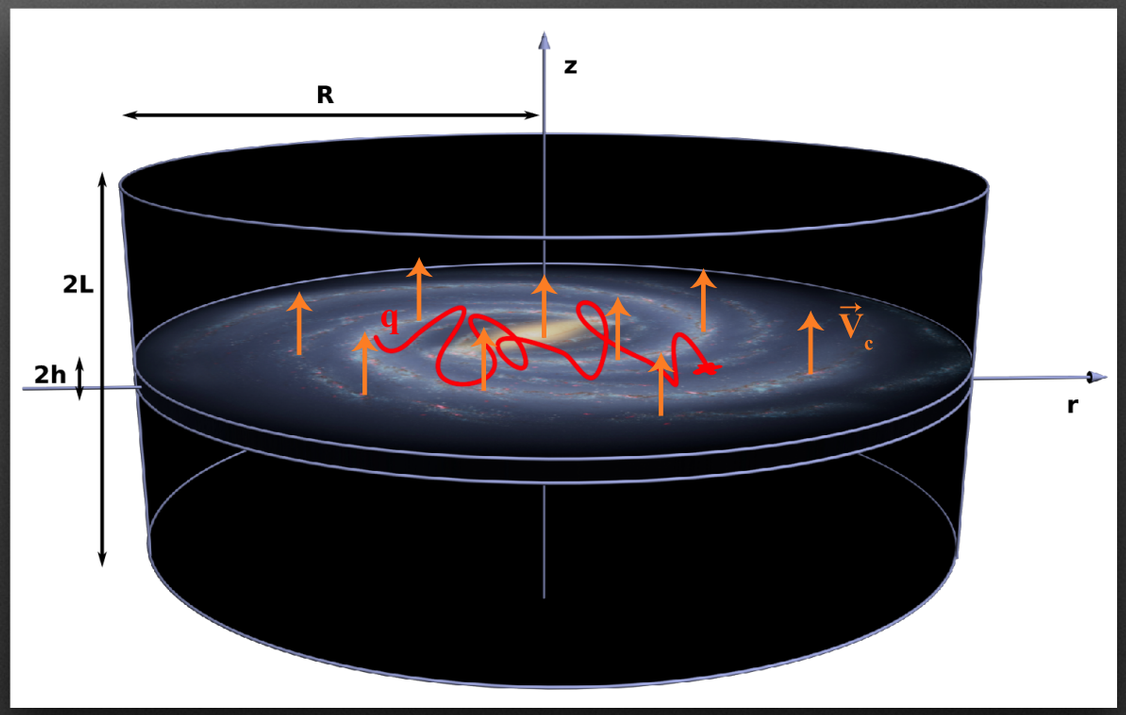
solar modulation, geomagnetic cut-off

Diffusion Model

Diffusion equation becomes solvable assuming a cylindrical geometry of the Galaxy with 2 zones: the galactic disc & the diffusive halo

- Semi-analytical approach
  e.g. USINE @ lpsc.in2p3.fr/usine
  ✅ fast computation
  ⛔ simplified description of the interstellar medium

- Numerical approach
  e.g. GALPROP @ galprop.stanford.edu
  ✅ data based description of the interstellar medium
  ⛔ very slow



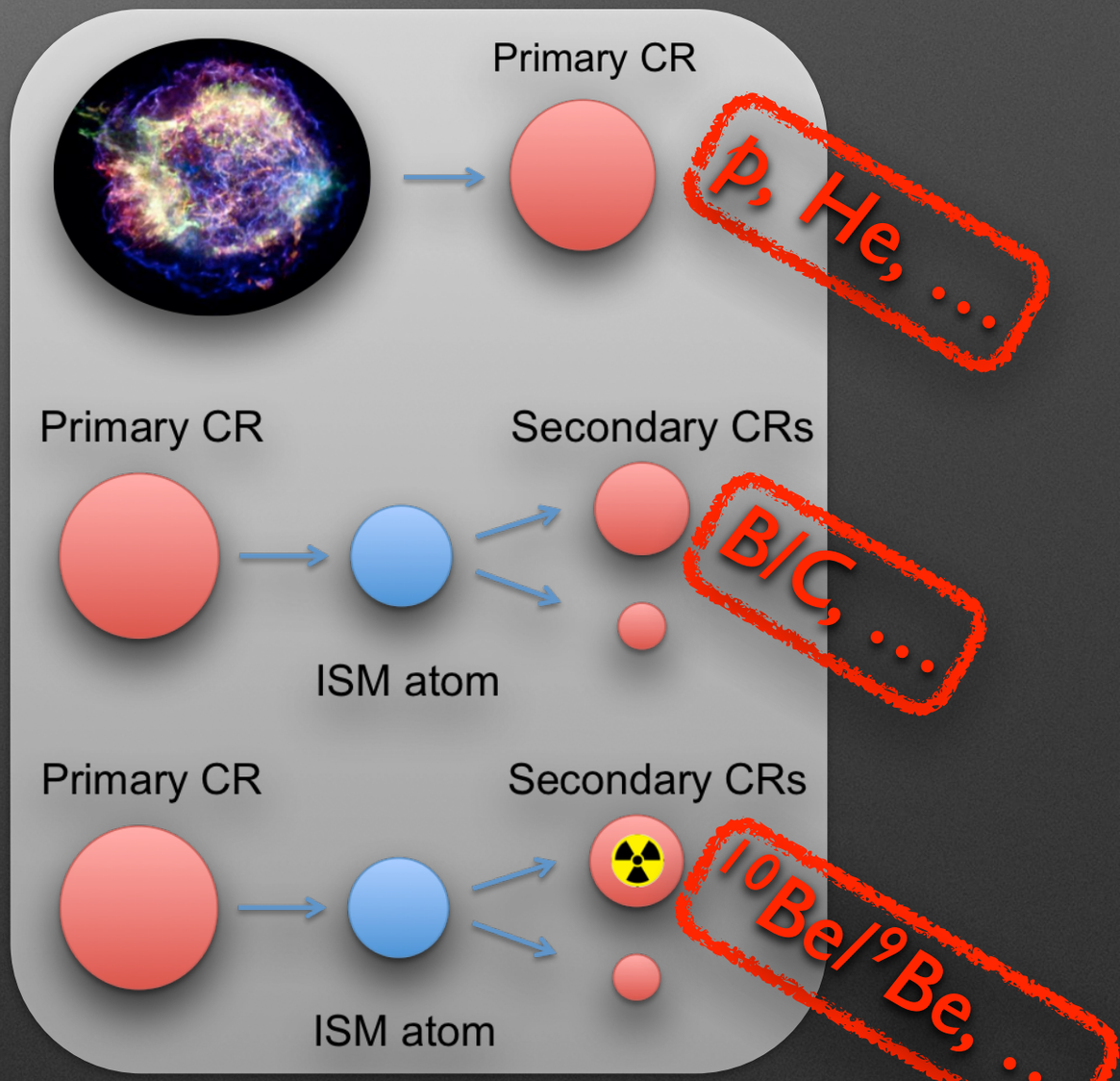
Parameters and observables

The most important parameters are linked to

- the acceleration mechanisms
  injection spectrum: $Q(R) \propto qR^{-\alpha}$

- the propagation mechanisms
  diffusion: $K(R) \propto K_0 R^{\delta}$
  convection: V_C
  re-acceleration: V_A

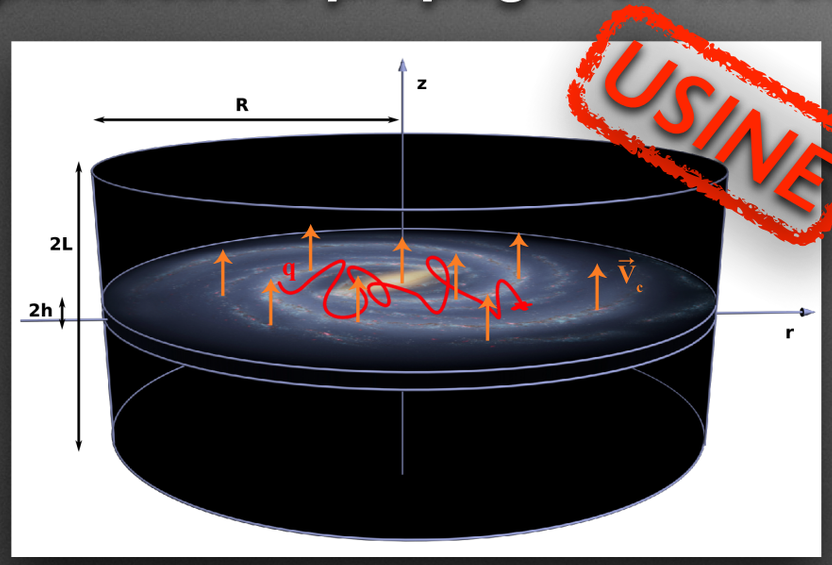
- the geometry of the Galaxy
  diffusive halo size: L



lpsc.in2p3.fr/cosmic-rays-db

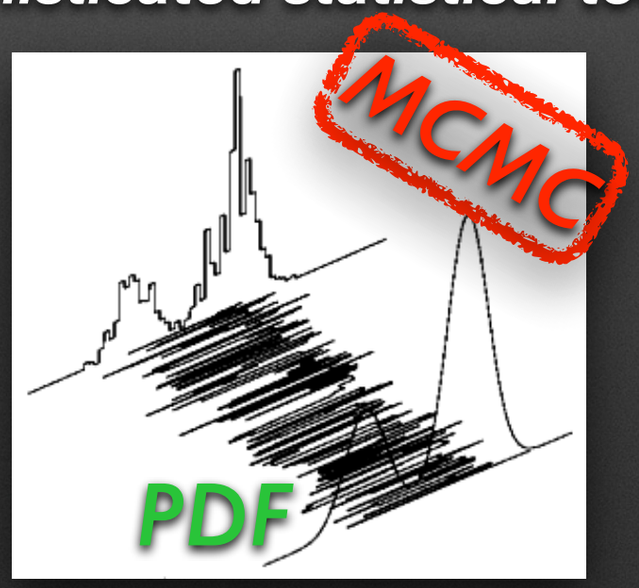
Constraining propagation models

sophisticated propagation models



precise experimental data

sophisticated statistical tools



parameters

observables

USINE @ lpsc.in2p3.fr/usine

GreAT @ lpsc.in2p3.fr/great

6 publications [Putze, Coste, Derome, Donato, Maurin, Perotto, Taillet (2009 - 2014)]

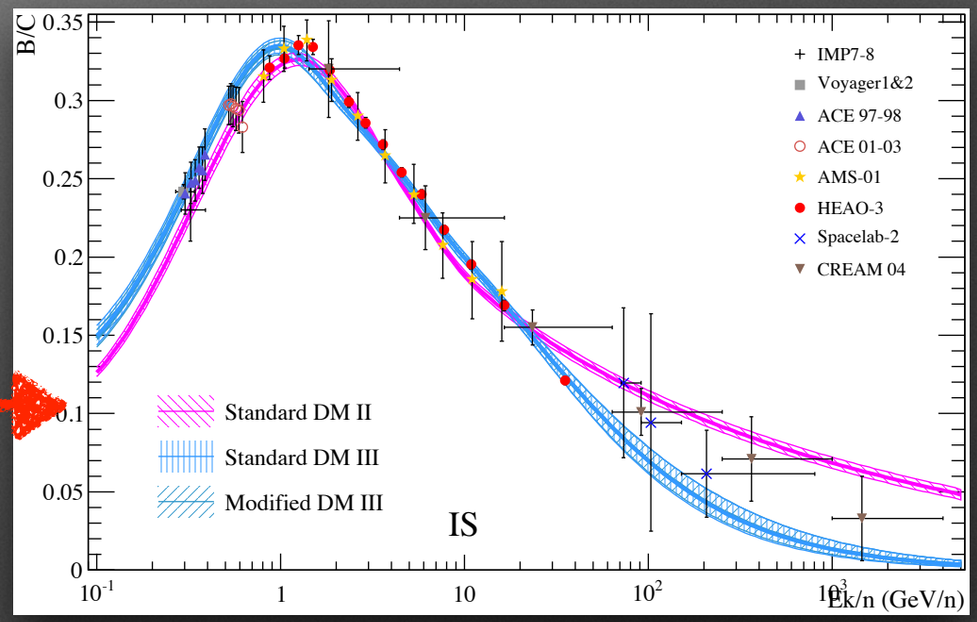
Which model is the best?

Diffusion models with re-acceleration and/or convection preferred, but diffusion slope δ varies from 0.3 to 0.8

Same results for

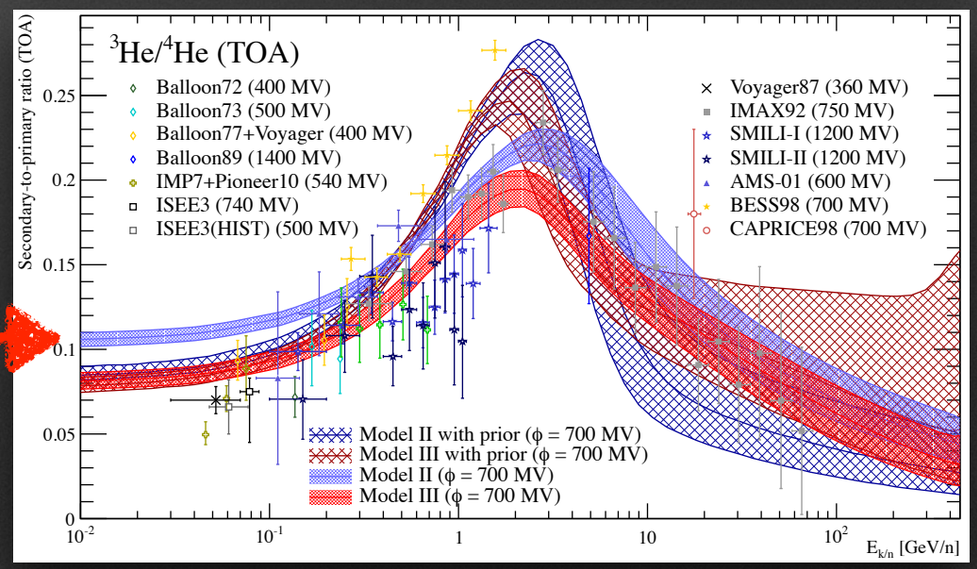
- B/C
  - ✅ abundant
  - ✅ elemental separation needed

  [Putze, Derome, Maurin, *A&A* (2010)]



- $^3He/^4He$
  - ✅ very abundant
  - ⛔ isotopic separation needed

  [Coste, Derome, Maurin, Putze, *A&A* (2012)]



How big is the diffusive halo?

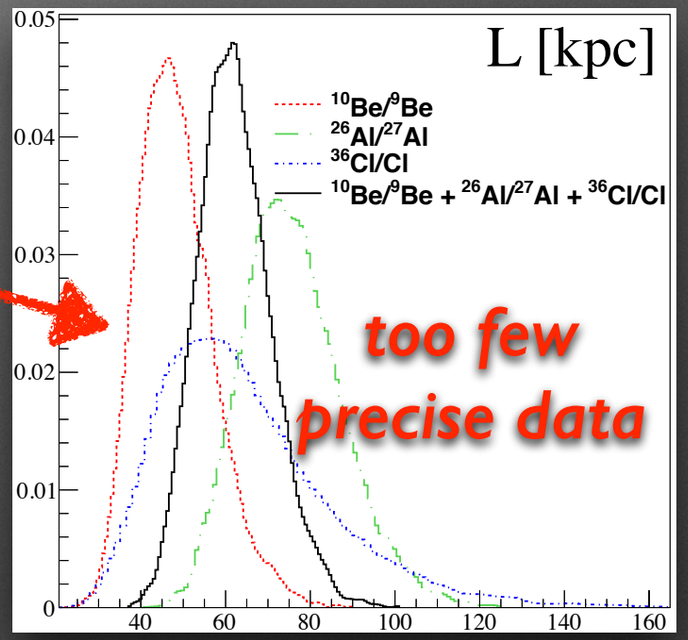
L determines the amount of dark matter contribution in cosmic rays!

Radioactive secondaries:

first PDF of L from an MCMC analysis

- ⛔ too few precise data
- ⛔ very sensitive to the LISM

[Putze, Derome, Maurin, *A&A* (2010)]

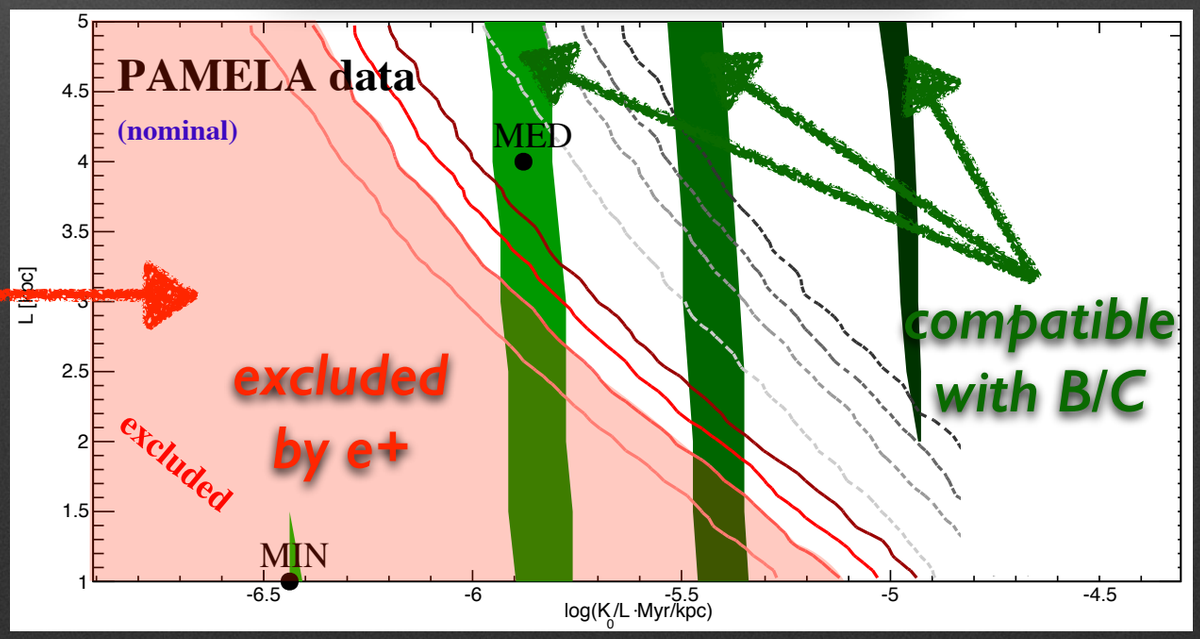


Secondary positrons:

first direct exclusion of small values of L

- ✅ precise data available
- ⛔ sensitive to solar modulation

[Lavalle, Maurin, Putze, *PRD* (2014)]

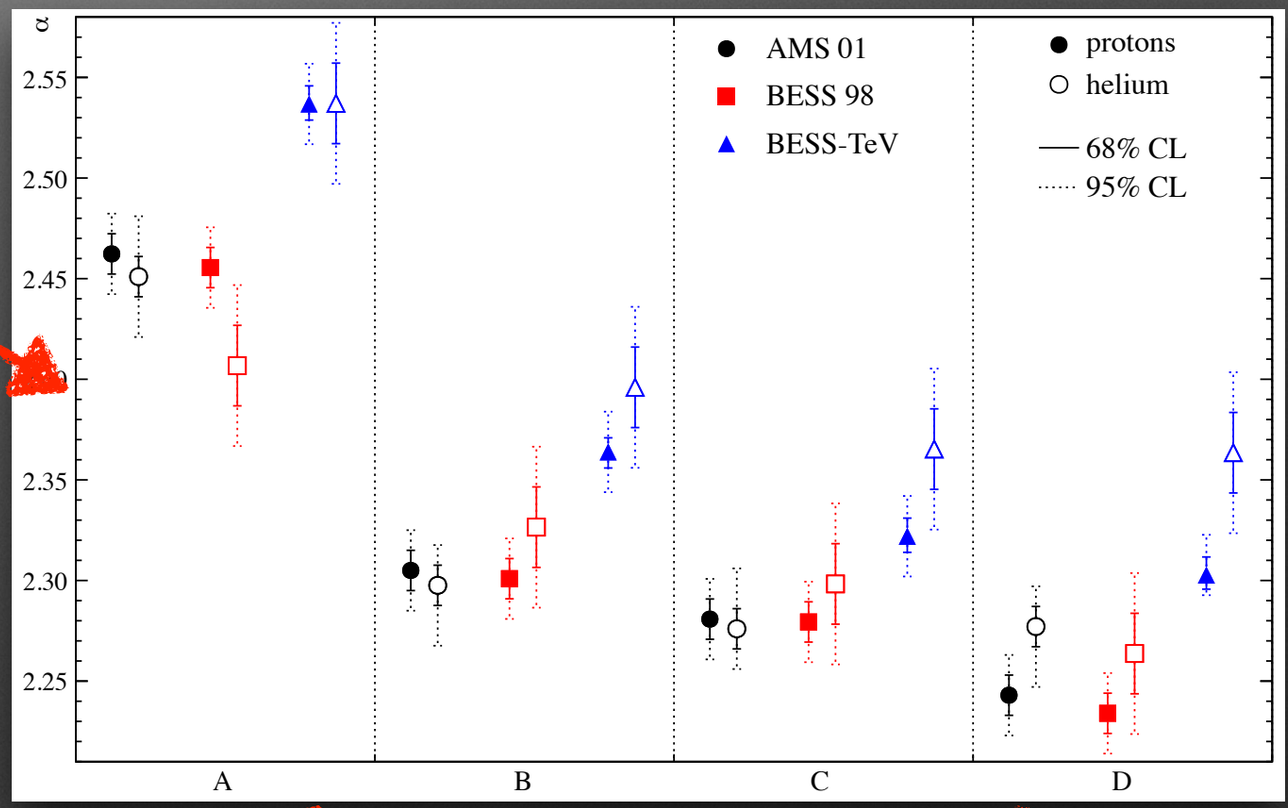


What the primaries tell us…

source slope $2.25 \leqslant \alpha \leqslant 2.5$ for diverse propagation models

source slope α similar for all primaries Z = 1, …, 26

→ universality of the injection mechanism

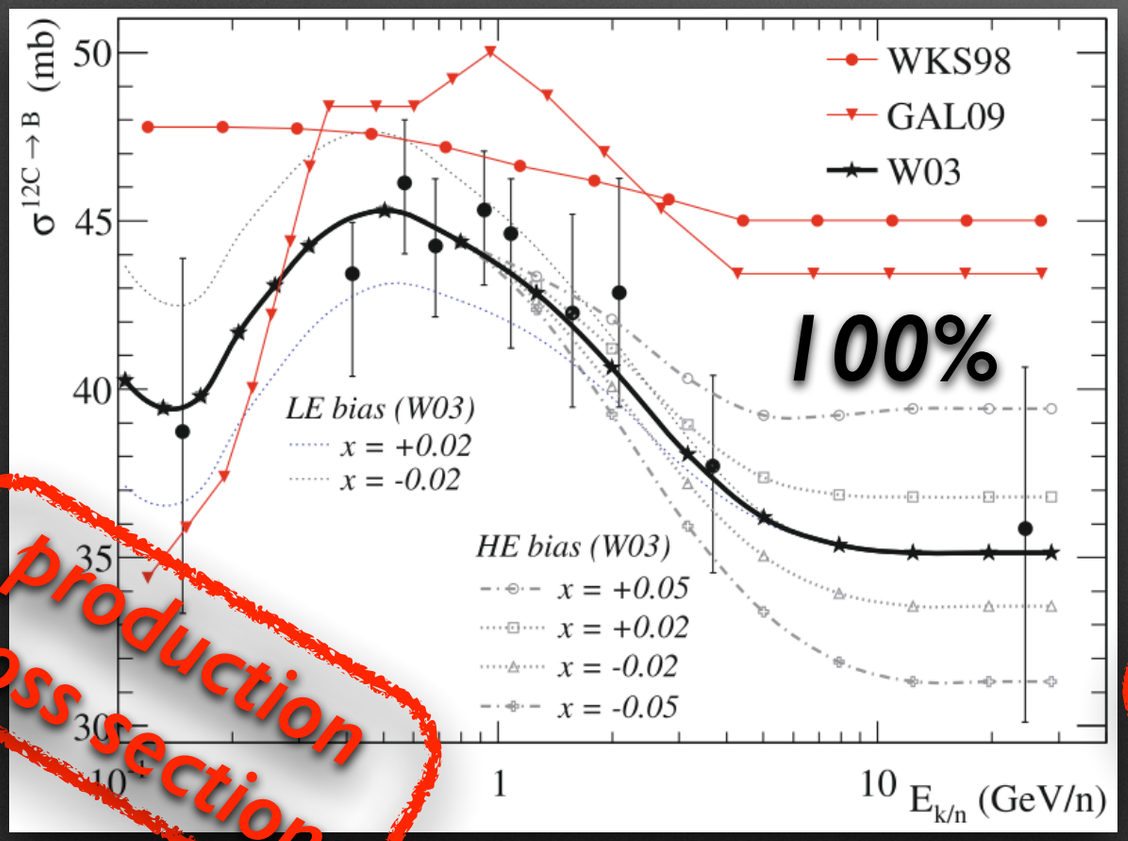


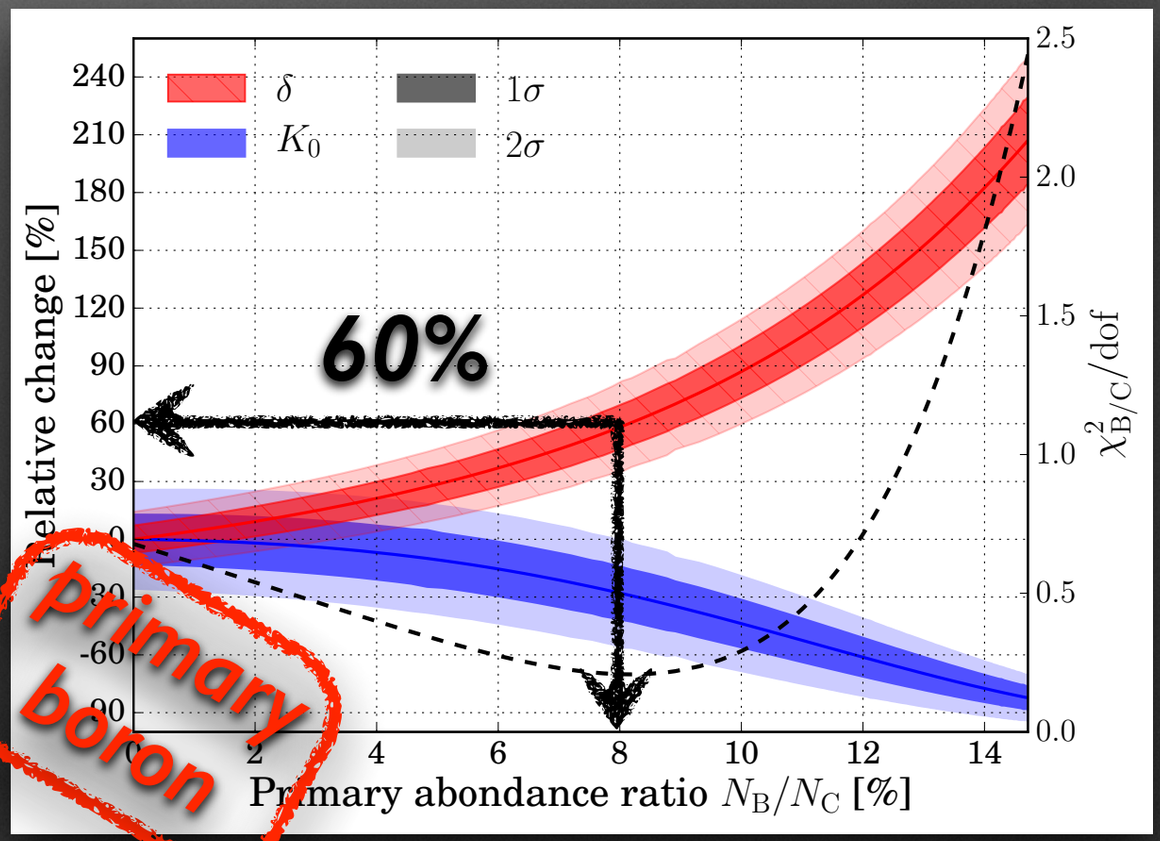
different propagation models

[Putze, Maurin, Donato, *A&A* (2011)]

What about theoretical uncertainties?

Precise cosmic-ray measurements give small statistical uncertainties, and theoretical uncertainties from model ingredients and hypotheses are dominating!

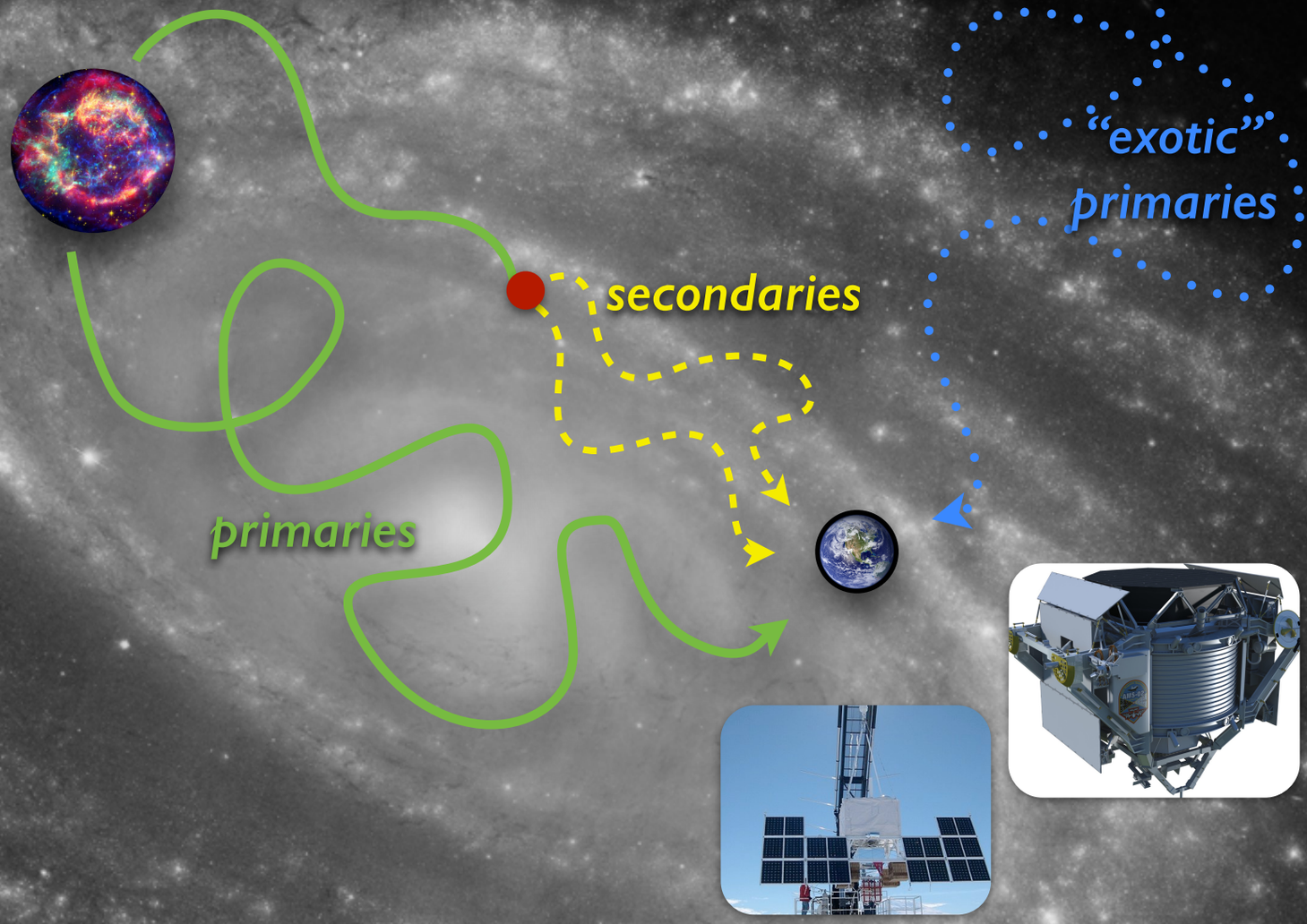




Parameter estimation already very tricky in a simple configuration…

[Génolini, Putze, Salati, Serpico, *in preparation*

Indirect dark matter searches



charged cosmic-ray channels: e^+, $\bar{p}$, …

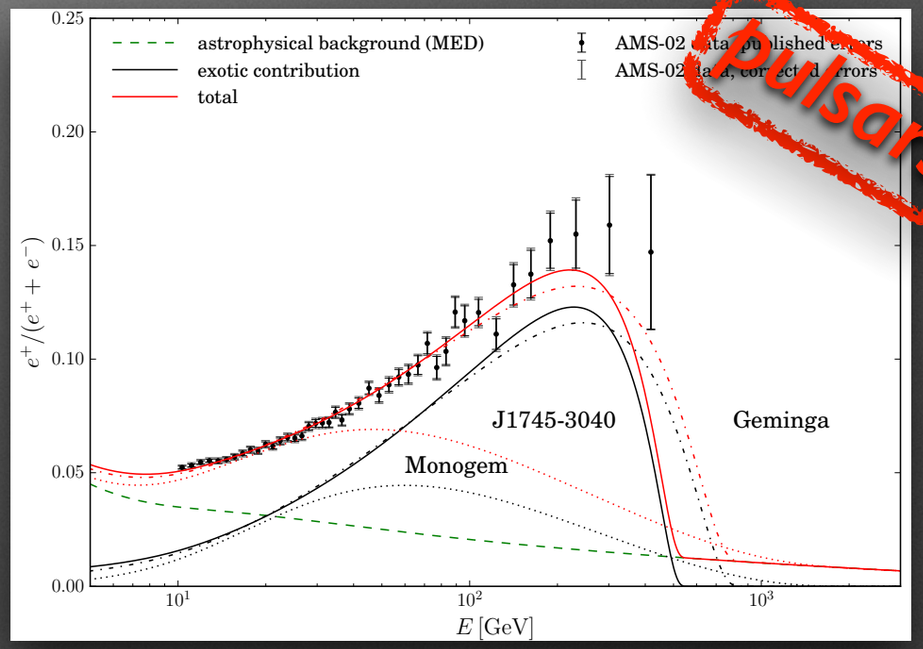
Positrons — difficult probes for dark matter searches

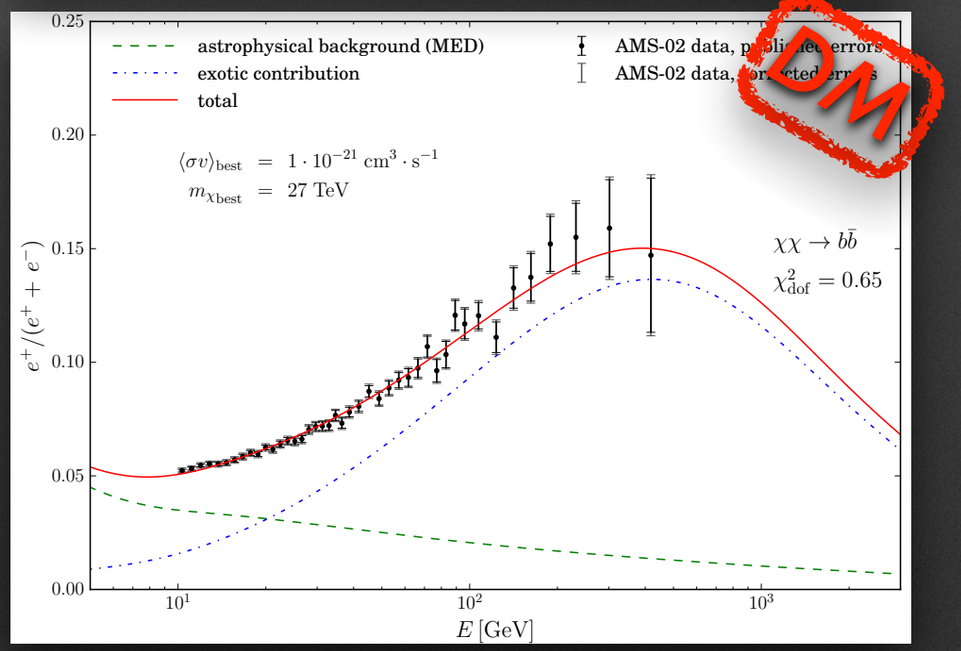
Well modelled with

- secondaries:
  - ✅ diffusion models
  - ⛔ uncertainties on propagation parameters

- primaries:
  - ✅ pulsars, dark matter annihilation/decay, acceleration of secondaries in sources, …
  - ⛔ very large uncertainties
  - ⛔ large boost factor needed for dark matter interpretation

but no unique interpretation…

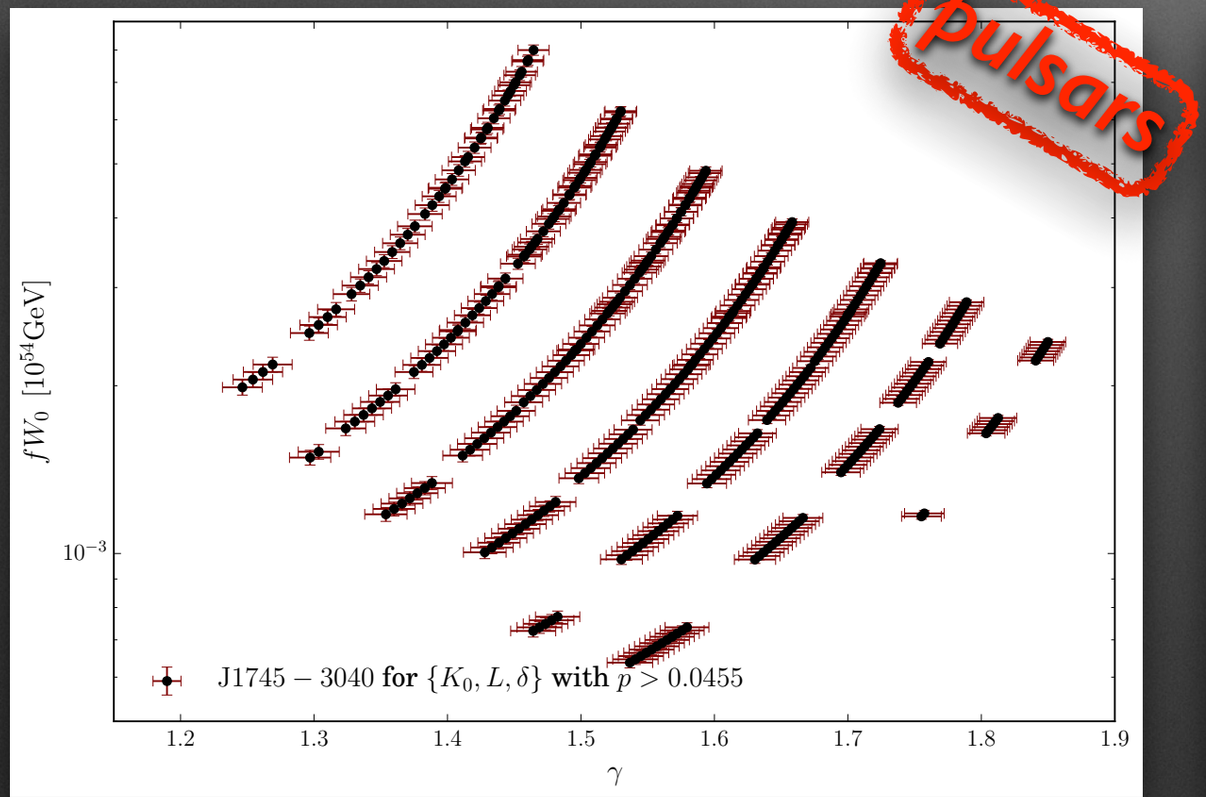


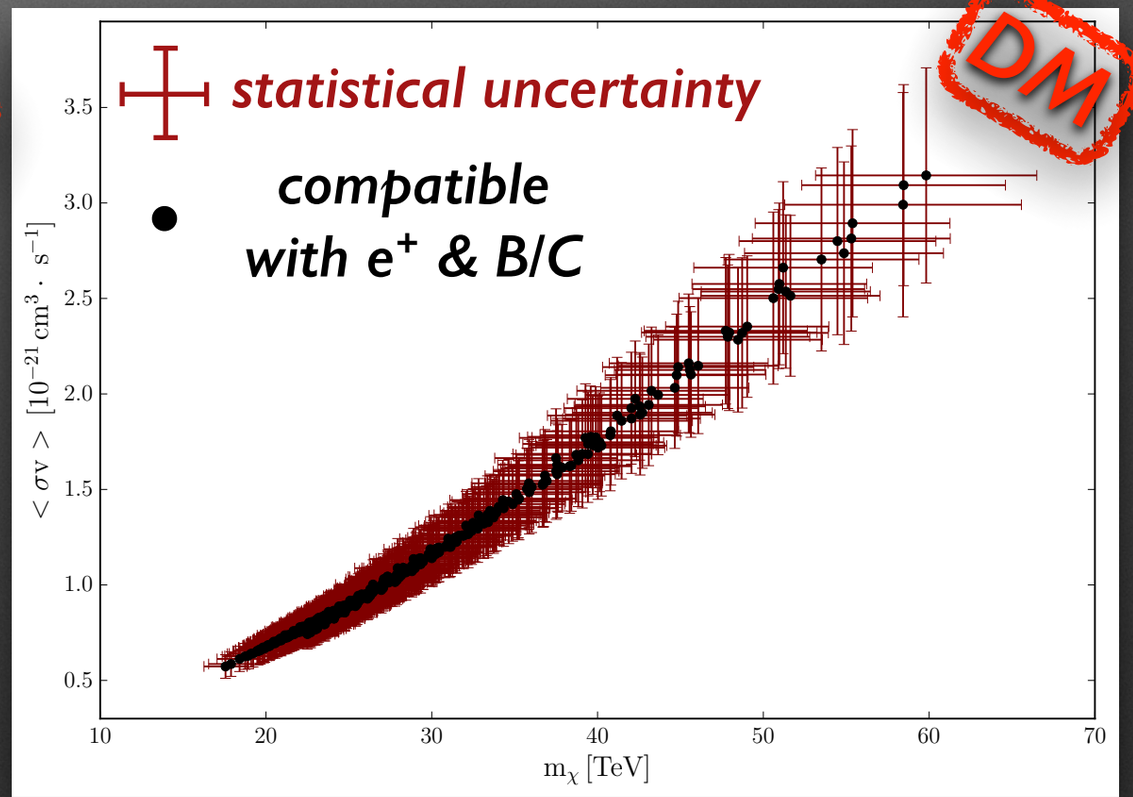


[Boudaud *et al.*, *A&A* (2015)]

Positrons — propagation uncertainties

Scan over propagation parameters compatible with the B/C ratio



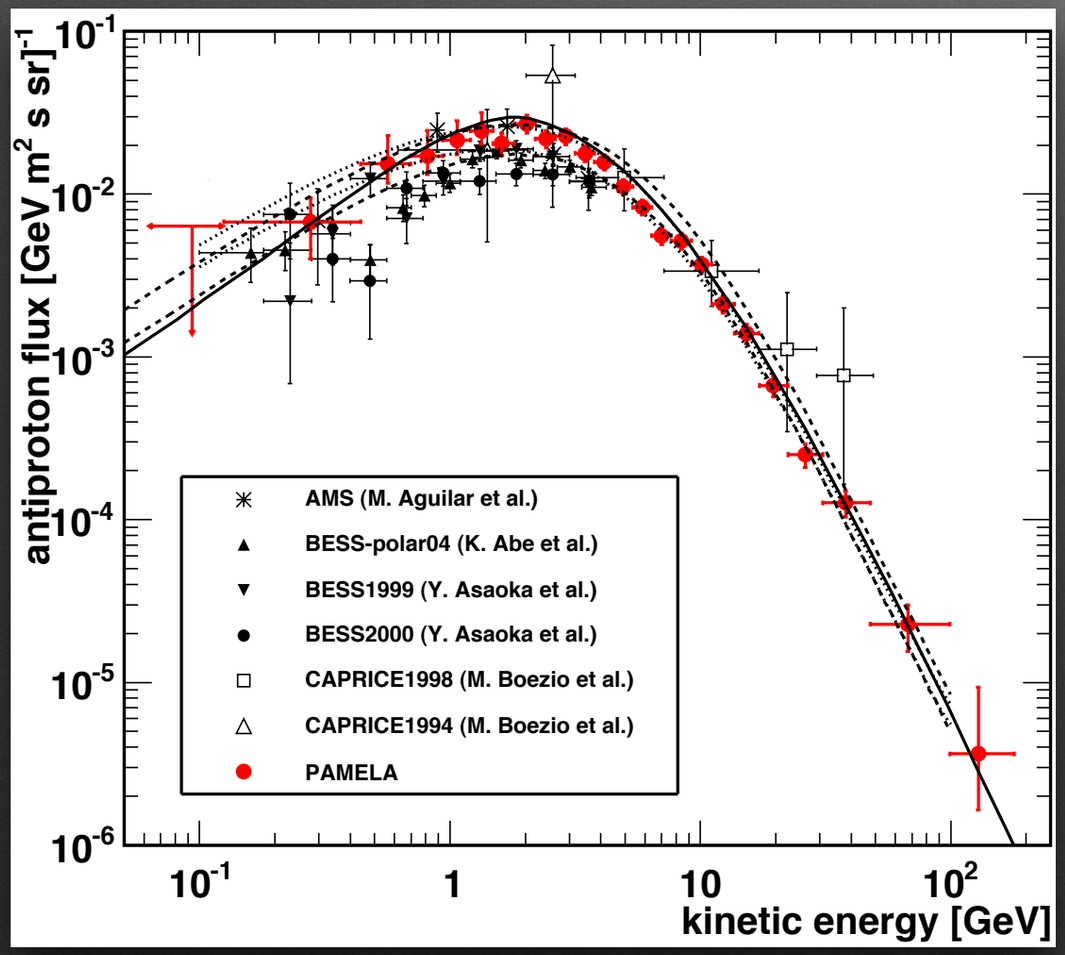


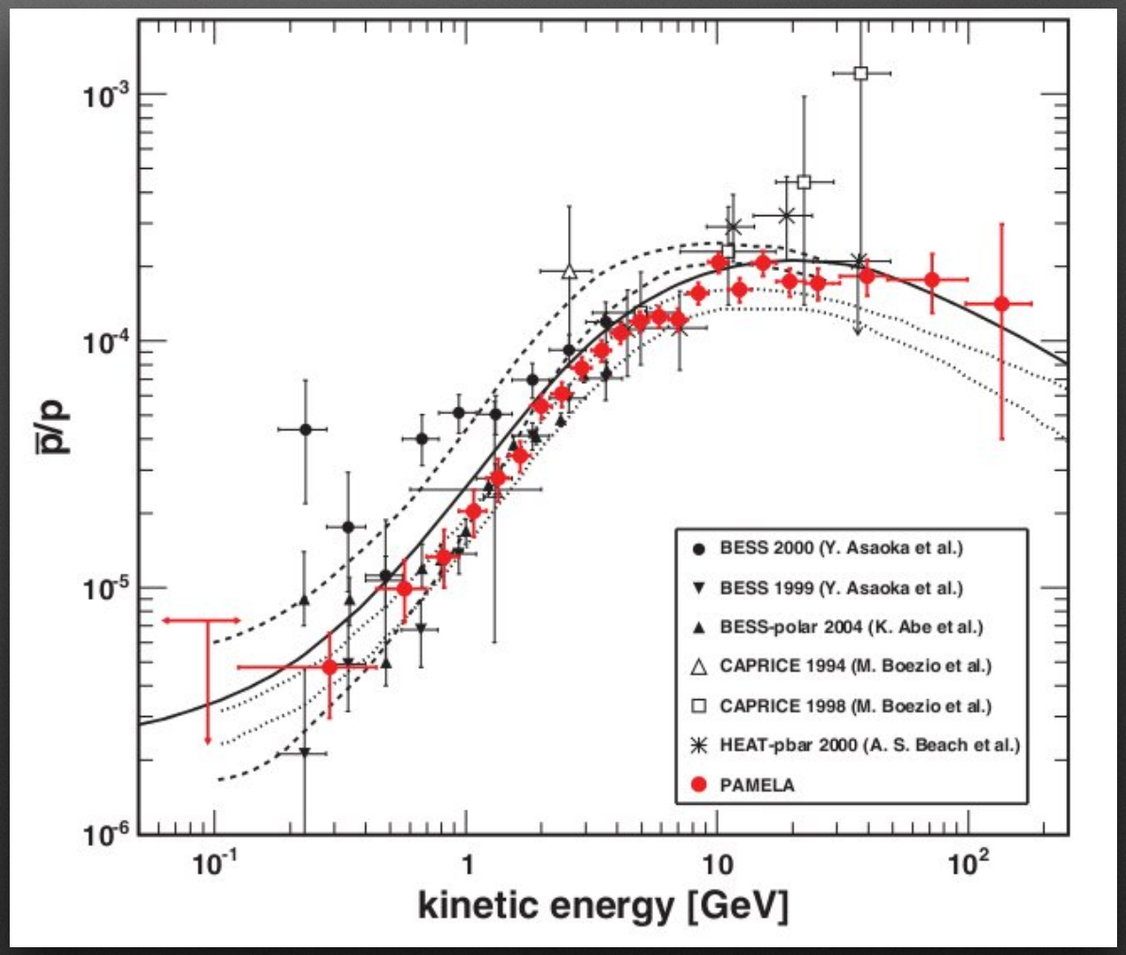
Systematic uncertainties from propagation parameters are dominating!

[Boudaud *et al.*, *A&A* (2015)]

Antiprotons — strong constraints for dark matter

Recent antiproton measurements in very good agreement with a pure secondary origin





But production cross sections are not known at high energies!

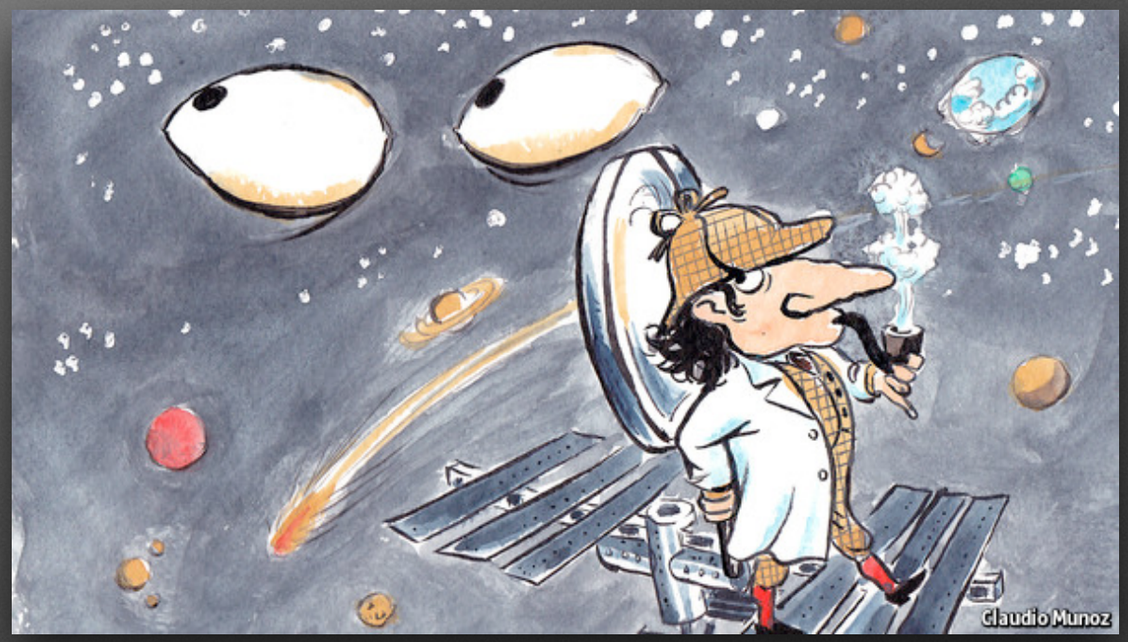
[Adriani *et al.*, *PRL* (2010)]

Conclusion

- Current propagation models suffer from large uncertainties on ingredients
  What you get out depends on what you put in…

- More and more precise cosmic-ray data will be available soon
  Need for better models/ingredients

- Cosmic rays are complementary and competitive with collider and direct dark matter searches



Are you hunting for dark matter?

- Your dark matter candidate should reproduce all the available data
  → global fits
  → GAMBIT