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

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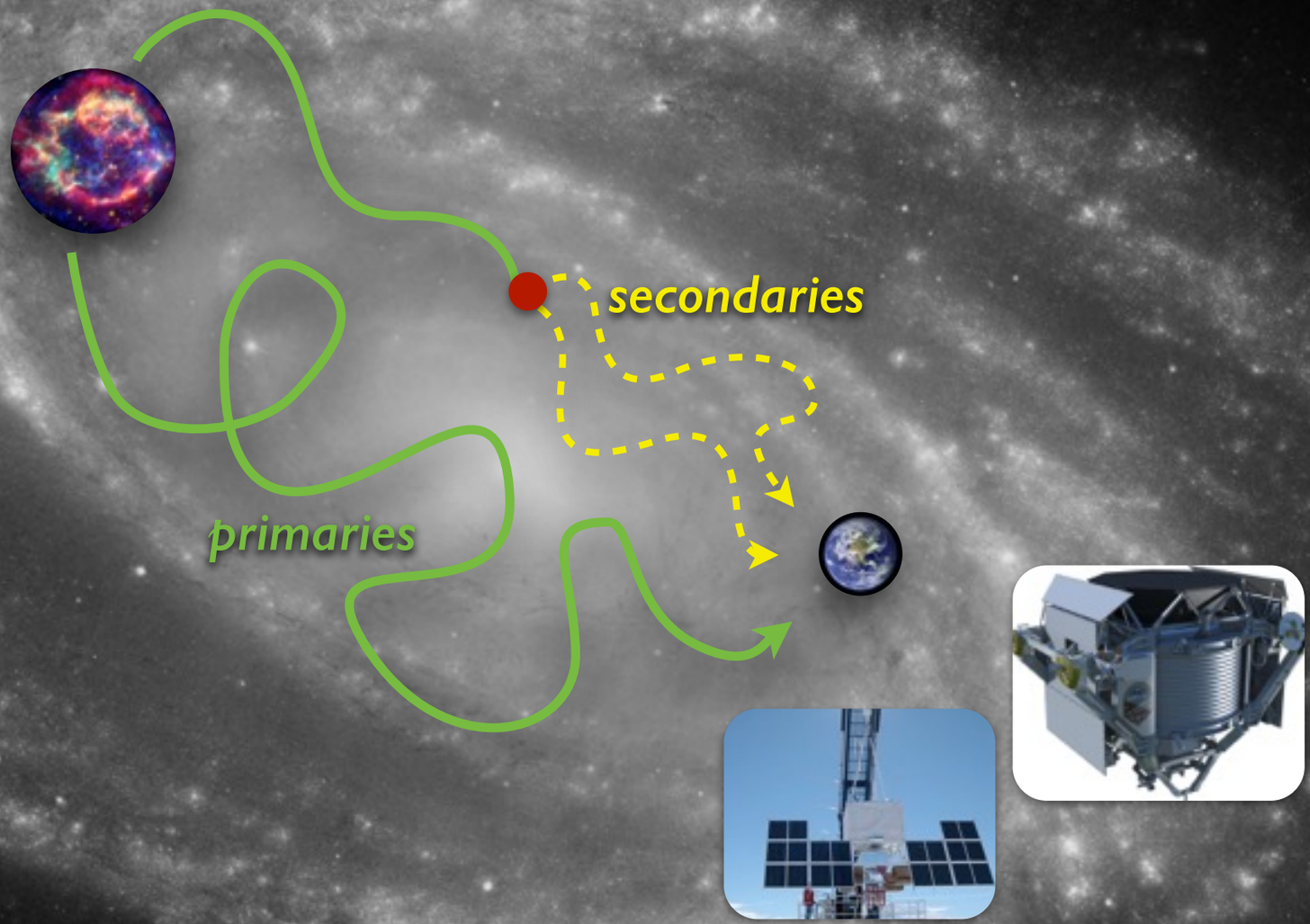
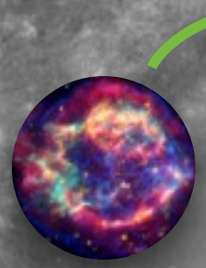
LAPTh/LAPP

Gamma Rays and Dark Matter 2015
Obergurgl University Center


secondaries
primaries

1. Sources & Acceleration

diffusive shock acceleration



secondaries

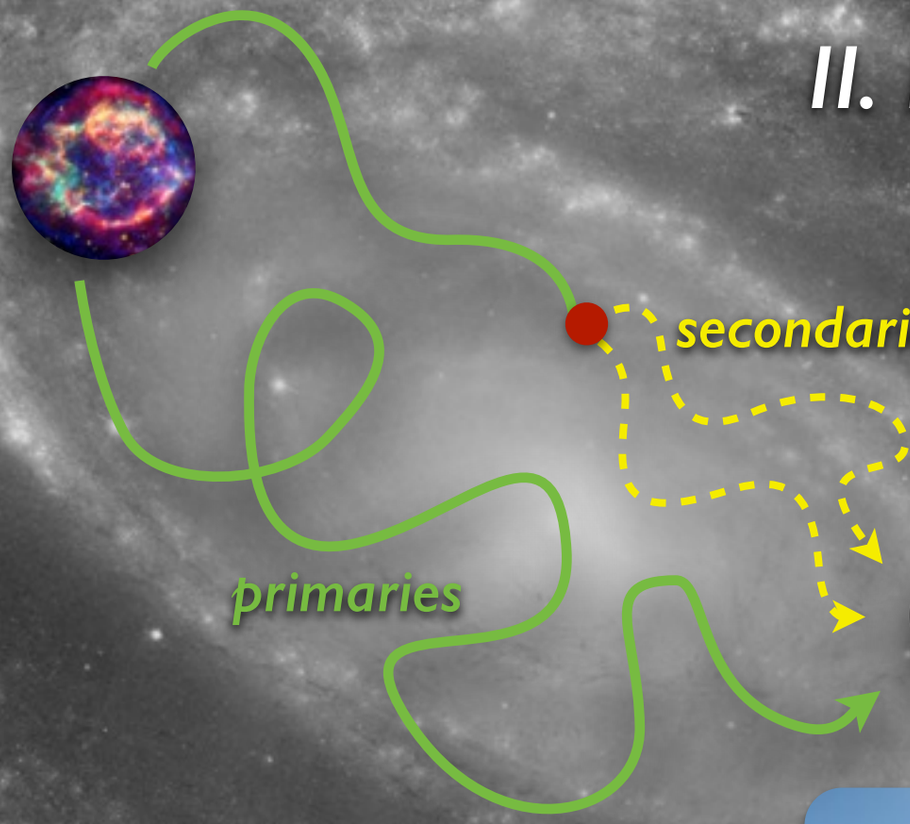
primaries

I. Sources & Acceleration

diffusive shock acceleration

II. Propagation in the ISM

diffusion, convection, re-acceleration



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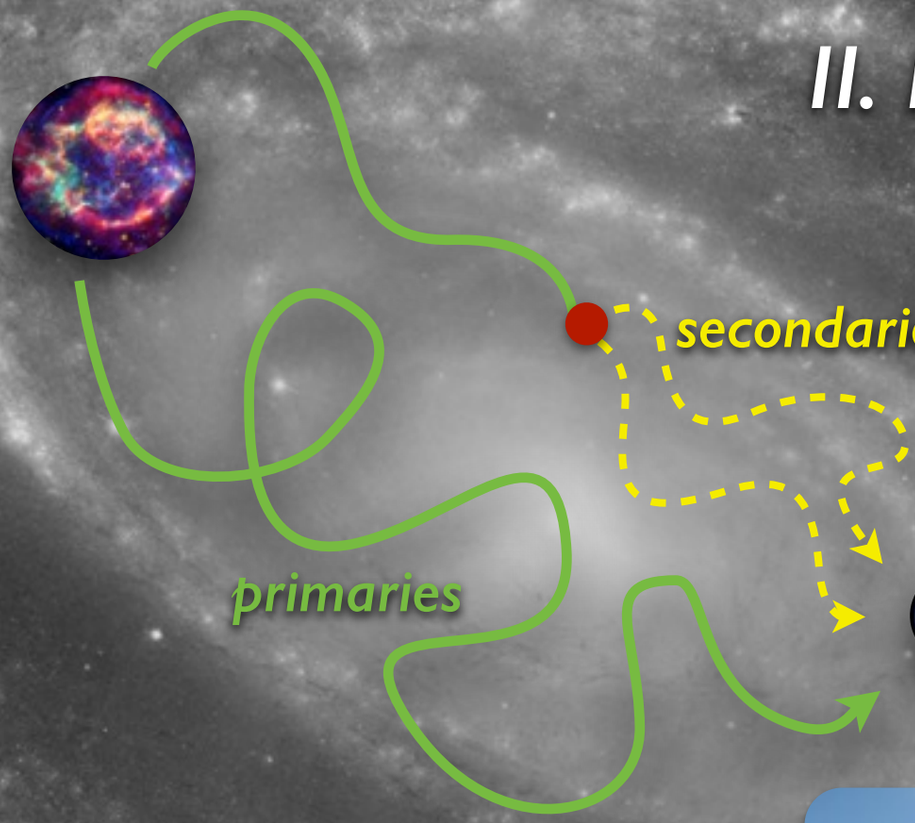


III. Solar System & Detection

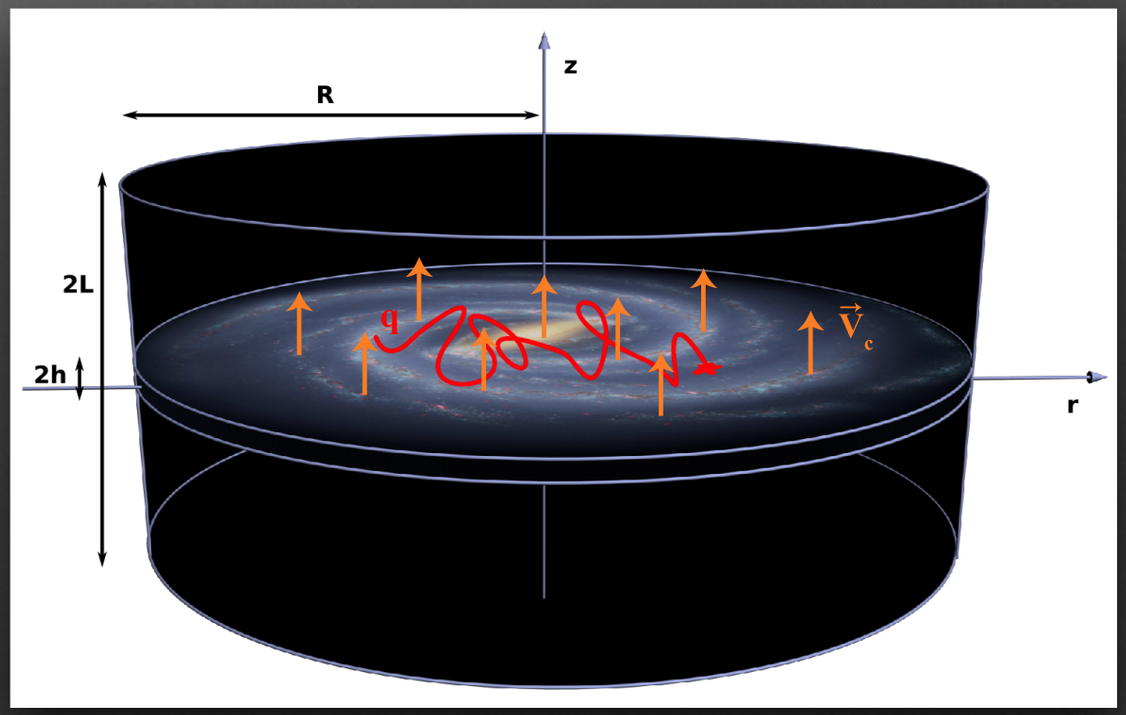
solar modulation, geomagnetic cut-off

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

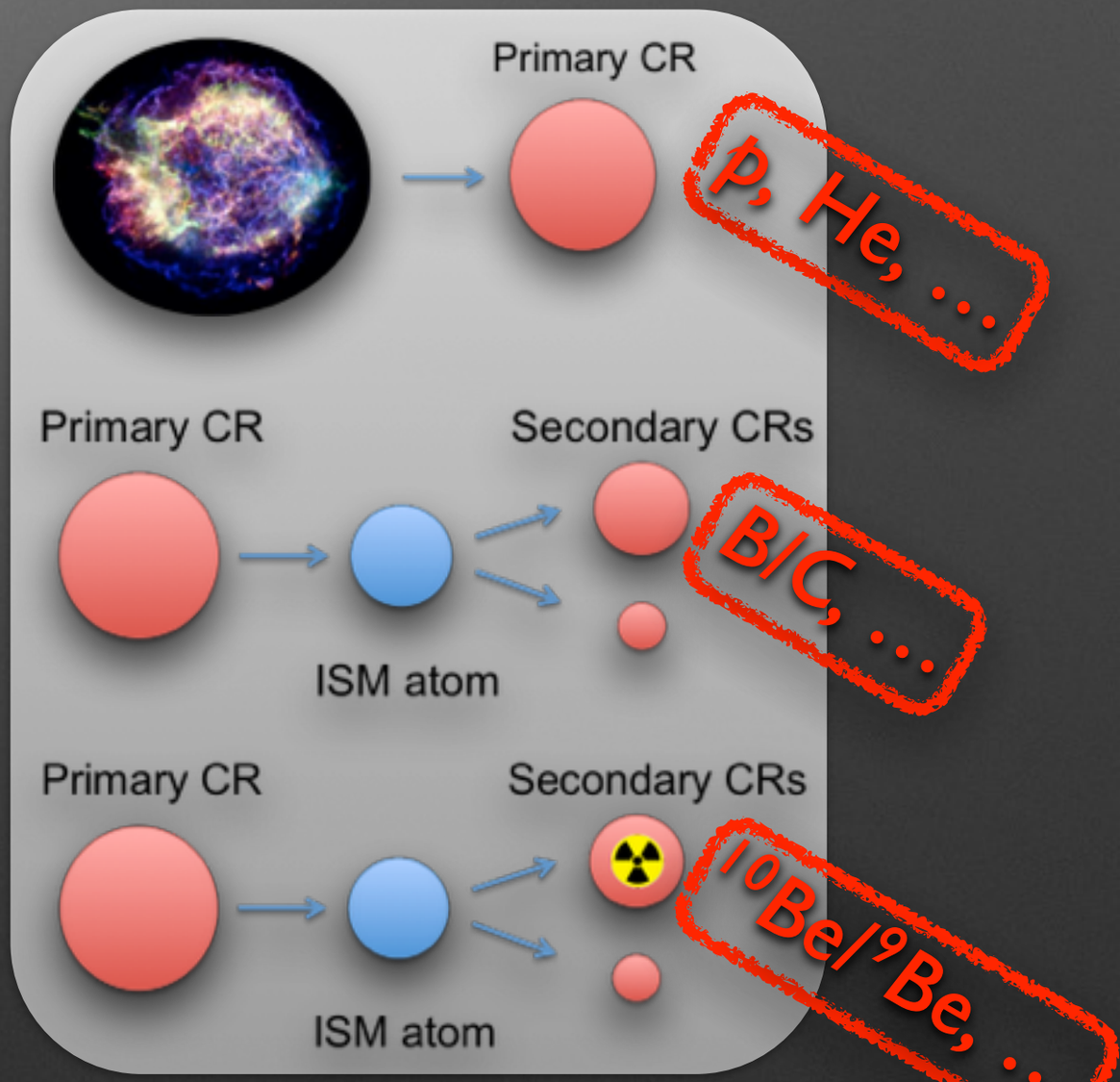
- Numerical approach
  e.g. GALPROP @ galprop.stanford.edu
  ✅ data based description of the interstellar medium
  ⛔ very slow



Parameters and observables

The most important parameters are linked to

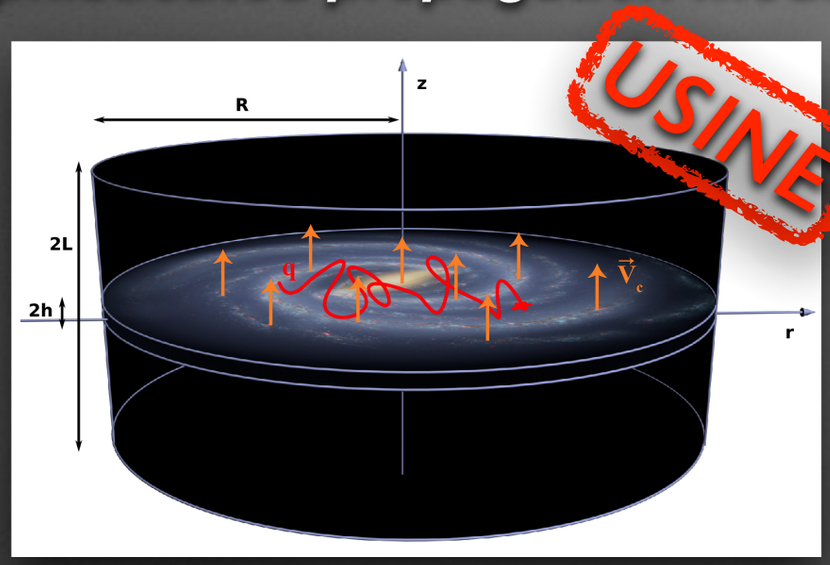
- the acceleration mechanisms
  injection spectrum: $Q(R) \propto qR^{-\alpha}$
- the propagation mechanisms
  diffusion: $K(R) \propto K_0 R^{\delta}$
  convection: V_C
  re-acceleration: V_A
- the geometry of the Galaxy
  diffusive halo size: L



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)]

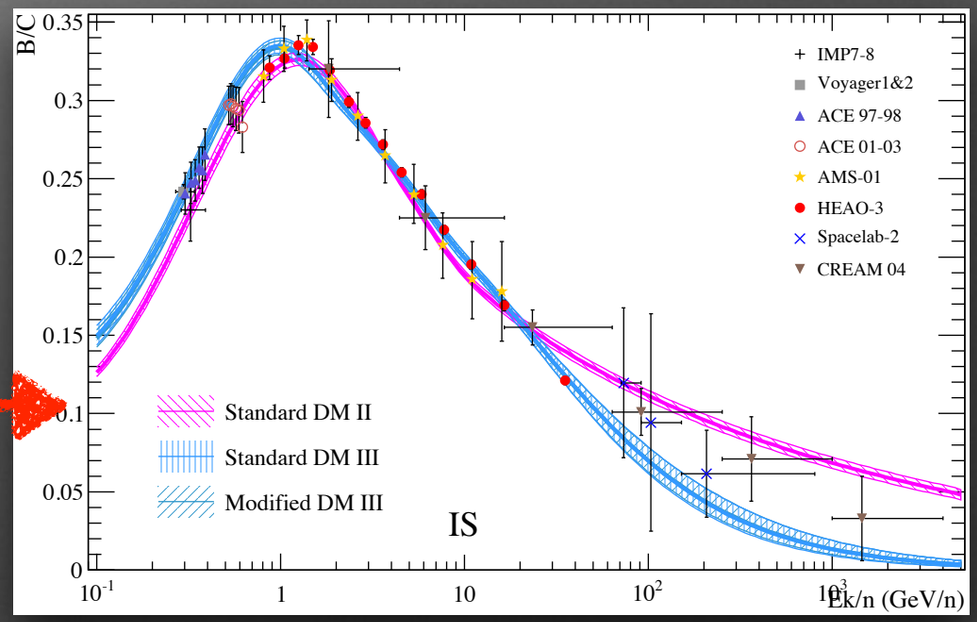
Which model is the best?

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

Same results for

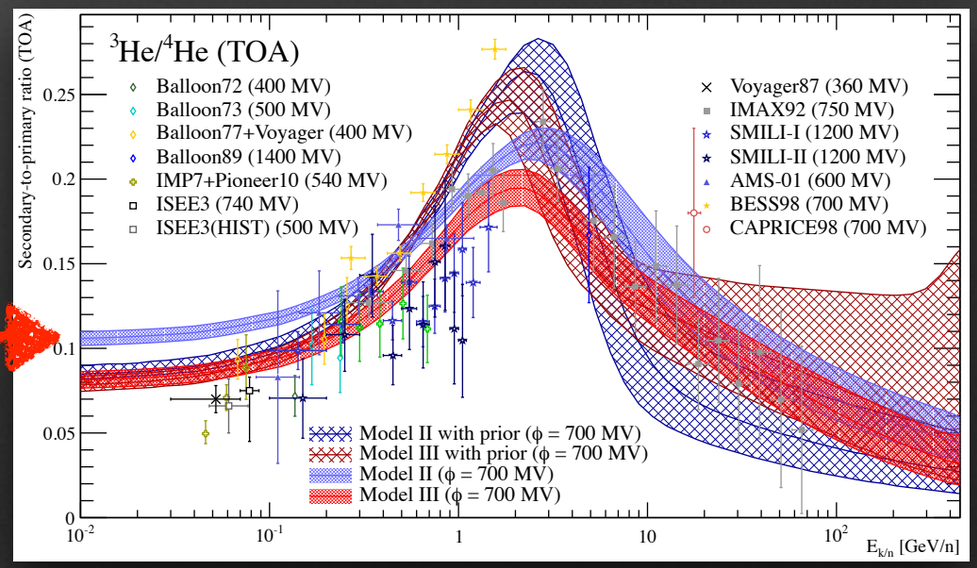
- B/C
  - ✅ abundant
  - ✅ elemental separation needed

  [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?

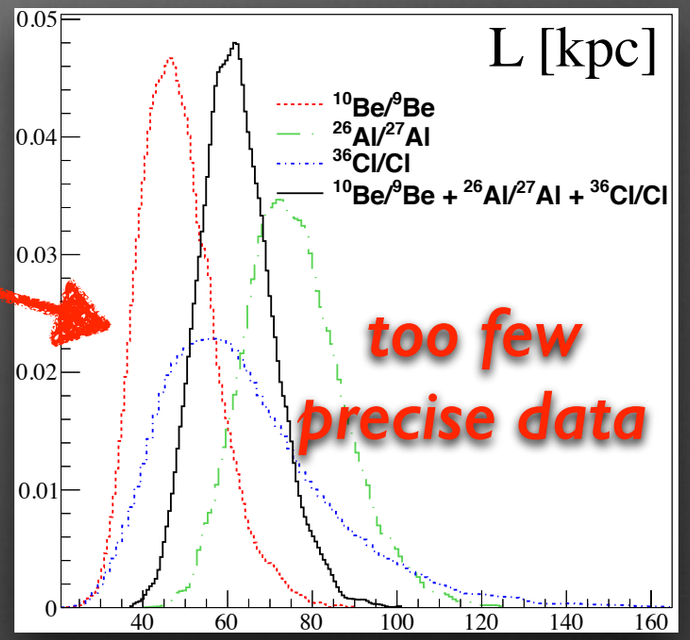
L determines the amount of dark matter contribution in cosmic rays!

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)]

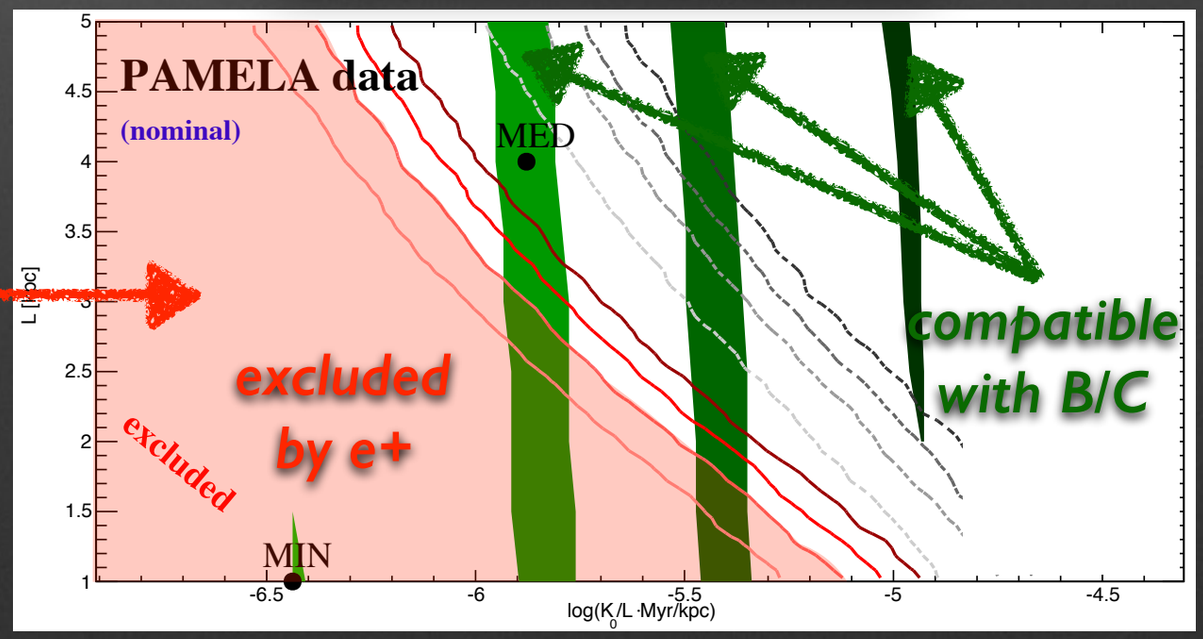


Secondary positrons:

first direct exclusion of small values of L

- ✅ precise data available
- ⛔ sensitive to solar modulation

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



What about theoretical uncertainties?

Theoretical uncertainties from model ingredients and hypotheses are dominating statistical uncertainties!

Cross sections

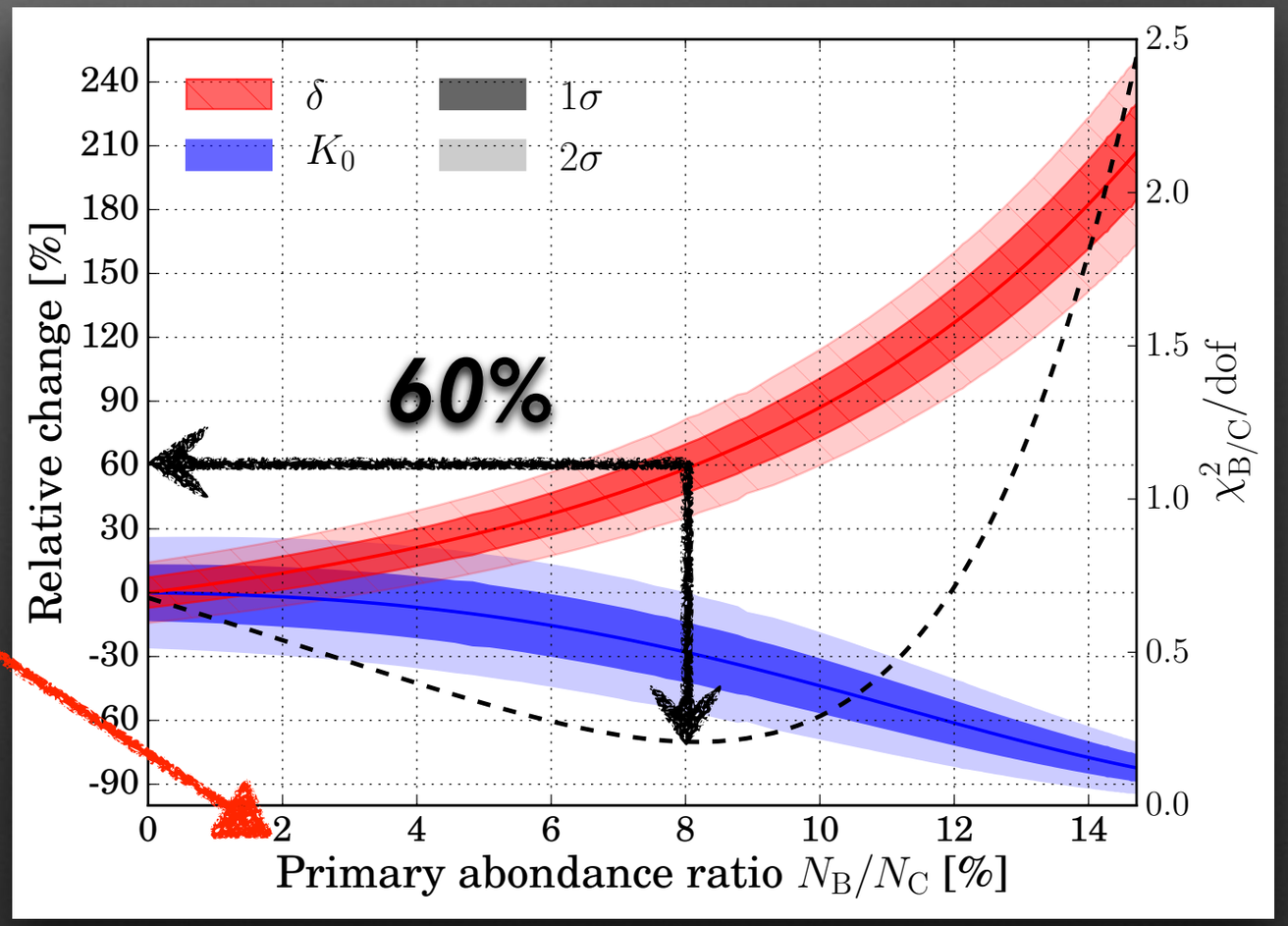
First estimation of their impact on parameter constraints: ***100%***

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

Primary boron injected at source

First estimation of their impact on parameter constraints: ***60%***

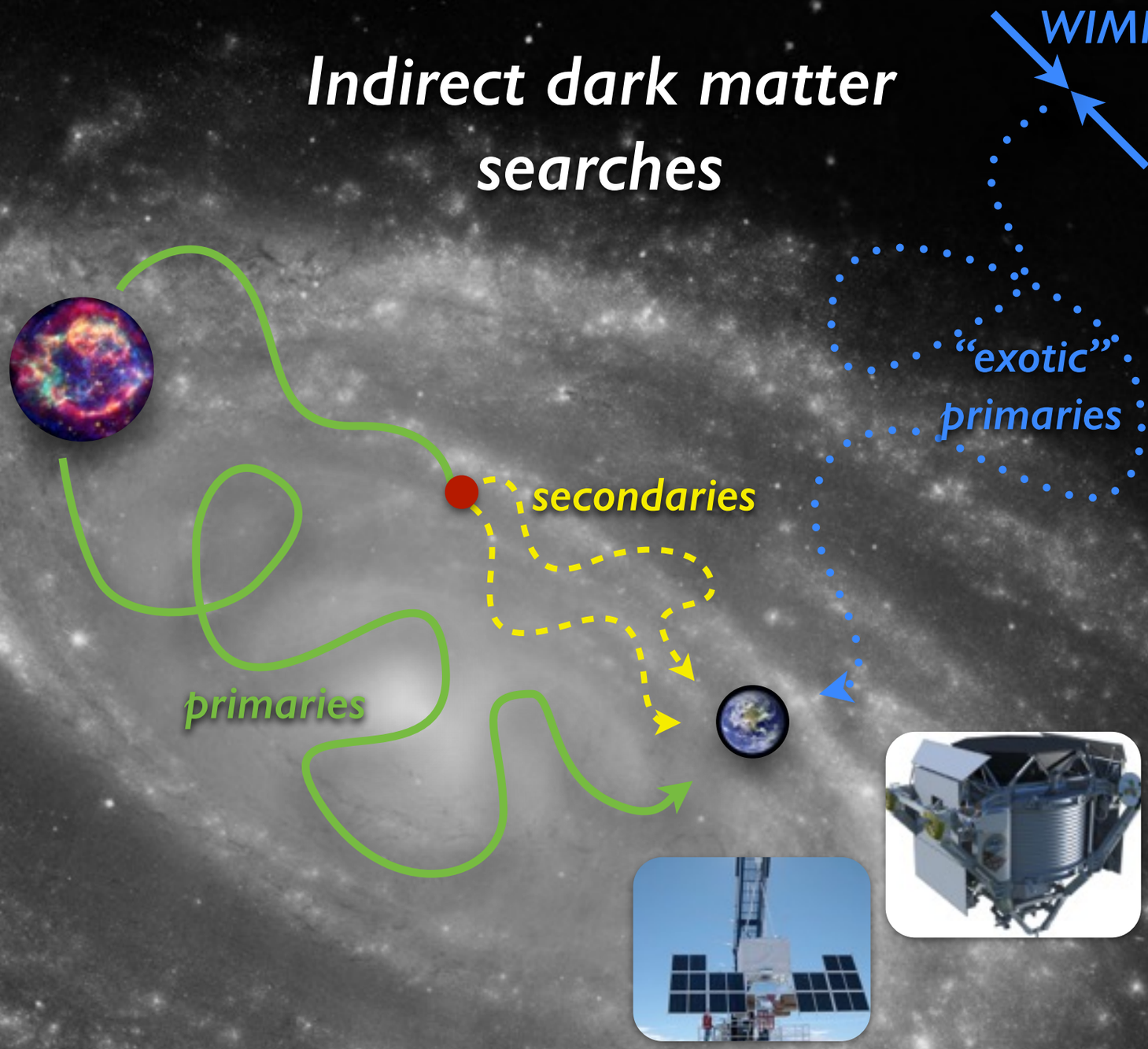
[Génolini, Putze, Salati, Serpico, *A&A* (2015)]



Parameter estimation already very tricky in a simple configuration…

[Génolini, Putze, Salati, Serpico, *A&A* (2015)]

Indirect dark matter searches



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

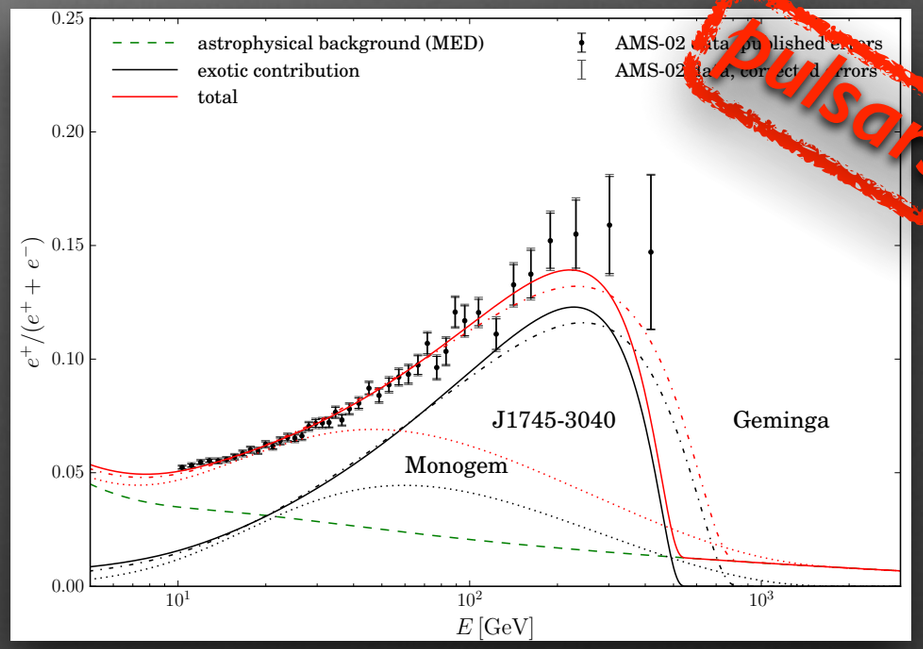
Positrons — difficult probes for dark matter searches

Well modelled with

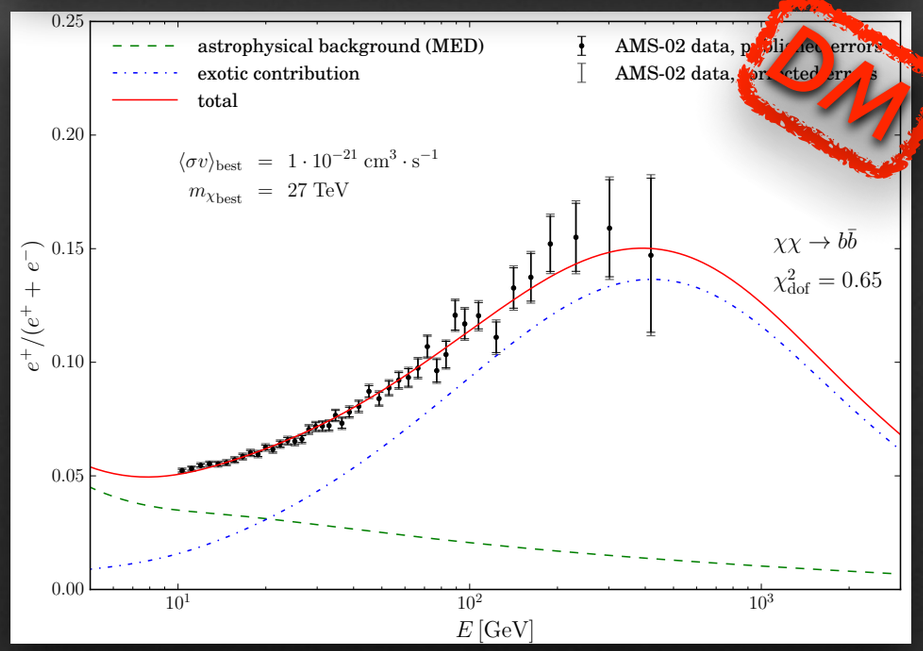
- secondaries:
  - ✅ diffusion models
  - ⛔ uncertainties on propagation parameters

- 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…



Pulsars

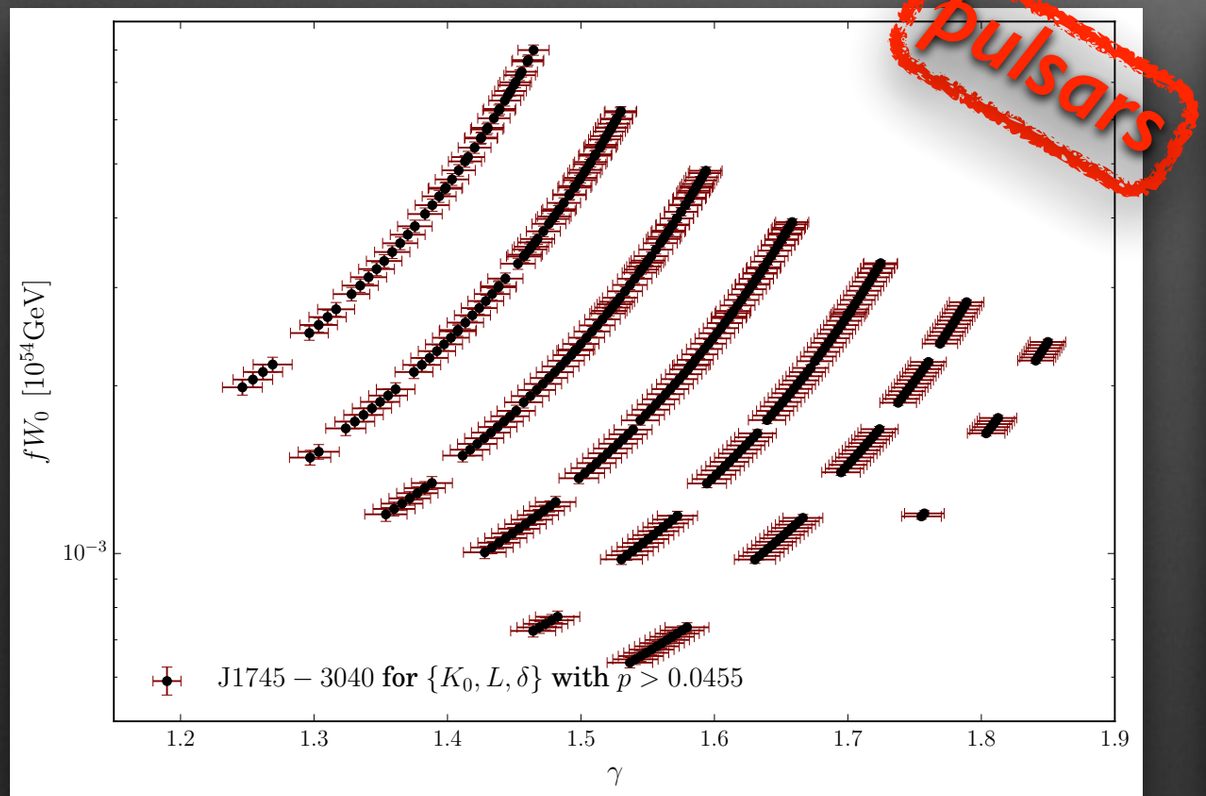


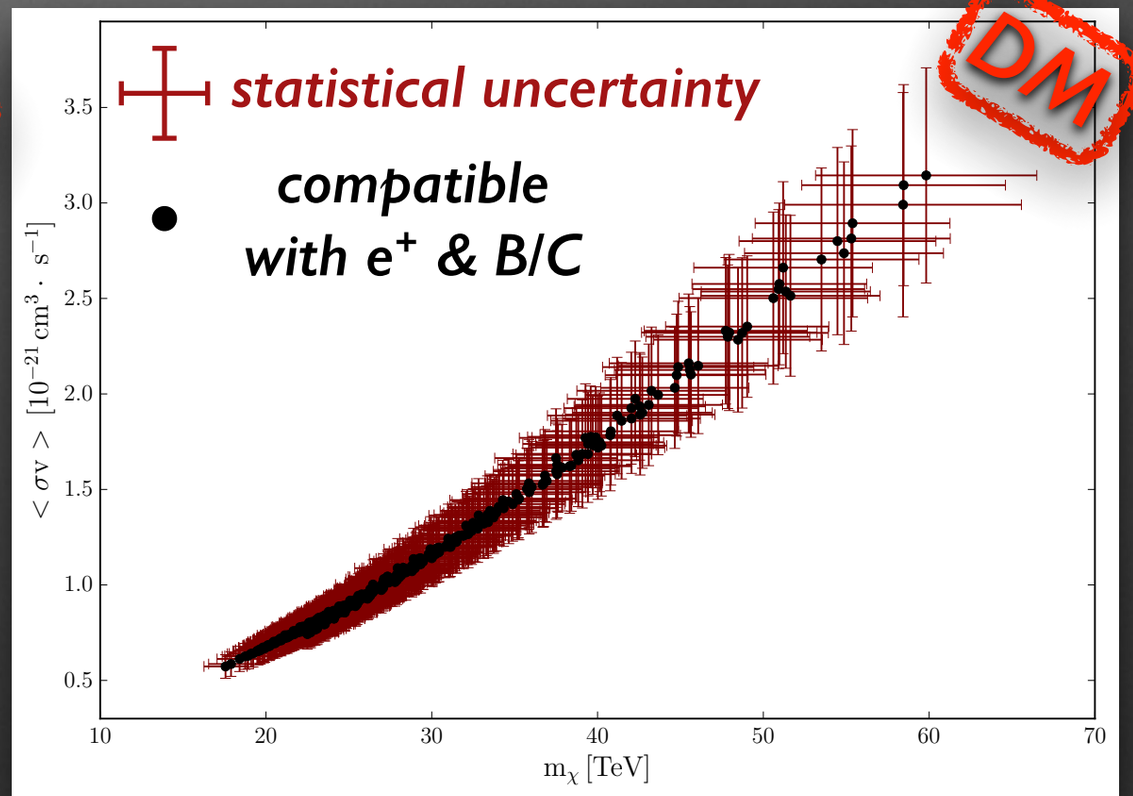
DM

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

Positrons — propagation uncertainties

Scan over propagation parameters compatible with the B/C ratio





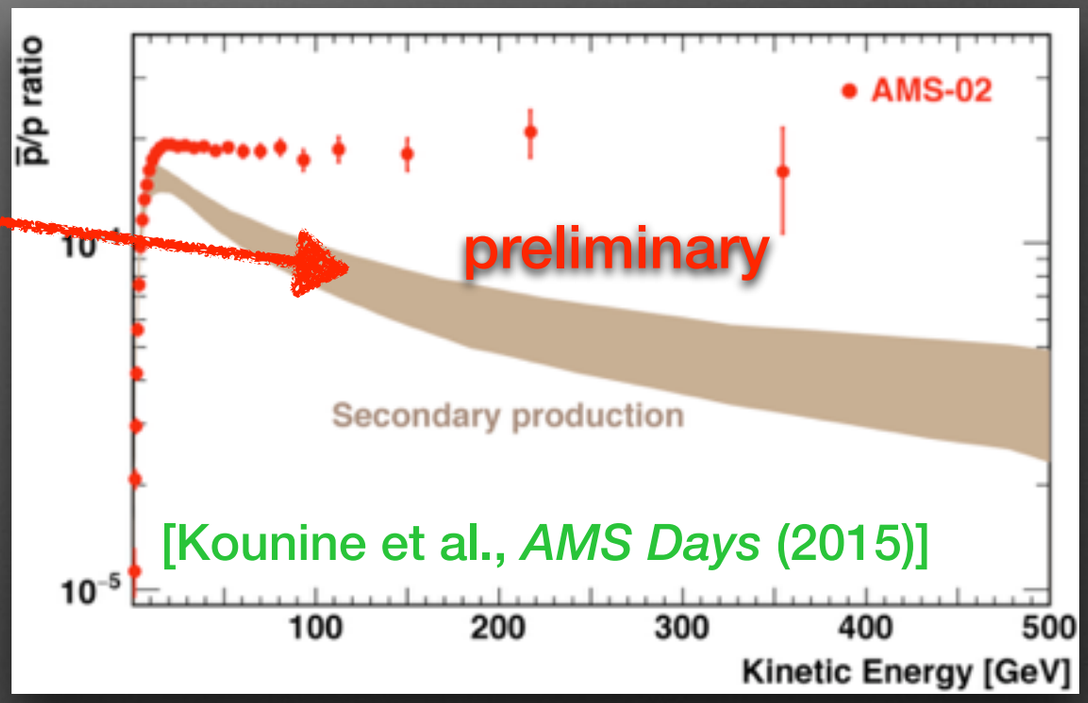
Systematic uncertainties from propagation parameters are dominating!

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

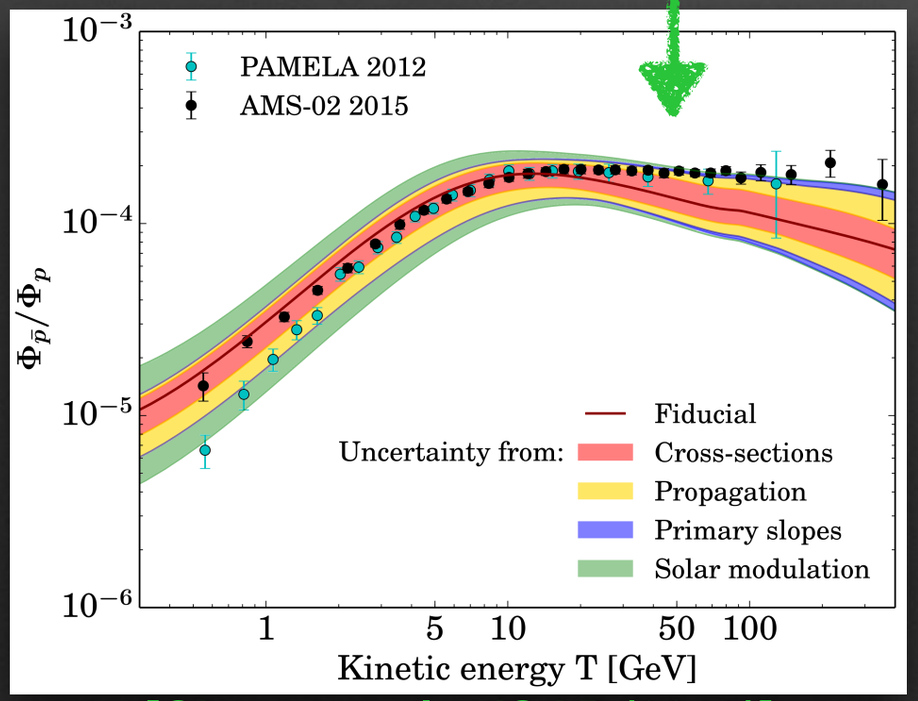
Antiprotons — strong constraints for dark matter

Theoretical prediction based on pre-AMS knowledge

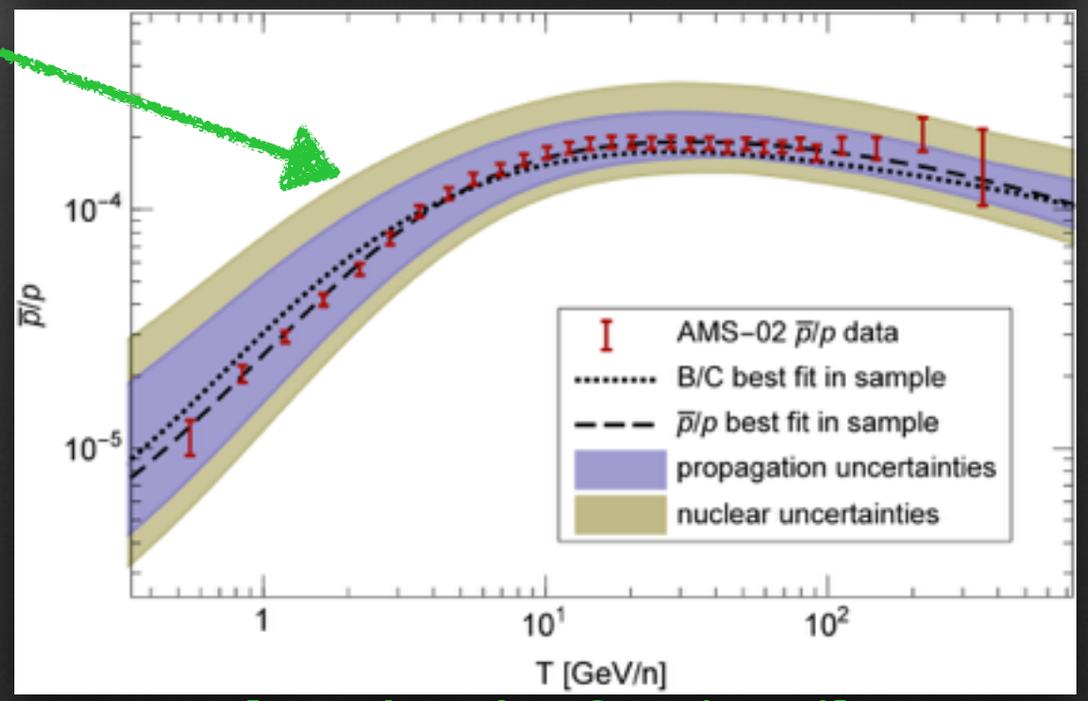
Updated secondary production and its uncertainties ***not*** in tension with antiproton-to-proton ratio



[Kounine et al., *AMS Days* (2015)]



[Giesen et al., *JCAP* (2015)]



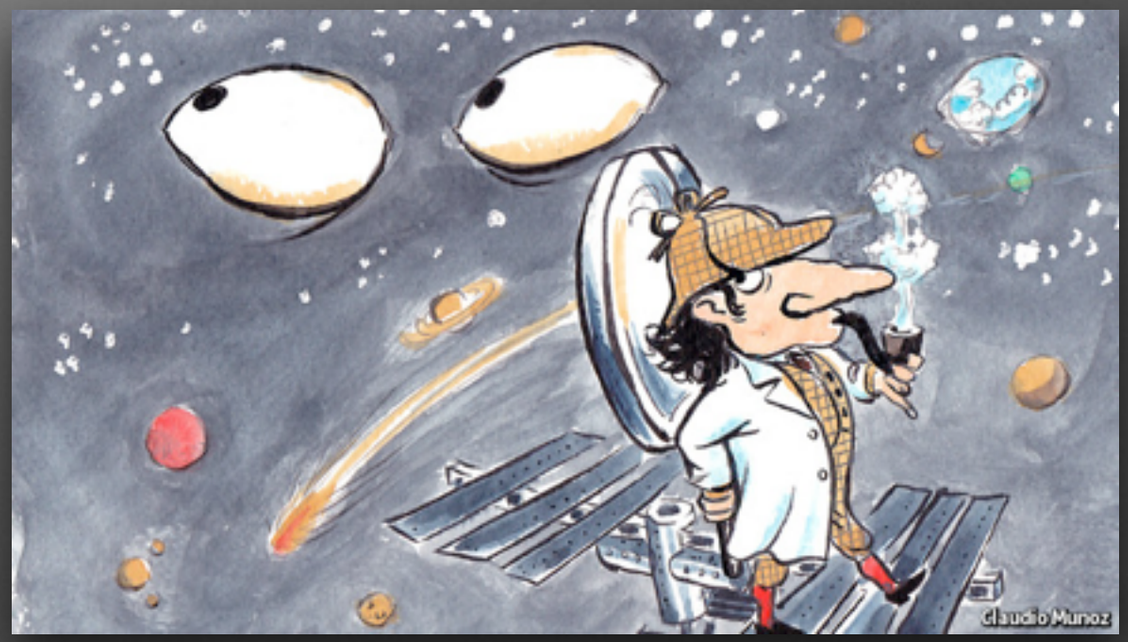
[Kappl et al., *JCAP* (2015)]

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