Report on the DarK Matter work package

Work package coordinators:

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Theoretical Astroparticle Physics Workshop, Torino, July 10, 2015

Dark Matter: one of the longest-standing open issues

- Plenty of evidence from cosmological-astrophysical tests (actually indirect evidence assuming General Relativity as theory of gravity).
- Few guidelines from cosmological-astrophysical data on a particle physics embedding (from ultralight scalars to superheavy states, from moderately large self-interactions to gravitational coupling only).
- A few main guidelines (prejudices) when considering an early Universe production mechanism (thermal, off-thermal, as a condensate, gravitational, ...).
- A few main guidelines (prejudices) when considering a DM within a particle physics motivated scenario (DM at the weak scale and the hierarchy problem, DM and the strong CP problem, DM and the flavour problem, ...).

Deeply stuck in the no-direction/any-direction morass!

One way out within the work package expertise:

- A union of units and researchers with diversified competences in cosmology, astrophysics and elementary particle physics, but common language to build up a synergetic effort.
- Theoretical expertise for a theoretical approach, keeping at the same time a link to experimental collaborations and observational campaigns.
- An effort to avoid ambulance chasing, still a critical perspective on recently claimed “hints” of detection (positron, antiproton, Galactic Center, … “excesses”).
- On one hand, the emphasis on smoking-gun signals (antideuteron searches, definite spectral features in photon channels, …).
- On the other, the multi-wavelength (e.g.: radio to gamma), multi-messenger (e.g.: photons, cosmic rays & neutrinos), multi-technique (e.g.: direct versus indirect versus accelerators), … approach to dig small signals out of large backgrounds.

The first year of results for the work package:

About 50 published papers or preprints, with level of research at the forefront in the international panorama. Aspects considered so far include (please forgive me for failing to list here your favourite work):

- Tests via numerical simulations (Torino) or theoretical aspects (L'Aquila/LNGS + Torino) of alternatives/extensions to GR as theory of gravity.
- Cosmological tests on DM properties, such as on DM-dark energy interactions (LNF/La Sapienza) or on the lifetime of DM particles (Napoli/Salerno).
- The "non-WIMP" side of the DM puzzle: from superheavy states (L'Aquila/LNGS), to PeV decaying DM (Napoli/Salerno), to axions and ALPs (Bari/Lecce + LNF/La Sapienza + L'Aquila/LNGS), to asymmetric DM models (LNF/La Sapienza)

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talk by D. Montanino

talk by M. Krauss

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- Possible connections between shortcomings in the standard picture of Galactic cosmic ray propagation and an exotic cosmic ray component from pair annihilations or decays of DM particles (Torino + SISSA).

- A closer look to some of the proposed golden channels for DM indirect detection: antideuterons (Torino), dwarf satellites of the Milky Way (Torino + SISSA), the Galactic center (Torino + SISSA).

- Study of cross-correlations between the diffuse extragalactic gamma-ray flux and cosmological tracers of DM structures, such as galaxy catalogues, cosmic shear and CMB lensing (Torino).

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  talk by A. Vittino
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  talk by M. Valli
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Short outlines of few ideas not covered in other talks (please forgive me for failing to choose your favourite topic):

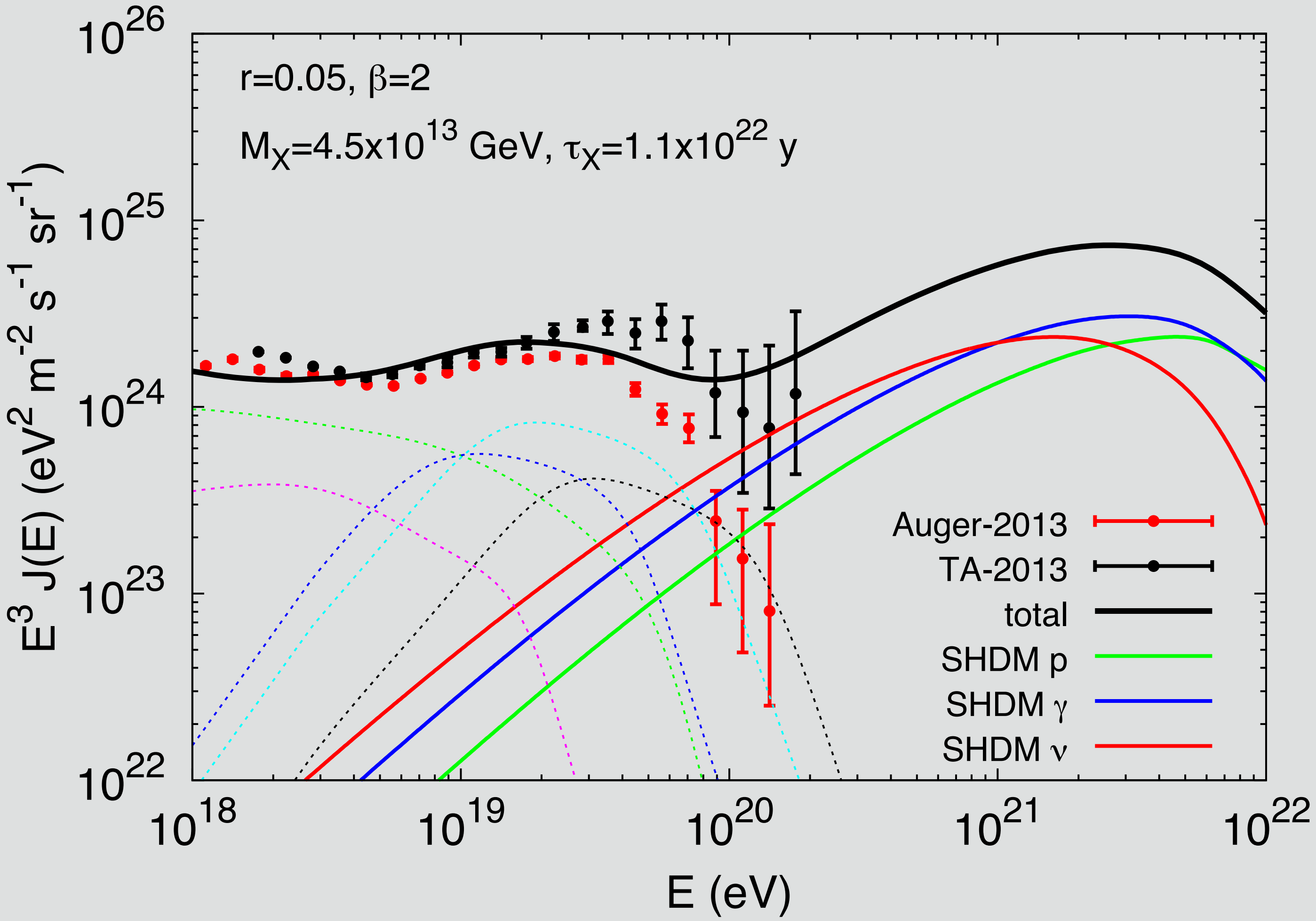
Inflation scale, superheavy DM & ultra high-energy CRs:

Aloisio, Matarrese & Olinto, arXiv:1504.01319

A few ingredients and their consequences:

a) CMB B-mode determination of the tensor-to-scalar ratio r ⇒ determination of the inflation potential height; b) gravitation particle production at the end of dS phase ⇒ determination of the mass scale for superheavy DM;

c) finite lifetime for superheavy DM ⇒ search for beyond GZK events connected to decays of Galactic DM.



Model independent limits on DM lifetime:

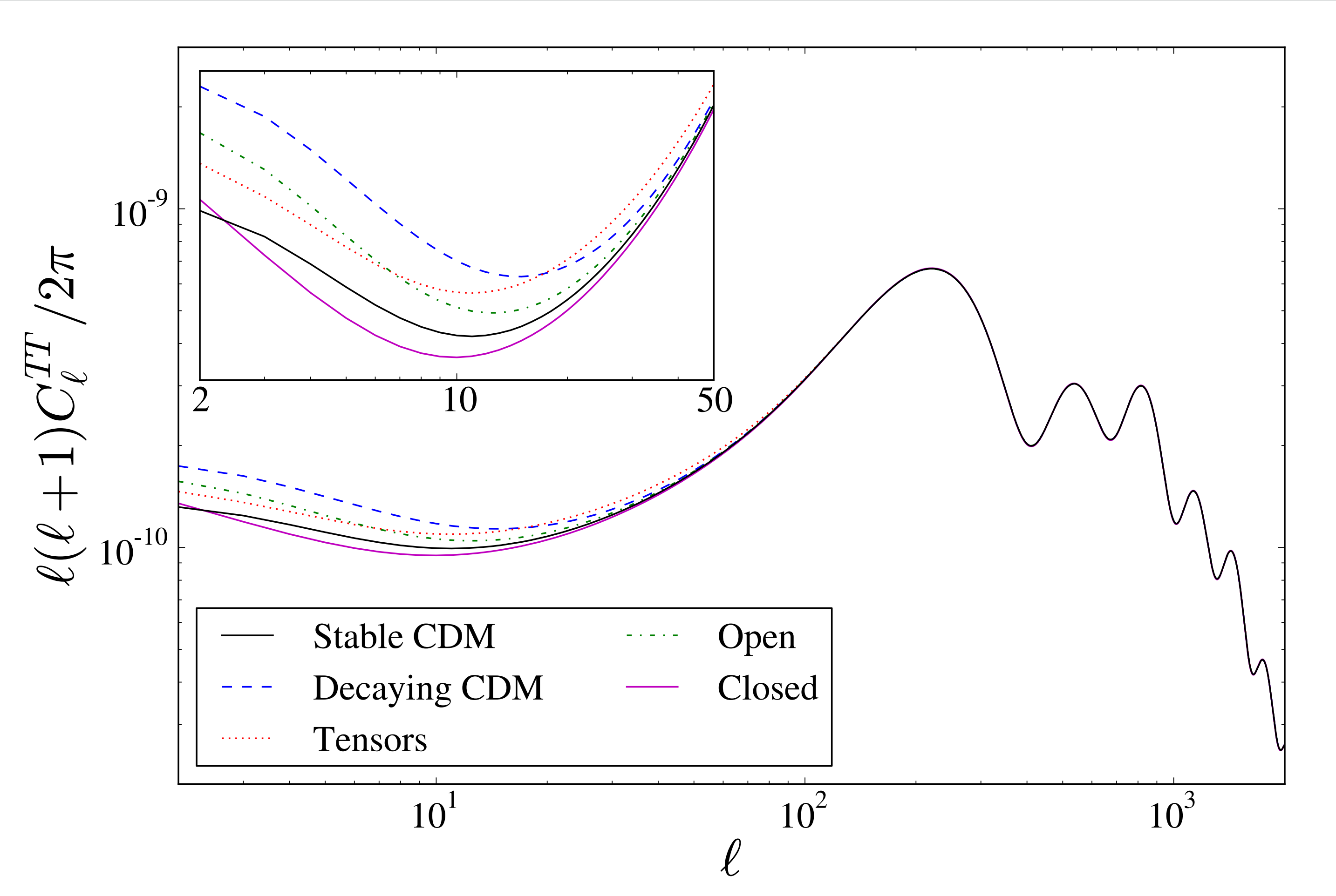
Audren, Lesgourgues, Mangano, Serpico, Tram, arXiv:1407.2418

Goal: derive a bound on the lifetime of DM particles from purely gravitational considerations (limits often quoted at the level, e.g., of 10^{29}s depend on the mass scale of the DM particle - most often WIMPs at the EW scale - and a visible decay mode - most often γ-rays). Here the only assumption is the decay into radiation.

Late time replacement of a part of the matter term with a radiation component, inducing:

a) change in the background evolution;
b) imprint on perturbations on large scale.

Looking at the CMB: a change in the angular diameter distance of LSS; late ISW; a change in CMB lensing.



Degeneracy with other effects at small l

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Planck + WMAP polarization + WiggleZ + BOSS + (BICEP2):

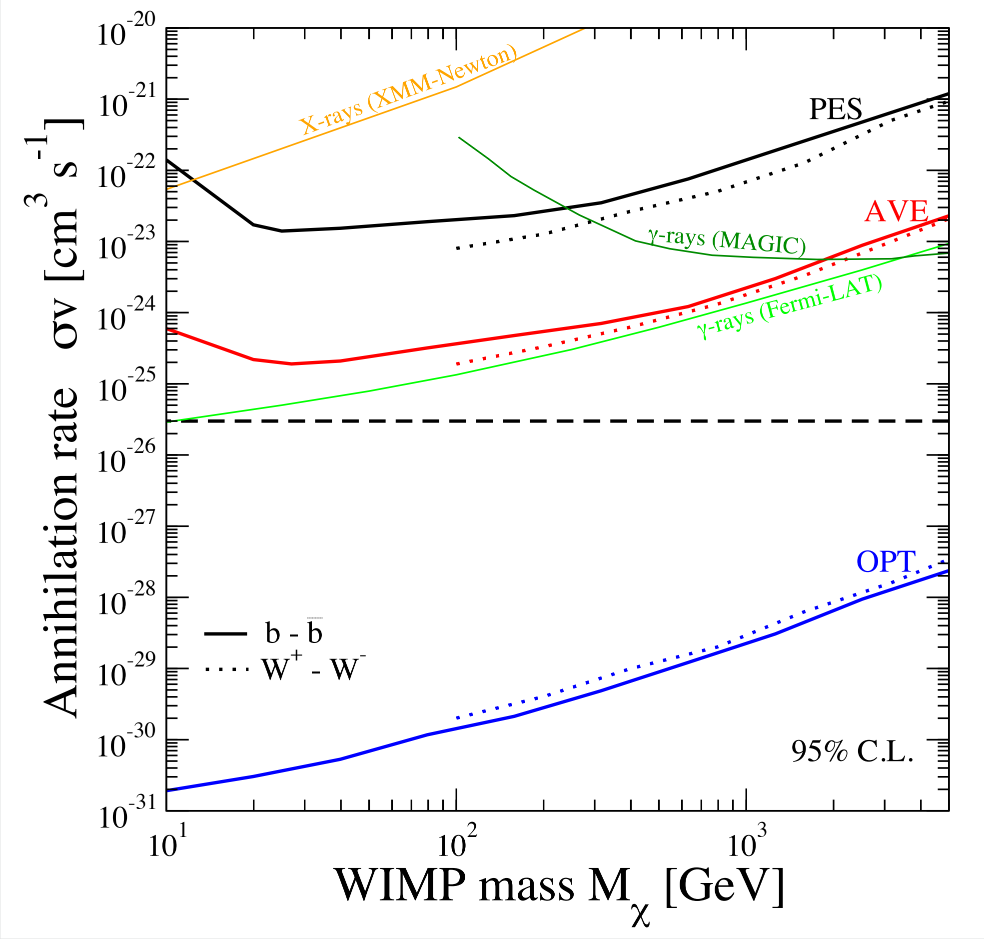
Model	ΛCDM + $\{\Gamma_{\rm dcdm}, r\}$		ΛCDM + $\{\Gamma_{\rm dcdm}, r, \Omega_k\}$	
Data	A	B	A	B
$100\,\omega_{\rm b}$	$2.231^{+0.025}_{-0.024}$	$2.226^{+0.024}_{-0.024}$	$2.247^{+0.028}_{-0.030}$	$2.247^{+0.028}_{-0.029}$
H_0 [km/s/Mpc]	$68.89^{+0.62}_{-0.61}$	$68.92^{+0.61}_{-0.62}$	$68.21^{+0.79}_{-0.79}$	$68.07^{+0.83}_{-0.80}$
$10^9 A_s$	$2.145^{+0.044}_{-0.050}$	$2.143^{+0.044}_{-0.047}$	$2.157^{+0.046}_{-0.054}$	$2.156^{+0.045}_{-0.052}$
n_s	$0.9643^{+0.0055}_{-0.0056}$	$0.9666^{+0.0055}_{-0.0056}$	$0.9705^{+0.0071}_{-0.0077}$	$0.9742^{+0.0072}_{-0.0076}$
$\tau_{\rm reio}$	$0.082^{+0.012}_{-0.011}$	$0.082^{+0.011}_{-0.011}$	$0.08676^{+0.012}_{-0.013}$	$0.08792^{+0.011}_{-0.013}$
$\omega_{\rm dcdm+dr}$	$0.1142^{+0.0016}_{-0.0014}$	$0.1142^{+0.0017}_{-0.0014}$	$0.1117^{+0.0026}_{-0.0023}$	$0.1113^{+0.0025}_{-0.0023}$
$\Gamma_{\rm dcdm}$ [km s^{-1}Mpc^{-1}]	< 5.9	< 5.0	< 6.0	< 4.9
r	< 0.13	$0.164^{+0.032}_{-0.040}$	$0.05273^{+0.012}_{-0.053}$	$0.1713^{+0.033}_{-0.039}$
$10^2\Omega_k$	–	–	$-0.3517^{+0.28}_{-0.26}$	$-0.4405^{+0.30}_{-0.27}$
$\tau_{\rm dcdm}$ [Gyr]	> 160	> 200	> 160	> 200

Constraints on DM from radio surveys of dwarf satellites:

Regis et al., arXiv:1407.4948

Search for extended synchrotron emission connected to DM pair-annihilation or decay yields within dwarf satellites of the Milky Way (DM dominated objects with negligible intrinsic backgrounds from standard astrophysical sources). A survey of six of them performed with ATCA in the 1.1-3.1 GHz band. No evidence for extended emission was found ⇒ limits on the DM parameter space:

Constraints depending on assumptions regarding diffusion properties and magnetic field strengths within the dwarfs, but competitive with γ-ray surveys.



A high-risk & high-gain target, a potentially large improvement with LOFAR and SKA

Antiproton cross sections and CR data:

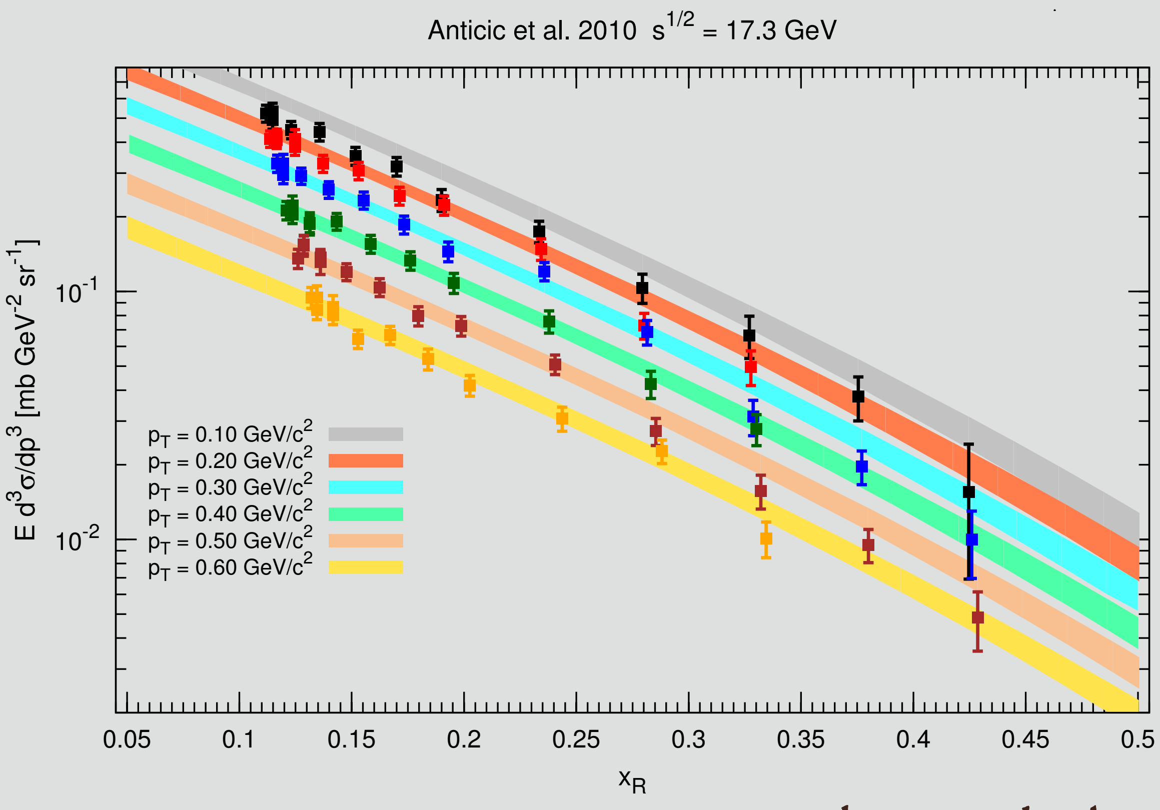
di Mauro, Donato, Goudelis & Serpico, arXiv:1408.0288

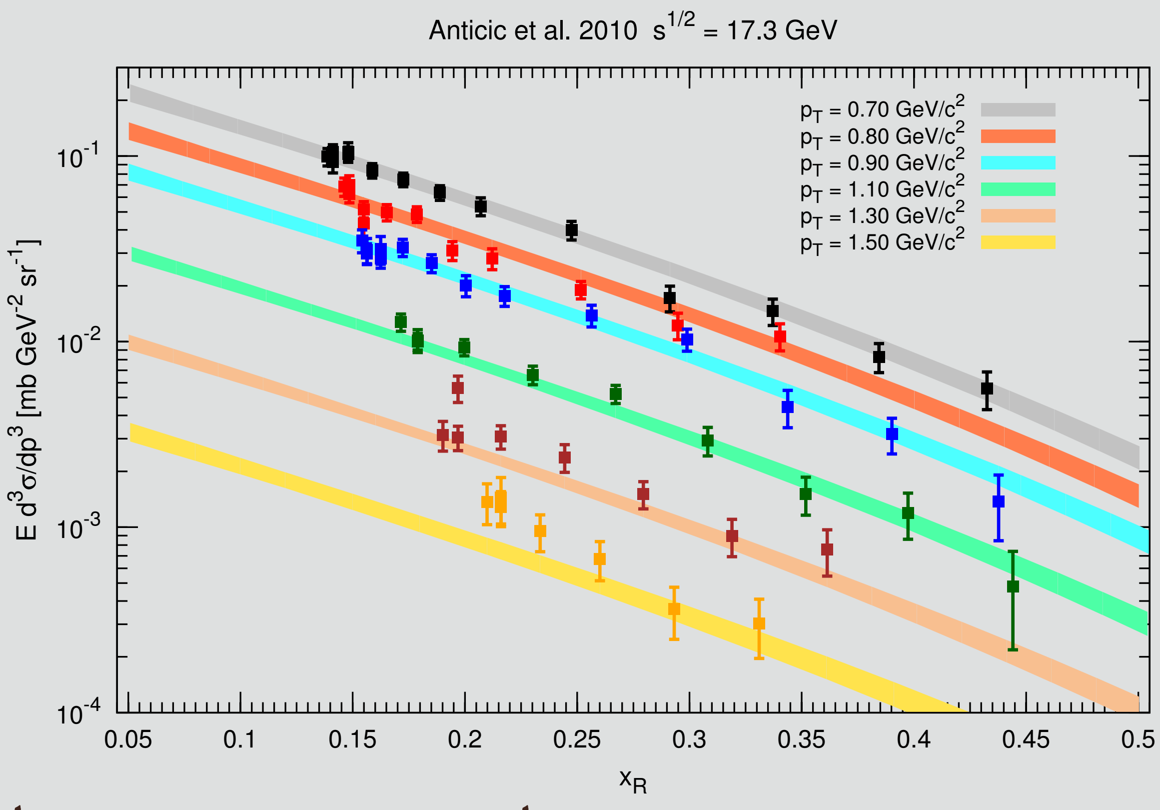
A new analysis of the impact of uncertainties in antiproton production cross sections on the theoretical prediction for the secondary antiproton cosmic ray flux. All available data (including for first time NA49 data) on the differential cross section for the process:

$$pp \to \bar{p} + X$$

are used in tho analysis for a parametric fit in the form (under scaling hypothesis):

$$E\frac{d^3\sigma}{dp^3} = \sigma_{\rm in}(s)(1-x_R)^{C_1}e^{-C_2 x_R}\left|[C_3(\sqrt{s})^{C_4}e^{-C_5 p_T} + C_6(\sqrt{s})^{C_7}e^{-C_8 p_T^2} + C_9(\sqrt{s})^{C_{10}}e^{-C_{11}p_T^3}]\right|$$





x_R is the radial scaling ≈ E / maximal E

Antiproton cross sections and CR data:

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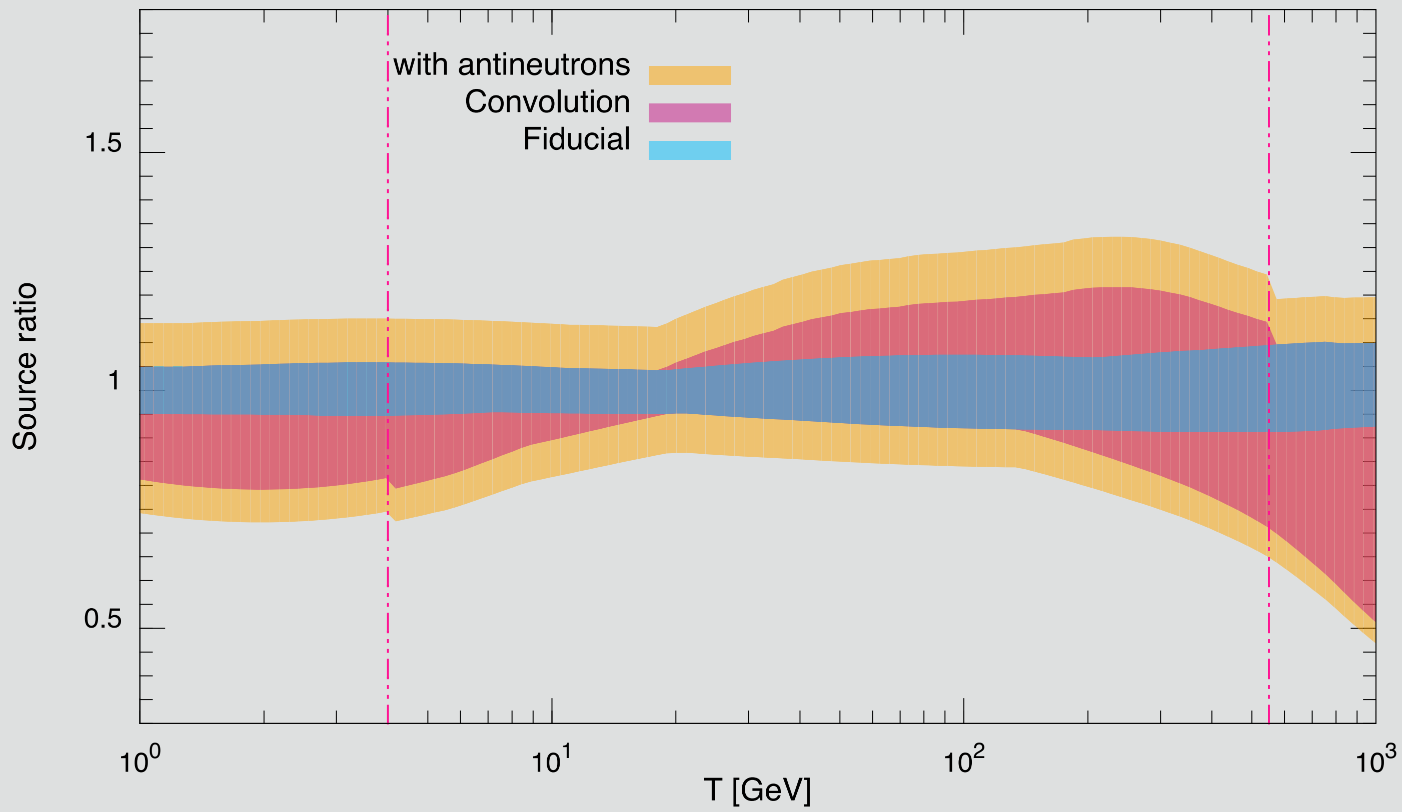
The uncertainty on the antiproton source function (pp term only) is then found to be of order 10% if adopting the fiducial model from the fit; of order 20% up to 50% - outside the region where bulk of the data is available - for a more conservative error propagation; even larger taking into account antineutrons decays:



Fix the background and single out eventual DM contributions

NOTE: Antiprotons from heavier nuclei are not included; in particular p-He, He-p & He-He are expected to contribute to the antiproton yield up to about 50% at low T. No data available on these processes!

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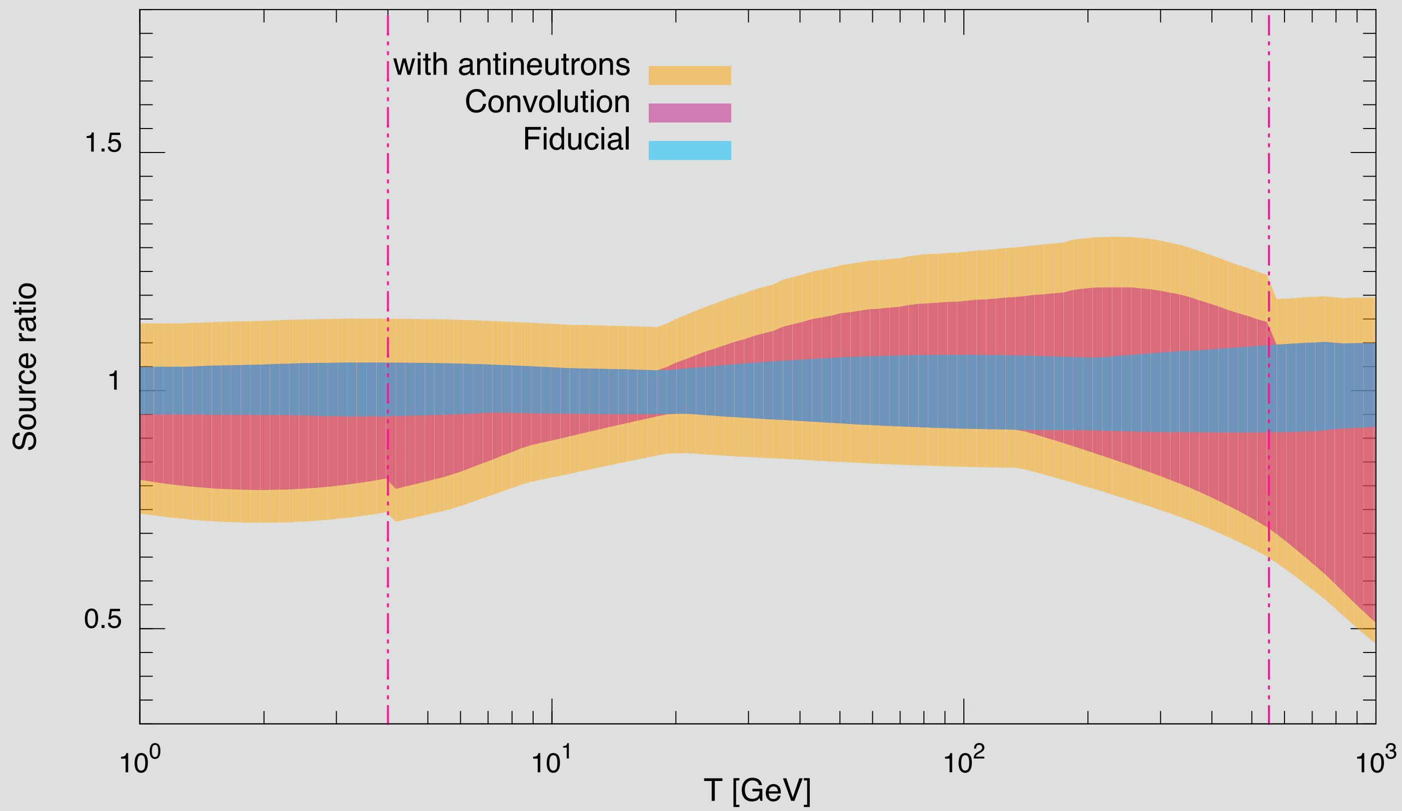


Fix the background and single out eventual DM contributions

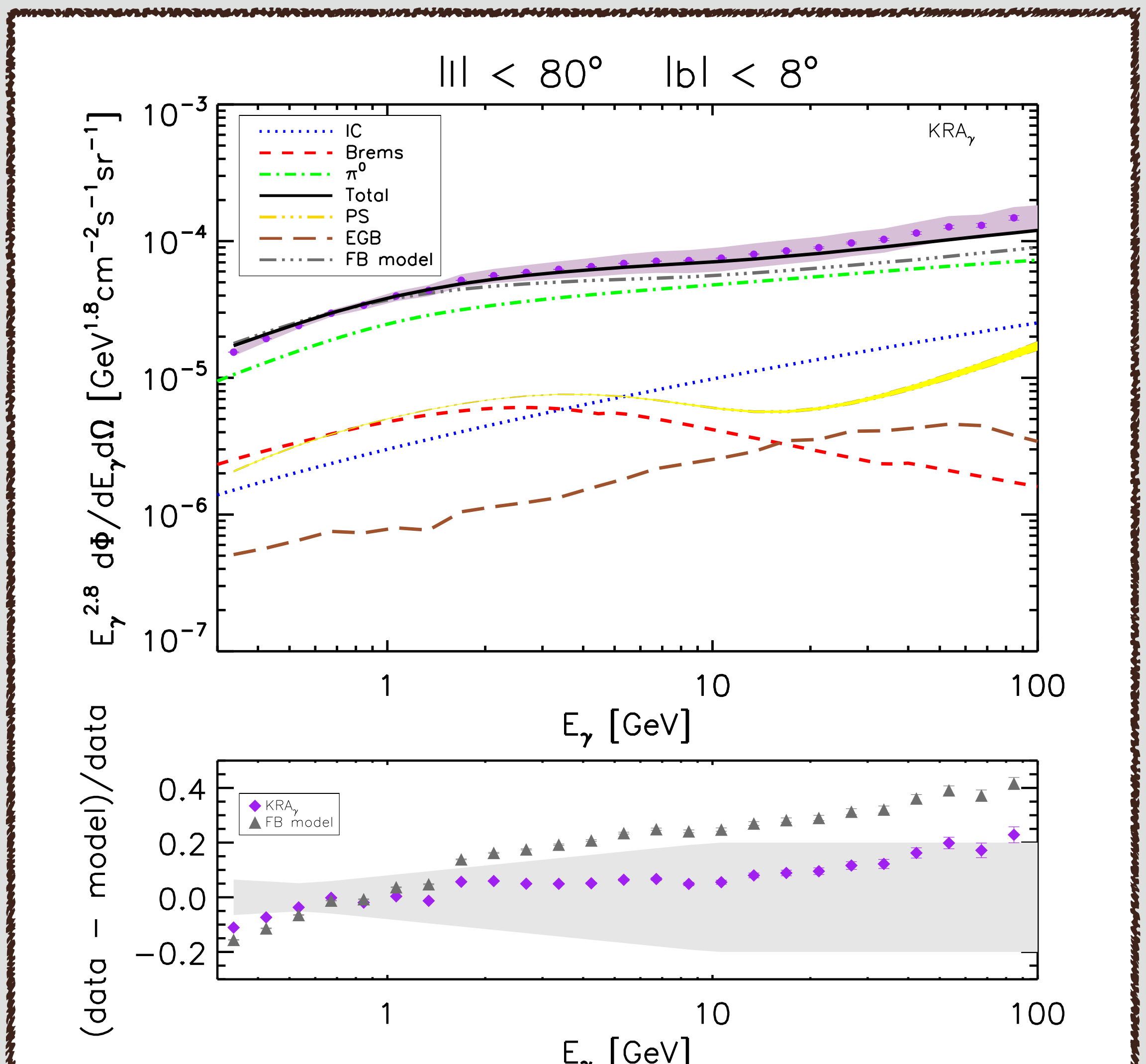
In the last year, the Torino Unit, INFN Torino, the INFN "What Next" roadmap have been promoting an experimental & theoretical challenge on the p-He cross section estimate, see, e.g., the workshop on this topic in Torino, July 6-7, 2015.

Insights on galactic CR propagation from the γ-ray sky:

Gaggero, Urbano, Valli & PU, arXiv:1411.7623

γ-ray emissivities in the Galaxy are, to some extent, a by-product of the model for transport of galactic CRs. The standard approach: extrapolate to the whole Galaxy what we can learn about the local CR transport from local CR measurements. An oversimplified approach, sufficient to match FERMI LAT data in most regions of the sky, but systematically underestimating the flux above few GeV towards the inner Galactic plane:

evidence for radial gradients in CR transport? Model with flattering of the rigidity scaling for the diffusion coefficient:



Again: Fix the background and single out eventual DM contributions

Perspectives for the work package:

- Keep walking on the path of the multi-disciplinary approach, strengthening collaborations within people with variegated expertise (within units and across units).

- At the italian level, an effort in synergy with INFN: the TAsP (Theoretical Astroparticle Physics) group most of us are member of, as well as the opportunities being opened by participating to the "What Next" roadmap.

- At the international level, build up on the capability to collaborate with outstanding scientists, as already shown by papers produced in this first period.

- Let data guide our steps: from cosmological and astrophysical observations, to ground and space experiments, from underground searches to the LHC, the field may soon take directions requiring an especially open-minded attitude.