# Particles in the sky: new directions in the search for dark matter signals


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INFN Torino


PLANCK 2012 - From the Planck scale to the Electroweak scale

Warsaw– 28.05.2012

# Particles in the sky

Astrophysical signals offer a wide range of opportunities toward the identification of dark matter as an elementary particle

| Signals |
| --- |
| Direct detection |
| Cosmic Antiprotons |
| Electrons/Positrons |
| Antideuterons |
| Neutrinos (from Sun, Earth, MW) |
| Gamma rays (galactic, extra-gal.) |
| |
| |
| |
| |
| Radio (galactic, extra-gal.) |
| |
| CMB (recombination, SZ-effect) |

# Particles in the sky

Astrophysical signals offer a wide range of opportunities toward the identification of dark matter as an elementary particle

| Signals | Hints |
|---|---|
| Direct detection | DAMA, CoGeNT, CRESST |
| Cosmic Antiprotons | |
| Electrons/Positrons | PAMELA, FERMI high-E features |
| Antideuterons | *yet to come …* |
| Neutrinos (from Sun, Earth, MW) | |
| Gamma rays | "FERMI" excess toward the GC |
| | "FERMI" haze, FERMI bubbles |
| | "FERMI" 120 GeV line |
| | "FERMI" excess in galaxy clusters |
| | INTEGRAL 511 keV line |
| Radio | "WMAP" haze |
| | ARCADE excess |
| CMB (recombination, SZ-effect) | |

# Direct detection

# Current direct detection experiments

- Background-rejection experiments (CDMS, XENON, CRESST, ...)
  - Do not exploit a specific signature of the signal
  - Rely on reduction/interpretation of background

- Annual modulation experiments (DAMA, CoGeNT)
  - Exploit a specific signature
  - Required to be highly stable over long periods

# Current direct detection experiments

- Background-rejection experiments (CDMS, XENON, CRESST, ...) — CRESST: $4.7\,\sigma$ C.L.
  - Do not exploit a specific signature of the signal
  - Rely on reduction/interpretation of background

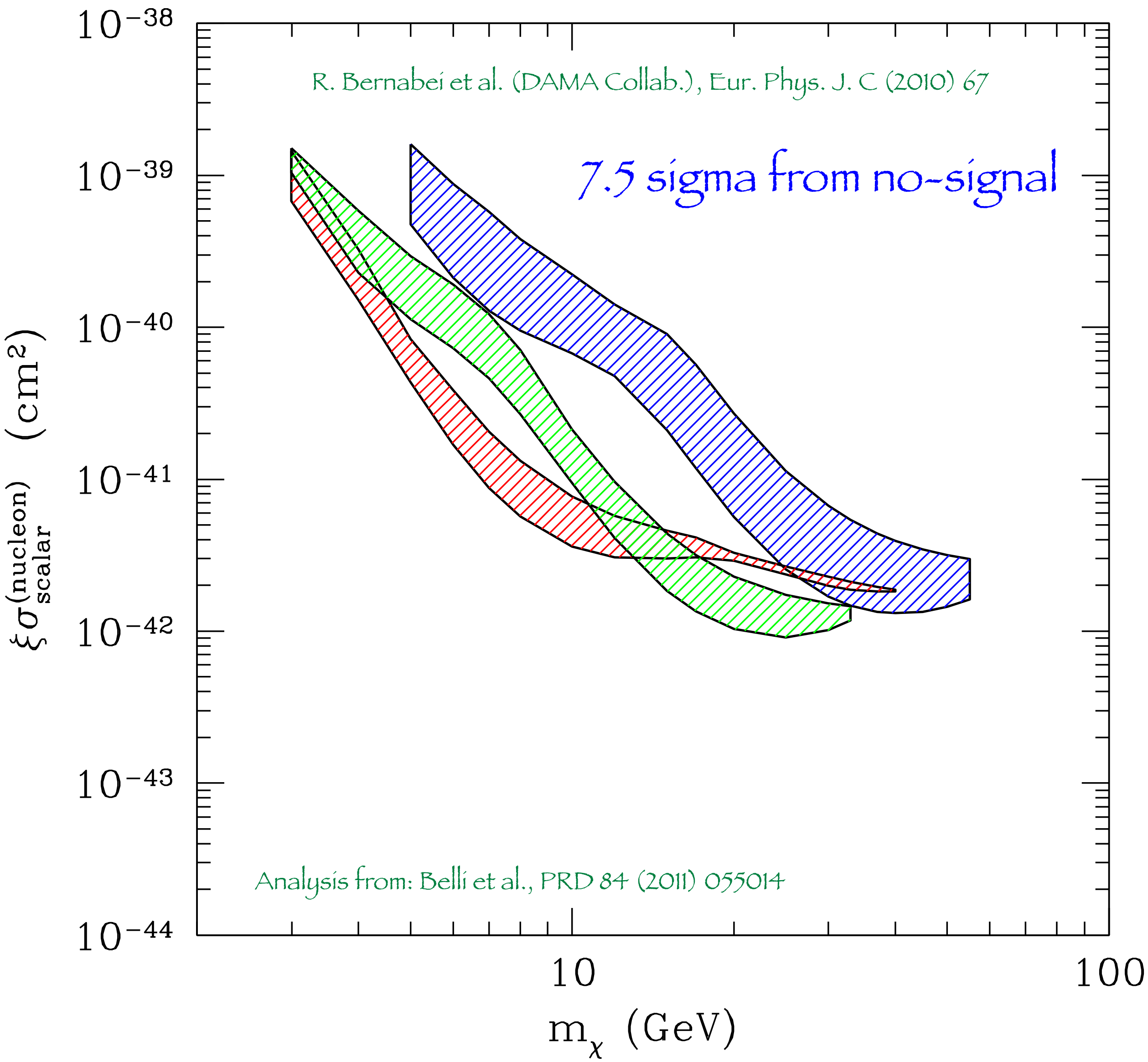
- Annual modulation experiments (DAMA, CoGeNT) — DAMA: $8.9\,\sigma$ C.L., CoGeNT: $2.8\,\sigma$ C.L.
  - Exploit a specific signature
  - Required to be highly stable over long periods

# DAMA annual modulation regions

"Canonical" halo

E-dep. quenching(*)

No channeling

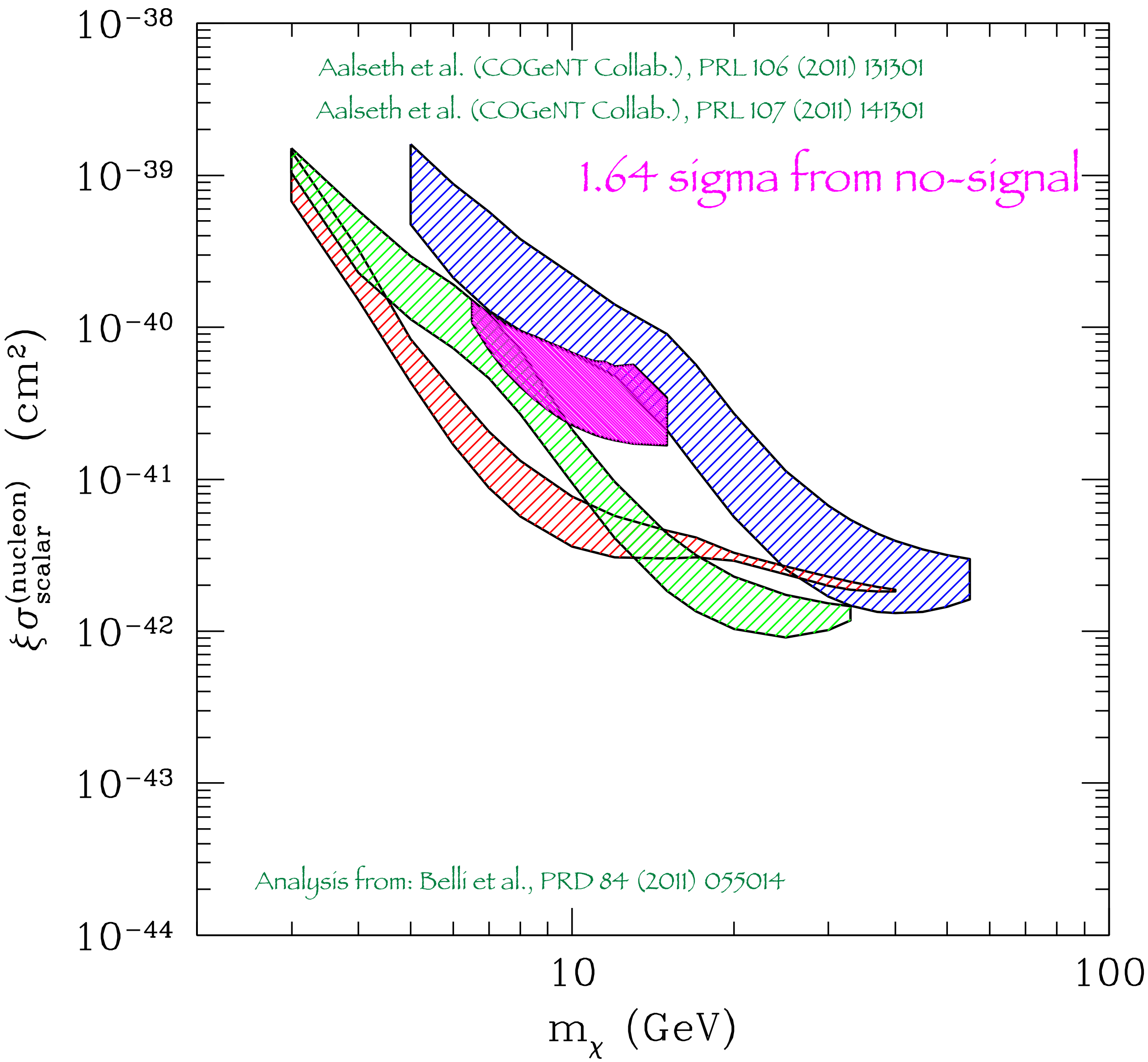



(*) Tretyak, Astrop. Phys. 33 (2010) 40

# CoGeNT annual modulation region

"Canonical" halo

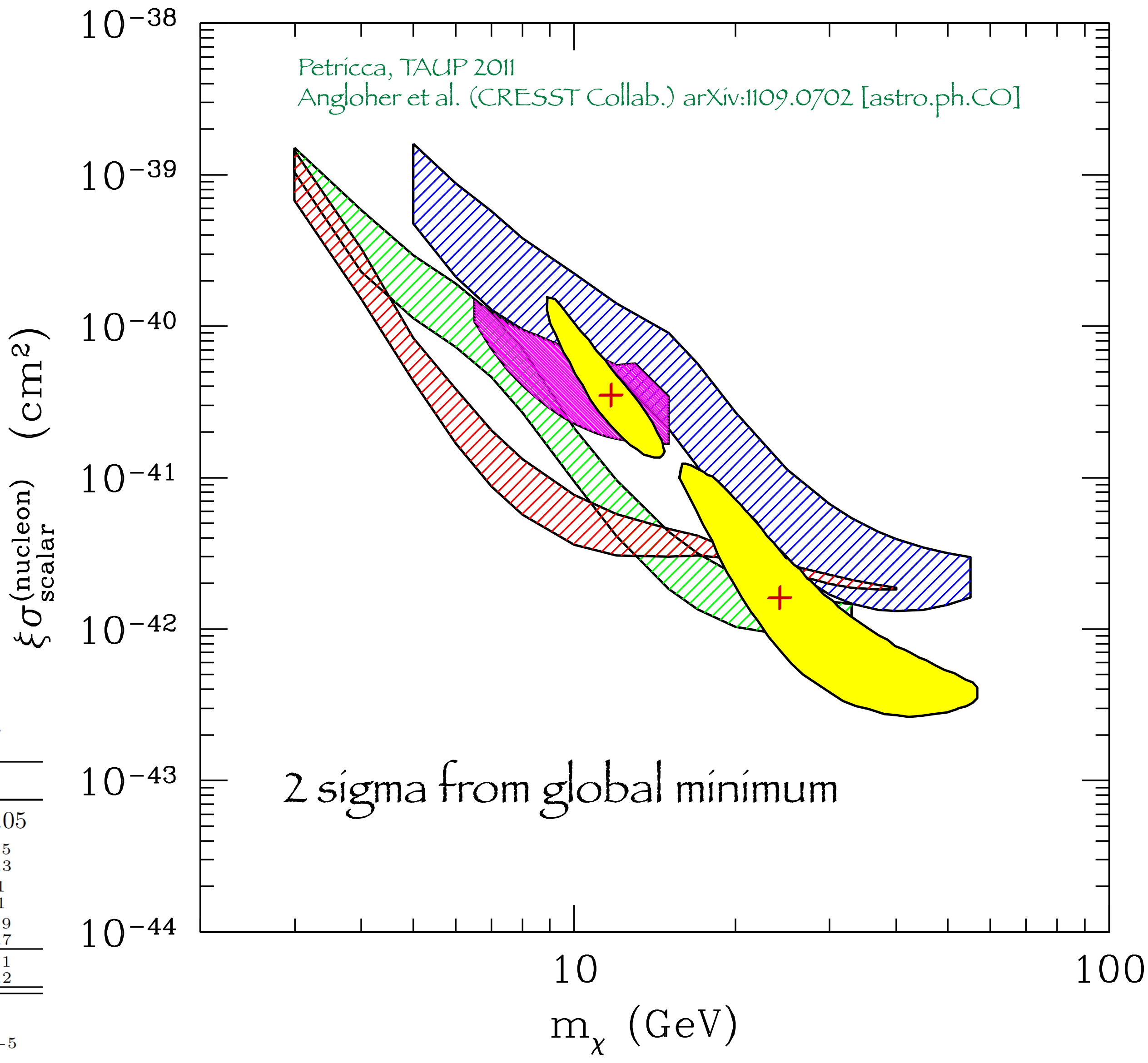
Fixed quenching



# CRESST regions

"Canonical" halo

Fixed quenching

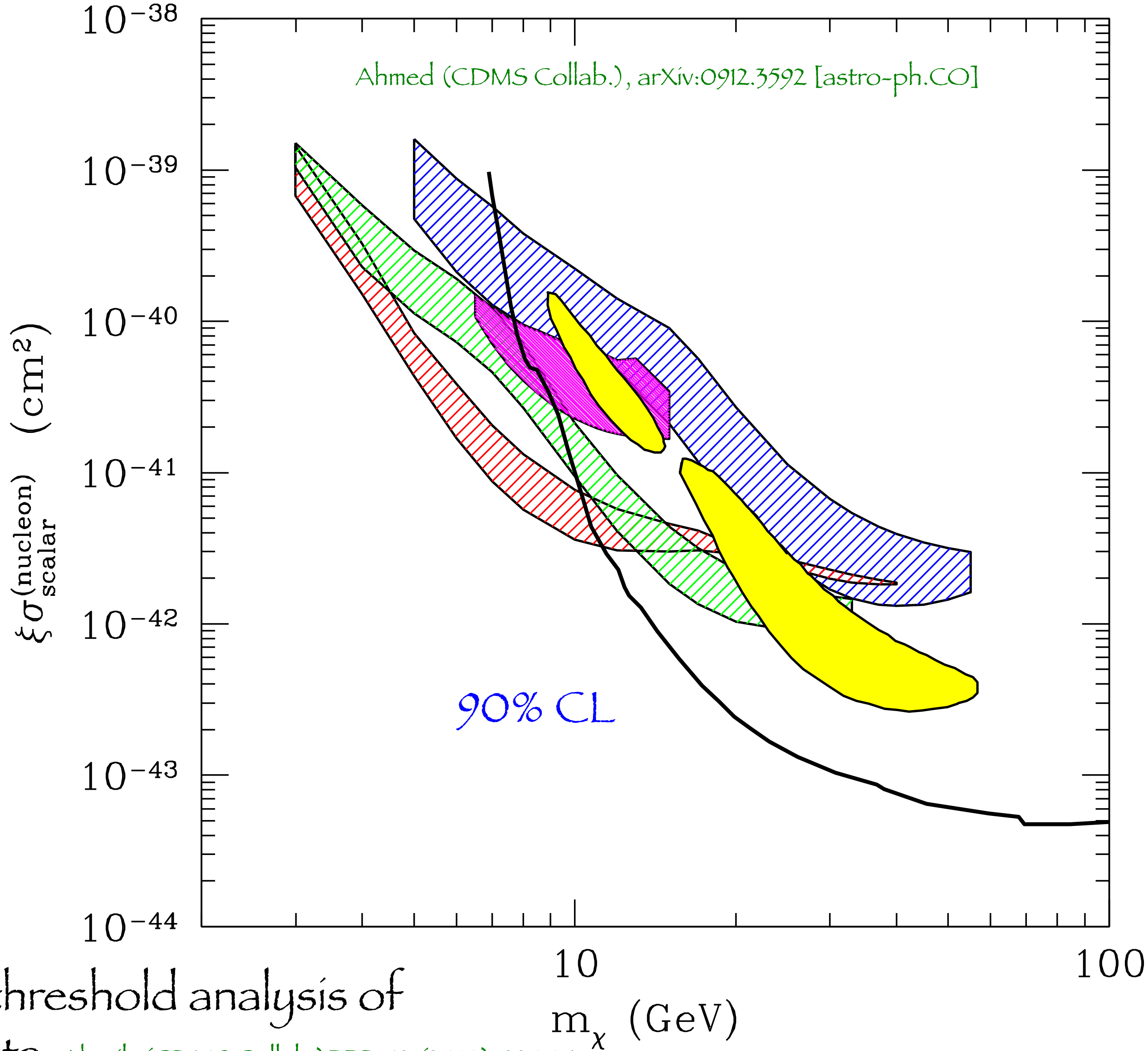



| | 4.7 σ | 4.2 σ |
|---|---|---|
| | M1 | M2 |
| $e/\gamma$-events | $8.00 \pm 0.05$ | $8.00 \pm 0.05$ |
| $\alpha$-events | $11.5^{+2.6}_{-2.3}$ | $11.2^{+2.5}_{-2.3}$ |
| neutron events | $7.5^{+6.3}_{-5.5}$ | $9.7^{+6.1}_{-5.1}$ |
| Pb recoils | $15.0^{+5.2}_{-5.1}$ | $18.7^{+4.9}_{-4.7}$ |
| signal events | $29.4^{+8.6}_{-7.7}$ | $24.2^{+8.1}_{-7.2}$ |
| $m_\chi$ [GeV] | 25.3 | 11.6 |
| $\sigma_{\rm WN}$ [pb] | $1.6 \cdot 10^{-6}$ | $3.7 \cdot 10^{-5}$ |

# CDMS Soudan combined

"Canonical" halo

Fixed quenching

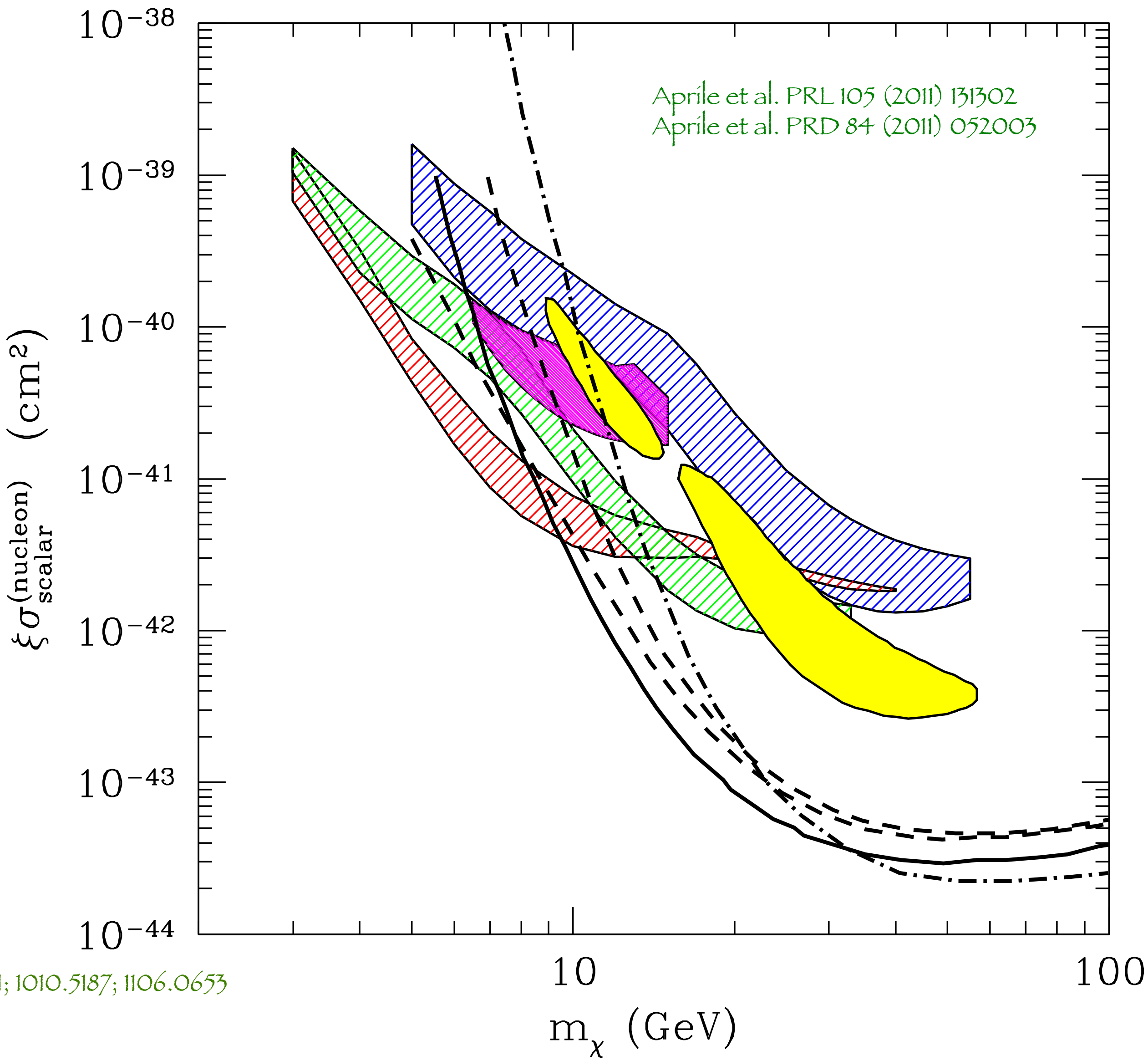



Also: attempt of low-threshold analysis of CDMS shallow site data Akerib (CDMS Collab.) PRD 82 (2010) 122004

# XENON 100

"Canonical" halo

Fixed quenching




Collar, 1005.0838; 1005.2615; 1006.2031; 1010.5187; 1106.0653
XENON 100 Collab. 1005.2615
Savage et al. 1006.0972

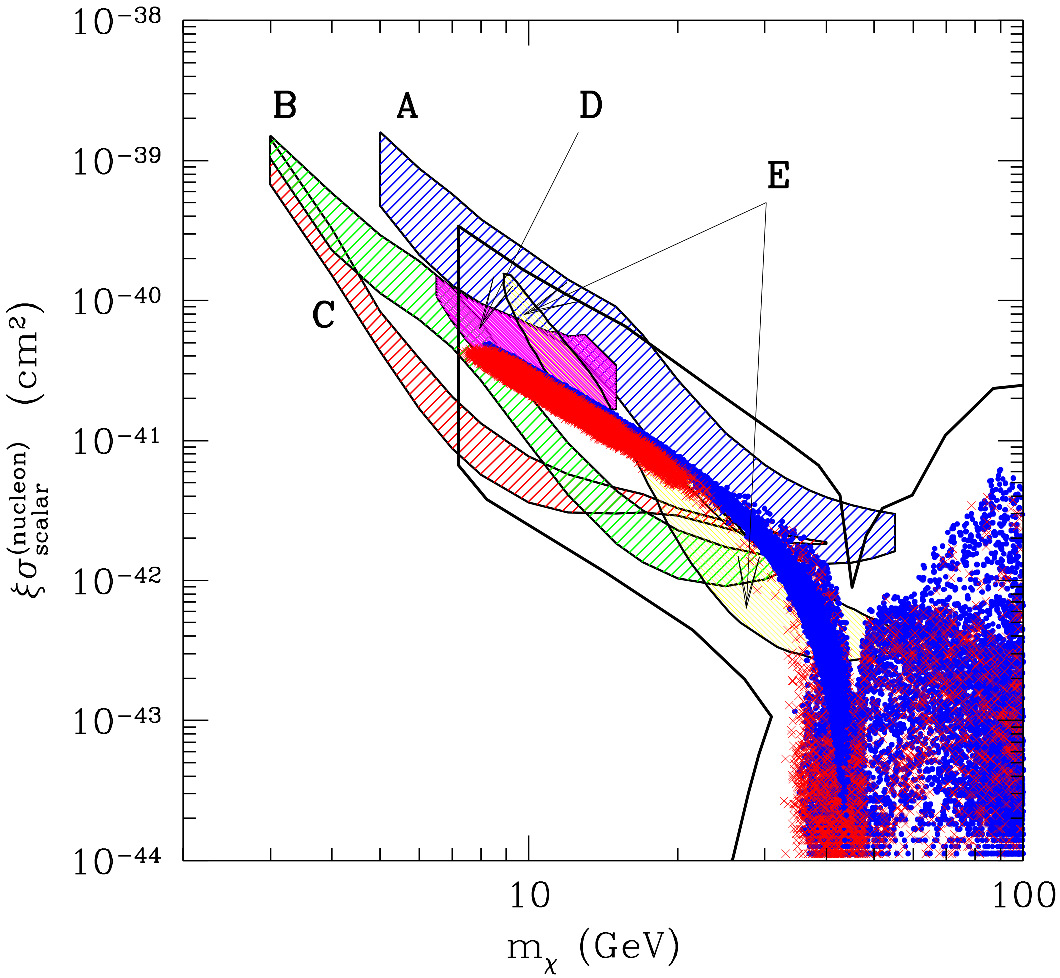
Bound on light DM dependent on the "scintillation efficiency" at low recoil energies

# Direct detection

- Exciting experimental results: 3 positive hints
  - DAMA: 9 sigma, exploits signature, stable over 15 years
  - CoGeNT: 2 sigma, exploits signature
  - CRESST: 4 sigma, irreducible excess of events
  - All compatible for DM around 10-20 GeV
- Two main (currently) null experiments: XENON, CDMS
  - Crucial to understand issues relevant for light DM
  - Or maybe the whole host of experimental data is telling us something about the mechanism of interaction and/or about the DM halo structure
- Theoretical models for light DM are largely available
  - some ad-hoc, some in well motivated frameworks (neutralinos in low energy SUSY, sneutrinos in models motivated by neutrino mass physics, NMSSM, ...)

# Light neutralinos in the MSSM

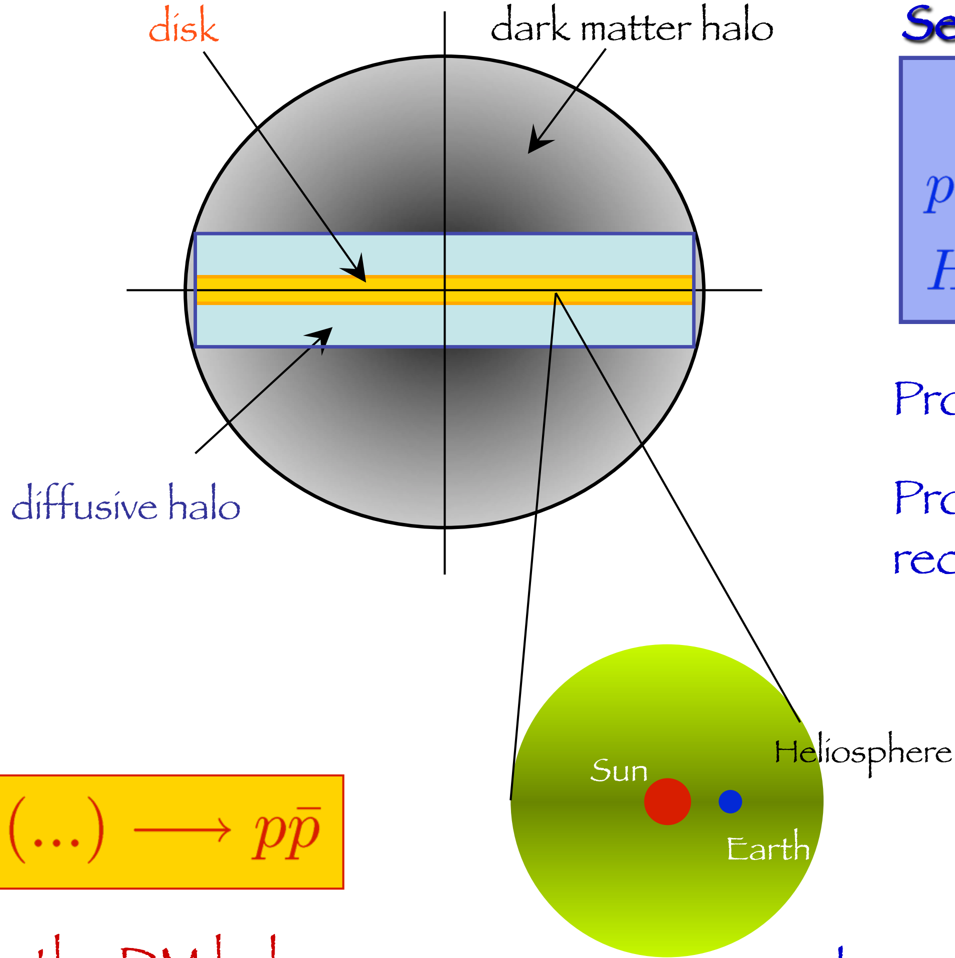
MSSM (8 params) with gaugino non universality
Light neutralinos, light pseudoscalar higgs, medium tanbeta




A. Bottino et al., PRD 67 (2003) 063519; PRD 78 (2008) 083520; PRD 83 (2011) 015001; PRD 84 (2011) 055014

# Antimatter in Cosmic Rays
# Antiprotons

# Cosmic Antiprotons




## Secondaries

$$p_{\rm CR} + p_{\rm ISM} \longrightarrow \bar{p}$$
$$p_{\rm CR} + He_{\rm ISM} \longrightarrow \bar{p}$$
$$He_{\rm CR} + p_{\rm ISM} \longrightarrow \bar{p}$$

Produced in the disk

Propagation and energy redistribution in the diffusive halo

solar modulation

## DM signal

$$\chi\chi \longrightarrow (\ldots) \longrightarrow p\bar{p}$$

Produced in the DM halo

Propagation and energy redistribution in the diffusive halo

# Propagation equation

$\psi = dn/dE$

$$\partial_z \left( V_C \, \psi \right) \, - \, K \, \Delta\psi \, + \, \partial_E \left\{ b^{\rm loss}(E) \, \psi \, - \, K_{EE}(E) \, \partial_E \psi \right\} \, = \, q \left( \mathbf{x}, E \right)$$

convection — diffusion — energy losses — reacceleration — source term

Diffusion: uniform in the whole (disk + diffusive halo) volume ($L$) $\quad K(E) \, = \, K_0 \, \beta \, \left( \mathcal{R}/1 \, \mathrm{GV} \right)^{\delta}$

Galactic wind away from the disk in vertical direction $\quad V_c$

Reacceleration on random hydrodynamic waves (in the disk only) $\quad K_{EE} \, = \, \frac{2}{9} \, {V_a}^2 \, \frac{E^2 \beta^4}{K(E)}$

Energy losses:

- Ionization: interaction with the neutral IS matter
- Coulomb scattering: interaction with ionized plasma (thermal electrons)

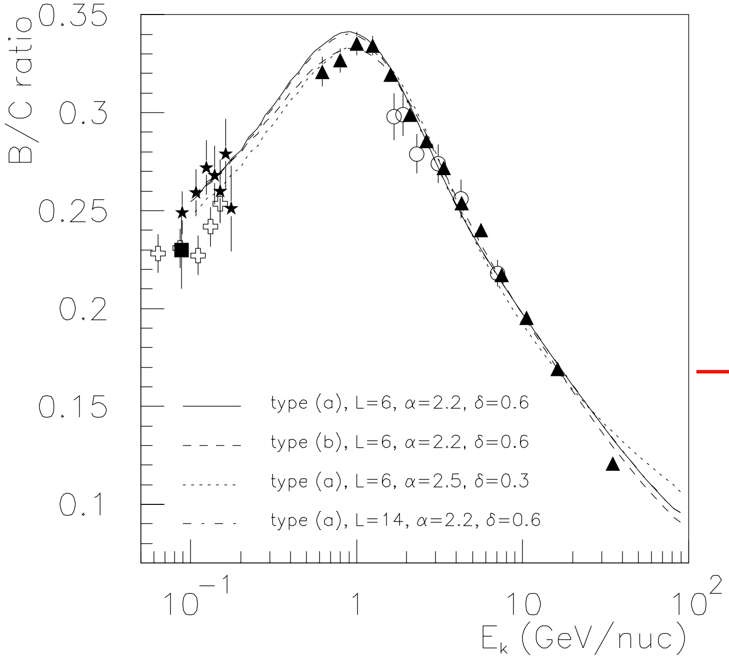
Inelastic (non-annihilating) scattering and annihilation

# Solution and model validation

$q_{\bar{p}}^{\text{source}}(r, z, T_{\bar{p}})$ —— Propagation in the Galaxy ——→ $\Phi_{\bar{p}}(r, z, T_{\bar{p}})$

GALPROP
DRAGON
USINE
"Torino code"
(...)

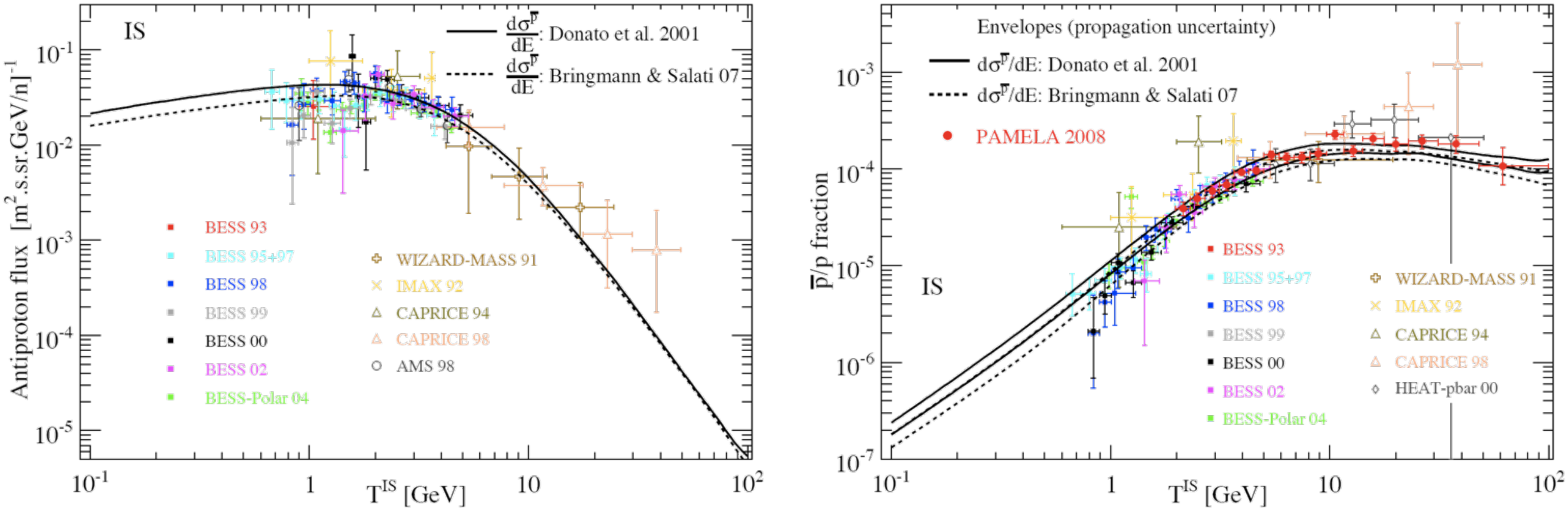
The params are constrained by secondary/primary ratios, mainly B/C




| case | $\delta$ | $K_0$ (kpc$^2$/Myr) | $L$ (kpc) | $V_c$ (km/sec) | $V_A$ (km/sec) | $\chi^2_{\mathrm{B/C}}$ |
|---|---|---|---|---|---|---|
| max | 0.46 | 0.0765 | 15 | 5 | 117.6 | 39.98 |
| med | 0.70 | 0.0112 | 4 | 12 | 52.9 | 25.68 |
| min | 0.85 | 0.0016 | 1 | 13.5 | 22.4 | 39.02 |

[D. Maurin et al. Astron. Astrophys. 394 (2002) 1039]

# Secondary antiprotons

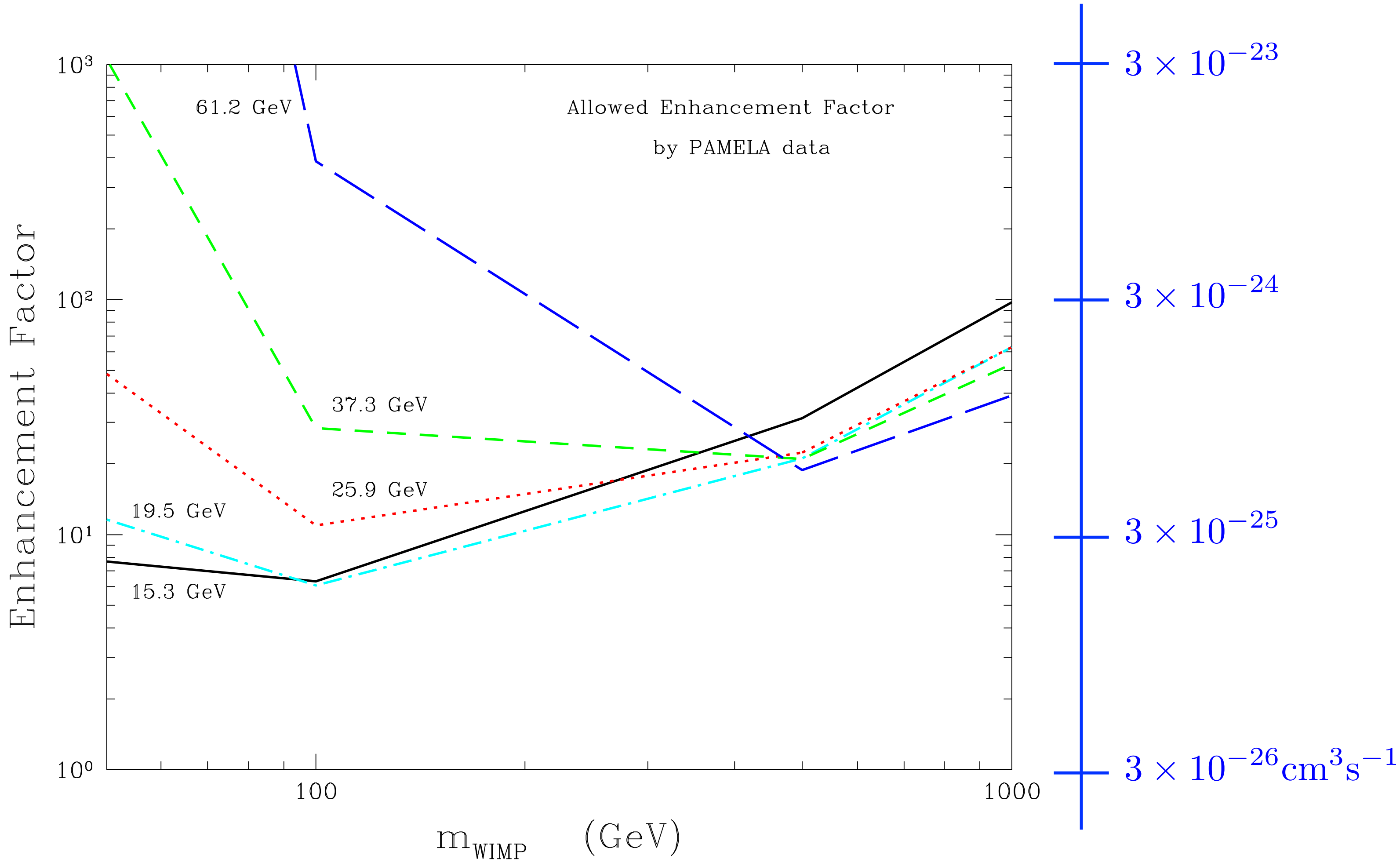



Antiproton flux

Antiproton/proton fraction

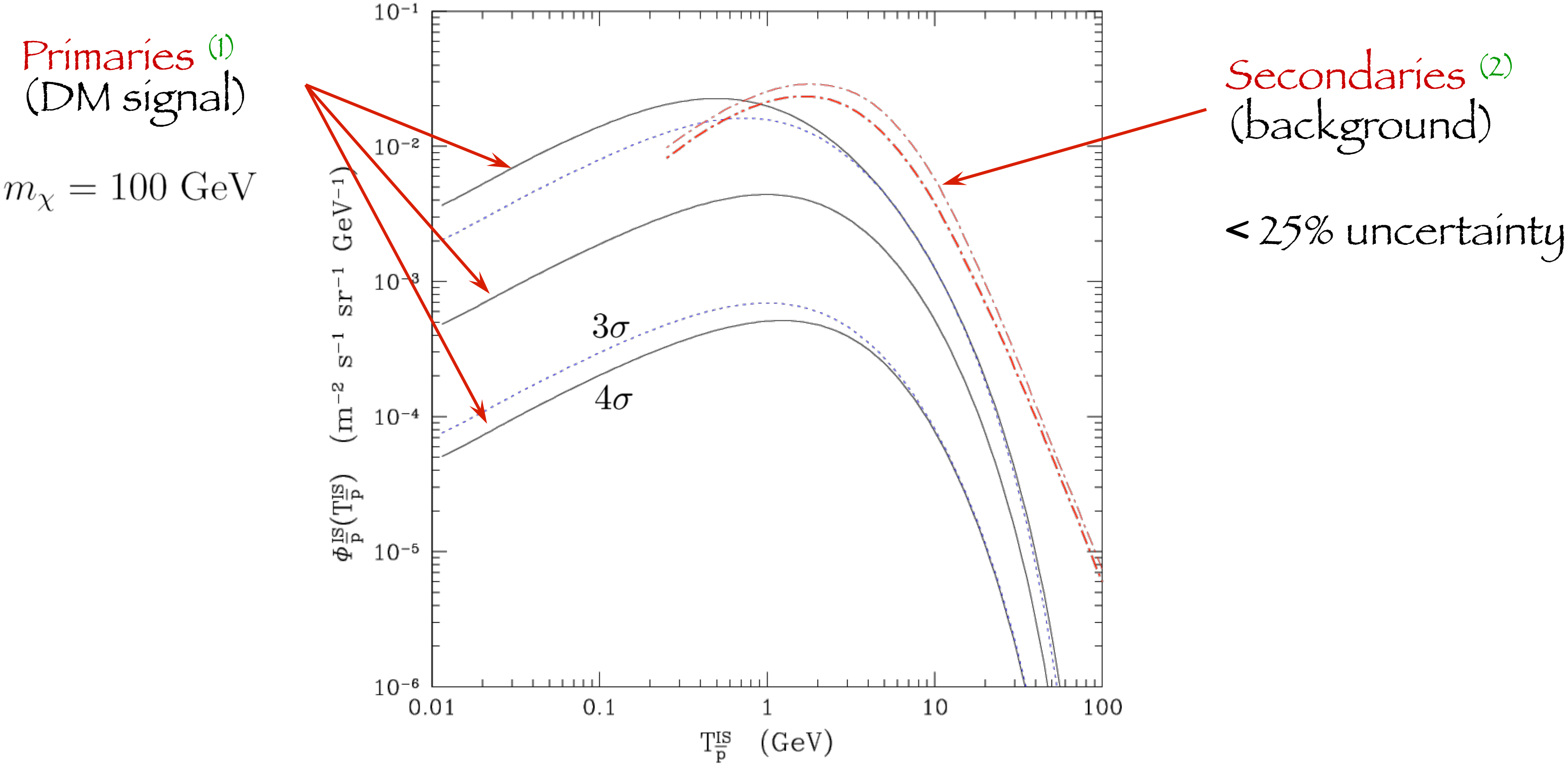
F. Donato, D. Maurin, P. Brun, T. Delahaye, P. Salati, PRL 102 (2009) 071301

# Bounds from antiprotons




F. Donato, D. Maurin, P. Brun, T. Delahaye, P. Salati, PRL 102 (2009) 071301

# Interstellar antiproton fluxes




(1) F. Donato, N. Fornengo, D. Maurin, P. Salati, R. Taillet, PRD 69 (2004) 0603501

(2) D. Maurin et al. Astron. Astrophys. 381 (2002) 539

| case | $\delta$ | $K_0$ (kpc$^2$/Myr) | $L$ (kpc) | $V_c$ (km/sec) | $V_A$ (km/sec) | $\chi^2_{B/C}$ |
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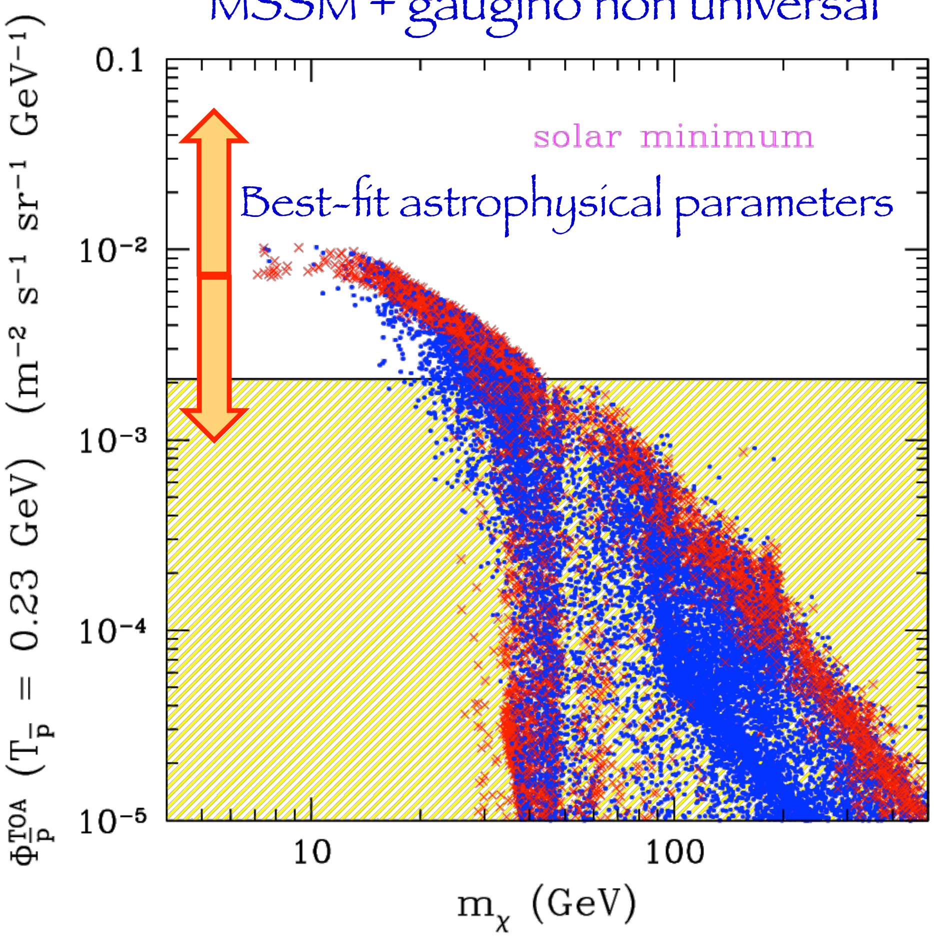
| min | 0.85 | 0.0016 | 1 | 13.5 | 22.4 | 39.02 |

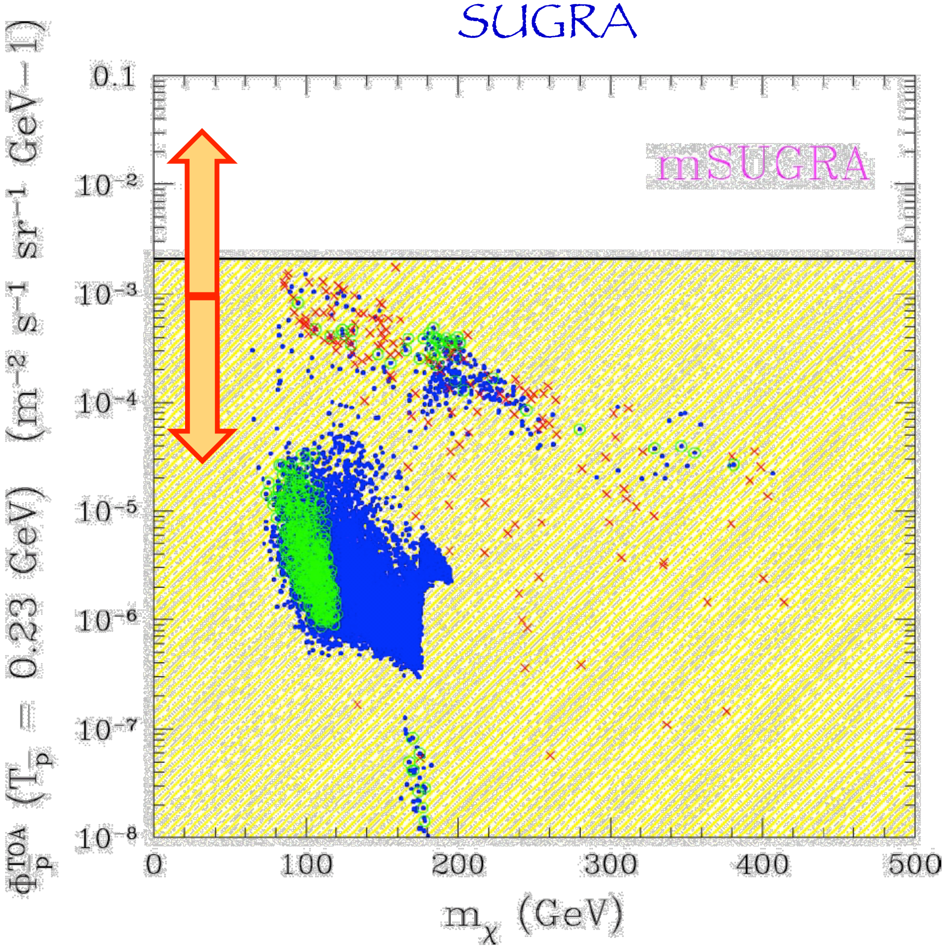
# Theoretical predictions for neutralinos

MSSM + gaugino non universal




A. Bottino, F. Donato, N.F., S. Scopel, PRD 70 (2004) 015005

SUGRA




F. Donato, N.F., D. Maurin, P. Salati, R. Taillet, PRD 69 (2003) 063501

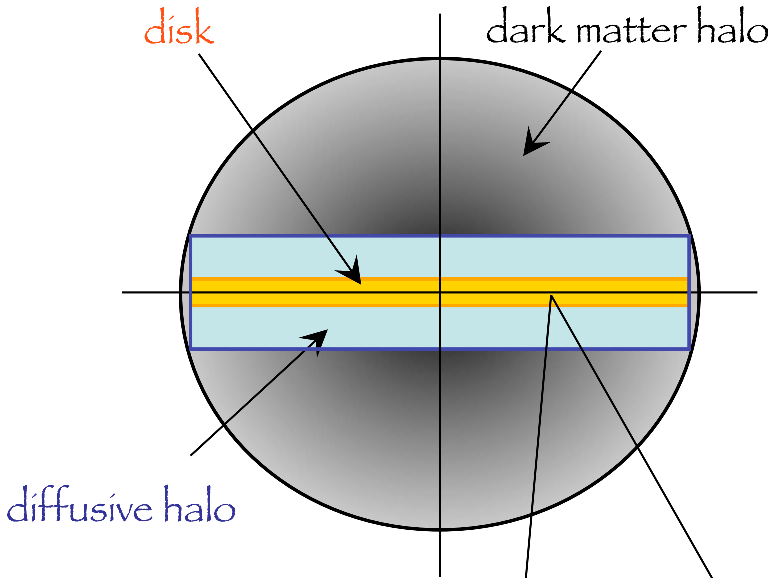
# Antiprotons

- No spectral features observed
- Predictions for background component agree well with data
- Large statistics data in wide energy ranges are available/coming (PAMELA, AMS)
- Required: new cosmic ray data (B/C) in order to sharpen theoretical uncertainties on propagation modeling (error reduction on signal predictions)
- Refinements on theoretical models of propagation (non isotropic duffusion, spectral breaking, etc) possible but relevant only if data can discriminate

# Antimatter in Cosmic Rays
# Antideuterons

# Cosmic antideuterons

F. Donato, N. Fornengo, P. Salati, PRD 62 (2000) 043003




## Secondaries

$$p_{\,\mathrm{CR}} + p_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$
$$p_{\,\mathrm{CR}} + He_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$
$$He_{\,\mathrm{CR}} + p_{\,\mathrm{ISM}} \longrightarrow \bar{D}$$

Produced in the disk

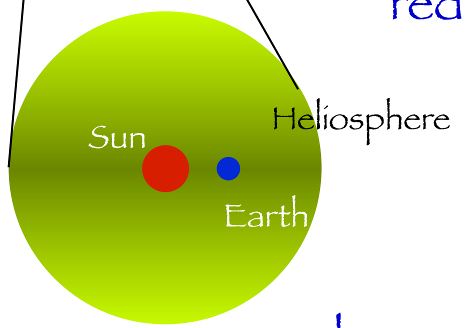
Propagation and energy redistribution in the diffusive halo

## DM signal

$$\chi\chi \longrightarrow (.....) \longrightarrow p\bar{p}\ n\bar{n}$$
$$\bar{p} + \bar{n} \longrightarrow \bar{D}$$ Coalescence

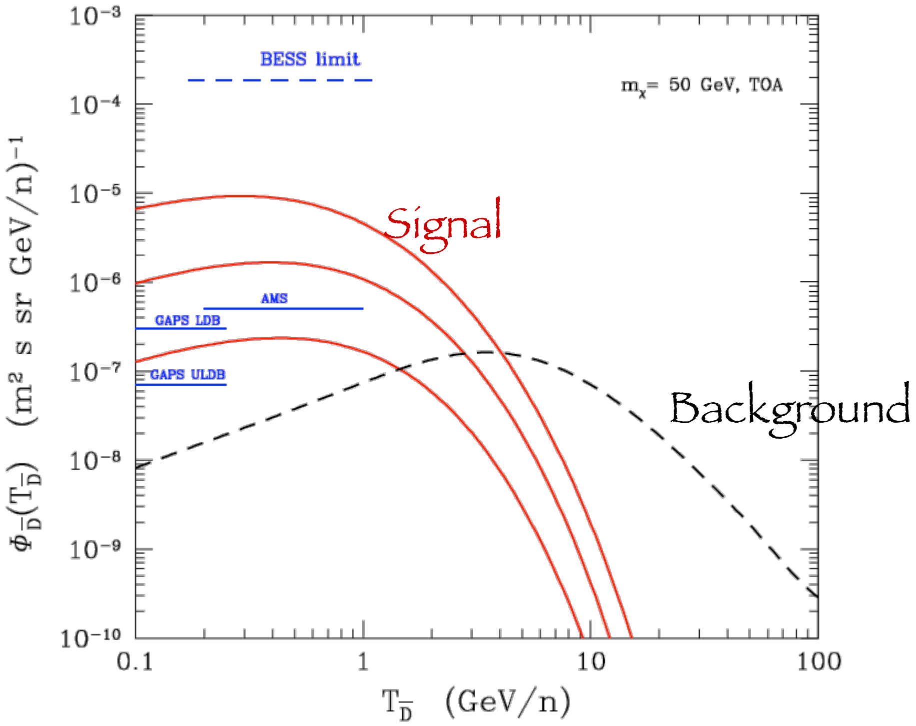
Produced in the DM halo

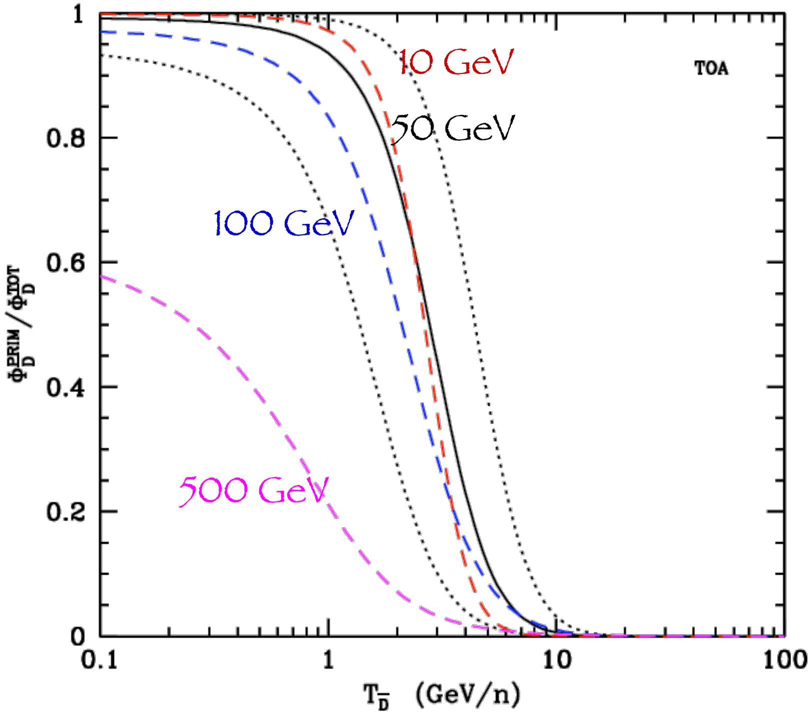
Propagation and energy redistribution in the diffusive halo




solar modulation

# TOA fluxes and S/B gain




Signal with astrophysical uncertainty band for:

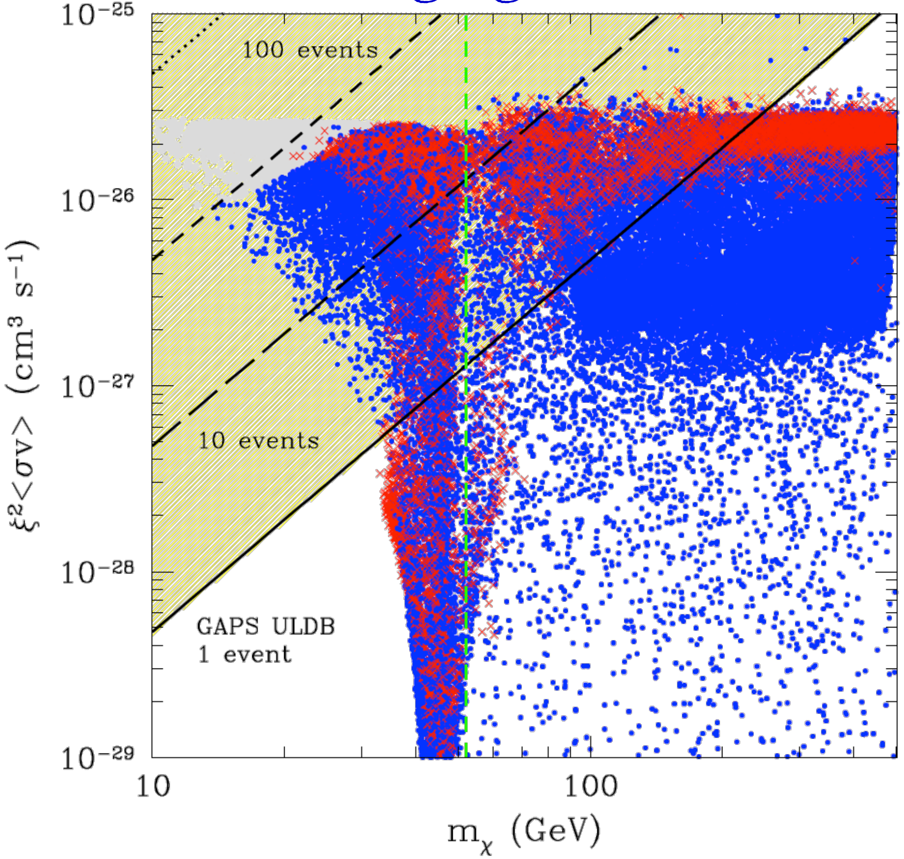
- 50 GeV WIMP mass
- WMAP relic abundance

Signal/(Back+Signal) ratio

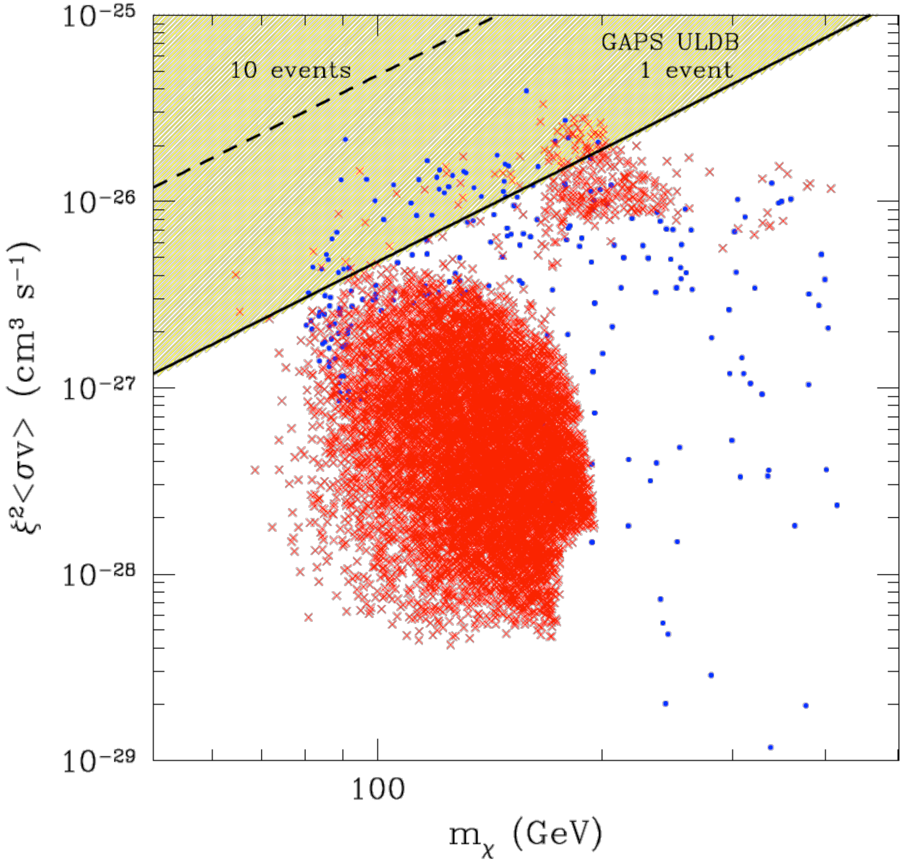
A. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

# Theoretical predictions

MSSM + gaugino non universal



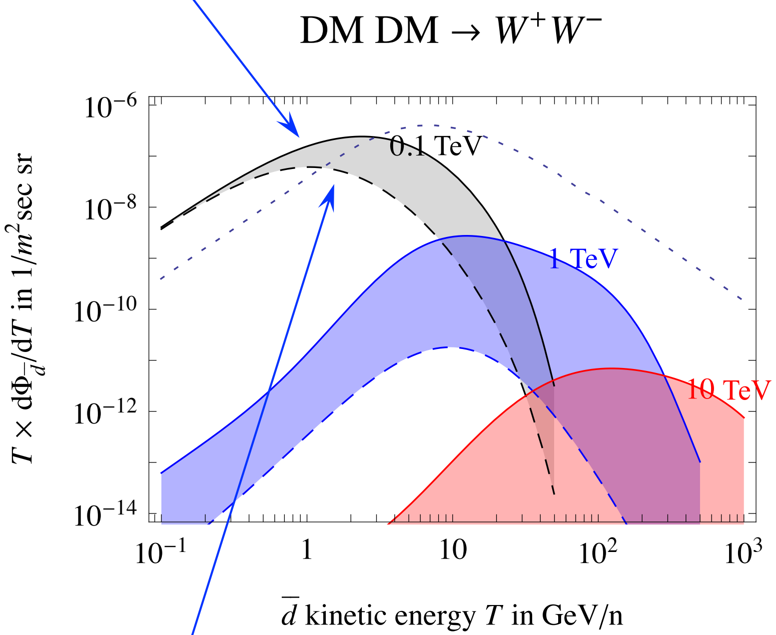

SUGRA

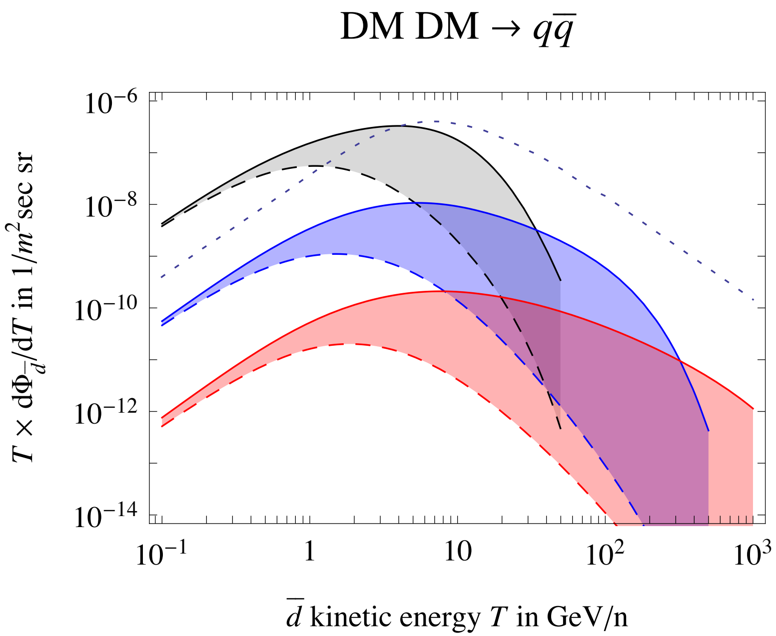



A. Donato, N. Fornengo, D. Maurin, PRD 78 (2008) 043506

# Coalescence

Jet correlations (from MC)




"Spherical" approach

M. Kadastik, M. Raidal, A. Strumia, PLB 683 (2010) 248
See also: Y. Cui, J.D. Mason, L. Randall, JHEP (2010) 1011

# Antideuterons

- Data are expected in the next 5 years (GAPS, AMS)
  - AMS: in space and taking data
  - GAPS: prototype flight in May 2012, ballon flight from Antarctica in 2014

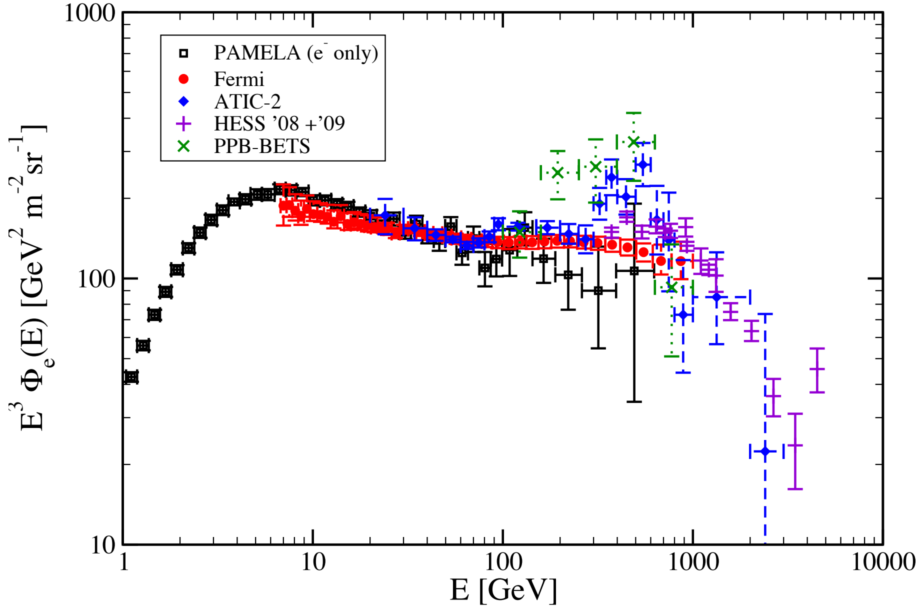
- Potentially a channel for discovery in a wide portion of parameter space

- Improved theoretical predictions are under development (antiD coalescence, propagation)

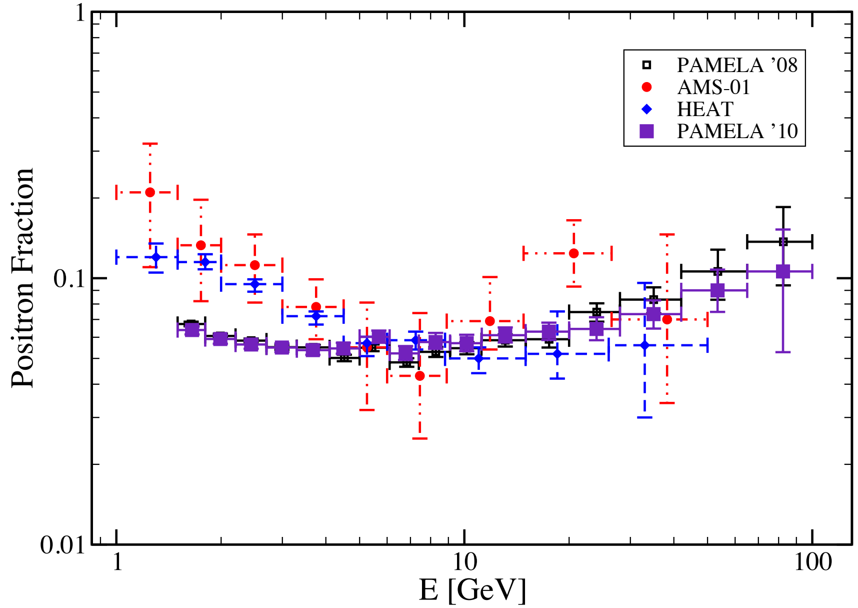
# Antimatter in Cosmic Rays
# Positrons/Electrons

# Electrons and positrons

electrons + positrons

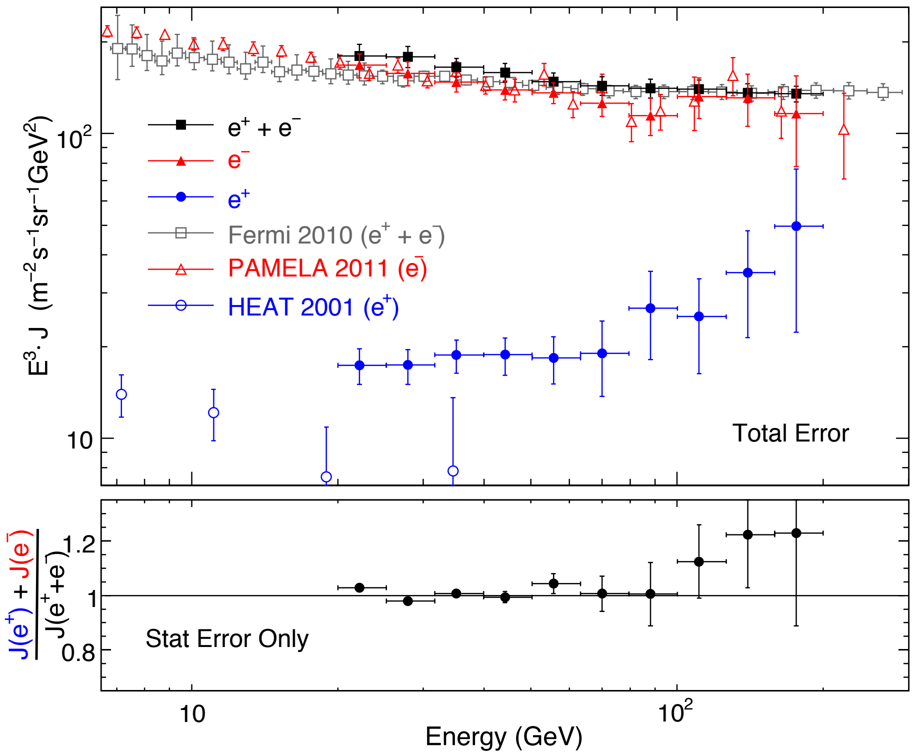


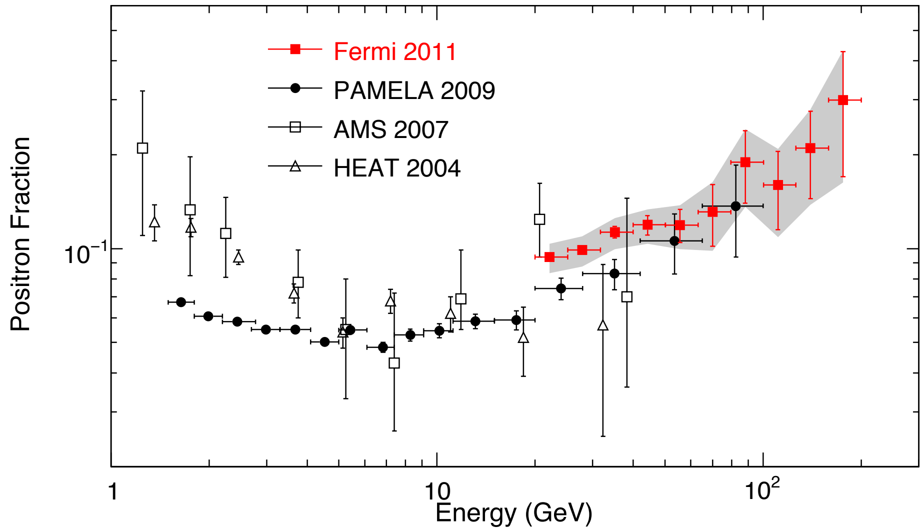

positron fraction




From P. Serpico, arXiv:1108.4827

# FERMI separation of e+ and e-




Ackermann et al., arXiv 1109.0521

# Electrons and positrons in Cosmic Rays

Primaries:

e- from SN remnants
e+,e- from pulsars
DM annihilation, decay

Secondaries:

$$p + H \longrightarrow (\ldots)\ \pi^{\pm} \longrightarrow (\ldots)\ e^{\pm}$$

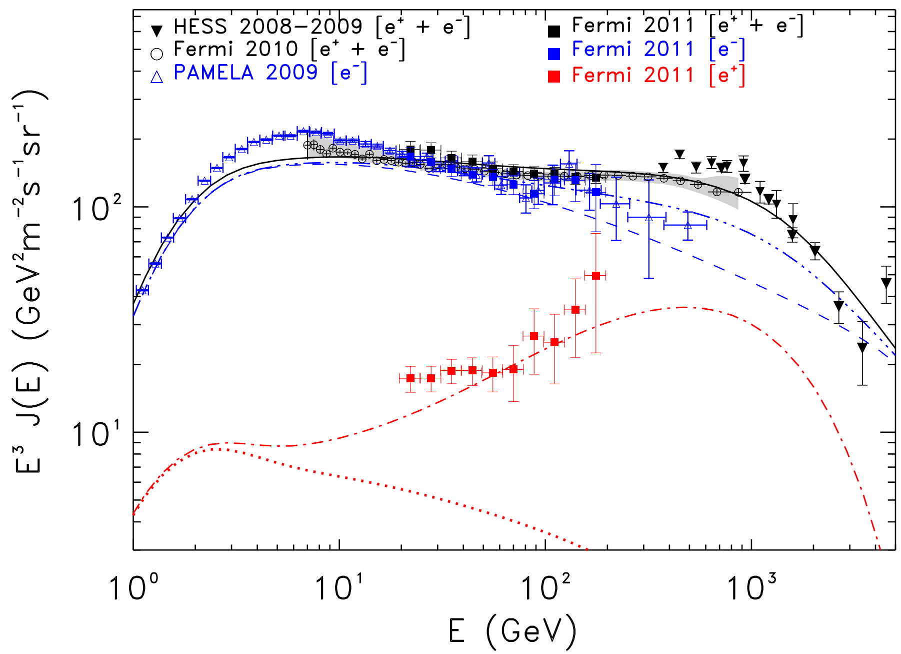
Dominant processes in transport:

space diffusion
energy losses — synchrotron radiation on galactic mag fields
inverse Compton on radiation fields (CMB, stellar)

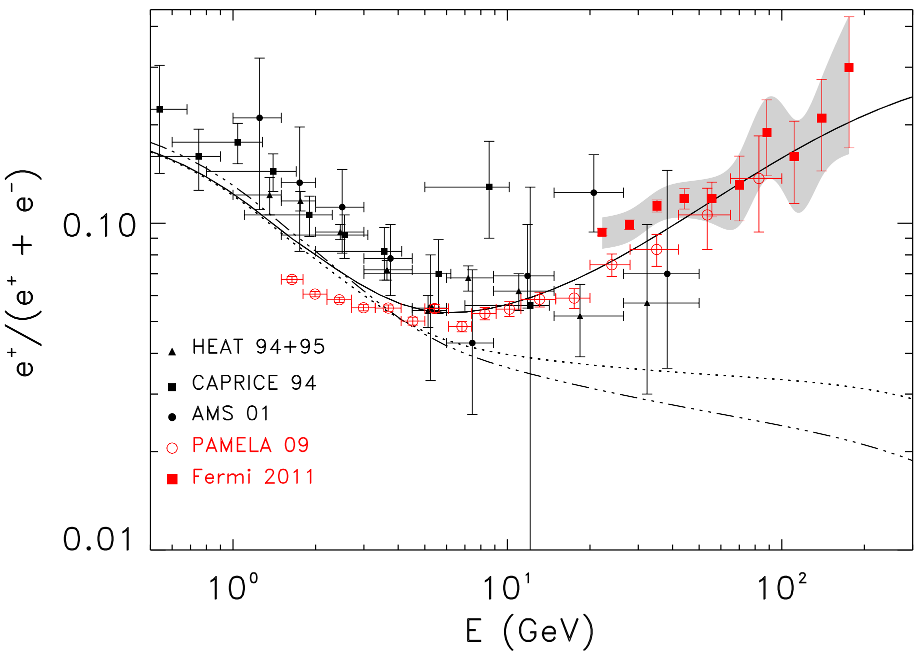
$$\partial_t \psi - K\,\Delta\psi + \partial_E\{b^{\text{loss}}(E)\,\psi\} = q\,(\mathbf{x}, E)$$

# Astrophysical interpretation

electrons + positrons

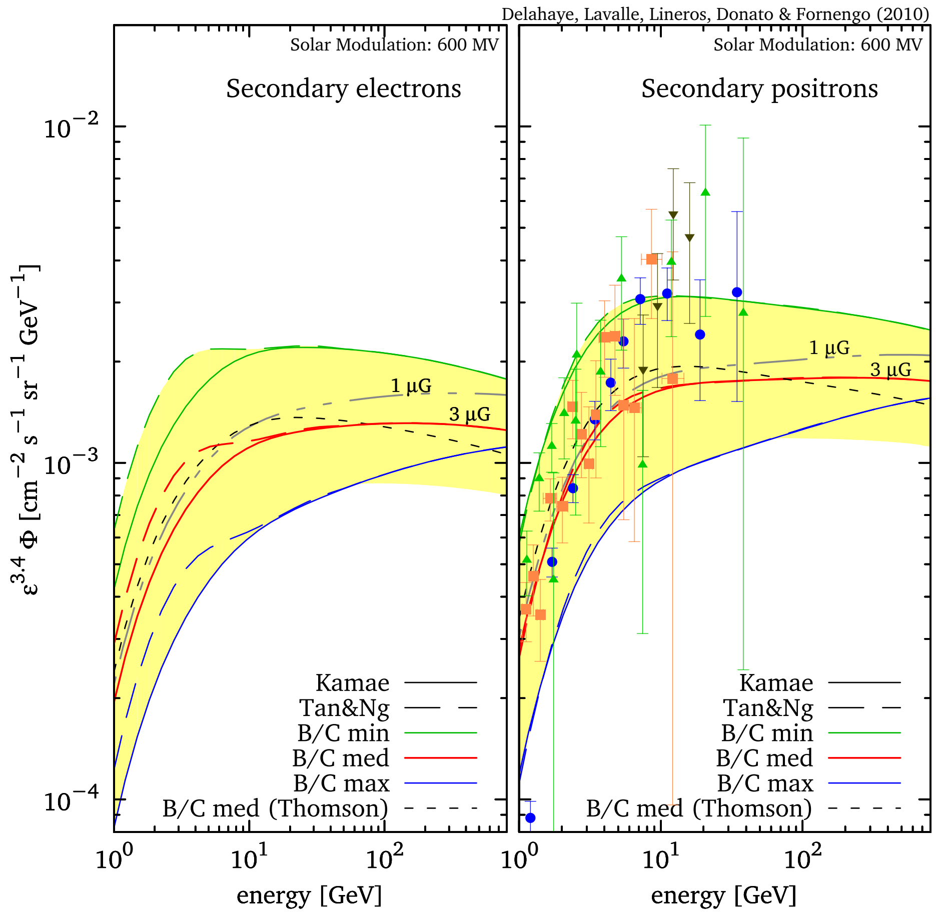



positron fraction



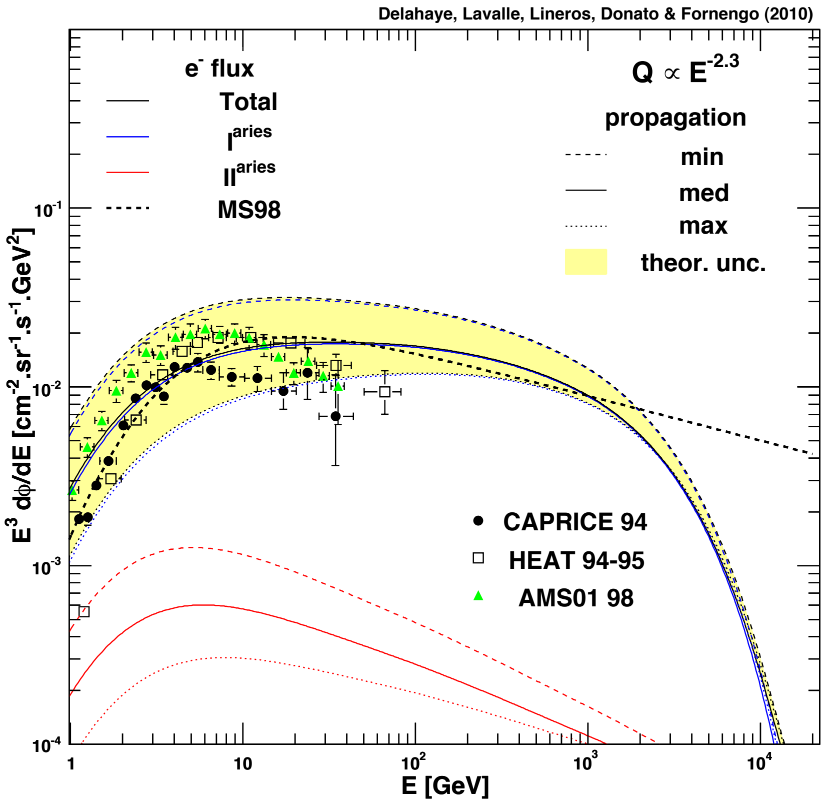

D. Gaggero, D. Grasso, arXiv:1110.6626 (see also references therein)

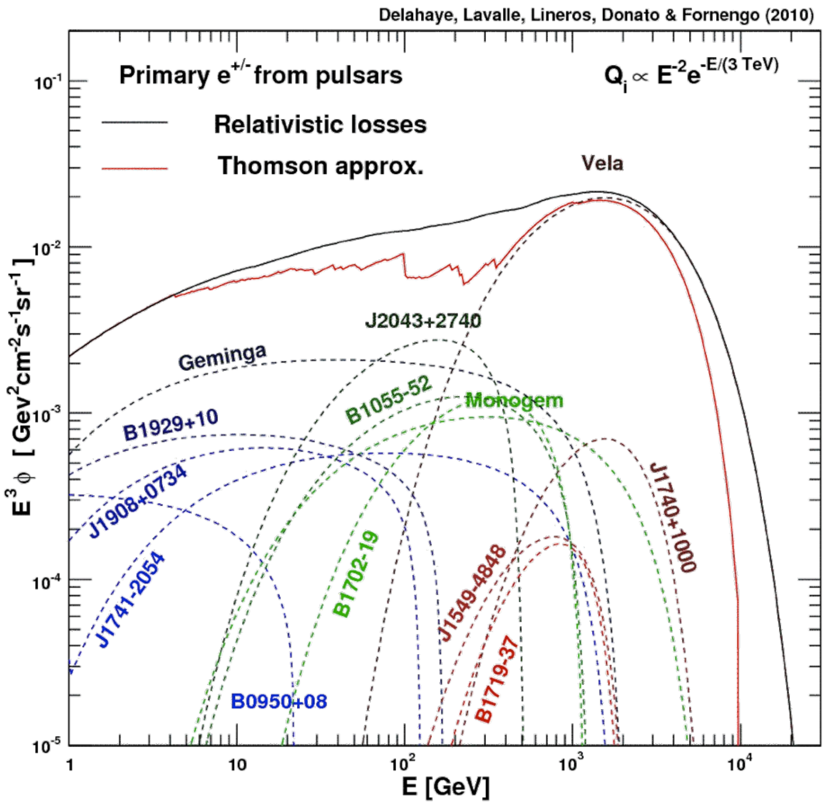
# Secondary e+,e- : fluxes and uncertainties




T. Delahaye, J. Lavalle, R. Lineros, F. Donato, N. Fornengo, A&A 524 (2010) A51

# Primary $e^+,e^-$: fluxes and uncertainties



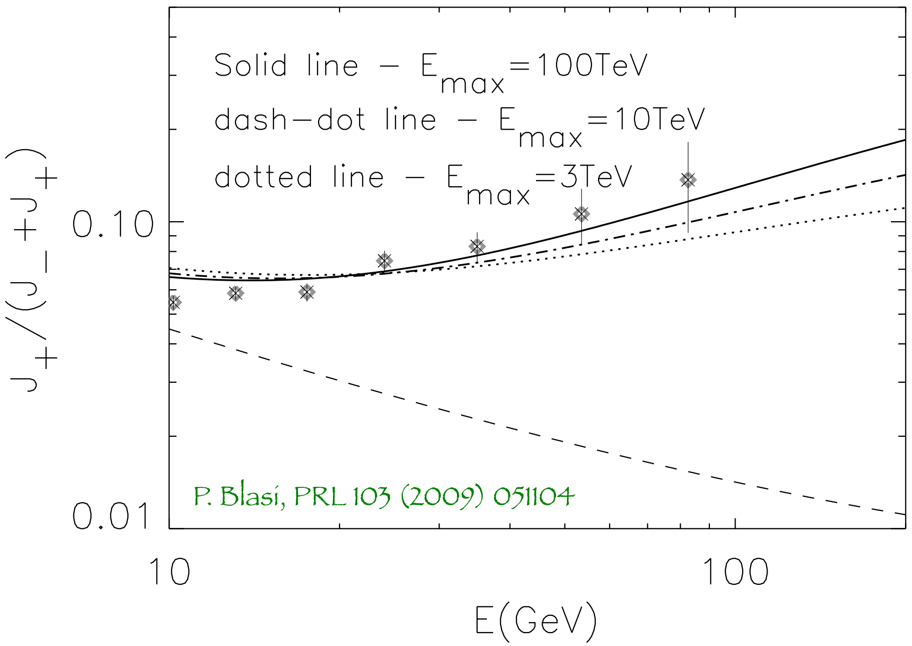



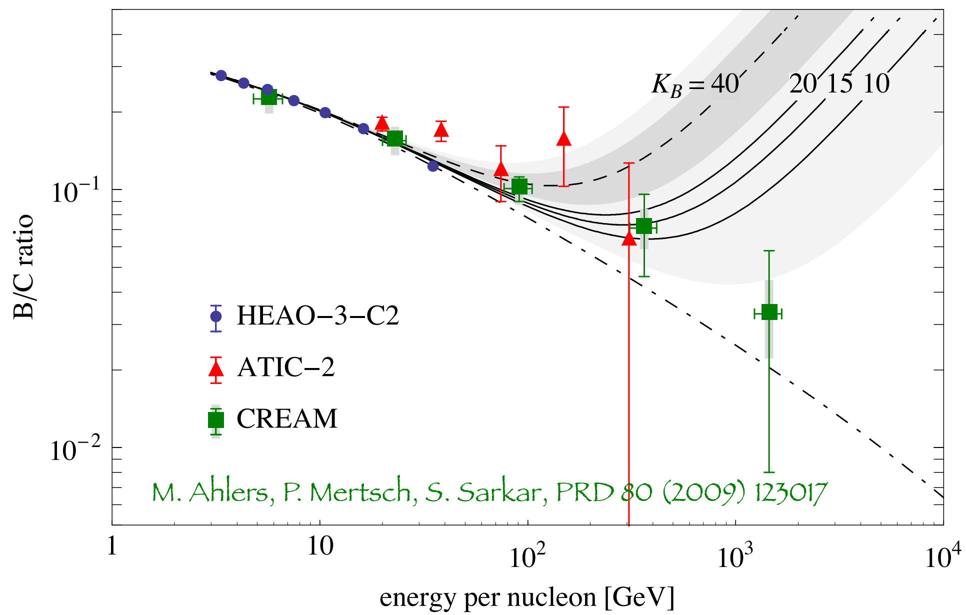

Distant sources (smooth)

Local sources

J. Lavalle, T. Delahaye, R. Lineros, F. Donato, N. Fornengo, arXiv:1002.1910 [astro-ph.HE]

# Secondary positrons in SNR



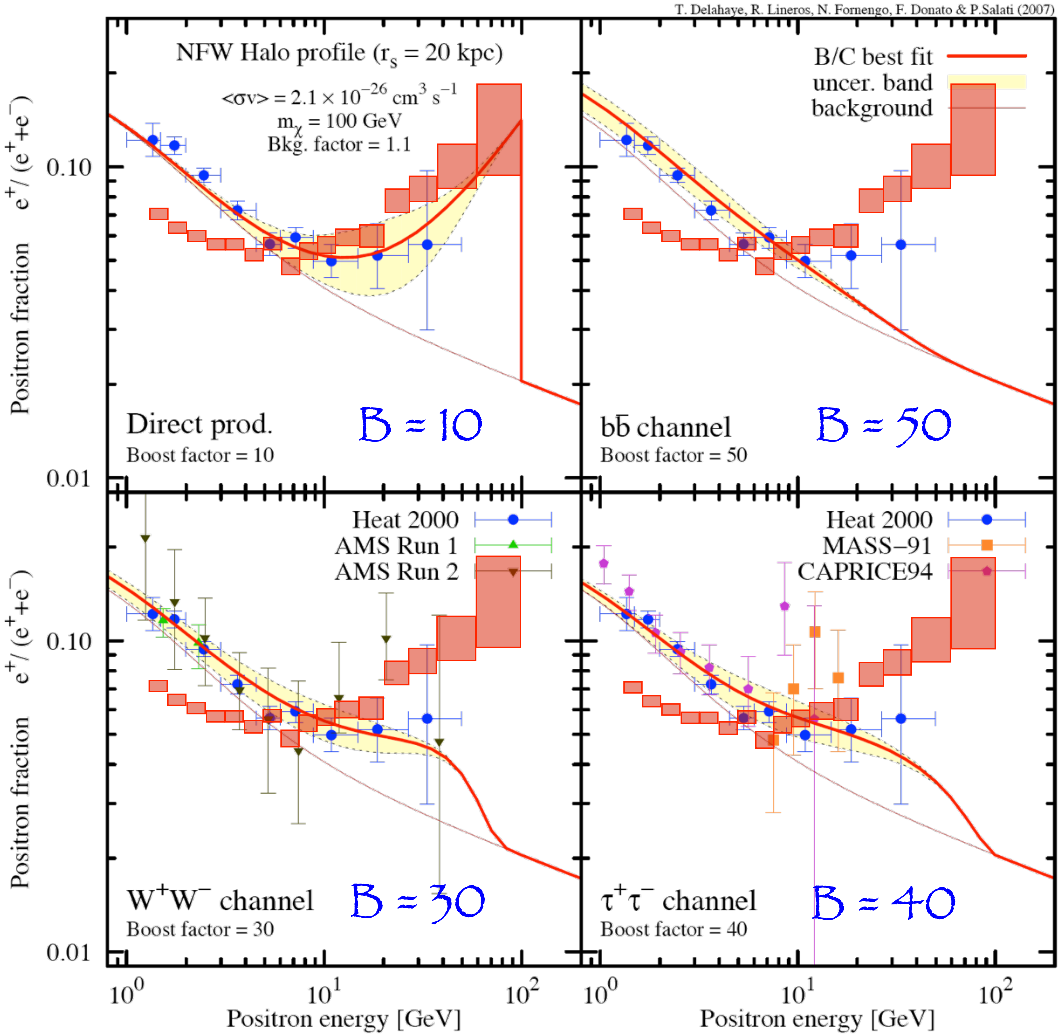




- secondary production of positrons from hadronic interactions inside SNR
- secondary positrons (and electrons) participate in the acceleration process and turn out to have a very flat spectrum, which after propagation in the Galaxy, this leads to the observed positron 'excess'
- unavoidable effect, though its strength depends on the values of the environmental parameters during the late stages of evolution of SNR

# Positron fraction: including a DM signal

$m_\chi \simeq 100$ GeV

$\langle\sigma v\rangle = 2.1 \cdot 10^{-26}\text{cm}^3\text{s}^{-1}$



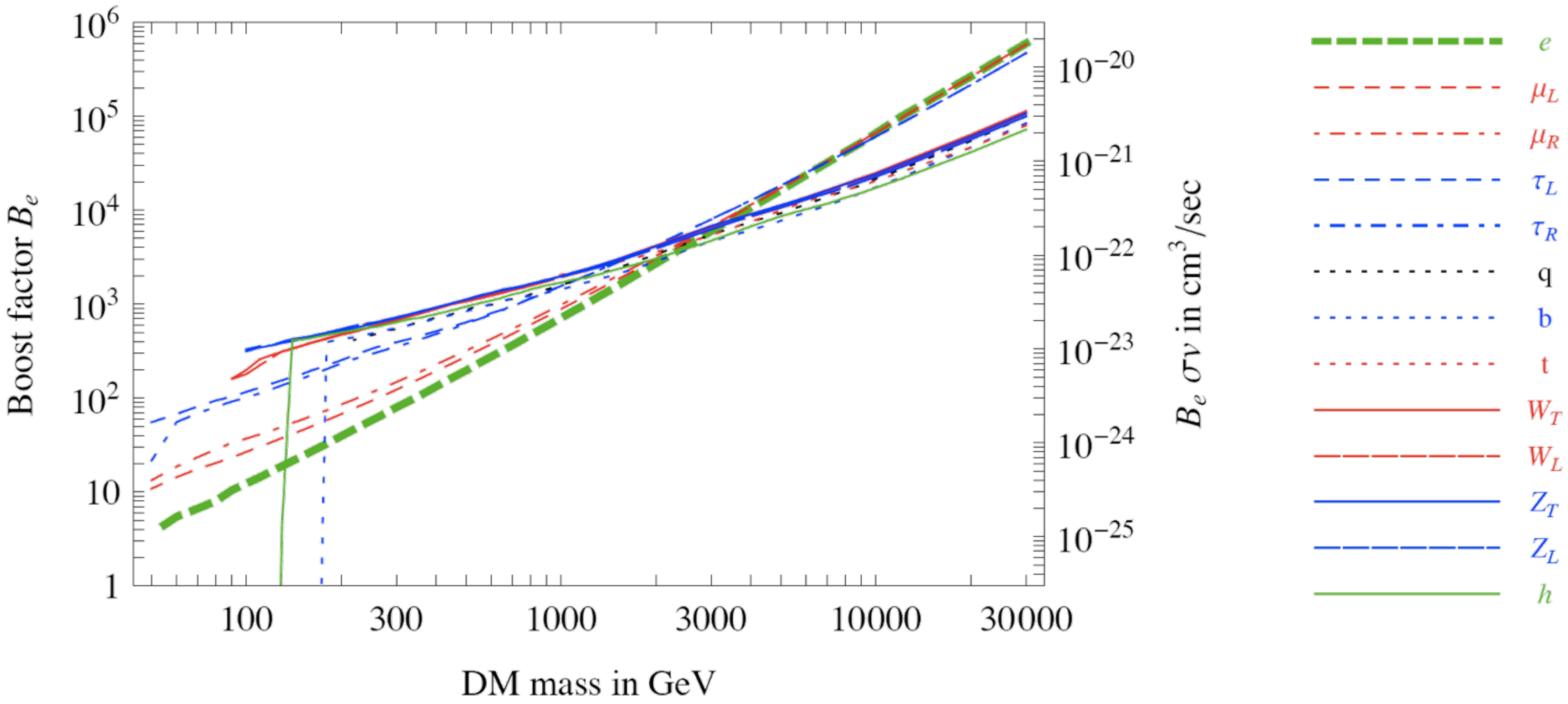

PAMELA 2008

T. Delahaye, R. Lineros, F. Donato, NF, P. Salati, Phys. Rev. D 77 (2008) 063527

For annihilation cross section consistent with WMAP for a thermal relic

Smooth NFW halo

# Model independent analysis

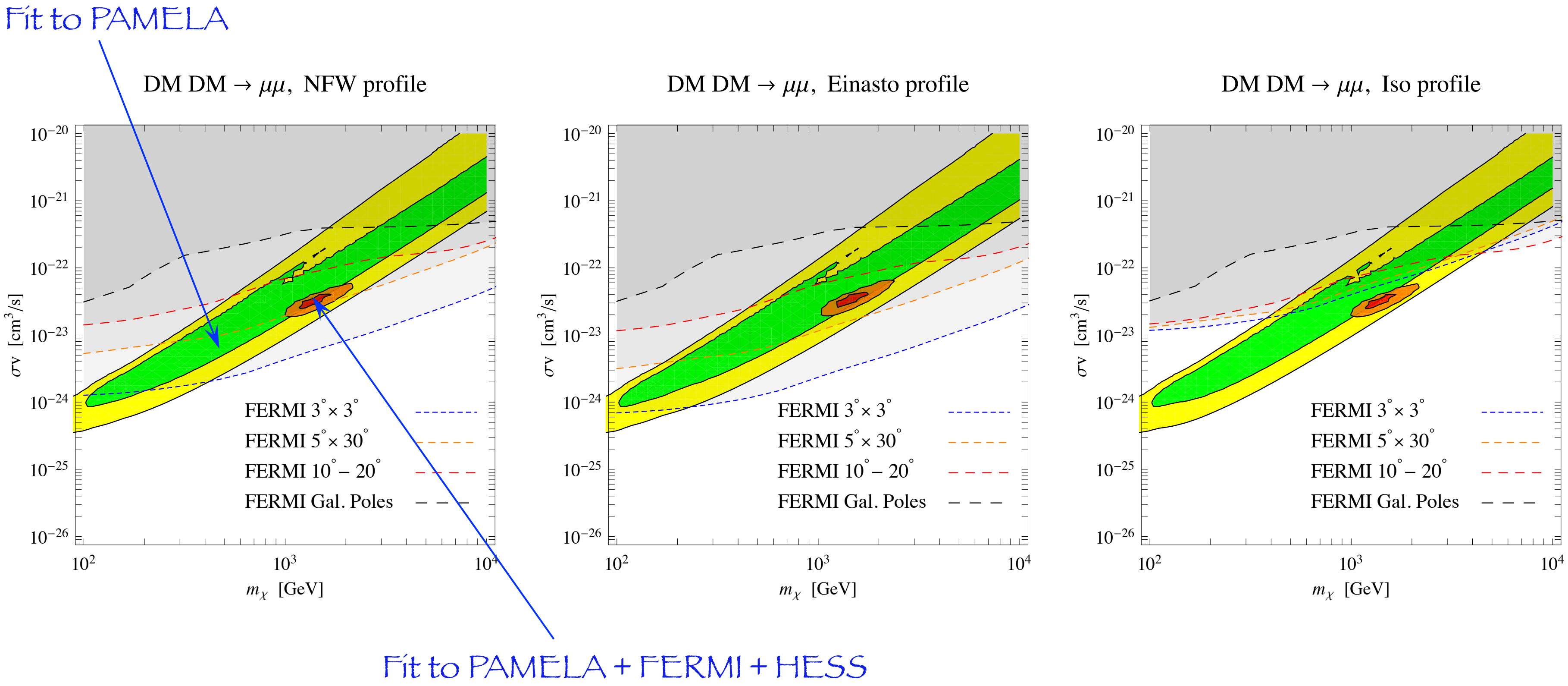



Large "boosts" are required

Leptonic production required (otherwise accompanied by too-many antiptotons, unless DM is very heavy)

M. Cirelli, M. Kadastik, M. Raidal, A. Strumia, arXiv:0809.2409v3 [hep-ph]

# Bounds from gamma rays




showering photons

IC gamma rays, from upscattering of ISRF photons by energetic e+/e- injected by DM

Cirelli, Panci, Serpico, NPB 840 (2010) 284

# Interpretation of leptonic CR data

- DM: problematic
  - Requires large boosts
    - Astrophysical: quite unlikely
    - Particle physics (Sommerfeld): somehow contrived, constrained
    - Cosmological: constrained, requires modified cosmology
  - Requires leptophilic DM: may be arranged, but not viable for most of the "canonical" DM candidate (neutralinos, sneutrinos)
  - Almost excluded by diffuse galactic gamma rays produced by IC

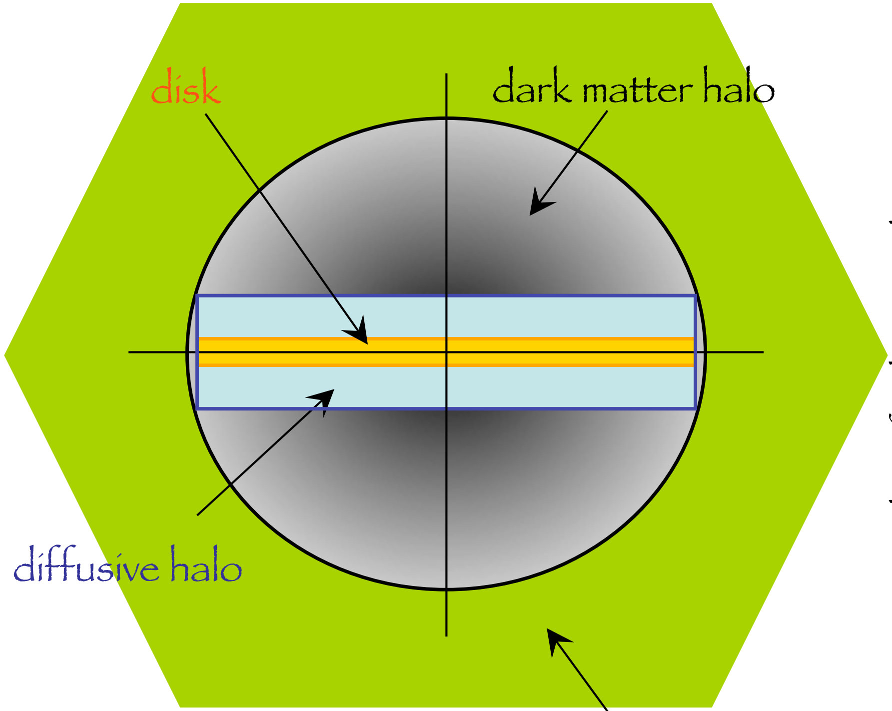
- Astrophysical interpetation
  - Pulsars and SNR may account for the excess
  - Energetics not fully understood, but consistent with models

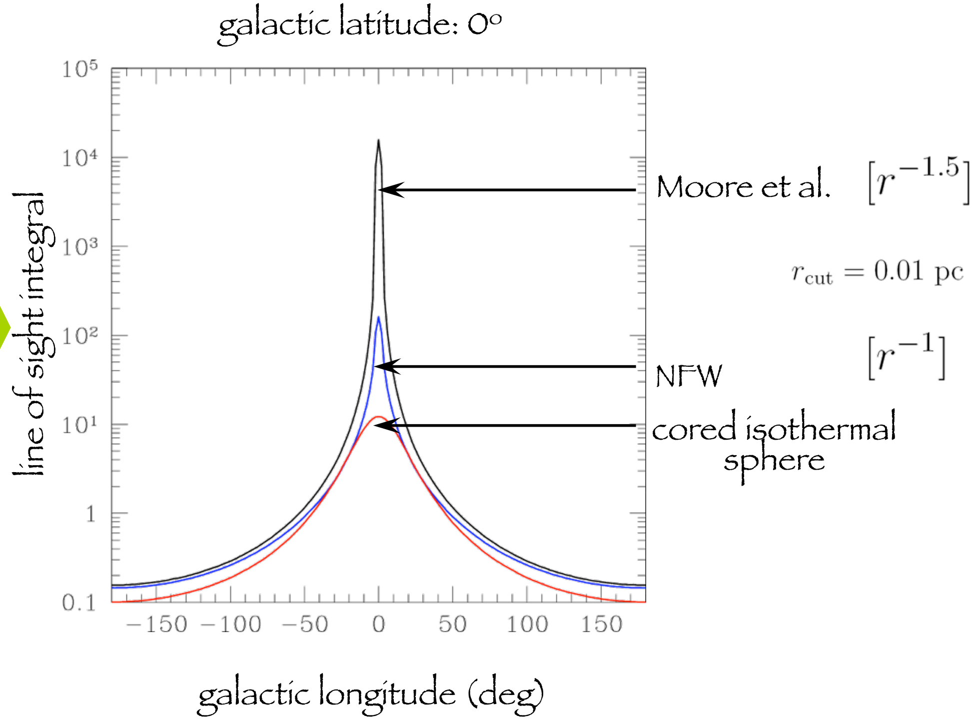
# Cosmic-ray leptons

- Large statistics, wide energy range data are available (FERMI, PAMELA, HESS, ...) and more to come soon (AMS)
- Fine structure in spectra may (expected to) emerge, especially at large energy (although interpretation in terms of presence/absence of DM will hardly be conclusive)
- Astrophysical interpretation (pulsars, SNR) currently more plausible (nevertheless remind that large uncertainties are present)
- If DM contribution to the flux is only subdominant, hard times for discovery
- Anisotropies?

# Gamma Rays

# Gamma-ray signal



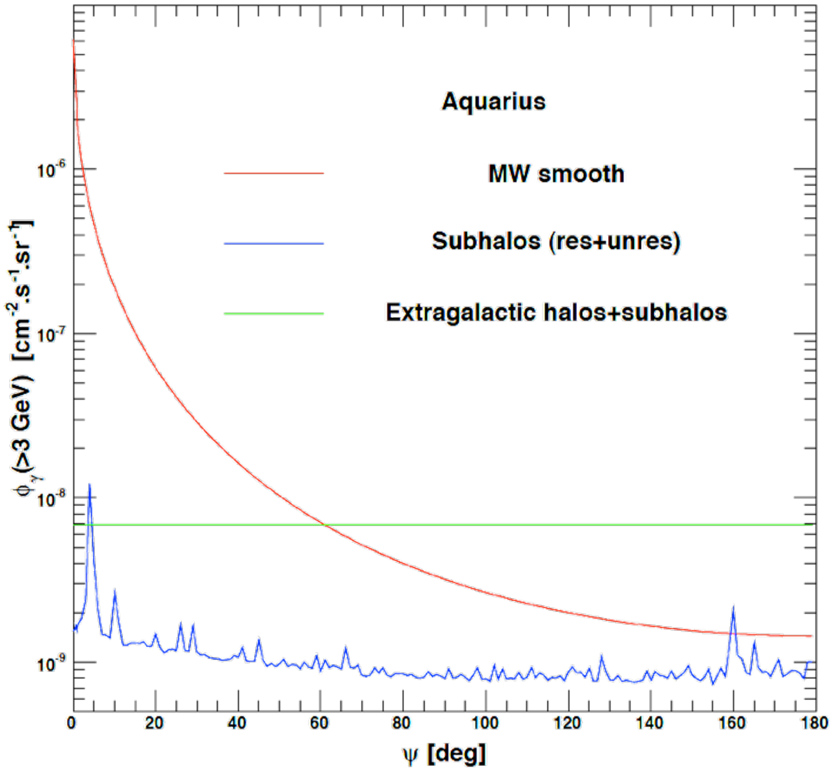




## DM signal

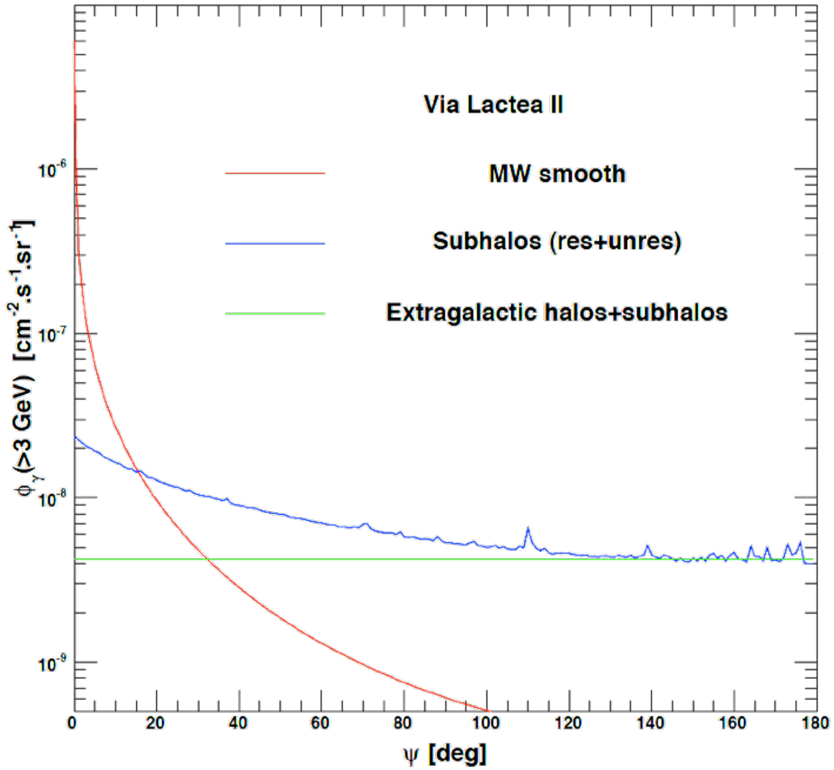
$$\chi\chi \longrightarrow (.....) \longrightarrow \gamma \quad \text{diffuse}$$
$$\chi\chi \longrightarrow [1\ loop] \longrightarrow 2\gamma \quad \text{line}$$

The flux is strongly dependent on the DM density profile

# Subhalos and extragalactic



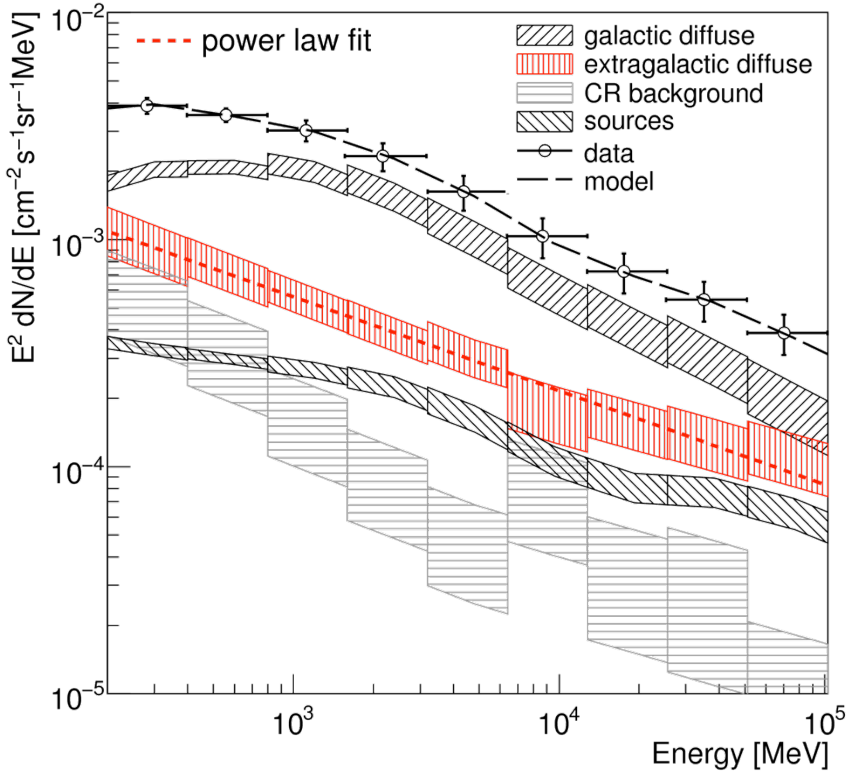

Angle from the GC

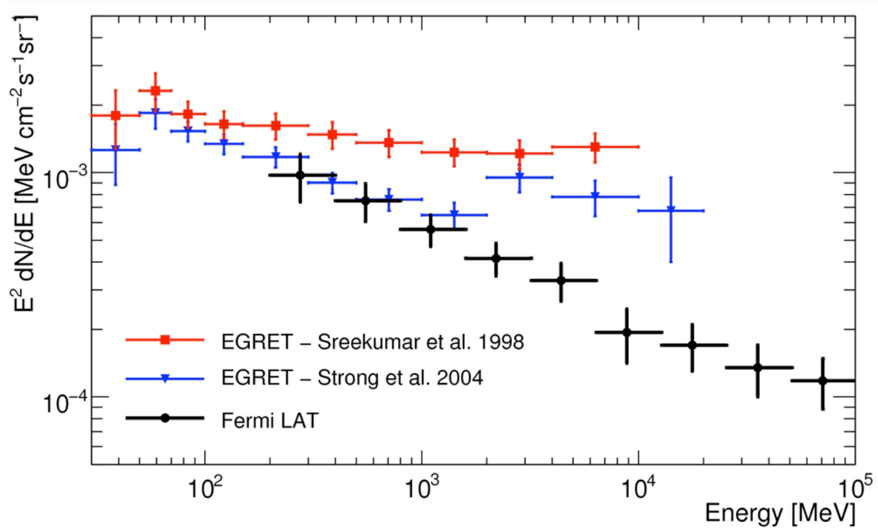



Angle from the GC

L. Pieri et al., arXiv:0908.0195 [astro-ph.HE]

# FERMI LAT data on gamma rays



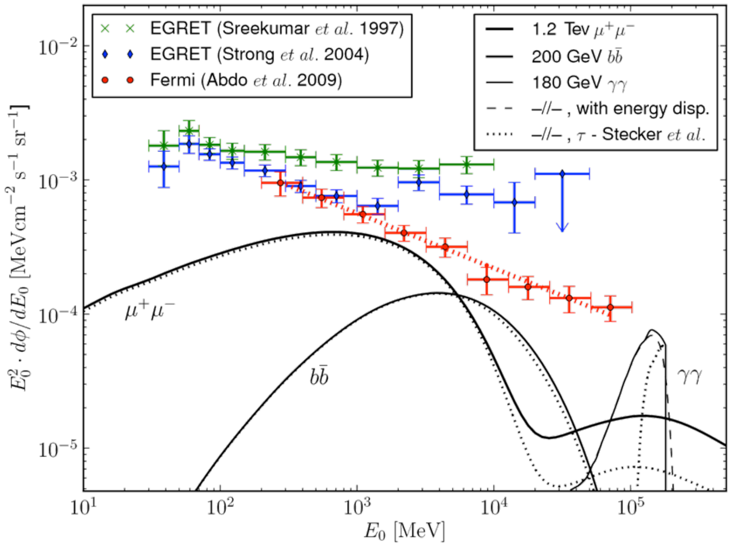



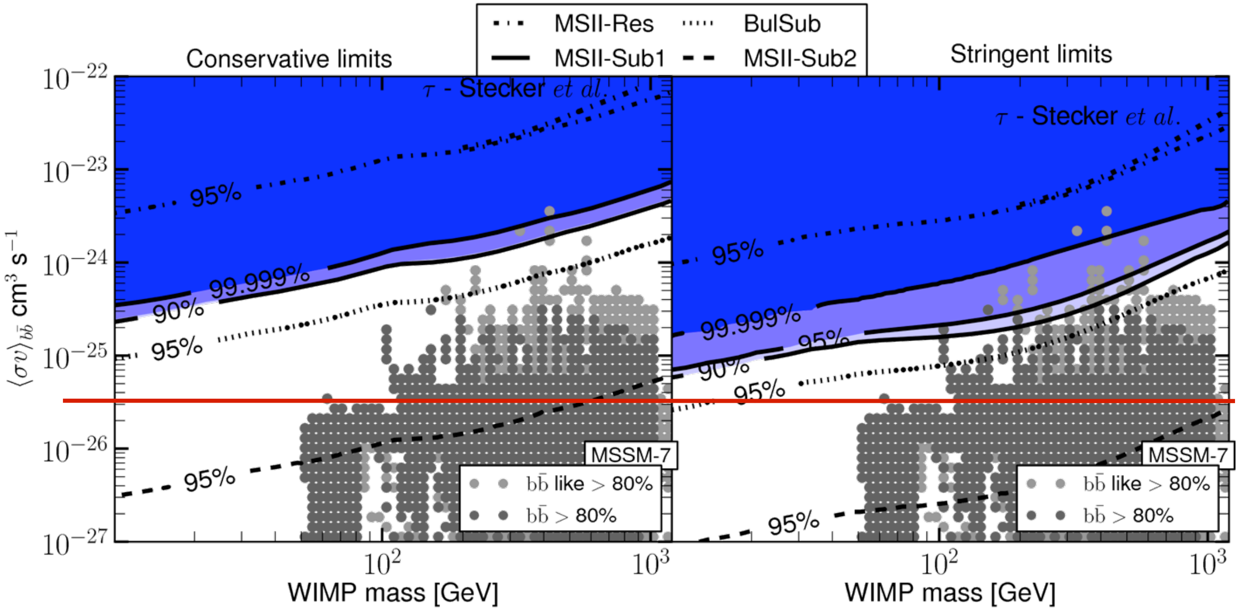

Gamma-ray intensity for |b|>10°

"Extra-galactic" diffuse emisson
Consistent with a single power-law

Abdo et al. , PRL 103 (2009) 251101

# Bounds on cosmological DM annihilation



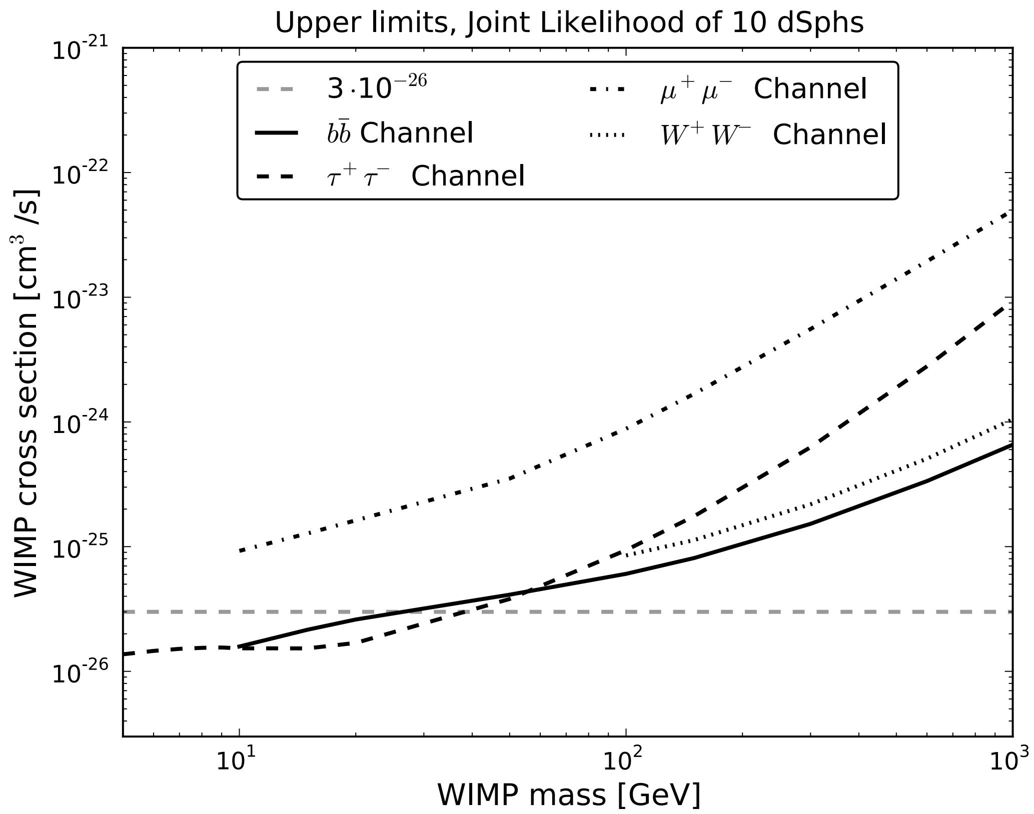




Abdo et al. , JCAP04 (2010) 014

# FERMI analysis on Milky-Way satellites

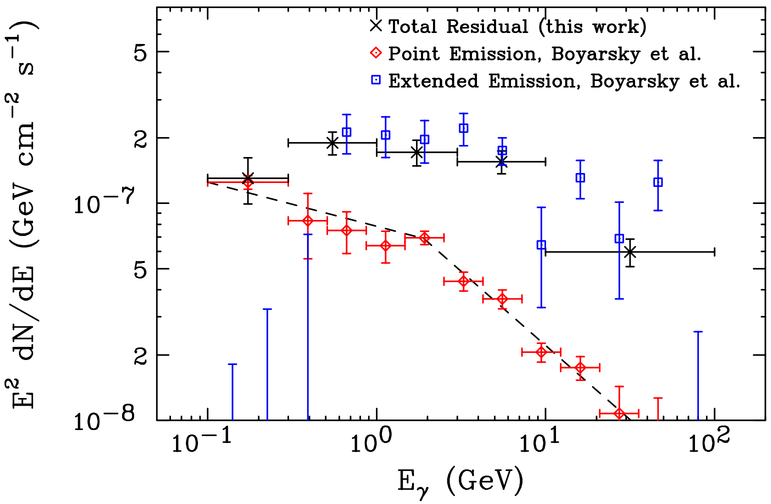
| Name | l | b | d | $\overline{\log_{10}(J)}$ | $\sigma$ |
| --- | --- | --- | --- | --- | --- |
| | deg. | deg. | kpc | $\log_{10}[\mathrm{GeV}^2\mathrm{cm}^{-5}]$ | |
| Bootes I | 358.08 | 69.62 | 60 | 17.7 | 0.34 |
| Carina | 260.11 | −22.22 | 101 | 18.0 | 0.13 |
| Coma Berenices | 241.9 | 83.6 | 44 | 19.0 | 0.37 |
| Draco | 86.37 | 34.72 | 80 | 18.8 | 0.13 |
| Fornax | 237.1 | −65.7 | 138 | 17.7 | 0.23 |
| Sculptor | 287.15 | −83.16 | 80 | 18.4 | 0.13 |
| Segue 1 | 220.48 | 50.42 | 23 | 19.6 | 0.53 |
| Sextans | 243.4 | 42.2 | 86 | 17.8 | 0.23 |
| Ursa Major II | 152.46 | 37.44 | 32 | 19.6 | 0.40 |
| Ursa Minor | 104.95 | 44.80 | 66 | 18.5 | 0.18 |

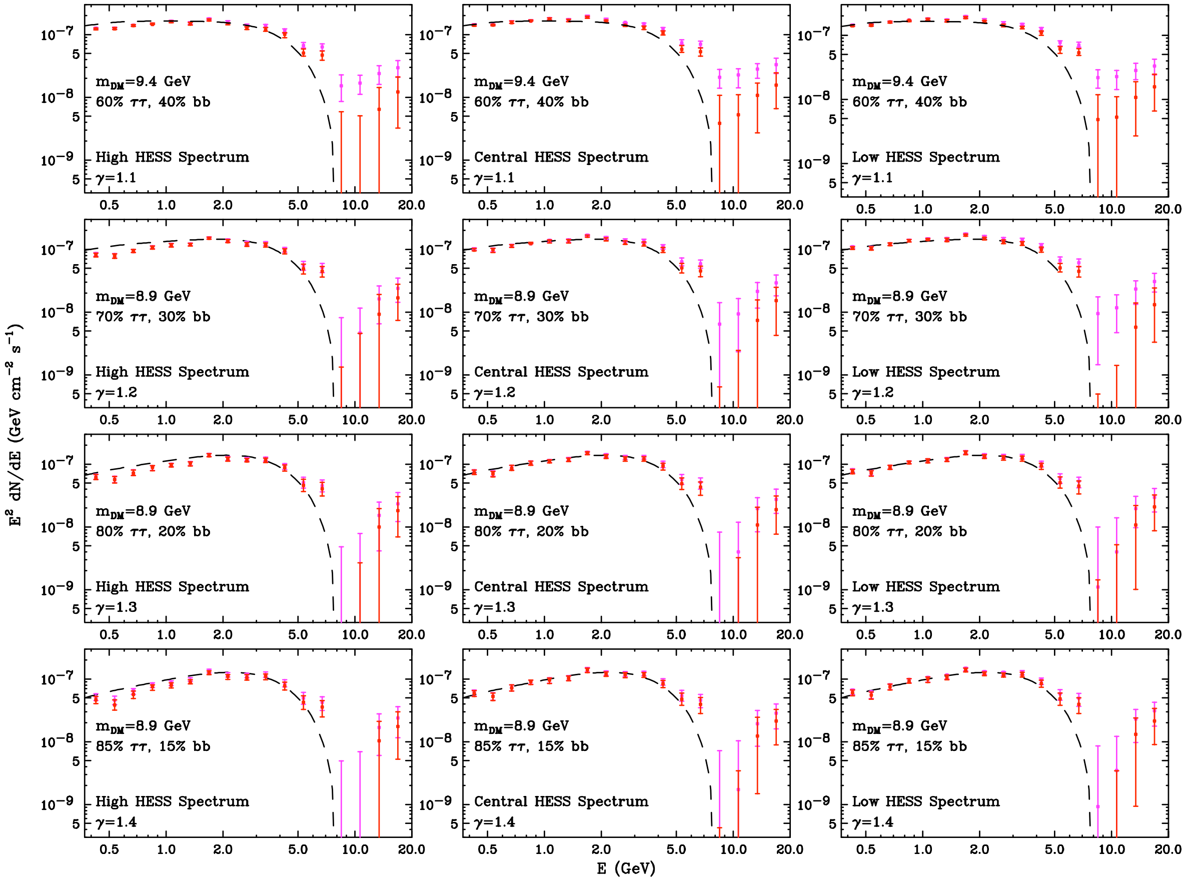
joint likelihood analysis to 10 satellite galaxies




Ackermann et al., arXiv:1108.3546
See also: Geringer-Sameth, Koushappas, arXiv:1108.2914

# FERMI-LAT excess toward the GC ?




[1] Hooper, Goodenough, PLB (2011) 697 (2011)
[1] Hooper, Linden, PRD 84 (2011) 123005

[2] Boyarsky, Malyshev, Ruchayskiy, PLB (2011) 705

[1] Spatially extended emission toward the GC
Compatible with 7-12 GeV DM (annihilation into leptons)
25-45 GeV DM (annihilation into hadrons)

[1] Compatible also with collisions of high-E protons accerated by the SMBH with gas

[2] Consistent with diffuse emission from point sources (with different spectrum from [1])

# Gamma-rays structure in clusters?

- Extended gamma-ray emission from the Virgo, Fornax and Coma
- Excess emission within three degrees of the center, peaking at the GeV scale
- Not accounted for by known Fermi sources or by the galactic and extragalactic backgrounds

- Compatible with: 2-10 GeV ot > 1 TeV DM (annihilating to leptons)
  20-60 GeV DM (annihilating to hadrons)

- Potentially compatible with the GC-extended emission

- CR induced gamma-rays can account for it, with a lower significance than for DM

- In any case, very weak hint

Han, Frenk, Eke, Gao, White, arXiv:1201.1003

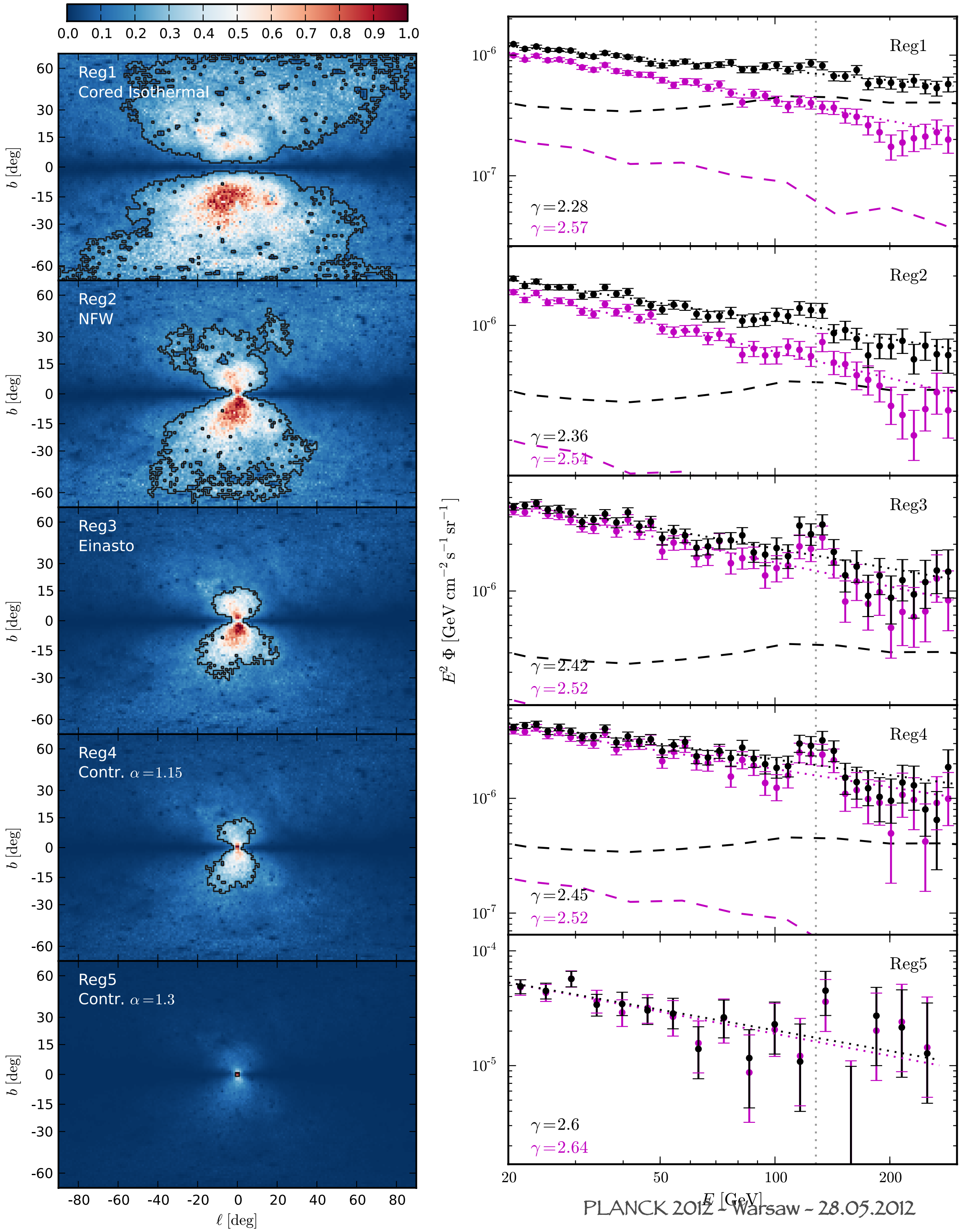
# Gamma-ray line ?

4.6 sigma (3.3 sigma with LEF) indication for a line feature at 130 GeV photon energy

evidence based on 50 photons

For annihilating DM implies:

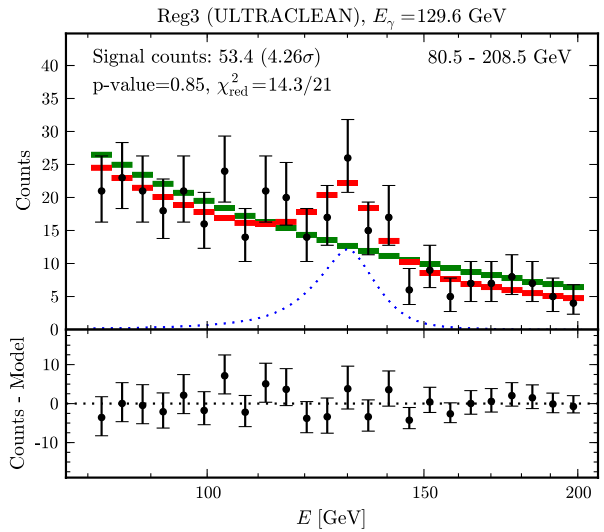
mass of about 130 GeV
annihilation cross section of
$1.27 \times 10^{-27}$ cm$^3$ s$^{-1}$



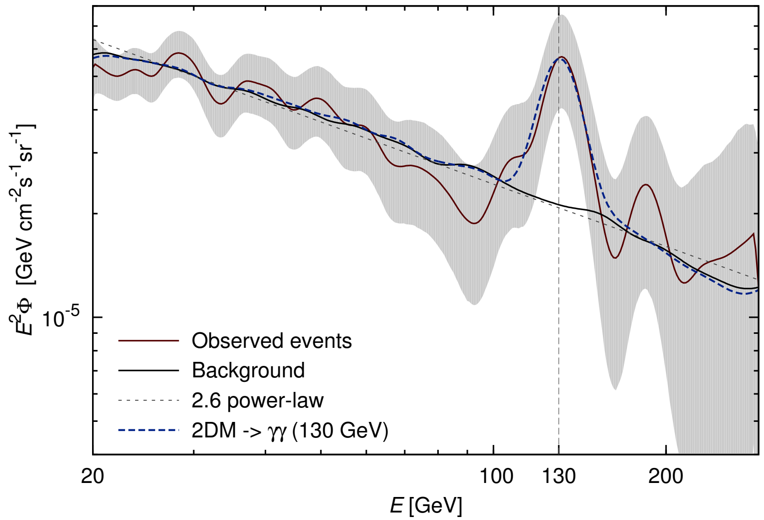

Weniger, arXiv:1204.2797
See also: Bringman et al. arXiv:1203.1312

# Gamma-ray line ?

Weniger, arXiv:1204.2797




Tempel, Hektor, Raidal, arXiv:1205.1045




Spatial target regions optimize S/N for specific DM profiles

Best evidence for Einasto profile

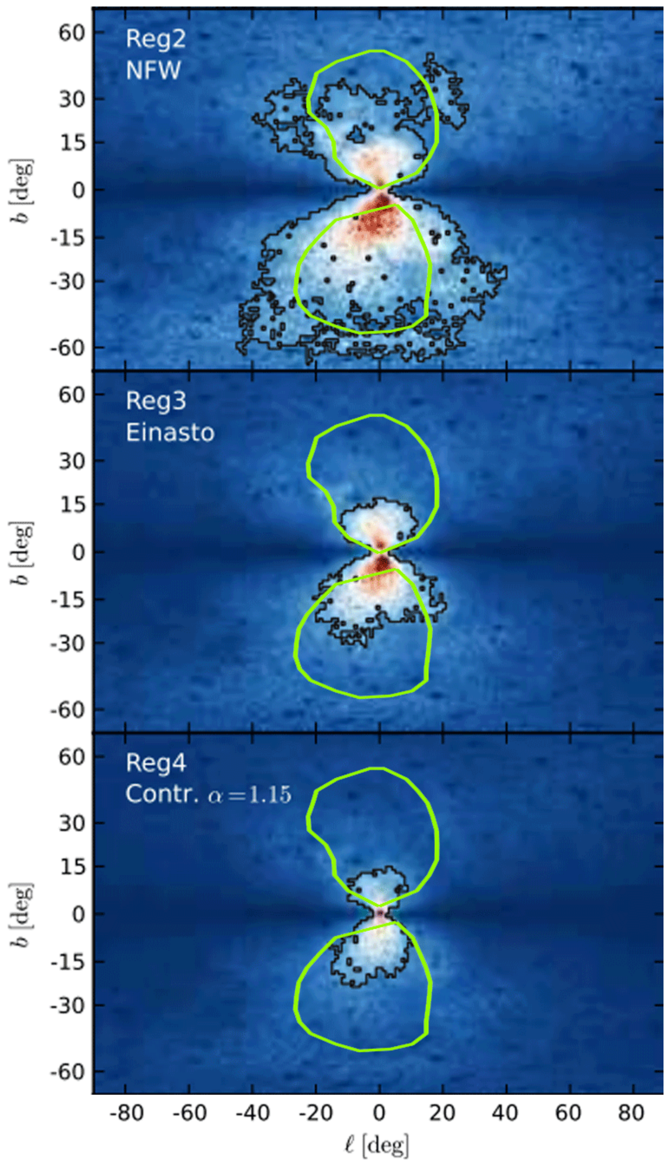
Data-driven spatial target regions

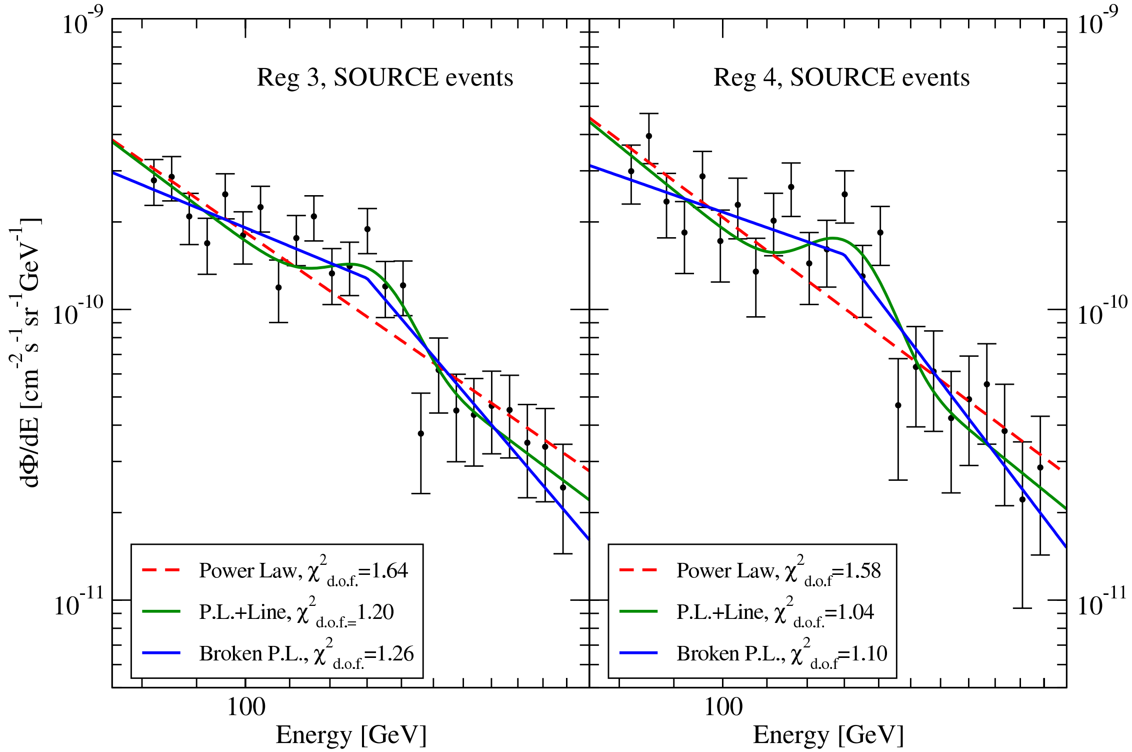
The excess originates from relatively small disconnected regions, the most important relevant being the GC

Target regions may indicate DM clumps

Very sharp spectral feature: "true" line, excludes internal bremsstrahlung

# Gamma-ray line?




- target regions vastly overlap with the region corresponding to the "FERMI bubbles"
- the line feature could refer to hard photons in the FERMI bubbles regions, where the gamma-ray spectrum has a spectral break at (100 – 150) GeV

# Gamma rays

- High quality data in a wide energy range available (FERMI, HESS, ...), both on resolved and unresolved sources (diffuse background)

- Galactic and extragalactic modelling under deep scrutiny: bounds on DM improving fast

- Dwarph-spheroidals (as DM dominated systems) are offering a very good opportunity for DM investigation

- Anisotropy may allow to study DM substructures

# Multi-wavelength signals

# Multiwavelength emission

From the interaction of electrons/positrons with the (extra)galactic environment:

Synchrotron emission on magnetic fields: from radio to X-ray band

Inverse Compton on radiation fields (CMB, stellar): X-rays, gamma-rays

For:

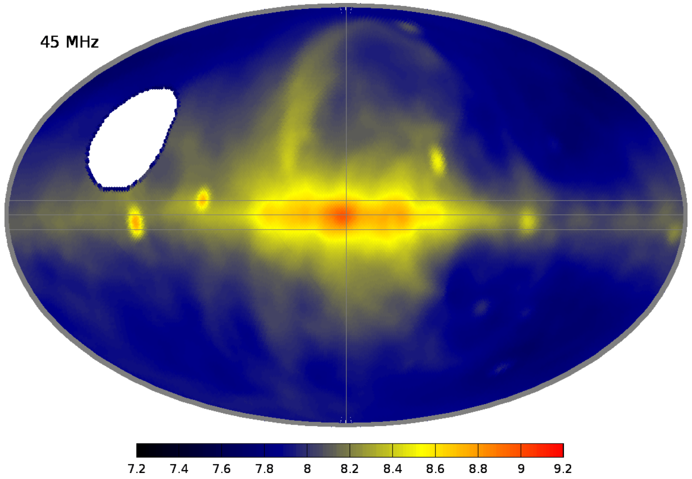
magnetic field intensity of O(microG) (like in the case of our galaxy

electrons/positrons of GeV-TeV energies (like those produced by WIMP DM)

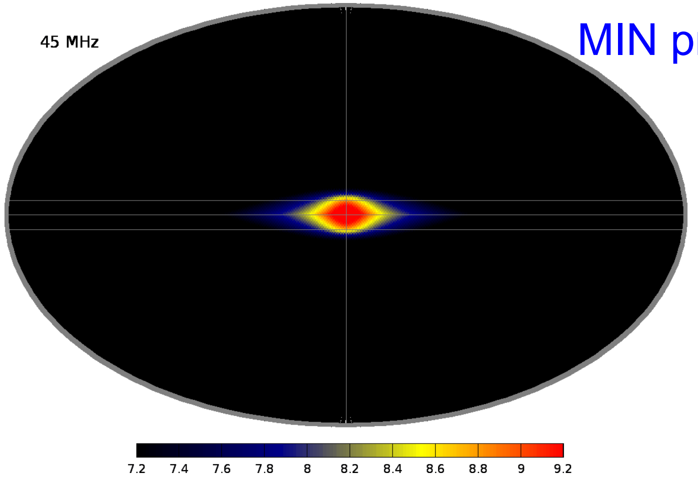
the synchrotron emission falls in the MHz-GHz range (radio band)

# Radio sky at 45 Mhz

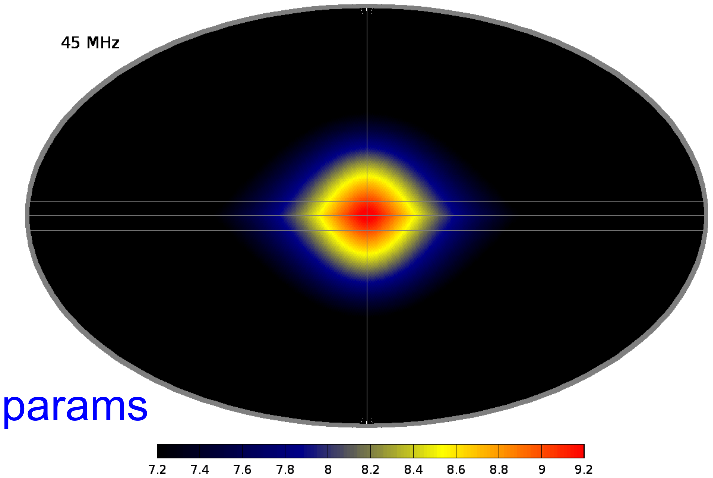
observed

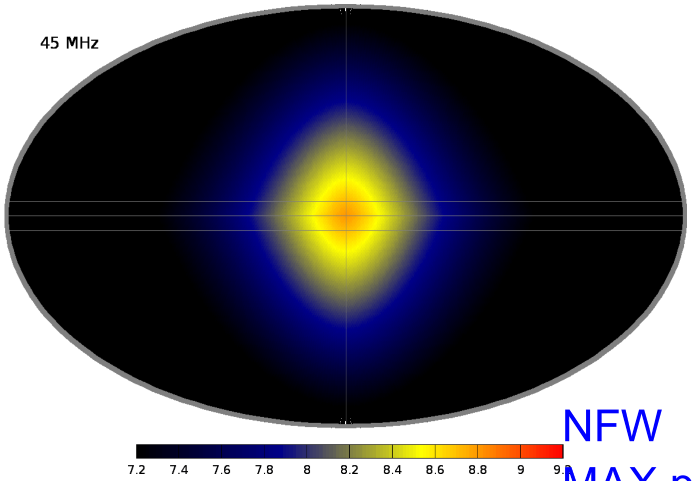



NFW
MIN propag params




NFW
MED propag params




NFW
MAX propag params

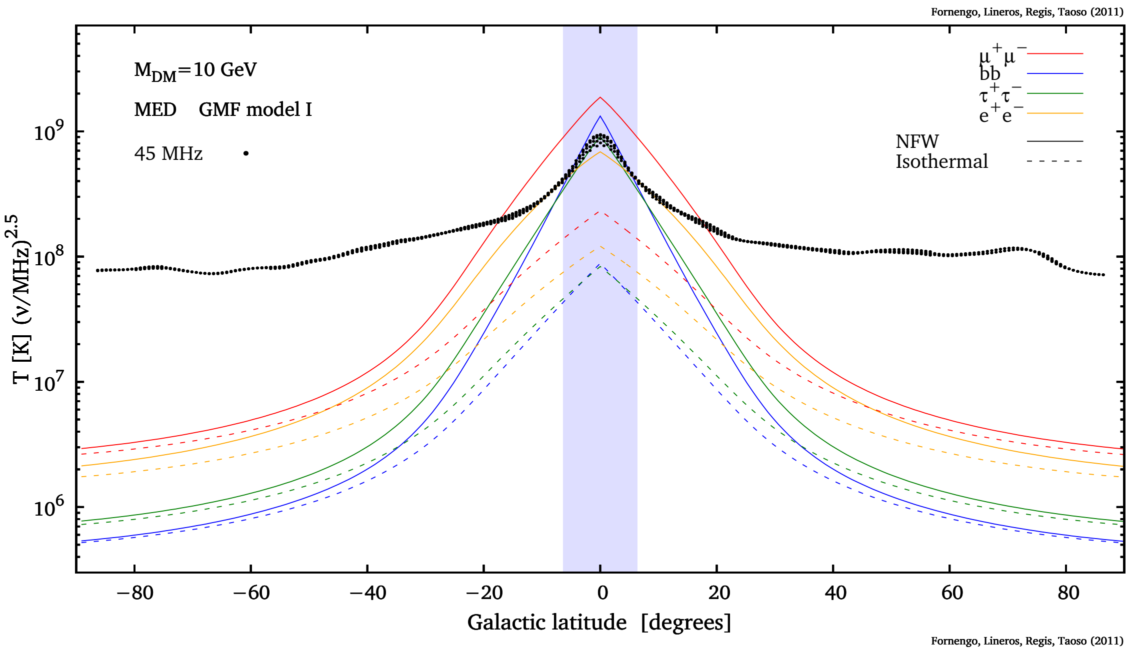
10 GeV DM
Annihilation into muon with thermal cross section
Exp decaying B(r,z) with $B_{TOT}$ = 10 microG

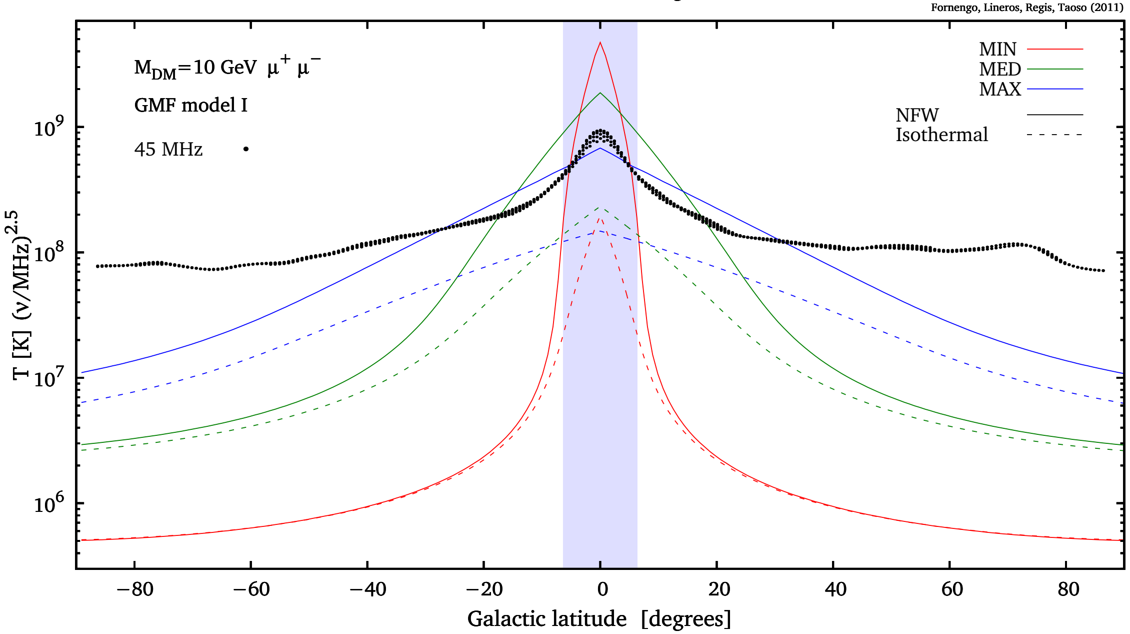
NF, Lineros, Regis, Taoso, arXiv:1110.4337

# Galactic radio signal

45 MHz

Data: |l| < 3°
DM models: l = 0°



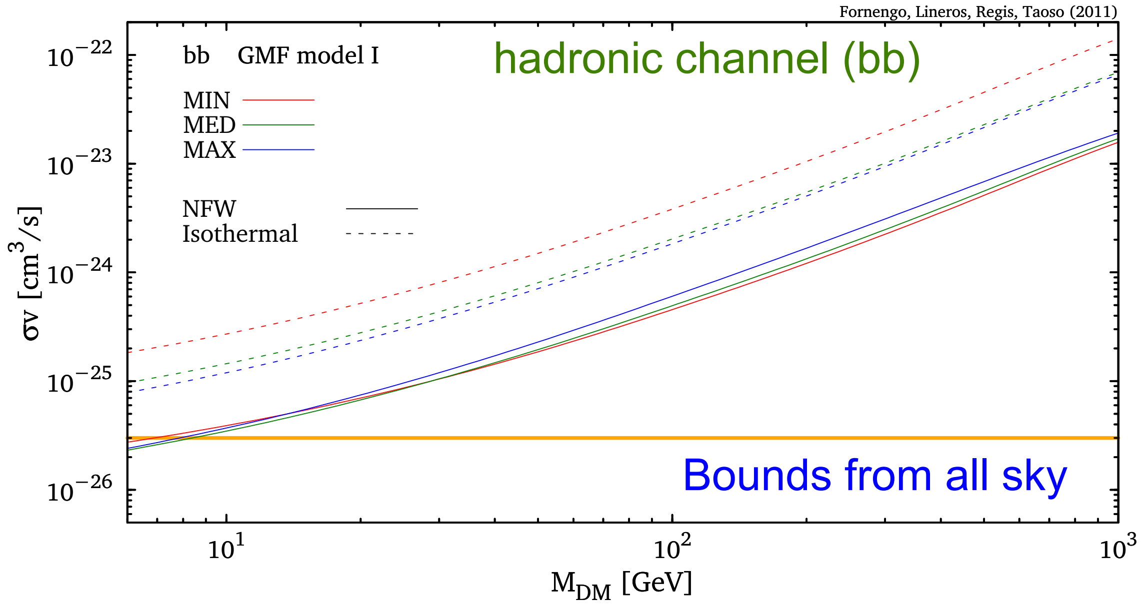



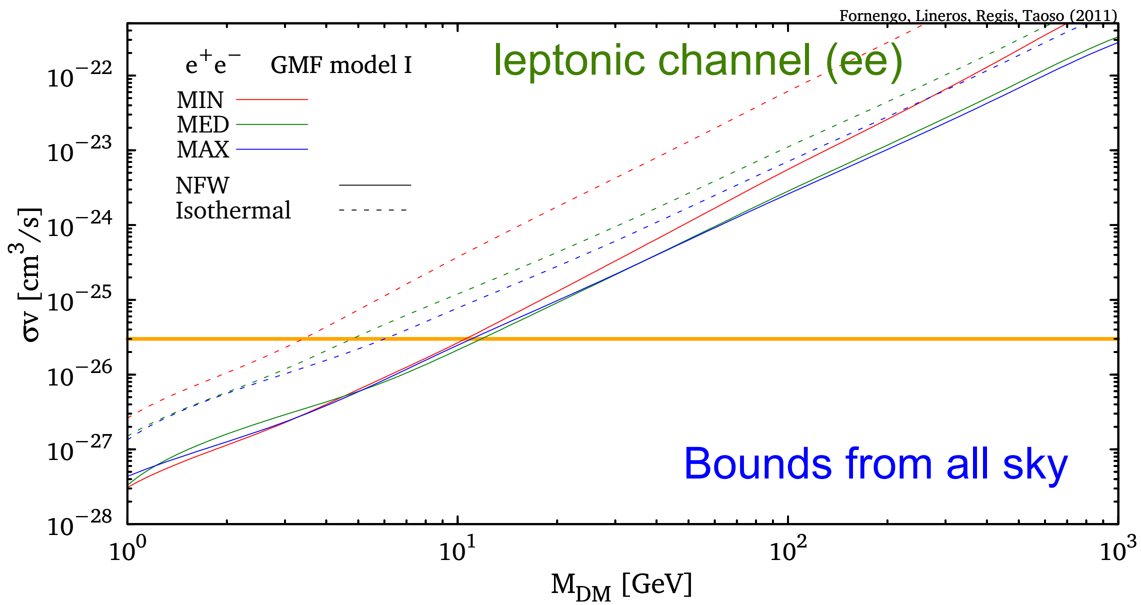

NF, Lineros, Regis, Taoso, arXiv:1110.4337

# Galactic radio signal

45 MHz

Bounds from all sky

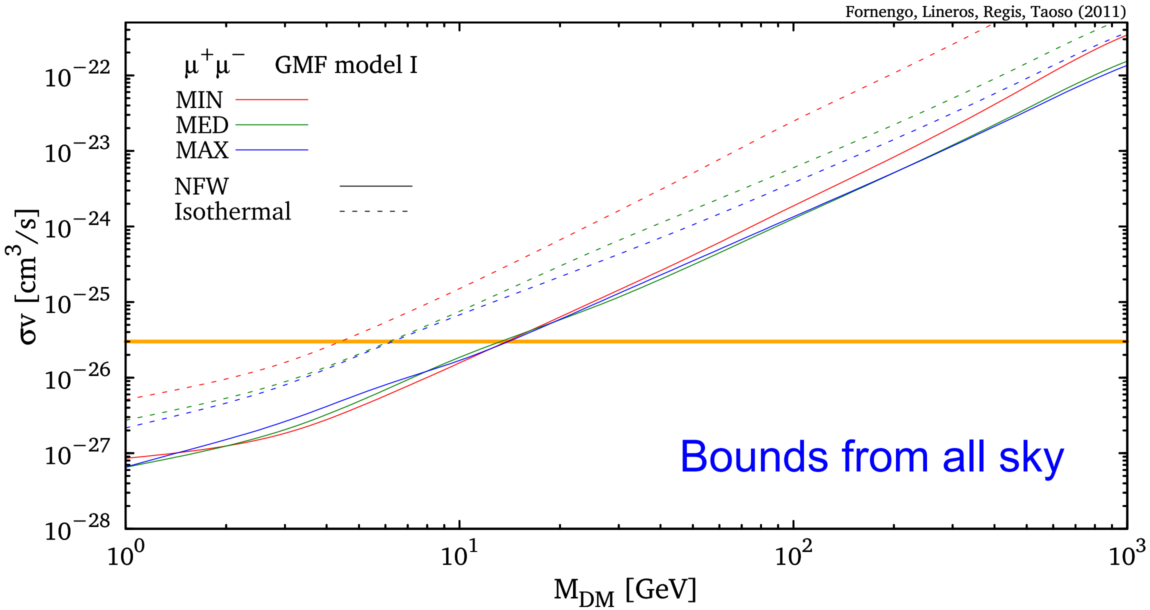


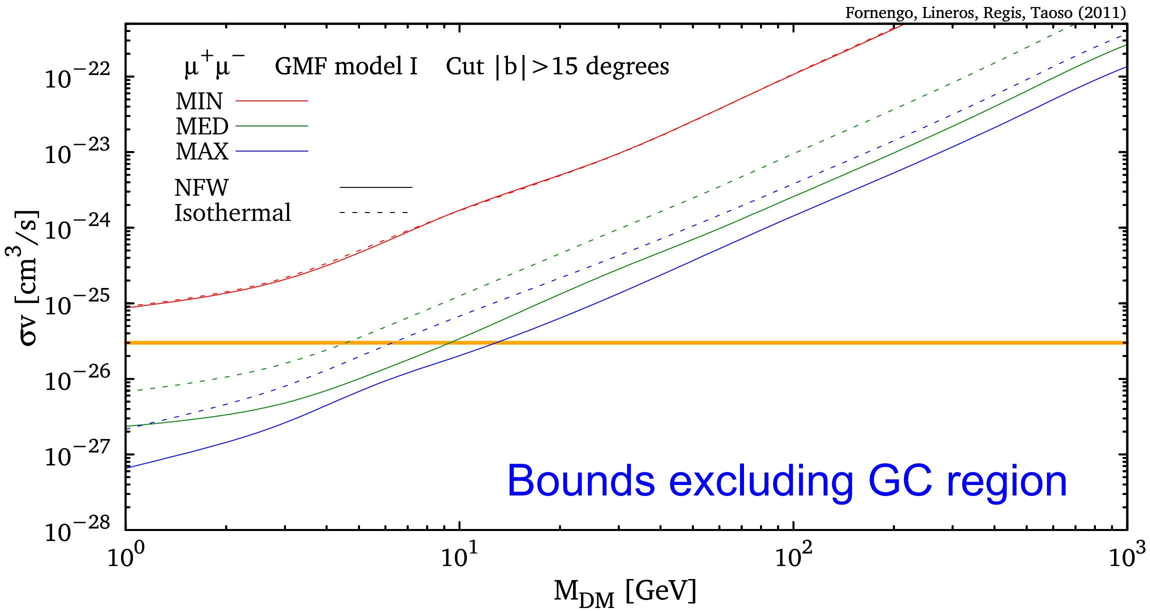




NF, Lineros, Regis, Taoso, arXiv:1110.4337

# Galactic radio signal

45 MHz

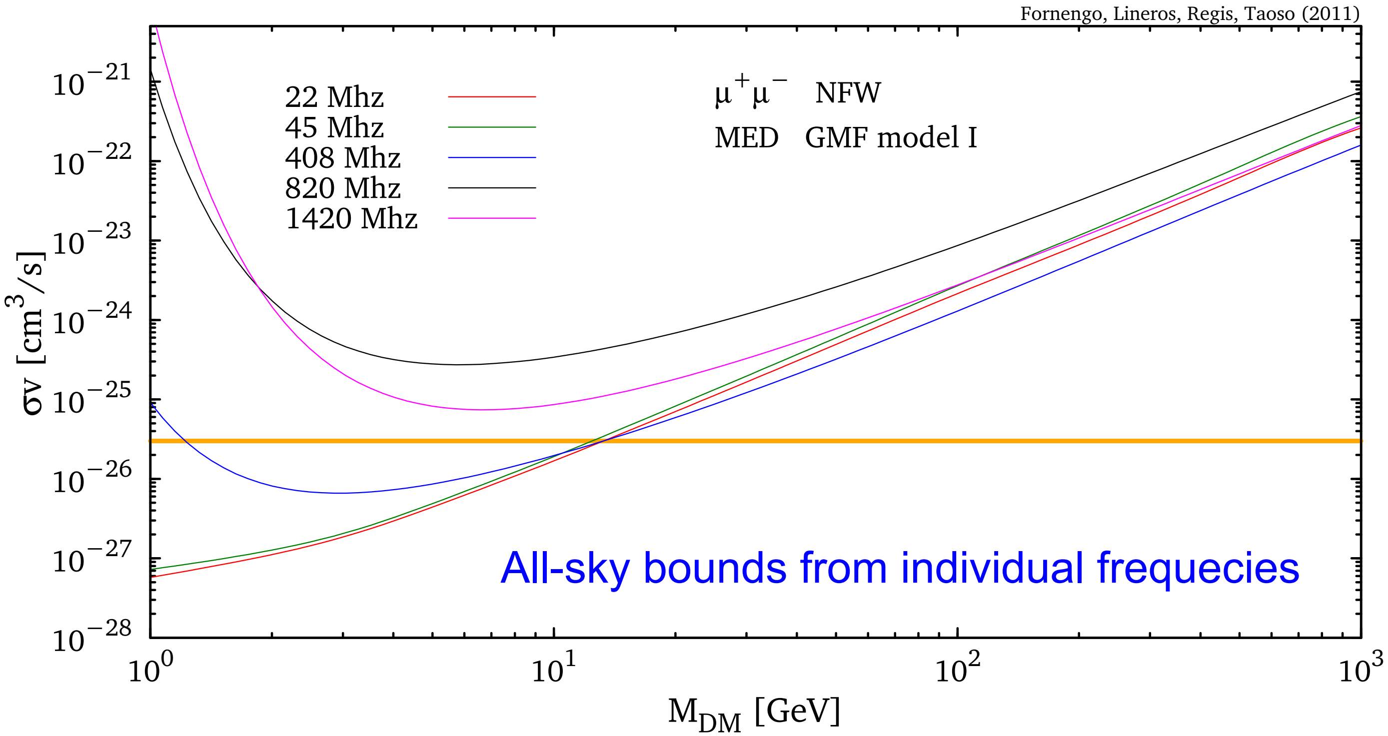



NF, Lineros, Regis, Taoso, arXiv:1110.4337

# Galactic radio signal

| $\nu$ [MHz] | Survey | rms noise [K] |
|---|---|---|
| 22 | DRAO | 5000 |
| 45 | Guzman et al. | 3500 |
| 408 | Haslam et al. | 0.8 |
| 820 | Dwingeloo | 1.4 |
| 1420 | Stockert | 0.02 |




NF, Lineros, Regis, Taoso, arXiv:1110.4337

# ARCADE excess

- After subtraction of an isotropic component, ARCADE reports a remaining flux (interpreted as extragalactic) 5-6 times larger than the total

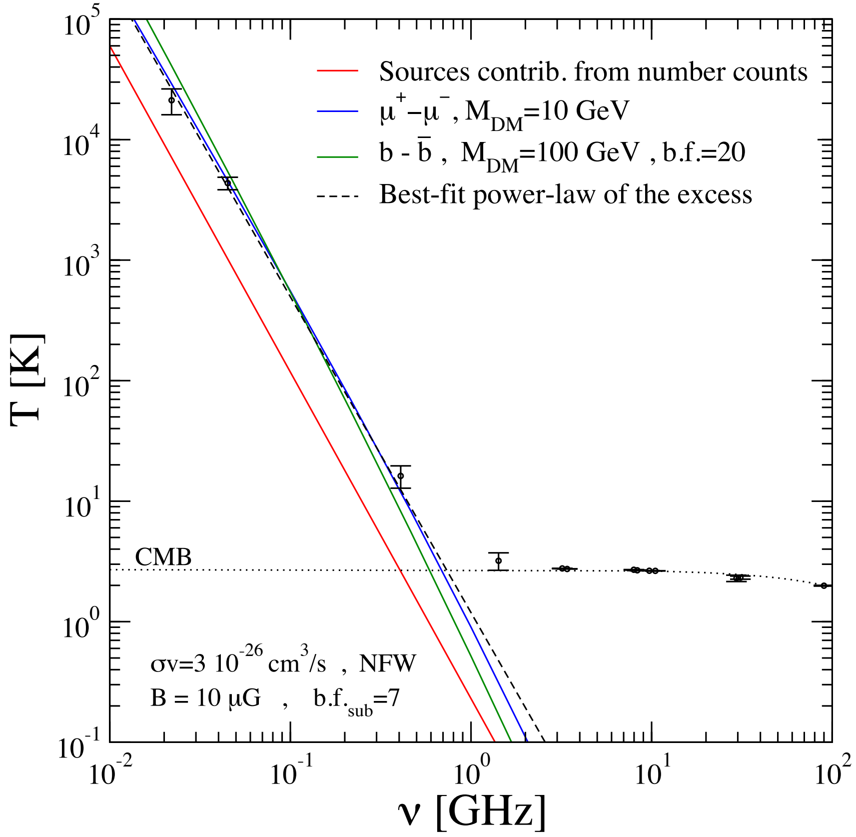
ARCADE:
Singal et al., Astrophys. J. 730 (2011) 138
A. Kogut et al., Astrophys. J. 734 (2011) 4

- Contribution from detected extragalactic radio sources

- Extrapolating the source number counts to lower (unreached) brightness, the excess remains

- Systematics effects and galactic sources seems excluded

- Such a level of radio extragactic emission does not appear to have an immediate explanation in terms of standard astrophysical scenarios,, expecially when multiwavelength constraints are applied

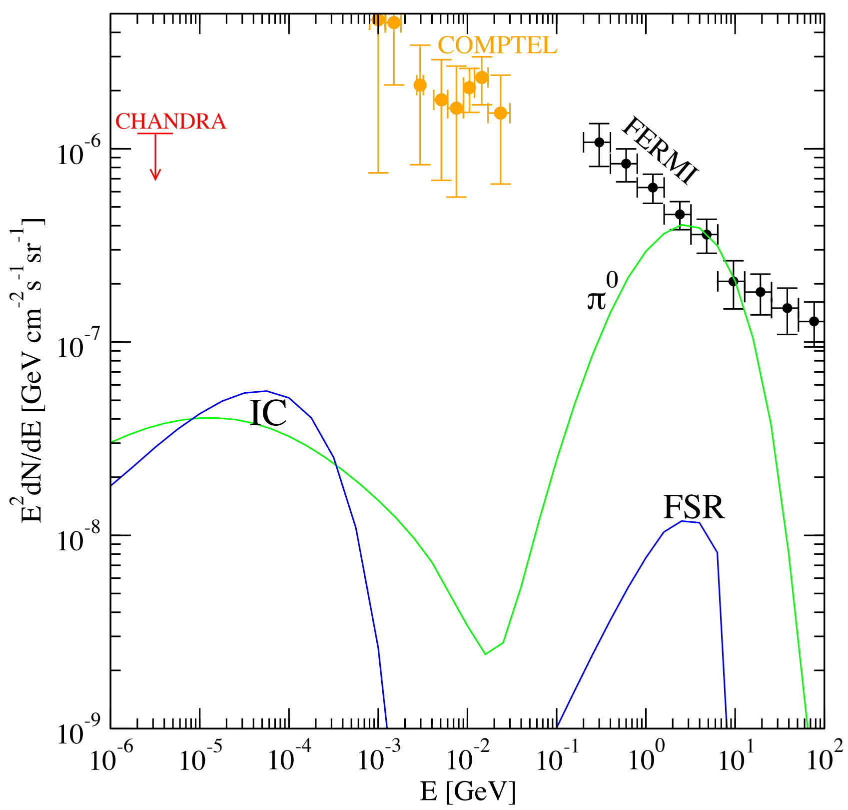



Fornengo, Lineros, Regis, Taoso, PRL 107 (2011) 27

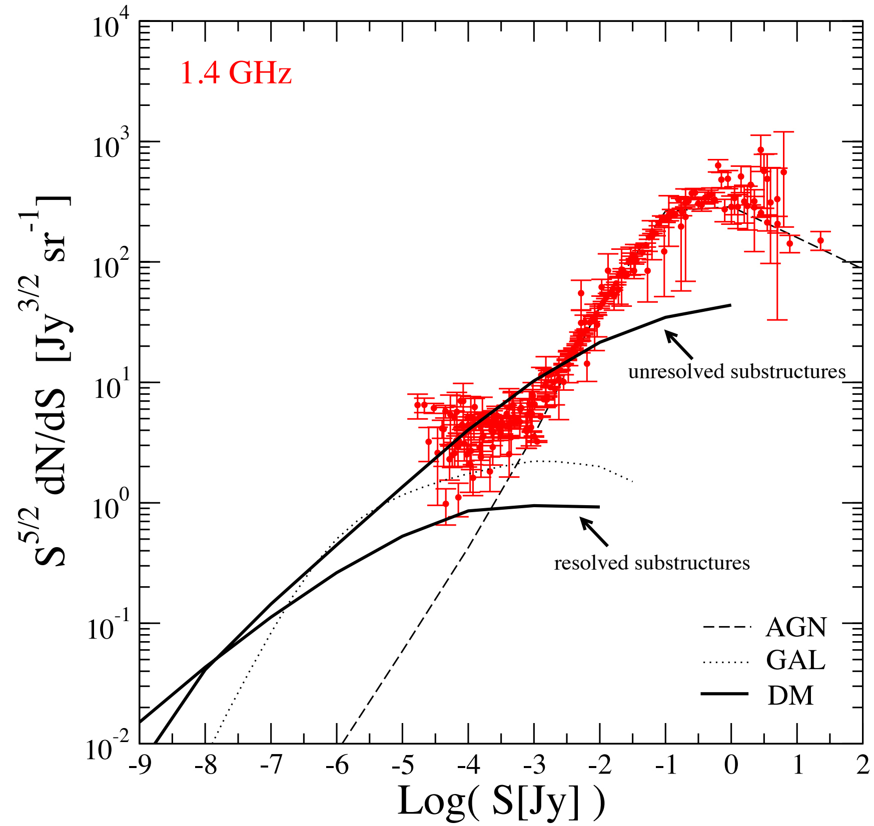
DM can easily explain the excess without special fine tunings
(Slight) preference for light (around 10 GeV) and leptophilic DM

# ARCADE excess

## corresponding multiwavelength signals




## differential number counts




Fornengo, Lineros, Regis, Taoso, PRL 107 (2011) 27

See also: Hooper et al., arXiv:1203.3547

# Further stories

- Neutrinos as DM messengers
  - From the GC: typically correlate with gamma-rays, low detection rates
  - From Earth and Sun: potentially detectable, irreducible background given by atm neutrinos (down-going nu-tau a prosiming channel?) Fornengo, Niro, JHEP 11 (2011) 24
- WMAP haze: excess of microwave emission at GC [?] Finkbeiner, Ap. J. 614 (2004) 186
  - Spherical, radius 4 Kpc
  - Synchrotron emission from electron component?
- FERMI haze: excess of gamma-ray emission at GC [?] Finkbeiner et al.,rarXiv:0910.4583
  - Inverse Compton counterpart of the WMAP haze?
- Sunyaev-Zeldovich effect on CMB in galaxy clusters
  - Very small effect, but prospects for the future Colafrancesco, AA 422 (2004) L23
- Recombination and CMB
  - May pose significant limits for light DM

Galli, Iocco, Bertone, Melchiorri, PRD 80 (2010) 023505; PRD 84 (2011) 027302
Zhang, Chen, Lei, Si, PRD 74 (2006) 103519 (2006)
Zhang, Chen, Kamionkowski, Si, Zheng, PRD 76 (2007) 061301

- Anisotropies in the gamma and radio sky
  - May probe DM substructures

Ando, Komatsu, PRD 73 (2006) 023521; PRD 75 (2007) 063519
Hensley, Siegal-Gaskins, Pavlidou, ApJ 723 (2010) 277
Siegal-Gaskins, Pavlidou, PRL 102 (2009) 241301
Ackerman et al., arXiv:1202.2856

Zhang, Sigl, JCAP 0809 (2008) 027
Fornengo, Lineros, Regis, Taoso, JCAP 03 (2012) 33

# Conclusions

- Astrophysical signals offer a wide range of opportunities toward the identification of dark matter as an elementary particle
- At the same time, they have to cope with (typically) dominating, uncertain and sometimes even unknown astrophysical backgrounds
- For each type of signal, the two components (signals and backgrounds) cannot be studied independently (they have different origin, but they typically share the same physical processes in the astrophysical environment – only exception: direct searches)
- Whenever possibile, exploit specific signatures (e.g. annual modulation in direct detection; antideuterons at low energies; line in gamma-rays)
- The large set of available observables, and the rapid progress both in theoretical ideas and experimental capabilities, are offering an integrated approach with great potentialities – STAY TUNED!