AMS Italia 30/11/2011

Recent Results in 0.1 GeV-10 TeV Cosmic Rays Physics and AMS-02 Dark Matter Search: opportunities in hadronic channels

Nicolo' Masi
Bologna University and INFN

- DM HALO AND CR PROPAGATION MODELS: FLUX UNCERTAINTIES
- PAMELA AND FERMI: DM LEPTONIC AND PHOTONIC SIGNATURES
- HADRONIC SIGNALS: ANTIPROTON AND ANTIDEUTERON FLUXES
- DARK MATTER AND AMS-02: GOOD CANDIDATES UPDATE
- ALTERNATIVES AND CONCLUSIONS

DM halo and CR Propagation

DM Halo Candidates: Isothermal, three parameters spherical halo (NFW, Moore, Cored isothermal), Burkert, Einasto… - function of α, β, γ, a **astrophysical/gravitational parameters and solar system ones,** $r_\odot$ **and** $\rho_\odot$

$$\rho(r) = \rho_\odot \left(\frac{r_\odot}{r}\right)^\gamma \left[\frac{1+(r_\odot/a)^\alpha}{1+(r/a)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

Spherical Generic DM Halo

CR Propagation Models with DM: Steady-state Parker Equation with a primary flux source term

$$Q(T,\vec{r}) = \frac{1}{2}\frac{\rho^2(\vec{r})}{m_\chi^2}\sum_f \langle\sigma v\rangle_f \frac{dN^f}{dT}$$

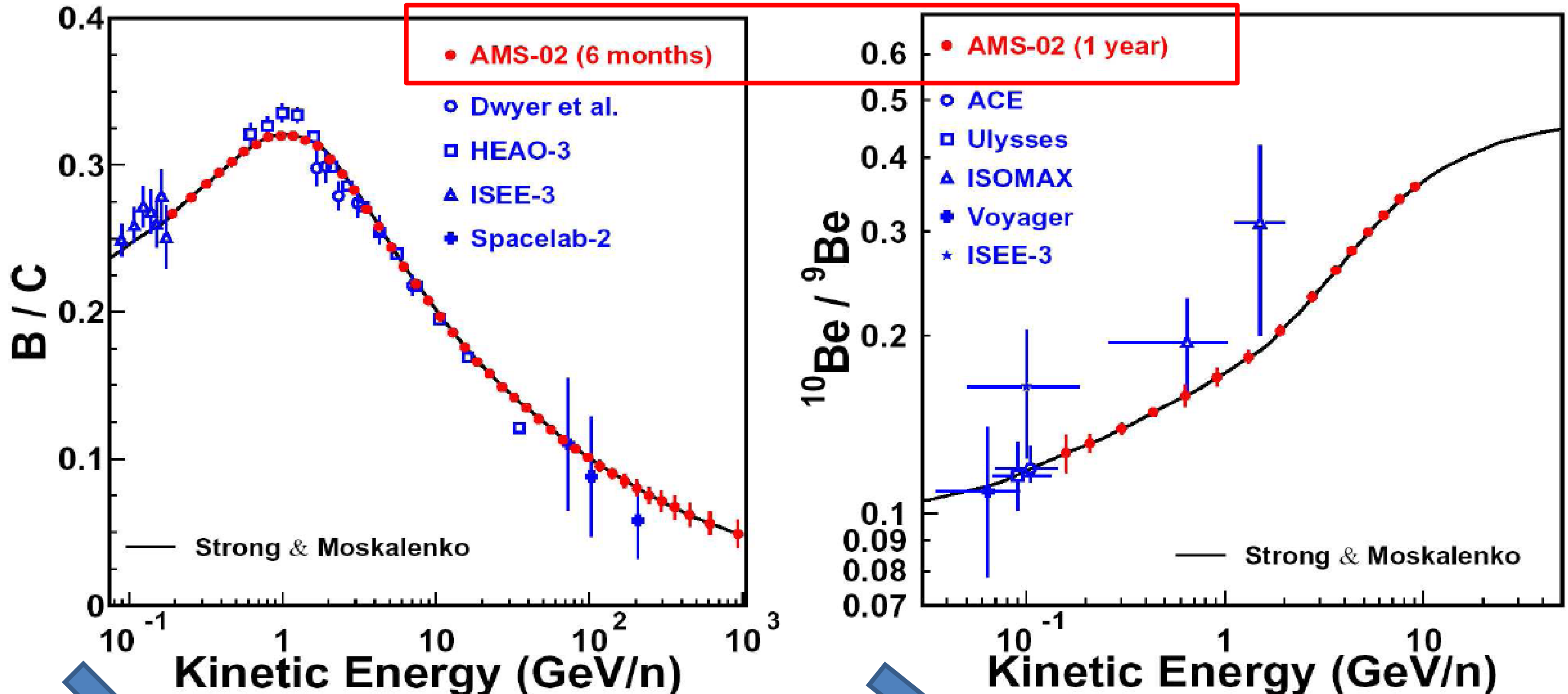
DM Flux Source

Propagation Parameters From B/C and Be Isotopes Measures

Case	δ	K_0 (kpc^2/Myr)	L (kpc)	V_c (km/s)	V_A (km/s)	$\chi^2_{B/C}$	r_w (kpc) [1 GeV/10 GeV]	r_{sp} (kpc) [1 GeV/10 GeV]
max	0.46	0.0765	15	5	117.6	39.98	29.0/73.0	26.0/57.0
med	0.70	0.0112	4	12	52.9	25.68	2.4/9.2	4.4/15.0
min	0.85	0.0016	1	13.5	22.4	39.02	0.33/1.8	0.69/3.1

CR Propagation Constraint

Sapinski - Comsic Ray Astrophysics with AMS-02 Experiment



Average grammage (traversed matter)

Average residence time in the Galaxy

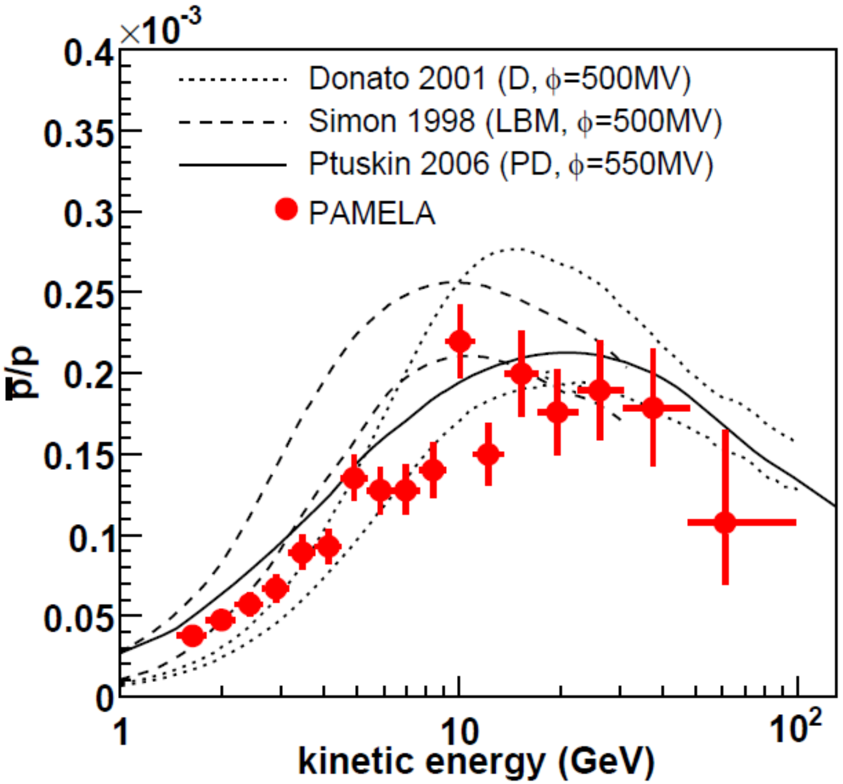
Light nuclei ratios to fix the propagation parameters and improve the accuracy of GALPROP, DRAGON and friends

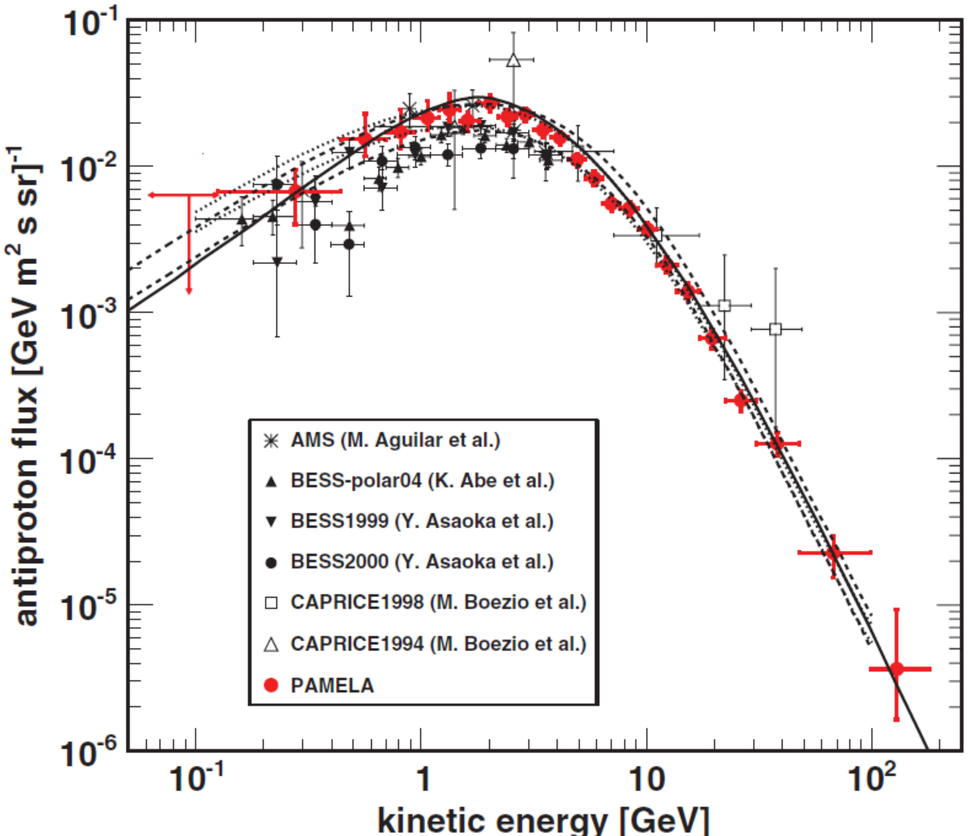
PAMELA & FERMI

PAMELA

PAMELA results on the Cosmic-Ray Antiproton Flux from 60 MeV to 180 GeVin Kinetic Energy (2010)

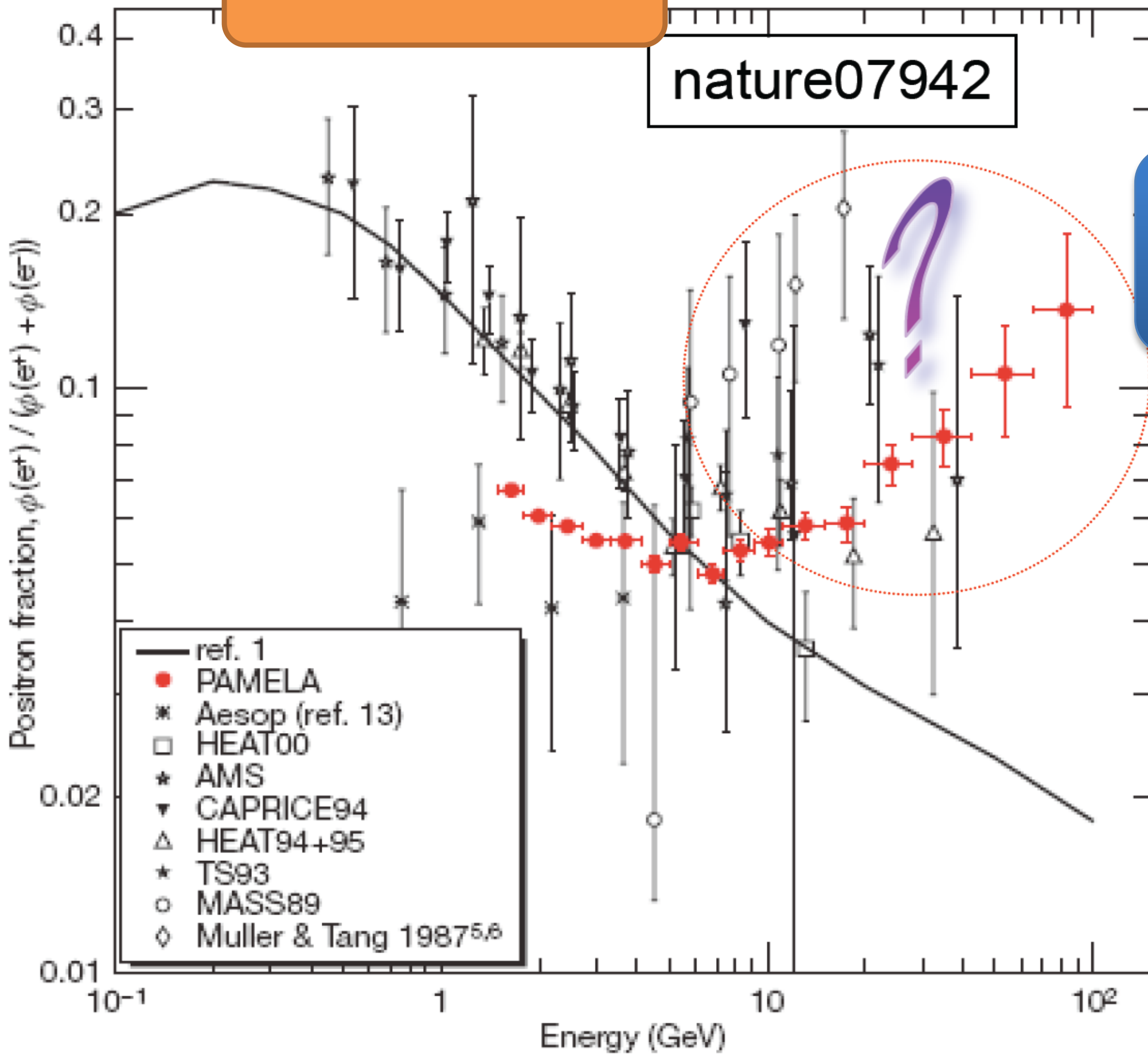
Antiproton Channel





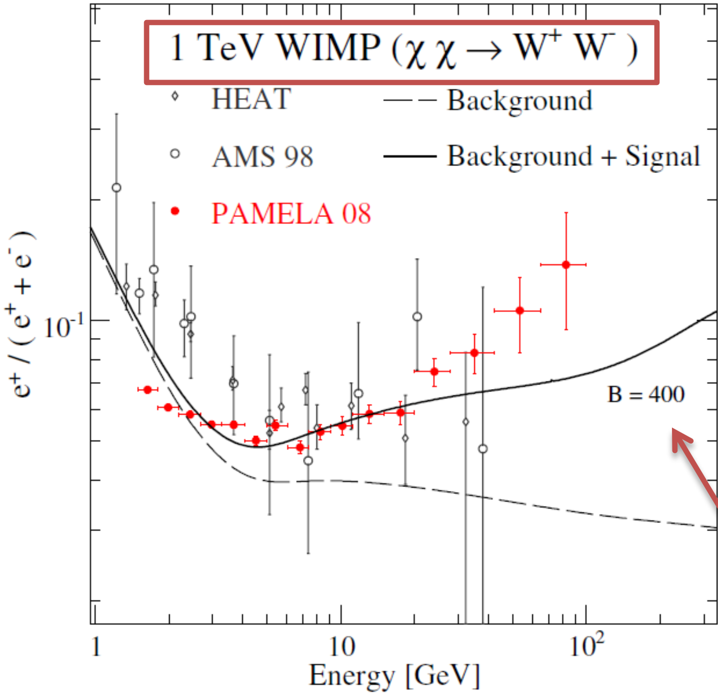
A perfect secondary spectrum: **No Dark Matter Signal**

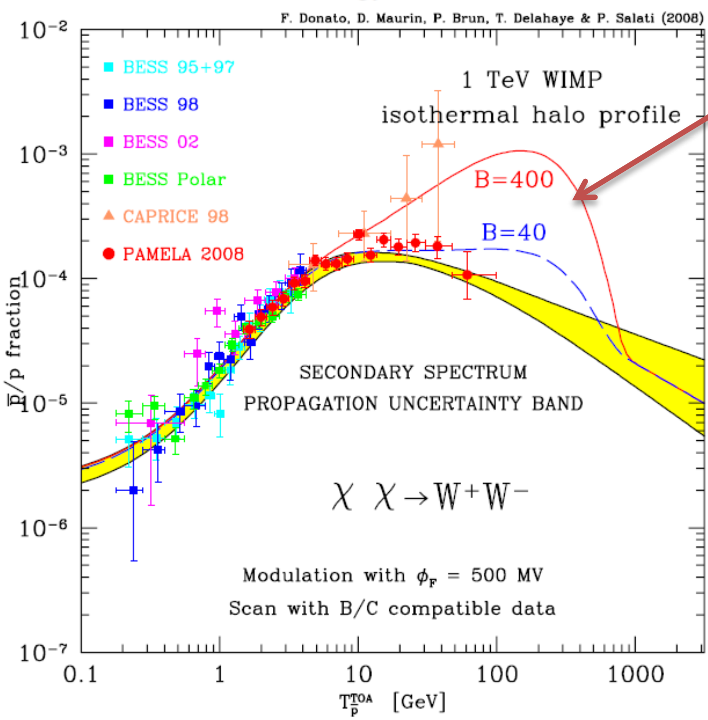
Positron Channel



New Physics?

We have to explain this **tension**





Let's consider the cross section:

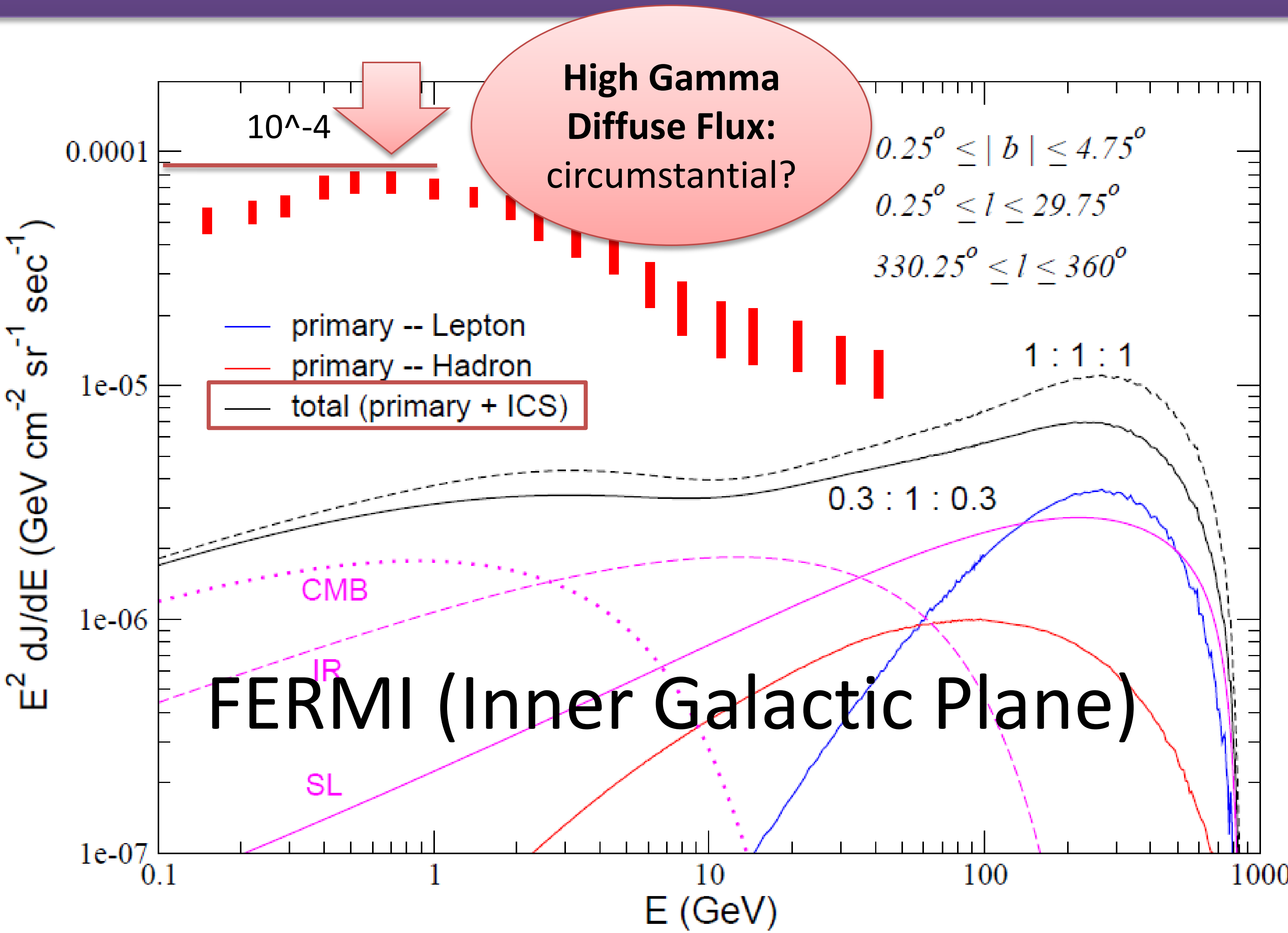
Donato - Constraints on WIMP Dark Matter from the High Energy PAMELA antip-p Data (2009)

$$\langle \sigma v \rangle_{ann} \sim a + bv^2 + c\frac{1}{v}$$

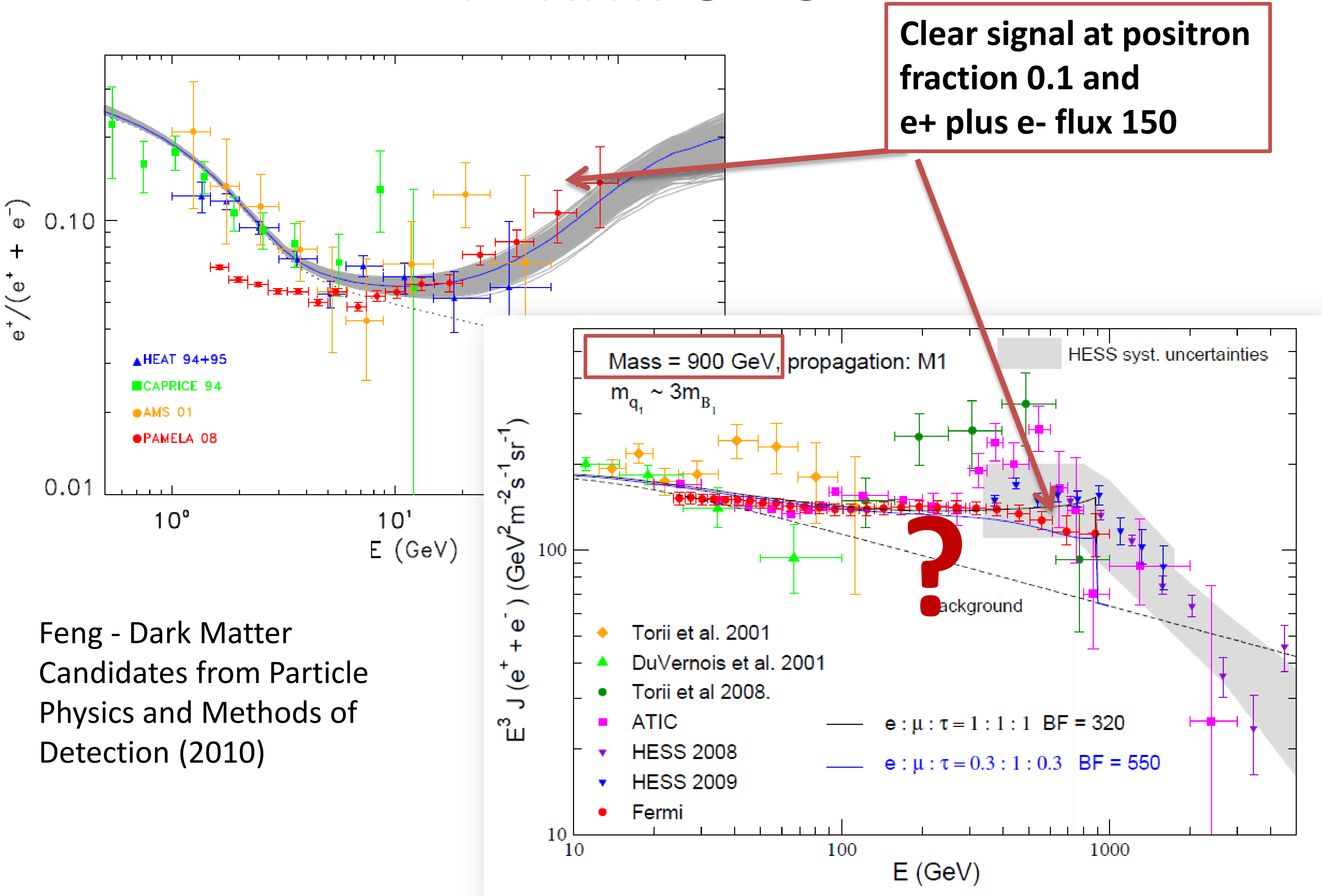
Feynman representation of Sommerfeld enhancement/annihilation cross section boost

Inadequate production for a 1 TeV WIMP near the WW resonance: **to grant PAMELA results we need heavier candidates and high BF, or leptophilic ones**

Gamma Ray & FERMI

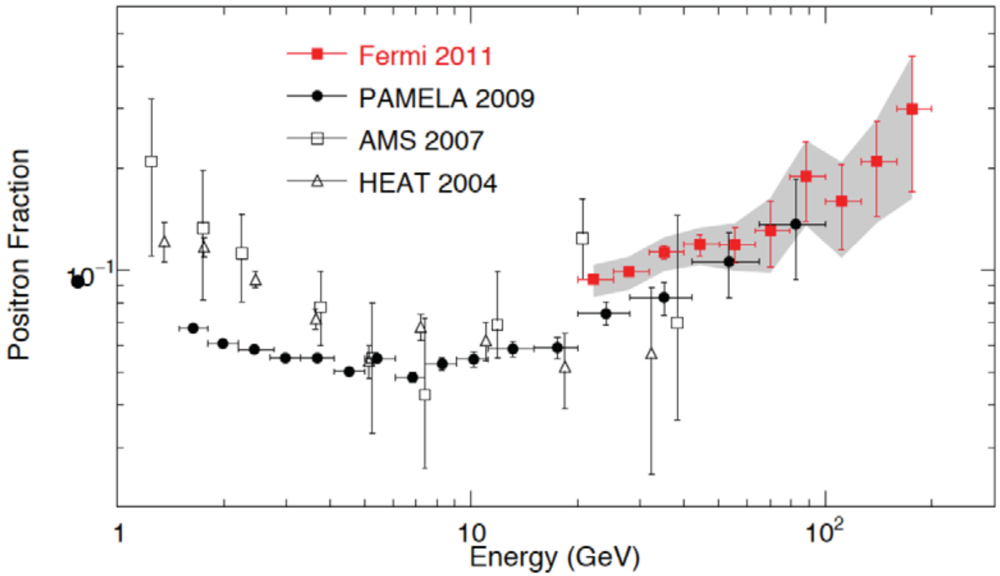


FERMi e+ e-

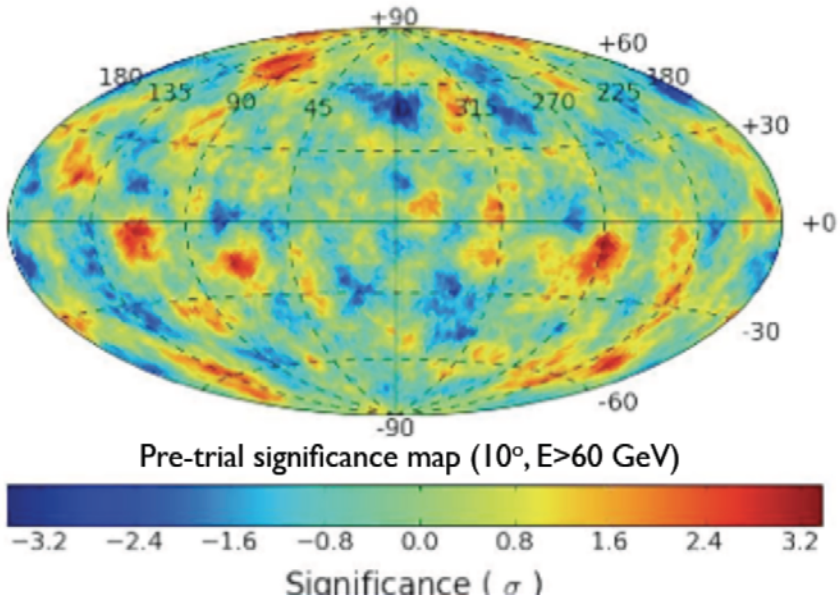


Feng - Dark Matter Candidates from Particle Physics and Methods of Detection (2010)

FERMI spectrum of CR e- and e+



Ackerman et al, Astro-ph.HE, September 5, 2011



FERMI confirms PAMELA excess at high energies positron fraction at high energies is larger than the one predicted by models of cosmic ray propagation.

Local source of electrons and positrons:
=> SN, Pulsars ?

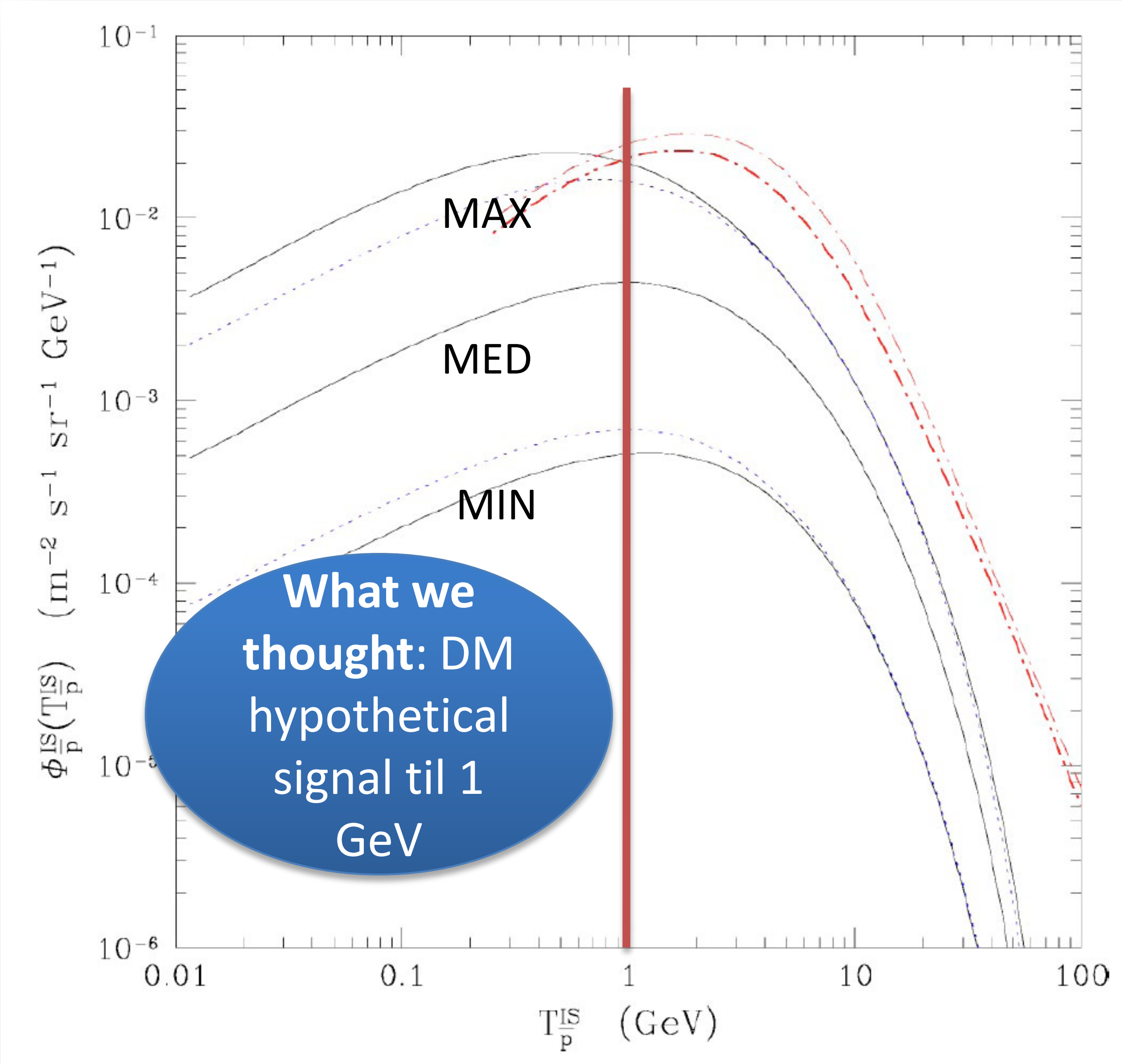
However, no significant anisotropy found for e^- and e^+ (which might have been expected from a local source)

from Drlica-Wagner, 2011

now => AMS-02

Hadronic Signals

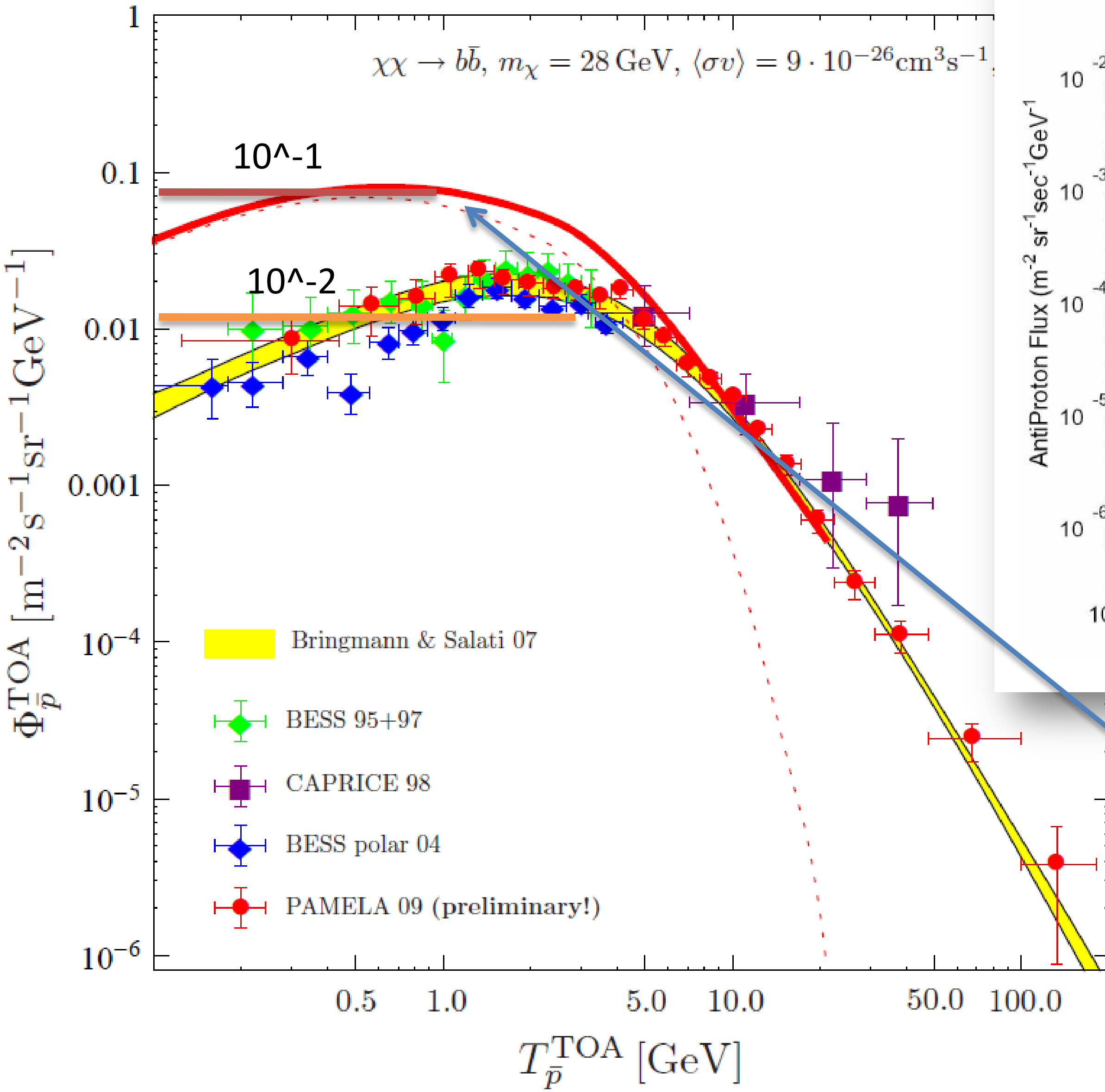
Antiproton

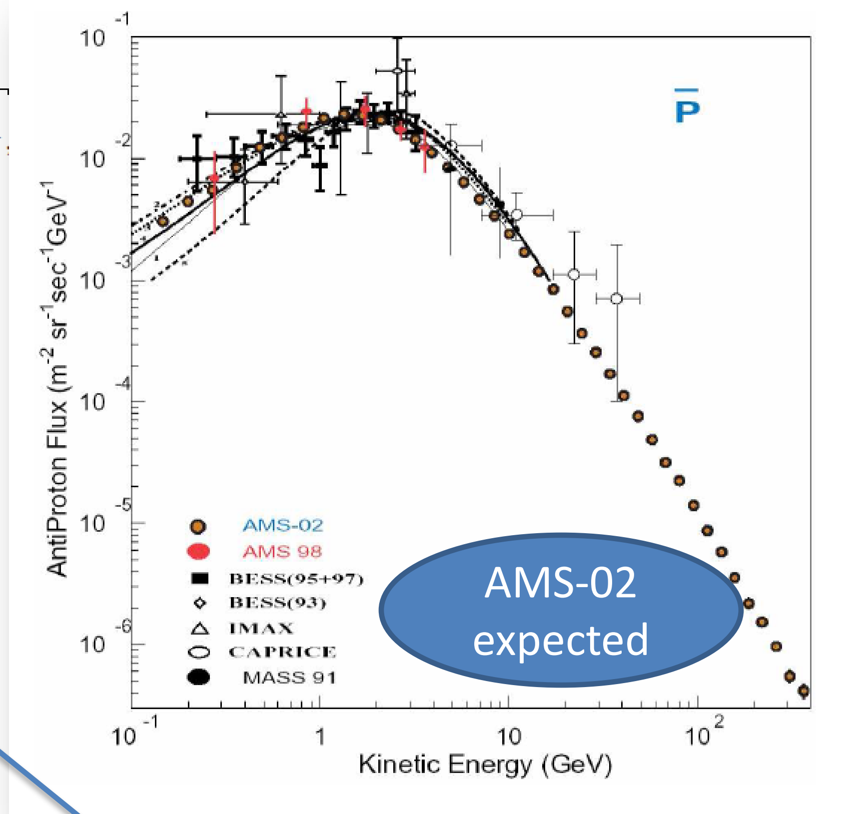


Donato - Antiprotons in cosmic rays from neutralino annihilation 2004

The black lines represent the primary flux from a M=100 GeV neutralino for MIN-MED-MAX (for different $\chi 2$ of B/C); the red lines correspond to the secondary flux

Bringmann - Antiproton and Radio Constraints on the Dark Matter Interpretation of the Fermi Gamma Ray Observations of the Galactic Center 2009



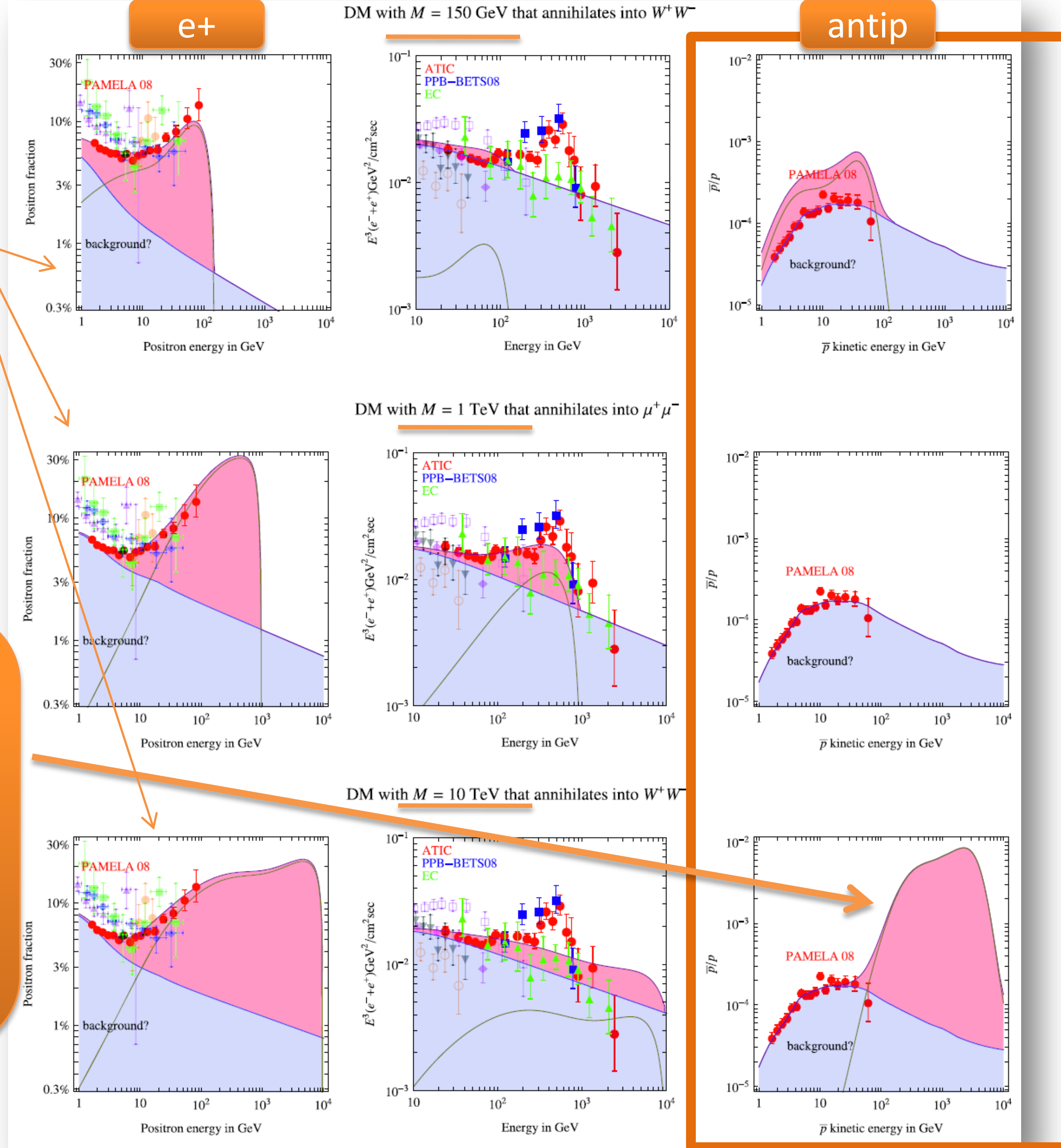


No theoretical Dark Matter Signal at all

Always promising positron search

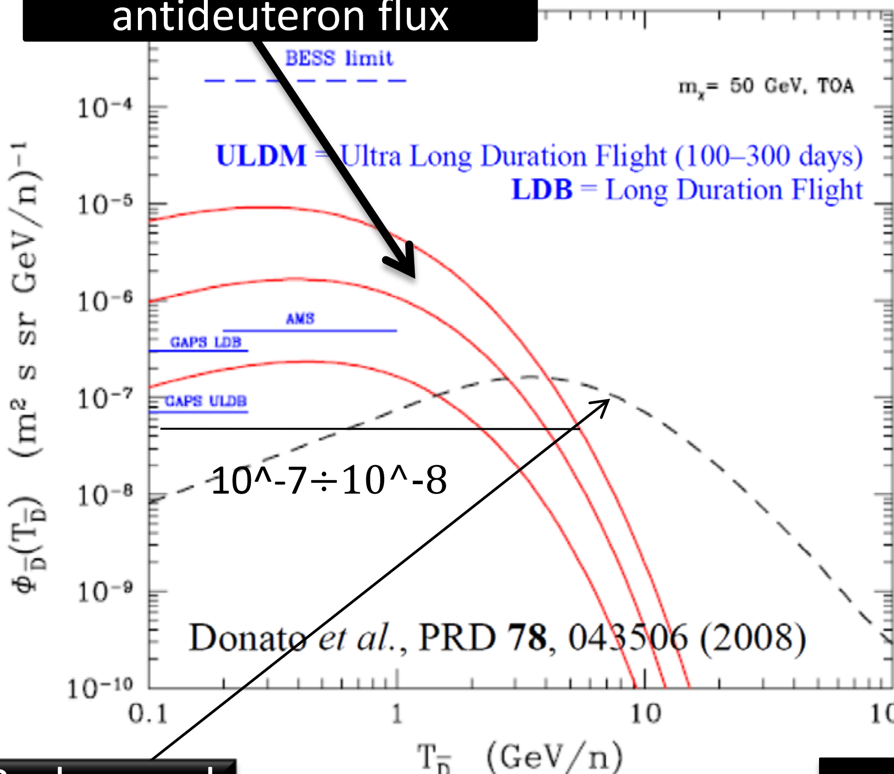
Cirelli - Model-independent implications of the e±, p, antip cosmic ray spectra on properties of Dark Matter 2009

New antiproton physics for AMS-02 in the 100 GeV - 1 TeV range for M ~ 10 TeV



Antideuteron

PAMELA can't reconstruct an absolute antideuteron flux

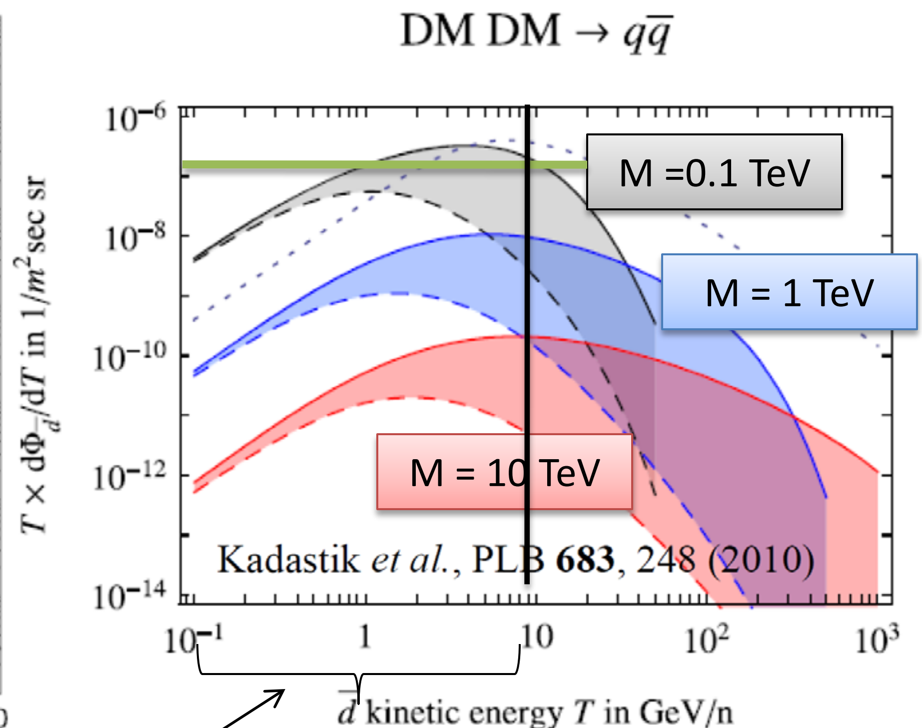


Background secondary flux

MIN, MED, MAX propagation

Light Dark Matter

AMS-02 sensitivity: 2÷5 · 10^-7



Low energy range

MED propagation and NFW profile

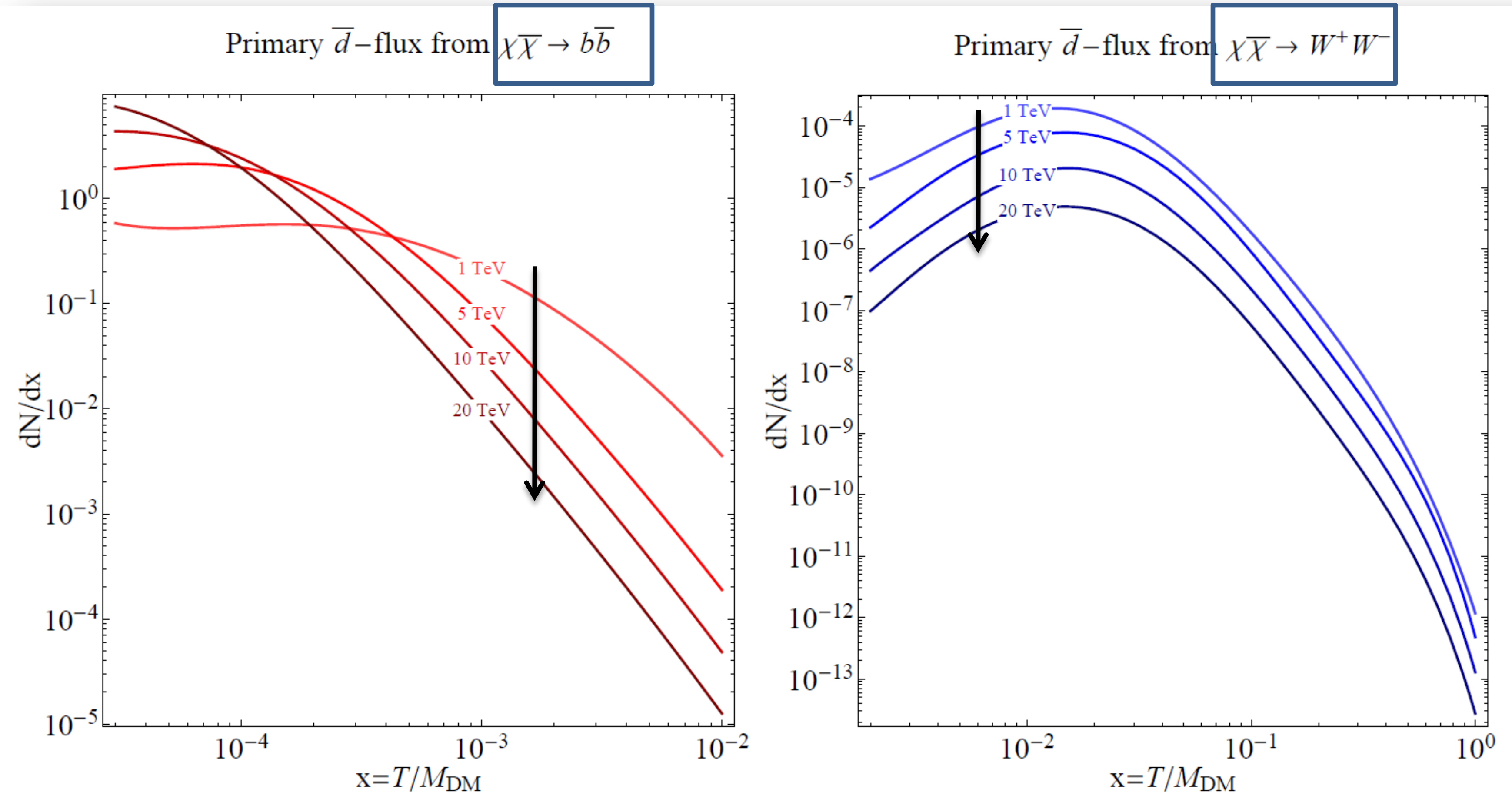
Not Light Dark Matter

Flux and Uncertainties comparison

Mass and Decay Channel

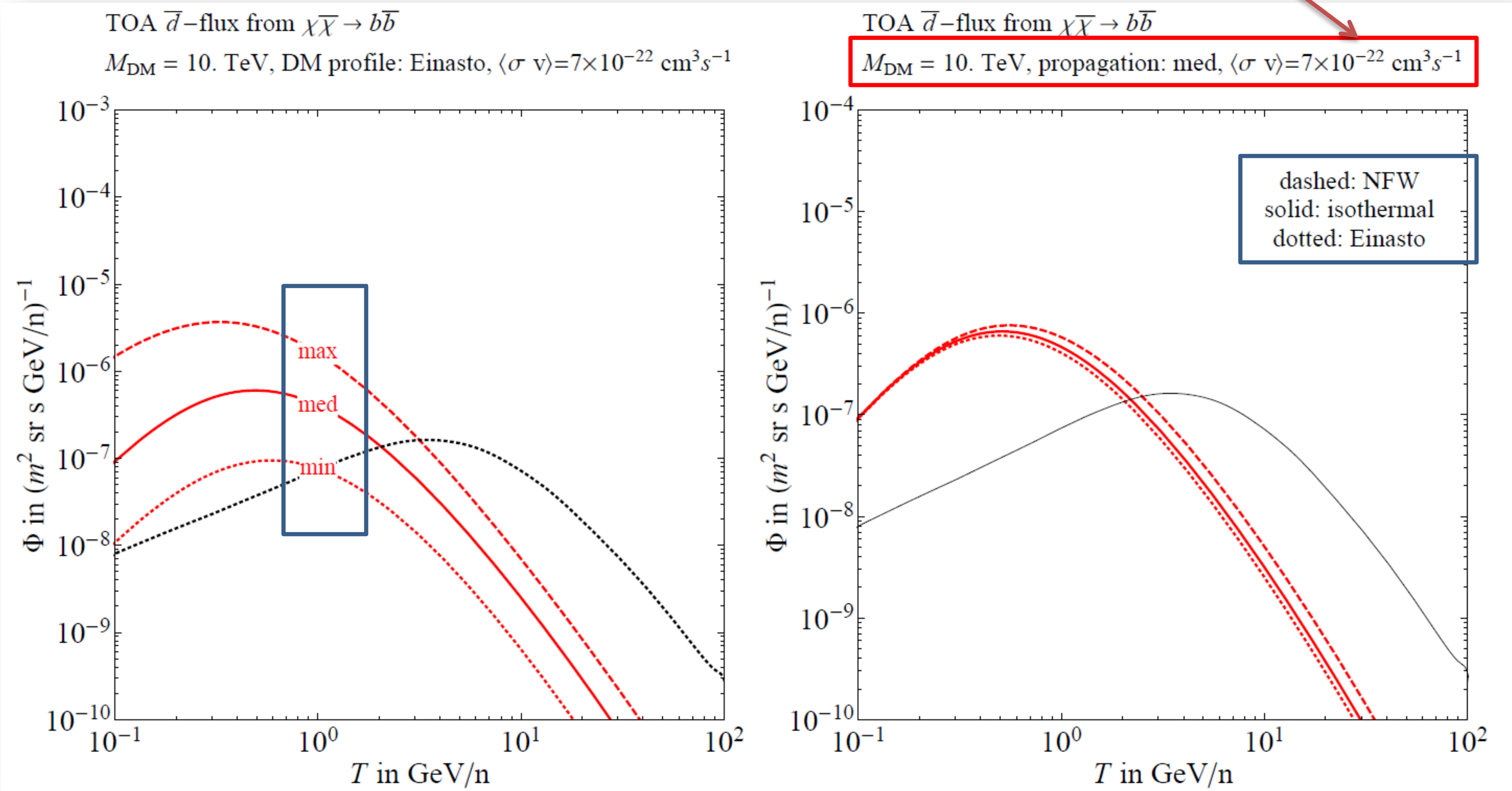
For heavy hadrophilic high cross section WIMP

Cirelli - Anti-deuterons from heavy Dark Matter 2009

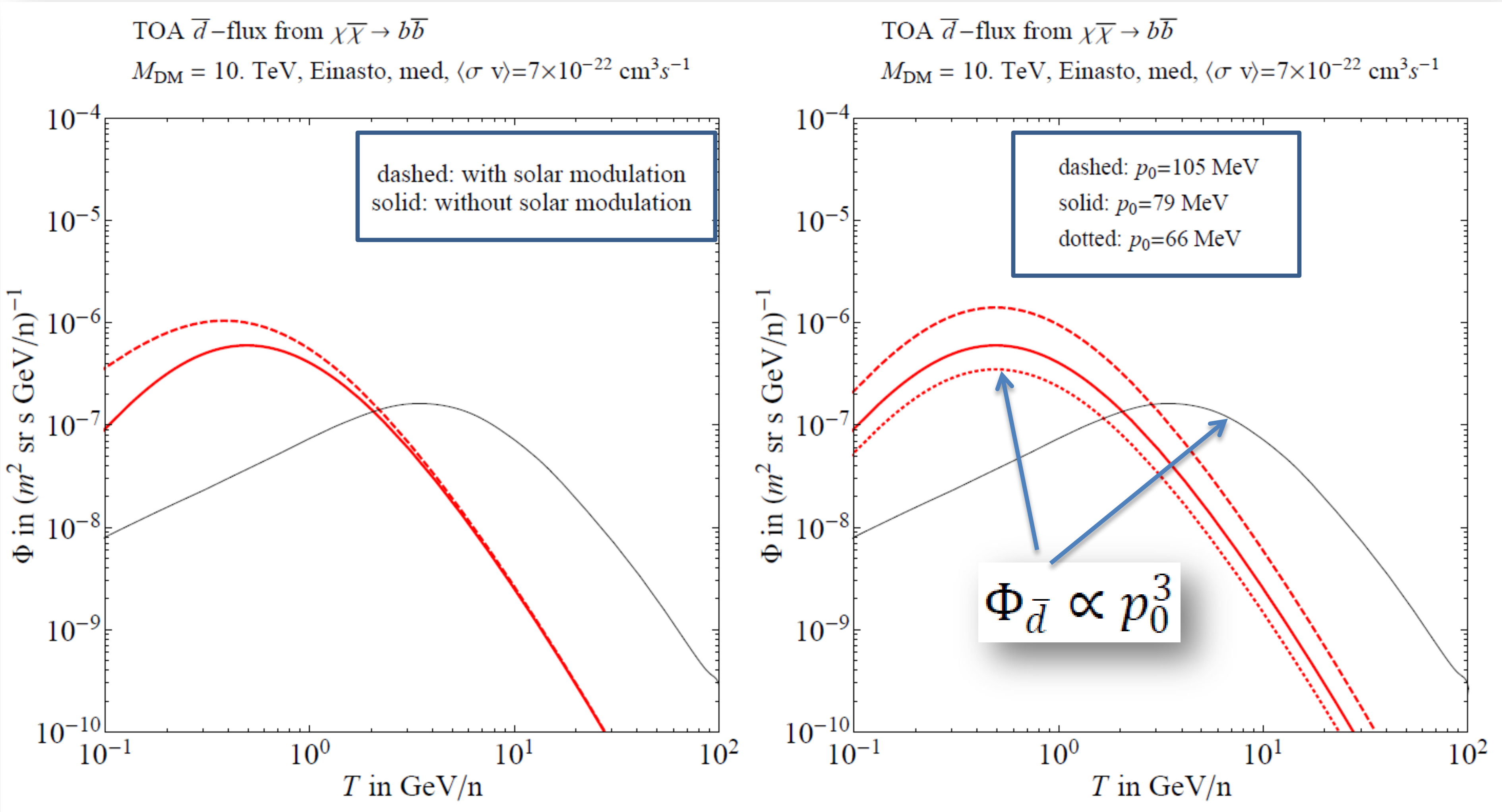


Propagation and Halo Models

WDs suggest
$\langle \sigma v \rangle < 10^{-23} cm^3 s^{-1}$



Solar Modulation and coalescence impulse

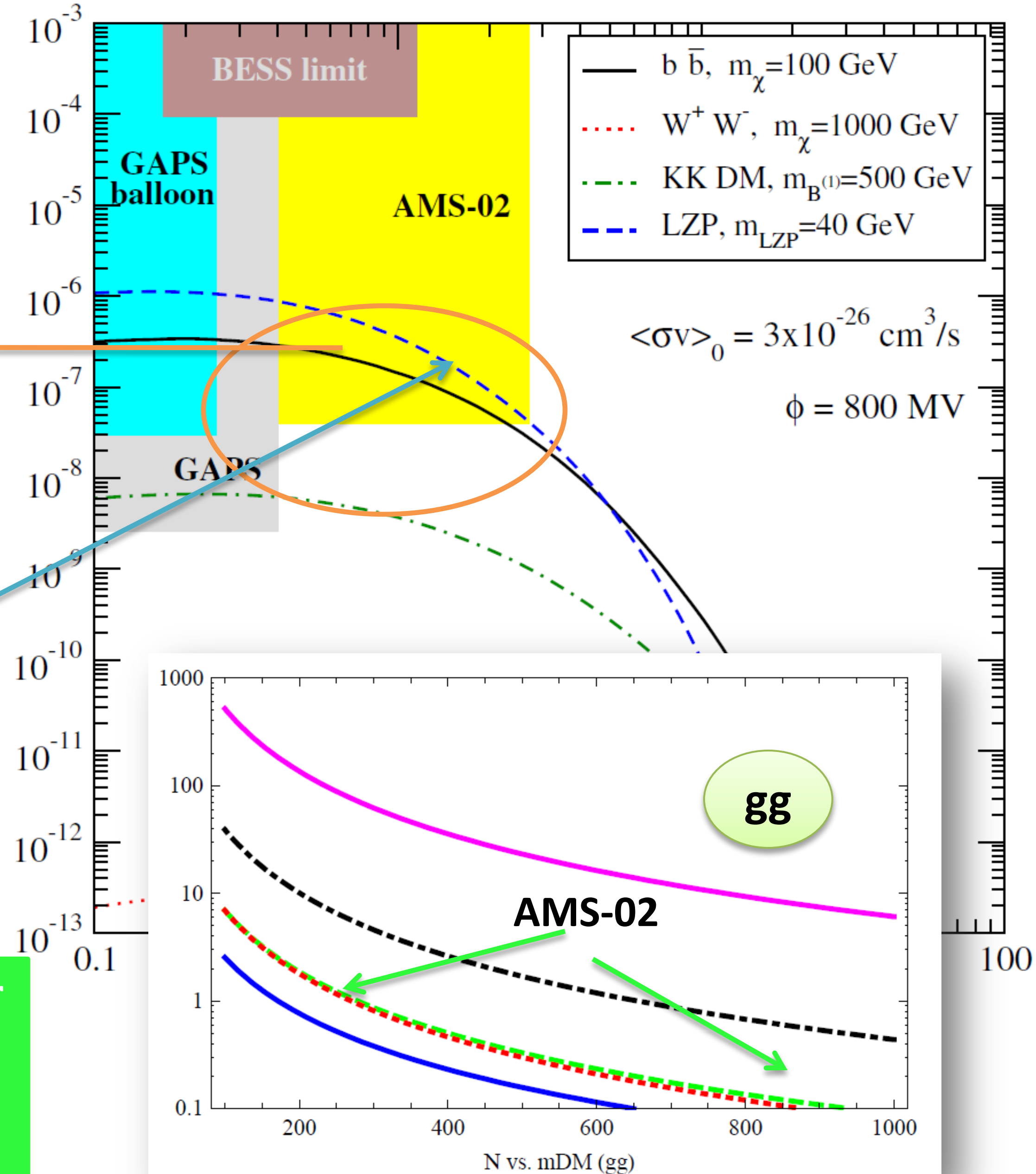


Profumo - Low energy antideuterons shedding light on dark matter 2005

Antideuteron flux from neutralino, KK Photon and right-handed neutrino LZP

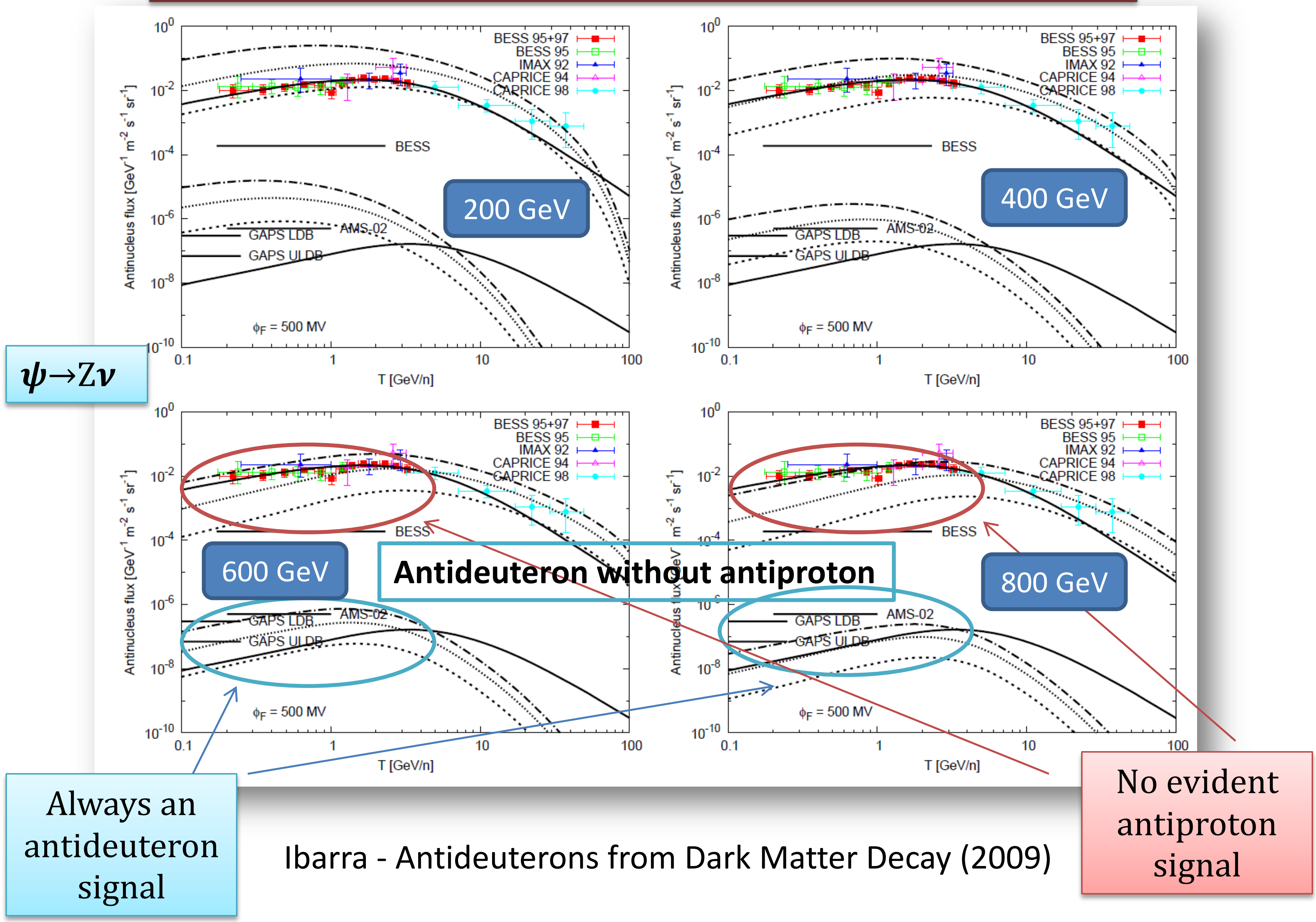
Always 10^-6÷10^-7 fluxes for few GeV

Light ν_R LZP provides measurable fluxes for AMS-02



0.1÷2 antideuterons for a 200 ÷900 GeV WIMP in the high rate gg channel, in one year

Antideuteron & Antiproton



Ibarra - Antideuterons from Dark Matter Decay (2009)

DM Candidates and AMS-02

Neutralino

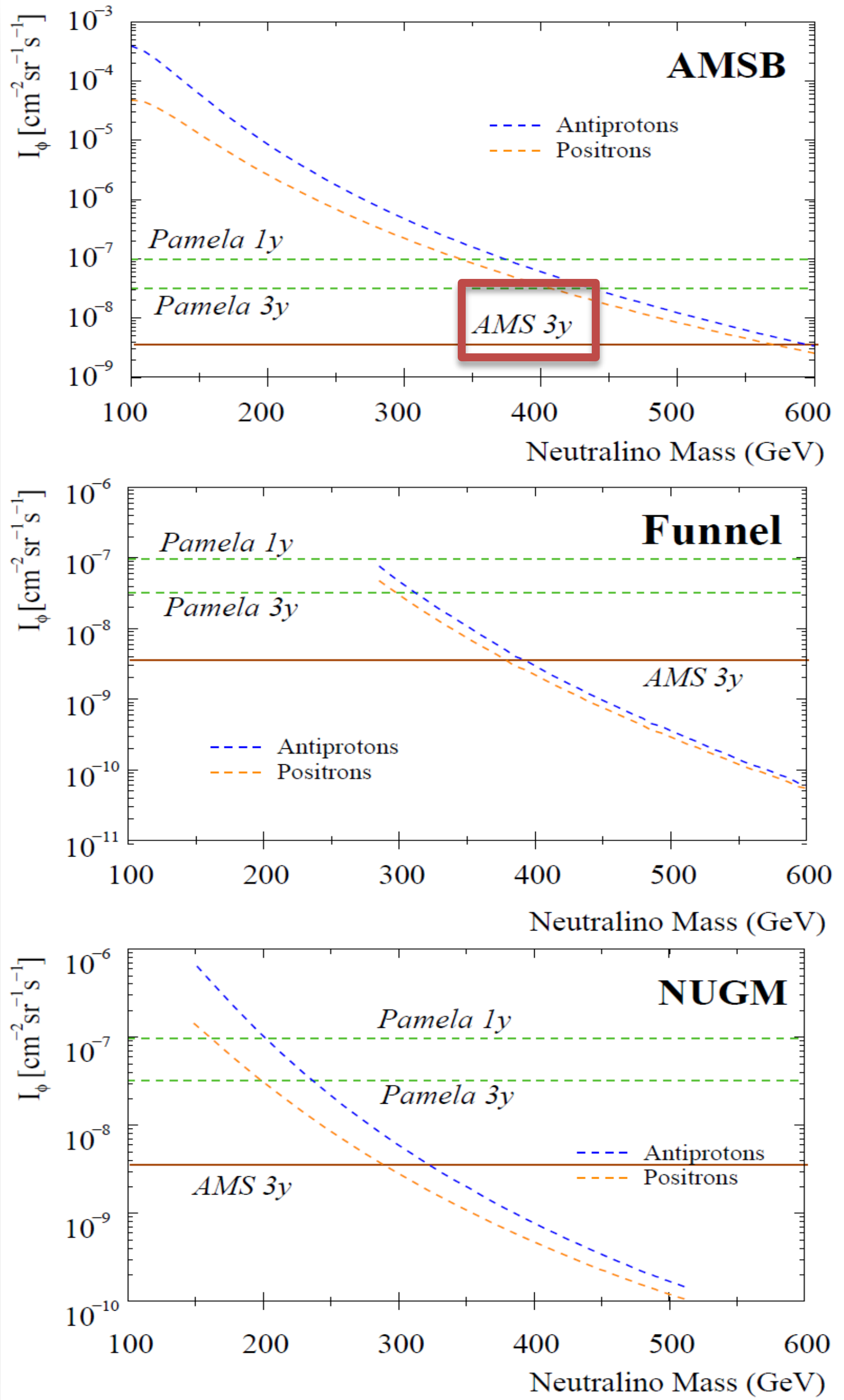
Discrimination parameter I_ϕ

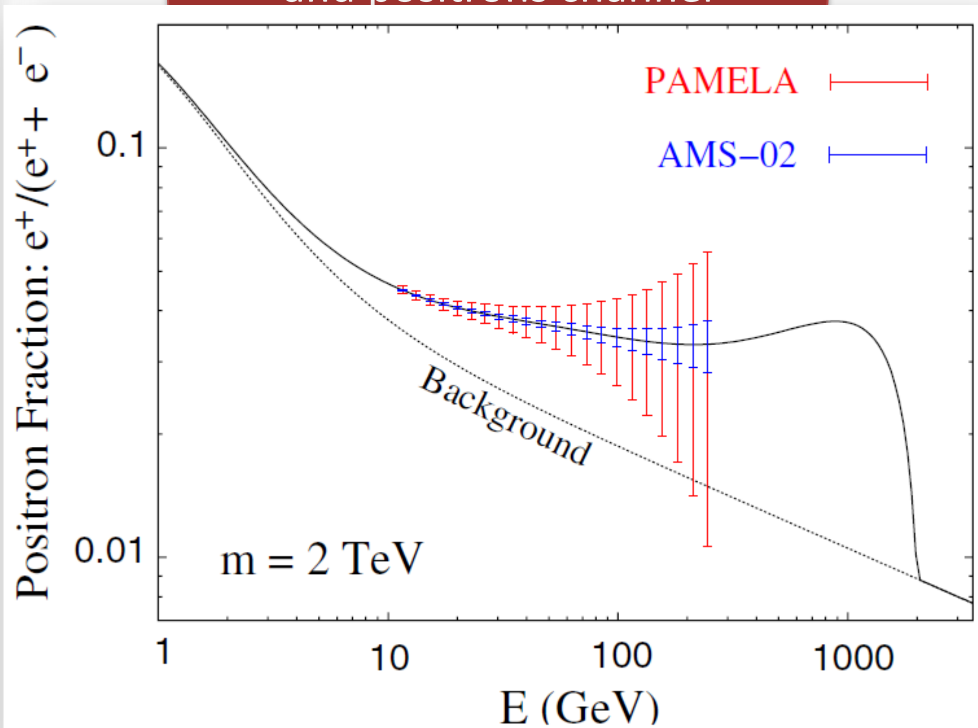
f… :

th… is

Expected clear positron signal from heavy Wino

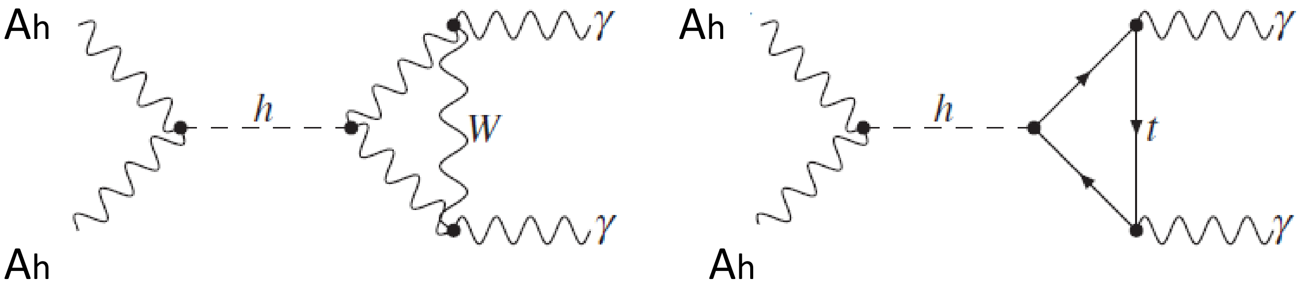
AMS-02, both in antiproton and positrons channel





Little Higgs Theory

DM Annihilation - favored process

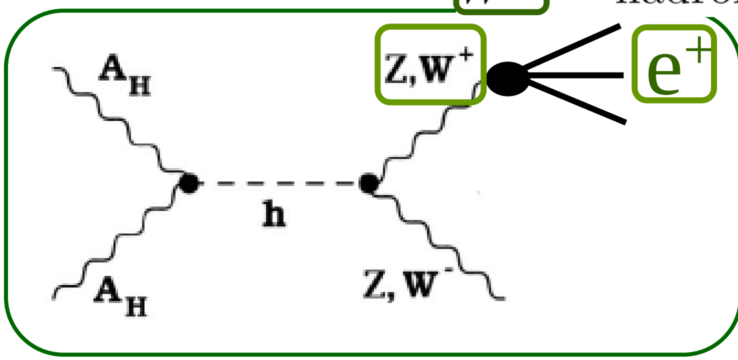


Birkedal - Little Higgs dark matter 2006

$$W^{\pm} \rightarrow \text{hadrons} \rightarrow \pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$$

$$W^{+} \rightarrow \mu^{+}\nu \rightarrow e^{+}\nu\bar{\nu}\nu$$

$$W^{+} \rightarrow e^{+}\nu$$



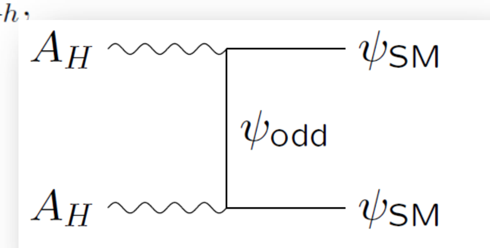
Production rate of e+ from the annihilation.

@ LHC Collider: hadronic channel

$$pp \rightarrow W_h^+ W_h^- \rightarrow W^+ W^- A_h A_h,$$

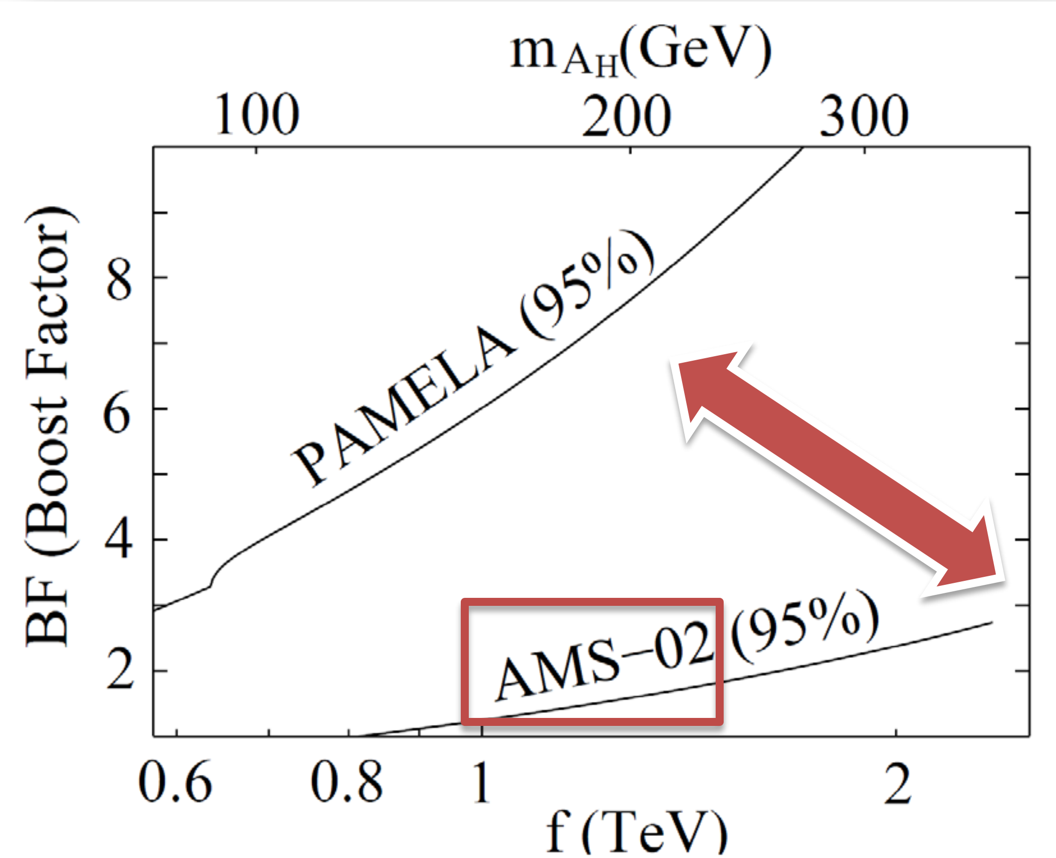
$$pp \rightarrow W_h^{\pm} Z_h \rightarrow W^{\pm} h A_h A_h,$$

$$pp \rightarrow W_h^{\pm} A_h \rightarrow W^{\pm} A_h A_h,$$



TeV T-odd fermion

95% C. L. contour within WMAP constraint for Little Higgs Dark Matter parameters space

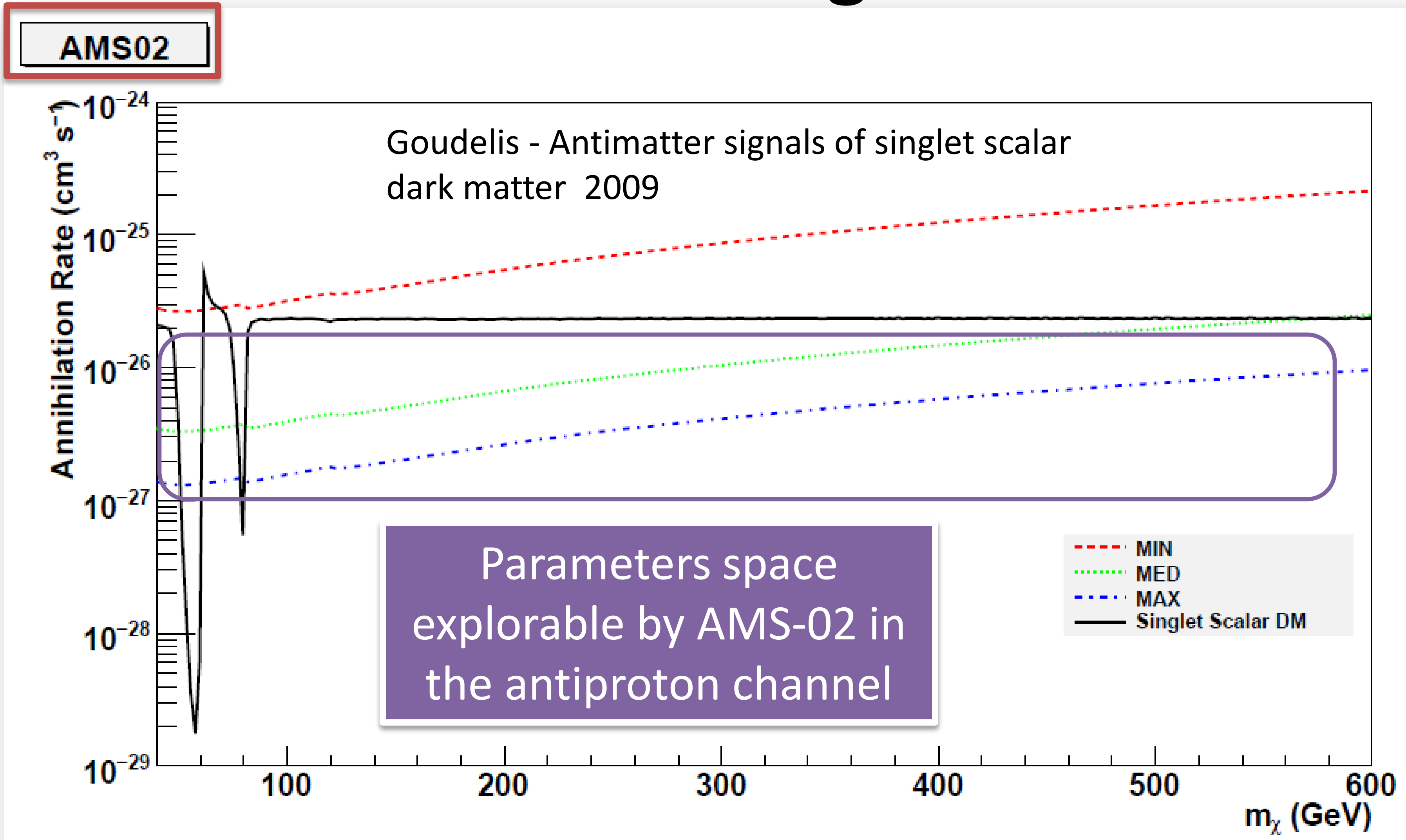


AMS-02

Wide range of the parameter space including the region BF = 1

The region above the line can be distinguished from the background.

Scalar Singlet

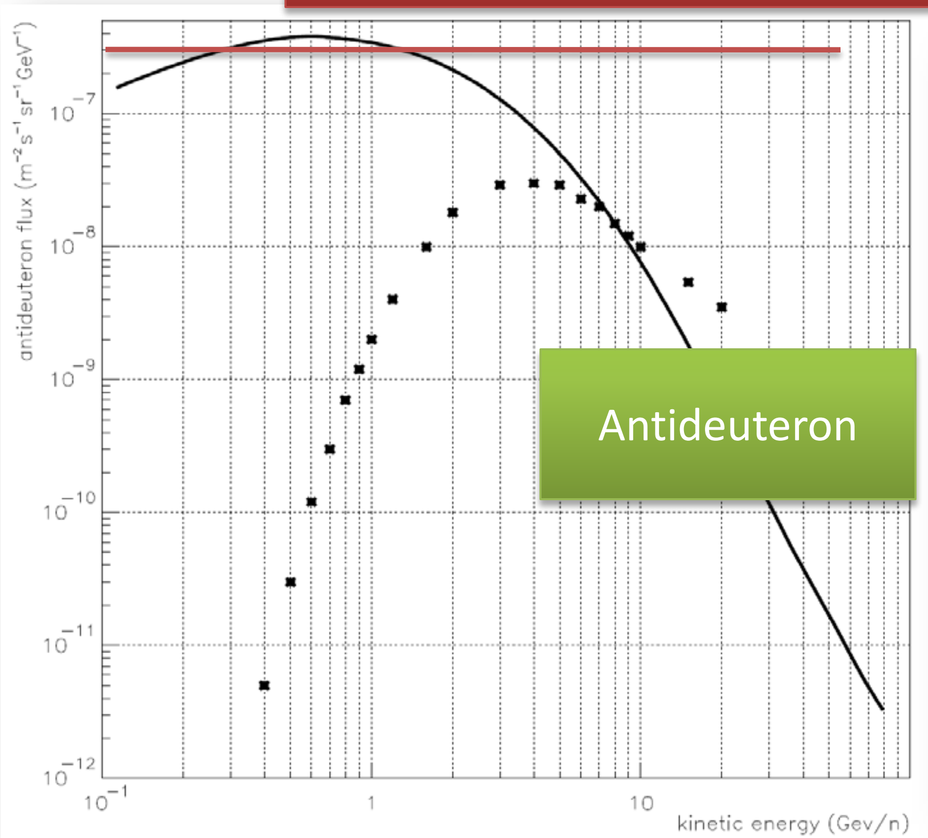


Primordial Black Holes

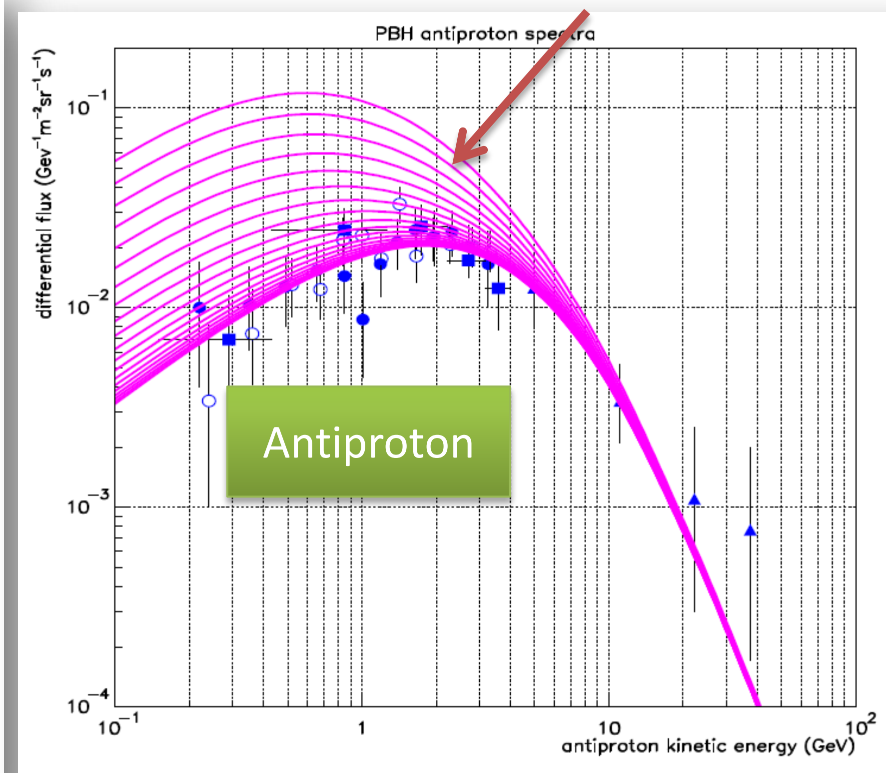
Barrau-Antideuterons as a probe of primordial Black Holes 2003

Barrau - ANTIMATTER FROM PRIMORDIAL BLACK HOLES

AMS sensitivity: not a good candidate

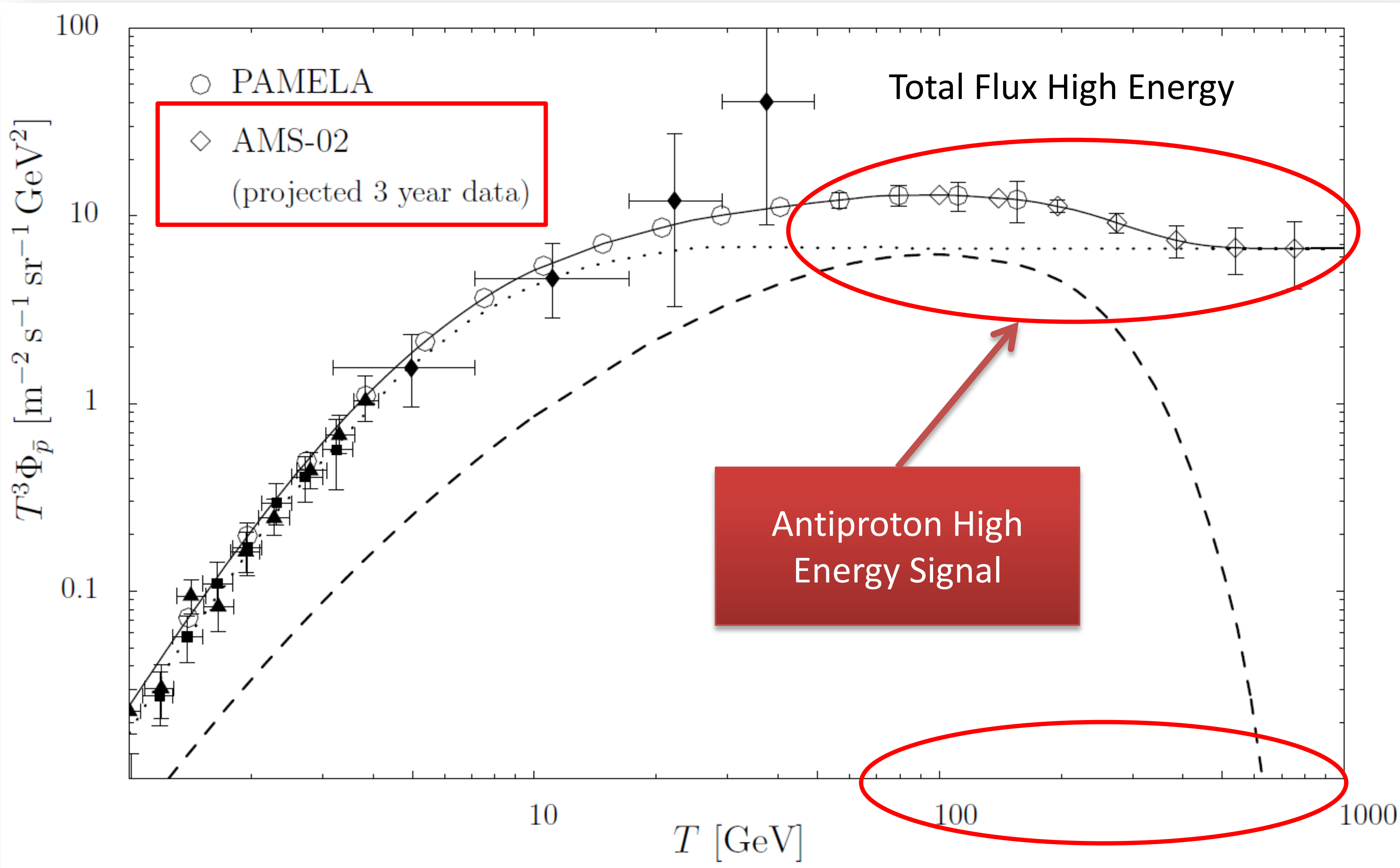


Not observed



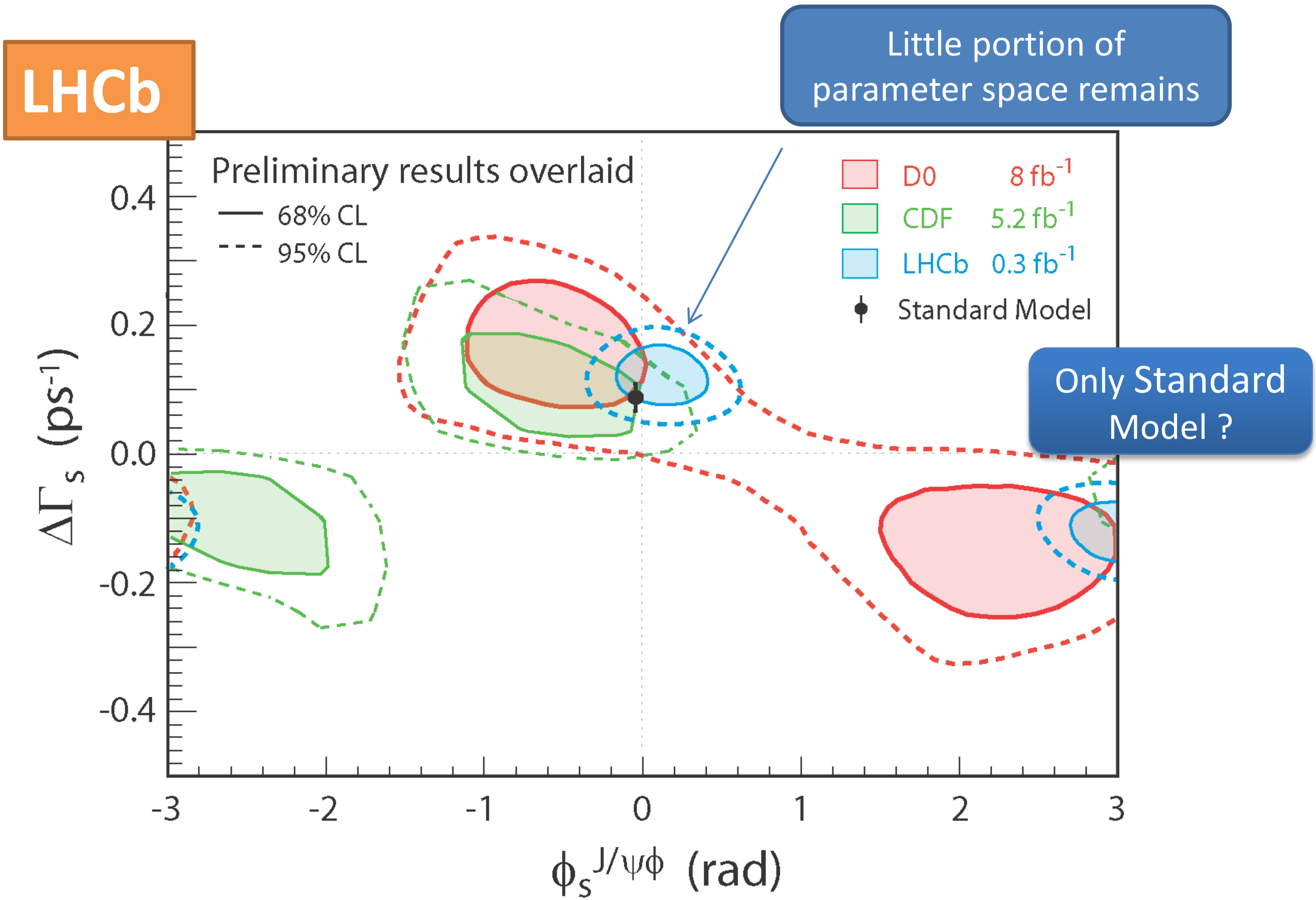
KK Theory and LKP

Bringmann - High-energetic Cosmic Antiprotons
from Kaluza-Klein Dark Matter 2005

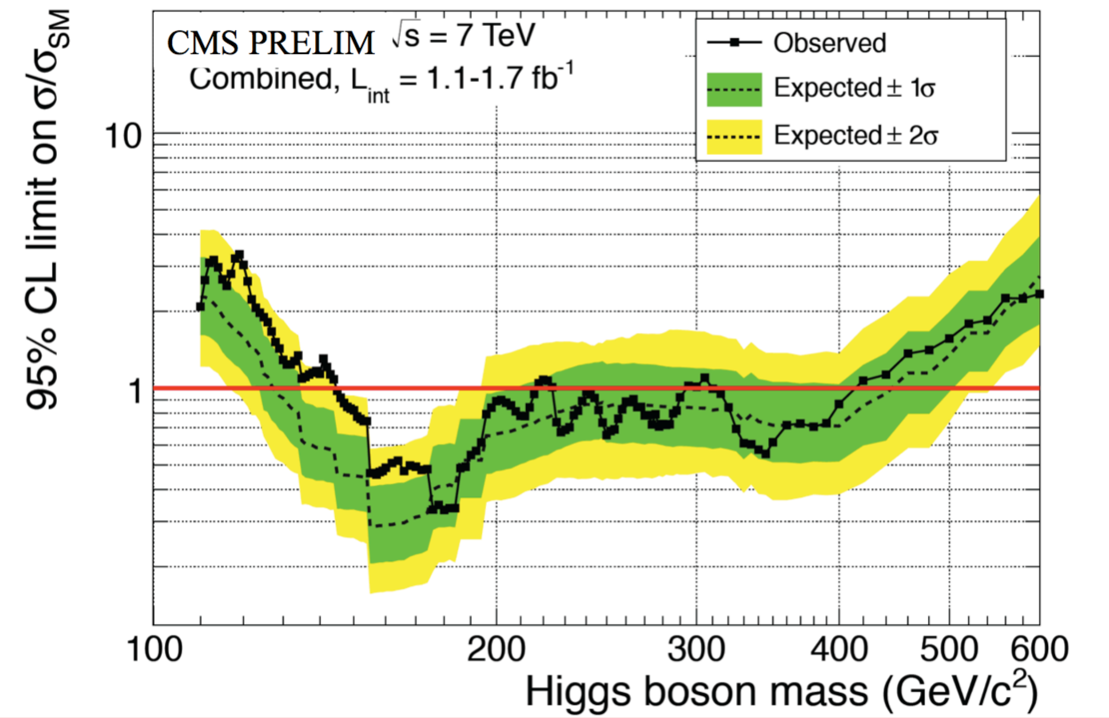


All We Know and What We'll See:
Update Autumn 2011

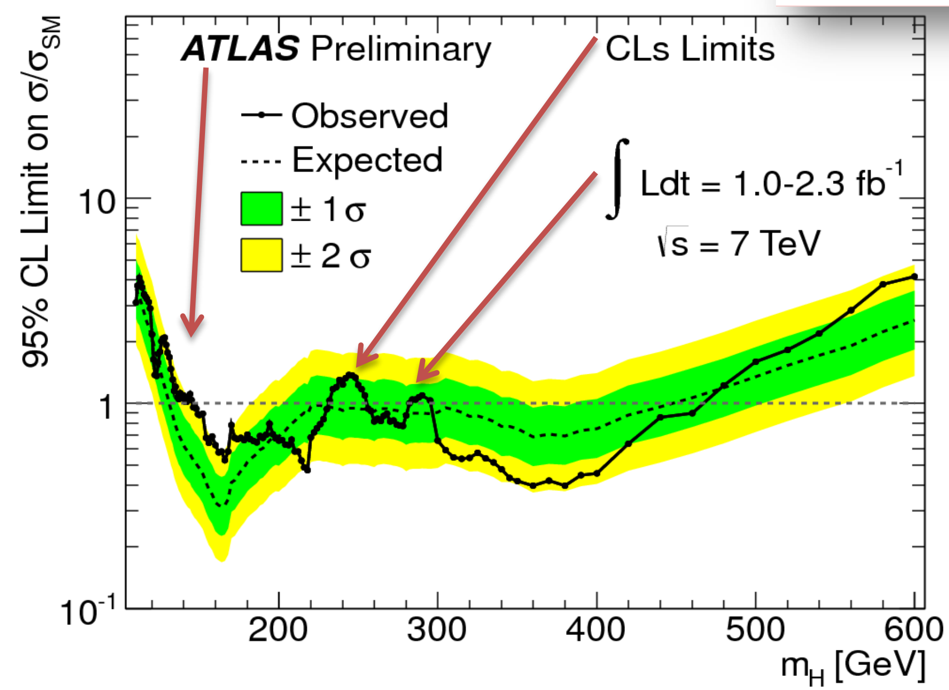
LHC News from Mumbai Conference



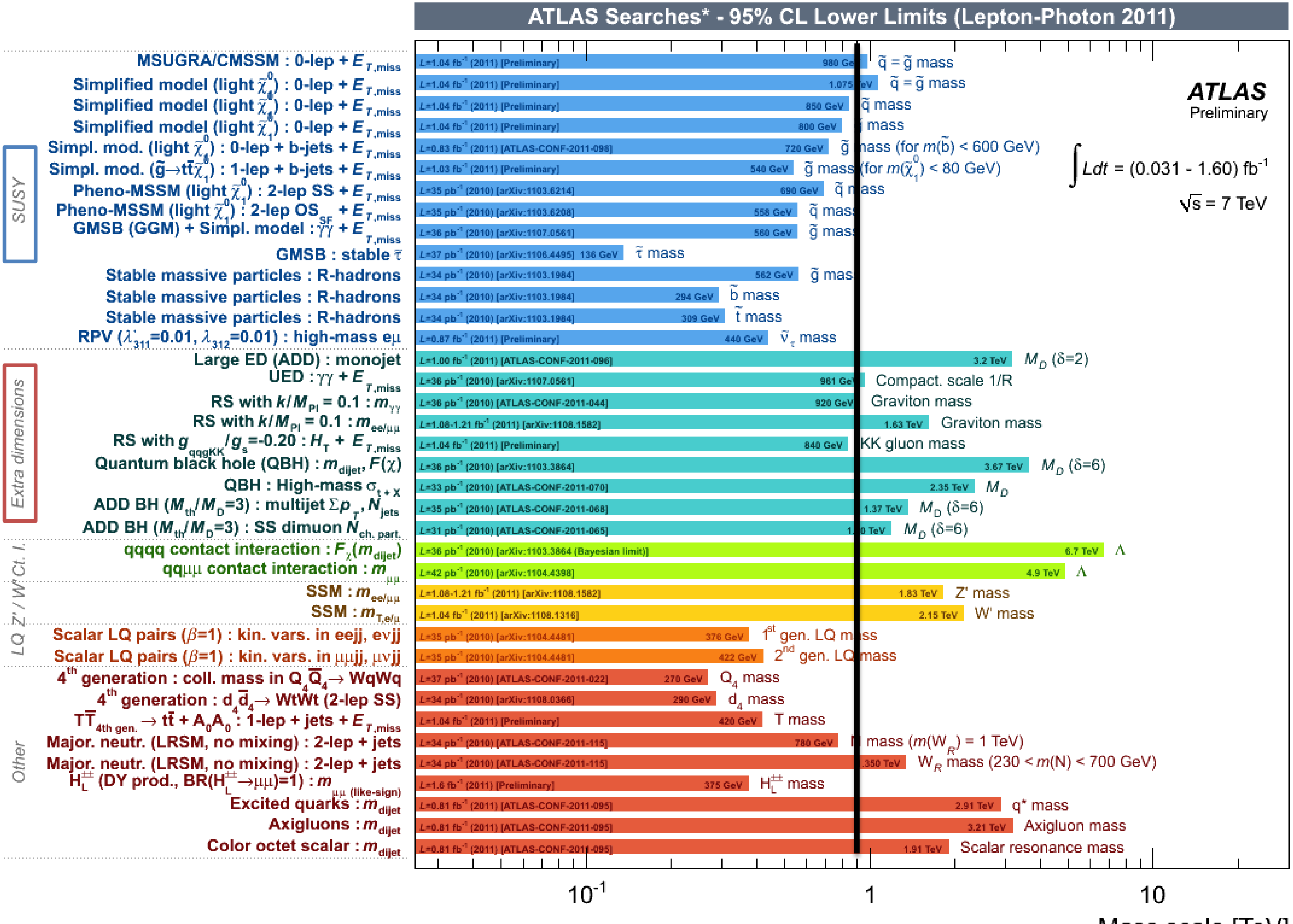
CMS



ATLAS



Out of theoretically expected mass range exclusion of 145 to 440 GeV, three ranges have been excluded – 145 to 216 GeV, 226 to 288 GeV and 310 to 400 GeV. Anything above 400 GeV is unlikely and the crucial 130 to 145 GeV window is still open. These mass ranges have been excluded with 98% confidence level.



*Only a selection of the available results leading to mass limits shown

A SUSYless and Higgsless scenario leads us to ……

Technicolor? (A leptophilic solution)

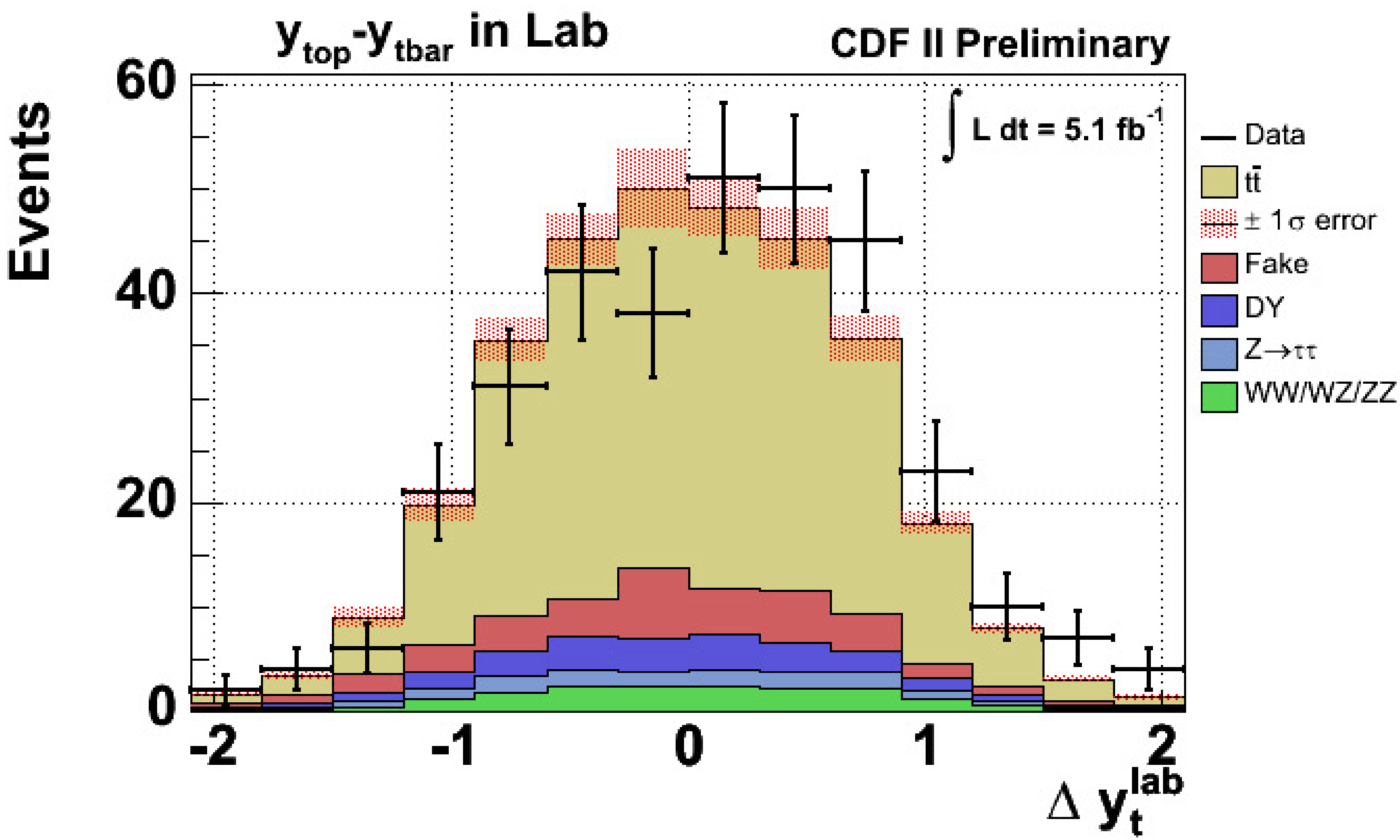


Table 1 - DM Candidates properties

	Spin	Mass	Simmetry	Correct $\Omega_{DM}h^2 \approx 0.11$	Expected $\langle\sigma v\rangle_{ann} \approx 1\ pb$	Motivation	DetectableAnnihil. /Decay Products	Leptophilic (e,μ,τ especially)
SUSY χ - Wino AMSB LSP	½ M	300 GeV÷10 TeV	R	√	$\gtrsim$	Gauge Hierarchy Problem	p-channel: ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	√ (perhaps:HS?)
SUSY χ – Bino/Higgsino LSP	½ M	100 GeV÷1 TeV	R	√	$\lesssim$	Gauge Hierarchy Problem	p-channel: ν, γ, e$^+$, $\bar{p}, \bar{d}$	√ (perhaps:HS?)
NMSSM $\tilde{S}$ NLSP	½ M	10÷100 GeV	R	√	$\lesssim$	Gauge Hierarchy Problem	$\bar{p}$	–
UED $B^{(1)}$ LKP	1	300 GeV÷few TeV	KK	√	0.6	String Theory	ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	√ (perhaps)
KK Warped GUT ν_R LZP	1/2	30 GeV÷1 TeV	Z_3	√	1	String Theory	ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	–
Singlet Scalar S	0	200÷600 GeV	Z_2	√	1	Minimal	$\bar{p}, \bar{d}$, leptons	–
PBH (&Holeum)				X	– :(Hawking Rad.)	Astrophysical	$\bar{p}, \bar{d}$	X
Little Higgs A_h LTP	1	600÷1200 GeV	T	√	0.8	Gauge Hierarchy Problem	ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	√ (hadron inhibited)
Axion a	0	10^{-5}÷10^{-3} eV	PQ	√ (thermal+nonthermal)	– :(Primakoff eff.)	Strong CP Problem	γ	Also leptophilic models may produce antip by EW corrections
Sterile ν_S	1/2	1÷15 keV	Z_N	X	– :(Oscillation)	ν Mass	X-Ray, ν	
Gravitino $\tilde{G}$	3/2	200÷600 GeV	R	X	$\lesssim$	Gauge Hierarchy Problem	ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	
Technicolor DD, ϕ	Bosonic (0)	few TeV	TB	√	$\lesssim$	EWSB: Unitarity & Renormalization	ν, γ, e$^+$	√
MDM (4th generation)	1/2	1÷10 TeV	Y	√	$\approx$	Only SM Physics	ν, γ (Gamma), e$^+$, $\bar{p}, \bar{d}$	–
Tulin Antibaryonic DM Y,Φ	1/2	2÷3 GeV	B	√	– :(IND)	Antimatter	IND: $mesons \rightarrow leptons$	√

HS: Hidden Sector

Wrong relics

(*) : ill-favored
X : NOT (correct, possible)
– : not defined
M : Majorana fermion

Light candidates

GHP: most relevant

Scalar, vector, Dirac fermion, Majorana fermion, Rarita-Schwinger fermion

Table 2 - DM Candidates detection

	Favorite detection	AMS-02 detection	LHC sensitivity	LHC exclusion	PAMELA/FERMI Consideration	SUSY dependence	Higgs dependence
SUSY χ - Wino AMSB LSP	IND	e$^+$, $\bar{p}, \bar{d}, \gamma$	√	No SUSY $\tilde{g}, \tilde{q}$ signal for M < 1 TeV	Wino with M > 2 TeV	Y	Y
SUSY χ – Bino/Higgsino LSP	IND	e$^+$, $(\bar{p}, \bar{d}, \gamma)^{(*)}$	√		ill-favored or barely leptophilic	Y	Y
NMSSM $\tilde{S}$ NLSP	DIR	$\bar{p}$	√		Nearly excluded	Y	Y
UED $B^{(1)}$ LKP	IND	e$^+$, $\bar{p}, \bar{d}, \gamma$	√	No ED particle signal for M < 1 TeV, *no yet* extra dimensions	Massive, HE $\bar{p}, \bar{d}$	N	N
KK Warped GUT ν_R LZP	DIR/IND	e$^+$, $\bar{p}, \bar{d}$	√		No constraint	N	N
Singlet Scalar S	IND	e$^+$, $\bar{p}$	√	Waiting…	No constraint	N	Y
PBH (&Holeum)	IND	$\bar{p}, \bar{d}$	√	No hard γ, e$^\pm$, no μQBH for M < 3 TeV	No LE $\bar{p}$ signal	N	N
Little Higgs A_h LTP	IND	e$^+$, $\gamma^{(*)}$	√	No LTP without Higgs	No constraint	N	Y
Axion a	DIR/LAB	X	X	X	No constraint	N	N
Sterile ν_S	DIR	X	√	No evidence	No constraint	N	N
SUSY Gravitino $\tilde{G}$	IND	e$^+$, $\gamma^{(*)}$	√	No SUSY signal, no graviton for M < 2 TeV	No constraint	Y	Y+graviton
Technicolor DD, ϕ	IND	e$^+$, $\gamma^{(*)}$	√	Waiting…	No constraint	N	N
MDM (4th generation)	IND	e$^+$, $\bar{p}, \bar{d}$	√	No 4th q generation for M < 400 GeV	No LE $\bar{p}$ signal	N	Y
Tulin Antibaryonic DM Y,Φ	IND	(e$^+$)$^{(*)}$	X	X	No constraint	N	N

An independent model

Not our business

Difficult to prove

Without SUSY

A complex scenario

Little Higgs, KK Theory, PBH, Singlet Scalar, Axion, Technicolor, MDM, Sterile Neutrino, Antibaryonic DM……

Without Higgs

A not good scenario

KK Theory, PBH, Axion, Technicolor, Sterile Neutrino, Antibaryonic DM……

With only our 4 dimensions

A realistic exclusion

Axion, Technicolor, Sterile Neutrino, Antibaryonic DM……

A bad scenario

Detectable with AMS-02: Technihadron

Alternatives:

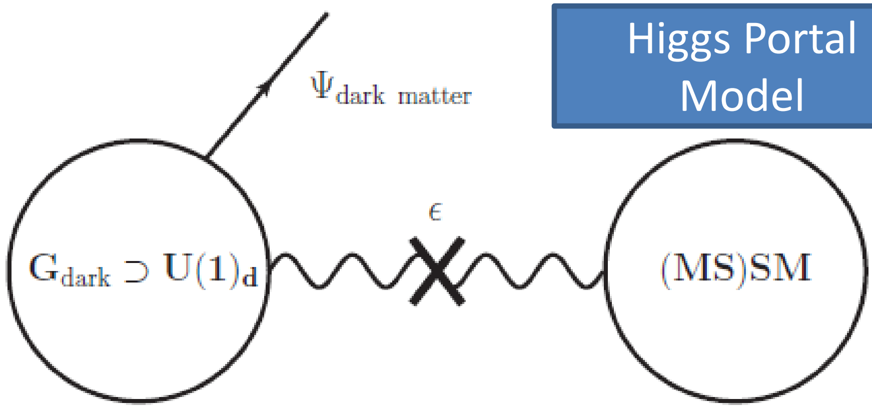
Hidden Sector?

Hidden Sector Dark Matter

- The large cross-section and leptophilic signals suggest non-minimal models of dark matter.
- Arkani-Hamed et al. propose that these anomalies can be explained if dark matter is charged under a hidden sector gauge group that kinetically mixes with SM gauge symmetries and is broken at the GeV scale.

Higgs Portal Model

Also the HS depends on Higgs and SUSY!



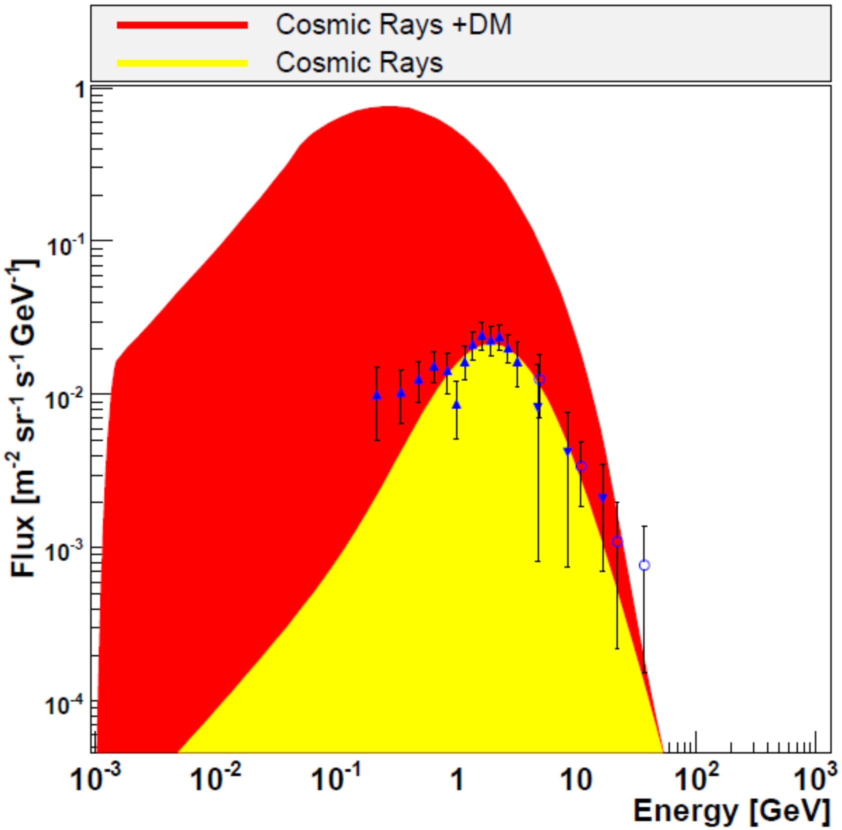
N. Arkani-Hamed, D. Finkbeiner, T. Slatyer, and N. Weiner, **0810.0713**.

N. Arkani-Hamed and N. Weiner, **0810.0714**

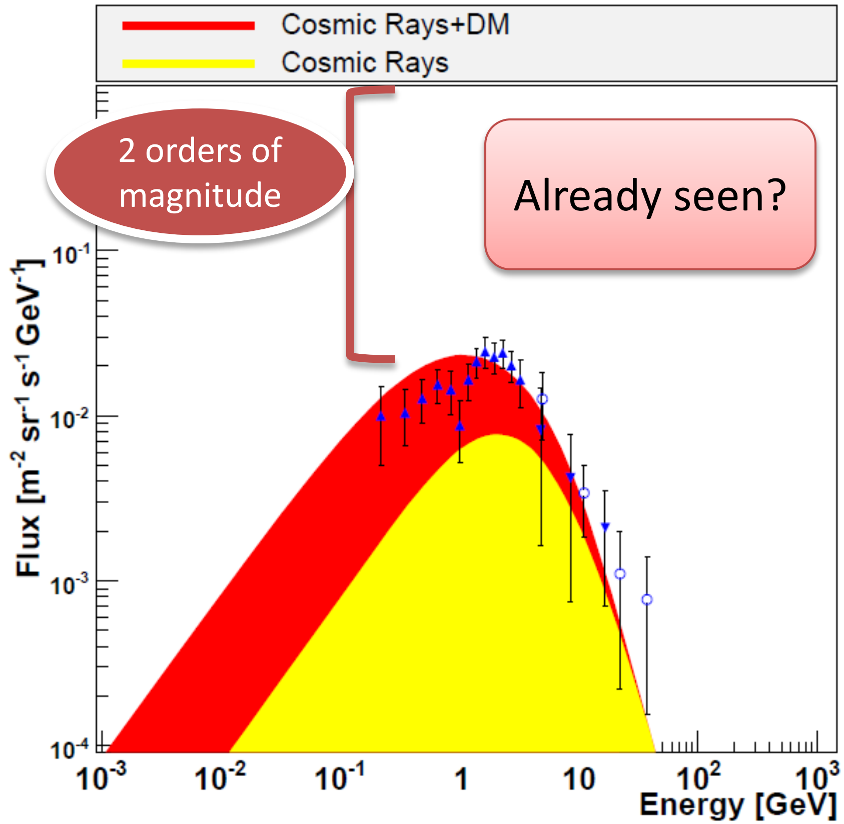
Is Our Propagation Model Wrong?

A disturbing alternative

Gebaur - Uncertainties of the **antiproton** flux from Dark Matter annihilation in comparison to the EGRET excess of diffuse gamma rays 2008



Isotropic



Anisotropic

Only Astrophysical Sources?

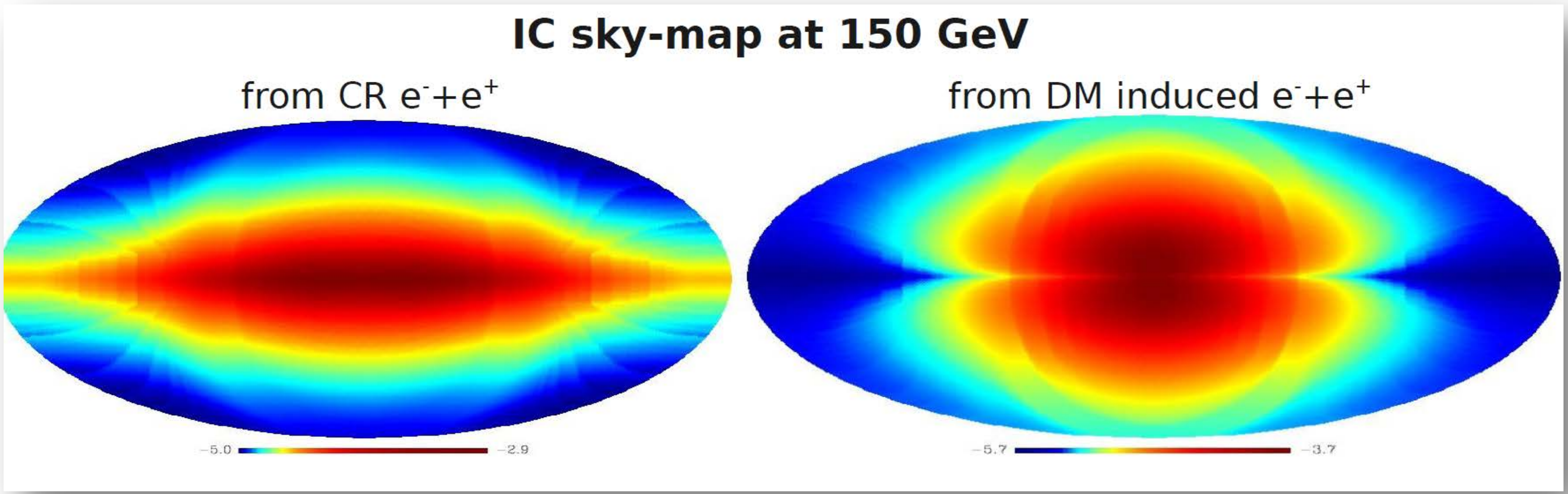
e+ Primary fluxes: DM vs astrophysical sources

- CR sources and astrophysical primary sources of positrons are confined to the Galactic Disc, while the DM component has a spherical distribution
- The ratio of DM signal vs CR/astrophysical signal in the diffuse emission is clear enhanced at mid-high latitudes:

<u>No excess=No DM origin</u>

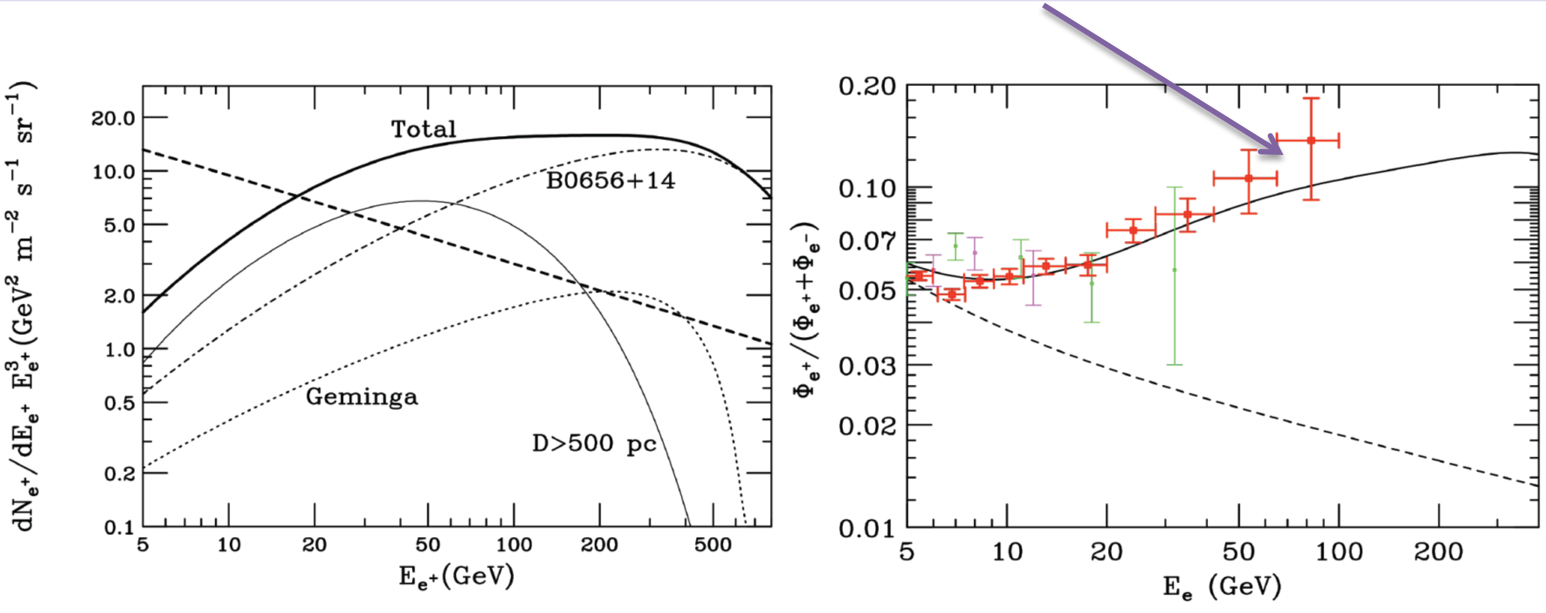
Diffuse emission

Dark matter:
e^-/e^+: IC and synchrotron emission
γ–ray prompt emission : π^0 decay (DMτ) and final state radiation (DMe and DMμ)



e+ from WD and SN Pulsar

Combination of Galactic contribution and two nearby pulsars, **Geminga** (157 pc) and **B0656+14** (290 pc), *can* fit *PAMELA* excess (and perhaps also *Fermi* bump)



Hooper, Blasi & Serpico, JCAP 0901:025,2009

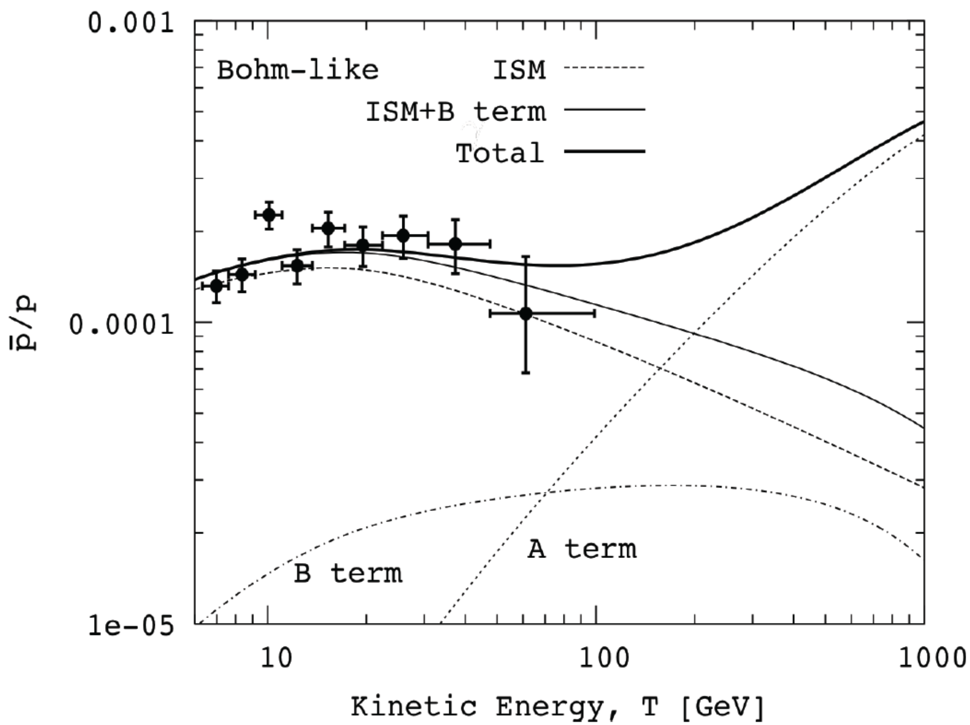
The signal from nearby pulsar is expected to generate a detectable dipole anisotropy in the CR electron spectrum, providing a method by which FERMI would be capable of discriminating between pulsar and dark matter origins of the positrons anomaly: **for DM sources the anisotropy is in the direction of the Galactic Center, for pulsar is in the opposite direction (Geminga+B0656+14)**

But are old SNR also involved?

What about the antiproton-to-proton ratio?

	$\bar{p}/p$
Dark matter	(✓)
Pulsars	✓
Acceleration of secondaries	✓

Blasi & Serpico, PRL 103:081103,2009



Secondary acceleration model predicts rise *beyond* 100 GeV

Conclusions

- **The CR fluxes are a function of the halo model, of the parameters set MIN-MED-MAX adopted for the CR propagation (and nuclear coalescence properties, in the case of antideuterons) and of the DM candidate properties.**
- **Uncertainties are reflected almost exclusively on primary flux from dark matter** (for the secondary don't exceed 25%). **The greatest uncertainties are given by propagation models: about two orders of magnitude, one above one below the MED set.** Decay models and the radial distribution of the halo slightly affect the flux, even if a higher DM density induces a greater annihilation cross section. Clusters and spikes in the inner galaxy, due to the dynamics of the supermassive BH, can significantly increase the flux or generate localized sources, detectable in gamma and neutrinos.
- **The joined results of PAMELA and FERMI pose tight constraints on DM properties.** The antiproton flux between 0.1 and few GeV is perfectly described by a secondary flux from spallation. The positron flux is discordant instead. The annihilation cross section must be high.
- **PAMELA shows that DM must be very massive (10 TeV),** with hadronic annihilation products shifted in the high energy range, **or not too massive (200 GeV ÷ 1 TeV) but leptophilic.**
- **From the absence of Low Energy antiprotons and the solid prediction of antip on antid ratio, one can estimate an upper limit for antideuteron flux**. We can say that the antideuteron events expected in three years are less than ten.
- **Opportunities in antideuterons channel, in the low energy range 0.2 ÷ 4 GeV, are not null but disadvantaged, as AMS-02 can see some antideuterons only from not too heavy candidates (< 500 GeV ÷ 1 TeV)**, probably excluded by PAMELA and FERMI results in antiprotons, positrons and gamma. In any case, the antideuterons background is, in terms of intensity and possibility to distinguish the primary signal, much less disadvantageous than the antiprotons one.

- **The hadronic Low Energy region is realistically obsolete and should be replaced with a High Energy research.** Higher masses correspond to lower fluxes and less chances for AMS-02 to see a signal beyond the sensitivity of $5 \cdot 10^{-7}$. It's possible, even if not probable, that AMS-02 will see neither antiprotons nor antideuterons at GeV scale.

  In function of AMS-02 performances, an hadronic research related to very heavy DM particle can still be made between 70 and 500 GeV, to restart from PAMELA signal.

- **The positron signal, on the other hand, is of course the fundamental channel for DM study.** In terms of intensity of annihilation products fluxes, AMS-02 can see a positron peak for all DM candidates capable of producing e+ beyond 100 GeV.

In summary: the recipe

Dark Matter Parameters Space for a non-leptophilic candidate:

$M_{DM} \geq 2\,TeV$

$\tau_{DM} \approx 10^{26} s$

$\langle \sigma v \rangle \sim 10^{-(26 \div 23)} cm^3 s^{-1}$

$\rho_{\odot} = 0.3 \div 0.4\; GeV\; cm^{-3}$

Channels: bb, tt, gg

Halo

$$\frac{\rho(r)}{\rho_\odot} = \begin{cases} (1 + r_\odot^2/r_s^2)/(1 + r^2/r_s^2) & \text{isothermal, } r_s = 5\,\text{kpc} \\ (r_\odot/r)(1 + r_\odot/r_s)^2/(1 + r/r_s)^2 & \text{NFW, } r_s = 20\,\text{kpc} \\ (r_\odot/r)^{1.16}(1 + r_\odot/r_s)^2/(1 + r/r_s)^{1.84} & \text{Moore, } r_s = 30\,\text{kpc} \\ \exp(-2[(r/r_s)^\alpha - (r_\odot/r_s)^\alpha]/\alpha) & \text{Einasto, } r_s = 20\,\text{kpc},\ \alpha = 0.17 \end{cases}$$

Antiproton & Antideuteron Search :

High Energy $\bar{p}, \bar{d}$ *Fluxes of* $10^{-(5 \div 6)} [GeV\; m^2\; s\; sr]^{-1}$

for Kinetic Energy of $70 \div 500\; GeV/n$