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Complete photon spectra from WIMPs

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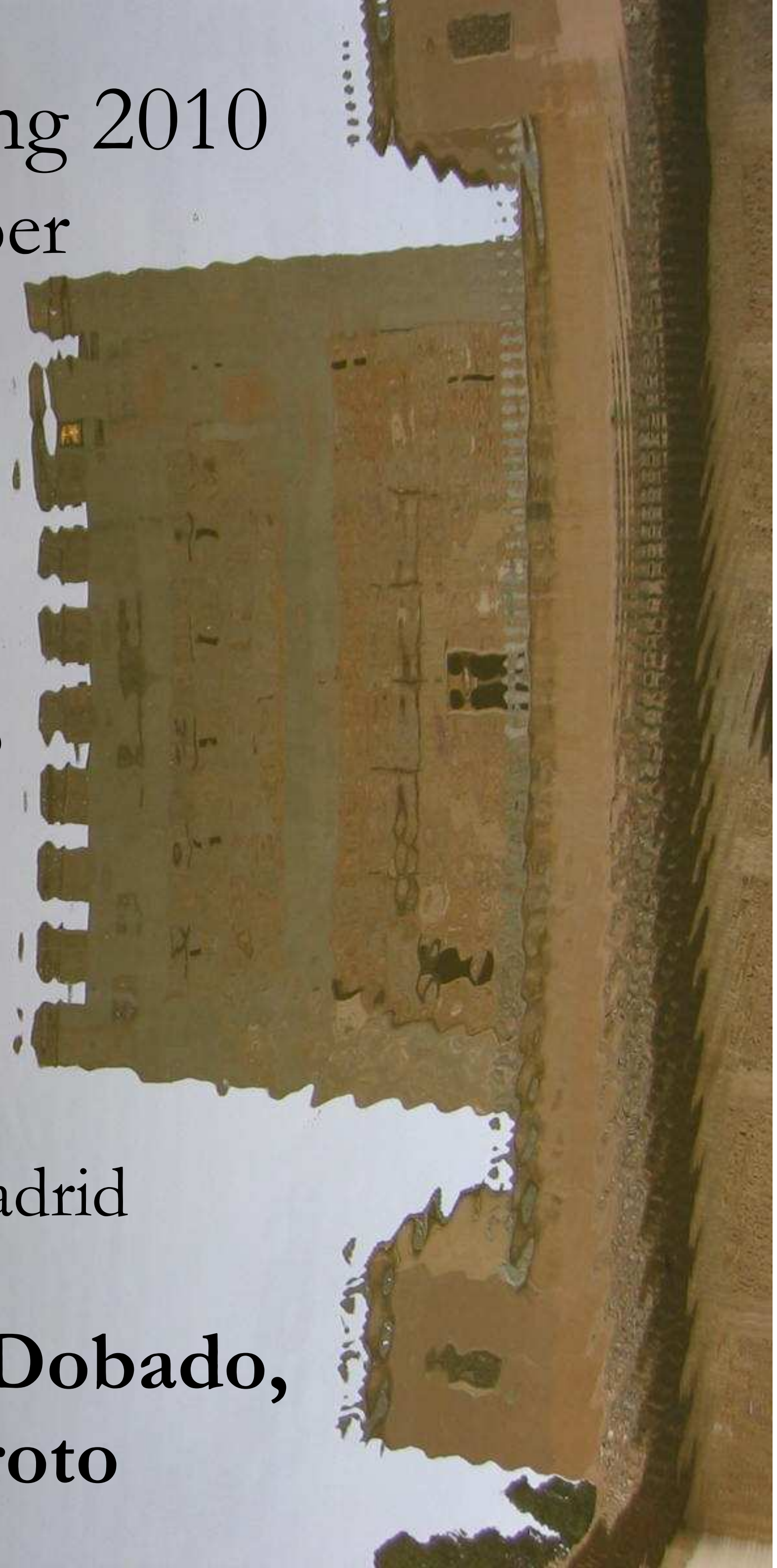


SOME QUESTIONS…

- How many photons are produced from particle - antiparticle decay and hadronization processes?

- How are these photons distributed in the accessible energy range?

ON THIS TALK...

I. Overview

- Indirect searches.
- Montecarlo simulation: PYTHIA.

II. Implementation, results and analysis

- Procedure and statistics.
- PYTHIA software and simulation results.
- Analytical expressions for each annihilation channel.
- Fits to the WIMP mass-dependent parameters.

III . Conclusions

I. OVERVIEW

- Gamma rays fluxes from galactic sources

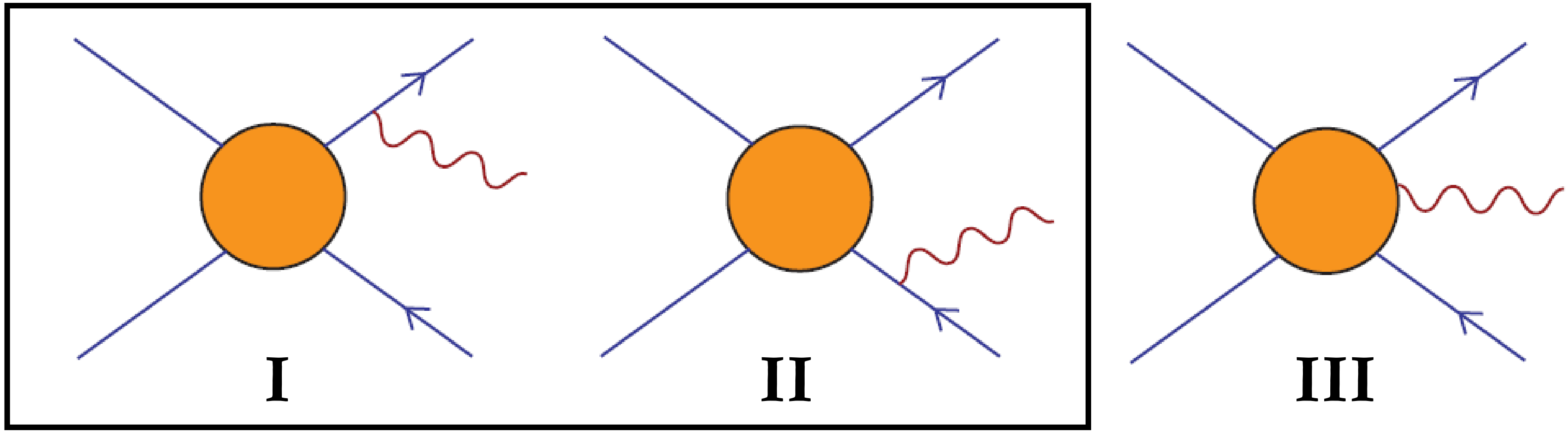
$$\frac{\mathrm{d}\,\Phi_\gamma^{\mathrm{DM}}}{\mathrm{d}\,E_\gamma} = \underbrace{\frac{1}{4\pi M^2}\sum_i \langle\sigma_i v\rangle \frac{\mathrm{d}\,N_\gamma^i}{\mathrm{d}\,E_\gamma}}_{\text{Particle model dependent}} \times \underbrace{\frac{1}{\Delta\Omega}\int_{\Delta\Omega}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\rho^2[r(s)]\;\mathrm{d}s}_{\text{Dark matter density dependent}}$$

- We will focus on differential number of photons $\frac{\mathrm{d}\,N_\gamma^i}{\mathrm{d}\,E_\gamma}$.

- This is an essential piece to interpret photons fluxes as coming from DM annihilation.

- Model dependence comes from annihilation cross section of DM particles.

INTERNAL BREMSSTRAHLUNG…



Bringmann, Bergström and Edsjö **JHEP 0801:049,2008**.

✓ Internal bremsstrahlung contributions **I** and **II** will be included in the performed simulations.

✓ Model dependent contribution **III** is negligible except for models and energies for which lines contribution is dominant over the secondary photons.

Cannoni, Gómez, Sánchez-Conde, Prada & Panella PRD 81 : 107303, 2010.

✓ Dominant contribution of photons at low and intermediate energies photons is produced in decay of outgoing particles.


MONTECARLO
SIMULATION:
PYTHIA

- Physical process to get gamma rays from WIMPs:

Firstly: Annihilation of WIMPs (mainly by pairs) in SM particles.

Secondly: Those unstable SM products decay and/or hadronize.

$$E_{\rm CM} = 2\,M \quad \text{Center of mass frame}$$

- Simulate $E_{\rm CM}$ ⇔ Simulate different WIMP masses.

- Package **PYTHIA 6.418** version was used.

- Variable $x \equiv E_\gamma / M$ in the interval [0, 1].

Energy bins:

$$[10^{-5},\ 10^{-3}]\ [10^{-3},\ 0.2]\ [0.2,\ 0.5]\ [0.5,\ 0.8]\ [0.8,\ 1.0]$$

STATISTICS

✓ What is the number of gamma rays for each simulation?

In $\mathbf{10^7}$ units …

Particle \ Mass (GeV)	100	125	150	200	250	350	500	1000
t	-	-	-	0.70	0.86	0.32	2.81	1.41
W	5.21	-	1.91	6.85	-	7.83	2.91	2.85
Z	0.42	6.01	2.91	14.93	-	14.21	2.81	2.02

Quark \ Mass (GeV)	50	100	200	500	1000	2000	5000	7000	8000
b	11.69	1.91	2.62	2.61	8.81	2.20	3.81	-	1.70
c	2.41	1.99	16.82	2.81	2.81	3.81	12.00	-	3.00
d	1.04	1.96	2.42	2.81	2.81	2.81	2.31	-	-
s	15.30	2.00	1.97	2.81	9.82	2.71	2.71	11.00	1.35
u	2.05	11.86	2.42	2.81	3.82	10.85	5.91	-	2.11

ANALYTICAL EXPRESSIONS TO FIT PYTHIA SIMULATIONS

✓ Now that simulations have been performed, proposed analytical expressions:

I. Quarks (except for top quark) and tau lepton:

$$x^{1.5}\frac{\mathrm{d}N_\gamma}{\mathrm{d}x} = a_1 \exp\left(-b_1 x^{n_1} - b_2 x^{n_2} - \frac{c_1}{x^{d_1}} + \frac{c_2}{x^{d_2}}\right) + q\, x^{1.5} \ln\left[p(1-x)\right] \frac{x^2 - 2x + 2}{x}$$

- Two increasing and two decreasing exponential factors.
- Logarithm term: Weizsacker-Williams effect.
- Parameter *p* is usually $(M/m_{particle})^2$ free in principle here.
- Some parameters are constant and others mass-dependent.

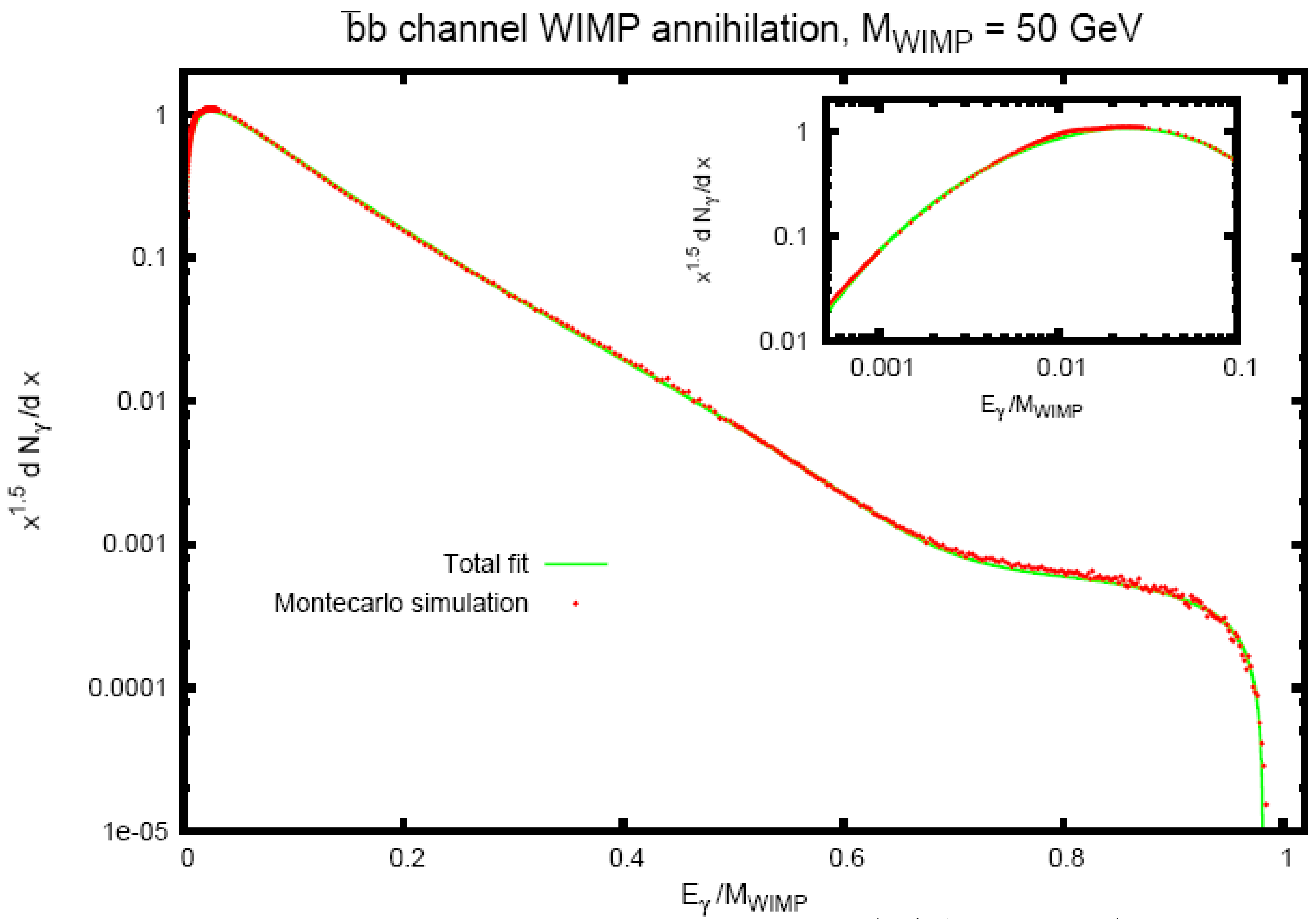
QUARK b RESULTS

- Five parameters are mass independent:

$$a_1 = 10.0,\ b_2 = 11.0,\ c_2 = 0.0151\ ,\ d_2 = 0.55,\ q = 0.00026.$$

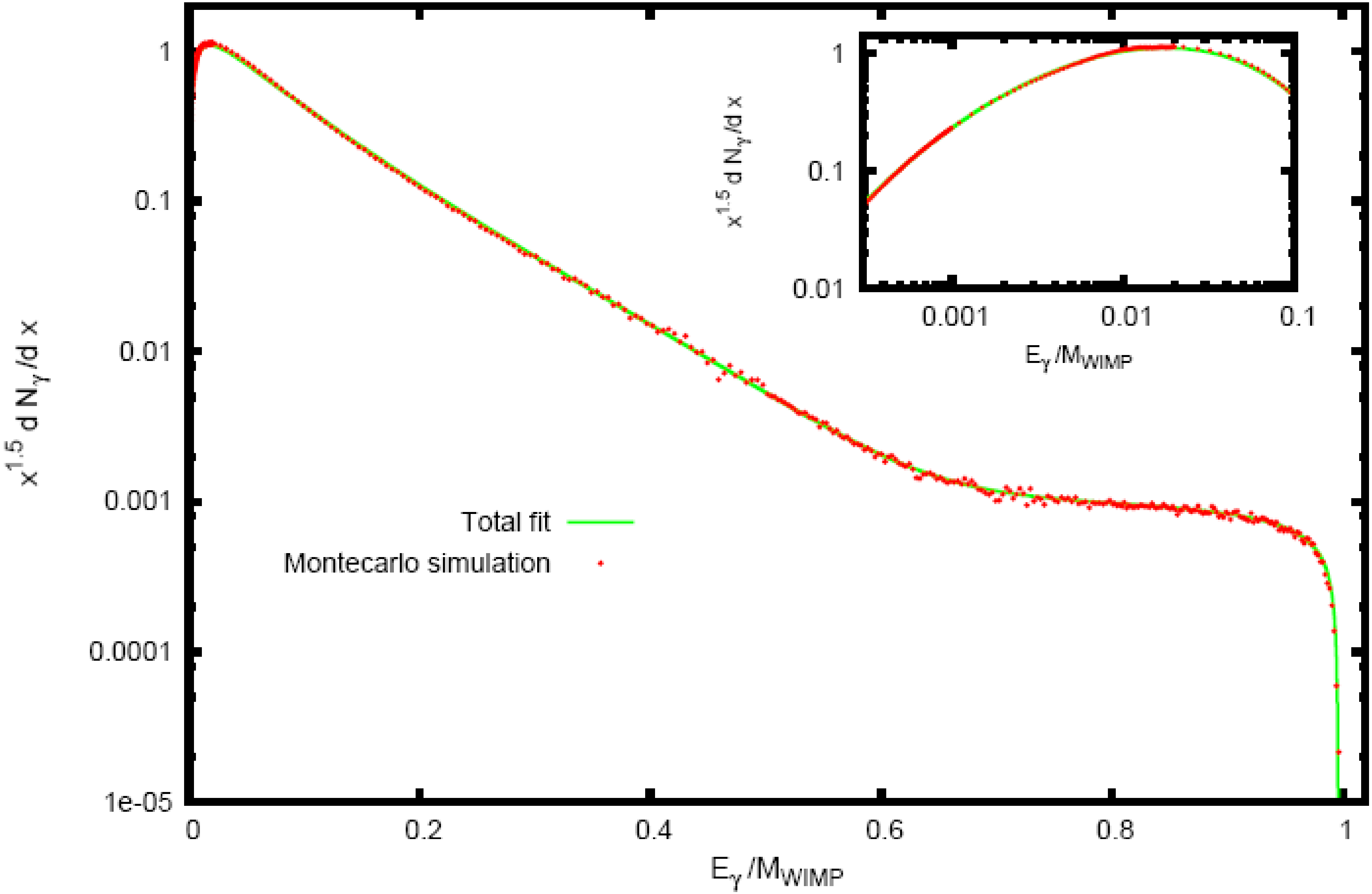
- Six mass-dependent parameters.

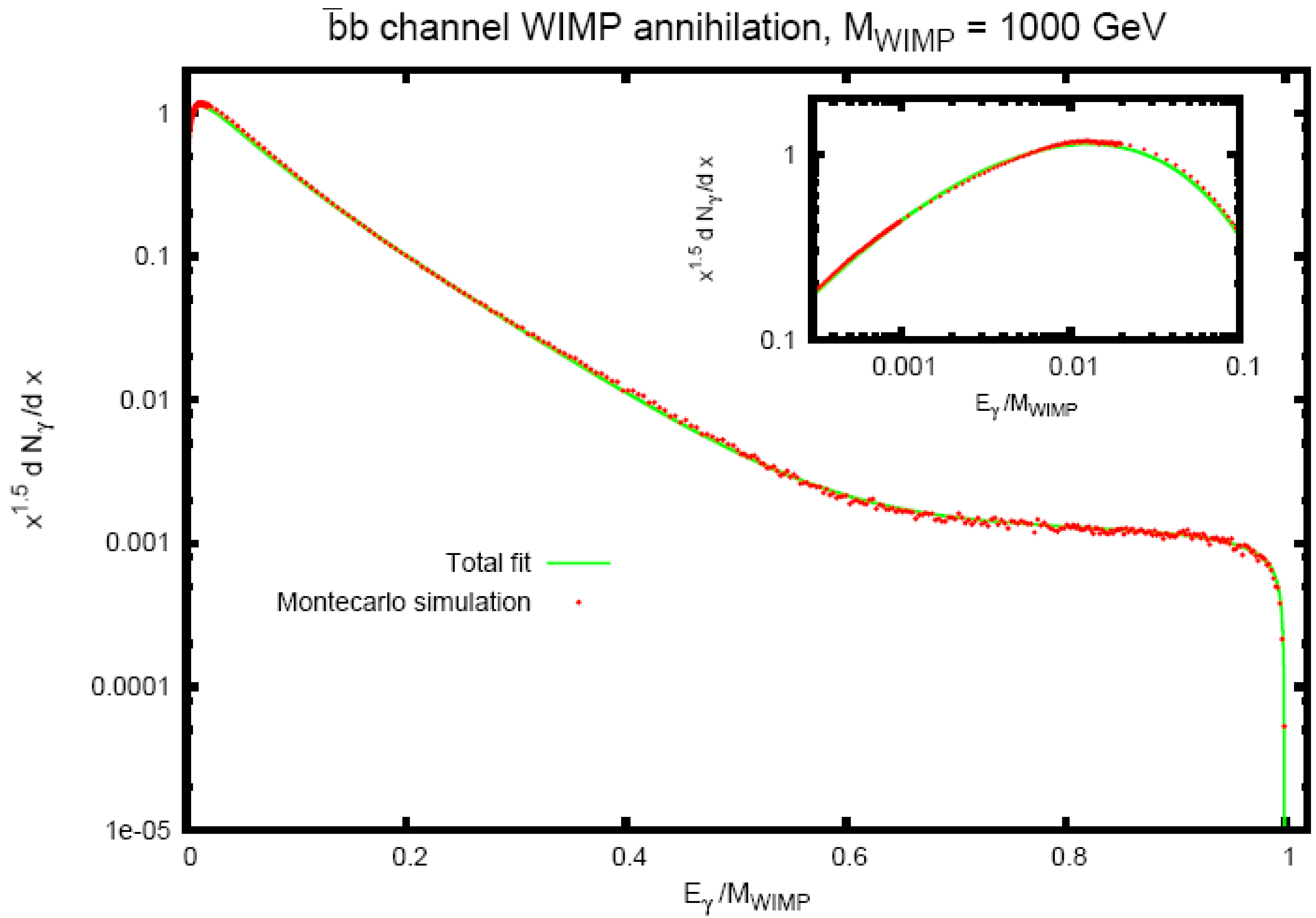
WIMP mass (GeV)	b_1	n_1	n_2	c_1	d_1	p
50	19.5	6.48	0.710	0.365	0.393	57.8
100	17.1	5.80	0.695	0.403	0.360	138
200	13.1	5.01	0.680	0.415	0.340	281
500	8.76	4.04	0.660	0.431	0.319	623
1000	6.00	3.36	0.647	0.447	0.305	1030
2000	4.60	2.85	0.640	0.460	0.294	1620
5000	3.00	2.26	0.634	0.479	0.280	2670
8000	2.35	2.00	0.629	0.490	0.274	3790



A. de la Cruz-Dombriz ERE2010

$\bar{b}b$ channel WIMP annihilation, M_{WIMP} = 200 GeV





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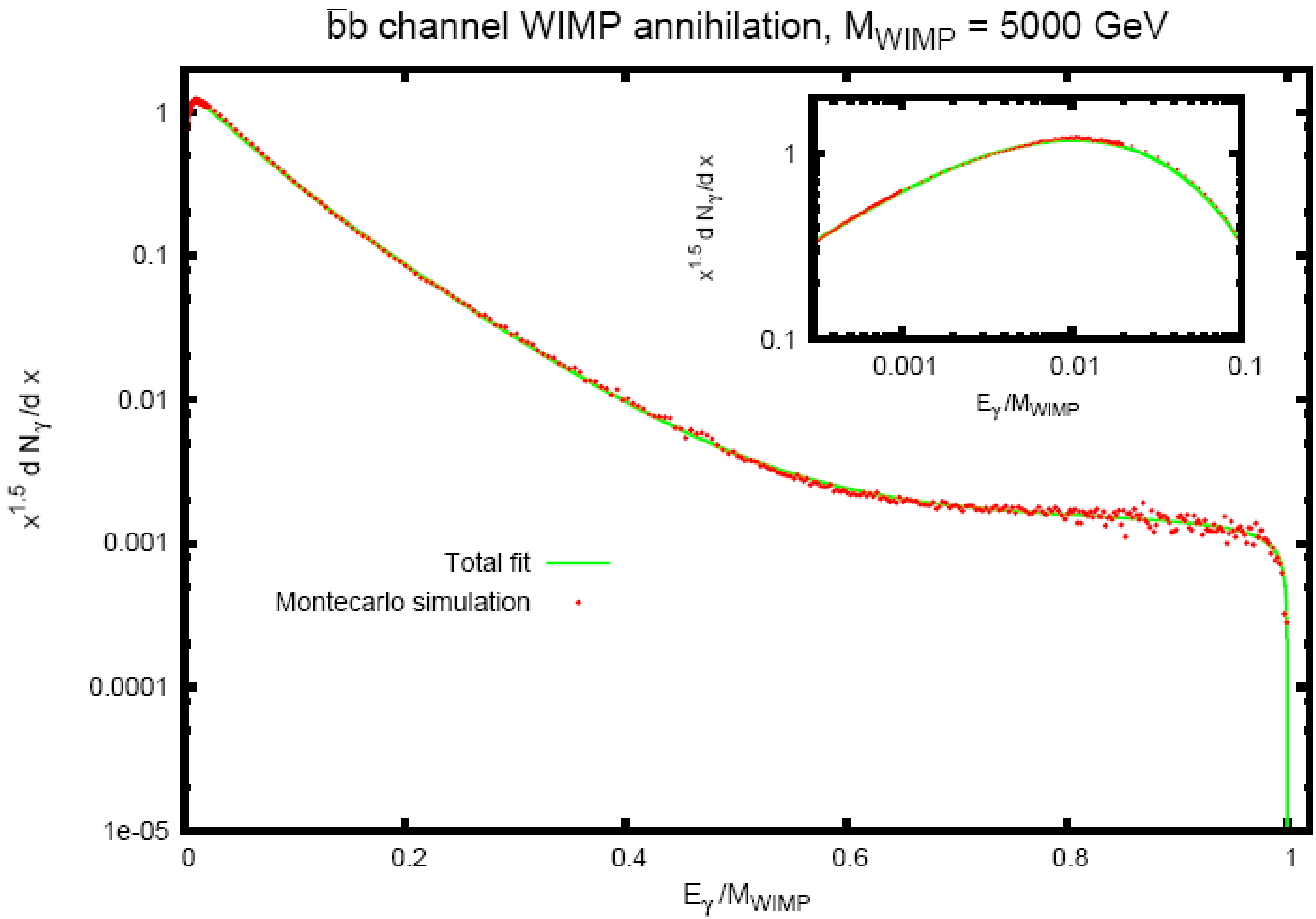

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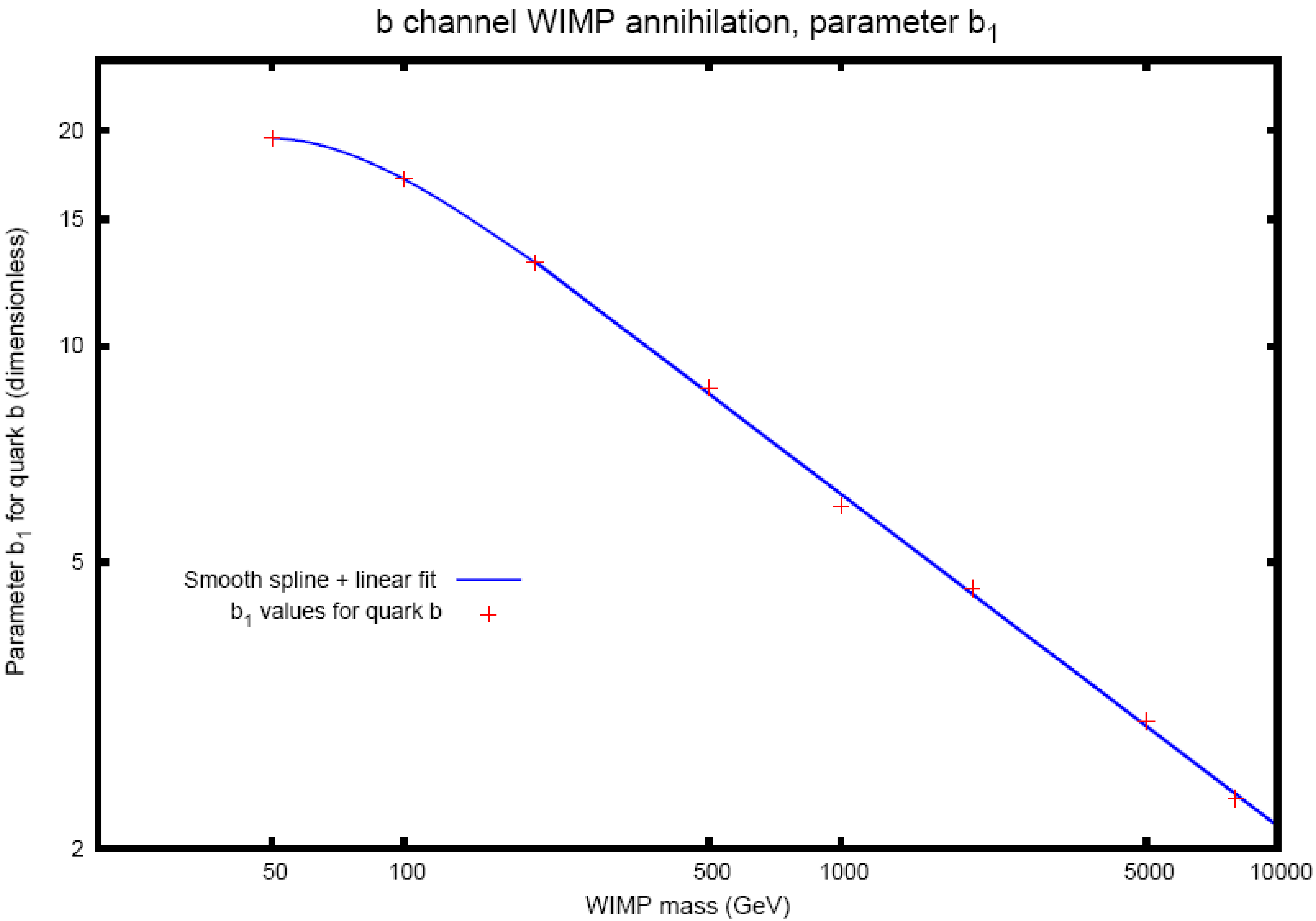


✓ In general, parameters follow a linear law at high masses and deviate at low masses.

τ LEPTON RESULTS

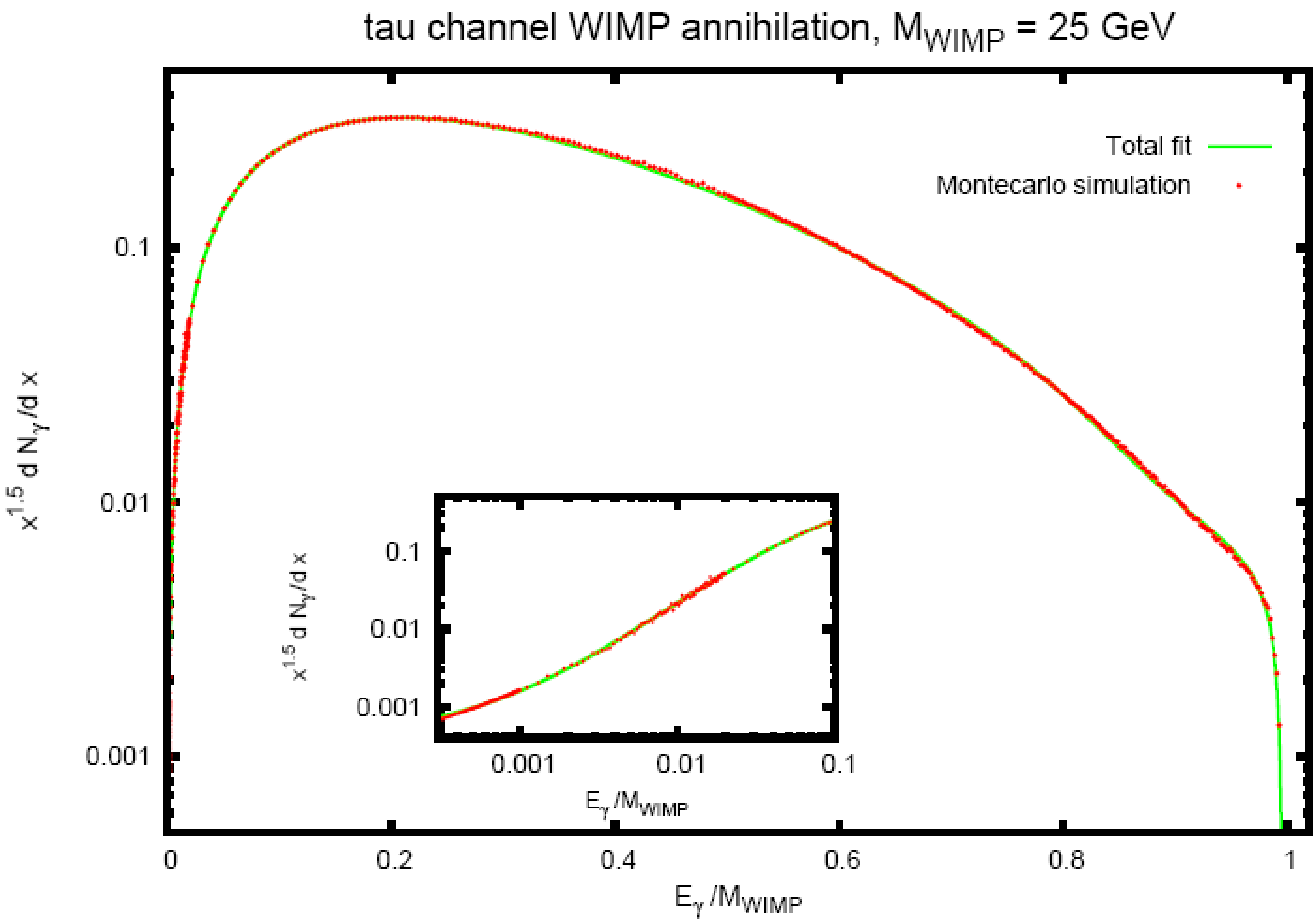
✓ Only **two** parameters are mass-dependent.

$a_1 = 14.7,\ b_1 = 5.4,\ b_2 = 5.31,\ n_2 = 1.40$

$c_1 = 2.54\ ,\ d_1 = 0.295\ ,\ c_2 = 0.373$

$d_2 = 0.47$ and $q = 0.0026$

WIMP mass (GeV)	n_1	p
25	10.1	221
50	10.0	767
100	9.91	2520
200	9.80	8660
500	9.67	$4.01 \cdot 10^4$
1000	9.57	$1.35 \cdot 10^5$
10^4	9.25	$4.80 \cdot 10^6$
$5 \cdot 10^4$	9.14	$5.44 \cdot 10^7$



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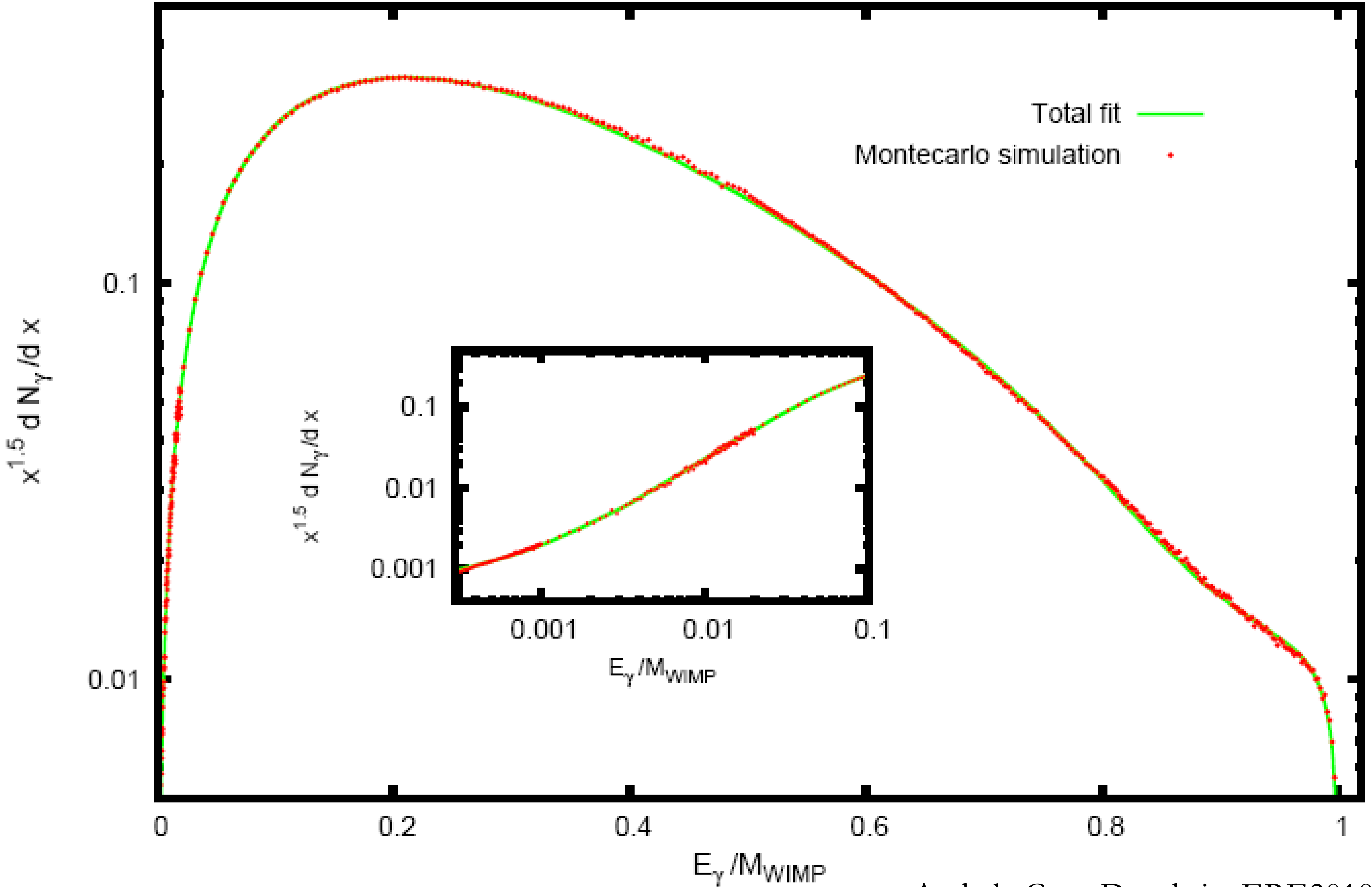
tau channel WIMP annihilation, M_{WIMP} = 100 GeV



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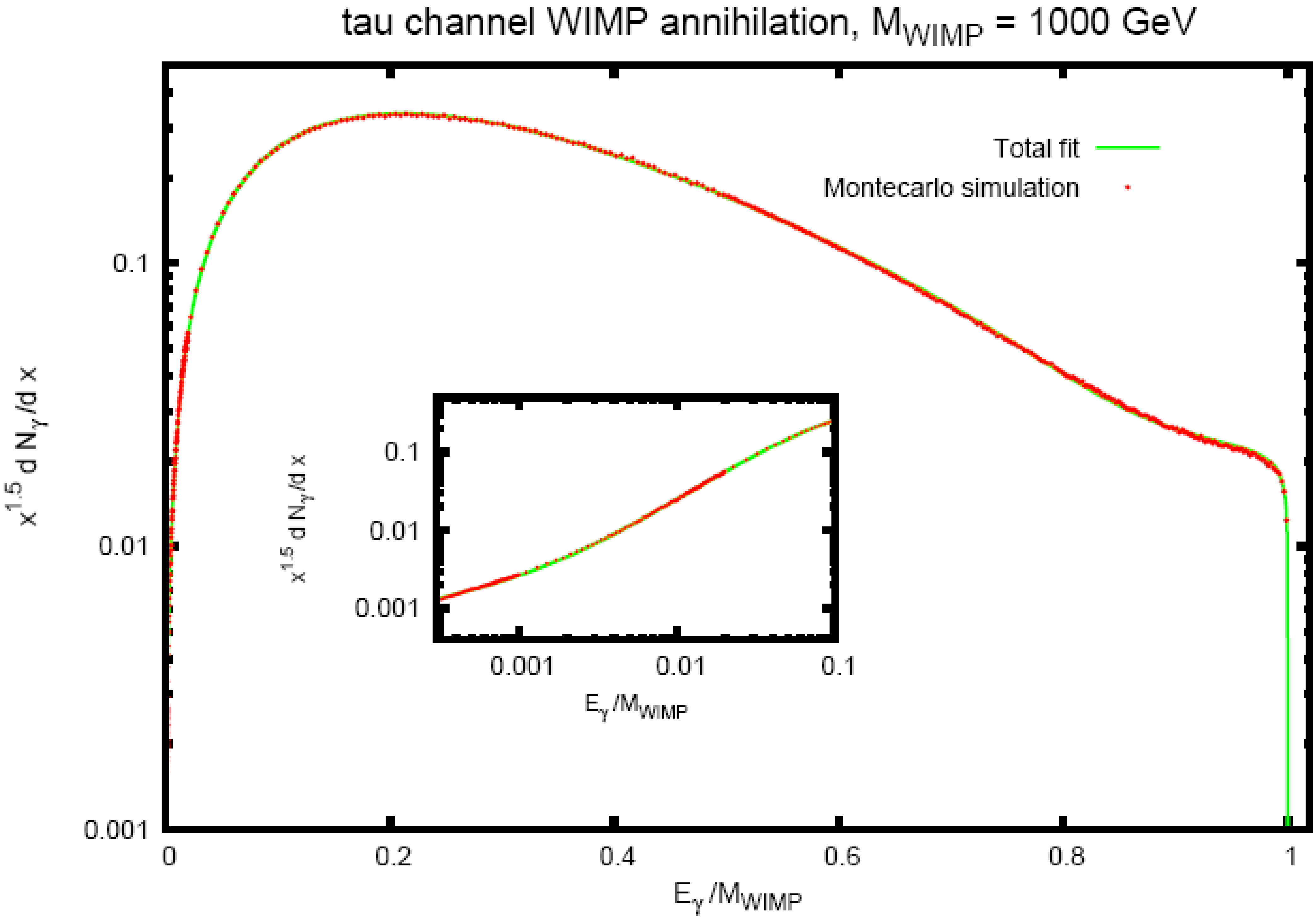

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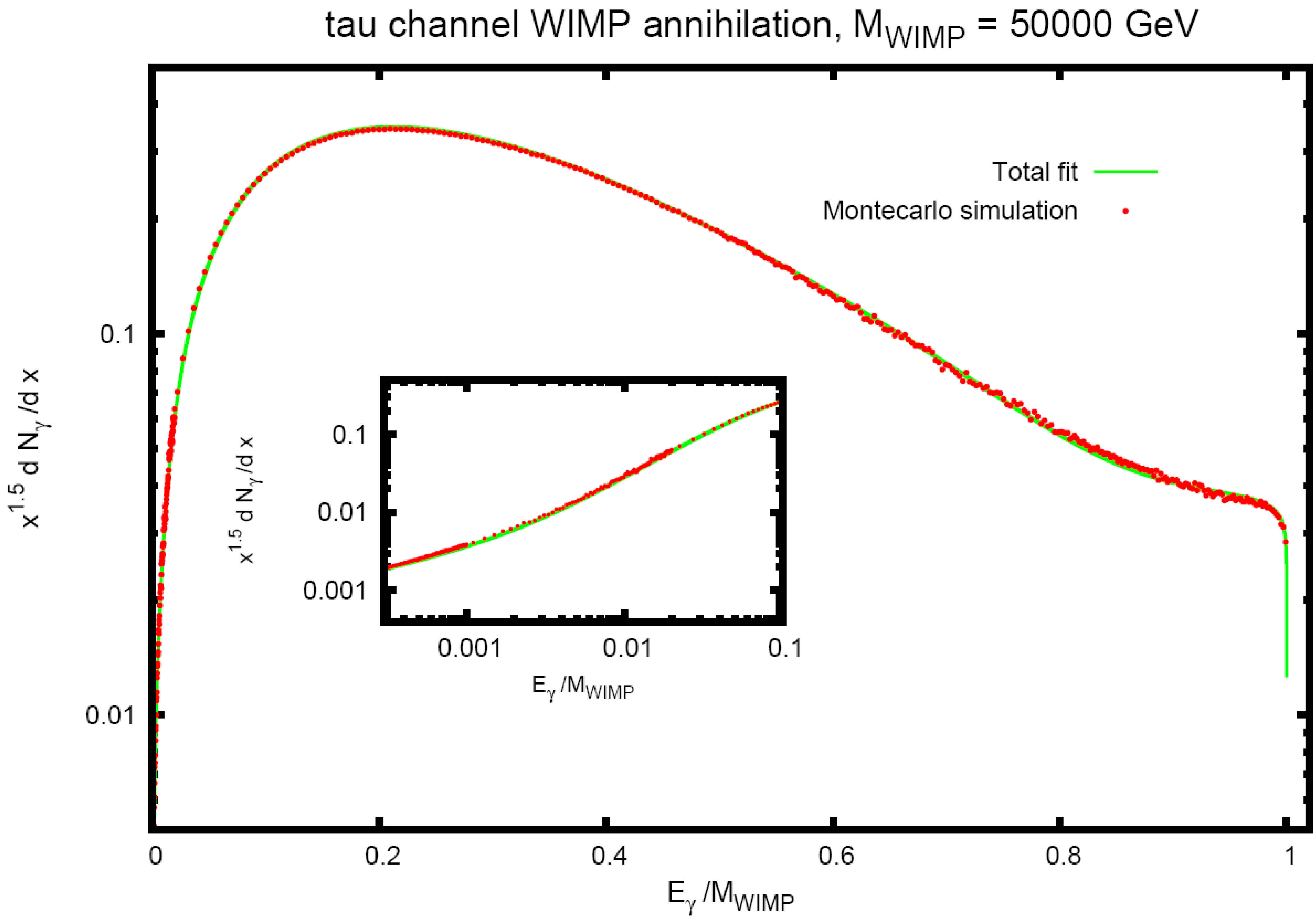

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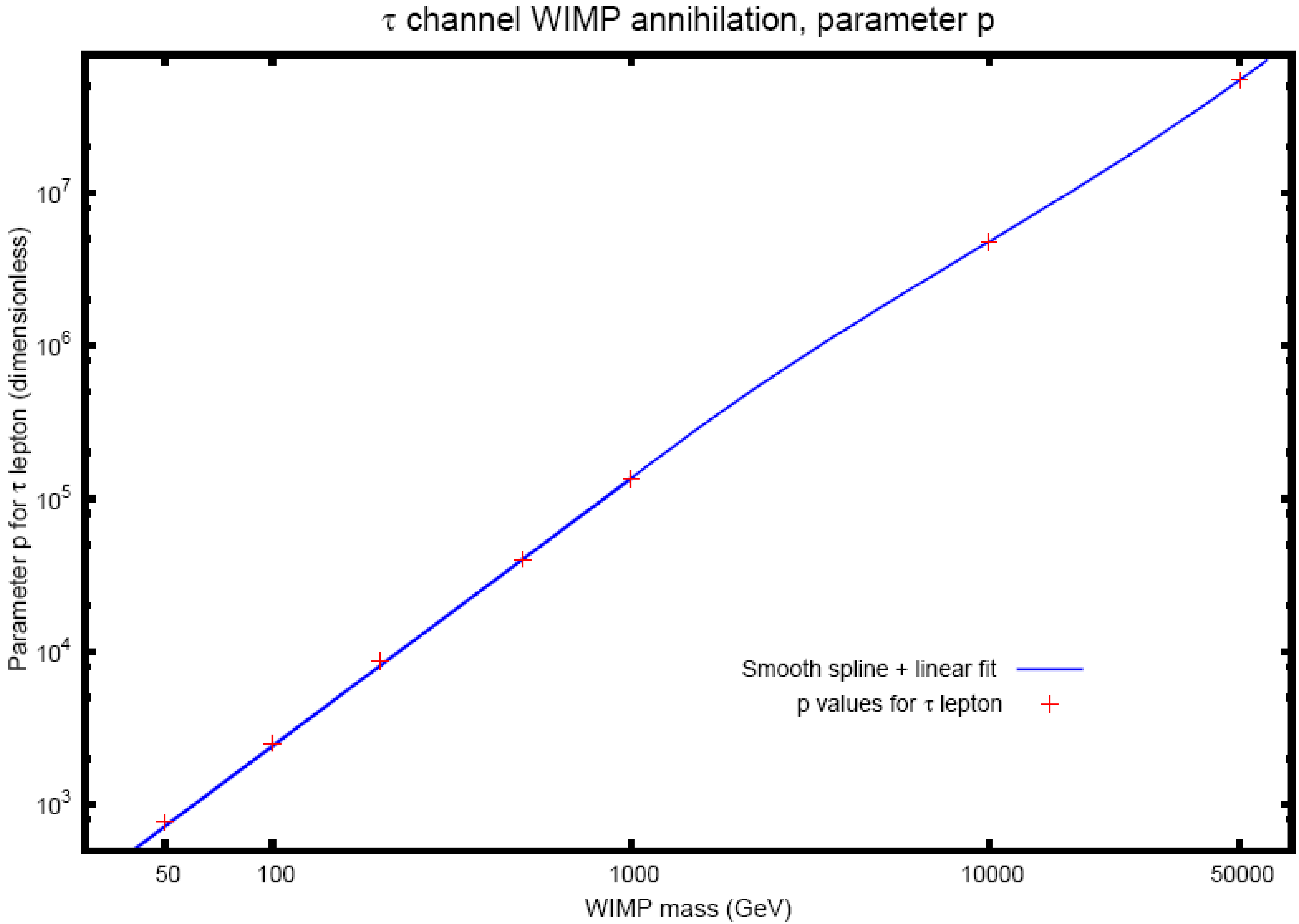


τ channel WIMP annihilation, parameter p
Parameter p for τ lepton (dimensionless)
10^7
10^6
10^5
10^4
10^3
50
100
1000
10000
50000
WIMP mass (GeV)
Smooth spline + linear fit
p values for τ lepton

II. Gauge bosons W and Z:

$$x^{1.5}\frac{\mathrm{d}N_\gamma}{\mathrm{d}x} = a_1 \exp\left(-b_1\, x^{n_1} - \frac{c_1}{x^{d_1}}\right)\left\{\frac{\ln[p(j-x)]}{\ln p}\right\}^q$$

- One increasing and one decreasing exponential factor.
- Logarithm term acquires a multiplicative behaviour.
- Parameter j allows to cut-off high energy photons.

III. Quark top:

$$x^{1.5}\frac{\mathrm{d}N_\gamma}{\mathrm{d}x} = a_1 \exp\left(-b_1\, x^{n_1} - \frac{c_1}{x^{d_1}} - \frac{c_2}{x^{d_2}}\right)\left\{\frac{\ln[p(1-x^l)]}{\ln p}\right\}^q$$

- One increasing and two decreasing exponential factors.
- Logarithm term also acquires a multiplicative behaviour.

W GAUGE BOSON RESULTS

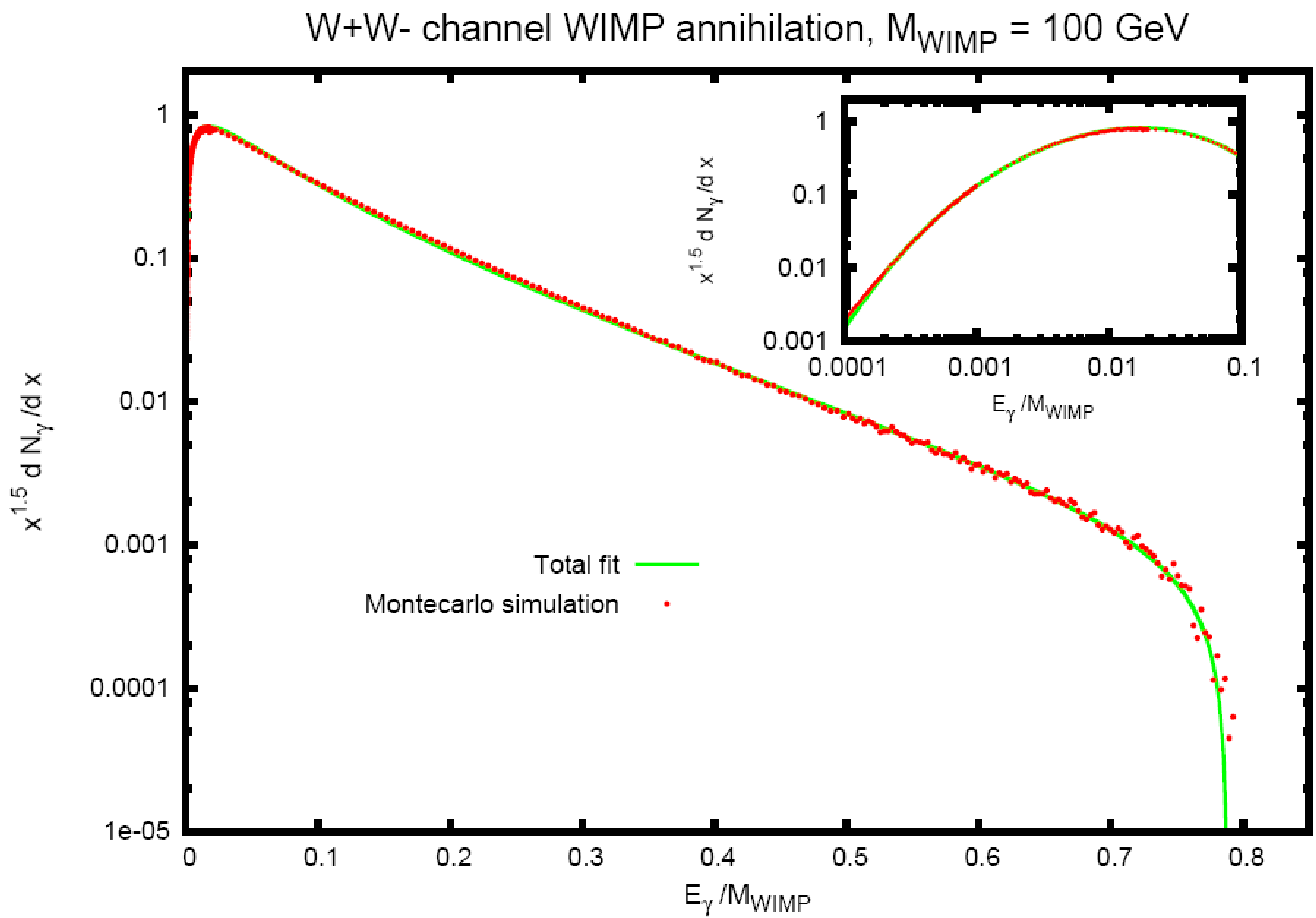
- Three parameters are mass independent.

$$a_1 = 25.7 \quad , n_1 = 0.51 \text{ and } q = 3.0$$

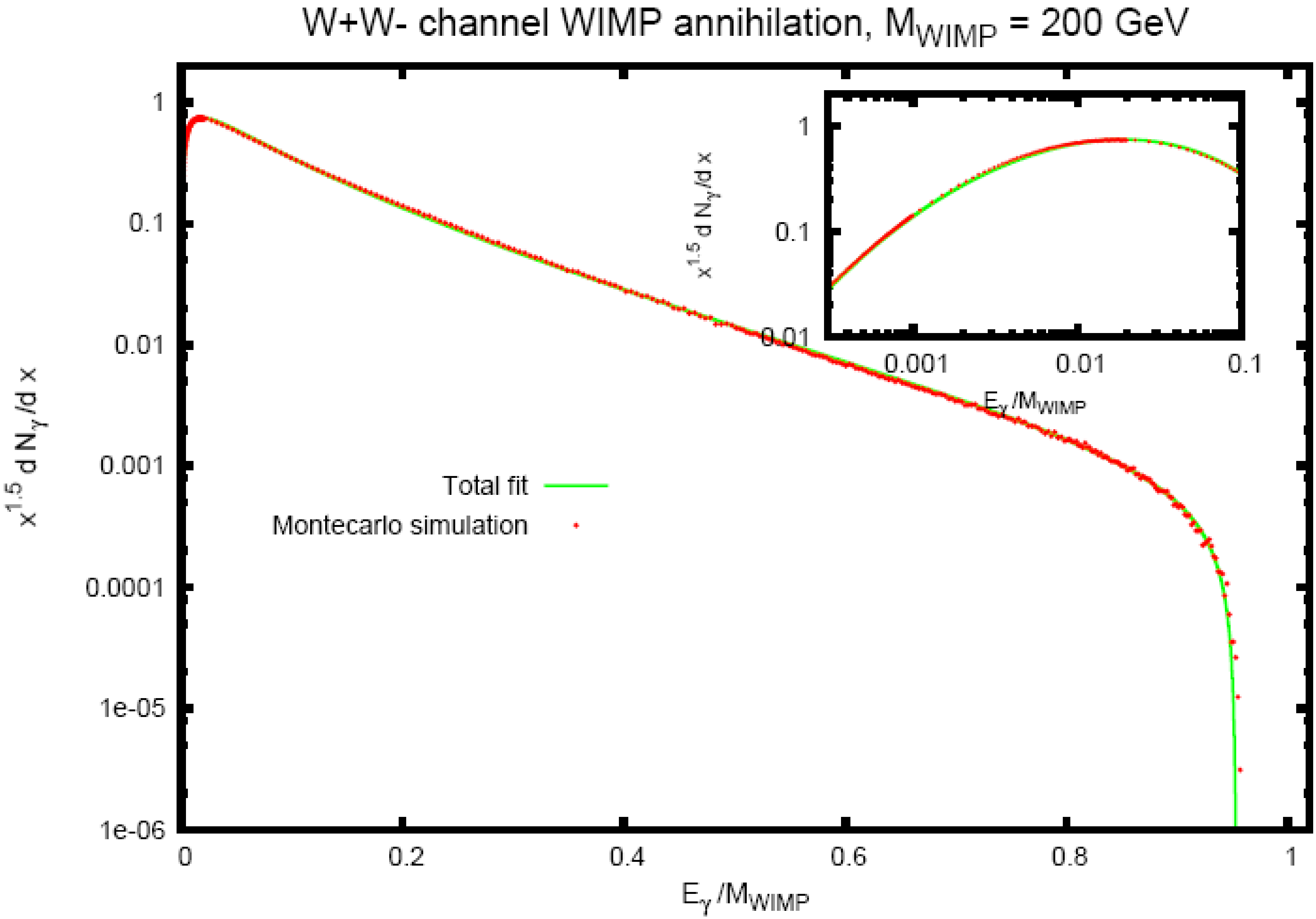
- Five mass-dependent parameters.

WIMP mass (GeV)	b_1	c_1	d_1	p	j
100	9.48	0.651	0.292	973	0.790
150	8.87	0.808	0.261	783	0.919
200	8.64	0.882	0.250	684	0.955
350	8.56	0.907	0.245	593	0.991
500	8.51	0.917	0.244	560	0.996
1000	8.45	0.931	0.242	535	1.000

- From 1000 GeV onwards, spectra do not change if masses increase.



W+W- channel WIMP annihilation, M_WIMP = 100 GeV
x^1.5 d N_γ /d x
E_γ /M_WIMP
1
0.1
0.01
0.001
0.0001
1e-05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Total fit
Montecarlo simulation
0.0001
0.001
0.01
0.1



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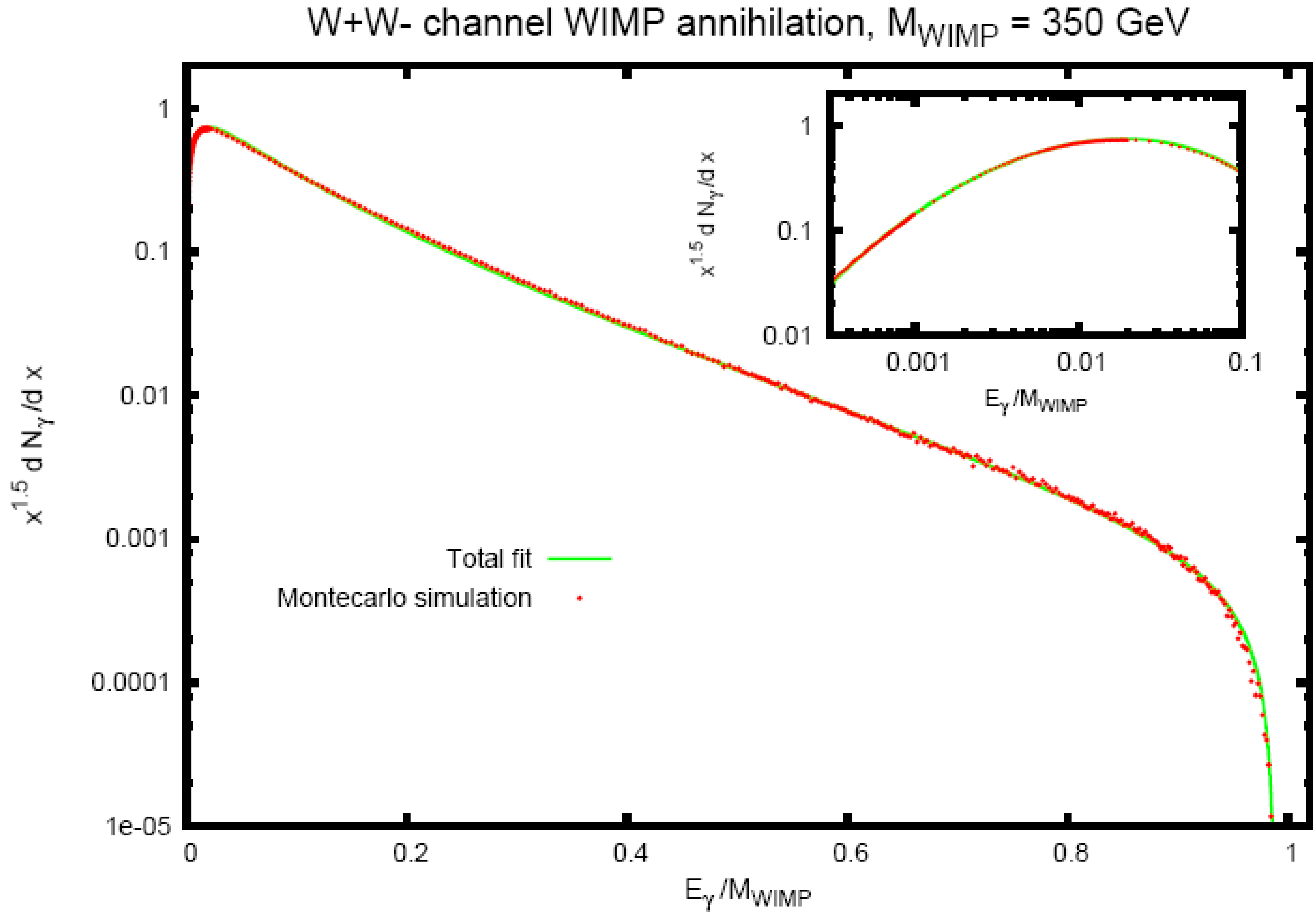
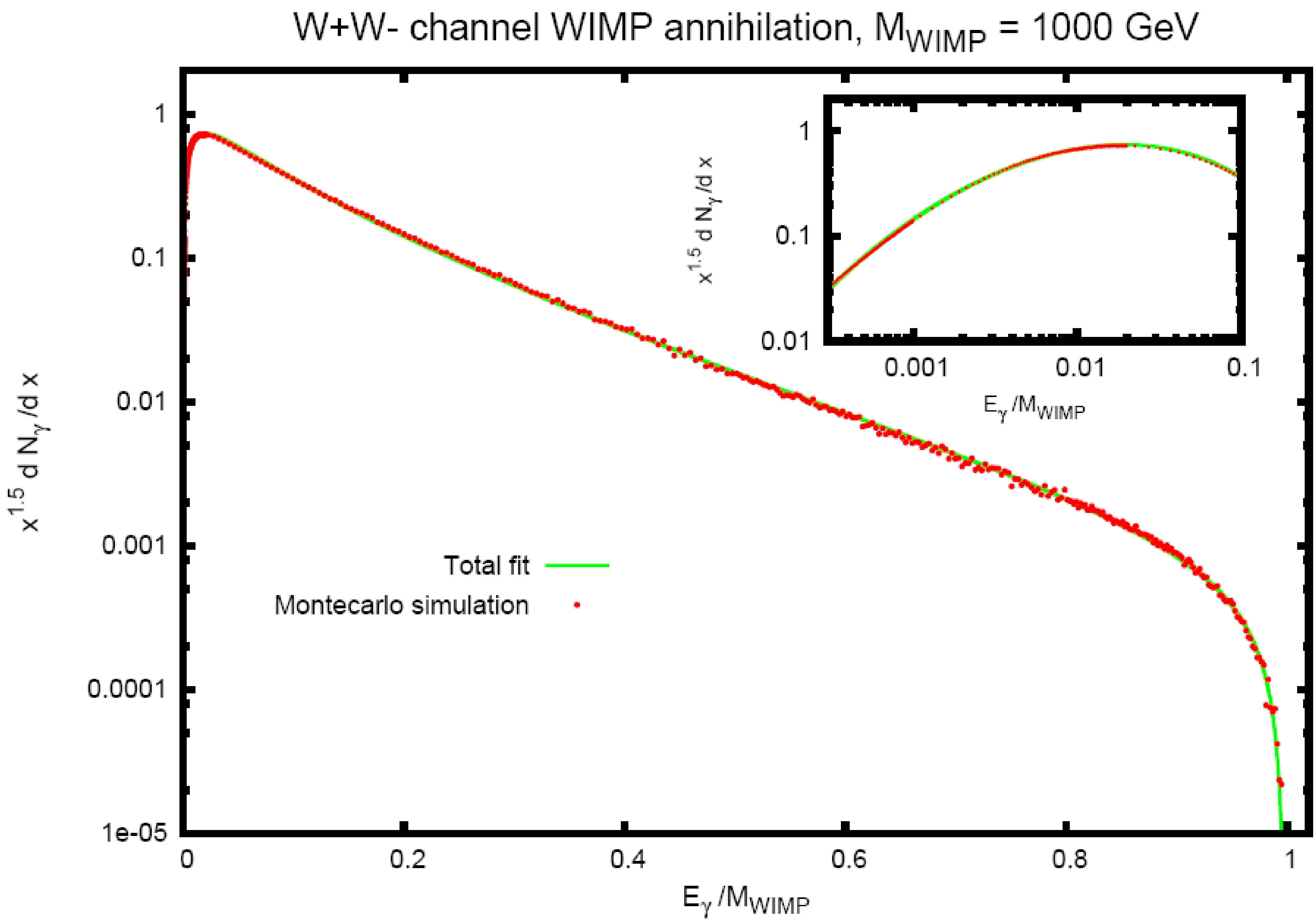


W+W- channel WIMP annihilation, M_WIMP = 350 GeV
x^1.5 d N_γ /d x
E_γ /M_WIMP
Total fit
Montecarlo simulation
1
0.1
0.01
0.001
0.0001
1e-05
0
0.2
0.4
0.6
0.8
1



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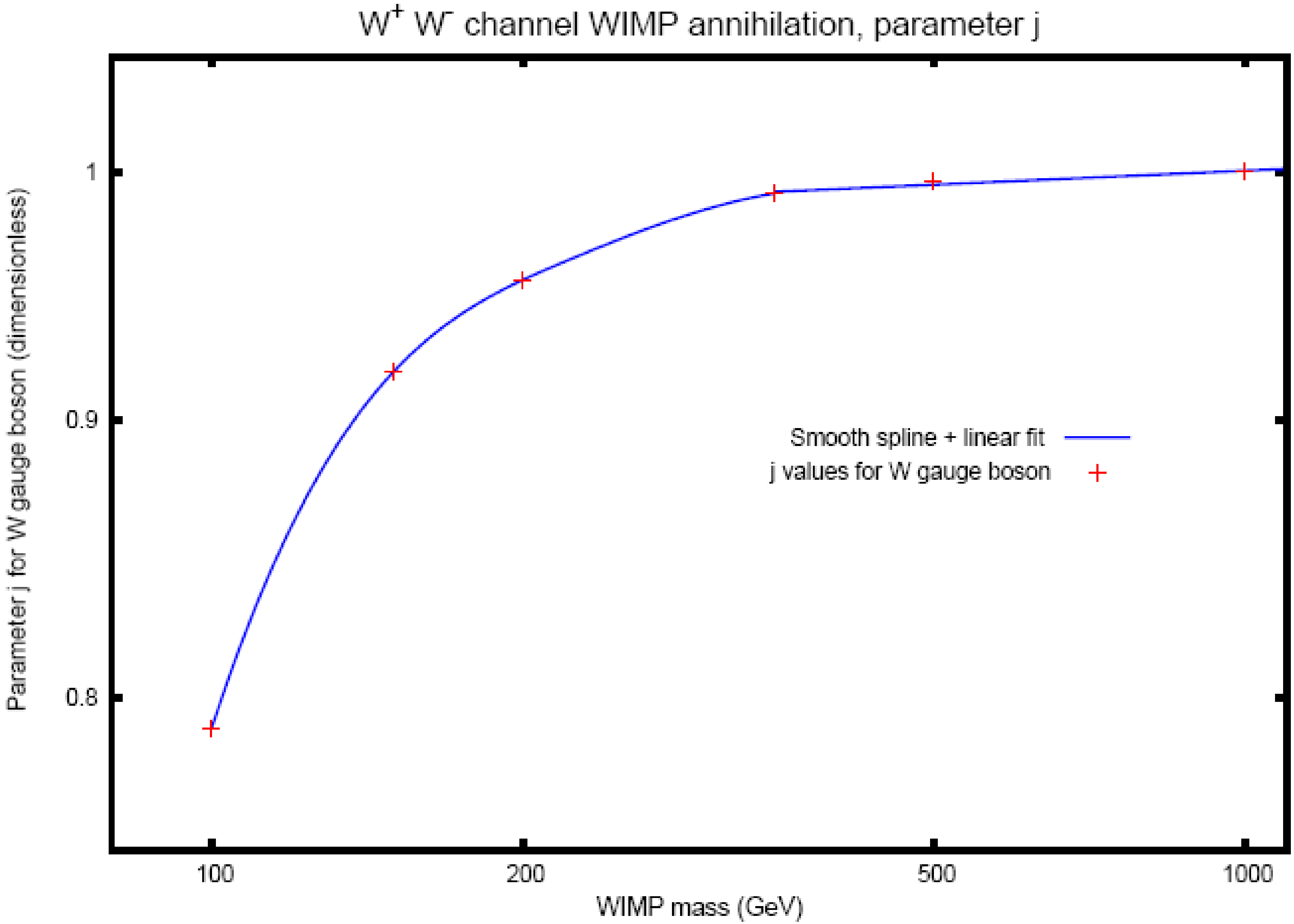


✓ In general, parameters follow a linear law at high masses and deviate at low masses.

TOP QUARK RESULTS

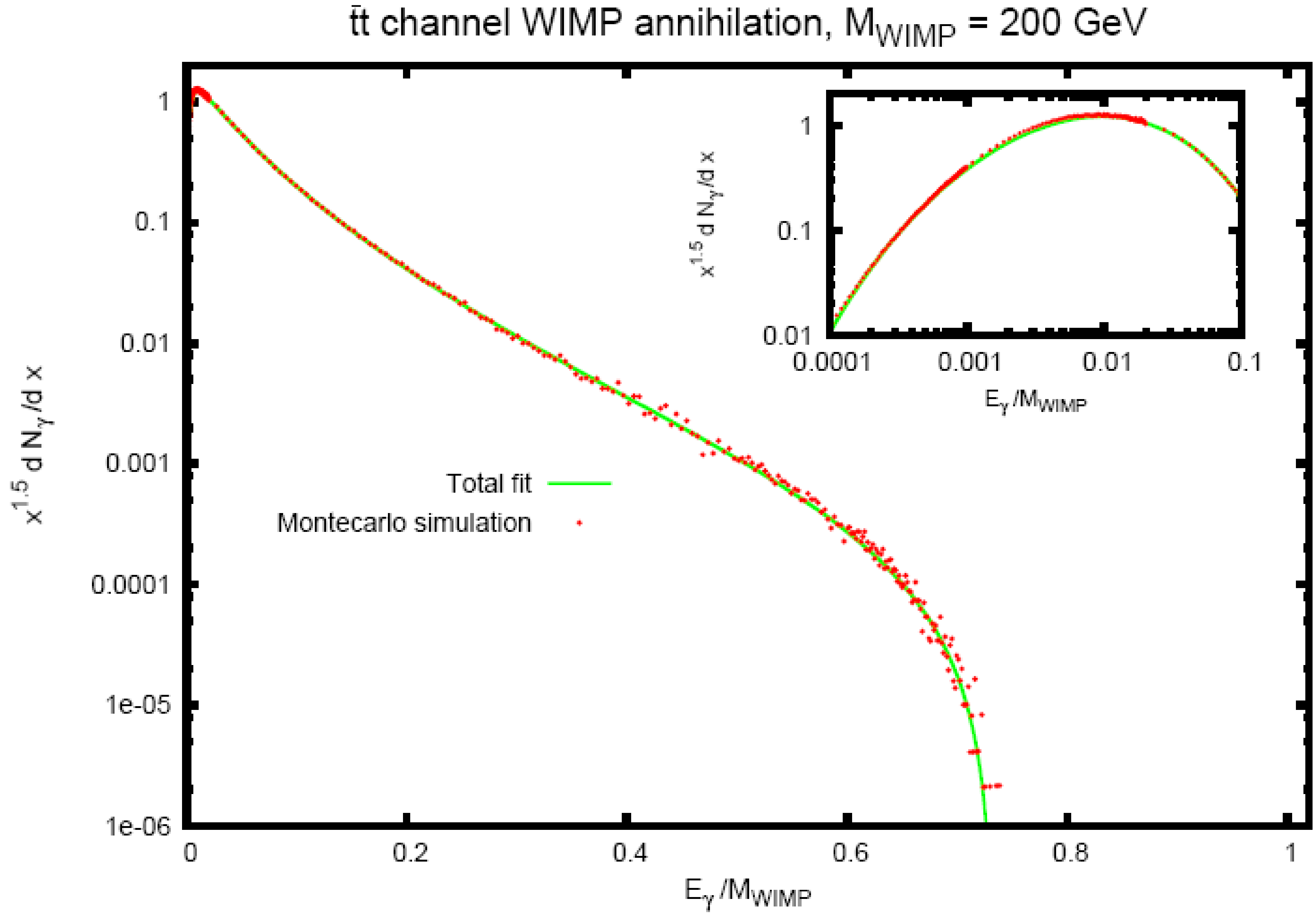
- Four parameters are mass independent.

$$a_1 = 290 \; | , \; c_1 = 1.61, \; d_1 = 0.19 \text{ and } d_2 = 0.844$$

- Six parameters are mass dependent.

WIMP mass (GeV)	b_1	n_1	c_2	p	q	l
200	14.4	0.477	$3.34 \cdot 10^{-4}$	1.34	1.76	4.42
250	13.5	0.457	$1.54 \cdot 10^{-4}$	1.95	1.96	4.14
350	13.0	0.448	$5.99 \cdot 10^{-5}$	3.78	2.32	3.74
500	12.8	0.442	$1.69 \cdot 10^{-5}$	7.40	2.75	3.36
1000	12.4	0.436	$1.80 \cdot 10^{-6}$	30.0	3.85	2.72

- Spectra for low masses do not attain the highest available energy. As WIMP masses grow, the spectra approach this energy.



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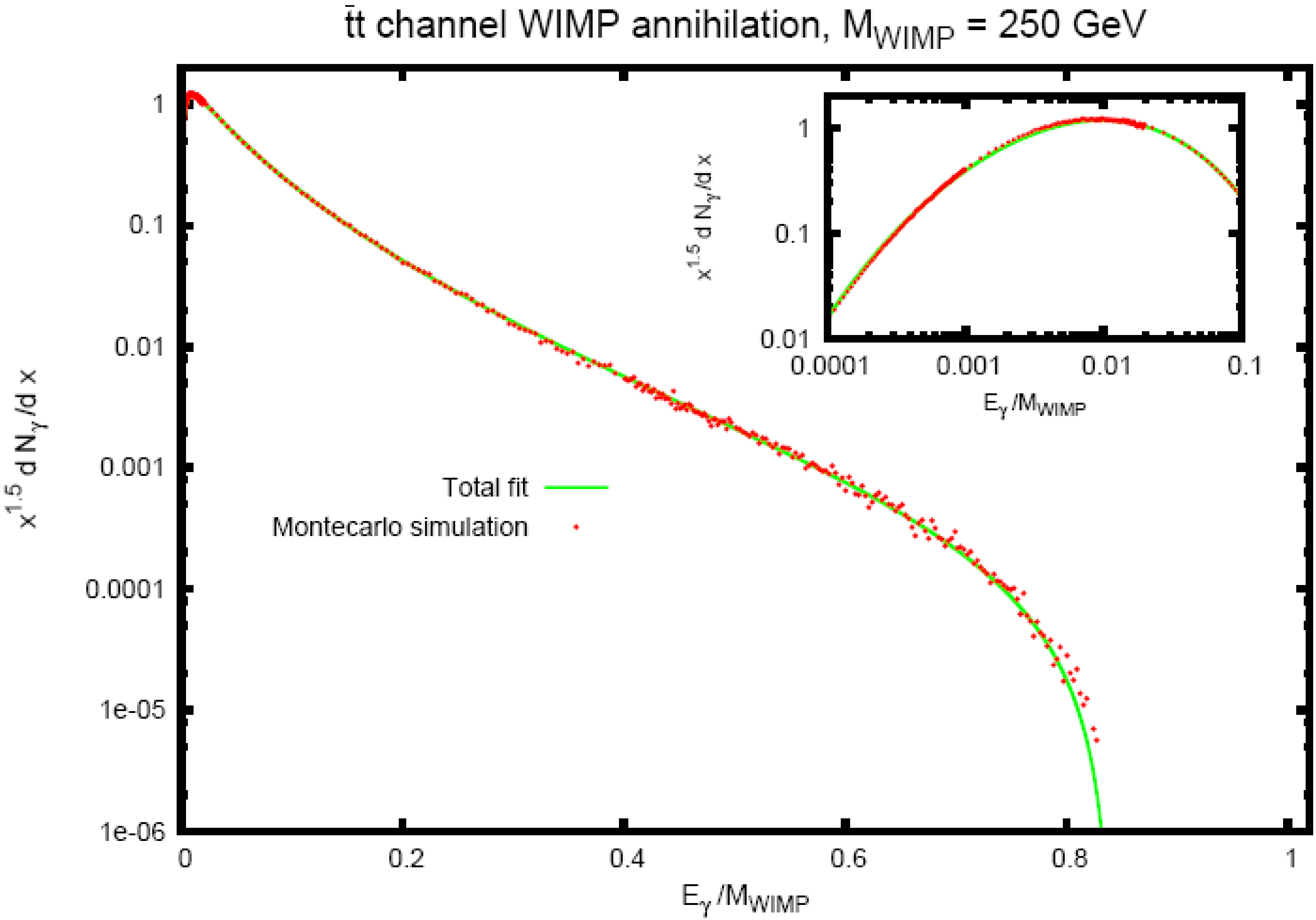

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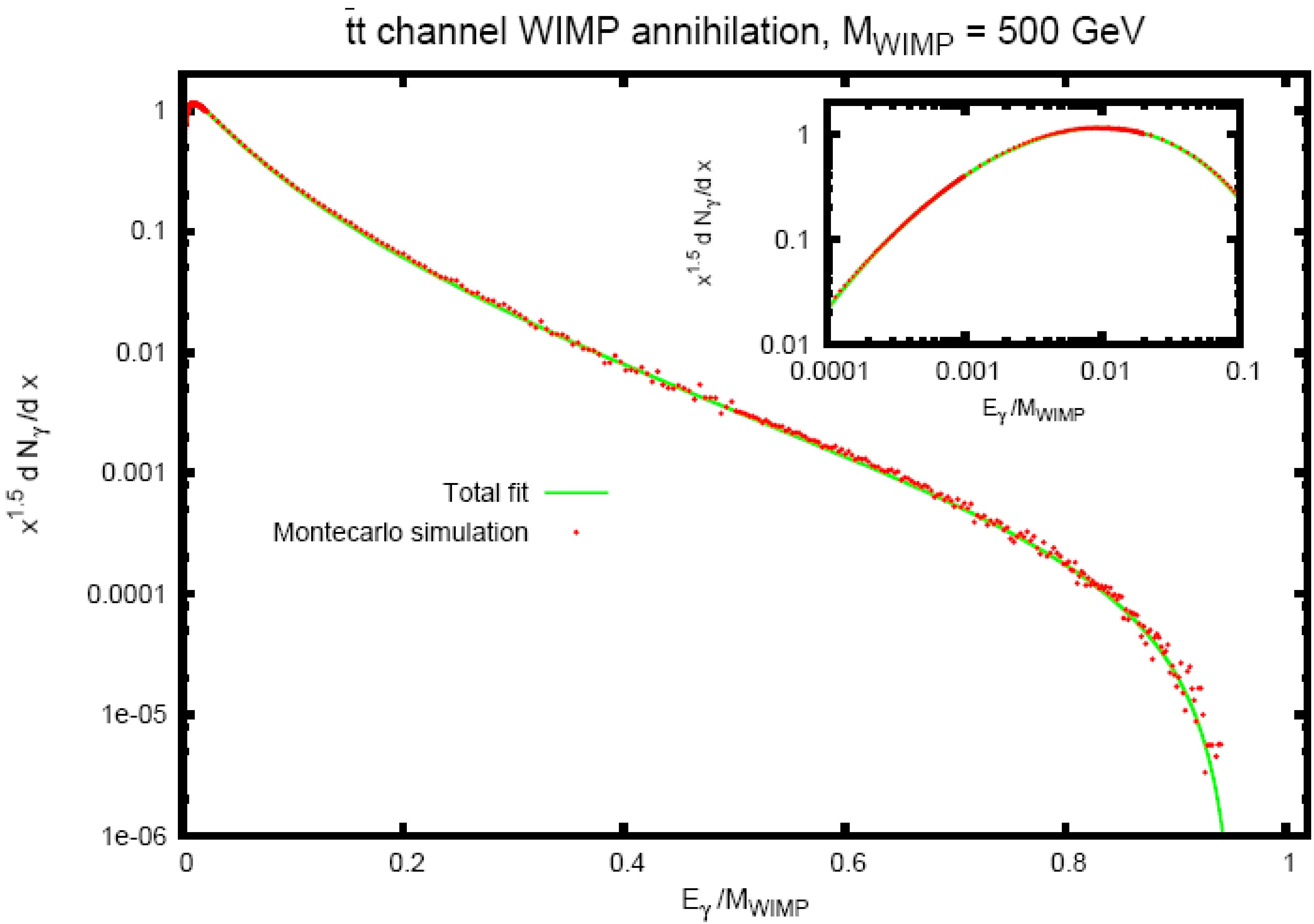

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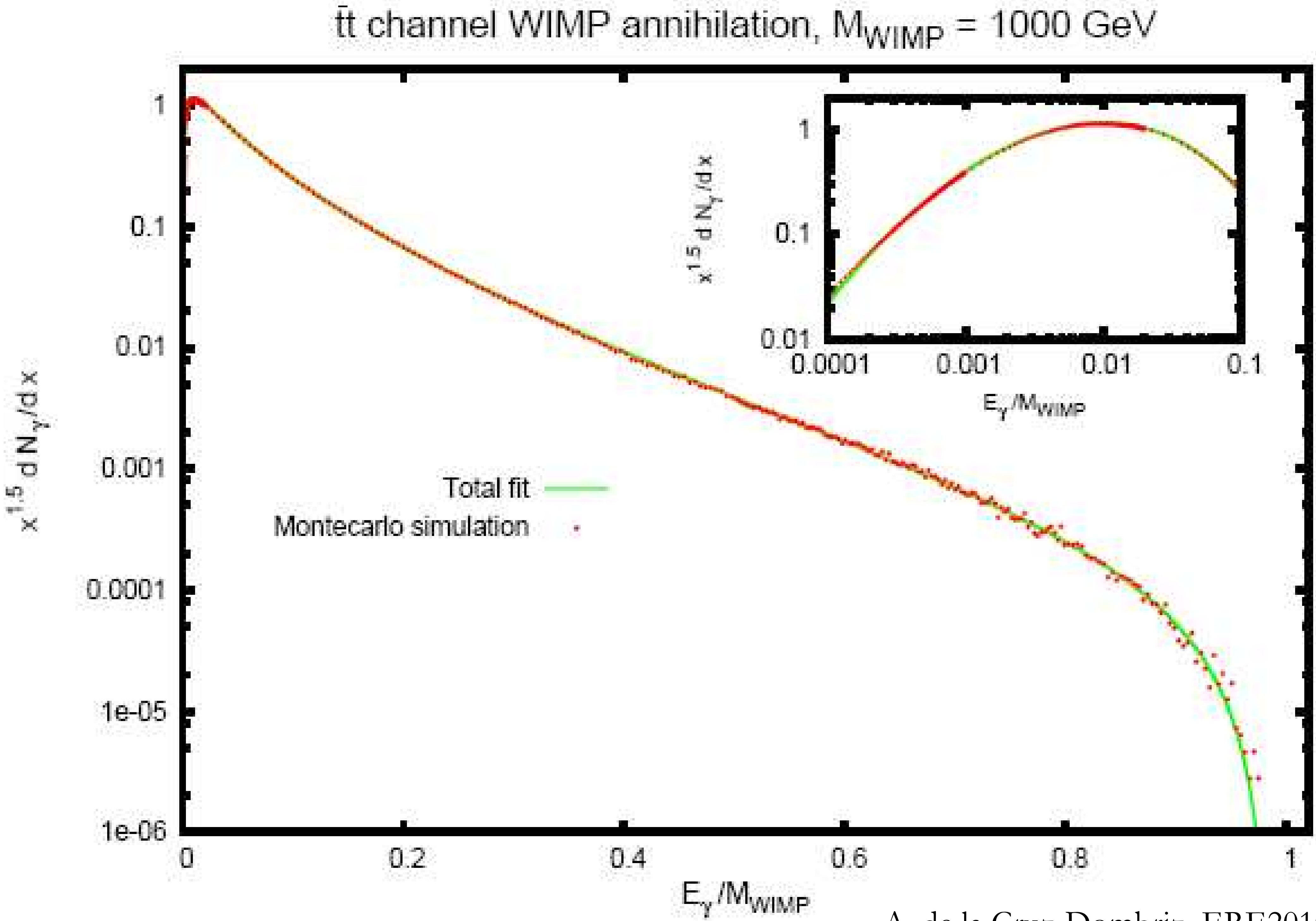

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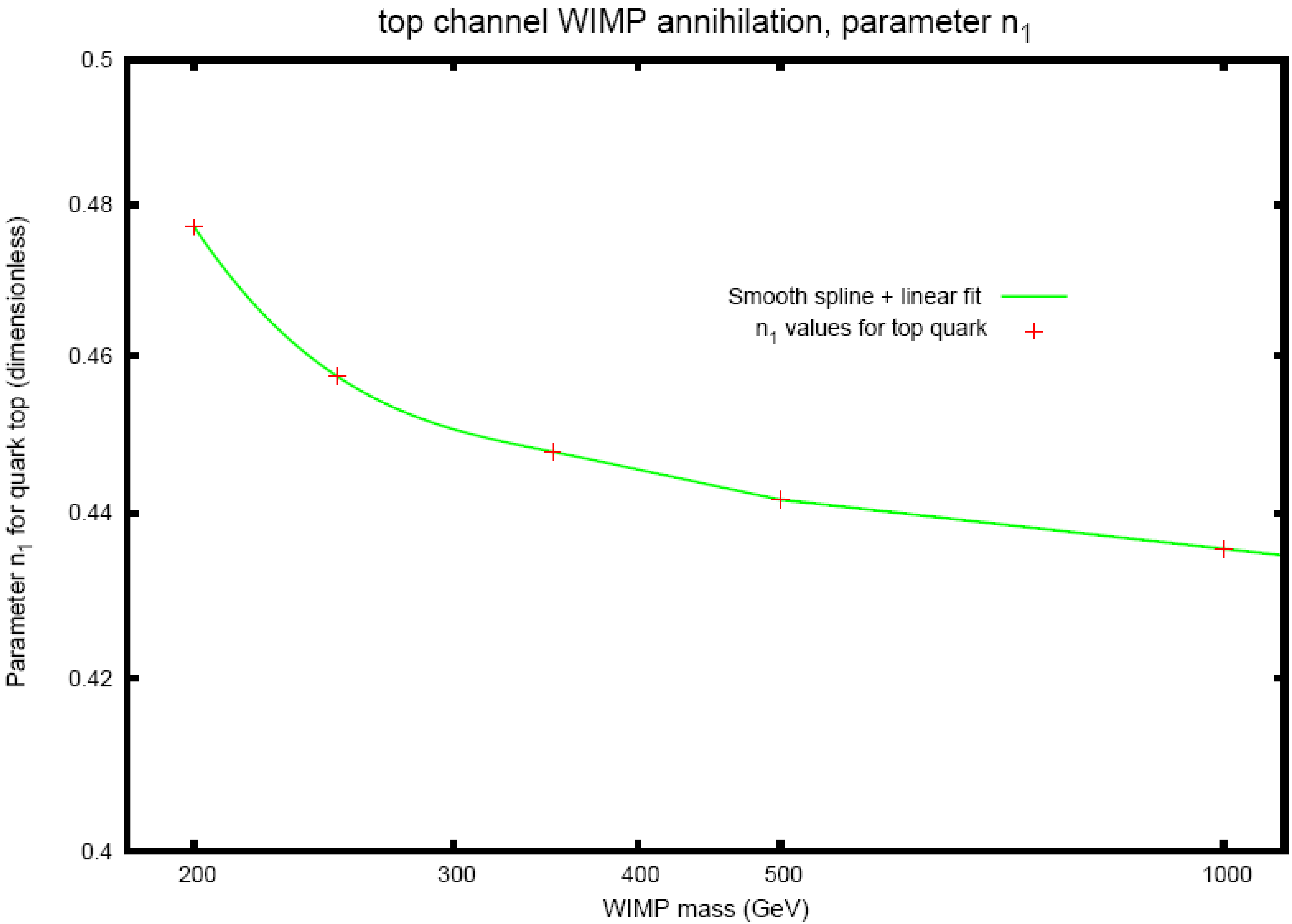

✓ In general, parameters follow a linear law at high masses and deviate at low masses.

III. CONCLUSIONS

- Gamma rays spectra for WIMP annihilation into Standard Model particles have been obtained for each individual channel.
- Decays into gauge bosons W and Z, quarks and tau lepton were studied in a wide range of WIMP masses.
- Three fitting formulae for different channels have been proposed: W and Z, top quark and the rest of quarks+tau.
- Spectra mass dependence has been studied for each channel.
- Channel relevance in photon production can be established from this research.
- Presented results may be useful if for some WIMP DM candidates, DarkSusy-like packages are not available