color code:
Priscilla, Bjoern, Krisztian, Kevin, Deborah

BP: Todo: All tables need to be abbreviated to a sensible number of sig. digits.

0.1 Scalar s-channel Mediator

One of the most simple UV complete extension of the effective field theory approach is the addition of a scalar mediator between DM and SM. ~~A scalar particle mediator can be a very simple addition to the SM~~. ~~If it is chosen~~ In case this mediator is as a gauge singlet it can have tree-level interactions with a singlet DM particle that is either a Dirac or Majorana fermion, or DM that is a scalar itself. The spin-0 mediator ~~could still be chosen as~~ can either be a real or complex scalar, which are distinguished by the fact that a complex scalar contains both scalar and pseudoscalar particles, whereas the real ~~option contains~~ field can be only a scalar field. We will consider two choices for DM simplified models: one where the interaction with the SM is mediated by the real scalar, and the second where we consider only a light pseudoscalar (assuming that the associated scalar is decoupled from the low-energy spectrum).

Couplings to the SM fermions can be arranged by mixing with the SM Higgs. Such models have intriguing connections with Higgs physics, and can be viewed as generalizations of the Higgs portal to DM. The most general scalar mediator models will ~~of course~~ have renormalizable interactions between the SM Higgs and the new scalar ϕ or pseudoscalar a, as well as ϕ/a interactions with electroweak gauge bosons. Such interactions are model dependent, often subject to constraints from electroweak precision tests, and would suggest specialized searches which cannot be generalized to a broad class of models (unlike, for instance, the $\not{E}_T$ + jets searches). As a result, for this class of minimal simplified models with spin-0 mediators, we ~~suggest to~~ will focus primarily on ~~the~~ couplings to fermions and ~~the~~ loop-induced couplings to gluons. ~~The possibility that the couplings~~ Possible couplings to the electroweak sector may also lead to interesting DM phenomenology ~~should however be kept in mind~~ BP: Broken sentence and can be studied in the context of Higgs Portal DM.

0.1.1 Fermionic DM

Minimal Flavor Violation (MFV) ~~dictates~~ implies ~~that the coupling of a scalar to the SM fermions~~ scalar couplings to fermions are ~~will be~~ proportional to the fermion masses. However, ~~it allows these couplings to be scaled by separate factors~~ can differ for ~~the up-type quarks, down-type quarks, and the~~ for up- and down-type quarks and charged leptons. Assuming that DM is a fermion χ, which couples to the SM only through a scalar ϕ or pseudoscalar a, the most general tree-level Lagrangians compatible with the MFV assumption are [?, ?]:

$$\begin{aligned}\mathcal{L}_{\text{fermion},\phi} &= \mathcal{L}_{\text{SM}} + i\bar{\chi}\partial\!\!\!/\chi + m_\chi\bar{\chi}\chi + |\partial_\mu\phi|^2 + \frac{1}{2}m_\phi^2\phi^2 + \\ &\quad g_\chi\phi\bar{\chi}\chi + \frac{\phi}{\sqrt{2}}\sum_i\left(g_u y_i^u\bar{u}_i u_i + g_d y_i^d\bar{d}_i d_i + g_\ell y_i^\ell\bar{\ell}_i\ell_i\right) , \qquad (1)\\ \mathcal{L}_{\text{fermion},a} &= \mathcal{L}_{\text{SM}} + i\bar{\chi}\partial\!\!\!/\chi + m_\chi\bar{\chi}\chi + |\partial_\mu a|^2 + \frac{1}{2}m_a^2 a^2 + \\ &\quad ig_\chi a\bar{\chi}\gamma_5\chi + \frac{ia}{\sqrt{2}}\sum_i\left(g_u y_i^u\bar{u}_i\gamma_5 u_i + g_d y_i^d\bar{d}_i\gamma_5 d_i + g_\ell y_i^\ell\bar{\ell}_i\gamma_5\ell_i\right)(2)\end{aligned}$$

Here the sums run over the ~~there~~ all SM ~~families~~ generations ~~and we are using~~ the Yukawa couplings y_i^f are normalized to $y_i^f = \sqrt{2}m_i^f/v$ ~~with~~ where $v \simeq 246\,\text{GeV}$ represents the Higgs vacuum expectation value (VEV). ~~Since the DM particle χ receives most of its mass most likely not from electroweak symmetry breaking but from another (unknown) mechanism, we parametrize the DM-mediator coupling by g_χ rather than by a Yukawa coupling $y_\chi = \sqrt{2}m_\chi/v$.~~

BP: Previous sentence sounds speculating and I'd remove that, at least backup with reference. Prefer to just say: We parametrise the DM-mediator coupling as g_χ.

The most general Lagrangians including new scalars or pseudoscalars will have a potential containing interactions with the SM Higgs field h. As already stated ~~above,~~ we choose ~~to take a more~~ a minimal set of ~~possible~~ interactions and leave the discussions of the couplings in the Higgs sector to ~~the~~ section ~~on~~ about Higgs portal DM. Given this simplification, the minimal set of parameters under consideration is

$$\left\{m_\chi,\ m_{\phi/a},\ g_\chi,\ g_u,\ g_d,\ g_\ell\right\} . \qquad (3)$$

The simplest choice of couplings known as Minimal Simplified Dark Matter model (MSDM) (following here notation used Buchmüller et al., Buckley et al. etc. which makes a lot of sense) $g_u = g_d = g_\ell$, which is realized in singlet scalar extensions of the SM.

If one extends the SM Higgs sector to a two Higgs doublet model, one ~~can~~ obtains ~~other coupling patterns~~ more complex couplings such as $g_u = \cot\beta$ and $g_d = g_e = \tan\beta$ ~~with~~ where $\tan\beta$ denoting the ratio of VEVs of the two Higgs doublets. The case $g_u \neq g_d \neq g_\ell$ requires ~~more~~ additional scalars ~~, whose masses could be rather heavy~~ with potentially large masses.

~~For simplicity, we will use~~We assume universal SM-mediator couplings $g_v = g_u = g_d = g_\ell$ in the remainder of this work ~~, though one should bear in mind that finding ways to experimentally test this assumption would be very useful.~~ BP: That sounds like we don't know what we are doing. If there is no indication otherwise the easiest assumptions is always the most scientific to chose (also listening to some phenomenologists this seems not always to be the case ;-))

The ~~signal strength~~ The expected signal of DM pair production depends on the production rate defined by the dark matter mass m_χ, mediator $m_{\phi/a}$

and the couplings g_i and also the branching ration defined by the total decay width of the mediator ϕ/a. ~~In the minimal model~~ While we cannot specify a width only from the couplings, we can calculate the minimum possible width (assuming only decays into the dark matter and the Standard Model fermions) that is consistent with a given value of $g_\chi g_{\rm SM}$. These are given by Eq. (4)[?].

BP: Removed the initial two equations as they are identical except of an index and used only one with proper indices and also two two line instead of extending beyond the text width.

$$\begin{aligned}\Gamma_{\phi,a} = &\sum_f N_c \frac{y_f^2 g_v^2 m_{\phi,a}}{16\pi}\left(1-\frac{4m_f^2}{m_{\phi,a}^2}\right)^{3/2} + \frac{g_\chi^2 m_{\phi,a}}{8\pi}\left(1-\frac{4m_\chi^2}{m_{\phi,a}^2}\right)^{3/2} \\ &+ \frac{\alpha_s^2 y_t^2 g_v^2 m_{\phi,a}^3}{32\pi^3 v^2}\left|f_{\phi,a}\left(\frac{4m_t^2}{m_{\phi,a}^2}\right)\right|^2\end{aligned} \tag{4}$$

whereas

$$f_\phi(\tau) = \tau\left[1+(1-\tau)\arctan^2\left(\frac{1}{\sqrt{\tau-1}}\right)\right], \qquad f_a(\tau) = \tau\arctan^2\left(\frac{1}{\sqrt{\tau-1}}\right). \tag{5}$$

The first term in each width corresponds to the decay into SM fermions (the sum runs over all kinematically available fermions, $N_c = 3$ for quarks and $N_c = 1$ for leptons). The second term is the decay into DM (assuming that this decay is kinematically allowed). The factor of ~~2~~ two between the decay into SM fermions and into DM is a result of our choice of normalization of the Yukawa couplings BP: Is this the best way to express that? I'd add:... due to spin dependencies. The last two terms correspond to decay into gluons. Since we have assumed that $g_v = g_u = g_d = g_\ell$, we have included in the partial decay widths $\Gamma(\phi/a \to gg)$ only the contributions stemming from top loops, which provide the by far largest corrections given that $y_t \gg y_b$ etc. At the loop level the mediators can decay not only to gluons but also to pairs of photons and other final states if ~~these are~~ kinematical accessible. However the decay rates $\Gamma(\phi/a \to gg)$ are ~~however~~ always larger than the other loop-induced partial widths, and in consequence the total decay widths $\Gamma_{\phi/a}$ are well approximated by the corresponding sum of the individual partial decay widths involving DM, fermion or gluon pairs. ~~Notice finally~~ It should be noted that if $m_{\phi/a} > 2m_t$ the total widths of ϕ/a will typically be dominated by the partial widths to top quarks.

0.2 DM+$t\bar{t}$ production

~~As discussed in Section 0.1, the MFV assumption entails a spin-0 mediator that couples most strongly to top quarks on account of Yukawa couplings~~. As discussed in Sec. 0.1, the MFV assumption leads for spin-0 mediators to quark mass dependent Yukawa couplings and therefore dominant couplings to top quarks.

~~For establishing benchmarks, DM tt models with a scalar phi or a pseudoscalar a are the most compelling.~~ [BP: Physics first:] Therefore DM+$t\bar{t}$searches are strongly physically motivated and it is important to establish benchmarks for collider searches following the assumptions described in Sec. 0.1, in particular a Dirac fermion DM particle, universal couplings and minimum width. ~~The simplifications mentioned in Section 0.1 are followed; namely, coupling of the mediator to SM Higgs are not considered and universal SM-mediator couplings are assumed. Another simplification is to assume minimal width, so that $\Gamma_{\phi,a}$is considered a dependent variable in the models. The DM particle is taken to be a Dirac fermion.~~

Benchmark points have been selected to ensure that ~~The primary consideration for selecting the set of benchmark points is to ensure~~ the kinematic features of the parameter space are sufficiently represented. Detailed studies were performed to identify points in the m_χ, $m_{\phi,a}$, g_χ, g_v (and $\Gamma_{\phi,a}$), parameter space that differ significantly from each other in terms of expected detector acceptance. Because missing transverse momentum ~~energy~~ is the key observable for searches, the mediator p_T spectra is taken to represent the main kinematics of a model. Another consideration in determining the set of benchmarks is to ~~restrict to cases where we have sensitivity~~ to focus on phase space where we expected to gain sensitivity during the LHC run in 2015. Based on the ~~estimated~~ projected integrated luminosity of $30\,\mathrm{fb}^{-1}$ expected for 2015, we disregard models with cross section times branching ratio smaller than 0.1 fb.

0.2.1 Parameter scan

The kinematics ~~show the strongest dependence~~ is most dependent on the masses m_χ and $m_{\phi,a}$. Figure **??** and **??** show typical depenencies for for scalar, pseudoscalar couplings respectively. ~~Examples of the dependence on mediator mass are given in Figs.ures **??** and **??** for the scalar and pseudoscalar respectively~~. ~~There are~~ The two relevant thresholds are: $m_{\phi,a} = 2m_\chi$ and $m_{\phi,a} = 2m_t$. When the mediator mass exceeds both ~~these~~ thresholds then the p_T spectra broadens with larger $m_{\phi,a}$ and the kinematics for ϕ and a are ~~quite similar~~ ~~comparable~~. The mediator p_T spectra changes significantly when crossing these thresholds. For instance In particular kinematics are different for an on-shell mediator compared to an off-shell mediator ($m_{\phi,a} < 2m_\chi$). Furthermore, the scalar case differs from the pseudoscalar one when $m_\phi < 2m_t$. Therefore, it is important to ~~have benchmark points~~ cover both sides of these thresholds with sufficient benchmark points.

Typically, ~~the kinematics show little dependence on the width – or equivalently on the couplings~~ typically only weak dependencies on width or equivalently couplings are observed (see Fig.~~ure~~ **??**), except ~~at~~ for large mediator masses of $\sim 1.5\,\mathrm{TeV}$ or for very small couplings of $\sim 10^{-2}$. These regimes where width effects are significant have ~~signal strengths~~ production cross section that are too ~~weak~~ small to be relevant for $30\,\mathrm{fb}^{-1}$ and are not considered here. However,

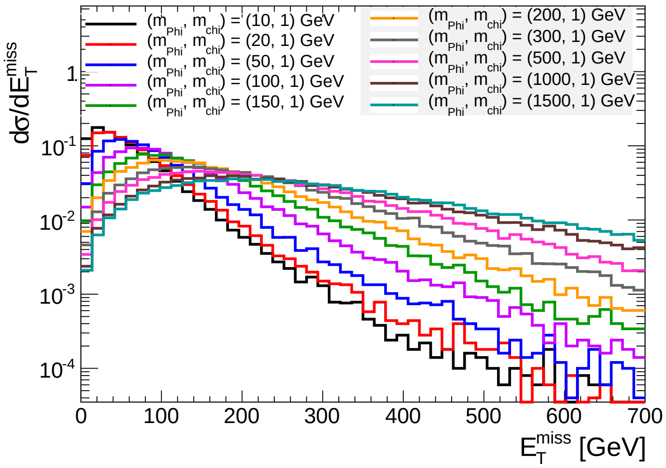

Figure 1: Example of the dependence of the kinematics on the scalar mediator mass. The Dark Matter mass is fixed to be 1GeV.

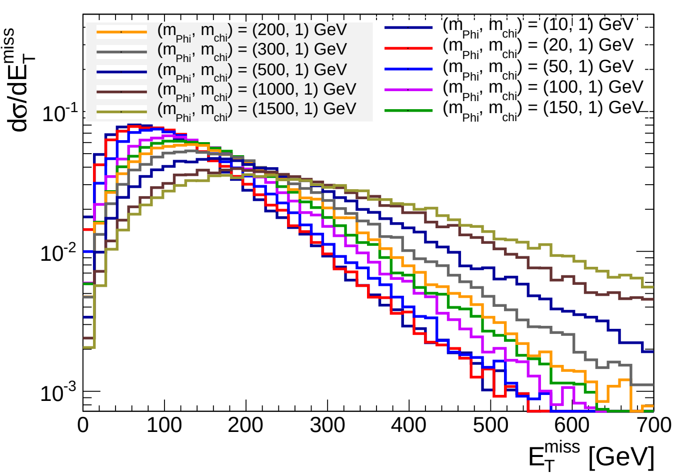

Figure 2: Example of the dependence of the kinematics on the pseudoscalar mediator mass. The Dark Matter mass is fixed to be 1GeV.

with the full dataset of Run-2, such models may be within reach. The generally weak dependence on typical width values can be understood as the parton distribution function ~~being~~ are the dominant effect on mediator production. In other words, for couplings $\sim O(1)$ the width is ~~broad~~ large enough that the p_T of the mediator is determined mainly by the PDF.

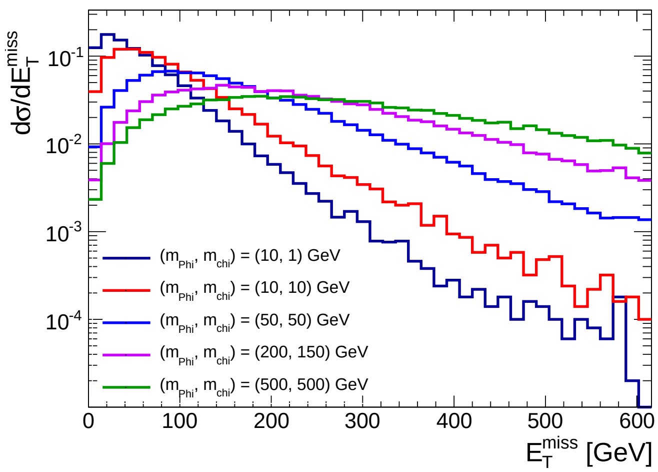

Figure 3: Example of the dependence of the kinematic for points of the grid proposed in Tab. **??** close to the $m_{\phi,a} \sim 2m_\chi$ limit.

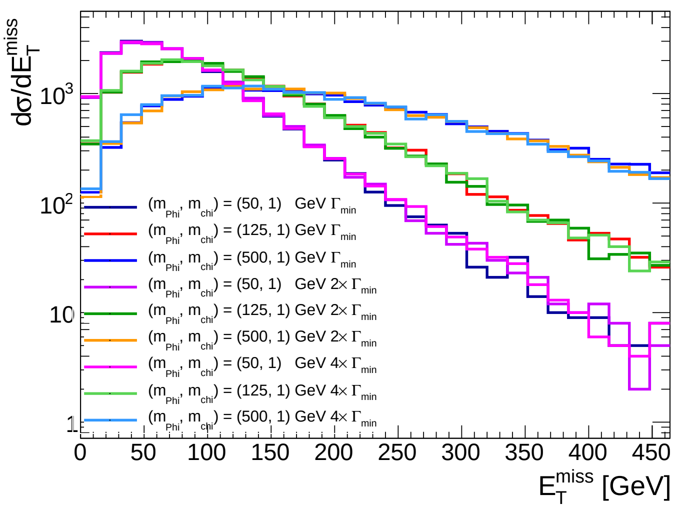

Figure 4: Study of the dependence of kinematics on the width of a scalar mediator. The width is increased up to four times the minimal width for each mediator and dark matter mass combination.

Another case where the width can impact the kinematics is when $m_{\phi,a}$ is slightly larger than $2m_\chi$. Here, the width determines the relative contribution between on-shell and off-shell production. An example is given in Fig.~~ure~~ **??**.

In our reccomendations we propose to use for semplicity the minimal width, as this is represents the most conservative choice to interpret the LHC results

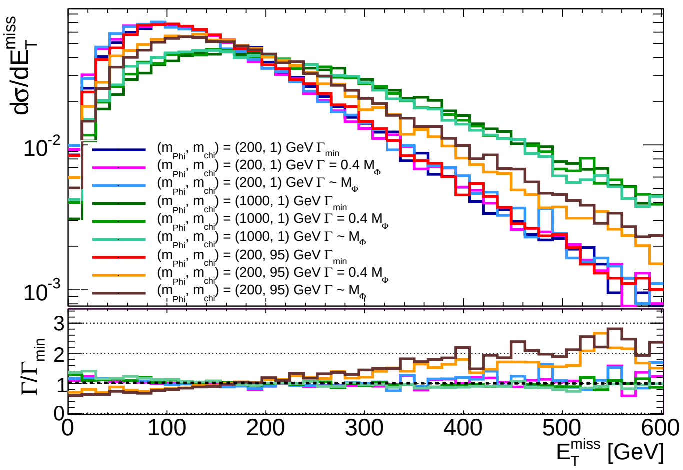

Figure 5: Dependence of the dependence of kinematics on the width of a scalar mediator. The width is increased up to the mediator mass. Choices of mediator and dark matter masses such that $m_{\phi,a}$ is slightly larger than $2m_\chi$ is the only case that shows a sizeable variation of the kinematics as a function of the width.

Given that the kinematics are similar for all couplings $\sim O(1)$, we ~~make a simplification to generate benchmark models with~~ we generate only samples with $g_\chi = g_v = 1$. It follows that the model should be a good approximation for non-unity couplings and $g_\chi \neq g_v$ provided that the sample is normalized to the appropriate cross section times branching ratio. While a simple scaling function can be found that works for a limited range of coupling values (see Fig.~~ure~~ **??** for example), we ~~opt~~ chose to provide instead a table of cross section times branching ratio values over a large range of couplings to support interpretation of search results (see Sec.tion **??**). The table covers lists couplings from $g = 0.1$ to $g = 3.5$, where the upper limit is chosen to ~~lie near but below the~~ close to the perturbative limit.

0.2.2 Benchmarks

The benchmark points are listed in Table **??**. In addition to the considerations discussed in the preceding subsections, very light DM fermions are included ($m_\chi = 1, 10\,\text{GeV}$) as these are beyond the reach of current direct detection experiments, and a few points are chosen to overlap with monojet benchmarks to facilitate comparison with searches in different final states.

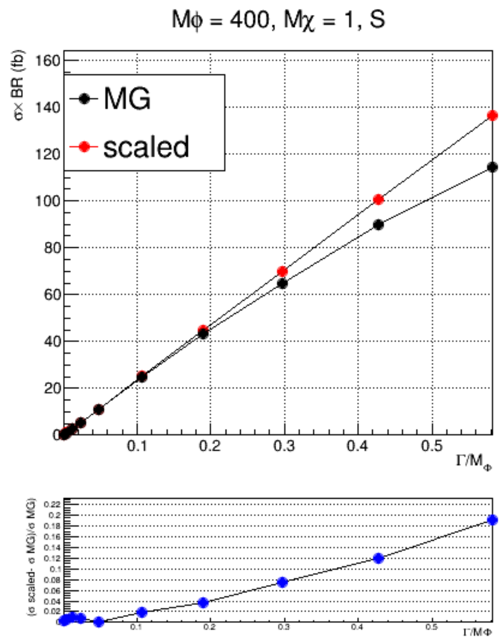

Figure 6: An example comparing a simple cross section scaling versus the computation from the generator, for a scalar model with $m_\phi = 400\,\mathrm{GeV}$ and $m_\chi = 1\,\mathrm{GeV}$. In this example, the scaling relationship holds for Γ_ϕ/m_ϕ below 0.2, beyond which finite width effects become important and the simple scaling breaks down.

m_χ (GeV)	$m_{\phi,a}$ (GeV)
1	10, 20, 50, 100, 150, 200, 300, 500, 1000, 1500
10	10, 20, 50, 100, 150, 200, 300, 500, 1000, 1500
50	50, 100, 150, 200, 300, 500, 1000, 1500
150	150, 200, 300, 500, 1000, 1500
500	500, 1000, 1500

Table 1: Simplified model benchmarks for $t\bar{t}$+DM production via spin-0 mediators decaying to Dirac DM fermions taking the minimum width presciption for $g_v = g_\chi = 1$.

0.2.3 Table of Cross Sections

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
0.1	10	1	0.00374318	0.207 ± 0.0006846
0.1	20	1	0.00784569	0.1121 ± 0.0003285
0.1	50	1	0.01987	0.03211 ± 0.0001005
0.1	100	1	0.0398141	0.007325 ± 2.416e-05
0.1	150	1	0.0597437	0.002396 ± 7.419e-06
0.1	200	1	0.0796724	0.001018 ± 3.398e-06
0.1	300	1	0.119549	0.0003394 ± 1.234e-06
0.1	500	1	0.310863	6.802e-05 ± 2.343e-07
0.1	1000	1	0.881329	5.817e-06 ± 2.356e-08
0.1	1500	1	1.40417	8.942e-07 ± 3.832e-09
0.1	10	10	0.000100	1.007e-05 ± 3.761e-08
0.1	20	10	0.000100	3.491e-05 ± 1.012e-07
0.1	50	10	0.0153395	0.03212 ± 0.0001037
0.1	100	10	0.0374747	0.007343 ± 2.011e-05
0.1	150	10	0.0581752	0.002389 ± 7.654e-06
0.1	200	10	0.0784937	0.001018 ± 6.258e-06
0.1	300	10	0.118762	0.0003373 ± 1.448e-06
0.1	500	10	0.310391	6.773e-05 ± 2.326e-07
0.1	1000	10	0.881093	5.81e-06 ± 2.245e-08
0.1	1500	10	1.40401	8.937e-07 ± 4.013e-09
0.1	50	50	0.0000233555	2.581e-07 ± 1.214e-09
0.1	100	50	0.0000492402	1.526e-06 ± 7.038e-09
0.1	150	50	0.0247905	0.002387 ± 8.272e-06
0.1	200	50	0.051794	0.00102 ± 3.216e-06
0.1	300	50	0.100226	0.0003366 ± 1.393e-06
0.1	500	50	0.299052	6.679e-05 ± 2.406e-07
0.1	1000	50	0.875378	5.764e-06 ± 2.472e-08
0.1	1500	50	1.4002	8.866e-07 ± 3.257e-09
0.1	100	150	0.0000492402	1.246e-08 ± 5.121e-11
0.1	150	150	0.0000765167	1.393e-08 ± 6.653e-11
0.1	200	150	0.000106902	1.693e-08 ± 8.493e-11
0.1	300	150	0.000190543	7.557e-08 ± 2.171e-10
0.1	500	150	0.213784	5.063e-05 ± 1.724e-07
0.1	1000	150	0.828844	5.365e-06 ± 2.028e-08
0.1	1500	150	1.36872	8.603e-07 ± 3.769e-09
0.1	200	300	0.000106902	1.415e-09 ± 5.97e-12
0.1	300	300	0.000190543	1.64e-09 ± 7.878e-12
0.1	500	300	0.111924	3.078e-09 ± 1.482e-11
0.1	1000	300	0.687162	3.828e-06 ± 1.416e-08
0.1	1500	300	1.26683	7.579e-07 ± 3.041e-09
0.1	500	500	0.111924	1.784e-10 ± 1.105e-12
0.1	1000	500	0.483444	1.98e-09 ± 9.199e-12

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_{χ} [GeV]	Γ_{min} [GeV]	σ
0.1	1500	500	1.05448	4.92e-07 ± 2.14e-09
0.3	10	1	0.0336886	1.876 ± 0.006611
0.3	20	1	0.0706112	1.006 ± 0.003894
0.3	50	1	0.17883	0.2886 ± 0.0009285
0.3	100	1	0.358327	0.06598 ± 0.000182
0.3	150	1	0.537693	0.0214 ± 6.701e-05
0.3	200	1	0.717052	0.009216 ± 3.533e-05
0.3	300	1	1.07594	0.003044 ± 1.194e-05
0.3	500	1	2.79777	0.0006105 ± 2.187e-06
0.3	1000	1	7.93196	5.256e-05 ± 2.165e-07
0.3	1500	1	12.6376	8.048e-06 ± 3.473e-08
0.3	10	10	5.69808	0.0008143 ± 3.272e-06
0.3	20	10	0.0000630938	0.002836 ± 9.724e-06
0.3	50	10	0.138055	0.2869 ± 0.0008971
0.3	100	10	0.337272	0.06606 ± 0.0002407
0.3	150	10	0.523576	0.02145 ± 8.01e-05
0.3	200	10	0.706443	0.009222 ± 2.807e-05
0.3	300	10	1.06886	0.003051 ± 1.001e-05
0.3	500	10	2.79352	0.0006115 ± 2.268e-06
0.3	1000	10	7.92983	5.24e-05 ± 1.964e-07
0.3	1500	10	12.6361	8.053e-06 ± 3.203e-08
0.3	10	50	5.69808	1.704e-05 ± 7.077e-08
0.3	20	50	0.0000630938	1.746e-05 ± 7.383e-08
0.3	50	50	0.000210199	2.071e-05 ± 8.162e-08
0.3	100	50	0.000443162	0.0001245 ± 3.888e-07
0.3	150	50	0.223114	0.02138 ± 6.22e-05
0.3	200	50	0.466146	0.009186 ± 3.168e-05
0.3	300	50	0.902031	0.003039 ± 1.09e-05
0.3	500	50	2.69146	0.0005971 ± 2.181e-06
0.3	1000	50	7.8784	5.222e-05 ± 1.907e-07
0.3	1500	50	12.6018	7.947e-06 ± 2.996e-08
0.3	100	150	0.000443162	1.004e-06 ± 4.682e-09
0.3	150	150	0.00068865	1.132e-06 ± 4.644e-09
0.3	200	150	0.000962116	1.349e-06 ± 6.834e-09
0.3	300	150	0.00171489	6.08e-06 ± 2.289e-08
0.3	500	150	1.92405	0.000456 ± 2.064e-06
0.3	1000	150	7.45959	4.818e-05 ± 1.84e-07
0.3	1500	150	12.3185	7.796e-06 ± 2.802e-08
0.3	200	300	0.000962116	1.144e-07 ± 4.635e-10
0.3	300	300	0.00171489	1.324e-07 ± 6.534e-10
0.3	500	300	1.00732	2.5e-07 ± 1.113e-09
0.3	1000	300	6.18446	3.439e-05 ± 1.376e-07

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
0.3	1500	300	11.4014	6.834e-06 ± 2.623e-08
0.3	500	500	1.00732	1.449e-08 ± 5.536e-11
0.3	1000	500	4.35099	1.487e-07 ± 6.617e-10
0.3	1500	500	9.49035	4.374e-06 ± 1.739e-08
0.7	10	1	0.183416	10.2 ± 0.03649
0.7	20	1	0.384439	5.462 ± 0.02022
0.7	50	1	0.97363	1.558 ± 0.004491
0.7	100	1	1.95089	0.3568 ± 0.001143
0.7	150	1	2.92744	0.1161 ± 0.0003685
0.7	200	1	3.90395	0.04995 ± 0.0001494
0.7	300	1	5.85789	0.01649 ± 5.579e-05
0.7	500	1	15.2323	0.003313 ± 1.464e-05
0.7	1000	1	43.1851	0.0002823 ± 1.233e-06
0.7	1500	1	68.8045	4.481e-05 ± 1.885e-07
0.7	10	10	0.0000310229	0.02403 ± 0.0001038
0.7	20	10	0.000343511	0.08347 ± 0.0004742
0.7	50	10	0.751635	1.553 ± 0.004764
0.7	100	10	1.83626	0.3569 ± 0.0009501
0.7	150	10	2.85058	0.1165 ± 0.0004139
0.7	200	10	3.84619	0.04984 ± 0.0001855
0.7	300	10	5.81933	0.01649 ± 6.843e-05
0.7	500	10	15.2092	0.003301 ± 1.289e-05
0.7	1000	10	43.1735	0.0002815 ± 1.129e-06
0.7	1500	10	68.7967	4.491e-05 ± 2.108e-07
0.7	10	50	0.0000310229	0.000511 ± 1.977e-06
0.7	20	50	0.000343511	0.0005184 ± 2.146e-06
0.7	50	50	0.00114442	0.0006176 ± 3.053e-06
0.7	100	50	0.00241277	0.003681 ± 1.333e-05
0.7	150	50	1.21473	0.1156 ± 0.0003755
0.7	200	50	2.53791	0.04988 ± 0.0001824
0.7	300	50	4.91106	0.01651 ± 6.317e-05
0.7	500	50	14.6535	0.003218 ± 1.523e-05
0.7	1000	50	42.8935	0.0002794 ± 1.049e-06
0.7	1500	50	68.6098	4.46e-05 ± 1.989e-07
0.7	100	150	0.00241277	2.968e-05 ± 1.364e-07
0.7	150	150	0.00374932	3.327e-05 ± 1.594e-07
0.7	200	150	0.00523819	4.04e-05 ± 1.861e-07
0.7	300	150	0.00933663	0.0001787 ± 7.694e-07
0.7	500	150	10.4754	0.00243 ± 1.128e-05
0.7	1000	150	40.6133	0.0002573 ± 1.014e-06
0.7	1500	150	67.0675	4.239e-05 ± 1.707e-07
0.7	100	300	0.00241277	3.132e-06 ± 1.547e-08

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
0.7	150	300	0.00374932	3.227e-06 ± 1.433e-08
0.7	200	300	0.00523819	3.393e-06 ± 1.437e-08
0.7	300	300	0.00933663	3.918e-06 ± 1.628e-08
0.7	500	300	5.4843	7.383e-06 ± 2.87e-08
0.7	1000	300	33.6709	0.0001801 ± 7.992e-07
0.7	1500	300	62.0745	3.644e-05 ± 1.473e-07
0.7	500	500	5.4843	4.301e-07 ± 1.836e-09
0.7	1000	500	23.6887	3.684e-06 ± 2.358e-08
0.7	1500	500	51.6697	2.291e-05 ± 9.843e-08
1.	10	1	0.374318	20.79 ± 0.08102
1.	20	1	0.784569	11.08 ± 0.0396
1.	50	1	1.987	3.146 ± 0.01331
1.	100	1	3.98141	0.7199 ± 0.002775
1.	150	1	5.97437	0.2354 ± 0.0008189
1.	200	1	7.96724	0.1009 ± 0.0003854
1.	300	1	11.9549	0.03369 ± 0.0001155
1.	500	1	31.0863	0.006652 ± 2.898e-05
1.	1000	1	88.1329	0.0005705 ± 2.817e-06
1.	1500	1	140.417	9.244e-05 ± 4.273e-07
1.	10	10	0.000063312	0.1009 ± 0.00035
1.	20	10	0.000701043	0.3475 ± 0.002265
1.	50	10	1.53395	3.139 ± 0.01028
1.	100	10	3.74747	0.7158 ± 0.002486
1.	150	10	5.81752	0.236 ± 0.0007591
1.	200	10	7.84937	0.1013 ± 0.0003668
1.	300	10	11.8762	0.03374 ± 0.0001403
1.	500	10	31.0391	0.006631 ± 2.585e-05
1.	1000	10	88.1093	0.0005663 ± 2.515e-06
1.	1500	10	140.401	9.408e-05 ± 4.698e-07
1.	10	50	0.000063312	0.00212 ± 8.815e-06
1.	20	50	0.000701043	0.002149 ± 9.604e-06
1.	50	50	0.00233555	0.002568 ± 1.017e-05
1.	100	50	0.00492402	0.01523 ± 5.043e-05
1.	150	50	2.47905	0.2351 ± 0.0008404
1.	200	50	5.1794	0.09993 ± 0.0003164
1.	300	50	10.0226	0.03349 ± 0.0001351
1.	500	50	29.9052	0.006402 ± 2.604e-05
1.	1000	50	87.5378	0.0005634 ± 2.601e-06
1.	1500	50	140.02	9.211e-05 ± 4.909e-07
1.	100	150	0.00492402	0.0001247 ± 5.899e-07
1.	150	150	0.00765167	0.0001387 ± 5.889e-07
1.	200	150	0.0106902	0.000168 ± 7.656e-07

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
1.	300	150	0.0190543	0.0007464 ± 2.977e-06
1.	500	150	21.3784	0.004856 ± 1.95e-05
1.	1000	150	82.8844	0.0005122 ± 1.98e-06
1.	1500	150	136.872	8.662e-05 ± 3.821e-07
1.	200	300	0.0106902	1.422e-05 ± 6.147e-08
1.	300	300	0.0190543	1.626e-05 ± 6.865e-08
1.	500	300	11.1924	3.081e-05 ± 1.244e-07
1.	1000	300	68.7162	0.0003534 ± 1.392e-06
1.	1500	300	126.683	7.258e-05 ± 3.651e-07
1.	500	500	11.1924	1.777e-06 ± 9.67e-09
1.	1000	500	48.3444	1.331e-05 ± 6.551e-08
1.	1500	500	105.448	4.443e-05 ± 1.988e-07
1.5	10	1	0.842215	46.59 ± 0.1797
1.5	20	1	1.76528	24.52 ± 0.08387
1.5	50	1	4.47075	6.903 ± 0.02244
1.5	100	1	8.95817	1.577 ± 0.005493
1.5	150	1	13.4423	0.5224 ± 0.002309
1.5	200	1	17.9263	0.2259 ± 0.0008625
1.5	300	1	26.8985	0.07529 ± 0.0003407
1.5	500	1	69.9442	0.01445 ± 6.469e-05
1.5	1000	1	198.299	0.001234 ± 5.694e-06
1.5	1500	1	315.939	0.0002179 ± 1.024e-06
1.5	10	10	0.000142452	0.5117 ± 0.002037
1.5	20	10	0.00157735	1.763 ± 0.01031
1.5	50	10	3.45138	6.906 ± 0.02283
1.5	100	10	8.4318	1.568 ± 0.006489
1.5	150	10	13.0894	0.5162 ± 0.001934
1.5	200	10	17.6611	0.2249 ± 0.0008153
1.5	300	10	26.7214	0.07541 ± 0.0002941
1.5	500	10	69.8379	0.01447 ± 6.923e-05
1.5	1000	10	198.246	0.001242 ± 6.739e-06
1.5	1500	10	315.903	0.0002157 ± 8.805e-07
1.5	10	50	0.000142452	0.01068 ± 4.527e-05
1.5	20	50	0.00157735	0.01093 ± 6.079e-05
1.5	50	50	0.00525498	0.01302 ± 6.649e-05
1.5	100	50	0.011079	0.07677 ± 0.0002445
1.5	150	50	5.57786	0.5195 ± 0.001577
1.5	200	50	11.6536	0.2195 ± 0.0006711
1.5	300	50	22.5508	0.07353 ± 0.0003291
1.5	500	50	67.2866	0.0139 ± 6.13e-05
1.5	1000	50	196.96	0.001209 ± 7.038e-06
1.5	1500	50	315.045	0.0002109 ± 8.631e-07

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
1.5	100	150	0.011079	0.0006295 ± 3.008e-06
1.5	150	150	0.0172162	0.000706 ± 3.661e-06
1.5	200	150	0.0240529	0.00086 ± 3.608e-06
1.5	300	150	0.0428723	0.003751 ± 1.304e-05
1.5	500	150	48.1013	0.01046 ± 4.013e-05
1.5	1000	150	186.49	0.001072 ± 4.469e-06
1.5	1500	150	307.963	0.0001931 ± 1.022e-06
1.5	200	300	0.0240529	7.176e-05 ± 3.641e-07
1.5	300	300	0.0428723	8.3e-05 ± 3.627e-07
1.5	500	300	25.183	0.000155 ± 6.658e-07
1.5	1000	300	154.611	0.0007234 ± 2.773e-06
1.5	1500	300	285.036	0.0001529 ± 7.694e-07
1.5	500	500	25.183	9.099e-06 ± 4.301e-08
1.5	1000	500	108.775	5.335e-05 ± 2.699e-07
1.5	1500	500	237.259	8.736e-05 ± 4.268e-07
2.	10	1	1.49727	82.65 ± 0.3408
2.	20	1	3.13828	43.1 ± 0.1487
2.	50	1	7.948	11.84 ± 0.04278
2.	100	1	15.9256	2.712 ± 0.01209
2.	150	1	23.8975	0.9056 ± 0.004237
2.	200	1	31.869	0.3952 ± 0.001653
2.	300	1	47.8195	0.132 ± 0.0004713
2.	500	1	124.345	0.02461 ± 0.0001101
2.	1000	1	352.532	0.002071 ± 1.061e-05
2.	1500	1	561.669	0.0003815 ± 1.4e-06
2.	10	10	0.000253248	1.627 ± 0.005672
2.	20	10	0.00280417	5.528 ± 0.03152
2.	50	10	6.13579	11.98 ± 0.04005
2.	100	10	14.9899	2.696 ± 0.01091
2.	150	10	23.2701	0.8981 ± 0.004067
2.	200	10	31.3975	0.3921 ± 0.001675
2.	300	10	47.5047	0.1312 ± 0.0005524
2.	500	10	124.156	0.02454 ± 0.0001302
2.	1000	10	352.437	0.002051 ± 9.73e-06
2.	1500	10	561.606	0.0003797 ± 1.522e-06
2.	10	50	0.000253248	0.03397 ± 0.0001354
2.	20	50	0.00280417	0.03452 ± 0.0001623
2.	50	50	0.00934219	0.04088 ± 0.0001623
2.	100	50	0.0196961	0.24 ± 0.0008579
2.	150	50	9.9162	0.8991 ± 0.002903
2.	200	50	20.7176	0.382 ± 0.001411
2.	300	50	40.0903	0.1287 ± 0.0005596

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
2.	500	50	119.621	0.02328 ± 0.0001255
2.	1000	50	350.151	0.001995 ± 1.184e-05
2.	1500	50	560.08	0.0003671 ± 1.741e-06
2.	10	150	0.000253248	0.001822 ± 7.946e-06
2.	20	150	0.00280417	0.001842 ± 8.453e-06
2.	50	150	0.00934219	0.00187 ± 8.818e-06
2.	100	150	0.0196961	0.001985 ± 8.101e-06
2.	150	150	0.0306067	0.002231 ± 1.131e-05
2.	200	150	0.0427607	0.002694 ± 1.215e-05
2.	300	150	0.0762174	0.01186 ± 4.862e-05
2.	500	150	85.5134	0.01769 ± 8.02e-05
2.	1000	150	331.538	0.001716 ± 7.617e-06
2.	1500	150	547.49	0.0003242 ± 1.537e-06
2.	100	300	0.0196961	0.0002092 ± 8.197e-07
2.	150	300	0.0306067	0.0002152 ± 8.37e-07
2.	200	300	0.0427607	0.0002275 ± 8.607e-07
2.	300	300	0.0762174	0.0002609 ± 1.05e-06
2.	500	300	44.7698	0.0004931 ± 2.01e-06
2.	1000	300	274.865	0.001119 ± 5.167e-06
2.	1500	300	506.731	0.0002432 ± 1.053e-06
2.	300	500	0.0762174	2.367e-05 ± 1.206e-07
2.	500	500	44.7698	2.871e-05 ± 1.09e-07
2.	1000	500	193.378	0.000131 ± 5.569e-07
2.	1500	500	421.793	0.0001323 ± 5.222e-07
2.5	10	1	2.33949	128.4 ± 0.4393
2.5	20	1	4.90356	65.92 ± 0.2248
2.5	50	1	12.4187	17.77 ± 0.0663
2.5	100	1	24.8838	4.051 ± 0.01562
2.5	150	1	37.3398	1.364 ± 0.004927
2.5	200	1	49.7953	0.6008 ± 0.002928
2.5	300	1	74.718	0.2036 ± 0.0008994
2.5	500	1	194.29	0.03629 ± 0.0001865
2.5	1000	1	550.831	0.002918 ± 1.235e-05
2.5	1500	1	877.608	0.0005639 ± 2.327e-06
2.5	10	10	0.0003957	3.918 ± 0.0159
2.5	20	10	0.00438152	13.54 ± 0.05349
2.5	50	10	9.58718	18.03 ± 0.06068
2.5	100	10	23.4217	4.025 ± 0.01458
2.5	150	10	36.3595	1.36 ± 0.00698
2.5	200	10	49.0586	0.5979 ± 0.002445
2.5	300	10	74.2262	0.2016 ± 0.0006995
2.5	500	10	193.994	0.03579 ± 0.0001738

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
2.5	1000	10	550.683	0.002902 ± 1.515e-05
2.5	1500	10	877.509	0.0005651 ± 2.275e-06
2.5	10	50	0.0003957	0.08298 ± 0.000365
2.5	20	50	0.00438152	0.08474 ± 0.0003631
2.5	50	50	0.0145972	0.09986 ± 0.000455
2.5	100	50	0.0307751	0.5855 ± 0.001667
2.5	150	50	15.4941	1.359 ± 0.005802
2.5	200	50	32.3712	0.5728 ± 0.002188
2.5	300	50	62.6411	0.1938 ± 0.0008665
2.5	500	50	186.907	0.03384 ± 0.0001589
2.5	1000	50	547.111	0.002773 ± 1.645e-05
2.5	1500	50	875.125	0.0005349 ± 3.534e-06
2.5	10	150	0.0003957	0.004461 ± 1.951e-05
2.5	20	150	0.00438152	0.004473 ± 2.159e-05
2.5	50	150	0.0145972	0.00451 ± 1.808e-05
2.5	100	150	0.0307751	0.00486 ± 1.984e-05
2.5	150	150	0.0478229	0.00548 ± 2.35e-05
2.5	200	150	0.0668136	0.006545 ± 2.81e-05
2.5	300	150	0.11909	0.02878 ± 0.0001168
2.5	500	150	133.615	0.02572 ± 0.00011
2.5	1000	150	518.027	0.002339 ± 1.101e-05
2.5	1500	150	855.453	0.0004622 ± 2.297e-06
2.5	100	300	0.0307751	0.0005104 ± 2.62e-06
2.5	150	300	0.0478229	0.000526 ± 2.091e-06
2.5	200	300	0.0668136	0.0005503 ± 2.402e-06
2.5	300	300	0.11909	0.0006368 ± 2.911e-06
2.5	500	300	69.9528	0.001197 ± 4.697e-06
2.5	1000	300	429.476	0.001499 ± 6.445e-06
2.5	1500	300	791.767	0.0003277 ± 1.439e-06
2.5	300	500	0.11909	5.773e-05 ± 2.645e-07
2.5	500	500	69.9528	6.973e-05 ± 3.037e-07
2.5	1000	500	302.152	0.0002498 ± 1.042e-06
2.5	1500	500	659.052	0.000172 ± 8.531e-07
3.	10	1	3.36886	185.9 ± 0.8608
3.	20	1	7.06112	92.49 ± 0.3581
3.	50	1	17.883	24.38 ± 0.08507
3.	100	1	35.8327	5.551 ± 0.02275
3.	150	1	53.7693	1.878 ± 0.008801
3.	200	1	71.7052	0.8398 ± 0.004651
3.	300	1	107.594	0.2856 ± 0.001301
3.	500	1	279.777	0.04861 ± 0.0002143
3.	1000	1	793.196	0.003716 ± 1.874e-05

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
3.	1500	1	1263.76	0.0007294 ± 3.217e-06
3.	10	10	0.000569808	8.181 ± 0.03184
3.	20	10	0.00630938	28.05 ± 0.09412
3.	50	10	13.8055	24.97 ± 0.07128
3.	100	10	33.7272	5.485 ± 0.01916
3.	150	10	52.3576	1.858 ± 0.007406
3.	200	10	70.6443	0.8336 ± 0.003435
3.	300	10	106.886	0.2832 ± 0.001293
3.	500	10	279.352	0.04802 ± 0.0003129
3.	1000	10	792.983	0.003669 ± 1.542e-05
3.	1500	10	1263.61	0.0007221 ± 3.036e-06
3.	10	50	0.000569808	0.1714 ± 0.0007653
3.	20	50	0.00630938	0.1751 ± 0.000689
3.	50	50	0.0210199	0.2073 ± 0.001019
3.	100	50	0.0443162	1.21 ± 0.003153
3.	150	50	22.3114	1.896 ± 0.007571
3.	200	50	46.6146	0.787 ± 0.002939
3.	300	50	90.2031	0.2685 ± 0.001344
3.	500	50	269.146	0.04468 ± 0.0002221
3.	1000	50	787.84	0.003505 ± 1.861e-05
3.	1500	50	1260.18	0.0006823 ± 3.857e-06
3.	10	150	0.000569808	0.009285 ± 4.234e-05
3.	20	150	0.00630938	0.00924 ± 4.234e-05
3.	50	150	0.0210199	0.009462 ± 3.85e-05
3.	100	150	0.0443162	0.01017 ± 4.443e-05
3.	150	150	0.068865	0.01124 ± 5.221e-05
3.	200	150	0.0962116	0.01366 ± 6.834e-05
3.	300	150	0.171489	0.05937 ± 0.0002495
3.	500	150	192.405	0.03448 ± 0.0001467
3.	1000	150	745.959	0.00288 ± 1.359e-05
3.	1500	150	1231.85	0.0005735 ± 3.925e-06
3.	50	300	0.0210199	0.001039 ± 3.982e-06
3.	100	300	0.0443162	0.001056 ± 4.834e-06
3.	150	300	0.068865	0.001096 ± 4.922e-06
3.	200	300	0.0962116	0.001147 ± 5.869e-06
3.	300	300	0.171489	0.001327 ± 6.728e-06
3.	500	300	100.732	0.00245 ± 9.636e-06
3.	1000	300	618.446	0.001853 ± 7.863e-06
3.	1500	300	1140.14	0.0003934 ± 2.083e-06
3.	150	500	0.068865	0.0001123 ± 4.327e-07
3.	200	500	0.0962116	0.000114 ± 5.127e-07
3.	300	500	0.171489	0.0001206 ± 5.124e-07

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
3.	500	500	100.732	0.0001447 ± 6.102e-07
3.	1000	500	435.099	0.0004016 ± 1.656e-06
3.	1500	500	949.035	0.0002061 ± 8.548e-07
3.5	10	1	4.58539	257.5 ± 0.9241
3.5	20	1	9.61097	123.8 ± 0.4645
3.5	50	1	24.3407	31.59 ± 0.09614
3.5	100	1	48.7723	7.04 ± 0.02954
3.5	150	1	73.186	2.417 ± 0.01038
3.5	200	1	97.5987	1.089 ± 0.004308
3.5	300	1	146.447	0.3709 ± 0.001616
3.5	500	1	380.808	0.06035 ± 0.0003762
3.5	1000	1	1079.63	0.004345 ± 2.711e-05
3.5	1500	1	1720.11	0.0008581 ± 3.653e-06
3.5	10	10	0.000775572	15.08 ± 0.0569
3.5	20	10	0.00858777	51.42 ± 0.1478
3.5	50	10	18.7909	32.56 ± 0.1113
3.5	100	10	45.9065	6.963 ± 0.03199
3.5	150	10	71.2646	2.38 ± 0.009493
3.5	200	10	96.1548	1.079 ± 0.004244
3.5	300	10	145.483	0.369 ± 0.001602
3.5	500	10	380.229	0.05978 ± 0.0003017
3.5	1000	10	1079.34	0.004302 ± 2.412e-05
3.5	1500	10	1719.92	0.0008525 ± 3.878e-06
3.5	10	50	0.000775572	0.3176 ± 0.001314
3.5	20	50	0.00858777	0.3229 ± 0.001215
3.5	50	50	0.0286105	0.3857 ± 0.001618
3.5	100	50	0.0603192	2.228 ± 0.00751
3.5	150	50	30.3684	2.477 ± 0.008787
3.5	200	50	63.4476	1.025 ± 0.003864
3.5	300	50	122.776	0.3483 ± 0.001614
3.5	500	50	366.338	0.05534 ± 0.0003035
3.5	1000	50	1072.34	0.004076 ± 2.371e-05
3.5	1500	50	1715.24	0.0008077 ± 4.889e-06
3.5	10	150	0.000775572	0.01719 ± 9.115e-05
3.5	20	150	0.00858777	0.01719 ± 8.334e-05
3.5	50	150	0.0286105	0.01754 ± 8.239e-05
3.5	100	150	0.0603192	0.01855 ± 8.371e-05
3.5	150	150	0.0937329	0.02099 ± 0.0001038
3.5	200	150	0.130955	0.0252 ± 0.0001138
3.5	300	150	0.233416	0.1096 ± 0.0006465
3.5	500	150	261.885	0.04374 ± 0.0002091
3.5	1000	150	1015.33	0.00334 ± 1.751e-05

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Table 2 – continued from previous page

Coupling (g)	m_{Phi} [GeV]	m_χ [GeV]	Γ_{min} [GeV]	σ
3.5	1500	150	1676.69	0.0006583 ± 3.614e-06
3.5	10	300	0.000775572	0.001925 ± 9.279e-06
3.5	20	300	0.00858777	0.001916 ± 1.026e-05
3.5	50	300	0.0286105	0.001918 ± 8.166e-06
3.5	100	300	0.0603192	0.001958 ± 7.426e-06
3.5	150	300	0.0937329	0.002036 ± 8.81e-06
3.5	200	300	0.130955	0.002123 ± 8.379e-06
3.5	300	300	0.233416	0.002448 ± 9.259e-06
3.5	500	300	137.107	0.004413 ± 2.588e-05
3.5	1000	300	841.774	0.002184 ± 1.014e-05
3.5	1500	300	1551.86	0.0004471 ± 2.349e-06
3.5	10	500	0.000775572	0.0002016 ± 7.906e-07
3.5	20	500	0.00858777	0.0002011 ± 9.138e-07
3.5	50	500	0.0286105	0.0002018 ± 9.929e-07
3.5	100	500	0.0603192	0.0002033 ± 8.104e-07
3.5	150	500	0.0937329	0.0002067 ± 8.026e-07
3.5	200	500	0.130955	0.0002106 ± 8.439e-07
3.5	300	500	0.233416	0.0002225 ± 9.256e-07
3.5	500	500	137.107	0.0002686 ± 1.162e-06
3.5	1000	500	592.219	0.0005877 ± 2.823e-06
3.5	1500	500	1291.74	0.0002318 ± 1.11e-06

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