On the way to the Dark Matter Simplified Models for Run-2

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From Higgs to Dark Matter 2014 Geilo, Norway 14 - 17 December 2014

Two recent white papers

Simplified Models for Dark Matter and Missing Energy Searches at the LHC

Jalal Abdallah, Adi Ashkenazi, Antonio Boveia, Giorgio Busoni, Andrea De Simone, Caterina Doglioni, Aielet Efrati, Erez Etzion, Johanna Gramling, Thomas Jacques, Tongyan Lin, Enrico Morgante, Michele Papucci, Bjoern Penning, Antonio Walter Riotto, Thomas Rizzo, David Salek, Steven Schramm, Oren Slone, Yotam Soreq, Alessandro Vichi, Tomer Volansky, Itay Yavin, Ning Zhou, Kathryn Zurek <http://arxiv.org/abs/1409.2893>

Interplay and Characterization of Dark Matter Searches at Colliders and in Direct Detection Experiments Sarah A. Malik, Christopher McCabe, Henrique Araujo, Alexander Belyaev, Celine Boehm, Jim Brooke, Oliver Buchmueller, Gavin Davies, Albert De Roeck, Kees de Vries, Matthew J. Dolan, John Ellis, Malcolm Fairbairn, Henning Flaecher, Loukas Gouskos, Valentin V. Khoze, Greg Landsberg, Dave Newbold, Michele Papucci, Timothy Sumner, Marc Thomas, Steven Worm <http://arxiv.org/abs/1409.4075>

EFT validity To sum over the possible *p*T*,* ⌘ of the jets, we integrate the cross sections over values typically considered in the experimental searches and we can thus define the following ratio of the following ratio of t

500

90 %

 $\%$ CL limit on

 Λ [GeV]

1000

1500

2000

2500

sections in the control of the control of

-proton cross section @cm2

Region I

[1307.2253](http://arxiv.org/abs/arXiv:1307.2253)

[1308.6799](http://arxiv.org/abs/1308.6799)

[1411.0535](http://arxiv.org/abs/1411.0535)

s-channel simplified models In order to model mediator production, we will consider simplified models with the mediators to the dark sector associated with scalar *S*, pseudo-scalar *P*, vector *Z*⁰ and axial-vector *Z*⁰⁰ fields with interactions, the recent Higgs discovery and assumes that the coupling strength of the new scalars to Standard Model fermions is

• Yukawa couplings are taken proportional to the Higgs Yukawa couplings. *t* ⇤*t*), may significantly enhance the "minimal widths" which we define as, pseudo-scalar, vector or axial-vector mediator. The left diagram shows an electronical mediator mediator media r proportional to the ringgraph representation of the same process.

5

[GeV]

DM $\mathsf{E}% _{T}$

 \overline{c}

[GeV]

DM s

 \overline{c}

 $\ddot{ }$

 $6⁰$

 $\mathbf{8}$

ا0

 $\ddot{ }$

 $6⁰$

 $\mathbf{8}$

ا0

Additional heavy sector particles the recent Higgs discovery and assumes that the coupling strength of the new scalars to Standard Model fermions is proportional to their SM Yukawa couplings. $\mathcal{L}(\mathcal{$ povertional to the s [1411.0535](http://arxiv.org/abs/1411.0535)

• Let us consider additional heavy degrees of freedom charged under $SU(N_c)$ \rightarrow EFT Lagrangian in $\frac{0.1}{s^{g} = s_x = 1}$ \bullet - Let us consider additional heavy degrees of freedom charge The middle graph represents the full description of the same process, including the same process, including the fermion mass σ F_{model} is a graph index $\text{CI}(\text{N})$ \mathbf{p} is equalled axial-vector mediator. The mediator of the mediator of the mediator \mathbf{p} coupling to gluons. The middle graph represents the full description of the same process, including the fermion mass dependence o let us consider additional heavy degrees of freedom charged under Ect as consider additional neary degrees of incedent enarged and consider $g_g=0.25$ $g_g = g_\chi = 1$ 0.1 $g_t = 0.1$ $g_y = 1$ 0.1

- Higher dimensional operators are relatively less suppressed at high energies compared to their 4-dimensional counterparts. \bullet $\,$ Higher dime compared to their 4-dimensional counterparts. particles involved in the minimal processes at the microscopic level, thereby correctly capturing the kinematic features generalist the process of the set o
In the set of the set colored states which couple the mediator can be integrated out provided integrated which is much larger than the energy scale To be able to probe new physics models with particle masses below the characteristic interaction scale of the h • Higher dimensional operators are relatively less suppressed at high energies torripared to their redifferential counterparts. <u>f</u> gare for a belowing in which the dark matter particles 100 GeV and the mediator is 100 GeV and the mediator i left corresponds to the democratic choice of mediator-top and mediator-DM coupling (*g^t* = *g* = 1, whilst that on the right corresponds to the case in which *g^t* = *g/*10 = 0*.*1.
	- Setting $NP = 2 TeV$ and assuming g_{NP} is $O(1)$, EFT can be used for values $g_g < -0.1$ **e** Setting NP = 2TeV and assuming gup is $\Omega(1)$ FFT can be used for values $\sigma \leq \infty$ $\mathcal{T}_{\mathcal{S}}$ simplified model framework for dark sector searches at colliders showledge at constitution and dark sector showledge a list of \mathcal{S} ming g_{NP} is $O(1)$, EFT can be used for values $g_g < \sim 0.1$ maximum *g^g* which can be safely probed at the 14 TeV LHC is around *g^g <* 0*.*3. Figure 10 illustrates the usual result
	- Should a propagating resonance be found in the mono-jet channel, coupling constraints on loop-induced heavy particles can be investigated. **e** Should a propagating resonance be found in the mono-jet c decays into other particles, including dark matter. In general such benchmark models would be characterised by the axial-vector) and the decay channel (e.g. *s*-channel or *t*-channel production of two dark matter fermions, or other DM of the new physics model. and mond for channel, coupling k relevant α interactions which first produce a mediator particle in a proton-proto decays into other particles, including dark matter. In general such benchmark models would be characterised by the ch that higher dimensional operators are relatively less suppressed and to the management and to the to the to the rico do round in the mono-joc channer, couping modifies the four-dimensional Lagrangian. The results parameter in the suggest that, showled a propagation suggest that monoming resonance be found in the mono-

[1410.6497](http://arxiv.org/abs/arXiv:1410.6497)

4

Scalar simplified models channels: missing transverse energy with a social pairs, with a social pairs, and with a social p quarks. We apply our constraints to the special case of the 125 GeV Higgs as the scalar mediator in Section V. We then conclude by outlining additional searches and improvements that could be made for future analyses.

$$
\mathcal{L}_S = \mathcal{L}_{\text{SM}} + \frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m_\phi^2 \phi^2 + i \bar{\chi} \partial \chi - m_\chi \bar{\chi} \chi - g_\chi \phi \bar{\chi} \chi - \sum_{\text{fermions}} g_\nu \frac{y_f}{\sqrt{2}} \phi \bar{f} f,
$$

$$
\mathcal{L}_A = \mathcal{L}_{\text{SM}} + \frac{1}{2} (\partial_\mu A)^2 - \frac{1}{2} m_A^2 A^2 + i \bar{\chi} \partial \chi - m_\chi \bar{\chi} \chi - i g_\chi A \bar{\chi} \gamma^5 \chi - \sum_{\text{fermions}} i g_\nu \frac{y_f}{\sqrt{2}} A \bar{f} \gamma^5 f.
$$

- 5 parameters: DM mass, mediator mass, DM-mediator coupling, flavor-universal SM-mediator coupling, mediator width **b** parameters: Dry mass, mediator mass, Dry-mediator coupling, the cross section for data matter production, and scattering to nucleons is producted to nucleons is product of \overline{A} perspecters: DM mass modister mass DM modister caupling Separative flavor-universal SM-mediator coupling, mediator width dominated by the tree-level terms, though as in Higgs production, loop e↵ects can be important in the (*A*)+ heavy parameter If the external particles in the loop induced *g g* (*A*) interaction are on-shell, then it can be exactly calculated ivor-universal sin-Hiediator coupling, inequator wiquit
- Keeping the width as a free parameter allows for couplings to additional particles, perhaps in an expanded dark sector.
The width as free parameters on the width with without specific with without specific with without specific with Keeping the width as a free parameter allows for couplings to additional particles, perhaps in an expanded dank sector.
 *L*_{*S}* and *i*s a second in Section Minimal Flame Wireless II</sub> in a single coupling value, as in Higgs physics. A similar diagram induces couplings to photons. At leading-order, the Keeping the width as a free parameter allows for couplings f $m = 4$ additional the additional terms 4 an expa *gv v ded dark sector.*
- Fermion couplings follow Minimal Flavor Violation **The find complings follow Finducial Flavor molation** '
I bas follow Minimal Flavor Violation *g^v* where ⌧ = 4*m*² *^t /m*² (*A*), *y^t* is the top Yukawa, *v* is the Higgs vacuum expectation value, and the function *f*(⌧) is

f(⌧) =

1

⇣

- Mediator couplings to SM fermions are proportional to the Higgs Yukawa couplings. dark matter cannot be primarily an *SU*(2)*^L* multiplet with *Y* 6= 0, due to direct detection bounds. If is a complete ے .
۲٫ ar coupling *v* ⌧*f* (⌧) *G^µ*⌫*G*˜*µ*⌫*A* + *i*↵ s are prop α artional to the Higgs Yukawa coupling mons are proportional
- Dominant production at the LHC would be through ggF as the tree-level couplings to light quarks are Yukawa-suppressed. The mixture mixture mixture mixture mixture, and mediator to a new strateg Dominant production at the LHC would be through ggh as the tree-level couplings be an *SU*(2)*^L* doublet while still avoiding direct detection constraints. This again involves mass terms in the dark f -H) would pula be through ggF as the tree-level coup W_{max} is shown that the extension can be accurated for a be accurated for an arbitrary top and arbitrary top and W_{max}

.
...

, ⌧ *<* ¹ *.* (5)

Bounds from DD, ID, thermal relic The finite width is not relevant to these constraints (barring widths of order *m*), so the bound is placed on the combination *gg^v* as a function of dark matter and mediator masses, independent of width. In Figure 5, we show the upper limits placed by LUX and CDMS-lite at the 95% confidence level (CL) on the coupling combination *ggv*, as a function of the scalar mediator and dark matter masses. The discontinuity visible at *m* ⇠ 6 GeV is a $\overline{1410.6497}$ $\overline{1410.6497}$ $\overline{1410.6497}$ Though the source of the source of the source of \mathbf{P}_1 be accommodated by annihilation through a pseudoscalar mediators with Standard Model couplings proportional to Yukawas [99–104], as in our benchmark simplified model. In this paper, we use only the 95% CL upper limits on the indirect annihilation cross section into pairs of *b*-quarks from the FGST dwarf analysis [82], converted to limits on our model parameters by calculating the velocity averaged C. Thermal Relic Abundance

- The pseudo-scalar model has no velocity or momentum section with protons and
- $\bullet \quad$ < σv is proportional to v^2 → no significant signals in ID $(v \le 10^{-2}c)$.
- Thermal abundance is shown $\frac{1}{\sqrt{2}}$ morning abdituative is shown $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$

Heavy flavour searches Recently however, ATLAS has published a dedicated search for dark matter produced in associated with *b*-tagged [1410.6497](http://arxiv.org/abs/arXiv:1410.6497)

 j is 20.3 fb¹ j and relevant j of j categories in the relevant for i both, the analysis vetoes events with leptons that have *p^T >* 20 GeV and requires *E^T >* 300 GeV. The azimuthal

• With MVF, the mediator is most strongly coupled to the heaviest fermions. **Lindawith in our** *Simples* World in the Models inconstant we cannot specify a width only from the coupled to the heaviest fermions q

• The b-tagged channel places significantly weaker constraints than the mono-jet or top channels. find b ca_oood charmer praces signification, wearter constrained enter the mono joe of top distribution (and thus the MET) can be increased relative to the narrow width approximation. This is a result of the narrow width approximation. This is a result of the narrow width approximation. This is a result of the n FIG. 11: 95% CL upper limits on *gg^v* for scalar mediators from collider searches as a function of */m*, assuming and geven dimension process signification wediter constraints chan end inche $s = s$ shown as the solid colored (red or blue) line for the Full Theory including heavy \sim

the mediator.

Minimal Simplified Dark Matter models 1407.8257 moark matter mo direct detection experiments $\mathbf{57}$. As we are particularly interested in the complementarity interested in between hadron collider and direct detection searches for dark matter, we do not consider the case of case when the detection experiment of the contribution experiment of the contribution of t

- s-channel vector and axial-vector simplified models A s has been discussed in the literature \mathcal{I}_1 , the mediator width mediator widt
- It is possible to have mixed vector and axial-vector couplings. However, such interactions are suppressed by v_{DM} ² for the direct detection ($v_{DM} \sim 10^{-3}$). also been discussed elsewhere in the literature [8, 11, 16, 32, 43–56]. Although the collider \bullet it is possible to have mixed vector and axial-vector \bullet $\frac{d}{dx}$ is characteristic directed by the same four parameters. ossible to have mixed vector and axial vector couplings However $\frac{1}{\pi}$ is the decay contribute to media so that the total width is the total width i
	- No additional visible or invisible decays contribute to the width.

$$
\Gamma_{\text{med}} \equiv \Gamma(Z' \to \bar{\chi}\chi)\Theta \left(M_{\text{med}} - 2m_{\text{DM}}\right) + \sum_{q} \Gamma(Z' \to \bar{q}q)\Theta \left(M_{\text{med}} - 2m_{q}\right)
$$

- 4 parameters: M_{med}, m_{DM}, g_q, g_{DM} \bullet \bullet \bullet \bullet parameters: M_{med} , m_{DM} , g_{d} , g_{DM}
- The results can be interpreted in the following way: \bullet The results can be interpreted in the following way:
- m_{DM} vs. M_{med}, for fixed g_q and g_{DM} **Digital experiments in the complementary interest of an use of an use of the complementary interest in the complementary in the complemen**
- \bullet M_{med} vs $g_q = g_{DM}$, for fixed m_{DM} this case of opinion experiments have detection experiments in the sensitivity.
	- \bullet m_{DM} vs $g_q = g_{DM}$, for fixed M_{med}

D_{avid} Jaich **g**David Šálek **gradu vseudování a vector (right panel) and axial-vector (right panel) mediator. The parameter**

EFT limitations

- EFT overstates the limit at low M_{med} or large m_{DM} as the suppressed off-shell mediator production is not taken into account.
- The underlying coupling structure is not resolved by EFT.

The red dot-dashed line shows the LUX limit. The left and right panels are for axial-vector and right panels are for

Implications from relic density it comes out to be (in units of the critical energy density of the universe) of the universe) of the universe) ⌦DM*h*² ' h*v*iann **[1410.7409](http://arxiv.org/abs/1410.7409)** where h*v*iann is the total thermally-averaged annihilation cross section, and the factor of 2 in the numerator is made explicit to emphasize that we are assuming a non-self-conjugate that we are assuming a nonia danaitu or ^h*v*i⇤ . ⁴*.*⁰ ⇥ ¹⁰⁹ GeV2*.* (2.4) 5. the coupling to the first generation of quarks is no less than the coupling to other SM fermions. In this situation, the relic density constraint gives a range within which the dark sector parameters enhanced couplings to other SM particles relative to *u, d* quarks in order to avoid overproduction, or alternatively, the DM is produced by some mechanism other than thermal production. T_{max} summarize, under our generic assumption cross section must satisfy section must satis

- Planck measurement $\Omega_{\rm DM}^{\rm obs} h^2 = 0.1199 \pm 0.0027$ • Planck measurement $\Omega_{\text{DM}}^{\text{obs}}h^2 = 0.1199 \pm 0.0027$ $\Omega_{\text{DM}}h^2 \simeq \frac{2 \times 2.4 \times 10^{-10} \text{ GeV}^{-2}}{4 \text{ eV}}$ k measuremen 1
- DM interacts with the first-generation quarks. $\langle \sigma v \rangle_* \equiv \langle \sigma v \rangle_{\chi \bar{\chi} \to u \bar{u}} + \langle \sigma v \rangle_{\chi \bar{\chi} \to d \bar{d}}$, \bullet DM interests with the first consustion cusules $\left(\begin{array}{cc} \vee & \vee & \vee \end{array} \right)$ Signification when the integration when $\frac{1}{2}$ and the $\frac{1}{2}$ \frac \sum is interfaced when end in be gonoration quarrely $\sum_{k=1}^{\infty} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2} \sum_{k=1}^{\infty} \frac{1}{2}$

\n- • Planck measurement
$$
\Omega_{DM} h^2 = 0.1199 \pm 0.0027
$$
 $\Omega_{DM} h^2 \simeq \frac{2 \times 2.4 \times 10^{-10} \text{ GeV}^{-2}}{\langle \sigma v \rangle_{\text{ann}}}$
\n- • DM interacts with the first-generation quarks. $\langle \sigma v \rangle_* \equiv \langle \sigma v \rangle_{\chi \bar{\chi} \to u \bar{u}} + \langle \sigma v \rangle_{\chi \bar{\chi} \to d \bar{d}},$
\n

lepton gen*.*

quark gen*.*

- Besides that, there can be additional channels. $D_{\rm{max}}$ abundance must match the one recently measured by the one recently measured by the Planck collaboration, $D_{\rm{max}}$ • Besides that, there can be additional channels.
- Let us assume the coupling to the first-generation quarks is no less than the coupling to other SM fermions. he first-generation qu Now, a fundamental question which one should ask is the following: under the optimistic $\sqrt{\frac{\nu v}{\tan n}} \geq \frac{\sqrt{\frac{\nu v}{\pi}}}{\sqrt{\frac{\nu v}{\pi}}} \geq \frac{3}{3} \sqrt{\frac{\nu v}{\pi}} = \pm \sqrt{\frac{\nu v}{\pi}}$ true nature of the DM? $\mathbf y$ to the first-generation quarks is no less than the coupling $\mathbf y$ ρ_{σ} is compatible viewing ρ_{σ} is compatible ρ_{σ} in ρ_{σ} is ρ_{σ} in $\frac{1}{\sqrt{1-\frac{1}{\pi}}}\left(\frac{1}{\pi}\right)$ from direct $\frac{1}{\pi}$ is $\frac{1}{\pi}$ indirect $\frac{1}{\pi}$ in $\frac{1}{\pi}$ is important $\frac{1}{\pi}$ in $\frac{1}{\pi}$ is important $\frac{1}{\pi}$ in $\frac{1}{\pi}$ is important $\frac{1}{\pi}$ in $\frac{1}{\pi}$ is i • Let us assume the coupling to the first-generation quarks is no less than the coupling section which is relic abundance is $\mathcal{L} = \sum_{i=1}^n \mathcal{L}_i$ $\langle \sigma v \rangle_{\rm ann} \leq \quad \sum \quad \langle \sigma v \rangle_{\ast} + \quad \sum \quad \frac{1}{3}$ $\frac{1}{3}\langle \sigma v \rangle_* = 4 \langle \sigma v \rangle_*$ to other SM fermions. $\sqrt{2}$ the $\sum_{n=1}^{\infty}$ the DM production must satisfy section must satisfy section must satisfy sat with α more accurate expression for the relic density later in the text, although the principles in the principles of the princi **be the find them remains the same remains on the same of the same in the coupling to the instruction descripti** to other SM fermions. $\langle \sigma v \rangle_{\rm ann} \leq \sum \langle \sigma v \rangle_* + \sum \langle \sigma v \rangle_*$

$$
1.0 \times 10^{-9} \,\mathrm{GeV}^{-2} \simeq \frac{1}{4} \langle \sigma v \rangle_{\text{ann}} \leq \langle \sigma v \rangle_{*} \leq \langle \sigma v \rangle_{\text{ann}} \simeq 4.0 \times 10^{-9} \,\mathrm{GeV}^{-2}
$$
lepton gen.

tion is the linear state is too small, the small, then \overline{a}

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the bounds of the bounds.

, (2.3)

1410.7409 Mediator width in the s-channel Z'

- The annihilation rate only depends on the product g_{DMgf}, the mediator width depends on each coupling individually.
- For fixed values of the mediator width, one can recast the limit on $\sqrt{\text{g}_D}$ and α bound on the ratio fix gf/g_{DM}.

- The widths are unphysical at large mediator masses (no solution exists).
	- avoid using arbitrary mediator widths!

Searches for narrow dijet resonances

- A naive hope is that limits set at higher \sqrt{s} and with larger integrated luminosity would supersede previous limits.
- However, backgrounds also increase so that the jet trigger thresholds need to be increased.
- Consequently, the sensitivity to lighter resonances may decrease.

- The coupling reach is rather poor at 700-900 GeV and below 300 GeV. reach is rather poor at 700-900 GeV and below 30
- Non-conventional methods, such as data scouting, are important for extending the LHC sensitivity in the sub-TeV mass range. e. \blacksquare

DM forum

- Following the discussions at the **[DM@LHC Workshop in Oxford](http://indico.cern.ch/event/312657/)**, a common forum among ATLAS, CMS and theorists has been established with the following goals:
	- Agree on a list of simplified models that both collaborations will use in Run-2.
		- useful, minimal set of building blocks for reinterpretation
		- practical for experiments, endorsed by theory community
		- s-channel, t-channel, heavy flavor, mono-W/Z/γ/H
	- Harmonize technical details (generator, parton matching, theory uncertainties).
	- Common treatment of EFT
	- Presentation of the results (complementarity of the searches)
	- Write a comprehensive document as a reference/explanation for ATLAS and CMS collaborations, theory and non-collider communities.

next DM @ LHC Workshop

GRavitation AstroParticle Physics Amsterdam

exact dates to be announced

Looking forward to seeing you in Amsterdam!

[Massimo Catarinella CC BY-SA 3.0](#page-12-0)

extra material

Log and log

- POWHEG BOX allows for generation of the $\frac{1.1}{1.0}$ • POWHEG BOX allows for generation of the 1.0
- Including NLO corrections results in a smal $\frac{10}{20}$ $\frac{20}{20}$ $\frac{50}{20}$ $\frac{100}{20}$ $\frac{20}{20}$ $\frac{50}{20}$ $\frac{10}{20}$ $\frac{20}{20}$ $\frac{50}{20}$ compared to LO. \mathcal{M} and \mathcal{M} and \mathcal{M} and \mathcal{M} and the corresponding \mathcal{M} and the corresponding \mathcal{M} reference value for the strong coupling constant. We find the scale *µ* which determines ↵*s*(*µ*) $\frac{1}{2}$ i.e. we define $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$
	- dynamic scale $dV_T = \sqrt{m_{\bar{\chi}\chi}^2 + p_{T,j_1}^2 + p_{T,j_1}}$ $\mu = \xi H_T/2 = \mu_R = \mu_F$ $\overline{}$

$$
m_{\bar{\chi}\chi}^2 + p_{T,j_1}^2 + p_{T,j_1} \qquad \qquad \mu = \xi H_T/2 = \mu_R = \mu_F
$$

- It also leads to substantial reduction in the dependence on the choice of the renormalisation and factorisation scales. *H^T* = \mathbf{m} $\frac{1}{2}$ $\$ **•** It also leads to substantial reduction in the dependence on the α prediction (green) and the NLOPS result with jet veto (purple). The shown predictions correspond dependence on the choice of the
- **e** It leads to more robust bounds. with *m*¯ denoting the invariant mass of the DM pair and *pT,j*¹ the transverse momentum of the hardest jet is just jet *jet in our analysis*, we study the theoretical errors in our analysis, we study the ambiguities of If the reads to more robust bounds.

• Pathological cancellation of scale uncertainties with AI LAS cuts due to the symmetric jet pT and MET cuts.
 $\frac{1}{\sqrt{2}}$ factor. Right panel: Fixed-order NLO results NLO result (Red), the inclusive NLOPS NLOPS NLOPS NLOPS N *ET*, *E*_{*Z*} *E*_{*Z*} *E*_{*Z*} *E*_{*Z*</sup> *E*_{*Z*} *E*_{*Z*}} **Clearly, and** *Early Cancellation of scale uncertainties* **with ATLAS** cuts due to the symmetric die rences between the two analyses concerning the impact of NLO analyses concerning the impact of NLO and PS e
PS e la psychologie analyses concerning the impact of NLO and PS e la psychologie and PS e la psychologie and athological cancellation of scale uncertainties with ATLAS cuts due to the symmetric prediction (green) and the NLOPS result with jet veto (purple). The shown predictions correspond

[1409.4075](http://arxiv.org/abs/1409.4075)

Future projections

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Higgs portal DM We can complete the e H **H** R **Z**² in eq. (3.8) in eq. (3.8) in a straightforward way, since H ^p2*^h* ⁺ *...* . Hence, the simplest recipe to express the DM coupling to Higgs boson in terms of

$$
\mathcal{L} = -H^\dagger H \bigg[\bar{\psi}_{\rm DM} \frac{(y_{\rm DM} + i y_{\rm DM}^P \gamma_5)}{2 v} \psi_{\rm DM} + \frac{\lambda_{\rm DM}}{4} s_{\rm DM}^2 \bigg]
$$

