Sensitivity of LHC searches to IDM via Recasting with CheckMATE2

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Based on ongoing work in collaboration with Tania Robens and Krzysztof Rolbiecki

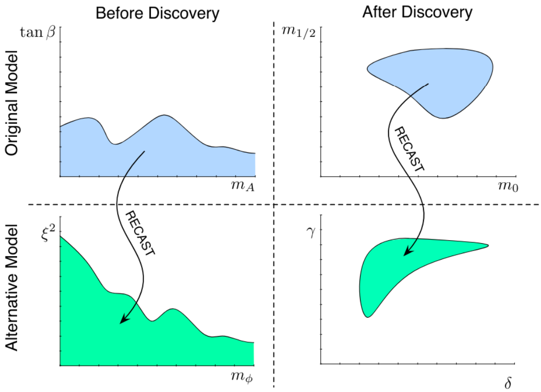
General motivation behind Recasting

- Dark matter remains one of the most elusive aspects of nature and SM of particle physics fails to provide an answer.
- Over past decades many models for DM beyond SM have been proposed by theorists, testable at the current and future collider experiments.
- Any such search analysis is extremely time and resource consuming.
- Ideally, a search *could be* sensitive to a broader class of models : central idea of *Recasting*.
- What impact does an existing analysis designed to probe one hypothesis have on an alternate signal hypothesis?

Why is it so powerful?

- One can reuse the background estimation as well as systematic uncertainties from the original search as well as observed data.
- One does not require to design event selection criteria.
- Only input that is required from the user, is the signal events.

A Schematic representation



Taken from JHEP 04 (2011) 038

The Caveat

- The experimental searches currently aim towards constraining a limited number of NP models.
- In reality the search invariably optimizes its analysis strategy, on the basis of some particular model, mostly driven by the simplicity and/or popularity of a model.
- Naturally the search will be most sensitive to the interesting regions of those particular models.
- It does *not* necessarily make the search insensitive to every other model at our disposal.

- In many cases the search *can be* insensitive to *other* models.

  1. The signal rates in an alternative model is too low.

  2. If the kinematical cuts optimized for one model cut off interesting regions of another model.

- We demonstrate such a scenario through the recasting of a ATLAS DM search, optimized for 2HDMa to IDM.

Quick comparison between the two models

2HDMa:

- 2HDM + pseudoscalar
- CP-even neutral scalars h, H, charged scalar $H^{\pm}$ and two CP-odd scalars A, a.
- Fermionic DM candidate χ.
- Relatively relaxed direct detection bound due to pseudoscalar portal mechanism.

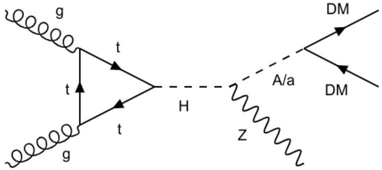
Inert Doublet Model:

- 2HDM with 0 vev for one doublet, unbroken Z_2 symmetry
- CP-even scalar h, charged scalar $H^{\pm}$.
- Scalar DM candidate H or A.
- stringent constraints from DD, observed relic.

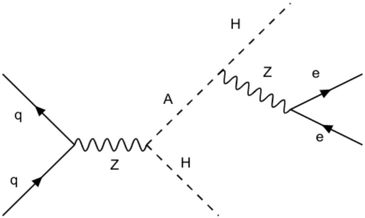
IDM has less free paramaters and more predictive power compared to 2HDMa.

Recasting $\ell^+\ell^- + \not{E}_T$ using full run-2 data (139 fb^{-1})

2HDMa:



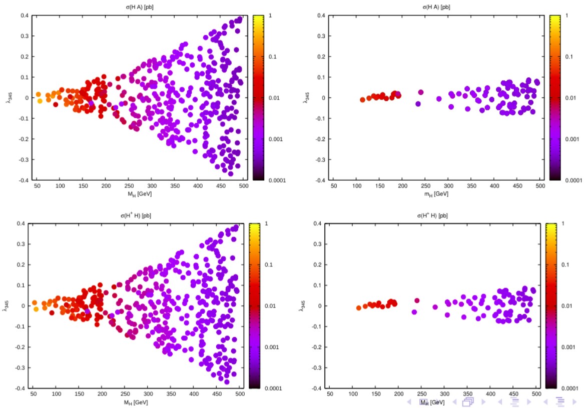
Inert Doublet Model:



Allowed parameter space of IDM

Updated constraints [LUX-ZEPLIN] [arXiv:2207.03764]

LUX | **LUX-ZEPLIN**



ATLAS Analysis cuts

The most sensitive search in the $\ell^+\ell^- + \not{E}_T$ channel comes from ATLAS collaboration *ATLAS Collaboration, Phys.Lett.B 829 (2022) 137066*. The following signal region was chosen.

- p_T of the leptons $> 20, 30$ GeV
- 76 GeV $< m_{\ell\ell} <$ 106 GeV
- $\not{E}_T > 90$ GeV
- $\Delta R_{\ell\ell} < 1.8$

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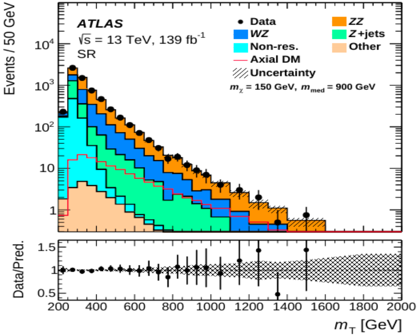


Final discriminant is m_T shape-fit.

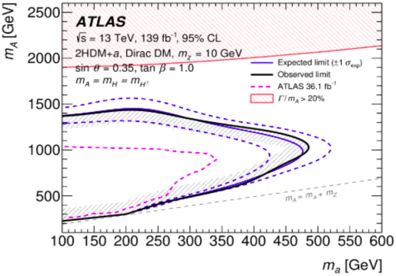
CHECKMATE

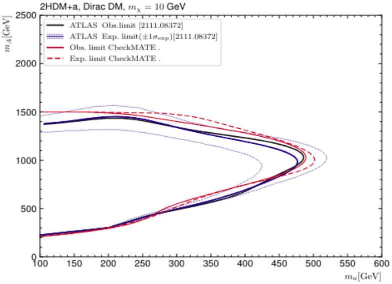
Current Members: Manimala Chakraborti, Nishita Desai, Florian Domingo, Jong Soo Kim, Krzysztof Rolbiecki, Roberto Ruiz de Austri, Ipsita Saha, Liangliang Shang, Mangesh Sonawane, Zeren Simon Wang, Yuanfang Yue

Former Members: Daniel Dercks, Manuel Drees, Herbert Dreiner, Frederic Ponzca, Jamie Tattersall, Thorsten Weber

- CheckMATE is a general tool for recasting arbitrary model
- Accepts events as .hepmc, .lhe; integration with Pythia and MadGraph
- based on Delphes for detector simulation
- using existing LHC searches calculates a limit on a given parameter point
- From SLHA file to the limit in one click
- one can easily constrain models that were not covered in the original ATLAS/CMS search
- currently more than 40 searches at 13 TeV coded, including 14 with full luminosity
- long-lived particles branch
- https://checkmate.hepforge.org/ and https://github.com/CheckMATE2/checkmate2

Validation with CheckMATE2

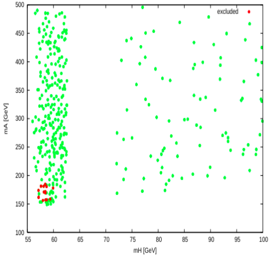


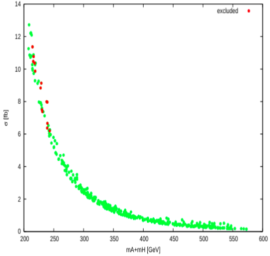


Constraint from *ATLAS Collaboration, Phys.Lett.B 829 (2022) 137066* and validation within CheckMATE courtesy I. Lara.

After Recasting with CheckMATE2

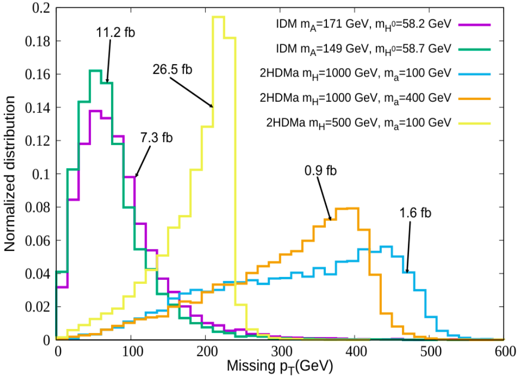
The major contribution comes from $pp \to HA$ production. But there are contributions $\lesssim 20\%$ from other diagrams(e.g Higgs-strahlung with Higgs invisible decay). A contribution from $H^{\pm}A$ production with hadronic W also included.





Scanned points taken from *Phys.Rev.D 93(2016)5,055026* Ilnicka, Krawczyk, Robens and later updated with new results.

Comparison of kinematics



2HDMa benchmarks shown here are all excluded, and IDM benchmarks are allowed.

Summary

- Our aim is to recast existing LHC searches to Inert Doublet model using CheckMATE2.
- Di-lepton+MET search from LHC is optimized in the context of 2HDM+pseudoscalar model.
- And we see that the search is *not* very sensitive to IDM in the regions that are allowed from the dark matter observations as well as theoretical and experimental constraints.
- The major reason behind this being very different kinematics in the two models.
- We would like to draw the attention of the experimentalists to the scenario, for LHC Run-3.
- We are also looking into soft leptons + MET final state as well as VBF production of Higgs boson decaying invisibly.

Back-up : Number of free parameters and constraints

The Model has 5 free parameters once v and m_h is fixed.
$M_H, M_A, M_{H^\pm}, \lambda_2, \lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5$

Theoretical Constraints: Positivity of the potential, vacuum stability, perturbativity

Experimental Constraints: Total width of h, W, Z, electroweak precision observables namely S, T, U, Higgs signal strength measurement, direct search for heavy scalars, reinterpreted/recasted LHC/LEP SUSY searches, dark matter relic density and direct detection constraints.