Search for dark matter produced in association with a hypothetical dark Higgs boson with the ATLAS detector

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T 99: Dark Matter IV

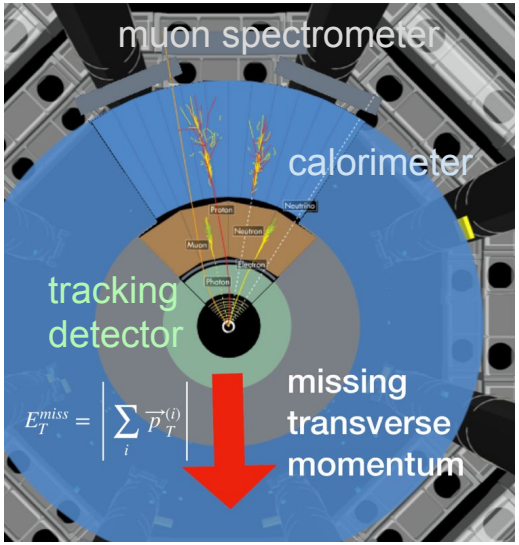
03.04.2020 - Bonn

BMBF-ErUM-Forschungsschwerpunkt
ATLAS-EXPERIMENT

Ausbau von ATLAS am LHC: Physik mit dem ATLAS-Experiment

ErUM-FSP T02
ATLAS

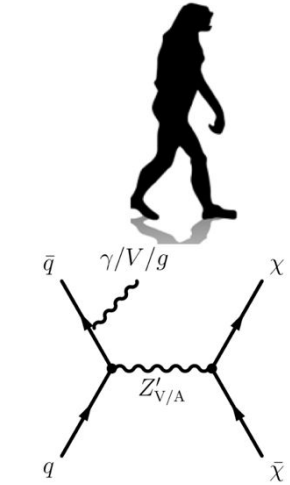
Dark matter searches at the LHC



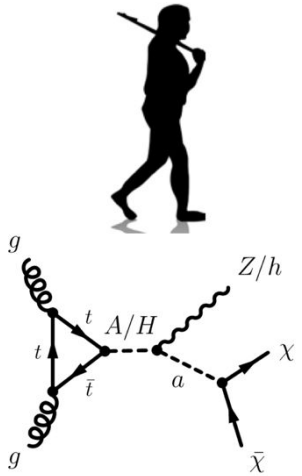
discover particle consistent with predicted properties of model

or constrain viable parameter space

guide towards interesting signatures



simplified models



consistent simplified models

complete models (e.g. SUSY)

Idea: Martin Bauer

Searches for DM with ATLAS

Dark matter models
(bottom-up approach)

Fruitful interplay between searches at collider experiments and models for DM production: consistent models – containing salient features of complete models – predict **new signatures**.

Two-mediator dark matter model

JHEP 09 (2016) 042

Searches in the context of
consistent simplified models
models with two mediators

Simplified model can satisfy requirements of gauge invariance and perturbative unitarity by introducing a spontaneously broken U(1)' symmetry.

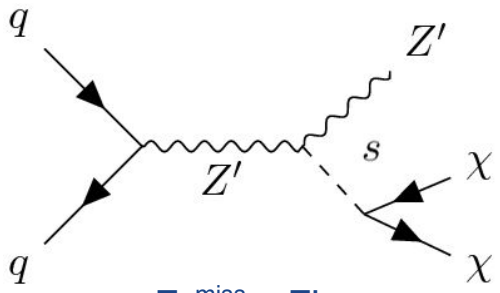
This gives rise to two s-channel mediators:

- spin-1 mediator: Z' boson
- spin-0 mediator: dark Higgs boson (s)

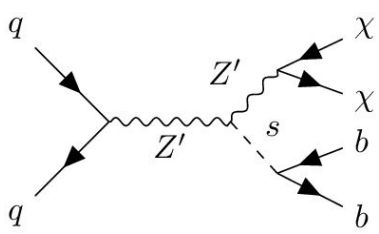
model parameters

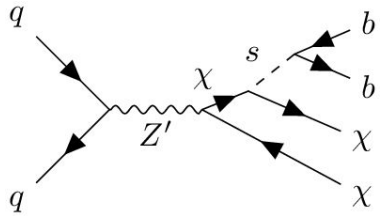
particle masses		coupling constants	
DM mass	m_χ	dark-sector coupling	g_χ or y_χ
Z' mass	$m_{Z'}$	quark–Z' coupling	g_q
dark Higgs mass	m_s	Higgs mixing angle	θ

New signatures emerge, depending on the parameter choices:



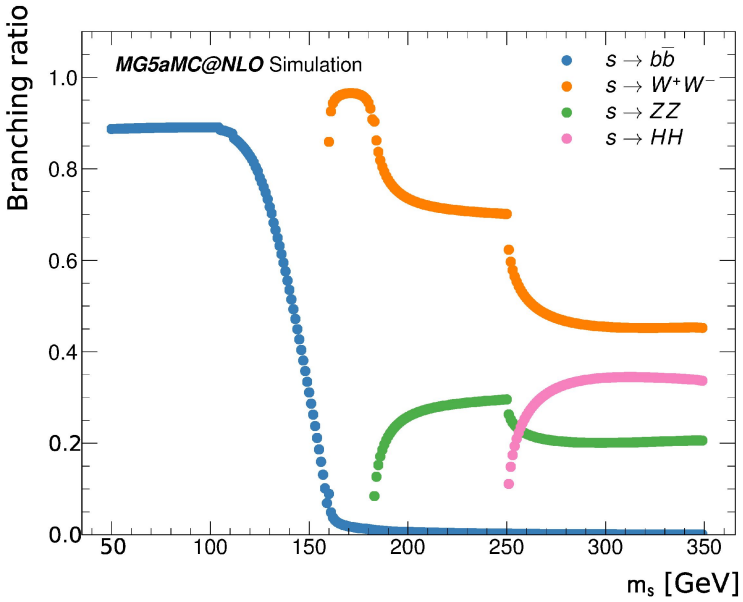
E_T^{miss} + Z'



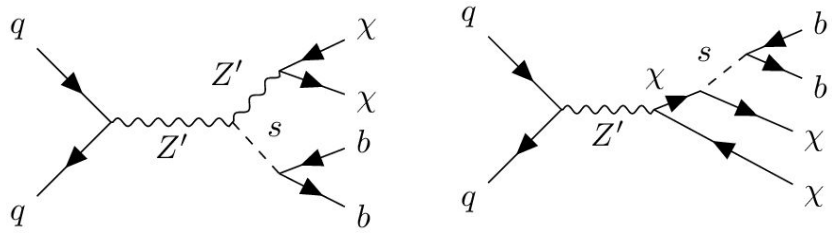


E_T^{miss} + dark Higgs

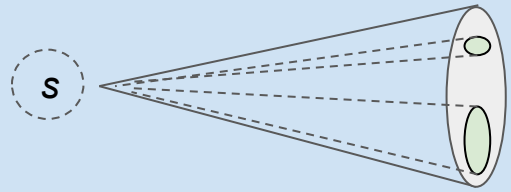
E_T^{miss} + dark Higgs



Dark Higgs mixing with SM Higgs enables decay to visible SM particles.



Possible searches in final states:

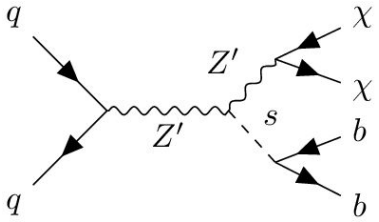


E_T^{miss} + dark Higgs (bb)

E_T^{miss} + dark Higgs (VV)

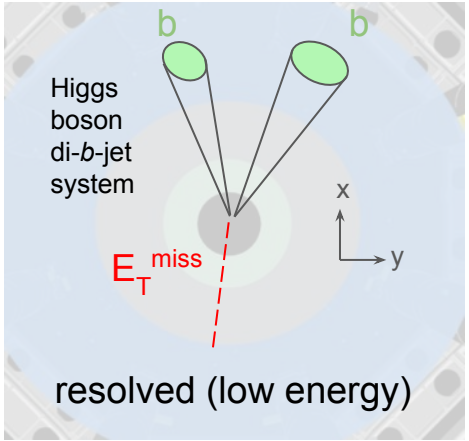
E_T^{miss} + dark Higgs (HH)

Signature #1:
E_T^{miss} + dark Higgs(bb)



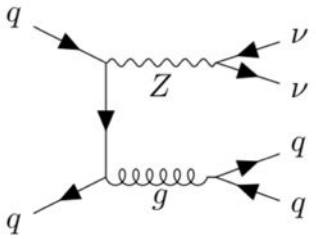
Signature: Dark Higgs boson *b*-jet (system) recoiling against E_T^{miss}

Strategy: Double-*b*-tagging based on track-based jets with adaptable radius allows for powerful background suppression also in merged event topologies

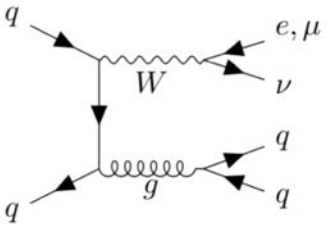


Dominant background processes:

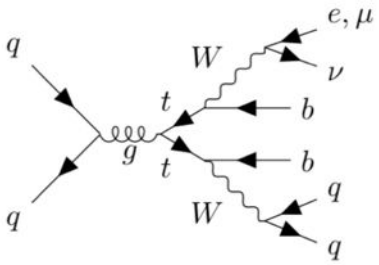
$Z \to \nu\bar{\nu}$ + jets

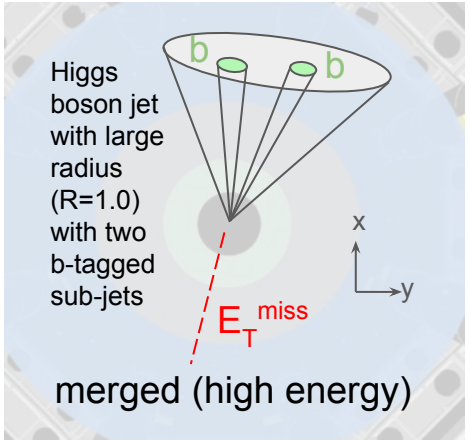


W + jets



$t\bar{t}$





Credit: Lukas Heinrich (CERN)

Reinterpretation of DM searches with recast

JHEP 04 (2011) 038

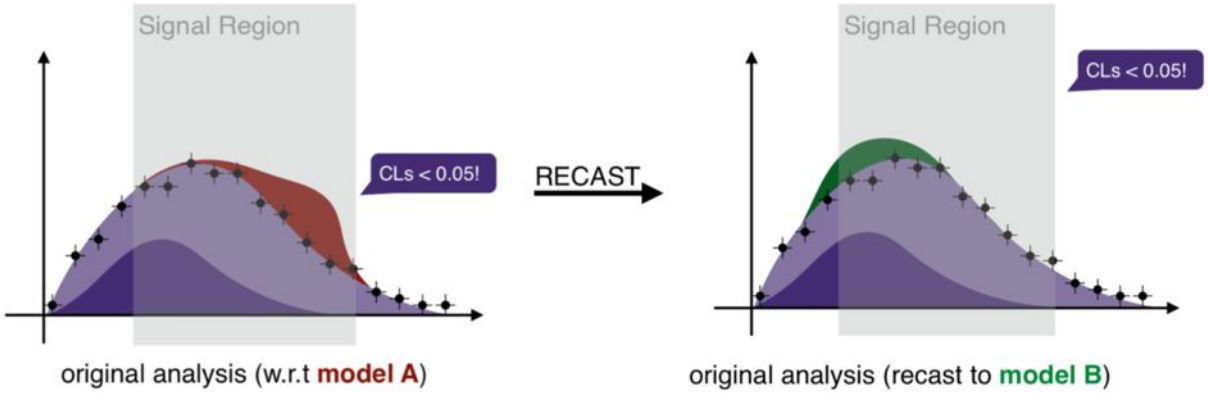
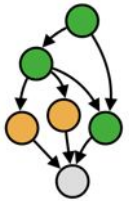


Illustration by Lukas Heinrich

Automated and truthful reinterpretation of an analysis made possible by capturing

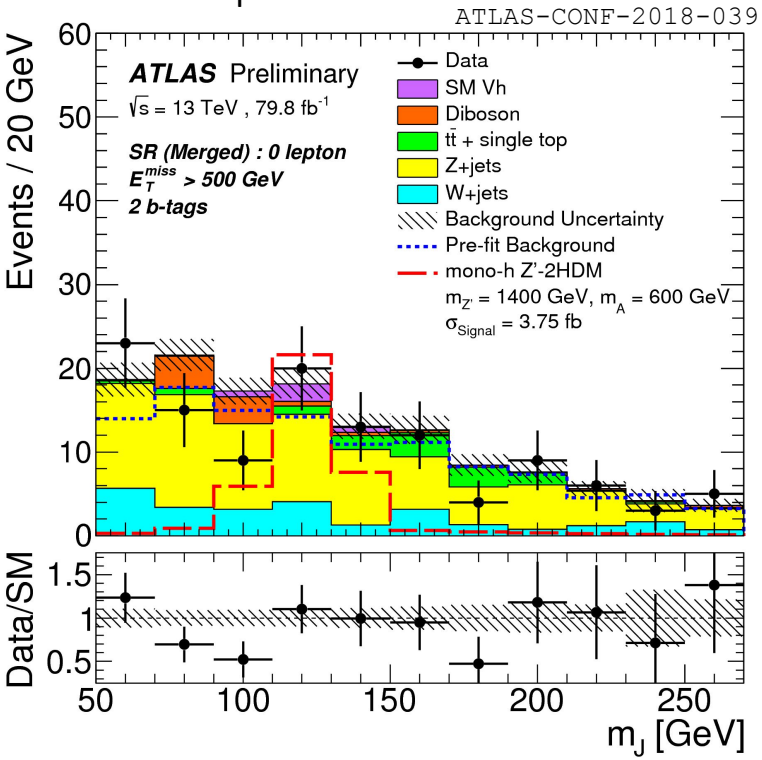
1. software
2. commands
3. workflow



Reinterpretation is based on **preserved data** and background estimate, which is combined with a new signal model piped through the analysis chain.

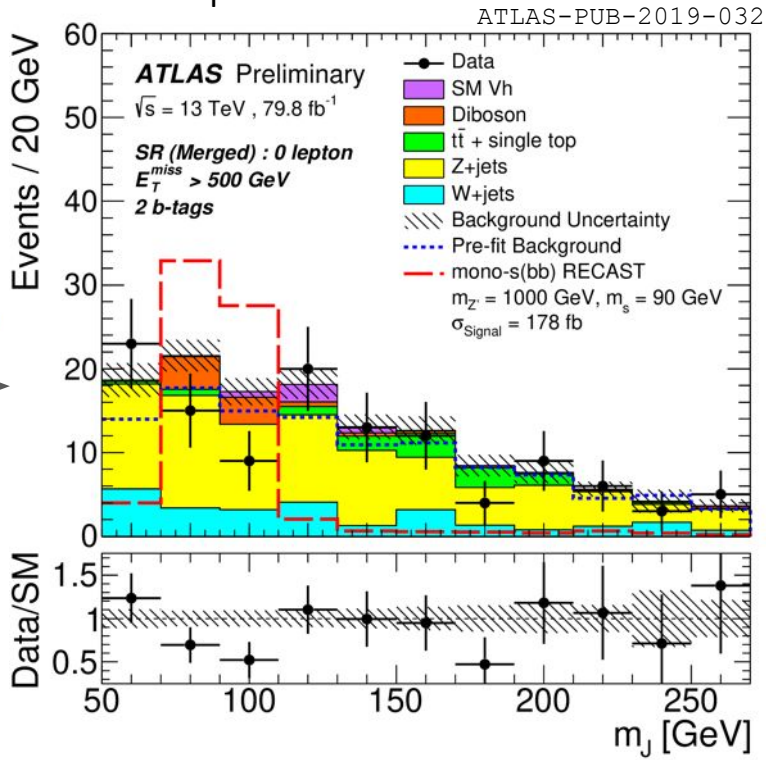
E_T^{miss} + dark Higgs(bb) RECAST re-interpretation results

E_T^{miss} + Higgs(bb)

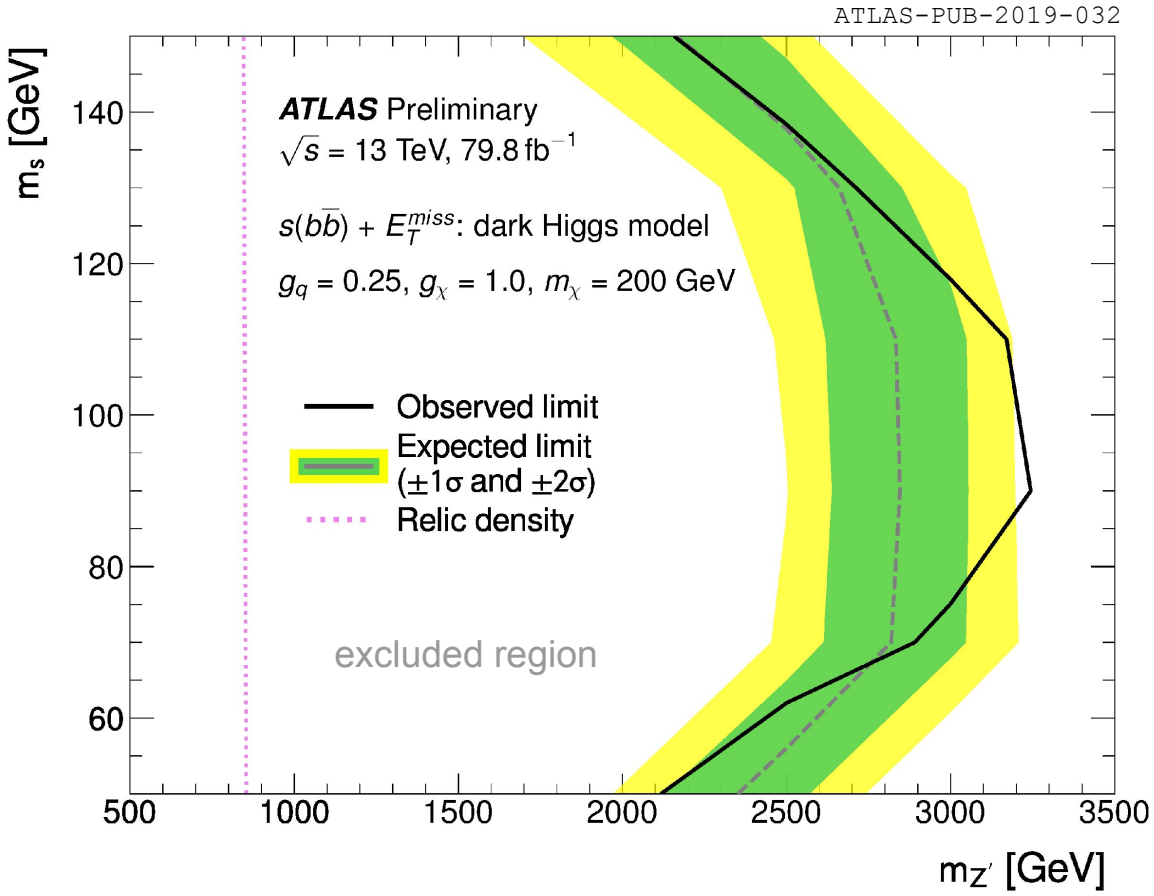


recast

E_T^{miss} + dark Higgs(bb)



E_T^{miss} + dark Higgs(bb) constraints on dark Higgs model

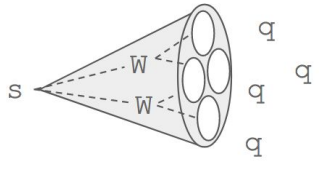


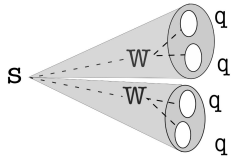
Signature #2:

E_T^{miss} + dark Higgs(WW) – hadronic

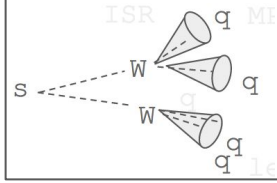
Signature: Dark Higgs boson decaying to W(qq) W(qq) recoiling against E_T^{miss} in event topologies depending on dark Higgs boson Lorentz boost

Merged: large-R jet



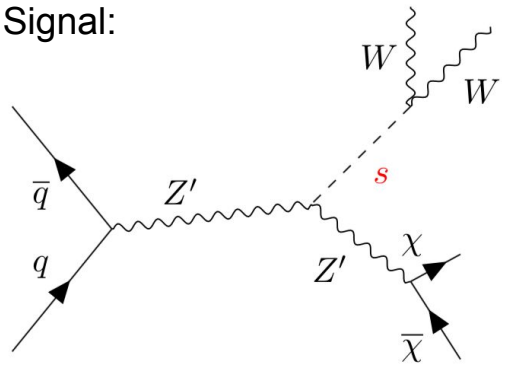


Intermediate: large-R & small-R jets



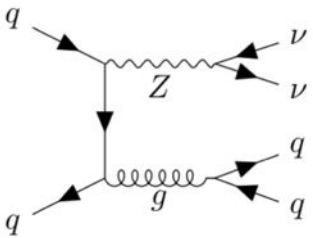
Resolved: small-R jets (jet combinatorics)

Signal:

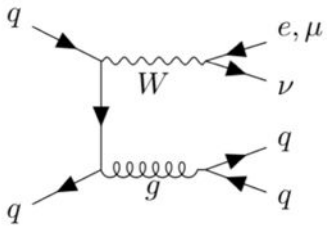


Dominant background processes:

$Z \to \nu\bar{\nu}$ + jets



W + jets



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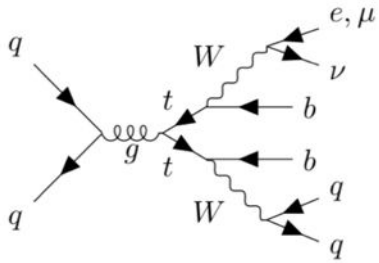
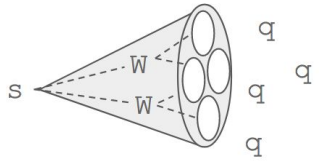
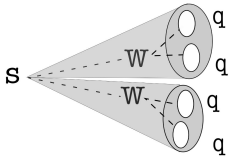


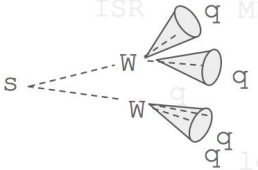
Analysis strategy: common pre-selection

Merged: large-R jet





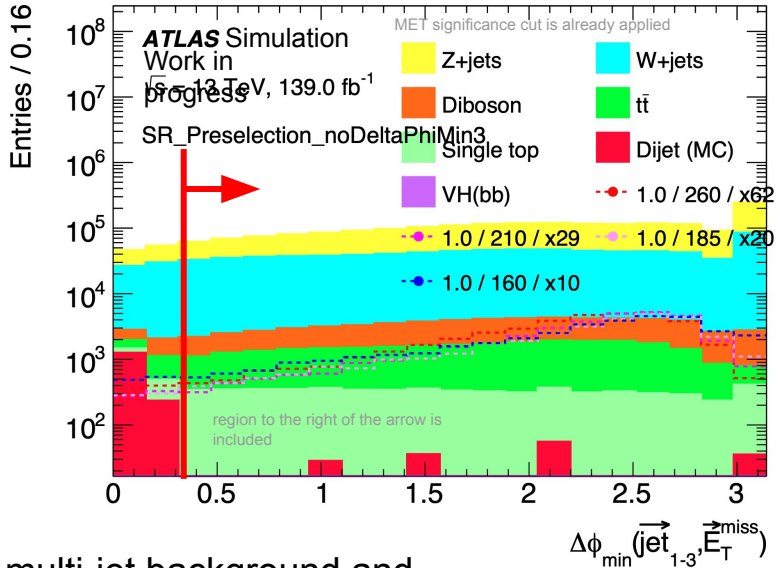
Intermediate: large-R & small-R jets



Resolved: small-R jets (jet combinatorics)

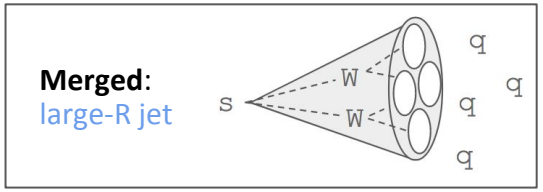
Common pre-selection requirements:

$0\,\ell$ SR
0 baseline ℓ
$E_{\mathrm{T}}^{\mathrm{miss}} > 200\,\mathrm{GeV}$
τ veto
0 b-tagged VR track jets in event
VR track jet ΔR overlap veto
$\Delta\phi_{\mathrm{jets}_{1,2,3}E_{\mathrm{T}}^{\mathrm{miss}}} > 0.35$
$\mathcal{S} > 15$
$\max(N(R\text{-scan jets}), N(\text{small-}R\text{ jets})) \geq 2$



Pre-selection requirements are designed to suppress multi-jet background and reduce dominant contribution of dominant background processes.

Analysis strategy: merged category



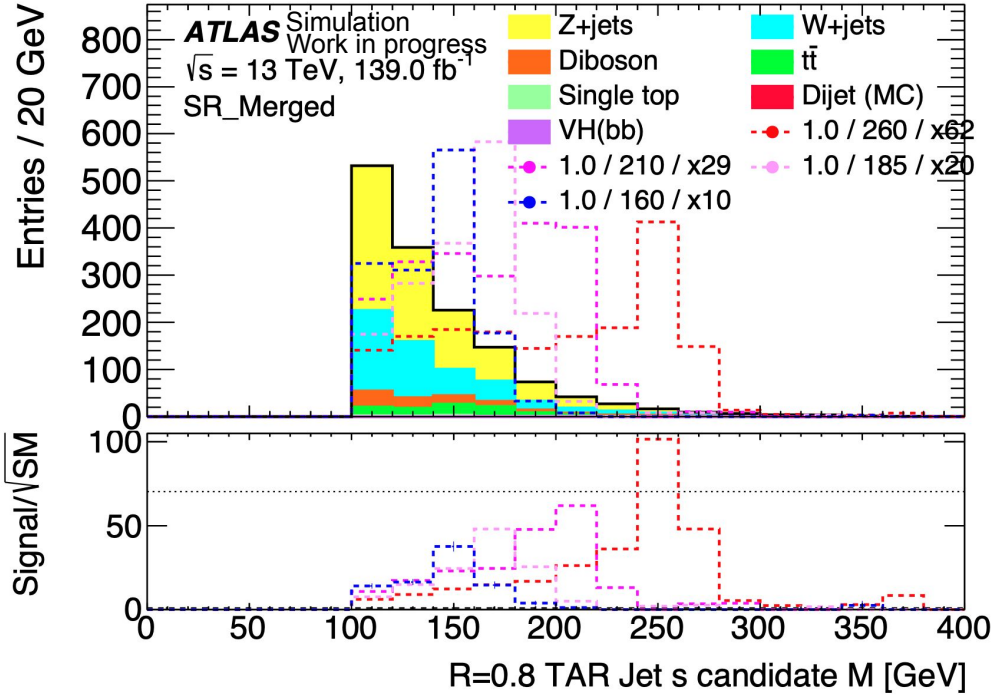
Dark Higgs candidate: single large-R TAR jet with tight requirements on jet substructure

Track-assisted re-clustering (TAR):

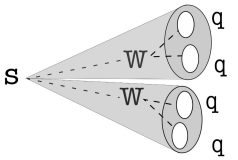
1. Create large-R jet with jet algorithm using R=0.2 jets as inputs
2. Match inner detector tracks to constituent R=0.2 jets
3. Compute R=0.8 jet substructure observables using tracking information

Selection requirements:

Merged
≥ 1 $R = 0.8$ TAR jet
$p_{\mathrm{T}}^{\mathrm{TAR\ Jet}} > 300$ GeV
$0. < \tau_{42} < 0.3$
$0. < \tau_{43} < 0.6$
100 GeV < m_{TAR} < 400 GeV



Analysis strategy: intermediate category



Intermediate: large-R & small-R jets

Dark Higgs candidate: large-R TAR jet supplemented with 1-2 R=0.2 jets

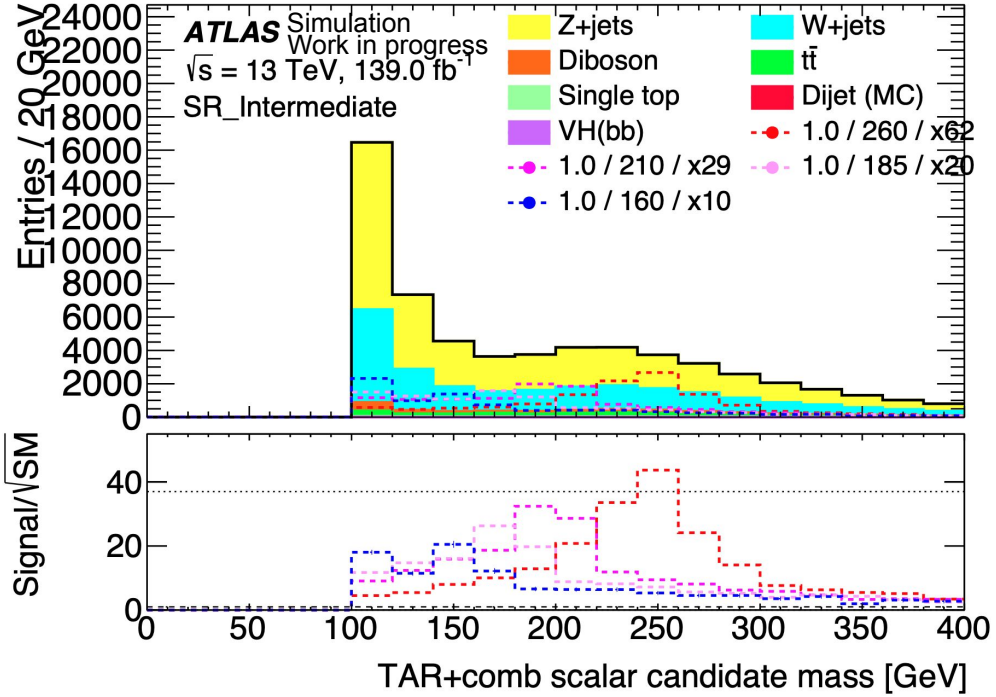
TAR+comb algorithm:

1. Select TAR jet with m^{TAR} > 60 GeV and jet substructure of two-prong decay.
2. If m^{TAR} < 100 GeV, create all possible di-jet pairs of R=0.2 jets within $\Delta R<2.5$ of TAR jet and add di-jet pair closest to W boson mass ($|m_{jj} - m_W|$) to TAR jet

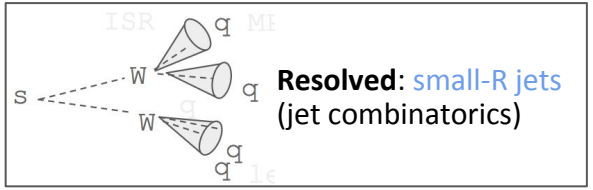
   If m^{TAR} > 100 GeV, assume that TAR jet contains 3/4 of dark Higgs decay and augment TAR jet with single R=0.2 jet

Selection requirements:

Intermediate
= 1 dark Higgs candidate reconstructed with TAR+Comb
100 GeV < $m_{TAR+Comb}$ < 400 GeV



Analysis strategy: resolved category



Resolved: small-R jets (jet combinatorics)

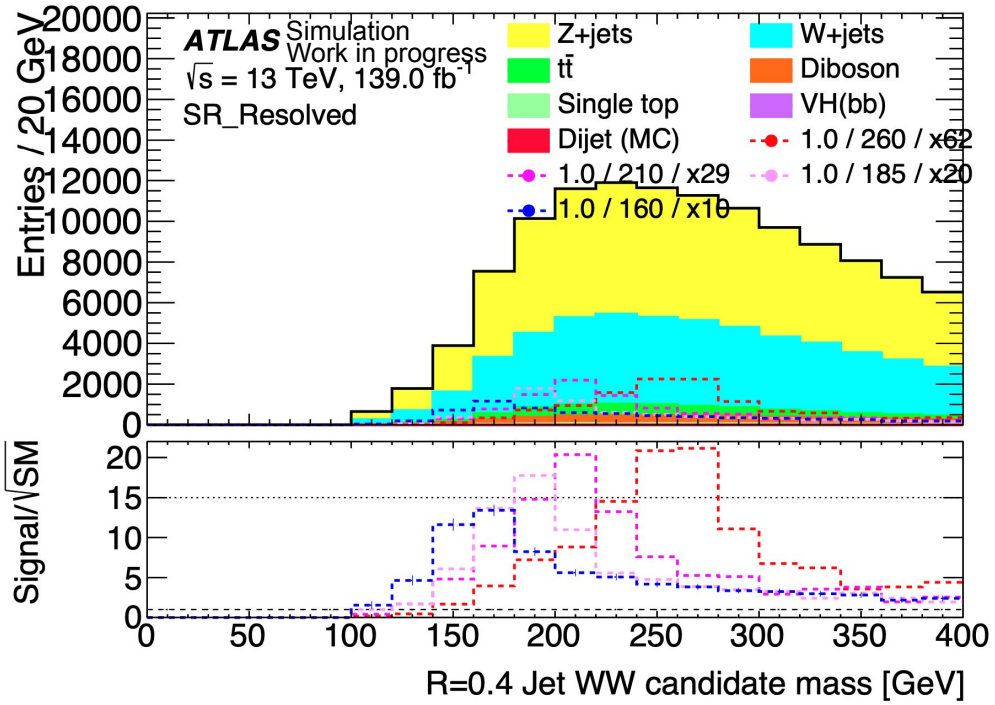
Dark Higgs candidate: system of 4 R=0.4 jets, selected by 2W algorithm

2W algorithm:

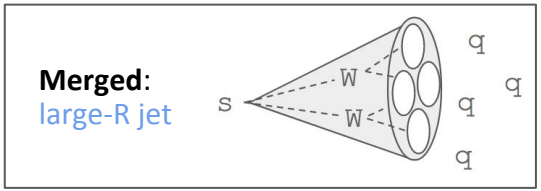
1. Create all possible combinations of di-jet system
2. Select the two di-jet systems closest to the W boson mass m_W = 80.4 GeV without identical constituents

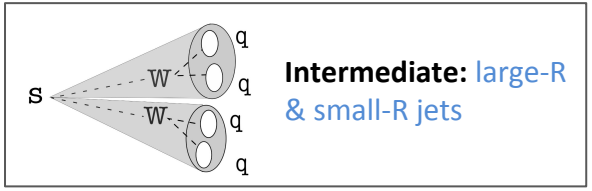
Selection requirements:

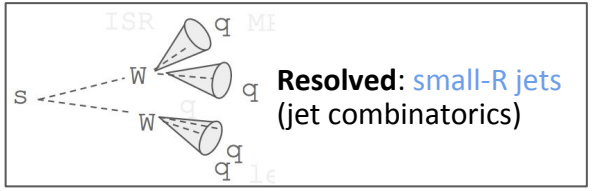
Resolved
≥ 4 small-R jets
= 1 dark Higgs candidate reconstructed with 2W algo
E_T^{miss} *exp(ΔR_{12}) > 40
100 GeV < m_{2W} < 400 GeV



Fit setup: signal and control regions



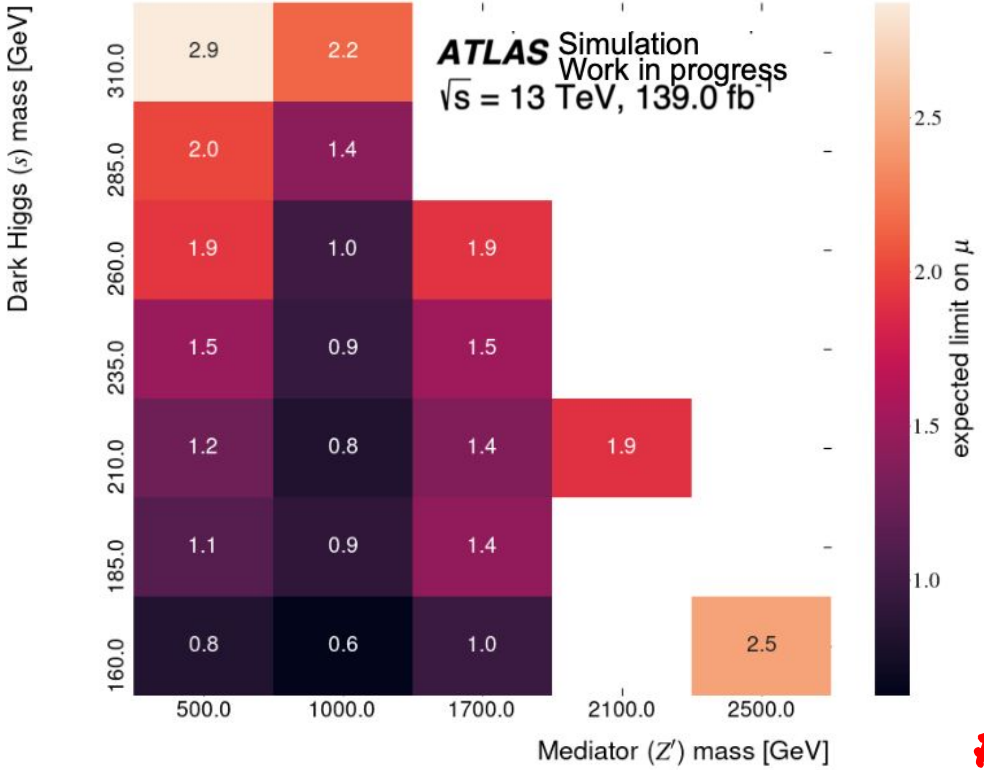


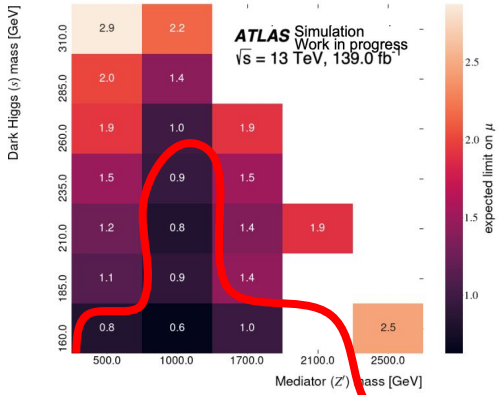


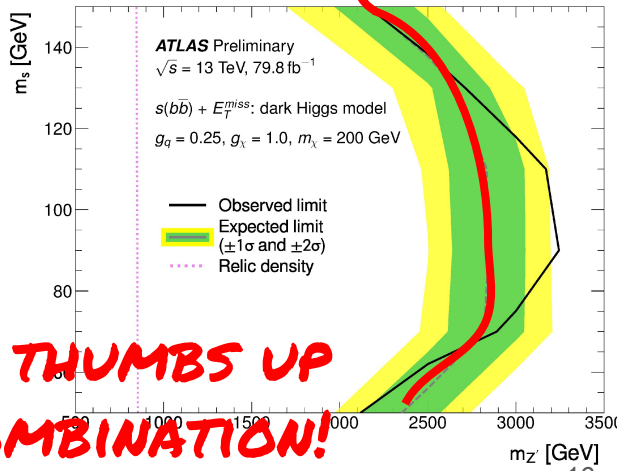
0 lepton signal region	more than 500 GeV	300 GeV - 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV
1 lepton control region	more than 500 GeV	300 GeV - 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV
2 lepton control region	more than 500 GeV	300 GeV - 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV	200 GeV - 300 GeV	300 GeV - 500 GeV	more than 500 GeV

1. Control regions constrain uncertainties on the background prediction in the signal region.
2. Partitioning signal + control region in E_T^{miss} bins enhances sensitivity.

E_T^{miss} + dark Higgs(WW) exp. constraints on dark Higgs model







THUMBS UP FOR COMBINATION!

Conclusions and outlook

- New signatures predicted by two mediator dark matter model motivate exploring yet uncovered region of phase-space at the LHC.
- Dark Higgs decaying to b-quarks viable parameter space constrained by RECAST of a ET^{miss} + Higgs(bb) search with partial Run-2 dataset
- Dark Higgs decaying to pair of hadronically decaying W bosons investigated for the first time at the LHC. Challenging signature requires dedicated analysis techniques, e.g. track-assisted reclustered jets.
- Outlook: Combination of dark Higgs decay modes for extensive coverage of model

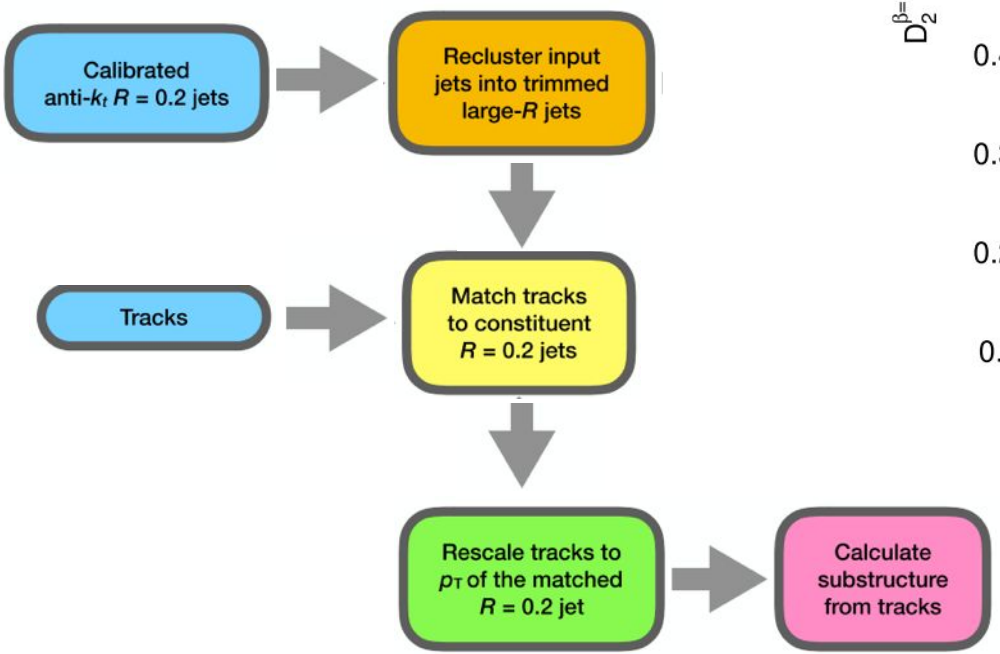
Any questions? I am happy to discuss now or later.

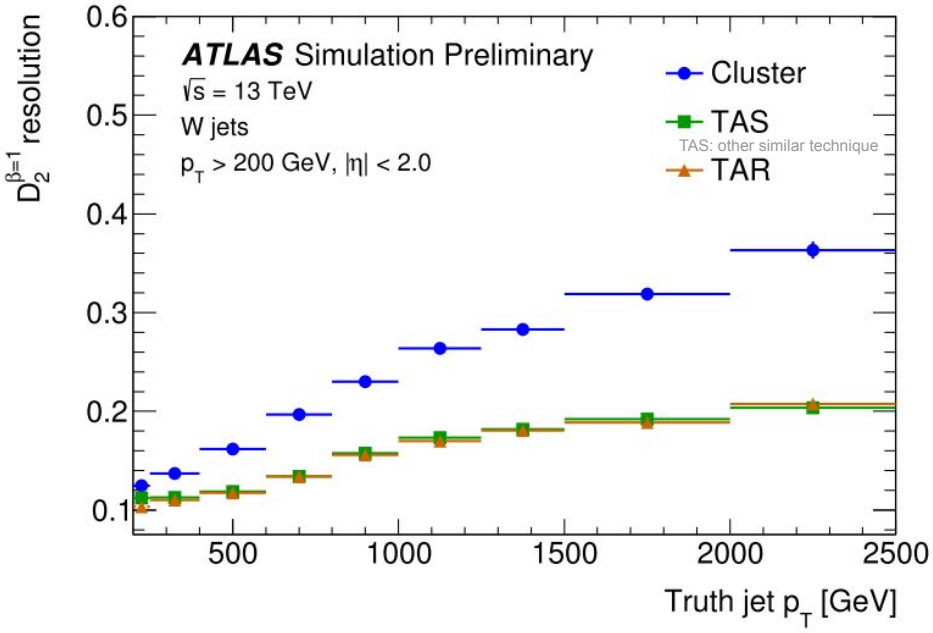
Contact:
philipp.gadow@cern.ch http://me.pgadow.de @philippgadow

Additional material

Outlook: flexible jets with precise jet substructure

Track-assisted reclustered (TAR) jets





N.B. Other developments also provide precise tracking-based substructure information: Track-calo-cluster jets (ATL-PHYS-PUB-2017-015)