DE LA RECHERCHE À L'INDUSTRIE

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Searches for dark matter with the ATLAS detector

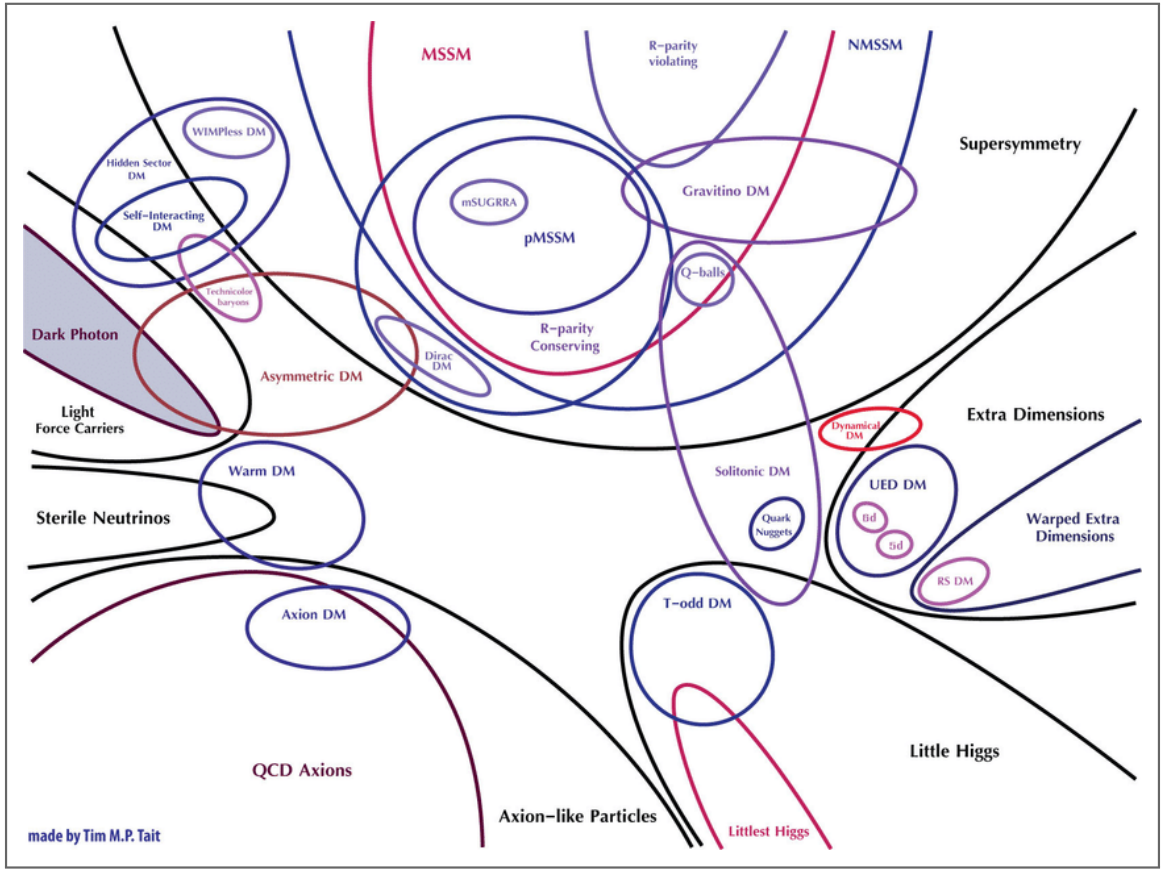
ICHEP 2022 @ Bologna (6-13 July)

Matthias Saimpert (IRFU) | on behalf of the collaboration

Thursday 07 July 2022

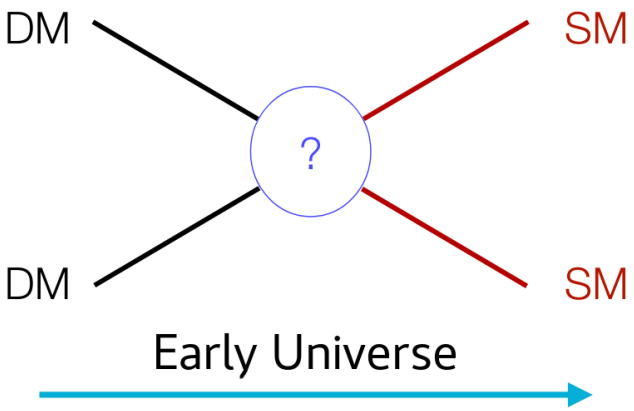
MODELS FOR DARK MATTER

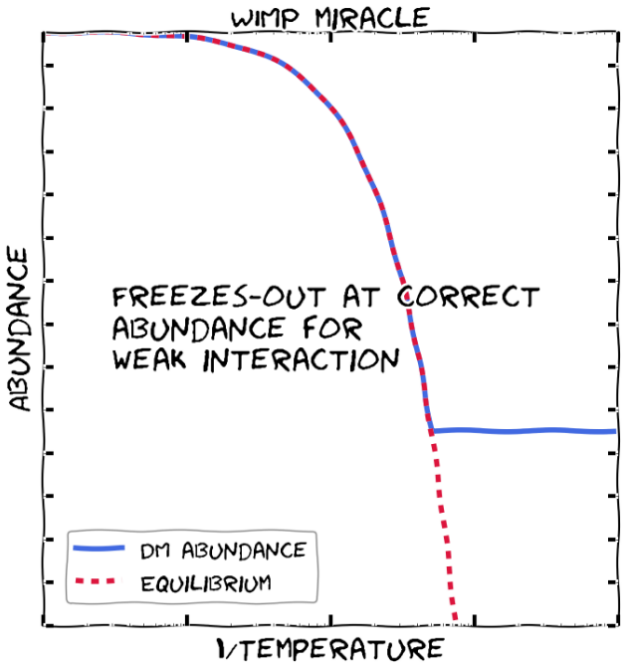
all ATLAS DM results available on the ATLAS EXOTIC public page



- Cosmological evidence for **dark matter (DM),** but no experimental hints on its nature
- Searching for **weakly-interating massive particles (WIMP)** w/ minimal assumptions is one of the main approaches pursued w/ ATLAS at the LHC → overview in this talk

WIMP HUNTING AT COLLIDERS





- WIMP abundance set by thermal freeze-out
  - weak interaction ($< \sigma v > \sim 10^{-26}$ cm^{3}s^{-1})

  $M_\chi \sim$ 1-1000 GeV $\rightarrow \Omega_c h^2 \sim 0.12$

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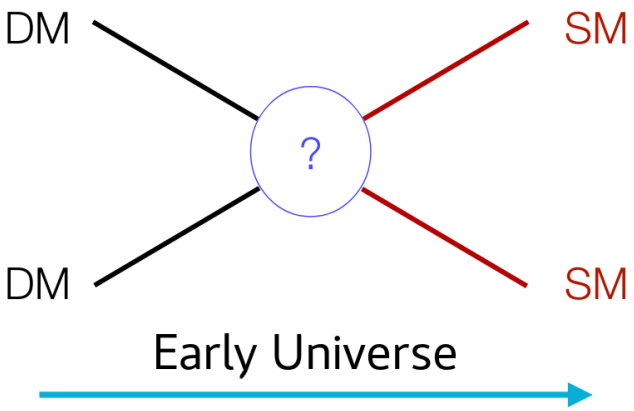

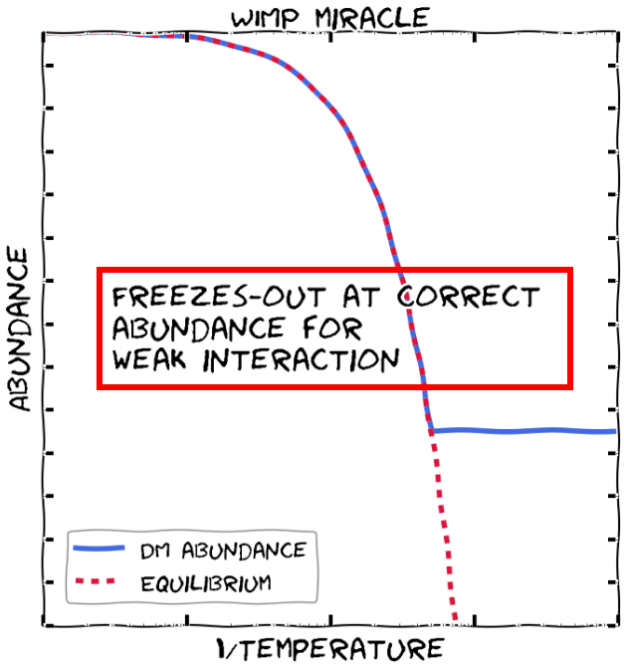

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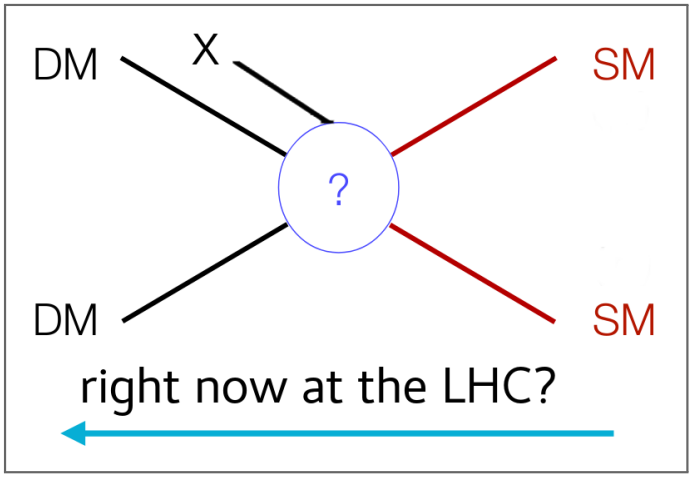

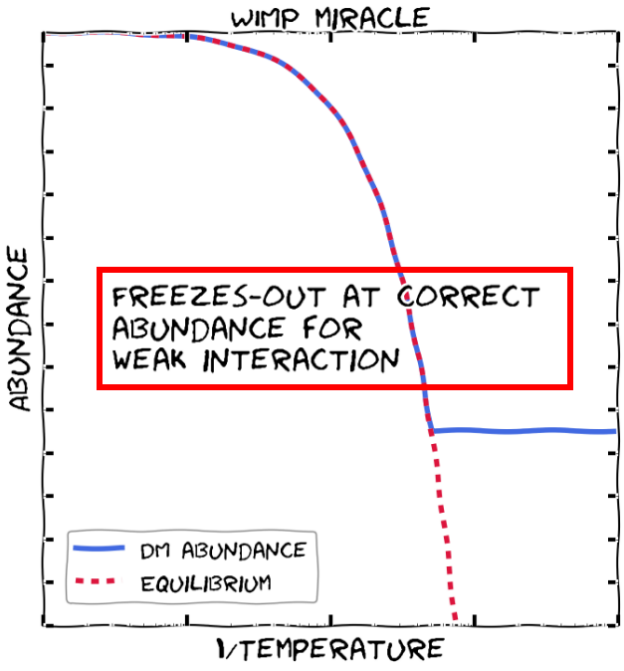

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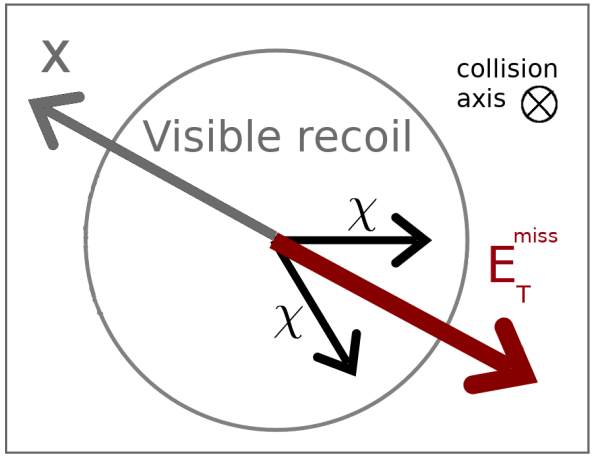
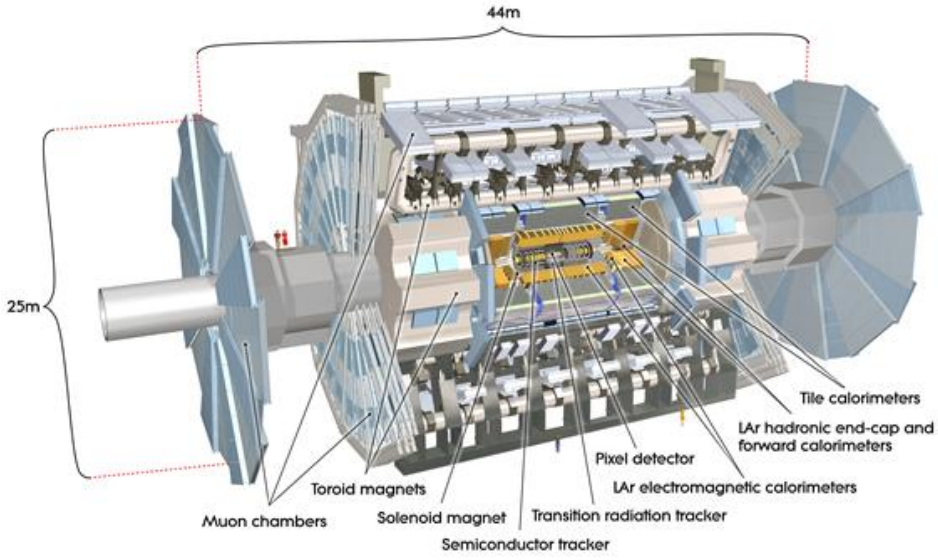
- **"mono-X" signatures at LHC**
  - X = jet, $\gamma, Z, W, ...$ $\rightarrow$ visible recoil
  - missing momentum in transverse plane (E_T^{miss})

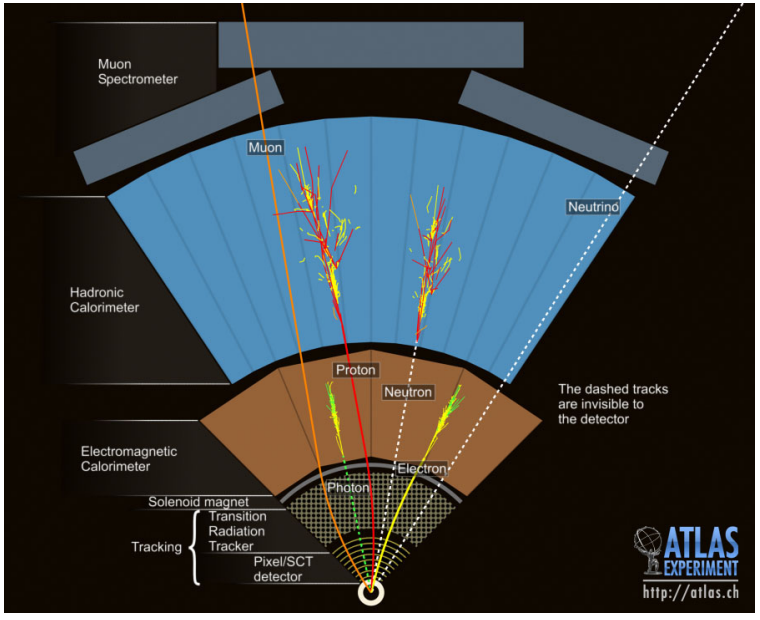


THE ATLAS DETECTOR AT THE LHC

ATLAS detector overview



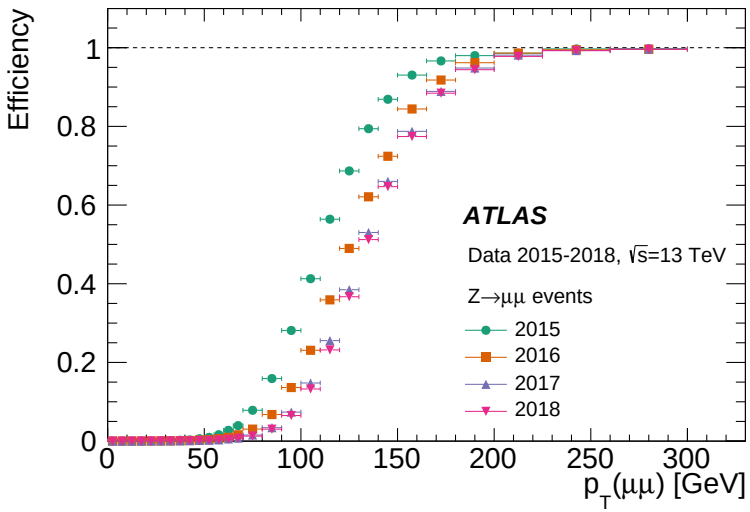
Particle identification



- Recording of LHC proton-proton collisions at $\sqrt{s}$ = 13 TeV
- Very large dataset collected during **Run 2 (2015-2018)**
  - 139 fb^{-1} available $\rightarrow$ 7.7M Higgs, 275M top quarks, 2800M Z bosons, ...
- Multi-purpose, **high efficiency/acceptance detector**

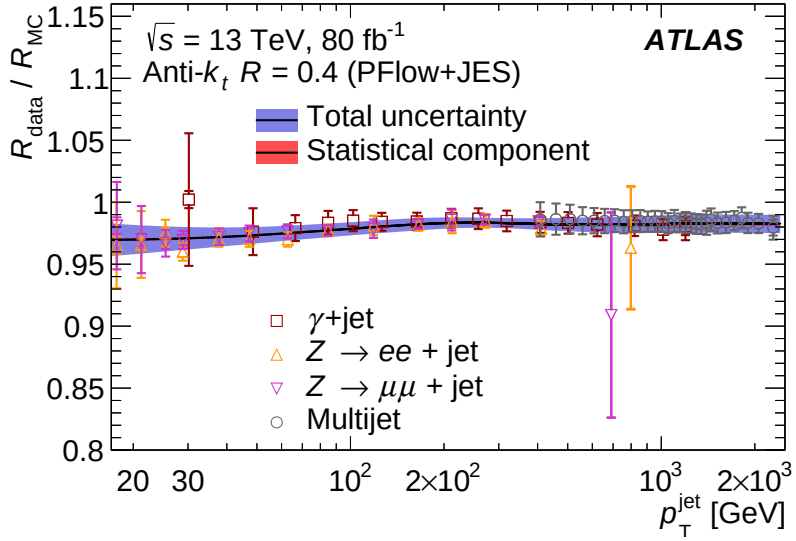
E_T^{miss} trigger

JHEP 08 (2020) 80



Jet energy scale

Eur. Phys. J. C 81 (2021) 689



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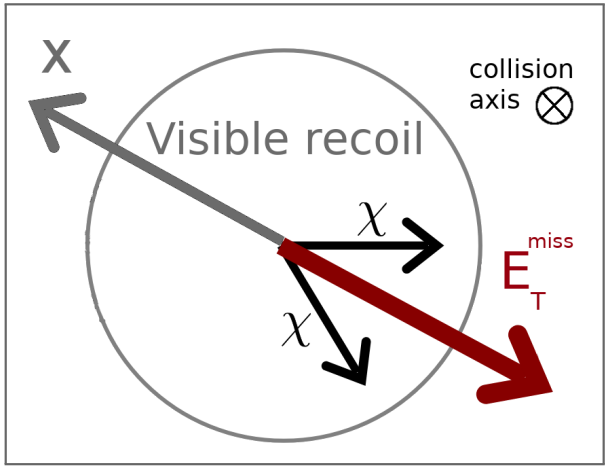
- Multi-purpose, **high efficiency/acceptance detector**
  - excellent online/offline reconstruction performance

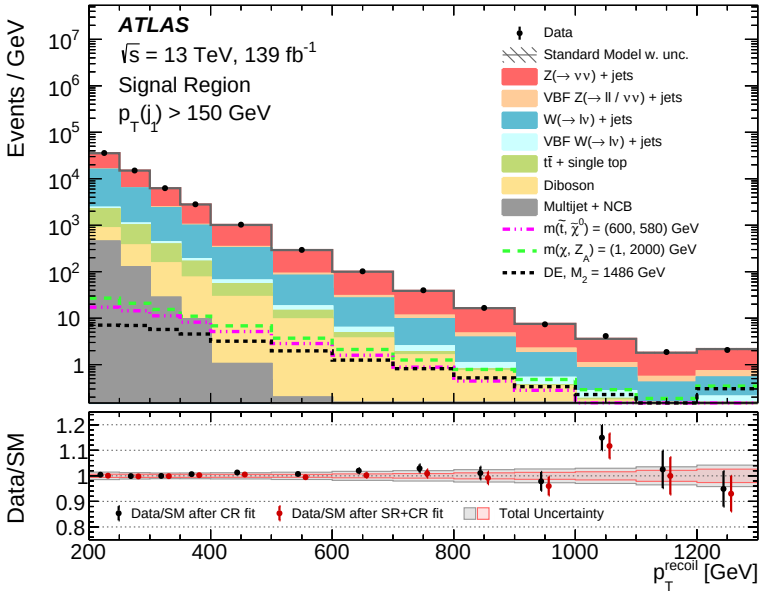
MONO-JET SEARCH ANALYSIS

Phys. Rev. D 103 (2021) 112006 – **'precision search'**

- **Signal region (SR) selection**
  - $E_T^{miss} > 200$ GeV – trigger
  - up to 4 jets well separated from E_T^{miss}
  - leading jet pT $>$ 150 GeV



SR postfit : no excess



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- **Background : $Z(\rightarrow \nu\nu)$, $W(\rightarrow \ell\nu)$ + jets**
  - constrained in 1/2-lepton regions
  - state-of-the-art W/Z+jets predictions EPJC 77, 829 (2017)
  - total background uncertainty : 2-4%, unc. in QCD/EW corrections significant

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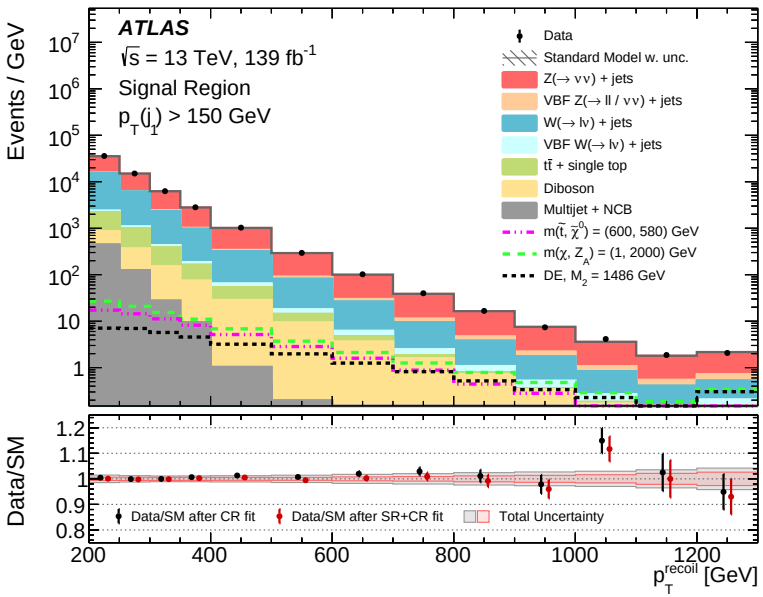
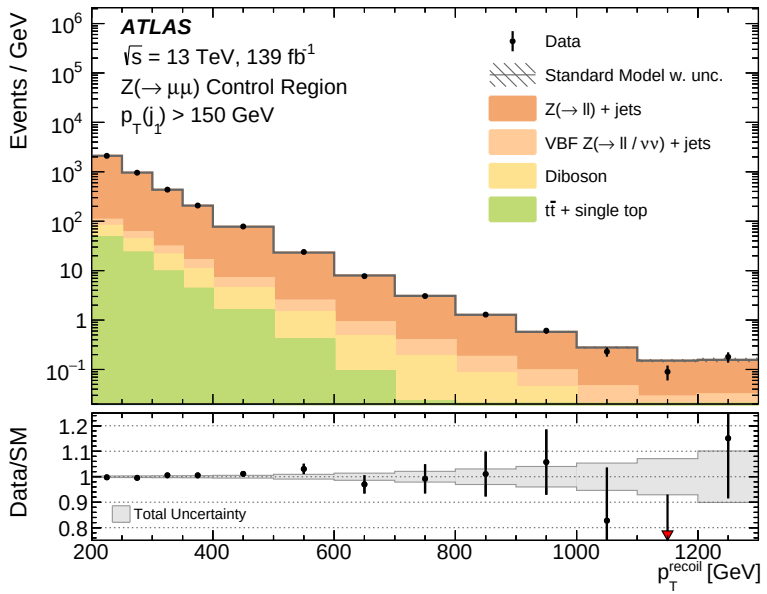


ex : $Z \rightarrow \mu\mu$ CR postfit



MONO-JET SEARCH RESULTS

Phys. Rev. D 103 (2021) 112006 – **'precision search'** ; dark sector reinterpretation : ATL-PHYS-PUB-2021-020

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  - DM mediated by axial vector Z_A incl. comparison w/ direct detection
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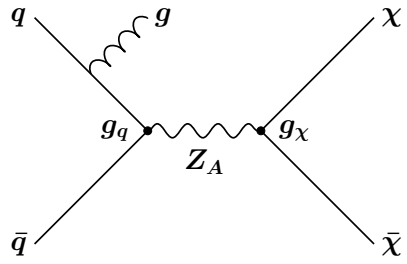
  - dark-energy scalar fields + other dark sector JHEP 05 (2019) 142



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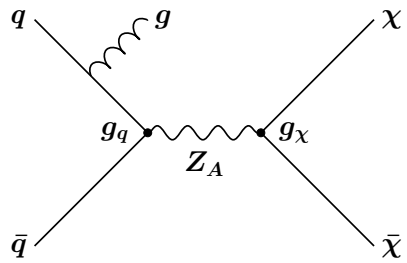
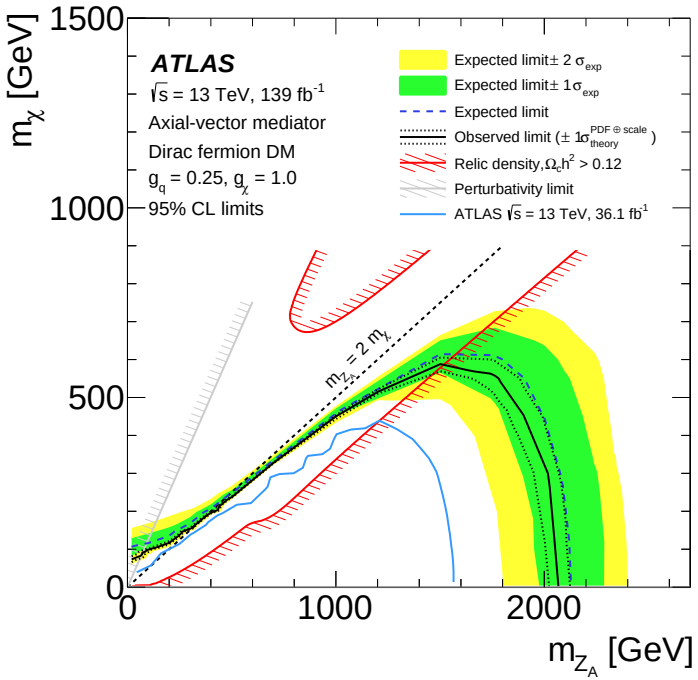


axial vector mediator interpretation

more ATLAS mono-X results : mono-γ, mono-V, mono-Z



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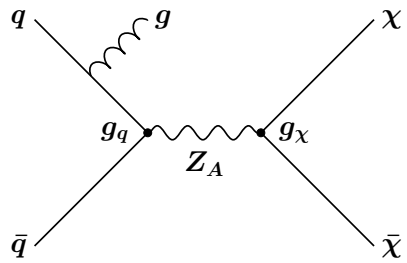

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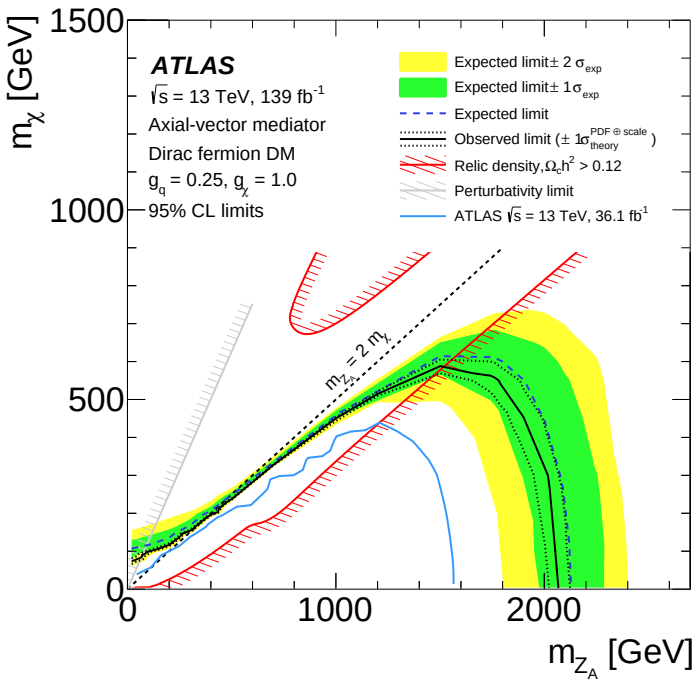
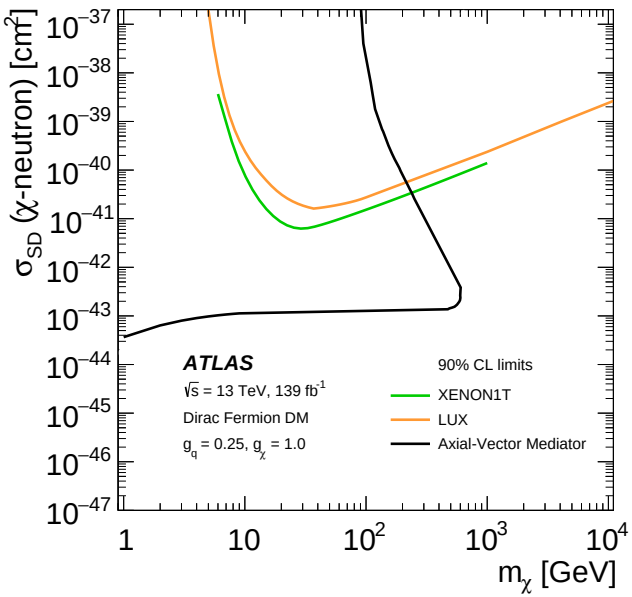


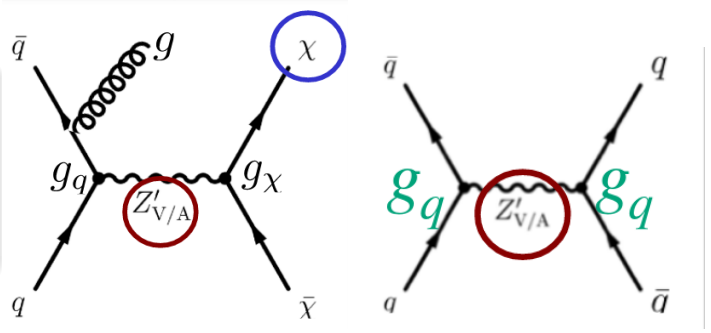
(model-dependent) comparison w/ direct detection
vector mediator and comparison w/ spin-independent also available



INTERPLAY W/ RESONANT SEARCH

ATL-PHYS-PUB-2022-036

- direct search for mediator particle in dijet mass spectrum
- look for bump over smoothly falling background (fit)
- sensitivity for $m < 2$ TeV limited by trigger threshold



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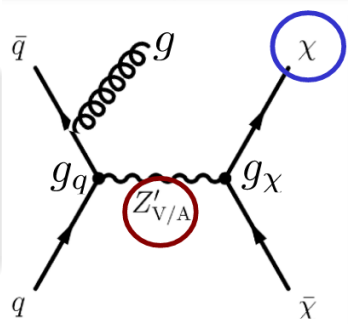
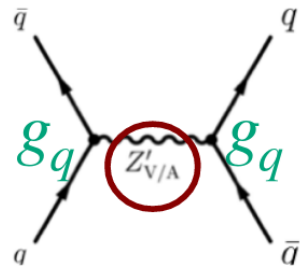
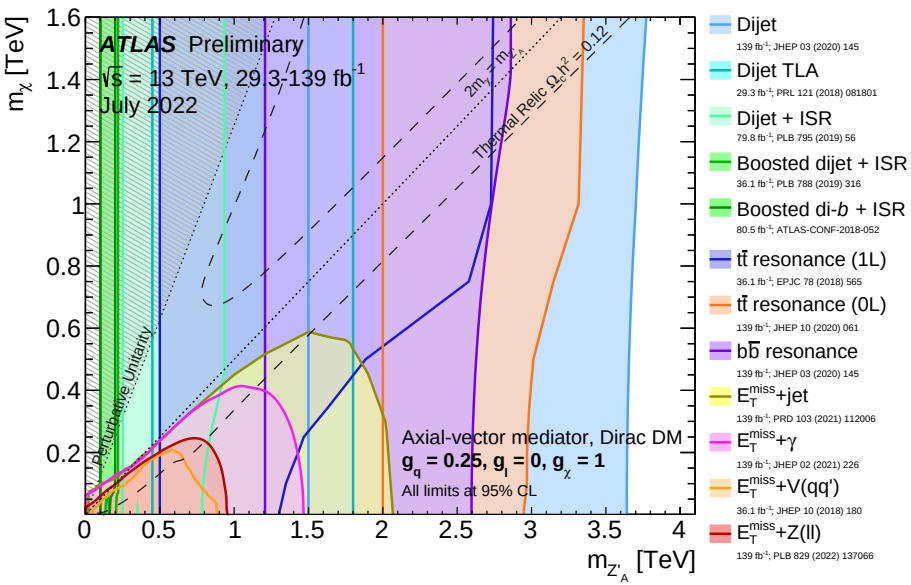


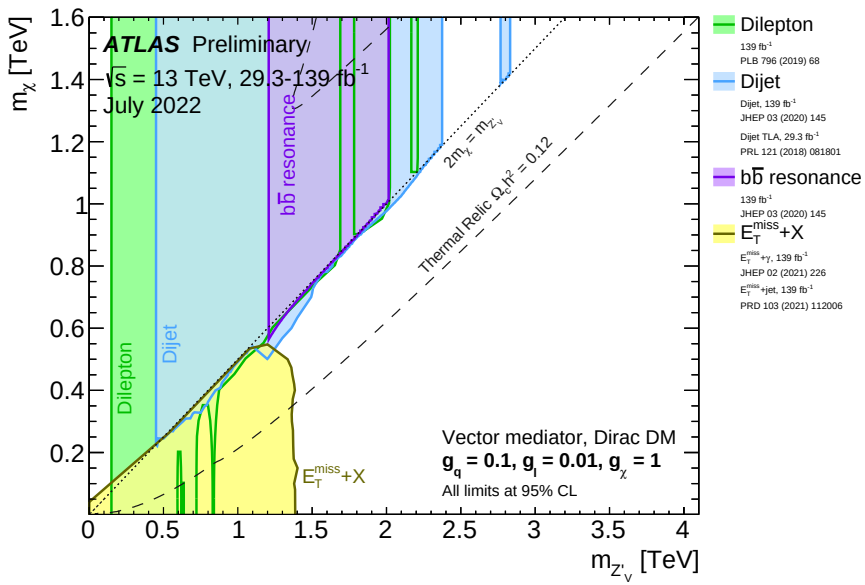


- **High complementarity with mono-X searches**

Z_A w/ large coupling to quarks



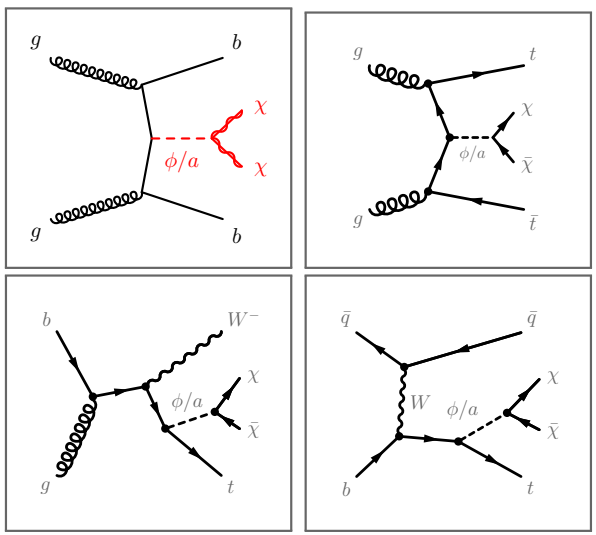
Z_V w/ small coupling to quarks and leptons



SEARCHES W/ THIRD GENERATION

JHEP 05 (2021) 093 ; ATLAS-CONF-2022-007

- **spin-0 mediator** under minimal flavour violation hypothesis → Yukawa-like couplings
- research program covers $b\bar{b} + E_T^{miss}$ and $t\bar{t} + E_T^{miss}$ incl. 0, 1, 2 lepton decays
- complementary sensitivity with $t\bar{t}/b\bar{b}$ resonance search



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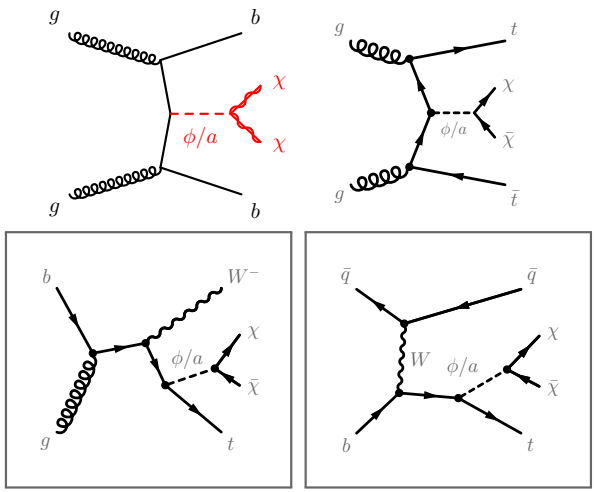

- recent extension of this program to $tq/tW + E_T^{miss}$ presented in **next talk**

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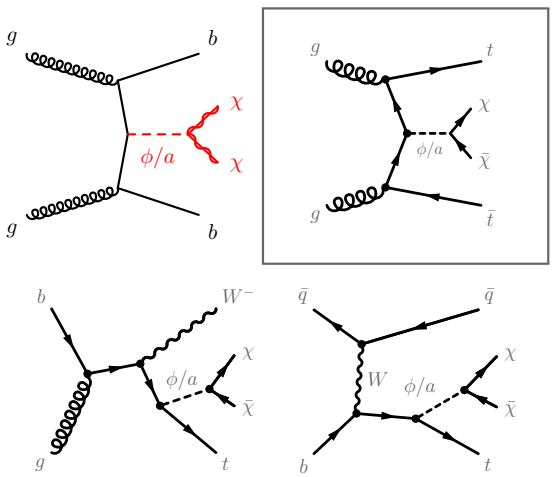

- extension to lower E_T^{miss} phase space (0-lepton)
- statistical combination

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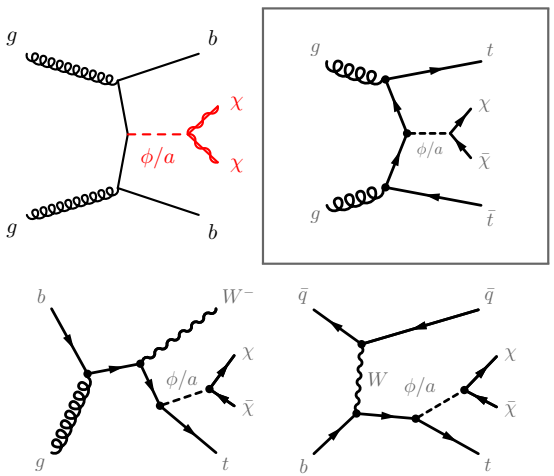

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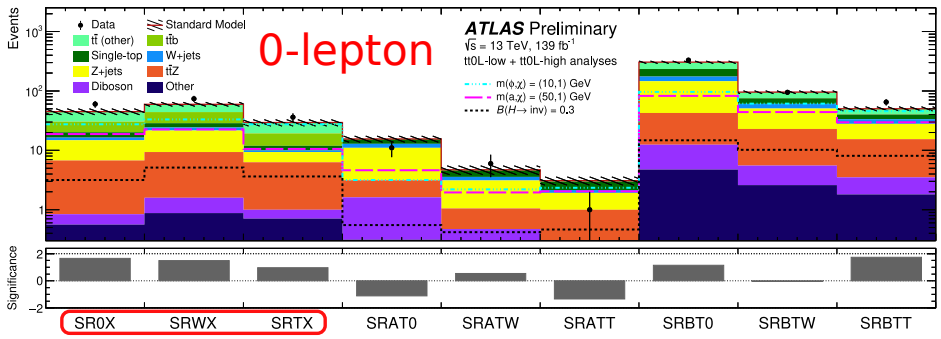
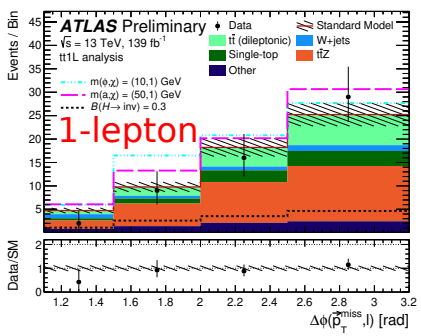
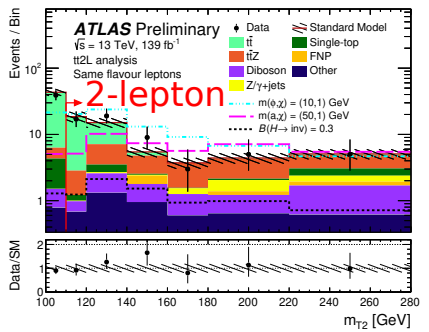
$t\bar{t} + E_T^{miss}$ 0L, 1L, 2L SRs : no significant excess

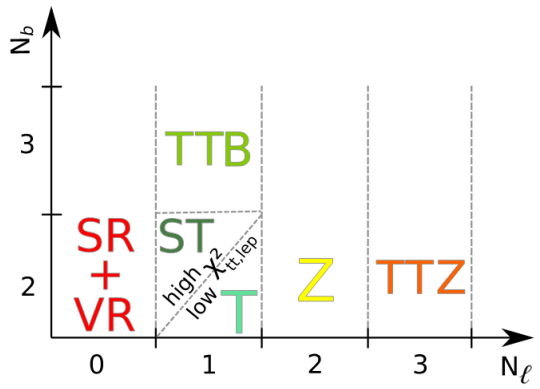






$t\bar{t}$ + E_T^{miss} 0-LEPTON CHANNEL

Eur. Phys. J. C 81 (2021) 1087, ATLAS-CONF-2022-007



control regions in 0-lepton analysis

- **initial analysis :** $E_T^{miss} > 250$ GeV – trigger,
  extended to $160 < E_T^{miss} < 250$ GeV w/ bjet trigger

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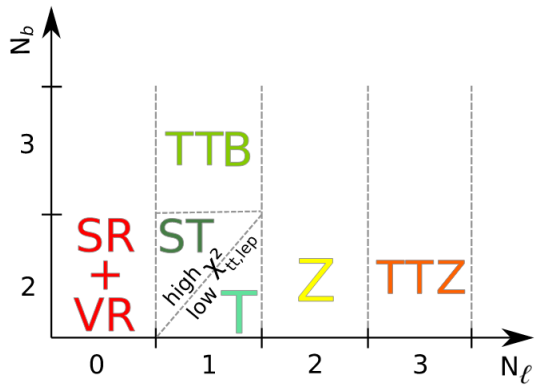

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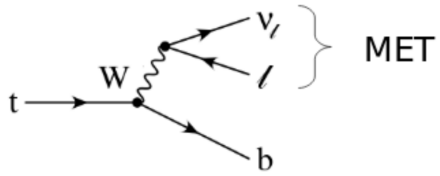

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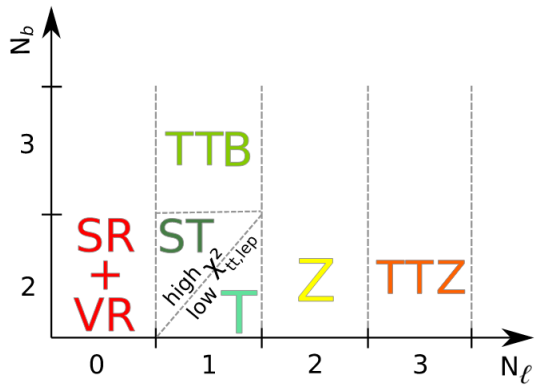

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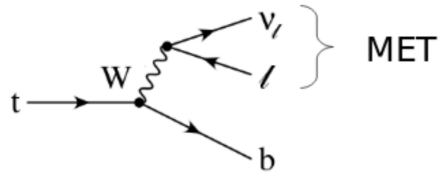

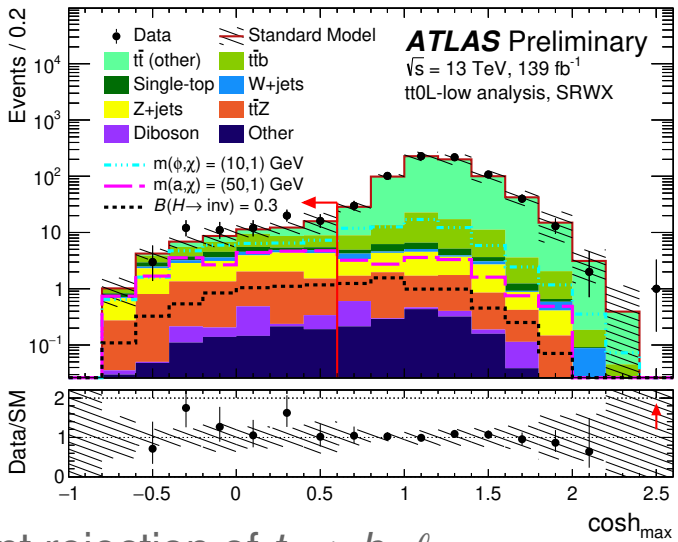

excellent rejection of $t \to b\nu\ell_{missed}$
thanks to m_t constraint

$t\bar{t}$ + E_T^{miss} 0-LEPTON CHANNEL

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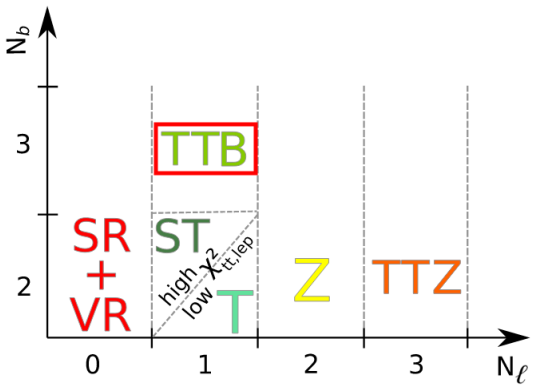

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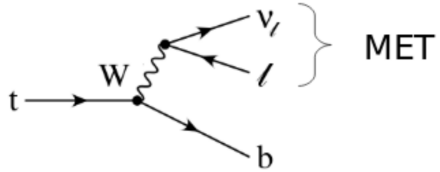
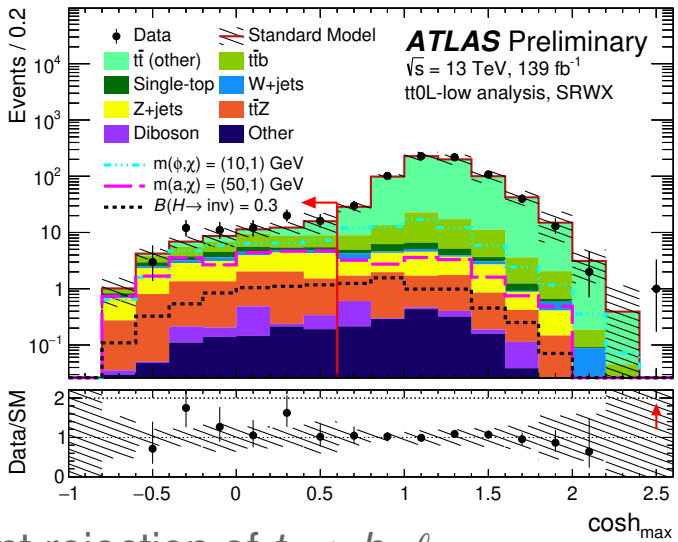
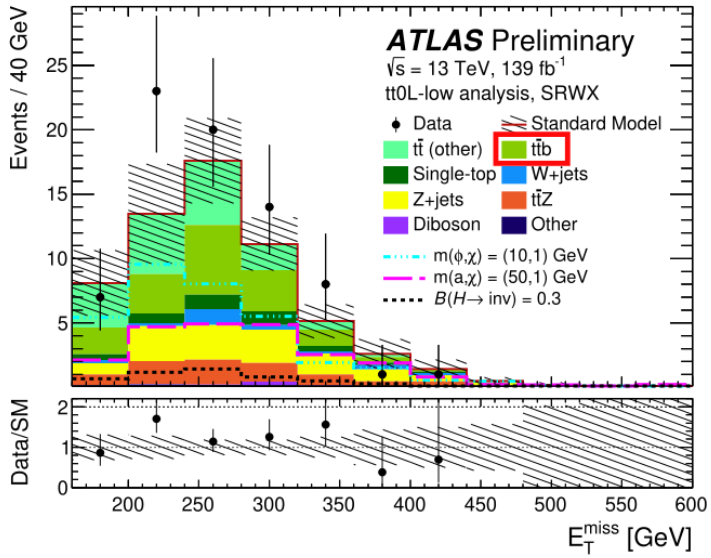




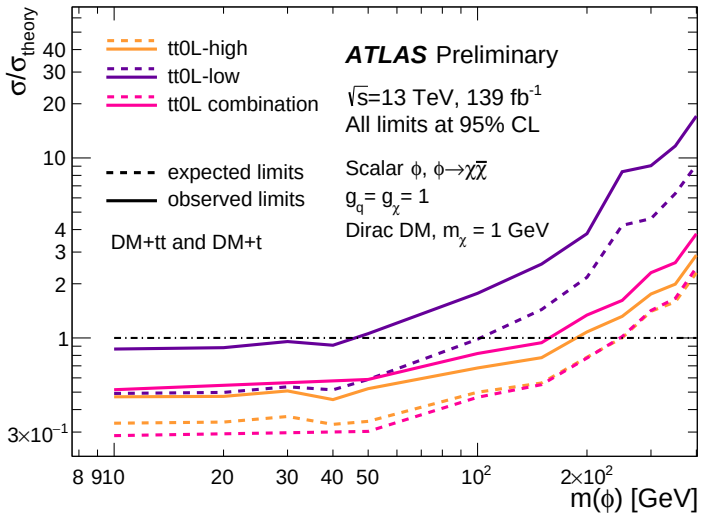
excellent rejection of $t \to b\nu\ell_{missed}$ thanks to m_t constraint

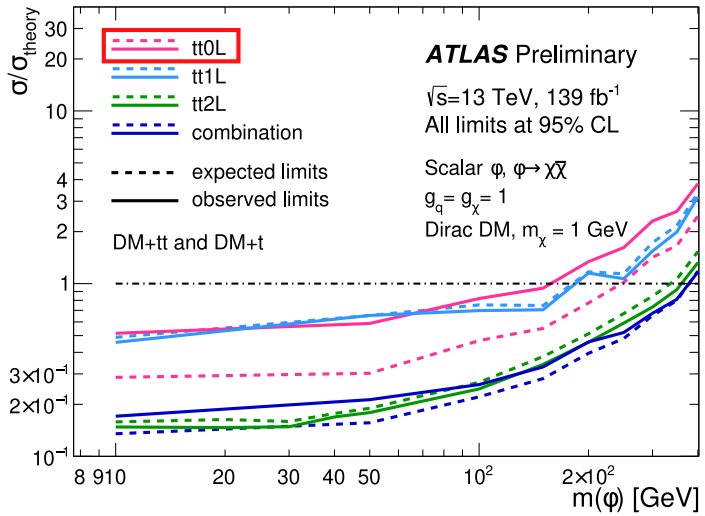
challenging residual $t\bar{t}$ + b at low E_T^{miss}



SPIN 0 MEDIATOR - COMBINATION

ATLAS-CONF-2022-007, ATL-PHYS-PUB-2022-036





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- data compatible w/ predictions within 2σ

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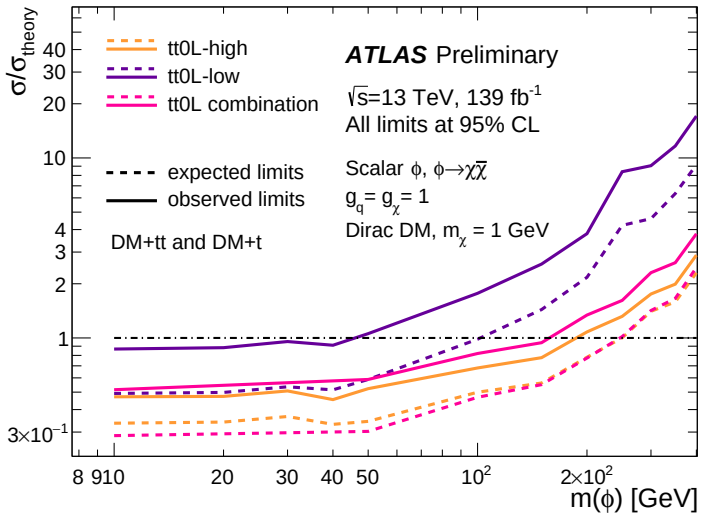

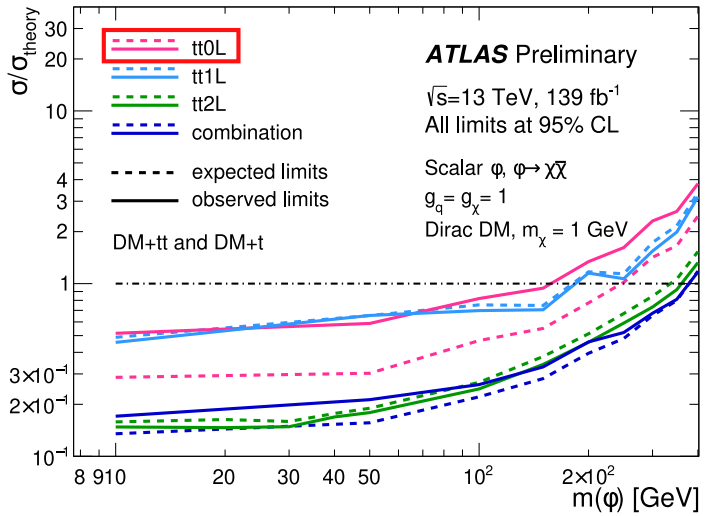

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  - $m_\phi < 370$ GeV for $g = 1$
  - $g > 0.17$ (0.14 exp.) at $m_\phi = 10$ GeV
- results for pseudo-scalar also available

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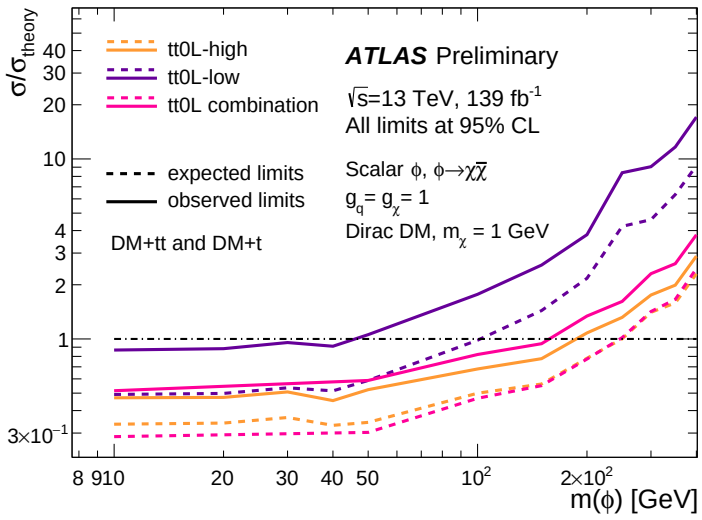
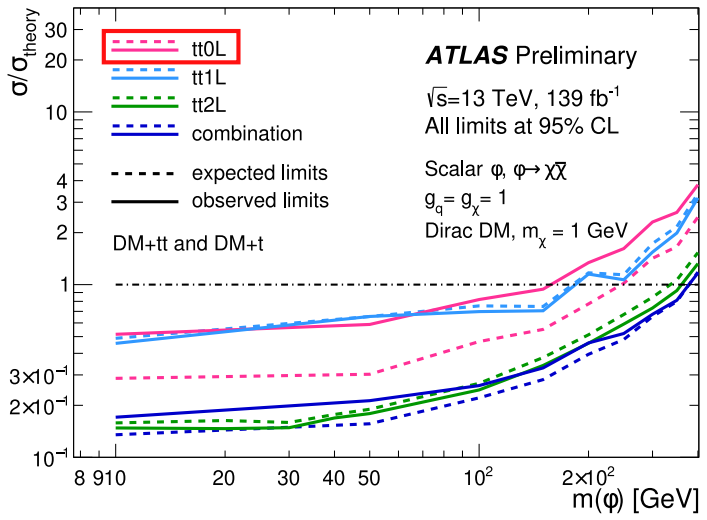
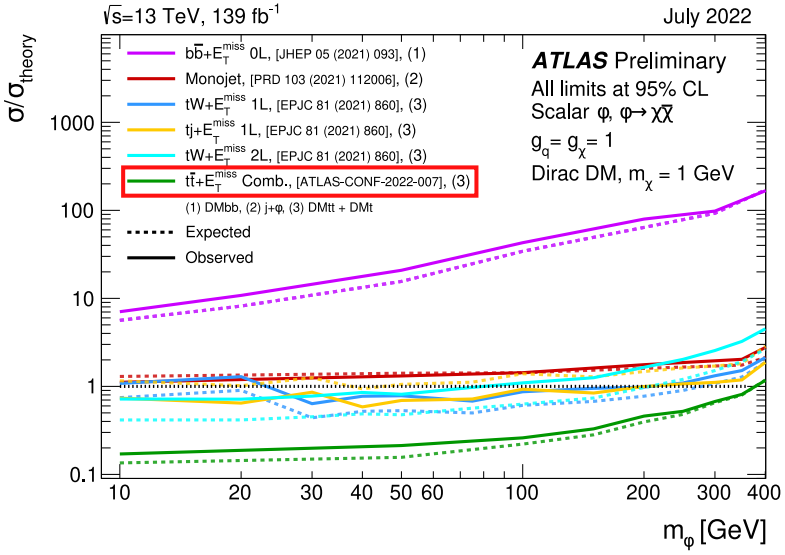
ATLAS-CONF-2022-007, ATL-PHYS-PUB-2022-036







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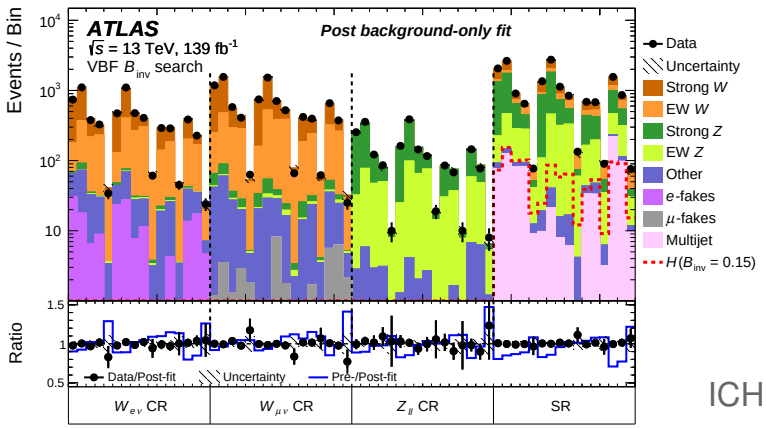
H→INVISIBLE SEARCHES

ATLAS-CONF-2022-007, Phys. Lett. B 829 (2022) 137066, EPJC 82 (2022) 105, arXiv:2202.07953 (acc. by JHEP)

- Particular case of scalar mediator → **SM Higgs boson**
- Assuming SM Higgs production (incl. *HVV* couplings) and searching for $H \to$ inv.
- Leading channels : VBF + E_T^{miss}, $Z(\to \ell\ell) + E_T^{miss}$, $t\bar{t} + E_T^{miss}$

- **VBF :** $\geq$ 2 jets with large $\Delta\eta$ and m_{jj}
  background : $Z \to \nu\nu$, $W \to l\nu$, multijet,
  statistical/systematic unc. comparable, total $\sim$ 5%

VBF + E_T^{miss} SRs & CRs : no excess



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- ***Z*($\to \ell\ell$) :** Z candidate recoiling $E_T^{miss} > 90$ GeV
  background : ZZ/WZ with neutrinos
  ZZ modeling and jet/E_T^{miss} calibration, total ~ 9%

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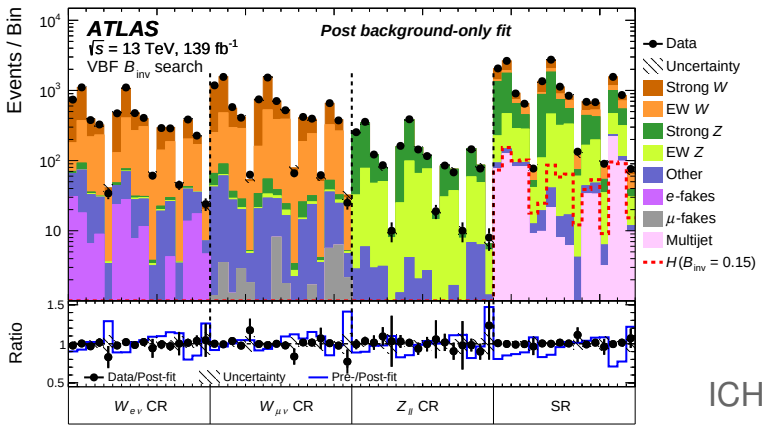
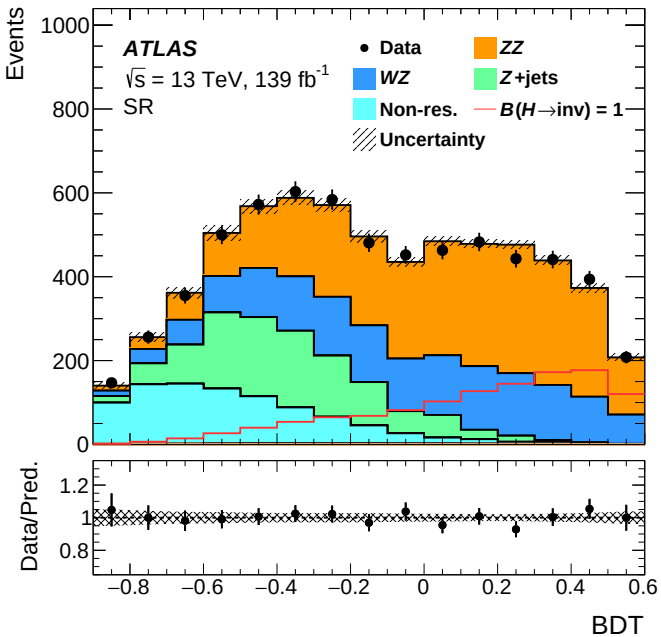


$Z(\to \ell\ell) + E_T^{miss}$ SR : no excess

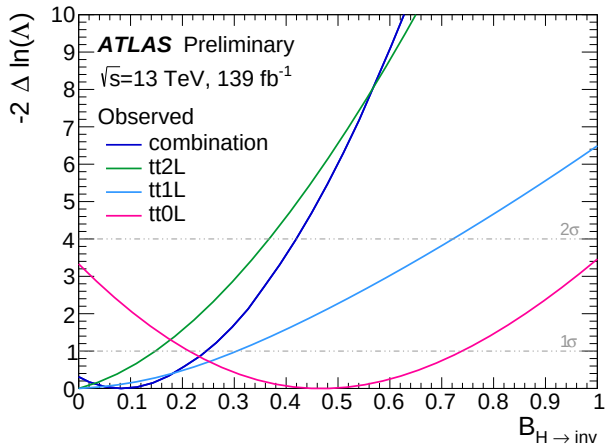


other interpretations also included, see publications

H→INVISIBLE RESULTS

ATLAS-CONF-2022-007, Phys. Lett. B 829 (2022) 137066, EPJC 82 (2022) 105, arXiv:2202.07953 (acc. by JHEP)

$t\bar{t}H(\rightarrow$ inv.)



Analysis	Best fit $\mathcal{B}_{H\rightarrow\text{inv}}$	Observed upper limit	Expected upper limit
$t\bar{t}H$ comb.	$0.08^{+0.16}_{-0.15}$	0.40	$0.30^{+0.13}_{-0.09}$

VBF H($\rightarrow$ inv.)

Observed	Expected	$+1\sigma$	-1σ	$+2\sigma$	-2σ
0.145	0.103	0.144	0.075	0.196	0.055

best fit $B_{H\rightarrow\text{inv.}} = 0.053 \pm 0.052$

VBF+γ H($\rightarrow$ inv.)

expected (observed) : $B_{H\rightarrow\text{inv.}} > 0.37$ (0.34)

ZH($\rightarrow$ inv.)

expected (observed) : $B_{H\rightarrow\text{inv.}} > 0.19$ (0.19)

best fit $B_{H\rightarrow\text{inv.}} = 0.003 \pm 0.09$

- **Now sensitive to BR($H \rightarrow$ inv.)$>$ 10% ; no hint for invisible Higgs decays so far**
- VBF and ZH channels stronger than ttH but more systematically-dominated + dependent on SM-like *HVV* coupling assumption

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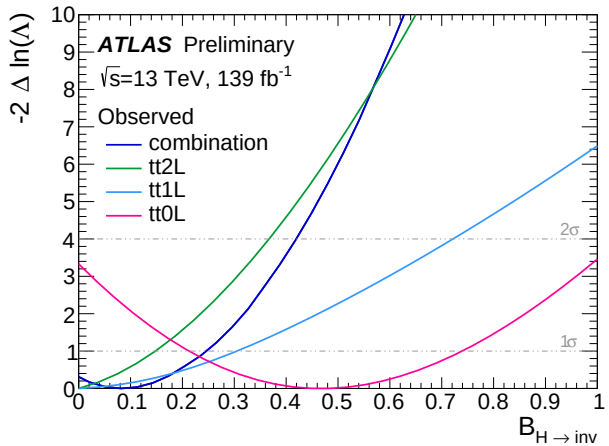

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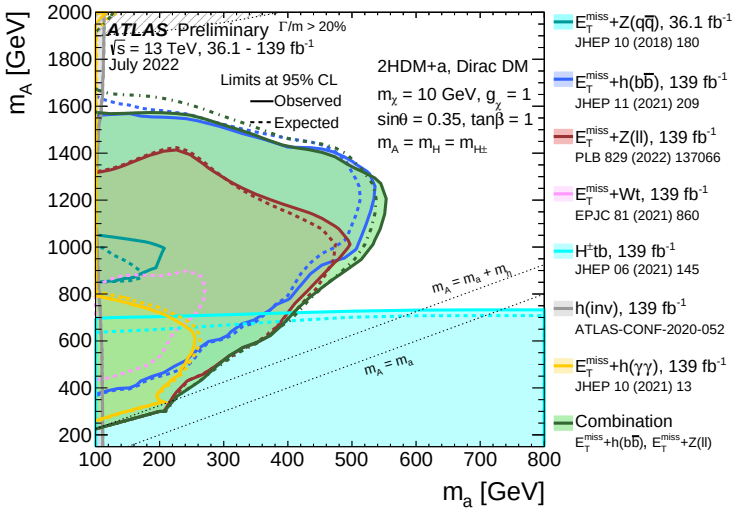
- Partial Run 1 + Run 2 combination available in ATLAS-CONF-2020-052 → full combination in progress (incl. e.g. mono-jet)

NEW GEN. OF SIGNAL MODELS

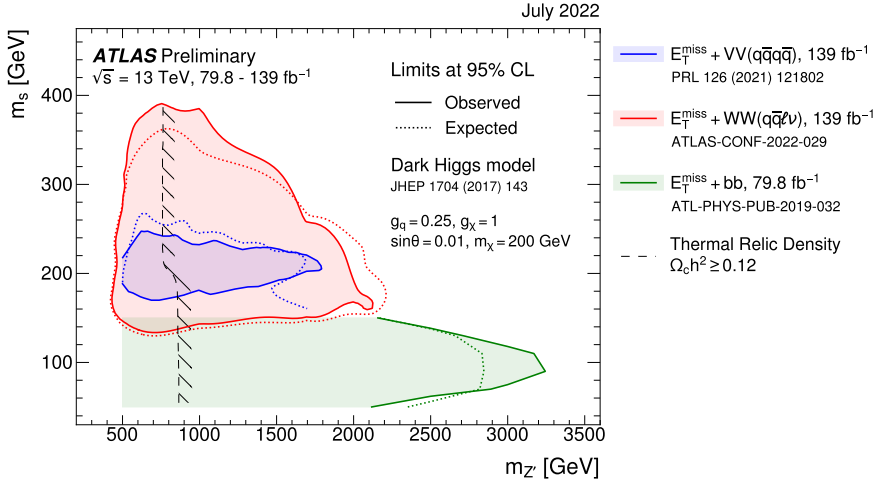
ATL-PHYS-PUB-2022-036

- **2HDM+a model :** pseudo-scalar mediator UV-complete extension, CERN-LPCC-2018-02
  - new signatures : mono-H, $Wt + E_T^{miss} \rightarrow$ see next talk
- **Dark Higgs model** JHEP 04 (2017) 143
  - new signatures : VV + E_T^{miss}, ...
- **Strongly-interacting dark sectors** JHEP 11 (2017) 196
  - new ATLAS result - BSM session, Friday at 18 :00 ATLAS-CONF-2022-038

2HDM+a
$\tan\beta = 1.0$, $\sin\theta = 0.35$, $m_A = m_H = m_{H^\pm}$



Dark Higgs summary plot (new)



SUMMARY

- **WIMPs** are actively searched for in ATLAS data
  - simplified single mediator models $\rightarrow$ mono-X searches
  - Higgs portal models $\rightarrow$ H decay to invisible searches
  - more complete models $\rightarrow$ 2HDM+a, dark Higgs, ...
- **Wide range of parameter space explored,** no hint so far
  - many signatures explored thanks to excellent detector performance
  - sensitivity more model-dependent but complementary to direct detection

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  - many signatures explored thanks to excellent detector performance
  - sensitivity more model-dependent but complementary to direct detection
- **Other ATLAS talks on related topics :**
  - mono-top (next)
  - search for SUSY electroweak (BSM session, today, 18 :30)
  - boosted resonances in hadronic final states (BSM session, Fri., 18 :00)
  - new phenomena in hadronic finals states (BSM session, Sat., 9 :45)
  - ...

Thank you for your attention

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