Searches for Dark Matter with the ATLAS experiment

Cosmology on Safari, Bonamanzi, January 2015

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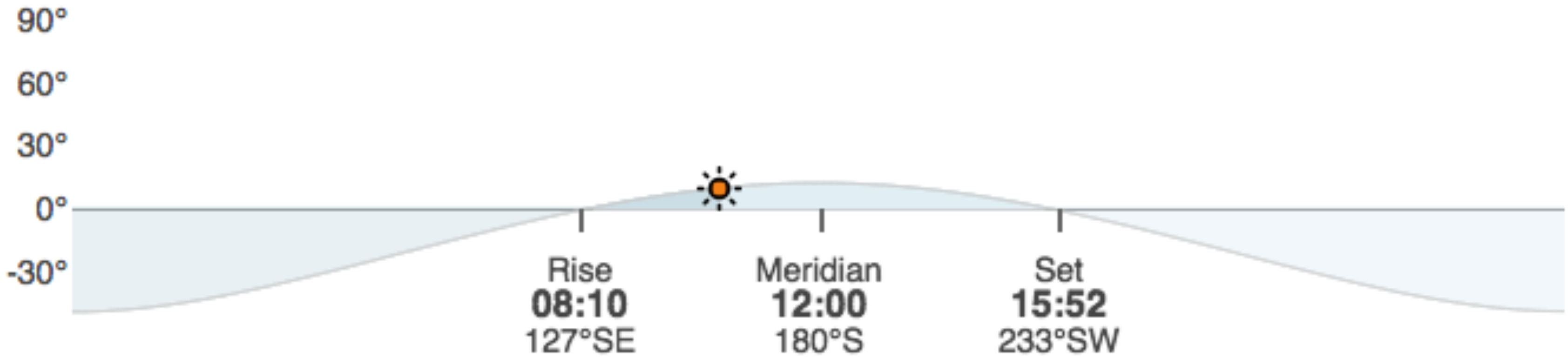
On behalf of the ATLAS collaboration

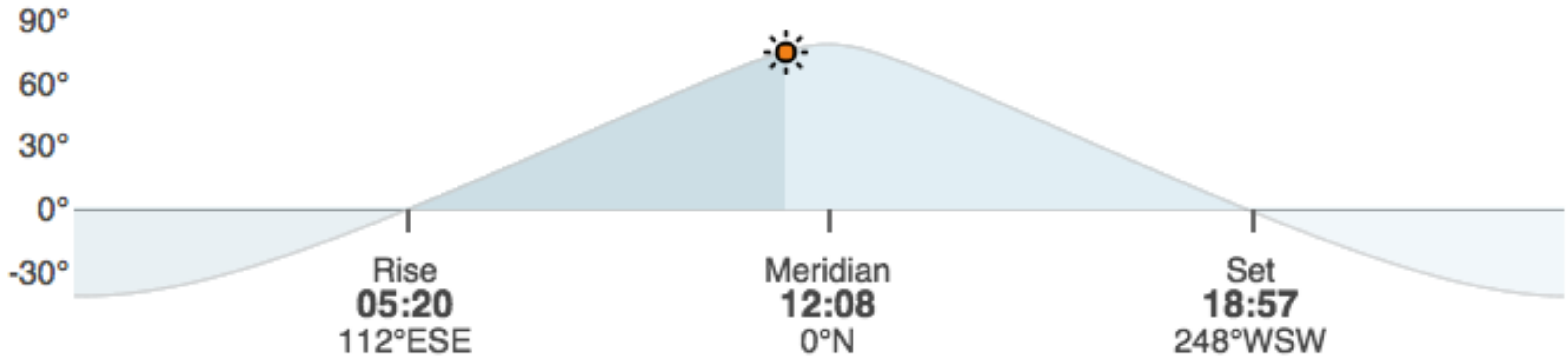
Stockholms universitet

Oskar Klein centre

ATLAS EXPERIMENT
http://atlas.ch



Today's Sun Position in Stockholm



Today's Sun Position in Durban

Thanks for the chance to come to Bonamanzi!

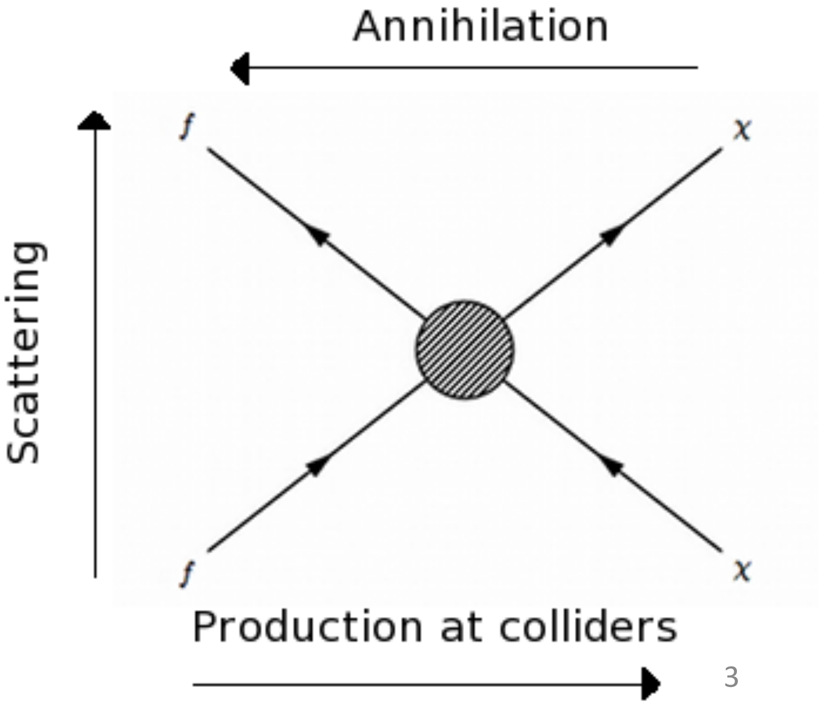
Introduction: WIMP hunting

Dark Matter particles:
Non-baryonic, neutral, cold (massive)
Hopefully weakly interacting: **WIMP**

Three complementary strategies:
- Direct detection (shake)
- Indirect detection (break)
- Collider production (make)

Scope of talk:
- Introduce the machinery
- Present some ATLAS strategies (mono-X, Invisible Higgs..)
- Present results and prospects

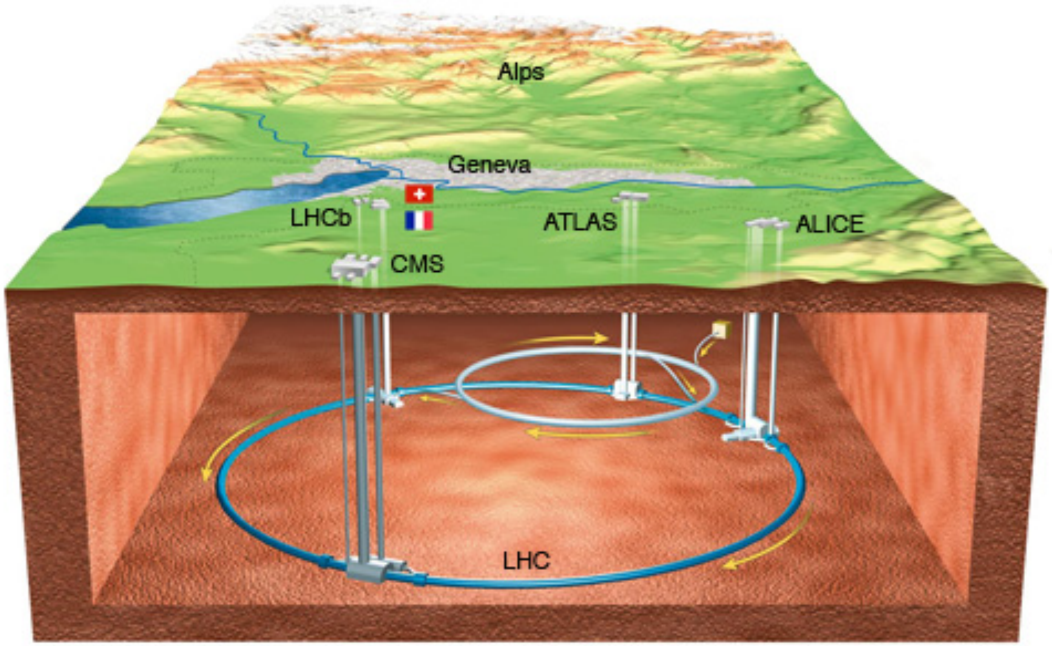
WIMPS/Leopards: Probably around, very hard to find..



The Large Hadron Collider

Proton collisions at unprecedented energies and high luminosity

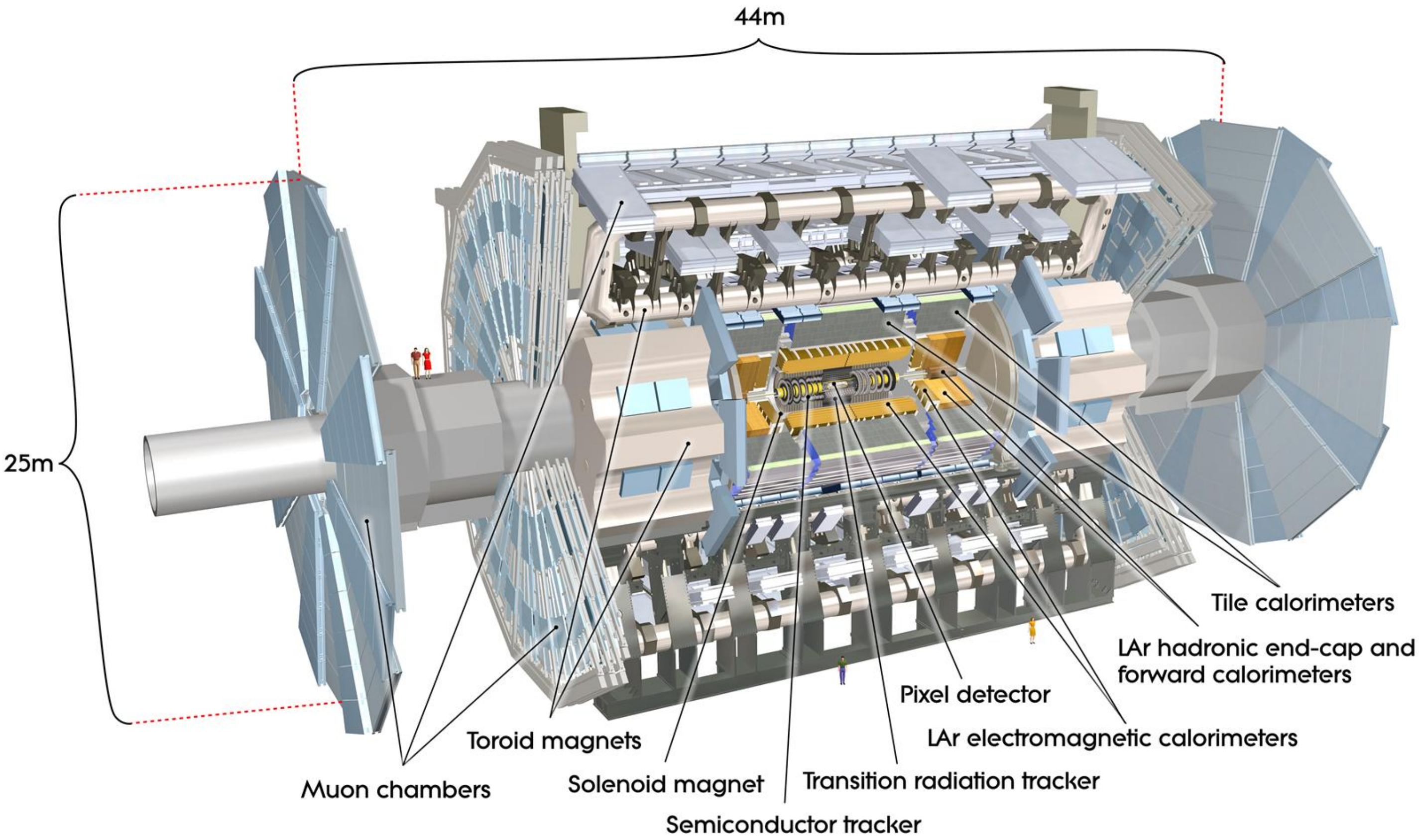
Design capacity of 2×10^{34} cm^{-2}s^{-1} @ 14 TeV



2011: 4.7 fb^{-1} @ 7 TeV (1 fb^{-1} = 10^{39} cm^{-2})
2012: 20.3 fb^{-1} @ 8 TeV
More integrated luminosity → Increased sensitivity to new physics

Restarting in April: 13 TeV center of mass collisions
Aiming for 300 fb^{-1} of 14 TeV collisions by the end of 2021

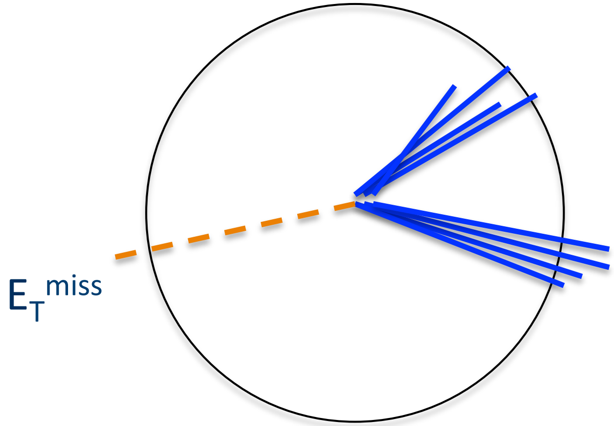
The ATLAS detector



Trackers, calorimeters, several muon detectors in order to detect e,μ,τ,γ, and hadronic jets originating in partons. Designed to examine 40 million events every second. A sophisticated 3-level trigger system in place, 100k events per second pass the first trigger level → O(100) events per second saved for analysis.

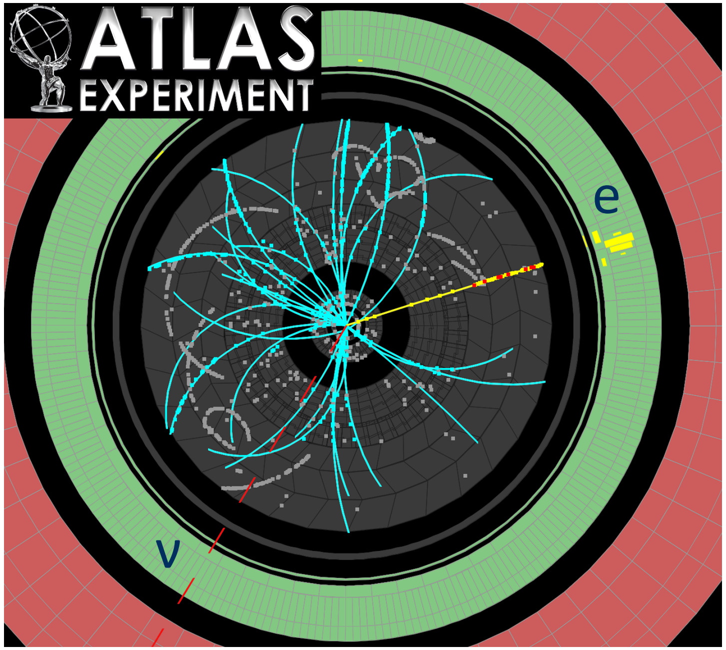
Detecting neutrinos and WIMPs

Hermetic detector: Conservation of momentum means no net momentum in *transverse* plane. Missingenergy in the transverse plane implies non-detectable particles.



Missing Energy:

$$\mathbf{E}_T^{miss} = -\sum \mathbf{p}_T^{jet} - \sum \mathbf{p}_T^{e} - \sum \mathbf{p}_T^{\mu} - \sum \mathbf{p}_T^{\gamma} - \sum \mathbf{p}_T^{soft}$$



Sensitive to transverse momentum carried by non-interacting particles – neutrinos or WIMPs.

Mono-X

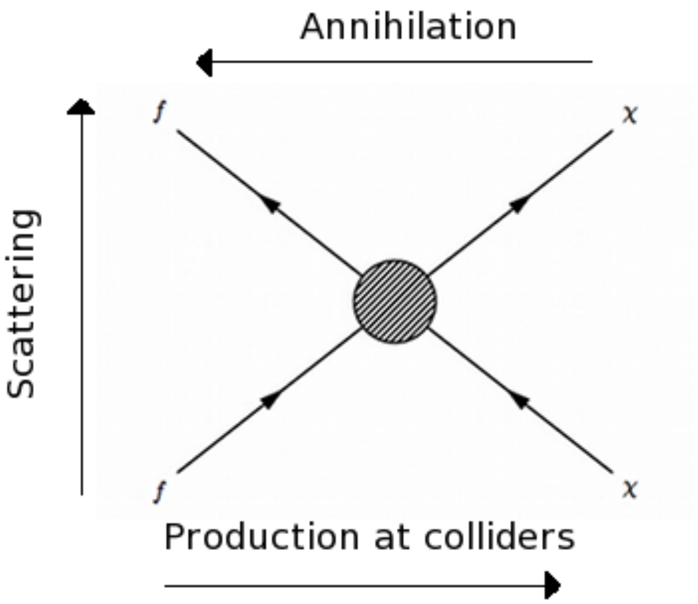
Pair produced WIMPs with an Initial State Radiation handle, or WIMPS produced in association with one or more SM particles

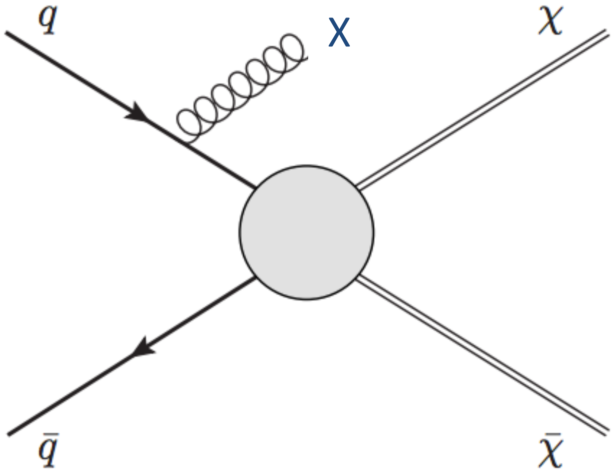
Large missing momentum recoiling against particle(s) from radiation

Final limits comparable to direct and indirect detection experiments

So far performed with radiation of

- Gluon/quark (mono-jet)
- Photon
- W and Z boson





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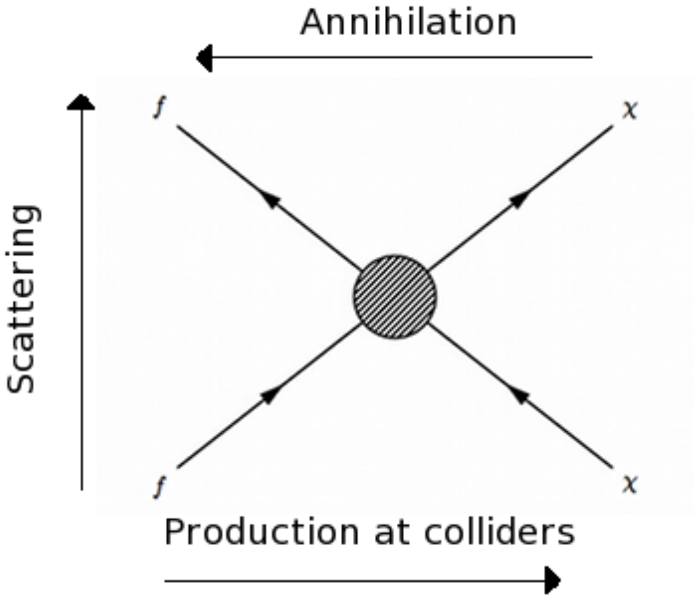
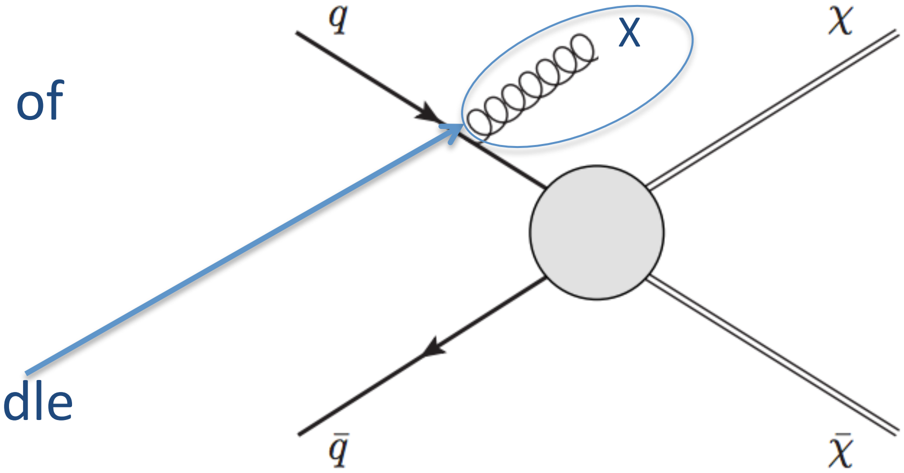
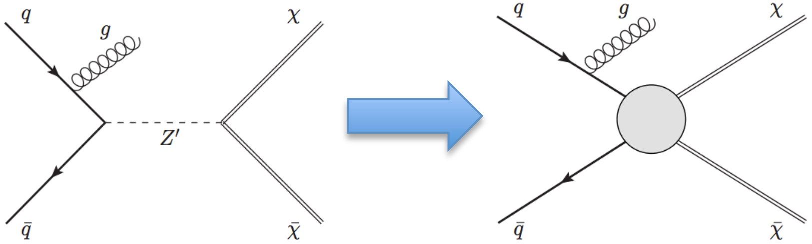




Handle

Mono-X



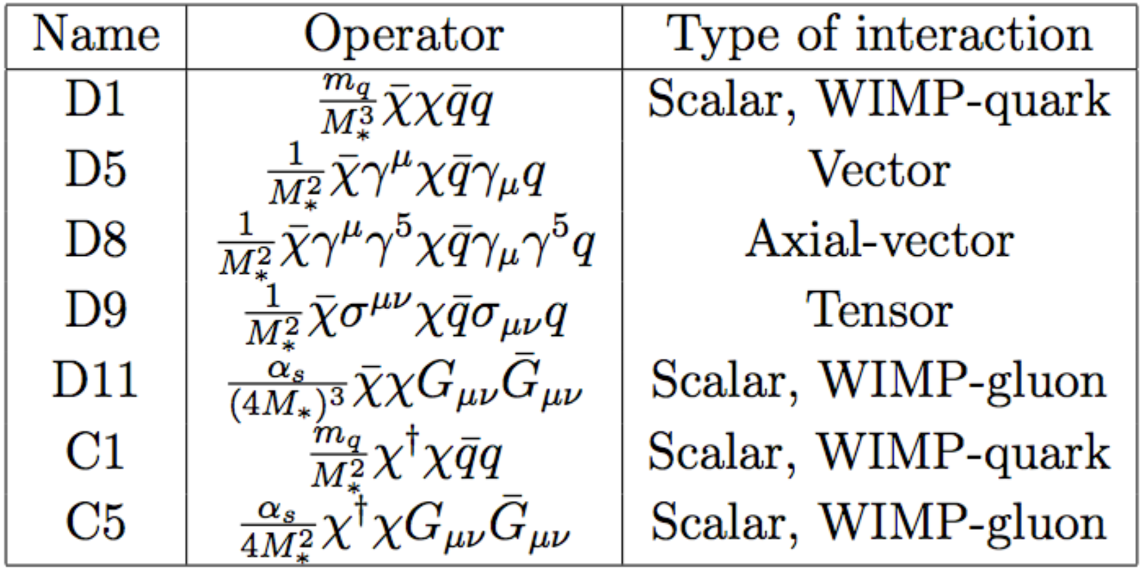
Effective Field Theory approach:

Mediator assumed very heavy → contact interaction

Assume an effective DM-SM operator and type of WIMP (scalar/fermion) – two free parameters: wimp mass and mass scale of interaction $M_* = m_{med} \sqrt{g_{SM} g_{DM}}$

Strength: Agnostic search, comparable to indirect/direct detection

Weakness: Incomplete description for Q (mom. transfer) > Λ (cutoff scale)



Name	Operator	Type of interaction
D1	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$	Scalar, WIMP-quark
D5	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	Vector
D8	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	Axial-vector
D9	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	Tensor
D11	$\frac{\alpha_s}{(4M_*)^3}\bar{\chi}\chi G_{\mu\nu}\bar{G}_{\mu\nu}$	Scalar, WIMP-gluon
C1	$\frac{m_q}{M_*^2}\chi^\dagger\chi\bar{q}q$	Scalar, WIMP-quark
C5	$\frac{\alpha_s}{4M_*^2}\chi^\dagger\chi G_{\mu\nu}\bar{G}_{\mu\nu}$	Scalar, WIMP-gluon

Full List in Goodman et. al in Phys. Rev. D82 116010 (2010)

Mono-X

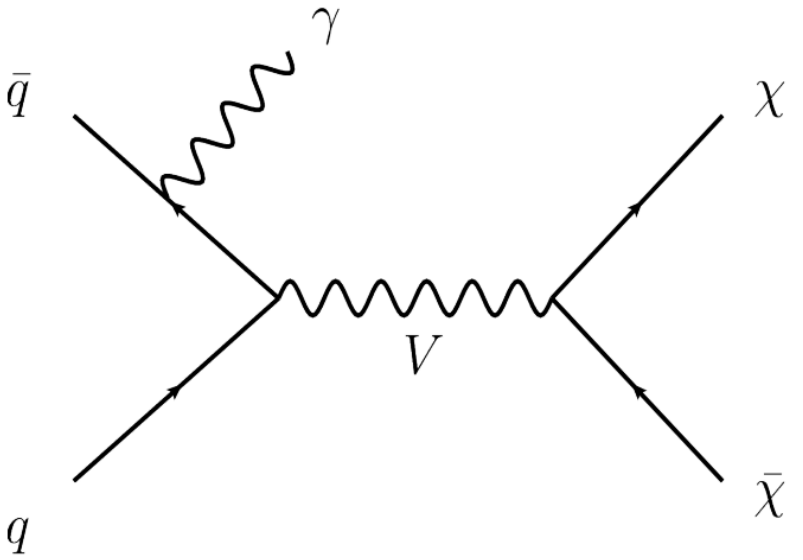
Simplified Model approach:

Include mediator explicitly

More model parameters → model on the right m_χ, m_V, Γ_V and $\sqrt{g_{SM} g_{DM}}$

Strength: Complete description for physics at LHC

Weakness: Some loss of generality to EFT



More Mono-X final states can be interpreted in simplified model framework but suppressed when based on ISR: mono-top, mono-Higgs…

Monojet

Event Selection:

1 Jet w. p_T > 120 GeV

E_T(miss) > 120 GeV

E_T(miss) back-to-back w. jet(s)

Maximum 2 jets

No leptons

Several signal regions with increasing E_T(miss) and jet p_T

Backgrounds:

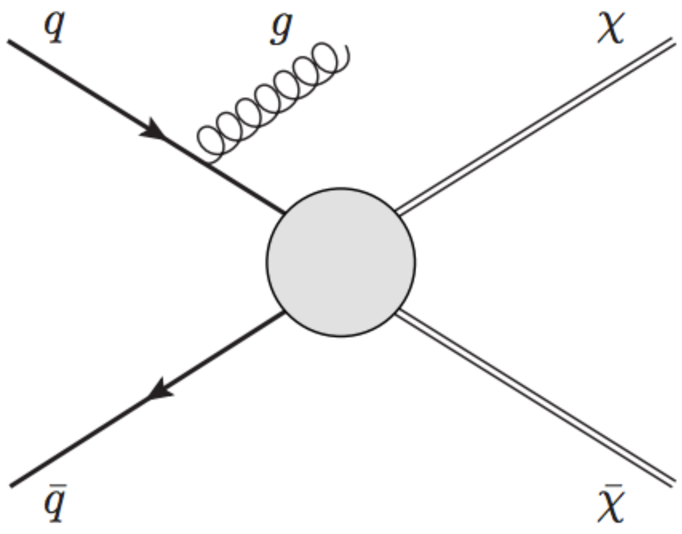
Z→νν (+ jets)

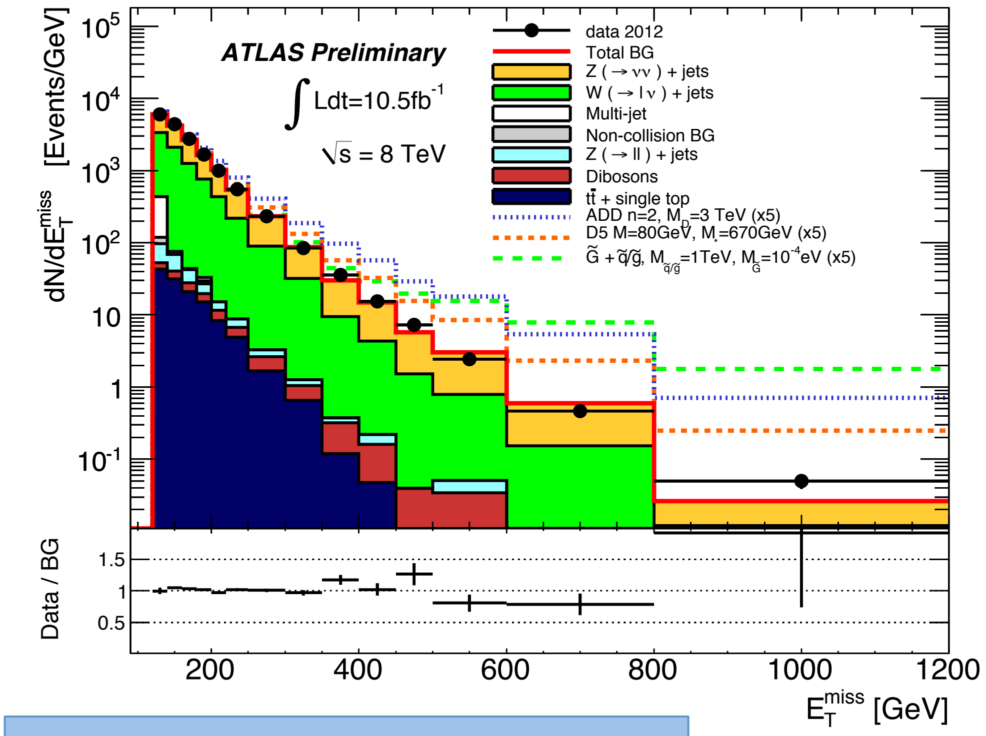
W→lν (+ jets) (lepton lost)

Estimated using 2 dedicated *Control Regions* (more in backup)

Less important: Top, multi-jet, Z→ll & Diboson production

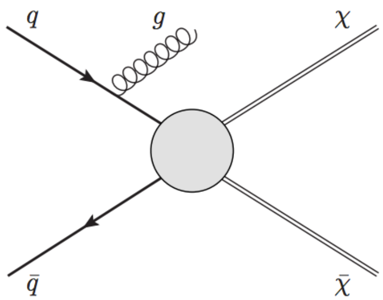
ATLAS-CONF-2012-147 (2012)

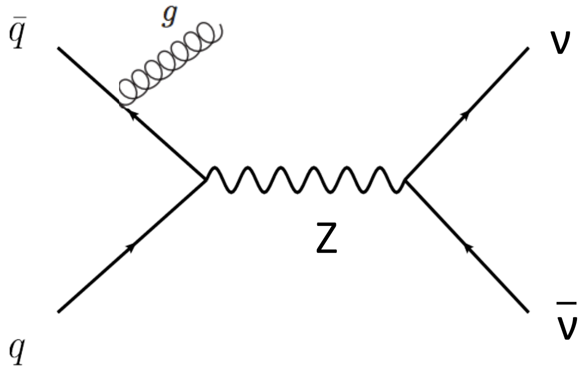




NOTE: BASED ON 10.5 fb^{-1}!

Monojet





Event Selection:

1 Jet w. p_T > 120 GeV

E_T(miss) > 120 GeV

E_T(miss) back-to-back w. jet(s)

Maximum 2 jets

No leptons

Several signal regions with increasing E_T(miss) and jet p_T

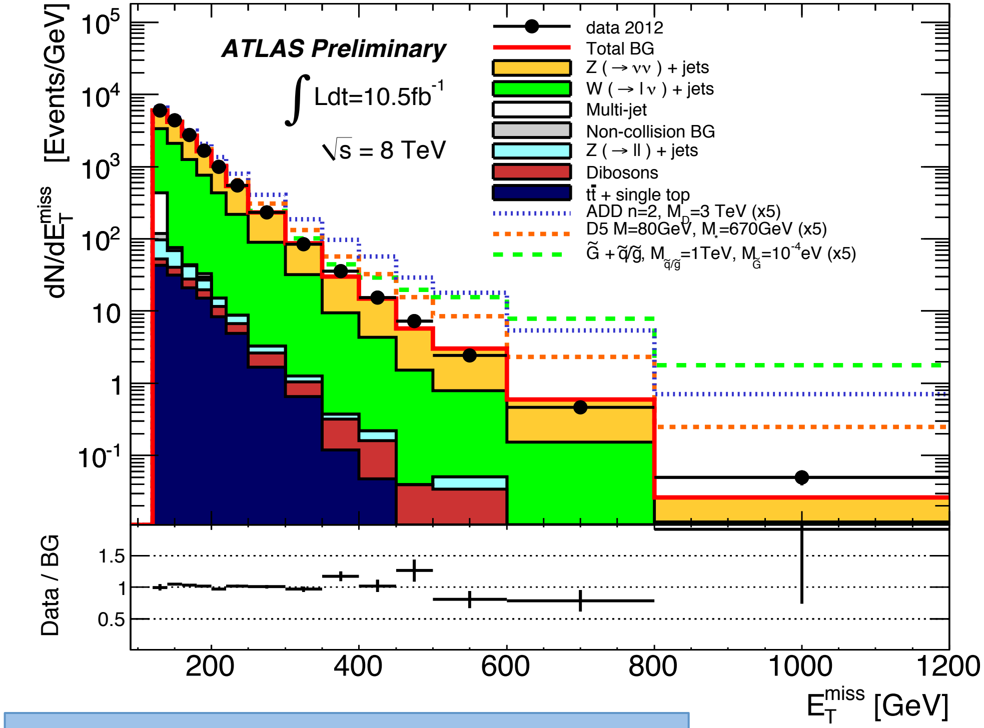
Backgrounds:

Z→νν (+ jets)

W→lν (+ jets) (lepton lost)

Estimated using 2 dedicated *Control Regions* (more in backup)

Less important: Top, multi-jet, Z→ll & Diboson production



ATLAS-CONF-2012-147 (2012)

NOTE: BASED ON 10.5 fb^{-1}!

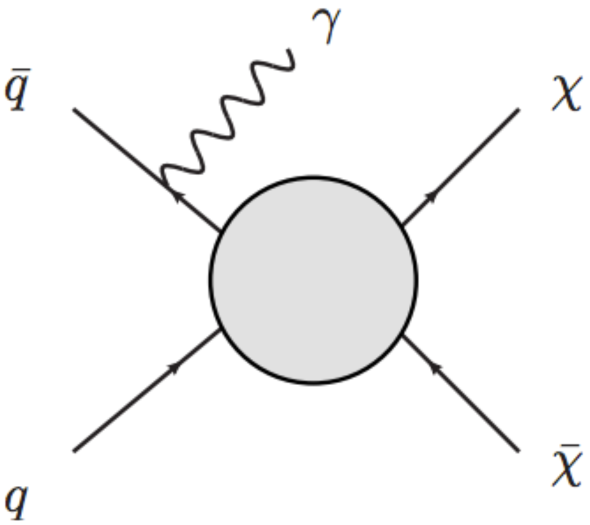
Monophoton

Event Selection:
Highly energetic photon, large MET, no leptons, not more than 1 jet

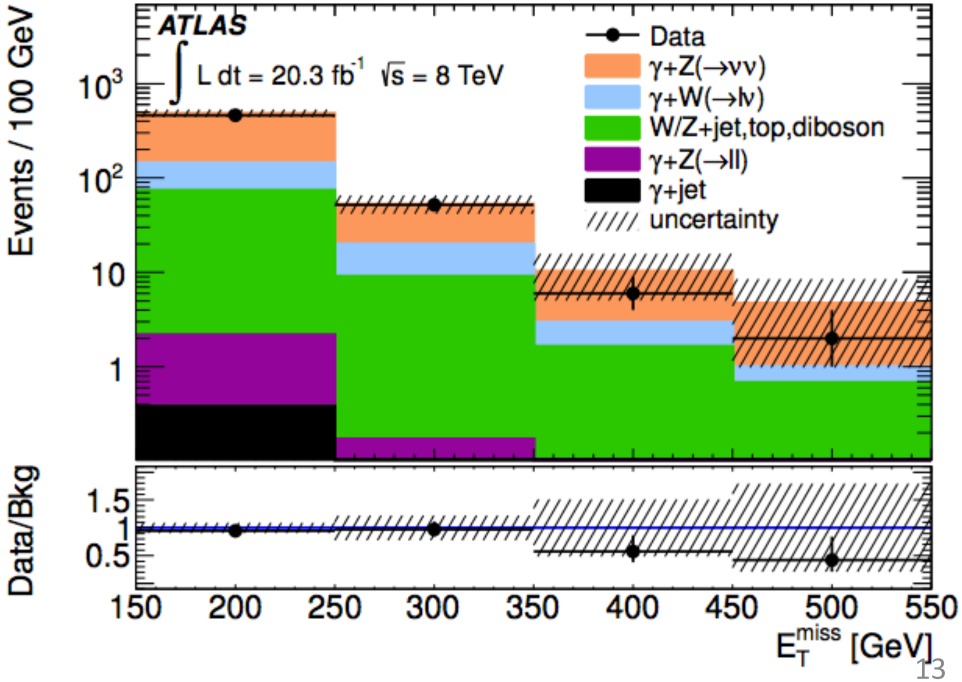
Backgrounds:
Z→νν + γ
Wγ and Zγ production (with leptons lost), W/Z production where lepton or jet taken to be γ

Estimated using dedicated *Control Regions* (more in backup)

Less important: Top pair, multi-jet, γ+jet & Diboson production



Signal Region



arXiv:1411:1559 (2014) (Submitted to Phys. Rev. D)

Mono-jet/photon Limits

No excess above SM expectations observed – used to set limits

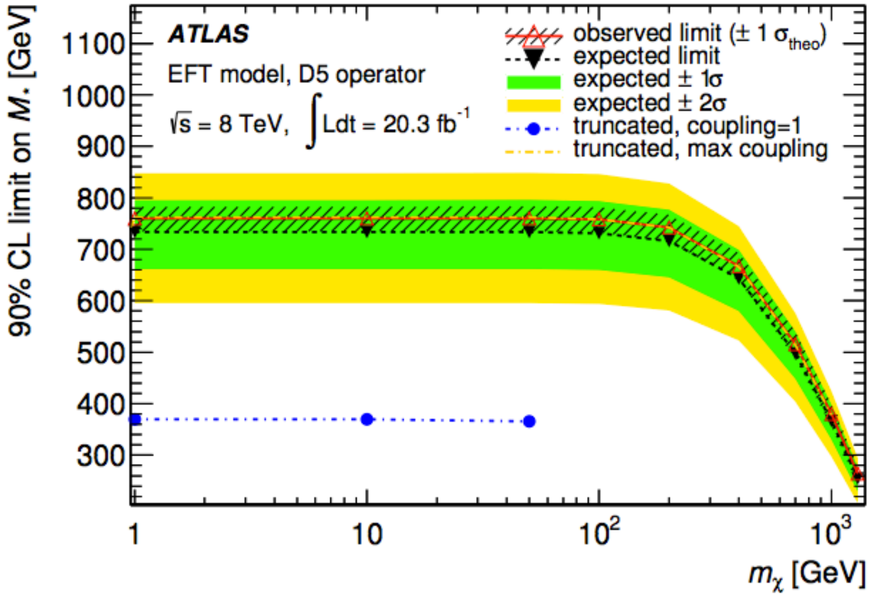
For EFT in monophoton, lack of validity handled by *truncation* of valid signal points.

Signal points removed if $Q > m_{med} = M_* / \sqrt{g_{SM} g_{DM}}$

Two choices of M_* tested, $g_{SM} g_{DM} = 1$ and $g_{SM} g_{DM} = 4\pi$

Monojet sets only ATLAS limits on operator D11 (gluon-DM interaction)

New monojet results using full 8 TeV dataset in the pipelines



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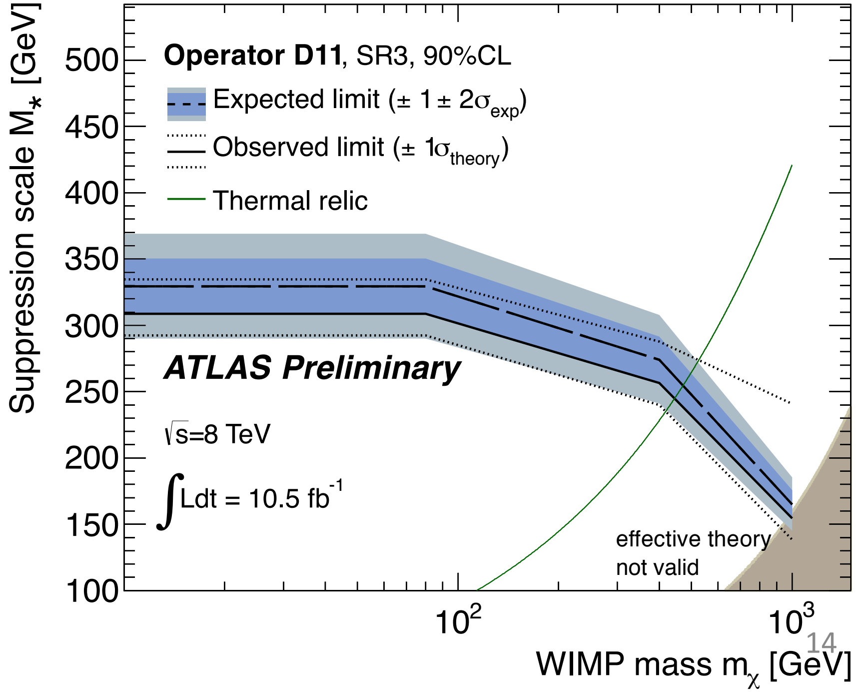
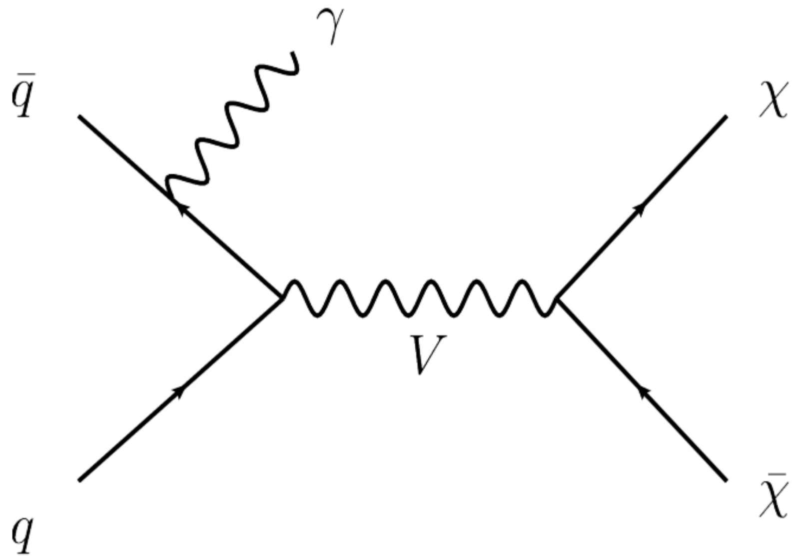


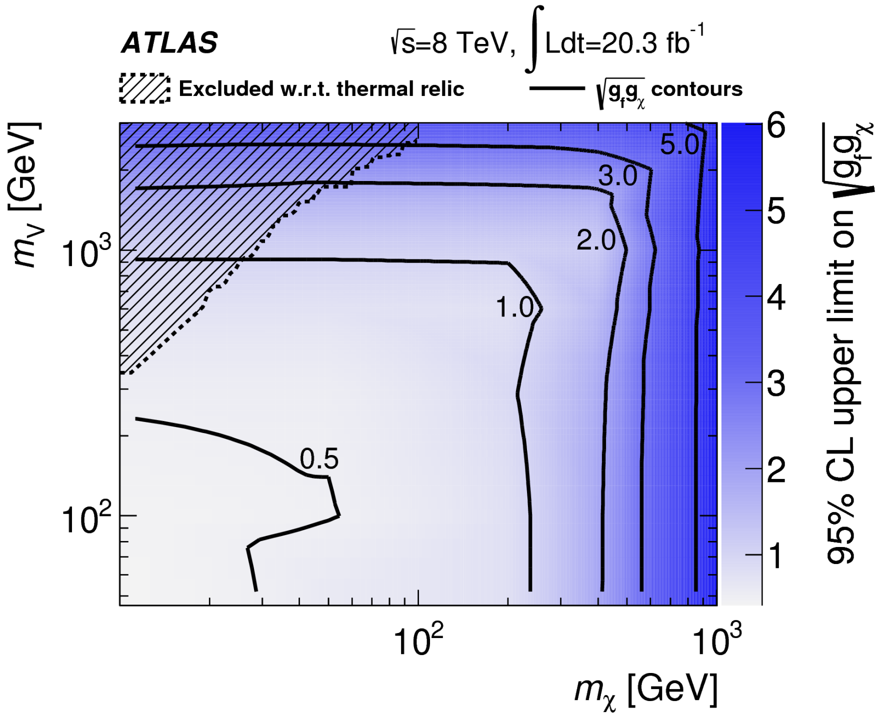
ATLAS-CONF-2012-147 (2012)

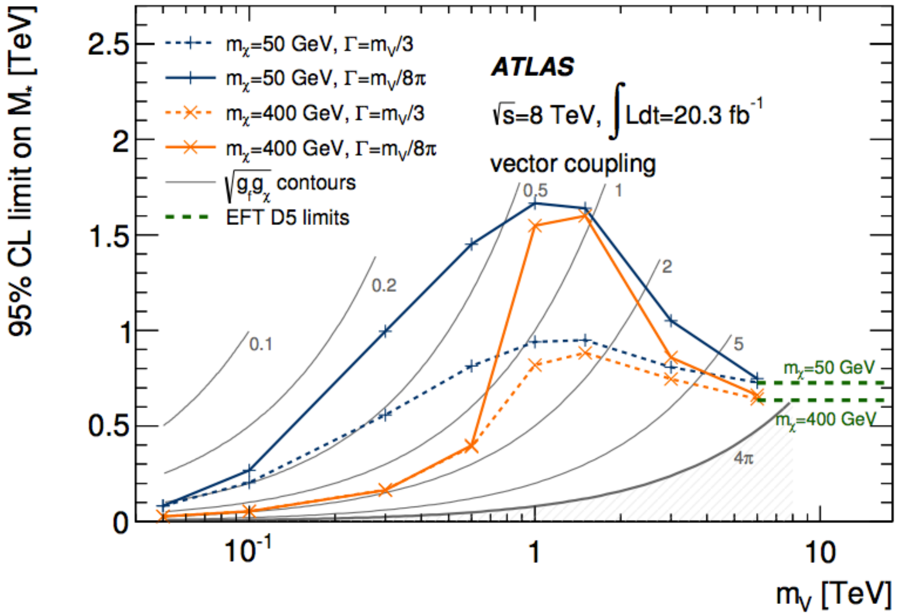
Mono-jet/photon limits

Monophoton simplified model w. Z'-like heavy gauge boson mediating DM-SM

Tested for $\Gamma = M_{med}/3$ and $\Gamma = M_{med}/4\pi$







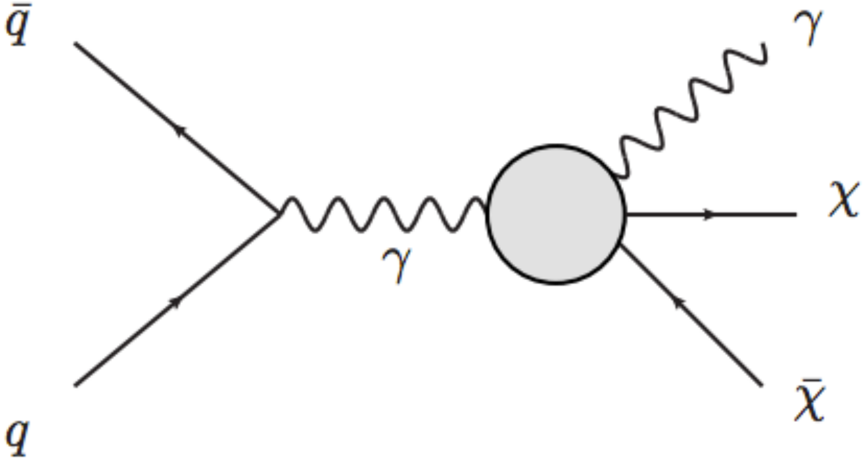
arXiv:1411:1559 (2014) (Submitted to Phys. Rev. D)

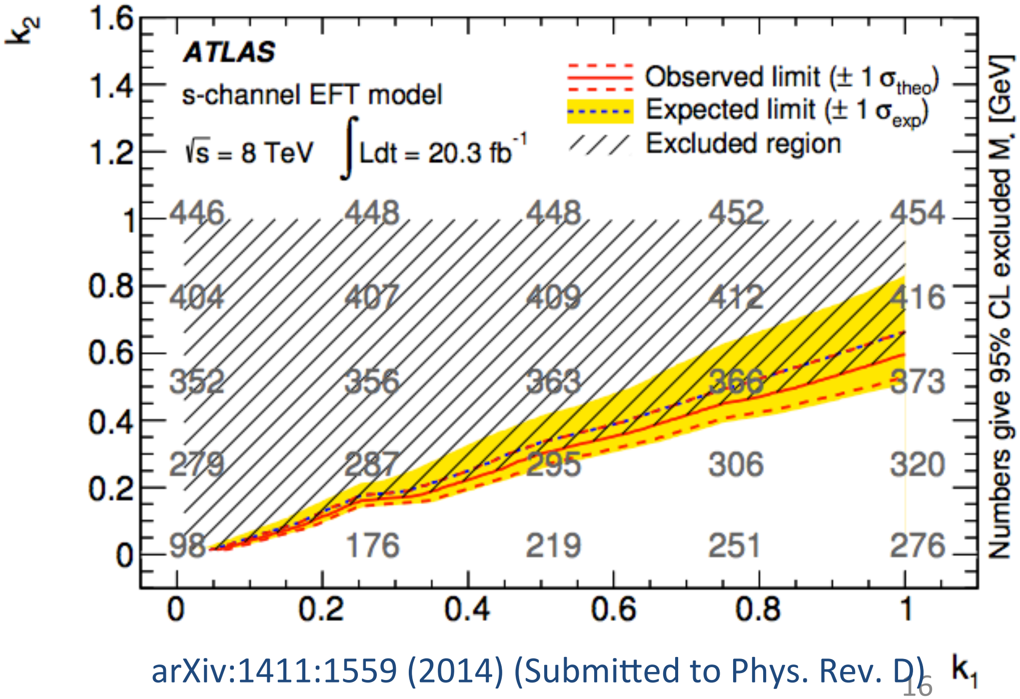
Mono-jet/photon limits

Second EFT model possible for monophoton, inspired by the Fermi-LAT 130 GeV line.

Using dim. 6 and dim. 7 operators introduced in A Nelson et al. in Physical Review D 89, 056011 (2014)

Parameters k_1 and k_2 control couplings of DM to U(1) and SU(2) gauge sectors respectively





arXiv:1411:1559 (2014) (Submitted to Phys. Rev. D)

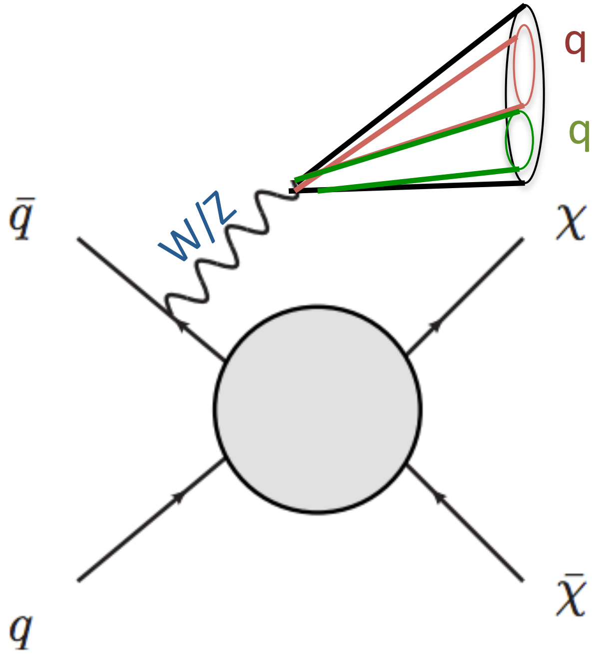
Mono-W/Z

Event Selection (hadronic):
1 big jet, containing 2 sub-jets, compatible with W/Z mass
Big jet p_T > 250 GeV
E_T(miss) > 350 or 500 GeV
No leptons or extra jets

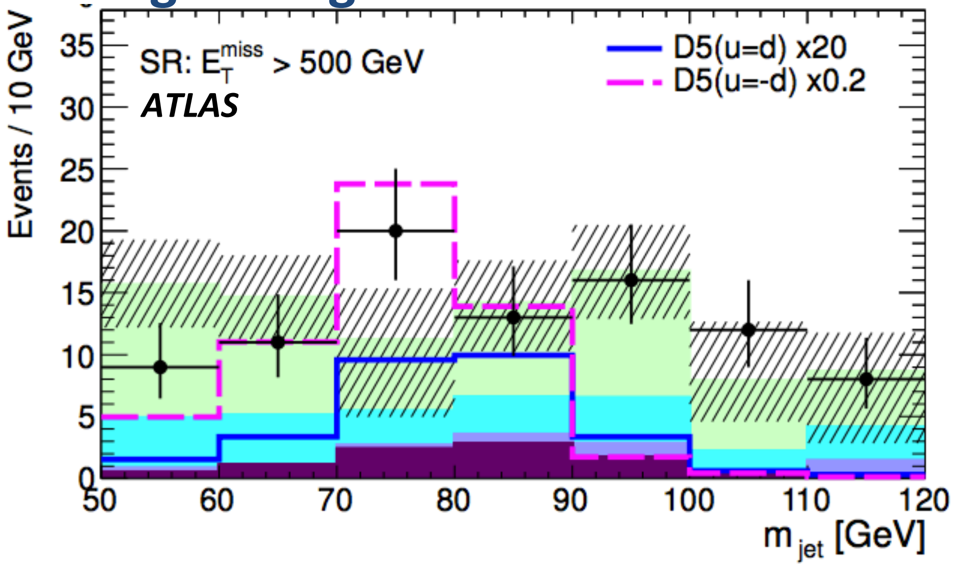
Backgrounds:
Z→νν (+ jets)
W→lν (+ jets) (lepton lost)

Estimated using dedicated *Control Regions* (more in backup)

Less important: Top, Z→ll & Diboson production



Signal Region



Light green: Z→νν, Blue: W/Z→leptons, Pink: top, Purple: WW/WZ/ZZ

Phys. Rev. Lett. 112, 041802 (2014)

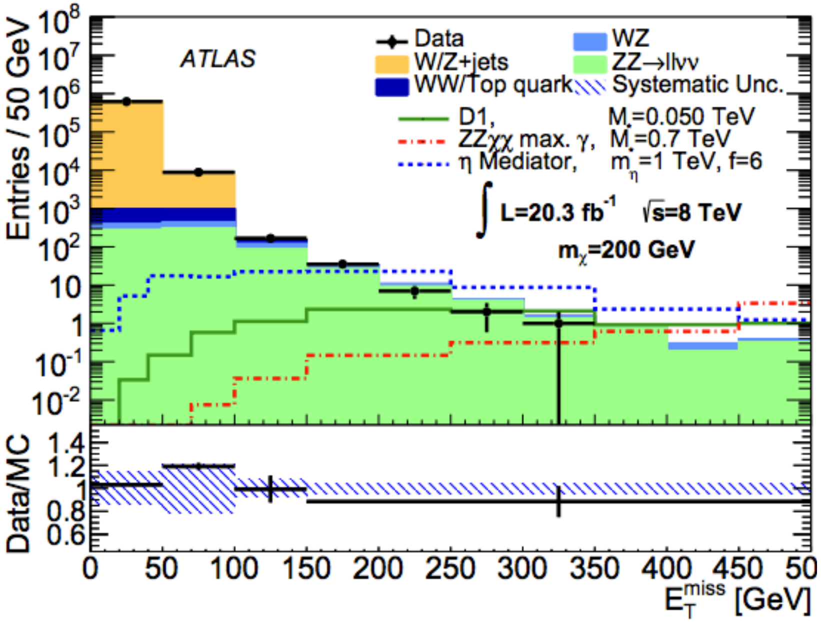
Mono-W/Z

Event Selection (leptonic Z):
2 leptons (ee or μμ) with invariant mass consistent with Z decay

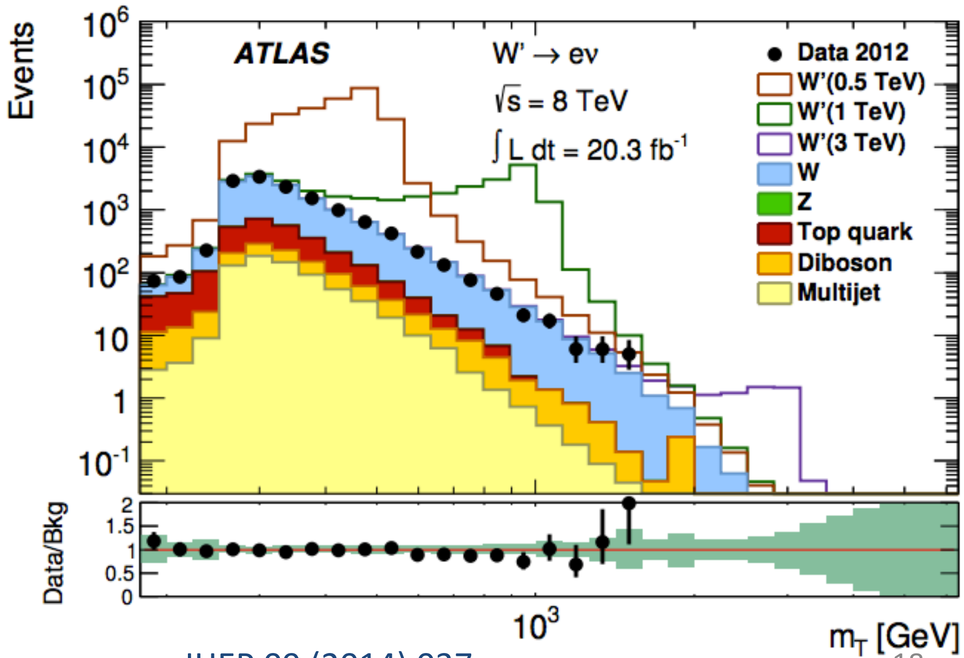
No jets, no third lepton.
Large E_T(miss).

Event Selection (leptonic W):
Exactly one high-momentum electron or muon, and E_T(miss) from neutrino

Large m_T (invariant mass in transverse plane), incompatible with decay from directly produced W



Phys. Rev. D. 90, 012004 (2014)

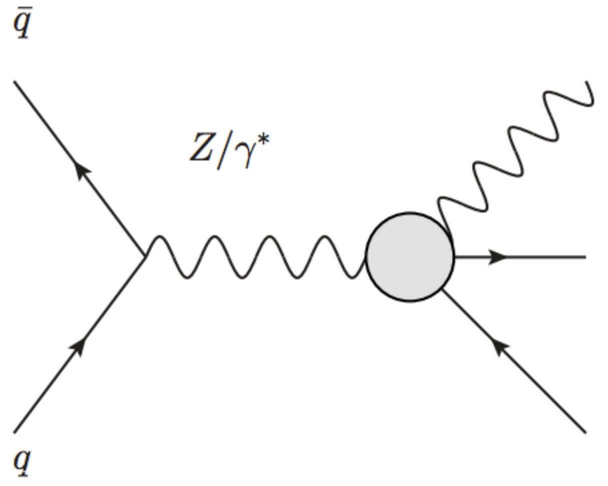


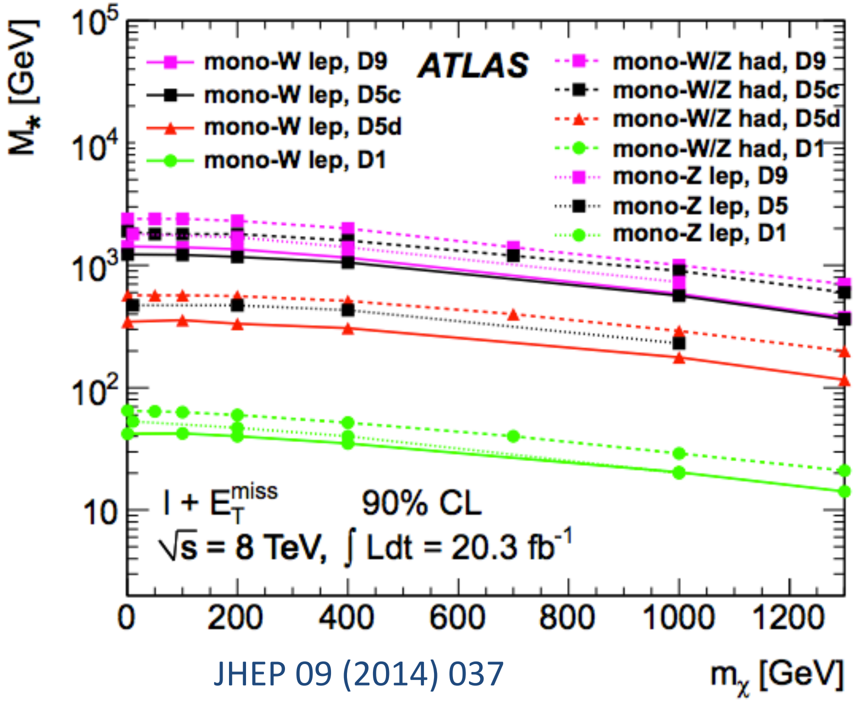
JHEP 09 (2014) 037

Mono-W/Z

Interference between diagrams with W radiating from d or u: Destructive if [C(u)=C(d)] or constructive if [C(u)= -C(d)]

Leptonic Mono-Z again allows test of Fermi-inspired 6-dim and 7-dim operator theory. Relative contribution of Z and γ is a parameter





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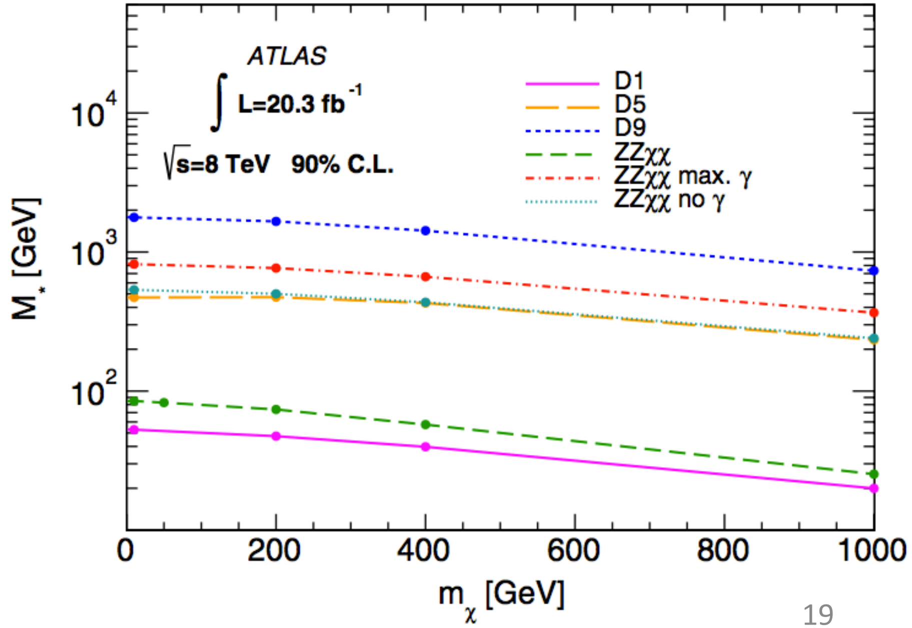
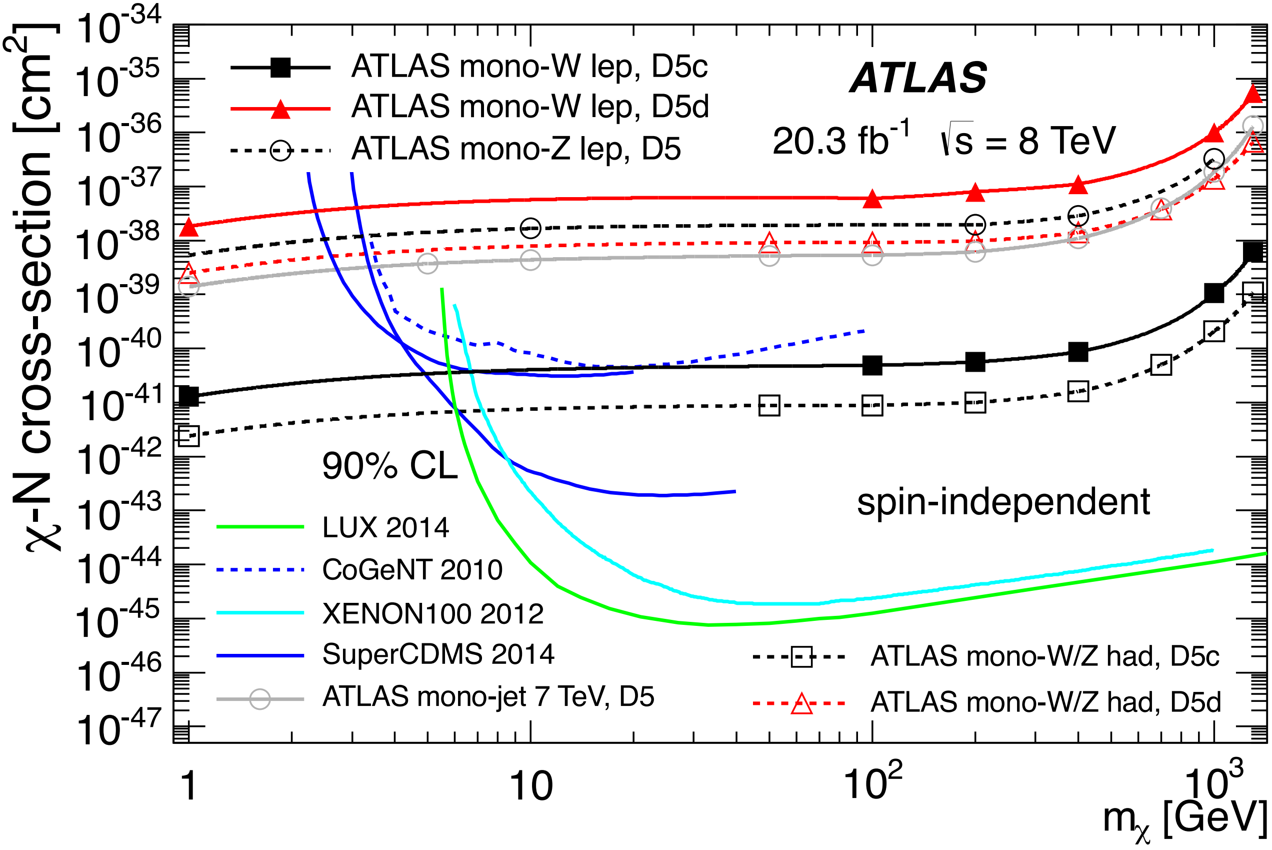


Phys. Rev. D. 90, 012004 (2014)

Compared to direct detection



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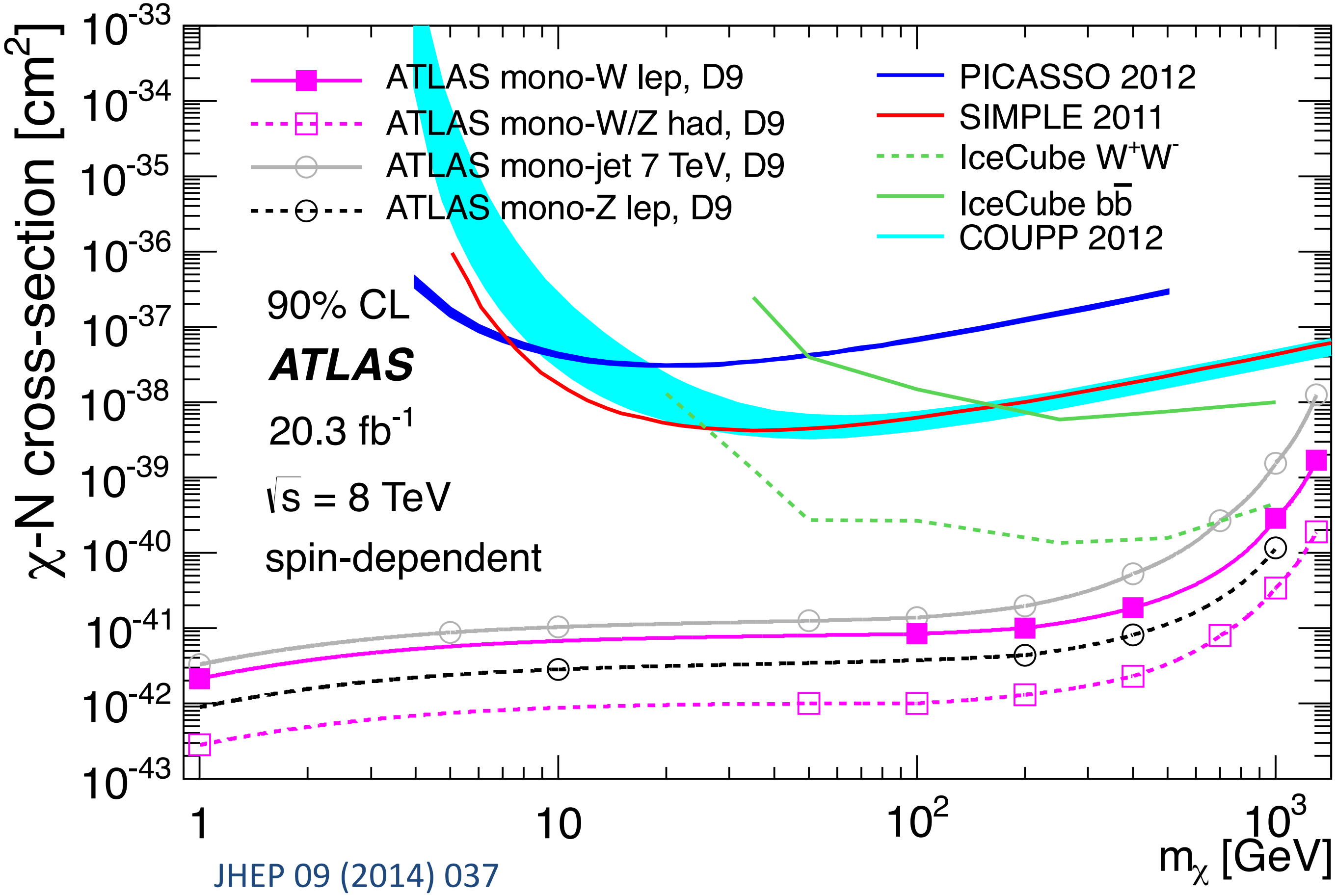
Spin-dependent: colliders set strong limits at very low WIMP mass: ***No lower mass limit***. Note again that the collider lines are under assumptions not made for non-colliders.

Mono-photon not included here – sets worse limits for the investigated operators

Compared to direct detection

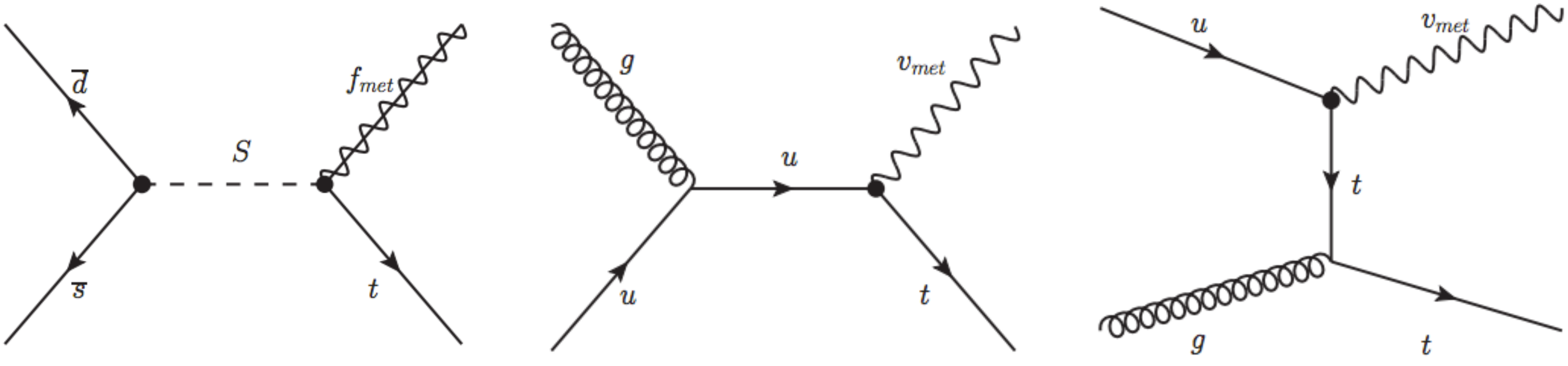


JHEP 09 (2014) 037

For spin-dependent interaction ATLAS is competitive over the full investigated mass range. Again: Note that collider results are under somewhat different sets of assumptions.

arXiv:1410:5404 (2014) (Submitted to EPJC)

Mono-top



Left: +2/3-charged boson S decays to top and a neutral fermion, which in turn may decay (possible in SU(5) or hylogenesis models).

Production of right-handed top quark and a spin-1 neutral color-singlet (possible in supersymmetry models). The neutral particle can decay to a pair of dark matter candidates.

Mono-top

Event Selection:

1 lepton (e,μ)

1 jet, tagged as from a b quark

E_T(miss) > 35 GeV

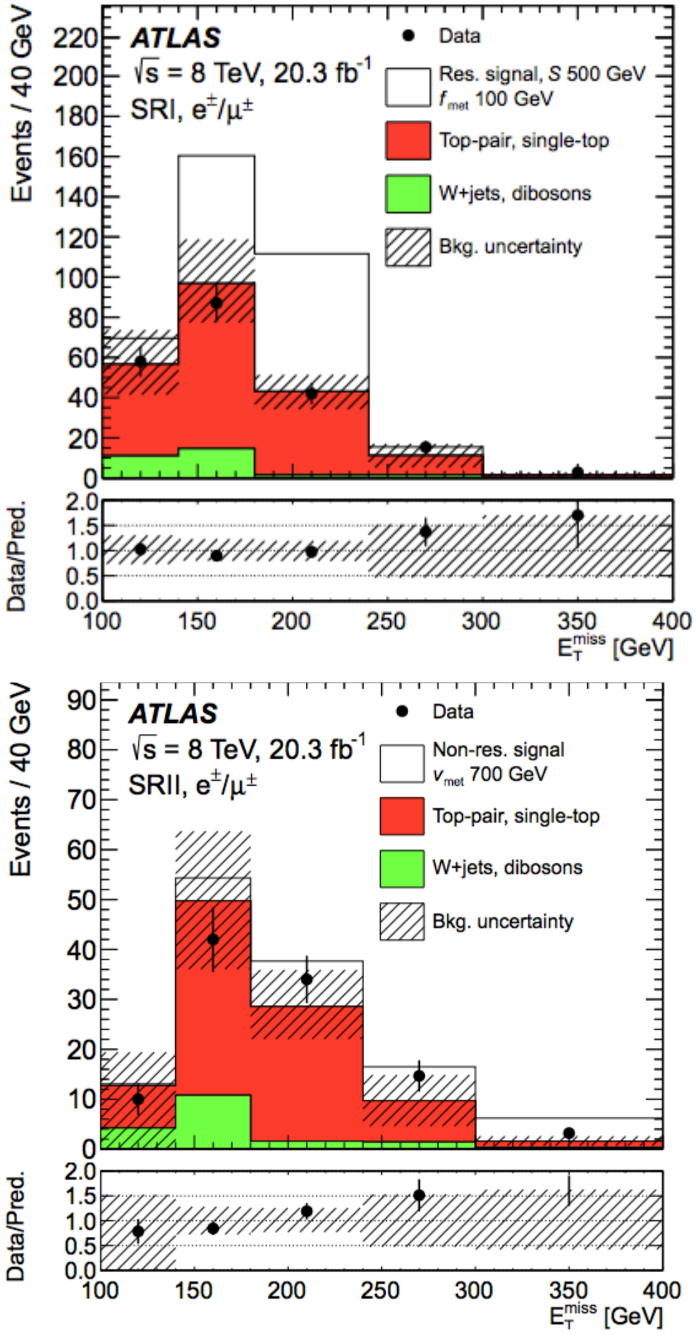
Topology of event consistent with t decay, in two somewhat differing signal regions

Backgrounds:

t quark pairs, W→lν (+ jets), multi-jet

Apart from multi-jet, estimated from simulation and tested in special *validation regions*.

Less important: Z→ll, Diboson production.



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Mono-top

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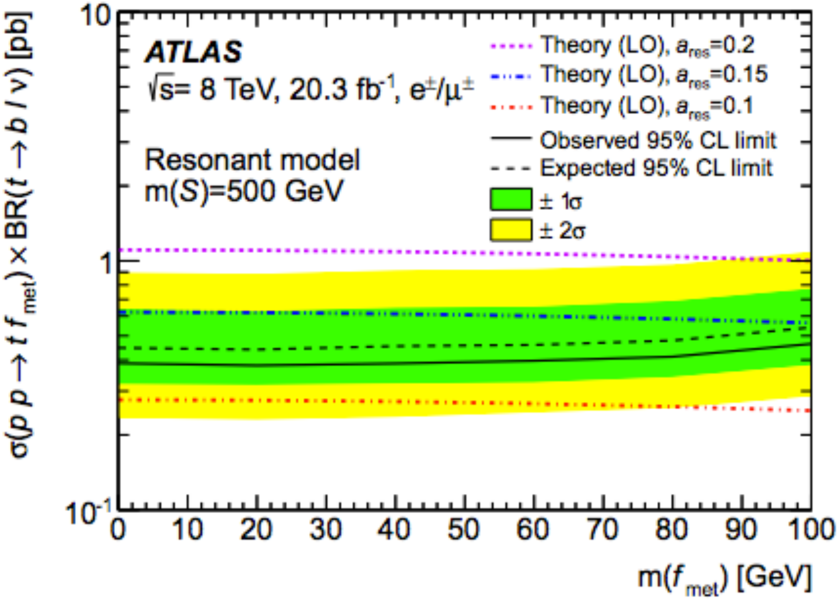
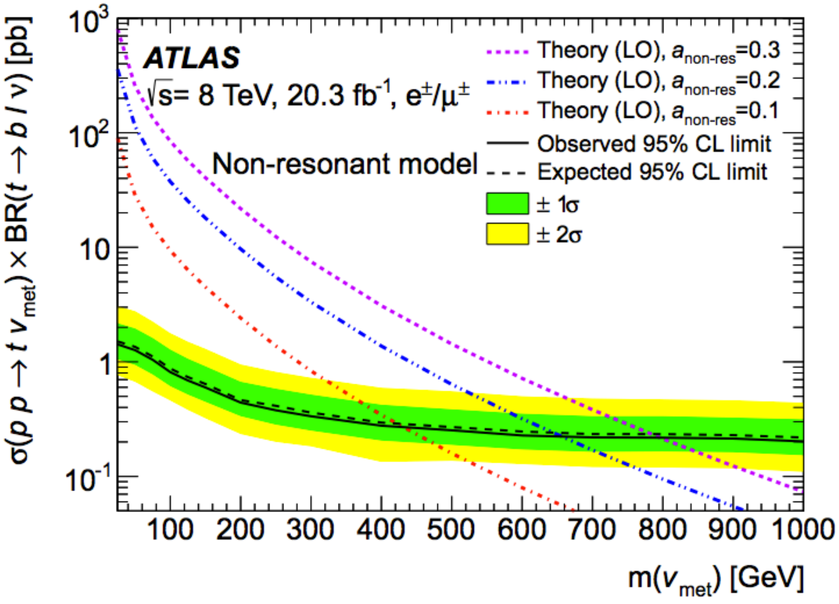


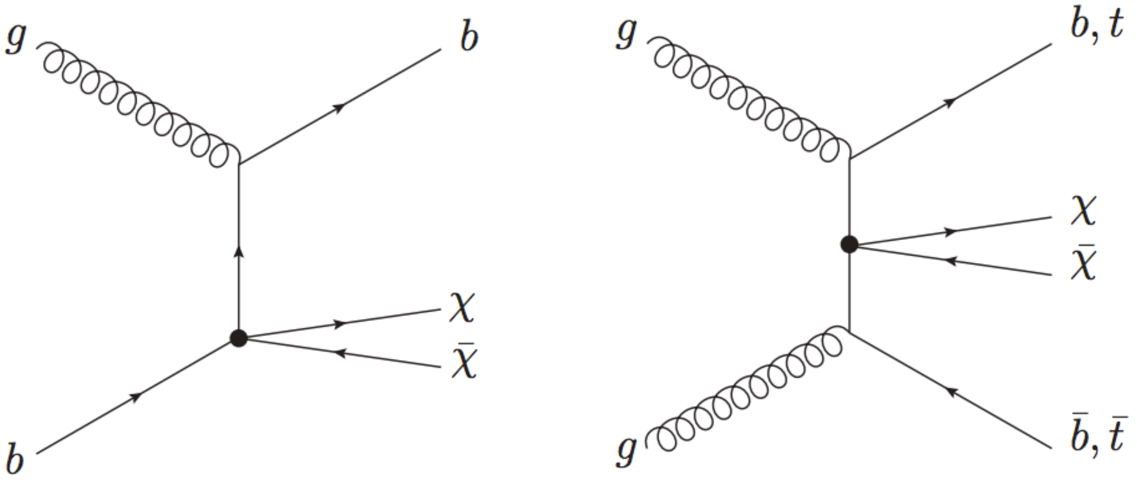


Model excluded if it predicts more events than the observed limit. In plots above a_{res} and $a_{non\text{-}res}$ are coupling matrices in the SM-nonSM vertices.

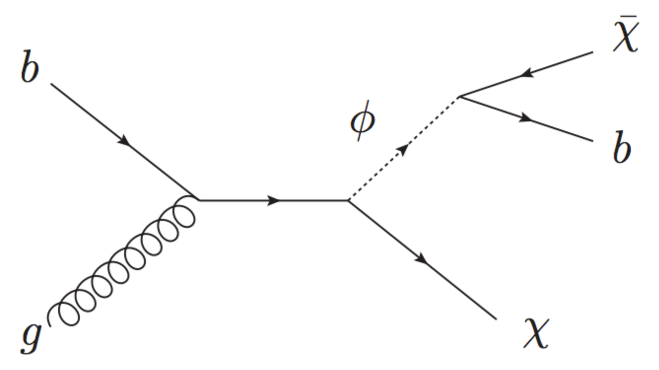
arXiv:1410.4031 (2014). Submitted to EPJC

Heavy flavor + MET

$\mathcal{O}_{\text{scalar}} = \sum_q \frac{m_q}{M_*^N} \bar{q} q \bar{\chi} \chi$ possible to probe using heavy quarks



Simplified Model with "b-flavored" DM (b-FDM). Proposed to explain the gamma ray excess from galactic centre seen by Fermi-LAT and interpreted as DM annihilating to b quark pairs.



Fermi line interpretation in T. Daylan et al. (2014) arXiv:1402.6703
b-FDM model in P. Agrawal et al. (2014) Phys. Rev D90, 063512

Heavy flavor + MET, top pair signal

Event Selection:

At least 4 jets, at least 1 from b

E_T(miss) > 270 GeV

1 lepton

Advanced kinematic cuts to reduce SM t pairs

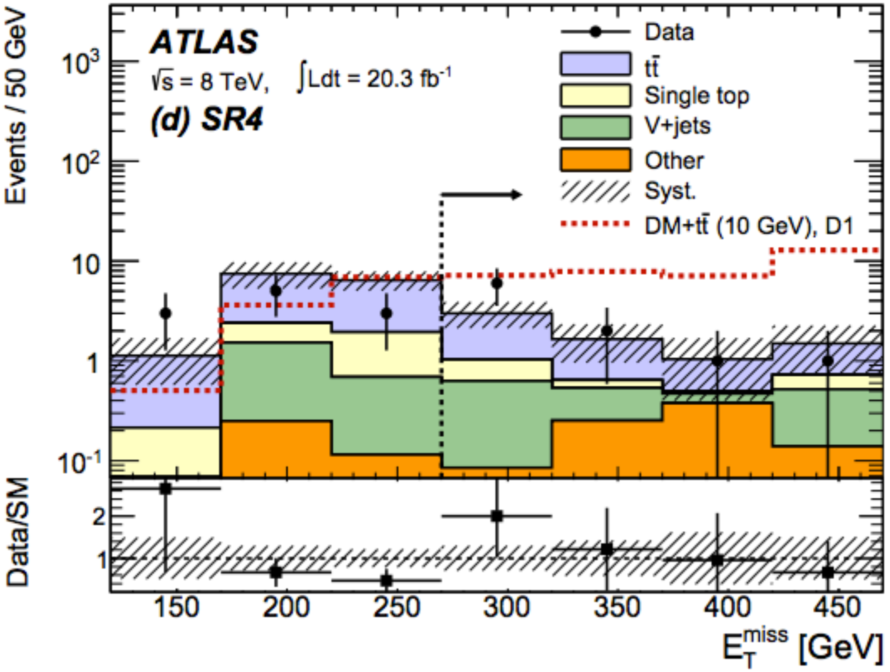
Backgrounds:

SM top quark pairs

Estimated using dedicated *Control Regions* (more in backup)

Less important: Single top production, W/Z+jets

This region used to search for tt pairs, where 1 top quark goes t→Wb→lvb and one goes t→Wb→qqb

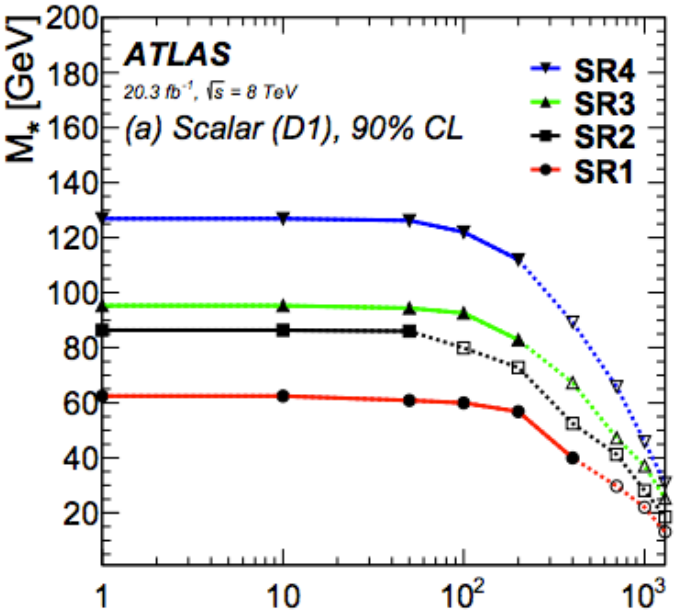


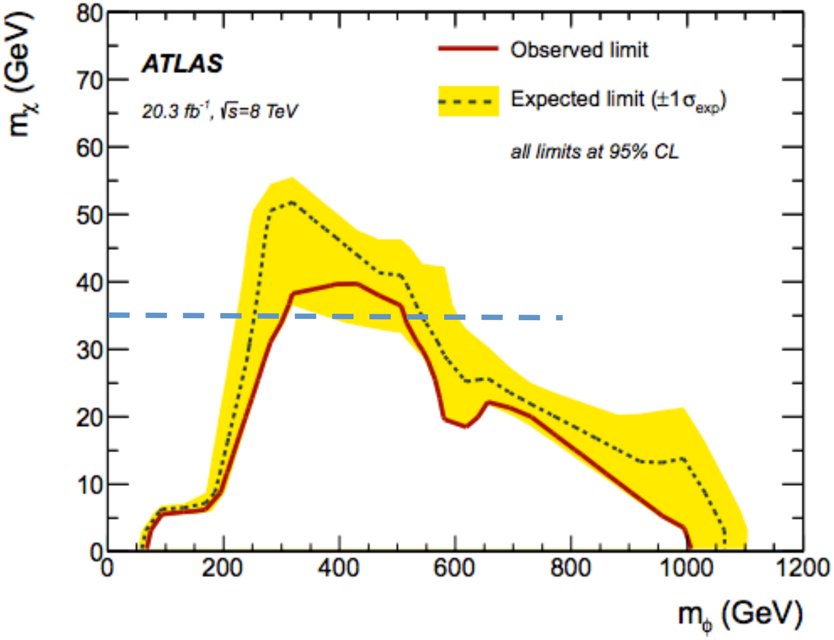
arXiv:1410.4031 (2014). Submitted to EPJC

Heavy flavor + MET

Limits on D1 operator strongest ATLAS limit. Notice truncation (lines become dotted)

At the interesting WIMP mass around 35 GeV, mediator masses between ~300-500 GeV excluded





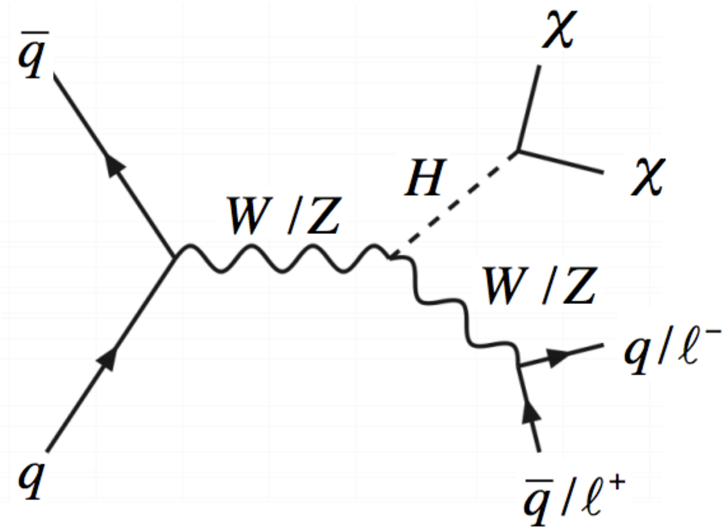
arXiv:1410.4031 (2014). Submitted to EPJC

Invisible Higgs

Some theoretical extensions to the SM have Higgs boson decay to invisible particles. Sensitive for $m_\chi < m_H/2$

Searches for Higgs → invisible performed in two ways

- Associated ZH decay, Z decaying to 2 leptons, H to WIMP pair
- Reinterpretation of Mono-W/Z hadronic – H → WIMPs, W/Z to jets



Associated ZH production, Z→ll, H→χχ

Event Selection:

2 leptons (ee, μμ)

Large E_T(miss)

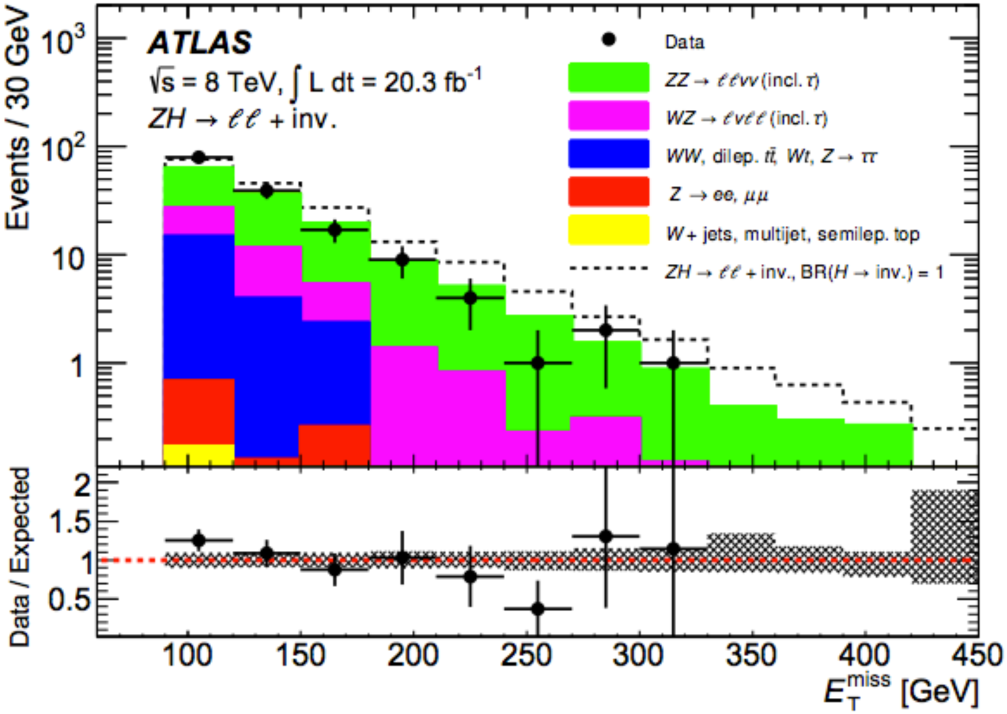
Leptons back-to-back with E_T(miss) (Z with Higgs)

No jets

Main backgrounds:

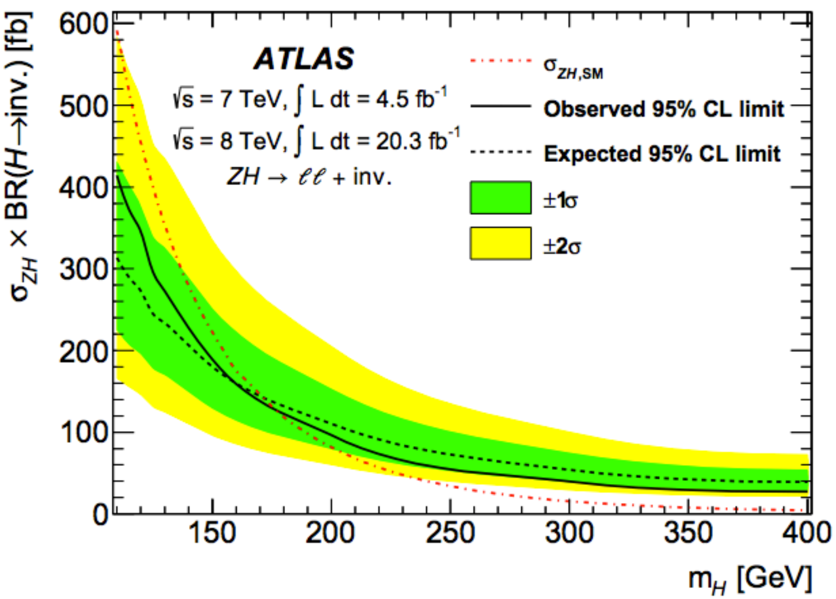
ZZ & WZ production

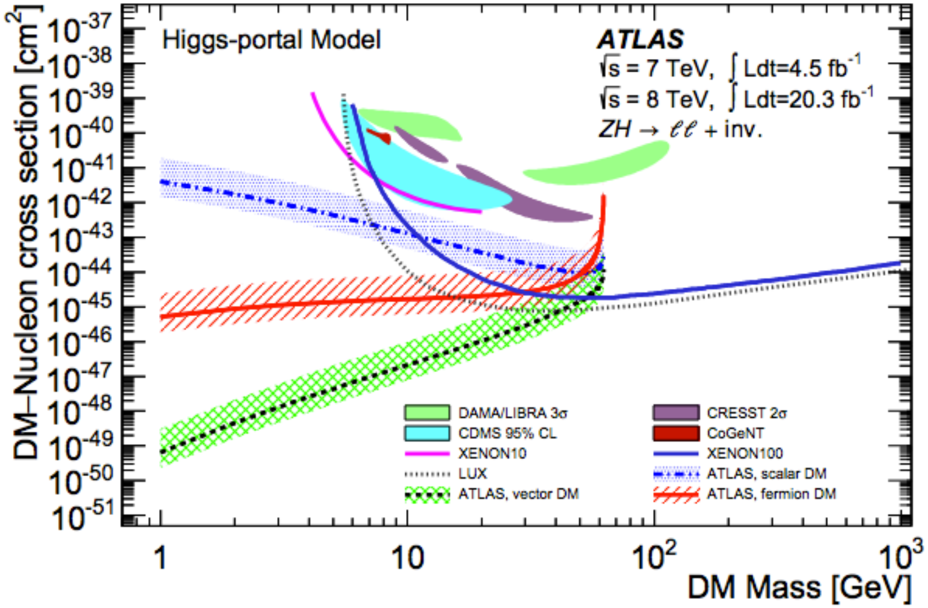
Estimated in simulation, tested in dedicated *Validation Regions* (more in backup)



Phys. Rev. Lett. 112, 201802 (2014)

Associated ZH production





BR(H→inv) < 75% at 95% CL, for the ~125 GeV Higgs. Converting production cross section to limits on Higgs Portal DM models provide strong, but of course very model-dependent limits.

Phys. Rev. Lett. 112, 201802 (2014)

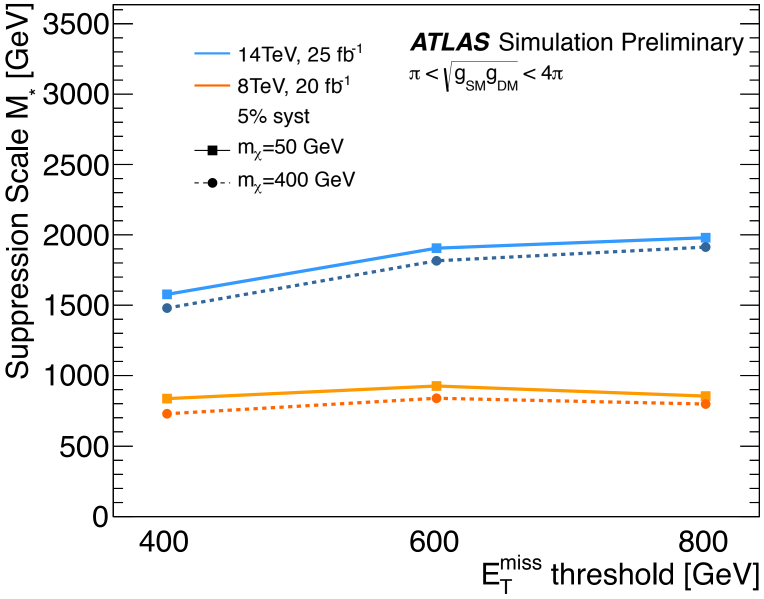
Prospects for Run 2

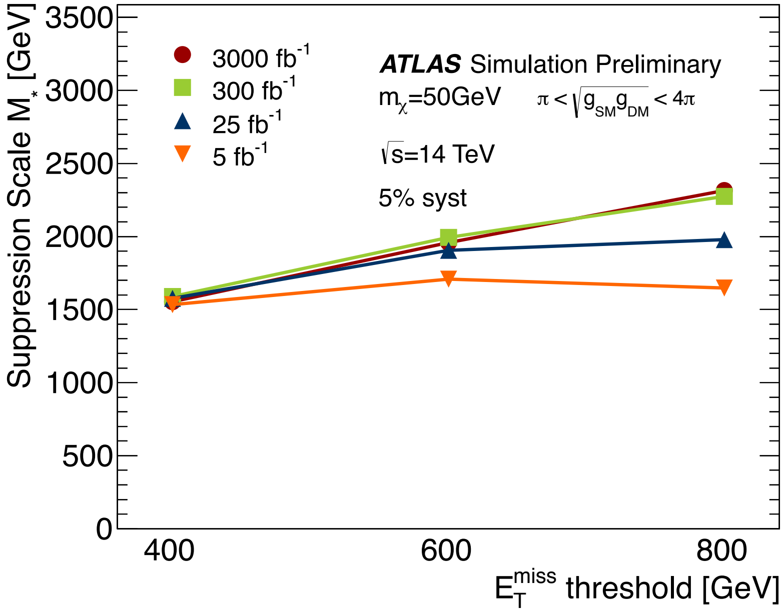
Going to 13-14 TeV energies increases the sensitivity to new physics

Also means challenges associated with the higher luminosity: Going from ~20 to ~60 interactions per crossing

Simulated monojet sensitivity: Large increase directly with higher energy, slower increase when going to 3000 fb^{-1}

Ambition to go towards a more systematic search with simplified models





ATL-PHYS-PUB-2014-007 (2014)

Summary

Findings are so far consistent with SM expectations, limits are set on new physics using EFT approach as well as in several simplified models

Searches of "Mono-X" type set upper limits on the effective scale of the DM-SM interaction for given WIMP masses. For given operators these limits can range up to above 1 TeV for low mass WIMPs

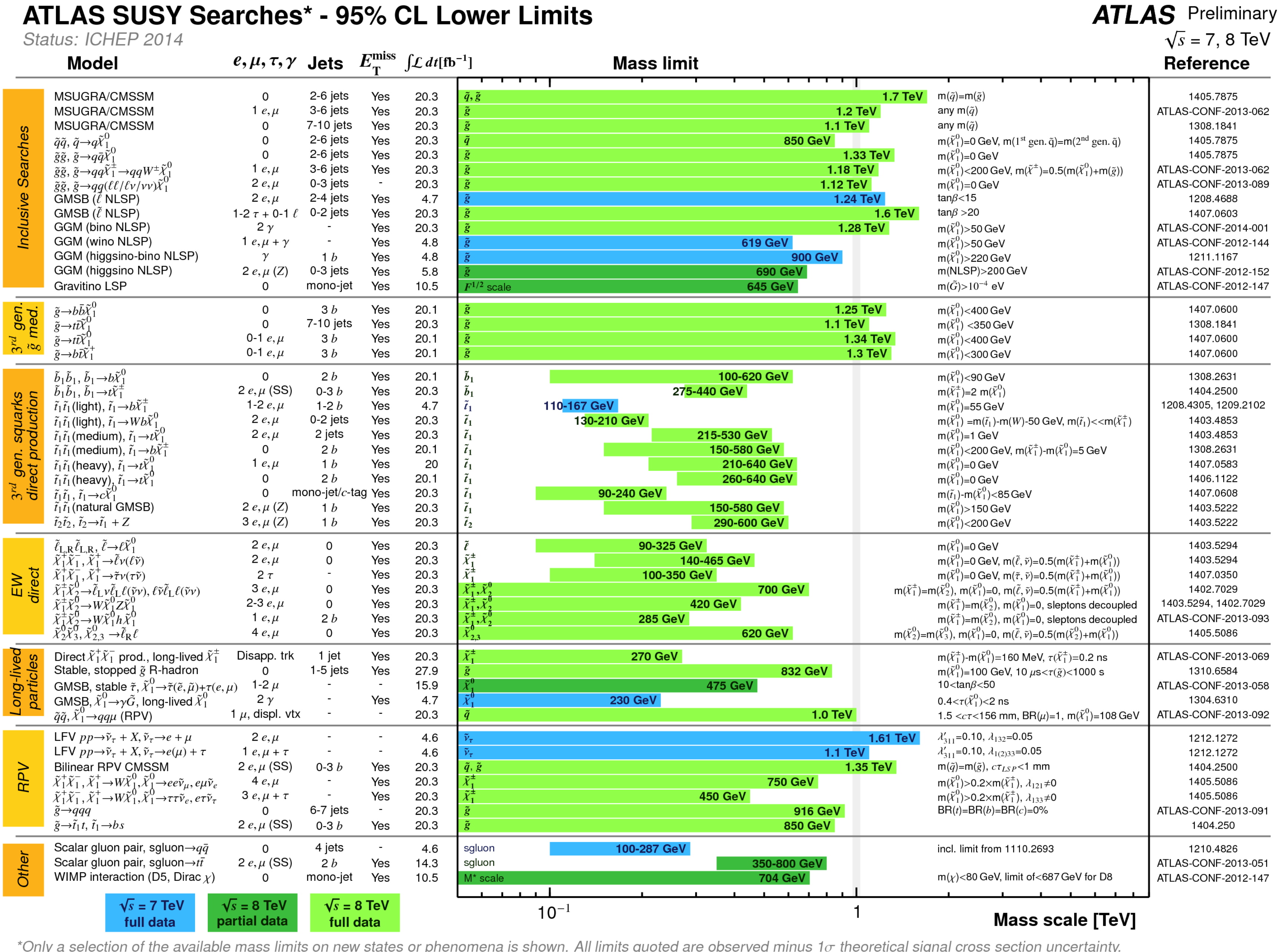
Compared to direct detection experiments ATLAS tends to set strong limits for low mass WIMPs in the spin-independent case, and over the whole covered mass range for the spin-dependent case

Searches for Higgs decays to invisible states and final states with quarks and E_T(miss) have been presented. Heavy quarks in the final state allows stricter limits on the scalar effective operator interaction, and the invisible Higgs searches so far set an upper limit on Higgs decay to invisible particles at 75%

ATLAS sensitivity at 14 TeV increases significantly with the higher energy, but not necessarily with more data: This will be an interesting year!

BACKUP SLIDES

SUSY searches



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

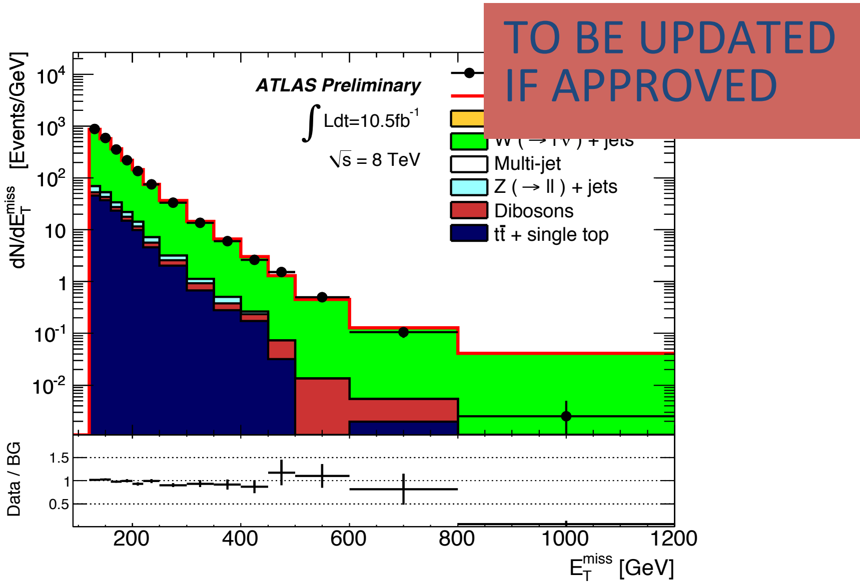
$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1405.7875
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any m($\tilde{q}$)	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any m($\tilde{q}$)	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1^{st} gen. $\tilde{q}$)=m(2^{nd} gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm \to qqW^\pm\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	m($\tilde{\chi}_1^0$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	m($\tilde{G}$)>10^{-4} eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	m($\tilde{\chi}_1^\pm$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	m($\tilde{\chi}_1^0$)=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-210 GeV	m($\tilde{\chi}_1^0$) =m($\tilde{t}_1$)-m(W)-50 GeV, m($\tilde{t}_1$)<<m($\tilde{\chi}_1^\pm$)	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$ 215-530 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$ 260-640 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to \tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to \ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to \tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to \tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to \tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 700 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 420 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 285 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0 \to \tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to \tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	0.4<τ($\tilde{\chi}_1^0$)<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}_1^0$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{121}\neq 0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to \tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e, μ (SS)	2 b	Yes	14.3	sgluon 350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	m(χ)<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Monojet background

Z→νν background, as well as W→lν background from three control regions with leptons



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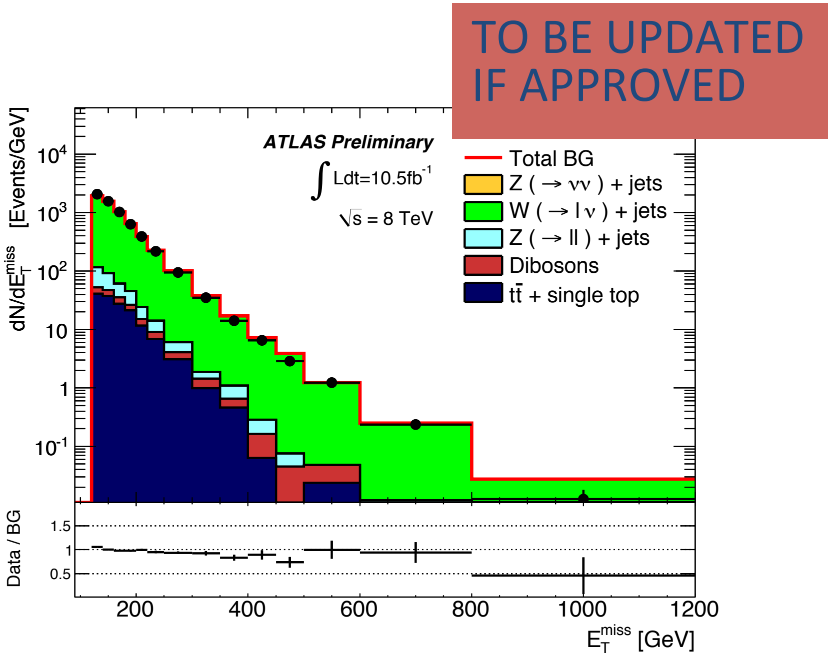

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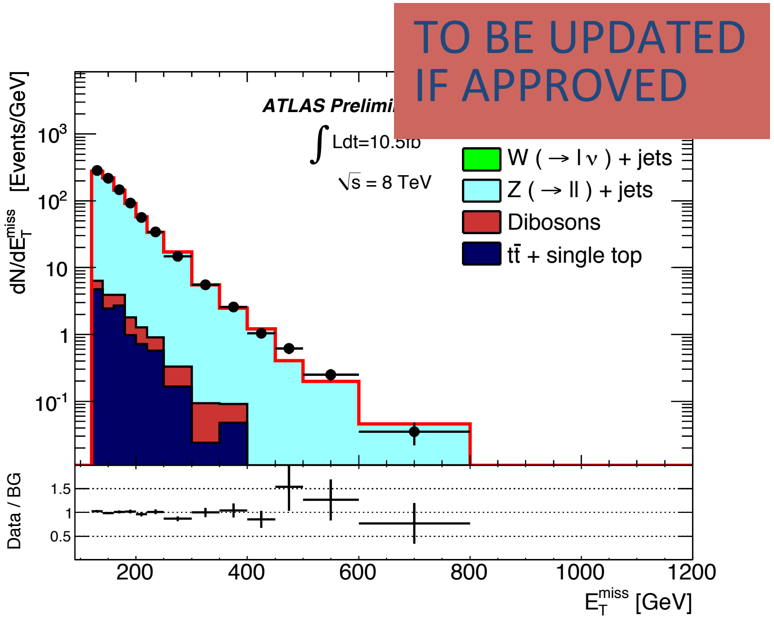
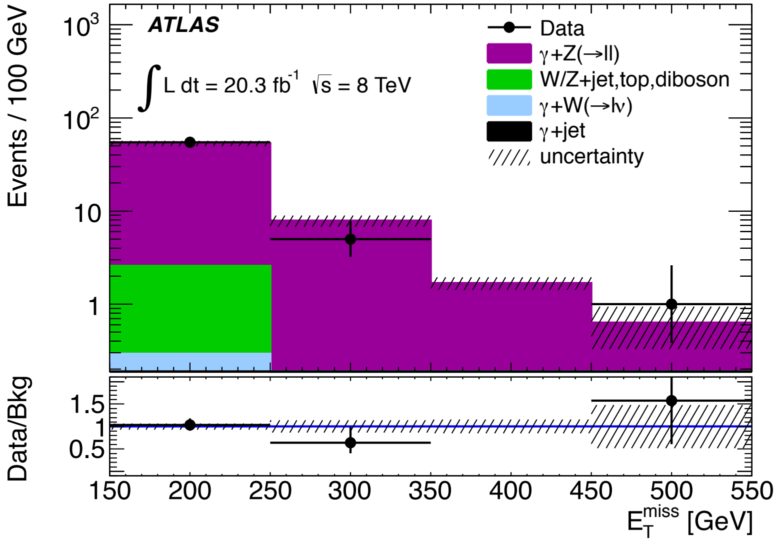
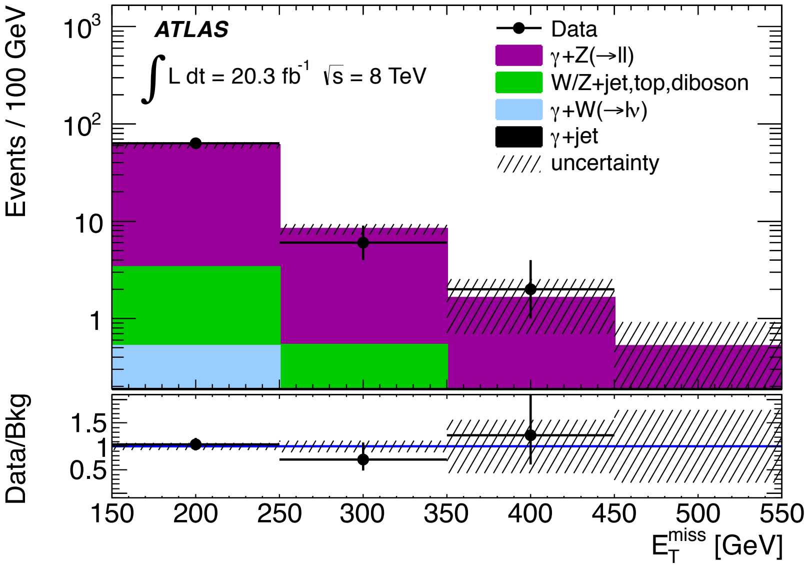


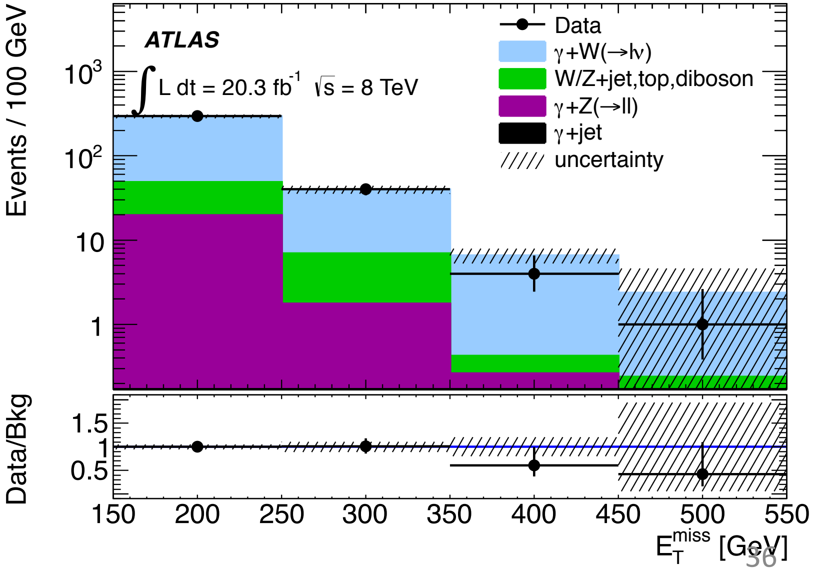
TO BE UPDATED IF APPROVED

Monophoton background

Z and W + γ backgrounds estimated using 3 control regions with leptons, where normalization factors are extracted and applied in SR.

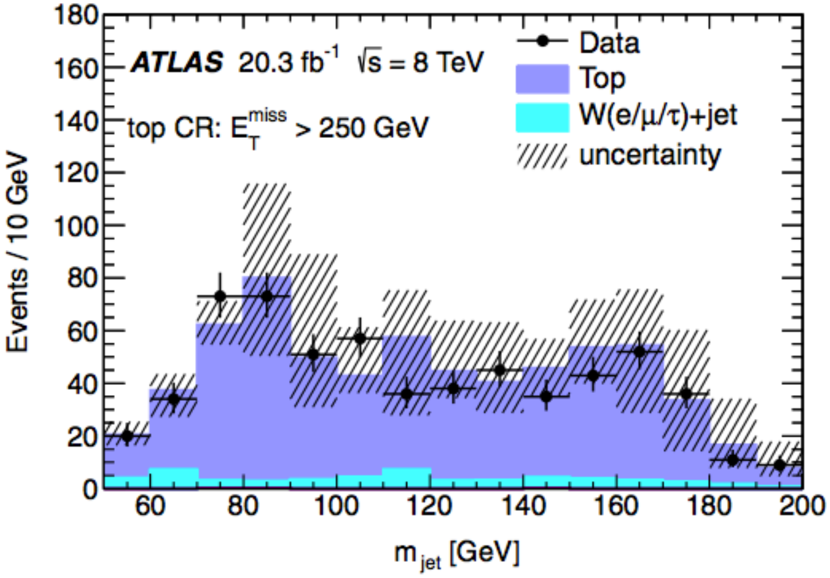






Mono-WZ hadronic

W hadronic decay with large jets validated in tt CR, where we demand one muon, two jets separated from big jet and at least one b-tag



W/Z + jets background estimated using control region with muon veto inverted, and extrapolation depending on m_{jet} extracted

Mono-WZ leptonic backgrounds

For leptonic W, multi-jet is estimated using enriched CR and *matrix method* or inverted isolation technique.

For leptonic Z:

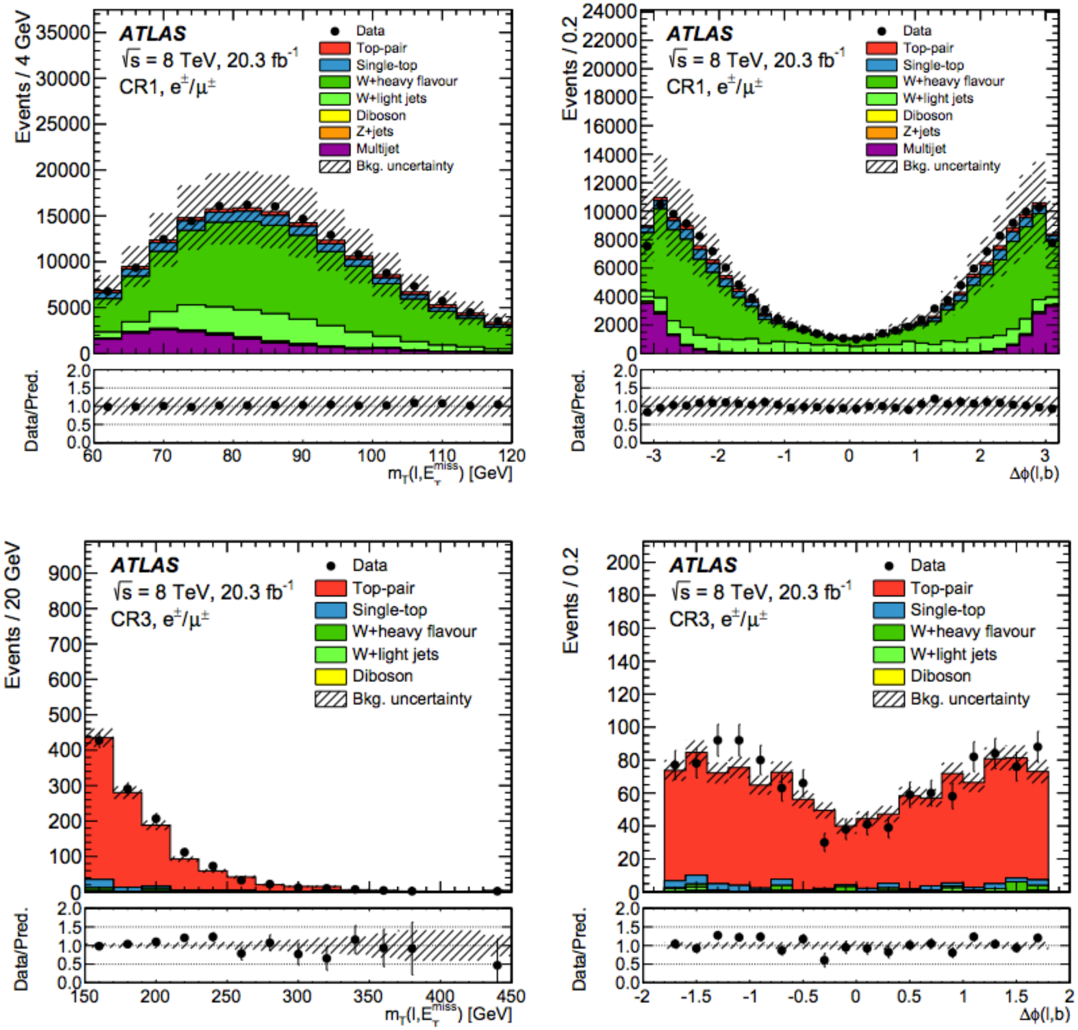
- WW, t, Wt and ττ using eμ CR
- Z + jets uses ABCD with E_T(miss) and η as the uncorrelated variables, and extrapolation of $\Delta\phi(E_T(\text{miss}), p_T^{ll})$ from low E_T(miss) region to SR
- W + jets extrapolated from reversed isolation at low E_T(miss) to SR.
- All validated in non-SR regions

Monotop Backgrounds

CR1 enriched in W+jets and multi-jet by putting it in W window

CR3 enriched in tt by requiring second b-jet and high m_T.

These CR:s are to validate the background estimates from MC



Heavy quark analysis background

Top pair background taken from control region where m_T lower and the requirements to reject these in SR are loosened

Wlν background from control region with inverted b-tagging requirement (0 b-jets)

ZH Backgrounds

WZ background validated in 3-lepton CR

Backgrounds with two leptons from non-W/Z decays estimated in an eμ CR

Zee and Zμμ backgrounds in *sideband* regions, all cuts apply except failing one or two topological cuts

Prospects for Run 2

Include more systematized simplified model searches

Several dedicated studies pointing out strategies using s-channel and t-channel vector or scalar mediators

(See eg. Abdallah et al, arXiv:1409.2893 (2014))

Many of these models open windows for new non-mono signatures (di- or multi-jets)