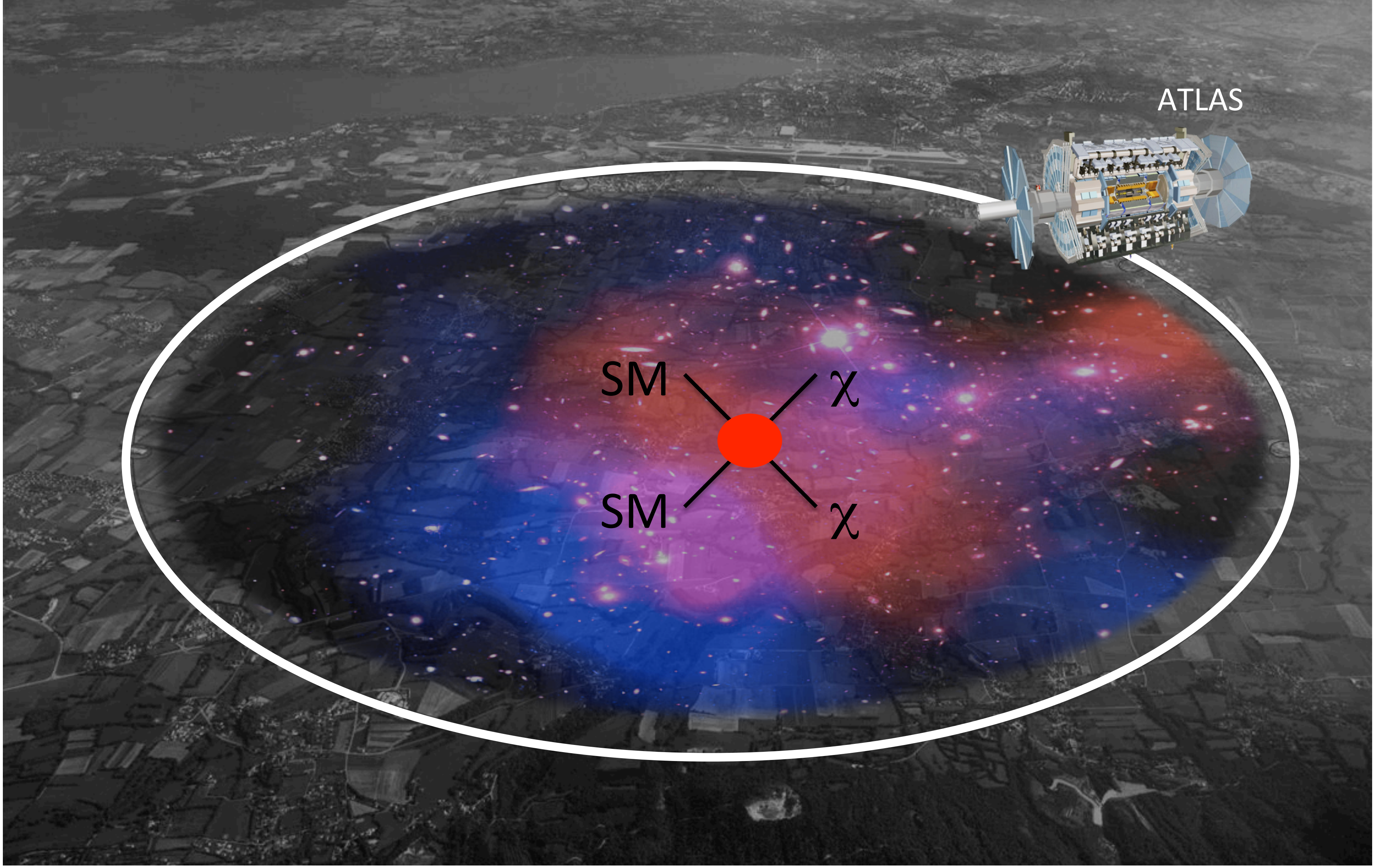
Dark matter searches with ATLAS

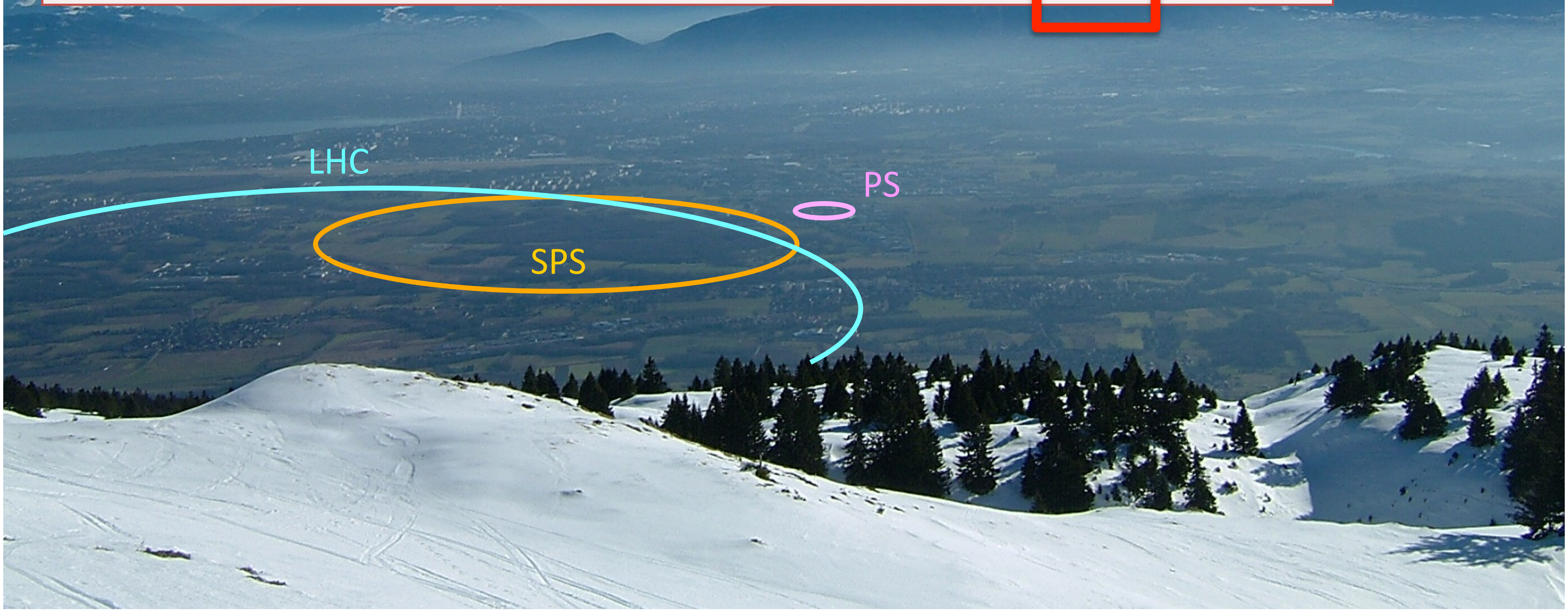
David Berge (GRAPPA & Nikhef, Amsterdam)
For the ATLAS Collaboration



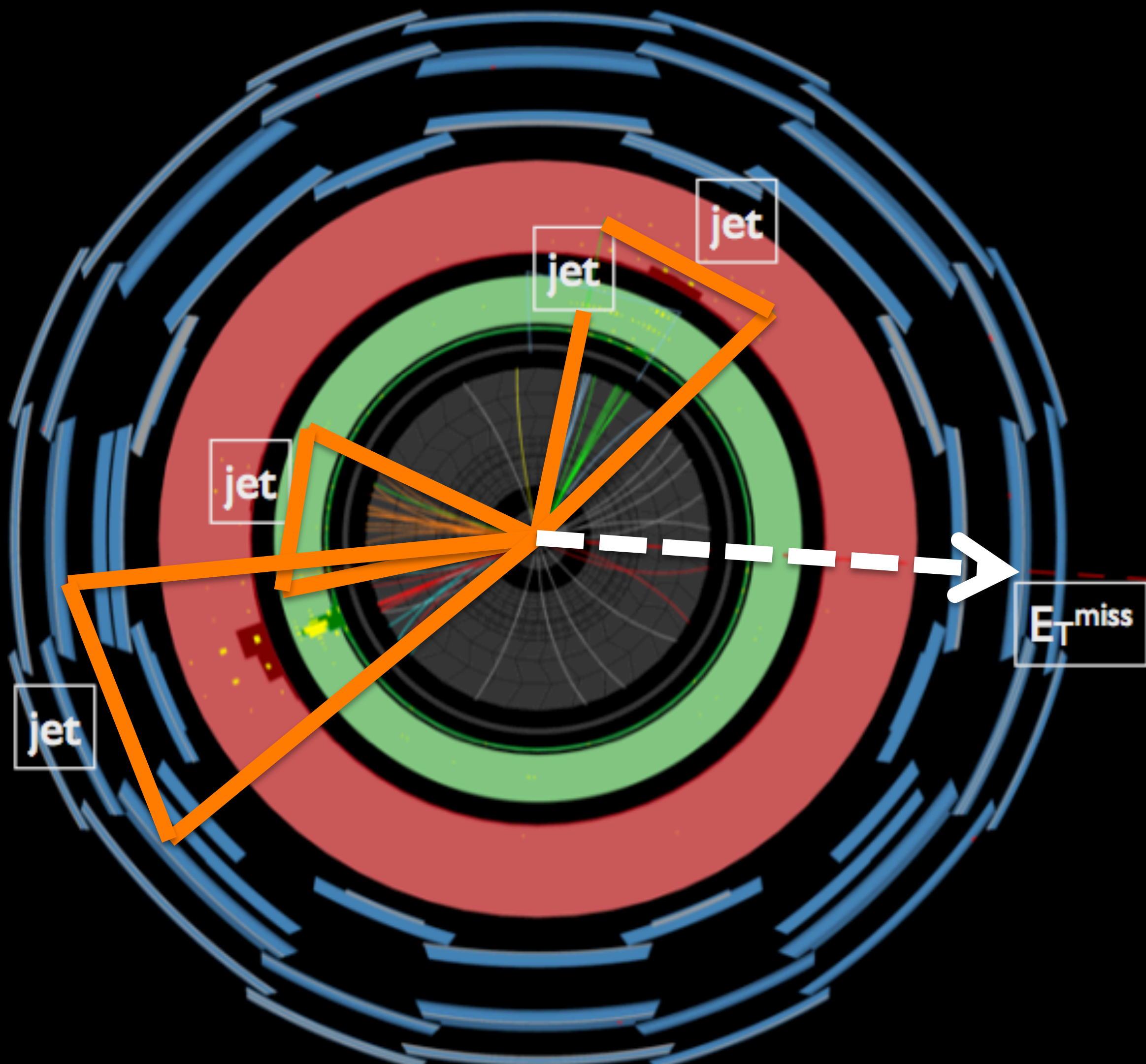
Two general-purpose experiments: ATLAS & CMS

The Large Hadron Collider

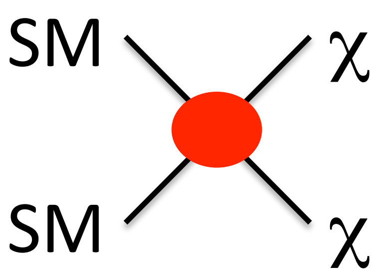
	2012 performance	2015 likely performance
Colliding bunches	1331	2520
Energy	4 TeV x 4 TeV	6.5 TeV x 6.5 TeV
Bunch spacing	50 ns	25 ns
Luminosity	7.7×10^{33} cm^{-2} s^{-1}	1.5×10^{34} cm^{-2} s^{-1}
Pile-up interactions	~35	$\boxed{\text{~40}}$



Task: measure transverse energy

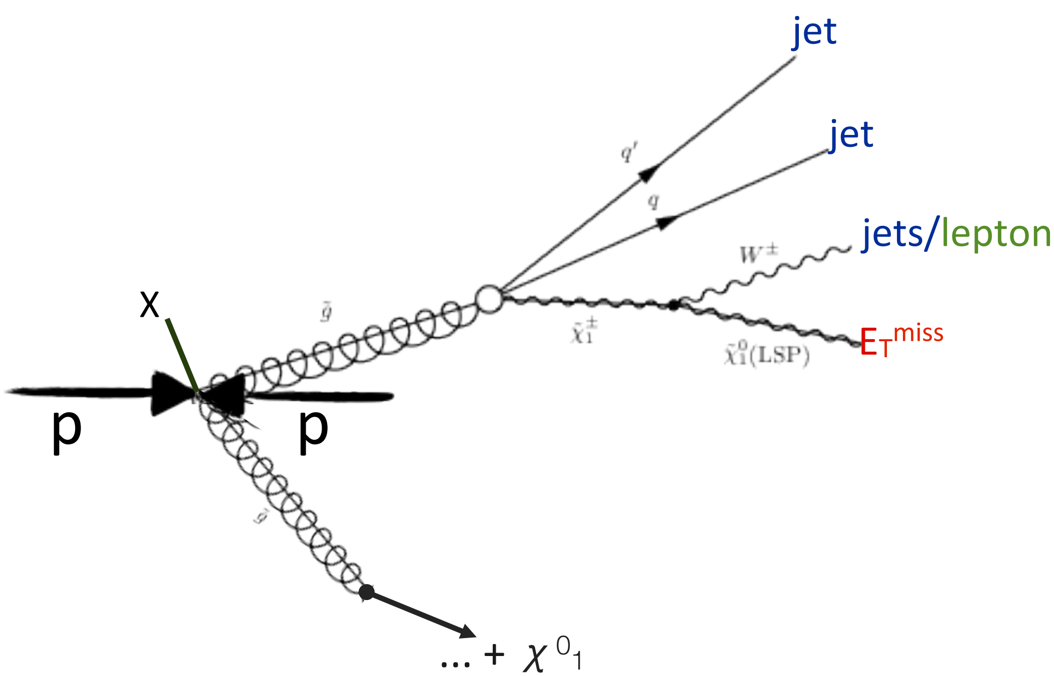


1: “Standard” Dark Matter Searches at Colliders



SUSY:

- High-p_T jets from squark & gluino decays
- Leptons from gaugino & slepton decays
- **Missing transverse energy from LSPs**



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

ATLAS Preliminary

$\int \mathcal{L}\,dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$		Mass limit		Reference
Incl. searches / Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	ATLAS-CONF-2013-047
	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	$\tilde{q}$	740 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	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	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	tanβ >18	ATLAS-CONF-2013-026
	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($\tilde{H}$)>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
Natural SUSY / 3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	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	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	ATLAS-CONF-2013-061
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	20.7	$\tilde{b}_1$	275-430 GeV	m($\tilde{\chi}_1^{\pm}$)=2 m($\tilde{\chi}_1^0$)	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(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	20.7	$\tilde{t}_1$	200-610 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(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	20.7	$\tilde{\chi}_1^{\pm}$	180-330 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	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
LLP + RPV / 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	22.9	$\tilde{g}$	832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	ATLAS-CONF-2013-057
	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	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^{\pm}$	760 GeV	m($\tilde{\chi}_1^0$)>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^{\pm}$	350 GeV	m($\tilde{\chi}_1^0$)>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	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	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Extended MSSM / 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

10^{-1} 1 **Mass scale [TeV]**

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

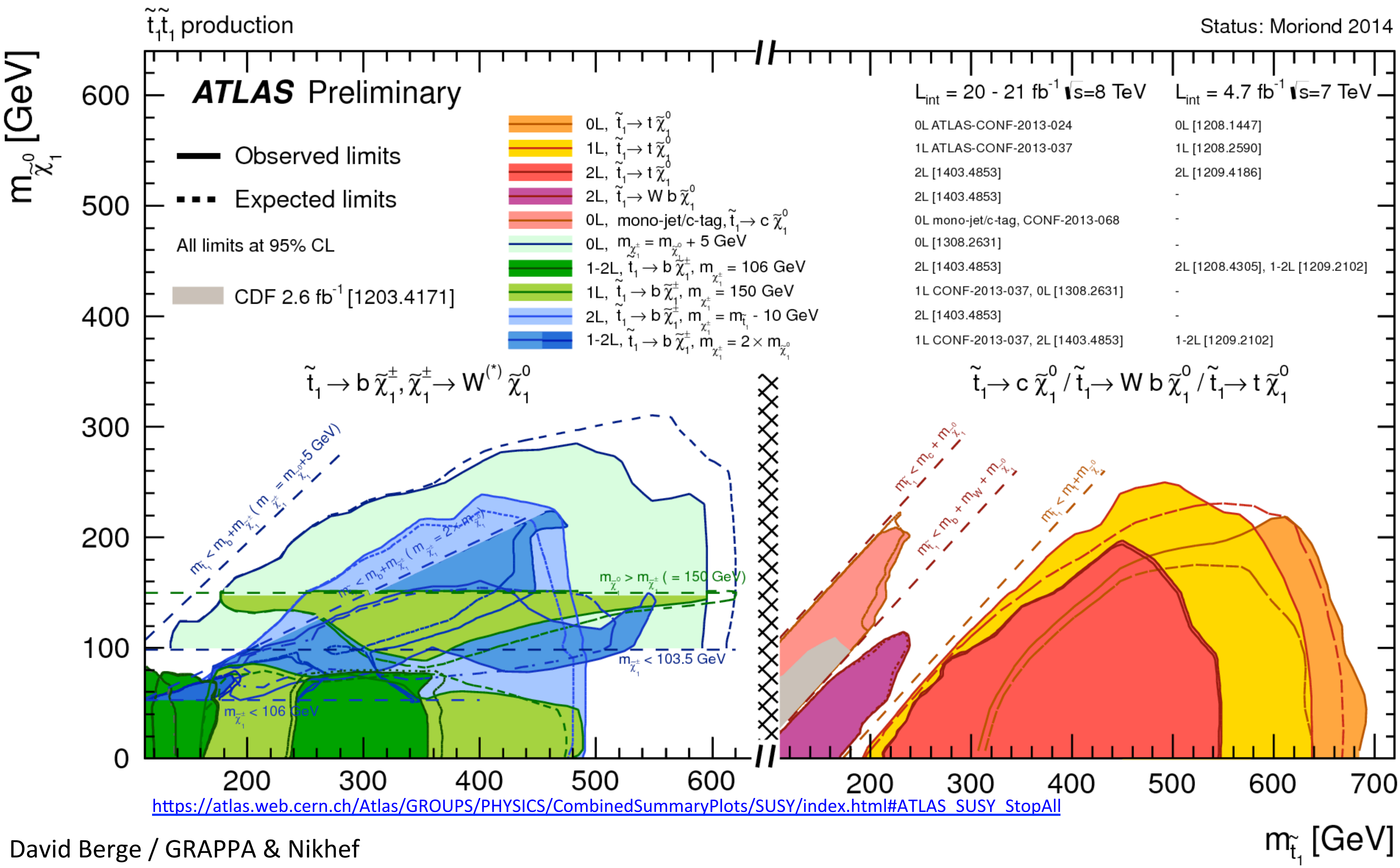
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

David Berge (GRAPPA) / TeVPA 2013

Natural SUSY searches

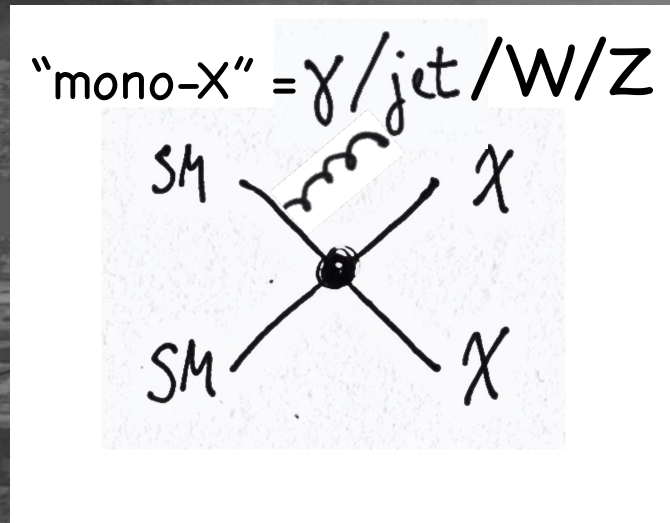
Search for 3rd generation squarks, leptons, b-jets, jets, missing Et

Probe SUSY as solution to the hierarchy problem



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/index.html#ATLAS_SUSY_StopAll

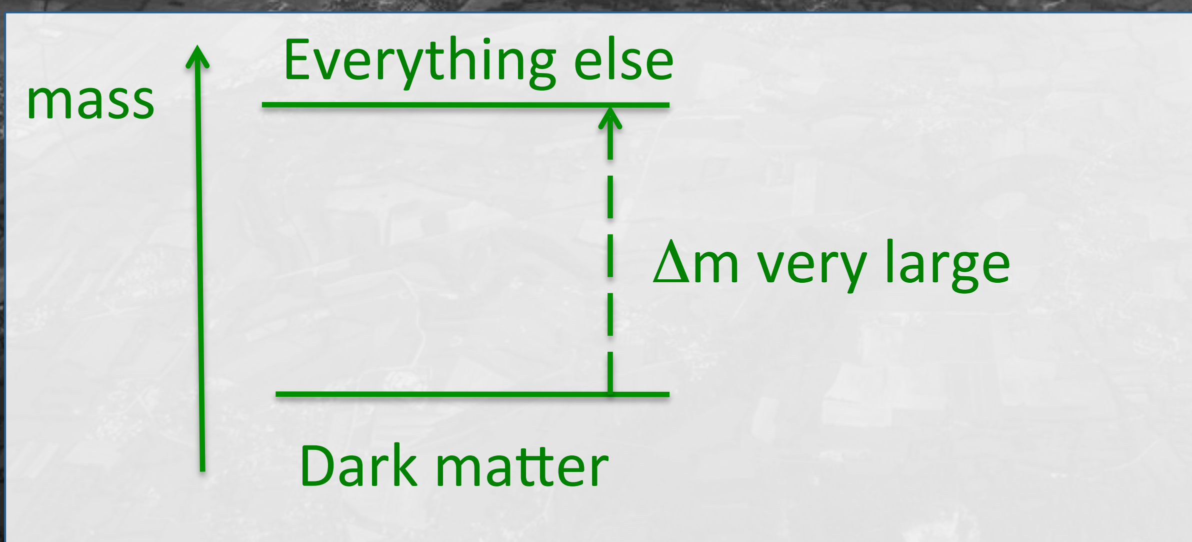
2: Dark Matter Pair Searches at Colliders

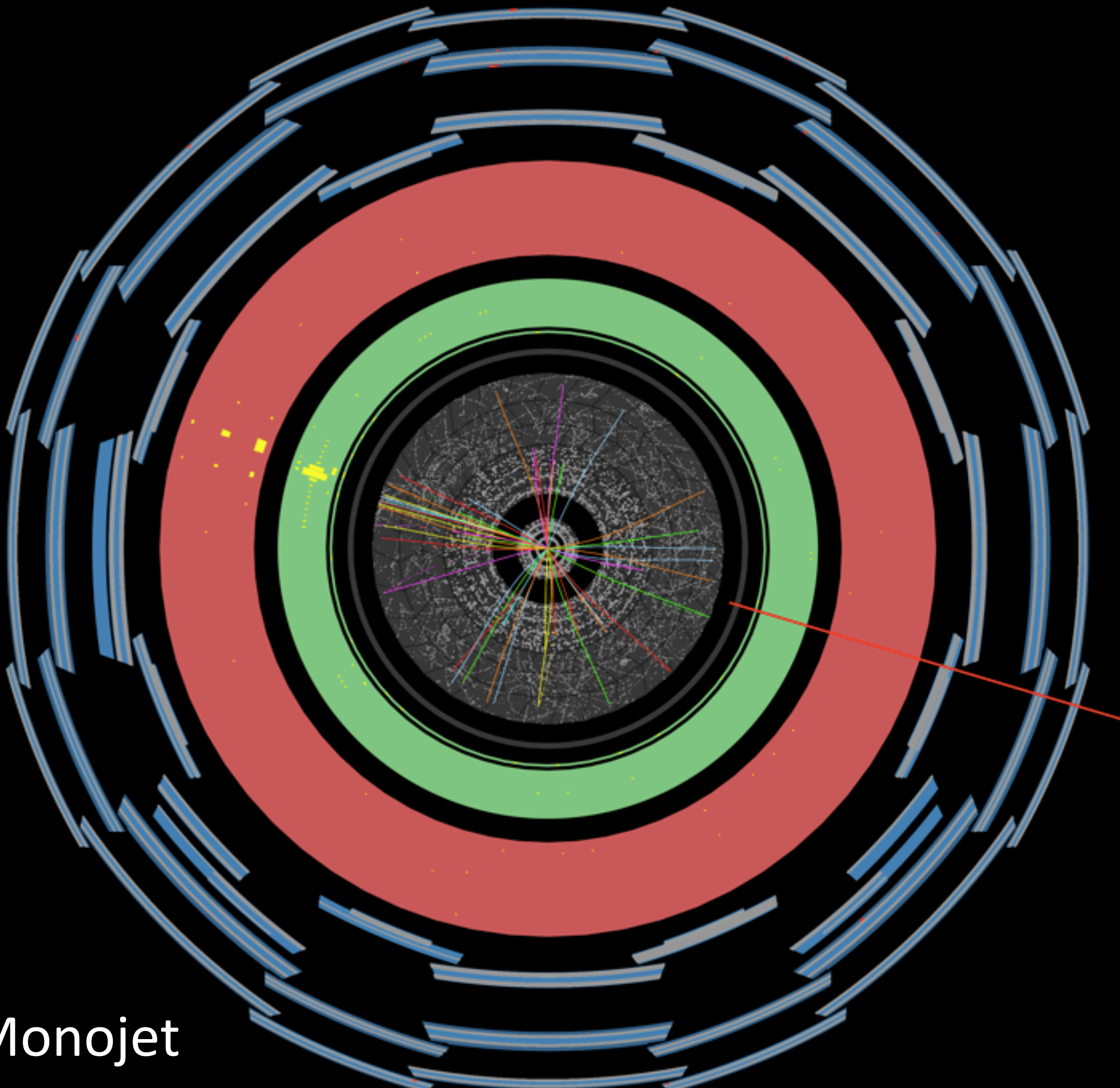


Assume contact interaction with mass suppression scale M*.

Dark matter mass m_χ, plus higher-dimensional operators (e.g. D1-D11), fix cross sections.

Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$





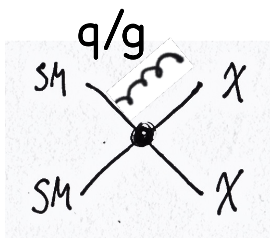
ATLAS Monojet

jet p_T 551 GeV

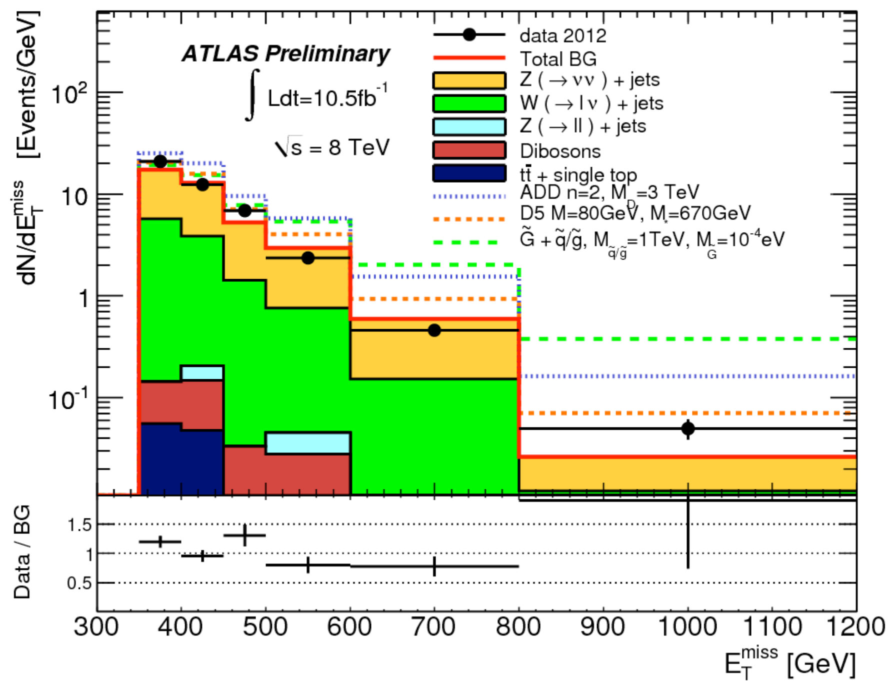
missing E_T 542 GeV

ATLAS Mono-X Suite

Monojets

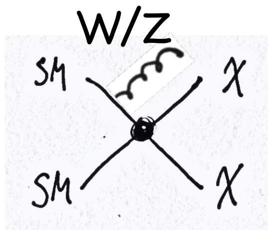


- 8 TeV, 10.5 fb^{-1}, ATLAS-CONF-2012-147
- 7 TeV, 5 fb^{-1}, JHEP 04 (2013) 075
- Central leading jet, balanced by missing E_T
- Veto on leptons
- Main background Z→ νν, estimated with W/Z → lepton control region

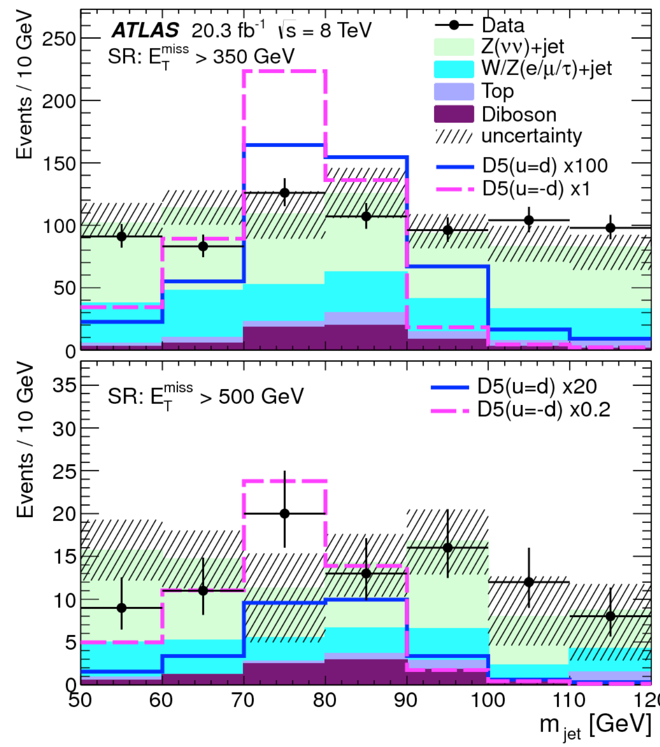


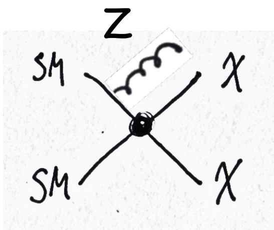
ATLAS Mono-X Suite

Mono-W/Z→qq



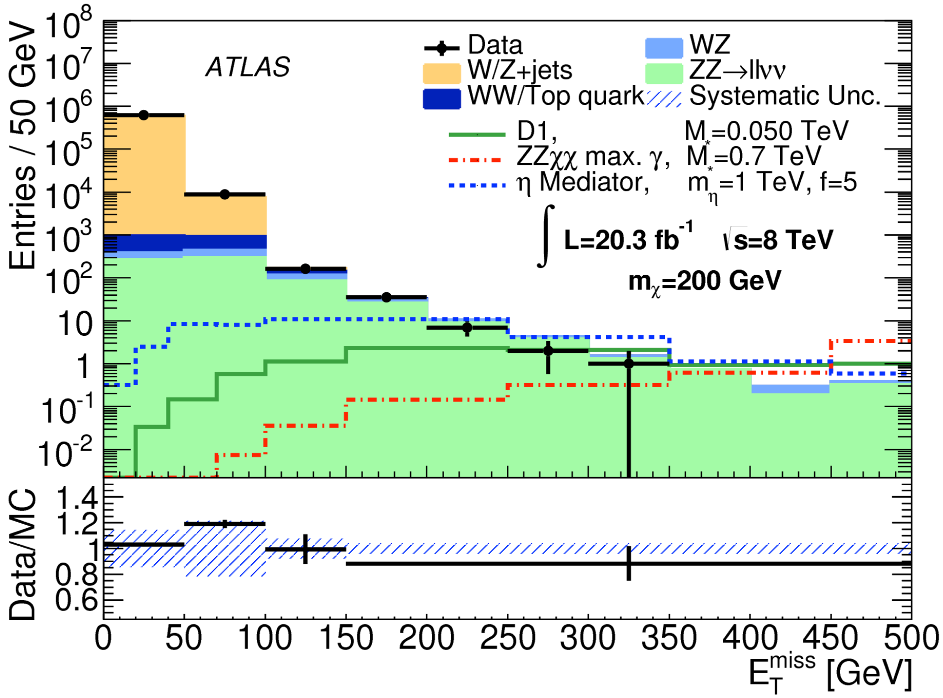
- 8 TeV, 20 fb^{-1}, PRL 112, 041802 (2014)
- Central massive fat jet, 50 GeV < m_{jet} < 120 GeV, validated in top control region, balanced by missing E_T
- Veto on leptons and photons
- Main background Z→ νν & W→ lν, estimated with W/Z → μ control region



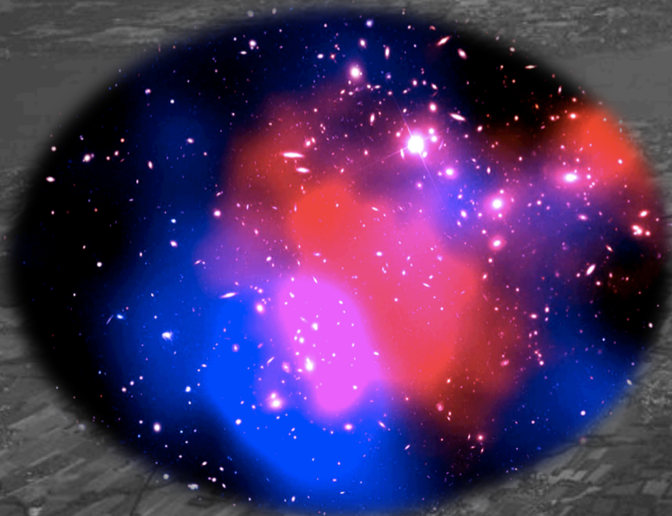


<u>Mono-Z→ll</u>

- 8 TeV, 20 fb^{-1}, PRD (submitted), arXiv:1404.0051
- Two leptons, Z invariant mass cut, balanced by missing ET
- Veto on >2 leptons and jets
- Main background SM ZZ/WZ (from NLO MC)



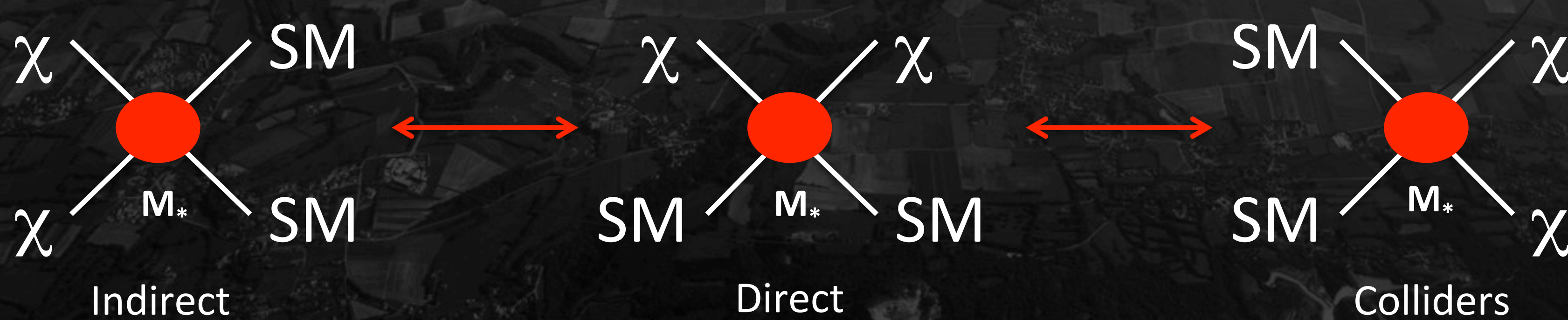
Dark matter contact interactions



Galaxy cluster Abell 2744

M* and m_χ fix dark-matter nucleon scattering and annihilation cross sections (for given interaction type)!

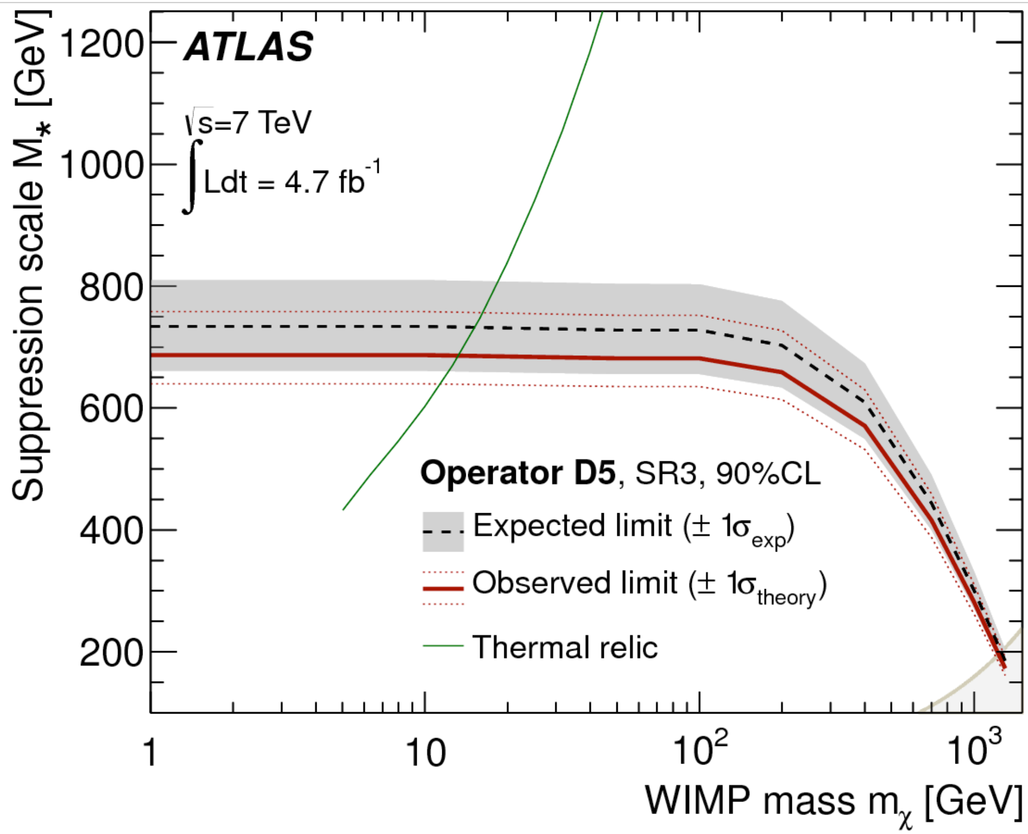
Particle Dark Matter Searches based on:



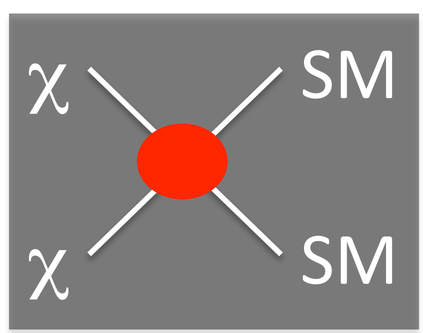
Monojets 7 TeV

Suppression scale M_* **lower** limits

arXiv:1210.4491

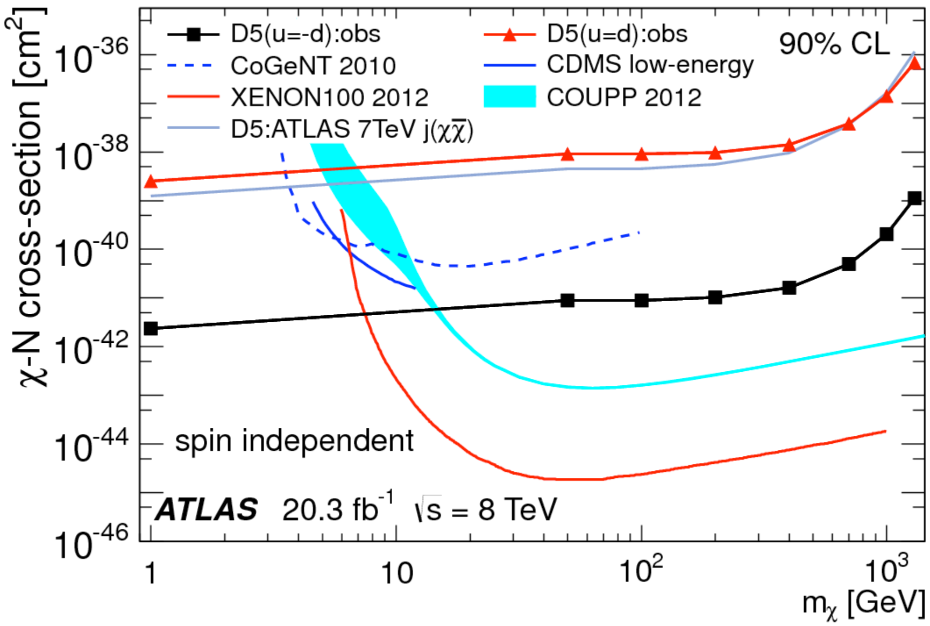


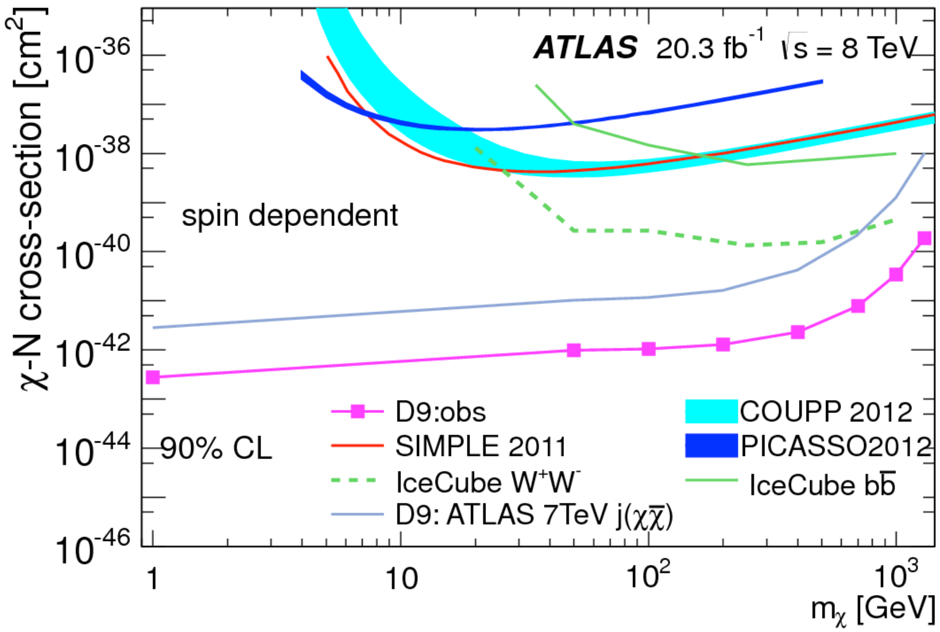
- M_* fixes coupling SM-χ
- Coupling fixes annihilation cross section χ to SM
- Relic density (WMAP) corresponds to cross section
- Probe thermal relic dark matter particle at LHC!
- Red above green line: conflict!
  - Exclusion for this operator, or
  - Additional annihilation channels (leptons!), or
  - Wrong assumptions



Mono-W/Z→qq vs Monojets

arXiv:1309.4017

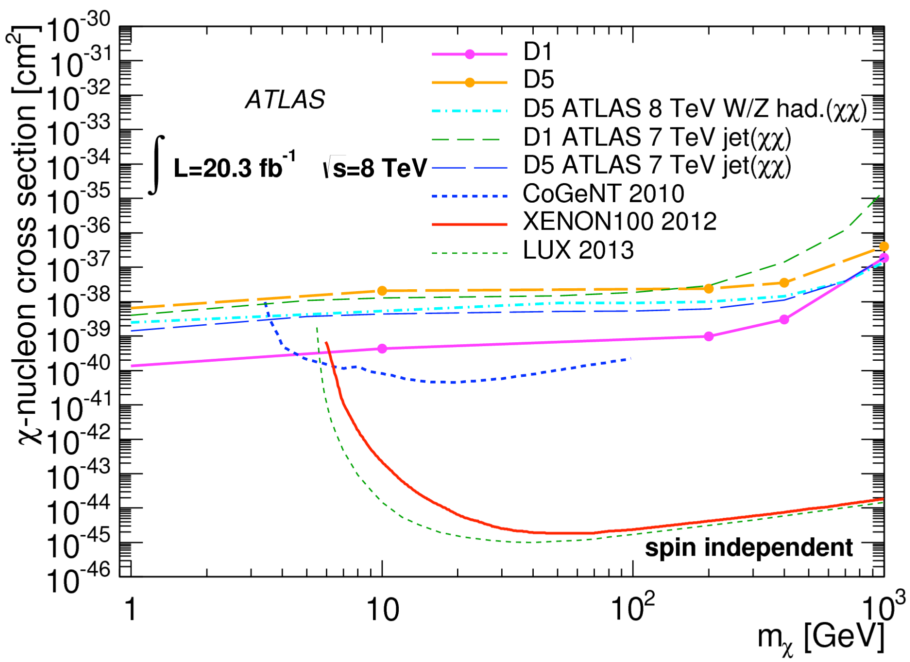


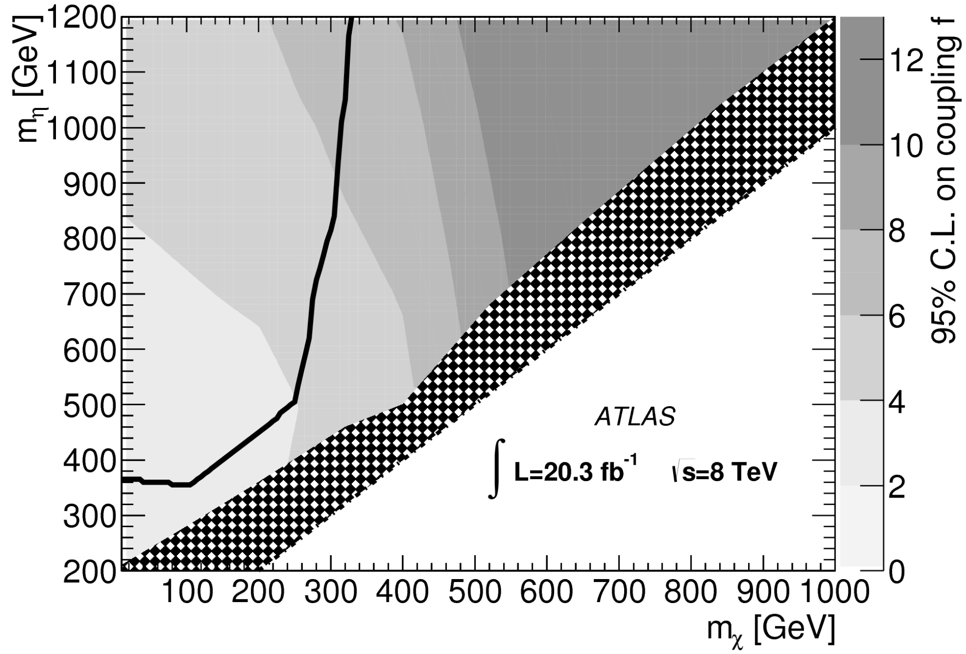


Constructive interference with potentially large effect!

Mono-Z→ll – EFT validity?

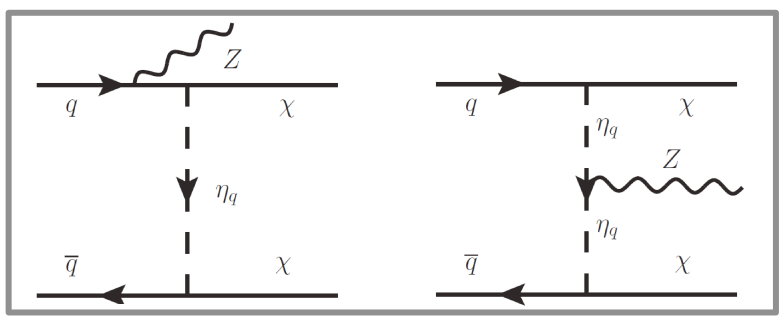
arXiv:1404.0051



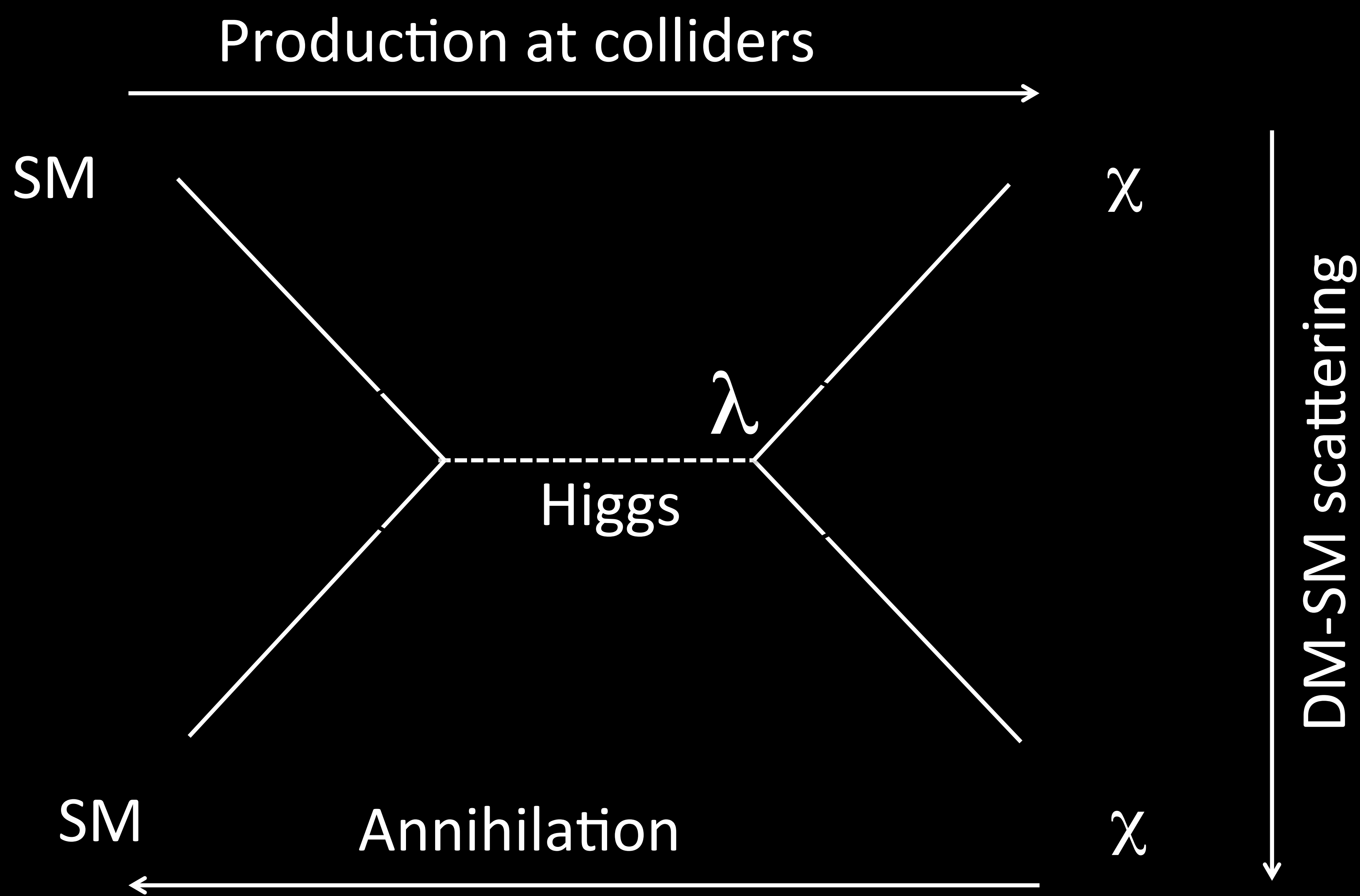


Effective Field Theory / assumptions of contact interactions not always valid (cf. C.McCabe's talk) → start to explore simplified models!

Limits on χ-η coupling constant f shown. Above black line, lower limit on f below f from relic abundance calculations.

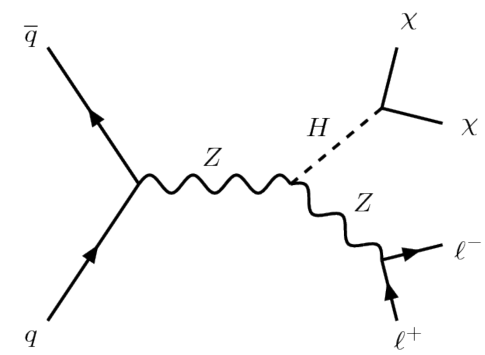


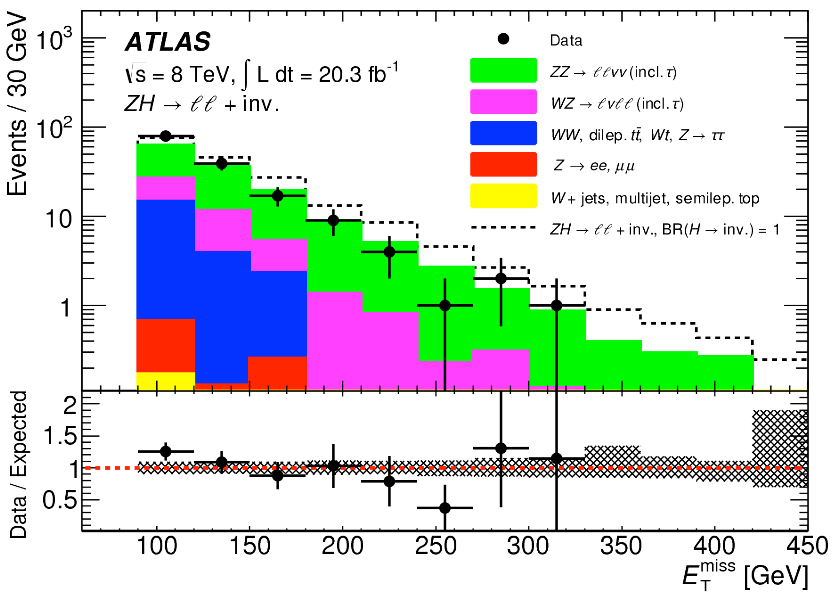
Higgs portal to dark sector

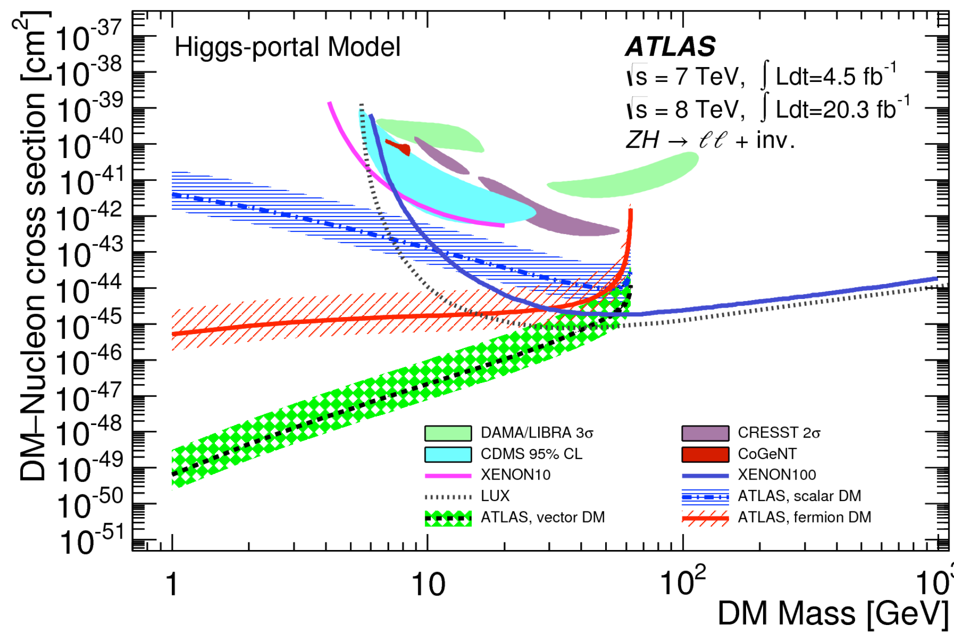


Higgs portal to dark sector

Direct search for invisible Higgs decays
PRL (submitted), arXiv:1402.3244
Constrain invisible Higgs width to
<75% of the full SM width







'Light' mediator, simplest connection of SM and dark sector.

Higgs portal to dark sector

A. Djouadi *et al.*, Phys. Lett. B 709, 65 (2012), arXiv:1112.3299

Direct search for invisible Higgs decays
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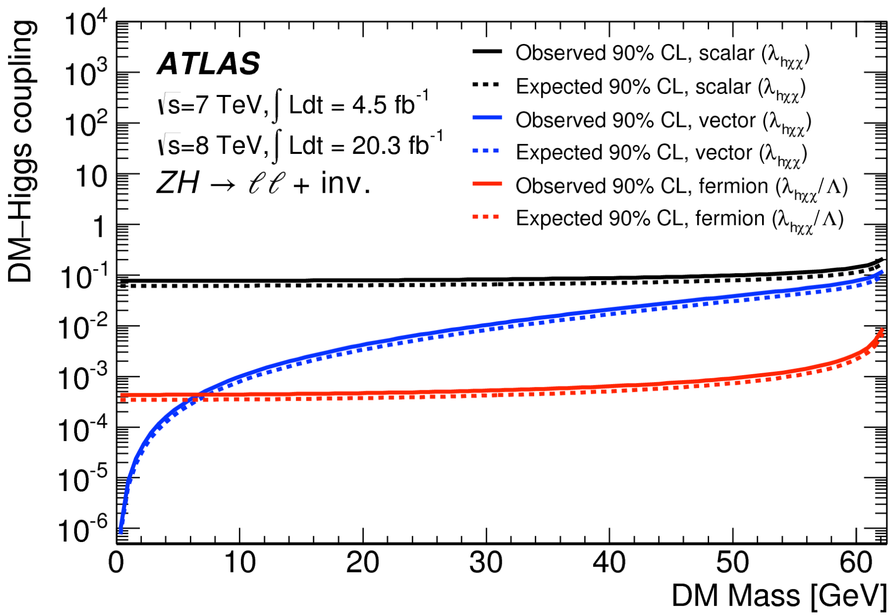

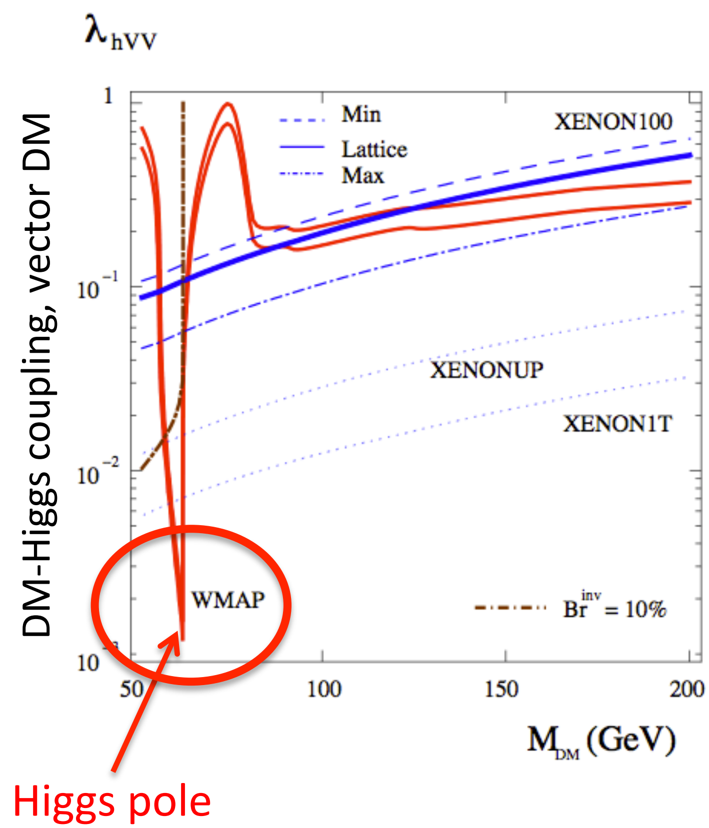

This, together with the relic density, basically rules out the simplest Higgs portals for DM up to half the Higgs mass, except right at the Higgs pole!

Conclusions

- The one model independent result we have about dark matter:

Conclusions

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We have not discovered a dark matter candidate particle yet at the LHC!

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- The one model independent result we have about dark matter:

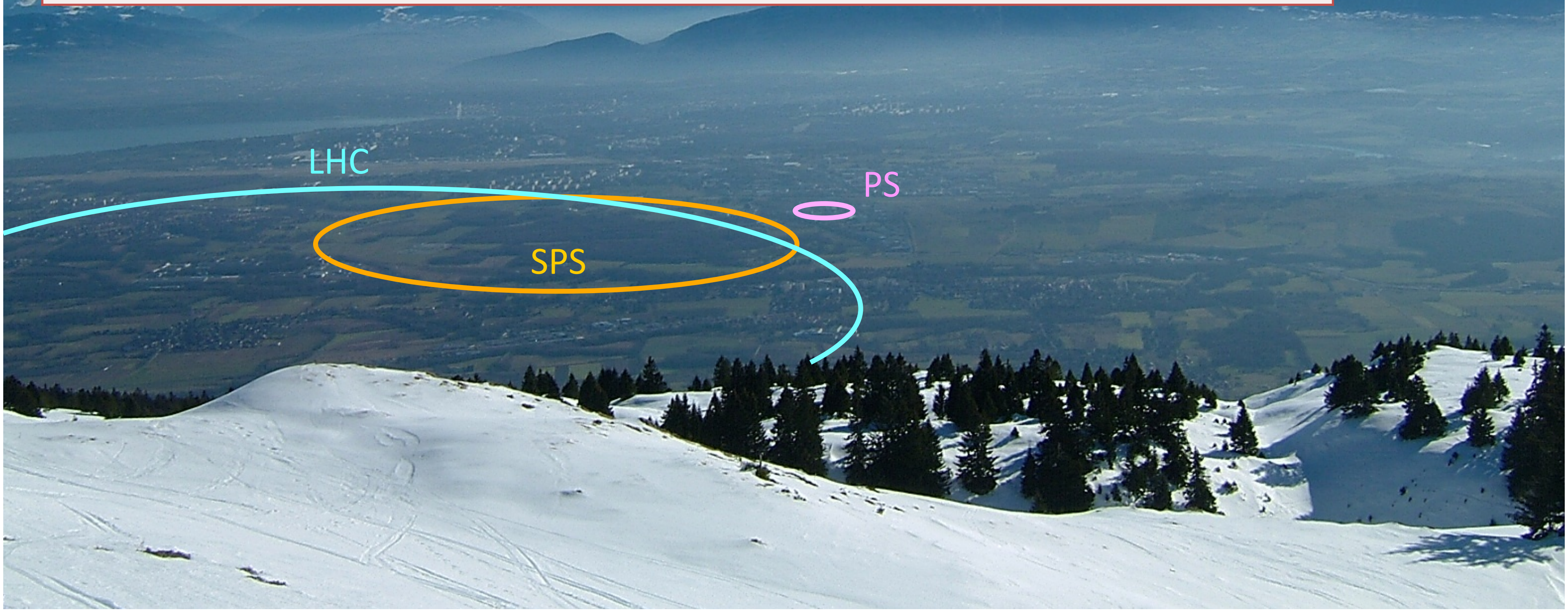
We have not discovered a dark matter candidate particle yet at the LHC!

- Intense search program optimised for dark matter (mono-X) or SUSY (R parity!)
- LHC Run-2 will hopefully tell us more at 13 or 14 TeV

- ATLAS public results:
  - Journal publications: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications
  - Conference notes with preliminary results, internally reviewed: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CONFnotes

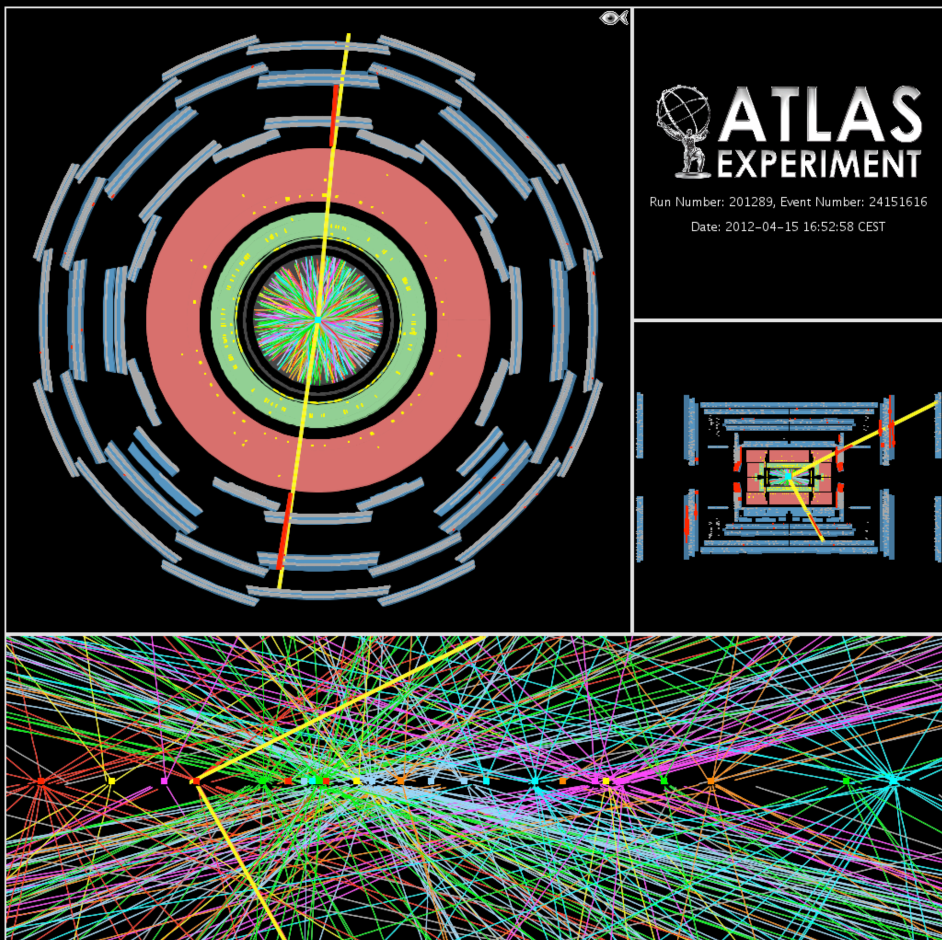
The Large Hadron Collider

	2012 performance	Design performance
Colliding bunches	1331	2808
Energy	4 TeV x 4 TeV	7 TeV x 7 TeV
Bunch spacing	50 ns	25 ns
Luminosity	7.7 x 10^{33} cm^{-2} s^{-1}	10^{34} cm^{-2} s^{-1}
Pile-up interactions	~35	~25

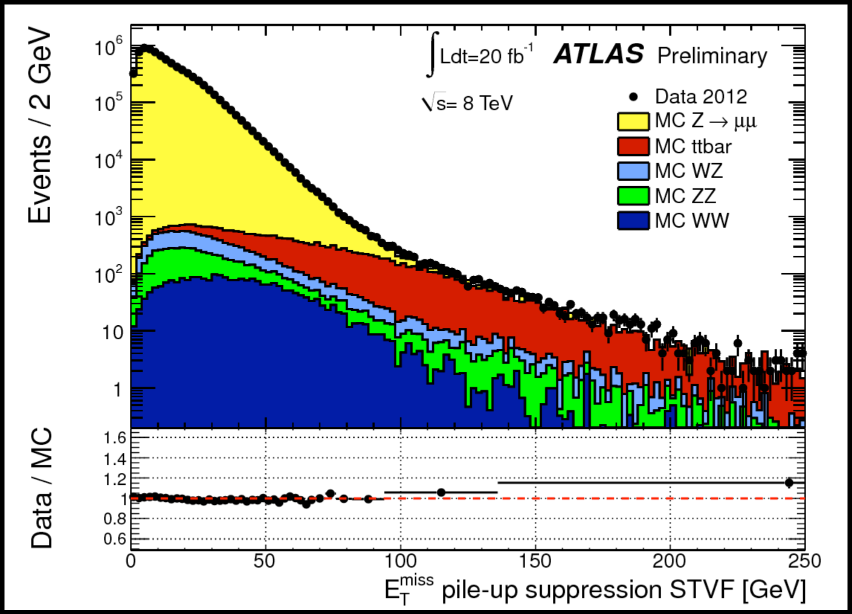


Difficulty: event pile-up

ATLAS-CONF-2013-082

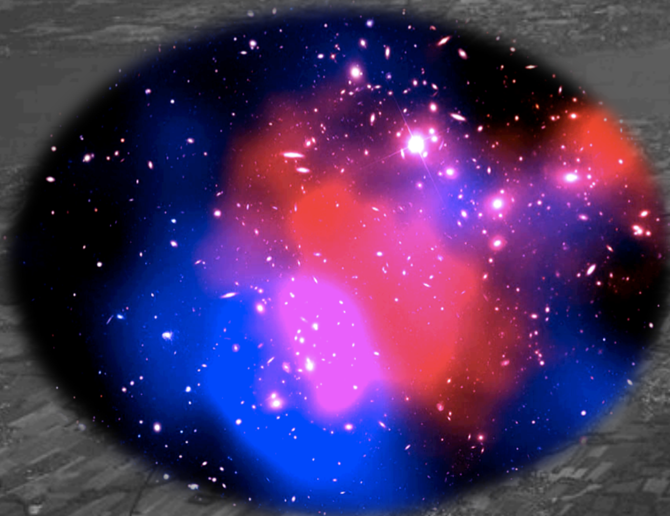


$Z \rightarrow \mu\mu$ event in ATLAS with 25 reconstructed vertices



With pile-up suppression algorithms

Going after the Dark at the LHC



Galaxy cluster Abell 2744

Data combinations and interpretations require assumptions about the red bubble!

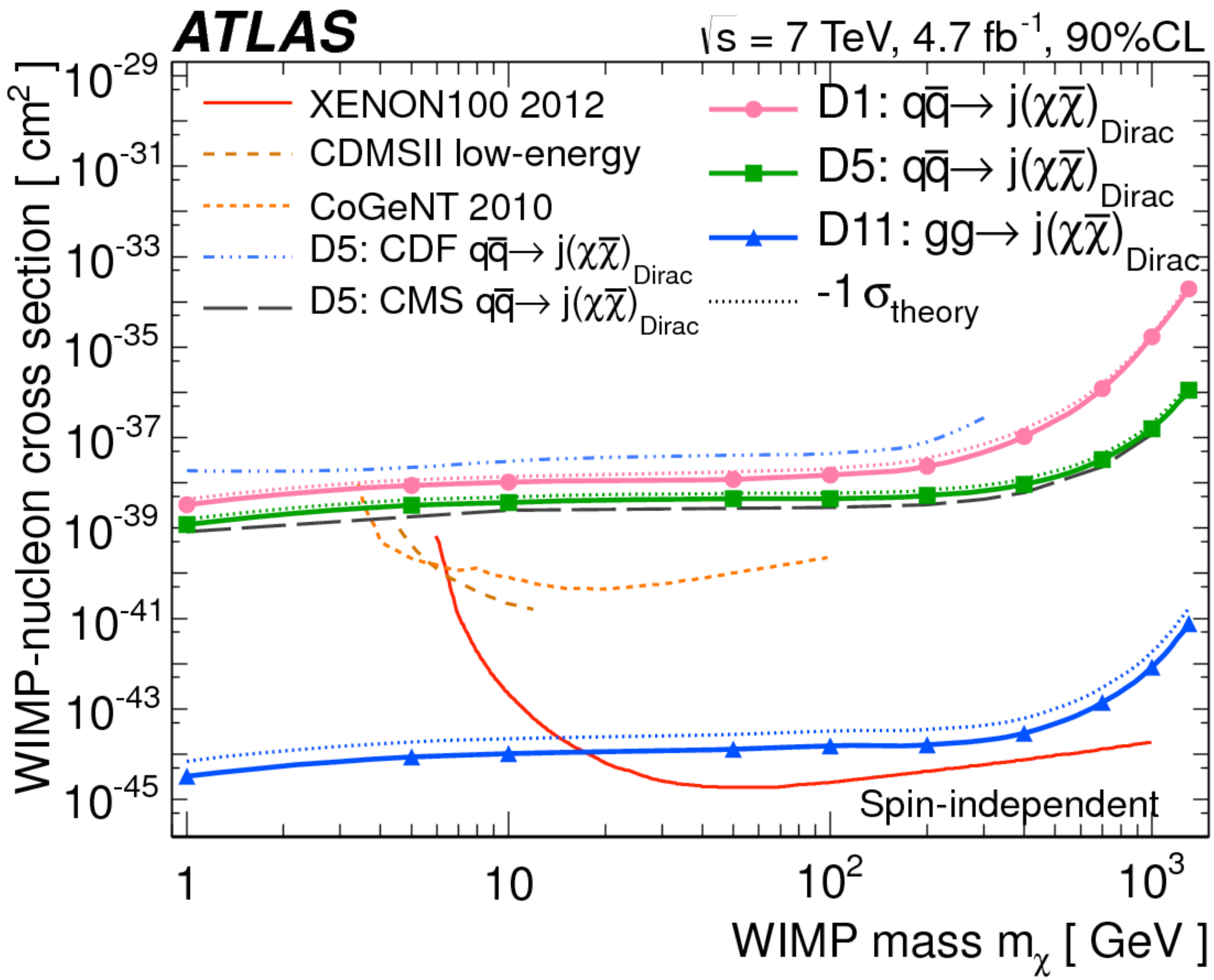
Particle Dark Matter Searches based on:

Indirect

Direct

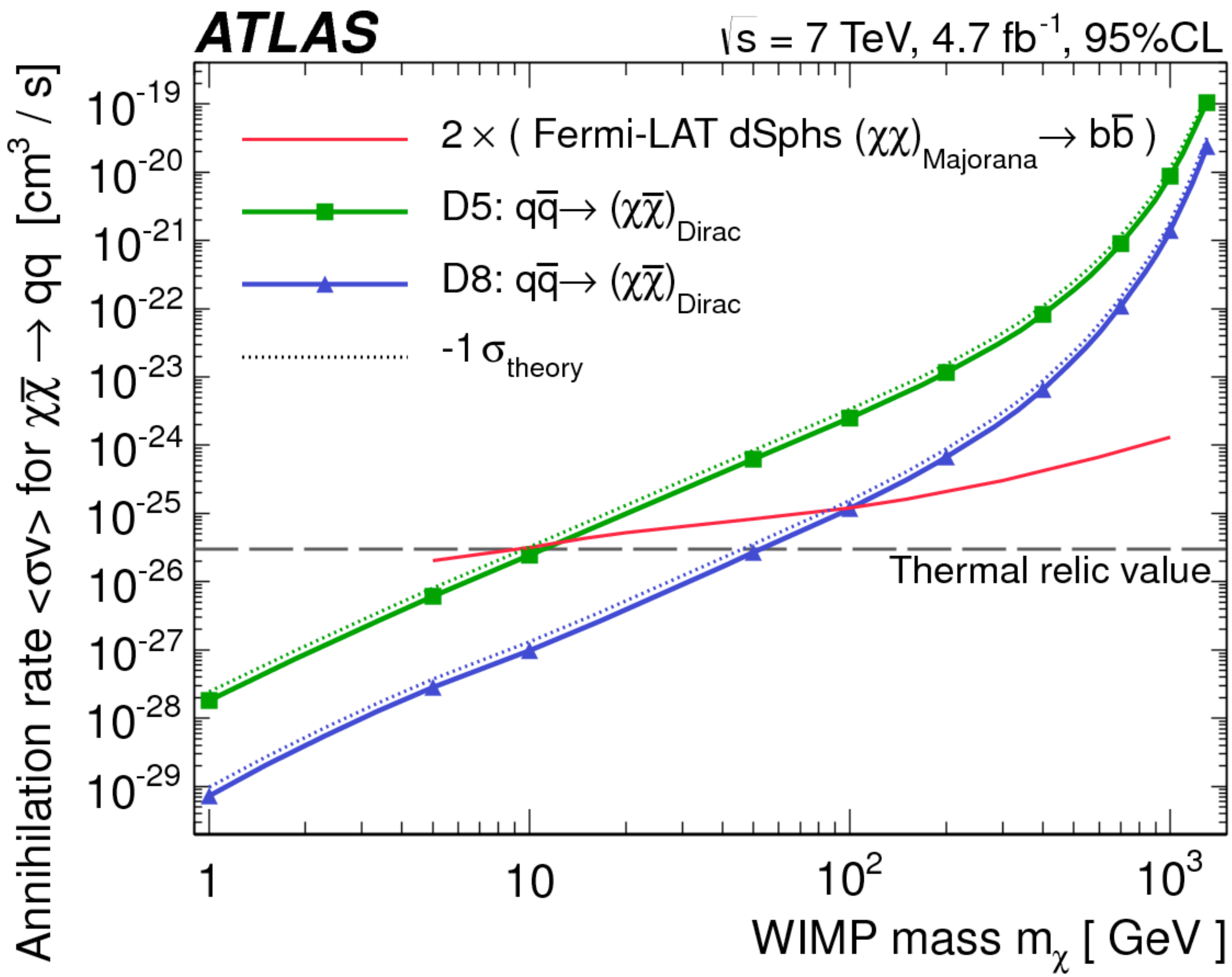
Colliders

Monojets 7 TeV



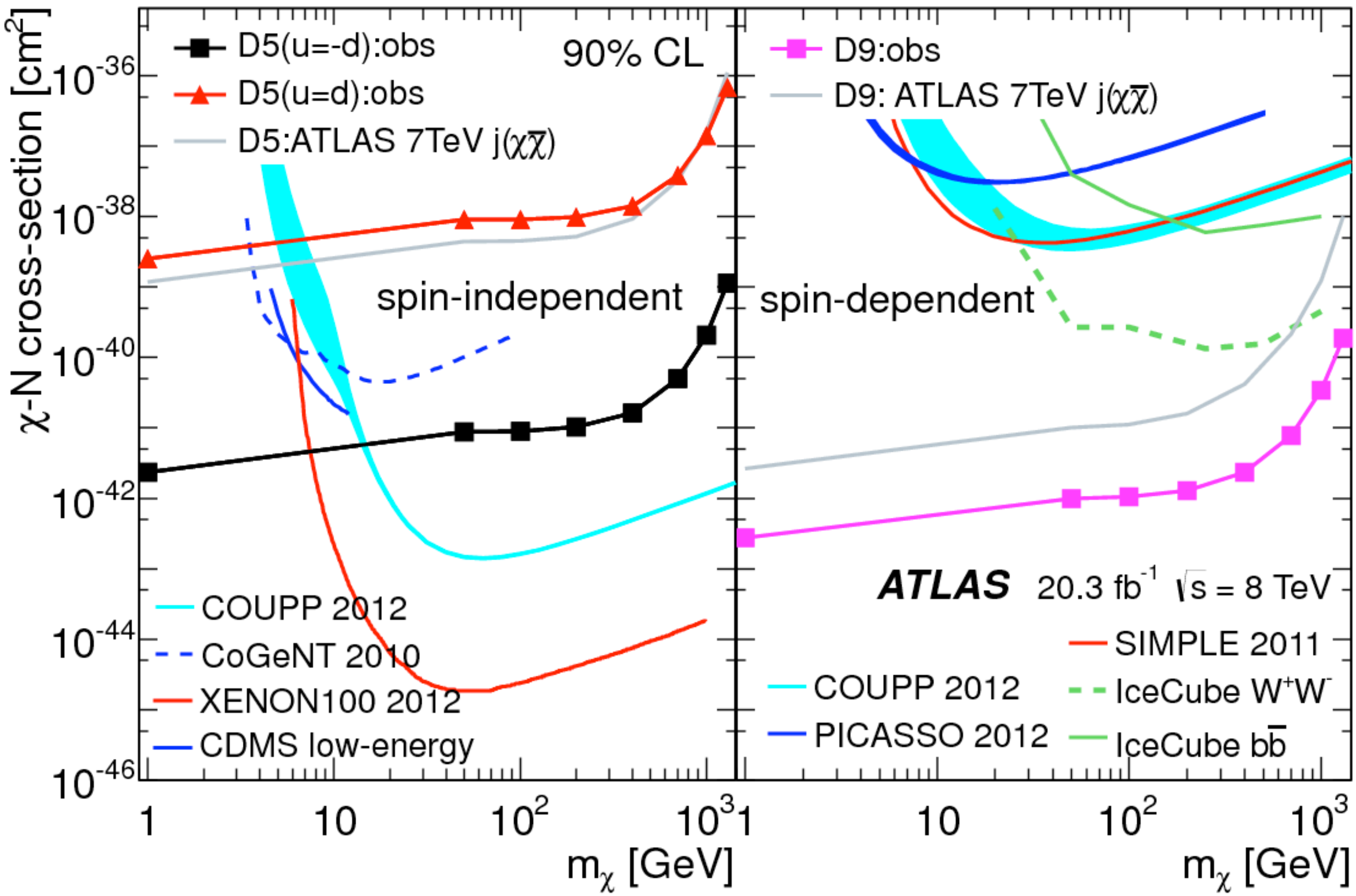
[arXiv:1210.4491](https://arxiv.org/abs/1210.4491)

Monojets 7 TeV



arXiv:1210.4491

Mono-W/Z→qq

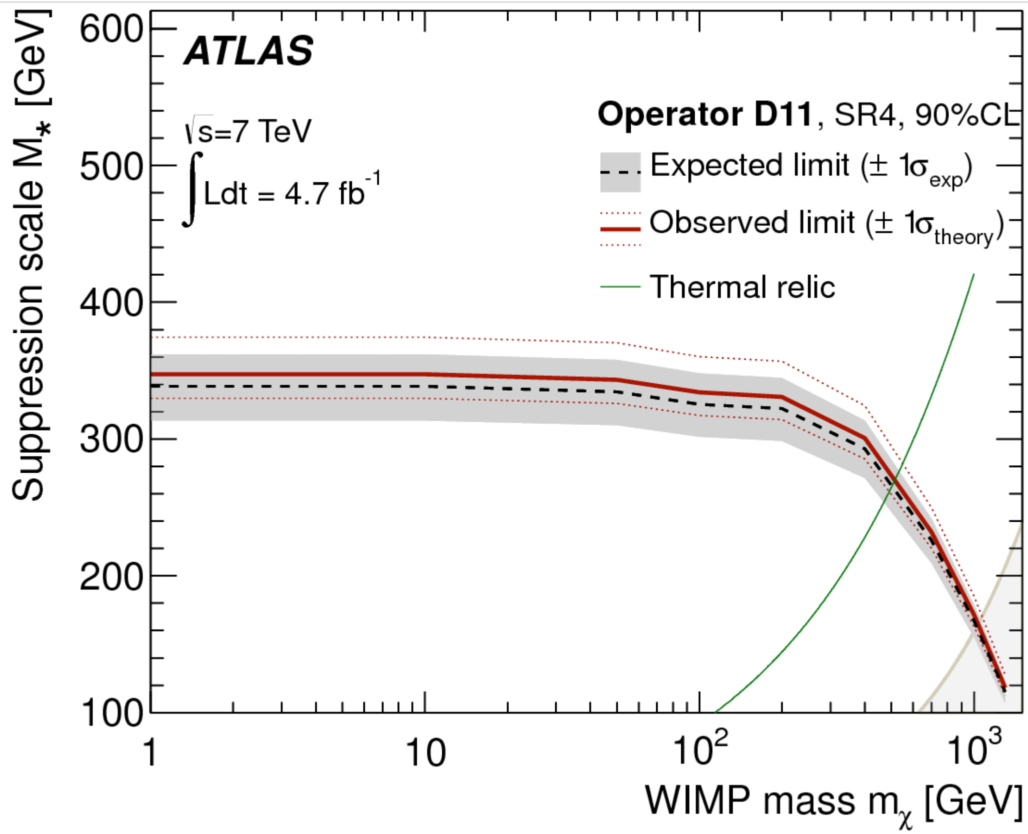


D5(u=-d):obs
D5(u=d):obs
D5:ATLAS 7TeV j(χχ̄)
90% CL
spin-independent
COUPP 2012
CoGeNT 2010
XENON100 2012
CDMS low-energy
χ-N cross-section [cm²]
m_χ [GeV]
D9:obs
D9: ATLAS 7TeV j(χχ̄)
spin-dependent
ATLAS 20.3 fb⁻¹ √s = 8 TeV
SIMPLE 2011
IceCube W⁺W⁻
IceCube bb̄
COUPP 2012
PICASSO 2012

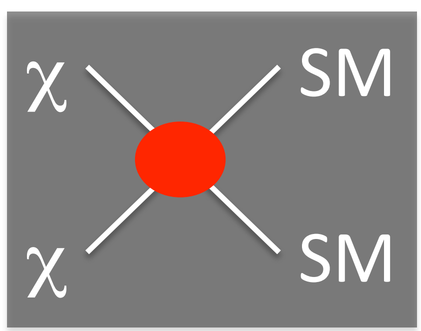
Monojets 7 TeV

Suppression scale M_* **lower** limits

arXiv:1210.4491



- M_* fixes coupling SM-χ
- Coupling fixes annihilation cross section χ to SM
- Relic density (WMAP) corresponds to cross section
- Probe thermal relic dark matter particle at LHC!
- Red above green line: conflict!
  - Exclusion for this operator, or
  - Negative interference needed, or
  - Additional annihilation (leptons!)

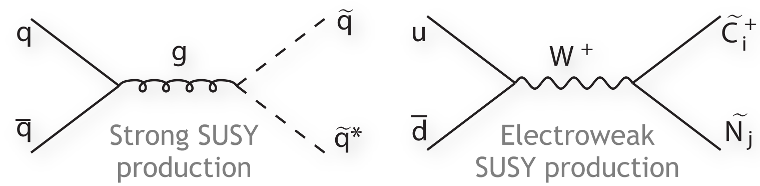


Reminder:

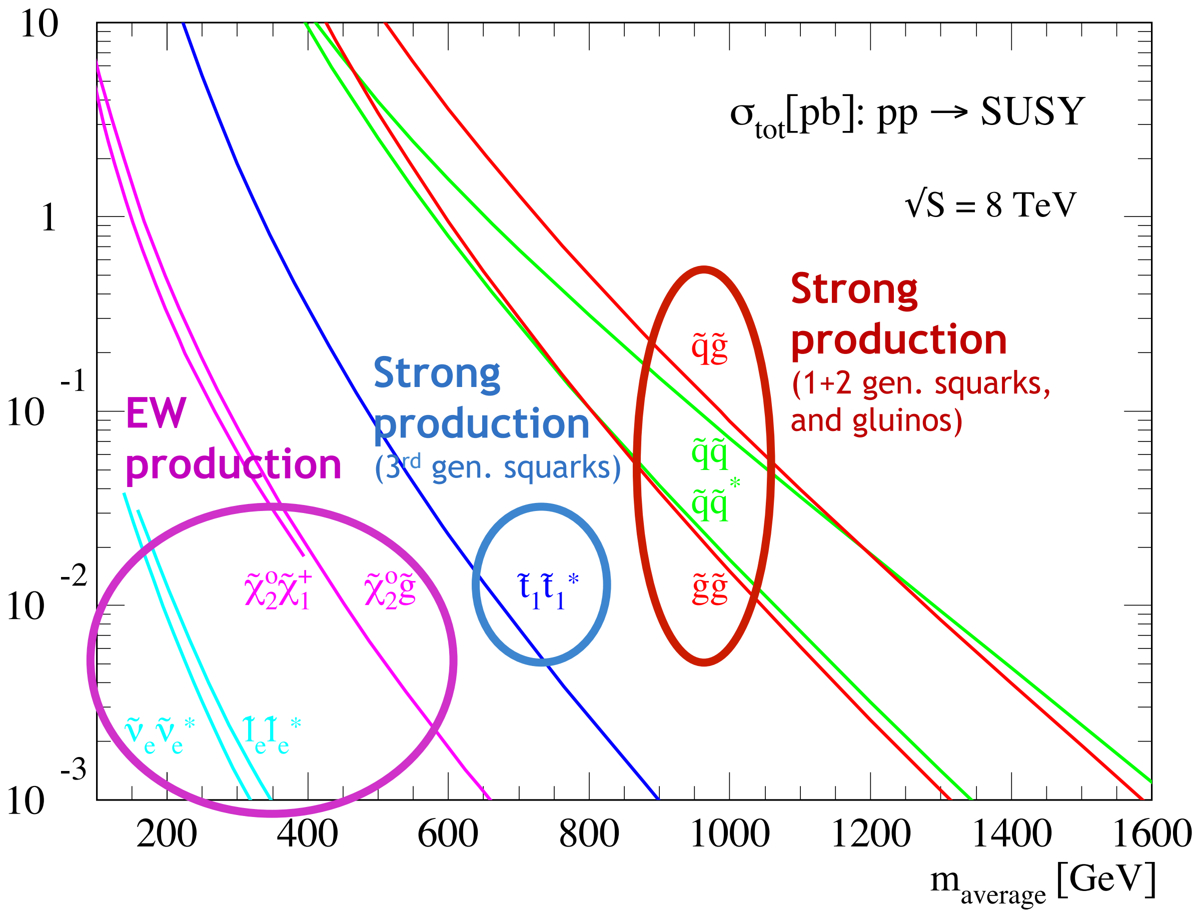
Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

Where do we start?

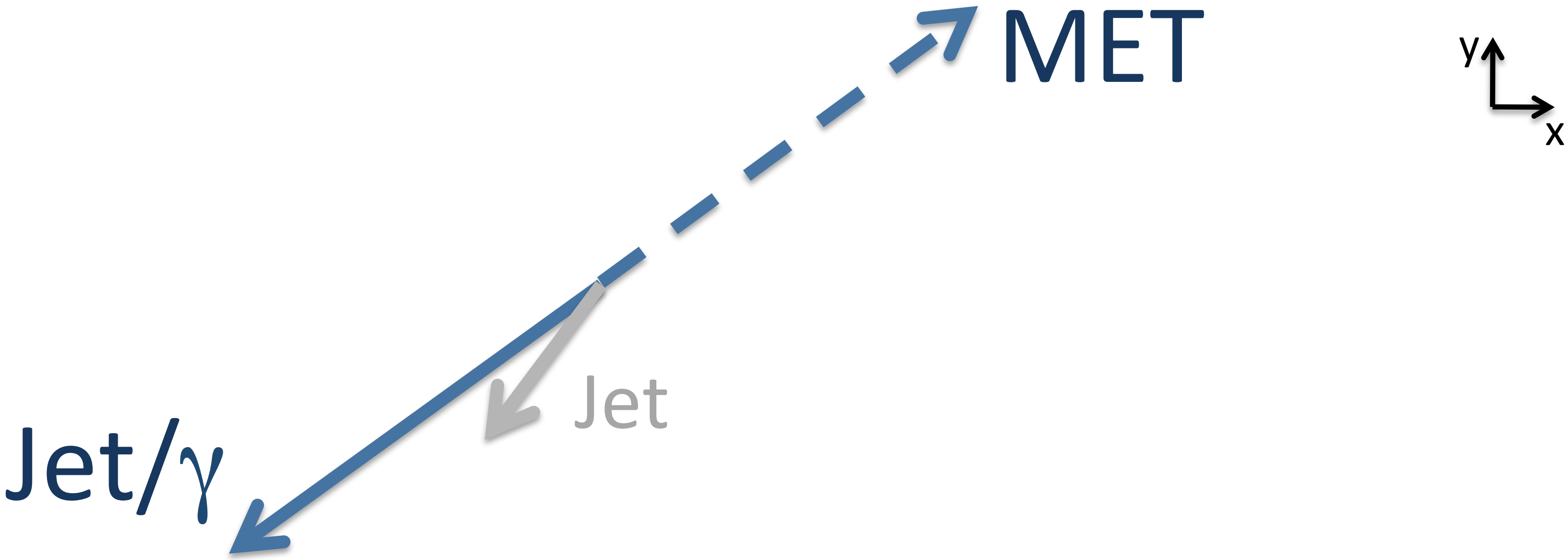
Huge parameter space, but guiding principles



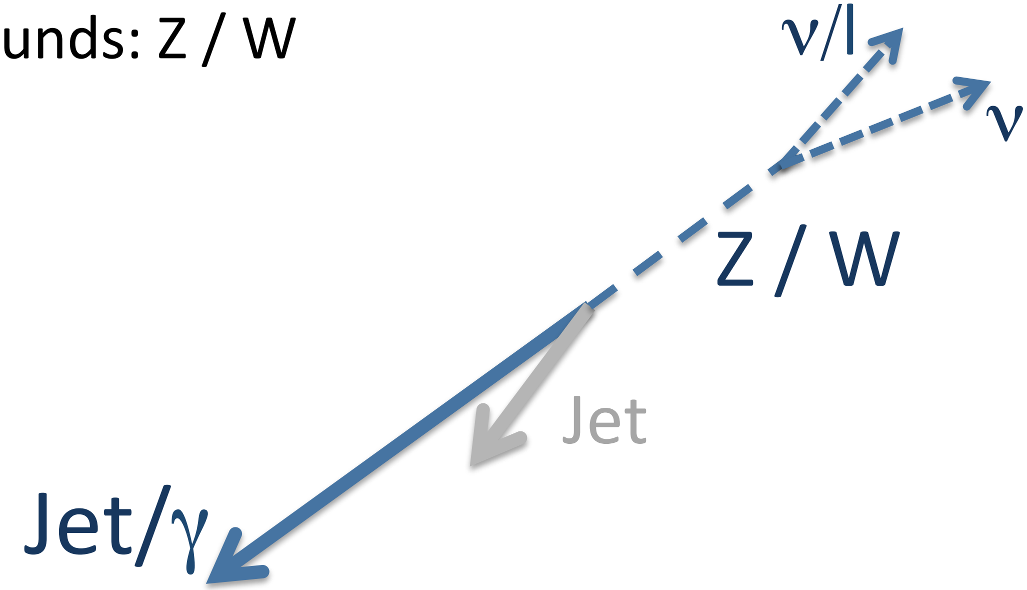
SUSY searches strategy driven by cross section and luminosity



Signal

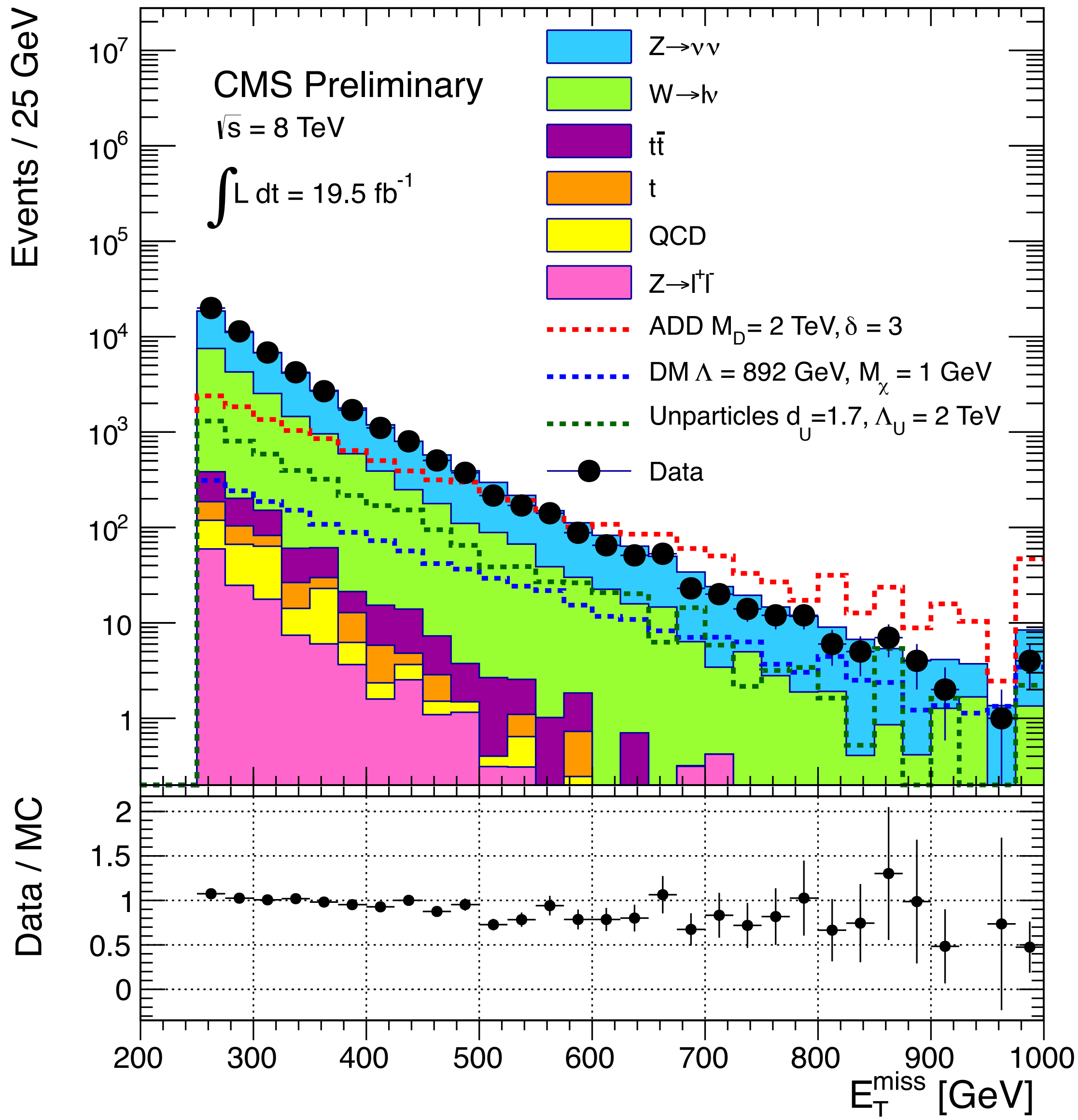


Backgrounds: Z / W



Nada! Set limits…

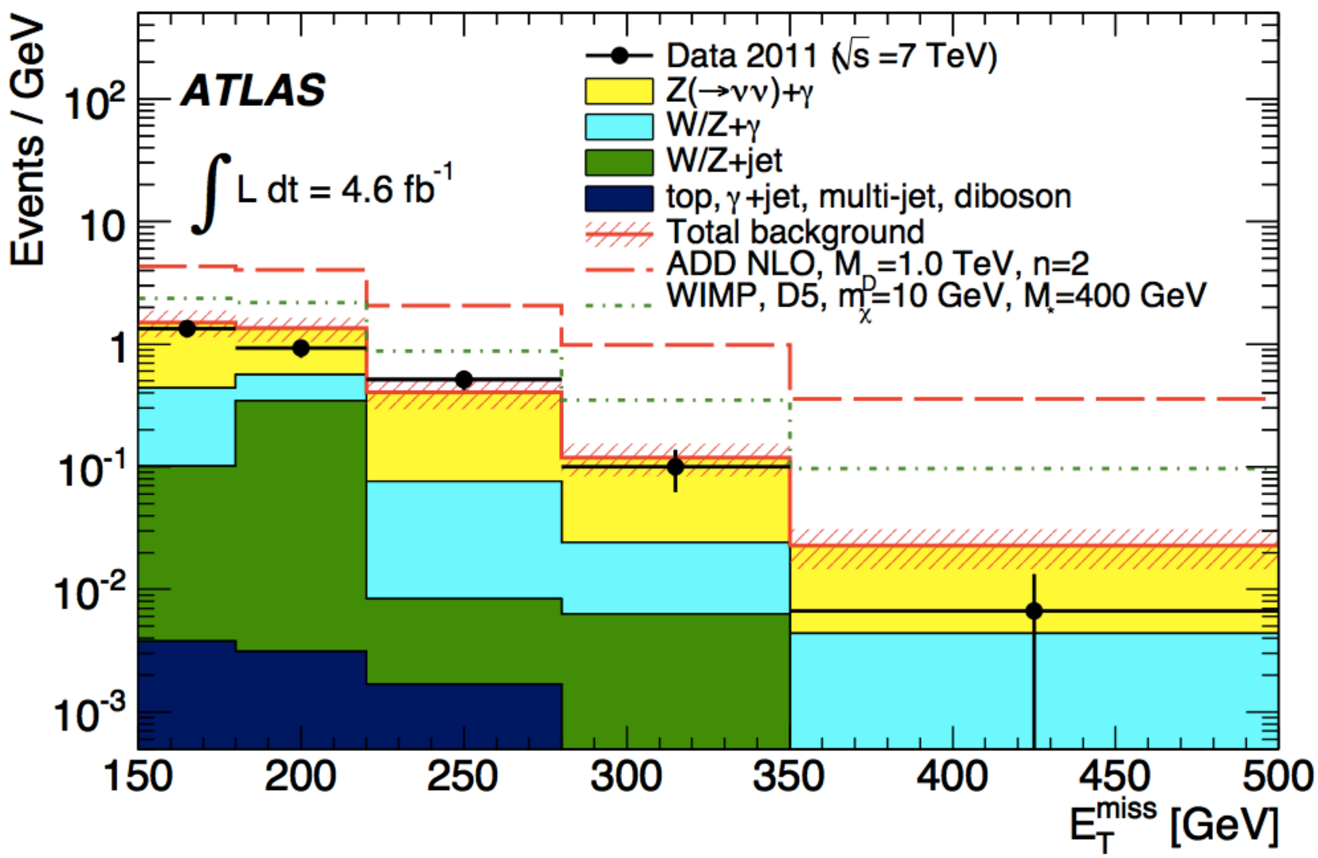
CMS EXO-12-048



CMS mono-jet, 20 fb^{-1} at 8 TeV

Nada! Set limits…

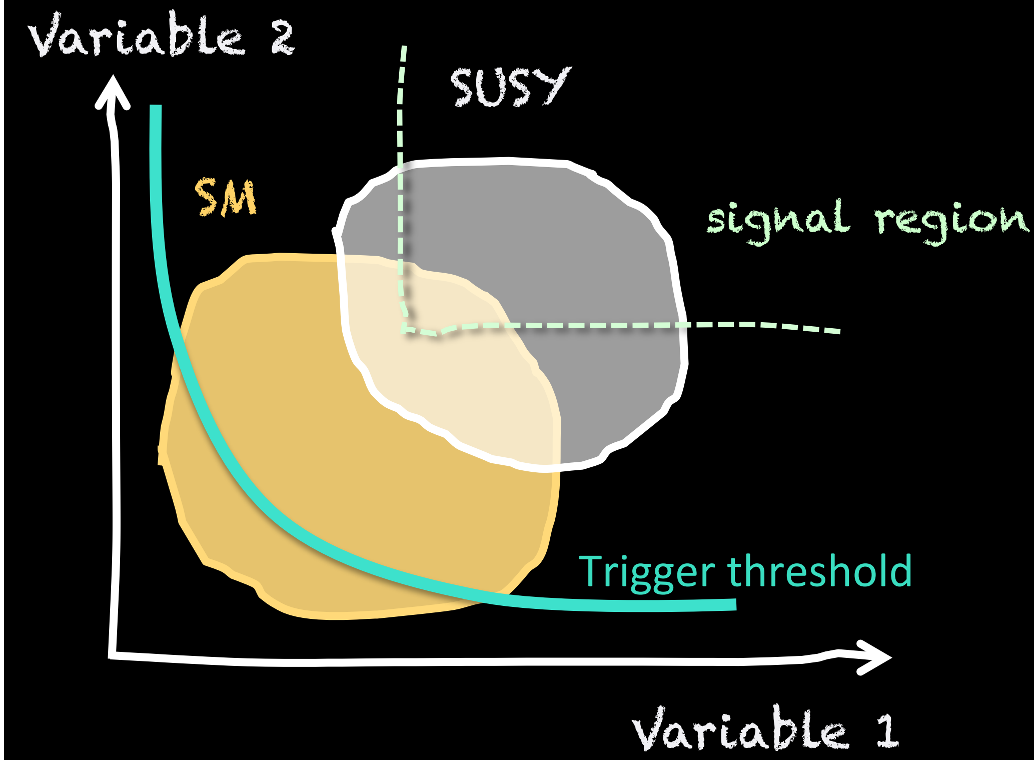
arxiv:1209.4625



ATLAS mono-γ, 4.6 fb^{-1} at 7 TeV

How do we search for SUSY ?

A brief primer …



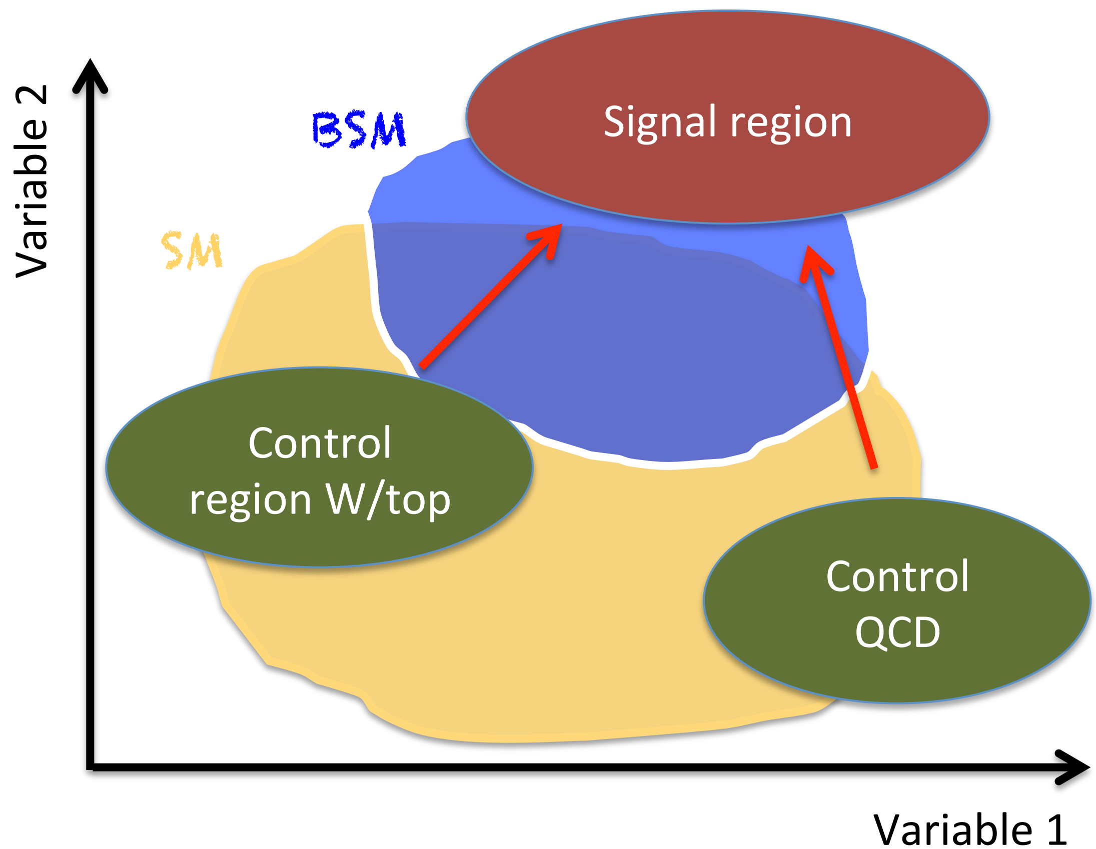
SUSY search analyses look for tails in distributions of observables sensitive to new heavy particles.

Can only exploit tails if detector response and SM backgrounds in signal region are understood.

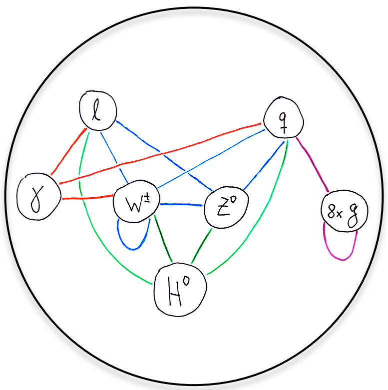
How do we search for SUSY ?

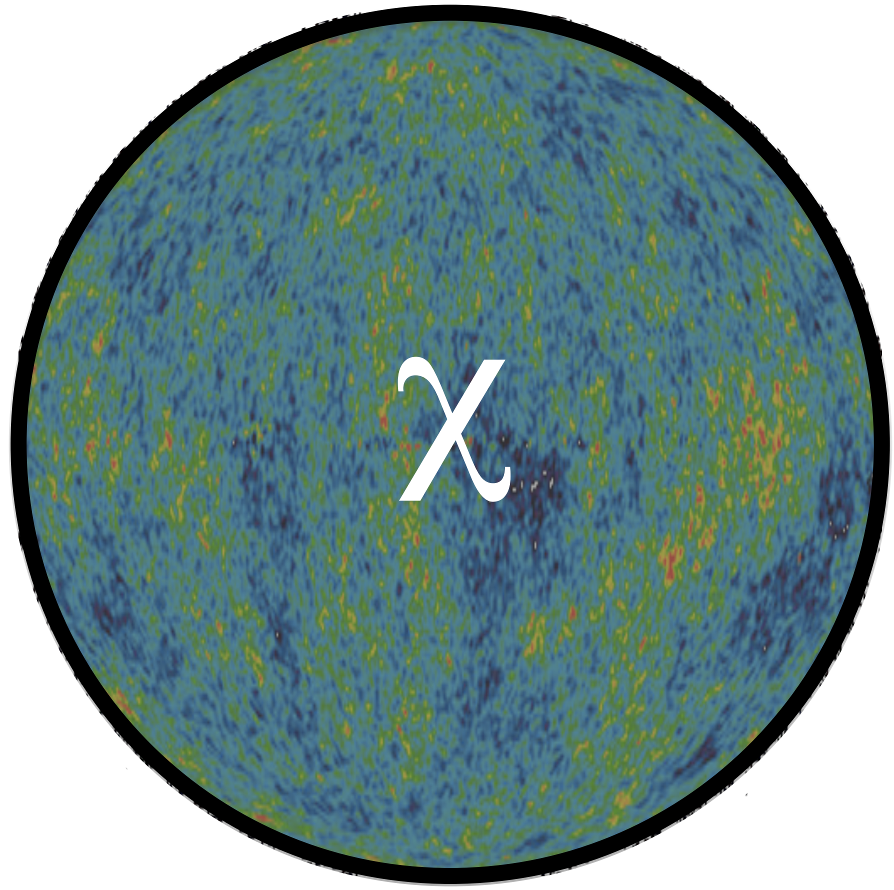
A brief primer …

CR → SR transfer factors taken from MC simulation (many systematic effects cancel).



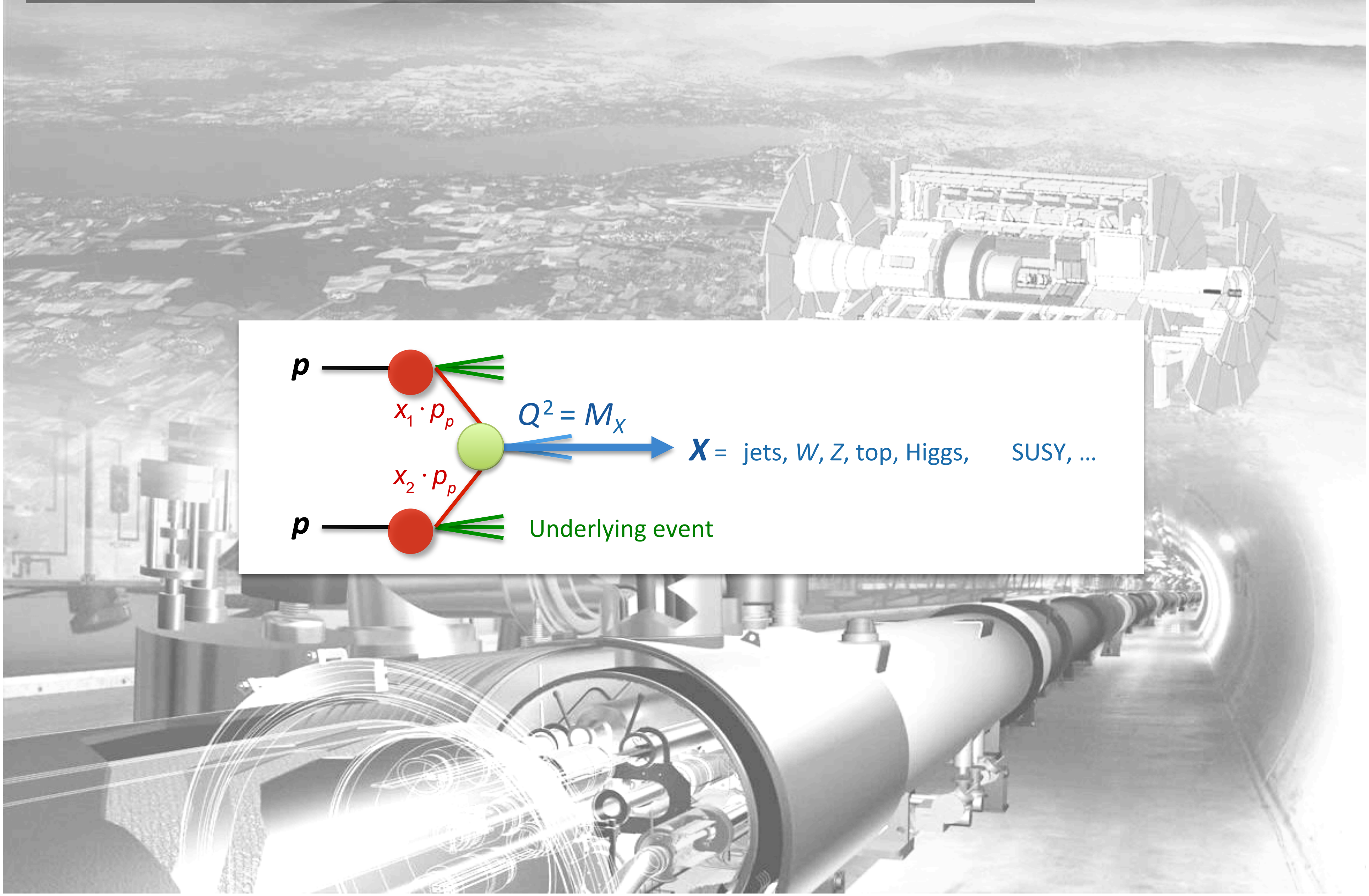
LHC Mission: Complete the Standard Model and Discover the Dark Sector (and more…)





1 : 5

Searches for weakly interacting particles



How to search for SUSY at the LHC

SUSY (more than) duplicates spectrum of particle states wrt. Standard Model

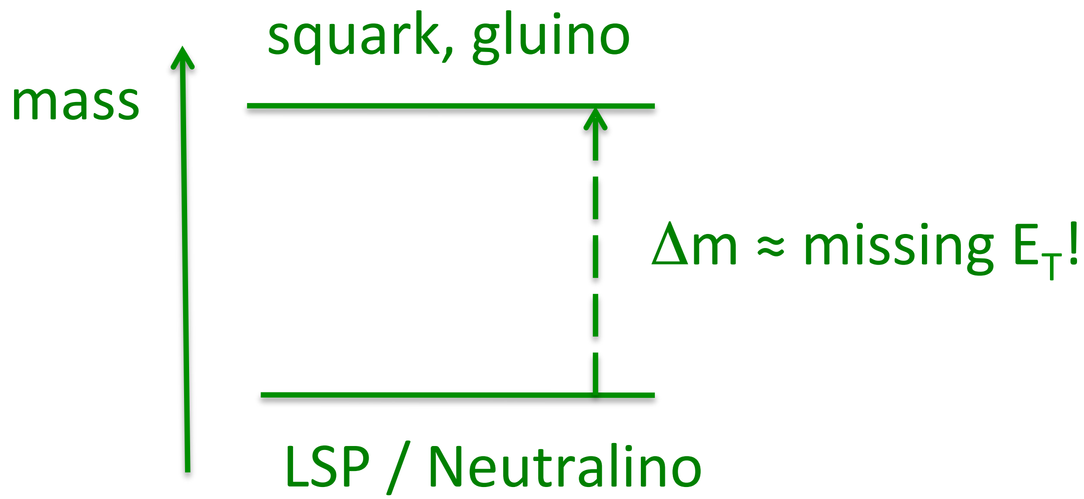
Sparticles decay in jets, leptons, taus, photons, invisible (MET), …

1. *R*-parity conserving (RPC) signatures:
    - Sparticles produced in pairs, each decays to (WIMP) LSP, mostly lightest neutralino or gravitino
    - One invisible LSP per decay chain → MET

2. *R*-parity violating (RPV) signatures:
    - Resonances or multijets / multileptons: single sparticle production or LSP decay
    - Displaced vertices from late LSP decay

3. Long-lived particles from:
    - Weak couplings (eg, RPV, gravitino)
    - High virtuality from heavy mediator sparticles (eq, heavy squarks in split SUSY)
    - Mass degeneracy (eg, *m* (chargino) ~ *m* (LSP) in AMSB)

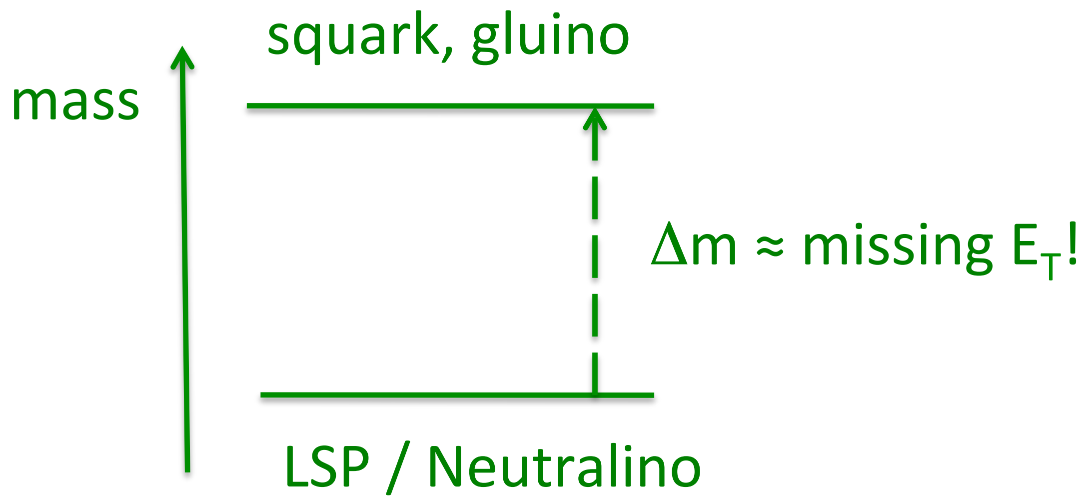
So what?



Amount of missing E_T depends on mass difference!

So what?

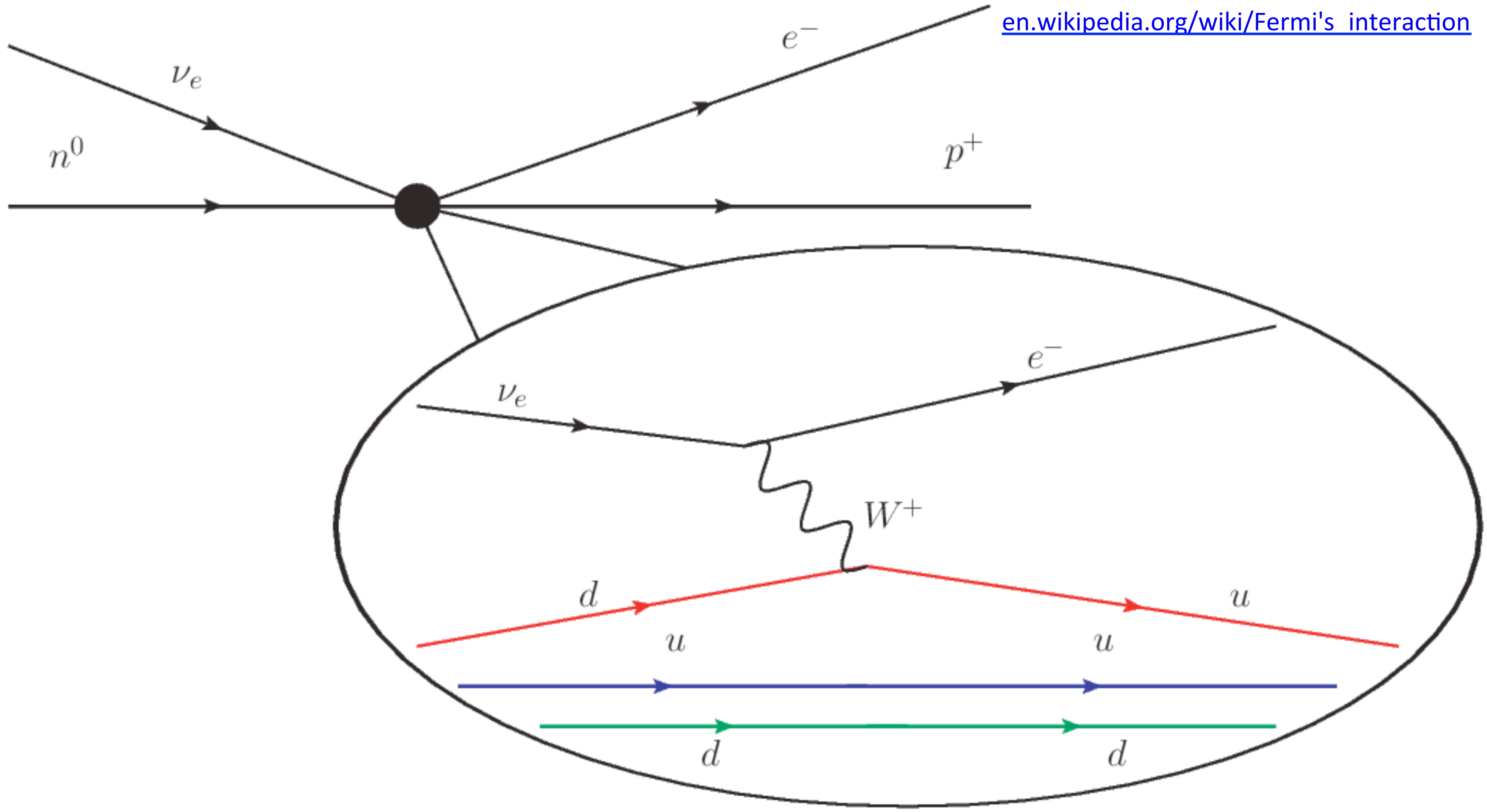
Can still search for pairs of “ISR-tagged” dark-matter particles, not particular SUSY signatures



Amount of missing E_T depends on mass difference!

Dark matter contact interactions

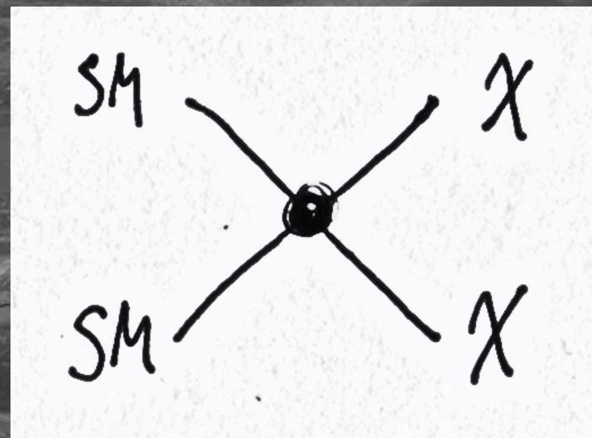
en.wikipedia.org/wiki/Fermi's_interaction

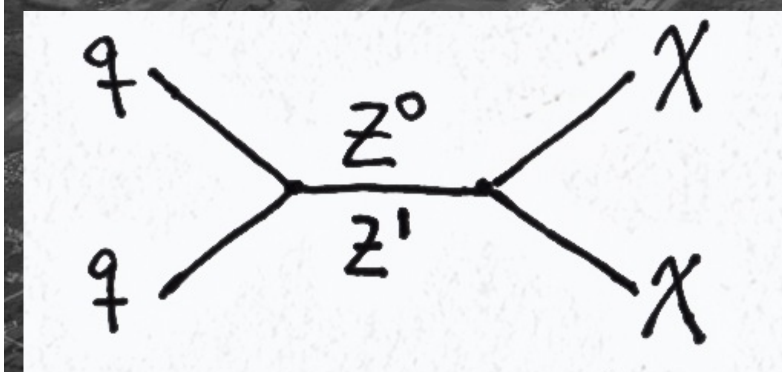


Just like Fermi did to describe β decay

$$\frac{G_F}{(\hbar c)^3} = \frac{\sqrt{2}}{8}\frac{g^2}{m_W^2} = 1.16637(1) \times 10^{-5}\ \mathrm{GeV}^{-2}$$

Dark matter contact interactions





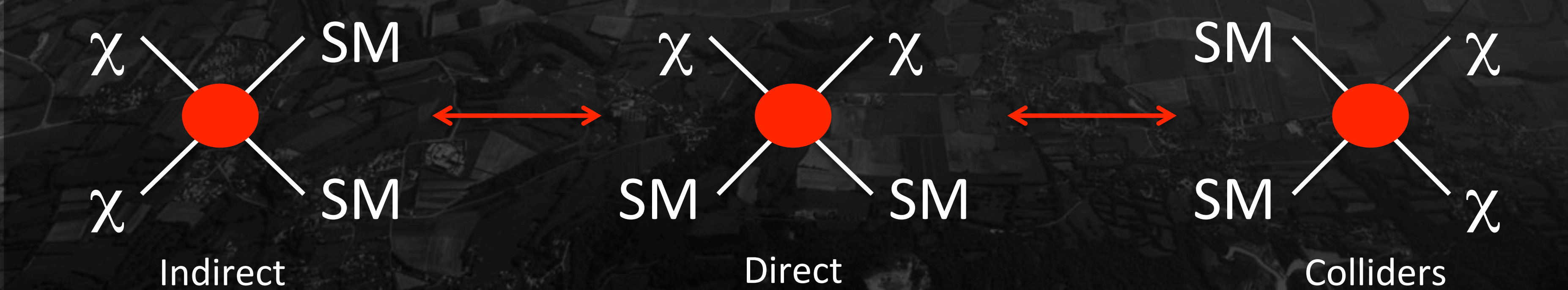
$$M_* = \frac{M_{Z'}}{g_{q\cdot\chi}}$$

Mass suppression scale

Dark matter contact interactions

Data combinations require assumptions about the red bubble!

Particle Dark Matter Searches based on:



Dark matter contact interactions

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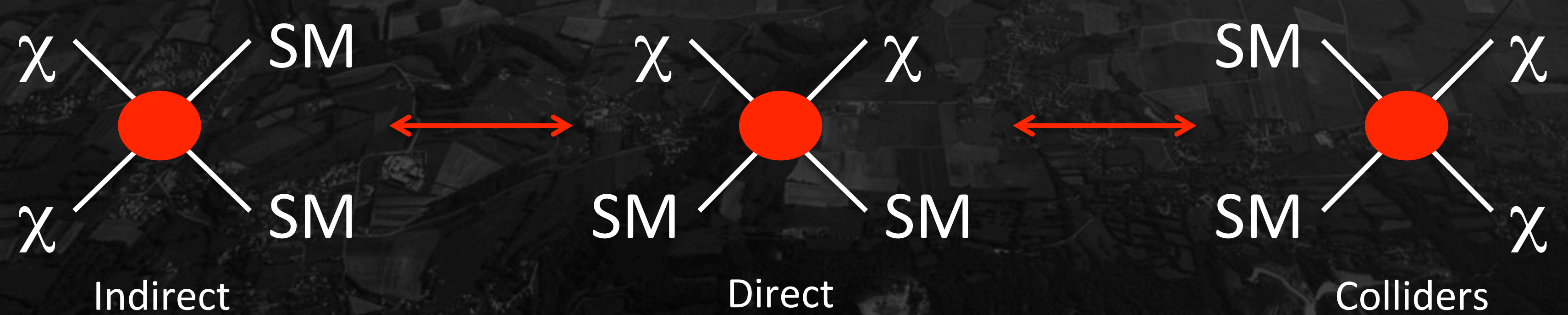
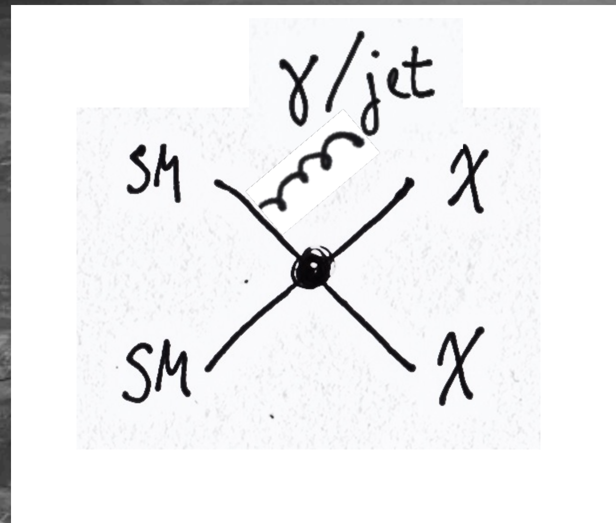
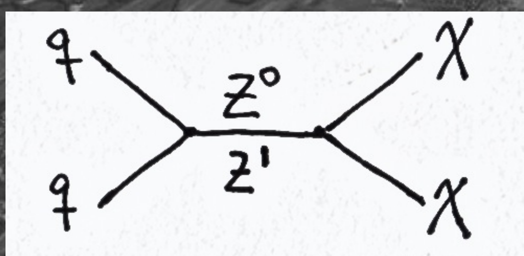
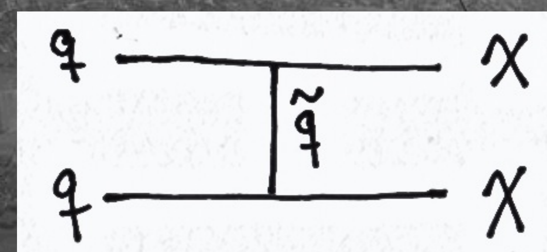


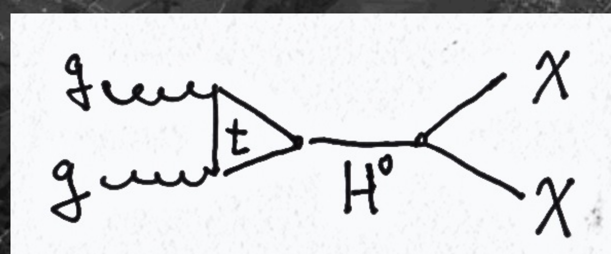
Dark matter contact interactions



"ISR tag"







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