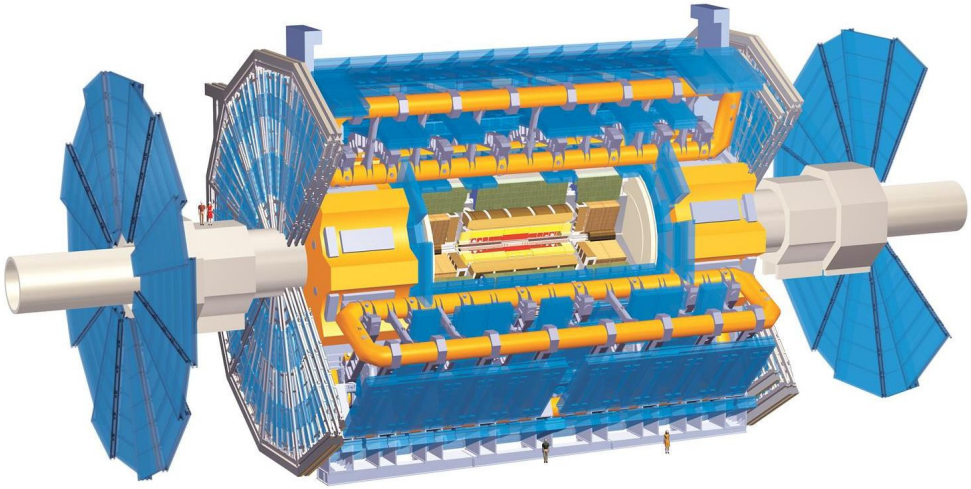
Dark matter and the LHC



David Milstead

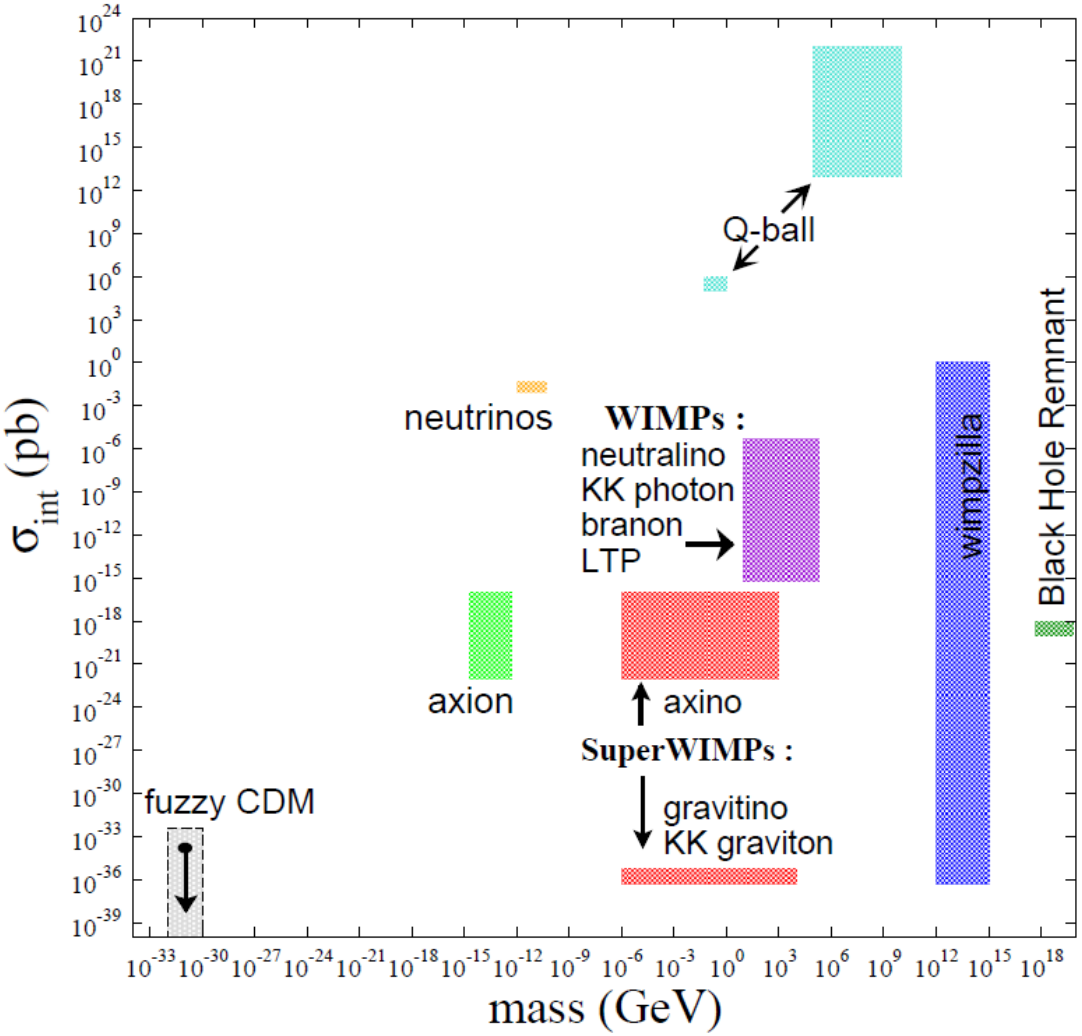
Stockholms Universitet

Dark matter candidates

A plethora of candidates/ideas

- Q-balls
- SuperWIMPs
- Gravitinos
- Axions ..

- Talk deals mainly with WIMPs



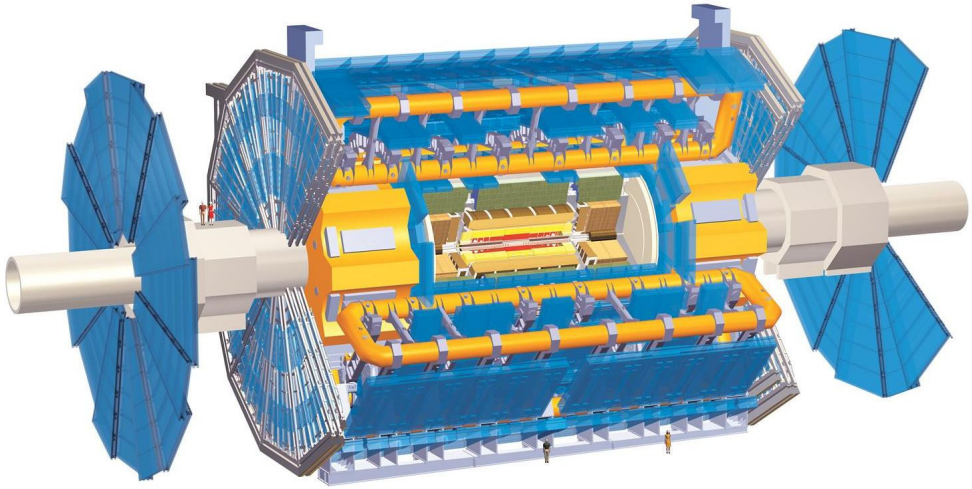
$$\frac{\Omega_{WIMP}h^2}{0.11} \approx \frac{3\times10^{-27}\,\mathrm{cm^3 s^{-1}}}{\langle\sigma v\rangle}$$

Typical gauge couplings and weak scale interaction

$\Rightarrow$ Mass $\approx$ 100 - 1000 GeV for correct relic density.

The LHC – an essential component of the DM story

- If DM is made of WIMPs, they will be produced at LHC in abundance
- Indirect DM detection using principally missing E_T signatures
- Unique role of LHC: multiple measurements allow understanding of underlying theory, determination of identity of DM



ATLAS Detector

multiple measurements of WIMP observables → Optimisation of parameters within a canididate theory, eg SUSY → DarkSUSY/ MicroMEGAS software → $\Omega_\chi h^2$

Standard SUSY Slide

- Improves the fine tuning problem, approximate gauge unification...
- Provides a dark matter candidate

Lightest neutralino: $\tilde{\chi}^0 = a_1\tilde{\gamma} + a_2\tilde{Z}^0 + a_3\tilde{H}_1^0 + a_4\tilde{H}_2^0$

gaugino Higgsino

Constrained models:

At GUT scale: Eg CMSSM

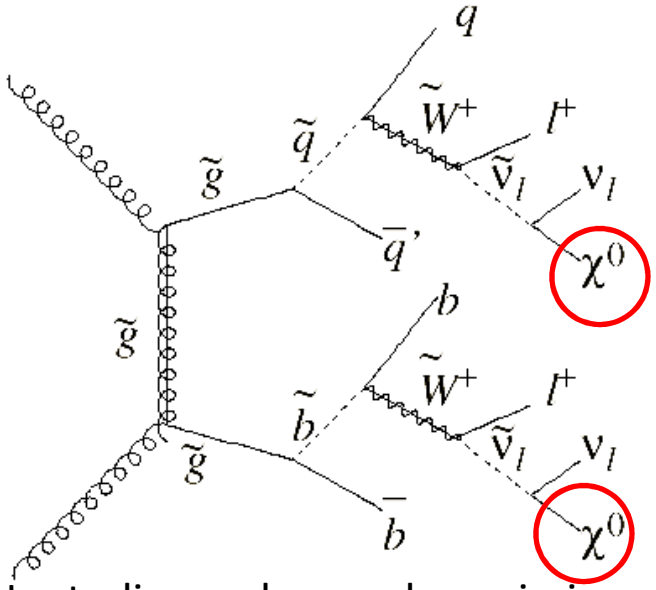
Gauginos mass=$m_{1/2}$; Scalar mass $m_{\tilde{q}}^2 = m_0^2$ $\tan\beta$ =ratio of MSSM Higgs VEVs

A_0 ≡ trilinear couplings μ=Higgsino mass parameter

Simplified models:

Decouple all particles not relevant for signature, simplified decay chains.

Search strategies for SUSY at the LHC



Neutralinos observed as missing transverse energy in association with cascade particles

Jet multiplicity + kinematics

Lepton multiplicity + kinematics

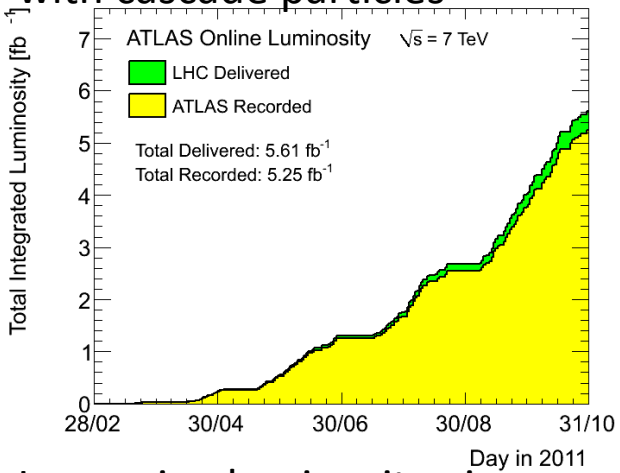
+ global event quantities

$$E_T^{miss} = -\left|\sum_i \vec{E}_T\right| \qquad m_{eff} = E_T^{miss} + \sum_i p_T^{jet}$$

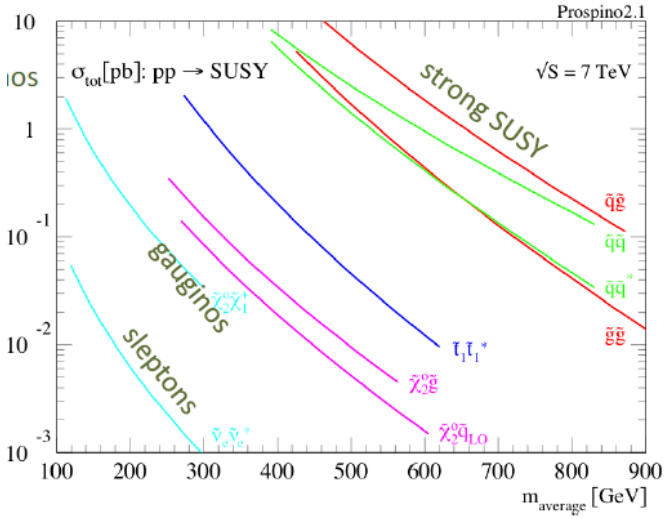
$$H_T = \sum_i p_T^{jet}$$

α_T exploits angular relation between jets....

.....

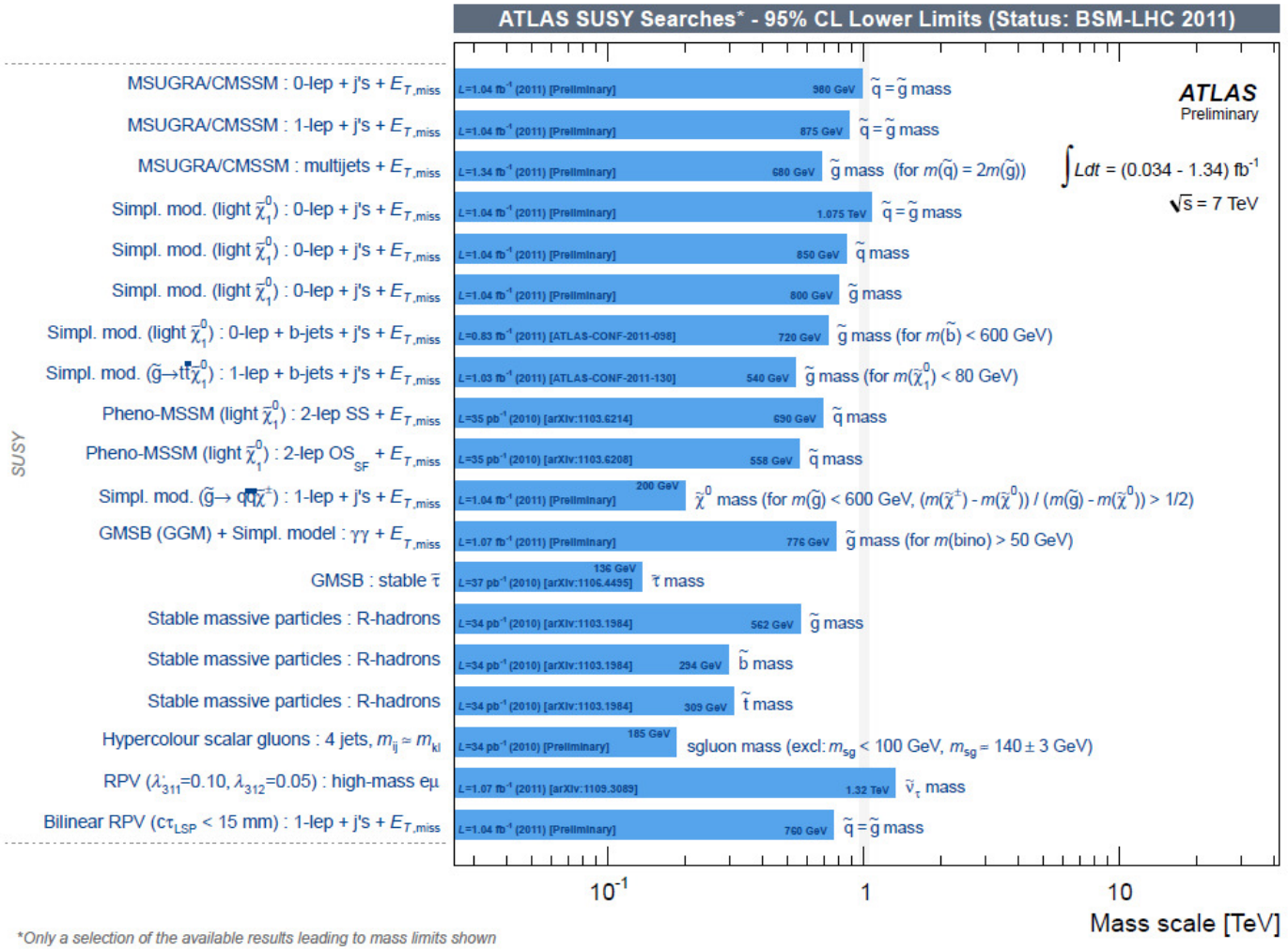


Increasing luminosity gives sensitivity to higher masses and rare processes.



Growing sensitivity for non-strong SUSY.

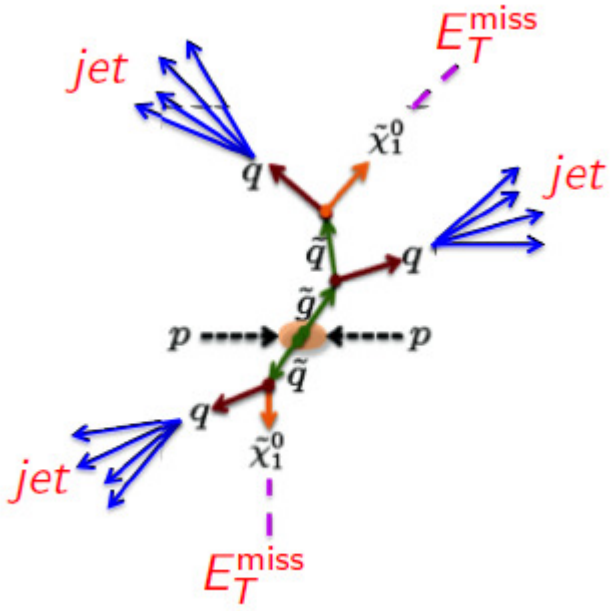
A body of searches already performed



Albeit with model dependence – limits starting to push SUSY up to and beyond 1 TeV

0-lepton searches

Different signatures correspond to different SUSY spectra.



$2-4$ jet searches

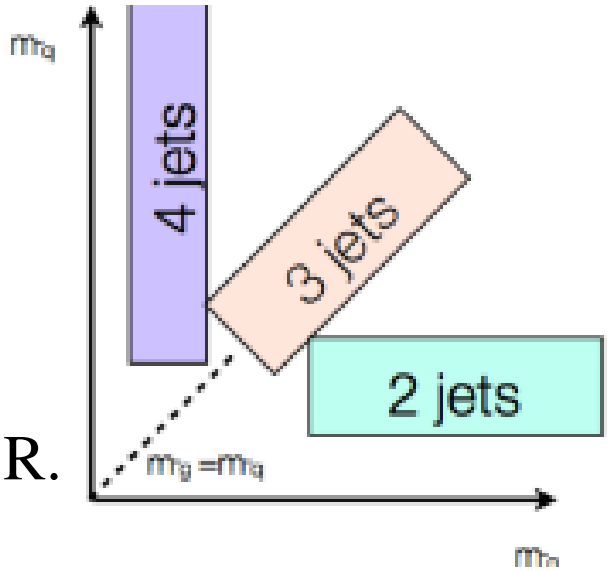
Larger E_T^{miss}, lower jet multiplicity

$$m_{eff} = E_T^{miss} + H_T \qquad H_T = \sum_{jets} p_T$$

$6-8$ jet searches

Lower E_T^{miss}, larger jet multiplicity

$$E_T^{miss} / \sqrt{H_T}$$ Invariant under jet multiplicities

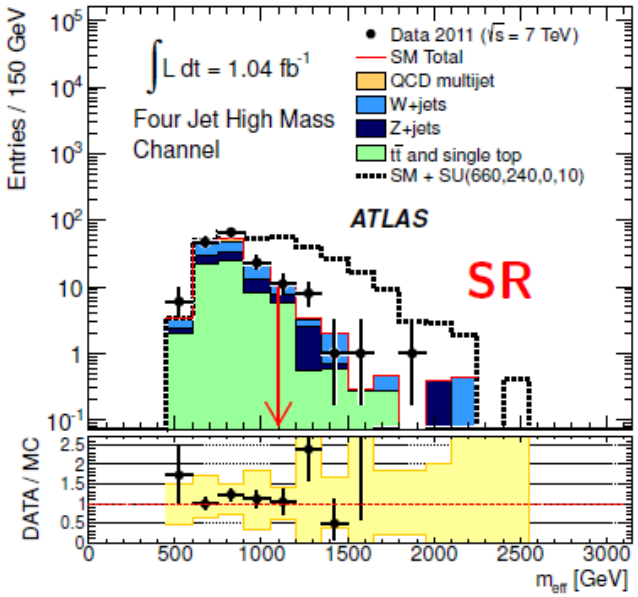


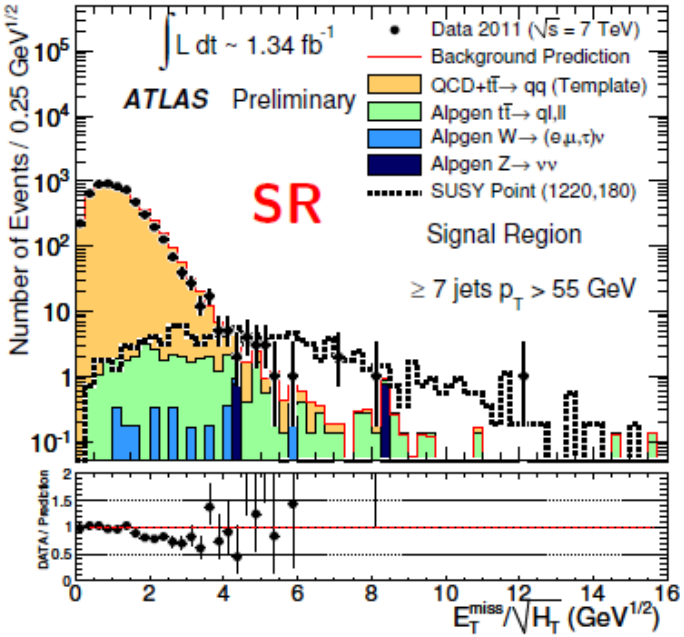
Suppress QCD with topological selections.

Five signal regions and 5 control regions per SR.

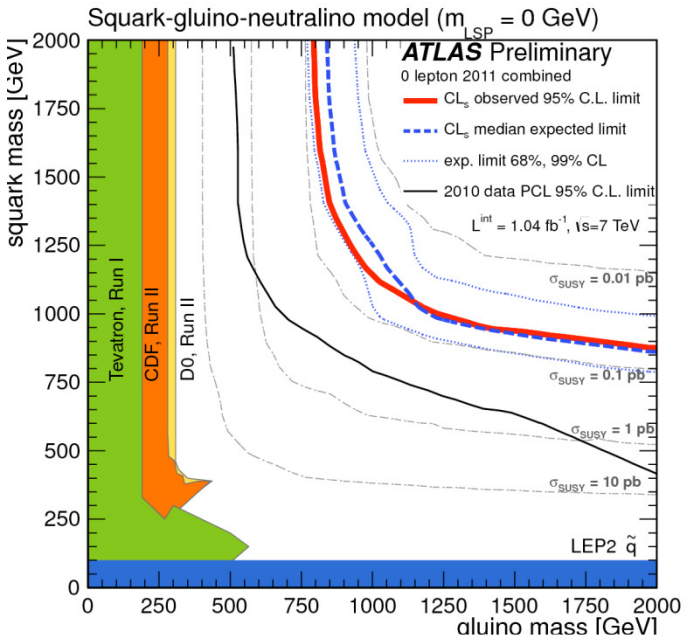
0-lepton results (~1fb^{-1})

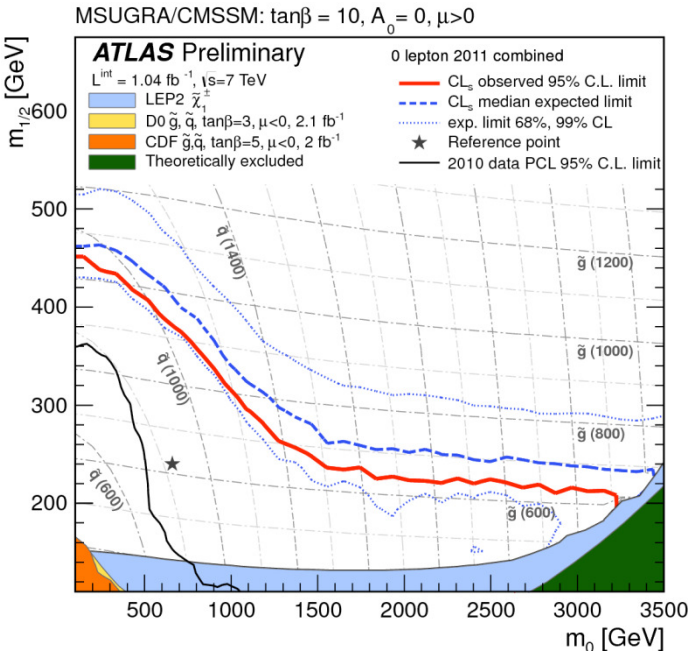
Observed yields





Interpretation

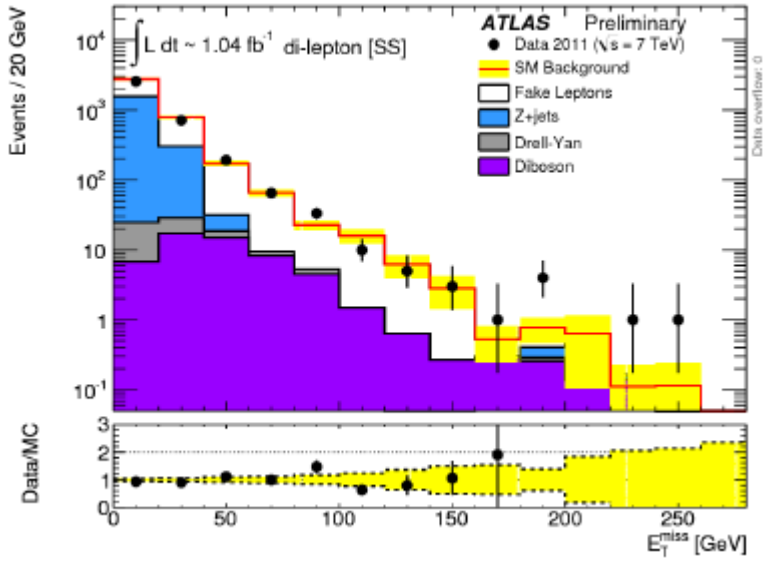




Dilepton search (~1fb^{-1})

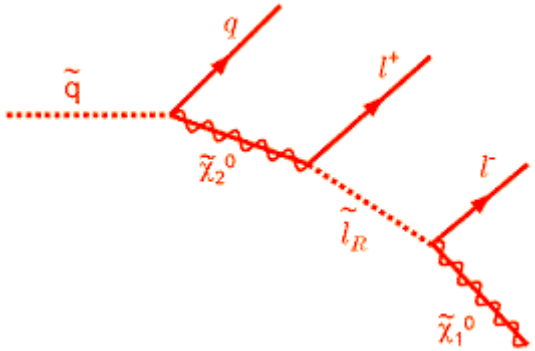
- 3 different analyses: OS, SS, OSSF
- Signal region with large MET but no jet requirement
- Data-driven fake estimation
- No excess

	Background	Obs.	95% C.L.
OS-SR1	$15.5 \pm 1.2 \pm 4.4$	13	9.5 fb
OS-SR2	$13.0 \pm 1.8 \pm 4.1$	17	15.2 fb
OS-SR3	$5.7 \pm 1.1 \pm 3.5$	2	5.0 fb
SS-SR1	$32.6 \pm 4.4 \pm 4.4$	25	10.2 fb
SS-SR2	$24.9 \pm 4.1 \pm 6.6$	28	20.3 fb



Multilepton searches

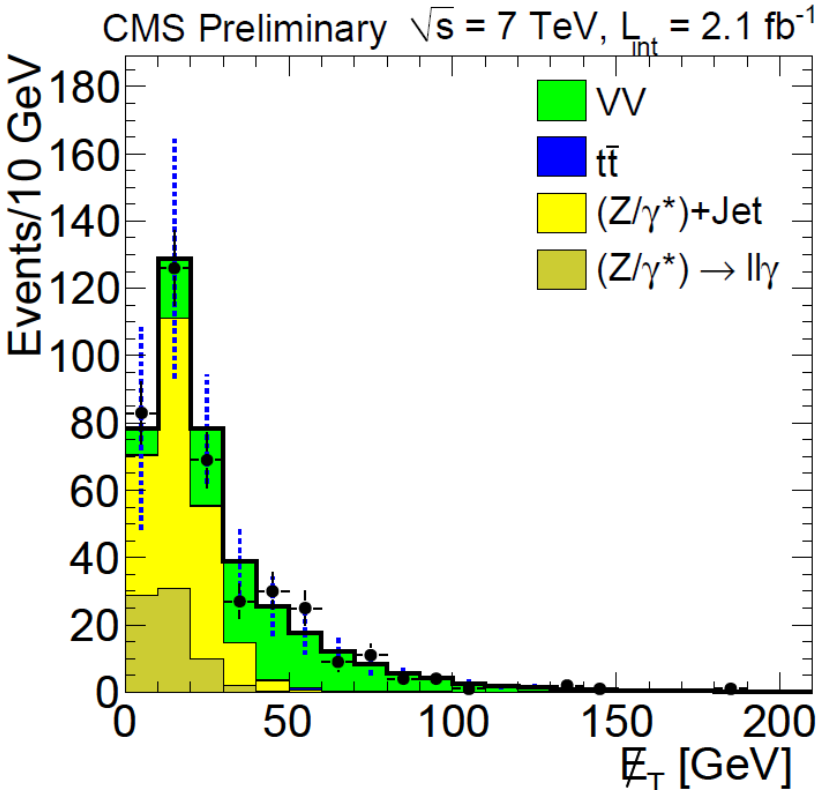
Generic study sensitive to extended decay chains and specific models.



CMS analysis (~2fb^{-1})

3-4 leptons

Selections on H_T, MET and Z-veto ..

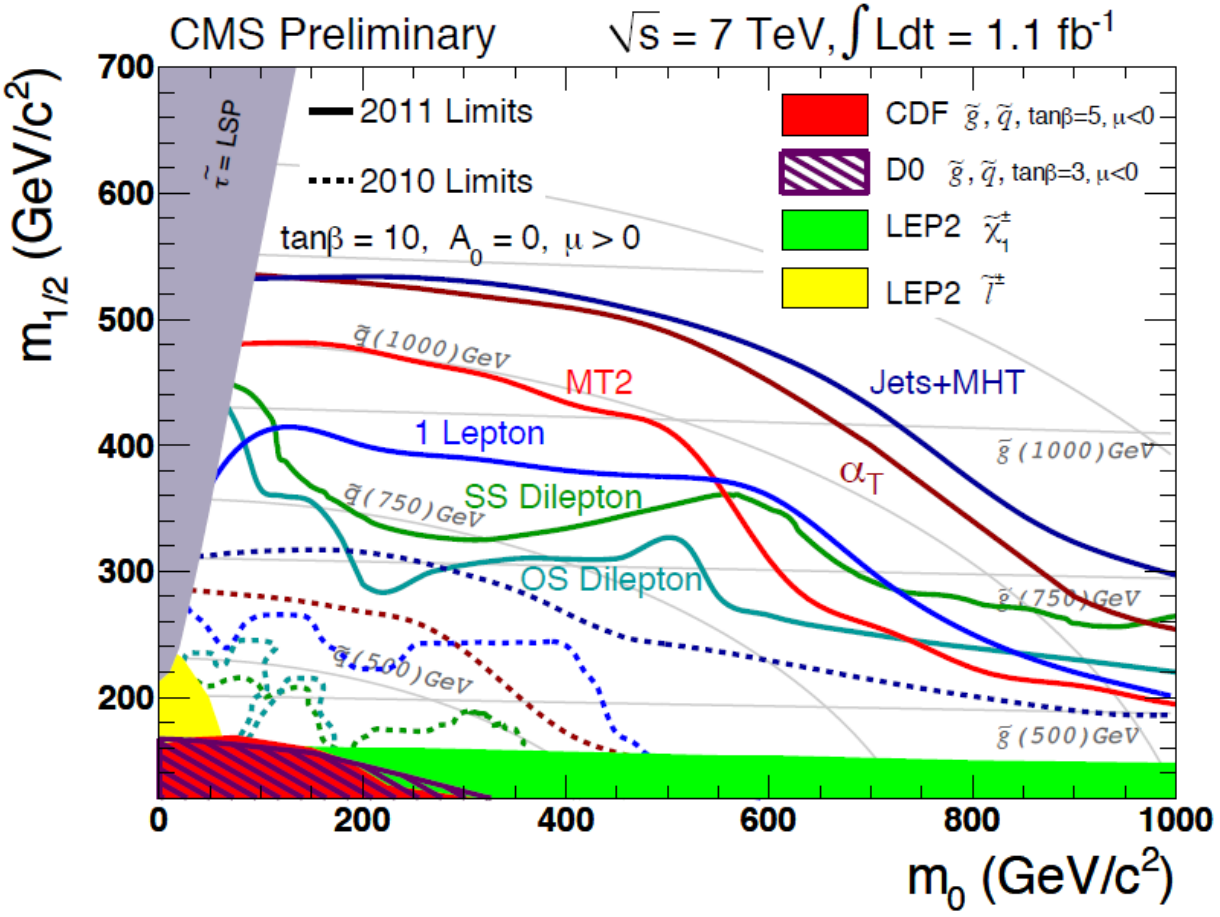


Results for different signal selections

Selection	N(τ)=0		N(τ)=1		N(τ)=2	
	obs	expected SM	obs	expected SM	obs	expected SM
$\geq$FOUR Lepton Results						
MET>50,H_T >200,noZ	0	0.003 ± 0.002	0	0.01 ± 0.05	0	0.30 ± 0.22
MET>50,H_T >200, Z	0	0.06 ± 0.04	0	0.13 ± 0.10	0	0.15 ± 0.23
MET>50,H_T <200,noZ	1	0.014 ± 0.005	0	0.22 ± 0.10	0	0.59 ± 0.25
MET>50,H_T <200, Z	0	0.43 ± 0.15	2	0.91 ± 0.28	0	0.34 ± 0.15
MET<50,H_T >200,noZ	0	0.0013 ± 0.0008	0	0.01 ± 0.05	0	0.18 ± 0.07
MET<50,H_T >200, Z	1	0.28 ± 0.11	0	0.13 ± 0.10	0	0.52 ± 0.19
MET<50,H_T <200,noZ	0	0.08 ± 0.03	4	0.73 ± 0.20	6	6.9 ± 3.8
MET<50,H_T <200, Z	11	9.5 ± 3.8	14	5.7 ± 1.4	39	21 ± 11
THREE Lepton Results						
MET>50,H_T >200,no-OSSF	2	0.87 ± 0.33	21	14.3 ± 4.8	12	10.4 ± 2.2
MET>50,H_T <200,no-OSSF	4	3.7 ± 1.2	88	68 ± 17	76	100 ± 17
MET<50,H_T >200,no-OSSF	1	0.50 ± 0.33	12	7.7 ± 2.3	22	24.7 ± 4.0
MET<50,H_T <200,no-OSSF	7	5.0 ± 1.7	245	208 ± 39	976	1157 ± 323
MET>50,H_T >200,noZ	5	1.9 ± 0.5	7	10.8 ± 3.3	–	–
MET>50,H_T >200, Z	8	8.1 ± 2.7	10	11.2 ± 2.5	–	–
MET>50,H_T <200,noZ	19	11.6 ± 3.2	64	52 ± 13	–	–
MET<50,H_T >200,noZ	5	2.0 ± 0.7	24	26.6 ± 3.3	–	–
MET>50,H_T <200, Z	58	57 ± 21	47	44.1 ± 7.0	–	–
MET<50,H_T >200, Z	6	8.2 ± 2.0	90	119 ± 14	–	–
MET<50,H_T <200,noZ	86	82 ± 21	2566	1965 ± 438	–	–
MET<50,H_T <200, Z	335	359 ± 89	9720	7740 ± 1698	–	–
Totals 4L	13.0	10.4 ± 3.8	20.0	7.8 ± 1.5	45	30 ± 12
Totals 3L	536	539 ± 94	12894	10267 ± 1754	1086	1291 ± 324

No smoking gun but interesting observations to follow up with higher lumi

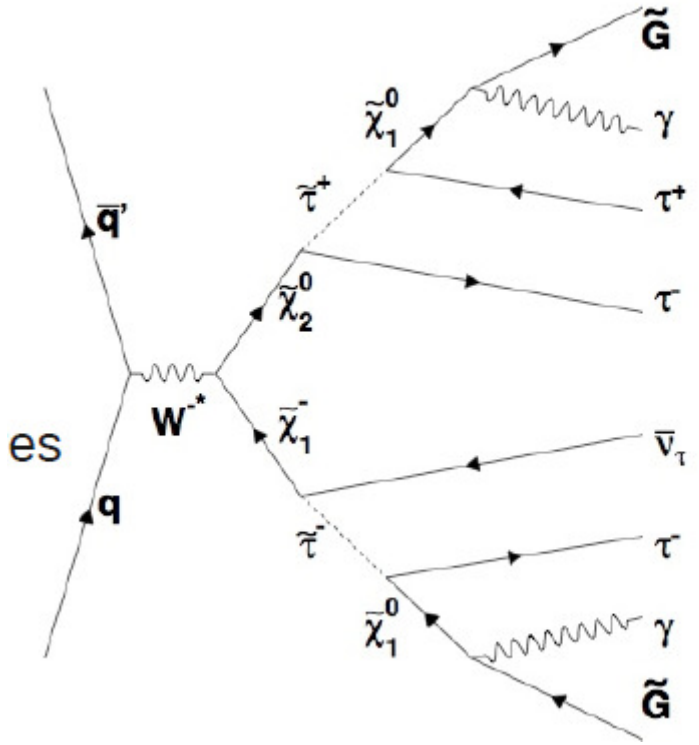
Compilation of exclusion limits



Hadronic searches give the best limits within this constrained model.
SUSY may not be constrained. All searches are complementary.

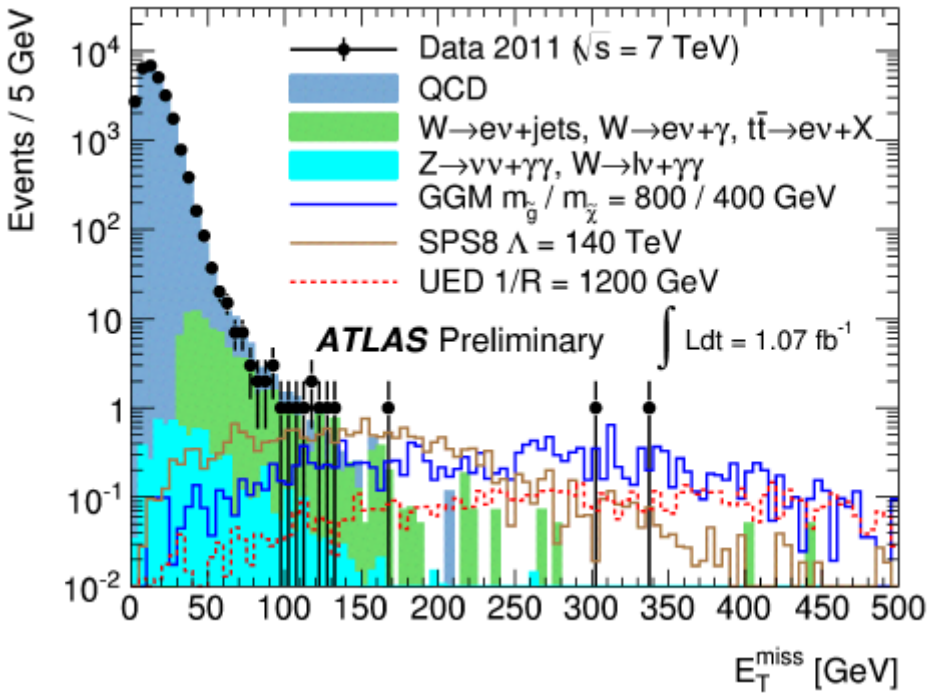
SUSY with photons

- GMSB scenario
- Gravitino (LSP)
- Possibility of photon + MET signature



Results

- Diphoton + MET
  - NLSP decay products
- Two em clusters
- MET>125 GeV

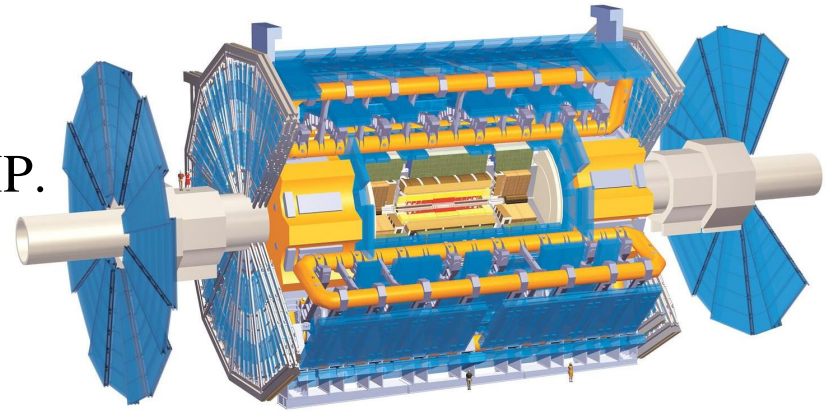


E_T^{miss} range [GeV]	Data events	Predicted background events				Expected signal events		
		Total	QCD	$W/t\bar{t}(\rightarrow e\nu)+X$	Irreducible	GGM	SPS8	UED
0 - 20	20881	-	-	-	-	0.20 ± 0.05	0.22 ± 0.04	0.02 ± 0.01
20 - 50	6304	5968 ± 29	5951 ± 28	13.3 ± 8.1	3.6 ± 0.3	0.45 ± 0.08	1.5 ± 0.1	0.11 ± 0.01
50 - 75	86	87.1 ± 3.3	60.9 ± 2.8	25.2 ± 1.7	1.0 ± 0.2	0.48 ± 0.08	2.2 ± 0.1	0.14 ± 0.01
75 - 100	11	14.7 ± 1.2	6.7 ± 0.9	7.4 ± 0.8	0.52 ± 0.10	0.8 ± 0.1	2.1 ± 0.1	0.15 ± 0.01
100 - 125	6	4.9 ± 0.7	1.6 ± 0.4	3.0 ± 0.5	0.32 ± 0.08	1.2 ± 0.1	2.5 ± 0.1	0.29 ± 0.02
> 125	5	4.1 ± 0.6	0.8 ± 0.3	3.1 ± 0.5	0.23 ± 0.05	17.2 ± 0.5	13.0 ± 0.3	9.67 ± 0.11

Could the WIMP not manifest itself as MET ?

Eg ATLAS size ~13m radius

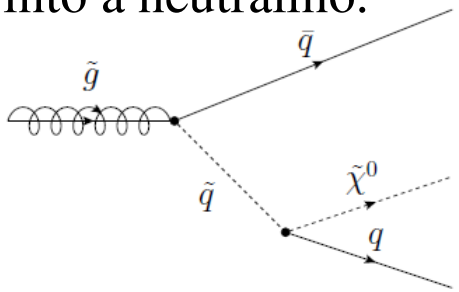
$\Rightarrow$ A particle with a lifetime ~10^{-7}m could traverse the detector and then decay into a WIMP.



Split-SUSY

Heavy scalars (>> TeV), light gauginos.

Long-lived gluino decaying via virtual squark lines into a neutralino.



Also, gravitino dark matter from NLSP meta-stable stau.

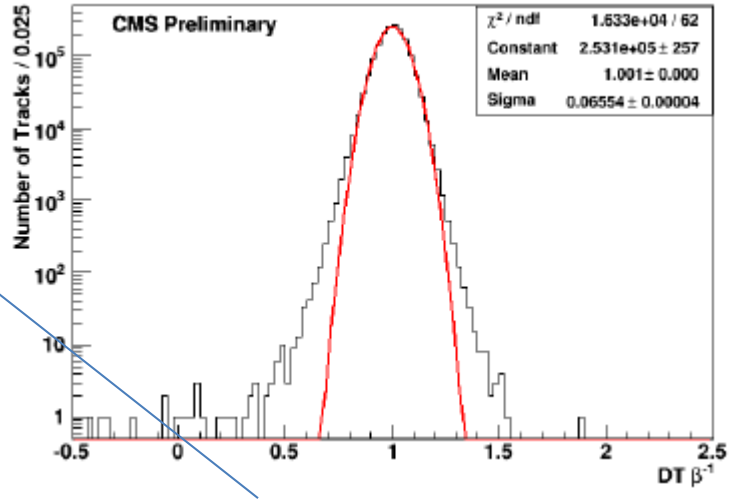
$$c\tau = 16\pi \frac{F^2}{M_{\rm NLSP}^5} \sim \left(\frac{\sqrt{F}}{10^7\ {\rm GeV}}\right)^4 \left(\frac{100\ {\rm GeV}}{M_{\rm NLSP}}\right)^5 10\ {\rm km}.$$

Hunting for SMPs

Muon

Calo

Inner tracking system

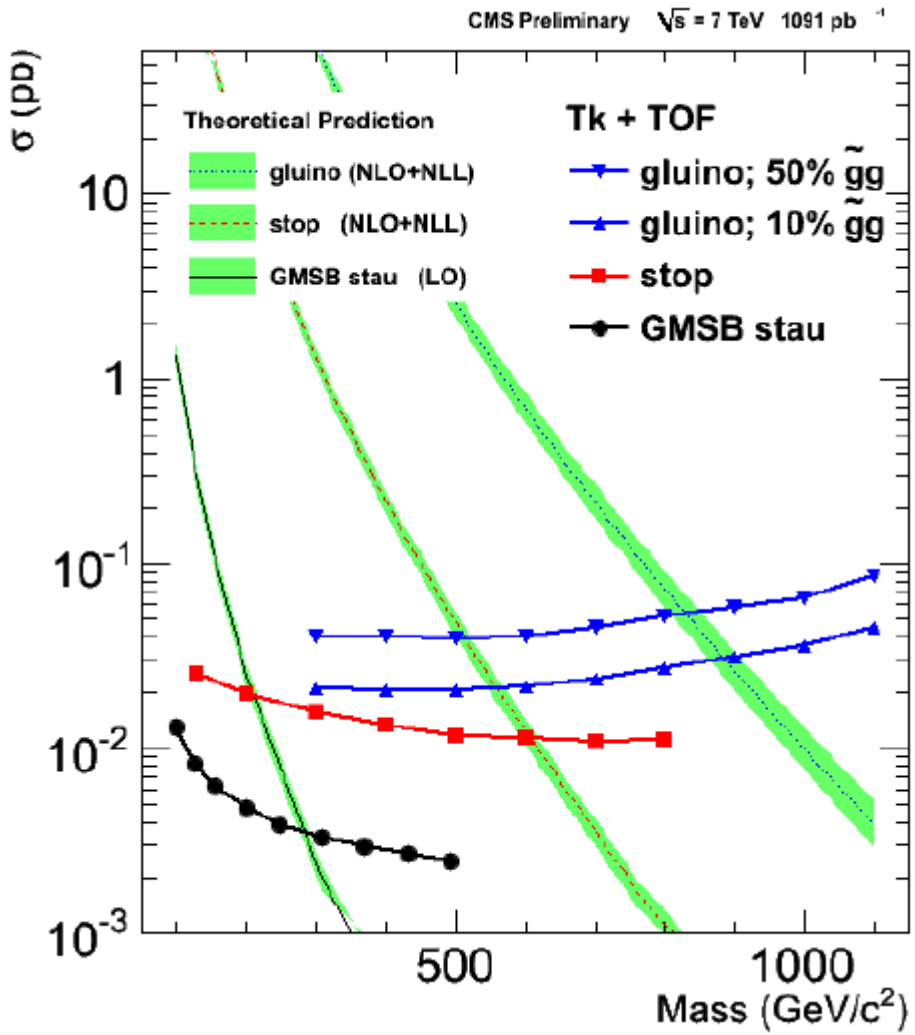


Speed from muon TOF

Ionisation energy loss from

Exploit speed-dependent observables

Results of stable massive interacting particle search



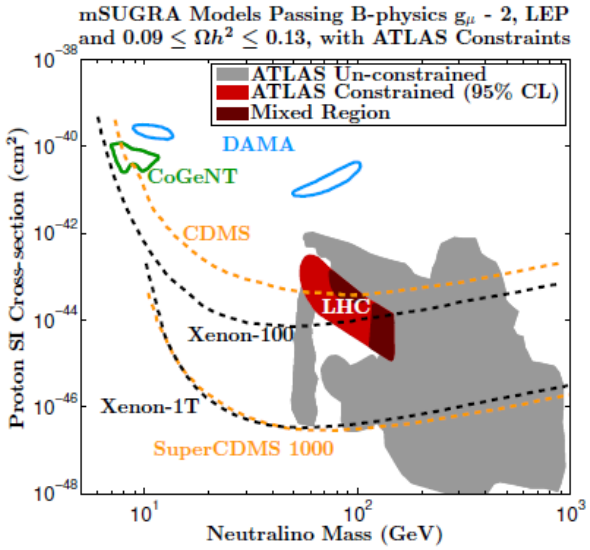
Gluino ~890 GeV

Stop ~830 GeV

Stau ~293 GeV (GMSB)

Summary

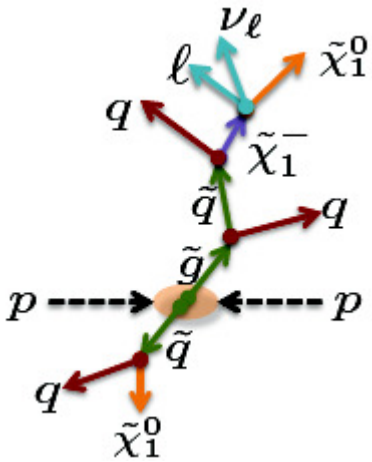
- The LHC is a WIMP factory (if they exist)
  - measure interactions and properties
- Wide range of signature-based searches performed.
- No smoking gun (nor a series of non-discoveries which came and went and caused excitement)
- Aim to discover WIMPs or gradually falsify the WIMP hypothesis as part of a program of direct and indirect community searches.



ArXiv:1103.5061

Jets + 1 lepton + MET

- Sensitive to lepton appearing in cascade
- ”Matrix method” for QCD background
  - ”loose” and ”tight” electrons
  - Data for ”loose” electron used to estim perforance for ”tight” electron



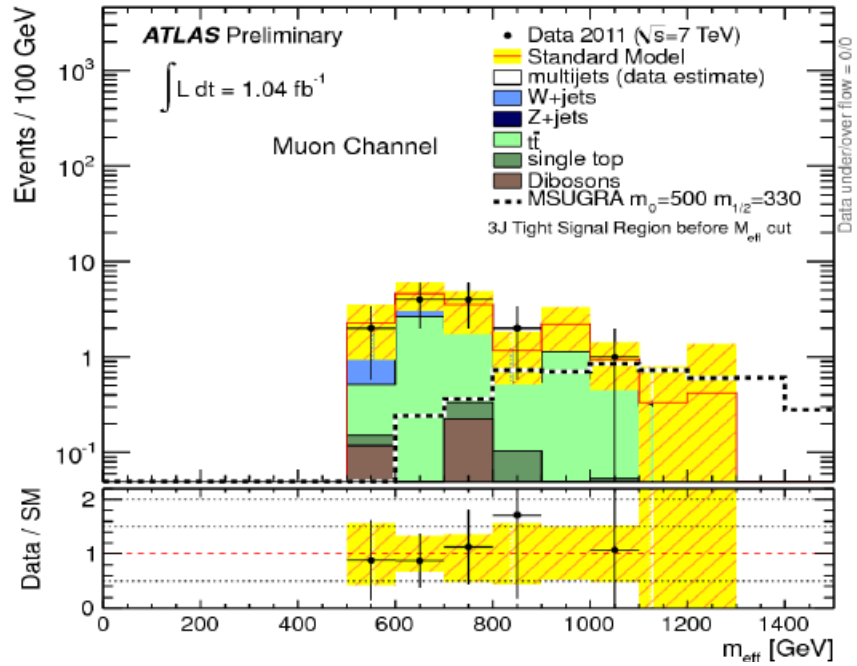
Results for 1-lepton search

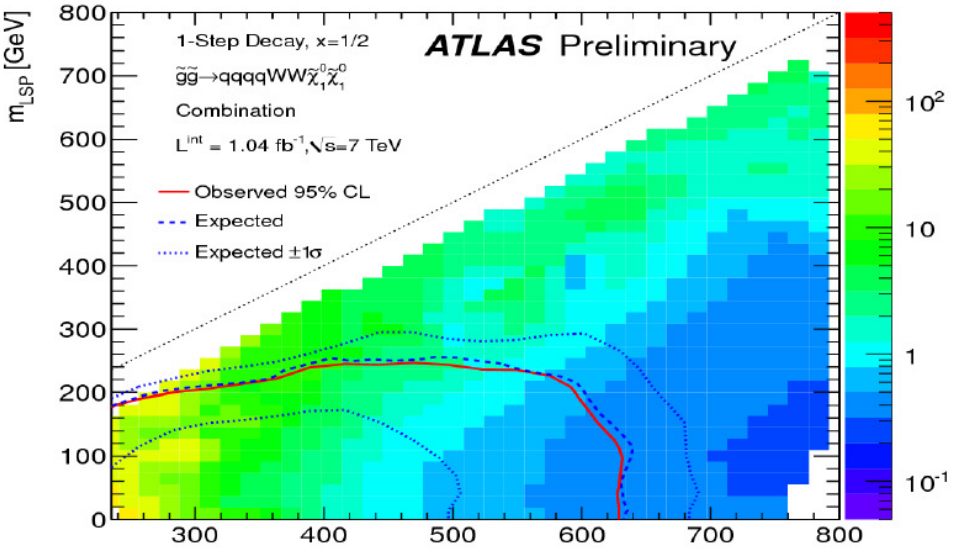
Fully/semi data-driven backgrounds.

Background from combined likelihood fit

No excess

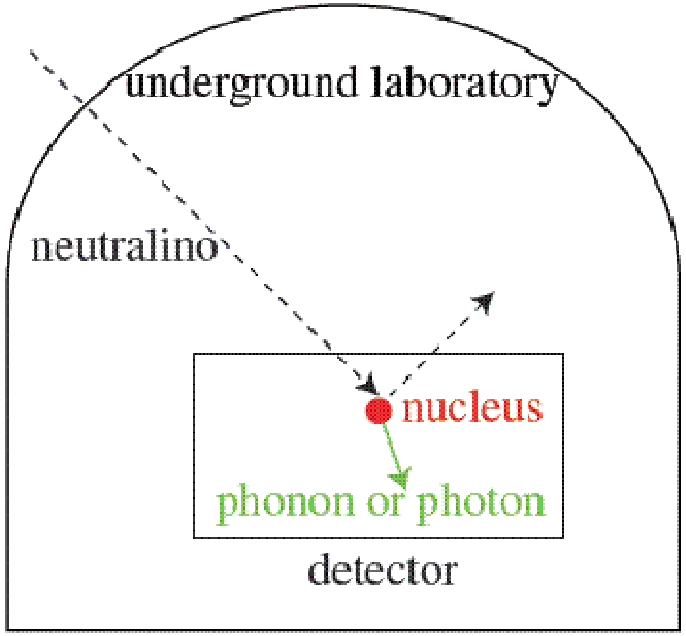
Interpretation within simplified model including intermediate chargino decay.

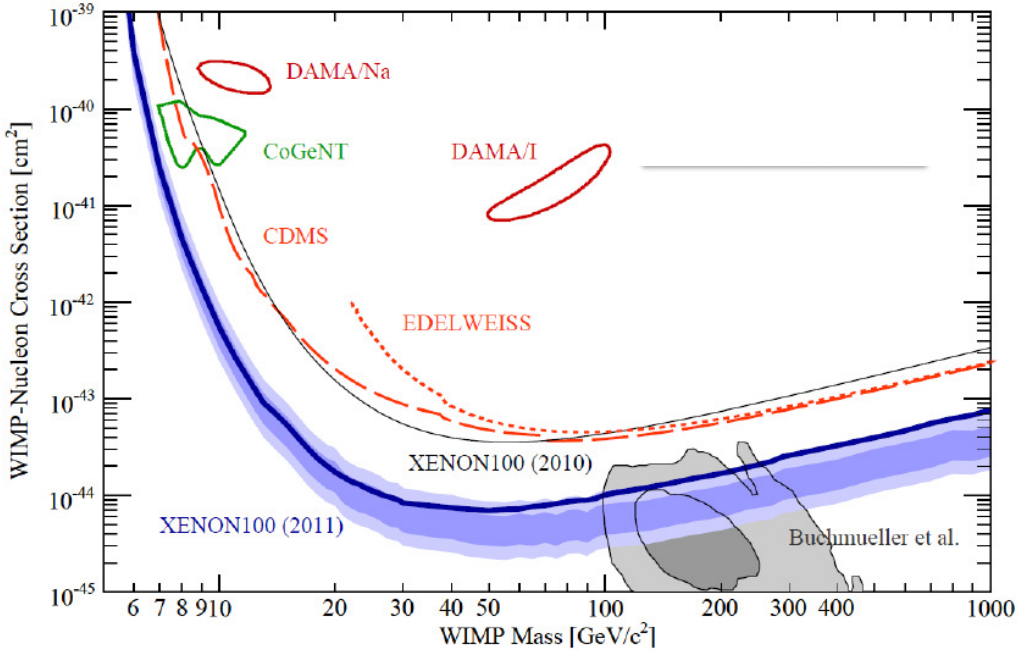




Direct Detection Experiments

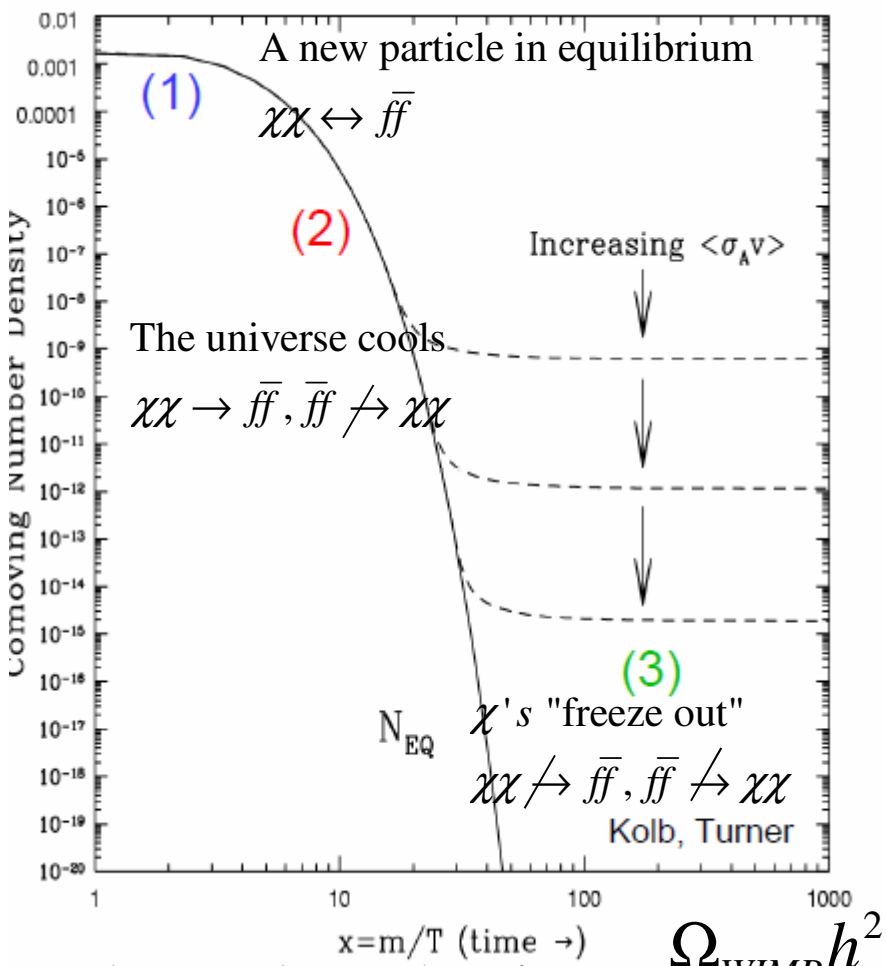
- Direct detection of interaction between DM particle & detector
- No unambiguous observation yet
  - Limits on cross section as a function of mass
- Detection would confirm presence of DM albeit with little clue as to its identity

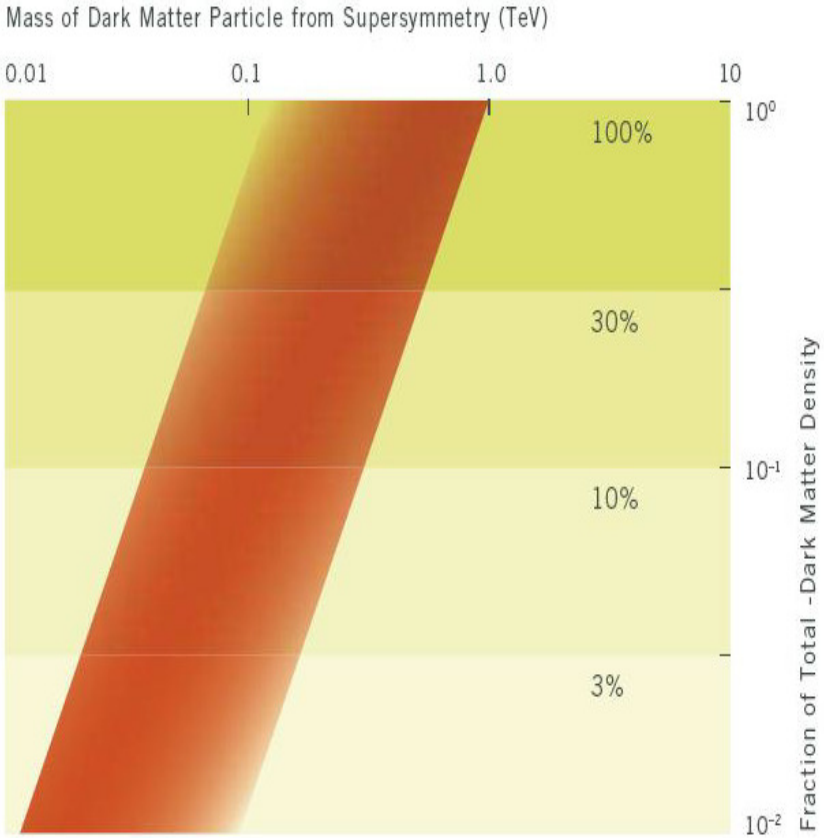




- Also indirect measurements from eg annihilation $\chi\chi \to \gamma\gamma, \gamma Z$

The WIMP miracle ?





Thermal production: $\frac{\Omega_{WIMP} h^2}{0.11} \approx \frac{3\times10^{-27}\,\mathrm{cm^3 s^{-1}}}{\langle \sigma v \rangle}$

Typical gauge couplings and weak scale interaction

$\Rightarrow$ Mass $\approx$ 100 - 1000 GeV for correct relic density.