ATLAS INCLUSIVE SEARCHES FOR SUSY AND DARK MATTER

Implications workshop
CERN, July 2012

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… from Higgs to SUSY

- Mass of the lightest MSSM Higgs boson h0 must fulfill:
  $M(h^0) < \cos(2\beta)\, M_Z$

  Weakend to $M(h^0) < 135$ GeV if radiative corrections are included

  "Aha, SUSY predicts a low mass higgs."

Higgs of 125 GeV consistent with
a) Degenerate stops
b) Quite heavy stops

Scenario might be

- 1st and 2nd gen. heavy
- Light stop required by naturalness
- Somehow light gluino

Most sensitive at early LHC:

- SUSY search for squarks and gluinos

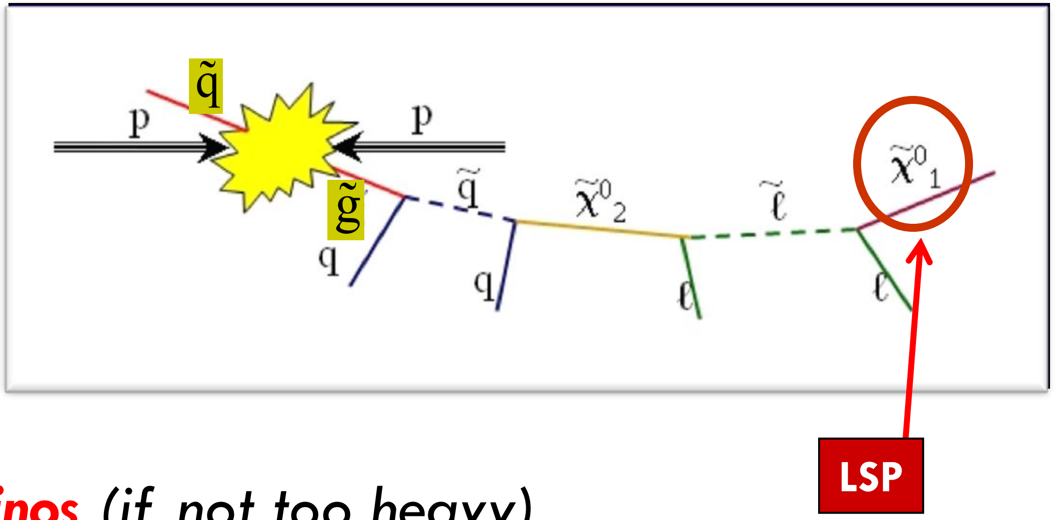
Maybe most sensitive if 1^{st} and 2^{nd} generation squarks are heavy due to 125 GeV Higgs :

- stop searches
- gluino searches

(maybe gaugino searches)

SUSY and the LHC : Signal

If R-Parity is conserved then SUSY particles are pair produced



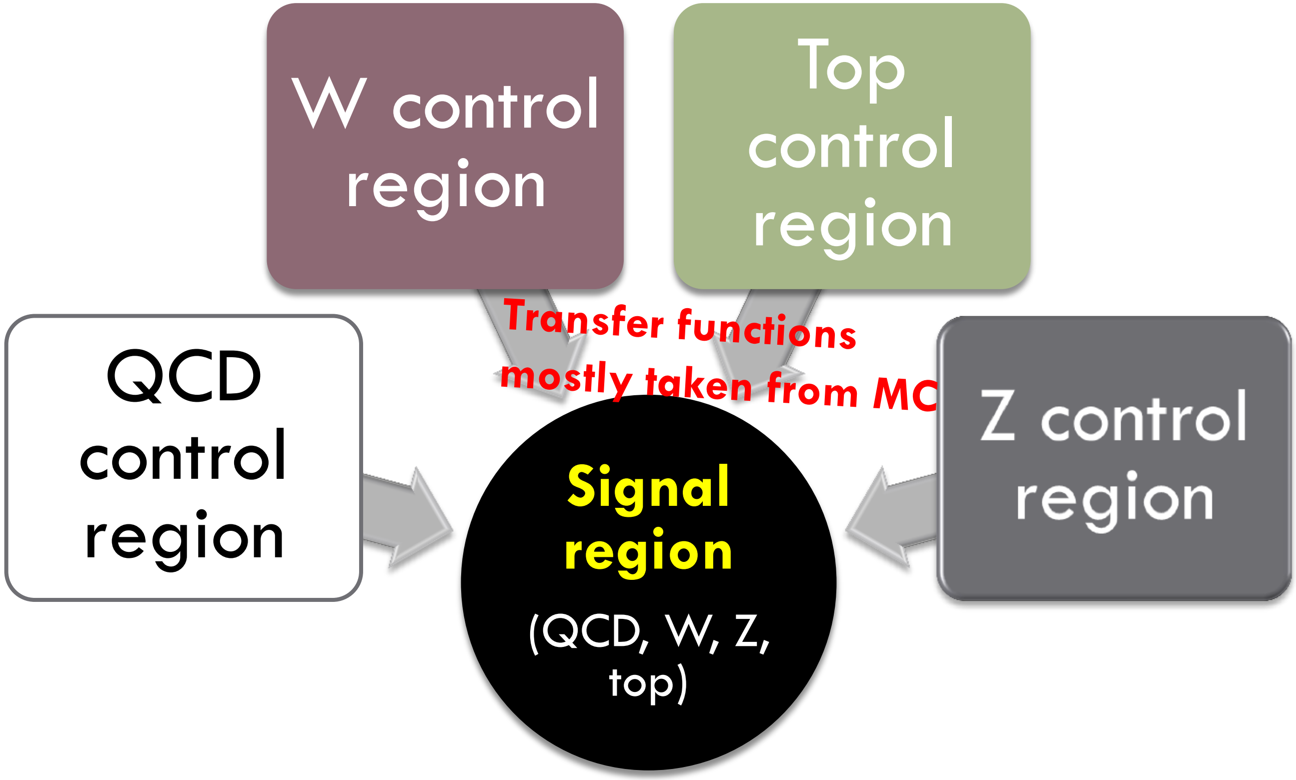
LHC:

Due to strong force dominant production of ***squarks*** *and* ***gluinos*** *(if not too heavy)*
Cascade decay to lighter SUSY particles and finally the lightest SUSY particle (LSP)

Similar conclusions /channels For many other models (Universal Extra Dimension, ADD, Little Higgs, ….)

Mass pattern in general SUSY unknown ! Searches need to be quite general and model-parameter-independent

Analysis model - control regions



- Measure number of events in control selections
- Predict number of events in signal region via a fit to control regions
- Important : Test model and transfer functions
  (e.g. by alternative control regions or methods)

SUSY searches overview

Short Title of the CONF note	Date	√s (TeV)	L (fb^{-1})	Document	Plots
Monophoton [ADD, WIMP] NEW	07/2012	7	4.7	ATLAS-CONF-2012-085	Link
Monojet [ADD, WIMP] NEW	07/2012	7	4.7	ATLAS-CONF-2012-084	Link
3 leptons + Etmiss [Direct Gauginos] NEW	07/2012	7	4.7	ATLAS-CONF-2012-077	Link
2 leptons + Etmiss [Direct Gauginos/sleptons] NEW	07/2012	7	4.7	ATLAS-CONF-2012-076	Link
Long-Lived Particles [R-hadron, slepton] NEW	07/2012	7	4.7	ATLAS-CONF-2012-075	Link
0 lepton + jets + Etmiss [Heavy Stop] NEW	07/2012	7	4.7	ATLAS-CONF-2012-074	Link
1 lepton + jets + Etmiss [Heavy Stop] NEW	07/2012	7	4.7	ATLAS-CONF-2012-073	Link
2 photons + Etmiss [GGM] NEW	07/2012	7	4.8	ATLAS-CONF-2012-072	Link
2 leptons + jets + Etmiss [Medium stop] NEW	07/2012	7	4.7	ATLAS-CONF-2012-071	Link
1-2 bjets + 1-2 leptons + jets + Etmiss [Light Stop] NEW					
2 leptons + jets + Etmiss [Very Light stop]					
3 bjets + 0lepton + jets + Etmiss [Gluino med. stop/sbo					
1 lepton + 3-4 jets + Etmiss					
Disappearing track + jets + Etmiss [AMSB]					
0 lepton + >=(2-6) jets + Etmiss					
Add. >=4 leptons + Etmiss Interpretation [RPV]					
Long lived Particle (Pixel-like)					
>=4 leptons + Etmiss	01/2012	7	2.05	ATLAS-CONF-2012-001	Link (inc. HEPData)
Z->ll + jets + Etmiss [GGM]	04/2012	7	1.04	ATLAS-CONF-2012-046	Link
Add. 2 leptons + jets + Etmiss interpretation [GMSB]	11/2011	7	1.04	ATLAS-CONF-2011-156	Link

ATLAS hunts now with a twofold strategy:

- Broad inclusive searches with many signal regions
- Highly optimized dedicated searches for exclusive SUSY signals

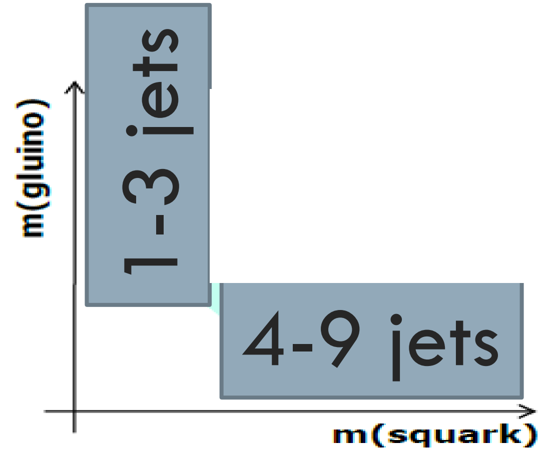
Example: Jets + E_t^{miss}

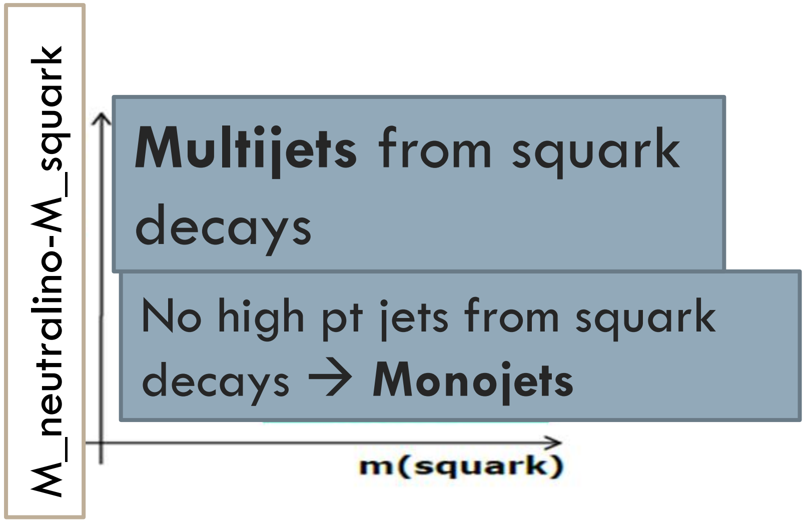
Studies are about 20 signal regions

From monojets to 9 jet events
(jets from squark/gluino decay
or if mass difference to LSP to low
No jets from squark/gluino decay)

From low MET to high MET
(best cut depends on ratio of produced particle mass to neutralino mass)

From high mass to low mass

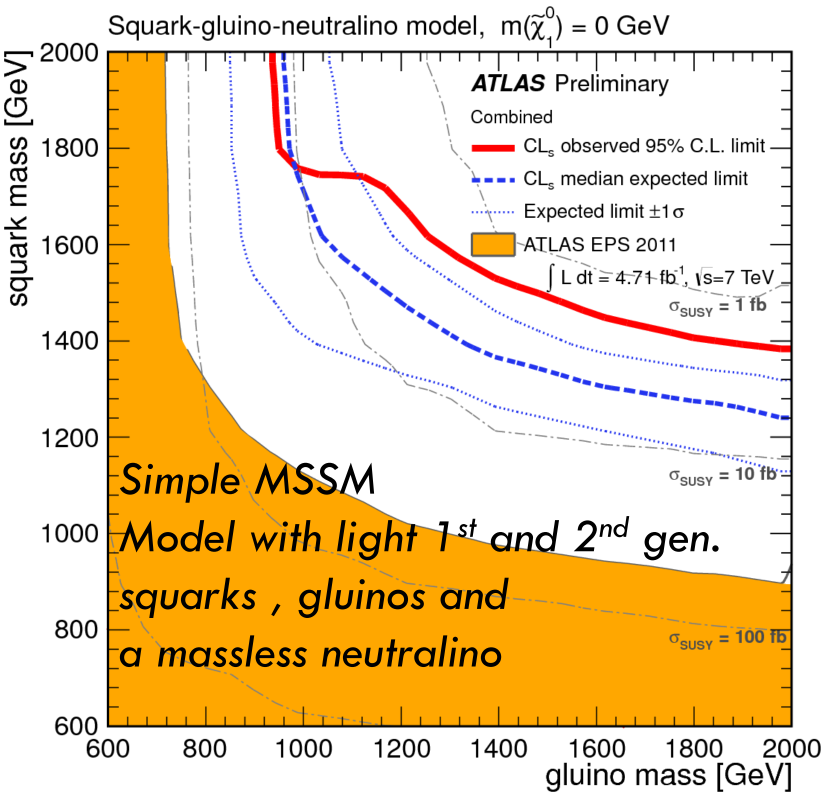




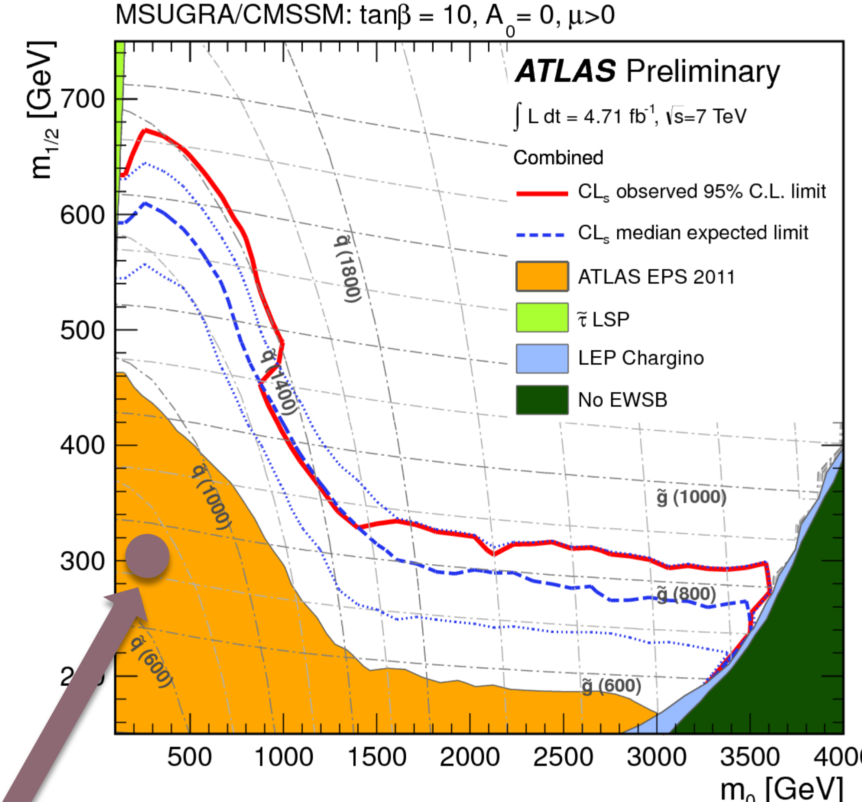
PLOTS NEED TO BE MADE NICE

Jets + E_t^{miss} : Results on 2011 data

Constrained MSSM Model with common Fermion and Boson Masses at the GUT scale



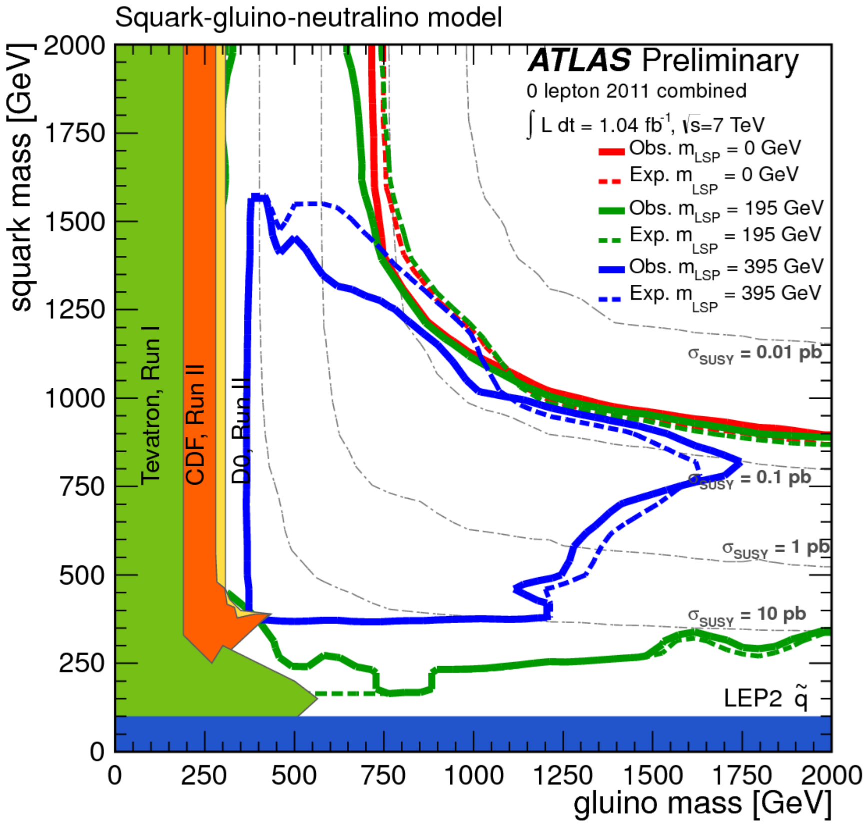
Simple MSSM
Model with light 1st and 2nd gen. squarks , gluinos and a massless neutralino



2009 "Best fit" cMSSM fit pre-LHC

Exclusion reach not strongly sensitive to sign(mu), tan beta and A_0

Jets + E_t^{miss} : LSP mass dependence



Not full dataset

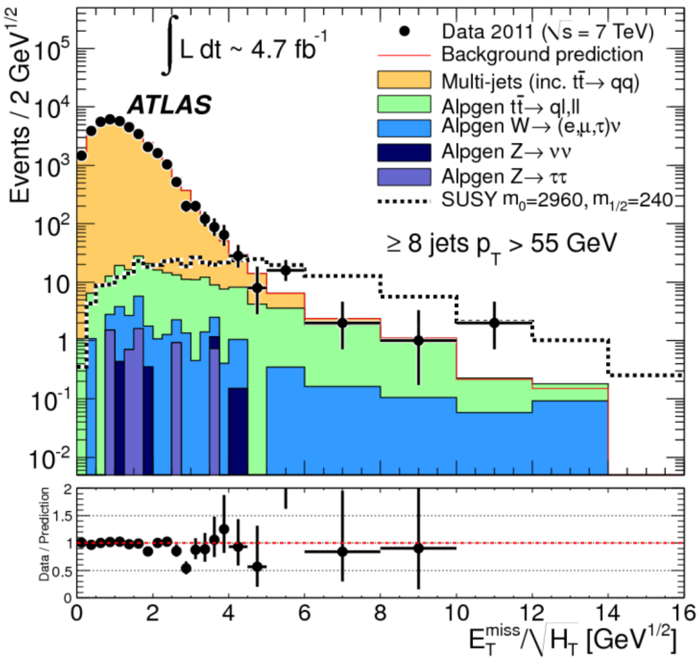
SUSY parameter space very large !

Here e.g. dependence of limits on neutralino (LSP) mass (old data)

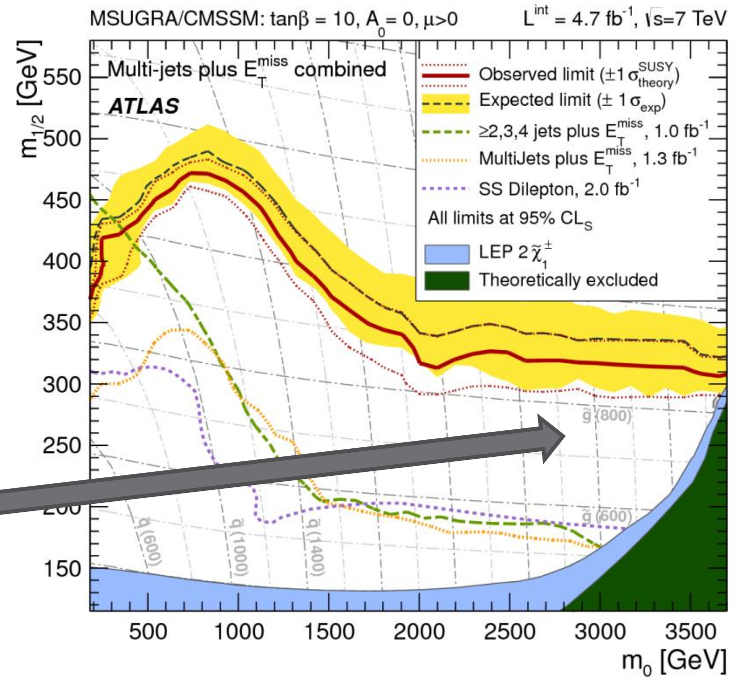
Investigated now with projections on “relevant” parameters (simplified models)

Jets + E_t^{miss} : High jet multiplicities

arXiv:1206.1760



Consider also very high jet multiplicities with dedicated analysis using Multijet triggers and lower MET significance signal regions (MET/√HT > 4 √GeV)



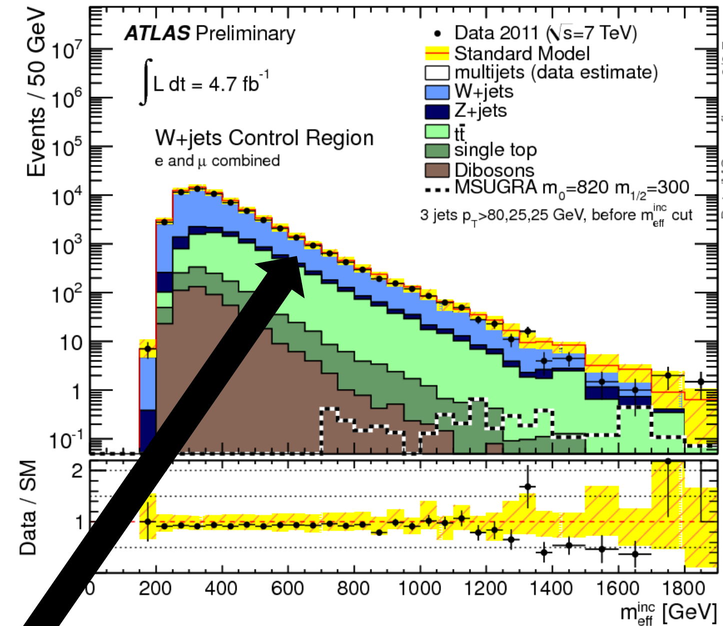
Sensitive to gluino production with long decay chains

(also limits to gluino mediated stops..)

Jets + E_t^{miss} + lepton

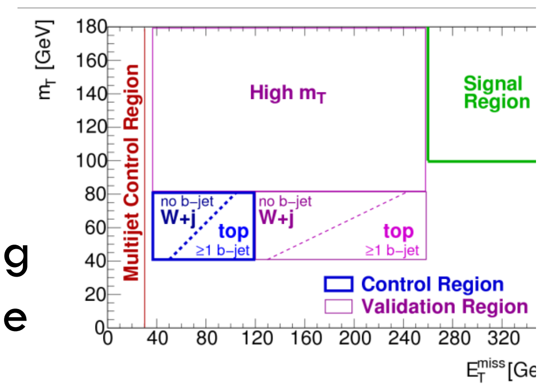
Exactly 1 electron or muon required

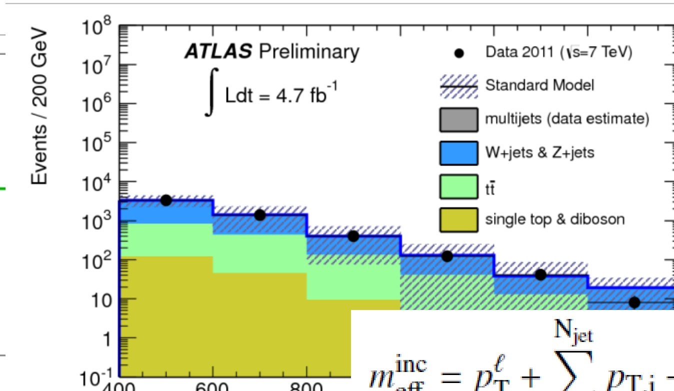
Use of a simultaneous fit to multiple signal regions and to the shapes of distributions within those signal regions (first time)



- **Fit in various jet bins, fit over constrained**
  → Constrains alpgen shape/nparton parameters (matching and scale)and B-jet uncertainty
- Control and validation regions in njet, transverse mass and missing transverse momentum plane

Also before fit nice description!
Effective mass distribution for the W validation region, nicely described after fit

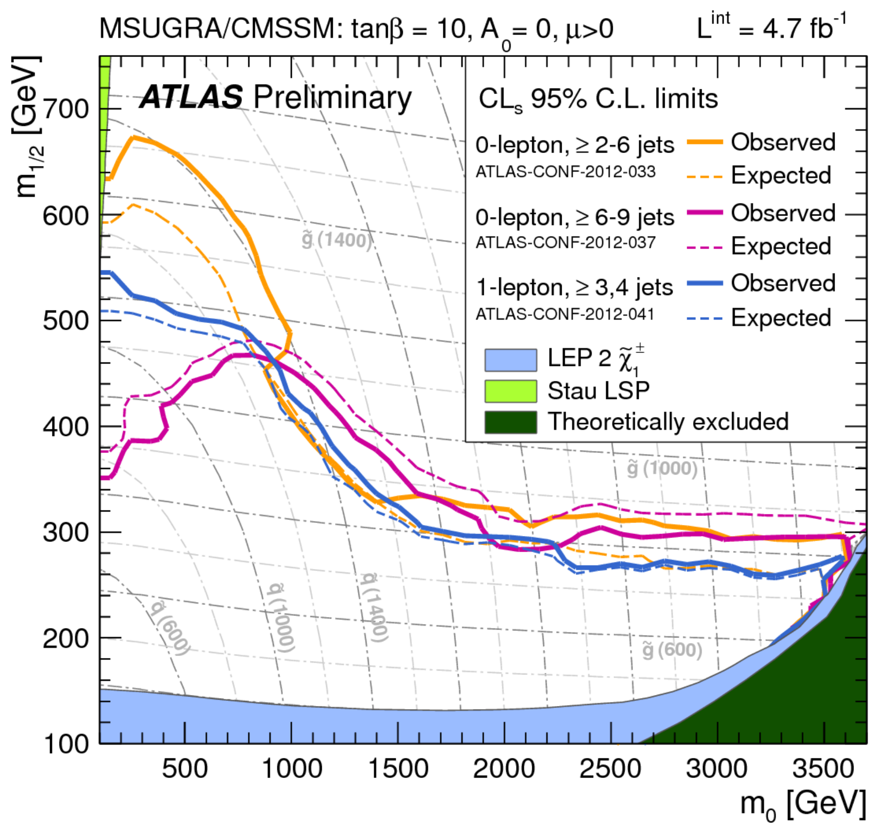




$$m_{\mathrm{eff}}^{\mathrm{inc}} = p_{\mathrm{T}}^{\ell} + \sum_{i=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},i} + E_{\mathrm{T}}^{\mathrm{miss}}$$

Jets + E_t^{miss} + lepton

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{obs}$[fb]
3-jet	1.3
4-jet	1.5
soft-lepton	3.7

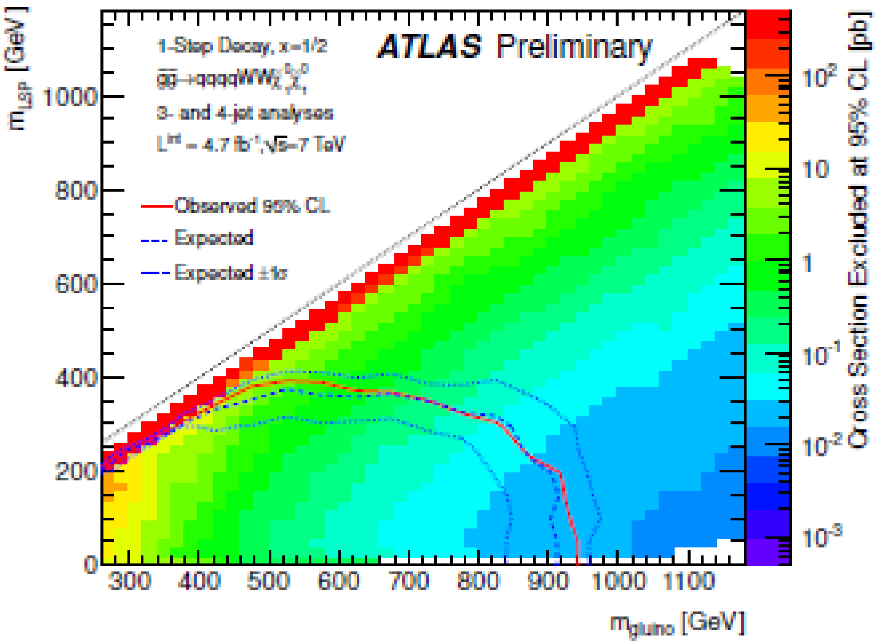


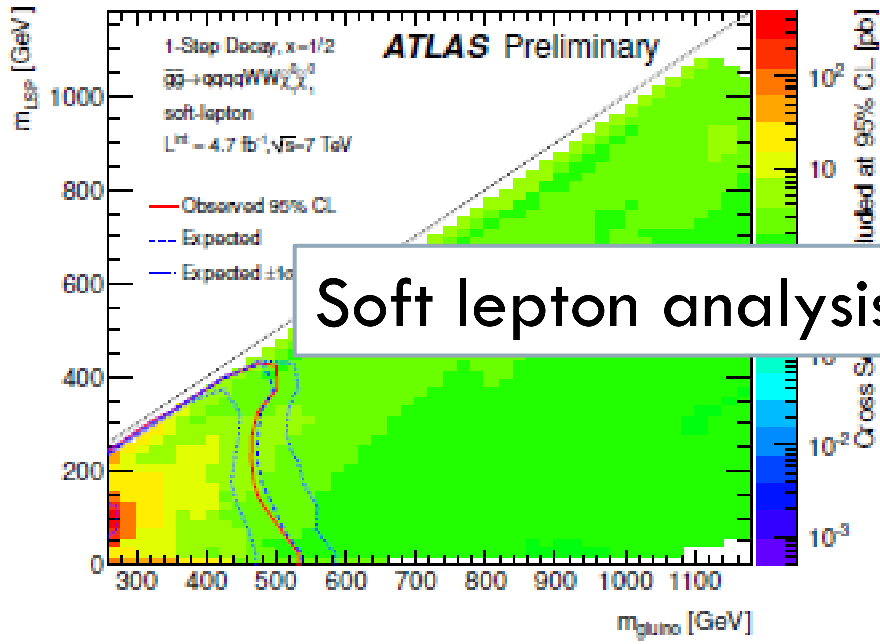
Comparison of expected and observed Limits of ATLAS 2-6 , 6-9 jet analysis and this analysis with 1-lepton

Note that these limits are (almost) independent and could (in principle) be combined

In addition now 1 lepton signal region with soft lepton (6-25 GeV) to cover SUSY decays with small mass differences

Jets + E_t^{miss} + lepton

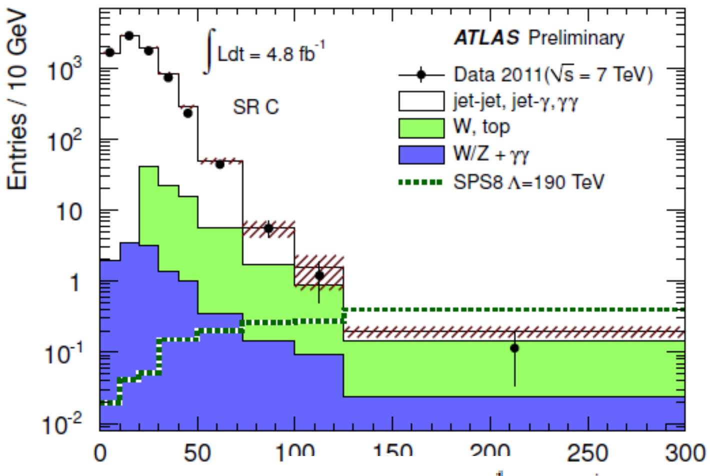




Soft lepton analysis

E_t^{miss} + Photon + Photon

Signal expected from **gauge mediated SUSY breaking** where the **neutralino** is the NLSP. If neutralino is a bino SM U(1) gauge boson it decays dominantly to **photon and gravitino** which is the LSP
or Universal Extra Dimensions (KK-photon decays to photon and gravition) typically leading to compressed spectra



$4.8 \pm 0.2\ fb^{-1}$

Signal region definition

	SR A	SR B	SR C
$\Delta\phi_{min}(\gamma, E_T^{miss}) >$	0.5	-	0.5
$H_T >$	600 GeV	1100 GeV	-
$E_T^{miss} >$	200 GeV	100 GeV	125 GeV

	SR A	SR B	SR C
QCD	$0.07 \pm 0.00 \pm 0.07$	$0.27 \pm 0.00 \pm 0.27$	$0.85 \pm 0.30 \pm 0.71$
Electroweak	$0.03 \pm 0.03 \pm 0.01$	$0.09 \pm 0.05 \pm 0.02$	$0.80 \pm 0.16 \pm 0.22$
$W(\rightarrow \ell\nu) + \gamma\gamma$	< 0.01	< 0.01	$0.18 \pm 0.13 \pm 0.18$
$Z(\rightarrow \nu\bar{\nu}) + \gamma\gamma$	< 0.01	< 0.01	$0.27 \pm 0.09 \pm 0.04$
Total	$0.10 \pm 0.03 \pm 0.07$	$0.36 \pm 0.05 \pm 0.27$	$2.11 \pm 0.37 \pm 0.77$
Observed events	0	0	2

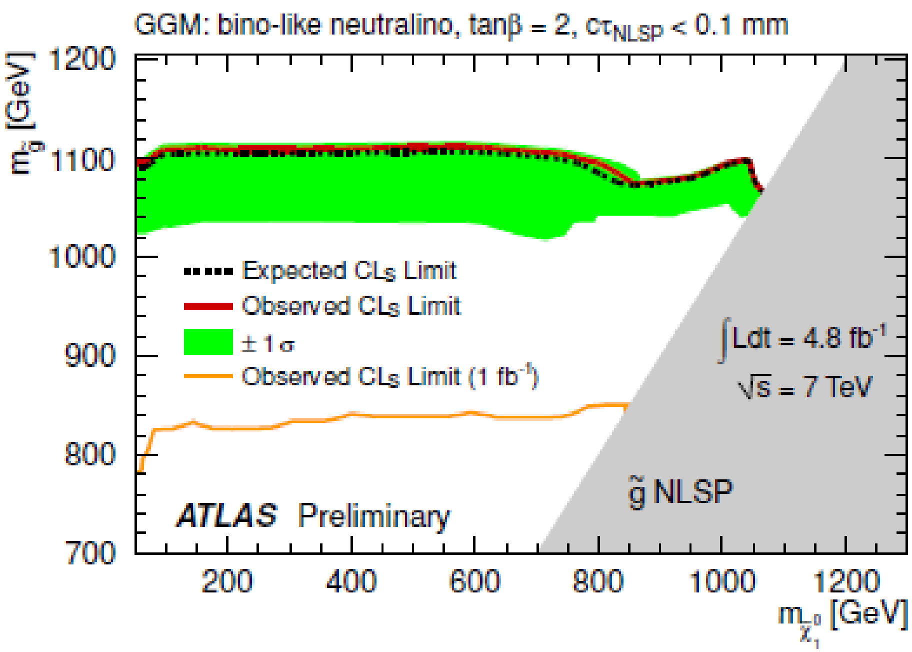
Optimization for squark/gluinos and SRC for intermediate-mass gaugino pairs that dominates the SPS8

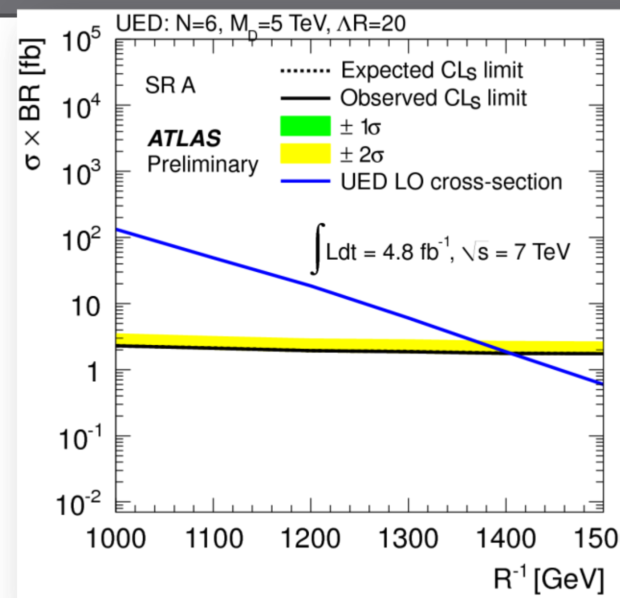
- QCD and EW by control samples, Irreducible via MC
- Better fighting bkg. from conversions

E_t^{miss} + Photon + Photon

Limits on a general gauge mediation model with bino-like neutralino decaying to photon + MET (squarks and gluinos, decoupled)

Gluino mass limit of 1100 GeV (almost independent of neutralino mass)





Limits on Universal Extra Dimension Models (1 universal Extra dimension) of compactivication R

Strong production via KK quarks/ KK gluons

Cascade decay to KK photon and

prompt gravitational decay to $\gamma^* \rightarrow \gamma + G$. G represents a tower of eV-spaced graviton states

Long lived sleptons and R-hadrons

- particles can be identified and their mass determined from speed and momentum and using

$$m = p/\gamma\beta$$

P from track curvature

Time of flight used to measure β

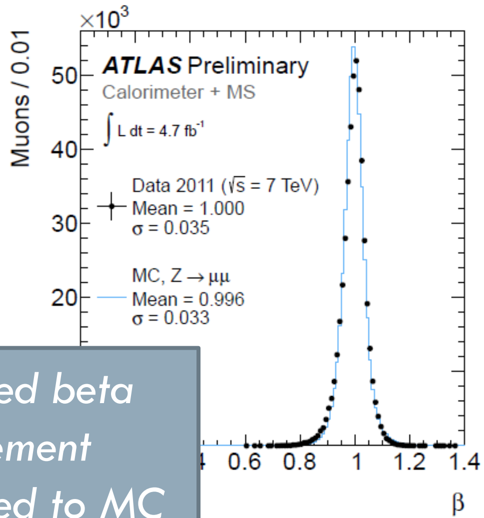
ATLAS tile and Lar calorimeter have sufficient time resolution (2 ns@1GeV) to measure beta, also beta measurement **from muon det.**

dE/dx, to measure $\beta\gamma$

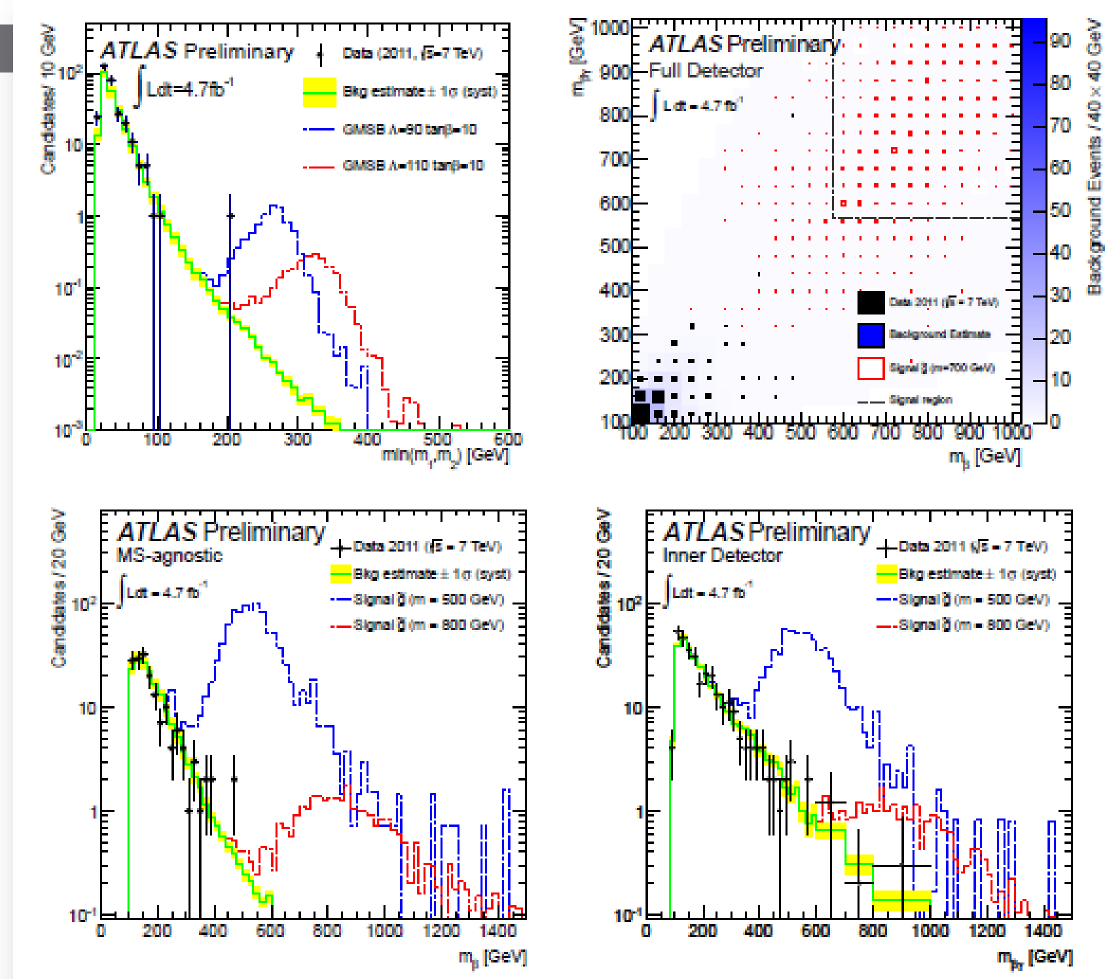
Pixel: From cluster charge measurements for the clusters associated with the track

1. **Slepton :** *identified as heavy muon in inner detector and muon spectrometer)*
   ➔ *interpreted in model with long lived stau (GMSB)*
2. **Squarks and Gluinos** *do hadronize and form R-Hadrons, neutral or charged states, may do charge flip on their way…*
   (so done with charge in inner detector only, everywhere or in muon detector only)

Long lived sleptons and R-hadrons



Combined beta measurement compared to MC



Event selection:

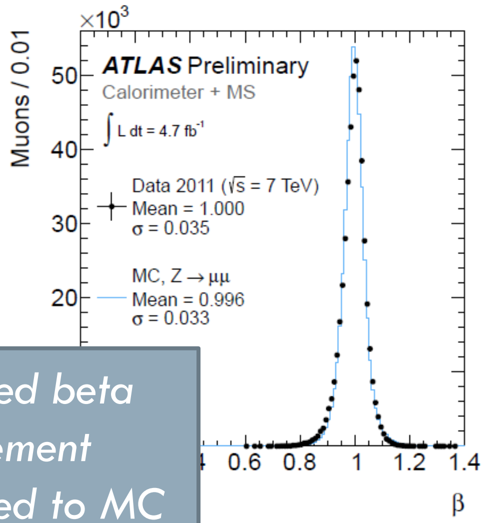
A) E_t^{miss} (R-hadron gives missing energy)

→3 R-Hadron signal regions

B) muon trigger for the slepton signals

Background from beta mismeasured muons/tracks
Background mostly from **random beta sampling**
(beta measurement independent from track , and signal low!)

Long lived sleptons and R-hadrons



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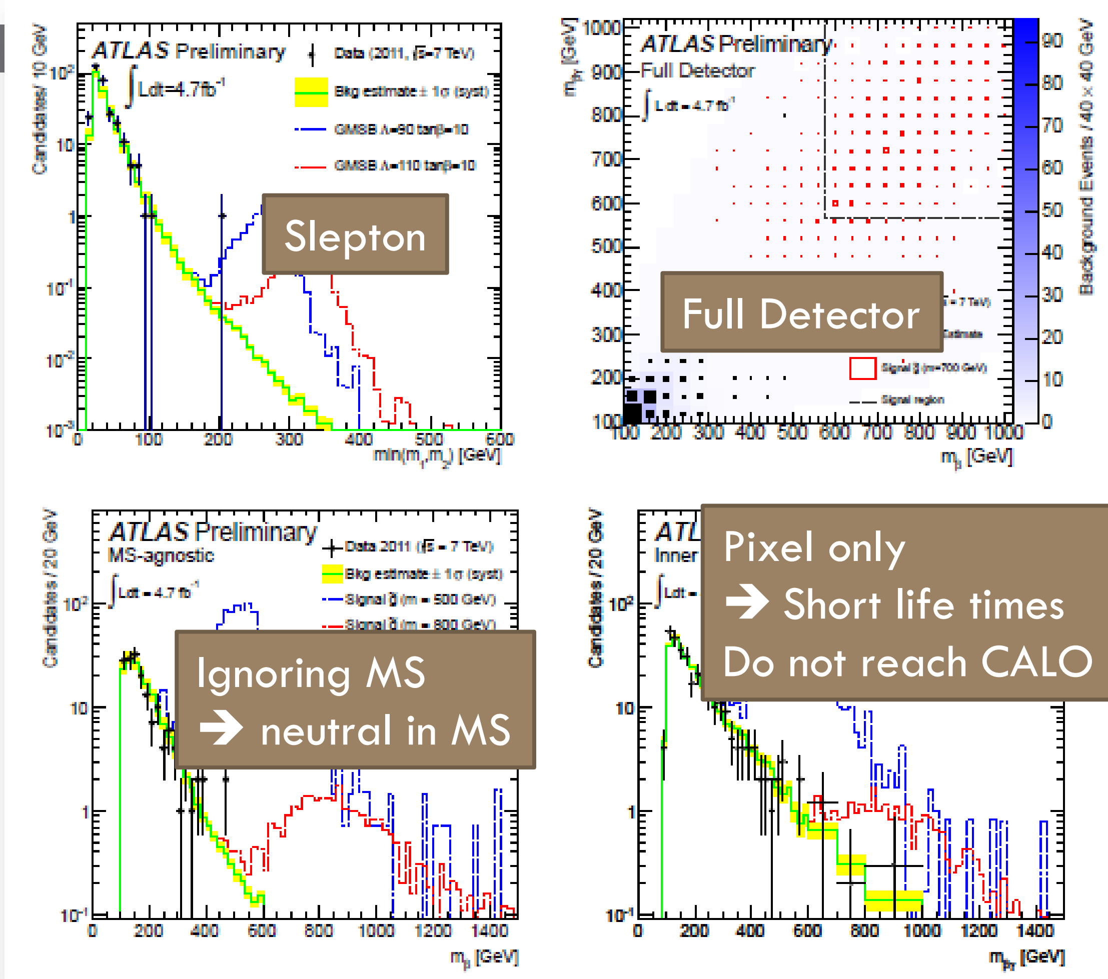


Slepton

Full Detector

Ignoring MS
➔ neutral in MS

Pixel only
➔ Short life times
Do not reach CALO

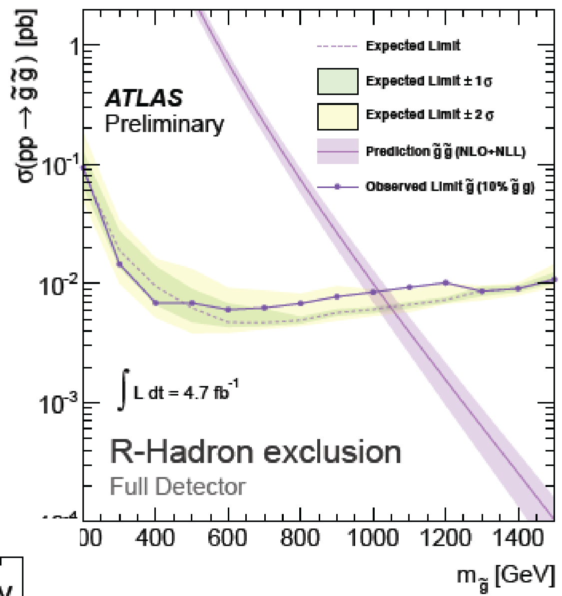
Event selection:
A) E_t^{miss} (R-hadron gives missing energy)
➔3 R-Hadron signal regions
B) muon trigger for the slepton signals

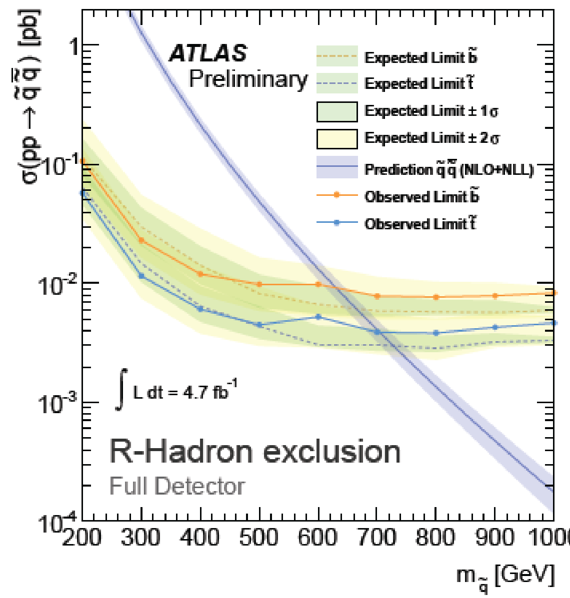
Background from beta mismeasured muons/tracks
Background mostly from **random beta sampling**
(beta measurement independent from track , and signal low!)

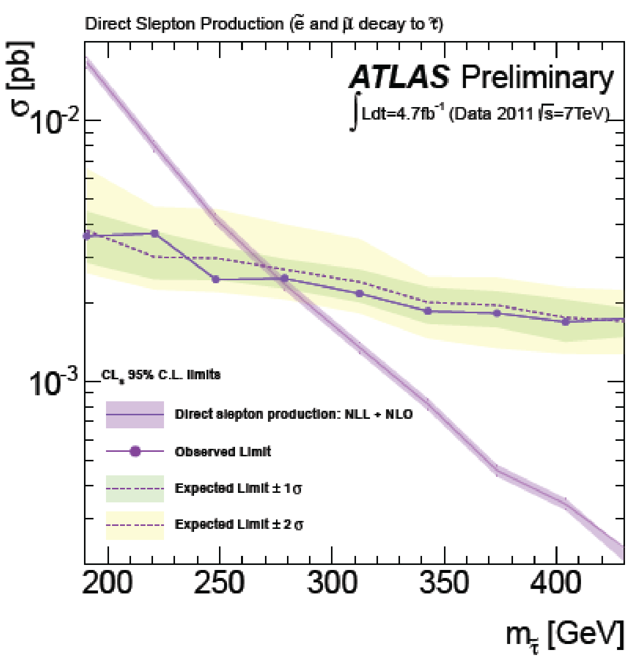
Long lived sleptons and R-hadrons

Limits from model-dependent mass cuts

R-Hadron exclusion using full detector





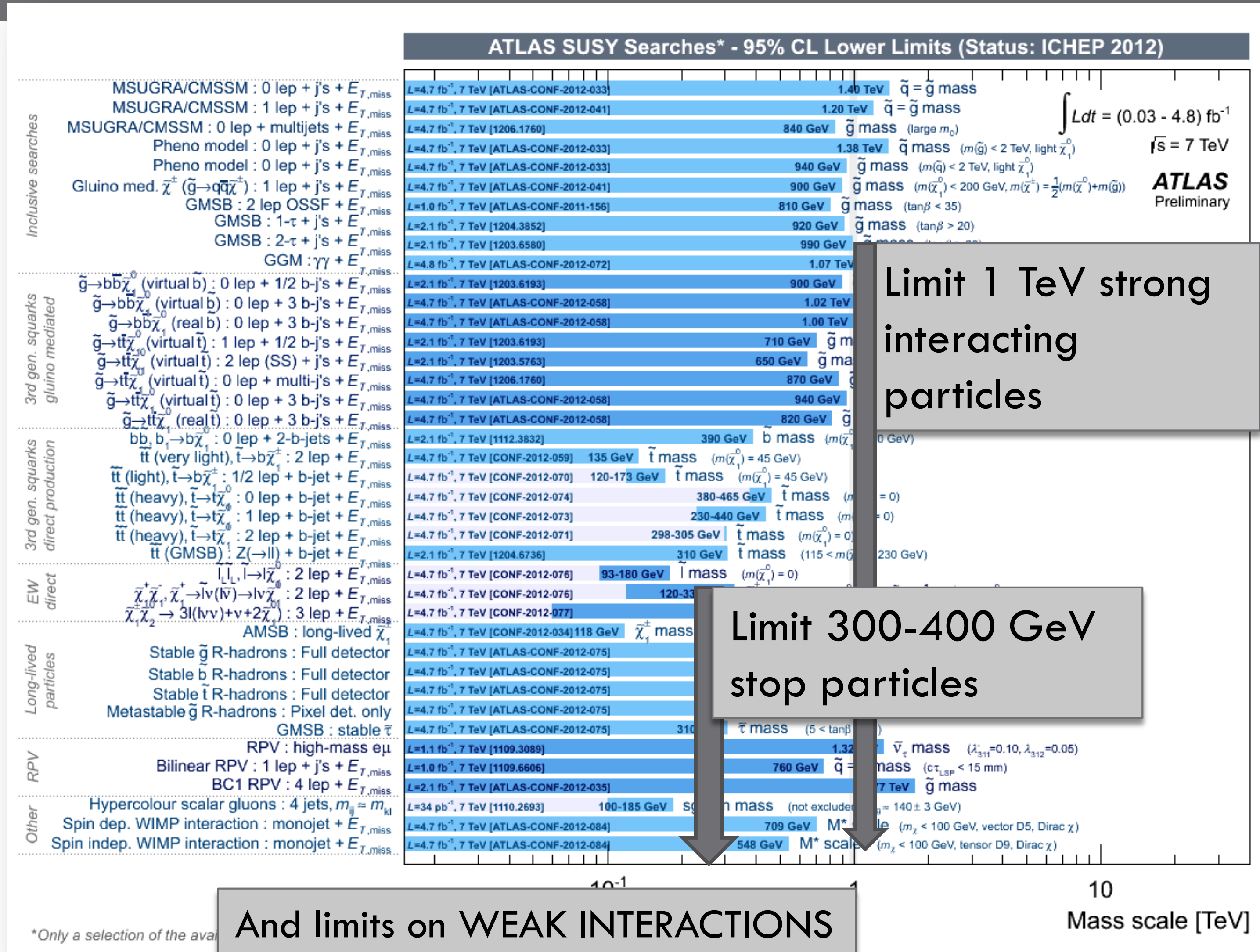


Mass limit on directly produced sleptons

DM production in SUSY decays

Summary of current limits, mostly on the production of Squarks and Gluinos

→ Strong constrains on SUSY models



Limit 1 TeV strong interacting particles

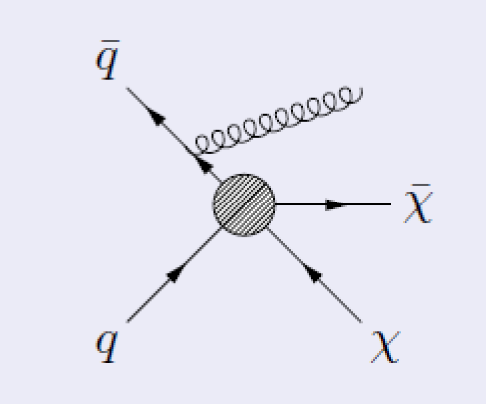
Limit 300-400 GeV stop particles

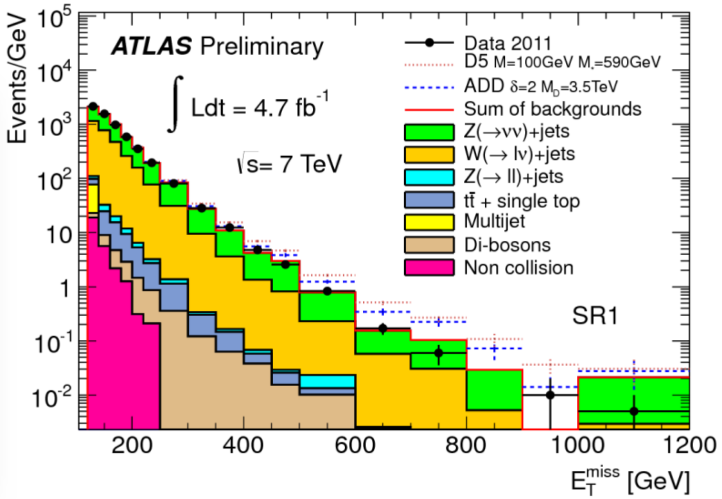
And limits on WEAK INTERACTIONS

Monojets/Monophotons

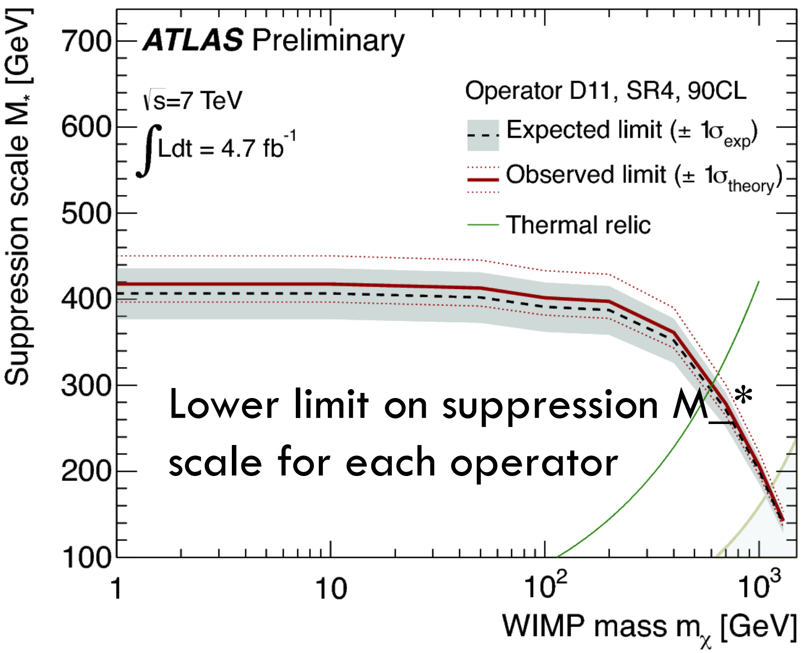
Looking for a jet from initial state Radiation to search for WIMP WIMP Events

- Signal is a Monojet/monophoton event !
- Missing momentum distribution





Assuming coupling ATLAS monojet searches can give bounds on WIMP-nucleon spin dependent cross section **(assuming new mediator with free coupling)** *Collider limit competitive if WIMP couple only via D11 (gg) coupling and for very low WIMP masses*



Lower limit on suppression M_* scale for each operator

Monojets/Monophotons

Looking for a jet from initial state Radiation to search for WIMP WIMP Events

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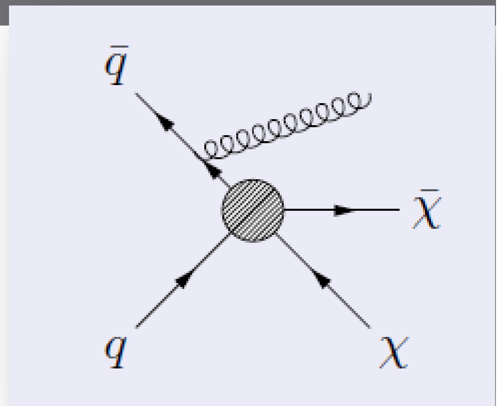
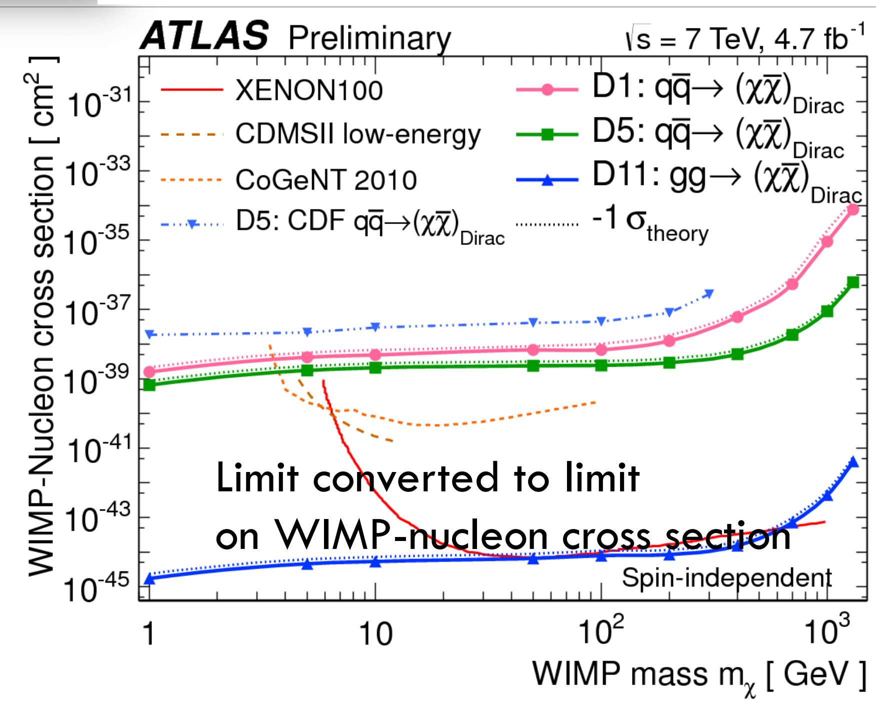


Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar\chi\chi\bar q q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar\chi\gamma^\mu\chi\bar q\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar\chi\gamma^\mu\gamma^5\chi\bar q\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar\chi\sigma^{\mu\nu}\chi\bar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



Assuming coupling ATLAS monojet searches can give bounds on WIMP-nucleon spin dependent cross section **(assuming new mediator with free coupling)** *Collider limit competitive if WIMP couple only via D11 (gg) coupling and for very low WIMP masses*

No SUSY ? → Are there ways out …

- Maybe SUSY is hidden ?
- → Close the gaps, e.g. low mass splittings, long decay chains
- → Search for a initial state radiation + NOTHING → Monojets
- Or SUSY is a bit heavier ?

  - For electroweak symmetry breaking not all SUSY particles have to be close to the 1 TeV scale, light stop and heavy 1st and 2nd gen. fermions → see talk by **Xavier Portell !**

  - If the Higgs is around 125 GeV, usually stop heavier, also other **SUSY particles expected to be >1 TeV ?**
- **Or SUSY looks a bit different ?**

  - Extend searches to non-standard SUSY scenarios

Summary

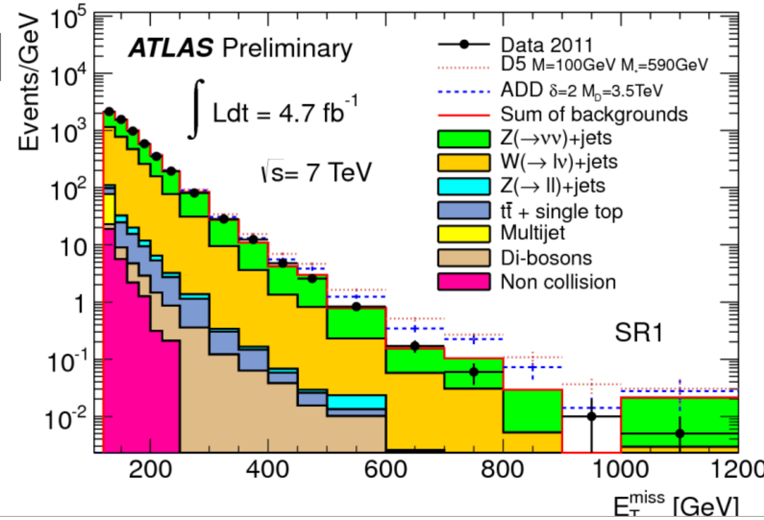
No signal, strong limits

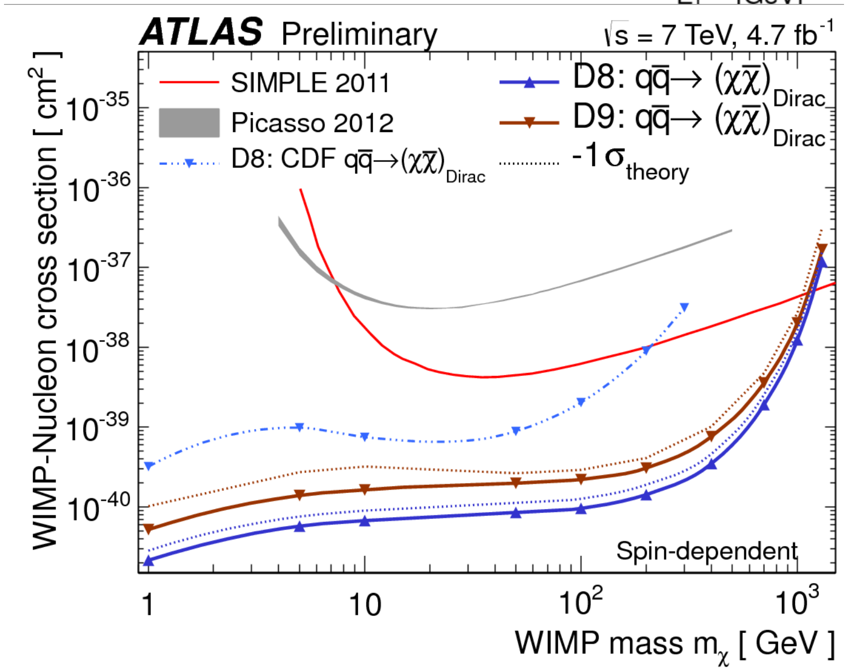
- Where is SUSY hidden ?

  Are we closing all “gaps” ?
- Is new physics hidden in an unexpected place ?

Monojets/Monophotons

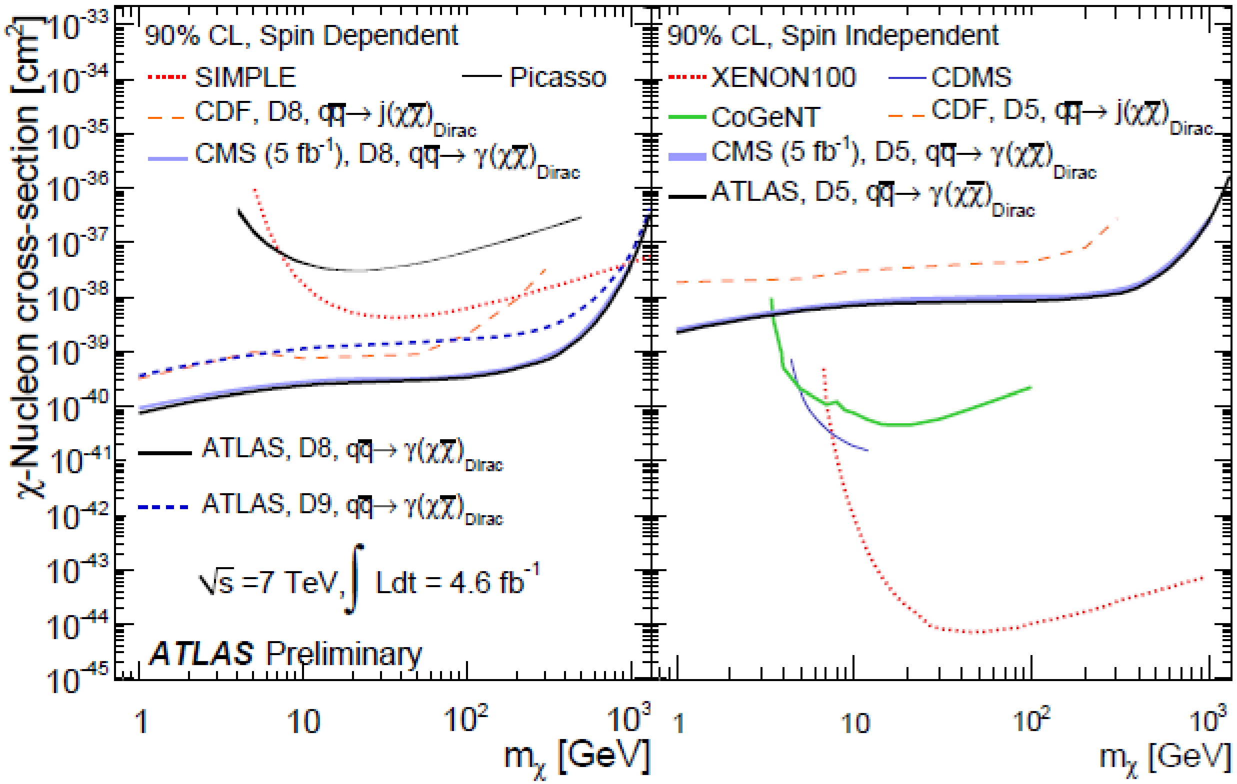
Looking for a jet
from initial state radiation
to search for WIMP WIMP
events!
- Signal is a Monojet event !
- Missing momentum
distribution as measured by
ATLAS





Assuming coupling ATLAS monojet searches can give bounds on WIMP-nucleon spin averaged cross section

Monojets/Monophotons



$$M_* \sim M / \sqrt{g_1 g_2}$$