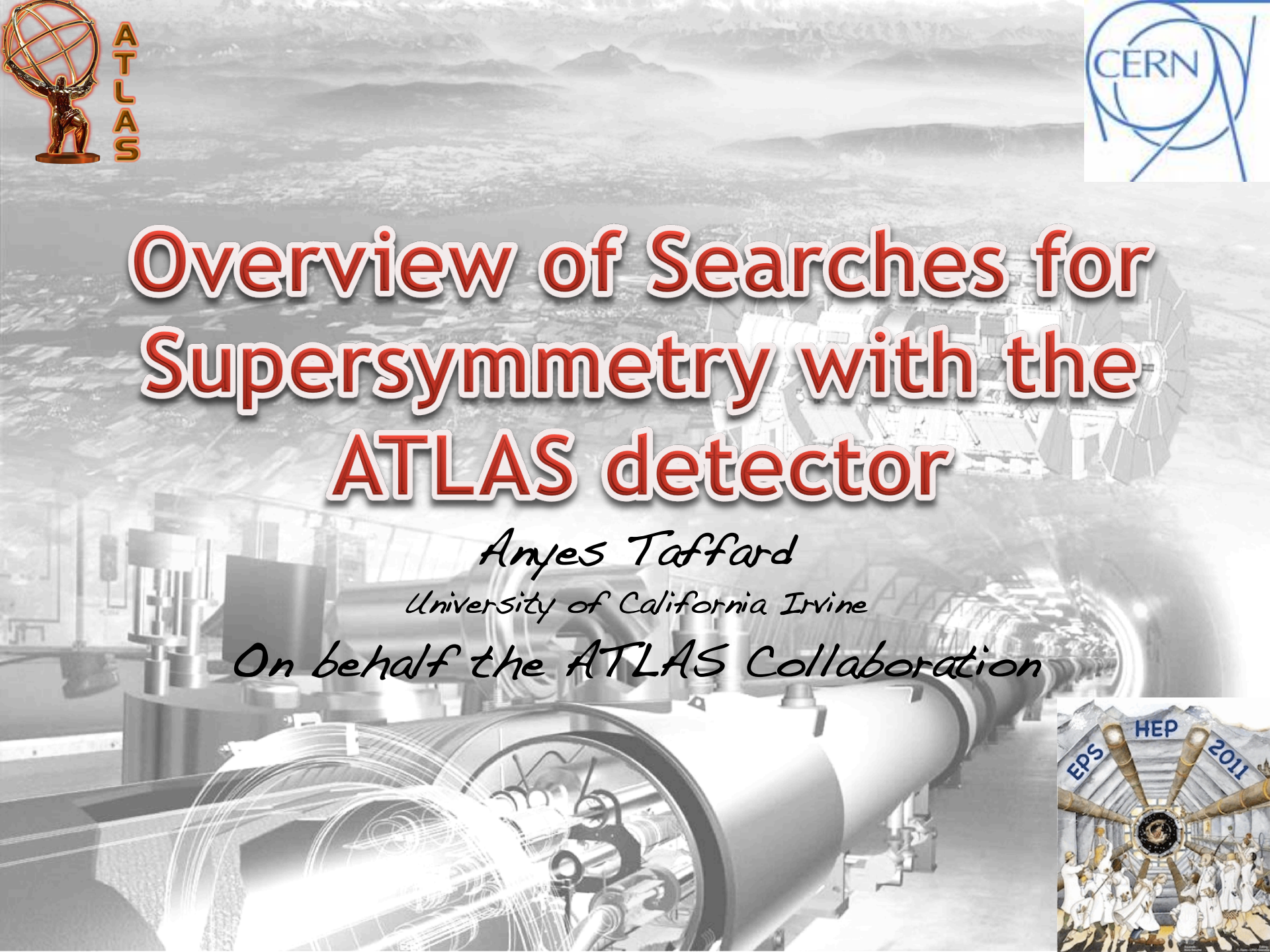
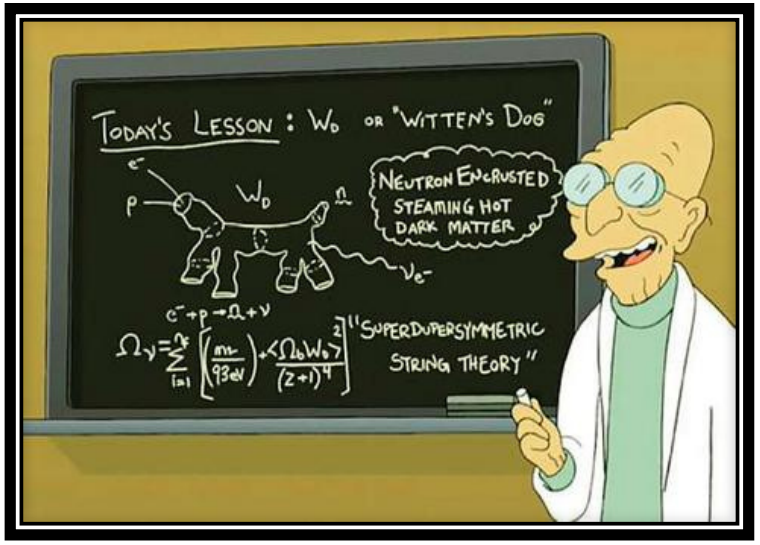

ATLAS
CERN
Overview of Searches for Supersymmetry with the ATLAS detector
Anyes Taffard
University of California Irvine
On behalf the ATLAS Collaboration
EPS HEP 2011

Outline

- Supersymmetry phenomenology at the LHC
- LHC operation and the ATLAS detector
- Overview of Supersymmetry searches in ATLAS
  - Focus on channels with a dark matter candidate
  - Emphasis experimental results
  - Latest results from 2011 data and 2010
- Conclusions and outlook

Links to Webpages:
ATLAS results
ATLAS SUSY results



Disclaimer:
Covering 8 analyses
Will occasionally be brief

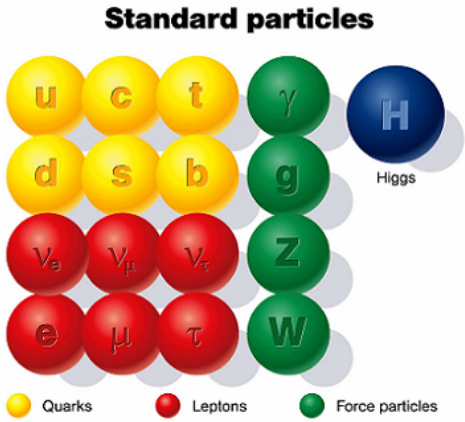
SuperSymmetry (SUSY) Introduction

One of the most popular extensions of the SM

✓ SUSY postulates "superpartners" to each SM particles and R-parity

$$R = (-1)^{3(B-L)+2s}$$

✓ If R-parity is conserved, SUSY particles are pair produced and the lightest one (LSP) is stable



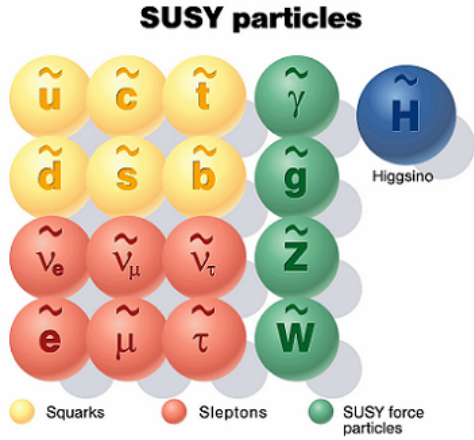
Why is SUSY popular ? It answers many open questions at once:

✓ Allows unification of gauge couplings

✓ Provides a solution to the hierarchy problem

- The fermion/boson contribution to the Higgs mass exactly cancel

✓ Offers a dark matter candidate



The SUSY experimental challenge:

✓ SUSY is very predictive in terms of spins and couplings, but tells us nothing about the masses, after symmetry breaking

✓ Results: 124 free parameters !

- All possible mass hierarchies between SUSY particles: 9! models

✓ Unknown mass hierarchy determines decay chain and (possibly long) lifetimes

So where do we start ?

Characteristic SUSY Decay Cascades

With R-parity conserved:

✓ SUSY production in pairs -> requires 2x SUSY mass!

✓ LSP→WIMP; Typically LSP spin ½ neutralino, linear combination of gauginos (typically mixture of photino and zino); LSP could also be gravitino

SUSY searches must be broad!

✓Gluinos and squarks couple strongly ⇒ dominant SUSY production at LHC

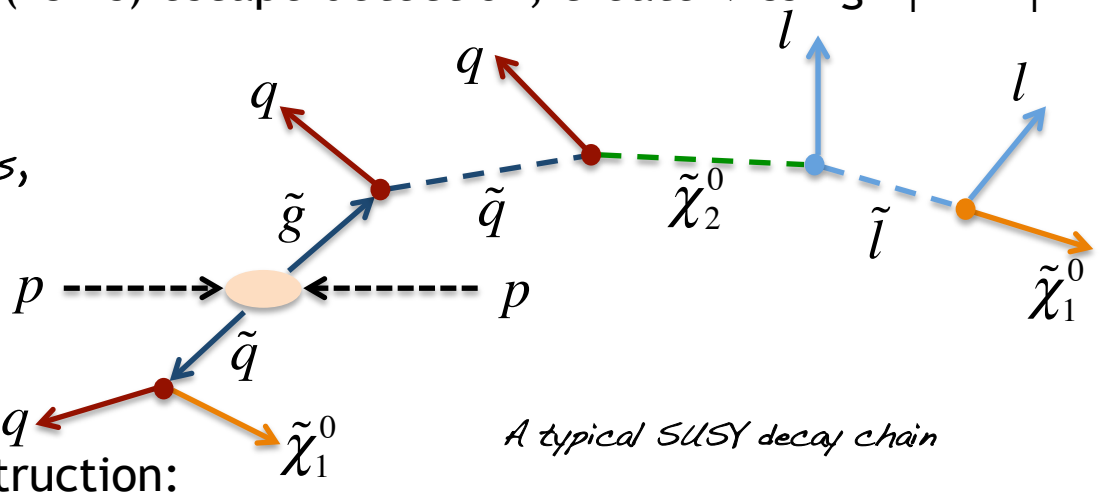
$$\sigma(\tilde{g}\tilde{g}) > \sigma(\tilde{q}\tilde{g}) > \sigma(\tilde{q}\tilde{q}) \text{ for } m(\tilde{g}) < 800 \text{ GeV}$$

$\tilde{q} \to q\tilde{\chi}_1^0$

$\tilde{g} \to qq\tilde{\chi}_1^0$

✓Lightest SUSY particles (LSP's) escape detection, create Missing $E_T \rightarrow E_T^{miss}$

Produce spectacular events with many hard jets, large MET and leptons None seen so far!



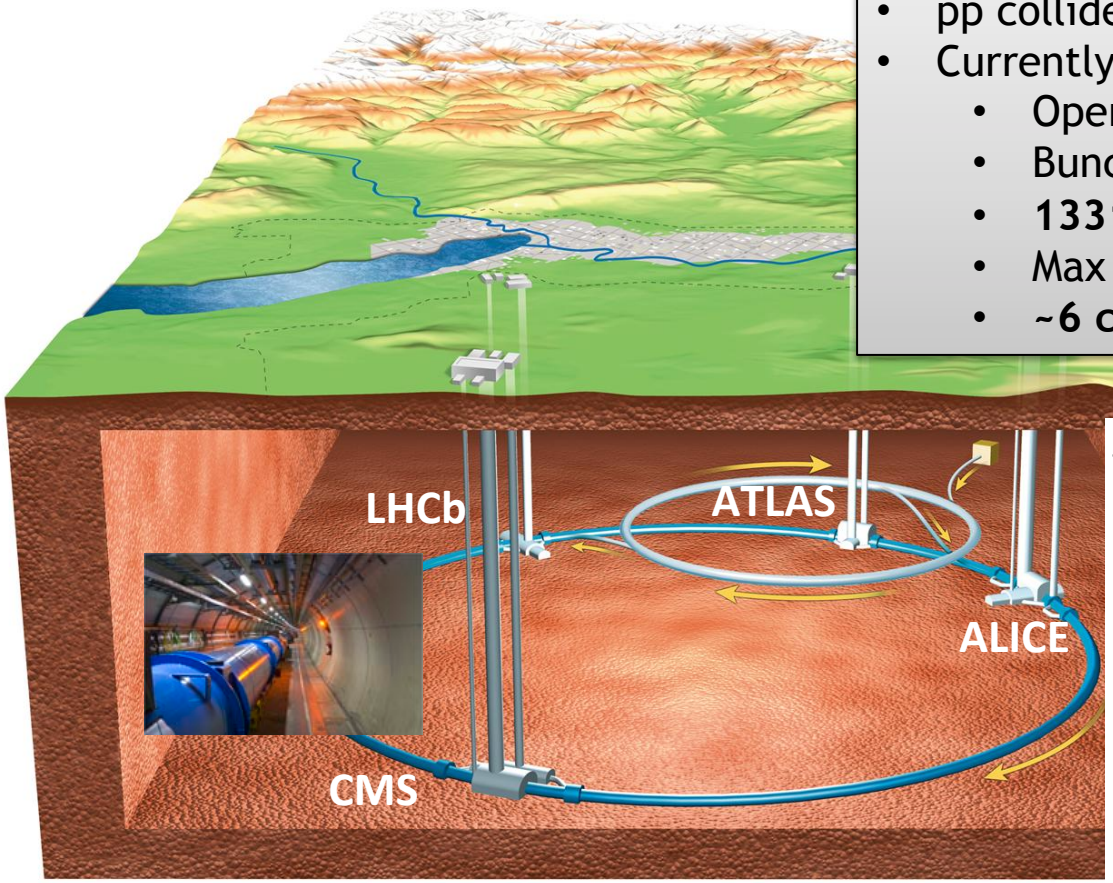
A typical SUSY decay chain

Incomplete event reconstruction:

- ✓ No mass peaks → SUSY evidence in tails of distributions
- ✓ Analysis concentrates on understanding backgrounds (top, W/Z+jets, QCD)
- ✓ Each background component is taken from/verified in control regions

The Large Hadron Collider

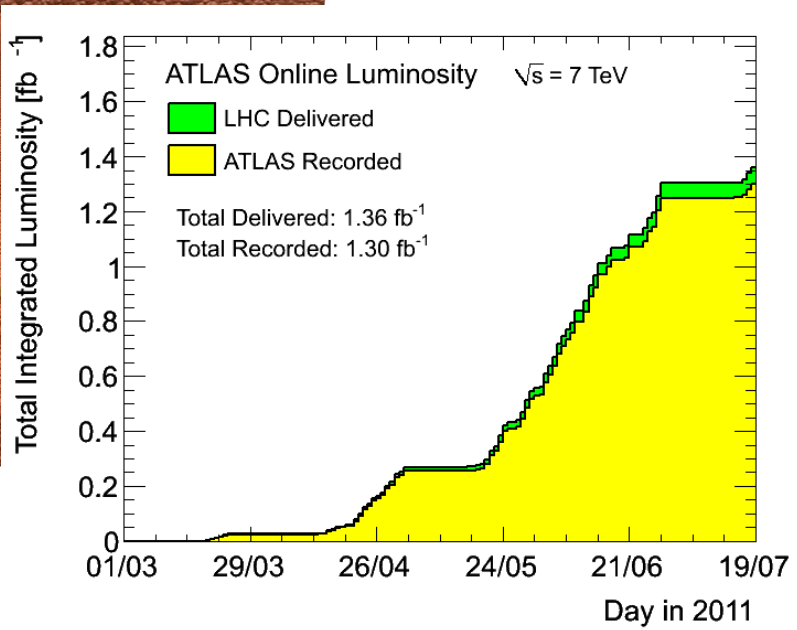
In 2011



LHC has 4 large experiments:
ATLAS, CMS, LHCb, ALICE

2011 LHC facts

- pp collider at 7 TeV center-of-mass energy
- Currently (July 2011):
  - Operating Peak Luminosity: **1.5×10^{33} $cm^{-2}s^{-1}$**
  - Bunch spacing: **50 ns**
  - **1331 bunches** colliding in ATLAS
  - Max integrated luminosity per fill **~60 pb^{-1}**
  - **~6 collisions per bunch crossing**



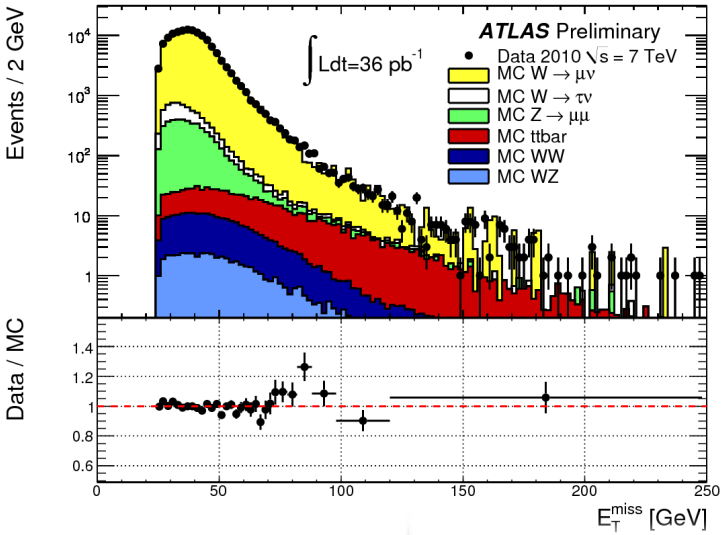
See Talk by V. Hedberg & poster by C. Gabaldon on luminosity measurement in ATLAS

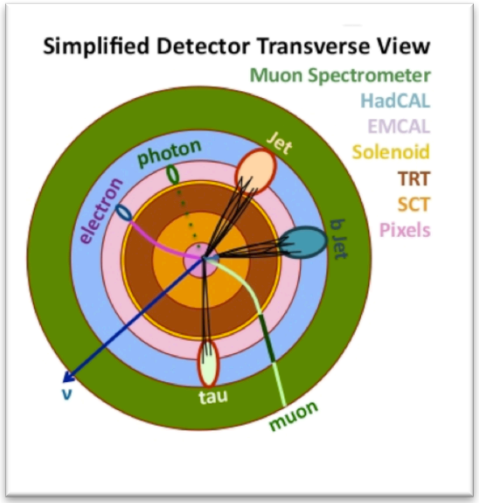
The ATLAS Detector

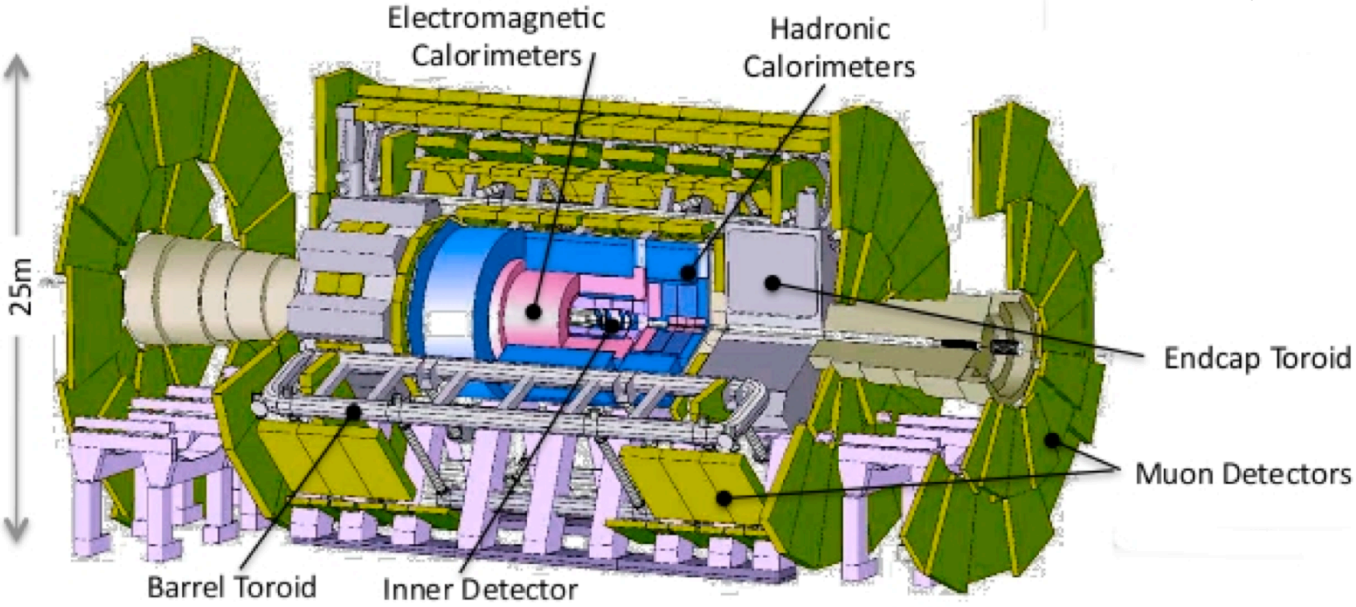
Multipurpose multi-layered detector

- Design specifications
  - ✓ Fast response and fast readout
  - ✓ High granularity
  - ✓ Radiation resistant
- Performance specifications
  - ✓ Large acceptance and hermeticity
  - ✓ Excellent jet and E_T^{miss} resolution
  - ✓ Excellent particle identification
  - ✓ Excellent vertex reconstruction
  - ✓ Standalone muon measurement

E_T^{miss} in W→μν







Overview of SUSY searches in ATLAS

Perform generic SUSY searches for a given final state guided by a SUSY model (eg. R-parity conserving SUSY)

Concept of model independent analysis:

- ✓ Inclusive selection for a given final state
- ✓ High efficiency for a broad range of model associated with final state

Almost all search analyses require data-driven estimates of backgrounds from data control region and extrapolation to signal region.

- ✓ This is the primary analysis challenge
- ✓ These estimate rely on pioneering SM measurements and accurate understanding of the physics objects

Statistically independent

Channel	Signature	Main backgrounds
0 lepton + jets + E_T^{miss}	≥2-4 jets, large E_T^{miss}, $m_{eff}^{(*)}$	W/Z+jets, top, QCD
1 lepton + jets + E_T^{miss}	e/μ, ≥3 jets, large E_T^{miss}, m_{eff}, m_T	Top, W/Z+jets, QCD
2 leptons (SS/OS) + E_T^{miss}	2 e/μ, large E_T^{miss}	SS: Fakes, diboson, top OS: top, Z+jets
≥3 leptons + E_T^{miss}	≥2 jets, E_T^{miss}, $m_{l^+l^-} \neq m_Z$	Z+jets, top
0 lepton + b-jets + $E_t^{miss(**)}$	1-2 b-jets, m_{eff}	Top, W/Z+jets, QCD
γγ + E_T^{miss}	2 γ, E_T^{miss}	QCD, top, Wγ+jets
+ more targeted analyses for SUSY scenarios with featured not covered by above inclusive searches. See exhaustive list on slide 21		

* $m_{eff} \equiv \sum_{i=1}^{n} |\mathbf{p}_T^i| + E_T^{miss}$

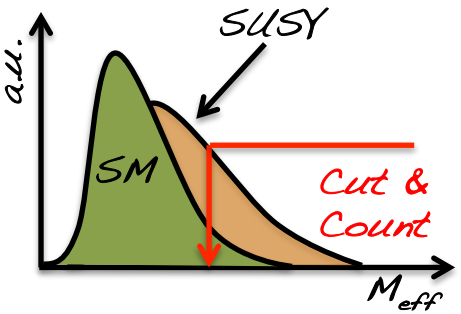
** Large mixing scenario can give light sbottom, stop with $\tilde{g} \to \tilde{b}_1 b,\ \tilde{g} \to \tilde{t}_1 t$

New: 1.04 fb^{-1} Jets+E_T^{miss} Search

- To maximize $m_{\tilde{g}}, m_{\tilde{q}}$ coverage, defines 5 signal regions:

Discard events with e(μ) p_T>20 GeV (10 GeV)

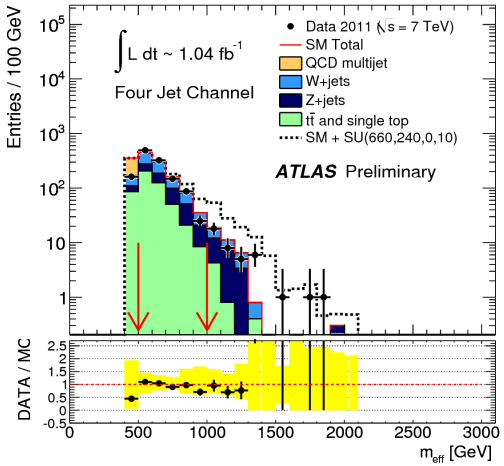
- ✓ $\tilde{q}\tilde{q} \to (q\tilde{\chi}_0^1)(q\tilde{\chi}_0^1)$
- ✓ $\tilde{g}\tilde{g} \to (qq\tilde{\chi}_0^1)(qq\tilde{\chi}_0^1)$
- ✓ $\tilde{g}\tilde{q} \to (qq\tilde{\chi}_0^1)(q\tilde{\chi}_0^1)$

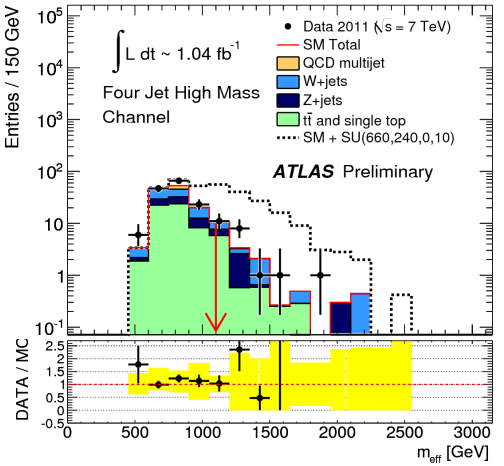


$$m_{eff} \equiv \sum_{i=1}^{n} \left|\mathbf{p}_T^i\right| + E_T^{miss}$$

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

Background Sources	
W+jets	Lepton measured as jets
Z/γ+jets	γ/leptons measured as jets
top	Hadronic τ decay
QCD jets	Mismeasurement of jets or ν in H.F decay
All background estimations are data-driven	





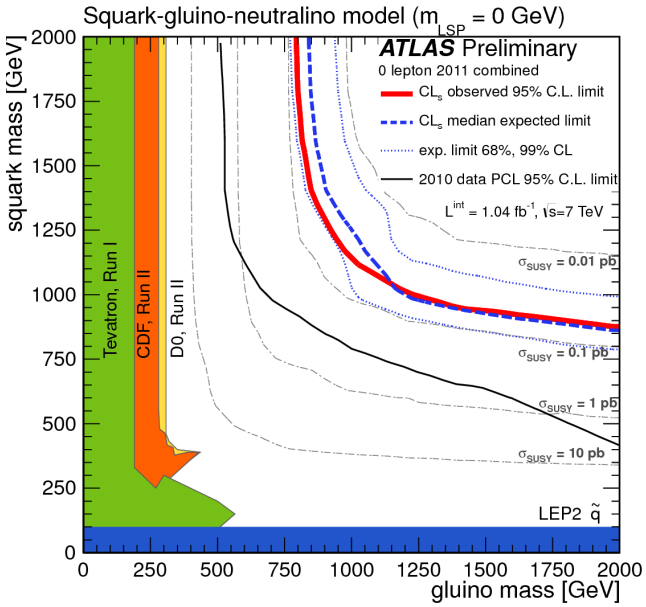
Process	≥2-jets	≥3-jets	≥4-jets M_{eff}>500 GeV	≥4-jets M_{eff}>10000 GeV	High mass
Total	62.3 ± 4.3 ± 9.2	55.0 ± 3.8 ± 7.3	984 ± 39 ± 145	33.4 ± 2.9 ± 6.3	13.2 ± 1.9 ± 2.6
Data	58	59	1118	40	18

New: 1.04 fb^{-1} Jets+E_T^{miss} Search Interpretation

Best expected signal region per model point is chosen

Phenomenological MSSM squark-gluino grids:

- ✓ masses from 100 GeV to 2 TeV, neutralino mass of 0
- ✓ Limits unchanged if LSP mass raised to 200 GeV

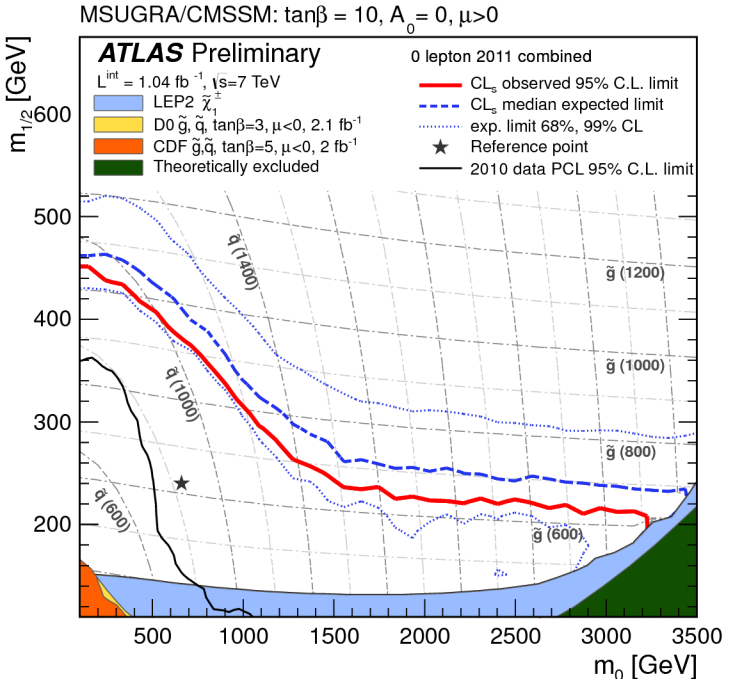


Exclude at 95% C.L

$m_{\tilde{g}} \leq 800$ GeV $\quad m_{\tilde{q}} \leq 850$ GeV

If $m_{\tilde{g}} = m_{\tilde{q}}$, masses < 1075 GeV

MSUGRA/CMSSM A_0=0, tanβ=10, μ>0



Exclude at 95% C.L

If $m_{\tilde{g}} = m_{\tilde{q}}$, masses < 980 GeV

Model independent fiducial cross section limit, 95% C.L.

≥2-jets	≥3-jets	≥4-jets M_{eff}>500 GeV	≥4-jets M_{eff}>10000 GeV	High mass
24 fb	30 fb	477 fb	32 fb	17 fb

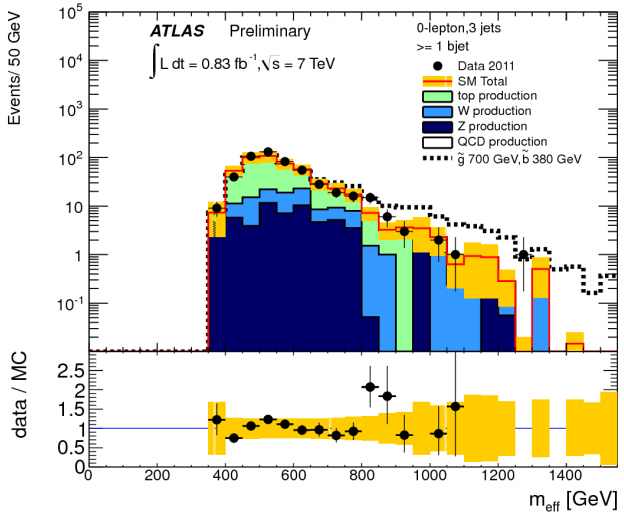
- Scalar mass parameters: m_0
- Gaugino mass parameter: m½
- Trilinear Higgs-sfermion-sfermion coupling: A_0
- Ratio of Higgs vacuum expectation values: tanβ
- Sign of SUSY Higgs parameter: sign(μ)

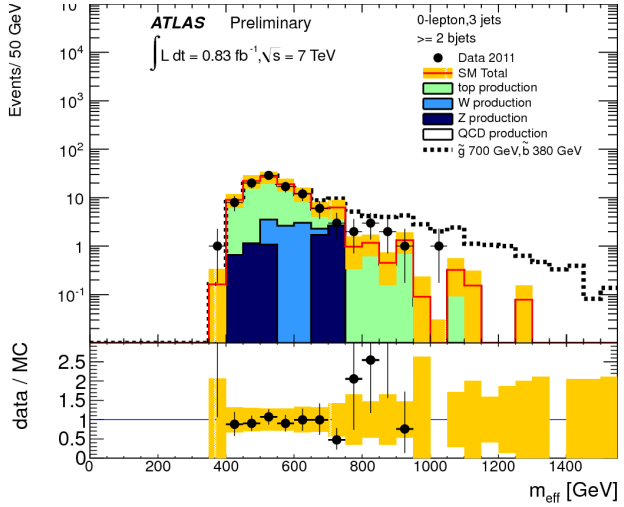
New: 0.83 fb^{-1}

b-jets + E_T^{miss}

Designed to be sensitive to 3rd generation squarks in R-parity conserving SUSY scenarios

- Analysis selection similar to the Jets+E_T^{miss} analysis, add the requirement of at least one b-jet
  - ✓ To maximize sensitivity define 4 signal regions





3J-A	3J-B	3J-C	3J-D
≥1 b-tag m_{eff}>500 GeV	≥1 b-tag M_{eff}>700 GeV	≥2 b-tag m_{eff}>500 GeV	≥2 b-tag M_{eff}>700 GeV

Process	3J-A	3J-B	3J-C	3J-D
Total	356^{+103}_{-92}	70^{+24}_{-22}	79^{+28}_{-25}	$13^{+5.6}_{-5.2}$
Data	361	63	76	12

Main systematics uncertainties: top theory cross section (~30%), JES (~20%), b-tagging (1-20%)

Model independent fiducial cross section limit, 95% C.L.

Signal Region	3J-A	3J-B	3J-C	3J-D
95% C.L N events	240	51	65	14
95% C.L σ (pb)	0.288	0.061	0.078	0.017

New: 0.83 fb^{-1}

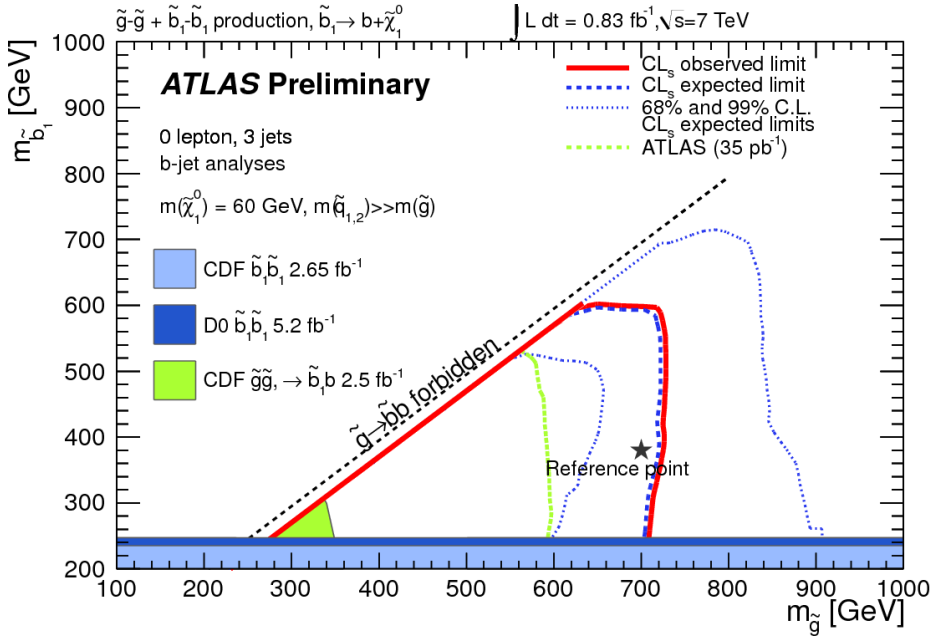
b-jets + E_T^{miss} Interpretation

Best expected signal region per model point is chosen

- Interpretation of the zero-lepton results in gluino-sbottom scenarios

Phenomenological MSSM

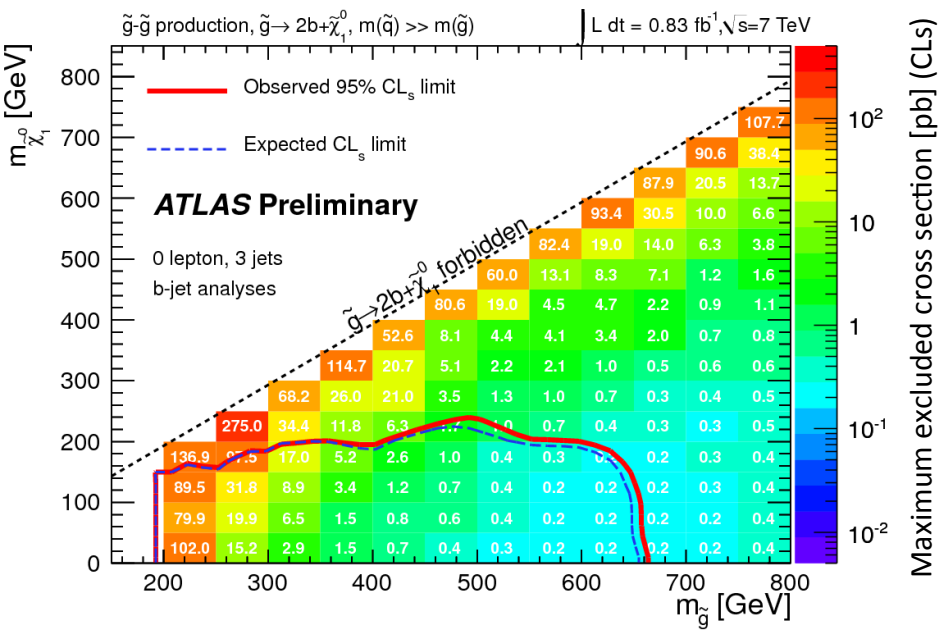
$BR(\tilde{g} \to \tilde{b}_1 b) = 100\%$ $BR(\tilde{b}_1 \to b + \tilde{\chi}_1^0) = 100\%$ $m_{\tilde{\chi}_1^0} = 60$ GeV



Gluino masses below 720 GeV excluded for sbottom masses below 600 GeV

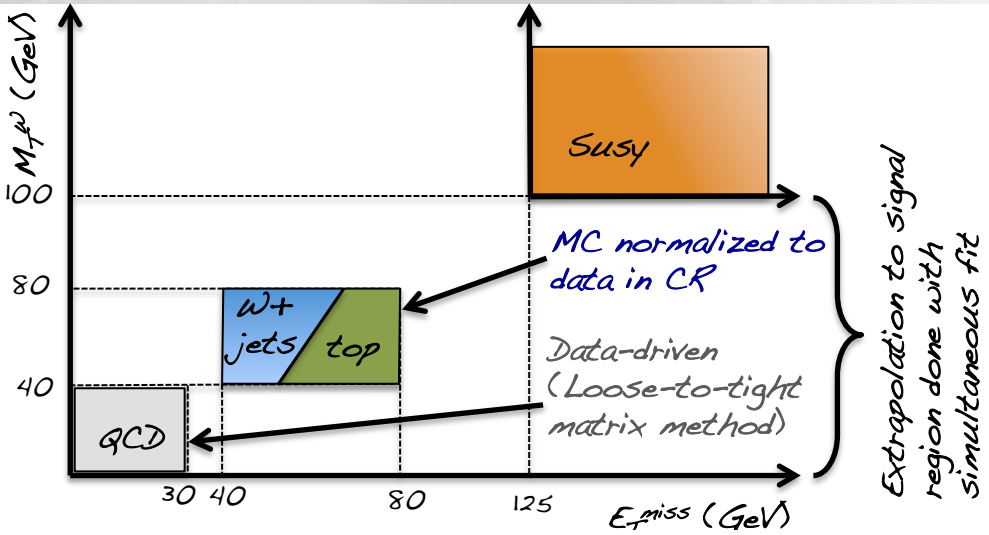
General simplified model

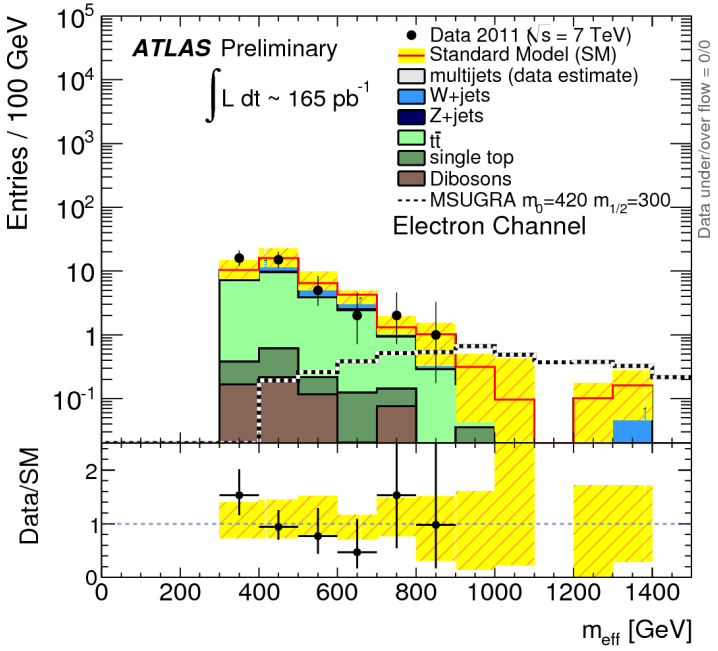
Gluino-gluino production with 3-body decay to $\bar{b}b\tilde{\chi}_1^0$



Gluino masses between 200-660 GeV excluded up to LSP mass of 160 GeV

New: 165 pb^{-1} 1 lepton + Jets + E_T^{miss}





Discard events with additional e(μ) p_T>20 GeV (10 GeV)

Signal region	e-channel	μ-channel
Lepton p_T (GeV)	>25	>20
3 leading jets p_T (GeV)	>60, >25, >25	
$\Delta\Phi(Jet_i, E_T^{miss})_{i=1,2,3}$	>0.2	
m_T (GeV)	>100	
E_T^{miss} (GeV)	125	
E_t^{miss}/m_{eff}	>0.25	
m_{eff} (GeV)	500	

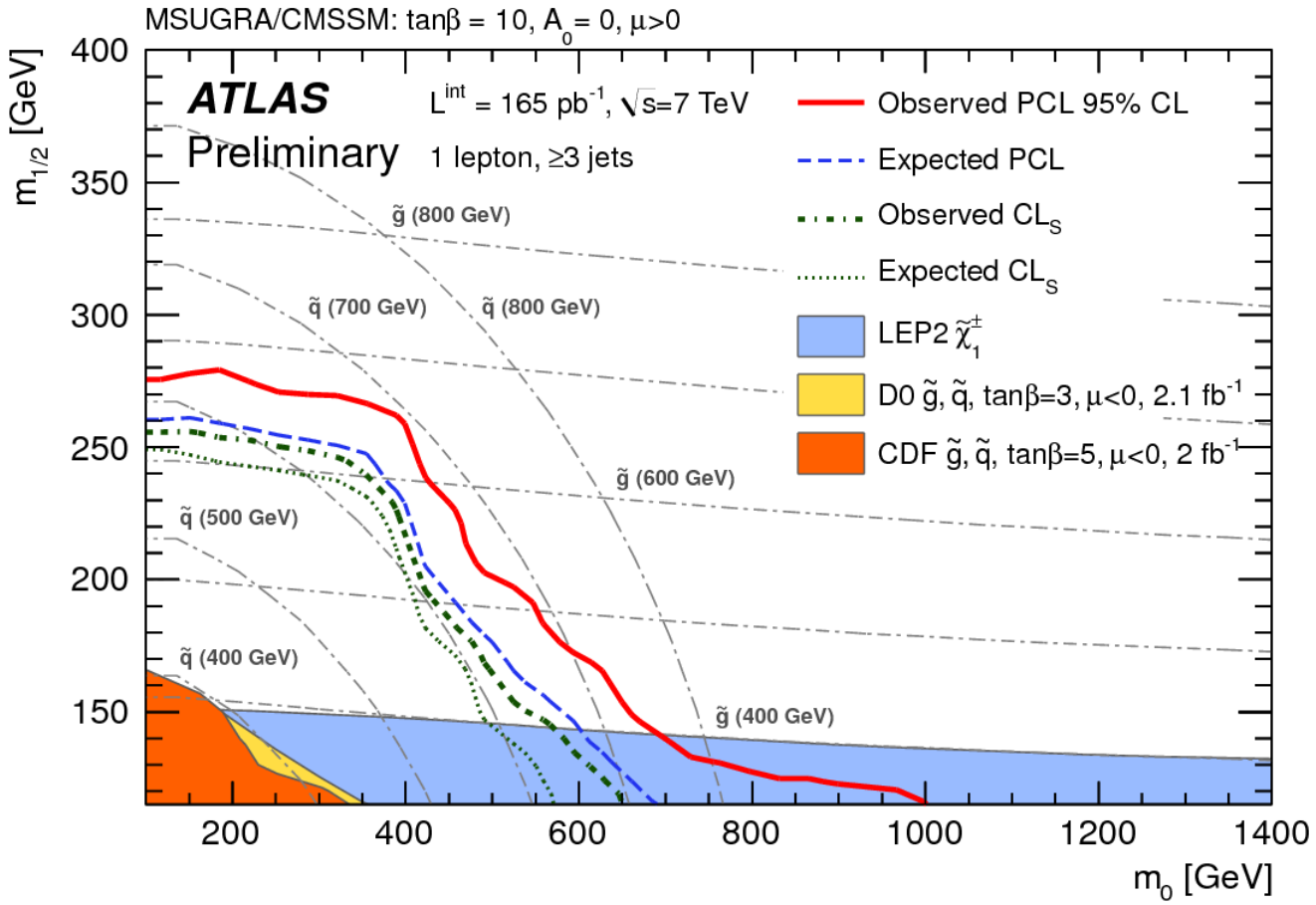
Uncertainties dominated by the JES, JER, limited MC statistics and theory uncertainty on background extrapolation

	e-channel	μ-channel
Total	14.5 ± 5.2	12.2 ± 3.8
Data	10	12

New: 165 pb^{-1}

1 lepton + E_T^{miss} Interpretation

MSUGRA/CMSSM A_0=0, tanβ=10, μ>0



Model independent fiducial cross section limit, 95% C.L.

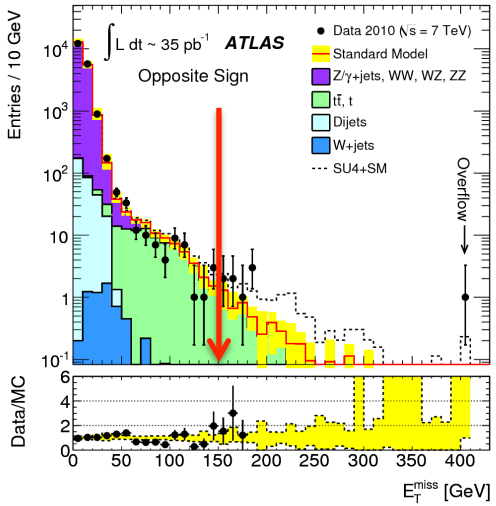
e-channel	μ-channel
41 fb	53 fb

Dilepton + E_T^{miss}

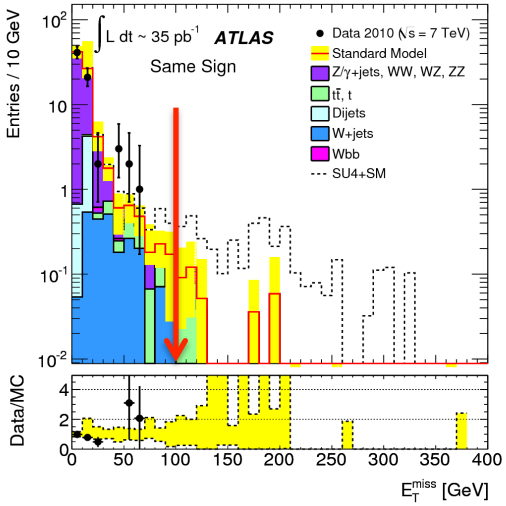
- 2 analyses:
  - Count SS/OS events
  - Opposite flavor subtraction in OS
    - $\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-$

$$S = \frac{N(e^{\pm}e^{\mp})}{\beta\left(1-(1-\tau_e)^2\right)} - \frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)} + \frac{\beta N(\mu^{\pm}\mu^{\mp})}{1-(1-\tau_\mu)^2}$$

B: ratio of e/μ efficiencies
τ : trigger efficiencies

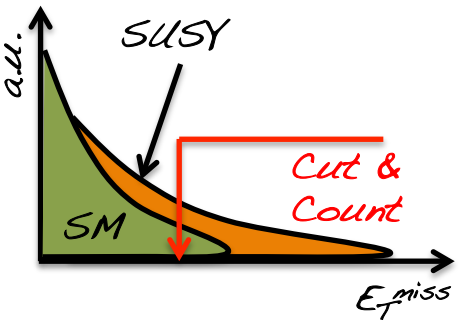


In OS, tail is ttbar;



SS channel: very small background

- Event selection:
  - Exactly 2 leptons,
    - Opposite-sign (OS)/Same-sign (SS)
  - E_T^{miss}>100(150) GeV for SS(OS)

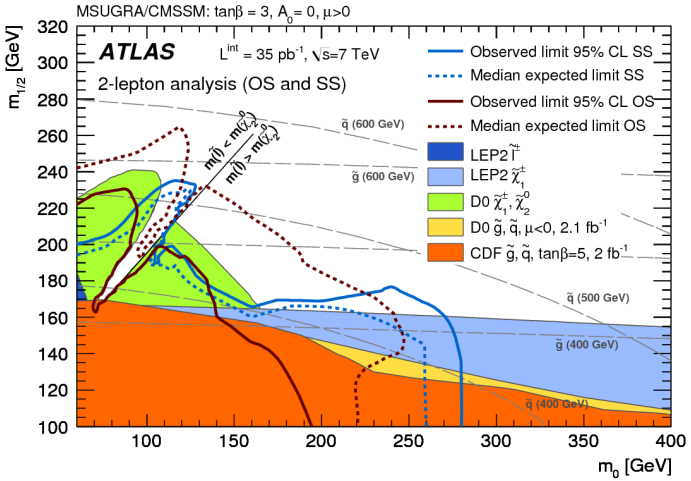


Flavor subtraction result $S_{obs} = 1.98 \pm 0.15(\beta) \pm 0.06(\tau)$ $\overline{S}_{exp} = 2.06 \pm 1.1$

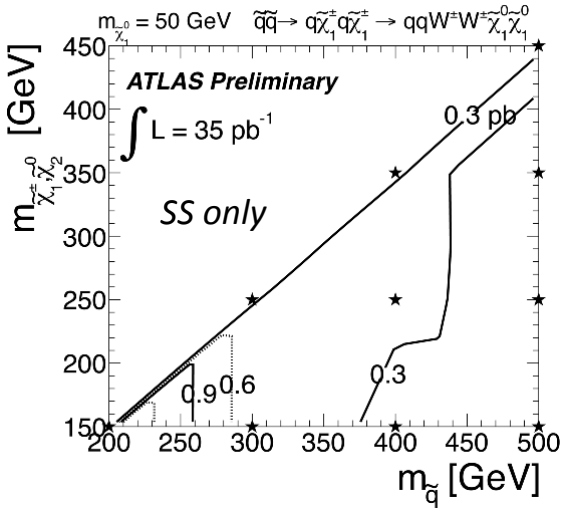
	OS channels			SS channels		
	$e^{\pm}e^{\mp}$	$\mu^{\pm}\mu^{\mp}$	$e^{\pm}\mu^{\mp}$	$e^{\pm}e^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}\mu^{\pm}$
Total	$0.92^{+0.42}_{-0.40}$	$1.39^{+1.41}_{-0.53}$	$1.43^{+1.45}_{-0.59}$	0.15±0.13	0.04±0.01	$0.09^{1.17}_{-0.03}$
Data	1	4	4	0	0	0

Dilepton + E_T^{miss} Interpretation

MSUGRA/CMSSM A_0=0, tanβ=3, μ>0



Limits obtained depend on SUSY mass hierarchy, but are in the range: $m_{\tilde{q}} > 450 - 690$ GeV



Simplified model example : upper limit on σ×BR for:

$\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^{\pm} q\tilde{\chi}_1^{\pm} \rightarrow qqW^{\pm}W^{\pm}\tilde{\chi}_1^0\tilde{\chi}_1^0$

Phenomenological MSSM squark-gluino grids:

Compress Spectrum (CS)

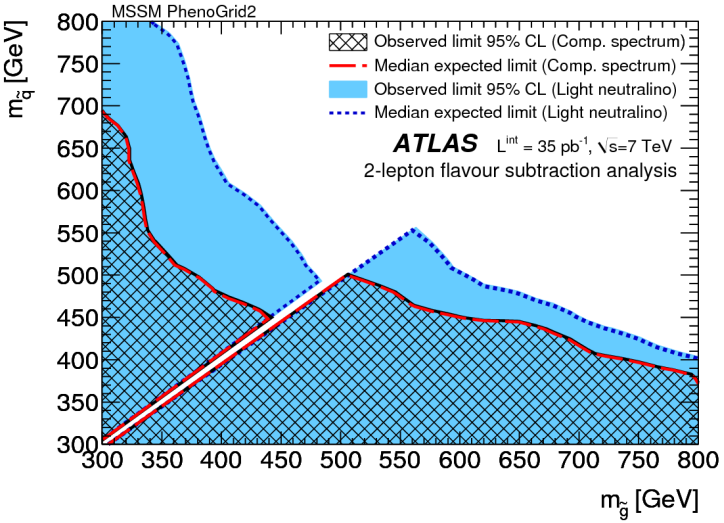
$$m_{\tilde{\chi}_2^0} = M - 50 \text{ GeV};\ m_{\tilde{\chi}_1^0} = M - 150 \text{ GeV};\ m_{\tilde{l}_L} = M - 100 \text{ GeV}$$

✓ With M=min(m_g,m_q)→soft final state kinematics

Light neutrino (LN)

$$m_{\tilde{\chi}_2^0} = M - 100 \text{ GeV};\ m_{\tilde{\chi}_1^0} = 100 \text{ GeV};\ m_{\tilde{l}_L} = M/2 \text{ GeV}$$

✓ →harder kinematics



Limit on number of new physics event at 95% C.L.

Flavor subtraction: $\overline{S}_s < 8.8 - 12.6$ events

Model independent fiducial cross section limit, 95% C.L.

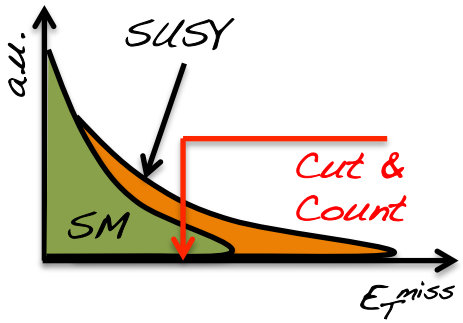
$e^{\pm}e^{\mp}$	$\mu^{\pm}\mu^{\mp}$	$e^{\pm}\mu^{\mp}$	$l^{\pm}l^{\pm}$
0.09 pb	0.21 pb	0.22 pb	0.07 pb

Multileptons

If gauginos and neutralinos are abundant, should see many leptons

Events selection:

- ≥3 e/μ (P_T>20,20,20/10 GeV)
- 2-jets p_T>50 GeV
- E_T^{miss}>50 GeV
- SFOS m_{ll}>20 & Z veto

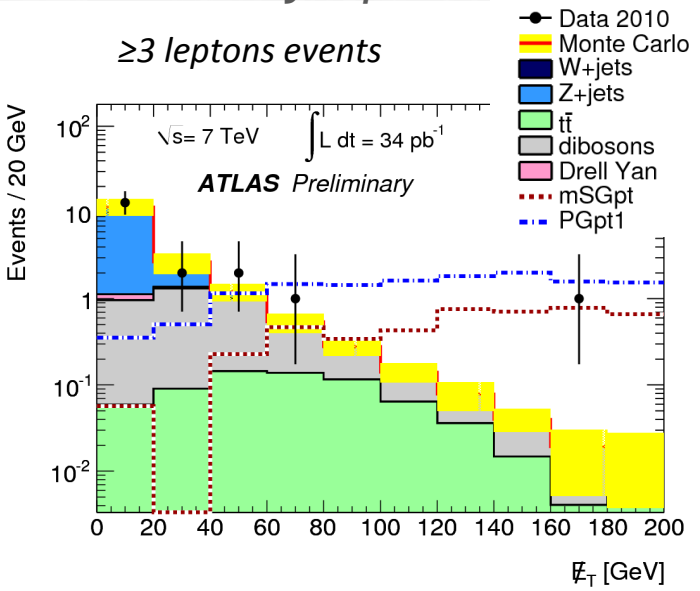


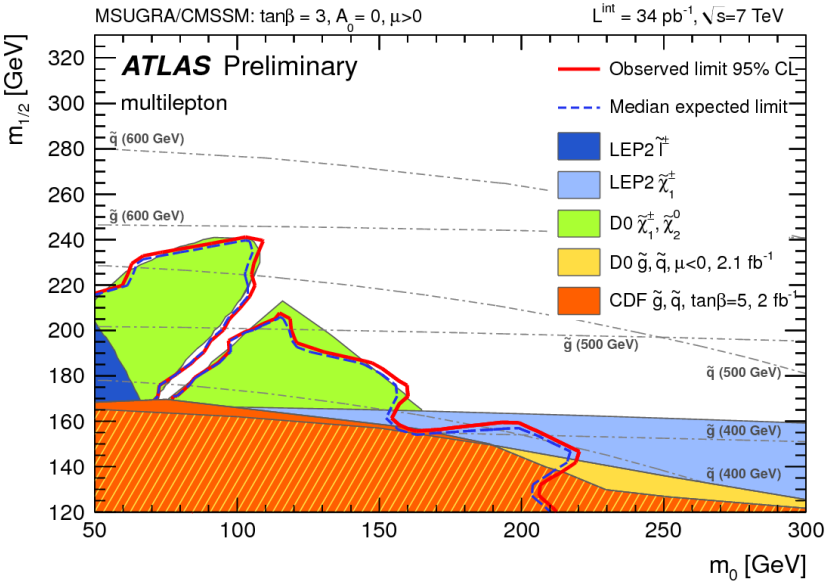
Before E_T^{miss} cut and Z-veto

- 3-lepton events:19 (SM:16.6±1.3)
- 4-lepton events: 0

After cuts, SM (ttbar) events expected

- $0.109 \pm 0.023(stat)^{+0.036}_{-0.025}$ (sys)
- Non-observed





mSugra interpretation : limits similar to Tevatron MSSGM Grid assuming $m_g = m_{sq} + 10$

$m_{\tilde{q}} > 540$ GeV ("compressed spectrum")

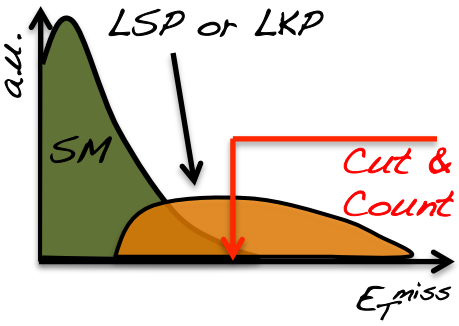
$m_{\tilde{q}} > 670$ GeV ("light neutralino")

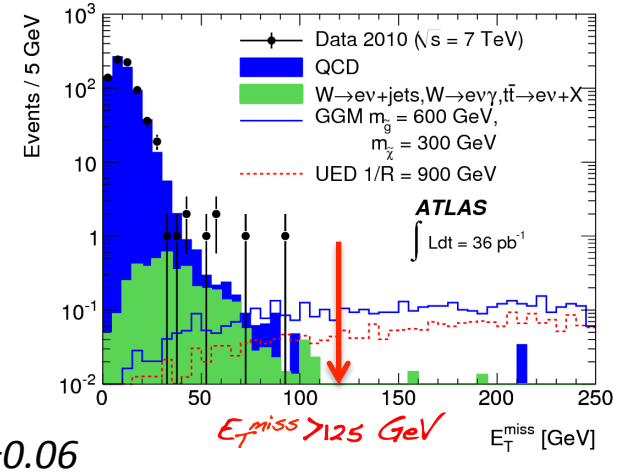
36 pb^{-1} Inclusive search with 2 photons and E_T^{miss}

Sensitive to gauge-mediated SUSY breaking and UED models

- In GMSB SUSY (SUSY breaking is gauge-mediated), the LSP is the gravitino, $\tilde{G}$
  - Final decay in the cascade is dominated by $\tilde{\chi}_1^0 \to \gamma\tilde{G}$, with 2 cascade per event
  - Signature: 2 γ & E_t^{miss}
- Similar topologies are generated in Universal Extra Dimension (UED)

  The lightest KK particle (LKP) is the Kaluza-Klein photon

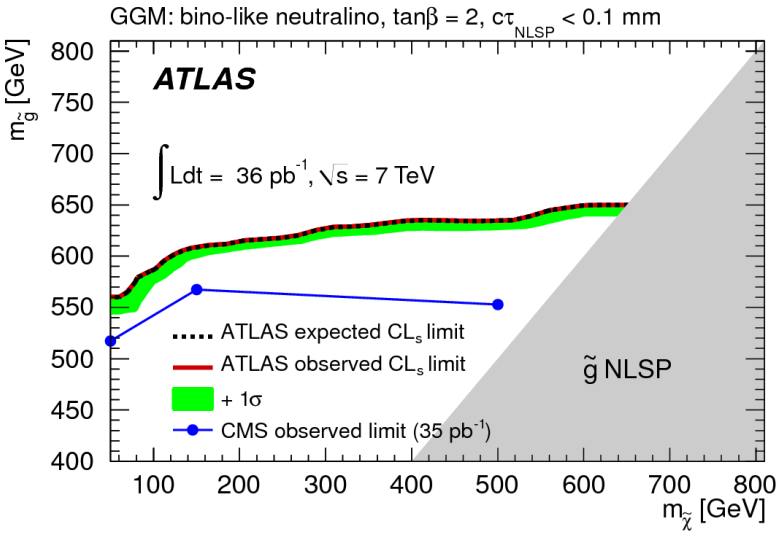




Expected background: 0.1±0.06
Non observed

95 % C.L upper limit: σ<0.38-0.65 pb in GGM model

$m_{\tilde{\chi}_1^0} = 150$ GeV, $m_{\tilde{g}} = 400 - 800$ GeV



Exclude GGM gluino mass<560 GeV, $m_{\tilde{\chi}_1^0} > 50$ GeV

UED compactification scale: $1/R_{UED}$<961 GeV

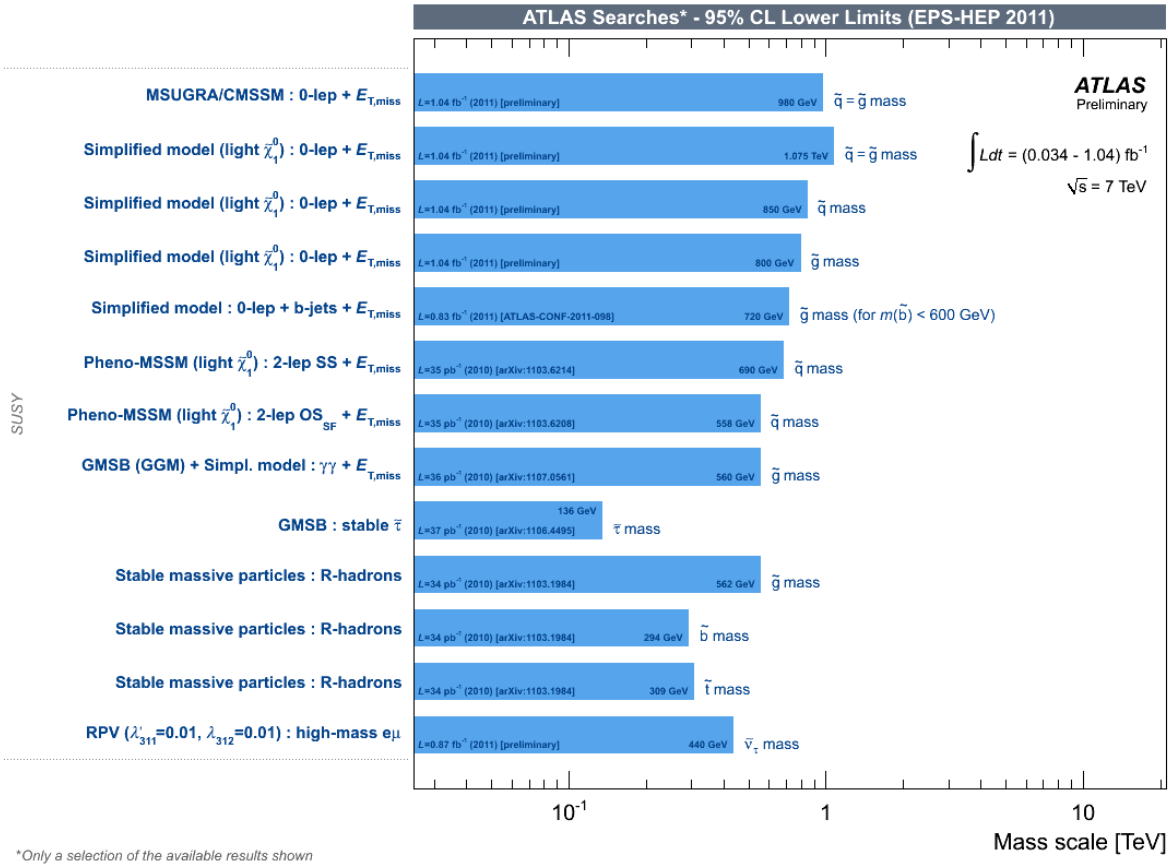
Conclusions & Outlook

Several limits have surpassed those from Tevatron/LEP.

- Expect 3-5 times more data by the end of 2011

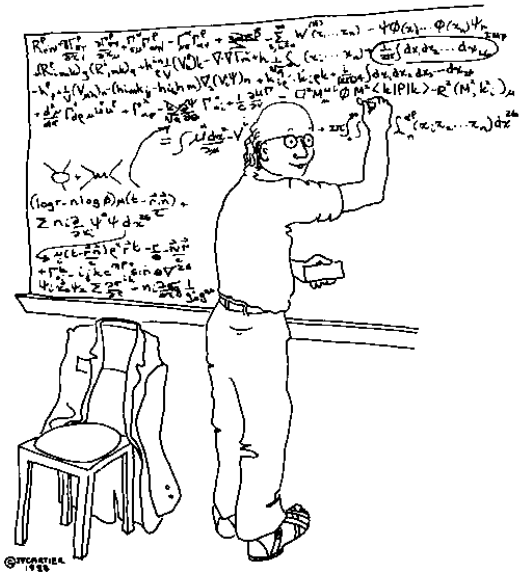
SUSY was NOT "just around the corner"

… must be hiding well …



*Only a selection of the available results shown

Or may be … need to go back to the drawing board



"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."

ATLAS SUSY Searches

ATLAS SUSY analyses		Publications	
E_T^{miss} + Jets + 0 lepton	New	arXiv:1102:5290 (35 pb^{-1}) [published in PLB]; ATL-CONF-2011-086 (163 pb^{-1}); arXiv:XXXX:XXXX To be submitted (1.04 fb^{-1})	Combination (35 pb^{-1}) ATL-CONF-2011-064
E_T^{miss} + Jets + 1 lepton	New	arXiv:1102:2357 (35pb^{-1}) [published in PRL]; ATL-CONF-2011-090 (163 pb^{-1});	
E_T^{miss} + b Jets + 0/1 lepton	New	arXiv:1103:4344 (35 pb^{-1}) [published in PLB]; ATL-CONF-2011-098 (833 pb^{-1})	
E_T^{miss} + Jets + 2 leptons (OS, SS, SF subtraction)		arXiv:1103:6214 (35 pb^{-1}) [published in EPJC]; ATL-CONF-2011-091 (simplified model interpretation to SS) arXiv:1103:6208 (35 pb^{-1}) [published in EPJC];	
E_T^{miss} + Jets + >= 3 leptons		ATL-CONF-2011-039 (34 pb^{-1})	
E_T^{miss} +γγ		arXiv:1107:0561 (36 pb^{-1}) [submitted to EPJCL];	
eμ resonance (RPV)	New	arXiv:1103:5559 (35 pb^{-1}) [published in PRL]; ATL-CONF-2011-109 (870 pb^{-1})	
Stable hadronising squarks & gluinos		arXiv:1103:1984 (34 pb^{-1}) [published in PLB];	
Heavy Long-lived charged particles		arXiv:1106:4495 (37 pb^{-1}) [submitted to PLB];	

Covered in this talk

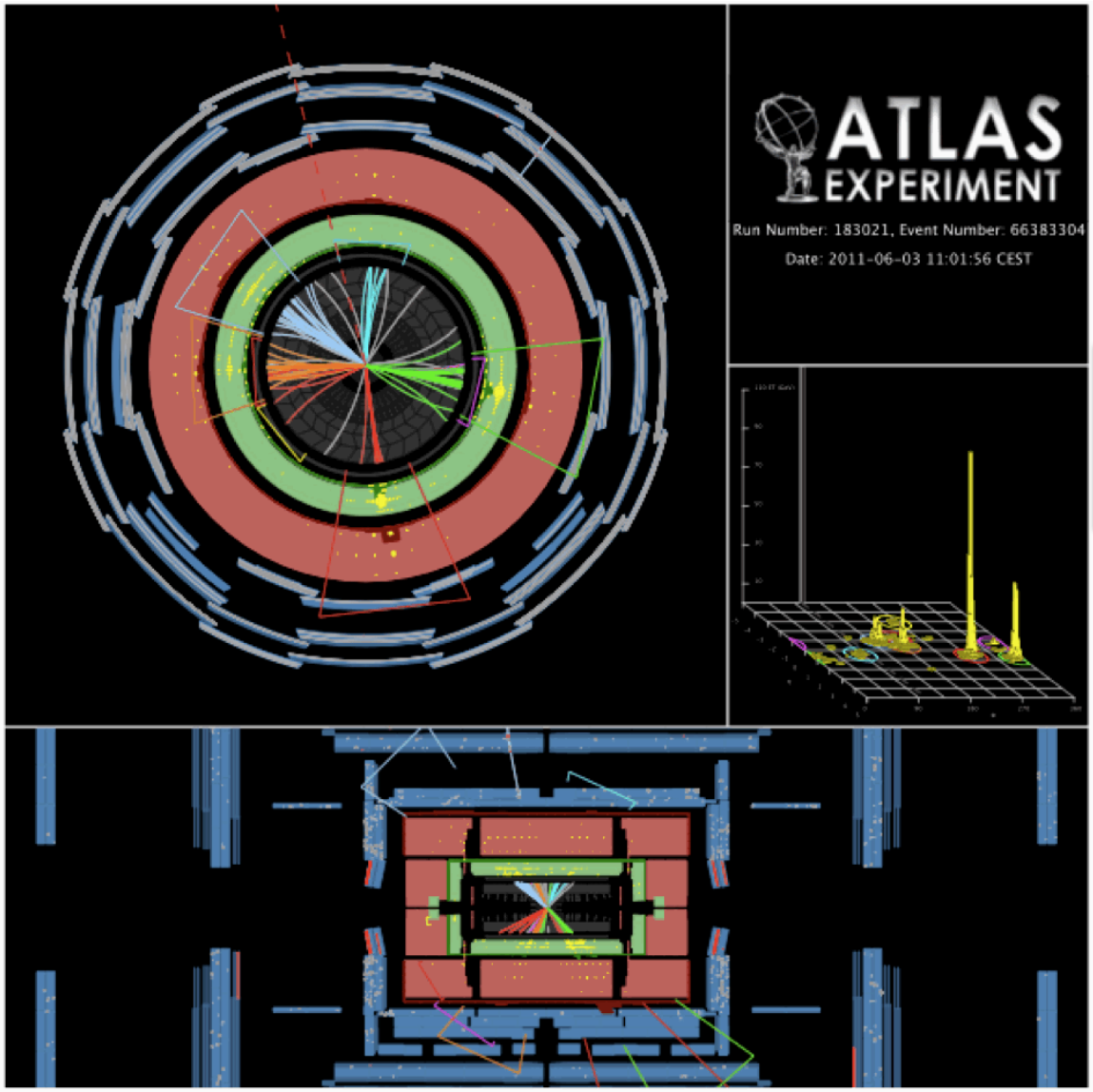
Related Presentation at EPS-HEP 2011

- Talks
  - Talk by H. Hayward [Higgs and New Physics Session - Saturday]
    - *Search for supersymmetry in lepton(photons), jets and E_T^{miss}*
  - Talk by I. Vivarelli [Higgs and New Physics Session – Saturday]
    - *Search for supersymmetry in jet(s) plus E_T^{miss}*
  - Talk by P. Jackson [Higgs and New Physics Session – Saturday]
    - *Search for R-Parity violating supersymmetry*
  - Talk by D. Charlton [Plenary Session – Monday]
    - *Searches for new physics and highlights from ATLAS*
- Posters
  - J. Lorenz
    - *SM background estimation in the 1-lepton SUSY search*
  - V. Rossetti
    - *Search for new physics in evens with monojets and large E_T^{miss}*

Backup

Jets+E_T^{miss} candidate

5-jets events with largest m_{eff}



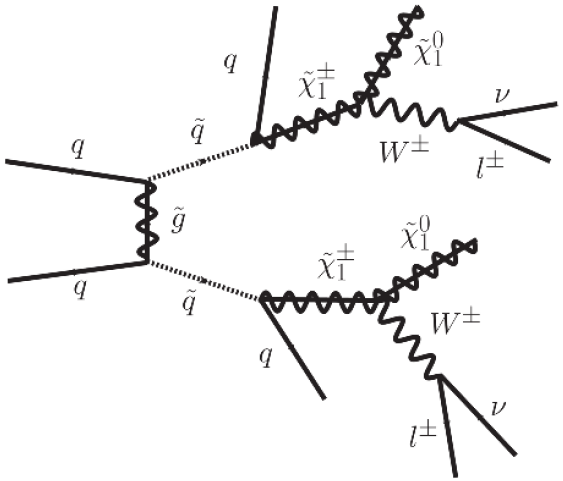
M_{eff}=1810 GeV
E_T^{miss}=460 GeV
Jet p_T=528, 418, 233, 171, 42 GeV

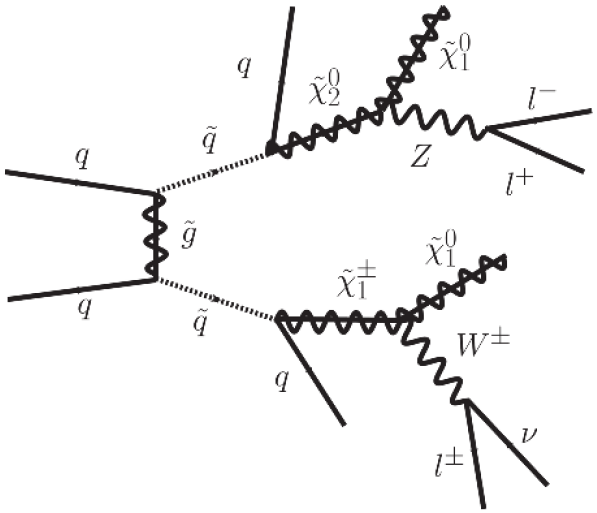
So where do we start ?

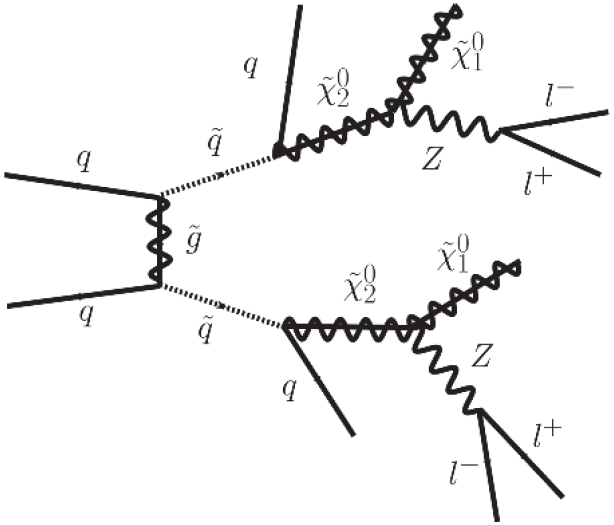
Simplify assumptions ⇒ From 100+ SUSY parameters to "a few"

- Constraint Minimal SUSY (CMSSM) (SUGRA: gravity-mediated)
  - LSP is the neutralino
  - Only has 5 free parameters defined at the GUT scale
    - Scalar mass parameters: m_0
    - Gaugino mass parameter: $m_{1/2}$
    - Trilinear Higgs-sfermion-sfermion coupling: A_0
    - Ratio of Higgs vacuum expectation values: $\tan\beta$
    - Sign of SUSY Higgs parameter: $\mathrm{sign}(\mu)$
- Phenomenological MSSM: more general 24 parameter MSSM framework, 2 grids:
  - Compressed particle spectrum → softer leptons
  - More favorable mass hierarchy, light LSP → harder leptons
- Simplified models
  - Characterize data in terms of small number of basic parameters (cross section, masses, BR)
  - Group large sector of parameter space into few simplified models with similar final state topologies
  - Experimental data translated to limit on cross section × BR
- GMSB mediation: NSLP is neutralino or stau, LSP is gravitino
- AMSB: Anomaly mediation: LSP is neutralino or sneutrino

Example of simplified model for dilepton + E_T^{miss}







Jets+E_T^{miss} CRs

- CR event selection is designed to provide data samples enriched in particular background sources

CR	SR Background	CR process	CR selection
CR1a	$Z(\to \nu\nu)$+jets	γ+jets	Isolated photon
CR1b	$Z(\to \nu\nu)$+jets	$Z(\to \ell\ell)$+jets	$\lvert m(\ell,\ell) - m(Z)\rvert < 25$ GeV
CR2	QCD jets	QCD jets	Reversed $\Delta\phi(j_i, E_{\mathrm{T}}^{\mathrm{miss}})$ cut
CR3	$W(\to \ell\nu)$+jets	$W(\to \ell\nu)$+jets	30 GeV $< m_T(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV, b-veto
CR4	$t\bar{t}$ and single-t	$t\bar{t} \to bbqq'\ell\nu$	30 GeV $< m_T(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV, b-tag

- CR1a (CR1b): reconstructed momentum of the photon (lepton pair system) added to the EtMiss
- CR2: data-driven smearing function modified wrt PLHC; MC jet response modified by extra Gaussian smearing and tail offset using dijet and Mercedes events
- CR2b introduced to estimate LAr hole background in SRs
- CR3, CR4: lepton treated as a jet in computation of kinematic variables
- CRs as close as possible to SRs
- No $\Delta\phi$(j, EtMiss) or EtMiss/Meff cuts applied in CR1b, CR3, CR4 except for 4jet, Meff>500GeV signal region

Jets+E_T^{miss} Transfer Factors

- Observed event counts in the CRs for each channel are used to generate coherently normalized SM background estimates for SR using the likelihood fit.
- CR contamination by other SM processes and/or SUSY signal events taken into account.
- Transfer Factors (TF) enable observations in the CRs to be converted into background estimates in the SR:

$$N(SR, est, proc) = N(CR, obs, proc) * \left[\frac{N(SR, raw, proc)}{N(CR, raw, proc)}\right].$$

- CR2 (QCD): TFs are estimated using data-driven technique based on smearing of jets in low EtMiss data events (seed events) with jet response function tuned by comparisons with QCD jets dominated control region.
- Other CRs: TFs are estimated using data-validated fully simulated Monte Carlo (MC) event samples
- The result of the likelihood fit per channel is set of normalized background estimates and uncertainties for the SR, together with a p-value for SR observation.

Example of CRs for 4-jet channel, m_{eff}>1000GeV