SUSY at the LHC

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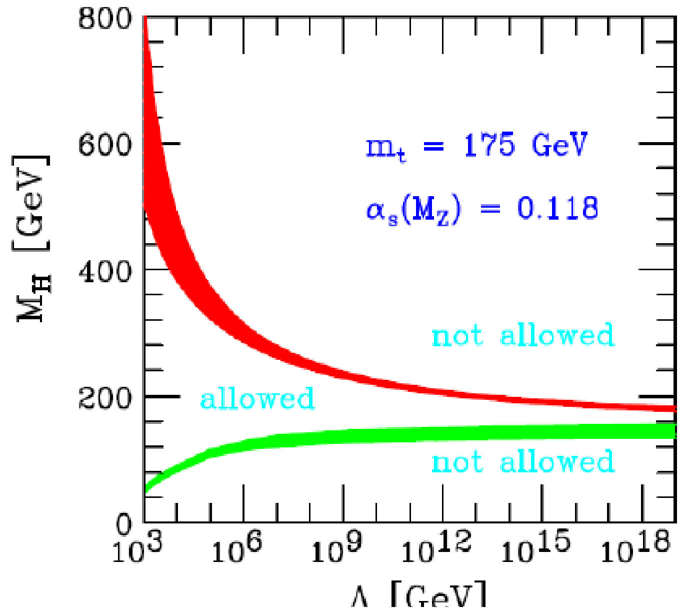
Why physics beyond Standard Model?

- Gravity is not yet incorporated in the model
- Hierarchy/naturalness problem

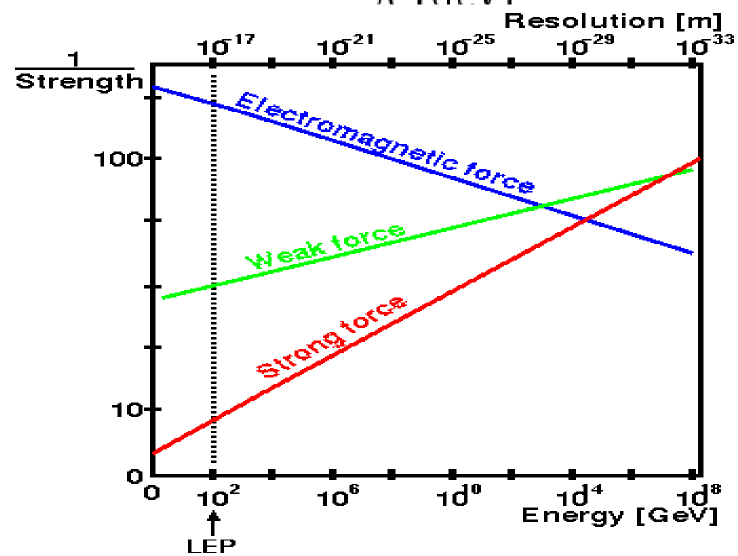


Standard Model valid only up to scale Λ<M_{pl}

Example: m_h=115 GeV Λ<10^6 GeV

Therefore Higgs mass becomes instable to quantum corrections from fermion loops:

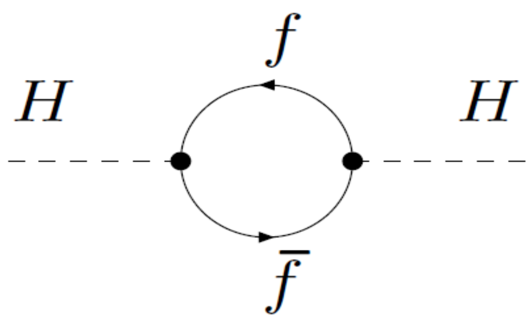
$$\delta m_H^2 \propto \lambda_f^2 \Lambda^2$$



- Lack of unification of couplings in SM
- Dark Matter problem: SM particles only account for a small fraction of the matter observed in the universe

Naturalness problem and SUSY solution

Correction to higgs mass from fermion loop:



$$\Delta m_H^2 \sim \frac{\lambda_f^2}{4\pi^2}(\Lambda^2 + m_f^2) +$$

Where Λ high energy cutoff

For Λ~M_{Planck}~10^{18} GeV corrections explode

Correction from scalar $\tilde{f}$

$$\Delta m_H^2 \sim -\frac{\lambda_{\tilde{f}}^2}{4\pi^2}(\Lambda^2 + m_{\tilde{f}}^2) + \ldots\ldots$$

Corrections have opposite sign. Cancellations if for each fermion degree of freedom one has scalars such that: $\lambda_{\tilde{f}}^2 = \lambda_f^2 \quad m_{\tilde{f}} = m_f$

Achieved in theory invariant under transformation Q:

$Q|\text{boson}\rangle = |\text{fermion}\rangle \qquad Q|\text{fermion}\rangle = |\text{boson}\rangle$ Supersymmetry

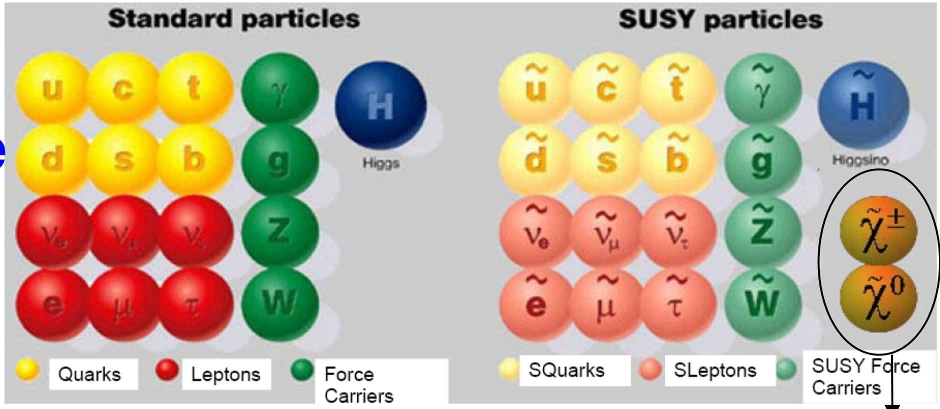
Very general class of theories, specialize to minimal model: MSSM

Minimal Supersymmetric Standard Model (MSSM)

Minimal particle content:

- A superpartner for each SM particle
- Two higgs doublets and superpartners:

 5 Higgs bosons: h, H, A, H^+,H^-



gaugino/higgsino mixing

- In unbroken SUSY particles and superpartners have the same mass
- No superpartner found to date: SUSY is broken
- Explicitly break SUSY: insert in Lagrangian all soft breaking terms
- 105 parameters. Reduced to ~20 using low energy constraints such as FCNC

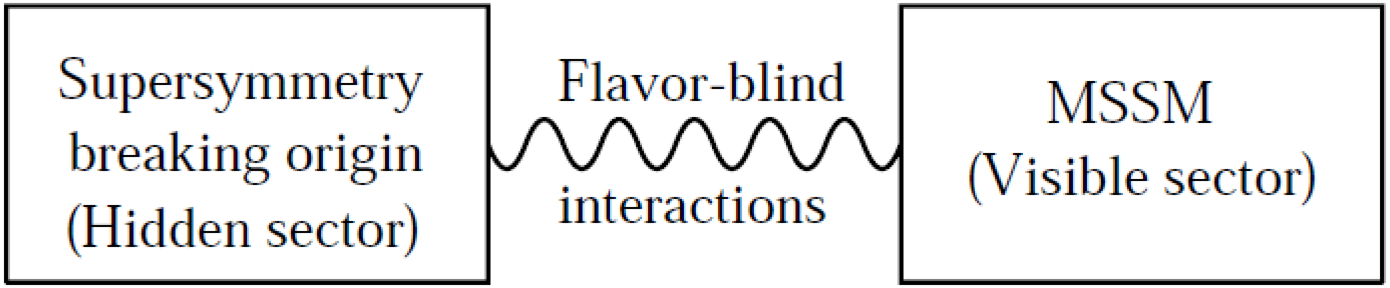
 $\rightarrow$ Diffcult theory to study and constrain

Additional ingredient: R-parity conservation: $R=(-1)^{3(B-L)+2S}$

- Sparticles are produced in pairs
- The Lightest SUSY particle (LSP) is stable, neutral weakly interacting
  - Excellent dark matter candidate
  - It will escape collider detectors providing nice experimental signature

SUSY breaking models

Spontaneous breaking not possible in MSSM, need to postulate hidden sector



Phenomenology of the model and free parameters determined by the nature of the messenger field mediating the breaking. Examples:

- Gravity: mSUGRA. Parameters: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}\,\mu$

  LSP is $\tilde{\chi}^0_1$: E_T^{miss} + jets signatures

- Gauge interactions: GMSB. Parameters: $\Lambda = F_m/M_m,\ M_m,\ N_5$
  $\tan\beta,\ sgn(\mu),\ C_{grav}$

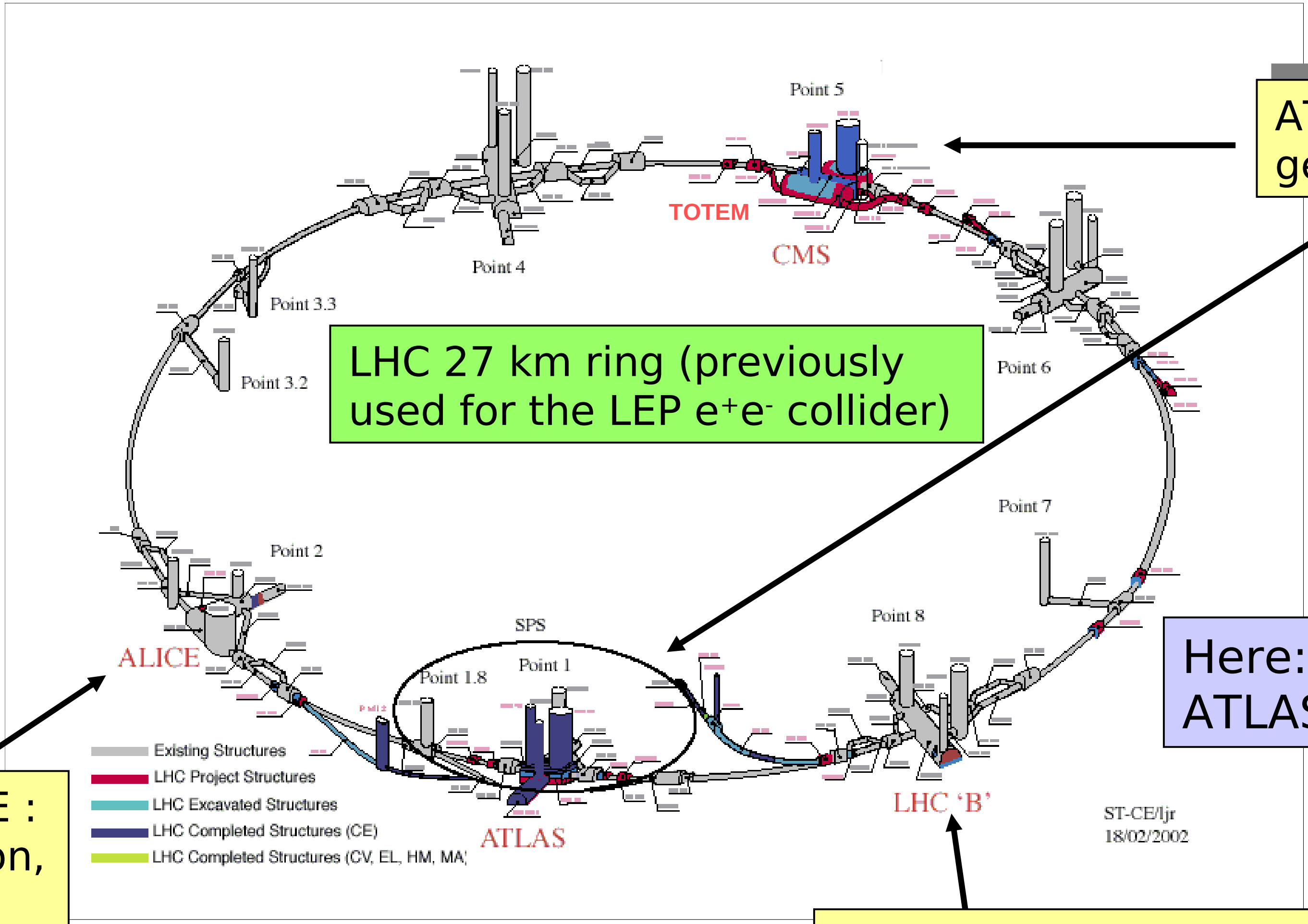
  LSP is light gravitino $\tilde{G}$. Signatures: γ+E_T^{miss} from $\tilde{\chi}^0_1 \to \gamma\tilde{G}$ if $\tilde{\chi}^0_1$ NLSP
  leptons+E_T^{miss} or long-lived leptons if slepton NLSP

- Anomalies: AMSB. Parameters: $m_0,\ m_{3/2},\ \tan\beta,\ sign(\mu)$

  Can have sparticle degeneracy with metastable decays

LHC

- pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (after 2012)
  $\sqrt{s}$ = 7 TeV $L_{initial}$ < few x $10^{33}\ cm^{-2}\ s^{-1}$ (before 2012)
  Note: $\sqrt{s}$ is x7 Tevatron, L_{design} is x30 Tevatron
- Heavy ions



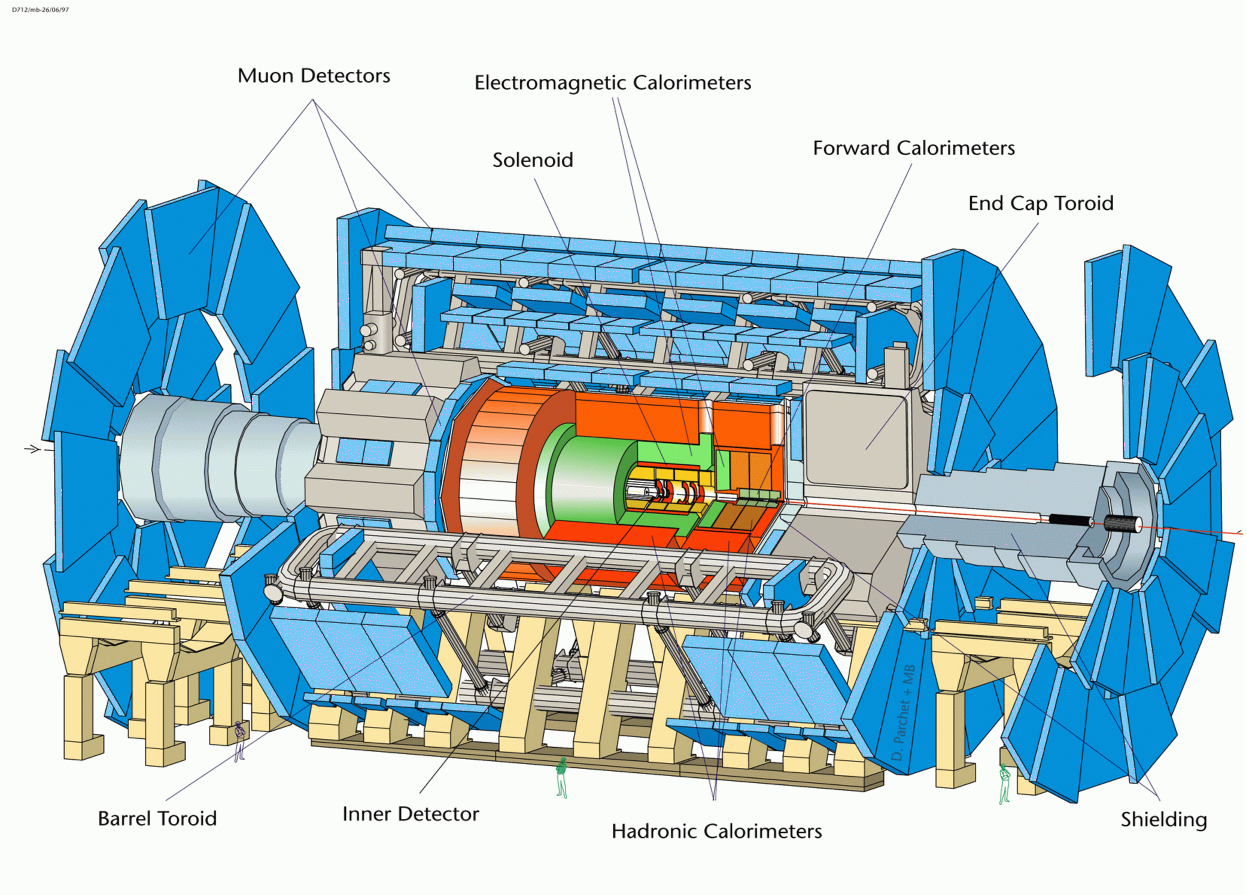
ATLAS and CMS : general purpose

LHC 27 km ring (previously used for the LEP e^+e^- collider)

Here: concentrate on ATLAS and CMS

ALICE : ion-ion, p-ion

LHCb : pp, B-physics, CP-violation



ATLAS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
~ 3000 km of cables

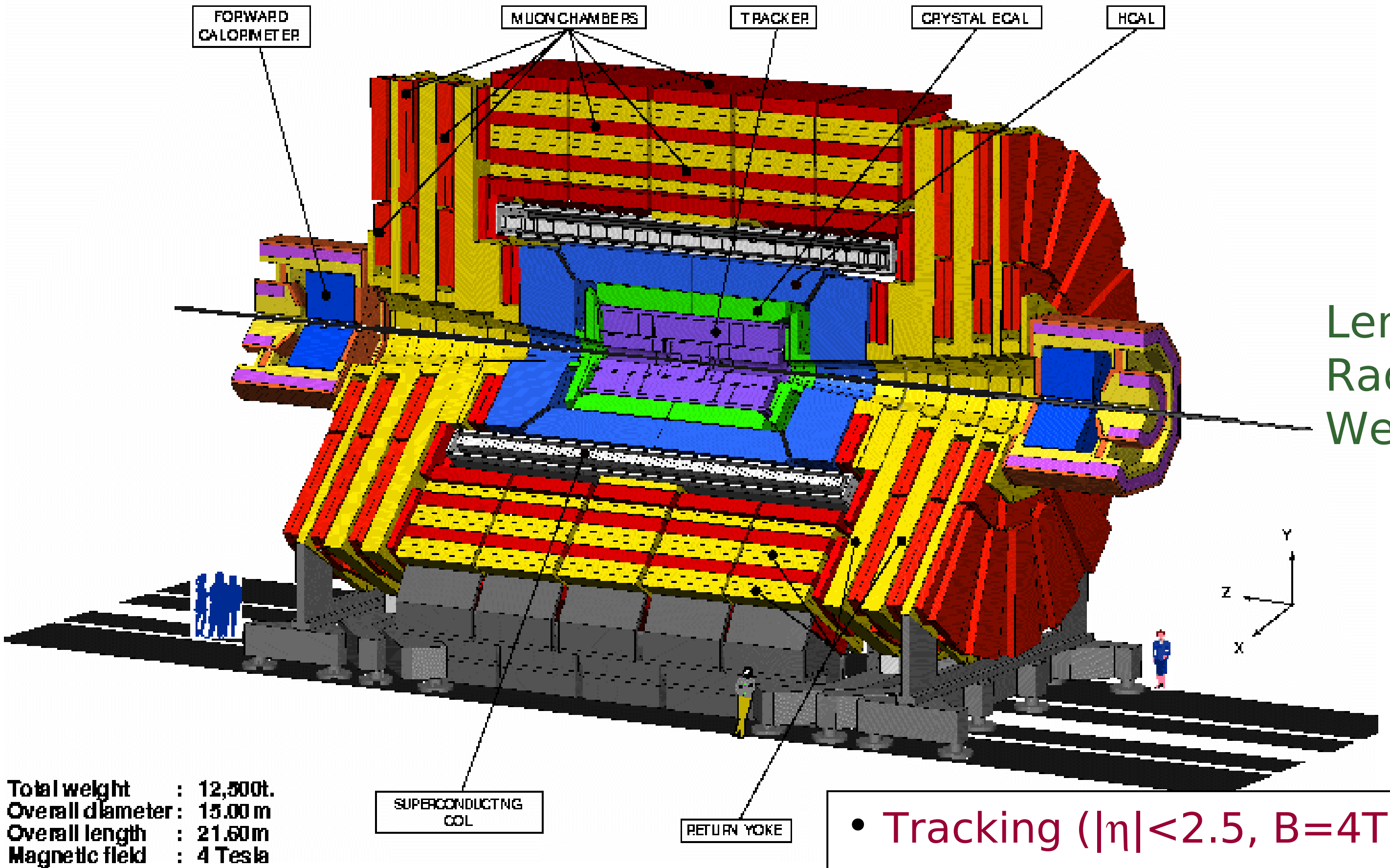
- Inner Detector (|η|<2.5, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/π separation)

- Calorimetry (|η|<5) :
  -- EM : Pb-LAr
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

- Muon Spectrometer (|η|<2.7) :
  air-core toroids with muon chambers

And ~2800 physicists from 169 Institutions, 37 countries, 5 continents

CMS



Length : ~22 m
Radius : ~7 m
Weight : ~ 12500 tons

- Tracking (|η|<2.5, B=4T) : Si pixels and strips
- Calorimetry (|η|<5) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass/scintillator (central+ end-cap), Fe/Quartz (fwd)
- Muon Spectrometer (|η|<2.5) : return yoke of solenoid instrumented with muon chambers

And …. > 2500 physicists from 180 Institutions from 38 countries from 5 continents

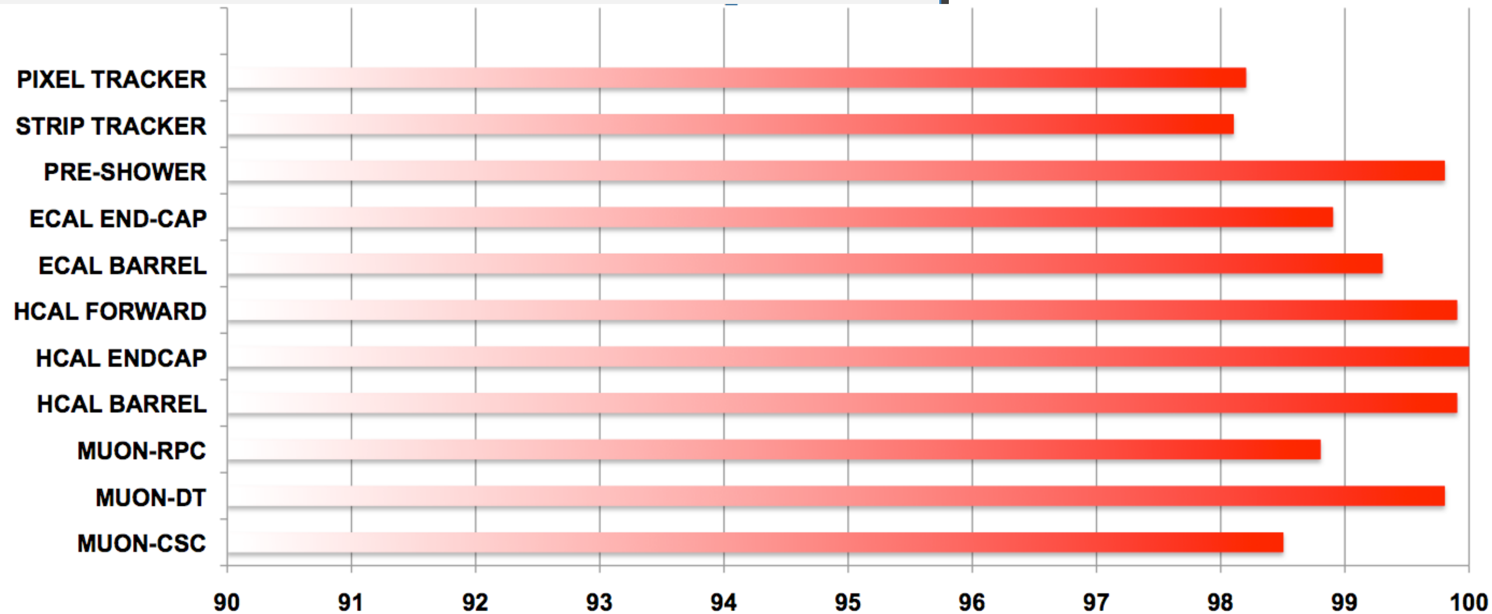
Detector performance

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.0	99.9	100	90.5	96.6	97.8	94.3	99.9	99.8	96.2	99.8

% of good quality data

ATLAS

CMS

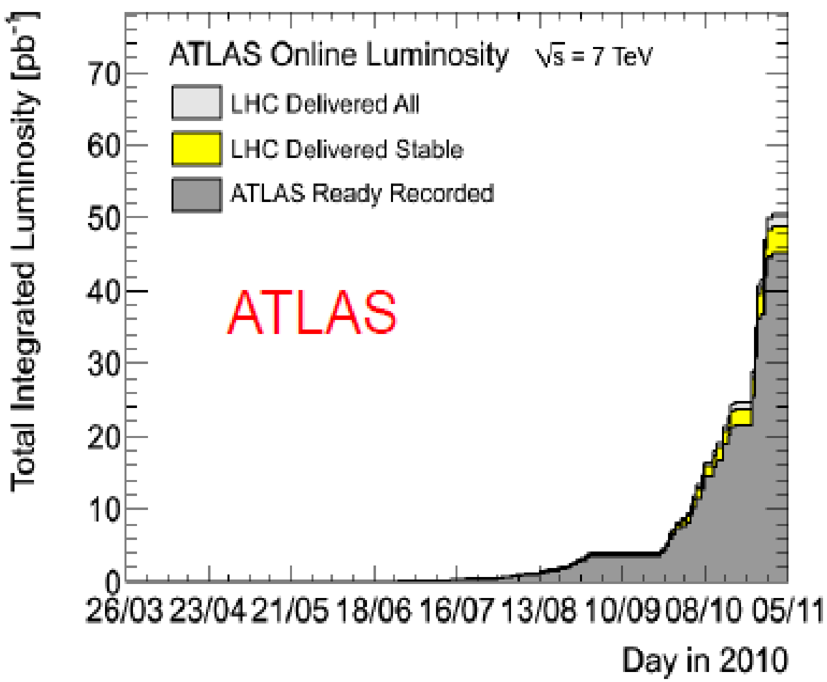


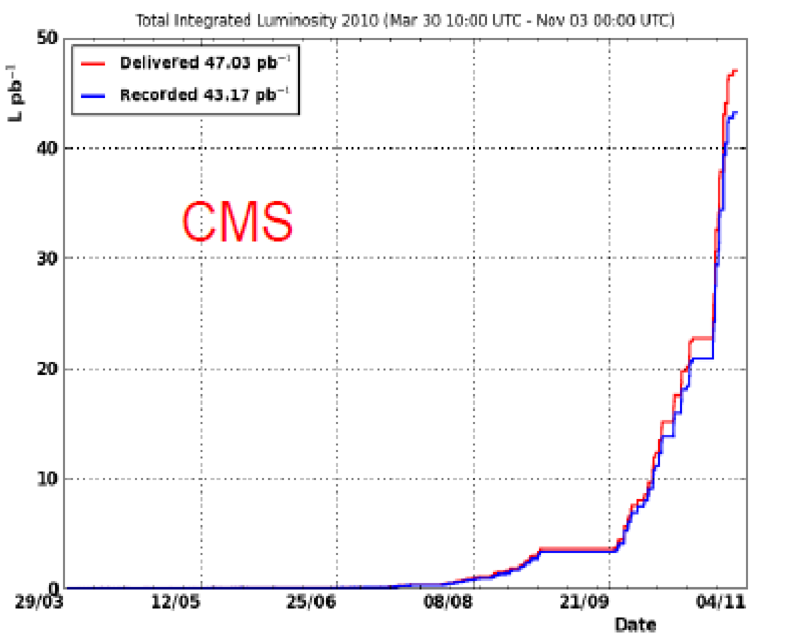
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

2010 collected luminosity

Both experiment have collected data with efficiency well in excess of 90%.

~45 pb-1 recorded, ~35-40 pb^{-1} available for analysis

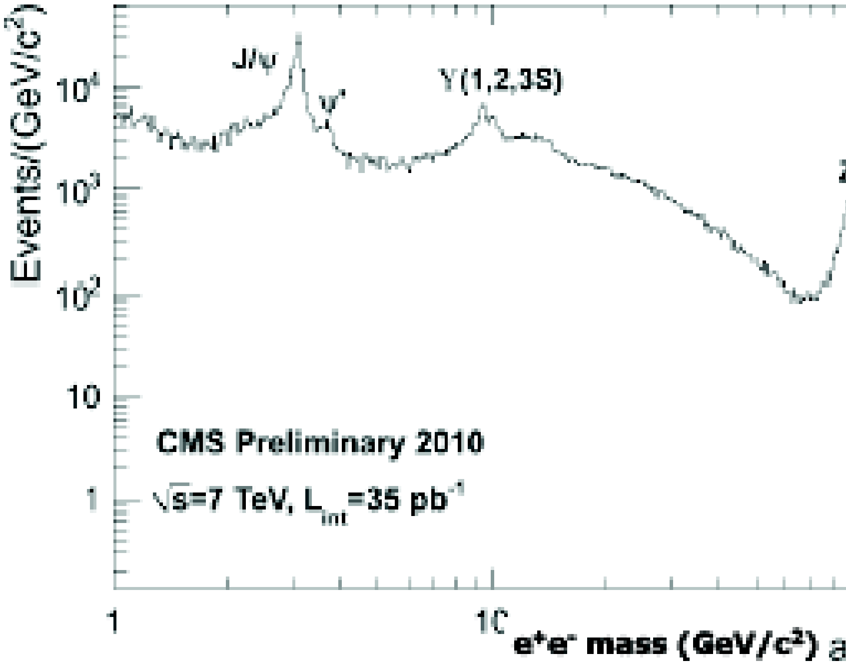




ATLAS and CMS physics program

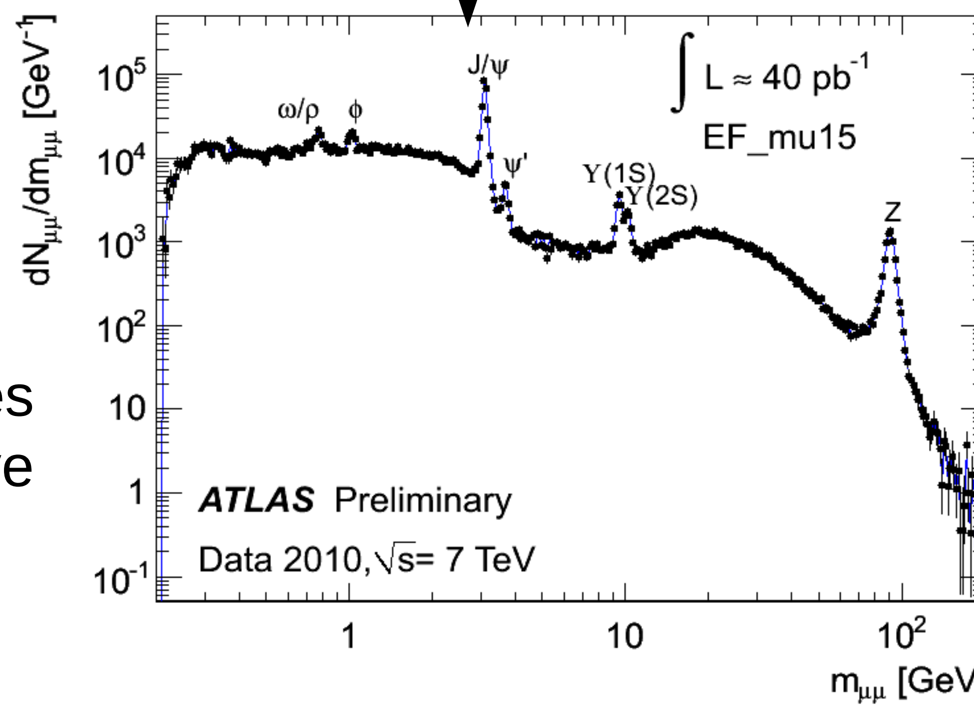
- Plans for 2010
  - Understand and continue to scrutinise the Standard Model of Particle Physics in a new energy regime
  - Search for new Physics beyond the Standard Model by:
    - Discovering new particles
    - Making precise measurements of properties of known particles
- Results:
  - Excellent agreement with SM in key measurements by summer confidence that we understand detectors
  - Wit the full data sample start vigorous program of searches for new physics targeted at 2011 winter conferences

Lepton-lepton mass spectra



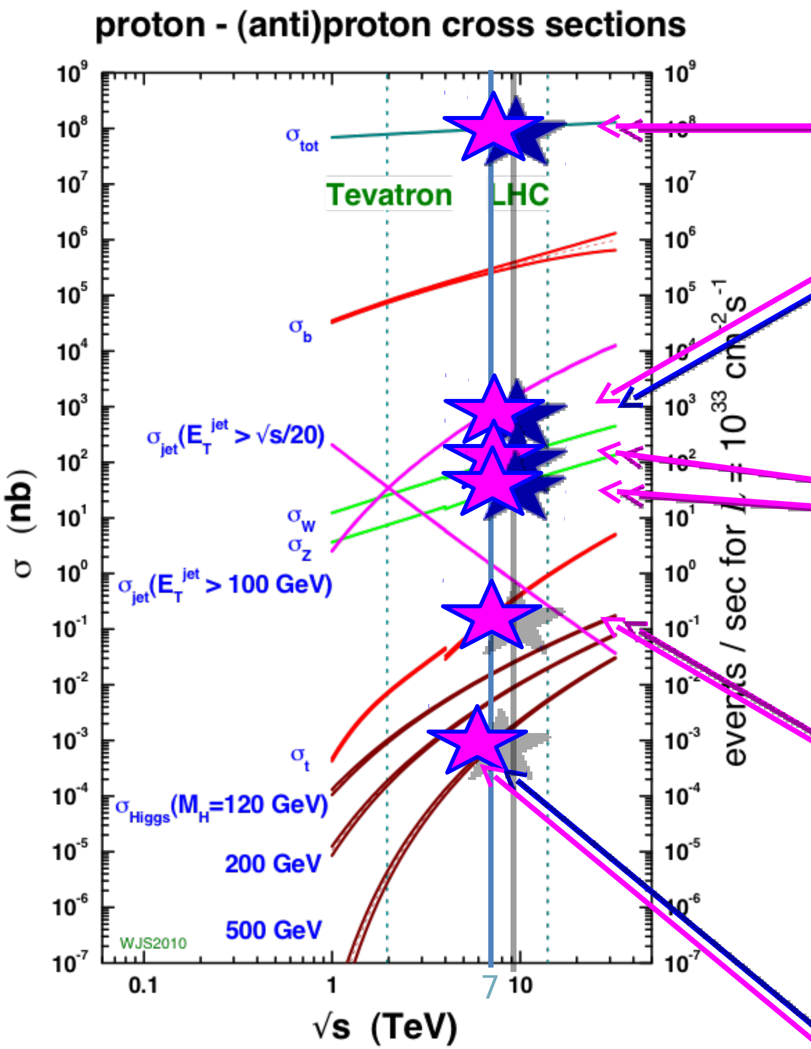
electrons

muons

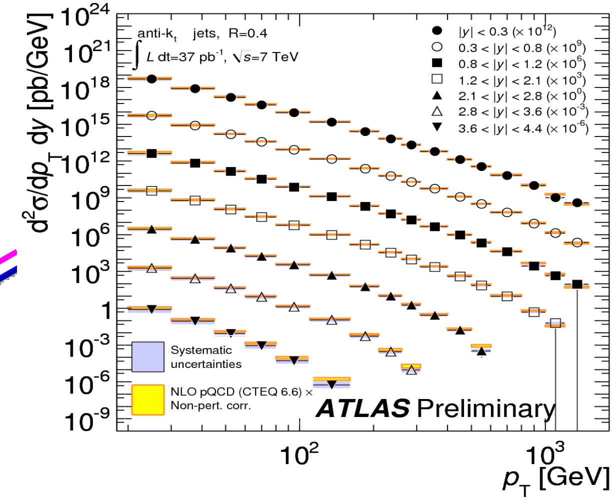


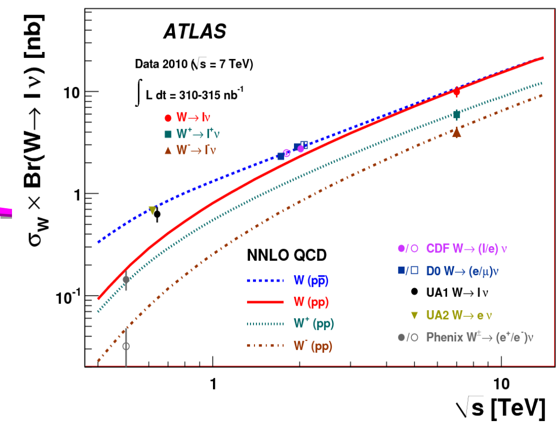
Excellent momentum resolution
Rediscover all known resonances
Ready for new resonances above
The Z

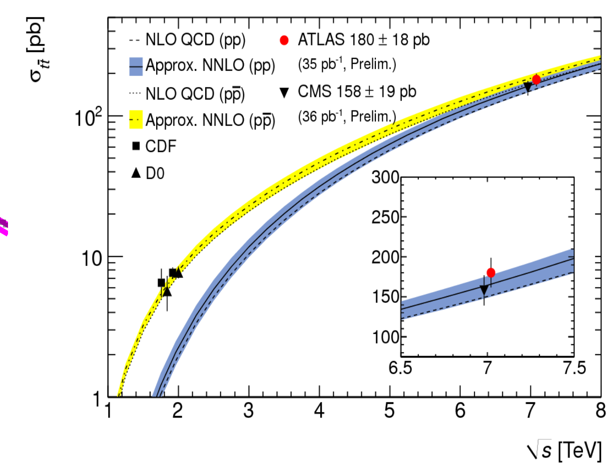
SM rediscovery



Soft events







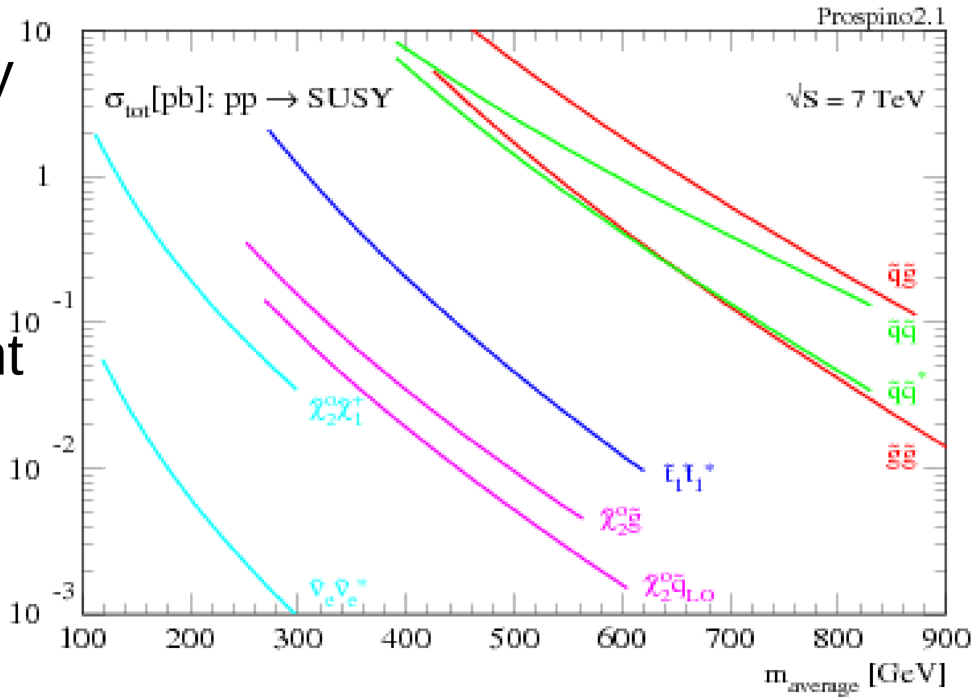
1 TeV SUSY

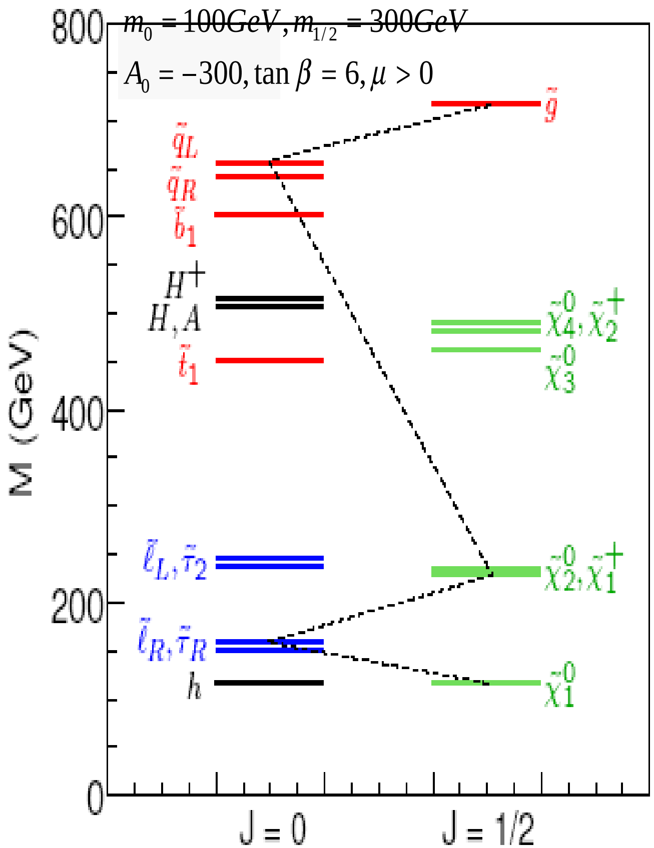
New physics searches

- 2010 Integrated luminosity at LHC ~ factor 100 lower than what cumulated at Tevatron
- Gain of a factor 3.5 in energy makes LHC competitive for high mass states
- Exploring physics beyond Tevatron important milestone for LHC
- Concentrate on signals where sensitivity dominated by statistics and not by systematics related to detector understanding
- SUSY very promising in this respect

SUSY at the LHC

- Production dominated by strongly interacting squarks and gluinos
- Squark and gluino cross-section only function of their mass, approximately model independent



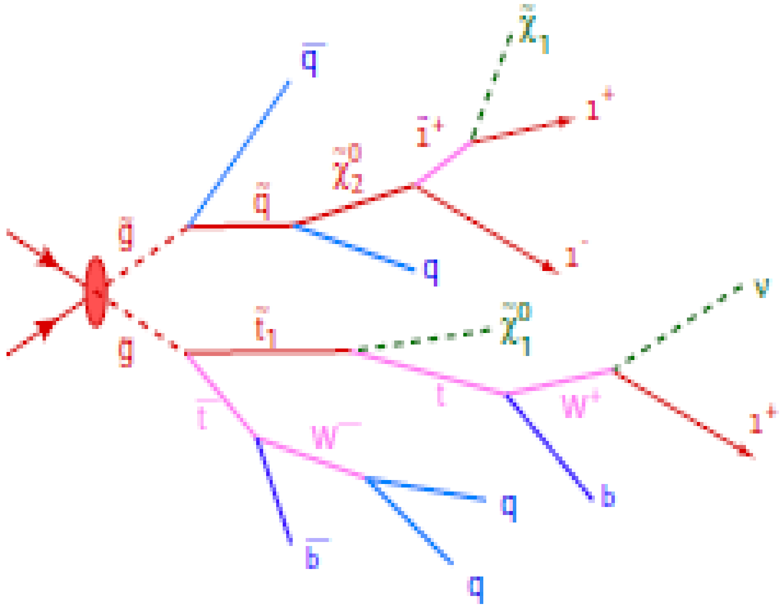


Squark and gluino decay to LSP through complex model dependent decay chain

Typically discovery potential depends On mass hierarchies in the chain

SUSY search strategy

Develop **model-independent** analysis: focus on robust generic signatures
Common to most models and with high rejection of Standard Model

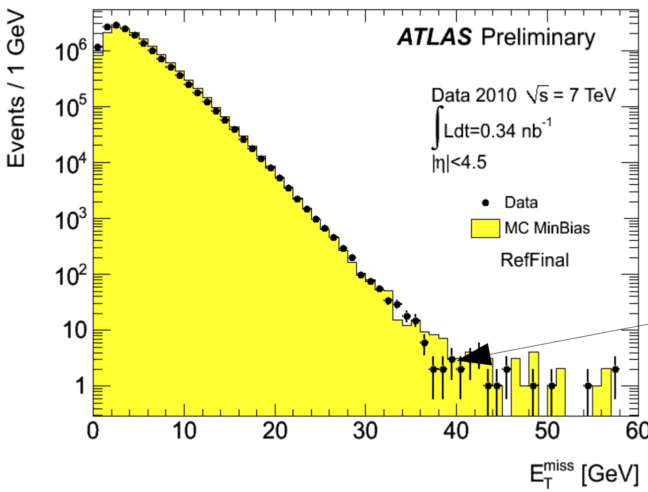


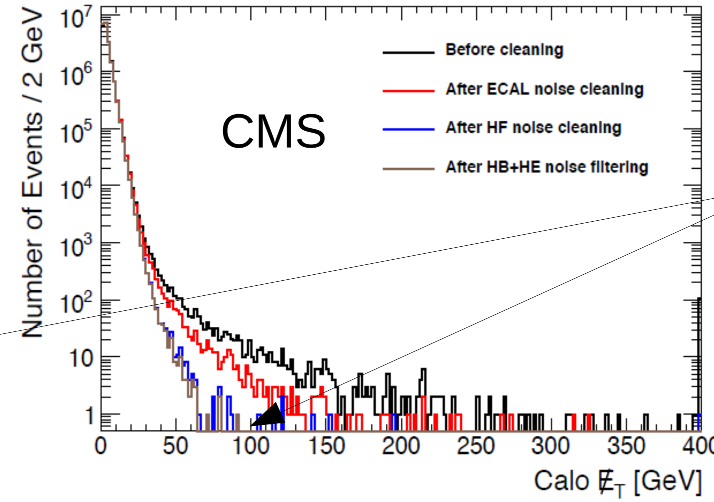
- Etmiss from LSP escaping detection
- High PT jets from squark/gluino decay
- Leptons from chargino/neutralino decays
- b-jets and τ-jets from decays of third generation sparticles
- γ from decays of χ^0_1 into gravitino in models with light gravitino

In addition:

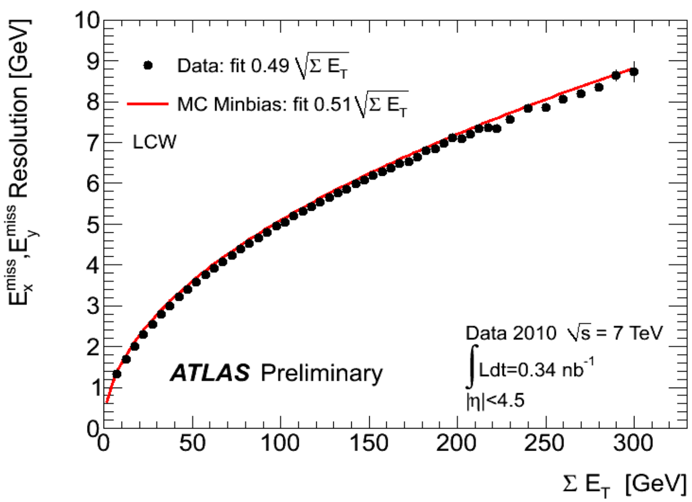
- RPV Models: can observe resonant peaks from sparticle decays
- Long-lived particles, both coloured (R-hadrons) and muon-like predicted
- in many model variations: GMSB, AMSB, Split-SUSY

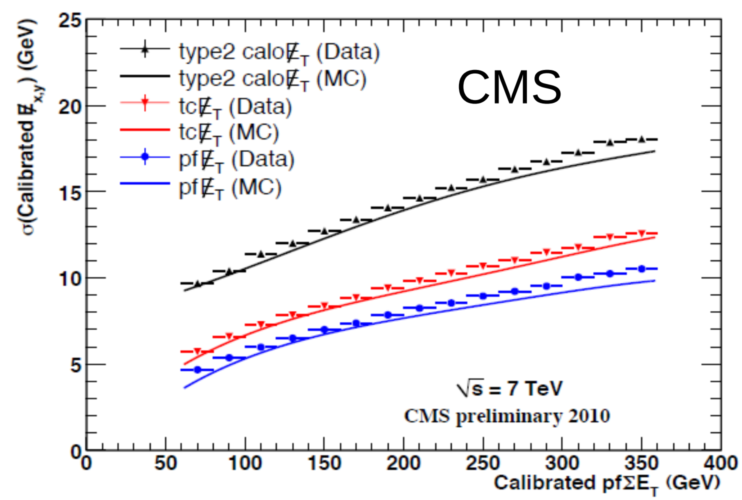
E_t^{miss} (MET) : the main experimental handle





Little or no tails in data!





Good agreement of resolution with MC predictions

E_t^{miss} (MET): vector sum of transverse momenta of all observed objects in detector

Very sensitive to any malfunctioning/miscalibration of detector

Remarkable understanding from very beginning of data-taking

The key issue: backgrounds

- Main sources of Etmiss:
  - Instrumental:
    - Mismeasurement of QCD jets in detector
    - Bad or noisy channels
    - Miscalibrated detector

    Estimate with data-driven methods
  - Physical
    - Processes with neutrinos in final state from decays of W and Z

    Excellent progress in MonteCarlo, use a mix of simulation and data-driven methods
  - Non-Collision backgrounds
    - Cosmics, beam halo, beam-gas

    Estimate from data

2010 SUSY analyses

Signature	ATLAS	CMS
jets+MET	arXiv:1102.5290	CMS-PAS-SUS-10-005 (MHT v MET) CMS-PAS-SUS-11-001 (α_t reloaded) CMS-PAS-SUS-10-009 (R vs M_R) "Razor" arXiv:1101.1628 (α_T)
lepton + jets + MET	PRL 106, 131802	SUS10006 (plots only)
bjets + (lepton) + MET	arXiv:1103.4344	CMS-PAS-SUS-10-011

2leptons + (jets) + MET	arXiv:1103.6214 (OS+SS) arXiv:1103.6208 (FS)	arXiv:1103.1348 (OS) arXiv:1104.3168 (SS)
multileptons + jets + MET	ATLAS-CONF-2011-039	SUS10008 (plots only)
diphoton+MET	arXiv:1012.4272 (3.1 pb^{-1})	arXiv:1103.0953
lepton+photon +MET		SUS110002 (plots only)

eμ	arXiv:1103.5559		RPV $\tilde{\nu}_\tau$
highly-ionising particle	arXiv:1102.0459 (3.1 pb^{-1})		highly charged object
slow particle	arXiv:1103.1984	JHEP03(2011)024 (3.1 pb^{-1})	R-hadron
empty bunch crossing		PRL106,011801 (10 pb^{-1})	stopped gluino

Rich harvest of public analyses, with common result: No deviation from Standard Model found

For this seminar, concentrate on MET analyses, and try to give a reasonably complete description of zero-lepton analyses, which have the highest reach and require the best detector control

0-lepton signatures

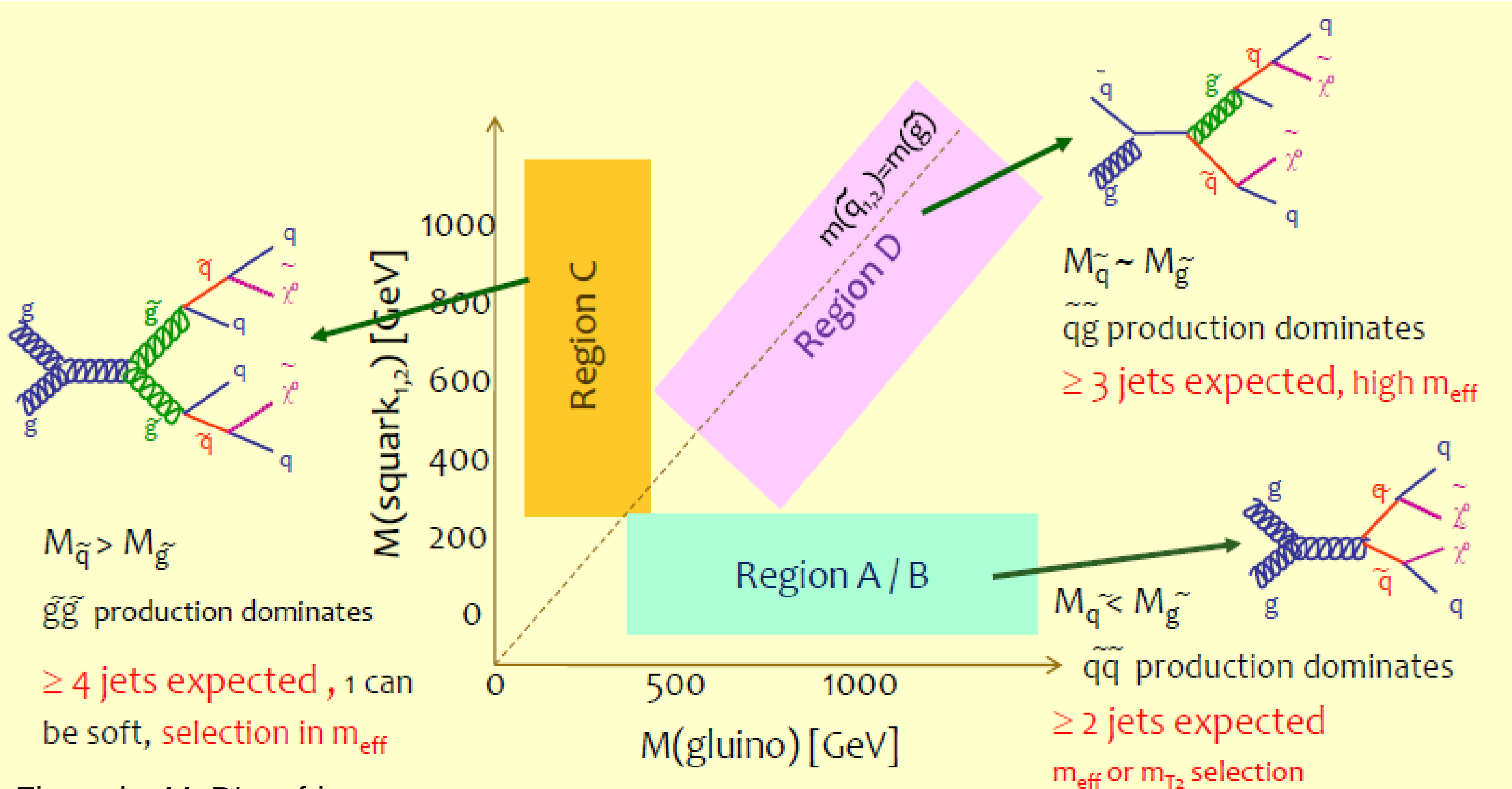


Figure by M. D'onofrio

For two-jets exploit topology of two heavy particles decaying into jets plus invisibles through ad-hoc variables: M_{T2}, α_T, R

ATLAS signal regions

Select events with jets, missing E_T and no lepton (e/μ veto)

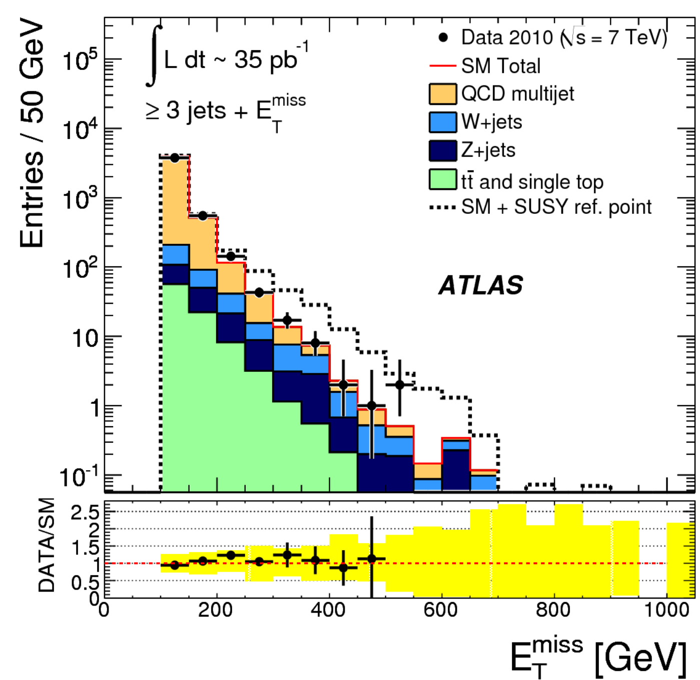
Signal regions definition on the basis of jet multiplicity
(n ≥2 jets or n≥3 jets), jet p_T and E_T^{Miss} thresholds, and:

$$m_{eff} \equiv \sum_{i-1}^{n} | p_T^{(i)} | + E_T^{miss}$$

$$m_{T2}(p_T^{(1)}, p_T^{(2)}, \not{p}_T) \equiv \min_{\vec{q}_T^{(1)}+\vec{q}_T^{(2)}=E_T^{miss}} \{\max(m_T(p_T^{(1)}, q_T^{(1)}), m_T(p_T^{(2)}, q_T^{(2)}))\}$$

$$m_T^2(p_T^{(i)}, q_T^{(i)}) \equiv 2\,| p_T^{(i)} | \, | q_T^{(i)} | - 2\, p_T^{(i)} \cdot q_T^{(i)}$$

		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–



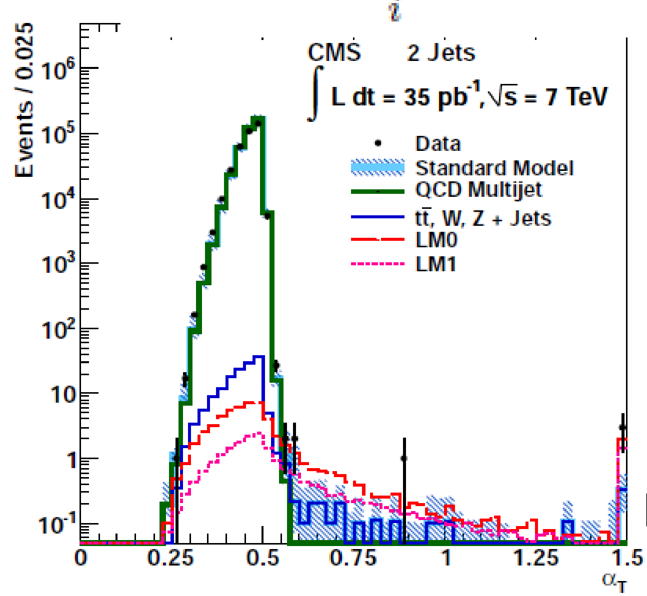
CMS signal regions

Variables:

$$H_T = \sum_i^{\text{jets}} |p_T^i| \qquad MHT = |\sum_i^{\text{jets}} \vec{p}_T^{\,i}| \qquad \alpha_T = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

If >2 jets build super-jets
Based on emispheres

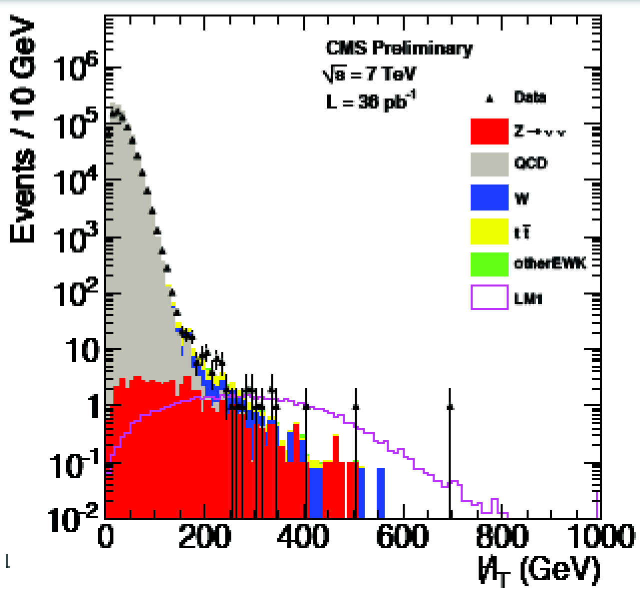
At least 2 jets with:
$p_T > 100$ GeV$/c$ $\quad |\eta| < 2.5$
Include additional jets with:
$p_T > 50$ GeV$/c$ $\quad |\eta| < 3$
Signal region defined by:
$H_T > 350$ GeV $\quad \alpha_T > 0.55$



α_T analysis

Exploit angular variable with α_T<0.5 for QCD events

No explicit use of MET



Selection (baseline):
At least 3 jets with:
$p_T > 50$ GeV$/c$
$|\eta| < 2.5$
Signal region defined by:
$H_T > 350$ GeV
$MHT > 150$ GeV

MHT analysis

CMS signal regions(2)

'Razor' analysis

Arranging all reconstructed objects into two emispheres with 3-momenta *p* and *q*. Define the variables R and M_R:

$$R = \frac{M_T^R}{M_R}$$

$$\mathrm{MET} = \vec{M}$$

$$M_R = 2\sqrt{\frac{(|\vec{p}|q_z - |\vec{q}|p_z)^2}{(p_z - q_z)^2 - (|\vec{p}| - |\vec{q}|)^2}}$$

$$M_T^R = \sqrt{\frac{|\vec{M}|(|\vec{p}| + |\vec{q}|) - \vec{M}\cdot(\vec{p} + \vec{q})}{2}}$$

For heavy particle decays:
MR peaked at a value depending
On particle mass

Selection:

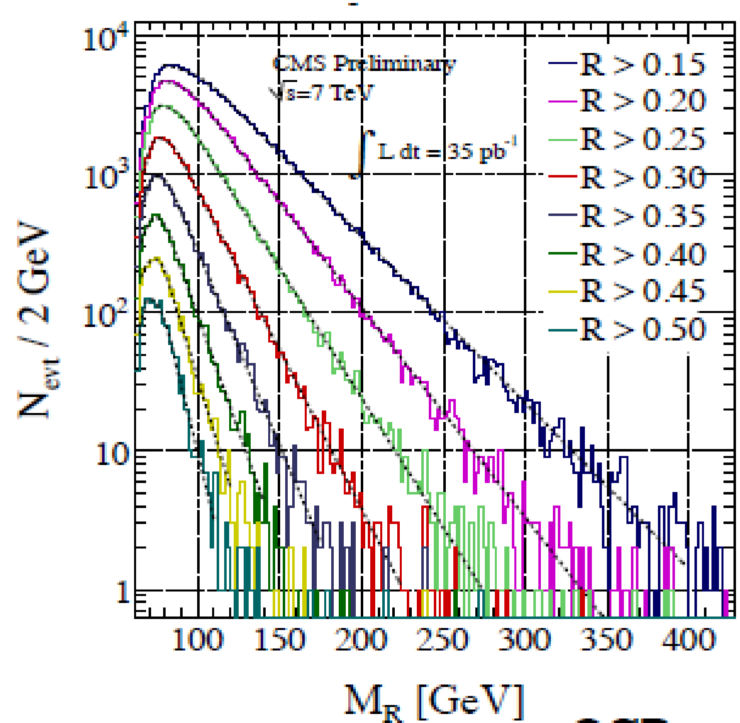
At least 2 jets with:

$$p_T > 30\ \mathrm{GeV}/c$$
$$|\eta| < 3$$

Signal region defined by:

$$R > 0.5$$
$$M_R > 500\ \mathrm{GeV}$$

For QCD:
M_R: exponentially decaying shape with slope depending from R cut: can use low-M_R normalisation to predict background at high M_R



QCD background estimates

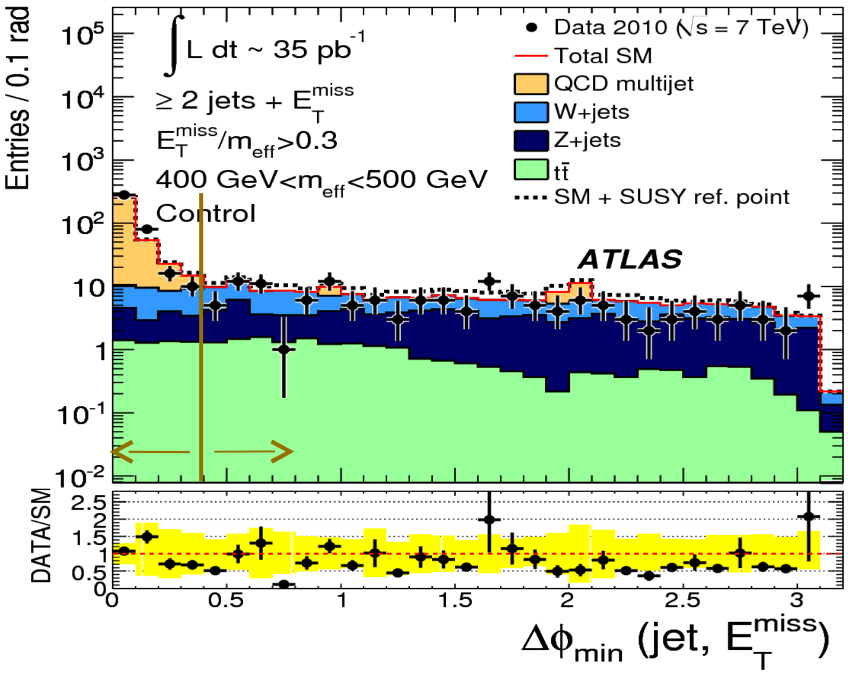
QCD-multijet background due to mis-reconstructed jets and neutrinos from heavy flavour leptonic decays

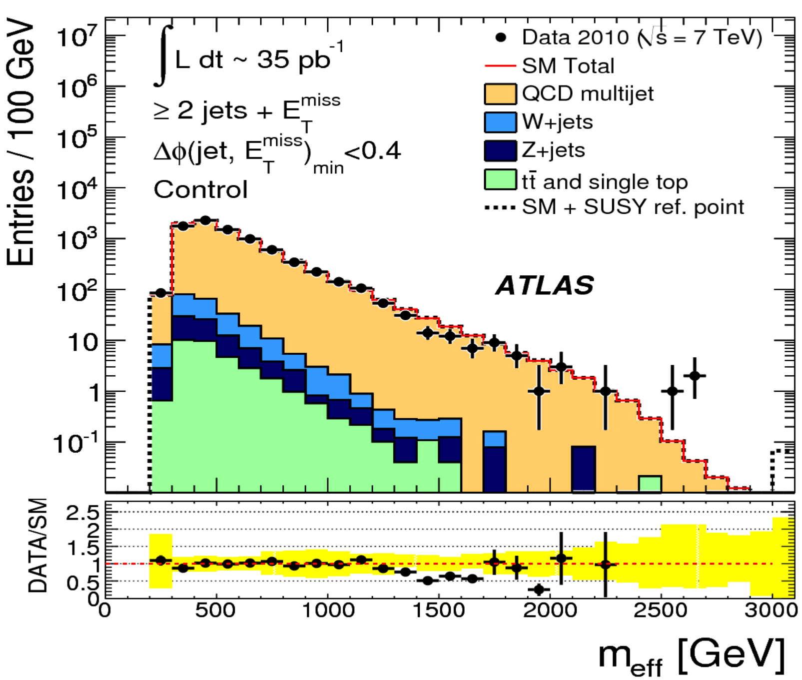
E_T^{Miss} aligned to one of the jets

ATLAS: partially data-driven estimate

Control region **$\Delta\phi(\mathrm{jet}, E_T^{Miss}) < 0.4$**

QCD dominated





Rescale MC samples in control region

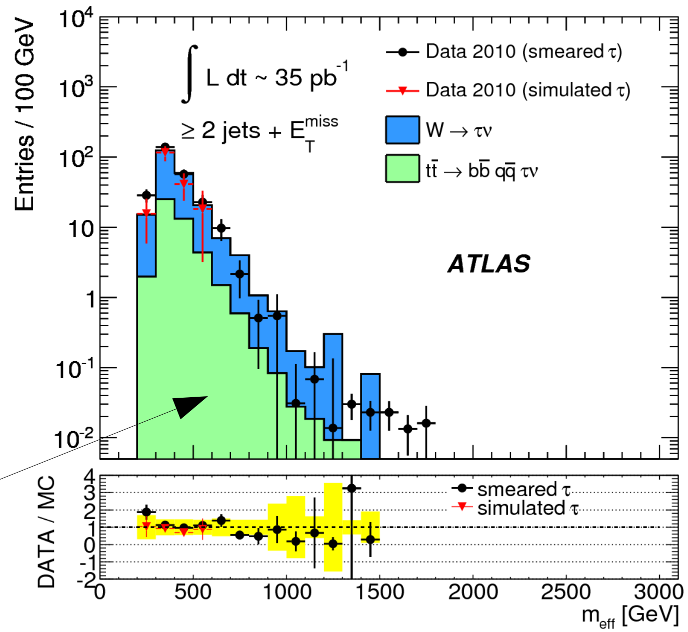
Cross-checked with:

- Fully data-driven techniques (Jet smearing) (also used by CMS MHT analysis)
- Alternate control region based on reversing key seletion cut: ETMiss/meff for ATLAS

W/Z+ jets and top backgrounds

Dominated by:

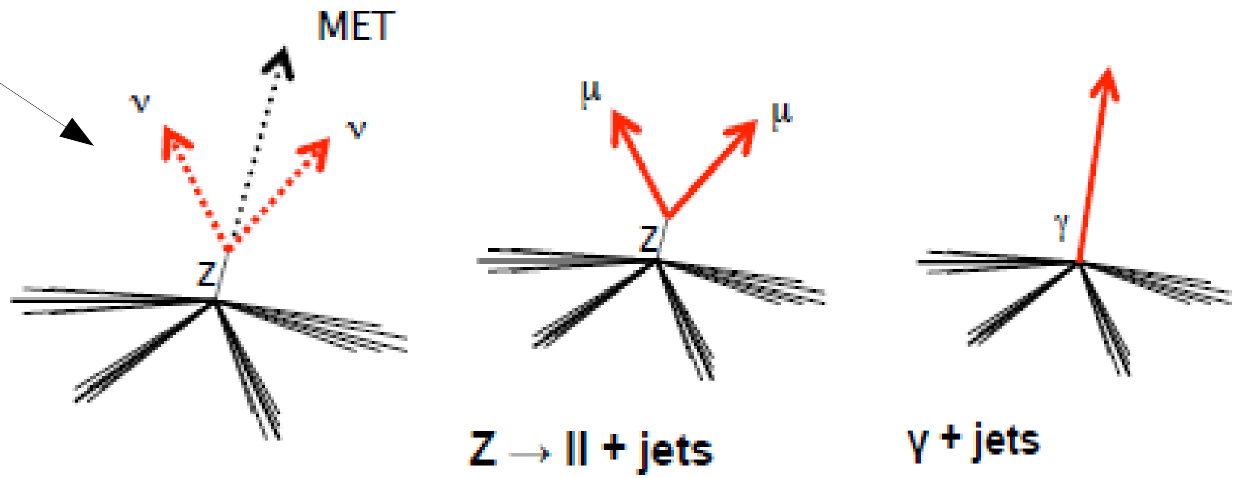
- $W \rightarrow \tau\nu$, $W \rightarrow$(missed) $e\mu$, $Z \rightarrow \nu\nu$
- Top pair production ($top \rightarrow \tau$)



Two approaches:

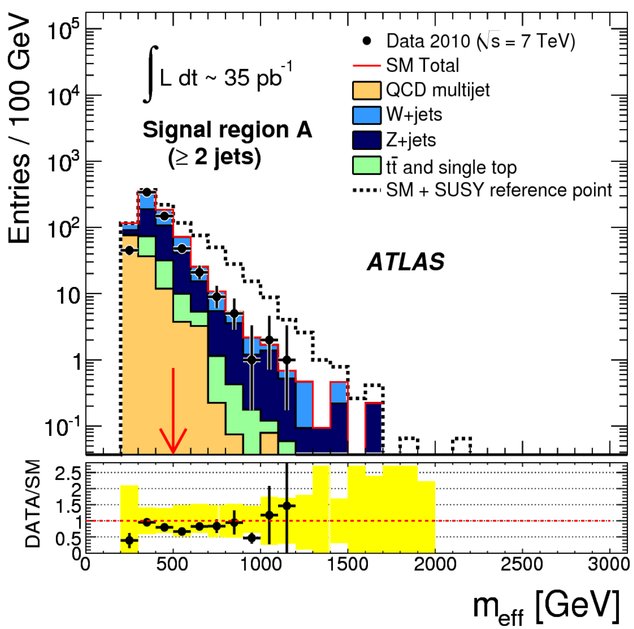
- MC central value and cross-check with data
  Small statisical error but sytematics from MC
- Replacement methods:
  - For τ decays, replace lepton in tt or W/Z with τ
  - For W/Z take leptonic decays and replace leptons with MET

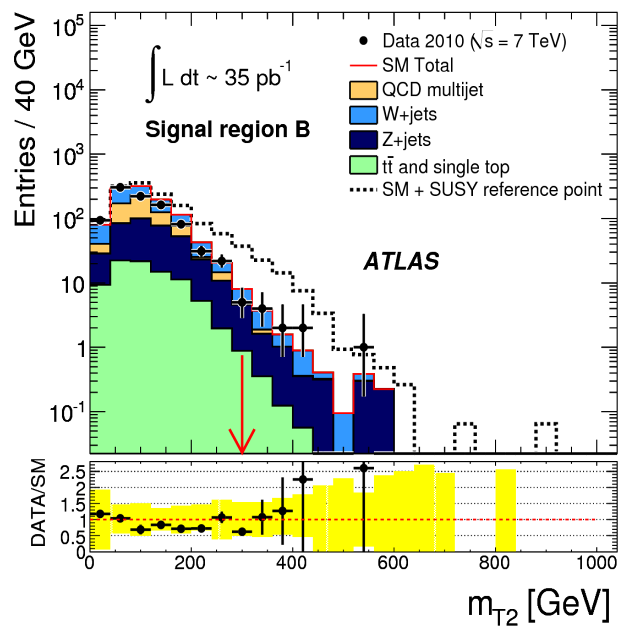
With 2010 data large statistical error
γ+jet (currently used in CMS) large statistics, but low ET background
And theo systematics



Results: ATLAS

	2 jet M_{eff}>500 GeV	2 jets M_{T2}	3 jet M_{eff}>500 GeV	3 jet M_{eff}>1000 GeV
	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\,^{+8}_{-7}[\mathrm{u}]$	$0.6\,^{+0.7}_{-0.6}[\mathrm{u}]$	$9\,^{+10}_{-9}[\mathrm{u}]$	$0.2\,^{+0.4}_{-0.2}[\mathrm{u}]$
W+jets	$50 \pm 11[\mathrm{u}]\,^{+9}_{-8}[\mathrm{j}] \pm 5[\mathcal{L}]$	$4.4 \pm 3.2[\mathrm{u}]\,^{+1.0}_{-0.7}[\mathrm{j}] \pm 0.5[\mathcal{L}]$	$35 \pm 9[\mathrm{u}]\,^{+7}_{-7}[\mathrm{j}] \pm 4[\mathcal{L}]$	$1.1 \pm 0.7[\mathrm{u}]\,^{+0.2}_{-0.3}[\mathrm{j}] \pm 0.1[\mathcal{L}]$
Z+jets	$52 \pm 21[\mathrm{u}]\,^{+11}_{-9}[\mathrm{j}] \pm 6[\mathcal{L}]$	$4.1 \pm 2.9[\mathrm{u}]\,^{+1.7}_{-0.8}[\mathrm{j}] \pm 0.5[\mathcal{L}]$	$27 \pm 12[\mathrm{u}]\,^{+7}_{-5}[\mathrm{j}] \pm 3[\mathcal{L}]$	$0.8 \pm 0.7[\mathrm{u}]\,^{+0.3}_{-0.0}[\mathrm{j}] \pm 0.1[\mathcal{L}]$
$t\bar{t}$ and t	$10 \pm 0[\mathrm{u}]\,^{+2}_{-2}[\mathrm{j}] \pm 1[\mathcal{L}]$	$0.9 \pm 0.1[\mathrm{u}]\,^{+0.2}_{-0.2}[\mathrm{j}] \pm 0.1[\mathcal{L}]$	$17 \pm 1[\mathrm{u}]\,^{+4}_{-3}[\mathrm{j}] \pm 2[\mathcal{L}]$	$0.3 \pm 0.1[\mathrm{u}]\,^{+0.1}_{-0.1}[\mathrm{j}] \pm 0.0[\mathcal{L}]$
Total SM	$118 \pm 25[\mathrm{u}]\,^{+23}_{-19}[\mathrm{j}] \pm 12[\mathcal{L}]$	$10.0 \pm 4.3[\mathrm{u}]\,^{+2.0}_{-1.7}[\mathrm{j}] \pm 1.0[\mathcal{L}]$	$88 \pm 18[\mathrm{u}]\,^{+18}_{-15}[\mathrm{j}] \pm 9[\mathcal{L}]$	$2.5 \pm 1.0[\mathrm{u}]\,^{+0.6}_{-0.4}[\mathrm{j}] \pm 0.2[\mathcal{L}]$
Data	87	11	66	2





<u>Exclude non-SM</u>:
N events
43.9(A), 11.9(B),
37.6(C), 3.5(D)
σ of
1.3 pb(A), 0.35 pb(B),
1.1 pb(C), 0.11 pb (D)

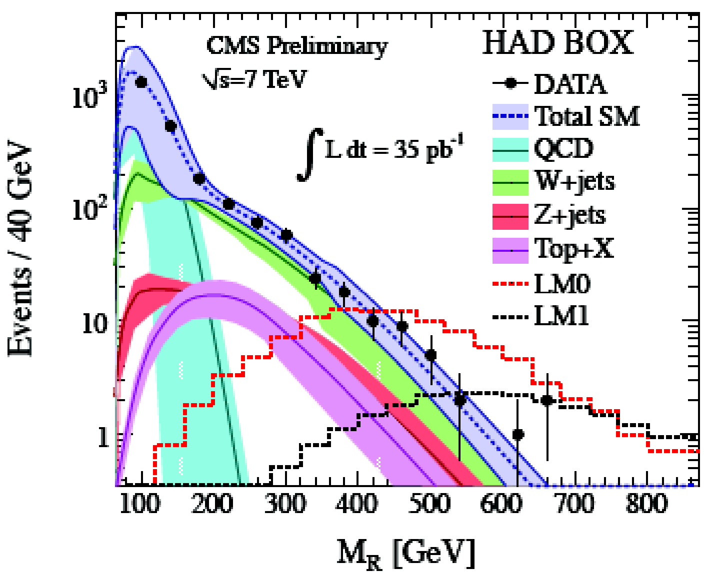
Results: CMS

Method	Baseline		High-$\not{H}_T$ ($\not{H}_T > 250$ GeV/c)		High-H_T ($H_T > 500$ GeV/c)	
$Z \to \nu\bar{\nu}$ from γ+jets	26.3	± 4.8	7.1	± 2.2	8.4	± 2.3
$t\bar{t}/W \to e, \mu$+X lost-lepton method	33.0	± 8.1	4.8	± 1.9	10.9	± 3.4
$t\bar{t}/W \to \tau_{hadr}$+X method	22.3	± 4.6	6.7	± 2.1	8.5	± 2.5
QCD Rebalance+Smear method	29.7	± 15.2	0.16	± 0.10	16.0	± 7.9
QCD factorization method	25.2	± 13.4	0.4	± 0.3	17.3	± 9.4
Total data-driven background	111.3	± 18.5	18.8	± 3.5	43.8	± 9.2
Observed in 36 pb^{-1} of data	111		15		40	
95% CL limit on signal events	40.4		9.6		19.6	

MHT analysis

α_T analysis

Predict: $9.4^{+4.8}_{-4.0}$ (stat) ± 1.0 (syst) events
Observe: 13 events



Razor analysis

Predict: 5.5 ± 1.4 events
Observe: 7 event

CMSSM/mSUGRA interpretation

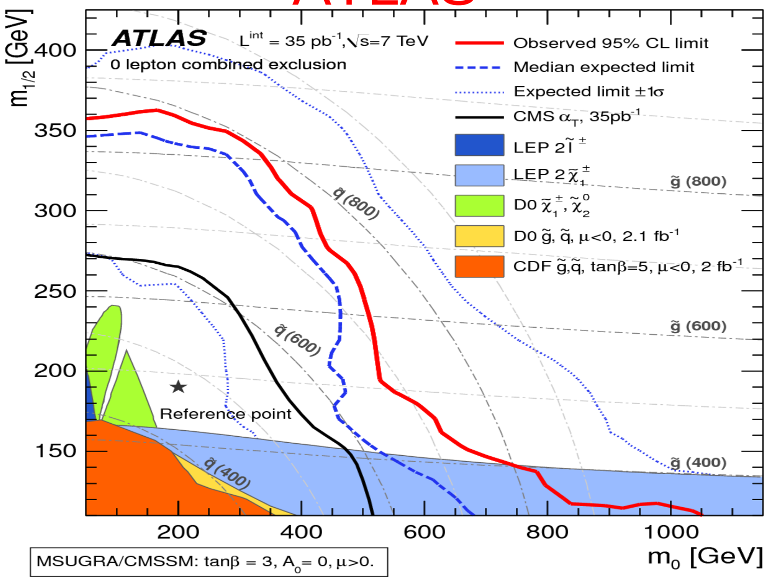
mSUGRA plane: masses at SUSY breaking scale

m_0=common scalar mass

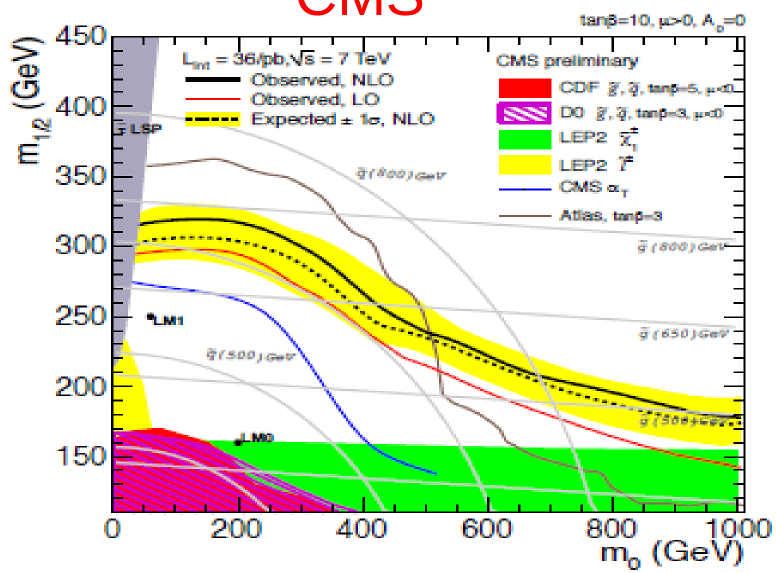
$m_{1/2}$= common fermion mass

Fix A=0, tanβ=3(10) , μ>0

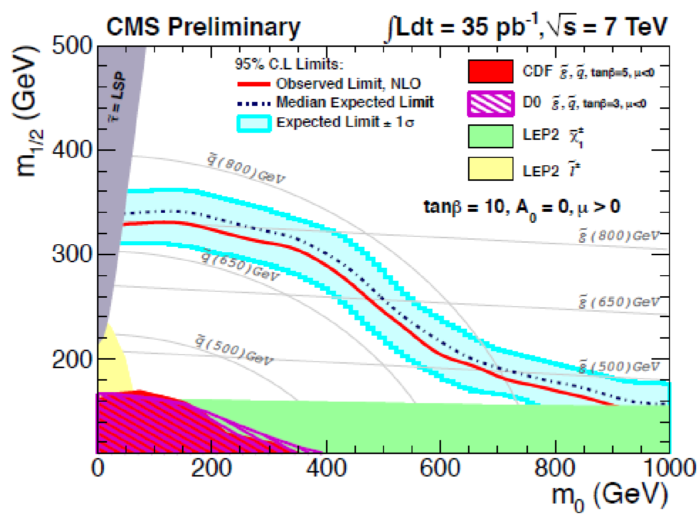
ATLAS



CMS



MHT



Razor

In this model, ATLAS reach is for 750 GeV mass if m(sq)=m(gl)

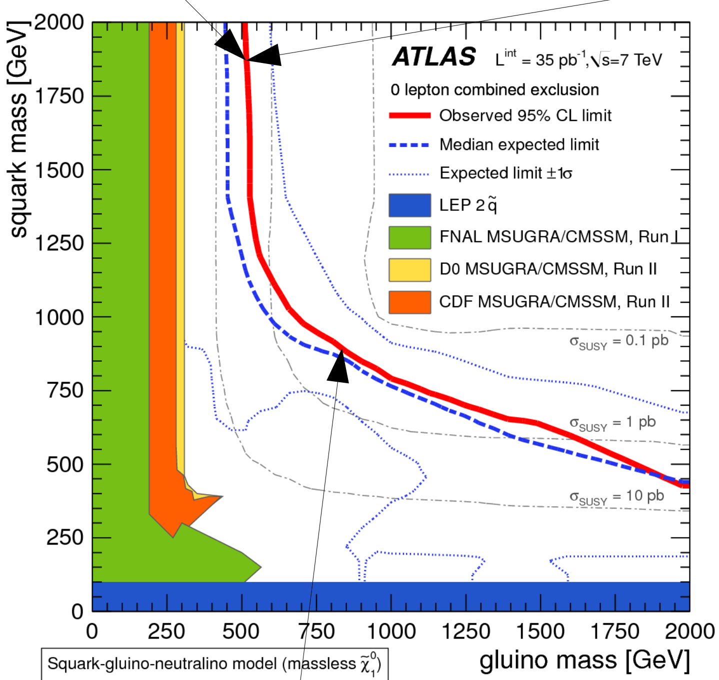
Lower jet cuts in CMS analysis
Favour high squark mass region
with high multiplicity of soft jets

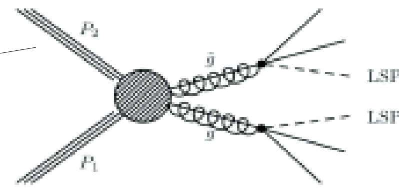
Topological Interpretation

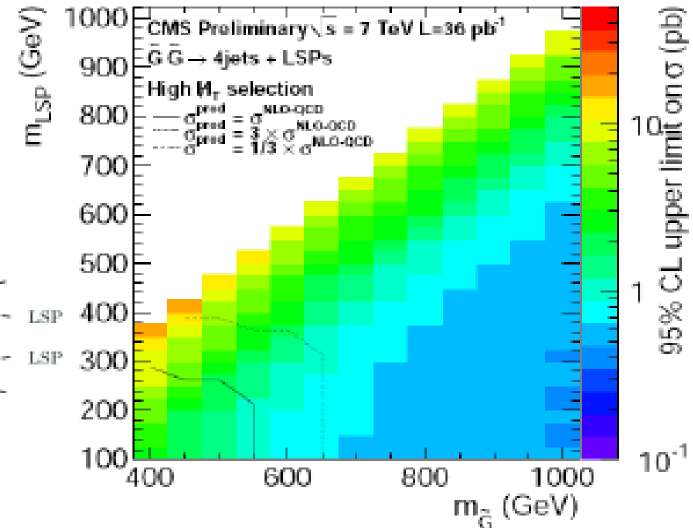
CMS

ATLAS: simplified MSSM model containing only gluinos, squarks of 1st and 2nd generation and massless chi01

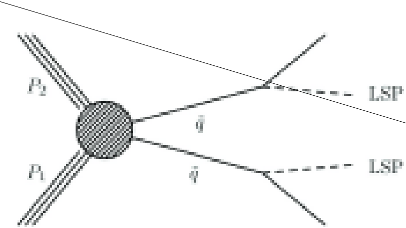
Excluded gluino mass below 500 GeV

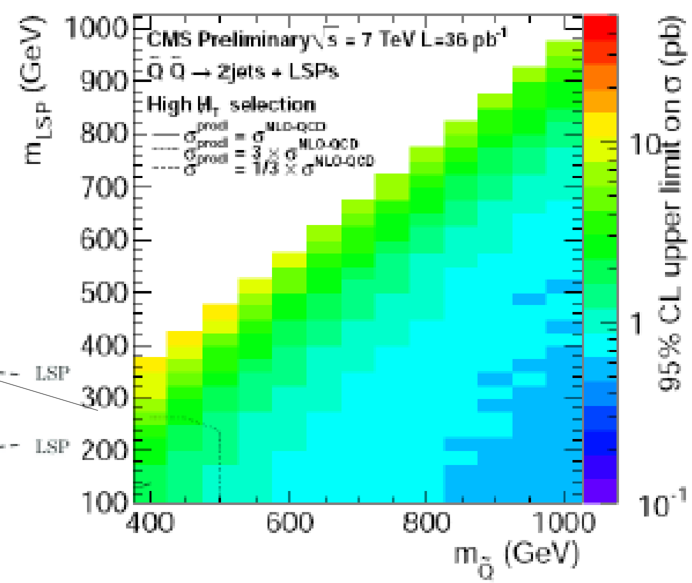






Generate single Process, limits On σ for process



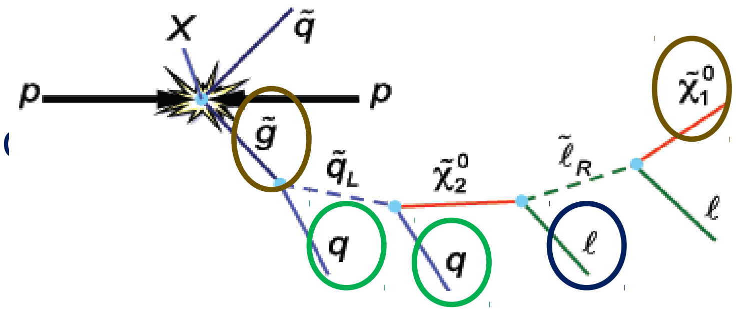


If msquark=mgluino exclude < 870 GeV

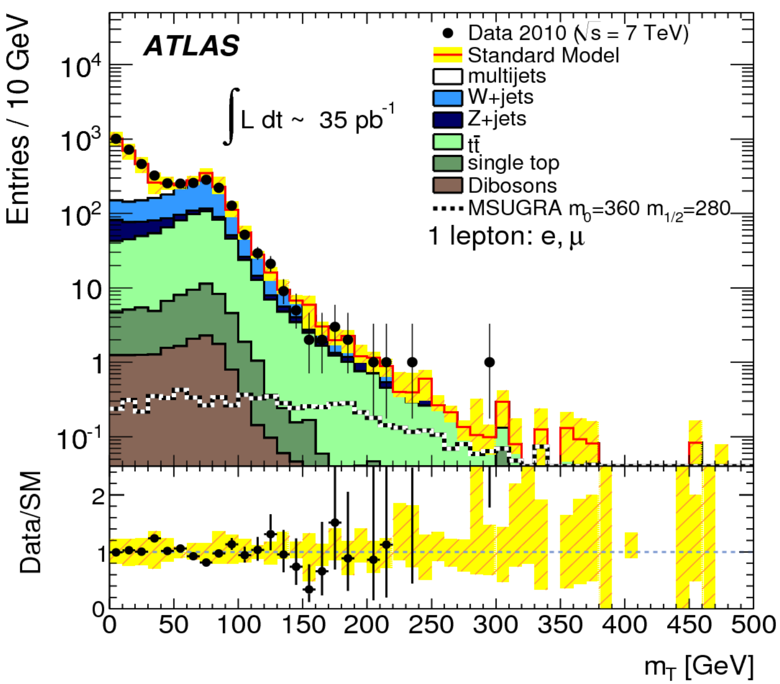
1-lepton search

Privilege signatures from gluino/squark cascade decays with intermediate steps

Isolated lepton suppresses QCD multijet backgroun and facilitates triggering



$$m_T \equiv \sqrt{2 \cdot p_T^l \cdot E_T^{Miss} \cdot (1 - \cos(\Delta\varphi(l, E_T^{Miss})))}$$



<u>Signal region ATLAS:</u>

Exactly 1 lepton (e or μ, pT>20 GeV)
+ ≥3 jets [pT> 60,30,30 GeV]

mT>100 GeV : suppress W+jets and top

MET/meff > 0.25 : suppress QCD

meff>500 GeV : enhance SUSY sensitivity

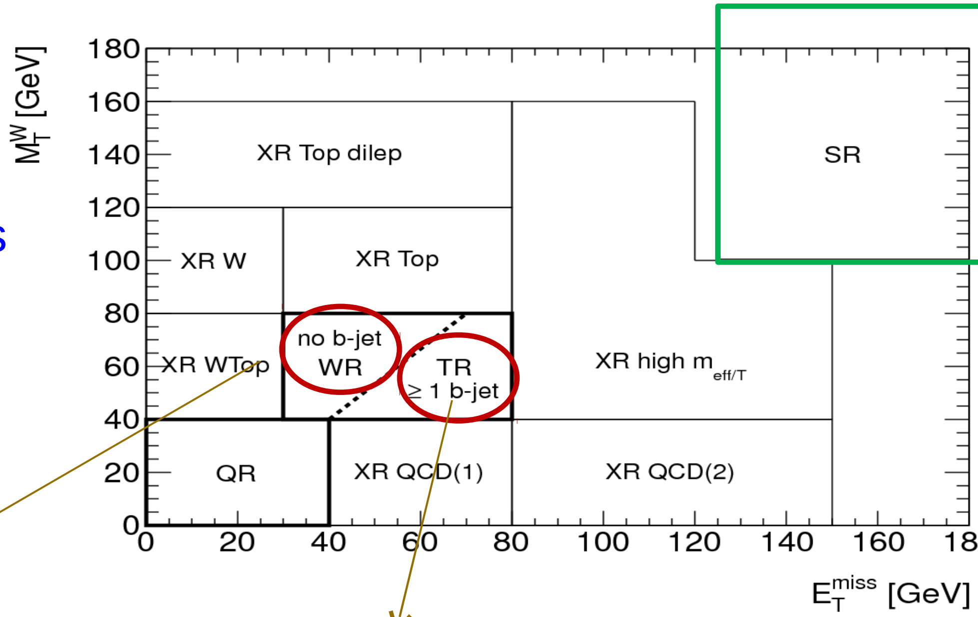
<u>Signal region CMS:</u>

Exactly 1 lepton (e or μ, pT>20 GeV)
+ ≥4 jets [pT> 30 GeV]

MET>250 : suppress QCD

HT>500 GeV : enhance SUSY sensitivity

SM background estimation (ATLAS)



Based on E_T^{miss} vs M_T

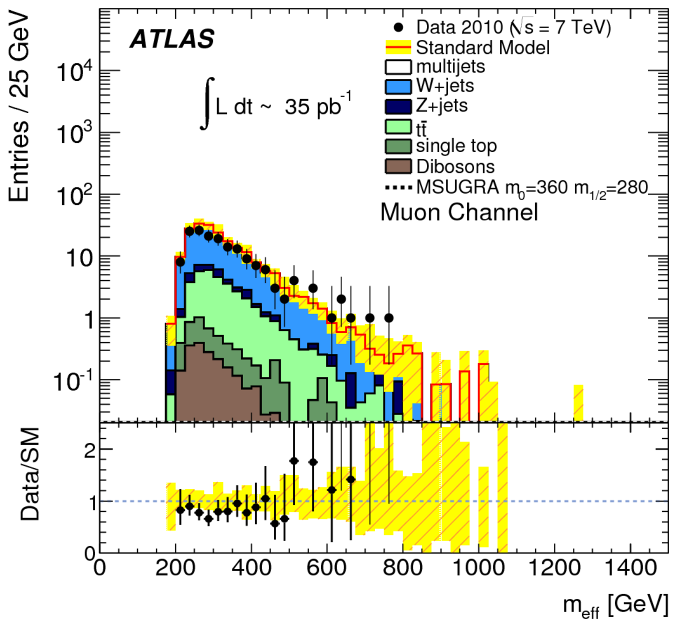
Define samples enriched in given process

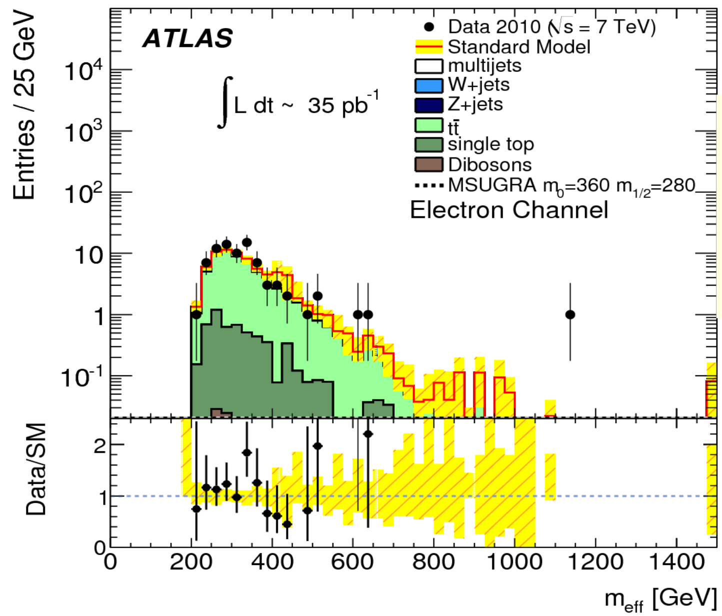
Constrain MC predictions to data in that region (rely on MC shapes)

Extrapolate to other regions

Evaluate Uncertainties on extrap. factors

W-enriched sample (require < 1 b-tagged jet)



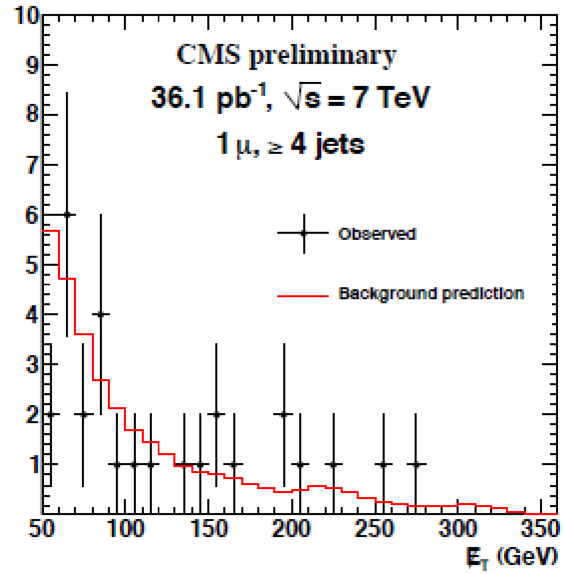


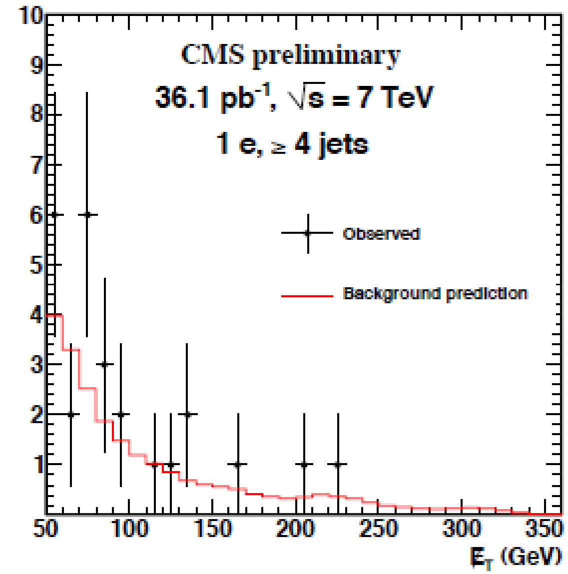
top-enriched sample (require ≥ 1 b-tagged jet)

SM background estimation (CMS)

Exploit the fact that for W decays the charged lepton and neutrino p_T spectra are on average approximately the same

Use lepton p_T spectra to predict MET





- Take muon p_T spectrum (cleaner than electron)
- Correct for acceptance, efficiency and polarisation effects
- MET resolution worse than for e/μ ➔ measure in data and smear
- Powerful technique based on fundamental physics

1 lepton results and interpretation

ATLAS

1 event/channel (data),

1.81±0.75 (2.25±0.94) SM in e (μ)

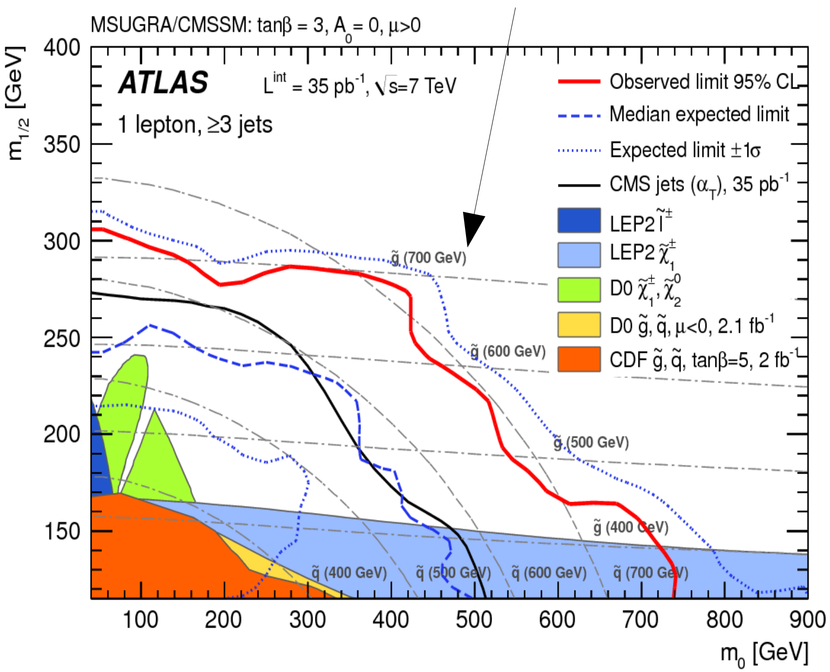
95% C.L. upper limits on N events from new physics: 2.2 (ele), 2.5 (muon)

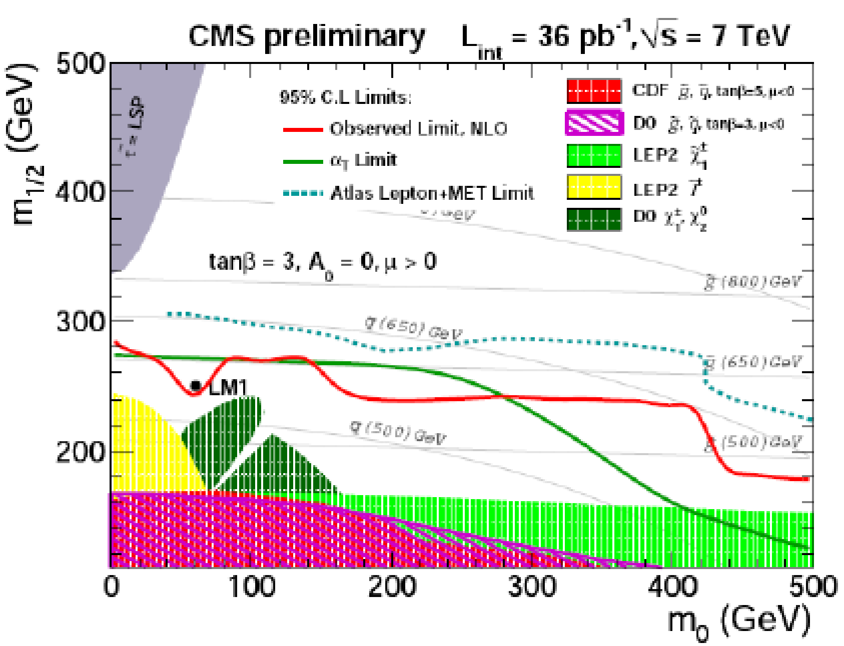
Effective x-sect limit: 0.065 pb and 0.073 pb

700 GeV on m(gluino) in CMSSM

CMS

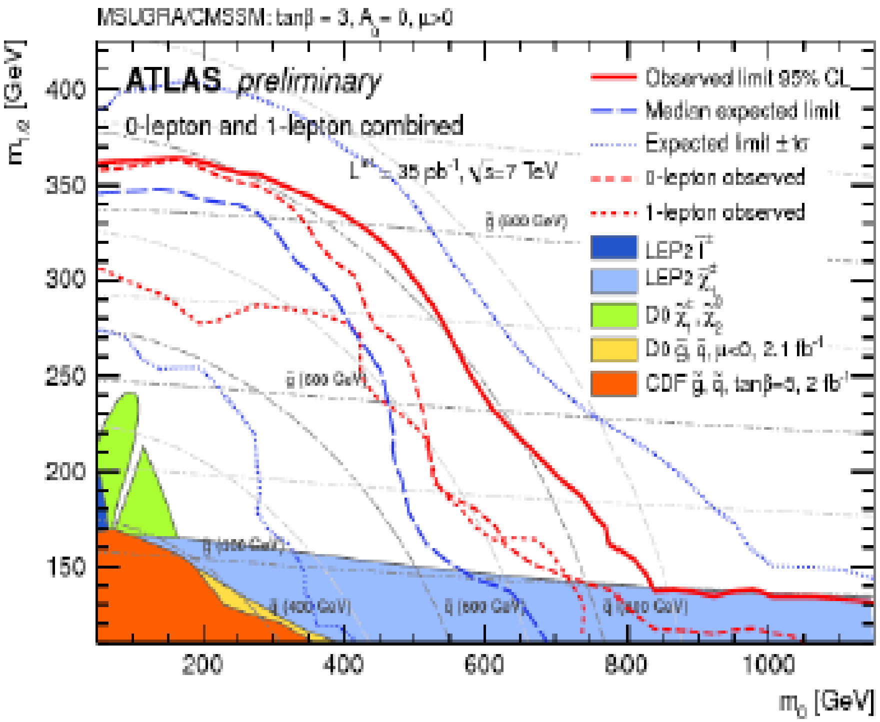
Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0



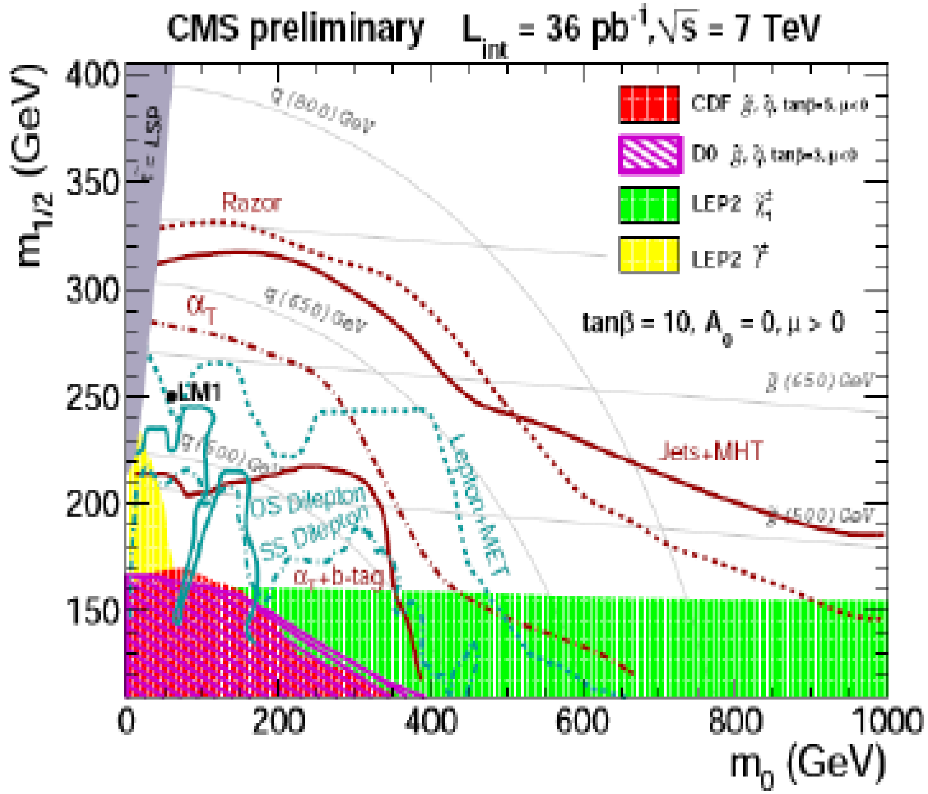


cMSSM/mSUGRA the state of the art

ATLAS: combination of 0-lepton and 1-lepton channels



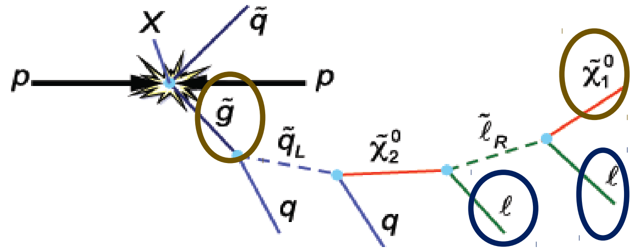
CMS: summary of SUSY searches 2010



2-lepton analysis (ATLAS)

Search for dilepton (e,μ) pairs from neutralino/chargino decays

Two search strategies, requiring opposite-sign (OS) and same-sign (SS) dileptons events



Event selection

· exactly two leptons

· M(ll) > 5 GeV

Signal regions

· OS: ETMiss > 150 GeV

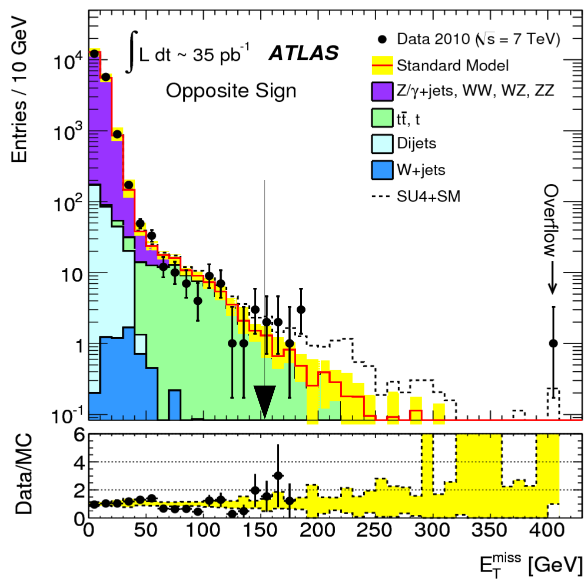
· SS: ETMiss > 100 GeV

Main SM Background

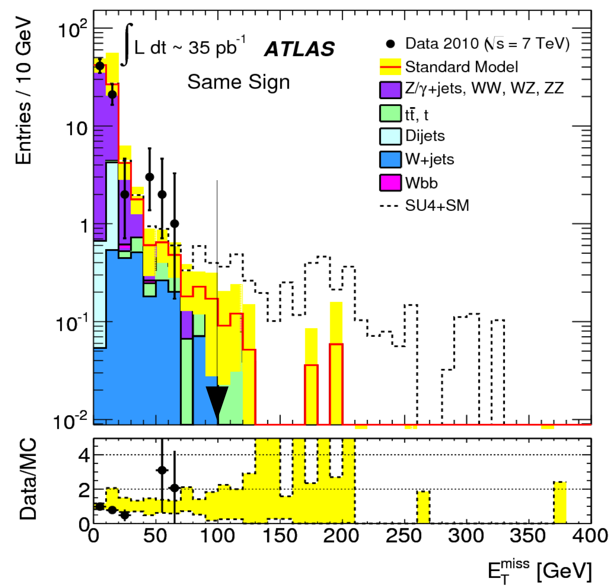
· OS: **top pair** (estimate in CR)

· SS: misidentified leptons (fakes) data-driven basd on loose-tight lepton id

Opposite-Sign



Same-Sign



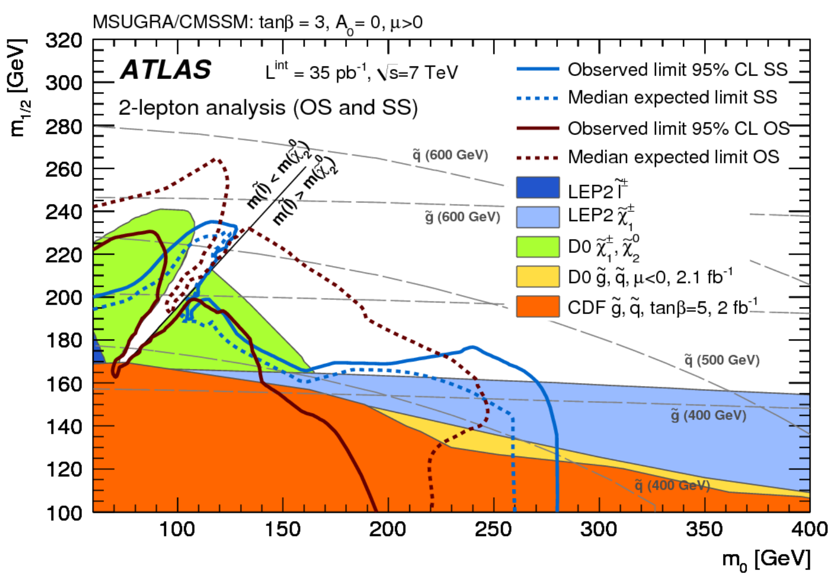
CMS: similar analysis for OS, but requiring jets and HT
More complex analysis with several signal regions for SS

Results and mSUGRA interpretation

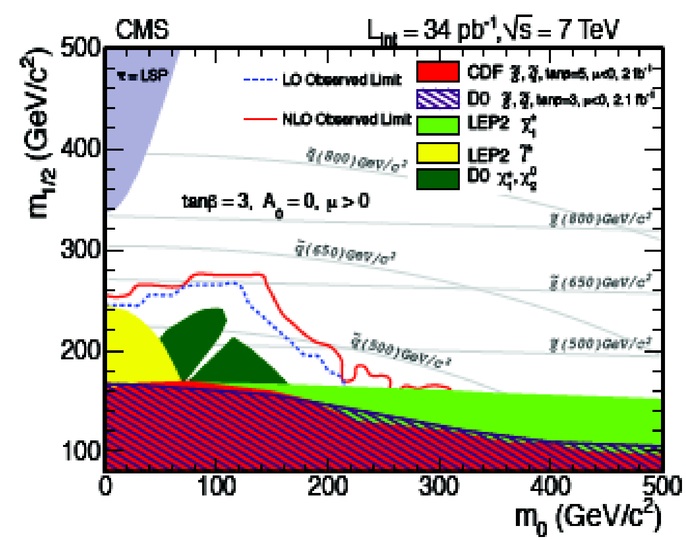
ATLAS

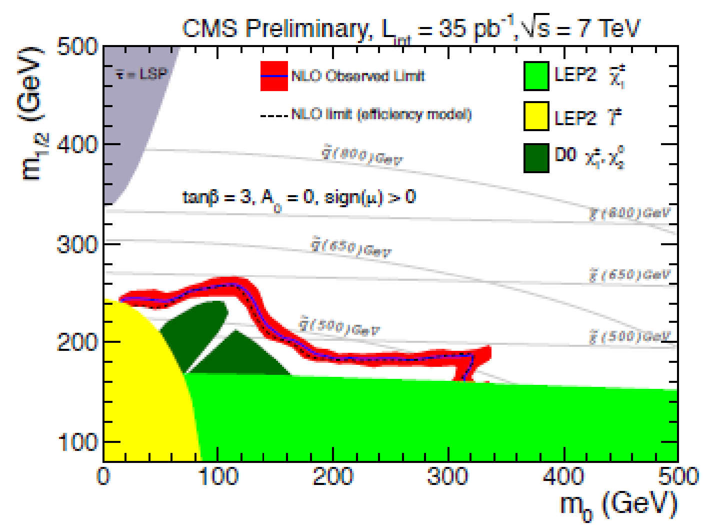
Agreement between data and SM expectations within uncertainties:

- Use sum of ee,μμ,eμ channel for SS, combination of the three channels for OS
- 95% C.L. upper limits on effective cross section σ • A•BR from new physics:
    - SS: σ<0.07 pb
    - ee: 0.09 pb, μμ: 0.21 pb, eμ: 0.22 pb



CMS





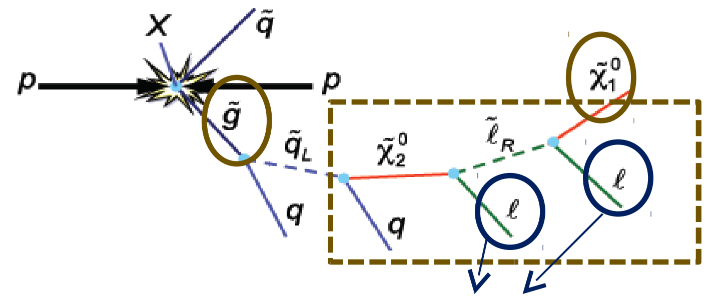
2-lepton: a different approach

Search for **excess of identical flavour** opposite-sign lepton pairs:

Sensitive to SUSY particle cascade no excess expected in SM (aside for Z/γ* sources)

Subtraction SF - OF allows **"cancellation" of systematic uncertainties**:

If discovery: measure SUSY particle masses



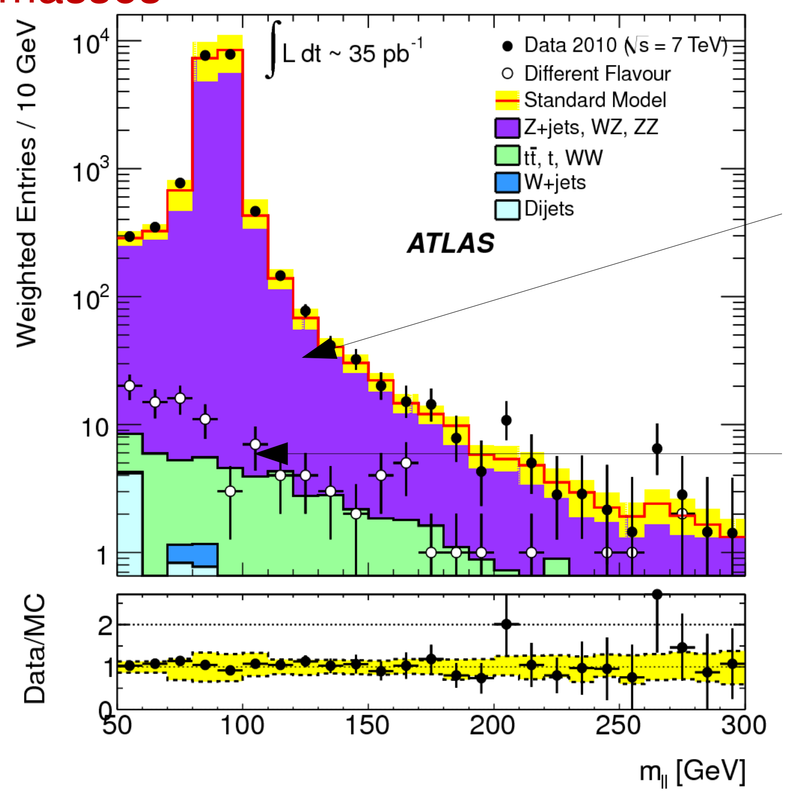
Same flavor from lepton flavor conservation

Event selection

- exactly two leptons (ee,μμ,eμ)
- M(ll) > 5 GeV
- ETMiss > 100 GeV

Main SM Background

- top pair, Wt-channel single top
  → self-cancelling
- residual Z/γ*+jets
  → use low ETMiss CR



before ETMiss cut

Same flavours

Different flavours

Same-flavor results

From N(ee), N(eμ) and N(μμ), same flavour excess: **S=N×Eff×Acc.**

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

ε_e, ε_μ = ID efficiency

$\beta = \varepsilon_e/\varepsilon_\mu$

τ_e, τ_μ = trigger efficiency

Observed

$$\boxed{S_{obs.} = 1.98 \pm 0.15(\beta) \pm 0.02(\tau_e) \pm 0.06(\tau_\mu)}$$

Expected

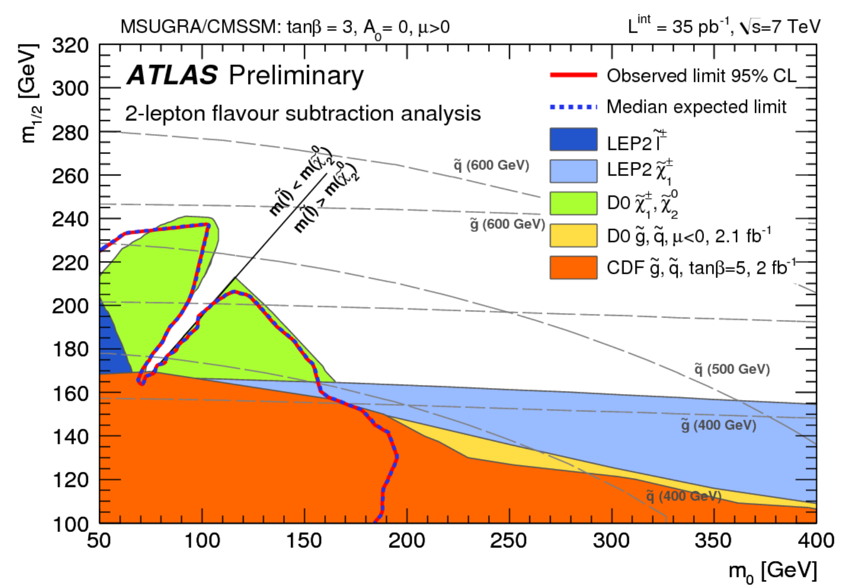
If no signal

$$\bar{S}_b = 2.06 \pm 0.79(stat.) \pm 0.78(sys.)$$

Compatibility between S_{obs} and S_b

Used to put limit on S_s, possible signal contribution, through Monte Carlo experiments

$S_s < 8.8$ at 95% CL



2-lep MSSM interpretation (ATLAS)

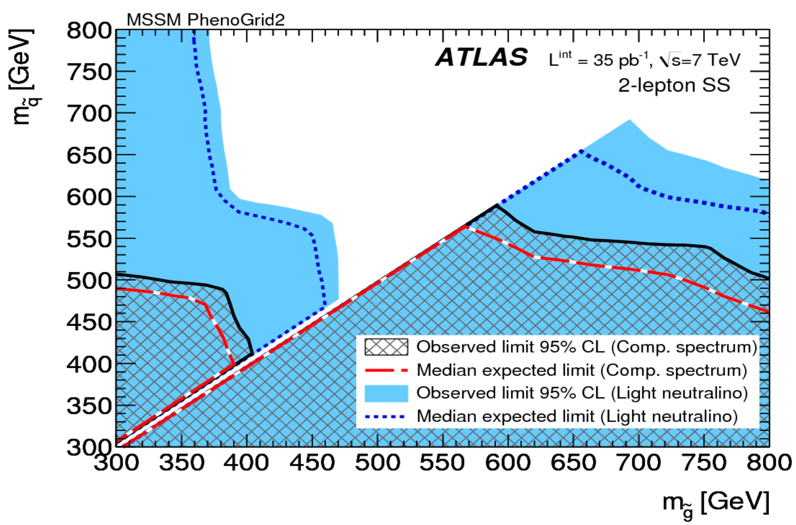
Consider more general MSSM 24-parameter framework, where sleptons are in the gluino and squark decays chains :

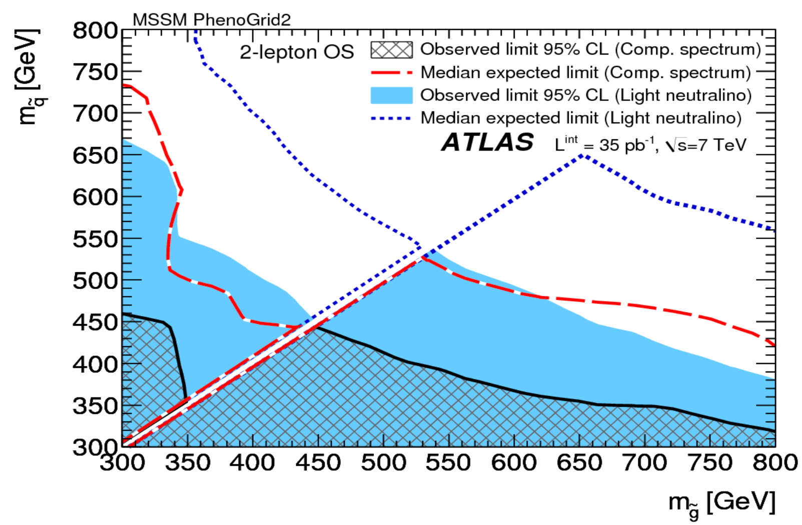
m_A=1000 GeV, $\mu=1.5\cdot$min(mgl,mq) , tanβ=4, At=μ/tanβ, Ab=Al=μtanβ

$m(\tilde{l}_R)=m(\tilde{l}_L)$, $m(\tilde{q}_R)=m(\tilde{q}_L)$, 3rd generation at high mass

"compressed spectrum" (CS): $m(\tilde{\chi}^0_2)$ =M - 50 GeV, $m(\tilde{\chi}^0_1)$=M - 150 GeV, $m(\tilde{l}_L)$=M - 100 GeV, with M=min(mgl,mq) $\rightarrow$ soft final state kinematics

"light neutralino" (LN): $m(\tilde{\chi}^0_1)$=100 GeV , $m(\tilde{\chi}^0_2)$ =M-100 GeV, $m(\tilde{l}_L)$=M/2 GeV hard kinematics





Limits on squark mass for
$m(\tilde{g})=m(\tilde{q})$+10 GeV

OS: $m(\tilde{q})$>560 GeV (LN), >450 GeV (CS)
SS: $m(\tilde{q})$>690 GeV (LN), >590 GeV (CS)

b-jets + Etmiss

Third generation squarks might be lighter than 1st, 2nd generation, possibly high cross sections: Final state enriched in b-jets
$\rightarrow$**search in events with jets (≥1 b-jet) +ETMiss (+ 0/ ≥ 1) leptons**

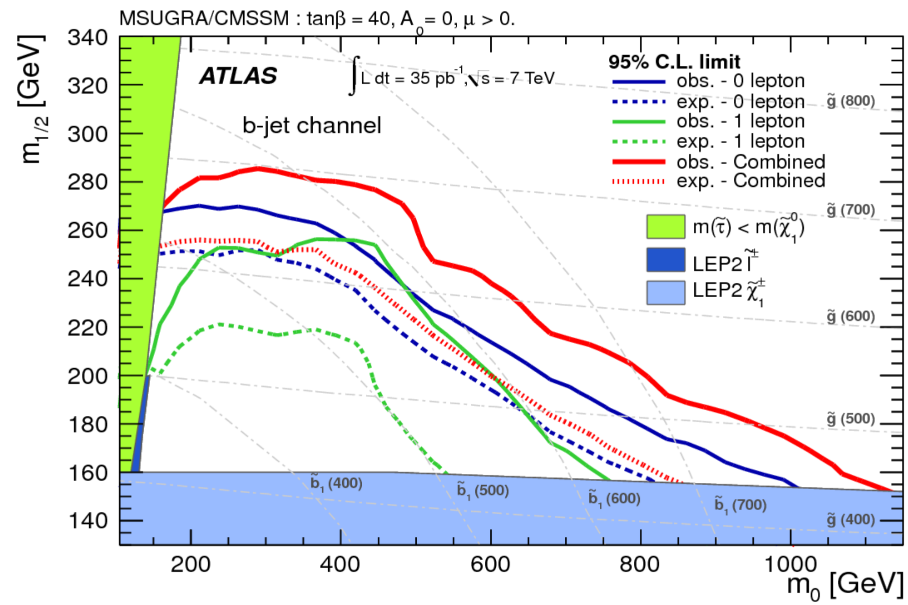
ATLAS: two analyes: 0 lepton + 3 jets, 1-lepton+ 2 jets, selections similar To corresponding Etmiss analyses, but requiring at least one of the jets to be b-tagged

CMS: extension of the α_T analysis

ATLAS results

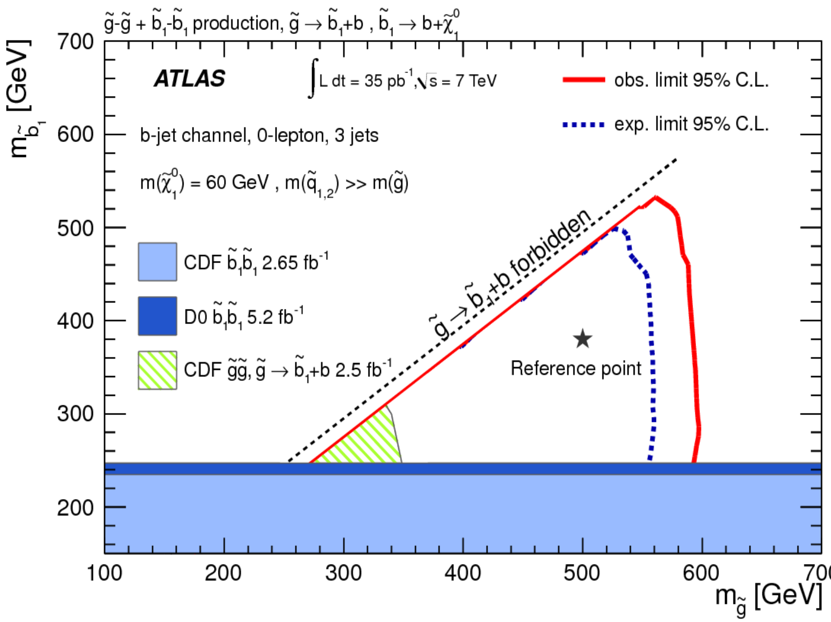
	0-lepton	1-lepton Monte Carlo	1-lepton data-driven
$t\bar{t}$ and single top	12.2 ± 5.0	12.3 ± 4.0	14.7 ± 3.7
W and Z	6.0 ± 2.0	0.8 ± 0.4	-
QCD	1.4 ± 1.0	0.4 ± 0.4	$0^{+0.4}_{-0.0}$
Total SM	19.6 ± 6.9	13.5 ± 4.1	14.7 ± 3.7
Data	15	9	9

Interpretation in high tanβ (=40) region where 3rd generation has lower masses



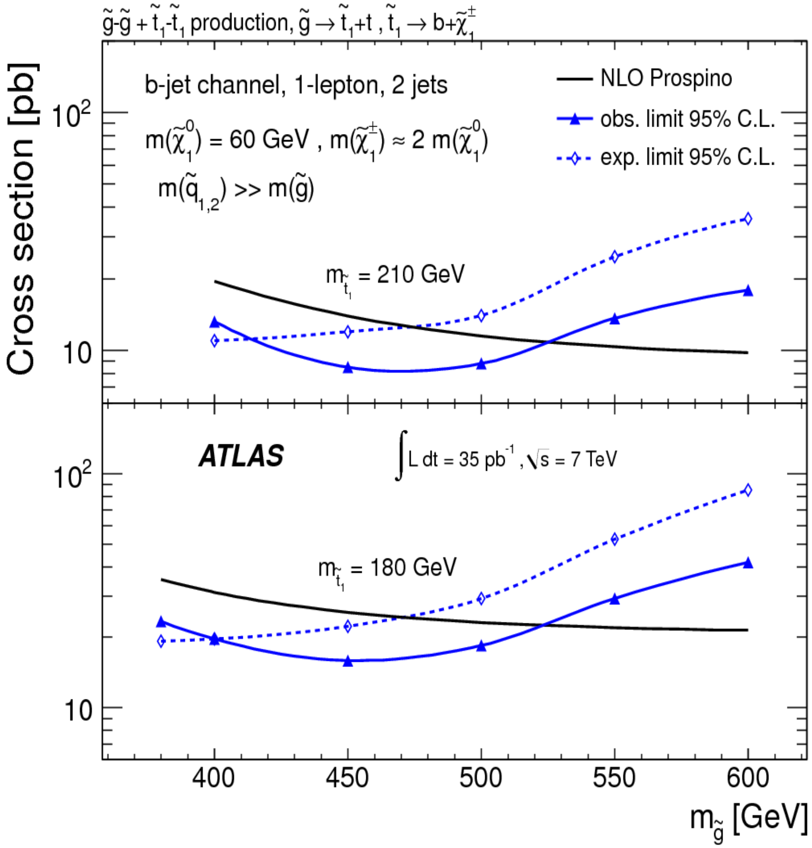
Interpretation in pheno MSSM

$\tilde{g} \to \tilde{b}_1 b \quad \tilde{b}_1 \to b\tilde{\chi}_1^0$



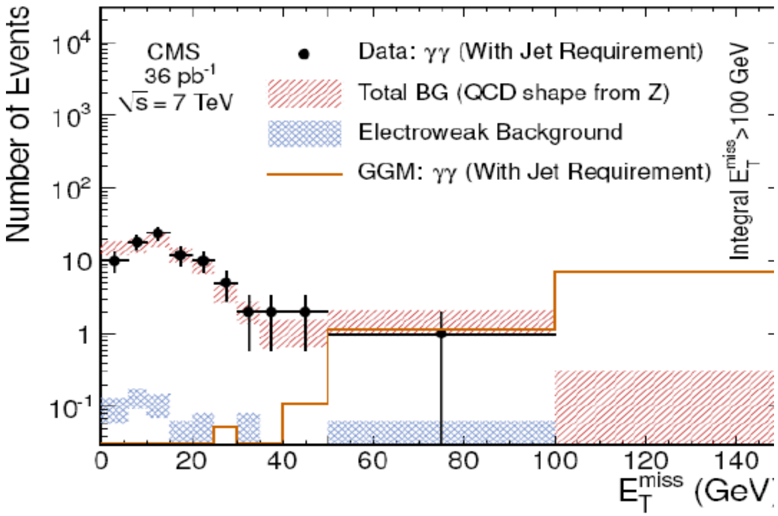
Gluino masses below 590 GeV excluded for sbottom masses below 500 GeV

$\tilde{g} \to \tilde{t}_1 t \quad \tilde{t}_1 \to t\tilde{\chi}_1^{\pm}$



Gluino masses below 520 GeV excluded for stop masses below 300 GeV

Photons+Etmiss (CMS)

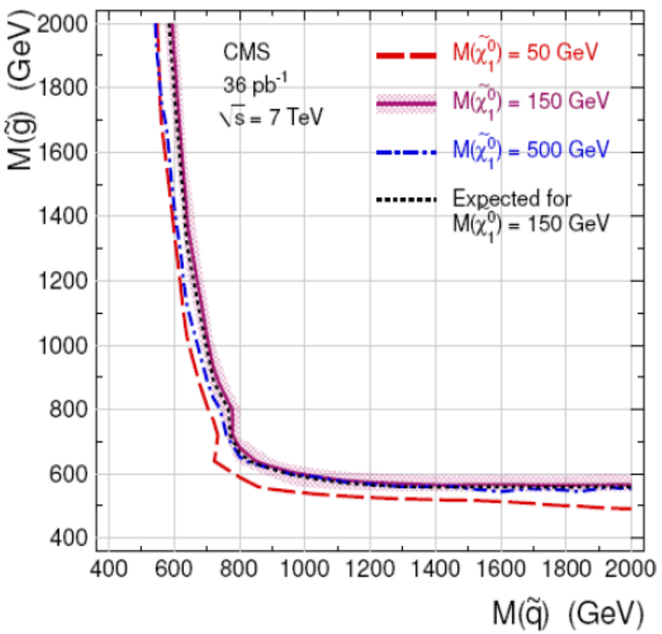


Require:
Two photons with pT>30 GeV
Within |h|<1.8
At least 1 jet ET>30 GeV

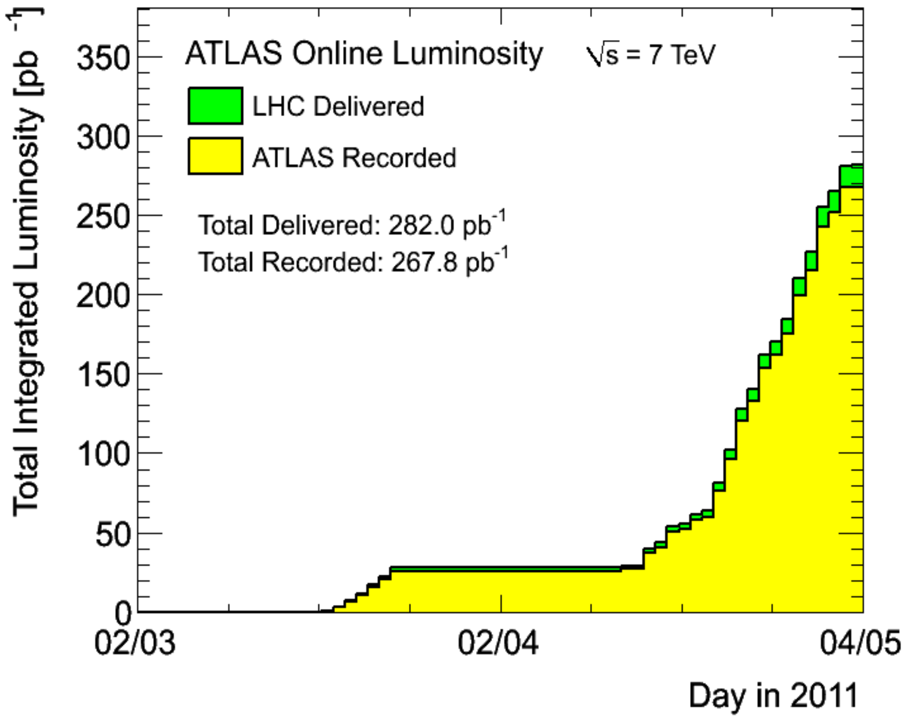
Dominant BG QCD estimated from Etmiss Shape in Z sample

Observe 1 event with MET>50 GeV
Consistent with 1.2±0.8 background

Consider gauge-mediated model with squark and gluino decaying to jets and neutralino with neutralino decaying to photon+gravitino



Outlook



Peak luminosity reached: $0.8 \times 10^{32}\ s^{-1}cm^{-2}$
Cumulated 6x 2010 luminosity
Expect 10^{33} by next week (increase to 900 bunches from 700)
>20 pb^{-1} for best day to now
1 fb^{-1} target well within reach
We will probably get more!

Increase of SUSY sensitivity: cross-section goes like m(SUSY)$^{-8}$
Acessible masses go approximately as lumi to the 1/8.
2010 reach: ~700 GeV. Expect to explore up to TeV in 2011 and well beyond in 2012

Conclusions

- 2010 great year for LHC and experiments
- Thanks to excellent performance of accelerator and detectors main Standard Model analyses performed very quickly
- On this basis, detailed searches for SUSY performed
  - No signal obeserved in any of the analyses
  - Mass scales up to ~700 GeV tested, very exciting, but also very disappointing result: SUSY was not `around the corner'
- 2011-2012 decisive years for SUSY, mass scales well in excess of TeV will be tested