Supersymmetry searches in ATLAS and CMS in hadronic final states

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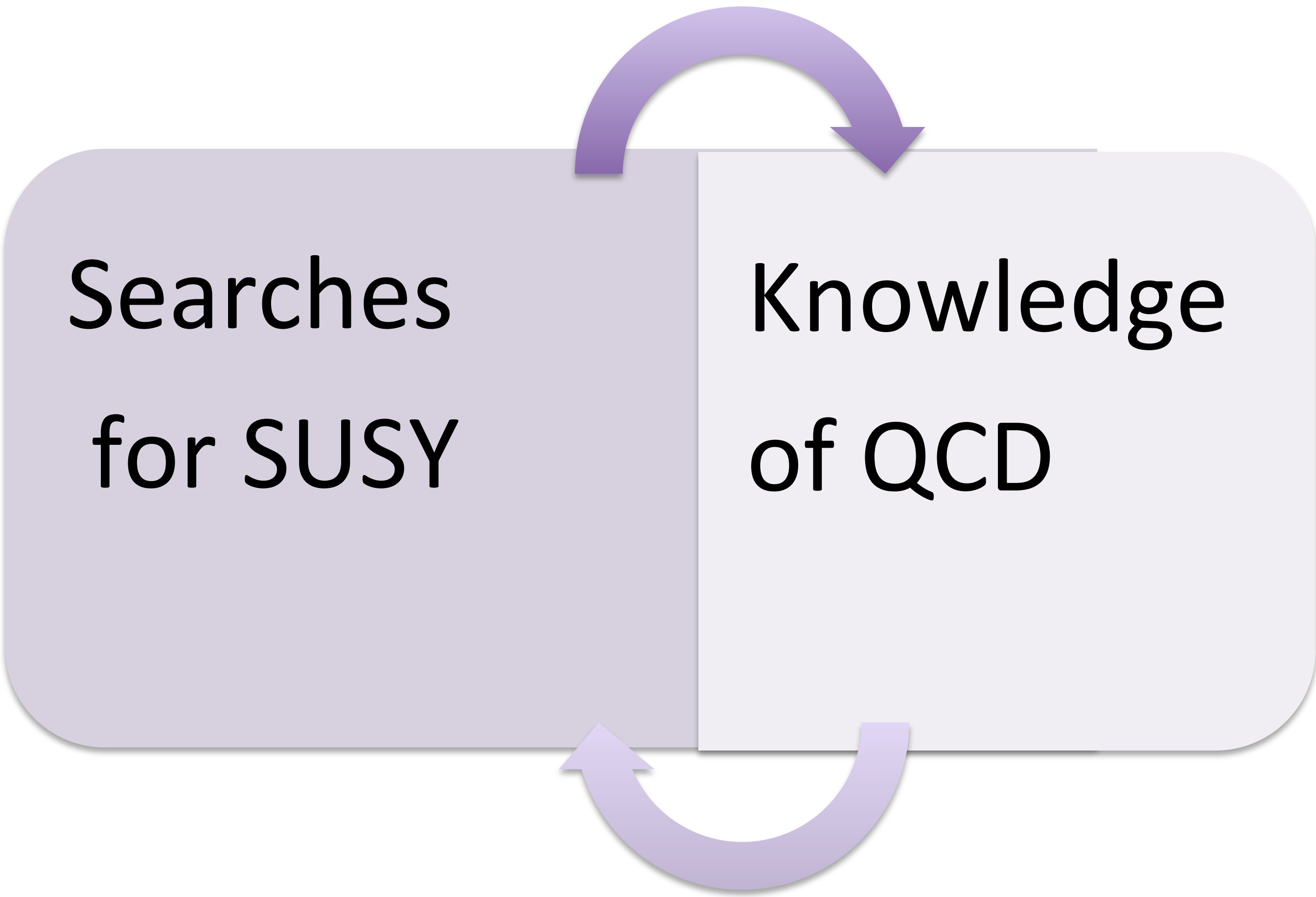
This presentation



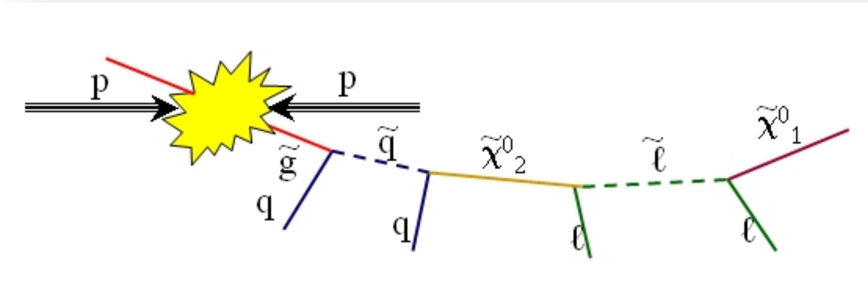
Multijet topologies,
Boosted objects,
High mass, non-back-to-back topologies, Initial state radiation

Multijet topologies, parton shower and resummations.

Outline

- Part 1: **Concept** of hadronic SUSY searches
- Part 2: Recent analysis as an **example**
- Part 3: **Overview** of hadronic SUSY searches
  and limits
- Part 4: A quick look at 13 TeV…
- Part 5: Summary for **discussion**

Production rate



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

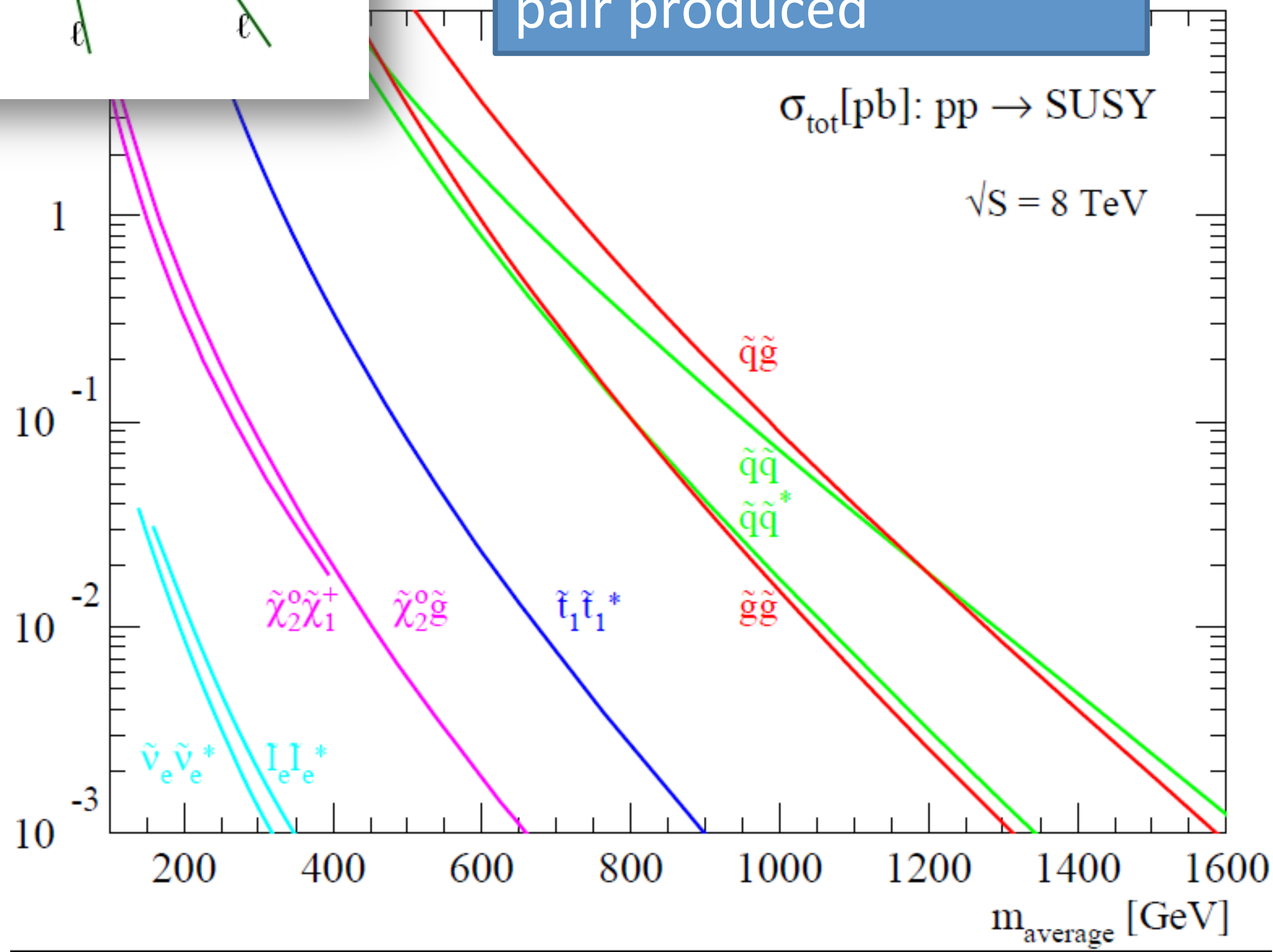
25000

2500

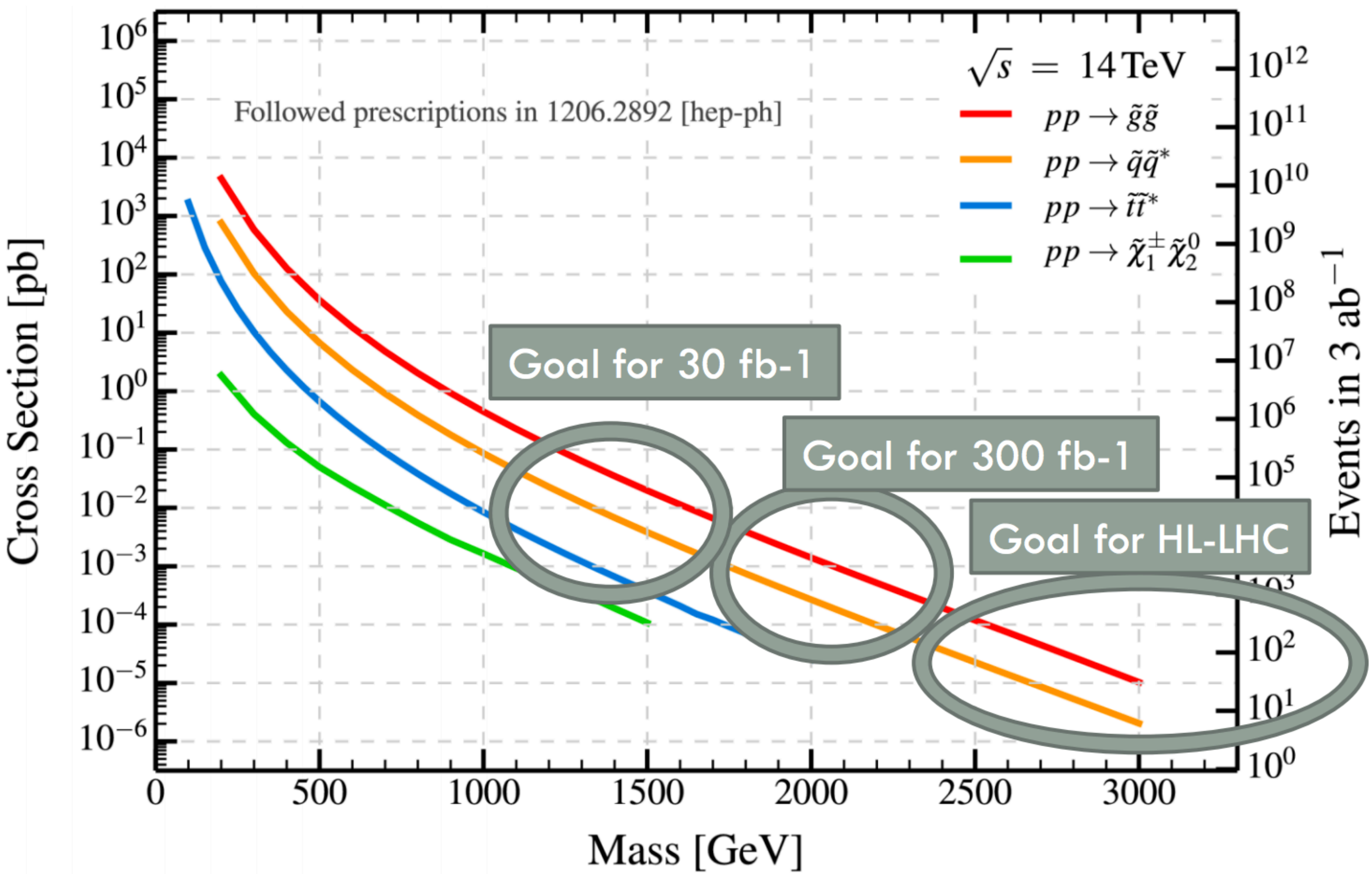
250

Events in Run-1 data

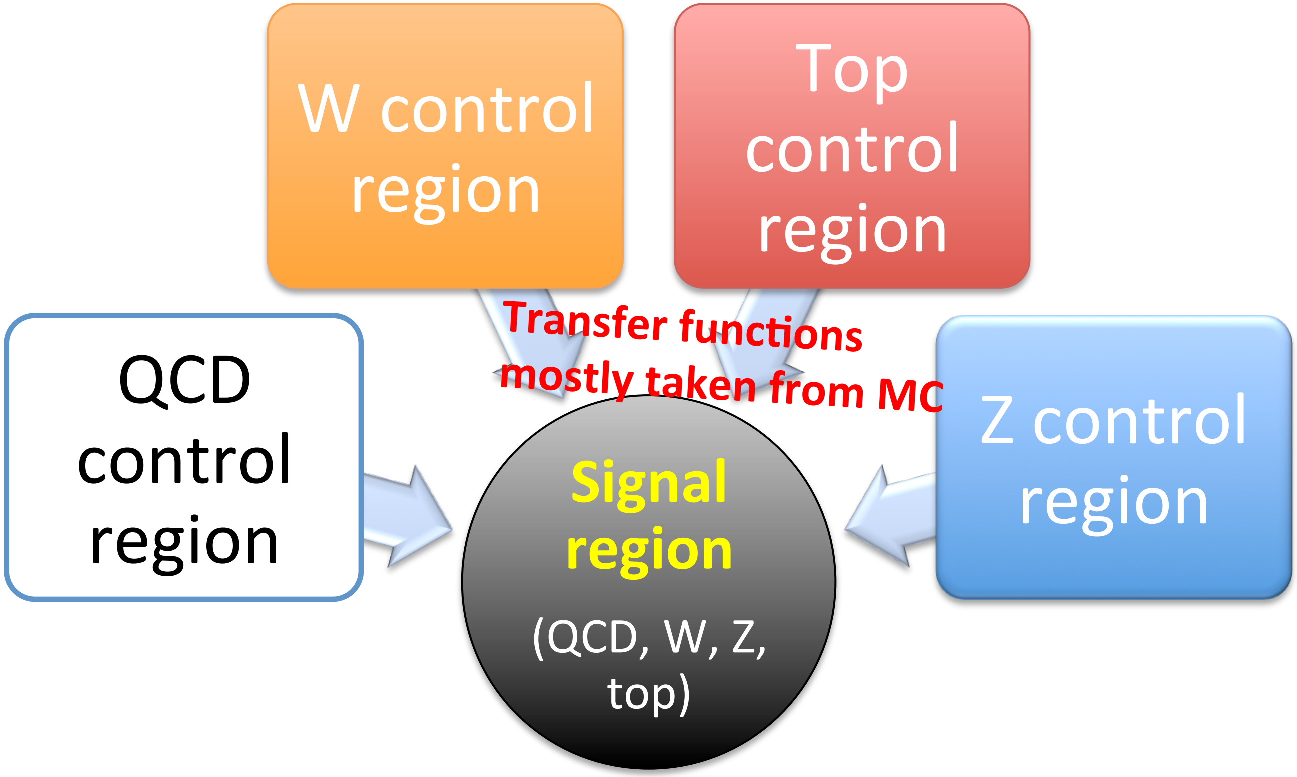
25



Where are we going?



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)

Analysis model - control regions

W control region

Top control

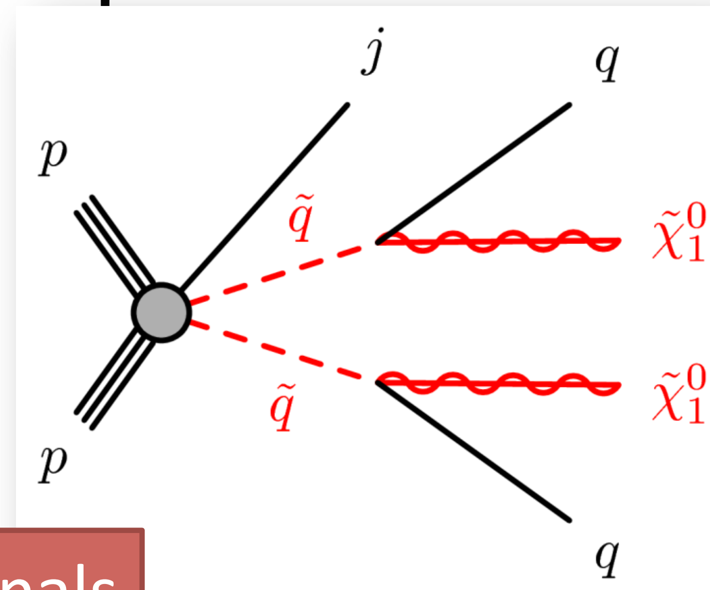
top)

Experimental uncertainties:
- Trigger efficiency
- Jet energy scale and resolution
- Lepton energy scale and efficiency
- E_T^{miss} soft component
- b-tagging
- Luminosity
- pileup modelling

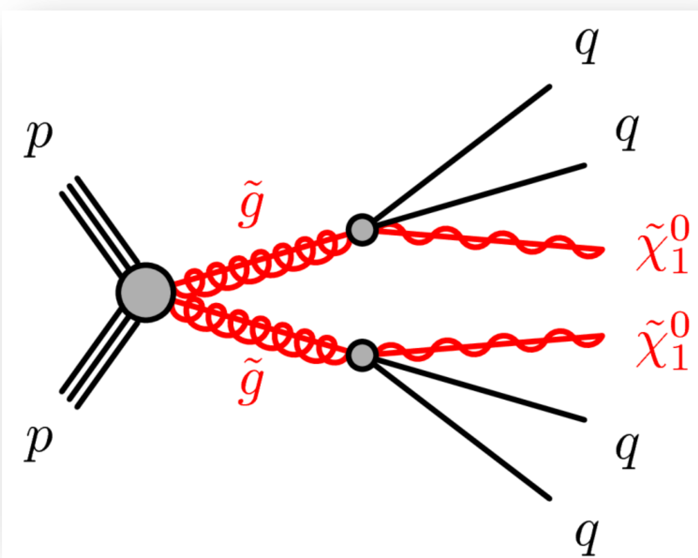
Theory uncertainties:
- Generator modelling (μ_F, μ_R, ME/PS matching, α_s scale choice when possible - otherwise compare generators)
- PS uncertainties (typically compare Pythia and Herwig)
- PDF choice

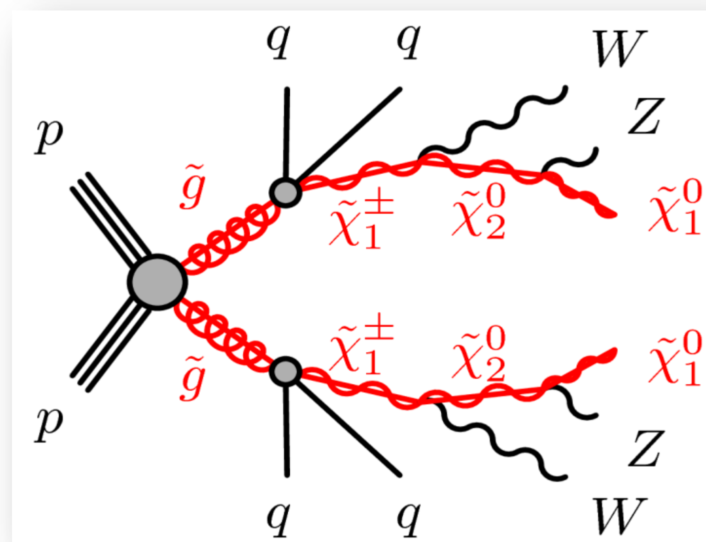
- Measure number of events in control selections
- Predict number of events in signal region via a fit to control regions
- Important : Test model and transfer functions
  (e.g. by alternative control regions or methods)

Large range of jet multiplicities needed



Typical signals

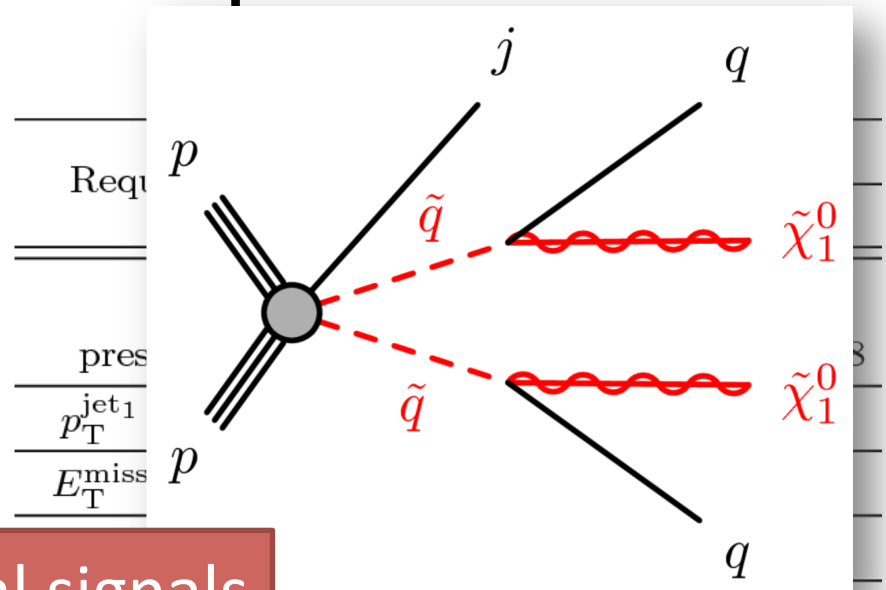




Large range of jet multiplicities needed

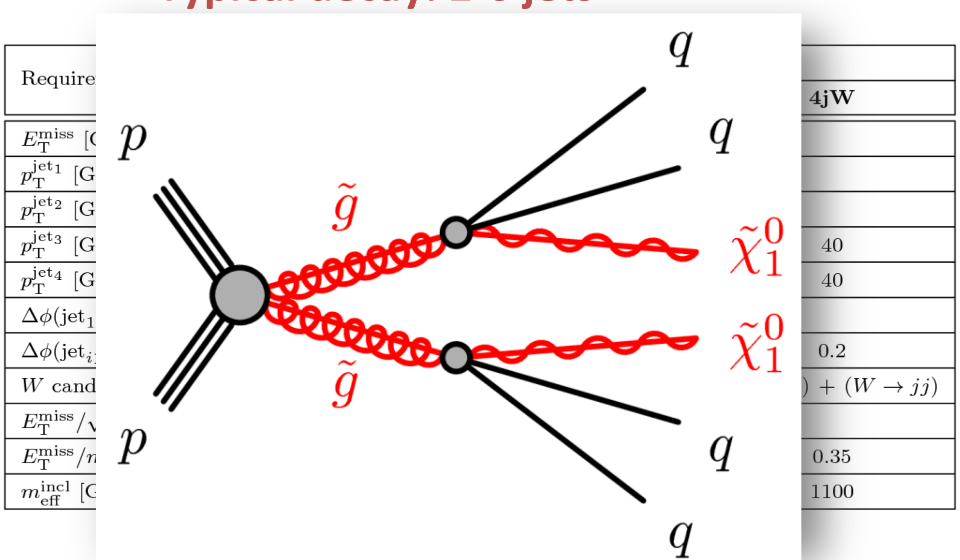
Compressed "Monojets":

Anti-tag on low 30 GeV
P_t jets
➔ Needs description of low
Jet multiplicities
and missing transverse
momentum object, relying on
Initial state radiation

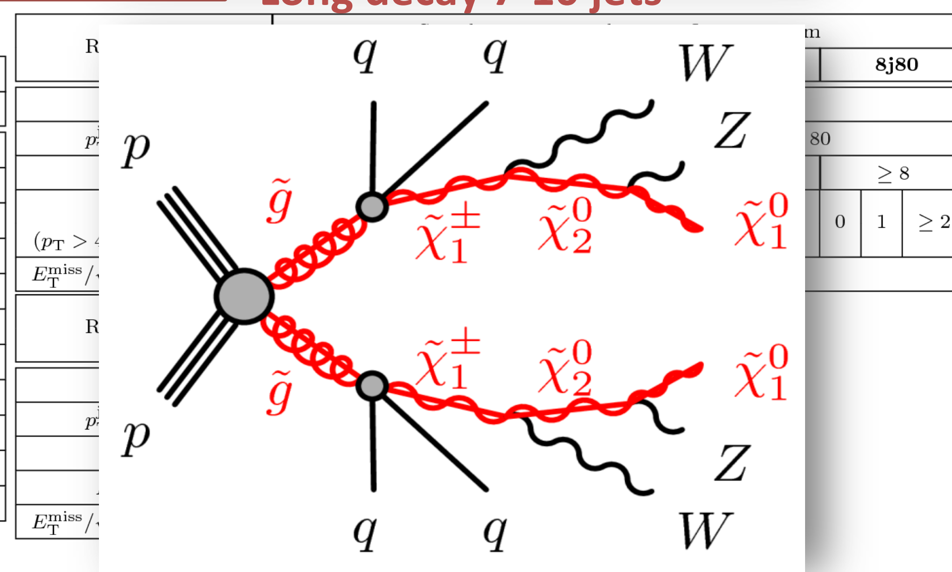


Typical signals

Typical decay: 2-6 jets



Long decay 7-10 jets



Large range of jet multiplicities needed

Compressed "Monojets":

Anti-tag on low 30 GeV
P_t jets
➔ Needs description of low
Jet multiplicities
and missing transverse
momentum object, relying on
Initial state radiation

Requirement	Signal region		
	[illegible]	**M2**	**M3**
[illegible]ets preselection	At most three jets wi[illegible] $p_T > 30$ GeV and $\lvert\eta\rvert < 2.8$		
$p_T^{jet_1}$ [GeV] >	280	340	450
E_T^{miss} [GeV] >	220	340	450
$\Delta\phi(\text{jet}, \boldsymbol{E}_T^{miss})$ >	0.4		

Typical decay: 2-6 jets

Requirement	Signal region					
	2jl	**2jm**	**2jt**	**2jW**	**3j**	**4jW**
E_T^{miss} [GeV] >	160					
$p_T^{jet_1}$ [GeV] >	130					
$p_T^{jet_2}$ [GeV] >	60					
$p_T^{jet_3}$ [GeV] >	–				60	40
$p_T^{jet_4}$ [GeV] >	–					40
$\Delta\phi(\text{jet}_{1,2,(3)}, \boldsymbol{E}_T^{miss})_{min}$ >	0.4					
$\Delta\phi(\text{jet}_{i>3}, \boldsymbol{E}_T^{miss})_{min}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	8	15		–		
$E_T^{miss}/m_{eff}^{N_j}$ >	–			0.25	0.3	0.35
m_{eff}^{incl} [GeV] >	800	1200	1600	1800	2200	1100

Long decay 7-10 jets

Requ[illegible]	Signal regions in multi-jet [illegible] stream												
	[illegible]			[illegible]			[illegible]	**7j80**			**8j80**		
$\lvert\eta\rvert^{jet}$ <	2.0												
p_T^{jet} [GeV] >	50							80					
N_{jet}	= 8			= 9			≥ 10	= 7			≥ 8		
N_{b-jet} ($p_T > 40\,GeV, \lvert\eta\rvert < 2.5$)	0	1	≥ 2	0	1	≥ 2	—	0	1	≥ 2	0	1	≥ 2
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	4												

Requirement	Signal regions in multi-jet + M_J^{Σ} stream		
	8j50	**9j50**	**10j50**
$\lvert\eta\rvert^{jet}$ <	2.8		
p_T^{jet} [GeV] >	50		
N_{jet}	≥ 8	≥ 9	≥ 10
M_J^{Σ} [GeV]	> 340 and > 420 for each case		
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	4		

Part 2: Example analysis

Let's have a detailed look at a recent search for coloured SUSY by CMS to illustrate the background determination

Recent searches with M_T2

Two signal regions:

a) Jets, high pt, high M_T2

b) Search for mass peak with Higgs ➔bbar

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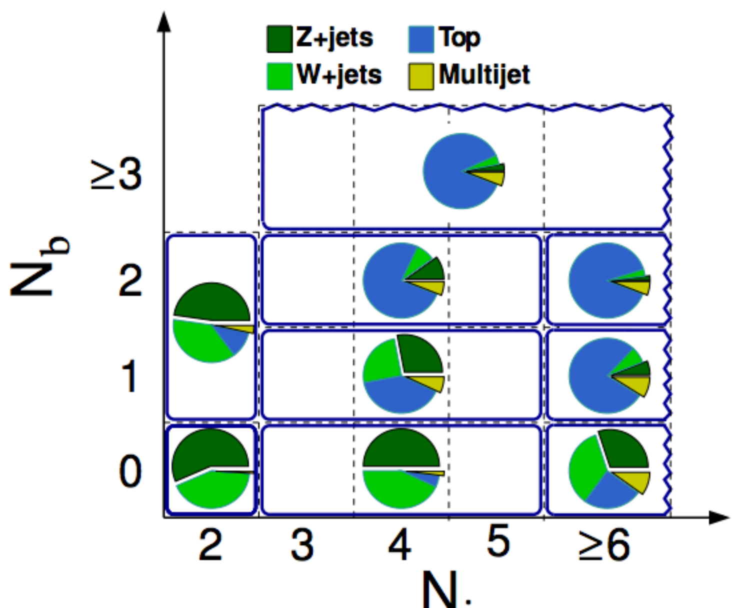
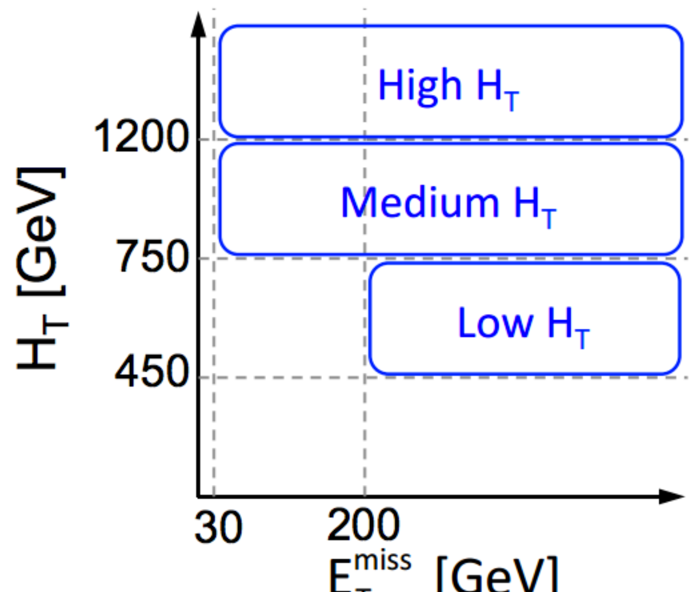
$$M_{T2}(m_X) = \min_{\vec{p}_T^{X(1)} + \vec{p}_T^{X(2)} = \vec{p}_T^{\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right],$$

M_T2 is generalization of transverse mass concept for 2 invisible particles

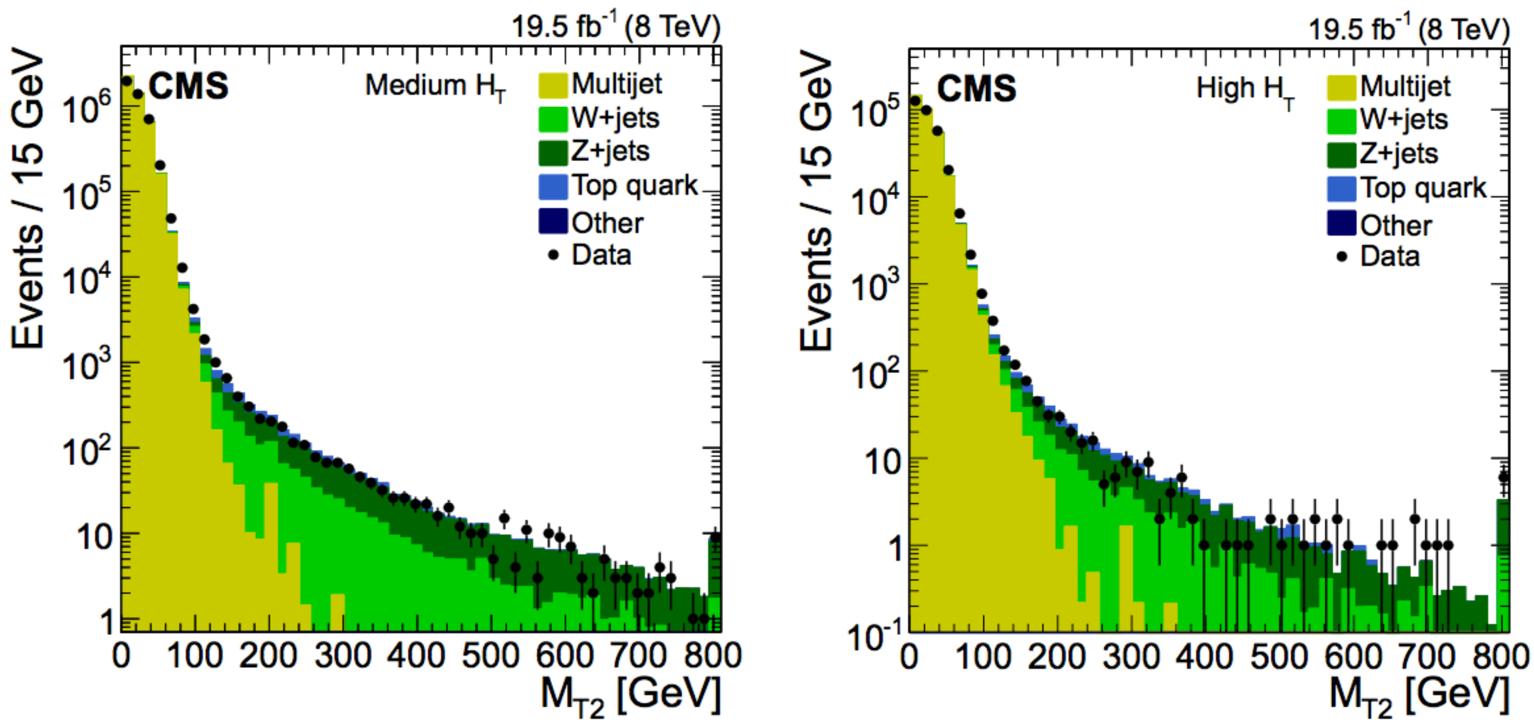




Definition of signal regions and their backgrounds and subsequent division in HT and Etmiss

Recent searches with M_T2

- Each of these regions is examined in M_T2 (Model-dependent test)
- Example M_T2 distributions for medium and high sum of jet pt (Ht)



Recent searches with M_T2

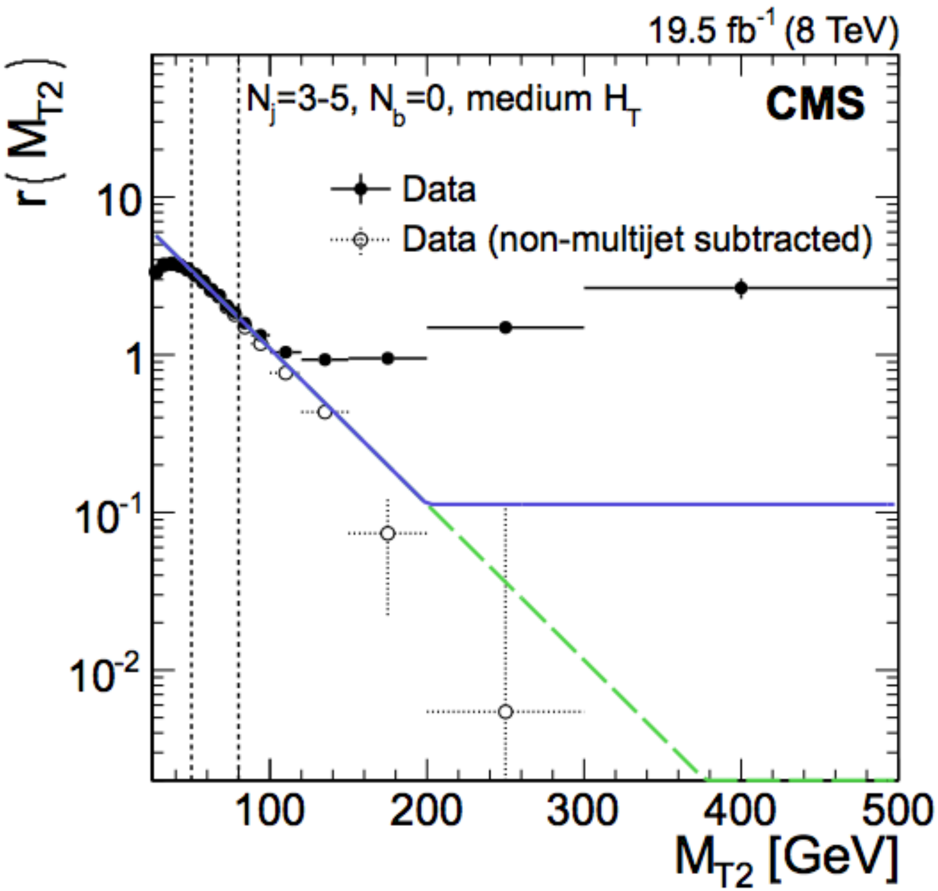
Example of background determination QCD multijets:

- QCD dominated region at low minimal delta phi between jet and MET
- Assumption is that transfer factor r (from control to signal region) is described by this parameterization:

$$r(M_{\mathrm{T2}}) \equiv \frac{N(\Delta\phi_{\mathrm{min}} > 0.3)}{N(\Delta\phi_{\mathrm{min}} < 0.2)} = \exp(a - b\, M_{\mathrm{T2}}) + c \qquad \text{for } M_{\mathrm{T2}} > 50\,\mathrm{GeV}.$$

The parameters a and b are obtained from a fit to data in the region 50 < MT2 < 80 GeV, see next slide, procedure validated with simulated QCD multijet events

Recent searches with M_T2



r is fixed to a constant (conservatively) for high M_T2.

Various uncertainties on method considered

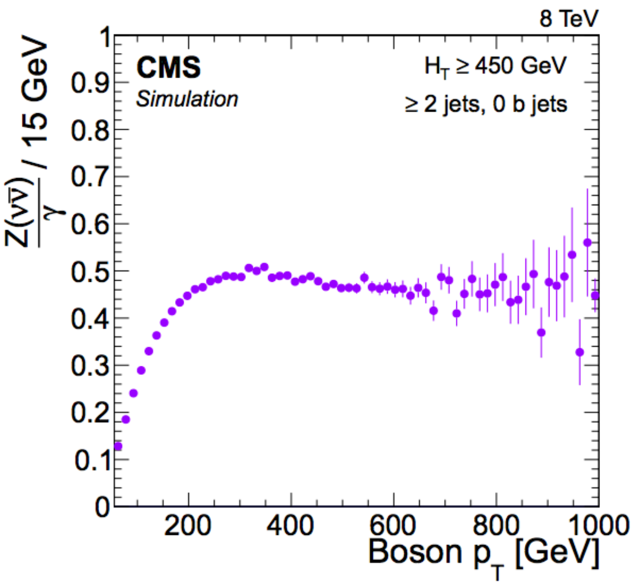
Note that QCD multijet background is small at high M_T2

Recent searches with M_T2

W+jets background and top background Mainly stemming from "lost" lepton events, 40% are taus

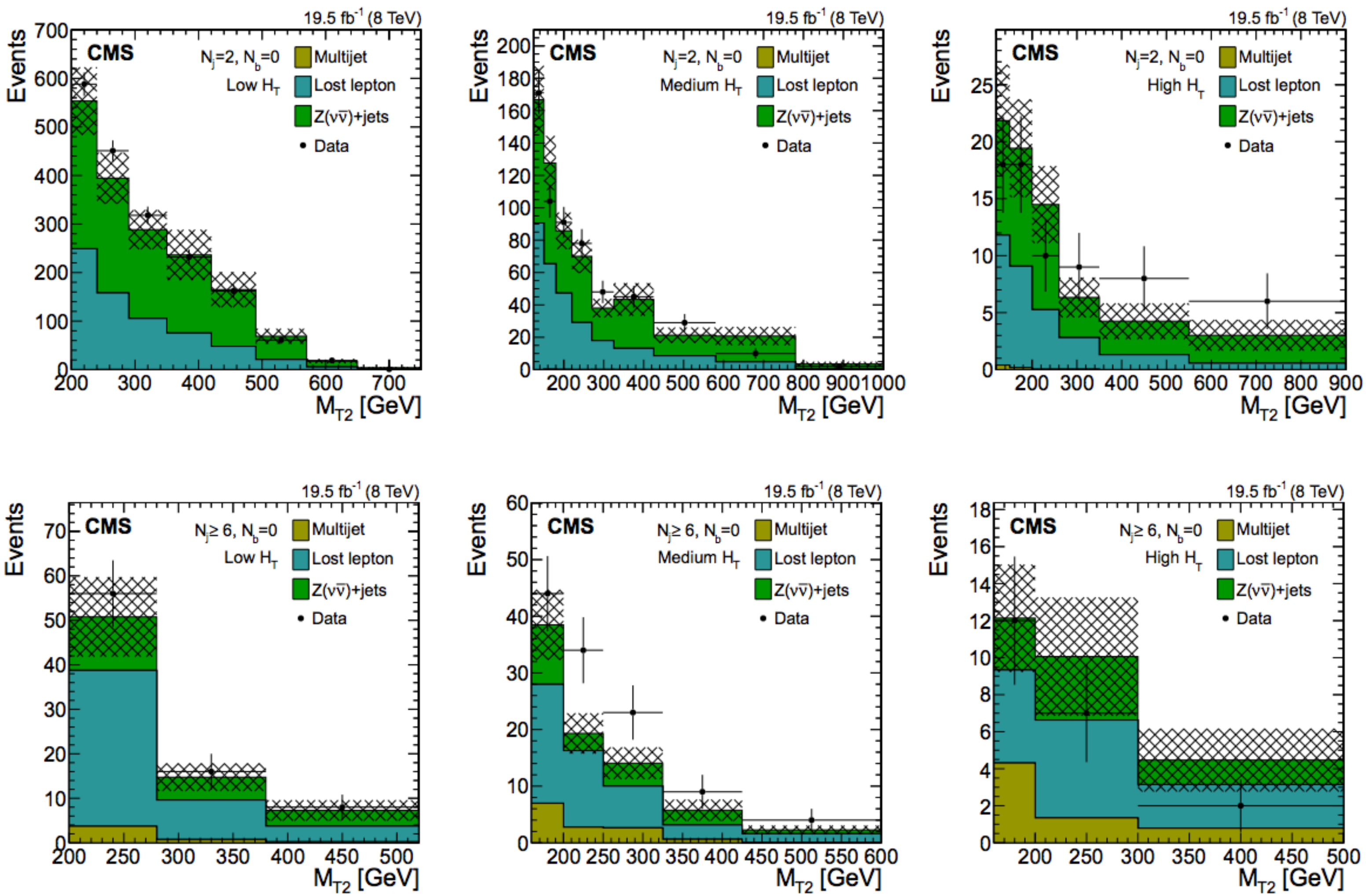
➔1. **Determined for each signal region by re-versing the zero lepton requirement** and asking 1 lepton and small transverse mass < 100 GeV
2. **A "lost lepton" factor is applied to determine the expected number of background events in signal region** taking into account the lepton efficiencies/acceptance "per signal region". *Uncertainties e.g. by tag-and-probe method.*

Z (νν)+jets background is estimated by selecting a control sample of γ+jets events and then subtracting the photon momentum in the computation of all the relevant event quantities, e.g. M_T2. *Z and gamma coupling expected to behave constant for pT_Z > M_Z (difference modeled with MC simulation)*



Recent search with M_T2

Results: Many many signal regions (6 plots from many):

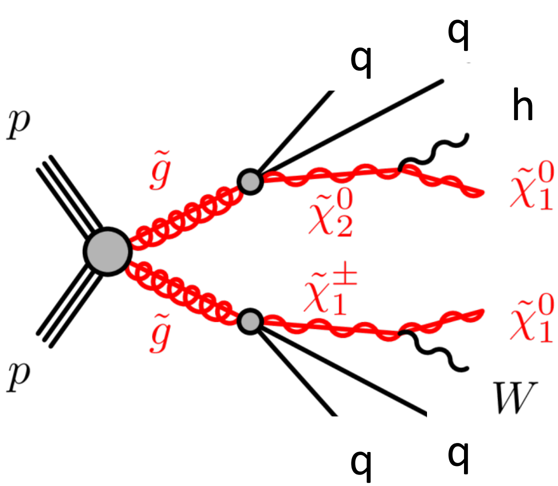


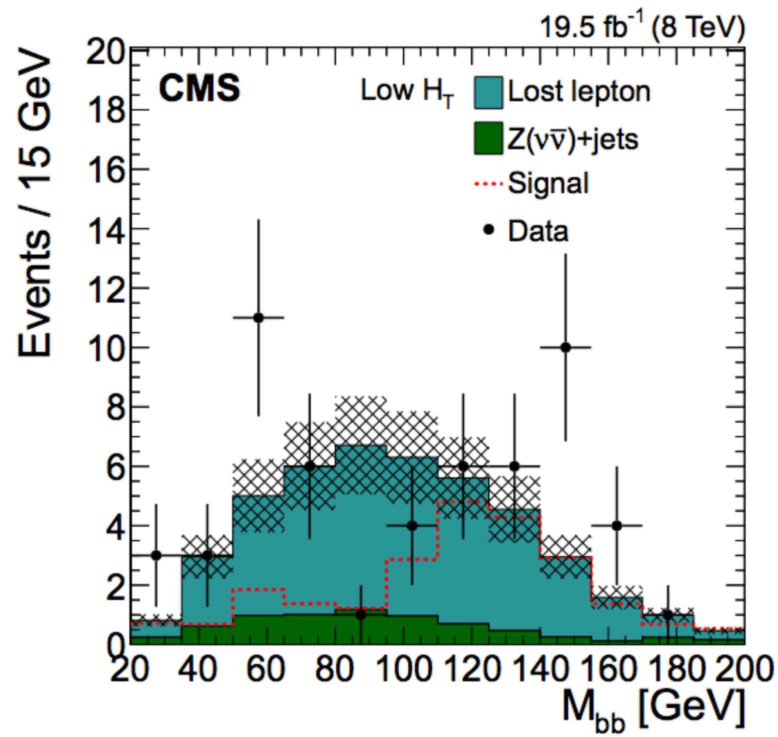
Recent searches with M_T2

- Higgs searches requires two b-tags close in delta R in mass(bb) bins
- Shape of mass(bb) is taken from low M_T2 regions since no correlation between M_T2 and mass(bb) is expected from simulation

Recent search with M_T2

Here is an example from Higgs signal region
Signal is gluino with Higgs decays..



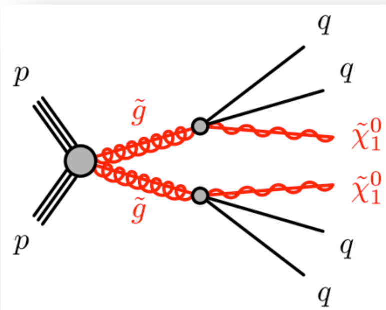


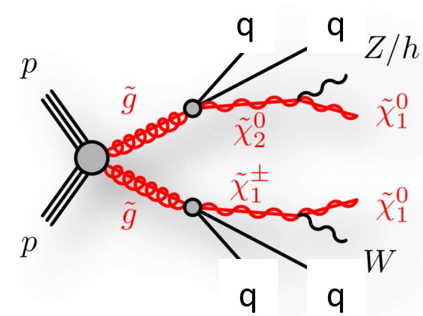
Interpretation: >40 signal regions considered and tested against SUSY predictions.

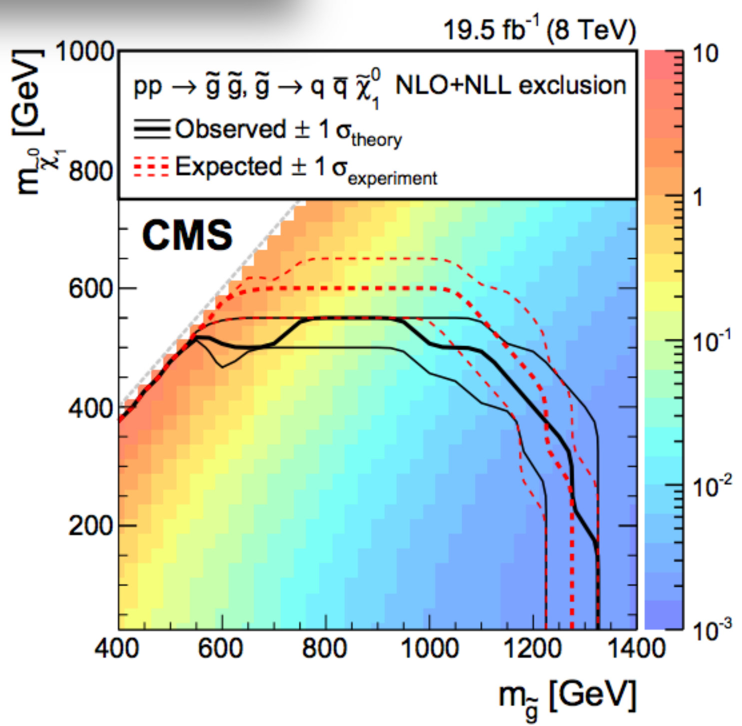
Regions are combined into a likelihood function and exclusion limits are calculated for various different models…

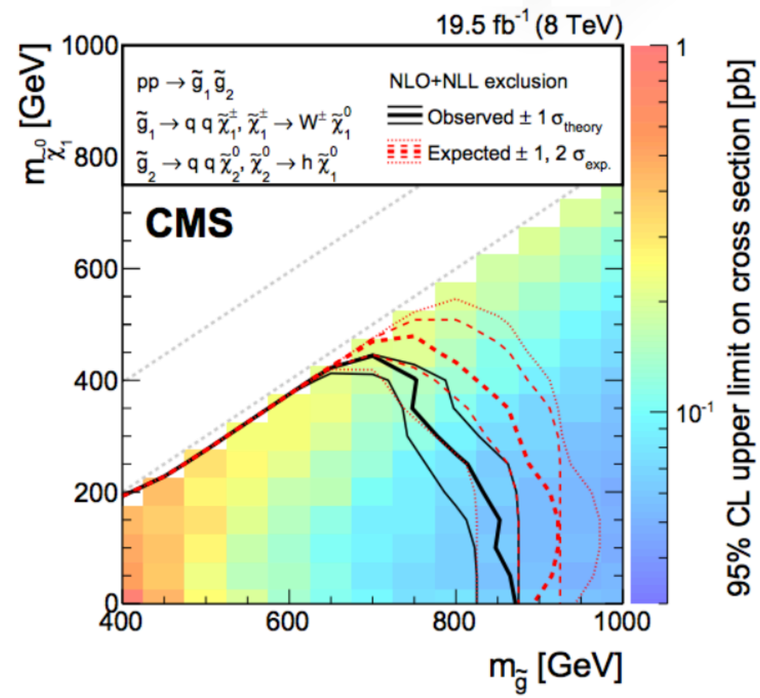
Limits and Signal Regions

Examples: Limits on gluino pair production for different gluino decays.
Longer decay chain limits problematic, first limit on gluinos with Higgs decays









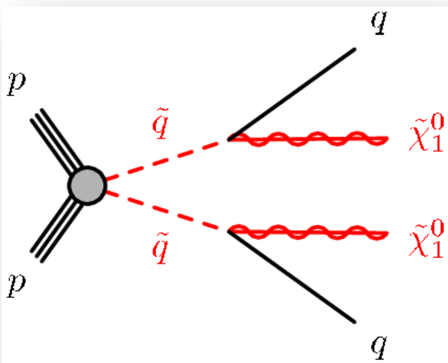
Run-1 data Overview

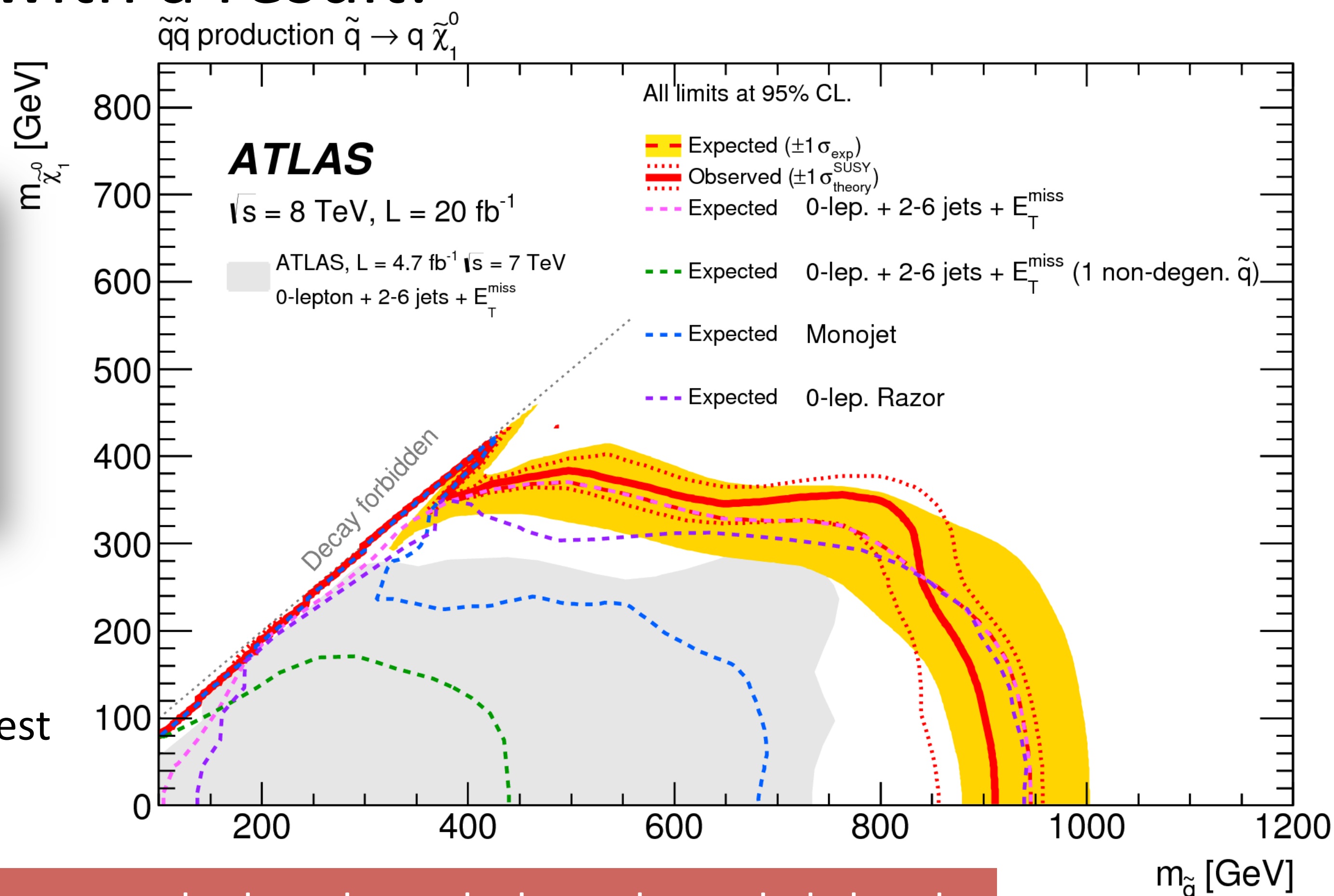
- Recent result from ATLAS 2015 summary papers
- Goals: **Combination**, **complementarity**, **coverage** in the landscape of minimal SUSY (MSSM)

- Summary of ATLAS constraints in the pMSSM, 1508.06608, Accepted by JHEP
- Inclusive squark/gluino searches , 1507.05525, Accepted by JHEP
- Third generation squarks (direct production), 1506.08616, Submitted to EPJC

Complementarity: 1^{st} and 2^{nd} generation squarks

- Let's start with a result:





Note 400 GeV limits for non-degenerated Squarks even in simplest decay chain

Sensitivity of different methods and search channels needed already for simplest decay scenario!

Background and signal regions

“Monojets”: Z->neutrinos and W->lepton neutrino dominant

Medium (2-6) jets:
Z+jets and top pairs

Signal regions in ATLAS are typically cut-and-count and limits derived by “best signal region” only
(CMS usually combines signal regions)

Many (7-10) jets:
QCD, top pairs

Coverage beyond simplified models

- Coverage studies by running >20 run-1 analyses over >300000 MSSM points
- All MSSM points selected to fulfill all worldwide constraints (e.g. on Dark Matter)

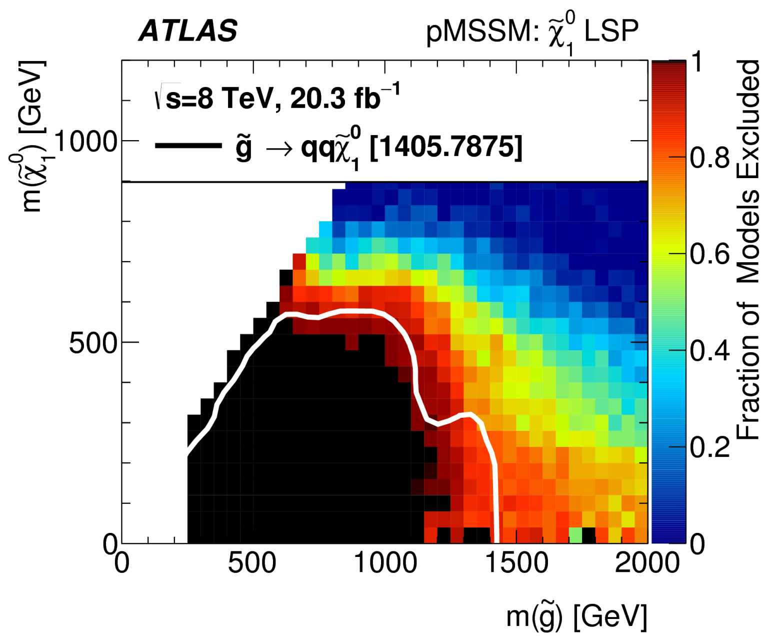
Analysis	Ref.	Category
0-lepton + 2–6 jets + E_T^{miss}	[57]	Inclusive
0-lepton + 7–10 jets + E_T^{miss}	[58]	
1-lepton + jets + E_T^{miss}	[59]	
$\tau(\tau/\ell)$ + jets + E_T^{miss}	[60]	
SS/3-leptons + jets + E_T^{miss}	[61]	
0/1-lepton + 3b-jets + E_T^{miss}	[62]	
Monojet	[63]	
0-lepton stop	[64]	Third generation
1-lepton stop	[55]	
2-leptons stop	[65]	
Monojet stop	[66]	
Stop with Z boson	[67]	
2b-jets + E_T^{miss}	[68]	
tb+E_T^{miss}, stop	[56]	
ℓh	[69]	Electroweak
2-leptons	[53]	
2-τ	[54]	
3-leptons	[52]	
4-leptons	[70]	
Disappearing Track	[71]	
Long-lived particle	[72,73]	Other
$H/A \to \tau^+\tau^-$	[74]	

Parameter	Minimum value	Maximum value
$\Delta\rho$	-0.0005	0.0017
$\Delta(g-2)_\mu$	-17.7×10^{-10}	43.8×10^{-10}
$BR(b \to s\gamma)$	2.69×10^{-4}	3.87×10^{-4}
$BR(B_s \to \mu^+\mu^-)$	1.6×10^{-9}	4.2×10^{-9}
$BR(B^+ \to \tau^+\nu_\tau)$	66×10^{-6}	161×10^{-6}
$\Omega_{\tilde{\chi}_1^0} h^2$	—	0.1208
$\Gamma_{invisible(SUSY)}(Z)$	—	2 MeV
Masses of charged sparticles	100 GeV	—
$m(\tilde{\chi}_1^\pm)$	103 GeV	—
$m(\tilde{u}_{1,2}, \tilde{d}_{1,2}, \tilde{c}_{1,2}, \tilde{s}_{1,2})$	200 GeV	—
$m(h)$	124 GeV	128 GeV

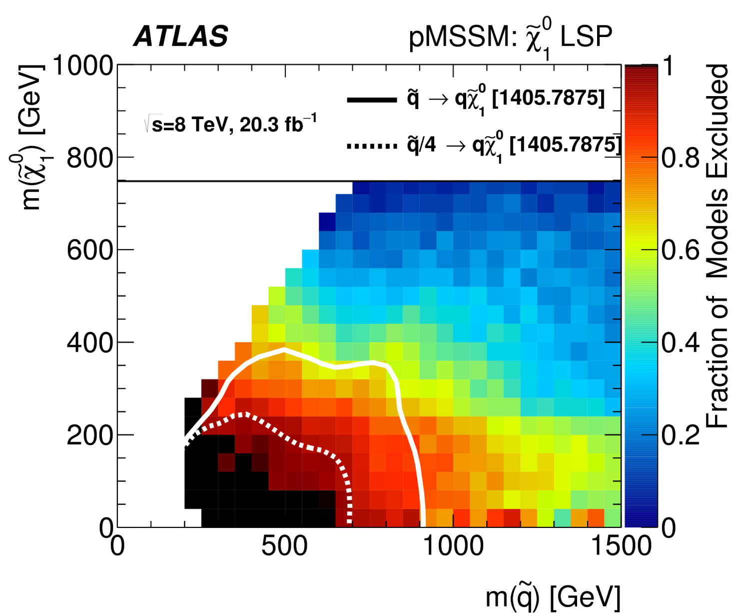
Here ATLAS, Similar studies from CMS

Coverage beyond simplified models

Fraction models in
gluino-neutralino space
(well covered by simplified models)



Most constraining search is 2-6 jets + MET



Fraction of models in min(squark)
vs neutralino space

➔ Less well covered by simplified models

➔ Different decays q_L and q_R, different Masses?

➔ Low mass squarks not excluded yet!

R_p violation multijets

no MET and a huge background from QCD.

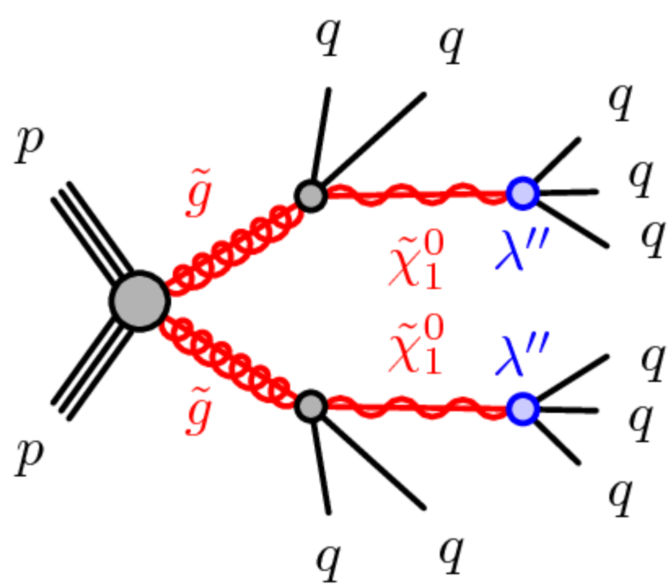
2 recent results on this:

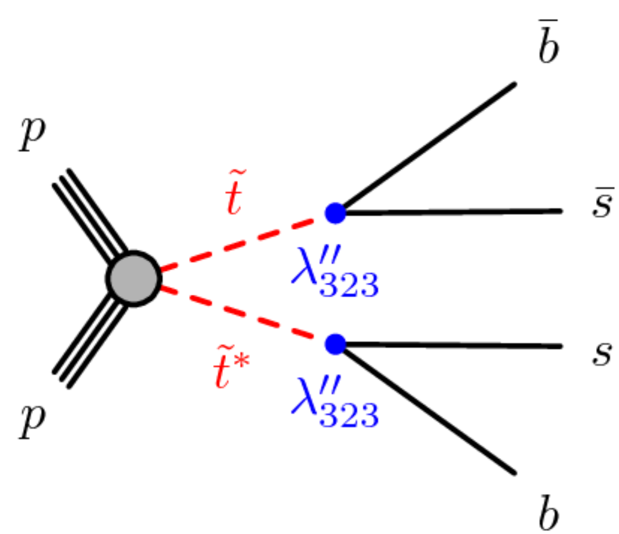
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2013-07/

(RPV gluino decays -> jets)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-026/

(RPV stop -> jets)





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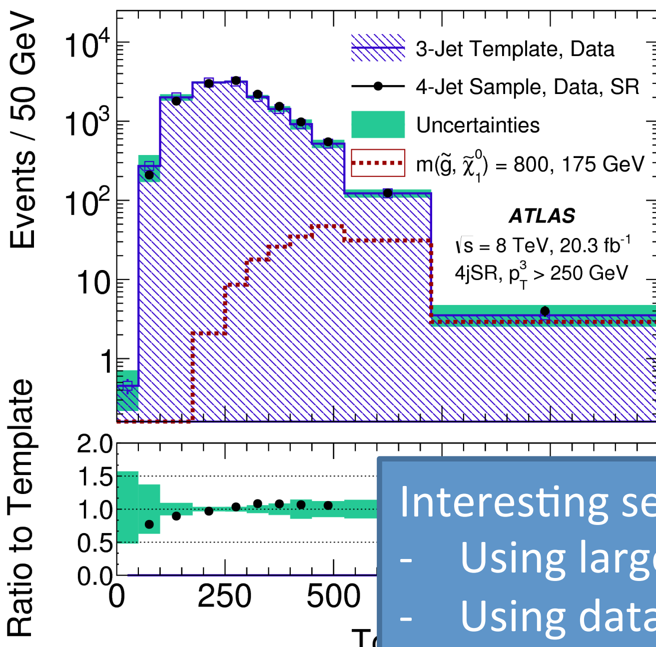

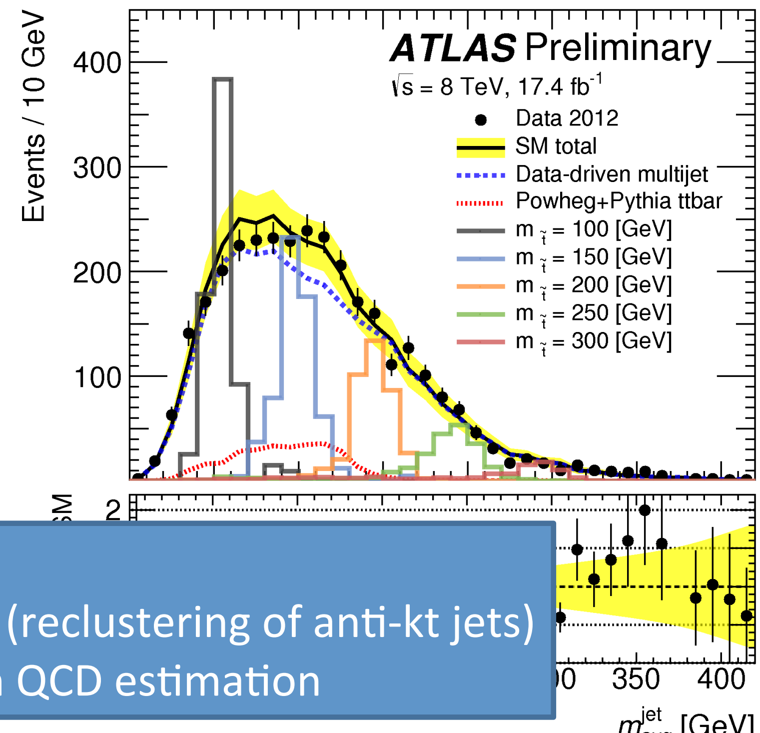

Interesting searches
- Using large R jets (reclustering of anti-kt jets)
- Using data-driven QCD estimation

R_p violation multijets

no MET and a huge background from QCD.

2 recent results on this:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2013-07/

(RPV gluino decays -> jets)

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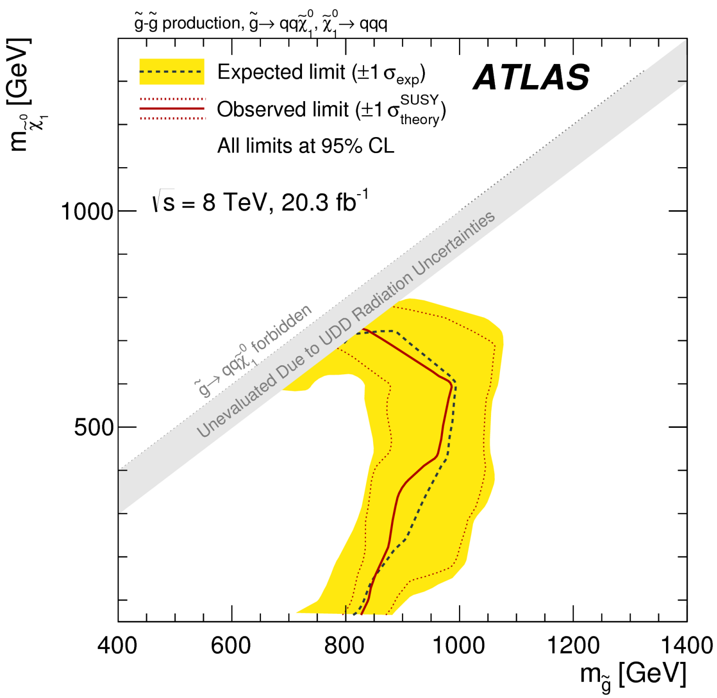
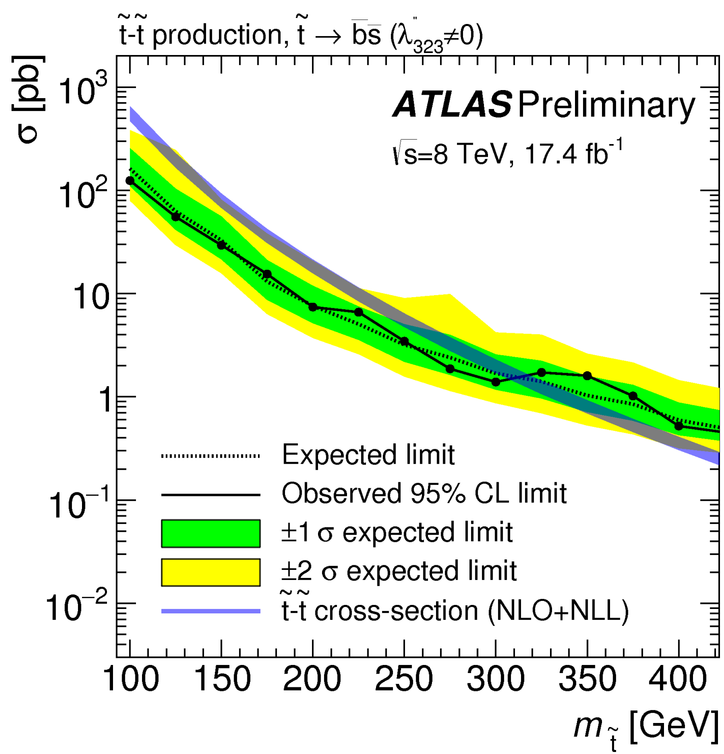
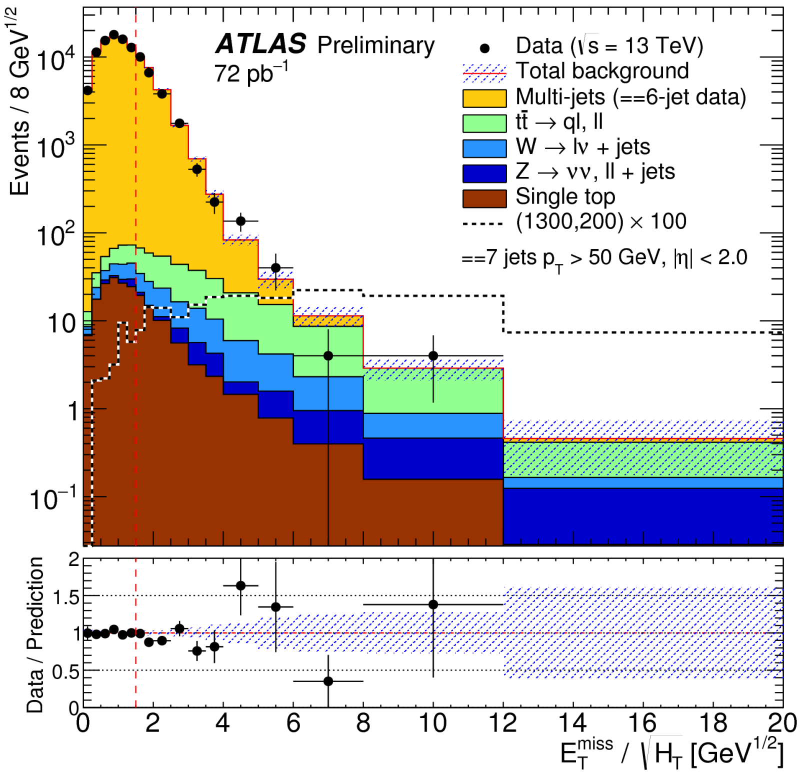




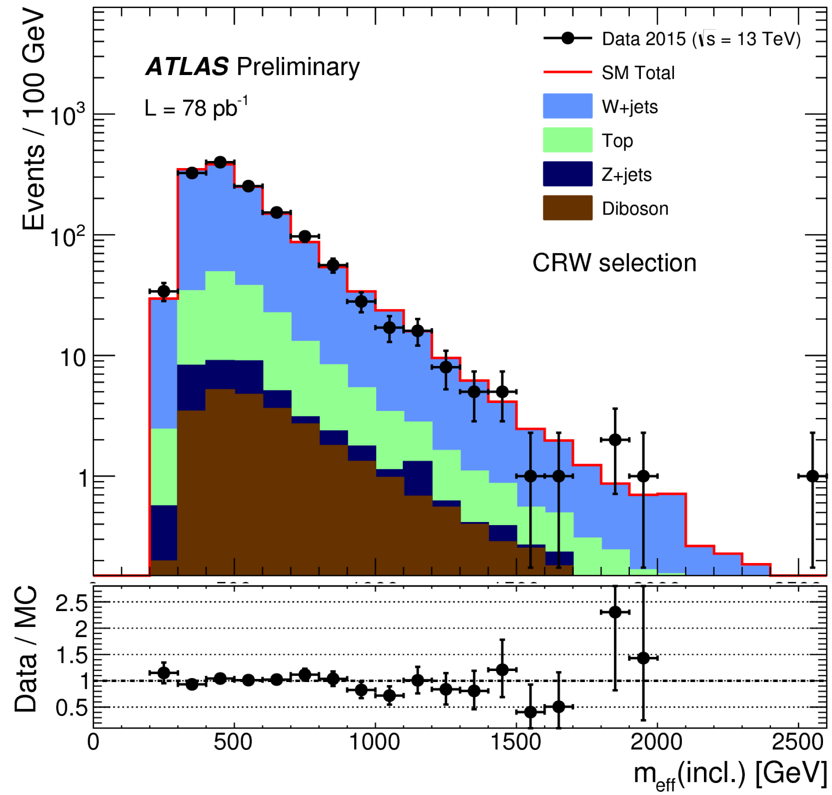
Run-2

Run-2 ATLAS example

- Various control distribution from ATLAS and CMS well described…even for 7 jets



ETmiss/√HT template (exactly 6 jets) applied to data with exactly 7 jets.



0-lepton 2 jet selection control region

All-hadronic search using M_{T2}

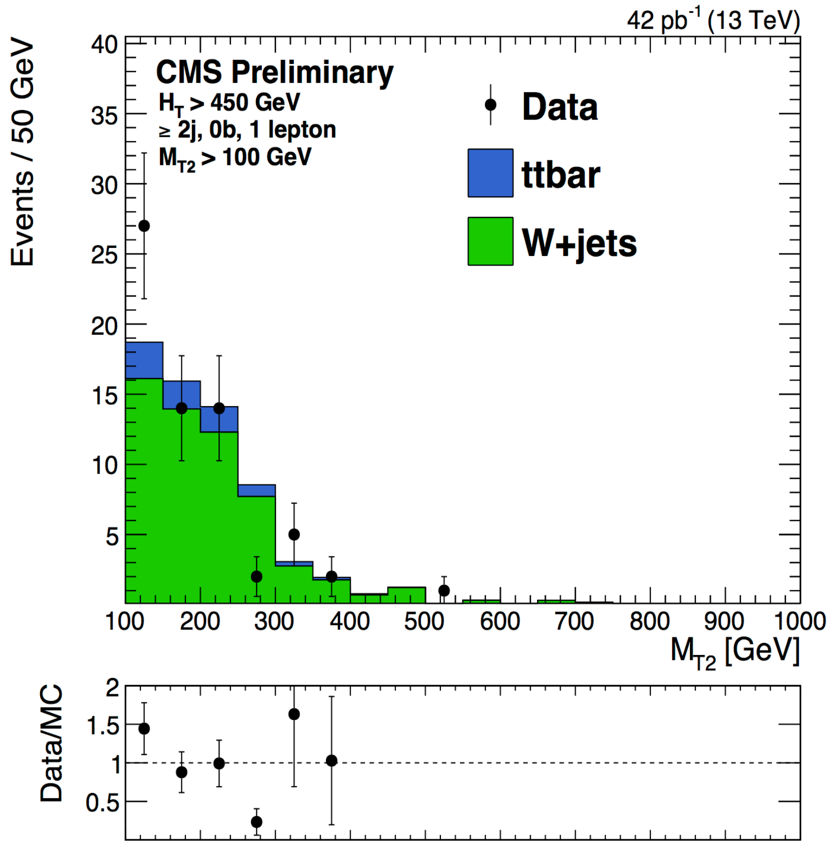
CMS-DP-2015-035

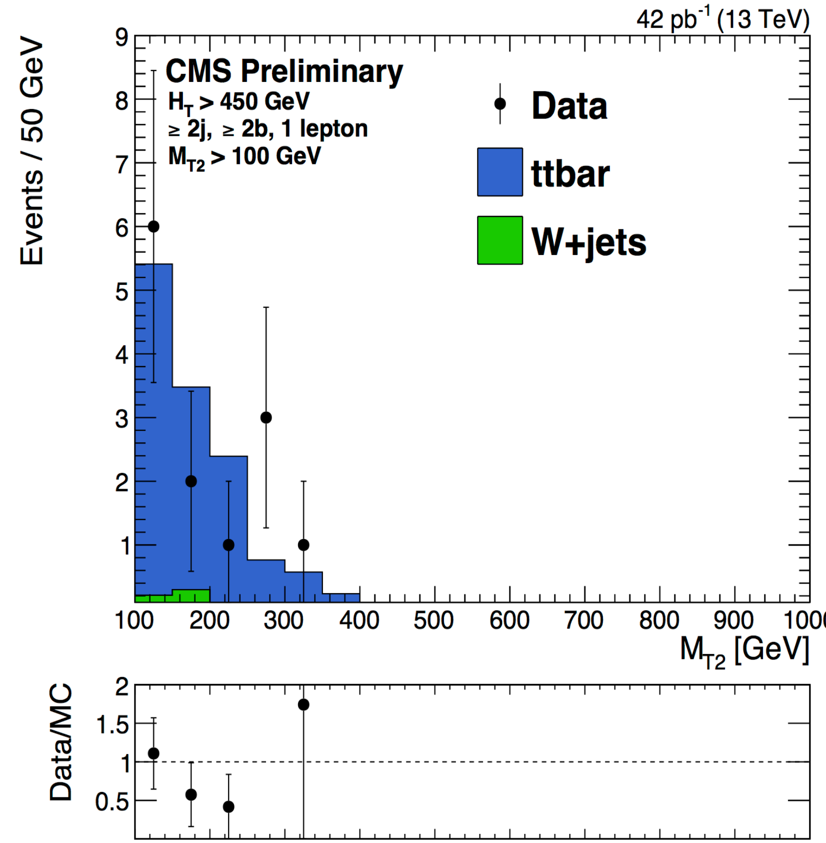
Run-2 CMS example

Inclusive search with M_{T2} in bins of H_T, N_j and N_b.

M_{T2} = sTransverse mass, designed for final states with 2 missing particles

An important background is W or top with missed leptons or taus.
Measure M_{T2} shape in single lepton control sample.





The M_{T2} distribution in the single-lepton control region is compared to (normalized) MC for events passing the baseline selection and having exactly zero (left) or two or more (right) b-tags.

Material for discussion

Run-2 provides 13 TeV center-of-mass:

- If DM particle is at 100 GeV still, likely to expect multiple decay steps (squarks to heavy neutralinos/ charginos)

➔ Possibly boosted multi-boson decays

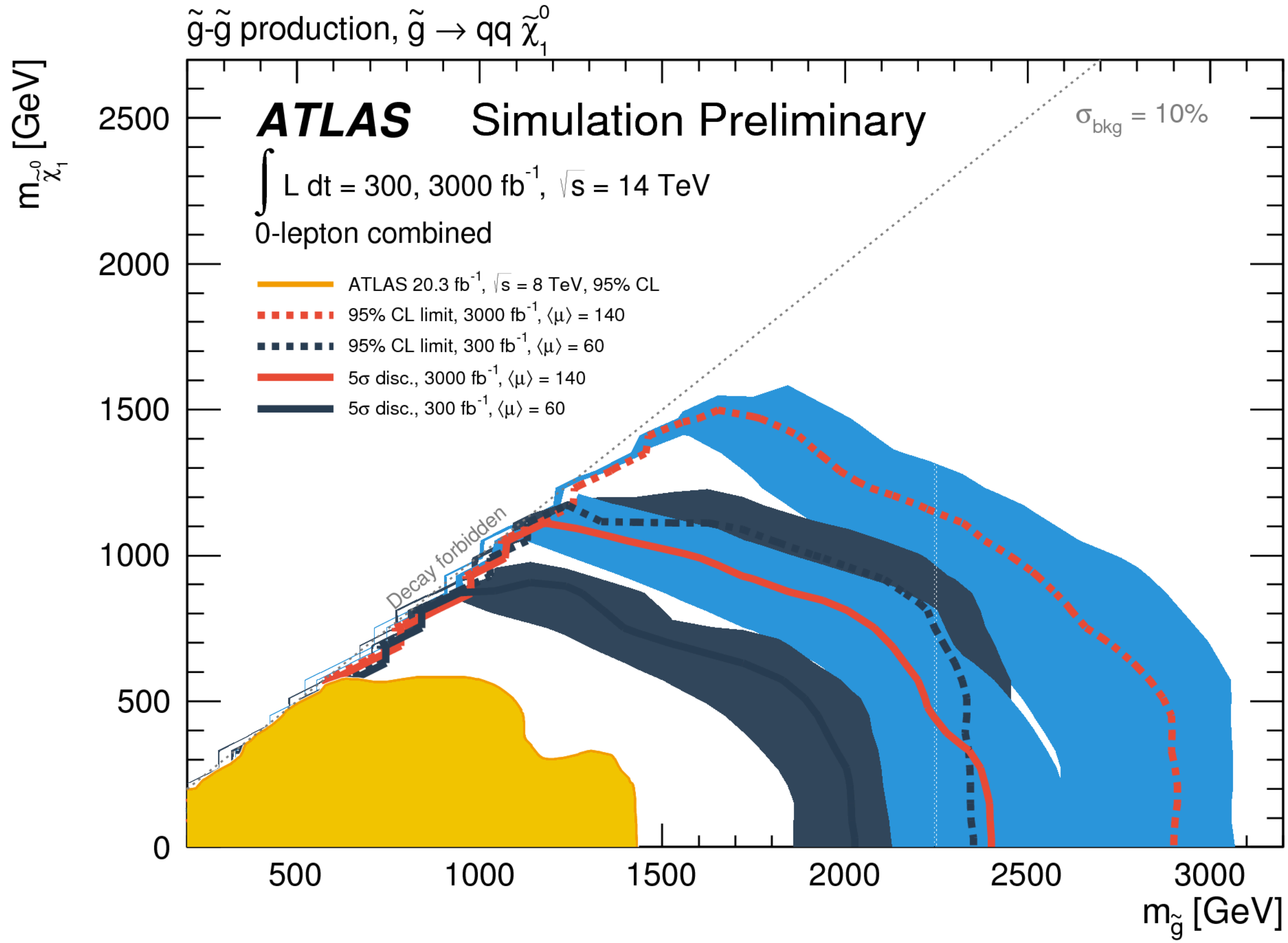
➔ **High jet multiplicities** become even more important

➔ **High boson multiplicities** become even more important (maybe 2-3 W/Z/h bosons per event)

- On the other side we should not forget the low mass squarks…. Low jet pt, low MET ➔ precision physics!?

Summary

- Final analyses of 8 TeV data with “highly developed techniques” also for background determination
- Still relying on MCs for **signal** and **background** *(note that Pdf uncertainties will become important at high susy masses)*
- **First 13 TeV data**
- **High jet and boson multiplicities becoming more important for SUSY searches**



$\tilde{g}$-$\tilde{g}$ production, $\tilde{g} \rightarrow qq\,\tilde{\chi}_1^0$
ATLAS Simulation Preliminary
$\int L\,dt$ = 300, 3000 fb^{-1}, $\sqrt{s}$ = 14 TeV
0-lepton combined
σ_{bkg} = 10%
ATLAS 20.3 fb^{-1}, $\sqrt{s}$ = 8 TeV, 95% CL
95% CL limit, 3000 fb^{-1}, $\langle\mu\rangle$ = 140
95% CL limit, 300 fb^{-1}, $\langle\mu\rangle$ = 60
5σ disc., 3000 fb^{-1}, $\langle\mu\rangle$ = 140
5σ disc., 300 fb^{-1}, $\langle\mu\rangle$ = 60
Decay forbidden
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{g}}$ [GeV]
0
500
1000
1500
2000
2500
3000

Additional material

All-hadronic search using M_{T2}

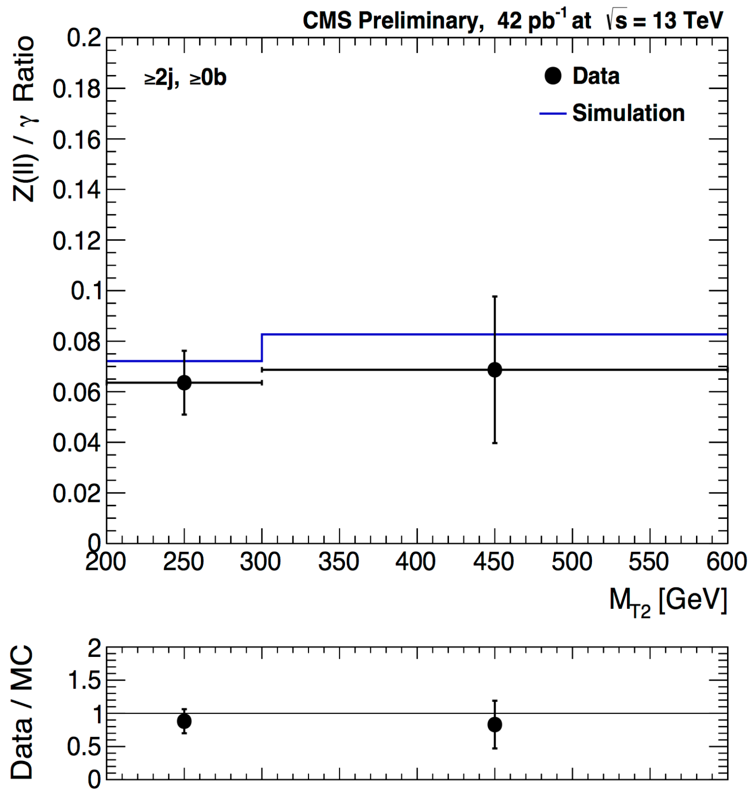
CMS-DP-2015-035

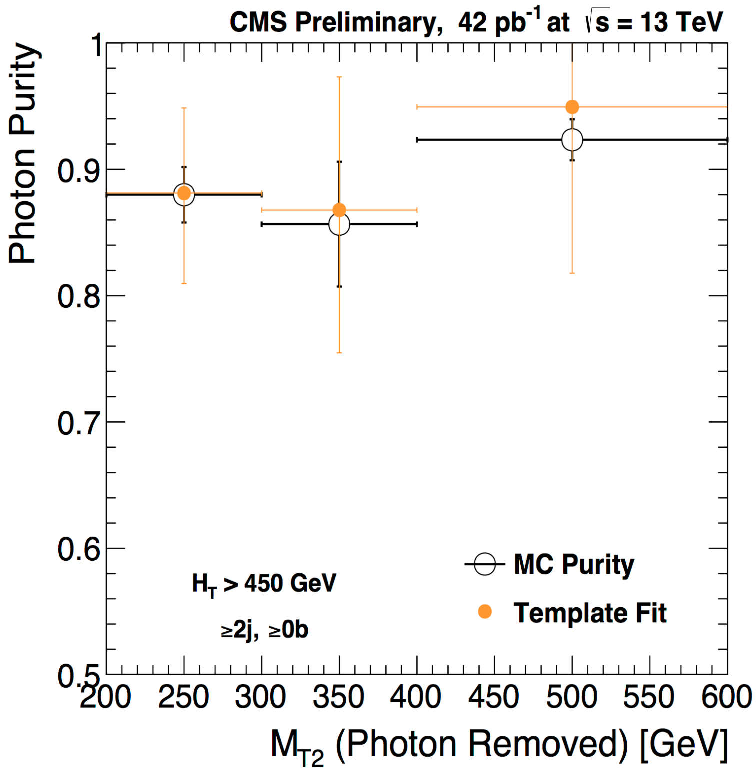
Run-2 CMS example

Inclusive search with M_{T2} in bins of H_T, N_j and N_b.

M_{T2} = sTransverse mass, designed for final states with 2 missing particles

Another important background is $Z \to \nu\nu$. Estimate with photon sample, multiplied by Z/γ ratio. Validate this by measuring the $Z \to \ell\ell$ to γ ratio & validating photon purity measurement.





Left: Ratio between the yields in the $Z \to \ell^+\ell^-$ control region and the photon control region as a function of M_{T2}. Right: Prompt photon purity in the photon control region as a function of M_{T2}, comparing the results of the template fit to the shower shape and the MC prediction.

M_t2 gamma+jet background

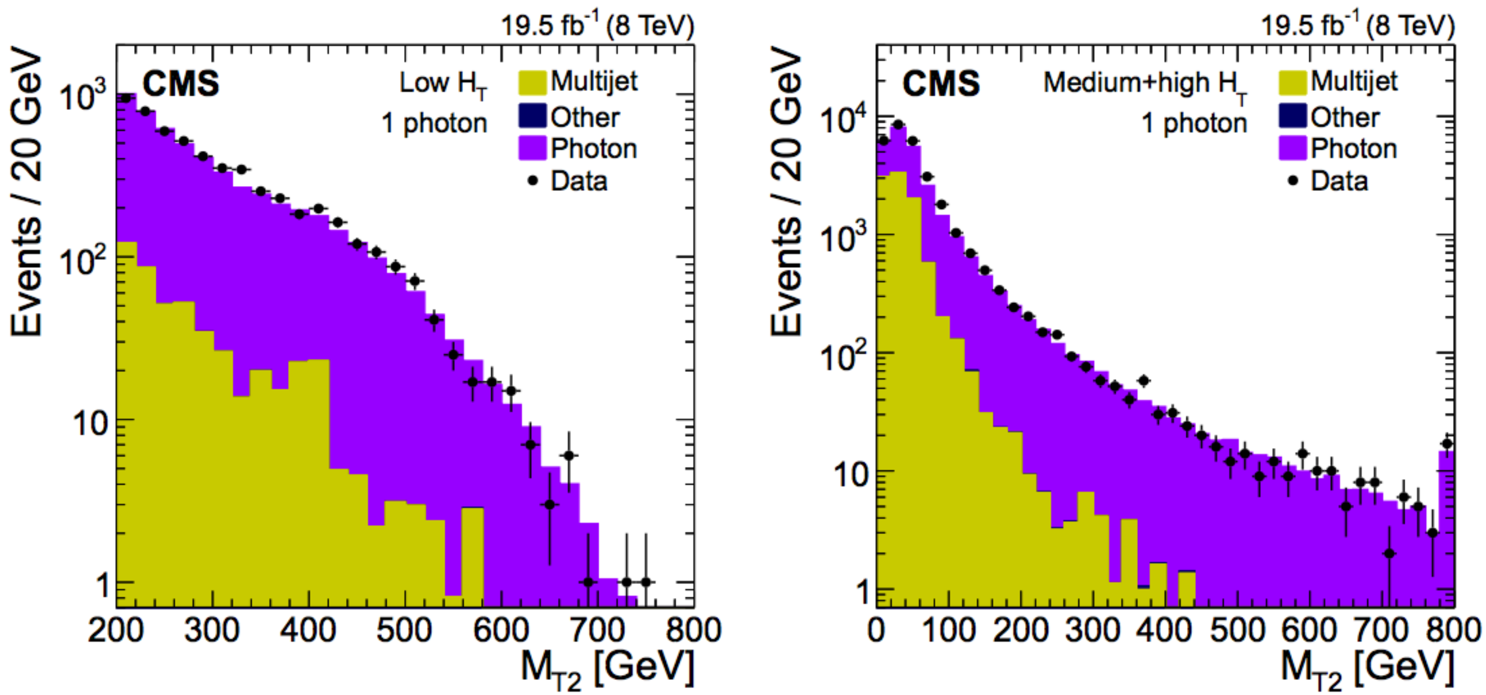


Figure 5: Distribution of the M_{T2} variable for data and simulation after requiring the presence of one photon, $N_b = 0$, and the remainder of the inclusive-M_{T2} selection criteria. Events satisfying the low-H_T selection (left), and the medium- and high-H_T selections (right) are shown. For these results, M_{T2} is calculated after adding the photon p_T to the E_T^{miss} vector.

MT_2 systematics

on the search region, and the typical ranges of effect are shown. Sources of uncertainty that change the shape of the M_{T2} distributions in the inclusive-M_{T2} analysis or the shape of the M_{bb} distributions in the M_{T2}-Higgs search are marked with a cross in the last column.

Process	Source/Region	Effect	Shape
Multijet	$M_{T2} < 200\,GeV$	10–50%	—
	$M_{T2} \geq 200\,GeV$	50–100%	—
W($\ell\nu$)+jets and Top	Lost-lepton method (sys $\oplus$ stat)	10–65%	—
	b-tagging scale factor	—	x
	Jet energy scale	—	x
	Matching scale	—	x
	Renormalization and factorization scales	—	x
	System recoil modelling	—	x
Z ($\nu\bar{\nu}$)+jets	Systematics on $Z(\nu\bar{\nu})/\gamma$ ratio ($N_b = 0$–1)	20–30%	—
	Systematics on 1b/0b ratio from $Z_{\ell\ell}$ ($N_b = 1$)	10–75%	—
	Statistics from γ+jets data ($N_b = 0$–1)	5–100%	—
	Simulation ($N_b \geq 2$)	100%	—
Signal	Integrated luminosity	2.6%	—
	Trigger efficiency	1%	—
	Parton distribution functions	5–15%	—
	b-tagging scale factor	5–40%	x

Overview plots

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

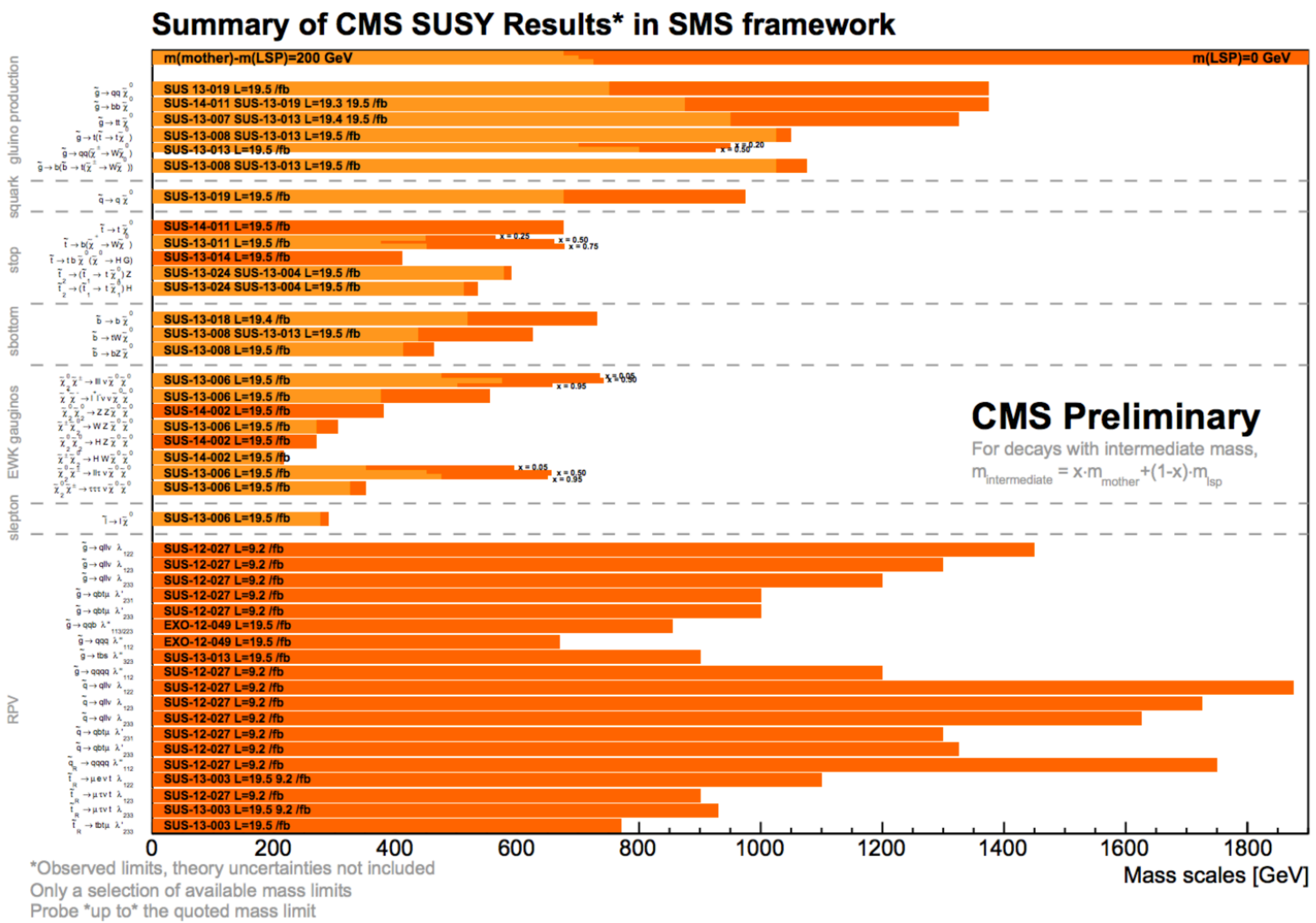
ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit ($\sqrt{s}$ = 7 TeV / $\sqrt{s}$ = 8 TeV)		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ /1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.8 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$ 100-440 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<10 GeV	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 780 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	0-1 e,μ	2-6 jets	Yes	20	$\tilde{g}$ 1.26 TeV	m($\tilde{\chi}_1^0$)<300 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	1507.05525
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8 × 10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	m($\tilde{\chi}_1^{\pm}$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 110-167 GeV ($\sqrt{s}$ = 7 TeV), 230-460 GeV	m($\tilde{\chi}_1^{\pm}$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-191 GeV, 210-700 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 700 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 420 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 250 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod.	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$ 124-361 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 270 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$ 482 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^{\pm}$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	2<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to eev/e\mu v/\mu\mu v$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{121}\neq 0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to q\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 870 GeV	m($\tilde{\chi}_1^0$)=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

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

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


Summary of CMS SUSY Results* in SMS framework
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-013 L=19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-019 L=19.5 /fb
SUS-14-011 L=19.5 /fb
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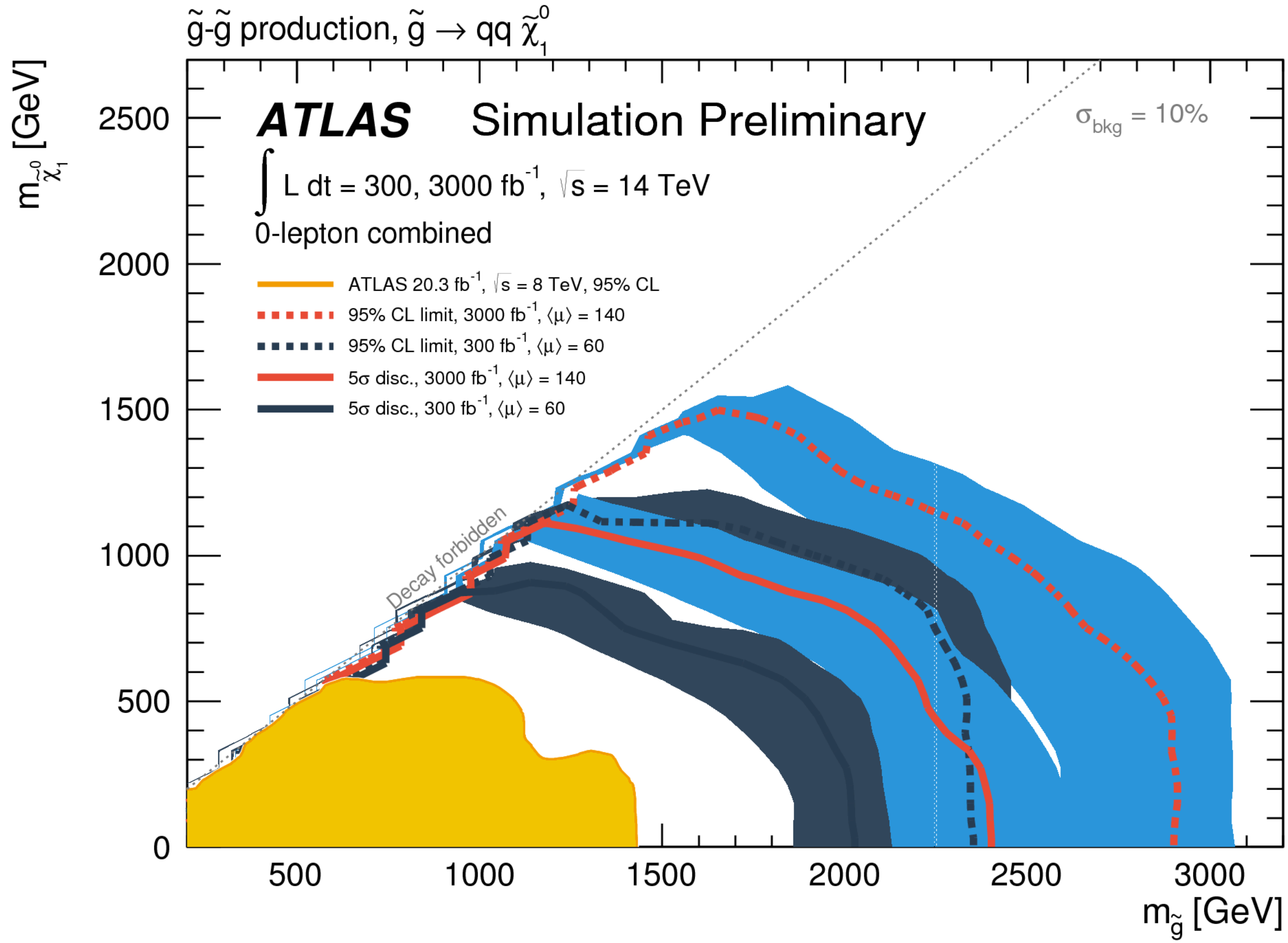
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother + (1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit



g̃-g̃ production, g̃ → qq $\tilde{\chi}_1^0$
ATLAS Simulation Preliminary
$\int L\,dt$ = 300, 3000 fb^{-1}, $\sqrt{s}$ = 14 TeV
0-lepton combined
ATLAS 20.3 fb^{-1}, $\sqrt{s}$ = 8 TeV, 95% CL
95% CL limit, 3000 fb^{-1}, ⟨μ⟩ = 140
95% CL limit, 300 fb^{-1}, ⟨μ⟩ = 60
5σ disc., 3000 fb^{-1}, ⟨μ⟩ = 140
5σ disc., 300 fb^{-1}, ⟨μ⟩ = 60
σ_{bkg} = 10%
Decay forbidden
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{g}}$ [GeV]
0
500
1000
1500
2000
2500
3000