Searches for supersymmetry at ATLAS and CMS

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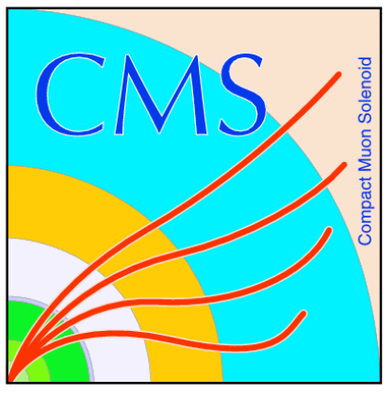
2016 Aspen Winter Conference on Particle Physics



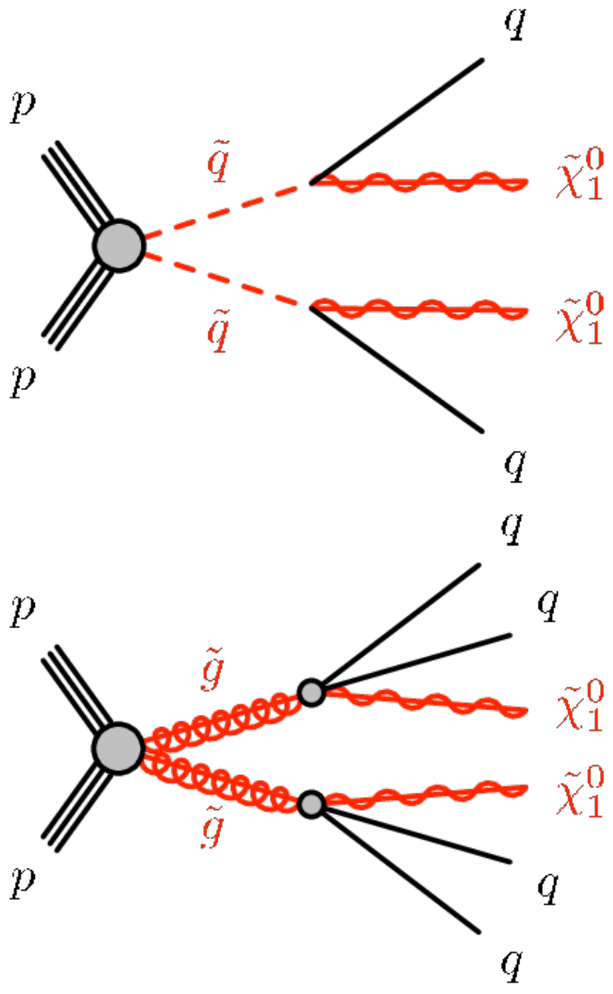
UCSB

Overview

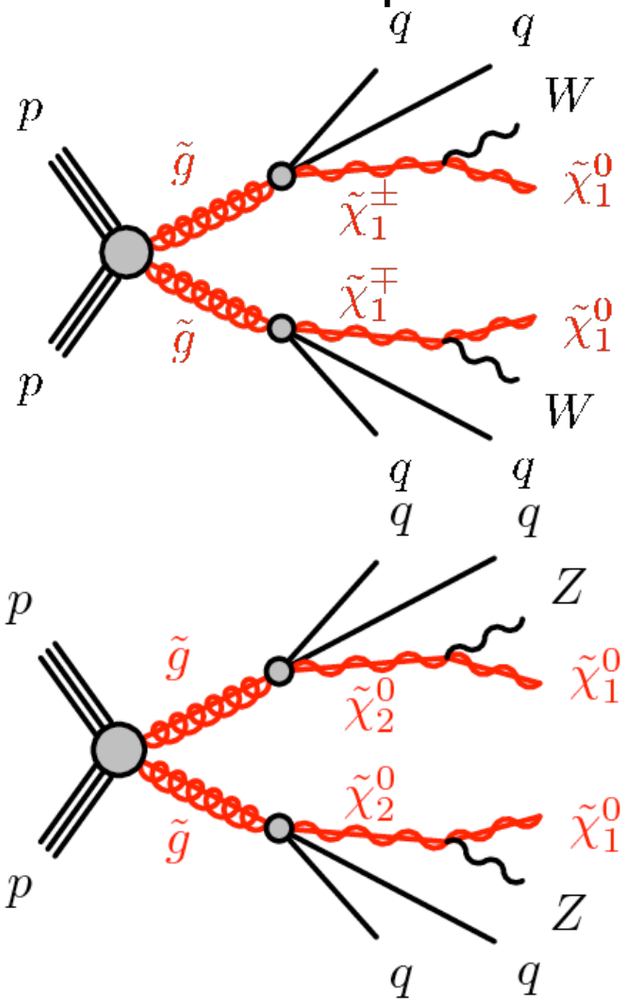
- Review of SUSY signatures
- Selected recent 8 TeV results
  - Soft lepton search from CMS
  - ATLAS constraints on pMSSM
- *15* results from analysis of data taken at 13 TeV

SUSY signatures for strong production

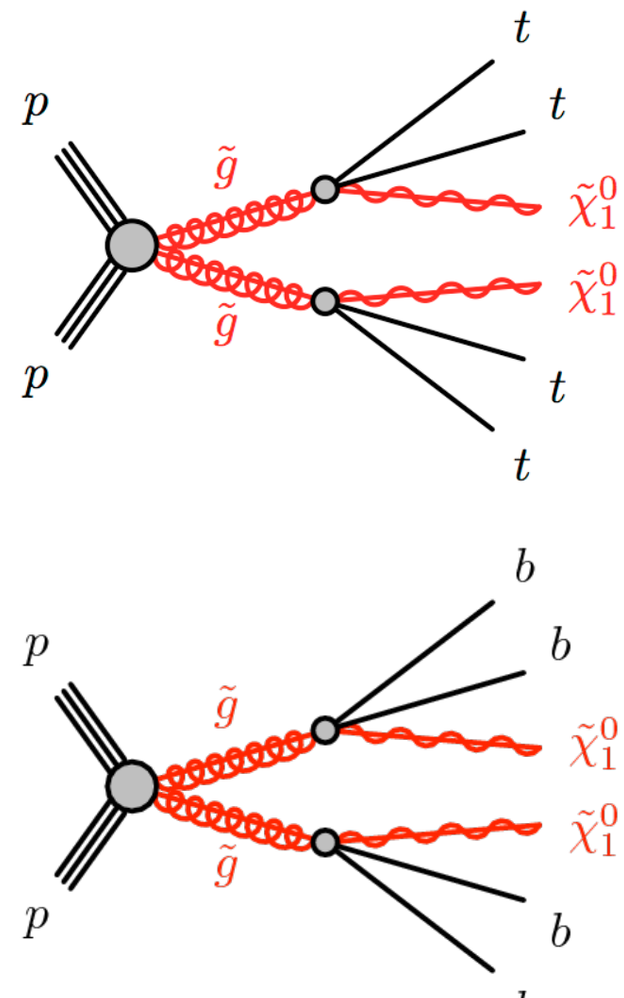
Fully hadronic



Large jet multiplicity and/or leptons



b-tagged jets



Most analyses in this talk assume decays to a stable LSP⇒ **large missing transverse energy**, except in cases of sparticle-LSP mass degeneracies

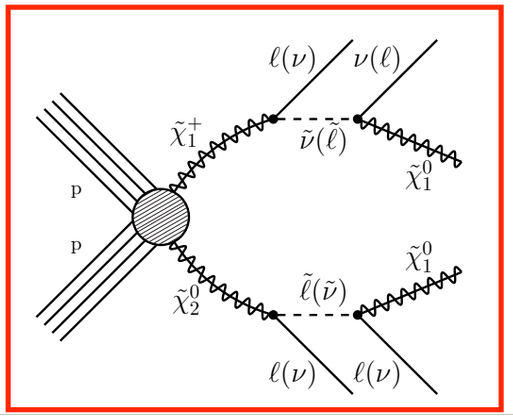
Many analyses are binned in N_{jet}, $N_{b,}$ and $N_{leptons}$ to provide broad coverage

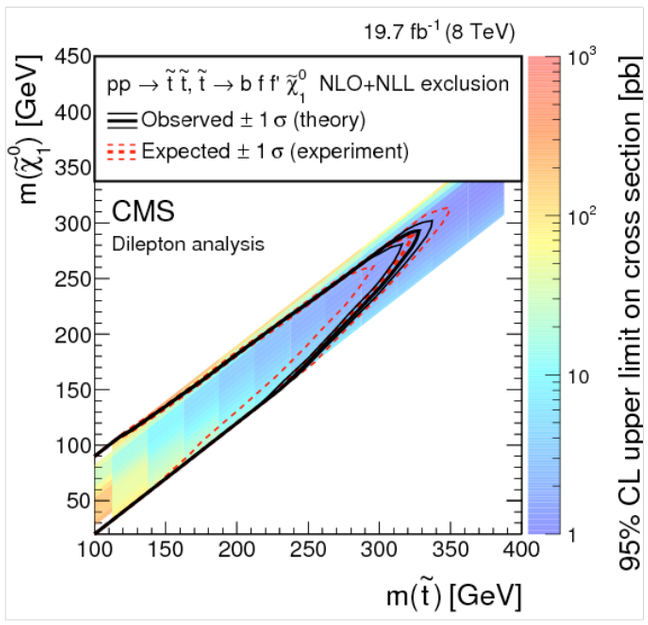
8 TeV results

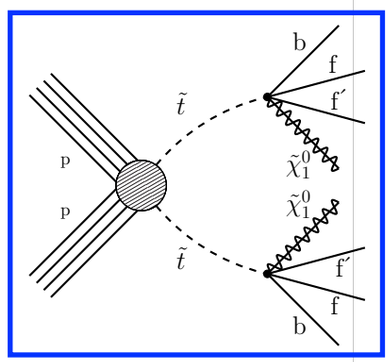
arXiv:1512.08002

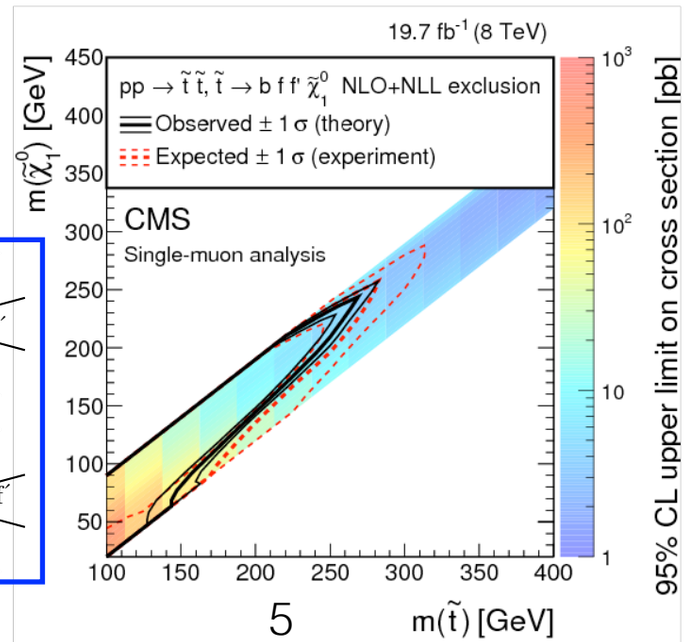
Soft lepton search

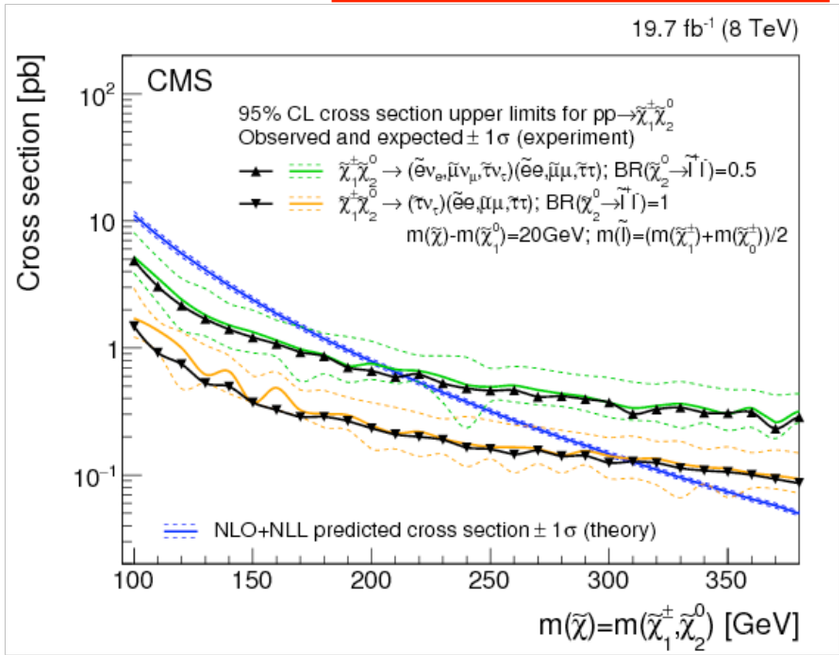
- Regions with small stop-LSP mass splittings:
  - More challenging due to smaller missing energy⇒require boost from hard ISR jet
  - Two-body and three-body stop decays kinematically forbidden
    - ⇒search for four-body decay of stop in 1-lepton and 2-lepton final states
- W and top (dominant bkg.) estimated from control regions with larger lepton p_T
- Limit of m_{stop}>316 GeV for m_{stop}-m_{LSP}=25 GeV
- Search also sensitive to neutralino-chargino production
  - Limit on χ_2^0 / χ_1^+ mass of 212 GeV for mass splitting for 20 GeV







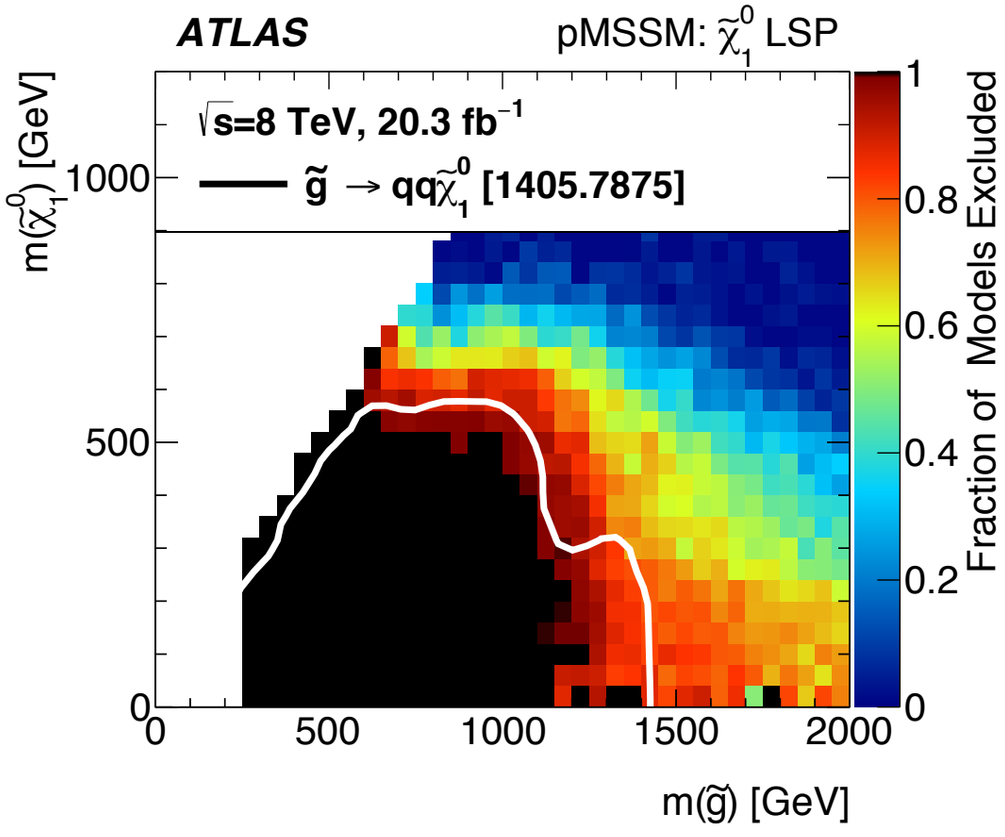




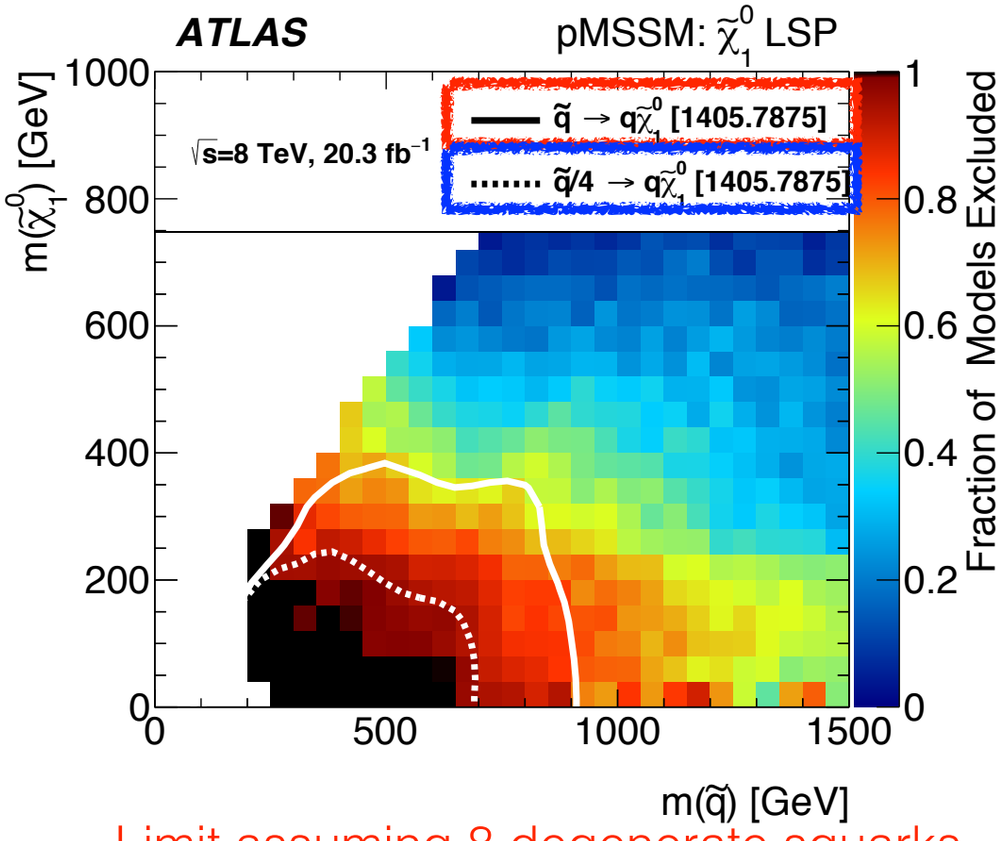
JHEP 10 (2015) 134

Gluino and squark mass limits in pMSSM

- Comprehensive analysis of 19-D subspace of MSSM
- Will only highlight results for comparison with 13 TeV results in this talk



Gluino mass constraints similar to simplified model expectations



Squark mass limits up to ~4 times weaker due to non-degeneracy of first two generations of squarks in pMSSM

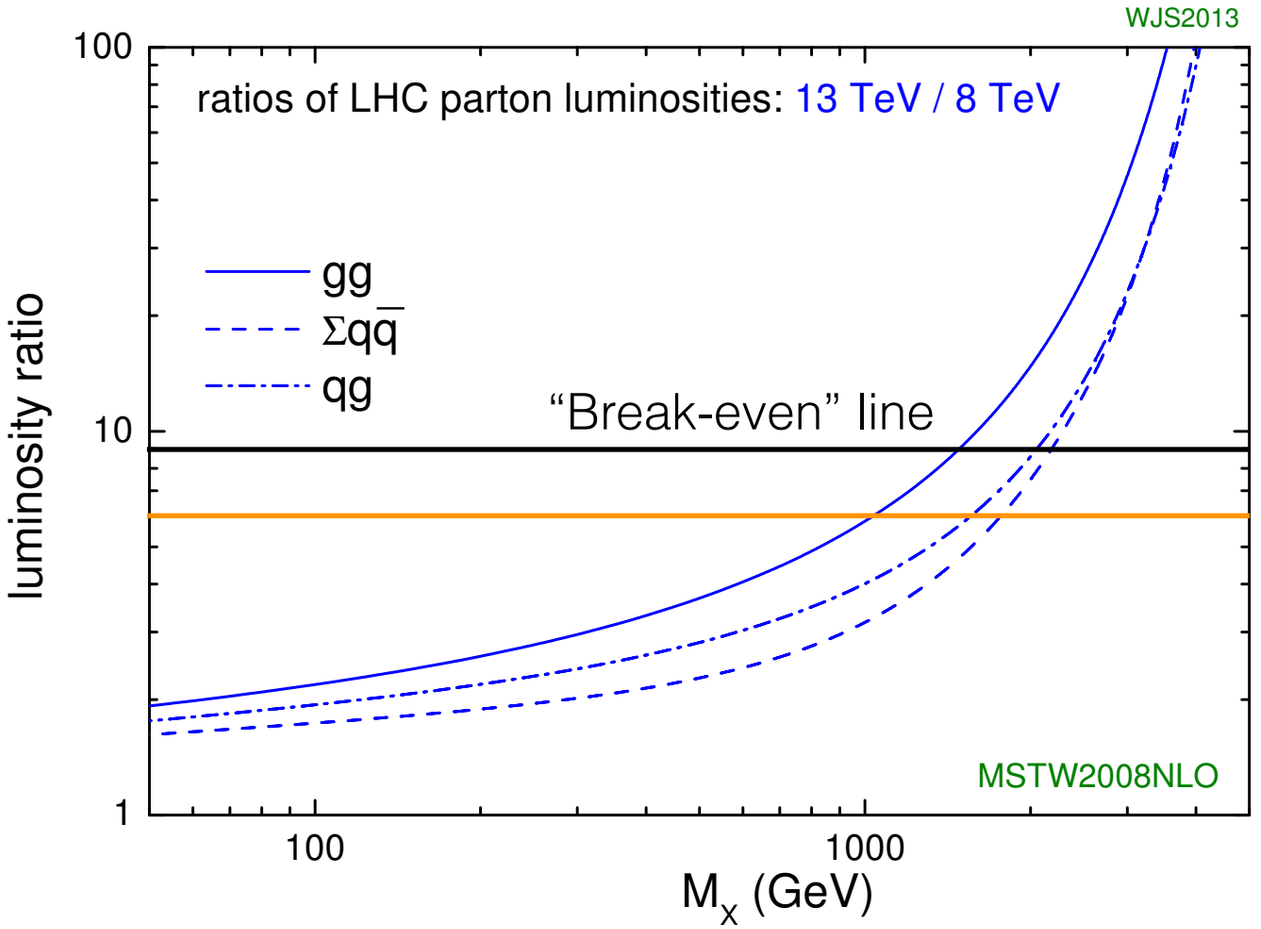
Similar CMS analysis: SUS-15-010

13 TeV results

For high mass objects, increase in parton luminosities overcomes limited integrated luminosity at 13 TeV

Integrated luminosity (fb^{-1}) good for physics

	8 TeV	13 TeV	Ratio
CMS	19.3-19.8	2.1-2.4	~9
ATLAS	20.1-20.3	3.2	~6



For gluinos near mass limits, a cross section ratio of L_{ATLAS}/L_{CMS} ~1.5 corresponds to ~75 GeV in gluino mass

$M_X=2*m_{sparticle}$ for pair production

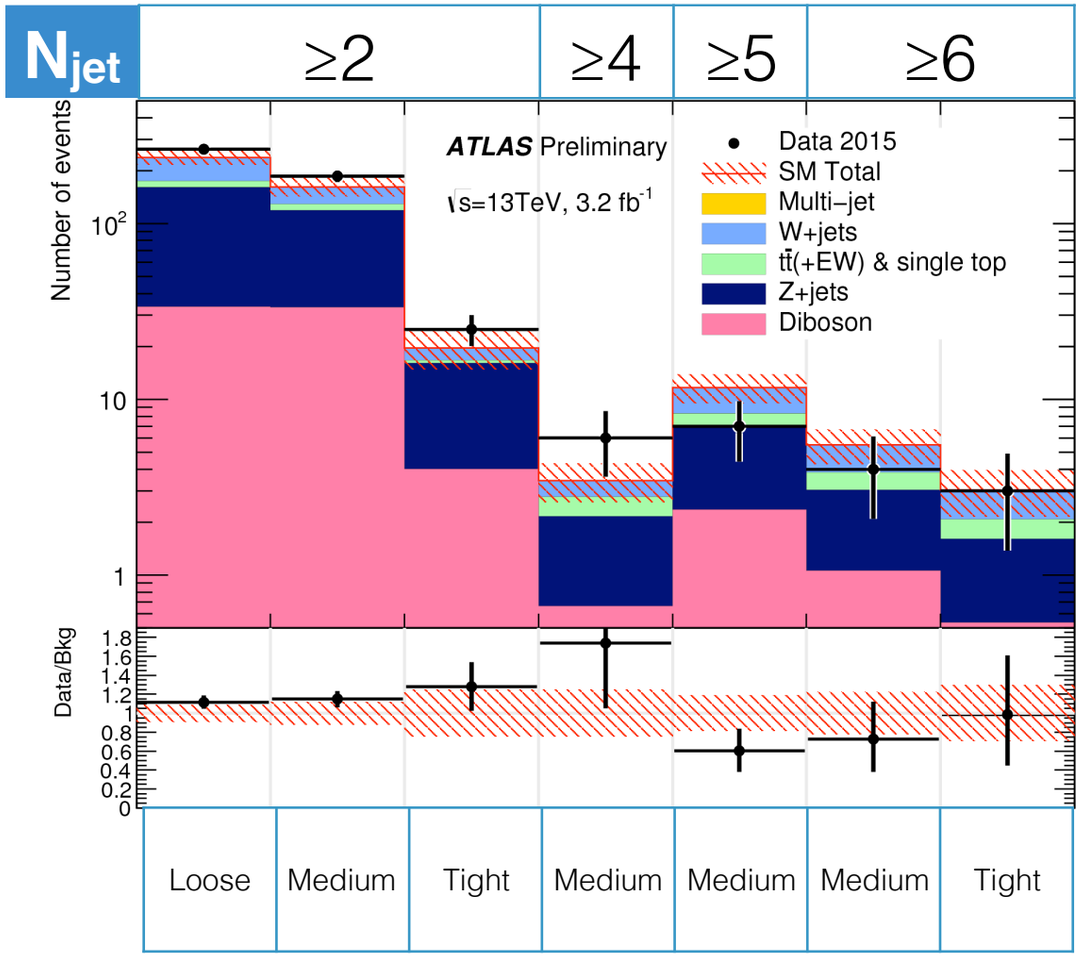
Increase in parton luminosities overcomes limited luminosity only for high mass objects⇒**focus on gluinos**, which have a large cross section above 1 TeV

Fully hadronic final states

ATLAS-CONF-2015-062

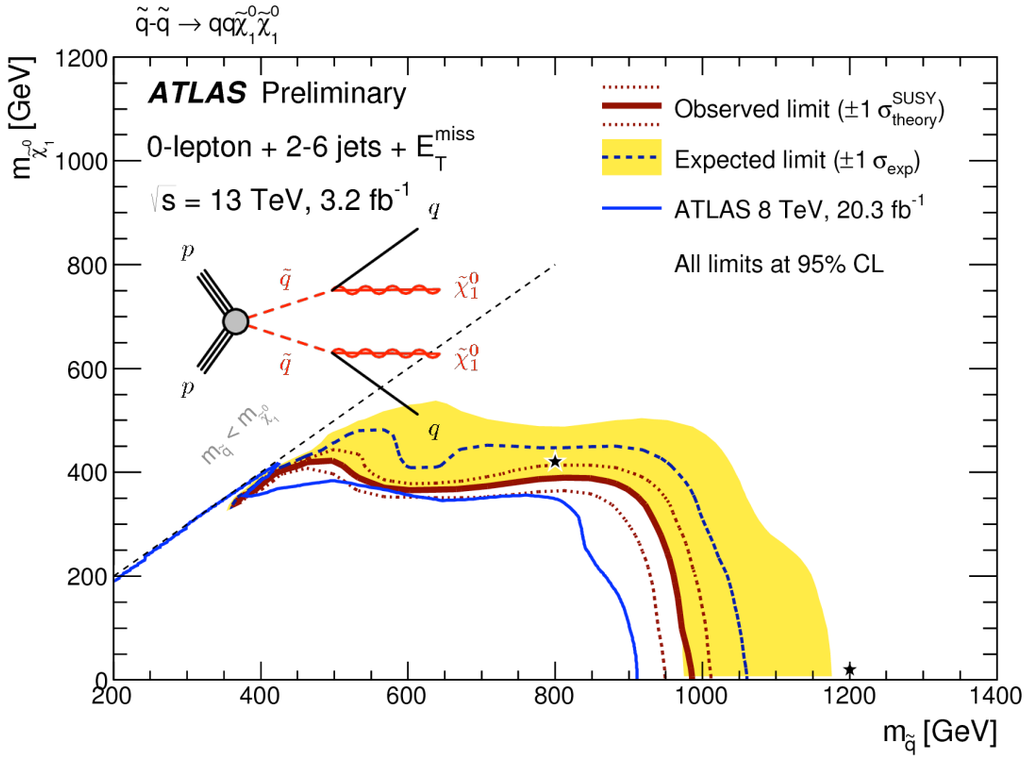
Search for squarks and gluinos in hadronic final states

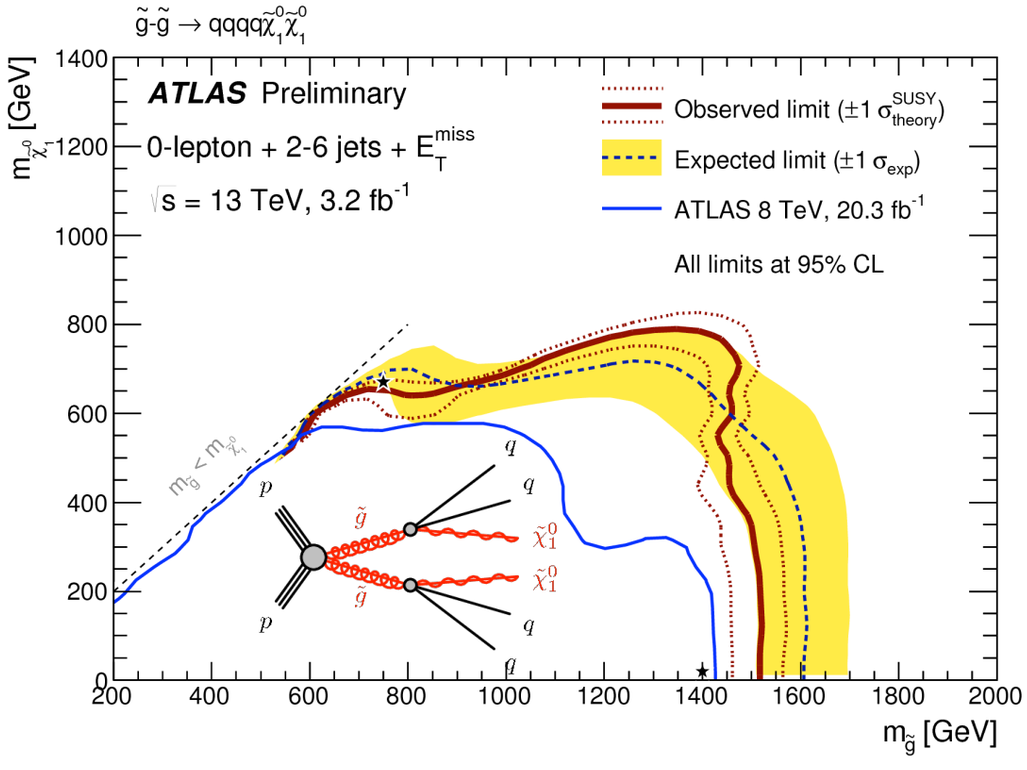
Signal regions binned in N_{jet} and degree of background rejection from kinematic variables (p_{T1}, p_{T2}, m_{eff})



Background estimation control regions (CR)

Background	Control region
Z→νν	γ+jets
top	lepton + M_T + b-tag
W	lepton + M_T + b-veto
QCD	MET/jet alignment

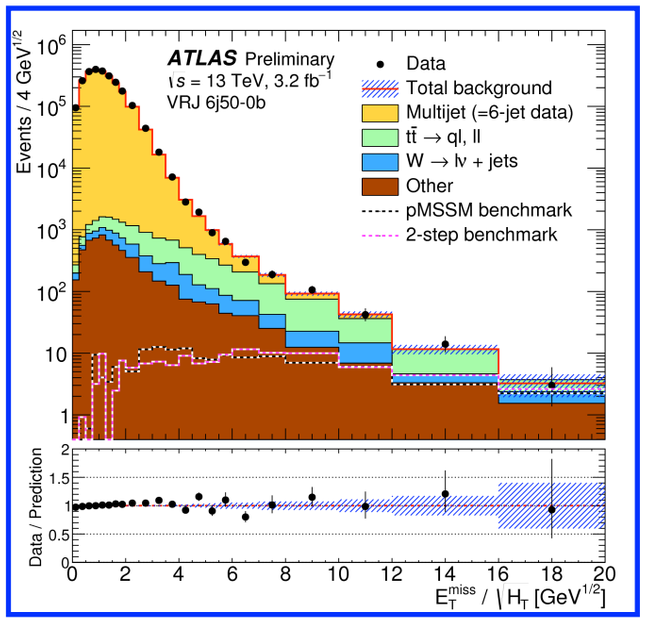


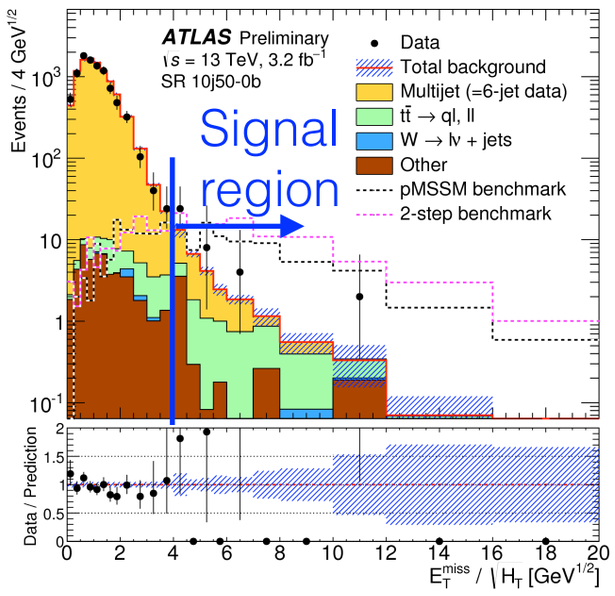


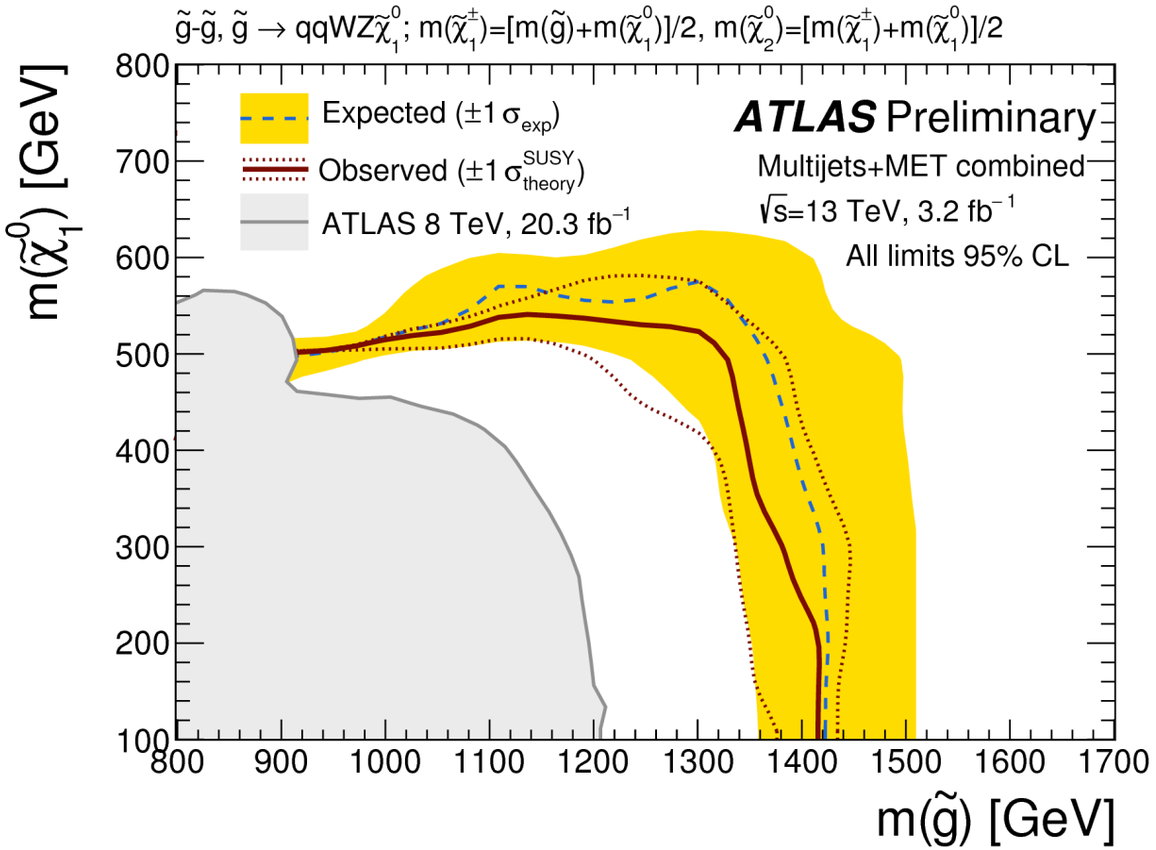
ATLAS-CONF-2015-077

Searches in for squarks and gluinos in fully hadronic final states (large jet multiplicity)

- Targets more complicated decay chains
- Binned in jet p_T selections (loose and tight), N_b and N_{jet}
- Looser MET selection than low multiplicity analysis
- Background prediction:
  - QCD shape from templates in lower jet multiplicity validation region and normalized in a control region
  - Top and W normalized to 1-lepton selection



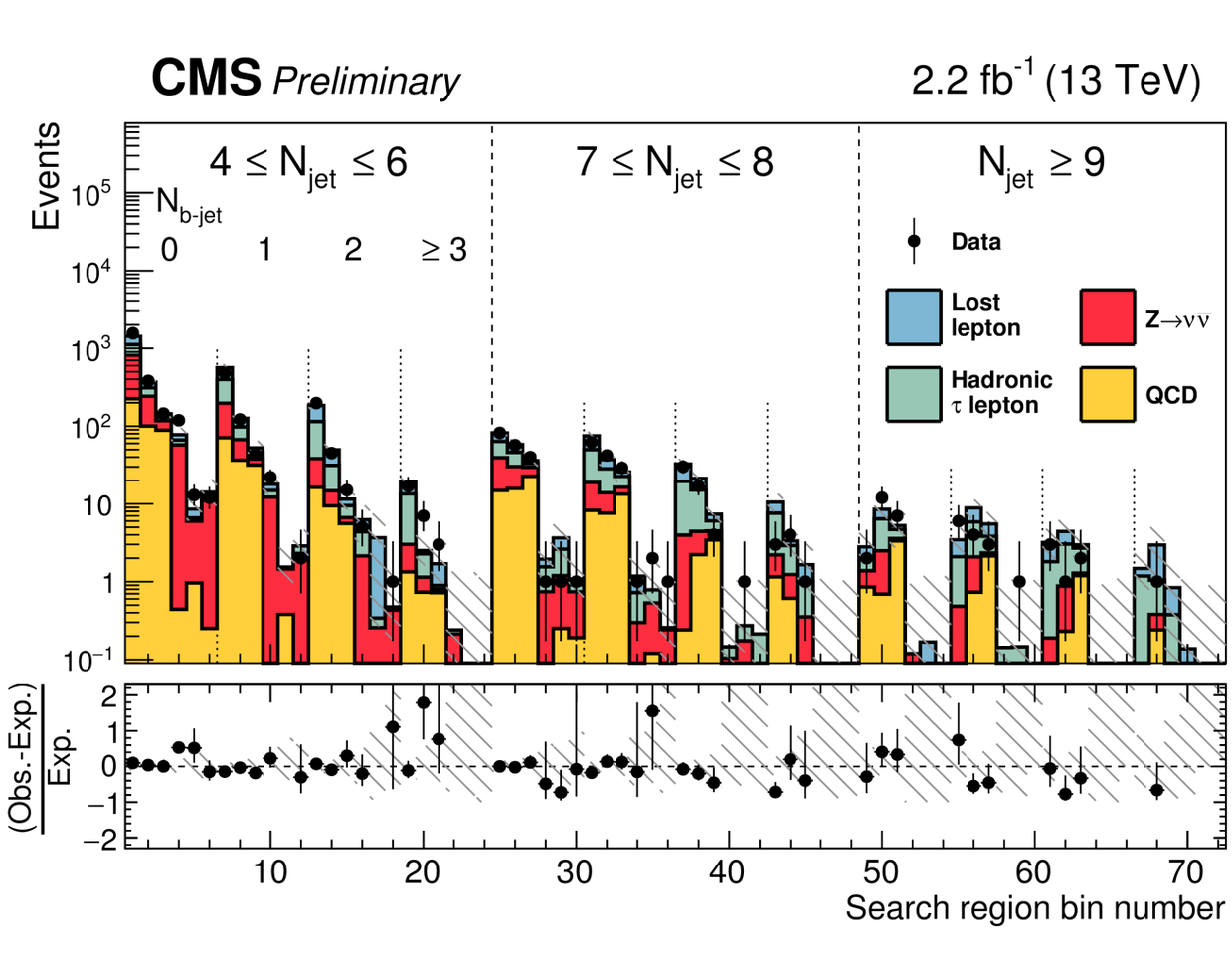


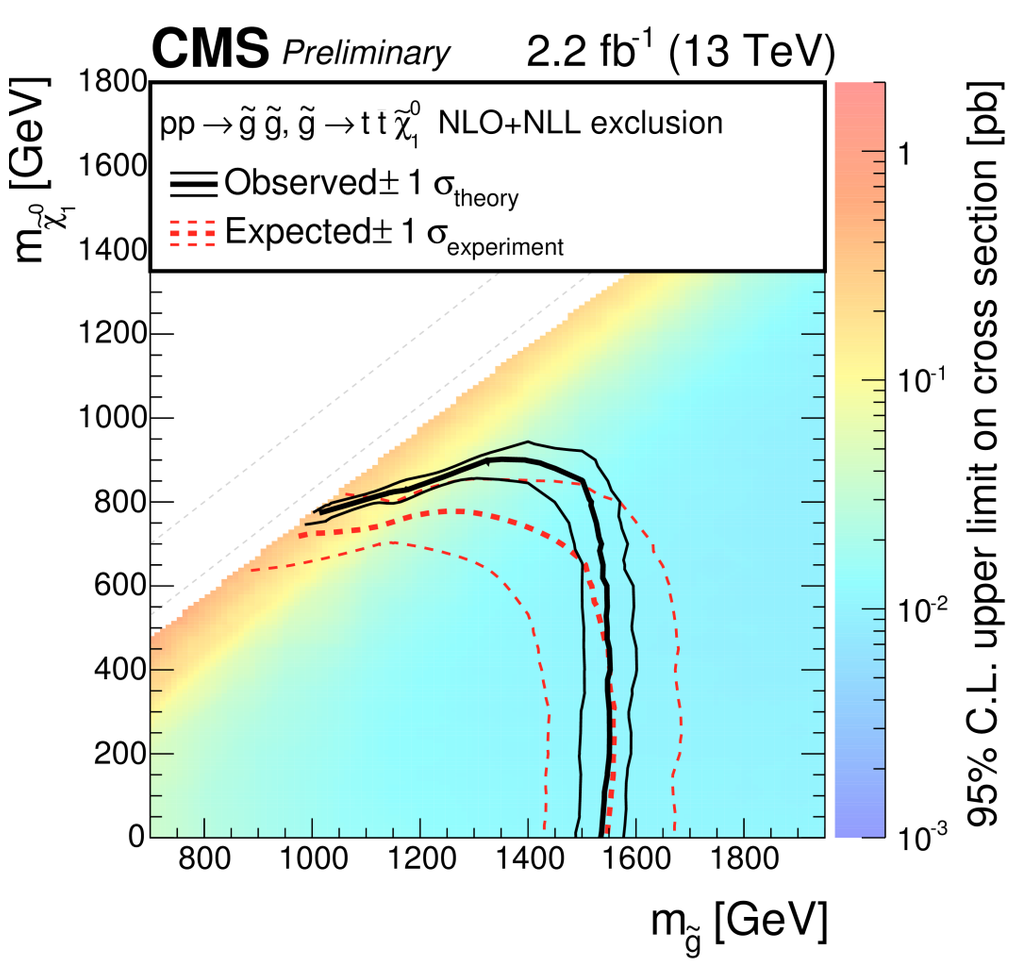


CMS-PAS-SUS-15-002

Multijet+missing H_T

- Targets gluino decays to $qq\chi^0$, $bb\chi^0$ and $tt\chi^0$
- Binned in N_{jet}, N_b, $H_{T,miss}$ and H_T
- Background predictions:
  - Lost lepton and hadronic tau background: single lepton CR
  - $Z\rightarrow\nu\nu$: scaled from $Z\rightarrow\mu^+\mu^-$ and γ+jets CR
  - QCD: CR with inverted $\Delta\phi$ cut between MET and leading jets

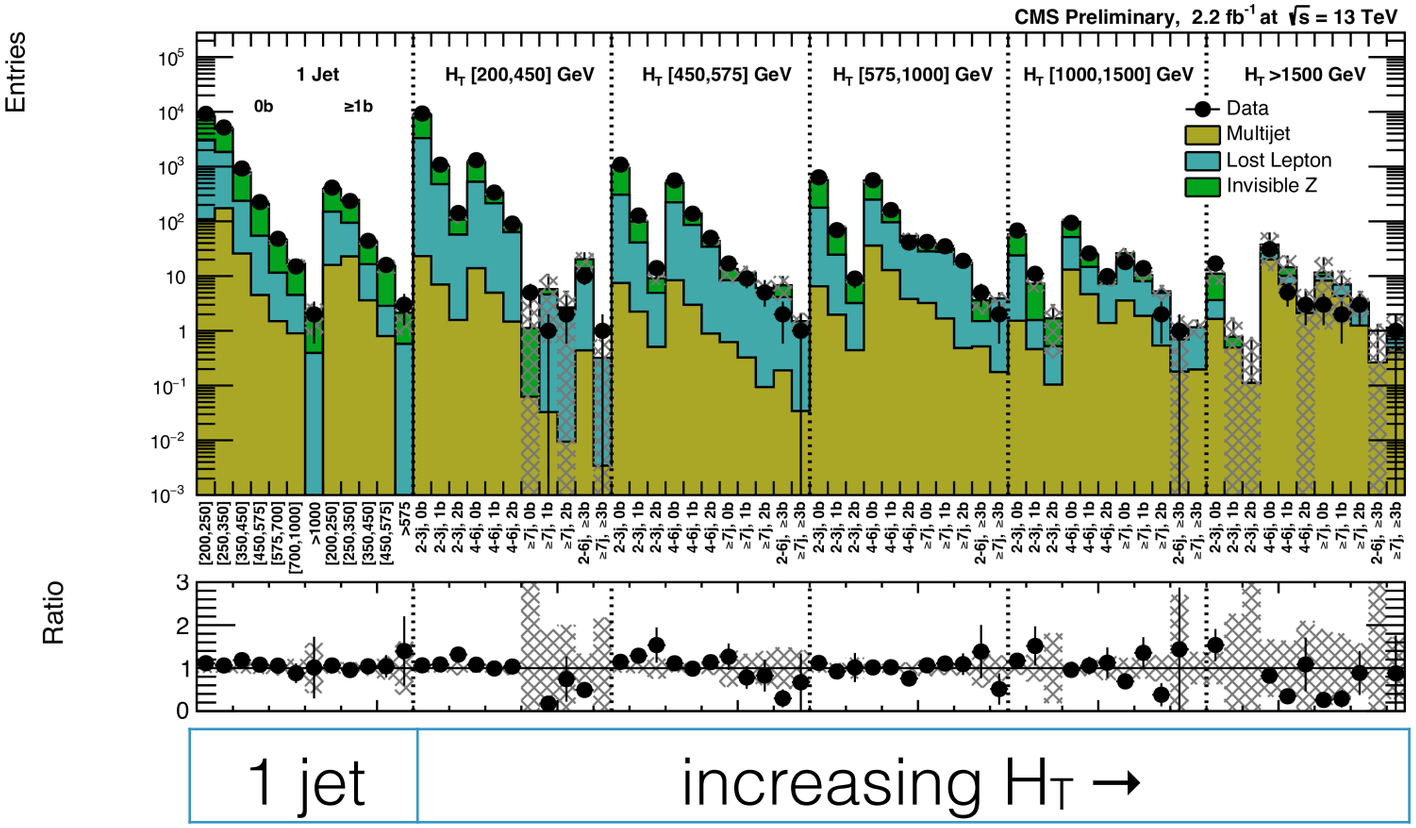


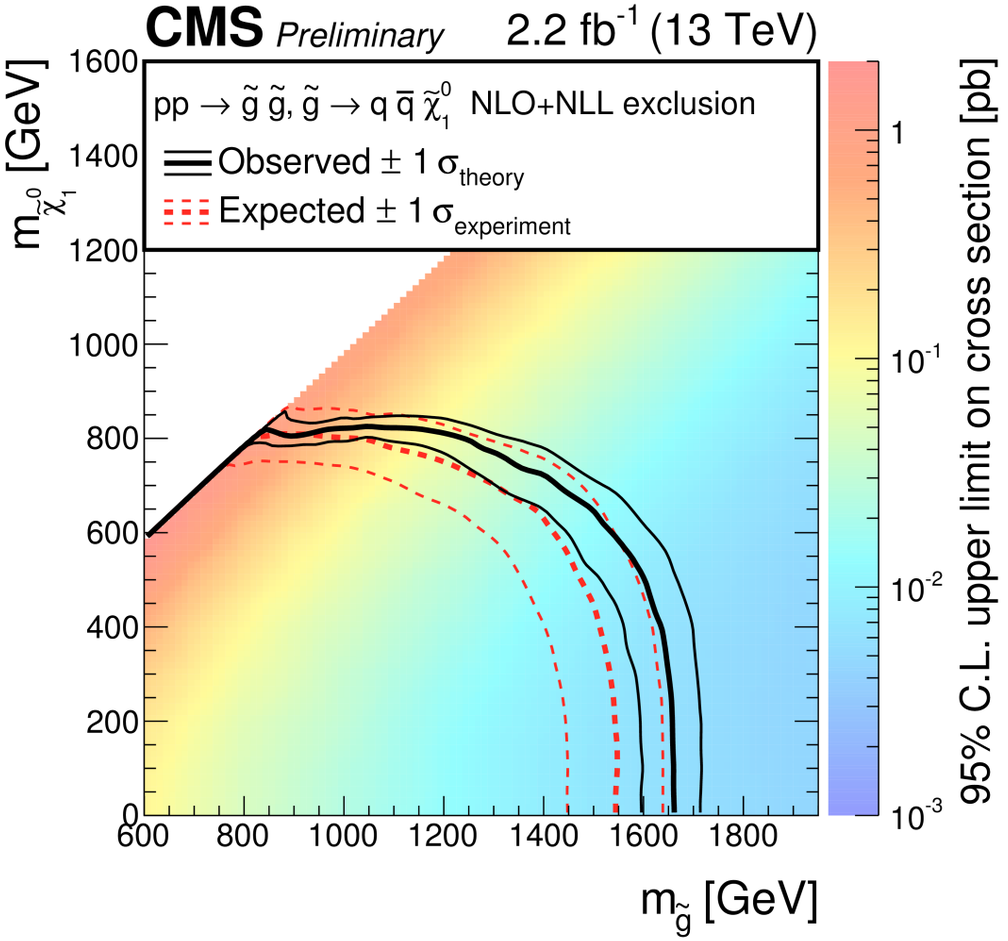


CMS-PAS-SUS-15-003

Search with M_{T2}

- M_{T2} is a generalization of M_T to two invisible particles
- Analysis binned in H_T, $H_{T,miss}$, N_{jet}, N_b
  - Extends to lower N_{jet} than multijet+missing H_T analysis, including a monojet bin
- Background prediction similar to multijet+missing H_T analysis

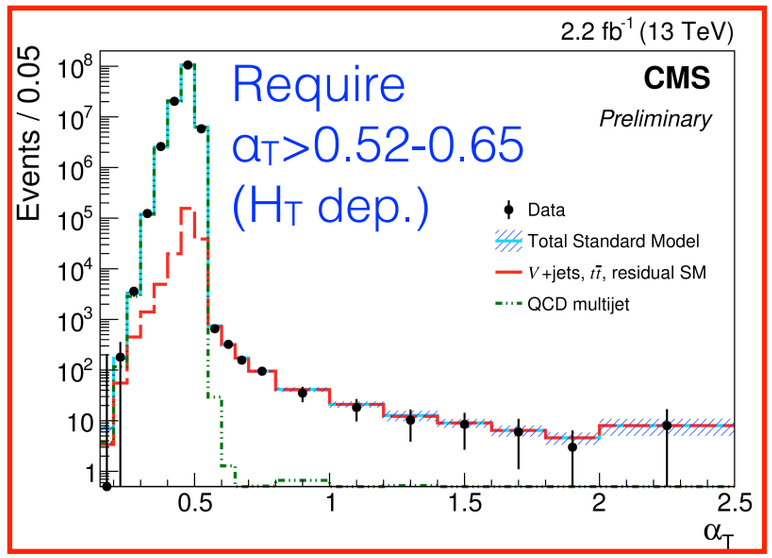


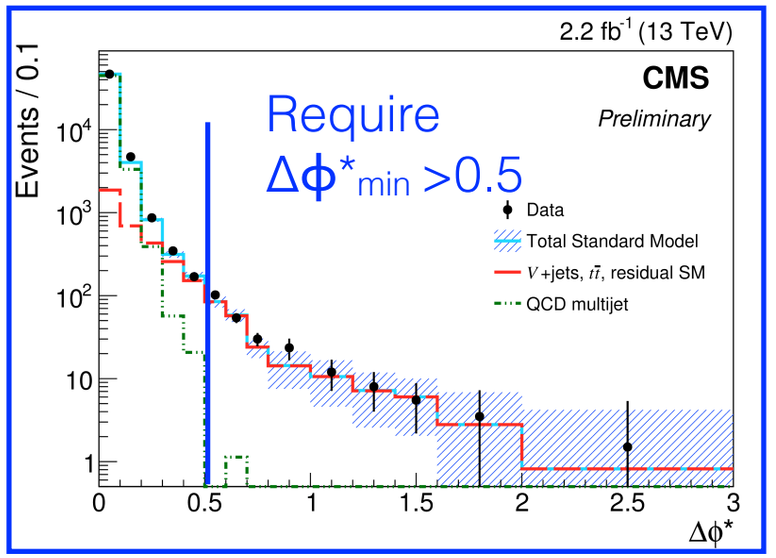


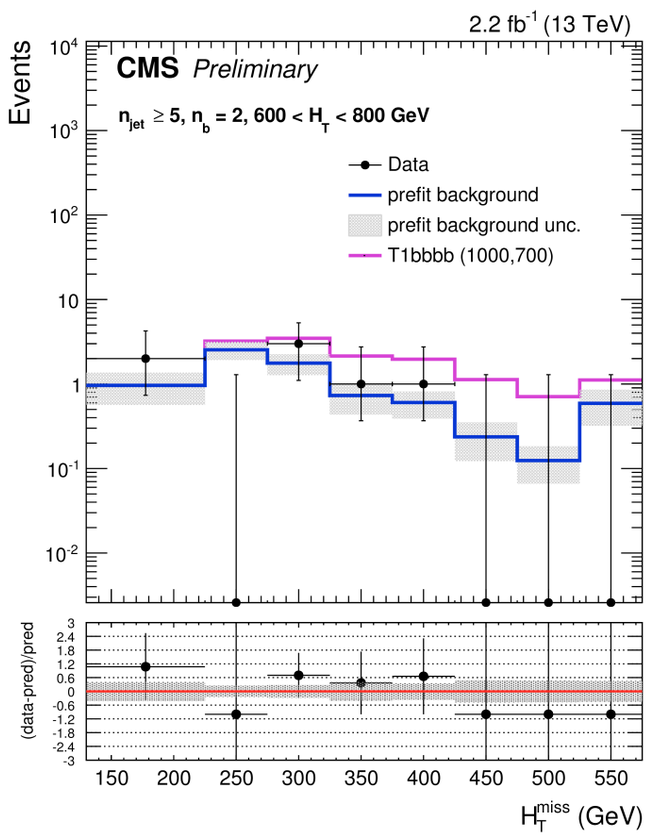
CMS-PAS-SUS-15-005

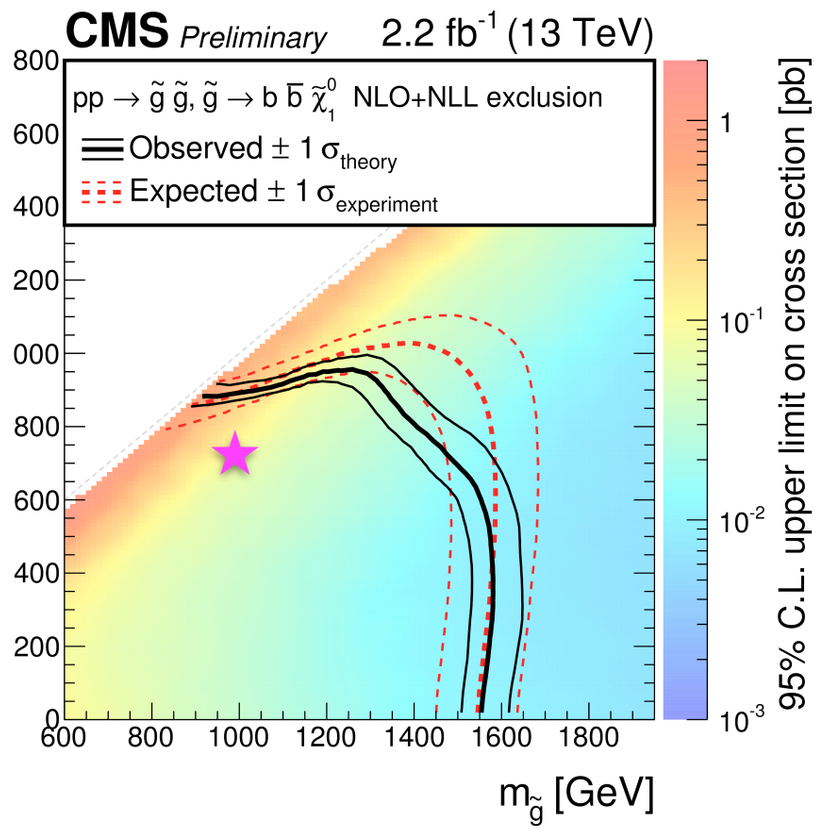
Search with α_T

- QCD suppression variables:
  - $\alpha_T = E_{T,jet\ 2}/M_T$ (for dijets)
  - $\Delta\phi^*_{min}$
  - $H_{T,miss}/E_{T,miss}$
- Signal regions:
  - N_{jet}=1 (new!), 2, 3, 4, ≥5
  - N_b=0, 1, 2, ≥3
  - 8 bins of H_T: 200 to ≥800 GeV
- Background yields from data control samples:
  - γ+jets, μμ+jets ($Z \rightarrow \nu\nu$ bkg)
  - μ+jets (other bkg)









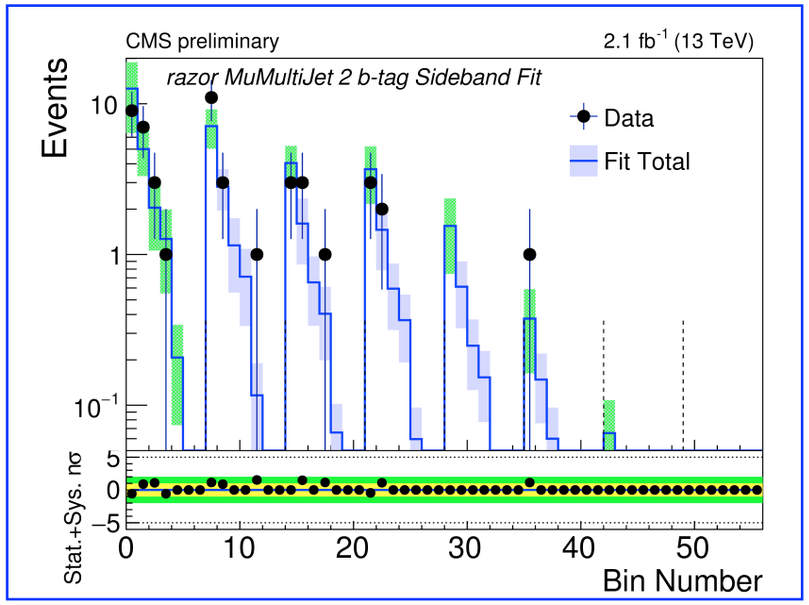
1-lepton final states

Inclusive search with razor variables (R,M_R)

- For a squark decaying to a quark and neutralino, M_R peaks at

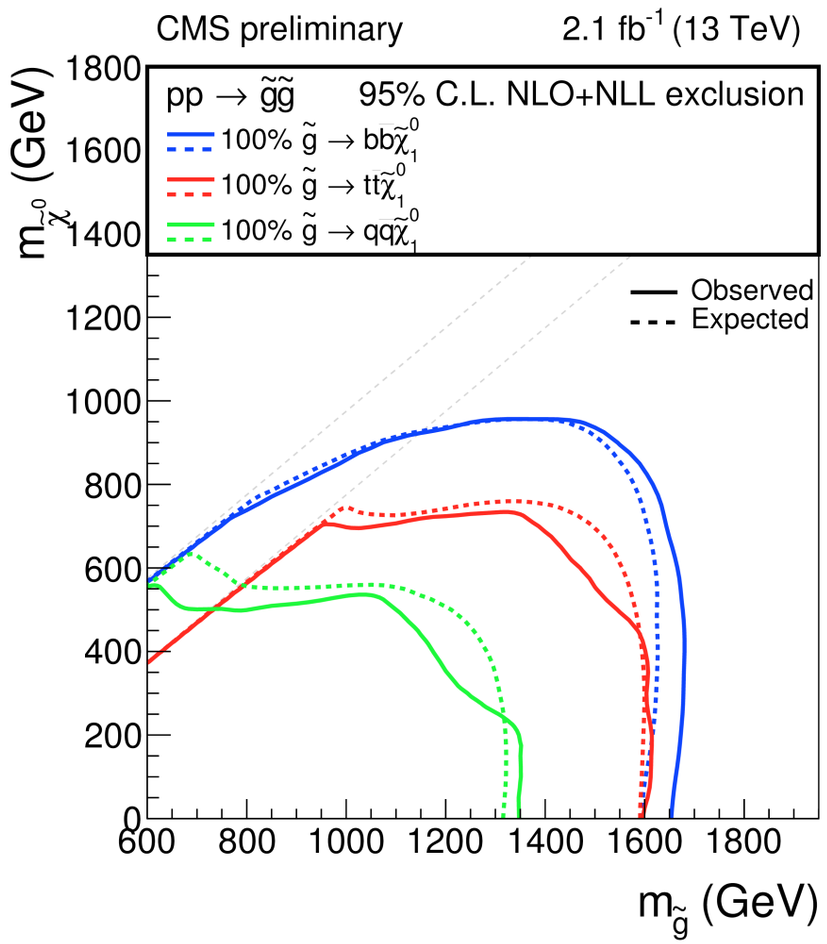
$$\frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}$$

and the background has an exponential shape



- Yields extracted from fits to 2-D (R^2, M_R) distributions

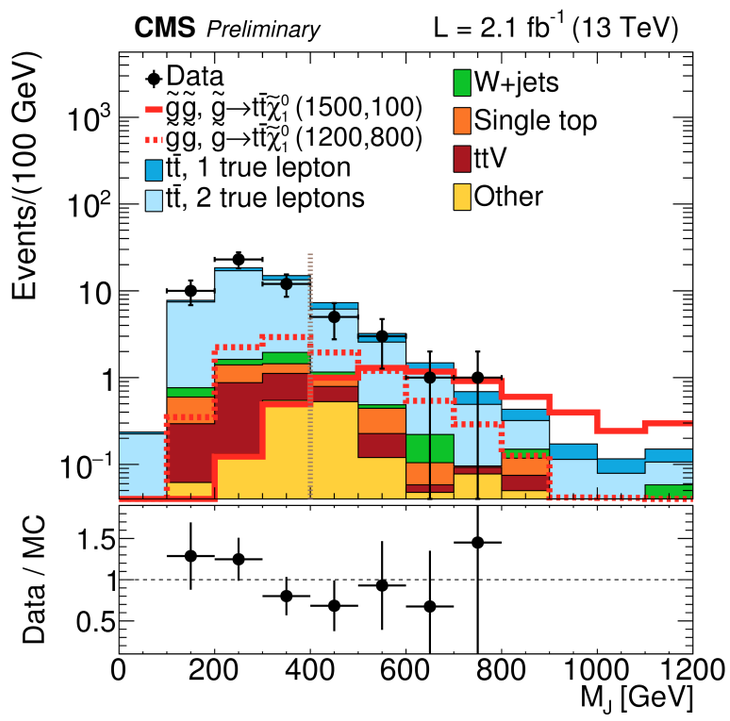
- Probes gluino→(qqχ^0, bbχ^0, ttχ^0):
  - N_{lep}=0, 1e, 1μ
  - N_b=0, 1, 2, ≥3
  - Binned in (R^2, M_R)

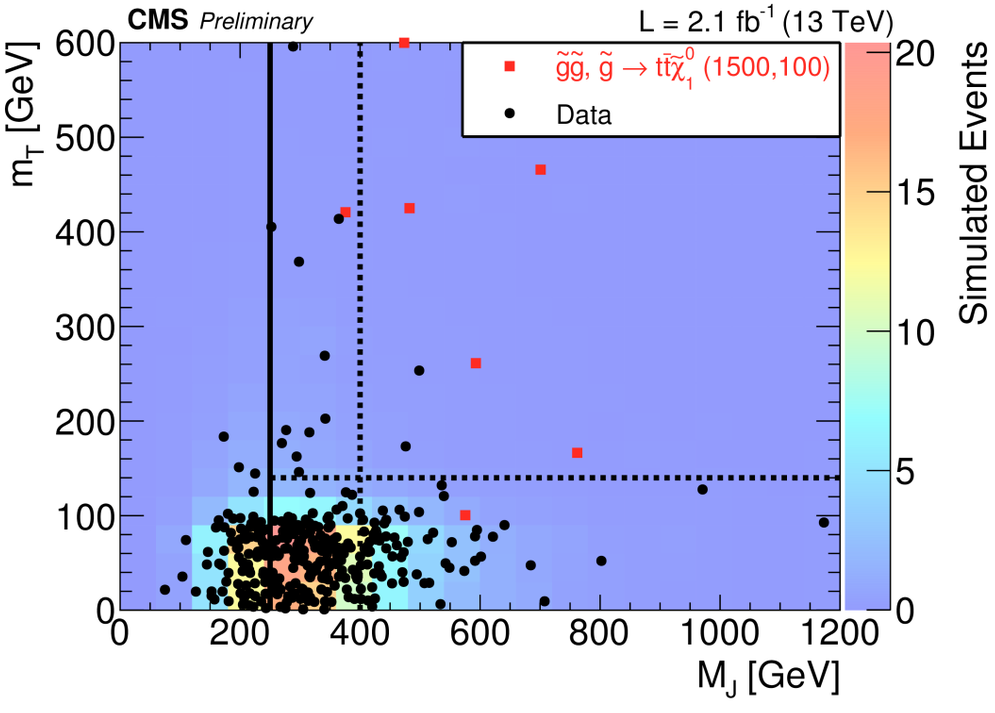


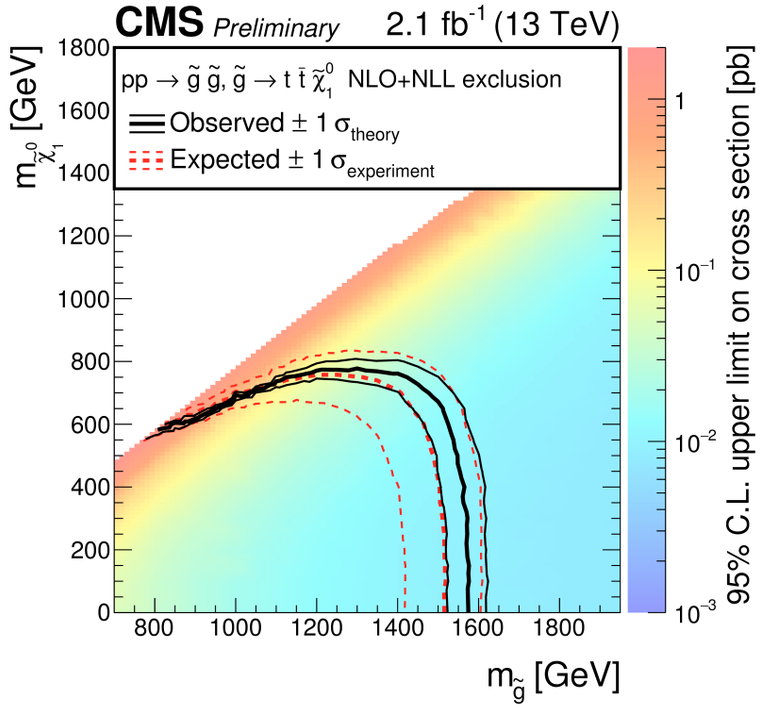
CMS-PAS-SUS-15-007

Single lepton and sum of masses of large-R jets

- Masses of large-R jets discriminate between decay products of heavy objects and SM background
  - In absence of ISR, sum of the masses of large-R jets, M_J, has an endpoint < 2 m_{top}
- Requires $N_b \geq 1$ and $N_{jet} \geq 6$ to probe gluino→ttχ^0
- M_J and M_T used as discriminating variables
- Background estimation (corrected ABCD method) exploits limited correlation between M_T and M_J



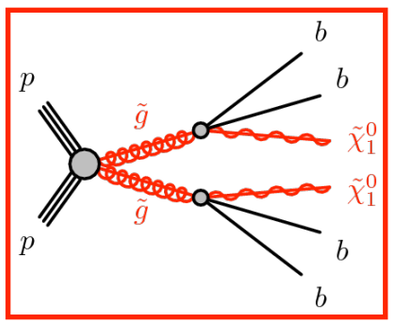


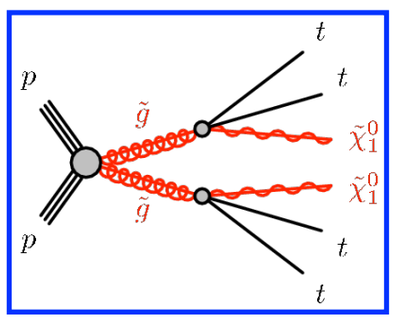


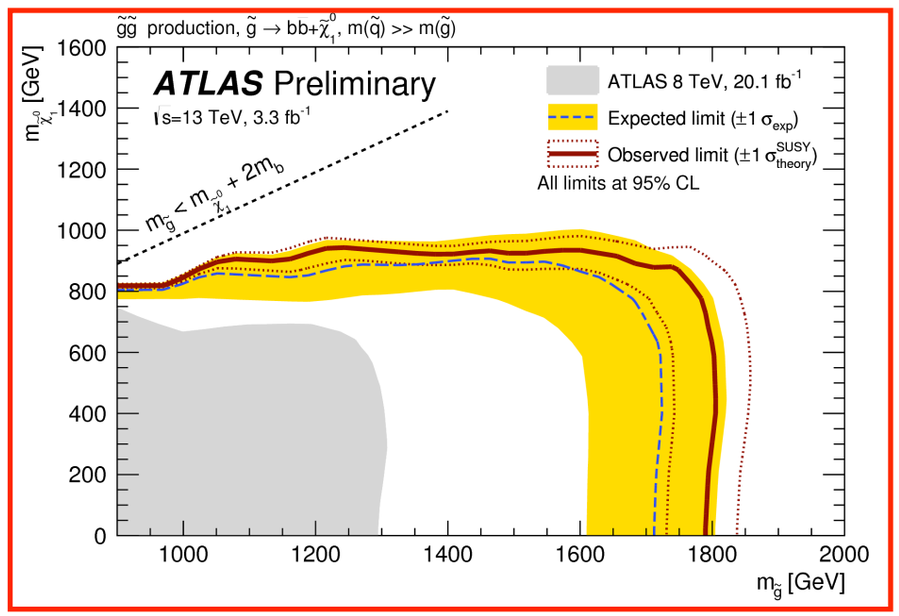
ATLAS-CONF-2015-067

Jets+MET+multiple b-jets

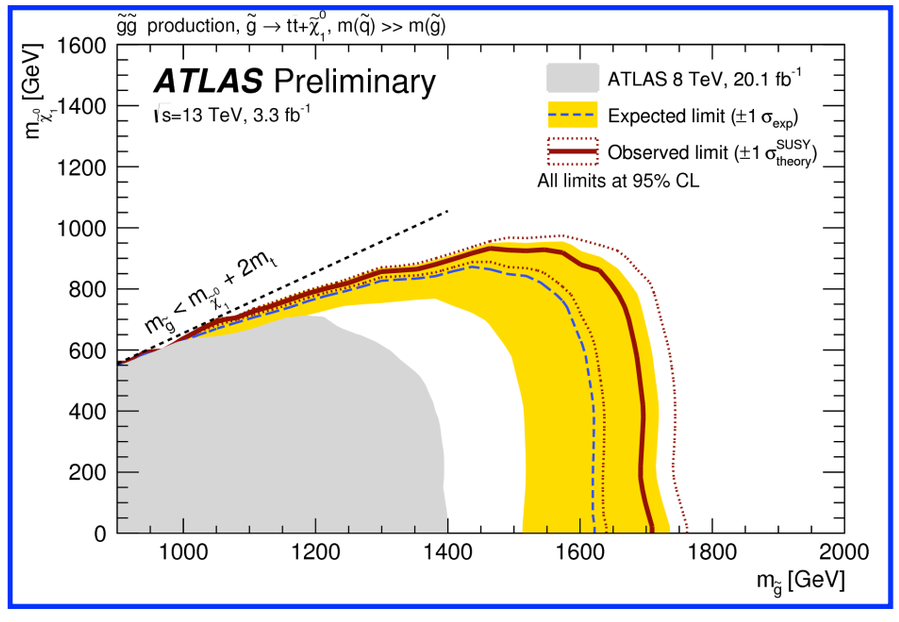
- Targets “Natural SUSY” models







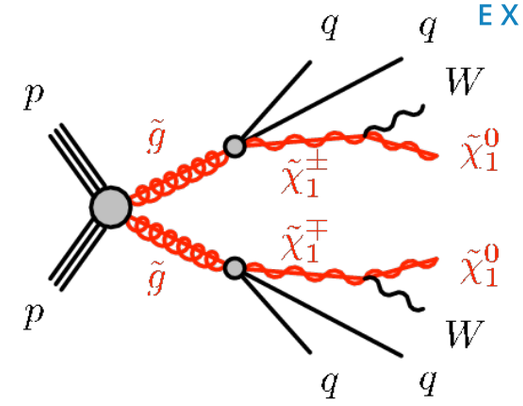
- Signal regions
  - 0, ≥1 leptons
  - ≥3 or 4 b-jets
- Tagging of boosted tops to improve sensitivity
- Backgrounds
  - Top from MET control regions
  - Other (small) backgrounds from MC

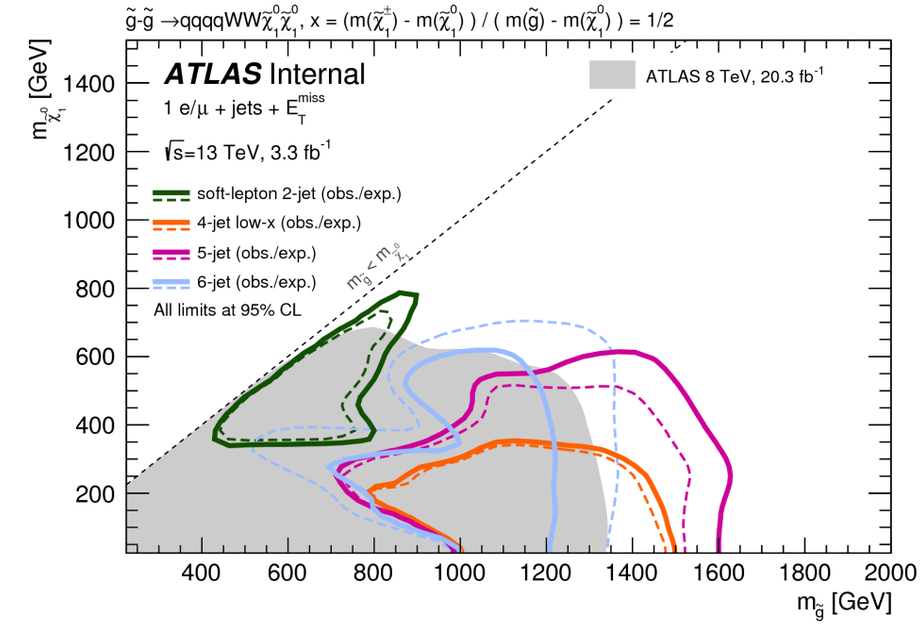


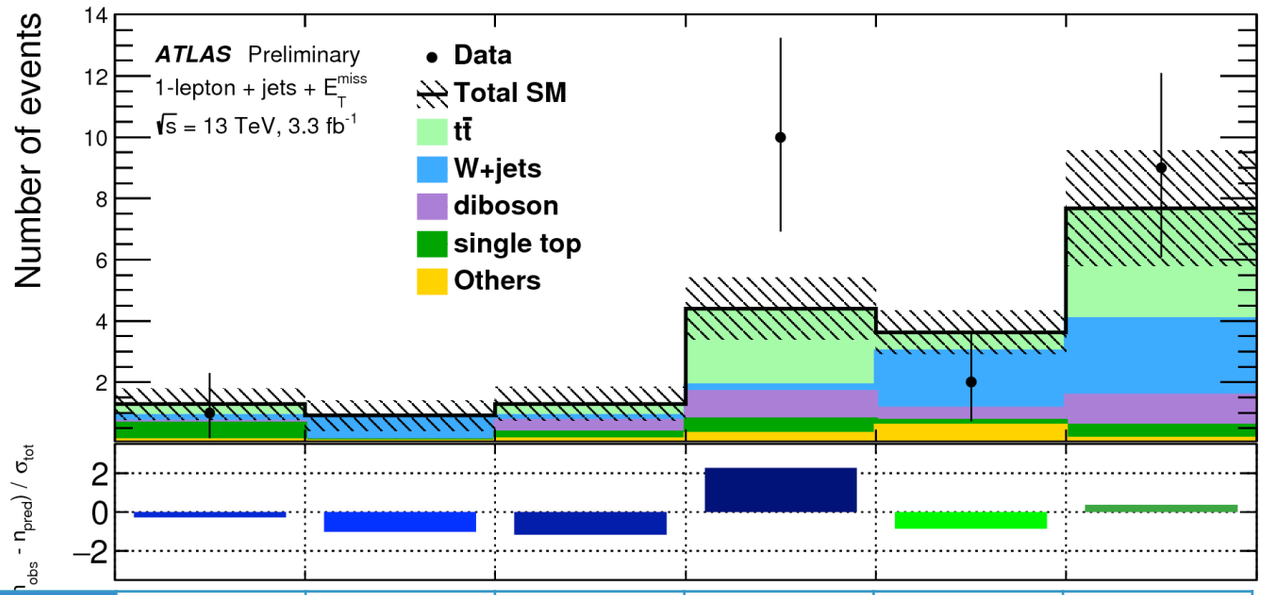
ATLAS-CONF-2015-076

1-lepton, jets+MET

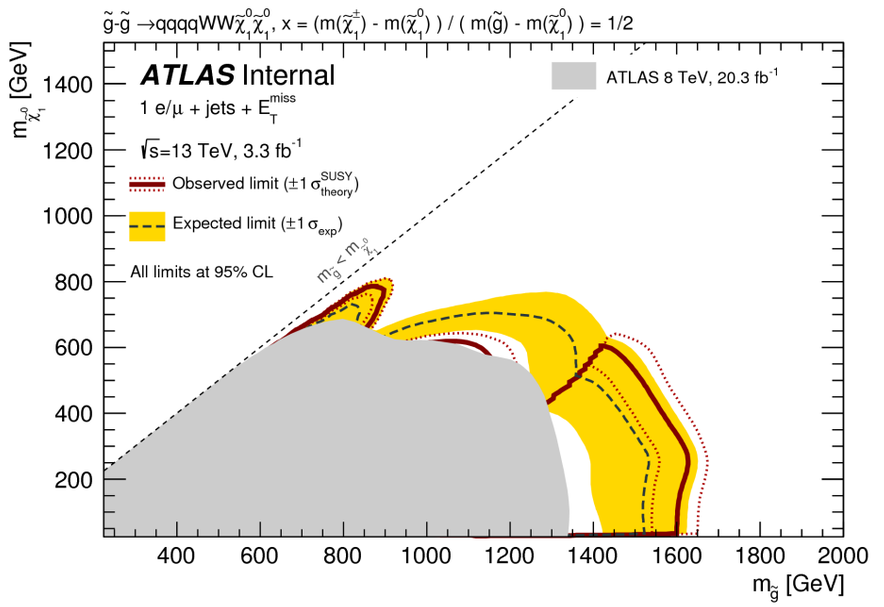
- Targets cascade decays of gluinos that include W bosons
- Regions with different kinematic cuts targeting compressed spectra or different chargino-neutralino mass splittings
- Top (W) predicted using 1-b (0-b) control regions in M_T and either $E_{T,miss}$, $E_{T,miss}/m_{eff}$ or aplanarity







N_{jet}	≥ 4	≥ 4	≥ 5	≥ 6	≥ 2	≥ 5
	large mass splitting	small mass splitting			soft lepton	



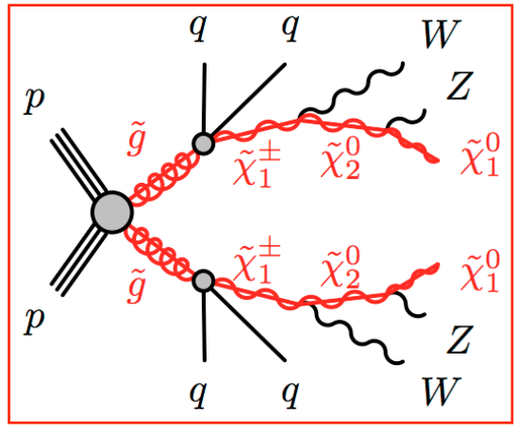
Dilepton and trilepton final states

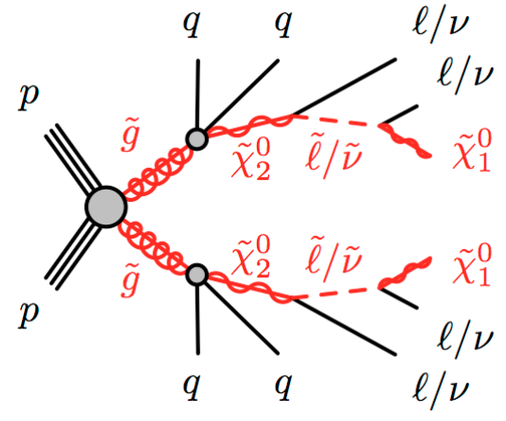
ATLAS-CONF-2015-078

Trileptons and same-sign dileptons

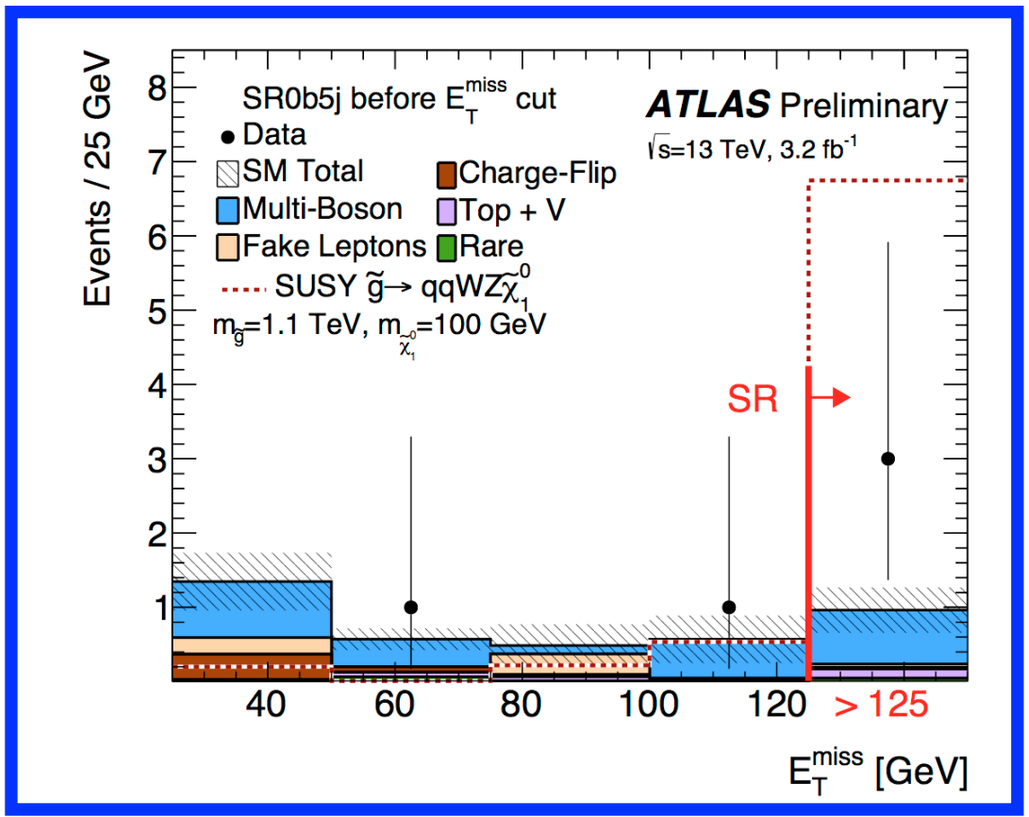
Sensitive to longer decay chains

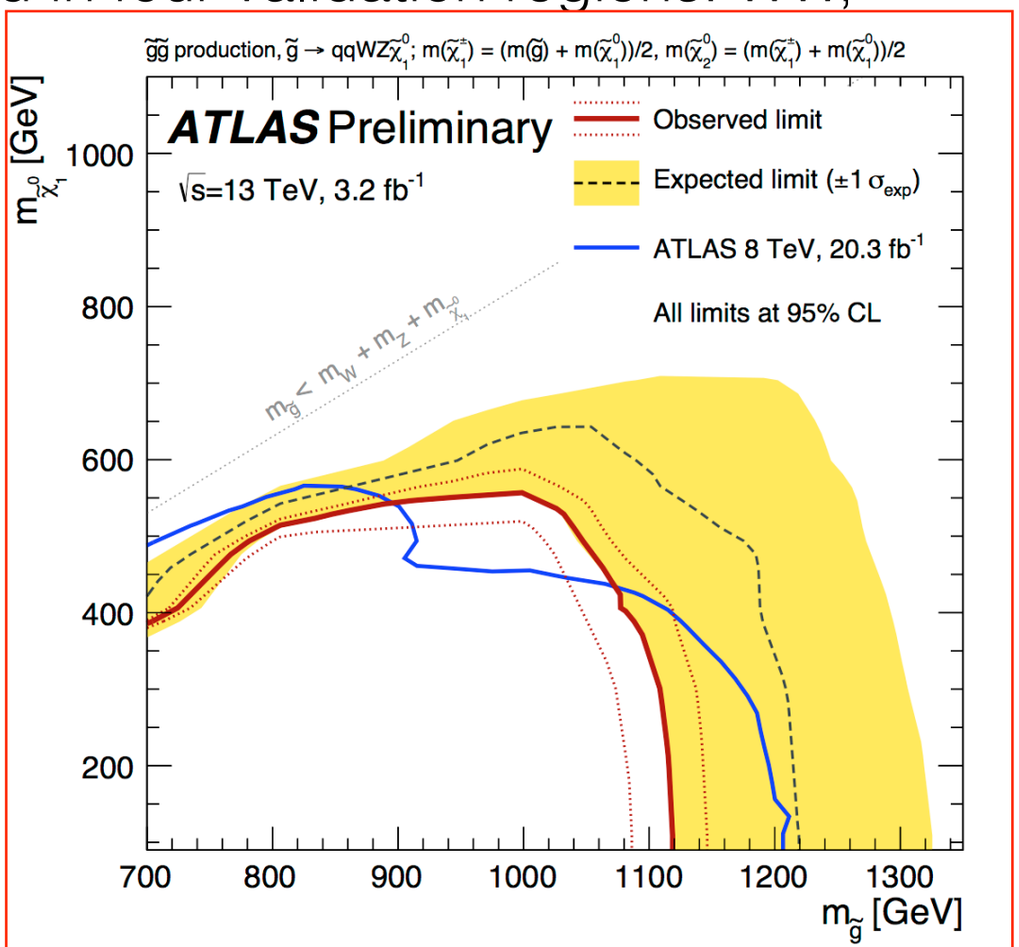
Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b\text{jets}}^{20}$	N_{jets}^{50}	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]
SR0b3j	≥3	=0	≥3	>200	>550
SR0b5j	≥2	=0	≥5	>125	>650
SR1b	≥2	≥1	≥4	>150	>550
SR3b	≥2	≥3	-	>125	>650





- Background estimation:
  - Fake leptons from loosened ID/isolation CR
  - Charge flip (only important for electrons) evaluated from $Z/\gamma^* \rightarrow e^+e^-$ sample
  - Other background from MC, cross-checked in four validation regions: WW, WZ, ttV, ttZ

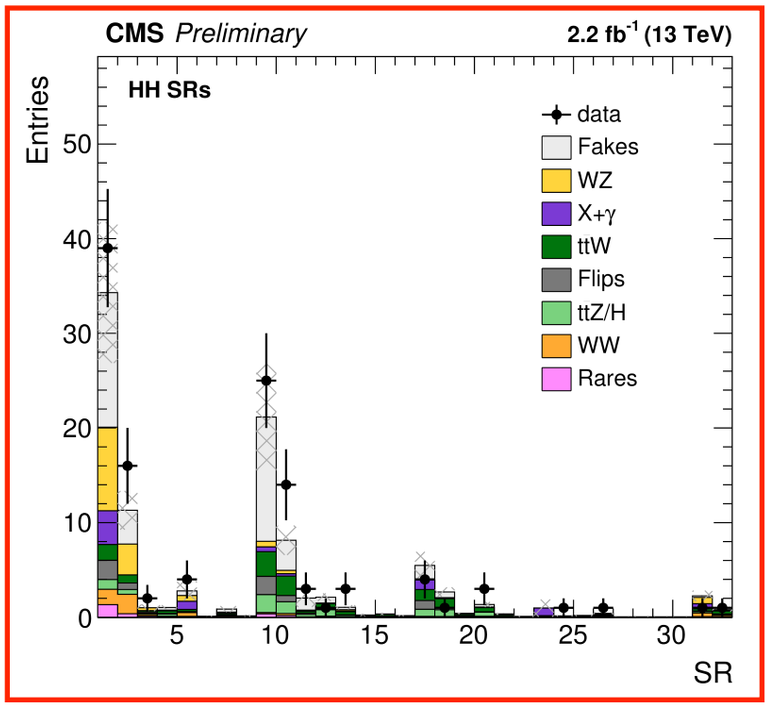


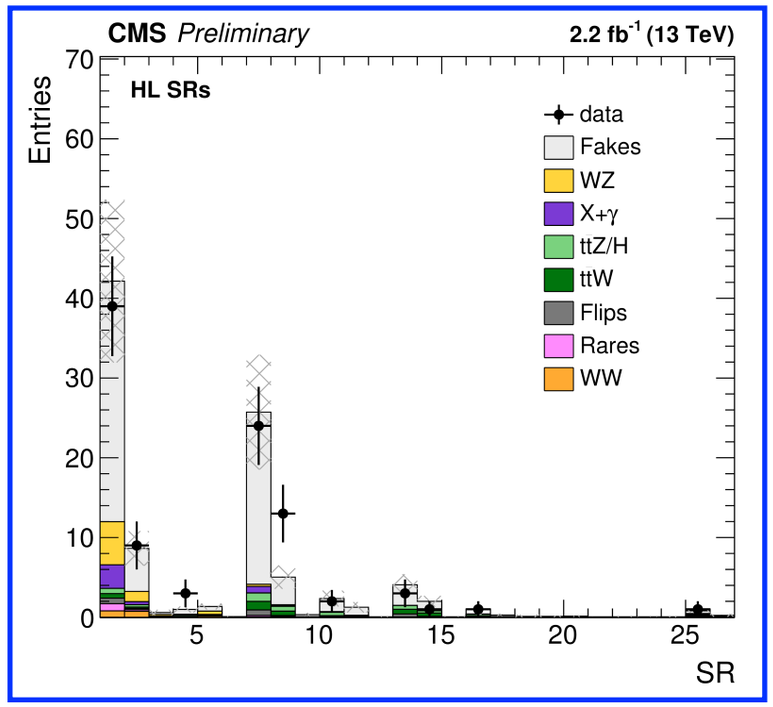


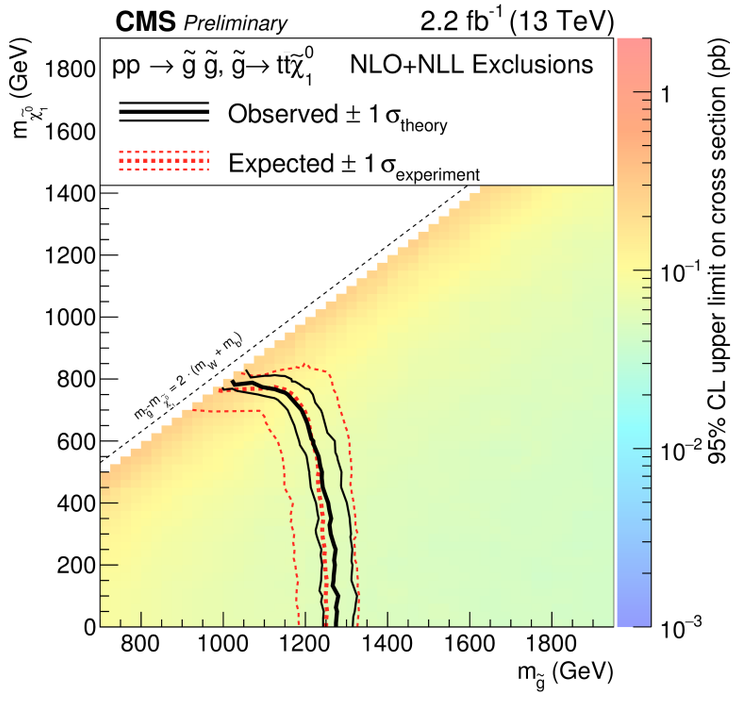
CMS-PAS-SUS-15-008

Same-sign dileptons

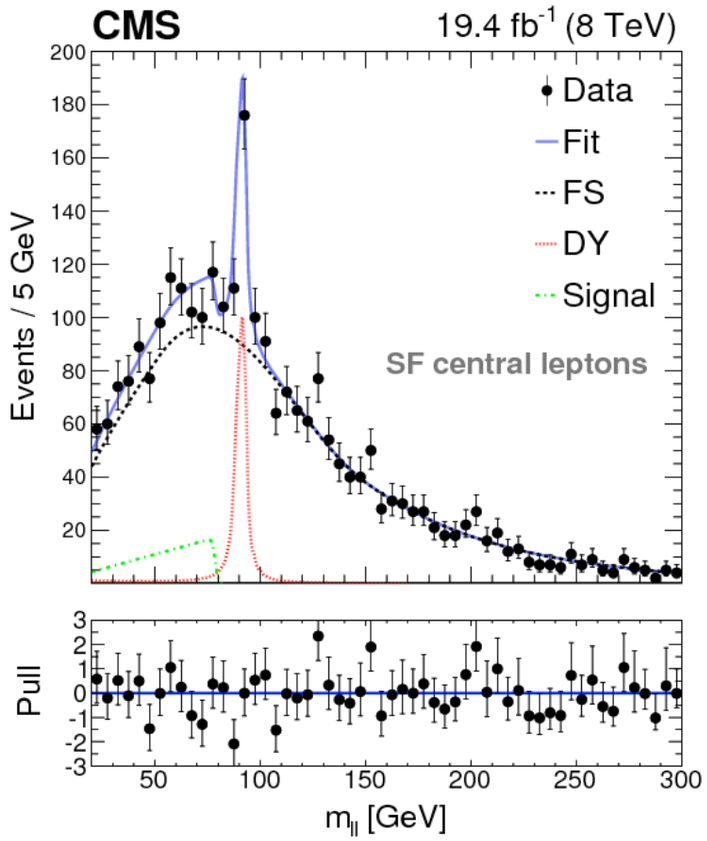
- Three exclusive lepton selections
  - high-high: Two leptons with p_T>25 GeV
  - high-low: One lepton with p_T>25 GeV and one with 10<p_T<25 GeV
  - low-low: Two leptons with 10<p_T<25 GeV
- Binned in $M_{T,min}$, $E_{T,miss}$, H_T and N_{jets}
- Background estimation:
  - Non-prompt (“fake”) leptons: scaling from CR with loosened ID and isolation requirements
  - WZ: normalized using CR with N_{jet}=2, N_b=0, N_{lep}=3, $E_{T,miss}$>30 GeV and a Z candidate







Reminder: opposite-sign, same-flavor anomalies at 8 TeV



2.6σ excess below Z, enriched in b-jets (seen only by CMS)

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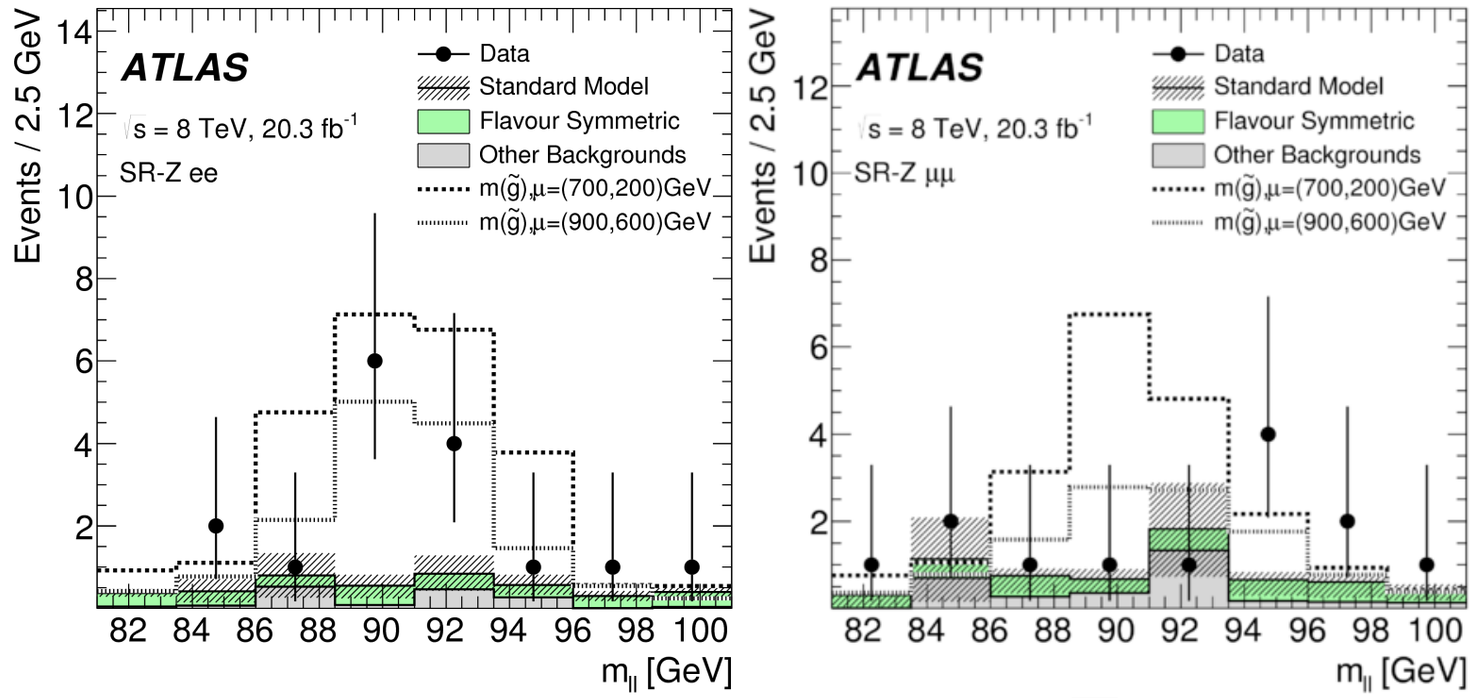

3.0σ excess on Z (seen only by ATLAS)

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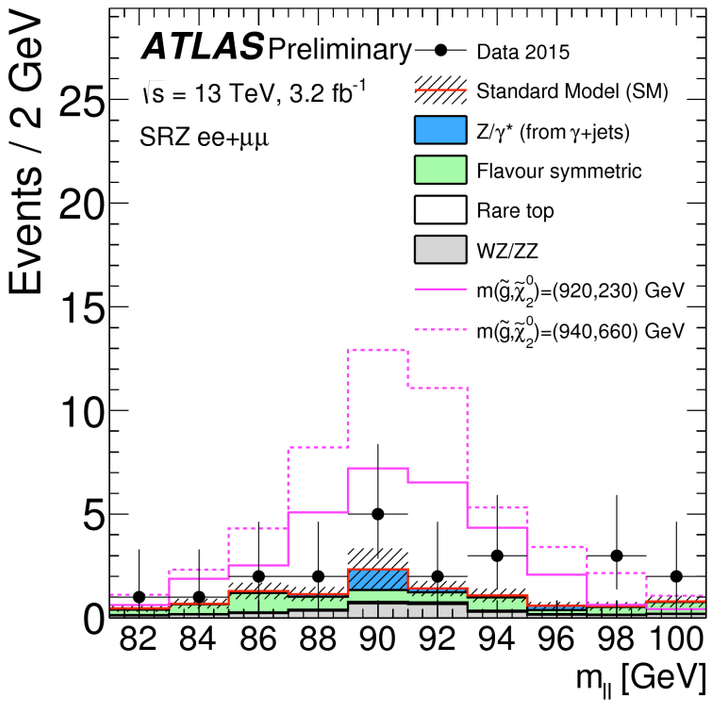
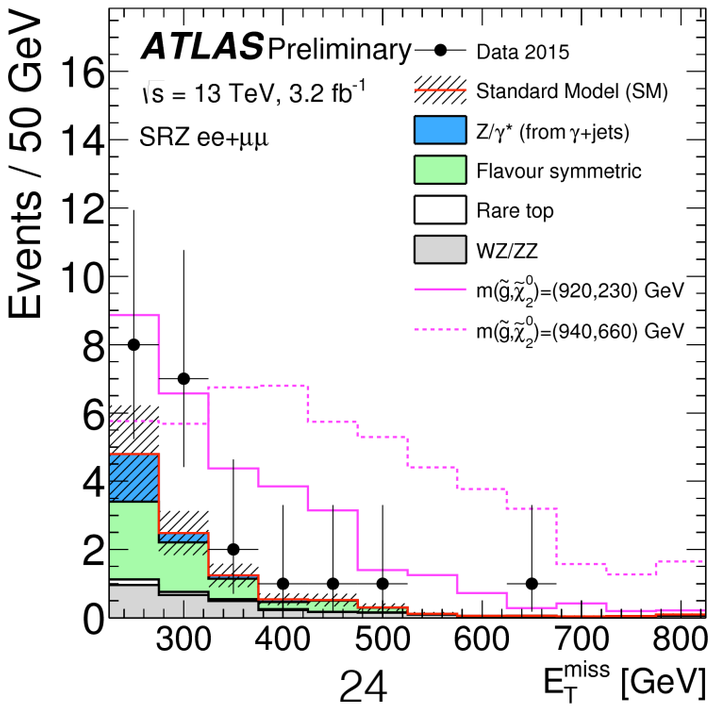
ATLAS-CONF-2015-082

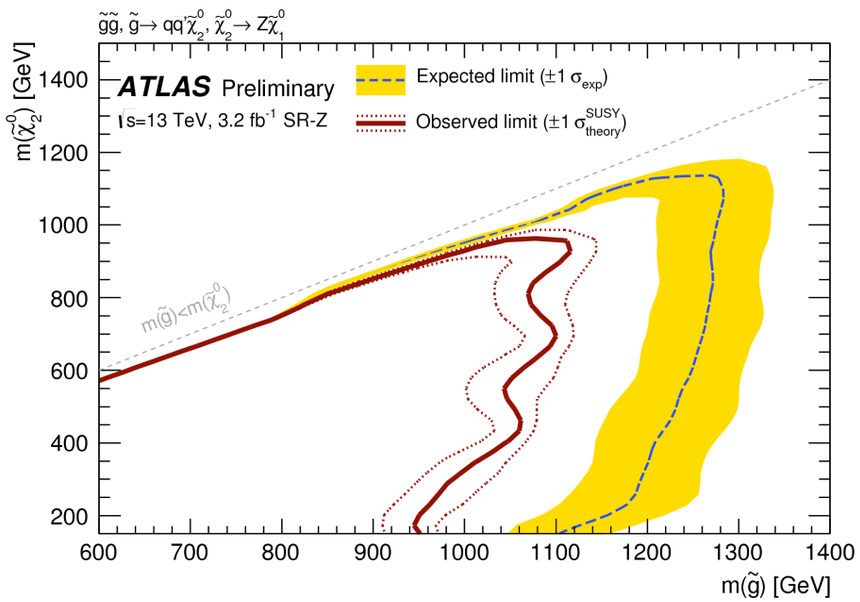
Z(→dileptons)+jets+MET

- Background estimation:
  - Z+jets from γ+jets, corrected for differences in boson p_T
  - In tt, tW or WW decays, $N_{ee}=N_{e\mu}=N_{\mu e}=N_{\mu\mu}$

    ⇒Predict same flavor bkg. from different flavor CR, corrected for trigger, ID and reconstruction efficiencies—correction factors within 10% of unity except near $|\eta|=0$
  - Diboson background from MC, cross-checked in validation regions
- 21 events observed (10 ee, 11 μμ) with predicted background of 10.3 ± 2.3 (2.2σ) in on-Z region





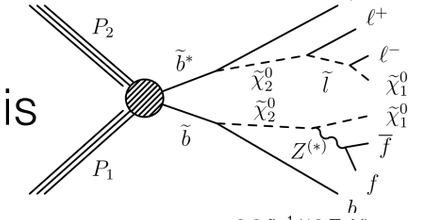


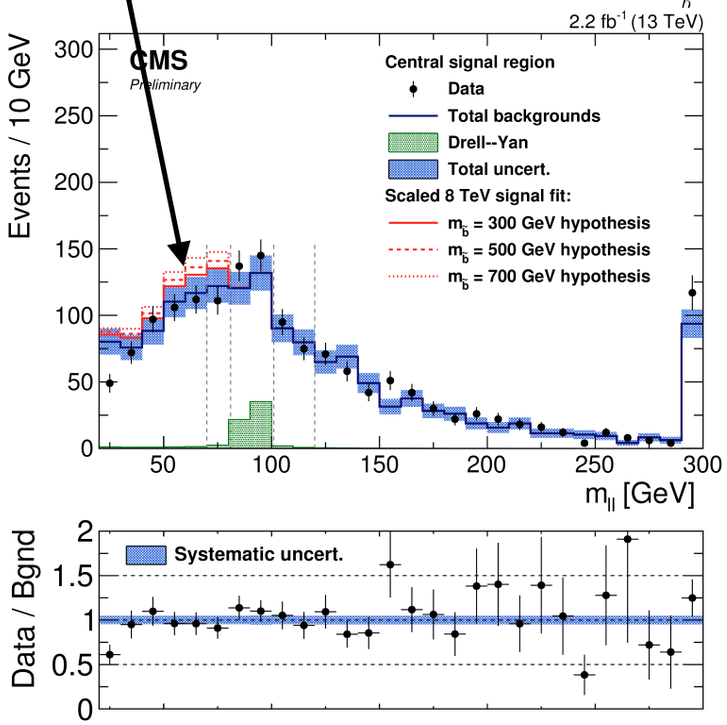
CMS-PAS-SUS-15-011

Edge in dilepton mass spectrum

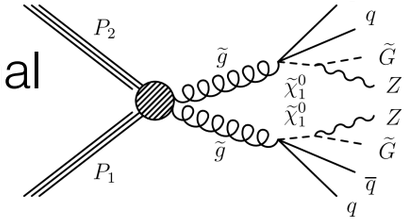
- Binning in b-tags added (new!)
- Background estimation:
  - Z+jets from ɣ+jets (MET templates)
  - Flavor symmetric (FS) background predicted with two independent methods from different flavor CR
- Both 8 TeV excesses are disfavored
  - Expect 61 (86, 117) events in below-Z signal region for $m_{sbottom}$= 300 (500, 700) compared to upper limit of 57 events
  - Expect 12 (19, 32) events in ATLAS signal region for m_{gluino}=500 (800, 1100) compared to upper limit of 9 events

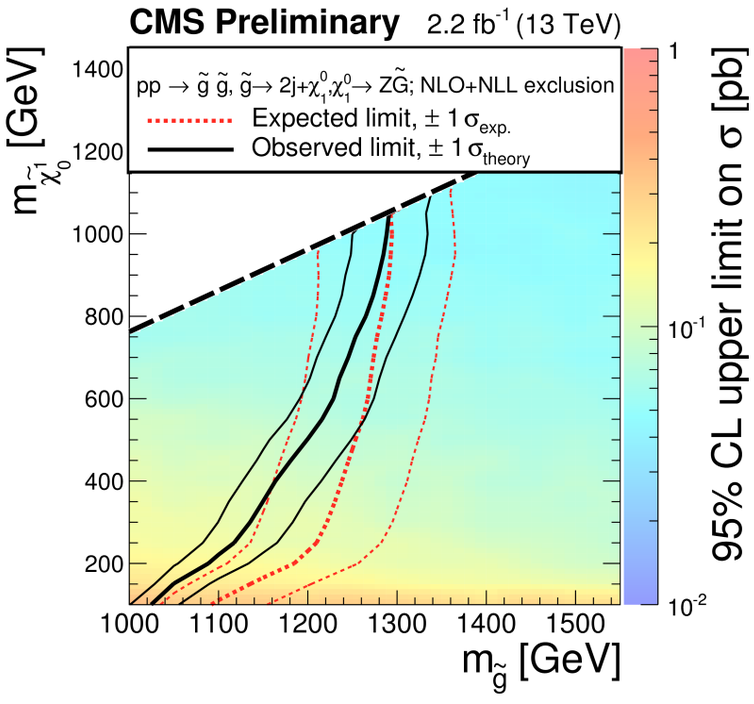
Scaled 8 TeV signal hypothesis



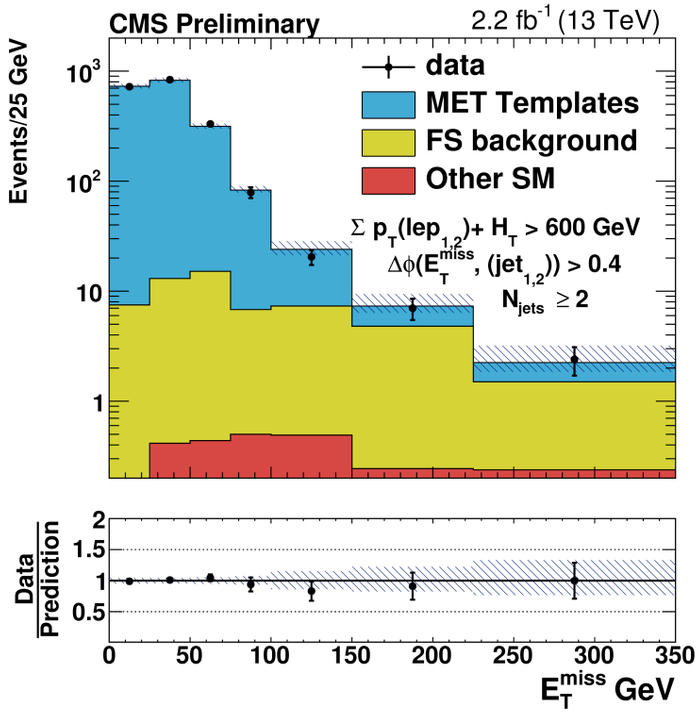


≈ATLAS signal model





No excess seen with ATLAS selection



Bottom squark pair production

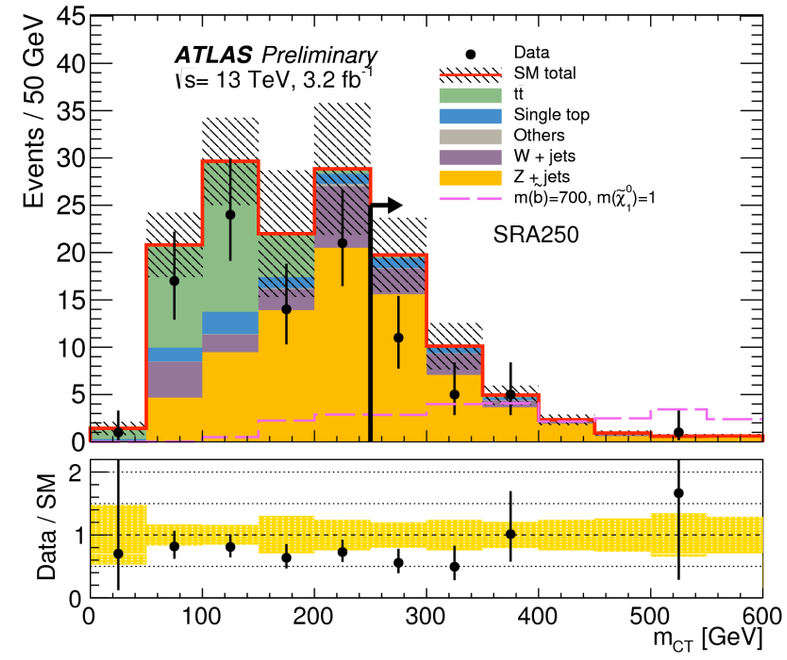
ATLAS-CONF-2015-066

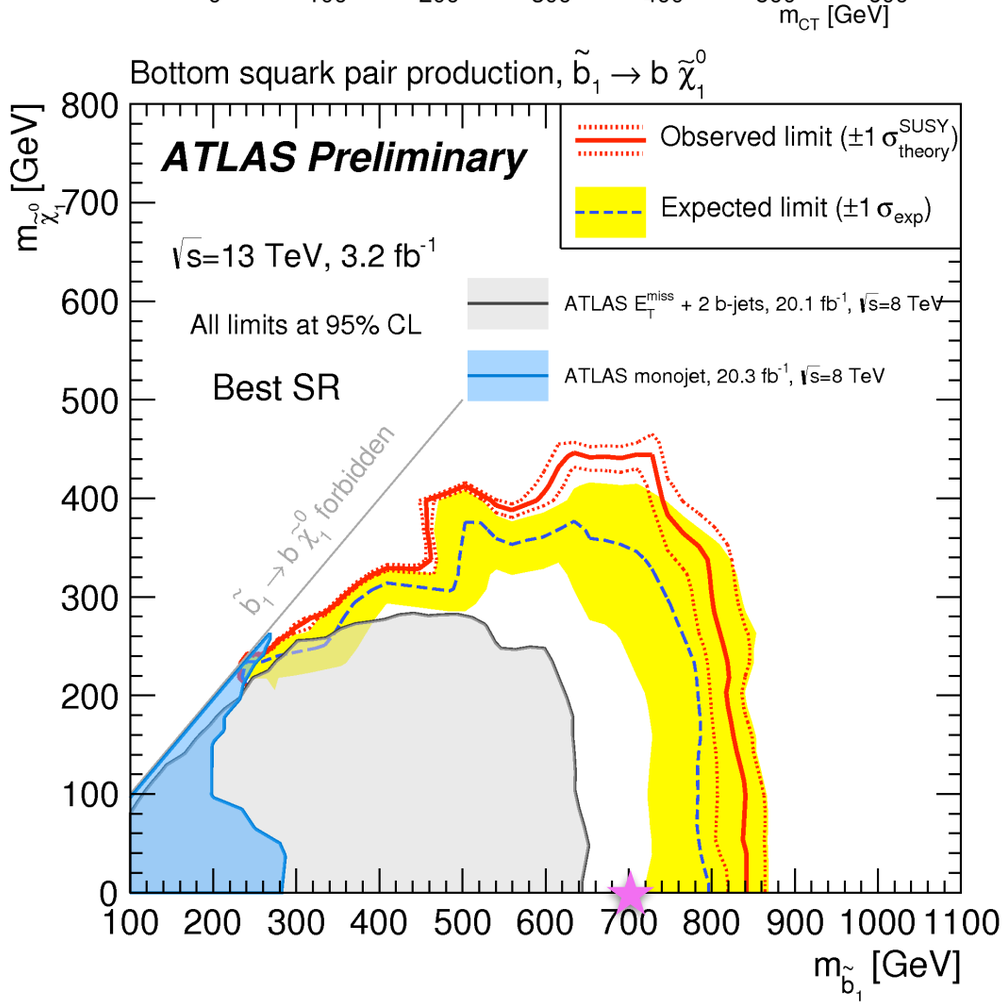
Bottom squark pair production

- Search using variable sensitive to masses of pair-produced, semi-invisibly decaying particles

$$m_{\mathrm{CT}}^2(v_1, v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\boldsymbol{p}_{\mathrm{T}}(v_1) - \boldsymbol{p}_{\mathrm{T}}(v_2)]^2$$

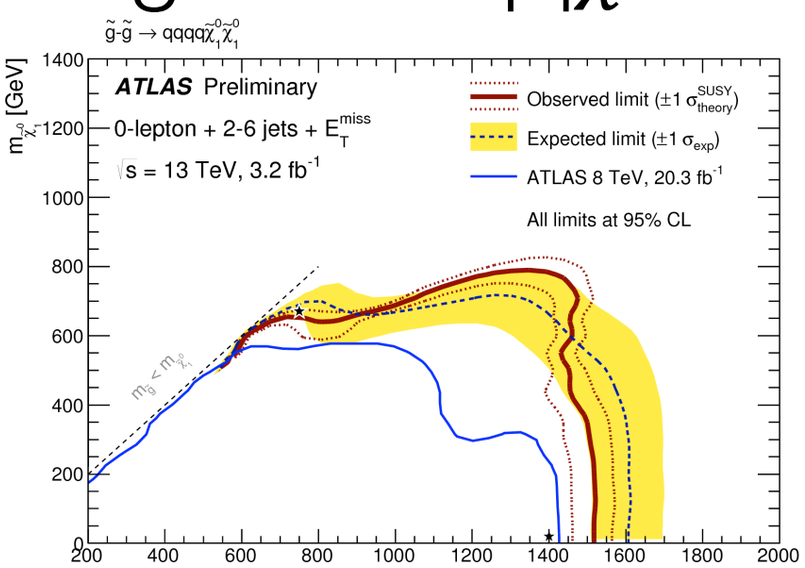
- Signal regions require two b-jets and
  - For small neutralino masses: MET>250 and M_{CT}>250, 350, 450
  - For compressed scenarios: p_{T1}> 300 (ISR selection), MET>400
- Background estimation:
  - W, Z and top estimated from control regions with 1 or 2 leptons



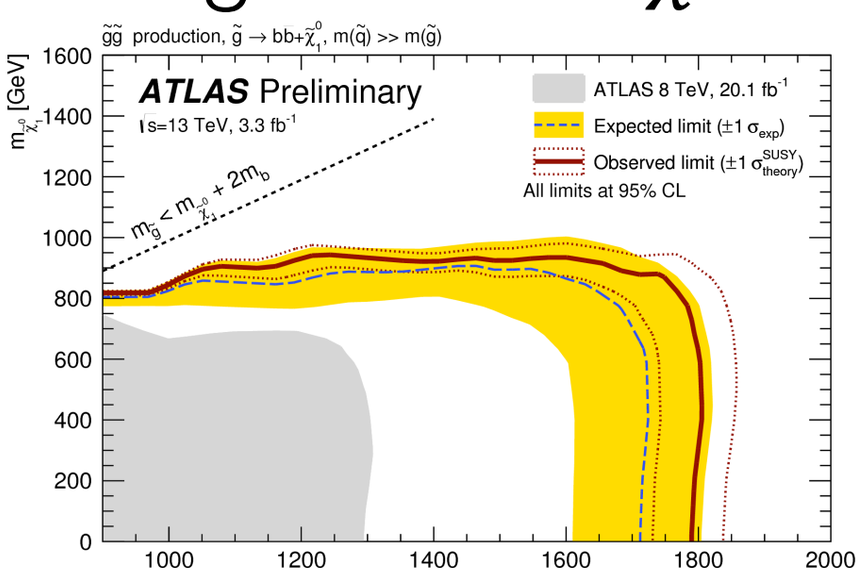


Summary of limits in simplified model framework

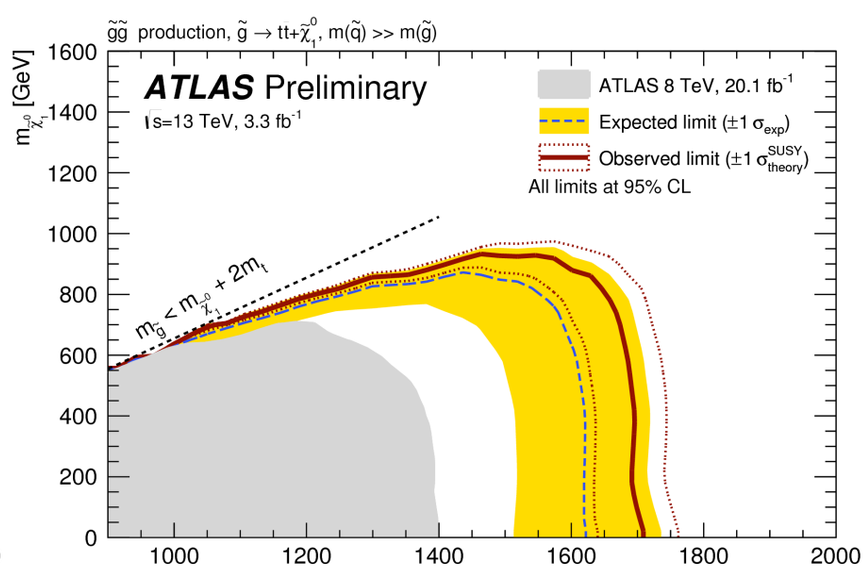
gluino→qqχ^0

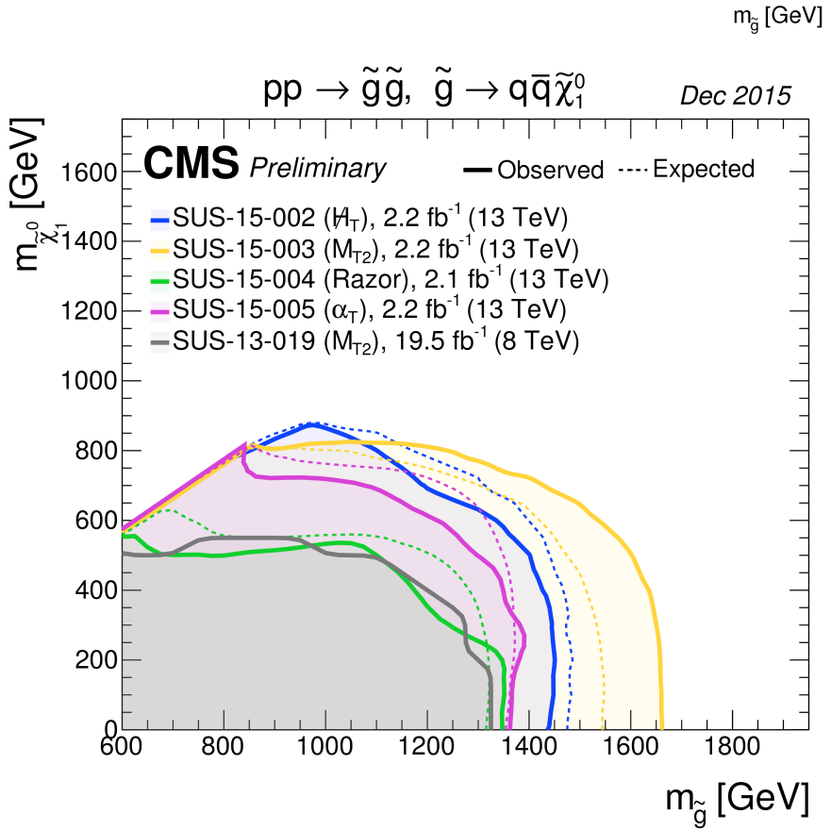


gluino→bbχ^0

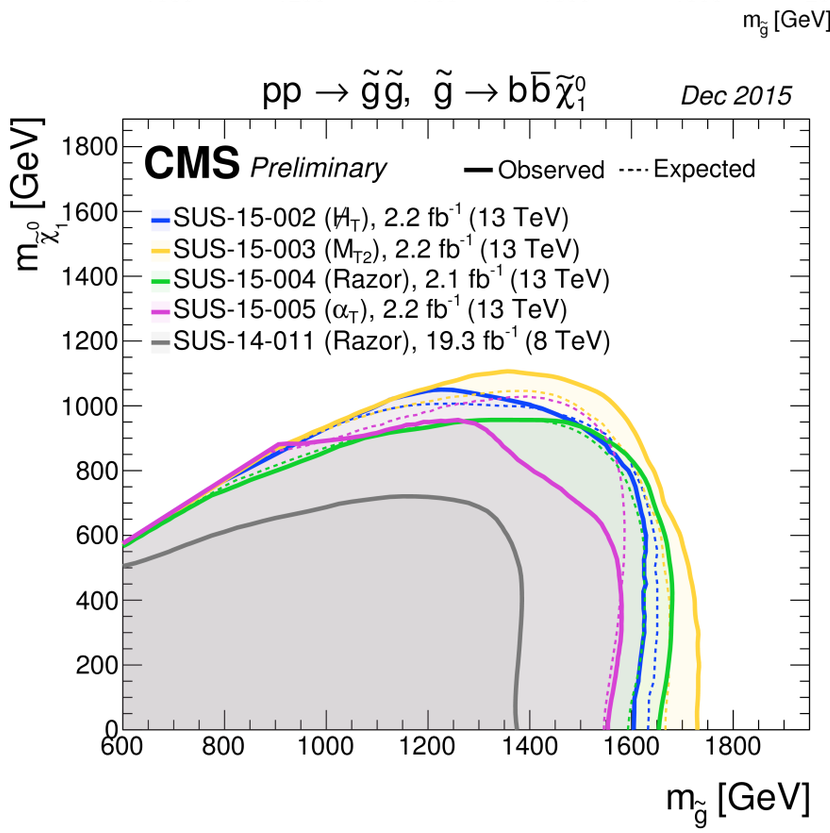


gluino→ttχ^0

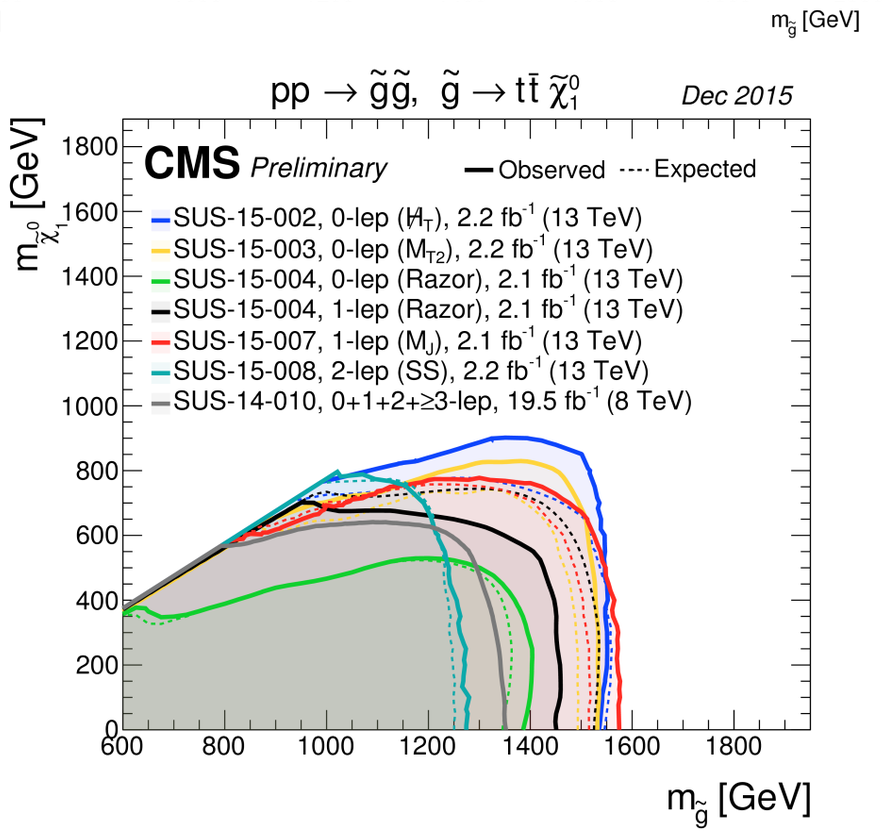




m_{gluino} >1655 GeV



m_{gluino} >1780 GeV



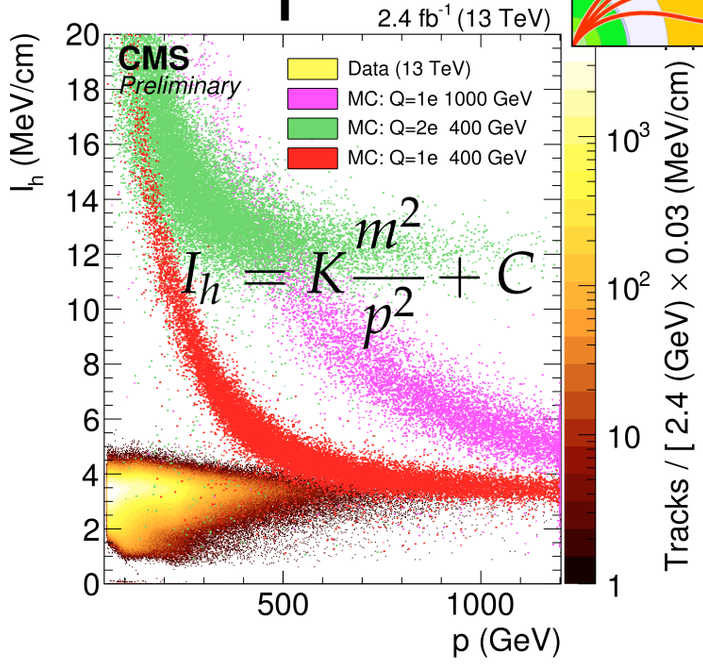
m_{gluino} >1675 GeV

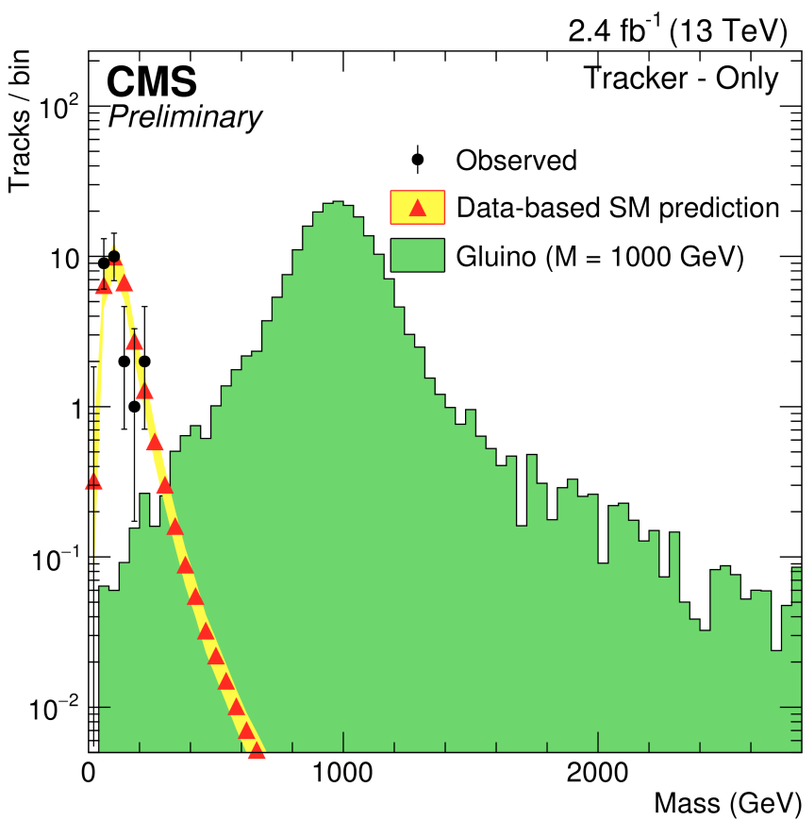
Long-lived sparticles

CMS-PAS-EXO-15-010

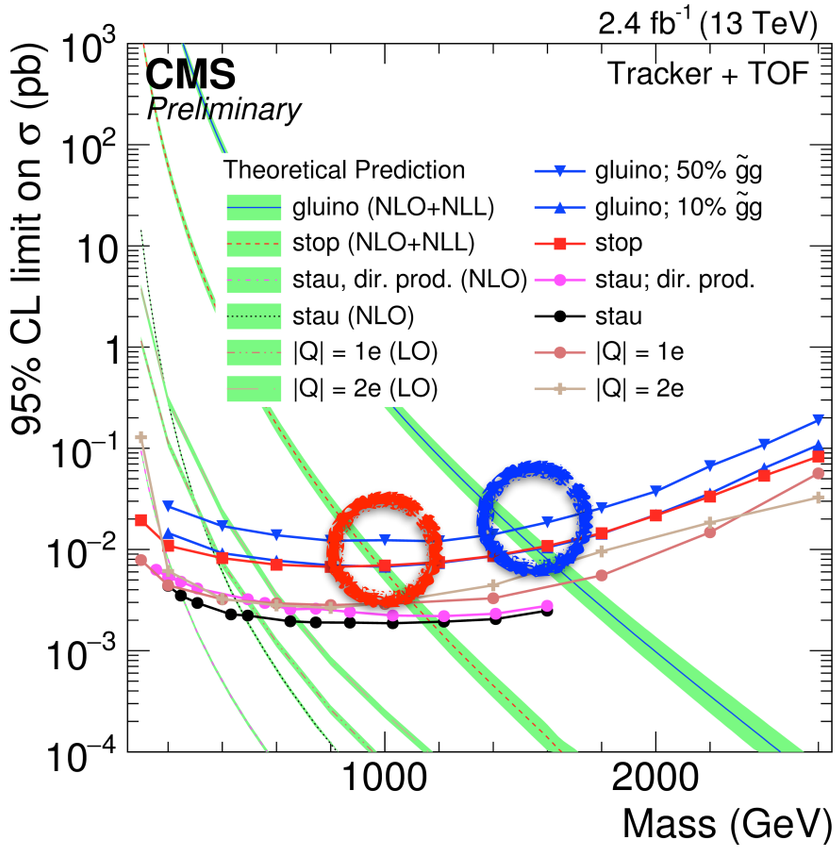
Long-lived gluinos and stops

- Gluino can be long lived in RPV or split-SUSY models
- Candidate mass calculated from dE/dx estimator or time of flight
- Two searches, background estimated with ABCD method:
  - tracker only (dE/dx)
  - tracker+muon system (dE/dx + TOF)





m_{gluino}=1000 GeV



m_{gluino}>1590 GeV

m_{stop}>1020 GeV

Summary

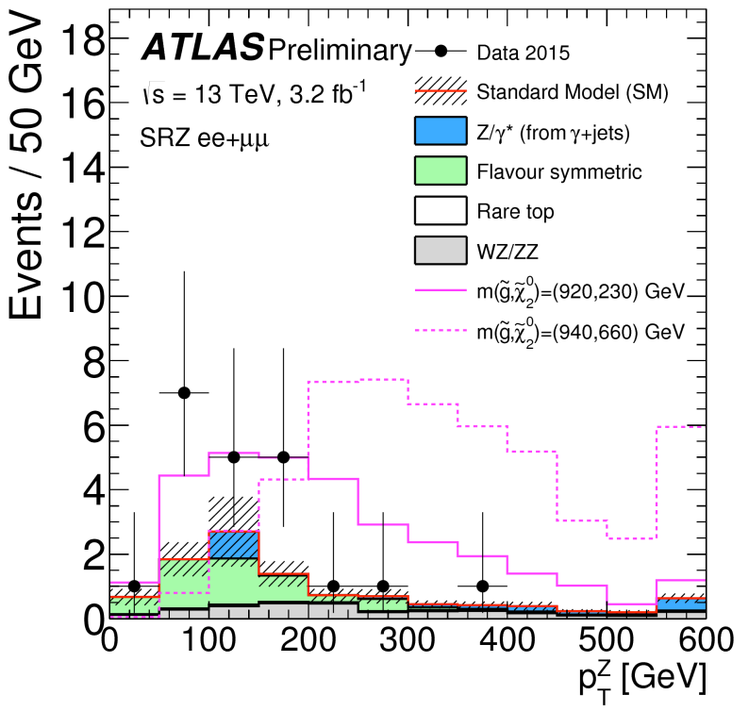
- ATLAS and CMS still producing new results from 8 TeV data
- 15 new results from 13 TeV data significantly increase mass reach. For benchmark case of light neutralinos:

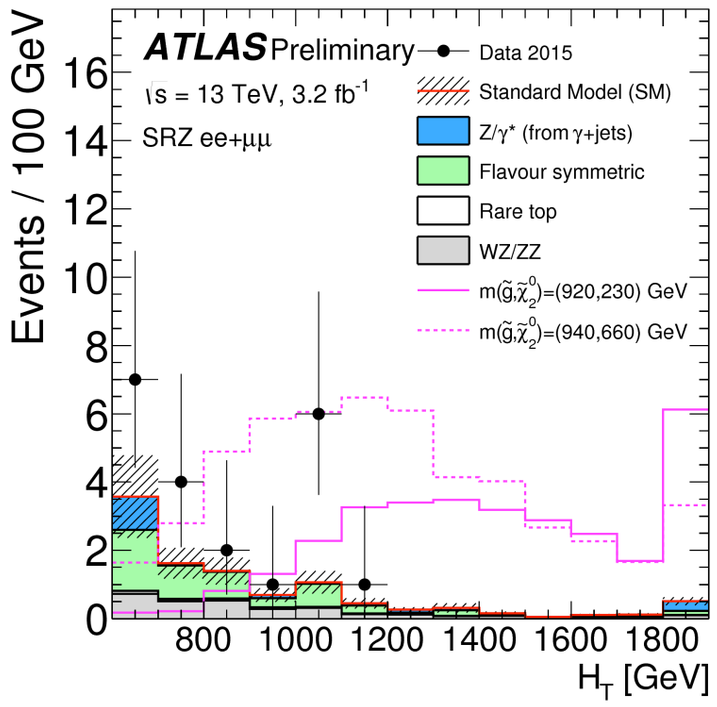
Final state	ATLAS limit	CMS limit
gluino→ttχ^0	1675 GeV	1600 GeV
gluino→bbχ^0	1780 GeV	1725 GeV
gluino→qqχ^0	1520 GeV	1655 GeV
Long-lived gluino	—	1600 GeV
Bottom squark	840 GeV	—

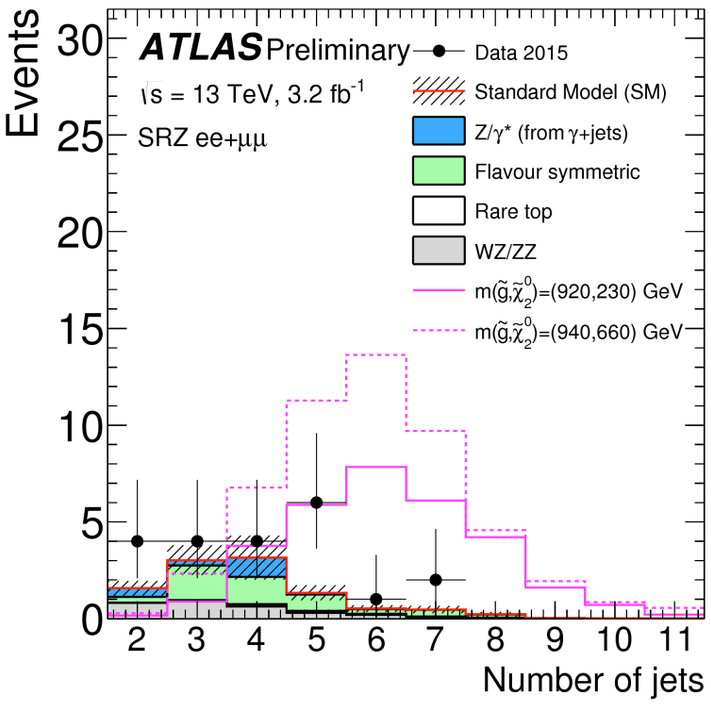
- No significant signals observed but more results still to come!

ATLAS SUSY results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
CMS SUSY results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Kinematic distributions for ATLAS on-Z search (13 TeV)

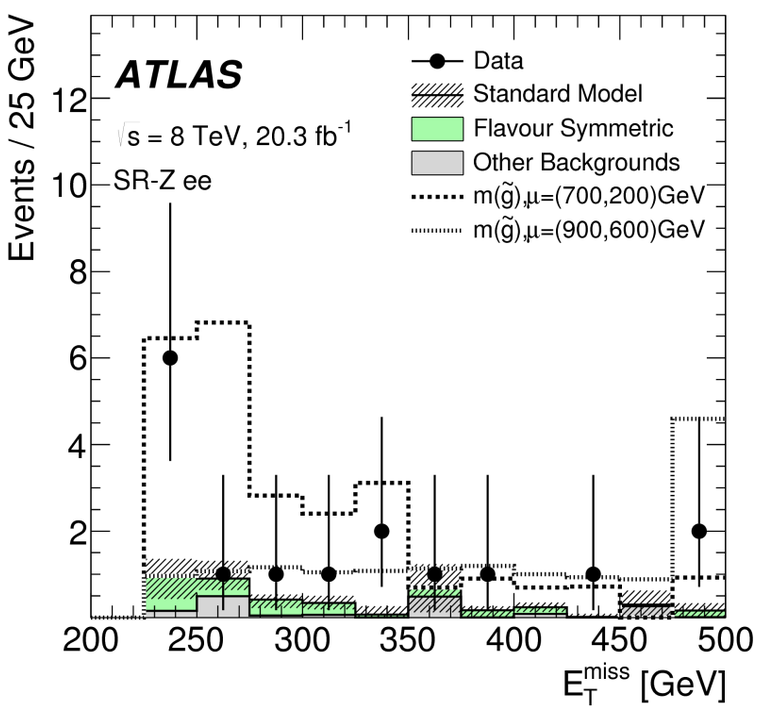


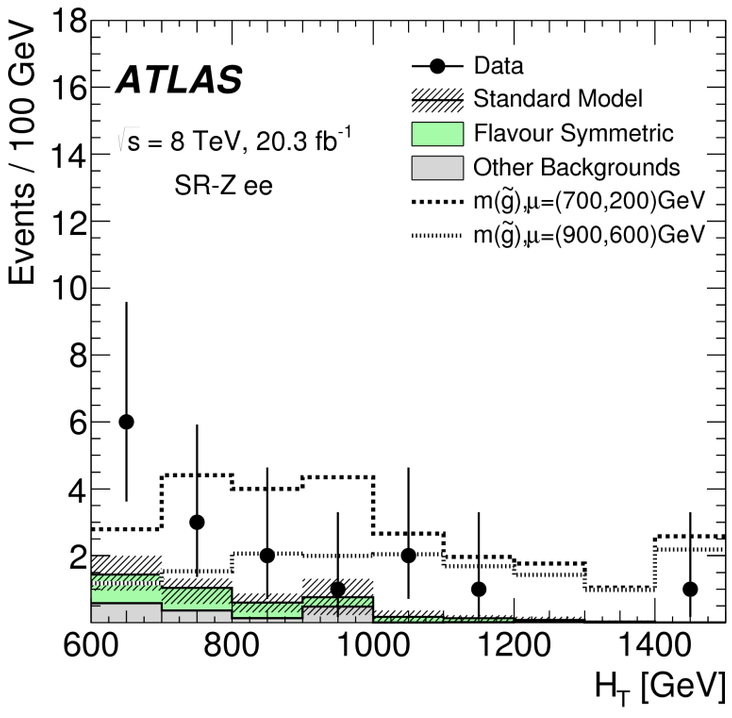


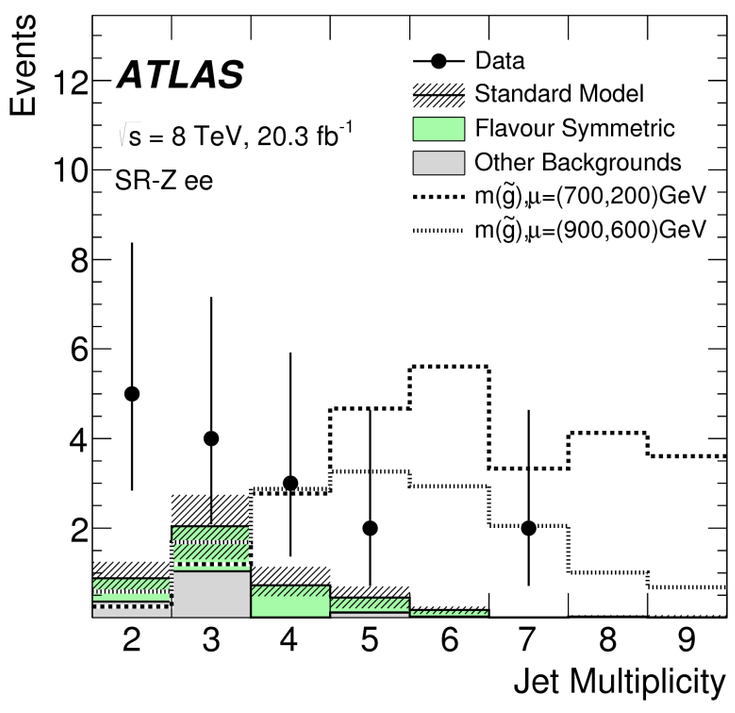


Backgrounds from MC, normalized to estimates from SR

Kinematic distributions for ATLAS on-Z search (8 TeV, ee)







Kinematic distributions for ATLAS on-Z search (8 TeV, μμ)