Supersymmetry Searches with ATLAS and CMS

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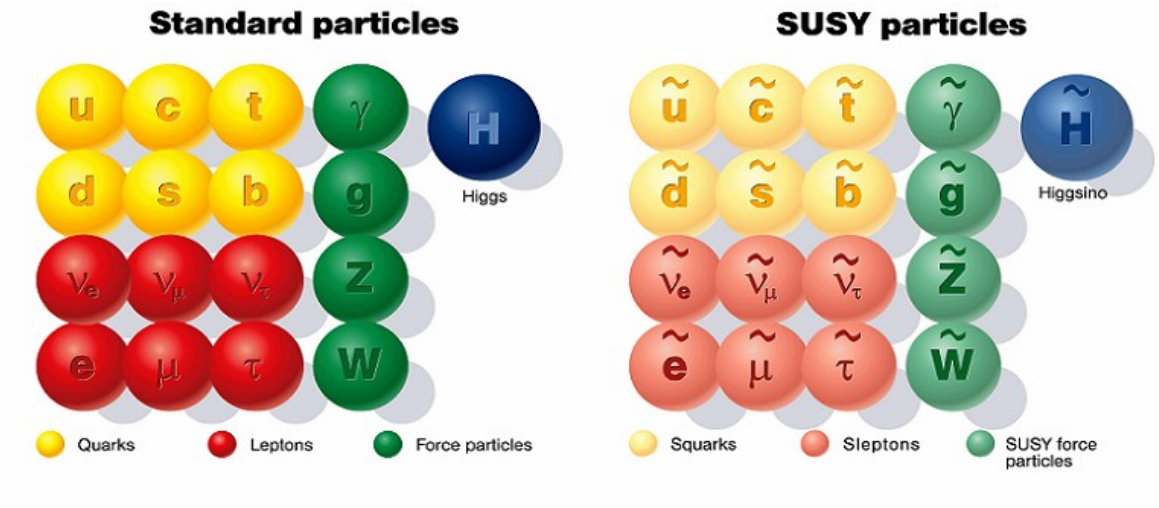
on behalf of the
ATLAS and CMS collaborations

Supersymmetry

- supersymmetry (SUSY) links fermions and bosons
  - → SUSY necessarily broken → gravity mediation, GMSB, AMSB
  - → requires a whole spectrum of new particles

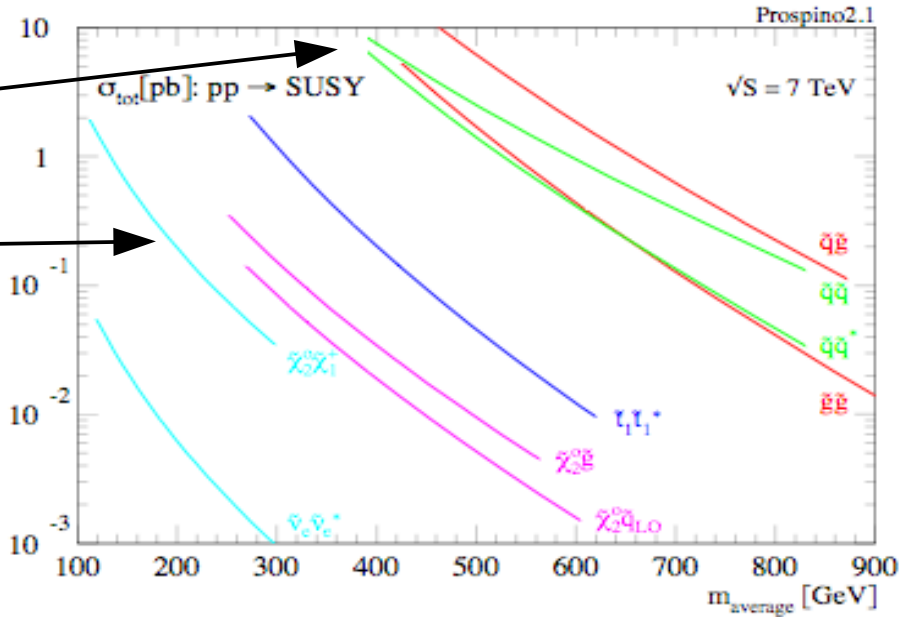


- elegant solution to the hierarchy problem
- unification of the gauge couplings

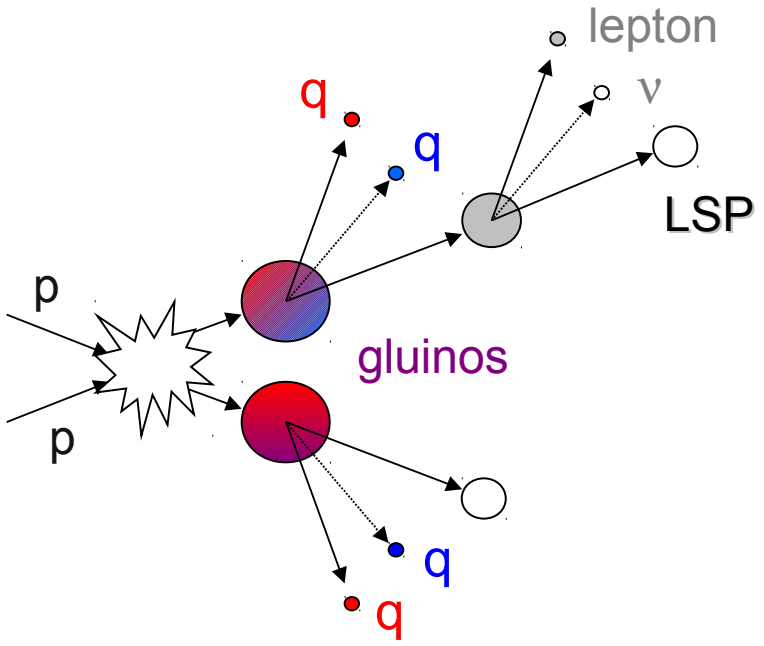
- R parity to avoid proton decay
  - → lightest supersymmetric particle (LSP) is stable
  - → SUSY can provide an excellent dark-matter candidate

Searching for SUSY at the LHC

- SUSY production
  - highest SUSY cross sections from gluino and squark production
  - also electroweak chargino/neutralino production becomes accessible



- complex decay phenomenology
  - diversity in decays determined by SUSY spectrum
- searches designed around expected signatures
  - missing transverse energy (MET) *
  - hadronic activity (HT)
  - leptons with different multiplicities
  - photons
  - heavy flavour
- multiple search regions

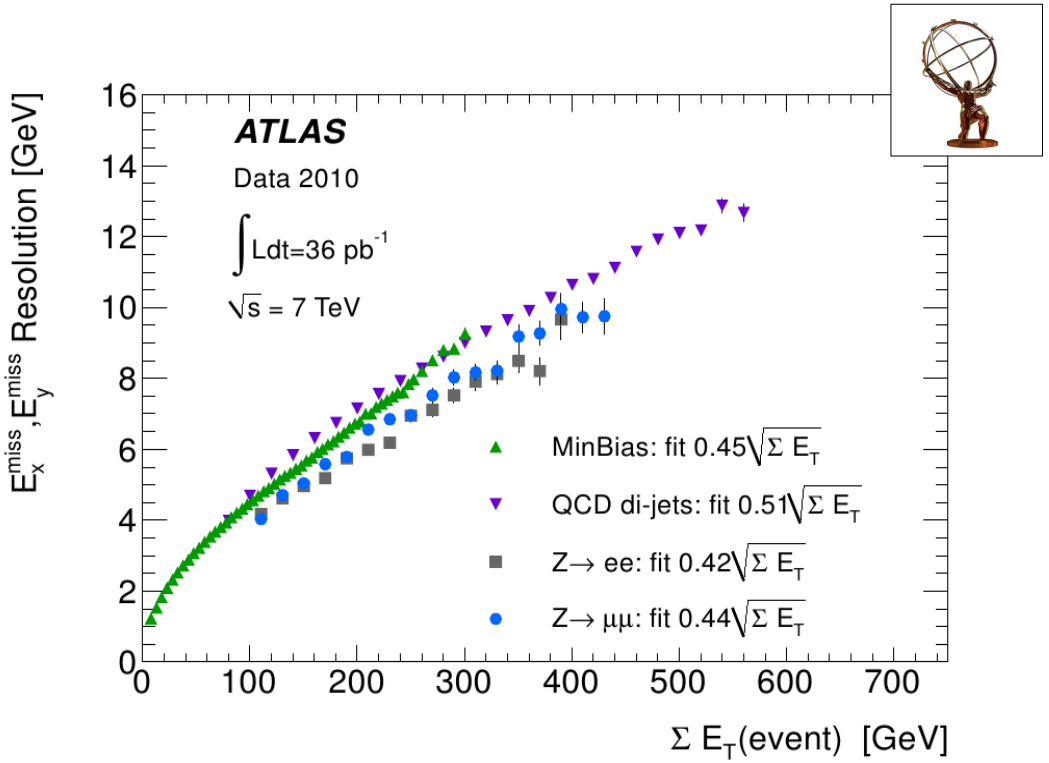


* non-MET based SUSY searches presented by David Adams and Morten Dam Jørgensen

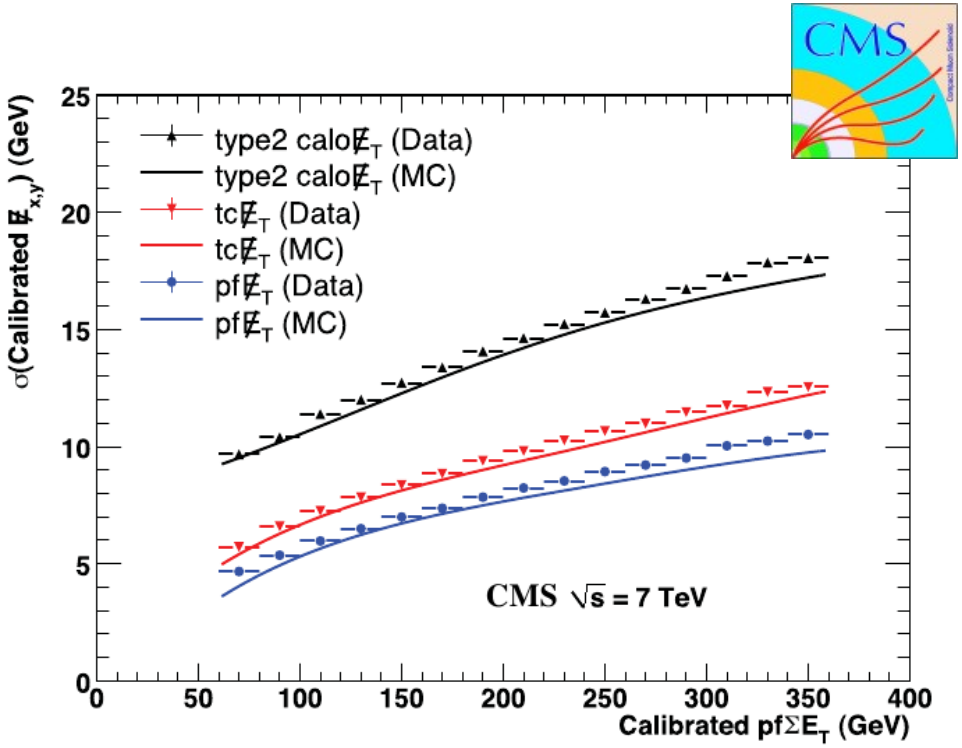
ATLAS and CMS

Key quantity: missing transverse energy

- most SUSY searches in CMS use particle-flow reconstruction
- MET performance in ATLAS and CMS (PF) comparable



Eur. Phys. J. C72 (2012) 1844



J. Instrum.6 (2011) P09001

Searches Presented

- photon search
  - CMS, 4.7 fb^{-1} [SUS-12-001]
  - ATLAS, 1.07 fb^{-1} [arXiv:1111.4116, accepted by PLB]
- search for disappearing tracks
  - ATLAS, 1.02 fb^{-1} [arXiv:1202.4847, submitted to EPJC]
- hadronic search
  - CMS, 4.4 fb^{-1} [SUS-12-005]
  - ATLAS, 1.34 fb^{-1} [arXiv:1110.2299, JHEP 11 (2011) 99]
- search with same-sign dileptons
  - CMS, 4.7 fb^{-1} [SUS-11-010-5fb]
  - ATLAS, 2.05 fb^{-1} [ATLAS-CONF-2012-004]
- multi-lepton search
  - CMS, 4.7 fb^{-1} [SUS-11-013 and EXO-11-045]
  - ATLAS, 2.06 fb^{-1} [ATLAS-CONF-2012-023]
- search for same-sign dileptons with b-jets
  - CMS, 4.7 fb^{-1} [SUS-11-020]

- all these searches and other recent results linked from
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Photon Search

CMS-SUS-12-001

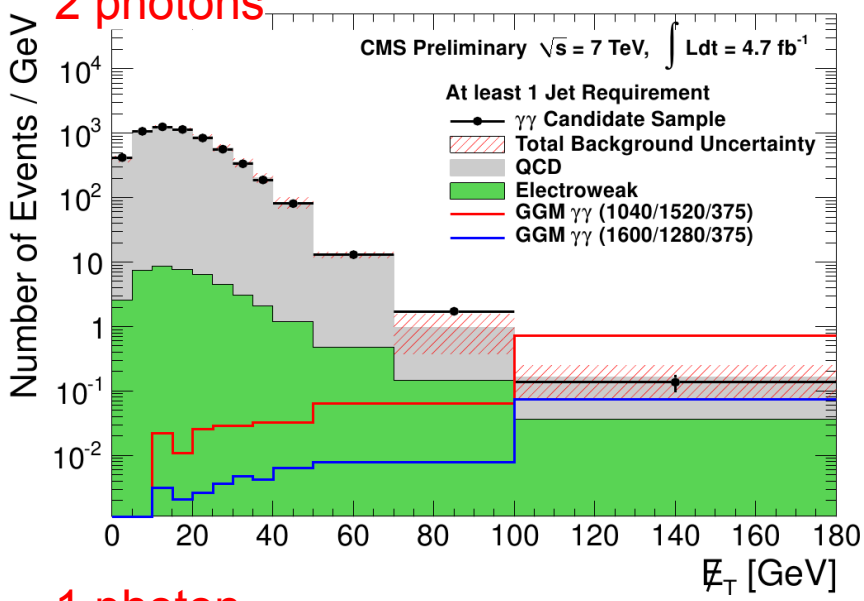
- two selections:
- 1 photon + 2 jet + MET > 100 GeV
- 2 photons + 1 jet + MET > 50 GeV

- QCD background:
  real photons or jets faking photons
  - ➔ MET distribution from control sample
  - ➔ single photon: reweigh with "photon" p_T
  - ➔ di-photon: normalized to γγ at low MET

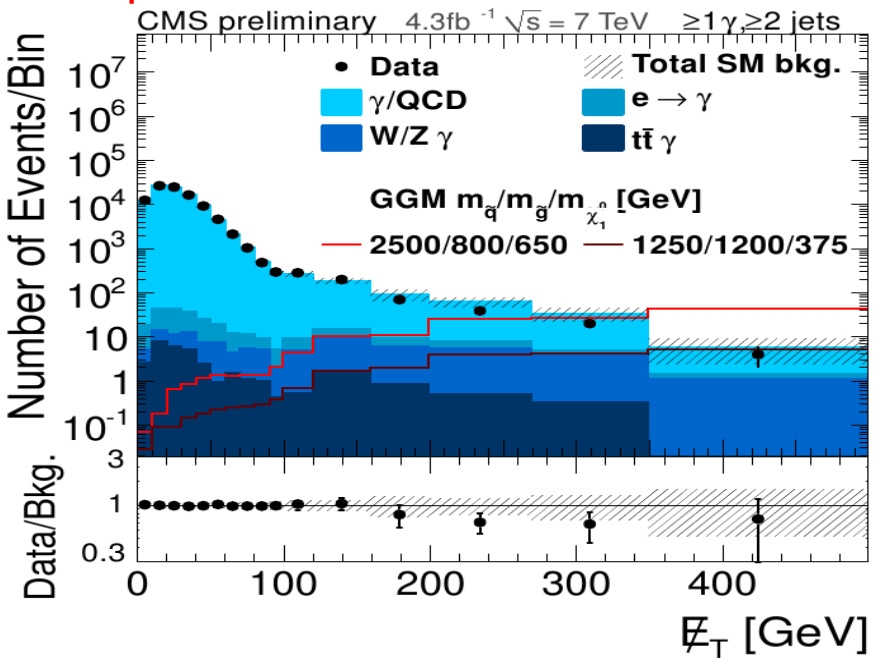
- electroweak background:
  electrons faking photons
  - ➔ from W decay: real MET
  - ➔ using measured e → γ fake rate

- other small backgrounds from simulation

2 photons



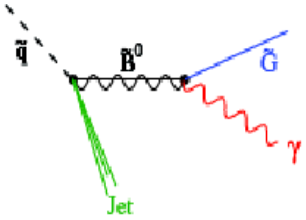
1 photon

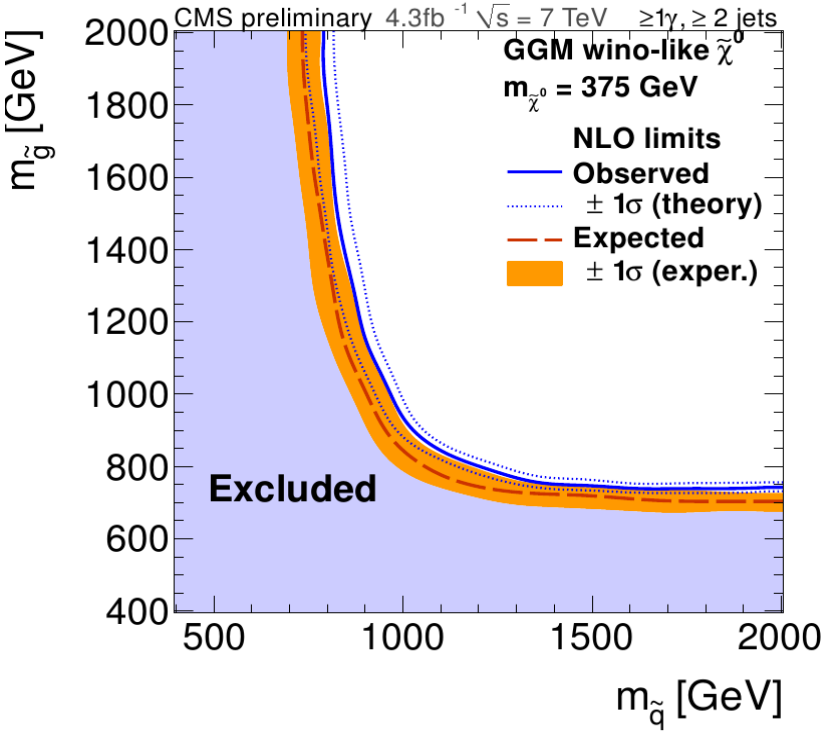


Photon Search

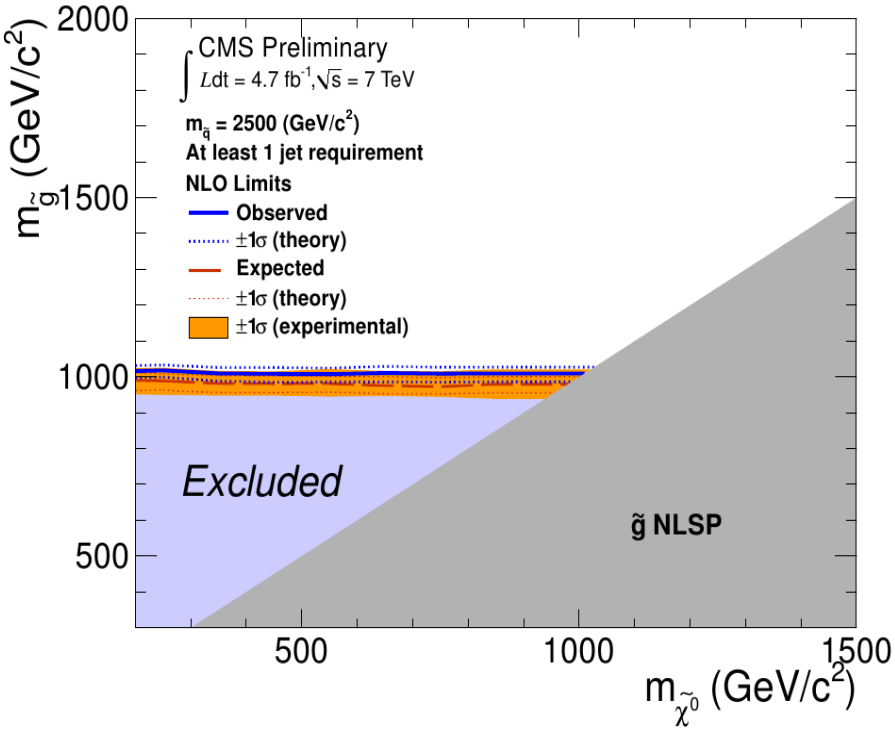
CMS-SUS-12-001

- interpretation in general gauge mediation (GGM), gravitino as LSP
- phenomenology driven by NLSP
  - ➔ considered simplified model with bino-like and wino-like neutralino NLSP





1 photon, wino-like NLSP



2 photons, bino-like NLSP

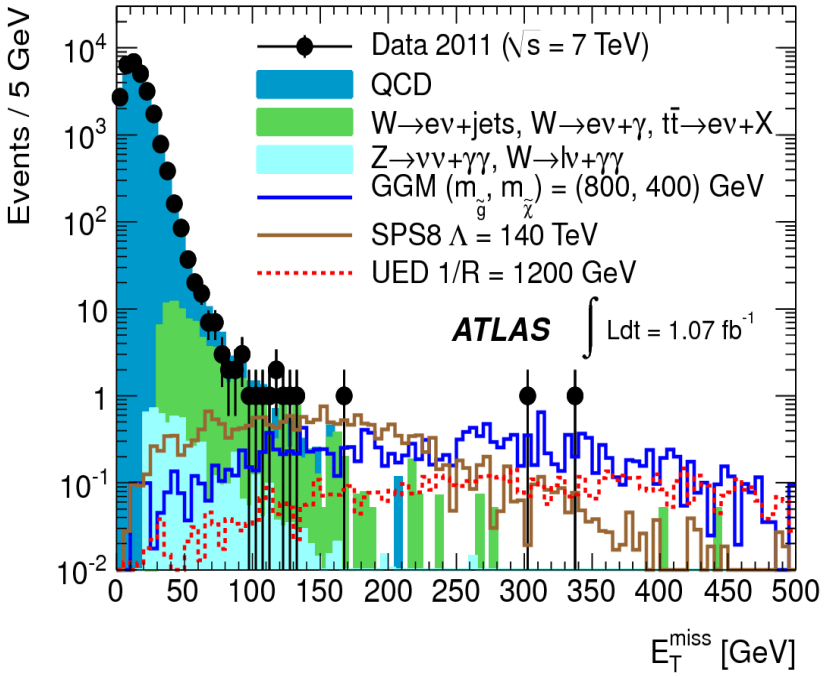
- also interpreted in a UED model

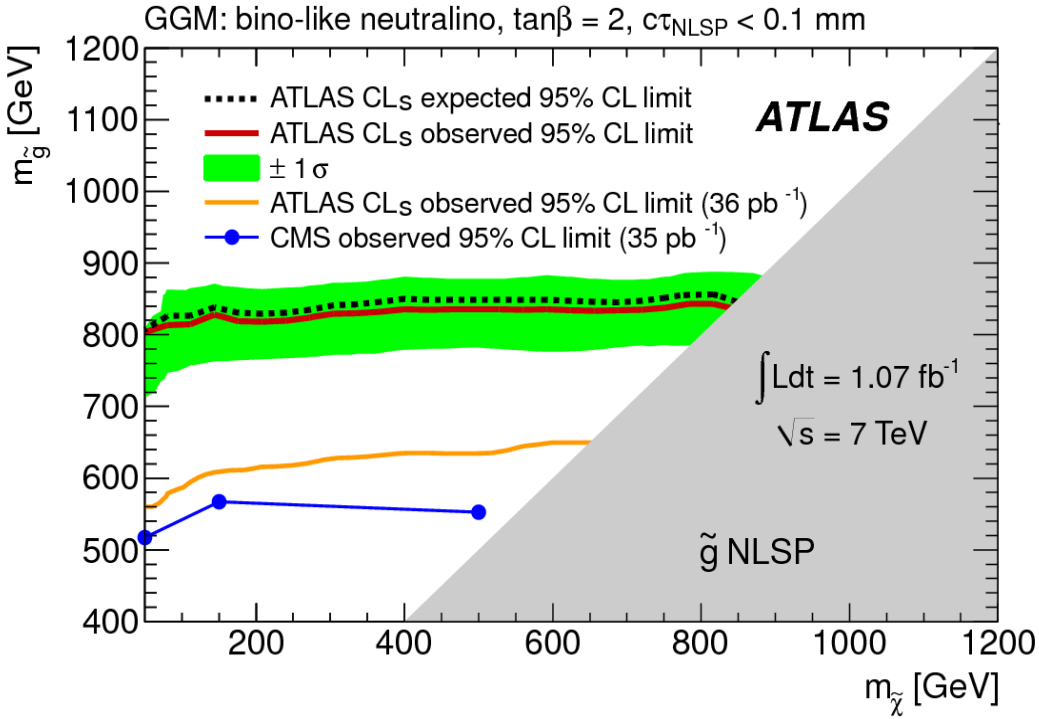
Photon Search

arXiv:1111.4116

- 2 photons + 1 jet + MET > 50 GeV

- background estimates from data with ~ identical techniques
  - ➔ QCD background also cross-checked by modeling MET with $Z \to e^+e^-$ control sample



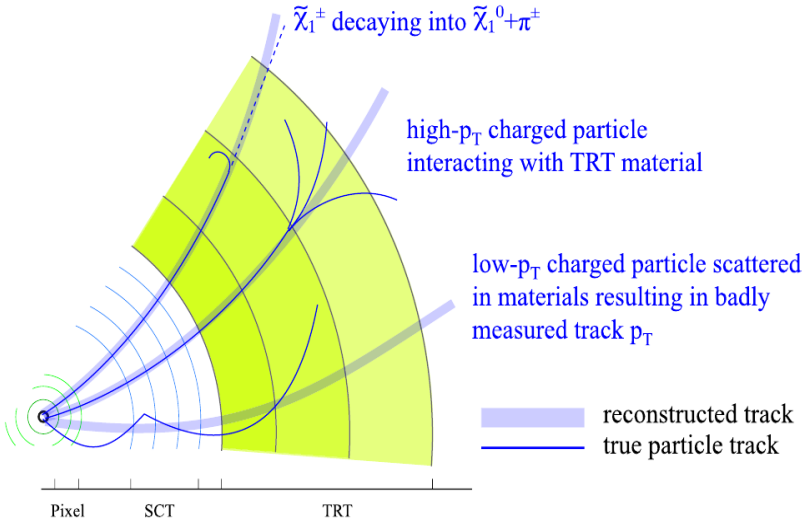


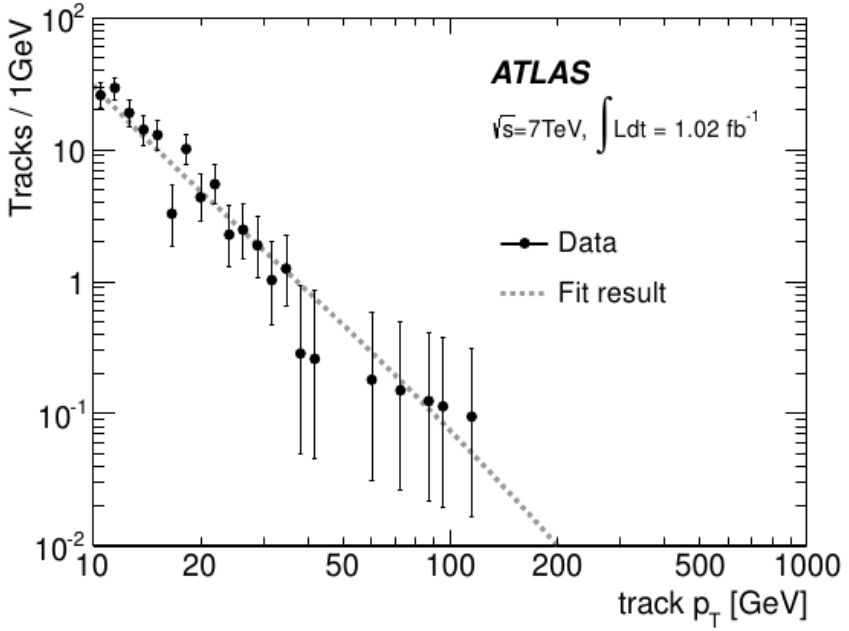
- also interpreted in SPS8 and UED models

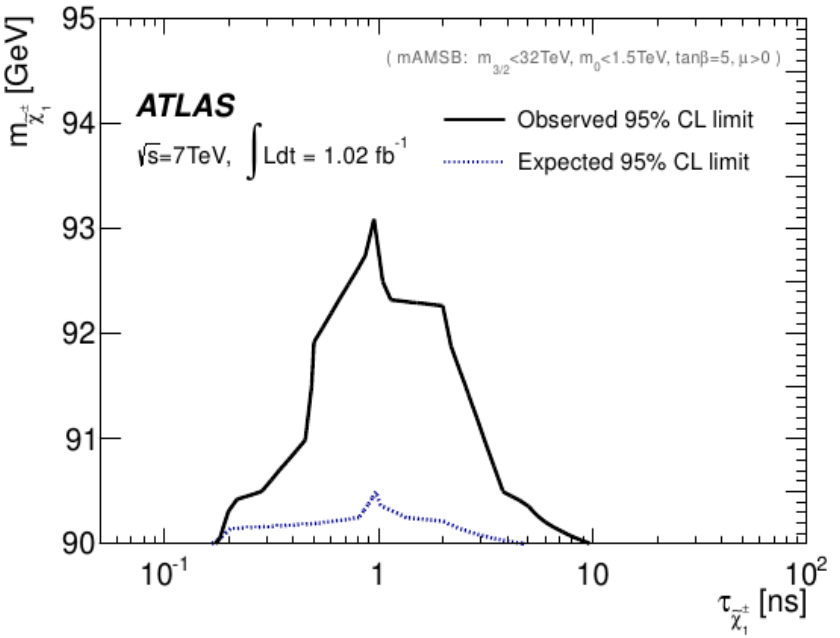
Search for Disappearing Tracks

arXiv:1202.4847

- motivated by AMSB scenario
  - → $\Delta M(\tilde{\chi}_1^+, \tilde{\chi}_1^0) \sim 200$ MeV
- gluino/squark production
  - → 3 jets, MET > 130 GeV
- number of outer TRT hits < 5



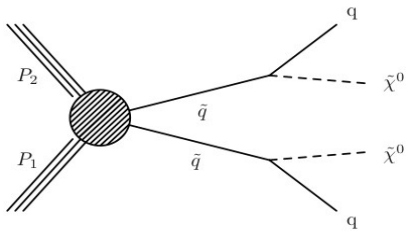




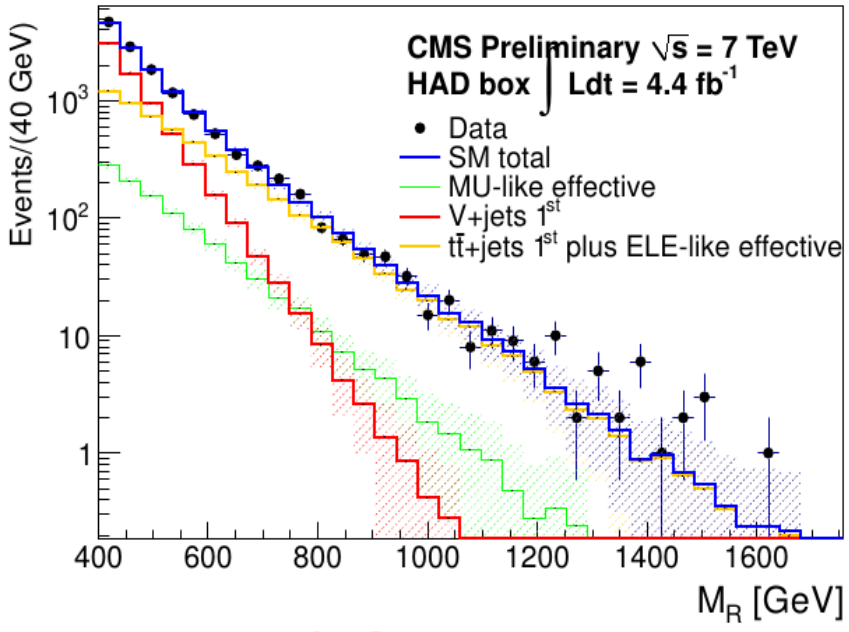
- backgrounds estimated from data
  - → combined shape fit derived from control samples
- p_T > 50 GeV: 13±1 expected, 5 observed

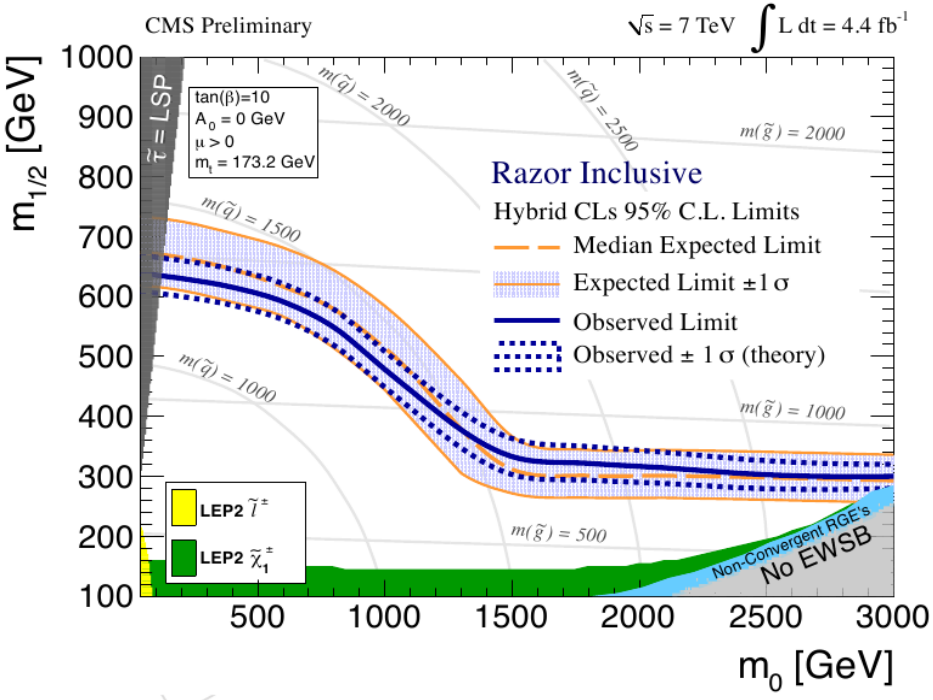
Search with Razor Variables

CMS-SUS-12-005



- the razor R: for S/B discrimination
  - sensitive to the ratio of missing and visible momentum
- M_R is sensitive to the scale of the new physics
- both R^2 and M_R fall exponentially: $F_j(M_R, R^2) = \left[k_j(M_R - M^0_{R,j})(R^2 - R^2_{0,j}) - 1\right] e^{-k_j(M_R - M^0_{R,j})(R^2 - R^2_{0,j})}$
- background strategy:
  - fit functional form (2 components) to data in control regions, and extrapolate
  - simultaneously use 0, 1 and 2 lepton samples

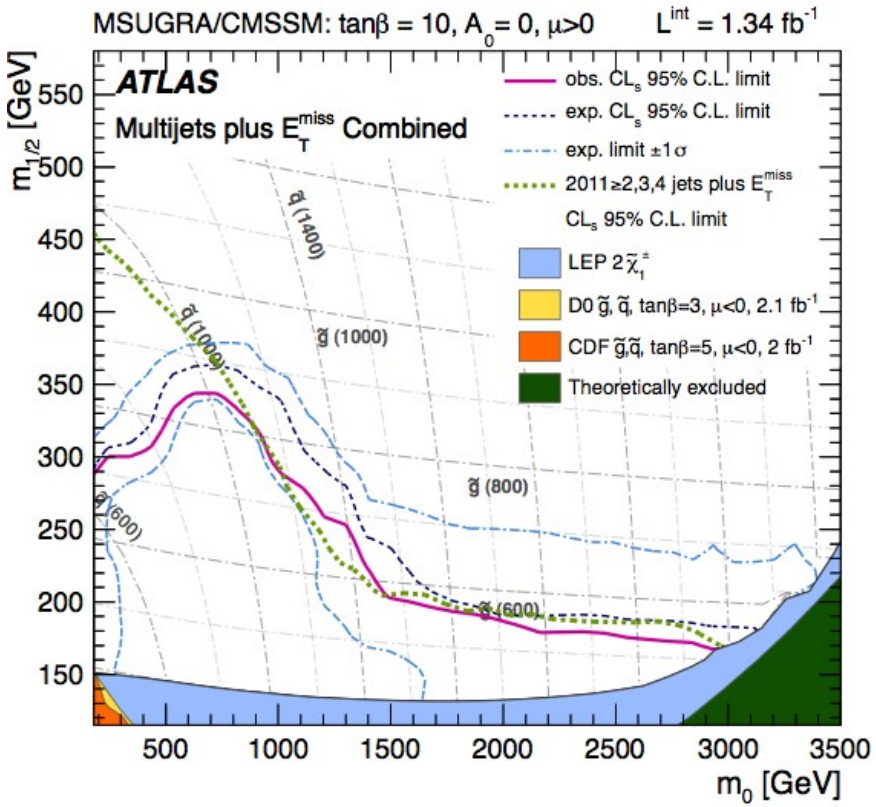


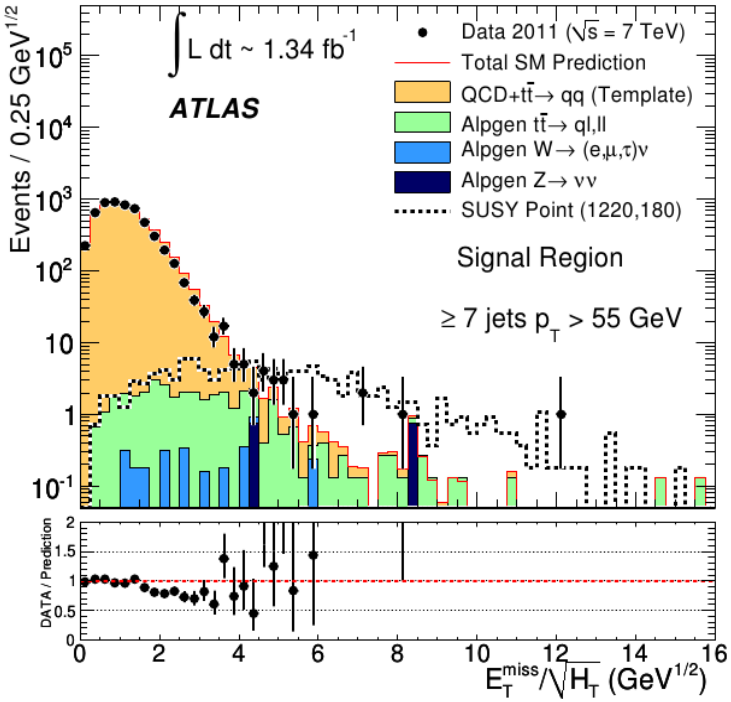


Hadronic MultiJet Search

JHEP 11 (2011) 99

- search for longer decay chains
- 4 signal regions
  - ➔ varying multiplicity (6,7,8 jet) and jet p_T cuts
- search variable: MET significance
  - ➔ MET/sqrt(HT) > 3.5



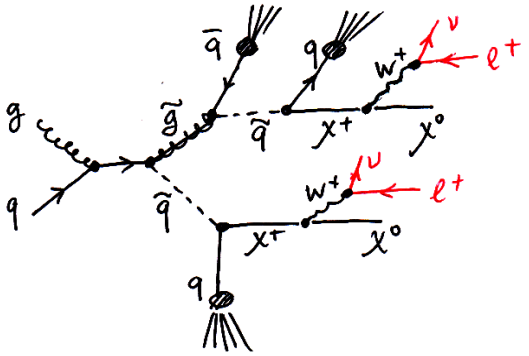


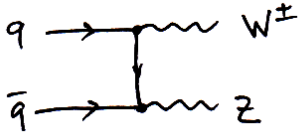
- challenge from QCD background
- estimated from data in control samples with lower jet multiplicity
  - ➔ and normalized at low MET significance
- better expected sensitivity at high m_0

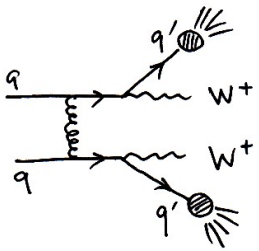
Search with Same-Sign Dileptons

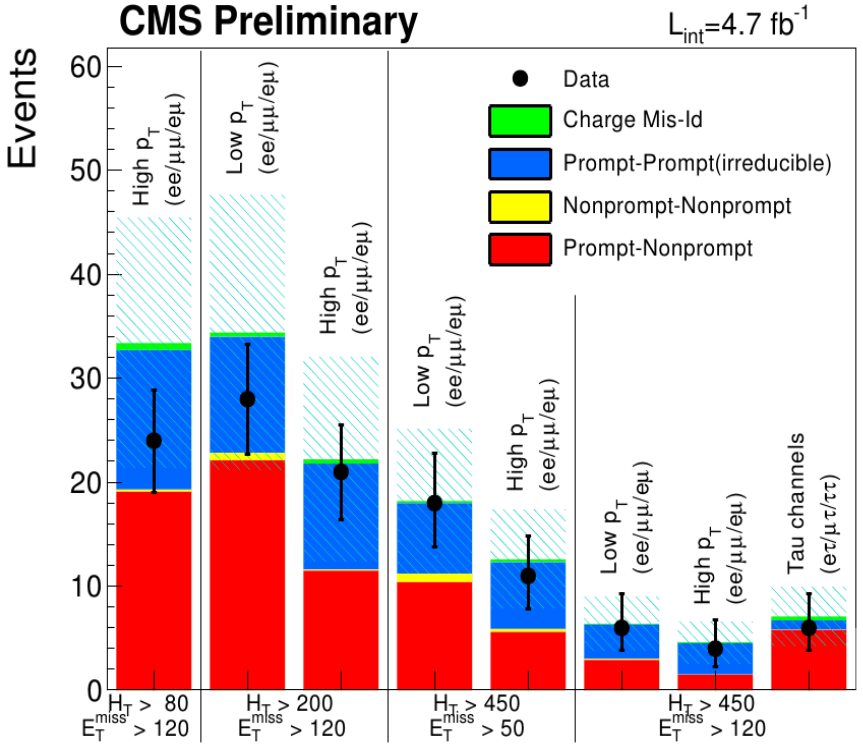
CMS-SUS-11-010

- SS dileptons arise from gluino pair production and both OS and SS squark pair production
- several search regions probing different mass splittings
  - → HT and MET
  - → low-p_T leptons: as low as 5 GeV
  - → including taus
- main background challenge: leptons from jets
  - → multiple data-driven methods
- charge mis-id background
  - → muons verified to be negligible (~10^{-5})
  - → electrons measured with $Z \to e^+e^-$ decays (~10^{-3})
- rare processes are becoming important
  - → $t\bar{t}W$, $t\bar{t}Z$, SS $W^{\pm}W^{\pm}$, ZZ, WZ





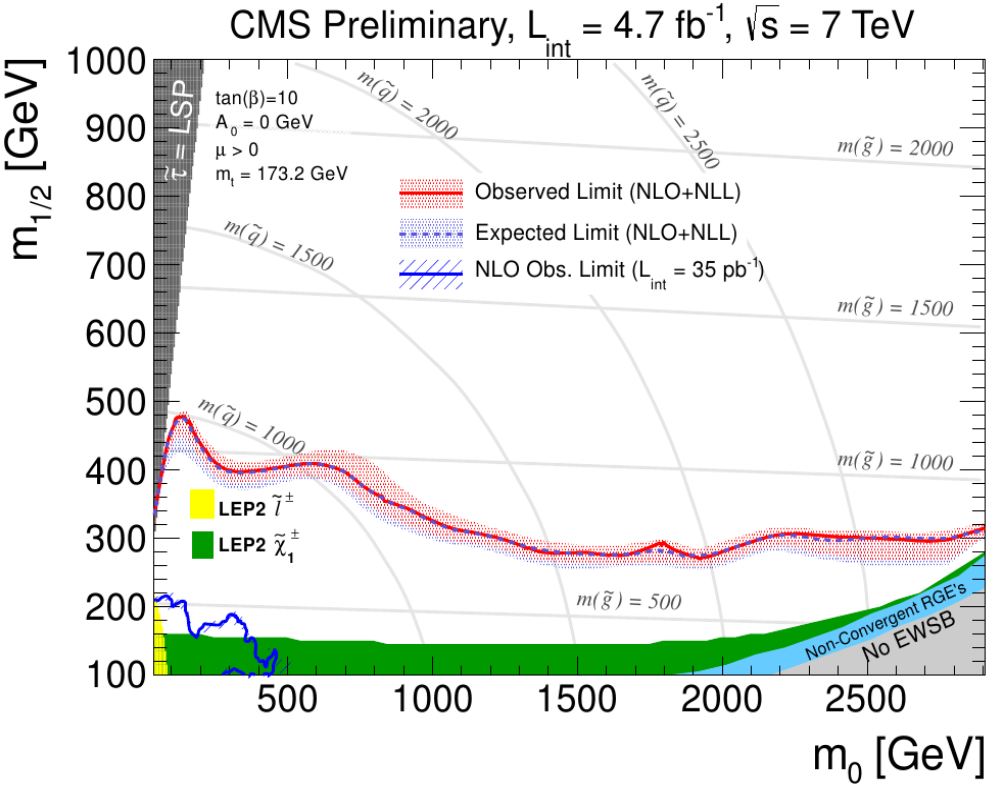




Search with Same-Sign Dileptons

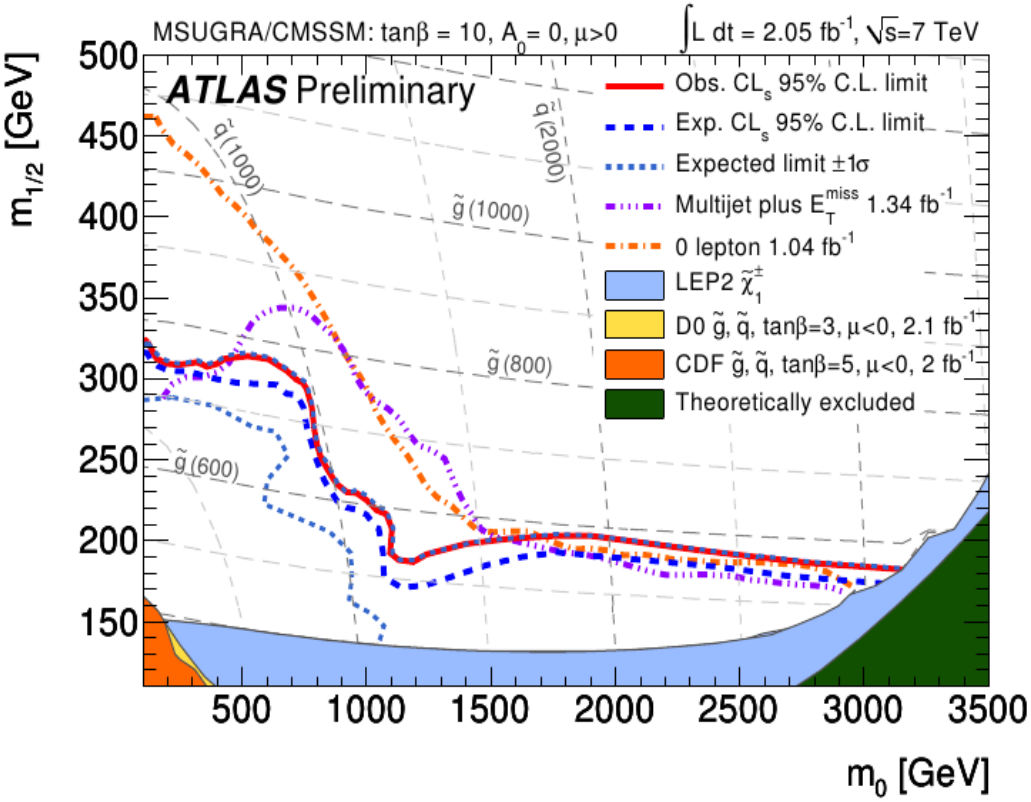
CMS-SUS-11-010

- data agrees with expected background
- results interpreted in CMSSM
  - ➔ also: efficiency model provided for reinterpretation



ATLAS-CONF-2012-004

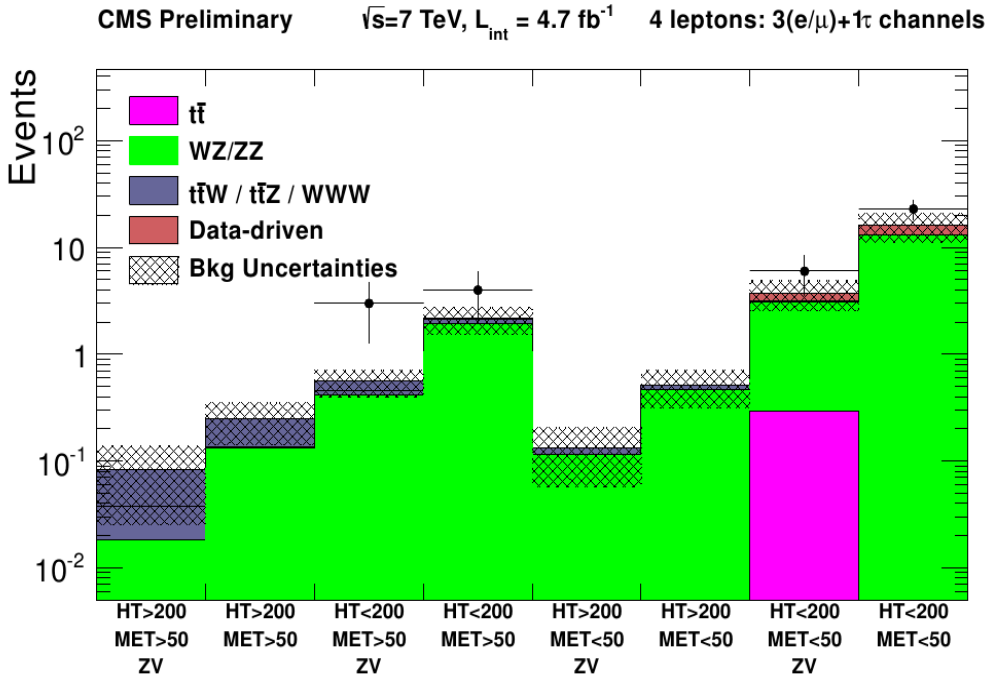
- 2 SS dileptons ($e^{\pm}$, $\mu^{\pm}$)
- MET > 150 GeV, 4 or more jets
- similar background estimates



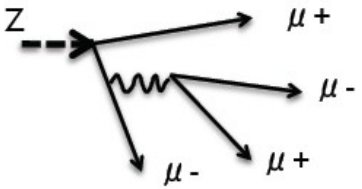
Multi-Lepton Search

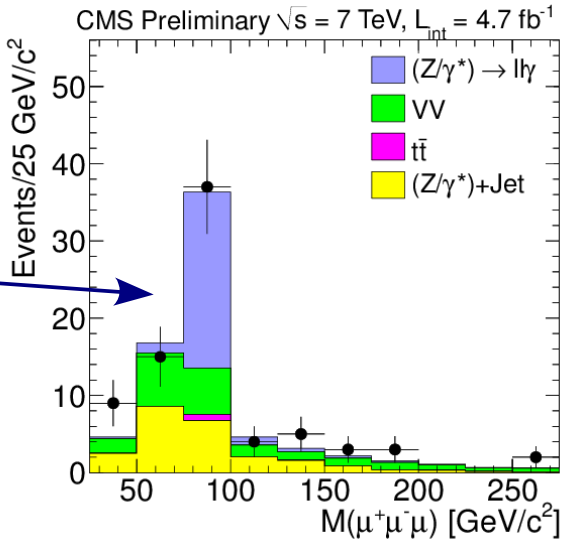
CMS-SUS-11-013
CMS-EXO-11-045

- multitude of search regions
  - 3 or 4 isolated leptons (e, μ and τ)
  - low vs. high HT and MET
  - presence of Drell-Yan pairs
  - in/out Z-mass window



- backgrounds
  - $t\bar{t}$, WZ, ZZ, $t\bar{t}Z$, $t\bar{t}W$
    - from MC, validated in control regions
  - Z+jets substantial at low MET
    - leptons from jets predicted from data
  - Drell-Yan → 4 leptons
    - internal and external asymmetric conversions
    - estimated from data

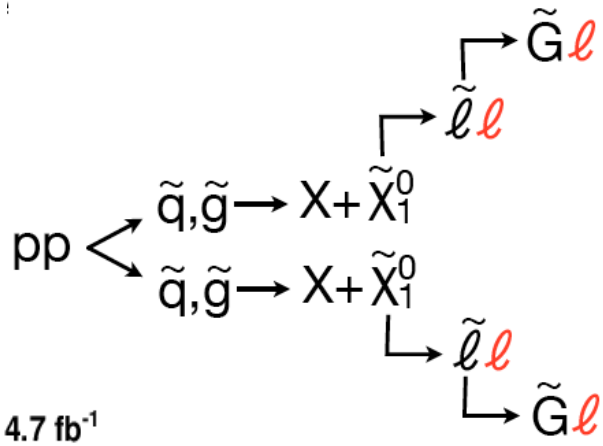


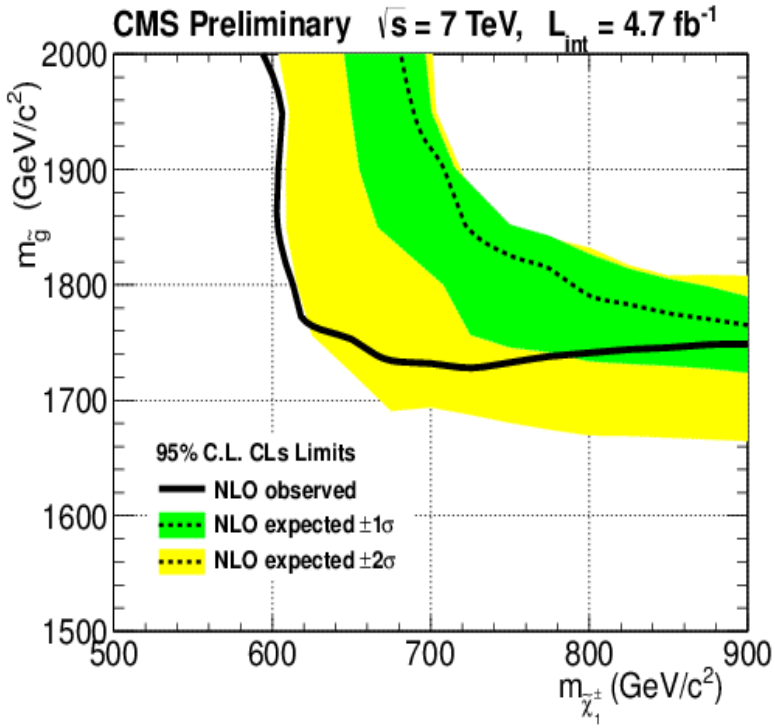


Multi-Lepton Search

CMS-SUS-11-013
CMS-EXO-11-045

- sensitivity for many models
  - → both strong and electroweak production
- interpretation in GMSM framework
  - → gravitino LSP
  - → degenerate sleptons: co-NLSP
  - → neutralino is bino-like and next in mass scale





- also interpretation in R-parity violating models

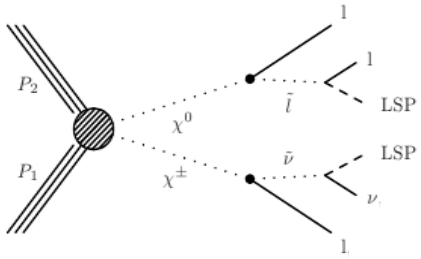
Beyond Squark-Gluino Searches

- squark-gluino mediated SUSY production was the first line of attack
  - large production cross section
  - rich phenomenology of final states to explore
- with the large luminosity available we now also become sensitive to more exclusive production modes
  - electroweak chargino/neutralino production
  - direct sbottom and stop production
- in general the third generation is special
  - desired light for SUSY naturalness
  - mixing can push the stop, sbottom and stau masses below other generations
- in the next slides a glimpse of EWK and 3rd generation results
- 3rd generation results from ATLAS presented in more detail tomorrow morning by Antoine Marzin

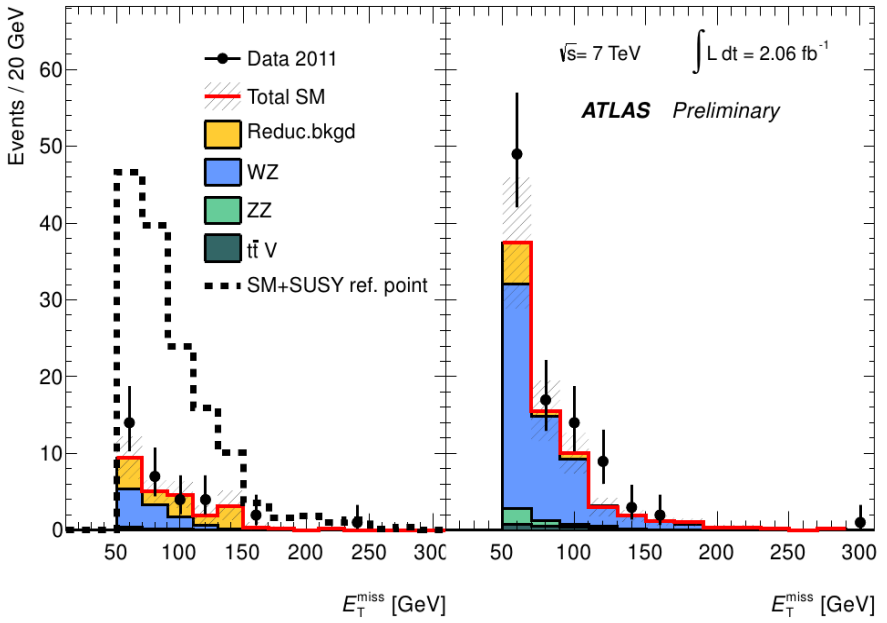
EWK Multi-Lepton Production

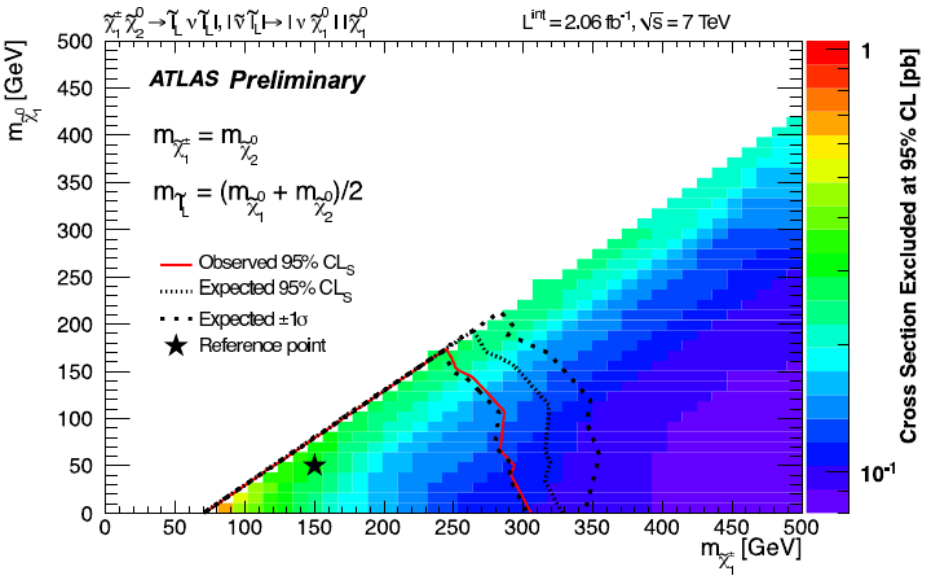
ATLAS-CONF-2012-023

- tri-leptons from chargino+neutralino production



- 3 isolated leptons (e and μ)
  - ➔ 2 regions in/out Z-mass window
- MET > 50 GeV
- no requirement on hadronic activity
  - ➔ b-jet veto for Z-depleted events
- diboson and $t\bar{t}V$ from MC
- $t\bar{t}$ and $\ell^+\ell^-\gamma^*$ from data
- interpretation in simplified model with degenerate $\tilde{\chi}_1^+$ and $\tilde{\chi}_2^0$
  - ➔ sleptons in between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$
- also interpreted in pMSSM





Search for Same-Sign Dileptons with b-Jets

CMS-SUS-11-020

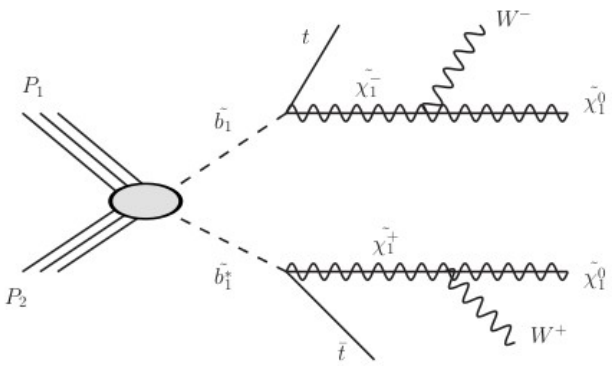
- similar selection as SS dilepton analysis
  - 2 same-sign isolated leptons (e, μ)
  - look at high MET / HT
  - at least 2 b-tagged jets
- several search regions (SR) for different kinematics
  - including 3 b-tag one
- 2nd b-tag requirement reduces top background by factor ~10

	SR1	SR2	SR3	SR4	SR5	SR6	SR7
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$\not{E}_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV	≥ 50 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV	≥ 320 GeV	≥ 320 GeV	≥ 200 GeV
q-flip BG	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.026 ± 0.009	0.008 ± 0.004
Fake BG	3.4 ± 2.0	1.8 ± 1.2	0.32 ± 0.50	1.5 ± 1.1	0.81 ± 0.78	0.15 ± 0.45	0.15 ± 0.45
Rare SM BG	3.2 ± 1.6	2.1 ± 1.1	0.56 ± 0.28	2.0 ± 1.0	1.04 ± 0.52	0.39 ± 0.20	0.11 ± 0.06
Total BG	7.7 ± 2.6	4.4 ± 1.6	0.9 ± 0.6	3.7 ± 1.5	2.0 ± 0.9	0.6 ± 0.5	0.3 ± 0.5
Event yield	7	5	2	5	2	0	0
N_{UL} (12% unc.)	7.4	6.9	5.2	7.3	4.7	2.8	2.8
N_{UL} (20% unc.)	7.7	7.2	5.4	7.6	4.8	2.8	2.8
N_{UL} (30% unc.)	8.1	7.6	5.8	8.2	5.1	2.8	2.8

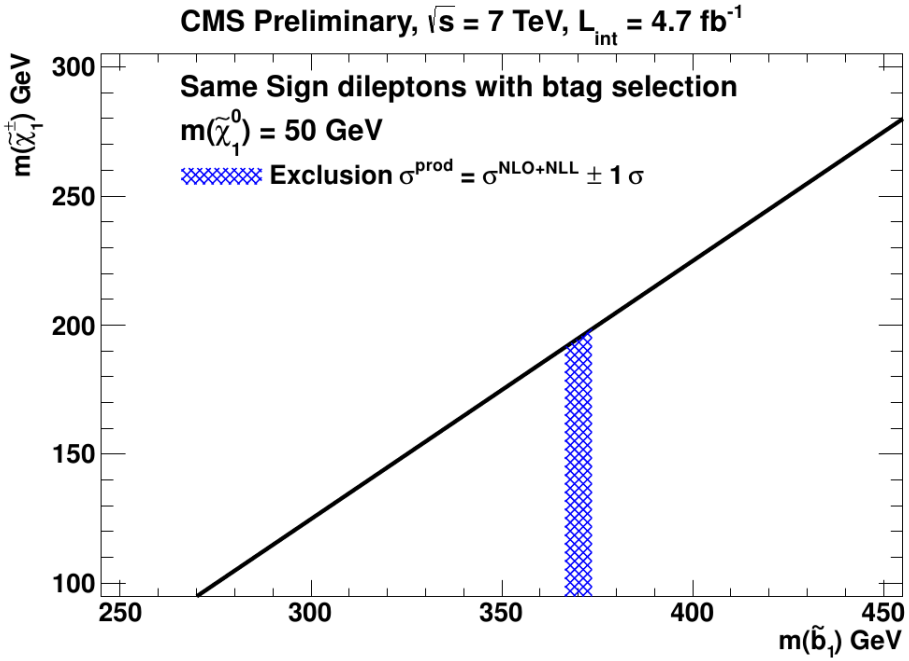
Search for Same-Sign Dileptons with b-Jets

CMS-SUS-11-020

- interpretation with direct sbottom production
  - sensitivity from SR1 and SR4
  - $m_{sbottom} > 380$ GeV



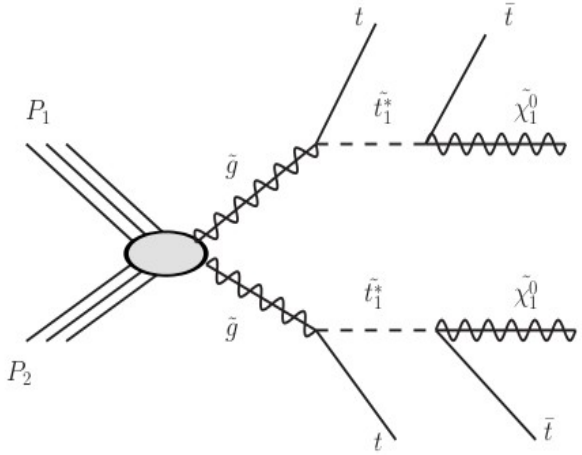
$pp \rightarrow t\bar{t}\,W^+W^- + MET$

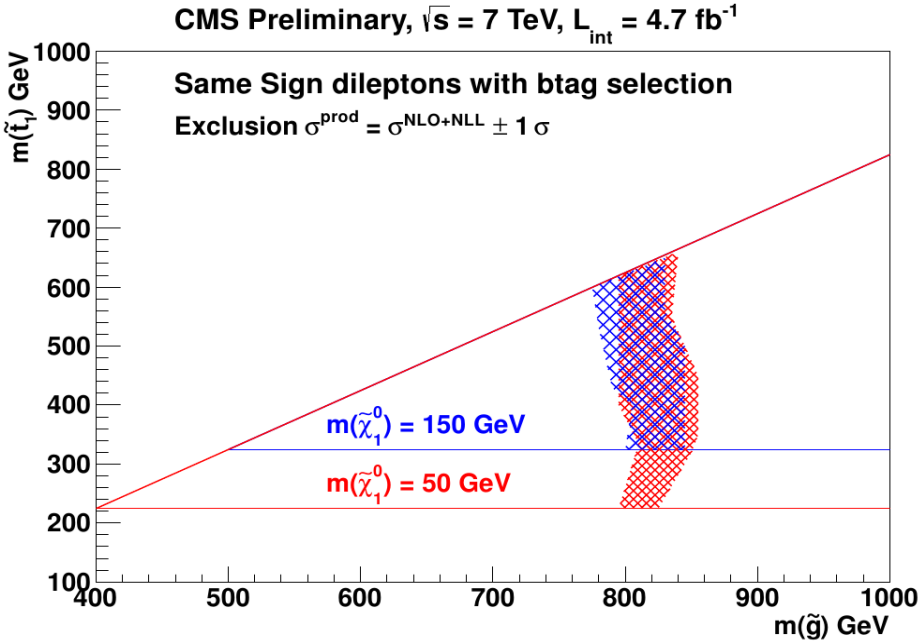


Search for Same-Sign Dileptons with b-Jets

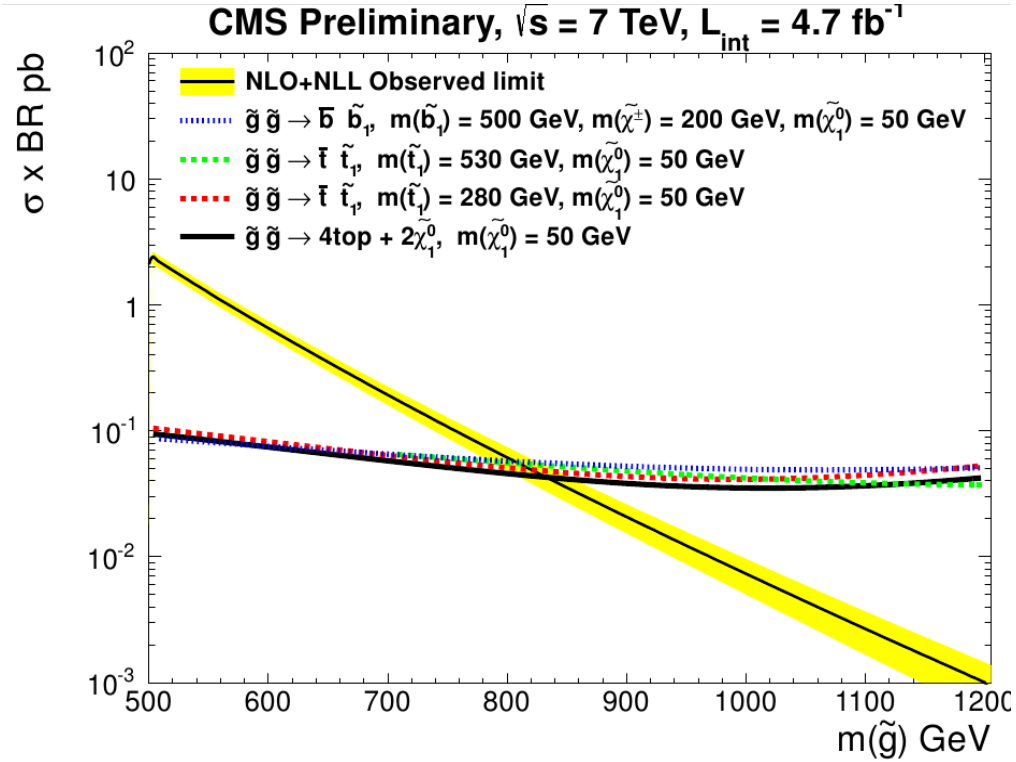
CMS-SUS-11-020

$pp \rightarrow t\bar{t}\,t\bar{t} + MET$
intermediate stops





- interpretation with gluino-mediated 4W+4b+MET final states
  - → SR3-SR6 contribute most
  - → $m_{gluino} > 800$ GeV



Supersymmetry Searches with ATLAS and CMS

- both ATLAS and CMS have a vibrant SUSY program
  - → many new results available and more to come soon
- SUSY searches keep covering ground rapidly
  - → factor 130 more LHC data in 2011 compared to 2010
  - → rare backgrounds are gaining importance
- all data compatible with expected backgrounds
- search strategies are becoming more diverse and advanced
  - → covering more corners of the phase space
- dedicated attention to 3rd generation and EWK production
  - → looking forward to the 2012 data!

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

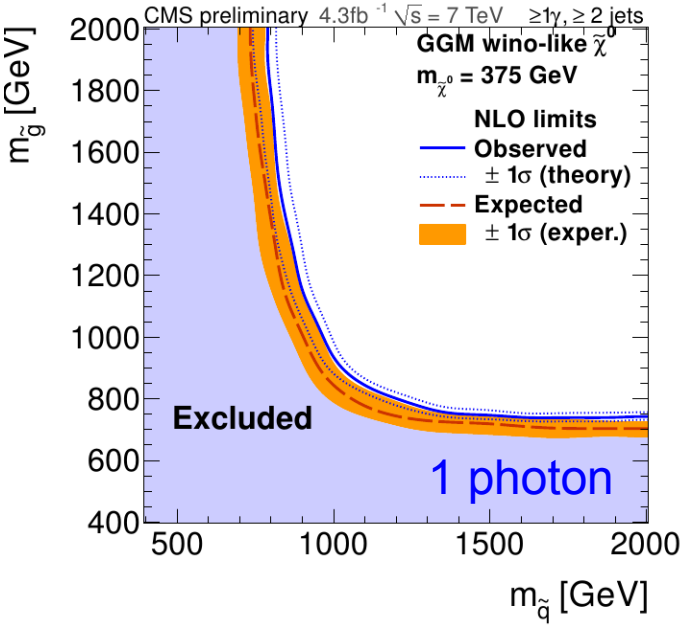
Backup Material

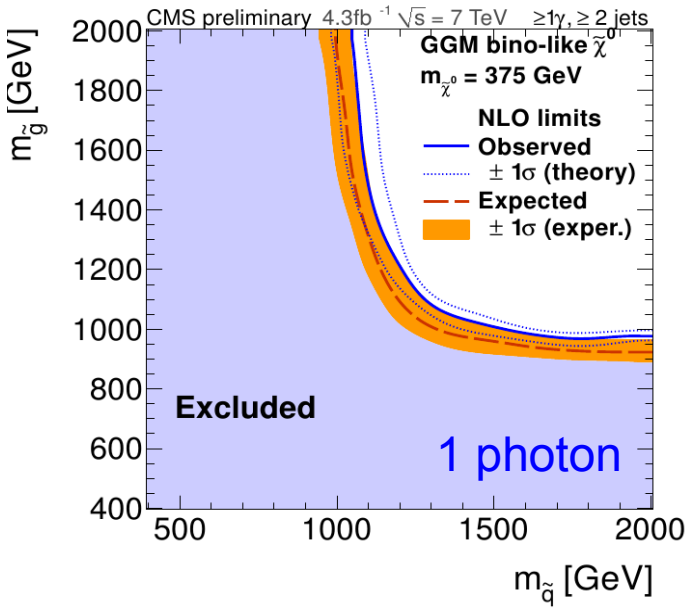
CMS Luminosity

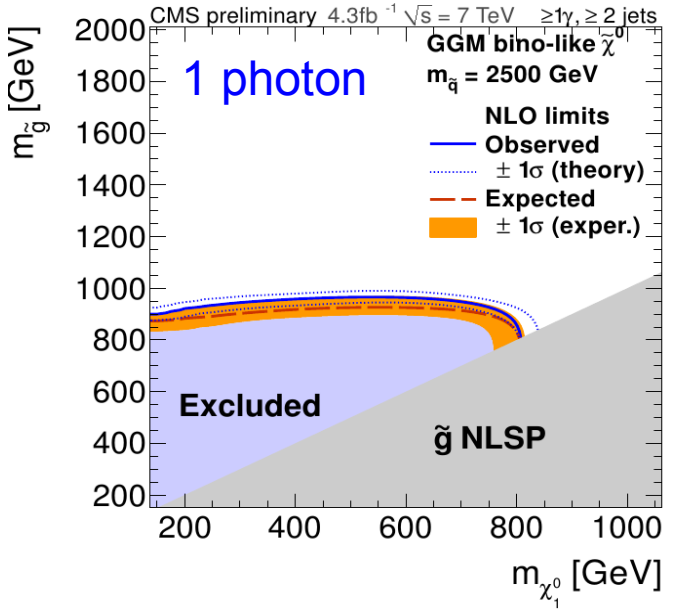
- in the process of precision determination of the luminosity collected by CMS in 2011, a slight time-dependent calibration drift was found in the calorimeter used as a luminometer.
- to remedy this, we developed an independent luminosity determination using the more stable and precise pixel tracker
- preliminary result presented at the LHC Luminosity Days suggests an upward change in the estimated luminosity for 2011 by ~6%, i.e. slightly outside the 1s-band of our original estimate of the luminosity uncertainty
  - ➔ the corresponding change for the low-luminosity part of the run (2011A), which is the basis of our new and published precision measurements, is ~3.5%, well within the quoted systematics
- we are finalizing determination of the new luminosity measurement, with significantly better precision
- the anticipated change has a very minor effect on our preliminary results and no visible change in published limits
- instability does not affect the 2010 luminosity determination, as it only affects high-luminosity running

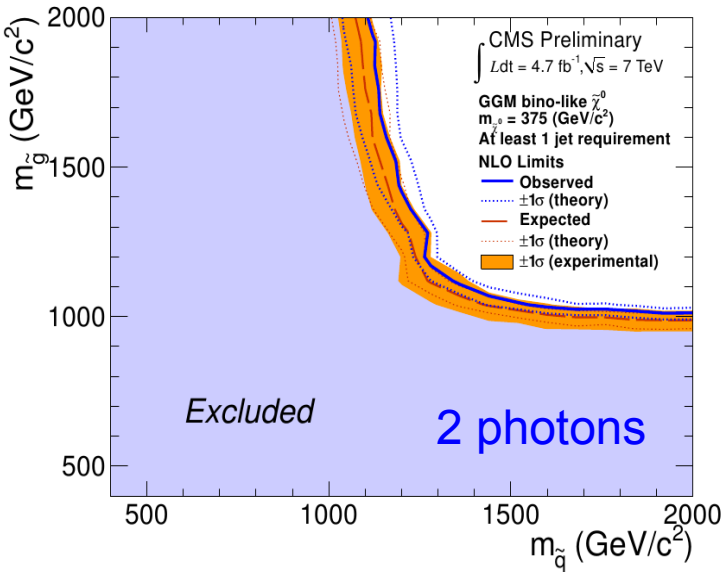
Photon Search

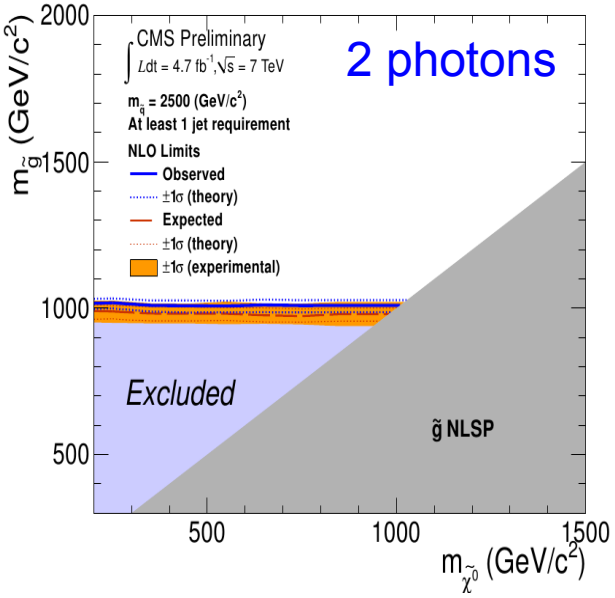
CMS-SUS-12-001











Search for Disappearing Tracks

arXiv:1202.4847

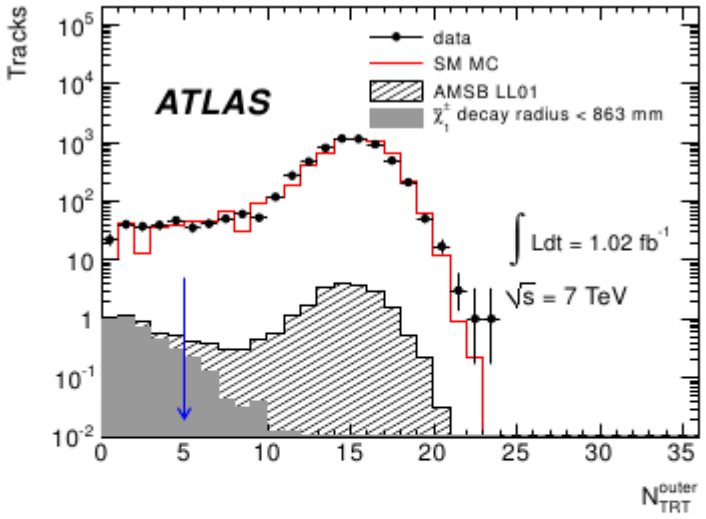
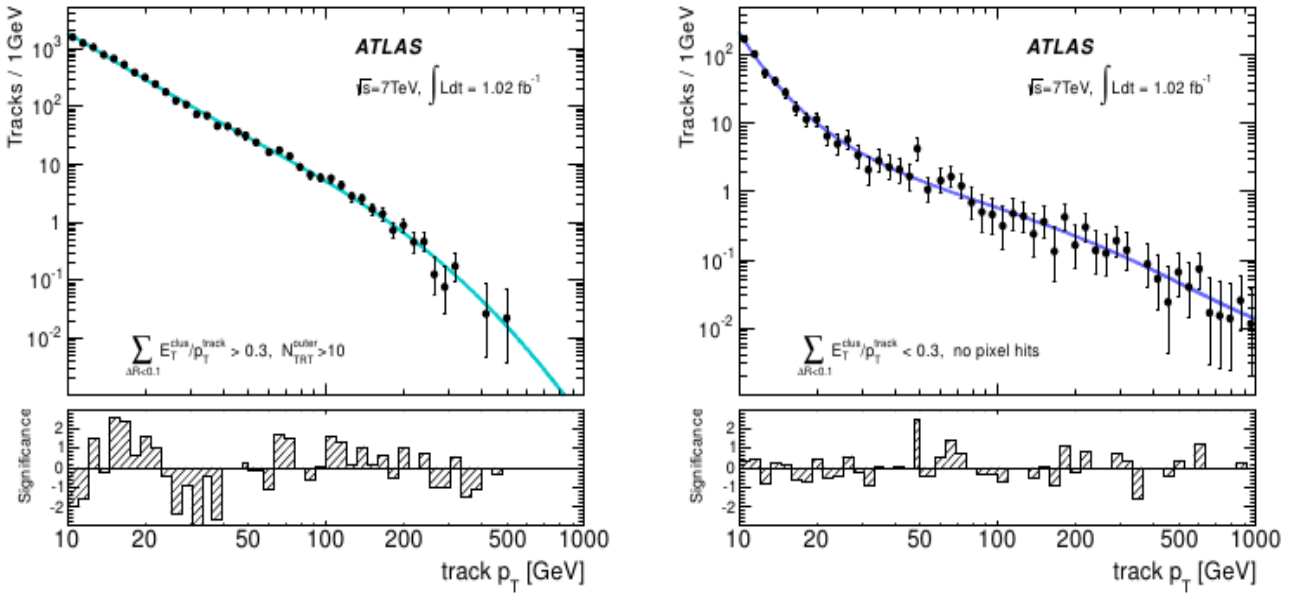


Fig. 1 The $N_{\mathrm{TRT}}^{\mathrm{outer}}$ distribution for data and signal events (LL01, $\tau_{\tilde{\chi}_1^\pm} = 1$ ns) with the high-p_{T} isolated track selection. The selection boundary is indicated by the arrow. The expectation from SM MC events, normalized to the number of observed events, is also shown. When charginos decay before reaching the TRT outer module, $N_{\mathrm{TRT}}^{\mathrm{outer}}$ is expected to have a value near zero; conversely, SM charged particles traversing the TRT typically have $N_{\mathrm{TRT}}^{\mathrm{outer}} \simeq 15$.



(a) High-p_{T} hadron track sample

(b) Bad track sample

Fig. 3 The p_{T} distributions of high-p_{T} hadron track (a) and bad track (b) background control samples. The data and the fitted model are shown by the solid circles and the line, respectively. The significance of the data-model difference on a bin-by-bin basis is also shown at the bottom of each figure.

Search for Disappearing Tracks

arXiv:1202.4847

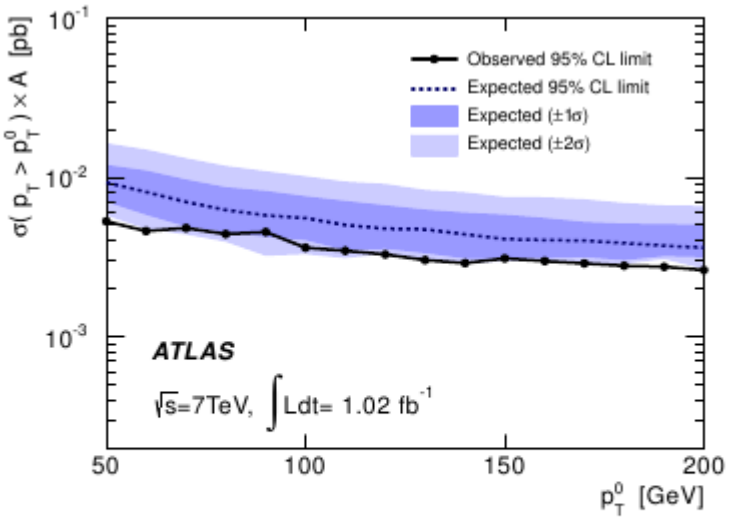


Fig. 6 Model-independent upper limits on the cross section (σ) times acceptance (A) for a non-SM physics process containing an isolated, disappearing track with $p_T > p_T^0$ as a function of p_T^0. The observed and expected bounds at 95% CL are shown.

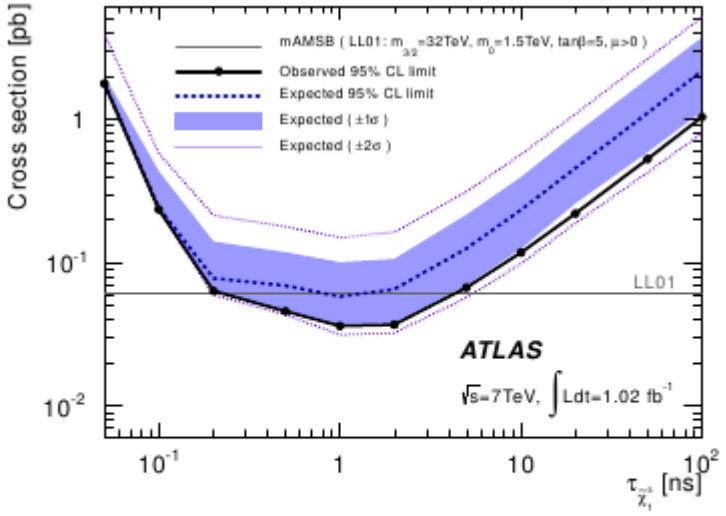
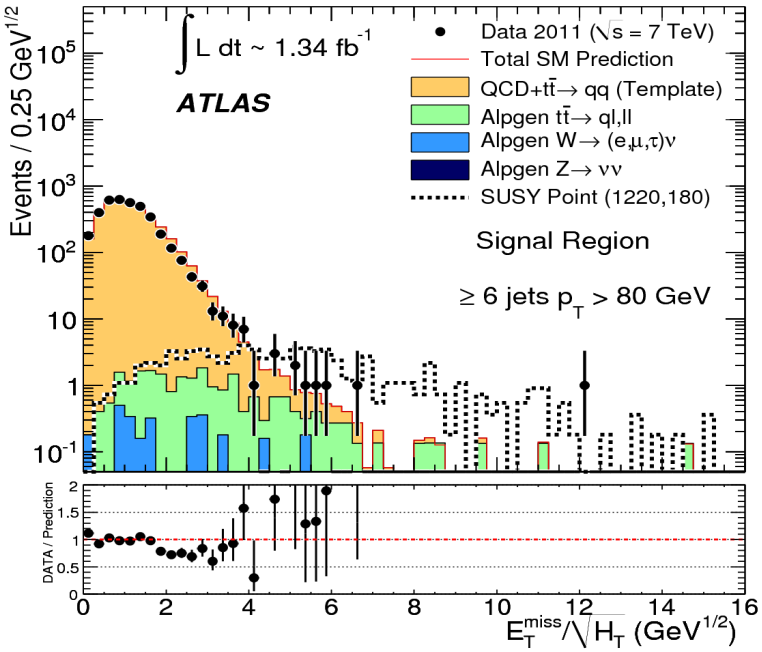
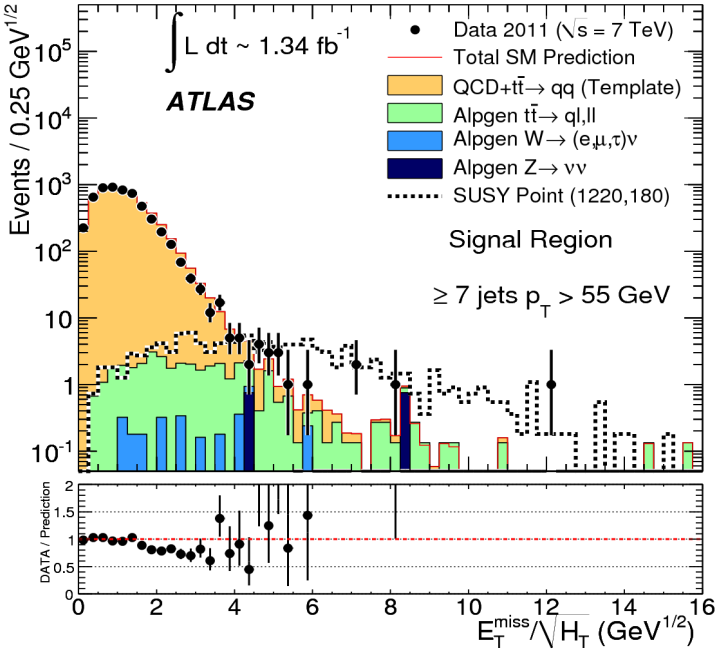


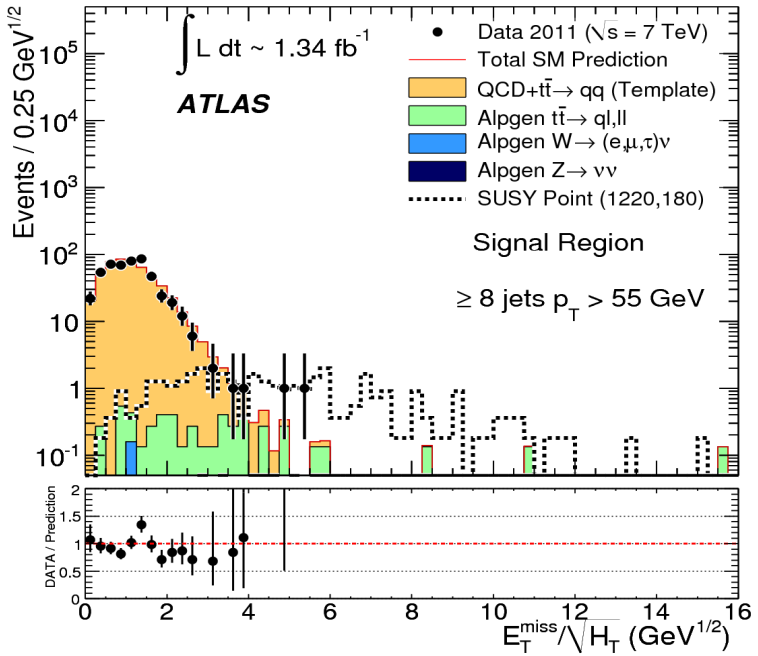
Fig. 7 The observed and expected 95% CL upper limits on the signal cross section as a function of chargino lifetime for $m_{\tilde{\chi}_1^\pm} = 90.2$ GeV. The band and the dotted line indicate the range in which the limit is expected to lie due to the fluctuations in the expected background.

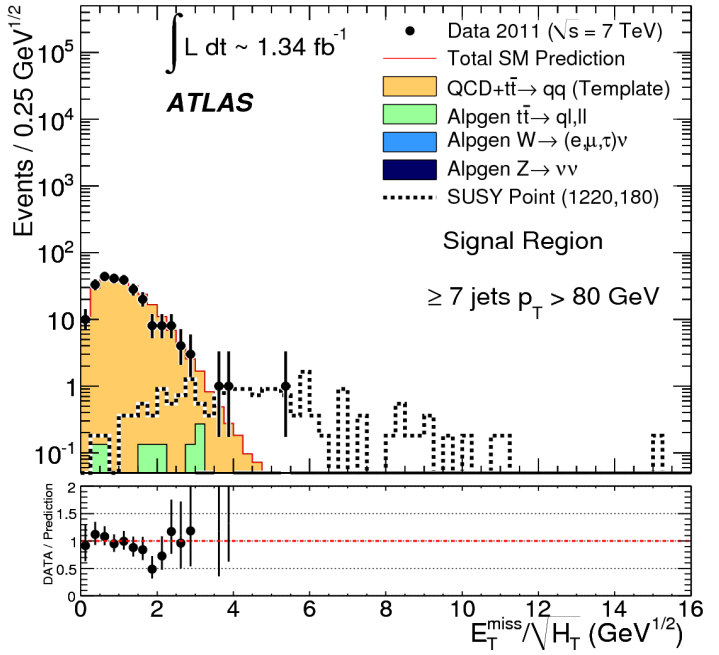
Hadronic MultiJet Search

JHEP 11 (2011) 99



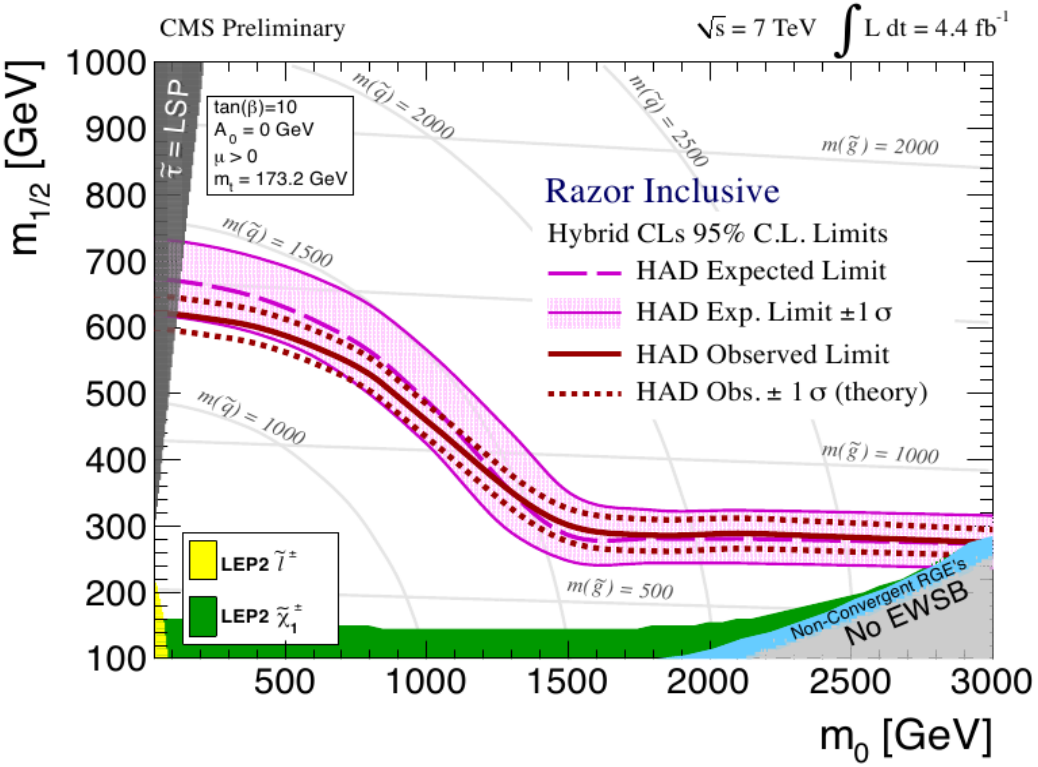


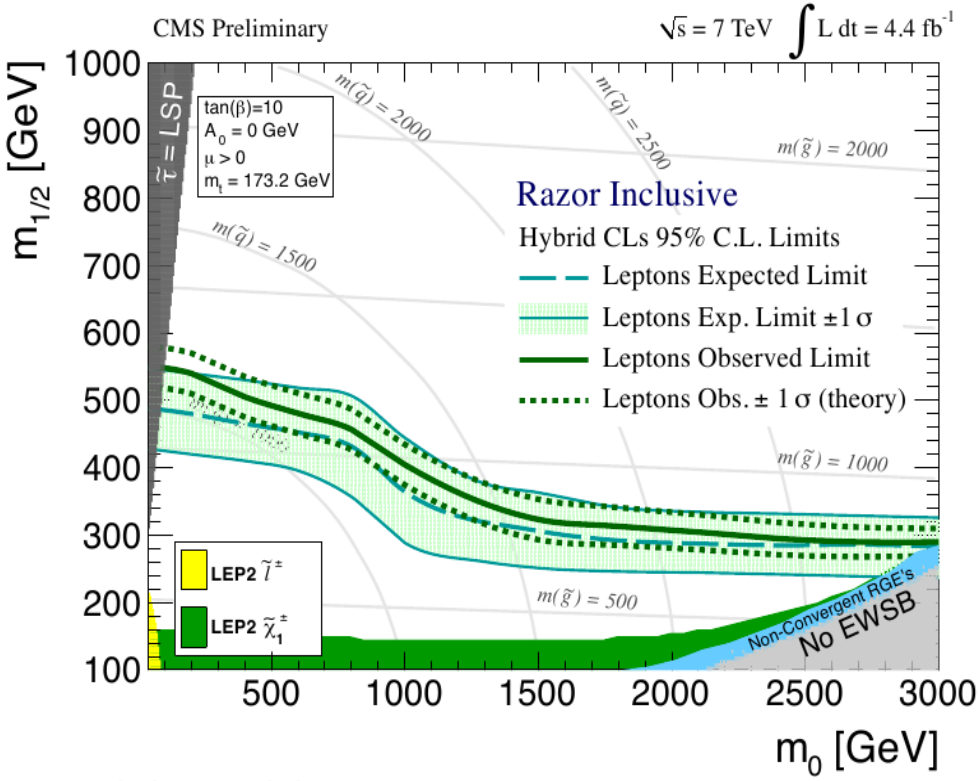




Search with Razor Variables

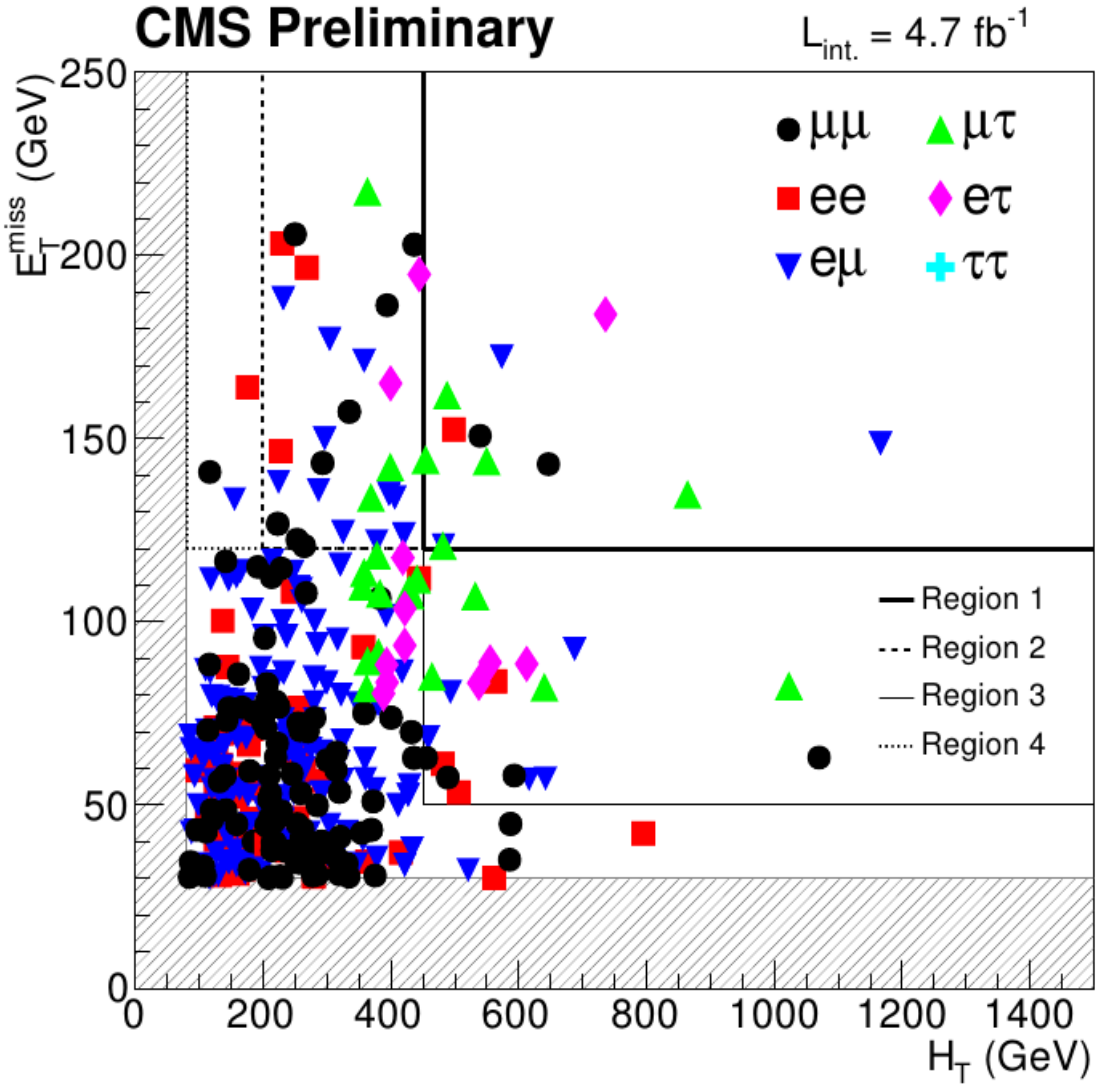
CMS-SUS-12-005





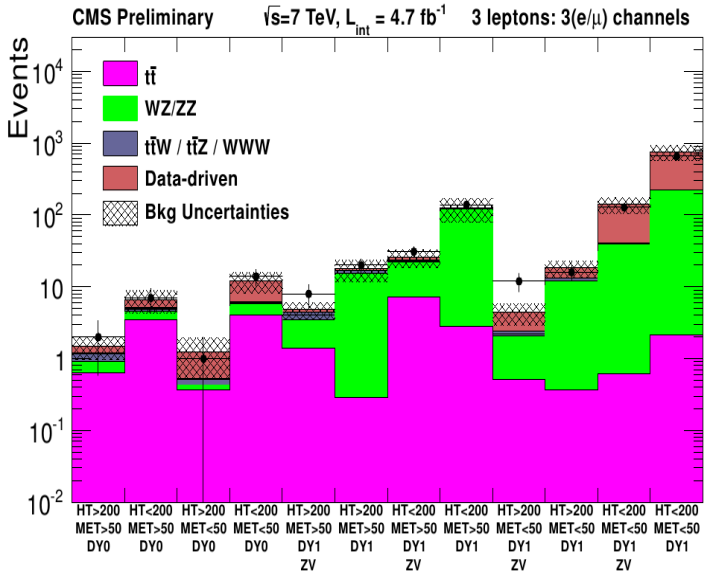
Search with Same-Sign Dileptons

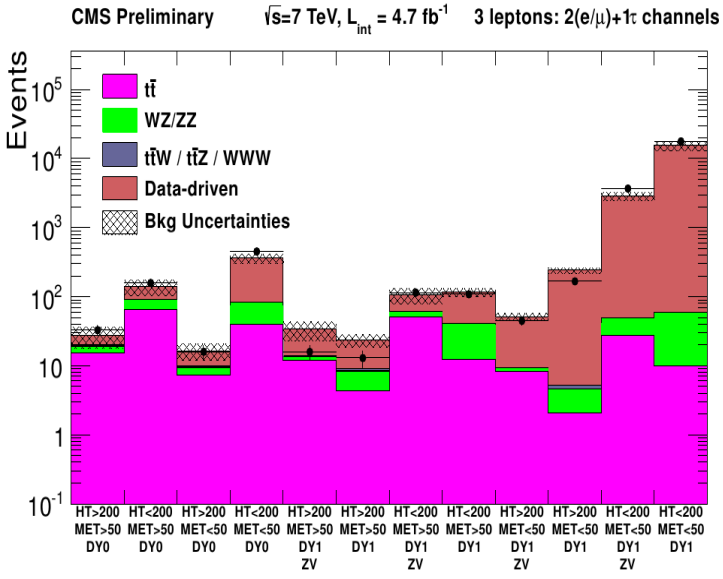
CMS-SUS-11-010

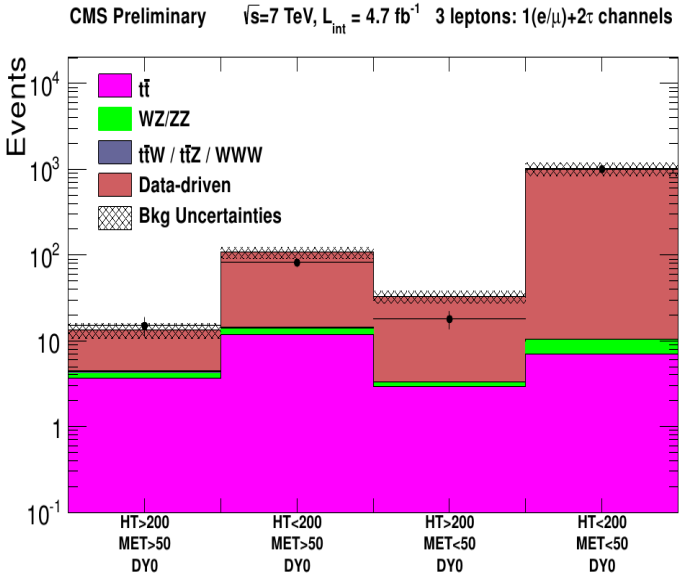


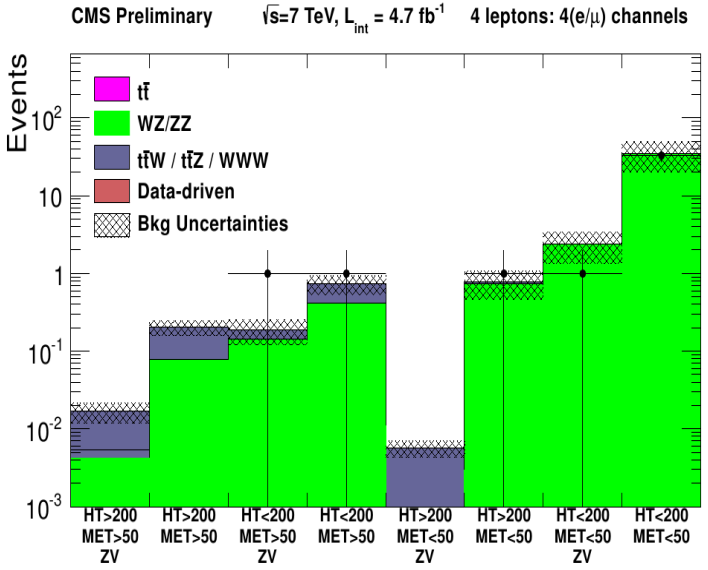
Multi-Lepton Search

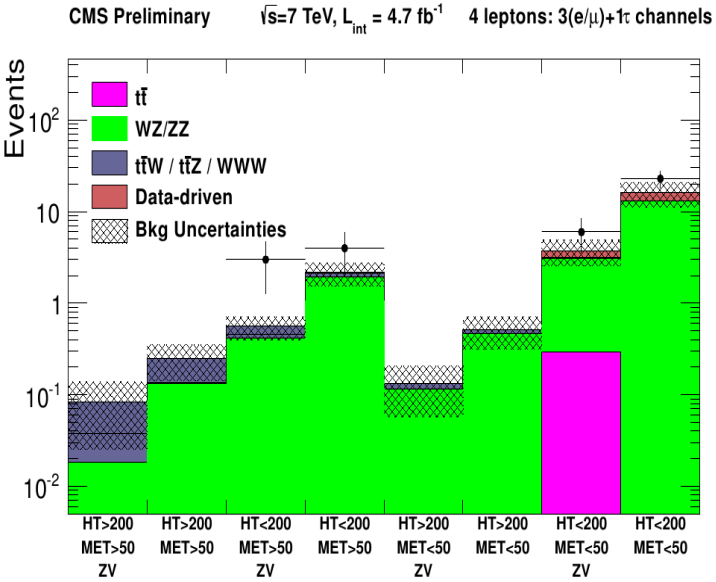
CMS-SUS-11-013
CMS-EXO-11-045

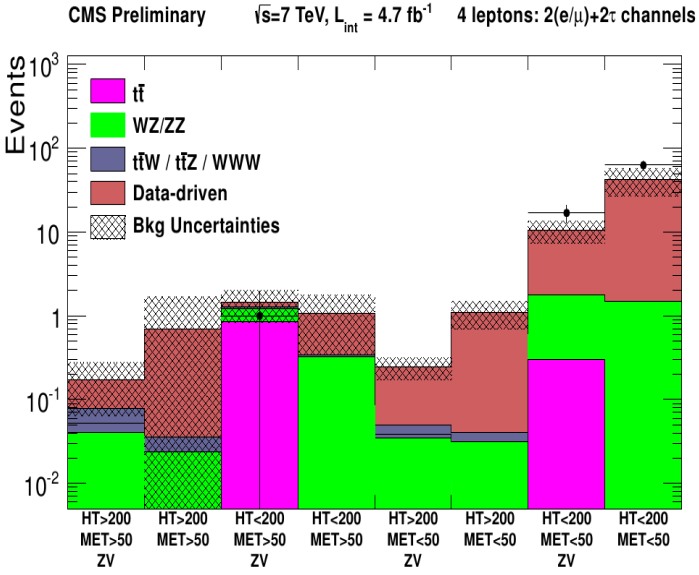












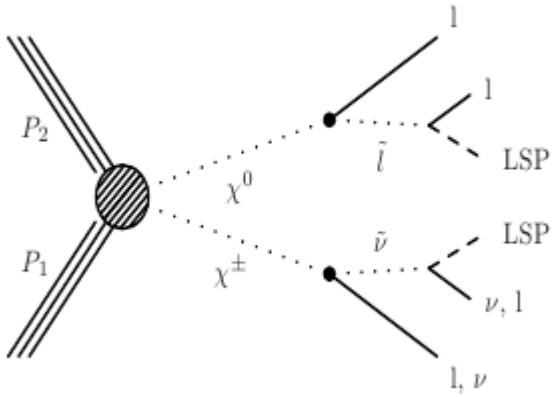
Same-Sign Dileptons in EWK Production

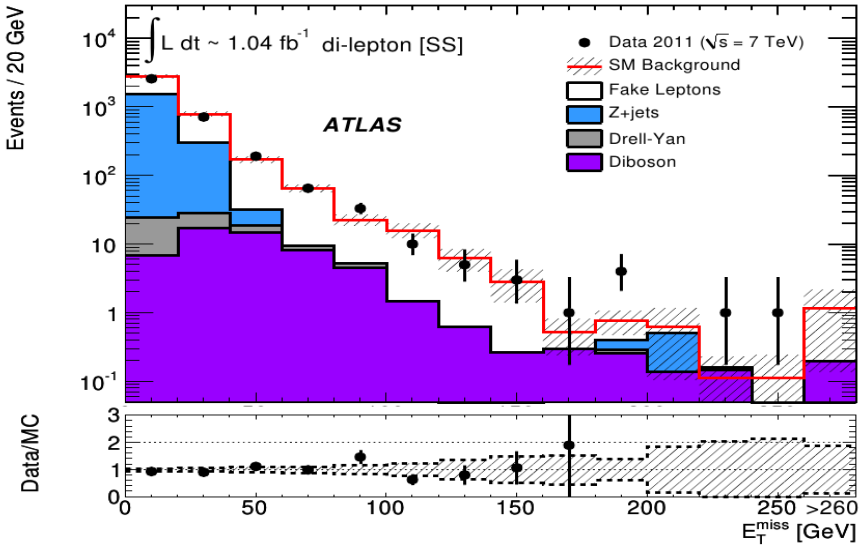
arXiv:1110.6189

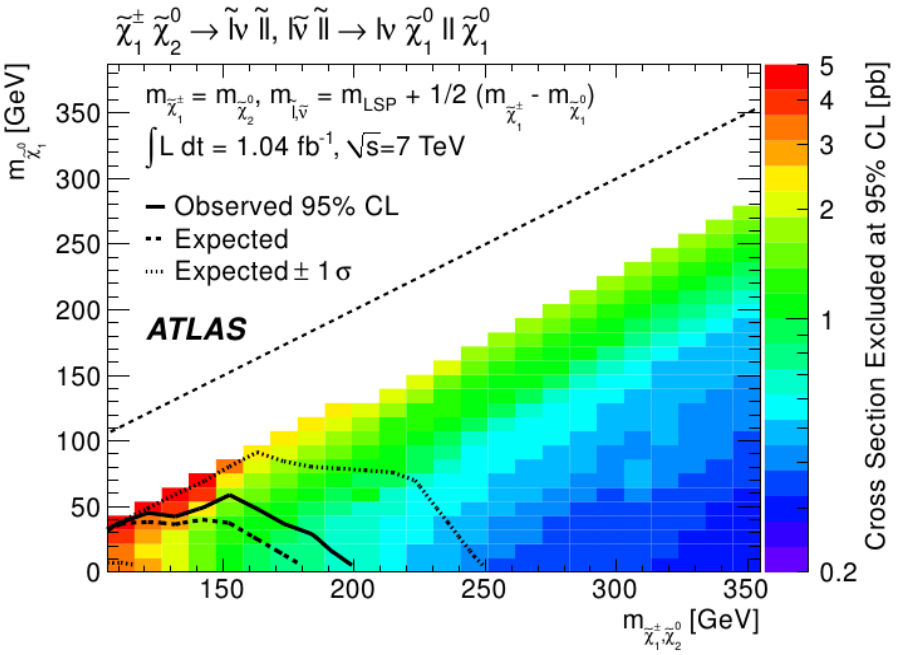
- isolated leptons (e and mu)
- MET > 100 GeV
- no constraints on hadronic activity

- similar background evaluation as for SS dilepton analysis

- interpretation in simplified model with direct chargino/neutralino production
  - ➔ leads to a 3-lepton + MET signature







EWK Multi-Lepton Production

ATLAS-CONF-2012-023

- SR1: Z-veto, b-veto
- SR2: on-Z
- VR1: Z-dominated control region
- VR2: ttbar dominated control region

Selection	VR1	VR2	SR1	SR2
$t\bar{t}V$	1.4±0.6	0.7±0.6	0.4±0.3	2.7±2.1
ZZ	6.7±1.8	0.03±0.04	0.7±0.2	3.4±0.9
WZ	61±15	0.4±0.2	11±3	58±14
Reducible Bkg.	56±35	14±9	14±4	7.5±3.9
Total Bkg.	125±38	15±9	26±5	72±15
Data	122	12	32	95

Search for Same-Sign Dileptons with b-Jets

CMS-SUS-11-020