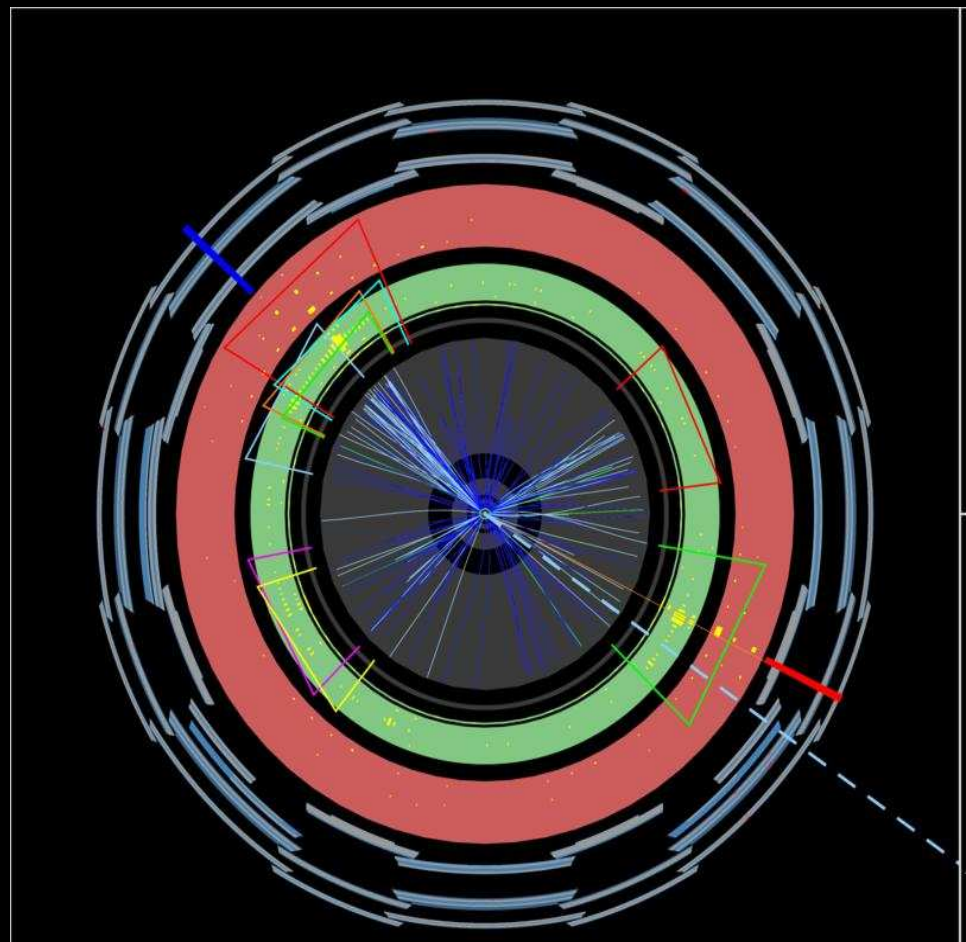
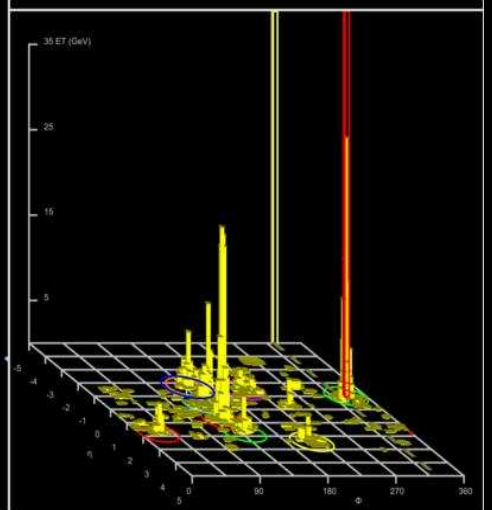
Inclusive Searches for Squarks and Gluinos with ATLAS

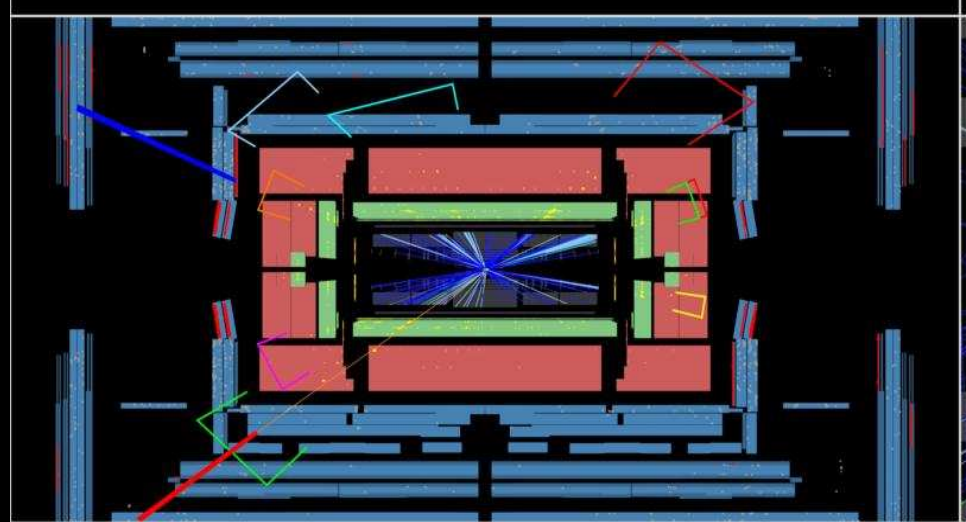
Marc Hohlfeld
Universität Mainz

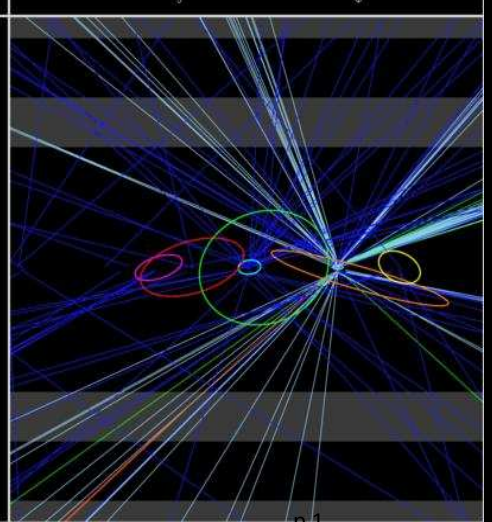
on behalf of the ATLAS Collaboration

SUSY 2013









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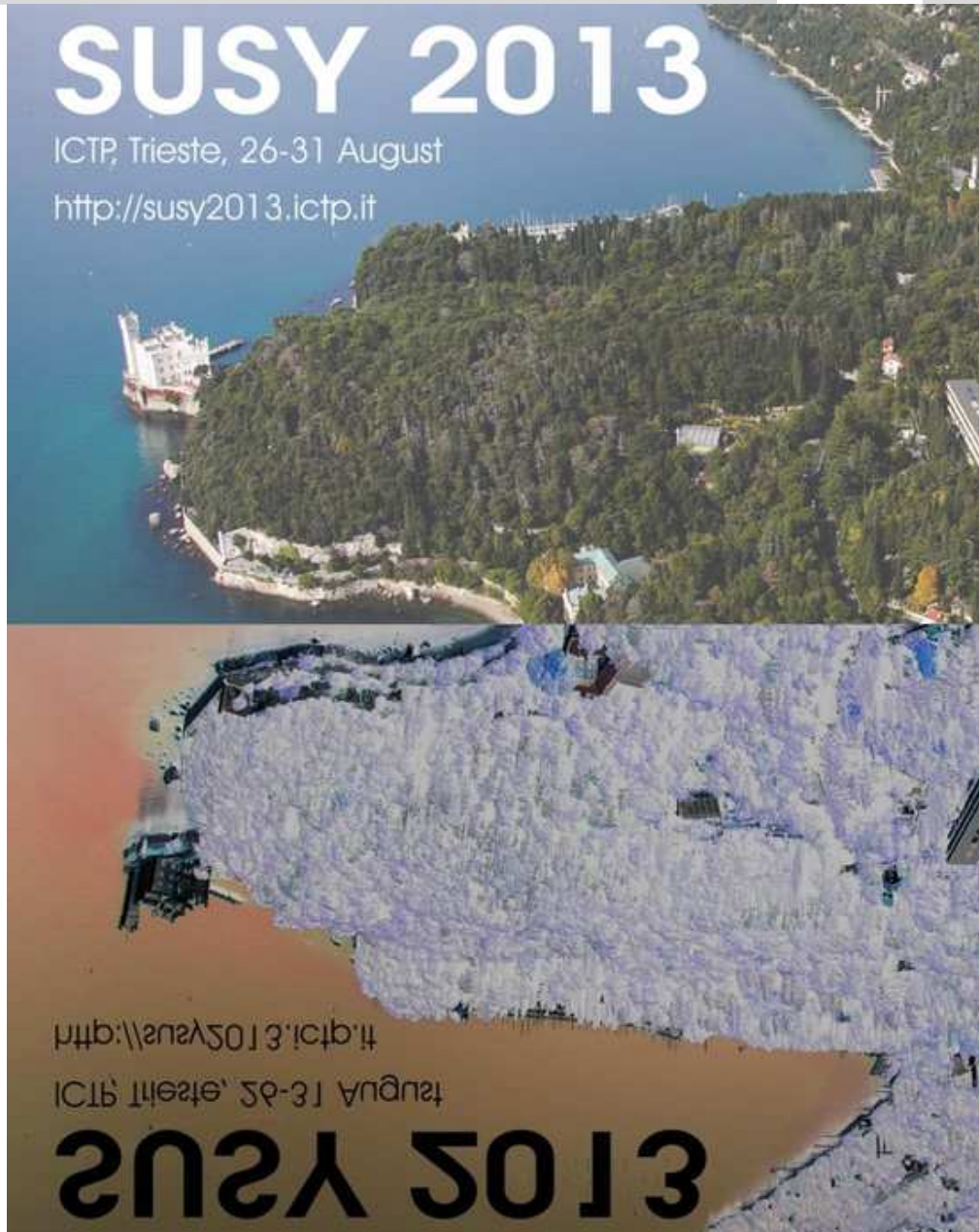
Outline

- Introduction
- Search for Supersymmetry
  - ▲ 0 lepton analyses
  - ▲ Analyses with 1 lepton
  - ▲ Analyses with 2 leptons
- Conclusion

Results based on full 2012 data set

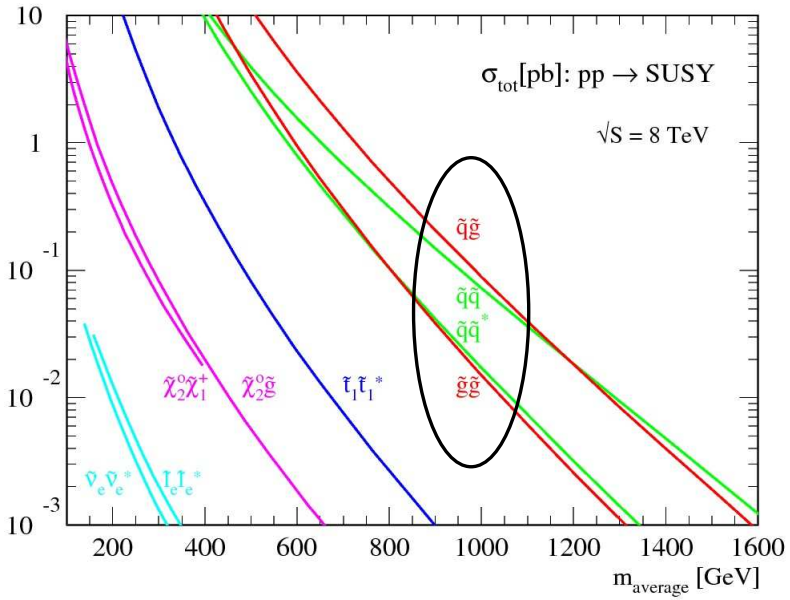
$\int \mathcal{L} dt = 20.3\ \mathrm{fb}^{-1}$



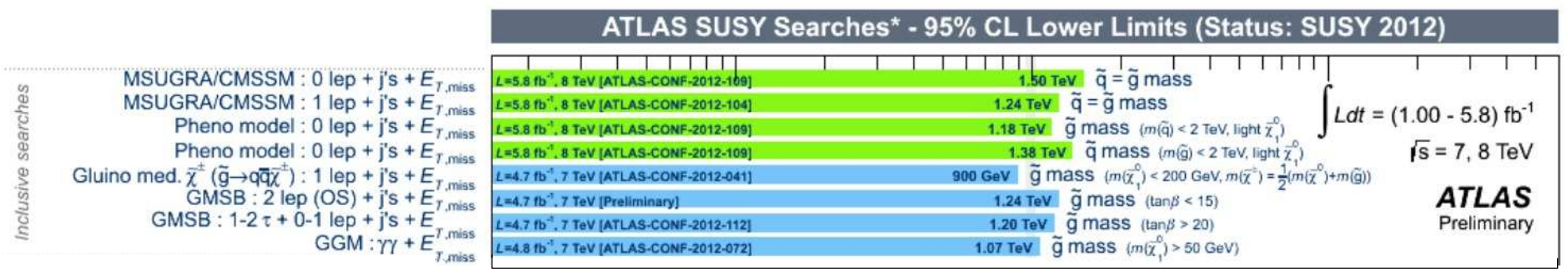
What Are We Looking For?

- Inclusive production of Squarks and Gluinos
  - ▲ Strong production $\Rightarrow$ High cross section
- Inclusive searches have been the work hor–ses since the beginning
  - ▲ The TeV scale was probed already with early searches
  - ▲ But these limits are not universal
    - ▶ Higher masses?
    - ▶ Non degenerate $1^{st}/2^{nd}$ gen. masses?
    - ▶ Compressed spectra?

$\Longrightarrow$ Much more to be explored



Status from last years SUSY 2012 update



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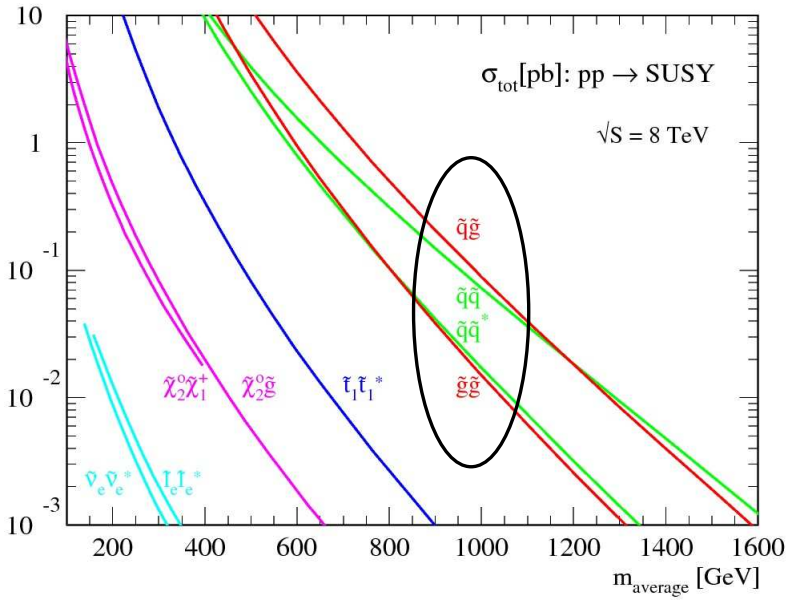
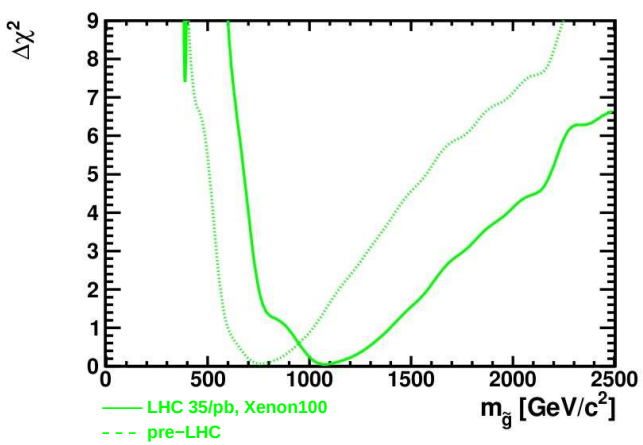
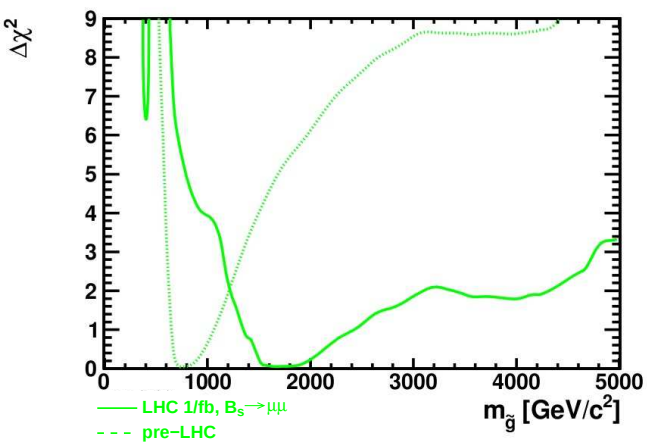


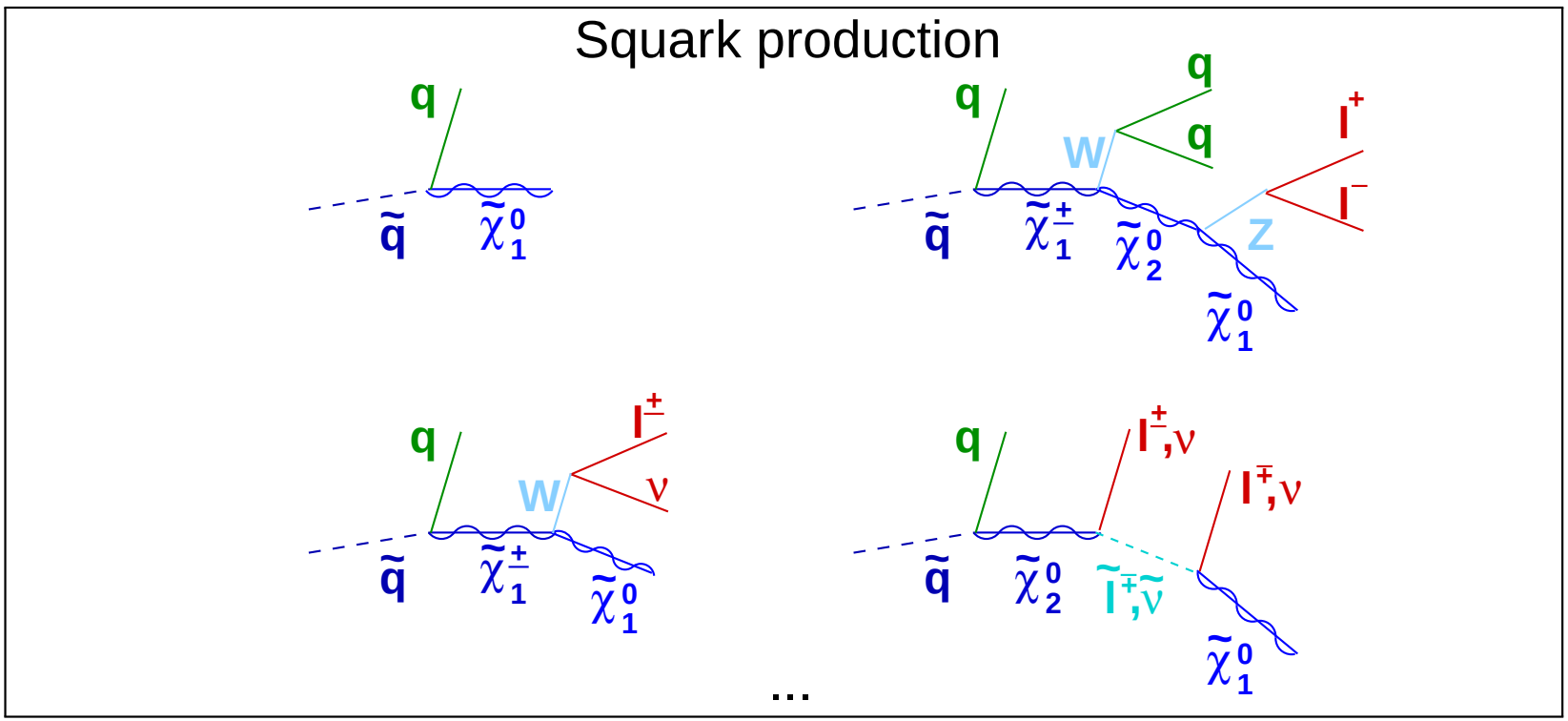




O. Buchmueller et al., 1106.2529 [hep–ph], 1110.3568 [hep–ph]

What Are We Looking For?

- Final states determined by decays chains of Squarks/Gluinos
  - ▲ Decays chains may contain charginos/neutralinos/sleptons/sneutrinos...



- Also consider long decay chains with many particles in the final state
- Final state consists of
  - ▲ k leptons + n jets + missing transverse energy $\not{E}_T$ (k = 0–2, n $\geq$2 to $\geq$10)
  - ▲ Dedicated selections involving third generation particles (eg b–jets)

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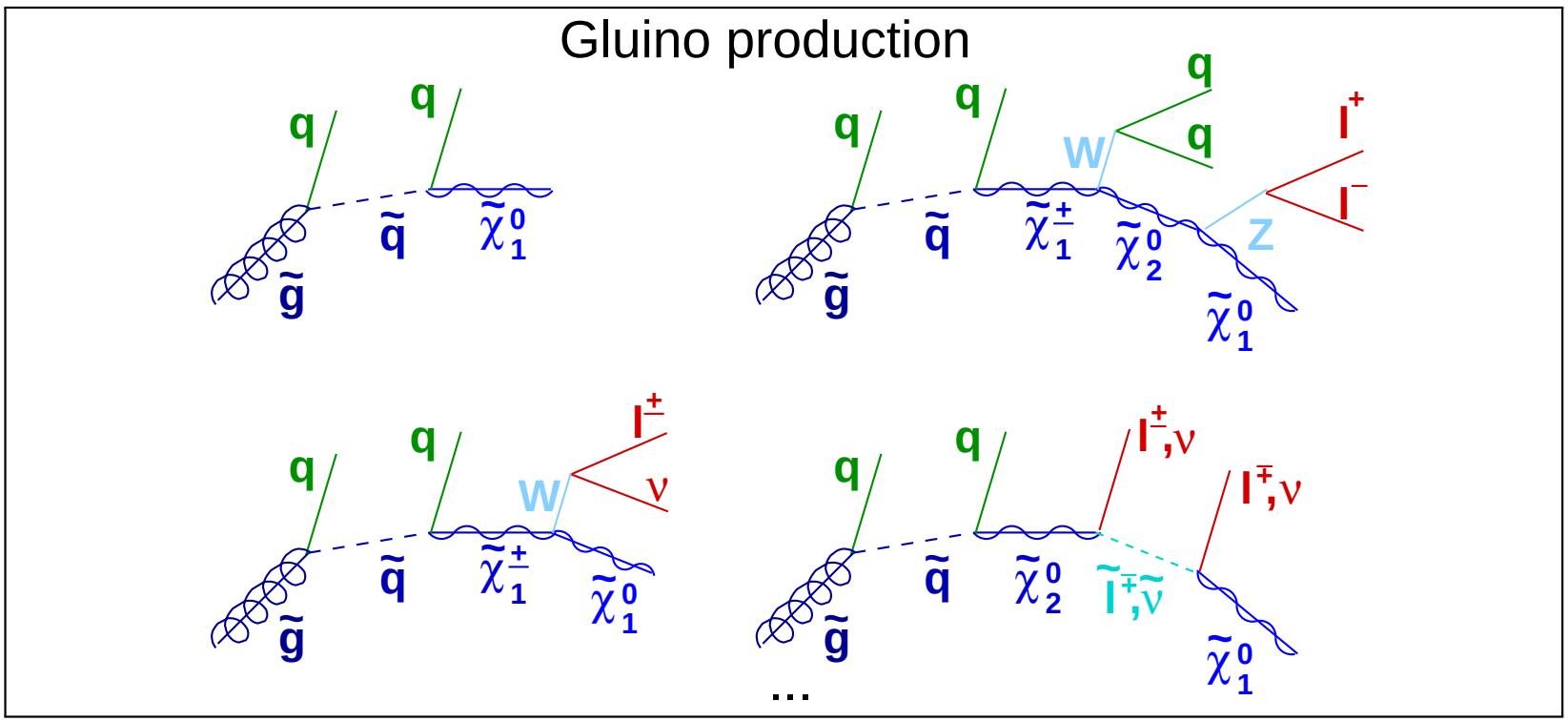

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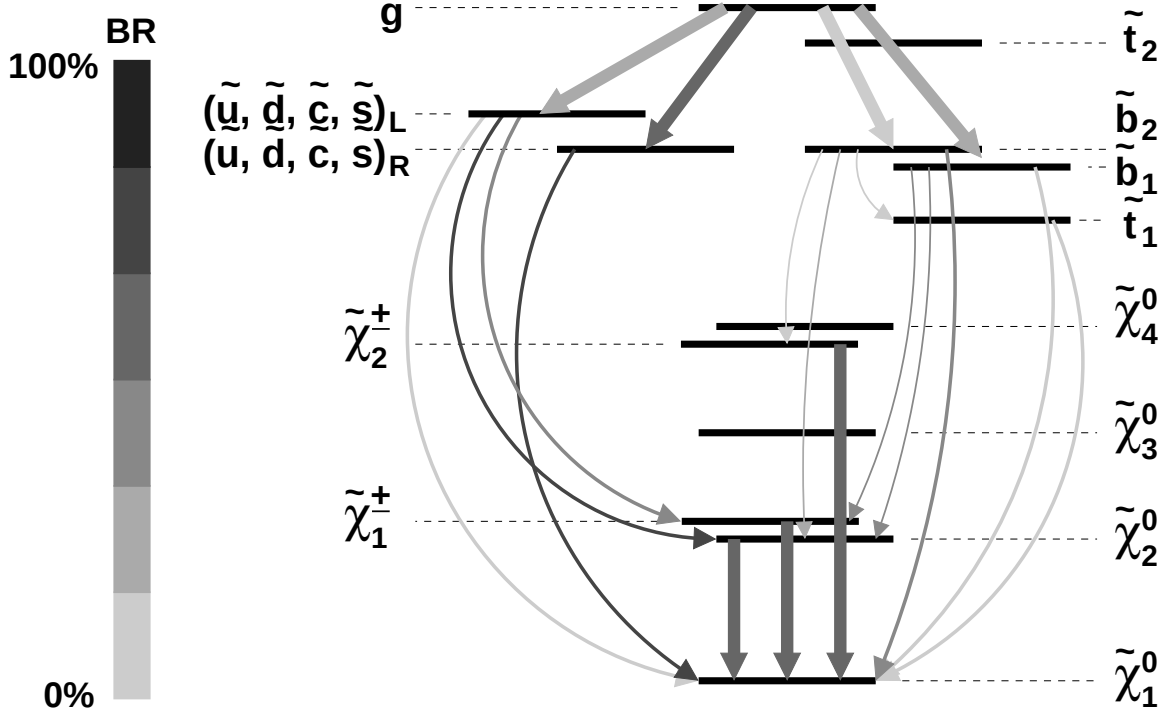

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- Depends on many parameters/masses
- Many decay chains, different final states

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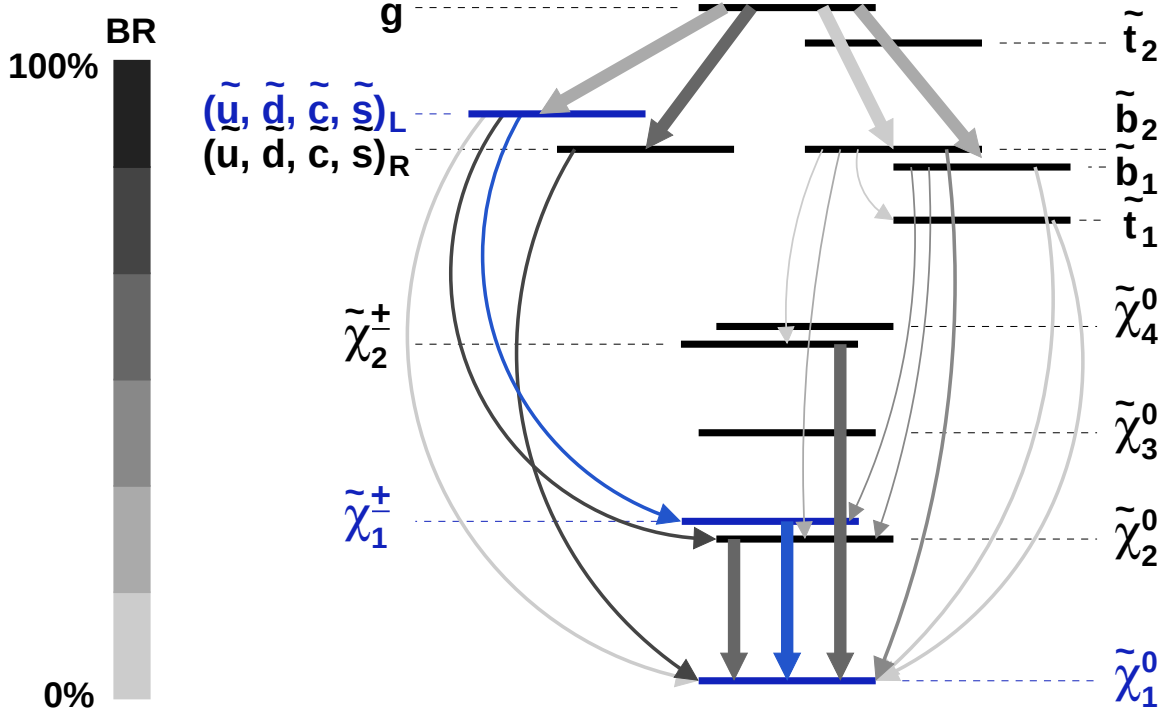

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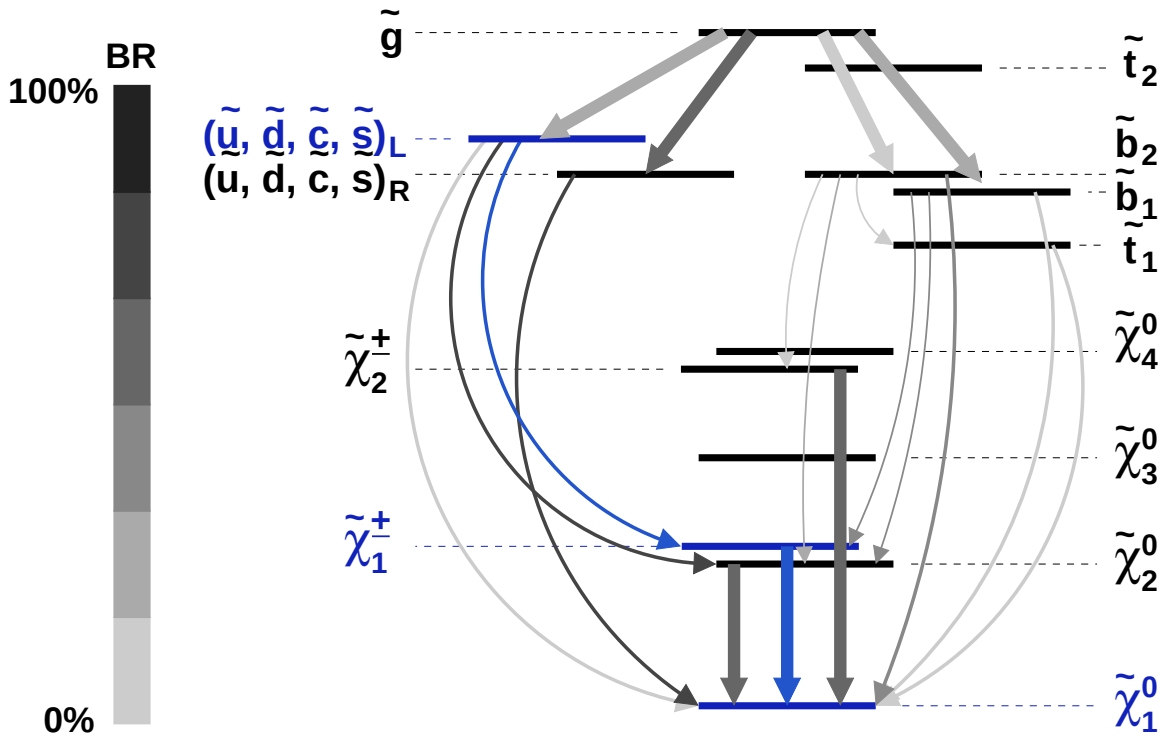

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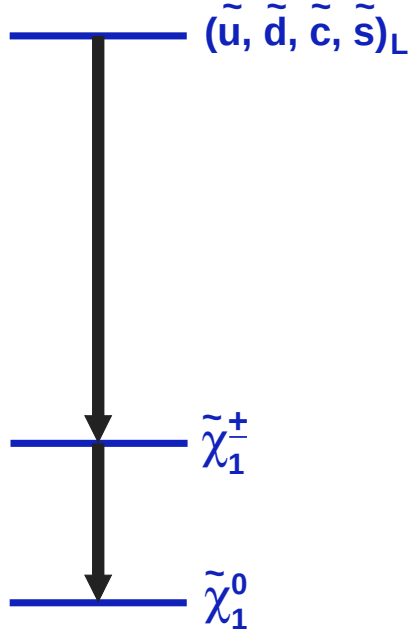
Phenomenological Model

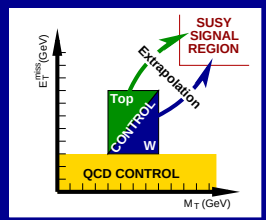


- Study specific decay chain
  - ▲ All other sparticles decoupled
- Only a few parameters/masses
- Easier to study mass dependence

How Are We Doing This?

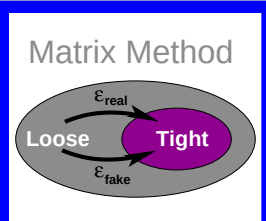
SM Backgrounds:
top pairs, single top, V+jets, dibosons, multijets,...

Main irreducible Backgrounds:
- Normalize MC prediction in dedicated Control Regions
- Extrapolate to Signal Regions using MC



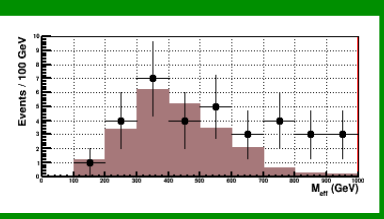
Minor irreducible Backgrounds:
- Pure MC based prediction

Reducible (fake) Backgrounds:
- Fully data driven method
  - Matrix method
  - Jet smearing
  - Templates



Validation Region:
- Cross check back-ground predictions
- Closer to SR

Signal Region:
- Look for excess



Combined global fit:
Consider experimental and theoretical uncertainties

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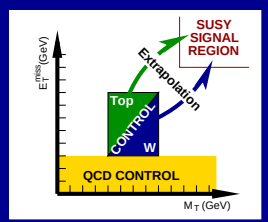

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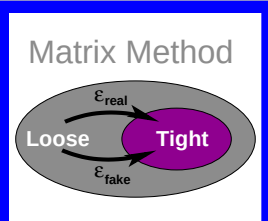

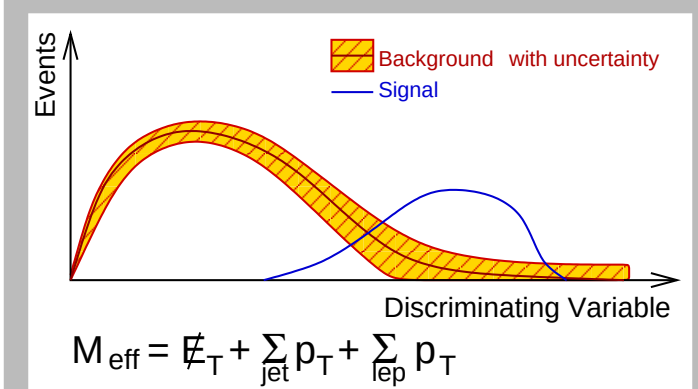

Validation Region:
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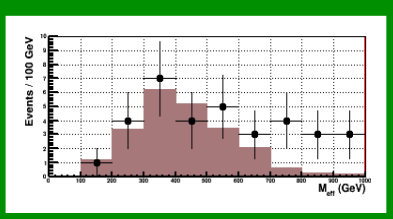

Combined global fit:
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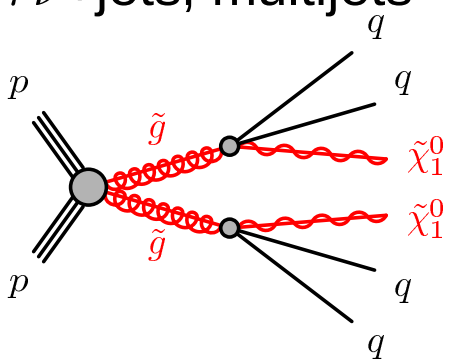
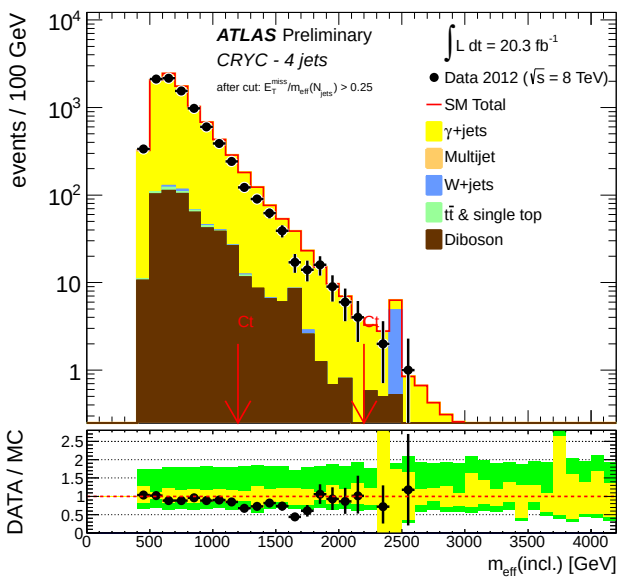
0 Lepton Channel (2–6 Jets)

- 0 lepton channel with veto on any electrons or muons
  - ▲ Pro: Large BR in chains without sleptons, additional jets from W/Z decays
  - ▲ Con: Possibly large backgrounds from Z$\to \nu\nu$+jets, W$\to \tau\nu$+jets, multijets
- Define 10 signal regions based on three requirements
  - ▲ Number of jets: $N_{jets} \geq 2$ to ≥ 6
  - ▲ Effective mass: $M_{eff} > 1000$ to > 2200 GeV
  - ▲ $\not{E}_T$ / M_{eff} ratio: > 0.15 to > 0.4
- Constrain main backgrounds in dedicated control regions
  - ▲ 4 CRs per signal region



CR	SM Process	CR Process	CR Selection
CRY	$Z \to \nu\nu + jets$	$\gamma + jets$	Isolated photon
CRW	$W \to \ell\nu + jets$	$W \to \ell\nu + jets$	trans. mass, b-veto
CRT	$t\bar{t}$ and single top	$t\bar{t}$ and single top	trans. mass, b-tag
CRQ	multijets	multijets	Reverse anti QCD cuts



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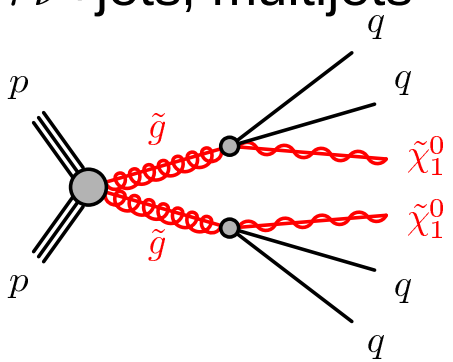

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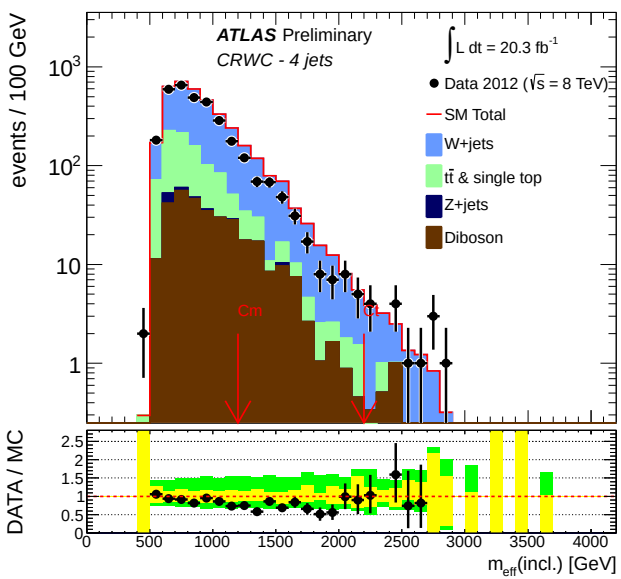

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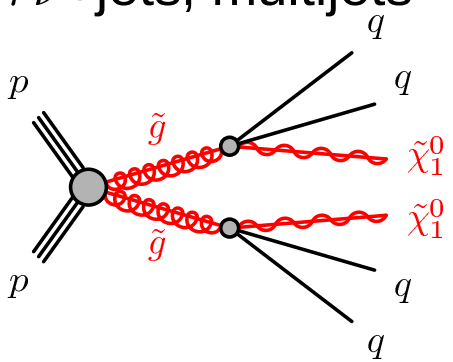

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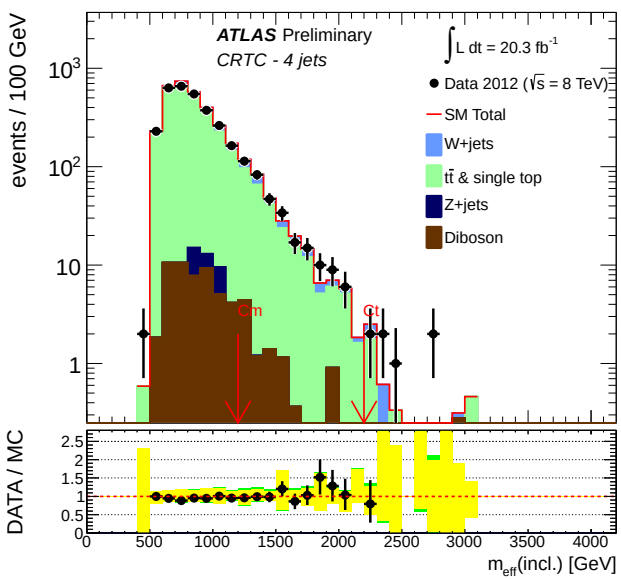
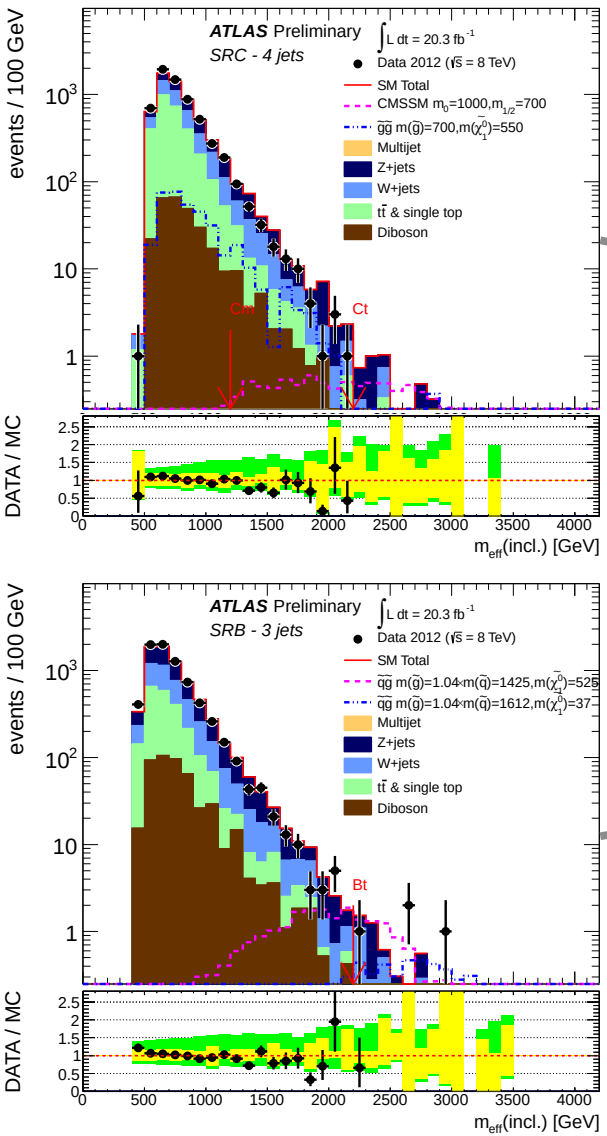


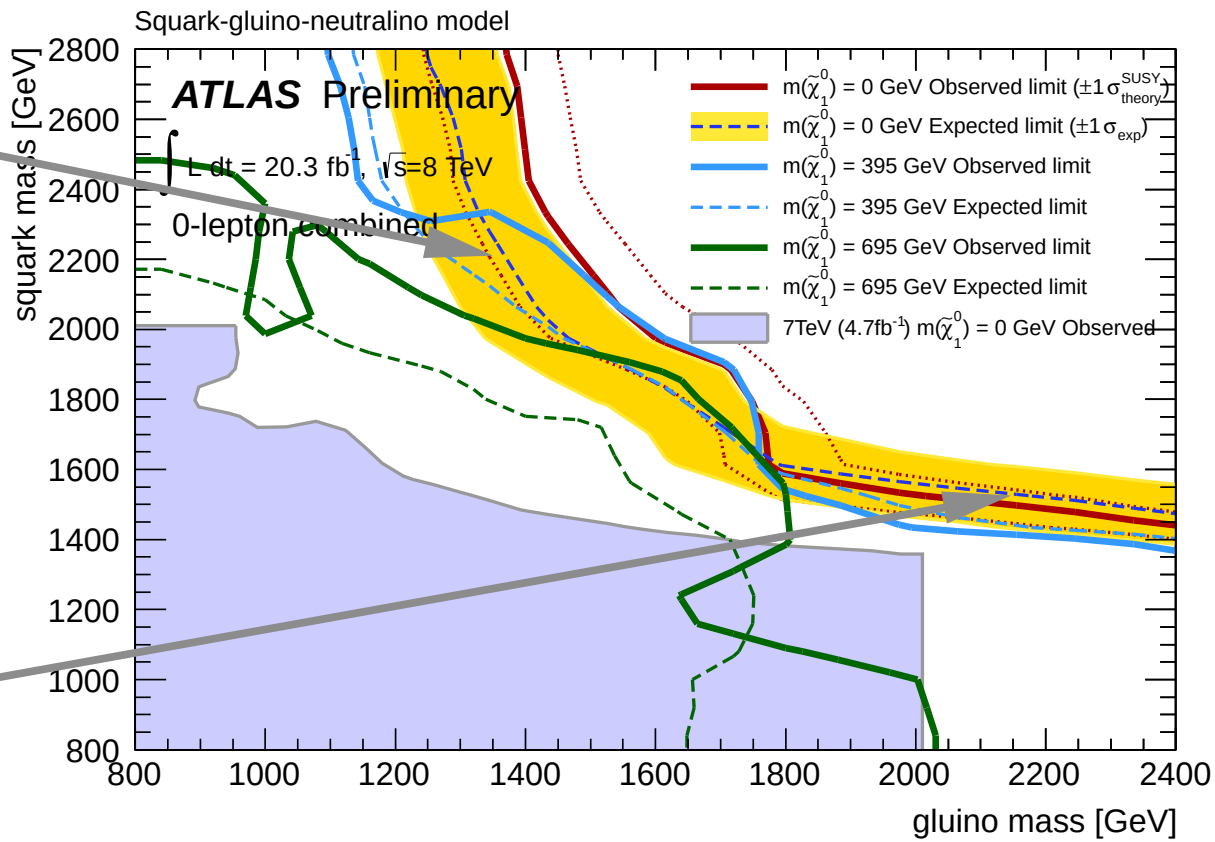
- Importance increases with increasing N_{jets}

0 Lepton (2–6 Jets) Selected Results ATLAS-CONF-2013-047

M_{eff} distributions in SR



Squark/Gluino pair production, direct decay to LSP
all other SUSY particles are decoupled



- Exclude Gluino (Squark) masses of 1.25 (1.4) TeV for all Squark (Gluino) masses and massless $\tilde{\chi}_1^0$
  - ▲ Limits degrade if spectrum is more compressed

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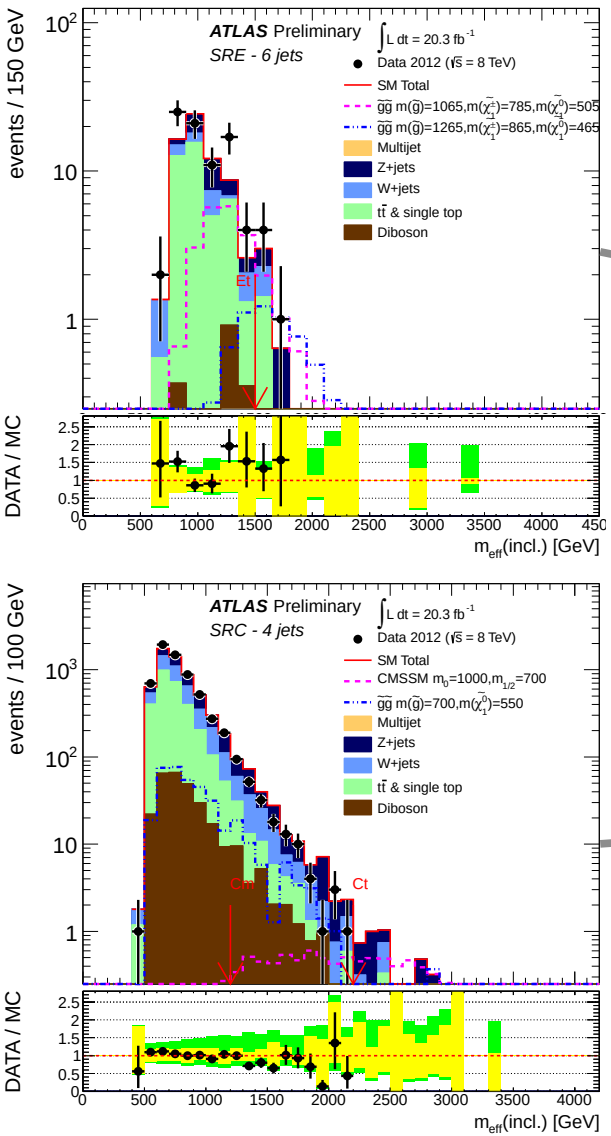

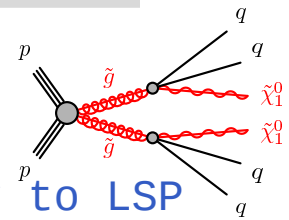

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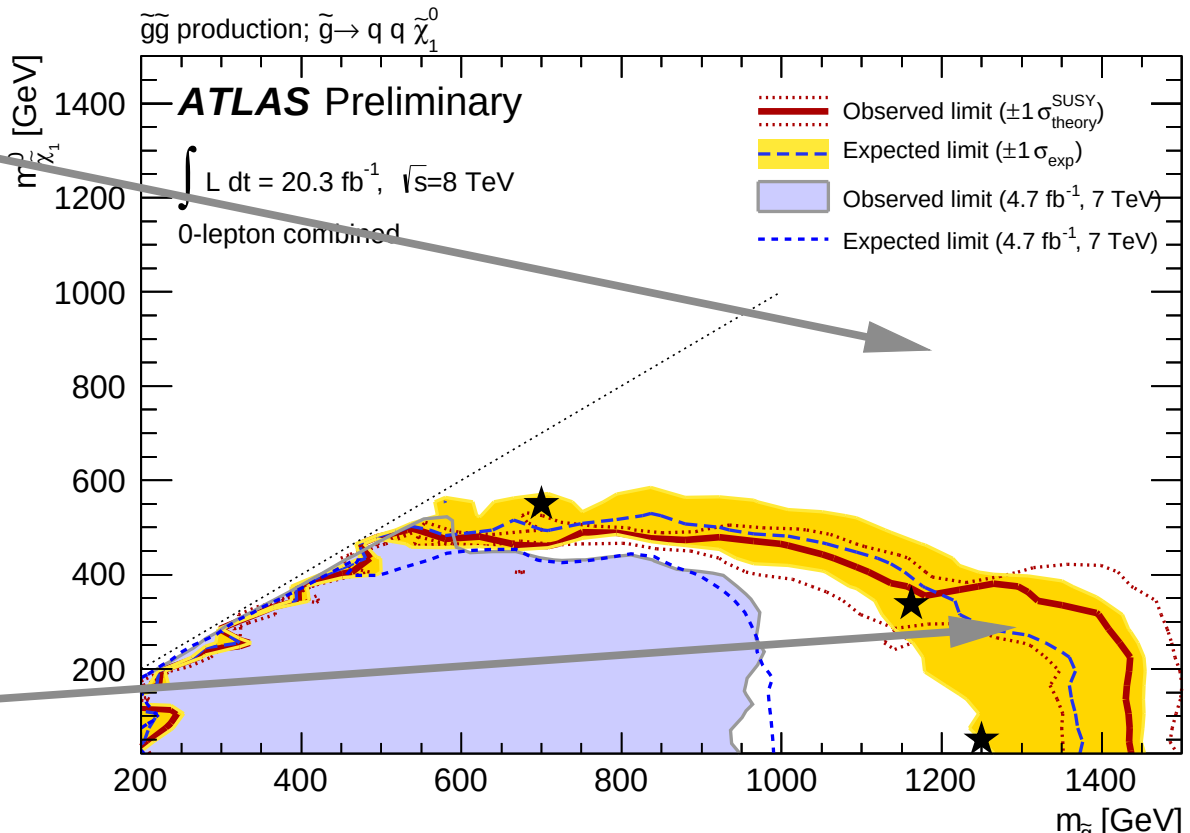
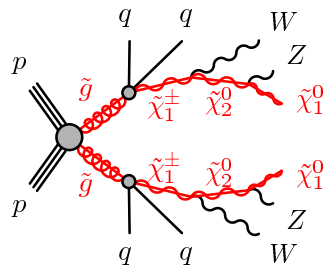


- Exclude Gluinos below 1.35 TeV for massless $\tilde{\chi}_1^0$
- Exclude Squarks (1st, 2nd generation) below 780 GeV for massless $\tilde{\chi}_1^0$

Multijets Channel (7 to $\geq$ 10 Jets)

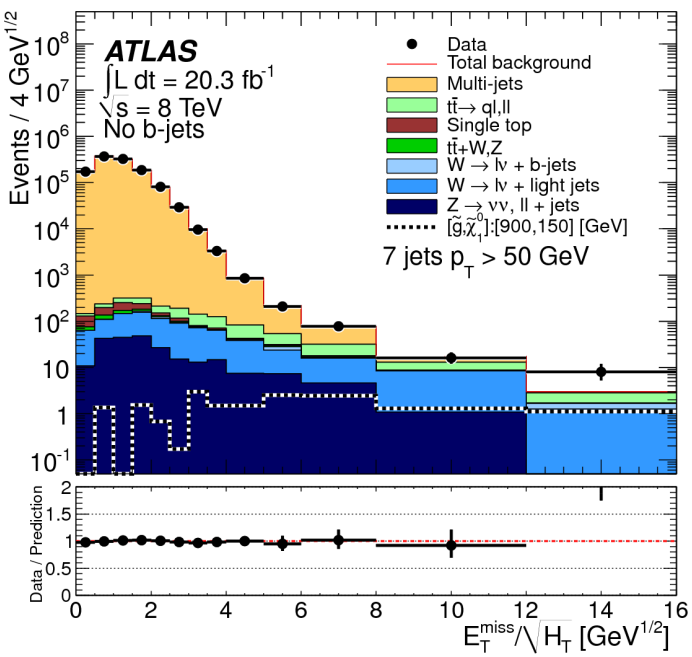
arXiv:1308.1841 [hep-ex]

- Increase jet multiplicity $\Longrightarrow$ Longer decay chains
  - ▲ Interpretation in various models, in particular those with many neutralinos/charginos in decay chain
  - ▲ Also divide channels by b–jet multiplicity (0–2)

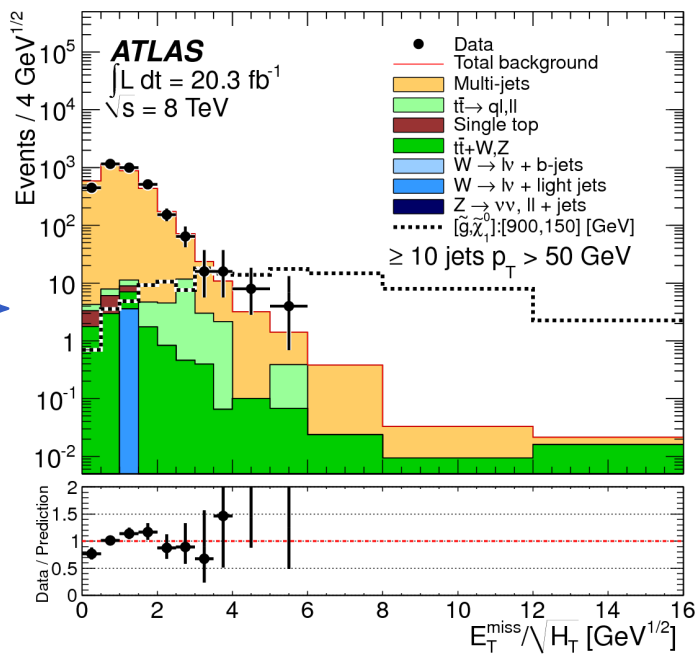


- Main discriminating variable $\not{E}_T/\sqrt{H_T} \Longrightarrow$ Almost independent of N_{jets}
  - ▲ Use shape in data from lower jet multiplicities to model multijets background
  - ▲ Use same number of b–jets in CR and SR to get the template for every SR
  - ▲ Only need to adjust out of cone energy for every N_{jets} bin

Control Region (7 jets)



Signal Region ($\geq$ 10 jets)



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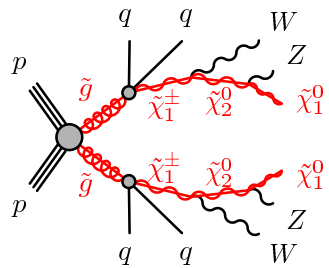
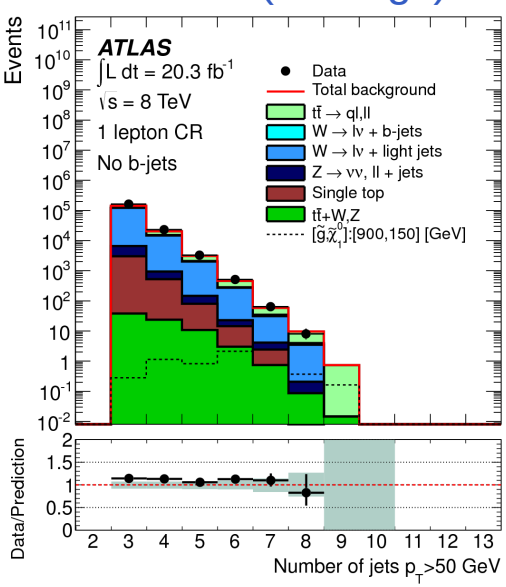


- Main discriminating variable $\not{E}_T/\sqrt{H_T} \Longrightarrow$ Almost independent of N_{jets}
- Other main backgrounds ($t\bar{t}$ and $W \to \ell\nu$+jets) normalized in 1/2 lepton CRs
  - ▲ Apply M_T and $\not{E}_T$ (1ℓ) or $m_{\ell\ell}$ (2ℓ) requirements
  - ▲ In 1ℓ CRs count leptons as jets (add to H_T)
  - ▲ In 2ℓ CRs treat leptons as neutrinos (add to $\not{E}_T$)

1ℓ CR (0 b-tags)



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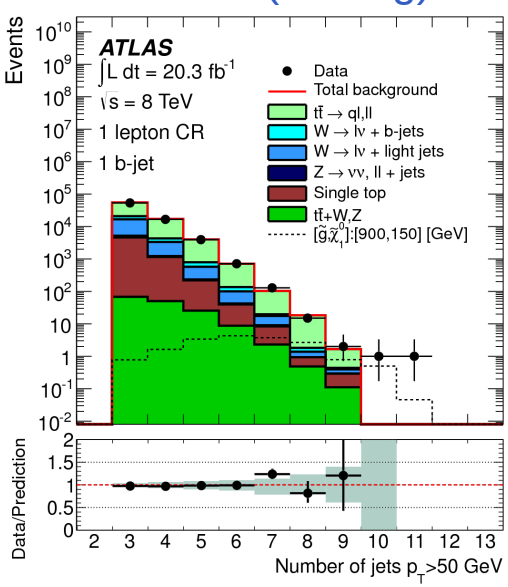
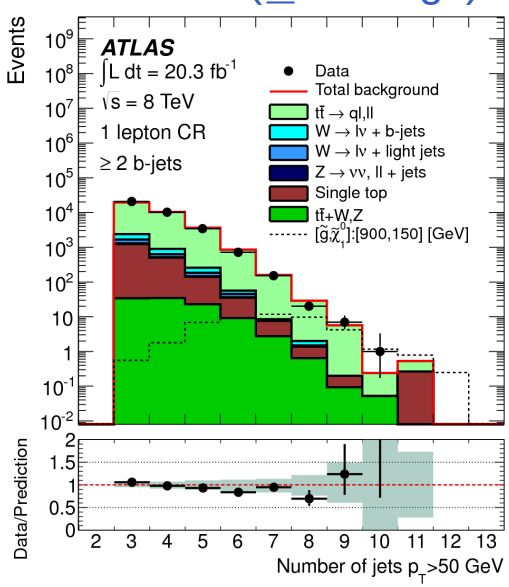


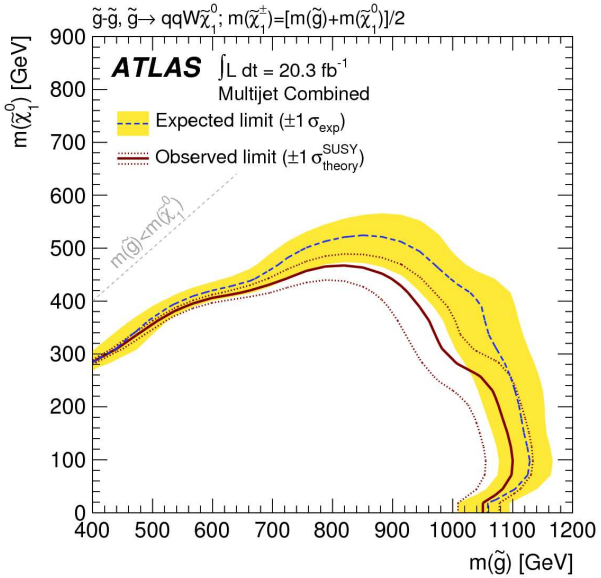
1ℓ CR ($\geq$ 2 b-tags)

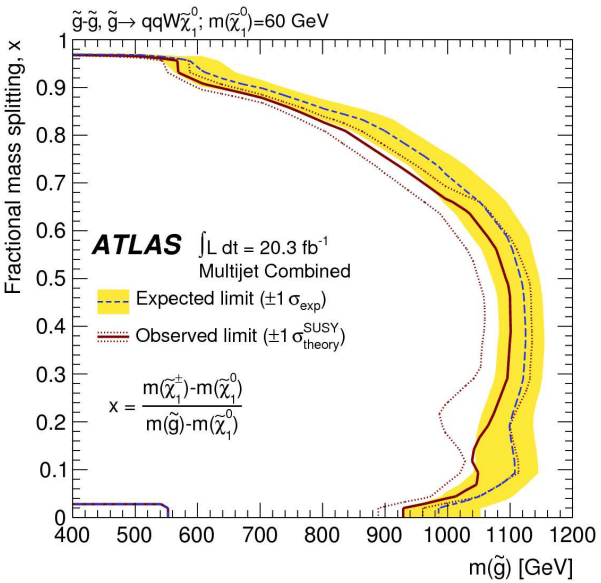


Multijets Channel Results

arXiv:1308.1841 [hep-ex]

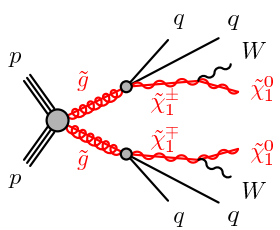
Decays via W boson





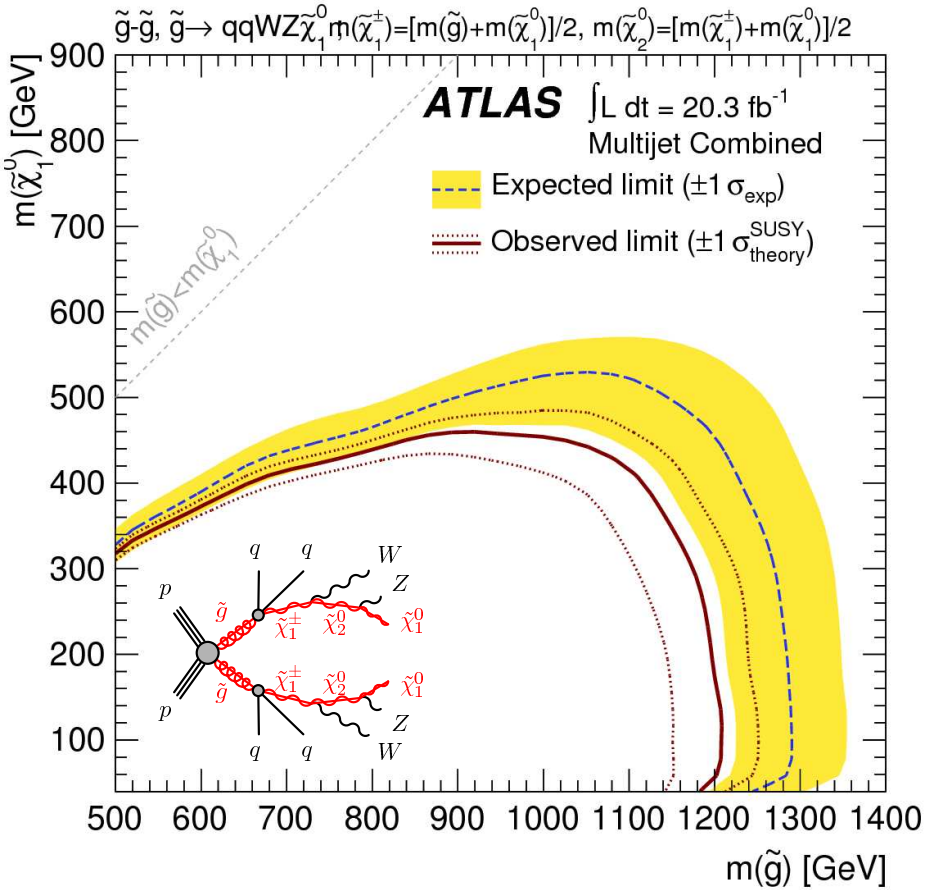
Gluino pair production

$$\Leftarrow x = \frac{m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}} - m_{\tilde{\chi}_1^0}} = \frac{1}{2}$$



$$\Leftarrow x = 0 - 1$$
$$m_{\tilde{\chi}_1^0} = 60\ \text{GeV}$$

Decays via W and Z bosons



- Exclude Gluino masses below 1 TeV (1.1 TeV) for the decays via W (W and Z) boson and $m_{\tilde{\chi}_1^0} < 200$ (300) GeV

  $\Rightarrow$ For interpretation in Gtt grid see talk from M. Barisonzi (Th. 14:30)

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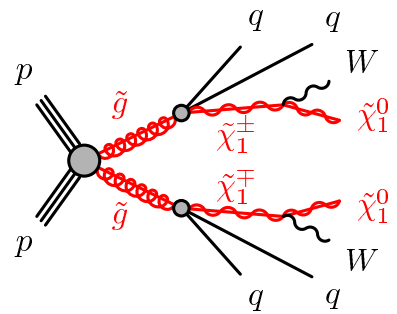
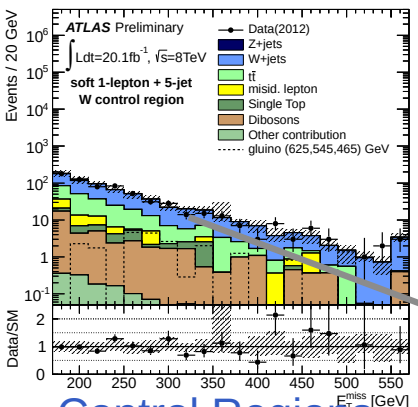
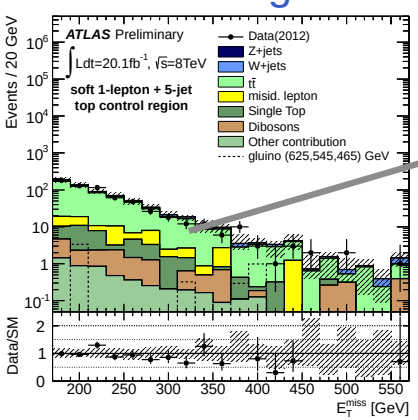
1 Lepton Channel

- Require exactly one lepton + $\geq$ 3–6 jets + $\not{E}_{\mathrm{T}}$
  - ▲ Soft lepton selection extends reach to compressed scenarios
- Main cuts for background suppression
  - ▲ $\not{E}_{\mathrm{T}}$ and $\mathrm{M_{eff}}$ ($p_T^{\ell} > 25$ GeV) and $\not{E}_{\mathrm{T}}$ and $\not{E}_{\mathrm{T}}$ / $\mathrm{M_{eff}}$ ($p_T^{\ell} \in$[6/10,25] GeV)

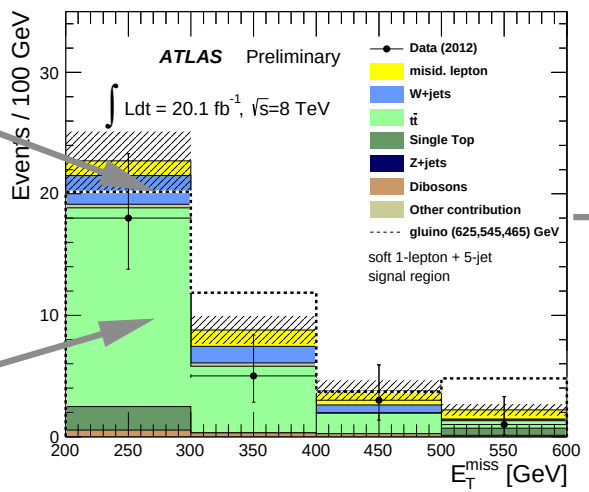




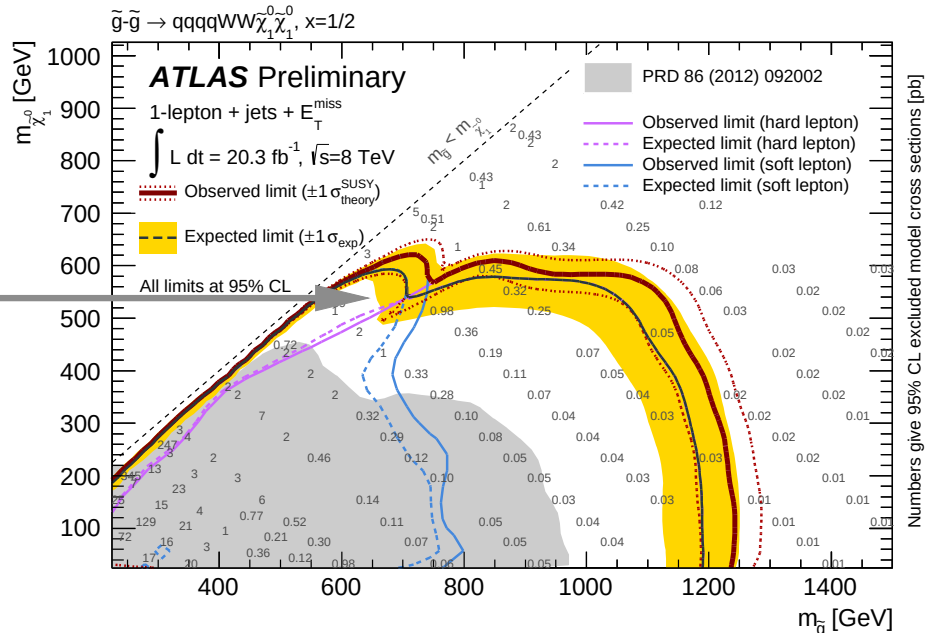
Control Regions



Soft Lepton Signal Region



Simplified 1 Step Gluino Gluino Model

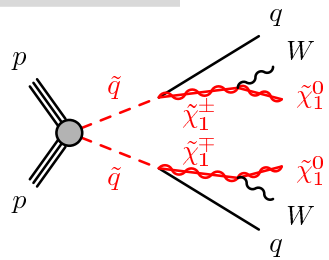


- Exclude Gluinos below 700 GeV for all $\Delta m(\tilde{g}, \tilde{\chi}_1^0) > 25$ GeV

2 Lepton Channel (Razor)

NEW

ATLAS-CONF-2013-089



- Search for dileptonic final states without Z bosons in the final state using the razor variables
- Razor variables
  - Build two mega-jets j_1, j_2 from visible decay products
  - Longitudinal: $M'_R = \sqrt{(j_{1,E} + j_{2,E})^2 - (j_{1,p_L} + j_{2,p_L})^2}$
  - Transverse: $M_T^R = \sqrt{\frac{|\not{\vec{E}}_T|(|\vec{j}_{1,p_T}|+|\vec{j}_{2,p_T}|) - \not{\vec{E}}_T \cdot (\vec{j}_{1,p_T}+\vec{j}_{2,p_T})^2}{2}}$

$$\Longrightarrow R = \frac{M_T^R}{M'_R}$$

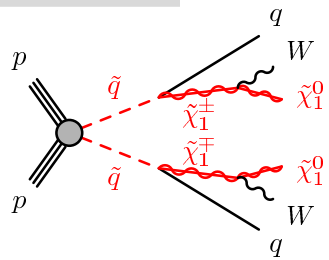
Signal Region definition

Region	Flavor	Z-veto	N_{jets}	R	M'_R (GeV)
SR1	$ee/\mu\mu$	yes	< 3	> 0.5	> 400
SR1	$e\mu$	no	< 3	> 0.5	> 400
SR2	$ee/\mu\mu$	yes	> 2	> 0.35	> 800
SR2	$e\mu$	no	> 2	> 0.35	> 800

2 Lepton Channel (Razor)

NEW

ATLAS-CONF-2013-089



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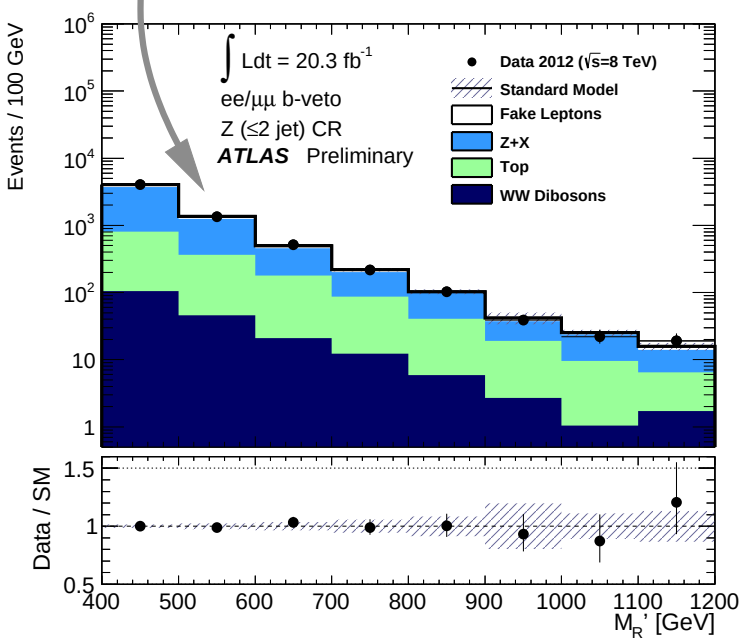
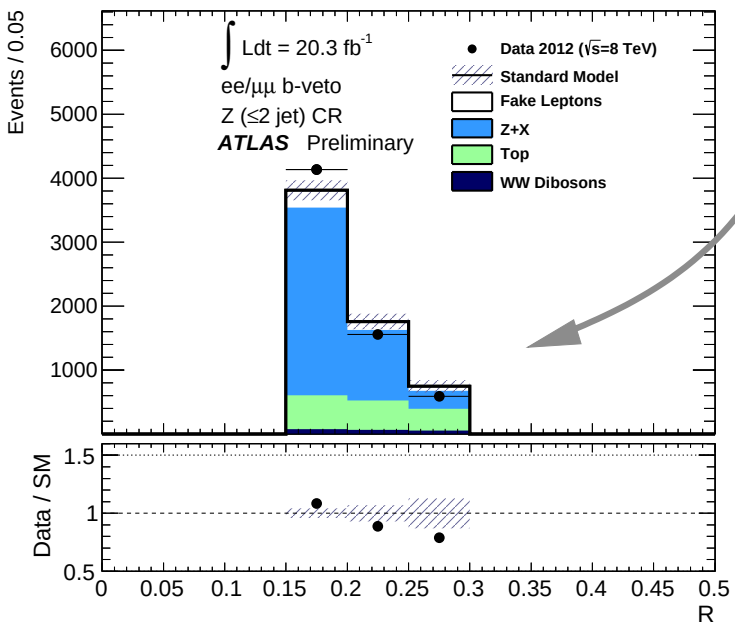
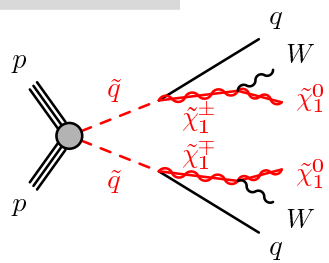




2 Lepton Channel (Razor)

NEW

ATLAS-CONF-2013-089



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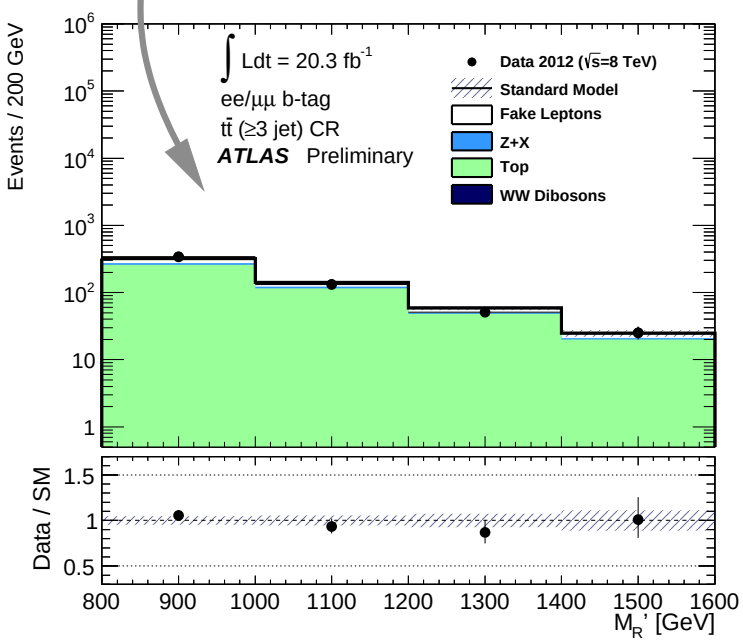
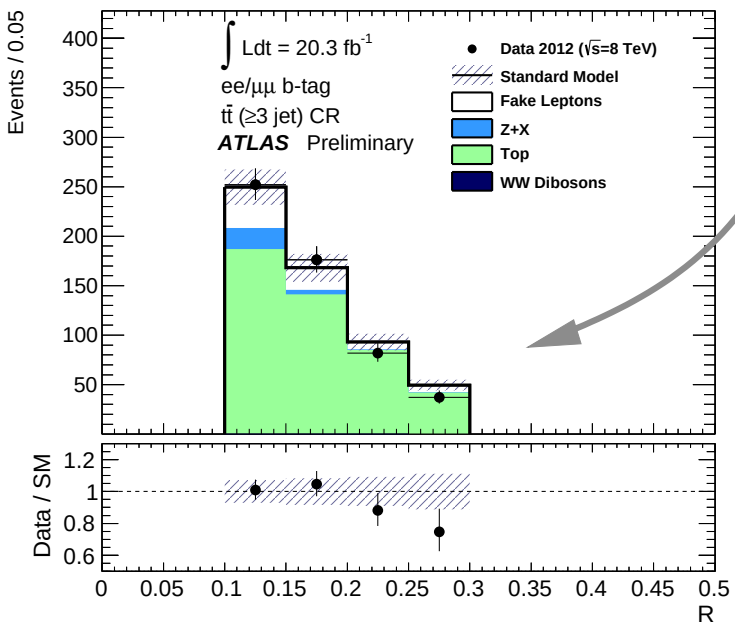
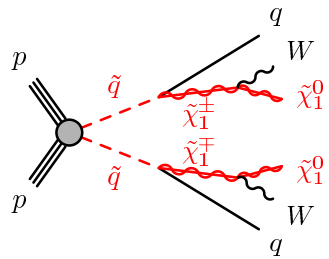




2 Lepton Channel (Razor)

NEW

ATLAS-CONF-2013-089



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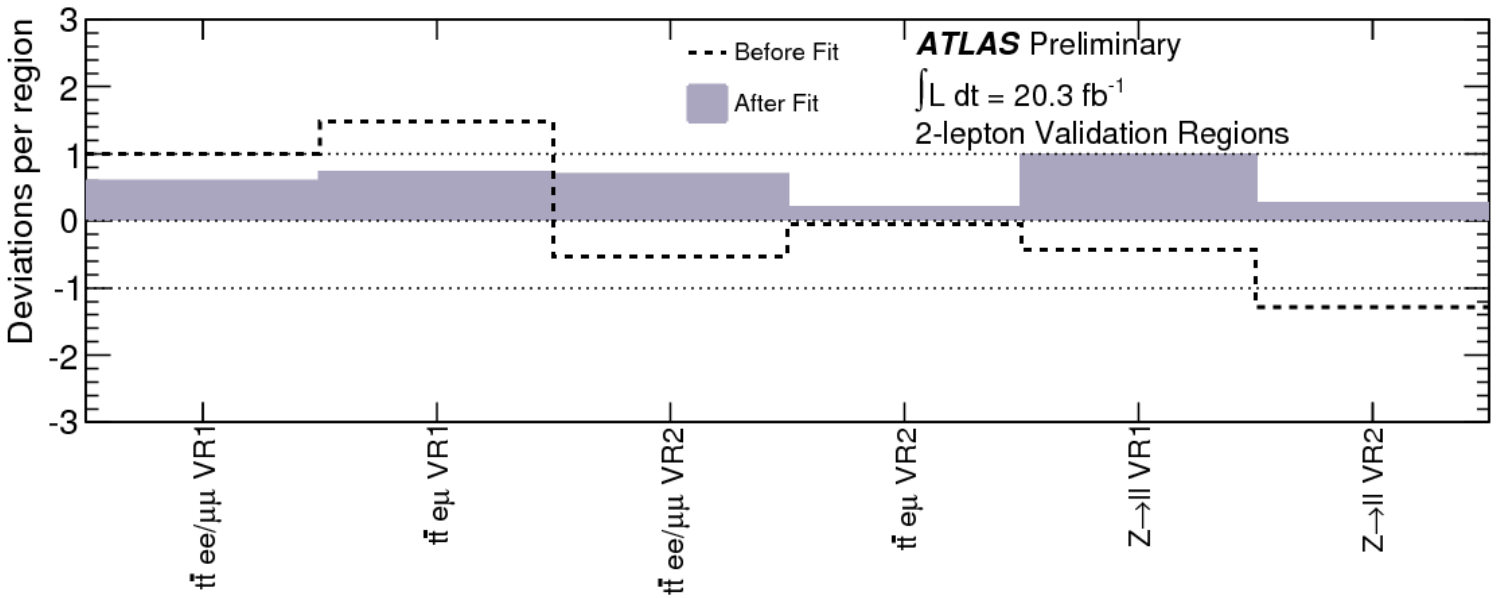
$$\Longrightarrow R = \frac{M_T^R}{M_R'}$$

Check CR→SR extrapolation in Validation Regions at lower M_R'



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2 Lepton Channel (Razor)

NEW

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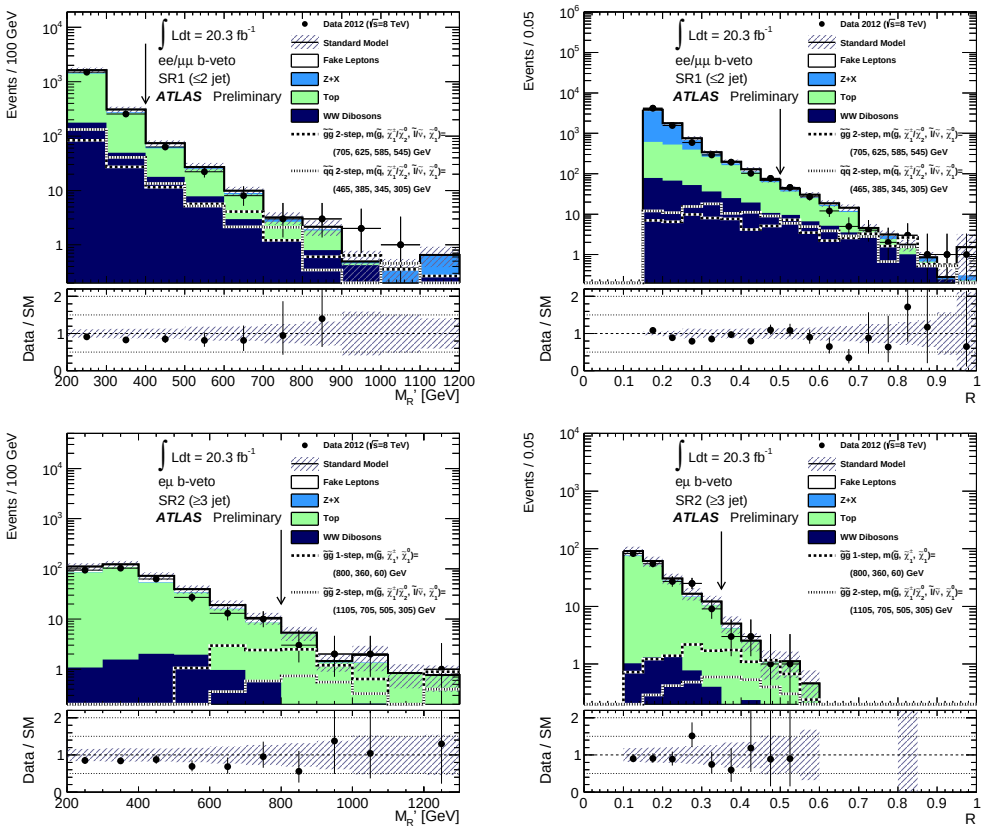
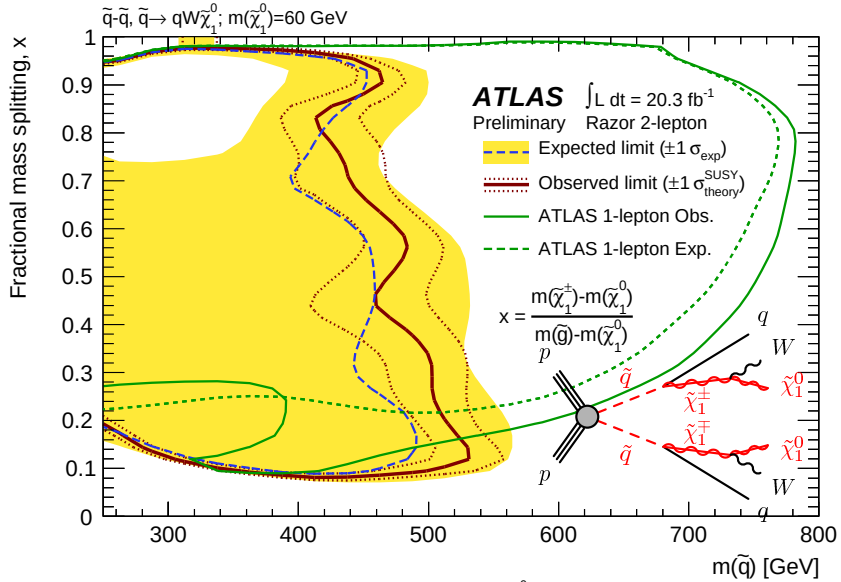
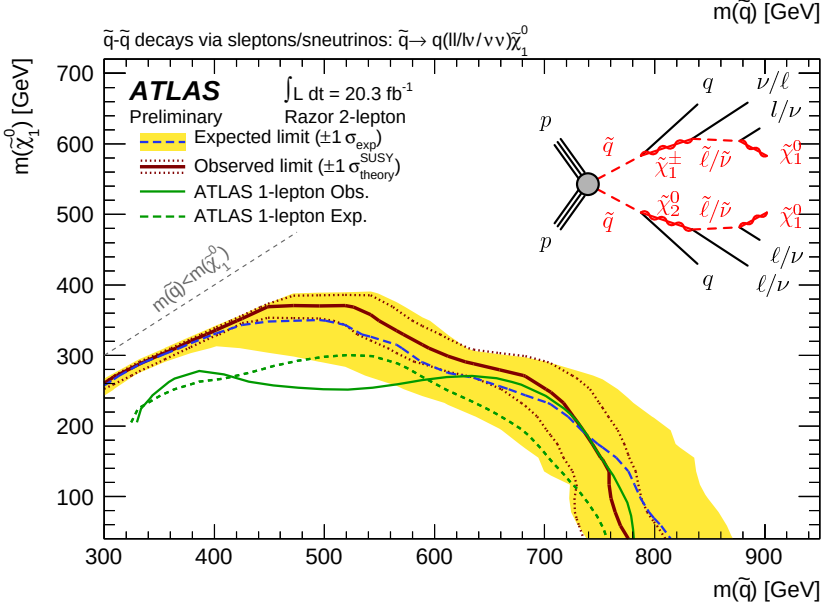
Region	SR 1 $ee/\mu\mu$	SR 1 $e\mu$	SR 2 $ee/\mu\mu$	SR 2 $e\mu$
Data	102	87	8	8
Background	117±16	103±15	11±3	10±3



Squark pair production





- Extend limits towards smaller mass differences

2 Lepton Channel (Razor)

NEW

ATLAS-CONF-2013-089

Region	SR 1 $ee/\mu\mu$	SR 1 $e\mu$	SR 2 $ee/\mu\mu$	SR 2 $e\mu$
Data	102	87	8	8
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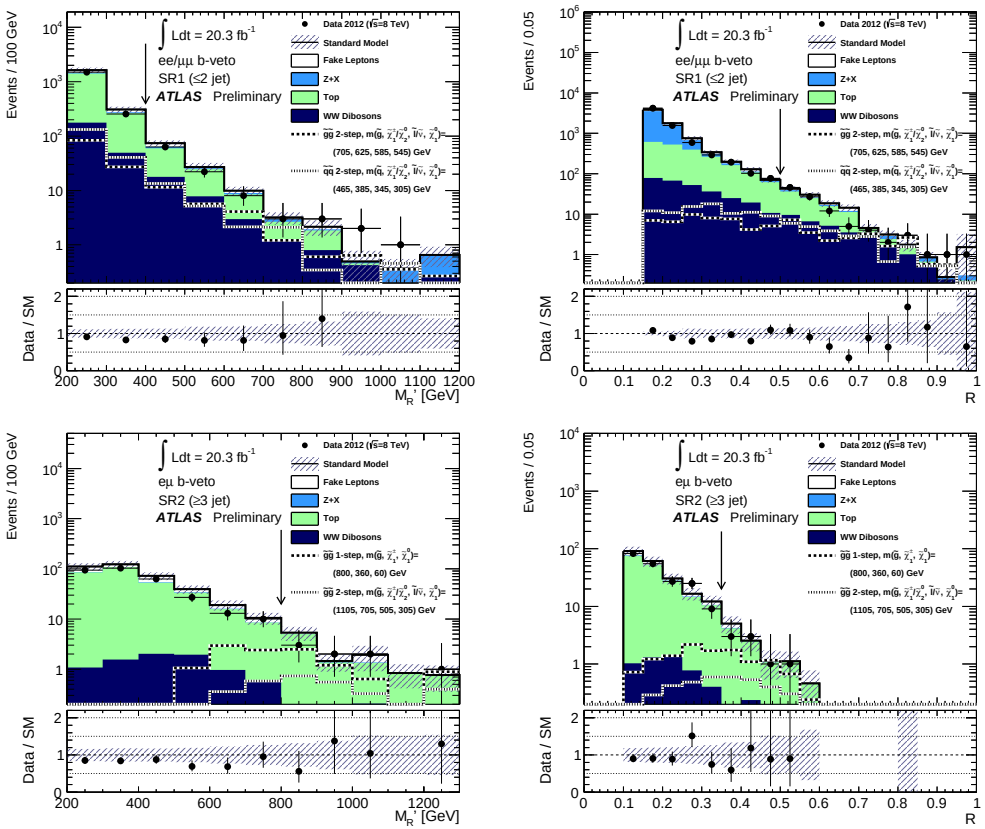
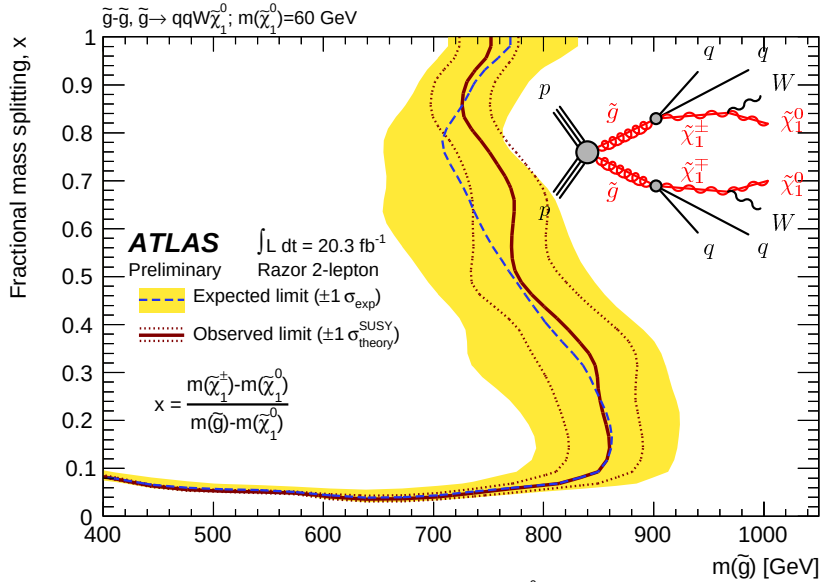
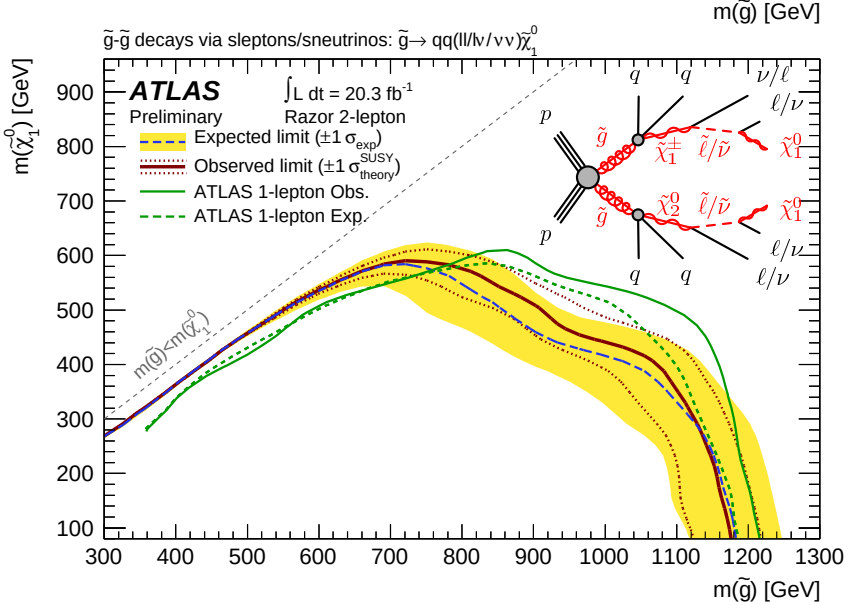


Gluino pair production



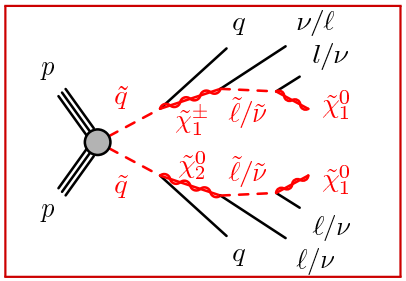


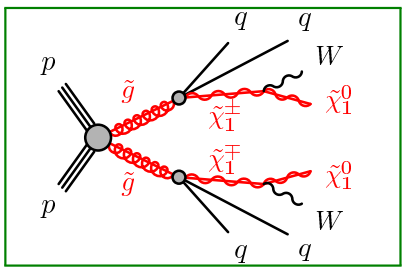
- Extend limits towards smaller mass differences

2 Lepton Channel (Same Sign)

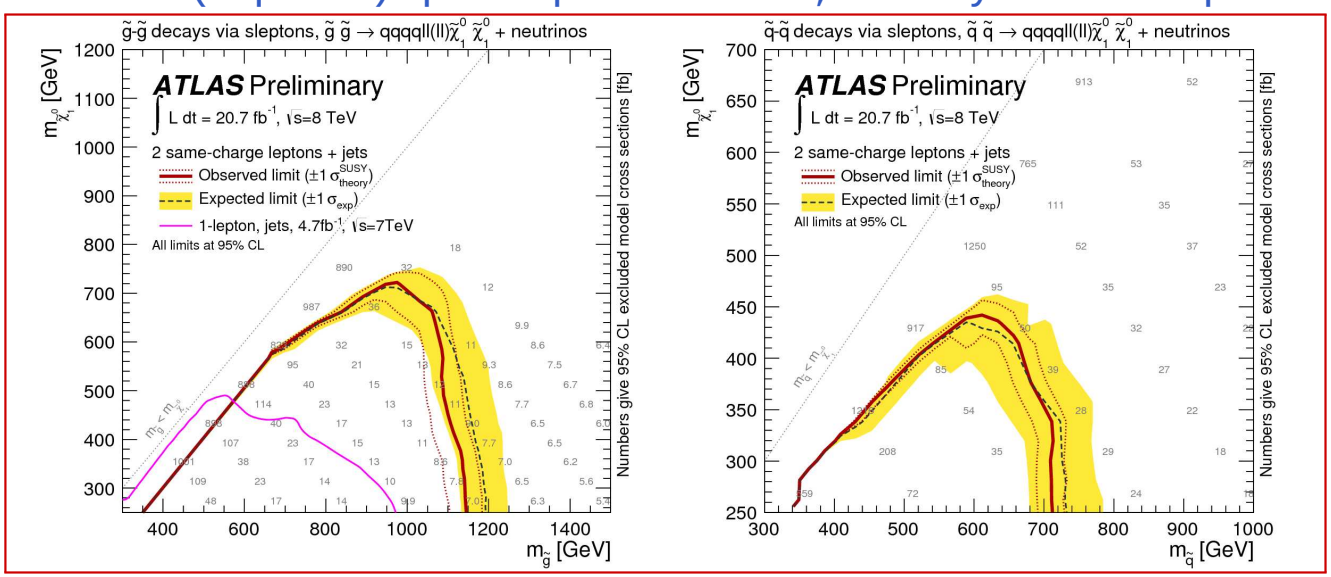
ATLAS-CONF-2013-007

- Same sign requirement has only tiny irreducible backgrounds
  - ▲ Dominated by $t\bar{t}$+V and diboson (WZ/ZZ+jets) background
- Other sources are charge misidentification (Z+jets) and fake lepton ($t\bar{t}$ and W+jets) backgrounds
  - ▲ Charge misidentification (only e): Measure charge mis–identification probability and apply to opposite sign events
  - ▲ Fake leptons: Use matrix method
- Discriminate background using $\not{E}_T$, M_{eff} and b-multiplicity

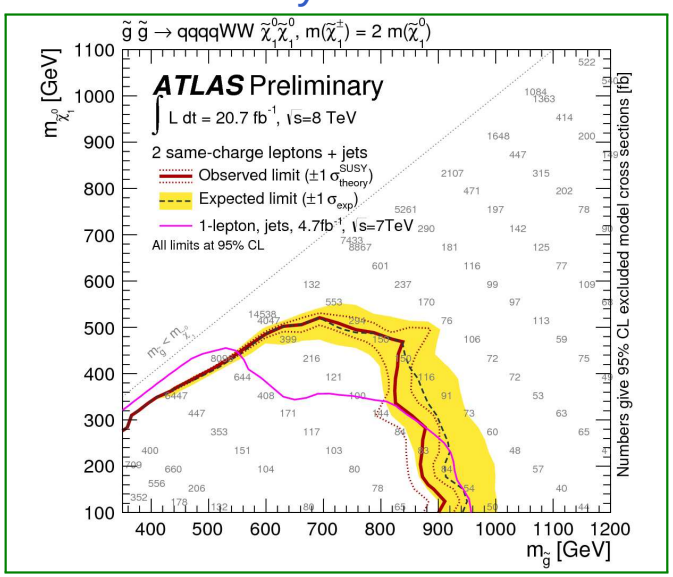




Gluino (Squark) pair production, decay via Sleptons



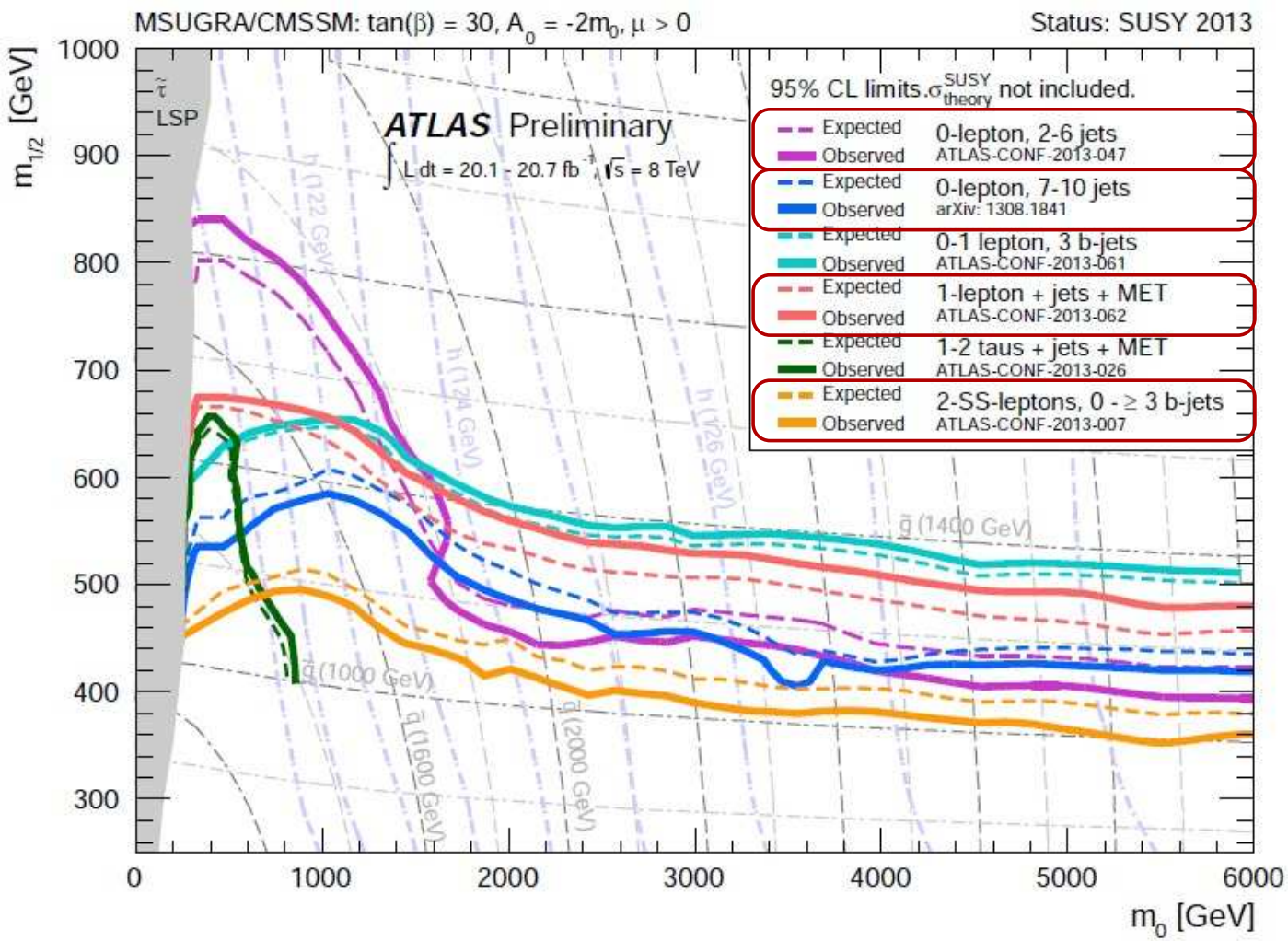
decay via W bosons



For more details see talk from M. Barisonzi (Th. 14:30)

MSUGRA/CMSSM Scenario

- MSUGRA/CMSSM scenario still a viable model to compare different analyses
  - ▲ Grid designed to meet the Higgs mass constraint



- Exclude Gluino masses below 1.35 TeV for all Squark masses

MSUGRA/CMSSM Scenario

- MSUGRA/CMSSM scenario still a viable model to compare different analyses
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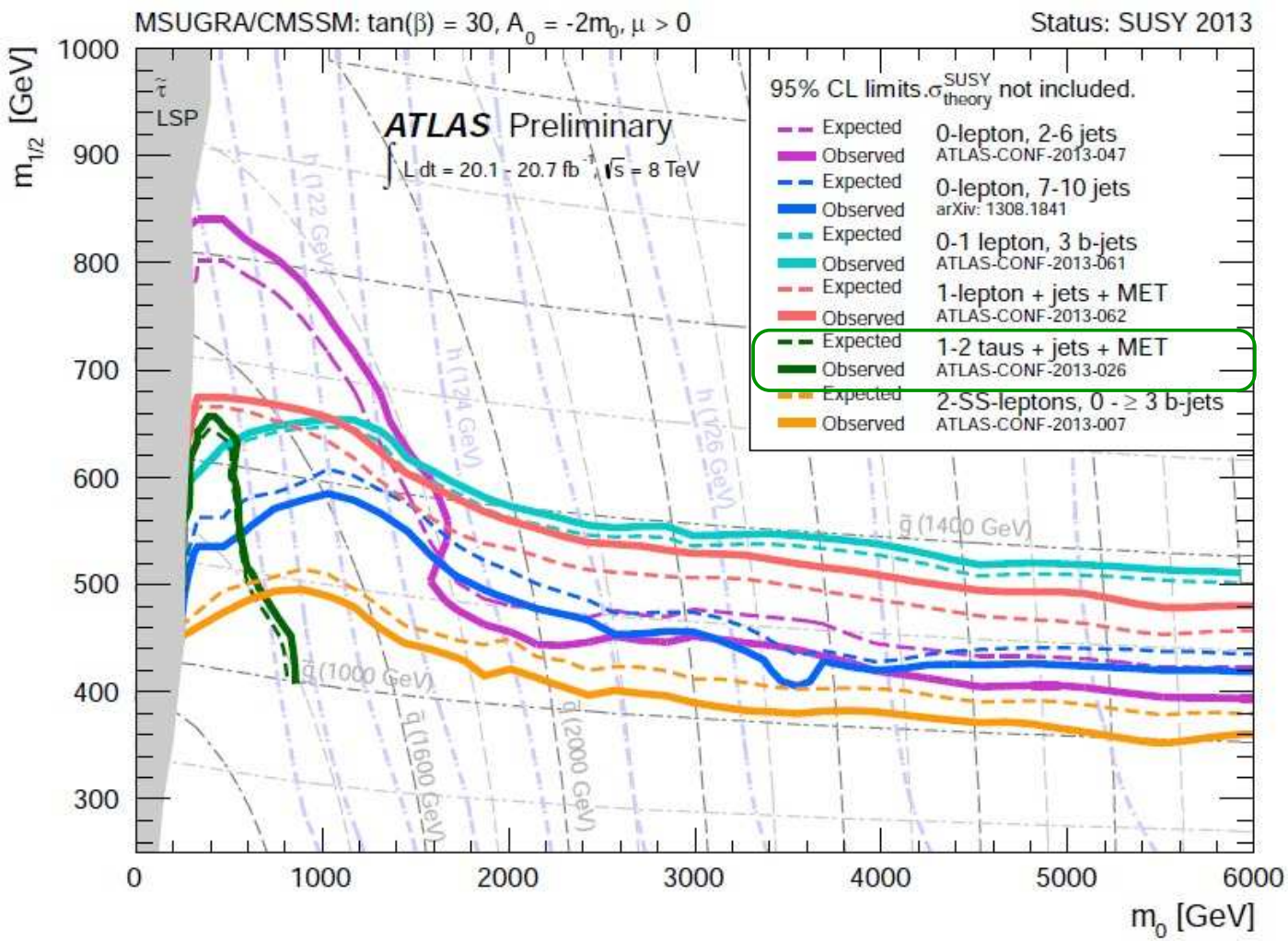
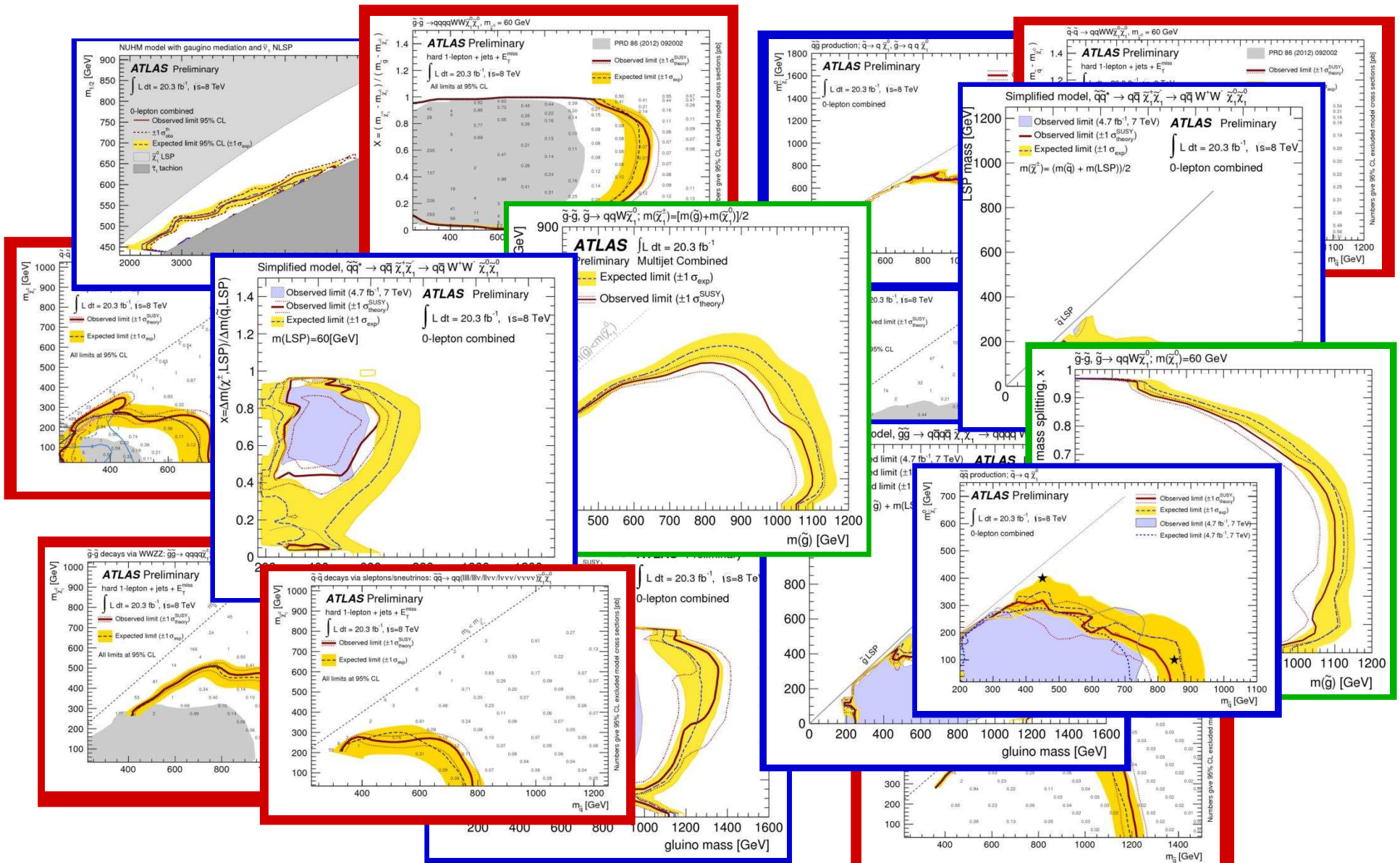


- Also dedicated inclusive search with τ-leptons $\Longrightarrow$ See talk from M. Tripiana (Tu. 14:30)

Many More Results From Inclusive Searches



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

Conclusion and Outlook

- ATLAS has extensively mined the data in search for supersymmetry
- The scope of the inclusive analyses has been broadened to cover more challenging scenarios
- Mass limits are pushed further into the TeV range
  - ▲ Limits up to 1.7 TeV for specific scenarios

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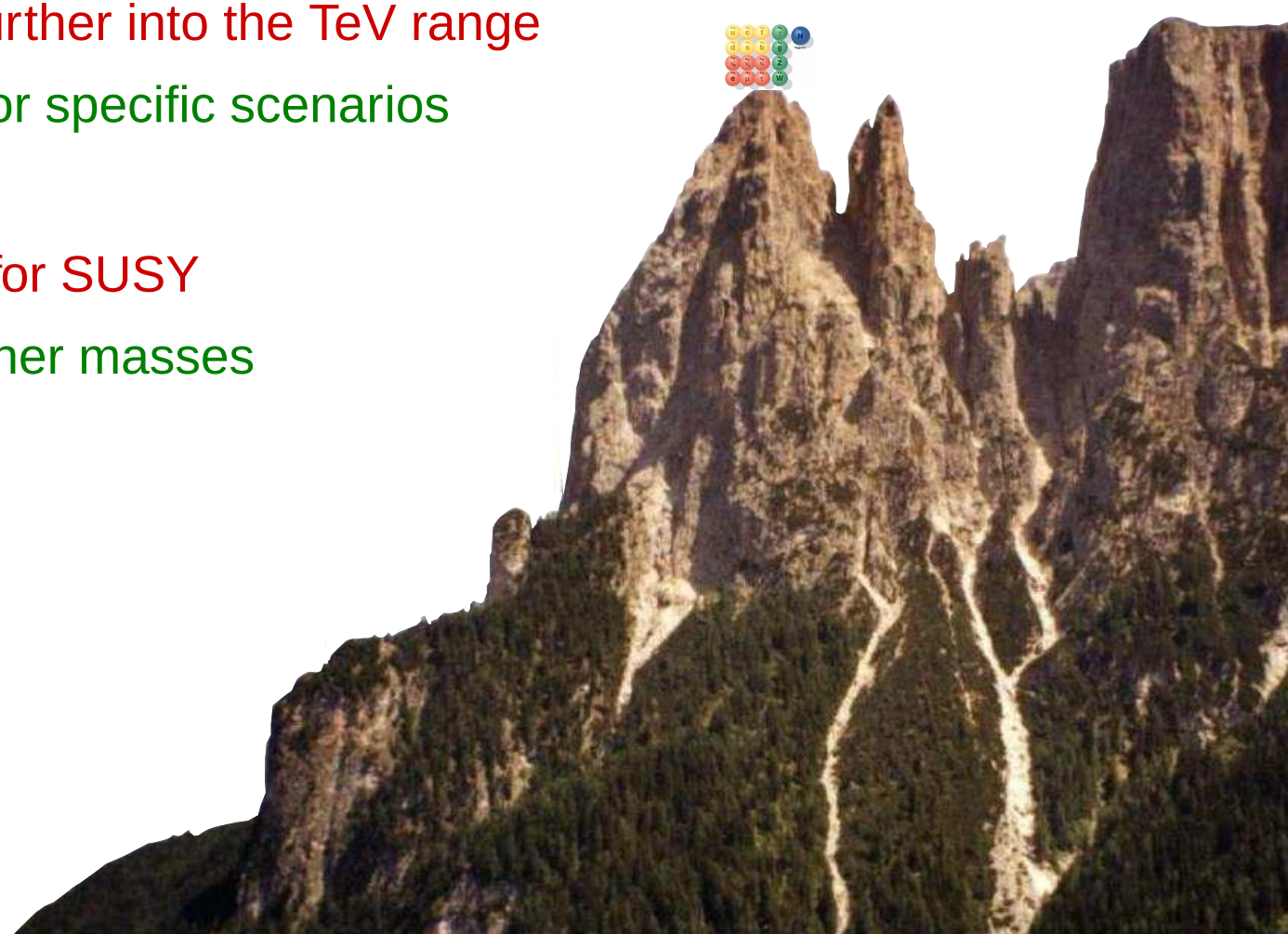
  - ▲ Need to test even higher masses



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- Mass limits are pushed further into the TeV range
  - ▲ Limits up to 1.7 TeV for specific scenarios
- The air is getting thinner for SUSY
  - ▲ Need to test even higher masses
  - ▲ Or to even more challenging scenarios
    - ► Compressed spectra, low p_T objects,...
- Be prepared for 2015 data!

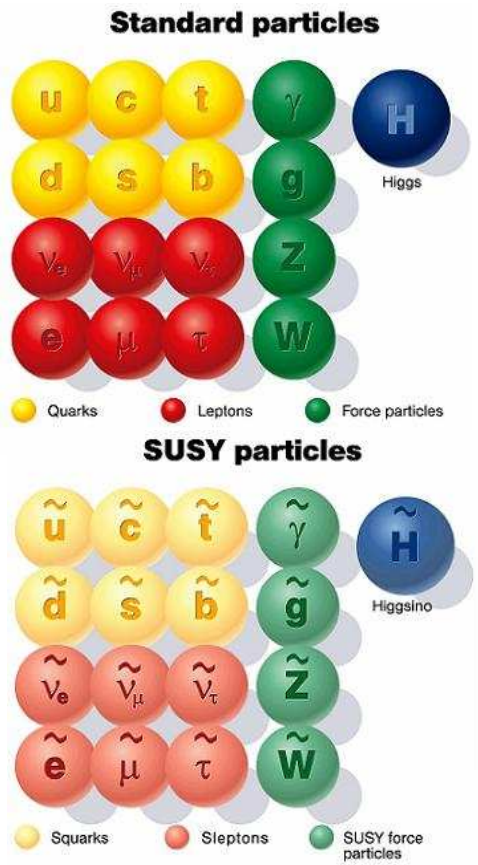
You would like to know more?

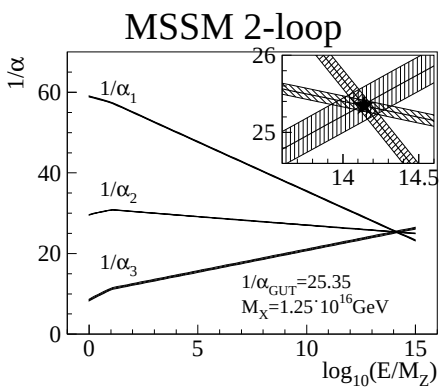
Going Beyond the Standard Model

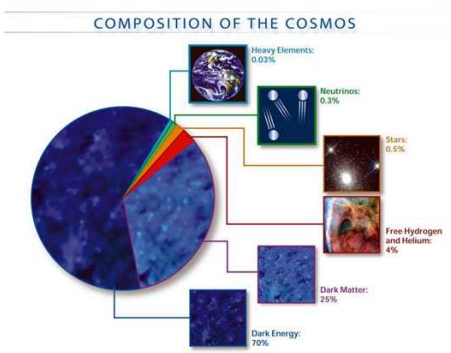
- The Standard Model is very successful...
  - ...but it cannot answer all questions and has some caveats
    - ⇒ Many ways and attempts to extend the Standard Model

- Supersymmetry
  - Extension of the Poincare group
    - Supersymmetric partner for every SM particle
    - Squarks, Gluinos, Charginos, Neutralinos,...

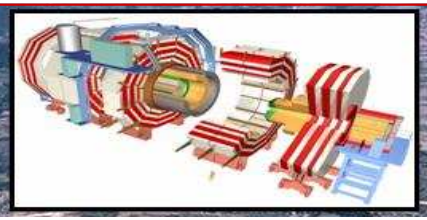
- Why Supersymmetry?
  - Cancellation of radiative corrections for the Higgs mass
  - Unification of the couplings
  - Provides a dark matter candidate

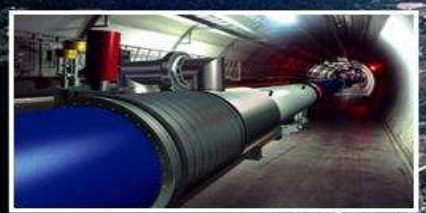


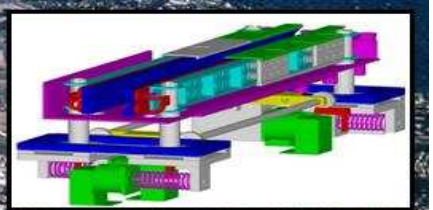


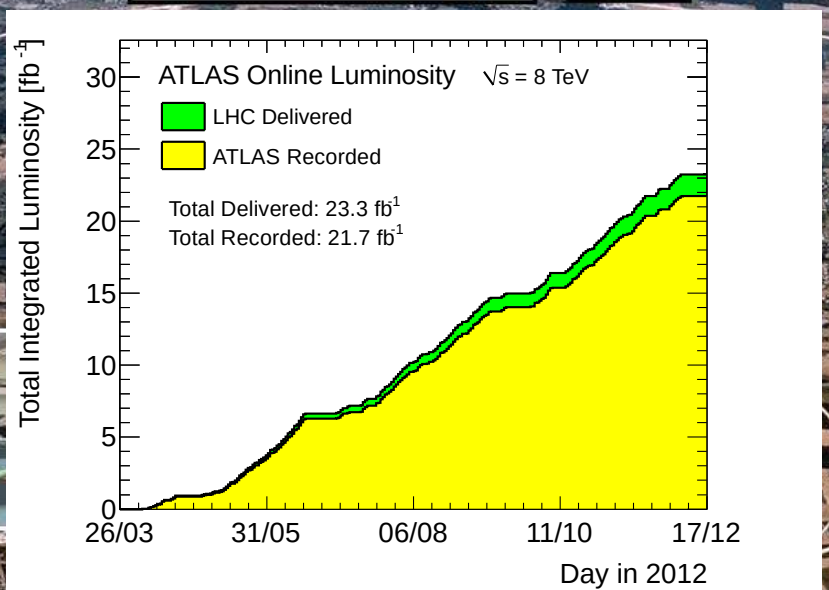


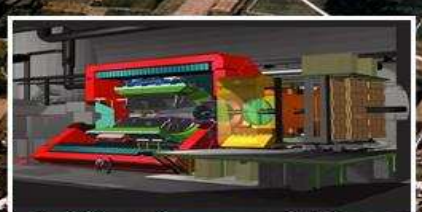
Proton–proton collisions at $\sqrt{s}$ = 8 TeV
Total luminosity used for analyses: $\int \mathcal{L}dt = 20.3\ \mathrm{fb}^{-1}$

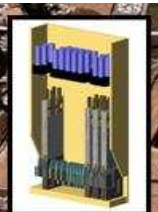






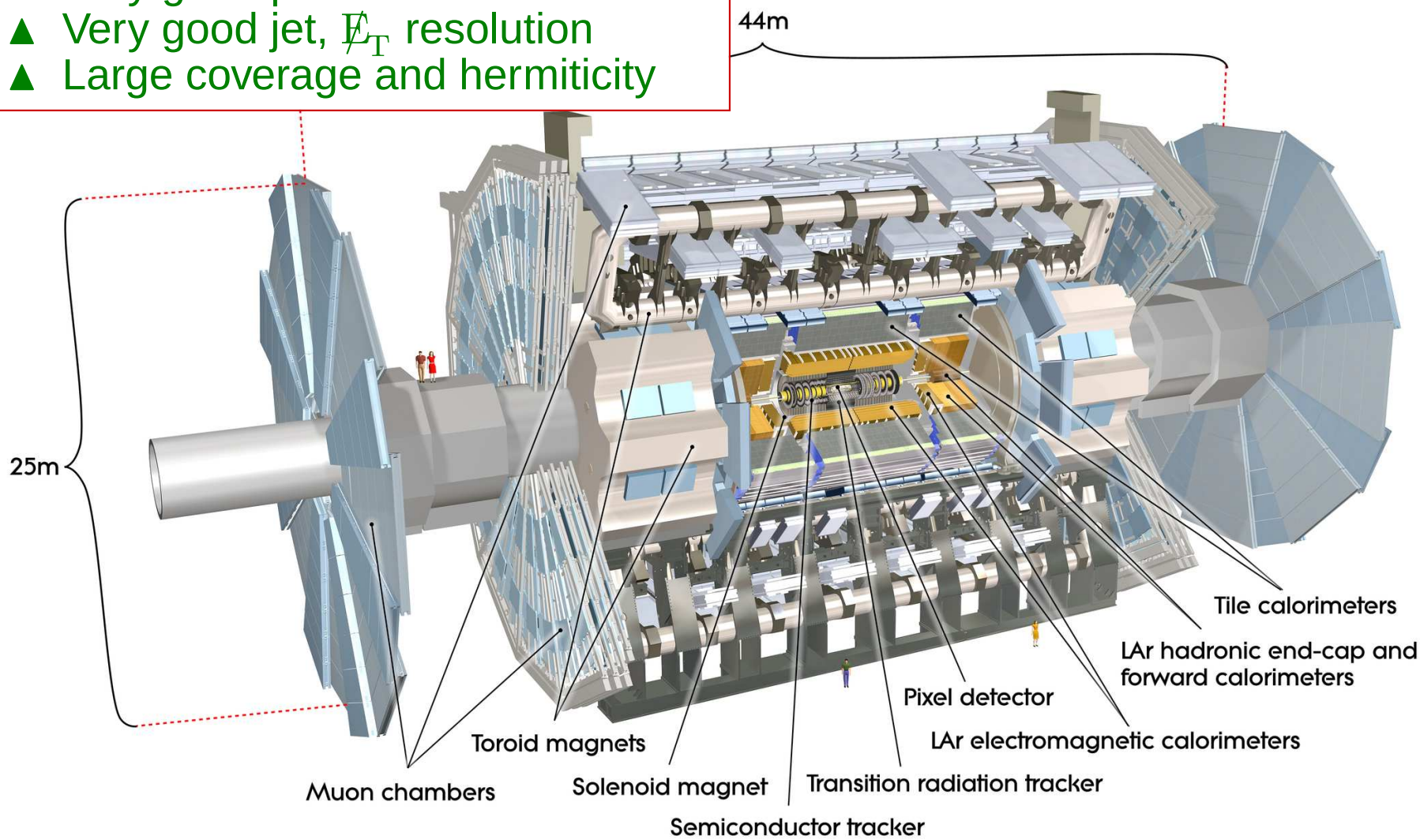






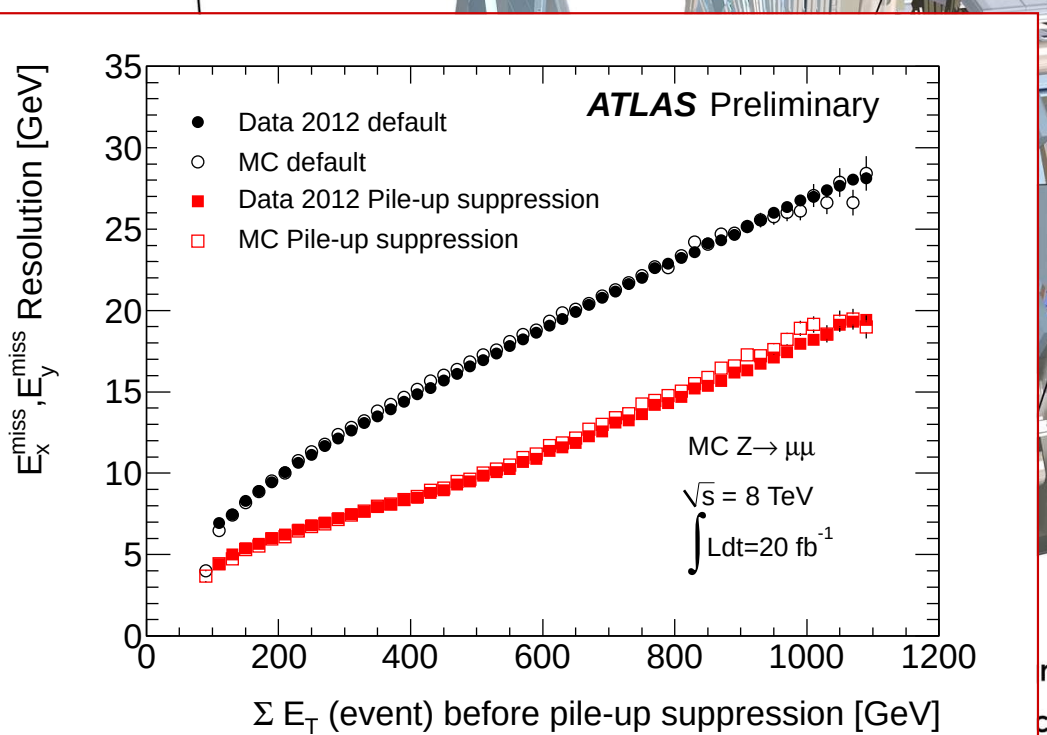
ATLAS Detector

- Emphasis on
  - ▲ Very good particle identification
  - ▲ Very good jet, $\not{E}_T$ resolution
  - ▲ Large coverage and hermiticity



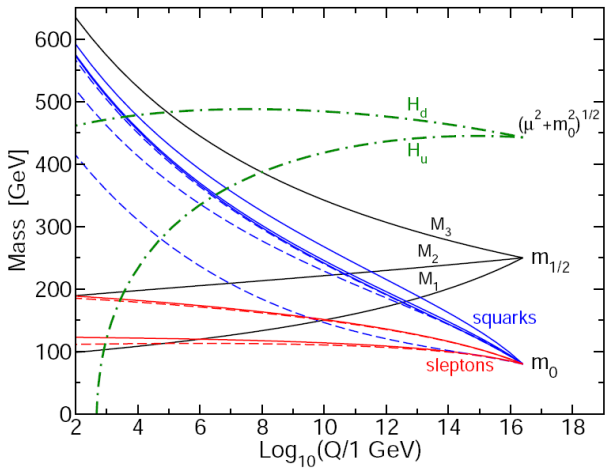
ATLAS Detector

- Emphasis on
  - ▲ Very good particle identification
  - ▲ Very good jet, $\not{E}_T$ resolution
  - ▲ Large coverage and hermiticity

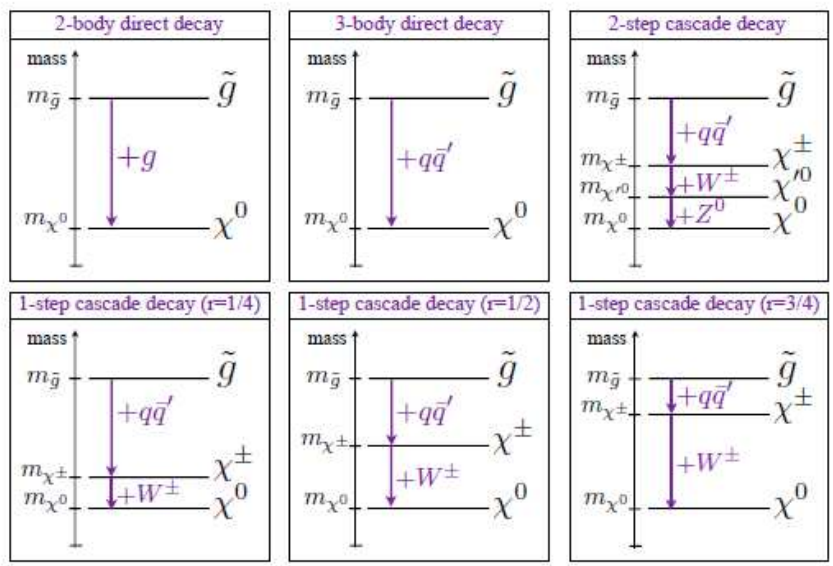


SUSY Model

- The reference model for SUSY searches is mSUGRA
  - ▲ Characterized by five parameters⇒ “easy”
    - ▶ Common scalar mass at GUT scale: m_0
    - ▶ Common Gaugino mass at GUT scale: $m_{1/2}$
    - ▶ Common trilinear coupling at GUT scale: A_0
    - ▶ Ratio of VEV of the neutral Higgs fields: $\tan\beta$
    - ▶ Sign of Higgs mass parameter: sign(μ)
  - ▲ R–parity conservation ⇒ stable LSP (Neutralino)



- Attempt to be less model specific
  ⇒ Simplified models
  - ▲ Pick specific production and decay chain
  - ▲ Vary masses of the particles involved in the chain
  - ▲ Can easier be interpreted in different scenarios
  - ▲ Quote limits on cross section times efficiency

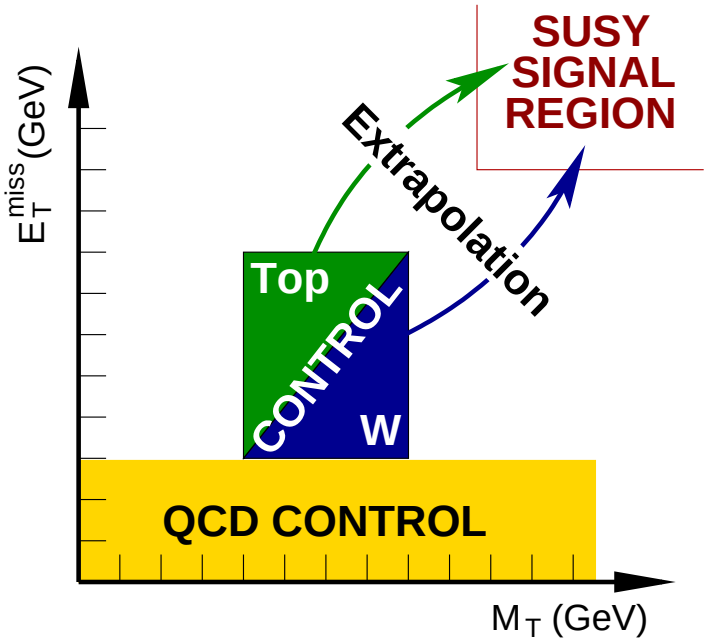


J. Wacker et al., hep-ph 1102.5338

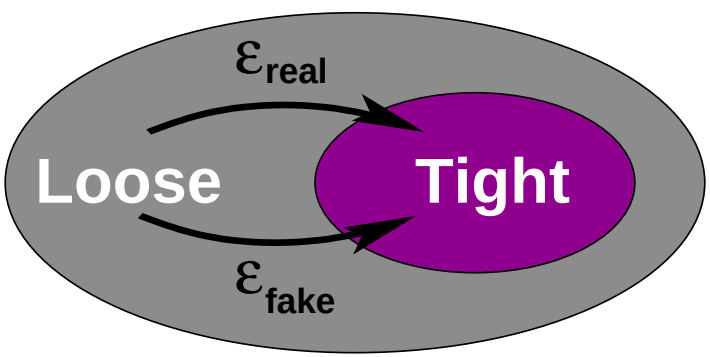
Background Strategy

W, Z, $t\bar{t}$ background

- Semi–data driven approach
- Select events in control regions (CR)
  - ▲ Normalise MC to data
- Extrapolate to signal region using MC
  - ▲ Assume shape is described correctly



QCD background



- Fully–data driven approach
- Measure real and fake efficiencies in CRs
- Apply Matrix Method to get contribution in SR