# 0-Lepton SUSY Analysis with the ATLAS Detector

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*9th Annual Meeting of the Helmholtz Alliance Terascale Meeting*

**DESY, Hamburg, November 17th - 18th, 2015**

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  - Event Selection & Signal Regions
  - Background Estimation
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Results based on:
2012 ATLAS data at $\sqrt{s}$ = 8 TeV, $L_{int}$ = 20.3 $fb^{-1}$,
2015 ATLAS data at $\sqrt{s}$ = 13 TeV, $L_{int}$ = 78.3 $pb^{-1}$

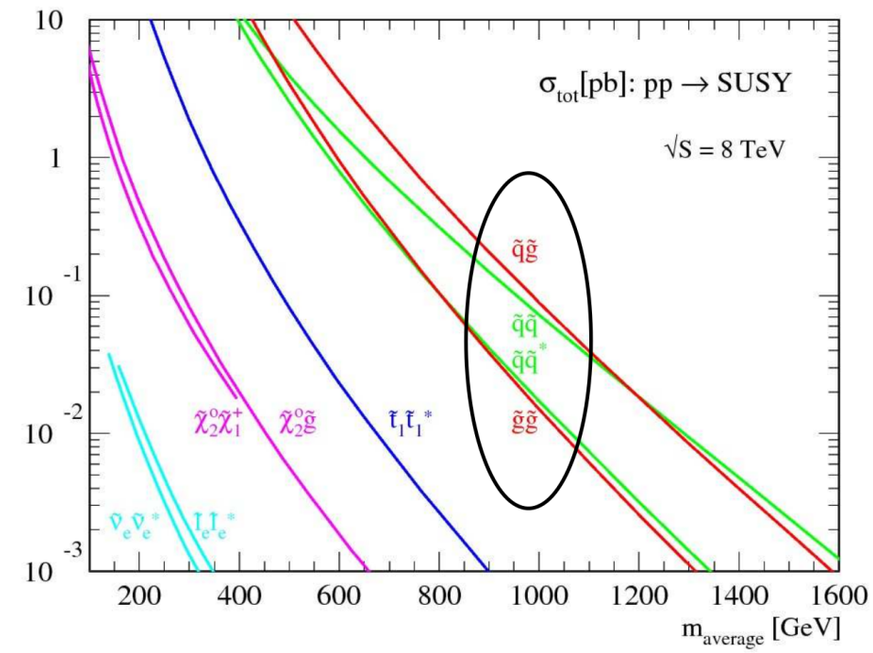
# Introduction

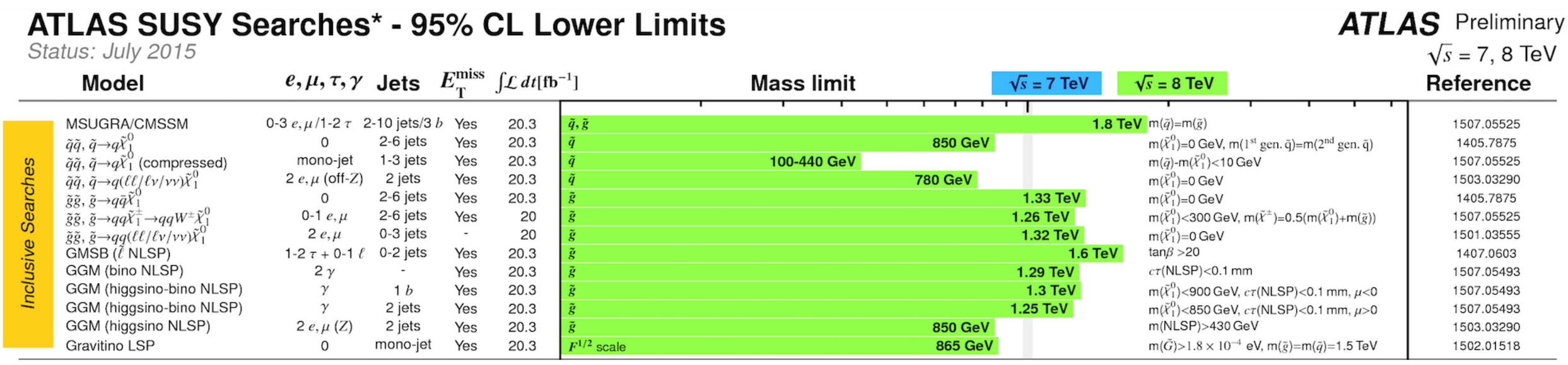
## SUSY in strong production

If SUSY is present at TeV scale, squarks and gluinos may be produced at LHC

Gluinos and squarks decay either directly or via a cascade into:

- **Jets**, coming from gluinos and squarks decays
- **LSP** (the Lightest Supersymmetric Particle), escaping the detector and resulting in MET (assuming R-parity conservation)
- and **Leptons**, coming from chargino or slepton decays



**ATLAS SUSY Searches* - 95% CL Lower Limits**

Status: July 2015

**ATLAS** Preliminary

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

| | Model | $e, \mu, \tau, \gamma$ | Jets | $E_T^{miss}$ | $\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$ | Mass limit ($\sqrt{s}$ = 7 TeV / $\sqrt{s}$ = 8 TeV) | | Reference |
|---|---|---|---|---|---|---|---|---|
| Inclusive Searches | MSUGRA/CMSSM | 0-3 $e,\mu$/1-2 $\tau$ | 2-10 jets/3 $b$ | Yes | 20.3 | $\tilde{q}, \tilde{g}$ 1.8 TeV | $m(\tilde{q})=m(\tilde{g})$ | 1507.05525 |
| | $\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}$ 850 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$) | 1405.7875 |
| | $\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed) | mono-jet | 1-3 jets | Yes | 20.3 | $\tilde{q}$ 100-440 GeV | $m(\tilde{q})-m(\tilde{\chi}_1^0)$<10 GeV | 1507.05525 |
| | $\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$ | 2 $e,\mu$ (off-Z) | 2 jets | Yes | 20.3 | $\tilde{q}$ 780 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1503.03290 |
| | $\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{g}$ 1.33 TeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1405.7875 |
| | $\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$ | 0-1 $e,\mu$ | 2-6 jets | Yes | 20 | $\tilde{g}$ 1.26 TeV | $m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$ | 1507.05525 |
| | $\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$ | 2 $e,\mu$ | 0-3 jets | - | 20 | $\tilde{g}$ 1.32 TeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1501.03555 |
| | GMSB ($\tilde{\ell}$ NLSP) | 1-2 $\tau$ + 0-1 $\ell$ | 0-2 jets | Yes | 20.3 | $\tilde{g}$ 1.6 TeV | $\tan\beta$ >20 | 1407.0603 |
| | GGM (bino NLSP) | 2 $\gamma$ | - | Yes | 20.3 | $\tilde{g}$ 1.29 TeV | $c\tau$(NLSP)<0.1 mm | 1507.05493 |
| | GGM (higgsino-bino NLSP) | $\gamma$ | 1 $b$ | Yes | 20.3 | $\tilde{g}$ 1.3 TeV | $m(\tilde{\chi}_1^0)$<900 GeV, $c\tau$(NLSP)<0.1 mm, $\mu$<0 | 1507.05493 |
| | GGM (higgsino-bino NLSP) | $\gamma$ | 2 jets | Yes | 20.3 | $\tilde{g}$ 1.25 TeV | $m(\tilde{\chi}_1^0)$<850 GeV, $c\tau$(NLSP)<0.1 mm, $\mu$>0 | 1507.05493 |
| | GGM (higgsino NLSP) | 2 $e,\mu$ (Z) | 2 jets | Yes | 20.3 | $\tilde{g}$ 850 GeV | m(NLSP)>430 GeV | 1503.03290 |
| | Gravitino LSP | 0 | mono-jet | Yes | 20.3 | $F^{1/2}$ scale 865 GeV | $m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV | 1502.01518 |

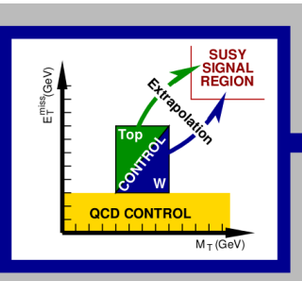
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/ATLAS_SUSY_Summary/ATLAS_SUSY_Summary.png

# Search Strategy (common for SUSY searches)

## How do we search for SUSY?

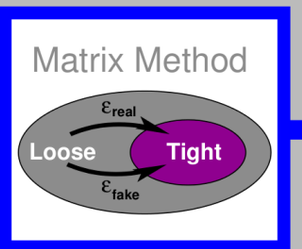
**SM Backgrounds:**
top pairs, single top, V+jets, dibosons, multijets,...

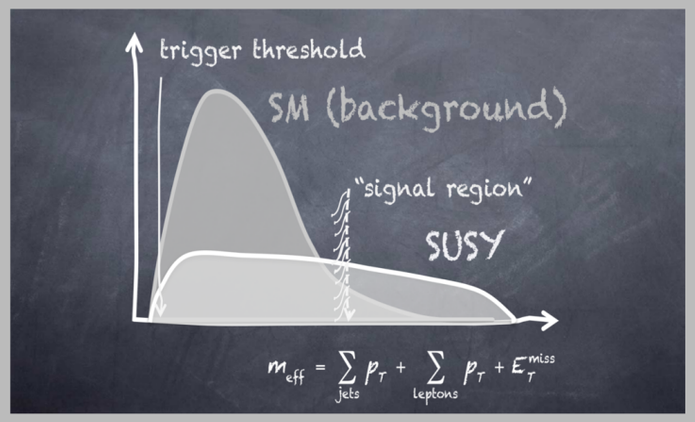
**Main irreducible Backgrounds:**
- Normalize MC prediction in dedicated Control Regions
- Extrapolate to Signal Regions using MC




**Minor irreducible Backgrounds:**
- Pure MC based prediction

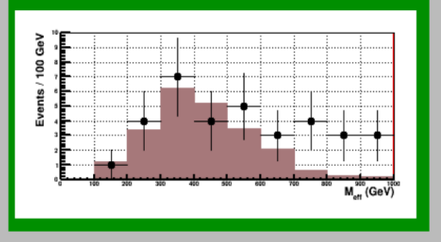
**Reducible (fake) Backgrounds:**
- Fully data driven method
  - Matrix method
  - Jet smearing
  - Templates




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

**Signal Region:**
- Look for excess




Combined global fit:
Consider experimental and theoretical uncertainties

from Marc Hohlfeld's talk at SUSY13

# Run I Analysis: Event Selection

## 0-Lepton + 2-6 jets

*Very powerful analysis requiring 2-6 jets, MET and no leptons*

| Requirement | Signal Region | | | | | |
|---|---|---|---|---|---|---|
| | **2jl** | **2jm** | **2jt** | **2jW** | **3j** | **4jW** |
| $E_T^{miss}$[GeV] > | 160 | | | | | |
| $p_T(j_1)$ [GeV] > | 130 | | | | | |
| $p_T(j_2)$ [GeV] > | 60 | | | | | |
| $p_T(j_3)$ [GeV] > | – | | | | 60 | 40 |
| $p_T(j_4)$ [GeV] > | – | | | | | 40 |
| $\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ > | 0.4 | | | | | |
| $\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ > | – | | | | | 0.2 |
| $W$ candidates | – | | | $2(W \to j)$ | – | $(W \to j) + (W \to jj)$ |
| $E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] > | 8 | 15 | | – | | |
| $E_T^{miss}/m_{eff}(N_j)$ > | – | | | 0.25 | 0.3 | 0.35 |
| $m_{eff}$(incl.) [GeV] > | 800 | 1200 | 1600 | 1800 | 2200 | 1100 |

| Requirement | Signal Region | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **4jl-** | **4jl** | **4jm** | **4jt** | **5j** | **6jl** | **6jm** | **6jt** | **6jt+** |
| $E_T^{miss}$[GeV] > | 160 | | | | | | | | |
| $p_T(j_1)$ [GeV] > | 130 | | | | | | | | |
| $p_T(j_2)$ [GeV] > | 60 | | | | | | | | |
| $p_T(j_3)$ [GeV] > | 60 | | | | | | | | |
| $p_T(j_4)$ [GeV] > | 60 | | | | | | | | |
| $p_T(j_5)$ [GeV] > | – | | | | 60 | | | | |
| $p_T(j_6)$ [GeV] > | – | | | | | 60 | | | |
| $\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ > | 0.4 | | | | | | | | |
| $\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ > | 0.2 | | | | | | | | |
| $E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] > | 10 | | – | | | | | | |
| $E_T^{miss}/m_{eff}(N_j)$ > | – | | 0.4 | 0.25 | 0.2 | | | 0.25 | 0.15 |
| $m_{eff}$(incl.) [GeV] > | 700 | 1000 | 1300 | 2200 | 1200 | 900 | 1200 | 1500 | 1700 |

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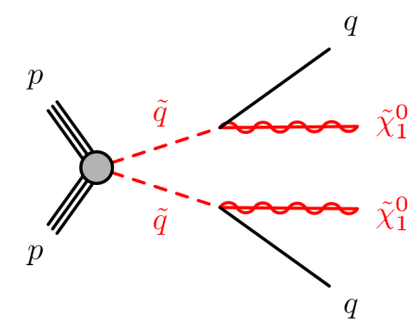
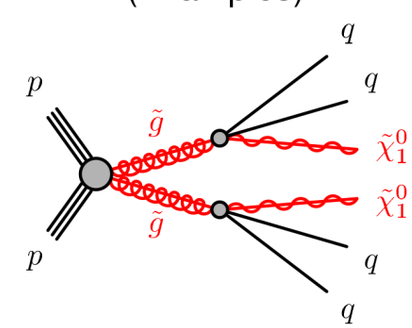



(Examples)




Main discriminating variables:

- $\Delta\phi(jet, E_T^{miss})$
- $m_{eff}(incl.)$
- $E_T^{miss}/\sqrt{H_T}$ or $E_T^{miss}/m_{eff}(N_J)$

$$m_{eff} \equiv \sum_{i=1}^{n} |p_T^i| + E_T^{miss}, \; H_T \equiv \sum_{i=1}^{n} |p_T^i|$$

# Background Estimation

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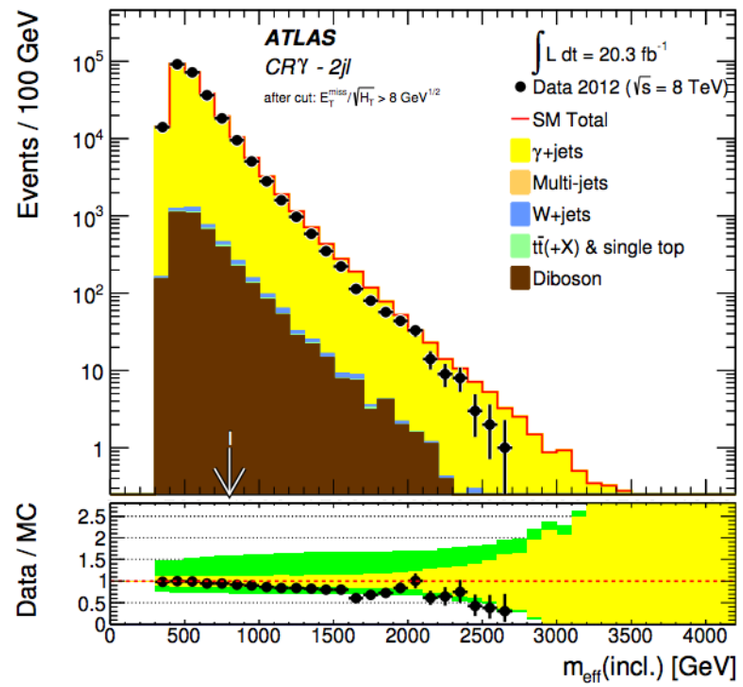
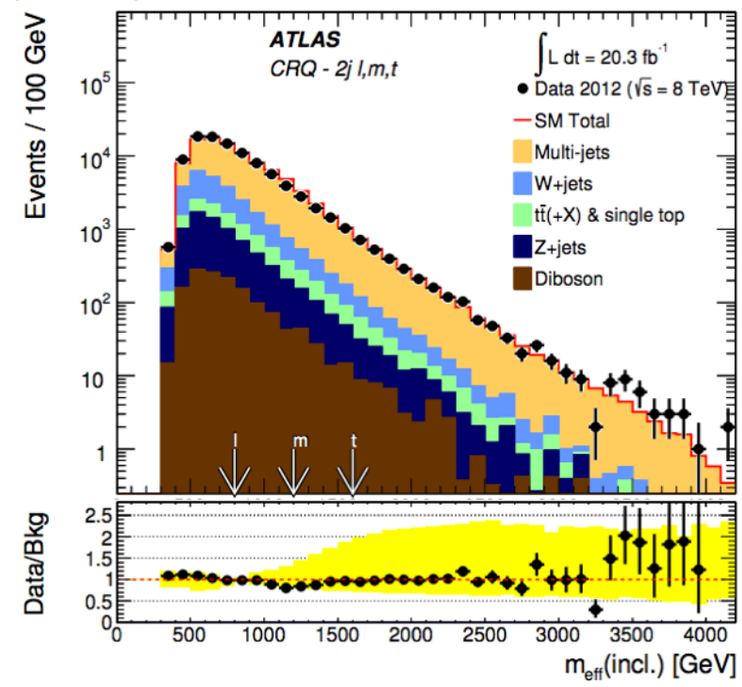
## Main background sources:

- **Z+jets** with Z decaying in **νν**
- **W+jets**
- **Top** (**ttbar**, **single top)**
- **Diboson**
- **QCD multijets**




4 Control Regions are assigned to each of the 15 Signal Regions to constrain background

| CR | SR background | CR process | CR selection |
|---|---|---|---|
| CRγ | $Z(\to \nu\nu)$+jets | γ+jets | Isolated photon |
| CRQ | Multi-jets | Multi-jets | SR with reversed requirements on (i) $\Delta\phi(\text{jet}, \mathbf{E}_T^{miss})_{min}$ and (ii) $E_T^{miss}/m_{eff}(N_j)$ or $E_T^{miss}/\sqrt{H_T}$ |
| CRW | $W(\to \ell\nu)$+jets | $W(\to \ell\nu)$+jets | $30\,\text{GeV} < m_T(\ell, E_T^{miss}) < 100\,\text{GeV}$, $b$-veto |
| CRT | $t\bar{t}$ and single-$t$ | $t\bar{t} \to b\bar{b}qq'\ell\nu$ | $30\,\text{GeV} < m_T(\ell, E_T^{miss}) < 100\,\text{GeV}$, $b$-tag |

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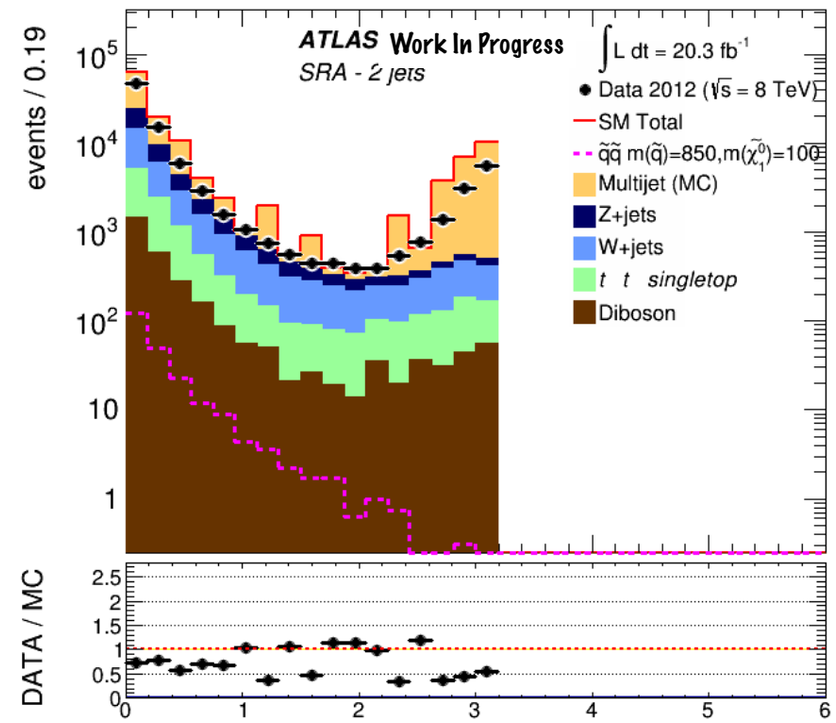
# Multijet Background Estimation -1

Multijet Background estimation is done via “smearing” method in 0Lepton analysis, which is fully data-driven

➡ Modeling is problematic: 100% systematic uncertainty is applied to the smearing method

**Independent method for MJ background estimation based on Track-$E_T^{miss}$**

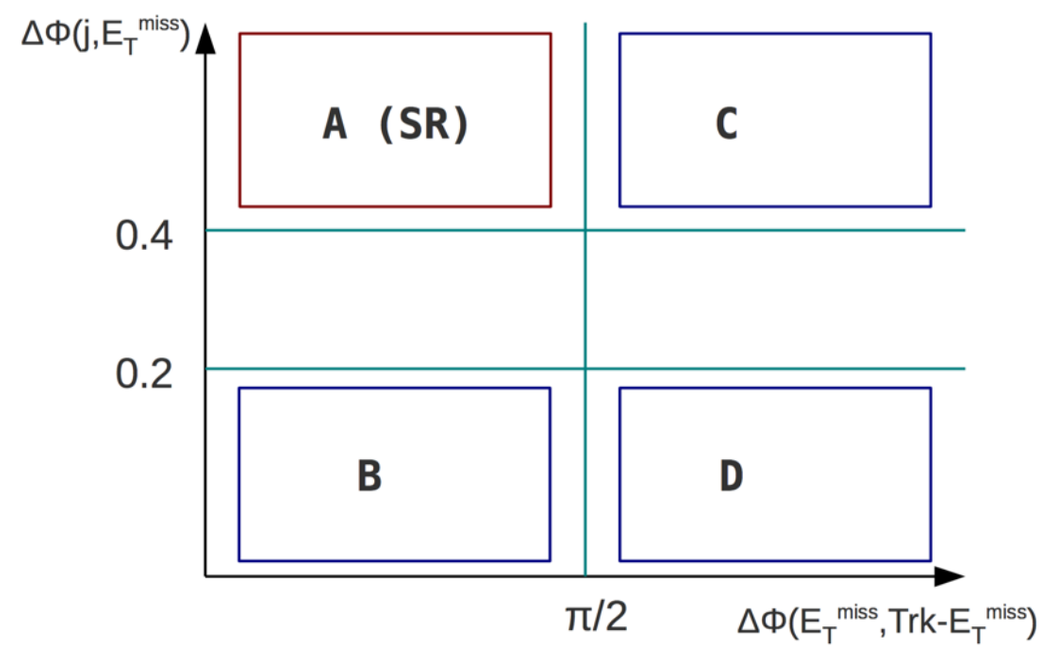
$$E_{T,\mathrm{track}}^{\mathrm{miss}} = \left| -\sum_{\mathrm{tracks}\in\mathrm{PV}} \vec{p}_{T_i} \right|$$




➡ Charged particles inside each jet produced in fragmentation processes. Fluctuations occur in fraction of energy from parton showering;

➡ $\Delta\phi(E_T^{miss}, \text{Track-}E_T^{miss})$ and $\Delta\phi(\text{jet}, E_T^{miss})$ are uncorrelated

➡ ABCD grid: number of Multijet (MJ) events in SR(A) propataged from regions B,C,D

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# Multijet Background Estimation - 2

| Signal Region | Track MET yield | Jet smearing method |
|---|---|---|
| 2j loose | 273.20 ± 40.93(stat) ± 301.01(syst) | $115.38 \pm^{140.35}_{115.38}$ |
| 2j medium | -1.08 ± 1.35(stat) ± 4.05(syst) | $0.41 \pm^{1.37}_{0.41}$ |
| 2j tight | -0.28 ± 0.37(stat) ± 0.41(syst) | $0.14 \pm^{0.44}_{0.14}$ |
| 4j veryloose | 33.60 ± 7.13(stat) ± 38.78(syst) | $1.69 \pm^{1.69}_{3.94}$ |
| 4j loose | 13.94 ± 4.04(stat) ± 15.67(syst) | $0.73 \pm^{1.57}_{0.73}$ |
| 4j medium | 0.04 ± 0.39(stat) ± 0.22(syst) | 0.0 ± 0.0 |
| 4j tight | -0.15 ± 0.25(stat) ± 0.07(syst) | 0.0 ± 0.0 |
| 5j medium | 0.00 ± 0.00(stat) ± 0.00(syst) | $0.99 \pm^{2.64}_{0.99}$ |
| 6j loose | 9.14 ± 5.60(stat) ± 9.38(syst) | $1.71 \pm^{2.95}_{1.71}$ |
| 6j medium | 1.32 ± 2.01(stat) ± 2.36(syst) | $0.44 \pm^{0.84}_{0.44}$ |
| 6j tight | -0.06 ± 0.30(stat) ± 0.10(syst) | $0.01 \pm^{0.03}_{0.01}$ |
| 6j verytight | 0.17 ± 0.54(stat) ± 0.42(syst) | $0.25 \pm^{0.39}_{0.25}$ |

➡ Systematics treatment: 30% fluctuation on SM-MC yield in each B,C,D region and propagating to A (SR);

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# Background Estimation & Results

## Background Extrapolation to the SRs:

- MC predictions are normalised via a Likelihood fit in dedicated control regions (CRs)
- Number of expected events in each SR is extrapolated from the CR using a transfer factor

$$N(\mathrm{SR,\,scaled}) = N(\mathrm{CR,\,obs}) \times \left[\frac{N(\mathrm{SR,\,unscaled})}{N(\mathrm{CR,\,unscaled})}\right]$$

- Multijet events are estimated using a fully data-driven technique

| Signal Region | 2jl | 2jm | 2jt | 2jW | 3j | 4jl- | 4jl | 4jm | 4jt | 4jW | 5j | 6jl | 6jm | 6jt | 6jt+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total bkg | $13000 \pm 1000$ | $760 \pm 50$ | $125 \pm 10$ | $2.3 \pm 1.4$ | $5.0 \pm 1.2$ | $2120 \pm 110$ | $630 \pm 50$ | $37 \pm 6$ | $2.5 \pm 1.0$ | $14 \pm 4$ | $126 \pm 13$ | $111 \pm 11$ | $33 \pm 6$ | $5.2 \pm 1.4$ | $4.9 \pm 1.6$ |
| Observed | 12315 | 715 | 133 | 0 | 7 | 2169 | 608 | 24 | 0 | 16 | 121 | 121 | 39 | 5 | 6 |
| $\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb] | 60 | 4.3 | 1.9 | 0.16 | 0.40 | 13 | 4.5 | 0.52 | 0.15 | 0.68 | 1.7 | 1.9 | 1.2 | 0.32 | 0.39 |
| $\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb] (asymptotic) | 62 | 4.0 | 1.8 | 0.12 | 0.40 | 13 | 4.3 | 0.45 | 0.12 | 0.63 | 1.6 | 1.8 | 1.1 | 0.30 | 0.36 |
| $S^{95}_{\mathrm{obs}}$ | 1200 | 90 | 38 | 3.2 | 8.2 | 270 | 91 | 10 | 3.1 | 14 | 35 | 39 | 25 | 6.6 | 7.9 |
| $S^{95}_{\mathrm{obs}}$ (asymptotic) | 1300 | 80 | 37 | 2.5 | 8.1 | 270 | 87 | 9 | 2.5 | 13 | 32 | 37 | 22 | 6.1 | 7.3 |
| $S^{95}_{\mathrm{exp}}$ | $1700^{+600}_{-500}$ | $110^{+40}_{-30}$ | $32^{+11}_{-10}$ | $4.0^{+1.7}_{-0.7}$ | $6.4^{+2.9}_{-1.3}$ | $240^{+90}_{-70}$ | $103^{+34}_{-29}$ | $16^{+6}_{-4}$ | $4.0^{+1.8}_{-0.9}$ | $11^{+5}_{-3}$ | $37^{+13}_{-10}$ | $31^{+12}_{-6}$ | $20^{+6}_{-4}$ | $6.2^{+2.6}_{-1.3}$ | $6.6^{+2.6}_{-1.6}$ |
| $S^{95}_{\mathrm{exp}}$ (asymptotic) | $1600^{+600}_{-400}$ | $110^{+40}_{-30}$ | $31^{+12}_{-8}$ | $4.1^{+2.4}_{-1.4}$ | $6.3^{+3.2}_{-2.0}$ | $240^{+90}_{-70}$ | $97^{+35}_{-25}$ | $15^{+6}_{-4}$ | $4.0^{+2.4}_{-1.4}$ | $11^{+5}_{-3}$ | $35^{+13}_{-10}$ | $30^{+12}_{-8}$ | $18^{+7}_{-5}$ | $6.3^{+3.1}_{-2.0}$ | $6.4^{+3.2}_{-2.0}$ |
| $p_0$ $(Z)$ | 0.50 (0.0) | 0.49 (0.0) | 0.29 (0.5) | 0.50 (0.0) | 0.24 (0.7) | 0.35 (0.4) | 0.50 (0.0) | 0.50 (0.0) | 0.50 (0.0) | 0.34 (0.4) | 0.50 (0.0) | 0.27 (0.6) | 0.25 (0.7) | 0.50 (0.0) | 0.36 (0.4) |

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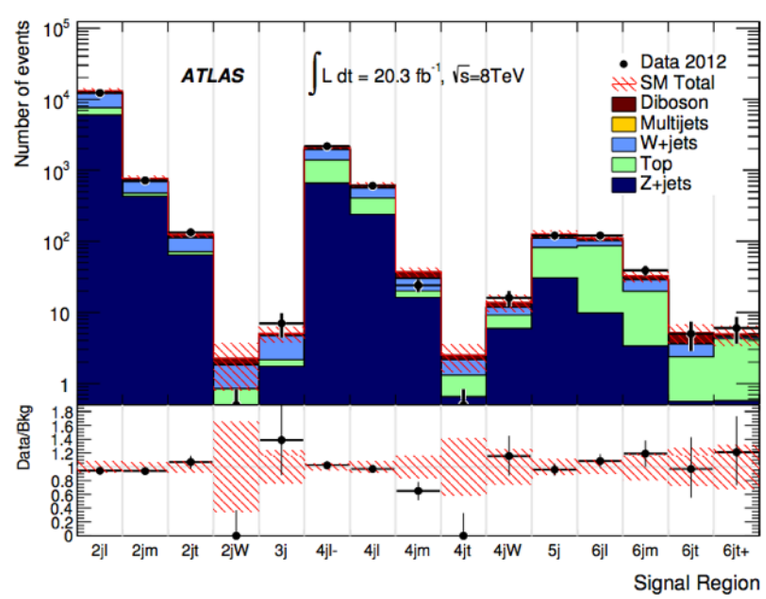
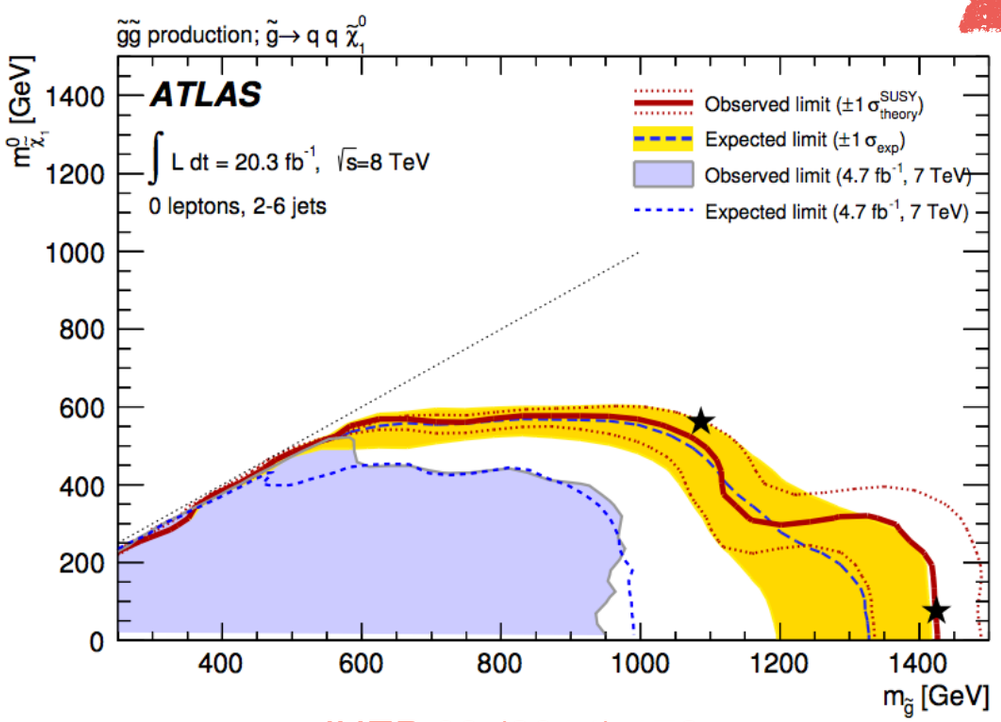


# Interpretations - Direct and 1-step decay grids

For each signal point, the signal region with the best expected sensitivity is used to set the exclusion limits. The expected and observed limits are shown at 95 % CL with 1 σ band due to experimental and theoretical uncertainties.

## Simplified Model:direct decay of gluinos/squarks

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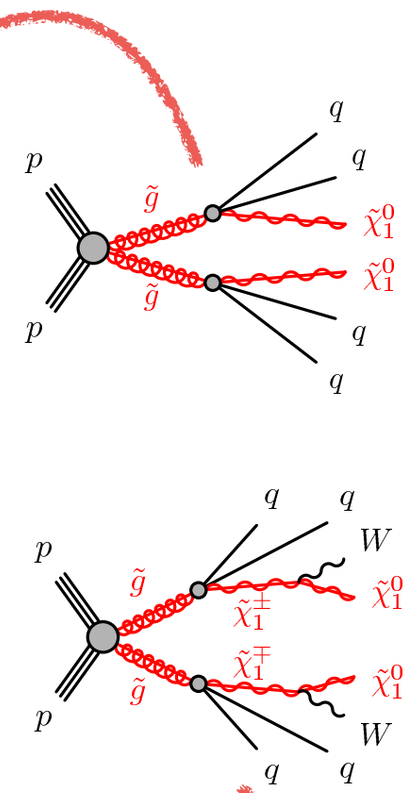
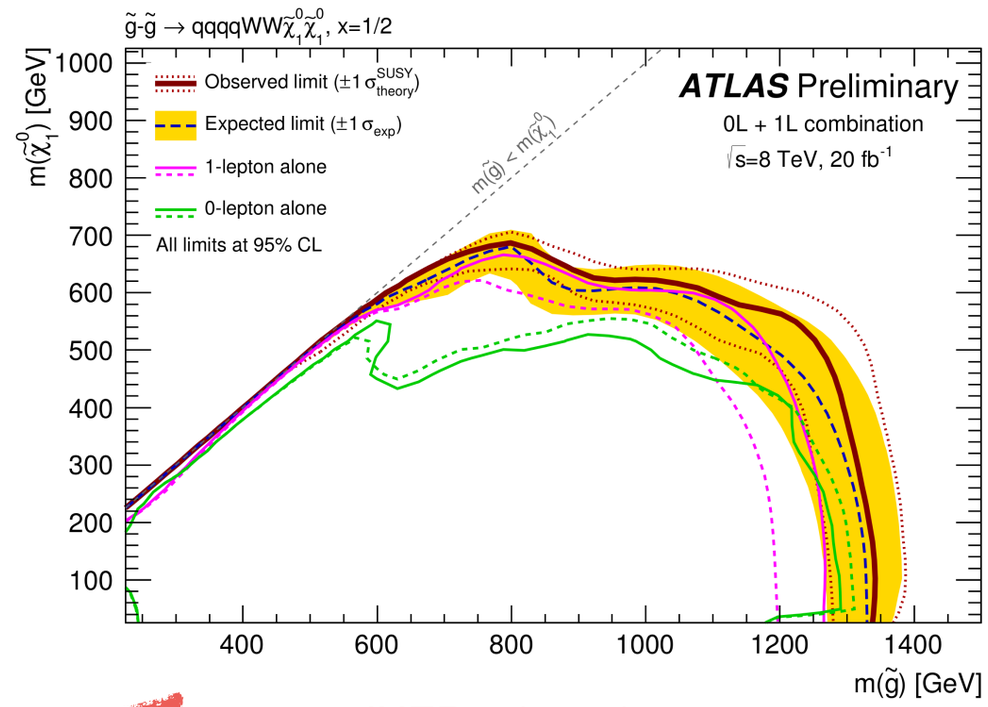



## Simplified Model: gluino pair decaying through chargino (1-step)




JHEP10(2015)054

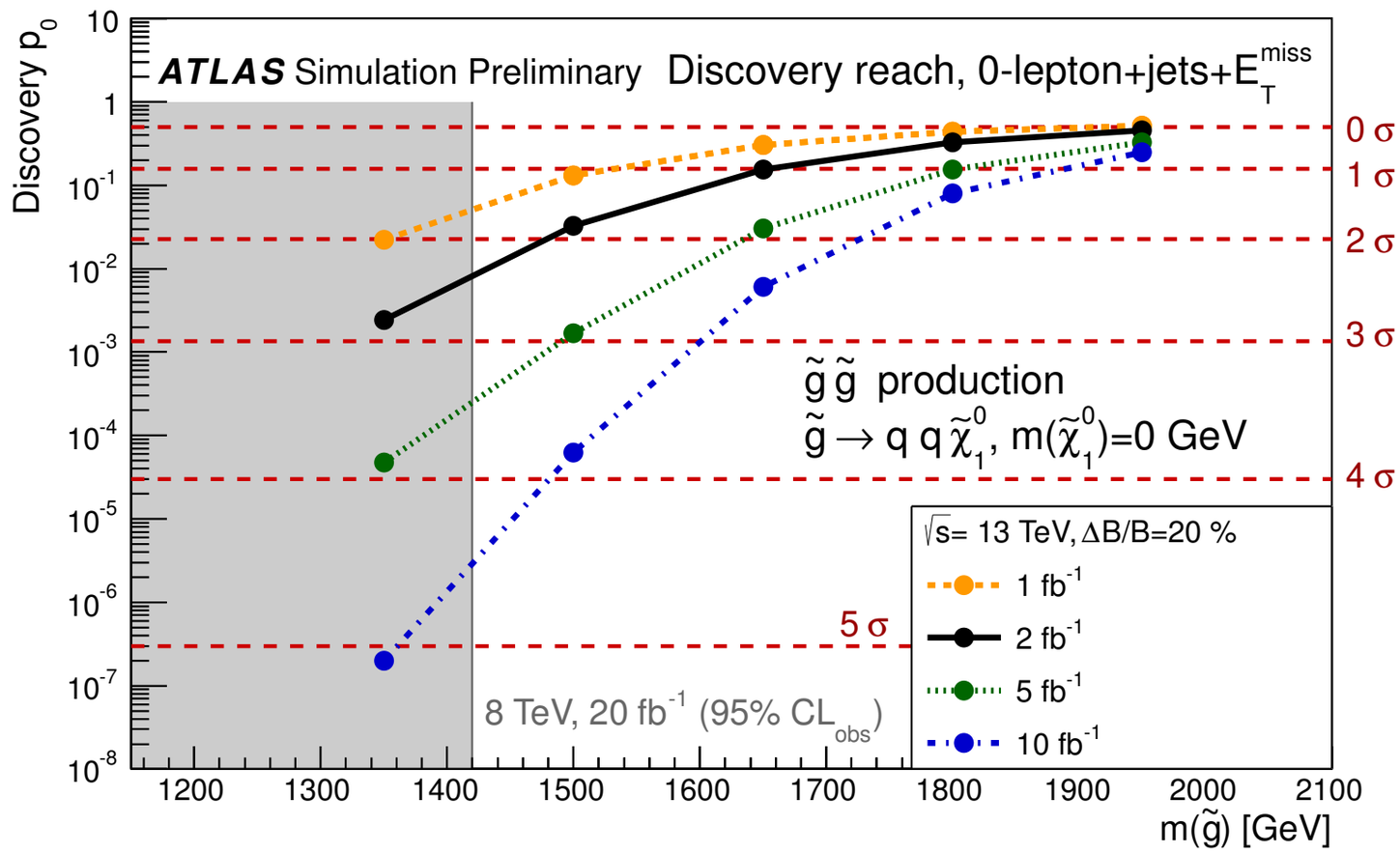
Strong production of gluino pairs with decoupled squarks. Gluinos required to decay to 2 jets and a neutrino LSP

Statistical combination of 0L and 1L analyses. Gain in 50 GeV for low LSP masses obtained wrt to indiindividual analysis

# RunII 0Lepton analysis

*The 2015 early analysis will follow the Run1-based approach*

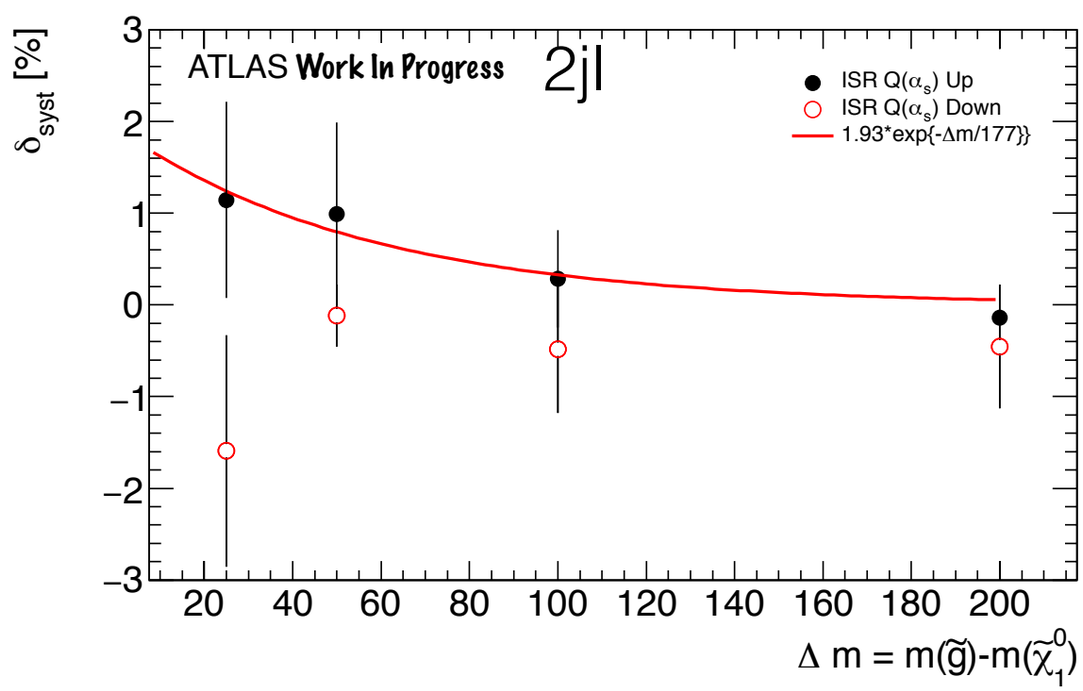
- Expected sensistivity with the early Run2 dataset based on fully simulated samples were provided for Moriond2015 for gg and qq direct grid
  - Access to a 3σ evidence for a $\tilde{g}$ with m in [1300,1500] GeV




ATLAS-PHYS-PUB-2015-005

# RunII: Signal Theory Unc. Studies

- Once established the correct setup for SUSY signal production, theoretical uncertainties on them must be calculated
- ISR radiation scales are of the most relevant source of uncertainty
  - it has been shown in previous studies that ISR modelling uncertainties could become significant for signals with a compressed spectrum
  - The amount of ISR variation is tested by varying simultaneously the $\alpha_s$ scale in MADGRAPH+PYTHIA8 by 0.5 and 2
  - the impact of scale variations on the signal acceptance for a simplified model with direct gluino pair production is shown
  - the acceptance uncertainty is parametrized as a function of $\Delta m = m(\tilde{g}) - m(\tilde{\chi}^0_1)$ [GeV]
  - Due to the limited statistics of the generated samples (100K events per point), the signal region cuts had to be relaxed and so far calculated for 2j loose signal region ($M_{eff}$ >700GeV)



# RunII 0Lepton analysis

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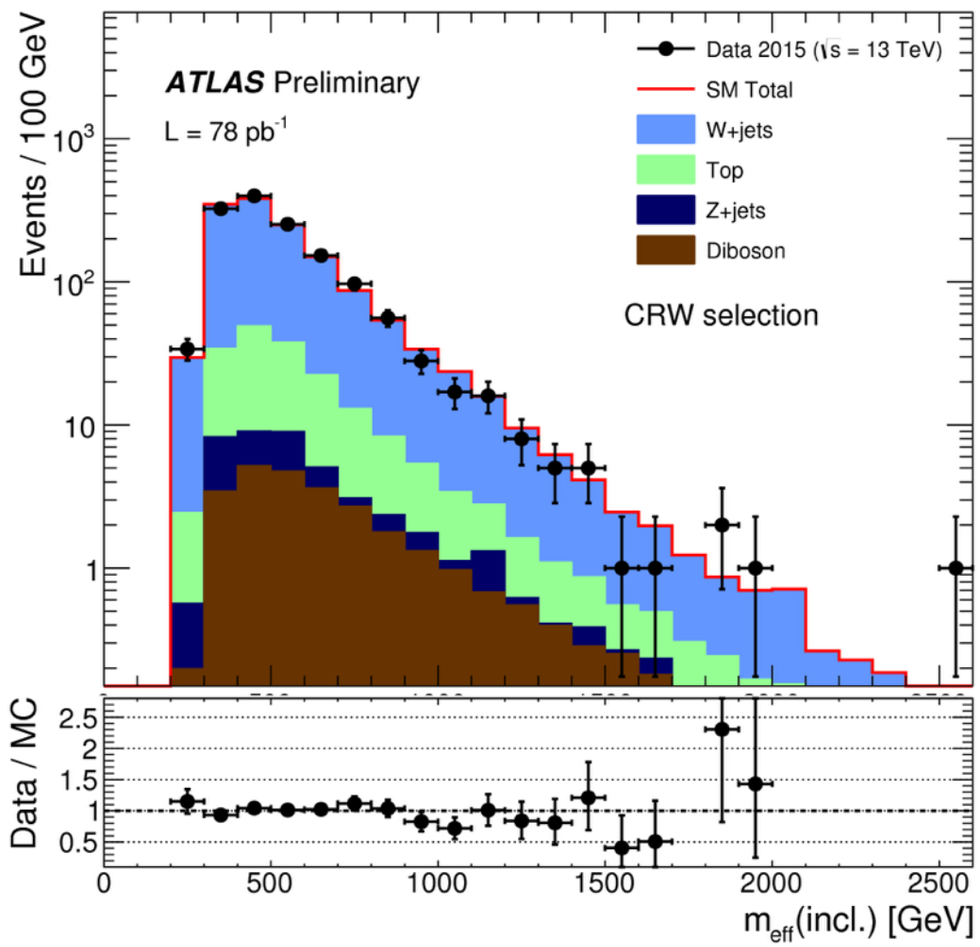
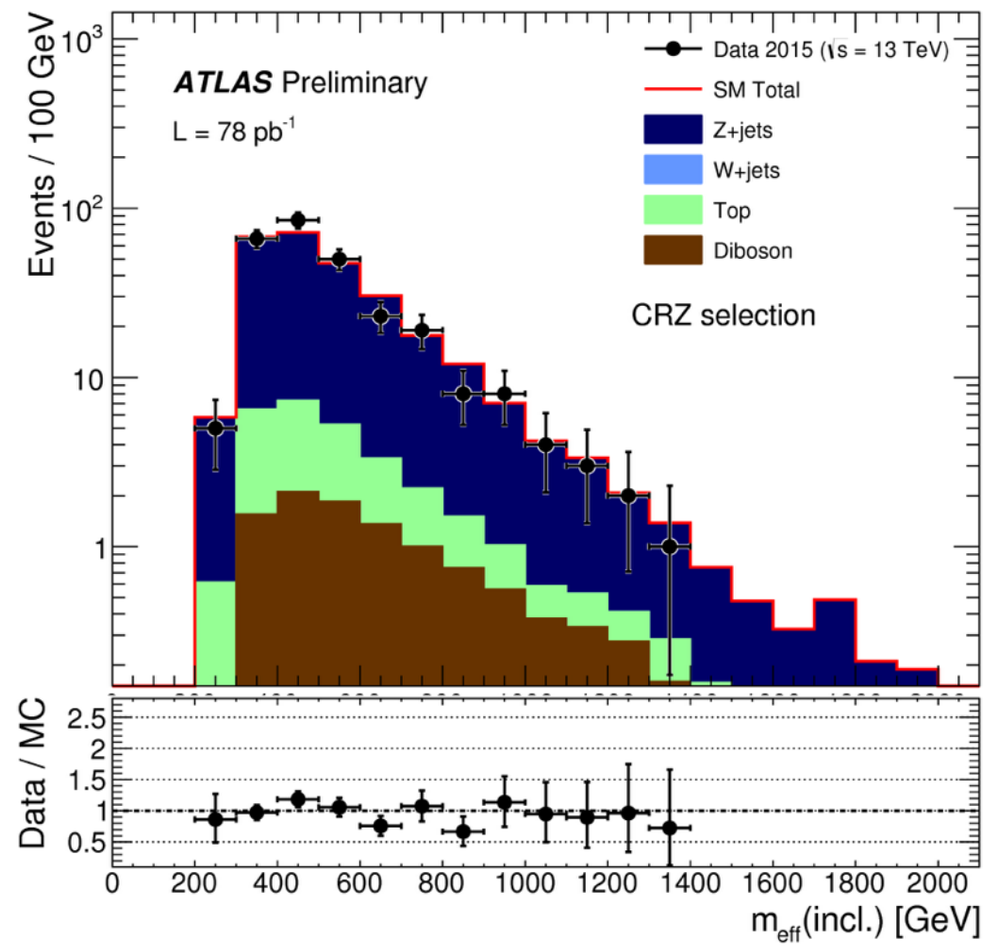
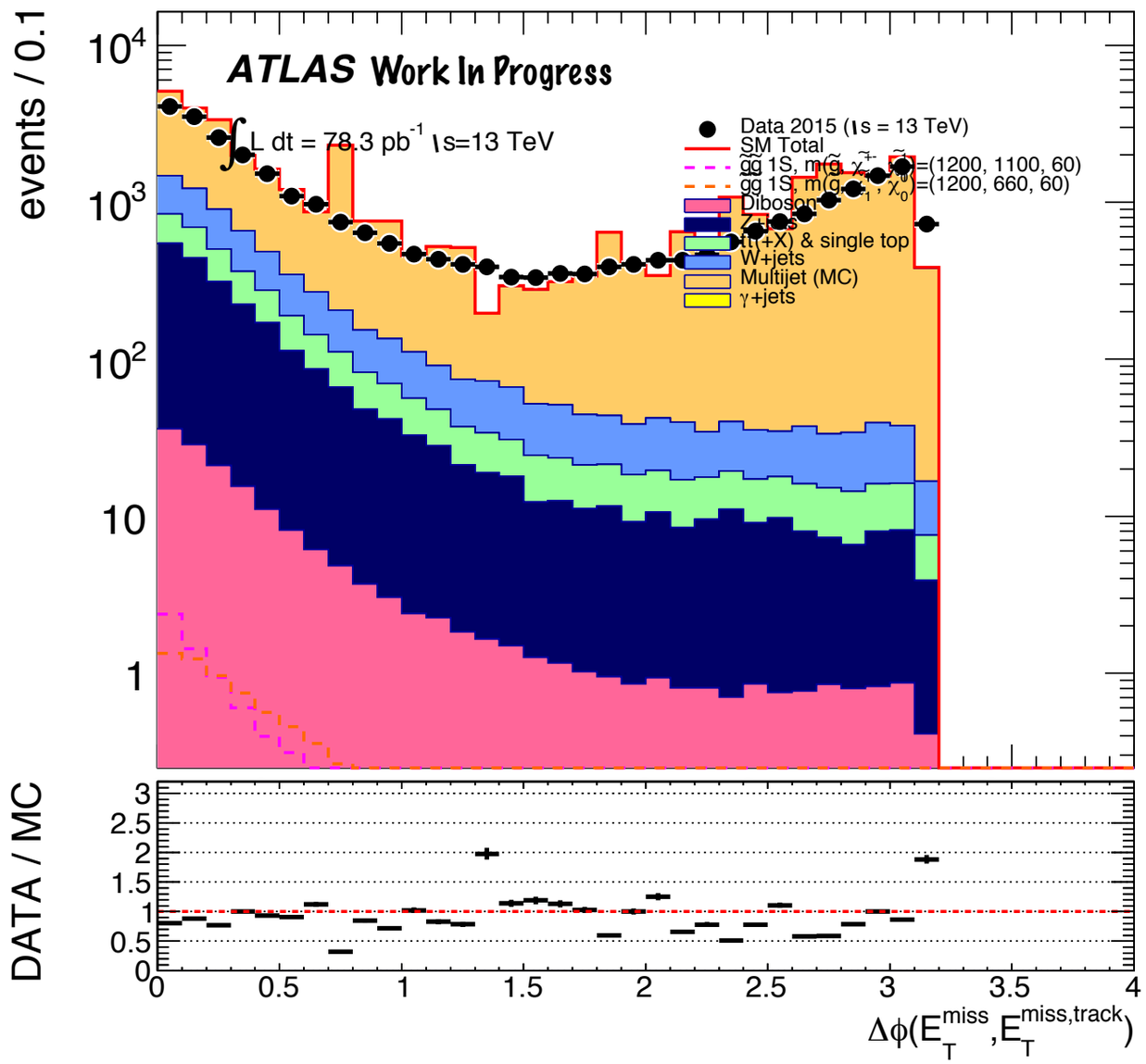



- Requiring an isolated electron or muon with pT>25 GeV, at least two jets with pT> 100, 60 GeV respectively, $E_T^{miss}$ > 100 GeV and 30 GeV <$m_T(\ell,ETmiss)$ < 100 GeV. The total MC background expectation is normalised to data.

- control region CRZ after requiring two isolated leptons of opposite sign and identical flavour with pT>25 GeV, at least two jets with pT> 100, 60 GeV respectively, $E_T^{miss}$ > 100 GeV and {66 GeV <$m\ell\ell$ < 116 GeV}. The total MC background expectation is normalised to data.

# RunII 0Lepton analysis




- Same study on $\Delta\phi(E_T^{miss}, \text{Track-}E_T^{miss})$ as done in RunI for the MJ background
- Plot with 78 $pb^{-1}$ of 13 TeV data in CR with no cut on $M_{eff}$ (similar to CR for QCD)
- Variable is behaving as expected

# Summary

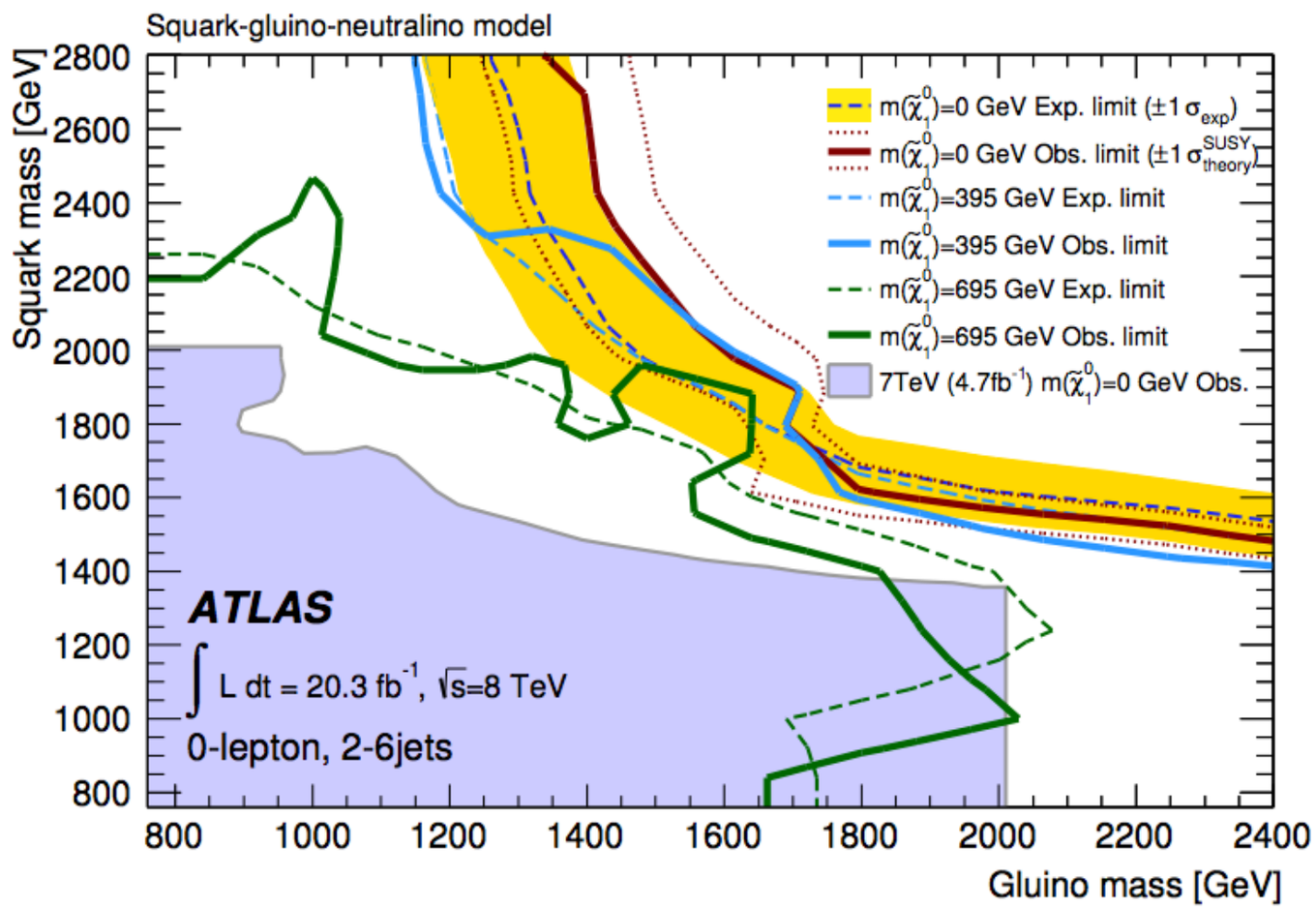
- Presented the 0Lepton (2-6 jets) SUSY search in ATLAS data for RunI e Run2
- The Run1 analysis has been published in 2014
- No significant excess above SM has been found
- Limits are placed on gluino mass (up to 1350 GeV) and squark mass (up to 850 GeV), depending on the scenario
- Several reinterpretations has been performed
- MC generators have been studied to get the MC15 setup for SUSY MC signals
- Theoretical systematic uncertainties studies are ongoing
- Several other studies are on going in the 0Lepton analysis team
- Looking forward to see new results from full 2015 dataset!

Thank you for your attention!

# Backup

# Interpretations - 2

## Simplified Phenomenological MSSM

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Model with only strong production of $\tilde{g}$ and first- and second-generation $\tilde{q}$ with direct decays to jets and lightest $\tilde{\chi}^0_1$ (0.395 GeV, 695 GeV).

# Interpretations -Further SRs

Two new SRs built and optimised to target squarks decays via Higgs

- Test of a MSSM model in which only the left-handed squarks of the first two generations, the two lightest neutralinos, and lightest charginos are assumed to be within the kinematic reach.
- Left-handed squarks can be pair produced only via t-channel gluino exchange and they can undergo a one-step decay

| Signal Region | **0L_4jt+** | **0L_5jt** |
|---|---|---|
| Total background | $1.04 \pm 0.43$ | $7.6 \pm 1.9$ |
| Observed events | 0 | 8 |

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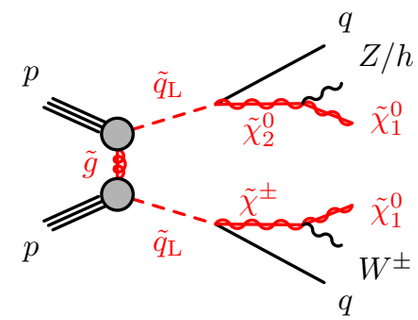


- measurements interpreted in a pMSSM model, which possesses three parameters: $m_{qL}$, $M_1$ and $M_2$, where $M_1$ and $M_2$ are the masses of bino and wino fields.
- For relatively light gluino mass of 1600GeV,a large range of squark masses (up to 1500 GeV) can be excluded

M1 = 60 geV and M2 varied independently

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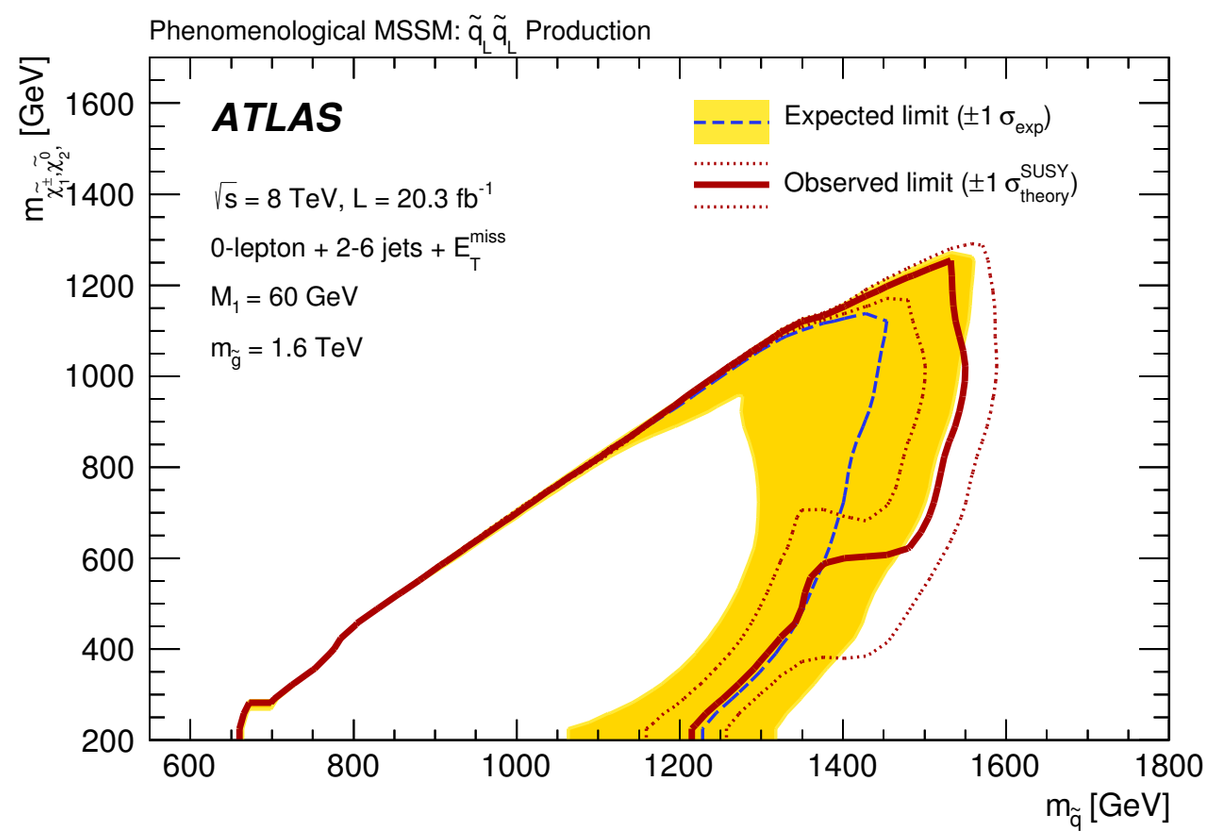


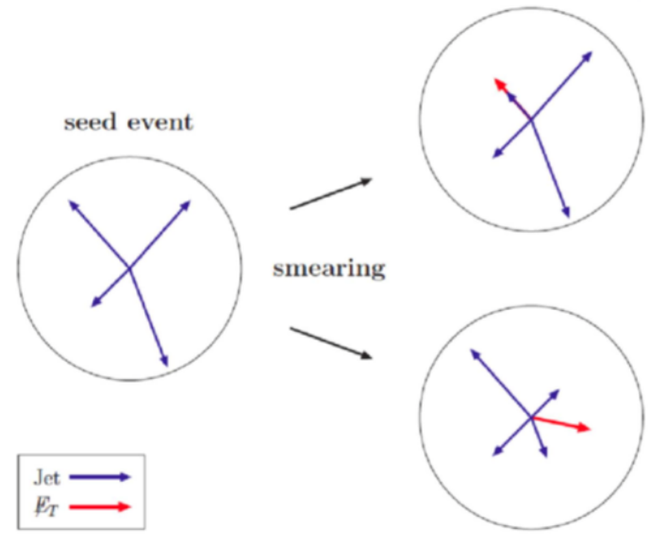
# 0-Lepton: Jet Smearing Method

- Select well measured seed events with low MET significance (S)

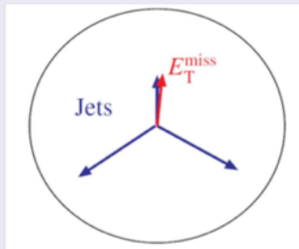
$$S = \frac{E_T^{miss}}{\sum |\vec{E_T^{miss}}|}$$

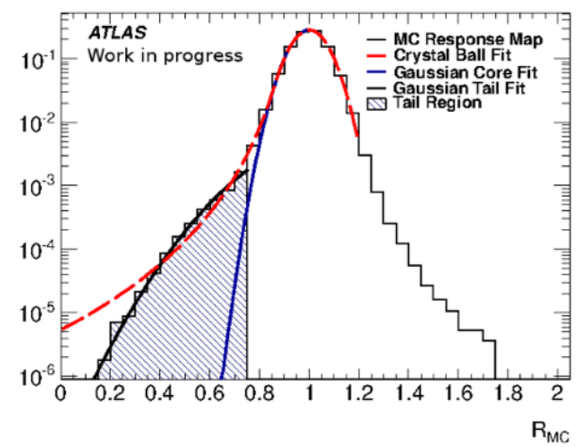
- *Smear* the jets in the seed event by multiplying the jet four vector by a random number from our jet response (R)

$$R_{MC} = \frac{p_T^{reco}}{p_T^{truth}}$$




An example Mercedes like event
where the MET is unambiguously associated with a jet in the event.




- Once the optimal jet response function has been found, the jet smearing method can then be applied to SUSY search channels to obtain:
  - Multijet distributions from pseudo-data sample;
  - estimate of the Multijet background for the Signal Regions via a Transfer Function

# 0-Lepton: W signal regions

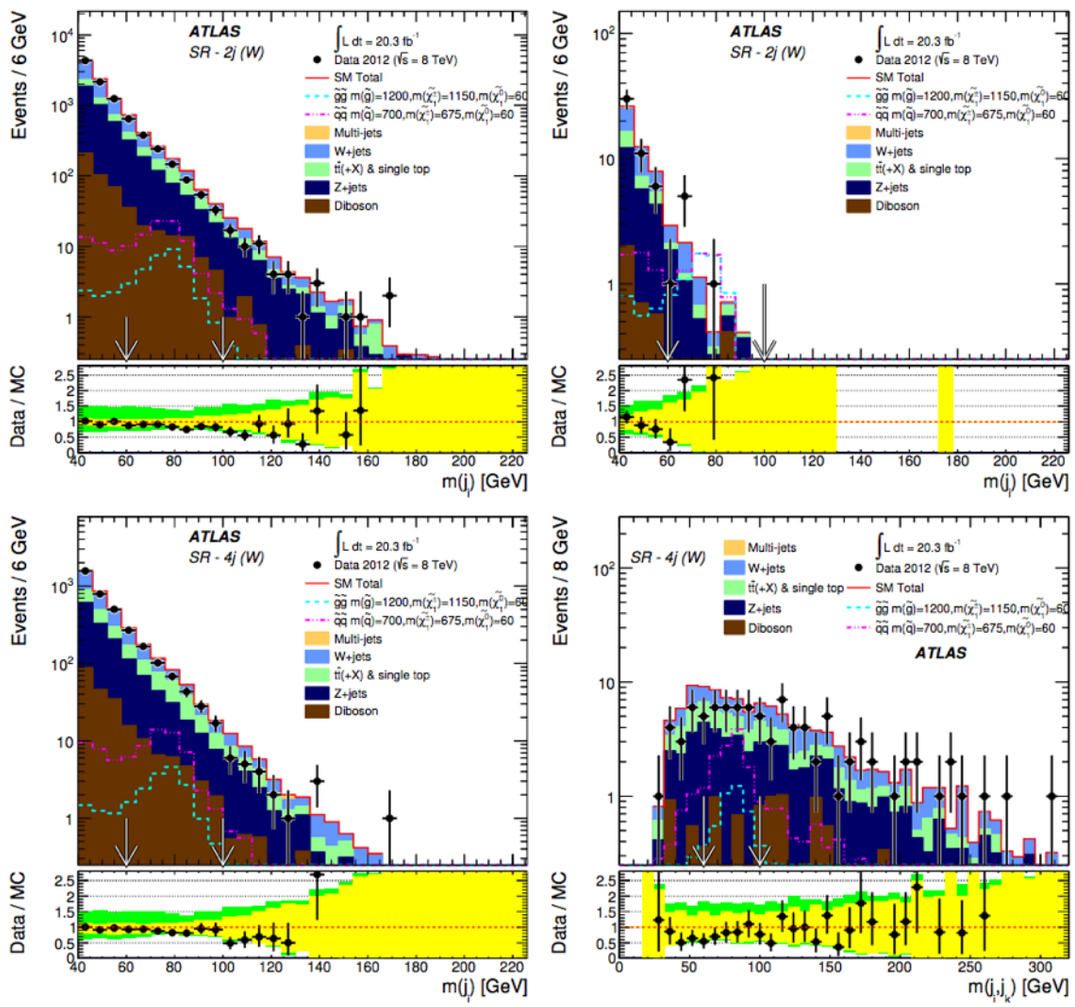
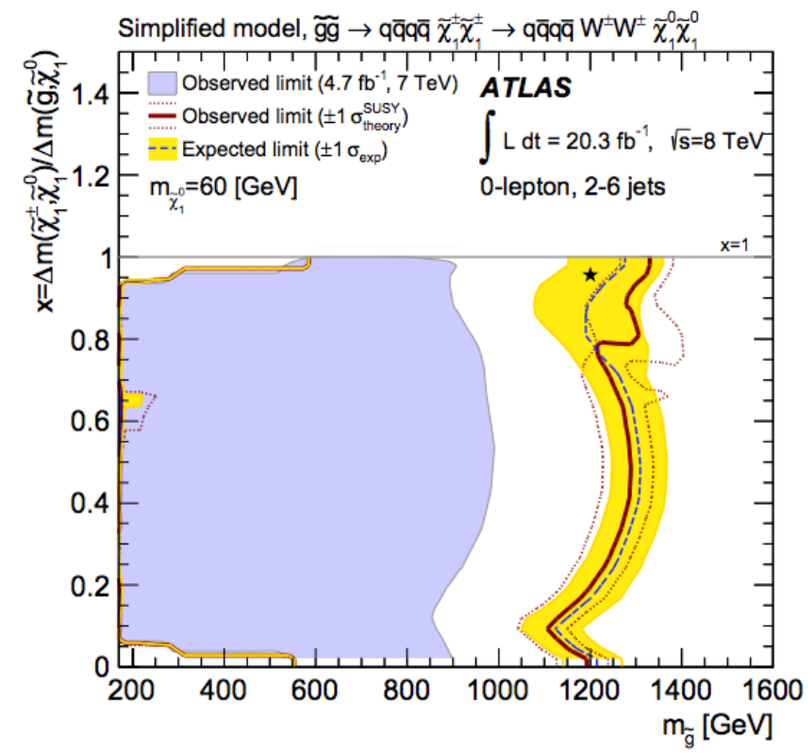
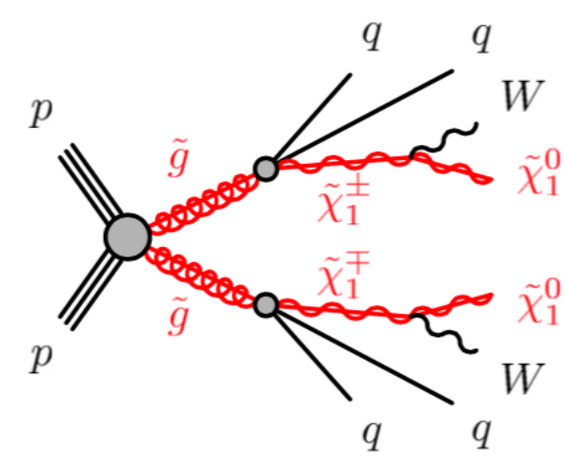



**Figure 6.** Observed jet and dijet mass distributions for the 2jW (top) and 4jW (bottom) signal regions for all unresolved $W$ candidates (left) and for an additional $W$ candidate after requiring at least one unresolved $W$ candidate (right). The additional $W$ candidate is unresolved (SR 2jW, top-right) or resolved (SR 4jW, bottom-right). With the exception of the multi-jet background (which is estimated using the data-driven technique described in the text), the histograms denote the MC background expectations prior to the fits described in the text, normalised to cross-section times integrated luminosity. In the lower panels the light (yellow) error bands denote the experimental systematic and MC statistical uncertainties, while the medium dark (green) bands include also the theoretical modelling uncertainty. Expected distributions for benchmark model points are also shown for comparison (masses in GeV). Arrows indicate the location of the mass window used in the final selection. See text for discussion of compatibility of data with MC background expectations.

Expected boosted W for large $\Delta m(\chi_1^{\pm}, \chi_1^0)$

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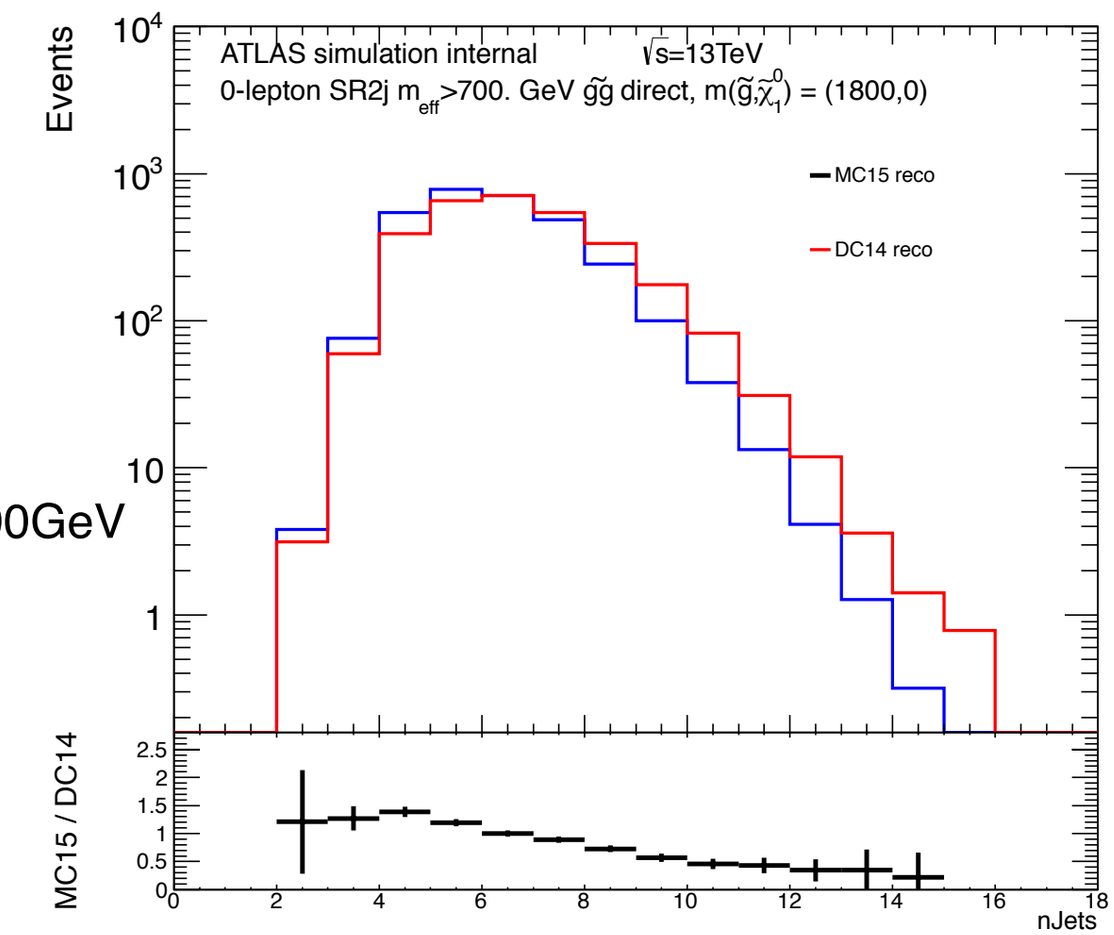
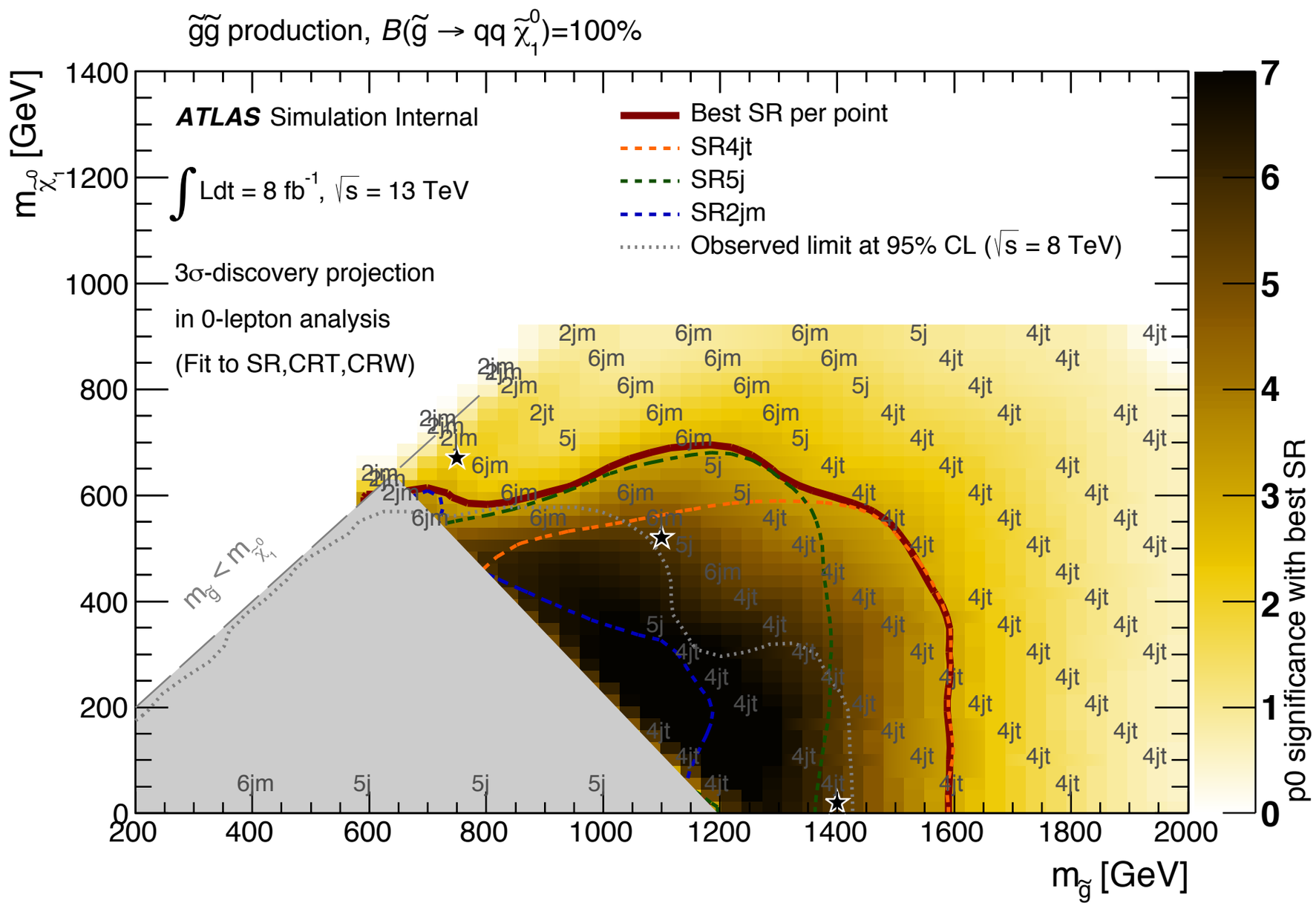
# Towards RunII: SUSY Signal Studies

**Signal modeling is crucial for robustness of the analysis**

- SUSY Signals for the Run1 analysis were modeled with different generators (Herwig++, Madgraph+Pythia6, etc)
- For Run2 a big effort was dedicated in comparing and validating different setups for the SUSY signal production.
  - ➡ 0Lepton analysis MC team particularly focused on GG/SS direct grid

- "MC15" setup was established:
  - MadGraph+Pythia8
  - NNPDF23LO
  - Compared with setup "DC14" for 8/13TeV samples

- Difference in $N_{jet}$ leaded to re-optimisation of the SR
- Used a loose selection: $N_{jet}$ >=2, $E_T^{miss}$>130GeV, $M_{eff}$>700GeV
- Study performed at TRUTH level



# Limits Prediction