THE QUEST FOR SUSY @ LHC

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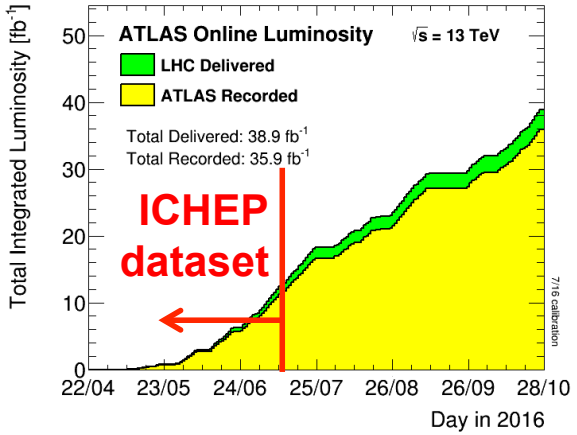
Scope of this talk (I)

- **18 ATLAS** SUSY conference notes since August
- **19 CMS** SUSY conference notes since August
- But only 20 minutes today … ☹
- So .... hard choices made to fit in today's slot
  - 8 analyses presented ! Some others flashed



- Talk focusing on **4 main topics**: different eras of LHC Run 2
  - **Strong** production searches ➔ **very early/early** searches
  - **Third generation** (focusing on stop searches) ➔ **early** searches
  - **Electroweak** production ➔ **ongoing** searches
  - **RPV** SUSY ➔ **preliminary** searches

Scope of this talk (II)

- Today's **highlights**
  - Studied **models**
    - Effective, simplified, …
  - Considered **experimental signatures**
    - All possible number of leptons: 0 to ≥ 3-leptons
  - Main **recent results**
    - Comparisons of sensitivities whenever possible

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  - Studied **models**
    - Effective, simplified, …
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    - All possible number of leptons: 0 to ≥ 3-leptons
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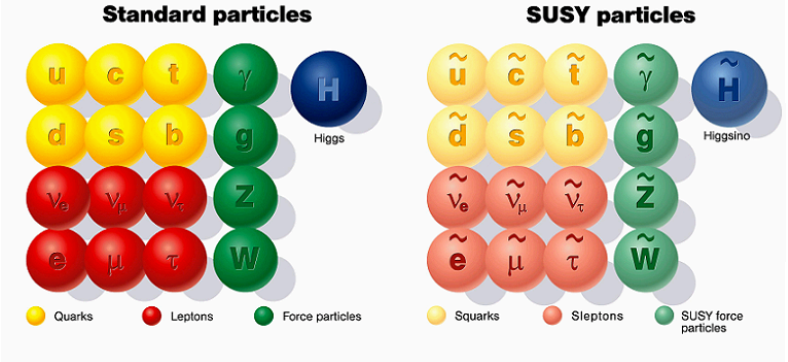
No discovery of SUSY announced today …

SUSY

- SUSY = one of the **most promising BSM theories** reachable @ LHC
  - Solves/proposes to solve many issues of the SM
    - Naturalness, dark matter, …
  - Rich phenomenology



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- **But**, many free parameters in the models
  - Mass spectrum to be determined
  - Couplings to be observed
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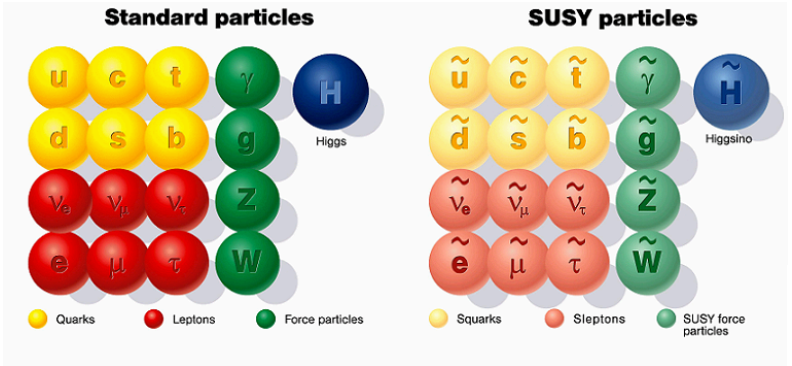

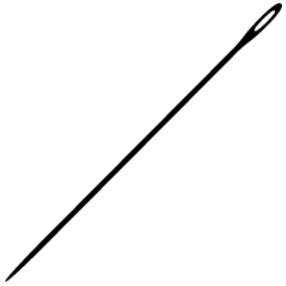

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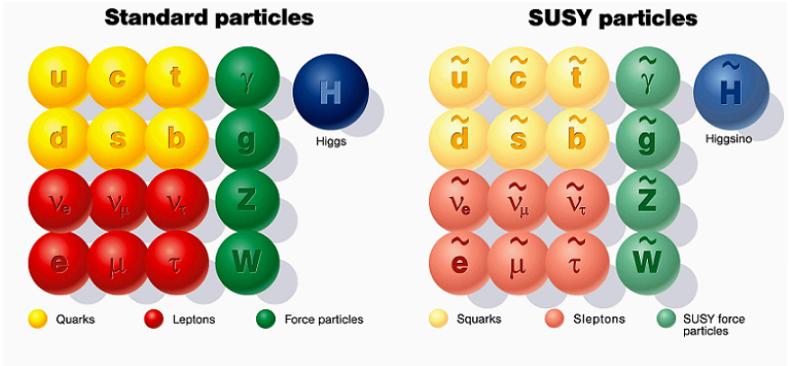
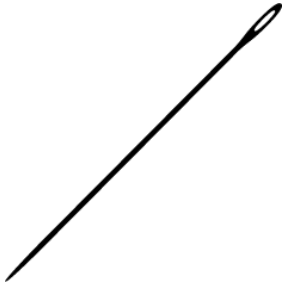




- **Extremely hard** to perform a full scan of the parameter space …
  - Mostly use (very) **simplified models** depending on O(2) parameters

Quest for SUSY @ LHC

- Mainly looked for by **ATLAS** and **CMS**
  - **Hard to reinvent the wheel**
    - Both experiments use **close recipes**:
      - Signatures, background modeling, systematic treatment, …
    - But with some **noticeable differences in strategy**
- In particular: **use of shapes** !
  - **CMS** heavily uses “shapes” or multi-channel approaches
    - **Pros**
      - *Improved sensitivity* (more information learnt from data/different phase space corners)
    - **Cons**
      - Depends on the *signal shape* … But is it known ?
      - *Background estimation* needs to be more refined (to account for shape effects)
  - **ATLAS** mostly using single-bin **cut-and-count** analyses
    - **Pros**
      - Easier to *recast* (only event count)
      - Only background *normalisation* to be corrected for
    - **Cons**
      - Slightly worse *sensitivity*

Outline

- **Strong production** : squarks and gluinos
- **3rd generation**: the top squark searches
- **Electroweak** SUSY
- **R-parity violating** SUSY

SQUARKS AND GLUINOS

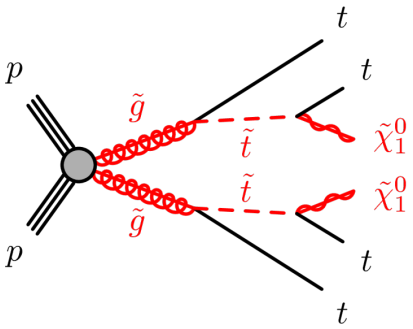
SUS-16-014
SUS-16-015
SUS-16-016
SUS-16-016
SUS-16-020
ATLAS-CONF-2016-052 *SUS-16-022*
ATLAS-CONF-2016-037 *SUS-16-030*

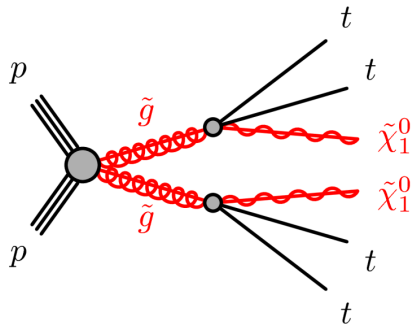
Squark and gluino productions

- Ideal target for the **early Run 2**
  - Large cross-section increase w.r.t. 8 TeV
  - Largely dominating w.r.t. EW for reasonably heavy squarks/gluinos

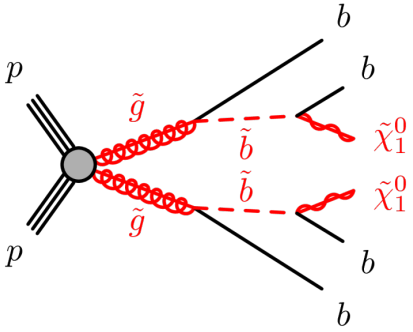
    ➔ **No need for very high lumi to be sensitive**

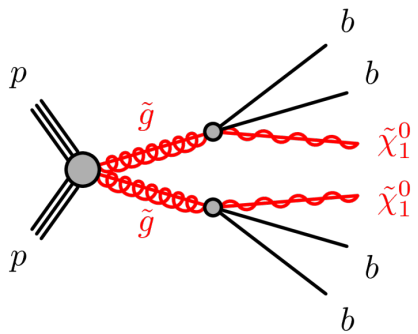
- Two main **simplified models** considered
  - **pp → tttt + N1N1**





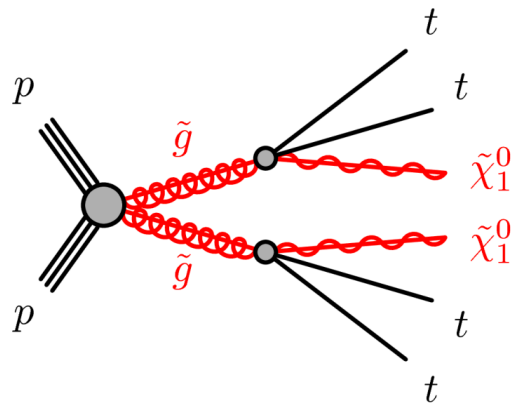
  - **pp → bbbb + N1N1**

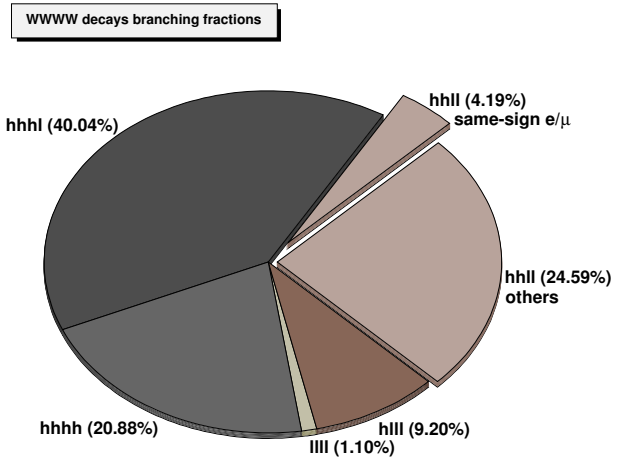




gg → tttt + N1N1

- Covered in both **ATLAS** and **CMS**
  - **4 top quarks** in the final state
    - Very **spectacular** final states !!!
      - 0 lepton ➔ large Njets (up to 12 hard jets)
      - 1 lepton ➔ large BR and clear signature
      - ≥2L ➔ particularly interesting in same-sign
- Signature always contains:
  - Many **jets**
  - Large **MET**
  - Many **b-jets**
- Dominating **backgrounds** sources
  - ttbar+jets / V+jets *via* MC or *via* instrumental background (fake leptons, lost leptons, …)





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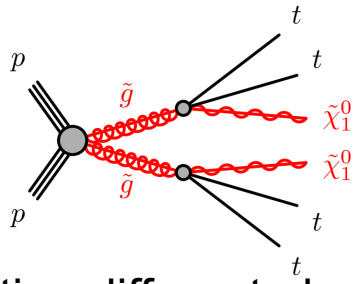
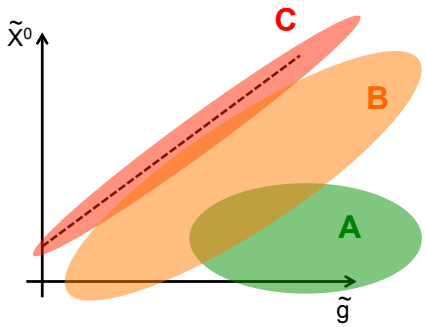
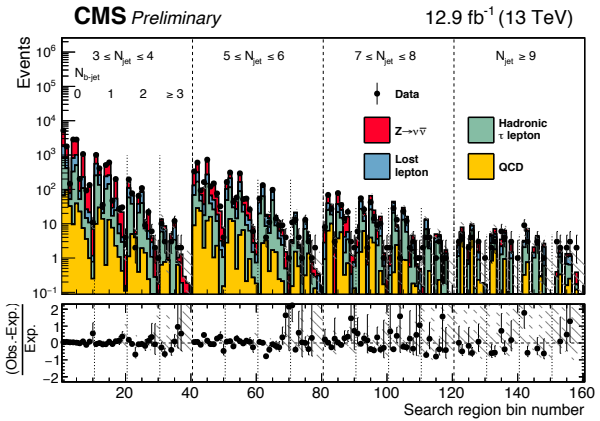
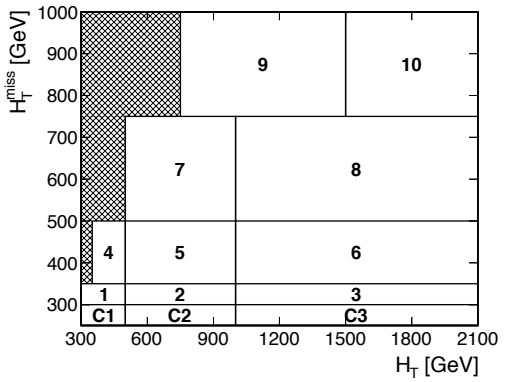


- **ATLAS** strategy
  - Tight **event-counting regions** targeting different phase space corners
  - Control regions (CR) defined to normalize backgrounds
  - Background validated in validation regions (VR)
  - Relies on kinematic/event variables:
    - m_{eff}, N_{jets}, $N_{b\text{-}jets}$, MET, $N_{leptons}$, m_T(b,MET), top-tagging, …



- **CMS** strategy
  - Large number of non-overlaping SRs (160 regions in 0L) combined altogether
  - CRs defined to estimate each background source individually
  - Closure tests performed to validate backgrounds prediction





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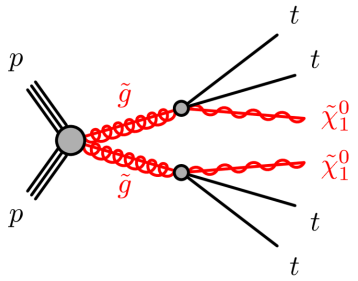
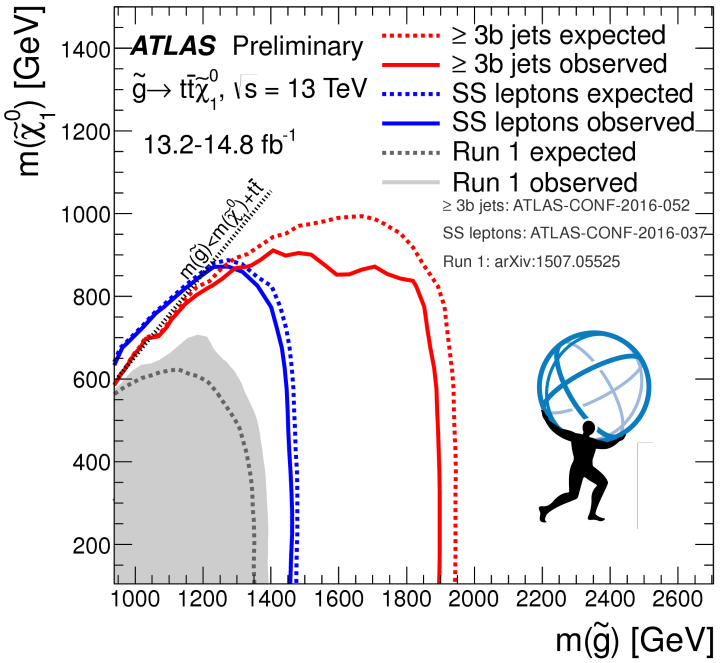
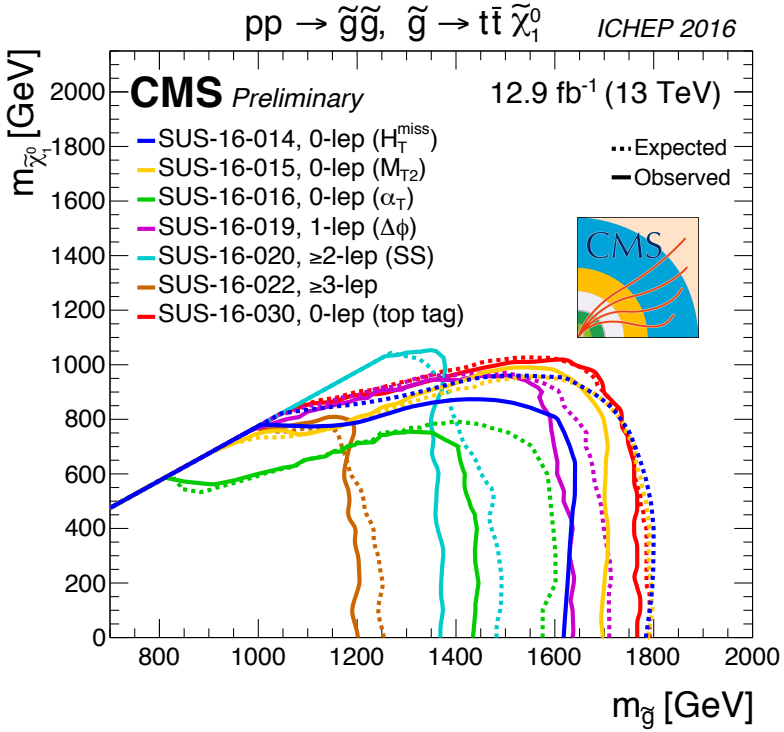


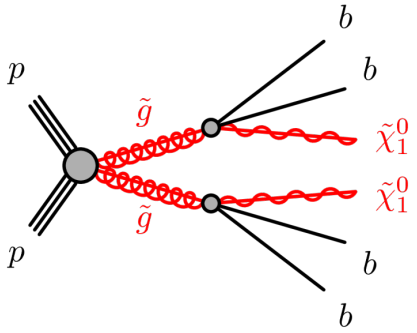
- **No significant excess** observed compared to background expectations





- Each analysis sensitive in **different corners**
  - same-sign more sensitive along diagonal, 0/1-lep for massless neutralinos
- ATLAS more sensitive due to 0L/1L channels statistical combination

gg → bbbb + N1N1



- Only accessible in **0L channel**
  - Multiple b-jets and high MET
  - Analysis strategies very close to previous one

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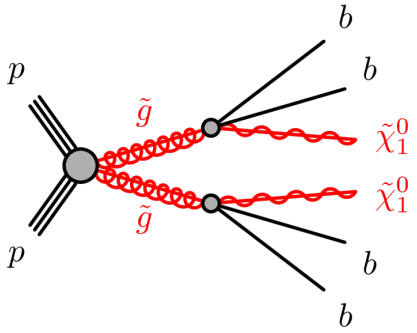

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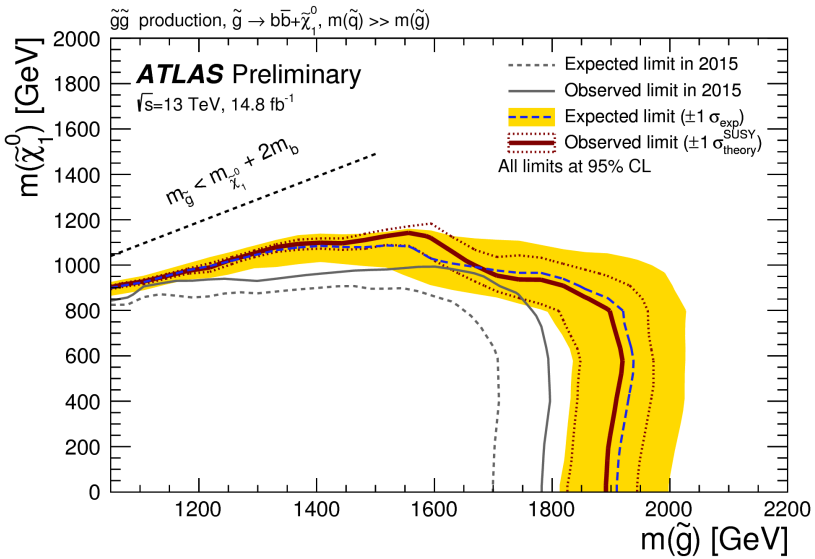
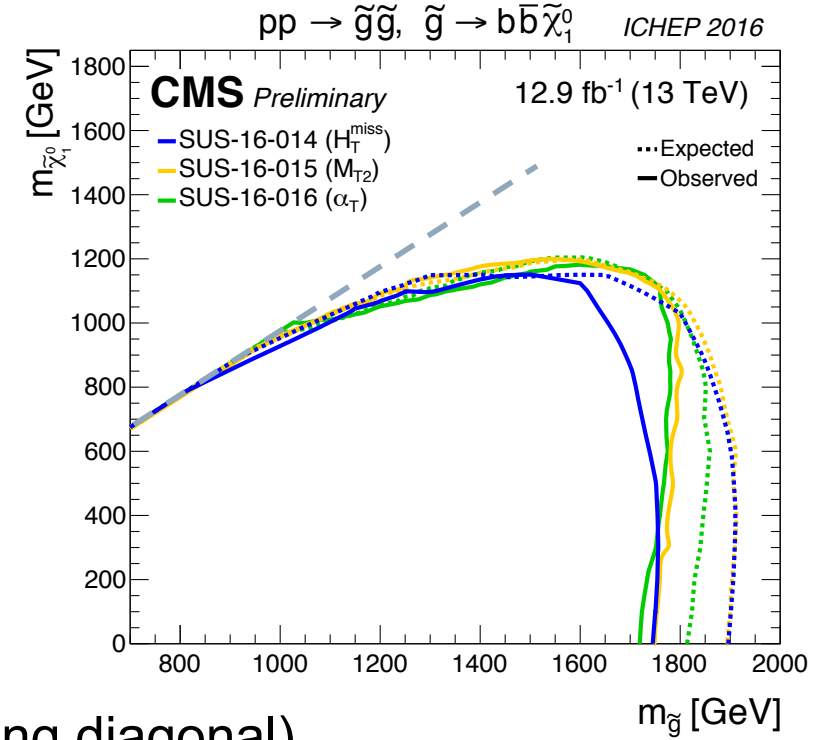




- **CMS more sensitive** (especially along diagonal)
  - Thanks to multi-bin combination ➔ recover SR inefficiencies in this regime

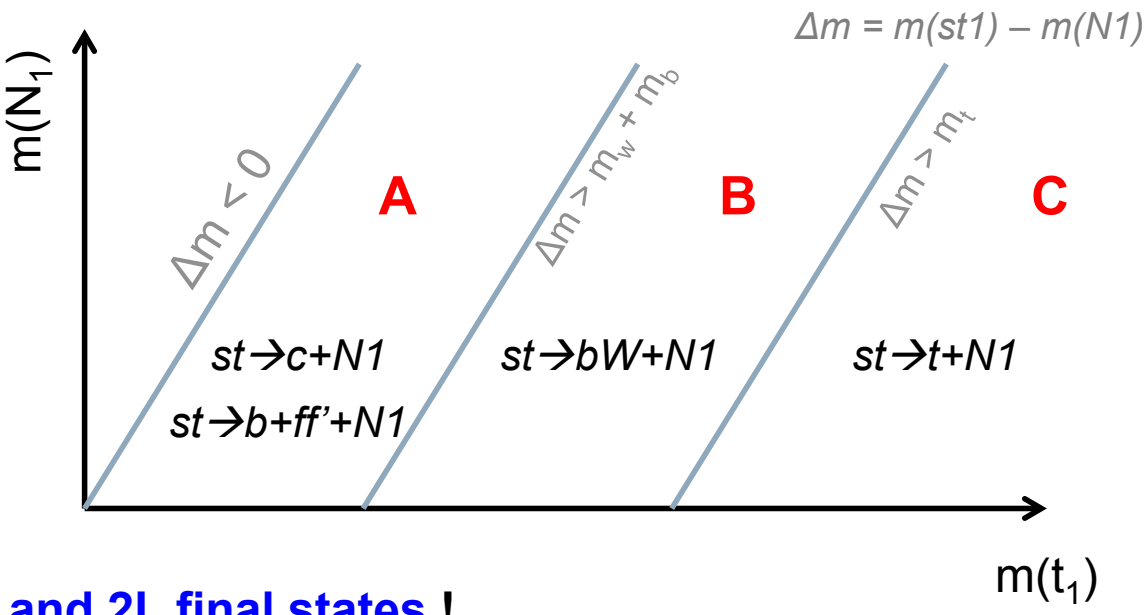
3RD GENERATION

… but only stop for today ...

ATLAS-CONF-2016-077 *SUS-16-029*
ATLAS-CONF-2016-050 *SUS-16-016*
ATLAS-CONF-2016-076 *SUS-16-027*

3rd generation squark searches (I)

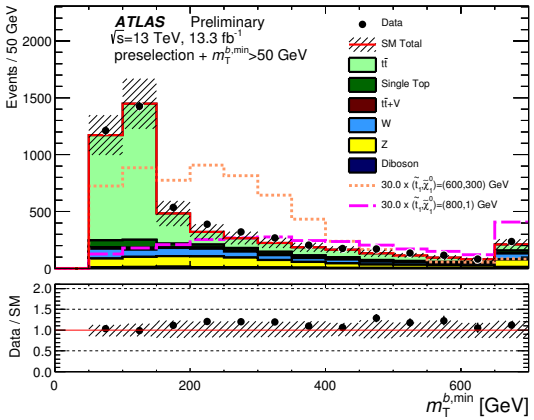
- **Simplified models** to depend on 2 parameters only
  - Top squark mass
  - Neutralino mass
- Different **mass splitings**
  - = different decay types
  - = different experimental signatures



- Can be searched for in **0, 1 and 2L final states !**
- **ICHEP** phase space coverage
  - CMS: 3 regions
  - ATLAS: only 2 (intermediate and high spliting)
- No dramatic change in **analysis strategies**

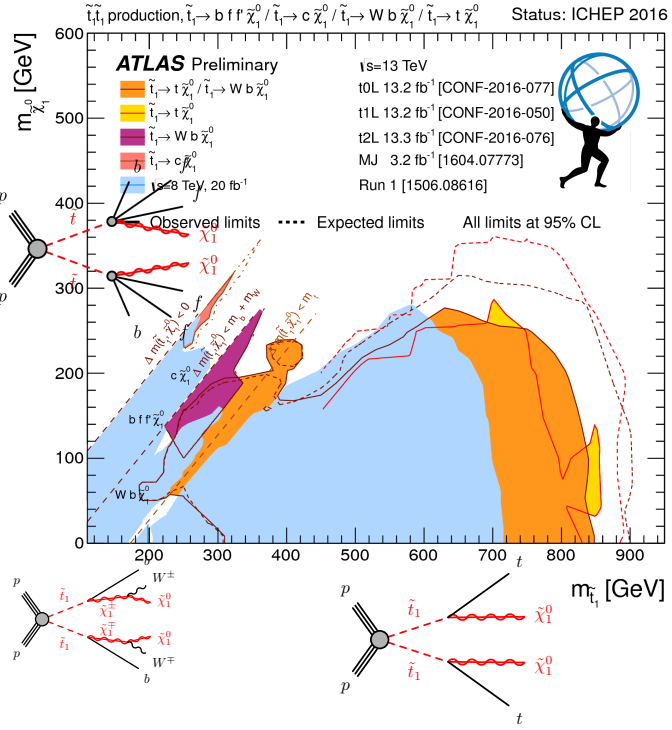
3rd generation squark searches (II)

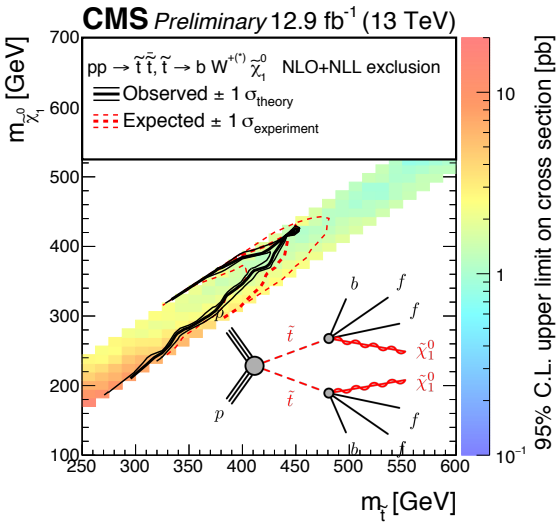
- **Analysis strategies**
  - Sensitivity to different kinematics: same problematic as for tttt/bbbb+N1
  - **High Δm searches**
    - High top p_T: top/W tagging algorithms (jet reclustering, substructure-based, …)
    - Use of $m_T^{b,min}$ (supresses ttbar+jets)
  - **Intermediate/low Δm**
    - Recursive Jigsaw (ISR-tagging) (ATLAS)
    - Anti-b-tagging (ISR-tagging) (CMS)
    - Lower jet multiplicity requirement
  - Same as previous section
    - ATLAS: few overlapping regions
    - CMS: full multi-channels combination

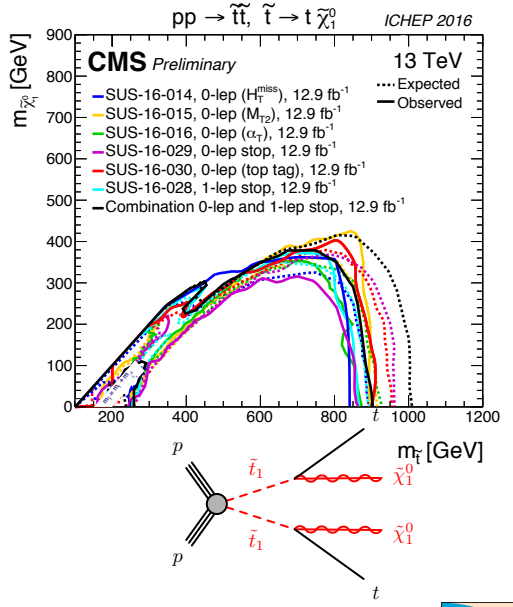


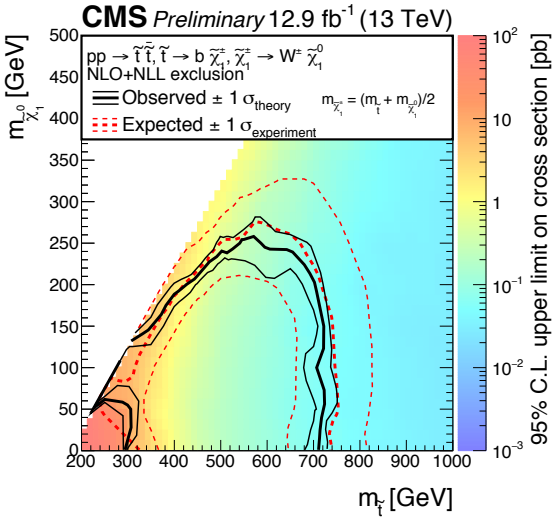
- **Can be searched for in 0, 1 and 2L final states !**
- CMS covering 3 regions with ICHEP dataset (ATLAS only 2)

3rd generation squark searches (III)









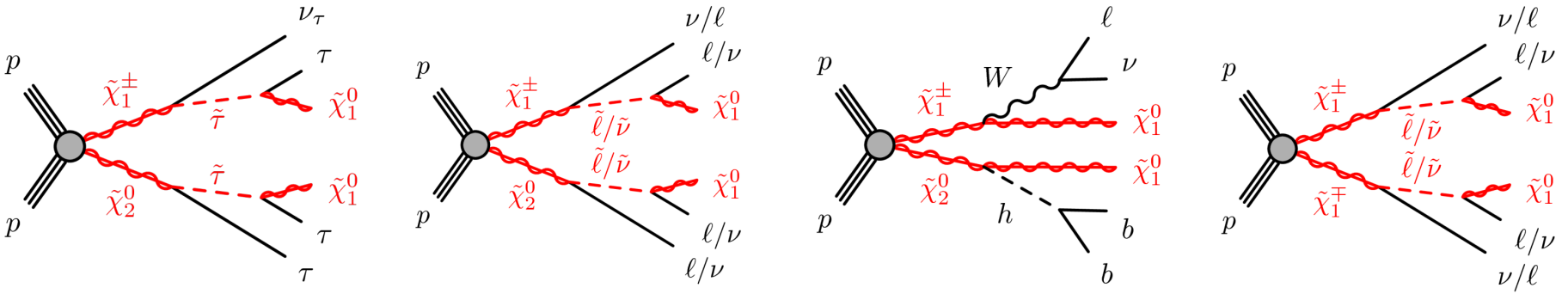
- Some slight **excesses** (~2-3σ) in ATLAS – weaker in CMS
- Senstitivity close between both experiments

ELECTROWEAK PRODUCTION

ATLAS-CONF-2016-093 *SUS-16-024*
ATLAS-CONF-2016-096 *SUS-16-026*

Electroweak production (I)

- Constraints on **gluinos/stops are quite stringent** …
- Despite lower expected cross-section, LHC starting to be sensitive **to EW SUSY production**
  - *e.g.* Direct production of electroweakinos

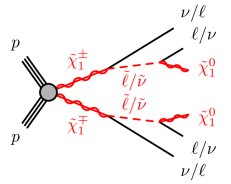


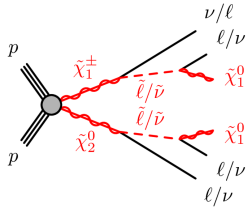
NB: C1 and N2 considered as degenerate

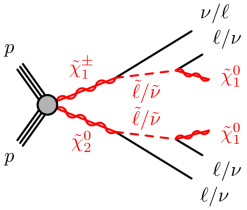
- For now, mainly **spectacular final states**
  - **Multiple leptons** (≥3 leptons – democratic charginos/neutralino decays)
  - **Multiple taus** (1 or 3 taus – tau-enriched or -dominated models)
  - Multiple **b-jets** (Higgs bosons in decay chain)

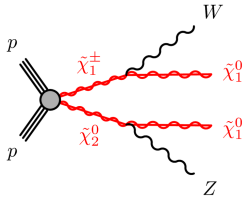
Electroweak production (II)

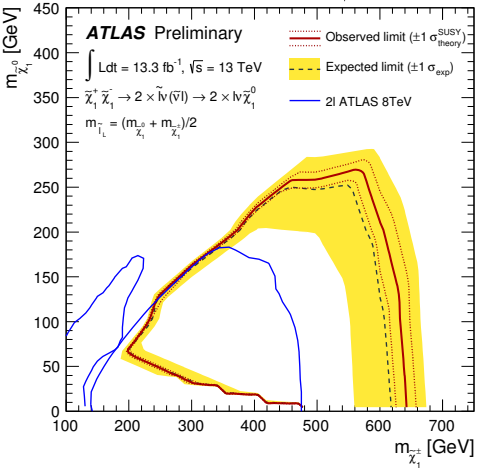
- Search in **multi-lepton** final states
  - Democratic decays of N2 and C1
- Searched for in **2-lepton** (C1C1 or C1N2 with unidentified leptons)
  - CMS uses information about tau leptons to classify events
  - ATLAS only uses electrons/muons
- Searched for in **≥3 leptons** (C1N2) or **≥4 leptons**

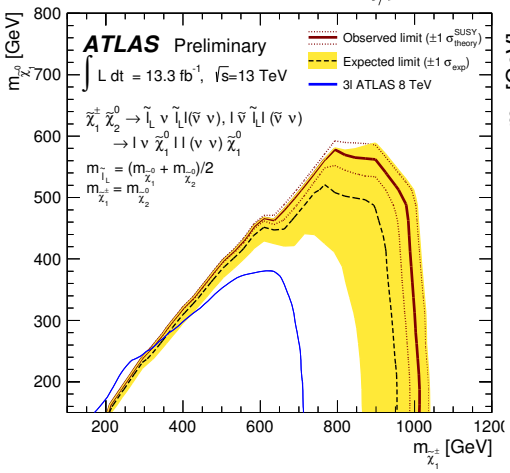


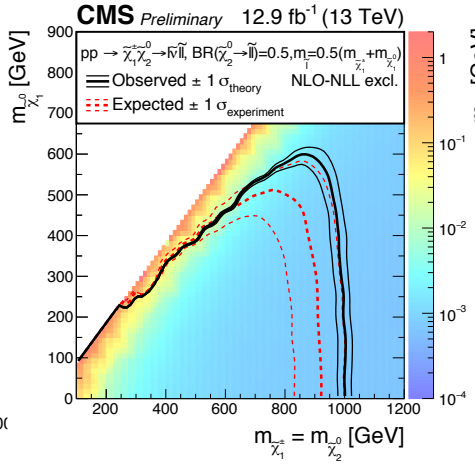


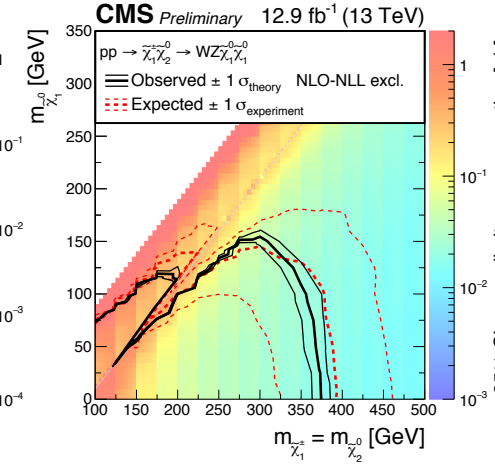






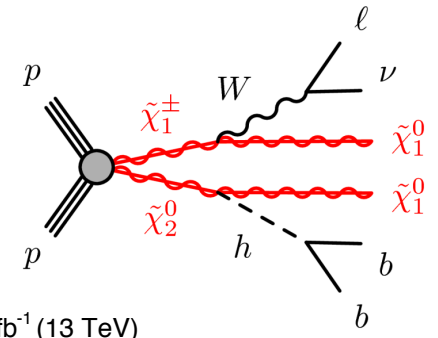


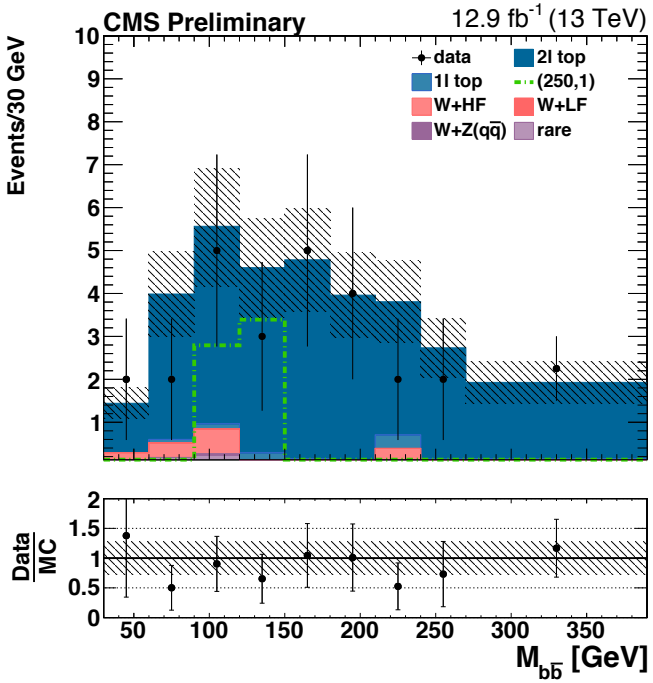


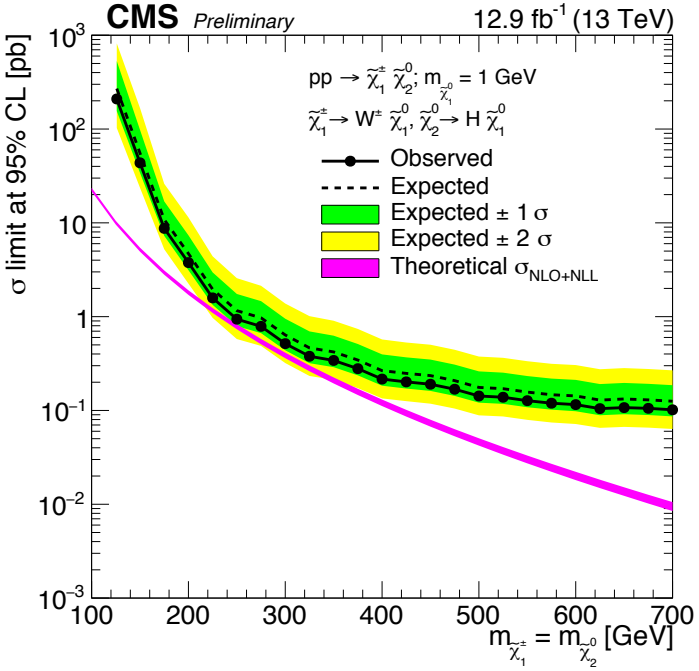


Electroweak production (III)

- Search for EW SUSY in **WH final states** (1-lepton)
  - Only considering H → bb decays (mass requirement)
  - *Massless* neutralino
  - Only one region (high energy + 2 b-jets)

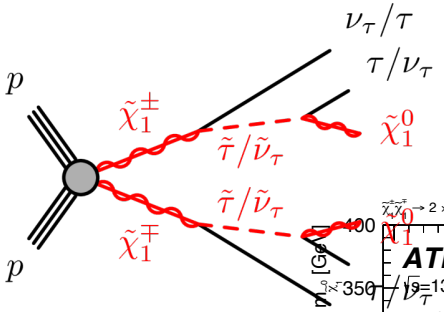


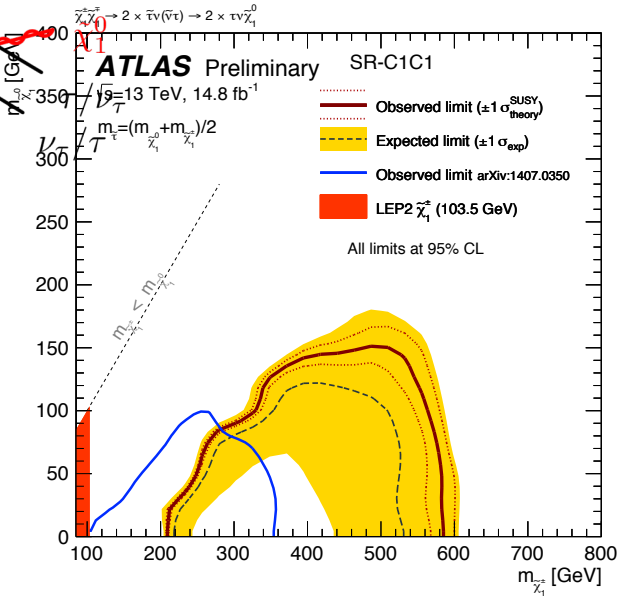


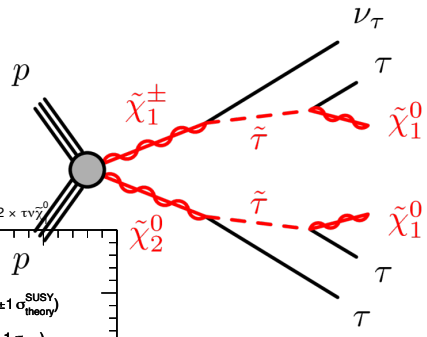


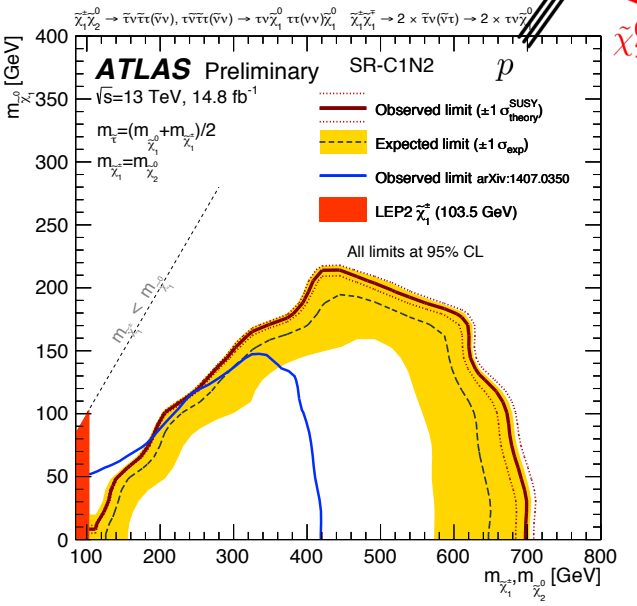
Electroweak production (IV)

- Search in **tau-lepton** events
  - ≥2 taus in events
    - Good for trigger !
  - b-jet and Z veto (ttbar/Z+jets suppressed)
  - Dominated by QCD background (misidentified taus)







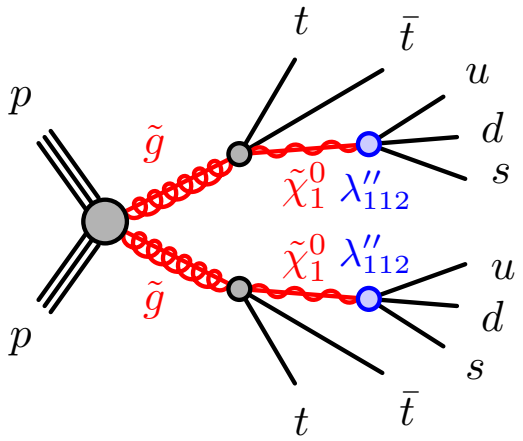


R-PARITY VIOLATING SUSY

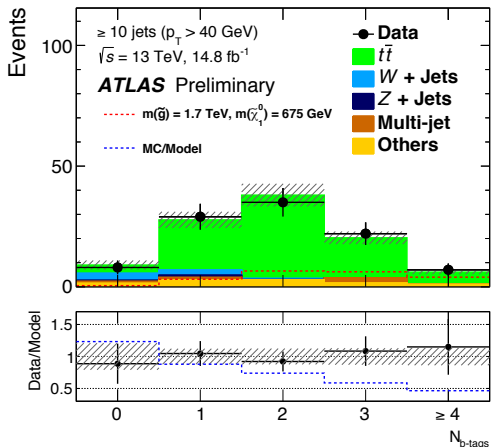
ATLAS-CONF-2016-094

RPV SUSY (I)

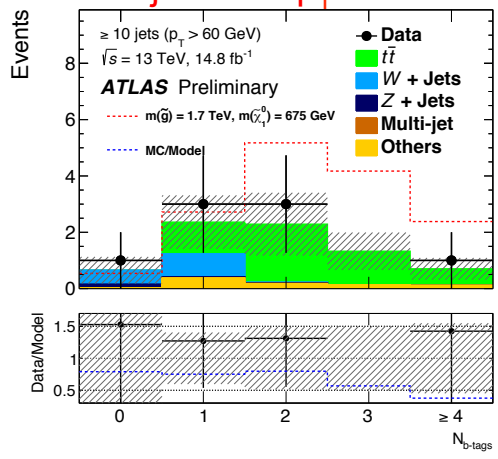
- Studied in ATLAS and CMS
  - No update from CMS with 2016 data
  - Focusing on **ATLAS program**
- R-parity violation described by one non-zero parameter: λ”
- Search performed in **1-lepton channel**
  - Very high jet multiplicity expected (up to 16 jets !!!!)
  - Multiple SRs with up to ≥10 jets
  - Background (ttbar+jets) estimated by fit to data in different jet multiplicity bins ➔ modeling looks excellent !

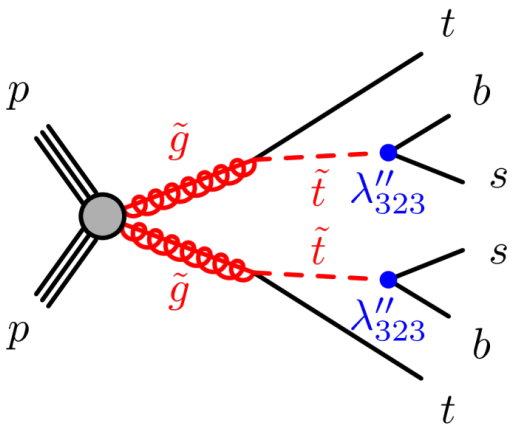


≥10 jets with p_T > 40 GeV

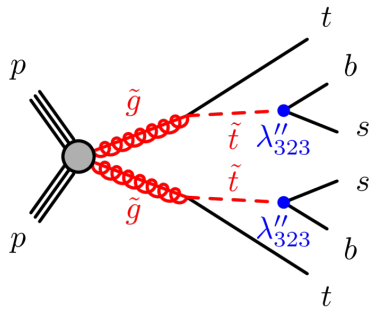


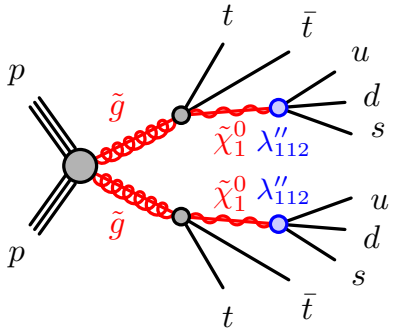
≥10 jets with p_T > 60 GeV

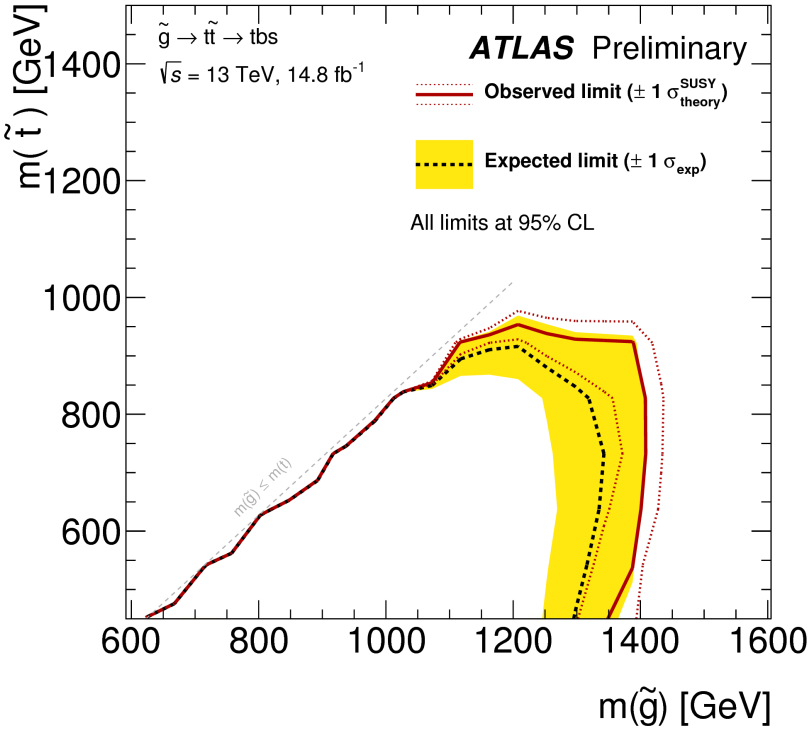


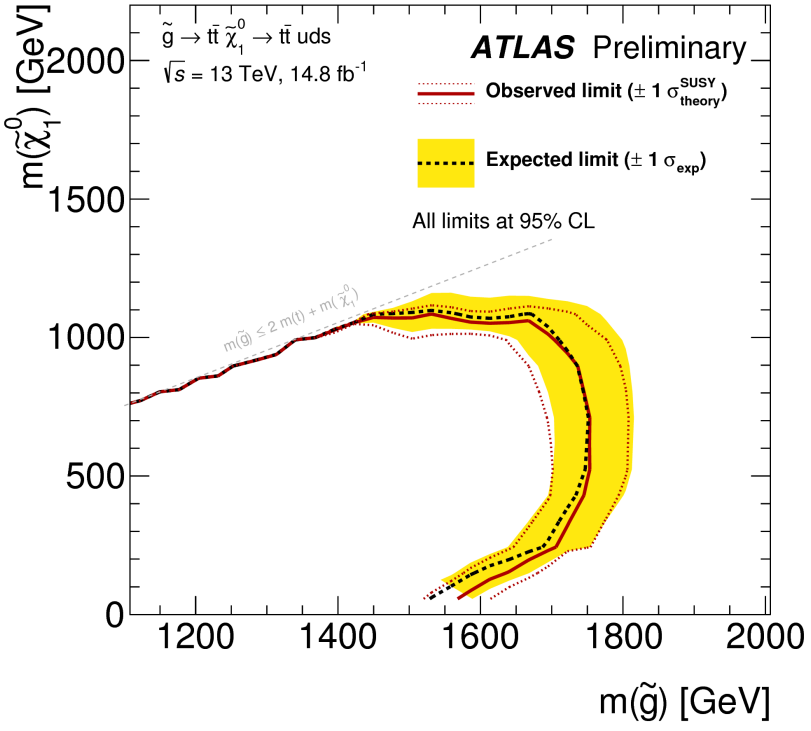


RPV SUSY (II)


p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{t}$
$\tilde{t}$
λ''_{323}
λ''_{323}
t
b
s
s
b
t


p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{\chi}_1^0$ λ''_{112}
$\tilde{\chi}_1^0$ λ''_{112}
t
$\bar{t}$
u
d
s
u
d
s
t
$\bar{t}$


$\tilde{g} \to t\bar{t} \to tbs$
$\sqrt{s}$ = 13 TeV, 14.8 fb^{-1}
ATLAS Preliminary
Observed limit ($\pm$ 1 σ^{SUSY}_{theory})
Expected limit ($\pm$ 1 σ_{exp})
All limits at 95% CL
$m(\tilde{g}) \le m(t)$
$m(\tilde{t})$ [GeV]
$m(\tilde{g})$ [GeV]
600
800
1000
1200
1400
1600


$\tilde{g} \to t\bar{t}\,\tilde{\chi}_1^0 \to t\bar{t}$ uds
$\sqrt{s}$ = 13 TeV, 14.8 fb^{-1}
ATLAS Preliminary
Observed limit ($\pm$ 1 σ^{SUSY}_{theory})
Expected limit ($\pm$ 1 σ_{exp})
All limits at 95% CL
$m(\tilde{g}) \le 2\,m(t) + m(\tilde{\chi}_1^0)$
$m(\tilde{\chi}_1^0)$ [GeV]
$m(\tilde{g})$ [GeV]
0
500
1000
1500
2000
1200
1400
1600
1800
2000

Conclusions & Outlooks

- **ATLAS & CMS heavily involved in SUSY searches @ 13 TeV**
  - Overall similar sensitivity despite some differences in strategies

- **First searches** for SUSY targeting **most promising final states**
  - *Strong* production
  - *3rd generation*
  - Sensitivity strongly improved wrt Run 1 …
    - **But still no discovery** ☹

- **Luminosity increasing** (together with gluino/squark contraints)
  - Study of "new" production mechanisms / signatures
    - EW SUSY, RPV, …
  - Also time to investigate new models / more realistic (but still simplified) ones