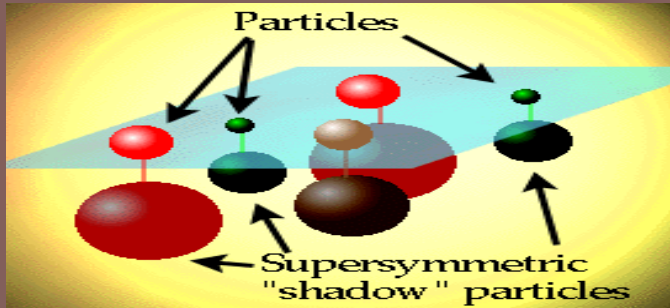
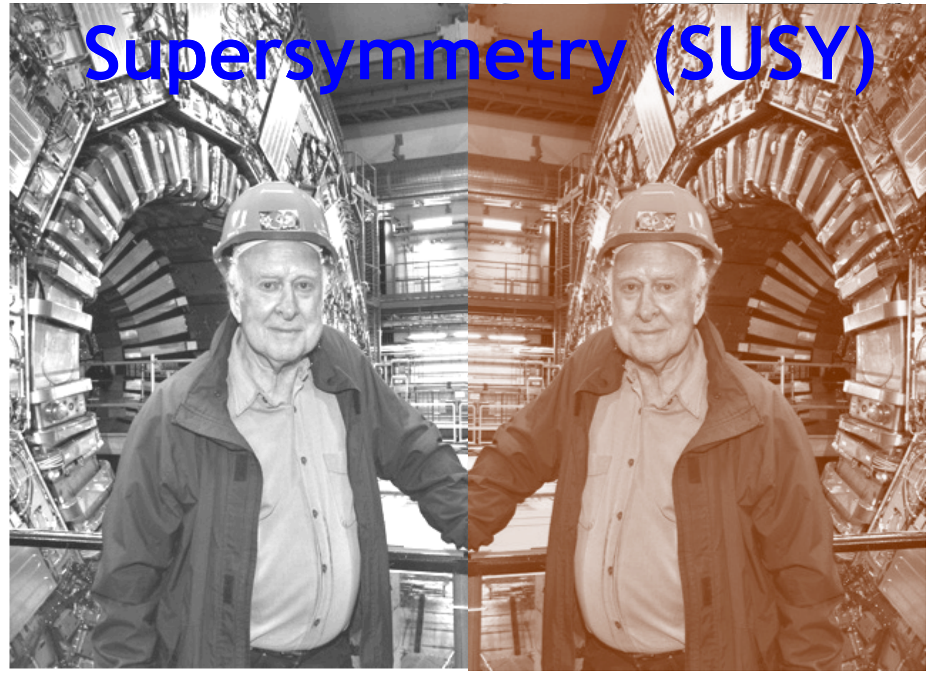


IHEP SUSY Group:

- 1st RPC SUSY Search group in China
- Faculty: Xuai Zhuang, Da Xu, Shan Jin, Feng LU
- Students: Huan Ren, Huajie Cheng, Peng Zhang, Yang Liu, Chenzheng Zhu

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences



ATLAS SUSY STUDY FROM IHEP

Xuai Zhuang (庄胥爱)

xuai.zhuang@cern.ch

IHEP, Beijing, China

Nov. 18 2016 创新团队年会

中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

SM and Beyond

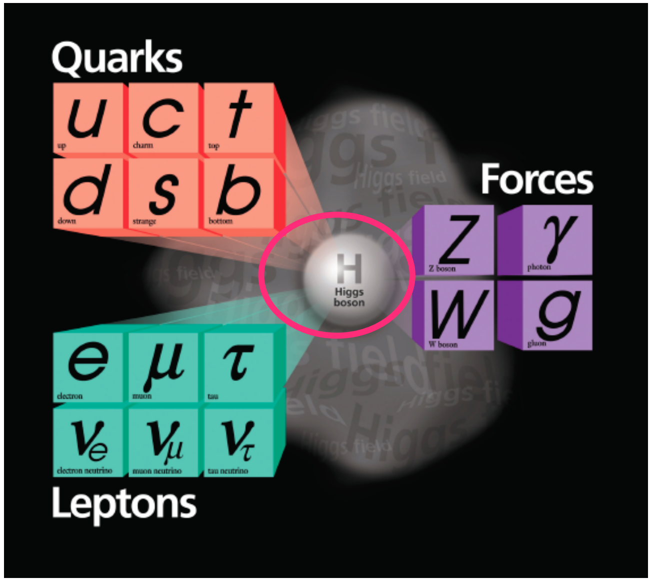


Photo: A. Mahmoud
François Englert

Photo: A. Mahmoud
Peter W. Higgs

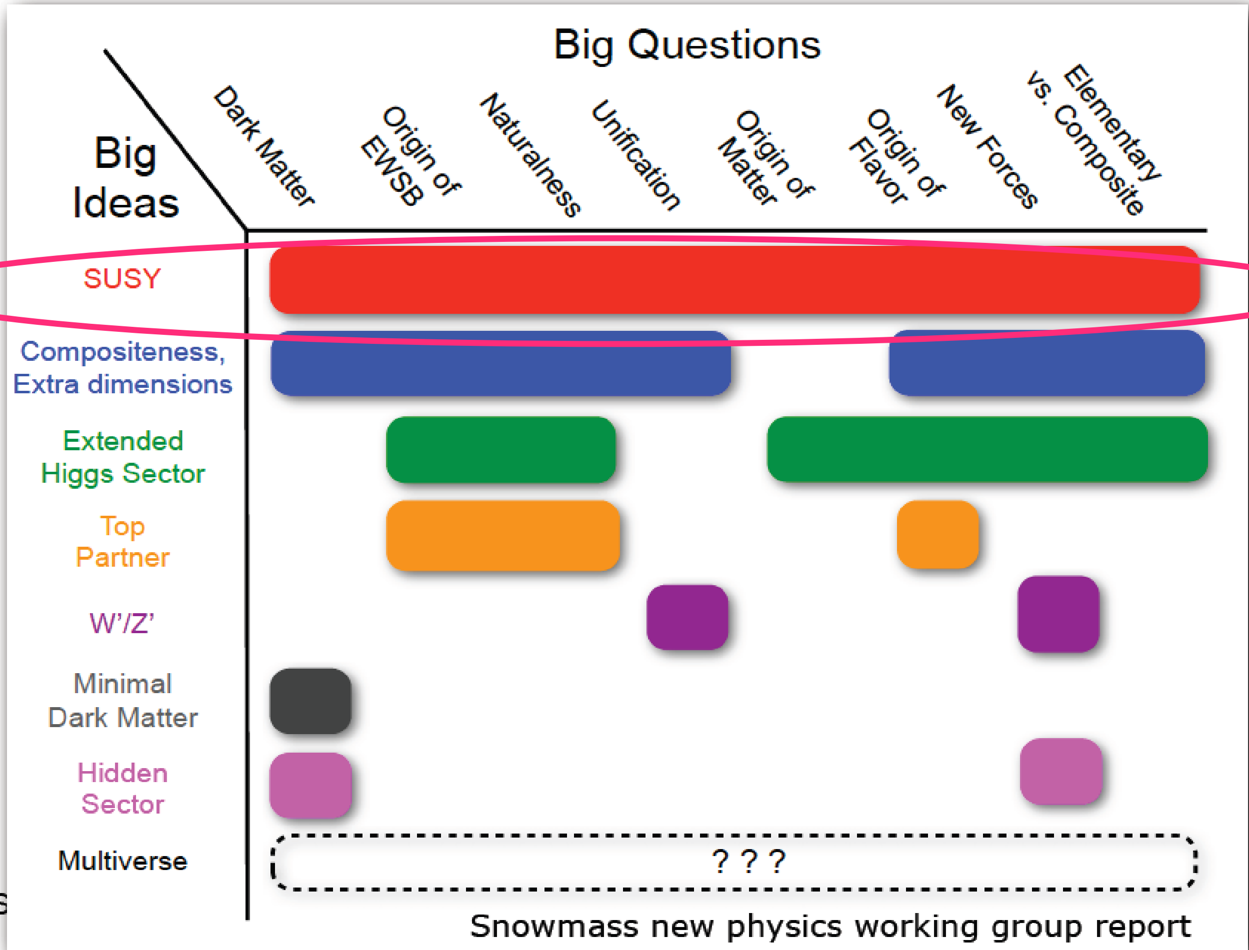
The Nobel Prize in Physics 2013
François Englert, Peter Higgs

- Higgs boson observed, SM fits the experimental data very well ➔ big success in EW scale

- While has problem in Planck scale:
  - Naturalness and "hierarchy" problem
  - Unification of gauge coupling
  - Dark Matter
  - ……

- Need a more fundamental theory in which SM is only a low-energy approximation ➔ **New Physics**

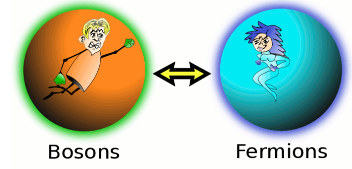
New Physics beyond the SM



S. S

- If SUSY is at TeV scale, it will be produced copiously at LHC
- SUSY search is one of the most hot topic at LHC and beyond

SUSY Introduction

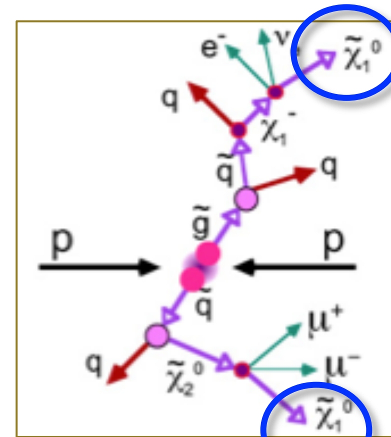


- **A symmetry which unified fermions (matter) and bosons (forces)** -> A fundamental theory
- **Conserved R parity (RPC):** (originally introduced for stability of proton)

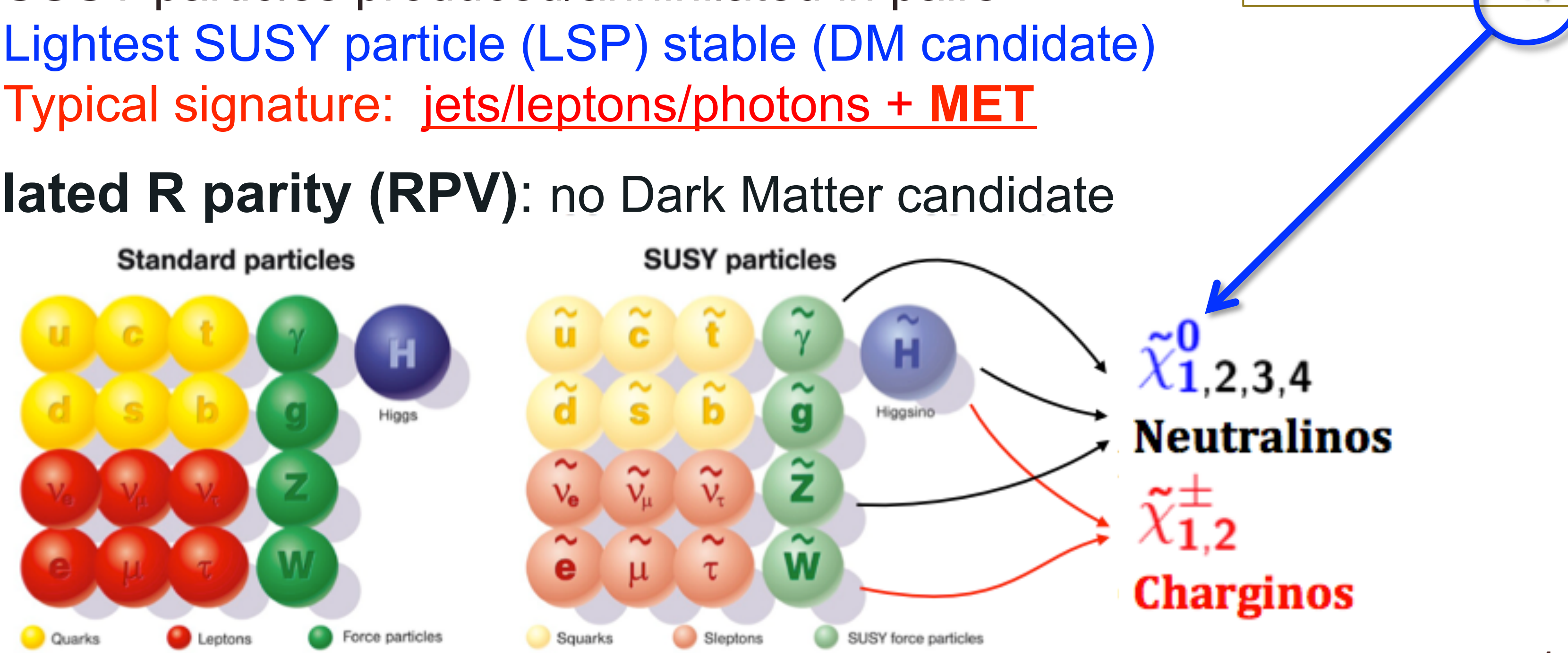
$$R = (-1)^{3(B-L)+2S}$$

R=+1 (SM)
R=-1 (SUSY)

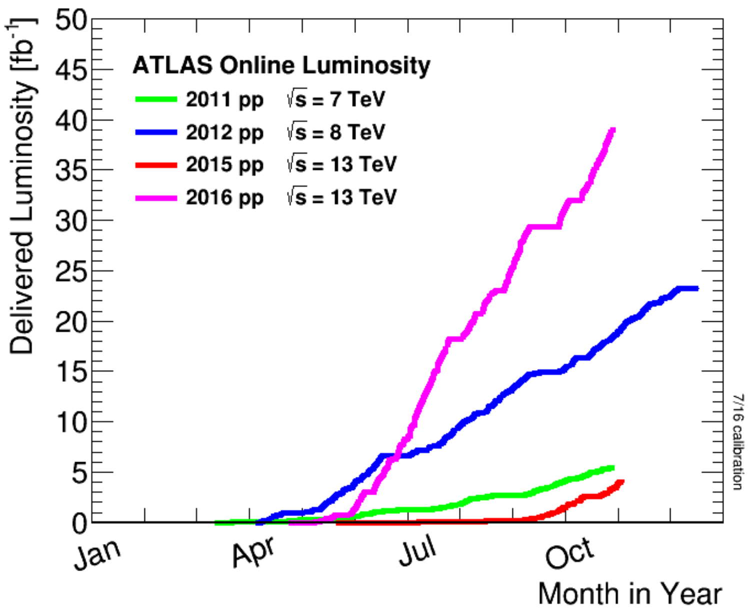
  - SUSY particles produced/annihilated in pairs
  - Lightest SUSY particle (LSP) stable (DM candidate)
  - Typical signature: jets/leptons/photons + **MET**

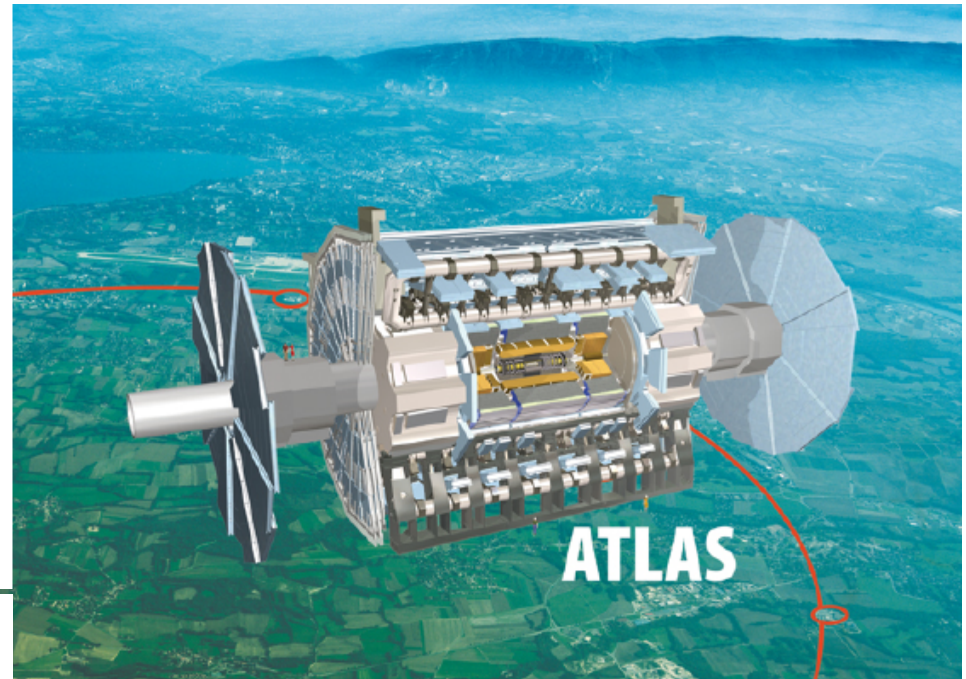


- **Violated R parity (RPV):** no Dark Matter candidate



Since 2010, ATLAS&CMS have invested huge efforts in SUSY search @LHC : Great Luminosity recorded





Run1:
~ 35 pb^{-1} 7 TeV data (2010)
~ 5 fb^{-1} 7 TeV data (2011)
~ 20 fb^{-1} 8 TeV data (2012)

Run2:
~ 3.2 fb^{-1} 13 TeV data (2015)
~ 33.2 fb^{-1} 13 TeV data (2016)

The results are based on 13-18 fb^{-1} @ 13 TeV (RUN2) for summer CONF

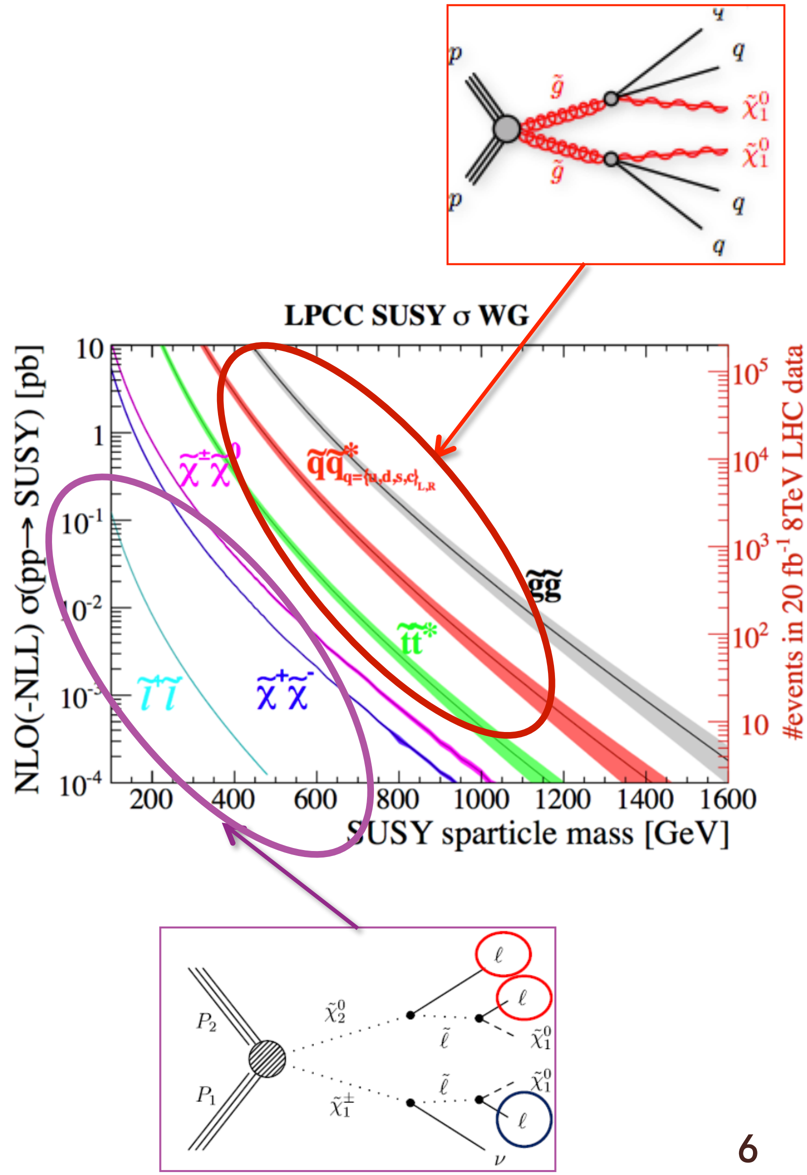
SUSY Search @ LHC

Strong production: targeting gluino and squarks (Inc. 3rd gen. squarks)

- ❑ Generic signatures :
  Multi -jets + n_lepton/n_photon(n=0,1, ≥2) + large E_T^{miss} (0L,**1 L, >=2L**)
- ❑ large xs, but heavy SUSY mass scale
- ❑ **IHEP topics:**
  ① 1L +jets +MET
  ② SS2L/3L +jets +MET

Weak production: targeting charginos, neutralinos and slepton

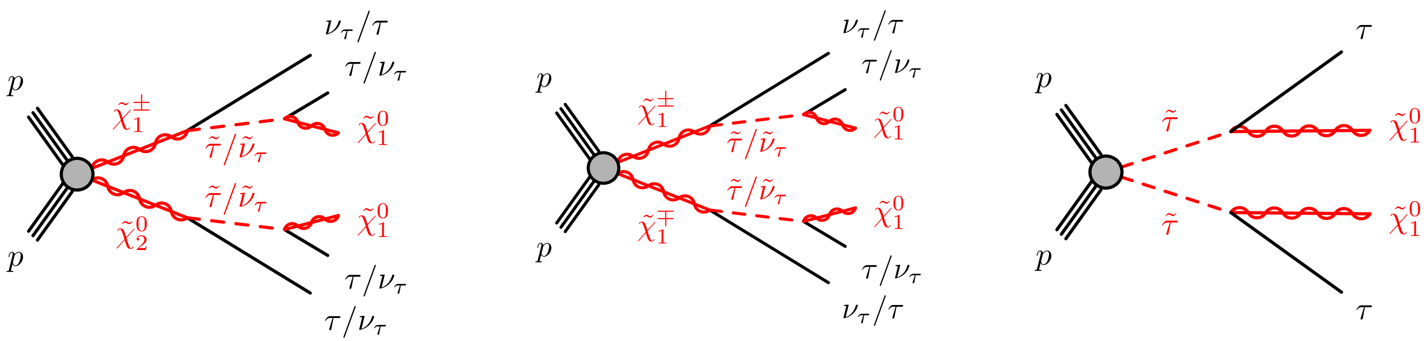
- ❑ Generic signatures:
  low–jet multiplicity + ≥ 2leptons + large E_T^{miss} (2/3/4L, **>=2tau**)
- ❑ low xs, but small SUSY mass scale
- ❑ **IHEP topic:**
  ④ >=2tau+MET



(1) EWK-2tau SUSY search

Run2

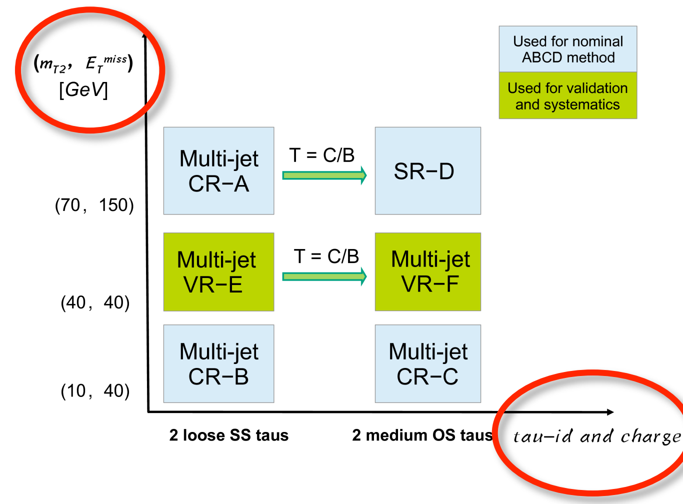
- Charginos and neutralinos are superpartners of the EW gauge bosons and Higgs bosons
- Naturalness suggests charginos and neutralinos should be light, could be the dominant SUSY production in LHC
- IHEP member firstly proposed the search for gaugino and stau with final state: 2tau + MET, which is also the first search in LHC experiment.
- IHEP play a leading role: contact person & editor/ approval talks

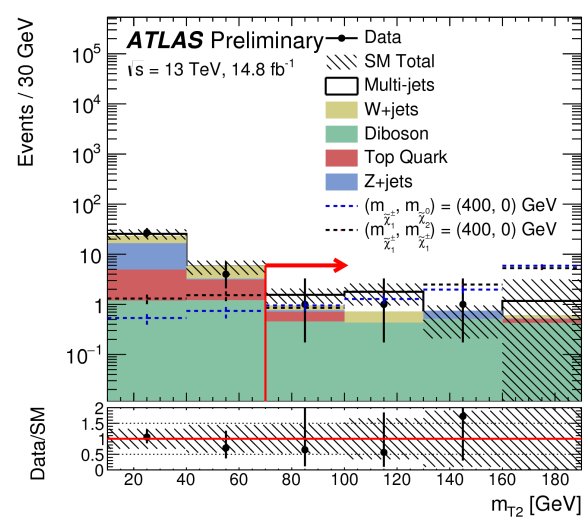


Results

- **2 SRs targeting different scenarios: 1 for C1N2, 1 for C1C1**
- **Main backgrounds:**
  - **Fake tau: W (normalized MC to data in WCR) and multi-jet (ABCD method)**
  - **Real tau: Diboson (MC simulation)**
- **ABCD method:**
  - **Extrapolation performed from A to D through TF (D = A * C/B)**
  - **Validation Region (Multi-jet VR-EF): used for validation and systematics**

Illustration of “ABCD” method

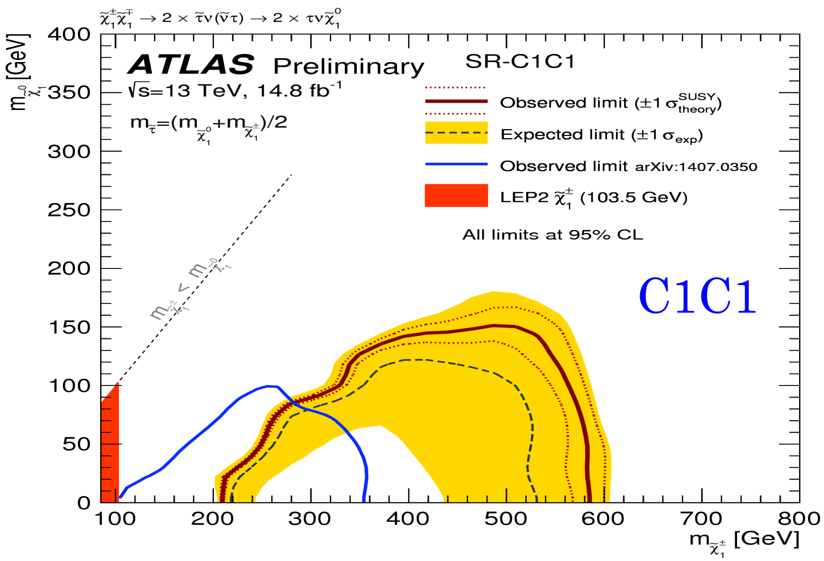


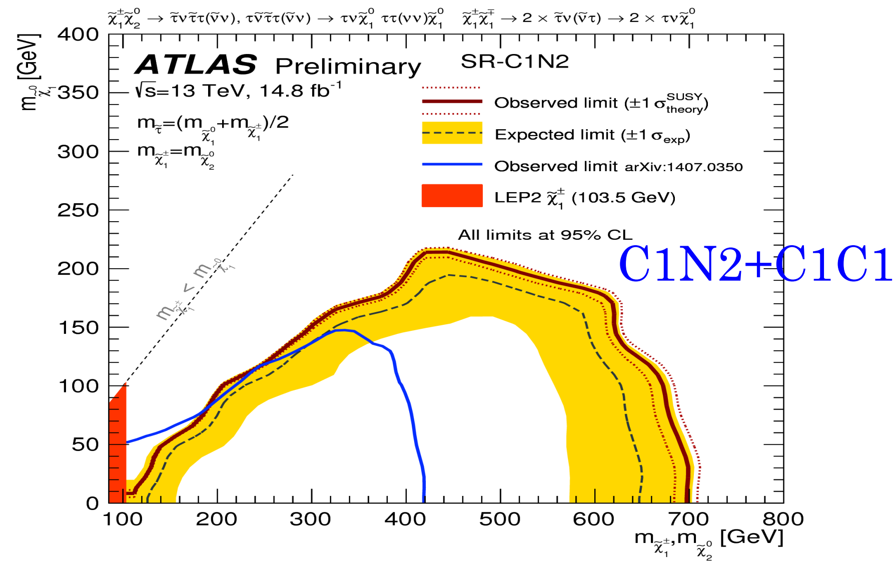


- **Good data/SM estimation in validation regions**
- **No significant excess in SRs, so set exclusion limit**

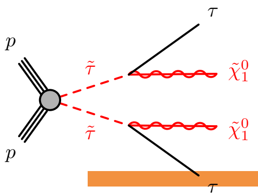
Exclusion Limits

ATLAS-CONF-2016-093



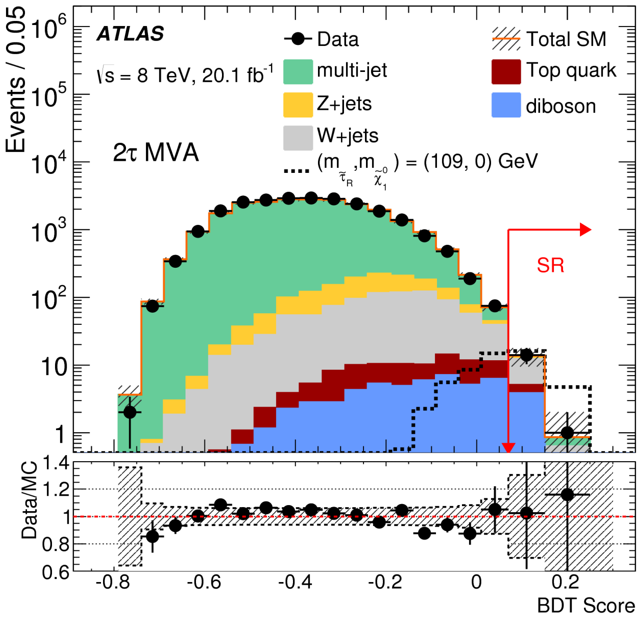


- **The results ATLAS-CONF-2016-093 have been showed at Search16 conference**
  - **C1N2+C1C1 production: C1/N2 mass up to 700 GeV excluded for massless N1**
  - **Wino-like Chargino (C1C1) production : C1 mass up to 580 GeV excluded for a massless N1**
- **Direct stau search not covered for 13 TeV data yet, next slides shows MVA study using Run1 data.**

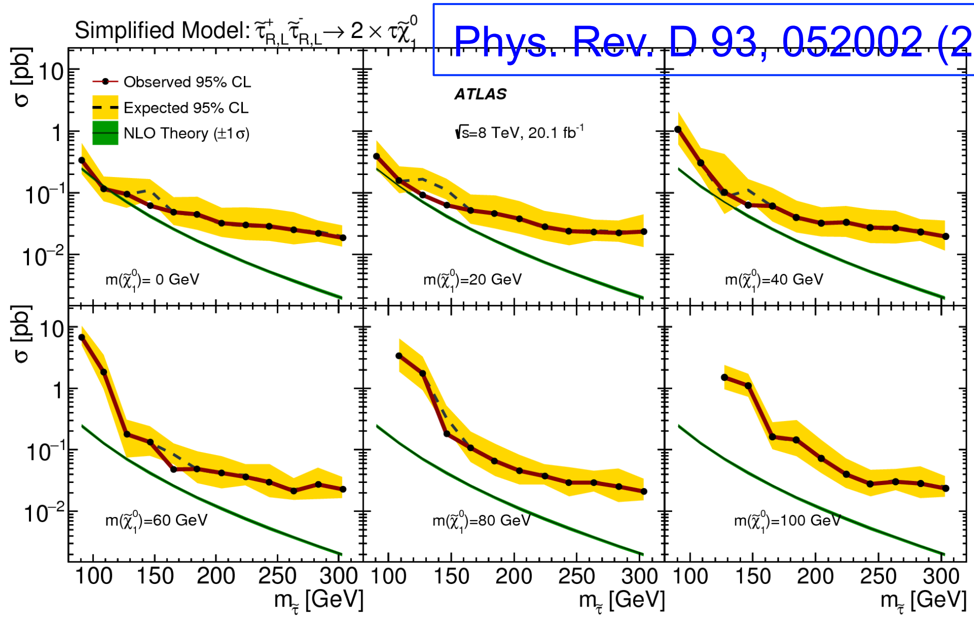


Direct stau MVA study

Run1

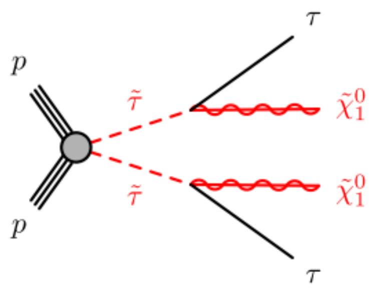


Phys. Rev. D 93, 052002 (2016)

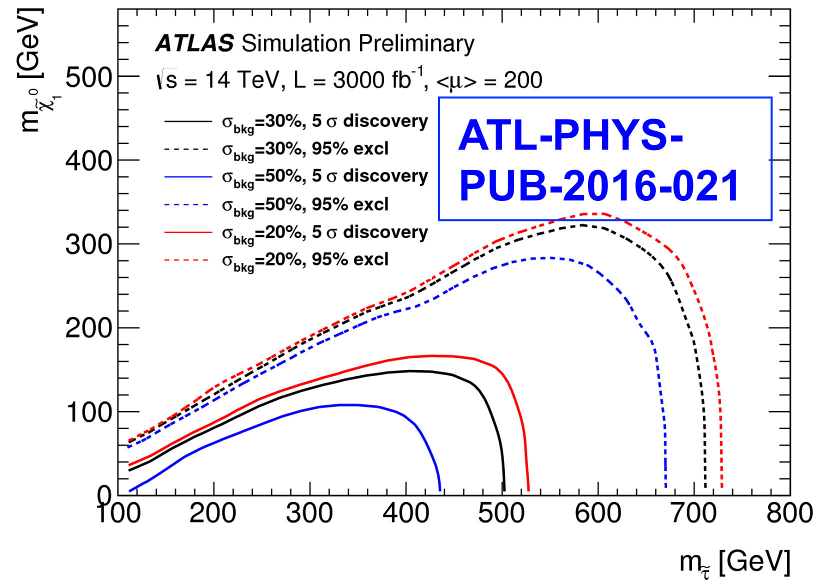


- 12 input variables used in MVA with good signal/bg separation: MET, Meff, mT2, m(ττ), mT(τ1), mT(τ2), τ1_pt, τ2_pt, Δφ(ττ), ΔR(ττ), Δφ(τ1,MET), Δφ(τ2,MET).
- There is around 20-100% improvement on sensitivity at low stau mass region.
- The results have been published at Phys.Rev.D 93, 052002 (2016).
- Direct stau upgrade study is at next slide.

Direct stau upgrade study



Solid line: 5σ discovery
Dashed line: 95% exclusion

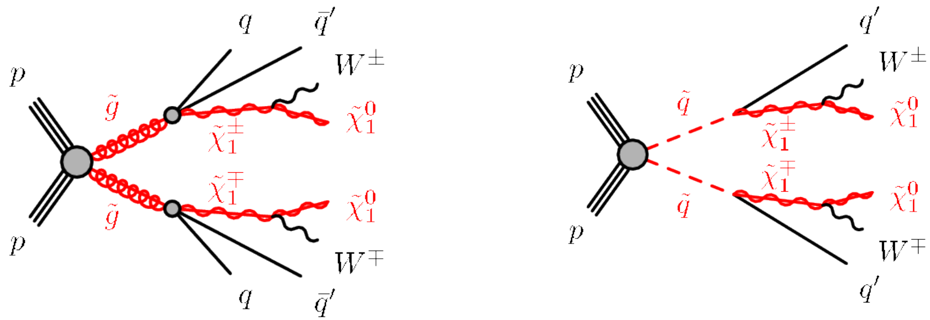


- **The direct stau search sensitivity has been studied for HL-LHC (14TeV 3000 fb^{-1})**
- **For a massless LSP, the 5σ discovery sensitivity (exclusion) reaches up to 500 (700) GeV in stau mass (30% syst.).**
- **The results ATL-PHYS-PUB-2016-021 have been showed at ECFA workshop at Oct. 2016.**

(2) 1L SUSY search

Run2

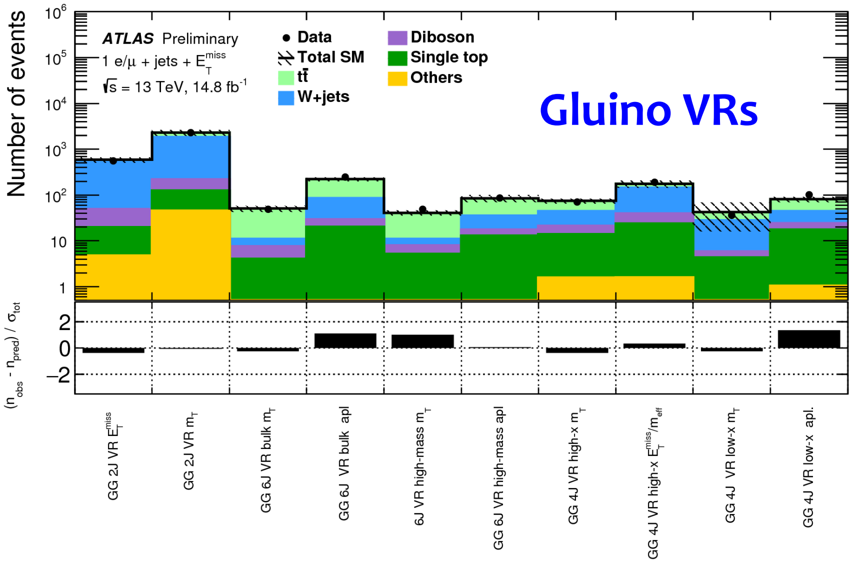
- Search for gluinos/squarks decaying via charginos and sleptons with 1l + jets + MET → hot topic for first data due to large xsec and low bg from lepton requirement

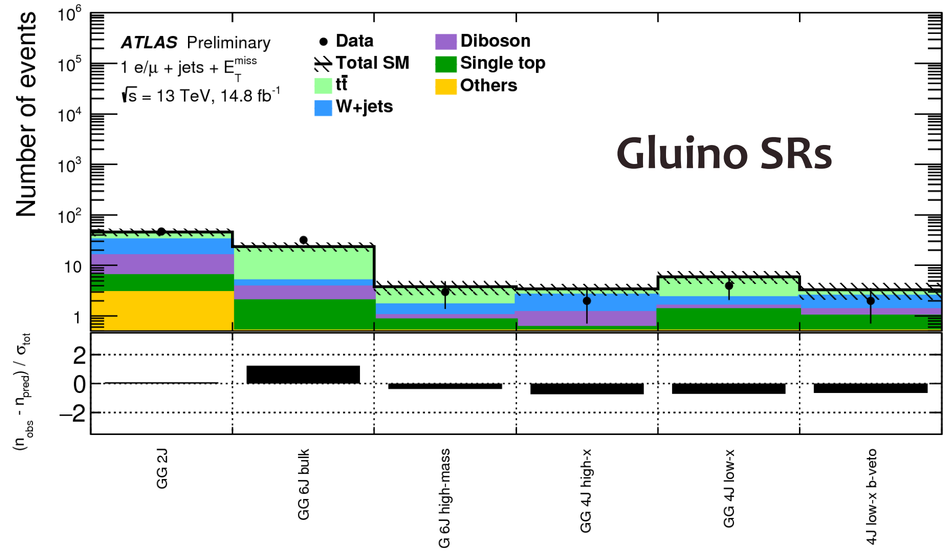


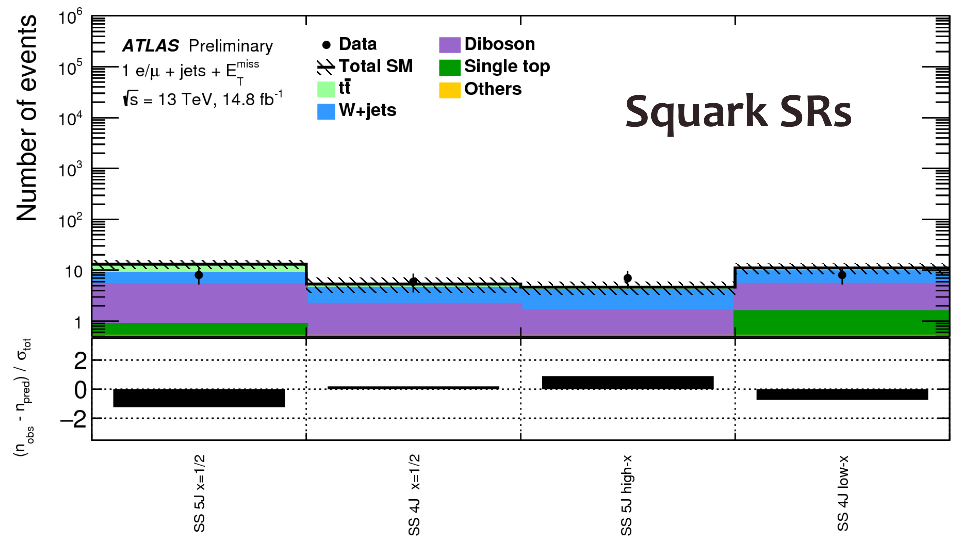
- 10 SRs defined targeting different search scenarios :
  - Scenarios with medium to large mass splitting ("hard lepton")
    - 9 SRs (5 GG, 4 SS) with jet multiplicity ranging from 4 to 6, large Meff, MET and mT
  - Compressed scenarios ("soft leptons")
    - 1SR for GG-softLept: >=2jets, large MET

- Main backgrounds: ttbar and W+jets, normalized MC to data in TCR and WCR, and validated in VRs

Results



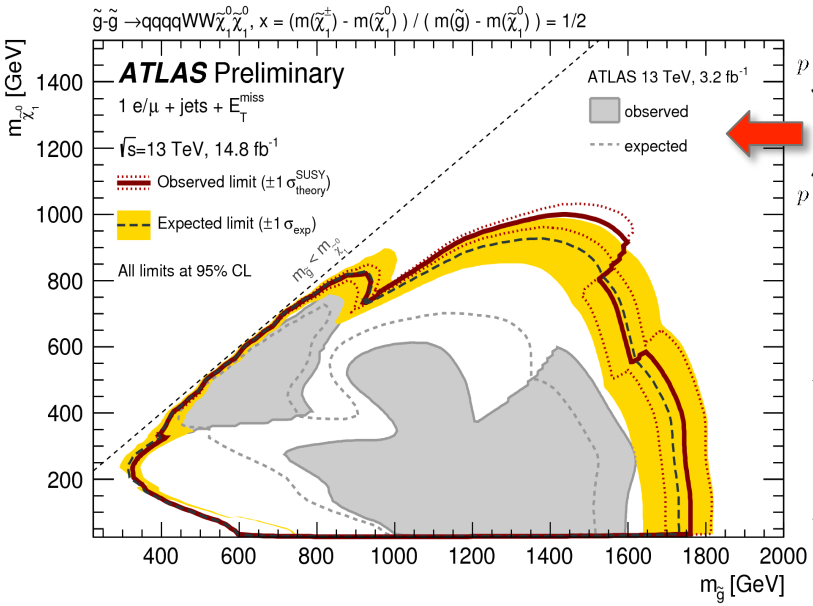


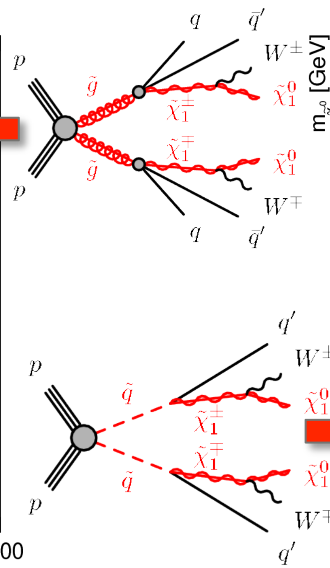


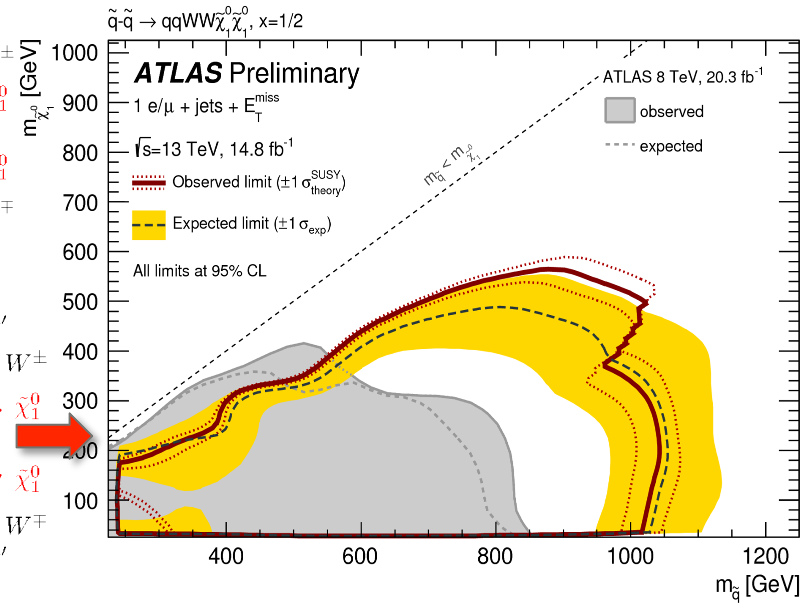
- **Good data/MC agreement in VRs**
- **No significant excess in all SRs → Set exclusion limit**

Exclusion Limits

ATLAS-CONF-2016-054





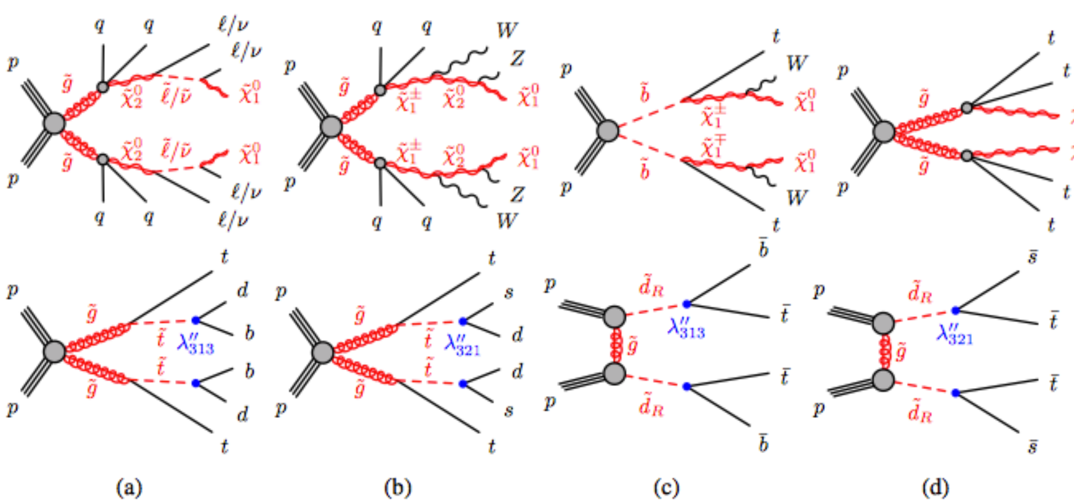


- Gluino (squark) masses up to 1.7 TeV (1.0 TeV) are excluded for low neutralino masses (≤ 400 GeV or ≤ 300 GeV)
- IHEP made a leading contribution (contact person/ contact editor/approval talks)

Run2

(3) SS/3L SUSY search

- Search for squarks/gluinos via long decay chain in **SS/3L** final states
  - Sensitive for a wide range of models (Fig. 1)
  - Very clean channels with only tiny SM bg (mainly top+V, diboson, triboson) → **A good tag for new physics**
- 6 RPC+3 PRV SRs defined, targeting specific scenarios
- Main backgrounds:
  - diboson and ttV: estimated from MC simulation, validated in VRs.
  - Fake background and charge flip: estimated in data

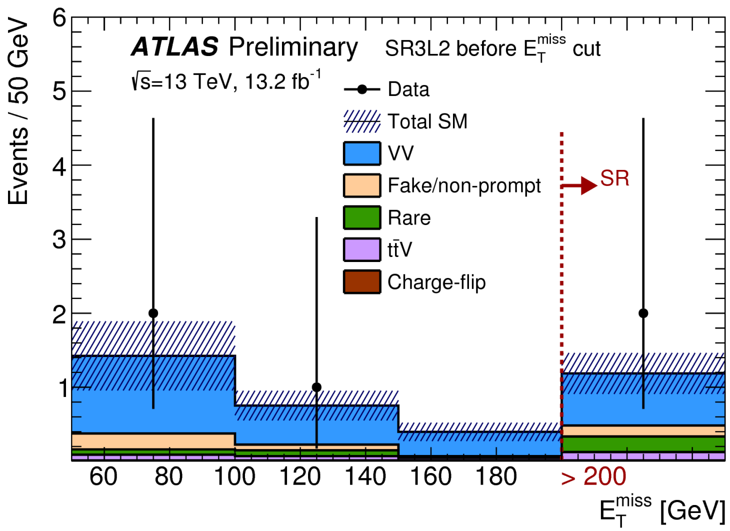


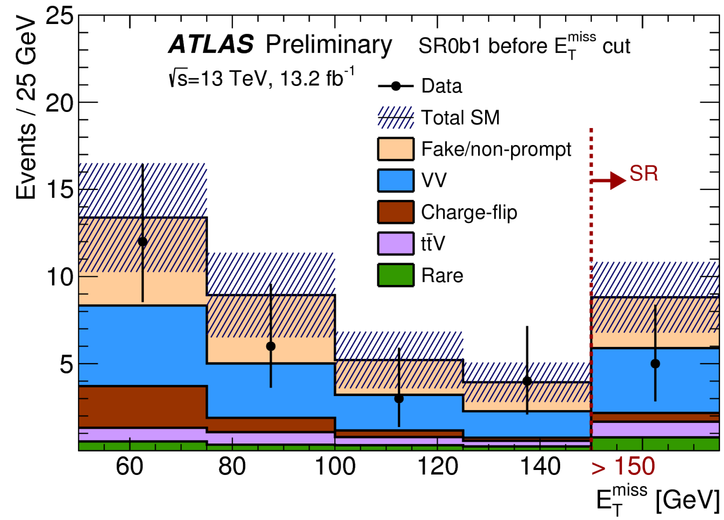
is

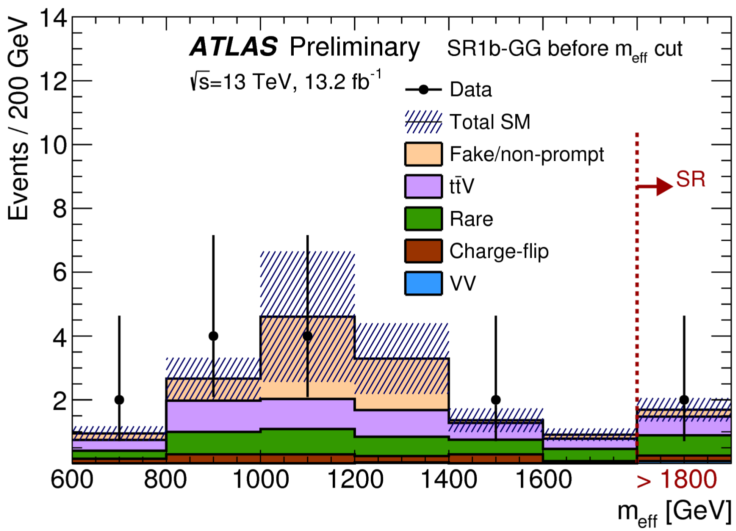
Figure 2: RPV SUSY processes featuring gluino (a,b) or right-handed down squark (c,d) pair production and decays via baryon number-violating couplings λ'' considered in this analysis.

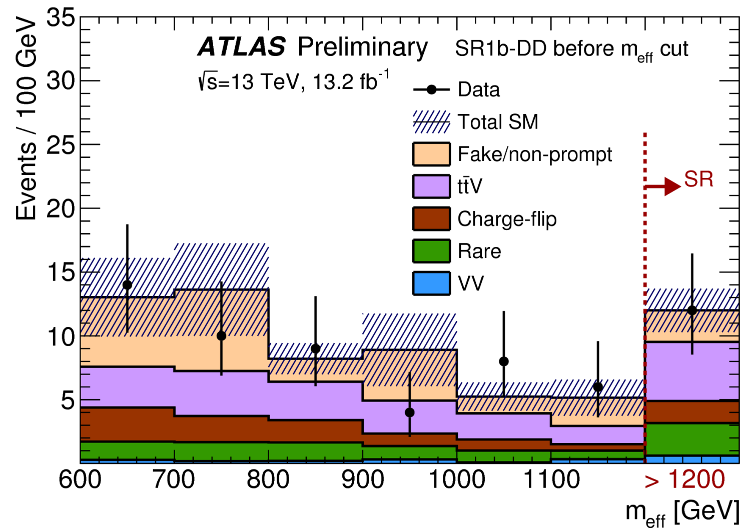
Results

- No significant excess observed in SRs





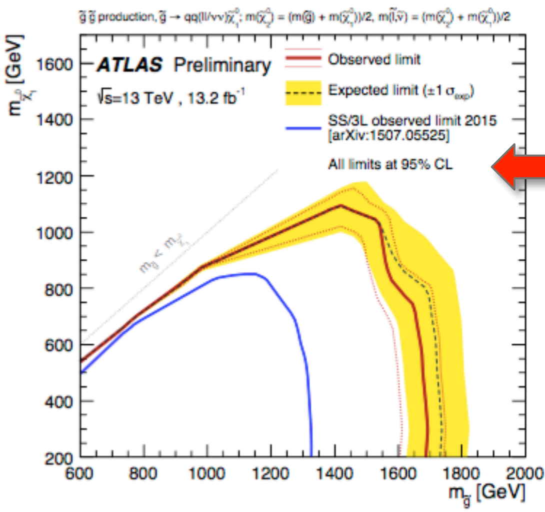


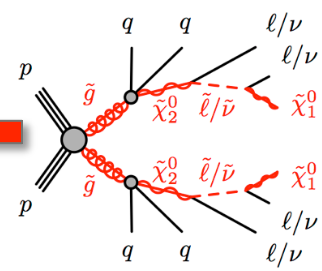


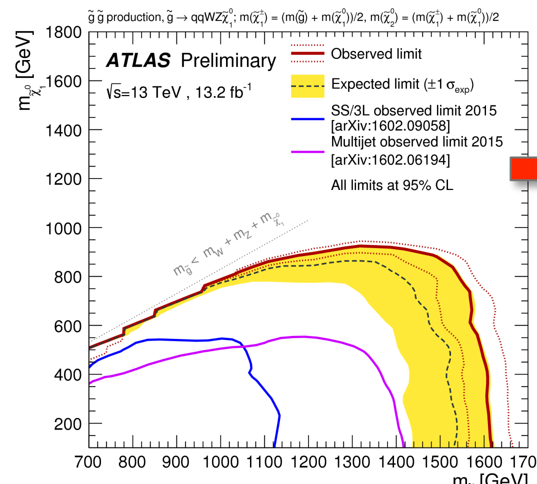
ATLAS-CONF-2016-037

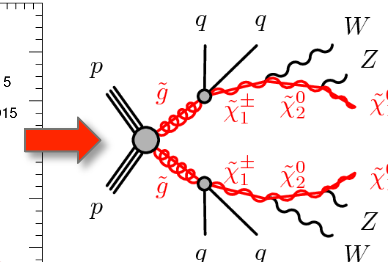
Exclusion Limits

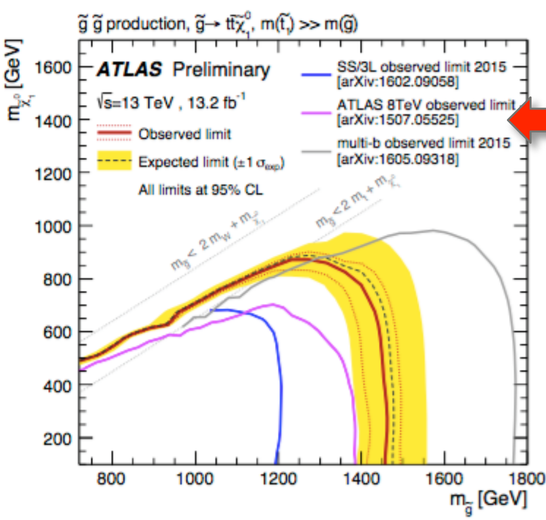
- Gluino mass <1.4-1.7 TeV and LSP mass < 850-1100 GeV are excluded for gluino pair production. ~b mass < 690 GeV excluded

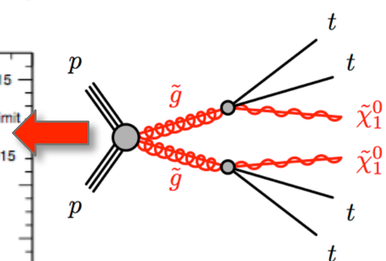


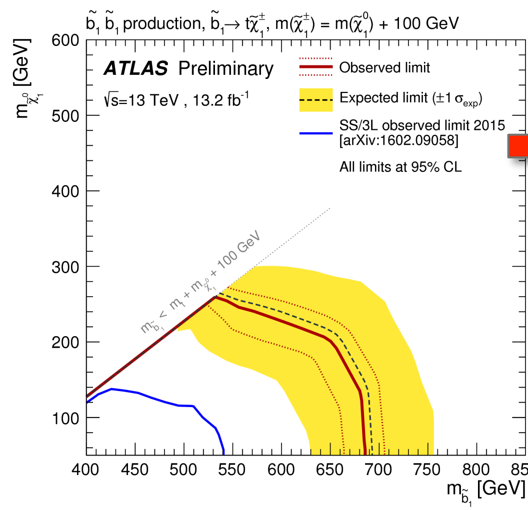


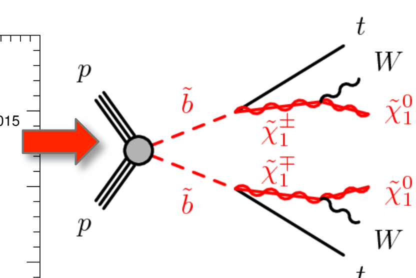








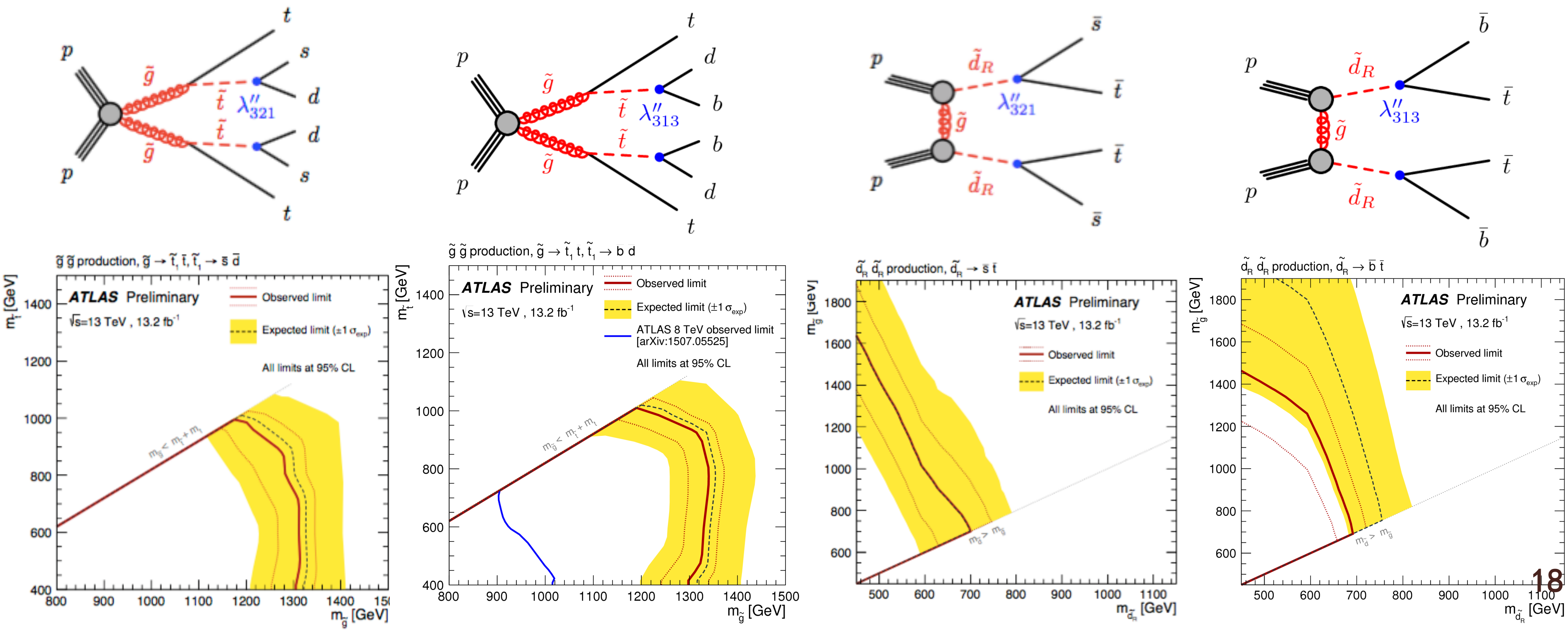




ATLAS-CONF-2016-037

Exclusion Limits

- **Gluino mass <1.3 TeV and LSP mass < 1 TeV excluded in RPV scenario.**
- **Right-handed down squark masses are probed up to $m_{\tilde{d}_R} \approx 700$ GeV in RPV scenarios.**
- **IHEP mainly contributed in SR definition and main background estimation in data, Gave approval talks for paper publication.**



IHEP contributions and publications

- **Electroweak SUSY search with 2taus:** contact person/editor/approval talks
  - [contact editor] Run1 8TeV EWK summary paper: **Phys. Rev. D 93, 052002 (2016)**
  - [contact editor] Run2 13TeV CONF NOTE: **ATLAS-CONF-2016-093 [SEARCH16]**
  - [contact editor] Upgrade 13TeV PUB NOTE: **ATL-PHYS-PUB -2016-021 [ECFA16]**
  - [Ongoing] Run2 13 TeV analysis: **aiming for Moriond2017 paper**
- **Inclusive SUSY search with 1 lepton:** contact person/editor/approval talks
  - [contact editor] Run2 13TeV signature paper: **Eur. Phys. J. C 76 (2016) 565**
  - [contact editor] Run2 13TeV CONF NOTE: **ATLAS-CONF-2015-076 [Moriond16]**
  - [contact editor] Run2 13TeV CONF NOTE: **ATLAS-CONF-2016-037 [ICHEP16]**
  - [Ongoing] Run2 13 TeV analysis: **aiming for Moriond2017 paper**
- **Inclusive SUSY search with SS/3L**: editor/approval talks
  - Run2 13TeV signature paper: **EPJC(2016)76(5), 1-26**
  - Run2 13TeV CONF NOTE: **ATLAS-CONF-2015-078 [Moriond16]**
  - Run2 13TeV CONF NOTE: **ATLAS-CONF-2016-054 [ICHEP16]**
  - [Ongoing] Run2 13 TeV analysis: **aiming for Moriond2017 paper**

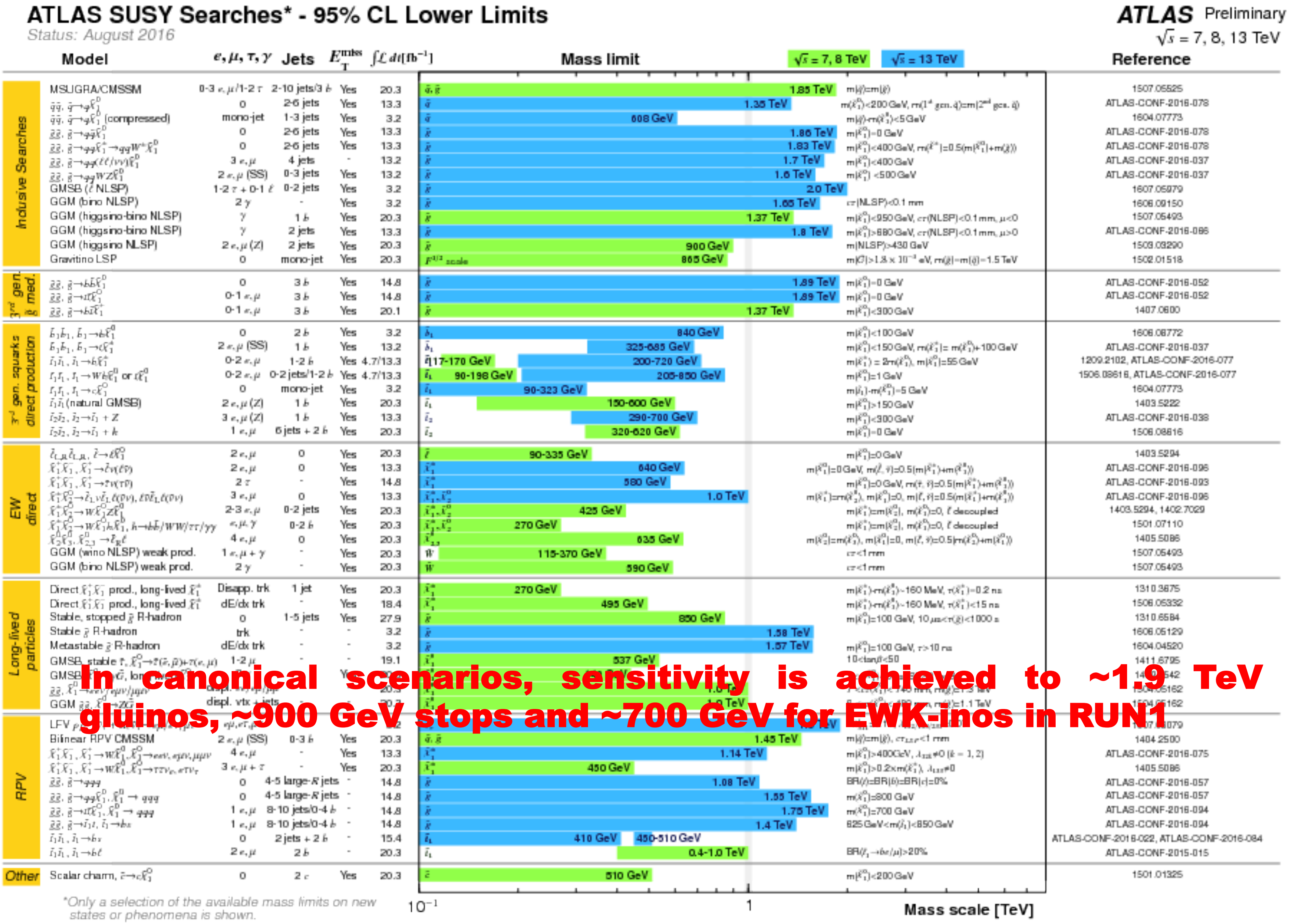
Paper
CONF note
Ongoing

- **Published 3 paper, 6 CONF/PUB notes, contact editors for 6 of them**
- **Ongoing 3 analyses aiming for Moriond paper**

Summary from IHEP SUSY Group

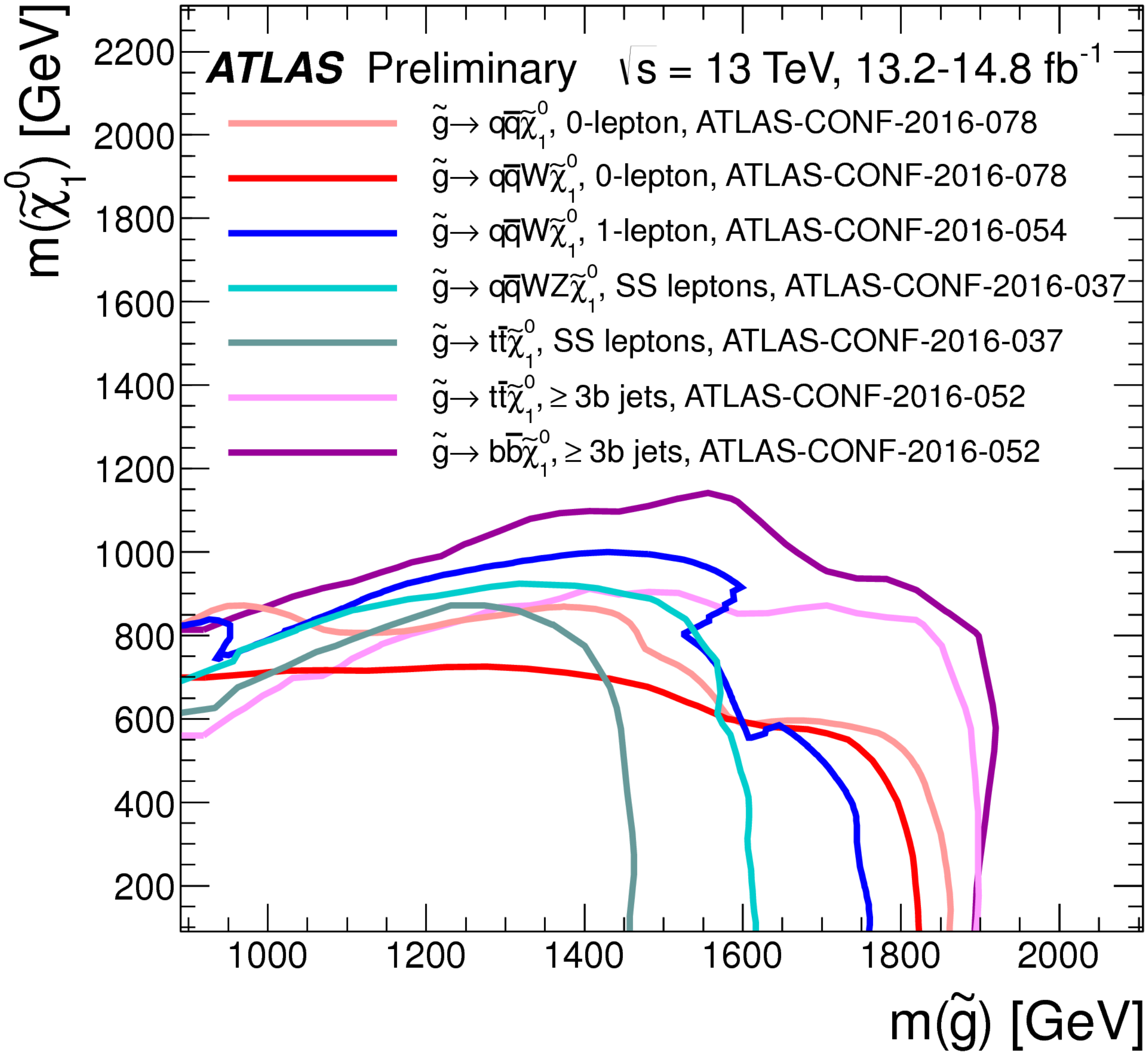
- 高能所SUSY实验小组：
  - 国内首个在LHC实验中进行R宇称守恒SUSY研究的实验小组（3名职工，5名研究生），已具有较强的国际竞争力。
  - 团队成员在国际合作组担任重要角色，已具有一定的国际知名度：
    - ATLAS SUSY EW 物理组召集人，ATLAS合作组委员会顾问组成员
    - ATLAS SUSY信号联络人，ATLAS HistFitter专家联络人
    - 2tau contact person, 1L contact, direct stau upgrade contact
    - Stop to stau Ed Board,

- 开展了3个热点课题，担任2个课题的联系人，3个分析的编辑，本年度已发表3篇文章，6篇CONF / PUB NOTEs，6个国际会议报告
  - → 基于2015＋2016年获取的13-15 fb^{-1} 13 TeV的数据，整个ATLAS SUSY组发表了12(18)篇paper (CONF note), 本团队在2(3)篇中做出主导或主要贡献



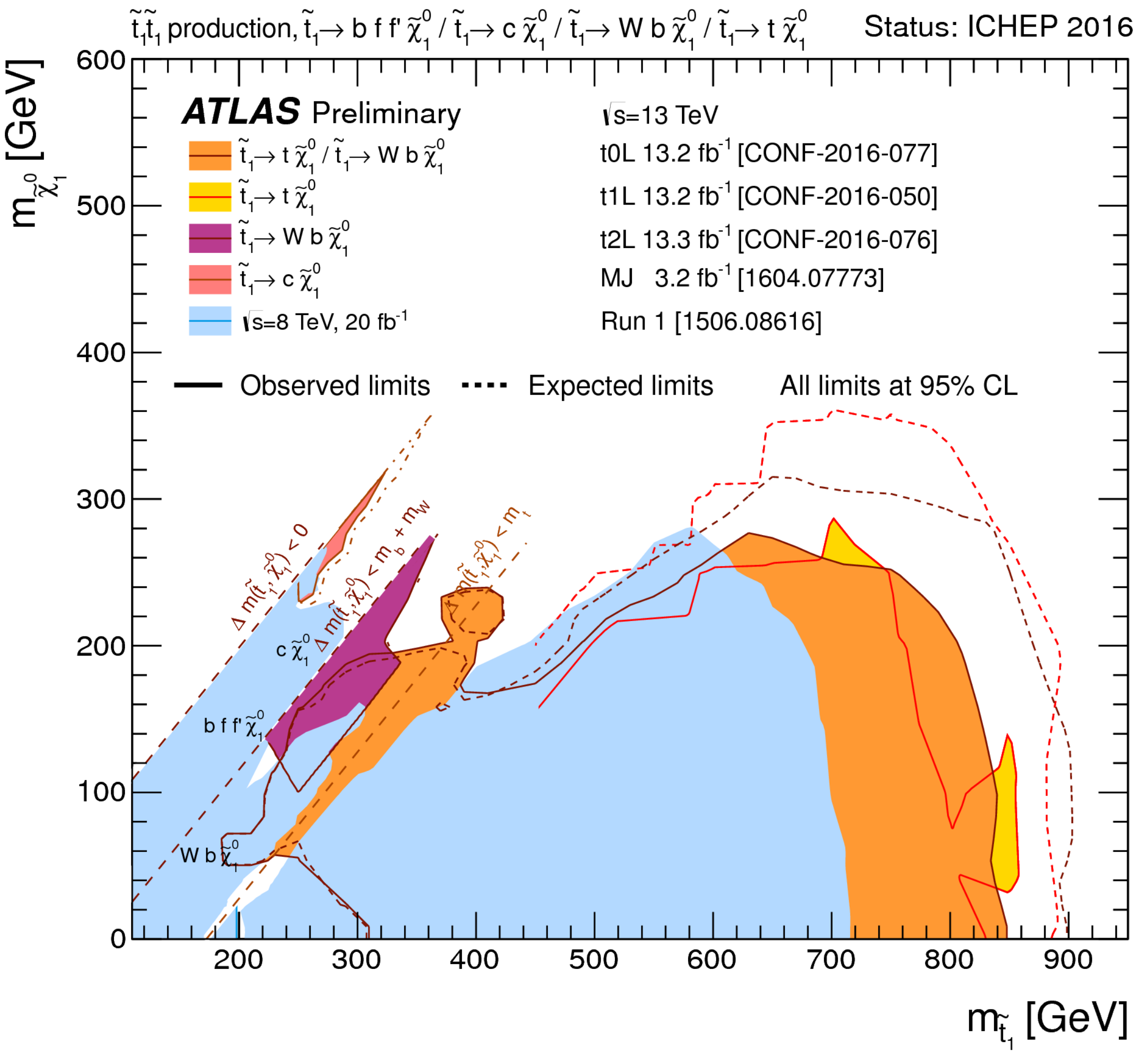
In canonical scenarios, sensitivity is achieved to ~1.9 TeV gluinos, ~900 GeV stops and ~700 GeV for EWK-inos in RUN1

Strong Production *(summary)*



- **Exclusion for m(~g) < 1.4-1.9 TeV for massless LSP**
- **exclusion up to m(LSP) ~0.9-1 TeV**

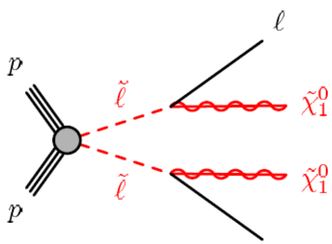
3rd Generation *(summary)*

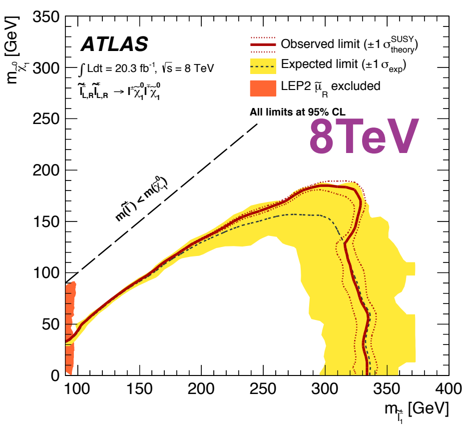


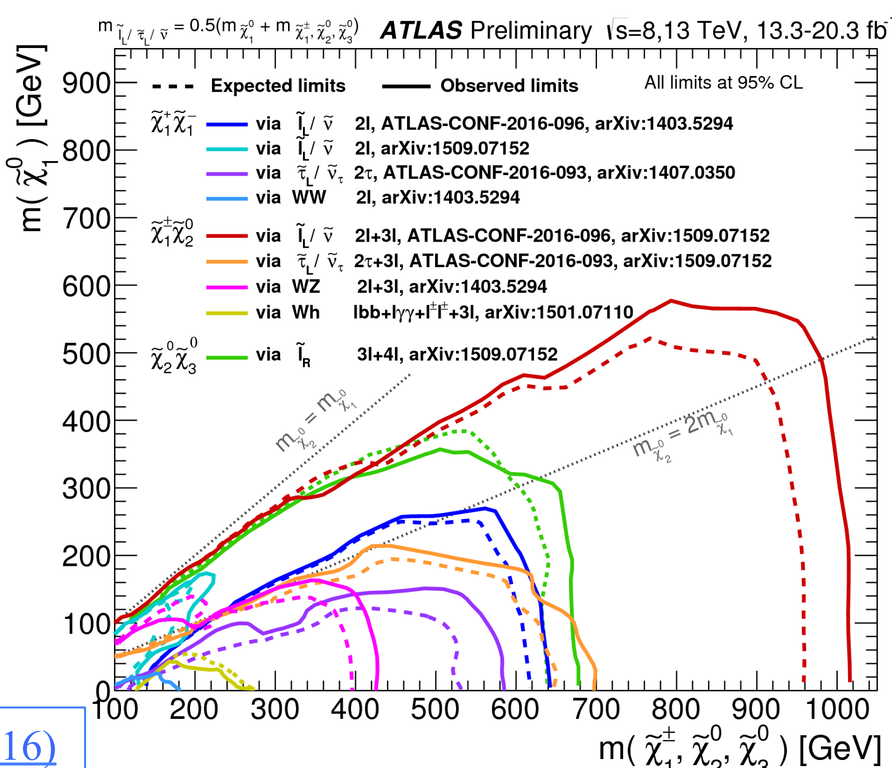
- **Exclusion for m(~t1) < ~840 GeV for massless LSP, exclusion up to m(LSP) ~250 GeV**

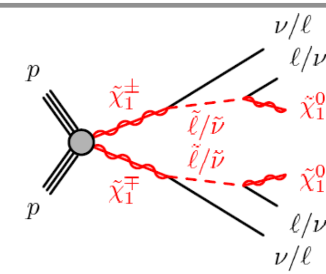
EWK Production: 1-4L(e,μ,τ) +MET *(summary)*

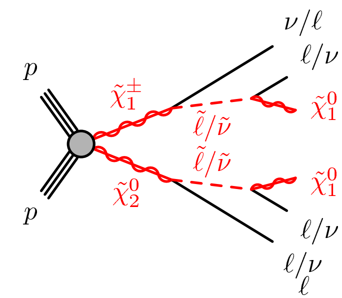
- Search for sleptons with 2L (e/μ) + MET FS → ~l > 330 GeV (8TeV)
- Search for charginos and neutralinos with 2-3L (e/μ/τ) + MET FS
  → Excludes electroweakino masses up to 400-1000 GeV
- Search for charginos and neutralinos via higgs decay (Wh→1l +bb, γγ, ll, ττ) → Excludes electroweakino masses up to 250 GeV (8TeV)

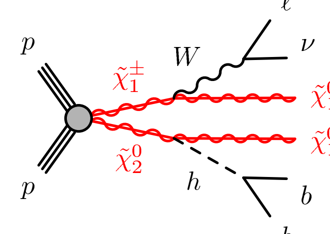






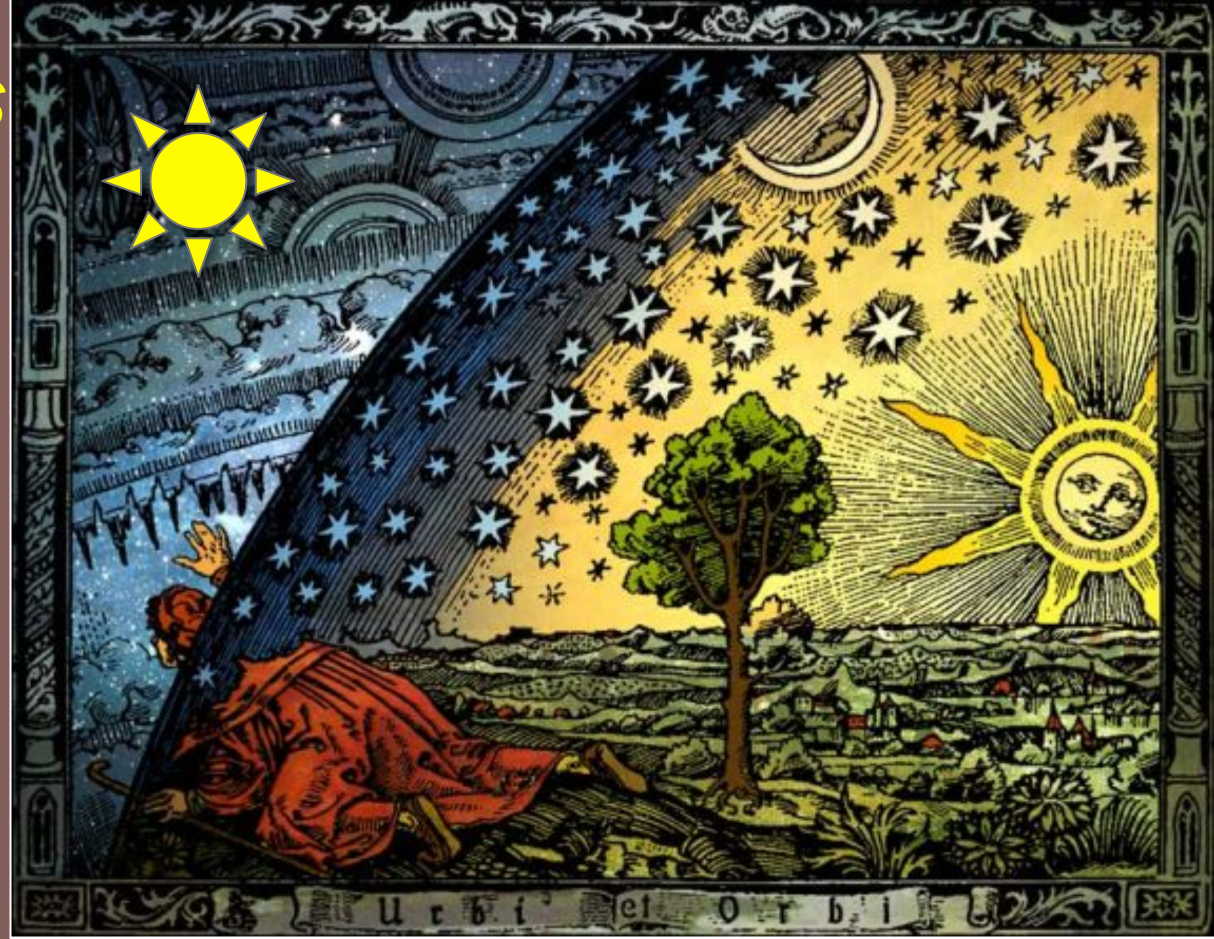






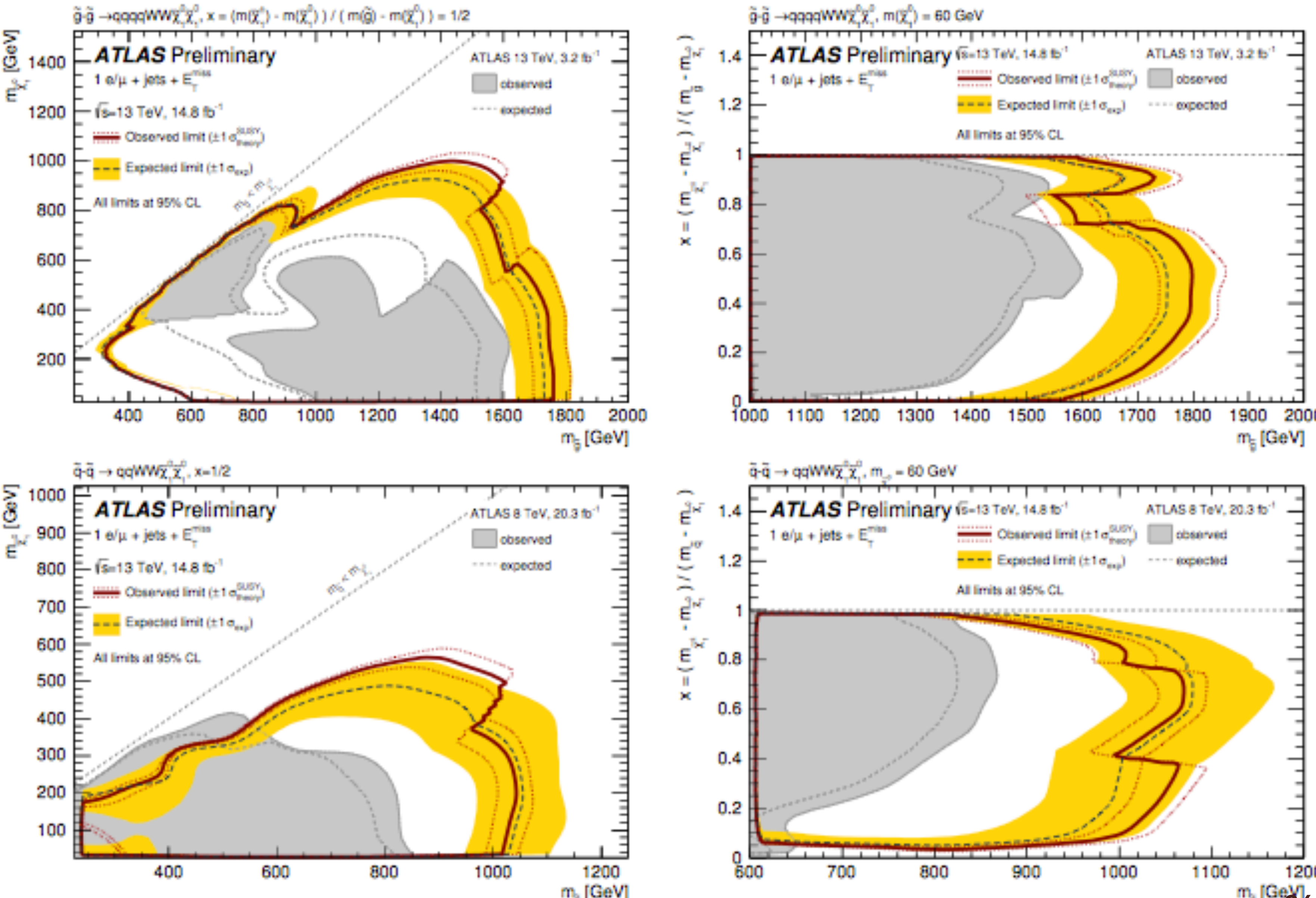
[Phys. Rev. D 93, 052002 (2016)]

Exciting times are ahead of us !



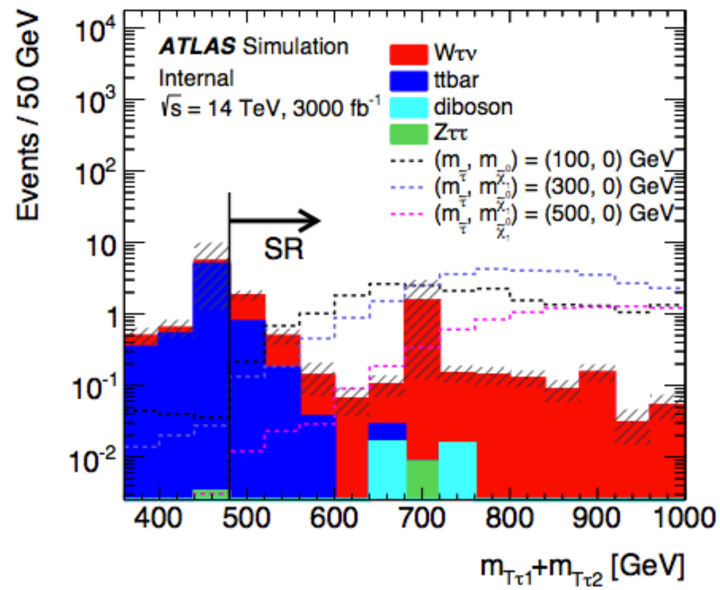
THANKS FOR YOUR ATTENTION!

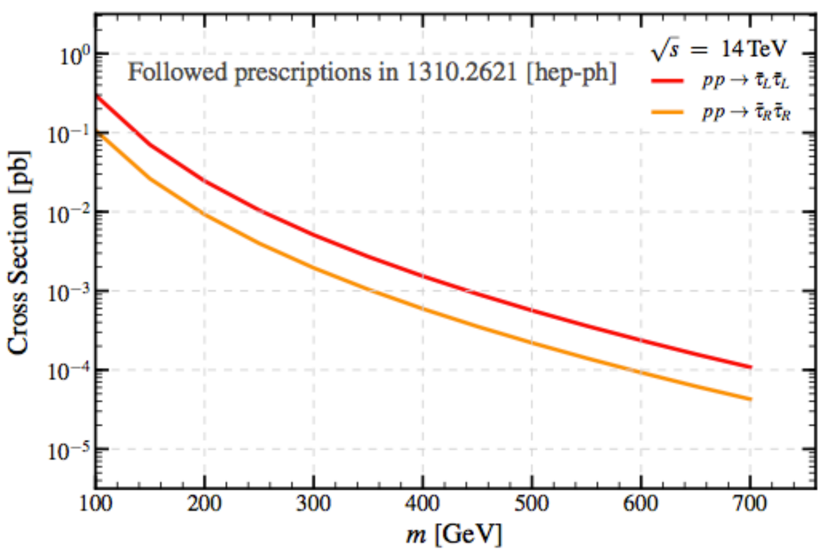
1L SUSY search (RUN2)

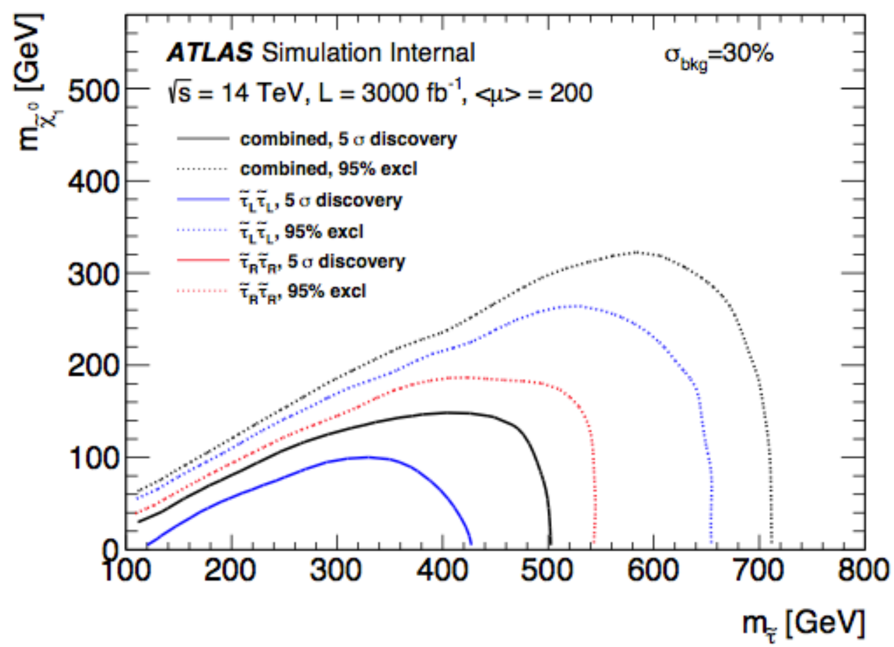


Direct stau upgrade study

SR Definition
≥ 2 OS taus
loose jet-veto
Z-veto
$\Delta R(\tau 1, \tau 2) < 3.5$
$E_{\mathrm{T}}^{\mathrm{miss}} > 280$ GeV
$m_{\mathrm{T2}} > 40$ GeV
$m_{\mathrm{T}\tau 1} + m_{\mathrm{T}\tau 2} > 480$ GeV







Direct stau MVA study

Rank	Variable	Variable Importance	Variable	Seperation
1	m_{eff}	1.325e-01	m_{eff}	6.880e-01
2	$\not{E}_T$	0.947e-01	mT(tau1)	5.610e-01
3	m_{T2}	8.932e-02	$\not{E}_T$	5.364e-01
4	deltaEta(tautau)	8.894e-02	tau1Pt	4.567e-01
5	deltaPhi(tautau)	8.888e-02	deltaPhi(tautau)	3.9468e-01
6	deltaPhi(tau1MET)	8.575e-02	tau2Pt	3.512e-01
7	deltaPhi(tau2MET)	7.509e-02	deltaPhi(tau2MET)	2.878e-01
8	tau1Pt	7.502e-02	mT(tau2)	2.657e-01
9	tau2Pt	7.111e-02	m_{T2}	1.926e-01
10	mass(tautau)	6.922e-02	mass(tautau)	1.900e-01
11	mT(tau1)	6.864e-02	deltaEta(tautau)	1.719e-01
12	mT(tau2)	6.081e-02	deltaPhi(tau1MET)	3.956e-02

Direct stau MVA study

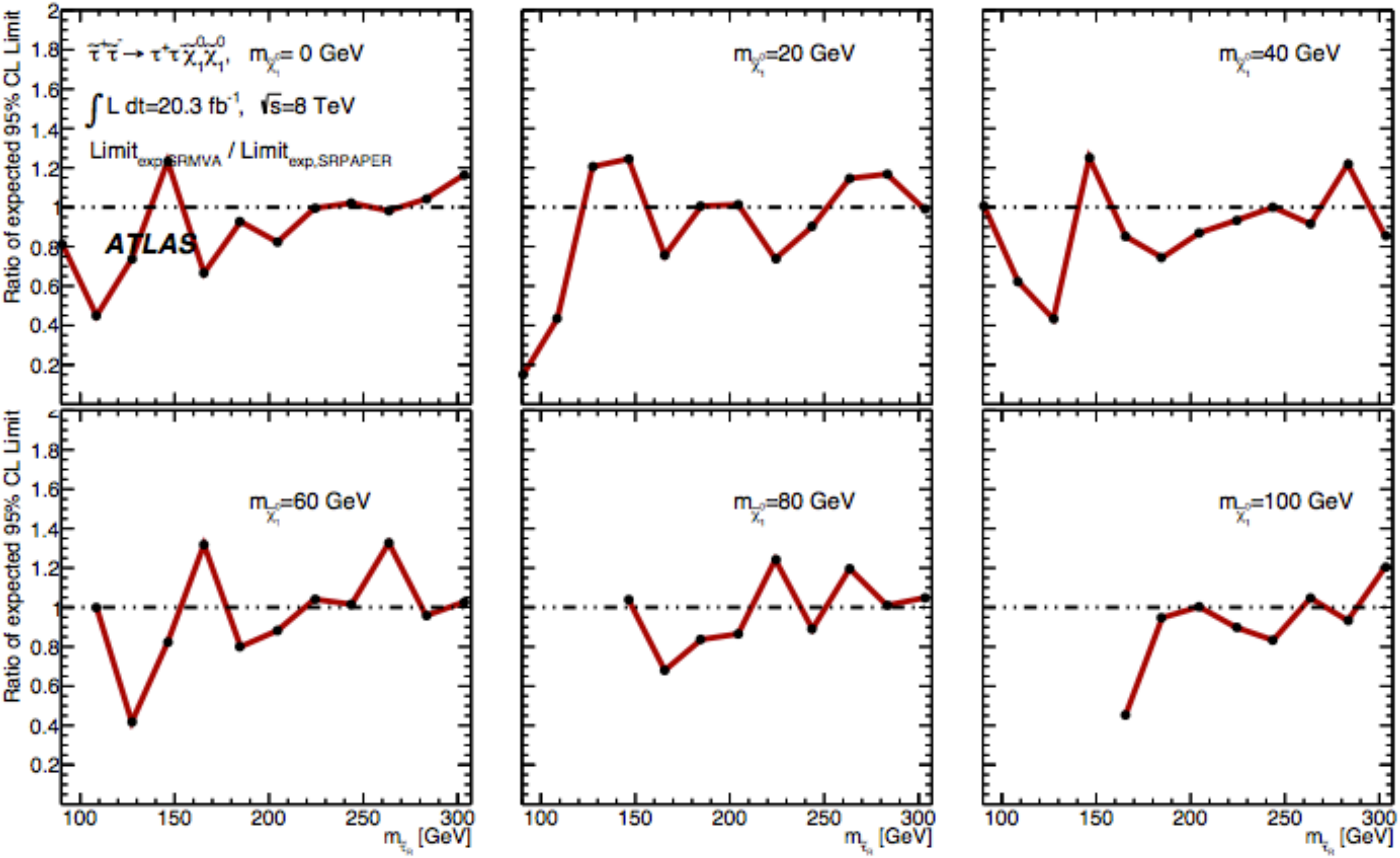
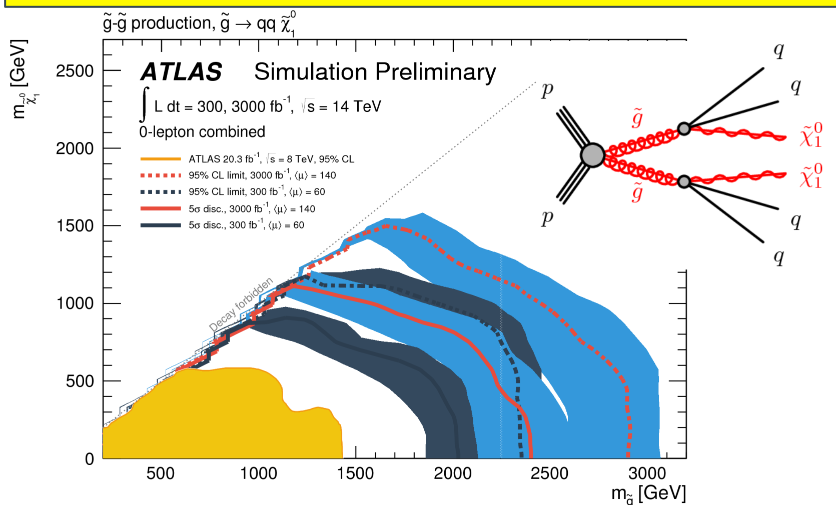


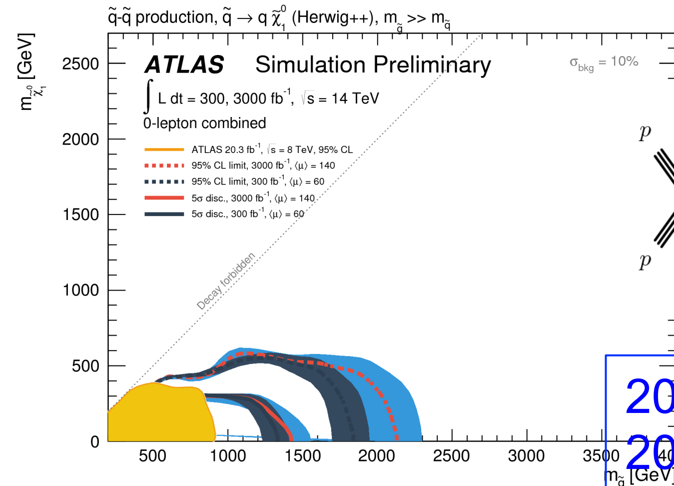
Figure 34: The ratio of the expected upper limits on the signal strength with the MVA SR in this note and the expected upper limits on the signal strength with the combined SR used in the previous paper.

Long term prospects

ATL-PHYS-PUB-2014-010

- ATLAS studied long term prospects for the (HL-)LHC with 300, 3000 fb^{-1}@14 TeV
- Discovery potential up **to 2.5 TeV gluinos, 1.3 TeV squarks/sbottom and 800 GeV Electroweakinos**





2018:~100 fb^{-1}
2023:~300 fb^{-1}
2037:~3000 fb^{-1}