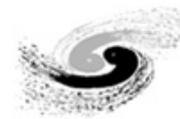


# SUSY Search Activities in ATLAS from CPPM and IHEP

Photo credits: Jodie WAY

Xuai Zhuang (IHEP, Beijing)

April. 8 2014



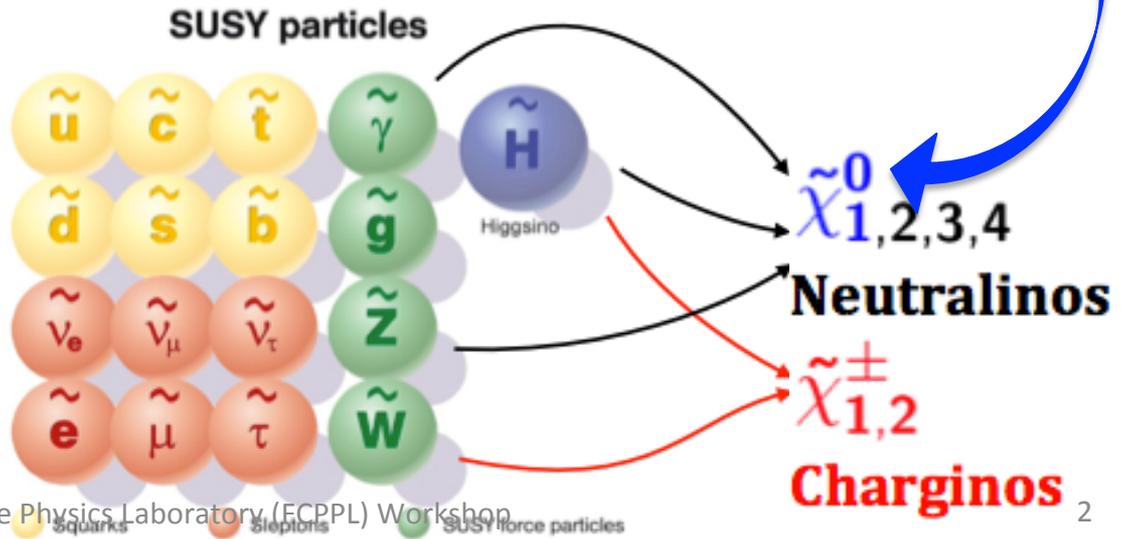
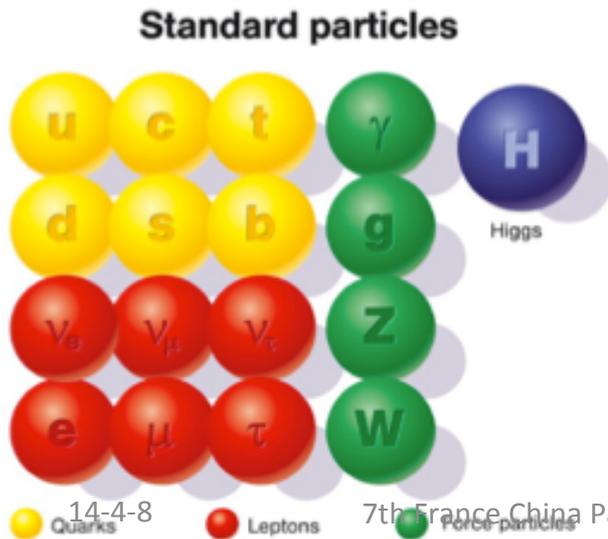
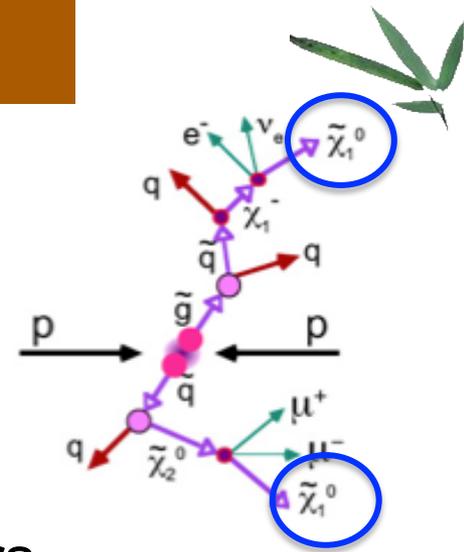
中国科学院高能物理研究所  
Institute of High Energy Physics Chinese Academy of Sciences

# SUSY Introduction

- Last possible extension of Poincare group:  
Fermion  $\leftrightarrow$  Bosons
- Conserved R parity (originally introduced for stability of proton)

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

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



# SUSY Searches @ LHC

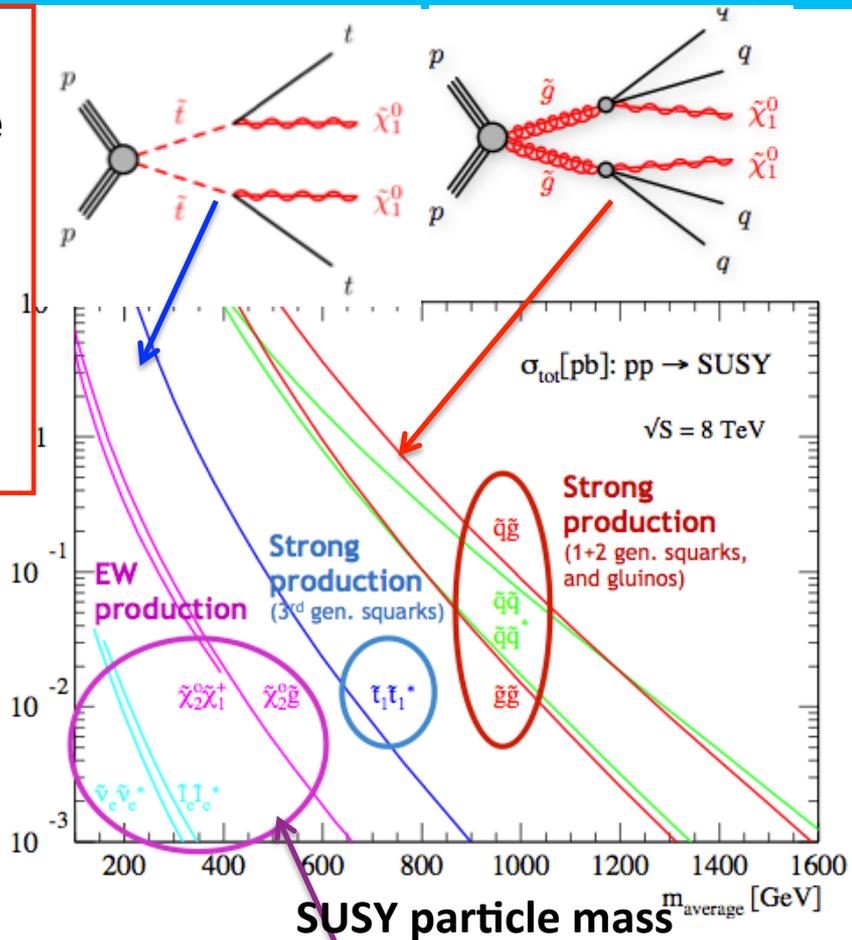


**Strong production:** gluino pair, gluino-squark and squark pair (include 3<sup>rd</sup> generation) production

1) Generic signatures :

Multi-jets + n\_lepton/n\_photon (n=0,1, ≥2) + large  $E_T^{miss}$  (0L, 1 L, ≥2L)

2) large xs, but heavy SUSY mass scale

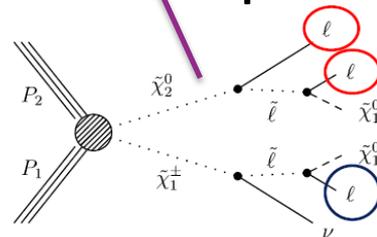


**Weak production:** direct gaugino/slepton production

1) Generic signatures:

low-jet multiplicity + ≥ 2leptons + large  $E_T^{miss}$  (2/3/4L, ≥2tau)

2) low xs, but small SUSY mass scale



# SUSY Searches @ LHC



**Strong production:** gluino pair, gluino-squark and squark pair (include 3<sup>rd</sup> generation) production

1) Generic signatures :

Multi-jets + n\_lepton/n\_photon (n=0,1, ≥2) + large  $E_T^{miss}$  (0L, 1 L, ≥2L)

IHEP: 1 soft lepton + jets + MET

CPPM: 2 SS / 3 leptons channel

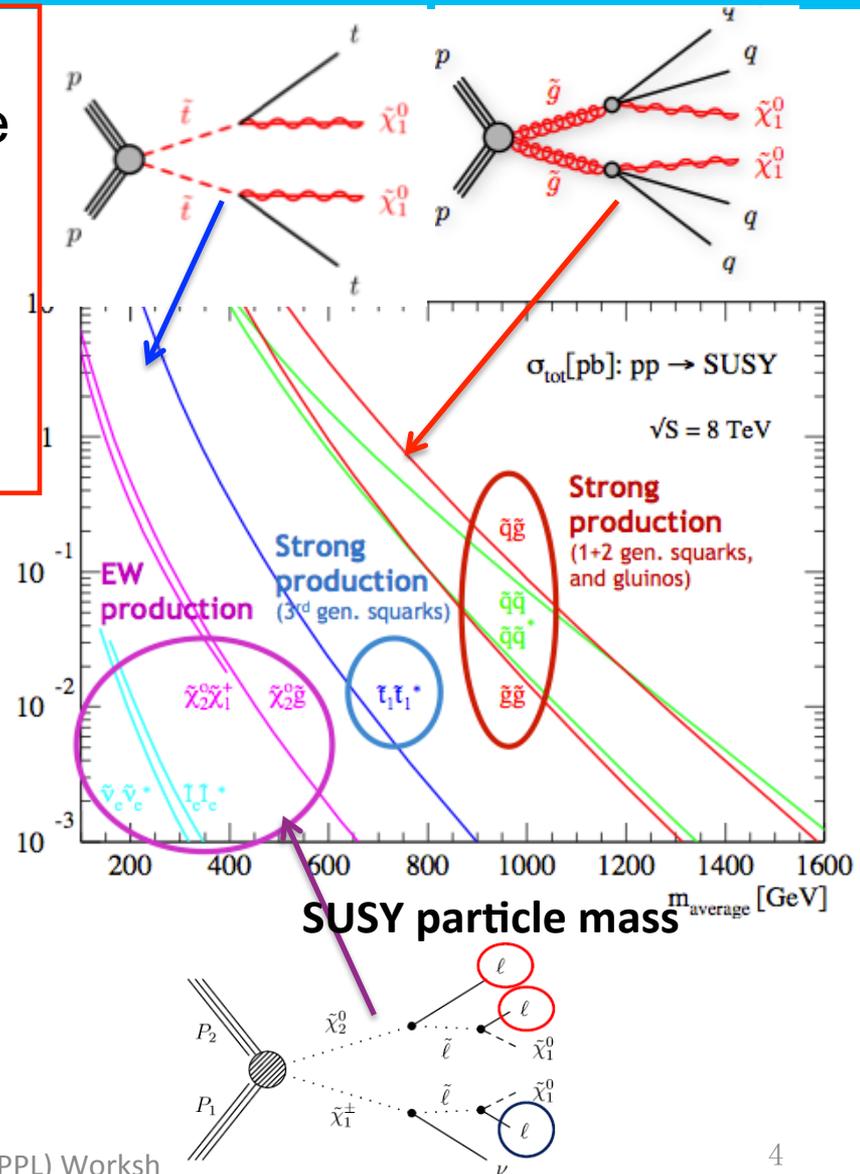
**Weak production:** direct gaugino/slepton production

1) Generic signatures:

low-jet multiplicity + ≥ 2leptons + large  $E_T^{miss}$  (2/3/4L, ≥2tau)

IHEP: ≥2tau + MET

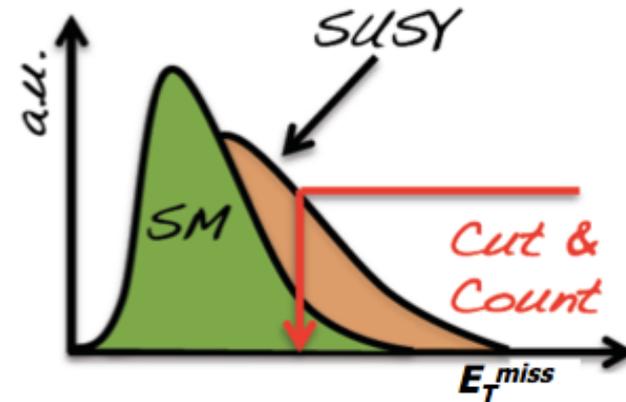
CPPM: 2L (e/mu) + MET



# SUSY Search Strategy

## □ SUSY search strategy: search for deviation from SM

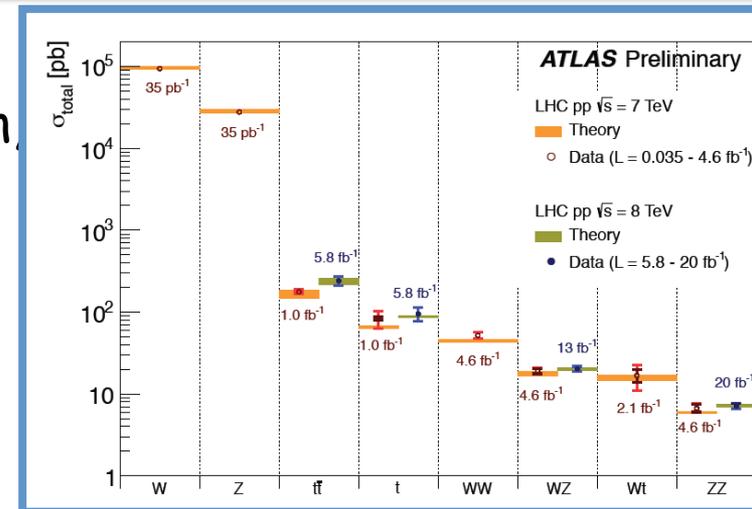
- rely on the SM understanding and detector understanding
- Try to establish excess of events in some sensitive kinematic distribution



## □ SM bkg (top, multijets, V, VV, VVV, Higgs)

- SM bgs understood very well
- No hints for new physics.
- Slightly overshoot in WW cross section, but not significant.

## SM “backgrounds”- the big picture



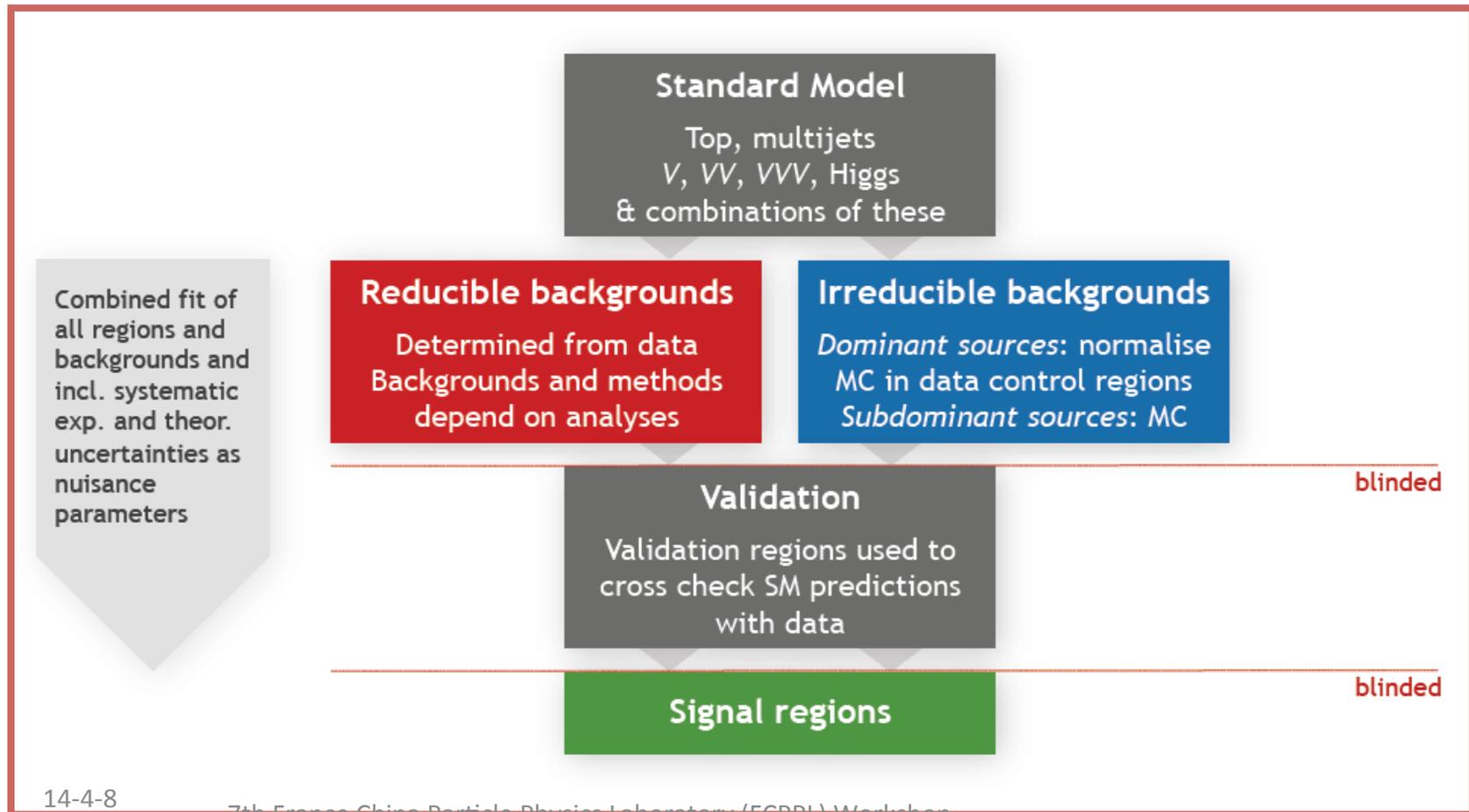
## □ SUSY sensitive variables:

- Missing transverse energy:  $E_T^{\text{miss}}$
- $H_T = \sum P_T^l + \sum P_T^{\text{jet}}$
- Effective mass:  $M_{\text{eff}} (= H_T + E_T^{\text{miss}})$

# SM backgrounds Estimation strategy



- Reducible BGs (e.x. fake BGs): data-driven estimation
- Irreducible BGs: if dominant: data-driven estimation, else, MC



# SUSY Models

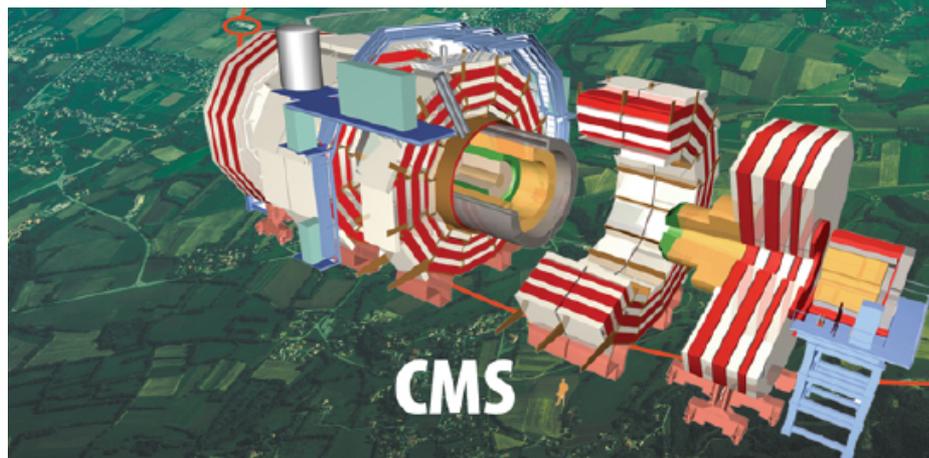
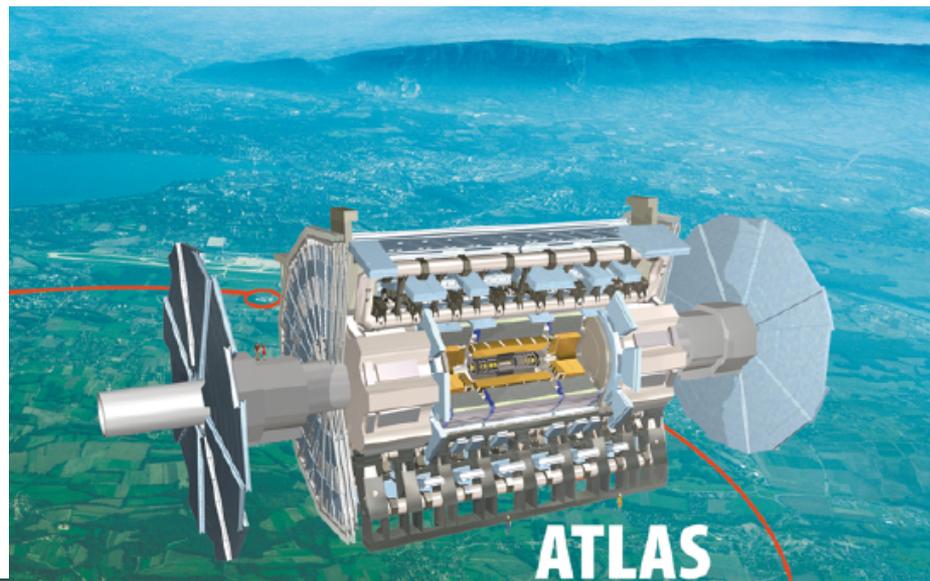
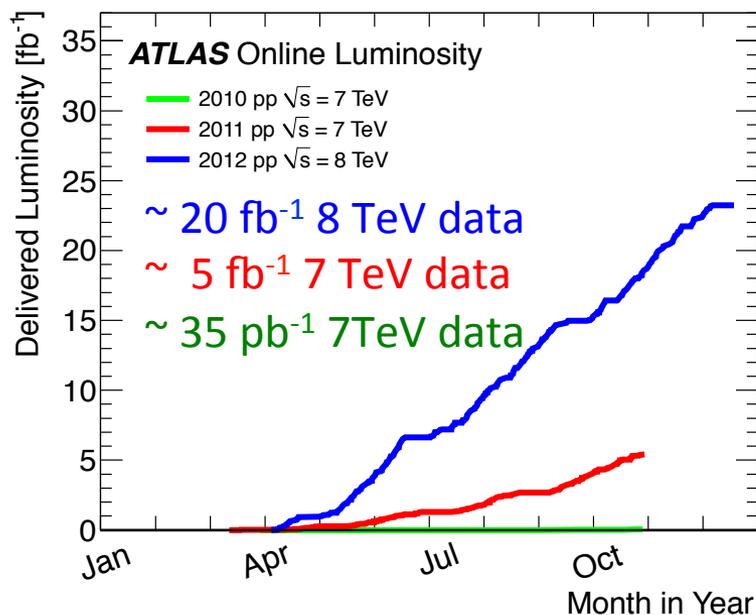
## □ Simplified Models:

- Not really a model (Br~100%, most masses fixed at high scales)
- Important tool for interpretation

## □ Phenomenological MSSM:

- 19 free parameters
  - ✓  $M_1, M_2, M_3$
  - ✓  $\tan \beta, \mu$  and  $m_A$
  - ✓ 10 sfermion mass parameters
  - ✓  $A_t, A_b$  and  $A_\tau$
- pMSSM captures “most” of phenomenologic features of R-parity conserving MSSM
- Comprehensive and computationally realistic approximation of the MSSM with neutralino LSP

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



# IHEP / CPPM SUSY Search Activities

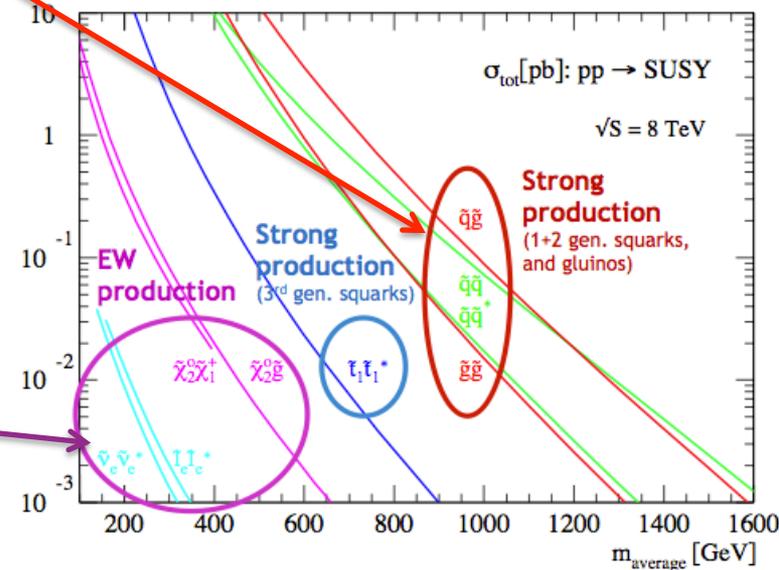


## ■ Inclusive SUSY search for squark, gluino

- ✍ with one soft lepton (IHEP)
  - ATLAS-CONF-2013-062
- ✍ with 2 SS/3 leptons (CPPM)
  - ATLAS-CONF-2013-007, ATLAS-CONF-2012-105

## ■ EW SUSY search for gauginos, sleptons with at least two leptons

- ✍  $\geq 2\tau$  (IHEP)
  - ATLAS-CONF-2013-028
- ✍  $=2 e/\mu$  (CPPM)
  - ATLAS-CONF-2013-049, arXiv: 1403.5294 (submitted to JHEP)



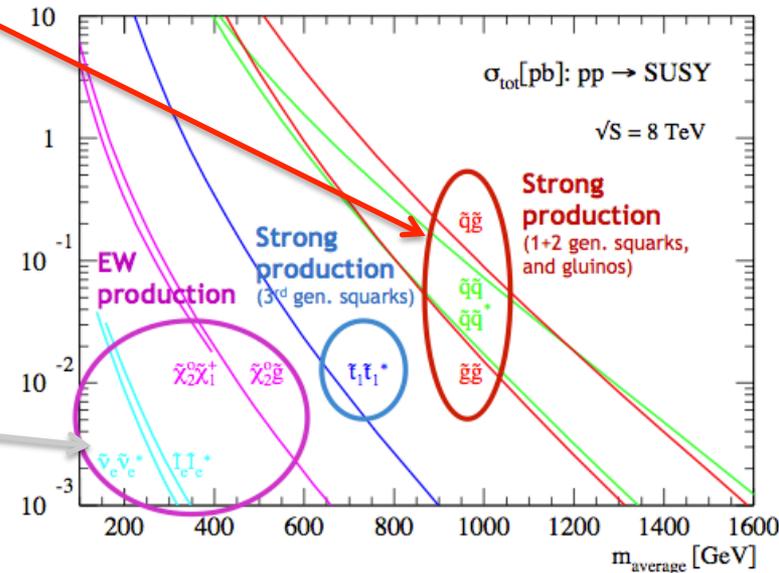


## ■ Inclusive SUSY search for squark, gluino

- ✍ with one soft lepton (IHEP)
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- ✍ with 2 SS/3 leptons (CPPM)
  - ATLAS-CONF-2013-007, ATLAS-CONF-2012-105

## ■ EW SUSY search for gauginos, sleptons with at least two leptons

- ✍  $\geq 2\tau$  (IHEP)
  - ATLAS-CONF-2013-028
- ✍  $== 2 e/\mu$  (CPPM)
  - arXiv:1403.5294 (submitted to JHEP)



# Inclusive SUSY search for squark, gluino



ATLAS-CONF-2013-062, ATLAS-CONF-2013-007

## ■ Motivation:

- SUSY strong production search has large cross section.
- 1l trigger can suppress QCD BG. If lepton is soft, it is very sensitive for compressed SUSY scenario (interesting for light SUSY, Higgsino LSP...) (IHEP)
- 2 Same Sign or 3 leptons channel with very small BG, high sensitivity for new physics (CPPM)

## ■ IHEP (2 SUSY approval talks for CONF note and paper):

- One CONF NOTE published in 2013: **ATLAS-CONF-2013-062**
- Paper draft [ATL-COM-PHYS-2013-1307](#) in ATLAS Collaboration for approval

## ■ CPPM (CONF note and paper editor, 2 SUSY approval talks):

- Two CONF NOTES published in 2013/2012: **ATLAS-CONF-2013-007(editor)**, **ATLAS-CONF-2012-105**
- Paper draft will be approved and put to arxiv today

# Signal Region Definition: soft lepton

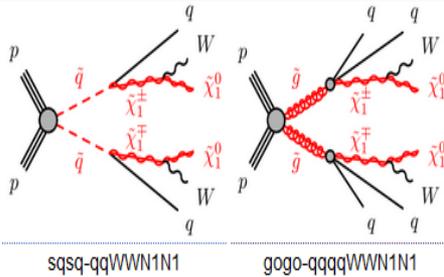
ATLAS-CONF-2013-062

Signature	Final states	Target physics/process
Inclusive ISR	1 soft-lepton + $E_T^{\text{miss}}$ + jets	$\tilde{g}\tilde{g} \rightarrow qq\tilde{q}\tilde{q}W^*W^*\tilde{\chi}_1^0\tilde{\chi}_1^0$ $\tilde{q}\tilde{q} \rightarrow qqW^*W^*qq\tilde{\chi}_1^0\tilde{\chi}_1^0$
ISR + bjet	1 soft-lepton + $E_T^{\text{miss}}$ + at least one b-jet	$\tilde{t}\tilde{t} \rightarrow bbW^*W^*\tilde{\chi}_1^0\tilde{\chi}_1^0$
2-bjet	1 soft-lepton + $E_T^{\text{miss}}$ + two b-jets	

## Three analyses:

Simplified Models  
GG/SS 1step grid

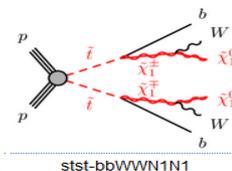
Stop pair production  
with higgsino LSP



**IHEP contribution: main SR (inclusive ISR) definition/optimization, trigger for all SR, BG estimation with simultaneous fit and interpretation for all SRs (dominant contribution from IHEP)**

	soft single-lepton	
	3-jet	5-jet
$N_\ell$	1 (electron or muon)	
$p_T^\ell$ (GeV)	[10,25] (electron) , [6,25] (muon)	
$p_T^{\text{add. } \ell}$ (GeV)	< 7 (electron), < 6 (muon)	
$m_{\mu\mu}$ (GeV)	-	-
$N_{\text{jet}}$	[3,4]	$\geq 5$
$p_T^{\text{leading jet}}$ (GeV)	> 180	
$p_T^{\text{subleading jets}}$ (GeV)	> 25	
$N_{b\text{-tag}}$	-	-
$E_T^{\text{miss}}$ (GeV)	> 400	> 300
$m_T$ (GeV)	> 100	
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$	> 0.3	
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0	

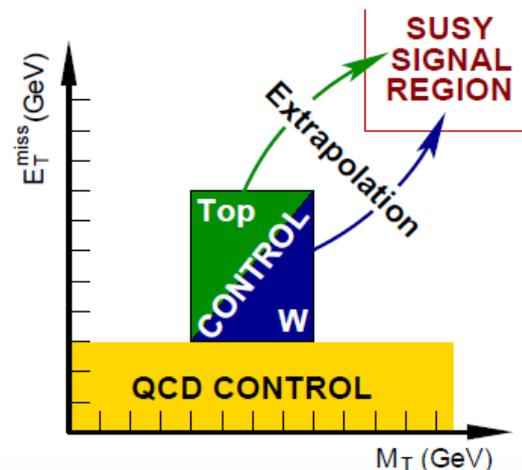
	soft single-lepton one b-jet		soft single-lepton two b-jets	
	low-mass	high-mass	low-mass	high-mass
$N_\ell$	1 (electron or muon)			
$p_T^\ell$ (GeV)	[10,25] (electron) , [6,25] (muon)			
$p_T^{\text{add. } \ell}$ (GeV)	< 7 (electron), < 6 (muon)			
$N_{\text{jet}}$	$\geq 3$		$\geq 2$	
$p_T^{\text{jets}}$ (GeV)	> 180,40,40	> 180,25,25	> 60,60	
$p_T^{\text{add. jets}}$ (GeV)	-		< 50	
$N_{b\text{-tag}}$	$\geq 1$ , but not the leading jet		2	
$E_T^{\text{miss}}$ (GeV)	> 250	> 300	> 200	> 300
$m_T$ (GeV)	> 100		-	
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$	> 0.35		-	
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0		-	
$\Delta\phi_{\text{min}}$	-		> 0.4	
$m_{\text{CT}}$ (GeV)	-		> 150	> 200
$H_{\text{FC}}(\text{GeV})$	-		< 50	-



# Background Estimation Strategy

ATLAS-CONF-2013-062

- ❑ **W/Z/ttbar background (dominant)**
- ❑ **Semi-data driven approach**
- ❑ **Normalize MC to Data in W/T-CR**
- ❑ **Extrapolate to SR using MC: assuming shape is described correctly**
- ❑ **Extrapolation done in simultaneous fit.**



$$\begin{aligned}
 N_{pred_j}^{SR} &= (N_{data}^{CR_j} - N_{other\ bkg}^{CR_j}) \times \frac{N_{pred}(MC^j, SR)}{N_{pred}(MC^j, CR_j)} \\
 &= (N_{data}^{CR_j} - N_{other\ bkg}^{CR_j}) \times C_{CR_j \rightarrow SR}^j
 \end{aligned}$$

- **QCD background (small bg)**
- **Fully-data driven approach**
- **Measure real and fake efficiencies in QCD-CRs**
- **Apply Matrix Method to get contribution in SR**

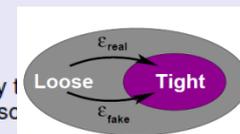
$$\text{QCD BG} = \frac{1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{fail} - \frac{1/\epsilon_{real} - 1}{1/\epsilon_{fake} - 1/\epsilon_{real}} \cdot N_{pass}$$

$N_{pass}$ : Events passing the signal selection cuts (*tight*)

$N_{fail}$ : Events satisfying relaxed lepton isolation criteria but not passing the signal selection cuts (*loose-but-not-tight*)

$\epsilon_{real}$ : Probability that a real event passes also the tight selection cuts

$\epsilon_{fake}$ : Probability that a loose QCD event passes also the tight selection cuts

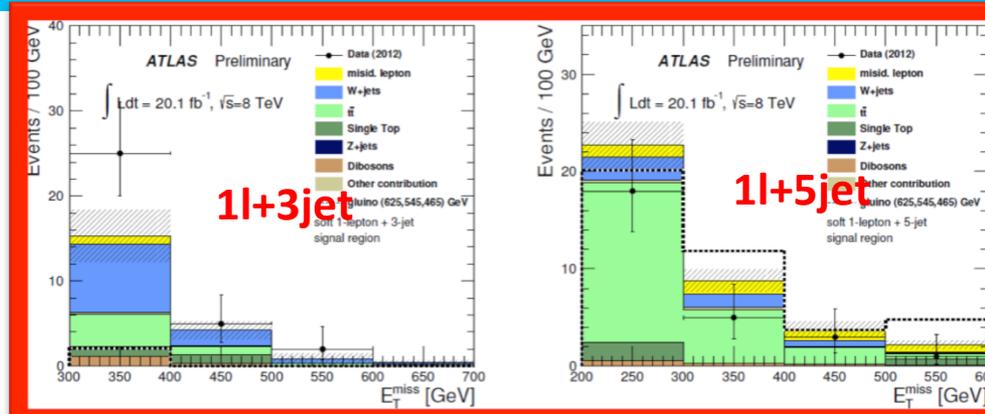


**Other small BGs (diboson, single top etc) are directly estimated from MC.**

# Results in soft lepton

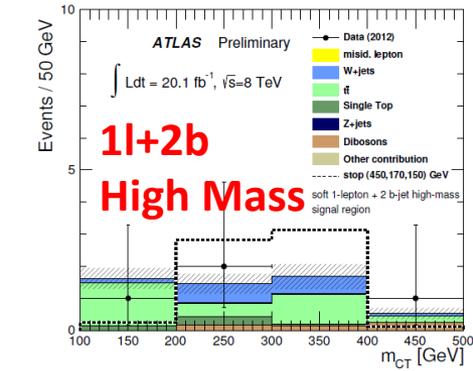
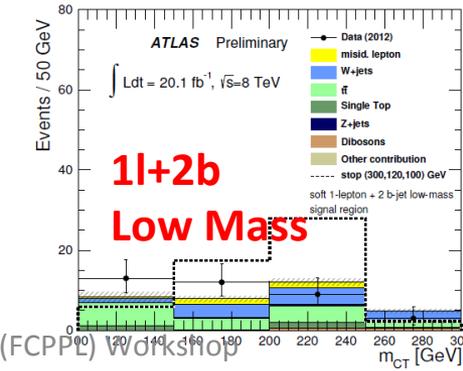
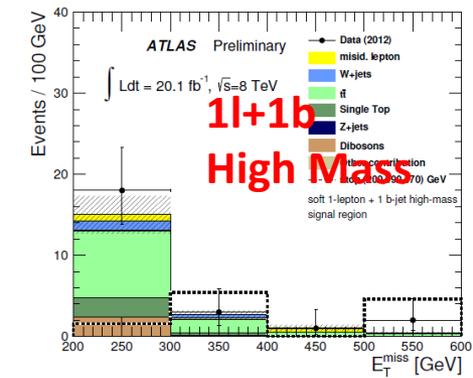
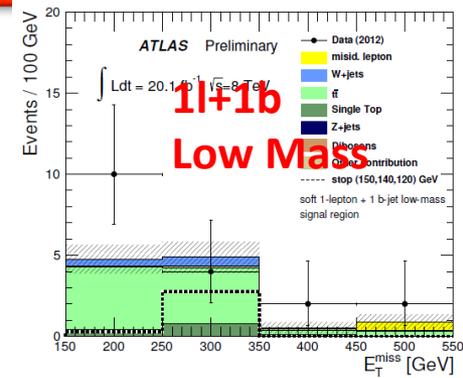
ATLAS-CONF-2013-062

	soft single-lepton	
	3-jet	5-jet
Observed events	7	9
Fitted background events	$5.6 \pm 1.6$	$14.8 \pm 3.7$
Fitted $t\bar{t}$ events	$1.3 \pm 1.0$	$7.8 \pm 3.3$
Fitted $W$ +jets events	$2.6 \pm 0.7$	$2.1 \pm 0.9$
Fitted diboson events	$0.6 \pm 0.4$	$0.7 \pm 0.4$
Fitted misidentified lepton events	$0.00^{+0.05}_{-0.00}$	$3.3 \pm 1.4$
Fitted other background events	$1.1 \pm 0.5$	$0.9 \pm 0.5$
MC expected SM events	$6.3 \pm 1.9$	$15.9 \pm 3.8$
MC expected $t\bar{t}$ events	$1.4 \pm 1.1$	$7.8 \pm 3.0$
MC expected $W$ +jets events	$3.1 \pm 0.9$	$3.2 \pm 0.9$
MC expected diboson events	$0.6 \pm 0.4$	$0.7 \pm 0.4$
Data-driven misidentified lepton events	$0.00^{+0.05}_{-0.00}$	$3.3 \pm 1.4$
MC expected other background events	$1.1 \pm 0.6$	$0.9 \pm 0.4$

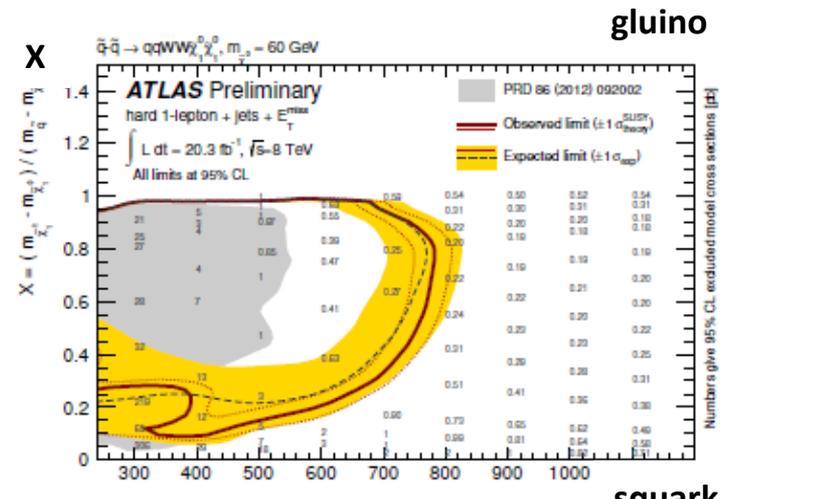
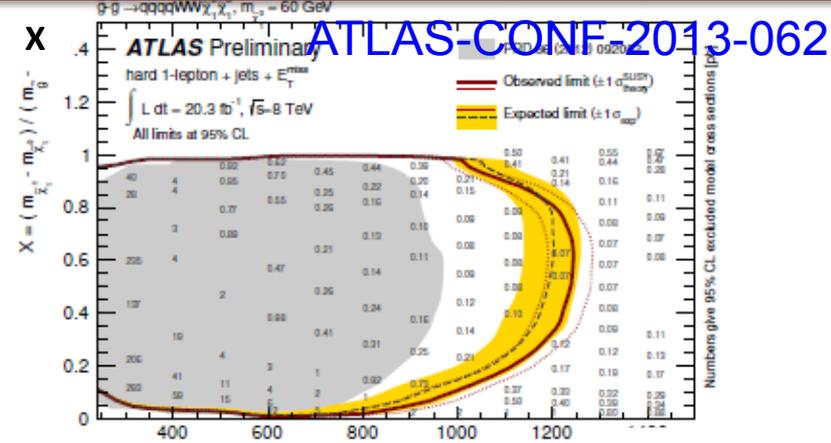
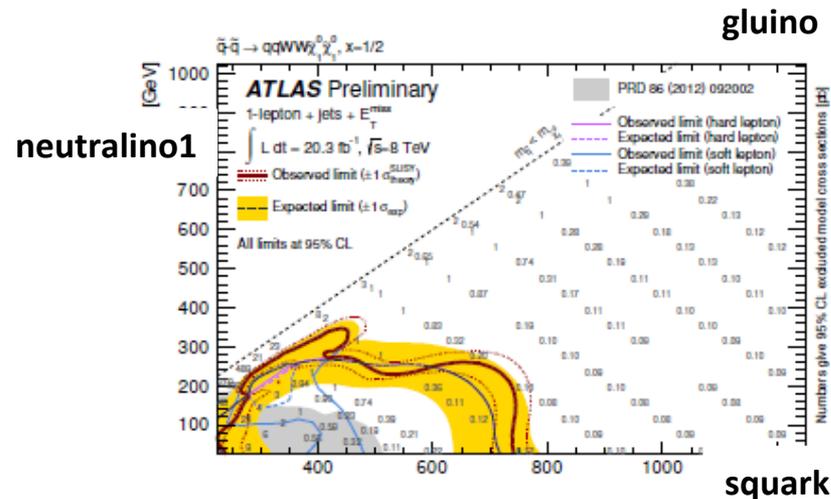
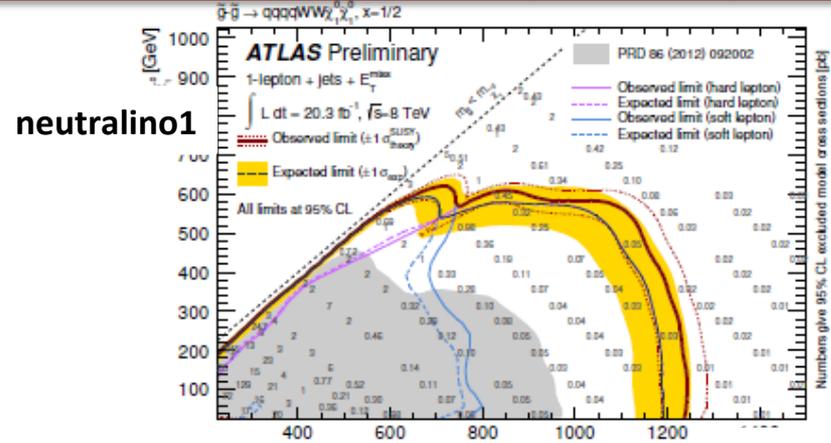


■ Data consistent with SM expectation.

	soft single-lepton one $b$ -jet		soft single-lepton two $b$ -jet	
	low-mass	high-mass	low-mass	high-mass
Observed	8	6	24	3
Fitted background	$6.1 \pm 1.4$	$4.0 \pm 1.1$	$24.1 \pm 4.1$	$3.6 \pm 1.4$
Fitted $t\bar{t}$ events	$4.0 \pm 1.1$	$2.3 \pm 0.7$	$9.4 \pm 4.5$	$1.6 \pm 1.0$
Fitted single-top events	$0.8 \pm 0.6$	$0.3 \pm 0.2$	$1.5 \pm 0.8$	$0.3^{+0.4}_{-0.3}$
Fitted $W$ +jets events	$0.6 \pm 0.2$	$0.5 \pm 0.3$	$8.8 \pm 3.1$	$1.1 \pm 0.5$
Fitted misidentified lepton events	$0.4^{+0.5}_{-0.4}$	$0.4^{+0.5}_{-0.4}$	$2.5 \pm 1.9$	$0.00^{+0.03}_{-0.00}$
Fitted other background events	$0.4 \pm 0.2$	$0.4 \pm 0.2$	$1.9 \pm 0.9$	$0.6 \pm 0.4$
MC expected SM events	$7.1 \pm 1.7$	$4.8 \pm 1.3$	$24.7 \pm 5.0$	$3.9 \pm 1.6$
MC expected $t\bar{t}$ events	$4.8 \pm 1.3$	$2.9 \pm 0.9$	$8.4 \pm 2.0$	$1.5 \pm 0.8$
MC expected single-top events	$0.8 \pm 0.6$	$0.3 \pm 0.2$	$1.5 \pm 0.8$	$0.3^{+0.4}_{-0.3}$
MC expected $W$ +jets events	$0.8 \pm 0.3$	$0.7 \pm 0.4$	$10.4 \pm 3.4$	$1.6 \pm 0.6$
Data-driven misidentified lepton events	$0.4^{+0.5}_{-0.4}$	$0.4^{+0.5}_{-0.4}$	$2.5 \pm 1.9$	$0.00^{+0.03}_{-0.00}$
MC expected other background events	$0.4 \pm 0.2$	$0.4 \pm 0.2$	$2.0 \pm 0.9$	$0.6 \pm 0.4$



# Exclusion Limit for soft lepton: Simplified model with 1<sup>st</sup>, 2<sup>nd</sup> gen squark and gluino production



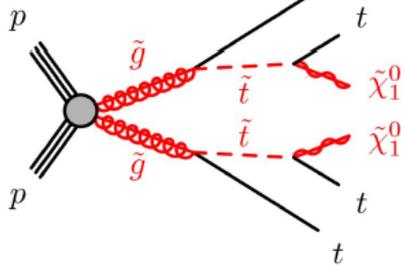
- $m_{\text{neutralino}} - m_{\text{gluino/squark}}$  mass plane
  - Gluino limits
    - Soft lepton analysis: powerful along the diagonal (the mass of sparticle and lightest neutralino are almost degenerate) The limit on gluino mass reaches up to 700GeV for all lightest neutralino mass, where mass difference is  $>25\text{GeV}$ .
    - Hard lepton analysis: exclude gluino up to 1.18TeV.
  - Squark limits (weaker due to lower cross-section)
    - Extends limit on squark mass to  $\sim 700\text{GeV}$ .

- $m_{\text{gluino/squark}} - x$  plane
- $x = (C1 - N1) / (G - N1)$  ;  $N1 = 60\text{GeV}$
- Gluino mass to  $\sim 1.2\text{TeV}$
- Squark mass to  $\sim 750\text{GeV}$

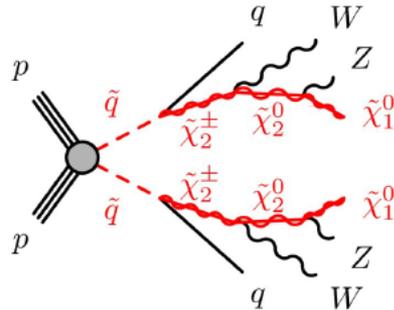
# SUSY Models and SR : SS 2I

ATLAS-CONF-2013-007

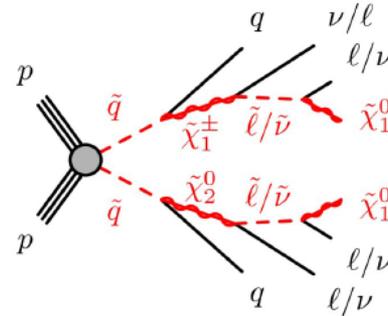
Natural SUSY, light 3<sup>rd</sup> gen. squarks → tops



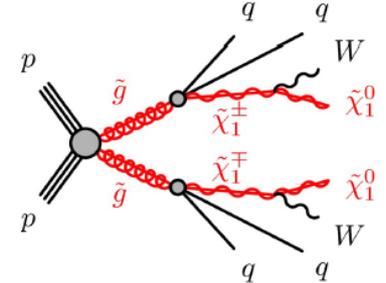
Gauginos cascades



Light sleptons



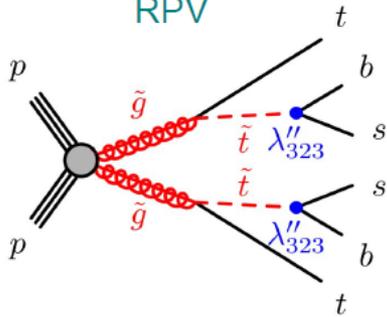
Majorana gluinos



## Signal regions definition

- few SRs, but sensitive to many models
- great discovery potential

RPV



Signal region	$N_{b\text{-jets}}$	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}$ $m_{\text{T}} > 100 \text{ GeV}, m_{\text{eff}} > 400 \text{ GeV}$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}, m_{\text{T}} > 100 \text{ GeV},$ binned shape fit in $m_{\text{eff}}$ for $m_{\text{eff}} > 300 \text{ GeV}$
SR1b	$\geq 1$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}$ $m_{\text{T}} > 100 \text{ GeV}, m_{\text{eff}} > 700 \text{ GeV}$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}, m_{\text{T}} > 100 \text{ GeV},$ binned shape fit in $m_{\text{eff}}$ for $m_{\text{eff}} > 300 \text{ GeV}$
SR3b	$\geq 3$	$N_{\text{jets}} \geq 4$	$N_{\text{jets}} \geq 5,$ $E_{\text{T}}^{\text{miss}} < 150 \text{ GeV}$ or $m_{\text{T}} < 100 \text{ GeV}$

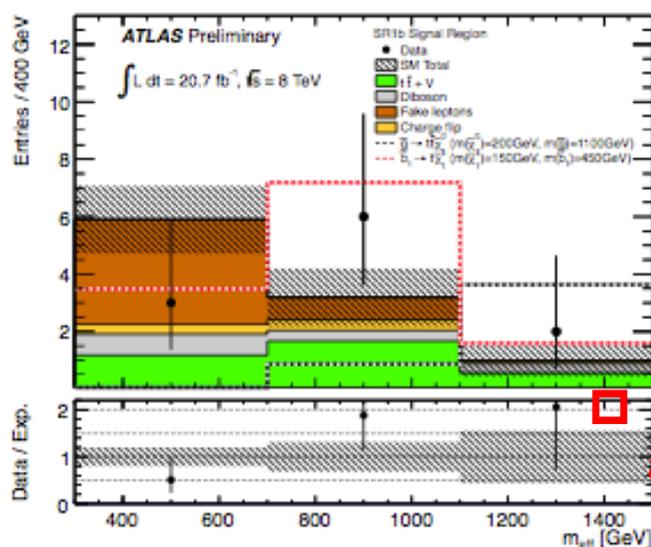
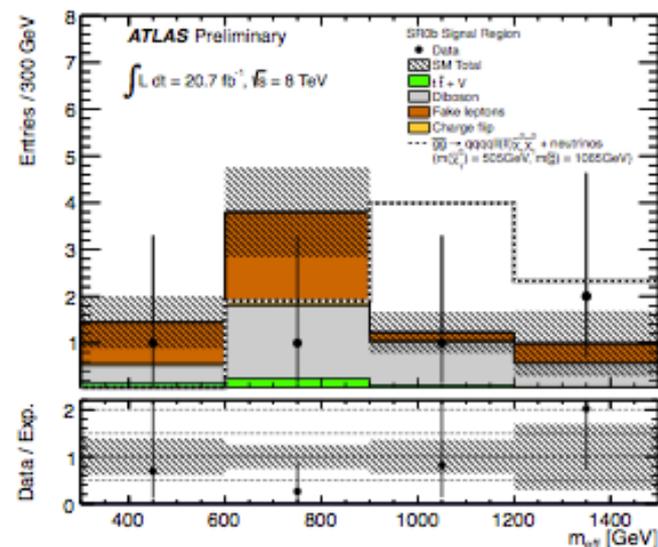
# Results : ss 21

ATLAS-CONF-2013-007

B) Exclusion case	SR0b	SR1b	SR3b
Observed events	5	11	1
Expected background events	$7.5 \pm 3.2$	$10.1 \pm 3.9$	$1.8 \pm 1.3$
Expected $t\bar{t} + V$ events	$0.5 \pm 0.4$	$3.4 \pm 1.5$	$0.6 \pm 0.4$
Expected diboson events	$3.4 \pm 1.1$	$1.4 \pm 0.7$	$< 0.1$
Expected fake lepton events	$3.4 \pm 2.9$	$4.4 \pm 3.1$	$1.0 \pm 1.1$
Expected charge mis-measurement events	$0.2 \pm 0.1$	$0.8 \pm 0.3$	$0.1 \pm 0.1$
$p_0$	0.5	0.39	0.5

□ CPPM contributed a lot in the whole analysis:

- SR definition
- Background estimates
  - rare SM processes
  - detector-like: lepton fakes and/or charge flip...
- interpretations



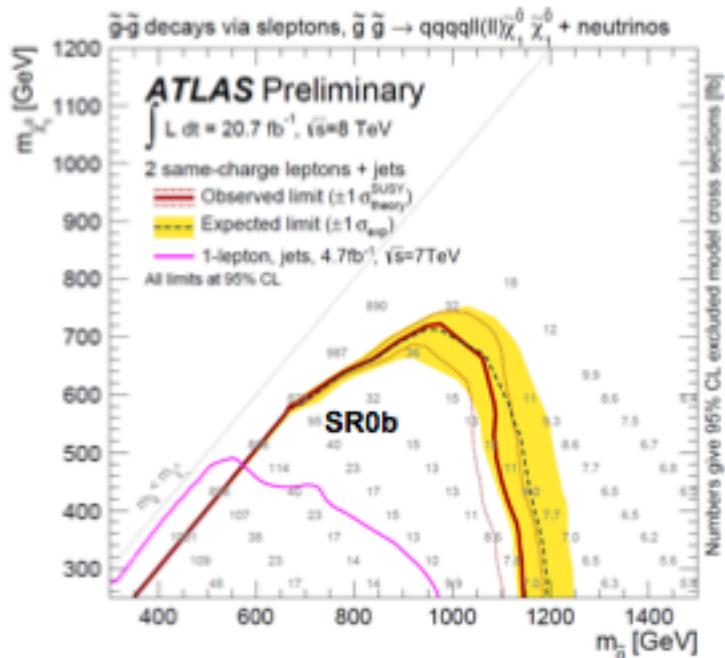
□ editor of one CONF note and combined paper

Figure 6: Effective mass distributions in the signal regions SR0b (left) and SR1b (right) using the exclusion case event sample. The last bin includes overflows.

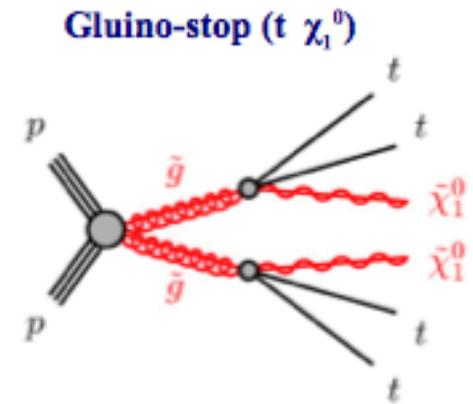
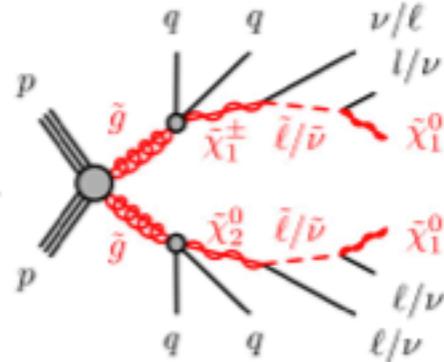
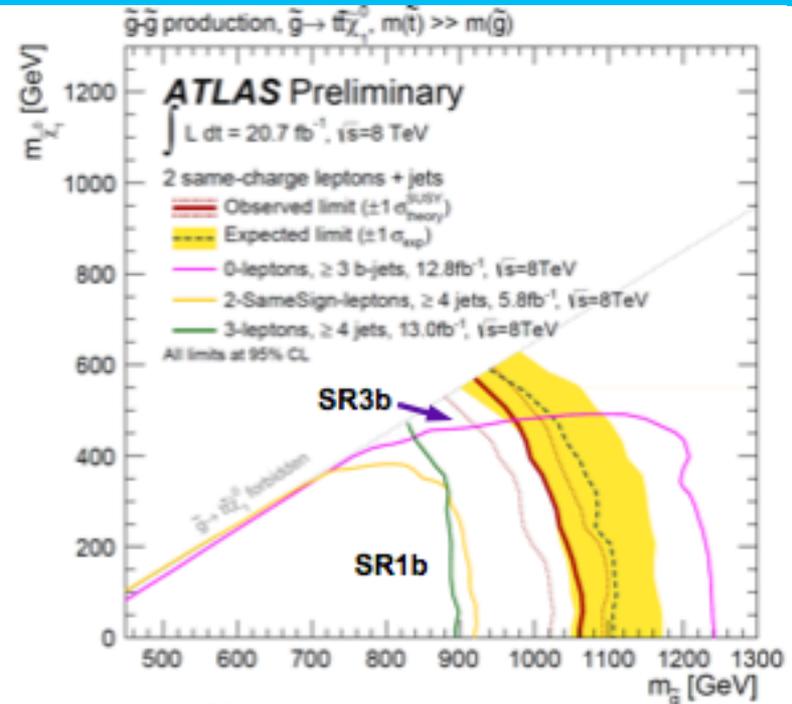
# Exclusions : SS 2I

ATLAS-CONF-2013-007

- All limits are using a fit based on likelihood method, and corresponds to **95% CL** using the  $CL_s$  calculation.
- Simultaneous fit to all three signal regions
- No deviation from the Standard Model is observed.

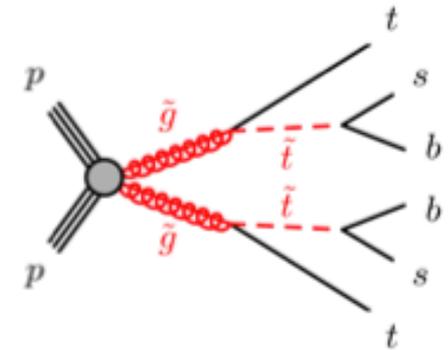
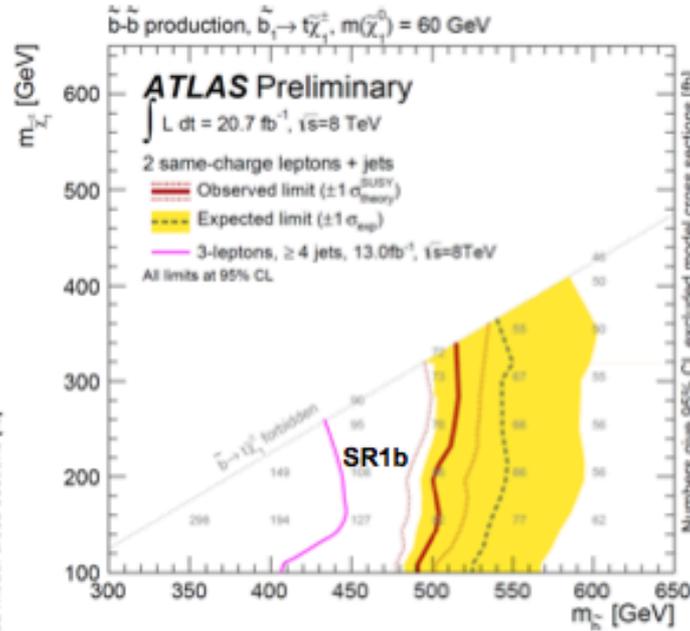
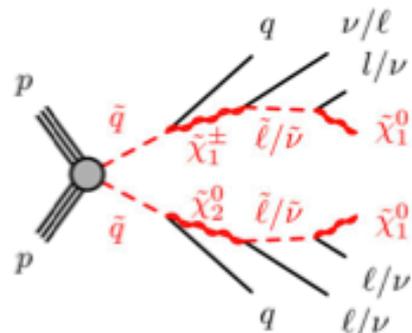


**Gluino-squark (via slepton)**

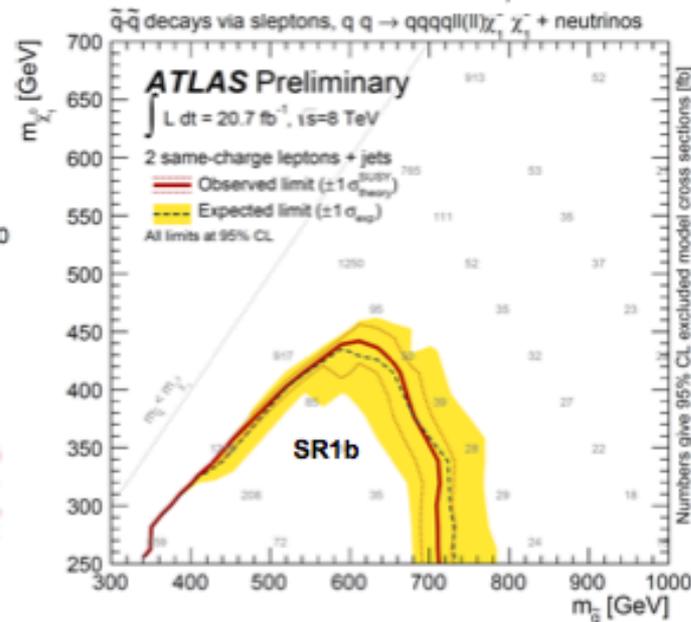


# Exclusions : SS 2I

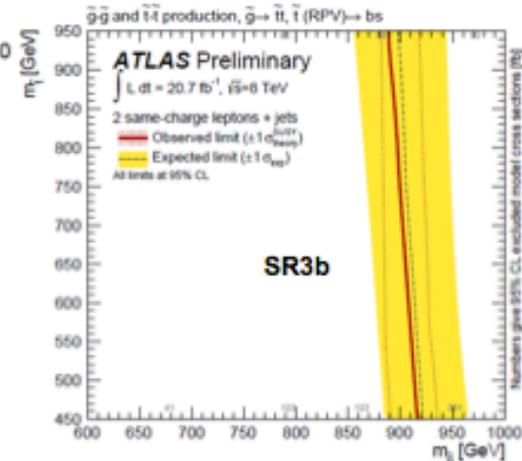
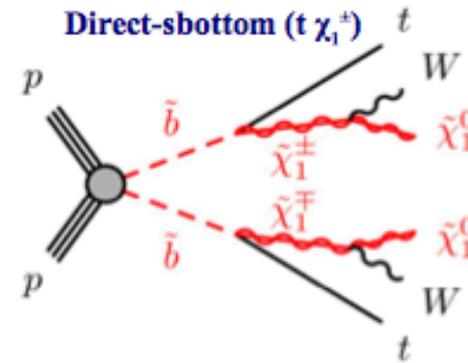
ATLAS-CONF-2013-007



**Gluino-stop (bs) RPV**



**Direct squark (via slepton)**



**SR3b**

**Towards Run II** – improve object definition, bkg estimates, new signal/control regions – hope to provide quick results with 2015 data

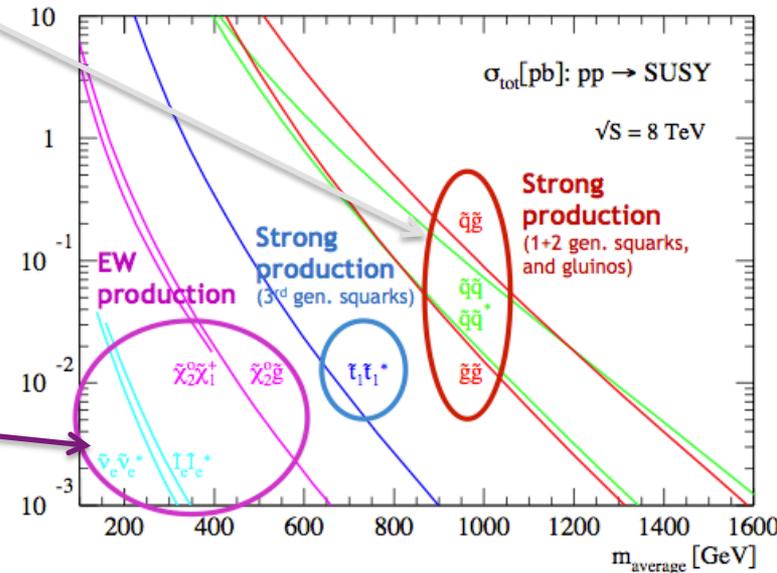
# IHEP / CPPM SUSY Search Activities



- Inclusive SUSY search for squark, gluino
  - ✍ with one soft lepton (IHEP)
    - ATLAS-CONF-2013-062
  - ✍ with SS di-muon (CPPM)
    - ATLAS-CONF-2013-007

## ■ EW SUSY search for gauginos, sleptons with at least two leptons

- ✍  $\geq 2\tau$  (IHEP)
  - ATLAS-CONF-2013-028
- ✍  $== 2 e/\mu$  (CPPM)
  - ATLAS-CONF-2013-049, arXiv: 1403.5294 (submitted to JHEP)



Naming conventions:  
C1: chargino  
N1: neutralino 1  
N2: neutralino 2

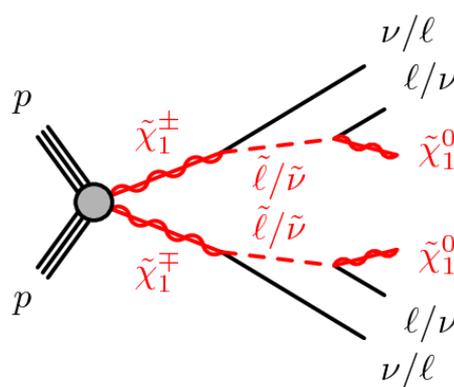
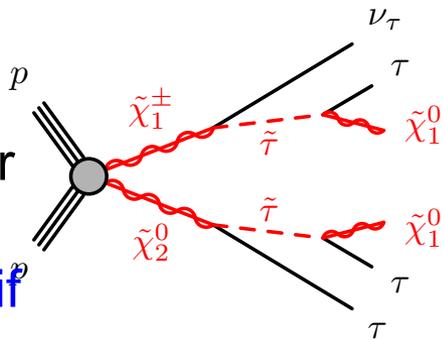
# ElectroWeak SUSY Search

(direct chargino/neutralino and slepton production)



- Search strategy depends on slepton mass and gauge mixture
- Final state: **2/3/4 leptons + MET** (l=e,mu,tau)

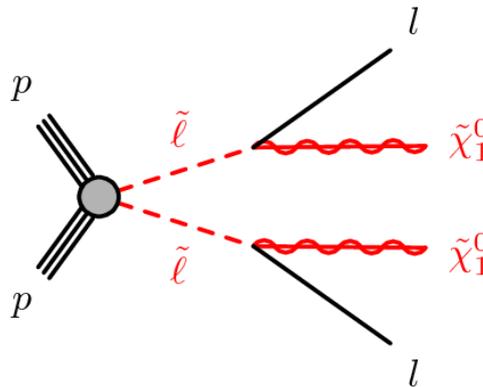
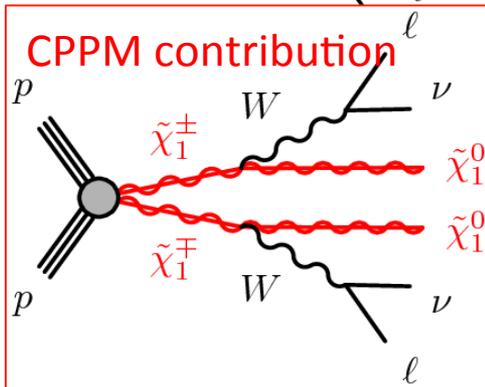
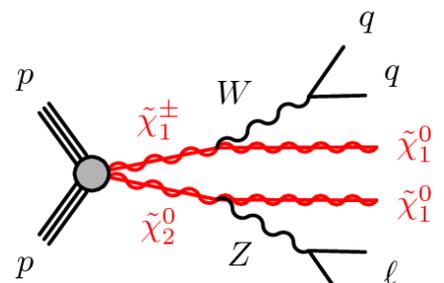
🍏 Largest cross section for wino-like C/Ns. Smaller if higgsino  $\geq 2\tau + \text{MET}$  FS if light sleptons



🍏 Large cross section for slepton-left

- 2l + MET (l = e/μ/τ)

🍏 If sleptons heavy, reduced BR to leptons (WZ+MET) Equivalent picture for C1C1 production (WW+MET)



🍏 Plausible possibility for light stau if other sleptons are heavy - 2l + MET (l = e/μ/τ)

# EW SUSY search with at least two leptons



ATLAS-CONF-2013-028, arXiv:1403.5294

- Interesting search in LHC:
  - If the gluinos and squarks are sufficiently heavy, the direct production of charginos/neutralinos/sleptons may be the dominant means of SUSY particles production at LHC.
  - Naturalness arguments indicate that third-generation sparticles/ charginos/neutralinos should have mass of a few hundred GeV.
- First gaugino and stau search from two hadronically decaying taus in LHC (IHEP)
- IHEP (CONF note and paper convener, editor, 3-4 SUSY and ATLAS approval talks ):
  - Published one CONF note in 2013: [ATLAS-CONF-2013-028](#)
  - Paper draft (ATL-COM-PHYS-2013-1307 ) in ATLAS Collaboration for approval..
- CPPM (CONF note editor, SUSY approval talk)
  - Published one CONF note in 2013: [ATLAS-CONF-2013-049](#)
  - Paper submitted to JHEP: [arXiv:1403.5294](#)

# Signal Regions: 2tau + MET



ATLAS-CONF-2013-028

Two SR defined:

- Main difference:
  - Jet veto (bjet, forward, central jet veto) (suppress top)
  - Bjet veto only (suppress top, cover signal events with ISR jet)
- Common
  - Z-veto: suppress Z+jets BGs
  - MET>40: suppress QCD/Z
- “stransverse mass”  $m_{T2}$ : a kinematic variable to discriminate events where two particles decay into one visible and one invisible particle
  - Optimized for each SR.
  - Large  $m_{T2}$  cut: enhance SUSY sensitivity

Signal region	requirements
OS $m_{T2}$	at least 1 OS tau pair jet veto Z-veto $E_T^{\text{miss}} > 40$ GeV $m_{T2} > 90$ GeV
OS $m_{T2}$ -nobjet	at least 1 OS tau pair b-jet veto Z-veto $E_T^{\text{miss}} > 40$ GeV $m_{T2} > 100$ GeV

Table 1: Definition of the signal regions.

$m_{T2}$  stransverse mass  
kinematic endpoint  $\sim$  mass of decaying particle

$$m_{T2} = \min_{\mathbf{q}_T} \left[ \max \left( m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T) \right) \right]$$

where  $m_T(\mathbf{p}_T, \mathbf{q}_T) = \sqrt{2(p_T q_T - \mathbf{p}_T \cdot \mathbf{q}_T)}$

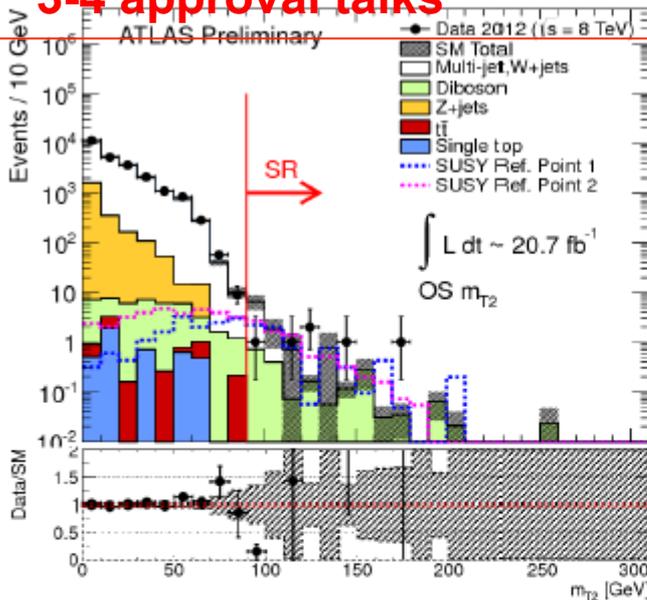
# Results: 2tau + MET



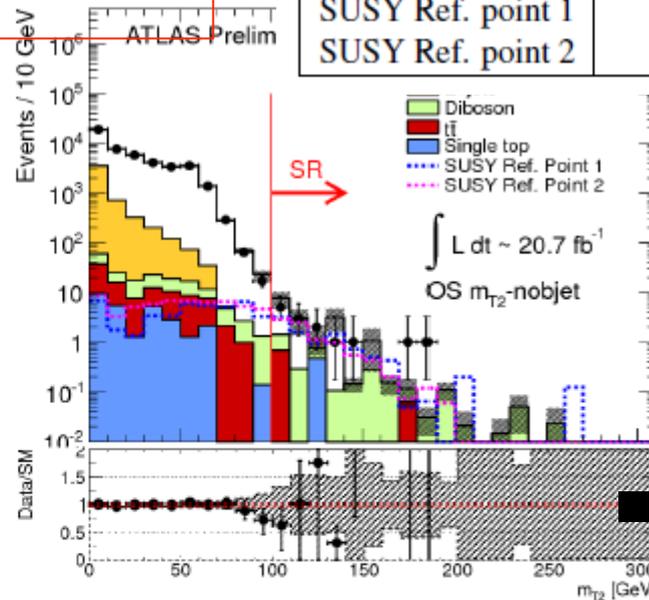
ATLAS-CONF-2013-028

- IHEP contribution(leading role): all SR definition, all BG estimation except diboson, all VRs, final results and interpretations.
- analysis convener, contact editor, 3-4 approval talks

SM process	SR OS $m_{T2}$	SR OS $m_{T2}$ -nobjet
top	$0.2 \pm 0.5 \pm 0.1$	$1.6 \pm 0.8 \pm 1.2$
Z+jets	$0.28 \pm 0.26 \pm 0.23$	$0.4 \pm 0.3 \pm 0.3$
diboson	$2.2 \pm 0.5 \pm 0.5$	$2.5 \pm 0.5 \pm 0.9$
multi-jet & W+jets	$8.4 \pm 2.6 \pm 1.4$	$12 \pm 3 \pm 3$
SM total	$11.0 \pm 2.7 \pm 1.5$	$17 \pm 4 \pm 3$
data	6	14
SUSY Ref. point 1	$6.8 \pm 1.0$	$9.2 \pm 1.2$
SUSY Ref. point 2	$7.5 \pm 0.7$	$8.9 \pm 0.7$



(a) SR OS- $m_{T2}$



(b) SR OS- $m_{T2}$ -nobjet

- Dominant BG: fake tau from QCD +W (ABCD method)
- Others: MC simulation

## Benchmark points

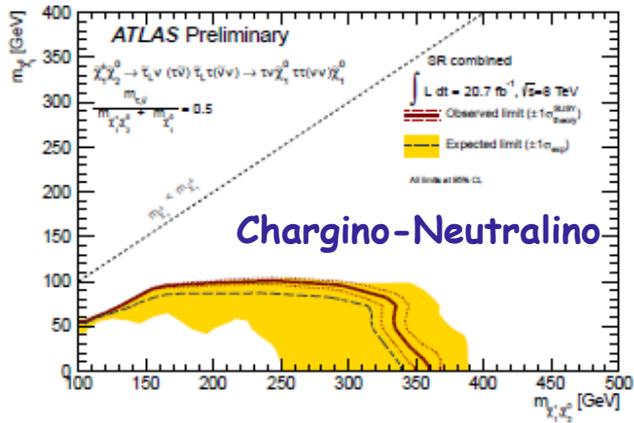
- SUSY Point Ref.1 (C1=250;N1=100)
- SUSY Point Ref.2 (C1=150;N1=50)

Figure 5:  $m_{T2}$  distribution for (a) SR OS- $m_{T2}$  and (b) SR OS- $m_{T2}$ -nobjet. The stacked histograms show the expected backgrounds. The white histogram represents the multi-jet and W+jets contribution obtained from data using the ABCD method. The SM backgrounds are normalized to  $20.7 \text{ fb}^{-1}$ . The lower plots show the distributions of data over SM background ratio.

# Exclusion Limits: 2tau + MET

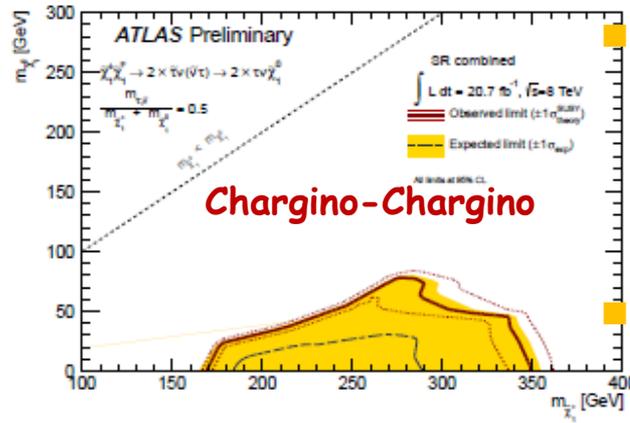


ATLAS-CONF-2013-028



(a)

simplified model

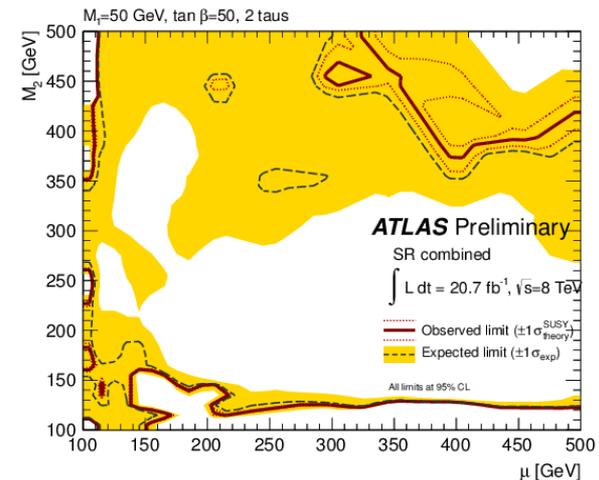


(b)

C1N2 production: C1/N2 mass up to 330(300) GeV excluded for N1 mass below 50(100) GeV  
 Wino-like Chargino production : C1 mass up to 350 GeV excluded for a massless lightest N1

Figure 6: 95% CL exclusion limits for Simplified Models with (a) chargino-neutralino and (b) chargino-chargino production. The SR with the best expected limit at each point is used. The dashed lines show

- Most pMSSM parameter space excluded
- The region at low M2 can not be excluded since it corresponds to points in the parameter space where the chargino and neutralino are lighter than the stau.
- The region at large M2 and mu corresponds to **direct stau production.**



pMSSM model

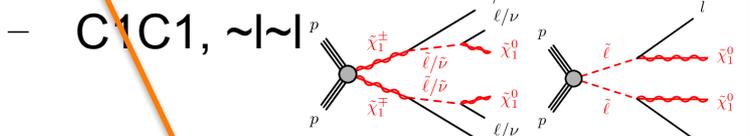
# Signal Regions: 2l (e/mu) + MET



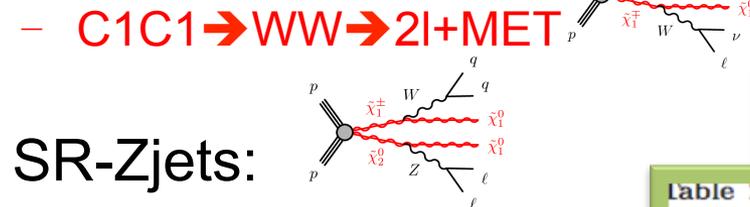
arXiv:1403.5294

Three SRs defined:

■ SR-mT2: mT2(90-150)



■ SR-WW: WW(a-c)



■ SR-Zjets:



Table 1. Signal region definitions. The criteria on  $|m_{\ell\ell} - m_Z|$  are applied only to SF events. The two leading central light jets must have  $p_{T,j} > 45$  GeV.

SR	SR	$m_{T2}^{90}$	$m_{T2}^{120}$	$m_{T2}^{150}$	WWa	WWb	WWc	Zjets
lepton flavour	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	SF
central light jets	0	0	0	0	0	0	0	$\geq 2$
central b-jets	0	0	0	0	0	0	0	0
forward jets	0	0	0	0	0	0	0	0
$ m_{\ell\ell} - m_Z $ [GeV]	$> 10$	$> 10$	$> 10$	$> 10$	$> 10$	$> 10$	$> 10$	$< 10$
$m_{\ell\ell}$ [GeV]	—	—	—	—	$< 120$	$< 170$	—	—
$E_T^{\text{miss,rel}}$ [GeV]	—	—	—	—	$> 80$	—	—	$> 80$
$p_{T,\ell\ell}$ [GeV]	—	—	—	—	$> 80$	—	—	$> 80$
$m_{T2}$ [GeV]	$> 90$	$> 120$	$> 150$	—	—	$> 90$	$> 100$	—
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	—	[0.3,1.5]
$m_{jj}$ [GeV]	—	—	—	—	—	—	—	[50,100]

Table 2. Control region definitions. The top CR for SR-Zjets requires at least two jets with  $p_{T,j} > 20$  GeV in  $|\eta| < 2.4$ , at least one of which is b-tagged.

CR	SR	$m_{T2}$ and WWb/c			WWa			Zjets
CR	WW	Top	ZV	WW	Top	ZV	Top	
lepton flavour	DF	DF	SF	DF	DF	SF	SF	
central light jets	0	0	0	0	0	0	$\geq 2$	
central b-jets	0	$\geq 1$	0	0	$\geq 1$	0	$\geq 1$	
forward jets	0	0	0	0	0	0	0	
$ m_{\ell\ell} - m_Z $ [GeV]	—	—	$< 10$	—	—	$< 10$	$> 10$	
$m_{\ell\ell}$ [GeV]	—	—	—	$< 120$	$< 120$	—	—	
$E_T^{\text{miss,rel}}$ [GeV]	—	—	—	[60, 80]	$> 80$	$> 80$	$> 80$	
$p_{T,\ell\ell}$ [GeV]	—	—	—	$> 40$	$> 80$	$> 80$	$> 80$	
$m_{T2}$ [GeV]	[50, 90]	$> 70$	$> 90$	—	—	—	—	
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	[0.3, 1.5]	

BG estimation: (semi-data-driven: CR → SR)

■ SR-mT2 and SR-WW:  
Dominant: WW, top, ZV

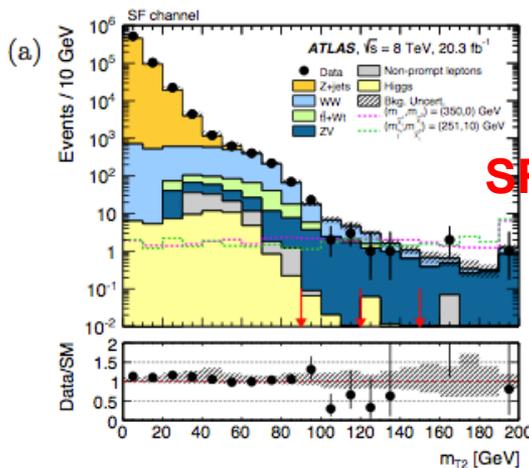
■ SR-Zjets:  
Dominant: ZV, Z+jets

# Results: $2l$ (e/mu) + MET

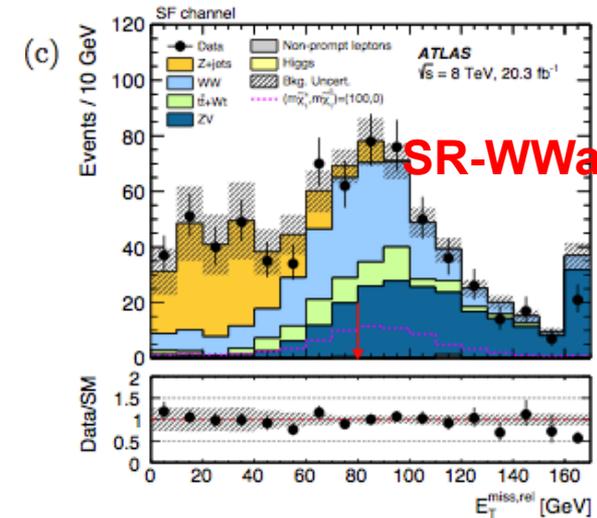
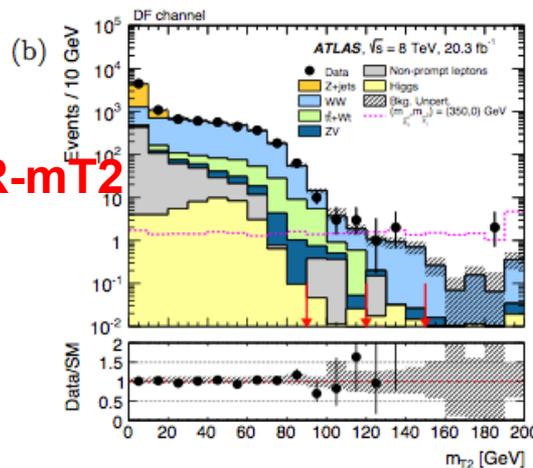


arXiv:1403.5294

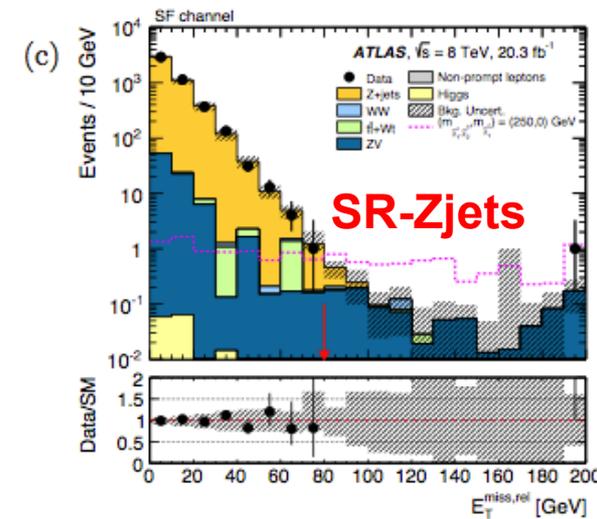
	SR- $m_{T2}^{90}$		SR- $m_{T2}^{120}$		SR- $m_{T2}^{150}$	
	SF	DF	SF	DF	SF	DF
Expected background						
WW	$22.1 \pm 4.3$	$16.2 \pm 3.2$	$3.5 \pm 1.3$	$3.3 \pm 1.2$	$1.0 \pm 0.5$	$0.9 \pm 0.5$
ZV	$12.9 \pm 2.2$	$0.8 \pm 0.2$	$4.9 \pm 1.6$	$0.2 \pm 0.1$	$2.2 \pm 0.5$	$< 0.1$
Top	$3.0 \pm 1.8$	$5.5 \pm 1.9$	$0.3^{+0.4}_{-0.3}$	$< 0.1$	$< 0.1$	$< 0.1$
Others	$0.3 \pm 0.3$	$0.8 \pm 0.6$	$0.1^{+0.4}_{-0.1}$	$0.1 \pm 0.1$	$0.1^{+0.4}_{-0.1}$	$0.0^{+0.4}_{-0.0}$
Total	$38.2 \pm 5.1$	$23.3 \pm 3.7$	$8.9 \pm 2.1$	$3.6 \pm 1.2$	$3.2 \pm 0.7$	$1.0 \pm 0.5$
Observed events	33	21	5	5	3	2
Predicted signal						
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (350, 0)$	$24.2 \pm 2.5$	$19.1 \pm 2.1$	$18.1 \pm 1.8$	$14.7 \pm 1.7$	$12.0 \pm 1.3$	$10.1 \pm 1.3$
$(m_{\tilde{t}}, m_{\tilde{\chi}_1^0}) = (251, 10)$	$24.0 \pm 2.7$	—	$19.1 \pm 2.5$	—	$14.3 \pm 1.7$	—
$p_0$	0.50	0.50	0.50	0.27	0.50	0.21
Observed $\sigma_{\text{vis}}^{95}$ [fb]	0.63	0.55	0.26	0.36	0.24	0.26
Expected $\sigma_{\text{vis}}^{95}$ [fb]	$0.78^{+0.32}_{-0.23}$	$0.62^{+0.26}_{-0.18}$	$0.37^{+0.17}_{-0.11}$	$0.30^{+0.13}_{-0.09}$	$0.24^{+0.13}_{-0.08}$	$0.19^{+0.10}_{-0.06}$



SR- $m_{T2}$



SR-WWa

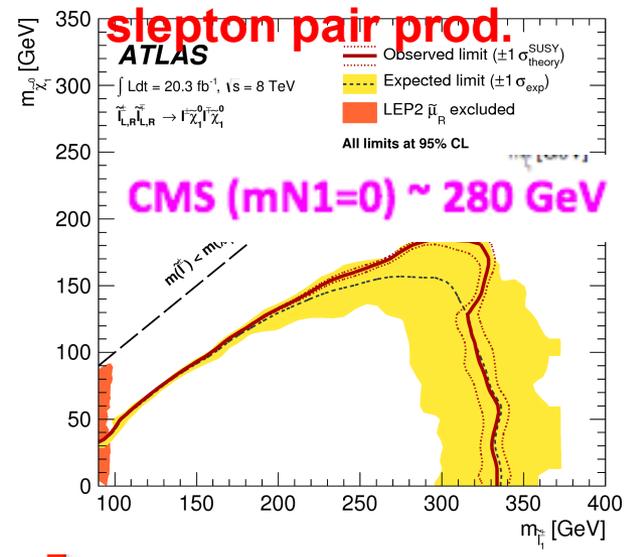
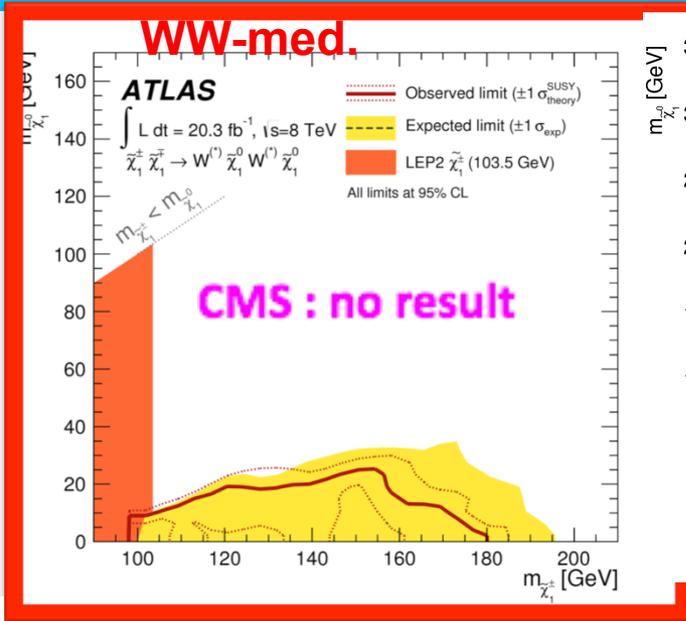
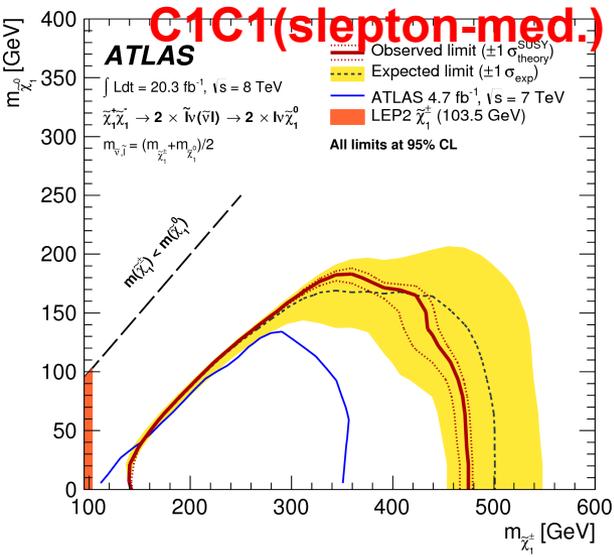


SR-Zjets

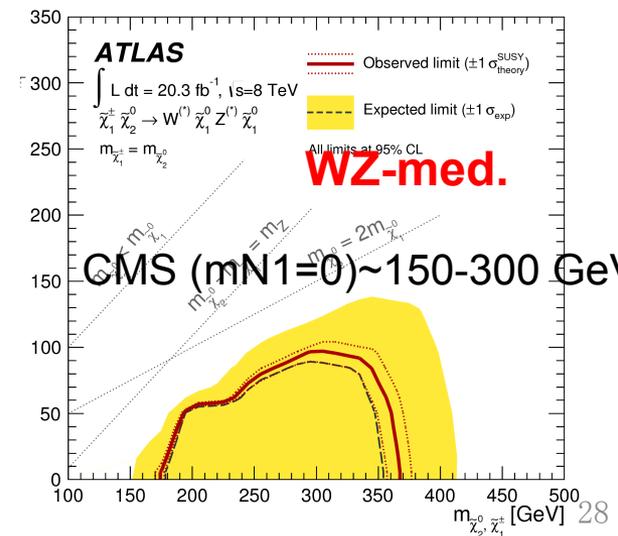
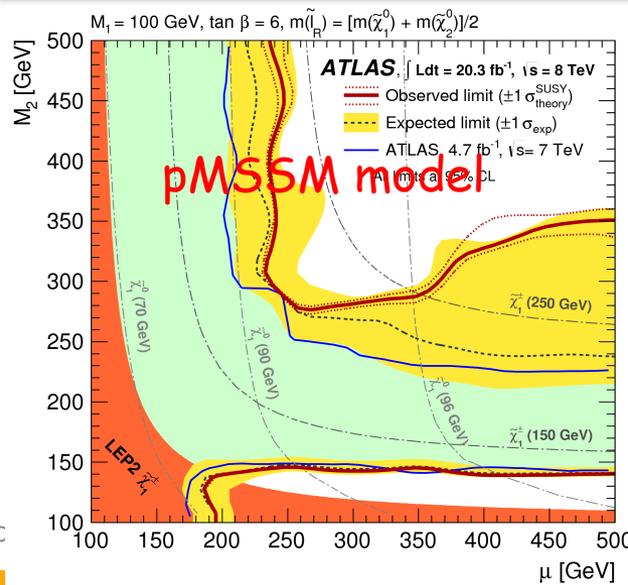
# Exclusion Limits: 2l(emu) + MET



arXiv:1403.5294

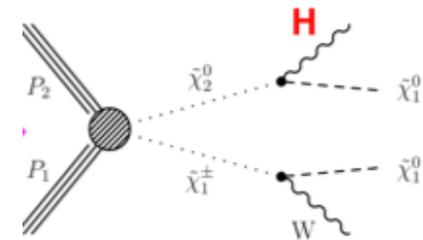


CMS (mN1=0) ~ 550 GeV (\*)  
 (\*) problem found with WW madgraph sample



# Run II preparation for 13-14 TeV data

- Prepare run-II for SUSY strong production for above 2 topics (one soft lepton, SS 2L) – ready before data-taking start-up
- EWK SUSY search (2L, 2tau)
  - Summary/legacy paper: end of summer (2L, 3L, 4L, 2tau combination)
    - Ditau:
      - Decay via Wh (2jet + 2tau)
      - MVA for Dstau
      - compressed scenario (SS, ISR jet ...)
    - 2L (e/mu) : compressed scenario
      - Run II preparation
- Already start C1N1,N1N2.... Sensitivity check for 13-14 TeV among CPPM and IHEP from last October
- More cooperation in the near future in inclusive SUSY search with 13-14 TeV



# Summary

- **Big contributions on SUSY search from CPPM and IHEP (Run I)**
  - ✓ **4 analysis (very wide coverage on SUSY search)**
    - **Inclusive SUSY search with one soft lepton (IHEP:2 approval talks)**
    - **Inclusive SUSY search with SS 2L (CPPM: conf note /paper editor, 2 approval talks) - leading role**
    - **EWK SUSY search with at least two taus (IHEP: convener, conf note / paper editor, 3-4 approval talks) - leading role**
    - **EWK SUSY search with 2L (emu) (CPPM: conf note editor, approval talk)**
  - ✓ **5 CONF notes published, 1 paper submitted, 3 papers in approval**
  - ✓ **One analysis convener, 3 CONF note and 2 paper editor, 8-9 approval talks**
- **High energy running in 2015 will significantly increase our sensitivity to many SUSY scenarios**
- **More cooperation between CPPM and IHEP in the future**

Looking forward to the next exciting years !

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**Thank You!**

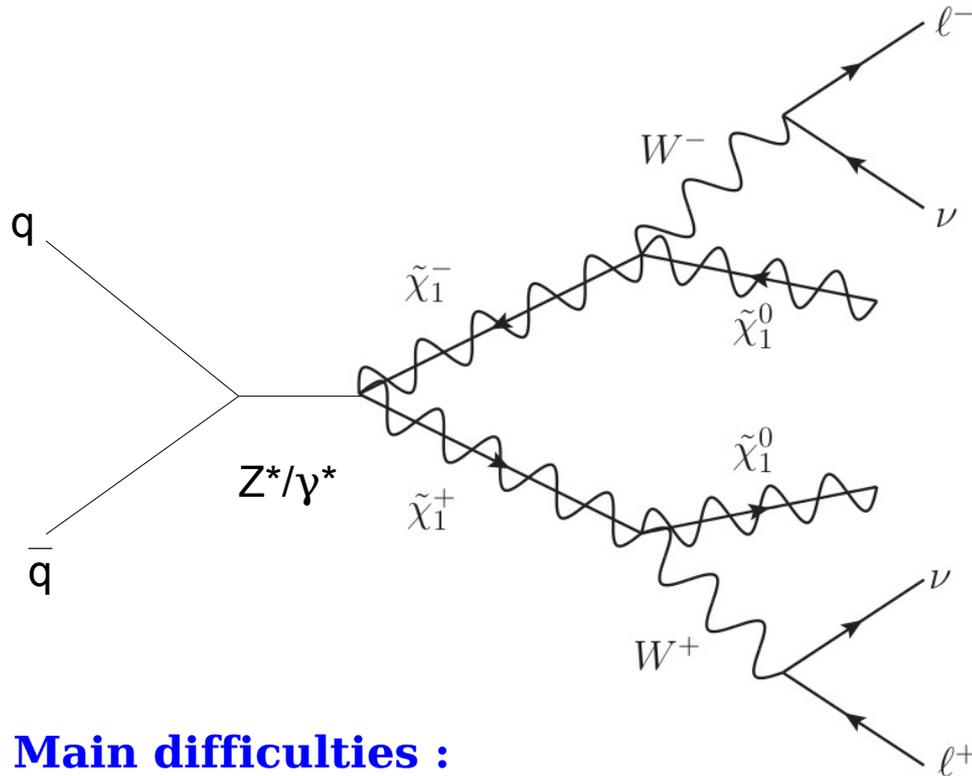


Looking forward to the next exciting years !

# Direct chargino pair production in 2 lepton + MET (1)

## - Hypothesis :

- $\tilde{\chi}_1^{+/-}$  NLSP Wino-like, decaying in on-shell W and in  $\tilde{\chi}_1^0$  LSP Bino-like
- $M(\tilde{\chi}_1^{+/-})$  between 100 and 300 GeV,  $M(\tilde{\chi}_1^0) < M(\tilde{\chi}_1^{+/-}) - M(W)$



## - Motivations :

=> Simple pair production with only 2 new particles

=> Weak limits on charginos by LEP :  $m(\tilde{\chi}_1^{+/-}) > 103$  GeV

=> No search in CMS

=> *"The considerable hole in current searches at the LHC is to the pair production of charginos"* [arXiv:1309.0528](https://arxiv.org/abs/1309.0528)

## - Main difficulties :

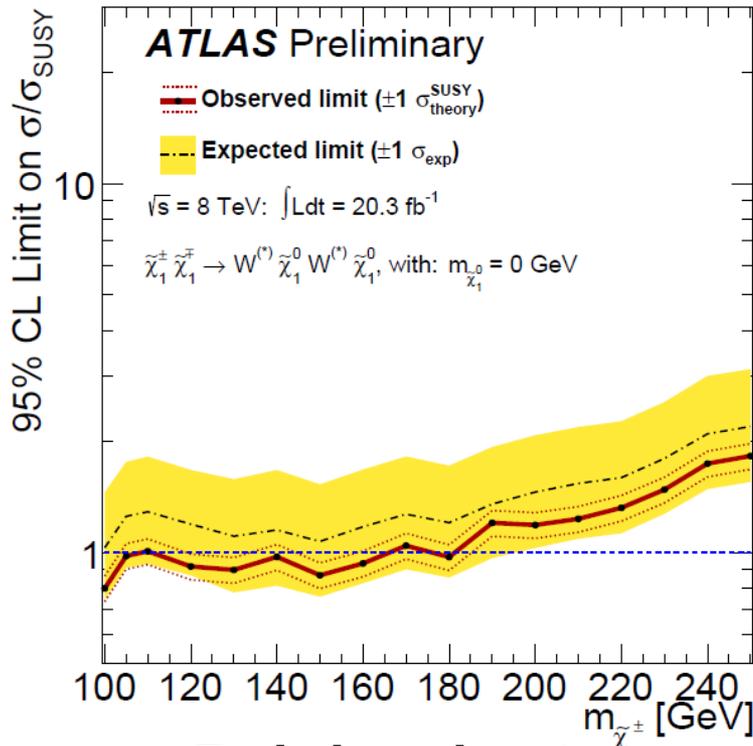
=> Low cross section , few picobarns or less. Requires high luminosity

=> Discrimination of WW background, Xsec = 60pb, S / B = 1 / 10

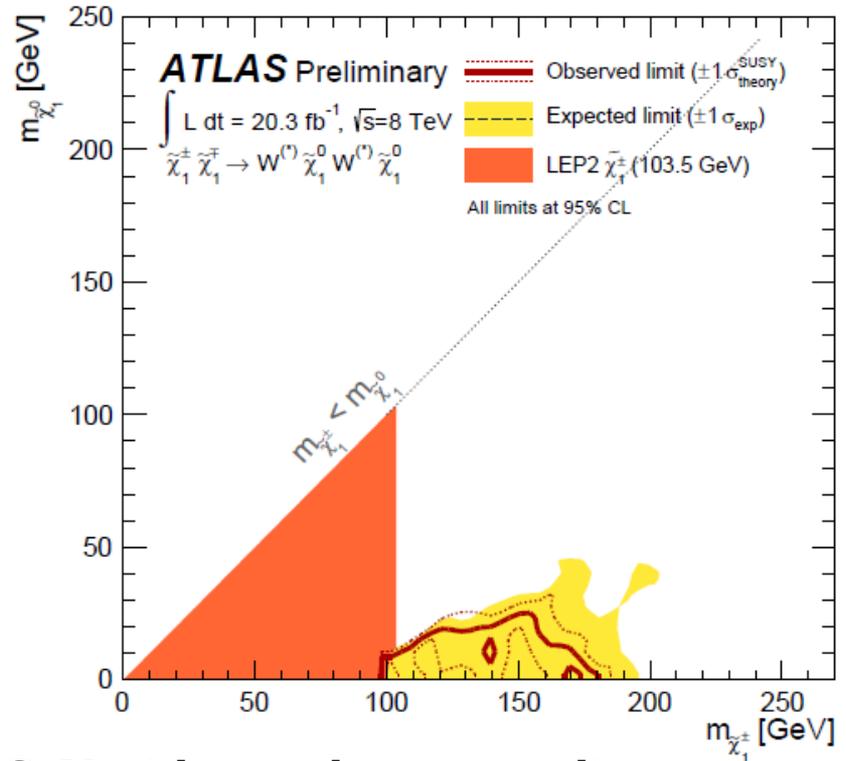
# Direct chargino pair production in 2 lepton + MET (2)

- Limits :

- Interpretation in simplified models : all others SUSY particle decoupled,  $\tilde{\chi}_1^{+/-} \rightarrow \tilde{\chi}_1^0 W$



→ Excluding chargino up to 180 GeV with massless neutralinos



→ **The only result at LHC for this scenario**

→ **CPM work now focused on prospect at 14 TeV :**

- 2 lepton analysis improvement and expected result

- Combination with new channels like 1 lepton + 2 jets channel

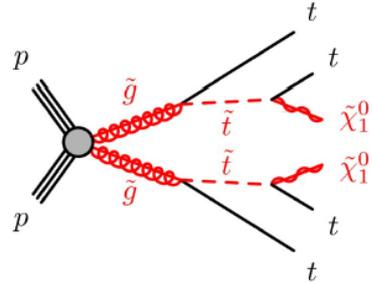
**Table 3.** Numbers of observed and predicted events in the CRs, data/MC normalization factors and composition of the CRs obtained from the fit. Systematic errors are described in section 8.

SR	$m_{T2}$ and $WWb/c$			$WWa$			Zjets
CR	$WW$	Top	$ZV$	$WW$	Top	$ZV$	Top
Observed events	1061	804	94	472	209	175	395
MC prediction	947	789	91	385	215	162	399
Normalization	1.14	1.02	1.08	1.12	0.97	1.04	0.99
Statistical error	0.05	0.04	0.12	0.08	0.08	0.12	0.06
Composition							
$WW$	84.6%	1.4%	5.0%	86.8%	1.7%	10.5%	1.3%
Top	10.4%	98.5%	<0.1%	7.3%	98.1%	2.8%	98.0%
$ZV$	2.0%	0.1%	94.9%	1.9%	<0.1%	82.9%	0.3%
Non-prompt lepton	1.9%	<0.1%	<0.1%	2.7%	<0.1%	<0.1%	<0.1%
Other	1.1%	<0.1%	0.1%	1.3%	<0.1%	3.7%	0.3%

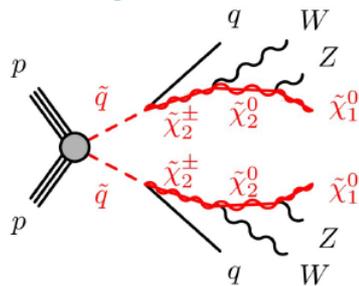
# SUSY search with same-sign leptons (I)

- Focus on signatures with 2SS/3 leptons and jets (+bjets) (+MET)
  - Low SM background, high sensitivity to new physics
- In particular SUSY, with strongly produced superpartners:

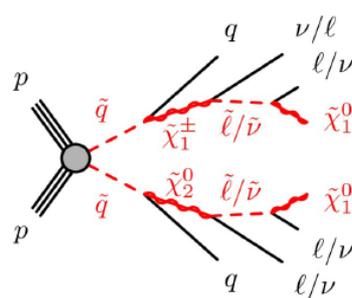
Natural SUSY, light 3<sup>rd</sup> gen. squarks  $\rightarrow$  tops



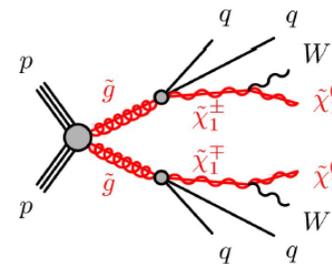
Gauginos cascades



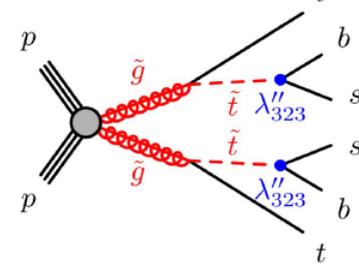
Light sleptons



Majorana gluinos



RPV



- **Current team** O. Ducu, J. Maurer, (A. Olariu for 14 TeV), CPPM & IFIN Bucharest

(other team members from Cambridge, Montréal, Chicago, Arlington, Freiburg)

- **Strongly involved since early 2012**, worked for the following public results:  
Paper in preparation with whole 2012 dataset, combining 2SS and 3lepton searches,

will be released to public in the coming days

Mar. 2013, 8 TeV, 20 fb<sup>-1</sup> <http://cds.cern.ch/record/1522430>

First ATLAS SUSY search presented with 20 fb<sup>-1</sup>

14-Feb-13 Aug. 2012, 8TeV, 5.8 fb<sup>-1</sup>

<http://cds.cern.ch/record/1472674>

# SUSY search with same-sign leptons (II)

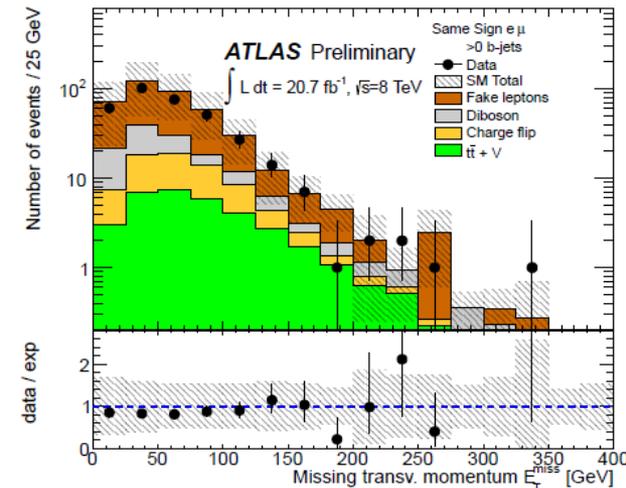
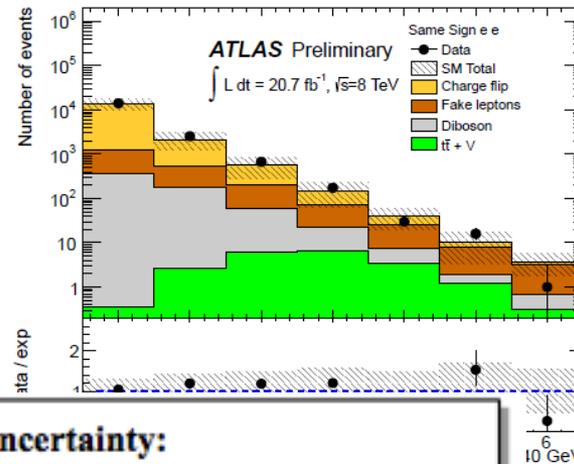
- Work in all sectors of the analysis:

## Signal regions definition

- few SRs, but sensitive to many models
- great discovery potential

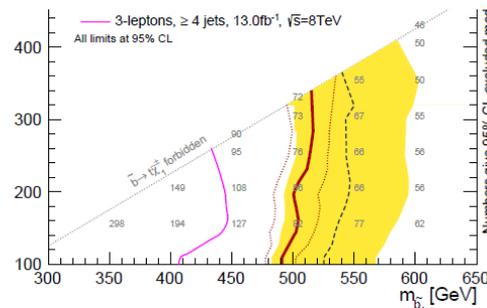
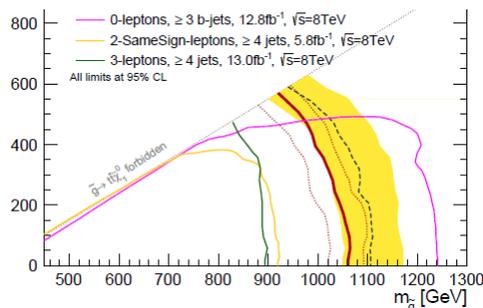
## Background estimates

- rare SM processes
- detector-like: lepton fakes and/or charge flip...
- data-driven methods used
- choice of validation regions



### Dominant source of systematic uncertainty:

- SR0b:** lepton fake rate, JES, b-tagging identification
- SR1b:** JES, lepton fake rate, ttV cross-section
- SR3b:** lepton fake rate, ttV cross-section



## Statistical interpretation

- CLs limits setting on various topological signal models
- upper bounds on visible cross-section for reinterpretation in other exotic scenarios

**Towards Run II** – improve object definition, bkg estimates, new signal/control regions – hope to provide quick results with 2015 data

Model	$e, \mu, \tau, \gamma$	Jets	$E_T^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference	
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$
	MSUGRA/CMSSM	1 $e, \mu$	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any $m(\tilde{q})$
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 740 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0 \rightarrow qqW^\pm\tilde{\chi}_1^0$	1 $e, \mu$	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}, m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell/\nu\nu/\nu\nu)\tilde{\chi}_1^0$	2 $e, \mu$	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	GMSB ( $\tilde{\ell}$ NLSP)	2 $e, \mu$	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	$\tan\beta < 15$
	GMSB ( $\tilde{\ell}$ NLSP)	1-2 $\tau$	0-2 jets	Yes	20.7	$\tilde{g}$ 1.4 TeV	$\tan\beta > 18$
	GGM (bino NLSP)	2 $\gamma$	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}_1^0)>50 \text{ GeV}$
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)>50 \text{ GeV}$
GGM (higgsino-bino NLSP)	$\gamma$	1 $b$	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)>220 \text{ GeV}$	
GGM (higgsino NLSP)	2 $e, \mu$ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	$m(\tilde{H})>200 \text{ GeV}$	
Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{g})>10^{-4} \text{ eV}$	
3 <sup>rd</sup> gen. $\tilde{g}$ med.	$\tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 $b$	Yes	20.1	$\tilde{g}$ 1.2 TeV	$m(\tilde{\chi}_1^0)<600 \text{ GeV}$
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)<350 \text{ GeV}$
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)<400 \text{ GeV}$
	$\tilde{g} \rightarrow b\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)<300 \text{ GeV}$
3 <sup>rd</sup> gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 $b$	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)<90 \text{ GeV}$
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow t\tilde{\chi}_1^\pm$	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.7	$\tilde{b}_1$ 275-430 GeV	$m(\tilde{\chi}_1^\pm)=2 m(\tilde{\chi}_1^0)$
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$	1-2 $e, \mu$	1-2 $b$	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	$m(\tilde{\chi}_1^0)=55 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	2 $e, \mu$	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-210 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W) - 50 \text{ GeV}, m(\tilde{t}_1) < m(\tilde{\chi}_1^\pm)$
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	2 $e, \mu$	2 jets	Yes	20.3	$\tilde{t}_1$ 215-530 GeV	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$	0	2 $b$	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}, m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)=5 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	1 $e, \mu$	1 $b$	Yes	20.7	$\tilde{t}_1$ 200-610 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^\pm$	0	2 $b$	Yes	20.5	$\tilde{t}_1$ 320-660 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-200 GeV	$m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < 85 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)>150 \text{ GeV}$
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}$
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	2 $e, \mu$	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow \tilde{\ell}\nu(\ell\bar{\nu})$	2 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow \tilde{\tau}\nu(\tau\bar{\nu})$	2 $\tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 180-330 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_L\nu\tilde{\ell}_L, \ell(\bar{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L, \ell(\bar{\nu}\nu)$	3 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0 Z$	2-3 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, \text{ sleptons decoupled}$
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0 h, \tilde{\chi}_1^\pm$	1 $e, \mu$	2 $b$	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, \text{ sleptons decoupled}$
Long-lived particles	Direct $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) = 160 \text{ MeV}, \tau(\tilde{\chi}_1^\pm) = 0.2 \text{ ns}$
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)=100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{g}) < 1000 \text{ s}$
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e, \mu)$	1-2 $\mu$	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	$10 < \tan\beta < 50$
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ , long-lived $\tilde{\chi}_1^0$	2 $\gamma$	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	$0.4 < \tau(\tilde{\chi}_1^0) < 2 \text{ ns}$
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0 \rightarrow q\tilde{q}$ (RPV)	1 $\mu, \text{ displ. vtx}$	-	-	20.3	$\tilde{q}$ 1.0 TeV	$1.5 < c\tau < 156 \text{ mm}, \text{BR}(\mu)=1, m(\tilde{\chi}_1^0)=108 \text{ GeV}$
RPV	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu$	2 $e, \mu$	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	$\lambda'_{311}=0.10, \lambda_{132}=0.05$
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	$\lambda'_{311}=0.10, \lambda_{1(2)33}=0.05$
	Bi-linear RPV CMSSM	1 $e, \mu$	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$ 1.2 TeV	$m(\tilde{q})=m(\tilde{g}), c\tau_{LS\mu} < 1 \text{ mm}$
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 $e, \mu$	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 760 GeV	$m(\tilde{\chi}_1^0)>300 \text{ GeV}, \lambda_{12120}, \lambda_{13320}$
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 350 GeV	$m(\tilde{\chi}_1^0)>80 \text{ GeV}, \lambda_{13320}$
	$\tilde{g} \rightarrow q\tilde{q}$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	$\text{BR}(t)=\text{BR}(b)=\text{BR}(c)=0\%$
$\tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow bs$	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.7	$\tilde{g}$ 880 GeV		
Other	Scalar gluon pair, sgluon $\rightarrow q\tilde{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693
	Scalar gluon pair, sgluon $\rightarrow t\tilde{t}$	2 $e, \mu$ (SS)	2 $b$	Yes	14.3	sgluon 350-800 GeV	
	WIMP interaction (D5, Dirac $\chi$ )	0	mono-jet	Yes	10.5	$M^*$ scale 704 GeV	$m(\chi) < 80 \text{ GeV}, \text{limit of } < 687 \text{ GeV for D8}$

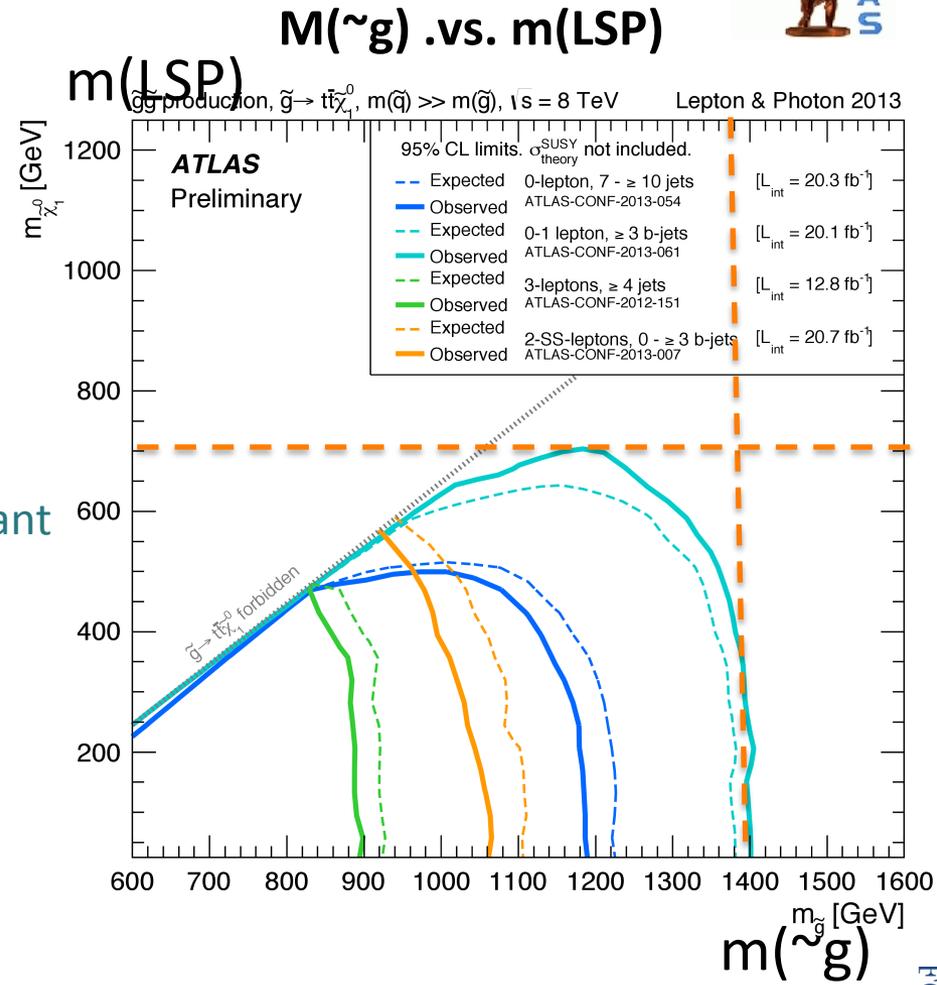
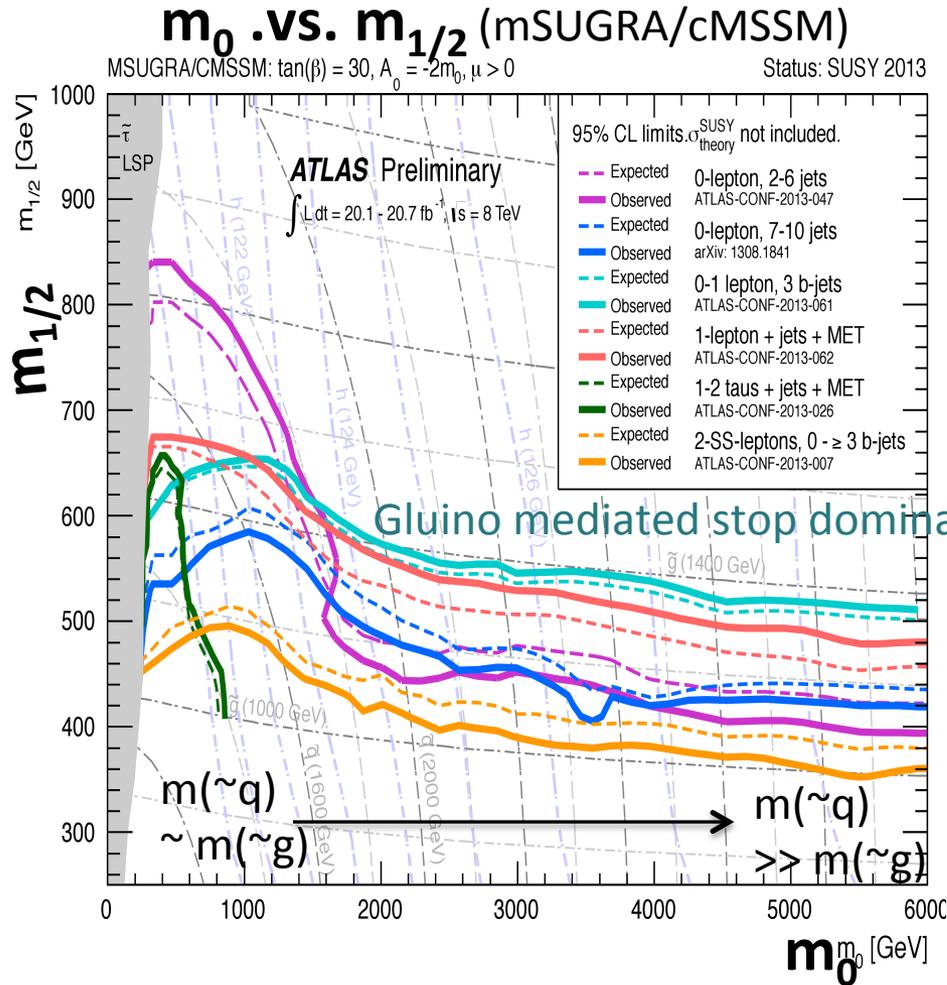
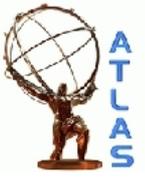
14-4  $\sqrt{s} = 7 \text{ TeV}$  full data

$\sqrt{s} = 8 \text{ TeV}$  partial data

$\sqrt{s} = 8 \text{ TeV}$  full data

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus  $1\sigma$  theoretical signal cross section uncertainty.

# Inclusive search for squark and gluino production



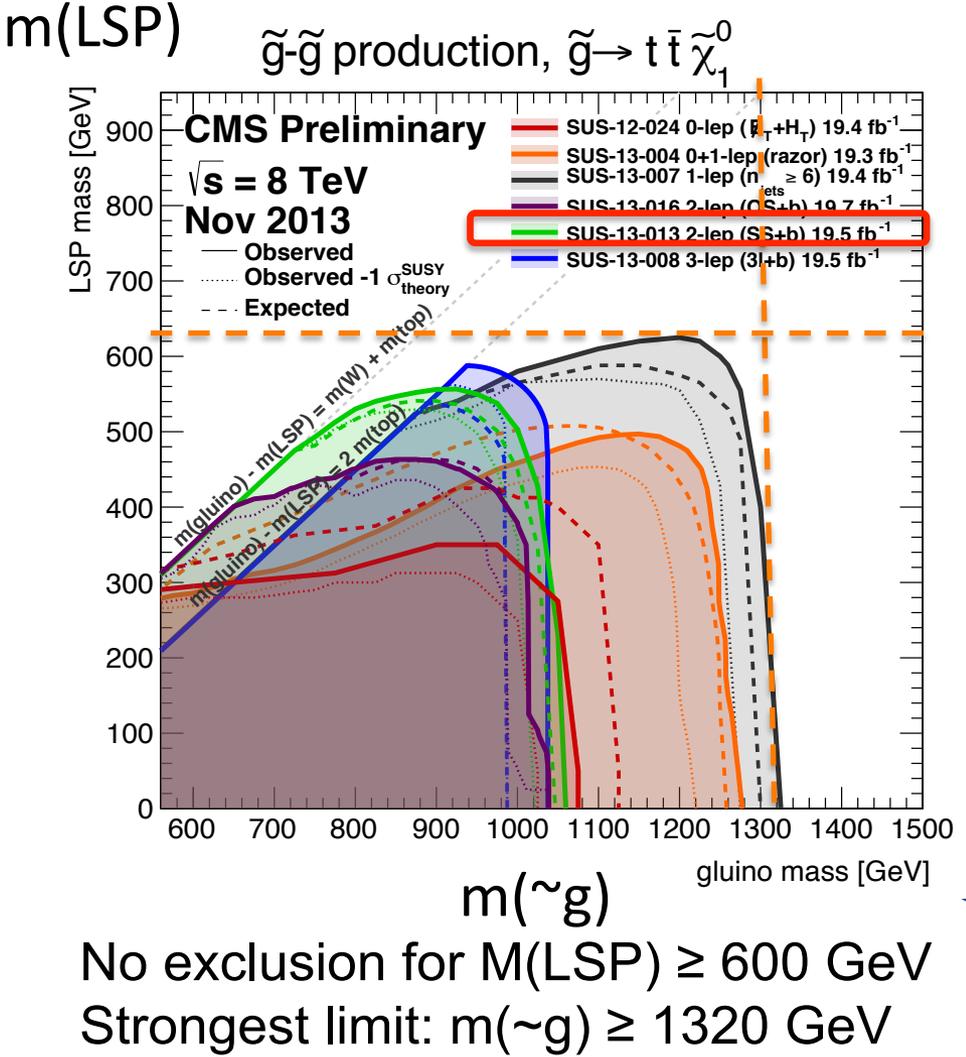
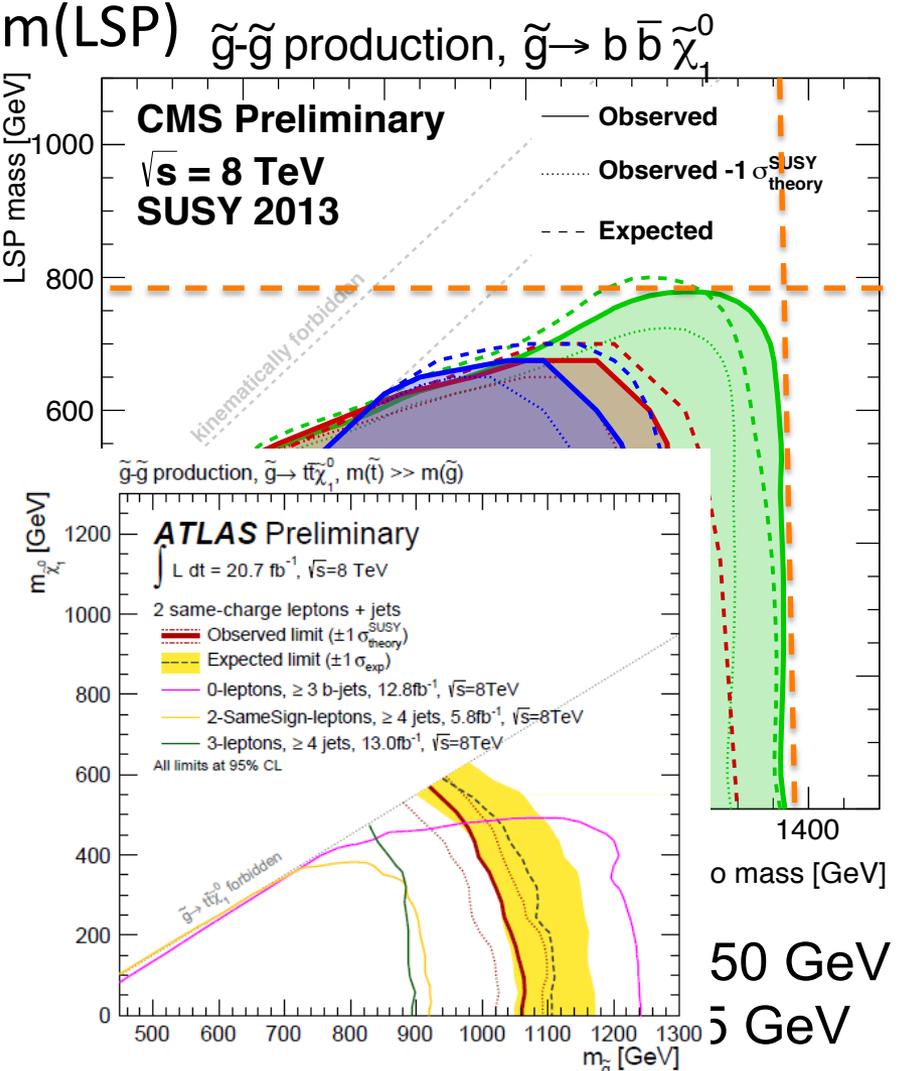
- $m(\tilde{q}) \sim m(\tilde{g})$ :  $m(\tilde{g}) > 1.7 \text{ TeV}$
- $M(\tilde{q}) \gg m(\tilde{g})$ :  $m(\tilde{g}) > 1.35 \text{ TeV}$
- Conditional/indirect limit on LSP:  $m > 200-300 \text{ GeV}$

No exclusion for  $M(\text{LSP}) \geq 700 \text{ GeV}$   
 Strongest limit:  $m(\tilde{g}) \geq 1400 \text{ GeV}$

# Summary of gluino-mediated stop/sbottom production

**4b + MET** final state:  
Hadronic searches most sensitive

**4t + MET** final state:  
Single lepton searches most sensitive

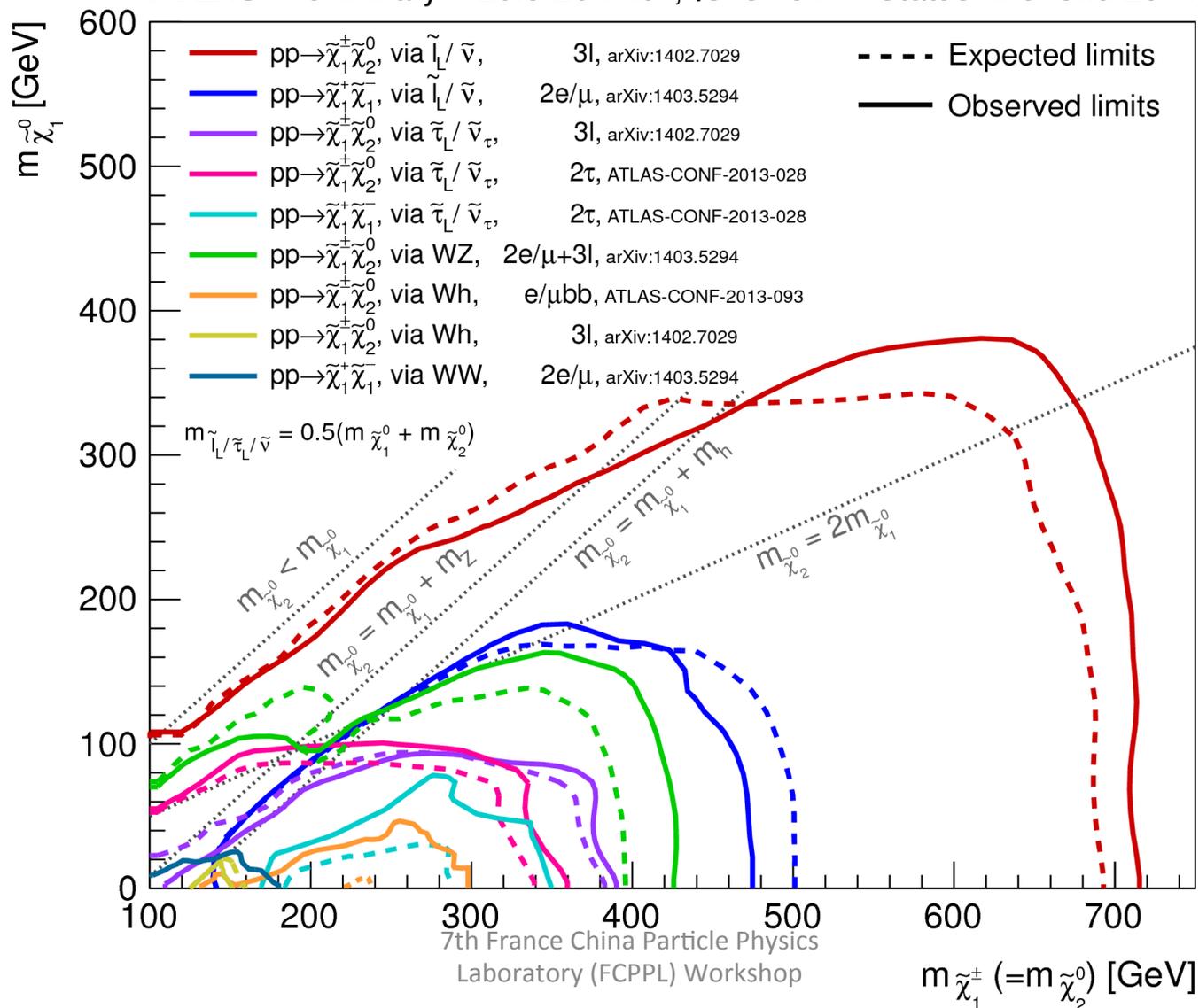


# ElectroWeak Production Summary



– Final state: **2-4l + MET (l=e/μ/τ)**

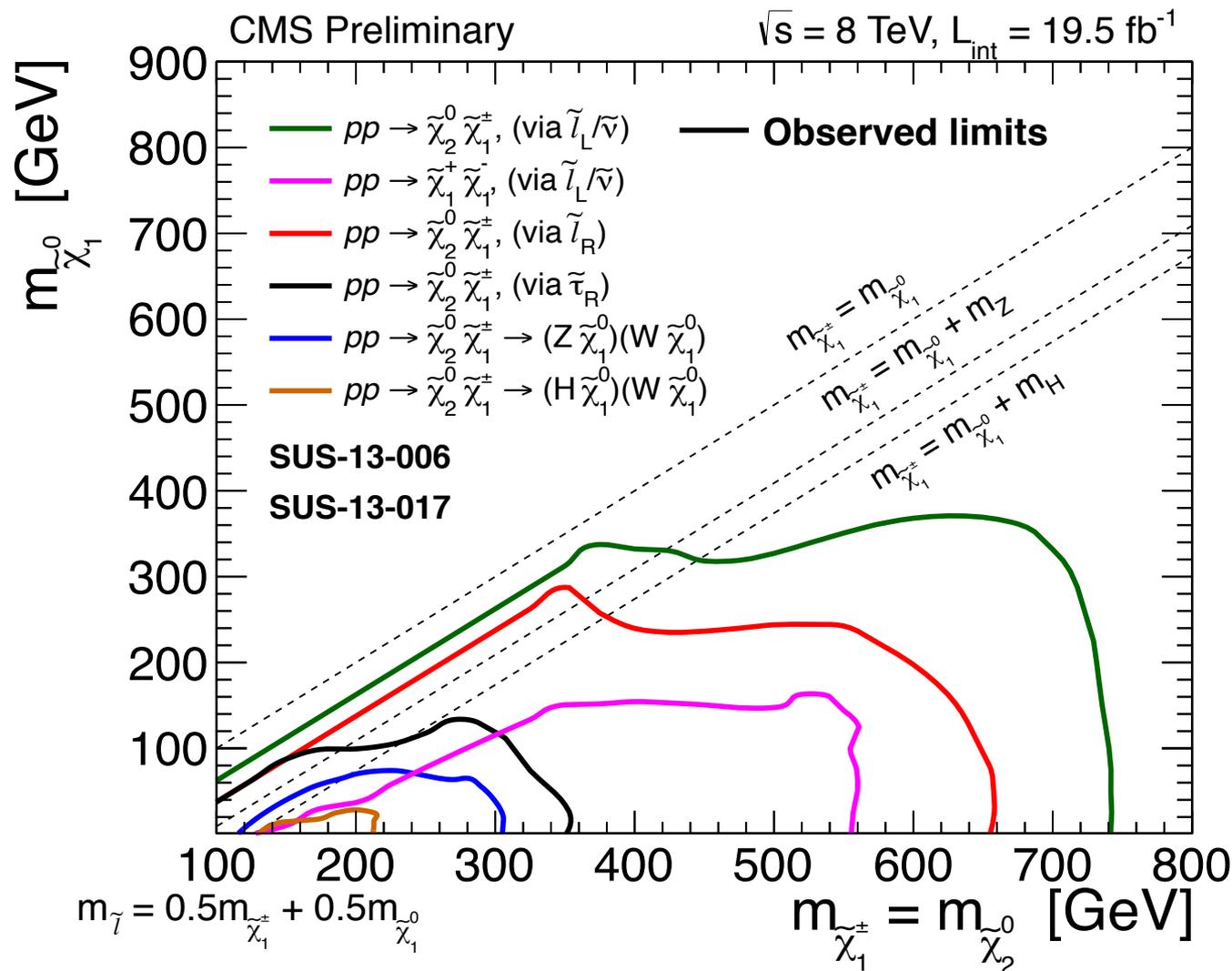
**ATLAS Preliminary** 20.3-20.7 fb<sup>-1</sup>, √s=8 TeV Status: Moriond 2014



# ElectroWeak Production Summary



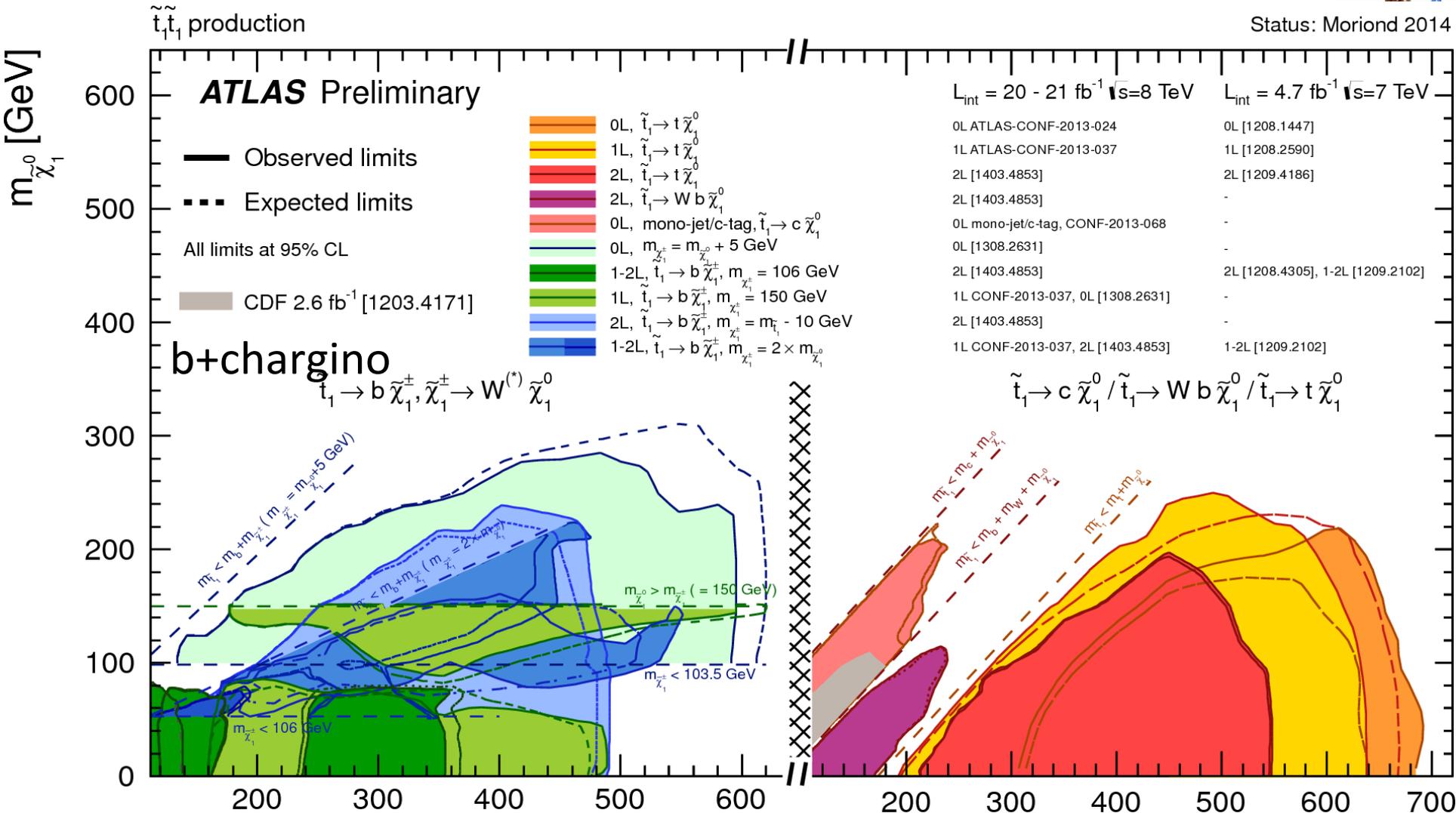
- Probe gauginos up to 300-740 GeV
- light slepton is more sensitive



# Direct stop pair production (summary)



Status: Moriond 2014



These plots overlay contours belonging to different stop decay channels, different particle mass hierarchies, and simplified decay scenarios

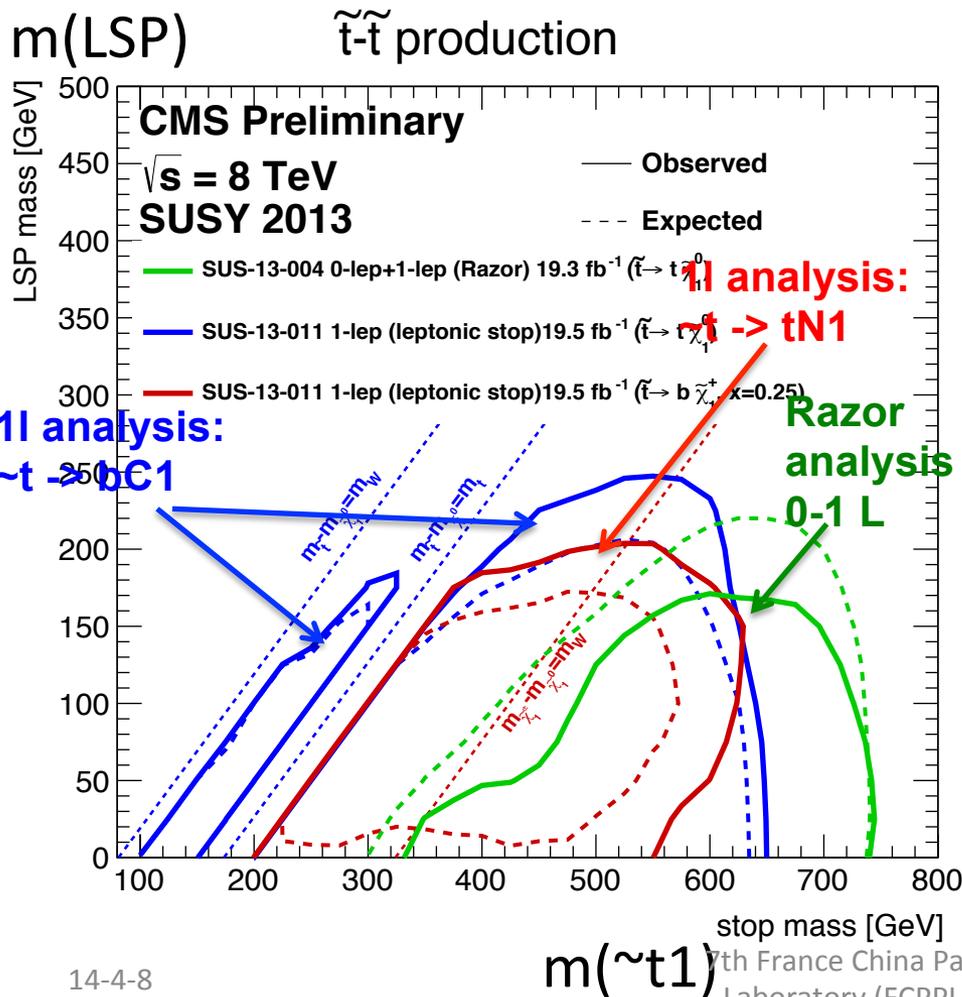
$m_{\tilde{t}_1}$  [GeV]

# Direct stop pair production

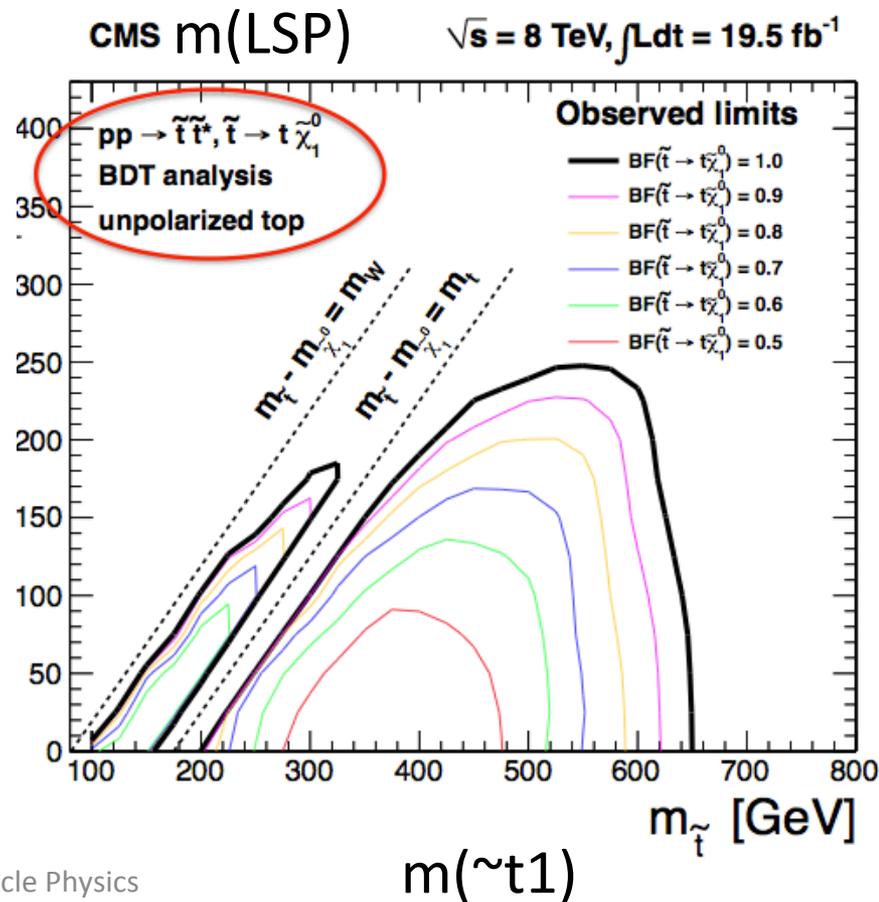
-  $t\bar{t}$  + MET (CMS-SUS-13-011; CMS-SUS-13-004)



100% BF for each decay channel

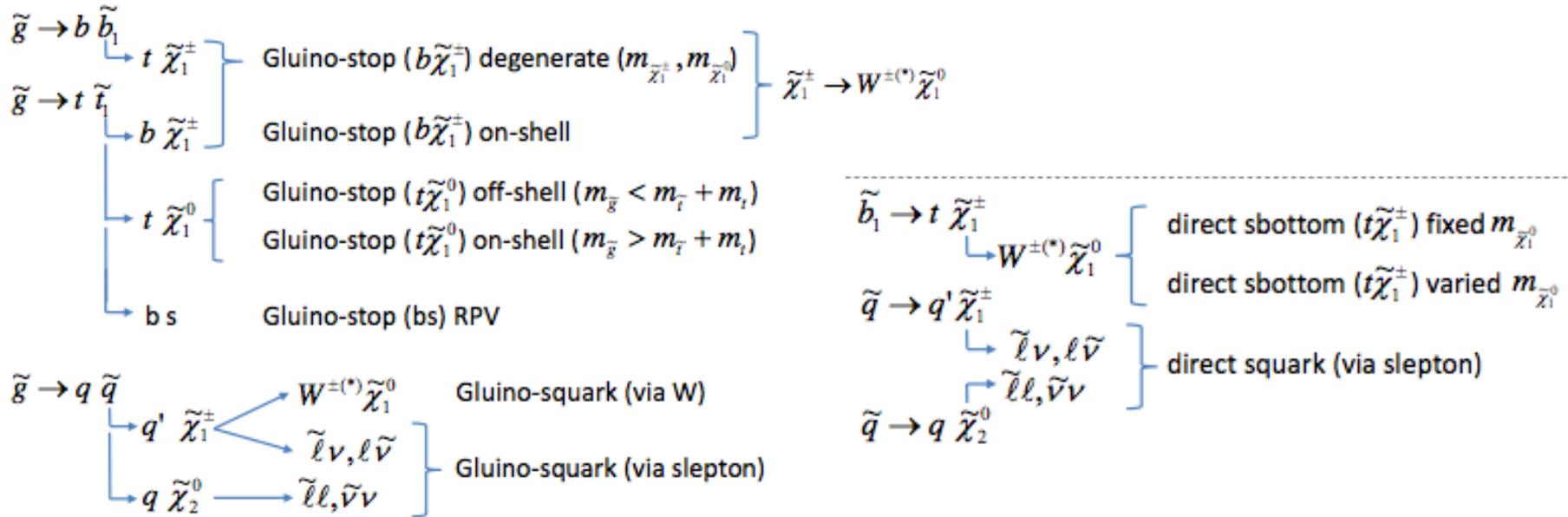


## Dependence on BF



# SUSY Models and SR : SS 2I

ATLAS-CONF-2013-007



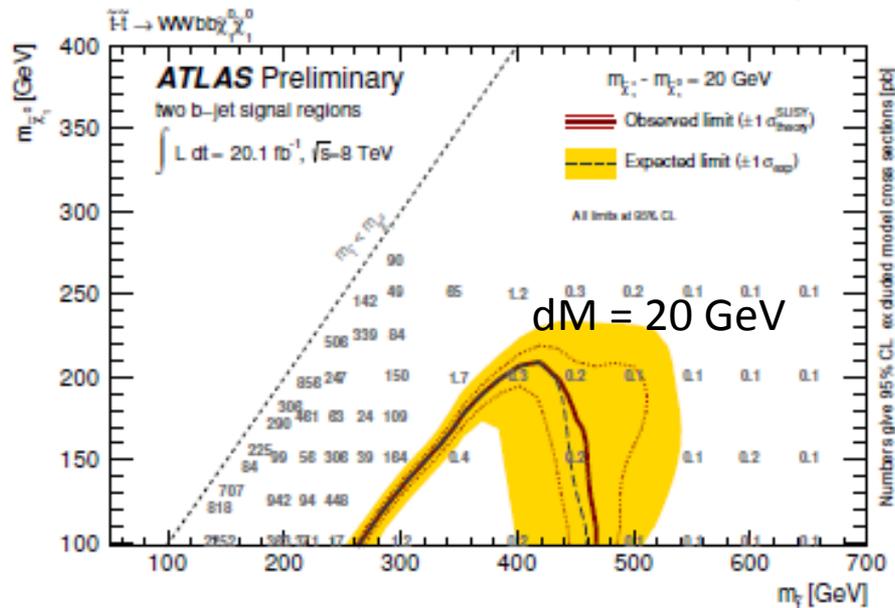
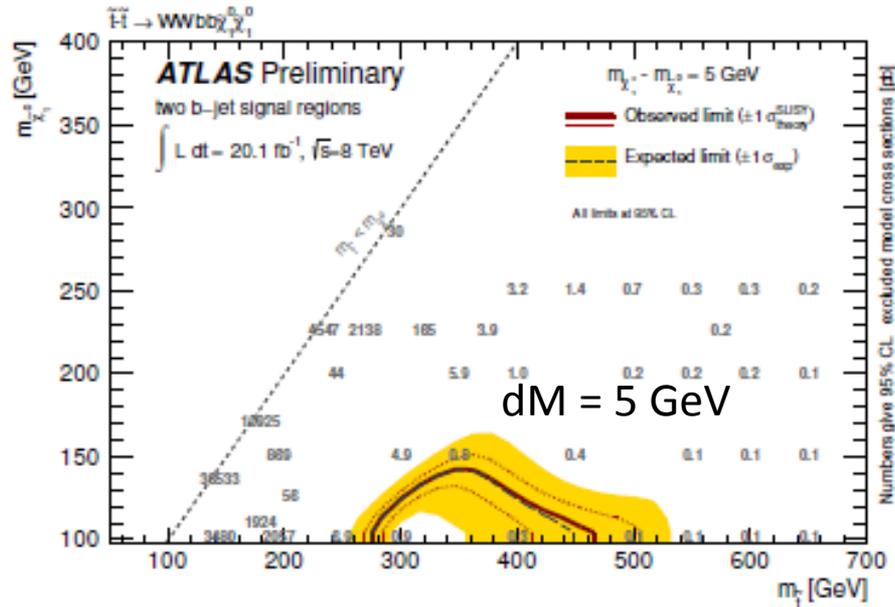
## Signal regions definition

- few SRs, but sensitive to many models
- great discovery potential

Signal region	$N_{b\text{-jets}}$	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}$ $m_{\text{T}} > 100 \text{ GeV}, m_{\text{eff}} > 400 \text{ GeV}$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}, m_{\text{T}} > 100 \text{ GeV},$ binned shape fit in $m_{\text{eff}}$ for $m_{\text{eff}} > 300 \text{ GeV}$
SR1b	$\geq 1$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}$ $m_{\text{T}} > 100 \text{ GeV}, m_{\text{eff}} > 700 \text{ GeV}$	$N_{\text{jets}} \geq 3, E_{\text{T}}^{\text{miss}} > 150 \text{ GeV}, m_{\text{T}} > 100 \text{ GeV},$ binned shape fit in $m_{\text{eff}}$ for $m_{\text{eff}} > 300 \text{ GeV}$
SR3b	$\geq 3$	$N_{\text{jets}} \geq 4$ -	$N_{\text{jets}} \geq 5,$ $E_{\text{T}}^{\text{miss}} < 150 \text{ GeV}$ or $m_{\text{T}} < 100 \text{ GeV}$

# Exclusion Limit for soft + b-jet(s): simplified model with stop production

ATLAS-CONF-2013-062



- Two b-jets region
  - $M_{\text{stop}} - m_{N1}$  mass plane (assuming most degenerate C1 and N1:  $dM = 5, 20 \text{ GeV}$ )
  - Limits extend up to stop mass  $\sim 420(450) \text{ GeV}$  in  $dM = 5(20) \text{ GeV}$ .

# Signal Grids



## ■ Simplified Model

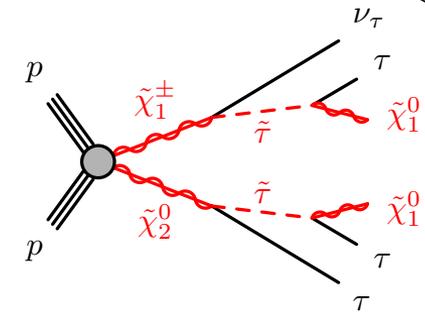
- modeA: **C1N2 (a)** ; modeC: **C1C1 (b)**
- C1,N2 decay with **100% branching fraction** to final states with (s)taus.
- All sparticles other than C1,N2,N1, stau and sneutrino are assumed to be heavy.
- Wino like C1,N2; bino like N1
- C1,N2: mass-degenerate. C1/N2: 0-400GeV; N1:0-250GeV.
- Stau,tau sneutrino: mass-degenerate.  $0.5 * [ (m_{\tilde{\chi}_1^\pm}, m_{N2}) + m_{N1} ]$

## ■ pMSSM

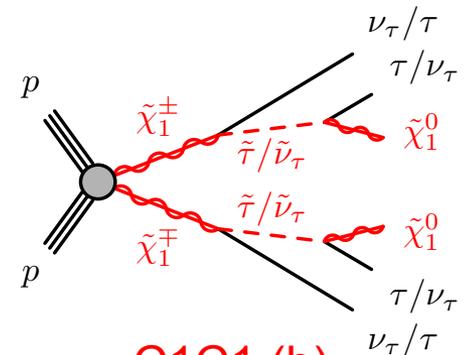
- $M_{\text{stau}} = 95 \text{ GeV}$ , Heavy squarks and gluinos
- $\tan \beta = 50$ ;  $M_1 = 50 \text{ GeV}$ ,  $M_2$  and  $\mu$ : 100-500 GeV
- In the case that stau/tau sneutrino are lighter than charginos/neutralinos (C1N2, C1C1 dominant)
- In the case that charginos/neutralinos are too heavy to produced at LHC (direct stau dominant)

## ■ Direct stau

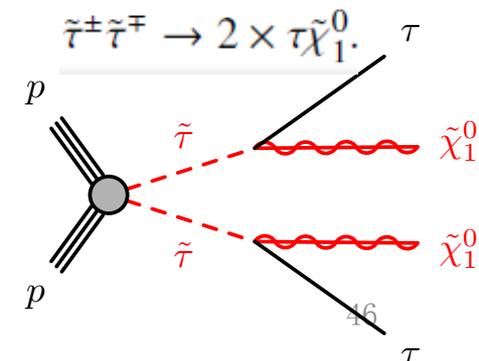
- A few signal points available in 2013
- already included in signature paper for this very challenging process



**C1N2 (a)**



**C1C1 (b)**



# BG components



SM process	SR OS $m_{T2}$	SR OS $m_{T2}$ -nobjet
top	$0.20 \pm 0.47 \pm 0.13$	$1.59 \pm 0.78 \pm 1.20$
Z+jets	$0.28 \pm 0.26 \pm 0.23$	$0.37 \pm 0.31 \pm 0.26$
diboson	$2.16 \pm 0.48 \pm 0.52$	$2.45 \pm 0.48 \pm 0.94$
QCD & W+jets	$8.38 \pm 2.64 \pm 1.36$	$12.23 \pm 3.34 \pm 3.02$
SM total	$11.0 \pm 2.7 \pm 1.5$	$16.6 \pm 3.5 \pm 3.4$

~75-80%

## Two Main Backgrounds

- **Fake tau: reducible BGs (dominant, ~75-80%, data-driven)**
  - QCD di-jets (2 fake taus); W+jets (1 fake tau, 1 real tau)
  - Estimated together with Data-driven approach (ABCD method)
- **Real tau: irreducible BGs**
  - Top, Z+jets, diBosons: (2 real taus)
  - Directly estimated from MC
  - The tau identification and trigger efficiency in MC is corrected with **different sets of scale factors** for real tau and fake taus from TauCP group

# Fake tau BG estimation: ABCD method



## Variables

- X-axis: TauID
- Y-axis: Mt2

## Signal Region

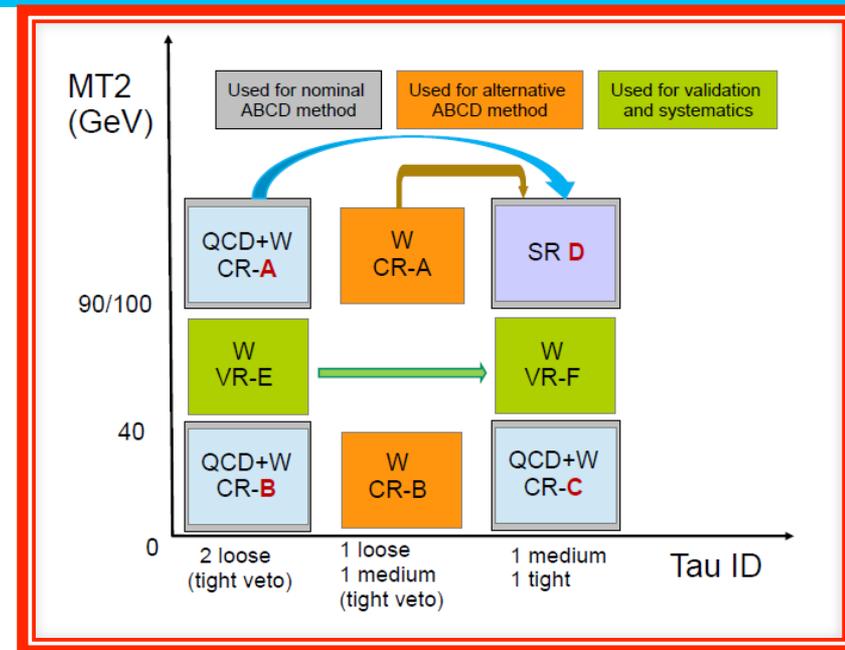
- SR **D**

## Baseline Control Regions

- QCD+W CR-**A/B/C**
- TF obtained from QCD event (low mT2 region from Data):  
**TF=C/B**
- Extrapolation performed from **A to D through TF**

## Alternative ABCD method (WCR-AB) has been checked.

## Validation Region (W VR-EF)



Regions	QCD+W Control Region			Signal Region
	A	B	C	D
OS $m_{T2}$	$m_{T2} > 90$ GeV $E_T > 40$ GeV at least 2 loose taus tight tau veto	$m_{T2} < 40$ GeV $E_T > 40$ GeV at least 2 loose taus tight tau veto	$m_{T2} < 40$ GeV $E_T > 40$ GeV at least 1 medium tau at least 1 tight tau	$m_{T2} > 90$ GeV $E_T > 40$ GeV at least 1 medium tau at least 1 tight tau
OS $m_{T2}$ -nobjet	$m_{T2} > 100$ GeV $E_T > 40$ GeV at least 2 loose taus tight tau veto	$m_{T2} < 40$ GeV $E_T > 40$ GeV at least 2 loose taus tight tau veto	$m_{T2} < 40$ GeV $E_T > 40$ GeV at least 1 medium tau at least 1 tight tau	$m_{T2} > 100$ GeV $E_T > 40$ GeV at least 1 medium tau at least 1 tight tau

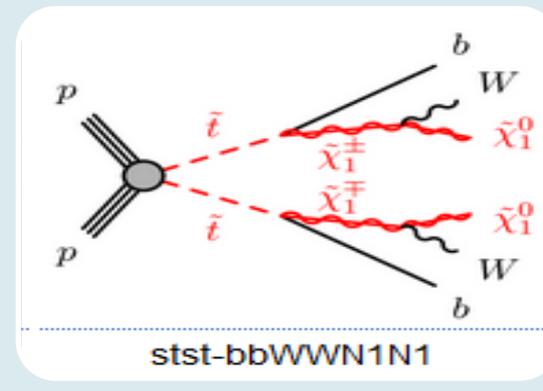
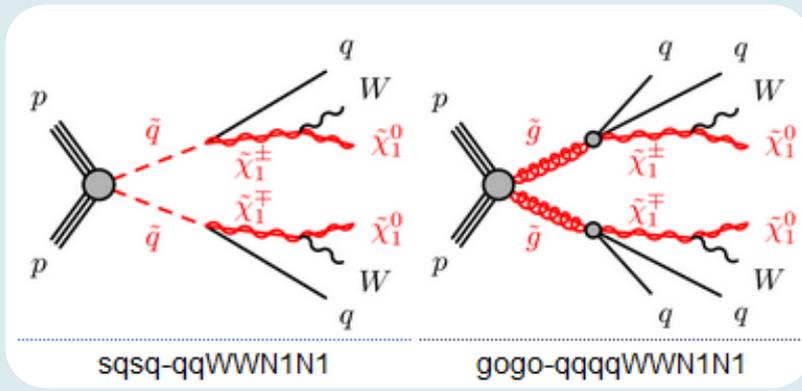
# EWK 2L (emu): systematics

**Table 4.** Systematic uncertainties (in %) on the total background estimated in different signal regions. Because of correlations between the systematic uncertainties and the fitted backgrounds, the total uncertainty can be different from the quadratic sum of the individual uncertainties.

	$m_{T2}^{90}$		$m_{T2}^{120}$		$m_{T2}^{150}$		WW <sub>a</sub>		WW <sub>b</sub>		WW <sub>c</sub>		Zjets
	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
CR statistics	5	3	6	4	8	4	5	5	5	3	6	4	1
MC statistics	5	7	7	12	10	23	3	4	5	8	6	10	14
Jet	4	1	2	1	5	7	3	6	4	2	4	3	11
Lepton	1	2	1	1	4	1	1	3	2	3	1	8	4
Soft-term	3	4	1	1	2	8	<1	2	3	5	1	6	5
b-tagging	1	2	<1	<1	<1	<1	1	1	1	2	<1	1	2
Non-prompt lepton	<1	1	<1	<1	1	<1	1	1	1	2	<1	1	<1
Luminosity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2
Modelling	11	13	21	31	18	40	6	6	8	10	15	19	42
Total	13	16	24	34	23	47	9	11	12	14	17	24	47

# Signal Grids

■ **Simplified models: Consider only a specific decay chain of supersymmetric particles, assume all sparticles not explicitly appearing in the decay chain to decouple/heavy**



## One step simplified models

The pair-produced strongly interacting sparticles decay via the lighter chargino (pure wino) into W and the lightest neutralino (pure bino).

### Free parameters:

1) **gl/sq, LSP**:  $m_{C1}$  is set as  $(m_{g/sq} + m_{LSP})/2$

2) **gl/sq, chargino**:  $m_{LSP} = 60 \text{ GeV}$

→ for incl. channels

14-4-8

## Simplified models involving top squark production

‘natural’ SUSY: at least one stop and higgsinos are light.

The lightest neutralino are higgsino-like.

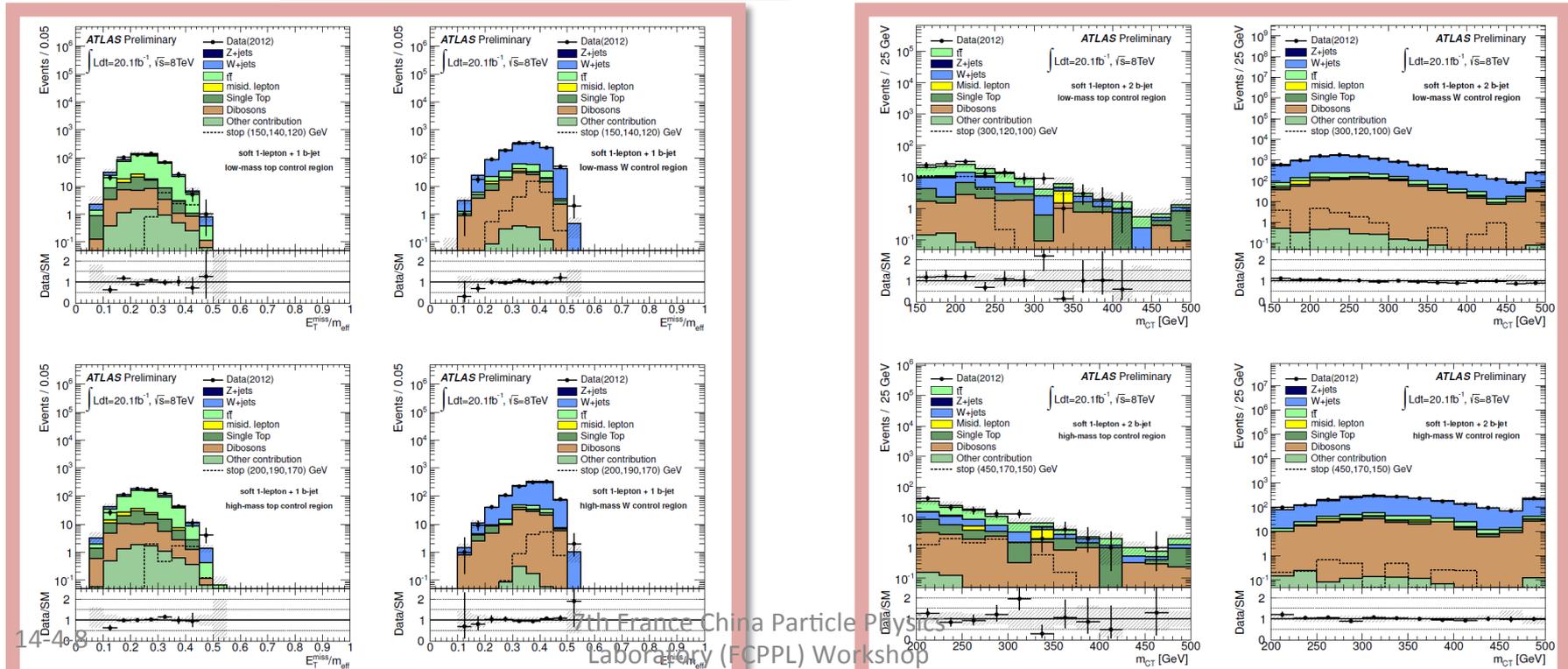
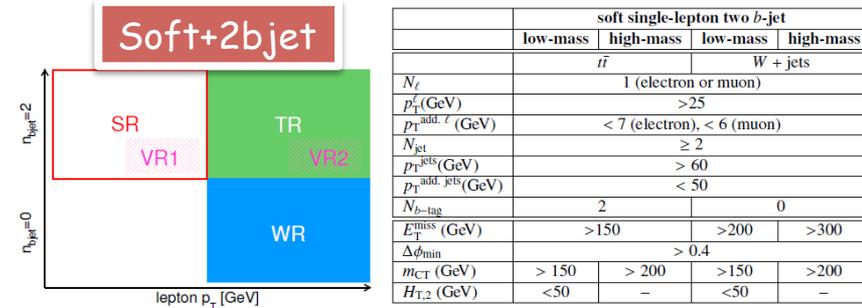
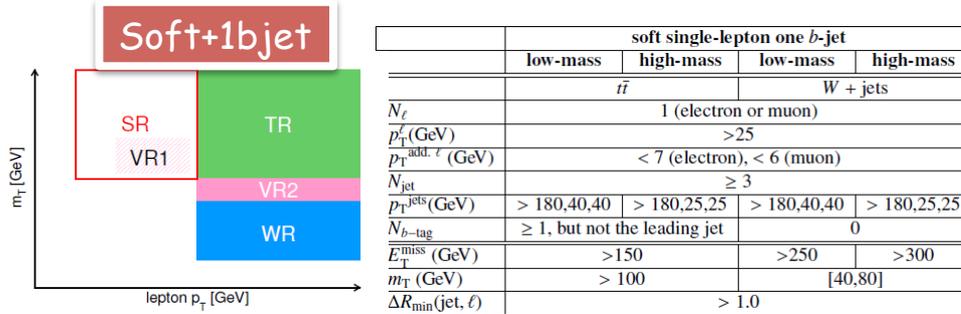
### Free parameters: Top squark and LSP

Two grids:  $M_{c1} - m_{LSP} = 5/20 \text{ GeV}$

→ For channels with soft lepton and b-jet(s)

# W/T-Control regions: - soft lepton+ bjet(s)

- CRs are built in high leptonPt region. - TCR: loosen E<sub>miss</sub>, require b-jet - WCR: veto b-jet, loosen m<sub>T</sub>



Focus on strong production: look at squark / gluino decays with two same-sign leptons in the final state.

## Motivation:

- gluinos are Majorana fermions : allows for same-sign lepton pair production.
- $\geq 3$  leptons can occur during cascade decays.
- Standard Model background is very low.

## Event selection:

- $E_T^{\text{miss}}$  only triggers if  $E_T^{\text{miss}} > 150$  GeV, single lepton triggers if leading lepton  $p_T > 40$  GeV (muons) or  $p_T > 70$  GeV (electrons) and dilepton triggers otherwise.
- Jets with  $p_T > 25$  GeV and  $|\eta| < 2.8$  ; if b-tagging is required the threshold  $p_T$  is lowered to 20 GeV.
- Signal leptons: isolated electrons with  $p_T > 20$  GeV and  $|\eta| < 2.47$ ;  
isolated muons with  $p_T > 20$  GeV and  $|\eta| < 2.4$ .

# Standard Model background

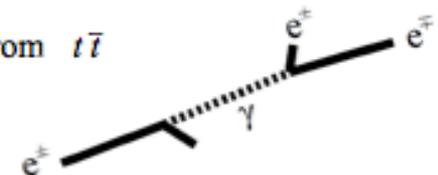
Three event categories can be considered, depending on number of b-jets identified in the final state: 0,  $\geq 1$ ,  $\geq 3$  b-jets.

## Irreducible:

- signal region with a b-jet veto: diboson production (WZ / ZZ plus jets).
- signal regions with at least one b-jets :  $t\bar{t}$  production with a vector boson, W or Z, decaying leptonically.
- these backgrounds are estimated from Monte-Carlo simulations.

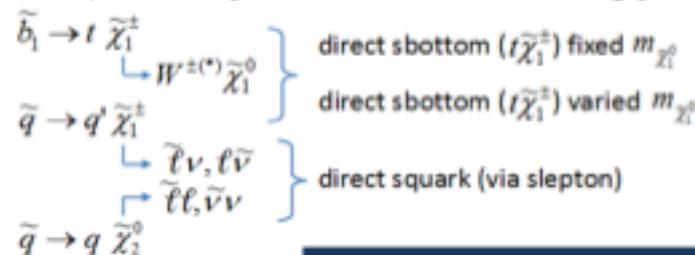
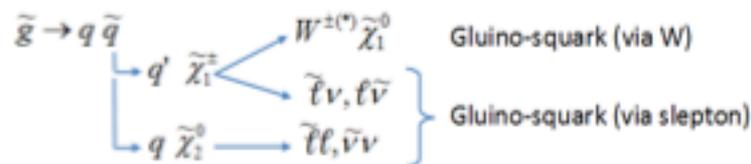
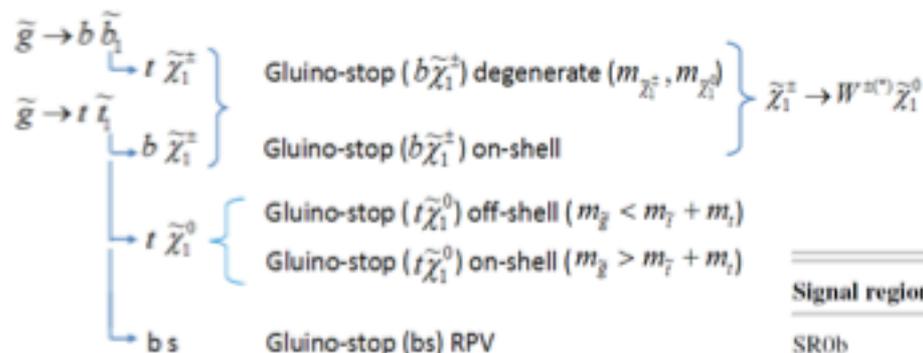
## Reducible: can be divided in charge mis-measurement, fake leptons.

- with the requirements imposed in the signal regions the only significant contribution is from  $t\bar{t}$
- **charge mis-measurement** → the probability of one electron to have a wrong charge.
- **fake leptons** stem from the weak b-hadron decay.
- these background are estimated using fully data – driven methods.



# SUSY models

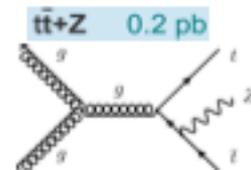
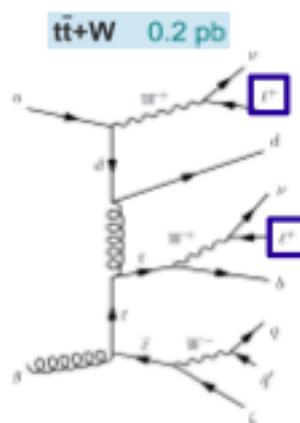
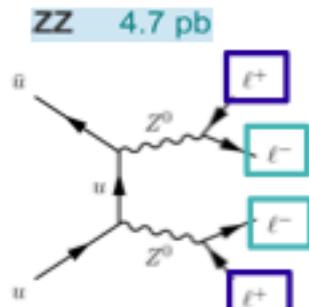
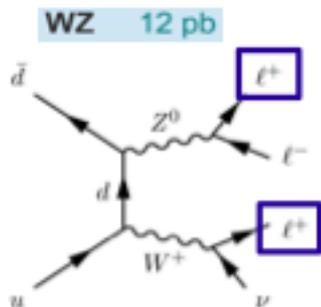
The results are interpreted in minimal supergravity (mSUGRA/CMSSM) and simplified models with strong pair production of SUSY particles.



## Signal regions definition

Signal region	$N_{b\text{-jets}}$	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3, E_T^{miss} > 150 \text{ GeV}$ $m_T > 100 \text{ GeV}, m_{eff} > 400 \text{ GeV}$	$N_{jets} \geq 3, E_T^{miss} > 150 \text{ GeV}, m_T > 100 \text{ GeV},$ binned shape fit in $m_{eff}$
SR1b	$\geq 1$	$N_{jets} \geq 3, E_T^{miss} > 150 \text{ GeV}$ $m_T > 100 \text{ GeV}, m_{eff} > 700 \text{ GeV}$	$N_{jets} \geq 3, E_T^{miss} > 150 \text{ GeV}, m_T > 100 \text{ GeV},$ binned shape fit in $m_{eff}$
SR3b	$\geq 3$	$N_{jets} \geq 4$	$N_{jets} \geq 5,$ ( $E_T^{miss} < 150 \text{ GeV}$ or $m_T < 100 \text{ GeV}$ )

## Same-sign signature in Standard Model

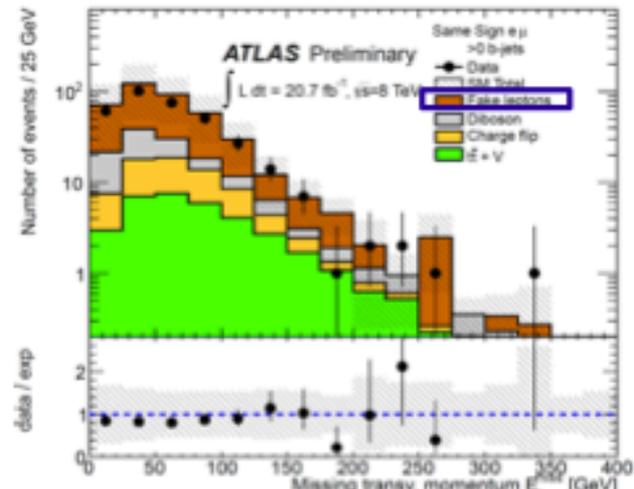
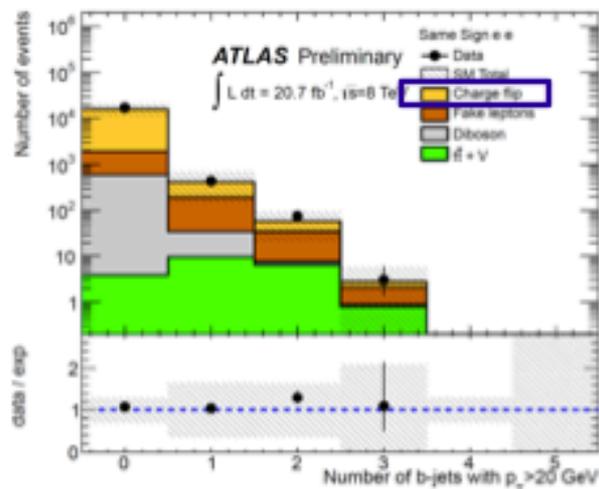
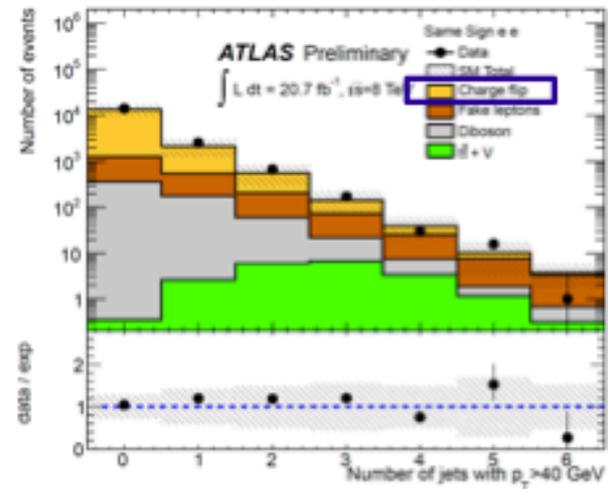


Not sizable contribution

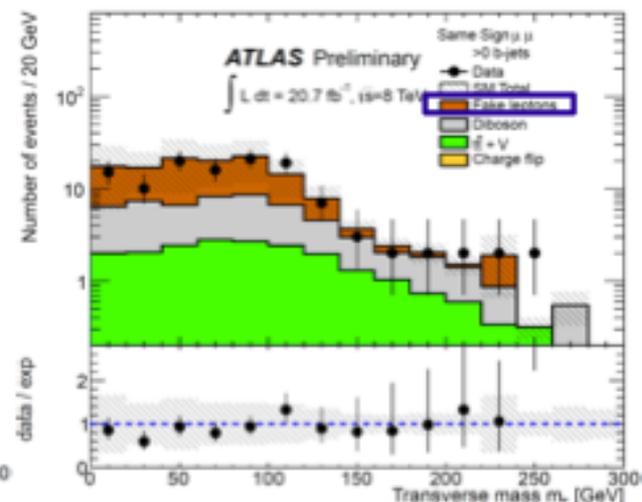
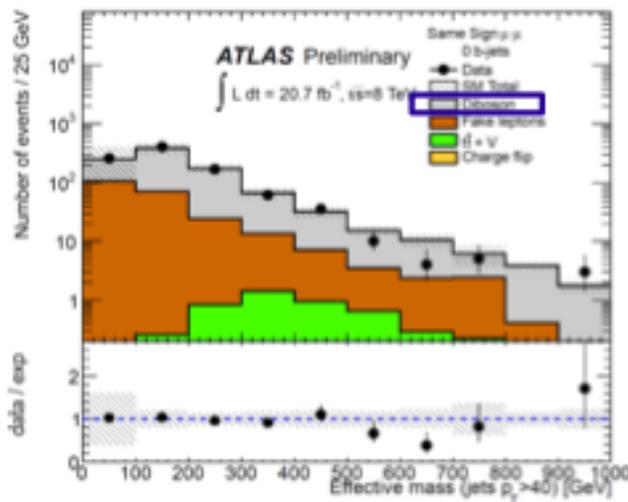
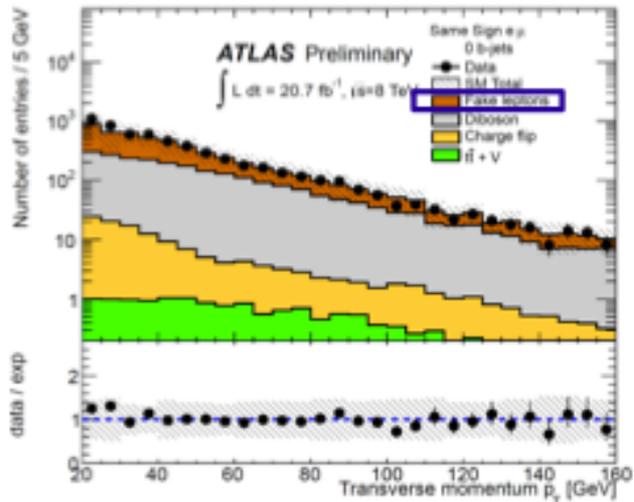
$$\frac{W^+W^+}{0.04 \text{ pb}} \quad \frac{W^+W^+W^+, W^+ZW^+, ZZZ^*}{0.4 \text{ pb}}$$

$$\frac{t\bar{t}+WW}{0.001 \text{ pb}} \quad \frac{t\bar{t}+H}{25\% \times 0.13 \text{ pb}} \quad \frac{WH, ZH}{25\% \times 1.1 \text{ pb}}$$

# Data and expected background comparison

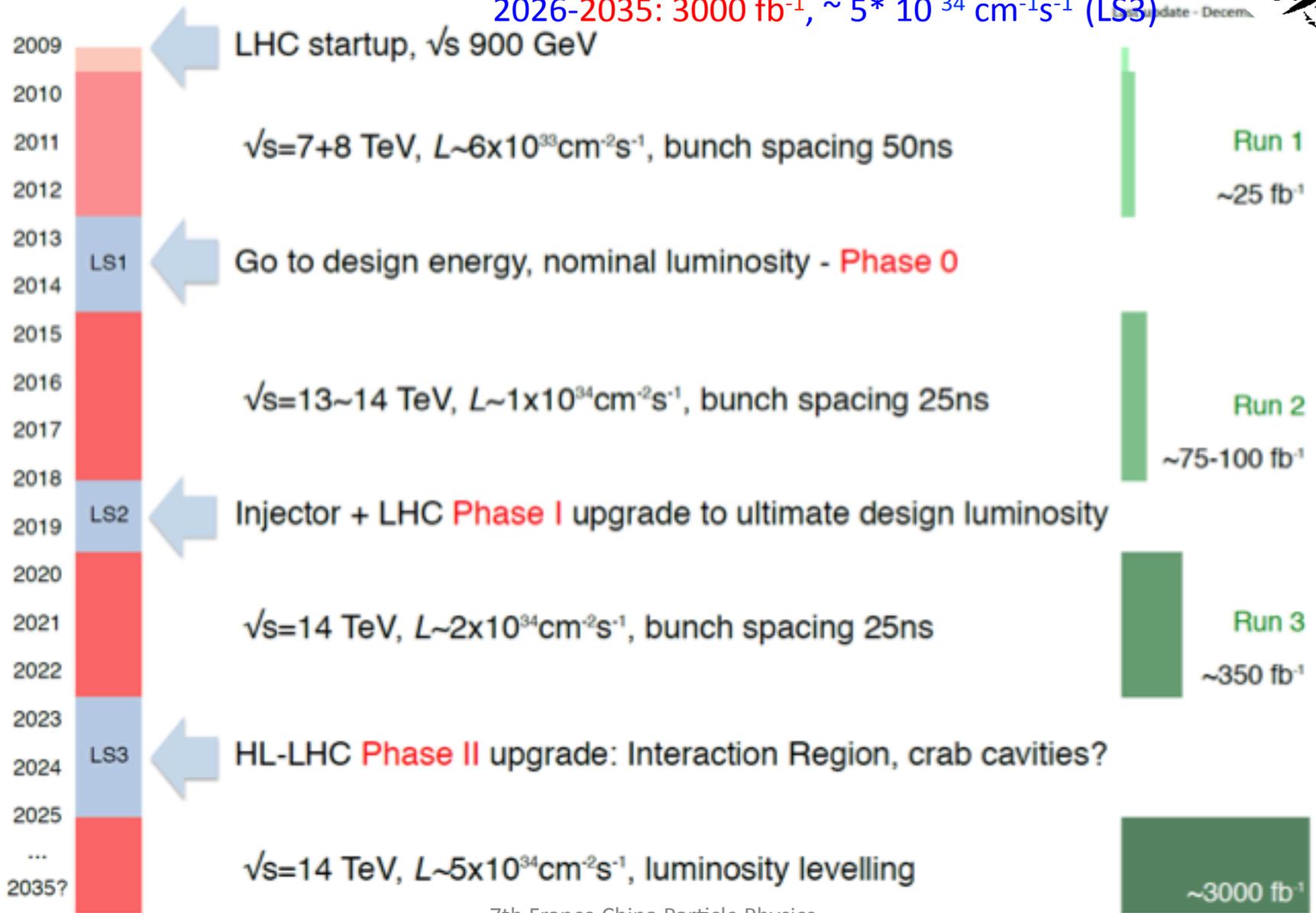


Background estimates are checked in  $e-e$ ,  $e-\mu$  and  $\mu-\mu$  channels, for several discriminating variables: good agreement, within est



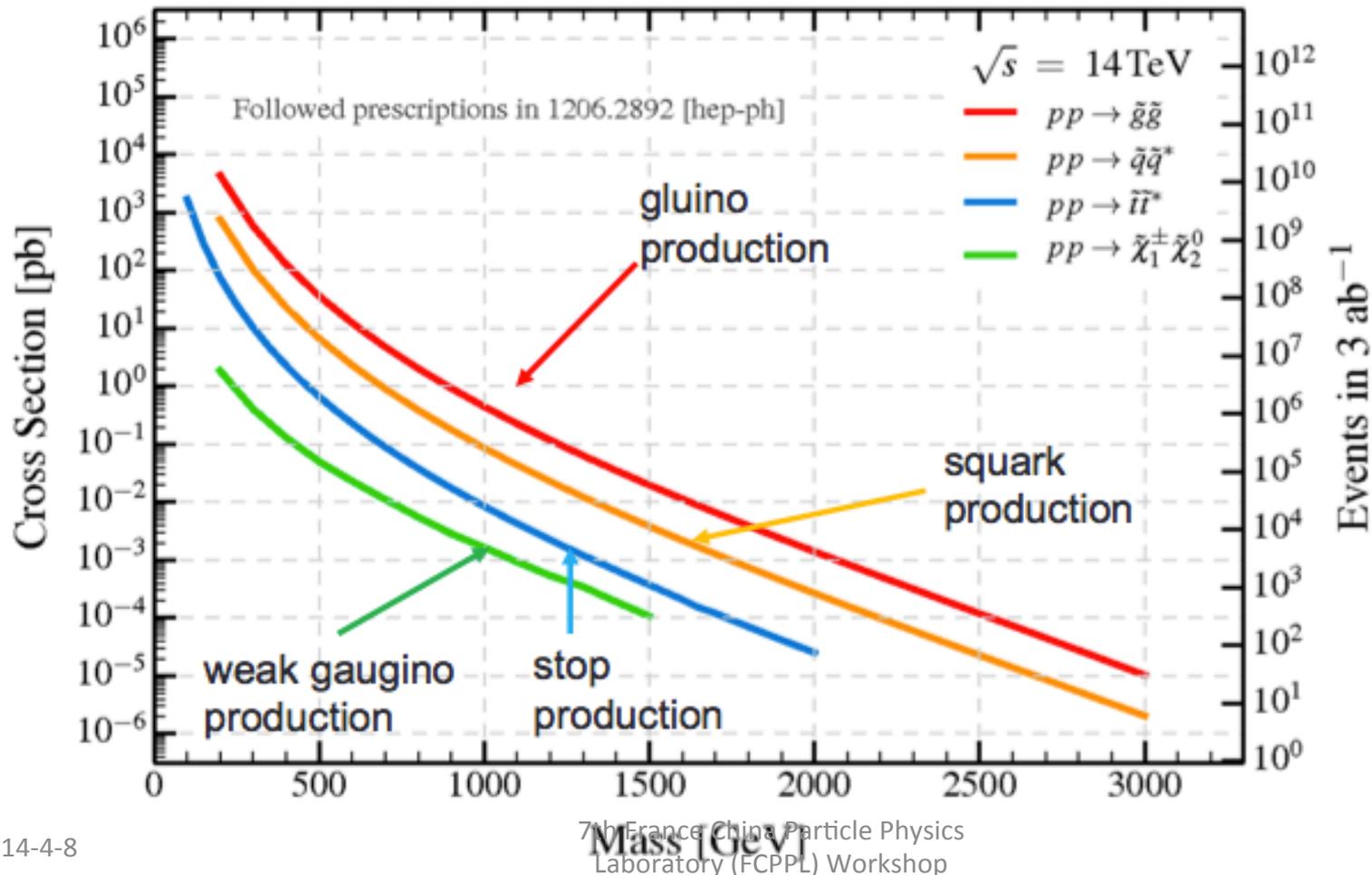
# LHC roadmap

2015-2017: 100 fb<sup>-1</sup>, ~ 1 \* 10<sup>34</sup> cm<sup>-2</sup>s<sup>-1</sup> (LS1)  
 2020-2022: 300 fb<sup>-1</sup>, ~ 2 \* 10<sup>34</sup> cm<sup>-2</sup>s<sup>-1</sup> (LS2)  
 2026-2035: 3000 fb<sup>-1</sup>, ~ 5 \* 10<sup>34</sup> cm<sup>-2</sup>s<sup>-1</sup> (LS3)



# SUSY Search at HL-LHC

- Limits set by Run-1 LHC:  $m_{\tilde{q}} < 0.7 \text{ TeV}$ ,  $m_{\tilde{g}} < 1.3 \text{ TeV}$
- Less stringent limits on sleptons, 3<sup>rd</sup> generation squark, weak gauginos
  - → Accessible at HL-LHC

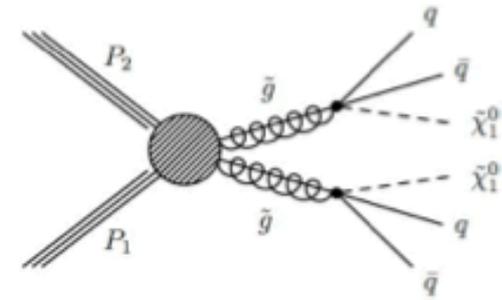


# Glauino production

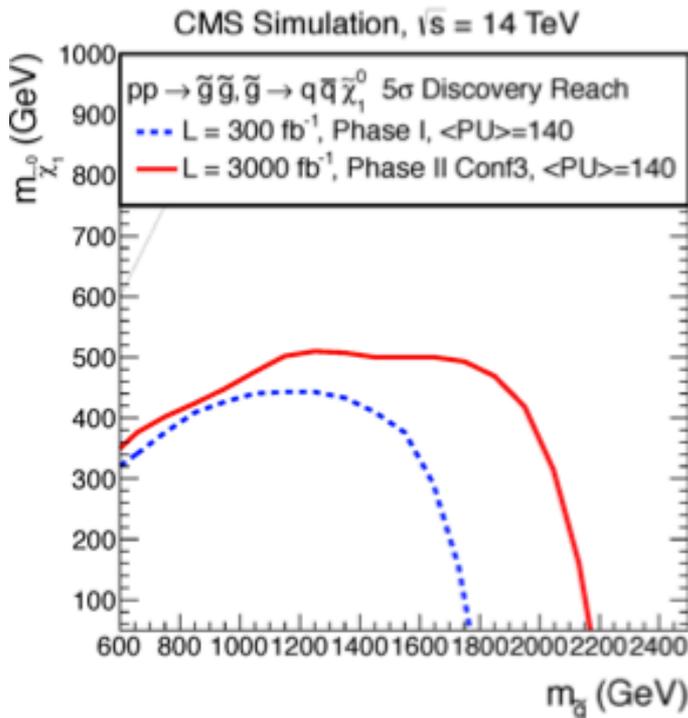


CMS-PAS-FTR-13-014

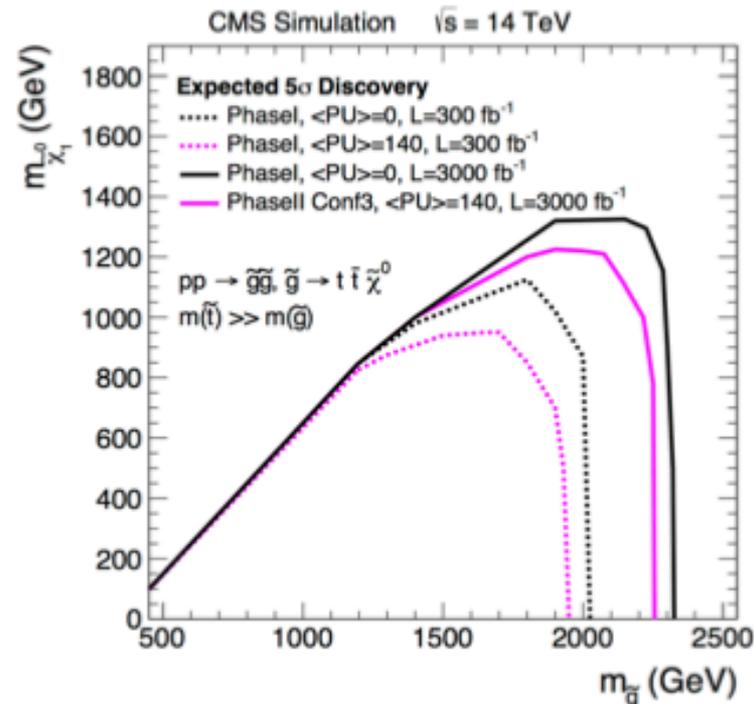
- Large production cross section
- Gluino masses up to 2.2 (1.8) TeV and LSP mass up to 500 (400) GeV can be discovered with 3,000 (300) fb<sup>-1</sup>



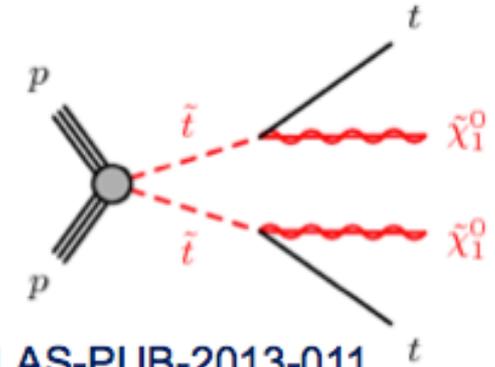
$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 : \text{Multijet, } E_T^{\text{miss}}$$



- In case gluino decays preferentially to top
  - $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ : Multijet,  $E_T^{\text{miss}}$ , 1-lepton



# Stop pair production

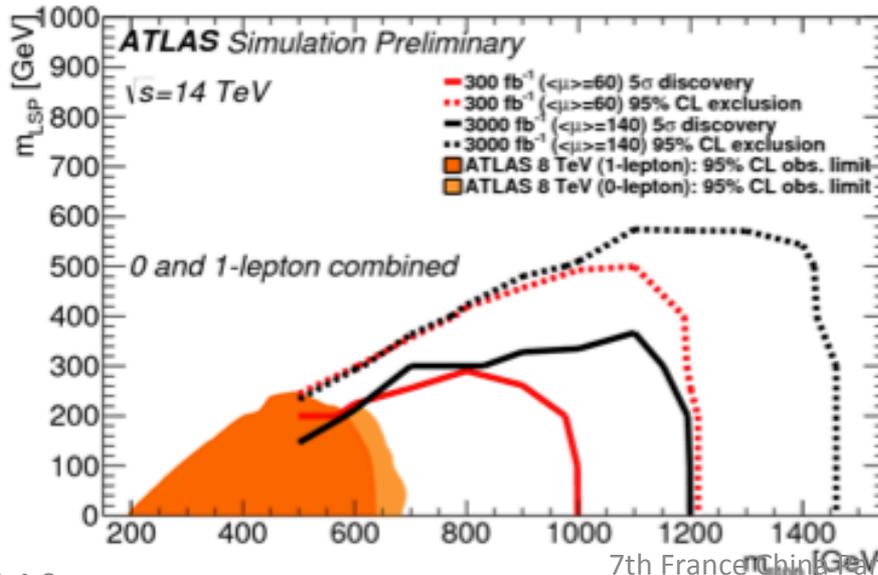
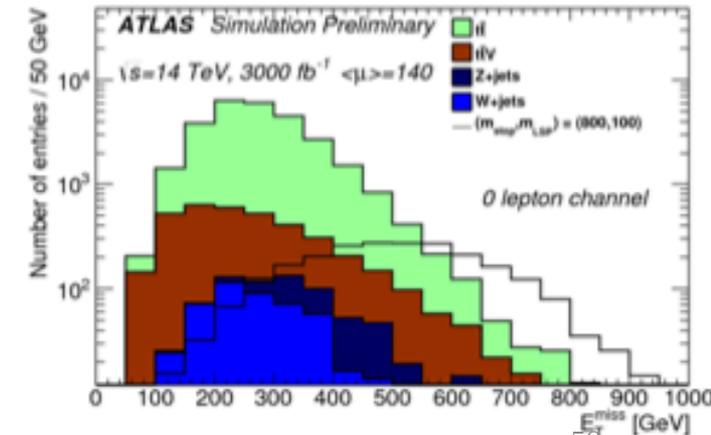
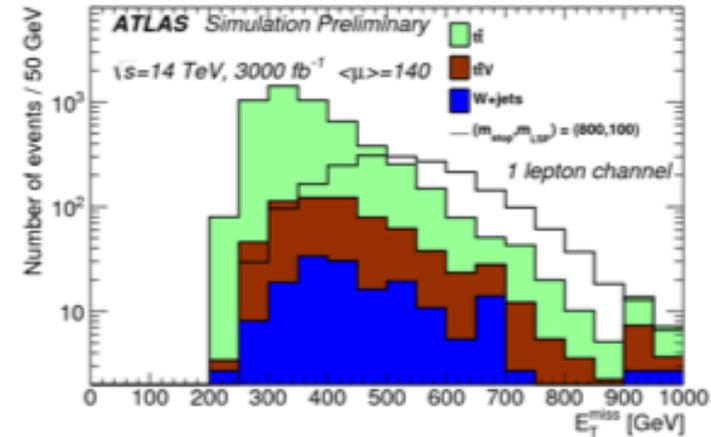


## Signature:

- Fully hadronic top decay:
  - 0-lepton, >6 jets with 2 *b*-tagged,  $E_T^{miss}$
- Semi-leptonic top decay:
  - 1-lepton, >4 jets with 1 *b*-tagged,  $E_T^{miss}$

5 $\sigma$  discovery up to 1.2 TeV at 3,000 fb<sup>-1</sup>  
(200 GeV gain from 300 fb<sup>-1</sup>)

ATLAS-PUB-2013-011

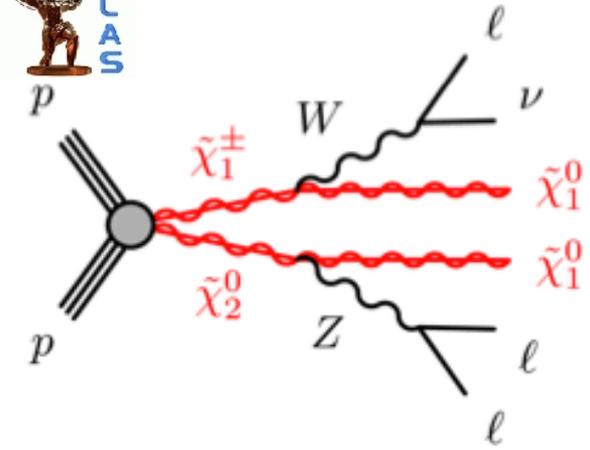


# Weak gaugino production (1)

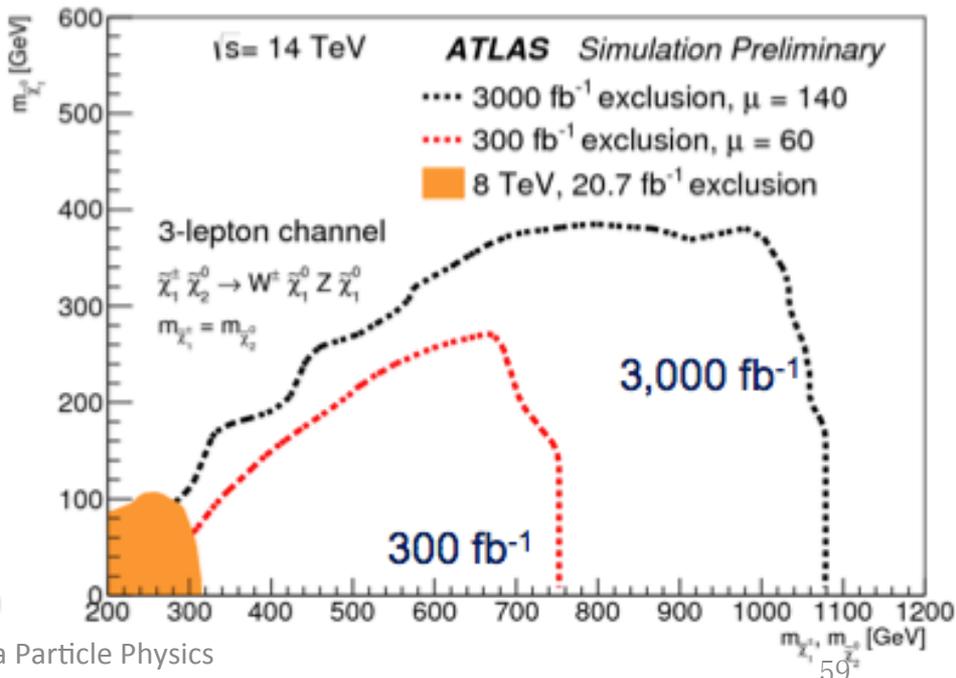
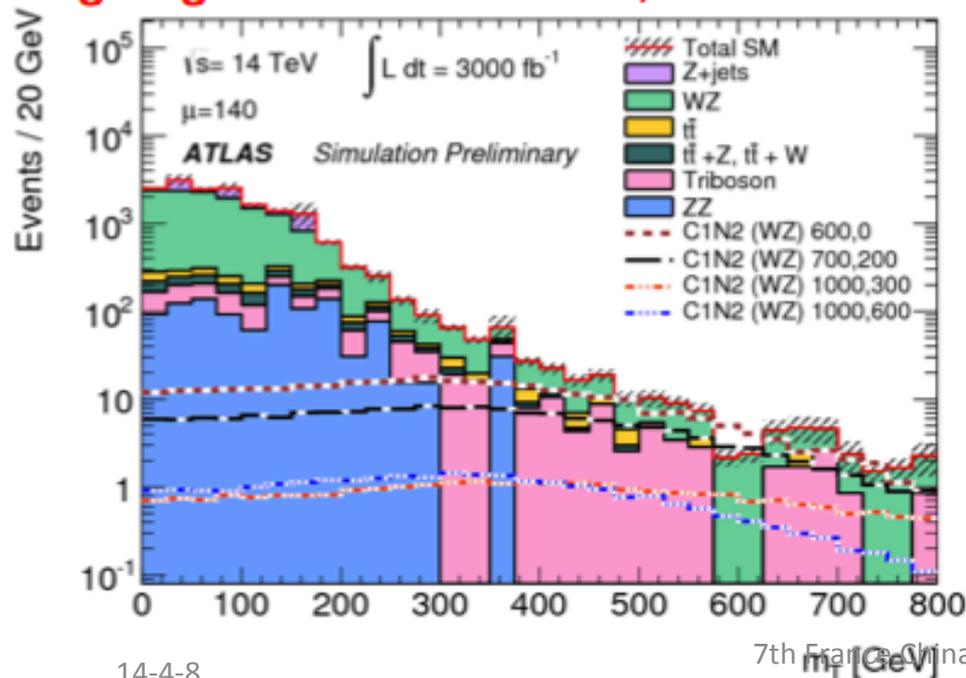


ATLAS-PUB-2013-011

- Direct production of  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$
- Signature:
  - 3 leptons ( $>10$  GeV)
  - $E_T^{miss} > 50$  GeV
  - b-jet veto



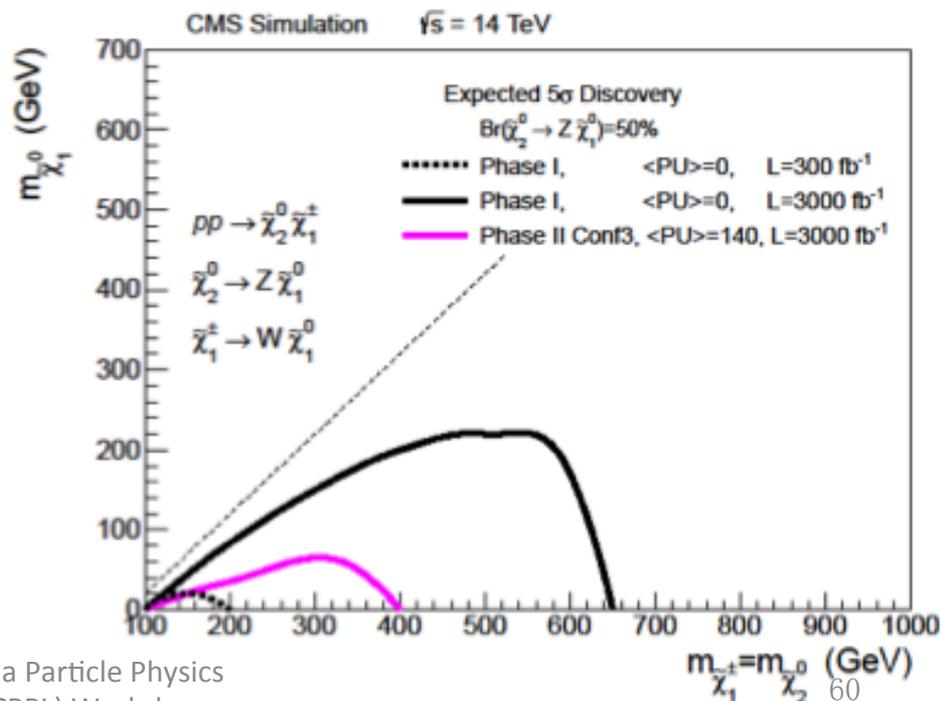
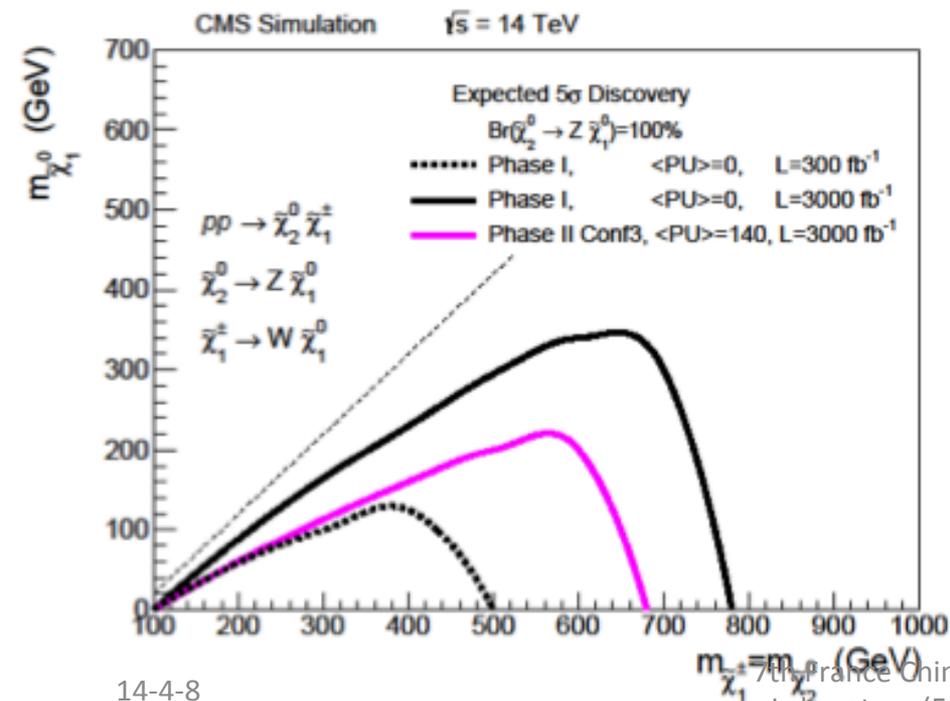
Excluded chargino mass (for massless LSP) is increased by 300 GeV by going from  $300 \text{ fb}^{-1}$  to  $3,000 \text{ fb}^{-1}$



# Weak gaugino production (2)

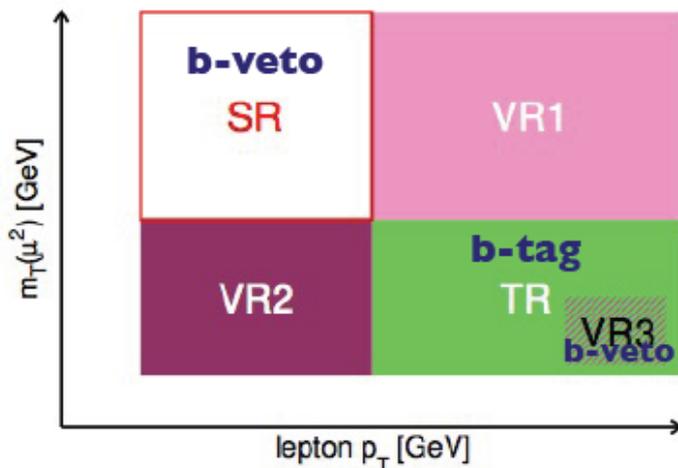
- 5 $\sigma$  exclusion region from CMS
  - Extend the mass range up to 700 GeV with 3,000 fb<sup>-1</sup>
- Assuming 100% or 50% branching ratios of  $\tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0$  and  $\tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0$

CMS-PAS-FTR-13-014

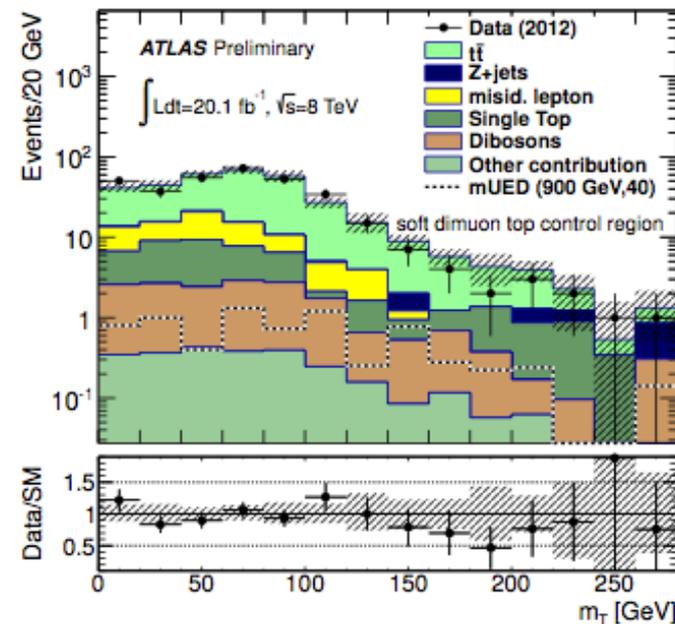


# W/T-Control regions - soft di-muon

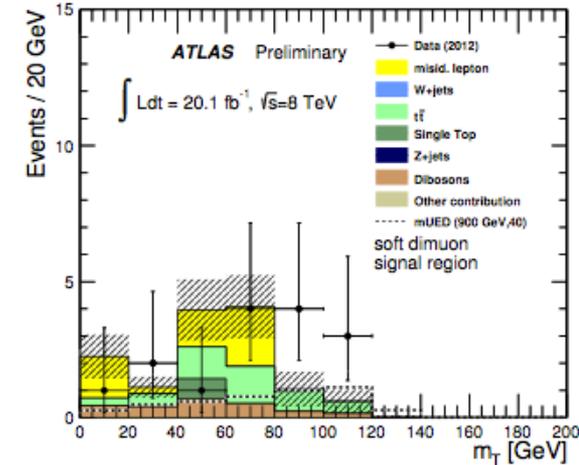
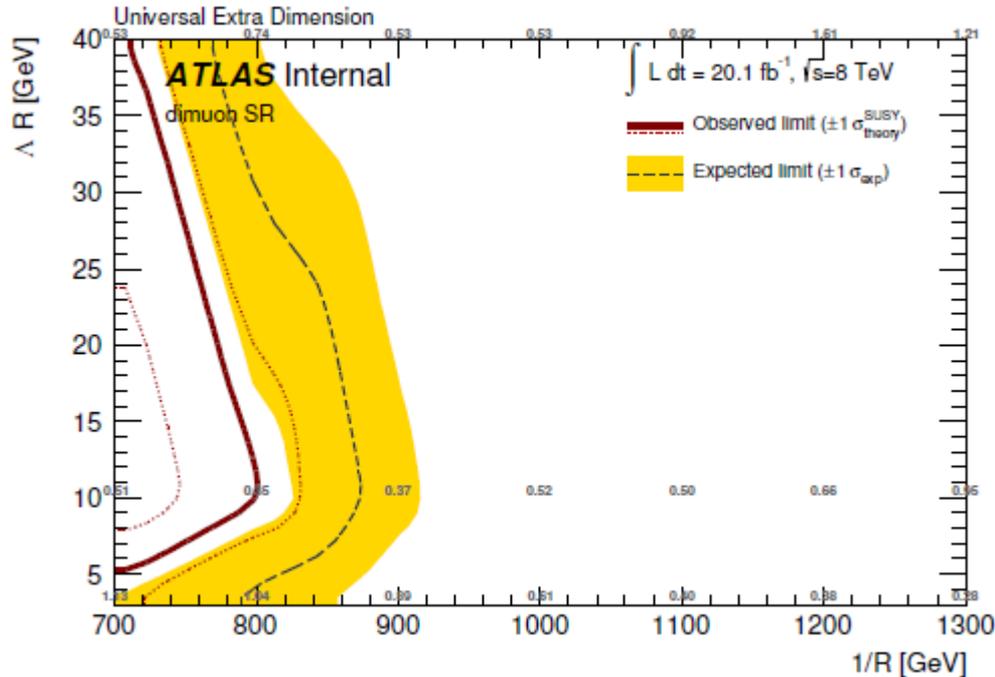
	SR2MU	CRT2MU	VR2MU1	VR2MU2	VR2MU3
$N_\mu$	== 2				
$p_T^{\mu 1}$ (GeV)	[6, 25]	> 25	> 25	[6, 25]	> 25
$p_T^{\mu 2}$ (GeV)	[6, 25]	> 6			
$p_T^{l3}$ (GeV)	< 6 (muon), < 7 (electron)				
$M_{\mu\mu}$ (GeV)	> 15; $ M_{\mu\mu} - M_Z  > 10$				
$N_{jet}$	$\geq 2$				
$p_T^{j1}$ (GeV)	> 70				
$p_T^{jet}$ (GeV)	> 25				
$b$ -tagging (MV1)	veto	$\geq 1$ b-jet	—		veto
$m_T^{\mu 2}$ (GeV)	> 80	< 80	> 80	< 80	
$E_T^{miss}$ (GeV)	> 170				
$\Delta R_{min}$	> 1.0				



$m_T(2^{nd} \mu)$  in TR  
before  $m_T$  cut



# Exclusion Contours (mUED 2MU)



- The expected exclusion reaches up to  $1/R$  values of 870 GeV, for a cut-off scale times radius ( $\Delta R$ ) of about 10.
- Given the small excess in this channel, the observed limit is lower, outside the experimental 1-sigma band, reaching only up to a compactification radius  $1/R \sim 740$  GeV depending on  $\Delta R$

# Discovery and exclusion

- P-value=probability that result is as/less compatible with the hypothesis

## DISCOVERY:

- The null hypothesis  $H_0$  describes background only
  - If the  $p$ -value of  $H_0$  is found below a given threshold, one can consider looking for a better model
  - In HEP,  $Z \geq 5$  is conventionally required to claim a discovery
- The alternative hypothesis  $H_1$  describes signal + background
  - The alternative hypothesis is supposed to fit the data very well for claiming a discovery

## EXCLUSION:

- The null hypothesis  $H_0$  describes signal + background
  - One is interested into setting an upper limit to the intensity of the signal alone
- The alternative hypothesis  $H_1$  describes background only
  - No real need to test for it
  - The background-only model becomes important only in case of discovery

# SUSY search at LHC:

## Identifying a signal/constraining SUSY parameters

- Results of searches presented in form of *raw numbers* and *limits*.
- Raw results
  - number of observed and expected events and uncertainty for each signal region.
- Interpretation for Limits (profile likelihood method, CLs prescription)
  - identifying a signal (discovery)
    - P-value for background-only hypothesis
    - No-signal  $\rightarrow$  95% CL model-independent limit on  $N_{\text{events}}$  in SR
  - constraining SUSY parameters (exclusion)
    - Model-dependent 95% CL limits on SUSY models
      - Observed and expected limits with theoretical and experimental uncertainties, respectively.

# Interpretation strategy

Based on the number of observed, expected events in all regions with all uncertainties:  
Probability density function (PDF)

From the constructed distribution of test statistic for  $s+b$ , find the p-value of the observation

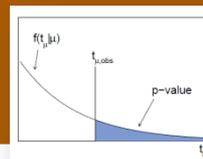
$$p_{\mu} = \int_{t_{\mu, \text{obs}}}^{\infty} f(t_{\mu} | \mu) dt_{\mu}$$

If  $CL_s < 0.05$ : the value of signal is excluded at 95% CL.....

$$CL_s = \frac{CL_{s+b}}{CL_b} = \frac{P_{s+b}}{1 - p_b}$$

Likelihood function:  $L(\mu, \theta)$   
 $\mu$ : signal strength (POI);  
 $\theta$ : nuisance parameters (NP)  
Profile Likelihood: constrain uncertainty (NP) as part of a likelihood fit

Construct the PDF of test statistic  $t_{\mu}$ : generate toy Monte Carlo or using asymptotic formula

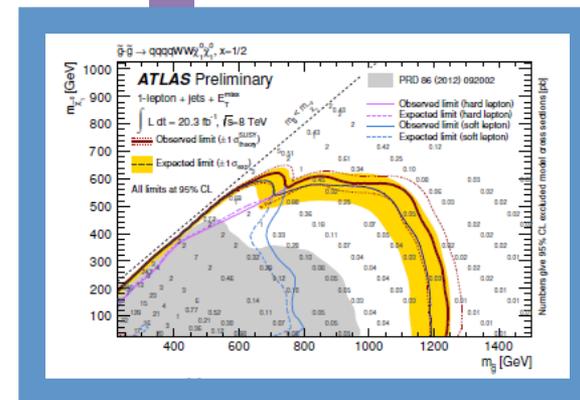


The above check has been done for each signal grid points on the SUSY model. The line can be drawn for the area where points are excluded

Construct test statistics  $t_{\mu}$  based on likelihood ratio  $\lambda$ :

$$\tilde{\lambda}(\mu) = \begin{cases} \frac{L(\mu, \hat{\theta}(\mu))}{L(\hat{\mu}, \hat{\theta})} & \hat{\mu} \geq 0, \\ \frac{L(\mu, \hat{\theta}(\mu))}{L(0, \hat{\theta}(0))} & \hat{\mu} < 0 \end{cases} \quad t_{\mu} = -2 \ln \lambda(\mu)$$

Find the observed test statistic for tested  $\mu$ :  $t_{\mu, \text{obs}}$



# Simultaneous fit I

- Background estimates in SRs are obtained by a *simultaneous fit* in each channel based on the profile likelihood method. Three dedicated fit for different purpose...
  - **Background-only fit**
    - Fit for all CRs, excluding SRs.
      - **Get background-only estimates.**
      - Also extrapolate to VRs (non used in fit, only for cross-check) and SRs.
  - **Discovery fit**
    - Fit for all CRs and SRs.
    - Signal contamination is turned off in CRs and set as a dummy number 1 in SR (so, the fitted non-SM signal strength = the excess in Nevents of SR)
      - **Get model-independent upper limit on signal in SR.**
  - **Exclusion fit**
    - Fit for all CRs and SRs.
    - Signal is turned on in all regions, according to model-dependent prediction.
      - **Got signal model-dependent exclusion from all CRs+SRs → final exclusion contours for SUSY model**
- The basic strategy is to share background information in all regions (CR,SR,VR). The background parameters are predominantly constrained by CRs with large statistics, which in turn reduces the impact of uncersts in

# Simultaneous fit II

- Input: **Probability density function** (Signal and background are described by a binned PDF in CRs, SRs and VRs -- technically it is implemented by a collection of histograms).
  - The number of observed events (described using a Poisson)
  - The  $t\bar{t}$  and  $W(Z)$ +jets backgrounds: MC prediction
    - $\rightarrow$  samples of all fit regions are scaled by **"free parameters"**  $\mu_{wz}/\mu_{top}$  (un-constrained scaling factors) to get an overall normalization.
  - The QCD multi-jet background estimate: data-driven prediction
    - $\rightarrow$  only allowed to vary within its uncertainties in the fit.
  - Smaller backgrounds as single top, dibosons and  $t\bar{t}$ +vector boson: MC prediction.
    - $\rightarrow$  only allowed to vary within uncertainties.
  - Signal samples of fit regions are scaled by "free parameter"  $\mu_{SIG}$ .
  - Statistical and systematic uncertainties are included as **nuisance parameters**, typically constrained by a Gaussian. Correlations between the systematics are considered.
- The product of the various PDF forms the likelihood.
- The fit maximizes the likelihood by adjusting parameters  $\rightarrow$  the optimal value/error of the free parameters and nuisance parameters are determined simultaneously when the PDF is fitted to Data.

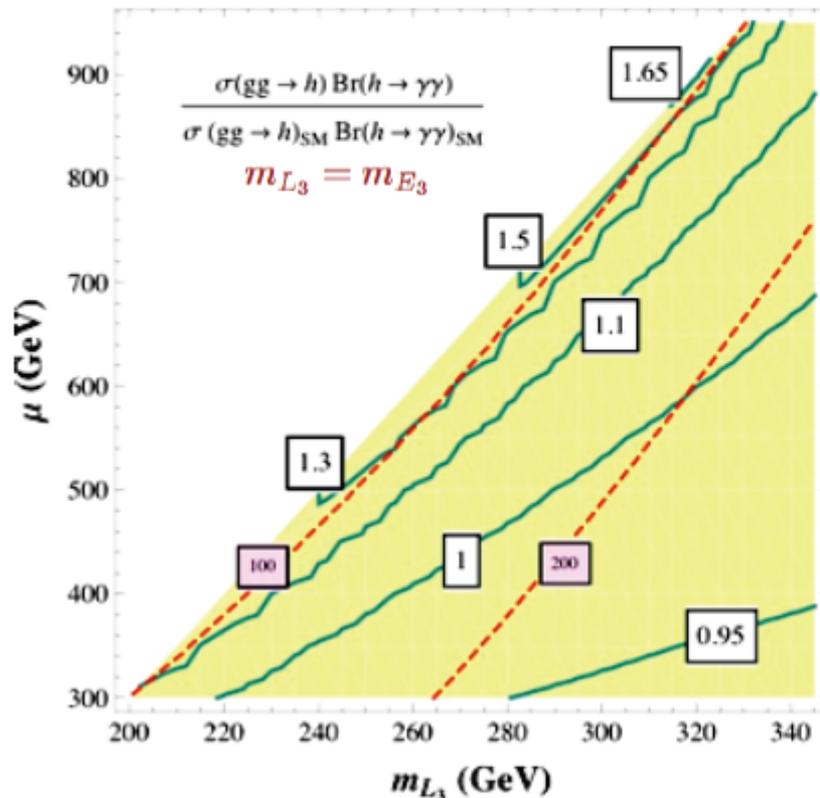


# Higgs Production in the di-photon channel in the MSSM

Charged scalar particles with no color charge can change di-photon rate without modification of the gluon production process

$$m_A = 1 \text{ TeV GeV}, A_\tau = 0 \text{ GeV}$$

$$M_\tau^2 \simeq \begin{bmatrix} m_{L_3}^2 + m_\tau^2 + D_L & h_\tau v (A_\tau \cos \beta - \mu \sin \beta) \\ h_\tau v (A_\tau \cos \beta - \mu \sin \beta) & m_{E_3}^2 + m_\tau^2 + D_R \end{bmatrix}$$



**Light staus with large mixing**

[sizeable  $\mu$  and  $\tan \beta$ ]:

**→ enhancement of the Higgs to di-photon decay rate**

Contours of constant

$$\frac{\sigma(gg \rightarrow h) Br(h \rightarrow \gamma\gamma)}{\sigma(gg \rightarrow h)_{SM} Br(h \rightarrow \gamma\gamma)_{SM}}$$

for  $M_h \sim 125 \text{ GeV}$

M. C. S. Gori, N. Shah, C. Wagner, I I +L.T.Wang' 12

**Higgs into di-photon rate can be enhanced via Staus**  
**without changing the Higgs into WW/ZZ rates**

# Model independent Upper Limit @ 95% CL

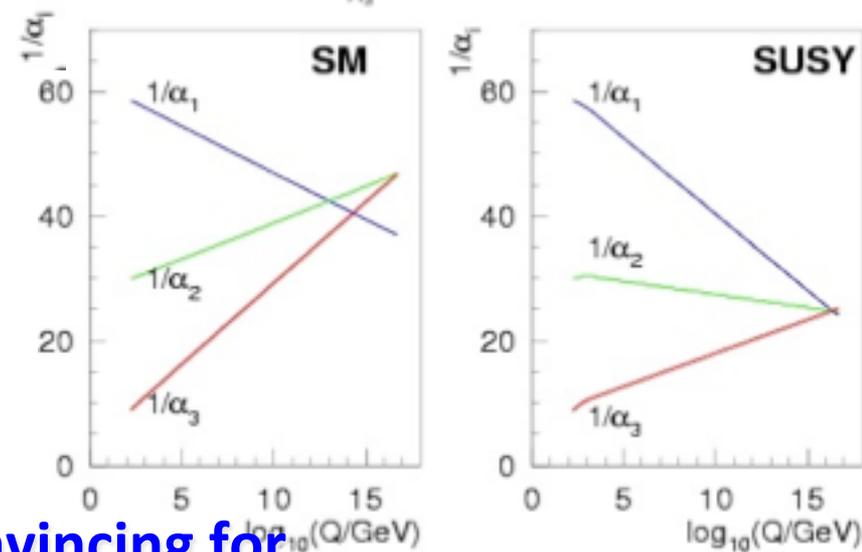
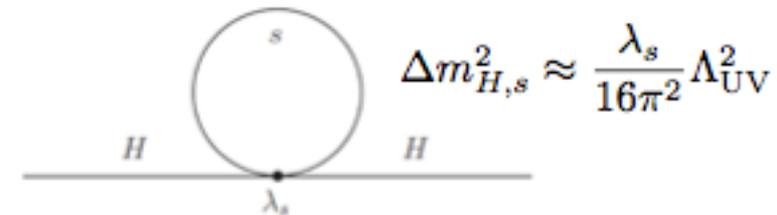
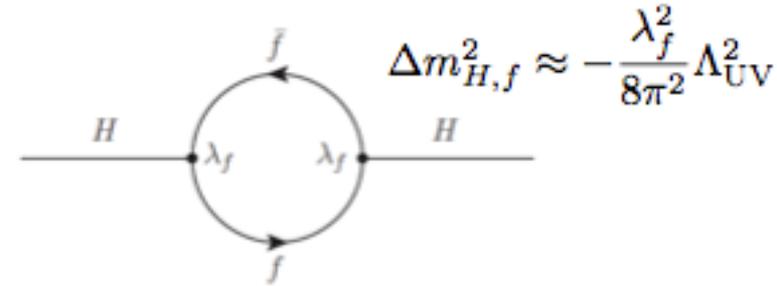
Signal channel	$\langle\epsilon\sigma\rangle_{\text{obs}}^{95}$ [fb]	$S_{\text{obs}}^{95}$	$S_{\text{exp}}^{95}$	$CL_B$	$p(s=0)$
SR-OS $m_{T2}$	0.27	5.6	$8.9_{-3.2}^{+2.7}$	0.14	0.50
SR-OS $m_{T2}$ -nobjct	0.50	10.4	$10.4_{-1.7}^{+0.6}$	0.48	0.50

Table 6: Left to right: 95% CL upper limits on the visible cross section ( $\langle\epsilon\sigma\rangle_{\text{obs}}^{95}$ ) and on the number of signal events ( $S_{\text{obs}}^{95}$ ). The third column ( $S_{\text{exp}}^{95}$ ) shows the expected 95% CL upper limit on the number of signal events, determined by setting the data to the expected background contribution (and  $\pm 1\sigma$  excursions on the expectation) of background events. The last two columns indicate the  $CL_B$  value, i.e. the confidence level observed for the background-only hypothesis, and the discovery  $p$ -value ( $p(s=0)$ ).

# SUSY Introduction

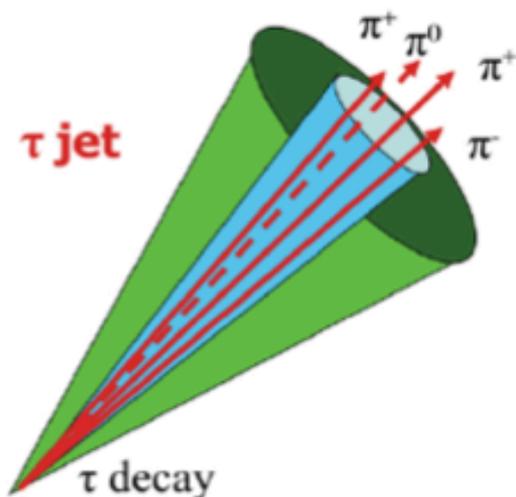


- Solve hierarchy problem without “fine tuning”
  - SUSY contributions to Higgs mass cancel SM contributions
- Unification of gauge couplings
  - New particle content changes running of couplings
- Provide Dark Matter candidate
  - Lightest SUSY particle (LSP) can be stable and only weakly interacting

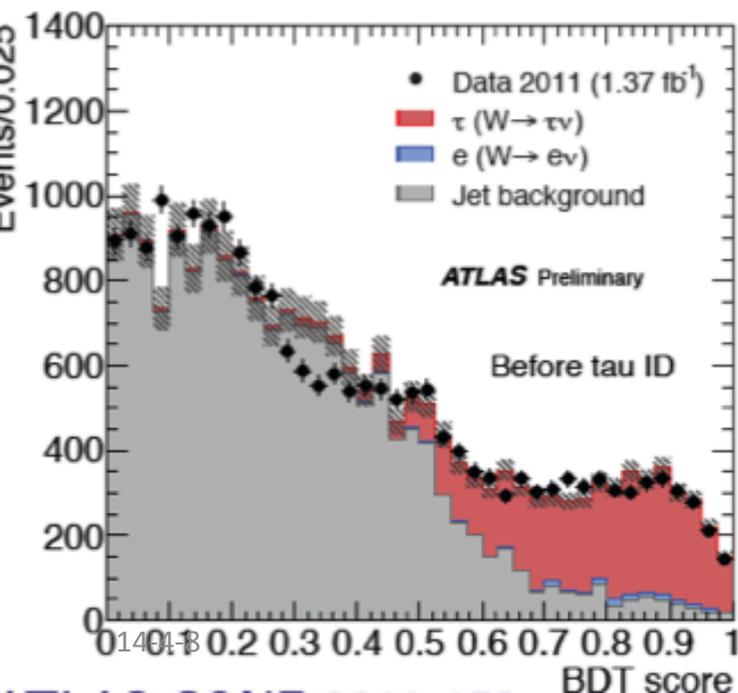


**Some of the arguments are most convincing for SUSY particles at ~TeV scale**

# Hadronic Taus



- Tau decays:
  - Leptonic (35%):  $\tau \rightarrow \nu_\tau l \bar{\nu}_l$
  - Hadronic (65%): decay to one or three charged pions, neutrinos and  $\pi^0$ 's
- Need to separate  $\tau$ 's from hadronic jets:
  - $\tau$  decay tends to be well collimated
  - Large electromagnetic component from  $\pi^0 \rightarrow \gamma\gamma$  decay



## Tau Object

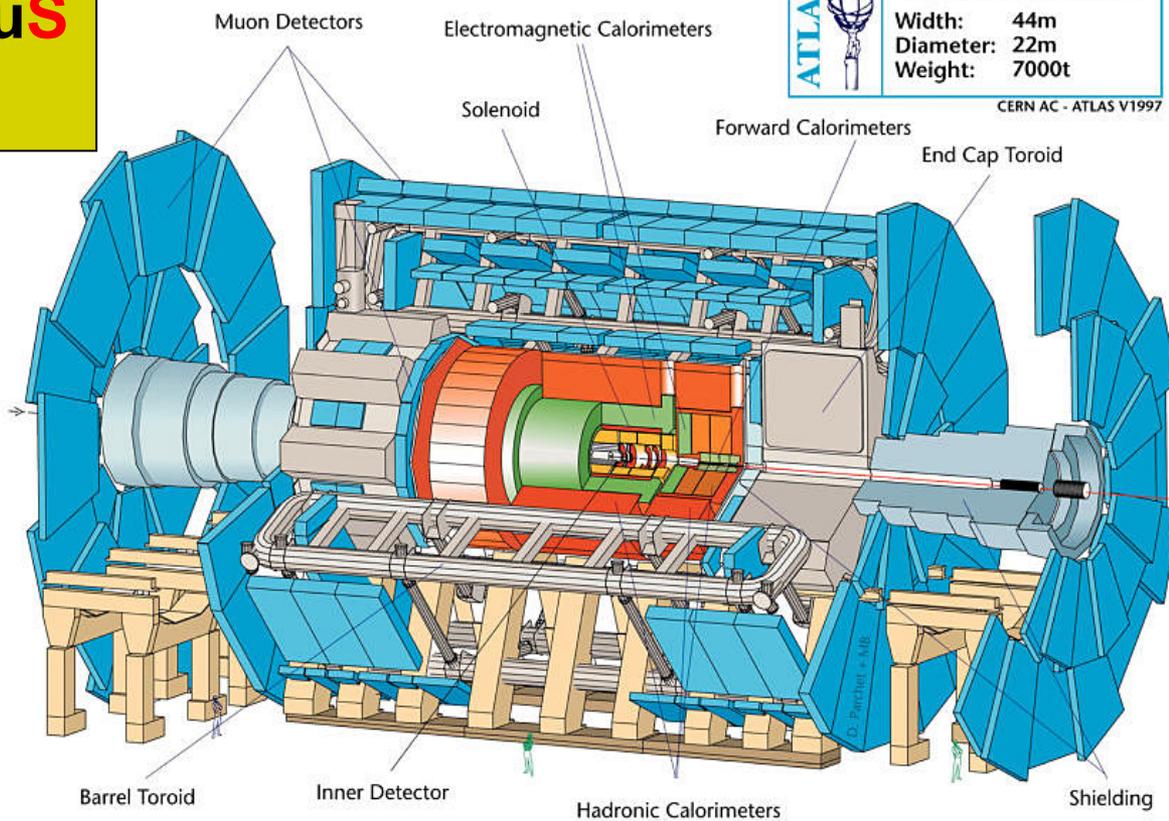
- ▷  $p_T > 20$  GeV,  $|\eta| < 2.5$
- ▷ 1 or 3 tracks with total charge  $\pm 1$
- ▷ Boosted decision tree (BDT) using variables sensitive to the longitudinal and transverse shower shape
- ▷ Working points:
  - **Loose:** efficiency: 60%; jet rejection: 20-50
  - **Tight:** efficiency: 30-50%; jet rejection: 30-200

# A Toroidal LHC Apparatus

- 42m×22m, 7000 ton

Detector characteristics	
Width:	44m
Diameter:	22m
Weight:	7000t

CERN AC - ATLAS V1997



Inner Detector (2T solenoid,  $|\eta| < 2.5$ ):

$$\sigma_{p_t}/p_t \approx 0.05\%/GeV \times p_t \oplus 1\%$$

Calorimetry:

\* electromagnetic,  $|\eta| < 3.2$

$$\sigma_E/E \approx 10\% \sqrt{GeV}/\sqrt{E} \oplus 0\%$$

\* hadronic (central,  $|\eta| < 1.7$ )

$$\sigma_E/E \approx 50\% \sqrt{GeV}/\sqrt{E} \oplus 3\%$$

\* hadronic (endcaps,  $1.7 < |\eta| < 3.2$ )

$$\sigma_E/E \approx 60\% \sqrt{GeV}/\sqrt{E} \oplus 3\%$$

\* hadronic (forward,  $3.2 < |\eta| < 4.9$ )

$$\sigma_E/E \approx 100\% \sqrt{GeV}/\sqrt{E} \oplus 5\%$$

Muon system ( $\sim 4T$  toroid,  $|\eta| < 2.7$ ):

$$\sigma_{p_t}/p_t \approx 10\% \text{ for } p_t(\mu) \approx 1 \text{ TeV}/c$$

➤ **Inner Detector:** Highly segmented silicon strips, determine very accurately charged particles trajectories

➤ **Solenoid Magnet:** Solenoid coil that generates a 2T magnetic field in the region of the Inner Detector

➤ **Electromagnetic Calorimeter:** Electron and photon energies are measured through electromagnetic showers

➤ **Hadronic Calorimeter:** Hadrons interact with dense material and produce a shower of charged particles

➤ **Toroid Magnets:** 8 toroidal coils that create a 0,4T magnetic field in the area of the Muon Spectrometer

➤ **Muon Spectrometer:** Muons traverse the rest of the detector and are measured in its outer layers

## 1.5 Monte Carlo samples

Several Monte Carlo (MC) generators are used to model the dominant SM processes and new physics signals relevant for the analyses. SHERPA [12] is used to simulate the top pair, diboson  $WZ^{(*)}$ ,  $W^{(*)}$ +jets, and  $Z^{(*)}$ +jets processes. Additional dedicated ALPGEN [13] samples are used for the  $W^{(*)}$ +jets, and  $Z^{(*)}$ +jets processes in the search for chargino and neutralino associated production. The generator MadGraph [14] is used for the production of  $t\bar{t}V$  ( $V = W, Z$ ) events and the production of  $WWW$ ,  $ZZZ$  and  $ZWW$  events (collectively referred to as 'triboson' or  $VVV$  in this note). The expected diboson yields are normalised to the SHERPA predictions. The top-quark pair-production contribution is normalised to approximate next-to-next-to-leading-order calculations (NNLO) [15]. The NNLO FEWZ [16, 17] cross-sections are used for normalisation of the inclusive  $W$ +light-flavour jets and  $Z$ +light-flavour jets. The expected triboson and  $t\bar{t}V$  yields are normalized to NLO. The CTEQ6L1 [18] parton distribution functions (PDFs) are used with MadGraph and the CT10 [19] PDFs with MC@NLO and SHERPA.

The signal MC samples are produced with HERWIG++ [20]. The yields are normalized to the NLO cross-section calculated with PROSPINO[21] in the case of electro-weakino production. They are normalized to NLO+NLL accuracy [22] for stop and sbottom production. The most relevant MC samples have equivalent luminosity (at 14 TeV) of at least  $1000 \text{ fb}^{-1}$ .

## 1.6 Expected sensitivity

For the analyses discussed in this document, limits are set using a significance-like variable, referred to as  $Z_n$  [23], which takes into account the systematic uncertainties on the background. The value of  $Z_n$  is required to be larger than 5 for discovery and larger than 1.64 for 95% CL exclusion <sup>2</sup>.

The most important sources of experimental systematic uncertainties are due to the energy resolution and scale uncertainty of jets, leptons and  $E_T^{\text{miss}}$ ; b-tagging efficiency; pile-up; and the trigger efficiency. For the dedicated studies at 14 TeV a coarse systematic uncertainty of 30% on the estimated sum of all backgrounds is assumed, which is consistent with the uncertainties found in published searches. The projection studies assume conservatively that the uncertainties determined for the 8 TeV analysis hold for the HL-LHC. Theoretical uncertainties on the SUSY yields due to the choice of renormalization and factorization scales and PDF are not considered in this study.