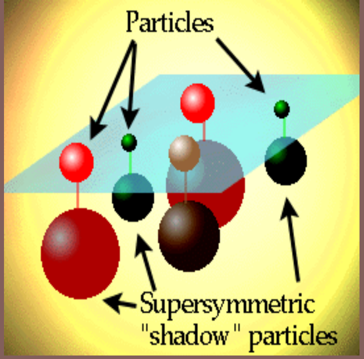


中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

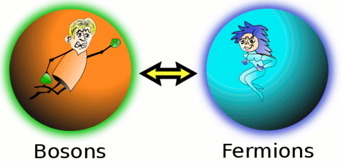
SUSY SEARCHES IN ATLAS FROM CPPM & IHEP

Xuai Zhuang

IHEP, Beijing, China

Apr. 8, 2015

SUSY Introduction

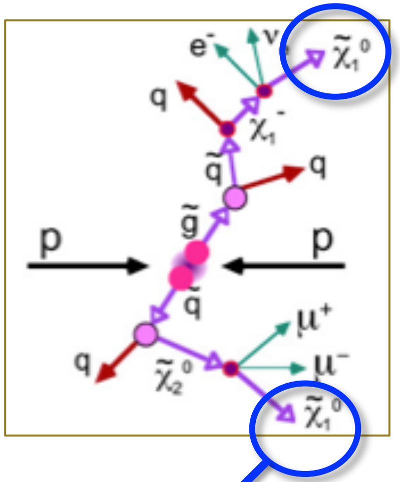


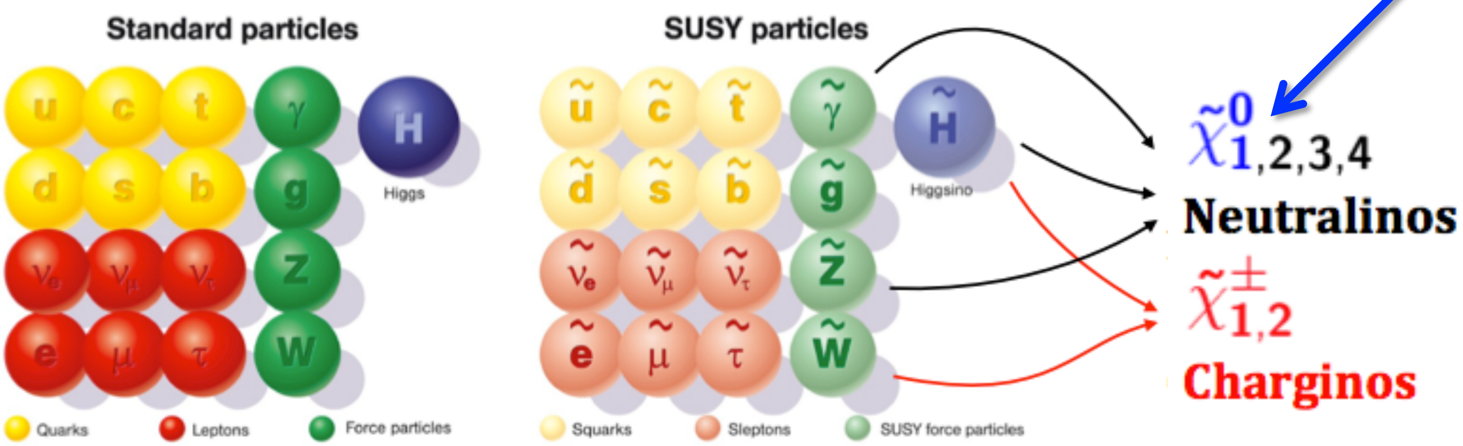
- **A symmetry which unify fermions (mater) and bosons (forces)** –> A fundamental theory
- **<u>Conserved R parity</u>** (originally introduced for stability of proton)

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

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

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



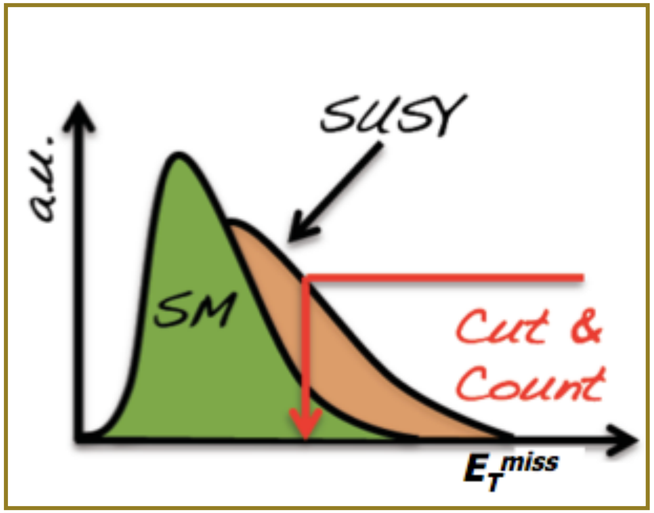


SUSY Search Strategy

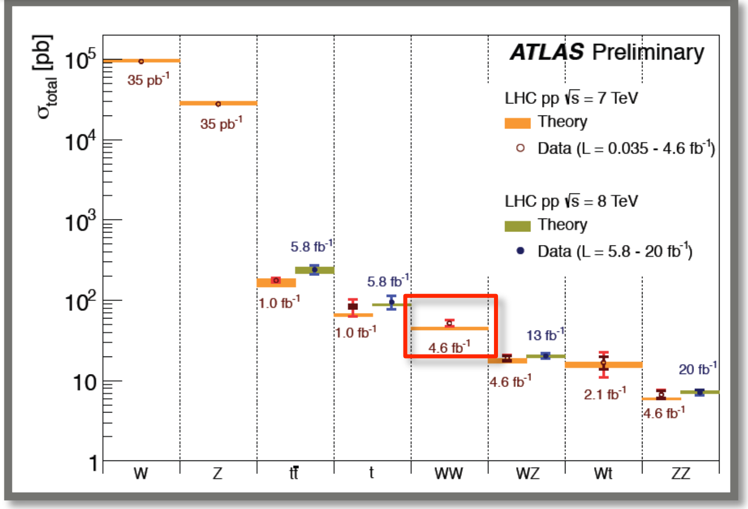
- **SUSY search strategy:** search for **deviation from SM**

- **SUSY sensitive variables:** Try to establish excess of events in some sensitive kinematic distribution

- **SM background:** the discovery of new physics can only be claimed when SM backgrounds are understood well or under control
  - SM bgs understood very well ☺
  - No hints for new physics ☹
  - Slightly overshoot in WW cross section, but consistent with NNLO xsec.

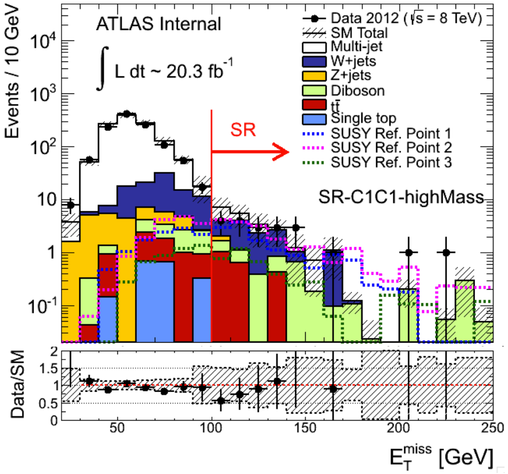


SM "backgrounds"– the big picture

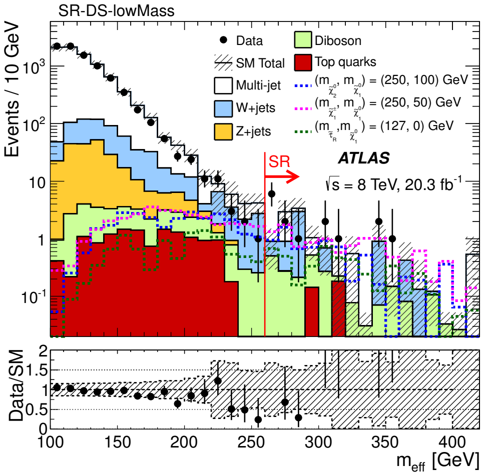


SUSY Sensitive Variables

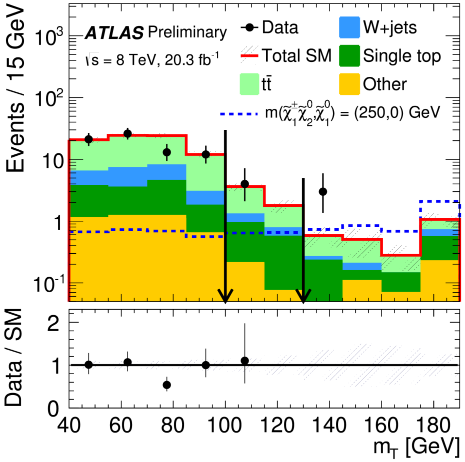
E_T^{miss}



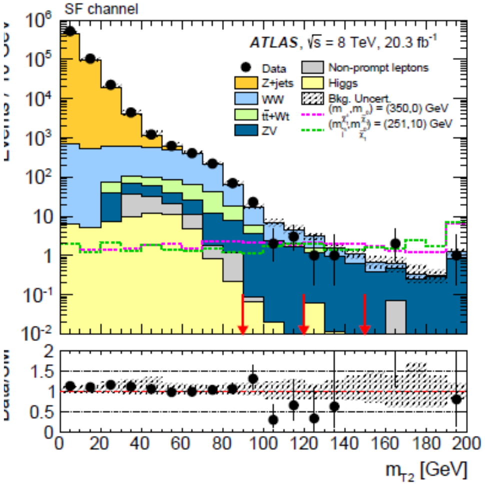
M_{eff}



mT



mT2



- **E_T^{miss}** from escaping LSP, to suppress bg from mis-measured jets and oth. SM BG
- Related to the sparticle mass scale, like effective mass (**M_{eff}**)

$$M_{\rm eff} \equiv \sum_{i=1}^{N_{\rm jets}} p_{\rm T}^{{\rm jet},i} + \sum_{j=1}^{N_{\rm lep}} p_{\rm T}^{{\rm lep},j} + E_{\rm T}^{\rm miss}$$

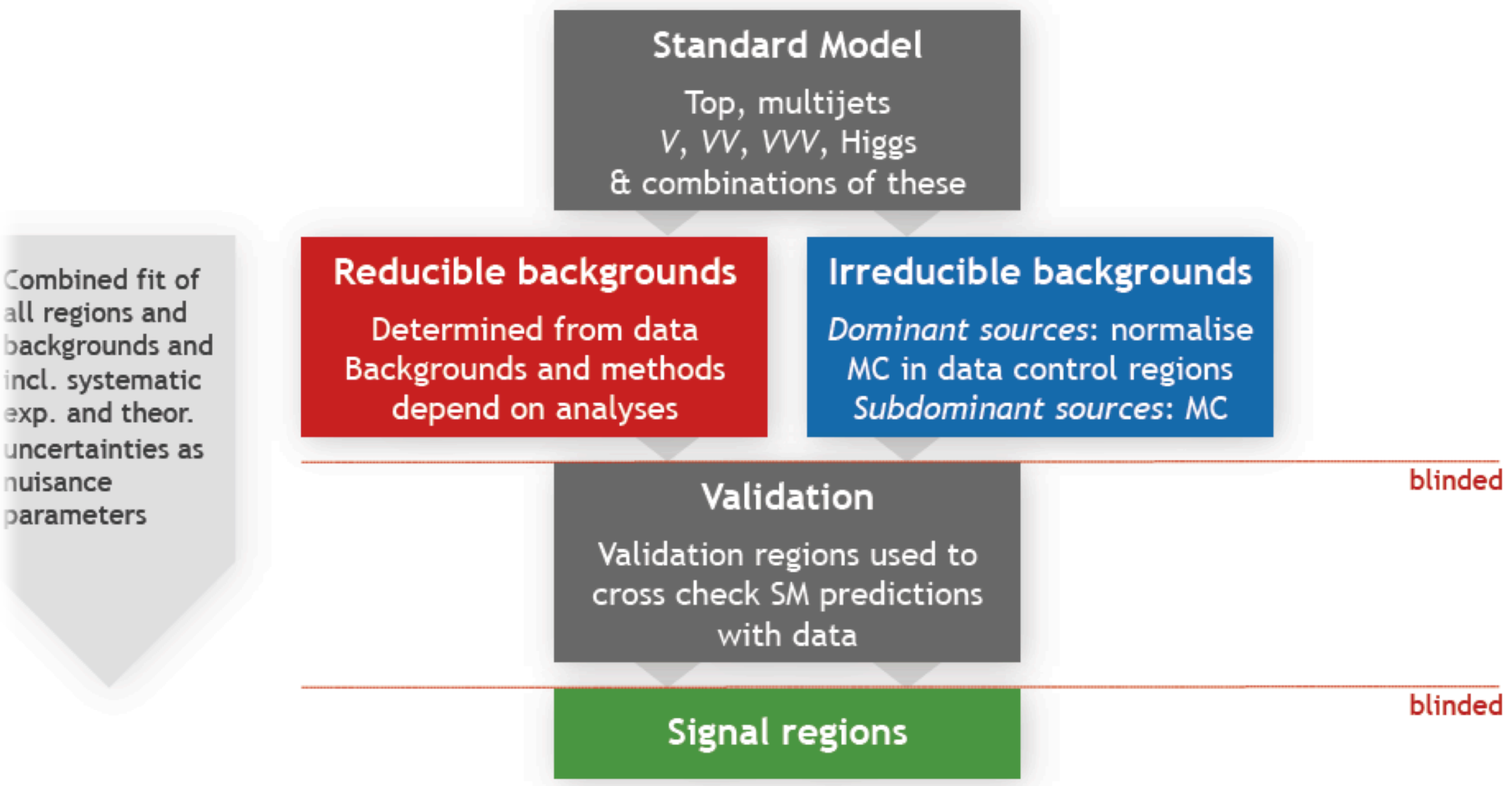
- **mT, mT2** (stransverse mass): suppress BG with Ws

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

- Many others …

SM Background Modeling

- **SUSY searches rely on accurate modeling of the Standard Model backgrounds**



Standard Model

Top, multijets
V, *VV*, *VVV*, Higgs
& combinations of these

Reducible backgrounds

Determined from data
Backgrounds and methods depend on analyses

Irreducible backgrounds

Dominant sources: normalise MC in data control regions
Subdominant sources: MC

Validation

Validation regions used to cross check SM predictions with data

Signal regions

Combined fit of all regions and backgrounds and incl. systematic exp. and theor. uncertainties as nuisance parameters

SUSY Search @ LHC

Strong production: gluino pair, gluino-squark and squark pair (include 3^{rd} **generation**) production

1） Generic signatures :

Multi -jets + n_lepton/n_photon(n=0,1, ≥2) + large E_T^{miss} **(0L,1 L, >=2L)**

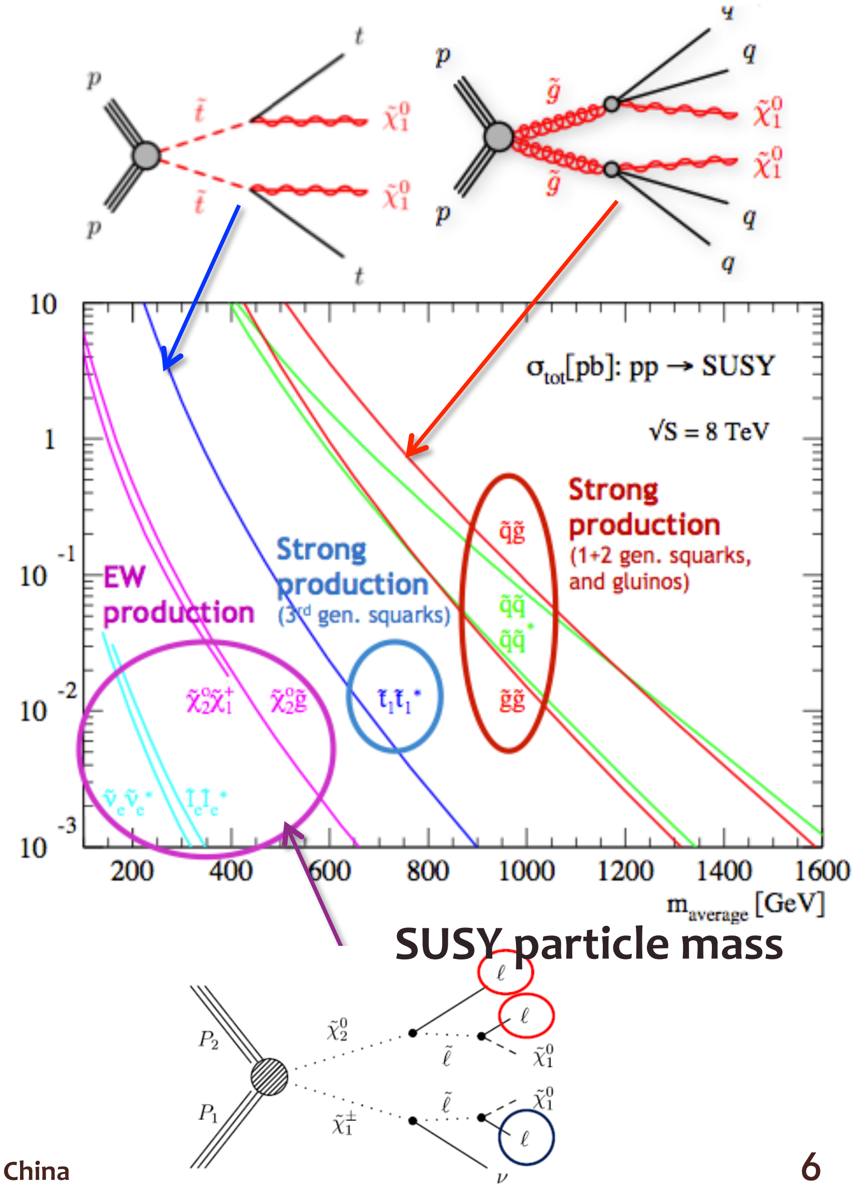
2） large xs, but heavy SUSY mass scale

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 Search @ LHC

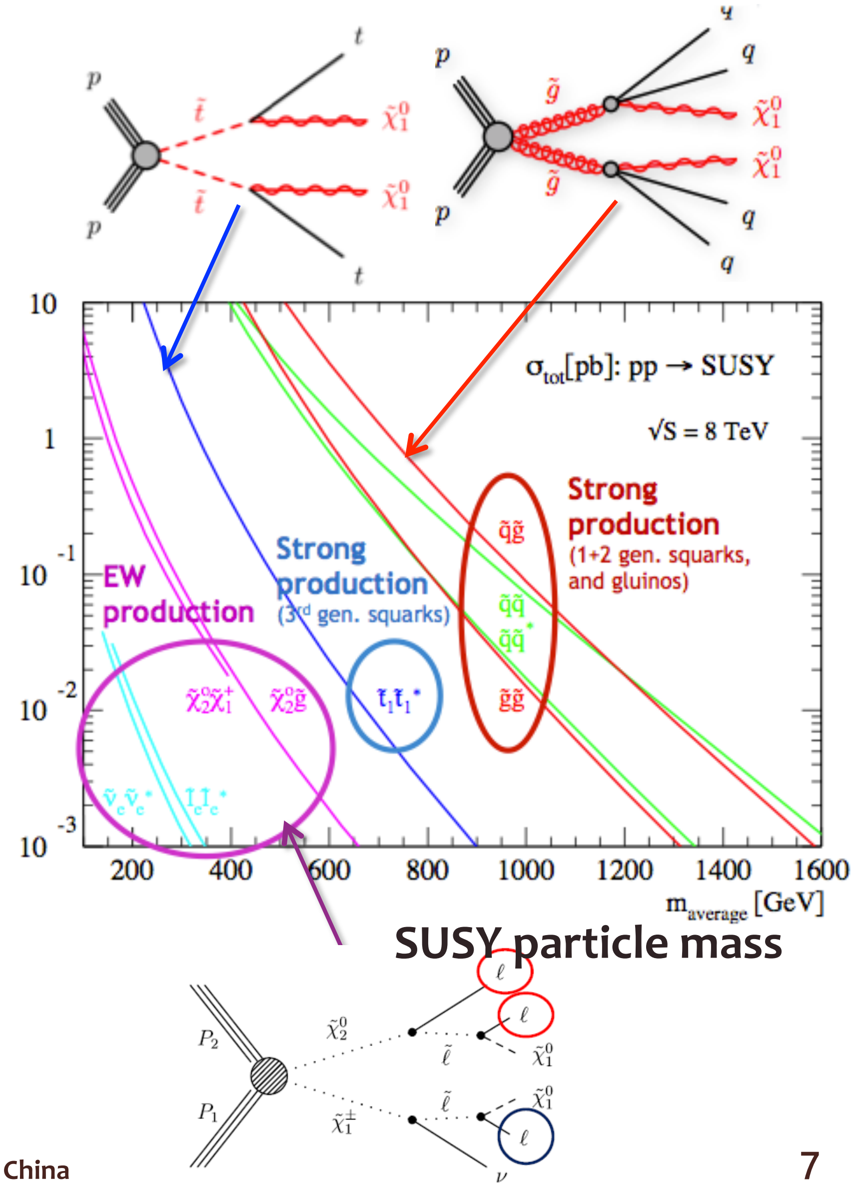
Strong production: gluino pair, gluino-squark and squark pair (include 3^{rd} **generation**) production

- 1 lept. +jets + MET (IHEP@RUN1+RUN2)
- Inclusive tau+X (IHEP@RUN1+RUN2)
- **2 SS/ 3 l+ 0-3 b-jets + MET (CPPM@RUN1; CPPM+IHEP@RUN2)**

Weak production: direct gaugino/slepton production

- **2tau+ MET (IHEP@RUN1+RUN2)**
- 2L + MET (CPPM@RUN1+RUN2)
- Wh->1lbb (CPPM@RUN1)

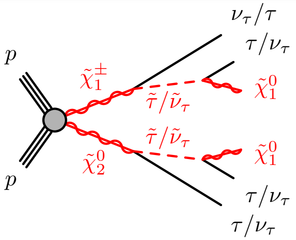
2）low xs, but small SUSY mass scale



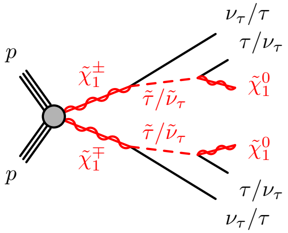
The results area based on 20 fb-1 @ 2012

1. Ditau Analysis - Motivation

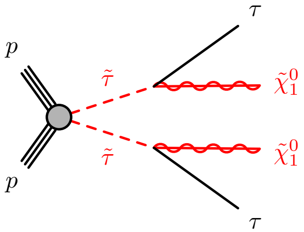
C1N2 via stau/sneutrino



C1C1 via Stau/sneutrino



Direct stau pair



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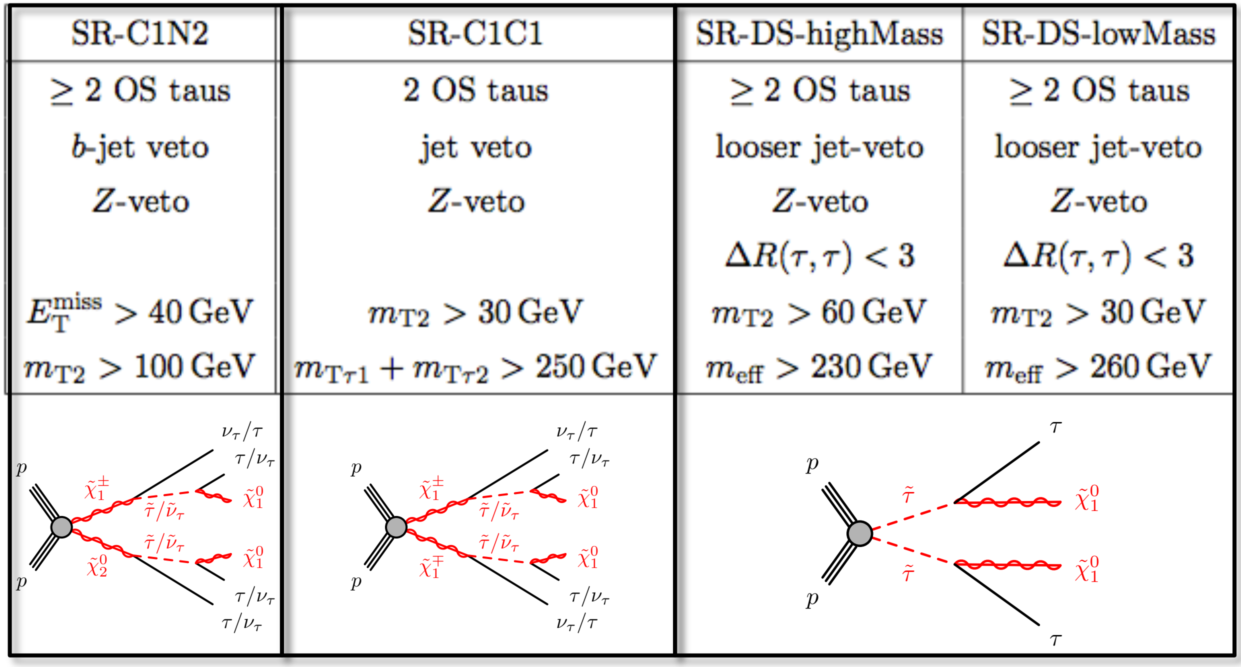
- ☐ **First search for production of C1C1 and Dstau with hardronic tau decays from the LHC !**
- ☐ **Leading contribution from IHEP**

- **Search for electroweak (EWK) SUSY below the TeV scale is motivated by naturalness arguments.**
- **EWK production has a low cross-section compared to strong production**
  - **Very challenging searches**
  - **But leads to multi-lepton signatures with very low SM background.**
- **If strong production is suppressed, EWK processes could be the dominant SUSY production at the LHC. (EWKino < 1 TeV)**
- Search for direct gaugino/stau production with final state: **2tau + MET**

Ditau analysis - SR



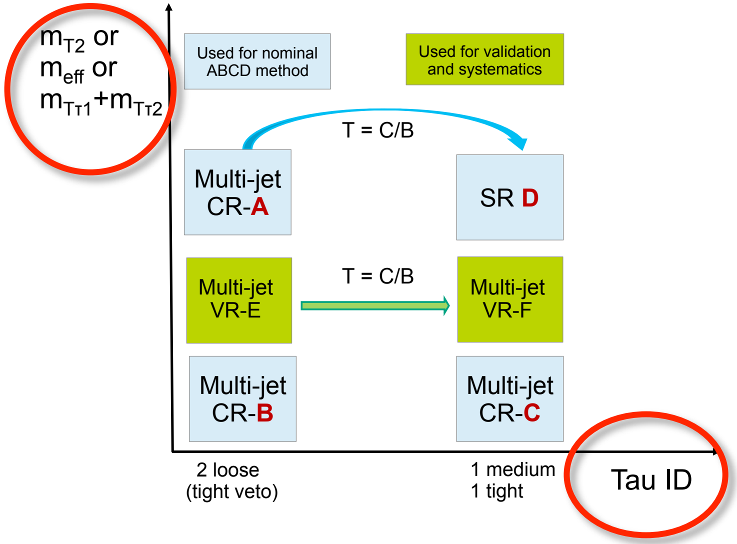
SR-C1N2	SR-C1C1	SR-DS-highMass	SR-DS-lowMass
≥ 2 OS taus	2 OS taus	≥ 2 OS taus	≥ 2 OS taus
b-jet veto	jet veto	looser jet-veto	looser jet-veto
Z-veto	Z-veto	Z-veto	Z-veto
		$\Delta R(\tau,\tau) < 3$	$\Delta R(\tau,\tau) < 3$
$E_{\mathrm{T}}^{\mathrm{miss}} > 40\,\mathrm{GeV}$	$m_{\mathrm{T2}} > 30\,\mathrm{GeV}$	$m_{\mathrm{T2}} > 60\,\mathrm{GeV}$	$m_{\mathrm{T2}} > 30\,\mathrm{GeV}$
$m_{\mathrm{T2}} > 100\,\mathrm{GeV}$	$m_{\mathrm{T}\tau1} + m_{\mathrm{T}\tau2} > 250\,\mathrm{GeV}$	$m_{\mathrm{eff}} > 230\,\mathrm{GeV}$	$m_{\mathrm{eff}} > 260\,\mathrm{GeV}$

- **b-jet veto:** N(B20)=0
- **jet veto:** N(B20)+N(L30)+N(F30)=0
- **looser jet-veto:** N(B20)+N(L50)+N(F3 0)=0

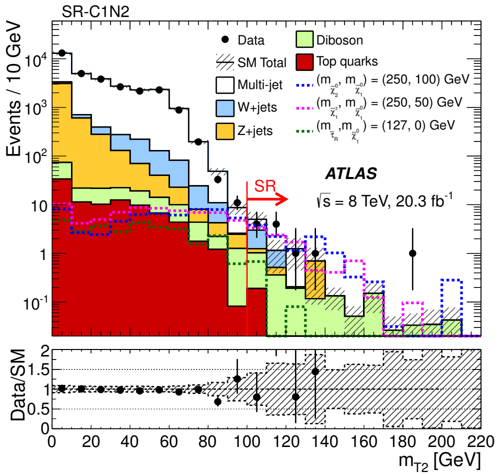
- 4 SRs designed targeting different scenarios: one for C1N2, one for C1C1 and two for Dstau
- Main backgrounds:
  - W+jets (1real+1fake): normalized MC to data in WCR
  - Multi-jet (2fake): ABCD data-driven estimation (next slide)

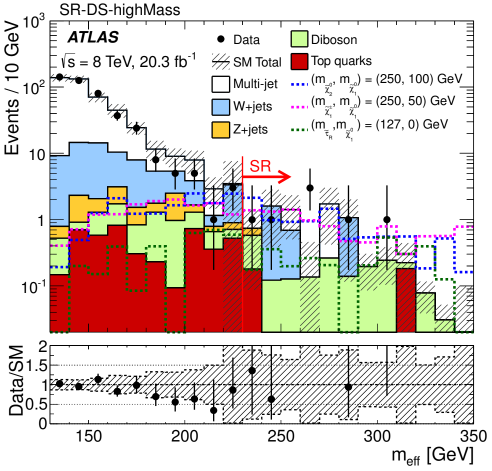
Ditau analysis – results

- **ABCD method:**
  - Define 4 regions from 2 un-correlated variables (Multi-jet CR-A/B/C, SR-D)
  - TF obtained from multi-jet event (low mT2/meff/ mTτ1+mTτ2 region from Data): TF=C/B
  - Extrapolation performed from A to D through TF (D = A * C/B)
- **Validation Region (Multi- jet VR-EF): used for validation and systematics**



No significant excess, set limit

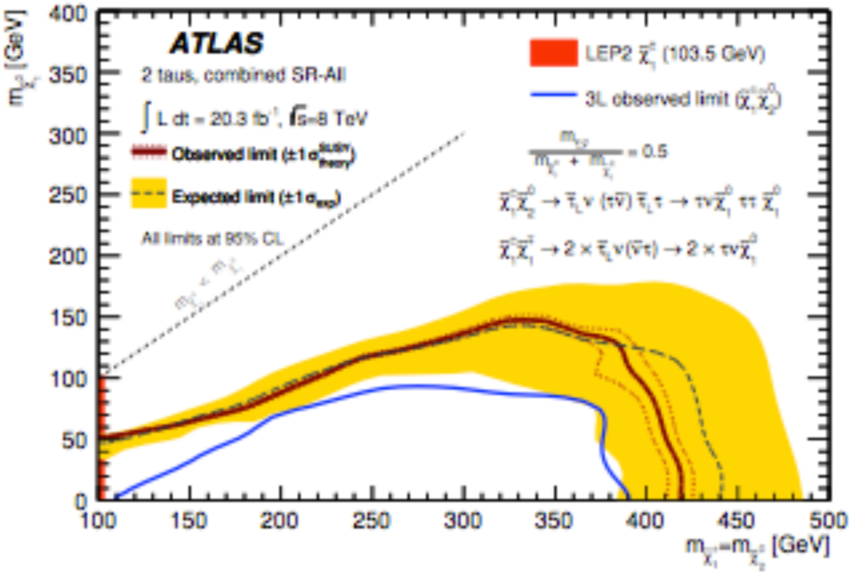




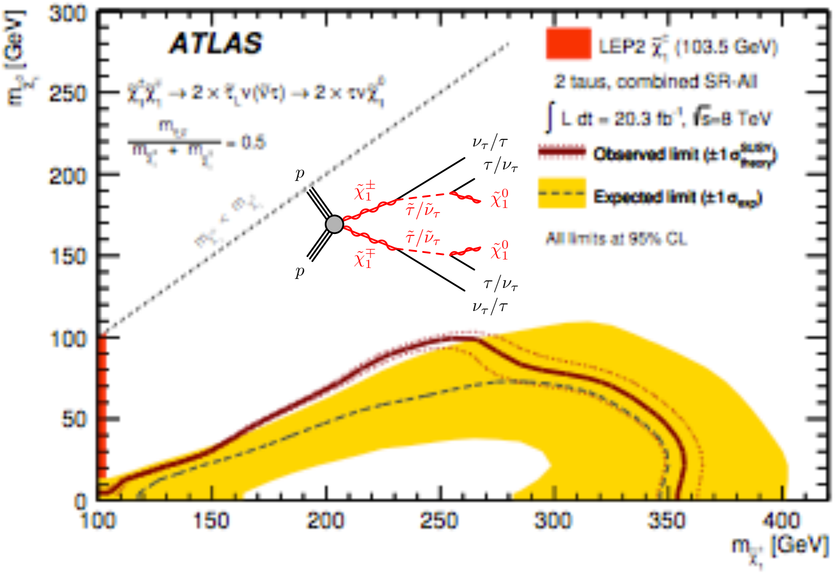
SM process	SR-C1N2	SR-C1C1	SR-DS-highMass	SR-DS-lowMass
Top	0.30 ± 0.19	0.7 ± 0.4	0.9 ± 0.4	1.3 ± 0.6
Z+jets	0.9 ± 0.5	0.20 ± 0.17	0.6 ± 0.4	0.40 ± 0.27
W+jets	2.2 ± 0.8	11.2 ± 2.8	2.7 ± 0.9	4.1 ± 1.2
Diboson	2.2 ± 0.9	3.8 ± 1.4	2.5 ± 1.0	2.9 ± 1.0
Multi-jet	2.3 ± 2.0	5.8 ± 3.3	0.9 ± 1.2	2.8 ± 2.3
SM total	7.9 ± 2.4	22 ± 5	7.5 ± 1.9	11.5 ± 2.9
Observed	11	12	7	15
Ref. point 1	11.3 ± 2.8	8.5 ± 2.2	10.2 ± 2.6	7.5 ± 2.0
Ref. point 2	9.2 ± 2.1	20 ± 4	12.4 ± 2.8	12.8 ± 2.7
Ref. point 3	0.8 ± 0.5	7.6 ± 1.9	3.8 ± 1.0	5.2 ± 1.3
p_0	0.20	0.50	0.50	0.21
Expected $\sigma_{\mathrm{vis}}^{95}$ (fb)	$< 0.42^{+0.19}_{-0.11}$	$< 0.56^{+0.25}_{-0.14}$	$< 0.37^{+0.17}_{-0.10}$	$< 0.51^{+0.18}_{-0.15}$
Observed $\sigma_{\mathrm{vis}}^{95}$ (fb)	< 0.59	< 0.37	< 0.37	< 0.66

Ditau analysis – limit

- Use SR with best expected limit per signal point for all interpretations



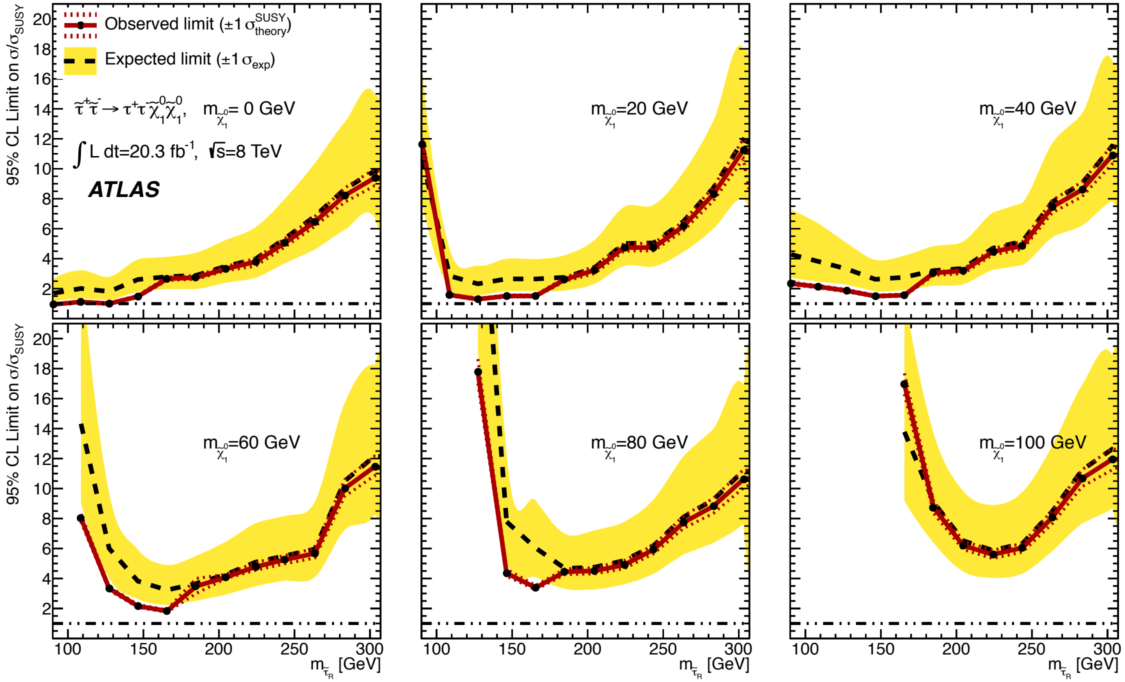
(a) $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ production



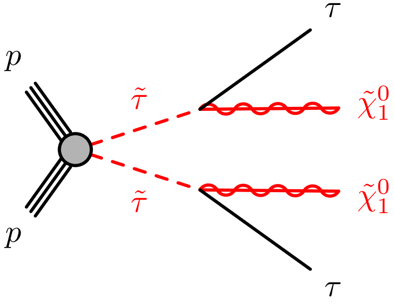
(b) $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ production

- C1N2+C1C1 production: C1/N2 mass up to **410 GeV** excluded for massless N1
- Wino-like Chargino production : C1 mass up to **345 GeV** excluded for a massless lightest N1

Ditau analysis – limit



Signal strength upper limit

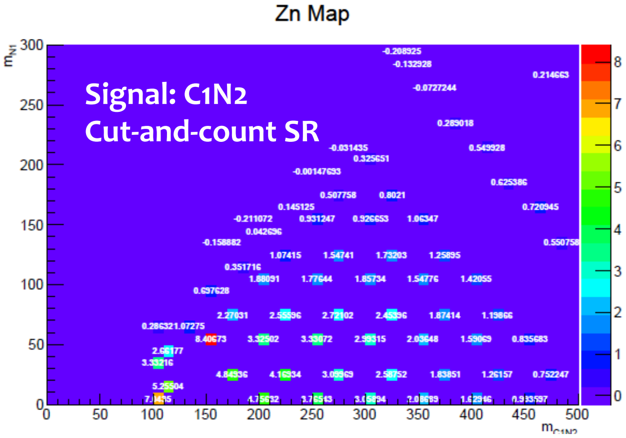


- For **large (low)** stau masses, **SR-DS-highMass (SR-C1C1)** provides the best upper limits
- **Multivariate analysis technique (MVA) has been used for direct stau search by HUAN (co-phd student between CPPM and IHEP), which has been approved by SUSY group for part of legacy/ summary paper.**

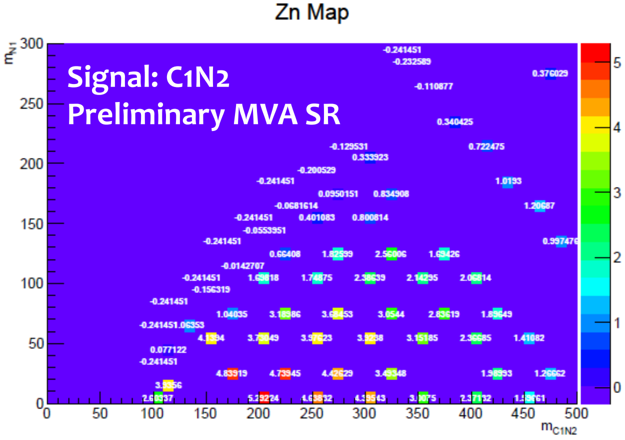
Ditau analysis – Run2 preparations

- **Run-2 preparations already started last year**
  - **13 TeV sensitivity check using pdf reweight from 8 TeV, comparable sensitivity from 10 fb-1@13 TeV with run1 => will combine run1 with run2 for first publication**
  - **SR re-optimization for run2: ongoing**
  - **Preliminary sensitivity checks have been done using MVA methods for 8 TeV samples.**
    - **Already competitive results seen using MVA for C1N2 grid.**
    - **Some hint on discrimination variables from MVA**
- **Will cover more challenge region (already checking in 8 TeV data now)**
  - C1N2 -> Wh (h->tautau): higgsino search
  - Compressed scenario: VBF C1N2/C1C1, ISR jet, …
  - ……

Original Selection



BDT Selection



2. SS2L/3L Analysis @ Run1

- **Target signals with gluino pair or guino-squark pair production resulting 2l SS or 3l final states**
- These SRs increase sensitivity to **longer decay cascades**, compressed mass spectra, 3rd generation squarks …
- This search benefits from low SM bg, it allows the use of relatively loose kinematic requirements on Emiss, increasing the sensitivity to the scenarios with small mass differences between SUSY particles (compressed scenarios) or where R-parity is violated. ➔ **sensitive to a wide variety of models based on very different assumptions.**
- **CPPM made a leading role in this analysis for run1: two PhD students (Otilia Ducu and Julien Maurer) involved in it (the former CPPM student Julien Maurer is co-contactor of this analysis for run2**

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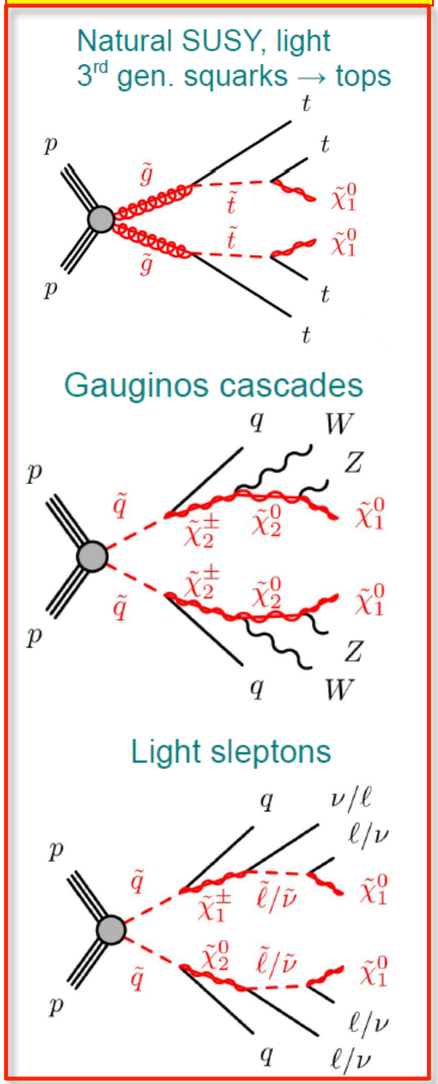
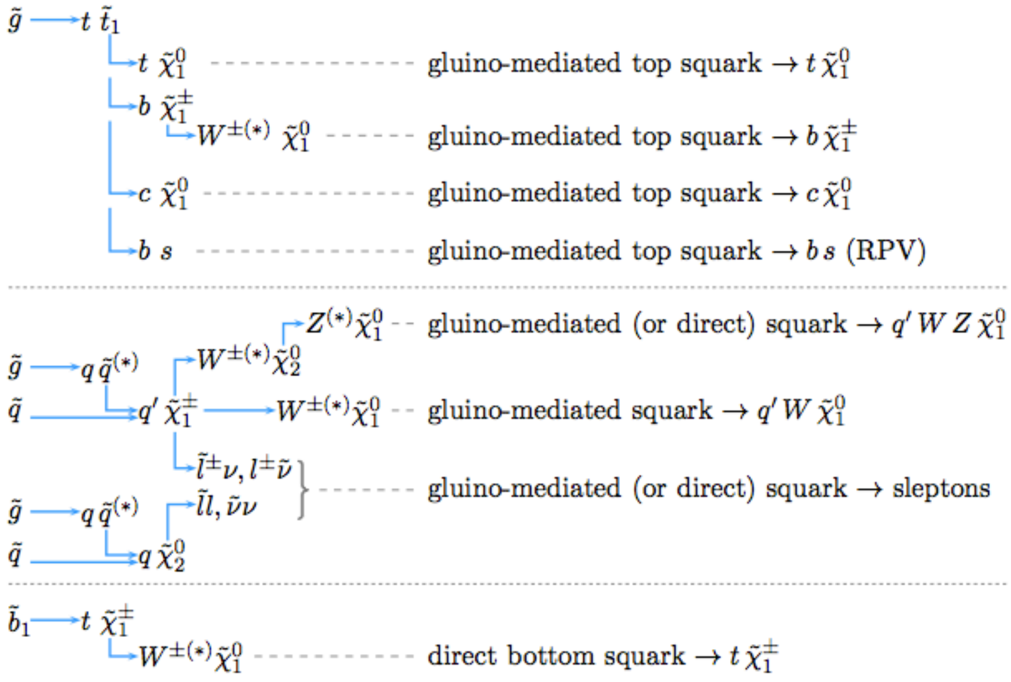

Natural SUSY, light 3rd gen. squarks → tops

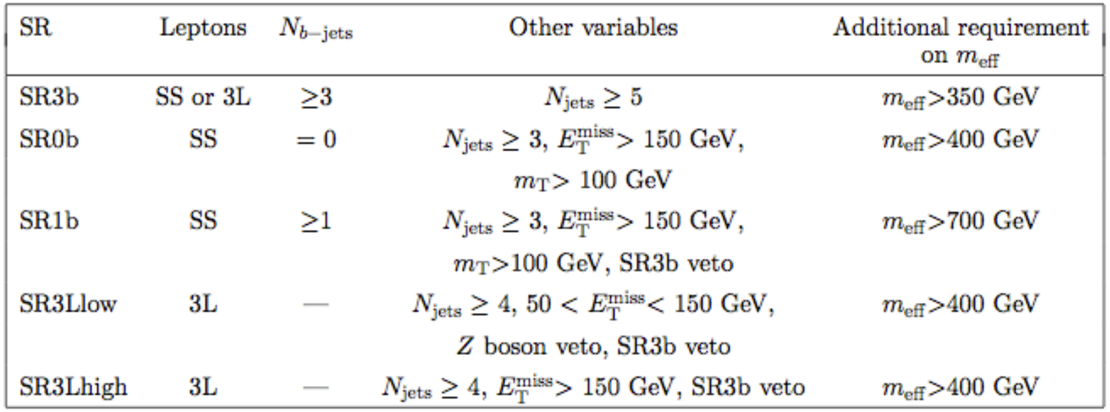
Gauginos cascades

Light sleptons

2. SS2L/3L Analysis @ Run1

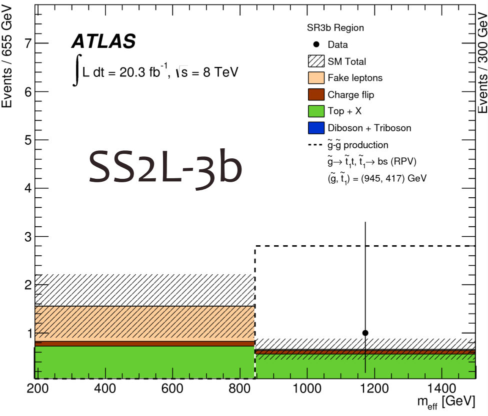
- **5 SRs with SS2L + 0 or 1 or 3 bjets, or 3L**
  - few SRs, but sensitive to many models
  - great discovery potential
  - Discriminating variable: **Meff, MET**
- Same Sign 2L: very clean channels with only tiny SM bg (mainly top+V, diboson, tri-boson)
  - Most data-driven
  - Fake lepton: MM
  - Charge mis-measurement: likelihood fit method (two Z control samples: OS, SS)
  - Others: MC

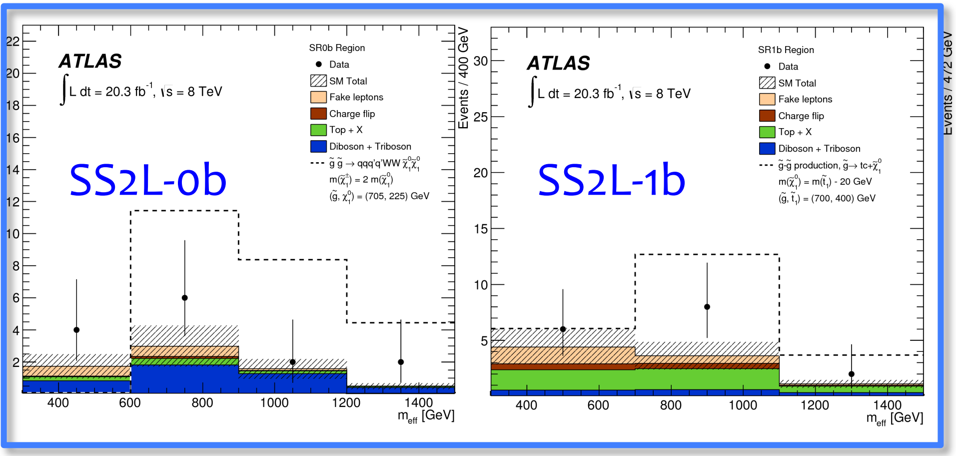


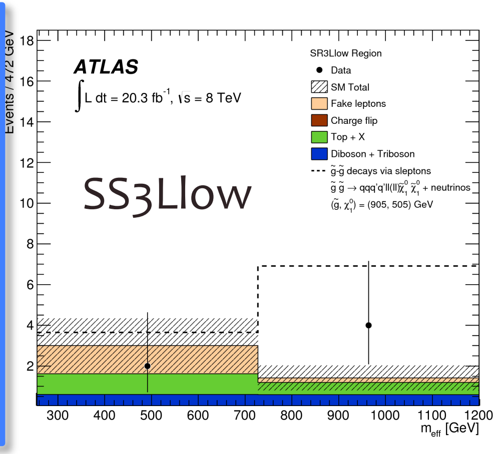


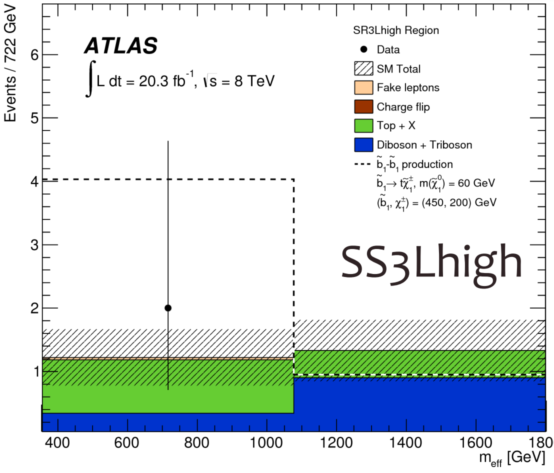
SR	Leptons	$N_{b-\text{jets}}$	Other variables	Additional requirement on m_{eff}
SR3b	SS or 3L	≥3	$N_{\text{jets}} \geq 5$	m_{eff}>350 GeV
SR0b	SS	= 0	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV	m_{eff}>400 GeV
SR1b	SS	≥1	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV, SR3b veto	m_{eff}>700 GeV
SR3Llow	3L	—	$N_{\text{jets}} \geq 4$, 50 < E_T^{miss}< 150 GeV, Z boson veto, SR3b veto	m_{eff}>400 GeV
SR3Lhigh	3L	—	$N_{\text{jets}} \geq 4$, E_T^{miss}> 150 GeV, SR3b veto	m_{eff}>400 GeV

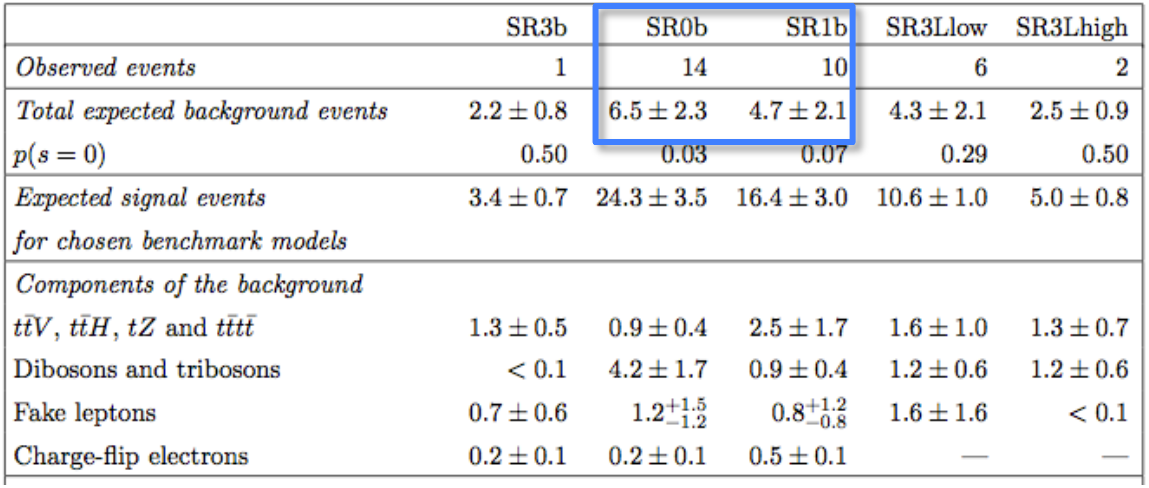
SS2L/3L Analysis @ Run1







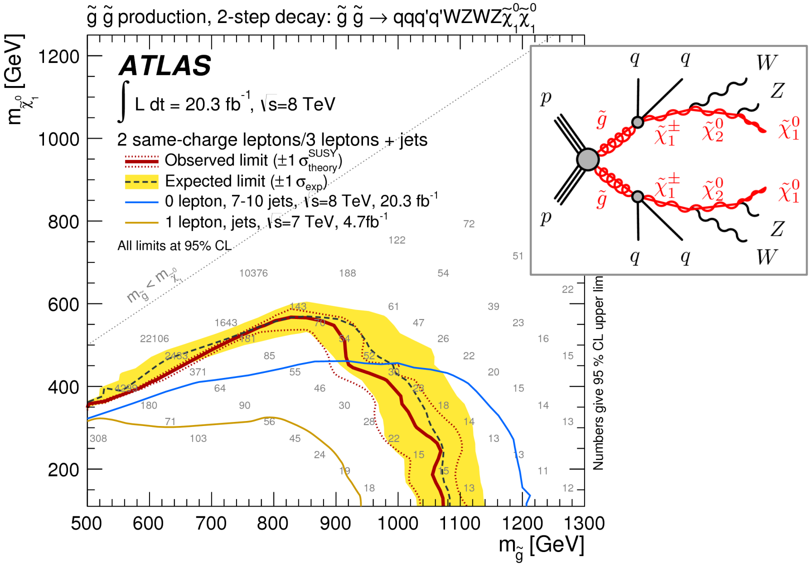


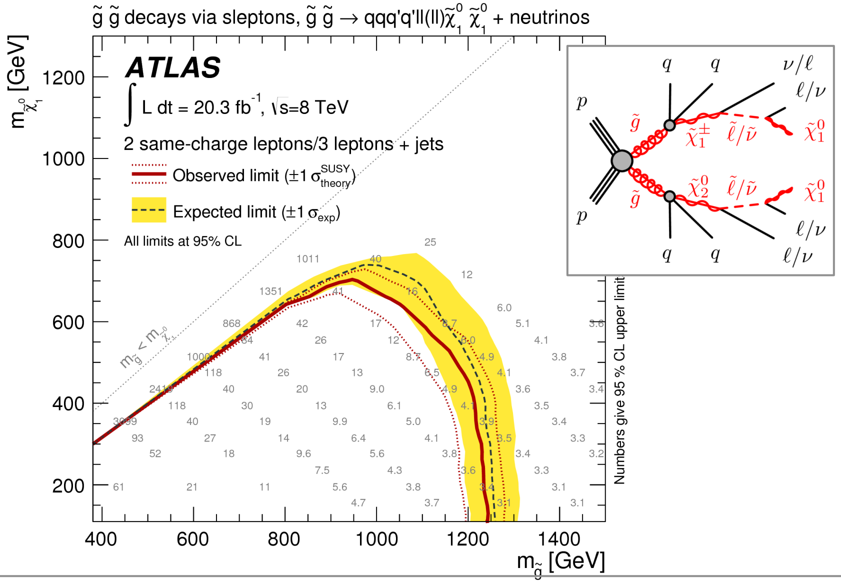


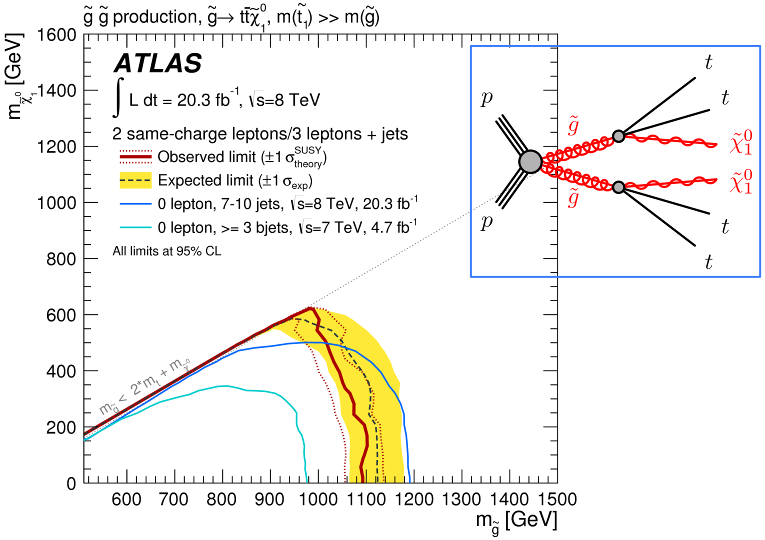
	SR3b	SR0b	SR1b	SR3Llow	SR3Lhigh
Observed events	1	14	10	6	2
Total expected background events	2.2 ± 0.8	6.5 ± 2.3	4.7 ± 2.1	4.3 ± 2.1	2.5 ± 0.9
$p(s = 0)$	0.50	0.03	0.07	0.29	0.50
Expected signal events	3.4 ± 0.7	24.3 ± 3.5	16.4 ± 3.0	10.6 ± 1.0	5.0 ± 0.8
for chosen benchmark models					
Components of the background					
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	1.3 ± 0.5	0.9 ± 0.4	2.5 ± 1.7	1.6 ± 1.0	1.3 ± 0.7
Dibosons and tribosons	< 0.1	4.2 ± 1.7	0.9 ± 0.4	1.2 ± 0.6	1.2 ± 0.6
Fake leptons	0.7 ± 0.6	$1.2^{+1.5}_{-1.2}$	$0.8^{+1.2}_{-0.8}$	1.6 ± 1.6	< 0.1
Charge-flip electrons	0.2 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	—	—

- **No significant excess for SR3b, SR3L**
- **Small excess on SR0b (1.8σ) and SR1b (1.5σ), SR0b+SR1b: 2.1σ**

SS2L/3L Analysis @ Run1







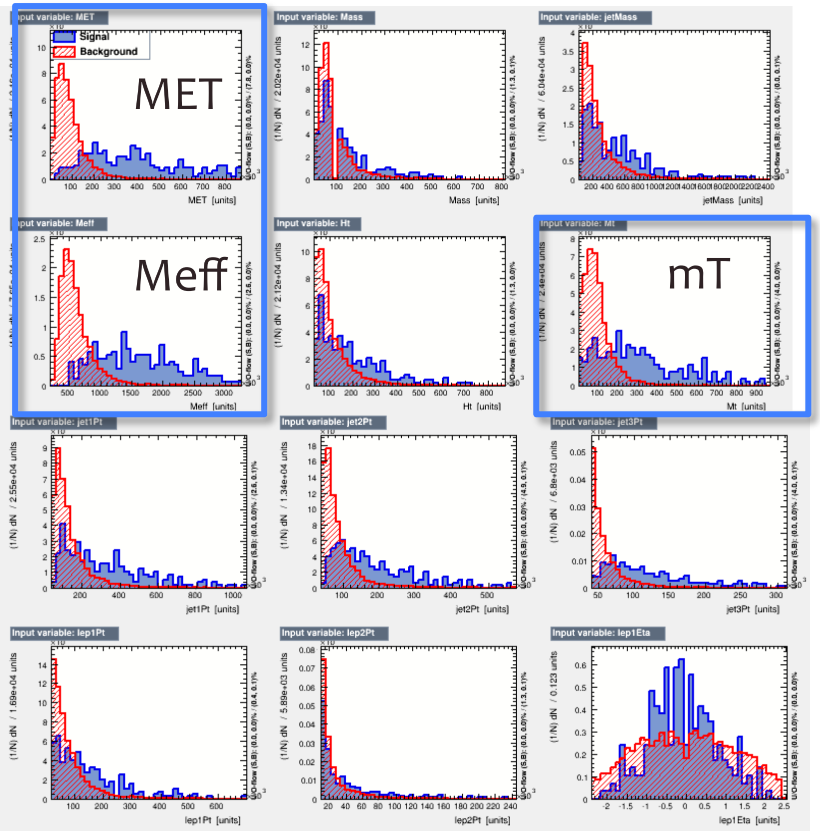
- Gluino-mediated top squark scenarios, favored by naturalness arguments, are excluded for **$m_{\tilde{g}}$ < [600–1000] GeV**, largely independently of the top squark mass and decay mode.
- Similar limits are placed on **gluino-mediated production** of first- and second- generation quarks for $m_{\tilde{\chi}_{01}}$ < [300–600] GeV.
- Many other interpretation in paper

SS2L/3L Analysis: Run2 preparation

- **From RUN1:**
  - Very clean channels with only tiny SM bg, and most of the BGs estimated from data, not too much dependent on MC

    ➔ **aim to very first publication for first several fb-1 run2 data, which is one of the most several promising analyses**
- **Manpower from CPPM+IHEP:**
  - **Run1: Otilia Ducu (PhD student) and Julien Maurer (former CPPM PhD student, now co-contacts of this analysis for run2)**
  - **Run2: 3 PhD students (Huan Ren, Sebastian Kahn, Otilia Ducu) and 5 seniors**
- **CPPM+IHEP Response for:**
  - **Optimized SR definition from cut-and-count (considering new discrimination variable from MVA)**
  - **BG data-driven estimation, like fake-bjet for SR3b (MM, which is validation due to low statistics for run1)**
  - **Systematics and final results …**

SS2L/3L Analysis: Run2 preparation

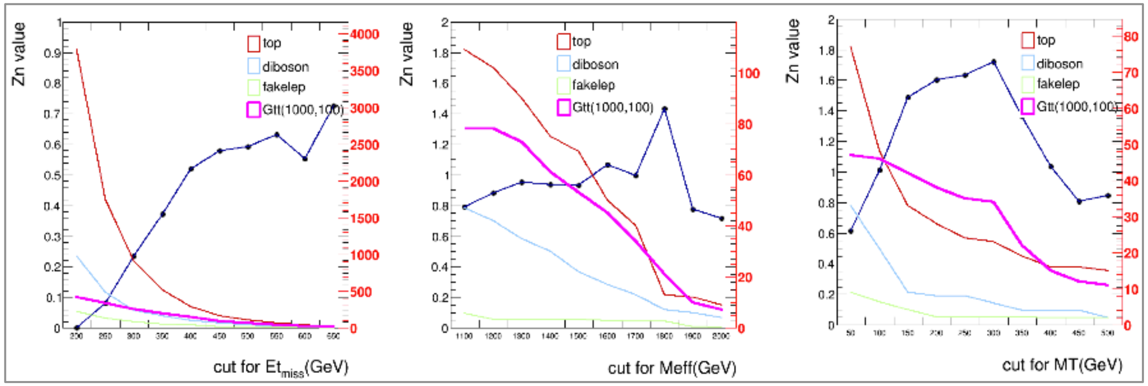


- Already checked with MVA for SR0b, will move on to SR1b
- Not too much gain from MVA since most powerful variables already used in the paper (Meff, MET), will add mT in SR optimization
- Using cut-and-count, given a very preliminary on SR1b definition: MET>450GeV, Meff>1600GeV， Mt>150GeV, will further optimize considering MVA hint

CPPM
/IHEP

variable	separation
Meff	0.62
MET	0.61
Mt	0.42
jet3Pt	0.4
jet2Pt	0.36
jet1Pt	0.31
lep1Pt	0.17
Ht	0.16
Mjj	0.15
let1Eta	0.12
Mll	0.07
lep2Pt	0.07

variable	importance
Meff	0.11
MET	0.11
jet3Pt	0.09
Mt	0.09
lep2Pt	0.09
lep1Pt	0.08
Ht	0.08
lep1Eta	0.08
jet1Pt	0.07
jet2Pt	0.07
Mjj	0.06
Mll	0.04

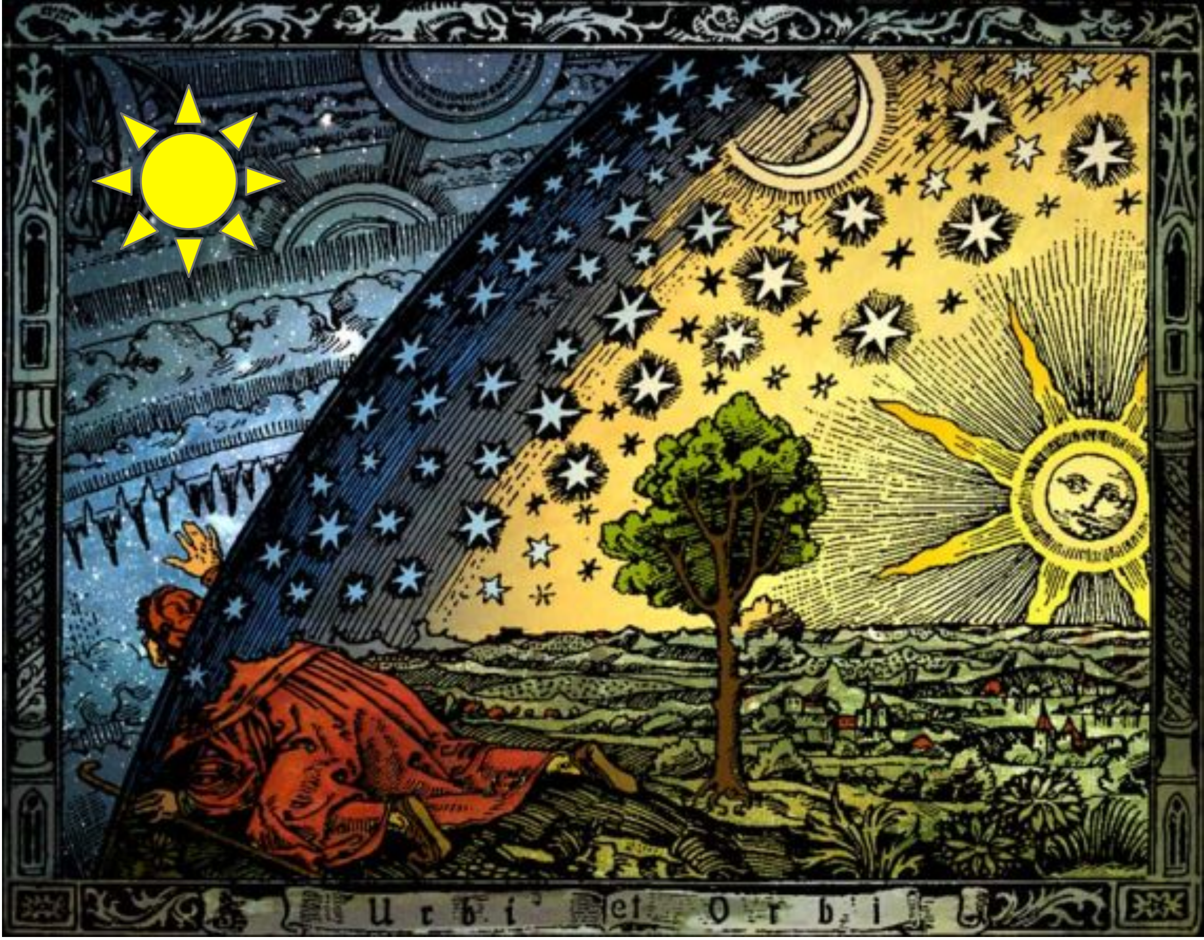


Outlook and Summary

- **Fruitful results from Run-1 for CPPM and IHEP**
  - ☐ Electro-weak SUSY search with at least 2taus
  - ☐ Electro-weak SUSY search with at least 2 leptons
  - ☐ Higgsino analysis from Wh->1lbb
  - ☐ Inclusive SUSY search with lepton
  - ☐ Inclusive SUSY search with tau+X
  - ☐ Inclusive SUSY search with SS 2 leptons/3L

- **Corporation from CPPM and IHEP for run2 on SS 2L/3L**
  - ☐ Already started & look forward to Run-2!

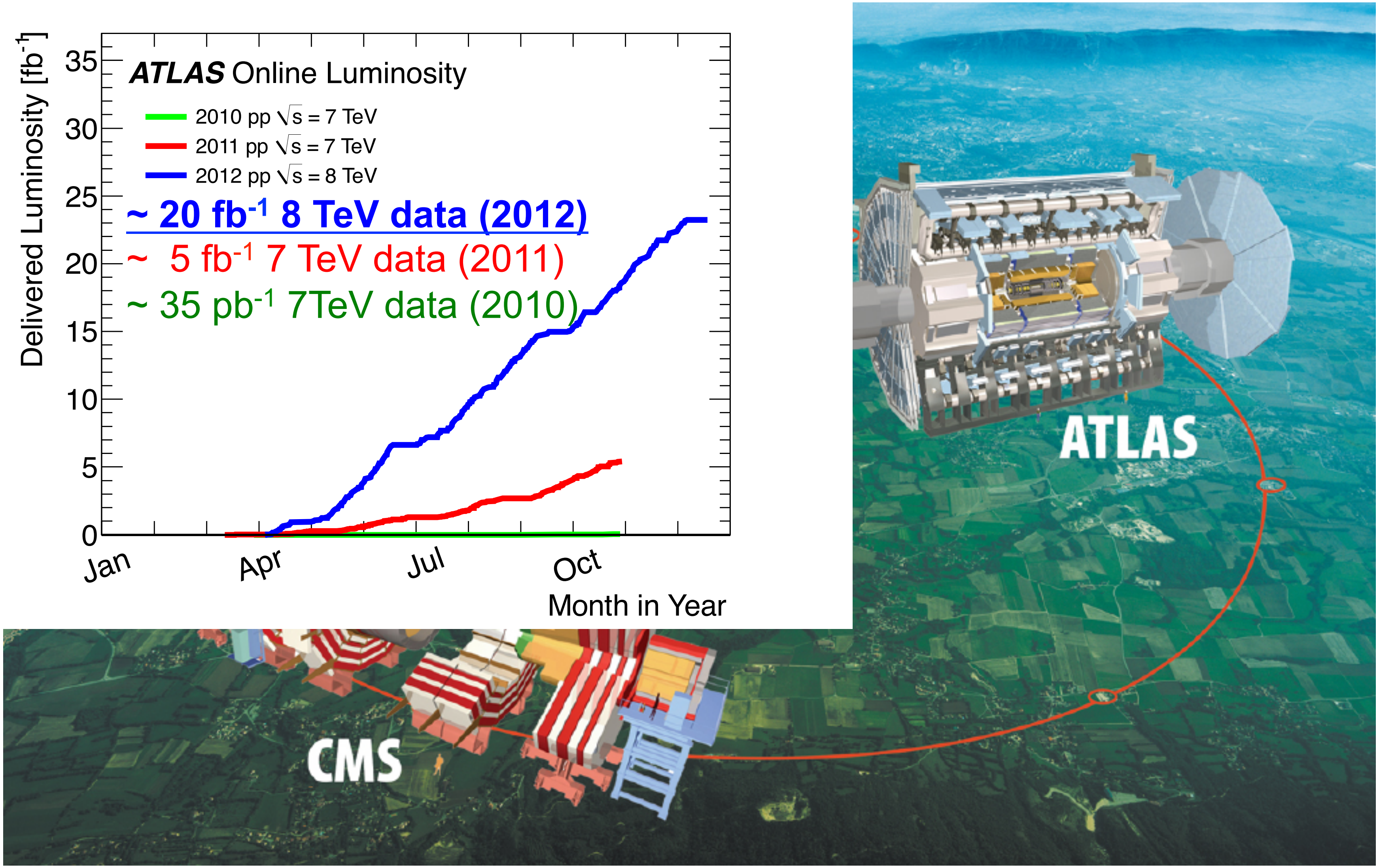
Exciting times are ahead of us !



THANKS FOR YOUR ATTENTION!

☺

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



~ 20 fb^{-1} 8 TeV data (2012)

~ 5 fb^{-1} 7 TeV data (2011)

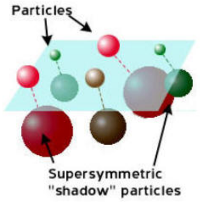
~ 35 pb^{-1} 7TeV data (2010)

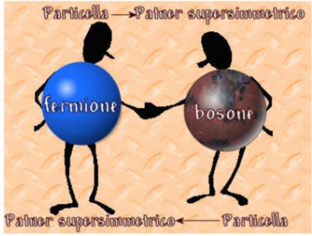
SUSY models: good sale in market

- ☐ Simplified Models:
  - Not really a model (Br~100%, most masses fixed at high scales)
  - Important tool for interpretation
- ☐ Phenomenological models:
  - pMSSM: captures "most" of phenomenologic features of R-parity conserving MSSM
    - 19 free parameters: M1,M2,M3 ; tan β, μ and $m_{A;}$ 10 sfermion mass parameters; A_t, A_b and A_T
    - Comprehensive and computationally realistic approximation of the MSSM with neutralino LSP
  - GGM (gravitino)
- ☐ Complete SUSY models: mSUGRA, GMSB …

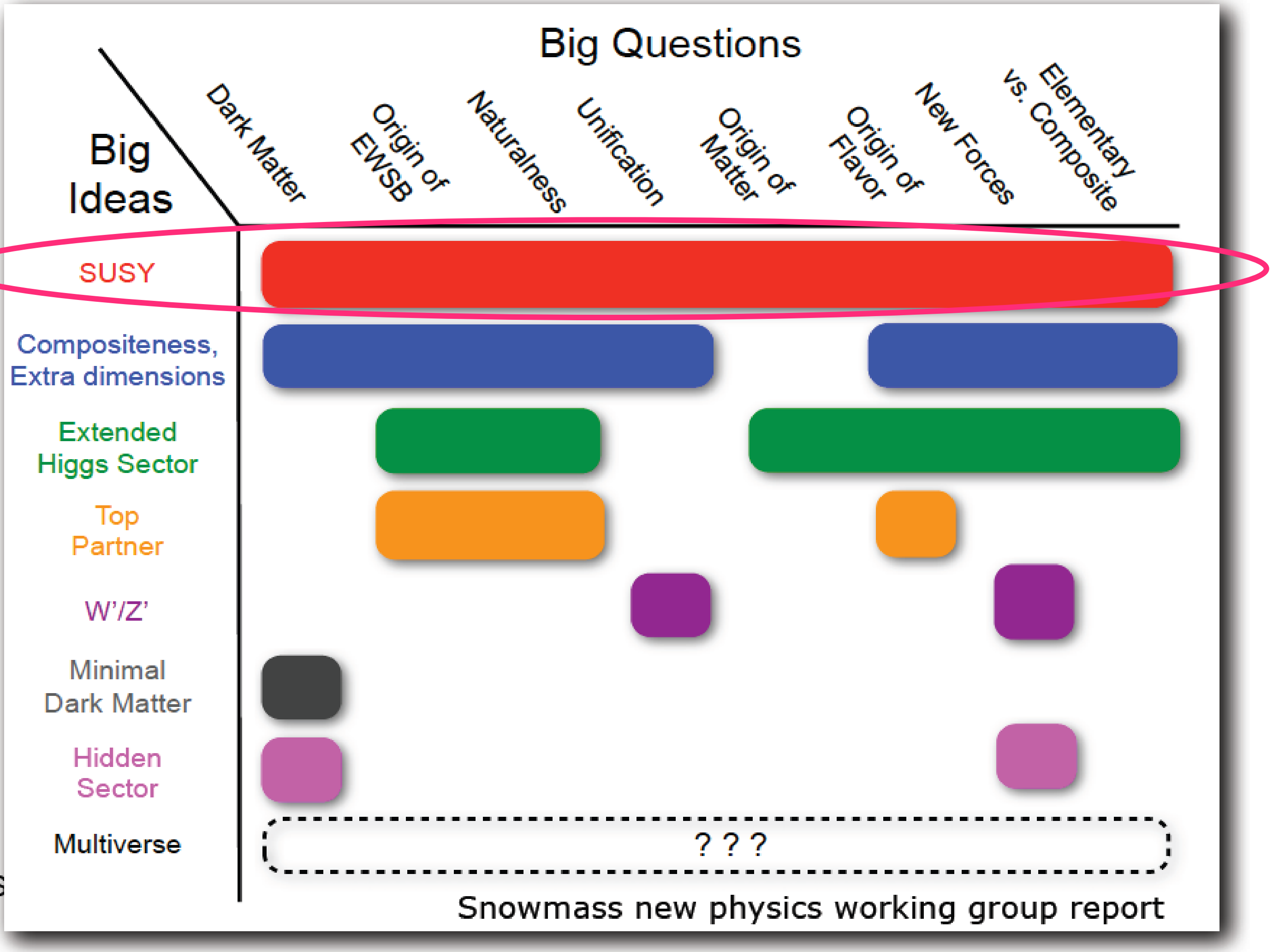
Outline

- SUSY Introduction
- SUSY Search Results in Run1
- Preparation for Run2
- Outlook and Summary





New Physics beyond the SM



Big Questions

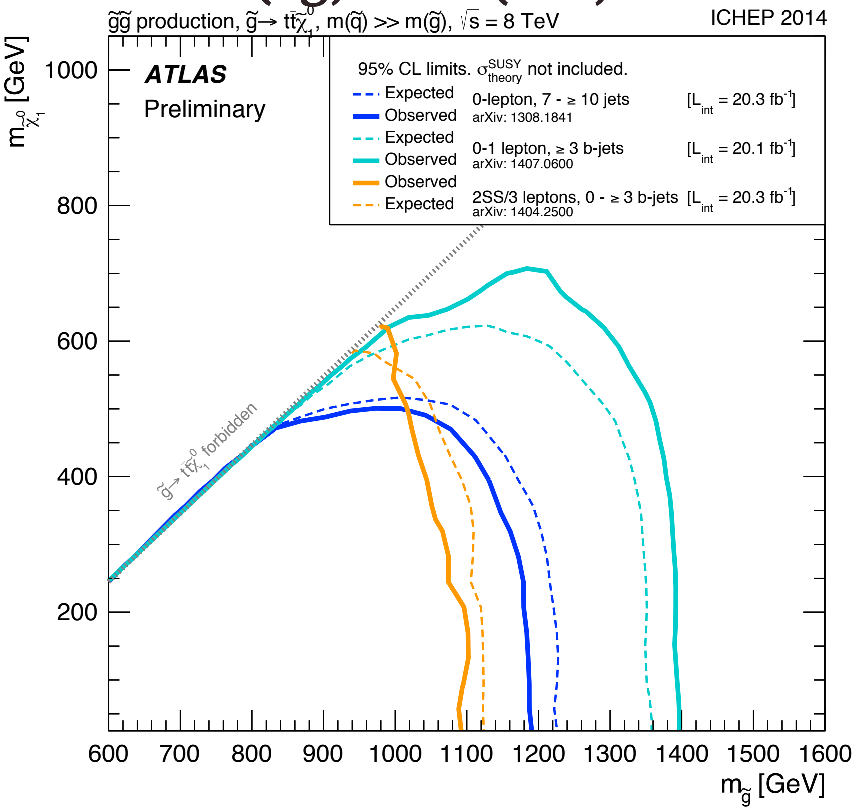
Big Ideas	Dark Matter	Origin of EWSB	Naturalness	Unification	Origin of Matter	Origin of Flavor	New Forces	Elementary vs. Composite
SUSY	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Compositeness, Extra dimensions	🟦	🟦	🟦	🟦		🟦	🟦	🟦
Extended Higgs Sector		🟩	🟩		🟩	🟩	🟩	🟩
Top Partner		🟧	🟧			🟧		
W'/Z'				🟪			🟪	
Minimal Dark Matter	⬛							
Hidden Sector	🟪						🟪	
Multiverse	? ? ?							

Snowmass new physics working group report

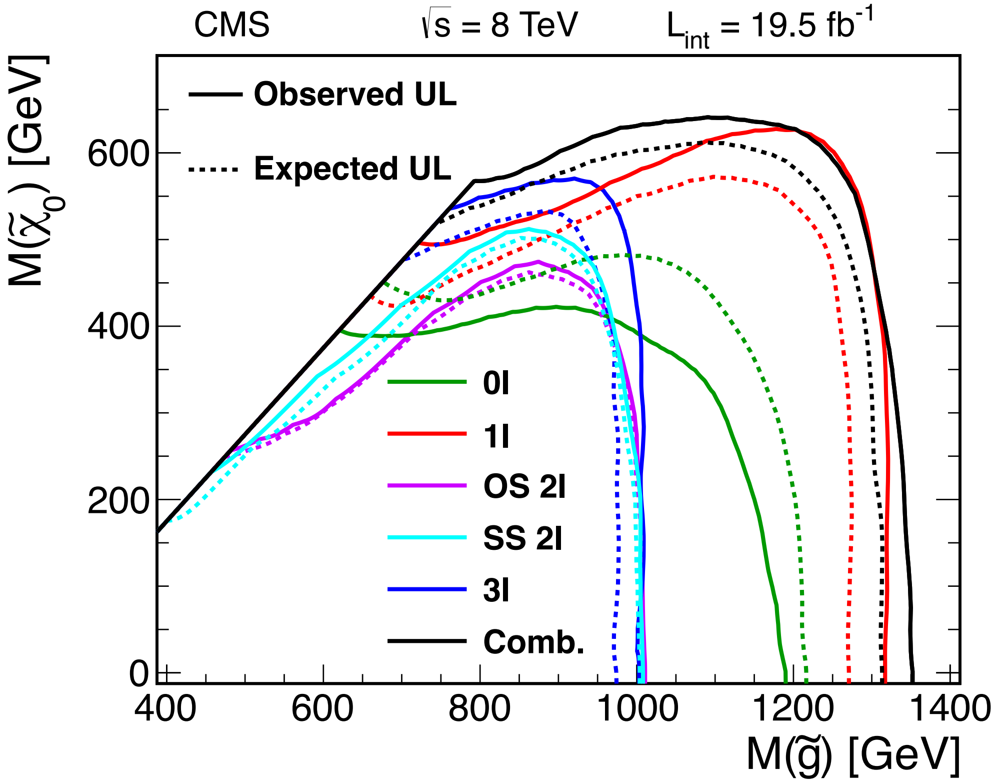
S. S

Inclusive search for squark and gluino production Summary

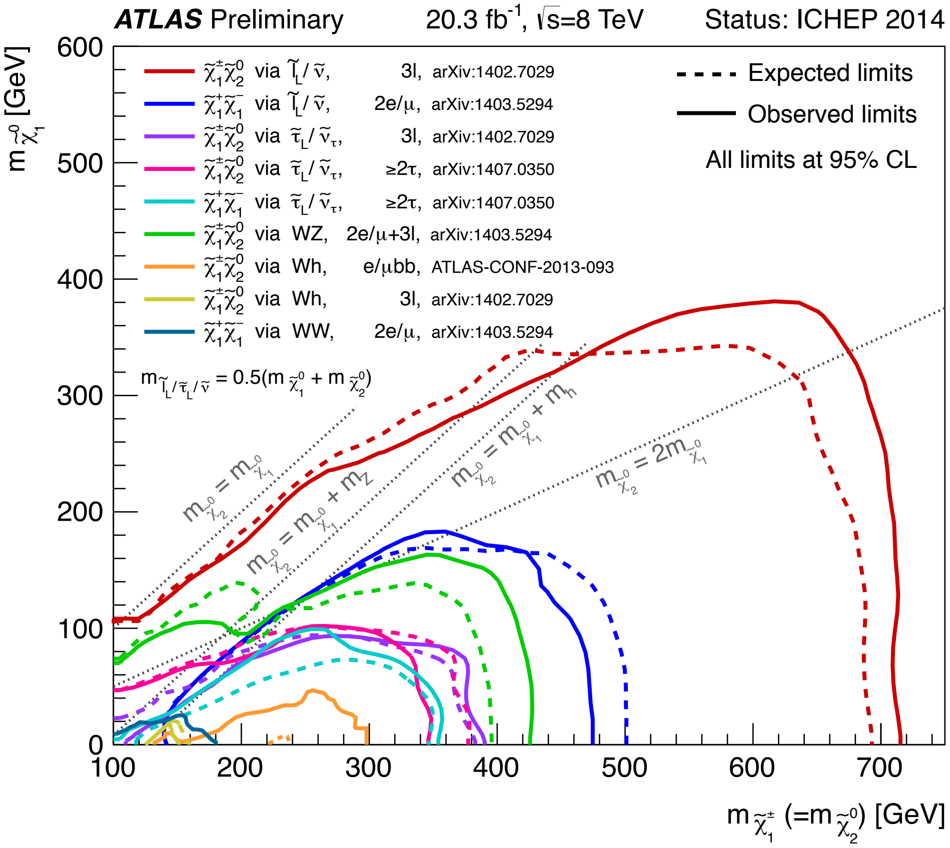
M(~g) .vs. m(LSP)

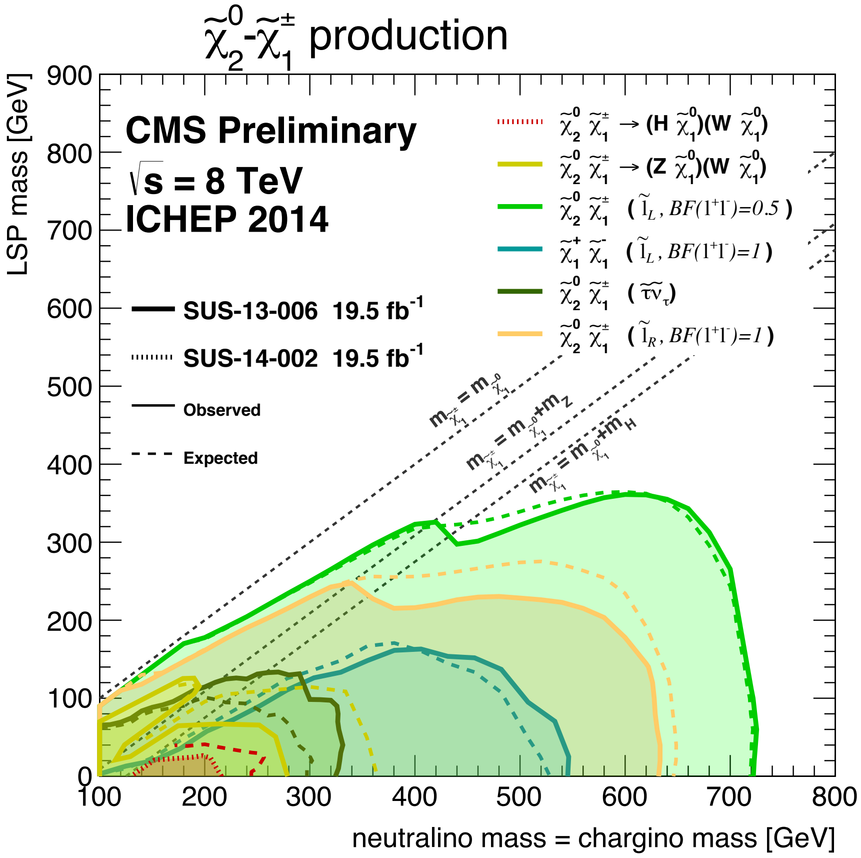


CMS: PAS-SUS-14-010(NEW)



ElectroWeak Production Summary



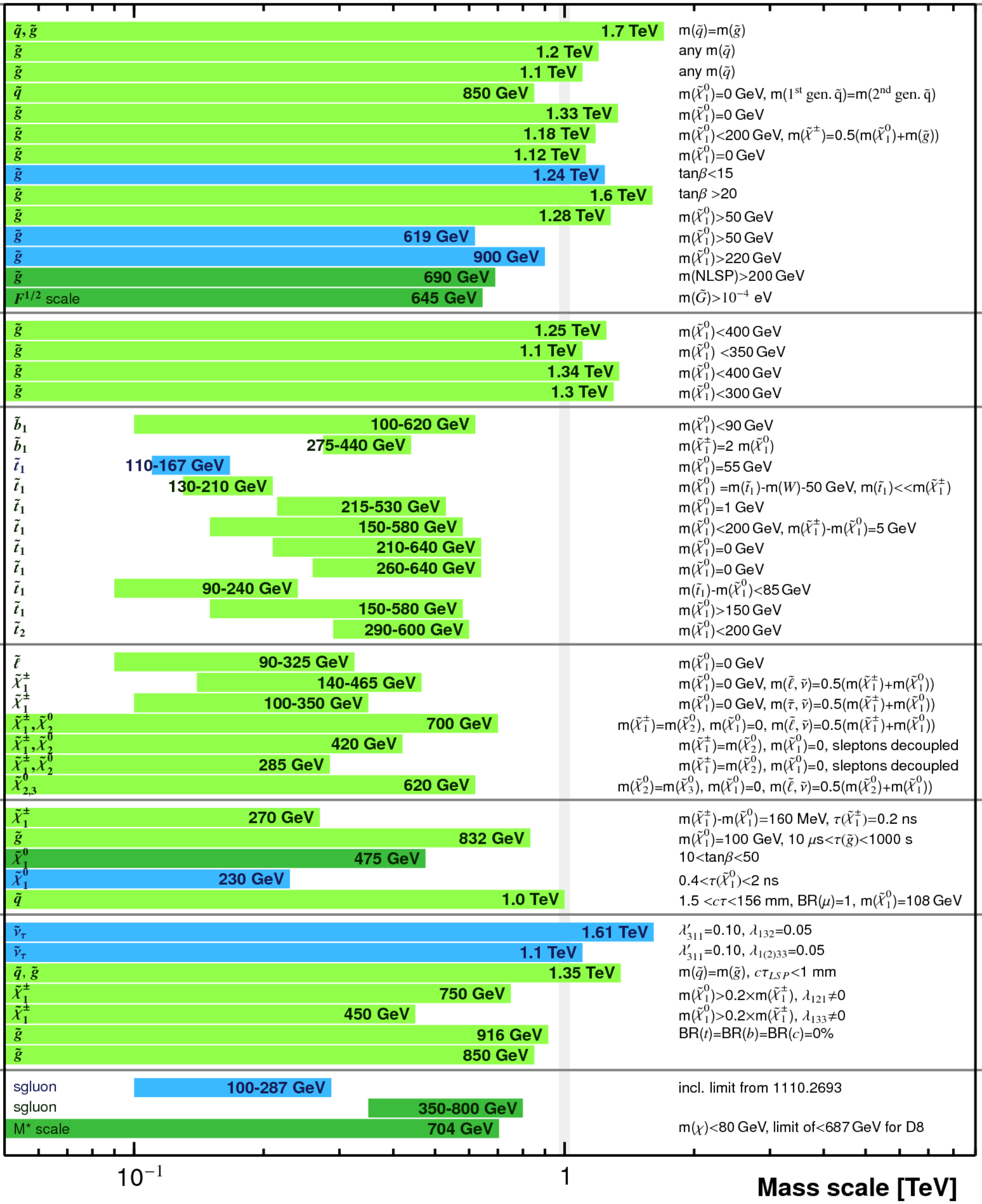


- Comparable for C1N2 via slepton
- CMS: SS improvement in compressed region; no results on C1C1 via stau and WW
- ATLAS: more results for compressed scenario will be ready soon

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

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



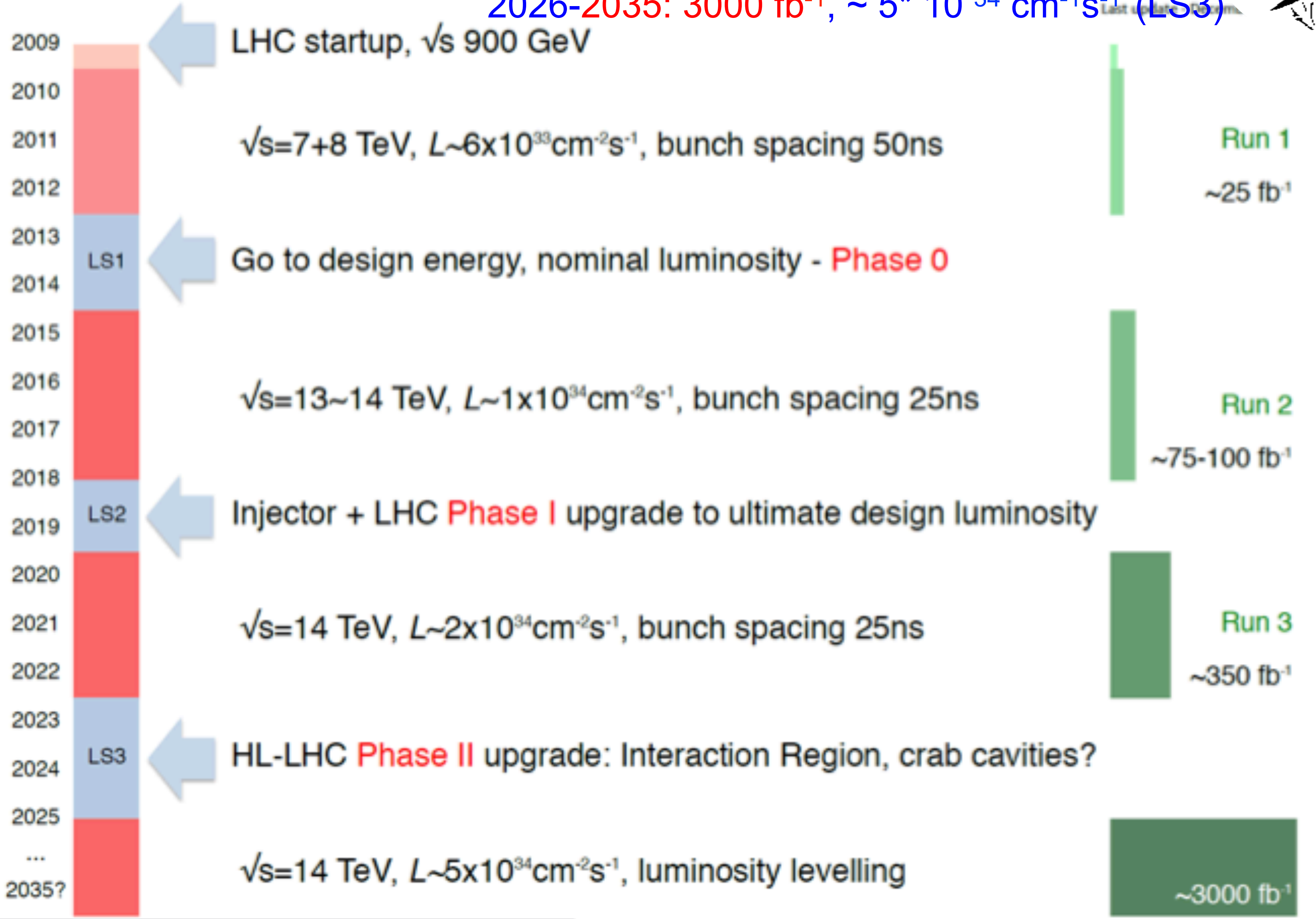
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1405.7875
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any m($\tilde{q}$)	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any m($\tilde{q}$)	1308.1841
	$\tilde{q}\tilde{q}$, $\tilde{q} \to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1^{st} gen. $\tilde{q}$)=m(2^{nd} gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g} \to qq\tilde{\chi}_1^{\pm} \to qqW^{\pm}\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}$, $\tilde{g} \to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 e, μ + γ	-	Yes	4.8	$\tilde{g}$	619 GeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	m($\tilde{\chi}_1^0$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	m($\tilde{G}$)>10^{-4} eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g} \to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \to t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	m($\tilde{\chi}_1^{\pm}$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	m($\tilde{\chi}_1^0$)=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1 \to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-210 GeV	m($\tilde{\chi}_1^0$) =m($\tilde{t}_1$)-m(W)-50 GeV, m($\tilde{t}_1$)<<m($\tilde{\chi}_1^{\pm}$)	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1 \to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$	215-530 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1 \to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20	$\tilde{t}_1$	210-640 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1 \to t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$	260-640 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2 \to \tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell} \to \ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+ \to \tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$	140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+ \to \tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	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($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	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, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	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, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0 \to \tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ 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 MeV, τ($\tilde{\chi}_1^{\pm}$)=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0 \to \tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0 \to \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<τ($\tilde{\chi}_1^0$)<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0 \to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}_1^0$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp \to \tilde{\nu}_{\tau} + X$, $\tilde{\nu}_{\tau} \to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_{\tau}$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp \to \tilde{\nu}_{\tau} + X$, $\tilde{\nu}_{\tau} \to e(\mu) + \tau$	1 e, μ + τ	-	-	4.6	$\tilde{\nu}_{\tau}$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+ \to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to ee\tilde{\nu}_{\mu}, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), λ_{121}≠0	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+ \to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_{\tau}$	3 e, μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), λ_{133}≠0	1405.5086
	$\tilde{g} \to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
Other	Scalar gluon pair, sgluon→$q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon→$t\bar{t}$	2 e, μ (SS)	2 b	Yes	14.3	sgluon	350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	m(χ)<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

🟦 $\sqrt{s}$ = 7 TeV full data
🟩 $\sqrt{s}$ = 8 TeV partial data
🟩 $\sqrt{s}$ = 8 TeV full data

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

LHC roadmap

2015-2017: 100 fb^{-1}, ~ 1* 10 ^{34} cm^{-1}s^{-1} (LS1)
2020-2022: 300 fb^{-1}, ~ 2* 10 ^{34} cm^{-1}s^{-1} (LS2)
2026-2035: 3000 fb^{-1}, ~ 5* 10 ^{34} cm^{-1}s^{-1} (LS3)



LHC startup, $\sqrt{s}$ 900 GeV

$\sqrt{s}$=7+8 TeV, $L\sim6\times10^{33}$cm^{-2}s^{-1}, bunch spacing 50ns

Go to design energy, nominal luminosity - Phase 0

$\sqrt{s}$=13~14 TeV, $L\sim1\times10^{34}$cm^{-2}s^{-1}, bunch spacing 25ns

Injector + LHC Phase I upgrade to ultimate design luminosity

$\sqrt{s}$=14 TeV, $L\sim2\times10^{34}$cm^{-2}s^{-1}, bunch spacing 25ns

HL-LHC Phase II upgrade: Interaction Region, crab cavities?

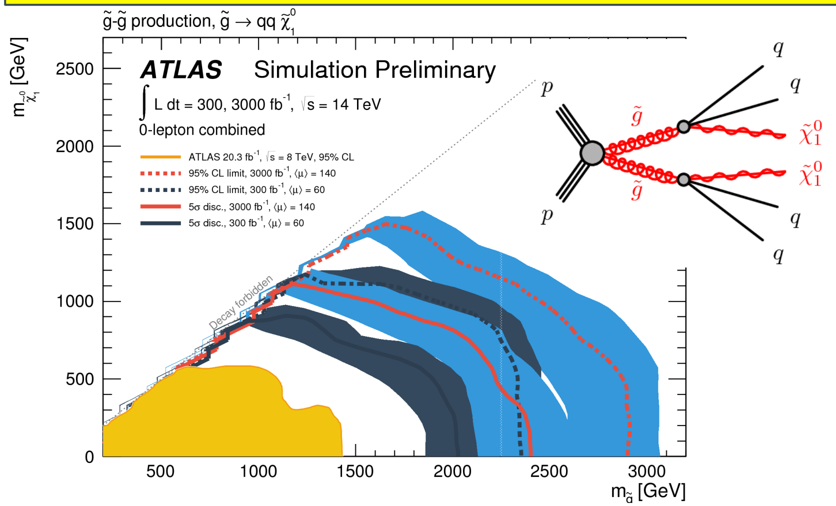
$\sqrt{s}$=14 TeV, $L\sim5\times10^{34}$cm^{-2}s^{-1}, luminosity levelling

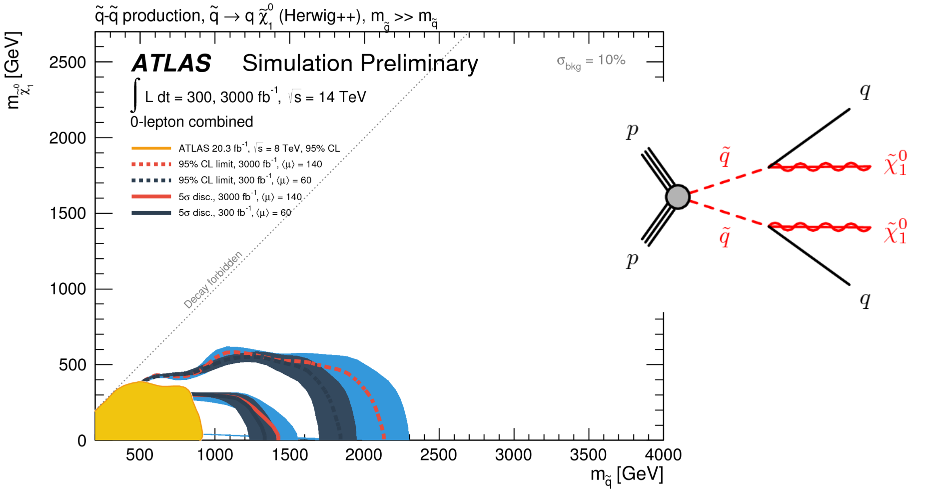
From LHCC Open meeting, 03.12.2013

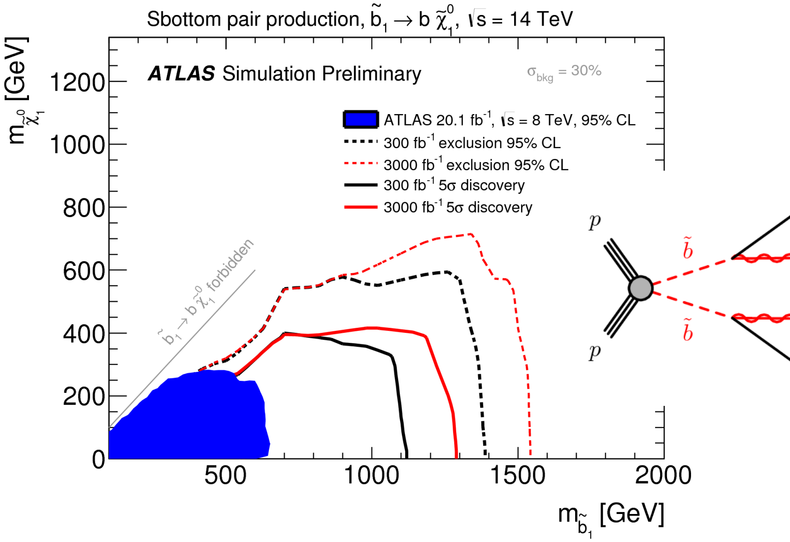
Long term prospects

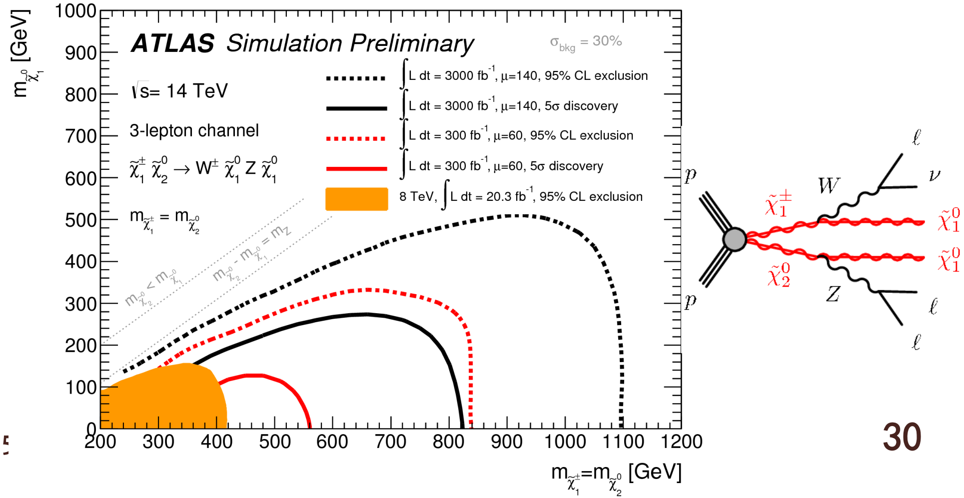
ATL-PHYS-PUB-2014-010

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







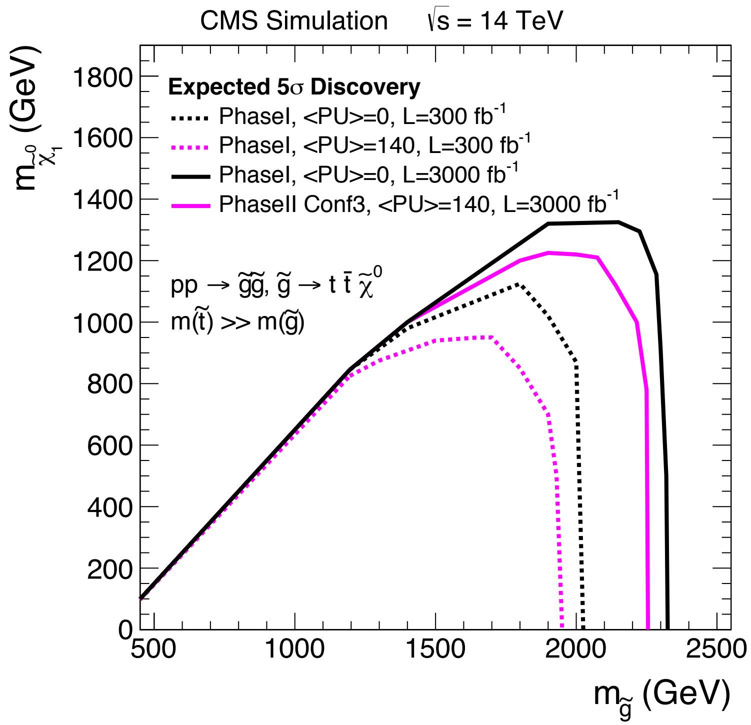


Long-term prospects

CMS and ATLAS studied long-term prospects for the (HL) LHC.

- with 300 and 3000 /fb at 14 TeV
- searches for gluino-mediated stop production reach beyond 2 TeV
- searches for direct stop production reach well beyond 1 TeV

CMS PAS FTR-13-014



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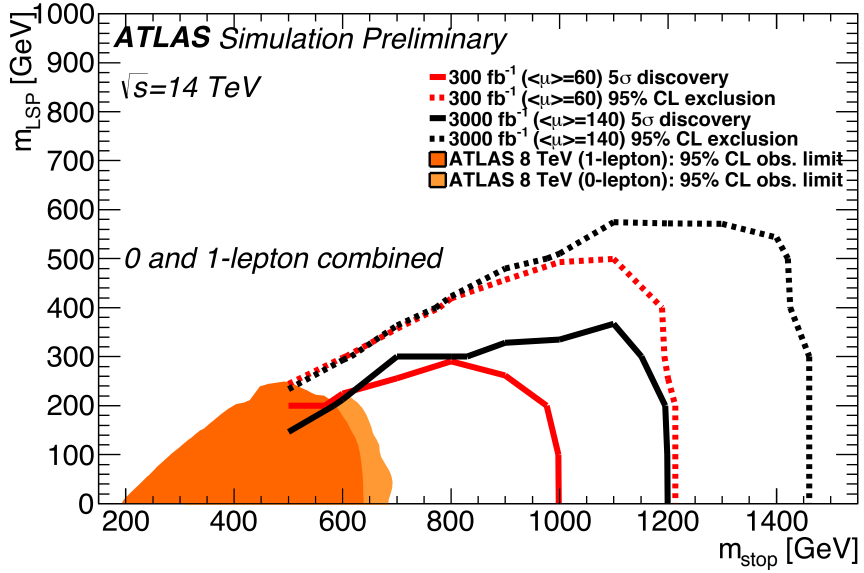


Interpretation strategy

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

Likelihood function: L(μ,θ)

μ: signal strength (POI);

θ: nuisance parameters(NP)

Profile Likelihood: constrain uncertainty (NP) as part of a likelihood fit

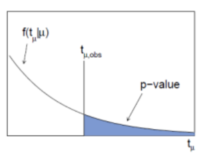
Construct test statistics t_μ based on likelihood ratio λ:

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

$$t_\mu = -2\ln\lambda(\mu)$$

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

Construct the PDF of test statistic t_μ: generate toy Monte Carlo or using asymptotic formula



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

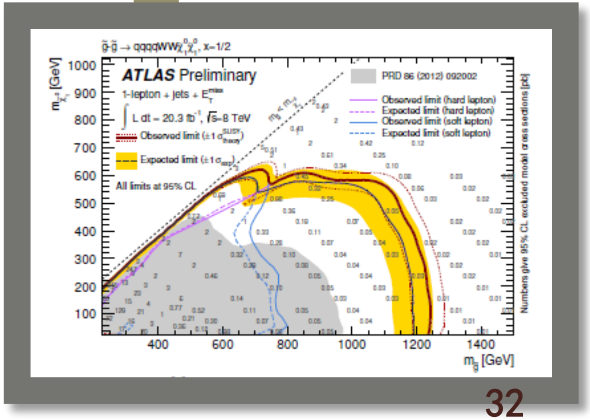
$$p_\mu = \int_{t_{\mu,\mathrm{obs}}}^{\infty} f(t_\mu|\mu)\,dt_\mu$$

If CLs<0.05: the value of signal is excluded at 95% CL……….

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

The above check has been done for each signal grid points on the SUSY model.

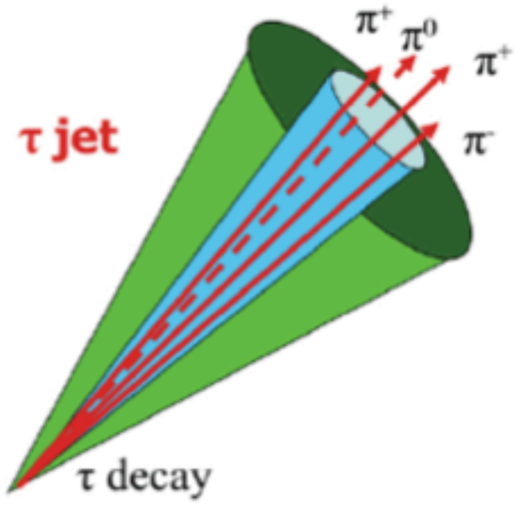
The line can be drawn for the area where points are excluded



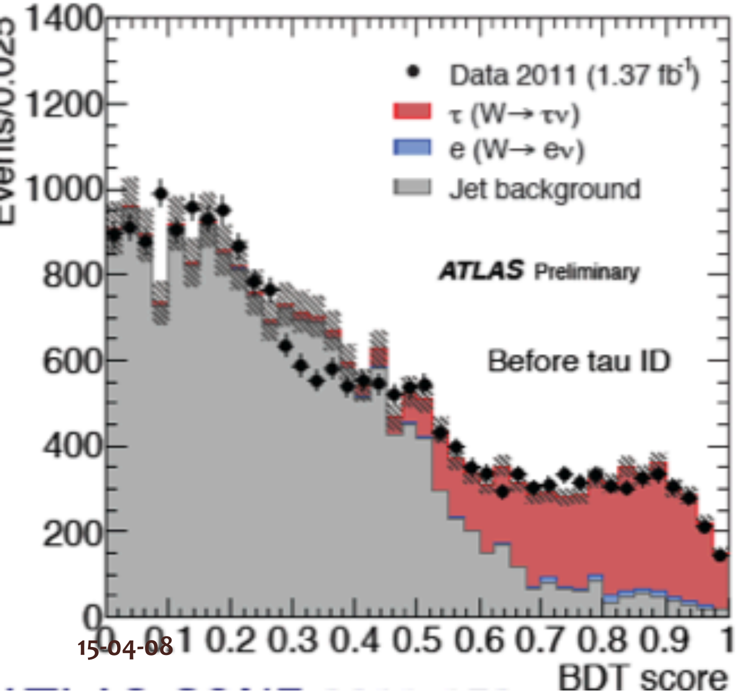
Simultaneous fit

- 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 uncerts in SR.

Hadronic Taus



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



Tau Object

- ▷ $p_T > 20$ GeV, $|\eta| < 2.5$
- ▷ 1 or 3 tracks with total charge ±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