Strongly interacting new physics: experimental prospects

Physics at the HL-LHC workshop May 2015
ATLAS and CMS results

12-May-2015

Sascha Caron (Nikhef and RU Nijmegen)

Outline:

- Intro and Expectations for early Run-1
- Run-2 simplified models and MSSM points :

a) 1st and 2nd gen. squarks and gluinos

b) sbottom and stop

Early run-2 projection studied

First showing early run-2 projection studies *(squarks, gluinos, sbottoms) for comparison*

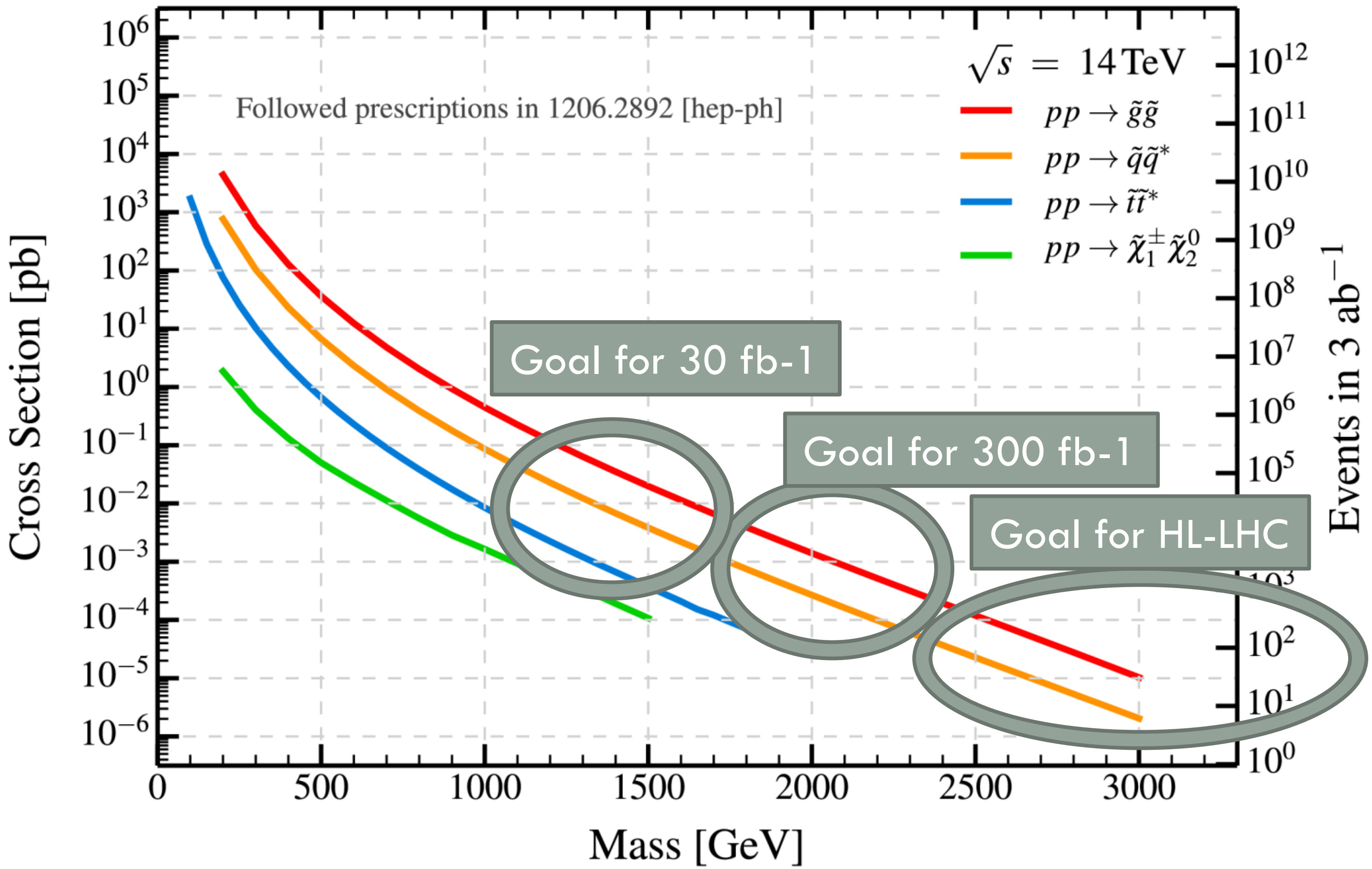
Expected timeline/ Luminosities:

2 fb-1 by "summer 2015", 10 fb-1 in the first year of Run-2 and 100 fb-1 by 2018.

Expected cross sections:

Physics process	cross section (pb) at 8 TeV	cross section (pb) at 13 TeV	
$t\bar{t}$	252	831	
W+jets	12087	20080	*2-3
Z+jets	1122	1906	
gluino pair production with $m_{\tilde{g}}$ of 1350 GeV	0.0013	0.034	
gluino pair production with $m_{\tilde{g}}$ of 1500 GeV	0.00039	0.014	*10-50
bottom-squark pair production with $m_{\tilde{b}_1}$ of 700 GeV	0.0081	0.067	

Where are we going?



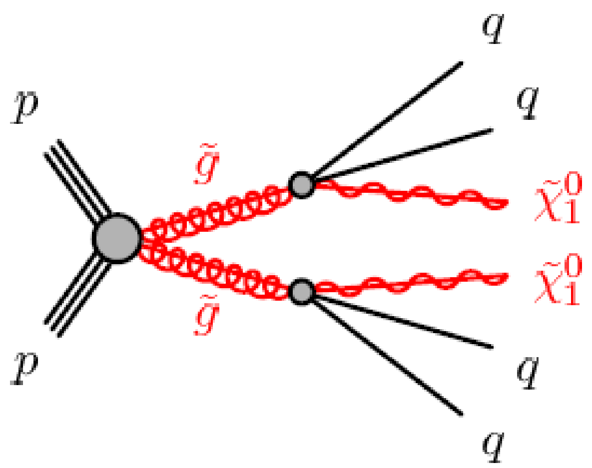
Early run-2 projection studied

Setup:

- *Samples at 13 TeV*
- *Fast and full (Geant) simulation*
- *NLO ttbar+Pythia (Powheg), W/Z+jets (Sherpa), SUSY and ttbar+V (Madgraph)*
- *Generated with 20-40 interactions per bunch crossing*

Early run-2 projection studied

Event section follows closely Run-1:
- 5-jets for gluinos, effective mass cut
Harsher for higher luminosities
- Studies assume massless neutralino

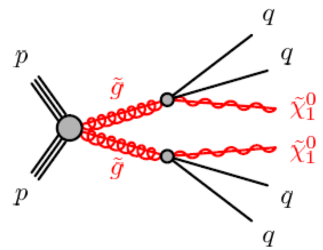


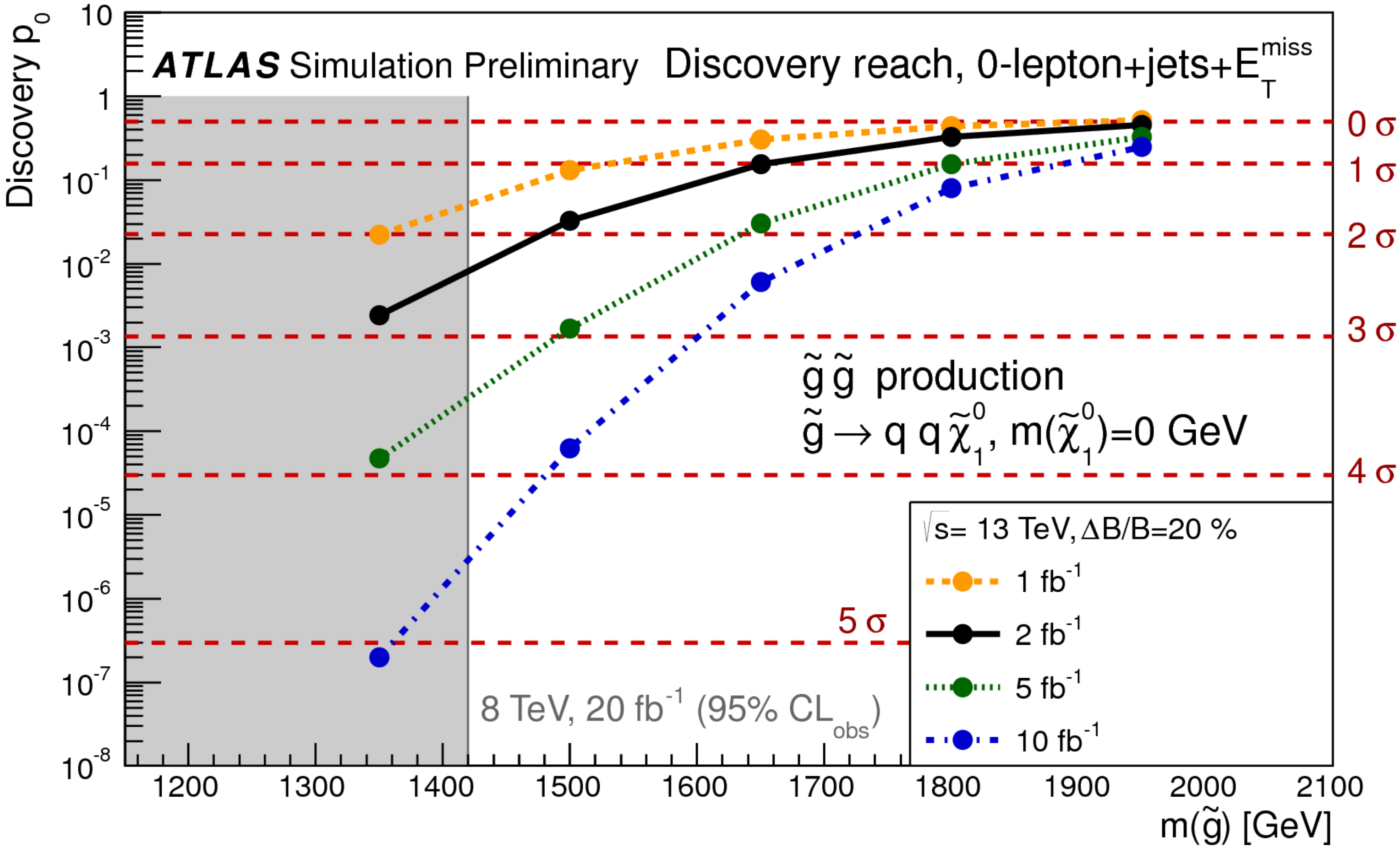
100% BR, all other SUSY particles decoupled/heavy.

Table 2: Optimised m_{eff}(incl.) selections in 5-jet signal region that target heavy gluinos with a hypothesis of 20% total uncertainties on the background prediction and integrated luminosities of 1, 2, 5, and 10 fb^{-1}. The total expected background yields after that m_{eff}(incl.) selection are listed with MC statistical uncertainty, respectively.

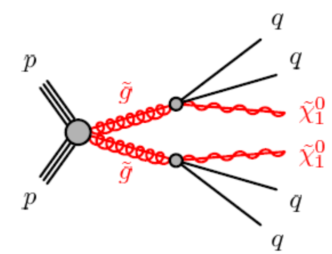
$\mathcal{L}_{int}$ (fb^{-1})	Mass of target gluinos (GeV)	m_{eff}(incl.) (GeV)	Total expected background yields
1	1350	> 2200	3.3 ± 0.5
2	1350	> 2400	3.3 ± 0.3
5	1500	> 2600	4.3 ± 0.5
10	1650	> 2600	8.7 ± 1.0

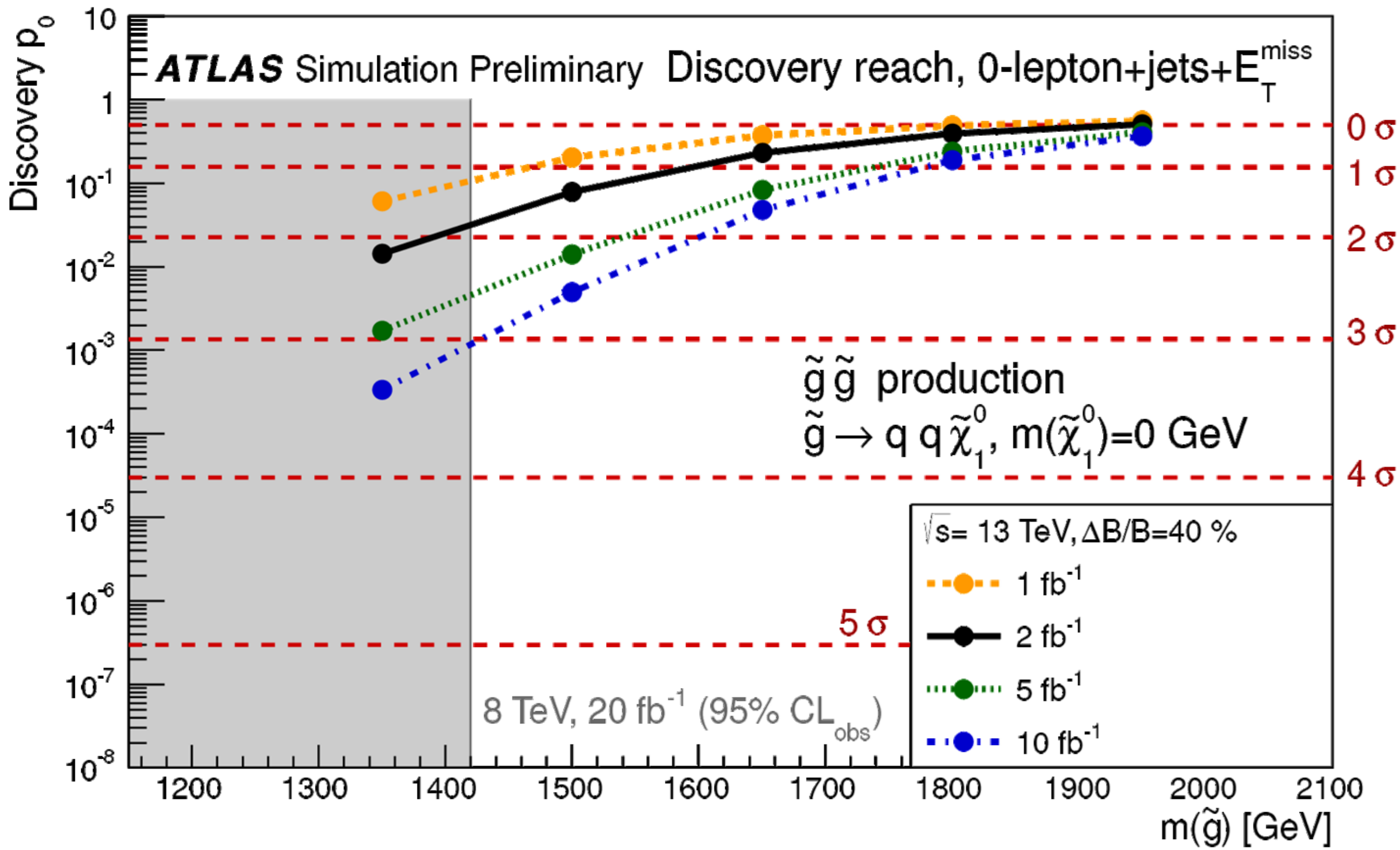
Early run-2 projection studied





Early run-2 projection studied





Summary Run-2 with 10 fb-1

- Simplified Gluino Model:

  Exclusion reach 1600-1700 GeV

  Discovery reach: **probably later with assumed systematics**
- Simplified Sbottom Model:

  Exclusion reach 900 GeV

  Discovery reach: **probably later with assumed systematics**

2014-2015 LHC-14 prospects

- **ATLAS: Strong SUSY production: What is our discovery and exclusion reach with HL-LHC ?**

  - squarks and gluinos vs neutralino mass HL-LHC

  - sbottom and stop vs neutralino mass HL-LHC

- **CMS: If evidence for a spectrum of new particles is discovered, an extensive program of measurements will be required to determine its properties.**

  - Signal scenarios inspired by minimal fine-tuning (naturalness) studied in detail

  - All hadronic, sbottom, stop and monojet searches targeting these scenarios

2014-2015 LHC-14 prospects

- **ATLAS: Strong SUSY production: What is our discovery and exclusion reach with HL-LHC ?**

  - squarks and gluinos vs neutralino mass HL-LHC

  - sbottom and stop vs neutralino mass HL-LHC

- **CMS: If evidence for a spectrum of new particles is discovered, an extensive program of measurements will be required to determine its properties.**

  - Signal scenari[…]ning (naturalness) studi[…]

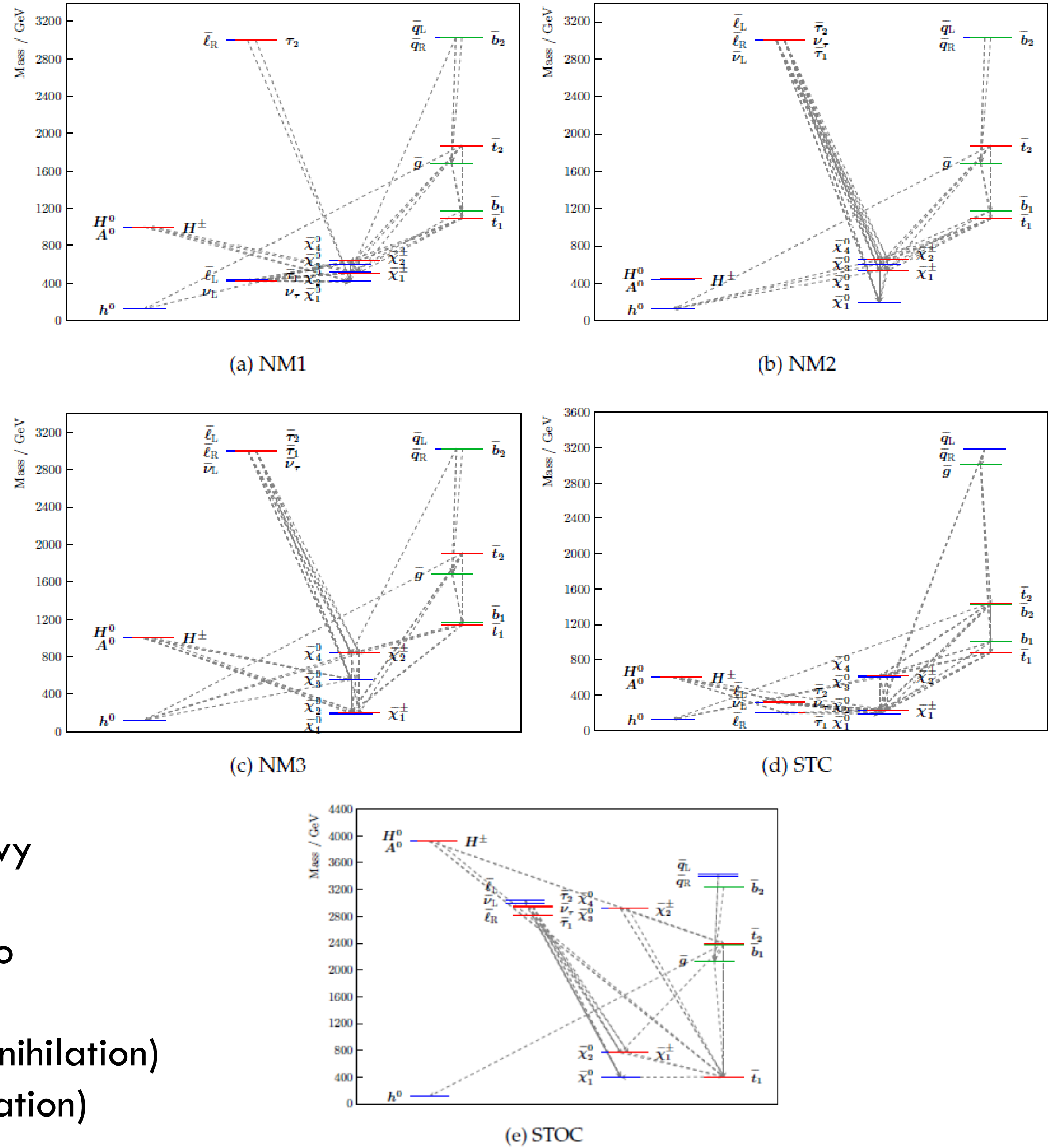
  - All hadronic, s[…]arches targeting these scenario[…]

I will be quicker on the CMS part
Especially on MSSM scenarios
since the next speaker Kenichi Hatakeyama
Will cover this in a more global view
with discovery stories.

Apologize for ATLAS-CMS imbalance…

MSSM spectra under study

NM1: light stau, light gauginos, rest heavy, N1=N2 mass
NM2: light N1, rest relatively heavy
NM3: N1=N2=C1 (higgsinos)
(all gluino relatively light, decay to 3rd generation)
STC: light stau/sleptons (stau coannihilation)
STOC: light stop_1 (stop coannihilation)



(a) NM1 (b) NM2 (c) NM3 (d) STC (e) STOC

Figure 2: Masses of the SUSY particles in five full-spectrum SUSY models in this document and their decay lines, which are drawn for branching fractions above 5%. Shown are (a) NM1, (b) NM2, (c) NM3, (d) STC, and (e) STOC.

CMS model /channel overview

Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300				$< 3\sigma$	$3-5\sigma$
	3000				$3-5\sigma$	$> 5\sigma$
all-hadronic (M_{T2}) search	300	$3-5\sigma$	$> 5\sigma$	$> 5\sigma$		
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$		
all-hadronic $\tilde{b}_1$ search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$> 5\sigma$	$< 3\sigma$
1-lepton $\tilde{t}_1$ search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$
monojet $\tilde{t}_1$ search	300					$3-5\sigma$
	3000					$3-5\sigma$
$m_{\ell^+\ell^-}$ kinematic edge	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$		
	3000	$> 5\sigma$	$< 3\sigma$	$< 3\sigma$		
multilepton + b-tag search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	
multilepton search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	
	3000	$3-5\sigma$	$3-5\sigma$	$< 3\sigma$	$3-5\sigma$	
ewkino WH search	300		$< 3\sigma$			
	3000		$3-5\sigma$			

$< 3\sigma$	$3-5\sigma$	$> 5\sigma$

HL projection scenarios

Expected timeline/ Luminosities/Assumptions:

- After 2018 luminosities up to 2*10^(-34) cm-2s-1, maximum average pileup events around 60 and 300 fb-1 data up to 2022
- Around 2022, upgrade to HL–LHC, 5*10^(-34)cm-2 s-1, pileup up to 140, and 3000 fb-1 around 2025-2032

ATLAS Setup:

Generator level MC modified with a smeared
and parameterized detector
response function from full simulations with pile up

CMS analysis strategy

- CMS studies 3 detector configurations:
  - Phase 1 (50 pileup), 300 fb-1
  - Phase 2 baseline (140 pileup), 3000 fb-1
  - Aged Phase 1 detector (beyond 300 fb-1)
- Preliminary configurations simulated with Geant and then implemented into Delphes fast simulation
- Pile up also included via Delphes
- Madgraph main generator

Light Squarks and Gluinos

Squarks/Gluinos in ATLAS

Table 7: Summary of selection requirements for the 300 fb^{-1} and 3000 fb^{-1} for the squark and gluino signal regions. The 2j, 3j and 4jl regions, targetting squark pair production, have two cuts on m_{eff}. The first is designed for scenarios where the gluino is decoupled, the other for the case in which the gluino mass is 4.5 TeV.

Signal regions optimized separately for each scenarios

Selection	Channel									
	2jl	2jm	3j	4jl	4jm	4jt	5j	6jl	6jm	6jt
$p_{\mathrm{T}}(j_1)$ [GeV] >	160									
$N_{\mathrm{jets}}(p_{\mathrm{T}} > 60$ [GeV]$) \geq$	2		3	4			5	6		
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160									
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ [rad] >	0.4 (j_1, j_2, j_3), 0.2 (all $p_{\mathrm{T}} > 40$ GeV jets)									
	$\langle\mu\rangle = 60$, 300 fb^{-1} scenario									
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$ >	–	–	0.3	0.40	0.25	–	0.20	0.30	0.15	0.20
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	8	15	–	–	–	10	–	–	–	–
m_{eff} [GeV] >	3600	3100, 4300	3600, 3000	3000, 2200	3200	3400	3000	2800	3400	3400
	$\langle\mu\rangle = 140$, 3000 fb^{-1} scenario									
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$ >	–	–	0.3	0.35	0.25	–	0.25	0.25	0.35	0.15
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	8	15	–	–	–	10	–	–	–	–
m_{eff} [GeV] >	4500, 5000	4500, 4900	4000	4000, 3800	4000	4500	4000	3400	3500	5000

Gluinos

Two benchmark Gluino models m_eff distributions for relevant signal regions 4jl and 6jt

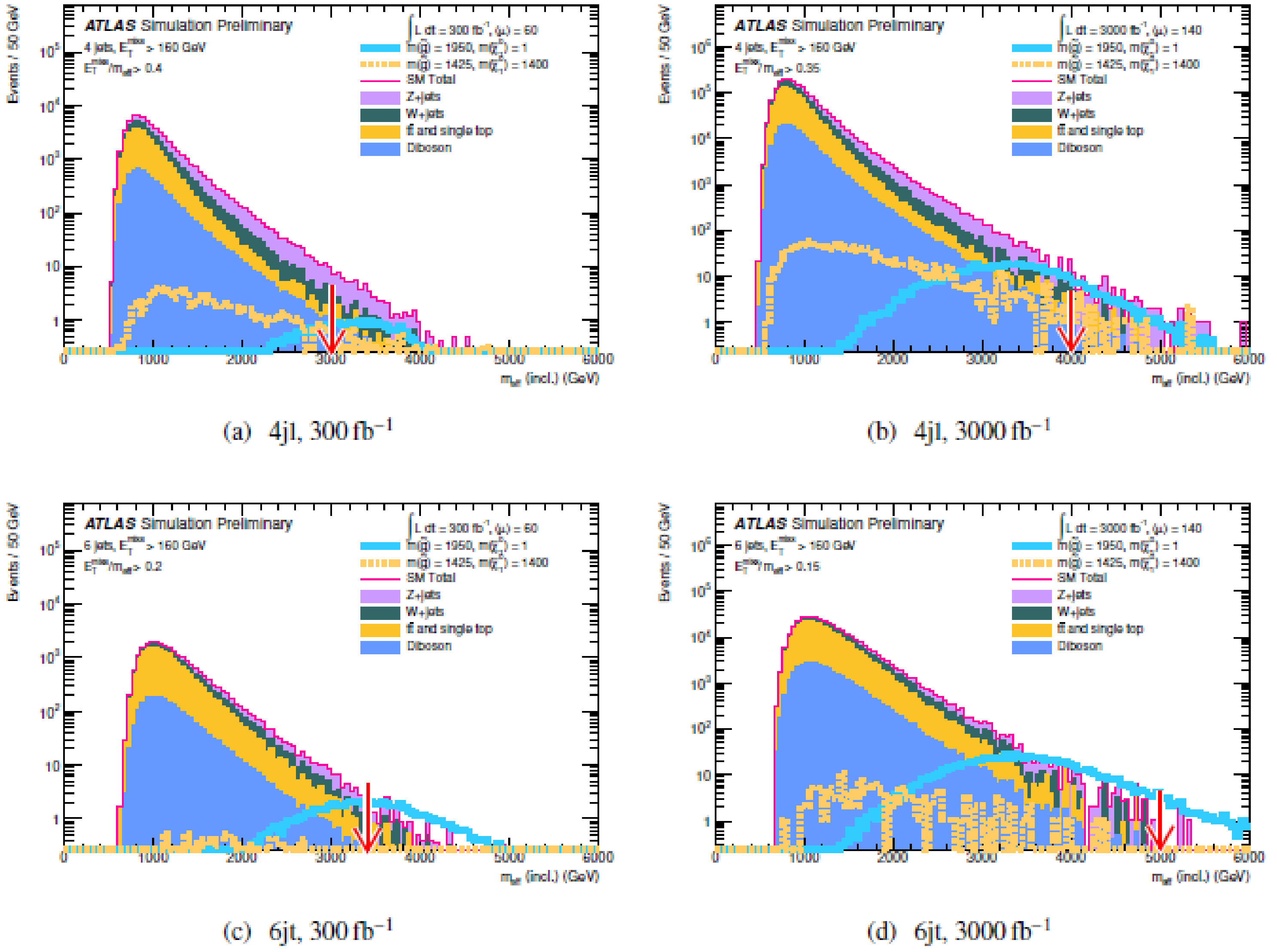
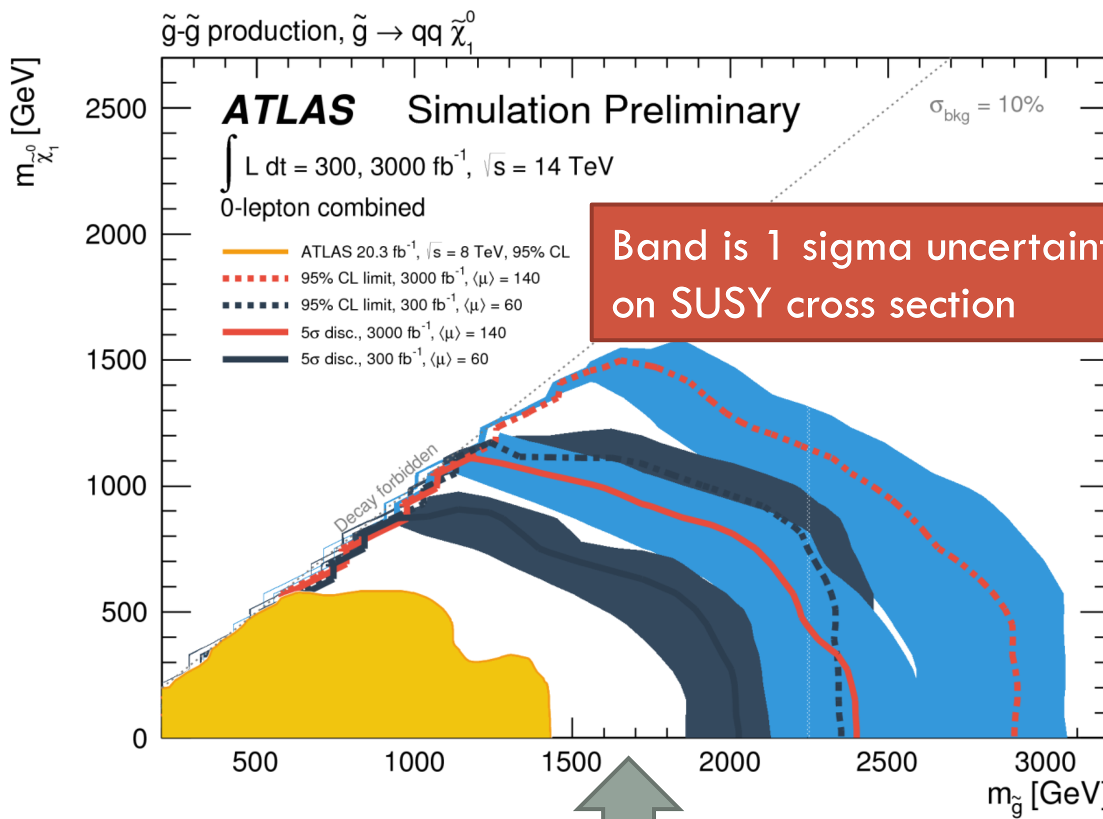


Figure 7: Distributions in m_{eff} for two benchmark signals models - one with $m_{\tilde{g}}$ = 1950 GeV and $m_{\tilde{\chi}_1^0}$ = GeV, the other with $m_{\tilde{g}}$ = 1425 GeV and $m_{\tilde{\chi}_1^0}$ = 1400 GeV. The signal regions shown are 4jl (top) and 6j (bottom) for 300 fb^{-1} (left) and 3000 fb^{-1} (right). All selection cuts are applied besides those on m_{eff} The arrows indicate the final cuts on m_{eff} for the chosen signal regions.

Gluinos simplified models in ATLAS

- Diboson background set to 10% (as found at 8 TeV)
- Total background uncertainty 10% (as for 8TeV)
- Cuts reoptimized for 300 and 3000 fb-1

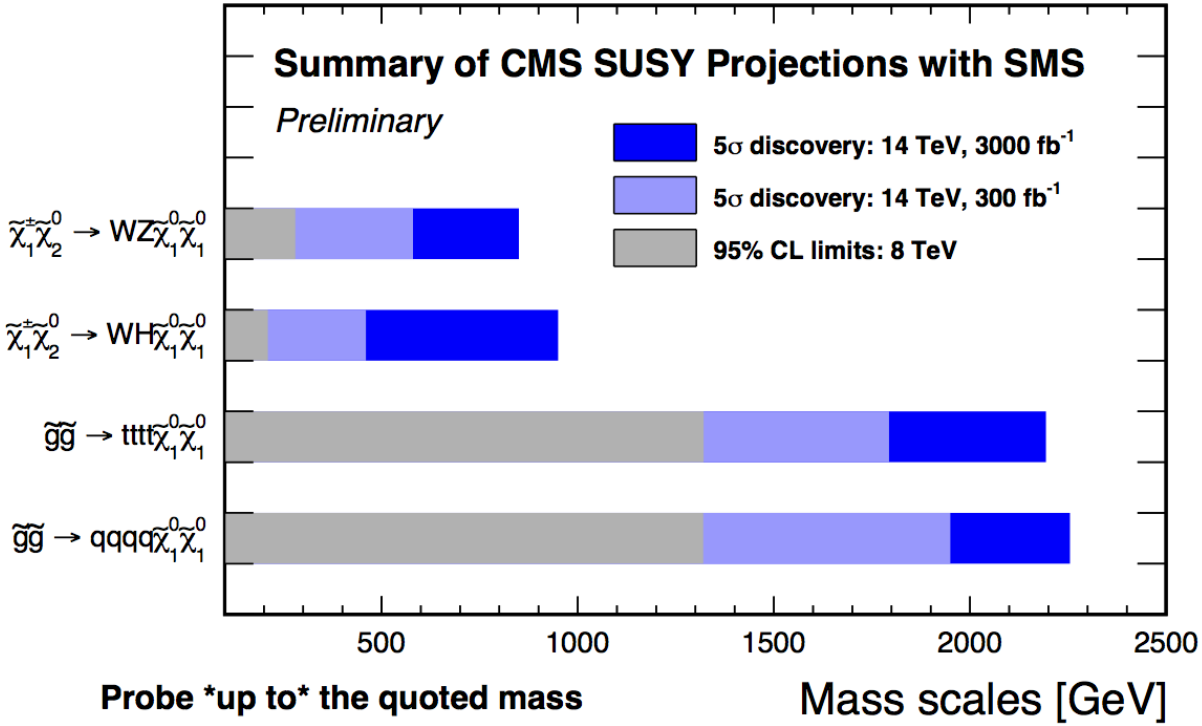


Band is 1 sigma uncertainty on SUSY cross section

- Large improvement in reach (especially also as function of neutralino mass)
- Reach slightly improved Compared to EU strategy
- Large theory uncertainty from Pdfs at high gluino mass

Early LHC run2 limit /signal ?

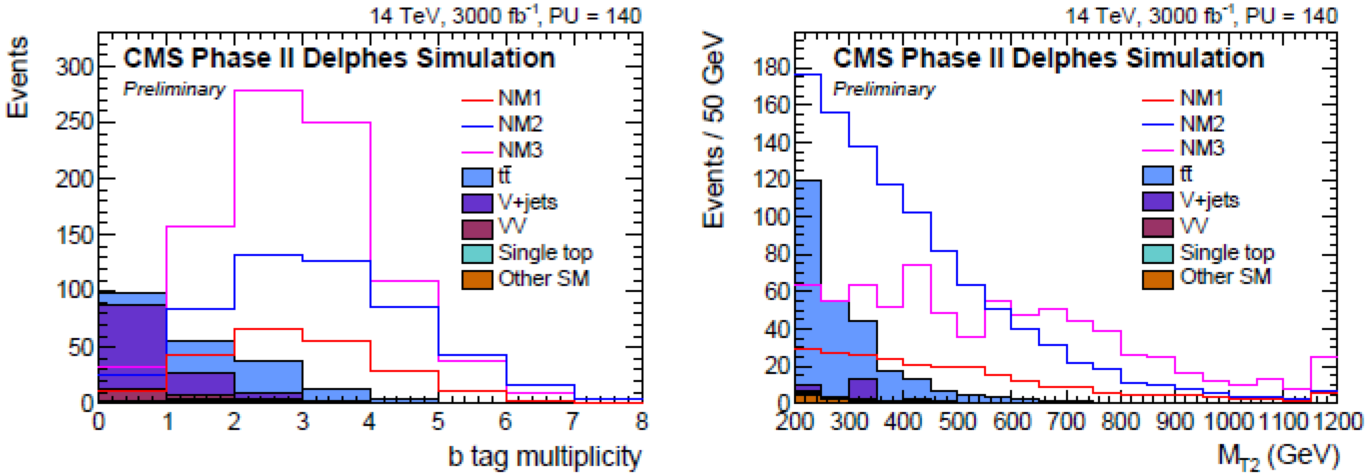
Gluinos / Simplified models in CMS



- CMS/ATLAS have (as expected) similar discovery/exclusion reach
- Limits on Gluinos (as expected from run-1) are quite decay independent

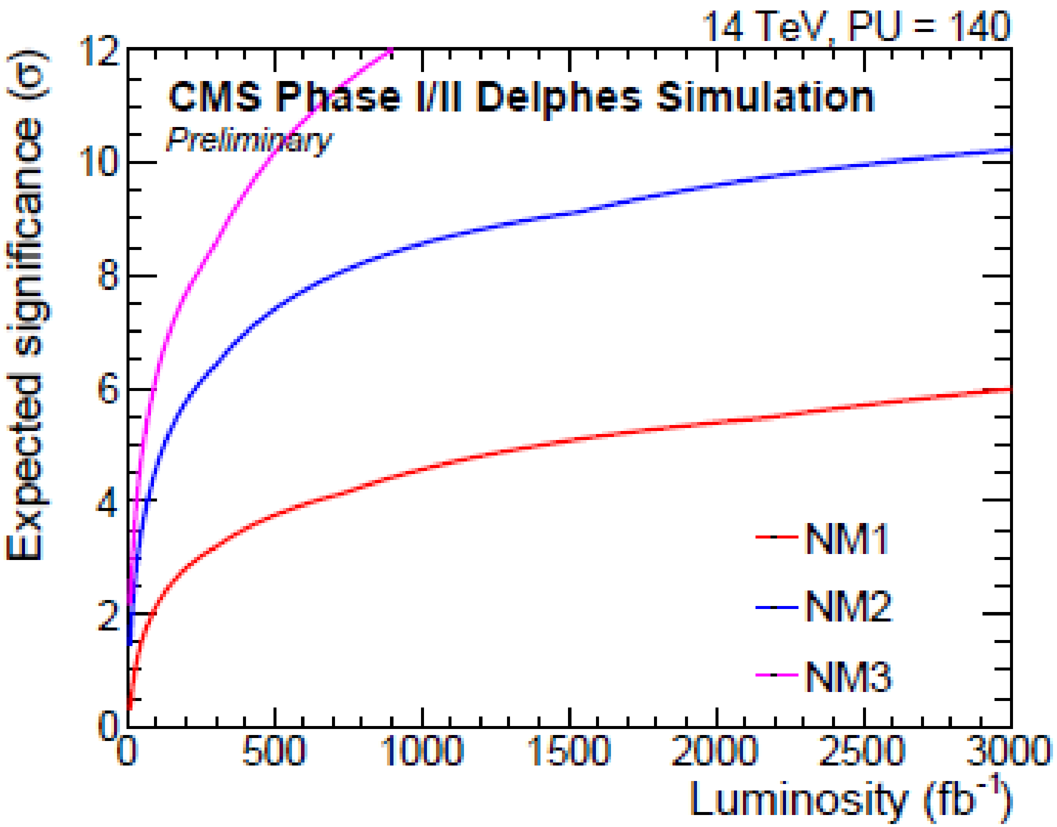
M_T2 searches all hadronic CMS

- Targets "natural" MSSM scenarios (NM1,2,3) with gluino production and decay to stops
- "stransverse" mass MT2 endpoint yields gluino mass
- >= 8 jets , at least three medium
- b-tags, HT > 1500 GeV, and MT2 requirements ranging from 500 to 800 GeV (optimized as function of luminosity)
- Assumed uncertainty comparable to 8 TeV search (45% due to limited statistics in control region)



M_T2 searches all hadronic CMS

Gluino mass always around 1600 GeV



Difference due to stop decays

NM1: higher branching into lepton final states (lepton veto)

NM2: higher chargino/ Neutralino masses

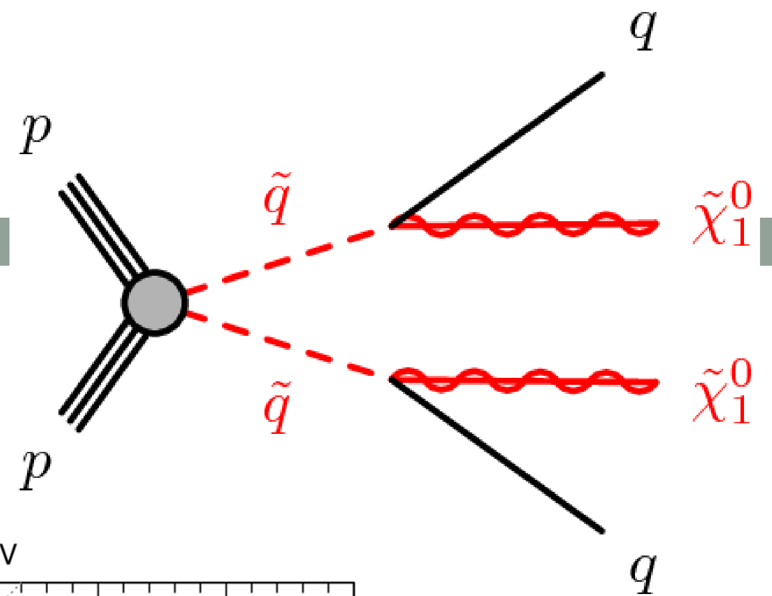
➔ Softer jets

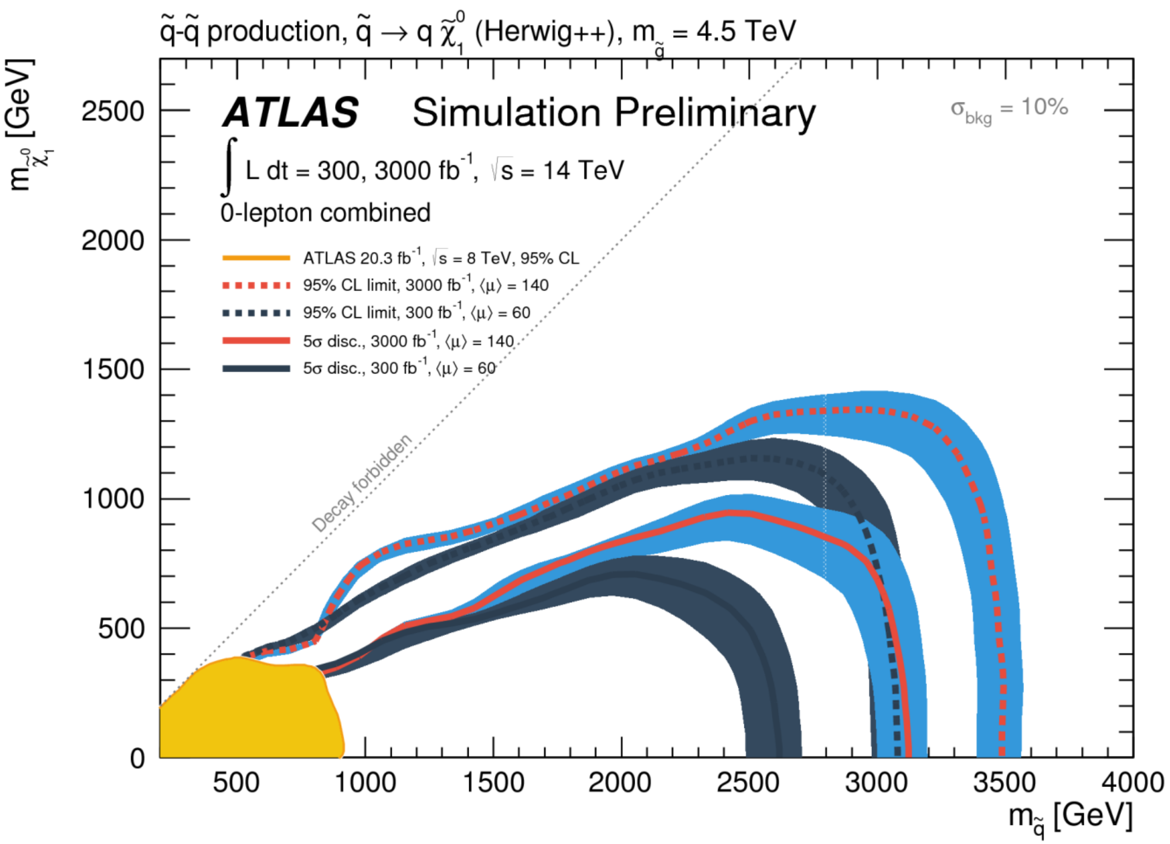
NM3: lower chargino, Neutralino masses

➔ Higher energetic jets

Squarks

- Simplified model, direct squark decays

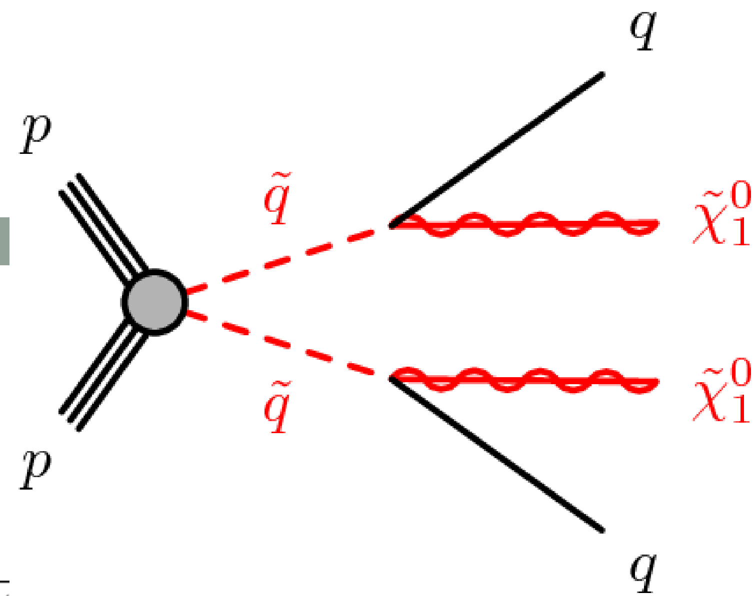


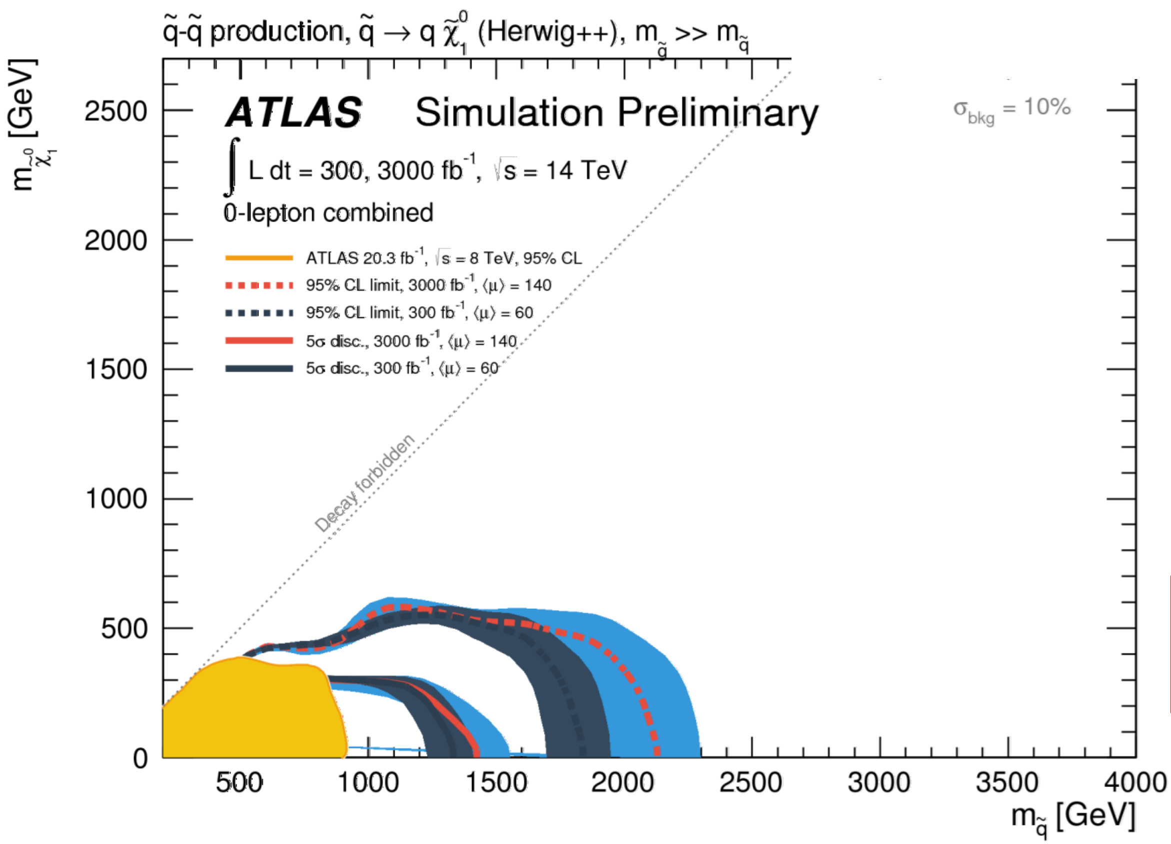


Squark limits if gluino mass is 4.5 TeV

Squarks

- Simplified model, direct squark decays



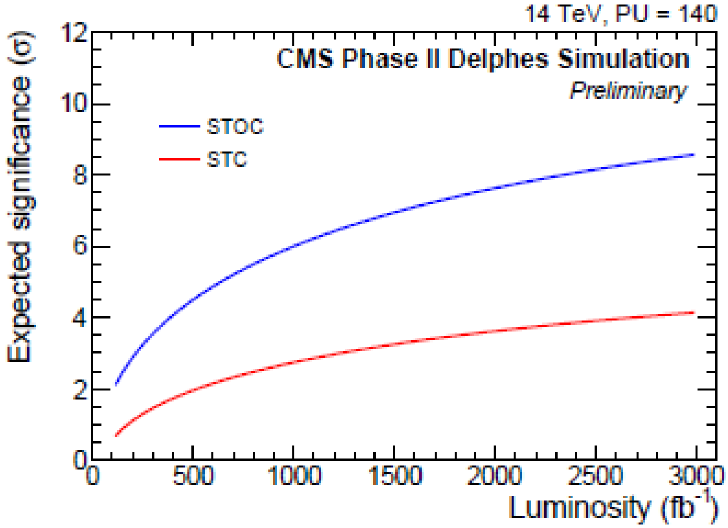


Squark limits if gluino mass extremely large

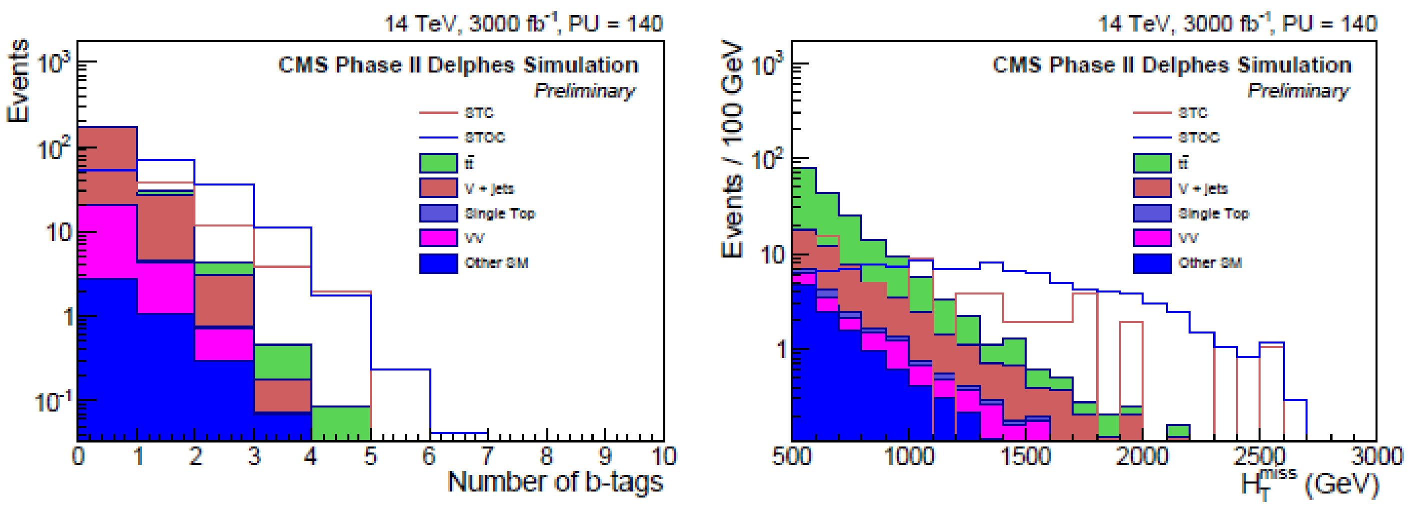
Huge effect from t-channel diagrams

MSSM: CMS H_T + MET search

- Aim of this search: Search for strong production
- In this projection study, one search region defined with: H_T > 2500 GeV, Nb-tags>=2, and H_Tmiss > 1300 GeV
- Assumed 30% background uncertainty based on Run-1 searches (in this channel)
- Investigation of Stop and Stau coannihilation model (via gluino and direct production)



MSSM: CMS H_T + MET search



(a) (b)

STOC:

$$\tilde{g} \rightarrow t\tilde{t}_1$$

STC:

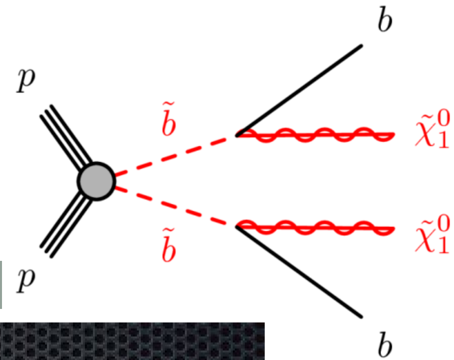
Sbotton, stop production (gluino too heavy)

Different distributions for different signatures.

Origin of excess will be better to investigate with HL.

3rd generation squarks

Sbottom pair production



- mCT drives exclusion to large values for the sbottom mass: sbottom pair has an endpoint at $\sqrt{m_{\tilde{b}}^2 - m_{\rm LSP}^2}/m_{\tilde{b}}$
- Dominant background Z(->vv)+bb;
  mCT cut removes ttbar (endpoint at ~150 GeV)

m_CT distribution for signal events

8 TeV analysis considered mCT cuts
Up to 350 GeV

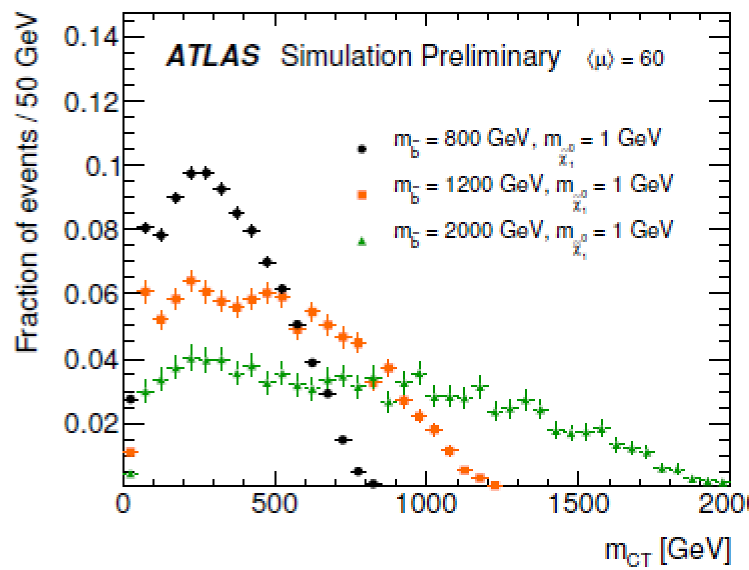


Figure 11: $m_{\rm CT}$ distribution for signal events.

$$M_{CT}^2(v_1, v_2) = 2p_T(v_1)p_T(v_2)(1 + \cos\phi_{12}),$$

Sbottom pair production

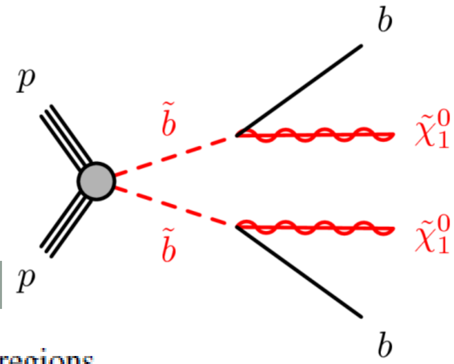


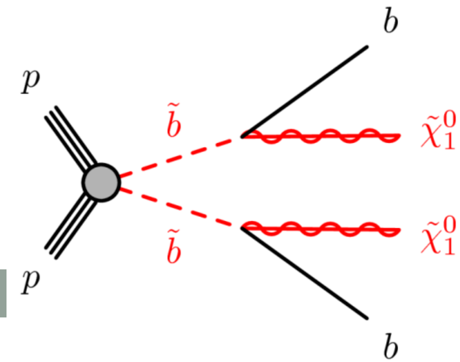
Table 10: Summary of selection requirements for the bottom squark pair production signal regions.

Selection	SRx
Lepton veto	No e/μ with $p_T > 7(6)$ GeV for $e(\mu)$
E_T^{miss}	> 150 GeV
Leading jet $p_T(j_1)$	> 130 GeV
Third jet $p_T(j_3)$	veto if > 50 GeV
b-tagging	leading 2 jets ($p_T > 50$ GeV, $\lvert\eta\rvert < 2.5$)
$\Delta\phi_{min}$	> 0.4
$E_T^{miss}/m_{eff}(2)$	$E_T^{miss}/m_{eff}(2) > 0.25$
m_{CT}	$> x$ GeV
m_{bb}	> 200 GeV

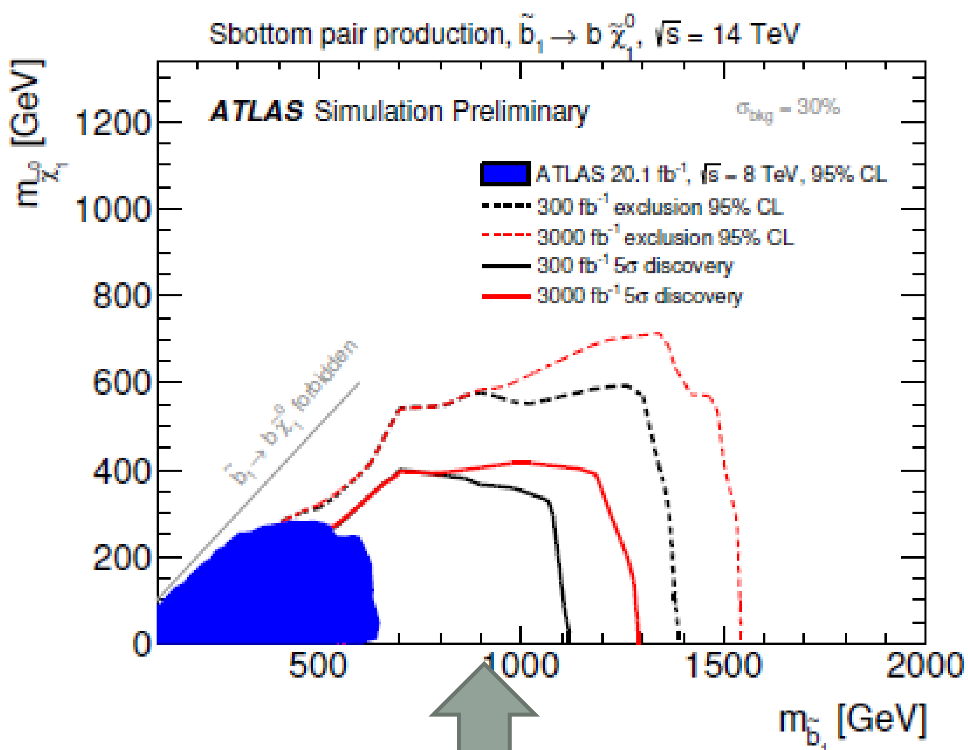
Table 11: Expected numbers of events for SM background and three bottom squark pair signal points, for different m_{CT} thresholds and an integrated luminosity of 300fb^{-1}. The uncertainties shown are statistical only.

	SRA300	SRA350	SRA450	SRA550	SRA650	SRA750
$(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (1000, 1)$	216 ± 4	200 ± 4	161 ± 4	118.5 ± 3.2	78.6 ± 2.6	44.0 ± 1.9
$(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (1400, 1)$	19.3 ± 0.9	18.4 ± 0.9	16.8 ± 0.8	14.9 ± 0.8	12.8 ± 0.7	10.2 ± 0.6
$(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (1600, 1)$	6.04 ± 0.28	5.84 ± 0.28	5.55 ± 0.27	5.19 ± 0.26	4.57 ± 0.25	3.78 ± 0.22
$t\bar{t}$	32.6 ± 3.0	14.8 ± 2.0	4.3 ± 1.1	1.5 ± 0.7	0.6 ± 0.4	0.29 ± 0.29
single top	146 ± 12	83 ± 8	41 ± 6	25 ± 5	12.7 ± 3.2	8.9 ± 2.5
Z+jets	508 ± 8	249 ± 5	70.5 ± 2.7	23.1 ± 1.5	9.1 ± 1.0	4.1 ± 0.7
W+jets	92 ± 5	44 ± 4	9.3 ± 1.7	2.9 ± 0.9	1.6 ± 0.8	0.9 ± 0.6
Other	5.4 ± 0.5	3.3 ± 0.4	1.59 ± 0.28	0.50 ± 0.16	0.18 ± 0.09	0.15 ± 0.08

Sbottom pair production



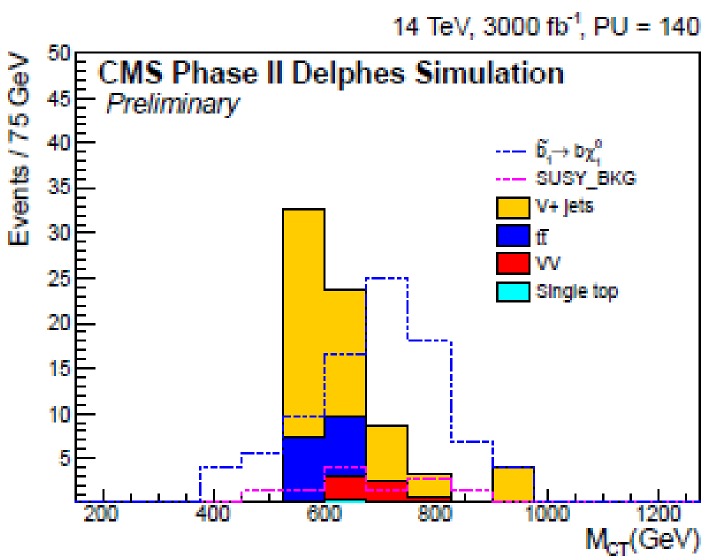
- Increase m_CT cut (no compressed specta targeted)
- Systematic uncertainties from 8 TeV analysis

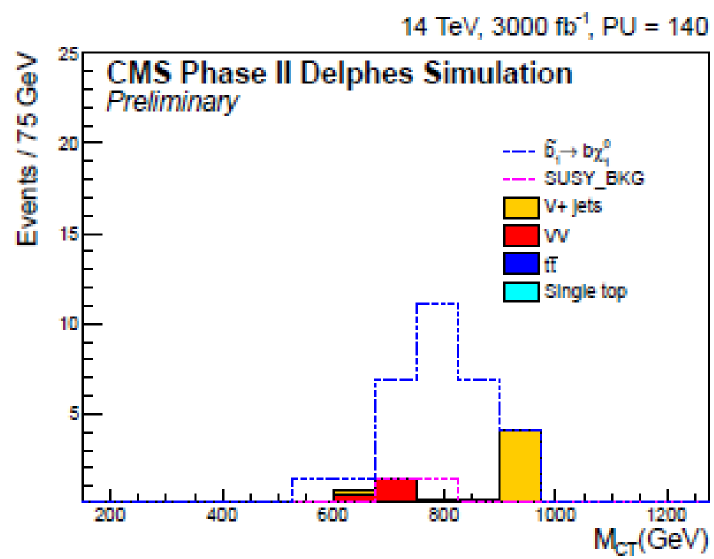


Early run-2 expected limit

Sbottom search with MSSM models

- Here targeting decay b1 ➔ b N1, which is the dominant decay mode of bottom squark in the stau coannihilation (STC) model scenario with branching fraction of 68%.
- Selection of 2 b-jets + MET
- Contransverse mass M_CT(j1, j2) distribution can have endpoint at $(m^2_{\tilde{b}_1} - m^2_{\tilde{\chi}^0_1})/m_{\tilde{b}_1}$





Sbottom search with MSSM models

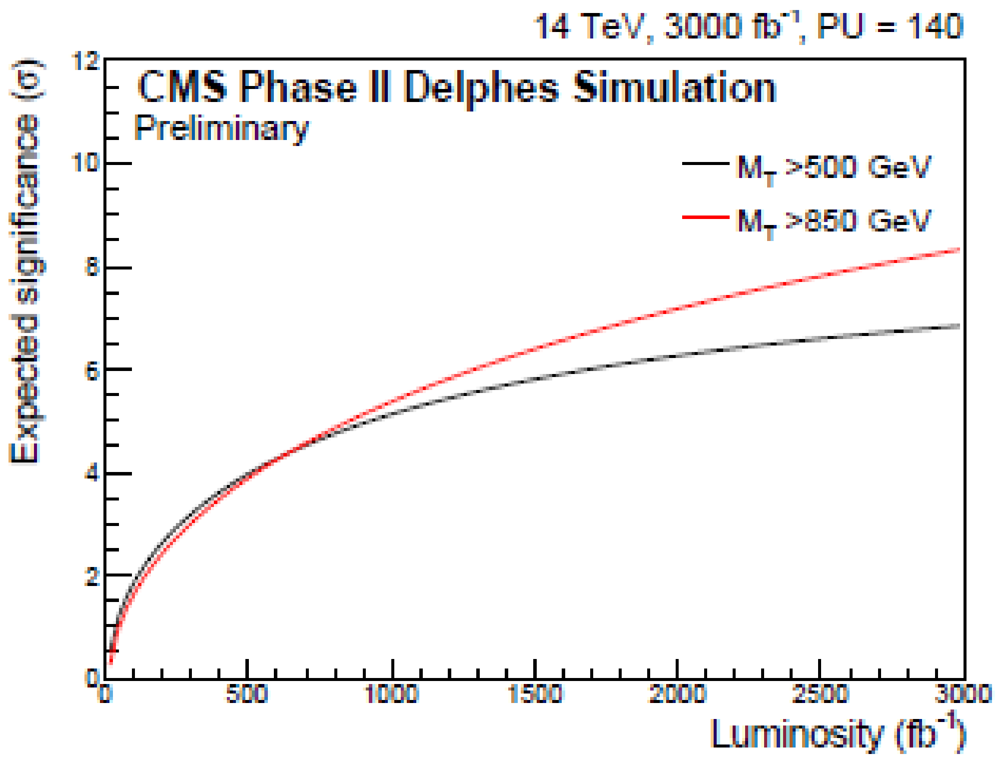
- 87% of MSSM events from sbottom
- Expected sensitivity for STC

(sbottom mass

= 1000 GeV)

Discovery only with

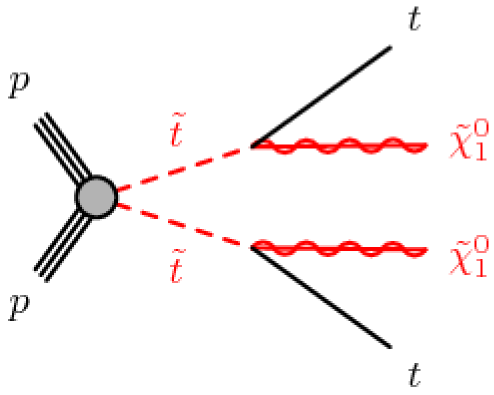
1000 fb-1 here…



Interesting to distinguish this from stop production …

Simplified Stop production

- Investigated stop simplified model, cuts on MET and m_T optimized for each scenario
- 0 and 1 lepton selection
- … and combination

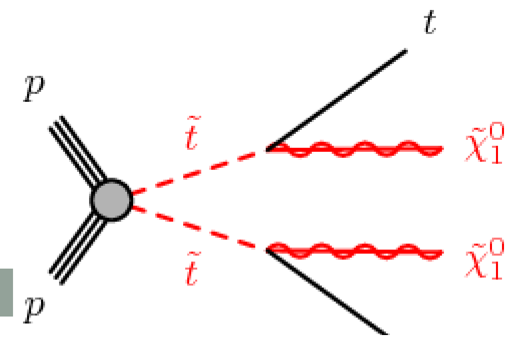


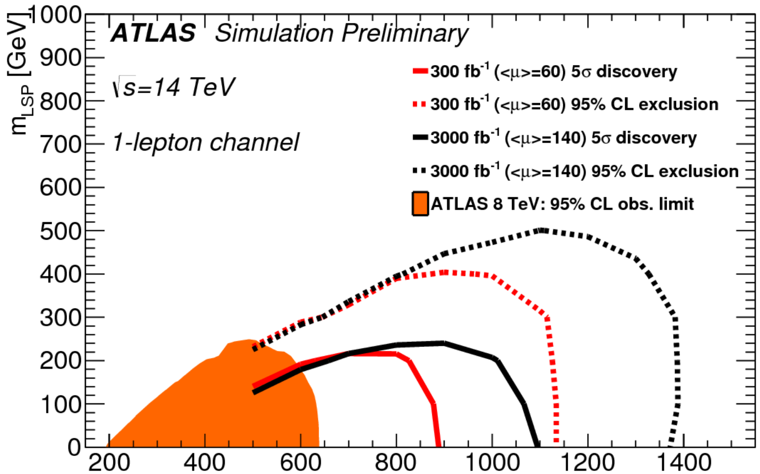
	300 fb^{-1}		3000 fb^{-1}	
m_{stop} (GeV)	E_T^{miss} (GeV)	m_T (GeV)	E_T^{miss} (GeV)	m_T (GeV)
500	350	250	400	250
600	400	300	450	300
700	500	350	500	350
800	550	350	550	350
900	600	400	600	400
1000	650	500	700	500
1100	700	500	750	550
1200	750	500	800	550
1300	750	500	800	550
1400	750	500	800	550
1500	750	500	800	550

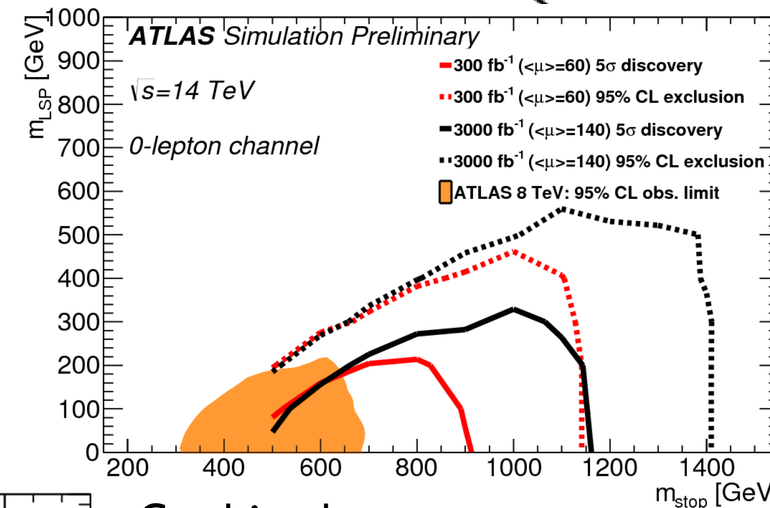
able 1: Minimum requirements on E_T^{miss} and m_T for the stop search in the 1-lepton channel as a function f the stop mass, for integrated luminosities of 300 fb^{-1}and 3000 fb^{-1}.

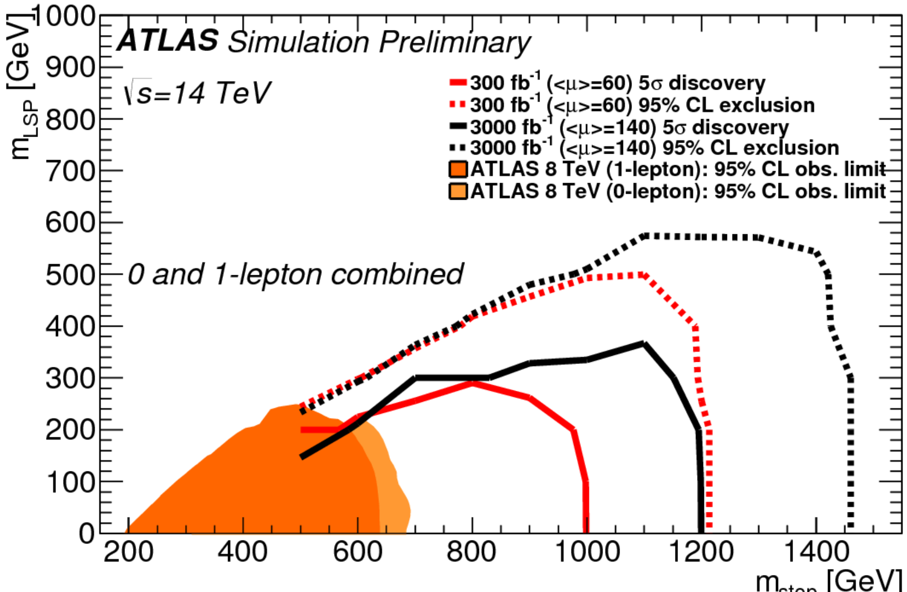
	(800,100)	(1100,100)
$t\bar{t}$	257±25	6.6±3.8
$t\bar{t}$+W	15±2	0.9±0.5
$t\bar{t}$+Z	71±7	8.5±2.3
W+jets	41±11	5.4±3.8
Total bkg	385±28	21.4±5.9
Signal	880±18	55.7±1.5

Stop production









Combined
Exclusion expected
up to 1500 GeV
With HL-LHC

Here (simplified models) discovery up to 1.2 with HL-LHC
In MSSM: Discovery up to 1 TeV likely only possible with HL-LHC

Stop production MSSM points

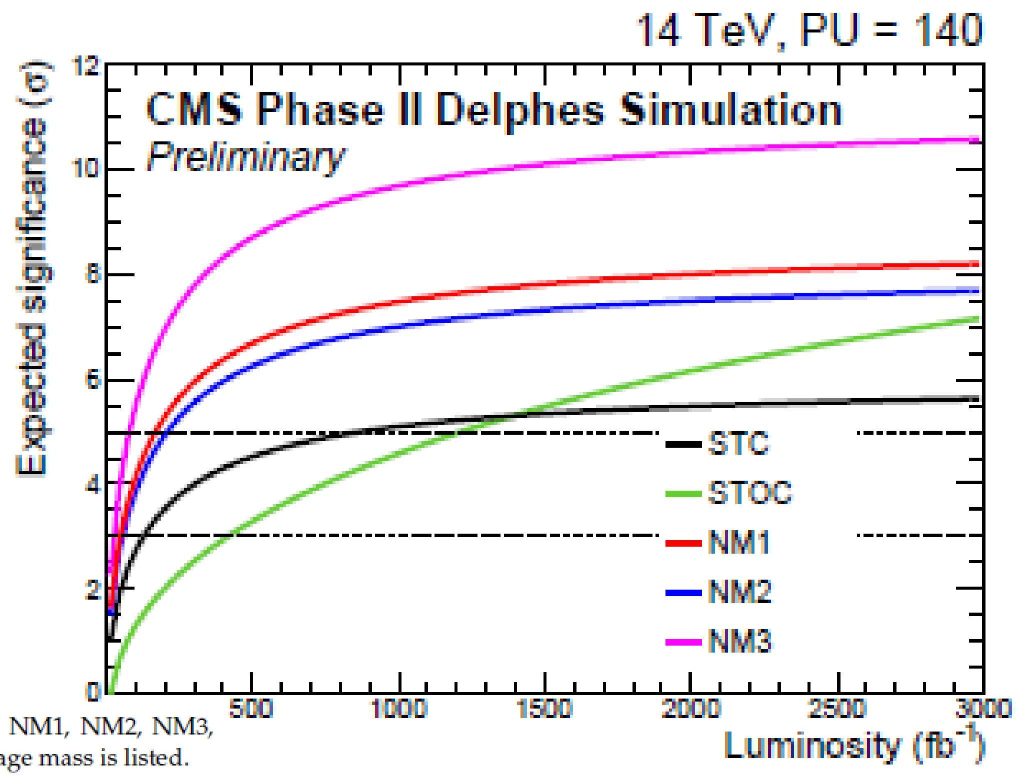
- Large variety of stop decays in MSSM
- As an example, in the STC model only 4% have stop → top N1 decay
- … In these models also gluino→ stop and sbottom production, all can populate same final state…
- Analysis similar to 8 TeV: 1lepton (e or mu), 5 jets, b-tag, MET > 400 GeV
- Centrality $\frac{\sum_i \text{jet}_i(p_T)+\text{lepton}(p_T)}{\sum_i \text{jet}_i(p)+\text{lepton}(p)}$ > 0.6 (SUSY more central)

Stop production MSSM points

Table 6: Search for direct stop production in the single-lepton channel: The event yields for the inclusive signal samples and several SM processes with $3000\,\text{fb}^{-1}$ at 14 TeV with 140 pileup interactions. The significances are determined by considering a systematic uncertainty on the background prediction of 15% and 25%. For the high E_T^{miss} search region, only 25% systematic uncertainty is considered as discussed in the text.

Selection	Total SM	STC	STOC	NM1	NM2	NM3
Exactly 1 e or μ	6160000000	271000	5170	88200	45600	12800
$N_{jets} \geq 5$	44900000	6550	361	6830	9380	5500
$N_{b\text{-jets}} = 1$ or 2	27700000	4370	259	3980	4830	3210
$E_T^{miss} > 400\,\text{GeV}$	108000	1610	146	2070	1970	2150
$\Delta\phi > 0.8$	84300	1420	127	1760	1630	1840
Centrality >0.6	48200	1050	99	1460	1350	1510
$M_T > 260\,\text{GeV}$	1320	523	77	733	702	1020
$M_{T2}^{W} > 260\,\text{GeV}$	291	349	61	563	518	794
Significance ($\delta B/B = 15\%$)		5.6	1.1	8.2	7.7	10.5
Significance ($\delta B/B = 25\%$)		3.4	0.6	5.0	4.7	6.4
$E_T^{miss} > 800\,\text{GeV}$	11	–	39	–	–	–
Significance ($\delta B/B = 25\%$)		–	5.7	–	–	–

Stop production MSSM points



… more on discovery stories in the next presentation..

(STOC different signal region)

e 15: Overview of the most relevant sparticle masses for the models NM1, NM2, NM3, and STOC. $\tilde{q}$ denotes the first two generation squarks, and their average mass is listed.

Sparticle	Mass (GeV)				
	NM1	NM2	NM3	STC	STOC
$\tilde{g}$	1686	1686	1686	3007	2132
$\tilde{b}_1$	1177	1177	1163	1000	2374
$\tilde{t}_1$	1092	1090	1144	882	402
$\tilde{t}_2$	1874	1875	1910	1446	2393
$\tilde{q}$	3025	3025	3026	3189	3417
$\tilde{\ell}^{\pm}_{L}$	432	3000	3000	318	3037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Compressed scenarios : Monojets

Important: Coannihilation nice to get right DM relic density…

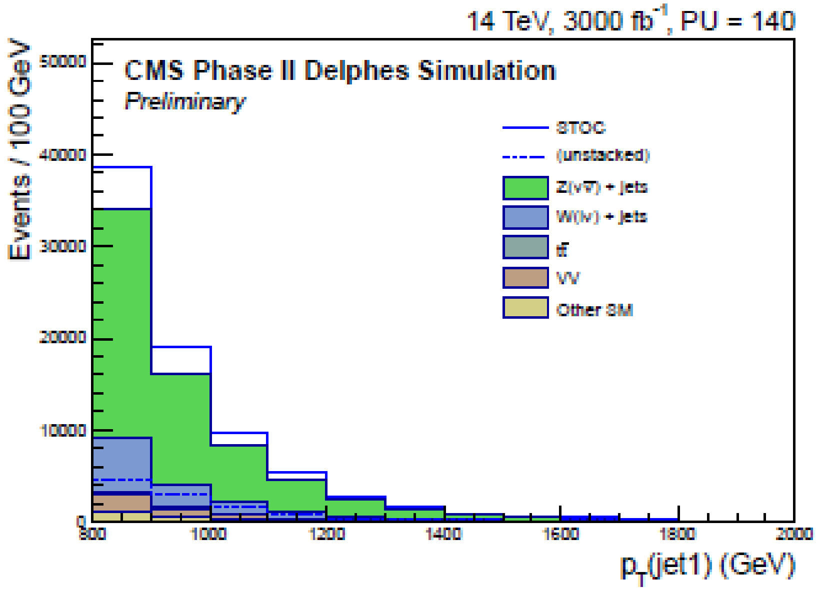
Stop coannihilation: Stop (400 GeV) compressed with N1,
usual decays not possible…
Here Stop → N1 charm dominant decay mode..
Signals can be detected via initial state radiation (monojet like signals)

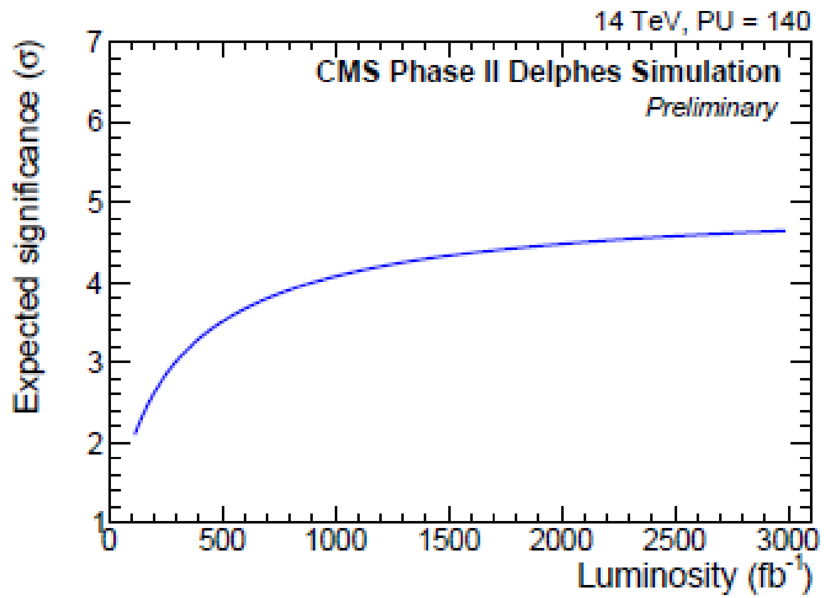
Require MET> 600 GeV, a leading jet, a veto on the 3rd jet
Best significance with pt_leadingjet > 900 GeV

Table 7: Search in the monojet signature: Background and signal event yields corresponding to $3000\,\mathrm{fb}^{-1}$. The pre-selection refers to events passing all the requirements except the final tight selection on the leading jet p_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$..

Selection	$Z(\nu\bar{\nu})$ + jets	$W(\ell\nu)$ + jets	$t\bar{t}$	VV	Other	Total SM	STOC
Pre-selection	$7.1 \cdot 10^7$	$5.0 \cdot 10^7$	$6.3 \cdot 10^6$	$2.5 \cdot 10^6$	$1.2 \cdot 10^7$	$14.2 \cdot 10^7$	$8.1 \cdot 10^5$
$E_{\mathrm{T}}^{\mathrm{miss}} > 600\,\mathrm{GeV}$	430000	102000	6440	27600	40700	606000	55700
$p_{\mathrm{T}}(j_1) > 900\,\mathrm{GeV}$	25800	5340	199	1950	1120	34400	6530

Compressed scenarios : Monojets





Excess > 4 sigma with 1000 fb-1

No 5 sigma discovery for 400 GeV stop here…

HL-LHC really necessary to get some significance…

Summary

- Prospects for light squarks, gluino, stop and sbottom searches for 300 fb-1and HL-LHC
- HL-LHC phase will be of utmost importance for **two reasons:**

A) **If discovery:** We need to understand what it is and this requires as much data as we can get !

B) **If no discovery:** We need to push “nature” as far as possible into the “unnatural” region and exclude the “miracle” DM SUSY scenarios as much as we can

Additional material

Signal and background yields

e 8: Yields for the main backgrounds and selected signal points simulated with $\langle\mu\rangle = 60$, normalised to $\mathcal{L} = 300\ \text{fb}^{-1}$. The signal samples sam
normalized for the scenario with a gluino mass of 4.5 TeV.

Region	SR2jl	SR2jm	SR3j	SR4jl	SR4jm	SR4jt	SR5j	SR6jl	SR6jm	SR6jt
W+jets	45.0 ± 3.5	2.7 ± 0.9	11.2 ± 1.8	11.8 ± 1.8	25.7 ± 2.7	113 ± 6	30.4 ± 2.9	8.5 ± 1.5	6.3 ± 1.3	3.6 ± 1.0
Z+jets	104.4 ± 3.1	16.9 ± 1.2	43.0 ± 2.0	48.5 ± 2.1	75.9 ± 2.6	111.1 ± 3.2	74.4 ± 2.6	20.7 ± 1.4	13.0 ± 1.1	10.0 ± 1.0
$t\bar{t}$	15.7 ± 1.8	1.6 ± 0.5	4.2 ± 0.8	5.1 ± 1.1	10.6 ± 1.5	45.9 ± 3.4	19.3 ± 2.2	5.2 ± 1.1	6.0 ± 1.2	3.4 ± 0.9
Diboson	18.4 ± 1.7	2.4 ± 0.5	6.5 ± 0.9	7.3 ± 1.0	12.5 ± 1.3	30.0 ± 2.4	13.8 ± 1.5	3.8 ± 0.8	2.8 ± 0.7	1.9 ± 0.5
Total background	183 ± 5	23.6 ± 1.7	64.9 ± 2.9	72.6 ± 3.1	125 ± 4	300 ± 8	138 ± 5	38.3 ± 2.5	28.1 ± 2.2	18.8 ± 1.7
$m_{\tilde{g}}$ = 1950 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	68.8 ± 0.6	12.48 ± 0.27	35.4 ± 0.5	18.41 ± 0.33	70.6 ± 0.7	102.4 ± 0.8	83.4 ± 0.7	25.6 ± 0.4	44.6 ± 0.5	35.4 ± 0.5
$m_{\tilde{g}}$ = 1425 GeV, $m_{\tilde{\chi}_1^0}$ = 1400 GeV	12.6 ± 1.2	3.7 ± 0.6	8.5 ± 1.0	7.5 ± 0.9	8.1 ± 0.9	6.2 ± 0.8	4.7 ± 0.7	1.6 ± 0.4	1.05 ± 0.33	1.05 ± 0.33
$m_{\tilde{q}}$ = 1050 GeV, $m_{\tilde{\chi}_1^0}$ = 900 GeV	2.5 ± 1.1	1.5 ± 0.9	2.0 ± 1.0	3.5 ± 1.3	6.4 ± 1.8	4.0 ± 1.4	7.4 ± 1.9	3.5 ± 1.3	1.5 ± 0.9	1.5 ± 0.9
$m_{\tilde{q}}$ = 2250 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	141.7 ± 0.9	60.1 ± 0.6	82.1 ± 0.7	39.2 ± 0.5	59.3 ± 0.6	58.9 ± 0.6	28.4 ± 0.4	7.84 ± 0.21	8.00 ± 0.21	7.57 ± 0.20

e 9: Yields for the main backgrounds and selected signal points simulated with $\langle\mu\rangle = 140$, normalised to $\mathcal{L} = 3000\ \text{fb}^{-1}$. The signal samp
les are normalized for the scenario with a gluino mass of 4.5 TeV.

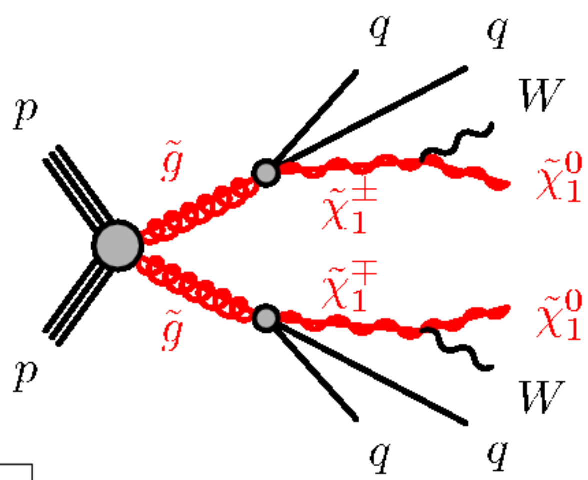
Region	SR2jl	SR2jm	SR3j	SR4jl	SR4jm	SR4jt	SR5j	SR6jl	SR6jm	SR6jt
W+jets	8 ± 5	5 ± 4	38 ± 10	8 ± 5	14 ± 6	101 ± 17	14 ± 6	25 ± 8	11 ± 5	0.00 ± 0.00
Z+jets	51 ± 7	51 ± 7	185 ± 13	78 ± 8	127 ± 11	125 ± 11	65 ± 8	85 ± 9	29 ± 5	3.6 ± 1.8
$t\bar{t}$	9 ± 4	9 ± 4	20 ± 5	7.0 ± 3.1	18 ± 6	37 ± 9	11 ± 4	17 ± 5	3.5 ± 2.1	1.4 ± 1.4
Diboson	7.6 ± 3.1	7.2 ± 2.9	10.4 ± 3.4	18 ± 5	29 ± 7	9.9 ± 3.5	14 ± 4	4.8 ± 2.6	0.6 ± 0.8	
Total background	76 ± 10	72 ± 9	269 ± 18	104 ± 11	176 ± 14	292 ± 23	99 ± 11	141 ± 14	48 ± 8	5.6 ± 2.4
$m_{\tilde{g}}$ = 1950 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	55.8 ± 1.8	43.4 ± 1.6	163.9 ± 3.1	75.2 ± 2.1	191.0 ± 3.4	159.1 ± 3.1	152.7 ± 3.0	257 ± 4	73.4 ± 2.1	36.0 ± 1.5
$m_{\tilde{g}}$ = 1425 GeV, $m_{\tilde{\chi}_1^0}$ = 1400 GeV	10.5 ± 3.3	15 ± 4	48 ± 7	19 ± 4	23 ± 5	8.4 ± 3.0	14 ± 4	7.4 ± 2.8	5.3 ± 2.4	0.00 ± 0.00
$m_{\tilde{q}}$ = 1050 GeV, $m_{\tilde{\chi}_1^0}$ = 900 GeV	5 ± 5	10 ± 7	15 ± 9	10 ± 7	15 ± 9	15 ± 9	10 ± 7	25 ± 11	5 ± 5	5 ± 5
$m_{\tilde{q}}$ = 2250 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	186 ± 3	208.2 ± 3.4	558 ± 6	254 ± 4	320 ± 4	182.6 ± 3.2	136.4 ± 2.7	75.2 ± 2.0	50.9 ± 1.7	13.6 ± 0.9

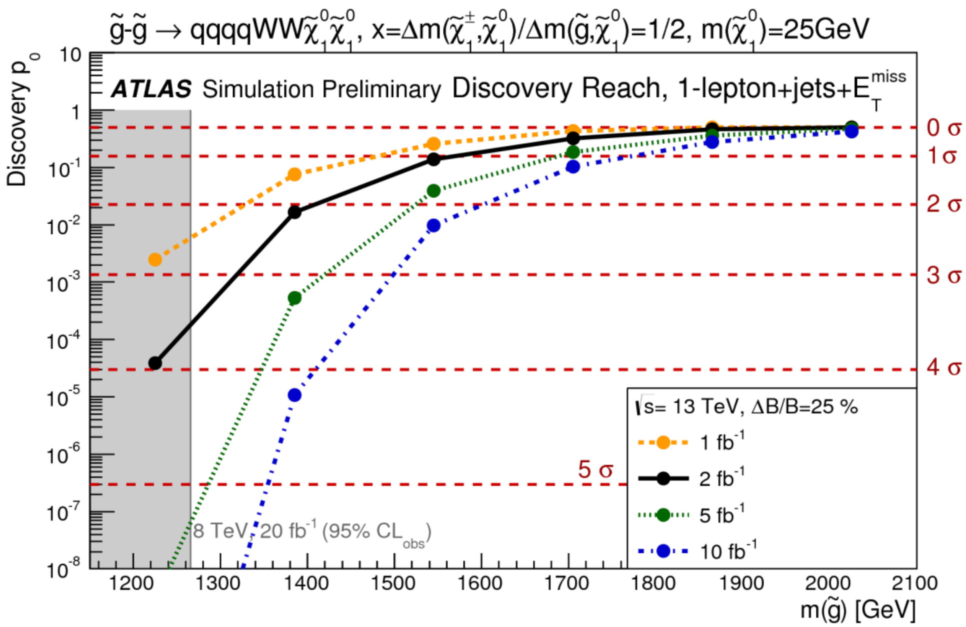
Early run-2 projection studied

Variation:

1 lepton selection

Decay via (heavy squark) to chargino

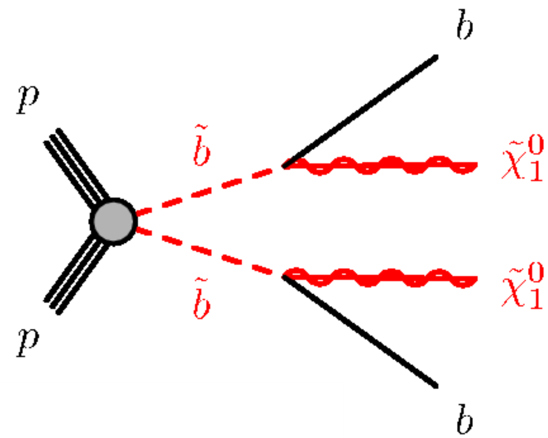


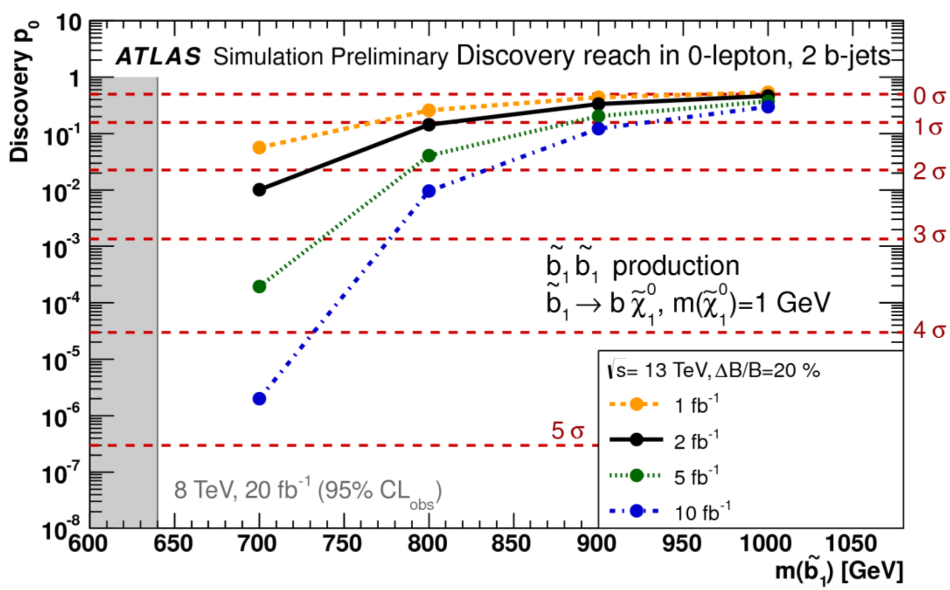


Early run-2 projection studied

Variation:

Sbottom_1 production
2-bjets and cut on so called
Co-transverse mass





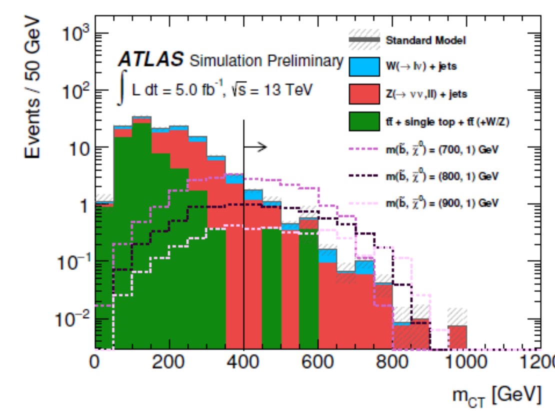


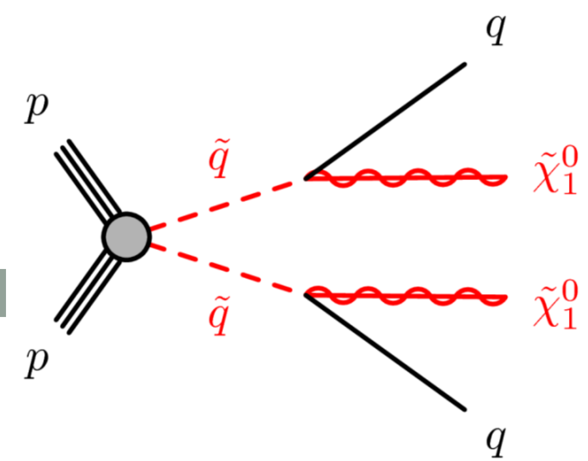
Table 15: Overview of the most relevant sparticle masses for the models NM1, NM2, NM3, STC, and STOC. $\tilde{q}$ denotes the first two generation squarks, and their average mass is listed.

Sparticle	Mass (GeV)				
	NM1	NM2	NM3	STC	STOC
$\tilde{g}$	1686	1686	1686	3007	2132
$\tilde{b}_1$	1177	1177	1163	1000	2374
$\tilde{t}_1$	1092	1090	1144	882	402
$\tilde{t}_2$	1874	1875	1910	1446	2393
$\tilde{q}$	3025	3025	3026	3189	3417
$\tilde{\ell}_L^{\pm}$	432	3000	3000	318	3037
$\tilde{\ell}_R^{\pm}$	3000	3000	3000	203	2997
$\tilde{\tau}_1$	427	2999	3000	194	2806
$\tilde{\chi}_1^0$	419	199	195	187	396
$\tilde{\chi}_2^0$	515	535	208	228	763
$\tilde{\chi}_3^0$	603	607	557	609	2913
$\tilde{\chi}_4^0$	644	656	837	617	2915
$\tilde{\chi}_1^{\pm}$	512	534	201	228	763
$\tilde{\chi}_2^{\pm}$	642	656	837	618	2915

Table 17: Main branching fractions of SUSY particles for the models NM1, NM2, NM3, STC, and STOC.

Decay	Branching fraction				
	NM1	NM2	NM3	STC	STOC
$\tilde{g} \to \tilde{t}_1 \bar{t}, \tilde{t}_1^* t$	59%	60%	53%	28%	50%
$\tilde{g} \to \tilde{b}_1 \bar{b}, \tilde{b}_1^* b$	41%	40%	47%	28%	50%
$\tilde{g} \to \tilde{t}_2 \bar{t}, \tilde{t}_2^* t$	-	-	-	22%	-
$\tilde{g} \to \tilde{b}_2 \bar{b}, \tilde{b}_2^* b$	-	-	-	21%	-
$\tilde{t}_1 \to t\tilde{\chi}_1^0$	0.6%	1.5%	39%	20%	-
$\tilde{t}_1 \to t\tilde{\chi}_2^0$	13%	13%	41%	5.4%	-
$\tilde{t}_1 \to t\tilde{\chi}_3^0$	22%	23%	1.3%	20%	-
$\tilde{t}_1 \to t\tilde{\chi}_4^0$	30%	30%	5.5%	9.2%	-
$\tilde{t}_1 \to b\tilde{\chi}_1^+$	16%	12%	2.1%	12%	-
$\tilde{t}_1 \to b\tilde{\chi}_2^+$	18%	21%	11%	34%	-
$\tilde{t}_1 \to c\tilde{\chi}_1^0$	-	-	-	-	99%
$\tilde{b}_1 \to b\tilde{\chi}_1^0$	1.5%	1.0%	1.3%	67%	-
$\tilde{b}_1 \to b\tilde{\chi}_2^0$	11%	10%	1.0%	2.2%	5.7%
$\tilde{b}_1 \to b\tilde{\chi}_3^0$	0.6%	0.6%	0.4%	8.2%	-
$\tilde{b}_1 \to b\tilde{\chi}_4^0$	4.5%	5.7%	5.7%	7.6%	-
$\tilde{b}_1 \to t\tilde{\chi}_1^-$	32%	34%	80%	3.4%	11%
$\tilde{b}_1 \to t\tilde{\chi}_2^-$	49%	48%	12%	12%	-
$\tilde{b}_1 \to W^- \tilde{t}_1$	0.4%	0.7%	-	$< 0.1\%$	65%
$\tilde{b}_1 \to b\tilde{g}$	-	-	-	-	18%
$\tilde{\chi}_1^+ \to \ell^+ \tilde{\nu}$	56%	-	-	-	-
$\tilde{\chi}_1^+ \to \nu \tilde{\ell}^+$	43%	-	-	100% (only $\nu_\tau \tilde{\tau}_1^+$)	-
$\tilde{\chi}_1^+ \to W^+ \tilde{\chi}_1^0$	1.8%	100%	-	-	-
$\tilde{\chi}_1^+ \to q\bar{q}' \tilde{\chi}_1^0$	-	-	70%	-	-
$\tilde{\chi}_1^+ \to \ell^+ \nu \tilde{\chi}_1^0$	-	-	30%	-	-
$\tilde{\chi}_1^+ \to \tilde{t}_1 \bar{b}$	-	-	-	-	100%
$\tilde{\chi}_2^0 \to \ell^+ \tilde{\ell}^-, \ell^- \tilde{\ell}^+$	59%	-	-	100%	-
$\tilde{\chi}_2^0 \to \tilde{\nu}\bar{\nu}, \tilde{\nu}^* \nu$	41%	-	-	-	-
$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$	$< 0.1\%$	12%	-	-	-
$\tilde{\chi}_2^0 \to H\tilde{\chi}_1^0$	-	88%	-	-	-
$\tilde{\chi}_2^0 \to q\bar{q}\tilde{\chi}_1^0$	-	-	56%	-	-
$\tilde{\chi}_2^0 \to \ell^+ \ell^- \tilde{\chi}_1^0$	-	-	10%	-	-
$\tilde{\chi}_2^0 \to \nu\bar{\nu}\tilde{\chi}_1^0$	-	-	21%	-	-
$\tilde{\chi}_2^0 \to q\bar{q}' \tilde{\chi}_1^\pm$	-	-	8.8%	-	-

Squarks/Gluinos



- Result on inclusive Squark / gluino reach from European Strategy for **massless neutralinos**
- 2014: Study reach in neutralino mass