Search for SUSY strong production at CMS at HL-LHC

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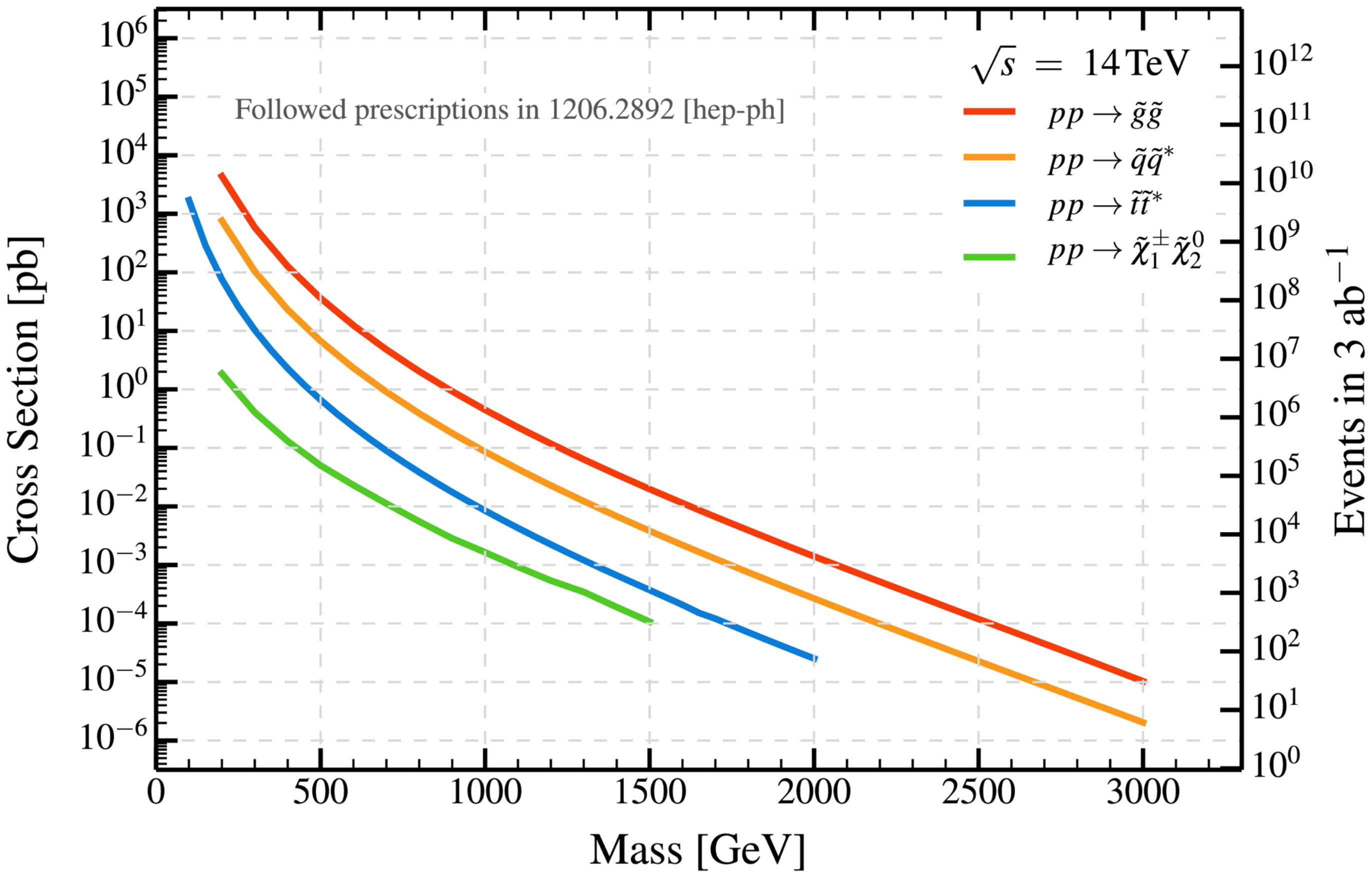
SUSY @ HL-LHC

- CMS has explored two goals of the HL-LHC SUSY program:
  - Mass reaches for discovery:
    - Strongly-produced SUSY
    - Weakly-produced SUSY (see Anadi's talk today)
  - Explore how HL-LHC measurements can illuminate the spectrum of new particles to be discovered in Run 2+3: "Discovery story"

References (for strong production of SUSY):

- CMS-PAS-SUS-14-012 & CMS-TDR-15-02 (CMS Phase 2 technical proposal), https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS14012
- CMS-PAS-FTR-13-014, https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFTR13014
- CMS-NOTE-13-002, http://arxiv.org/abs/1307.7135

SUSY Cross Section @ 14 TeV

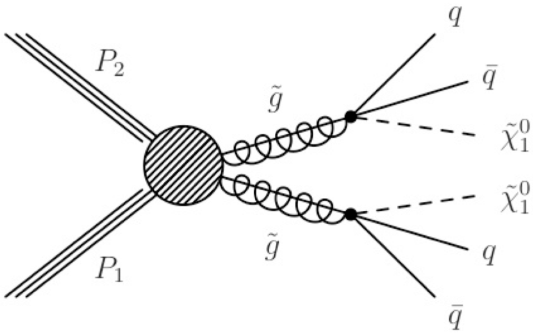


- High mass gluinos & light squarks >~2.5 TeV require HL-LHC
- 3rd generation squark cross sections are quite small → need high luminosities

Strategy & Disclaimer

- Use the Delphes fast simulation
  - The physics object performance in Delphes (v3.0.10) was validated against the full simulation of Phase 2 detector at the time of technical proposal
  - The significance calculation was done by the binominal significance (Zbi) for single bin analyses or rootstats tool from the LHC Higgs Combination group for multi-bin analyses
- These projections (related to strong SUSY production for HL-LHC) were made during LS1
  - Baseline selection in most cases "borrowed" from 8 TeV analysis
  - Tuning of few selected key variables and tightening of signal regions done for simple optimization
  - The systematic uncertainties are estimated based on those in 8 TeV analysis
  - This means these projections do not incorporate recent analysis developments adopted (e.g. top tagging, Higgs tagging etc)

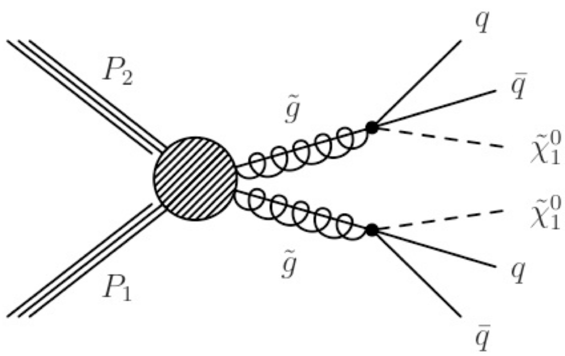
Jets + MHT Search: Overview

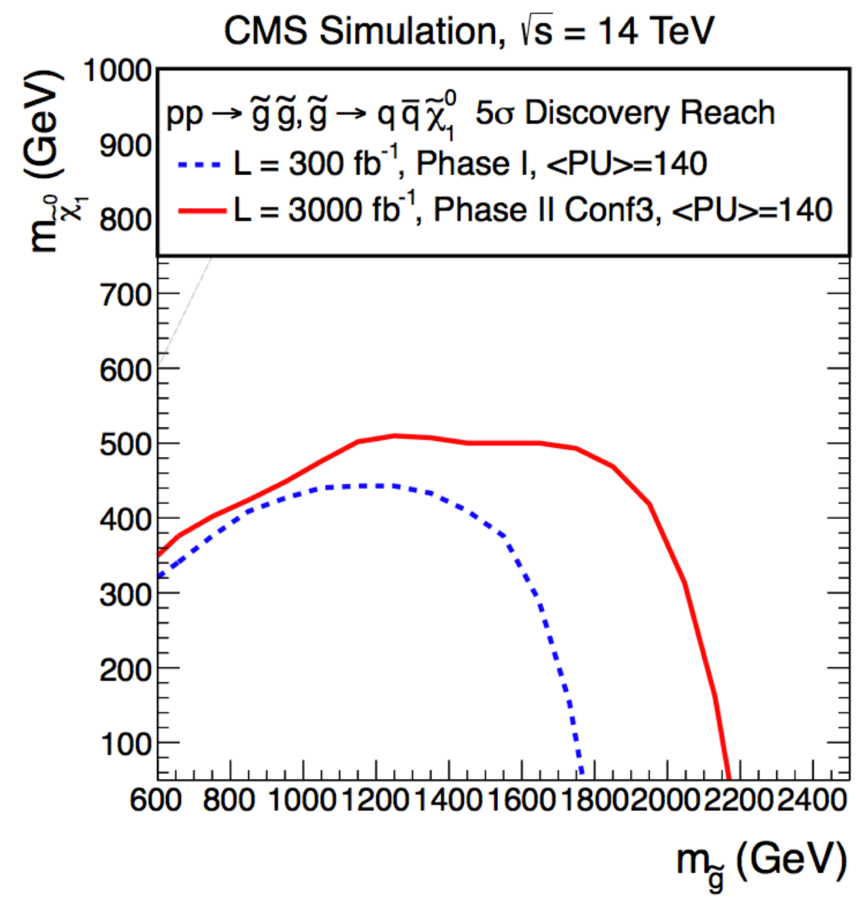


- Search for direct gluino production with multiple jets and large MET
  - Based on 8 TeV analysis - CMS-SUS-13-012
- Baseline selection
  - Electron and muon veto (p_T > 10 GeV and $|\eta|$ < 2.4 (μ) or 2.5 (e))
  - Njets > 3 (p_T > 50 GeV and $|\eta|$ < 2.5)
  - MHT > 200 GeV (with MHT=$|-\Sigma(p_T(\text{jets})|$ with p_T> 30 GeV))
  - HT > 500 GeV ($\Sigma(p_T$(jets) with p_T > 50 GeV and $|\eta|$ < 2.5))
  - $\Delta\Phi$(MHT, Jet(1,2,3) > 0.5, 0.5, 0.3
- Search region binned in HT & MHT for njets ≥ 6
  - In total, ~5 signal regions are defined. For each signal mass point, the search region that results in the best sensitivity is chosen.
  - c.f. recent 13 TeV search (CMS-SUS-16-033): 184 search regions defined by HT, MHT, Njets, Nb. Sensitivities from different search regions are combined statistically. These differences would make a factor 2-3 differences in xsec easily
- Systematic uncertainty: assume 30% similar to 8 TeV analysis

CMS-PAS-FTR-13-014

Jets + MHT Search: Results

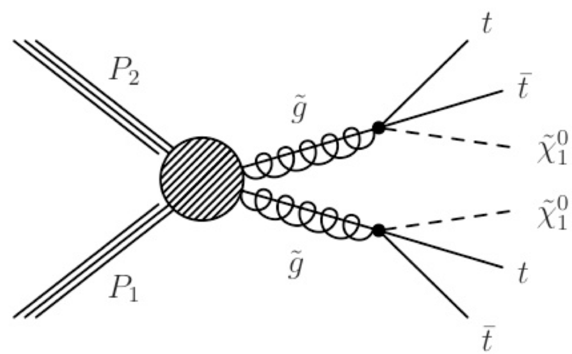




- Sensitive to gluino masses up to 2.2 TeV and LSP masses up to 500 GeV
- Gain of ~400 GeV in gluino mass discovery reach when going from 300 fb^{-1} to 3000 fb^{-1}

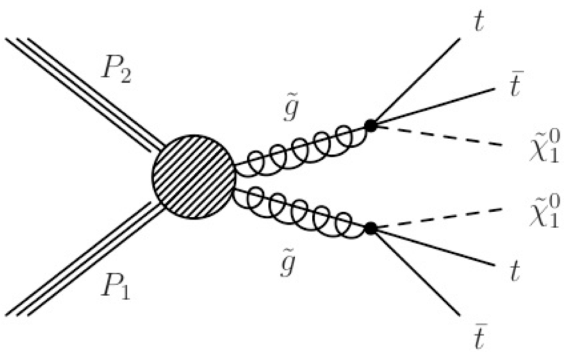
Single Lepton + b Search: Overview

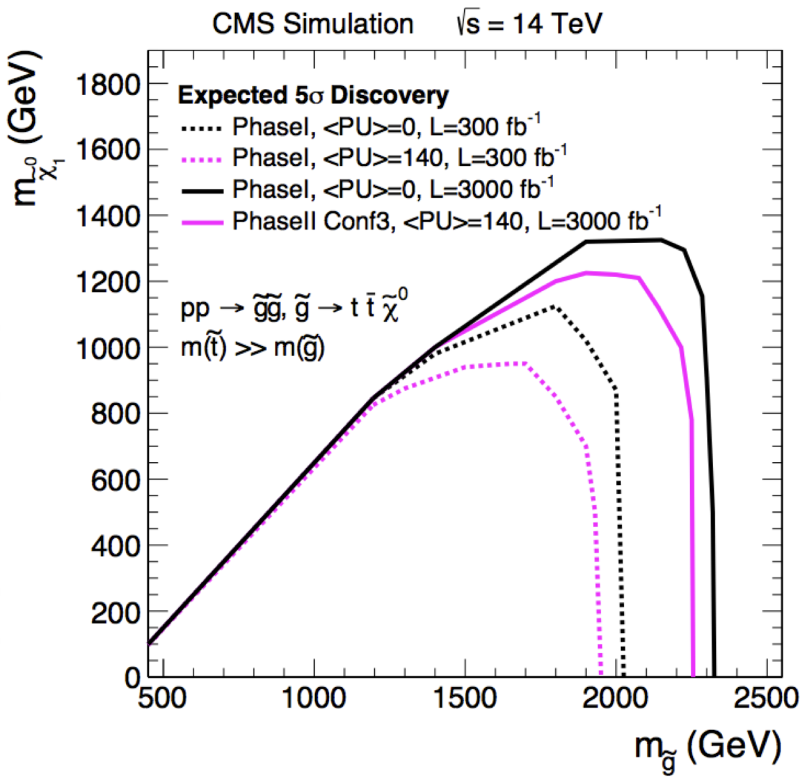
- 3rd generation squarks expected to be light compared to 1st and 2nd generation
  - Gluinos (if heavier than 3rd generation) can decay with large branching fraction to 3rd generation squarks



- Typical signature of such events:
  - Many jets
  - Among them several b-jets
  - Large MET
  - Angle between lepton and W (ΔΦ) larger for signal than for typical background (semileptonic ttbar), where MET and lepton are correlated

Single Lepton + b Search: Results



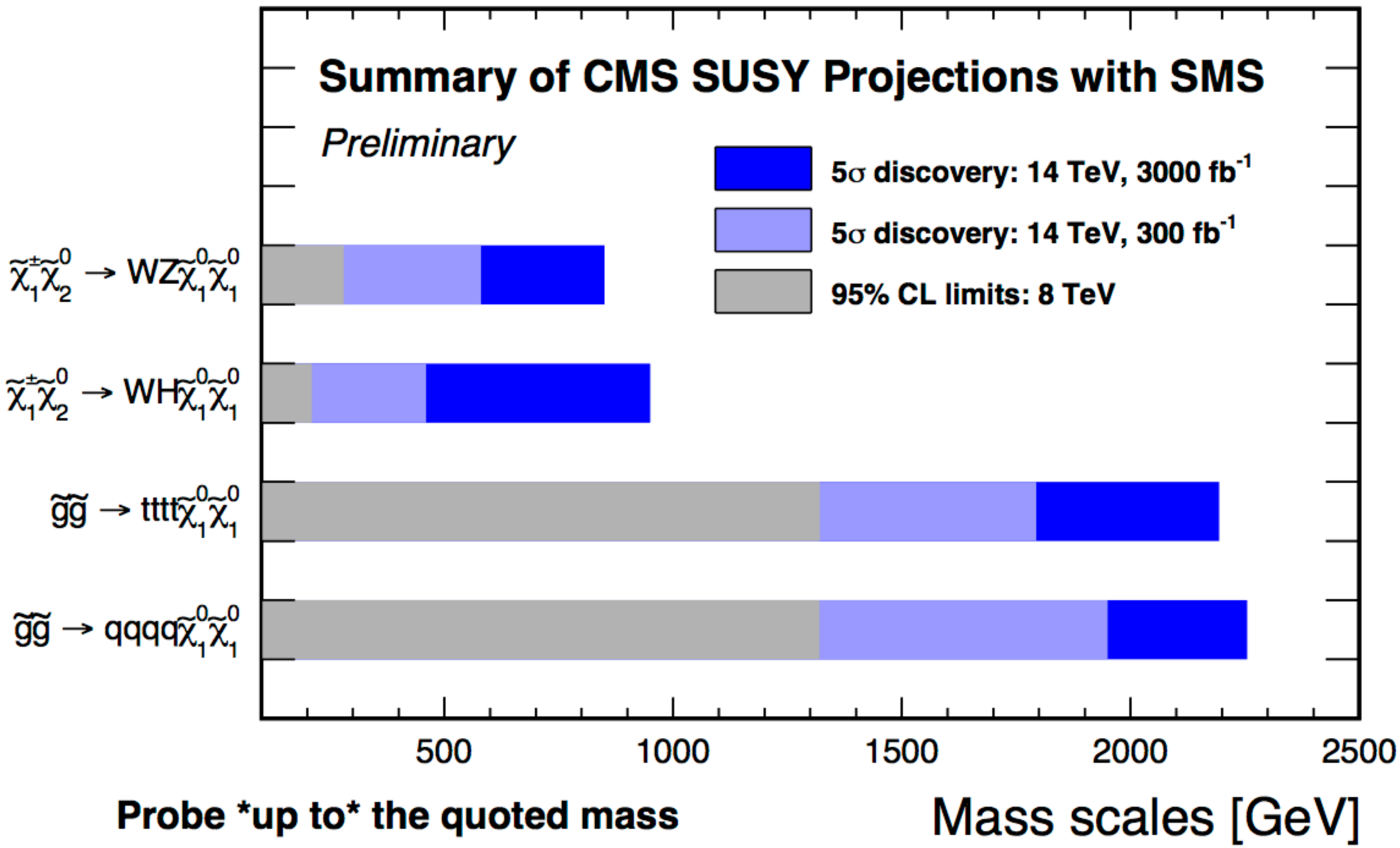


- Sensitive to gluino masses up to 2.3 TeV and LSP masses up to 1.2 TeV
- Gain of ~300 GeV in gluino mass discovery reach when going from 300 fb^{-1} to 3000 fb^{-1}

Mass Reach Summary

EWK SUSY

Strong SUSY



CMS-PAS-SUS-14-012
CMS-TDR-15-02

Discovery Scenario: Overview

- Explored:
  - Five different models.
  - Nine different experimental signatures.

Exploring SUSY model space →

Exploring experimental signature space ↓

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

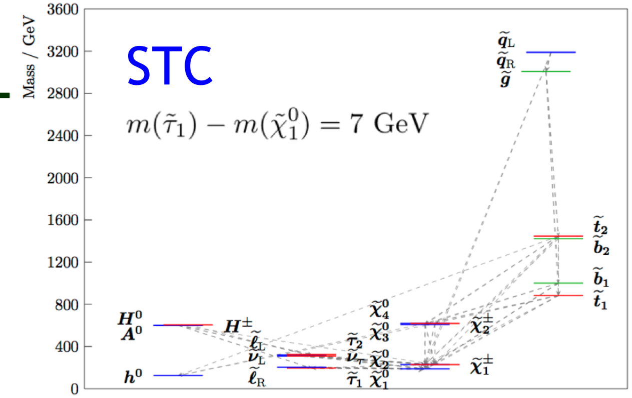
$< 3\sigma$	$3-5\sigma$	$> 5\sigma$

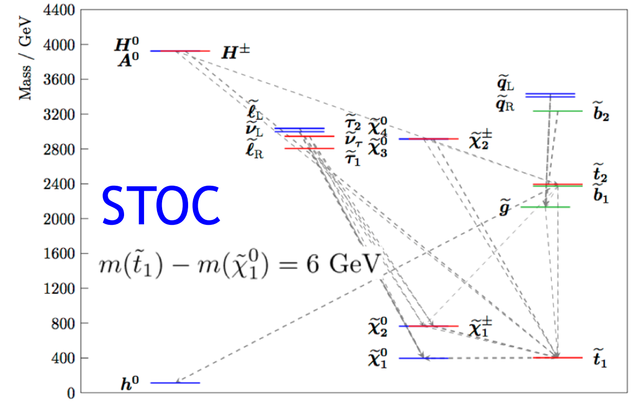
- Different types of SUSY models lead to different patterns of discoveries in different final states after different amounts of data.
- HL-LHC measurements can be crucial to illuminate a Run 3 discovery, and thus answer fundamental questions about gauge hierarchy or dark matter.

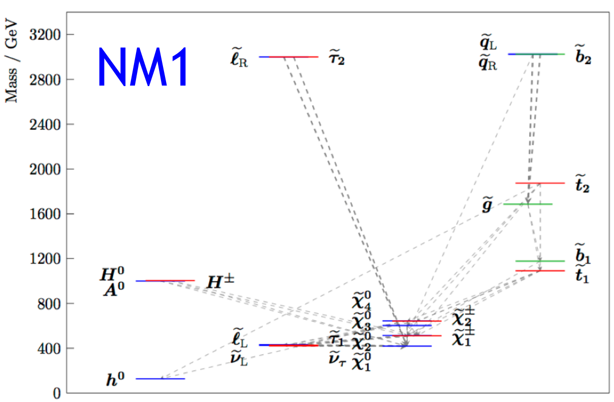
CMS-PAS-SUS-14-012
CMS-TDR-15-02

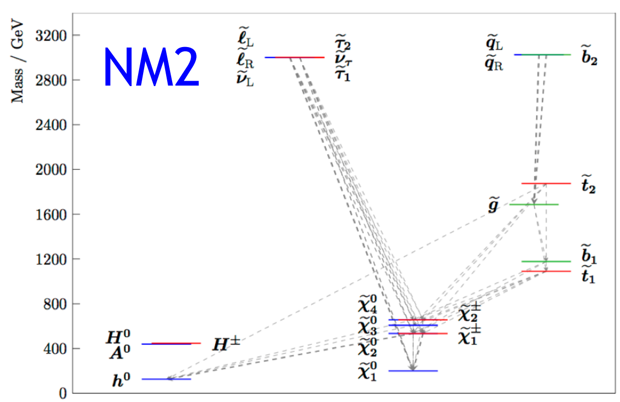
MSSM Models

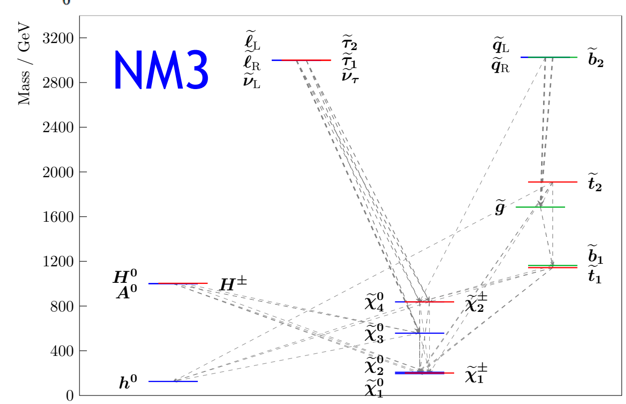
- Natural SUSY inspired models (NM1,2,3) and co-annihilation models (stop-coannihilation STOC, stau-coannihilation STC) motivated by dark matter
- The model should contain production and decay channels that could be discovered with up to 300 fb^{-1}: more features will be revealed with 3000 fb^{-1}











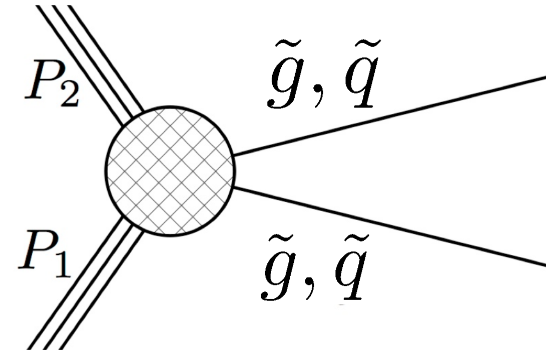
CMS-PAS-SUS-14-012
CMS-TDR-15-02

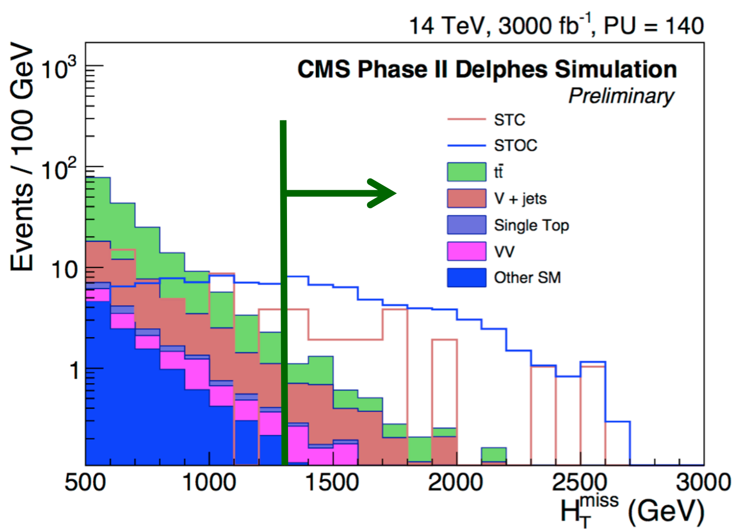
All-hadronic Search w/ HT+MHT

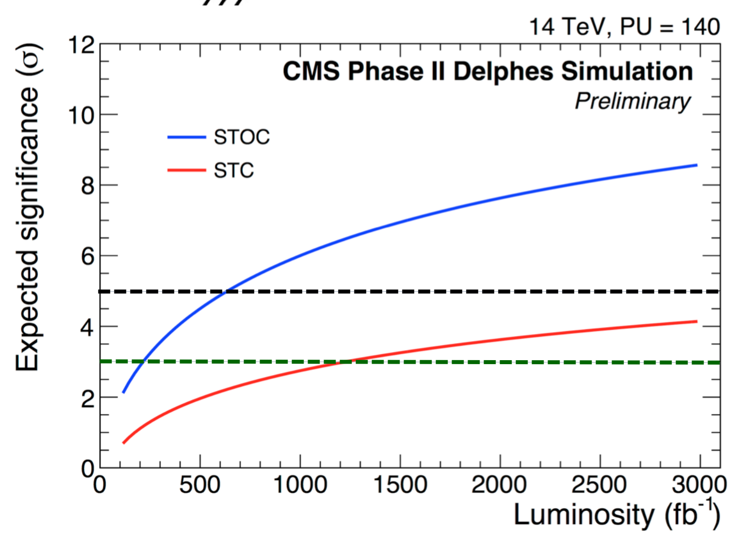
STOC, STC
searching for gluinos and squarks

- Search selection:
  - ≥3 jets
  - $\Delta\varphi(\text{MHT}, \text{jet}_{1,2,3})$ >0.5, 0.5, 0.3
  - Lepton vetos
  - ≥2 btags
  - H_T> 2.5 TeV
  - MHT> 1.3 TeV

Target signatures:







- 2.1 TeV gluino in STOC model is accessible with 600 fb^{-1} even with small ΔM(stop,LSP)
- Gluinos & Light squark of ~ 3 TeV in STC is ~discoverable w/ 3000 fb^{-1}

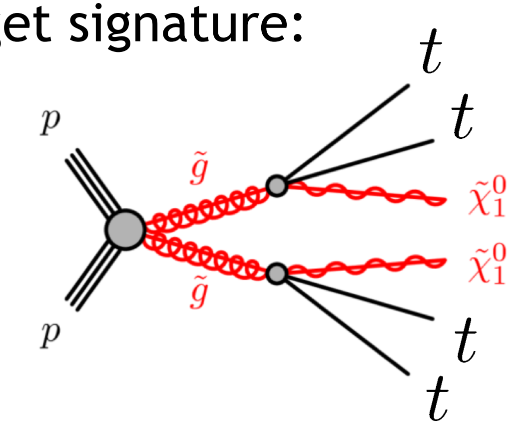
CMS-PAS-SUS-14-012
CMS-TDR-15-02

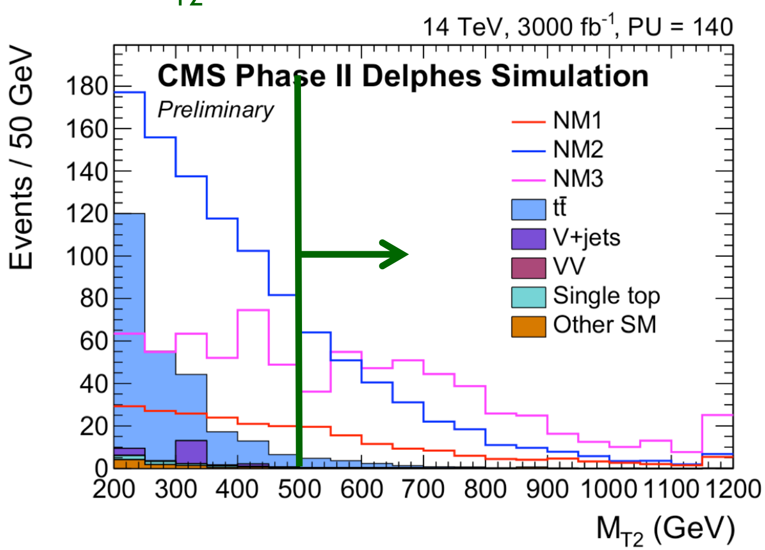
All-hadronic Search w/ MT2

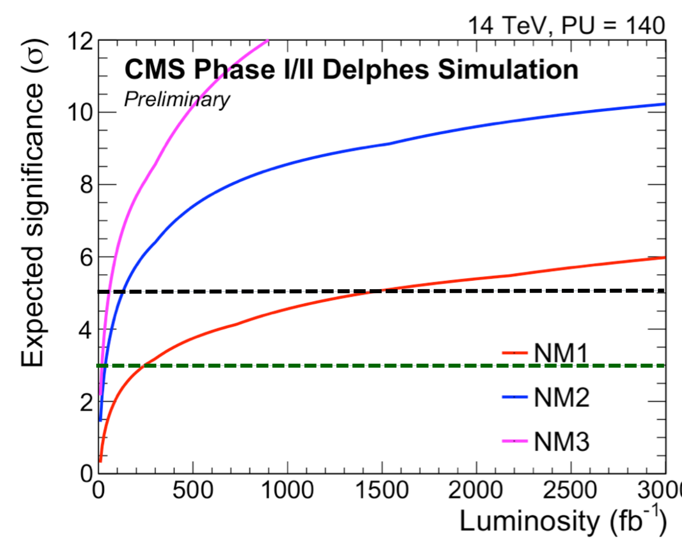
NM1, NM2, NM3 searching for gluino (or squark) pair production

- Search selection:
  - ≥8 jets
  - $\Delta\varphi(\text{MET},\text{jet}_{1,2,3}) > 0.4$
  - ≥3 b-tags
  - no leptons
  - $H_T > 2$ TeV
  - $M_{T2} > 500$-800 GeV

Target signature:







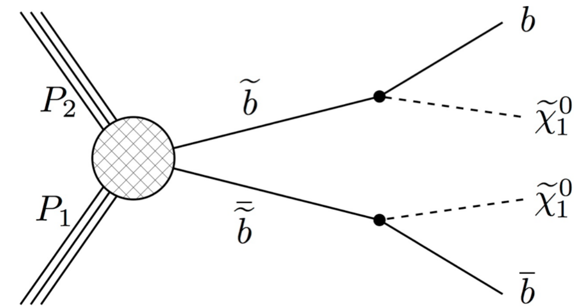
- Large mass gaps in NM3 → massive m_{T2} tails
  - Distinctive kinematic features indicate the structure of SUSY spectrum

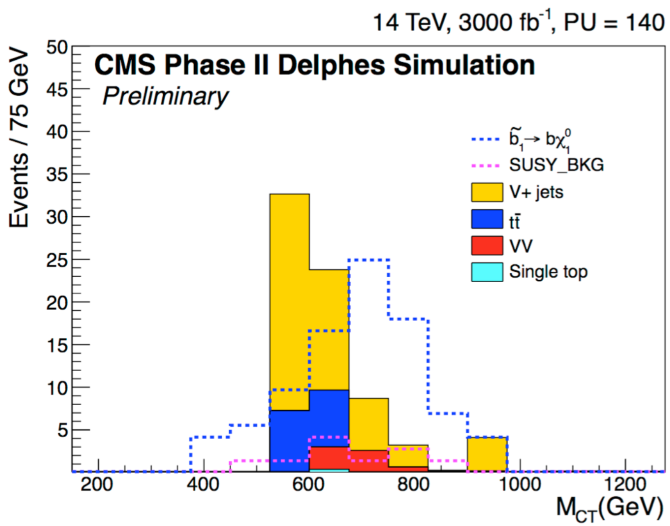
Search for Sbottom in bb+MET

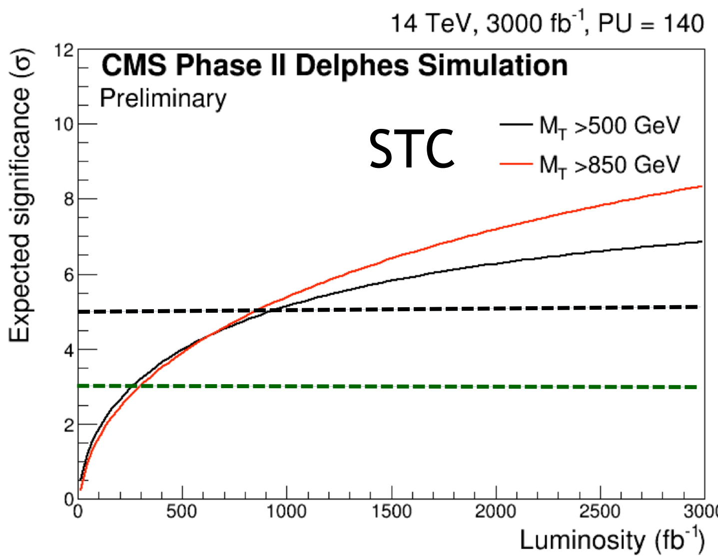
STC searching for sbottoms

- Search selection:
  - Lepton veto (e/μ)
  - =2 b-tags
  - Veto third jet
  - Δφ(b1,b2) < 2.5 (QCD rejection)
  - H_T > 750 GeV, MET > 450 GeV
  - $M_T(b_{1,2}$, MET) > 500 - 900 GeV

Target signature:







- 1 TeV sbottom is discoverable with 800 fb^{-1}
- M_{CT} endpoint with 3000 fb^{-1} tells us mass info: $(m(\tilde{b})^2 - m(\tilde{\chi}_1^0)^2)/m(\tilde{b})$

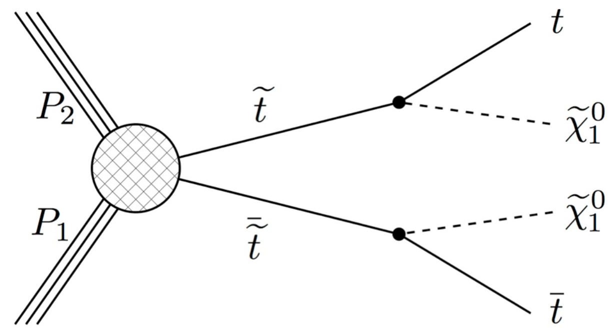
CMS-PAS-SUS-14-012
CMS-TDR-15-02

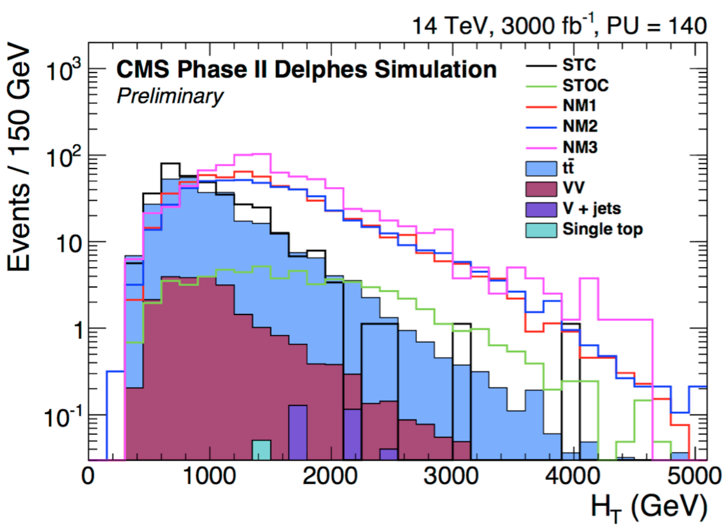
1-lepton Search

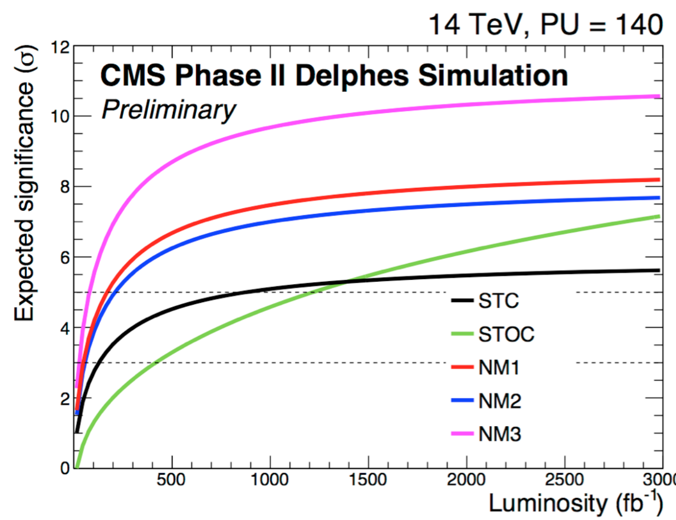
STC, NM1, NM2, NM3 searching for stop pair production

- Search selection:
  - 1 lepton (e/μ)
  - ≥5 jets 1 or 2 b-jets
  - Centrality > 0.6
  - $\Delta\varphi(MET, jet_{1,2}) > 0.8$
  - MET > 400 (800) GeV
  - M_T > 260 GeV, M_{T2}^W > 260 GeV

Target signature:





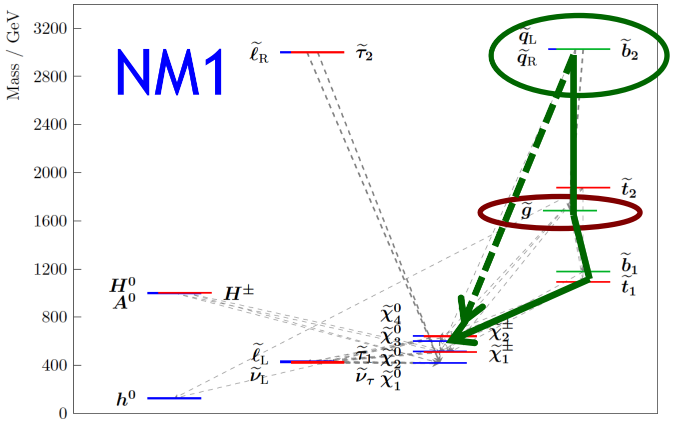


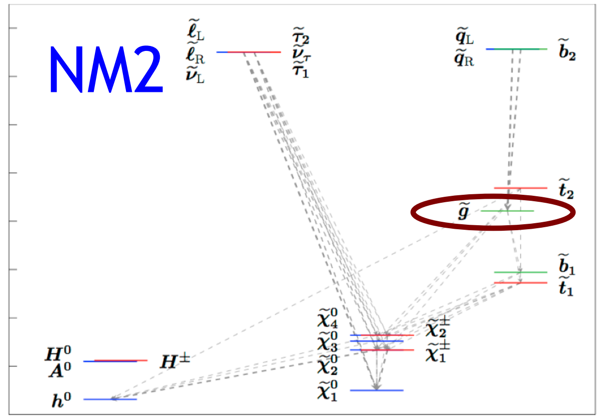
In STC model:

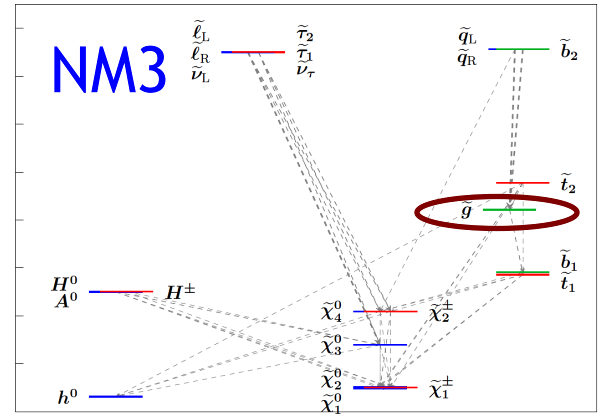
$\tilde{t}_1 \to t + \tilde{\chi}_1^0$ (20%)
$\tilde{t}_1 \to t + \tilde{\chi}_2^0$ (5%)
$\tilde{t}_1 \to t + \tilde{\chi}_3^0$ (20%)
$\tilde{t}_1 \to t + \tilde{\chi}_4^0$ (9%)
$\tilde{t}_1 \to b + \tilde{\chi}_1^+$ (12%)
$\tilde{t}_1 \to b + \tilde{\chi}_2^+$ (34%)

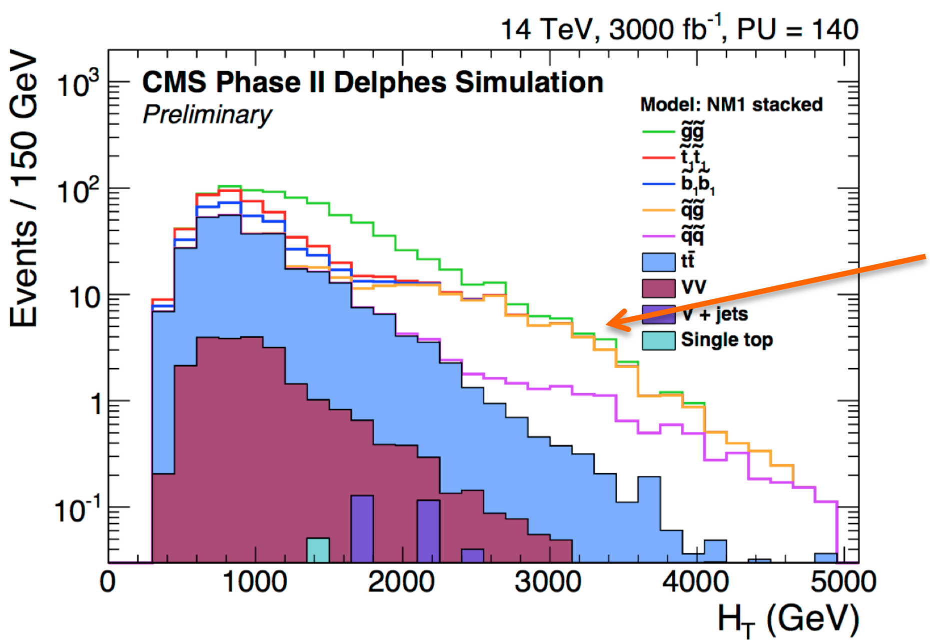
- For this stau-coannihilation (STC) model, 70% of the signal in the 1-lepton search comes from direct top squark production

1-lepton Search









First observation comes from Gluino pair production

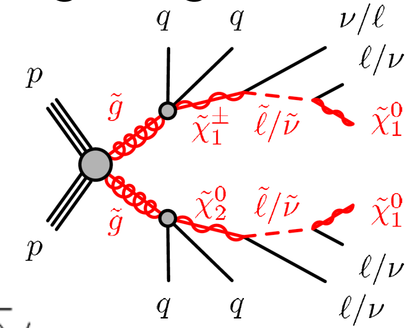
Gluino-squark production of 3TeV u/d/s squarks becomes visible with 3000 fb^{-1}

Observations in additional final states w/ HL-LHC

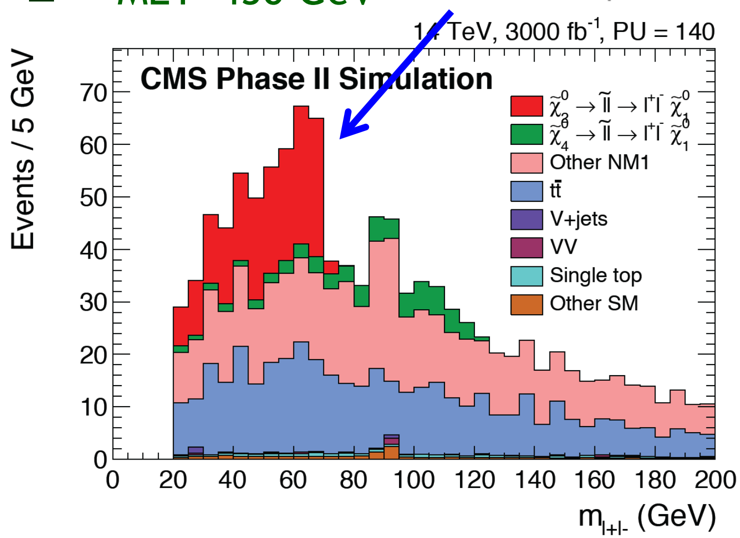
$M(l^+l^-)$ Kinematic Edge Search

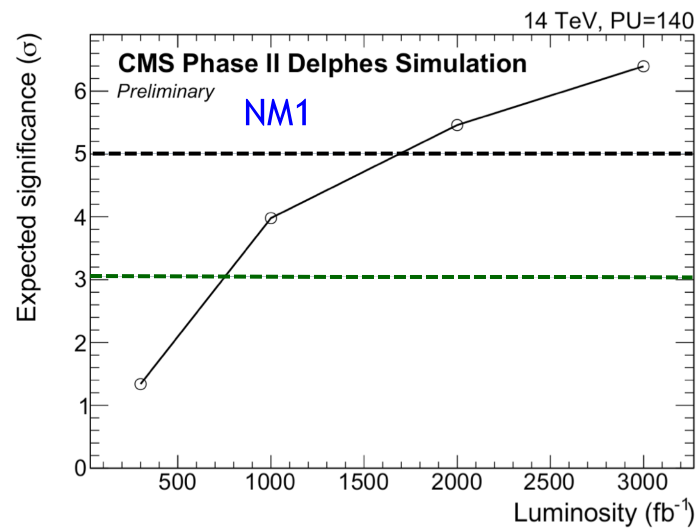
- Search selection:
  - An opposite-sign (OS) same-flavor (SF) l^+l^- pair (e/μ, $p_T>10$ GeV, $|\eta|<2.4$)
  - $m(l^+l^-)>20$ GeV
  - ≥6 jets ($p_T>40$ GeV, $|\eta|<2.4$), ≥1 btags
  - MET>450 GeV

Target signature:



$$m_{\text{edge}} = \sqrt{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}})(m^2_{\tilde{l}} - m^2_{\tilde{\chi}^0_1})}/m_{\tilde{l}}$$





- HL-LHC data can shed light on the EWK sector SUSY mass information, after the first discovery

NM1
searching for a kinematic edge in m(ll)

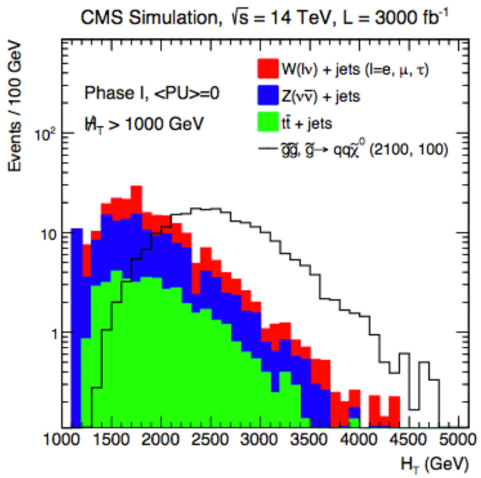
Conclusions

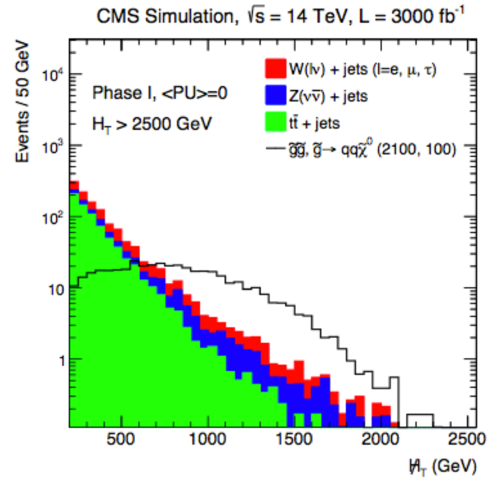
- In spite of absence of specific evidence, the motivation for SUSY has remained strong
  - Continues to be the most convincing framework to explain dark matter.
  - Discovery of the Higgs has given new urgency to find a “natural” explanation of the gauge hierarchy.
- We have investigated the mass reach for SUSY particles in the simplified models
  - We expect up to ~500 GeV mass extension with HL-LHC
  - The projections are likely on the conservative side, as we can’t predict what analysis improvements we will make
- We have explored how HL-LHC measurements can illuminate the spectrum of the new particles discovered in Run 2+3
  - Several major conclusions are:
    - The explored benchmark models would show at least some indication of excess w/ <300 fb^{-1}.
    - In order to map out the properties of a particle spectrum, it is essential to have a full pattern of results obtained at the highest integrated luminosities.

Backup

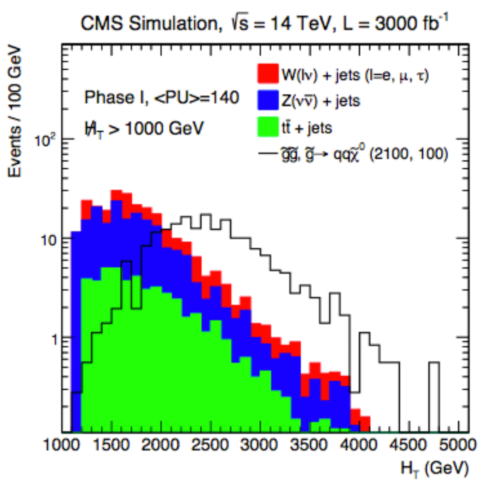
Jets + MHT Search

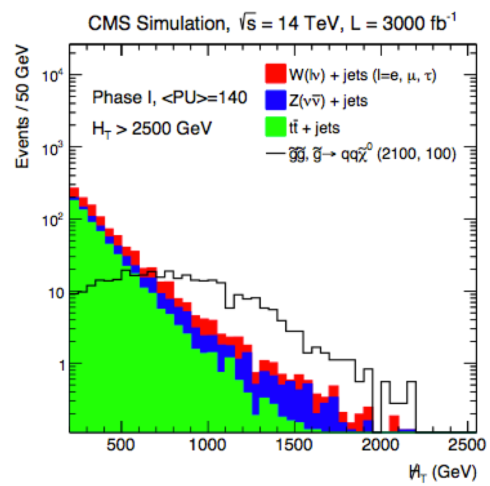
No pileup





140 pileup



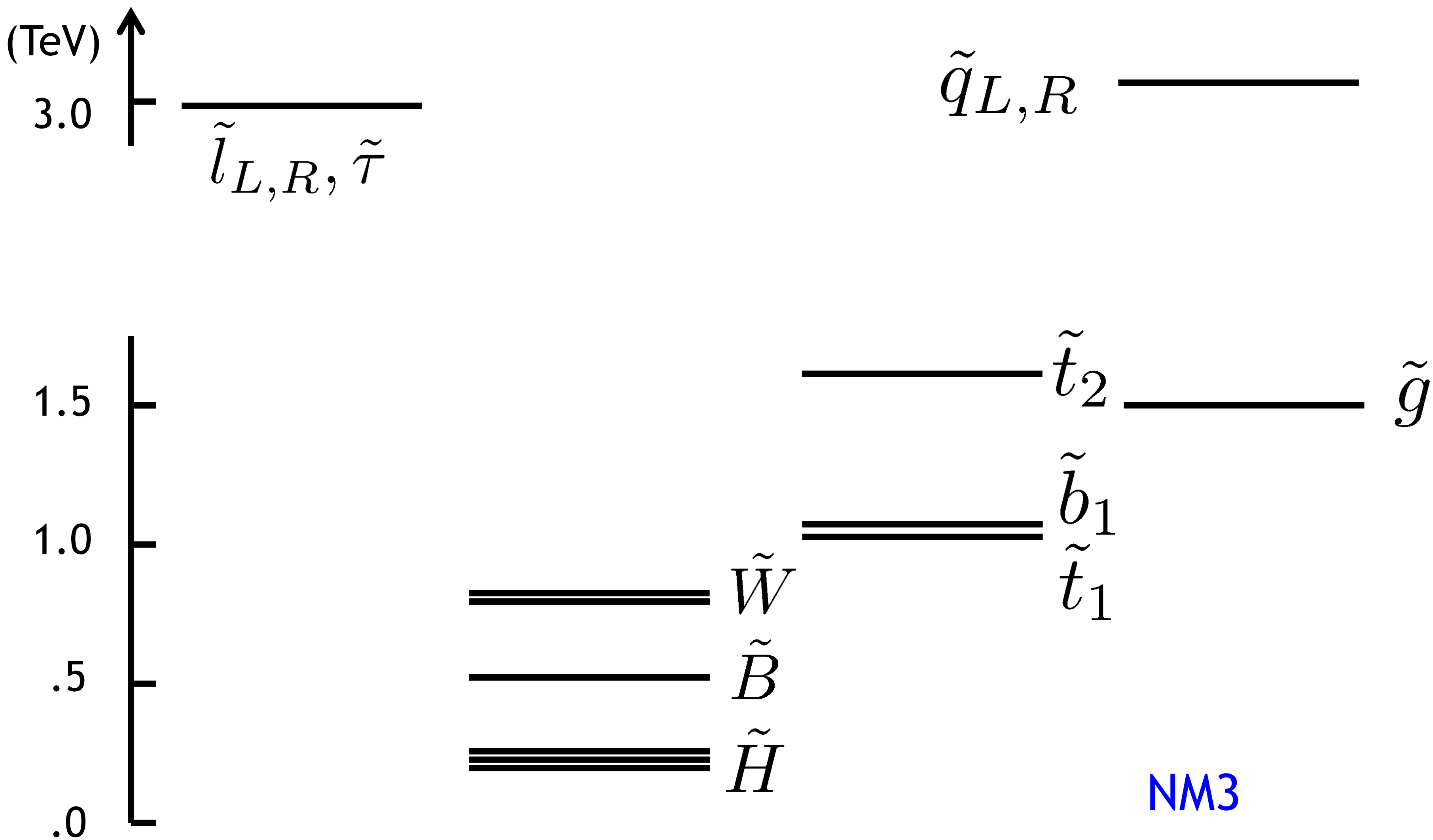


This analysis is not very pileup-dependent

Benchmark SUSY Models

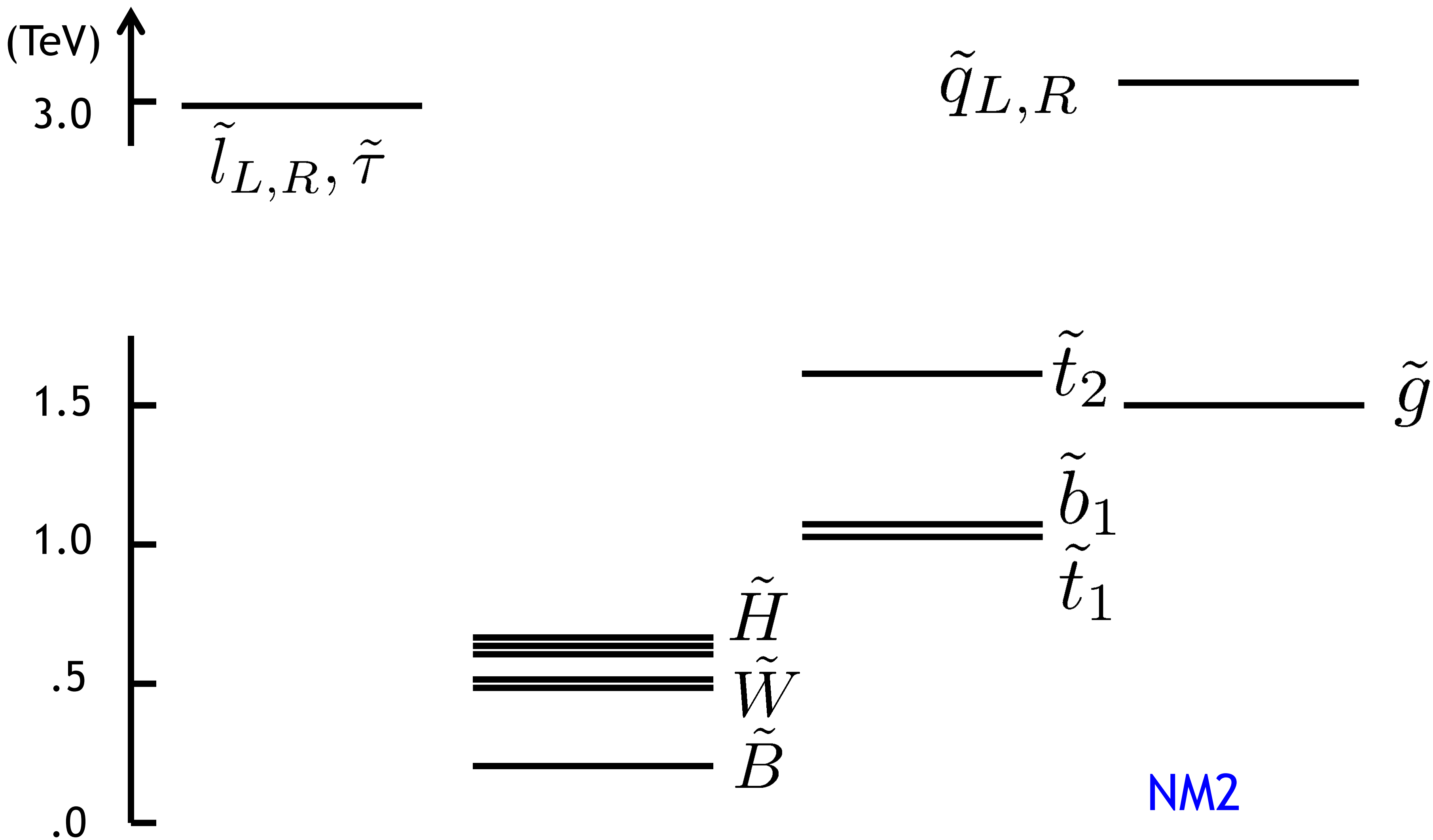
- Five benchmark full-spectrum SUSY models were constructed
  - The model should not be already excluded
    - The model should not be already excluded by existing SUSY & BSM higgs searches, and be consistent with existing measurements of the 125 GeV higgs, relic density, etc.
  - The model should contain production and decay channels that could be discovered with up to 300 fb^{-1}
  - The model should be well theoretically motivated
    - Natural SUSY inspired models (NM's) and co-annihilation models motivated by dark matter

Natural SUSY Models (NM's)



https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/NM3_slha.txt

Natural SUSY Models (NM’s)



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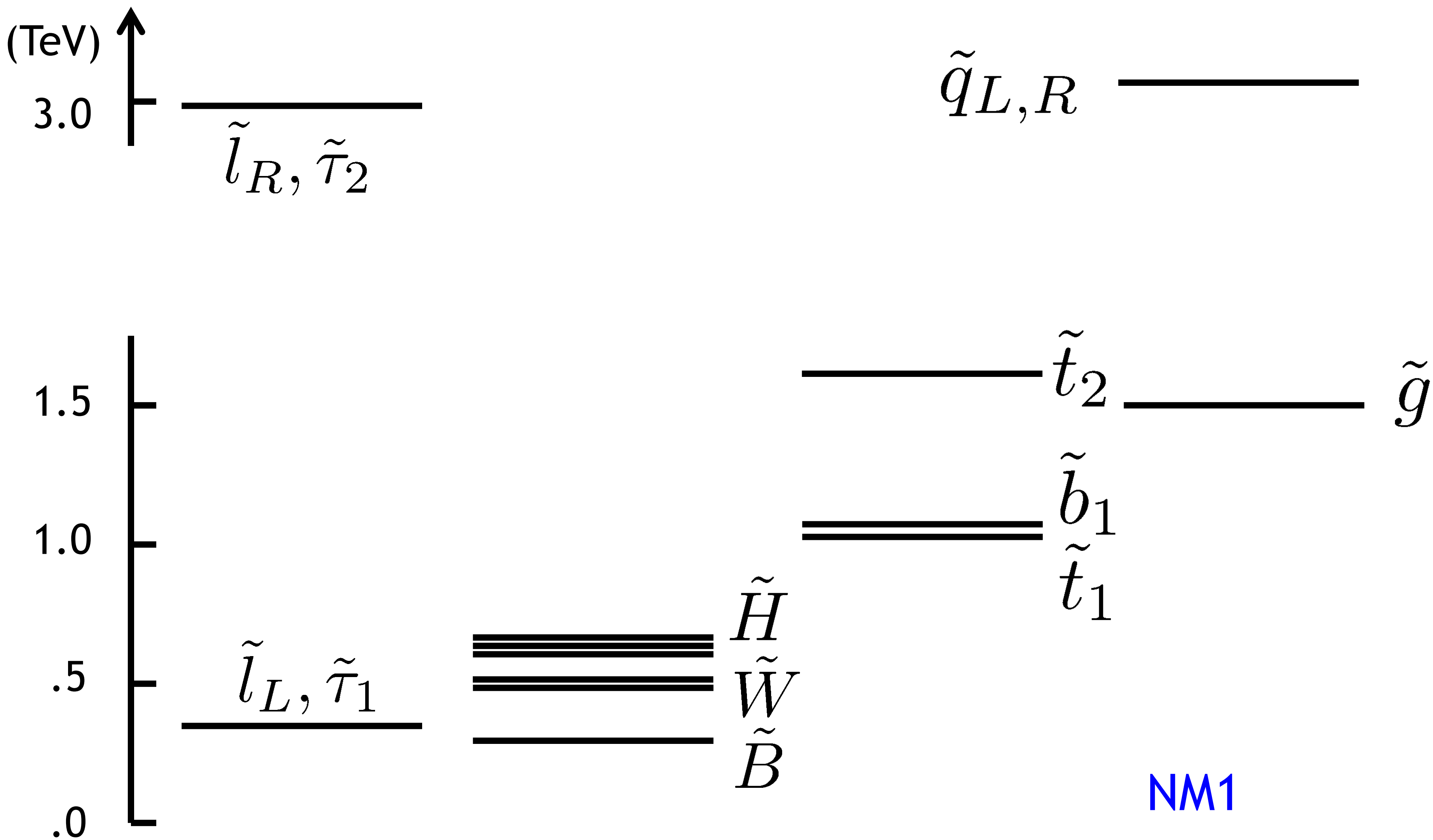
Natural SUSY Models (NM's)



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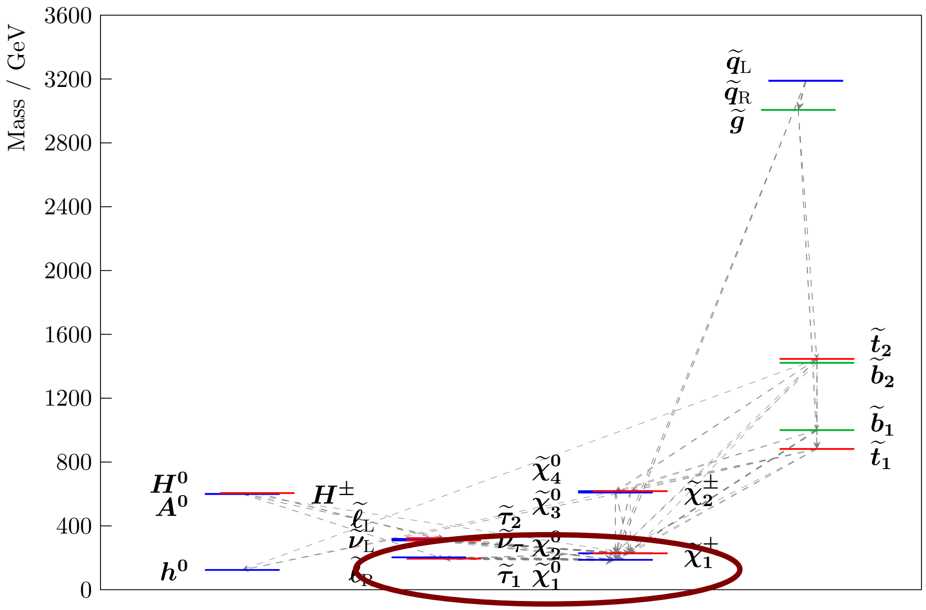
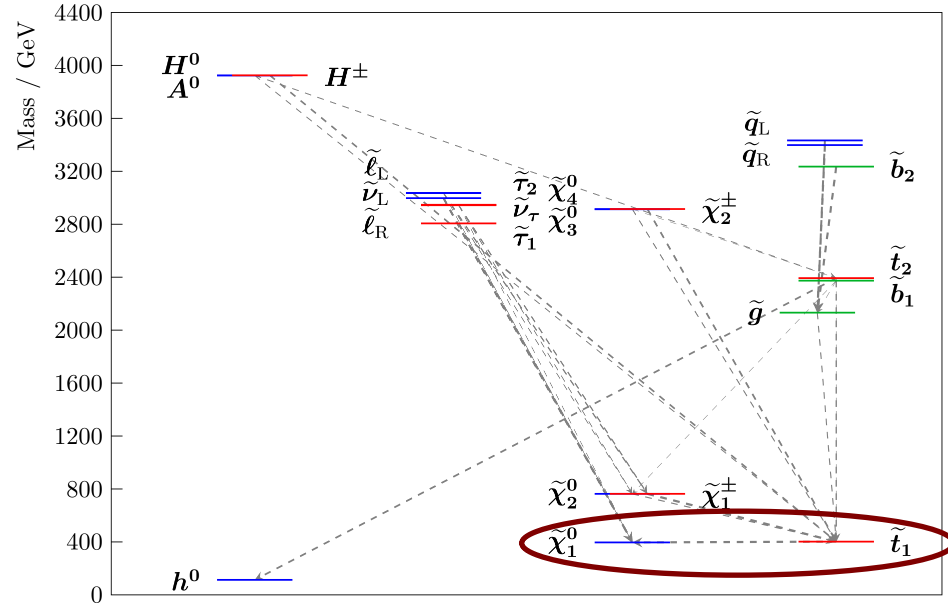
Co-annihilation Models

Stau coannihilation model (STC)



$$m(\tilde{\tau}_1) - m(\tilde{\chi}^0_1) = 7 \text{ GeV}$$

Stop coannihilation model (STOC)



$$m(\tilde{t}_1) - m(\tilde{\chi}^0_1) = 6 \text{ GeV}$$

https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/STC_slha.txt
https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/STOC_slha.txt

SUSY Particle Decays

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%

Decay	Branching fraction				
	NM1	NM2	NM3	STC	STOC
$\tilde{\chi}_1^+ \to \ell^+\tilde{\nu}$	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%	-	-
$\tilde{\chi}_2^0 \to \ell^+\nu\tilde{\chi}_1^-, \ell^-\bar{\nu}\tilde{\chi}_1^+$	-	-	4.0%	-	-
$\tilde{\chi}_2^0 \to \tilde{t}_1\bar{t}, \tilde{t}_1^* t$	-	-	-	-	100%

Top squark decay modes strongly depend on ewkino spectrum and composition

SUSY Particle Decays

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%

Decay	Branching fraction				
	NM1	NM2	NM3	STC	STOC
$\tilde{\chi}_1^+ \to \ell^+\tilde{\nu}$	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%	-	-
$\tilde{\chi}_2^0 \to \ell^+\nu\tilde{\chi}_1^-, \ell^-\bar{\nu}\tilde{\chi}_1^+$	-	-	4.0%	-	-
$\tilde{\chi}_2^0 \to \tilde{t}_1\bar{t}, \tilde{t}_1^* t$	-	-	-	-	100%

Bottom squarks often decay into a mode including a top quark, making it challenging to distinguish bottom squark from top squark

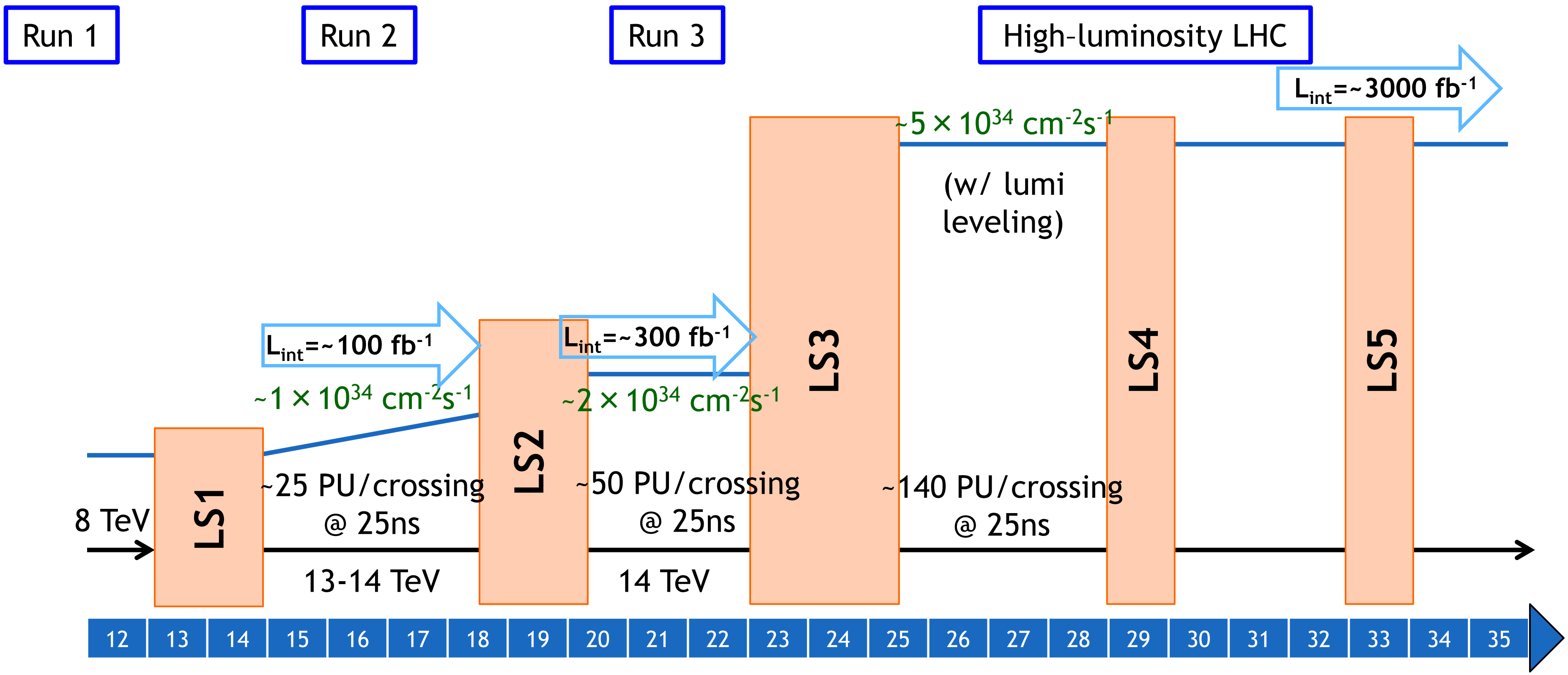
SUSY Particle Decays

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%

Decay	Branching fraction				
	NM1	NM2	NM3	STC	STOC
$\tilde{\chi}_1^+ \to \ell^+\tilde{\nu}$	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%	-	-
$\tilde{\chi}_2^0 \to \ell^+\nu\tilde{\chi}_1^-, \ell^-\bar{\nu}\tilde{\chi}_1^+$	-	-	4.0%	-	-
$\tilde{\chi}_2^0 \to \tilde{t}_1\bar{t}, \tilde{t}_1^* t$	-	-	-	-	100%

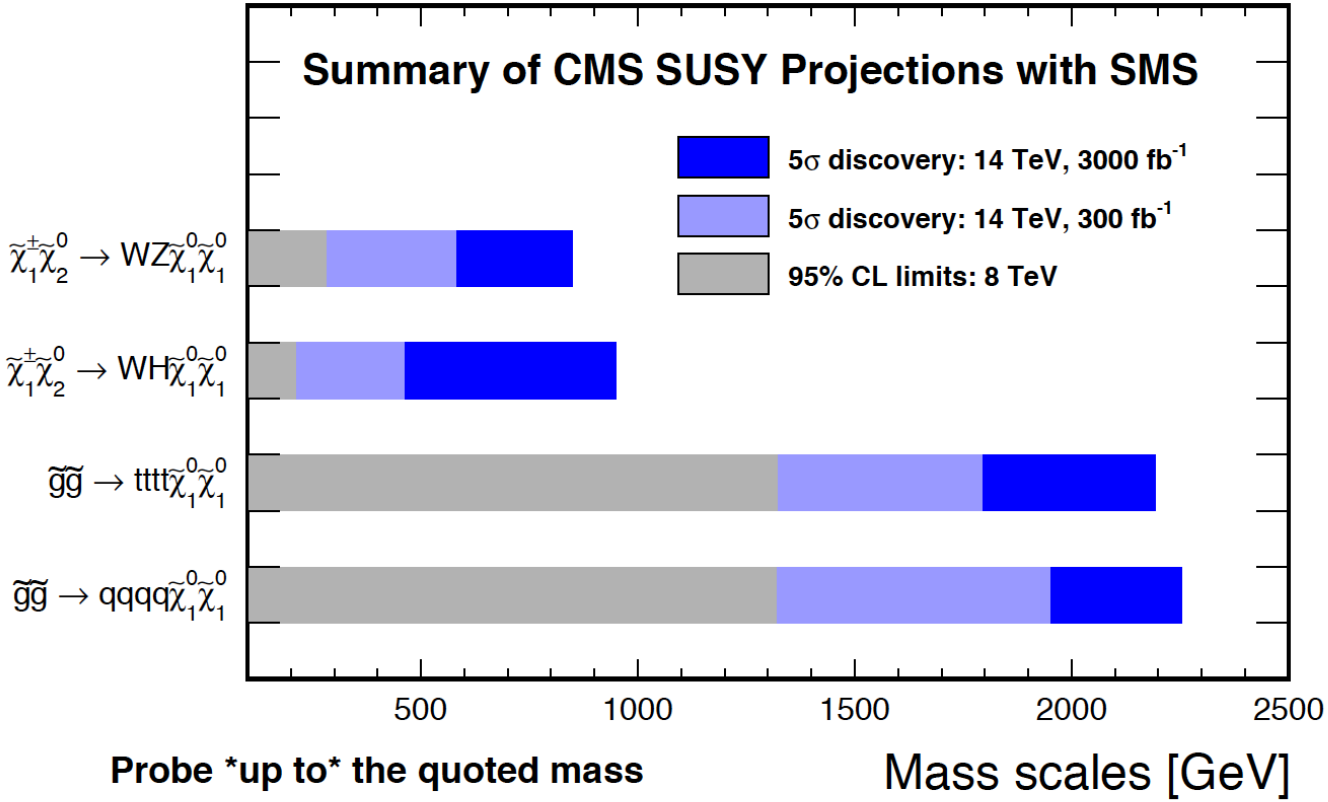
Obviously ewkino decays strongly depend on the ewkino spectrum and composition

LHC Evolution



Based on LHC schedule approved by CERN management, LHC experiment spokespersons and technical coordinators on Dec 2, 2013 Also, Bordry at ECFA HL-LHC workshop & Gregor.

SUSY Discovery Potentials w/ SMS



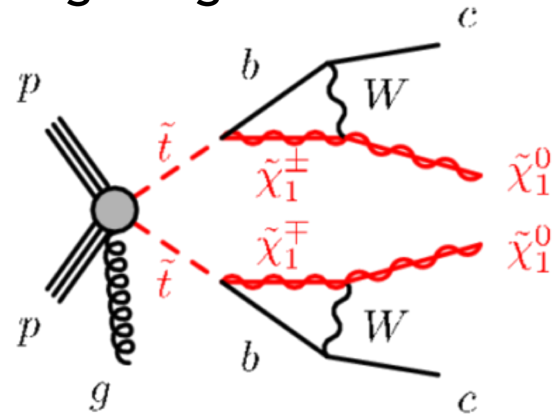
- HL-LHC increases mass reach for pair produced SUSY particles by up to 500 GeV.
- Largest relative gains in weak production processes.

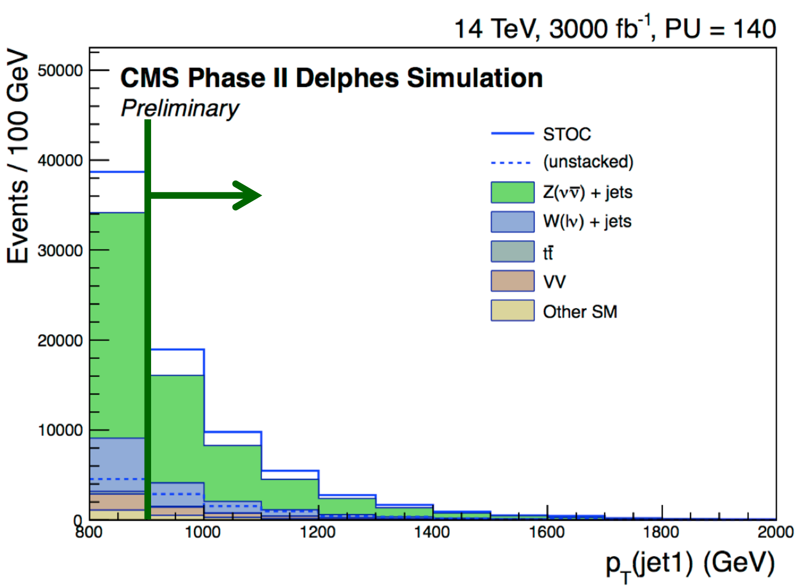
Monojet Stop Search

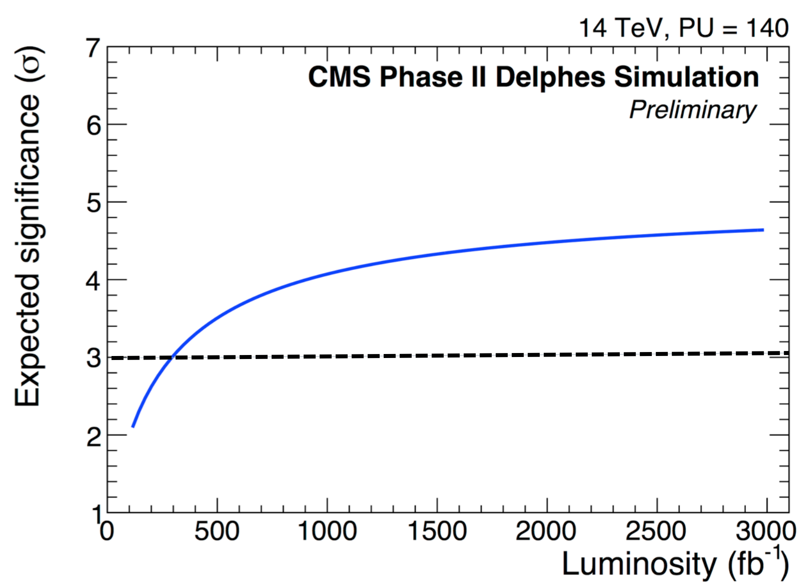
STOC
search for stop → invisible ($c \sim \chi_1^0$)

- Search selection:
  - $p_T(j_1) > 110$ GeV, $|\eta| < 2.4$
  - $\Delta\varphi(j_1, j_2) < 1.8$
  - Veto 3rd jet (p_T > 100 GeV, $|\eta| < 4.5$)
  - Electron/muon veto
  - MET > 600 GeV
  - $p_T(j_1)$ > 900 GeV

Target signature:



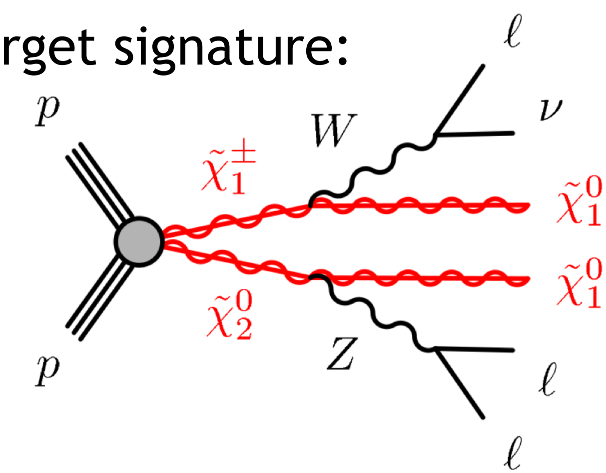




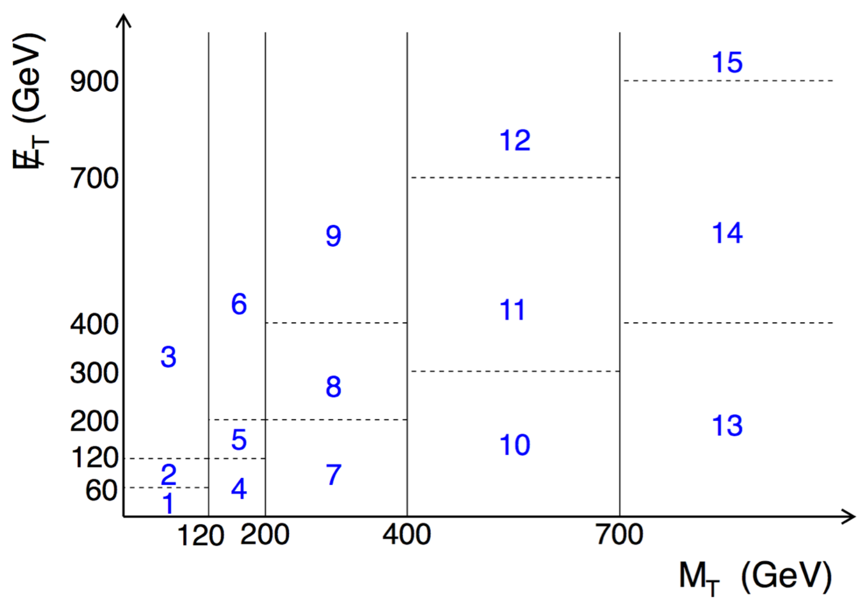
Search w/ Trileptons + MET

- Search selection:
  - 3ℓ (p_T>25/15/10 GeV) |η|<4
  - OSSF ($m_{\ell\ell}$) pair closest to Z(91 GeV):
    - On-Z: 75 GeV < $m_{\ell\ell}$ < 105 GeV
    - Off-Z: 105 GeV < $m_{\ell\ell}$
  - Veto events with b-jets (p_T >30 GeV)
  - Use binning in M_T vs MET

Target signature:



NM1, NM2, NM3, STC searching for EWKinos



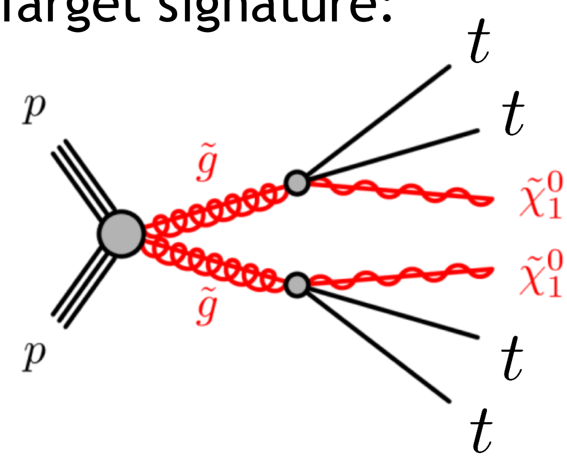
- Additional tighter search selection for heavy C1/N2:
  - 3ℓ (p_T>120/90/140 GeV)
  - Veto events with a jet (p_T >100 GeV)

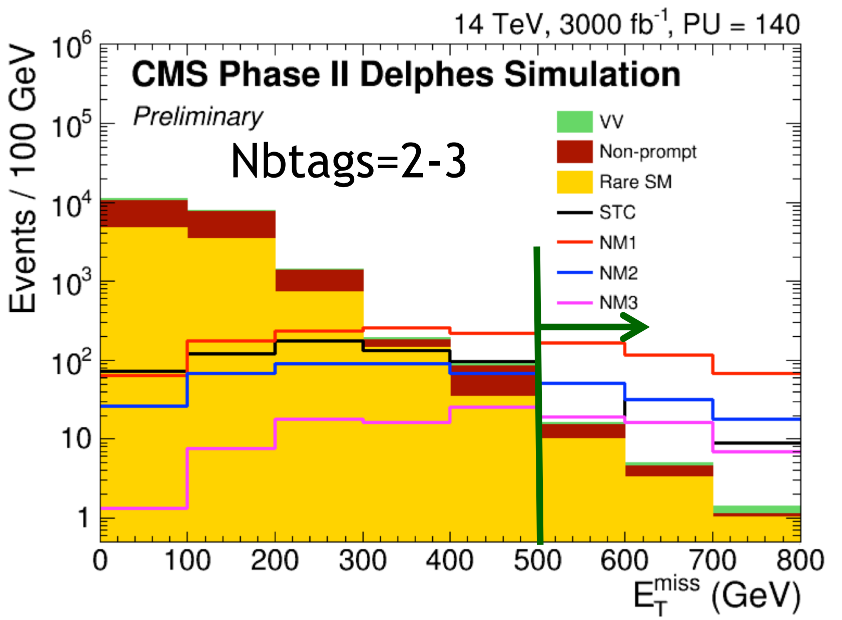
Searches w/ Trileptons + b-tags

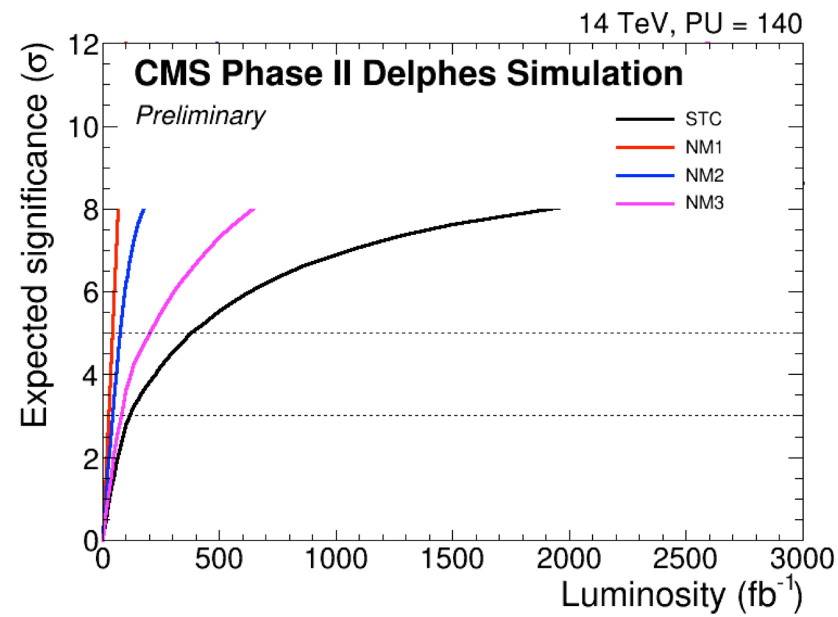
NM1, NM2, NM3, STC searching gluinos

- Search selection:
  - 3 leptons (p_T>25/15/10 GeV, |η|<4)
  - b-tags (2-3 or ≥4, p_T>50 GeV, |η|<1.8)
  - MET>500 GeV

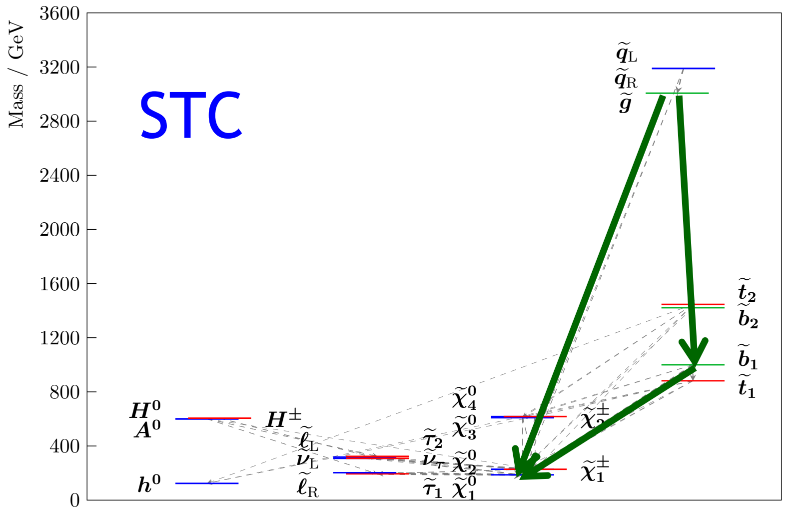
Target signature:

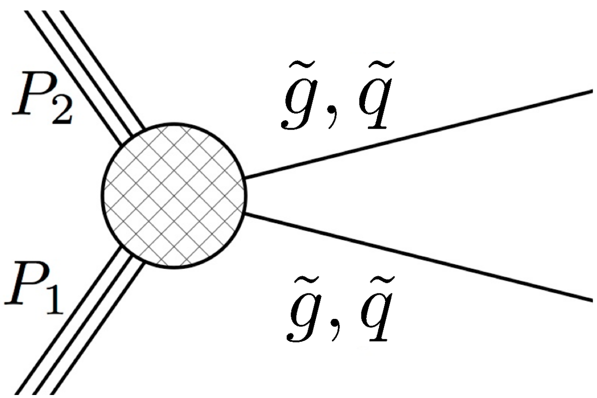




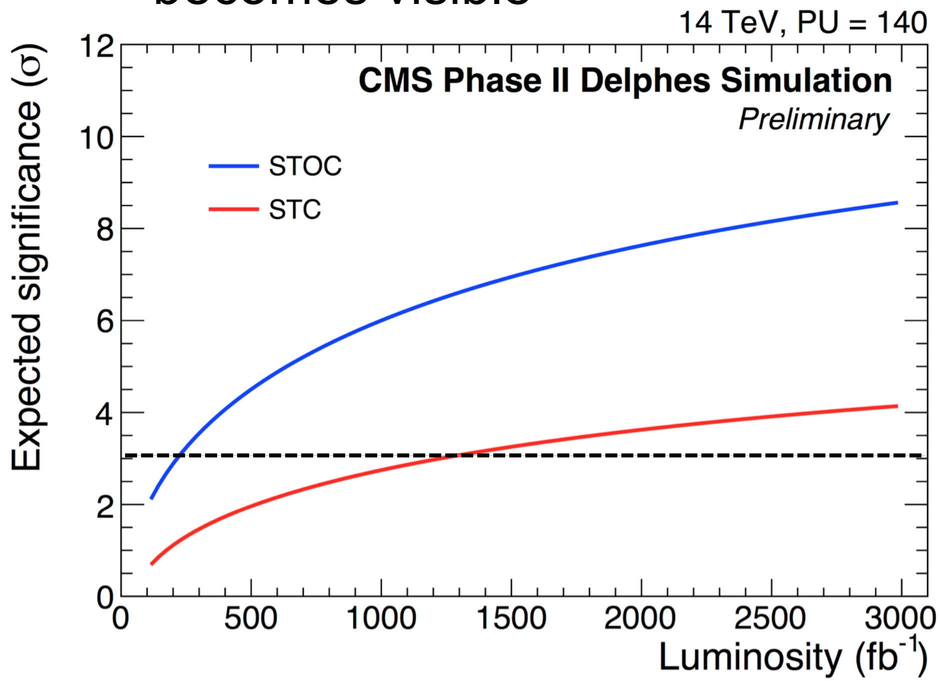


Discovery Scenarios: STC



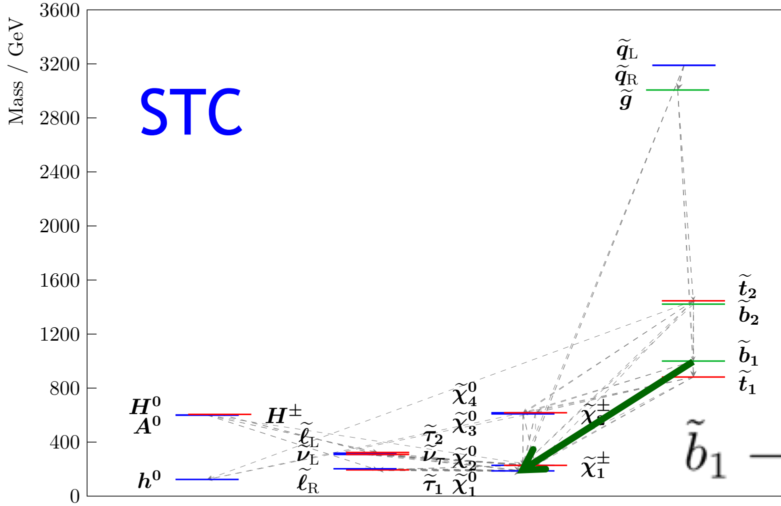


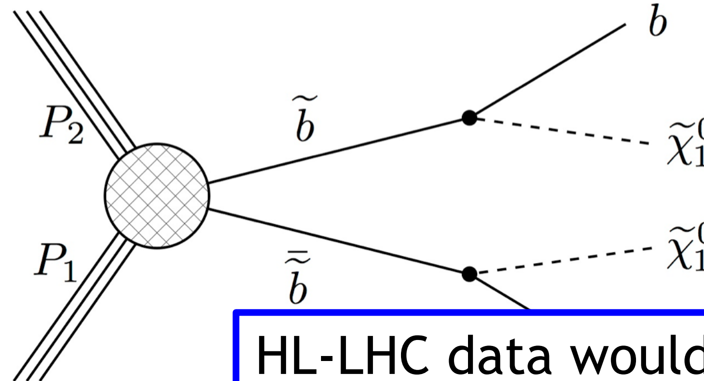
Gluino & squark production of 3TeV gluinos and u/d/s squarks becomes visible



Observations in additional final states w/ HL-LHC

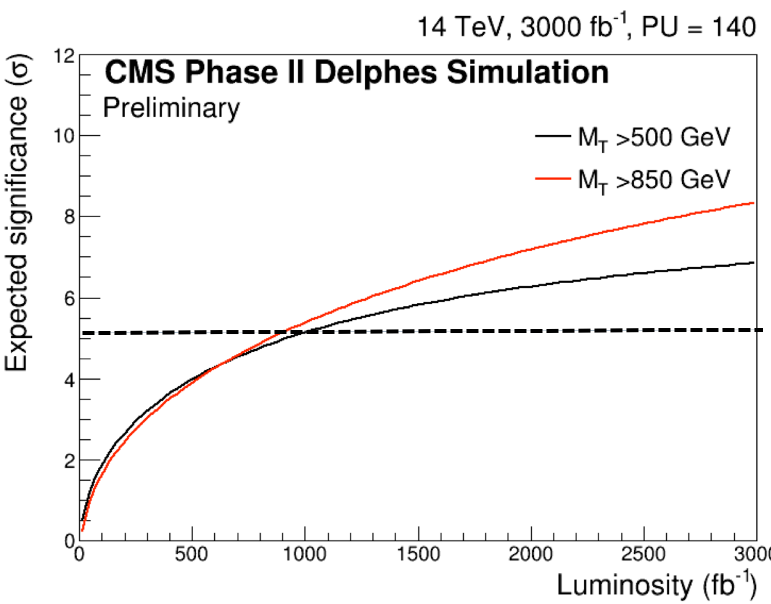
Discovery Scenarios: STC

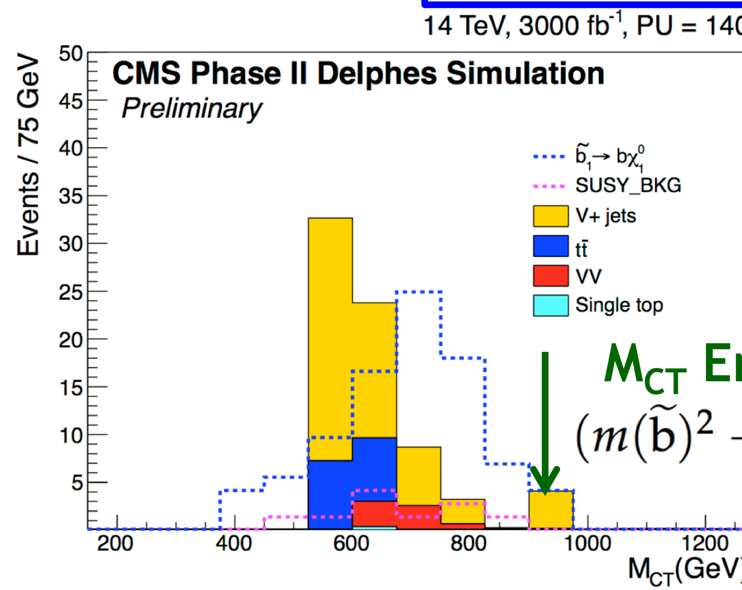




$$\tilde{b}_1 \to b + \tilde{\chi}_1^0 \ (67\%)$$

HL-LHC data would allow the endpoint mass measurements

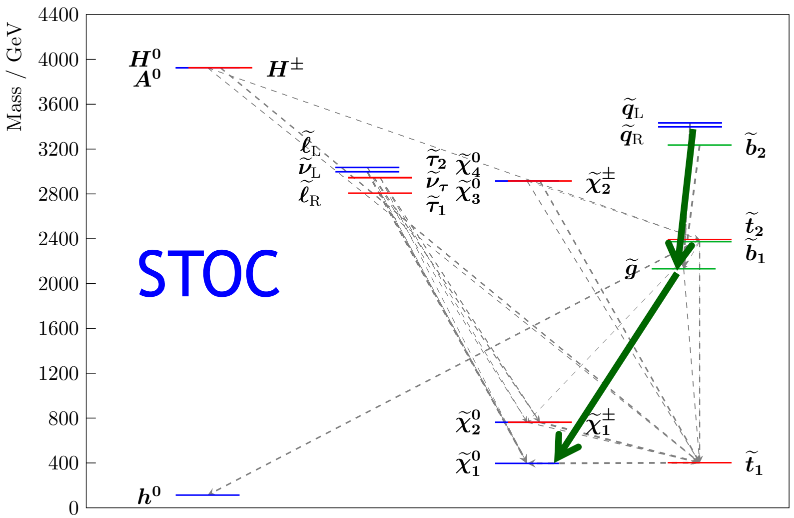


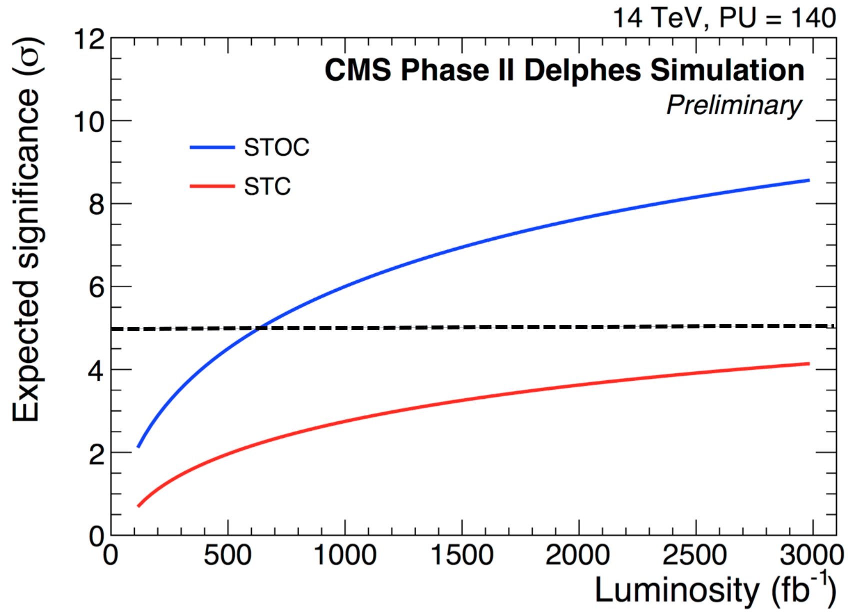


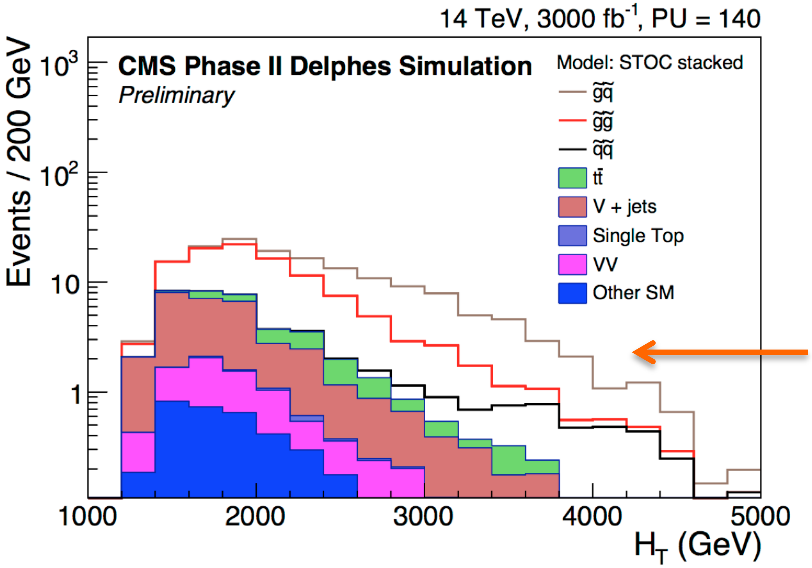
M_{CT} Endpoint at:

$$(m(\tilde{b})^2 - m(\tilde{\chi}_1^0)^2)/m(\tilde{b})$$

Discovery Scenarios: STOC



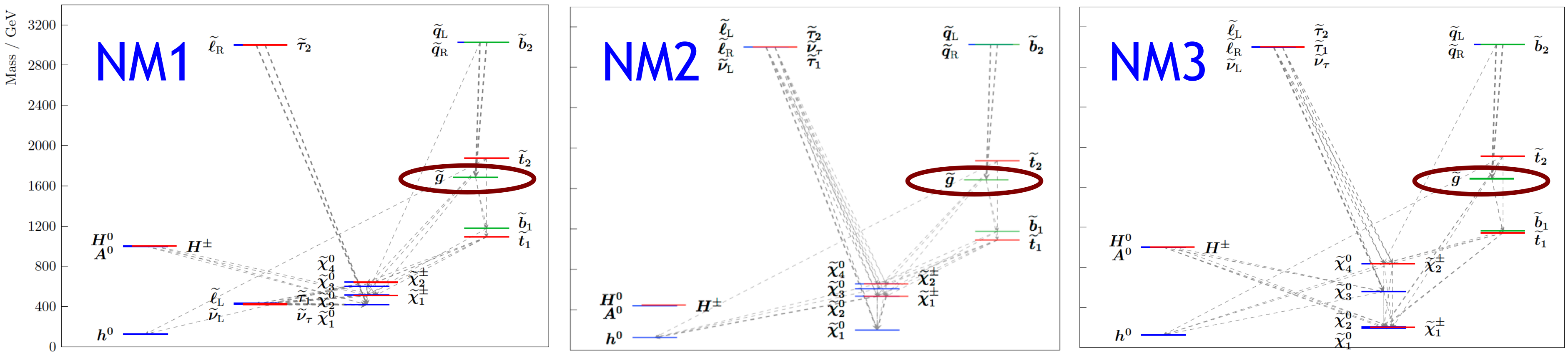




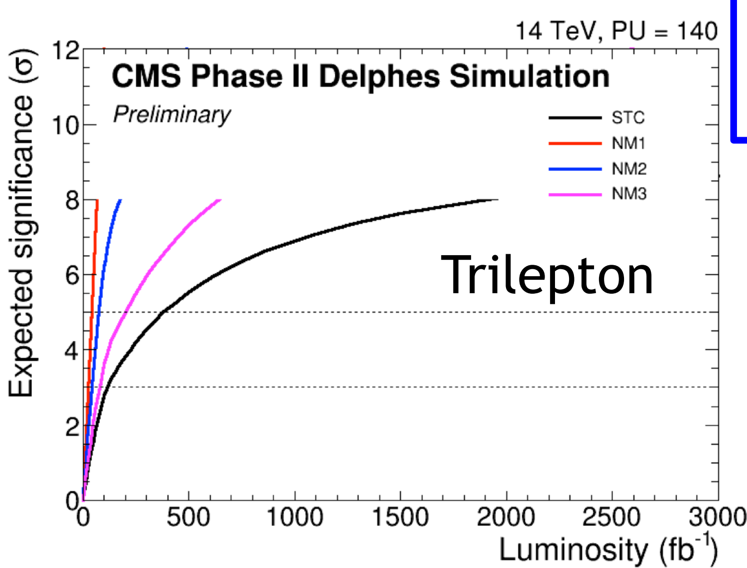
Observations in additional final states w/ HL-LHC

Gluino-squark production of 3.4TeV u/d/s squarks becomes visible

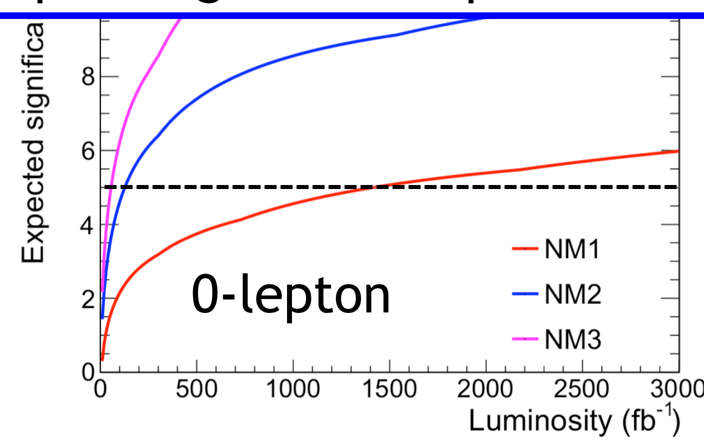
Discovery Scenarios: Natural Models



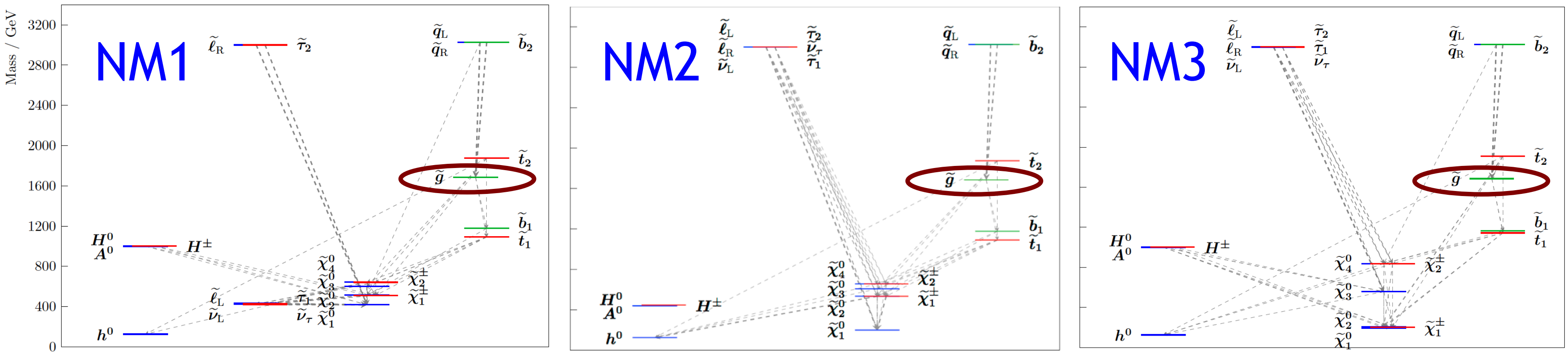
- Discovery of "gluino-like" signature in jets + MET + b-tags (w/ 0-, 1-, and multi-leptons) in Run 2+3.



Different analyses weigh in differently depending on SUSY spectrum

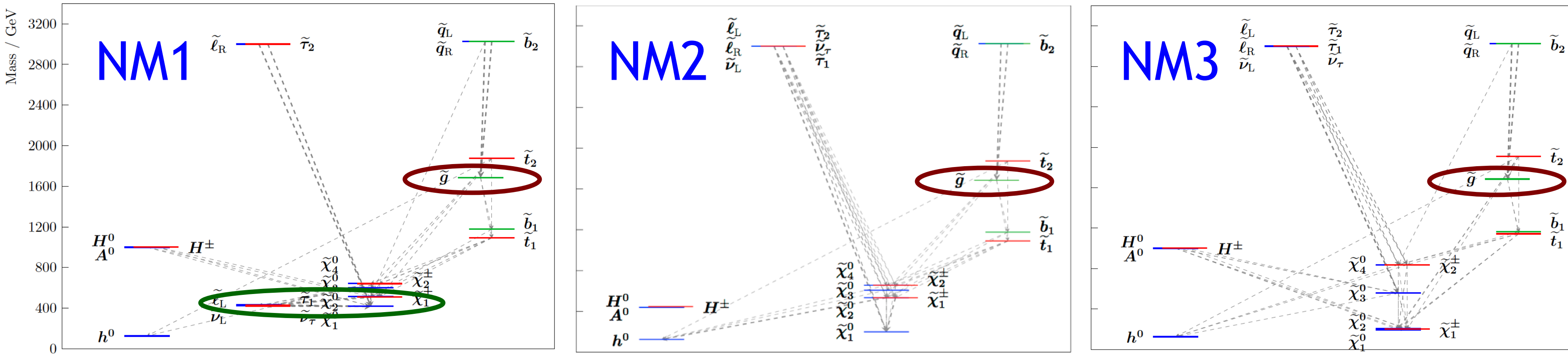


Discovery Scenarios: Natural Models



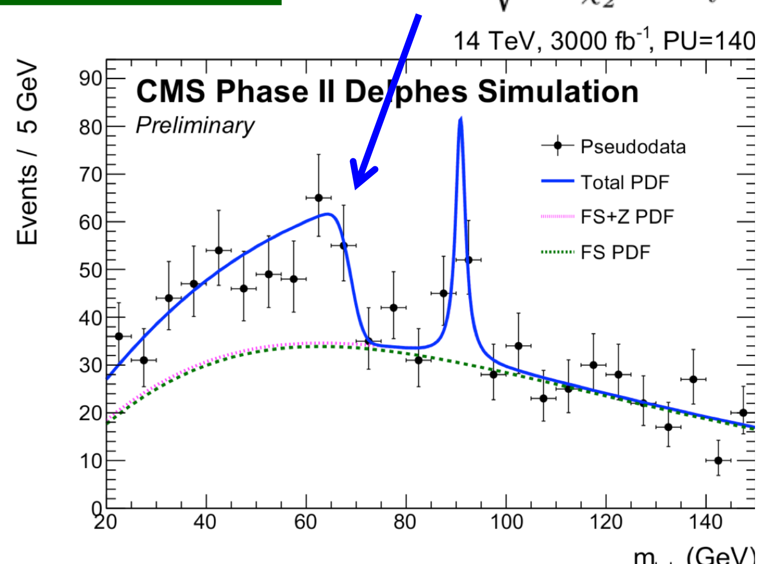
- Discovery of “gluino-like” signature in jets + MET + b-tags (w/ 0-, 1-, and multi-leptons) in Run 2+3.
- HL-LHC adds detailed measurements of:
  - Weakly interacting sector that gluinos cascade down to.
    - Discover which among several broad classes of SUSY models is implemented in nature.
  - Distinctive kinematic features indicate the structure of SUSY spectrum.
  - Observations in additional final states not visible yet in Run 3.

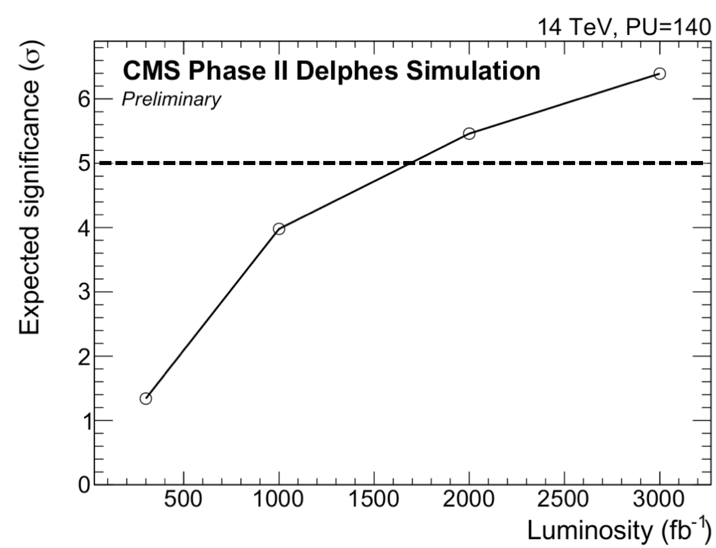
Discovery Scenarios: Natural Models



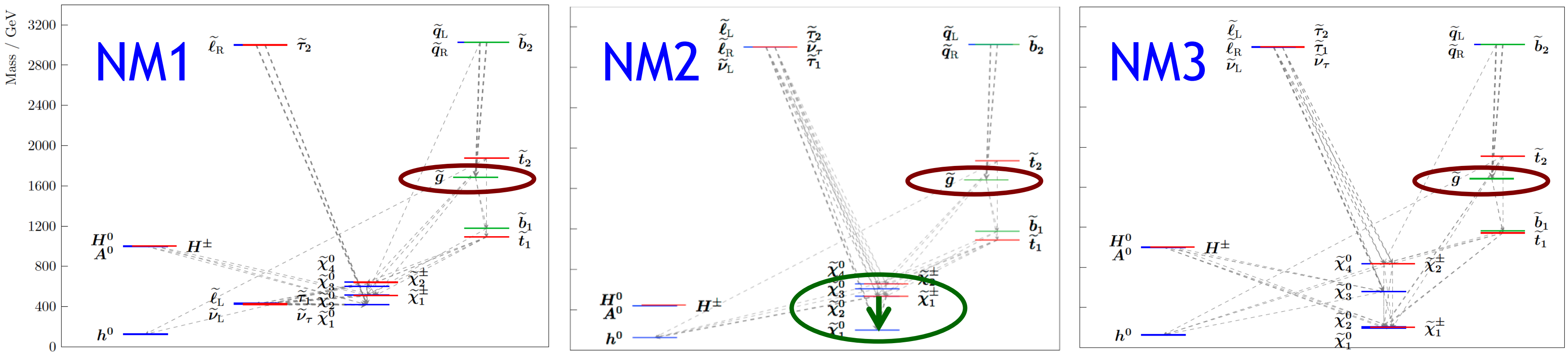
$$\tilde{\chi}_2^0 \to l\tilde{l} \to \tilde{\chi}_1^0 l^+ l^-$$

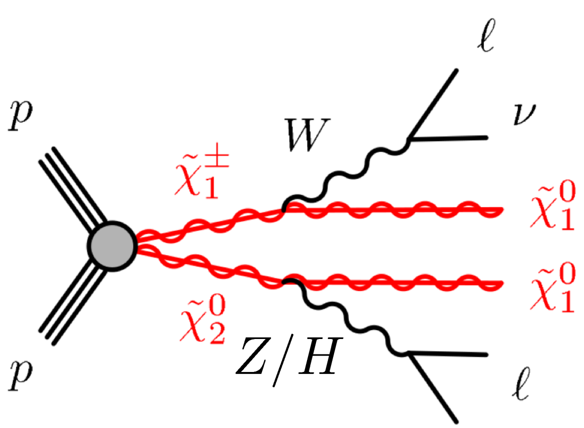
$$m_{\mathrm{edge}} = \sqrt{(m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{l}})(m^2_{\tilde{l}} - m^2_{\tilde{\chi}_1^0})} / m_{\tilde{l}}$$



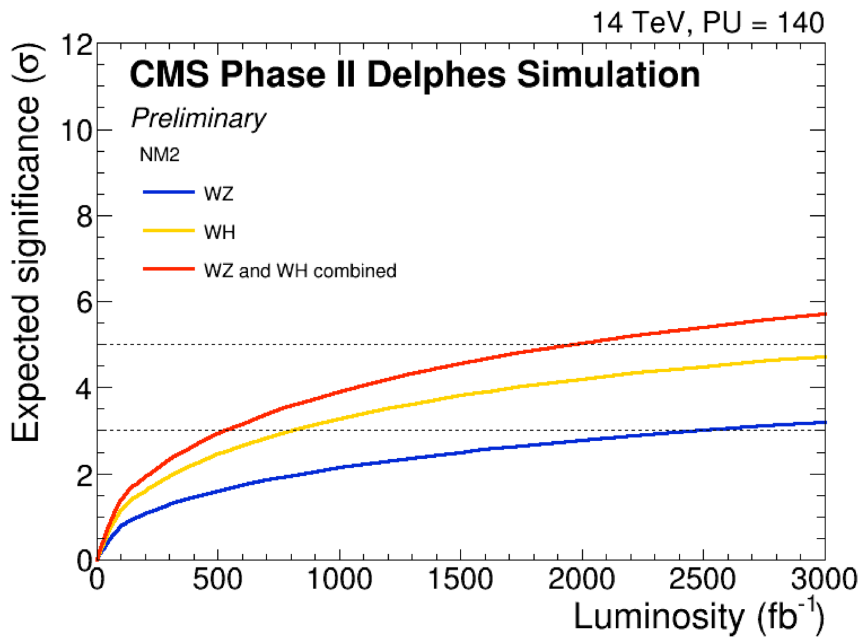


Discovery Scenarios: Natural Models

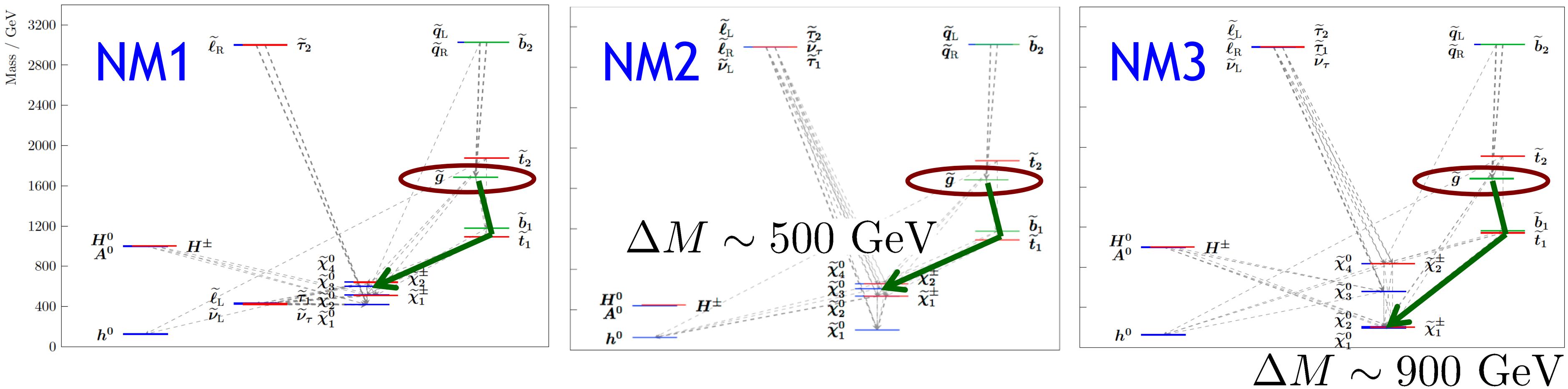




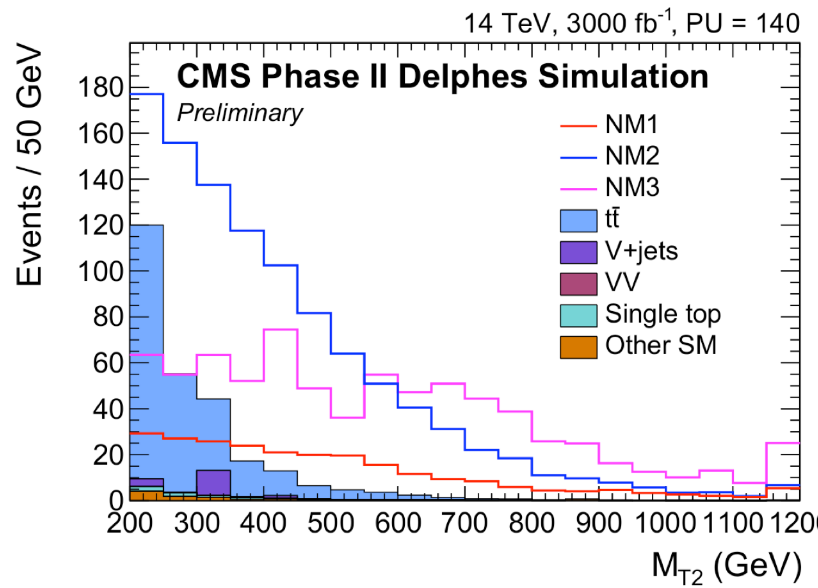
BR: 88% H
12% Z



Discovery Scenarios: Natural Models

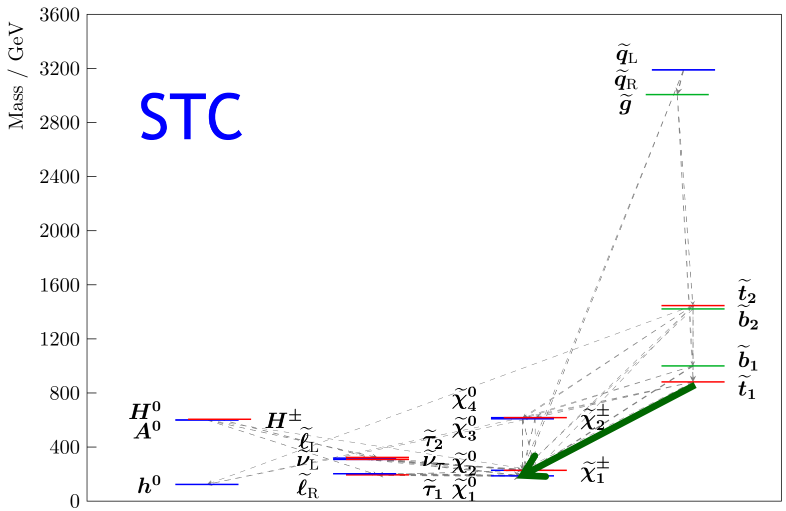


Large mass gaps in NM3
→ massive m_{T2} tails

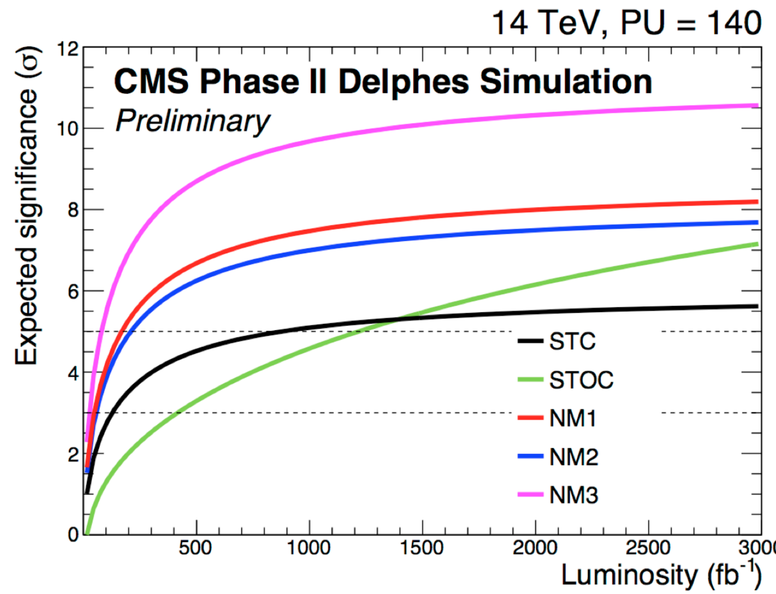


Distinctive kinematic features indicate the structure of SUSY spectrum

Discovery Scenarios: STC

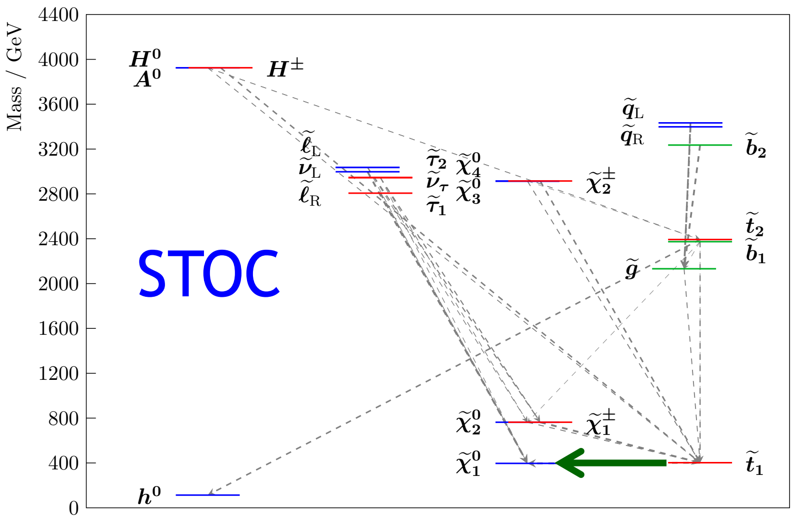


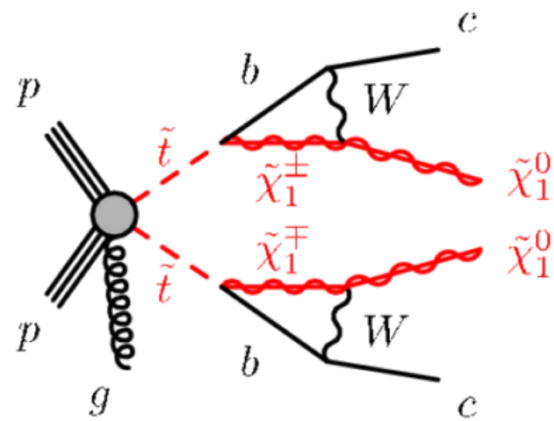
$$\tilde{t}_1 \to t + \tilde{\chi}_1^0 \ (20\%)$$
$$\tilde{t}_1 \to t + \tilde{\chi}_2^0 \ (5\%)$$
$$\tilde{t}_1 \to t + \tilde{\chi}_3^0 \ (20\%)$$
$$\tilde{t}_1 \to t + \tilde{\chi}_4^0 \ (9\%)$$
$$\tilde{t}_1 \to b + \tilde{\chi}_1^+ \ (12\%)$$
$$\tilde{t}_1 \to b + \tilde{\chi}_2^+ \ (34\%)$$



For this stau-coannihilation model, 70% of the signal in the 1-lepton search comes from direct top squark production

Discovery Scenarios: STOC





Compressed top squark (~3sigma) in Run 2+3