New Physics Prospects at High Luminosity LHC

International Conference on What's Next at LHC

TIFR, Mumbai, India, 6-8 Jan. 2014

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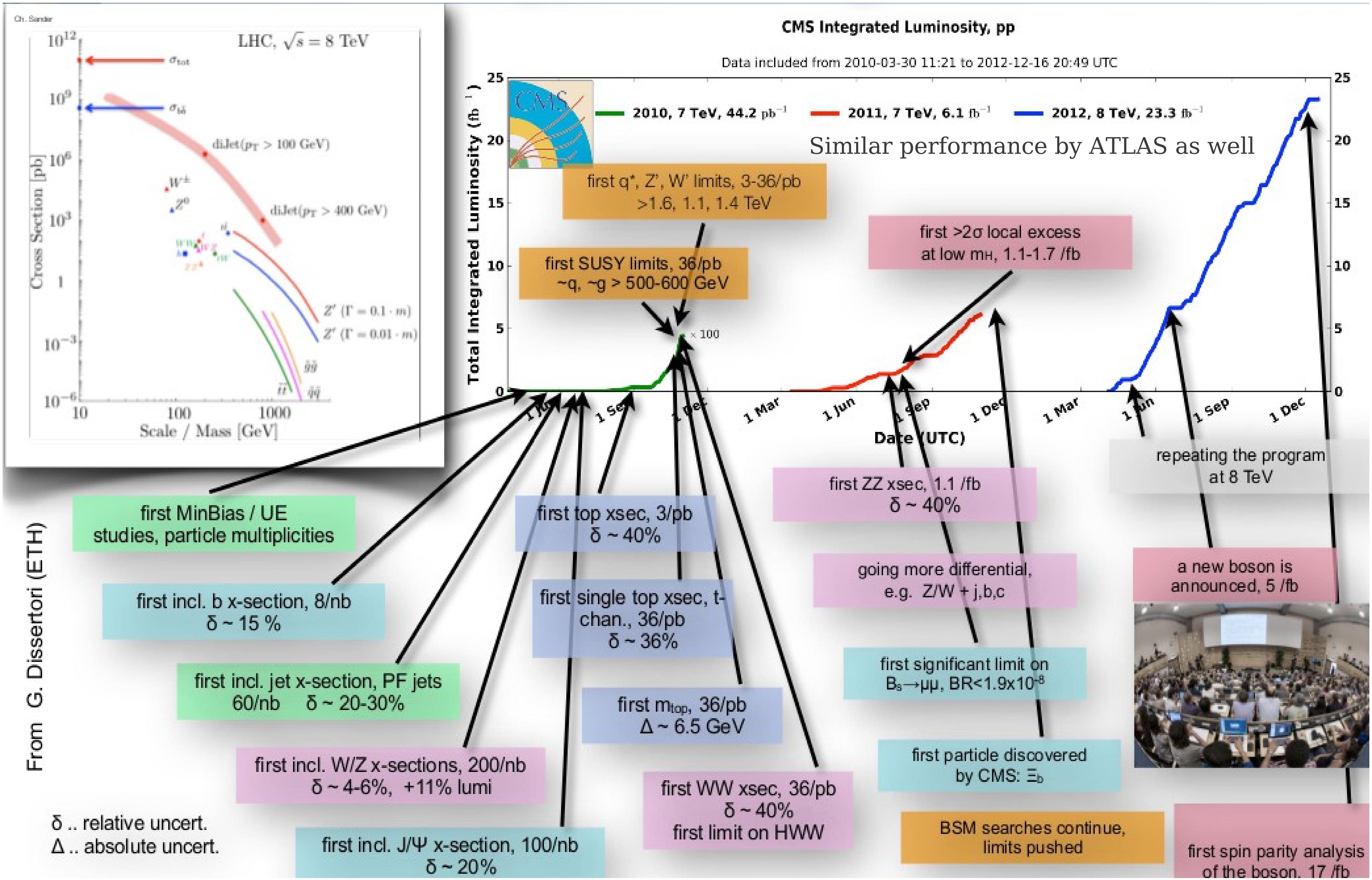
Amazing LHC!!!

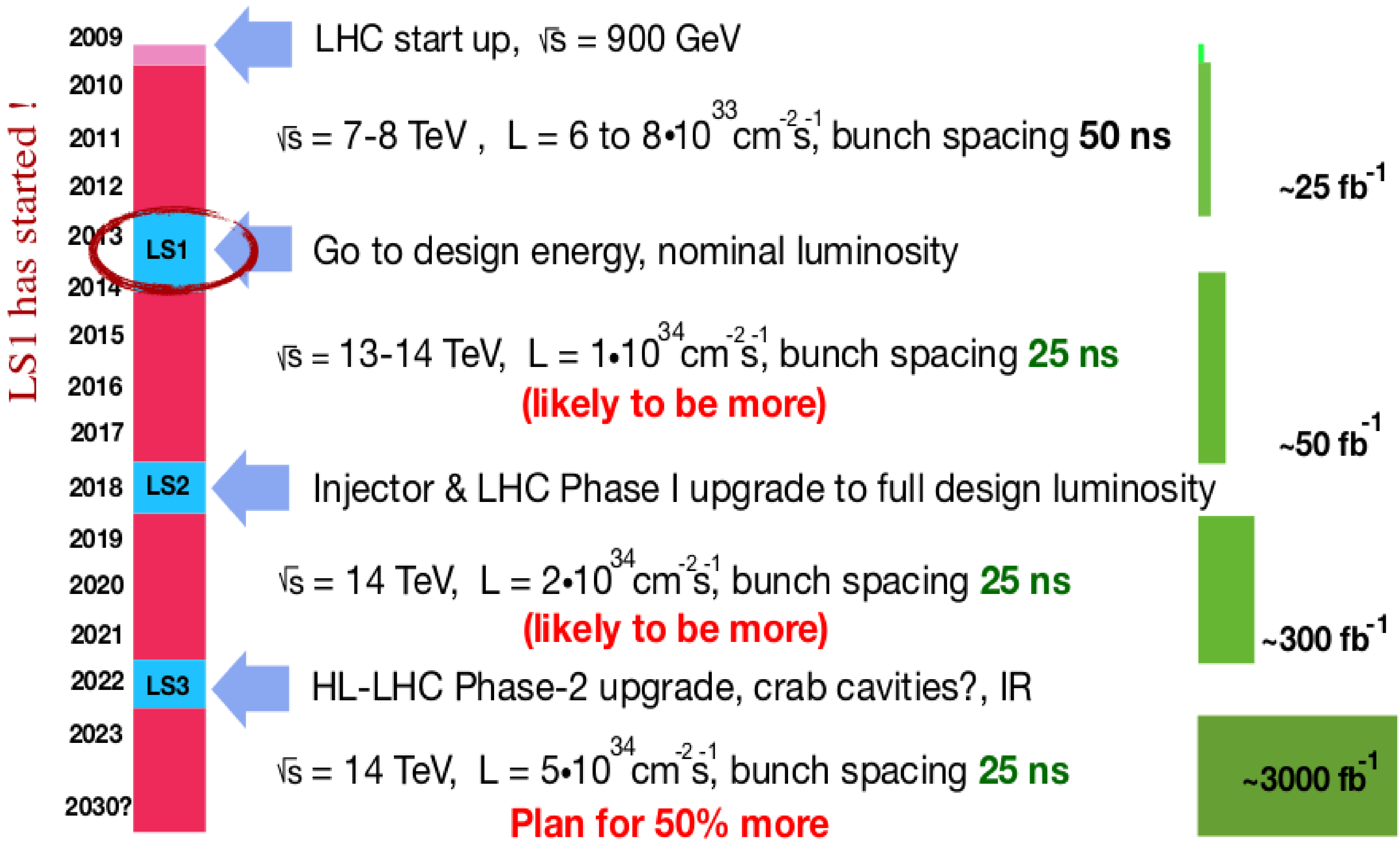


LHC, $\sqrt{s} = 8$ TeV
Cross Section [pb]
Scale / Mass [GeV]
diJet($p_T > 100$ GeV)
diJet($p_T > 400$ GeV)
CMS Integrated Luminosity, pp
Data included from 2010-03-30 11:21 to 2012-12-16 20:49 UTC
2010, 7 TeV, 44.2 pb⁻¹
2011, 7 TeV, 6.1 fb⁻¹
2012, 8 TeV, 23.3 fb⁻¹
Total Integrated Luminosity (fb⁻¹)
Date (UTC)
Similar performance by ATLAS as well
first q*, Z', W' limits, 3-36/pb >1.6, 1.1, 1.4 TeV
first SUSY limits, 36/pb ~q, ~g > 500-600 GeV
first >2σ local excess at low mH, 1.1-1.7 /fb
repeating the program at 8 TeV
first MinBias / UE studies, particle multiplicities
first top xsec, 3/pb δ ~ 40%
first ZZ xsec, 1.1 /fb δ ~ 40%
first incl. b x-section, 8/nb δ ~ 15 %
first single top xsec, t-chan., 36/pb δ ~ 36%
going more differential, e.g. Z/W + j,b,c
a new boson is announced, 5 /fb
first incl. jet x-section, PF jets 60/nb δ ~ 20-30%
first mtop, 36/pb Δ ~ 6.5 GeV
first significant limit on Bs→μμ, BR<1.9x10⁻⁸
first incl. W/Z x-sections, 200/nb δ ~ 4-6%, +11% lumi
first WW xsec, 36/pb δ ~ 40% first limit on HWW
first particle discovered by CMS: Ξb
BSM searches continue, limits pushed
first spin parity analysis of the boson, 17 /fb
δ .. relative uncert.
Δ .. absolute uncert.
first incl. J/Ψ x-section, 100/nb δ ~ 20%
From G. Dissertori (ETH)

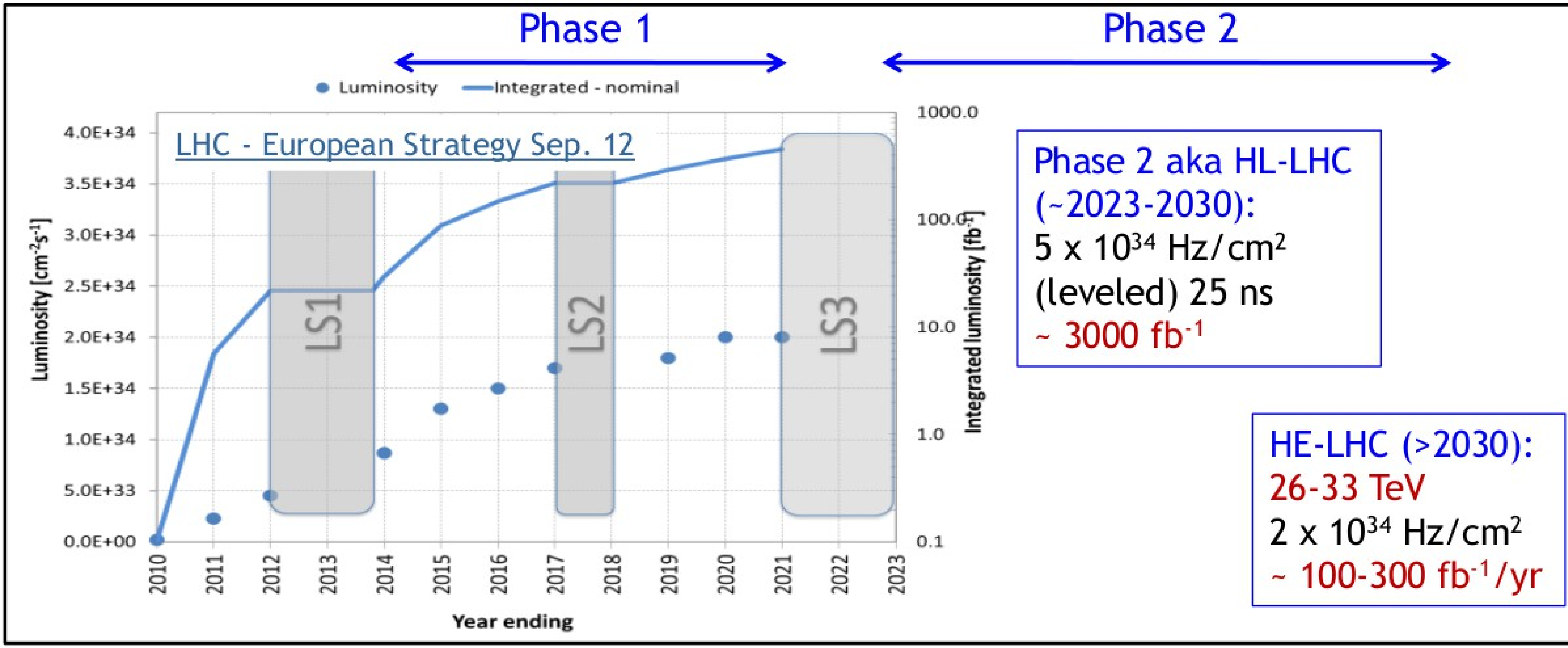
Outline

- LHC Evolutions
- Upgrade Strategy
- Simulation framework for HL-LHC
- Physics prospects of HL-LHC
  - SUSY Colored sector
  - Electrowinos in the light of Higgs bosons
  - Other BSM searches
- Summary and Outlook

LHC Evolution



LHC Evolution



LHC Phase-I: 13/14 TeV pp collisions with 50 – 80 pileup events

LHC Phase-II (HL-LHC): 13/14 TeV pp collisions with ~140 pileup events

LS1-LS2 baseline: 0.8 → 1.7 x 10^{34} Hz/cm^2 at 25 ns. ~300 fb^{-1} by LS2 @ 13-14 TeV

- Alternative with 1.8 x10^{34} Hz/cm^2 at 50 ns with lumi-leveling.

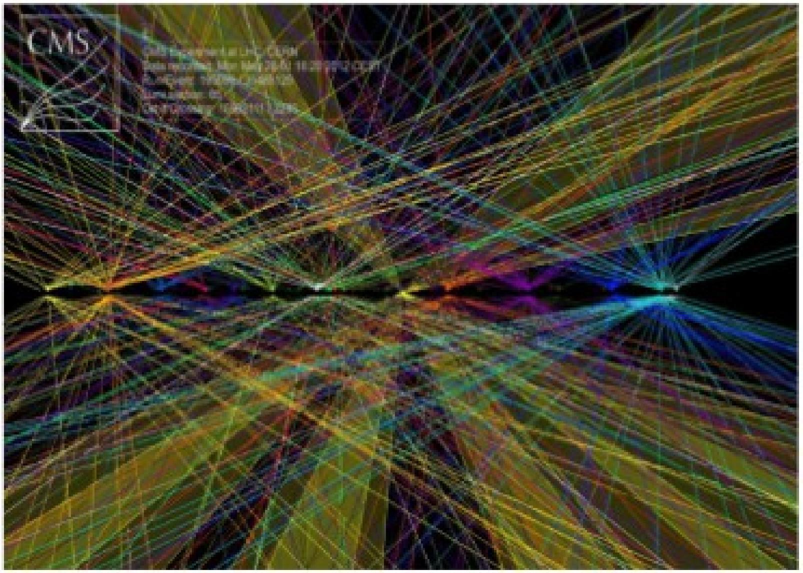
After LS2 injection chain upgrades: 25 ns will allow ≥ 2 x 10^{34} Hz/cm^2

High Luminosity LHC

<u>HL-LHC conditions</u>

- Increased LHC instantaneous luminosity
- Large number of pileup events (μ) in the same bunch crossing

➔ Luminosity leveling at $L = 5 \times 10^{34}$ ($cm^{-2}s^{-1}$) with $\langle\mu\rangle = 140$



	Peak L ($cm^{-2}s^{-1}$)
Until 2012	7×10^{33}
After Phase-1 upgrade	2.5×10^{34}
After Phase-2 upgrade	2×10^{35} (*)

(*) Maximum peak luminosity achievable by the machine

- ATLAS and CMS detectors must be upgraded to cope with high pileup condition
- Inner trackers must be replaced due to radiation damage
- Need new detectors (both hardware and software) to keep similar performance as now

Upgrade Strategy: ATLAS

See talk by Didier Contardo

LS1 Projects & Upgrades:

- New insert-able pixel layer
- Install staged chambers in the muon spectrometer to complete geometrical coverage
- A lot of consolidation work

Complete original detector
Address operational issues
Start upgrade for high PU

LS1 LS2 LS3

Phase 1 Upgrades:

- New Small Wheel forward muon chambers
- Finer calorimeter readout at Level-1
- Fast Track Trigger (FTK)
- Trigger/DAQ upgrades (including for above)
- Forward Physics Detector

Maintain performance at high PU

Phase 2 Upgrades:

- Tracker replacement (ITK)
- New Trigger/DAQ L0/L1 configuration
  - New (500/100 kHz) Calorimeter Front End Electronics
  - New Muon Front End Electronics
- Forward Calorimeters (if required)

Maintain performance at extreme PU
Sustain rates and radiation doses

Upgrade Strategy: CMS

LS1 Projects & Upgrades:

- Completes muon coverage (ME4)
- Improve muon trigger (ME1), DT electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD → SiPM)
- A lot of consolidation work

See talk by Didier Contardo

Complete original detector
Address operational issues
Start upgrade for high PU

Phase 1 Upgrades:

- New Pixels, HCAL SiPMs and electronics, and L1-Trigger
- Preparatory work during LS1:
  - new beam pipe
  - test slices of new systems

Maintain performance at high PU

Phase 2 Upgrades: scope to be defined in Technical Proposal (2014)

- Tracker replacement up to $|\eta| < 4$
- Forward Calorimeters, New EndCaps, Extension of muon coverage
- Pico-sec photon timing detector
- Further Trigger/DAQ upgrade: Track Trigger

Maintain performance at extreme PU
Sustain rates and radiation doses

Simulation framework for HL-LHC studies

ATLAS

See talk by Didier Contardo

- Parameterize the detector response based on GEANT simulation
- The simulation includes the currently proposed layout of the upgrade tracker
- $\langle\mu\rangle = 140$ ($\langle\mu\rangle = 50$) is assumed for 3000 fb^{-1} (300 fb^{-1})

CMS

- Assume detector upgrades and maintain current performance
- Fast detector simulation based on DELPHES with additional pileups
- Verify the parameterization with full simulation
- Studies using 140 PU, Phase-I detector, Phase-II: Configuration 3 and 4

Configuration 3

- Corresponds to Scenario 1 (replace EE and retrofit HE)
- Use EE shashlik resolution and transverse size
- Increase phi segmentation for HE to 4x *(demonstrate impact)*
- Use Phase II tracker (barrel + endcap)
- Complete muon coverage $1.6 < \eta < 2.4$
- Exclude $\eta > 4.5$ to simulate radiation damage in HF

Configuration 4

- Corresponds to Scenario 2 (replace the Endcap)
- Extended coverage (tracker + calorimeter + muon) $\eta \sim 4$
- Exclude $\eta > 4.5$ to simulate radiation damage in HF

Physics prospects at HL-LHC

Discovery of the Higgs boson at 7/8 TeV LHC

	ATLAS	CMS	
$\gamma\gamma$	7.4σ	3.2σ	◉ $X \to \gamma\gamma$ - it is neutral, can be spin-0 - can not be spin-1 (Young-Landau theorem) - can be spin-2, but unlikely/disfavored
ZZ (4l)	6.6σ	6.7σ	◉ $X \to$ ZZ, WW seen - the source for EWSB (vacuum exist)
WW	2.5σ	3.9σ	
$\tau\tau$	1.1σ	2.8σ	◉ $X \to \tau\tau$ seen, not $\mu\mu$, ee - Non-universal leptonic coupling
bb	-0.4σ	2.0σ	◉ $X \to$ bb seen, $X \to$ tt needed for gluon fusion - Non-universal quark coupling

Light Higgs, SM like weakly coupled boson m_h = 125 – 126 GeV, Γ < 1 GeV

What are the next steps?

Light Higgs, SM like weakly coupled boson m_h = 125 – 126 GeV, Γ < 1 GeV

There are several remaining issues:

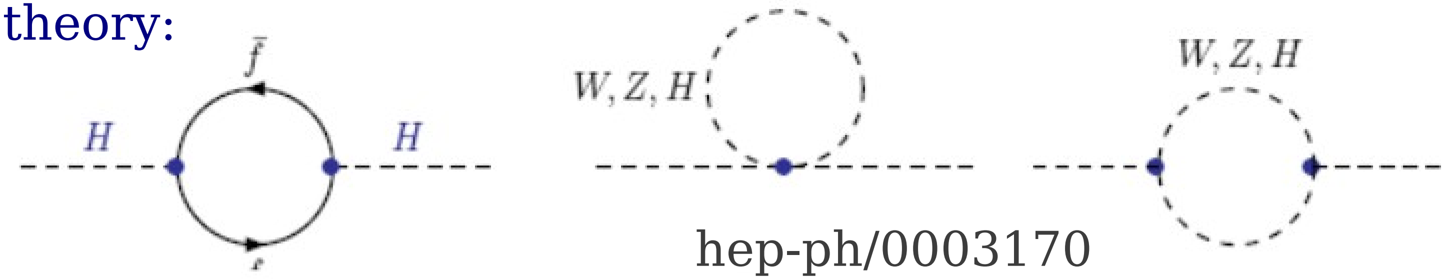
- Is it a SM Higgs?
- Is there more than one Higgs boson?
- Does this H decay to other unexpected things?

See talk by: Paolo Giacomelli

- Implication of SM Higgs searches on BSM scenarios?
- Can we use H to look for new physics?

Higgs is found – What about its mass corrections?

Using SM as effective theory:



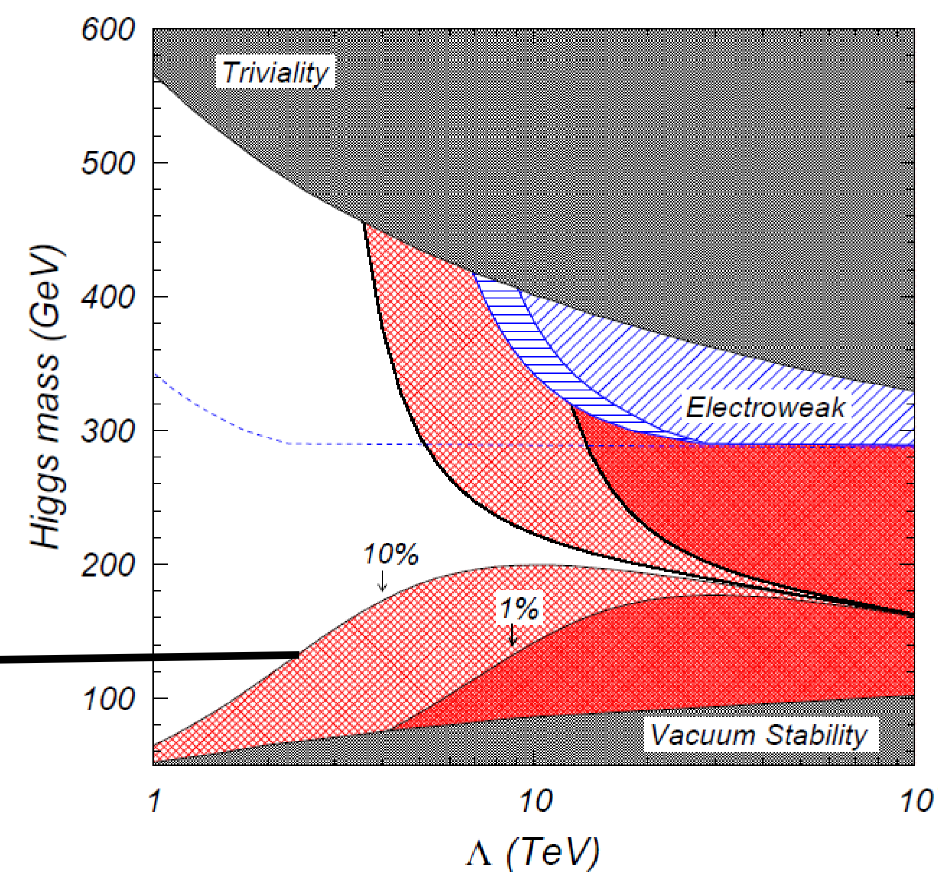
hep-ph/0003170

Corrections to the Higgs mass at one loop level.

$$\delta m_H^2 = \frac{3G_F}{4\sqrt{2}\pi^2}\left(4m_t^2 - 2m_W^2 - m_Z^2 - m_H^2\right)\Lambda^2$$

Either new physics appears at a scale Λ or there has to be a very delicate cancellation

Amount of fine-tuning



How much fine tuning is still natural?

Natural Supersymmetry

arXiv:1203.5539

$$\frac{1}{2}M_Z^2 = \boxed{\frac{(m_{H_d}^2+\Sigma_d)-(m_{H_u}^2+\Sigma_u)\tan^2\beta}{(\tan^2\beta-1)}} - \mu^2 .$$

"Tuned" due to the Higgs mass - Colored sector

SUSY weak sector

- Individual terms on right side should be comparable in magnitude

  - "Large" cancellations are "unnatural"

- |μ| can be a measure of naturalness

Σ - arises from radiative correction → $\Sigma_u \sim \frac{3 f_t^2}{16\pi^2} \times m_{\tilde{t}_i}^2 \left(\ln(m_{\tilde{t}_i^2}/Q^2) - 1\right)$

Stop mass

For, $\Sigma \approx 1/2 M_Z^2 \rightarrow m_{\tilde{t}_i} \approx 500$ GeV

Assuming μ ~ 150 (200) GeV → Mass(stop) ~ 1 (1.5) TeV

Other heavier Higgs can easily be in the TeV mass range and is perfectly natural:

$$m_A^2 \simeq 2\mu^2 + m_{H_u}^2 + m_{H_d}^2 + \Sigma_u + \Sigma_d$$

Natural Supersymmetry

R. Barbieri

The key equations:

$$\frac{m_h^2}{2} \approx -|\mu|^2 + m_u^2 + \ldots$$

$$\delta m_u^2 \approx -\frac{3y_t^2}{8\pi^2}(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + A_t^2) \log M/m_{\tilde{t}}$$

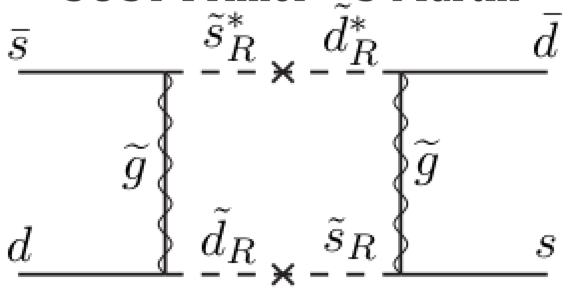
$m_{\tilde{b}_L}$

$$\delta m_{\tilde{t}}^2 \approx \frac{8\alpha_s}{3\pi} m_{\tilde{g}}^2 \log M/m_{\tilde{t}}$$

to be made more precise in any given SB-mediation scheme

see Dimopoulos, Giudice for SUGRA-mediation

SUSY Primer – S Martin



$K^0 \to \bar{K}^0$

Exp: 3.5 x 10^{-12} MeV

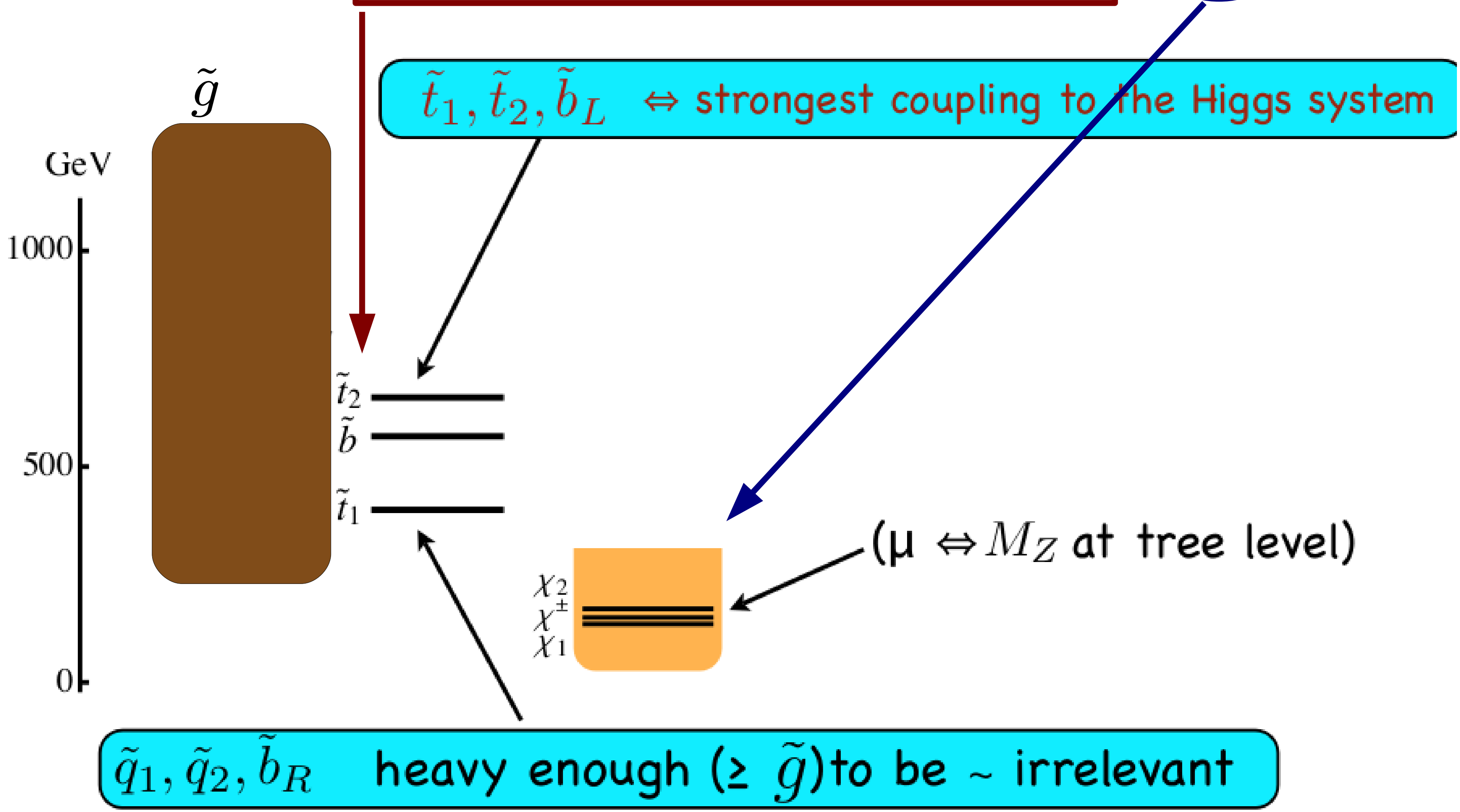
Gluino corrects at two loops level: should be lighter than few TeV

1^{st} and 2^{nd} generation sfermions ~ O(10) TeV, yielding decoupling solution to SUSY flavor problem

Quest for Naturalness: https://indico.cern.ch/conferenceDisplay.py?confId=216168

Natural Supersymmetry

$$\frac{1}{2}M_Z^2 = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u)\tan^2\beta}{(\tan^2\beta - 1)} - \mu^2 .$$



Naturalness in Supersymmetry

Let us re-examine naturalness based on recent experimental results

- SUSY Colored sector (gluino pair production, 1^{st} & 2^{nd} gen sfermions)

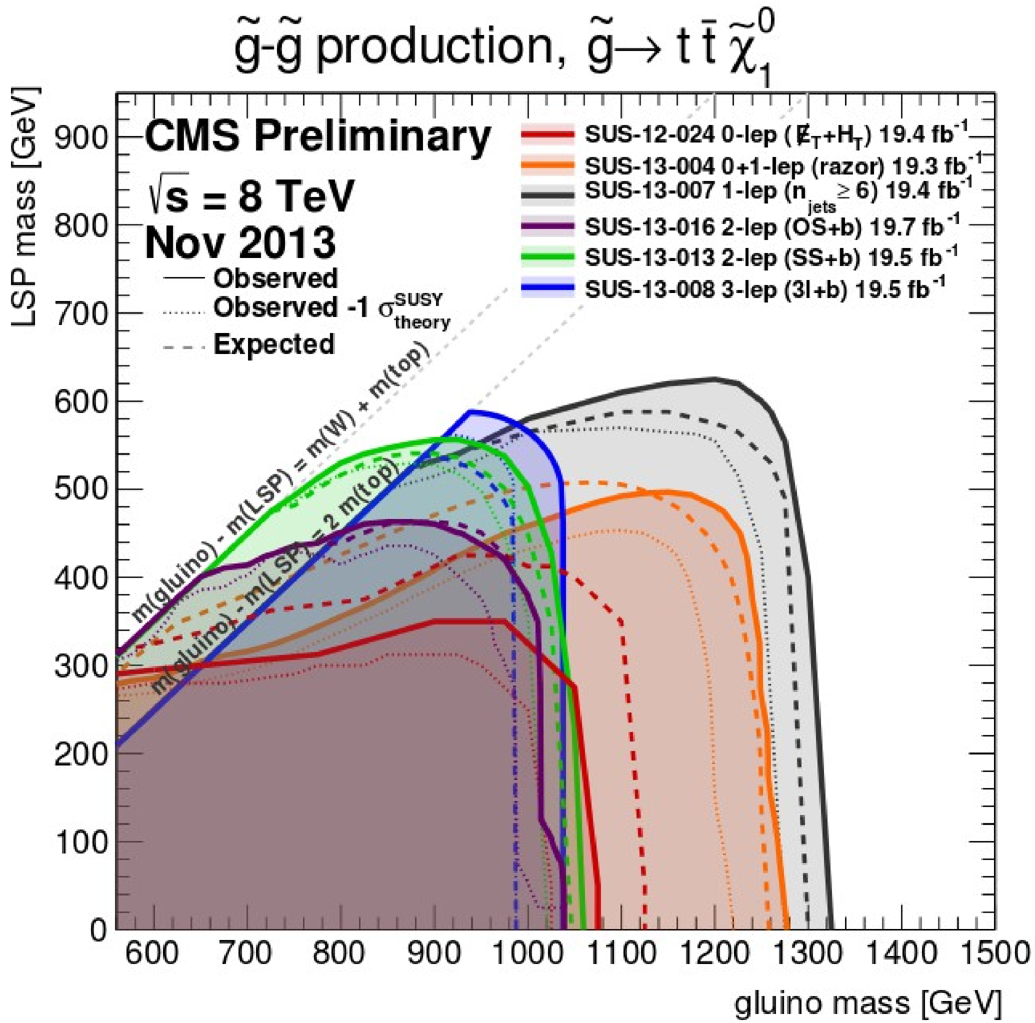
- Search for SUSY third generation particle production

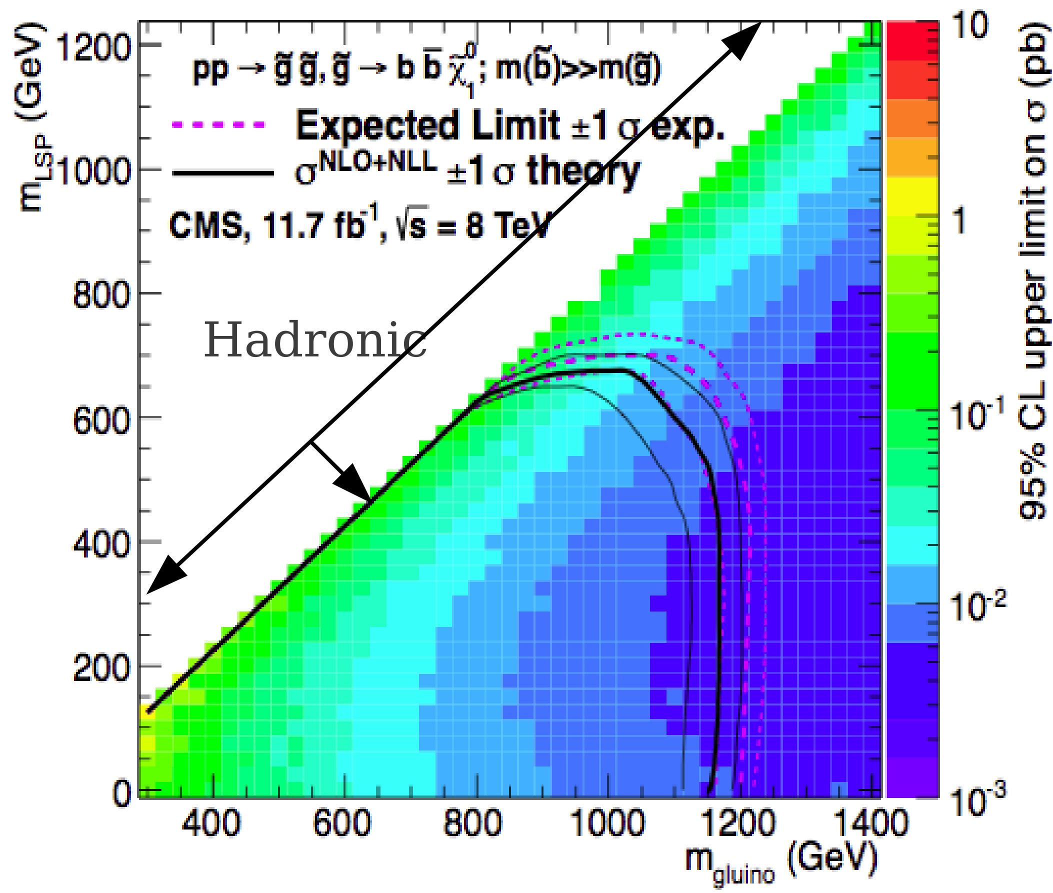
- Search for SUSY weak production

What can we do with 300 fb^{-1} and 3000 fb^{-1} using 13/14 TeV LHC?

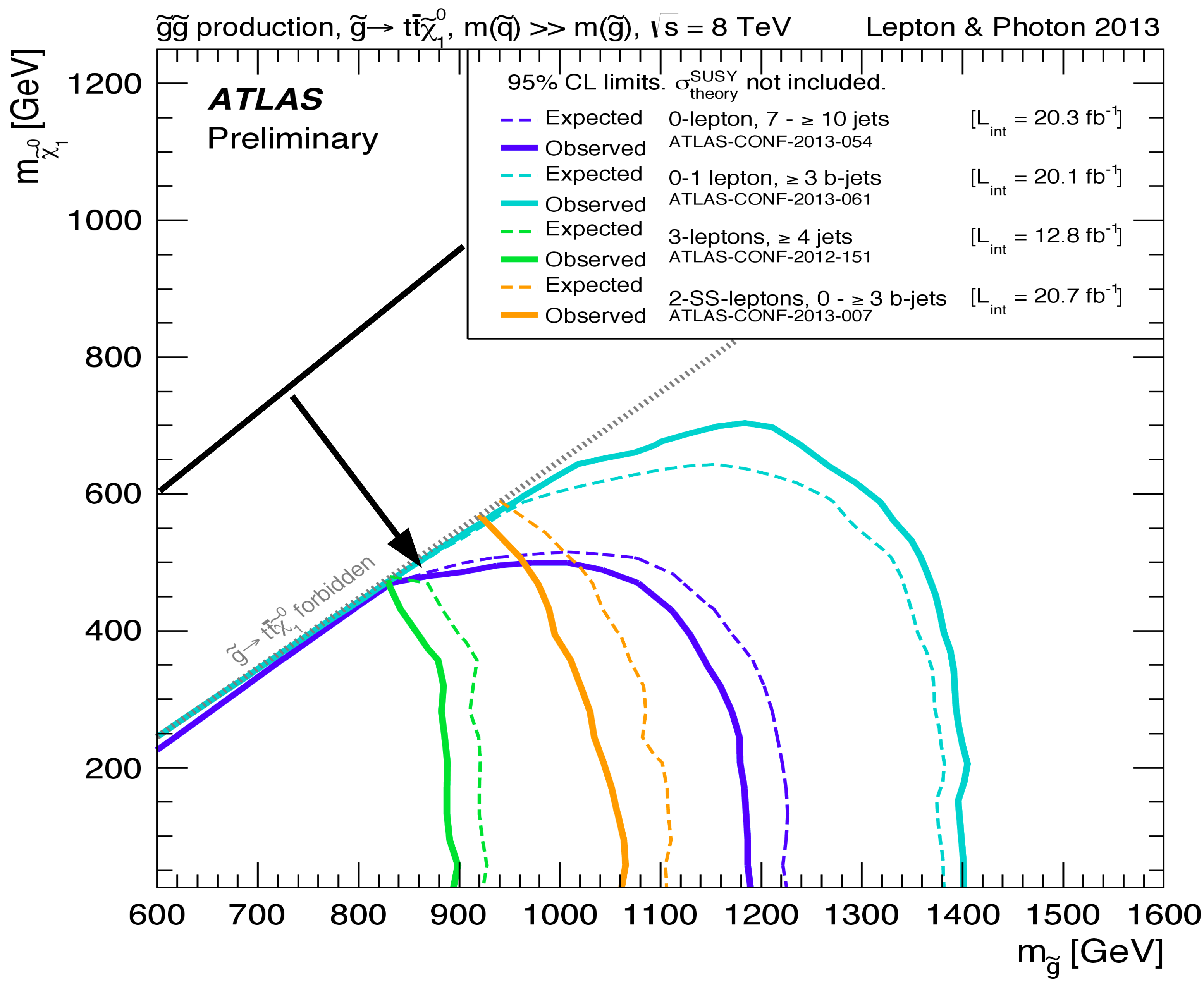
Gluino decays via stops:

- Gluino masses up to 1.32 TeV using One lepton analysis
- A large “compressed” region available for future studies





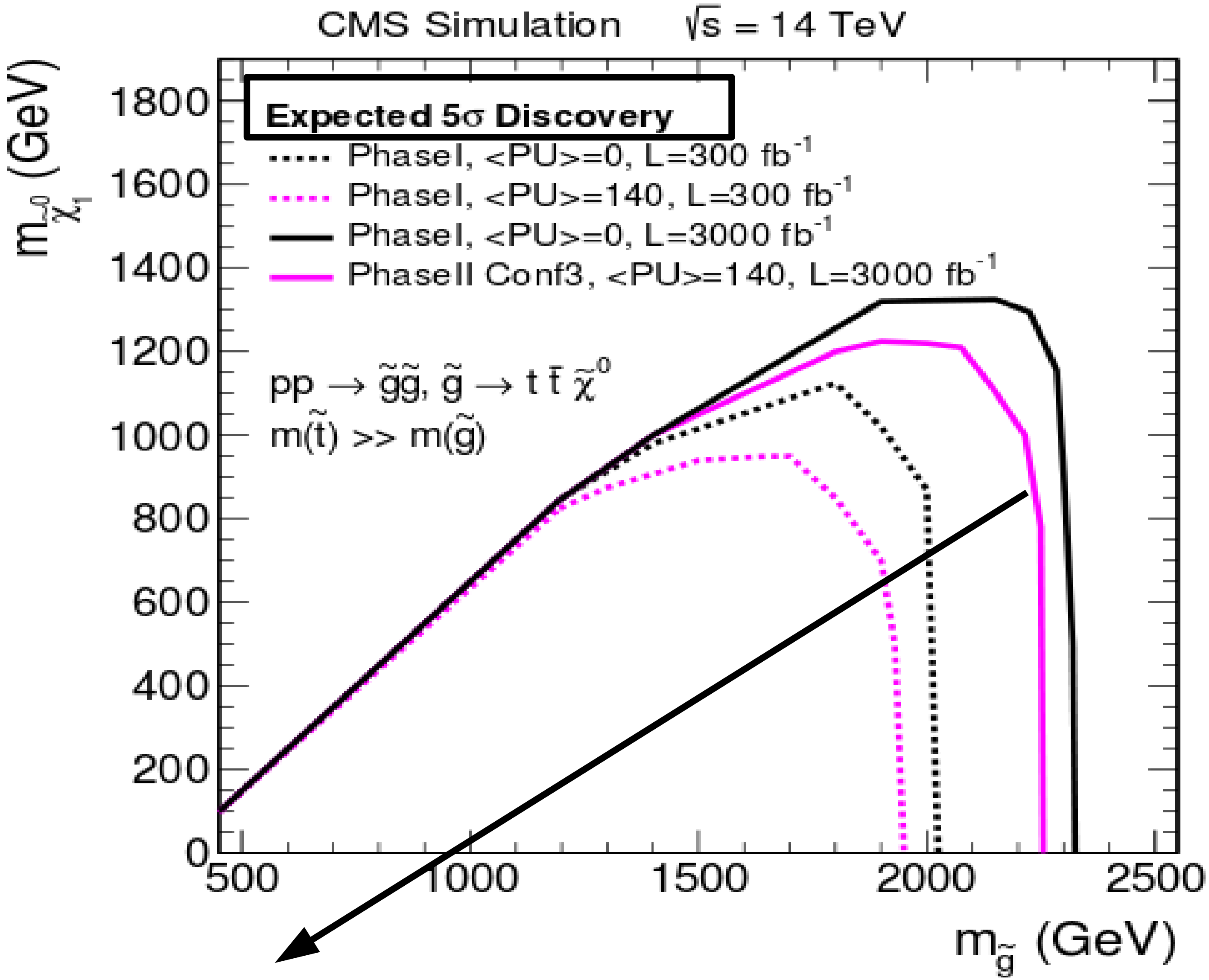
Gluino pair production



Mass range up to ~1.4 TeV can be excluded (within assumptions)

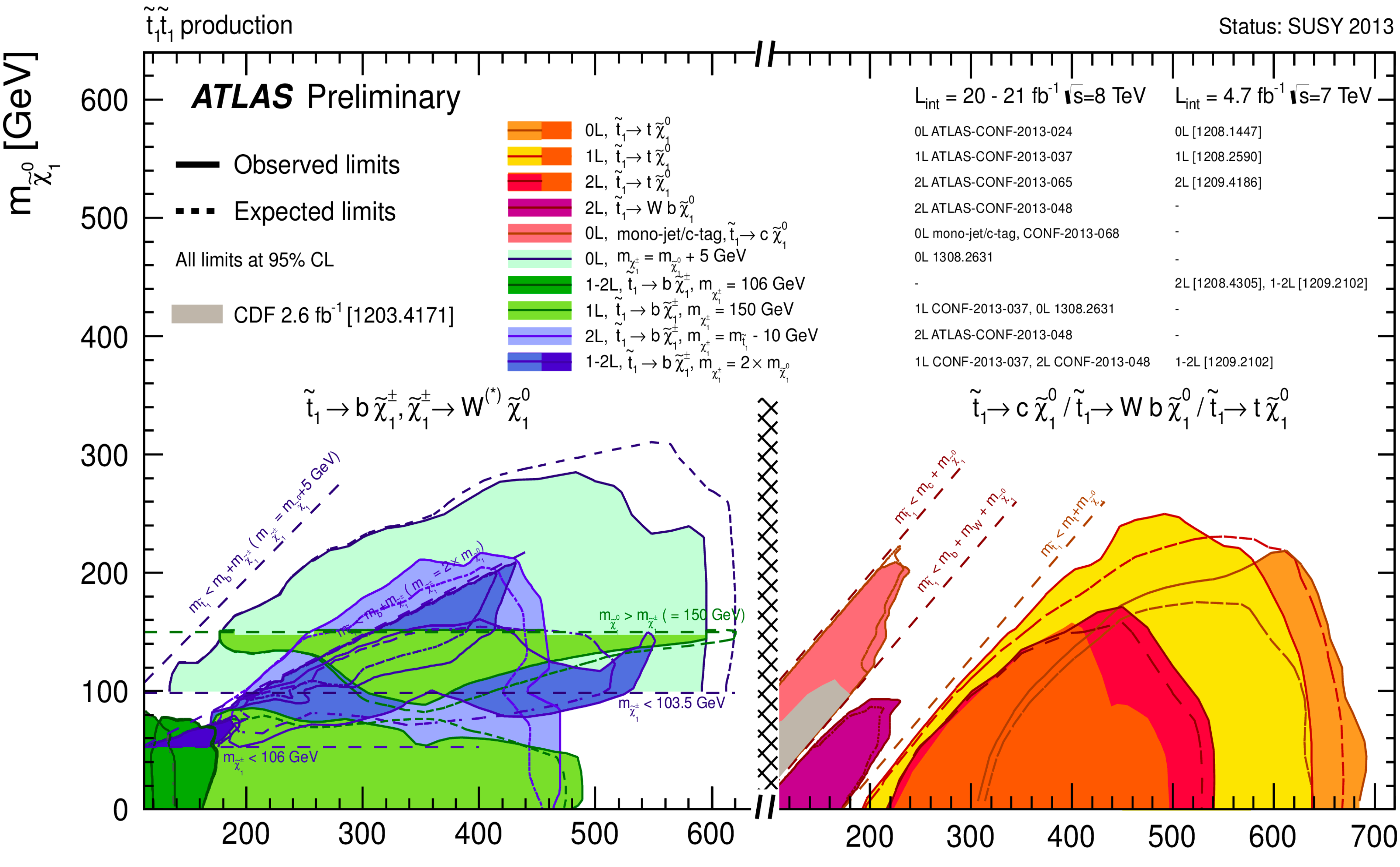
Gluino pair production using 14 TeV LHC

Multi-jet, 1 lepton + MET study:



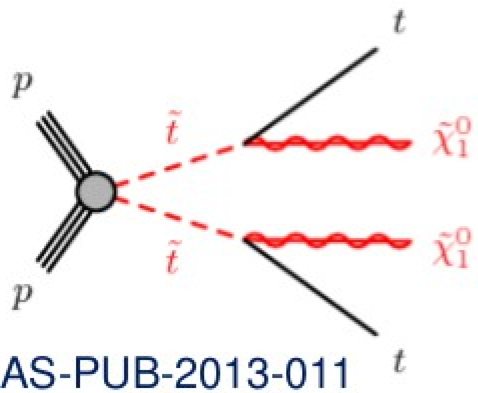
Gluino mass up to 2.2 TeV (LSP = 1.2 TeV) can be observed!

Direct stop productions



New analyses : stop → charm LSP, stop2 → stop1+Z

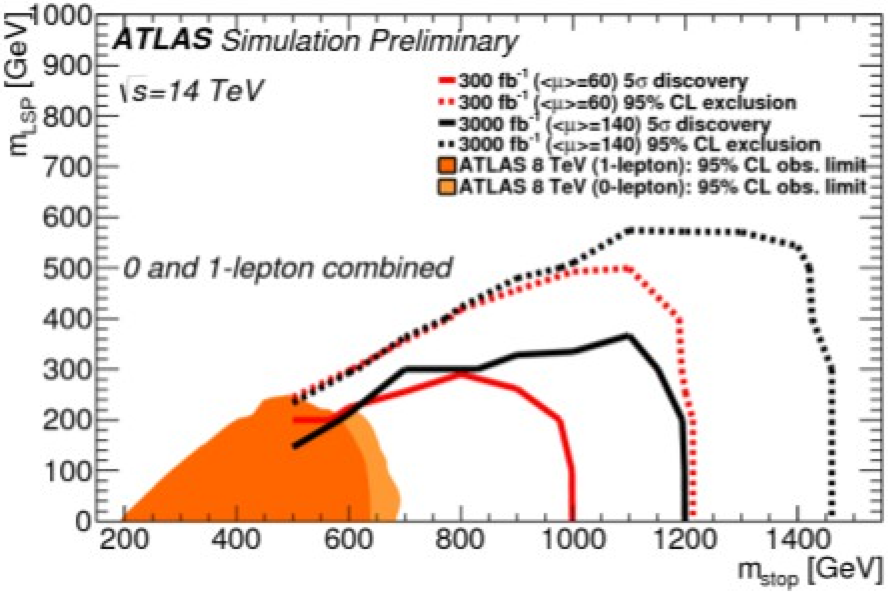
Direct stop production using 14 TeV LHC



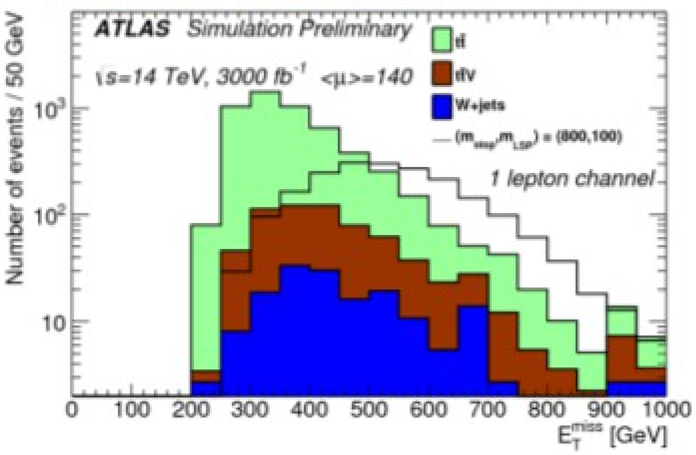
Signature:

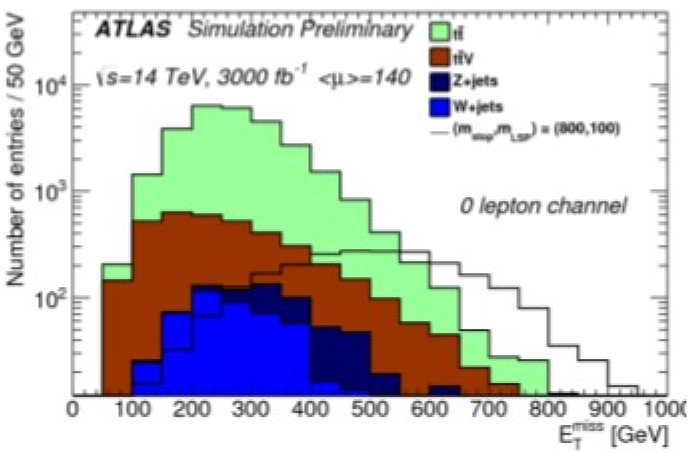
- Fully hadronic top decay:
  - 0-lepton, >6 jets with 2 *b*-tagged, E_T^{miss}
- Semi-leptonic top decay:
  - 1-lepton, >4 jets with 1 *b*-tagged, E_T^{miss}

5σ discovery up to 1.2 TeV at 3,000 fb^{-1}
(200 GeV gain from 300 fb^{-1})

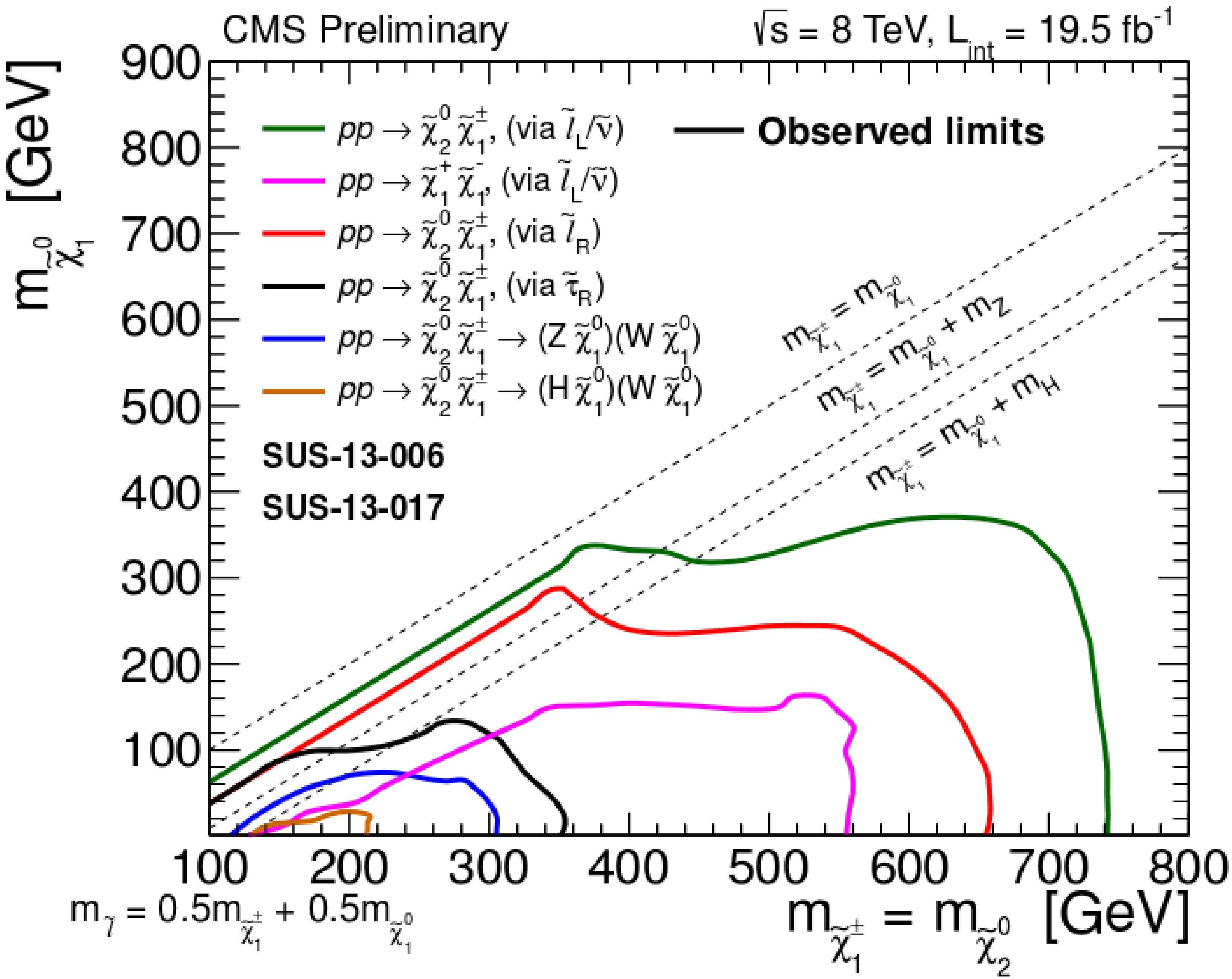


ATLAS-PUB-2013-011





Weak gaugino production



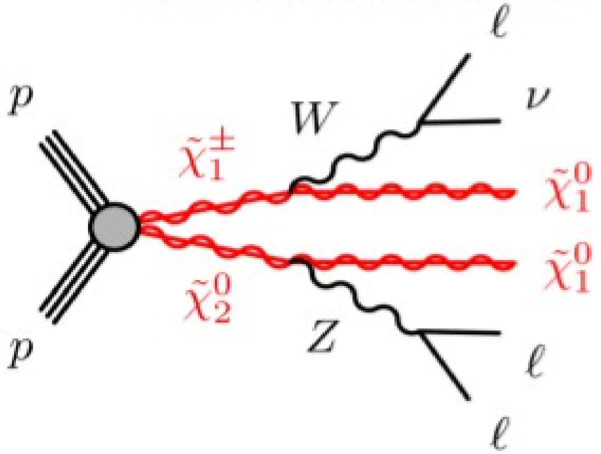
Enriched leptonic final states

Limits are weak in M1, M2 and μ space – See arXiv:1309.7342

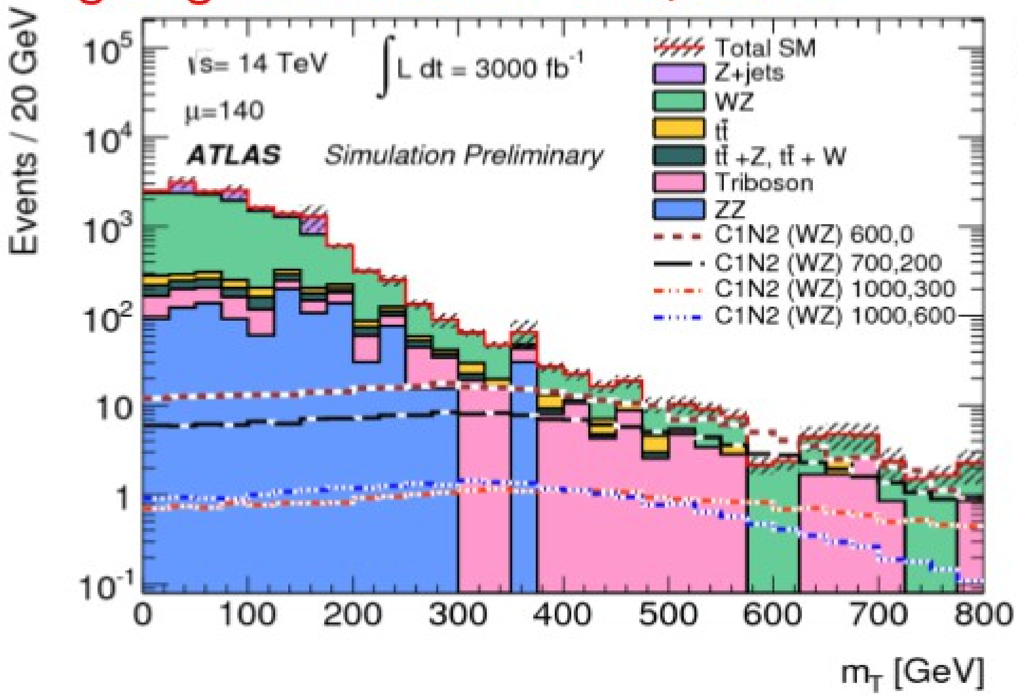
Weak gaugino production using 14 TeV LHC

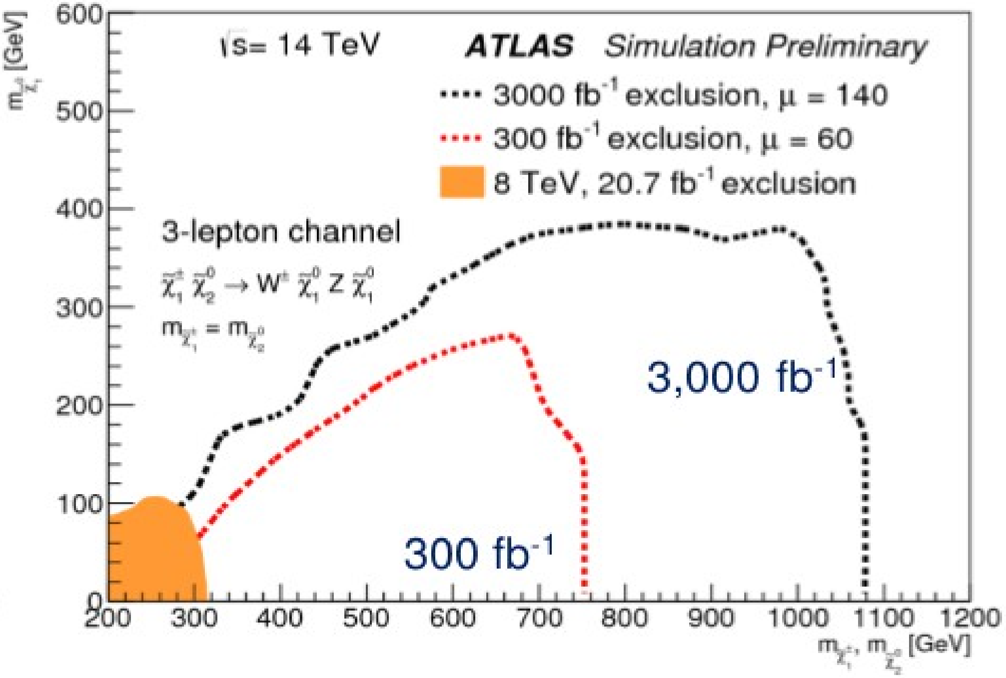
ATLAS-PUB-2013-011

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



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

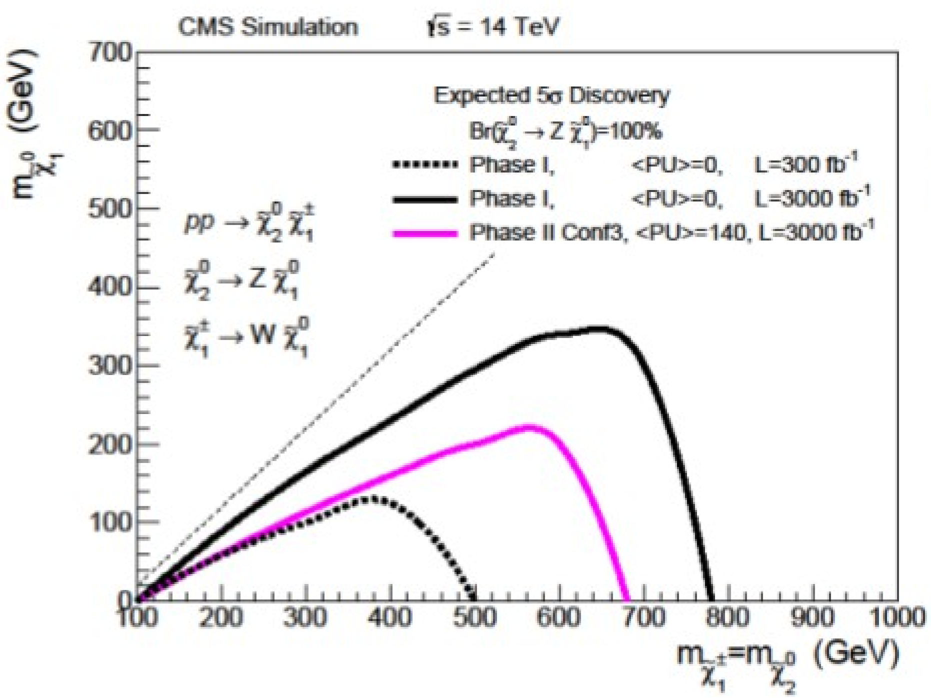


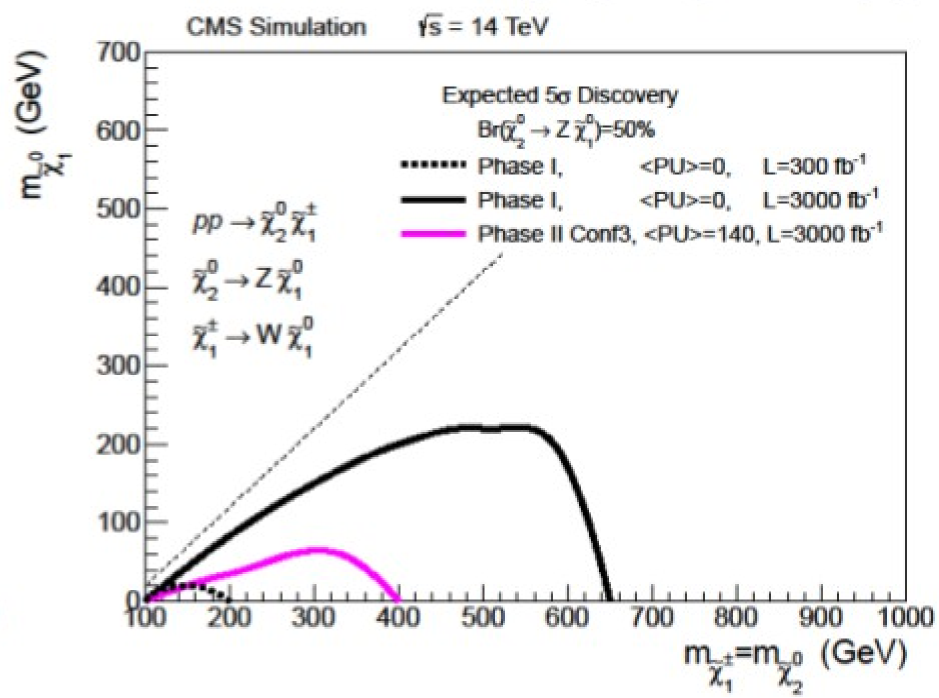


Weak gaugino production using 14 TeV LHC

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

CMS-PAS-FTR-13-014





Does this mean we can really discover SUSY EWK production:

~ 700 (400) GeV with 100 (50)% BR

Are simplified topologies, too simplified?

Electroweakinos in the Light of the Higgs Boson

T. Han, S. Padhi, S. Su, Phys. Rev. D88 (2013) 115010

Electroweakinos in the Light of the Higgs Boson

Assuming Higgs connection

- Natural SUSY → Light gauginos and Higgsinos

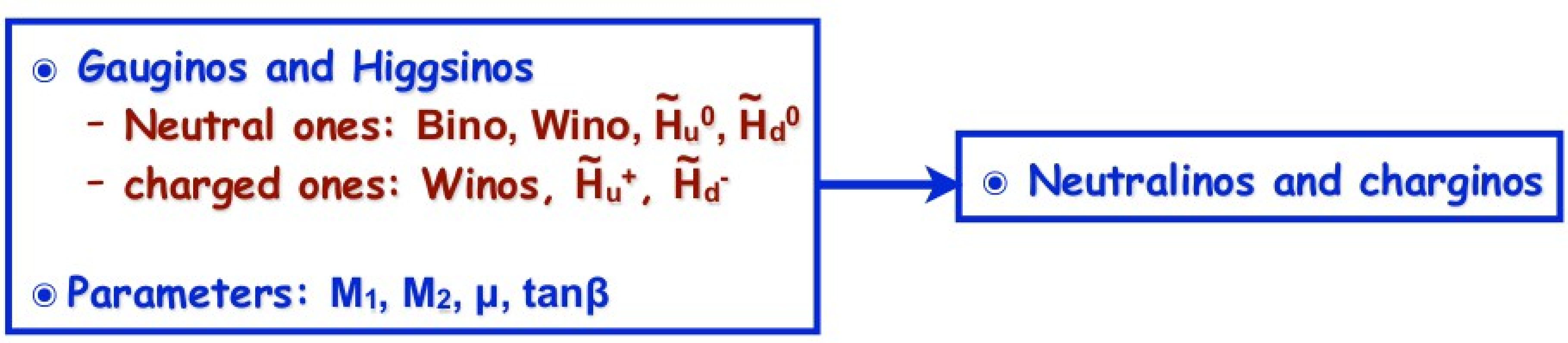
Colored superparticles might be heavy (See previous slides)

- Electroweak sector + stops/sbottoms might be the only accessible particles

- no indication from current LHC searches, m_{sq}, m_{gluino} > 1 TeV

Connection to lepton collider

In MSSM :



Assume LSP based on SUSY breaking mass parameters M1, M2 and μ

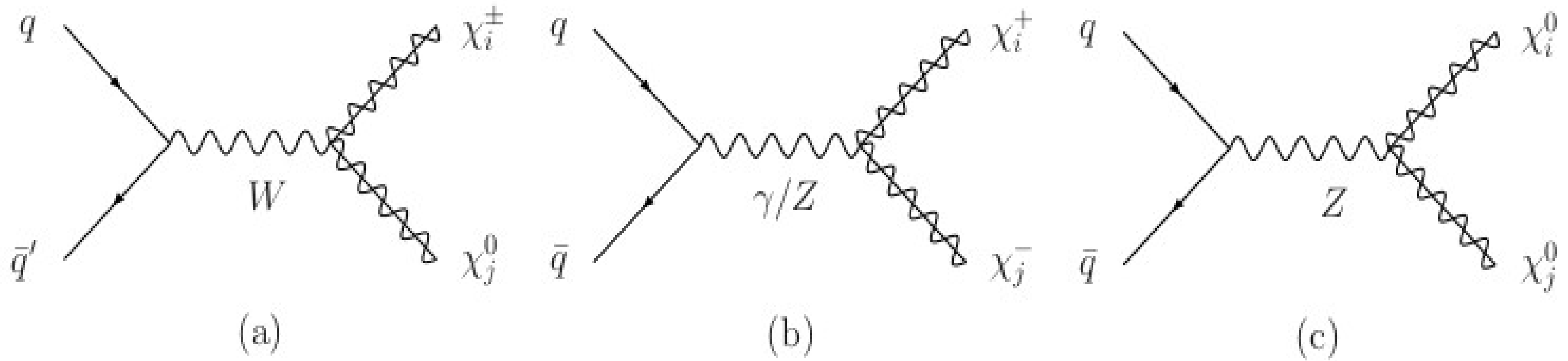
- Decouple the SUSY colored sector

There can be three cases:

a) Bino LSP (M1 < M2, μ)

b) Wino LSP (M2 < M1, μ)

c) Higgsino LSP (μ < M1, M2)



Masses: Bino LSP

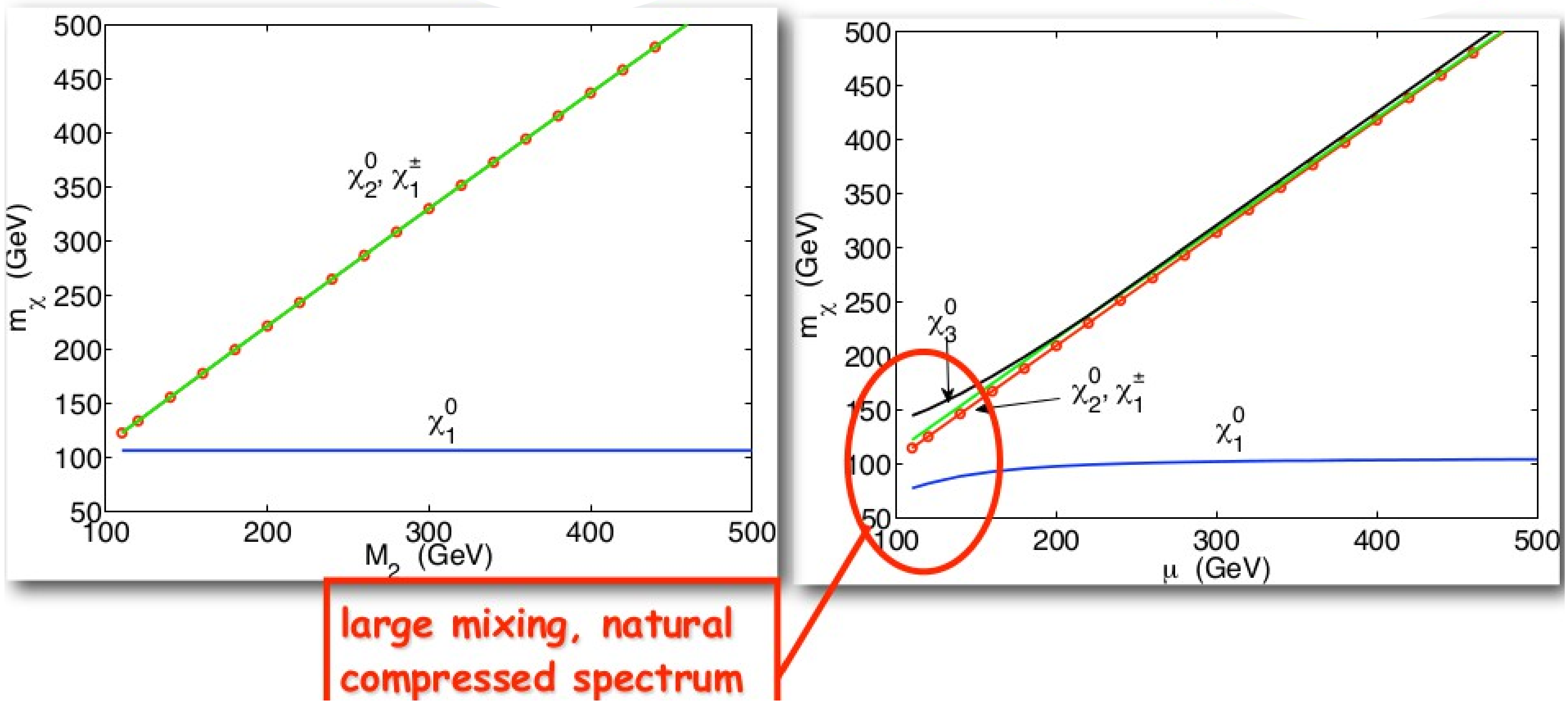
Case AI:
$M_1 < M_2 < \mu$

Case AII:
$M_1 < \mu < M_2$

arXiv:1309.5966

μ = 1 TeV

M2 = 1 TeV



$$\text{Case AI}: \quad M_2 < \mu, \quad \chi_1^\pm, \chi_2^0 \text{ are Wino}-\text{like}; \chi_2^\pm, \chi_{3,4}^0 \text{ are Higgino}-\text{like};$$

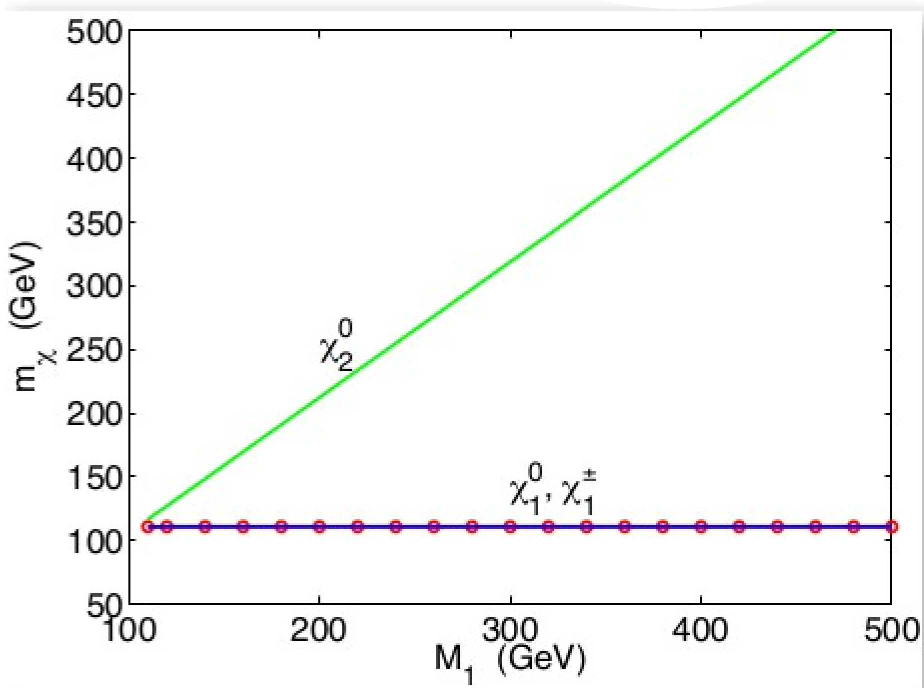
$$\text{Case AII}: \quad \mu < M_2, \quad \chi_1^\pm, \chi_{2,3}^0 \text{ are Higgino}-\text{like}, \chi_2^\pm, \chi_4^0 \text{ are Wino}-\text{like}.$$

Masses: Wino LSP

arXiv:1309.5966

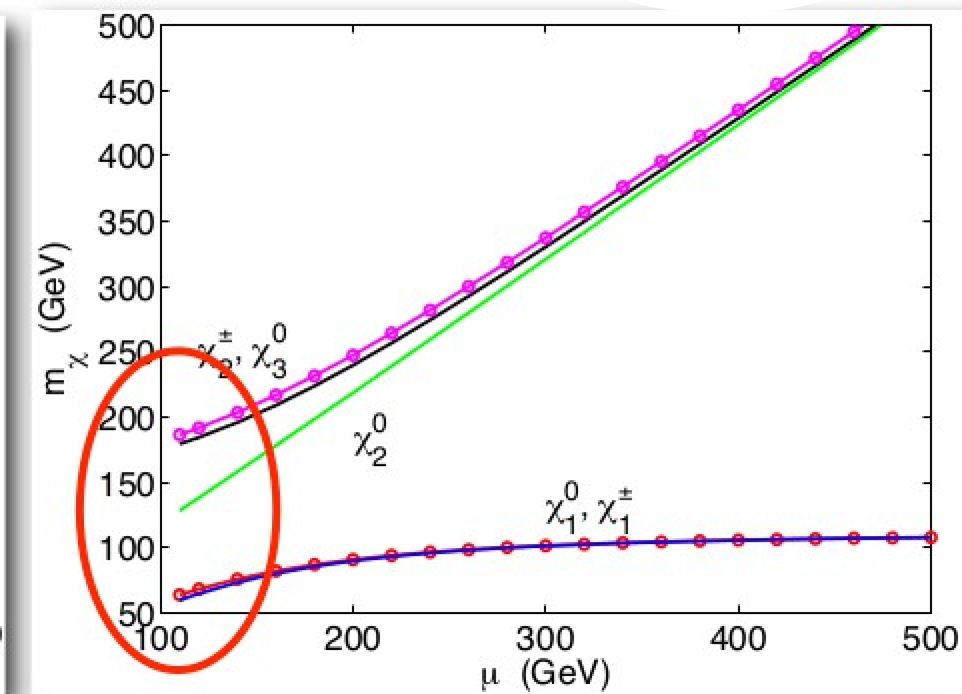
Case BI:
$M_2 < M_1 < \mu$

μ = 1 TeV



Case BII:
$M_2 < \mu < M_1$

M1 = 1 TeV



With wino LSP:

$$\text{Case BI}: \quad M_1 < \mu, \quad \chi_2^0 \text{ Bino} - \text{like}; \; \chi_2^\pm, \; \chi_{3,4}^0 \text{ Higgsino} - \text{like};$$

$$\text{Case BII}: \quad \mu < M_1, \quad \chi_2^\pm, \; \chi_{2,3}^0 \text{ Higgsino} - \text{like}; \; \chi_4^0 \text{ Bino} - \text{like}.$$

Masses: Higgsino LSP

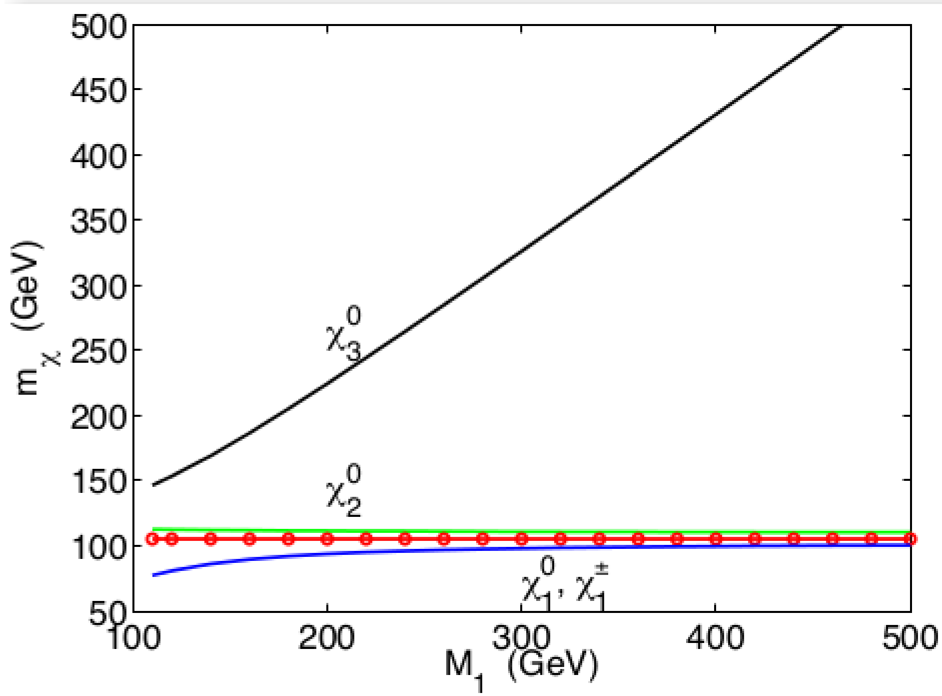
Case CI:
μ < M1 < M2

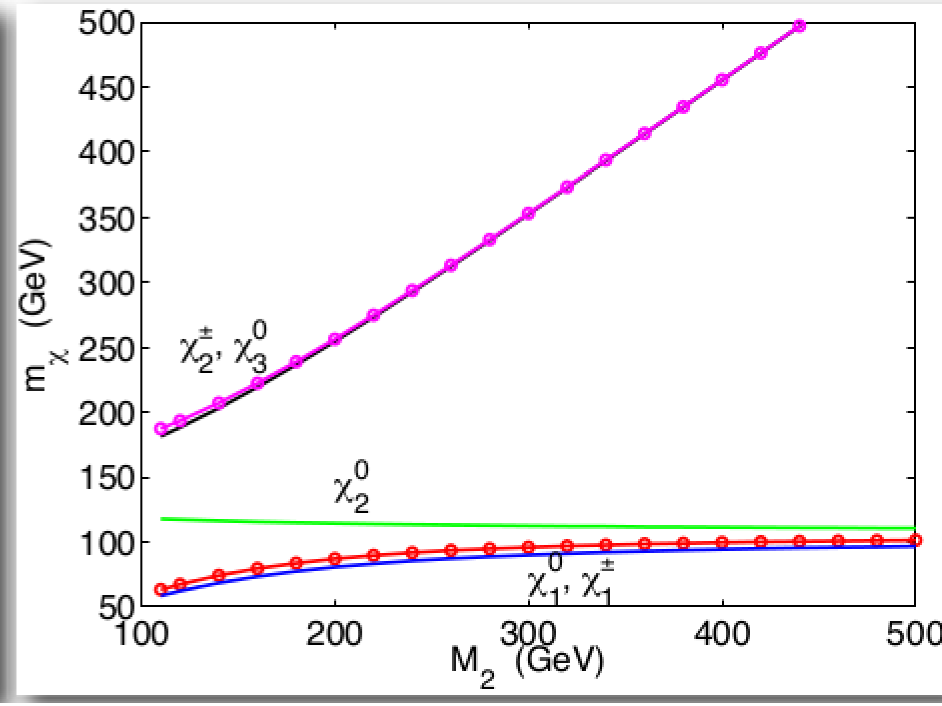
Case CII:
μ < M2 < M1

arXiv:1309.5966

M2 = 1 TeV

M1 = 1 TeV



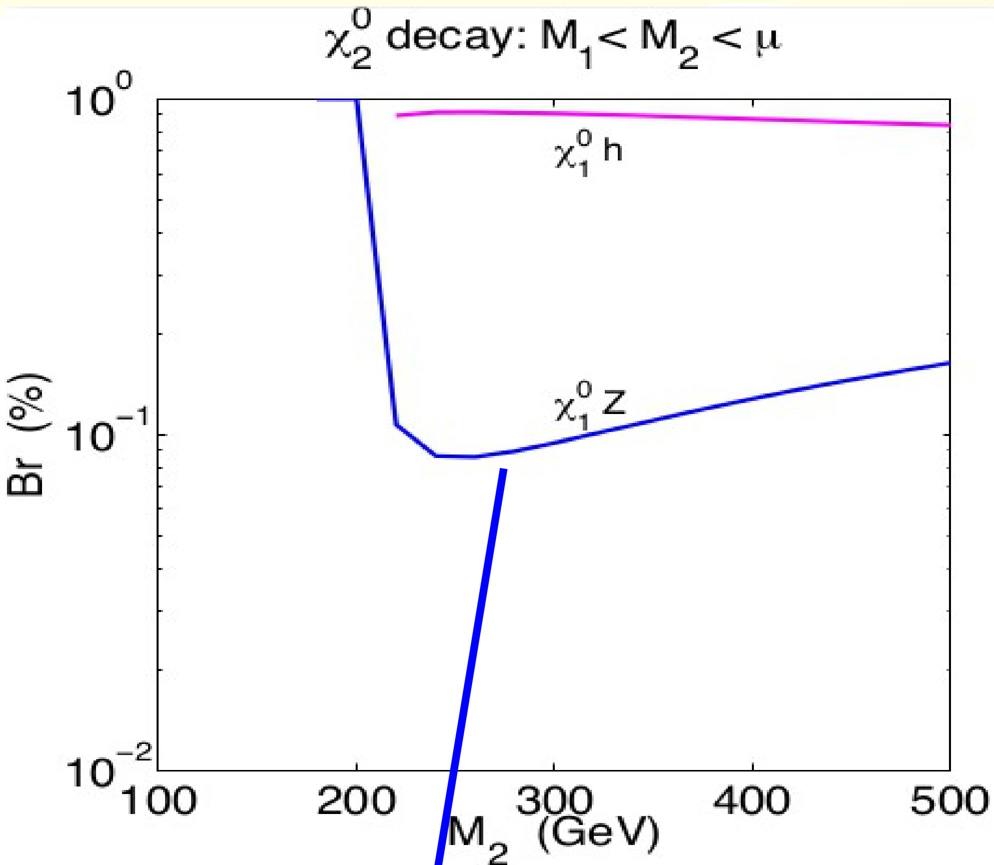


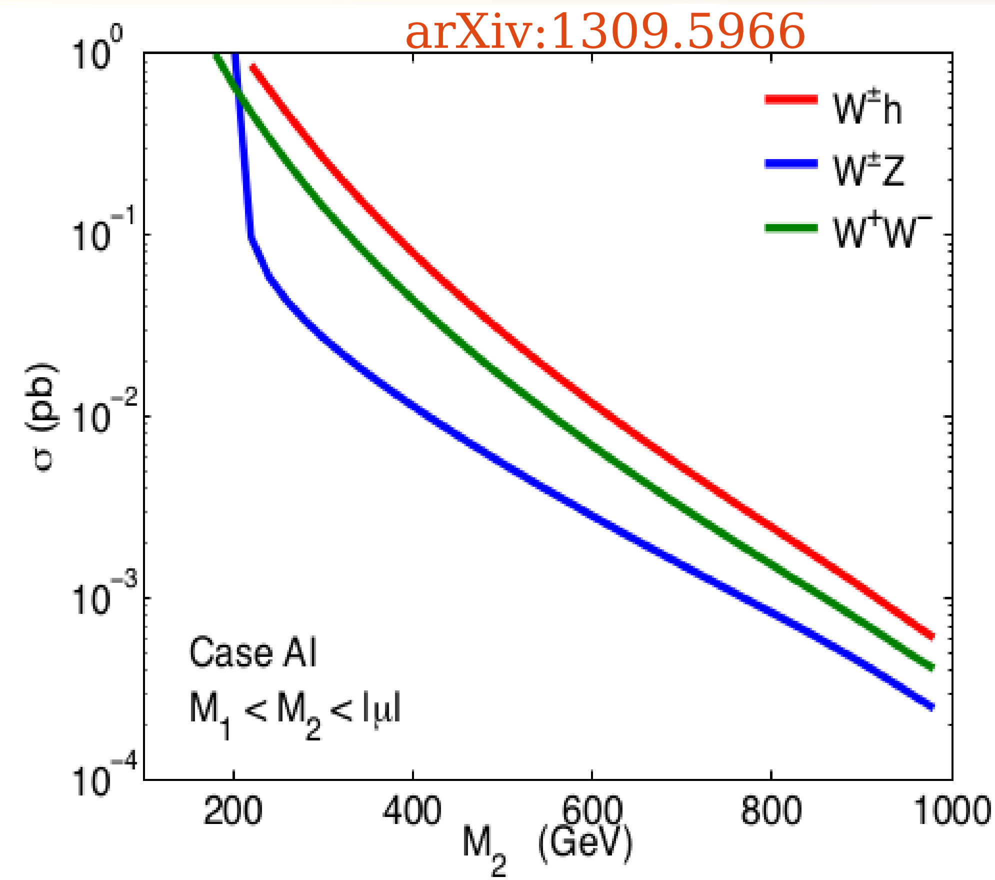
With higgsino LSP:

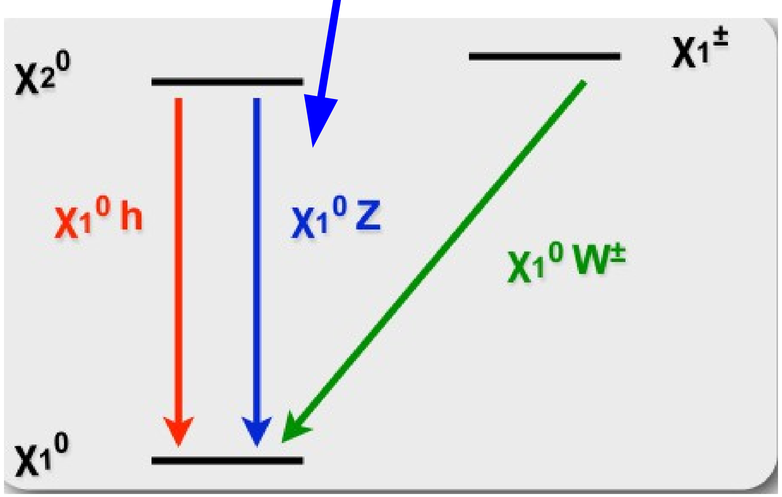
$$\text{Case CI}: \quad M_1 < M_2, \quad \chi_3^0 \ \text{Bino-like}; \ \chi_2^\pm, \ \chi_4^0 \ \text{Wino-like};$$

$$\text{Case CII}: \quad M_2 < M_1, \quad \chi_2^\pm, \ \chi_3^0 \ \text{Wino-like}; \ \chi_4^0 \ \text{Bino-like}.$$

Productions with Bino LSP







Decay to Higgs dominates over Z

Rich mixture of (W/Z/h)(W/Z/h) + MET

BR(WZ) < 100%

- sometimes highly suppressed

Wh complementary to WZ channel

- new discovery potential

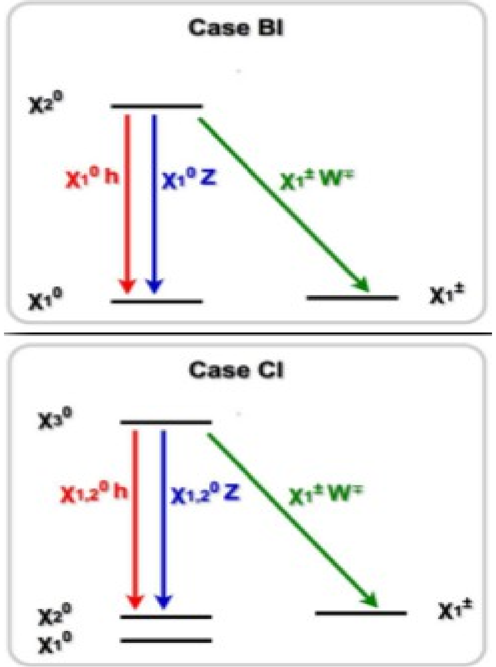
SUSY electroweak productions

	NLSP decay Br's		Production	Total Branching Fractions (%)						
				W^+W^-	$W^\pm W^\pm$	WZ	Wh	Zh	ZZ	hh
Case AI	$\chi_1^\pm \to \chi_1^0 W^\pm$	100%	$\chi_1^\pm \chi_2^0$			18	82			
$M_1 < M_2 < \mu$	$\chi_2^0 \to \chi_1^0 h$	82%(96–70%)	$\chi_1^+ \chi_1^-$	100						
Case AII	$\chi_1^\pm \to \chi_1^0 W^\pm$	100%	$\chi_1^\pm \chi_2^0$			26	74			
$M_1 < \mu < M_2$	$\chi_2^0 \to \chi_1^0 h$	74%(90–70%)	$\chi_1^\pm \chi_3^0$			78	23			
	$\chi_3^0 \to \chi_1^0 Z$	78%(90–70%)	$\chi_1^+ \chi_1^-$	100						
			$\chi_2^0 \chi_3^0$					63	20	17
Case BI										
$M_2 < M_1 < \mu$	$\chi_2^0 \to \chi_1^\pm W^\mp, \chi_1^0 h, \chi_1^0 Z$,	68%, 27%(31 – 24%), 5%(1 – 9%),	production suppressed.							
Case BII	$\chi_2^\pm \to \chi_1^0 W^\pm$	35%	$\chi_2^\pm \chi_2^0$	12	12	32	23	10	9	2
$M_2 < \mu < M_1$	$\chi_2^\pm \to \chi_1^\pm Z$	35%	$\chi_2^\pm \chi_3^0$	12	12	26	29	11	3	7
	$\chi_2^\pm \to \chi_1^\pm h$	30%	$\chi_2^+ \chi_2^-$	12		25	21	21	12	9
	$\chi_2^0 \to \chi_1^\pm W^\mp$	67%	$\chi_2^0 \chi_3^0$	23	23	23	21	7	2	2
	$\chi_2^0 \to \chi_1^0 Z$	26%(30–24%)								
	$\chi_3^0 \to \chi_1^\pm W^\mp$	68%								
	$\chi_3^0 \to \chi_1^0 h$	24%(30–23%)								
Case CI										
$\mu < M_1 < M_2$	$\chi_3^0 \to \chi_1^\pm W^\mp, \chi_{1,2}^0 Z, \chi_{1,2}^0 h$,	52%, 26%, 22%,	production suppressed.							
Case CII	$\chi_2^\pm \to \chi_{1,2}^0 W^\pm$	51 %	$\chi_2^\pm \chi_3^0$	14	14	27	23	11	6	5
$\mu < M_2 < M_1$	$\chi_2^\pm \to \chi_1^\pm Z$	26 %	$\chi_2^+ \chi_2^-$	26		26	24	12	7	5
	$\chi_2^\pm \to \chi_1^\pm h$	23 %								
	$\chi_3^0 \to \chi_1^\pm W^\mp$	54 %								
	$\chi_3^0 \to \chi_{1,2}^0 Z$	24 %								
	$\chi_3^0 \to \chi_{1,2}^0 h$	22 %								

arXiv:1309.5966

4 out of 6 cases result in compressed spectra

Nearly degenerate LSP pair production

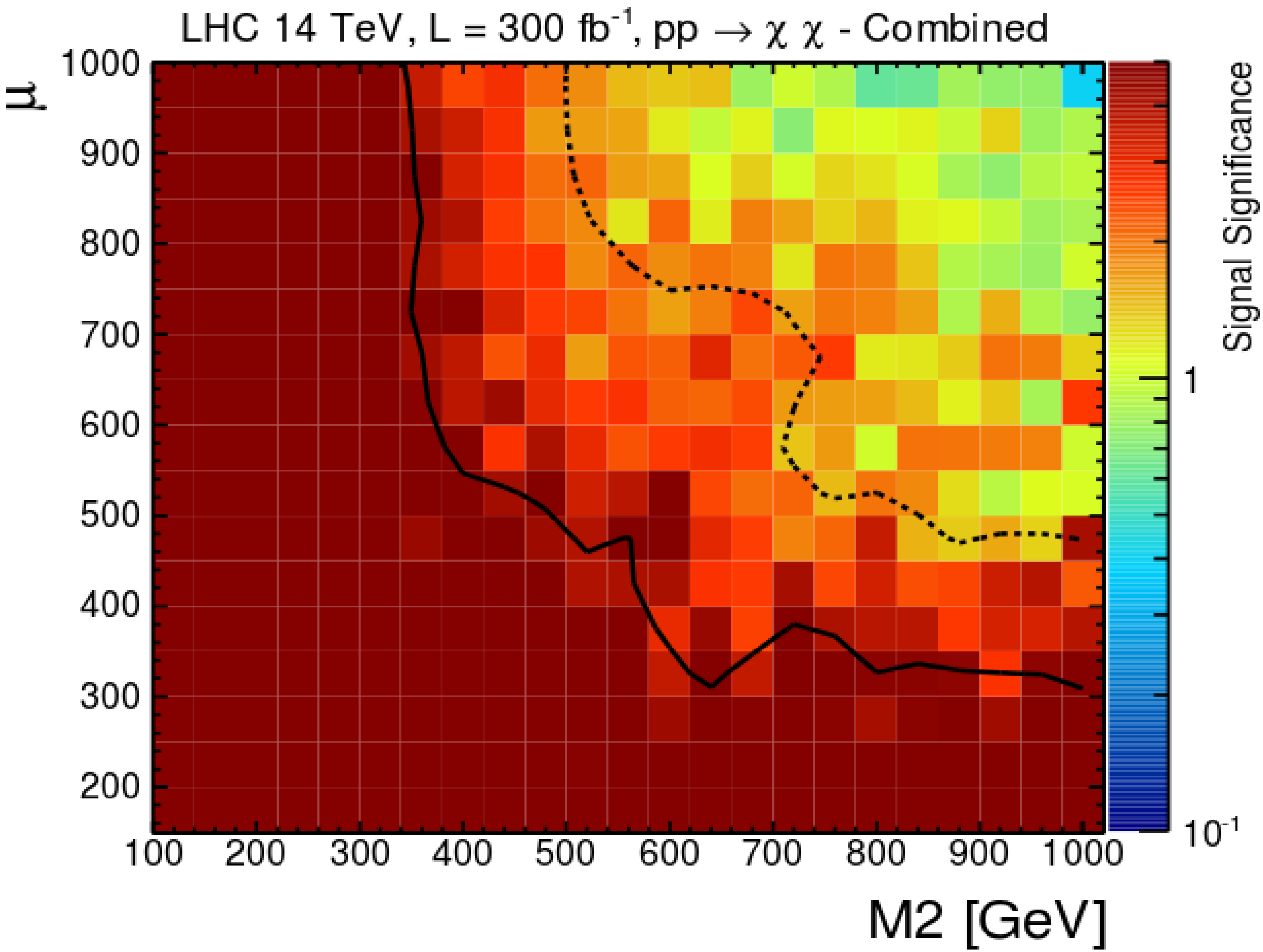


MET + ISR (Mono Jet studies)

Or VBF production

SUSY electroweak productions

arXiv:1309.5966



Large set of final states

Unique set of signals! **Opportunity to explore using HL-LHC**

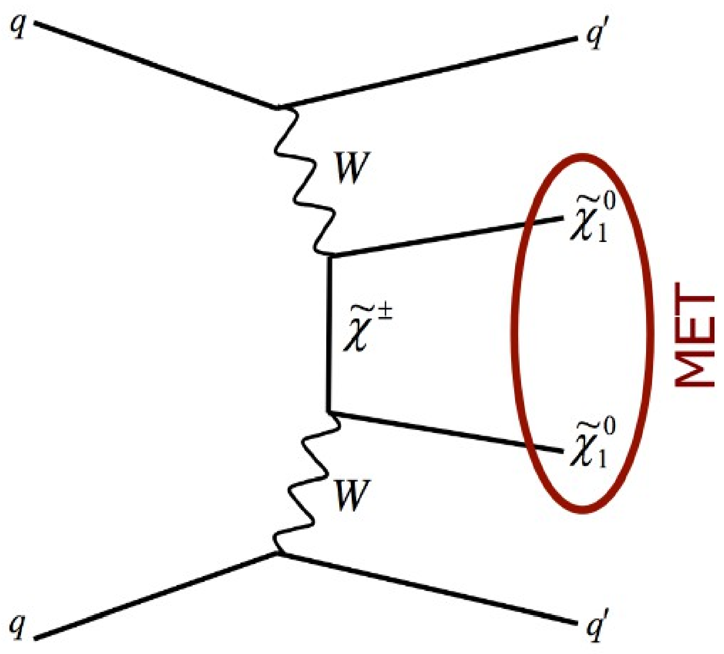
Compressed spectra using VBF

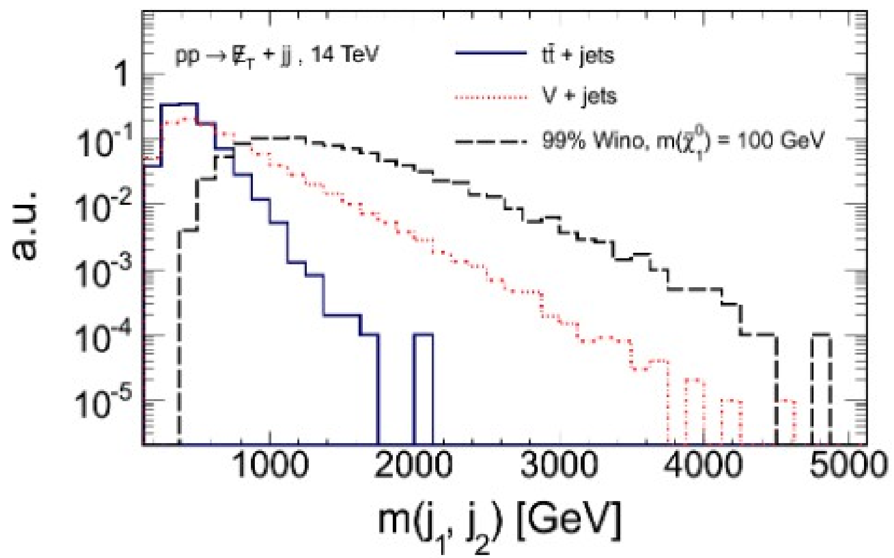
Vector Boson fusion process at the LHC

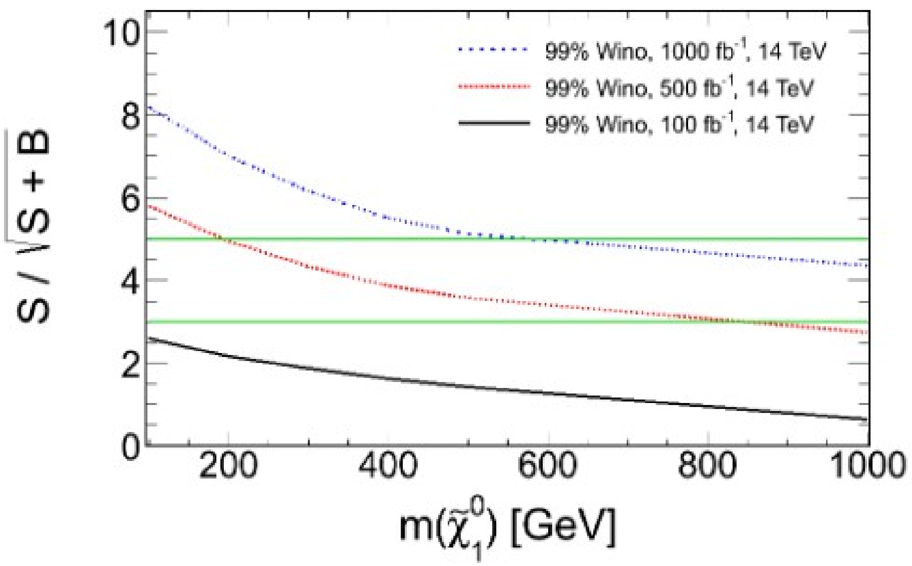
- Unique opportunity to search for new physics
- Extremely useful for compression regions
- With simplistic assumptions on simulation
    - Sensitive to New Physics at HL-LHC

Delannoy et. al.

Phys. Rev. Lett. 111 (2013) 061801

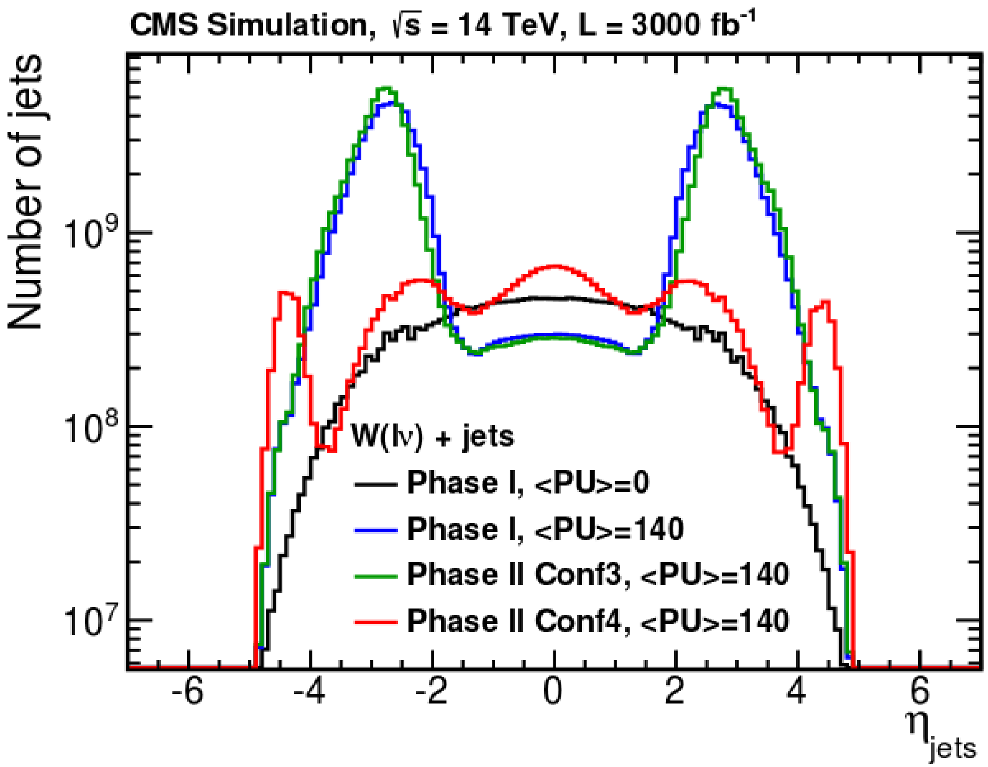






Challenges with VBF SUSY EWK searches

Number of jets rises dramatically in forward region without tracking



Particle Flow with veto on charged tracks not from PV helps

→ Important to make PF work with large PU

Calorimeter segmentation can also help reduce neutral deposits

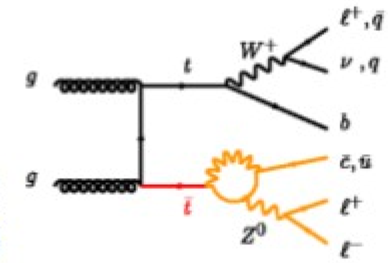
Pico-sec timing calorimeter will be very useful (Study in progress)

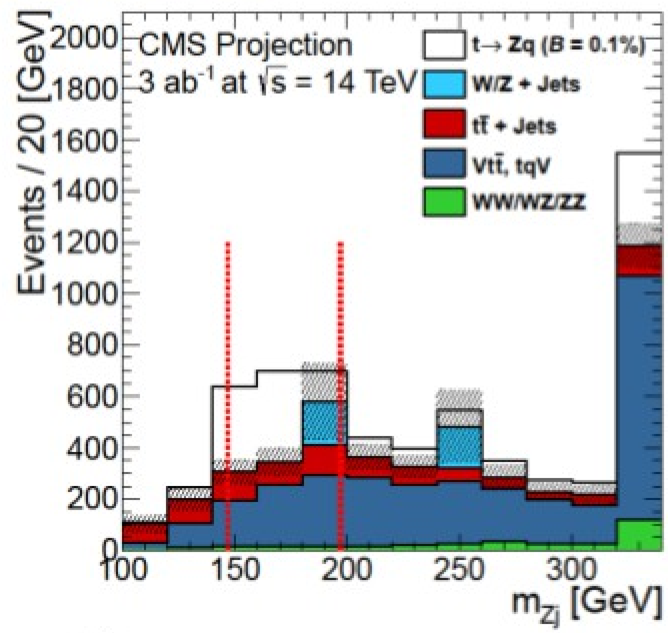
Other Beyond Standard Model studies

FCNC with top decays

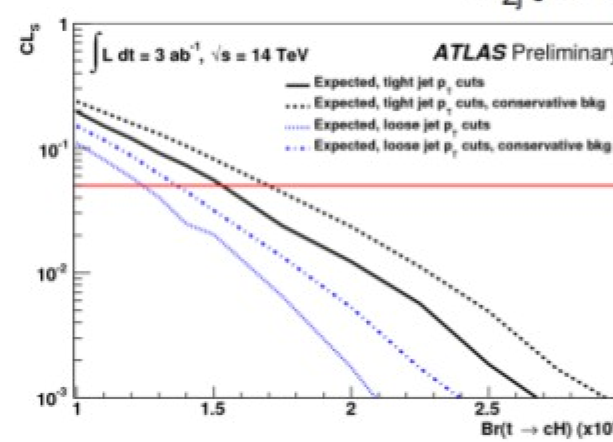
- Br($t \to Wb$)~100% in SM
- Flavor changing neutral current (FCNC) decay is highly suppressed
  - Br($t \to Zq$)~10^{-14} (SM)
  - Br($t \to cH$)~3×10^{-17}(SM)
- Search for or llq or $c\gamma\gamma$ final states
- ATLAS & CMS studies show sensitivity of 10^{-4} can be achieved in these channels with 3,000 fb^{-1}
  - Predicted by several extensions of SM (2HDM, RPV SUSY etc.)

ATLAS-PUB-2013-012
CMS-PAS-FTR-13-016





Process	SM	QS	2HDM-III	FC-2HDM	MSSM
$t \to u\gamma$	$3.7 \cdot 10^{-16}$	$7.5 \cdot 10^{-9}$	—	—	$2 \cdot 10^{-6}$
$t \to uZ$	$8 \cdot 10^{-17}$	$1.1 \cdot 10^{-4}$	—	—	$2 \cdot 10^{-6}$
$t \to uH$	$2 \cdot 10^{-17}$	$4.1 \cdot 10^{-5}$	$5.5 \cdot 10^{-6}$	—	10^{-5}
$t \to c\gamma$	$4.6 \cdot 10^{-14}$	$7.5 \cdot 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$2 \cdot 10^{-6}$
$t \to cZ$	$1 \cdot 10^{-14}$	$1.1 \cdot 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$2 \cdot 10^{-6}$
$t \to cH$	$3 \cdot 10^{-15}$	$4.1 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	$\sim 10^{-5}$	10^{-5}



Search for ttbar Resonances

Extra Dimensions can lead to wide ttbar resonances:

e.g: Kaluza-Klein gluon (g_{KK}) via the process pp $\rightarrow g_{KK} \rightarrow$ ttbar

Topcolor Z’ cases in models of strong electroweak symmetry breaking

through top quark condensation can lead to narrow resonances

from heavy Z' $\rightarrow$ ttbar

Final states:

a) dileptons + MET

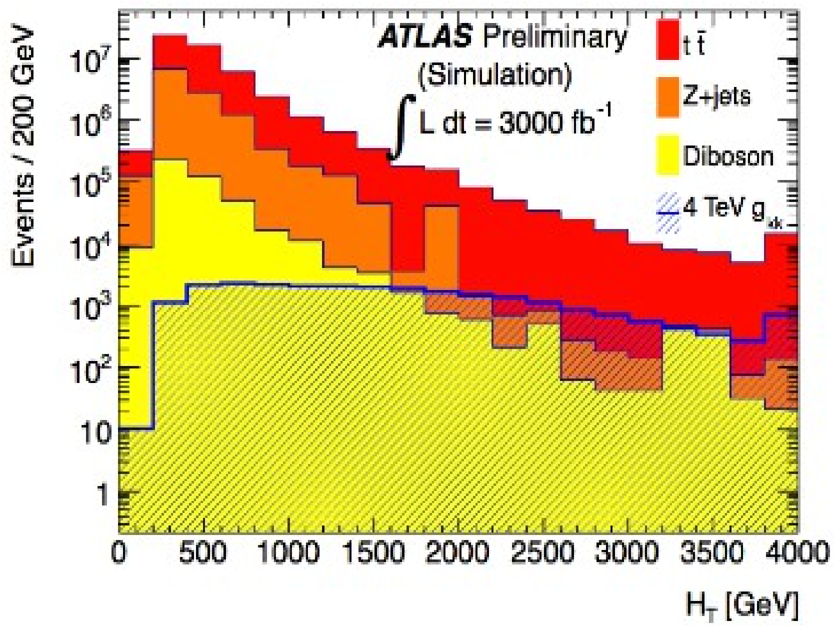
- Very clean state, difficult to reconstruct ttbar inv. mass

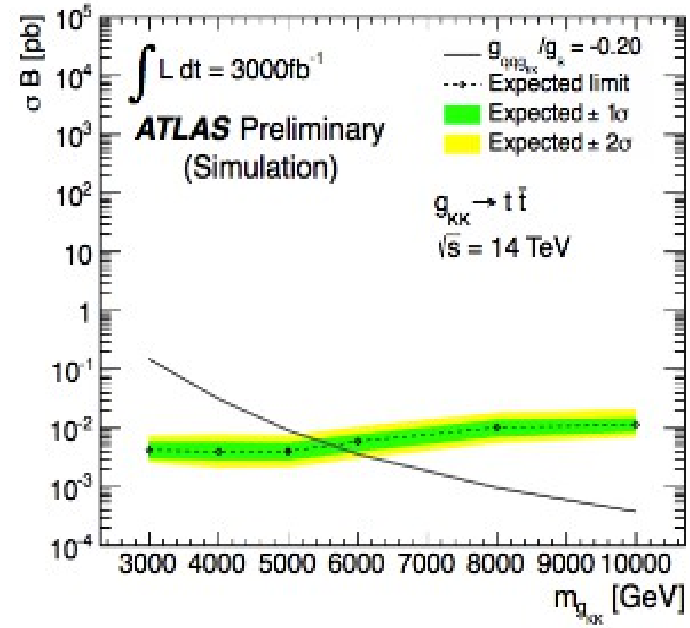
b) Semi-leptonic decays (Single lepton + MET)

- More complete reconstruction with large background

Search for ttbar Resonances

di-leptonic selection (similar results for single-lepton selection)





model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
Z'_{topcolor}	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)

(in TeV)

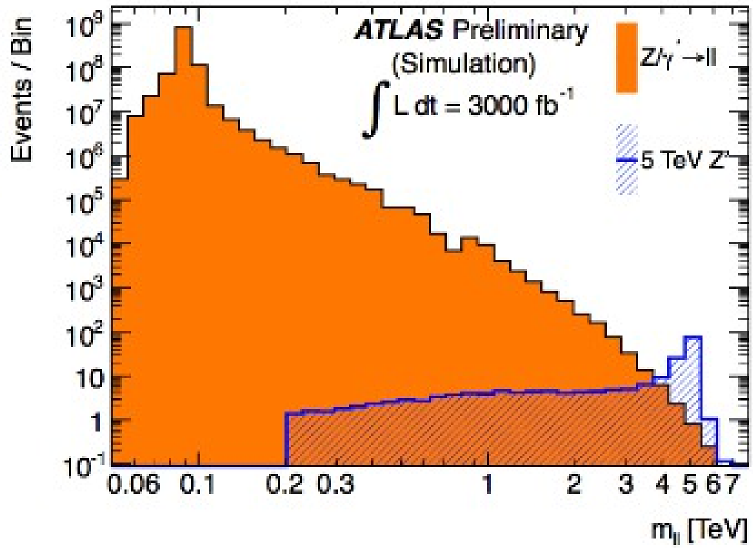
Mass reach for Kaluza-Klein gluons or Z′ can be enhanced by 50% with 3000 fb^{-1}

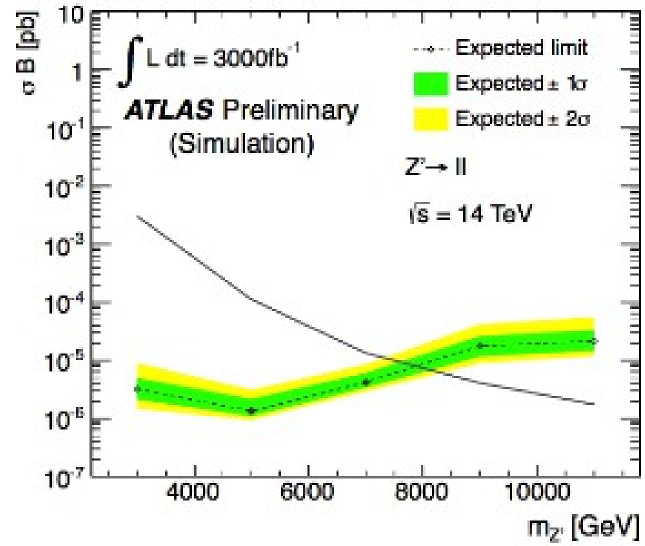
Z' decays to di-leptons

→ Main background: SM DY, ttbar, dibosons (small)

→ Upgraded detector should be able to suppress electron from γ conversion

ee final state (similar results for μμ)





model	$300\,\mathrm{fb}^{-1}$	$1000\,\mathrm{fb}^{-1}$	$3000\,\mathrm{fb}^{-1}$
$Z'_{SSM} \to ee$	6.5	7.2	7.8
$Z'_{SSM} \to \mu\mu$	6.4	7.1	7.6

(in TeV)

Mass reach for Z' → dileptons can be enhanced by 20% with 3000 fb^{-1}

Summary and Conclusions

There is a well-defined LHC roadmap including the HL-LHC

Detector upgrade R&D is in progress

- Goal is to have similar performance as the current detector with high PU
- Opportunity to contribute in algorithm developments/subtraction schemes

Huge array of measurements are possible with HL-LHC

- New Physics in colored sector as well as with Higgs in the final states
- Vector boson scattering with both Standard and Beyond Standard Physics
- Measurements of rare decays (not discussed here)

The results from ATLAS and CMS WILL set the agenda across the energy frontier for the foreseeable future!

Mass generation

Higgs Mechanism DOES NOT require a Higgs boson!

Higgs Mechanism: If a LOCAL gauge symmetry is spontaneously broken, then the gauge boson acquires a mass by absorbing the Goldstone mode.

The predicted Higgs boson is the left-over particle!

Higgs field → **4 = 3 + 1**

↑ longitudinal modes of W^+, W^-, Z

↑ physical Higgs Boson

Simulation framework for ECFA

Delphes-3 fast simulation

- Delphes3 supports addition of PU events

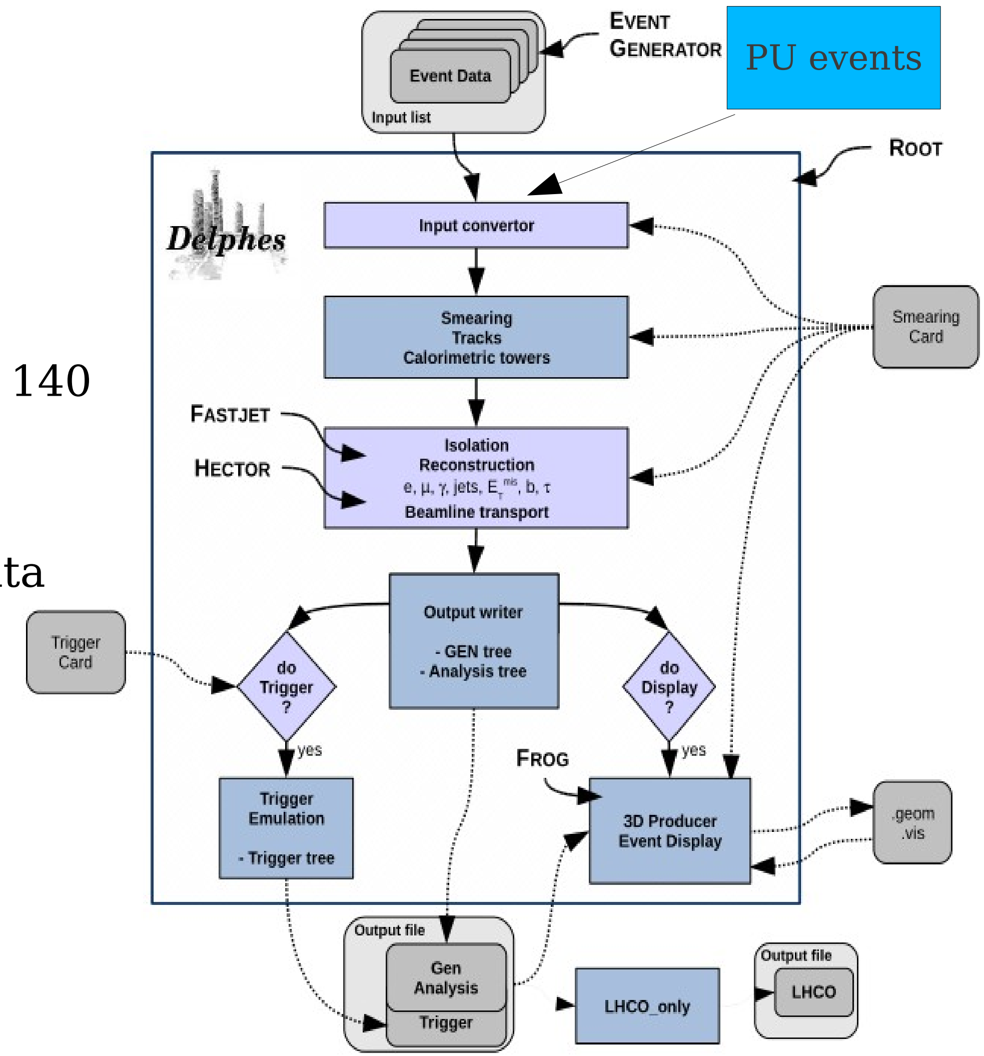
For Phase-I studies:

We use Delphes3 framework with:

- realistic detector performance with PU =0, 50, 140
- parameterize using available full simulation
- retain object performance as obtained using data

For Phase-II studies:

- use higher pileups – 140
- use Phase-II tracker up to $|\eta| < 4.0$
- 70 bins CAL segmentation in $\eta-\varphi$



Validation is crucial for all of these to work

- pileup subtraction is done ala particle flow (for tracks), and jet Rho method for neutrals

Pile-up implementation and subtraction

Pile-ups (PUs) are extracted using Minbias events with Z2* tune (CMS Tune)

Pile-up is based on implementation in Delphes

- Charged particles are subtracted at the mixing level
- Similar to vetoing "Charged tracks" NOT coming from the primary vertex.
- Neutral particles are subtracted based on fastjet area method (ρ method)
- In the endcap/fcal (outside the tracker acceptance) ρ method is used

The Z vertex spread in the beam direction, assuming gaussian - 5 cm

The resolution spread in the Z vertex direction – 0.1 cm

Magnetic Field = 3.8 Tesla

Radius of magnetic field coverage = 1.2 m

Object reconstruction and algorithms

Particle propagation:

Neutral: trajectory is a straight line from production point to the calo cell

Charged: Follow helicoidal trajectory until it reaches the calorimeter

Calorimeter:

- Finite segmentation in eta and phi: determines cell size
- Segmentation is uniform in the transverse direction
- Towers are computed using geometrical center of the cell

Tower energy: $$E_{Tower} = \sum_{particles} \ln\mathcal{N}\left(f_{ECAL} \cdot E, \sigma_{ECAL}(E,\eta)\right) + \ln\mathcal{N}\left(f_{HCAL} \cdot E, \sigma_{HCAL}(E,\eta)\right).$$

Particle Flow: If the momentum resolution of the tracking system is higher than the energy resolution of calorimeters, it can be convenient to use the tracking information within the tracker acceptance for the charged particles momenta

- Ncalo: the total number of hits that originate from all long-lived particles
- Ntrk: the number of hits that originate from a reconstructed track

If Ncalo = Ntrk; Momentum resolution of tracks are used

If Ncalo > Ntrk: Produce particle flow tower also using ECAL and HCAL info.

Mixed case: Subtraction of charged particle energy to determine neutral deposits