The Quest for Naturalness in Supersymmetry

LPC Topic of the Week

Nov. 5th 2012, FNAL, Chicago

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Many thanks for the discussions with:

R. Cavanaugh, M. Mangano, F. Wuerthwein, T. Han and S. Su

Outline

- Introduction
- Naturalness in Supersymmetry
- SUSY searches at the LHC
  - Inclusive searches
  - Third generation studies
  - SUSY electroweak(ino) production
- Charginos/Neutralinos in the light of the Higgs boson
- Summary and conclusion

Observation of the Higgs boson at the LHC

Observation of the Higgs-like boson at the LHC ushers in a new era in particle phys

ATLAS (hep-ex: 1207.7214) and CMS (hep-ex: 1207.7235)

CMS Combined local significance

Expected: 5.8σ

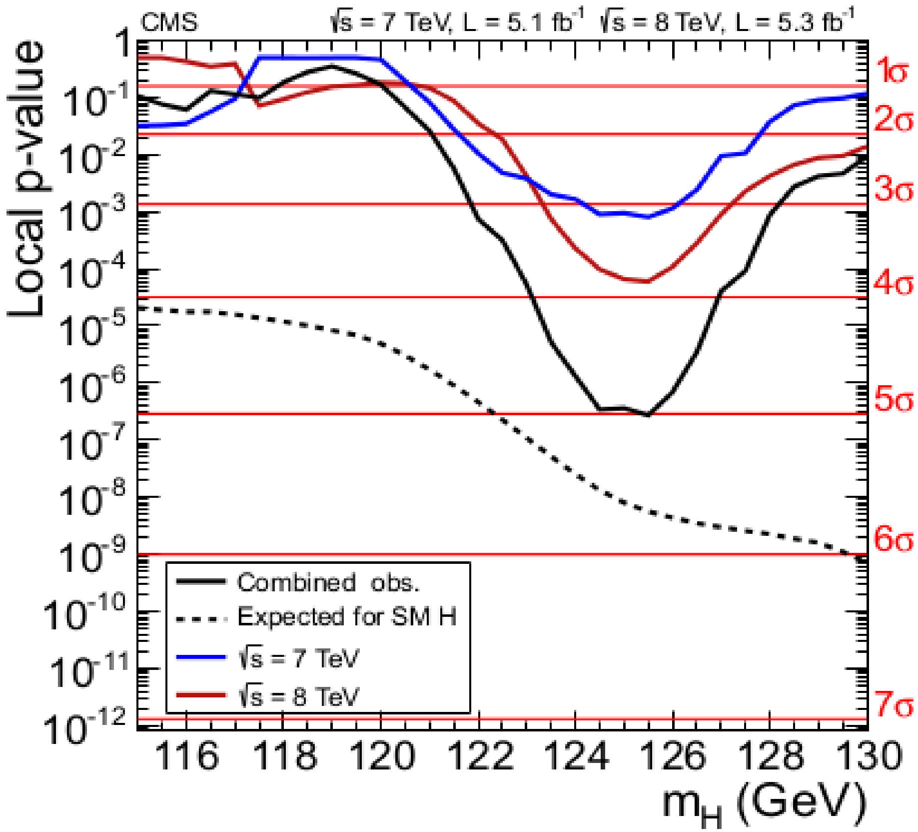
Observed: 5.0σ

ATLAS Combined local significance

(WW, ZZ, γγ)

Expected: 4.9σ

Observed: 5.9σ



Combined Mass fit:

M (CMS) = 125.3 ± 0.4 (stat.) ± 0.5 (sys.) GeV

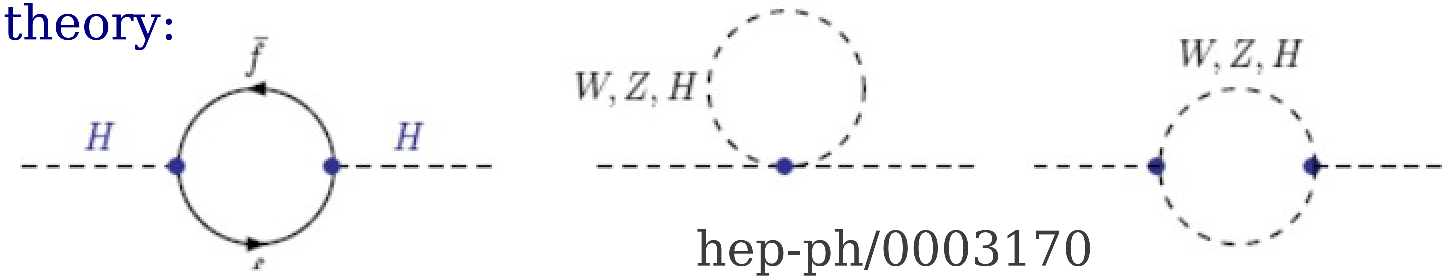
M (ATLAS) = 126.0 ± 0.4 (stat.) ± 0.4 (sys.) GeV

What does ~125 GeV Higgs indicate?

p-value: probability that background fluctuates to give an excess as large as the (average) signal size expected for a SM Higgs.

Higgs mass corrections

Using SM as effective theory:



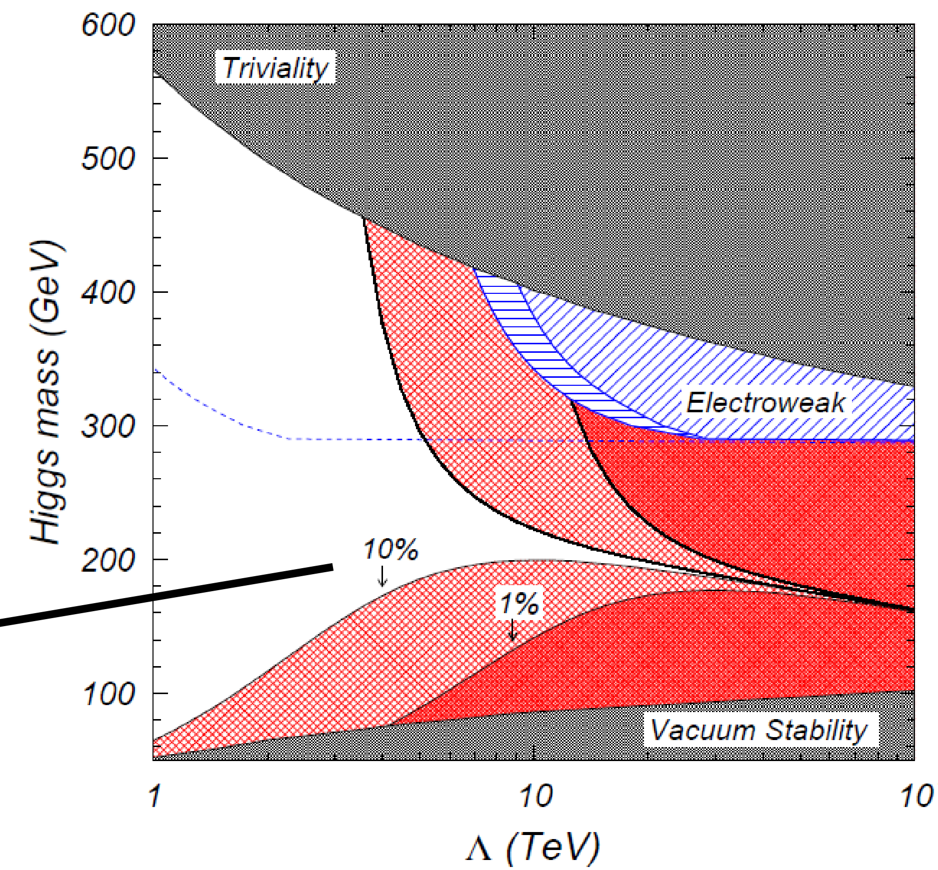
hep-ph/0003170

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



Fine tuning analogy

Giudice (arXiv:0801.2562)::

"The necessary accuracy needed to reproduce G_F/G_N is equal to the accuracy needed to balance a pencil as long as the solar system on a tip a millimeter wide."

Is the Higgs mass protected by some symmetry?

First SUSY search

First paper (to my knowledge) to explicitly search for SUSY: MARK-J at DESY

VOLUME 45, NUMBER 24 PHYSICAL REVIEW LETTERS 15 DECEMBER 1980

Experimental Study of Heavy Charged Leptons and Search for Scalar Partners of Muons at PETRA ($12 \text{ GeV} \leq E_{\text{c.m.}} \leq 36.7 \text{ GeV}$)

Data from the MARK-J detector on the reactions $e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-$ in the center-of-mass energy range from 12 to 36.7 GeV are presented. The μ, τ radii are shown to be $< 10^{-16}$ cm. A search has been made for the production of a new heavy lepton and for the production of spin-0 supersymmetric partners of the muon. 95%-confidence-level lower limits of 16 GeV for the mass of a new charged heavy lepton and 15 GeV for the mass of the scalar partners of the muon are obtained.

Naturalness in 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

Stop mass

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

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

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

R. Barbieri

The key equations:

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

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

$$m_{\tilde{b}_L}$$

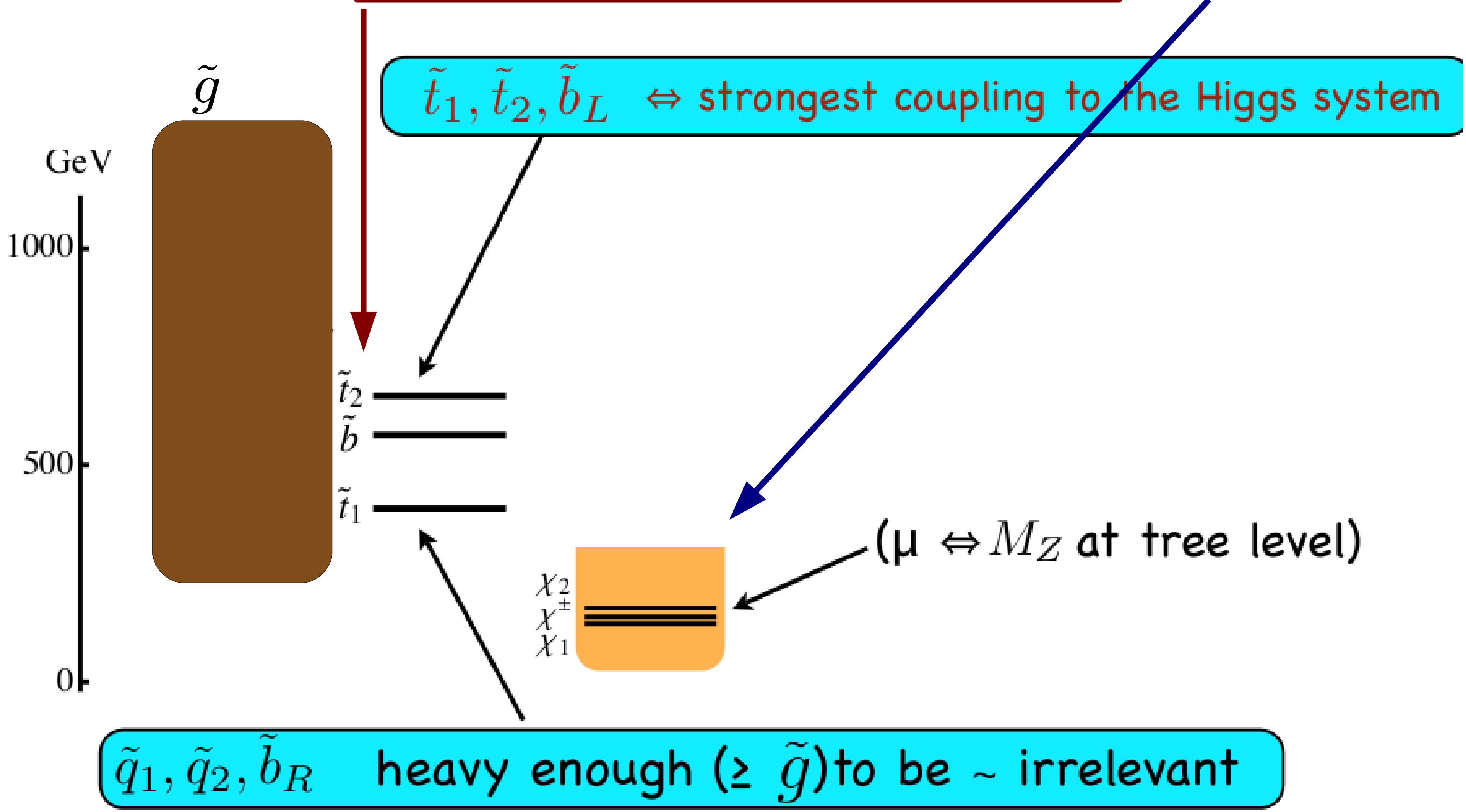
$$\delta m_{\tilde{t}}^2 \approx \frac{8\alpha_s}{3\pi} m_{\tilde{g}}^2 \log M/m_{\tilde{t}}$$

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

see Dimopoulos, Giudice for SUGRA-mediation

Naturalness in Supersymmetry

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



Naturalness in Supersymmetry

Re-examine naturalness based on recent experimental results:

- Inclusive SUSY searches

- Search for SUSY third generation particle production

- Search for SUSY weak production

Inclusive SUSY Searches

SUSY Search strategy

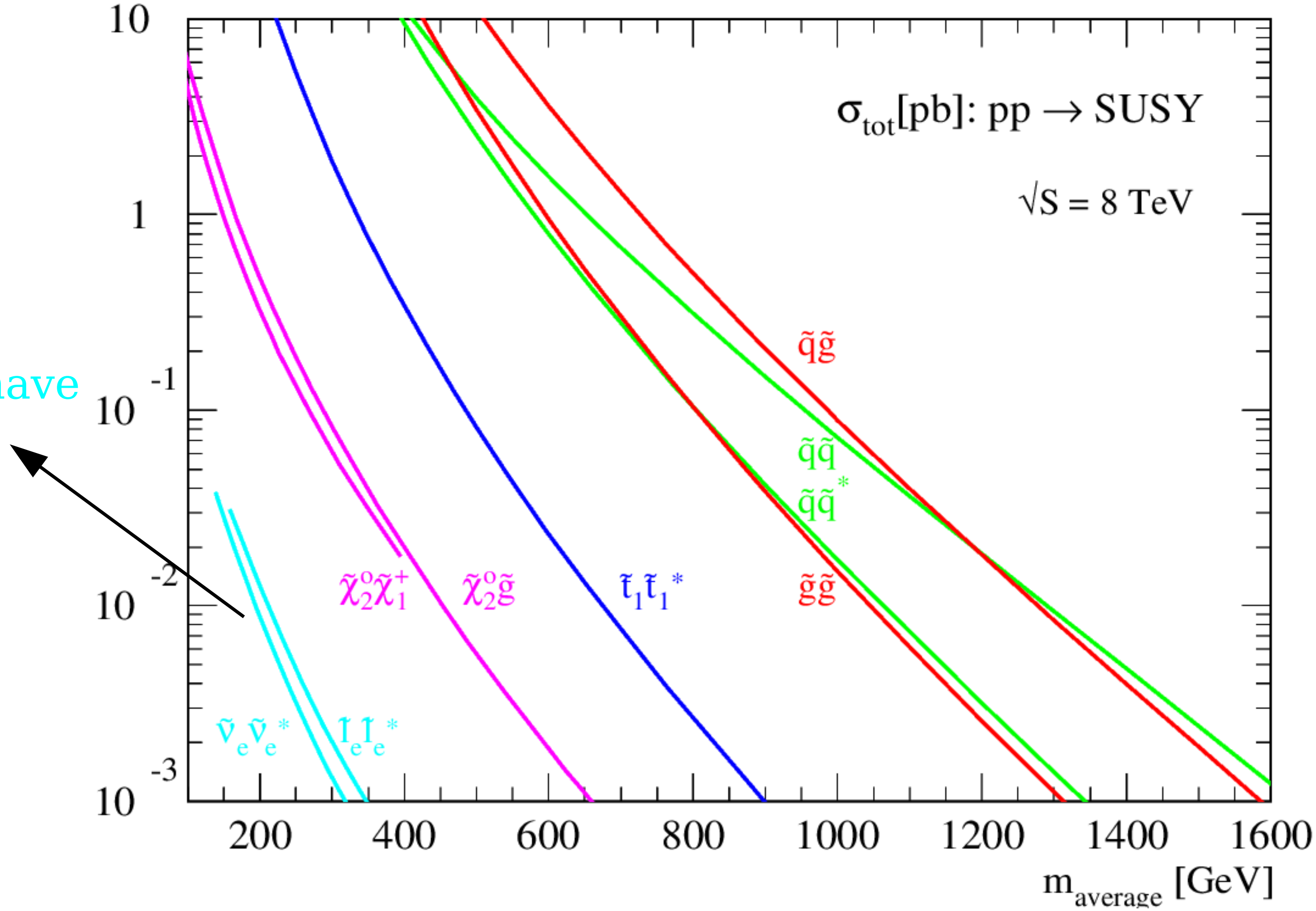
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

Searches are defined (explore MET +X signatures):

- Categorized by the number of leptons in final state
- Generic missing energy signatures
- Many include jet requirements to be sensitive to strong production
- Direct stop/sbottom production using btag jets
- Direct electroweak production – Sensitive to leptonic final state

SUSY sparticle production at the LHC

EWK-inos have low cross section



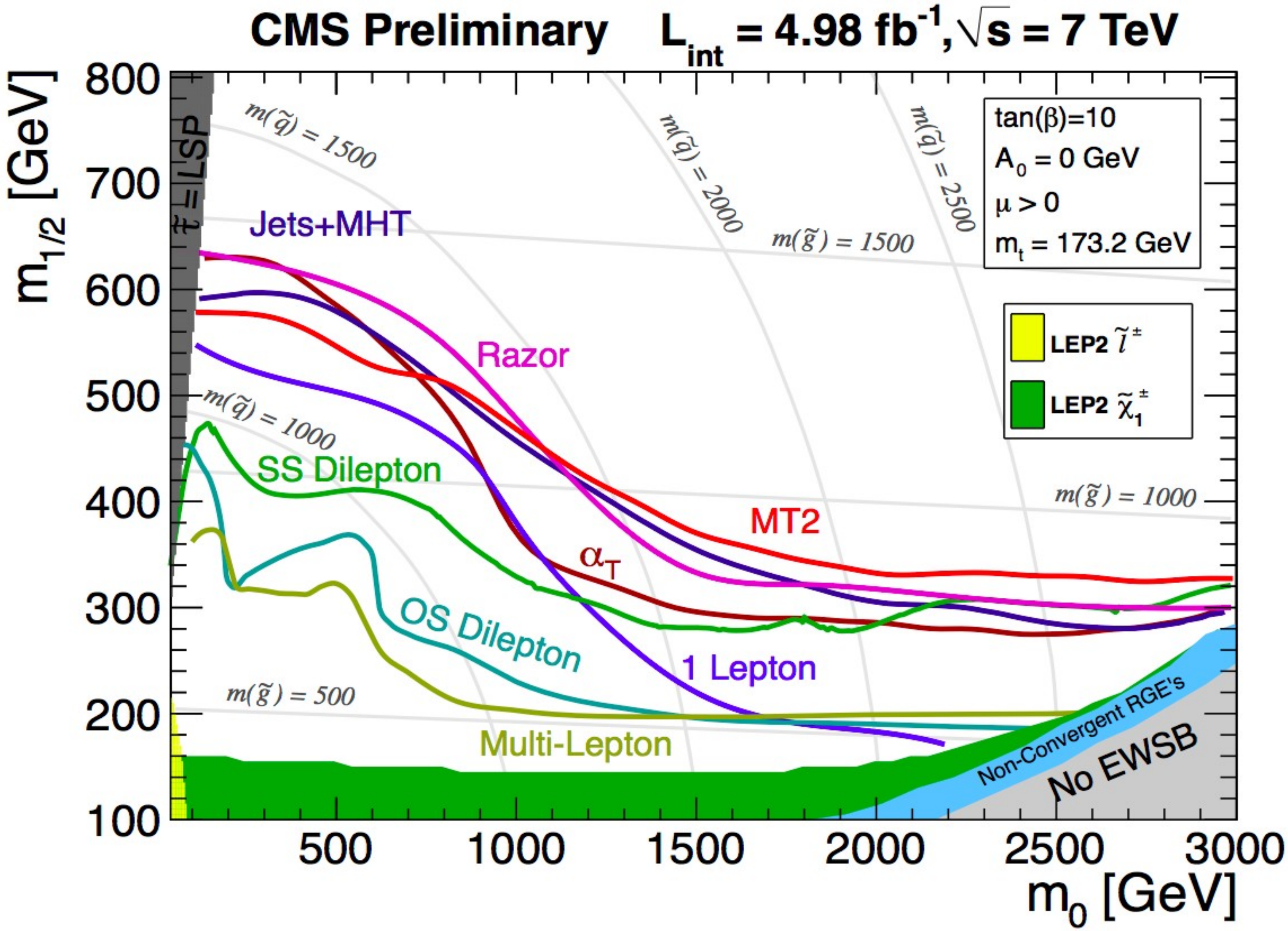
Largest cross sections are due to colored sources (squarks and gluinos)

- decouple them to study them individually

Stops and sbottoms have similar cross section, except at low sbottom masses

Inclusive SUSY searches

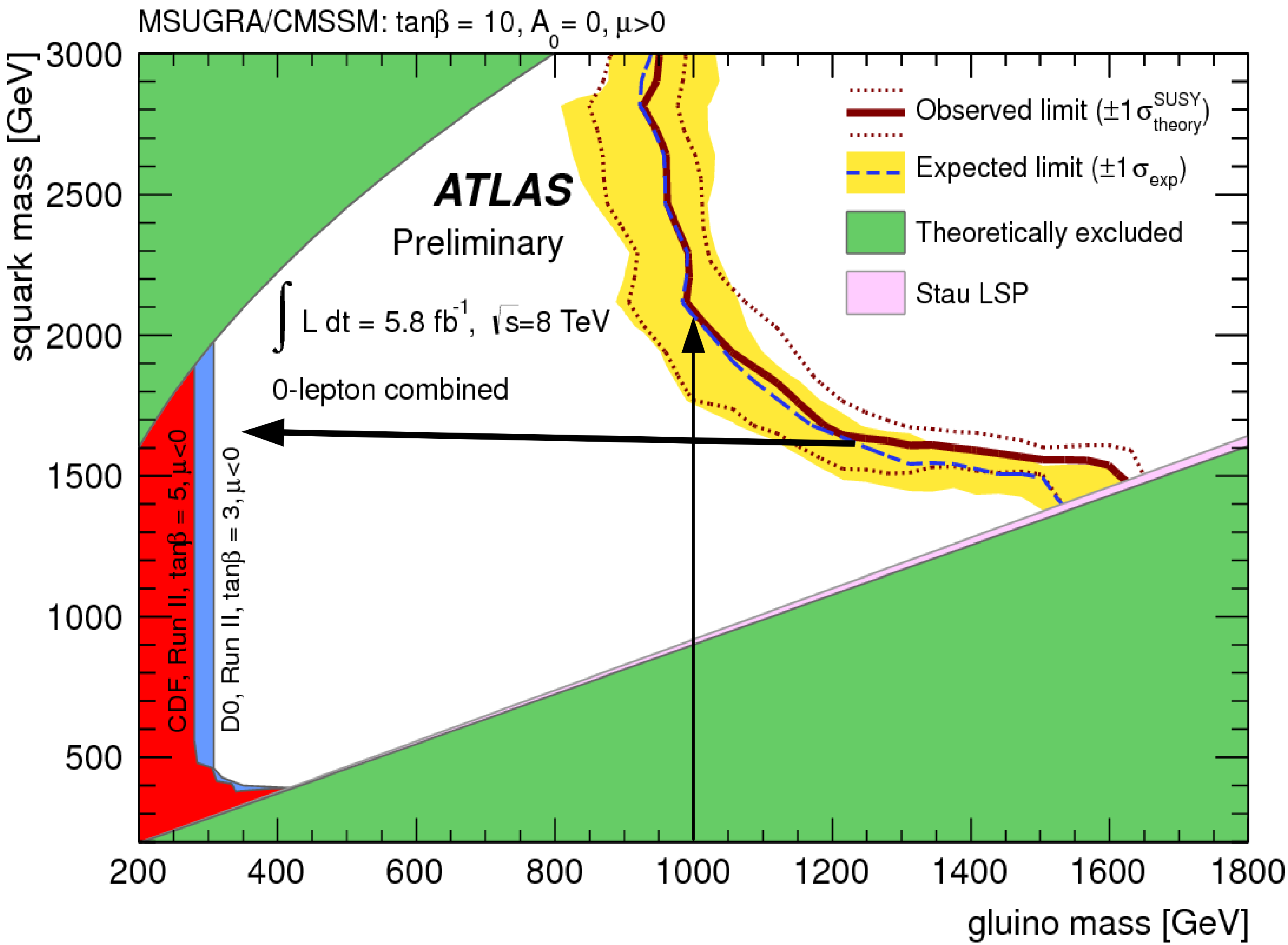
Landscape today – CMS Study



Impressive variety of inclusive SUSY searches – model dependent

Landscape today – ATLAS study

ATLAS-CONF-2012-109

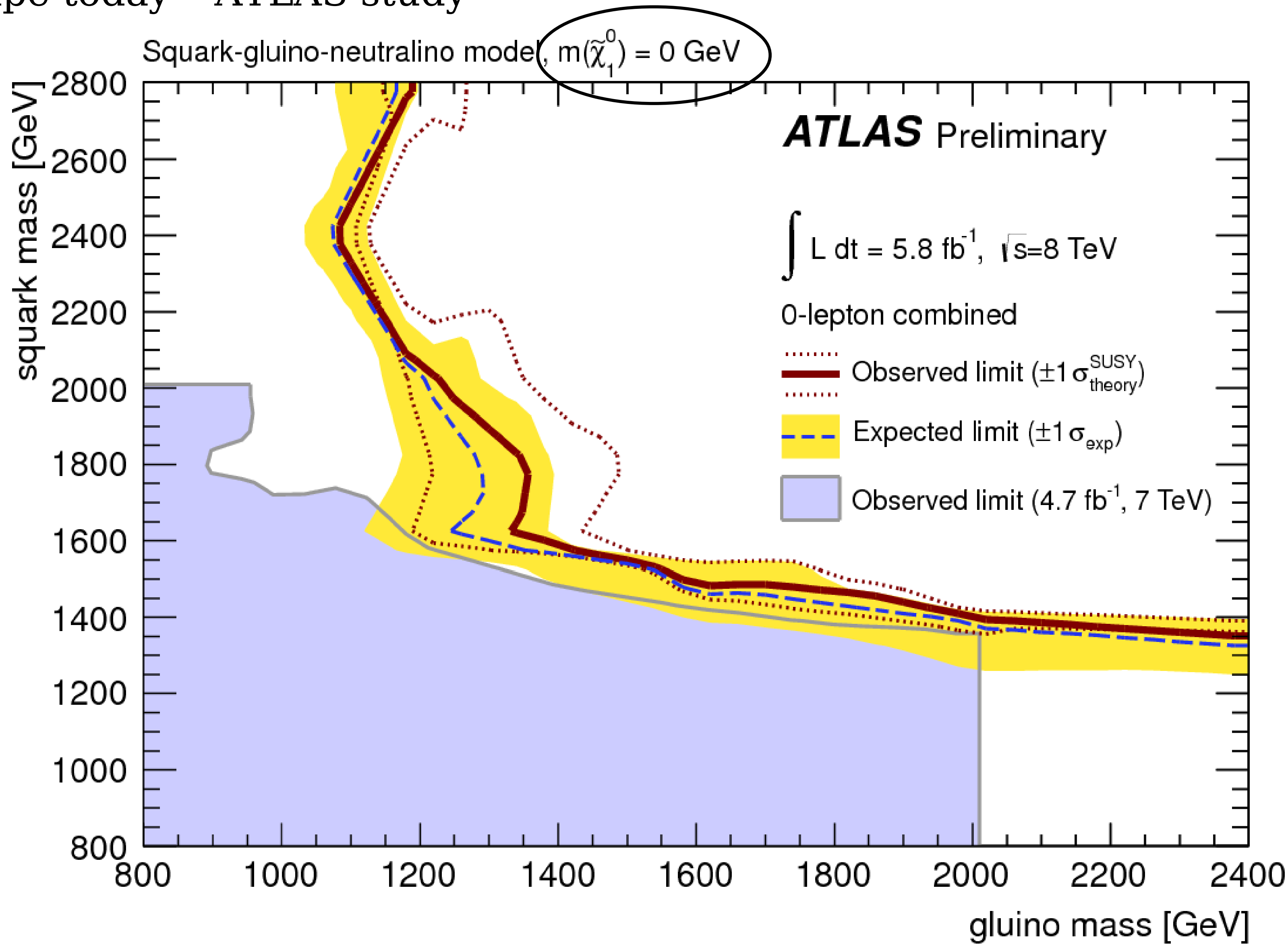


Impressive variety of inclusive SUSY searches – model dependent

Inclusive SUSY searches

Landscape today – ATLAS study

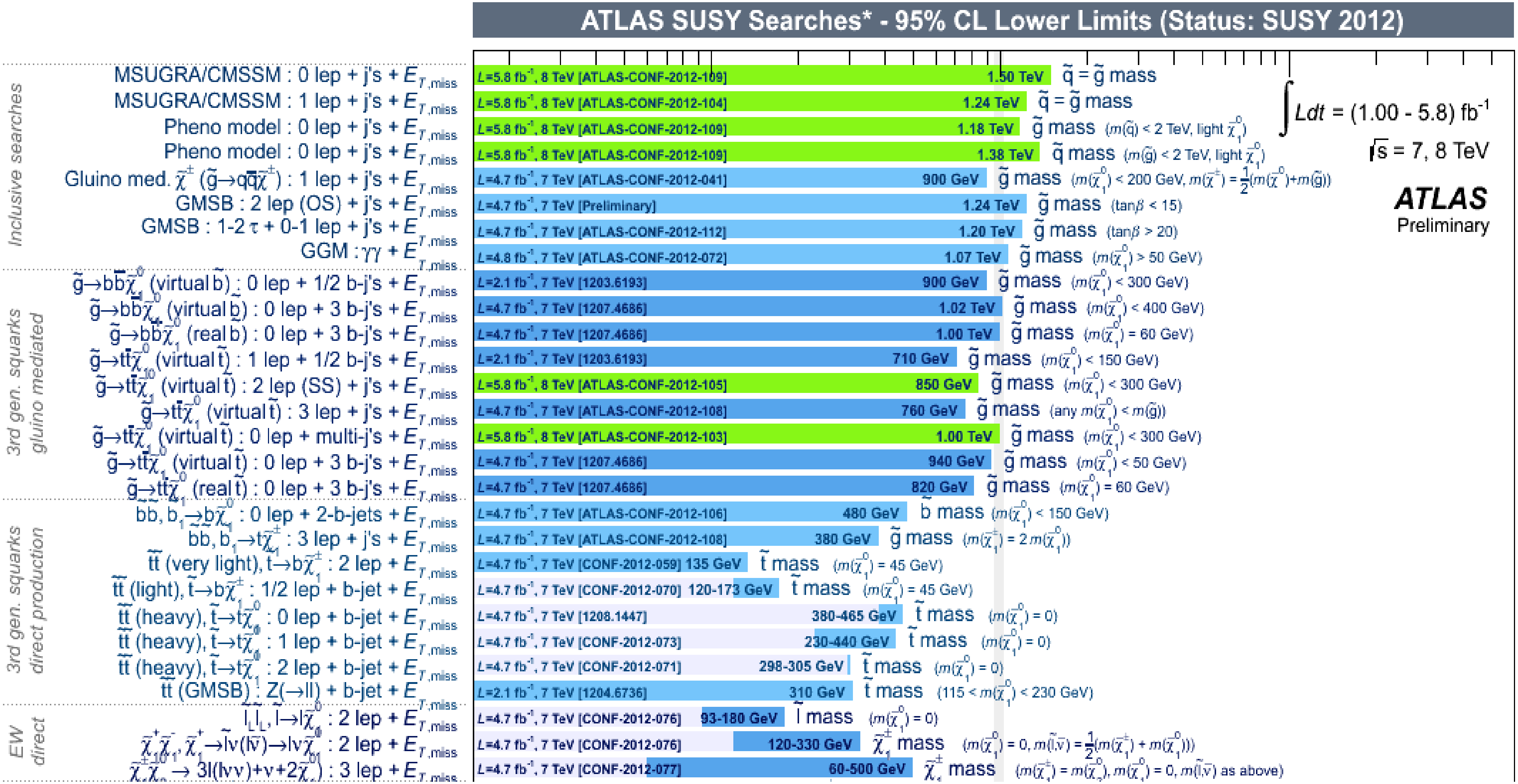
ATLAS-CONF-2012-109



Impressive variety of inclusive SUSY searches – model dependent

Inclusive search for squark and gluinos

ATLAS results (CMS similar)



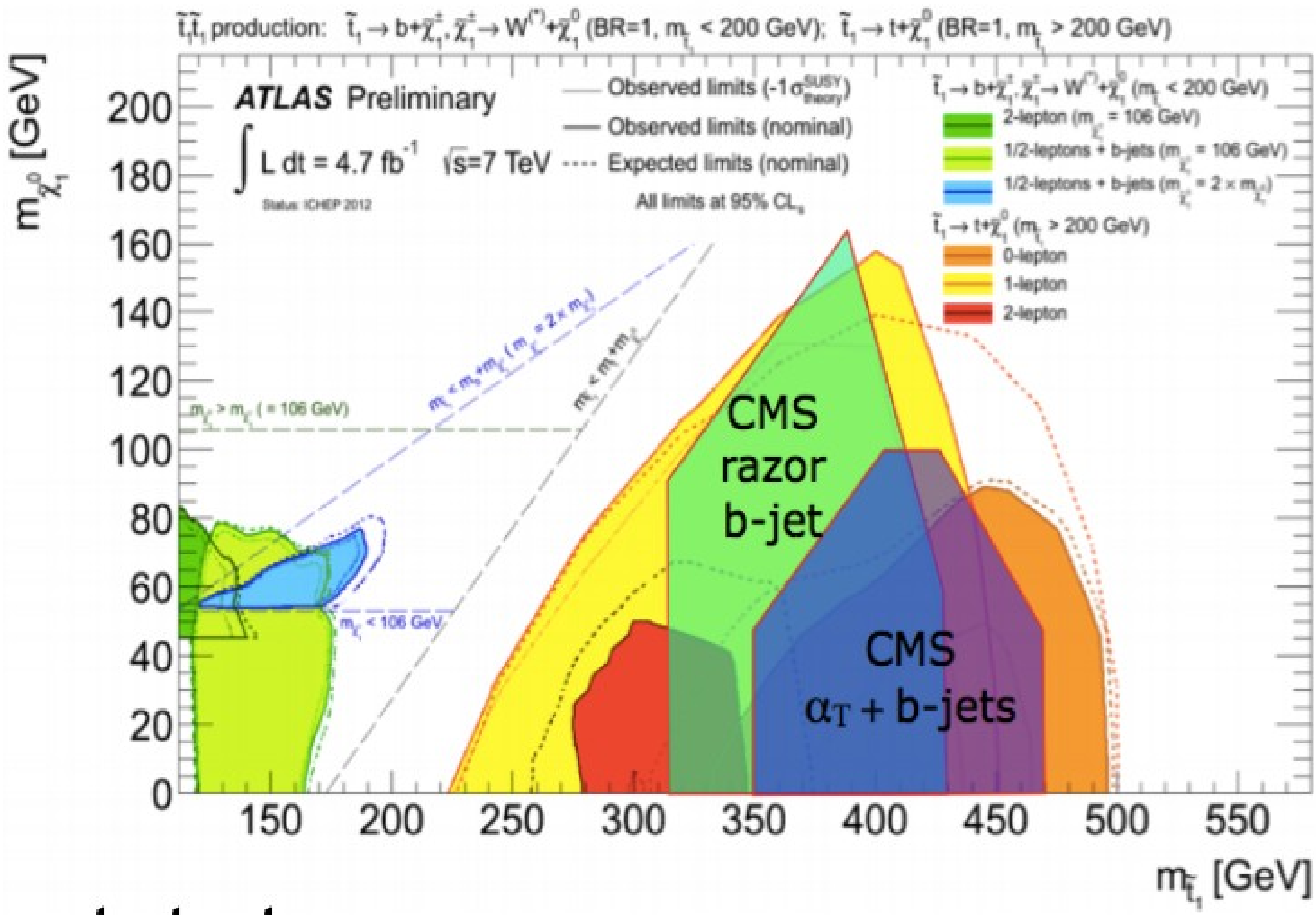
Both ATLAS and CMS experiments have excluded SUSY colored production

<u>up to the TeV scale</u> (with assumptions, not including direct stop/sbottom productions)

Search for SUSY third generation particle production

Third generation - stop searches

Direct stop production: $\tilde{t} \rightarrow t\tilde{\chi}^0_1; b\tilde{\chi}^{\pm}$



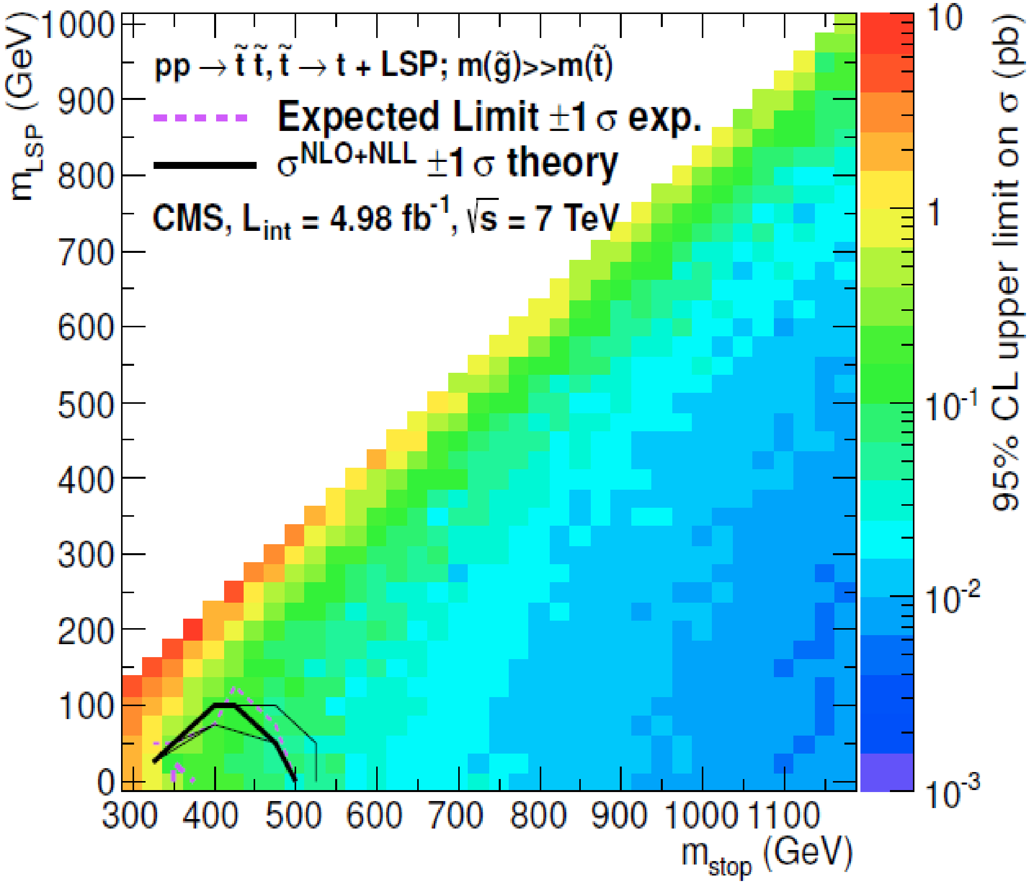
Daniele Alves
"Implications"
workshop
@CERN

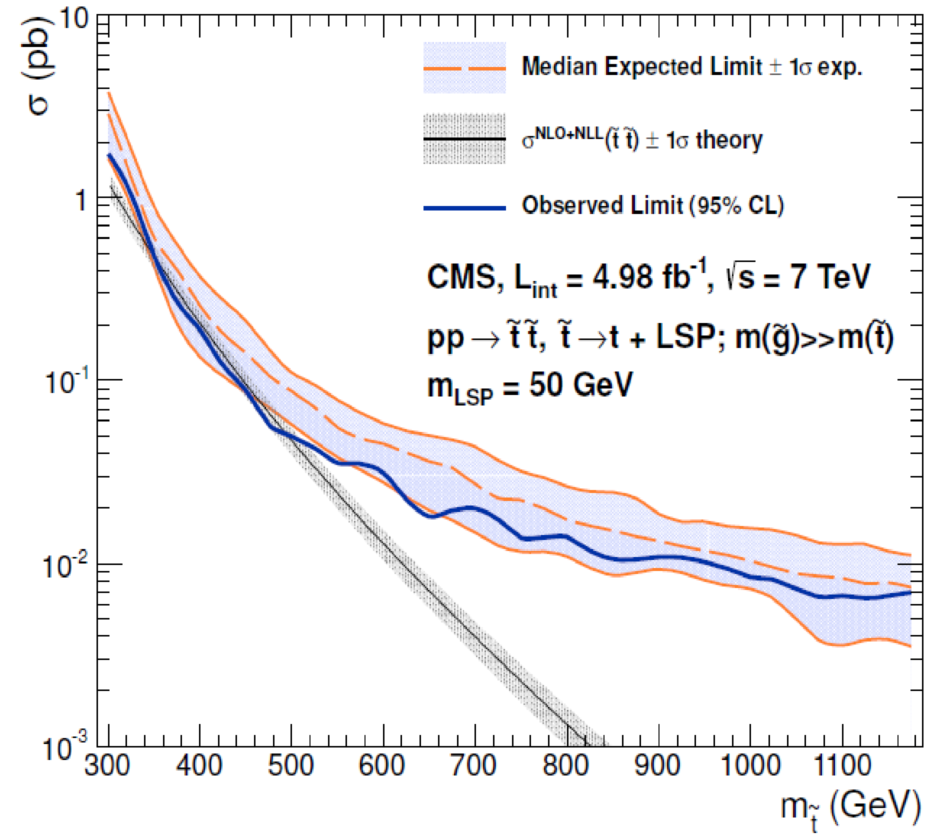
Impressive results from both collaborations

Bounds up to stop mass of ~500 GeV

Direct stop production: $\tilde{t} \rightarrow t\tilde{\chi}_1^0$

CMS-SUS-11-022-003

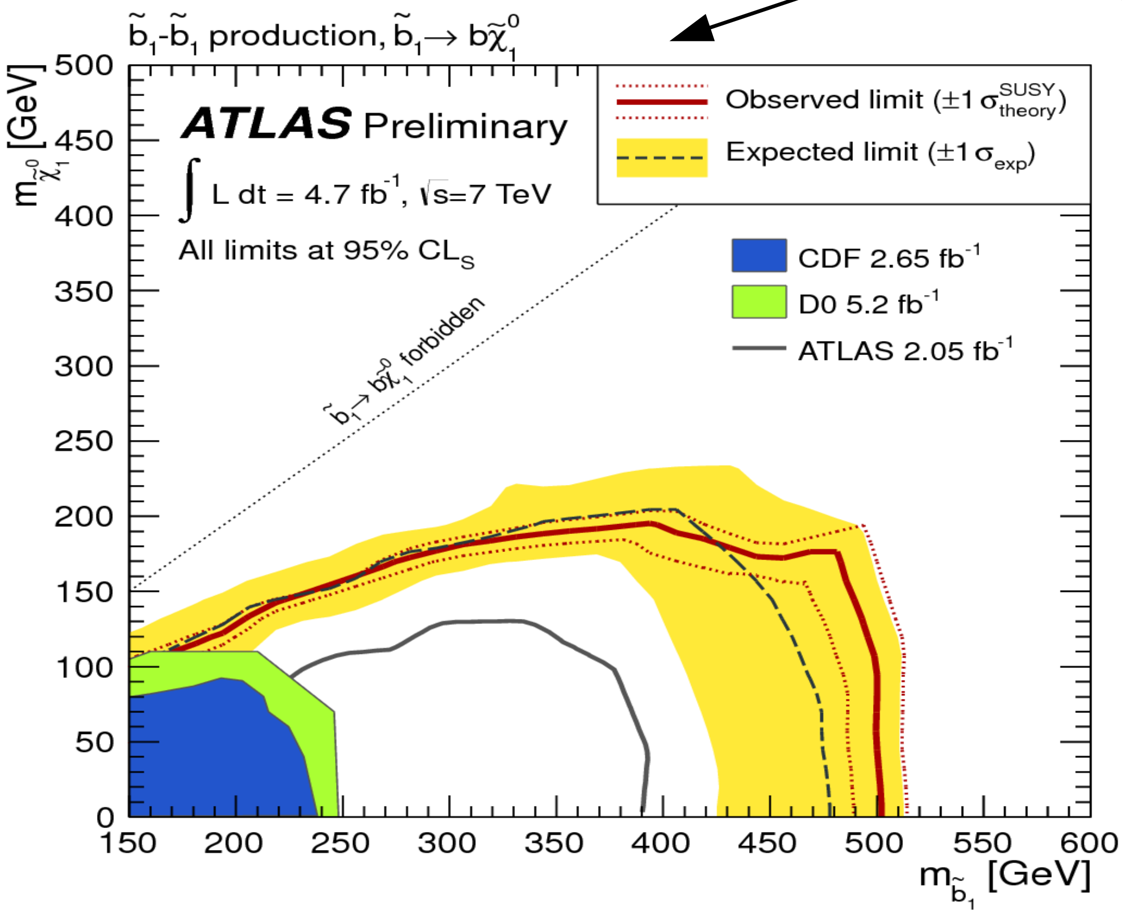


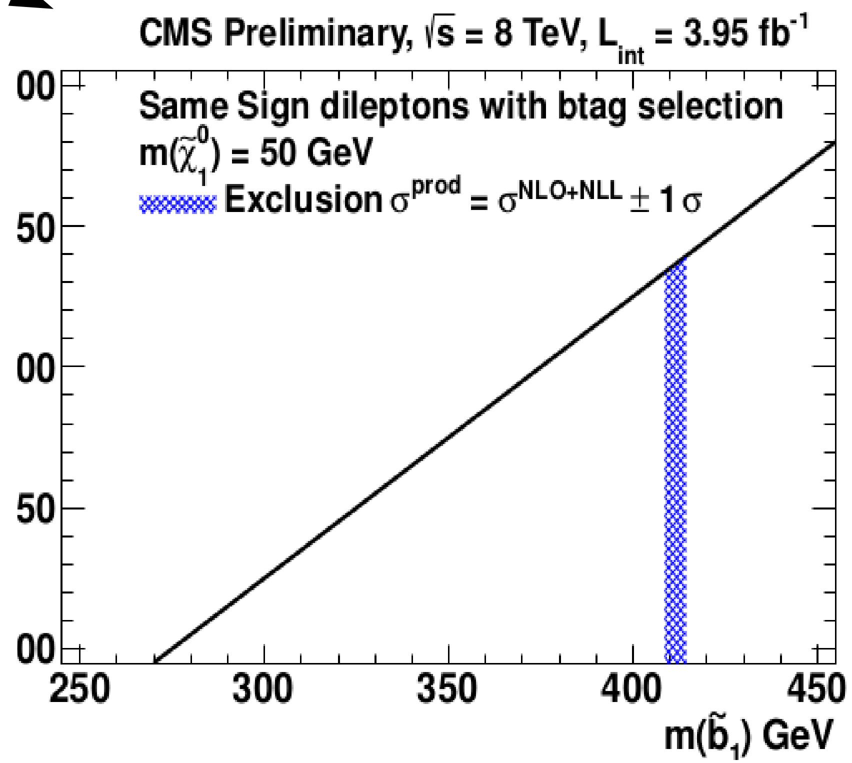


alpha_T based study with b-jets in the final state

For LSP mass = 50 GeV, Excluded stop mass between: 350 – 475 GeV

Sbottom production: $\tilde{b} \rightarrow b\tilde{\chi}_1^0; t\tilde{\chi}^-$



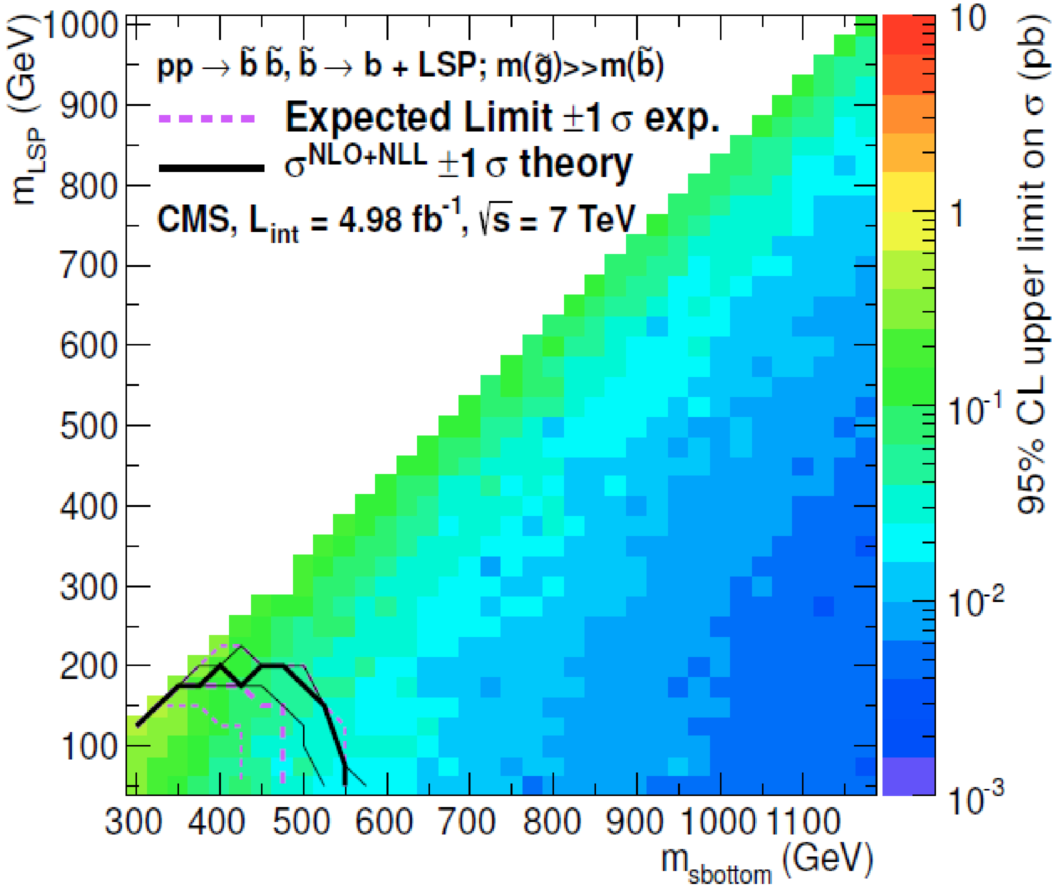


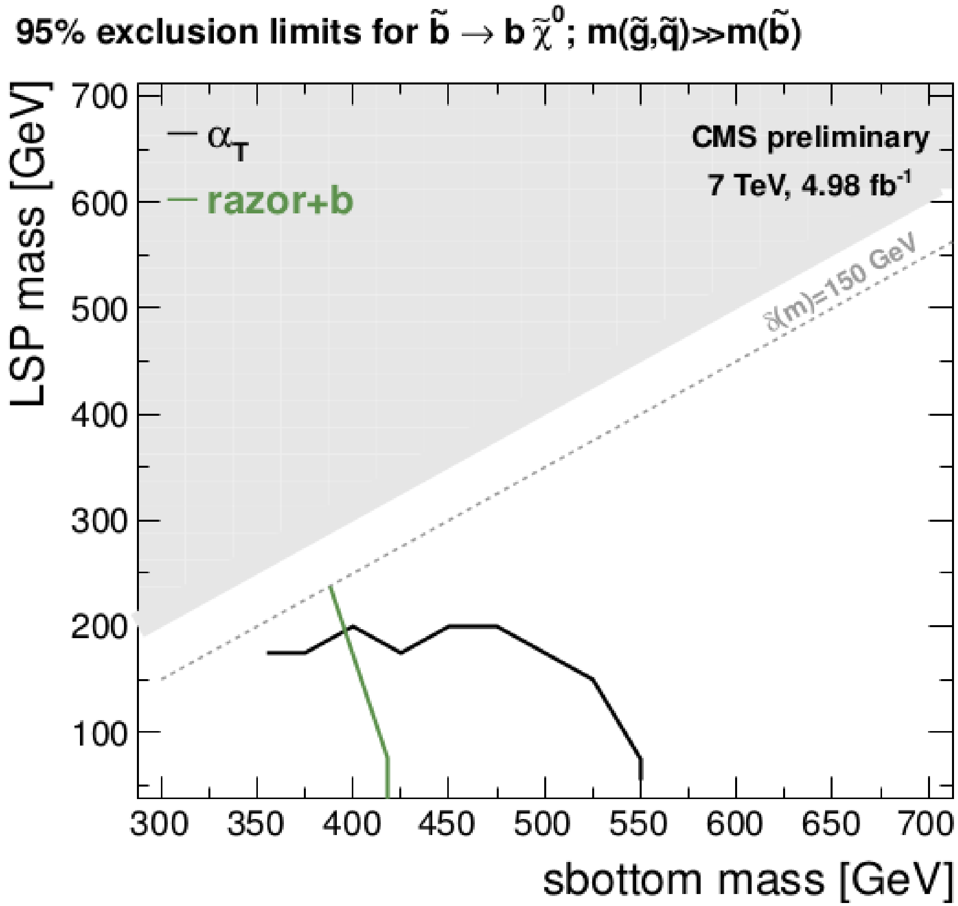
ATLAS hadronic btag jet (ATLAS-CONF-2012-106) searches provides

upper bound of ~500 GeV (LSP ~50 GeV)

CMS Same sign dileptons with btag (SUS-12-017)~ 410 GeV

Sbottom production: $\tilde{b} \rightarrow b\tilde{\chi}_1^0$

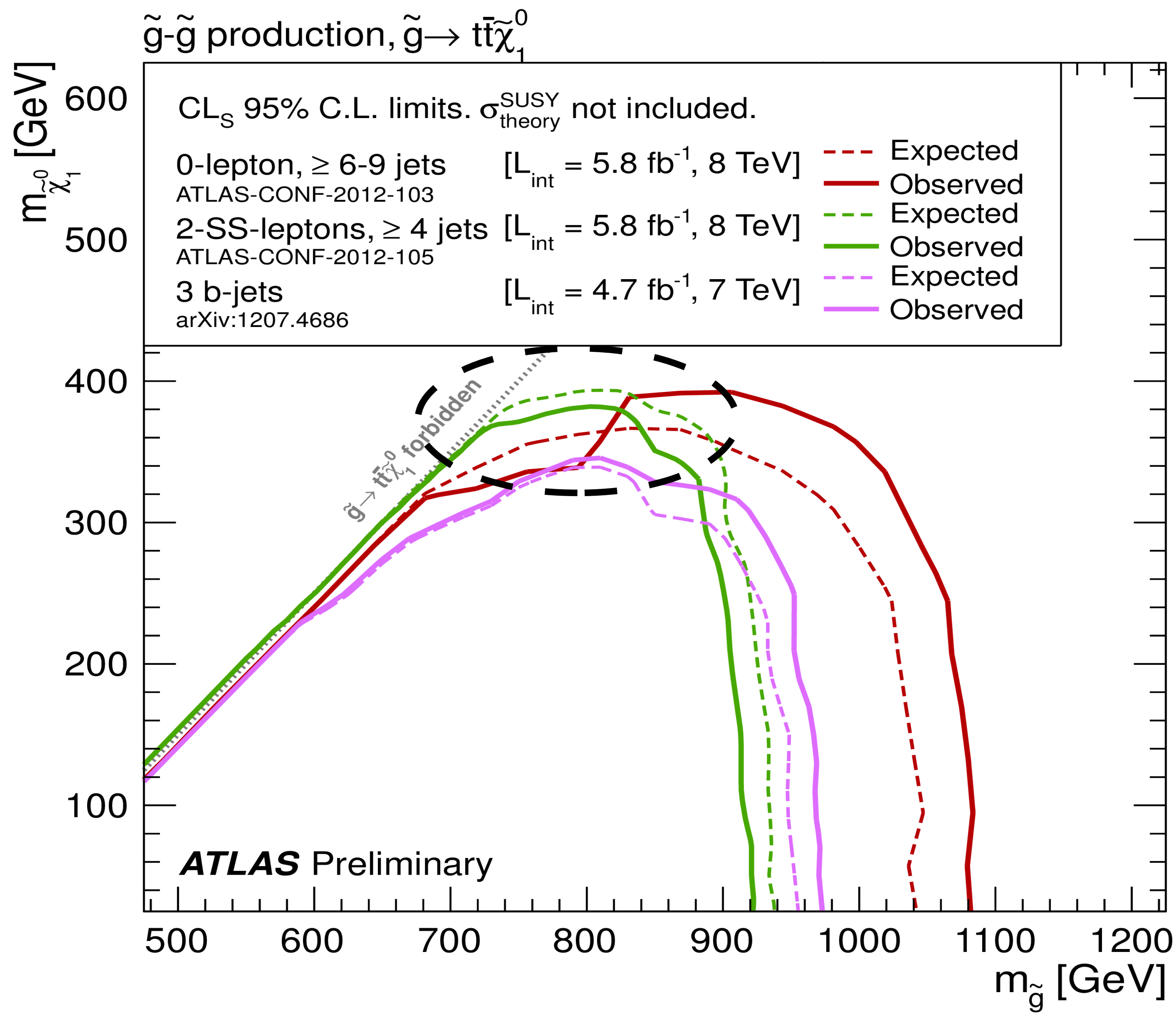




CMS hadronic studies exclude masses up to ~ 550 GeV (LSP = 50 GeV)

Third generation squark productions via gluinos

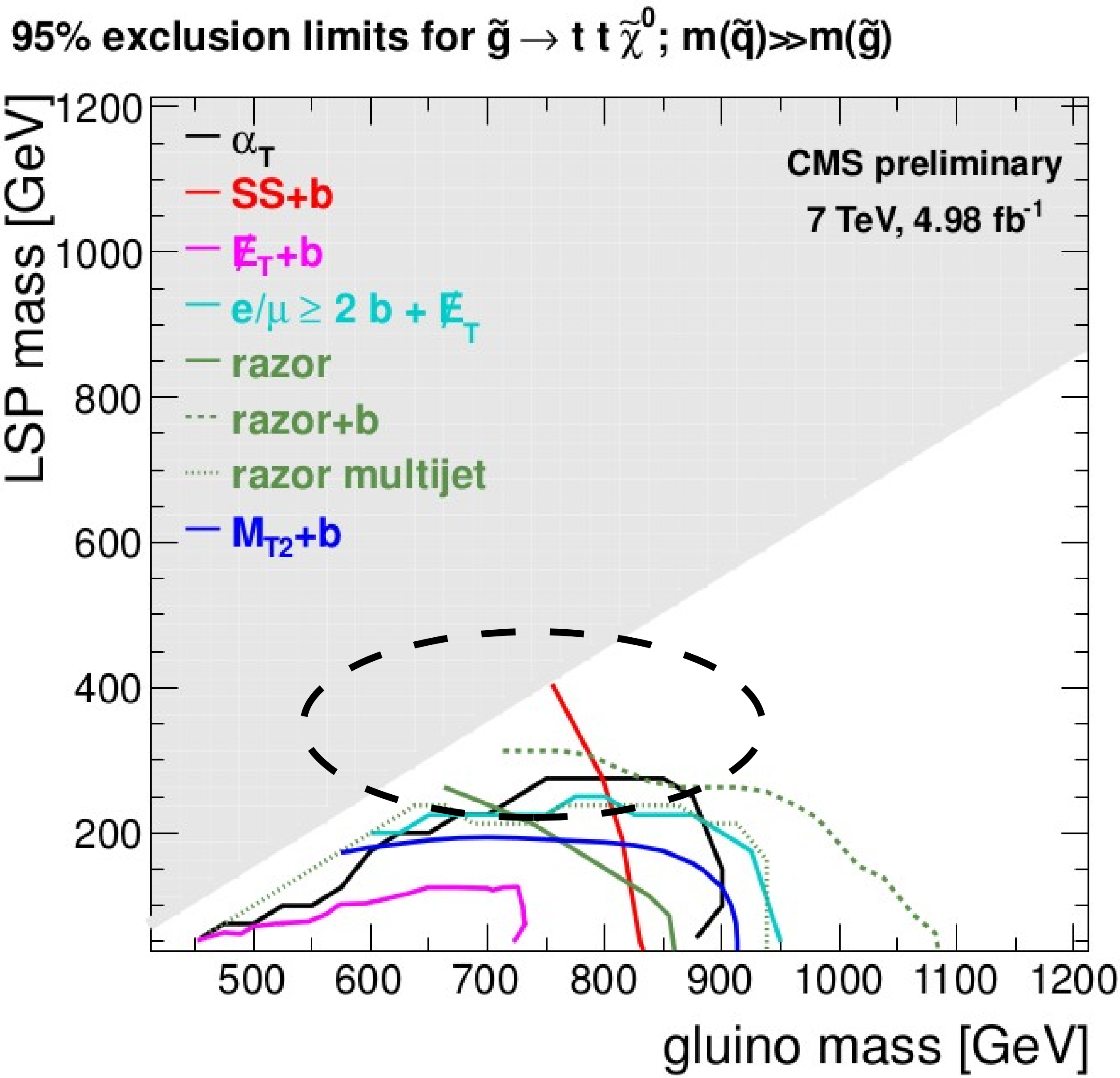
ATLAS-CONF-2012-103



Impressive summary results - excludes gluino mass ~ 1.1 TeV (LSP mass ~ 50 GeV)

Same sign dilepton study probes into the “compressed” area

Third generation squark productions via gluinos



Impressive summary results - excludes gluino mass ~ 1.1 TeV (LSP mass ~ 50 GeV)

Summary on SUSY Colored sector

Impressive search results (with assumptions) from both ATLAS and CMS Collab.

- For large 1st & 2nd generation squark masses, gluinos ~ 1.1 TeV excluded
- For large gluino mass, 1st and 2nd generation squarks ~ 1.5 TeV excluded
- With LSP mass ~ 50 GeV and decoupled gluinos
  - Direct stop production leads to mass limit ~ 500 GeV (ATLAS)
  - Direct stop production leads to mass limit ~ 350 - 475 GeV (CMS)
  - Direct sbottom production leads to mass limit ~ 550 GeV (CMS)
- Gluino production with third generation squarks ~ 1.1 TeV excluded

All of the above satisfies the naturalness conditions in SUSY

Searches for SUSY weak production

Chargino ($\tilde{\chi}_i^{\pm}; i=1,2$) and Neutralino ($\tilde{\chi}_i^0; i=1-4$) productions at LEP:

$$e^+e^- \to \tilde{\chi}^+\tilde{\chi}^- \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

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

Neutralino pairs via s-channel Z or t-channel with slepton exchange

Using mSUGRA or CMSSM framework

(assuming mixing in stau sector is small)

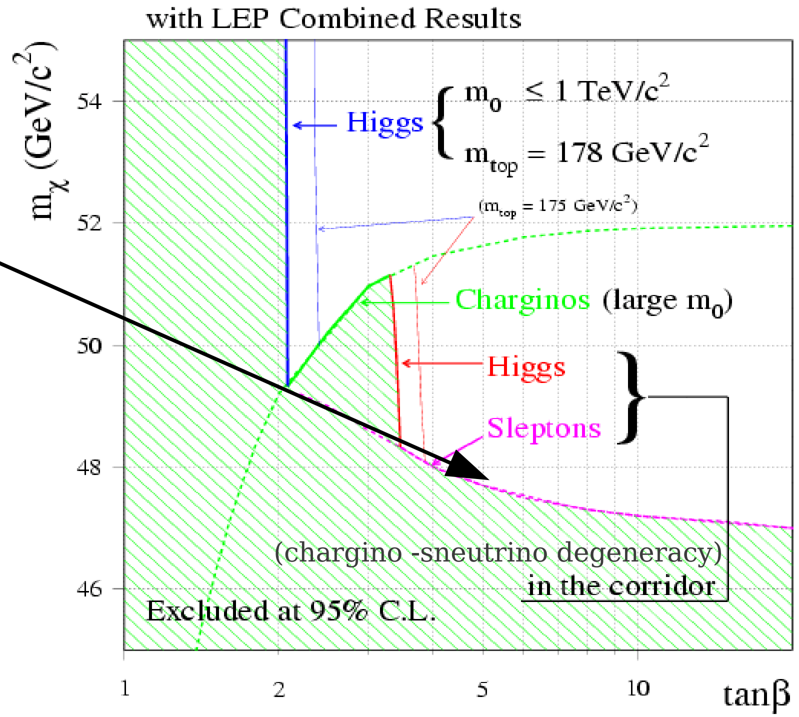
LSP mass below 47/50 GeV is excluded

However several assumptions are involved:

- mSUGRA / CMSSM
- gaugino mass unification
- tanβ < 3.3 limits at large M_0 (+higgs, chargino)

(M0 - common sfermion mass at GUT)

- tanβ > 3.3 the limit is using small M_0

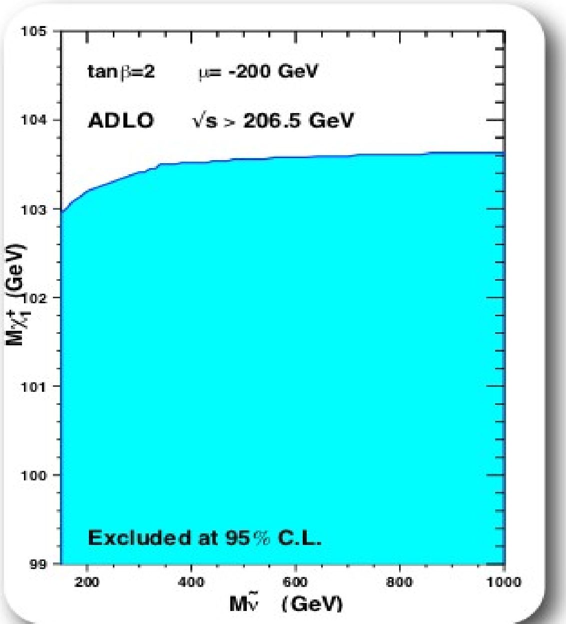


No mass limit in general outside these assumptions

Experimental constraints from LEP

Charginos via: s-channel γ/Z or t-channel with sneutrino exchange

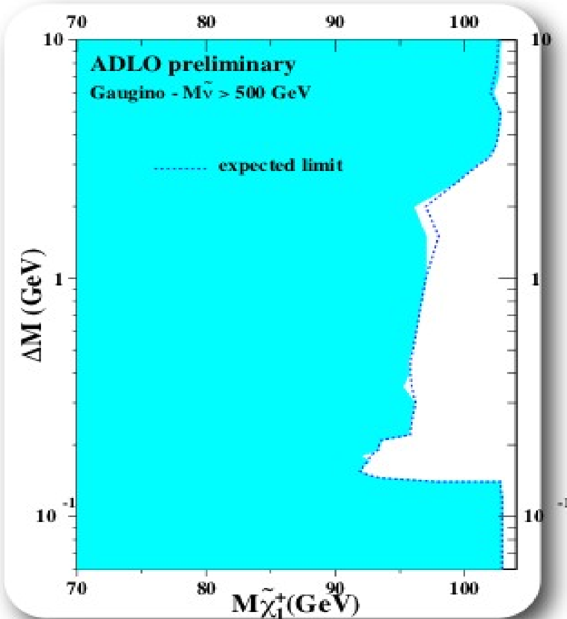
canonical case



$m\chi_1^\pm$ > 103.5 GeV for m_{snue} > 300 GeV

LEPSUSYWG/01-03.1

degenerate case



$m\chi_1^\pm$ > 91.9 /92.4 GeV

LEPSUSYWG/02-04.1

Unification of gaugino masses at GUT scale is assumed.

- M1 = (5/3)tan^2(theta_W) M2 ~ 0.5 M2

Canonical case:

- With M(sneutrino) > 300 GeV

Degenerate case:

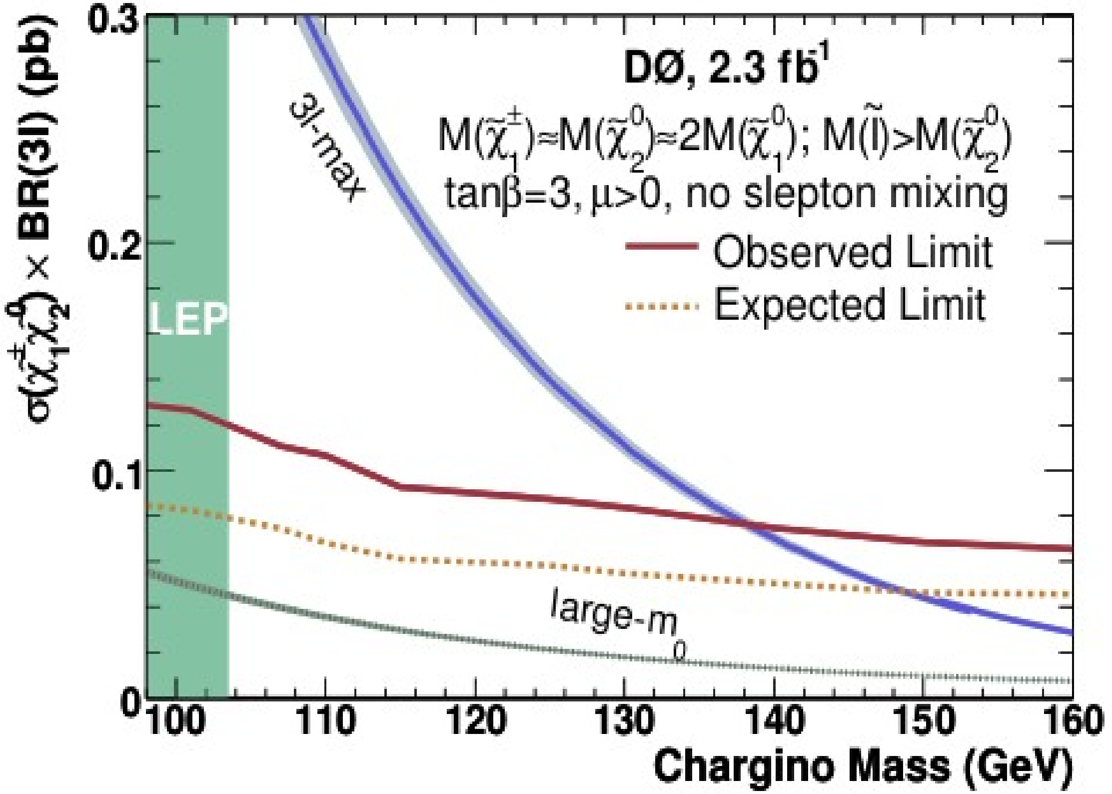
- M1 and M2 nearly degenerate
- Large M0 (m(snu) ~500 GeV)

In general **Charginos up to ~ 100 GeV** in mass are excluded by the LEP experiments

Experimental constraints from Tevatron

D0 Collaboration: $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

D0 Collab. Phys. Lett. B680, 34 (2009)



Three leptons + MET signature

- e, μ, and τ

4 Channels (eel, μμl, eμτl, μτl)

Dominant bkg: WZ, ZZ in MET tails

Within the context of MSUGRA

Assuming:

$$m_{\tilde{\chi}_1^{\pm}} \sim m_{\tilde{\chi}_2^0} \sim 2m_{\tilde{\chi}_1^0}$$

- and neglecting the slepton mixing

- sleptons and sneutrinos heavier than lightest charginos and next lightest neutralino

In the limit of heavy sleptons (large m0 scenario):

- the slepton mass is just above mass of $\tilde{\chi}_2^0$, leptonic BR is maximized (3l max case)

Chargino mass < 138 GeV is excluded by this study

Experimental constraints from Tevatron

CDF Collaboration: $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

CDF Note: 10636

Three leptons + MET signature

Several SRs in the plane - MET & M_{ll}

Modes:

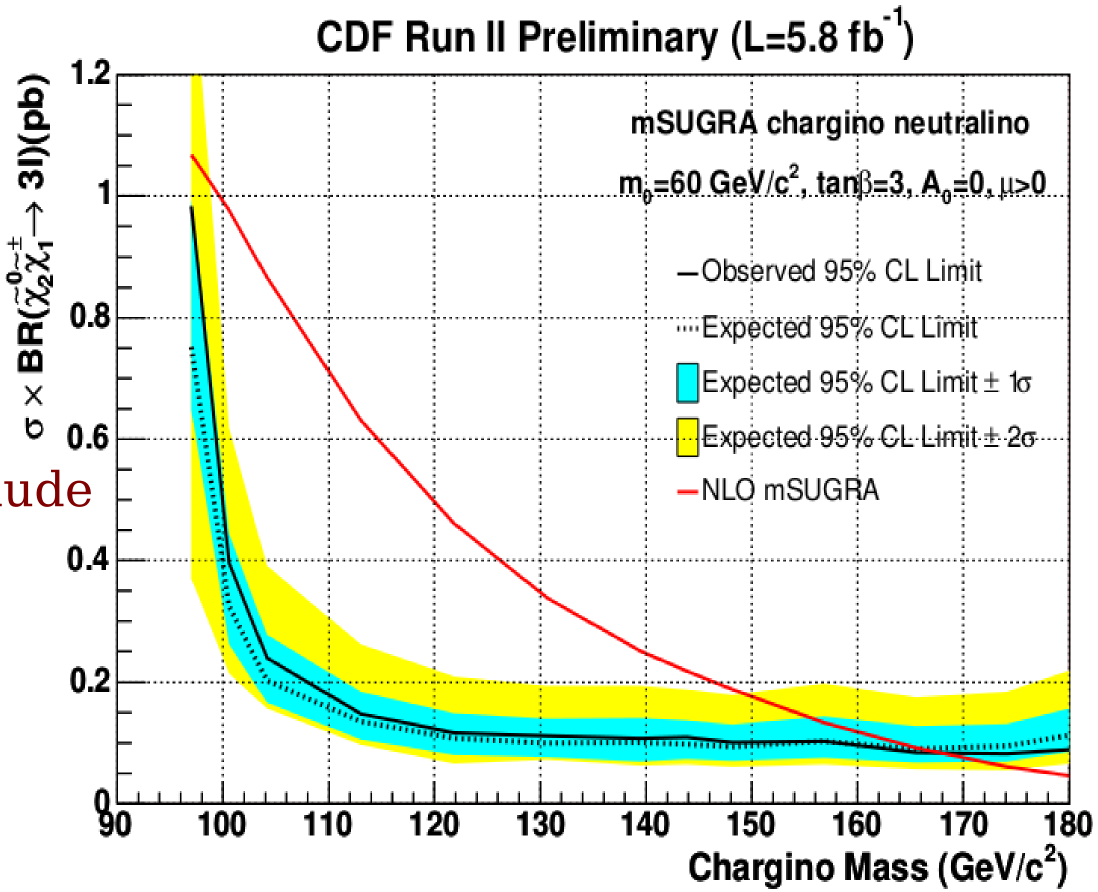
- eel, μμl ; l = e, μ, τ (or single track)

- Expanded the acceptance & also include low p_T leptons ~ 5 GeV threshold.

Major backgrounds:

- WZ, ZZ, dileptons + fakes

Within the context of MSUGRA



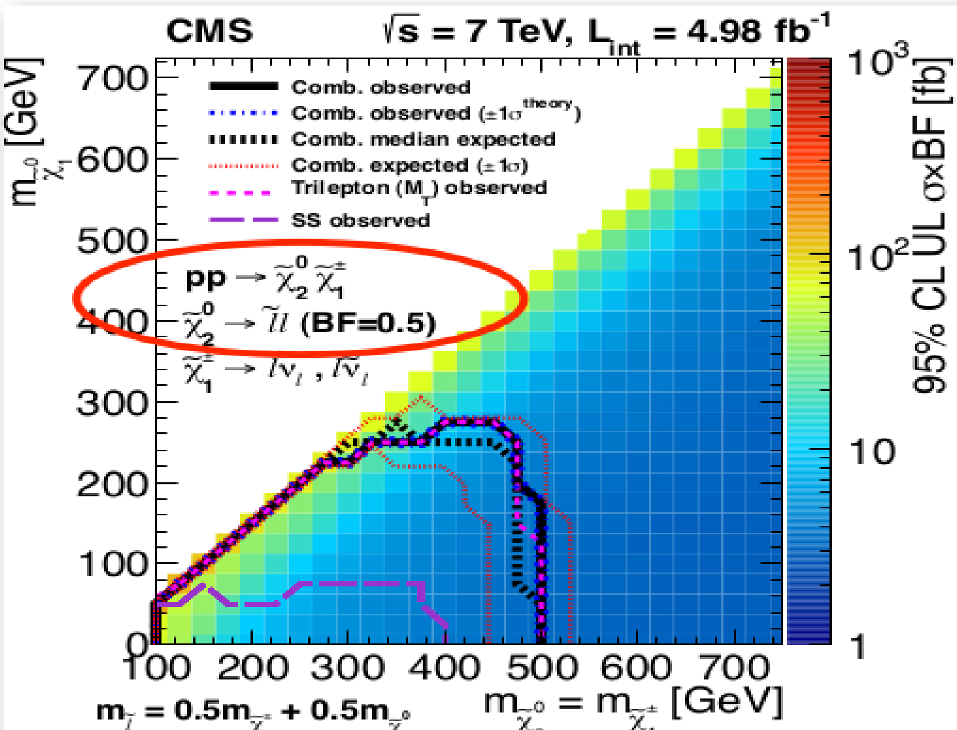
Exclude at 95% CL $\sigma(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(lll)$ above 0.1 fb

Chargino mass below 168 GeV is excluded by this study

Dominant modes $\tilde{\chi}_2^0 \tilde{\chi}_1^+$

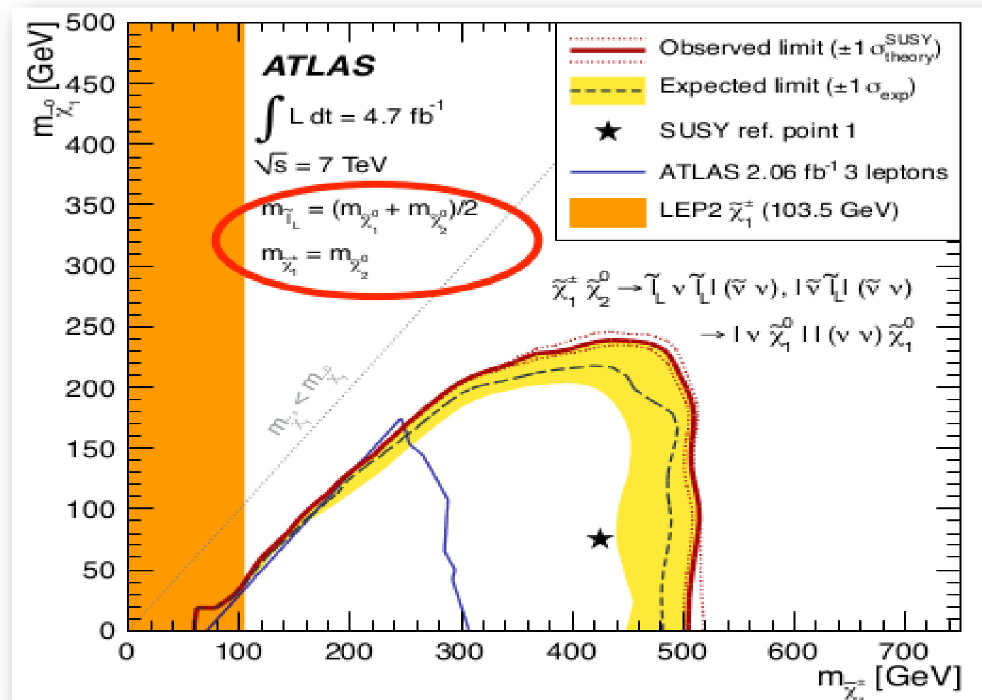
dilepton or trilepton + MET

CMS 1209.6620



trilepton + MET

ATLAS 1208.3144



60 GeV < $m_{\chi 1\pm}$ < 500 GeV

Limits are weaker for - heavy slepton_L

- $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ being Higgsinos
- small mass difference

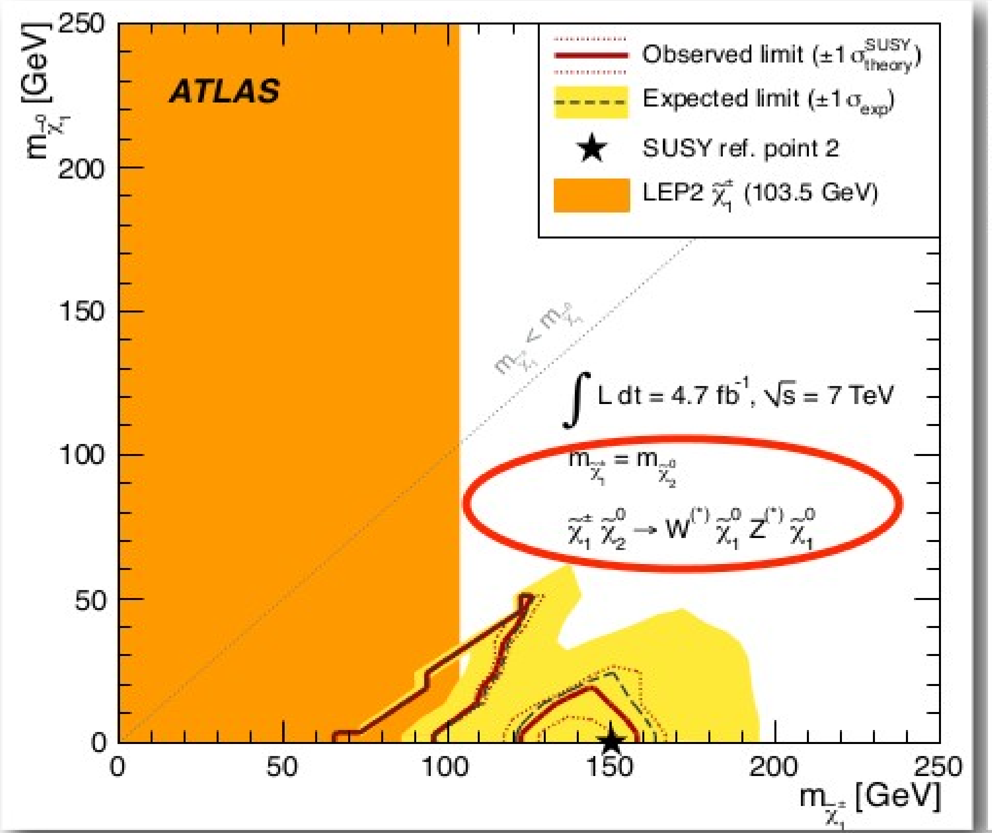
Lepton rich final state to enhance reach

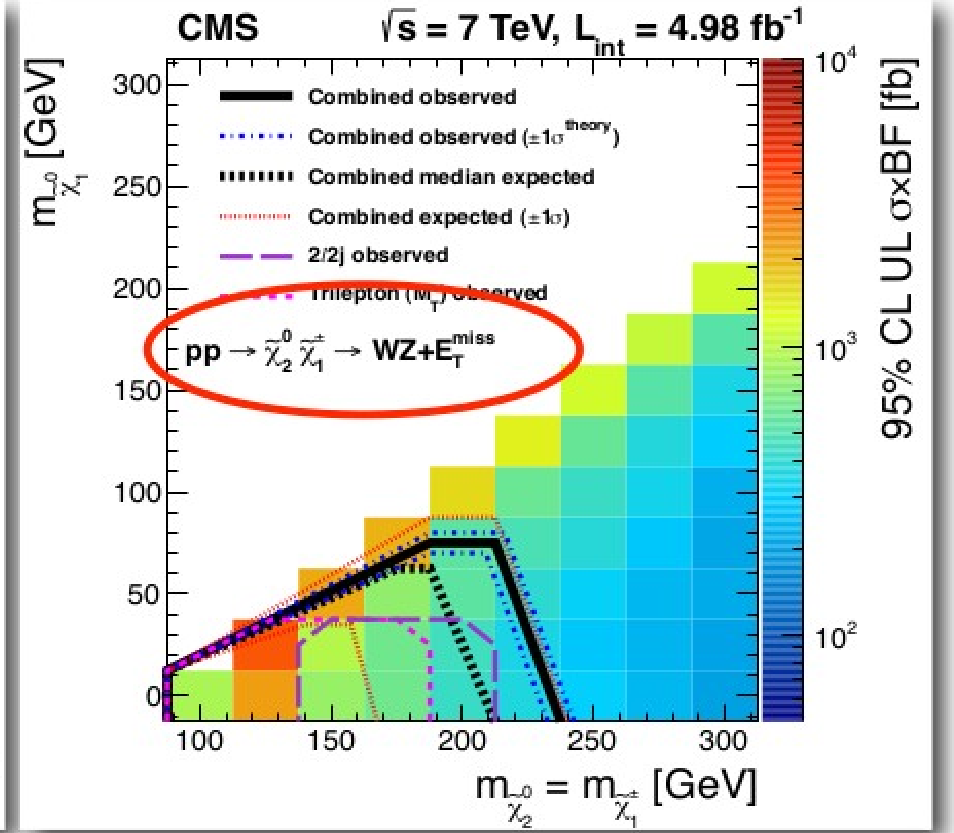
Dominant modes $\tilde{\chi}_2^0 \tilde{\chi}_1^+$

trilepton + MET

Much weaker limits!

dilepton/trilepton + MET





ATLAS 1208.3144

CMS 1209.6620

Excludes ~ 200 GeV for LSP mass of 50 GeV

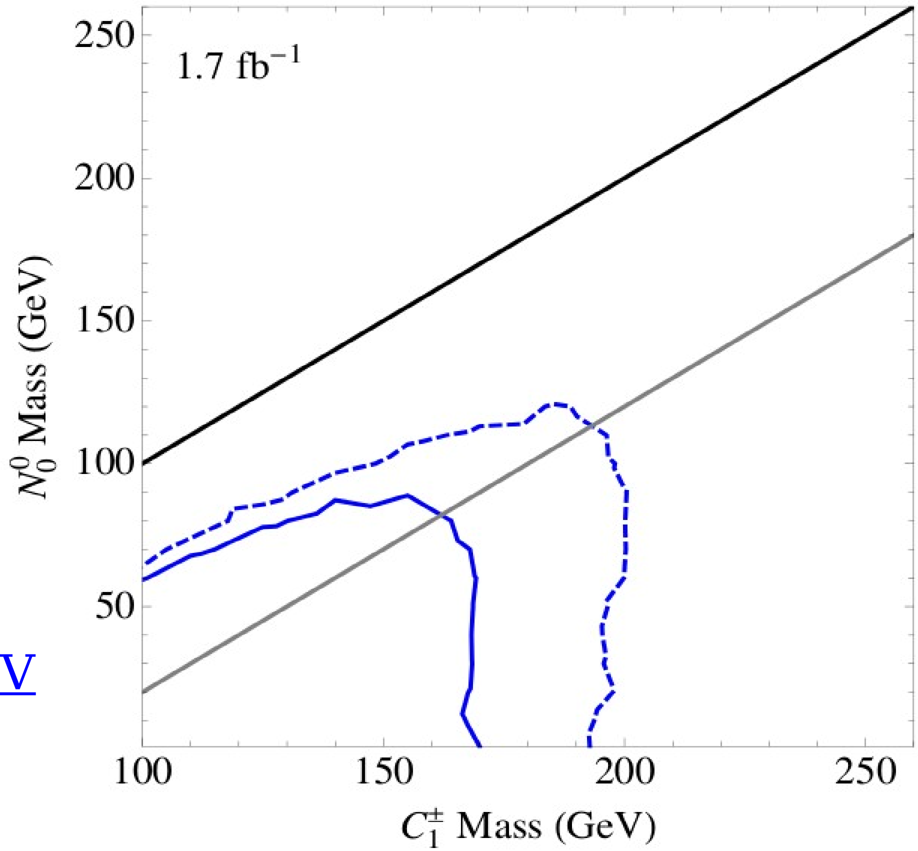
100% BR – Usually not realized

Direct electroweak production

The remaining dominant contribution in EWKino (light Wino) sector is from: $\tilde{\chi}^{+}\tilde{\chi}^{-}$

I think none of the LHC experiments have bounds in this mode

- *Re-interpretation/exclusion by M. Lisanti & N. Weiner (arXiv:1112.483)*
- Use H → WW (and H → ZZ) results from ATLAS and CMS
- Simplified topology



Dashed and solid lines indicate

- 1 and 2σ sensitivity

The sensitivity is defined as:

$$N_{\text{signal}} \geq 2 \times \sqrt{B_{\text{stat}}^2 + B_{\text{sys}}^2}.$$

Charginos are most likely above ~200 GeV based on this study

Charginos and Neutralinos in the light of the Higgs boson

In collaboration with T. Han (Pittsburg) and S. Su (Arizona)

Natural SUSY Charginos/Neutralinos

Assuming Higgs connection

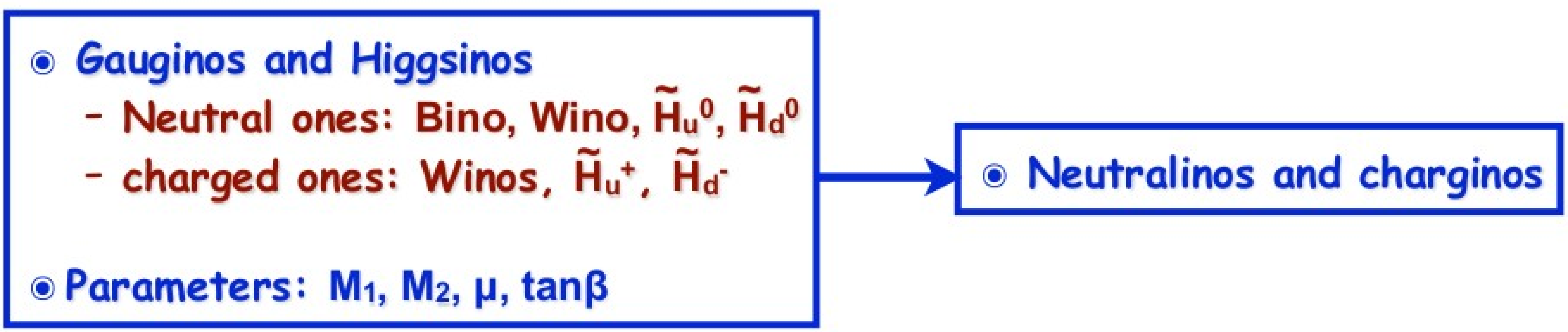
- Natural SUSY → Light gauginos and Higgsinos

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 :



Natural SUSY Charginos/Neutralinos

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

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)

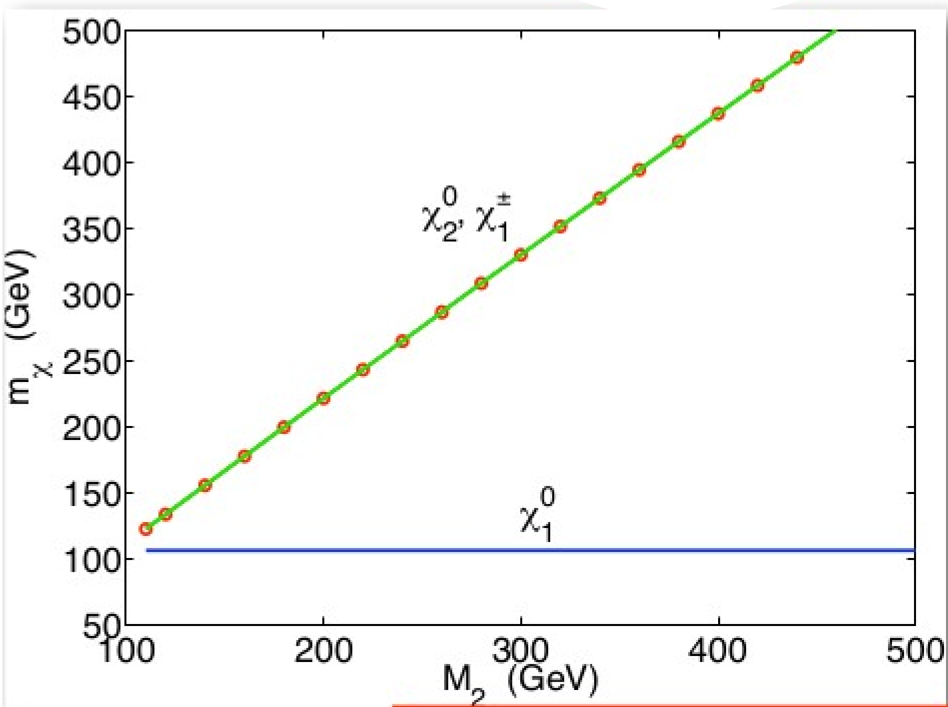
Masses: Bino LSP

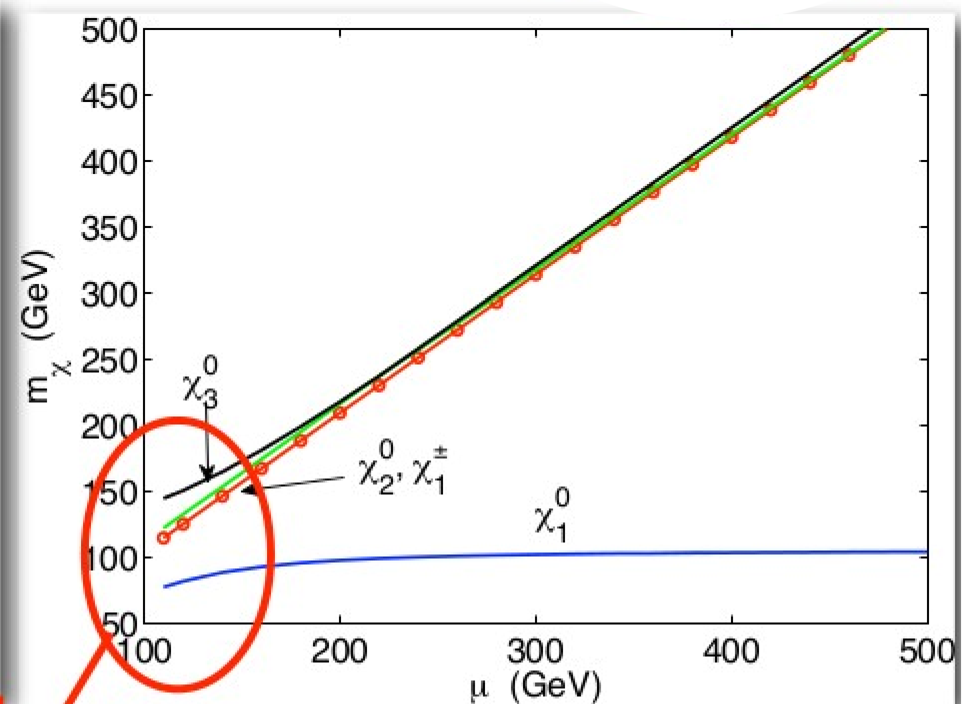
Case AI:
$M_1 < M_2 < \mu$

Case AII:
$M_1 < \mu < M_2$

μ = 1 TeV

M2 = 1 TeV





large mixing, natural compressed spectrum

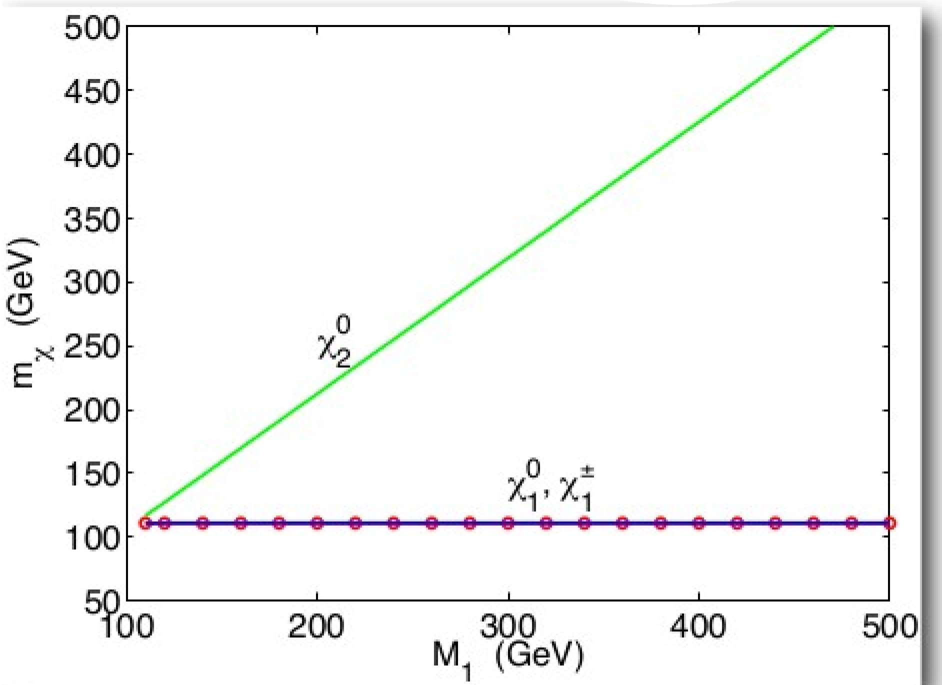
Case AI : $M_2 < \mu$, $\chi_1^\pm, \chi_2^0$ are Wino – like; $\chi_2^\pm, \chi_{3,4}^0$ are Higgino – like;

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

Masses: Wino LSP

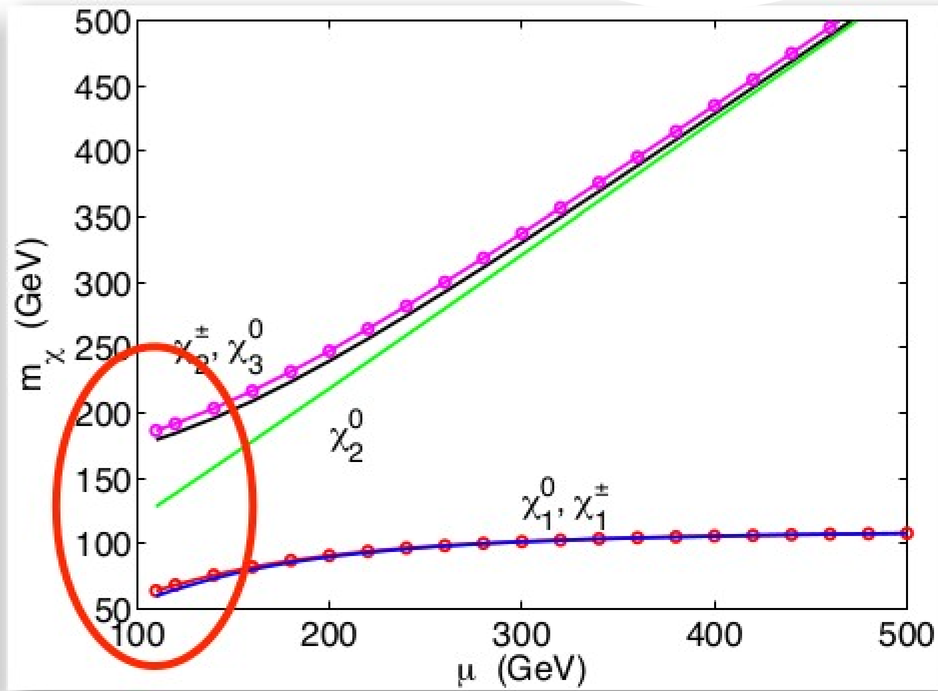
Case BI:
$M_2 < M_1 < \mu$

μ = 1 TeV



Case BII:
$M_2 < \mu < M_1$

M1 = 1 TeV



With wino LSP:

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

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

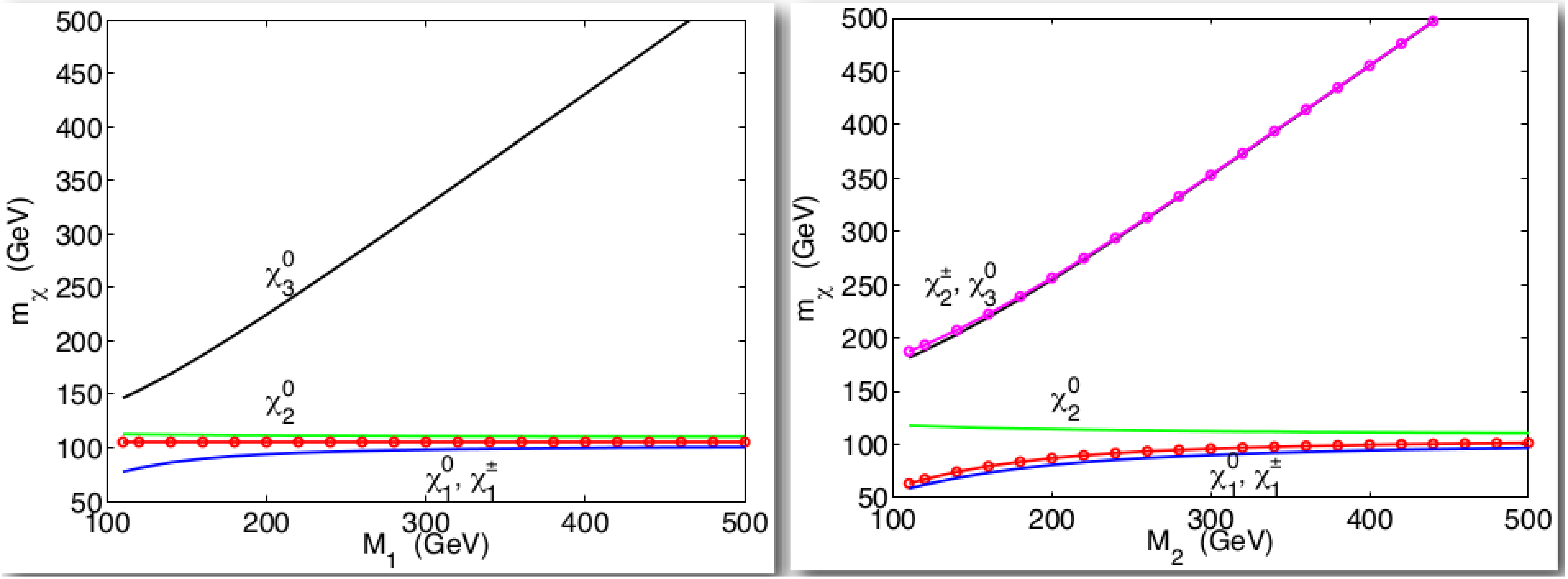
Masses: Higgsino LSP

Case CI:
$\mu < M_1 < M_2$

Case CII:
$\mu < M_2 < M_1$

M2 = 1 TeV

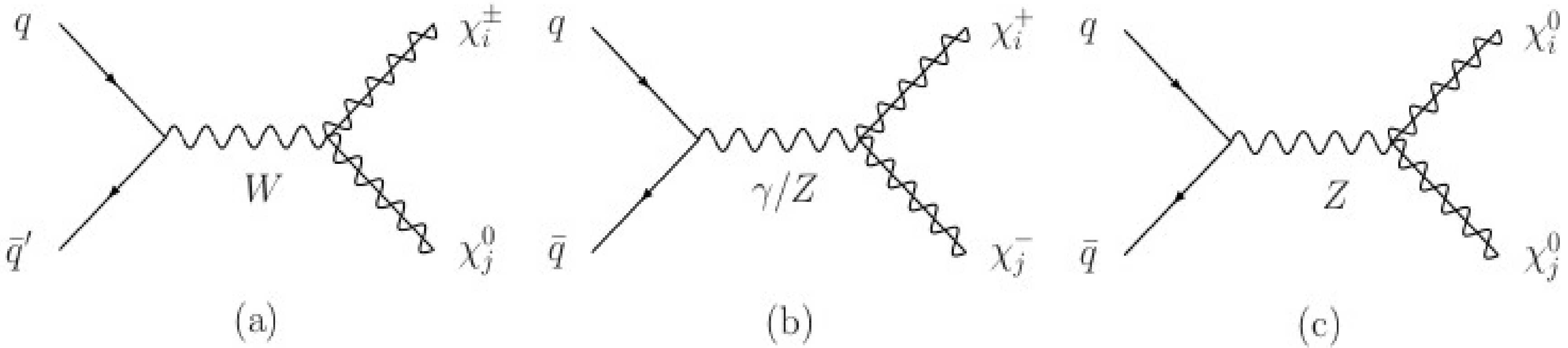
M1 = 1 TeV



With higgsino LSP:

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

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

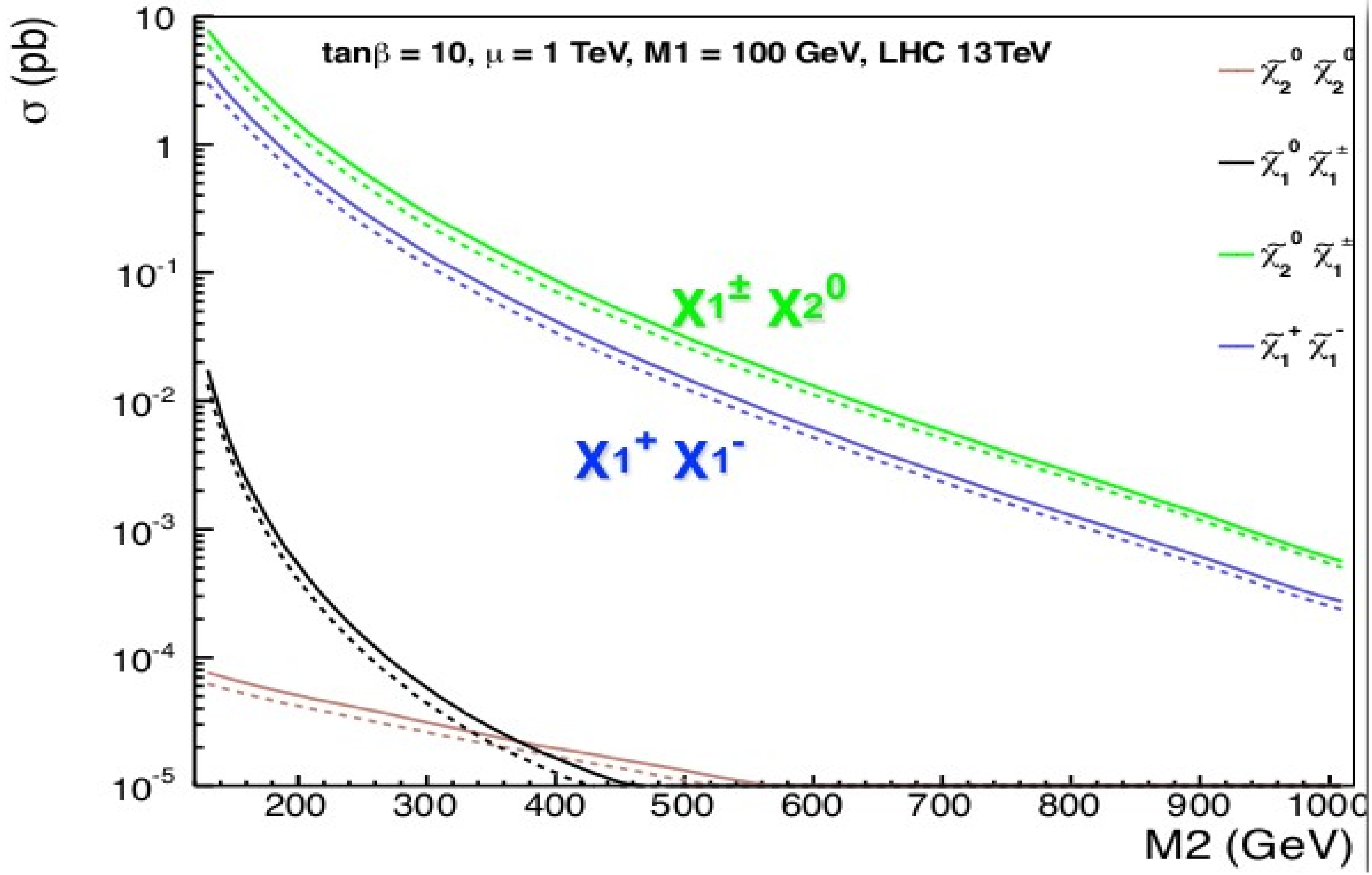


Dominant production:

- Wino pair production: $\chi_i^+\chi_j^-, \chi_i^\pm\chi_j^0$
- Higgsino pair production: $\chi_i^+\chi_j^-, \chi_i^\pm\chi_j^0, \chi_i^0\chi_j^0$

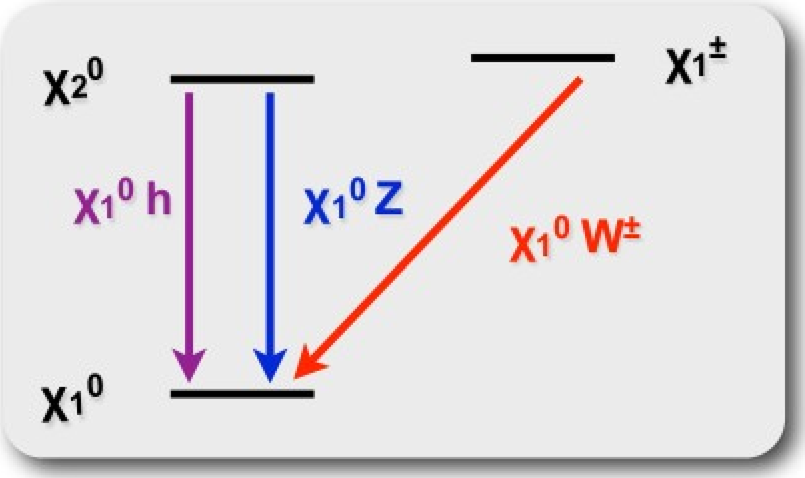
Productions of Bino LSP, Wino NLSP

Case AI: $M_1 < M_2 < \mu$

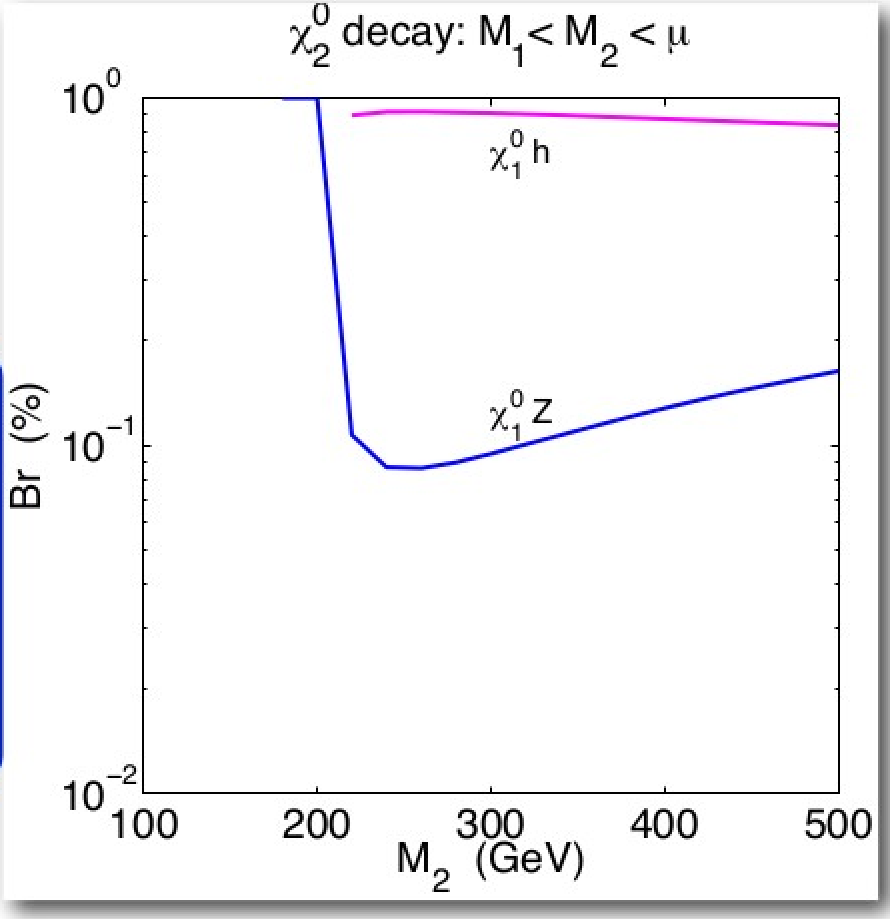


Dominant contributions are from: $pp \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 X, \tilde{\chi}_1^+ \tilde{\chi}_1^- X$

Decays with Bino LSP, Wino NLSP



$\chi_1^{\pm}$ decay 100% via on/off-shell W

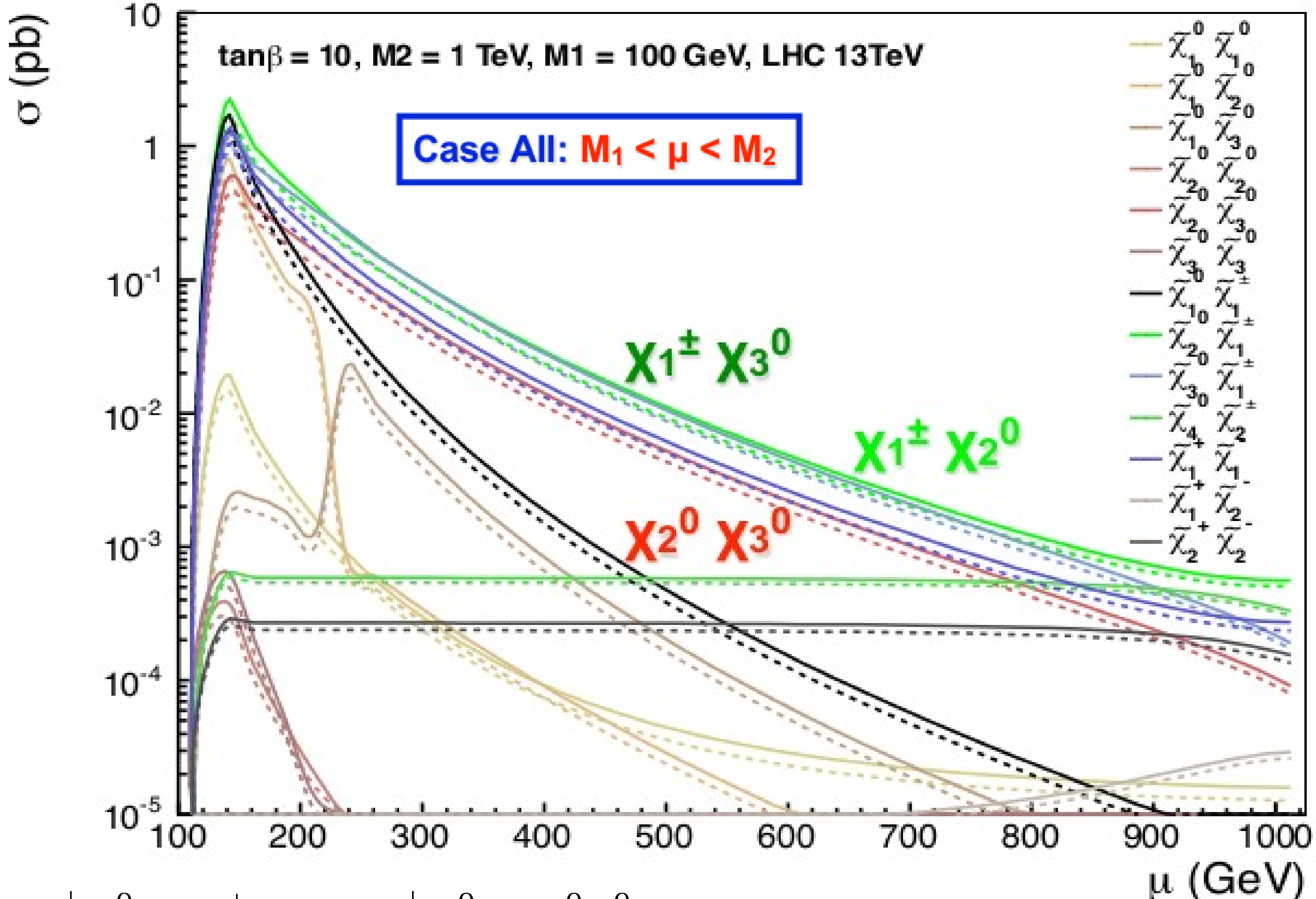


- below h threshold, decay via on/off-shell Z
- χ_2^0 on-shell decay to h dominate over on-shell Z for $\mu > 0$
- χ_2^0 decay to h and Z flipped for $\mu < 0$

Dominant contributions are from:

$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 X, \tilde{\chi}_1^{+}\tilde{\chi}_1^{-} X; \chi_1^{\pm} \rightarrow W^{\pm}\chi_1^0, \chi_2^0 \rightarrow (h/Z)\chi_1^0$$

Productions of Bino LSP, Higgsino NLSP



$$pp \to \chi_1^{\pm}\chi_2^0 X, \chi_1^+\chi_1^- X, \chi_1^{\pm}\chi_3^0 X, \chi_2^0\chi_3^0 X$$

$$\chi_1^{\pm} \to W^{\pm}\chi_1^0; \chi_2^0 \to (h/Z)\chi_1^0, \chi_3^0 \to (Z/h)\chi_1^0$$

For details on other LSP (M2, μ)
→ See the upcoming paper

SUSY weak productions

Final states that can be explored:

$$WW, WZ, Wh, Zh, ZZ, hh$$

- BR(WZ) < 100% in most cases, sometimes highly suppressed

- Wh complementary to WZ channel : a new discovery mode

- Zh/hh could also be explored.

Experimentally challenging depending on "compression" between the mass states:
(e.g: Also the depends on the choice of the LSP)

- If the mass difference is in MeV: $\chi_2^0 - \chi_1^0$ or $\chi_1^\pm - \chi_1^0$

  - Expect "appearing tracks" within few cms if the associated particle is neutral

  - Expect highly ionizing tracks (dE/dx) associated with charged particle

- If the mass difference is in GeV → prompt decays

In terms of searches:

1. If both parents are un-compressed:

- Standard analysis, trigger on any or both of the visible decay products

2. If one of the parents is compressed e.g: $\chi_2^0\chi_1^\pm; M(\chi_1^\pm) \approx M(\chi_1^0)$

- Use trigger based on one visible decay product

3. If both parents are compressed

- e.g: $\chi_1^+(\to W\chi_1^0)\chi_1^-(\to W\chi_1^0); M(\chi_1^\pm) \approx M(\chi_1^0)$

- Use mono-jet kind of analysis with trigger on ISR jets (Parked data?)

Possible future LHC searches with Higgs in the final state

Wh channel: 1l+jets + MET

- Isolated e(μ), Pt > 30(20) GeV, |eta| < 2.5
- Veto any additional e/μ with Pt > 10 GeV, |eta| < 2.5
- Veto any Taus or isolated Tracks
- 2 Jets Pt > 30 GeV, |eta| < 2.5
- Veto 3rd Jet with Pt > 20 GeV
- 2 bjets with Pt > 30 GeV, |eta| < 2.5
- 2 bjets in one hemi-sphere ←
- Invariant mass of two bjets 100 < M_{bb} (GeV) < 140
- MT (MET and the Higgs) > 200 GeV
- MET > 50 GeV

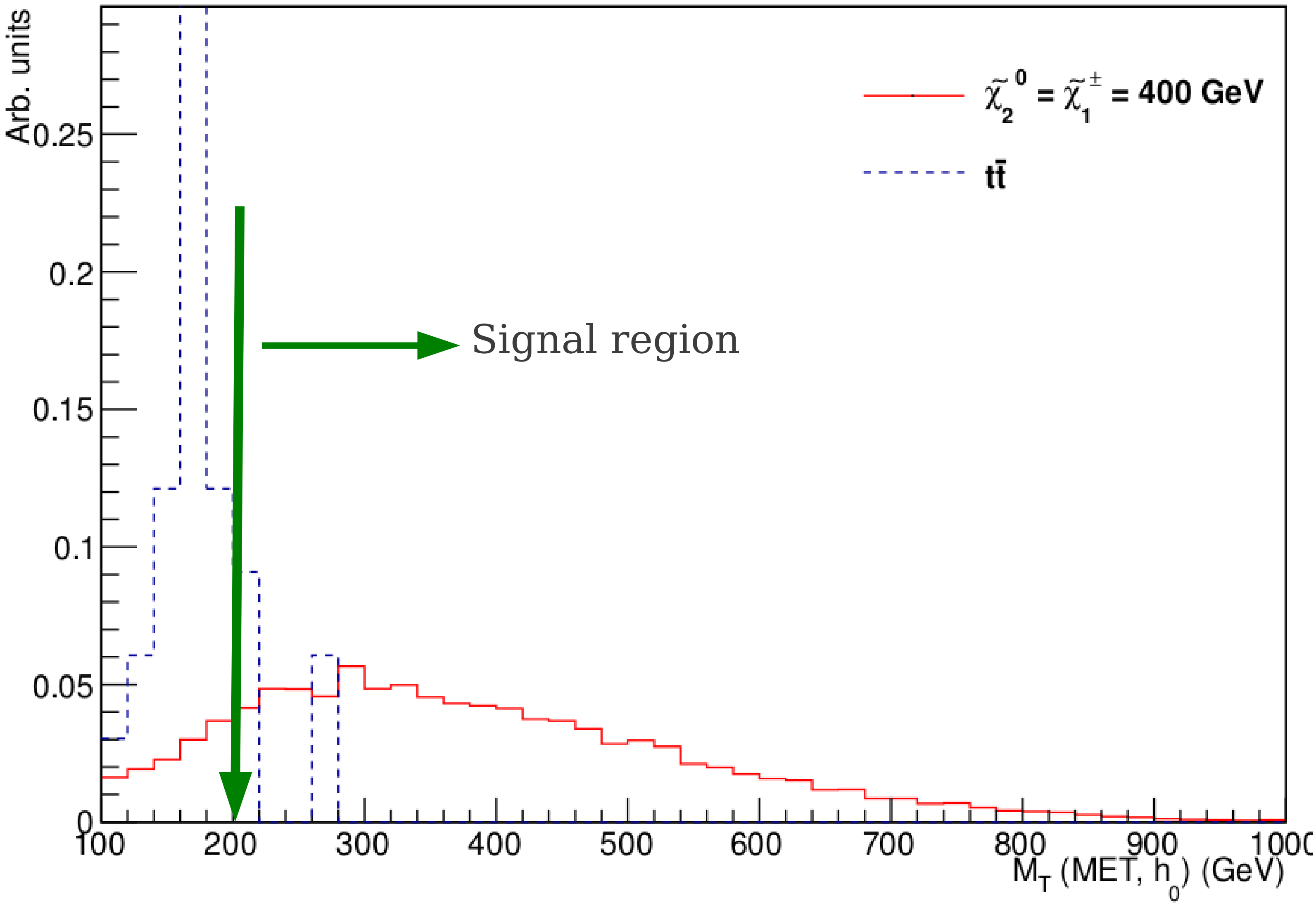
Signal regions:

(MT, MET) > (200, 50), (600, 50), (200, 100), (600,100) GeV

10 fb-1

Processes	MET > 50, MT > 200 (Baseline)	MET > 50, 200< MT < 400	MET > 50, 400 < MT < 600	MET > 50, MT > 600	MET > 100, MT > 200	MET > 100, 200 < MT < 400	MET > 100, 400 < MT < 600	MET > 100, MT > 600
Total bg	46.15 ± 12.01	43.27 ± 11.96	2.40 ± 1.02	0.48 ± 0.48	33.63 ± 10.69	30.75 ± 10.63	2.40 ± 1.02	0.49 ± 0.48

Possible LHC searches with Higgs in the final state

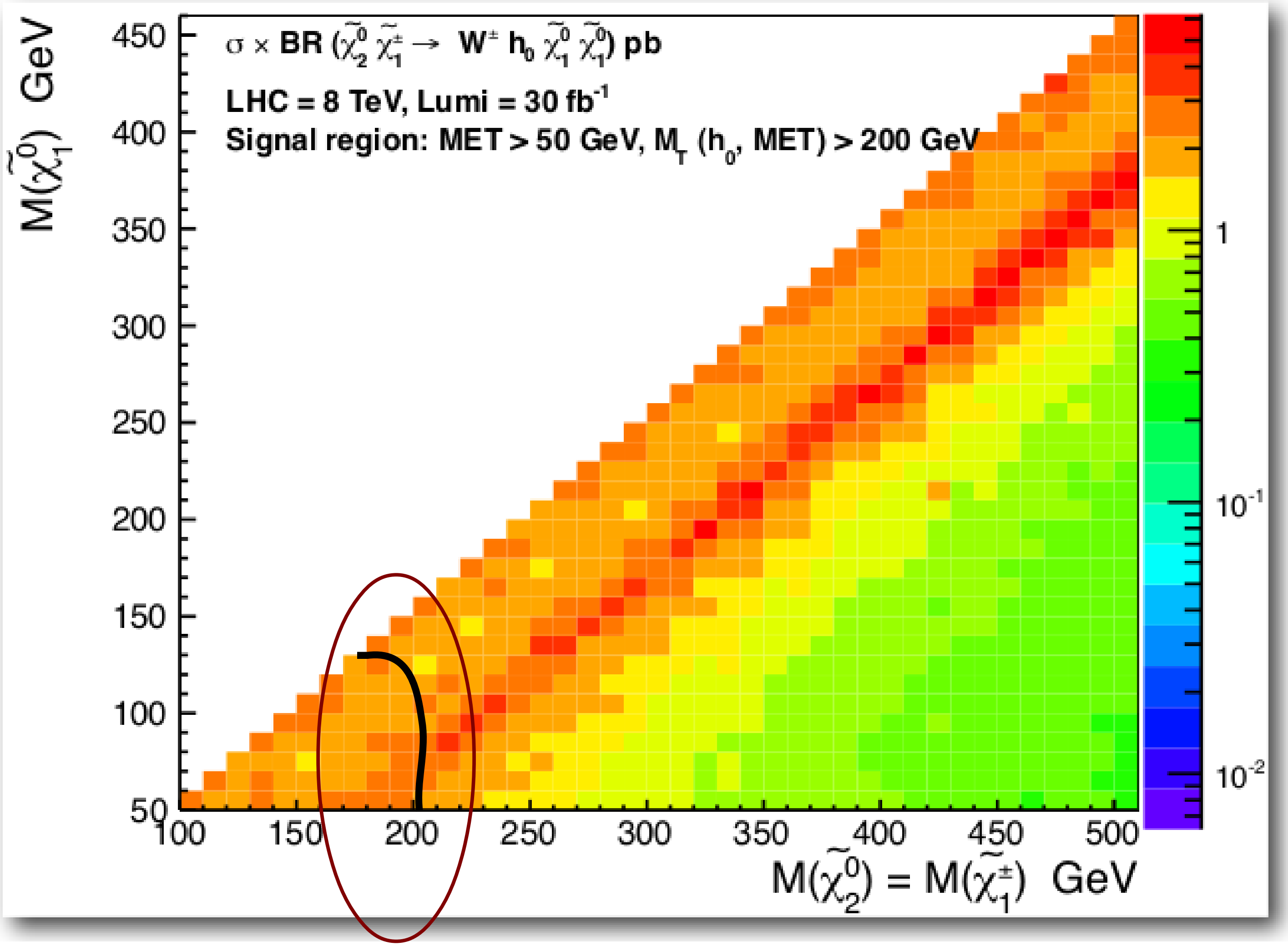


- Higgs Transverse Mass (Event simulation using Delphes)
- Background dominated by ttbar events

Possible LHC searches with Higgs in the final state

Wh: 1l+jets + MET

95% C.L. upper limit on signal cross section



With background only hypothesis, one can be sensitive to ~ 200 GeV in mass

Summary and Conclusion

Naturalness in SUSY can be valuable guiding principle for current/future searches

SUSY results from ATLAS and CMS show the breath of physics analyses

SUSY searches from the LHC

- constraints both squarks and gluinos up to TeV scale (with assumptions)
- the direct stop/sbottom limits up to ~500 GeV in mass
- the constraints on direct electroweak productions are soft.

Discovery of Higgs is just a starting point to move into a new territory

Search for new physics with Higgs in the final state

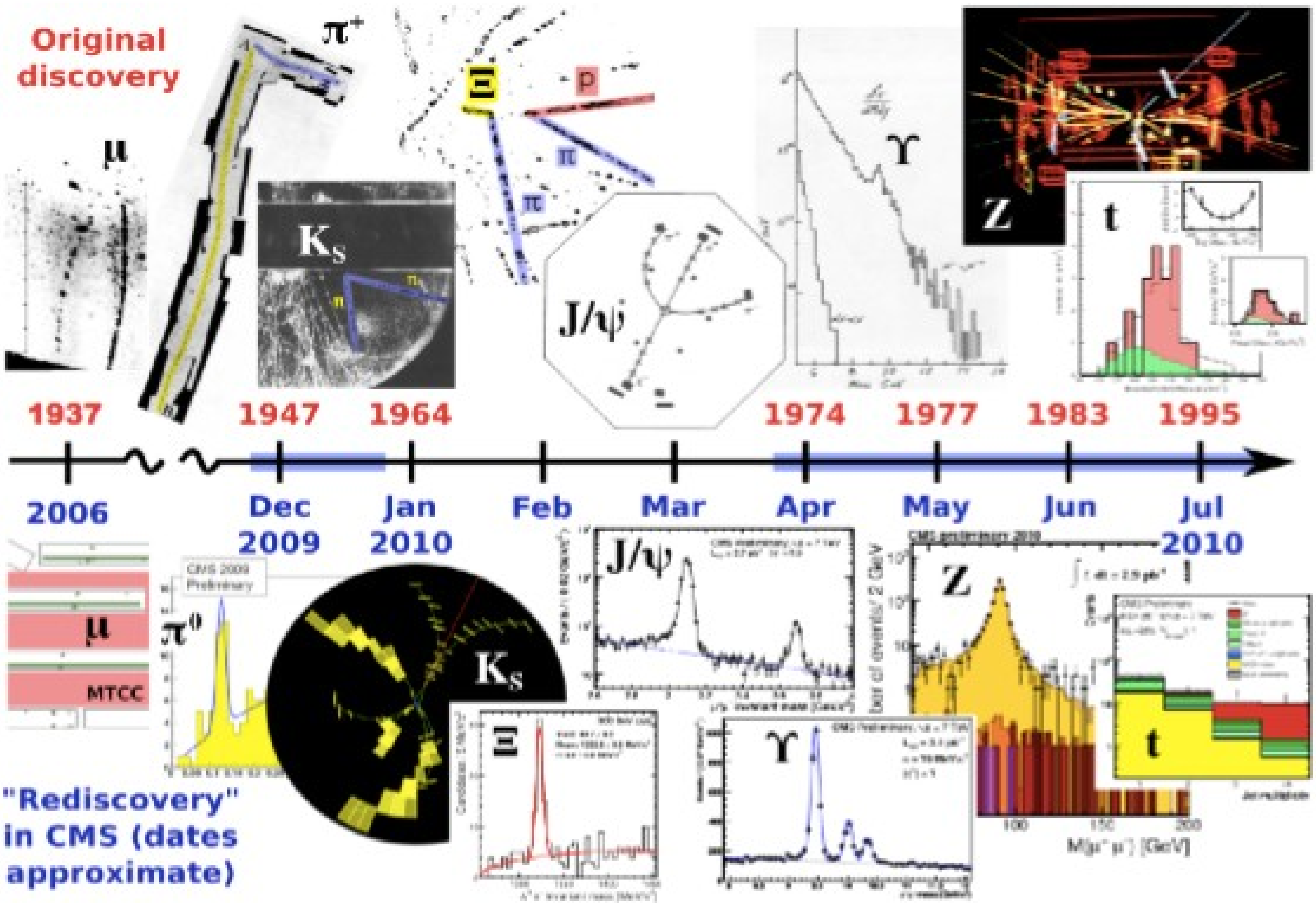
- Can be the next discovery mode ...

Studies towards naturally compressed spectra

→ Essential for next phase of LHC studies

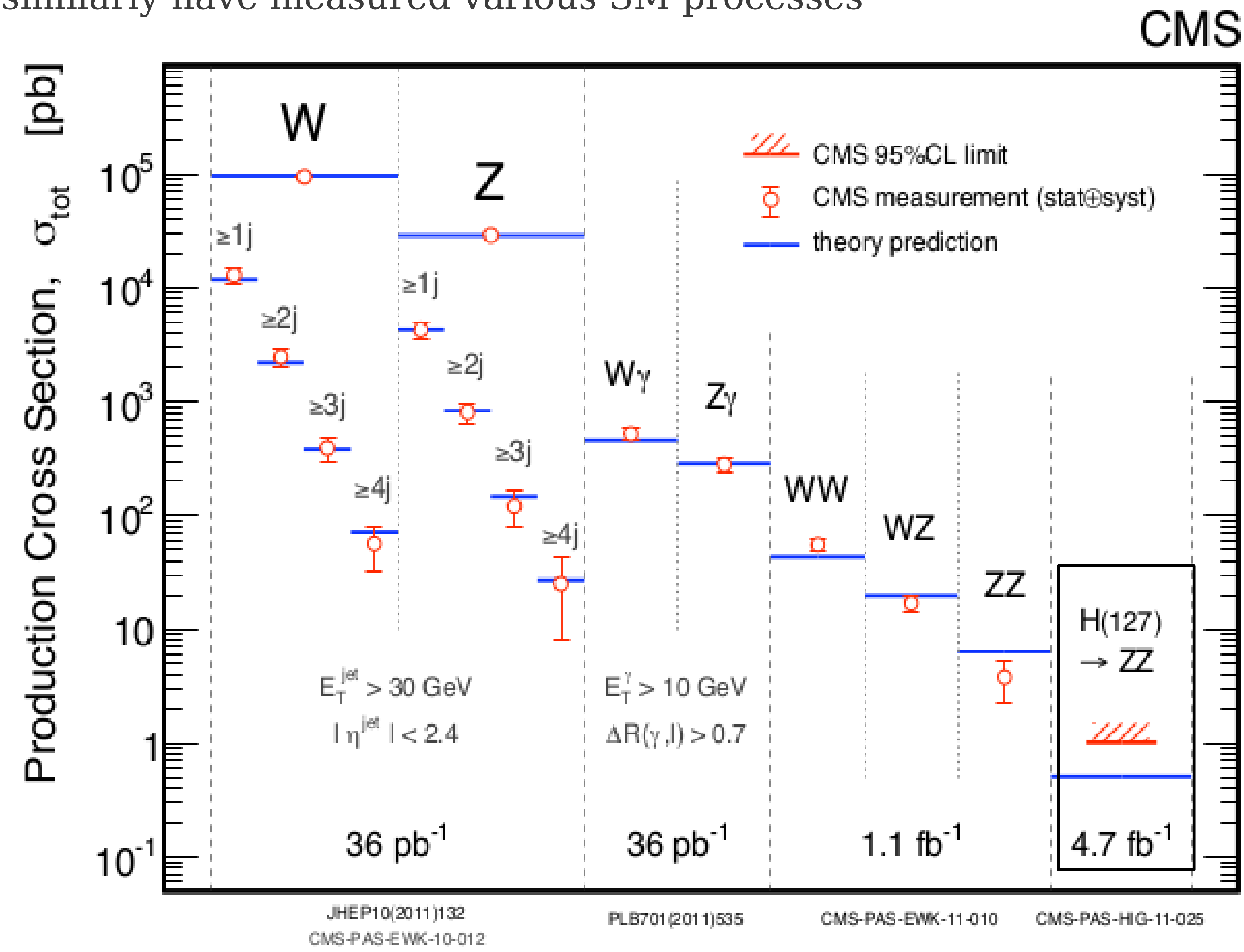
Backup slides

Re-Discovery of the Standard Model



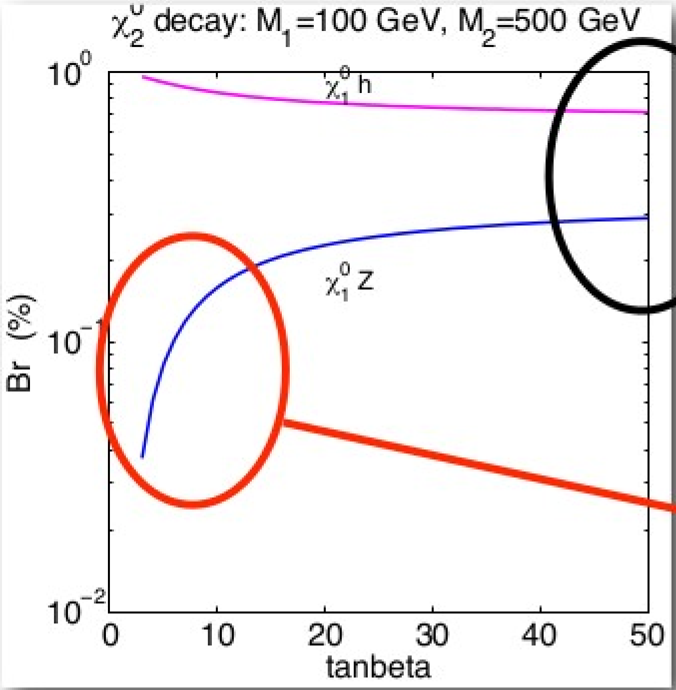
Standard Model Measurements

ATLAS similarly have measured various SM processes



Tanbeta dependency

- decay occur via mixing through Higgsino
- $M_2 >> M_1$, $\chi_2^0 \to \chi_1^0 Z$ dominated by the decay via Z_L (goldstone mode G^0)
- h, G^0 as mixture of H_u^0 and H_d^0



$$\Gamma(\chi_2^0 \to \chi_1^0 h) \propto \left(2 s_{2\beta} + \frac{M_2}{\mu}\right)^2 \left[(M_2 + M_1)^2 - m_h^2\right],$$

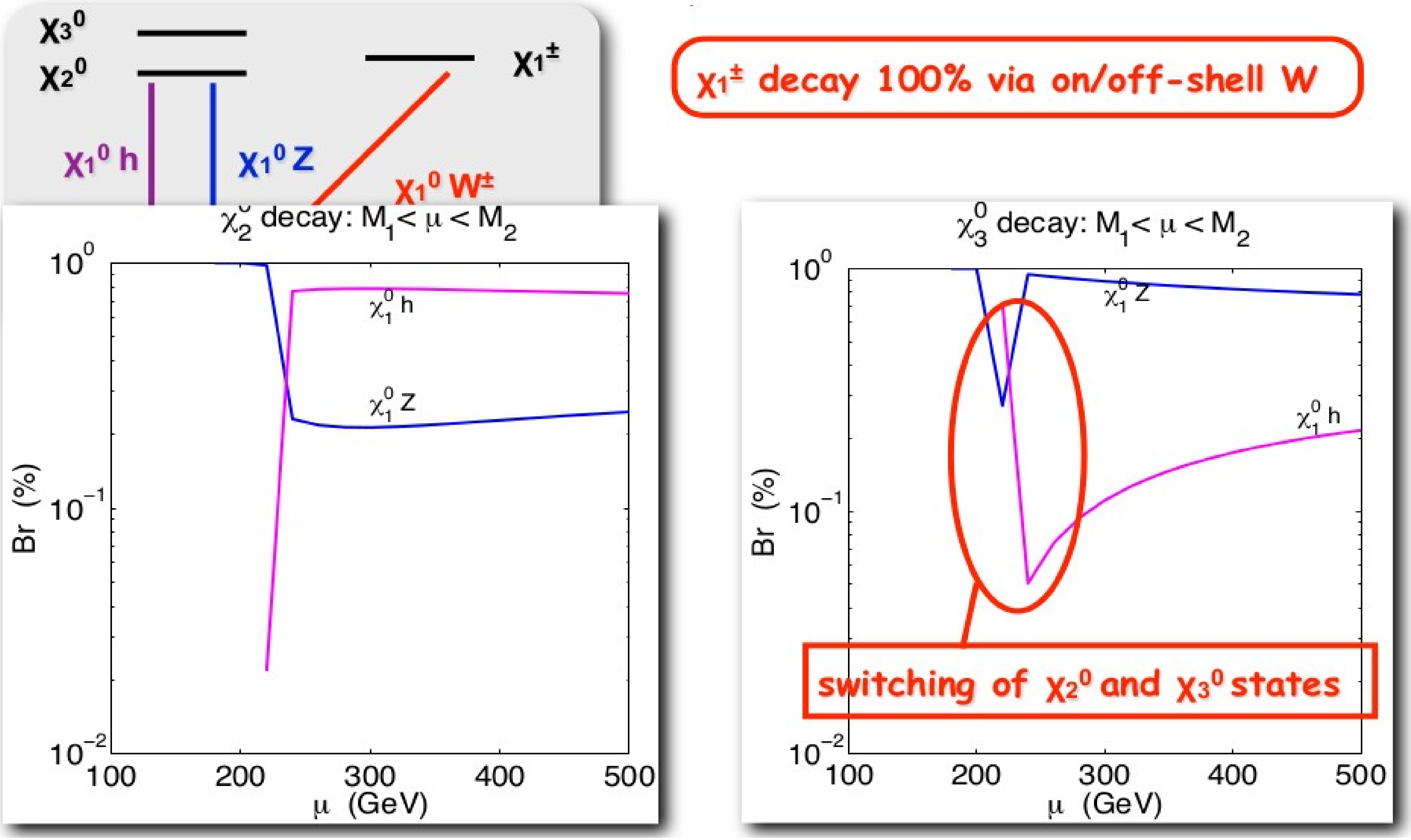
$$\Gamma(\chi_2^0 \to \chi_1^0 Z) \propto \left(c_{2\beta} \frac{M_2}{\mu}\right)^2 \left[(M_2 - M_1)^2 - m_Z^2\right].$$

large tanβ ; $[(M_2 + M_1)^2 - m_h^2] \,/\, [(M_2 - M_1)^2 - m_h^2]$

small tanβ , Z channel relatively suppressed

Case AII: Bino LSP-Higgsino NLSP

$\chi_1^\pm$ decay 100% via on/off-shell W



- **Neutralinos**

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix},$$

M_1 Bino
M_2 Wino
$|\mu|$ Higgsino
$|\mu|$ Higgsino

$$\begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \\ \chi_4^0 \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}\frac{m_Z}{M'}) & \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}\frac{m_Z}{M'}) & 1 & \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \mathcal{O}(\frac{m_Z}{M}) & \mathcal{O}(\frac{m_Z}{M}) & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \tilde{B} \\ \tilde{W}^0 \\ \tilde{H}_d^0 \\ \tilde{H}_u^0 \end{pmatrix}$$

- **Charginos** $\psi^{\pm} = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$

$$M_{\tilde{C}} = \begin{pmatrix} 0_{2\times 2} & X^T_{2\times 2} \\ X_{2\times 2} & 0_{2\times 2} \end{pmatrix}, \quad \text{with} \quad X_{2\times 2} = \begin{pmatrix} M_2 & \sqrt{2} s_\beta m_W \\ \sqrt{2} c_\beta m_W & \mu \end{pmatrix}$$

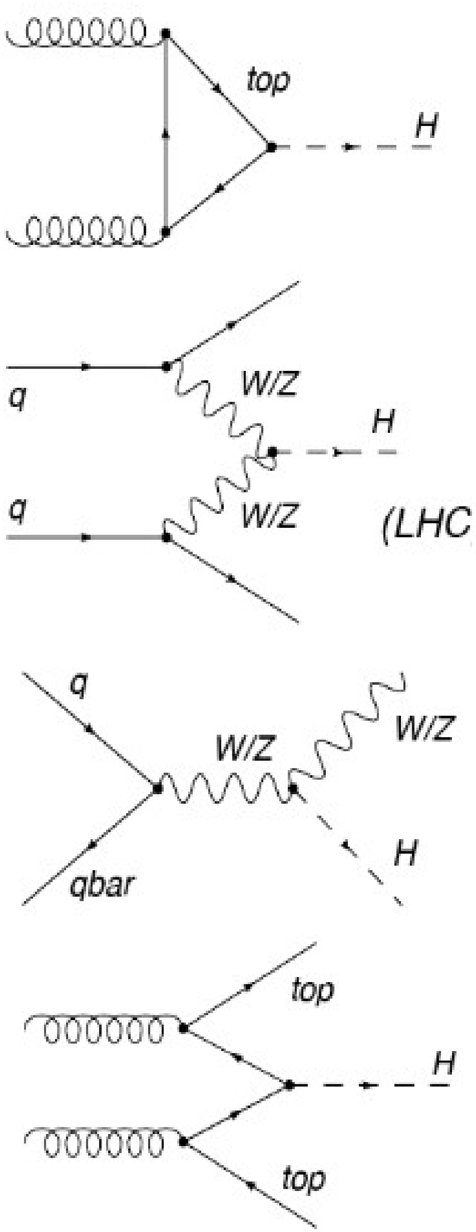
M_2 **Wino**

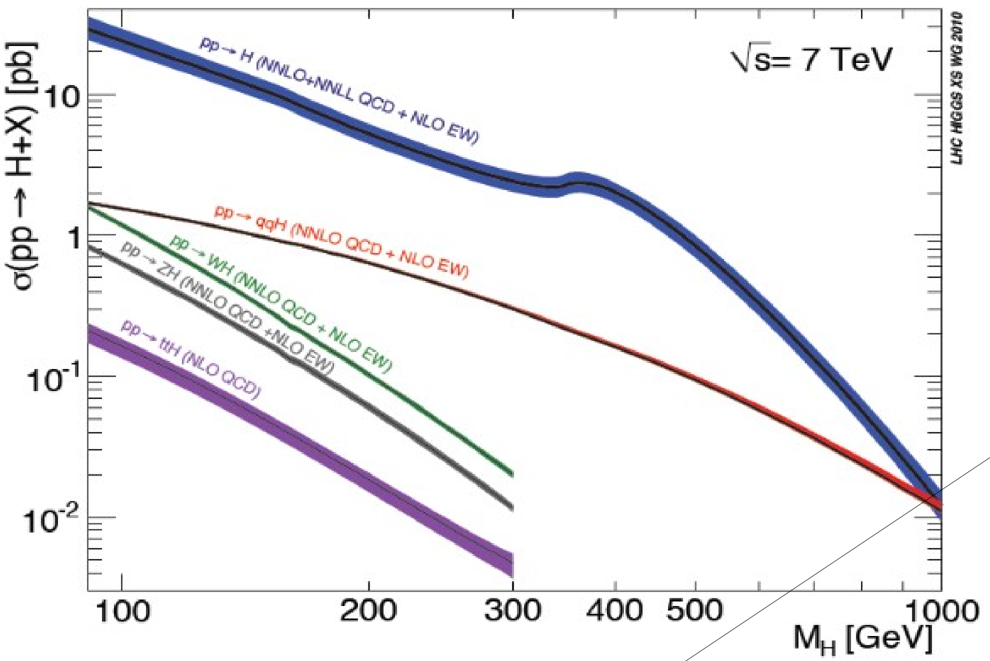
$|\mu|$ **Higgsino**

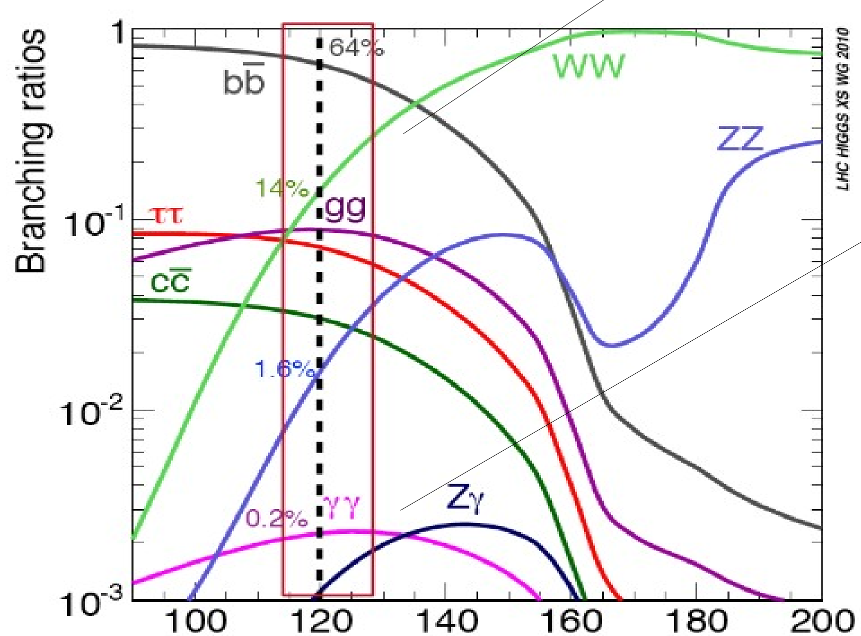
$$\begin{pmatrix} \chi_1^+ \\ \chi_2^+ \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & 1 \end{pmatrix} \begin{pmatrix} \tilde{W}^+ \\ \tilde{H}_u^+ \end{pmatrix}$$

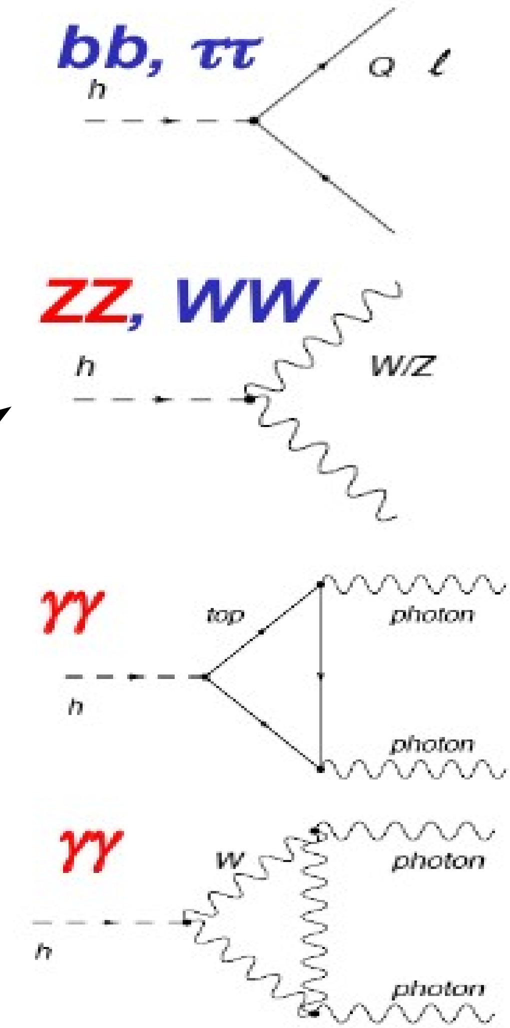
$$\begin{pmatrix} \chi_1^- \\ \chi_2^- \end{pmatrix} = \begin{pmatrix} 1 & \mathcal{O}(\frac{m_Z}{M}) \\ \mathcal{O}(\frac{m_Z}{M}) & 1 \end{pmatrix} \begin{pmatrix} \tilde{W}^- \\ \tilde{H}_d^- \end{pmatrix}$$

Higgs production and decay at the LHC









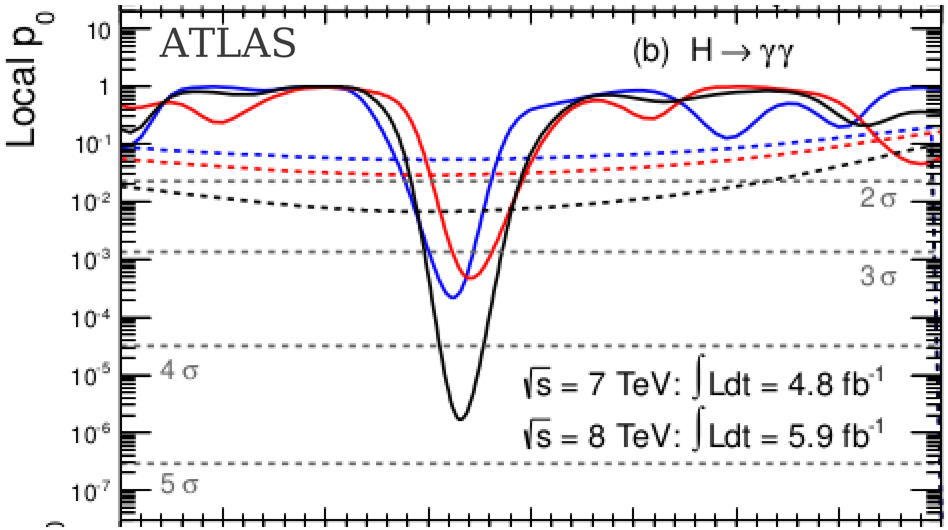
Expect:

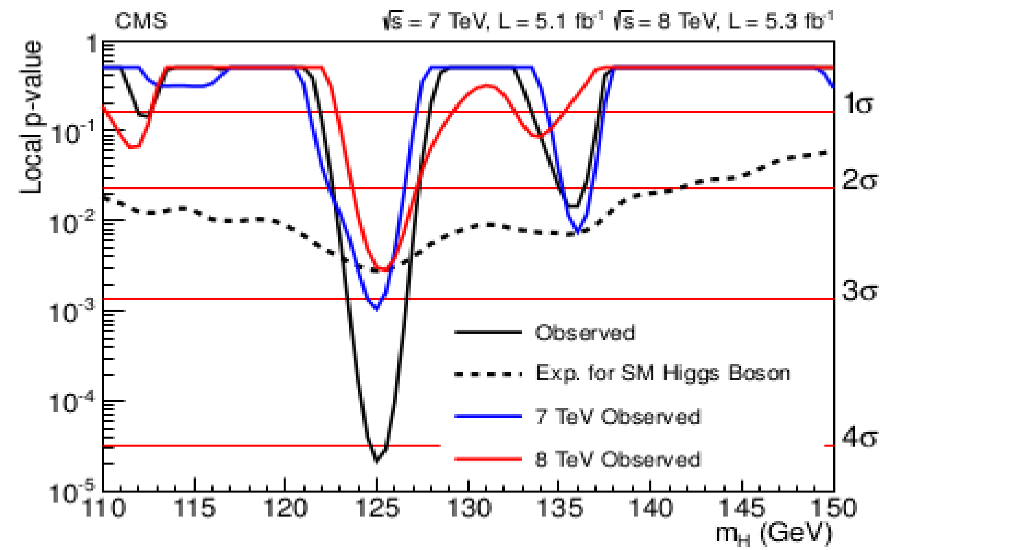
~ 400 γγ events

~ 10 ZZ events

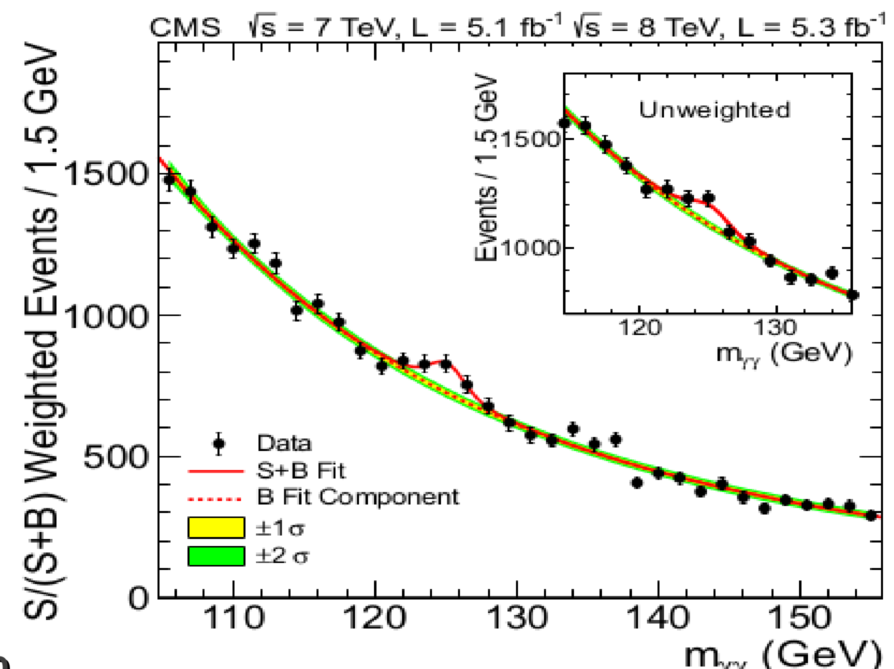
Discovery of Higgs boson at the LHC

ATLAS (hep-ex: 1207.7214) and CMS (hep-ex: 1207.7235) Higgs → $\gamma\gamma$ results





p-value: probability that background fluctuates to give an excess as large as the (average) signal size expected for a SM Higgs.



ATLAS: Observed a peak at 126.5 GeV

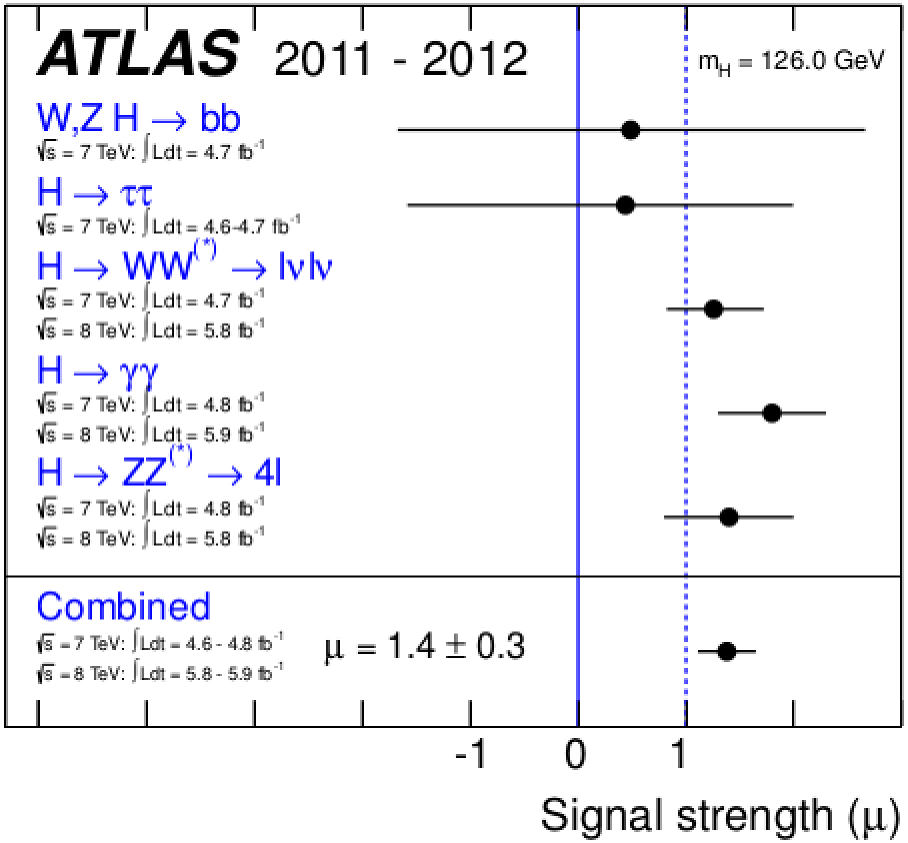
Local signif.: 4.5σ (obs), 2.4σ (expected)

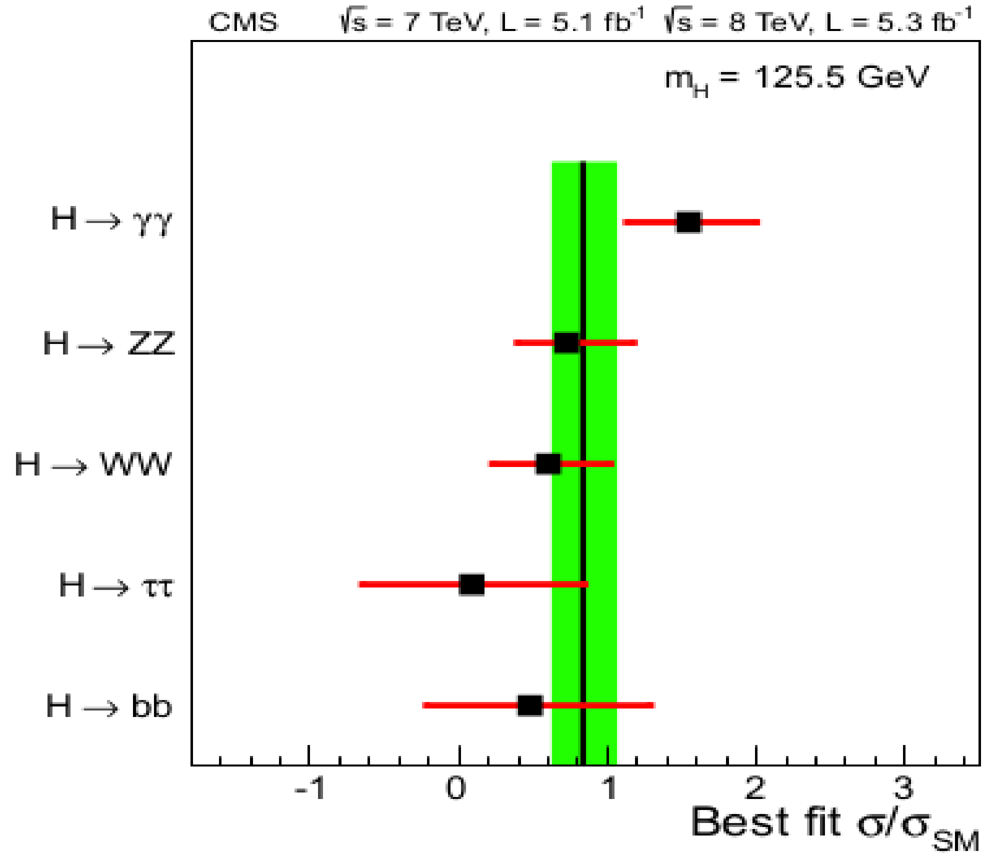
CMS: Observed a peak at 125.3 GeV

Local signif.: 4.1σ (obs), 2.8σ (expected)

Must be a spin 0 or 2 boson

Compatibility with SM Higgs boson

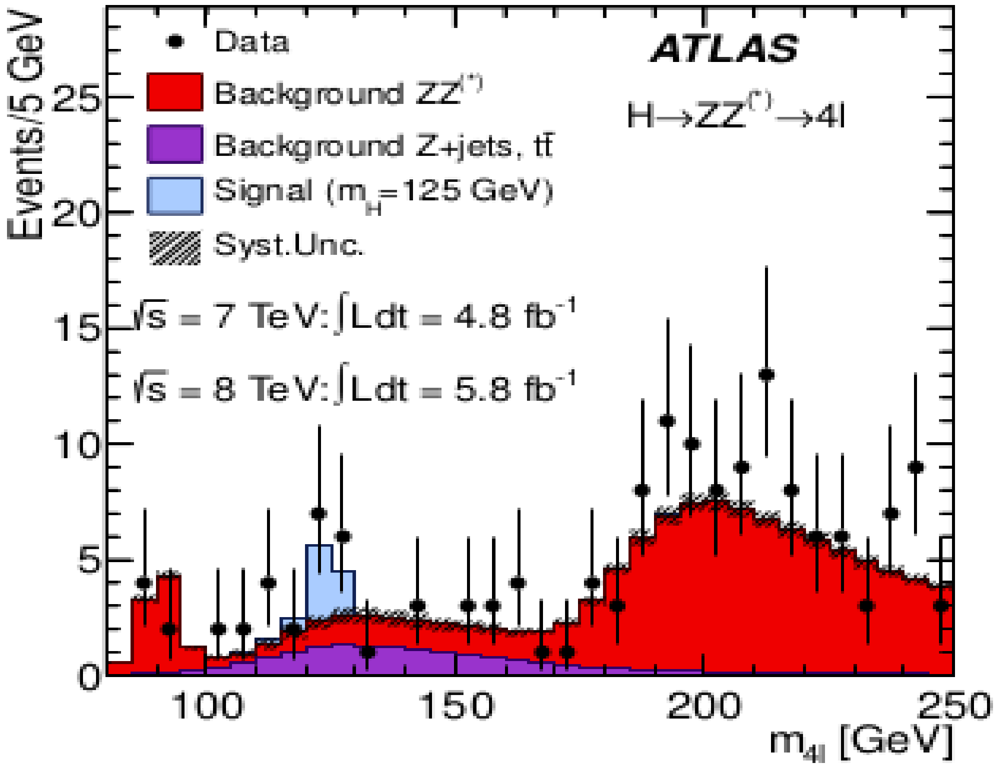


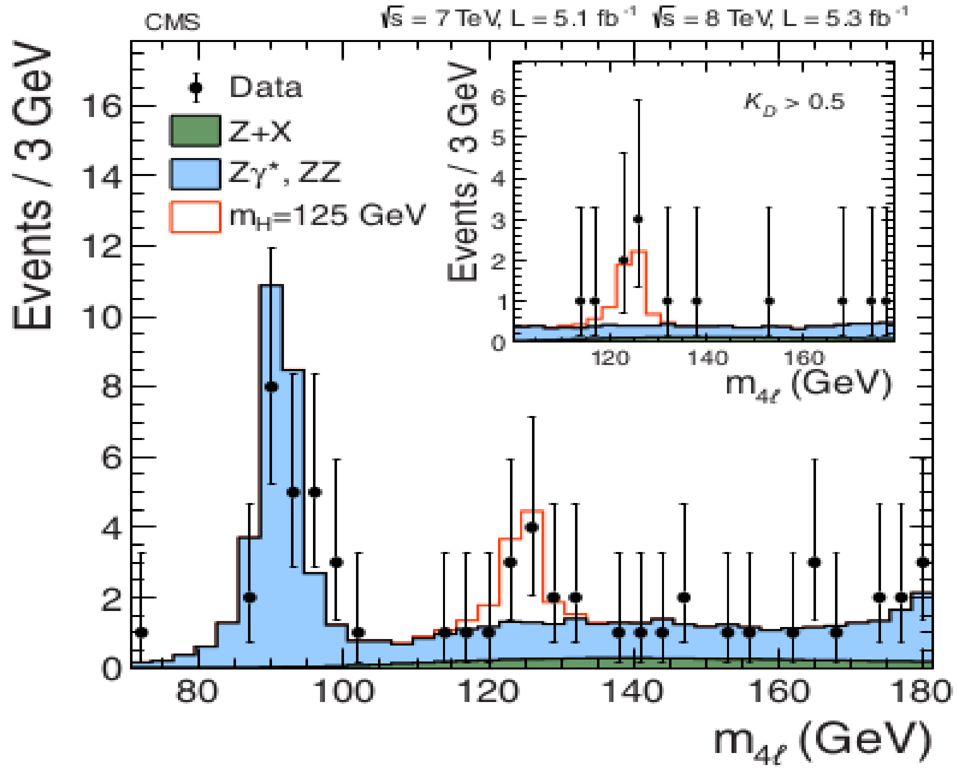


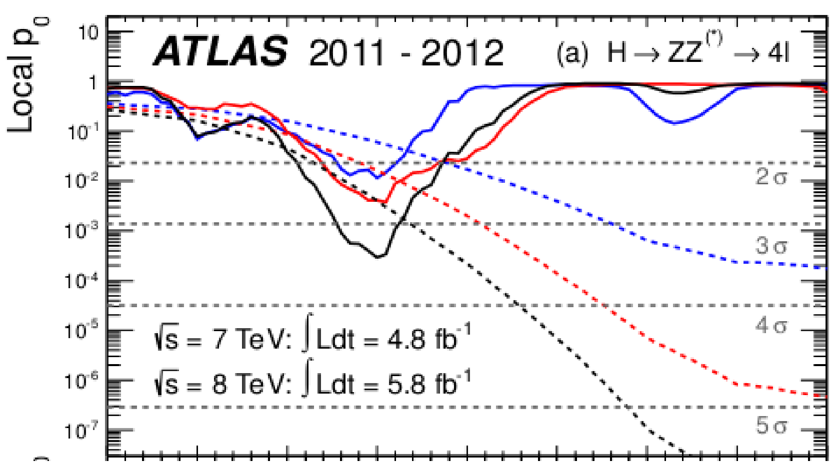
Results are self consistent within errors .. so far

Discovery of Higgs boson at the LHC

ATLAS (hep-ex: 1207.7214) and CMS (hep-ex: 1207.7235) Higgs → ZZ results







ATLAS: Observed a peak at 125 GeV

Local signif.: 3.6σ (obs), 2.7σ (expected)

CMS: Observed a peak at 125.5 GeV

Local signif.: 3.2σ (obs), 3.8σ (expected)

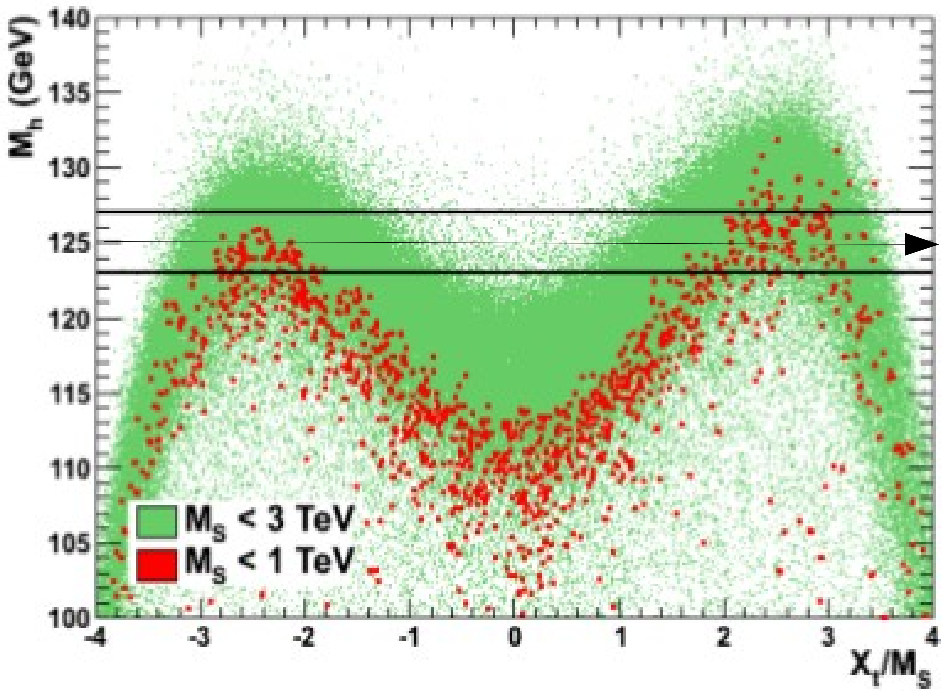
Impact of Higgs discovery on new physics

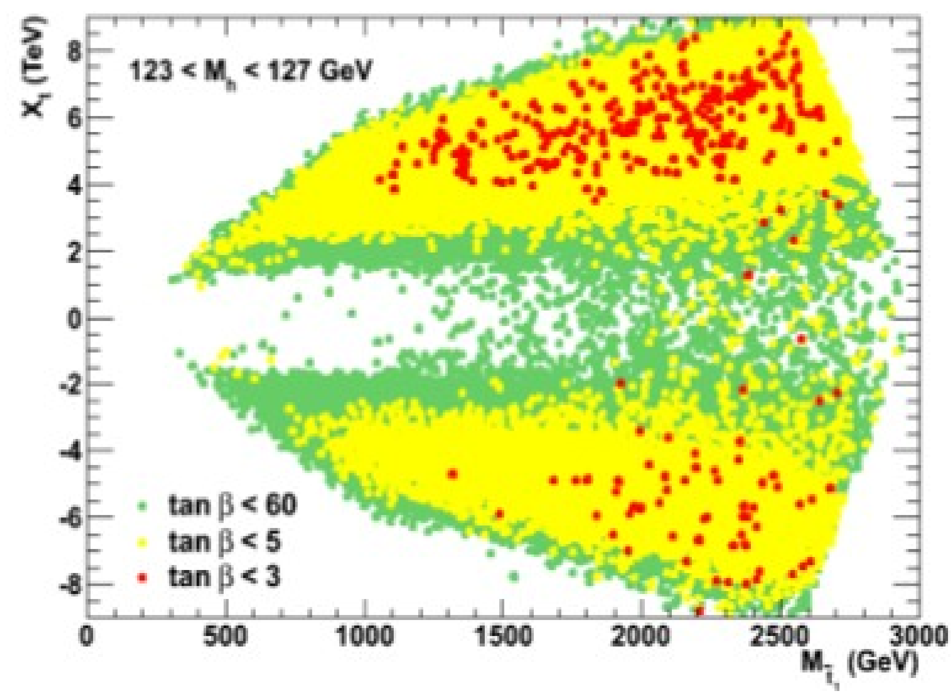
Consider Higgs to be $123 < M_h$ (GeV) < 127

$$M_h^2 \overset{M_A \gg M_Z}{\approx} M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1-\frac{X_t^2}{12M_S^2}\right)\right]$$

The consequences of this in pMSSM (19 parameters)

A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162





A large part of the pMSSM still survives

No mixing cases ($X_t \sim 0$) is excluded for $M_S < 1$ TeV

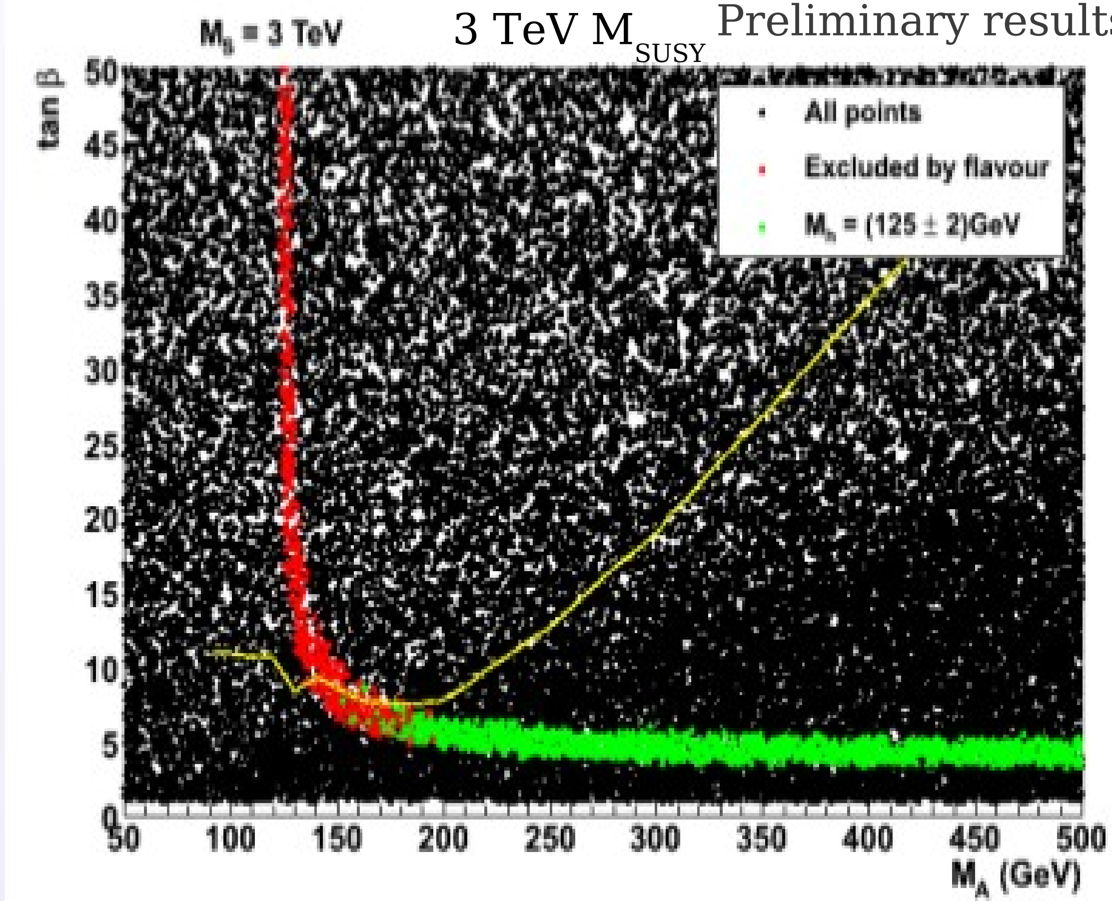
- Even at $M_S < 3$ TeV, chances are narrow

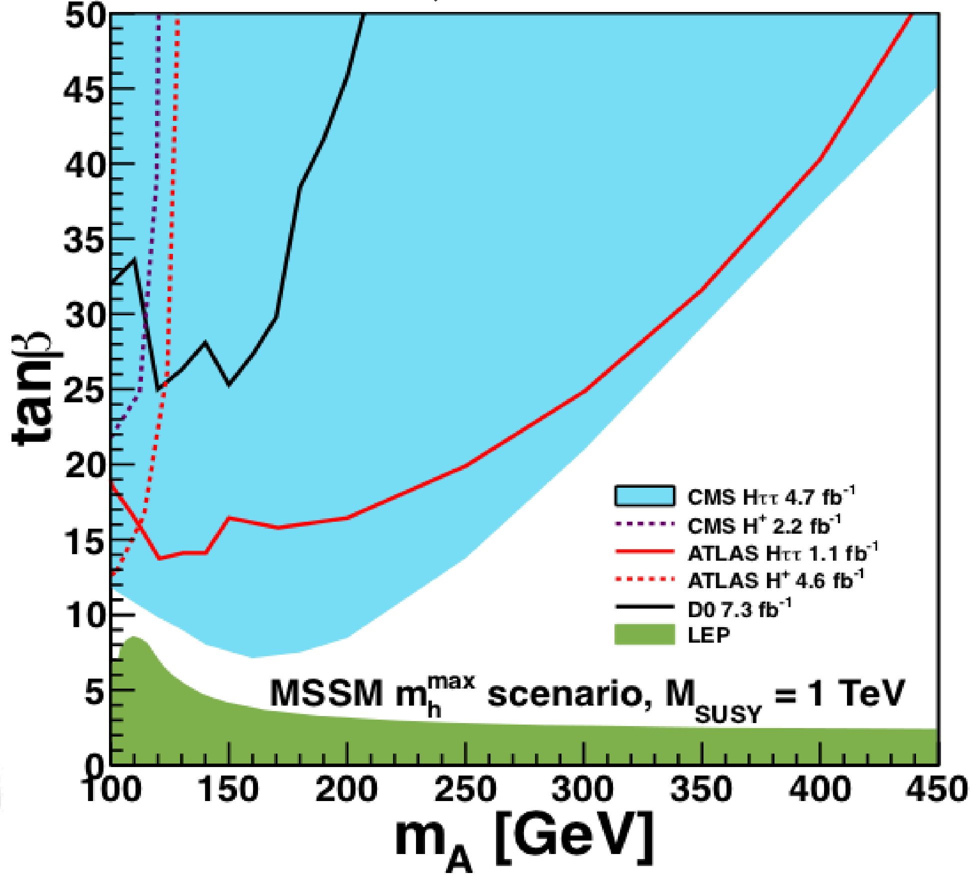
Small stop masses are still allowed

Impact of Higgs discovery on new physics

In the maximal mixing case ($X_t = \sqrt{6}\, M_S$) $123 < M_h\ (\mathrm{GeV}) < 127$

3 TeV M_{SUSY} Preliminary results: Nazila Mahmoudi, Moriond EWK





Very strong constraint on the neutral Higgs searches!

Flavour constraints: $b \to s\gamma, B \to \tau\nu$ and new LHCb B_s results