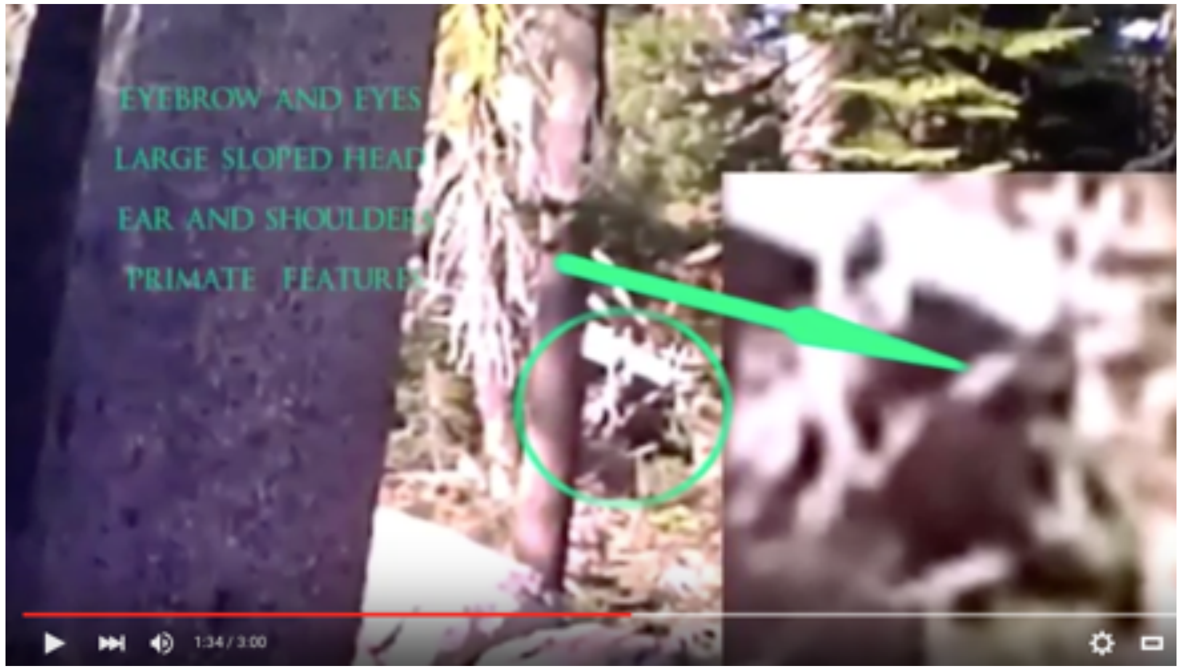
SFB 676 - Project B2

CMS Results on SUSY Searches

Christian Sander (Hamburg University)
on behalf of the CMS collaboration

23^{rd} International Conference on Supersymmetry and Unification of Fundamental Interactions
Lake Tahoe - August 23^{rd} to 29^{th} 2015

Lake Tahoe, 2012 (youtube)

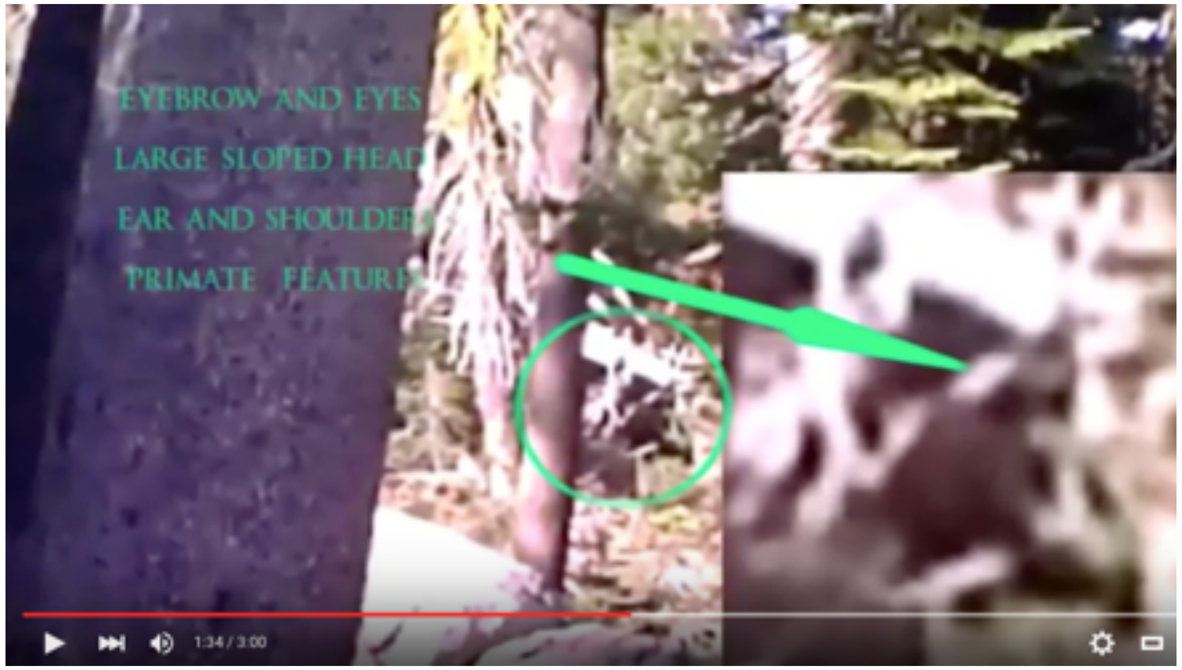


Evidence for "exotic phenomenon"

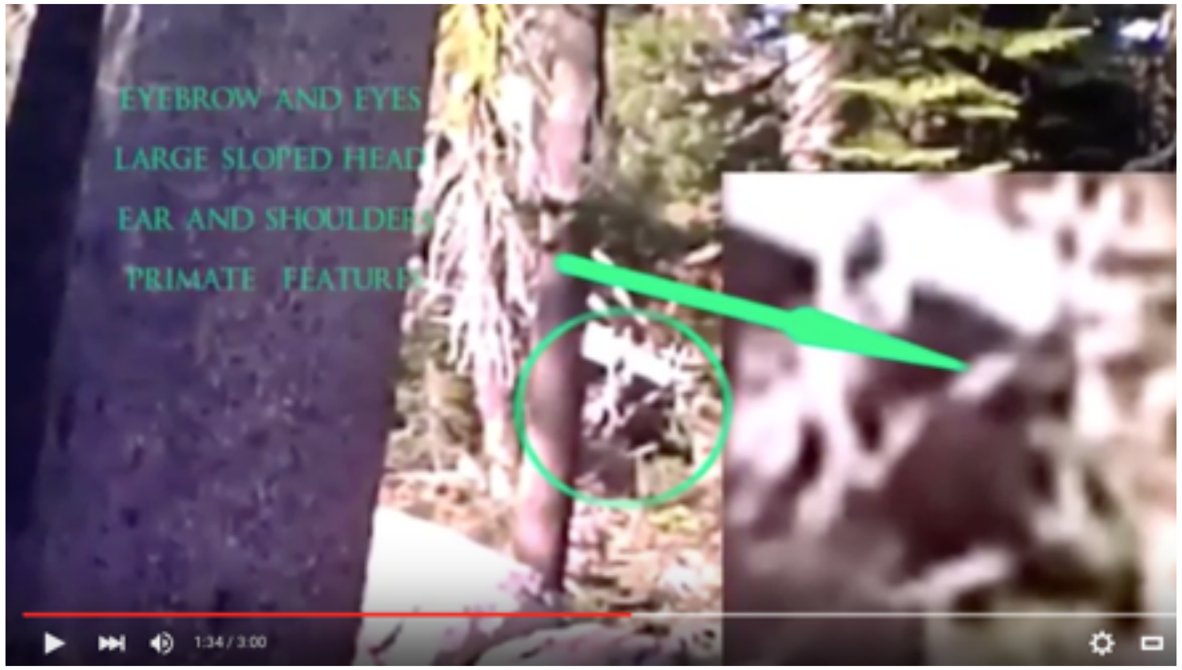
598k views in three years

for comparison: CERN Higgs discovery seminar: 87k views in tree years

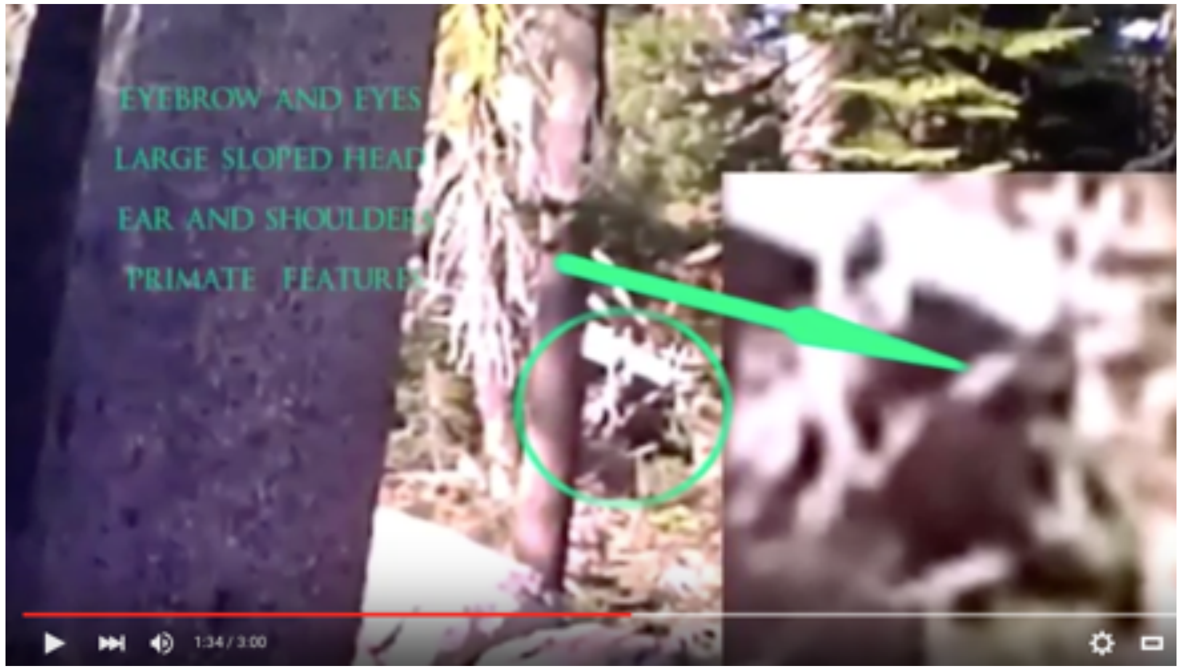
Lake Tahoe, 2012 (youtube)



Lake Tahoe, 2012 (youtube)



Lake Tahoe, 2012 (youtube)

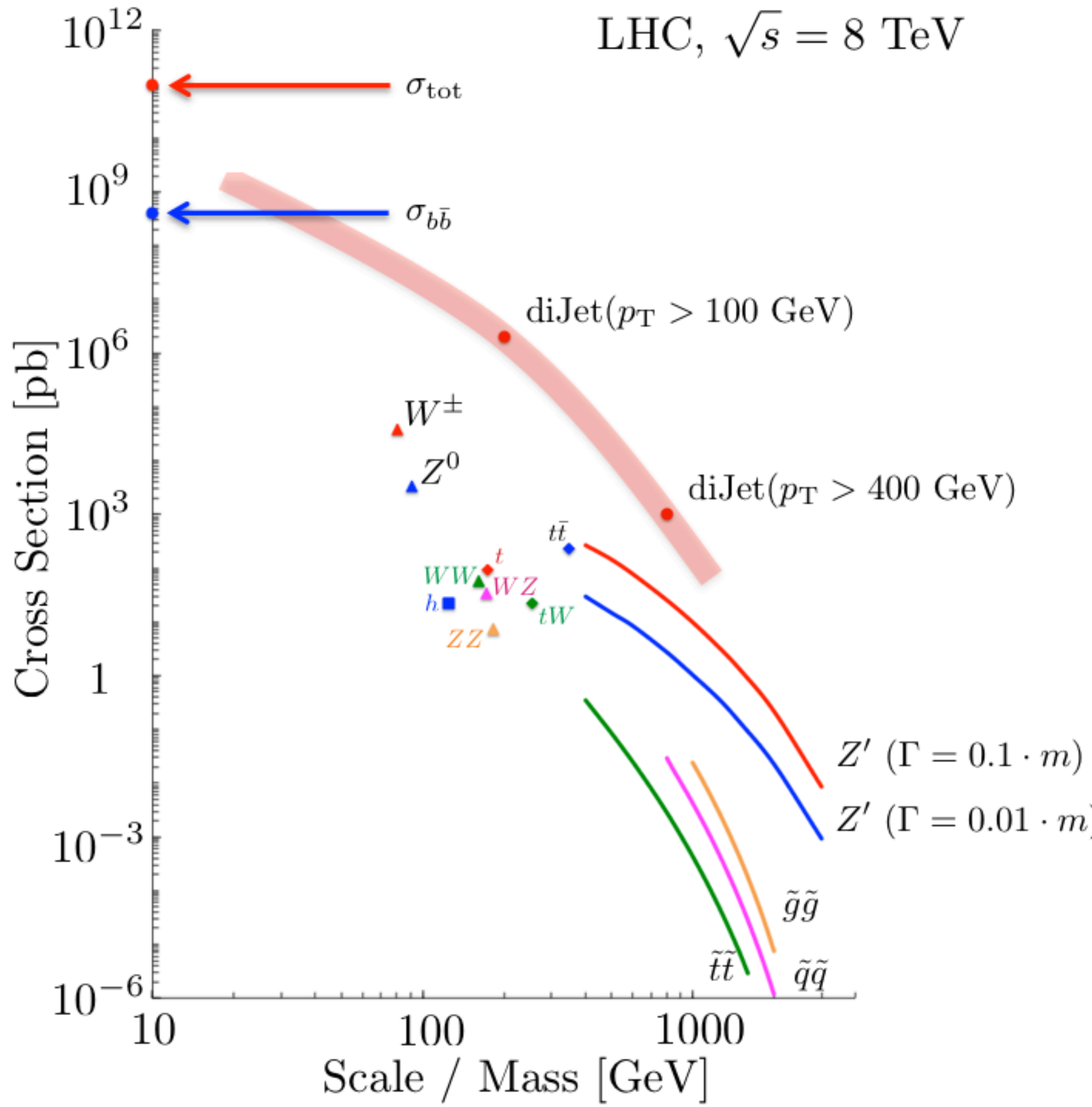


Outline

- **Introduction**
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- **Run II**
  - Commissioning at 13 TeV
  - Prospects for SUSY
- **Conclusions**

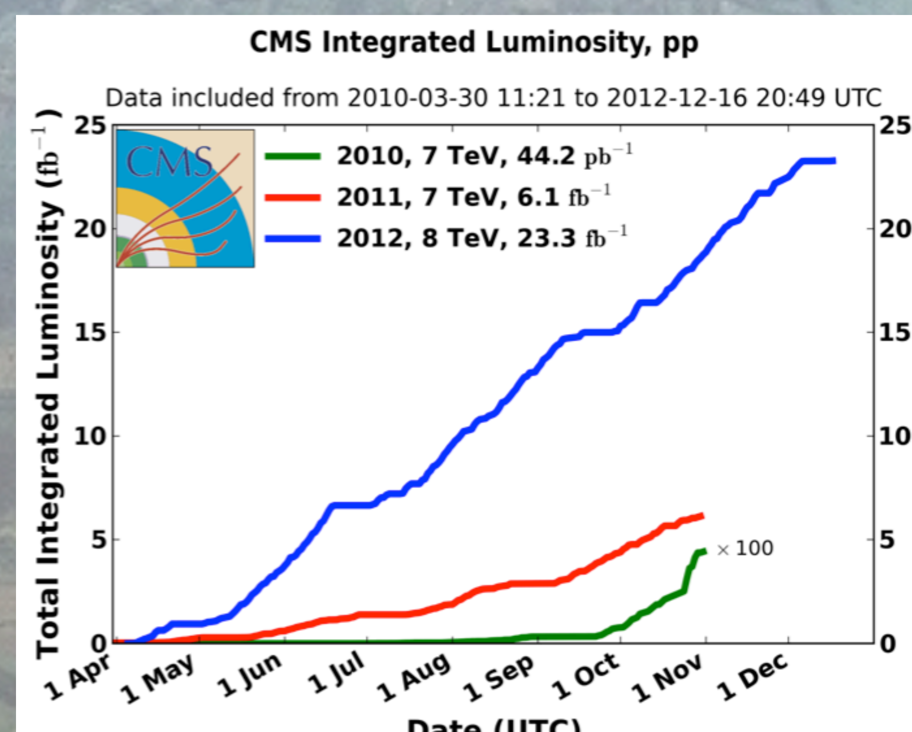
Introduction

- **SM is incomplete** (DM, hierarchy problem, gravity, neutral atoms …)
- **SUSY is able to provide simultaneously solutions** to some of these shortcomings
- **SUSY is broken**: Masses are heavy and cross sections are low
- Most attractive when masses in TeV range → searches @LHC
- **Challenge:** suppress and understand SM backgrounds with orders of magnitude larger cross sections



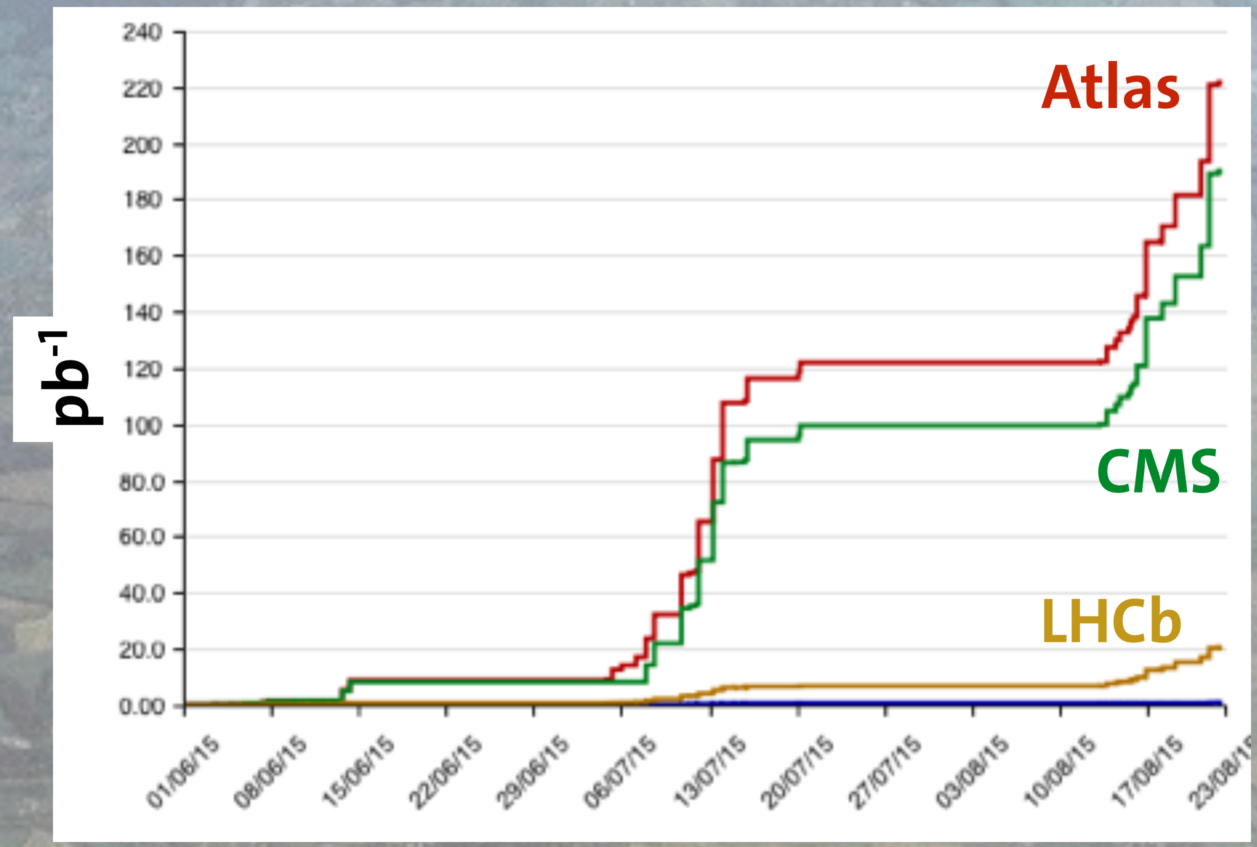
Large Hadron Collider

- 09: Data taking at $\sqrt{s}$=900 GeV and 2.36 TeV
- 10 & 11: $\sqrt{s}$=7 TeV, int. luminosity (~44 pb^{-1} & ~6.1 fb^{-1})
- 12: $\sqrt{s}$=8 TeV, int. Lumi (~23.3 fb^{-1})
- Heavy Ion collisions: Pb-Pb (and p-p) at $\sqrt{s}$=2.76 TeV/n; p-Pb at $\sqrt{s}$=5.02 TeV/n

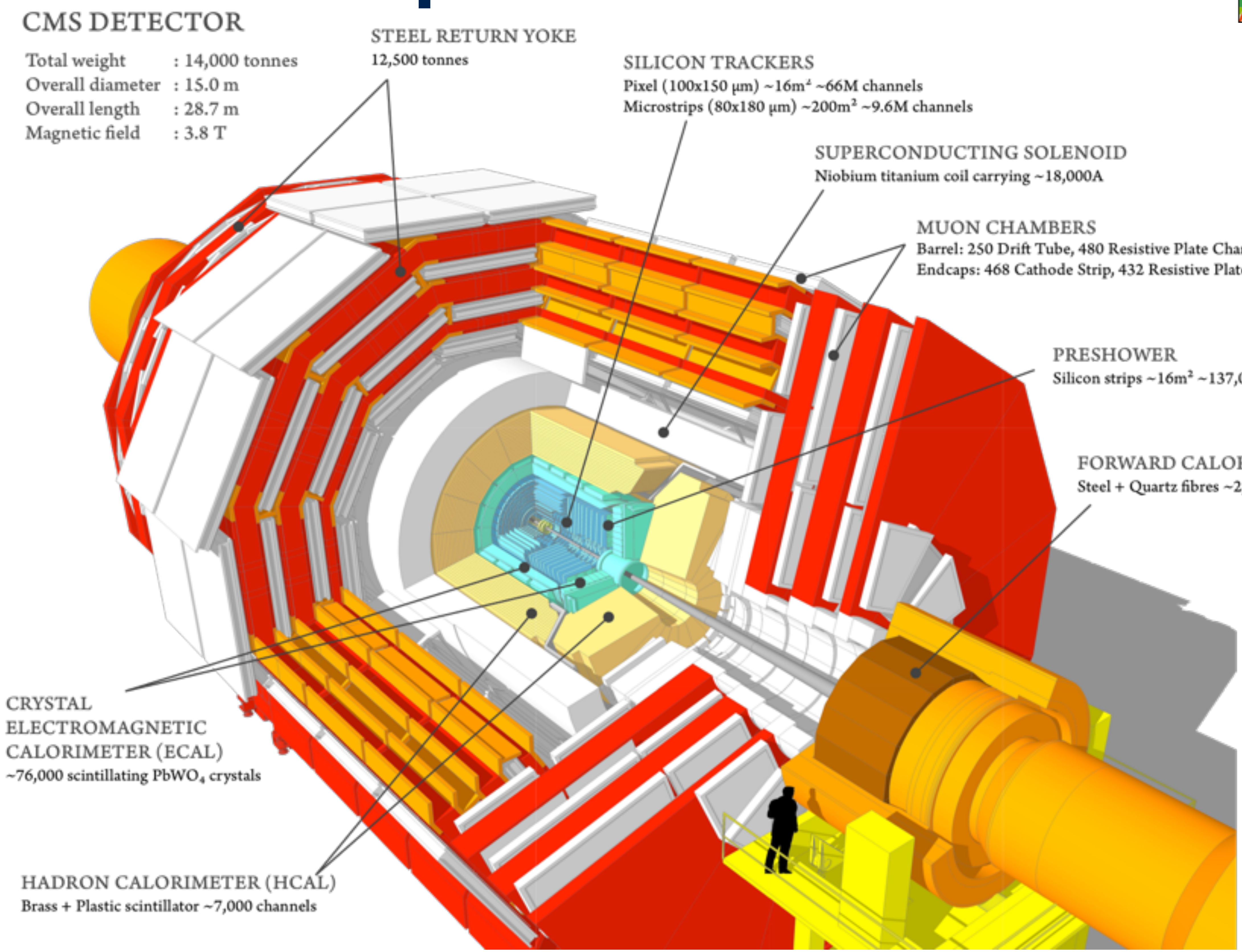


Large Hadron Collider

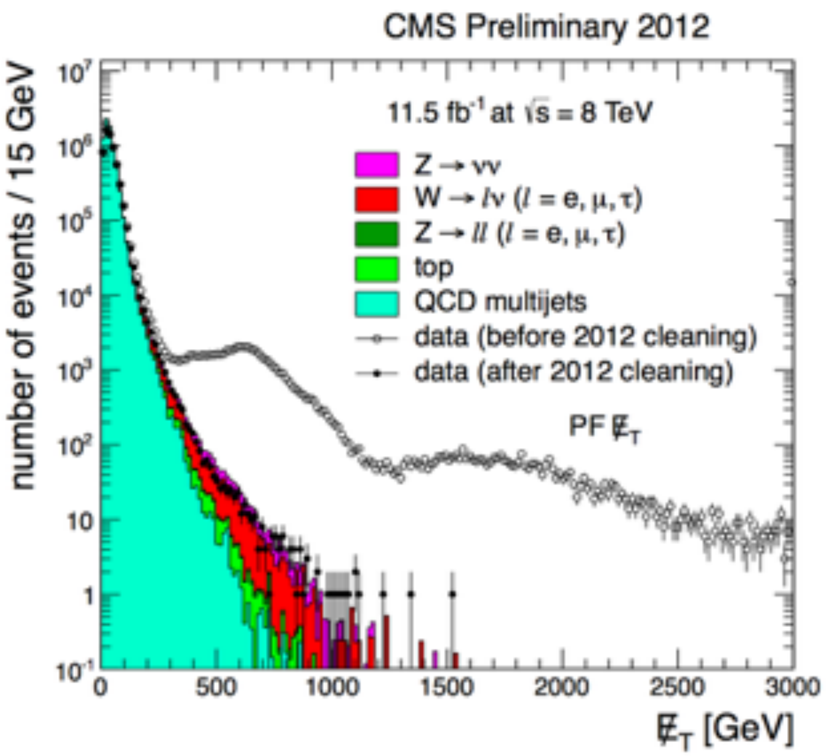
- 09: Data taking at √s=900 GeV and 2.36 TeV
- 10 & 11: √s=7 TeV, int. luminosity (~44 pb^{-1} & ~6.1 fb^{-1})
- 12: √s=8 TeV, int. Lumi (~23.3 fb^{-1})
- Heavy Ion collisions: Pb-Pb (and p-p) at √s=2.76 TeV/n; p-Pb at √s=5.02 TeV/n
- **Since June 15: √s=13 TeV (so far ~200 pb^{-1})**

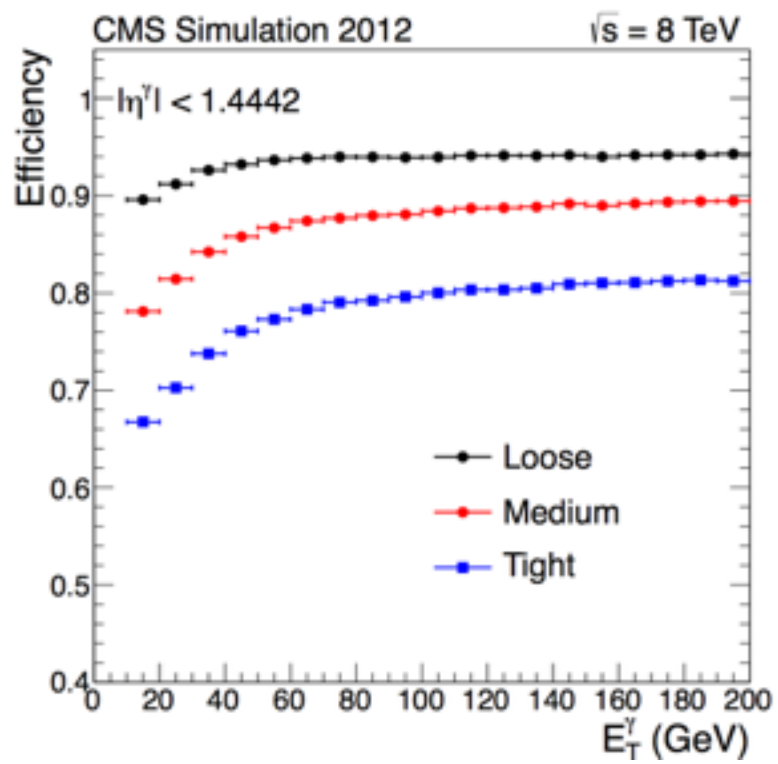


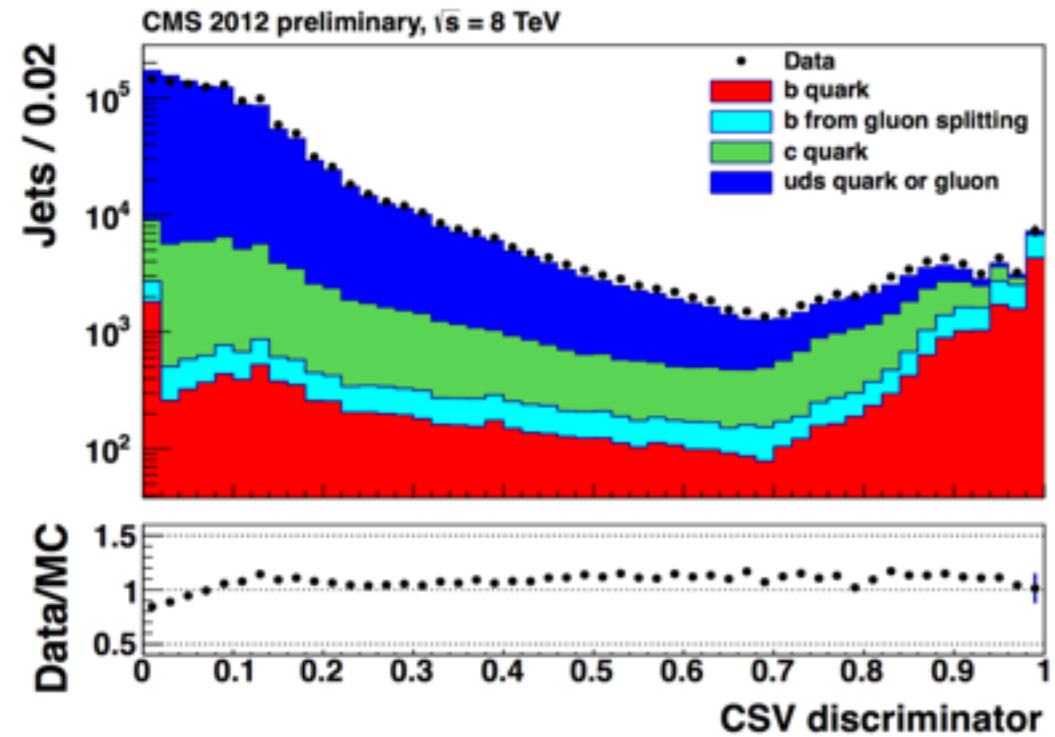
Compact Muon Solenoid

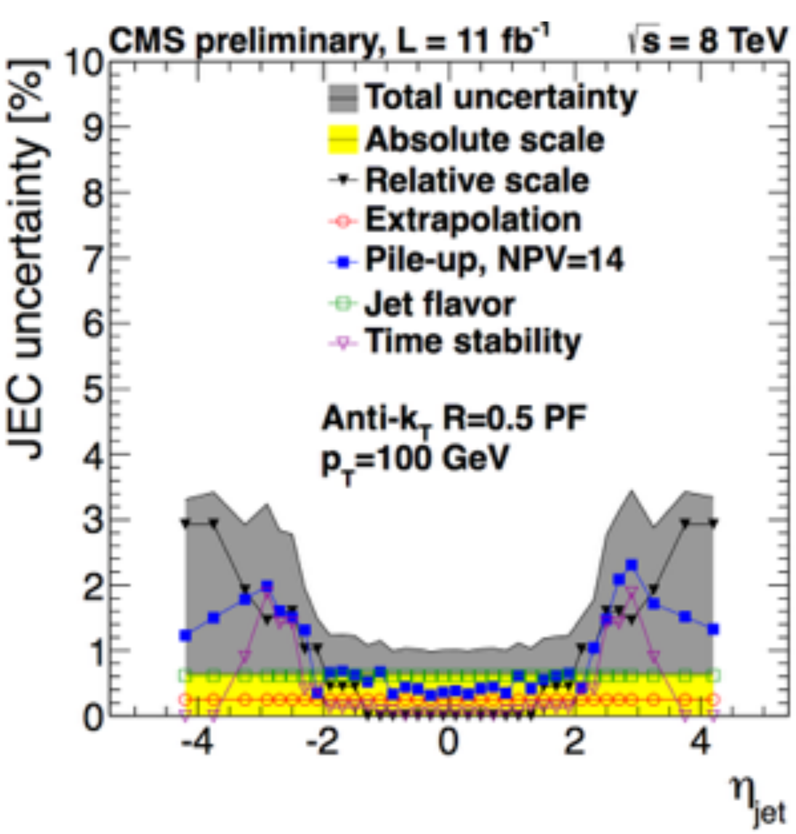


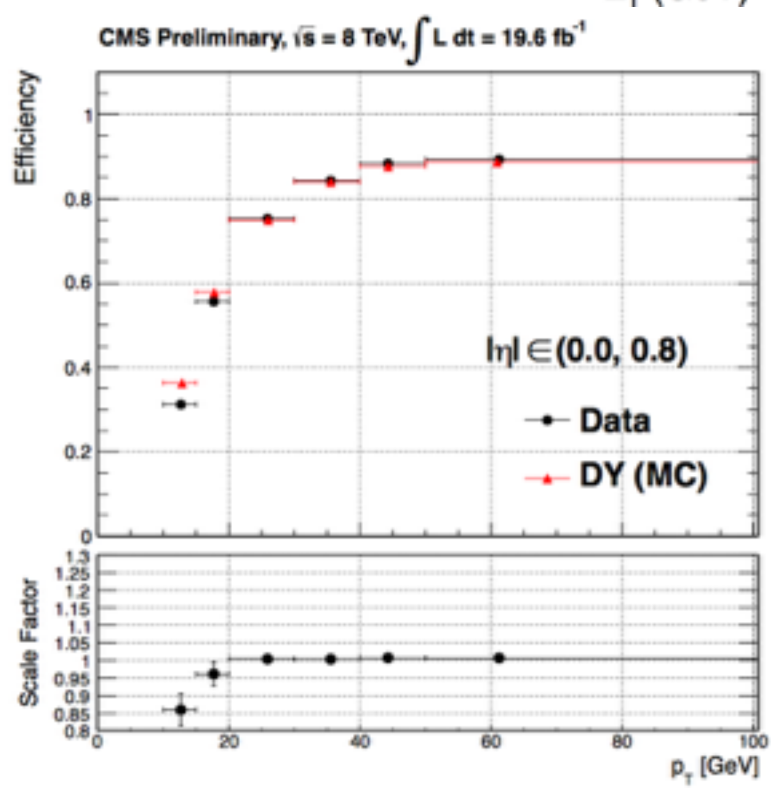
Physics Object Performance

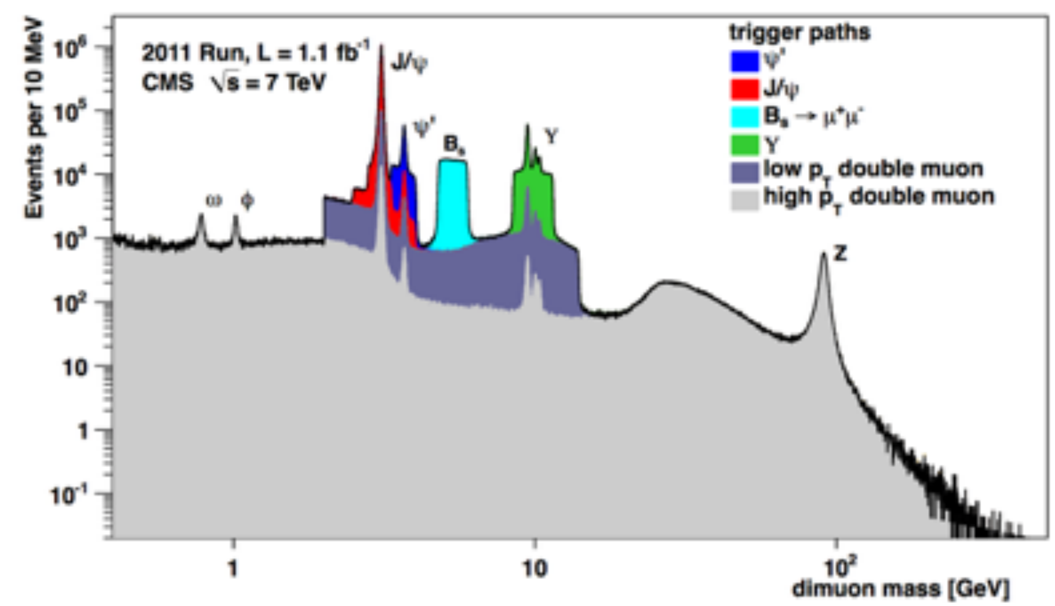








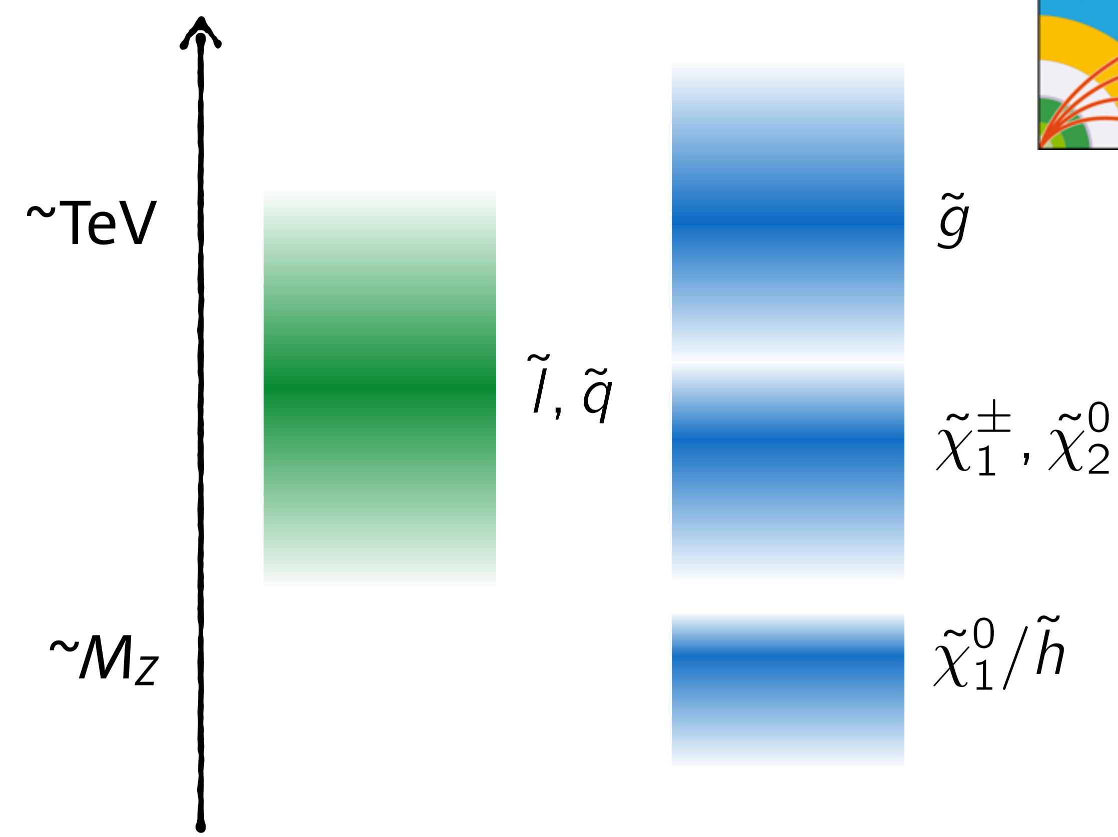


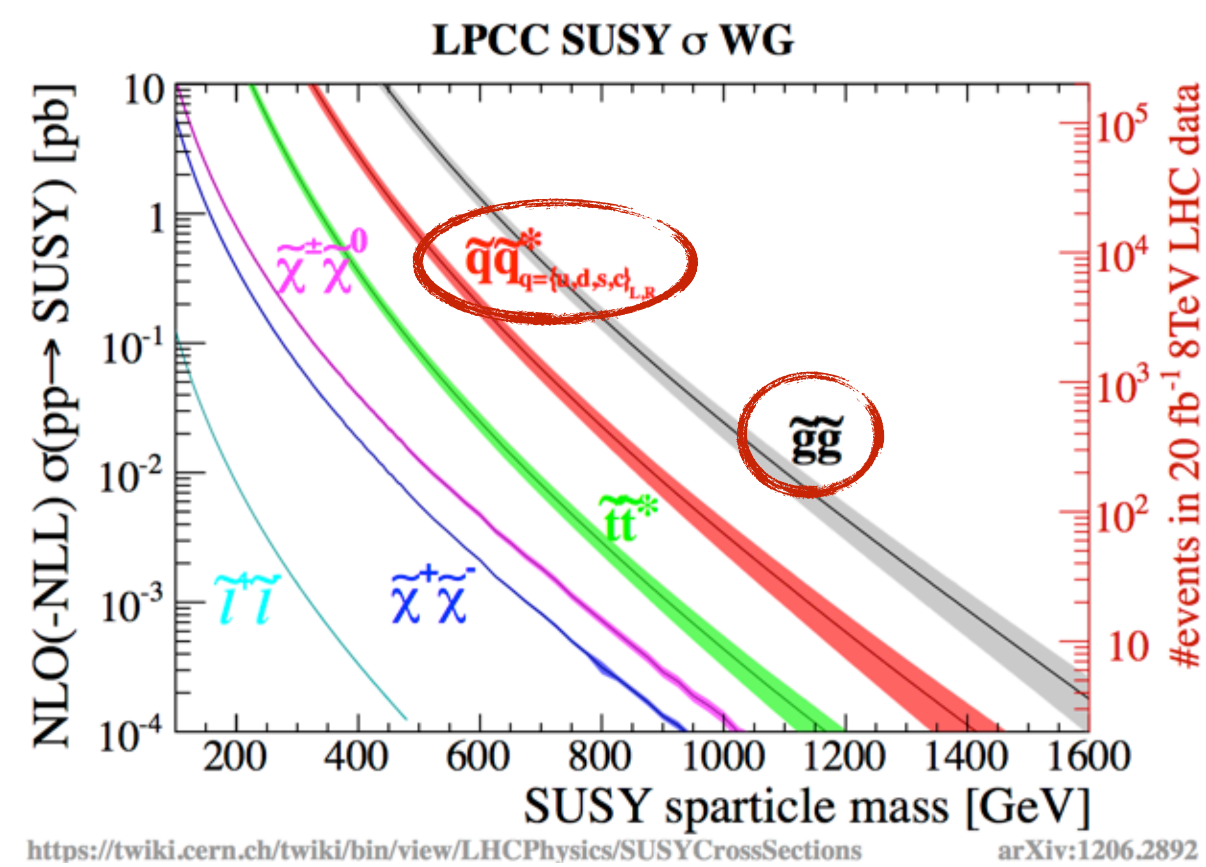


Great performance for all physics objects

Outline

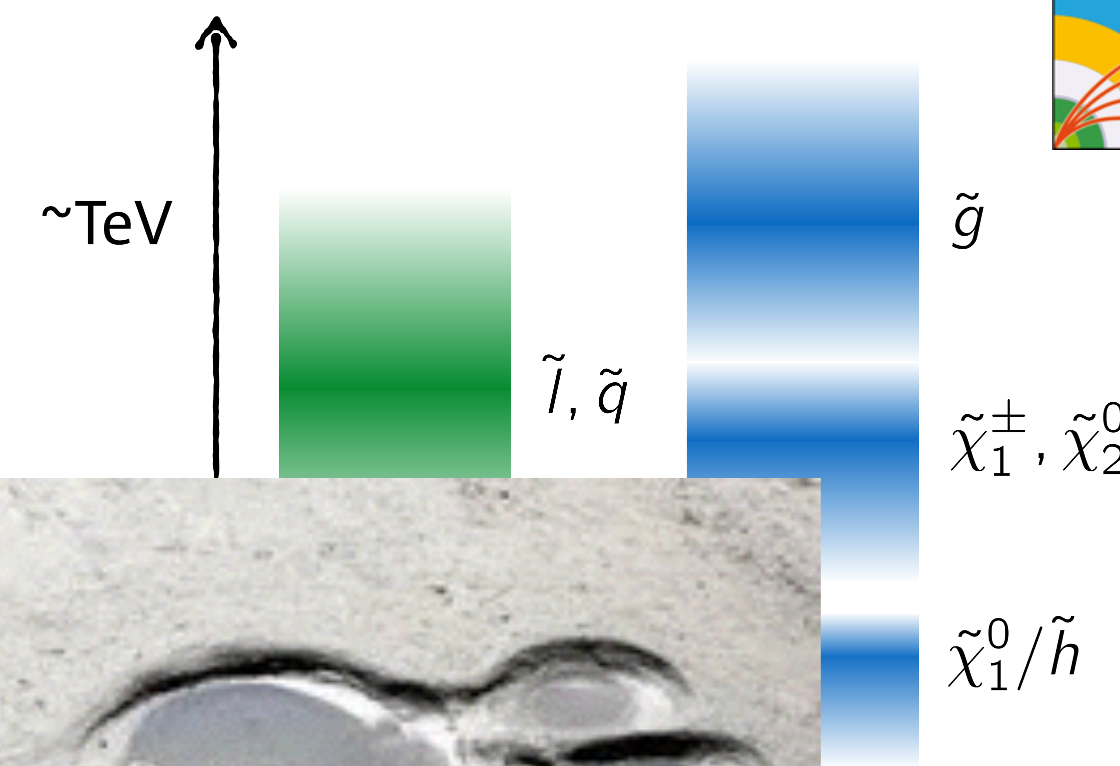
- Introduction
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- Run II
  - Commissioning at 13 TeV
  - Prospects for SUSY
- Conclusions

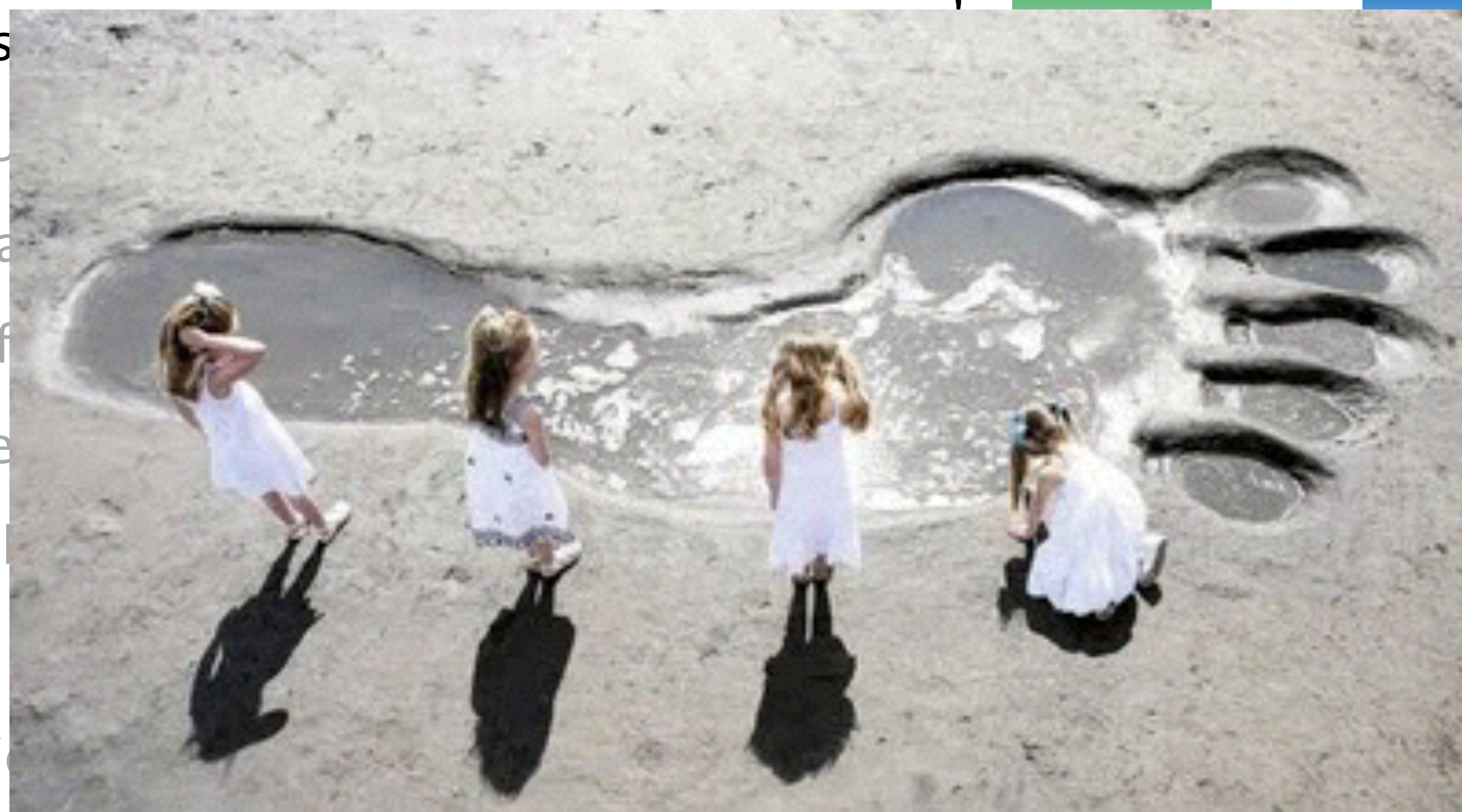


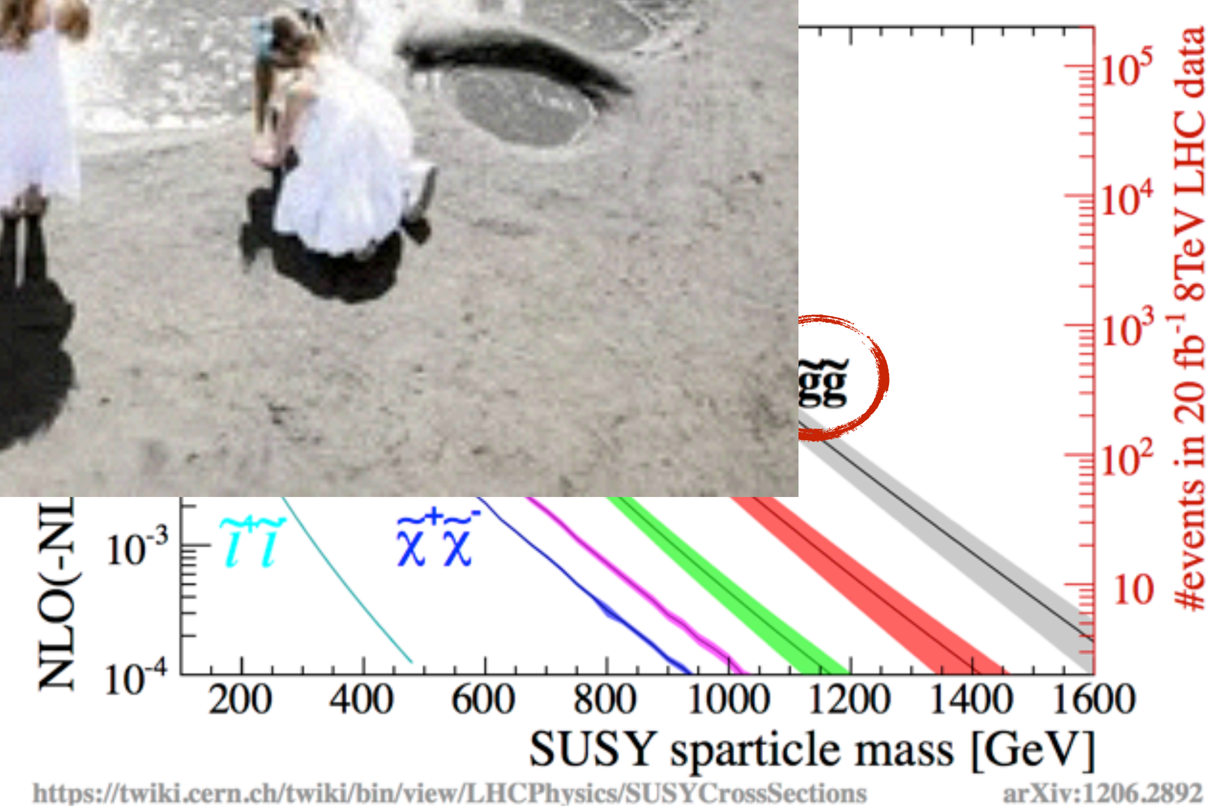


Outline

- Introduction
- **Run I**
  - Inclusive s
  - Stealth SU
  - 3rd genera
  - Searches f
  - pMSSM re
  - RPV searc
- Run II
  - Commissi
  - Prospects for SUSY
- Conclusions



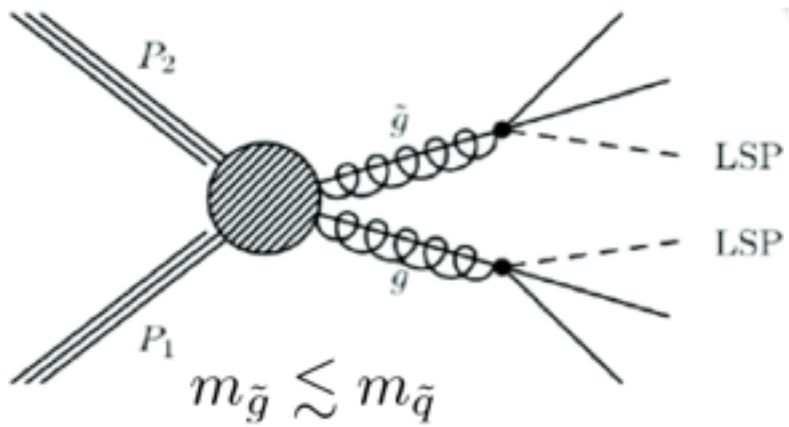


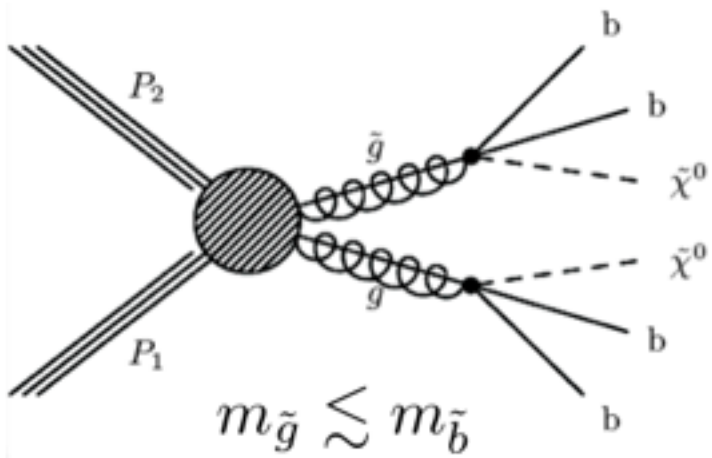


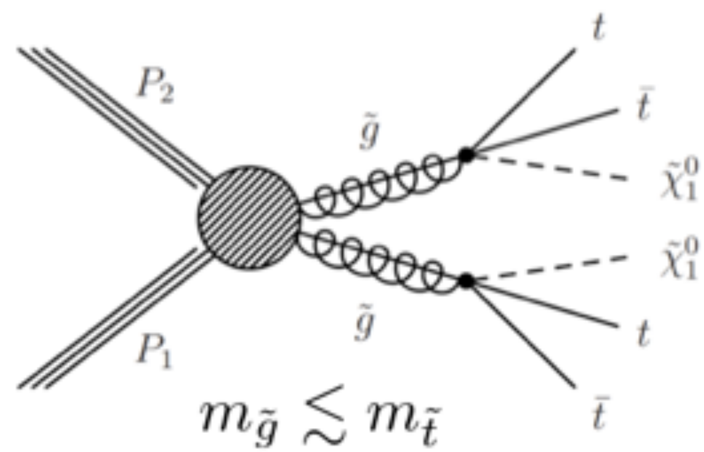
“Natural” SUSY Signatures

Light gluinos

- High N_{jet}
- Possibly: high $N_{\text{b-tag}}$
- Possibly: leptons (e.g. SS)

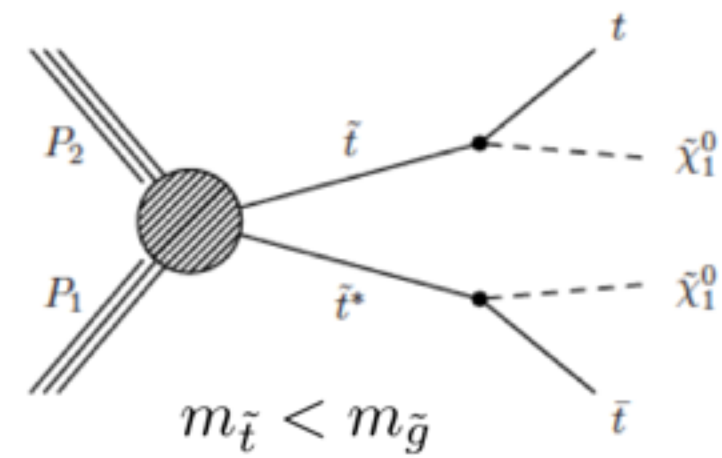






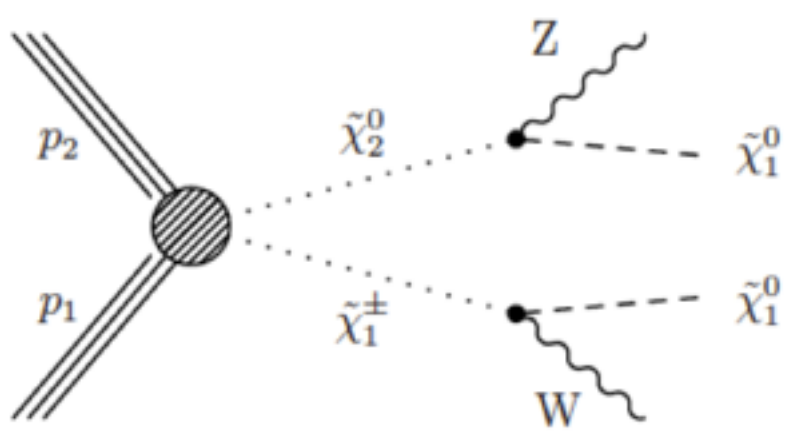
Light top-squarks

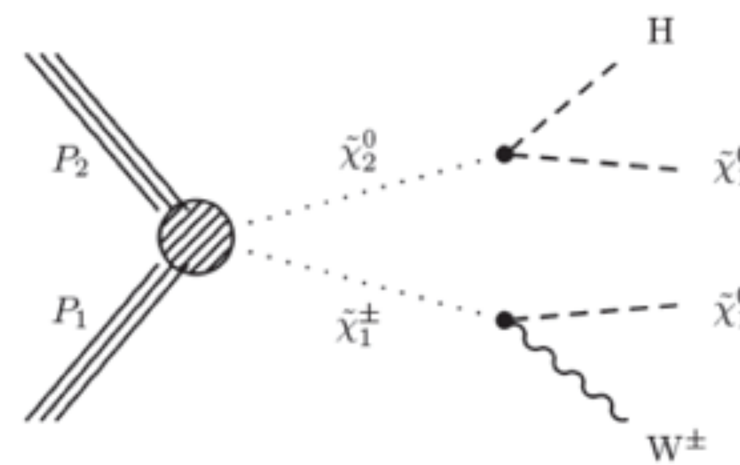
- Small cross section
- Possible signature: $t\bar{t}$ + MET



Light winos and higgsinos

- (Very) small cross section
- Clean signature, e.g. with leptons + MET





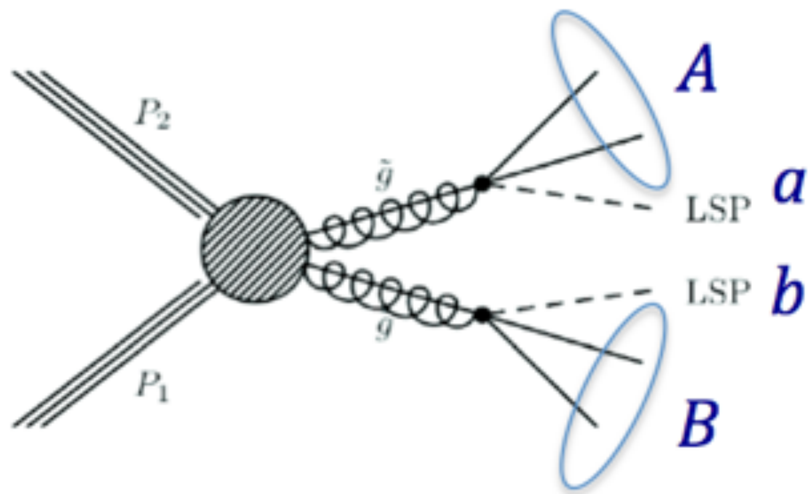
Inclusive Searches

F. Lacroix (Wed)

Very sensitive searches in all-jet final state, **for example:**

M**T2**: extension of transverse mass to two invisible particles

$$M_{T2}^2 = \min_{p_T^a + p_T^b = \not{E}_T} \left(\max \left(m_T^2(p_T^a, p^A), m_T^2(p_T^b, p^B) \right) \right)$$



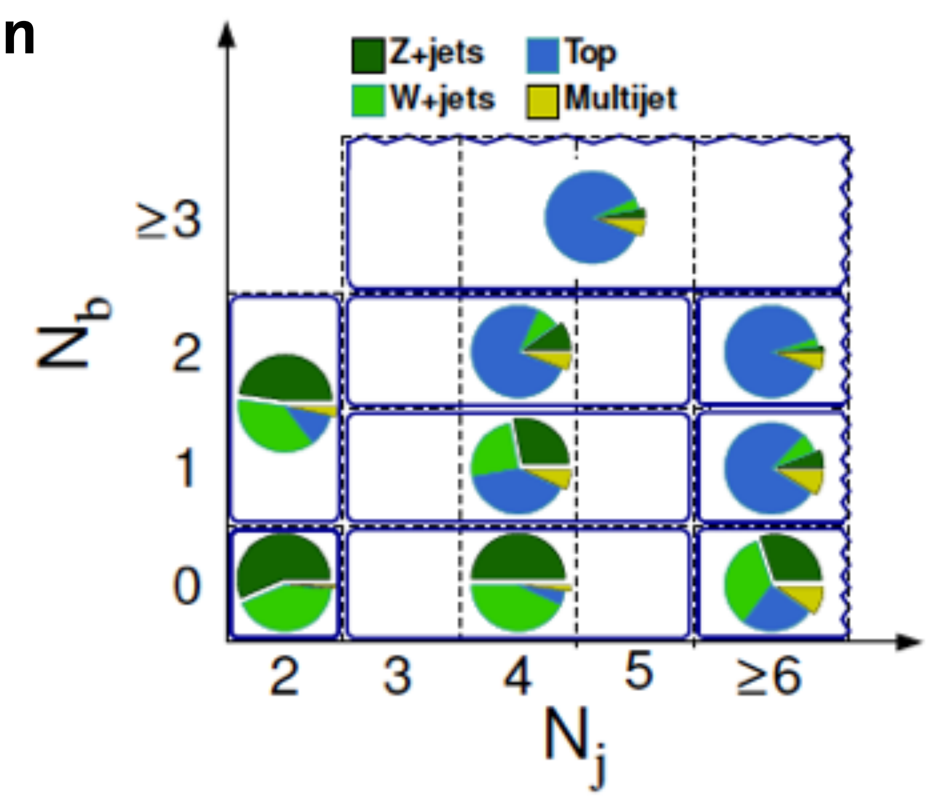
Trigger: H_T>650 GeV; MET>150 GeV; H_T>350 GeV & MET>100 GeV

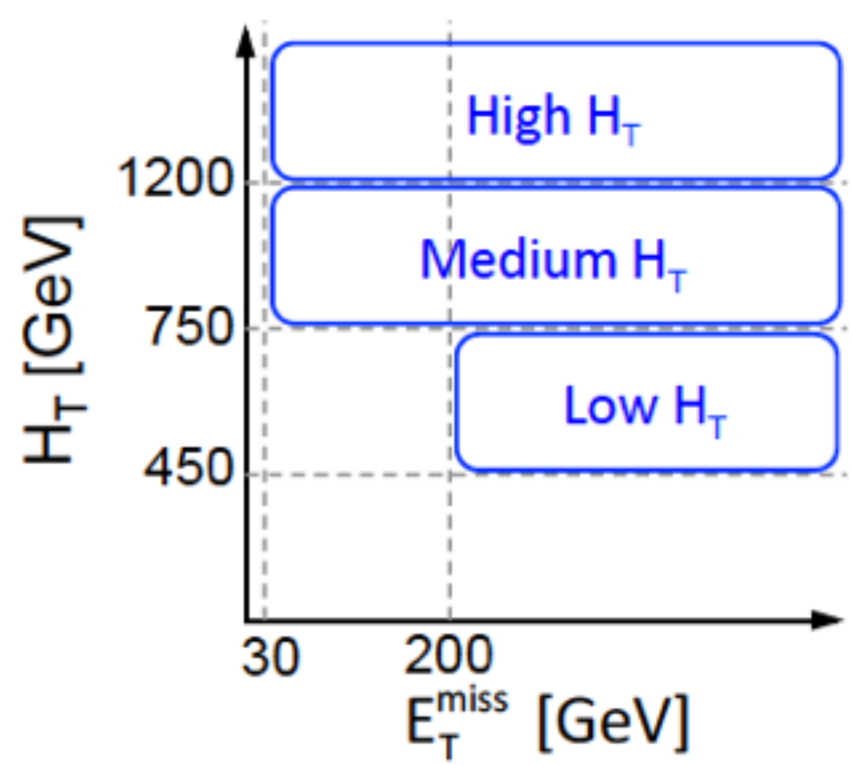
Selection: at least 2 jets; no light leptons (e or μ); M_{T2} in bins of H_T, N_{Jets}, $N_{b\text{-tags}}$

Data driven SM bg estimation

Sensitivity to several topologies:

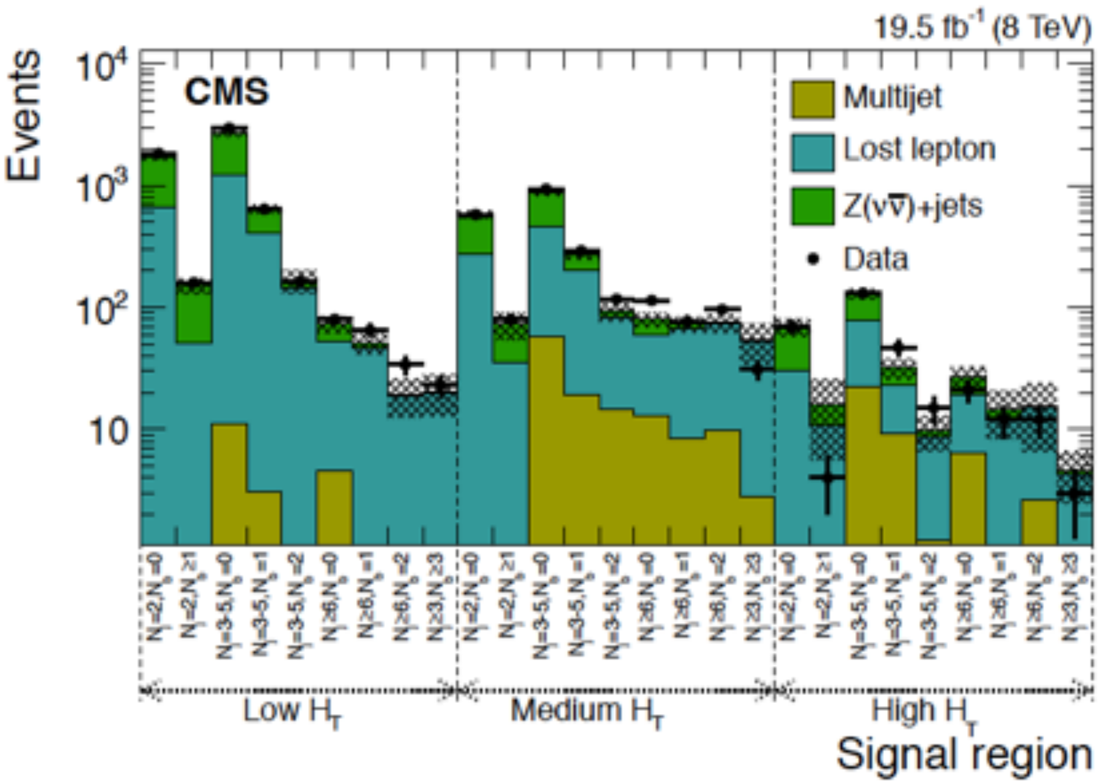
- Squarks (even stops)
- Gluinos
- h(125) in SUSY cascades



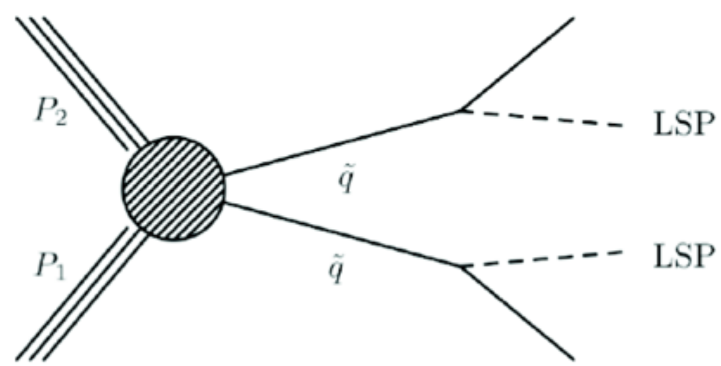


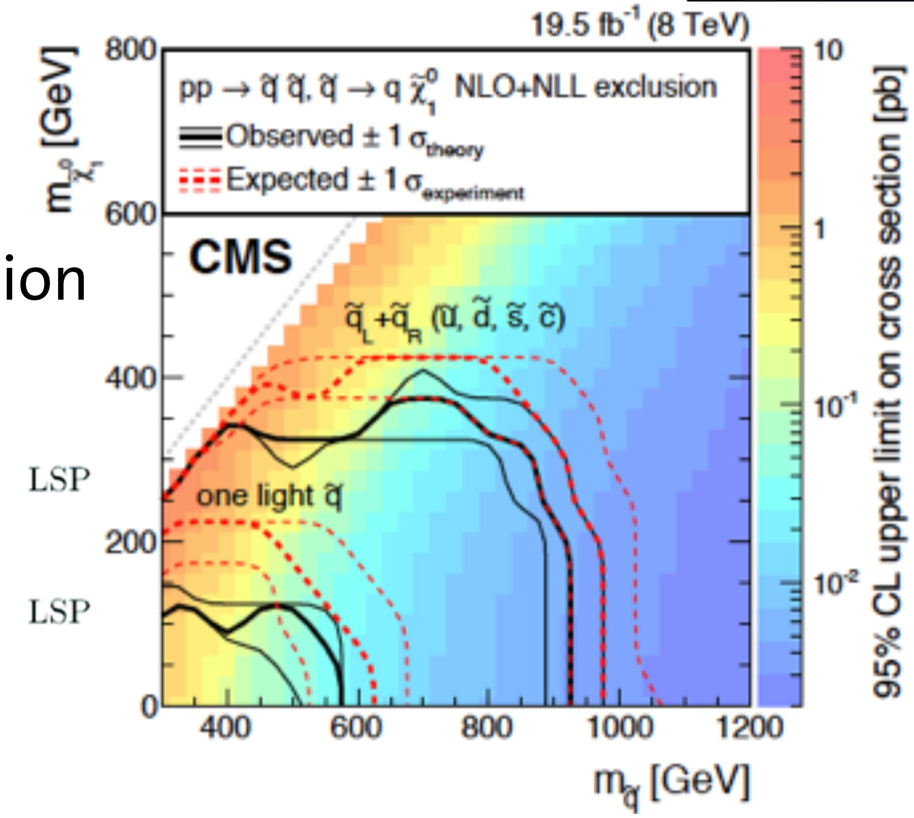
SUS-13-019, JHEP

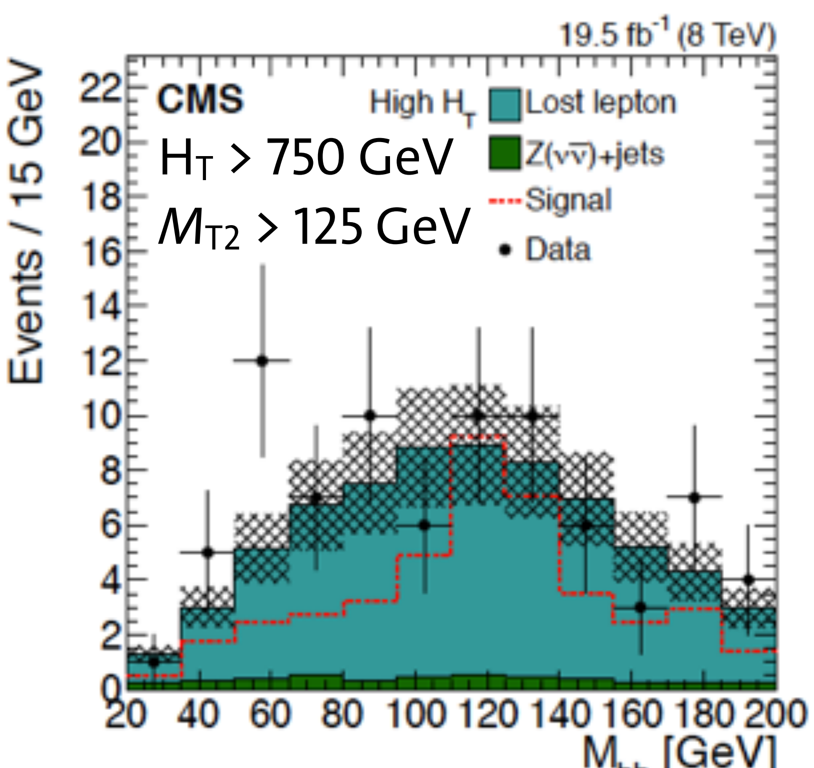
M_{T2}: Selection of Results



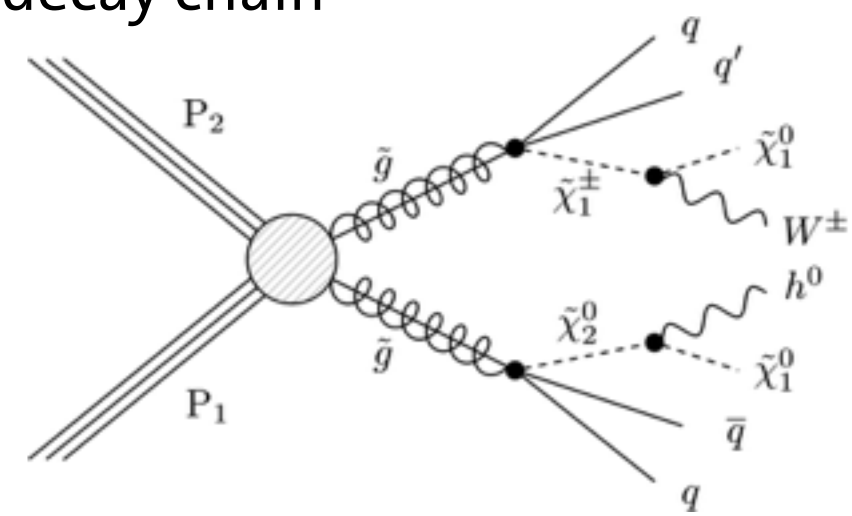
SMS Interpretation:
Direct squark production

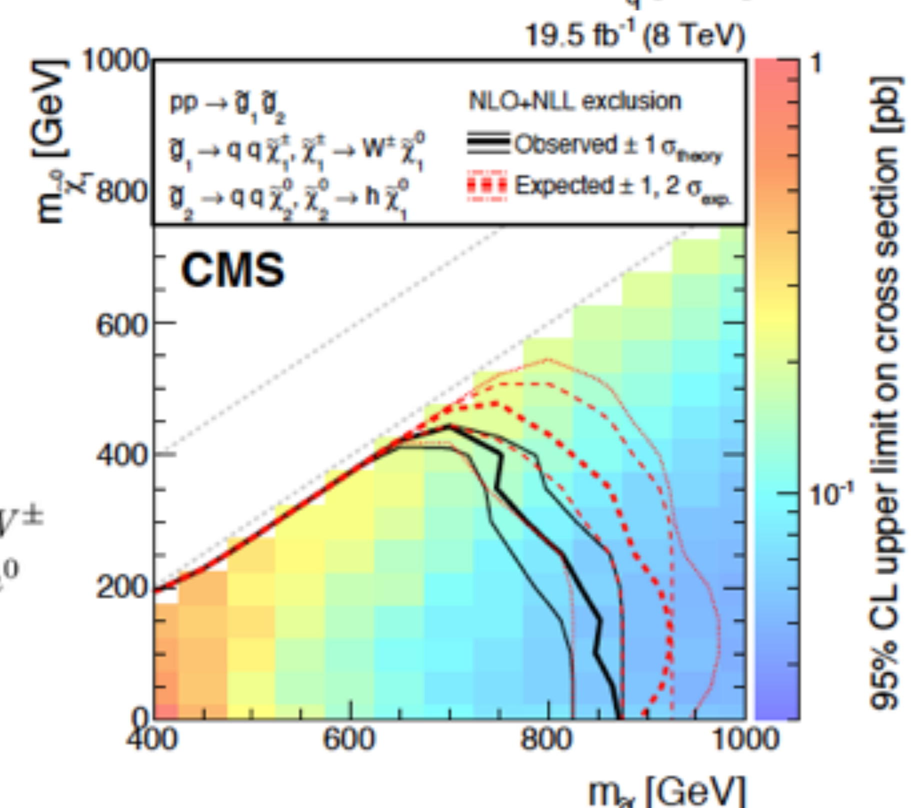






SMS Interpretation:
Gluino production with $h(125)$ in decay chain



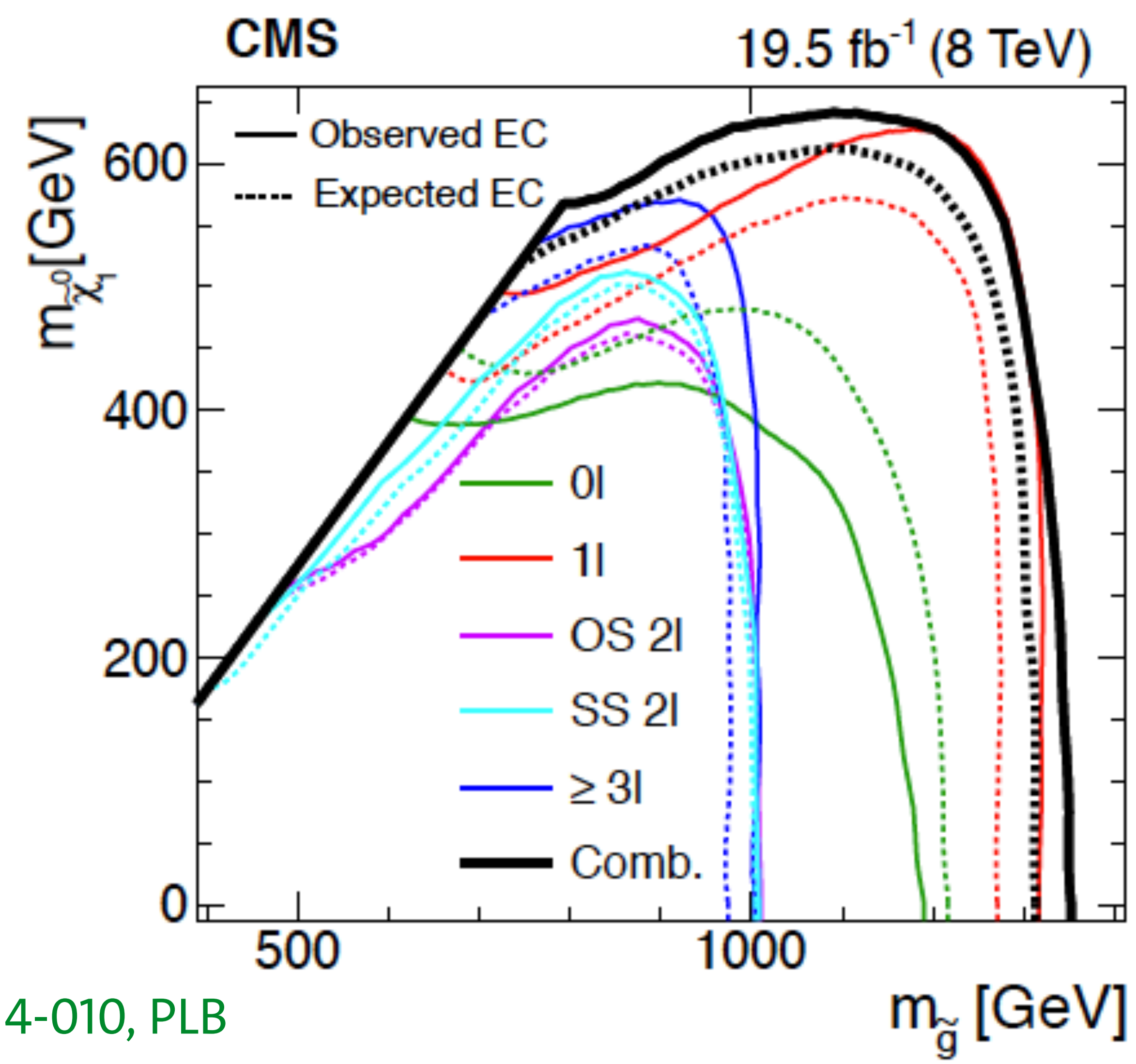


SUS-13-019, JHEP

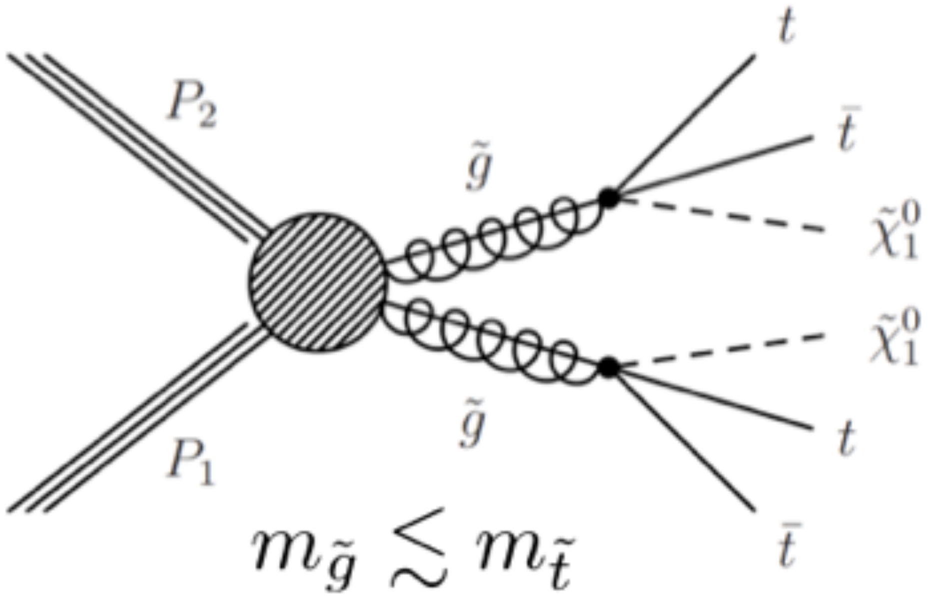
Gluino Mediated 3rd Gen. Squarks

- High object multiplicity (jets, leptons, *b*-tags)
- **Most sensitive search:** 1 lepton + 6 jets + 2 *b*-tags

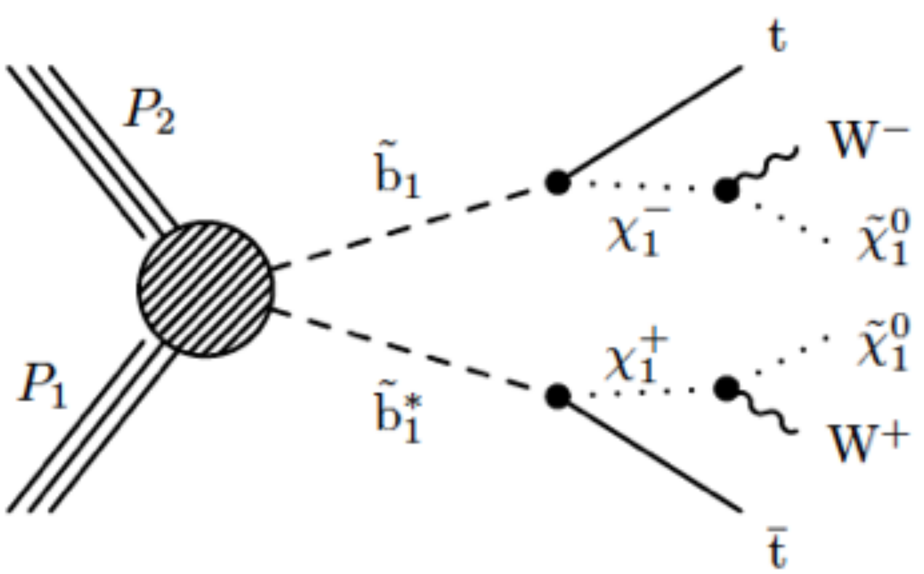
  $H_T > 400$ GeV & $S_T^{lep} = \not{E}_T + p_T^{lep} > 250$ GeV
- Combination of various searches:



SUS-14-010, PLB

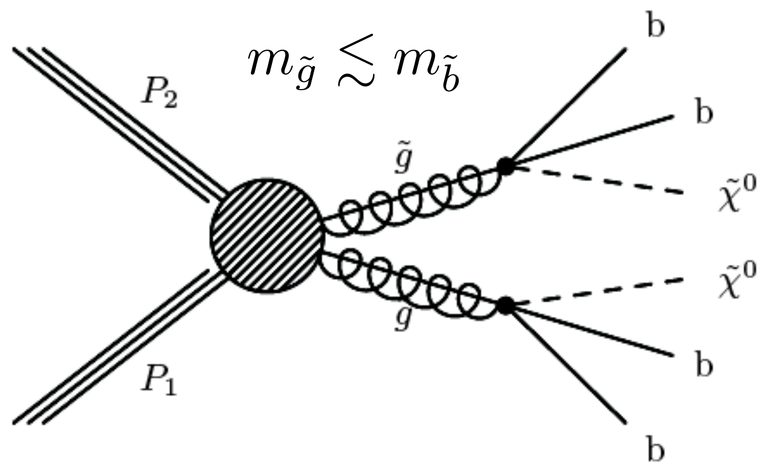


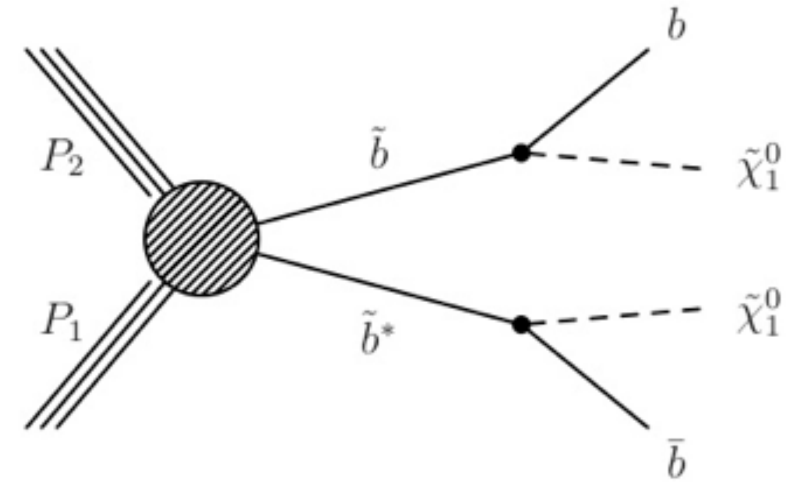
Also sensitive to other topolgies with 4*W* in final state:



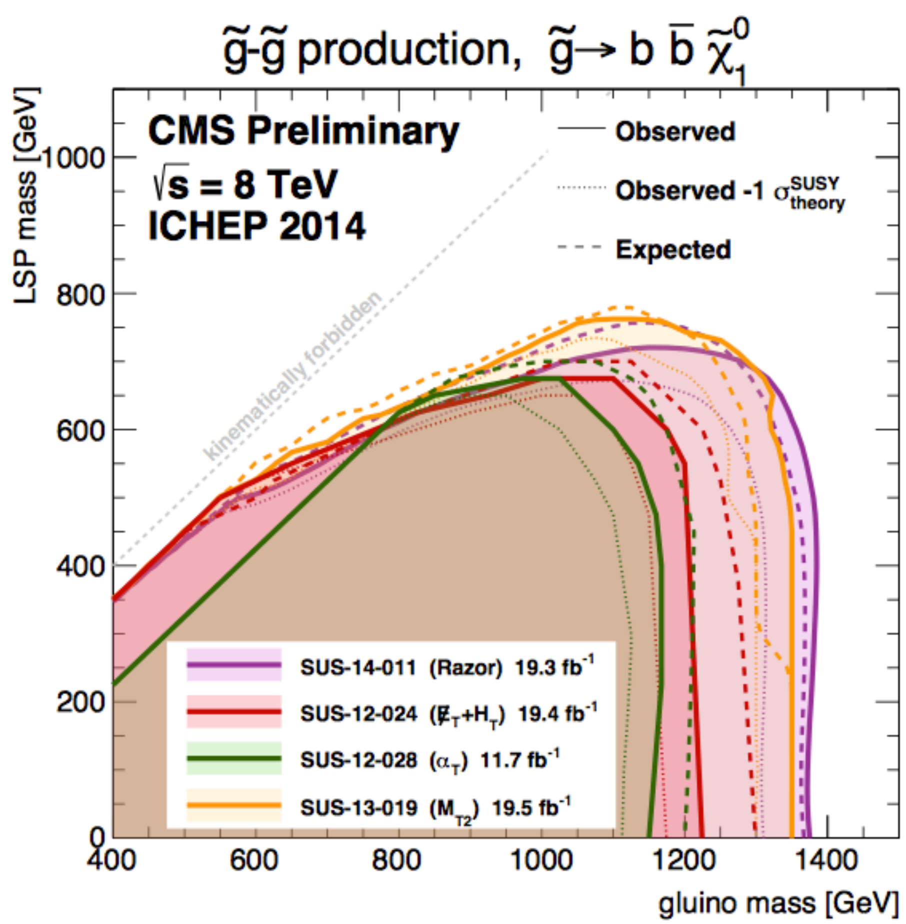
$\tilde{g}\tilde{g} \to b\bar{b}b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ & $\tilde{b}\tilde{b}^* \to b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$

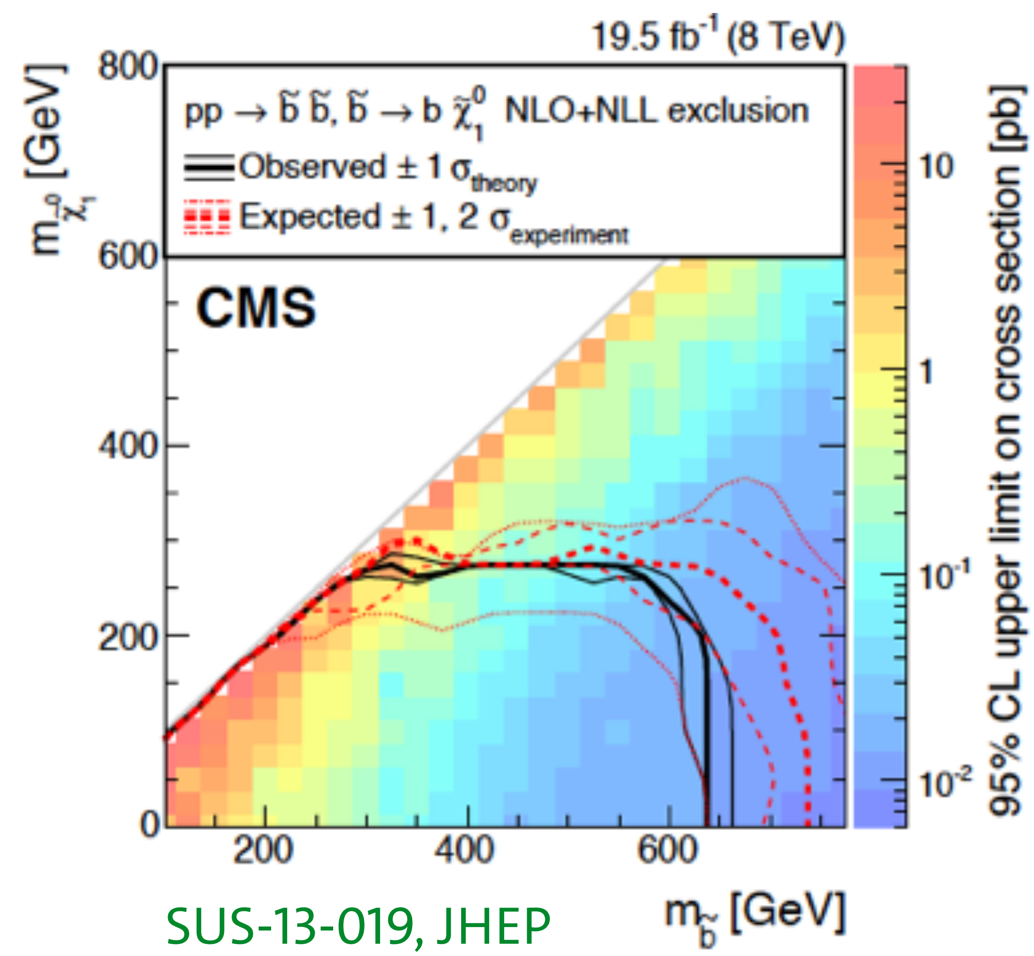
Hadronic searches with b-tags also sensitive to "light" bottom-squarks (direct production or gluino mediated)





Limits on SUSY masses comparable to SMS interpretations with light squarks

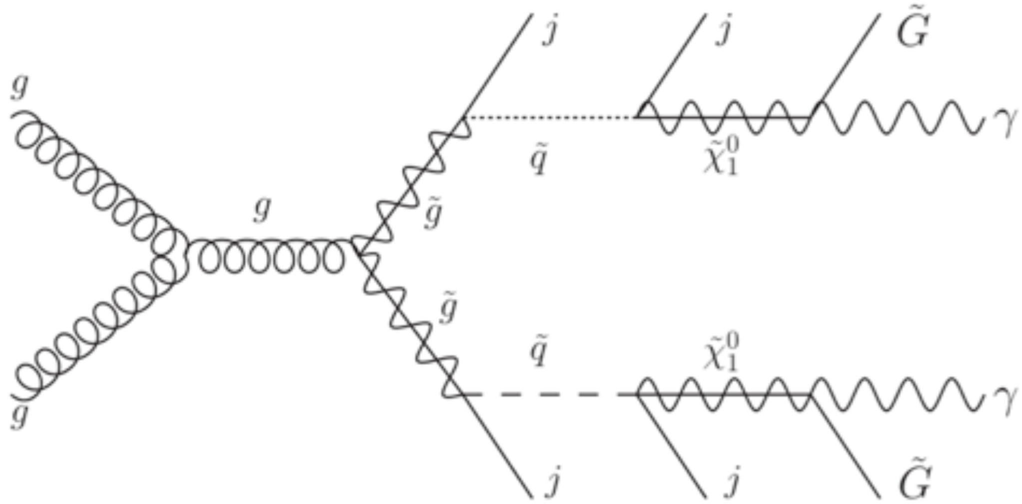


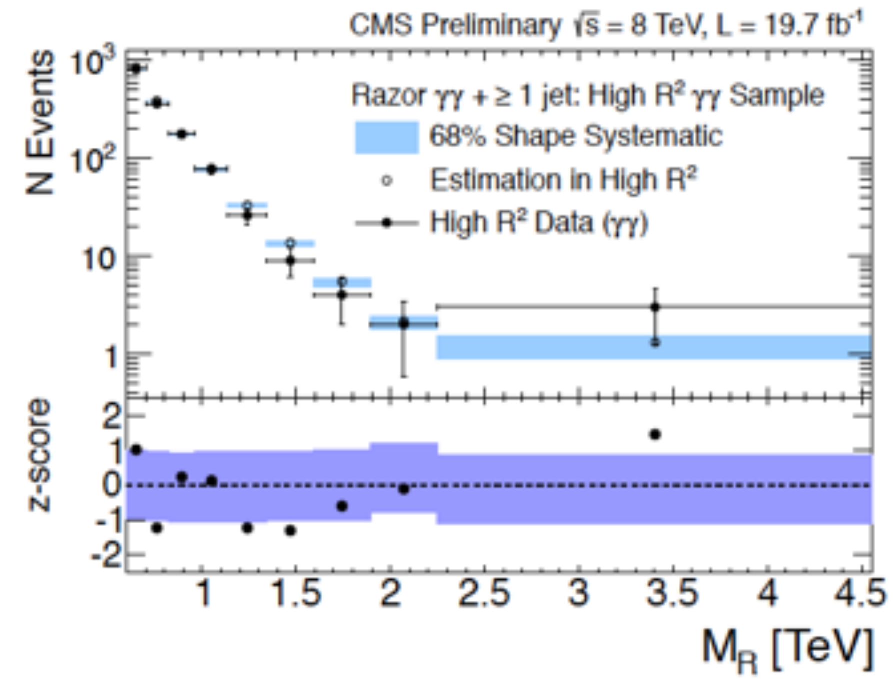


SUS-13-019, JHEP

Photons + Jets + MET

C. Herrera (Wed)





If LSP is gravitino, NLSP is neutralino (or chargino)

Dominant NLSP decays in **G**eneral **G**auge **M**ediation:

- "bino-like": $\tilde{\chi}_1^0 \to \gamma + \tilde{G}$
- "wino-like": $\tilde{\chi}_1^0 \to Z^0 + \tilde{G}$ or $\tilde{\chi}_1^{\pm} \to W^{\pm} + \tilde{G}$

Search with ≥1 γs, H_T > 400 GeV, MET > 100 GeV

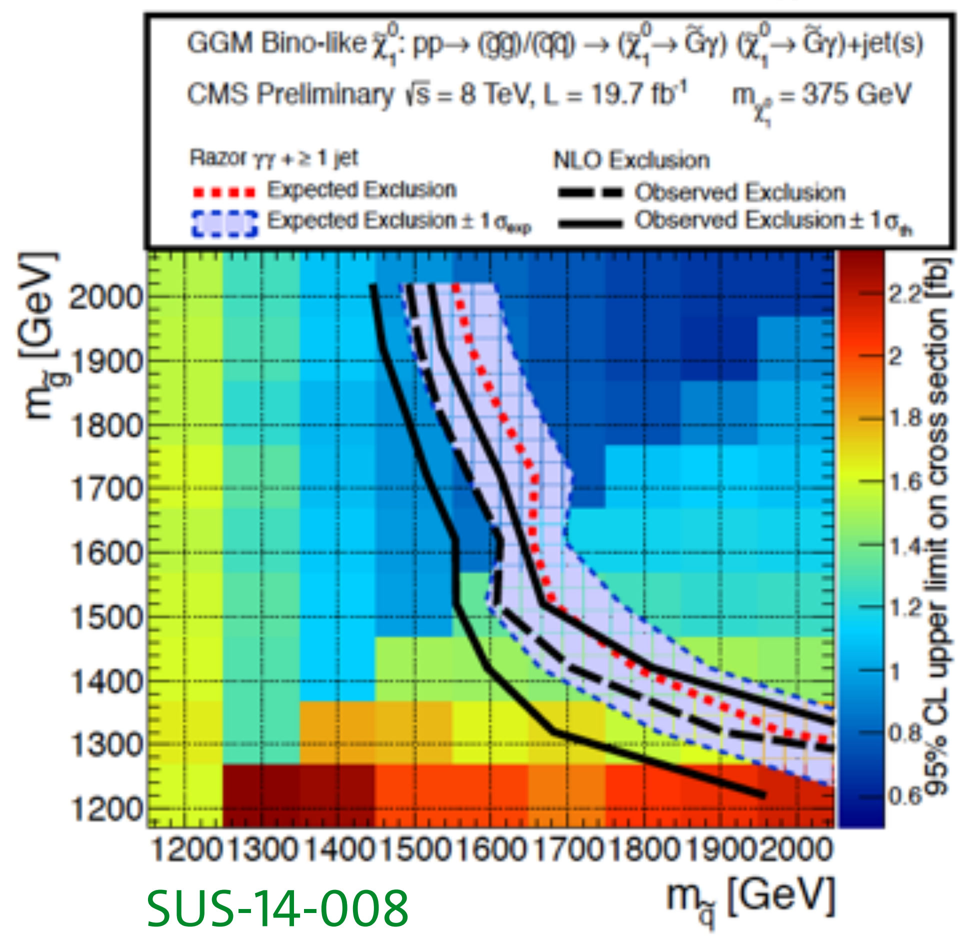
SUS-14-004, submitted to PRD

Search for 2γs+jets with razor variables M_R and R^2

$$M_R = \sqrt{(|\vec{p}_{q1}| + |\vec{p}_{q2}|)^2 - (p_{z,q1} + p_{z,q2})^2}$$

$$M_T^R = \sqrt{\frac{1}{2}\left(\not{E}_T(p_T^{q1} + p_T^{q2}) - \vec{\not{E}}_T(\vec{p}_T^{\,q1} + \vec{p}_T^{\,q2})\right)}$$

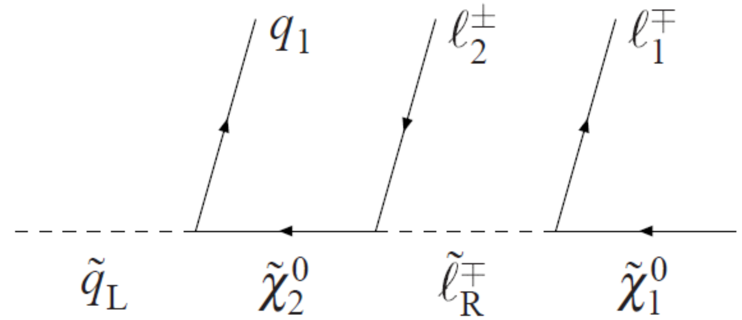
$$R = \frac{M_T^R}{M_R}$$



SUS-14-008

Di-Lepton + Jets: "The Edge"

Generic signature in when $\tilde{\chi}_2^0$ decay into the $\tilde{\chi}_1^0$ via a light slepton or off-shell Z, e.g.



Mass edge sensitive to mass differences

$$(m_{ll}^2)^{\text{edge}} = \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{l}_R}^2}$$

Search with MET > 150 (100) GeV + ≥ 2 (3) jets + 1 OSSF lepton pair:

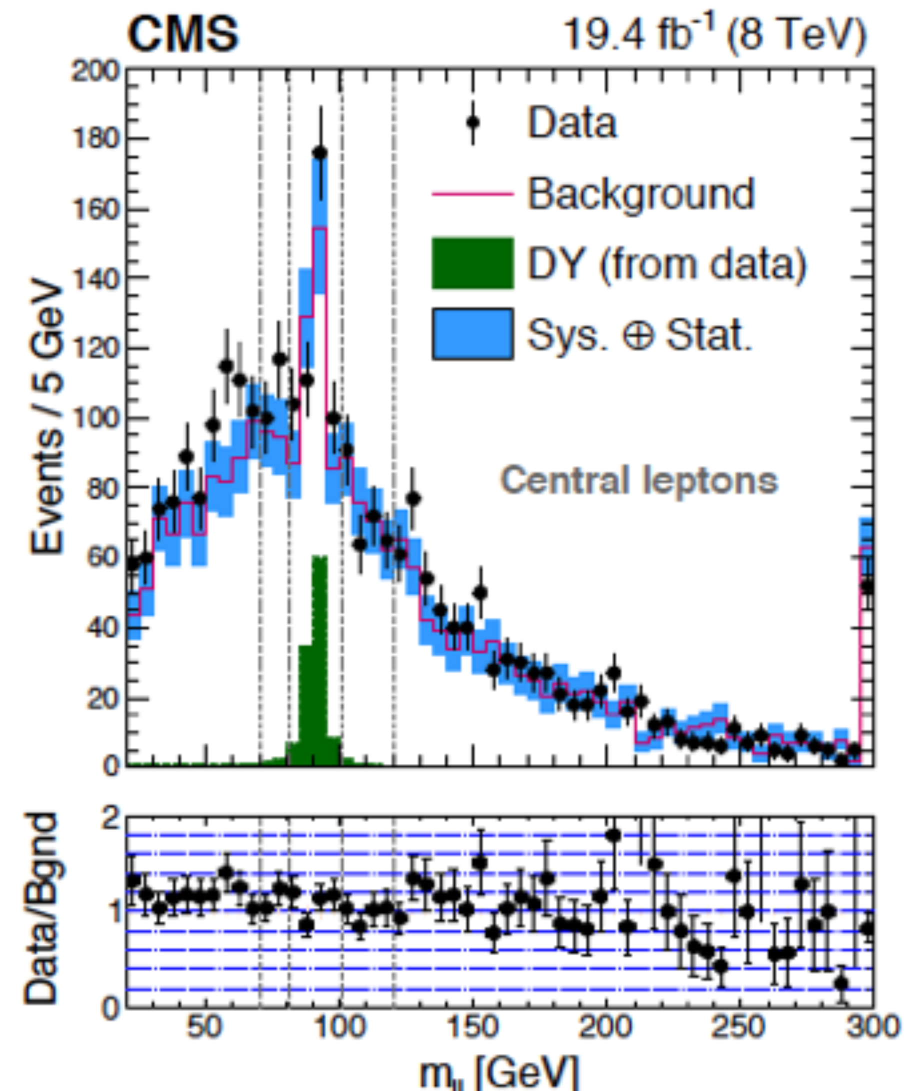
- Flavour symmetric background ($e\mu \leftrightarrow ee/\mu\mu$) from $t\bar{t}$-enriched CR (dominant)
- DY bg from line shape fit or JZB method

Best fit: $m_{ll}^{\text{edge}} = 78.7 \pm 1.4\ \text{GeV}$

... to be followed up at 13 TeV!

J.-F. Schulte (Tue)

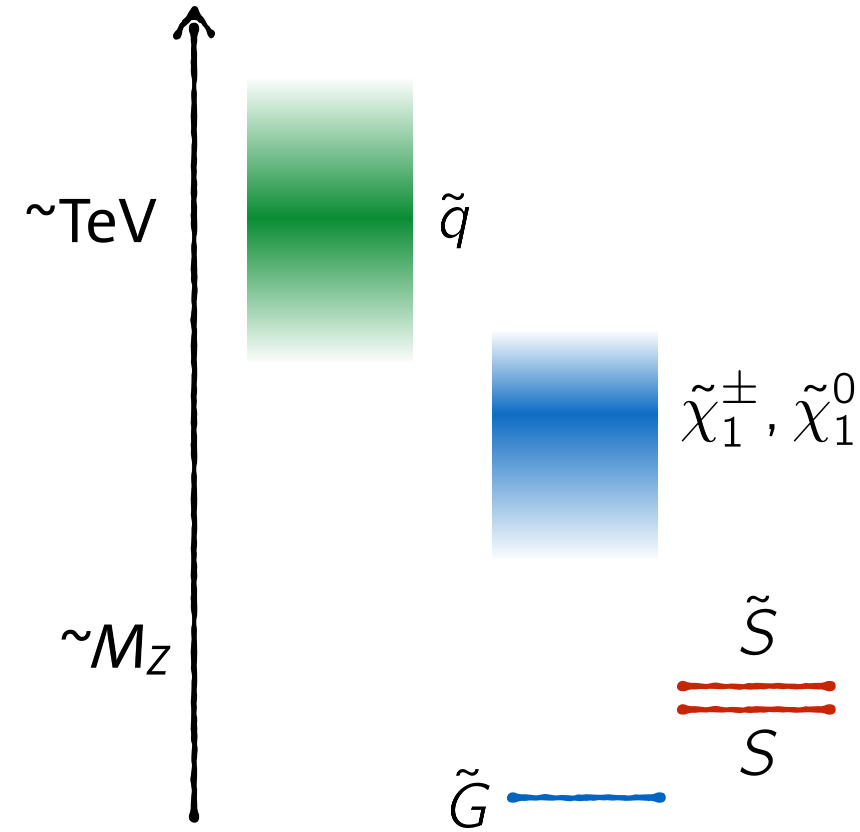
SUS-14-014, JHEP

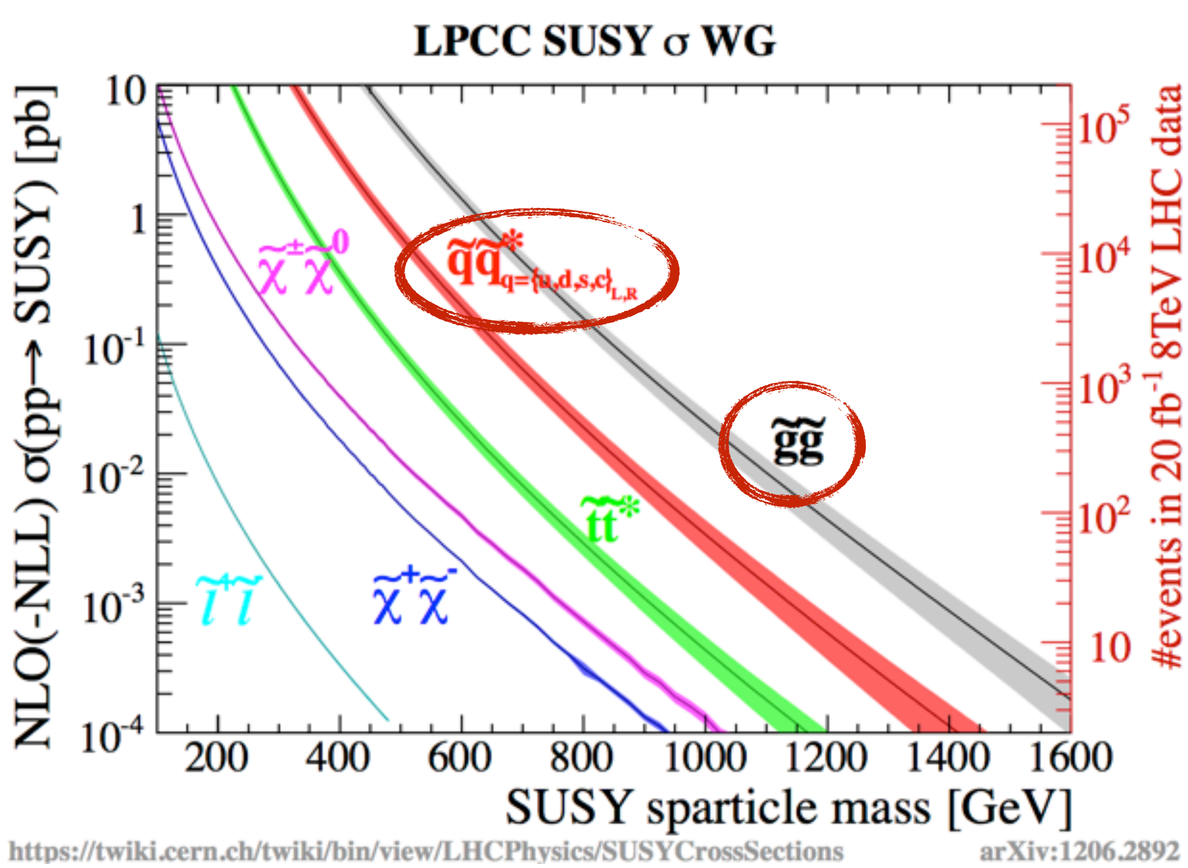


	Low-mass	
	Central	Forward
Observed	860	163
Flavor-symmetric	$722 \pm 27 \pm 29$	$155 \pm 13 \pm 10$
Drell–Yan	8.2 ± 2.6	2.5 ± 1.0
Total estimated	730 ± 40	158 ± 16
Observed − estimated	130^{+48}_{-49}	5^{+20}_{-20}
Significance	2.6σ	0.3σ

Outline

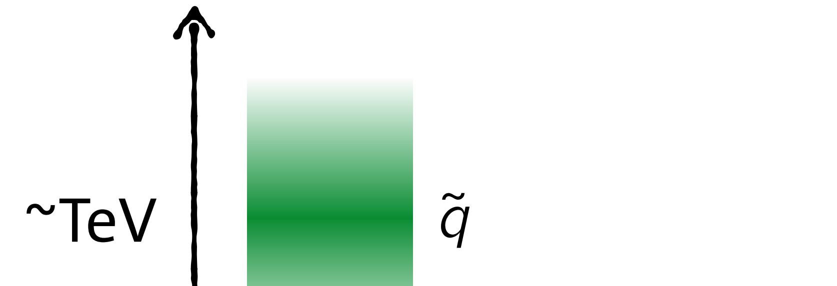
- Introduction
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- Run II
  - Commissioning at 13 TeV
  - Prospects for SUSY
- Conclusions

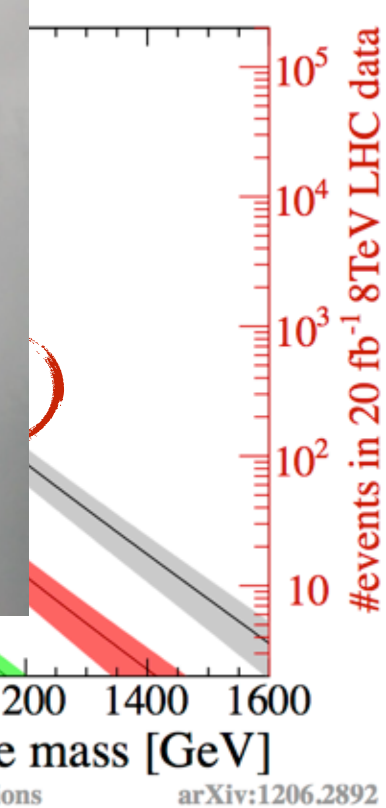




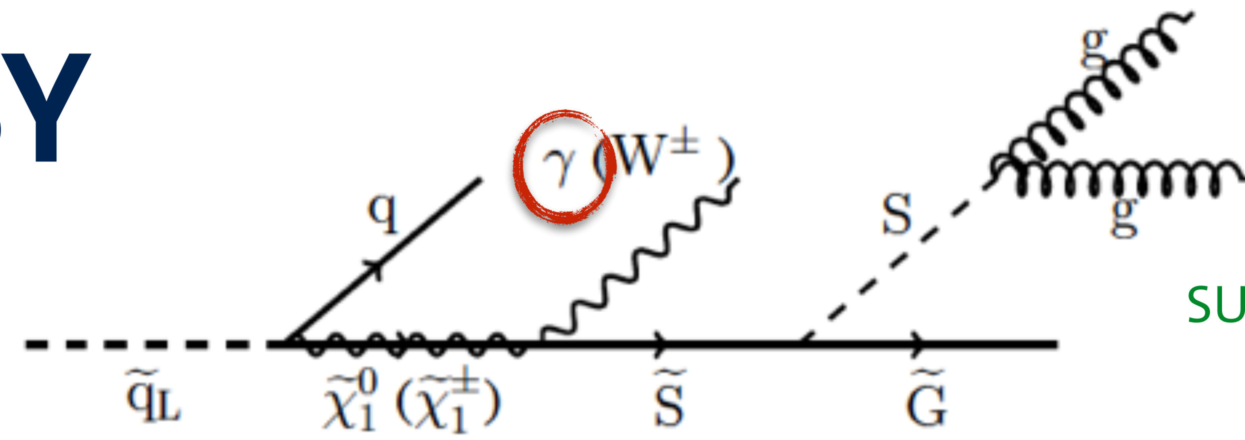
Outline

- Introdu
- **Run I**
  - Inclusi
  - Stealth
  - 3rd ge
  - Search
  - pMSSM
  - RPV se
- Run II
  - Comm
  - Prospe
- Conclusions





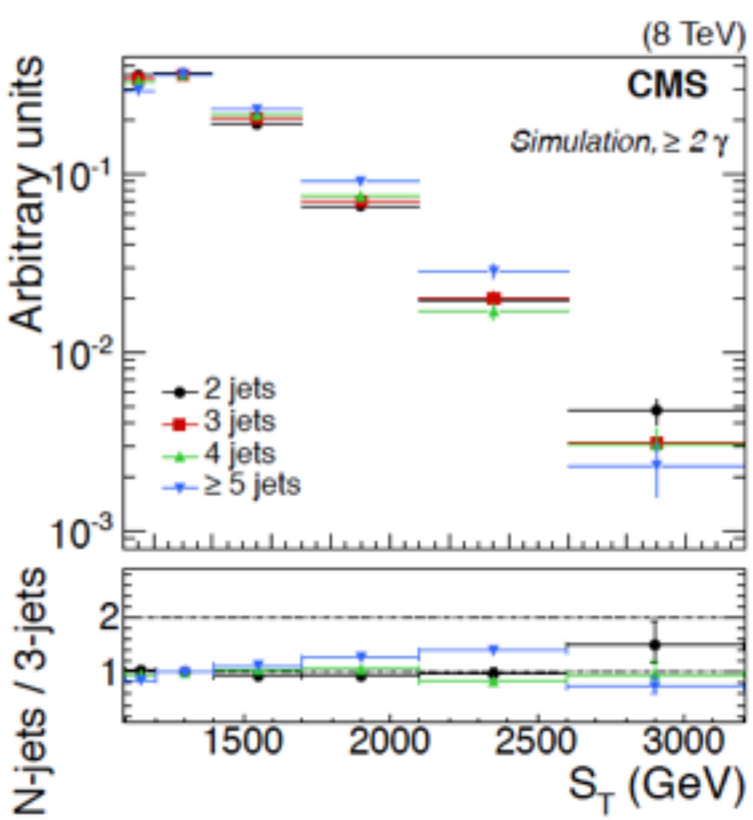
Stealth SUSY

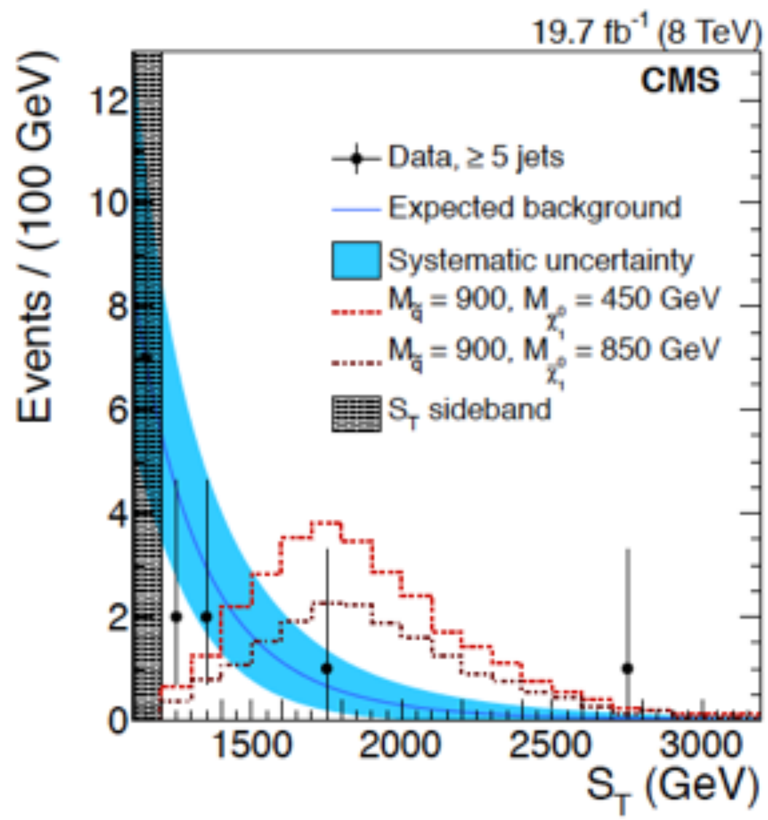


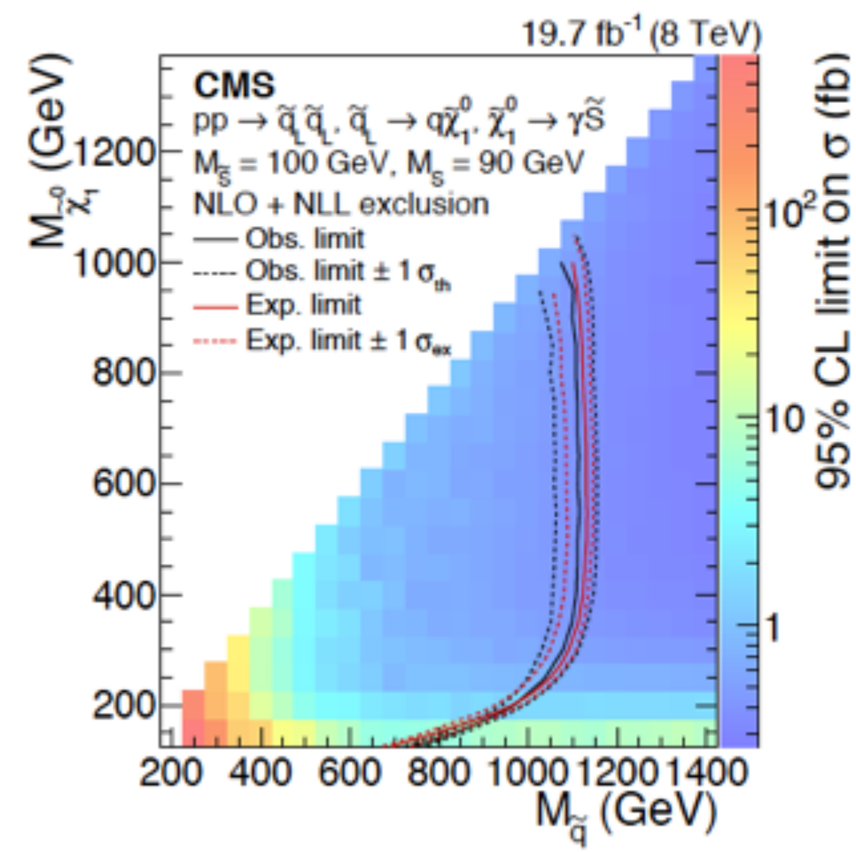
SUS-14-009, PLB

Low MET signatures:

- Compressed spectra; RPV SUSY ...
- **Hidden valley models** (additional singlet/singlino field): signature depends strongly of LSP/NLSP nature and mass difference: $\Delta m = m_{\tilde{S}} - m_S$ (here: 10 GeV)
- **Selection:** Jets (HT) + 1 or 2 photons; sensitive variable: $S_T = \not{E}_T + \sum_{\text{all objects}} p_T$
- Take S_T shape in signal depleted CR (low N_{Jet} = 3, S_T > 1200 GeV) and normalise in S_T side band: 1100 < S_T < 1200 GeV

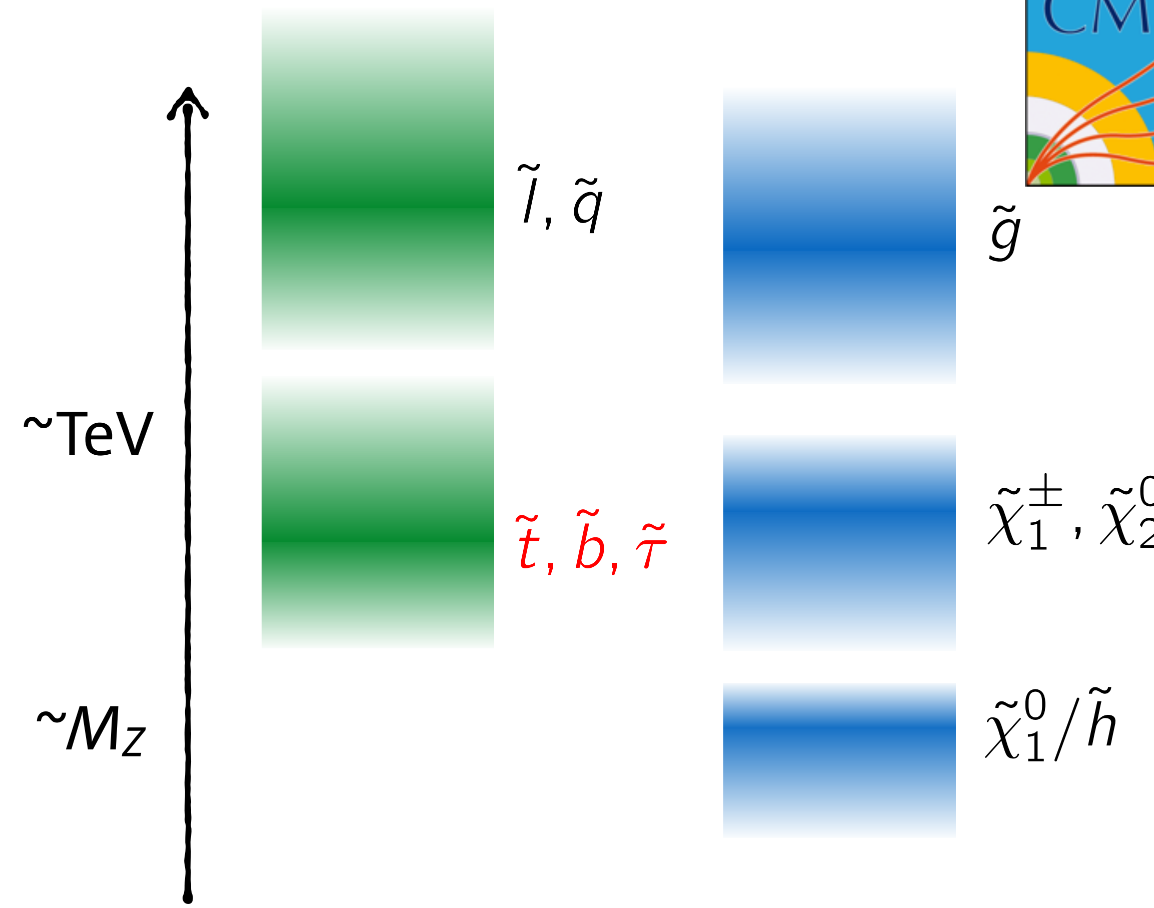


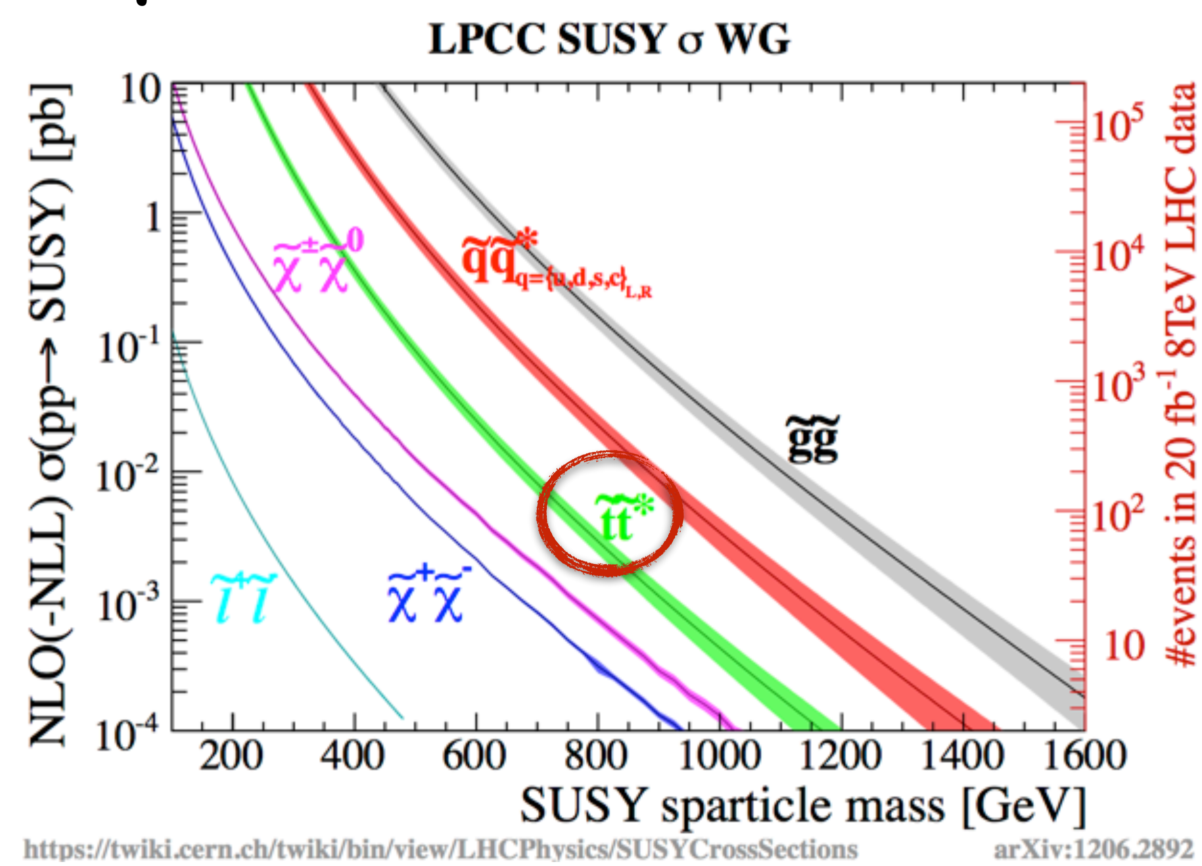




Outline

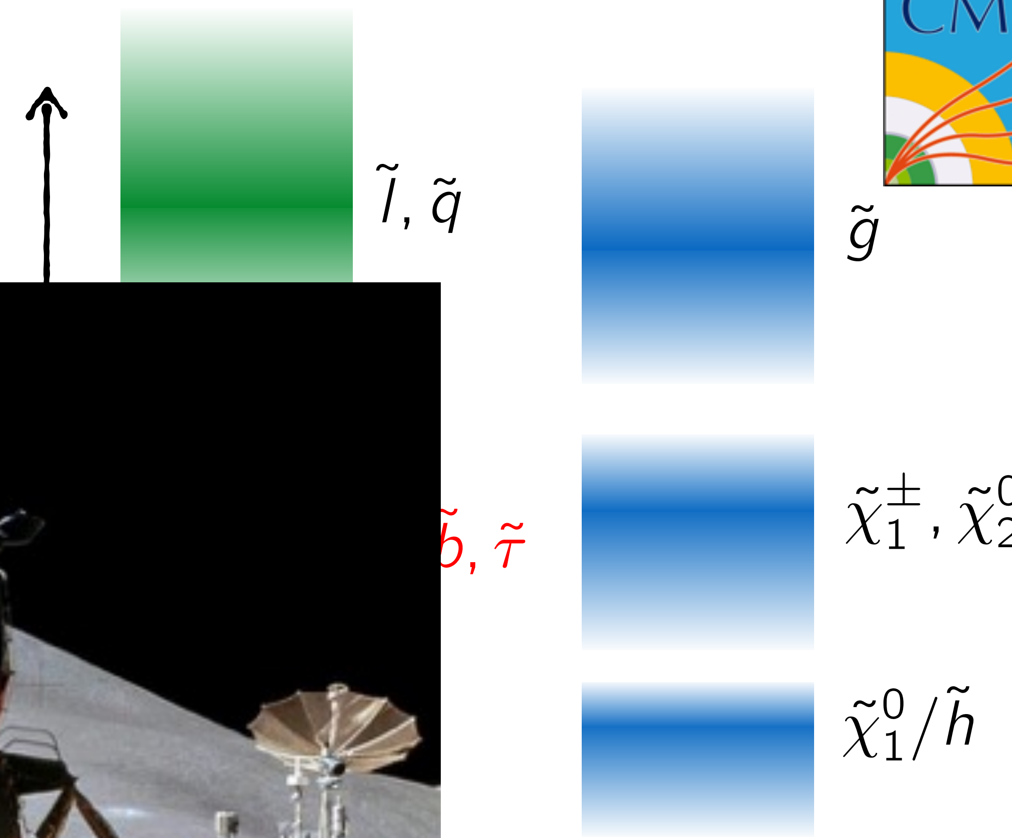
- Introduction
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- Run II
  - Commissioning at 13 TeV
  - Prospects for SUSY
- Conclusions

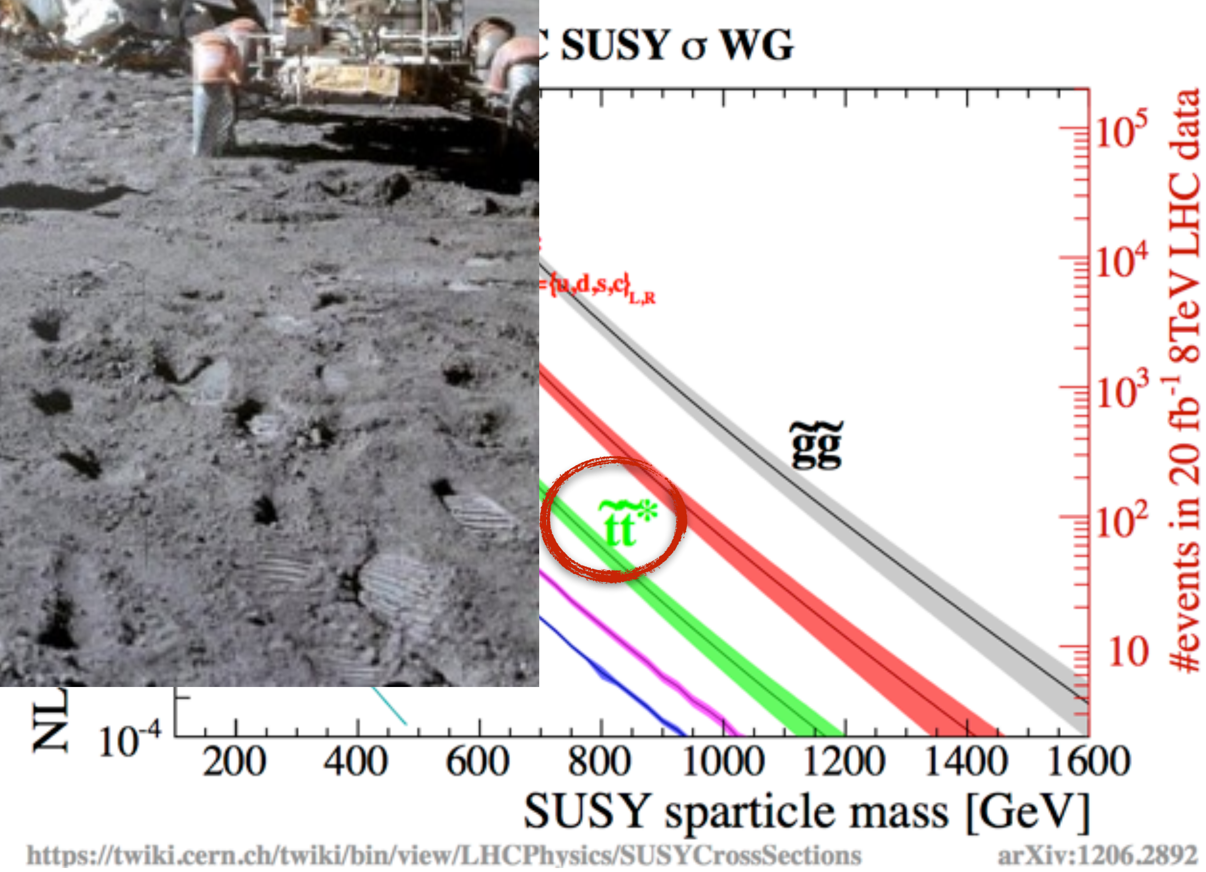




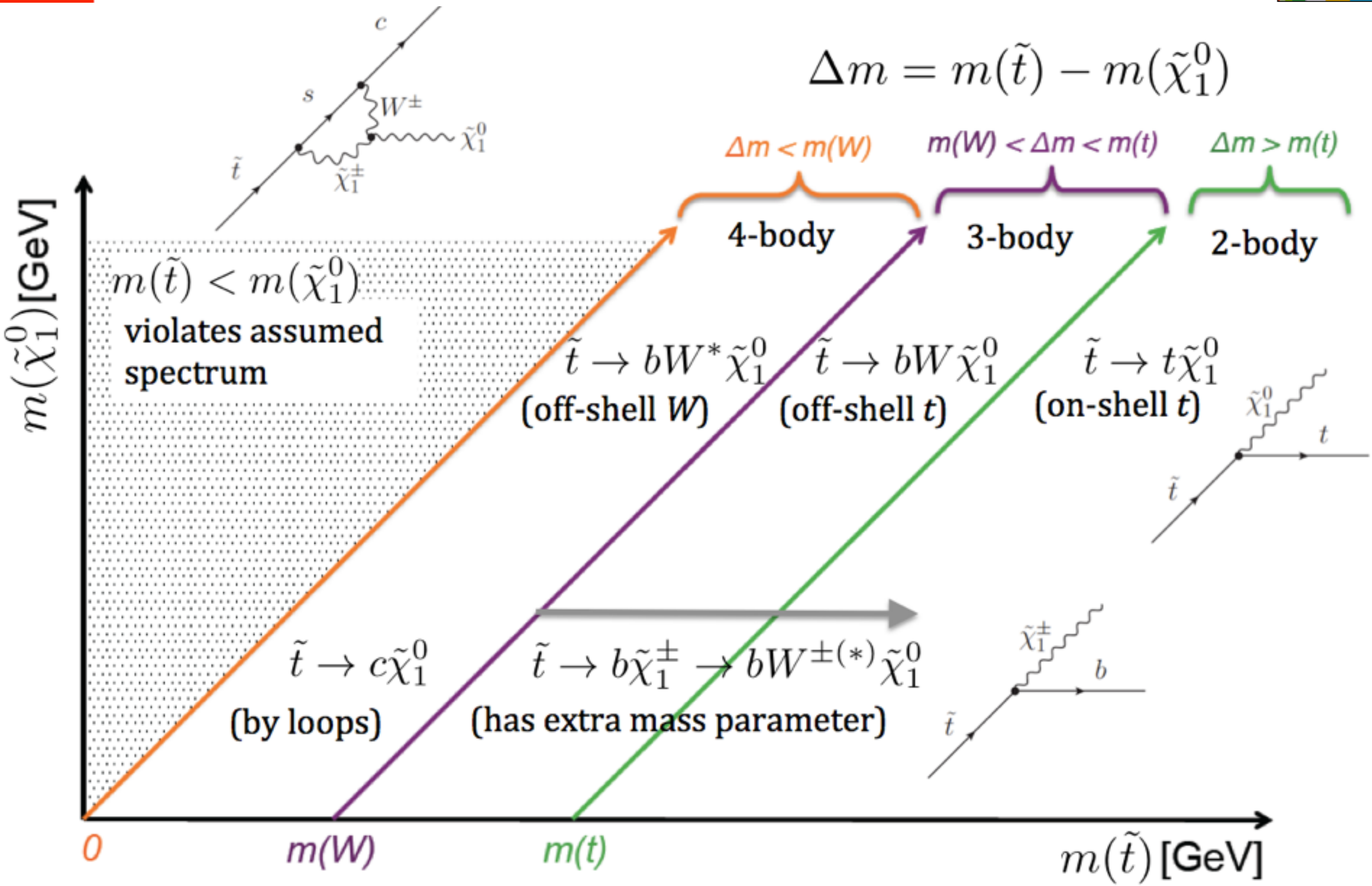
Outline

- Introduction
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation sea
  - Searches for EWK
  - pMSSM reinterpre
  - RPV searches
- Run II
  - Commissioning at
  - Prospects for SUS
- Conclusions





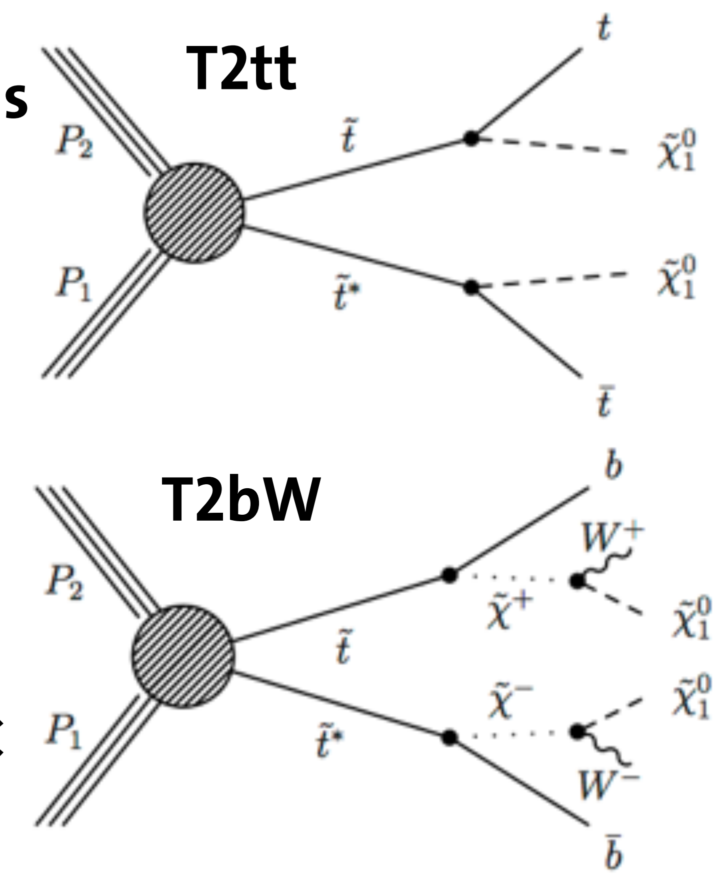
Light Top-Squarks



Hadronic Top-Squark Searches

Targets stop decay into LSP or charginos; optimised object definitions

- $e/\mu/\tau$ (MVA isolation): high bg rejection (lepton veto), high signal efficiency (events with non-prompt leptons not rejected)
- Jets ("picky" jets): Input for had. top identification; similar to top tagging, but focus on high eff. in $t\bar{t}$ dominated sample

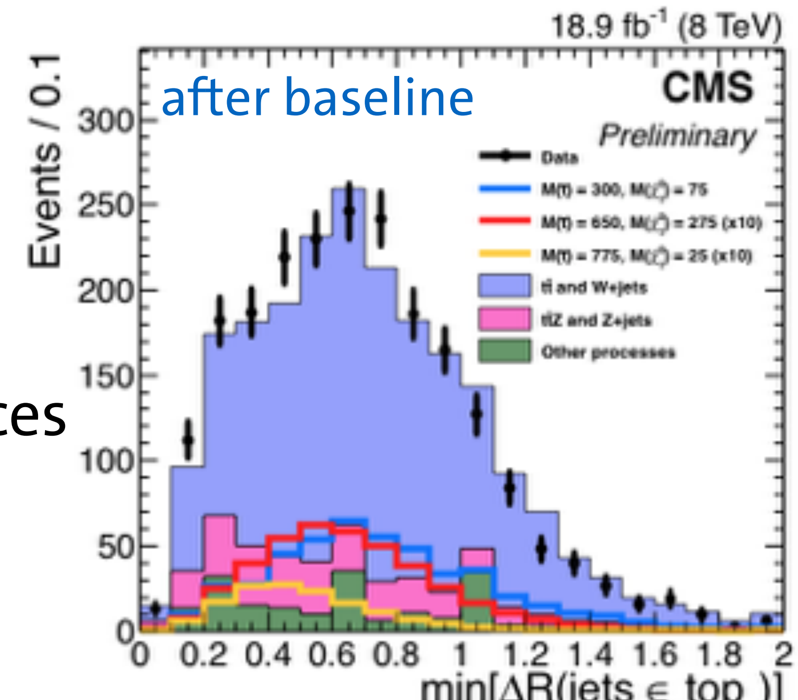


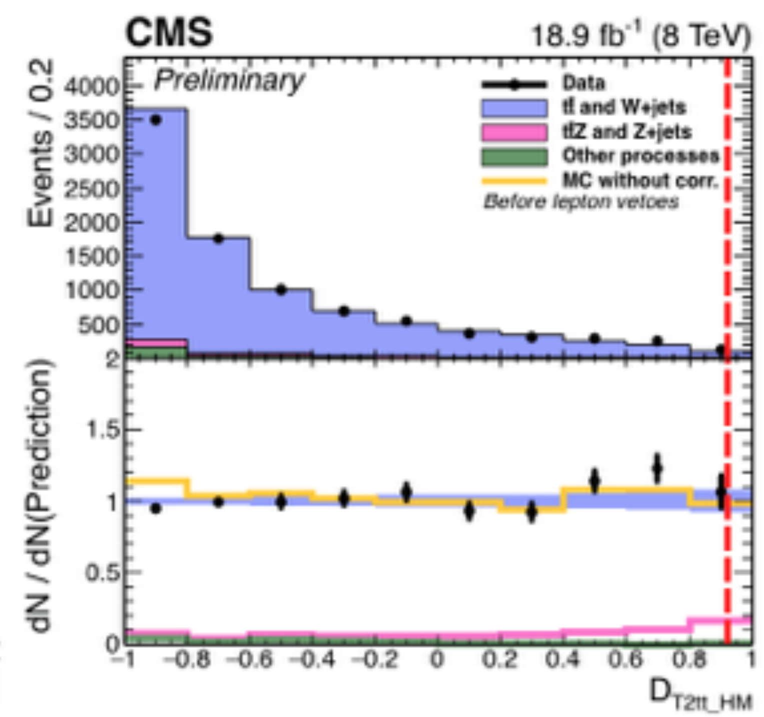
Trigger: MET80DiJet50

Baseline selection: MET > 175 GeV; 1st and 2nd jet p_T > 70 GeV and $|\eta|$ < 2.4; lepton veto; MET not aligned with three leading jets

Separate signal from bg with BDTs: 24 variables for T1tt; 14 for T2bW; training with various signal models

Estimation of SM bgs: Simulation corrected for various data-MC differences (e.g. lepton efficiencies, jet energy corrections, jet energy resolution …)





SUS-13-023

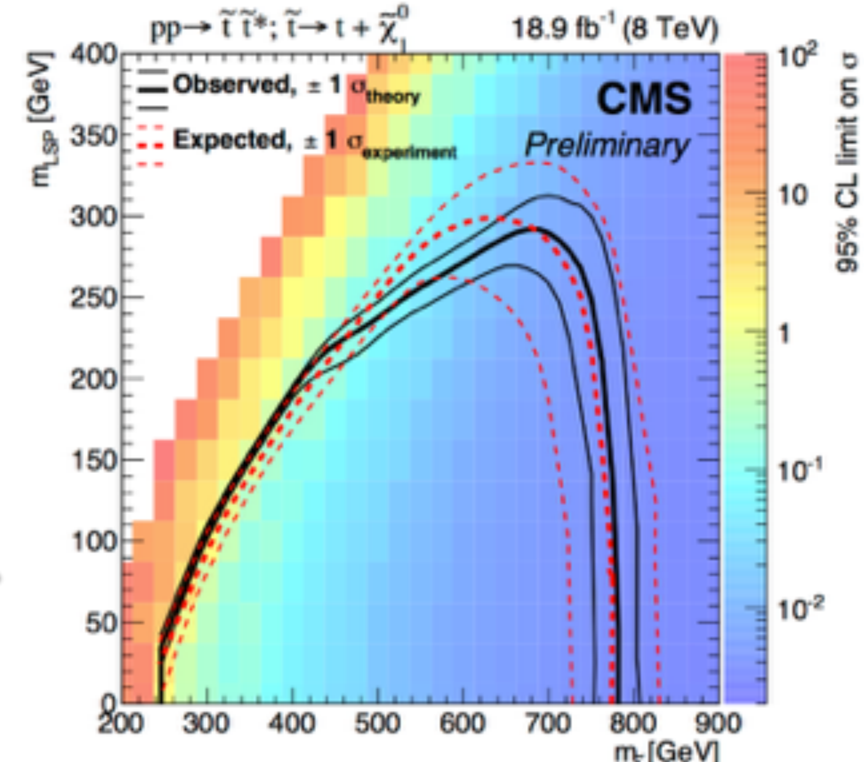
new!

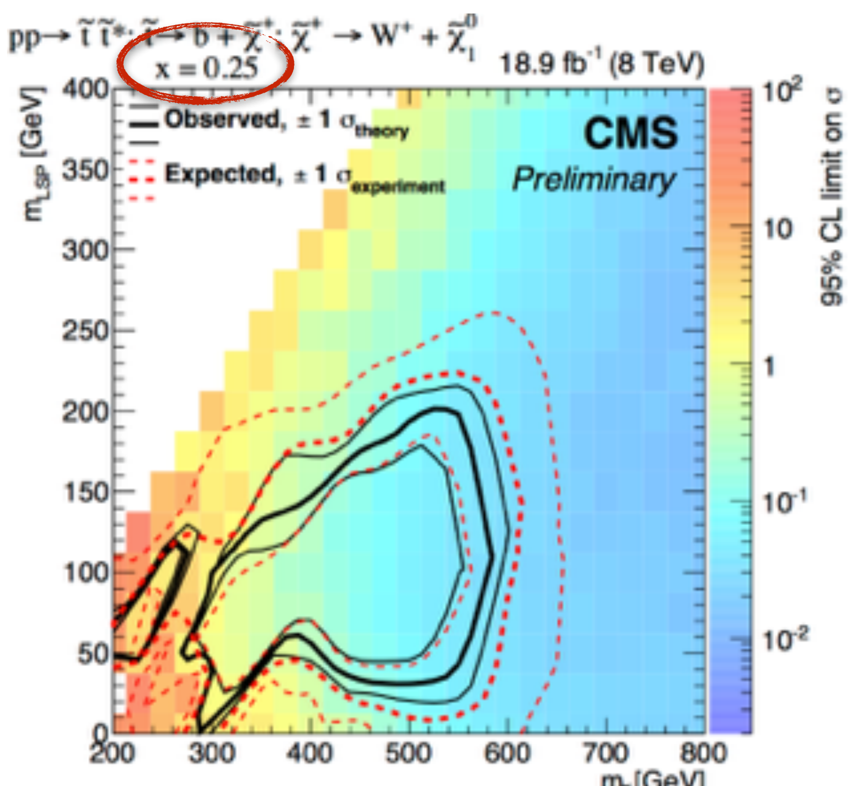
Hadronic Top-Squark Searches

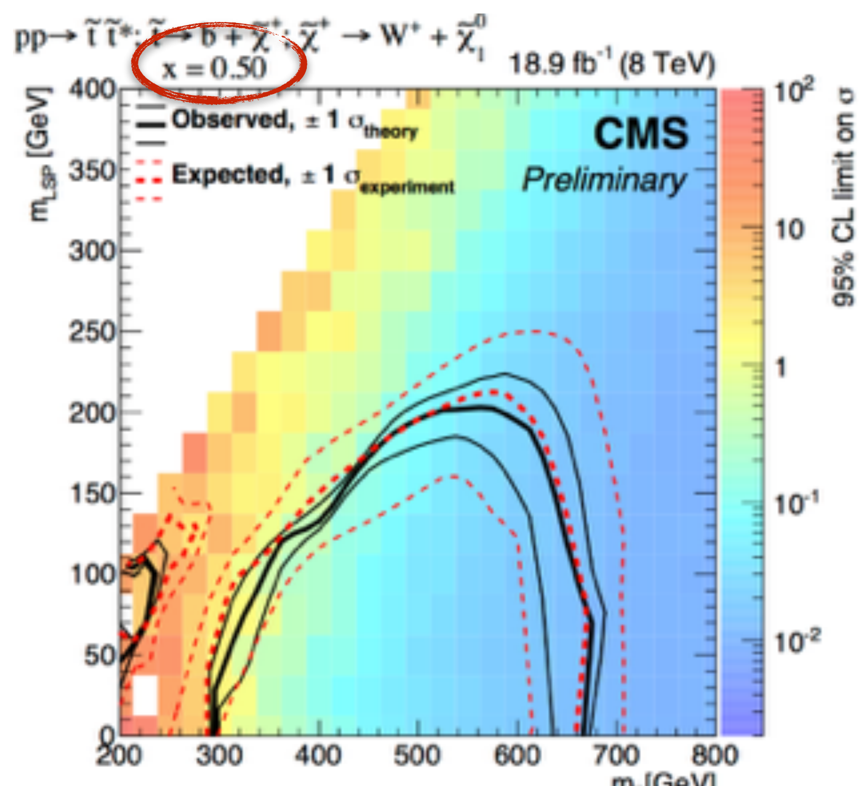
	T2bW				
Search region	LX	LM	MXHM	HXHM	VHM
$t\bar{t}$, W+jets, and single top yield	6.41 ± 2.08	30.35 ± 3.96	3.41 ± 1.05	12.06 ± 2.83	2.00 ± 0.78
Z+jets yield	1.88 ± 0.93	4.57 ± 1.67	1.66 ± 0.72	1.77 ± 0.73	1.24 ± 0.54
$t\bar{t}$Z yield	0.59 ± 0.30	2.46 ± 1.11	0.83 ± 0.39	1.72 ± 0.79	0.62 ± 0.29
QCD multijet yield	0.71 ± 0.35	0.36 ± 0.19	0.10 ± 0.12	0.01 ± 0.01	0.01 ± 0.01
Total background yield	9.6 ± 2.3	37.7 ± 4.4	6.0 ± 1.3	15.6 ± 3.0	3.9 ± 1.0
Data yield	12	47	6	14	4

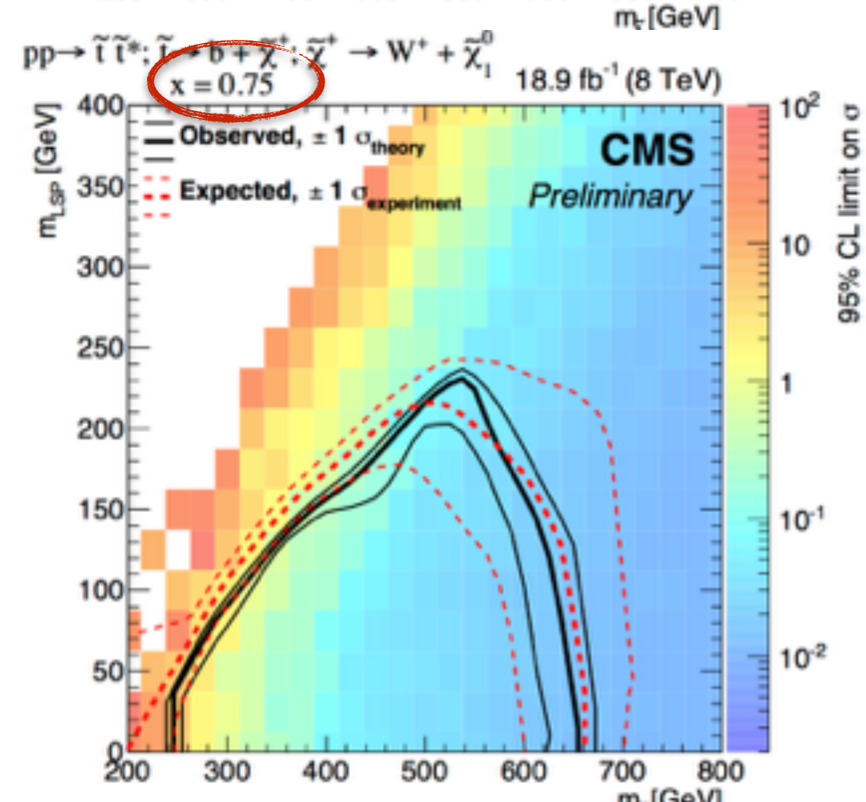
	T2tt			
Search region	LM	MM	HM	VHM
$t\bar{t}$, W+jets, and single top yield	19.76 ± 3.24	8.64 ± 1.81	3.21 ± 1.02	1.00 ± 0.53
Z+jets yield	0.69 ± 0.23	2.30 ± 0.90	1.92 ± 0.84	0.59 ± 0.28
$t\bar{t}$Z yield	1.34 ± 0.49	2.66 ± 1.27	1.62 ± 0.75	0.99 ± 0.52
QCD multijet yield	0.91 ± 0.58	0.17 ± 0.07	0.04 ± 0.02	0.01 ± 0.01
Total background yield	22.7 ± 3.3	13.8 ± 2.4	6.8 ± 1.5	2.6 ± 0.8
Data yield	16	18	7	2

new!









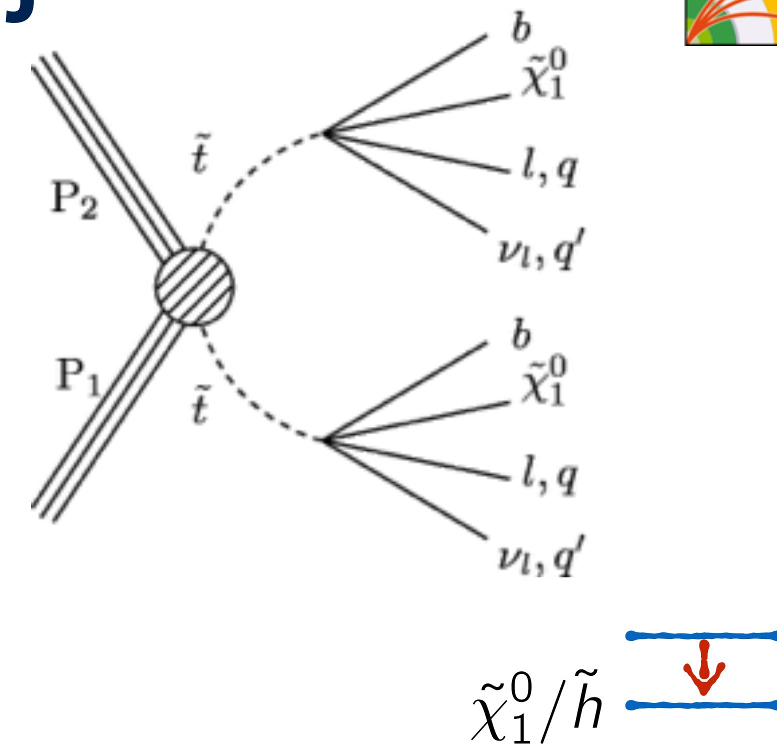
SUS-13-023

No excess observed: very competitive limits in SMS interpretation

Soft Leptons + Low N_{jet}

Targets compressed scenario: $m_{\tilde{t}_1} \approx m_{\tilde{\chi}_1^0}$

- Selection similar to mono-jet search and MET > 200 GeV
- At least one μ (p_T > 5 GeV)
- $C_T = \min(\not{E}_T, H_T - 100\ \text{GeV}) > 200\ \text{GeV}$
- **Single lepton:** Reject events with e/τ and further μ (p_T > 20 GeV)
- **Di-lepton:** one more e/μ (OS) with p_T > 15 GeV



C_T > 300 GeV, $q(\mu)$ = +e

no b-tags

M_T<60   60<M_T< 88 M_T>88 [GeV]

one b-tags(30<p_T<60 GeV)

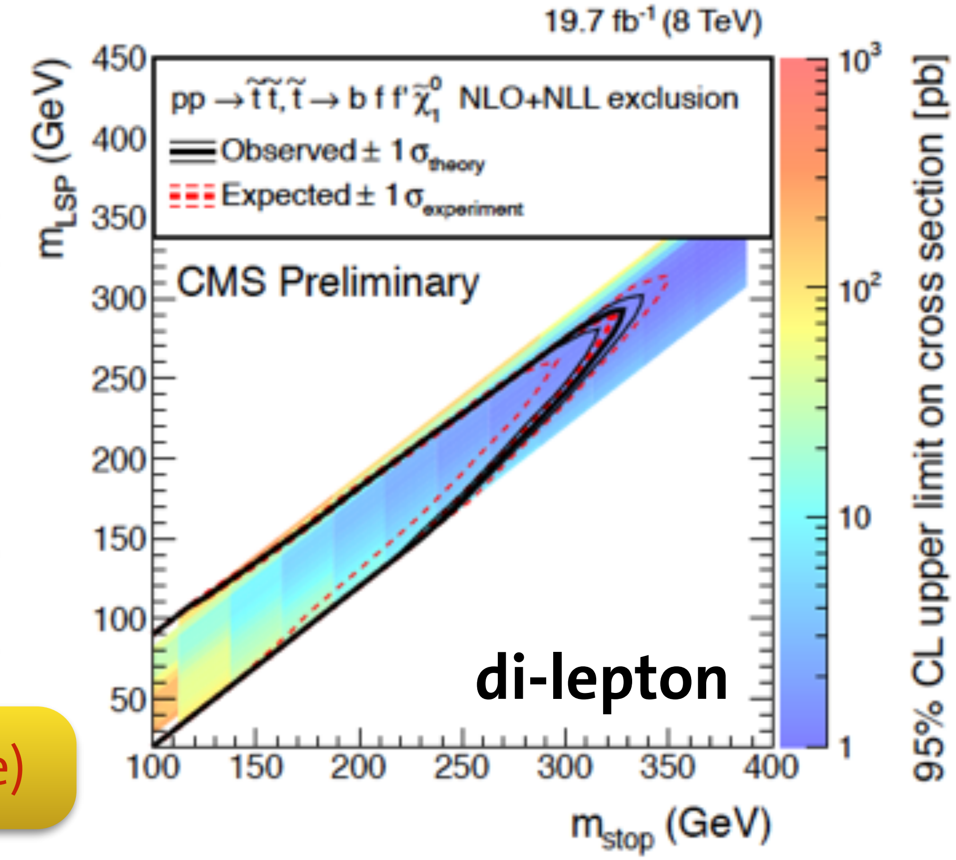
p_T (1st jet)>325 GeV

no b-tags

p_T (1st jet)>150 GeV

MET / H_T > 2/3

p_T (μ)		SRSL1a	SRSL1b	SRSL1c	SRSL2	p_T (ℓ_1)		SRDL
5–12	exp.	41.4 ± 6.3	29.7 ± 7.2	4.3 ± 1.5	11.3 ± 2.9	5–15	exp.	2.1 ± 0.6
GeV	obs.	42	17	3	16	GeV	obs.	2
12–20	exp.	44.2 ± 6.8	25.1 ± 6.2	3.1 ± 1.2	8.5 ± 2.4	15–25	exp.	5.6 ± 1.2
GeV	obs.	39	14	4	16	GeV	obs.	4
20–30	exp.	49.2 ± 7.5	26.5 ± 6.5	5.0 ± 1.8	12.2 ± 3.0			
GeV	obs.	40	28	5	9			
all	exp.	134.5 ± 19.8	81.3 ± 19.1	12.3 ± 4.0	32.1 ± 7.7	all	exp.	7.7 ± 1.4
	obs.	121	59	12	41		obs.	6



Further SMS interpretation for $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ production!

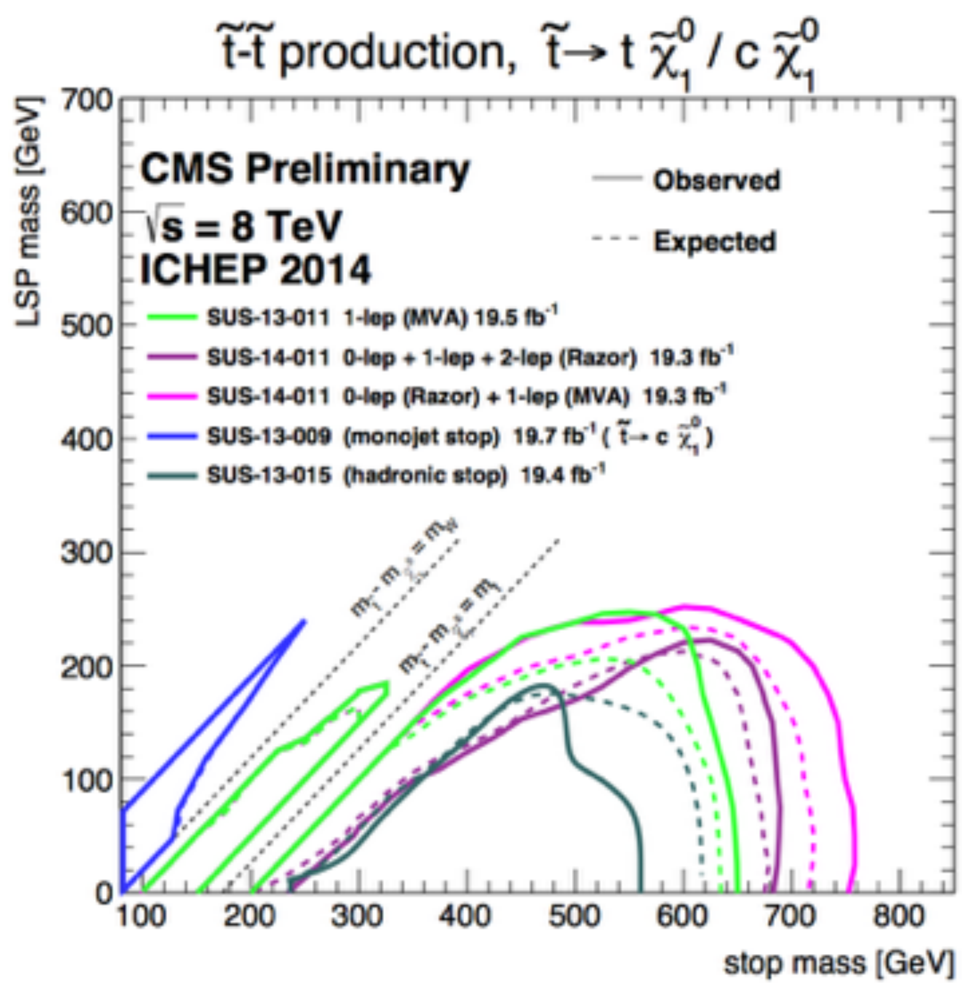
A. Agapitos (Tue)

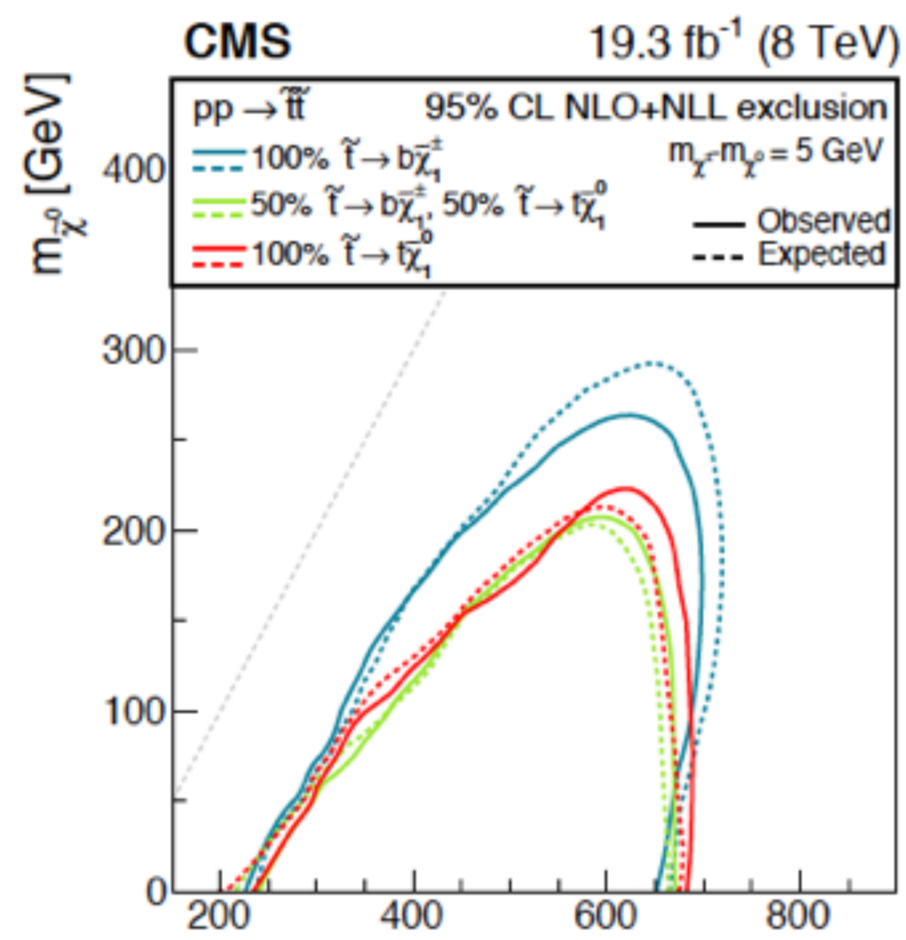
SUS-14-021

Summary: Top-Squarks

So far, no excess observed for any search channel:

- Mass limits in SMS interpretation up to $m_{\tilde{t}_1} < 760$ GeV for $m_{\tilde{\chi}_1^0} \lesssim 100$ GeV
- Mass limits depend slightly on branching ratios of $\mathrm{Br}(\tilde{t}_1 \to t\tilde{\chi}_1^0)$ and $\mathrm{Br}(\tilde{t}_1 \to b\tilde{\chi}_1^{\pm})$





SUS-13-004, PRD

J. Duarte (Mon)

A. Dräger (Fri)

Top-Squarks with Z / h

Kinematically challenging mass configuration: $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx m_t$

- Low MET hard to distinguish from SM $t\bar{t}$
- Possible handle by measurement of total $t\bar{t}$ cross section

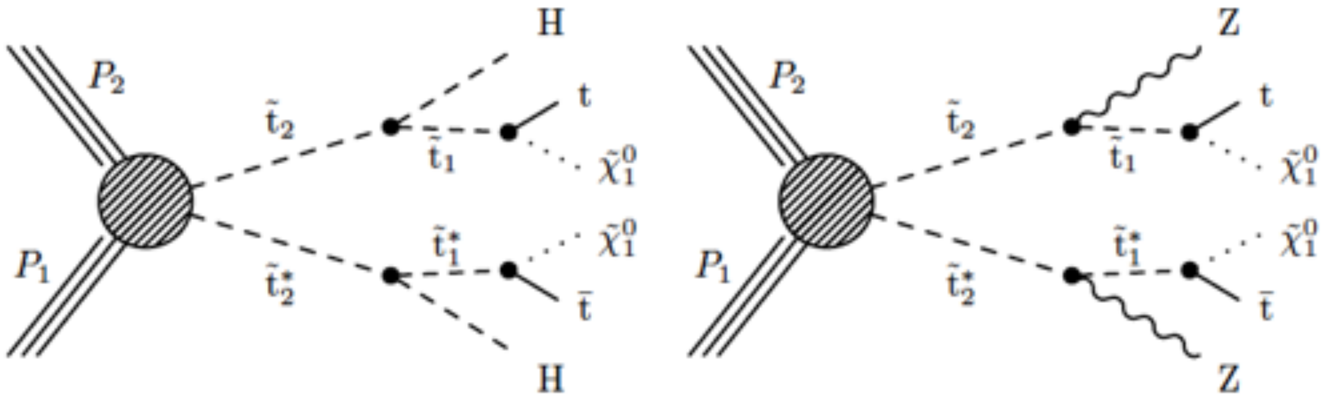
  e.g. M. Czakon et al. (2014), PRL

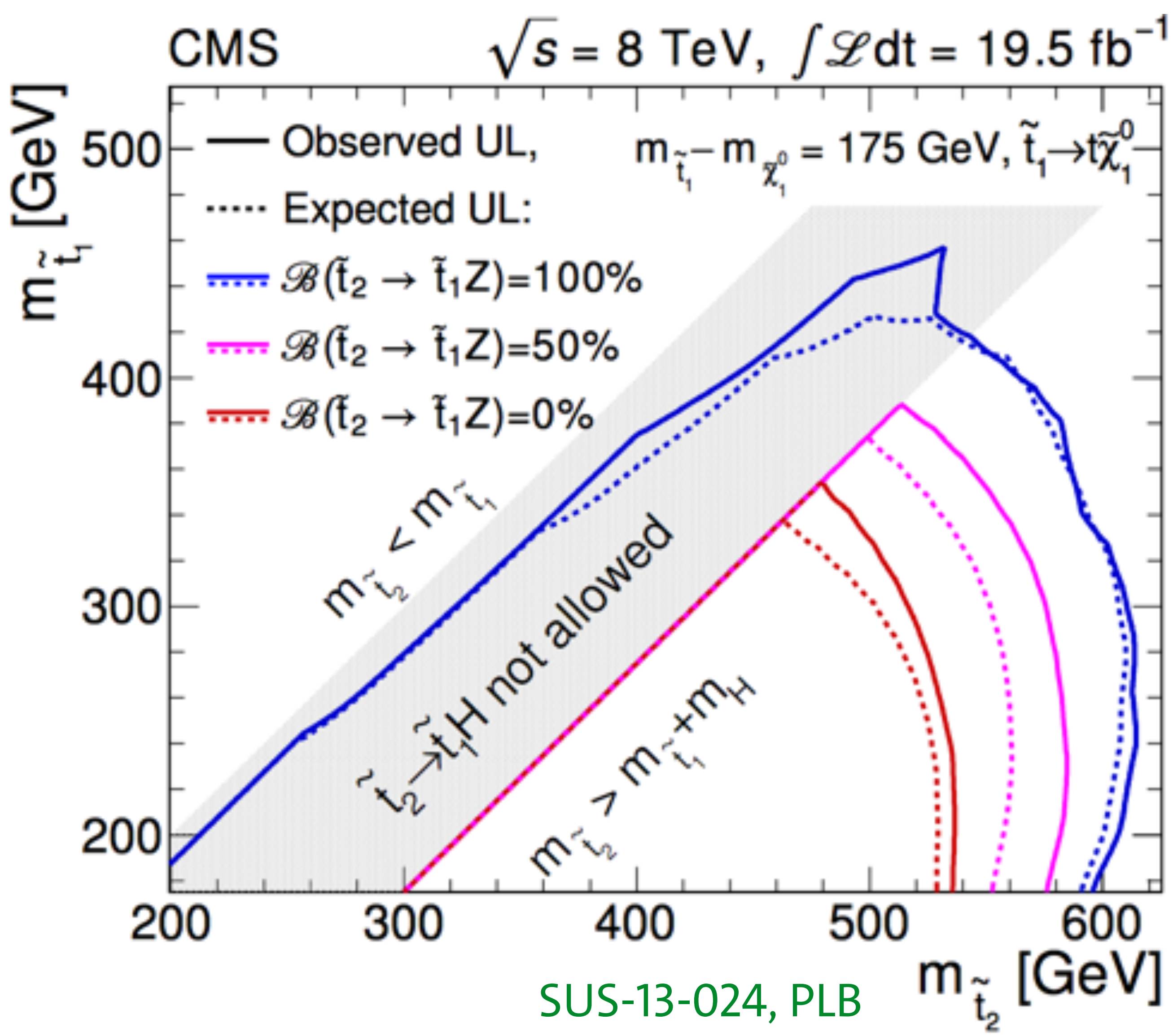
- ... or consider production of $\tilde{t}_2$:

  Decay to $\tilde{t}_1$ via h or Z

  Various SR with 1, 2 (SS or OS), or 3 leptons and different $N_{b\text{-tags}}$

  Weaker limits than for large mass gap scenarios; and $\tilde{t}_2$ required not to be too heavy



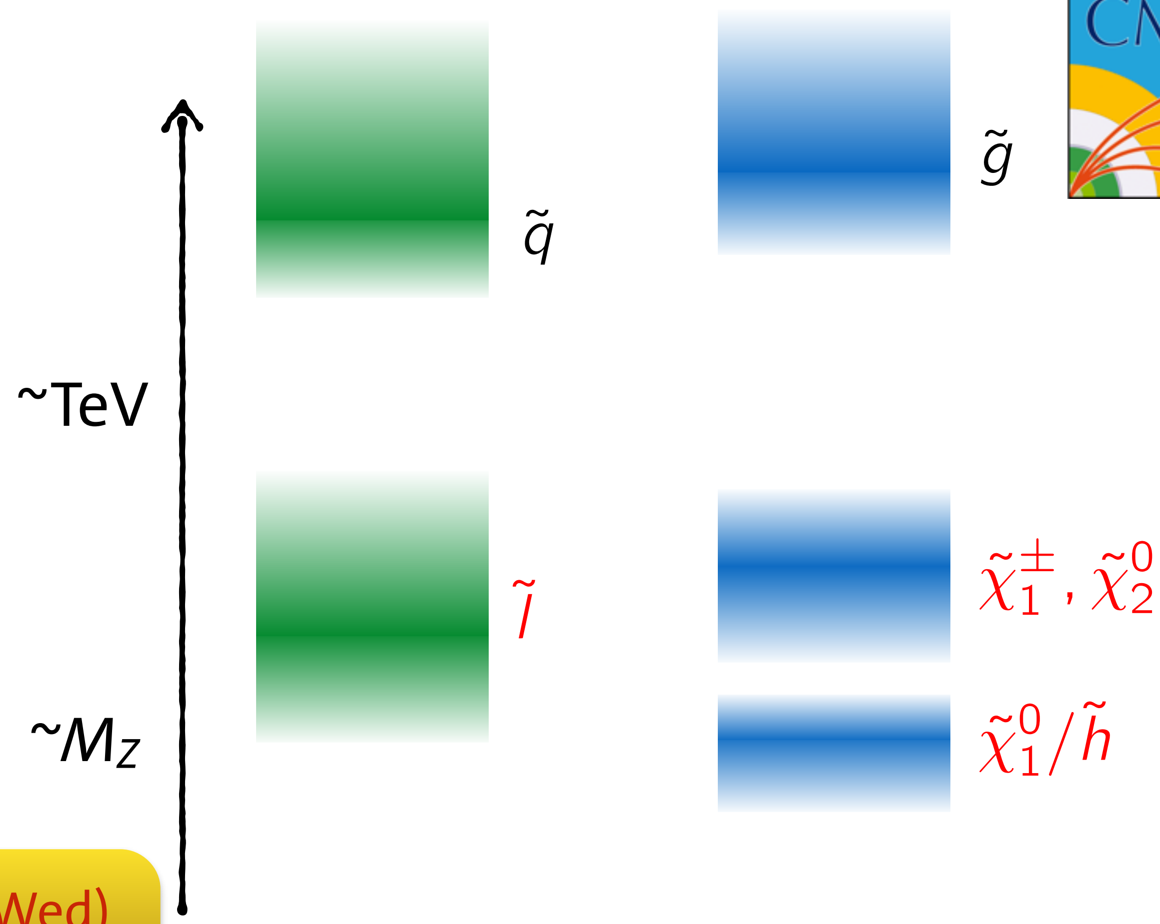


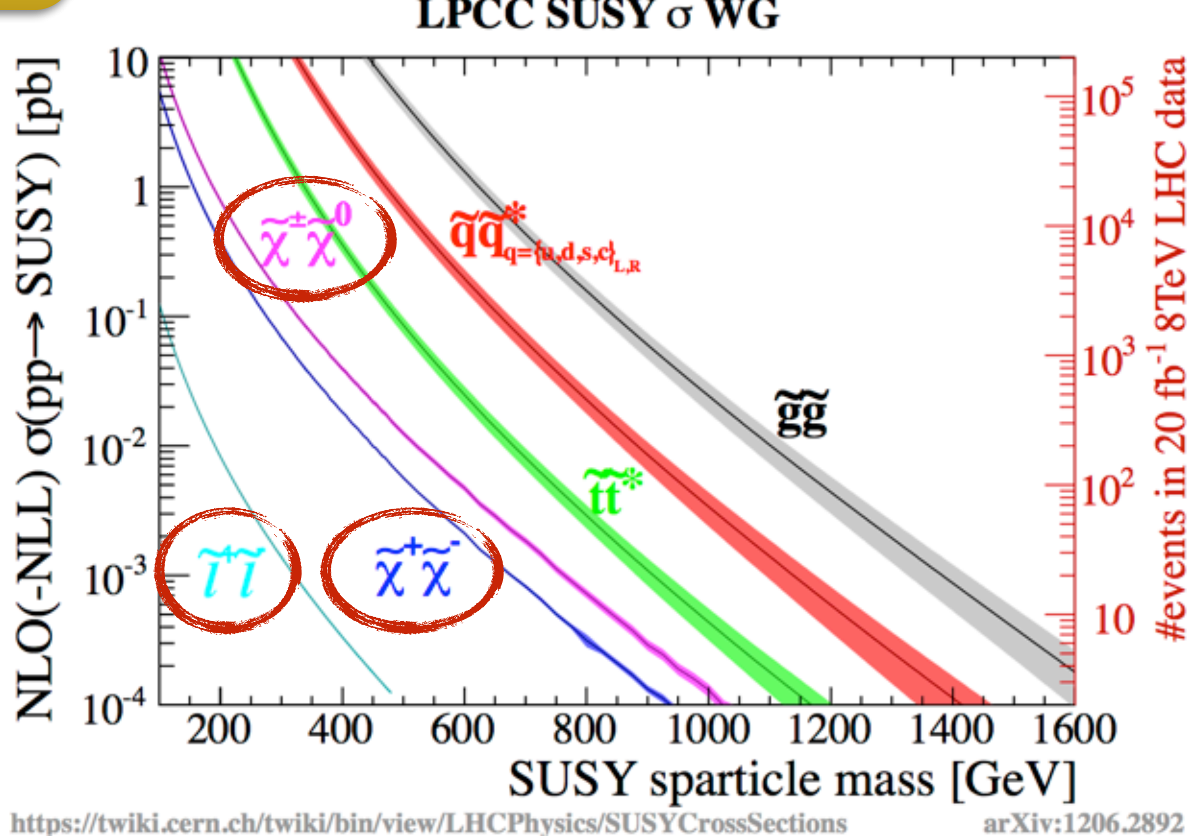
SUS-13-024, PLB

Outline

- **Introduction**
- **Run I**
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- **Run II**
  - Commissioning at 13 TeV
  - Prospects for SUSY
- **Conclusions**

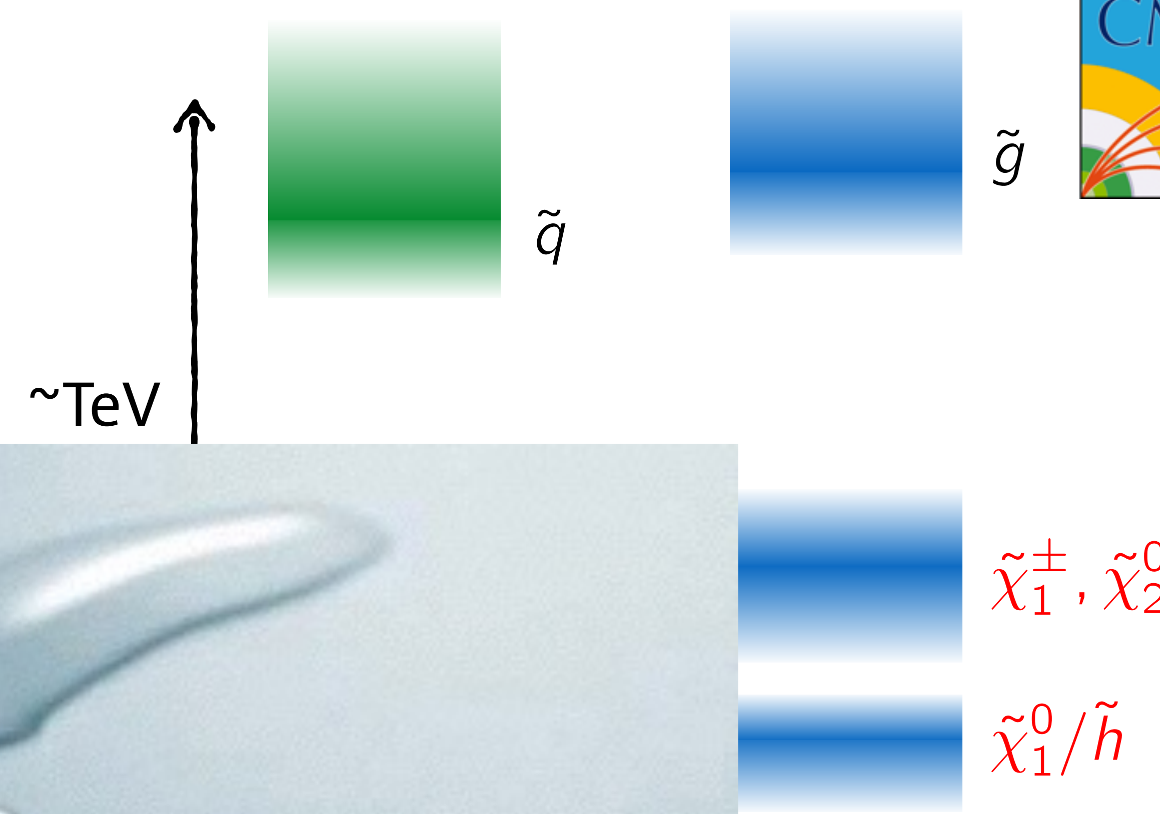
S. Maruyama (Wed)

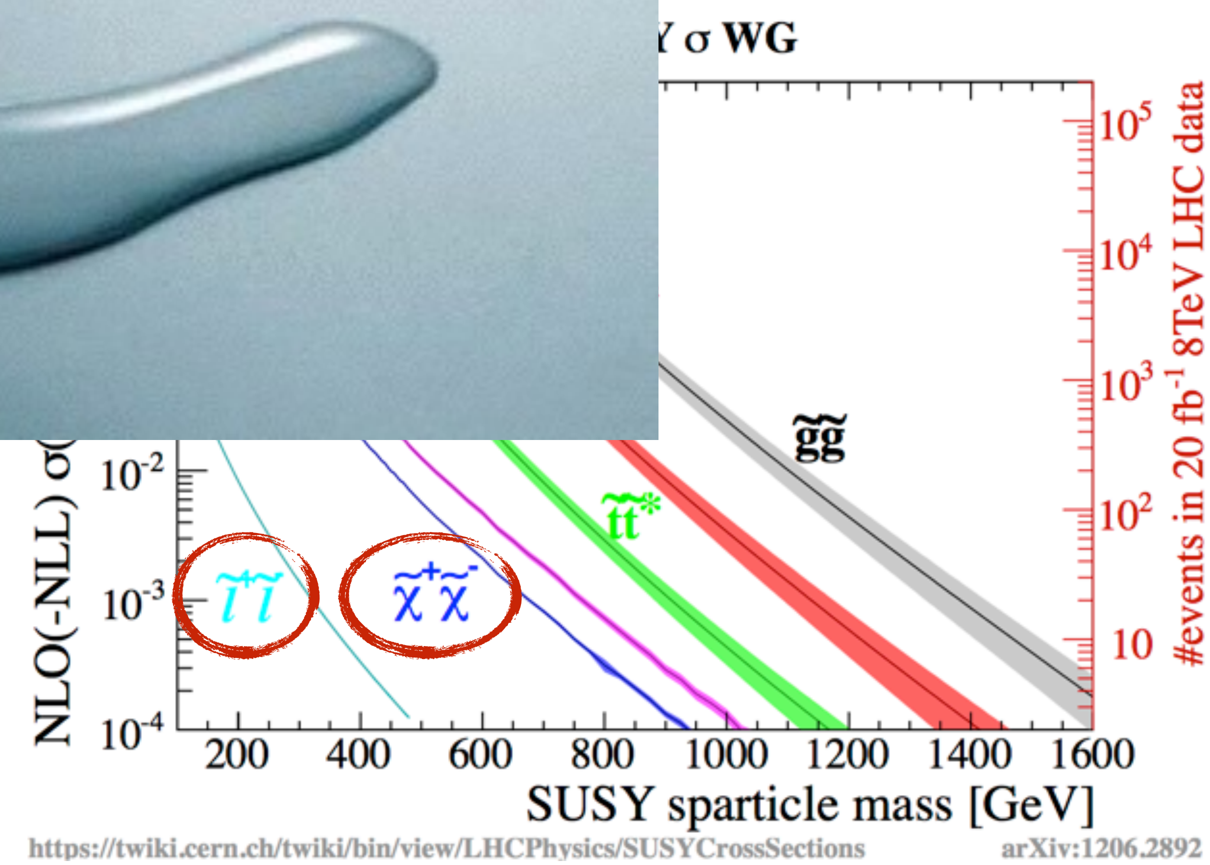




Outline

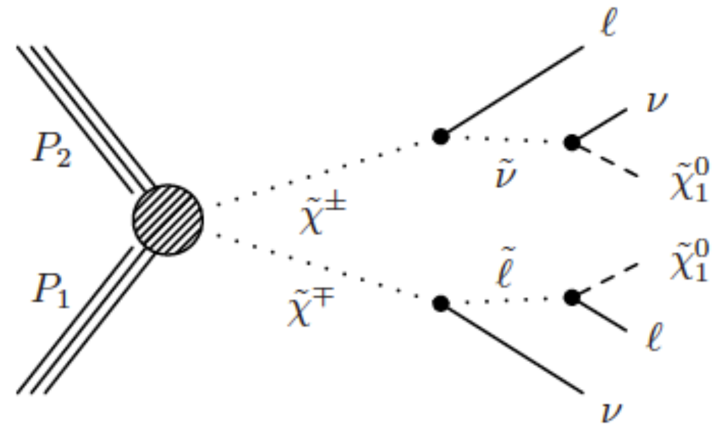
- Introduction
- **Run I**
  - Inclusive searc
  - Stealth SUSY
  - 3rd generatio
  - Searches for E
  - pMSSM reinte
  - RPV searches
- Run II
  - Commissioning at 13 TeV
  - Prospects for SUSY
- Conclusions

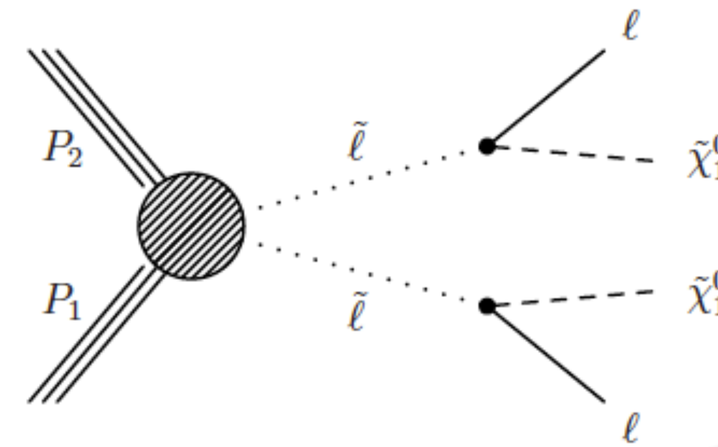


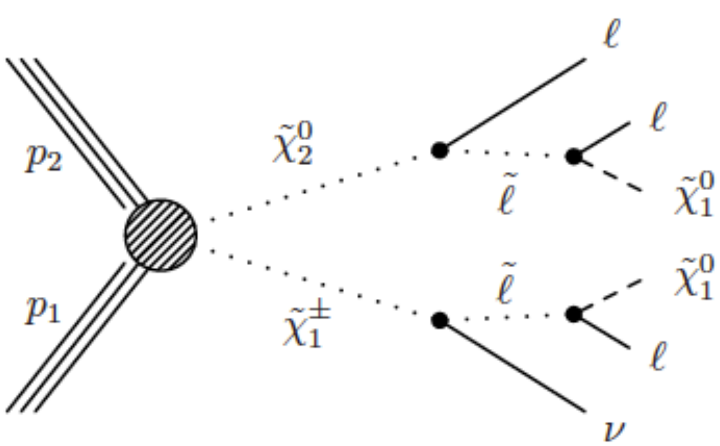


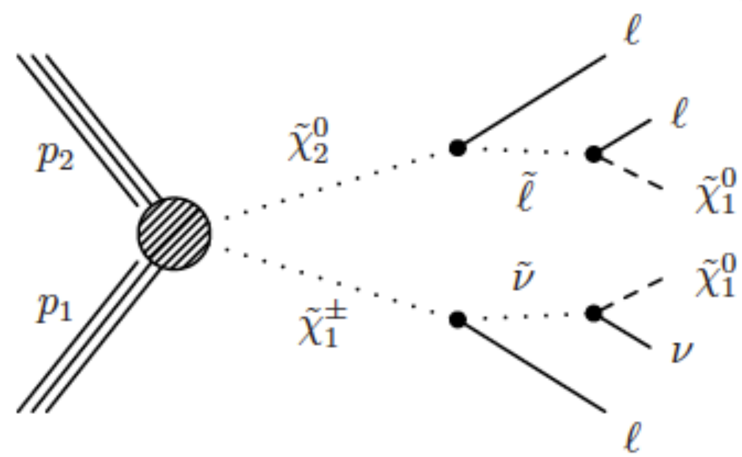
$\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ and $\tilde{l}$ Signatures

2 leptons
- Possibly 1 OSOF or OSSF pair

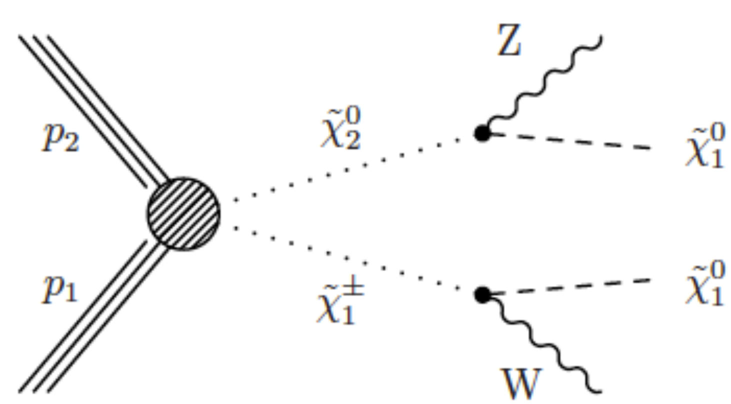






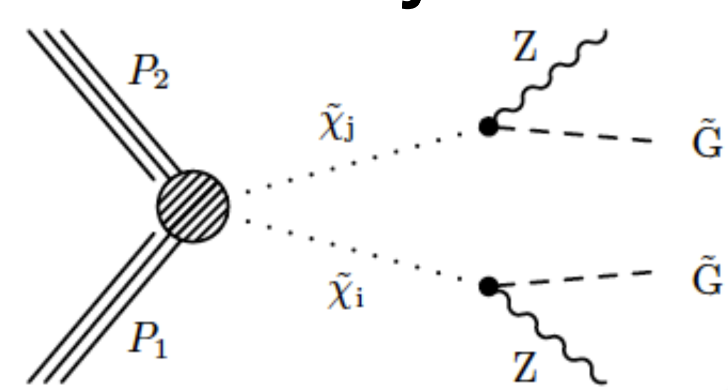


3 leptons
- Possibly 1 OSSF pair
- Possibly m_{ll} ~M_Z
- Possibly SS lepton pair (if one lepton is lost)

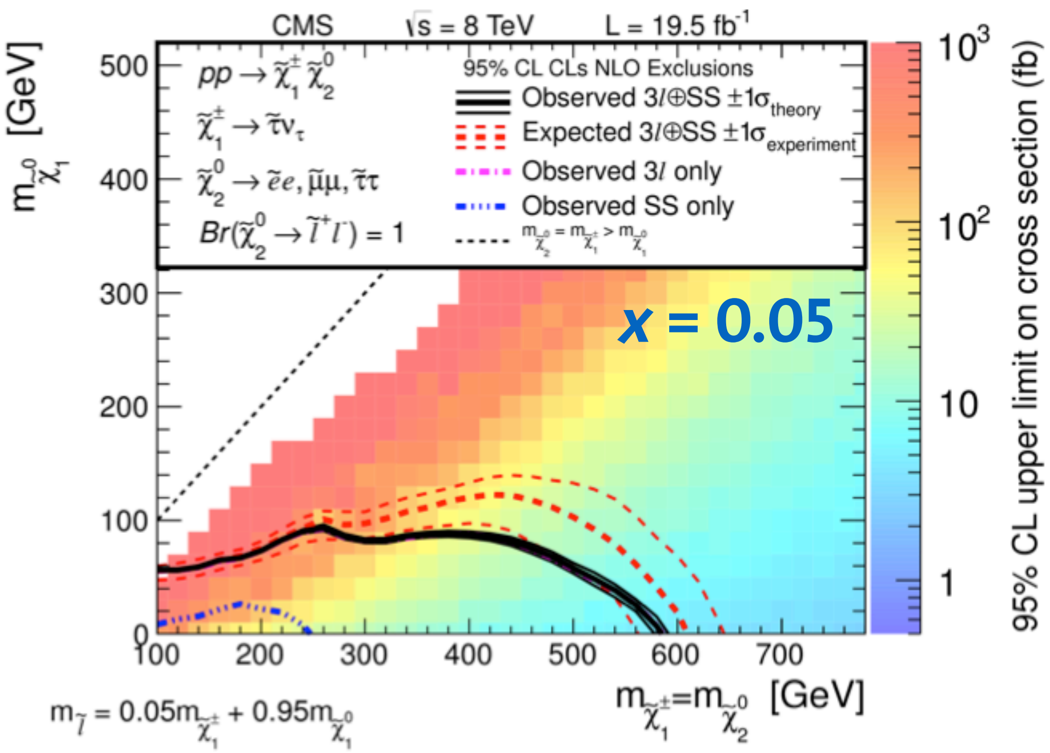


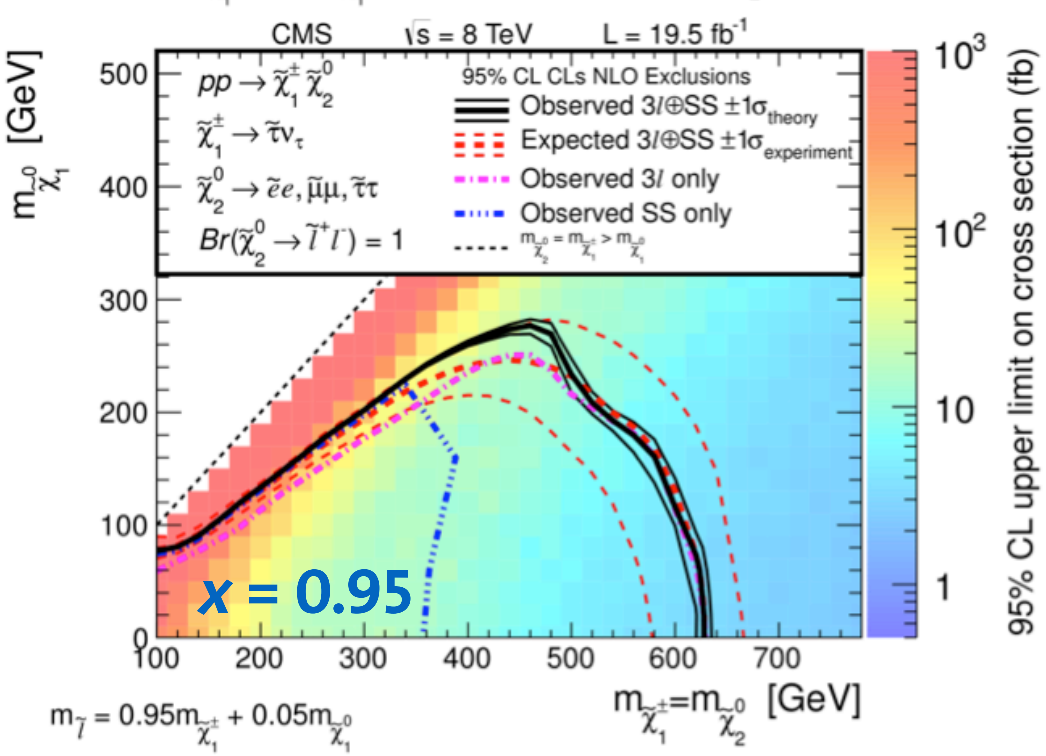
Up to 4 leptons
- Up to 2 OSSF pairs

Also: 2 l + 2 jets

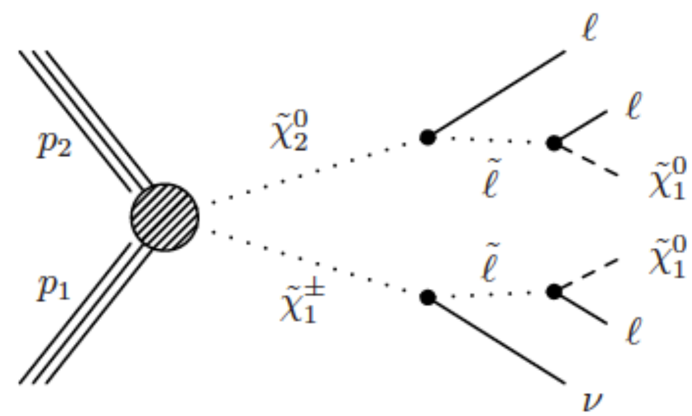


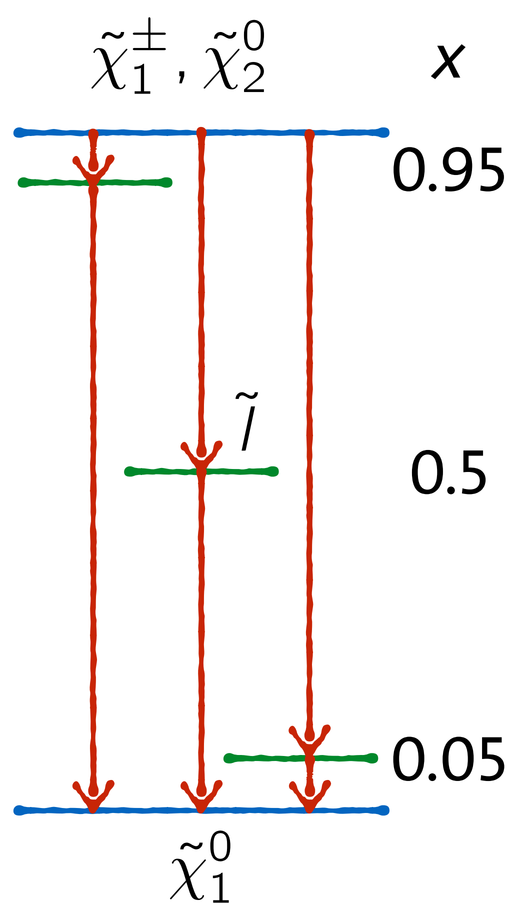
Multi-Lepton Interpretation



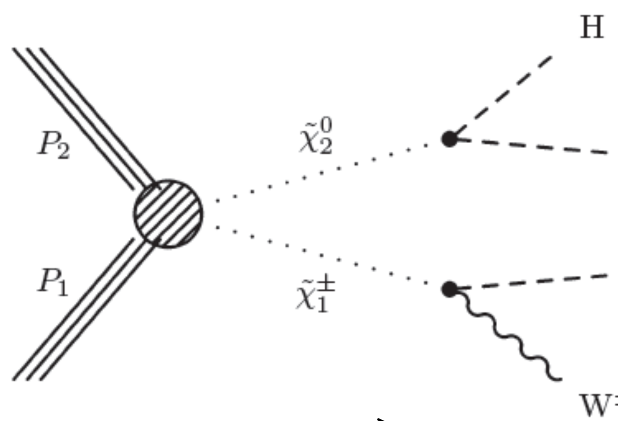


SUS-13-006, EJPC

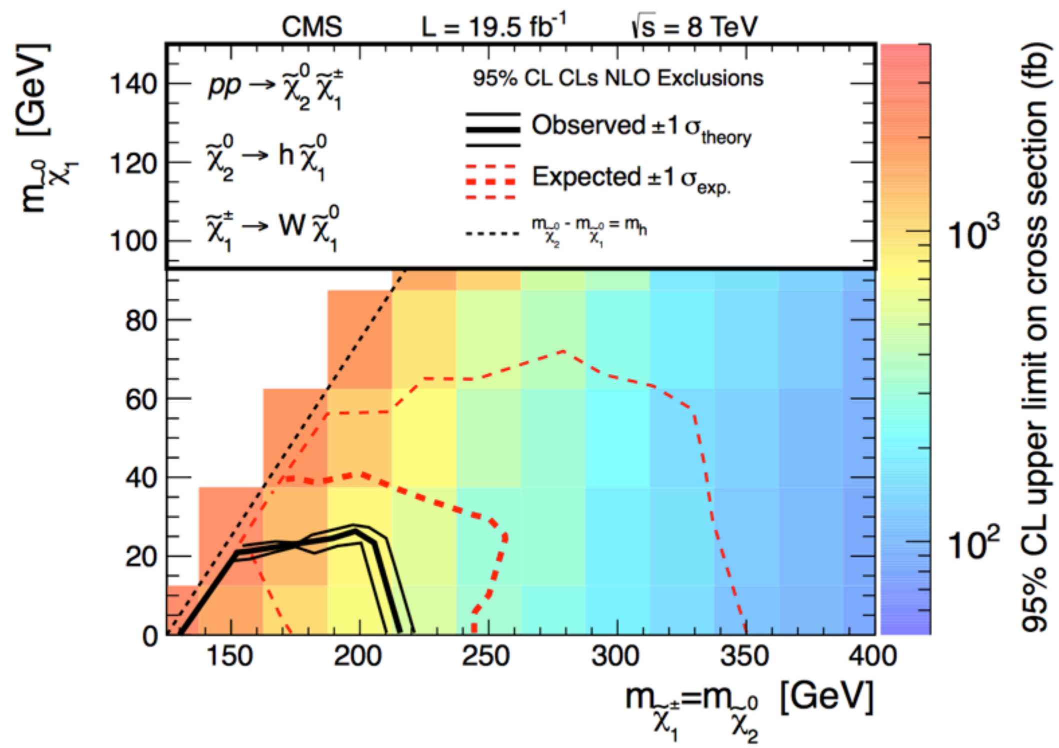




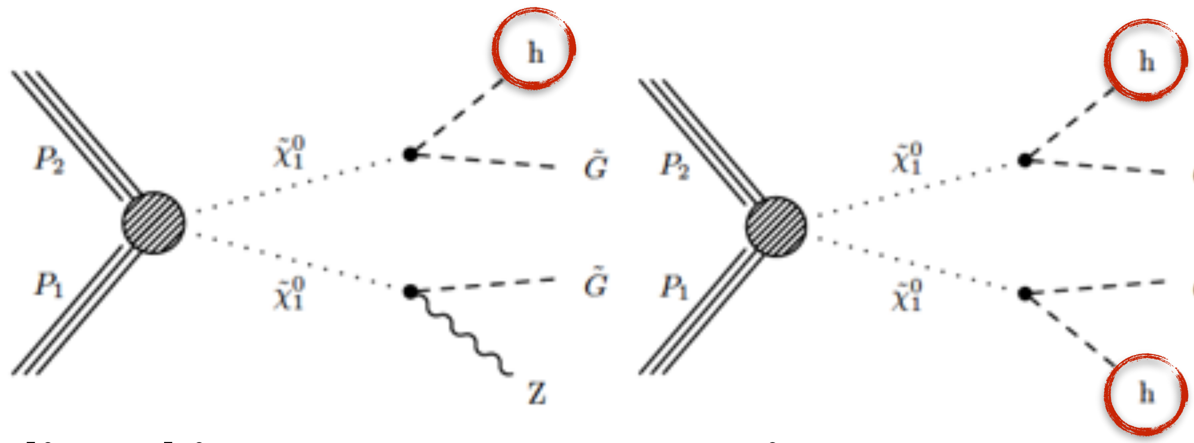
SUS-14-002, PRD



$$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} > m_H$$



hh / Zh / ZZ

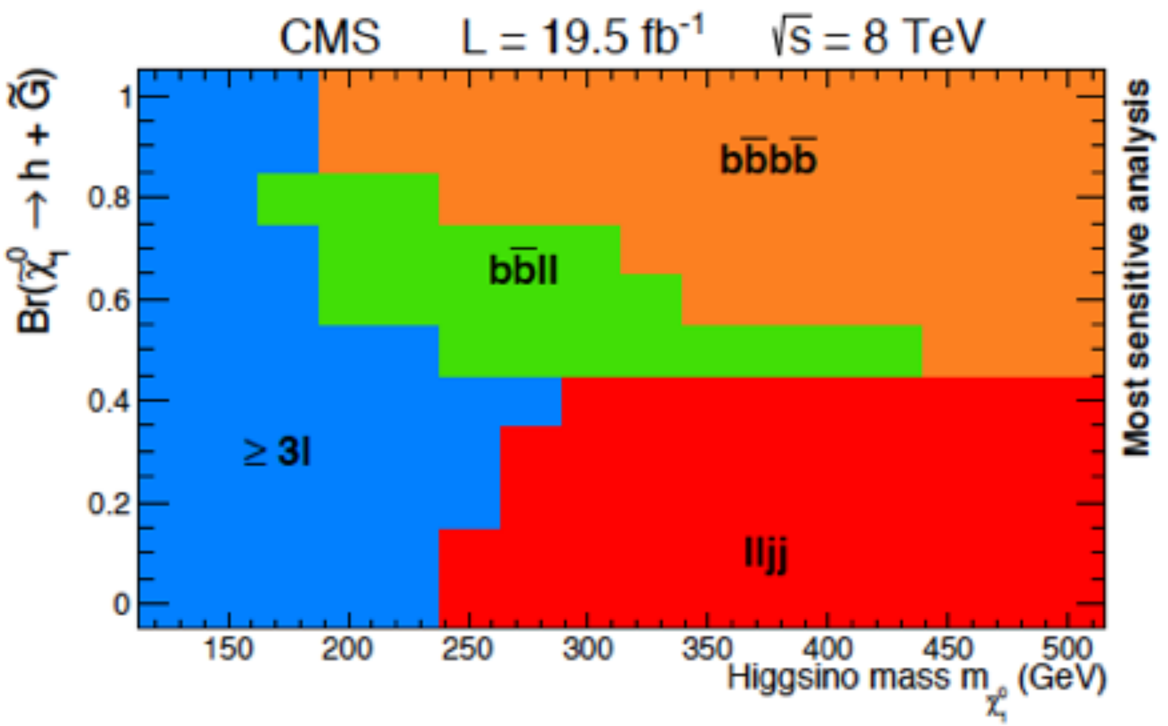


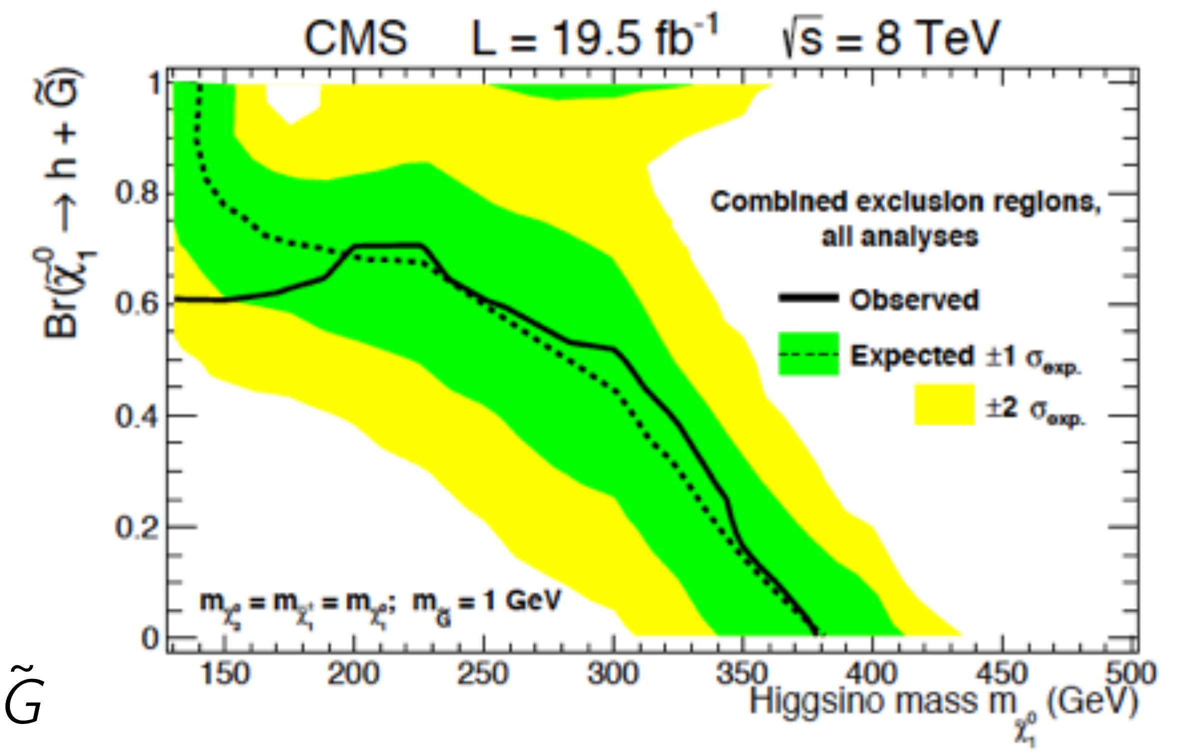
Predicted in many SUSY scenarios:

h in decay of $\tilde{\chi}^{\pm}, \tilde{\chi}^{0}$

Many possible signatures, depending on BR to *Z* or *h*

- *bb*+X
- *ll*+X
- ≥3*l*
- *bbbb* (sensitivity only for large BR $\tilde{\chi}^0 \to h\tilde{G}$)
- $\gamma\gamma$+X (small sensitivity)





So far, weak limits on higgsino mass for large BR $\tilde{\chi}^0 \to h\tilde{G}$

SUS-14-002, PRD

EWKinos and Sleptons: Summary

SMS interpretations have to be taken with some care:

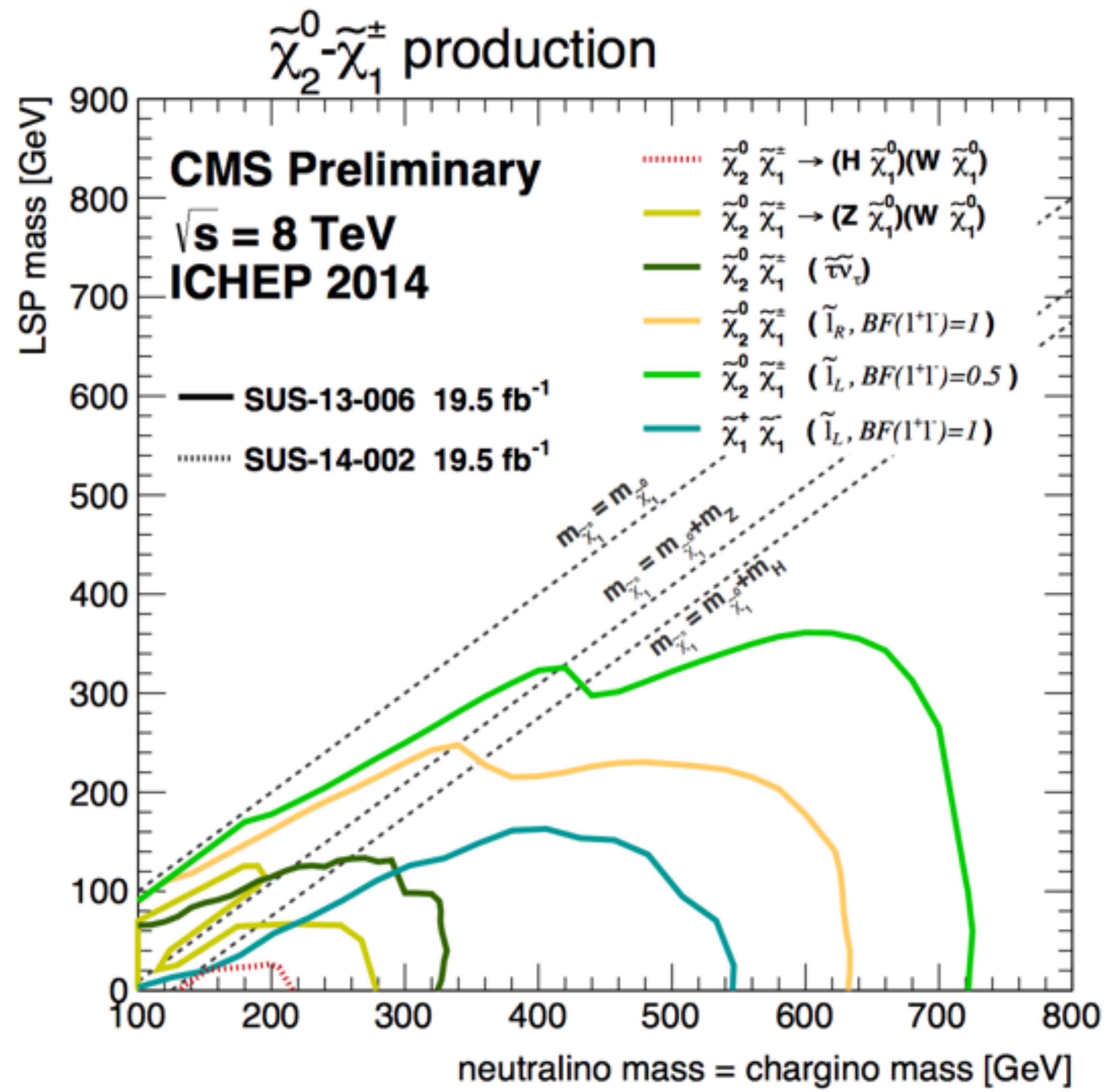
- If not specified otherwise, assuming BR of 100%

  → optimistic limits

  e.g. $\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0$ vs. $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$

- Challenging compressed spectra; for some scenarios sensitivity from heavy stable charged particle searches

  M. Kazana (Fri)



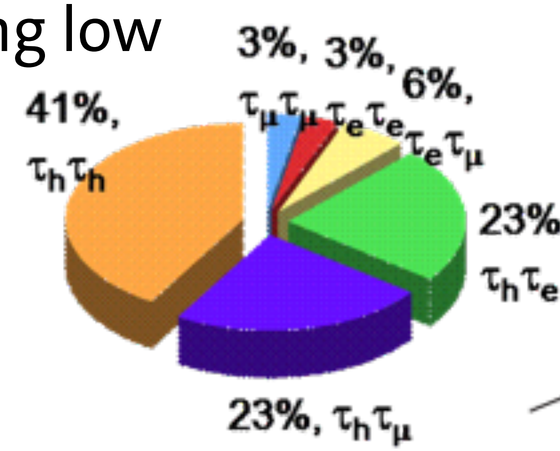
VBF + Leptons

Vector Boson Fusion: Small cross section but additional bg suppression power from two forward jets

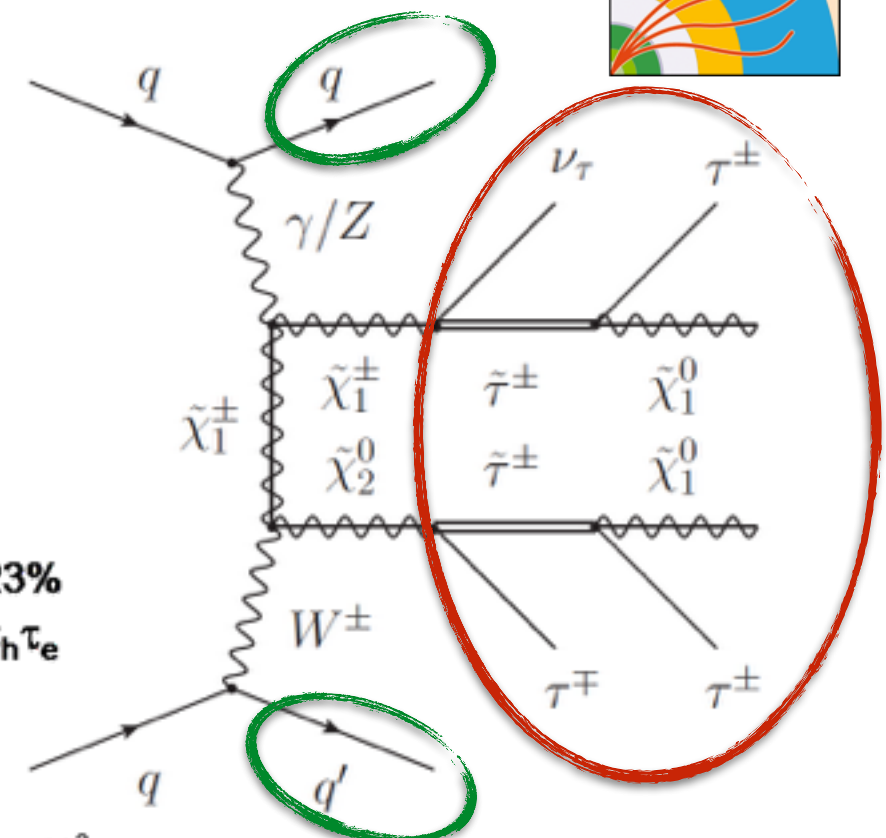
Aiming for compressed SUSY spectra; requiring low thresholds on leptons

$\mu\mu$ / $e\mu$ / $\mu\tau_{had}$ / $\tau_{had}\tau_{had}$ (LS and OS)

Trigger: Lepton triggers (IsoMu24 or DiTau35)



www-cdf.fnal.gov



VBF selection

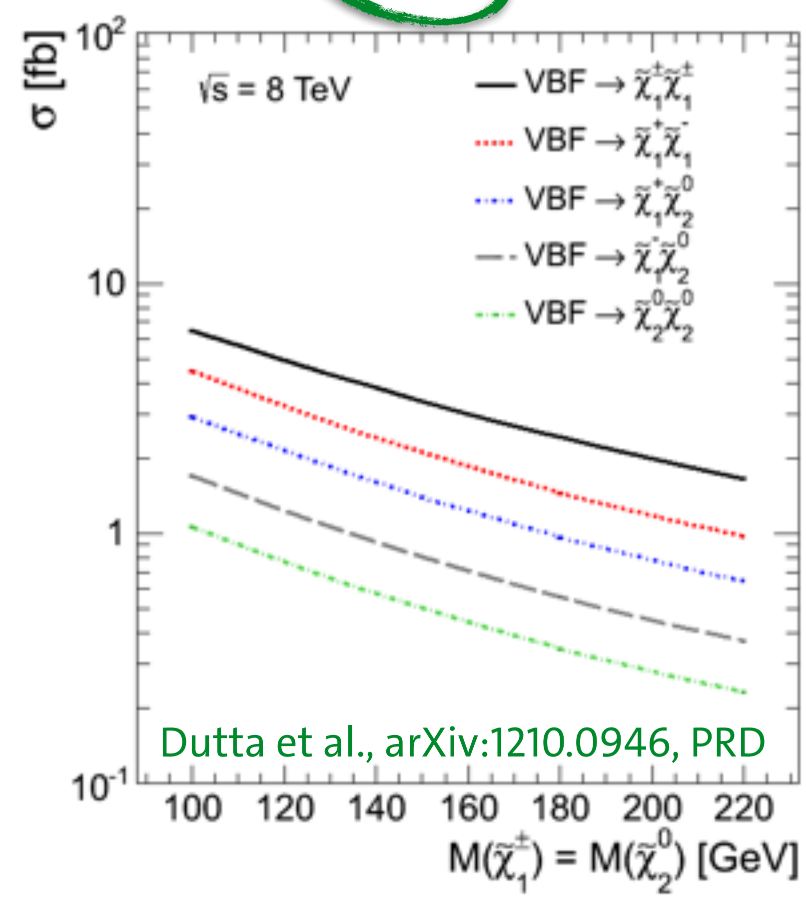
- Two jets (p_T>30/50 GeV with $\eta_1\eta_2$<0; large rapidity gap $|\eta_1$-$\eta_2|$>4.2 and invariant mass m_{12}>250 GeV)

Central selection

- MET>75 GeV (>30 GeV for $\tau_{had}\tau_{had}$); μ-p_T>30 GeV or τ_{had}-p_T>45 GeV
- Veto b-jets (p_T>20 GeV)

Background estimation: $N^{SR}_{bg,data} = N^{CR,central}_{MC} \cdot SF^{central}_{MC/data} \cdot \epsilon_{VBF}$

- From bg-dominated CR (central selection) and applying "VBF-efficiency" from other bg CR (e.g. incl. b-jet or l^+l^-)

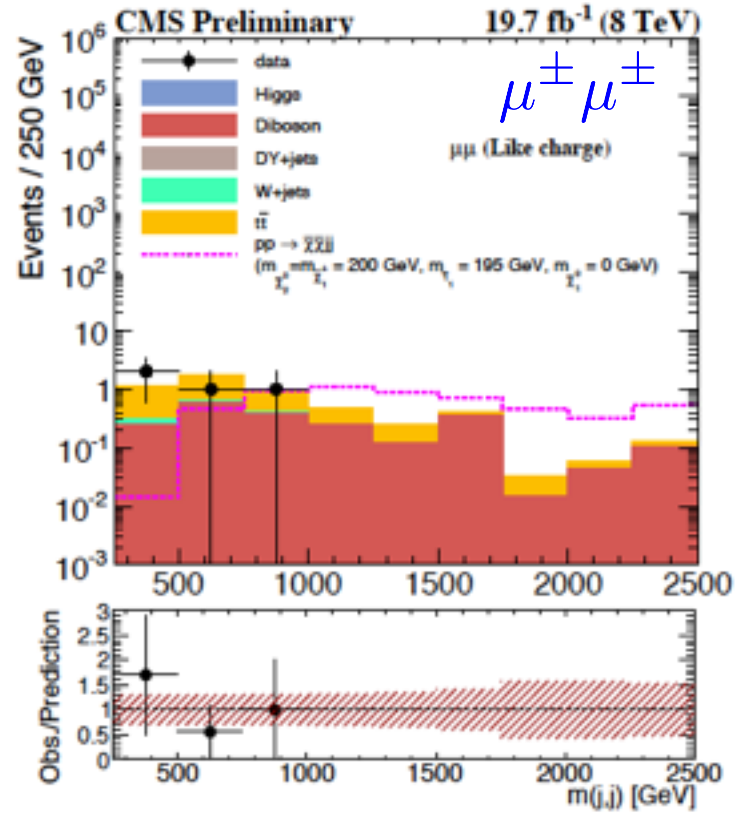


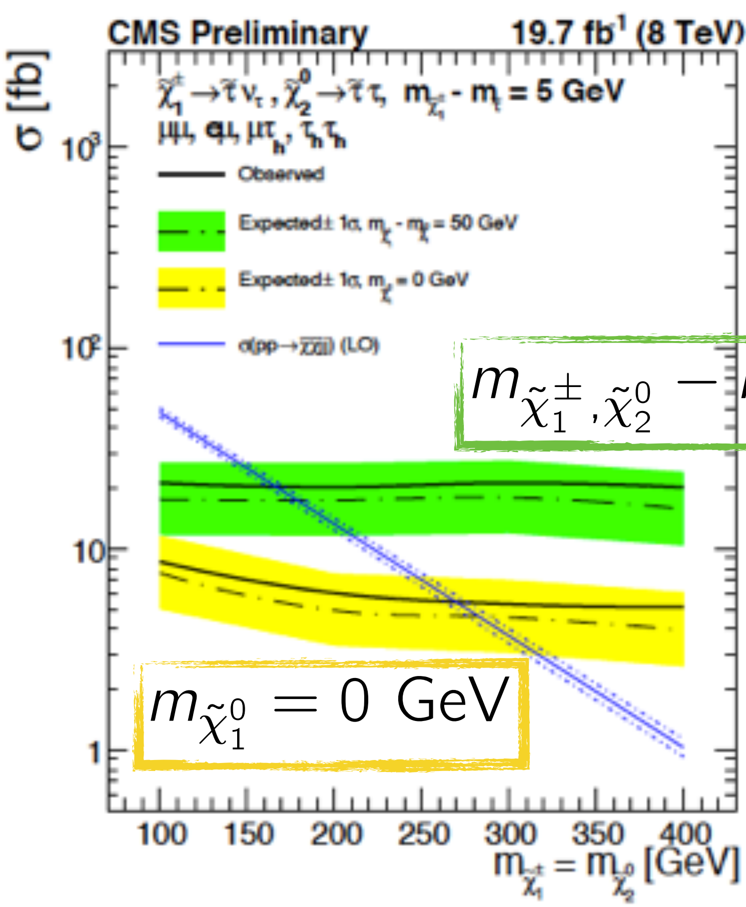
Dutta et al., arXiv:1210.0946, PRD

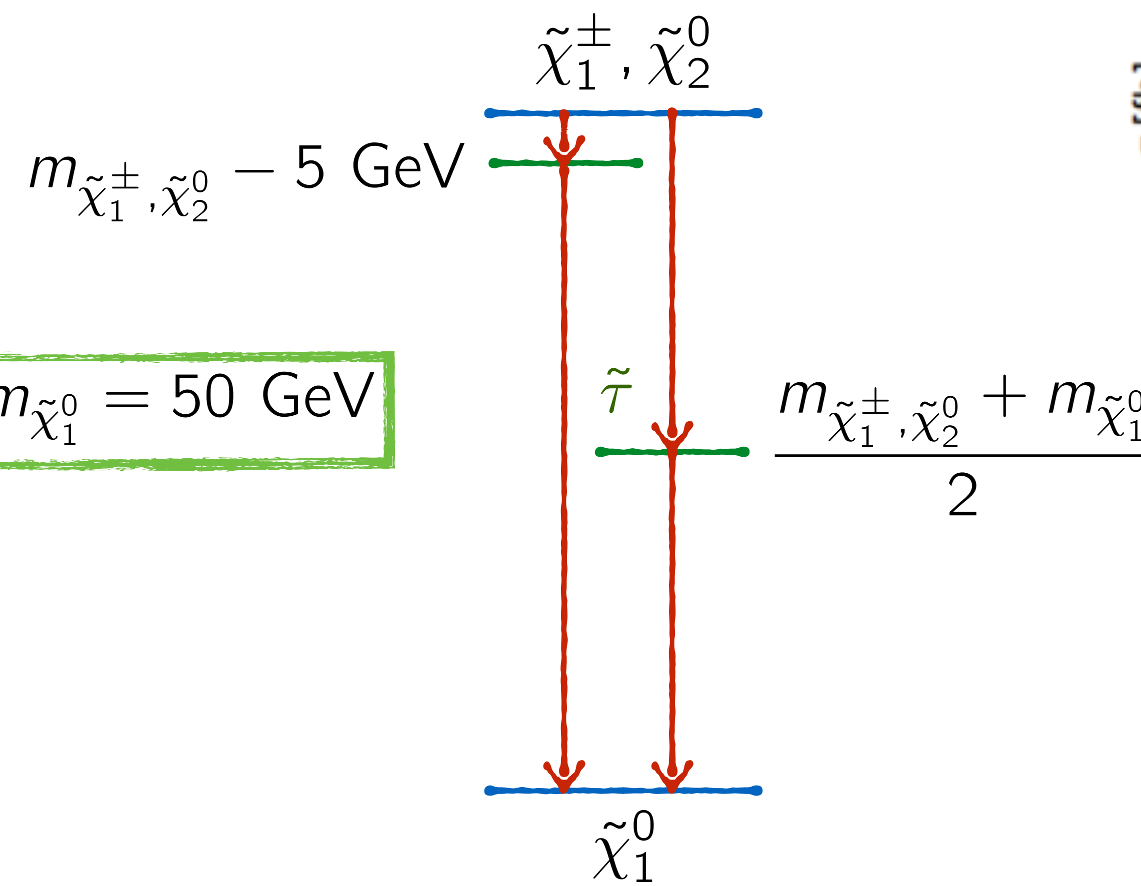
SUS-14-005

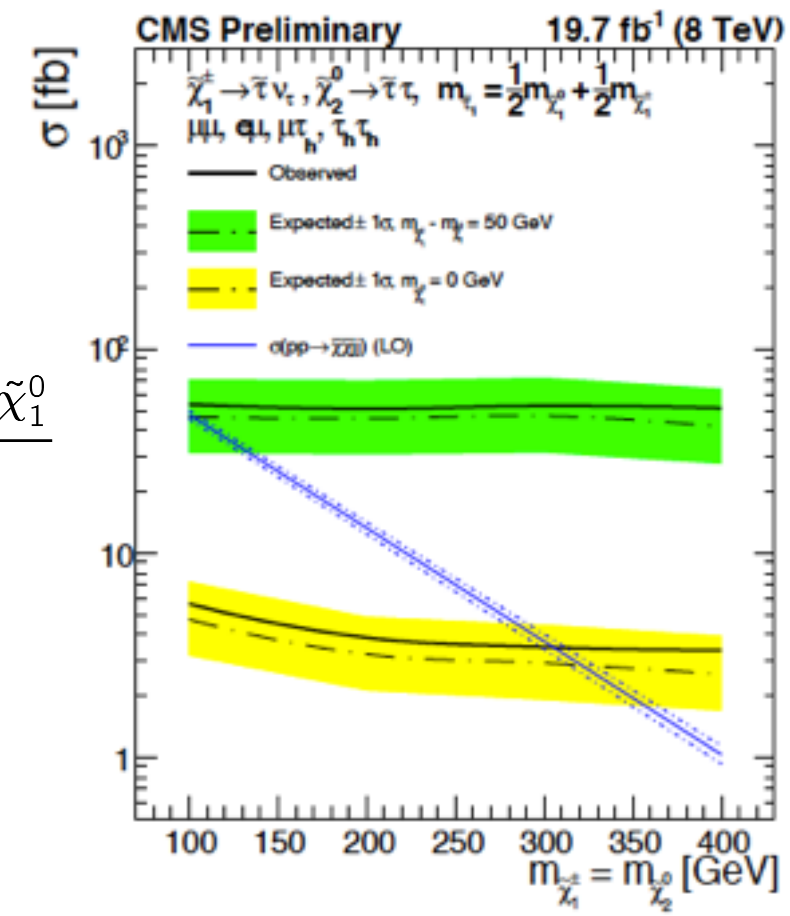
VBF + Leptons

Process	$\mu^\pm\mu^\pm jj$	$e^\pm\mu^\pm jj$	$\mu^\pm\tau_h^\pm jj$	$\tau_h^\pm\tau_h^\pm jj$
DY + jets	< 0.01	$0^{+1.7}_{-0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0^{+3.0}_{-0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9^{+0.4}_{-0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5^{+0.7}_{-0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	–	–	–	< 0.1
QCD	–	–	–	7.6 ± 0.9
Higgs	–	–	–	< 0.01
Total	5.4 ± 0.3	$5.4^{+3.5}_{-0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9









SUS-14-005

One of first SUSY searches with VBF signature

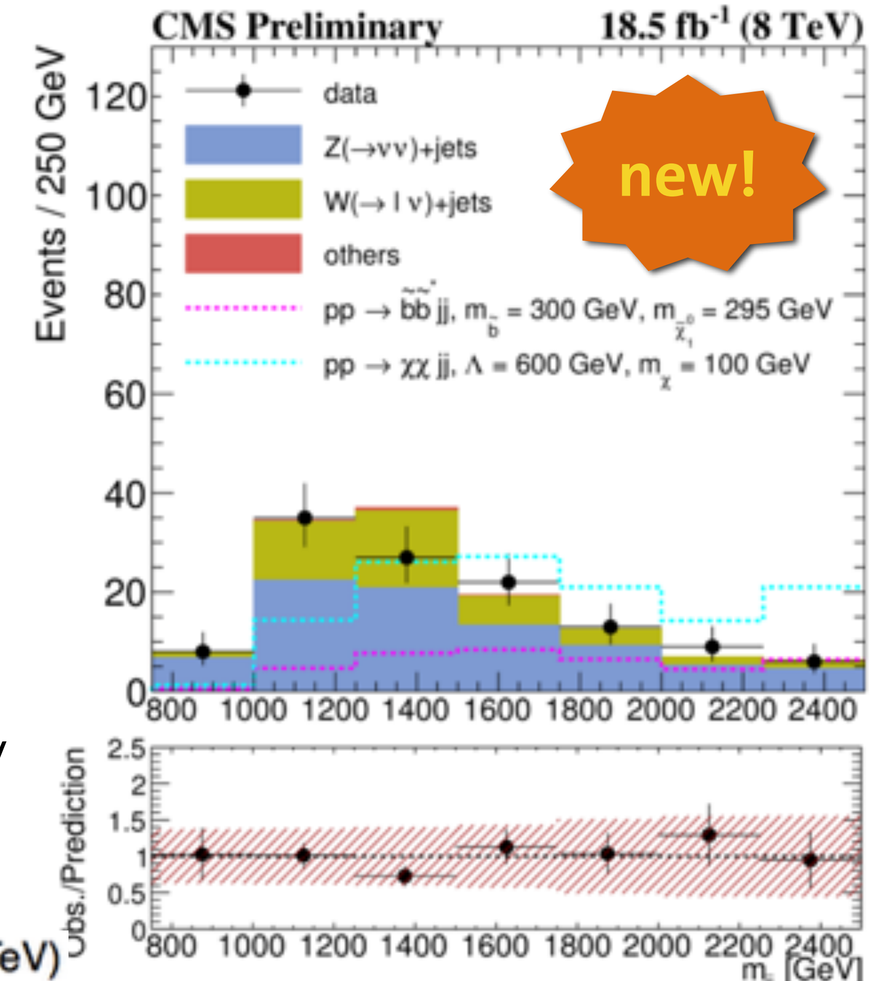
VBF + MET: Compressed SUSY / DM

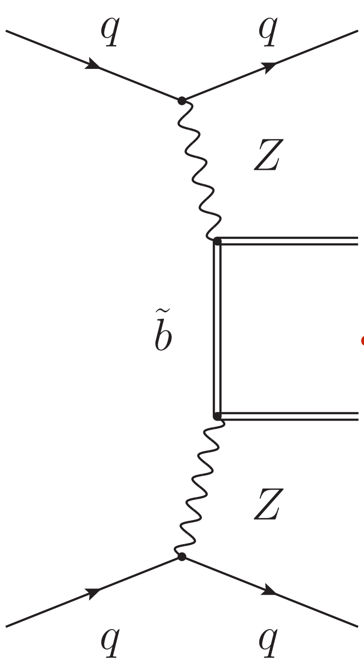
Trigger: MET65+VBFDiJet35

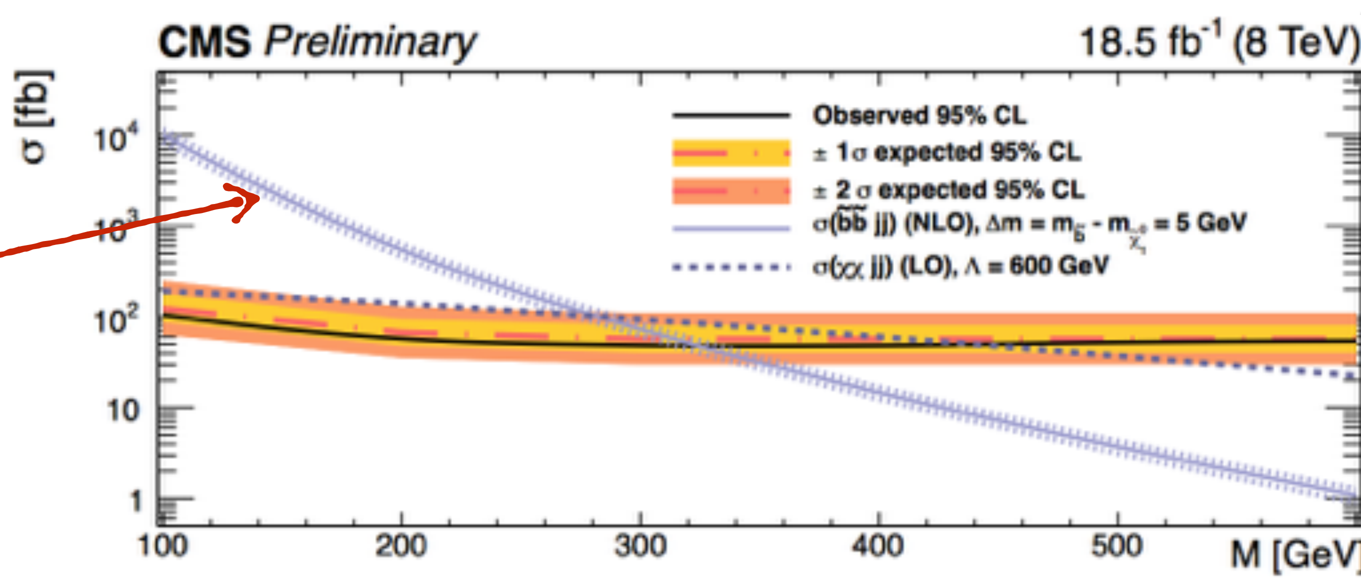
Selection: Two jets (p_T>50 GeV with $\eta_1\eta_2$<0; large rapidity gap $|\eta_1$-$\eta_2|$>4.2 and invariant mass m_{12}>750 GeV; no b-tag); MET>250 GeV; veto further jets (p_T>30 GeV)

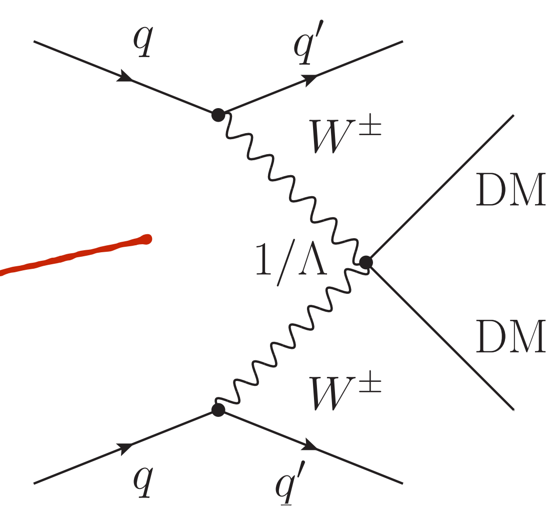
Dominant bgs: $(Z \to \nu\nu) + \text{jets}$ & $(W^{\pm} \to l^{\pm}\nu) + \text{jets}$ estimated from data

Interpretation in models with DM production via contact interaction and $\tilde{b}\tilde{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$ production with $m_{\tilde{b}} - m_{\tilde{\chi}_1^0} = 5$ GeV



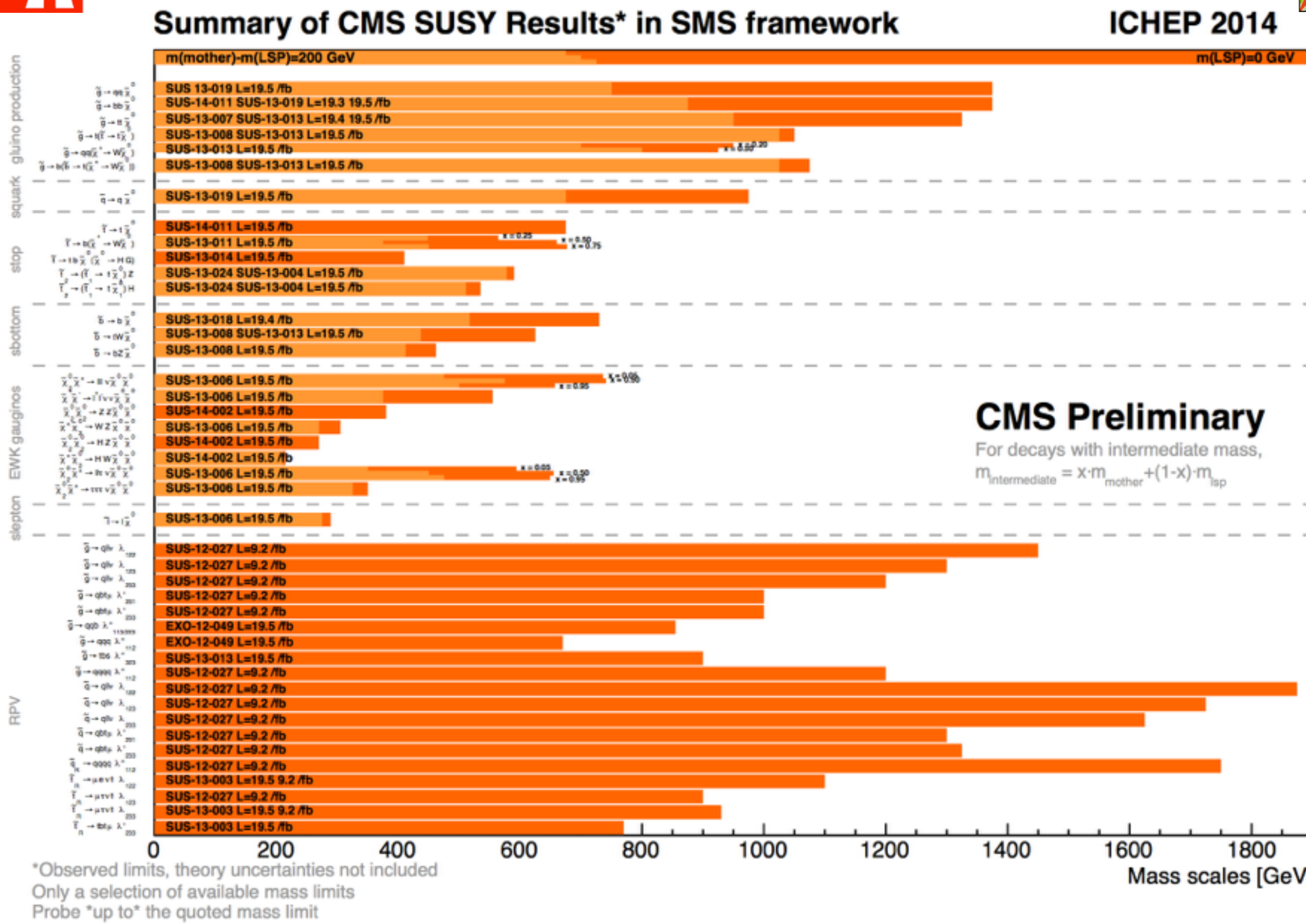






SUS-14-019

Compilation of SMS Results



pMSSM "Likelihood"

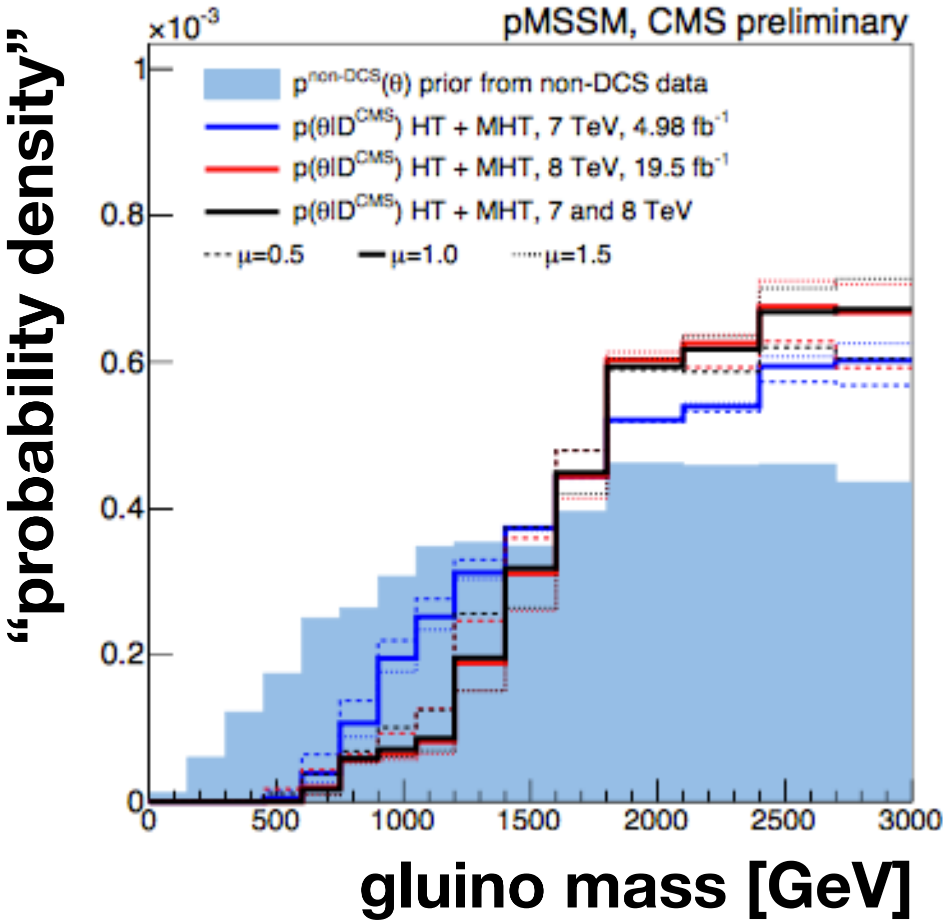
S. Bein (Wed)

19 free parameters:

- M_1, M_2, and M_3
- $\tan\beta$, μ, and m_A
- 10 sfermion mass parameters
- A_t, A_b, and A_τ

Constraints:

- No RPV
- No new sources of CP violation
- Mass degeneracy of 1st and 2nd gen.
- No FCNC



pMSSM captures "most" of phenomenological features of RPC MSSM with neutralino LSP

Challenge: Scan 19 dimensional parameter space

Likelihood, that observed data originates from model θ for given $b_i^{SM} \pm \Delta b_i^{SM}$ in each search bin:

$$\mathcal{L}(\text{data}|\theta) = \prod_{i=1}^{N_{\text{bins}}} \int p(d_i|s_i(\theta) + b_i)\,p(b_i|b_i^{SM}, \Delta b_i^{SM})\,db_i$$

Posterior probability: $\mathcal{L}(\theta|\text{data}) \propto \mathcal{L}(\text{data}|\theta) \cdot p(\theta)$

As expected: Probability density of mass of coloured particles shifted to larger masses

But: few light mass models remain (e.g. compressed SUSY)

SUS-13-020

R-Parity Violation

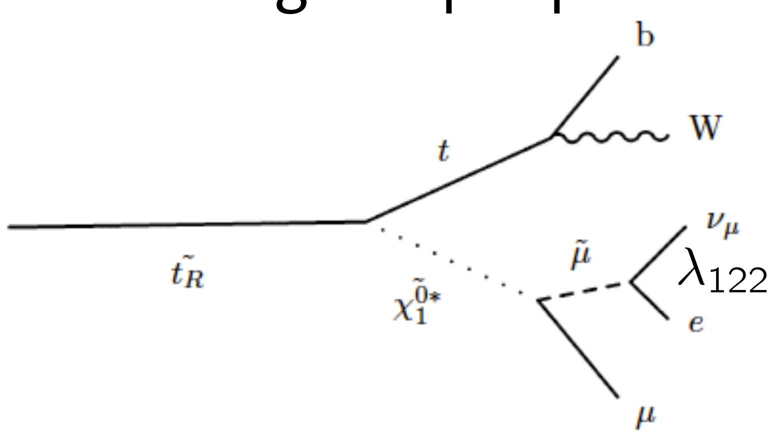
C. West (Fri)

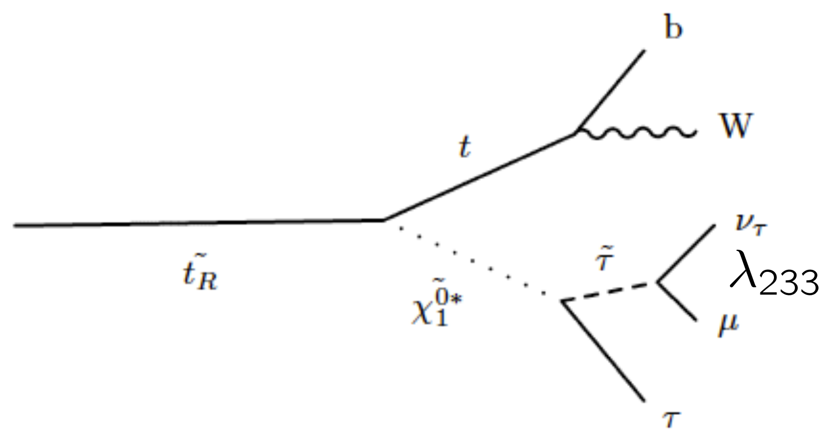
PRV violating terms not forbidden: $W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$

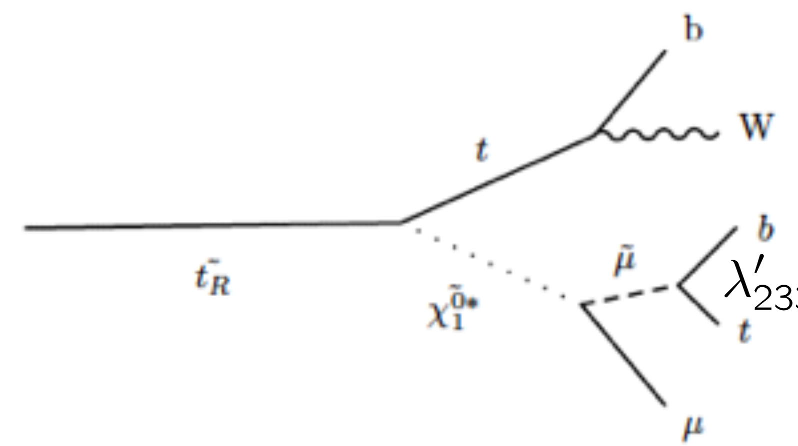
LSP not stable (no DM)

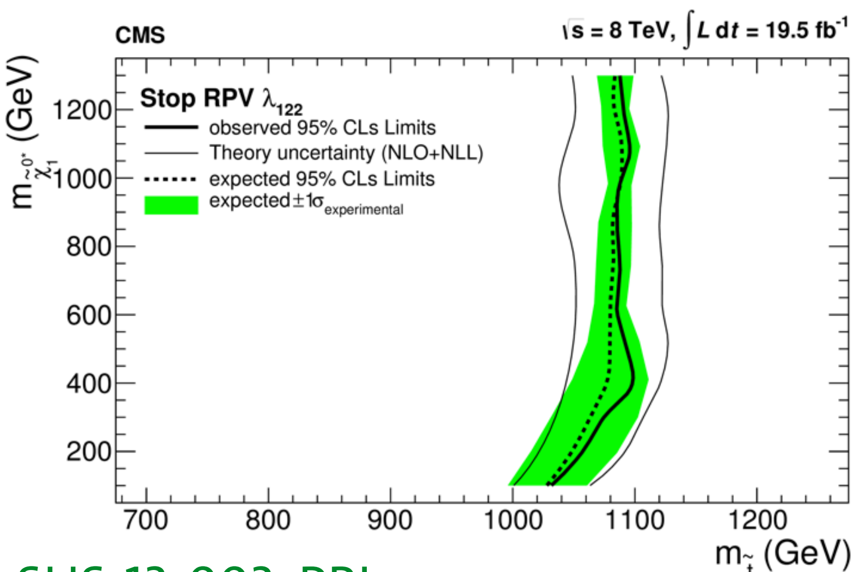
Other attractive features of SUSY remain (e.g. solution to hierarchy problem, gauge unification …)

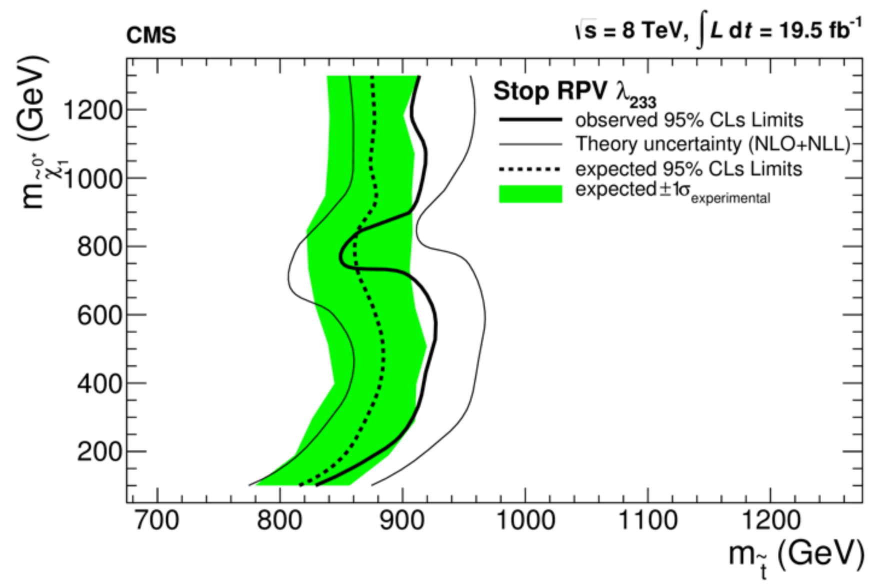
Search for light top-Squarks in final states with low MET

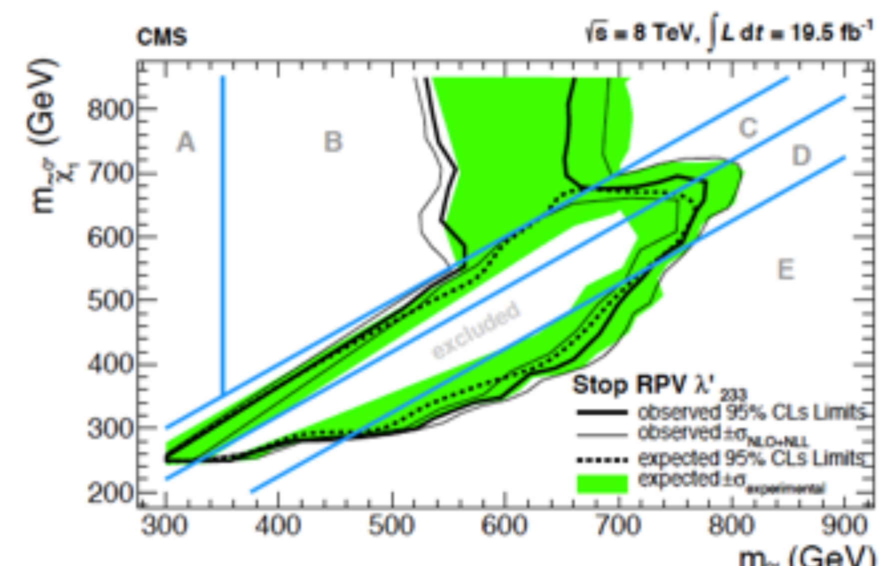












SUS-13-003, PRL

Outline

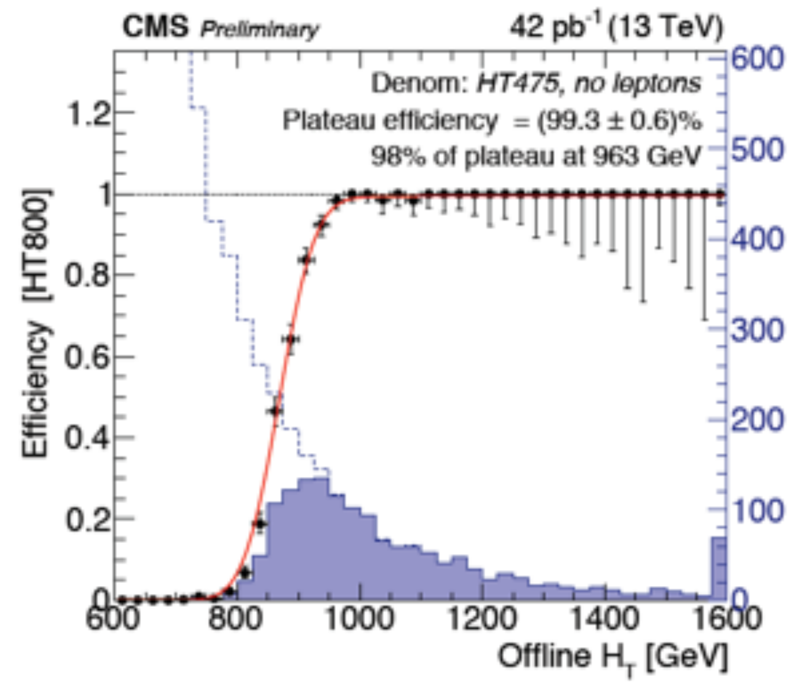
- Introduction
- Run I
  - Inclusive searches
  - Stealth SUSY
  - 3rd generation searches
  - Searches for EWK partners
  - pMSSM reinterpretation
  - RPV searches
- **Run II**
  - Commissioning at 13 TeV
  - Prospects for SUSY
- Conclusions

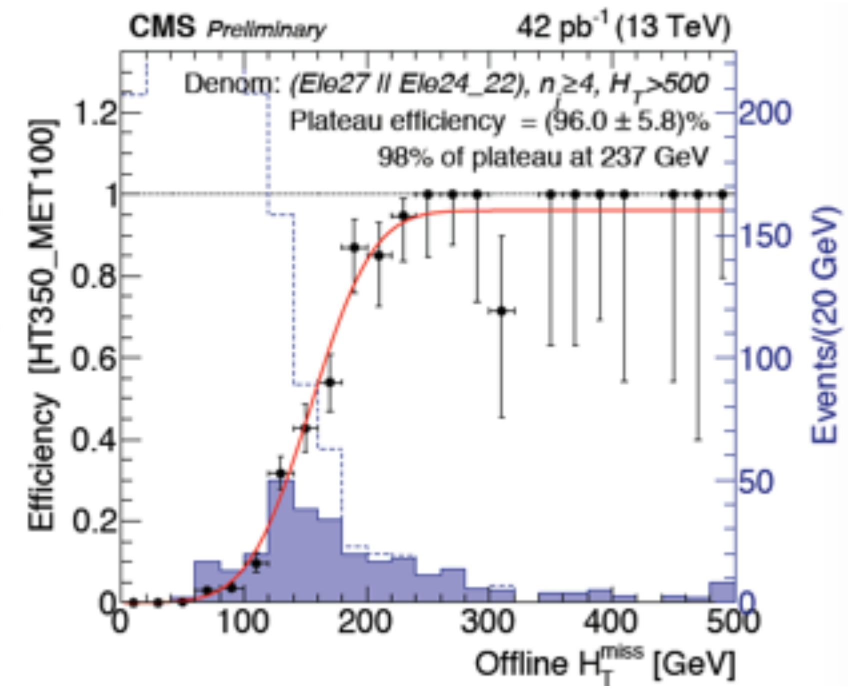
Commissioning @ 13 TeV

new!

Goal: Validate performance of key observables with first data at 13 TeV (42 pb^{-1})

- **Trigger efficiencies**





- **Bg enricher control samples**

  example: Jets + MHT

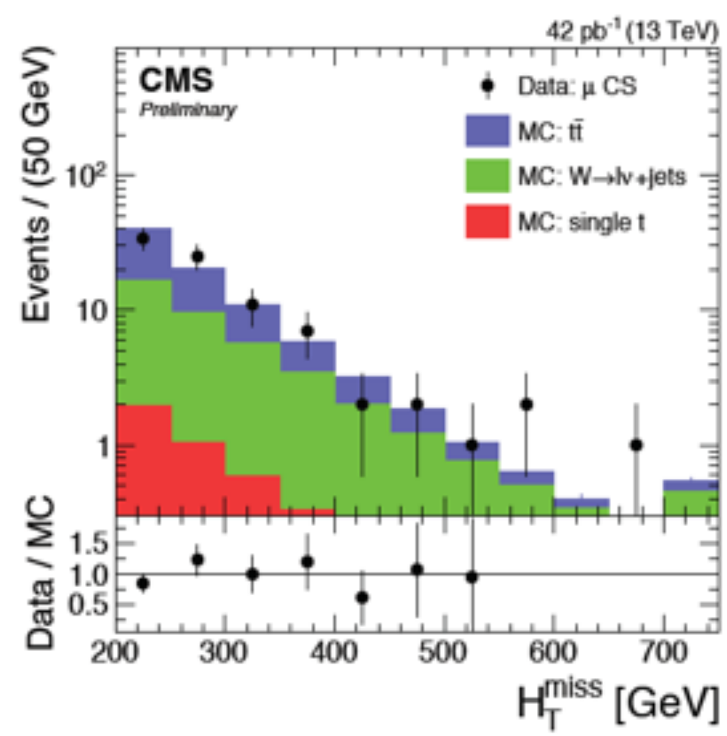
  $N_{jets} > 3$

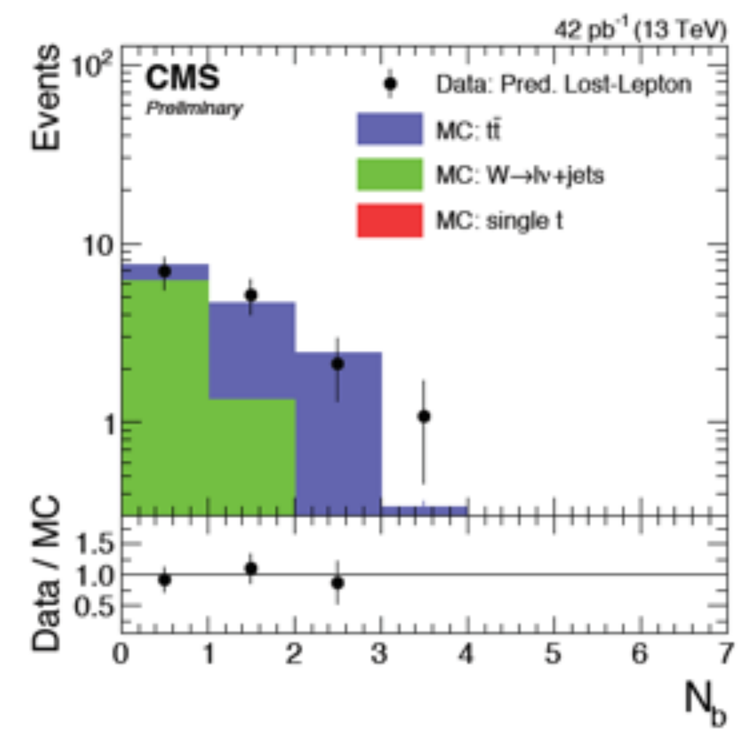
  $H_T > 500$ GeV

  MHT > 200 GeV

  $N_{lepton} = 1$

  (used for “lost leptons”)



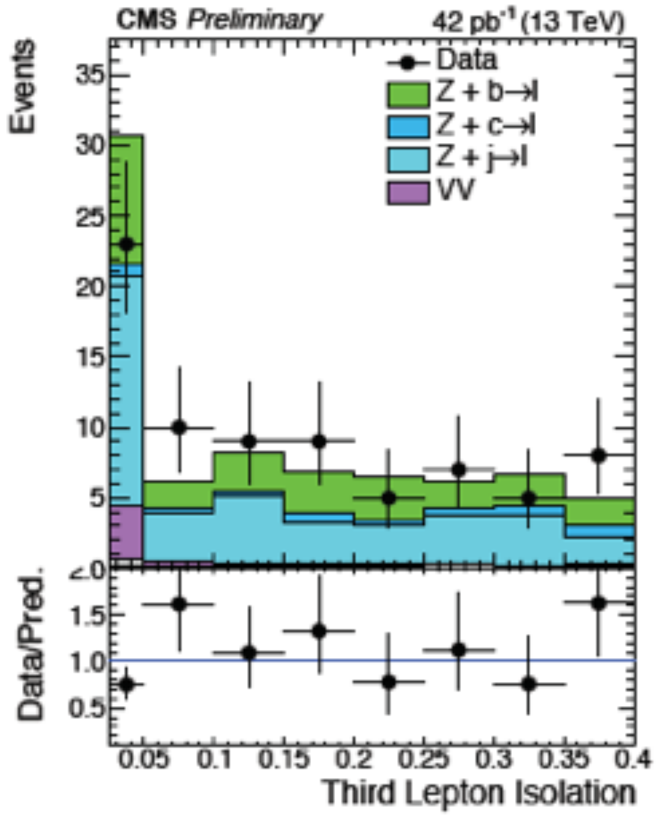


SUSY DPS

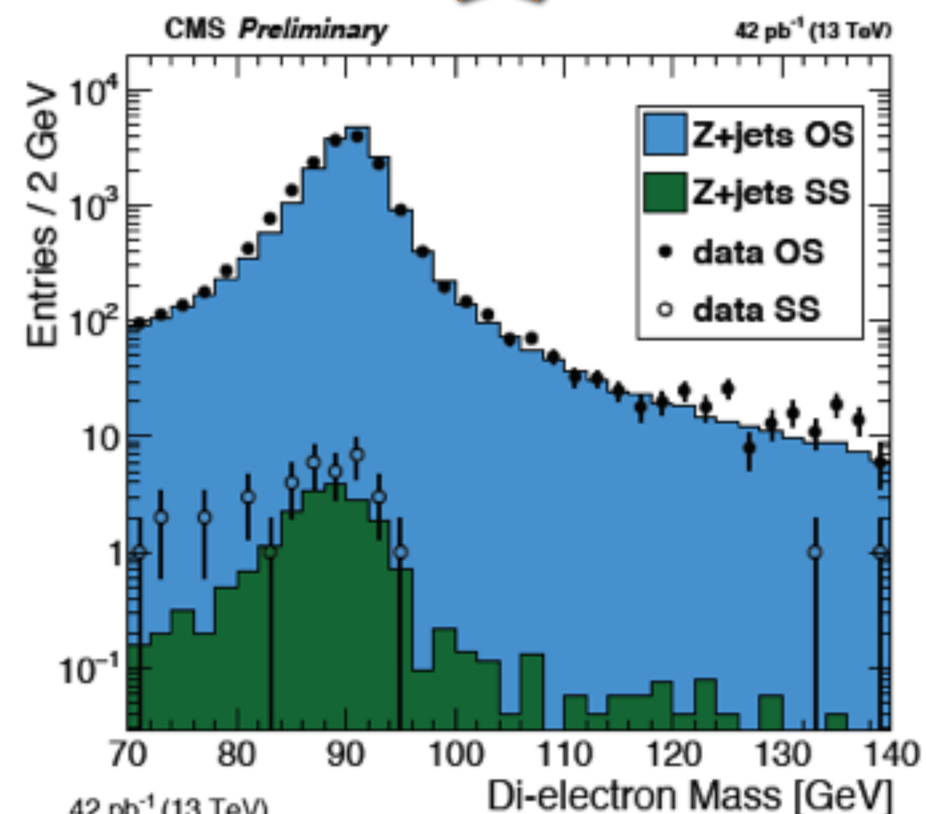
Commissioning @ 13 TeV

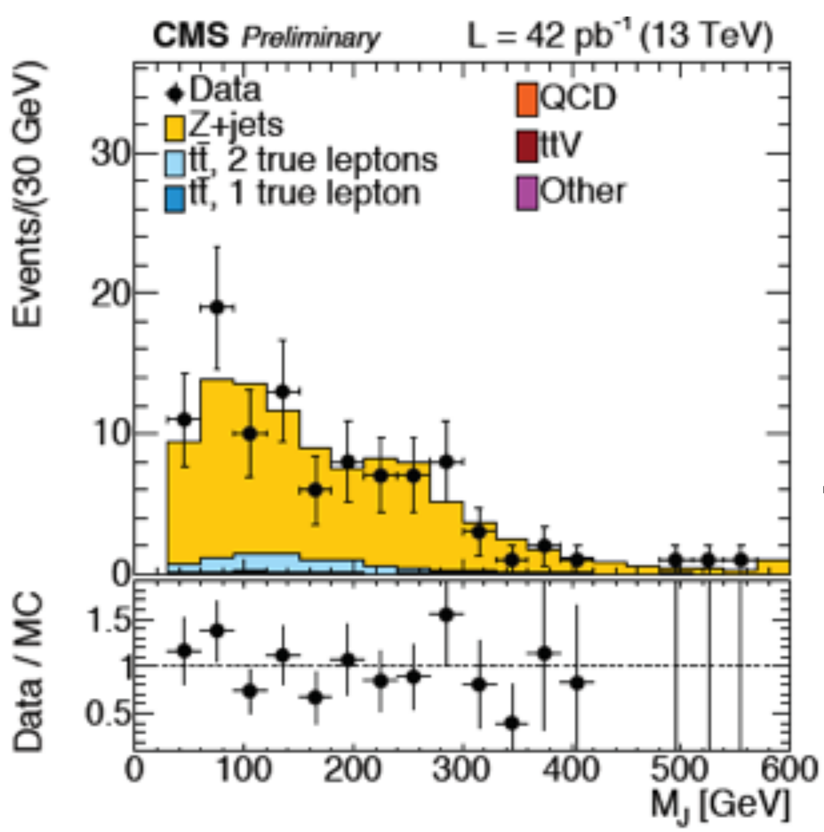
new!

Lepton isolation of third lepton in l^+l^- control sample

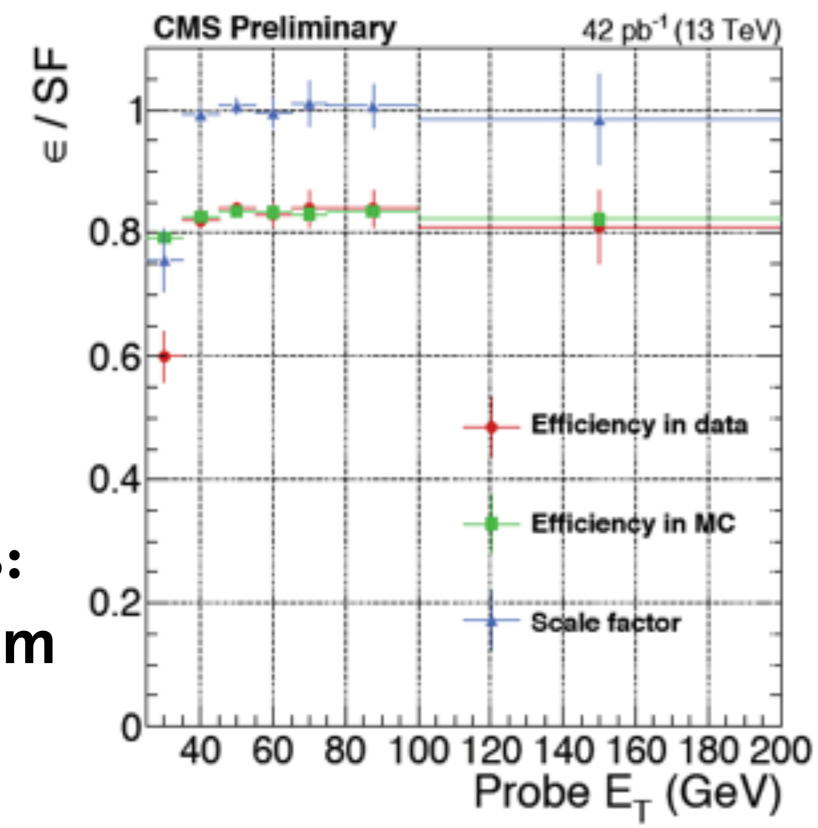


Electron charge mis-identification





Jet mass of ΔR=1.2 fat jets: Study tails from ISR



Photon identification efficiency from Tag & Probe

SUSY DPS

Prospects for Run 2

Increase of √s from 7/8 to 13/14 TeV

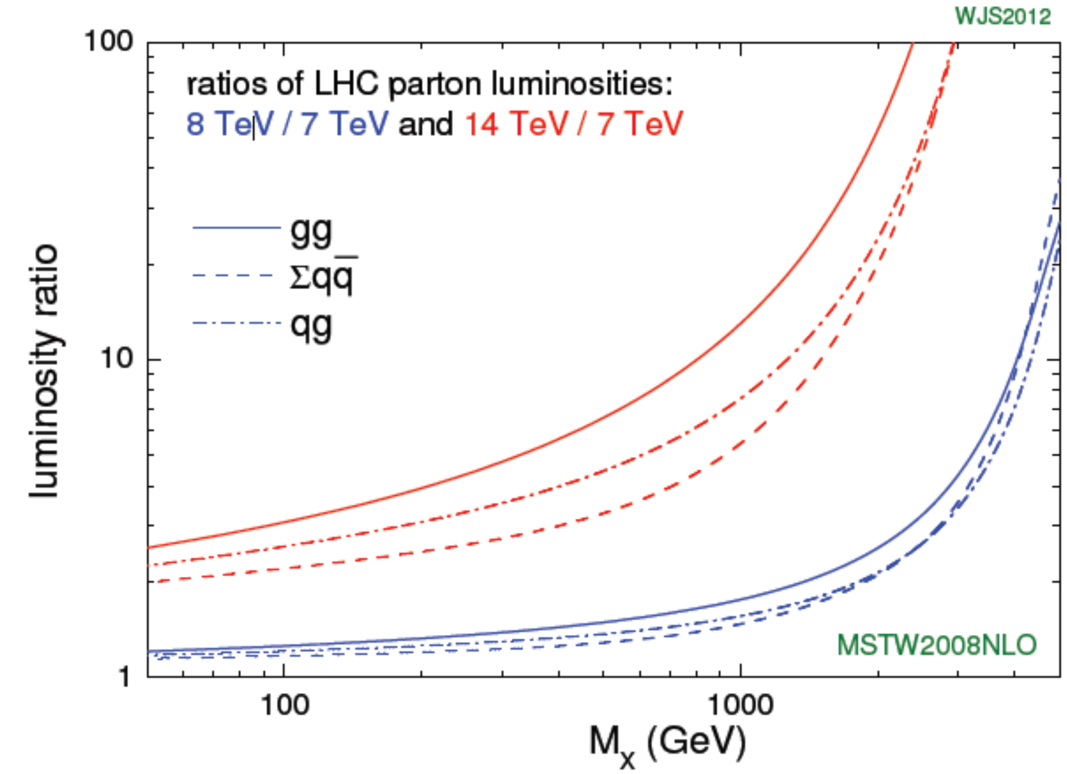
→ Large boost of sensitivity to heavy new particles

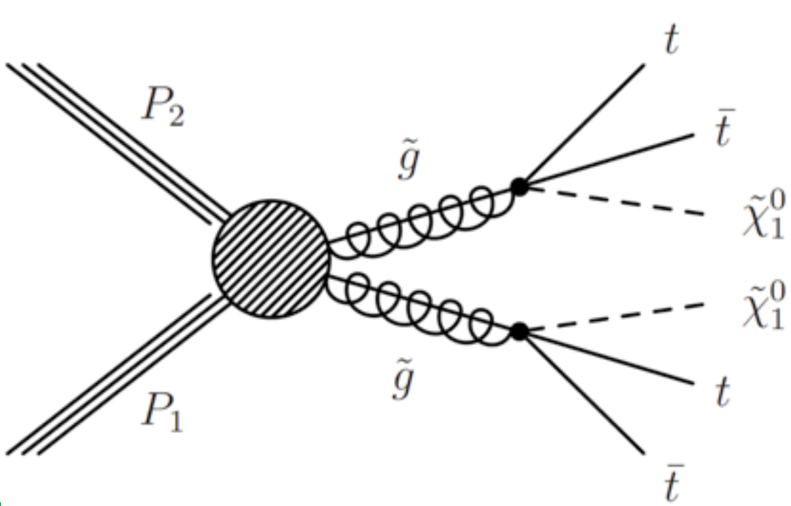
Similar sensitivity on gluino mass expected after first ~ fb^{-1}

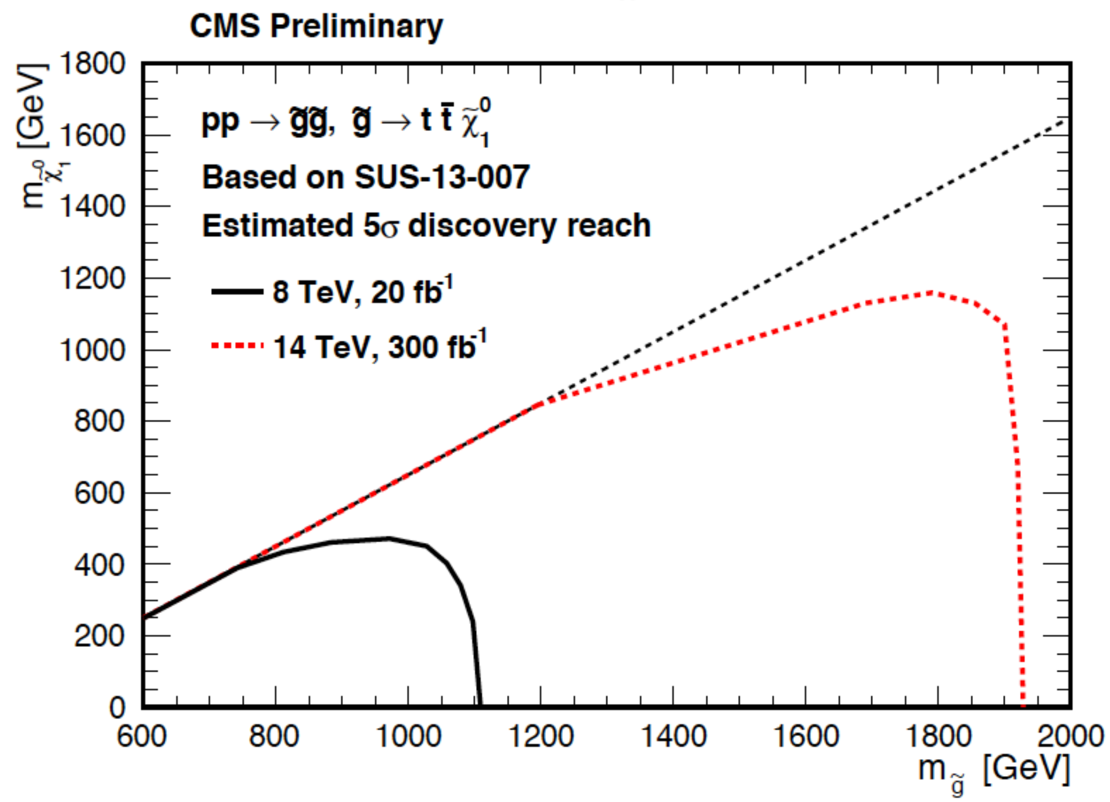
Similar sensitivity on light neutralinos/charginos/ stops after first ~5-10 fb^{-1}

Challenge: Large pile-up <PU> ~25 ... 50 (2015-17 and 2019-21)

Example: single lepton + multi-jet search for gluino-mediated top-squark production







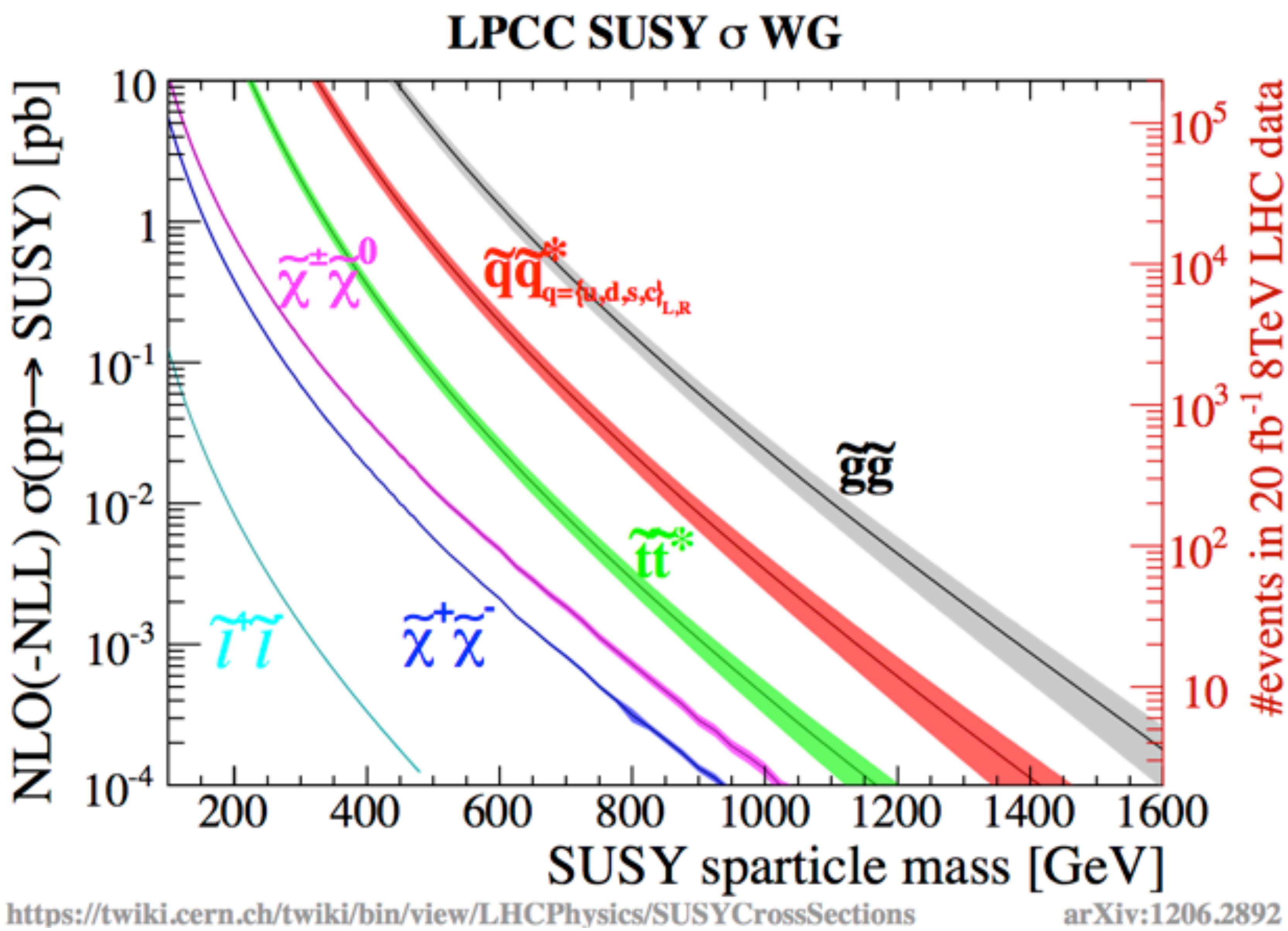
Snowmass report, arXiv:1307.7135

Conclusions

- Search for physics beyond the Standard Model, i. e. SUSY, is one of the main motivations for the LHC experiments
- CMS covers a large variety of possible final states, closing in on challenging scenarios such as compressed SUSY
- So far, no "significant" deviation from SM observed → stringent limits on many SUSY scenarios (in particular natural SUSY is under pressure)
- A first look at 13 TeV data shows promising performance → **very interesting results expected for Run 2**
- For **MANY** more results, see the public result pages: http://cms-results.web.cern.ch/cms-results/public-results/publications/


Backup

SUSY Production Cross Sections



Natural Supersymmetry

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

Tree level: light higgsinos

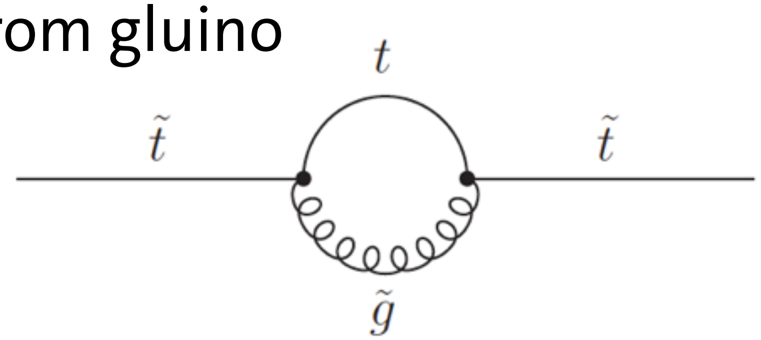
- For large $\tan\beta$ $\rightarrow M_Z^2 = -2(m_{H_u}^2 + |\mu|^2) + \cdots$
- $|\mu| \lesssim 200\mathrm{GeV}$ for $\Delta \leq 10$
  $\rightarrow$ Light higgsinos

1-loop: light top-squarks and winos

- Stop masses below ~400 GeV
- Wino masses below ~1 TeV

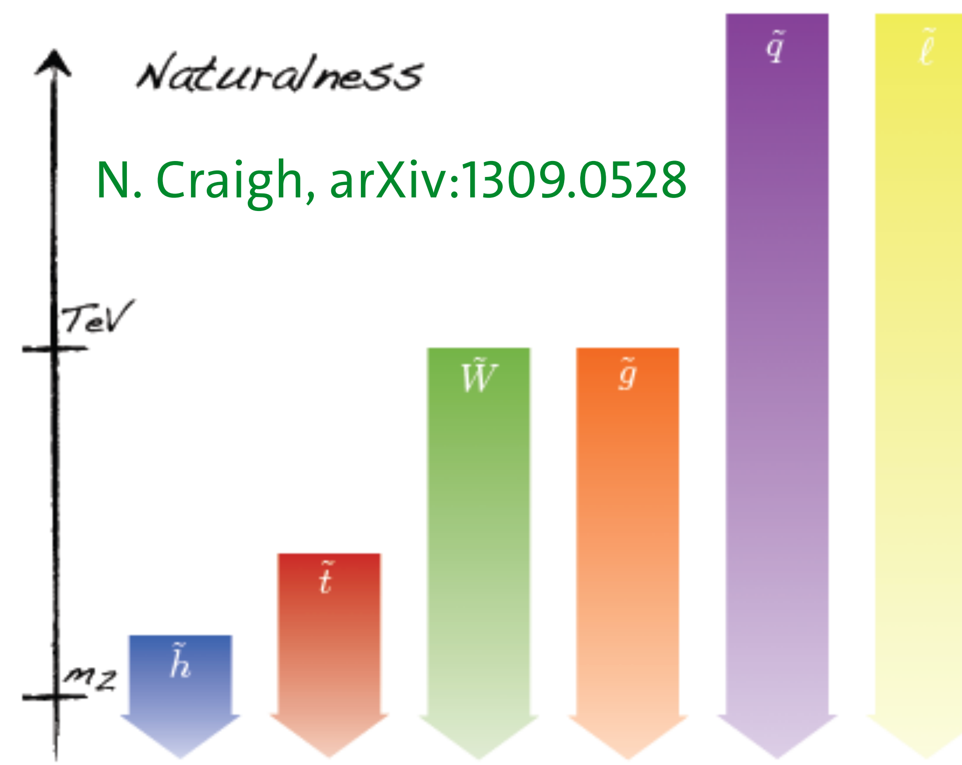
2-loop: light gluinos

- Related to naturalness of other scalars
- Stop mass get correction from gluino
  $\rightarrow m_{\tilde{g}} \lesssim 2m_{\tilde{t}}$



$$\Delta[a_i] = \frac{\partial \ln m_Z^2}{\partial \ln a_i^2}, \quad \Delta = \max \Delta[a_i]$$

For each fundamental parameter a_i (be aware of correlations)



SUSY mass scale motivated by EW naturalness

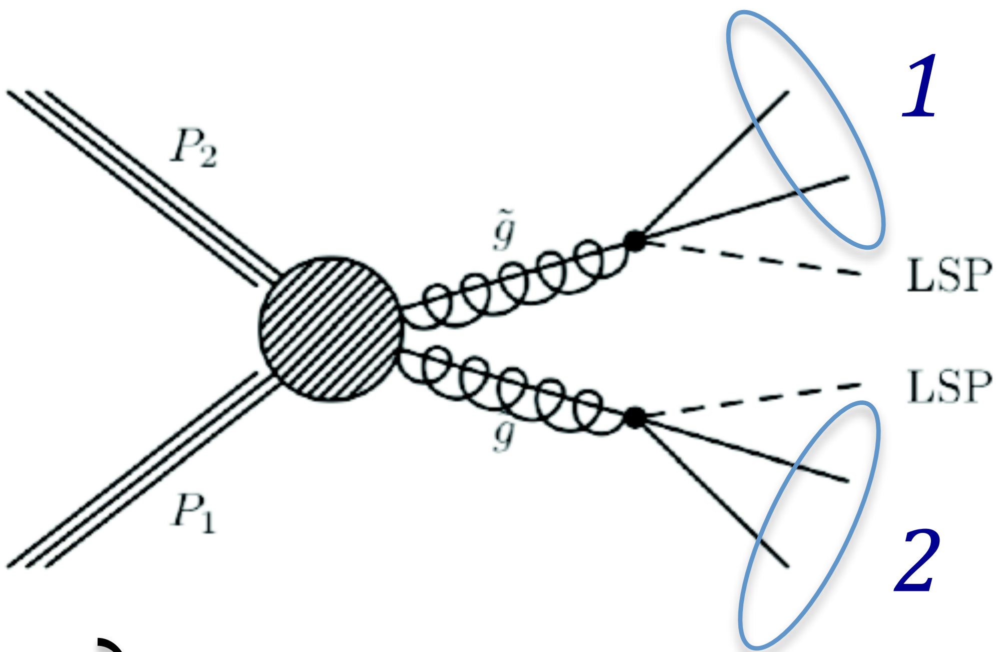
BUT: the "allowed" level of fine-tuning is a matter of taste

Inclusive Searches …

- Multi-jets + MHT $H_T = \sum |p_T|$

  SUS-13-012, JHEP

$$\not{H}_T = \left| -\sum \vec{p}_T \right|$$



- $\alpha_T = \frac{E_T^{2nd}}{M_T} = \frac{E_T^{2nd}}{\sqrt{2 p_T^{1st} p_T^{2nd}(1 - \cos\phi_{12})}}$

  SUS-12-028, EJPC

- "The razor":

$$M_R = \sqrt{(|\vec{p}_{q1}| + |\vec{p}_{q2}|)^2 - (p_{z,q1} + p_{z,q2})^2}$$

$$M_T^R = \sqrt{\frac{1}{2}\left(\not{E}_T(p_T^{q1} + p_T^{q2}) - \vec{\not{E}}_T(\vec{p}_T^{q1} + \vec{p}_T^{q2})\right)}$$

$$R = \frac{M_T^R}{M_R}$$

  SUS-13-004, PRD

- Same sign leptons

  SUS-13-013, JHEP

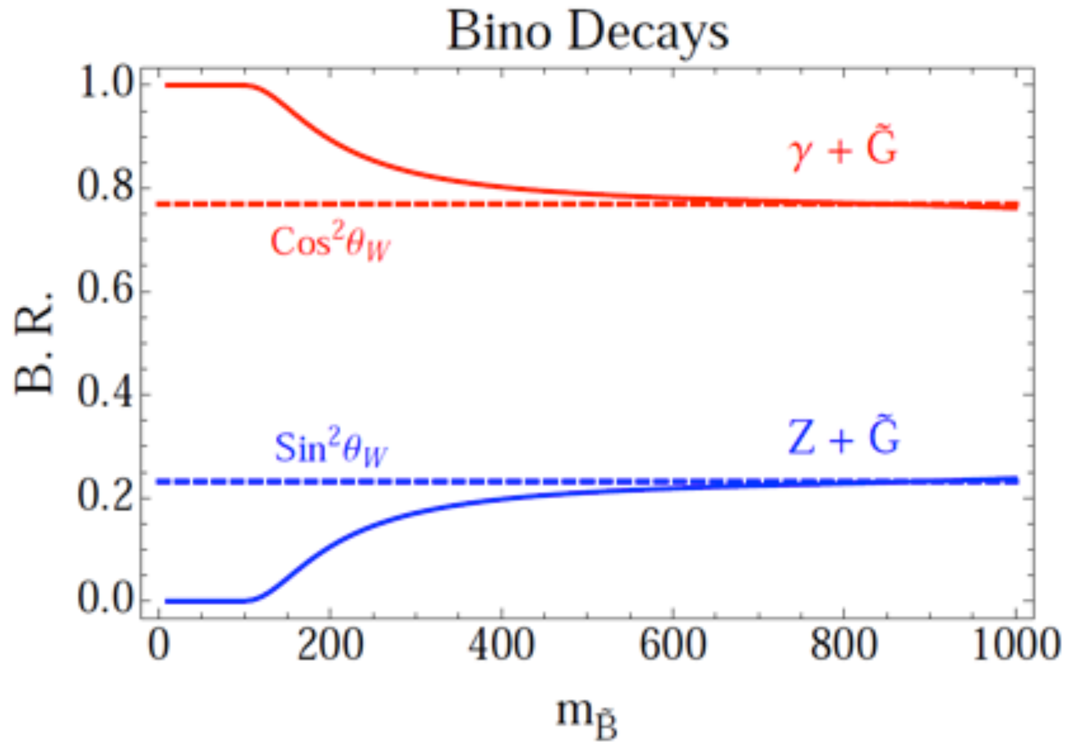
… a lot of complementary approaches

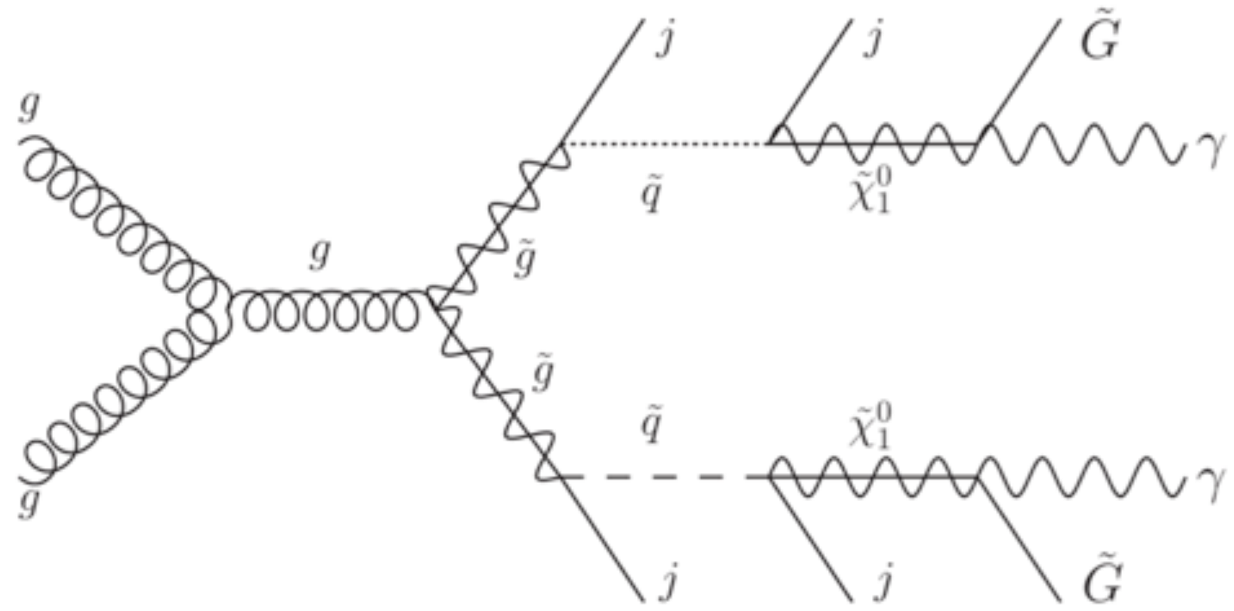
Photons + Jets + MET

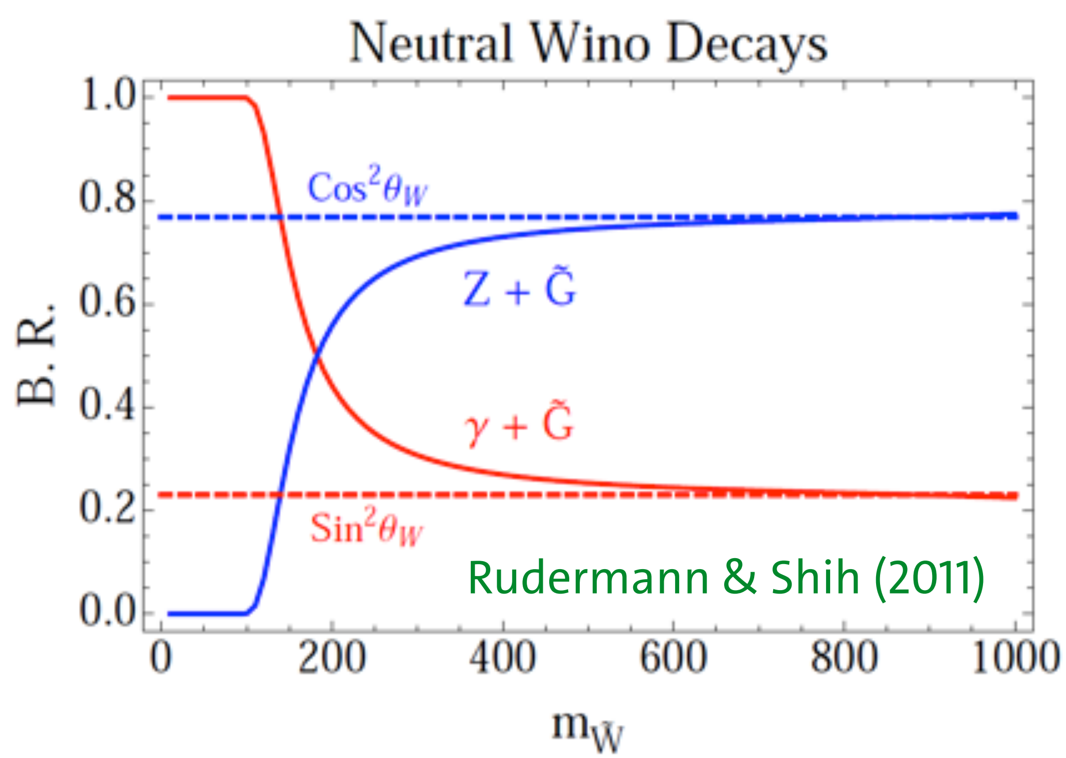
If LSP is gravitino, NLSP is neutralino (or chargino)

General **G**auge **M**ediation:

- "bino-like": $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
- "wino-like": $\tilde{\chi}_1^0 \rightarrow Z^0 + \tilde{G}$ or $\tilde{\chi}_1^\pm \rightarrow W^\pm + \tilde{G}$





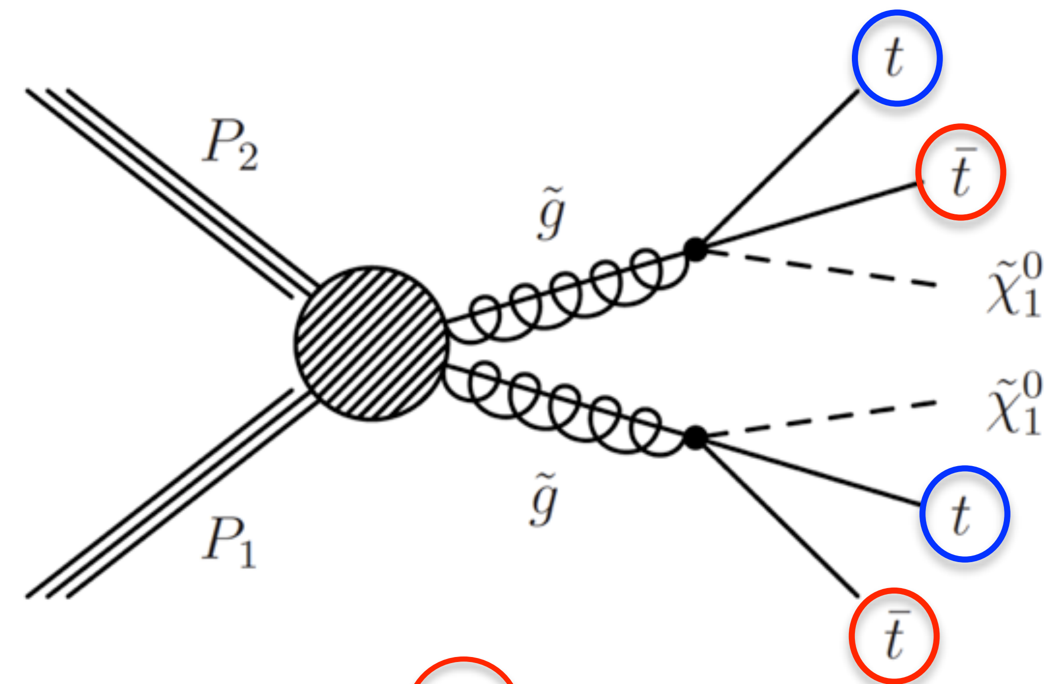


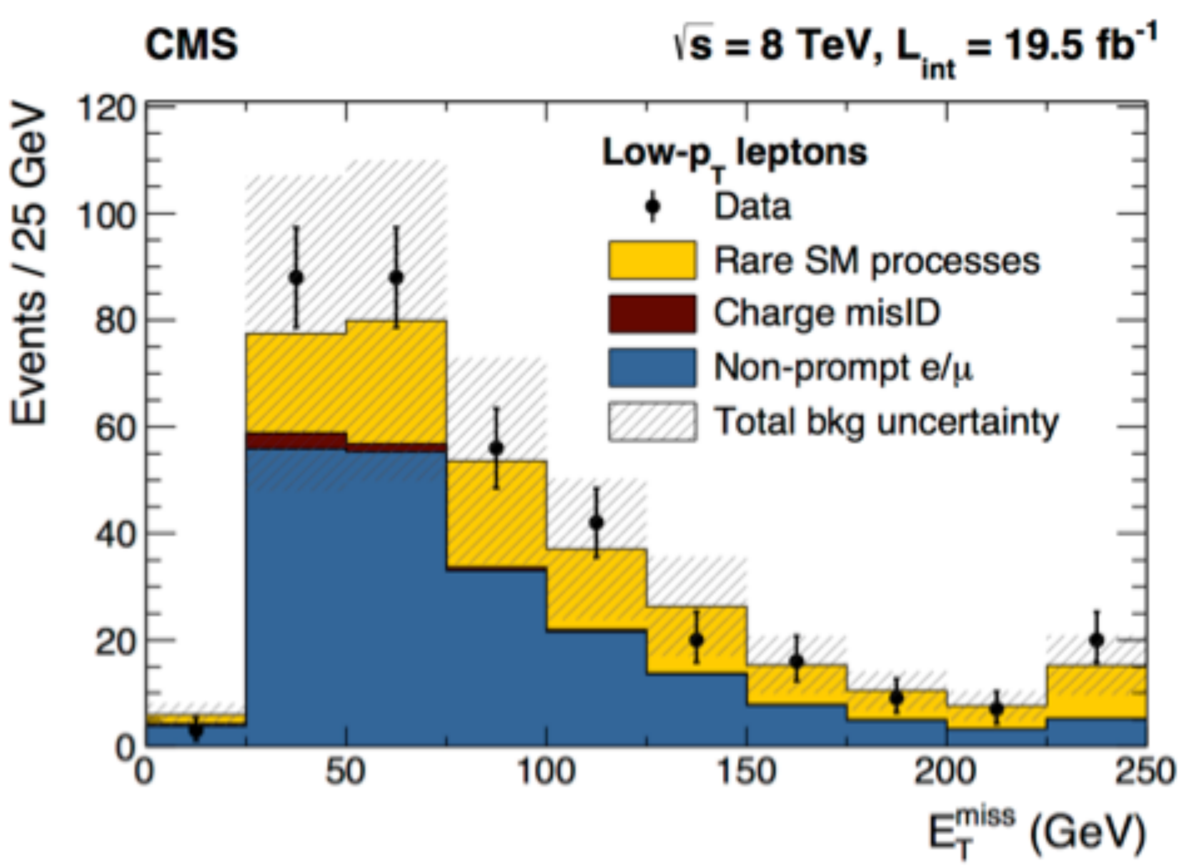
Same Sign Leptons

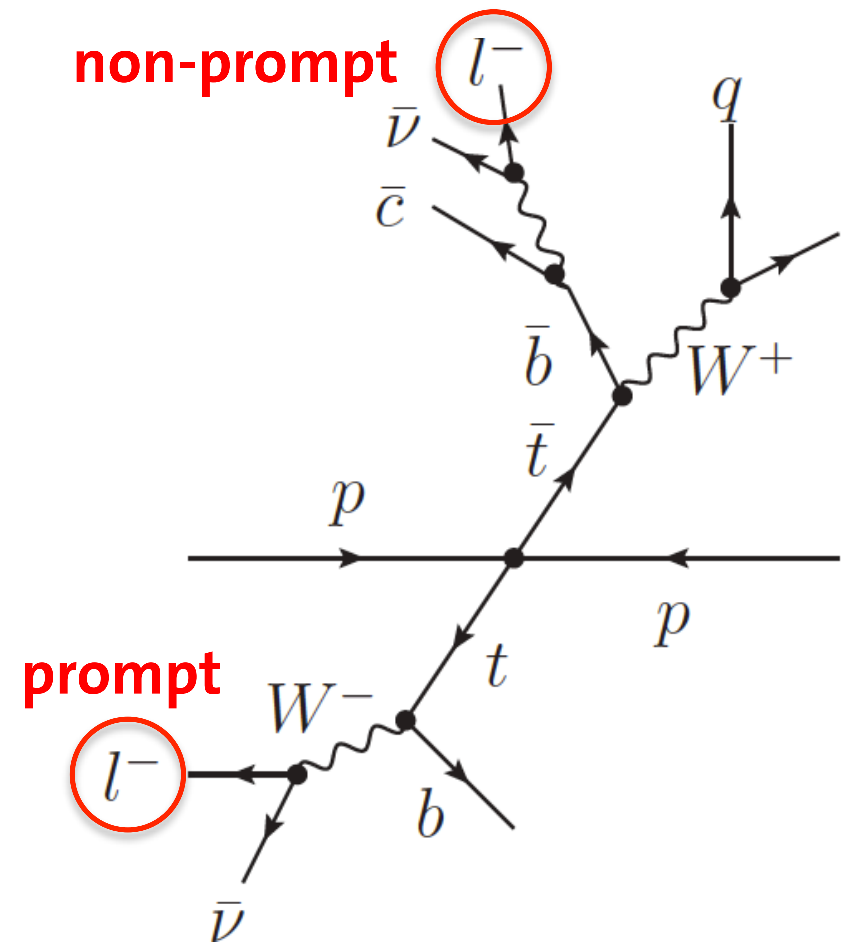
Very clear and generic SUSY signature

Small SM backgrounds

- Rare processes ($t\bar{t} + V,\ VV$)
- Non-prompt leptons (“fakes”)
- Charge mis-identification

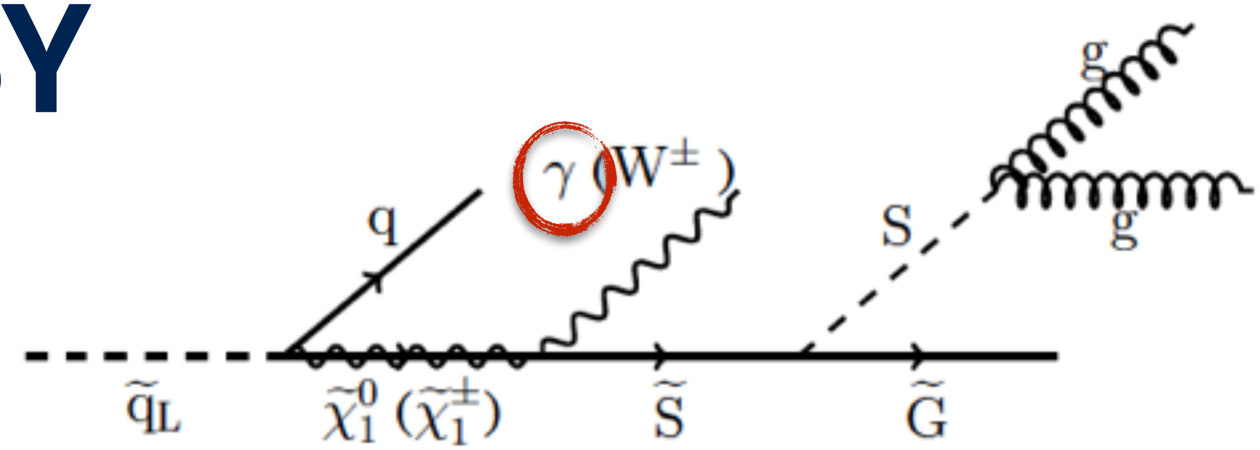






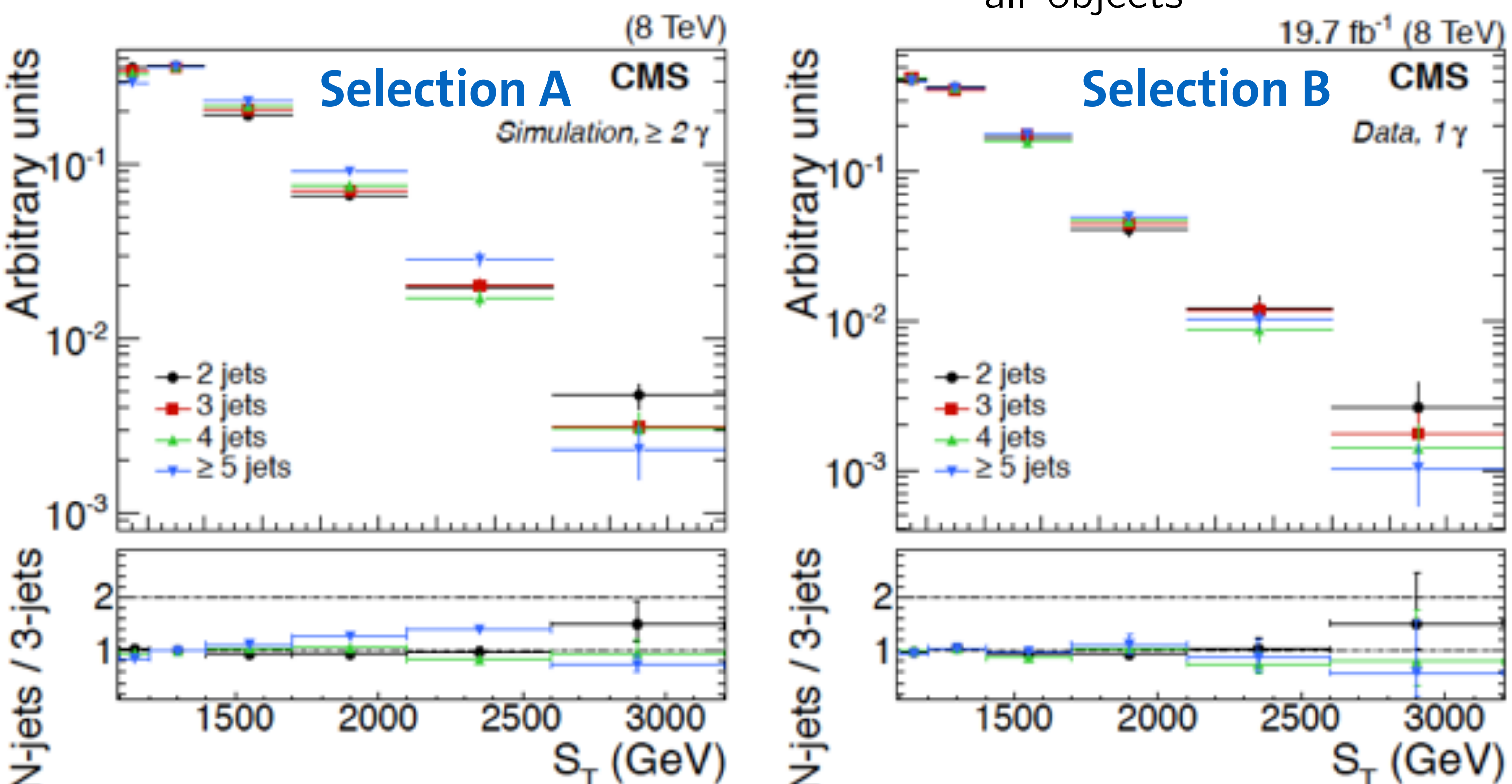
SUS-13-013, JHEP

Stealth SUSY



Low MET signatures:

- Compressed spectra; RPV SUSY …
- **Hidden valley models** (additional singlet/singlino field): signature depends strongly of LSP/NLSP nature and mass difference: $\Delta m = m_{\tilde{S}} - m_S$
- Sensitive variable: $S_T = \not{E}_T + \sum_{\text{all objects}} p_T$



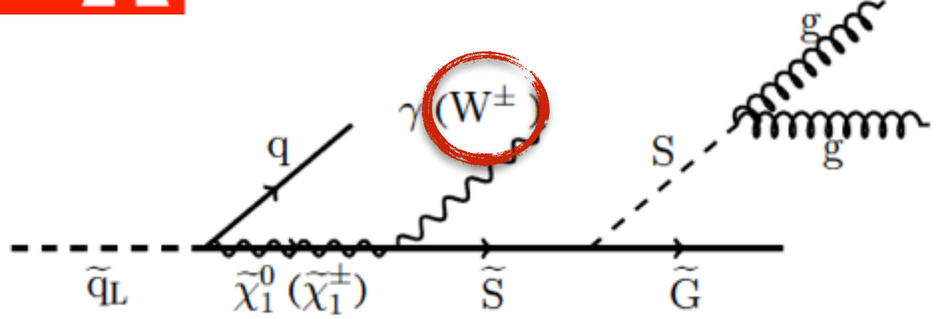
SUS-14-009, PLB

Photon + jets + MET:

Selection	N_{jets} (GeV)	γ_1 p_T (GeV)	γ_2 p_T (GeV)	H_T
A	≥2	>40	>25	>60
B	≥2	<75	—	>800

Take S_T shape in signal depleted CR (low N_{Jet} = 3, S_T > 1200 GeV) and normalise in S_T side band: 1100 < S_T < 1200 GeV

Stealth SUSY - Results



Similar analysis for final states with leptons:

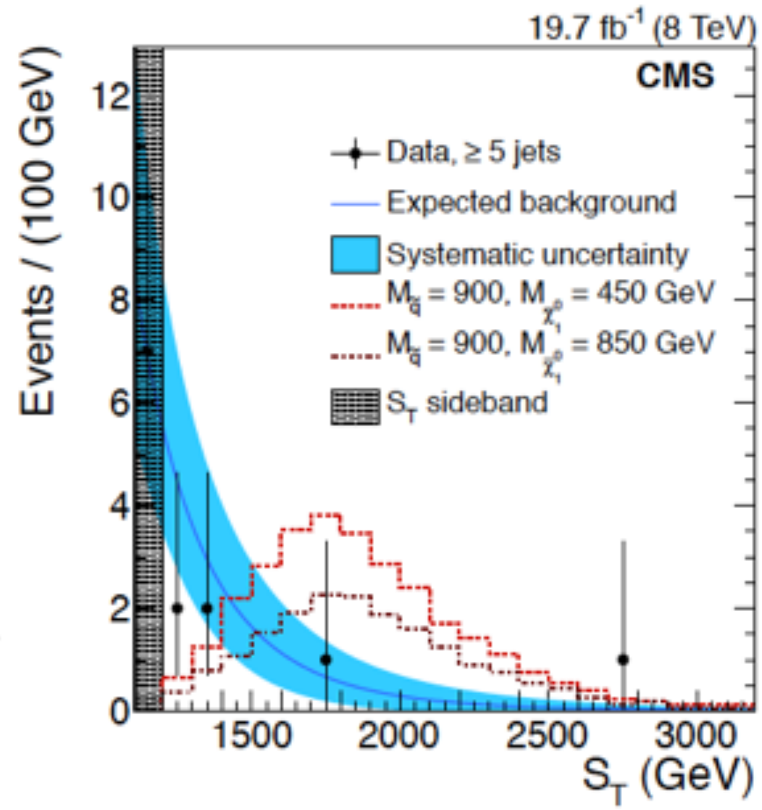
Definition of various SR and CR:

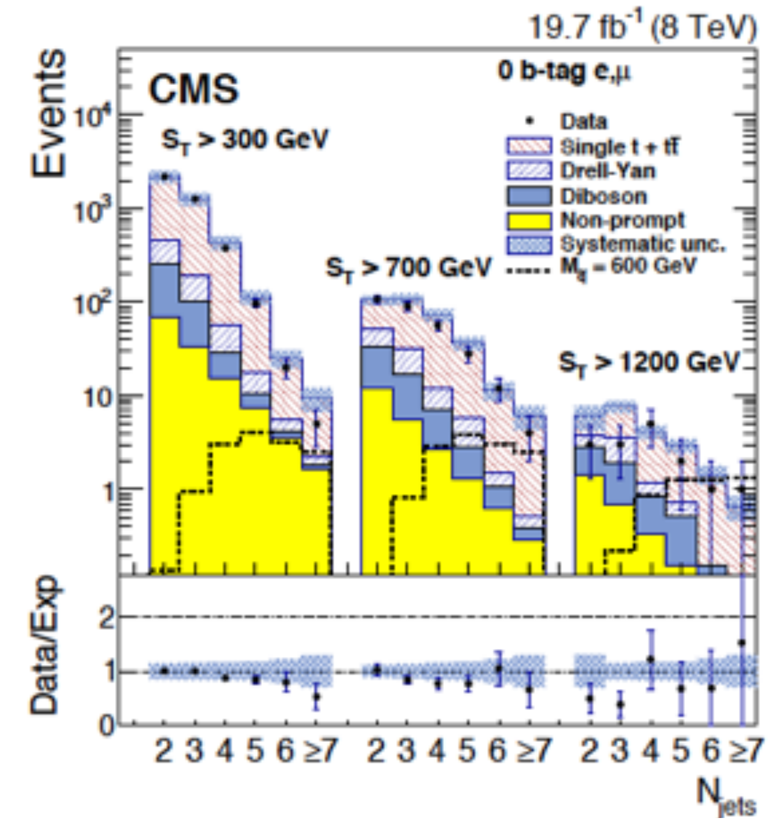
Sample	Leptons	N_{jets}	$N_{\text{b-jets}}$
Search	$e^\pm, \mu^\mp$	≥ 4	0
Top shape	$e^\pm, \mu^\mp$	≥ 2	≥ 2
Top normalization	$e^\pm, \mu^\mp$	<4	0
Drell–Yan	$\mu^\pm, \mu^\mp$	≥ 2	0
Non-Prompt	$e^\pm, \mu^\pm$	≥ 2	0

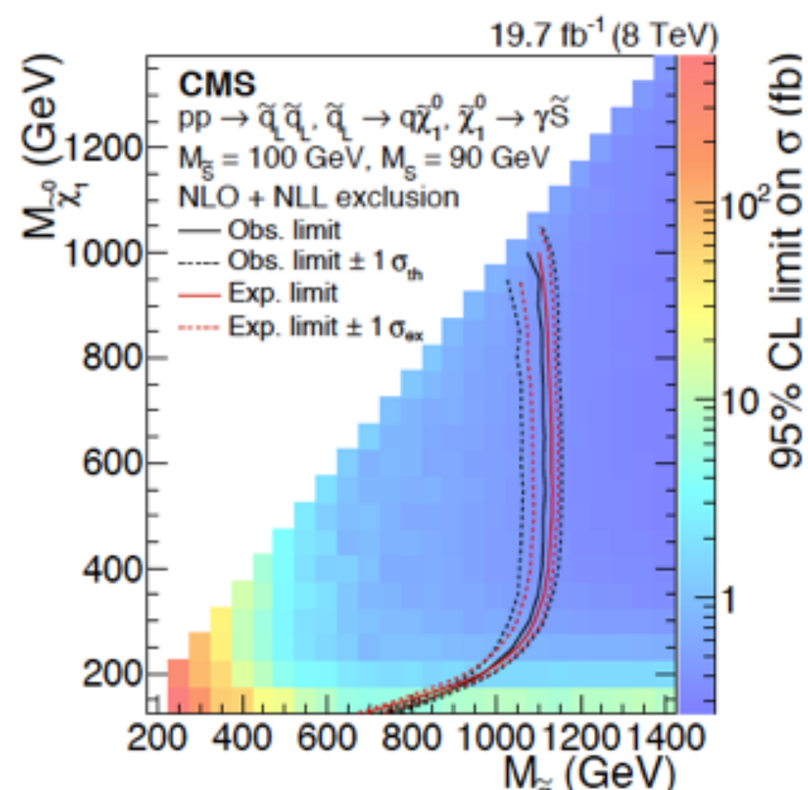
Interpretation in SMS with $\Delta m = 10$ GeV and $m_S = 100$ GeV

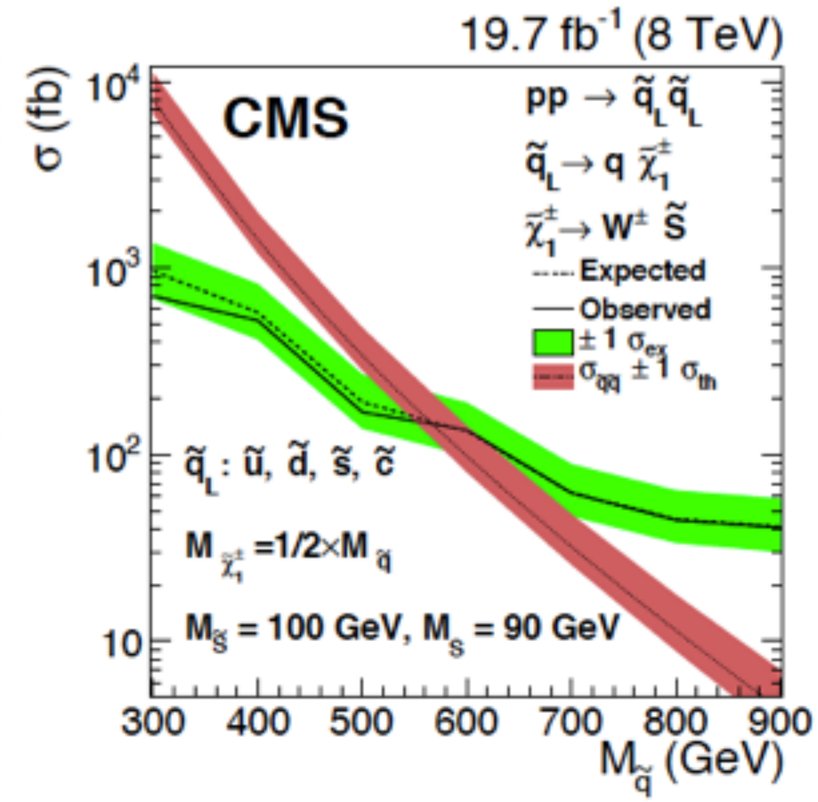
Large mass difference of squark and NLSP → boosted topologies and less isolated photons

Exclude squark masses up to ~1050 GeV (γs) and ~550 GeV (leptons)







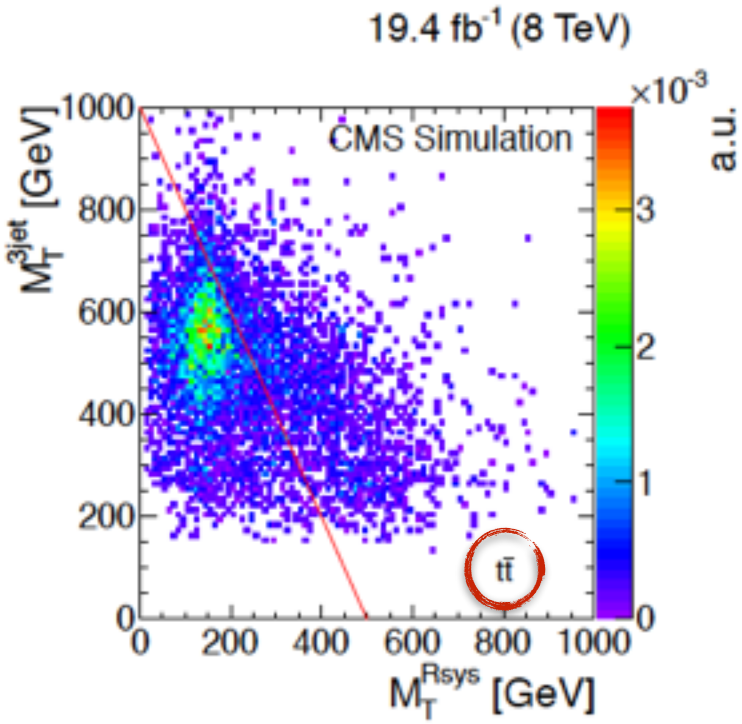


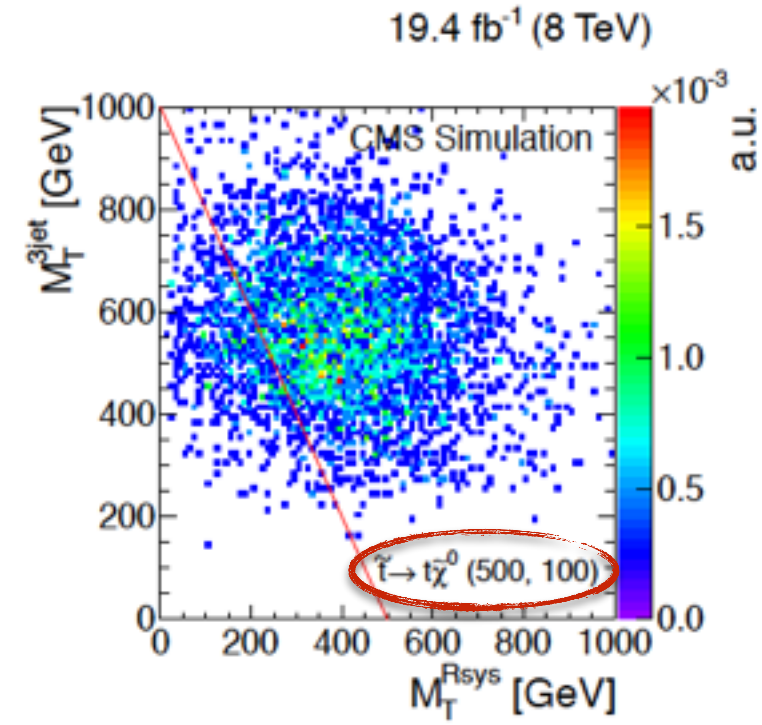
SUS-14-009, PLB

Hadronic Top-Squark Searches

Require on fully reconstructed hadronic top quark (3 jets within cone with $\Delta R<1.5$) $\rightarrow M_{\mathrm{T}}^{3\ \mathrm{jet}}$

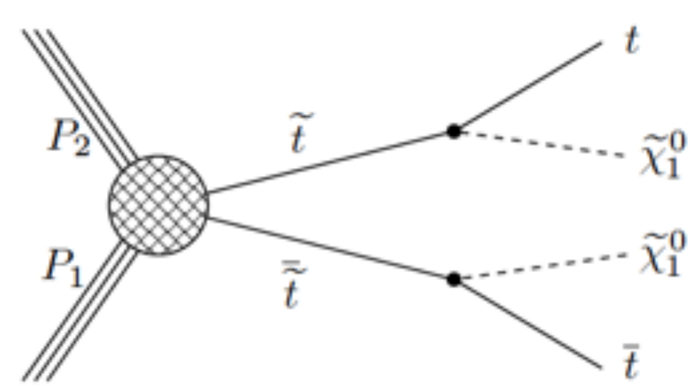
From remaining jets (including 1 b-tag and up to 2 additional jets) form further top candidate (with loser requirements) $\rightarrow M_{\mathrm{T}}^{\mathrm{Rsys}}$

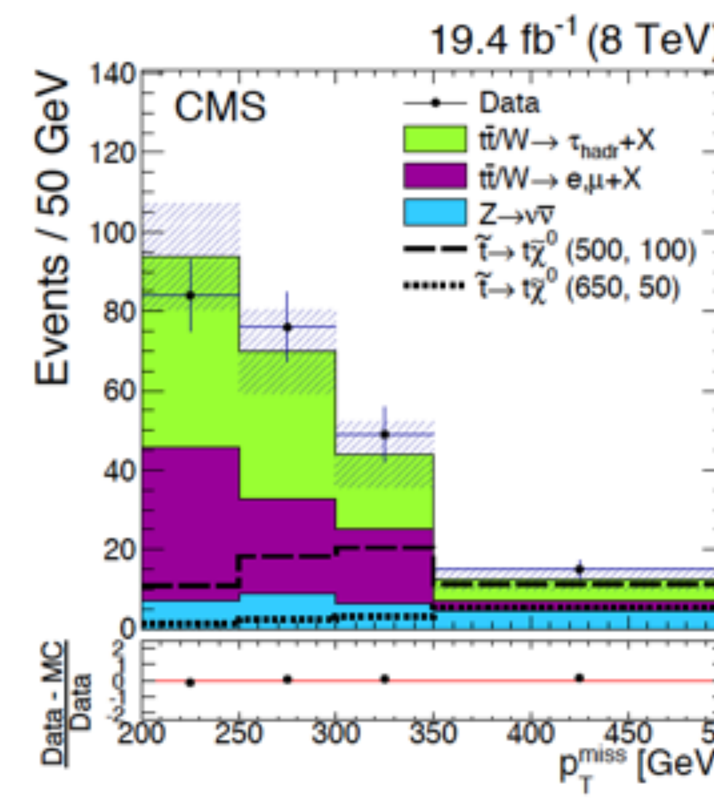




Discriminating variables:

- M_{T2}
- $\not{E}_T$
- $0.5 \cdot M_{\mathrm{T}}^{3\ \mathrm{jet}} + M_{\mathrm{T}}^{\mathrm{Rsys}}$





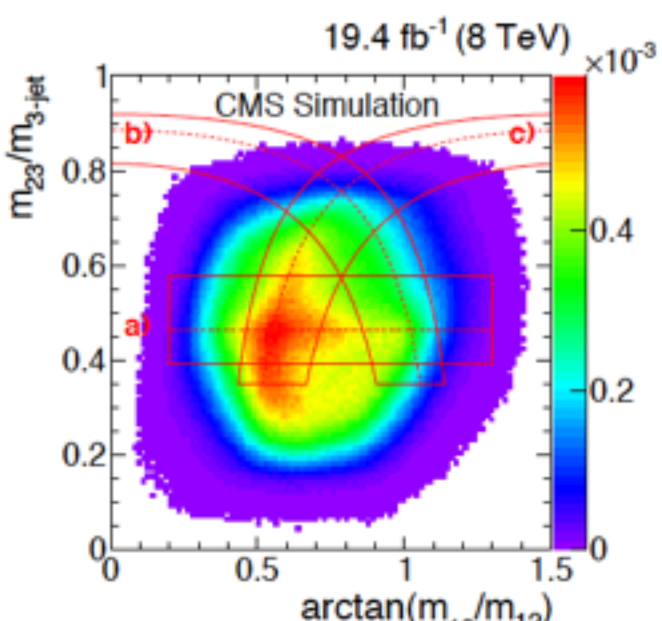
Search regions	$N_{\mathrm{b\ jets}}$				
	≥ 0	1		2	
Multijet t-tagged search		SM Pred.	Obs.	SM Pred.	Obs.
$p_{\mathrm{T}}^{\mathrm{miss}} \in [200, 350]$ GeV		148^{+29}_{-24}	141	81^{+13}_{-12}	68
$p_{\mathrm{T}}^{\mathrm{miss}} > 350$ GeV		$33.4^{+7.0}_{-7.8}$	30	$8.6^{+2.6}_{-2.4}$	15

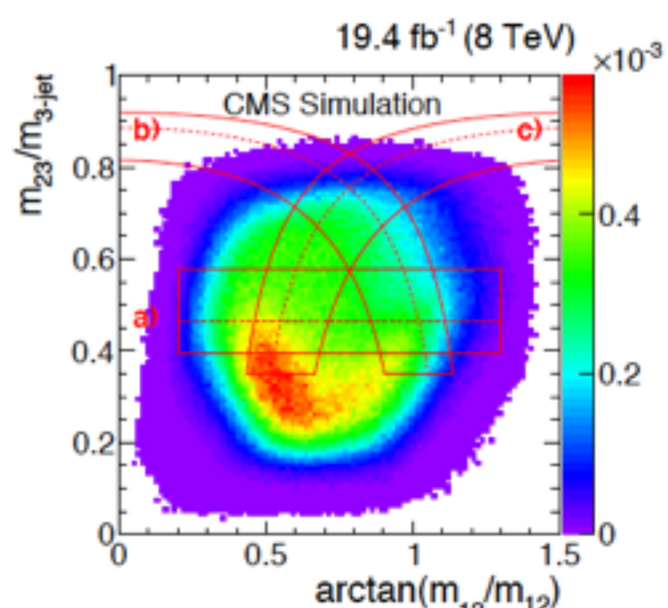
SUS-14-001, submitted to JHEP

Hadronic Top-Squark Searches

Background prediction:

Background source	$N_{\text{b jets}}$	$200 \le p_T^{\text{miss}} \le 350\,\text{GeV}$	$p_T^{\text{miss}} > 350\,\text{GeV}$
$\tau \to$ hadrons	$=1$	$62.2 \pm 5.6 \pm 5.6$	$12.3 \pm 1.7 \pm 2.6$
Lost lepton	$=1$	$48 \pm 6^{+11}_{-11}$	$7.0 \pm 2.4^{+3.2}_{-3.1}$
$Z(\nu\bar{\nu})$ +jets	$=1$	$17.9 \pm 1.4^{+5.1}_{-8.4}$	$11.3 \pm 1.0^{+3.8}_{-5.5}$
Multijets	$=1$	$17 \pm 3 \pm 24$	$2.0 \pm 1.1 \pm 2.7$
Rare processes	$=1$	1.9 ± 0.9	0.8 ± 0.4
Total	$=1$	148^{+29}_{-24}	$33.4^{+7.0}_{-7.8}$
$\tau \to$ hadrons	≥ 2	$41.5 \pm 4.3 \pm 5.3$	$4.3 \pm 1.4^{+1.0}_{-1.1}$
Lost lepton	≥ 2	$32.6 \pm 5.1^{+8.6}_{-8.2}$	$1.2 \pm 0.8 \pm 0.5$
$Z(\nu\bar{\nu})$ +jets	≥ 2	$4.6 \pm 0.6^{+2.8}_{-2.4}$	$1.8 \pm 0.4^{+1.6}_{-1.0}$
Multijets	≥ 2	< 0.5	< 0.5
Rare processes	≥ 2	1.9 ± 0.9	1.2 ± 0.6
Total	≥ 2	81^{+13}_{-12}	$8.6^{+2.6}_{-2.4}$

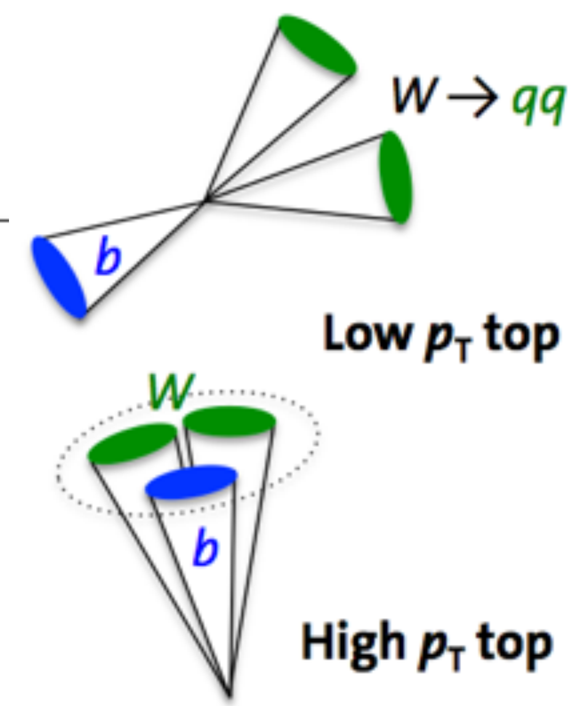




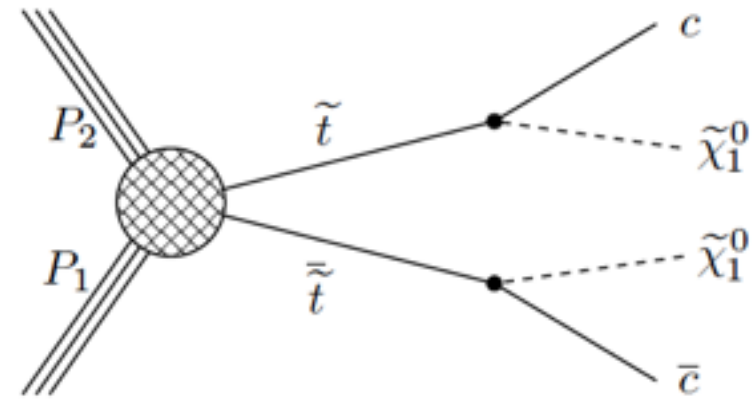
SUS-14-001, submitted to JHEP

Results:

Search regions	$N_{\text{b jets}}$: ≥ 0		1		2	
Multijet t-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$p_T^{\text{miss}} \in [200, 350]\,\text{GeV}$			148^{+29}_{-24}	141	81^{+13}_{-12}	68
$p_T^{\text{miss}} > 350\,\text{GeV}$			$33.4^{+7.0}_{-7.8}$	30	$8.6^{+2.6}_{-2.4}$	15
Dijet b-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$M_{CT} < 250\,\text{GeV}$			1540 ± 100	1560	93 ± 10	101
$M_{CT} \in [250, 350]\,\text{GeV}$			754 ± 68	807	50.0 ± 6.4	55
$M_{CT} \in (350, 450]\,\text{GeV}$			85 ± 10	101	6.5 ± 1.7	8
$M_{CT} > 450\,\text{GeV}$			16.0 ± 4.1	23	1.0 ± 0.9	1
ISR			356 ± 41	359	26.0 ± 4.1	28
Monojet search	SM Pred.	Obs.				
$p_T^{j1} > 250\,\text{GeV}$	35900 ± 1500	36600				
$p_T^{j1} > 300\,\text{GeV}$	17400 ± 800	17600				
$p_T^{j1} > 350\,\text{GeV}$	8060 ± 440	8120				
$p_T^{j1} > 400\,\text{GeV}$	3910 ± 250	3900				
$p_T^{j1} > 450\,\text{GeV}$	2100 ± 160	1900				
$p_T^{j1} > 500\,\text{GeV}$	1100 ± 110	1000				
$p_T^{j1} > 550\,\text{GeV}$	563 ± 71	565				



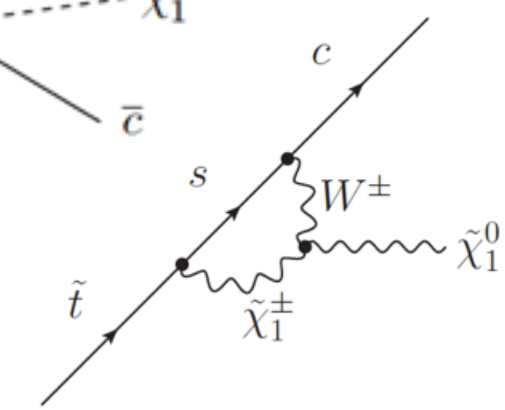
Compressed Top-Squark Scenarios



Compressed scenarios: $m_{\tilde{t}_1} \approx m_{\tilde{\chi}_1^0}$

→ Decay products (c-jets) very soft

Use mono-jet signature (as for DM searches)

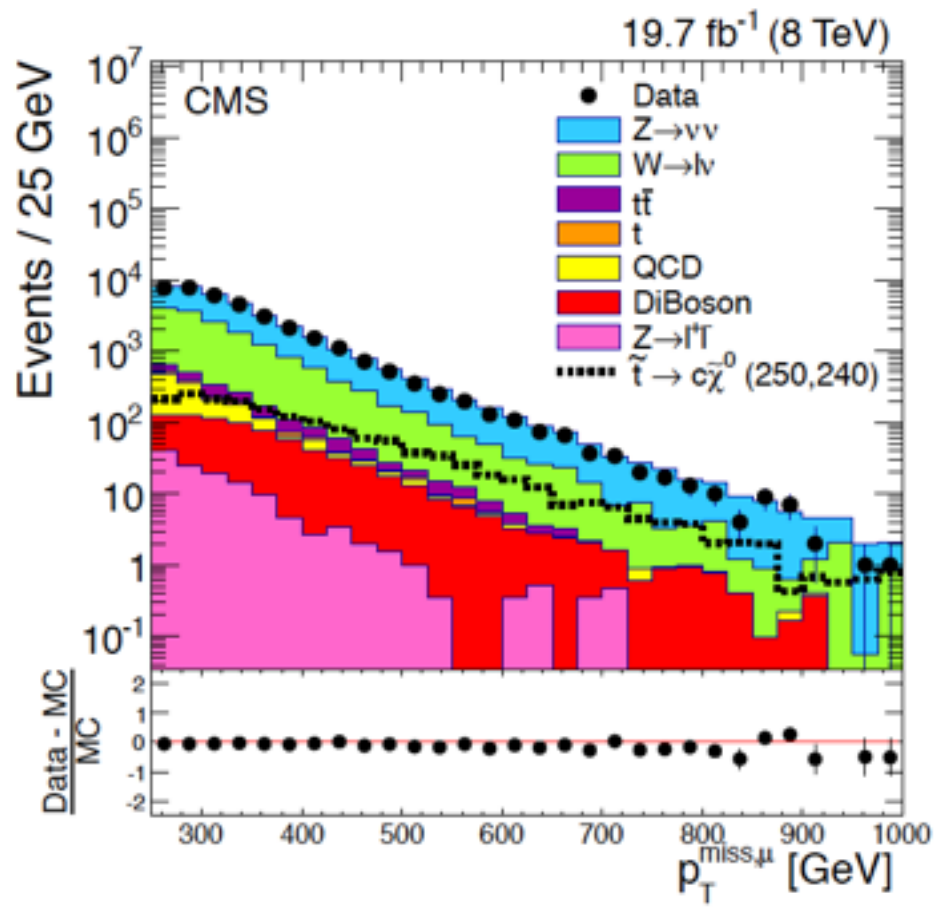


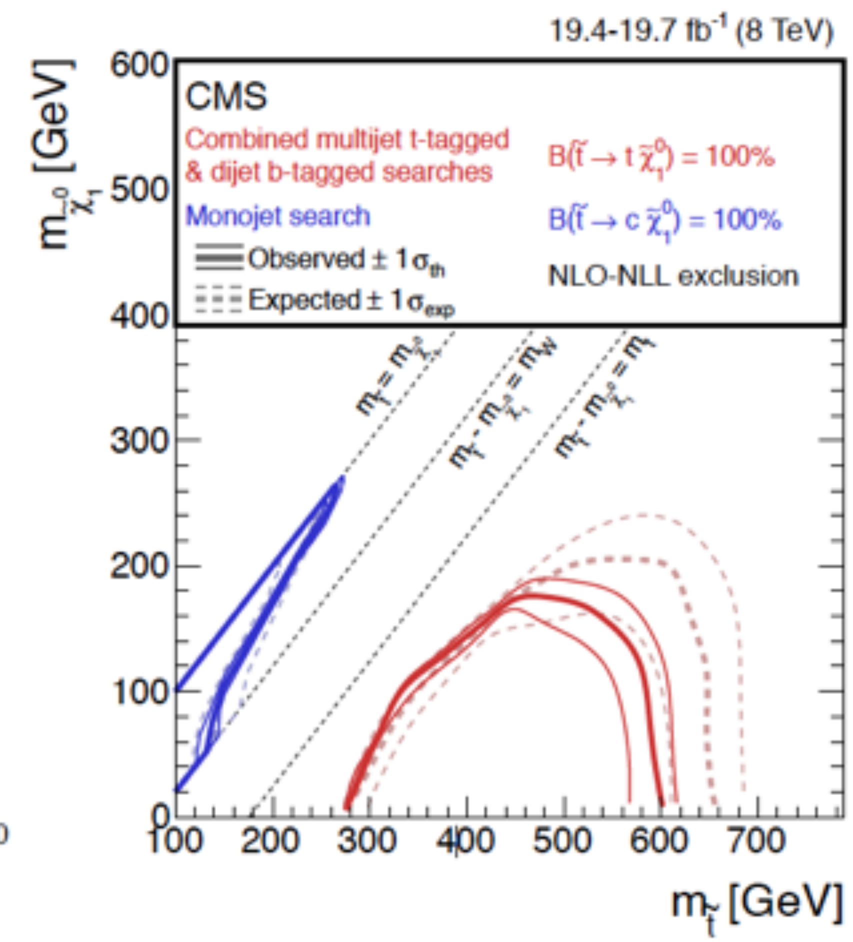
- MET > 120 GeV
- Leading jet p_T > 110 GeV
  & $|\eta|$ < 2.4
- N_{jet} (p_T > 60 GeV) ≤ 2
- Reject events with $e/\mu/\tau$

Dominant backgrounds:

- $(Z \to \nu\nu) + \text{jets}$
- $(W^\pm \to l^\pm\nu) + \text{jets}$

  estimated from 1 and 2 lepton control sample



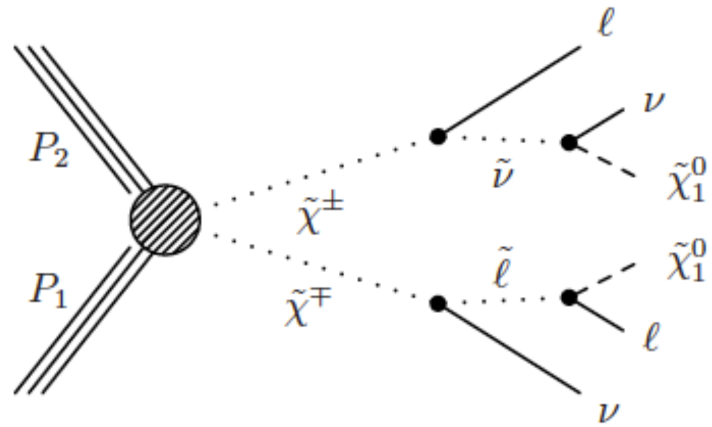


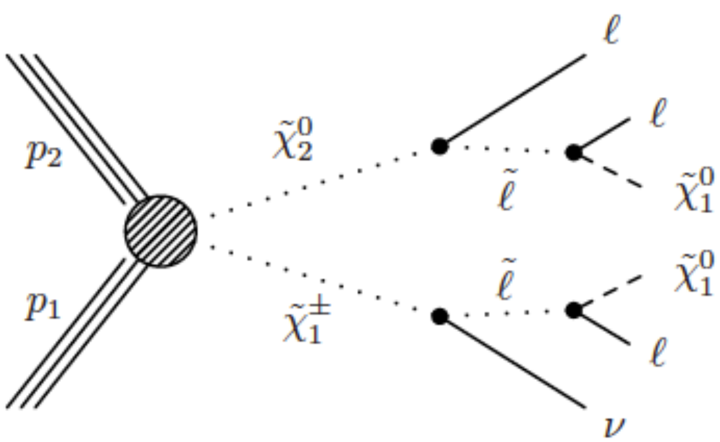
SUS-14-001, submitted to JHEP

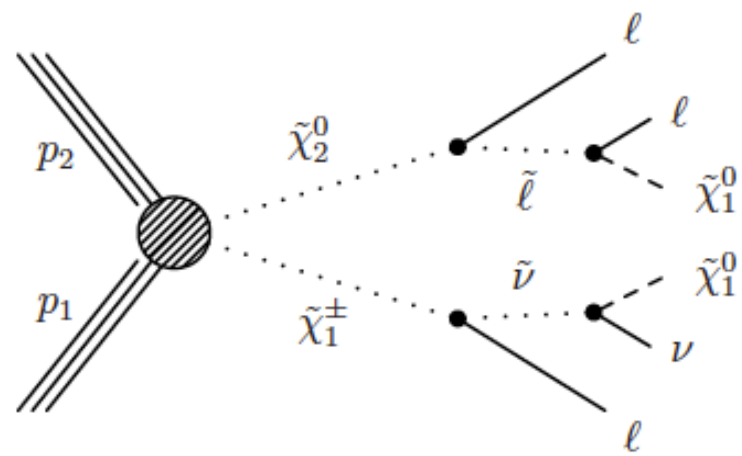
$\tilde{\chi}^0$, $\tilde{\chi}^\pm$ and $\tilde{l}$ Production

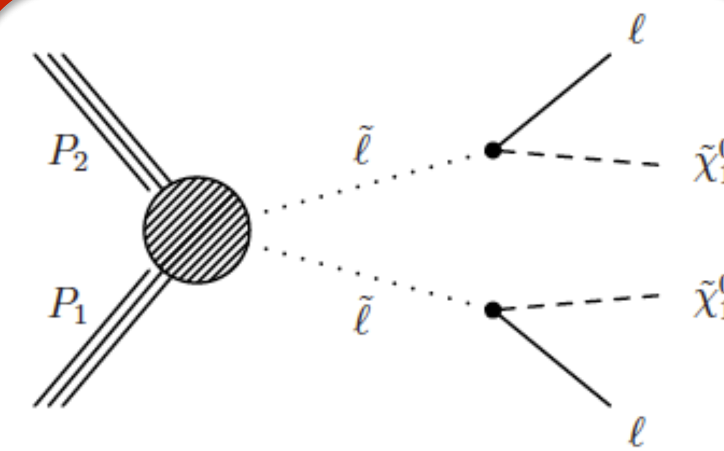
$\tilde{\chi}^0$, $\tilde{\chi}^\pm$:

Decay via sleptons







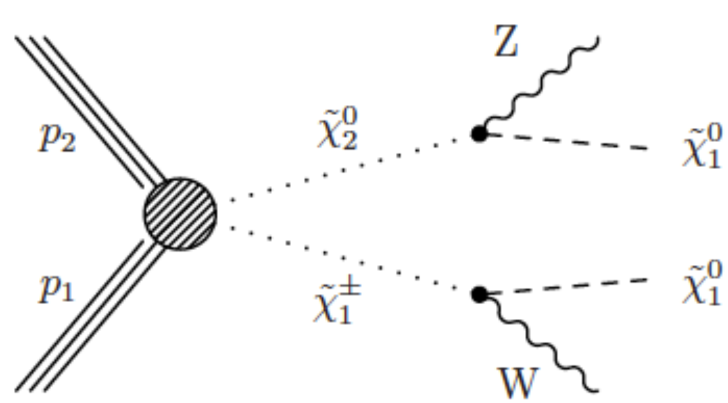


Direct slepton production

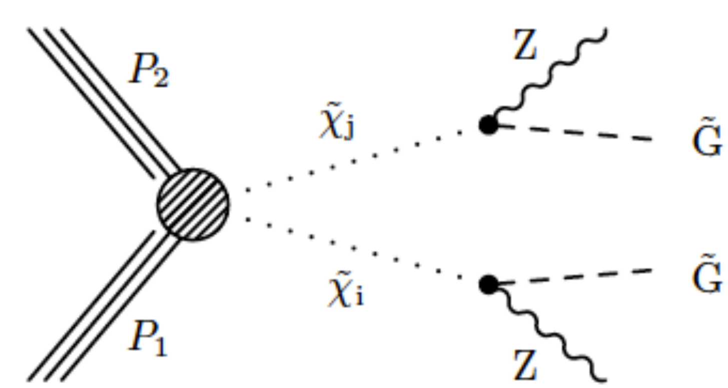
$\tilde{\chi}^0$, $\tilde{\chi}^\pm$:

Direct decay

$\Delta m(\tilde{\chi}^0,\ \tilde{\chi}^\pm) > m_{Z,W}$



ZZ enriched models, e.g. in GMSB



Multi-Lepton Searches

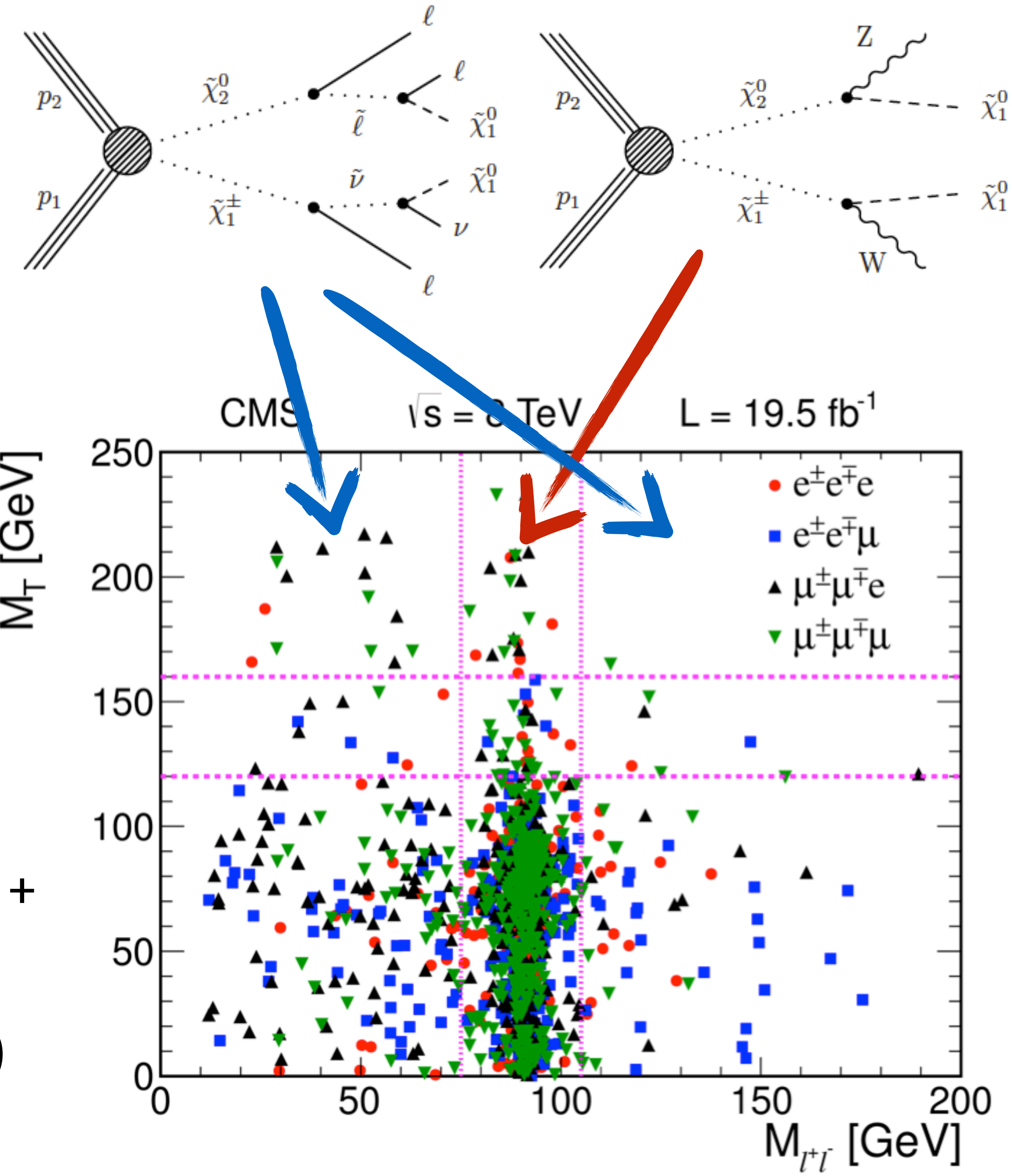
If coloured sparticles very heavy: possible dominant direct chargino/neutralino/slepton production

Leptonic decay modes provide clean signature:

- Many leptons (up to 4) + MET
- Possibly taus
- Possibly SS or OSSF lepton pairs with $m_{ll} = m_Z$
- Low jet activity
- In case of *WZ* + MET final state:

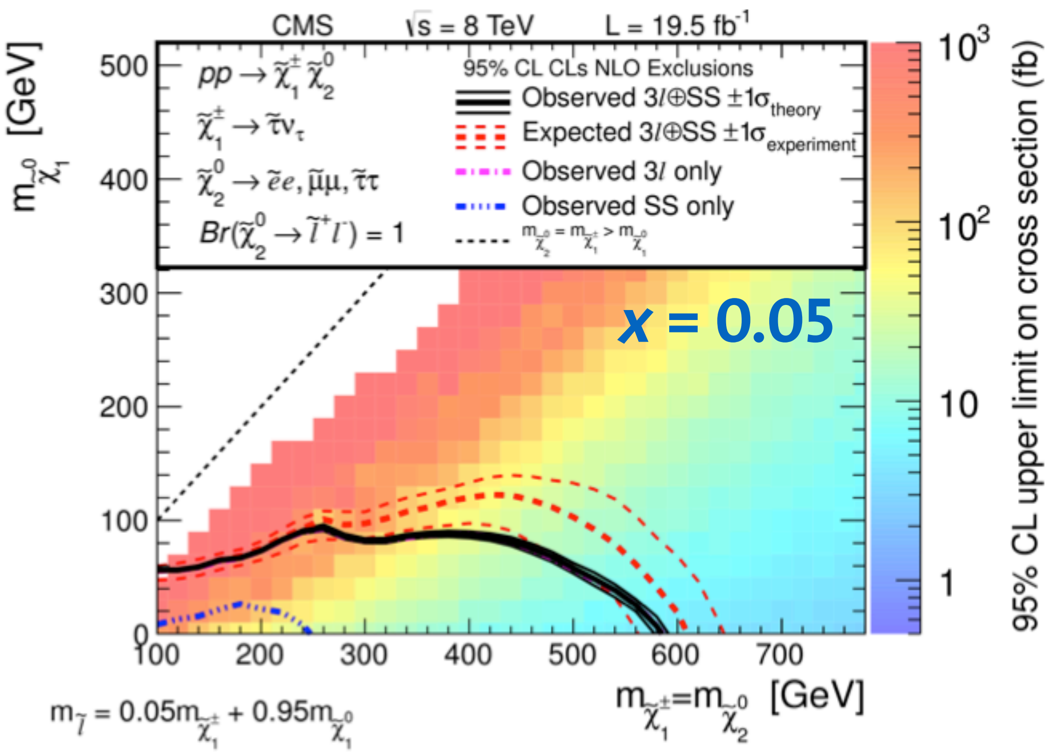
  $$M_{\mathrm{T}} = \sqrt{2 \not{E}_{\mathrm{T}} p_{\mathrm{T}}^{l} (1 - \cos \Delta\phi(l, \not{E}_{\mathrm{T}}))}$$

  is discriminating (typically $M_{\mathrm{T}} < M_W$ for bg)
- Moderate MET cut, e.g. >50 GeV (suppresses *Z* + jet events)
- m_{ll} > 12 GeV (suppresses low mass resonances)

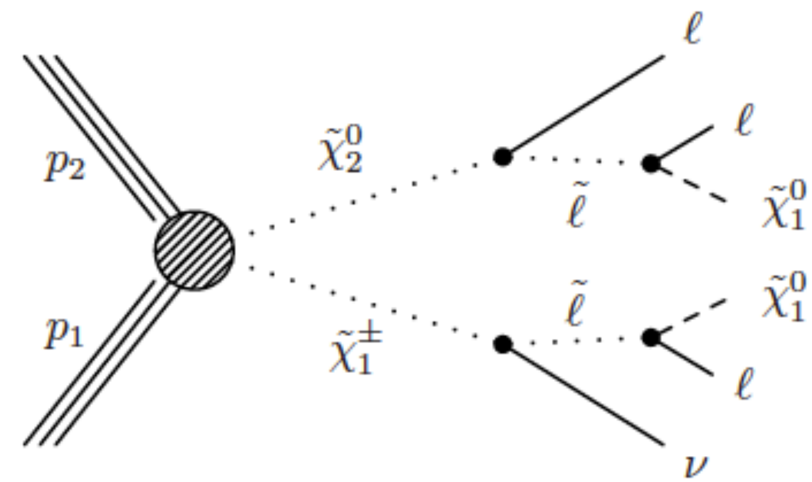


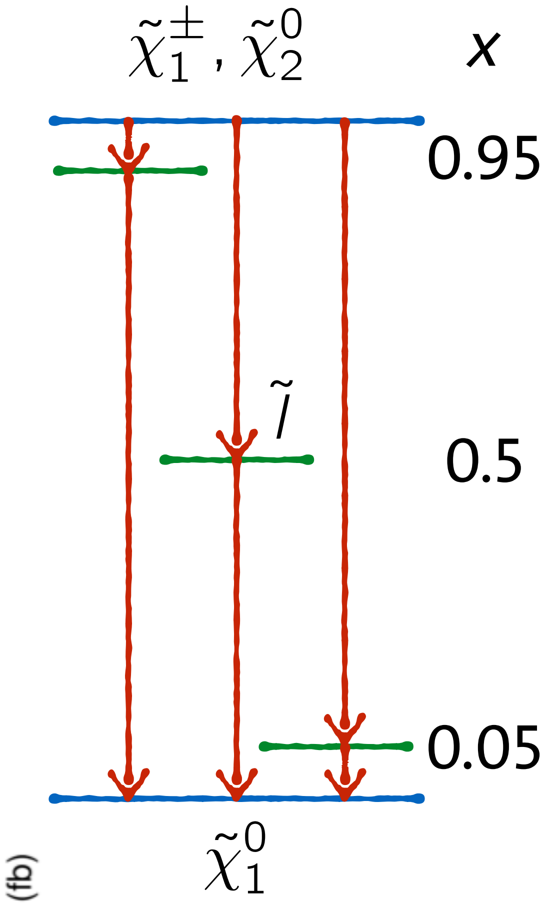
SUS-13-006, EJPC

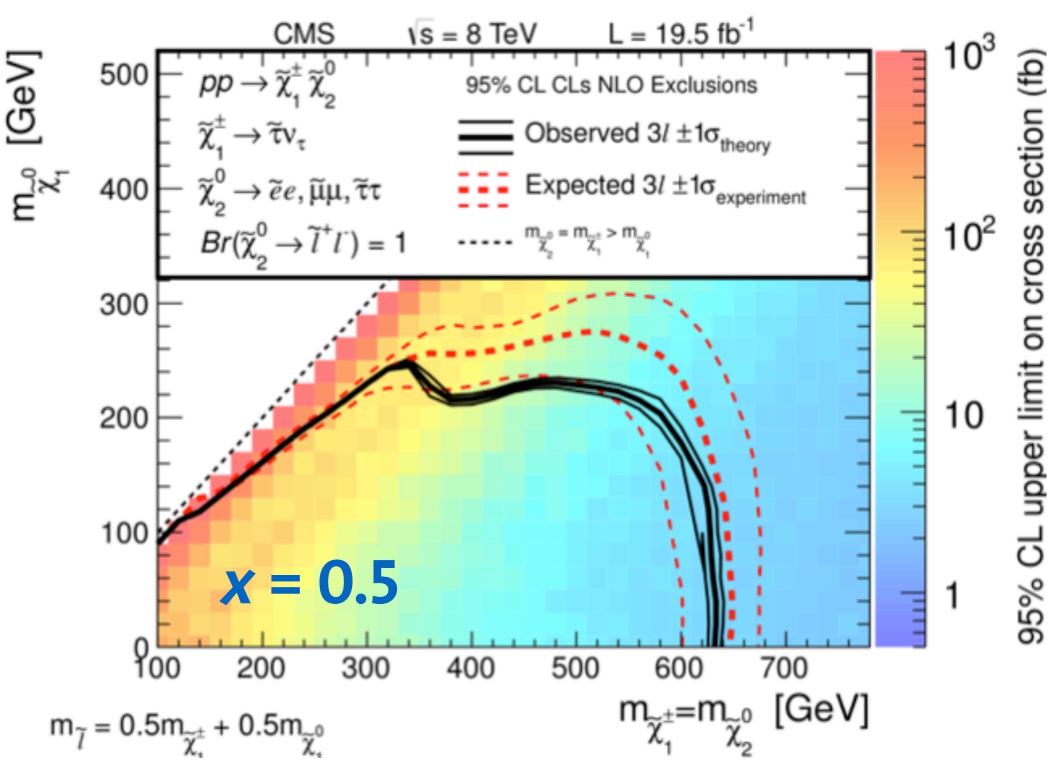
Multi-Lepton Interpretation

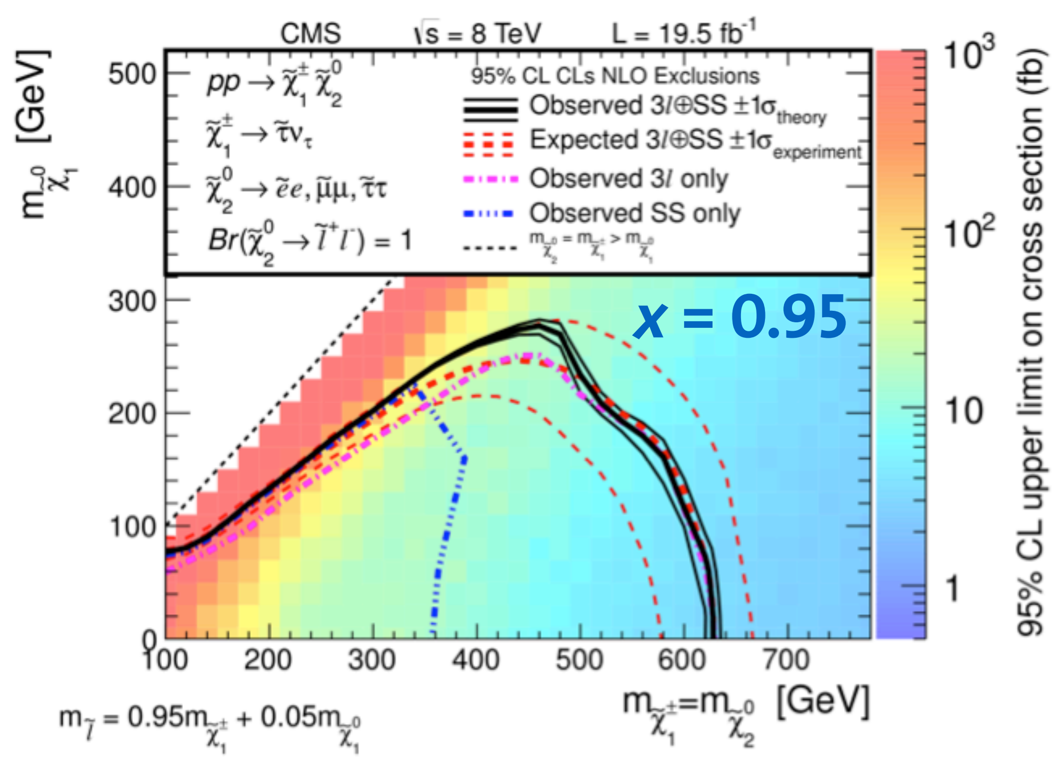


$$m_{\tilde{\ell}} = m_{\tilde{\chi}_1^0} + x_{\tilde{\ell}}\left(m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}\right)$$



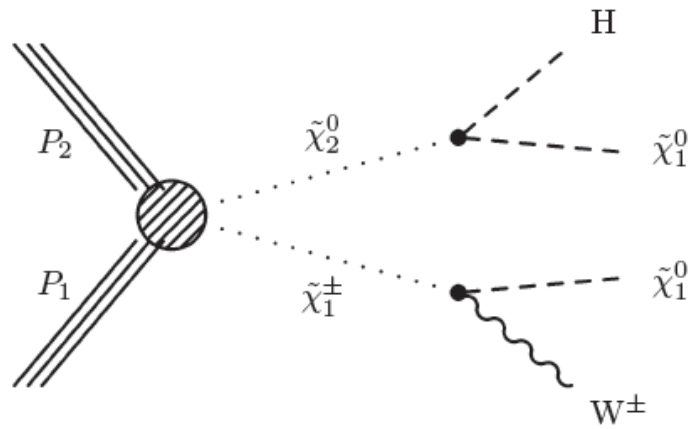






SUS-13-006, EJPC

hh / Zh / ZZ



$h(\to b\bar{b})W(\to e\nu/\mu\nu)$

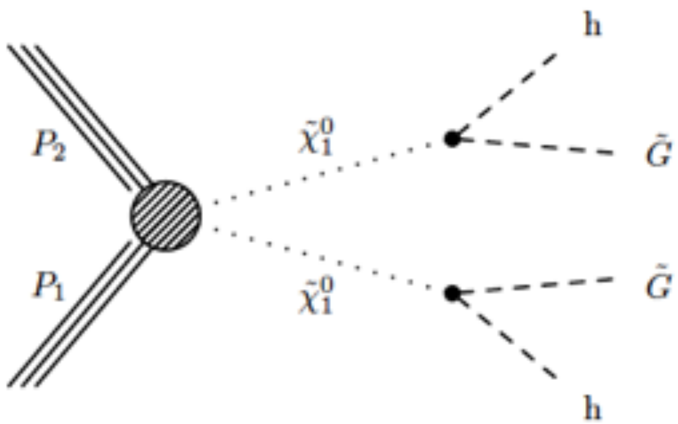
$h(\to W(\to l\nu)W(\to qq'))W(\to e\nu/\mu\nu)$

$h(\to WW/ZZ/\tau\tau)W(\to e\nu/\mu\nu)$

SUS-13-006, EJPC

$h(\to \gamma\gamma)W(\to e\nu/\mu\nu)$

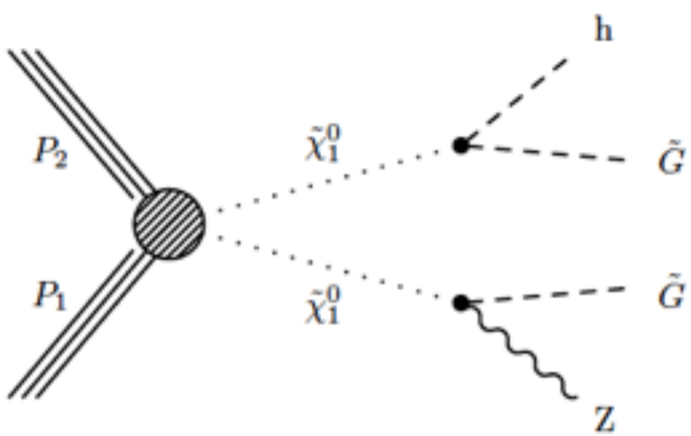
$h(\to \gamma\gamma)W(\to qq')$



$h(\to b\bar{b})h(\to b\bar{b})$

$h(\to \gamma\gamma)h(\to b\bar{b})$

$h(\to \gamma\gamma)h(\to ZZ/WW/\tau\tau)$



$h(\to \gamma\gamma)Z(\to ee/\mu\mu/\tau\tau)$

$h(\to \gamma\gamma)Z(\to qq)$

$h(\to b\bar{b})Z(\to ee/\mu\mu)$

SUS-14-002, PRD

VBF SUSY

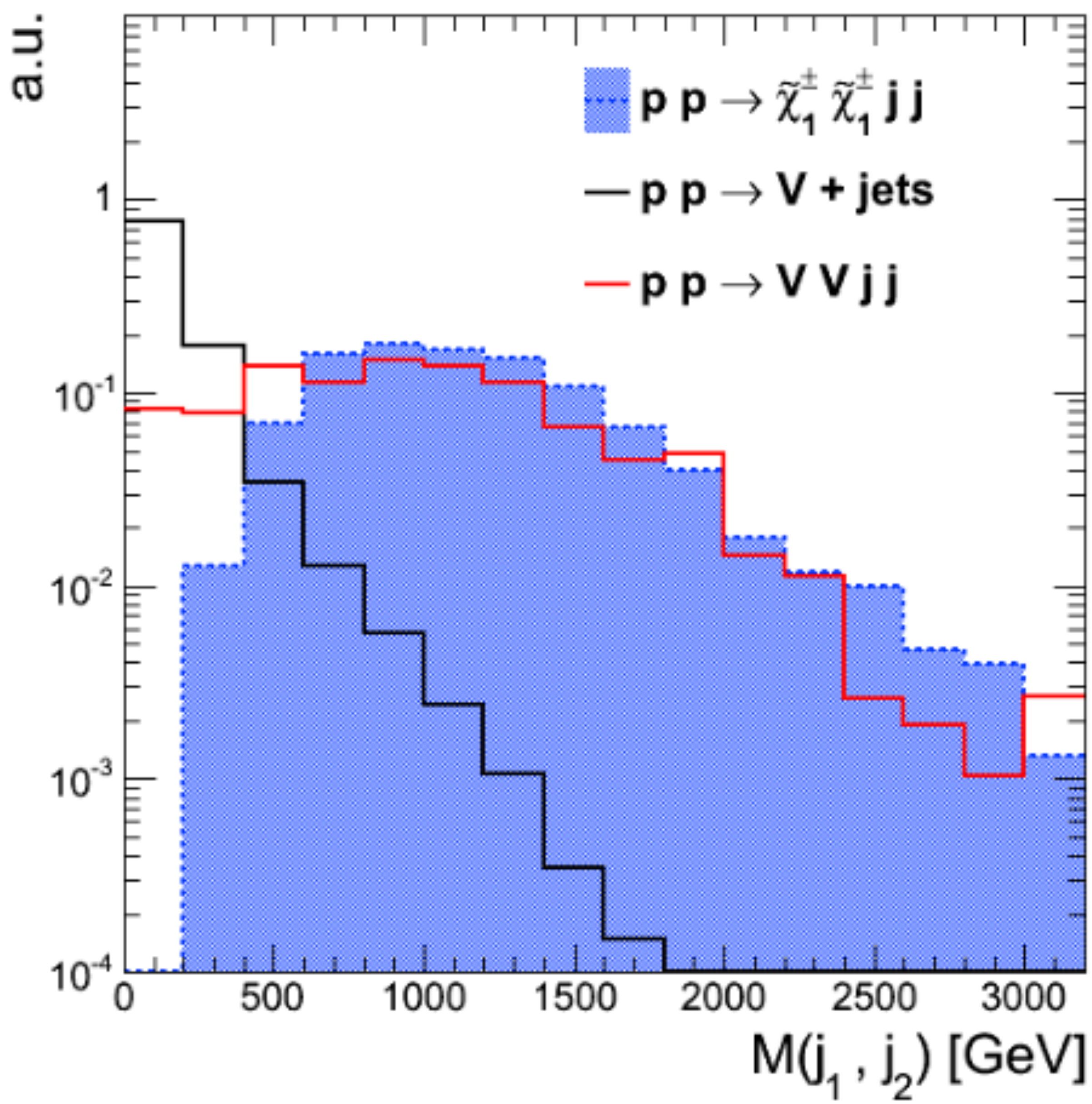


FIG. 3: $M_{j_1 j_2}$ distribution normalized to arbitrary units for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ pair production by VBF processes, V+jets background, and VV background produced by VBF processes.

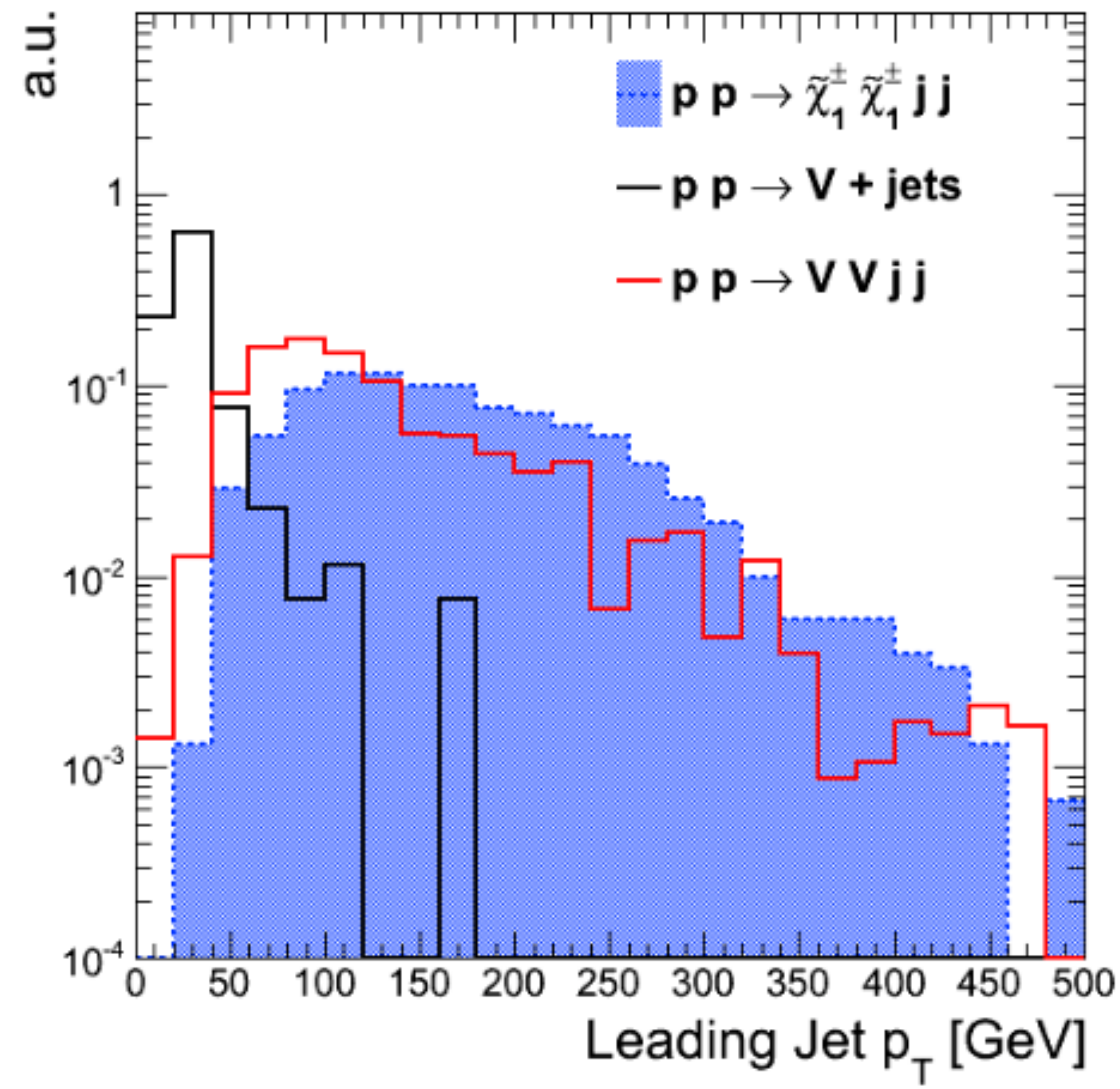
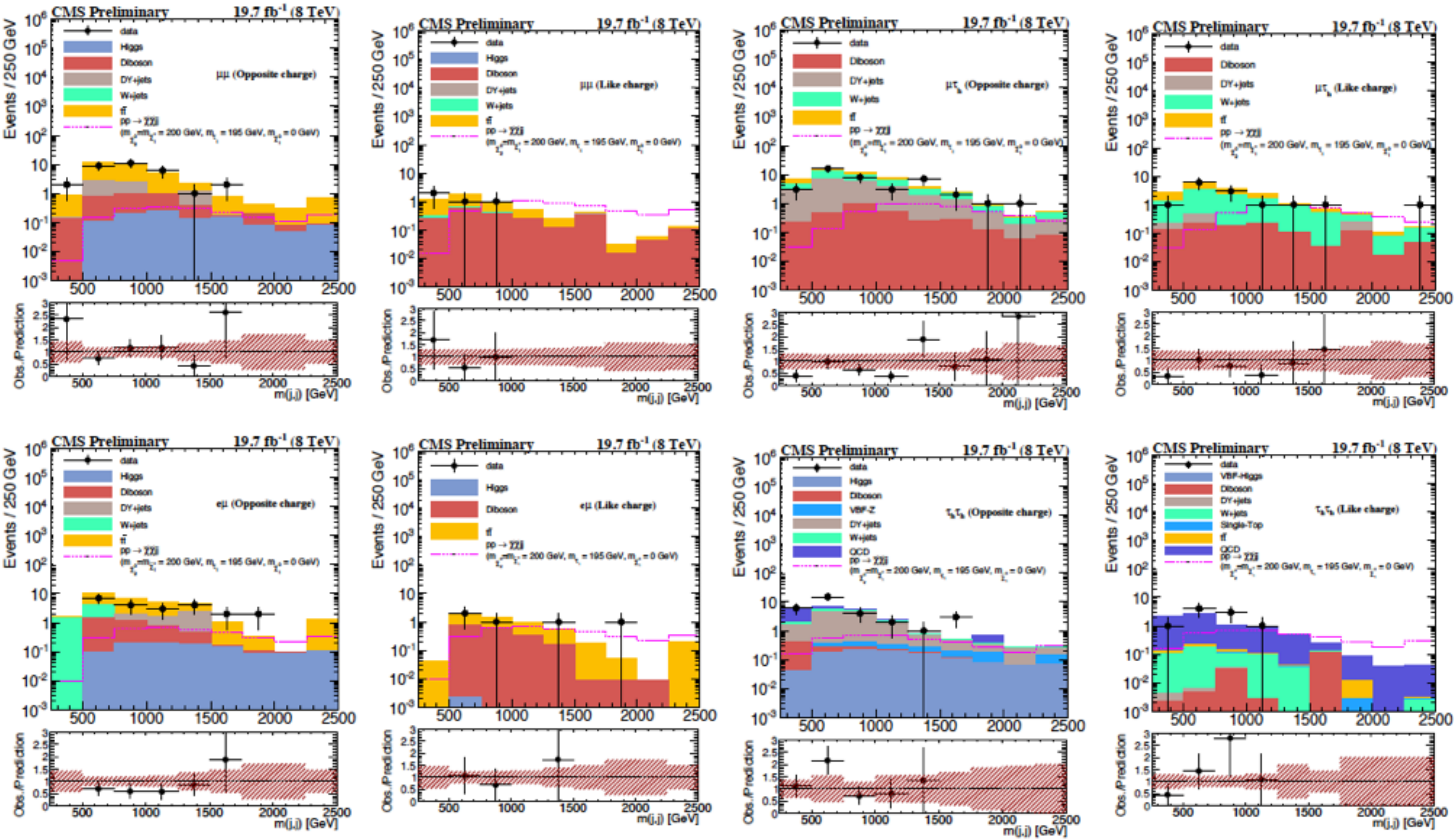


FIG. 4: p_{T} distribution of the leading jet normalized to arbitrary units for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ pair production by VBF processes, V+jets background, and VV background produced by VBF processes.

Dutta et al., arXiv:1210.0946, PRD

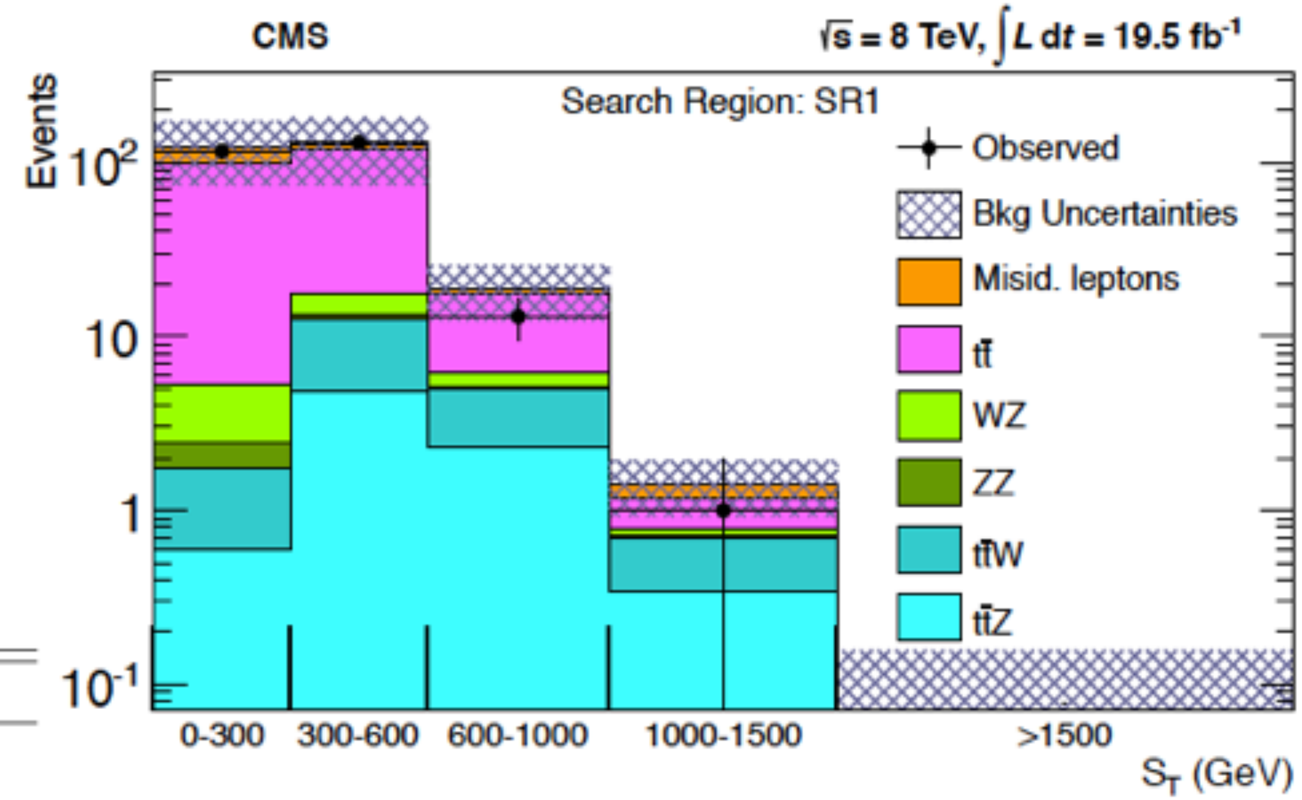
VBF SUSY: More Results



SUS-14-005

RPV Stop

SR	N_L	N_τ	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
			obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
SR1	3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1	1.43 ± 0.51	0	0.208 ± 0.096
SR2	3	≥ 1	710	698 ± 287	746	837 ± 423	83	97 ± 48	3	6.9 ± 3.9	0	0.73 ± 0.49
SR3	4	0	0	0.186 ± 0.074	1	0.43 ± 0.22	0	0.19 ± 0.12	0	0.037 ± 0.039	0	0.000 ± 0.03
SR4	4	≥ 1	1	0.89 ± 0.42	0	1.31 ± 0.48	0	0.39 ± 0.19	0	0.019 ± 0.026	0	0.000 ± 0.03
SR5	3	0	—	—	—	—	152	161 ± 51	15	21.0 ± 8.6	10	3.45 ± 1.77
SR6	3	1	—	—	—	—	193	150 ± 37	14	12.8 ± 3.5	0	2.04 ± 0.79
SR7	4	0	—	—	—	—	5	8.2 ± 2.6	2	0.93 ± 0.36	0	0.18 ± 0.08
SR8	4	1	—	—	—	—	2	3.2 ± 0.9	0	0.28 ± 0.13	0	0.08 ± 0.05

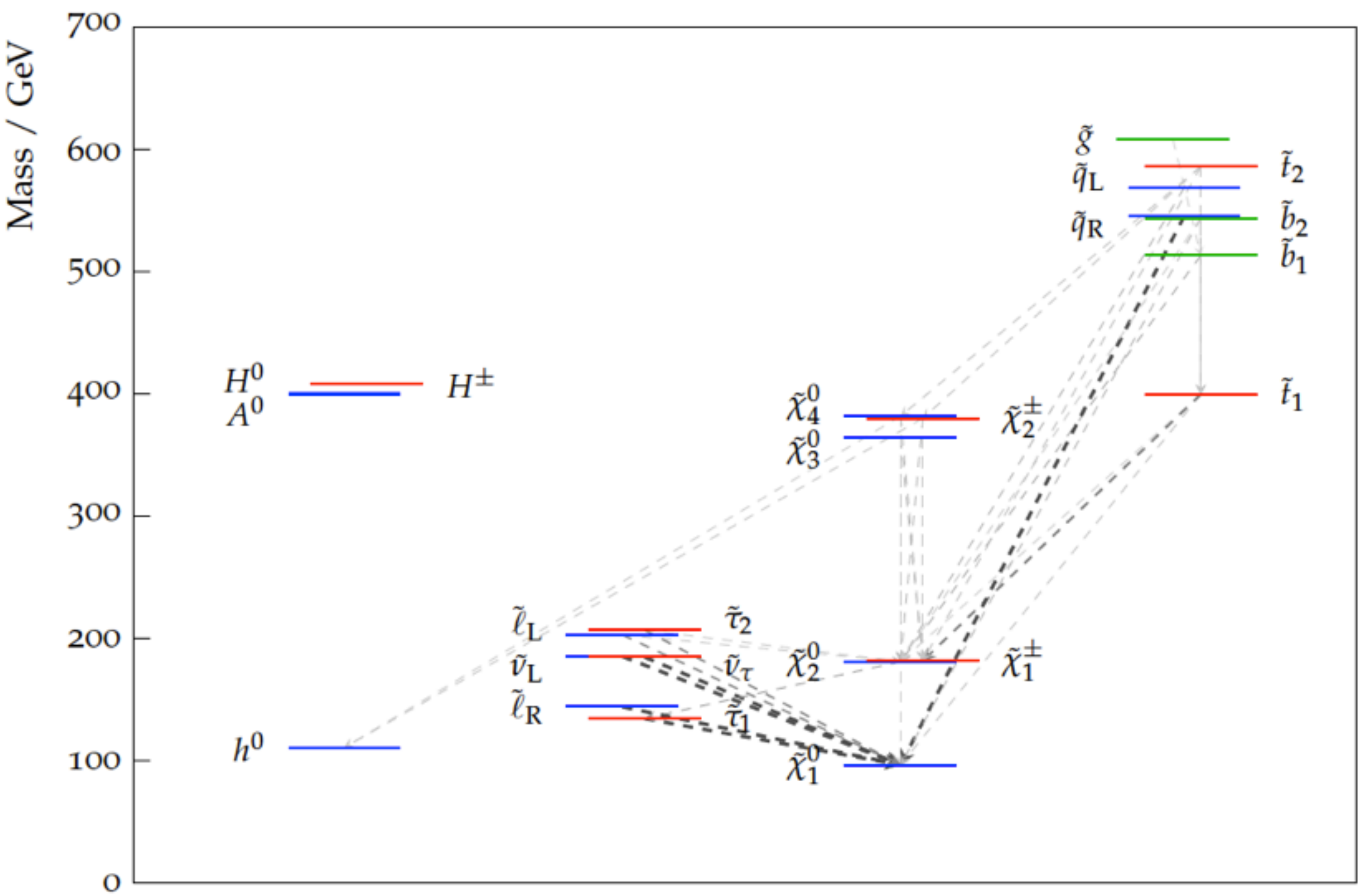


Label	Kinematic region	Decay mode
A	$m_t < m_{\tilde{t}_1} < 2m_t, m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \to t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \to t\mu t\bar{b}$ or $t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_{W^\pm} + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \to \ell\nu b\tilde{\chi}_1^0$ or $jjb\tilde{\chi}_1^0$
D	$m_{W^\pm} + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t}_1 \to bW^\pm\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1}$	$\tilde{t}_1 \to t\tilde{\chi}_1^0$

Simplified Models

Full models (e.g. CMSSM)

- **Good:** realistic signatures
- **Caveat:** fixed mass relation $m_{\tilde{g}} : m_{\tilde{W}} : m_{\tilde{B}} \approx 6 : 2 : 1$
- **Caveat:** hard to apply results on general models

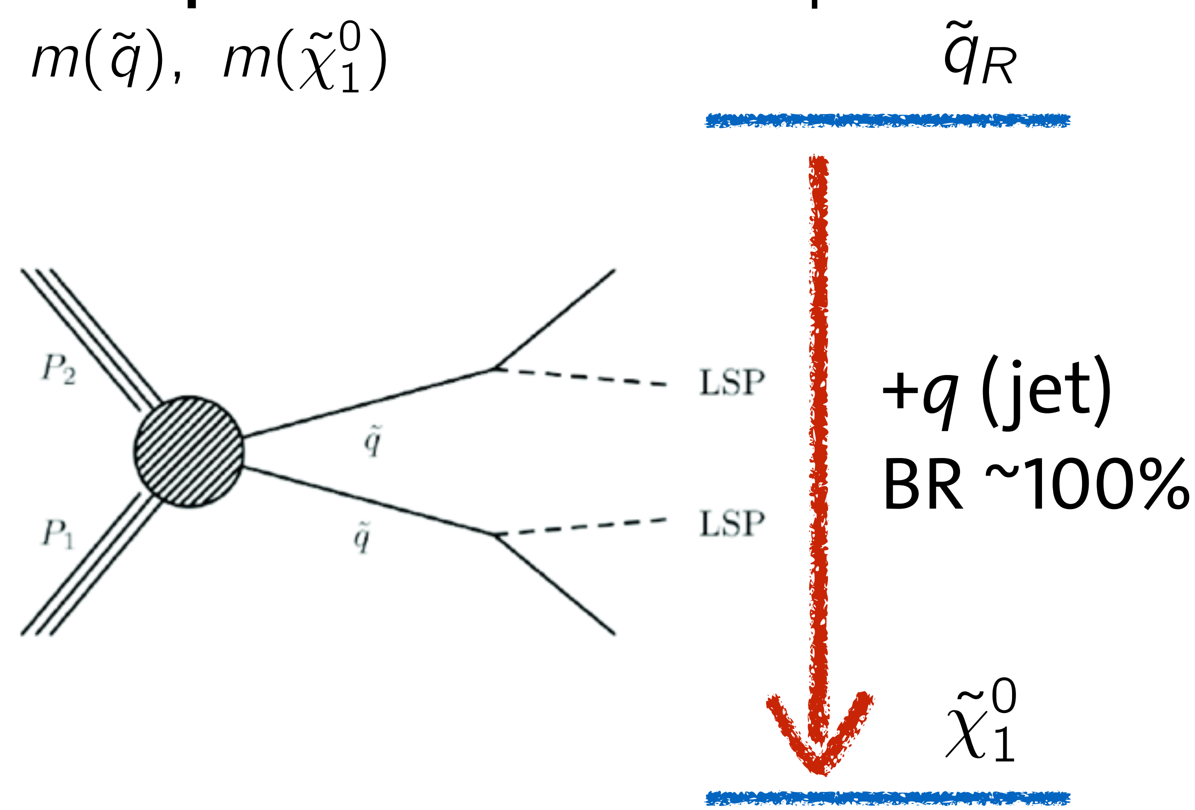


example CMSSM model, visualized by slhaplot

Simplified Model Searches (SMS)

- **Good:** as model independent as possible
- **Caveat:** overly optimistic (assuming exclusive BRs); careful interpretation is needed!

Example SMS with two free parameters: $m(\tilde{q}),\ m(\tilde{\chi}_1^0)$



Selection of pMSSM Models

Use Monte Carlo Markov Chain to generate ~20M pMSSM models according to preLHC data:

i	Observable $\mu_j(\theta)$	Constraint D_j^{preCMS}	Likelihood function $L(D_j^{\text{preCMS}}\|\mu_j(\theta))$	MCMC / post-MCMC
1	$BR(b \to s\gamma)$ [28, 29]	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian	MCMC
2a	$BR(B_s \to \mu\mu)$ [30]	observed CLs curve from [30]	$d(1 - CLs)/dx$	MCMC
2b	$BR(B_s \to \mu\mu)$ [31]	$3.2^{+1.5}_{-1.2} \times 10^{-9}$	2-sided Gaussian	post-MCMC
3	$R(B_u \to \tau\nu)$[32]	1.63 ± 0.54	Gaussian	MCMC
4	Δa_μ [33]	$(26.1 \pm 8.0^{\text{exp}} \pm 10.0^{\text{th}}) \times 10^{-10}$	Gaussian	MCMC
5	m_t [34]	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}($ GeV	Gaussian	MCMC
6	$m_b(m_b)$ [32]	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
7	$\alpha_s(M_Z)$ [32]	0.1184 ± 0.0007	Gaussian	MCMC
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \leq m_h \leq m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$	post-MCMC
9	sparticle masses	LEP [35] (via micrOMEGAs [24])	1 if allowed 0 if excluded	MCMC
10	prompt $\tilde{\chi}_1^\pm$	$c\tau(\tilde{\chi}_1^\pm) < 10$ mm	1 if allowed 0 if excluded	post-MCMC

Select randomly ~7300 models and do CMS detector simulation for 10k events each

Sampling ranges:

$$
\begin{gathered}
-3\,\text{TeV} \leq M_1, M_2 \leq 3\,\text{TeV} \\
0 \leq M_3 \leq 3\,\text{TeV} \\
-3\,\text{TeV} \leq \mu \leq 3\,\text{TeV} \\
0 \leq m_A \leq 3\,\text{TeV} \\
2 \leq \tan\beta \leq 60 \\
0 \leq \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \leq 3\,\text{TeV} \\
-7\,\text{TeV} \leq A_t, A_b, A_\tau \leq 7\,\text{TeV},
\end{gathered}
$$

SUS-13-020

Magnet

- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.
- Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system.
- Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system, requiring more frequent maintenance than usual.
- A comprehensive program to re-establish its nominal performance is underway.
- These recovery activities for the cryogenic system will be synchronised with the accelerator schedule in order to run for adequately long periods.
- A consolidation and repair program for the cryogenic system is being organised for the next technical stops and the longer technical stop at the end of the year.
- The Collaboration appreciates the priority being given to this issue by CERN's Technology Department, which is responsible for the maintenance and operation of the CMS magnet external cryogenic system.