SEARCHES FOR SUSY AT CMS

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Corfu 2017 - Workshop on SM & Beyond

September 7, 2017

Outline

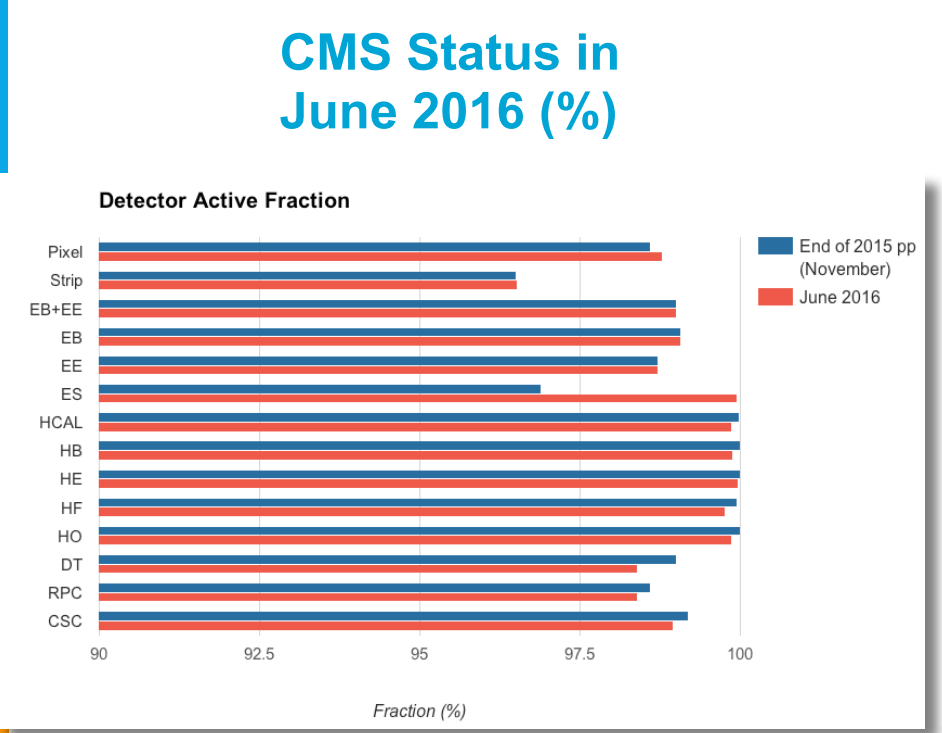
- LHC playground
- Easy SUSY
- Pulling all the stops (and sbottoms too!)
- Ms. SUSY and Mr. HIGGS
- Weak SUSY
- Shining light on SUSY
- Decompressing
- Conclusions

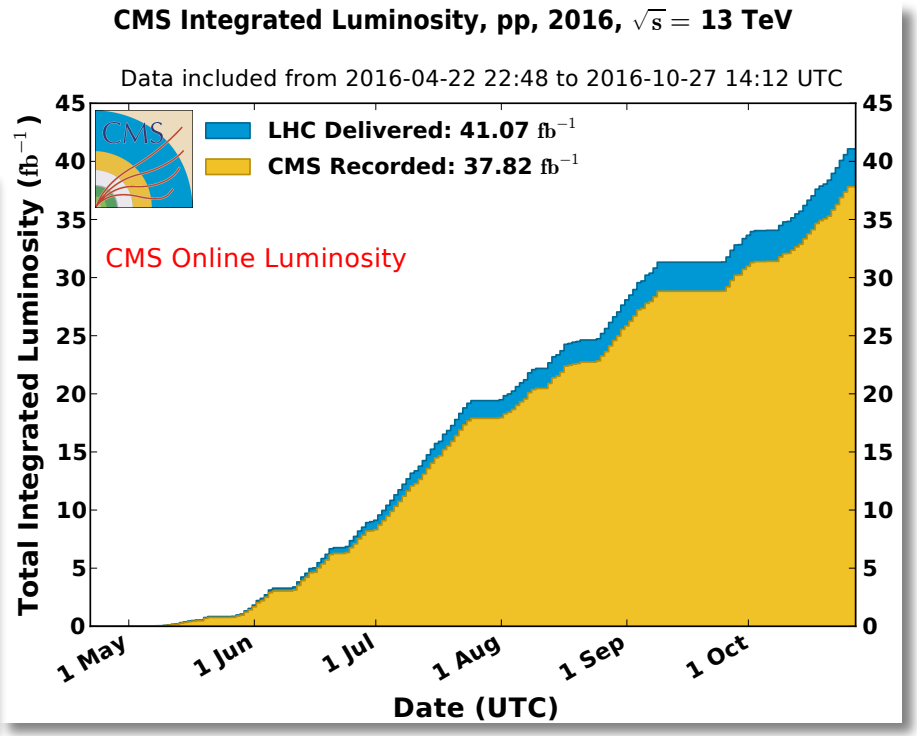
N.B.: I'll focus on most recent results (many were published in the past 3 months!). Will skip many of the slides in this talk due to a lack of time, but leave them in for future reference.

The LHC Performance

2016 Data Taking

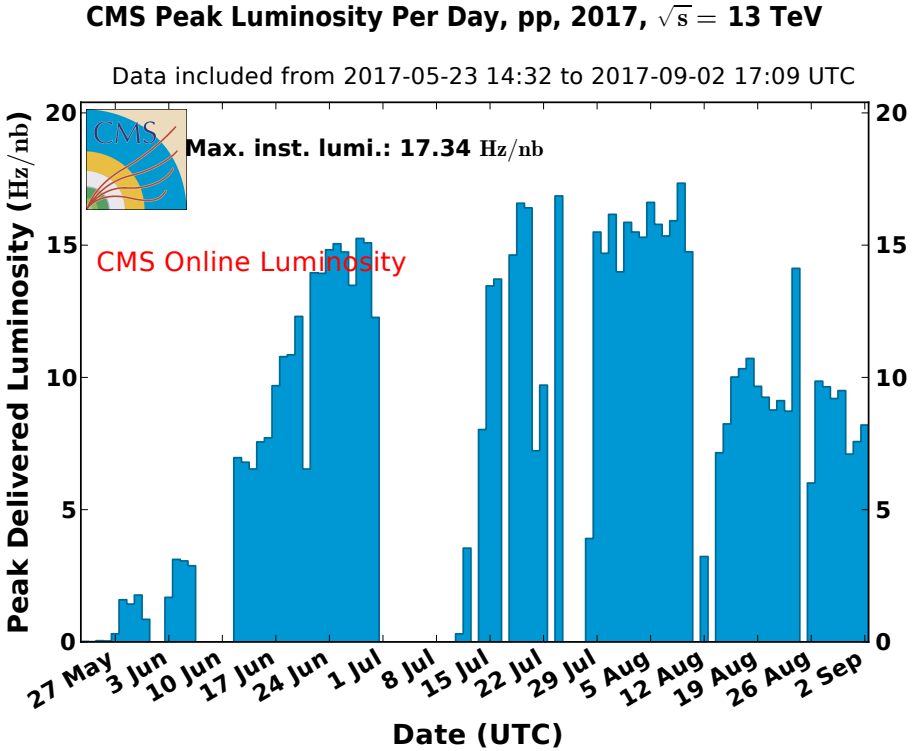
- About 40/fb has been delivered by the LHC in 2016, exceeding the integrated luminosity accumulated in all years before 2016 and expectations
- Thank you, the LHC, for a spectacular year!
- Most of the results in this talk are based on full 2016 data set

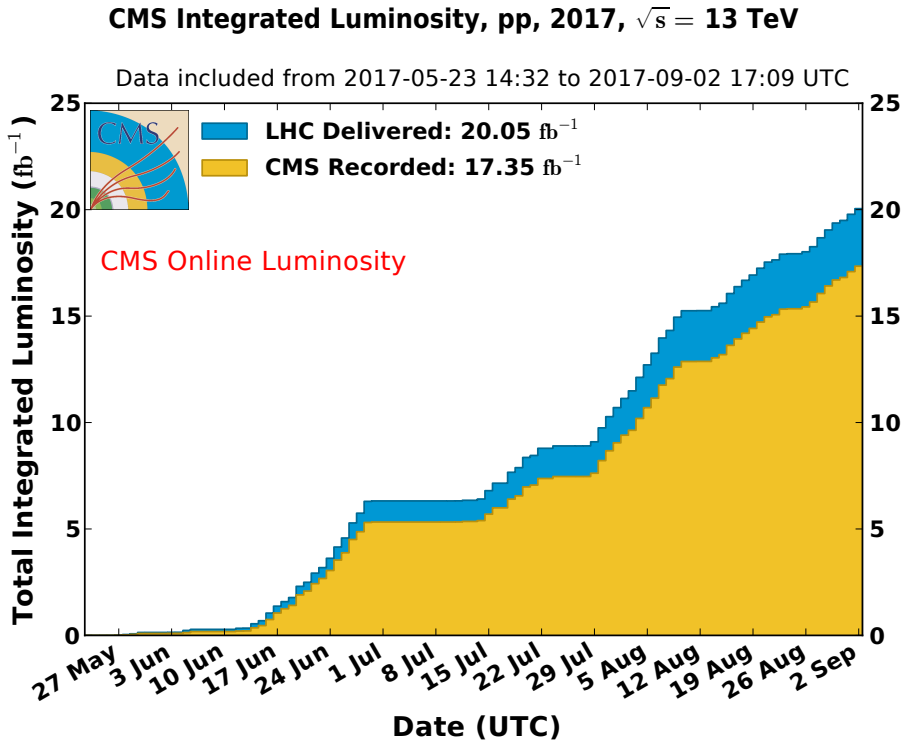




The 2017 Run Progress

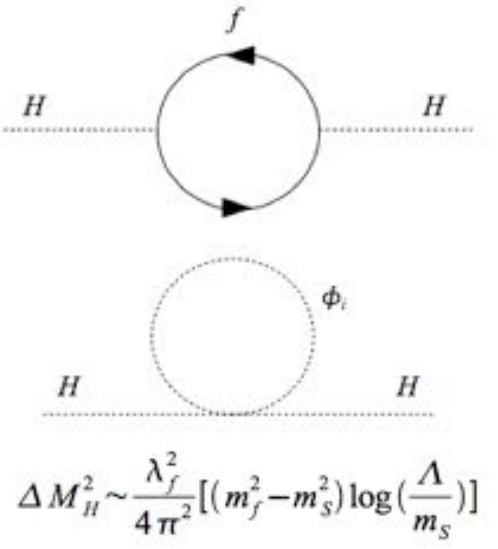
- LHC reached peak luminosity of 1.7 x 10^{34} $cm^{-2}s^{-1}$
  - Scaled down to the design luminosity recently due to a problem with one dipole
- CMS has installed new, 4-layer pixel detector
  - A bit of toothing pain, but taking data efficiently now
  - About half of last year data already on tape with about 10 weeks to go





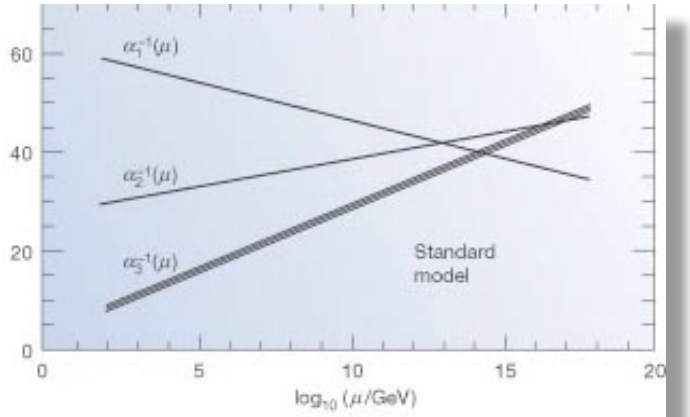

SUSY
Basics

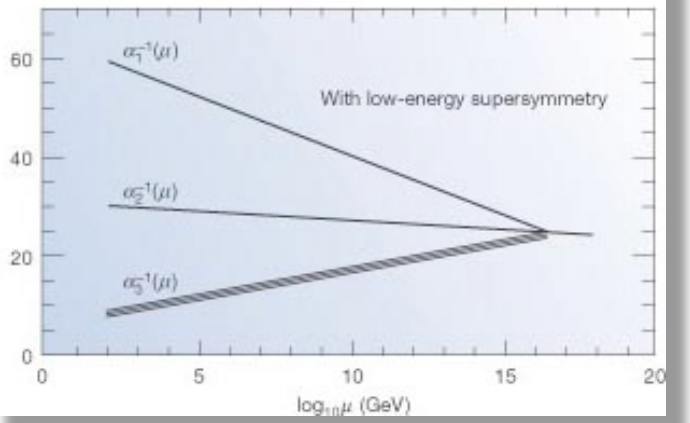
Three Miracles of SUSY



- Elegant solution to the hierarchy problem (i.e., why the Higgs boson mass is not found at the Planck scale)

- Gauge unification

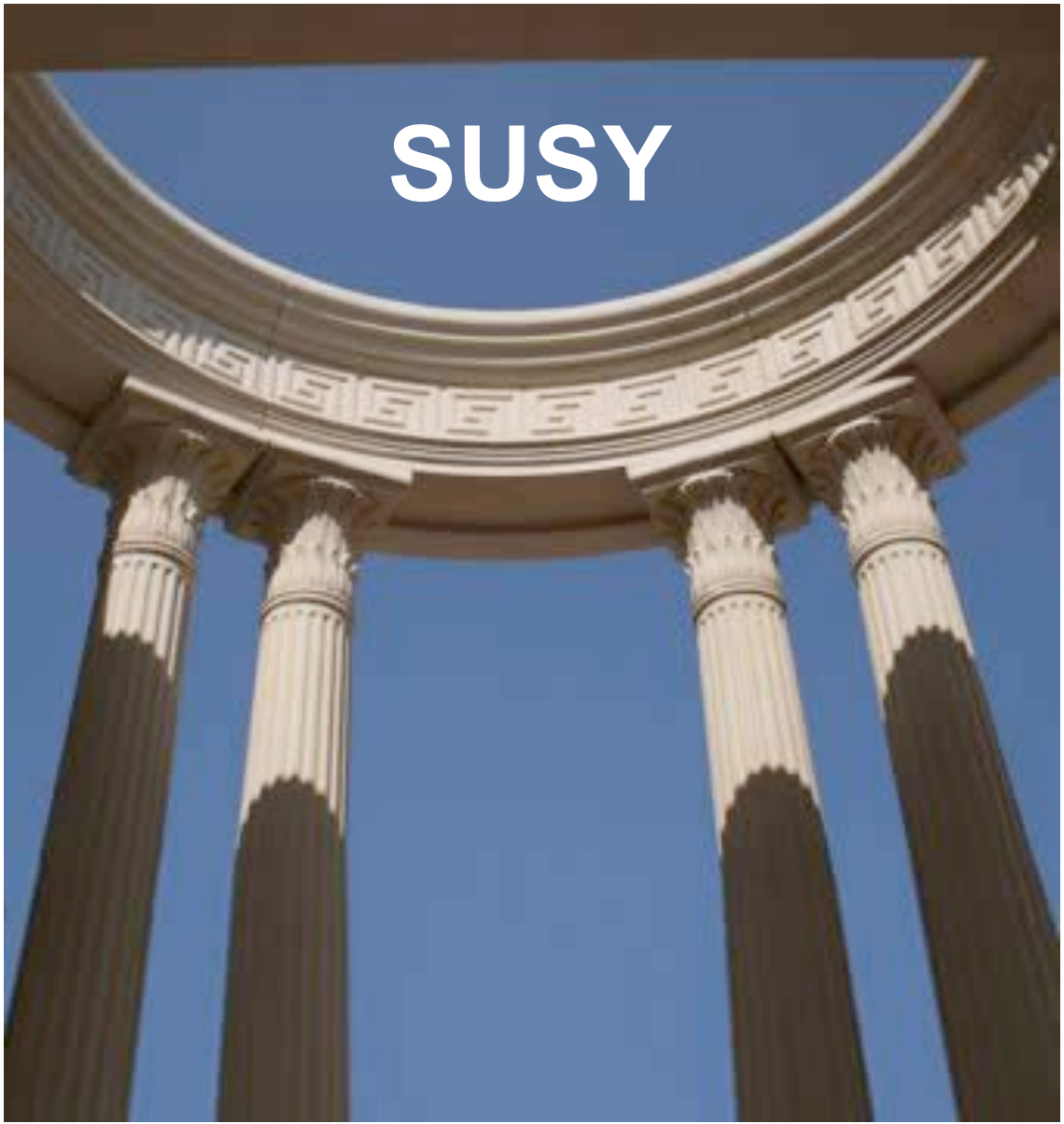




- Dark matter candidate with the right abundance

Four Pillars of SUSY Searches

- Signatures
- Kinematic optimization
- Background determination
- Interpretation

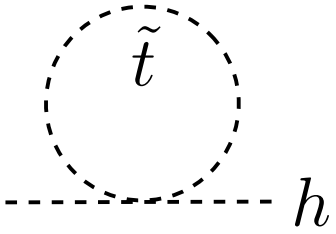


Fine-Tuning in (p)MSSM

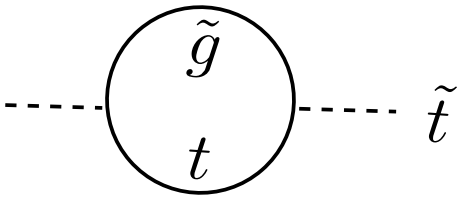
- Fine-tuning: cancellation of two or more large numbers
- In pMSSM: $m_Z^2 = -2(m_{H_u}^2 + |\mu|^2) + \frac{2}{\tan^2\beta}(m_{H_d}^2 - m_{H_u}^2) + \mathcal{O}(1/\tan^4\beta)$

|μ| is small → light higgsinos

m^2_{Hu} is small → lights stops (at one-loop level) and gluinos (at two-loop level)



$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\left(\underbrace{m_{Q_3}^2 + m_{u_3}^2}_{\text{stops}} + |A_t|^2\right)\ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

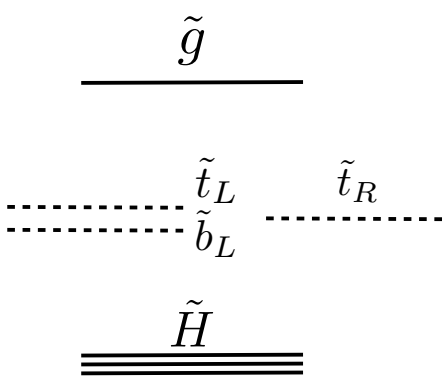


gluino-top loop drives the stop mass further up

Natural SUSY

- If SUSY is natural, we should find it soon:
  - And we most likely will find it by observing 3rd generation SUSY particles first
- Requires shifting of the SUSY search paradigm: going for the third generation partners, push gluino reach, and look for EW boson partners

Papucci, Ruderman, Weiler
arXiv:1110.6926



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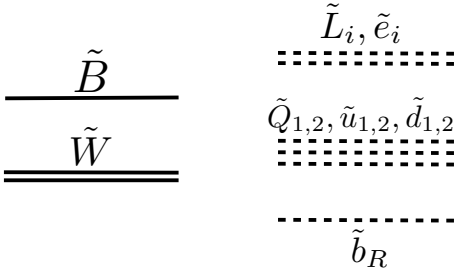

decoupled SUSY

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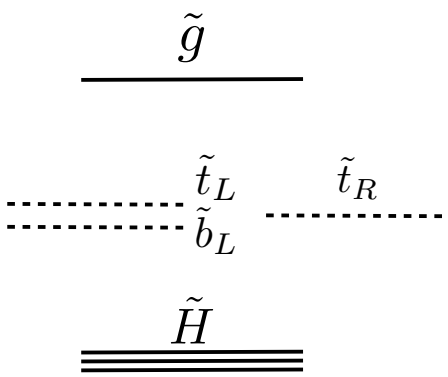

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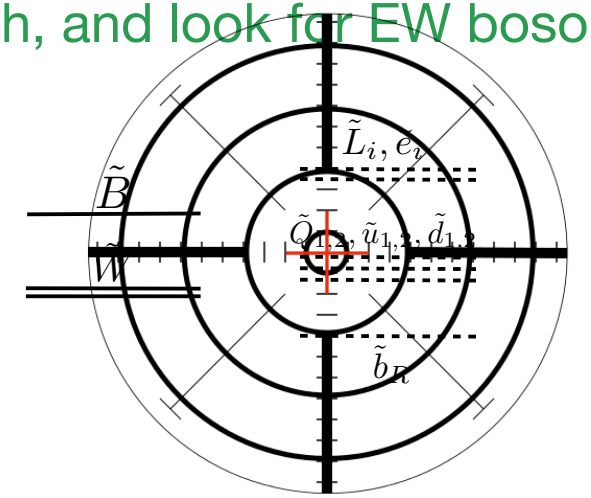

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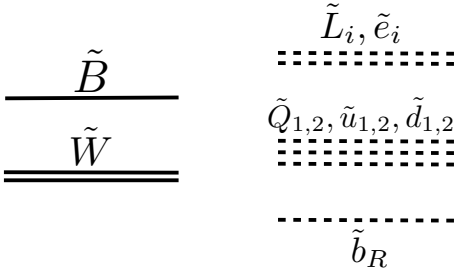
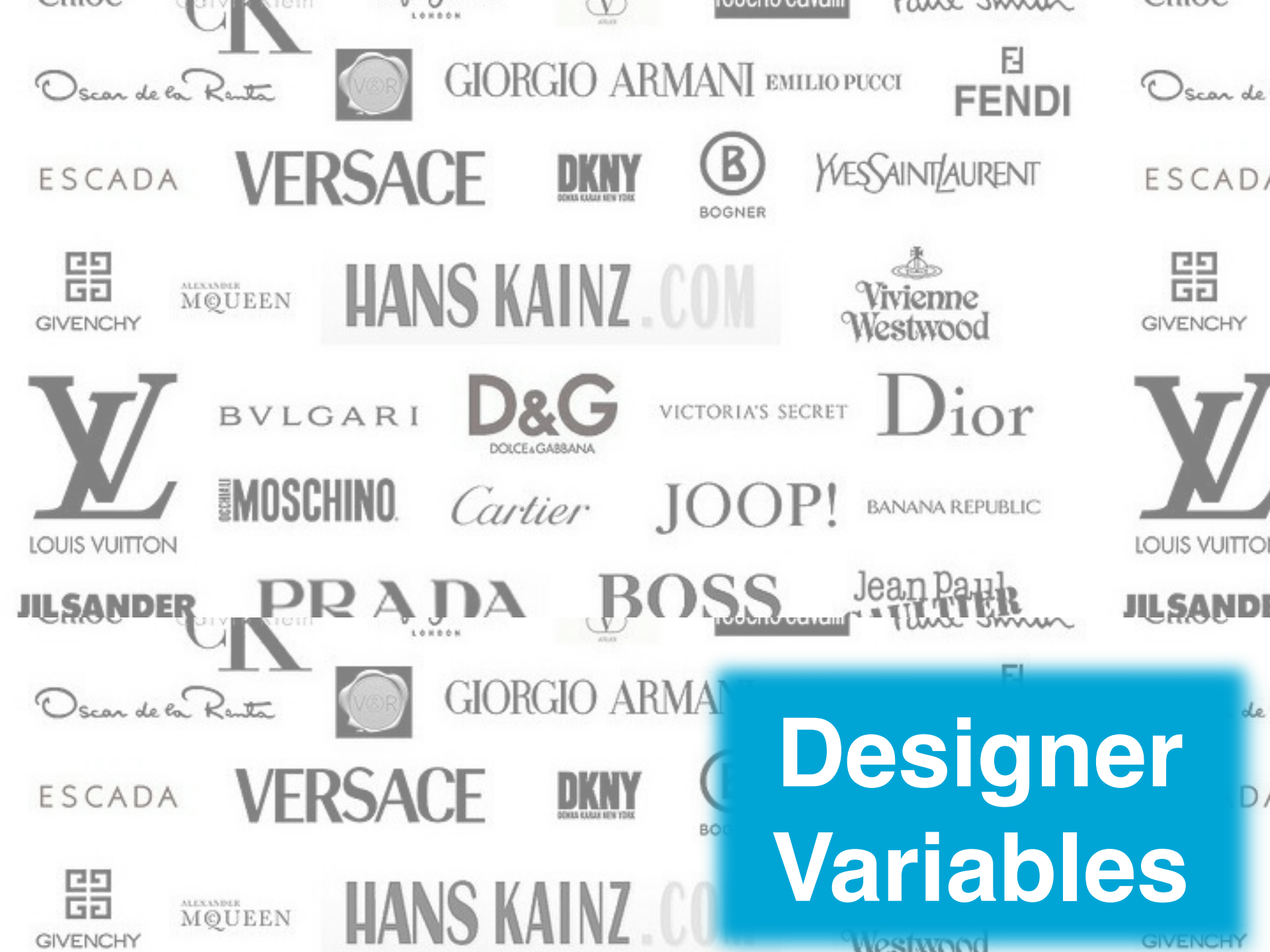
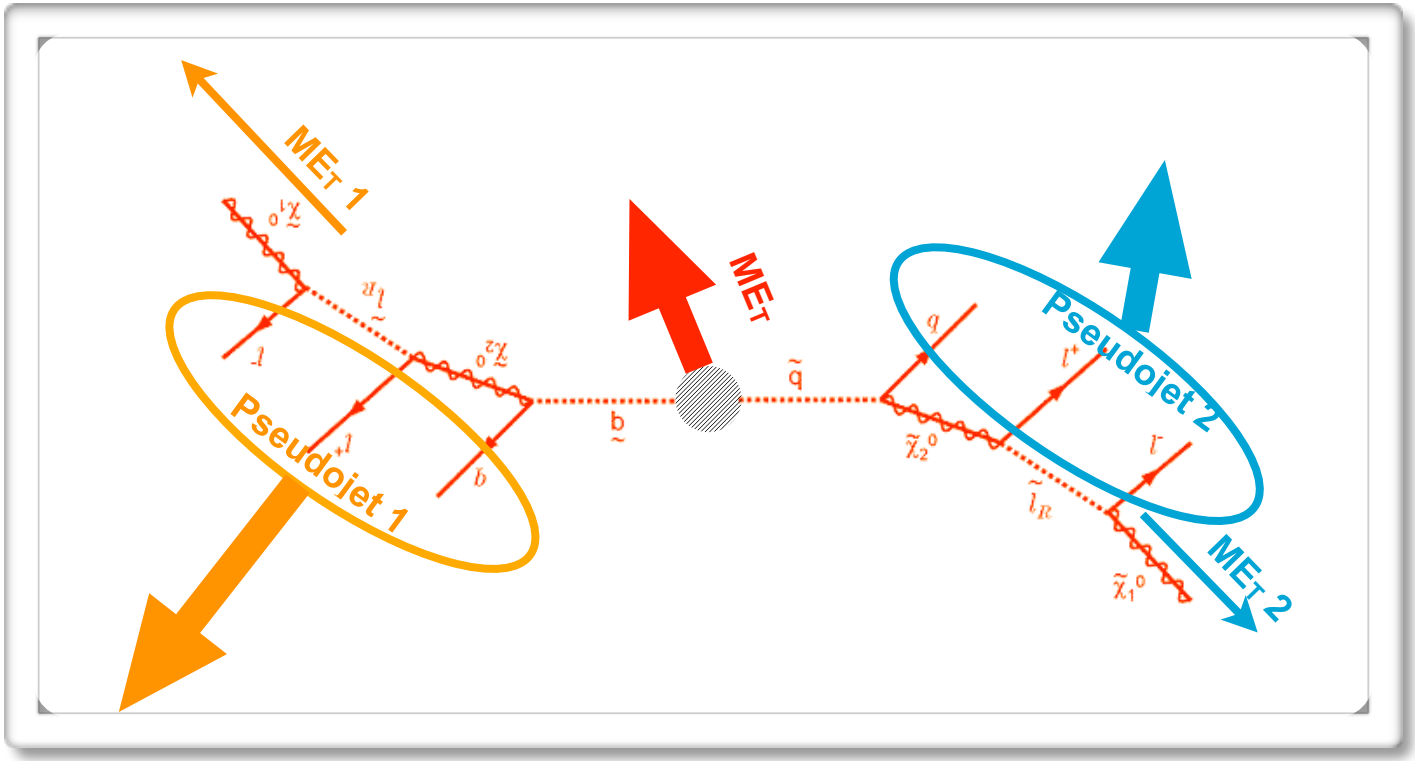


decoupled SUSY


Designer
Variables

SUSY Kinematics

- Look for pair-produced particles that cascade-decade with invisible particle emission
  - Generally can cluster all visible products in each hemisphere to form “pseudojets”, resulting in a dijet + ME_T topology
- How to optimize the search to reduce backgrounds and at the same time retain information about characteristic SUSY masses?
  - CMS explored a number of different kinematic variables to optimize SUSY searches



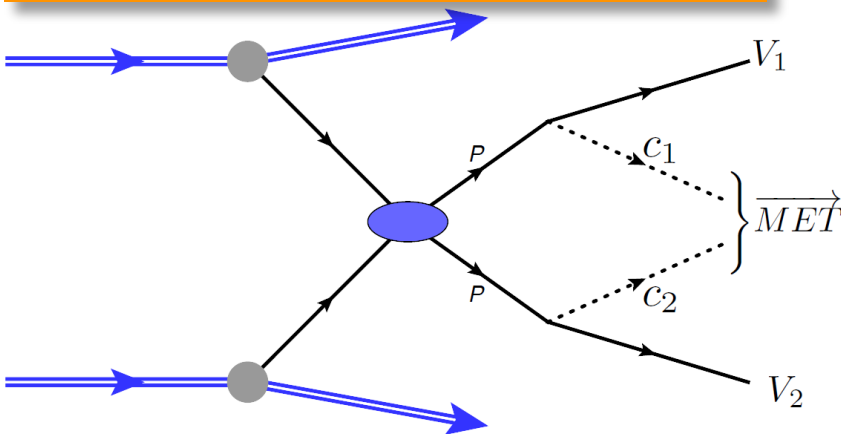
The M_{T2} Variable

- M_{T2}: ***"stransverse mass"*** - a generalization of the transverse mass in case of a pair of invisible particles
- For a simplified case of no extra jets and zero masses for visible and invisible systems:

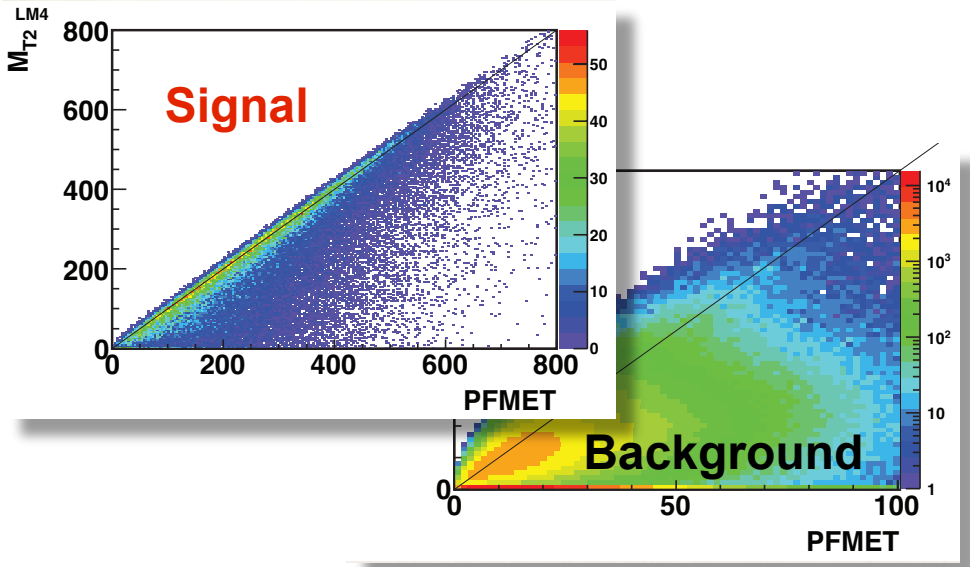
$$(M_{T2})^2 \simeq 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

  - M_{T2} ~ ME_T for symmetric SUSY-like topologies
- M_{T2} kills QCD background very efficiently:
  - M_{T2} ~ 0 for dijets
  - M_{T2} < ME_T in case of mismeasured dijets

Lesters & Summers, hep-ph/9906349

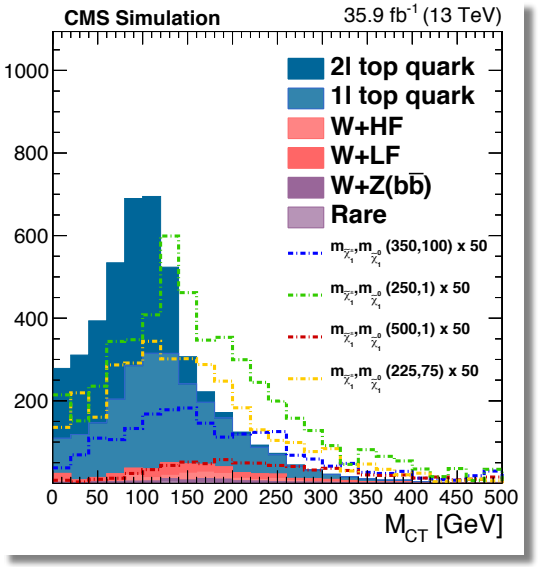


$$M_{T2} = \min_{p_T^{c1} + p_T^{c2} = \not{p}_T} \left[\max \left(m_T^{(1)}, m_T^{(2)} \right) \right]$$



More M_{T2}-like Variables

- Co-transverse mass M_{CT} [Tovey, arXiv:0802.2879; Polesello, Tovey, arXiv:0910.0174]
  - $M_{CT}^2(v_1, v_2) \equiv [E_T(v_1) + E_T(v_2)]^2 - [\mathbf{p_T}(v_1) - \mathbf{p_T}(v_2)]^2$
    where v_1 and v_2 are visible decay products of the two decay chains
  - Has an endpoint related to the mass of the decaying pair-produced states (X): $\frac{M_X^2 - M_{inv}^2}{M_X}$
  - For the tt background with lost leptons, using b-jets as visible particles $M_{CT} = \sqrt{2p_T^{b1}p_T^{b2}[1+\cos(\Delta\phi_{bb})]}$ and taking into account $M_X = M_t$ and M_{inv}, so the endpoint is at the top quark mass

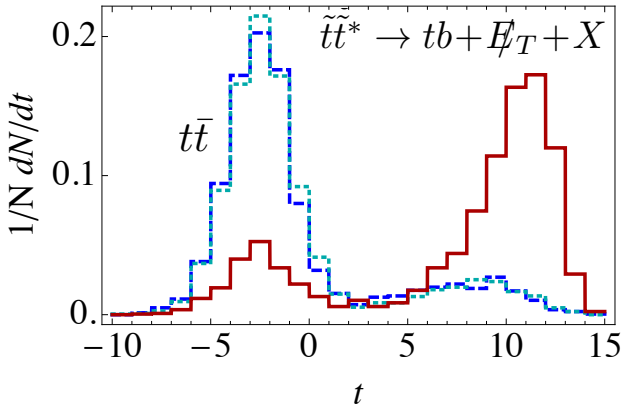


Topness

- Another designer variable to partially reconstruct decays where kinematic information is not sufficient for full reconstruction
  - Example: top quark pair dilepton decay
  - Construct: $$S(p_{Wx}, p_{Wy}, p_{Wz}, p_{\nu z}) = \frac{(m_W^2 - p_W^2)^2}{a_W^4} + \frac{(m_t^2 - (p_{b_1} + p_\ell + p_\nu)^2)^2}{a_t^4} + \frac{(m_t^2 - (p_{b_2} + p_W)^2)^2}{a_t^4} + \frac{(4m_t^2 - (\sum_i p_i)^2)^2}{a_{CM}^4}, \quad (1)$$

    where ai are typical resolutions
  - Define topness [Graesser, Shelton, arXiv:1212.4495]:

$$t = \ln(\min S)$$

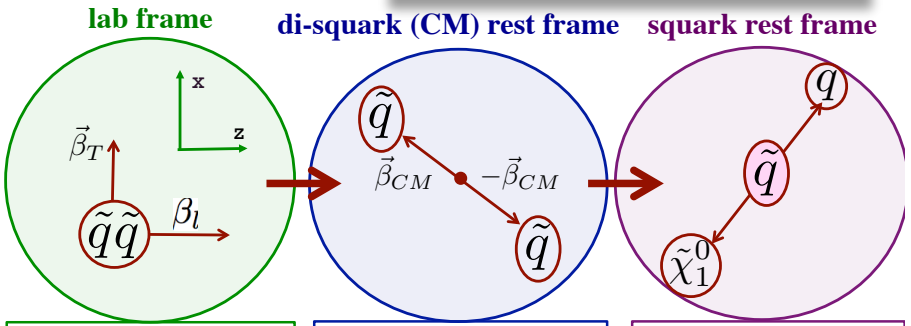


  - Minimizes c.o.m. energy of the event within constraints

The Razor Variables

- Introduced as an alternative to M_{T2} and other similar variables
- R-frame: the frame in which momenta of two (pseudo)jets are equal
  - Applicable to a larger class of events than jets+ME_T
- Transforms signal into a peaking distribution on top of exponentially falling background a.k.a. "bump hunt"

Rogan, arXiv:1006.2727



$|\vec{\beta}_T| \ll 1$
The di-squark rest frame is approximately related to the lab frame by one longitudinal boost
$\vec{\beta}_T = 0$

$2\gamma_{CM} M_{\tilde{q}} = \sqrt{\hat{s}}$
Squarks are heavy, so they are preferentially produced near threshold ($\gamma_{CM} \approx 1$)
$\vec{\beta}_{CM} \to 0$

$M_\Delta = \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}$
Characteristic scale of process is reflected in momenta of quarks and LSP's

$$M_R = 2\sqrt{\frac{(E^{j1}p_z^{j2} - E^{j2}p_z^{j1})^2}{(p_z^{j1} - p_z^{j2})^2 - (E^{j1} - E^{j2})^2}} \qquad \beta_R = \frac{E^{j1} - E^{j2}}{p_z^{j1} - p_z^{j2}}$$

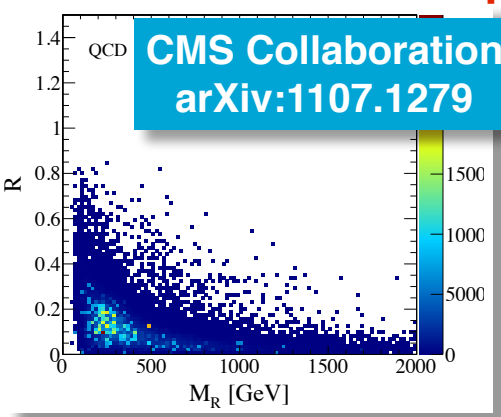
$$M_T^R = \sqrt{\frac{|\vec{M}|(|\vec{p}_T^{j1}| + |\vec{p}_T^{j2}|) - \vec{M} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

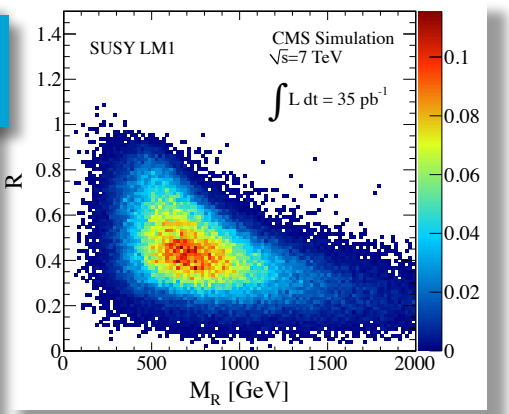
$$R \equiv \frac{M_T^R}{M_R}$$

R ~ ½ for signal and is exponentially falling for QCD background

$M_R \to M_\Delta$ for $\gamma_{CM} \to 0$: peaks for signal!
M_T^R has an endpoint at M_Δ

CMS Collaboration arXiv:1107.1279

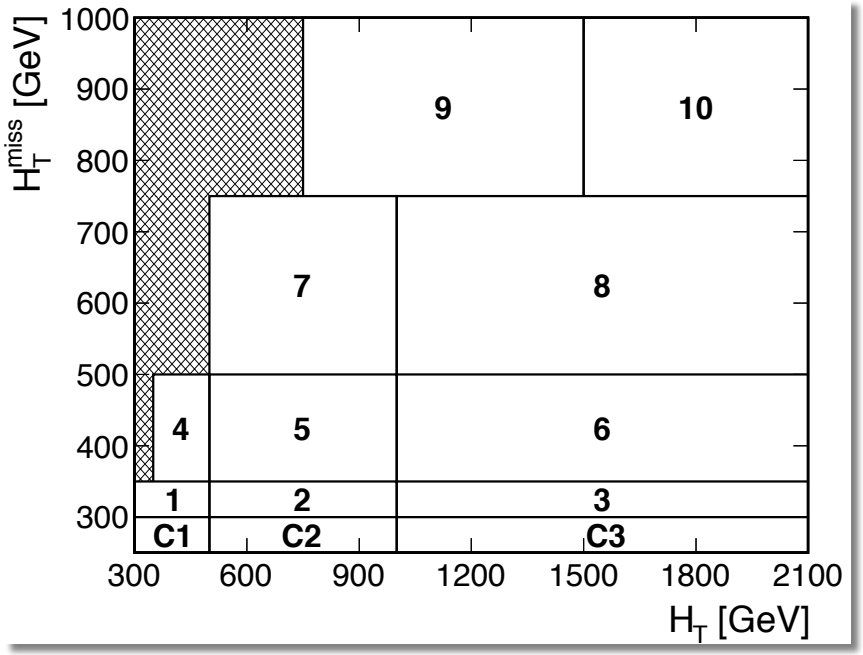





Easy
SUSY

H_T+MH_T Search

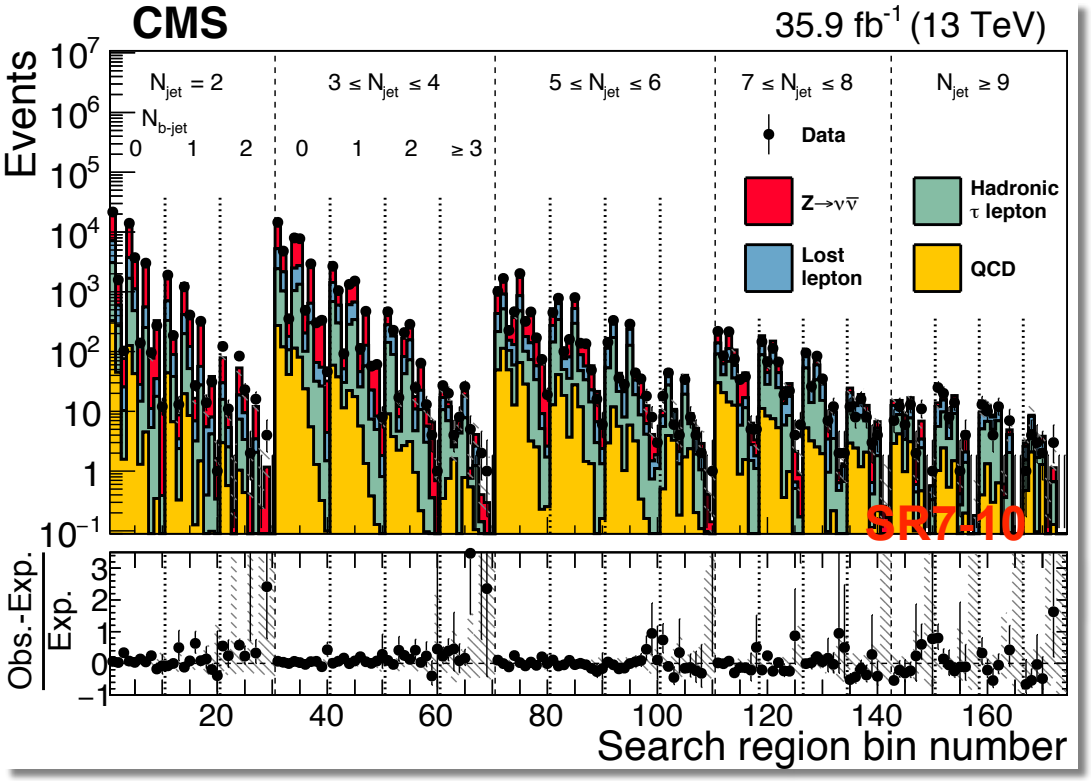
- Classical search in all-hadronic final states requiring at least two jets and significant H_T, MH_T > 300 GeV
- Categorization into 174 search regions (SRs):
  - N_j = 2, 3-4, 5-6, 7-8, ≥9
  - N_b = 0, 1, 2, ≥3
  - 10 (H_T,MH_T) regions (8 for $N_j \geq 7$
  - $\Delta\phi$ >0.5 (j_1, j_2) or >0.3 (j_3, j_4) (opening angle between the MH_T vector and the jet momentum)



- Also 10 aggregate larger search regions for easier reinterpretation
- Backgrounds determined mostly from control samples in data, augmented with simulations

Data/Background Prediction

- Data agree well with the background predictions



CMS Collaboration
arXiv:1704.07781

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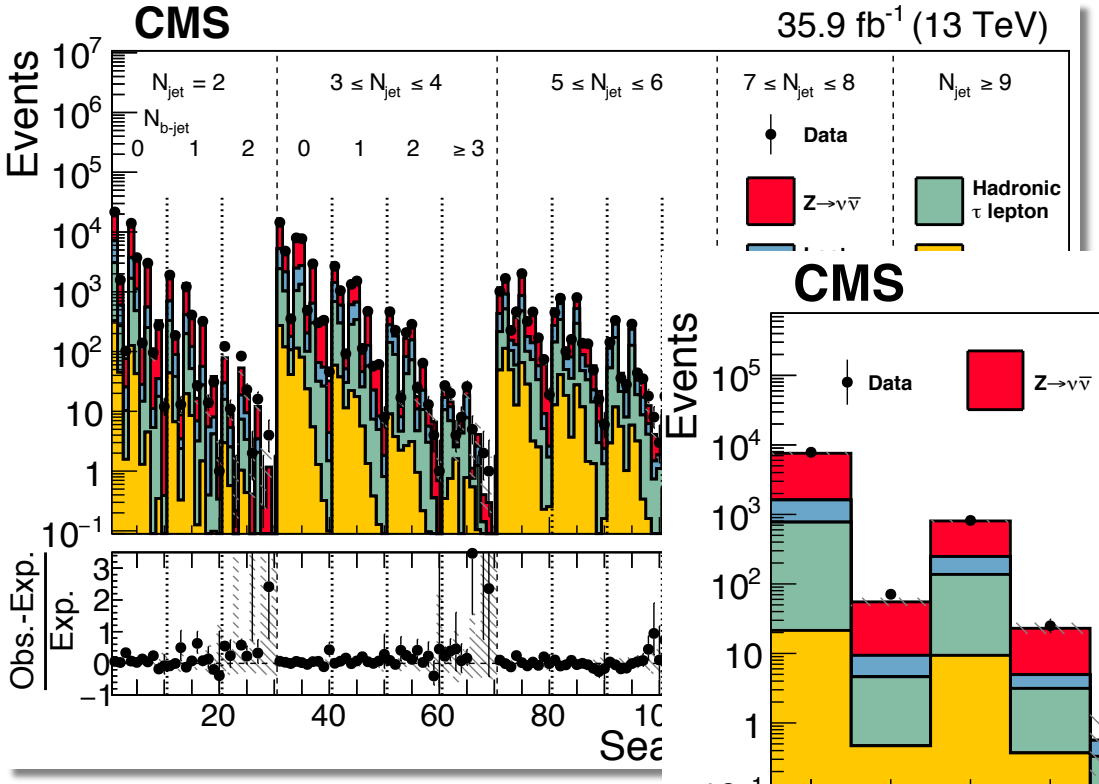

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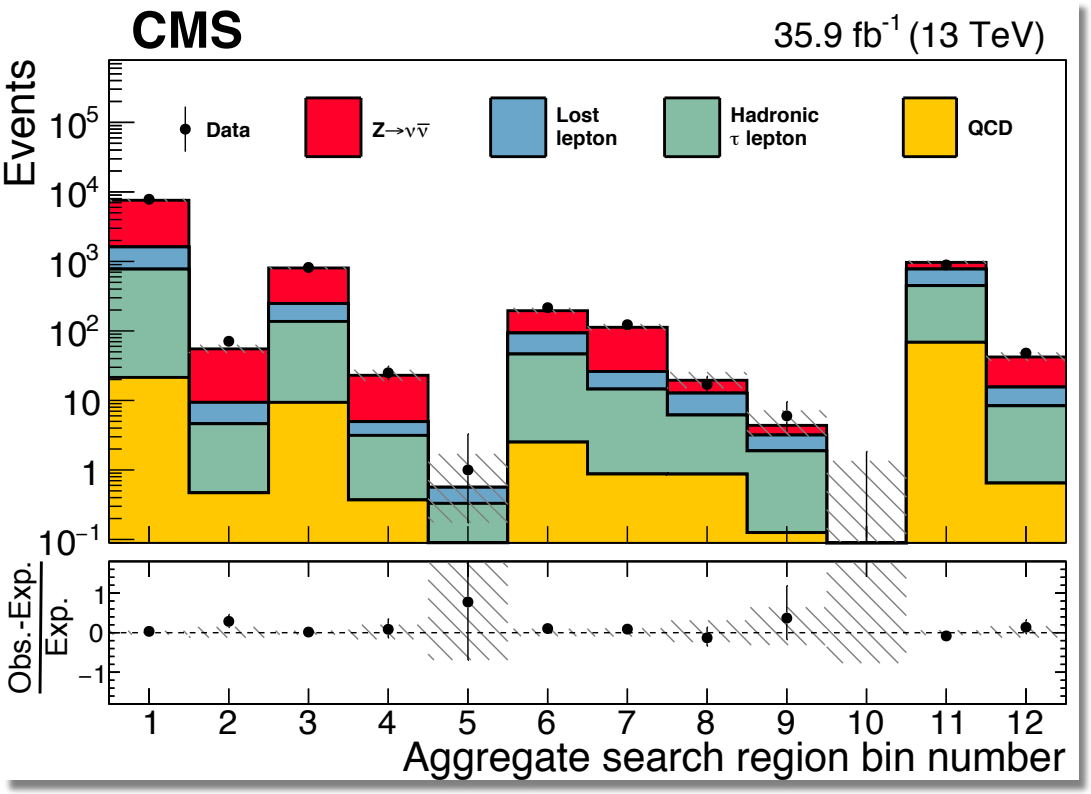
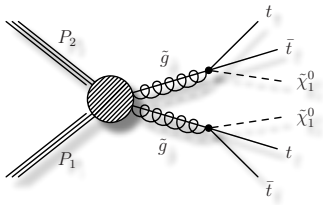
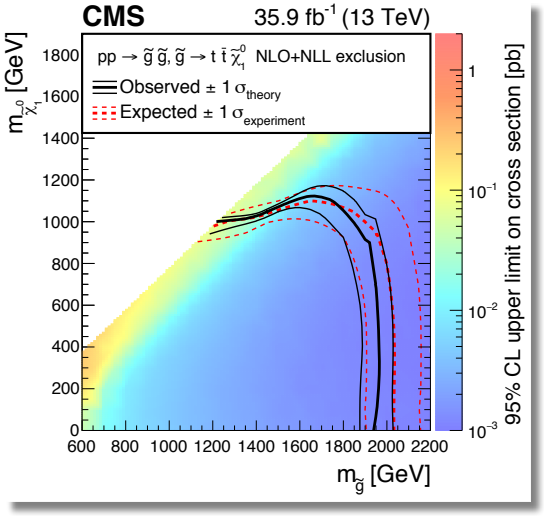
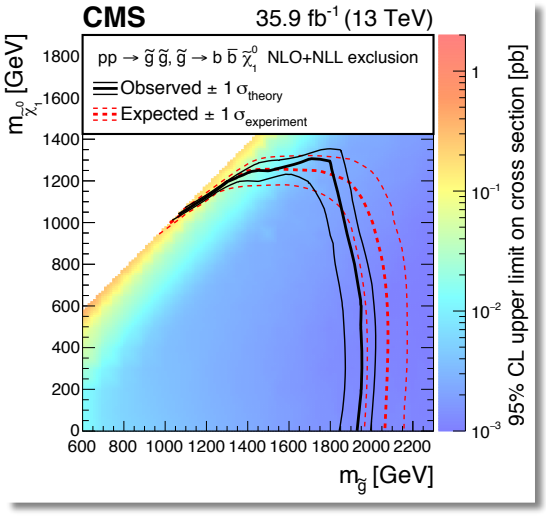
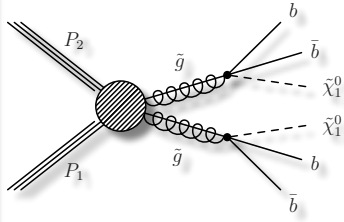


Gluino-Mediated Production









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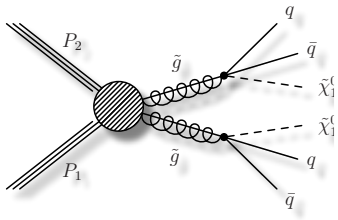
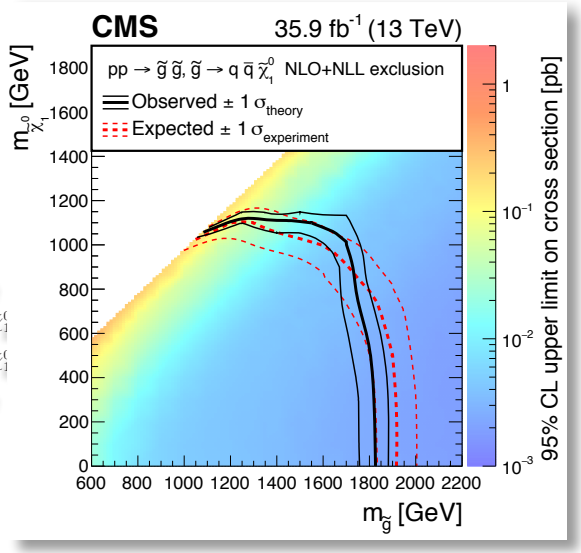
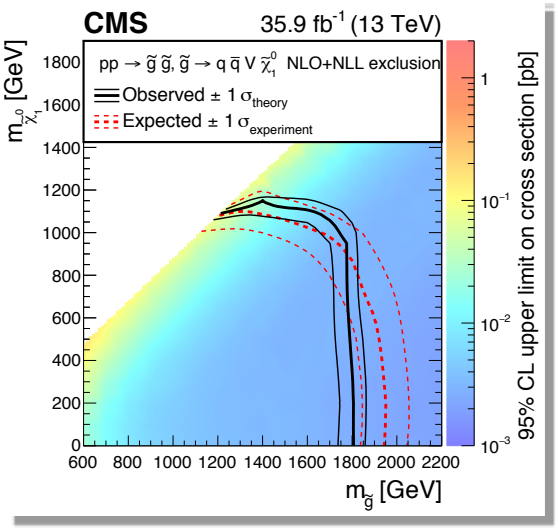
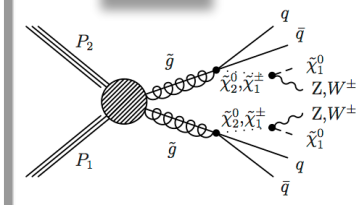
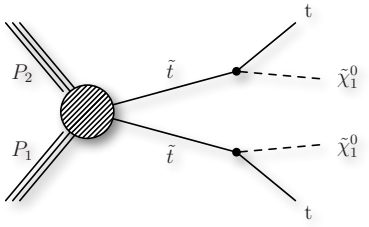


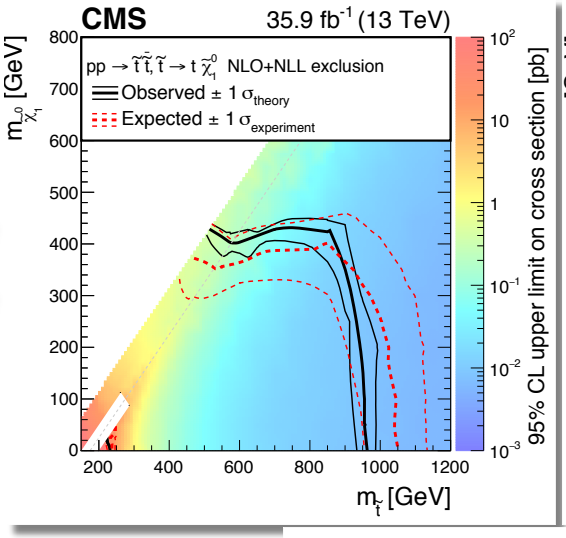


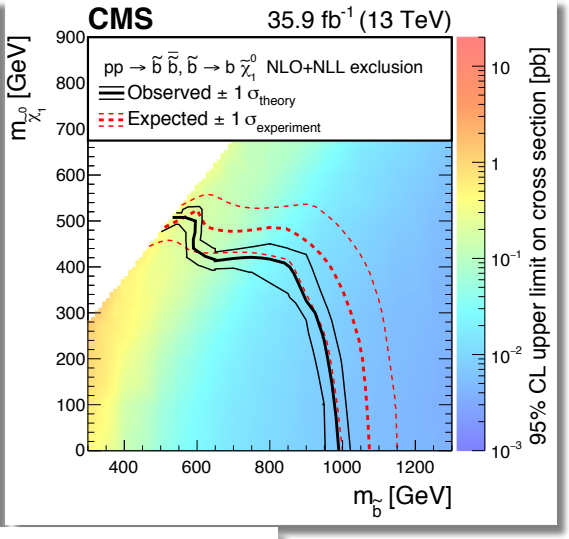


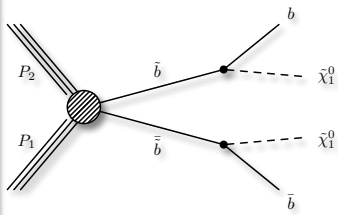


Direct Squark Production

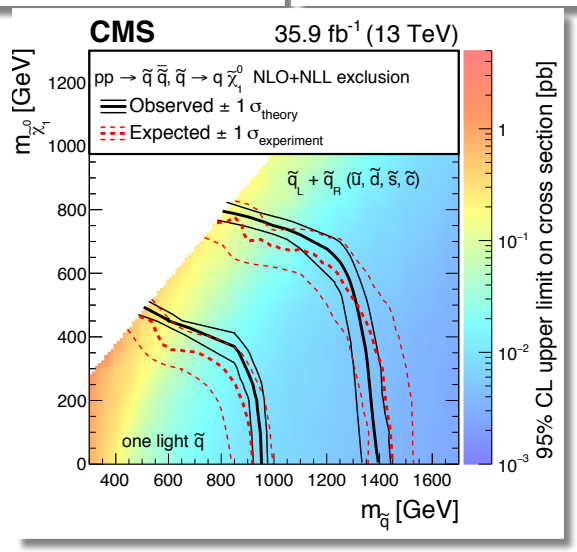


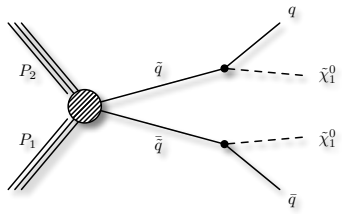






CMS Collaboration arXiv:1704.07781



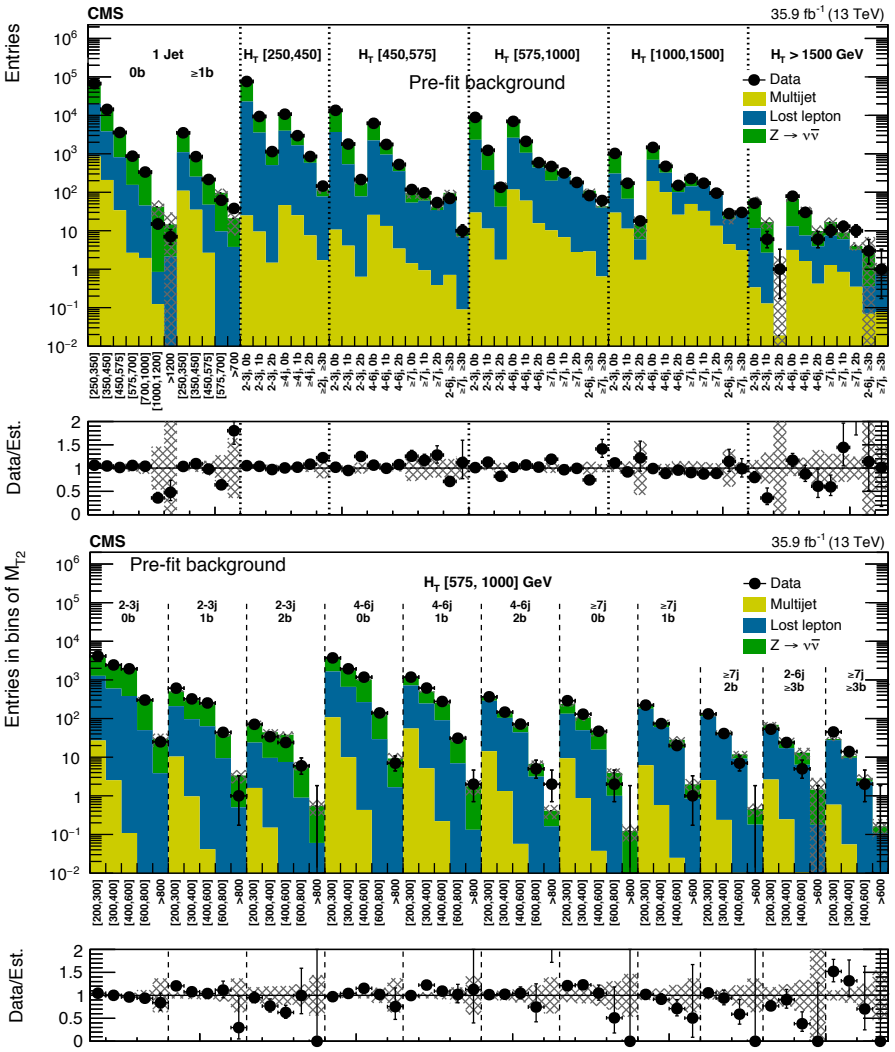


M_{T2} Search

- Similar to earlier M_{T2} analyses
  - Bin in N_j, N_b, H_T, and M_{T2}
  - Includes a monojet category (M_{T2} is not defined, so a simple selection is used) and five H_T multijet categories
  - $\Delta\phi>0.5$ (j_1, ..., j_4) or >0.3 (opening angle between the ME_T vector and the jet momentum
- Main backgrounds are lost lepton from W+jets and top quark events, irreducible Z($\nu\nu$)+jets, and multijet
  - Estimated from control regions in data, augmented with MC simulations

Background Predictions

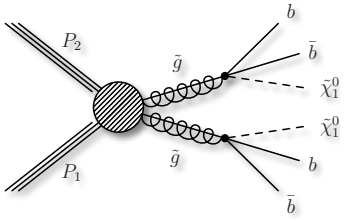
- Data/background expectation agreement in some of the bins

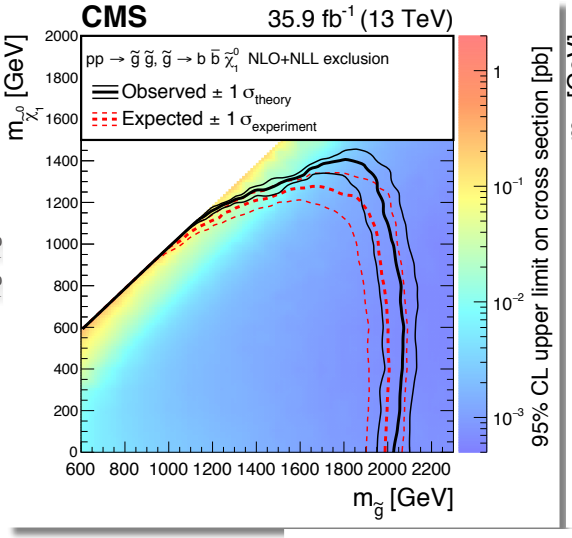


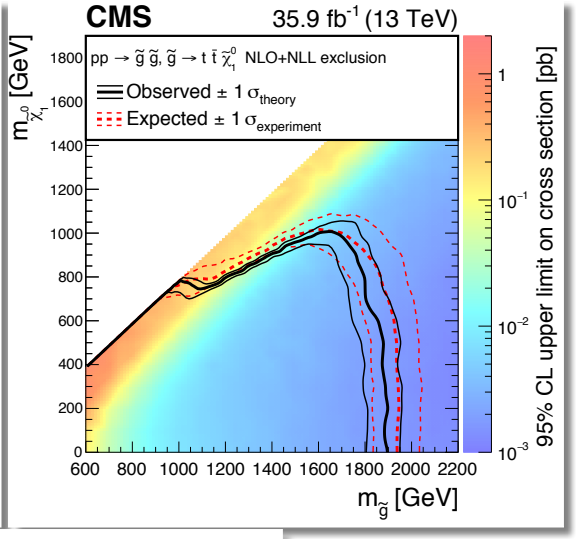
CMS Collaboration
arXiv:1705.04650

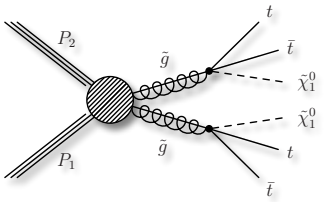
Gluino-Mediated Production

- Gluino-mediated sbottom, stop, and squark production limits

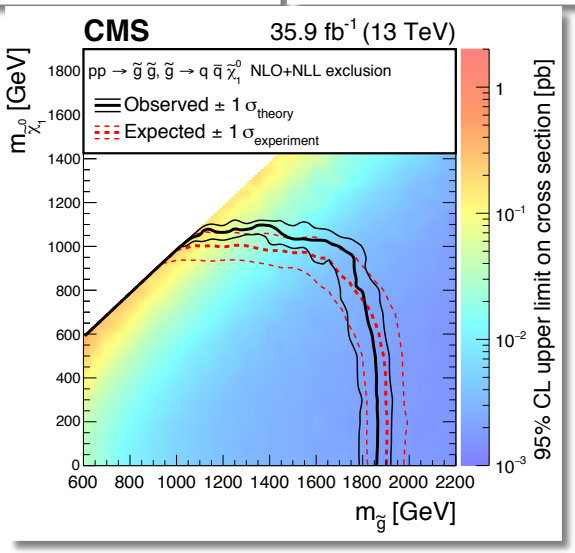


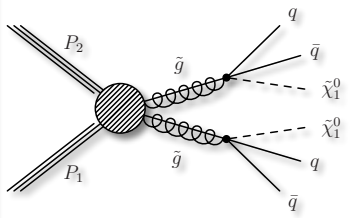






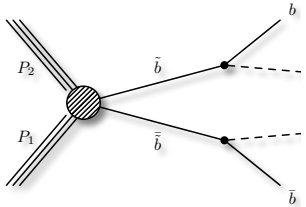
CMS Collaboration
rXiv:1705.04650

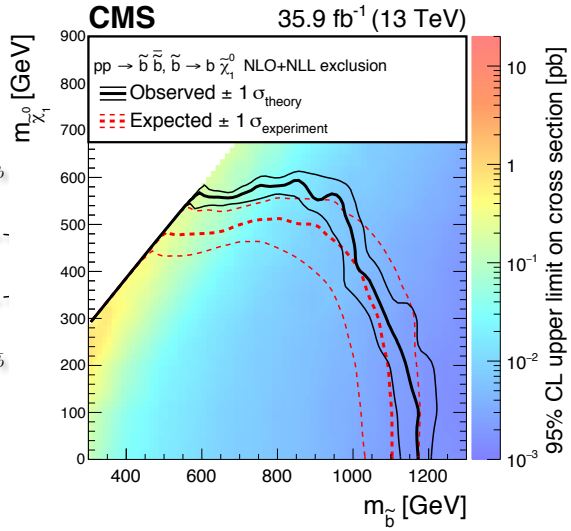


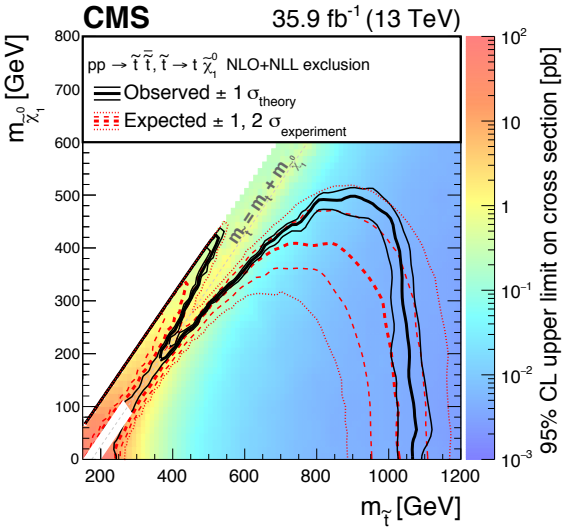


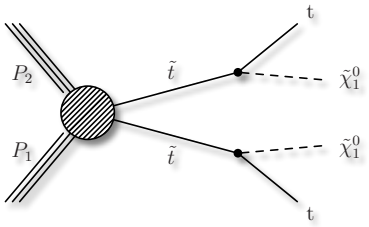
Direct Squark Production

- Limits on direct stop, sbottom, and squark production

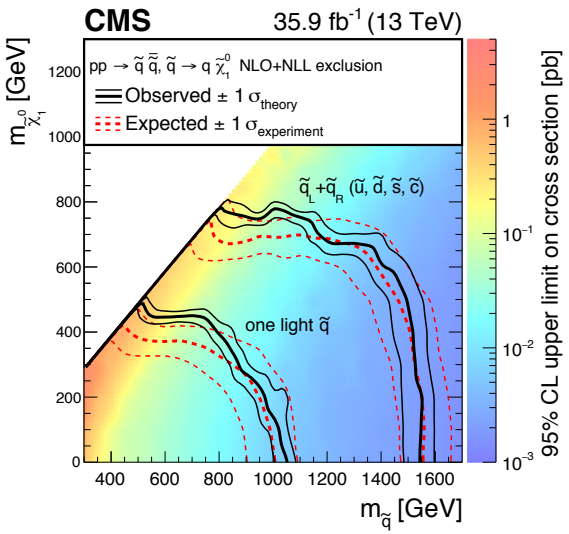


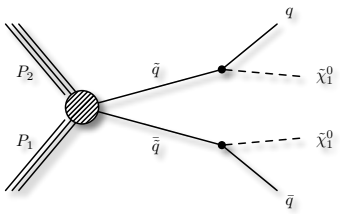






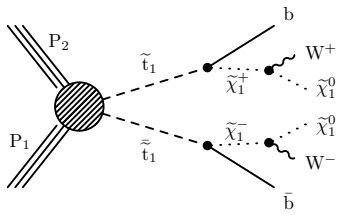
CMS Collaboration rXiv:1705.04650

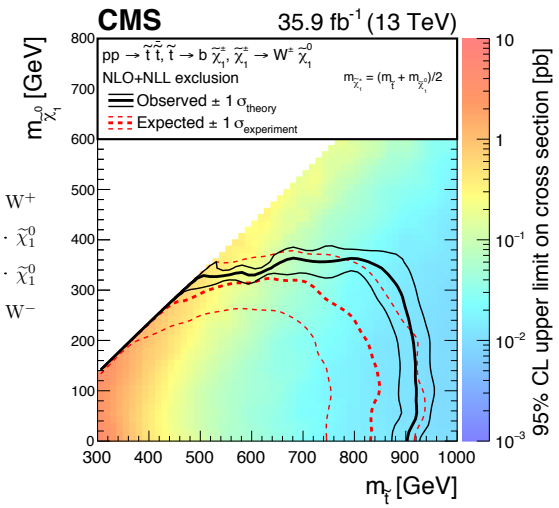


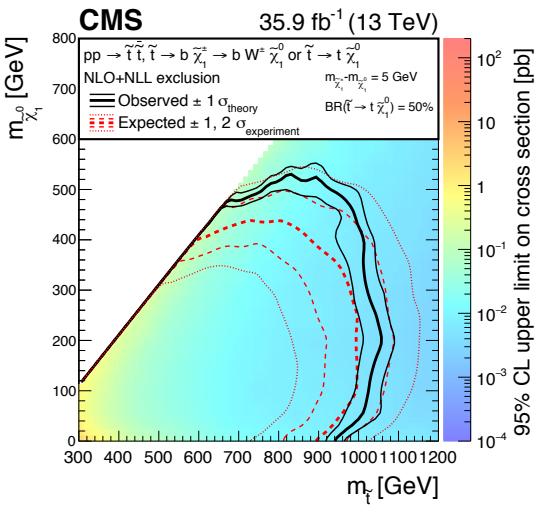


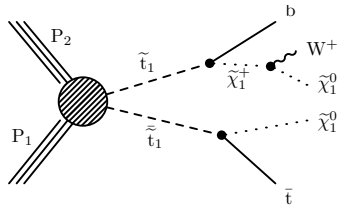
More Stop Decays

- More top squark interpretations, including FCNC decay

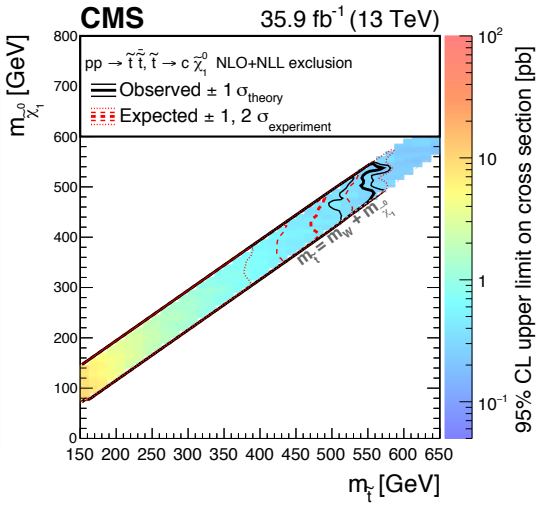


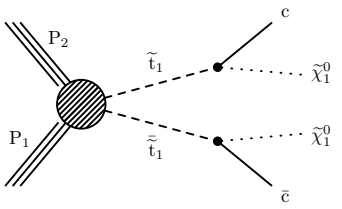






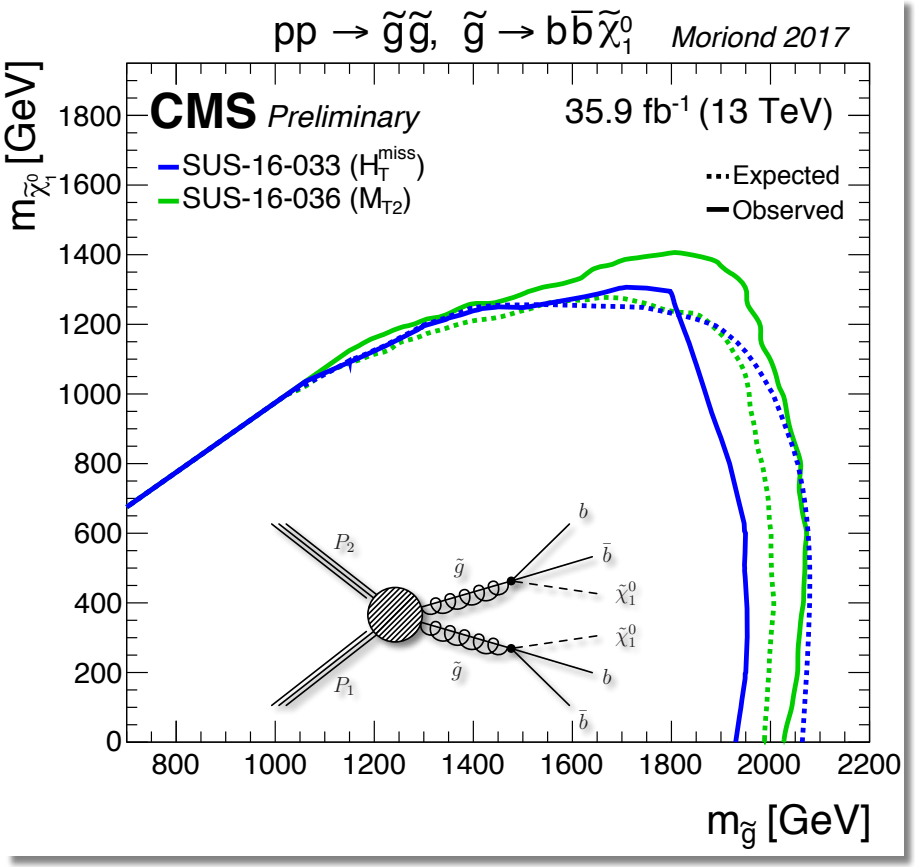
CMS Collaboration rXiv:1705.04650

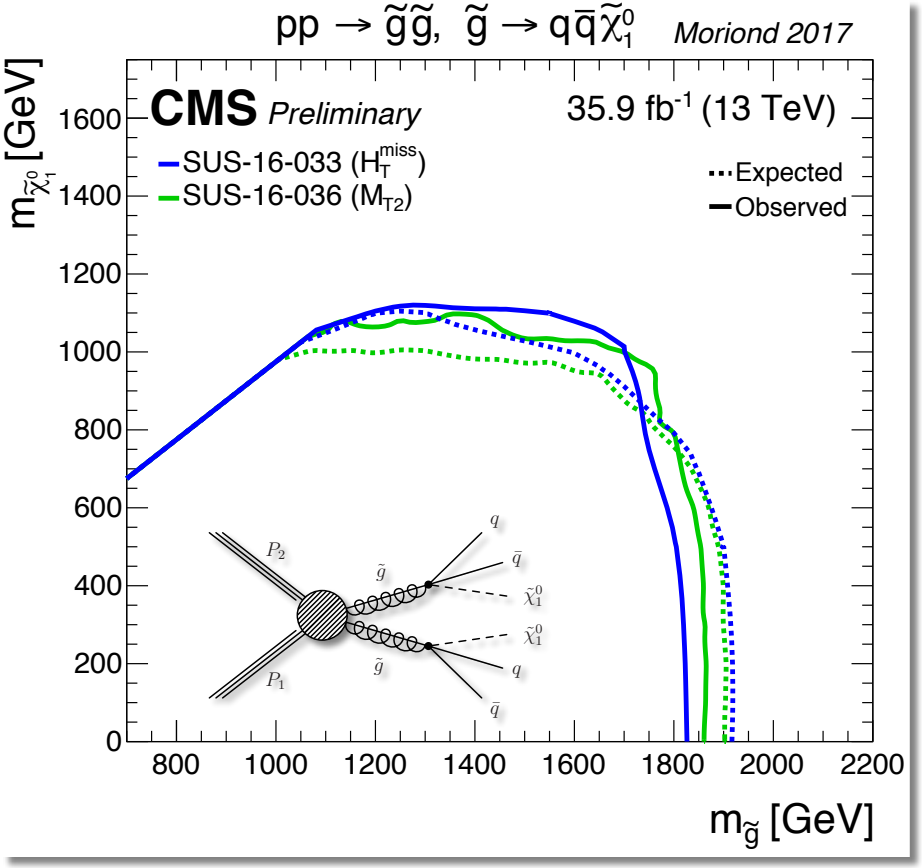




All-Hadronic Summary: Gluinos

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Moriond_2017_36_fb_1

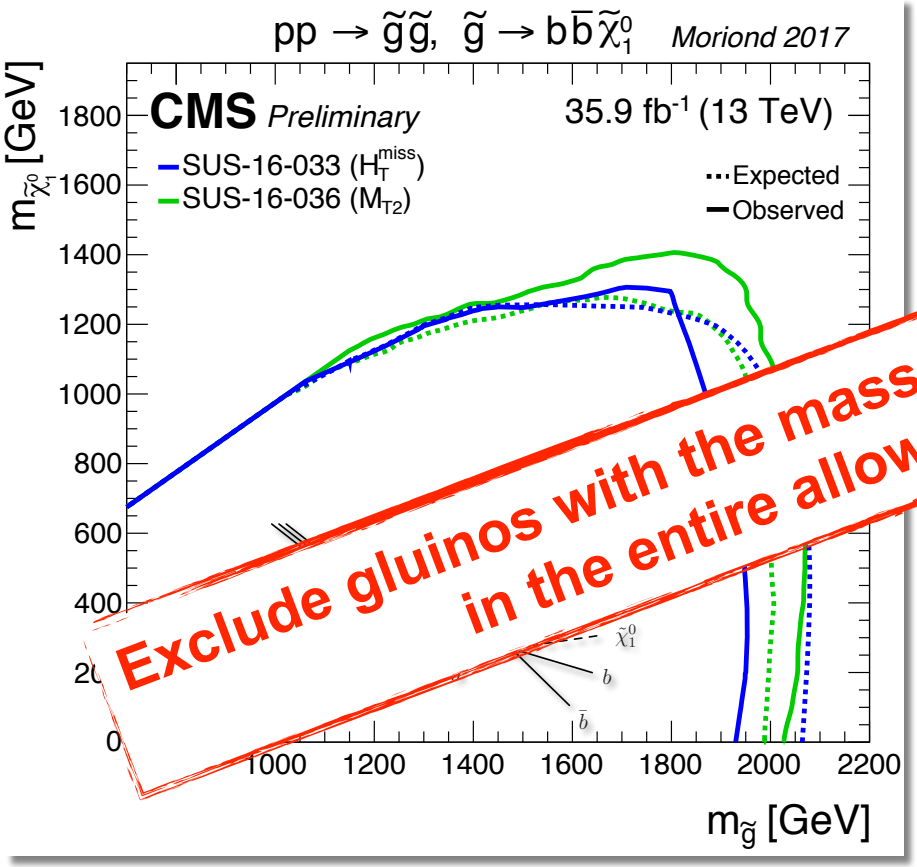


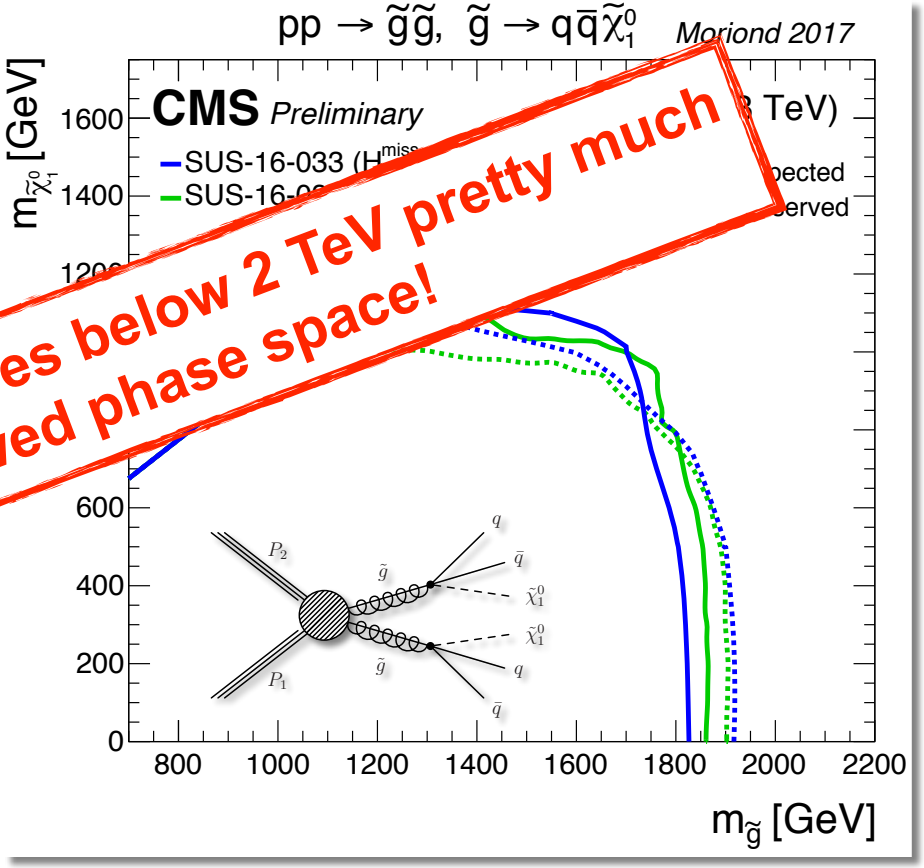


N.B. No significant improvement from the use of "designer variables" because of large cross section and very fine binning (limit-oriented analyses) - can be remedied by using "aggregate search regions" in case an excess is observed

All-Hadronic Summary: Gluinos

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Moriond_2017_36_fb_1



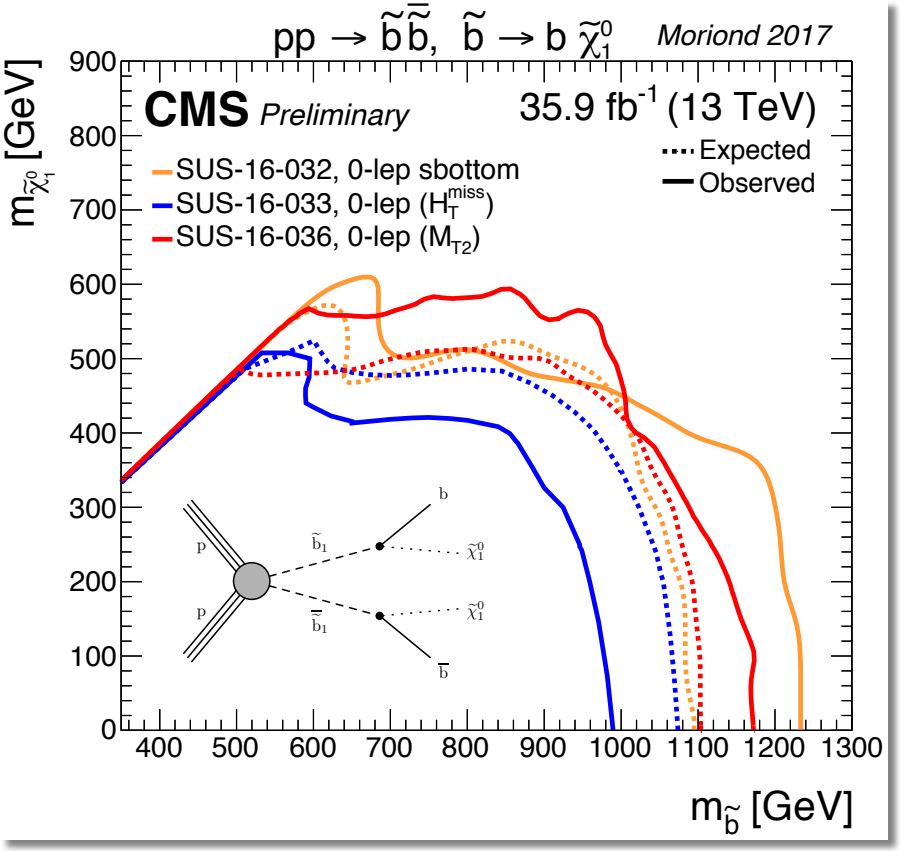


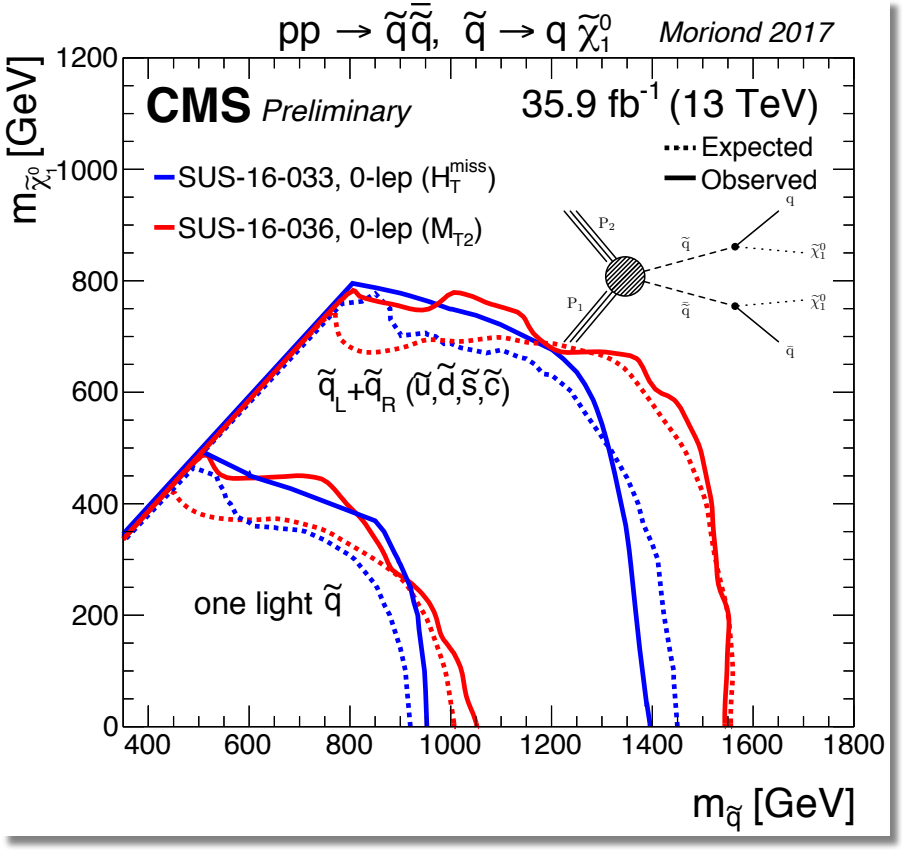
Exclude gluinos with the masses below 2 TeV pretty much in the entire allowed phase space!

N.B. No significant improvement from the use of "designer variables" because of large cross section and very fine binning (limit-oriented analyses) - can be remedied by using "aggregate search regions" in case an excess is observed

All-Hadronic Summary: Squarks

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Moriond_2017_36_fb_1





N.B. Here "designer variables" help a bit, particularly for light-generation squarks (SUS-16-032 also uses them, see later)

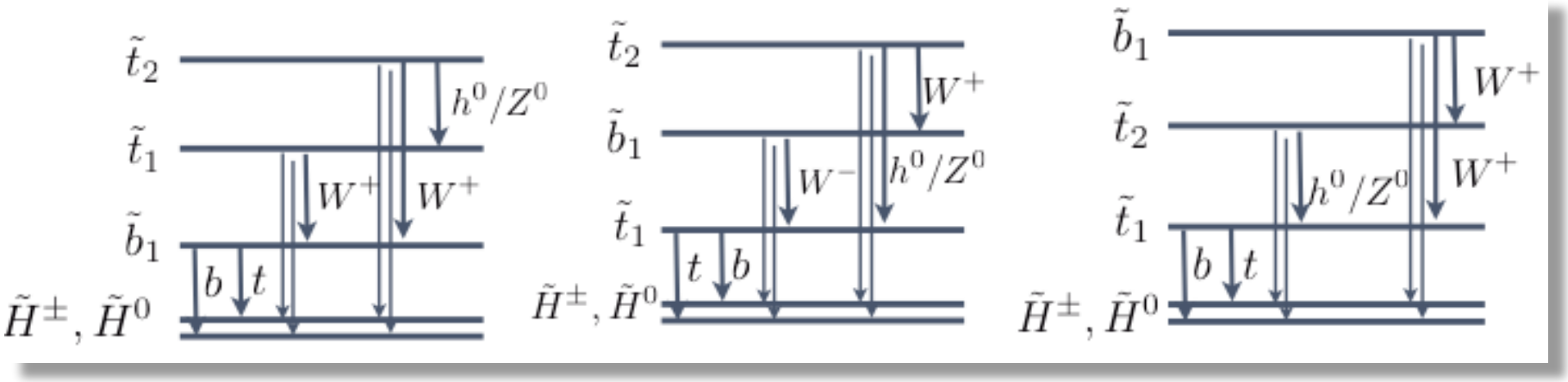
Searches for Third Generation

Pulling all the Stops

- Direct stop production offers several search channels, which go beyond all-hadronic searches and that rely on special techniques, e.g., top quark reconstruction in a resolved and boosted cases
  - All-hadronic searches with top quark reconstruction
  - All-hadronic searches targeting compressed spectra
- Also generic leptonic analyses that do not attempt to reconstruct top quarks in the decay chains, yet are highly optimized for top squarks
  - Single-lepton search for gluino-mediated and direct stop production
  - Same-sign dilepton search

Third Generation SMS

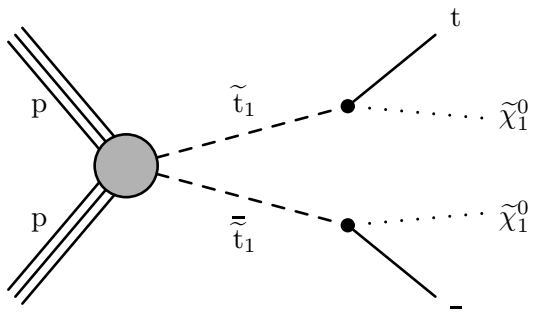
- Third-generation decays in natural SUSY are rather simple
- The kinematics is determined by just a few mass splittings
  - Most of other 100+ MSSM parameters are typically of little relevance, which simplifies the searches and interpretation a lot
- Hence, move from cMSSM, pMSSM, etc framework to SMS (Simplified Model Spectra) - simple Feynman diagrams capturing most relevant aspects of a particular process
- For example, for direct squark pair productions, relevant transitions and possible mass hierarchies are relatively few:

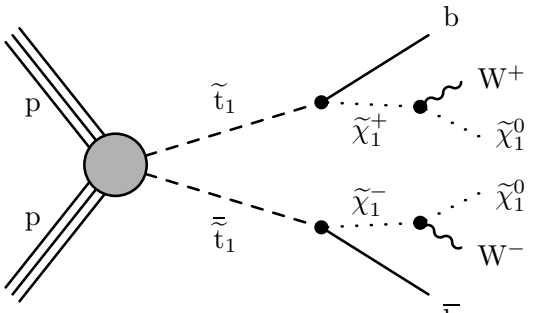


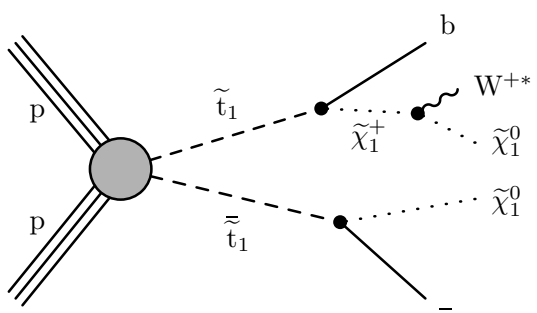
All-Hadronic Search

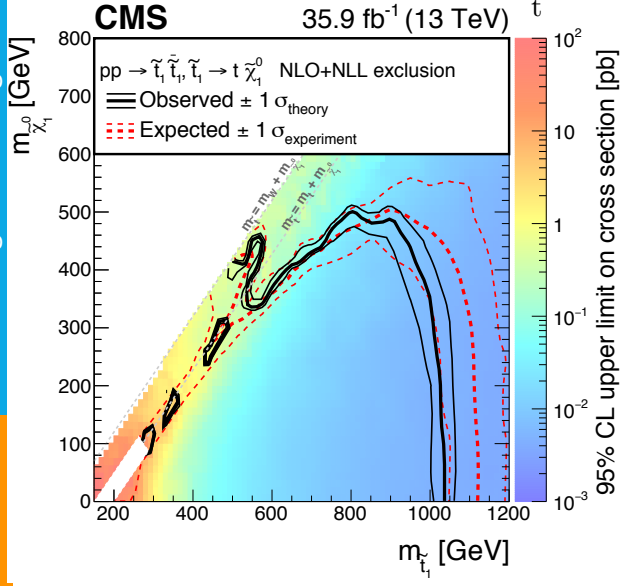
- Targets both compressed and non-compressed scenarios by binning in the number of (b) jets and ME_T, and reconstructing both boosted (merged) and resolved W and t candidates (high-ΔM) or ISR jet boost and number of SV (low-ΔM)

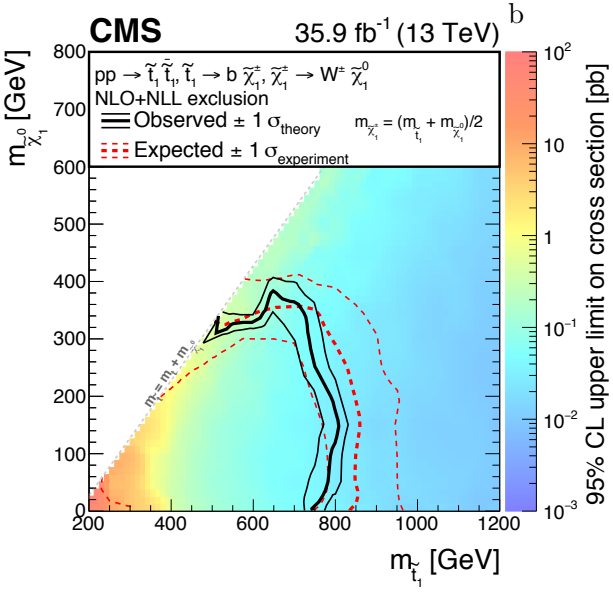
CMS Collaboration
arXiv:1707.03316

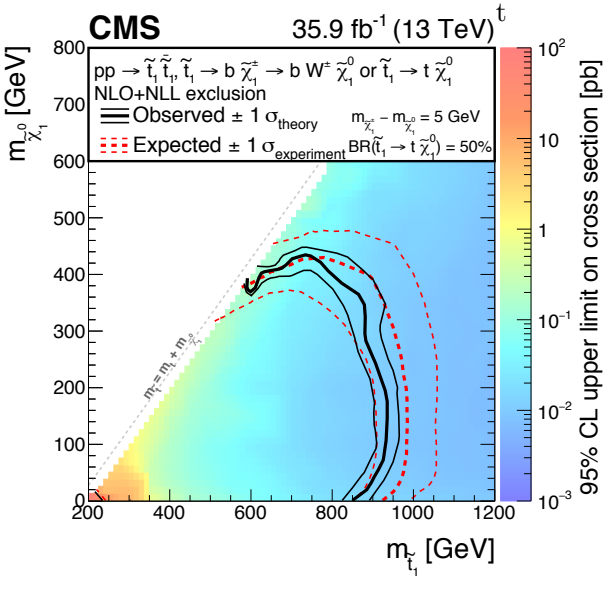








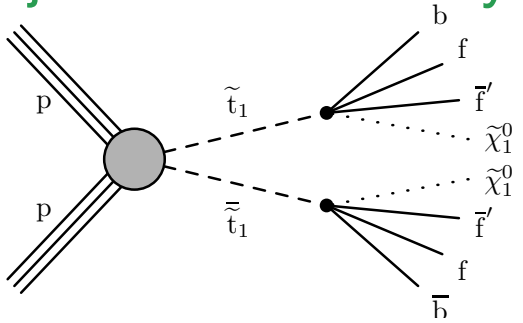


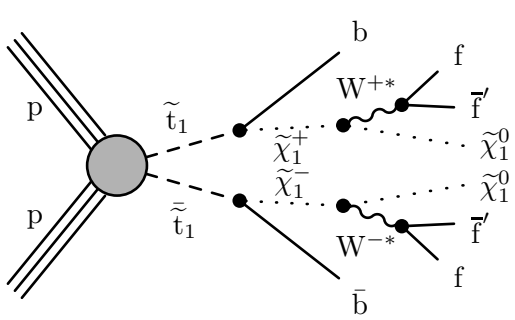


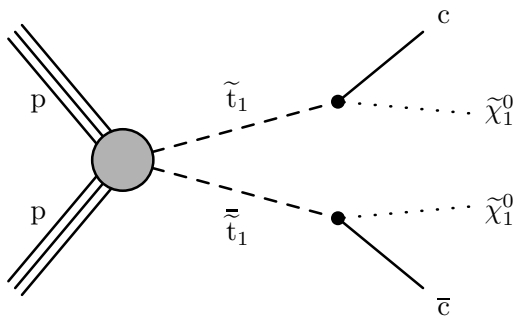
All-Hadronic Search (cont'd)

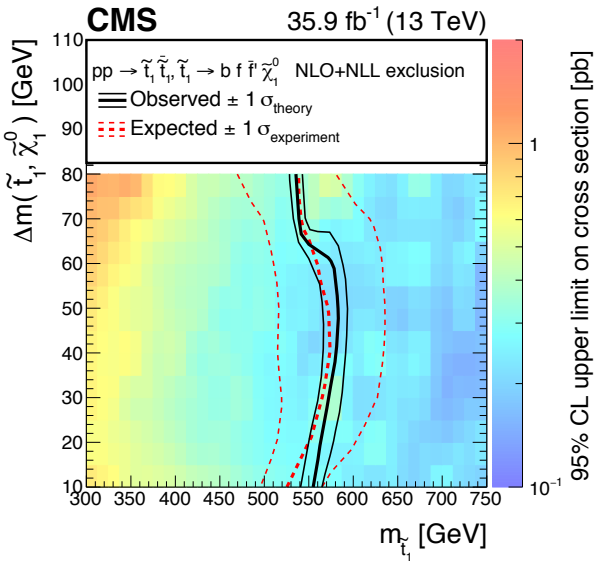
CMS Collaboration
arXiv:1707.03316

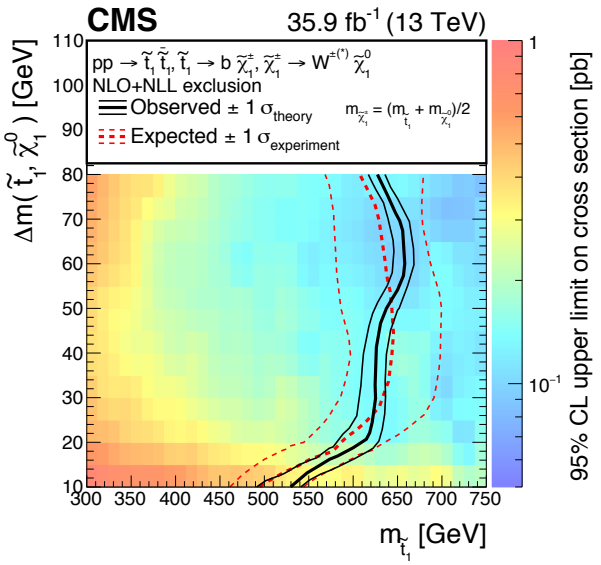
- Low-ΔM regions are sensitive to 4-body and chargino-mediated decays
- Sensitivity to FCNC decays comes from search regions with no b jets or secondary vertices

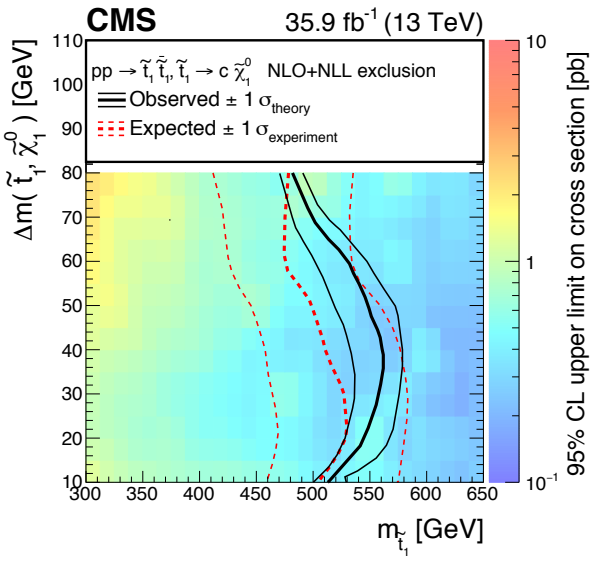






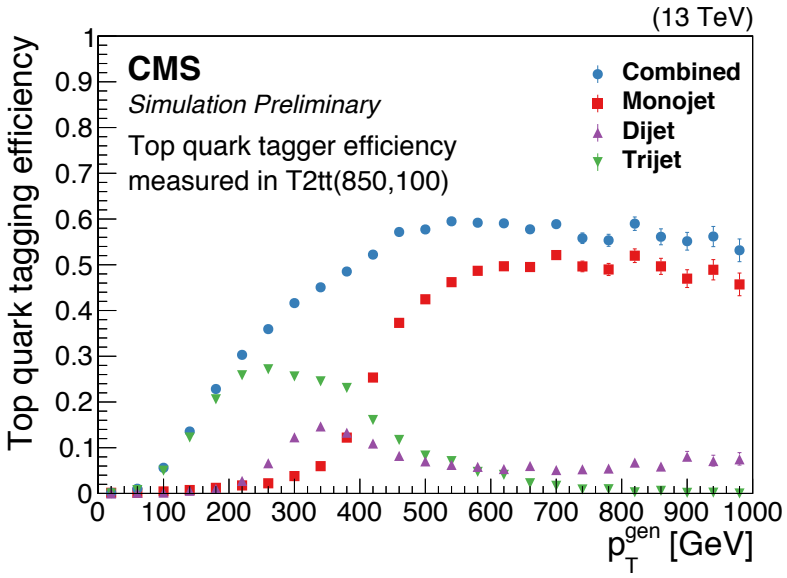




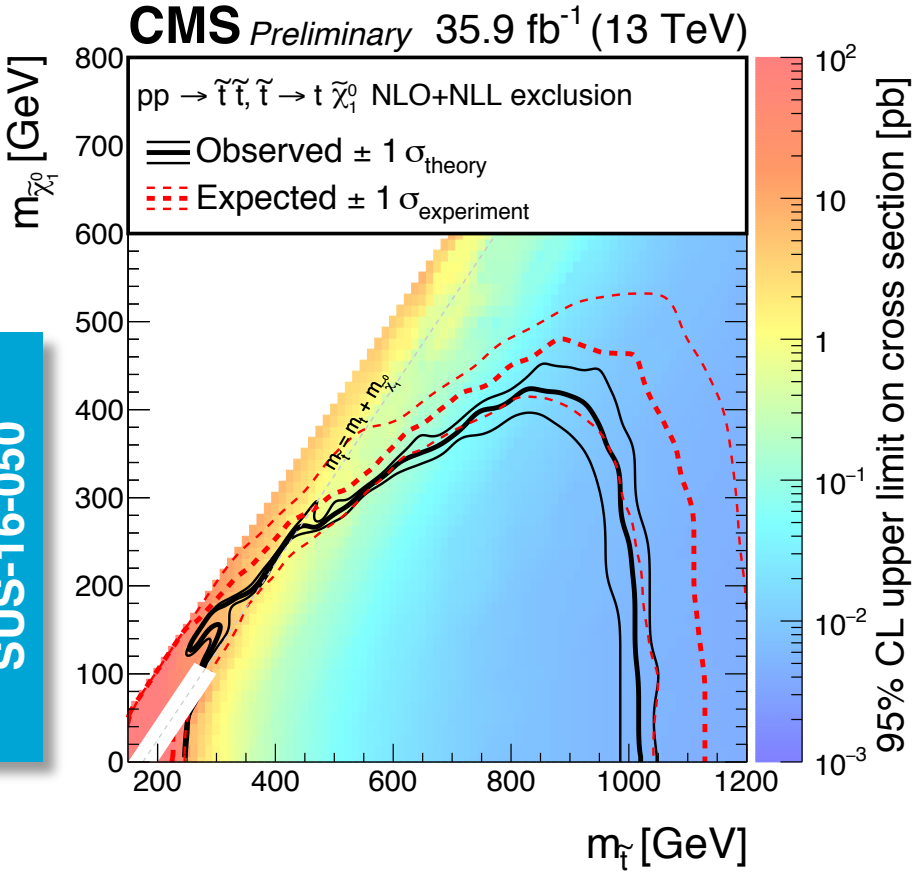


All-Hadronic Search w/ t Tagger

- Developed a sophisticated top quark tagged capable of optimal reconstruction merged and resolved topologies
- Uses M_{T2} (or H_T), ME_T, and number of (b) jets to define 83 search regions
- Sensitivity similar to the other all-hadronic search

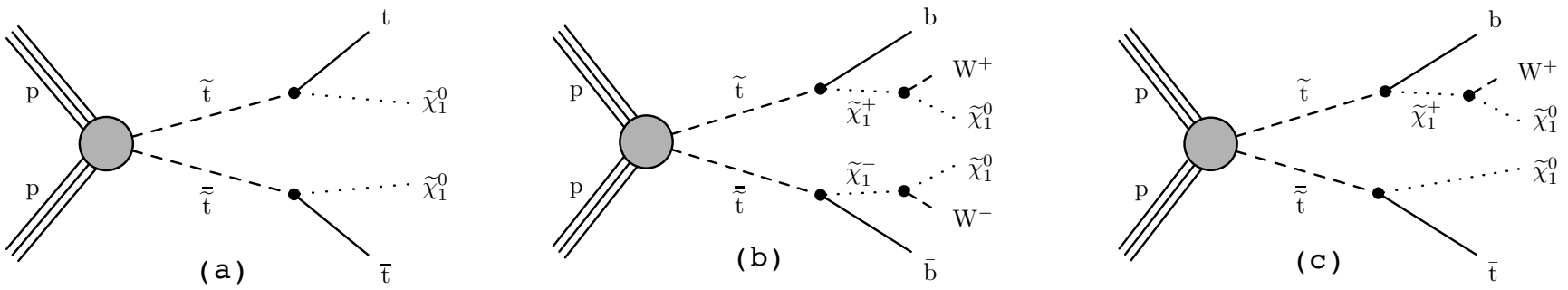


CMS Collaboration SUS-16-050



Single-Lepton Stop Search

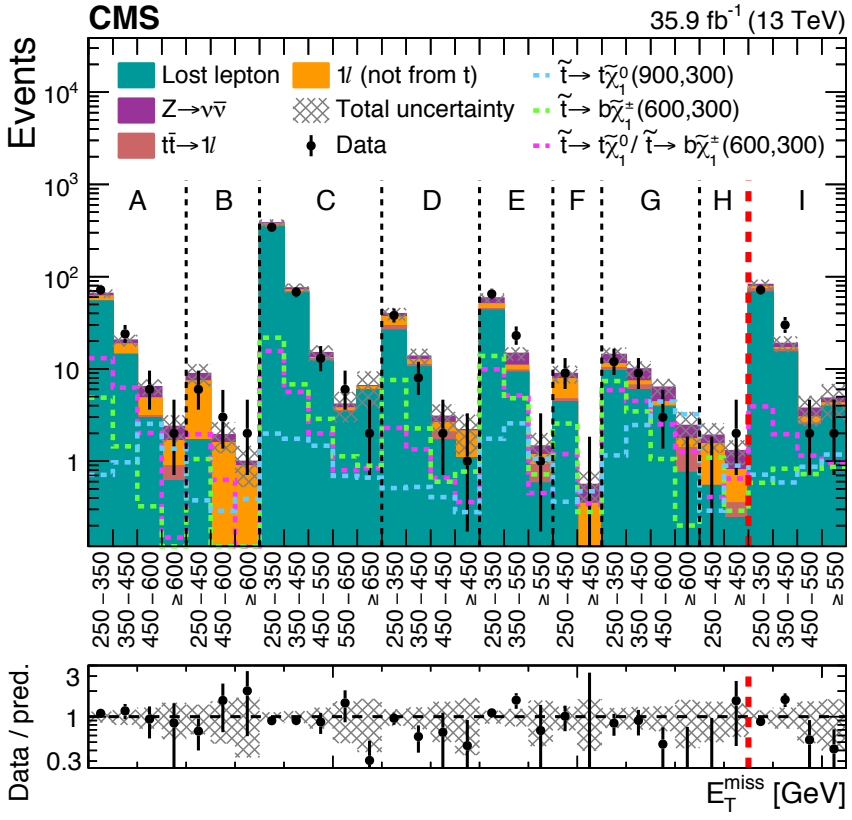
- Targets both neutralino- and chargino-mediated decays of the top squark, resulting in the same final state
- Require an e or μ, 2 or more jets (with 1 or more b-tagged) and $ME_T > 250$ GeV, and $M_T > 150$ GeV
- After these selections, the main background is from top quark pair production in the dilepton channel, with a lost lepton



Single-Lepton Results

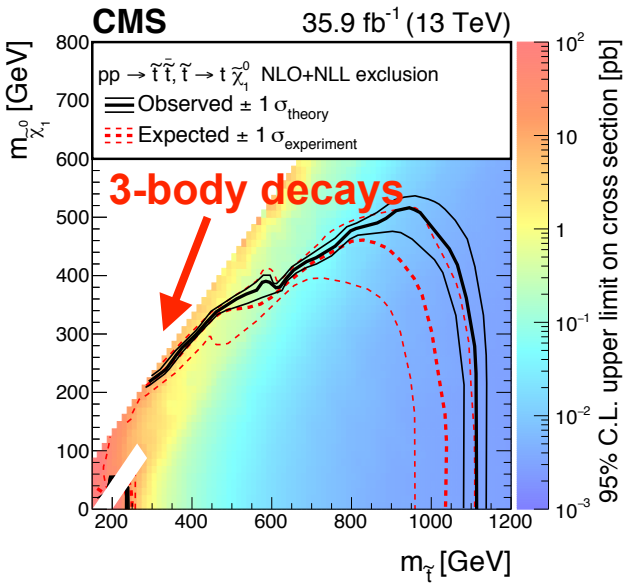
- No excess seen in any of the categories

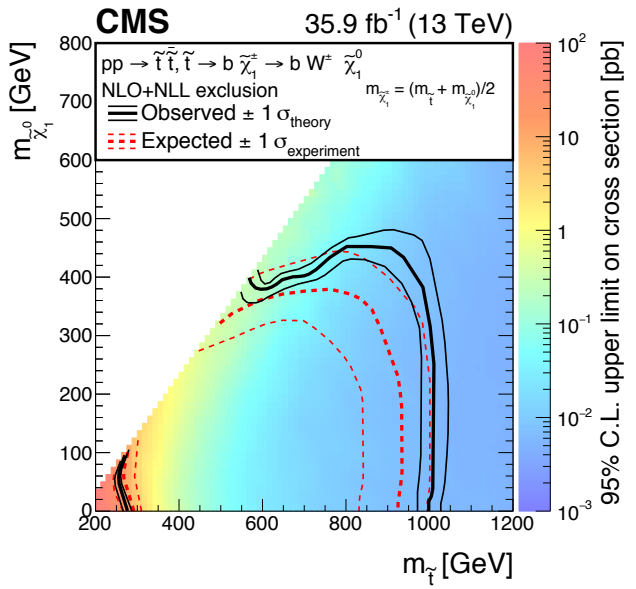
CMS Collaboration
arXiv:1706.04402



A: $N_J \leq 3$, $t_{mod} > 10$, $M_{lb} \leq 175$ GeV
B: $N_J \leq 3$, $t_{mod} > 10$, $M_{lb} > 175$ GeV
C: $N_J \geq 4$, $t_{mod} \leq 0$, $M_{lb} \leq 175$ GeV
D: $N_J \geq 4$, $t_{mod} \leq 0$, $M_{lb} > 175$ GeV
E: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} \leq 175$ GeV
F: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} > 175$ GeV
G: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} \leq 175$ GeV
H: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} > 175$ GeV

I: Compressed region





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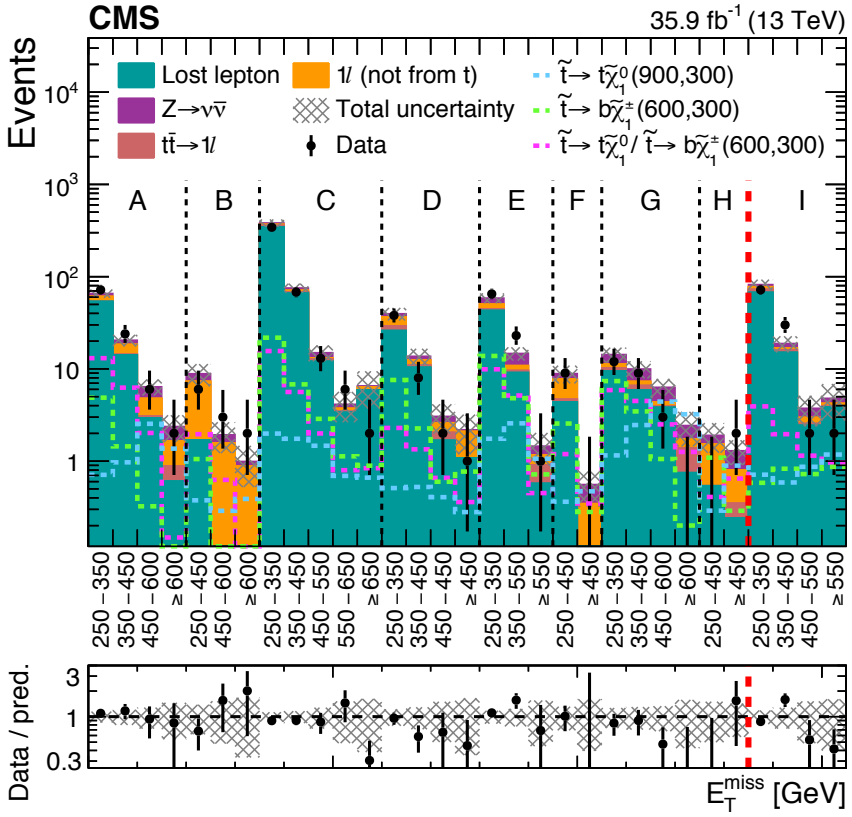
CMS Collaboration
arXiv:1706.04402



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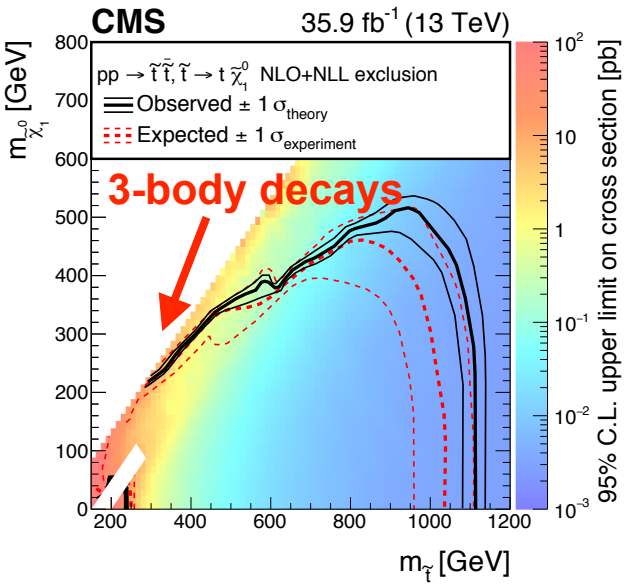
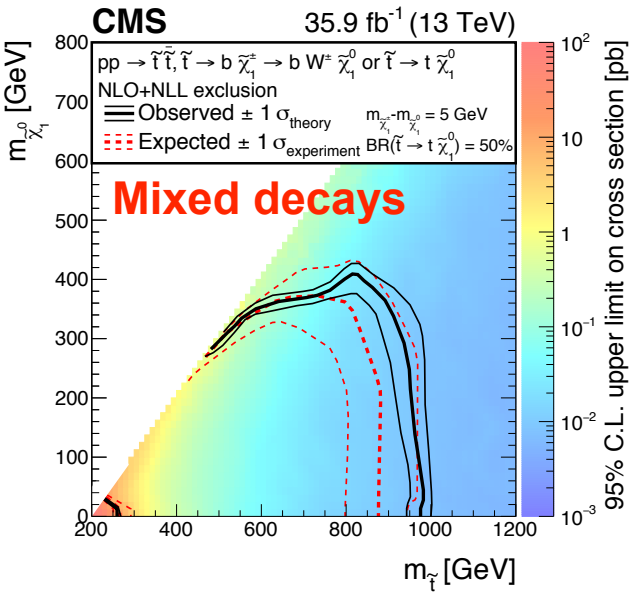
E: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} \leq 175$ GeV
F: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} > 175$ GeV
G: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} \leq 175$ GeV
H: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} > 175$ GeV

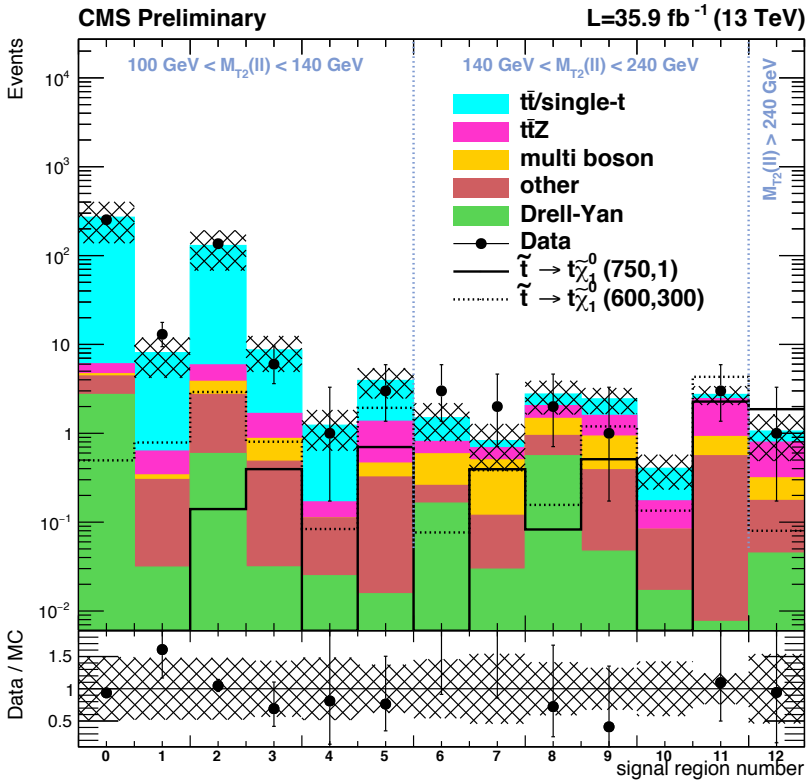
I: Compressed region



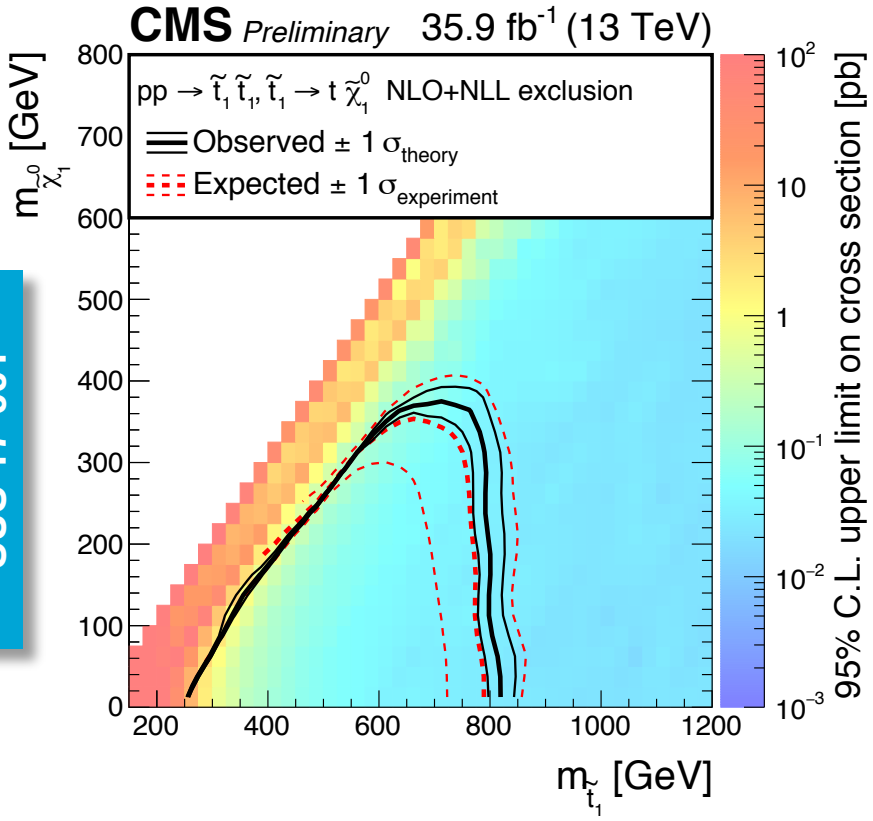


OS Dilepton Search

- Search for direct stop pair production in the dilepton final states, ee, eμ, μμ
  - Two MT_2 variables (*ll* and *blbl*) are used to control the top quark background and define 12 signal regions

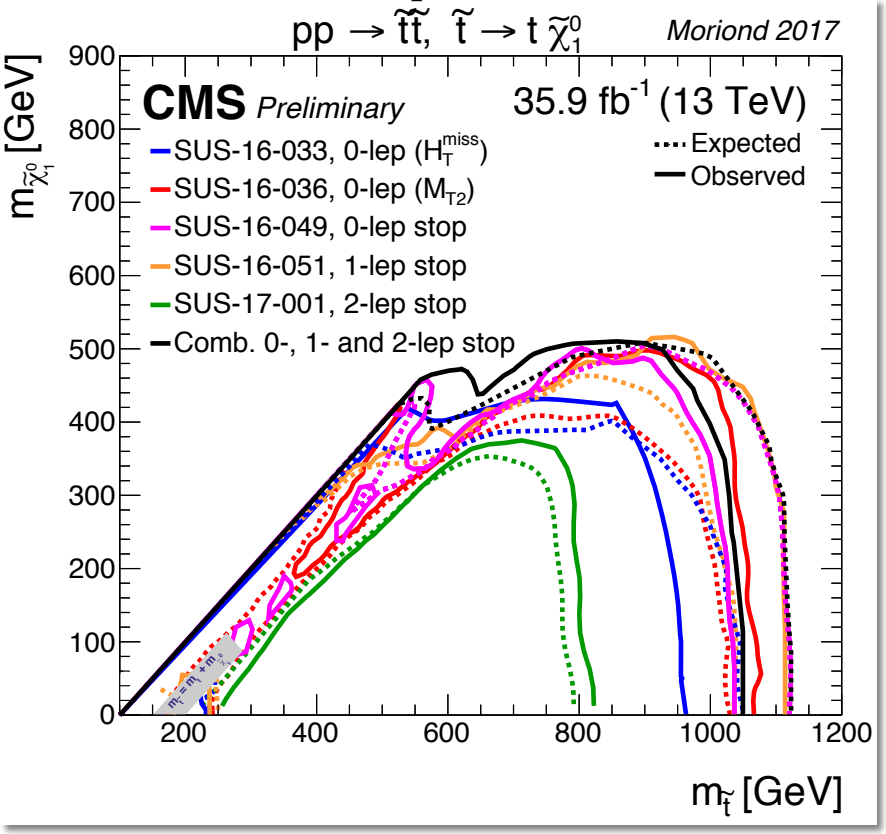


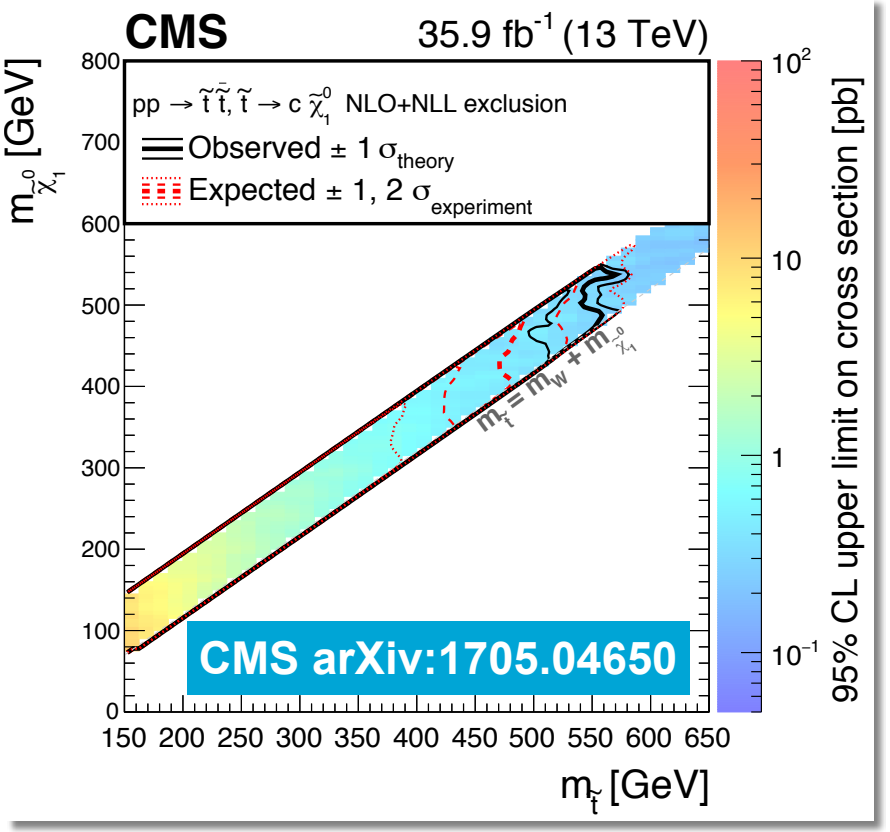
CMS Collaboration SUS-17-001



Top Squark Summary

- Direct top squark searches are fairly optimized for this particular SUSY signature and also explore 3- and 4-body decays, as well as FCNC ones



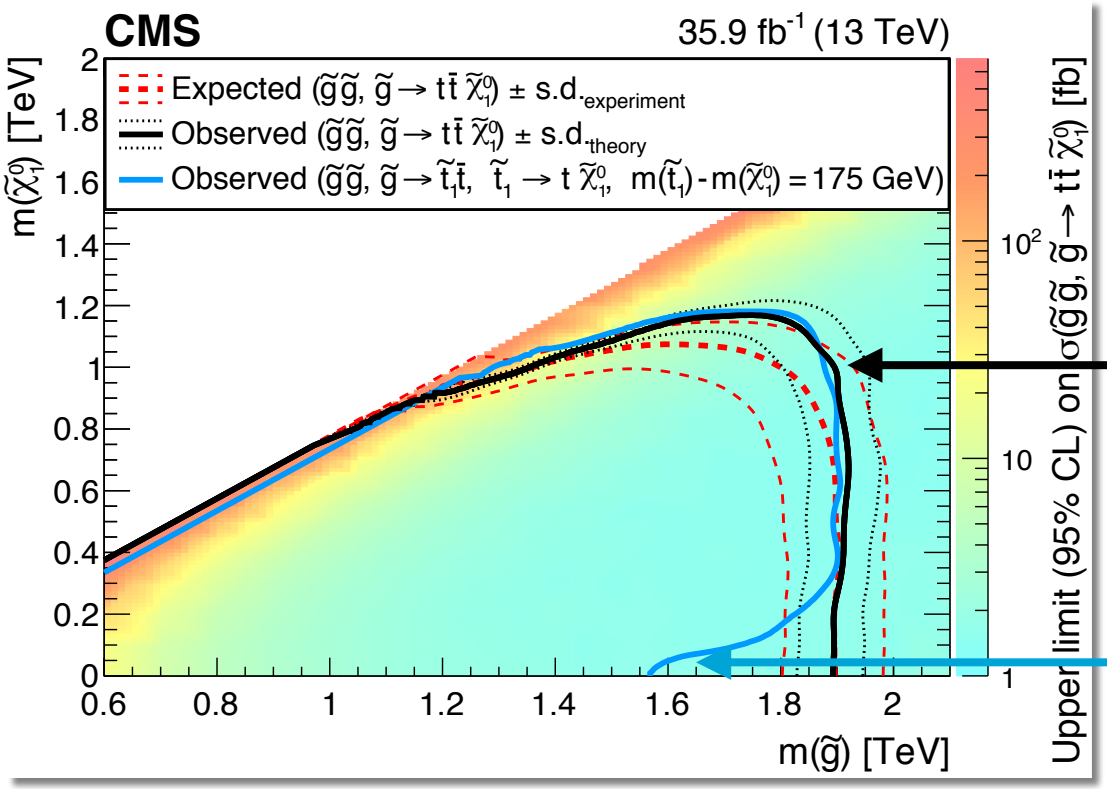


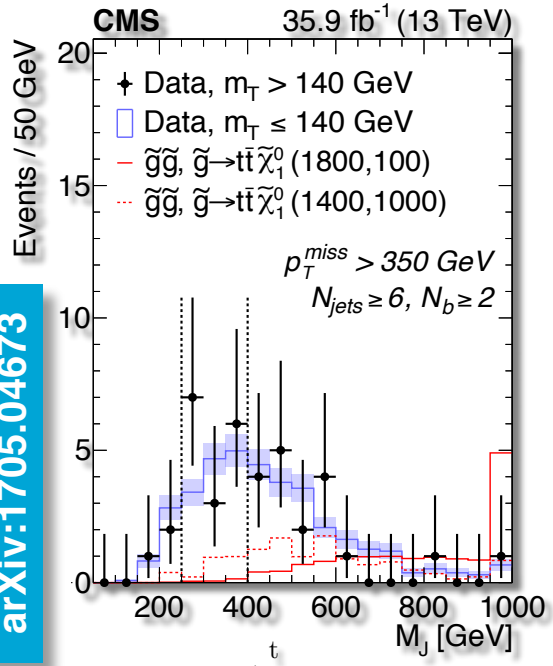
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Summer_Conferences_2017_36_fb_1


Beyond the Low-
Hanging Fruit

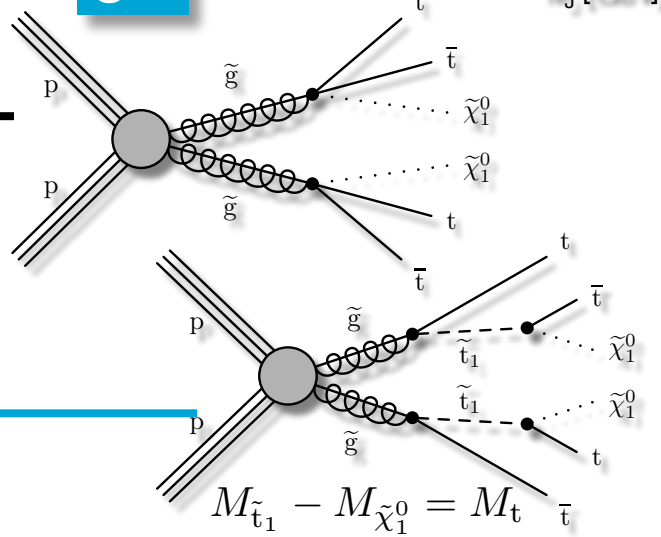
Single-Lepton Search w/ Merged Jets

- Target gluino mediated stop production using sum of large-radius jet masses, M_J
  - Highly sensitive at large gluino masses
  - Low sensitivity to stop mass, as indicated by the blue limit for compressed stop decay





CMS Collaboration arXiv:1705.04673

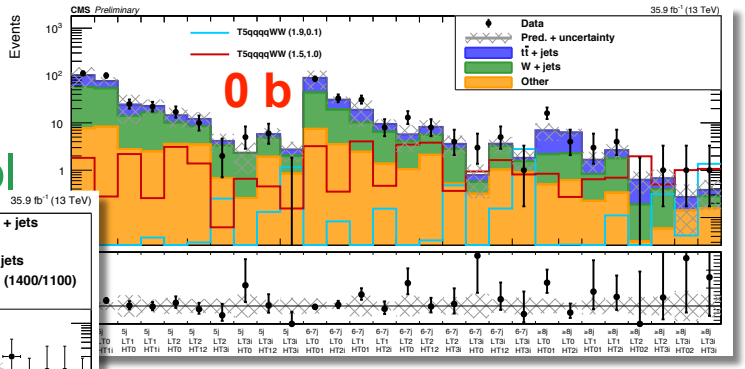


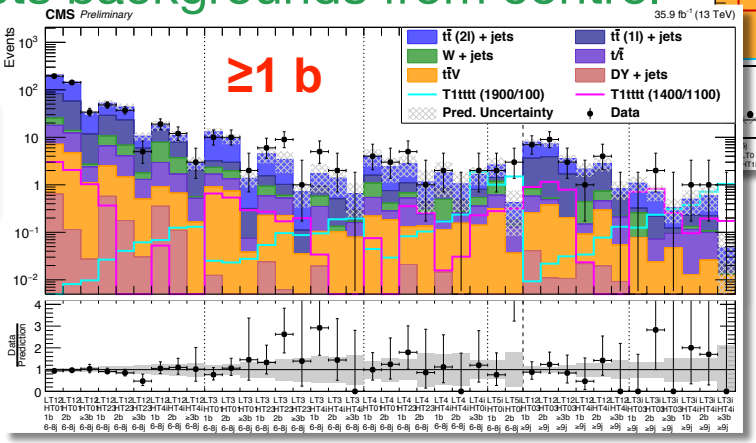
$$M_{\tilde{t}_1} - M_{\tilde{\chi}_1^0} = M_t$$

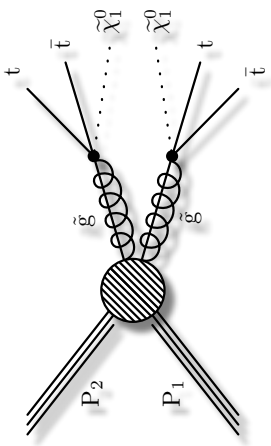
More Single-Lepton Searches

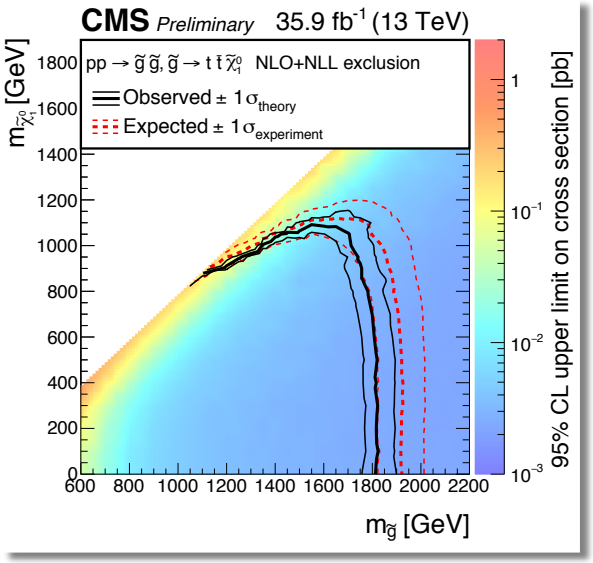
- Categorized in b-jet multiplicity (≥5 jets, no b and ≥6 jets, ≥1 b)
- Dominant tt/W+jets backgrounds from control samples in data

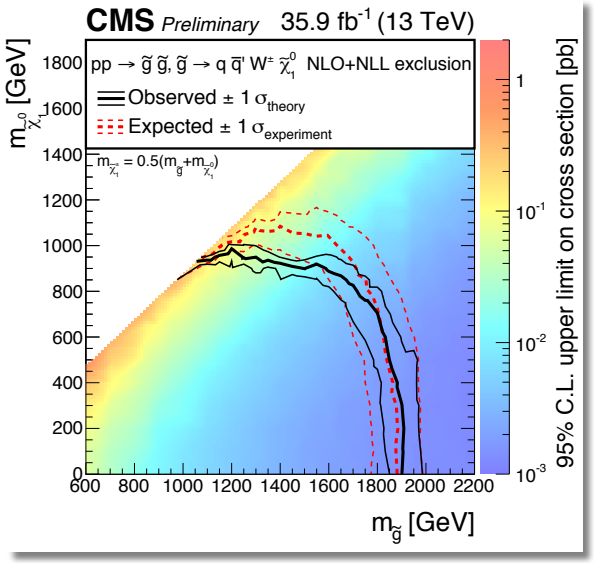
CMS Collaboration
SUS-16-042

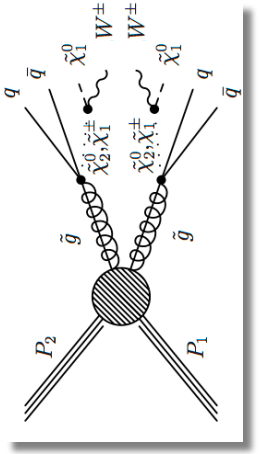






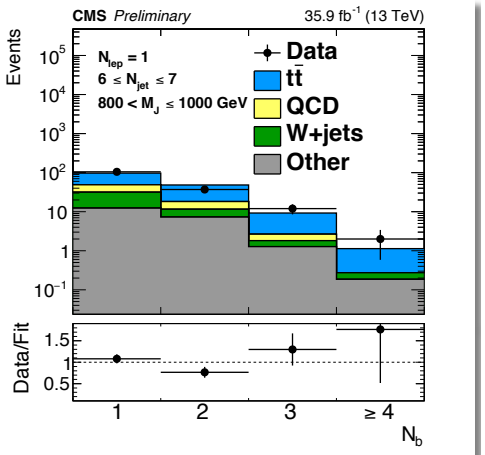


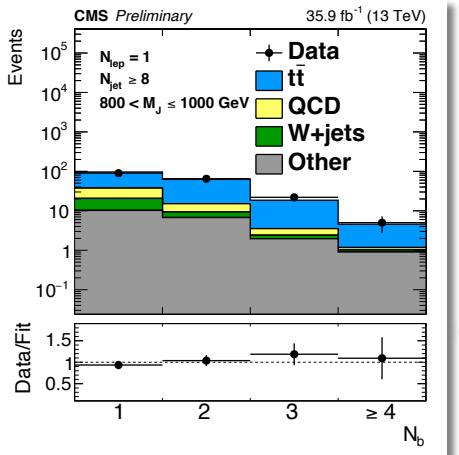


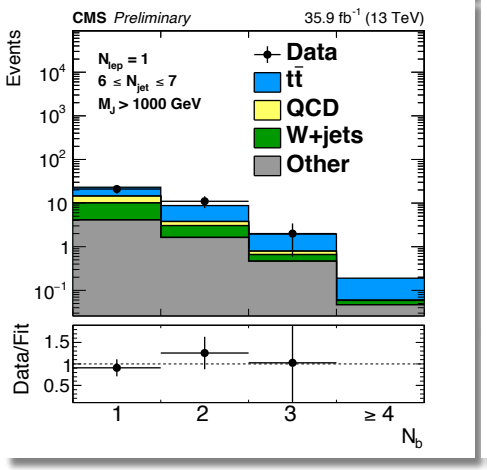


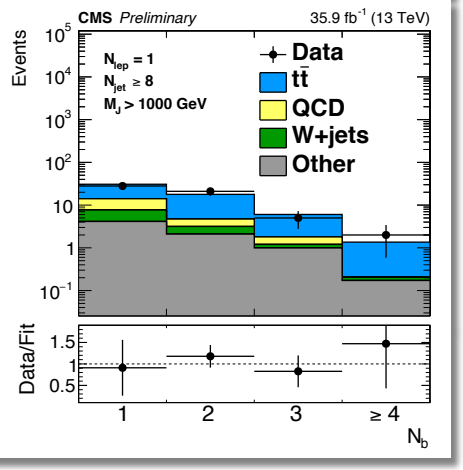
RPV SUSY w/ Single Lepton

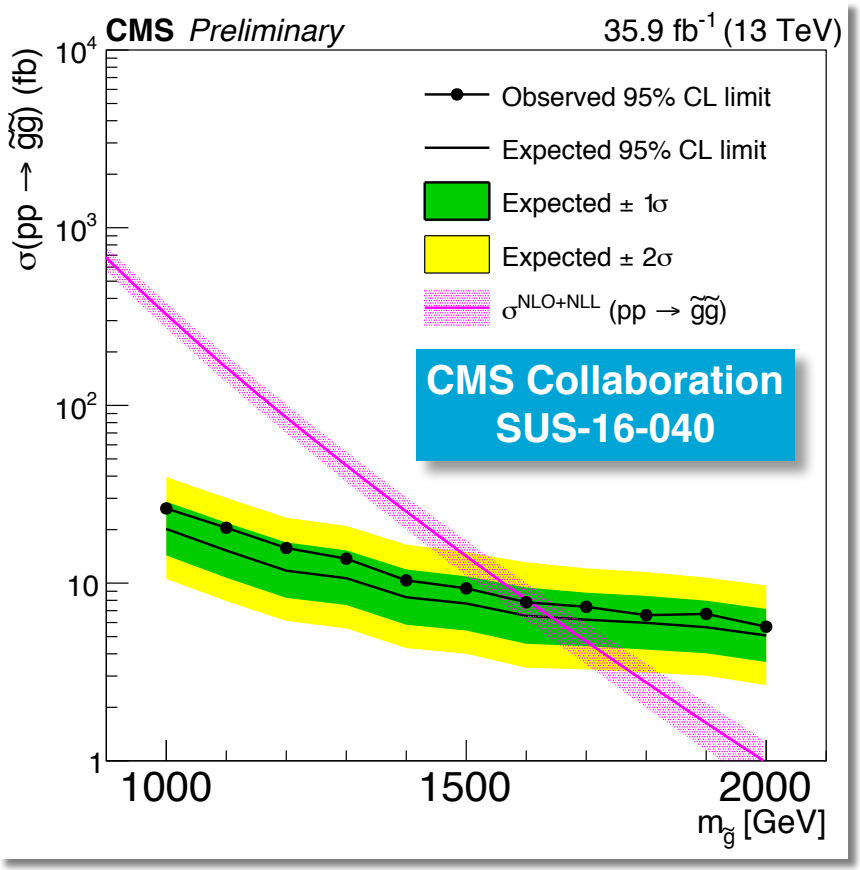
- Search for RPV gluino decay $\tilde{g} \to t\bar{\tilde{t}} \to tbs$ driven by the λ''^{332} coupling
- Also uses M_J as the sensitive variable; bins in number of (b) jets







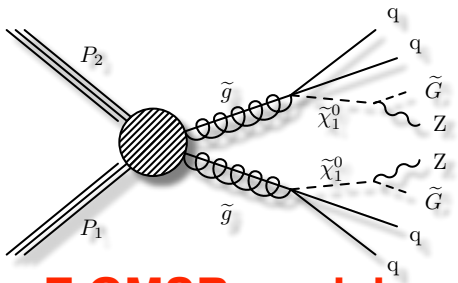




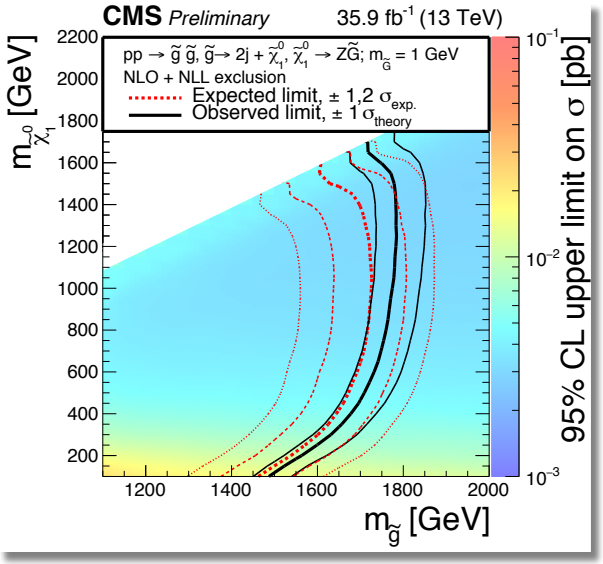
OS Dileptons

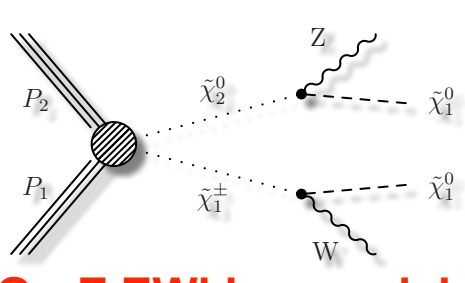
CMS Collaboration
SUS-16-034

- Classic channel where SUSY could result in an "edge" in dilepton mass
  - Some excitement from CMS Run 1 result (and ATLAS Run 1 on-Z excess)
  - Flavor-symmetric backgrounds estimated from eμ sample

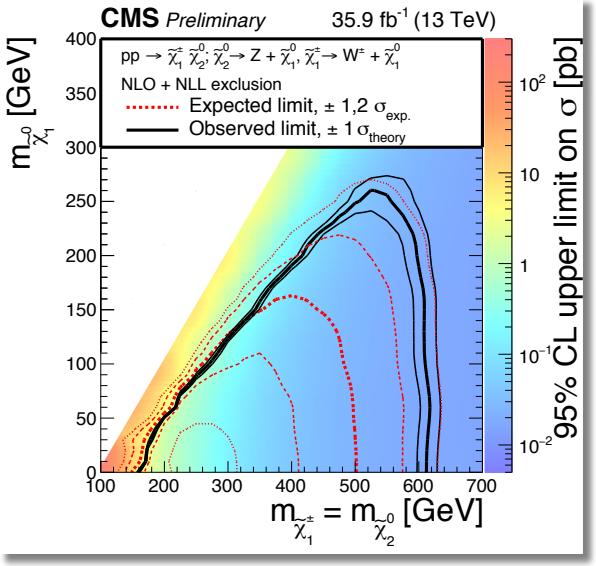


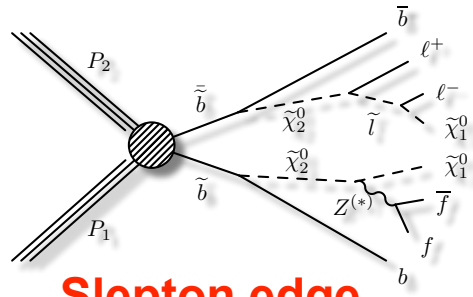
On-Z GMSB model



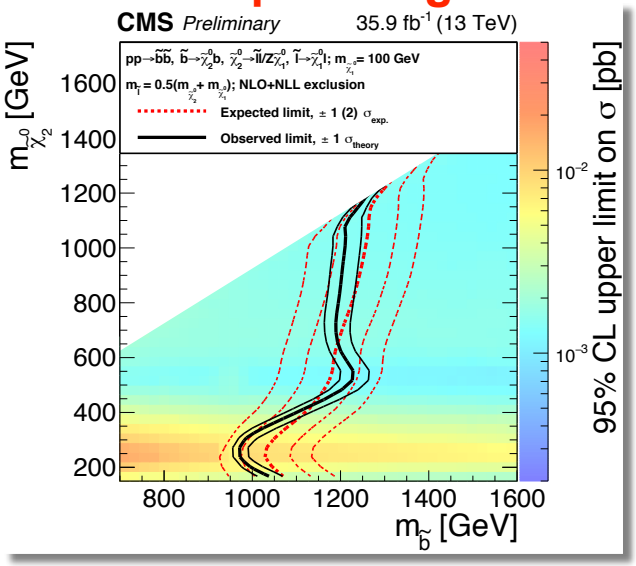


On-Z EWkino model





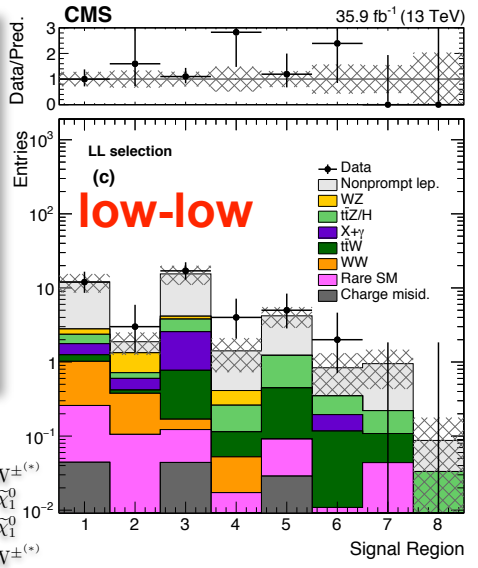
Slepton edge

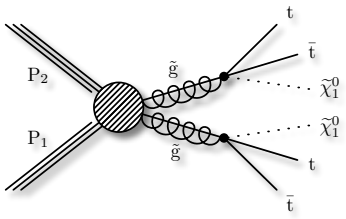


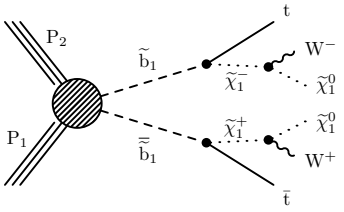
SS Dilepton Search

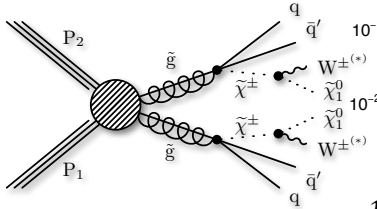
- Main background from non-prompt leptons
- Three regimes, depending on lepton p_T ($10 < p_T < 25$ GeV or >25 GeV) - high-high, high-low, low-low
- Further categorization in number of (b) jets, and H_T
- Sensitive to a number of models; a few representative ones are shown below

CMS Collaboration arXiv:1704.07323

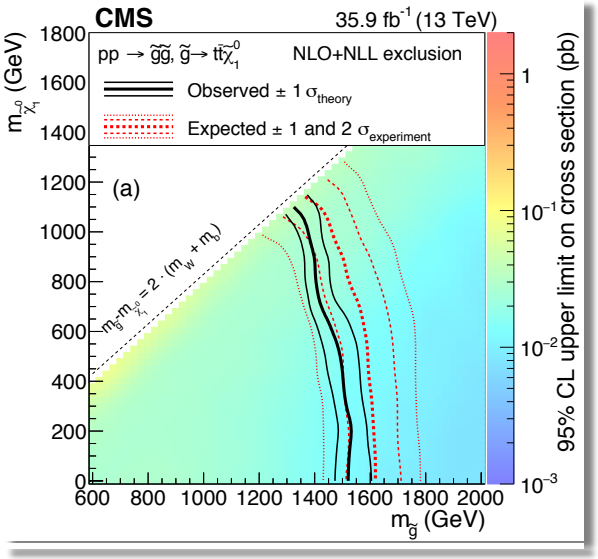


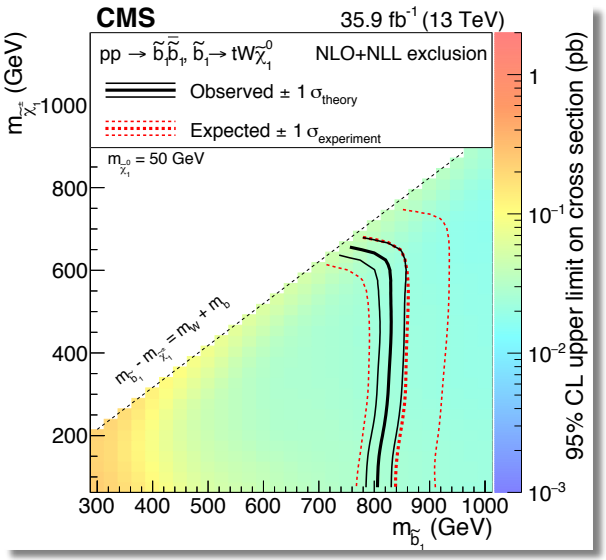


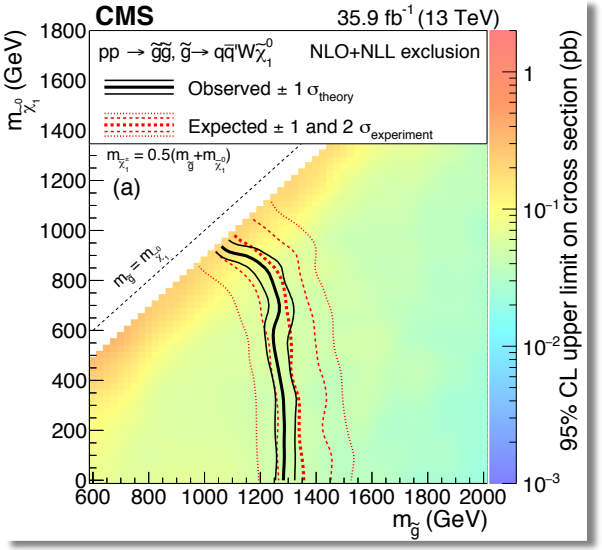




$$m_{\tilde{\chi}_1^\pm} = 0.5(m_{\tilde{g}} + m_{\tilde{\chi}^0})$$



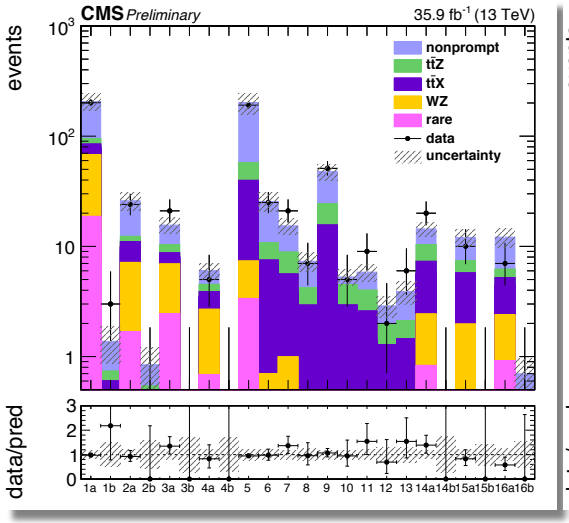


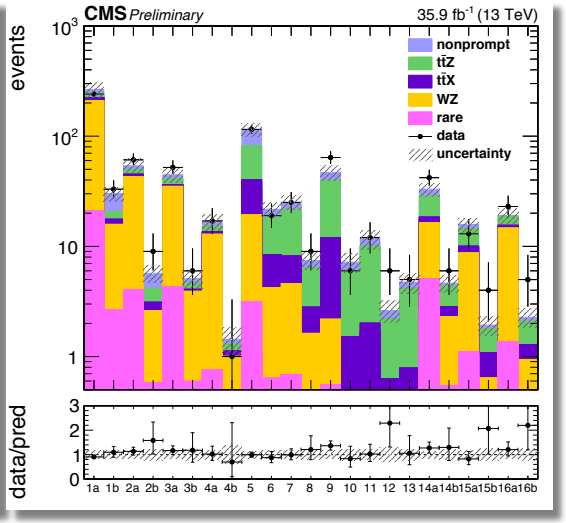


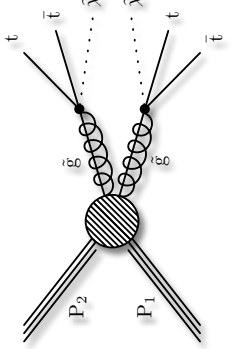
Multilepton Searches

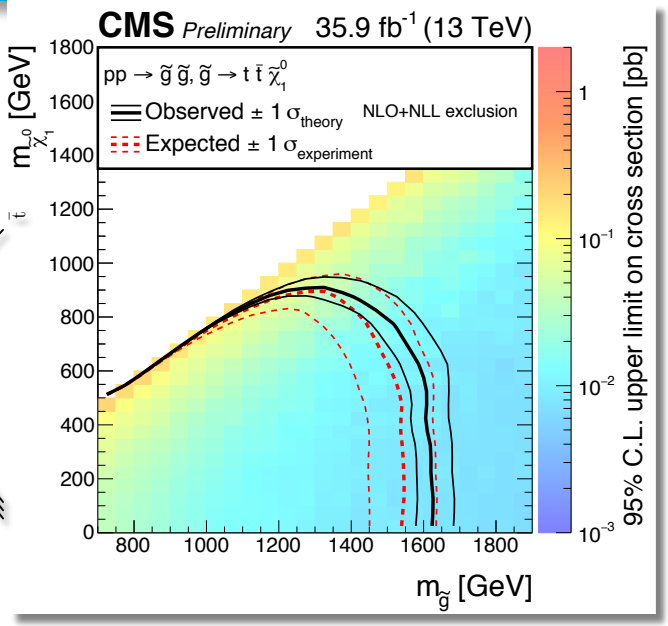
- Physics backgrounds from simulation (WZ/ZZ sample is normalized to data in a control region); misidentified-lepton backgrounds from data

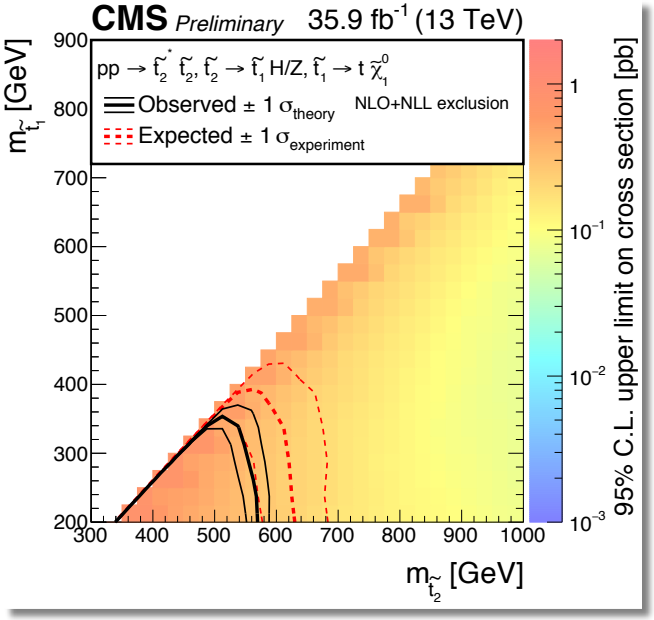
CMS Collaboration
SUS-16-041

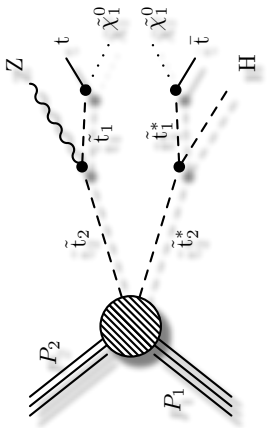






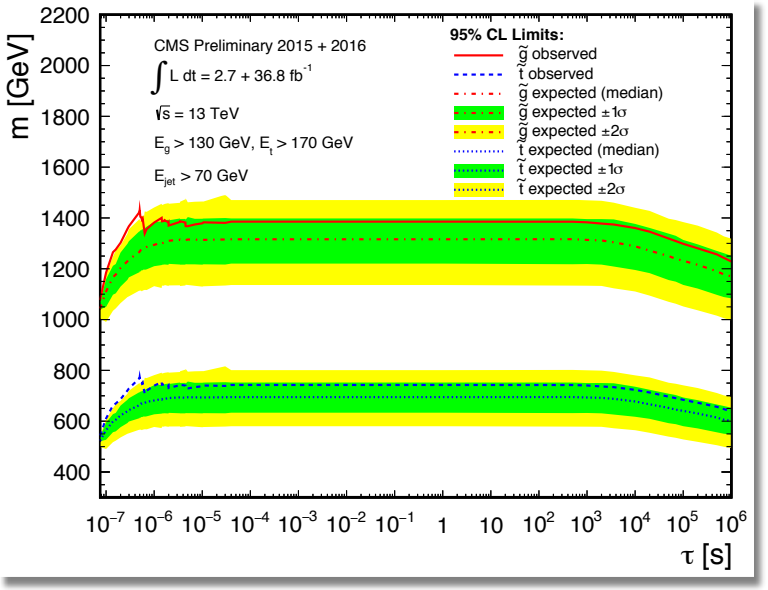




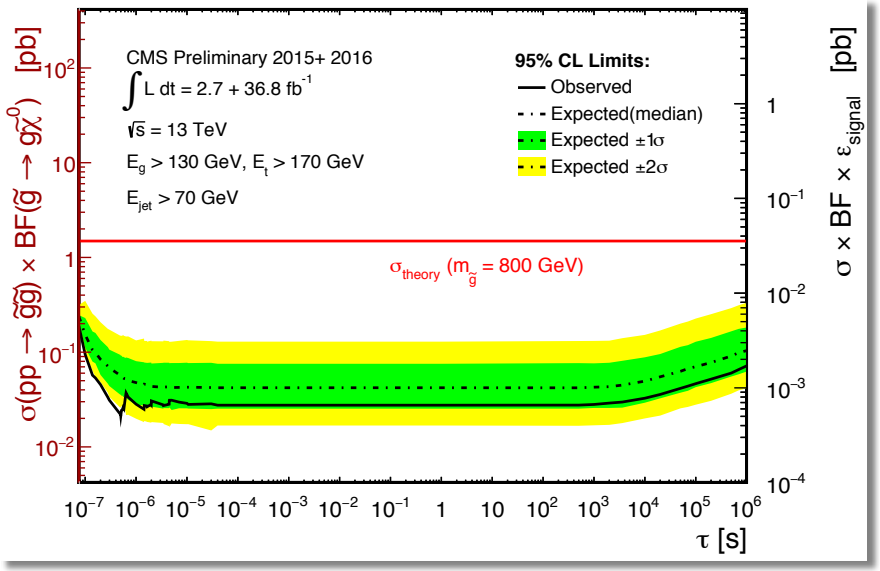


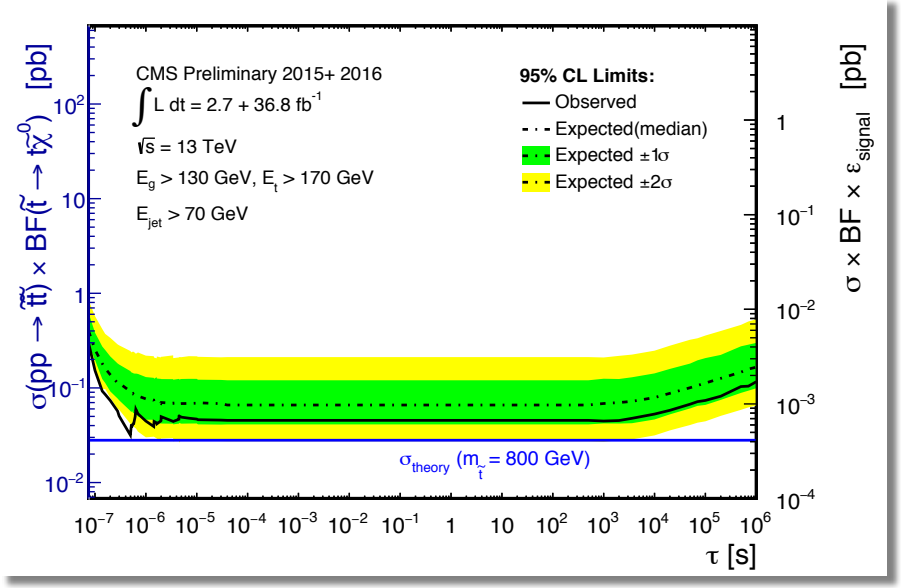
Search for Stopped Particles

- Search for long-lived gluinos and top squarks stopped in the detector and decaying out of sync with beam crossings in the CMS calorimeters
- Sensitive to 13 orders of magnitude in lifetime



CMS PAS EXO-16-004



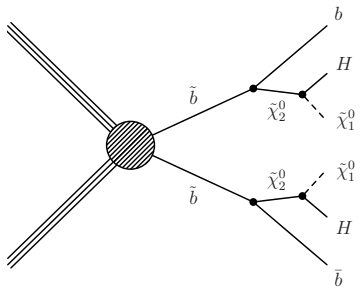


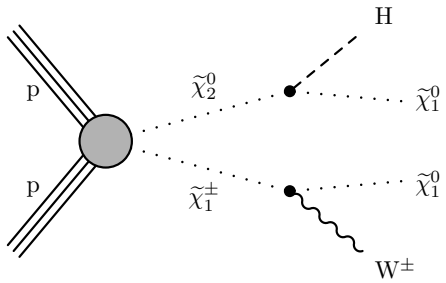
Clean-Shaved Higgs

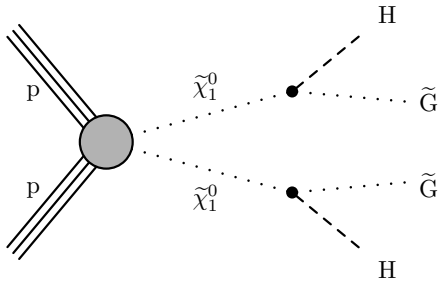
- New search for Higgs bosons in SUSY decay chains using Razor variables
  - Exploring clean H(γγ) decay mode for one of the Higgs bosons

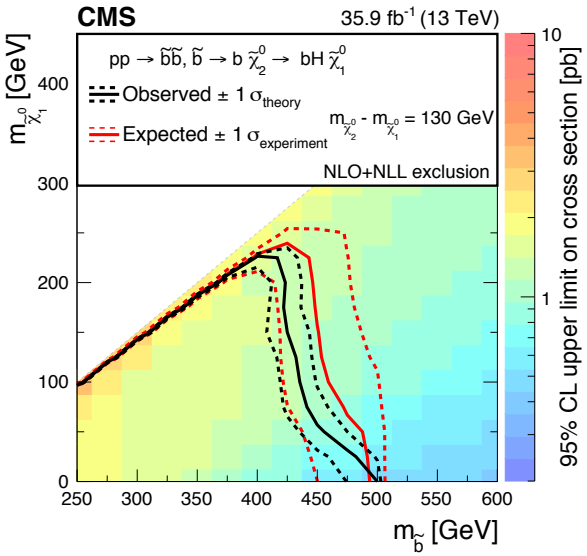
$$M_R \equiv \sqrt{(|\vec{p}^{j_1}| + |\vec{p}^{j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2},$$

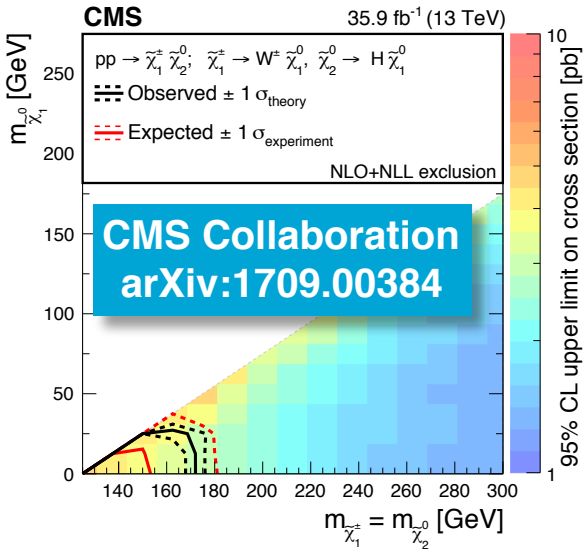
$$R^2 \equiv \left(\frac{M_T^R}{M_R}\right)^2,$$

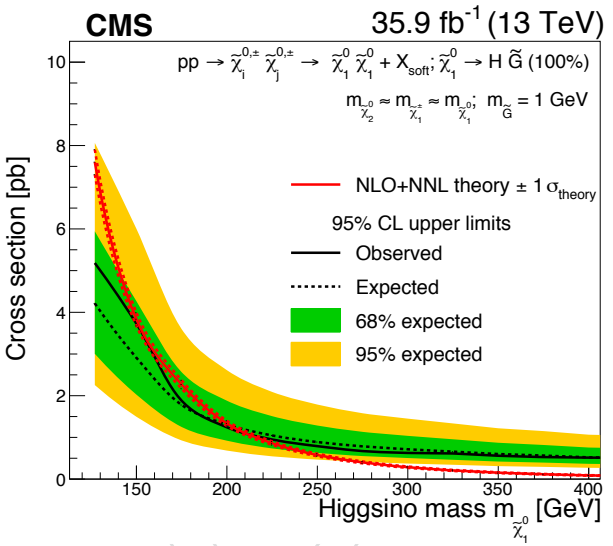












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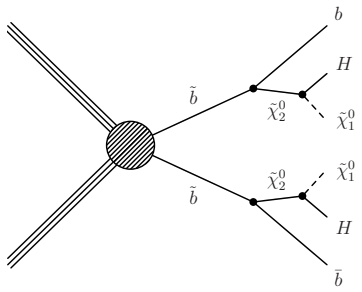
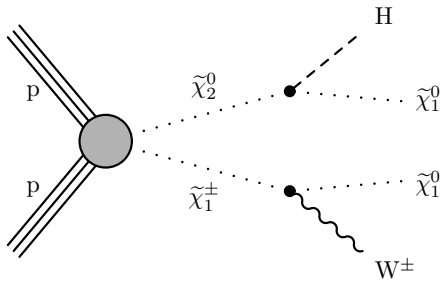
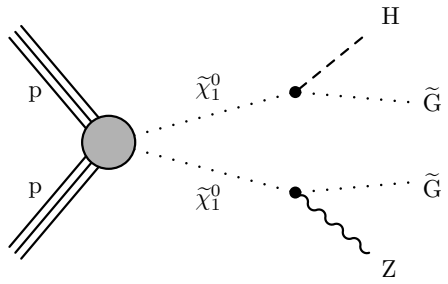
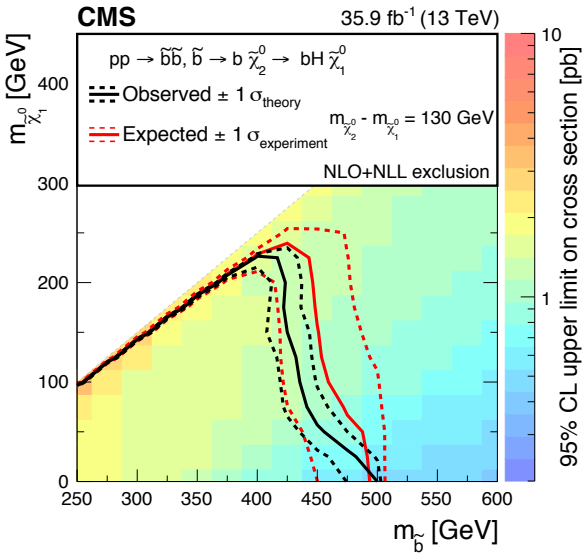
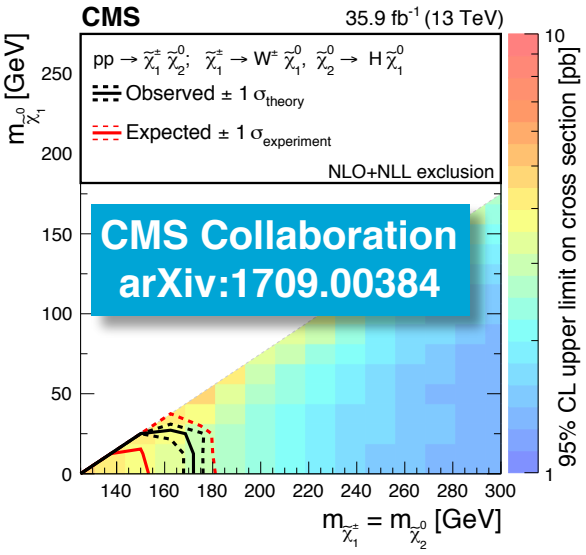
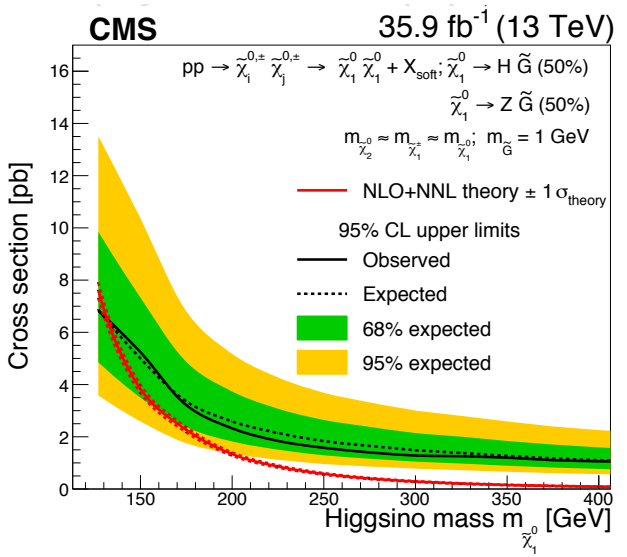












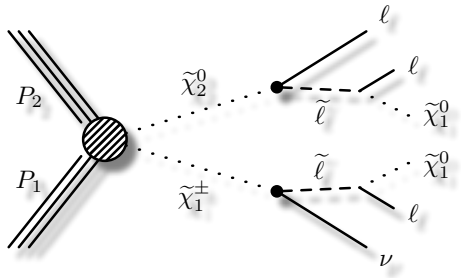

Weak
SUSY

EW Production: Multileptons

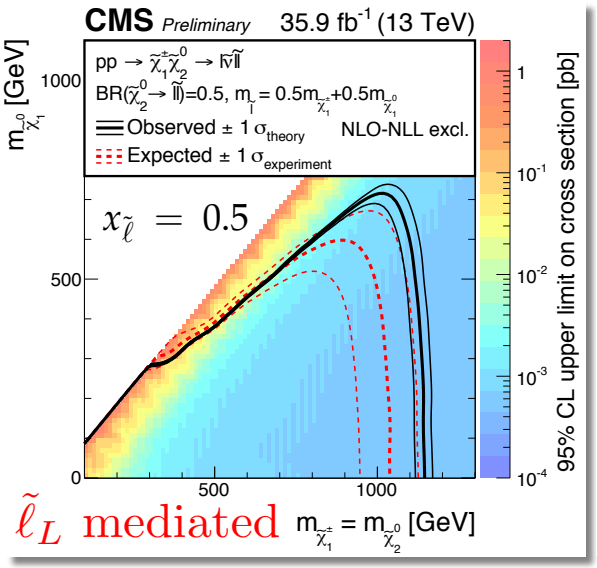
- Analysis uses SS dileptons (e, μ), trileptons (e, μ, up to two τ_h), and ≥4 leptons (e, μ, up to τ_h)
- Low backgrounds, mainly from simulation, WZ normalized to control sample
- Several signal scenarios considered

CMS Collaboration
SUS-16-039

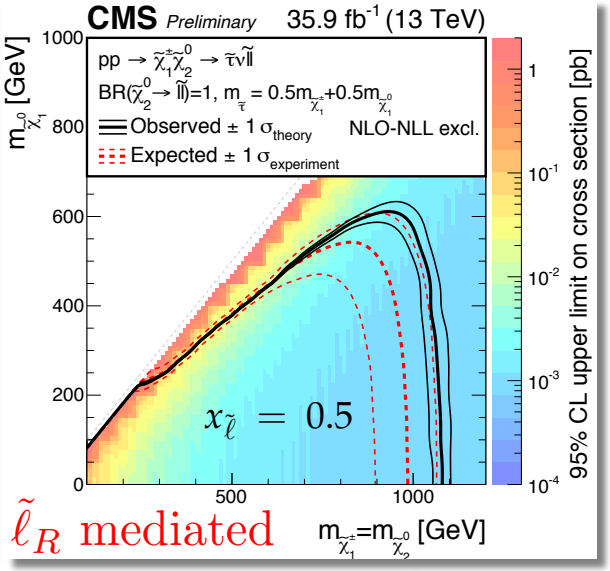
$$m_{\tilde{\ell}} = m_{\tilde{\nu}} = m_{\tilde{\chi}_1^0} + x_{\tilde{\ell}}\left(m_{\tilde{\chi}} - m_{\tilde{\chi}_1^0}\right)$$



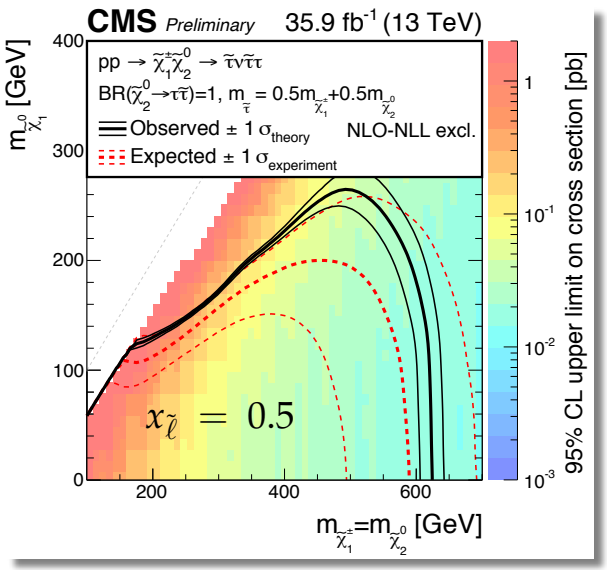
Slepton-mediated decays



Tau-enriched decays

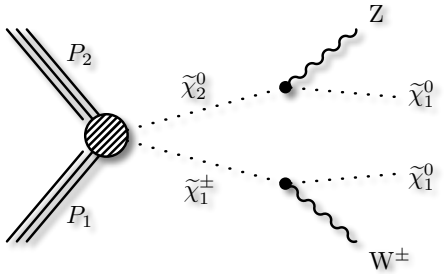


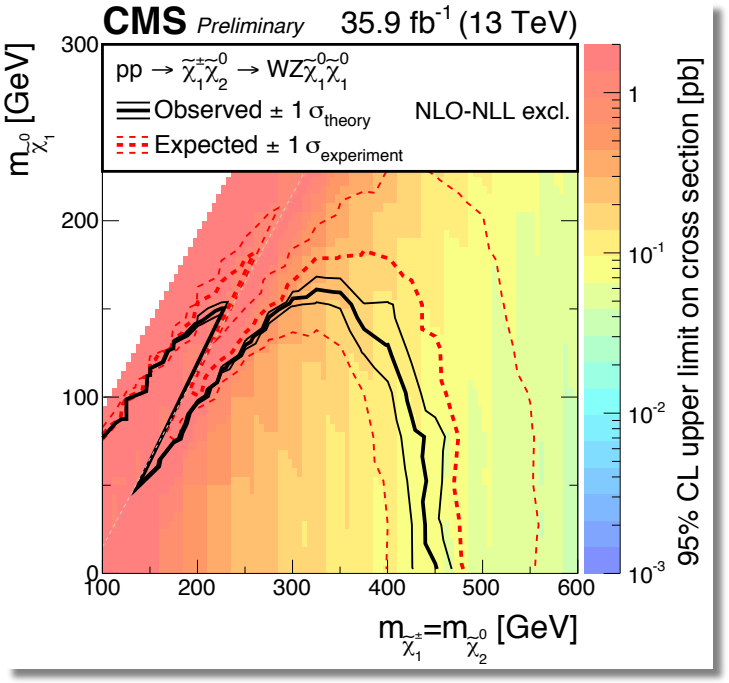
Stau-mediated decays

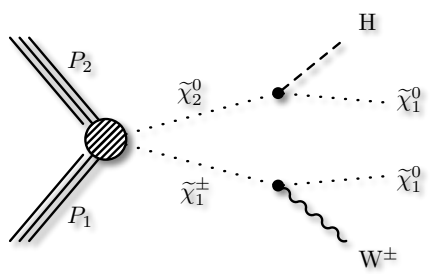


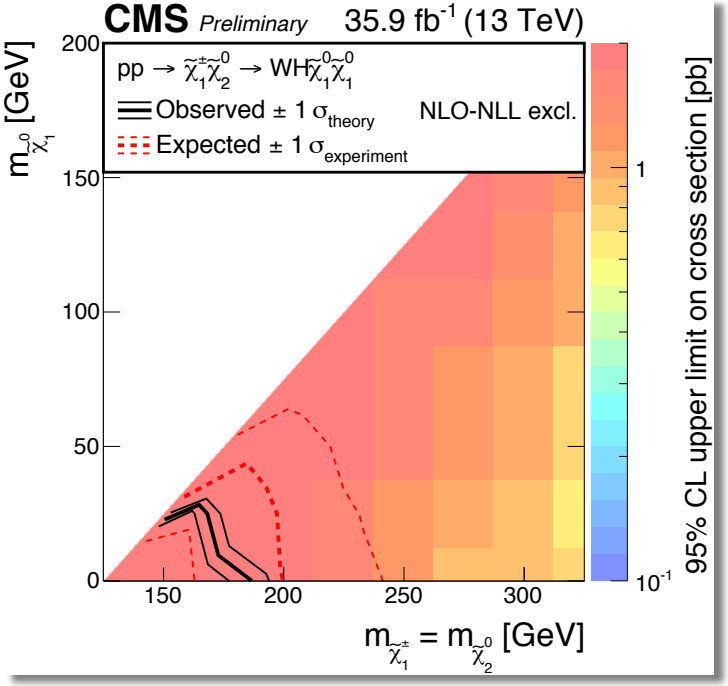
Multileptons (cont'd)

- Direct decays (with on shell or off-shell bosons)









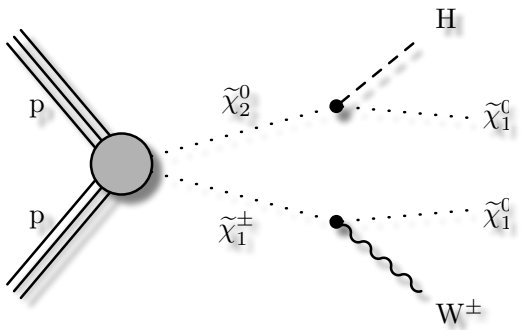
CMS Collaboration SUS-16-039

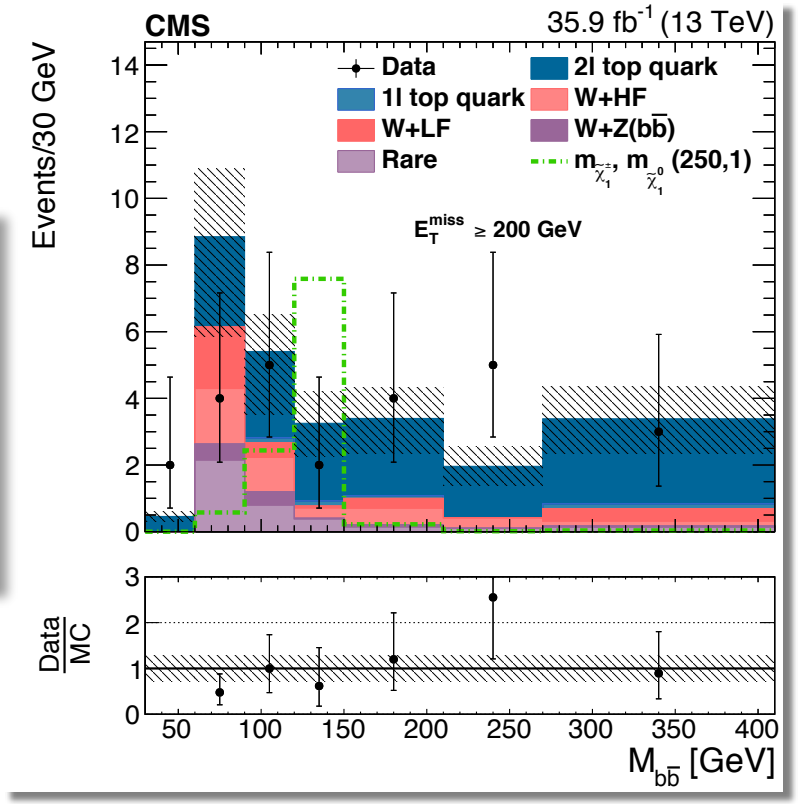
~200 GeV improvement over Run 1 limits

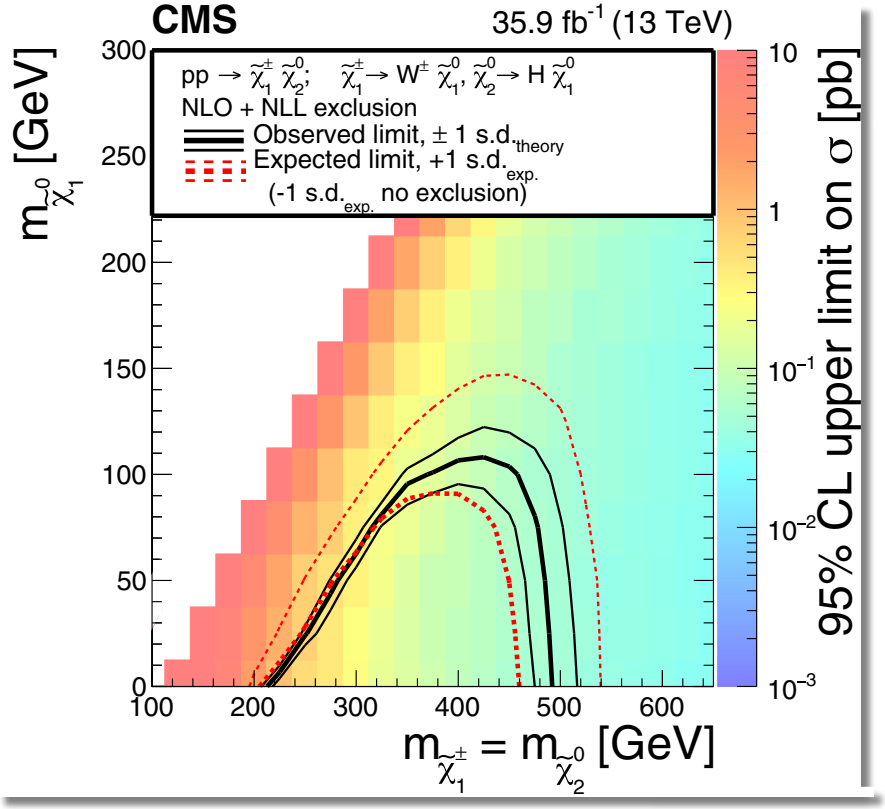
about the same as Run 1 limits

EWkinos via WH(bb)

- Looking for a mass peak in the bb mass spectrum after additional requirements on ME_T, M_T, M_{CT}
- Significant improvement relative to Run 1 results (~250 GeV in chargino mass)



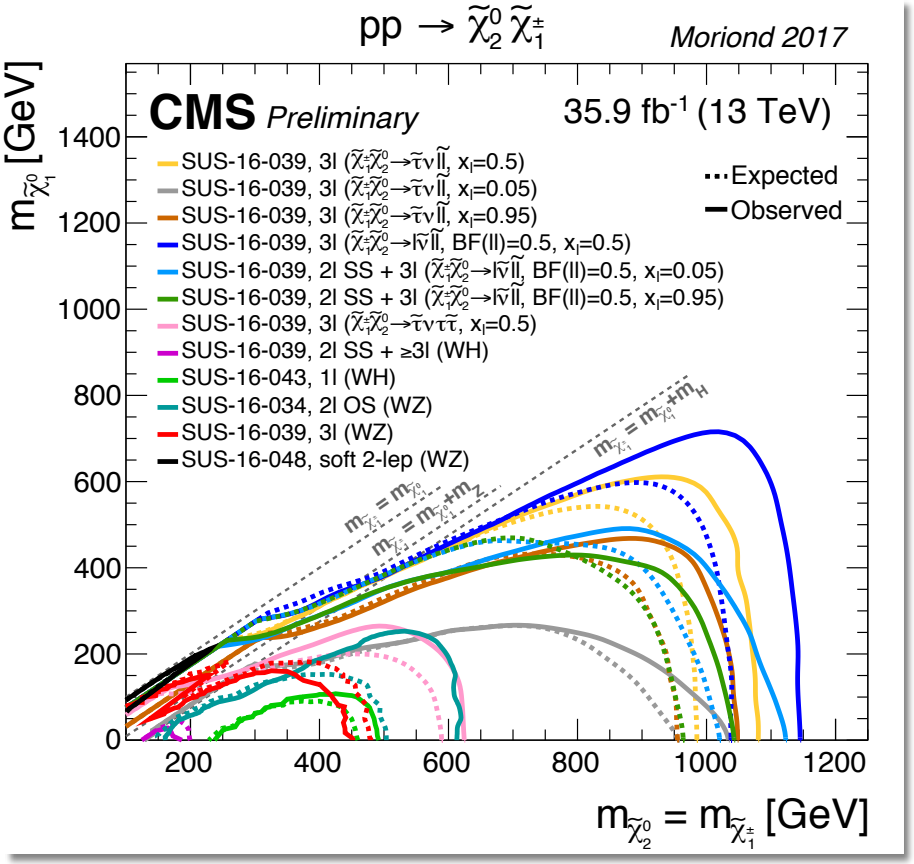




CMS Collaboration arXiv:1706.09933

SUSY: Electroweak Production

- Variety of channels and signatures, including the decays via WZ/WH



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Summer_Conferences_2017_36_fb_1

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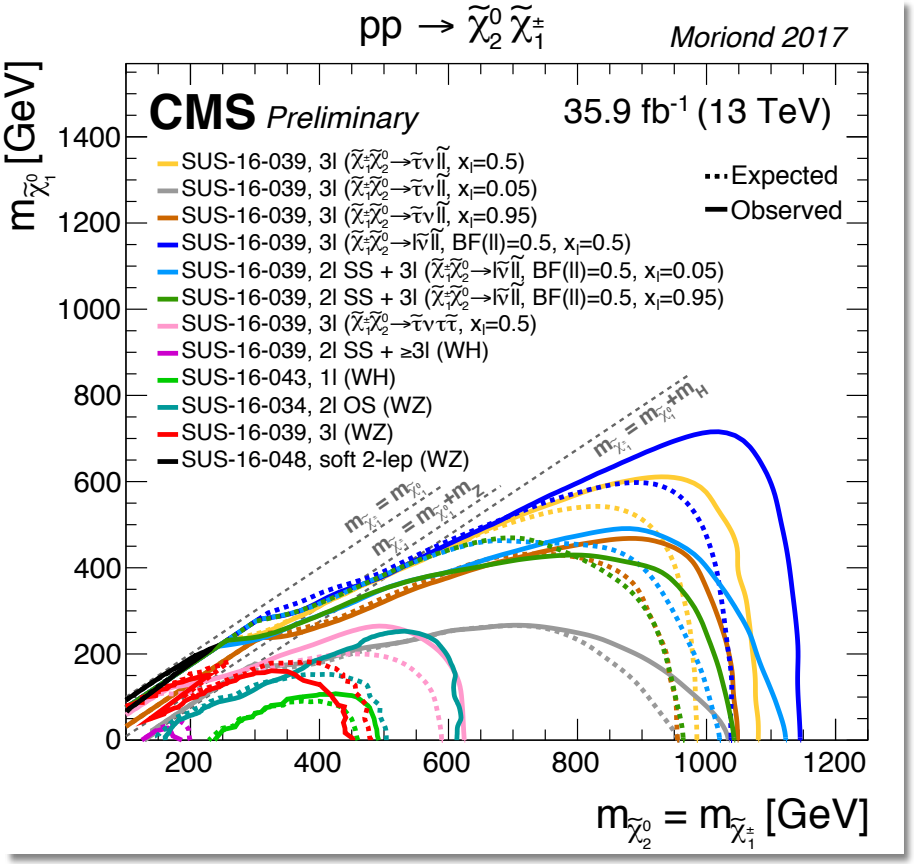

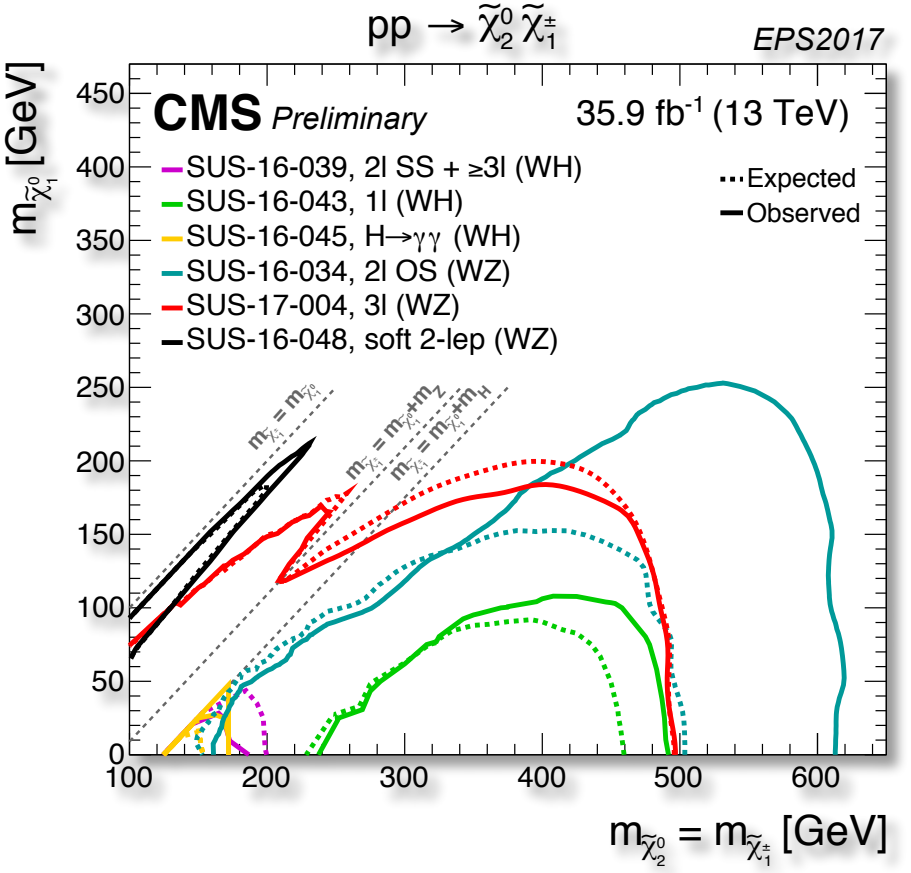

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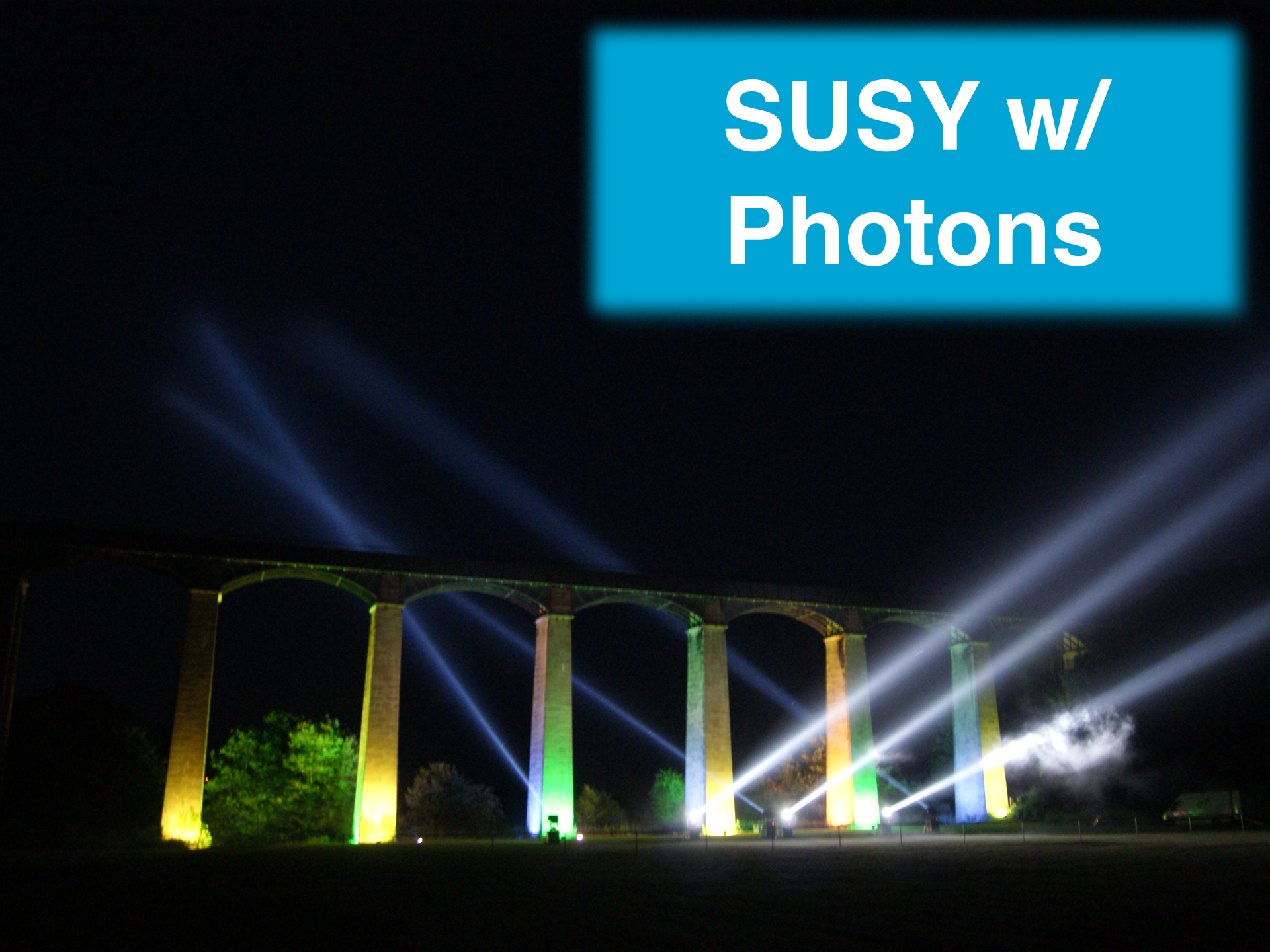
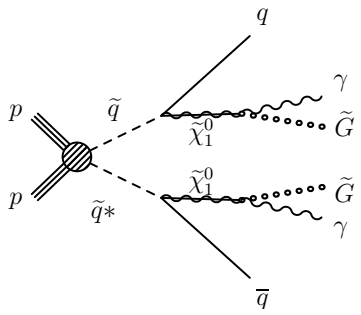
SUSY w/ Photons

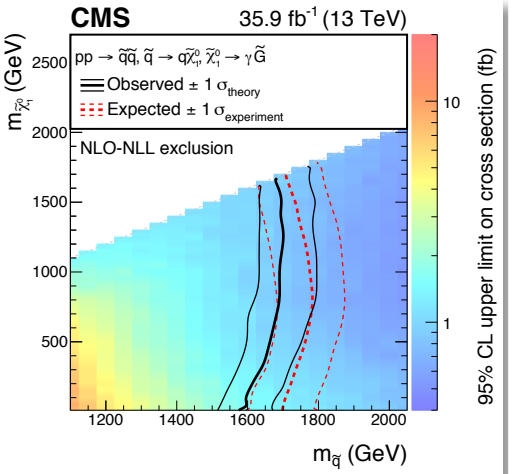


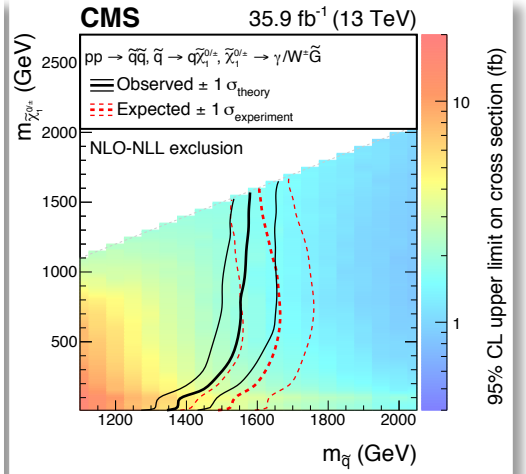
Search for Strong GMSB SUSY

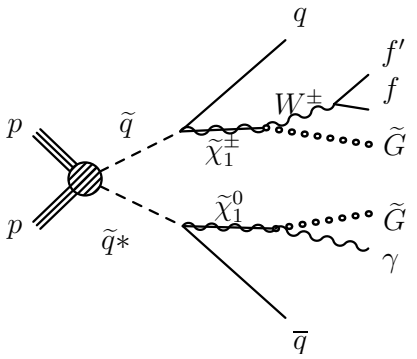
- One or two photons, (b) jets, leptons, and ME_T in the final state
- S_T^{γ} as a sensitive variable: $ME_T + \Sigma p_T^{\gamma}$

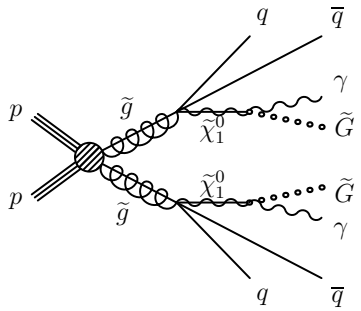
CMS Collaboration
arXiv:1707.06193

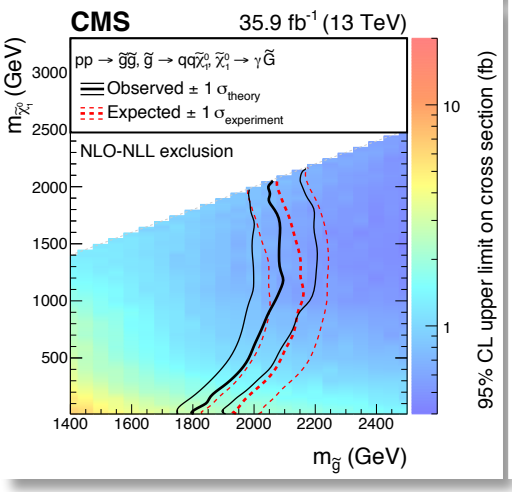


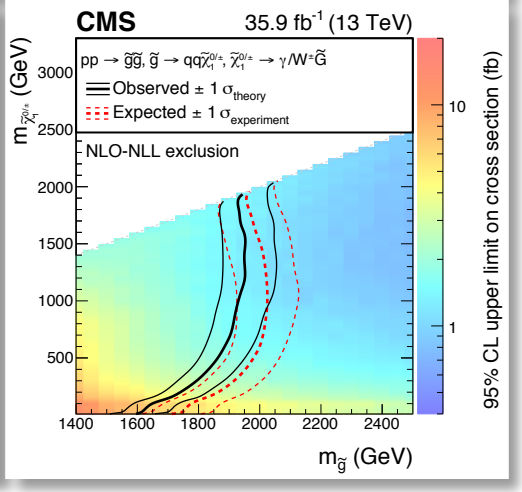


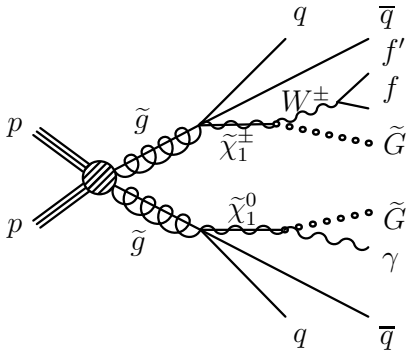












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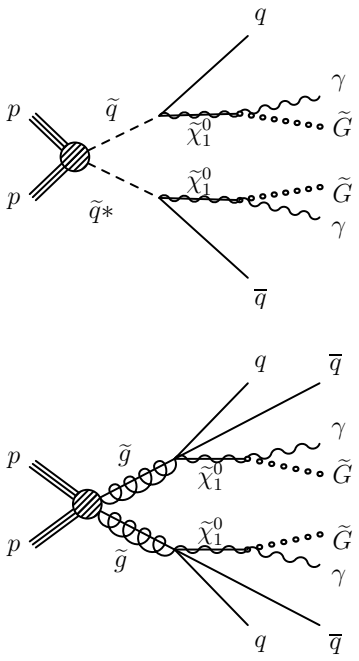
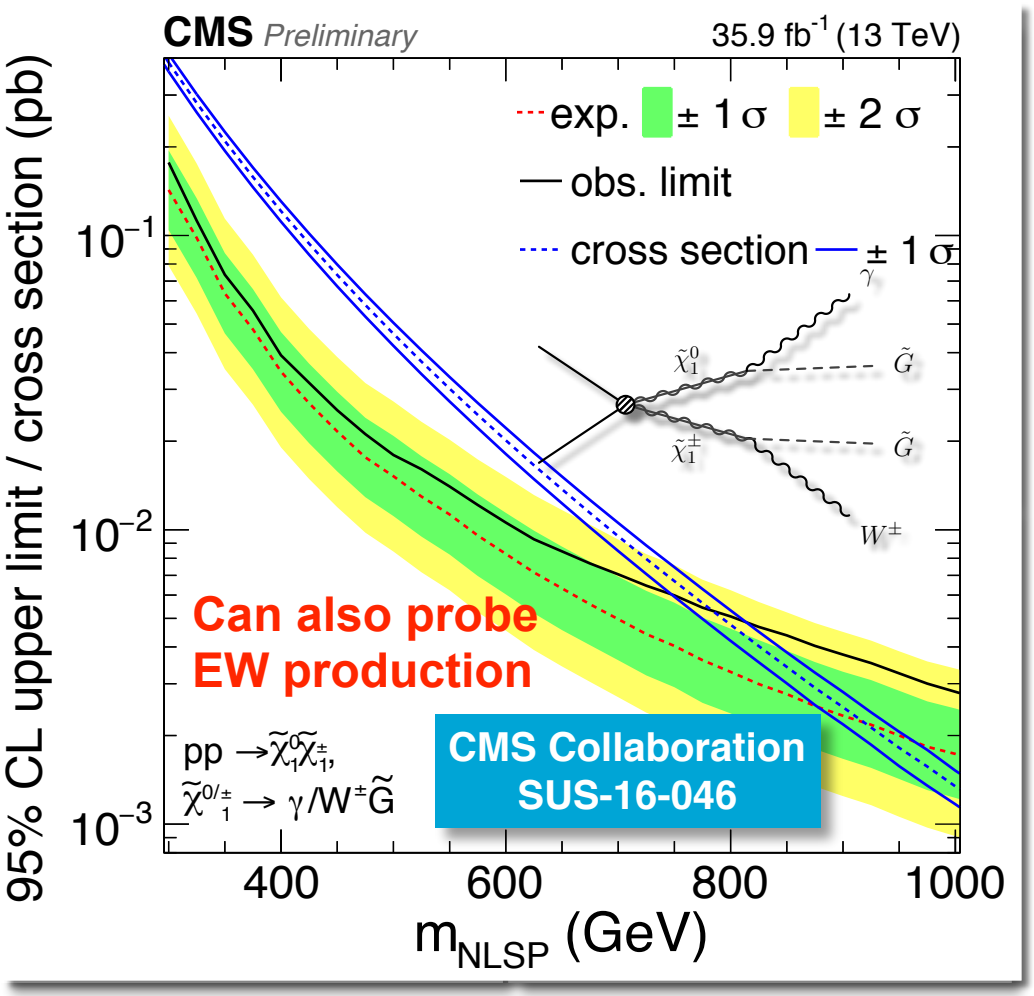
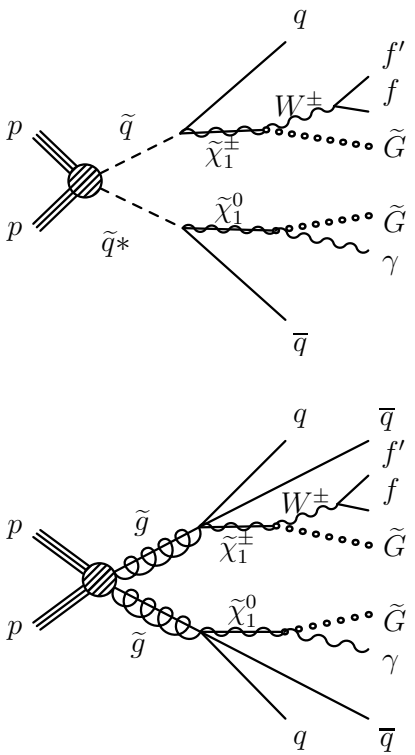




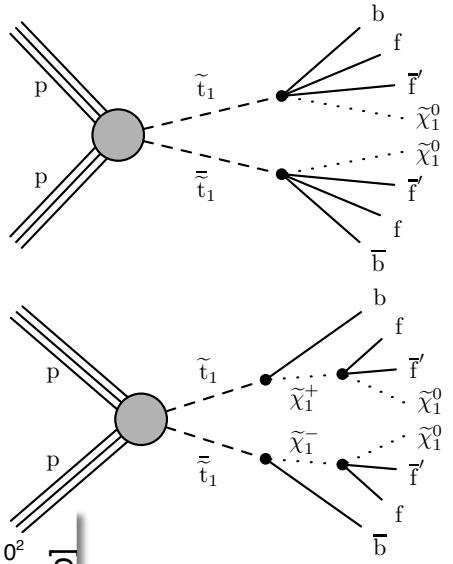
CMS Collaboration
arXiv:1707.06193

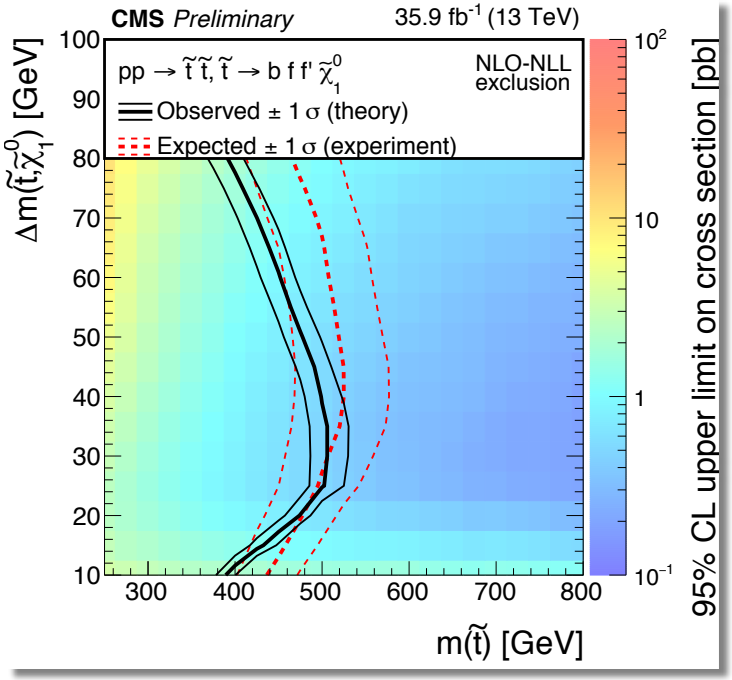


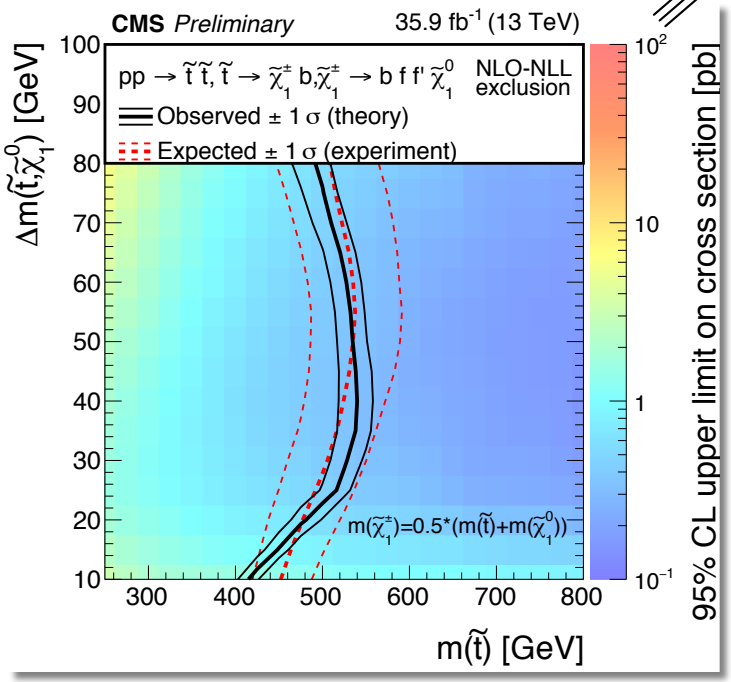

Compressed
SUSY

Search for 4-body Stop Decays

- For small mass splittings between stop and neutralino, expect 4-body decays via virtual chargino and W boson
- Require at least one soft lepton ($30 > p_T > 3.5$-5 GeV) and a hard ISR jet to aid the efficiency and triggering
- Background is dominated by diboson and W+jets production and determined using control regions in data
- Also sensitive to chargino-mediated stop decays



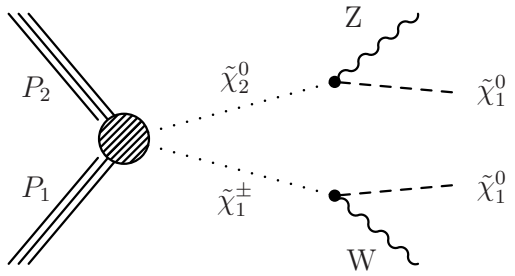


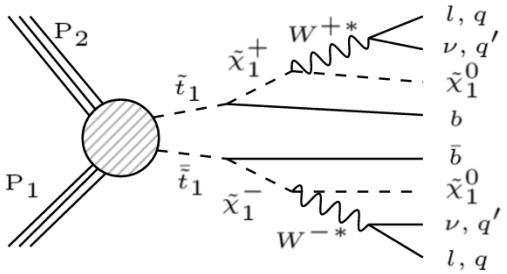


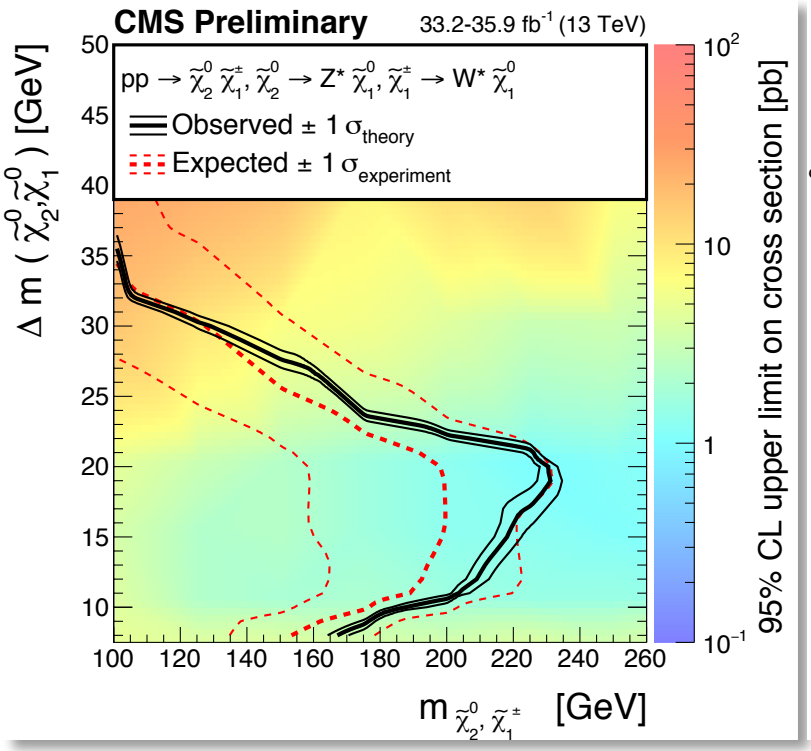
CMS Collaboration SUS-16-052

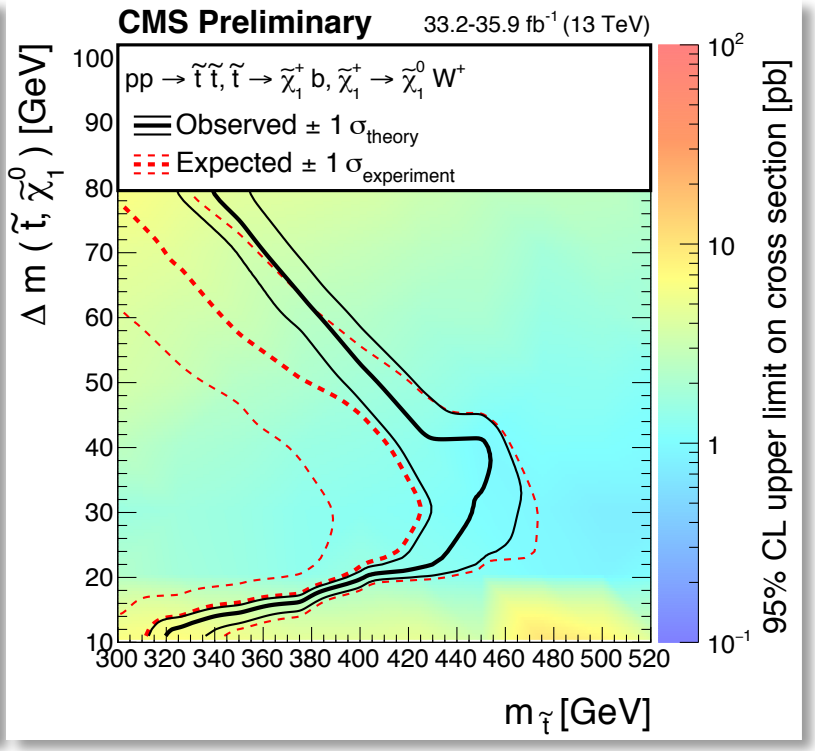
Soft OS Dilepton Search

- Could also require 2 OS dileptons ($5 < p_T < 30$ GeV) via dedicated trigger
- Sensitive to EW SUSY and direct stop production in small mass splitting scenarios









CMS Collaboration
SUS-16-048

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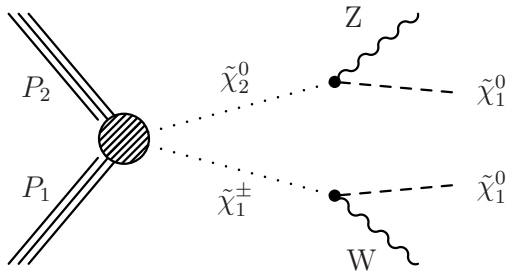

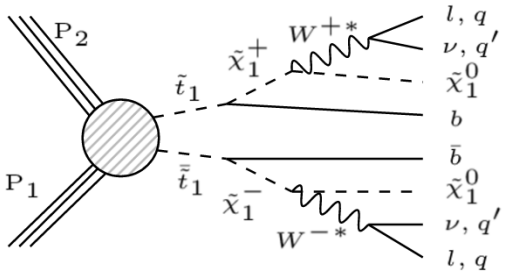

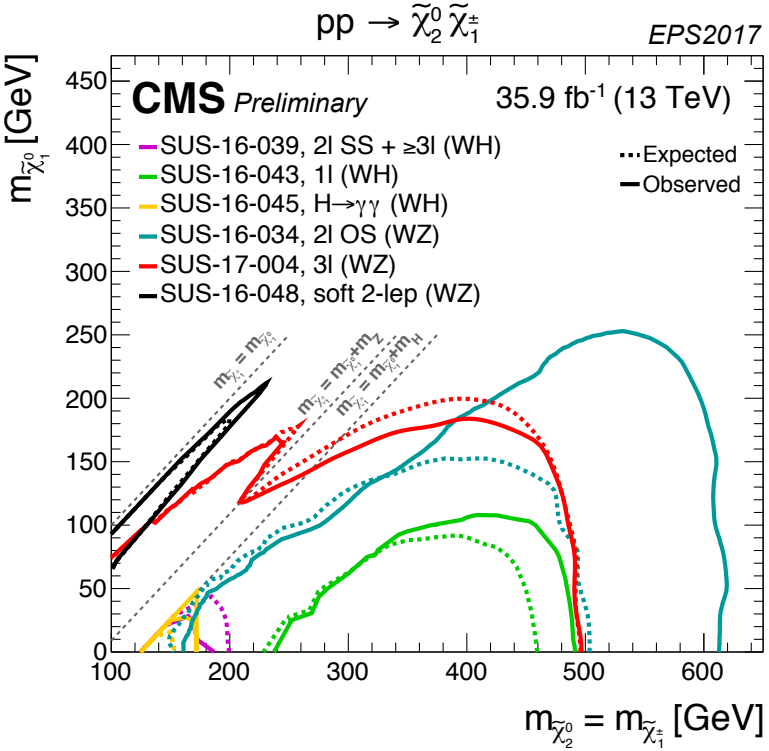

CMS Collaboration
SUS-16-048

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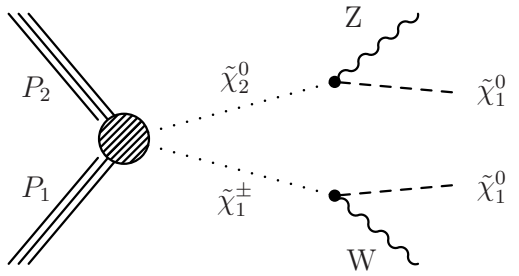
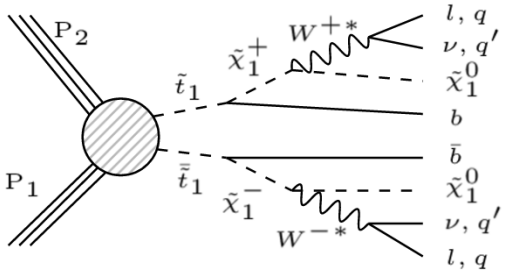
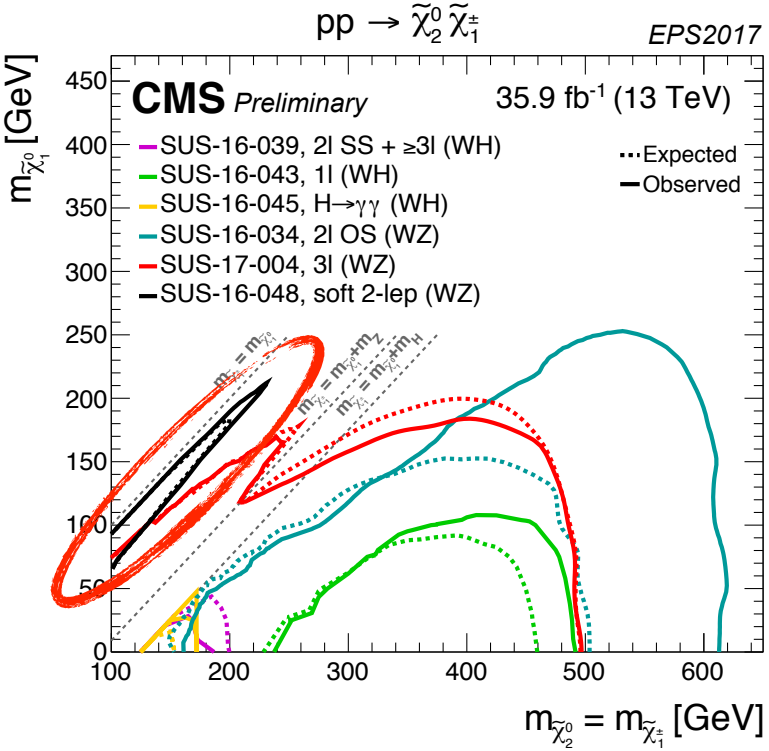


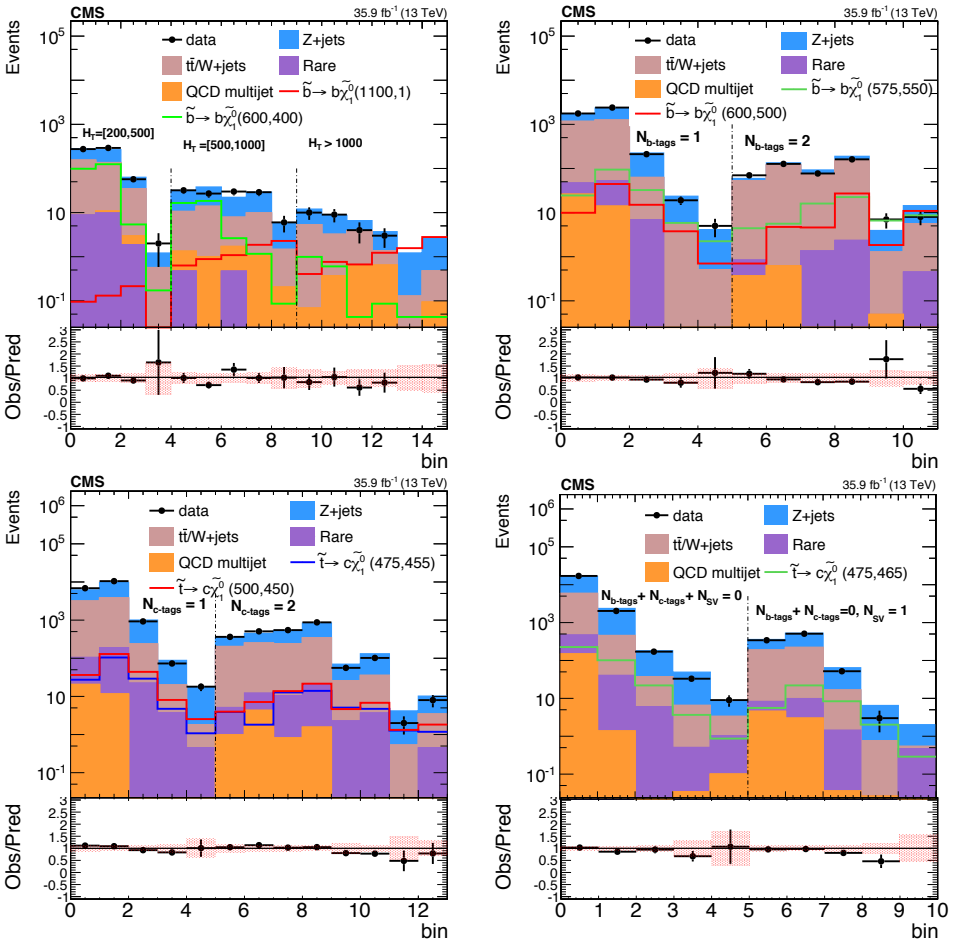




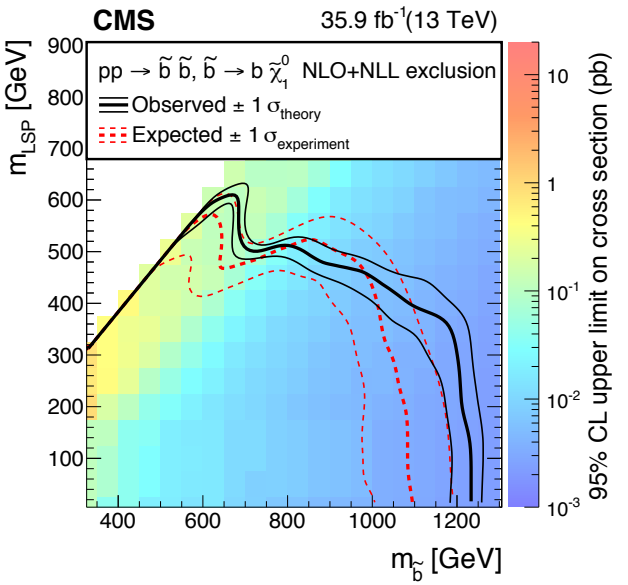
CMS Collaboration
SUS-16-048

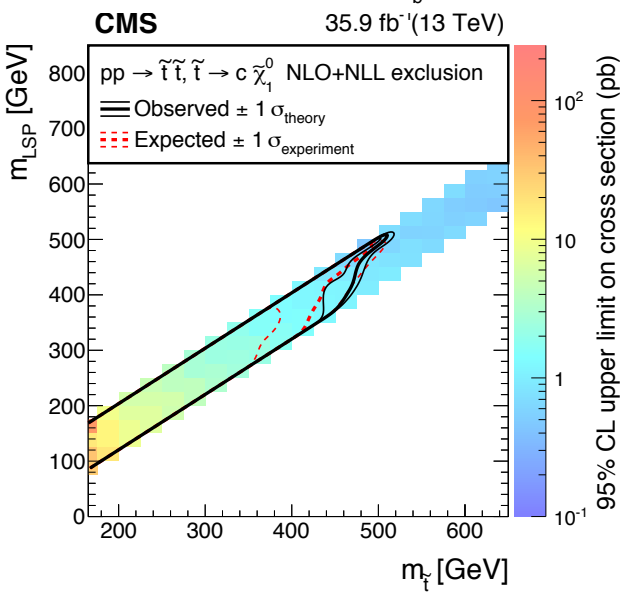
Compressed Stop/Sbottom Search

- Dedicated all-hadronic analysis with charm tagging and the use of M_{CT} variable: $M^2_{CT}(j_1, j_2) = 2p_T(j_1)p_T(j_2)(1 + \cos\Delta\phi(j_1, j_2))$



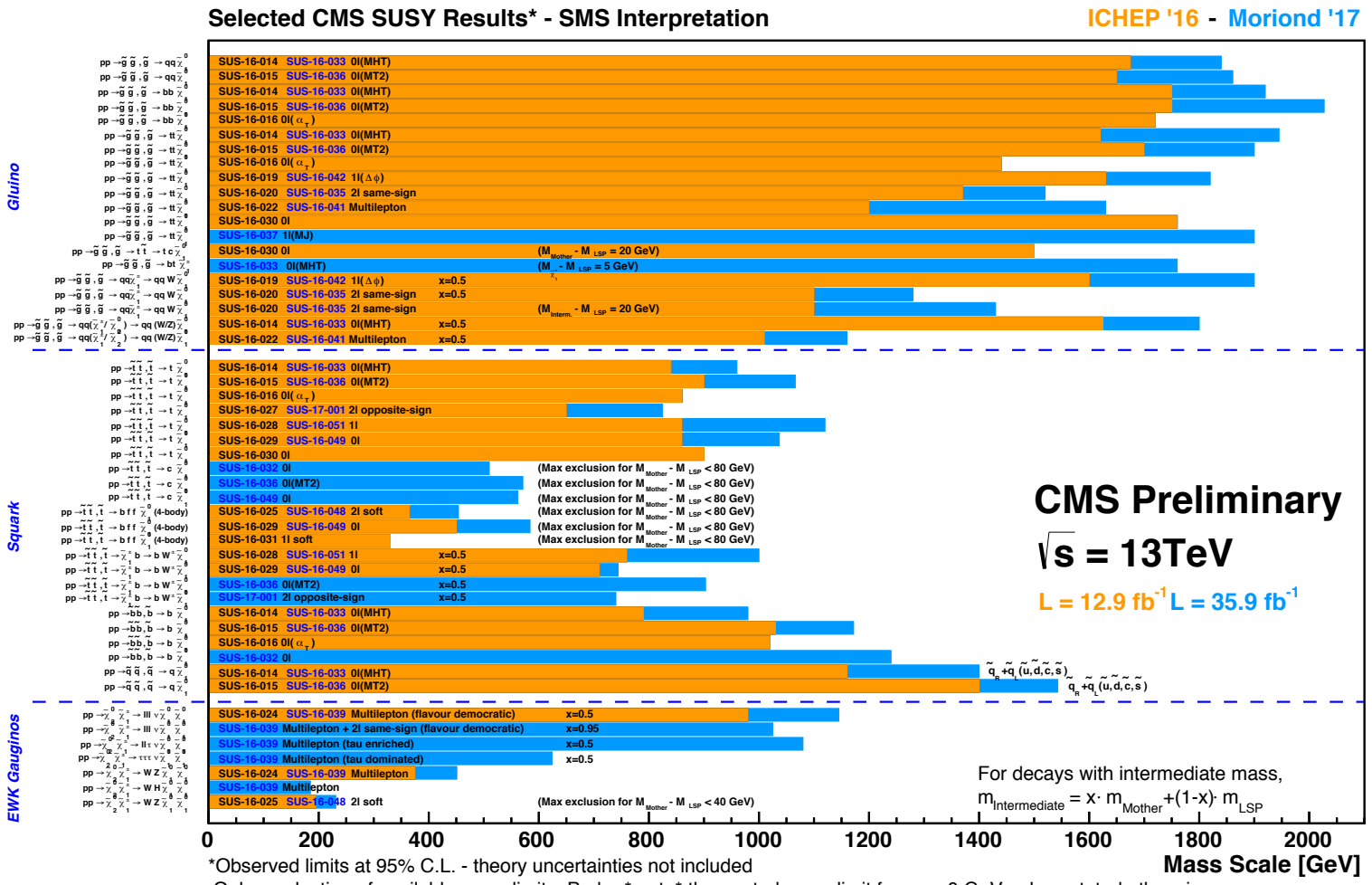
CMS Collaboration arXiv:1707.07274





Supersymmetry or Supercemetry?

✦ Summary of all recent results:



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Summer_Conferences_2017_36_fb_1

Read the Fine Print!

- Much of the natural SUSY parameter space has been probed
- Yet, keep in mind that:
  - Searches typically assume 100% branching fraction in a particular channel'
  - Many searches assume mass degeneracy between various SUSY particles, e.g. squarks
  - Interpretation is simplified via SMS
- Important to read the fine print!

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Paradigm Shift

- Having found no SUSY so far in "standard" channels (strong production, large mass splittings), the searches shifted in the following directions
  - Search for SUSY in compressed spectrum scenarios (e.g, stop nearly degenerate with top quark + neutralino masses)
    - Use ISR as an important tool to boost compressed system
  - Search for EW production of SUSY particles
    - First sensitivity for Higgsino pair production in Run 1; now rapidly increasing the reach
  - Search for SUSY via Higgs boson in decay chains
    - Just started to be sensitive
  - VBF SUSY production
    - Not yet sensitive - but a powerful tool for the future

New Paradigms and New Tools

- These new paradigms require new tools:
  - Soft-lepton triggers
  - Jet substructure techniques
  - Ever increasing use of ISR as a tag
  - Charm tagging
  - Use of "designer" kinematic variables
  - Optimal top quark reconstruction
- These tools are common between SUSY and many other searches, leading to significant cross-pollination spreading across the search fields and also now being used in precision measurements

Conclusions

- Number of SUSY searches performed in Run 2, some using novel techniques
- Generally exceed Run 1 sensitivity across the board
- Focus on natural SUSY, with or without compressed spectrum
- So far, no exciting signs have been seen, but the quest continues
- Doubling of the data set expected this year and future data will allow us to cover more parameter space and start probing EW SUSY production in variety of channels, including VBF
- Stay tuned - we are not done yet!

Hunting

not much to say