# Interpretation of CMS SUSY results and outlook to 14 TeV data taking

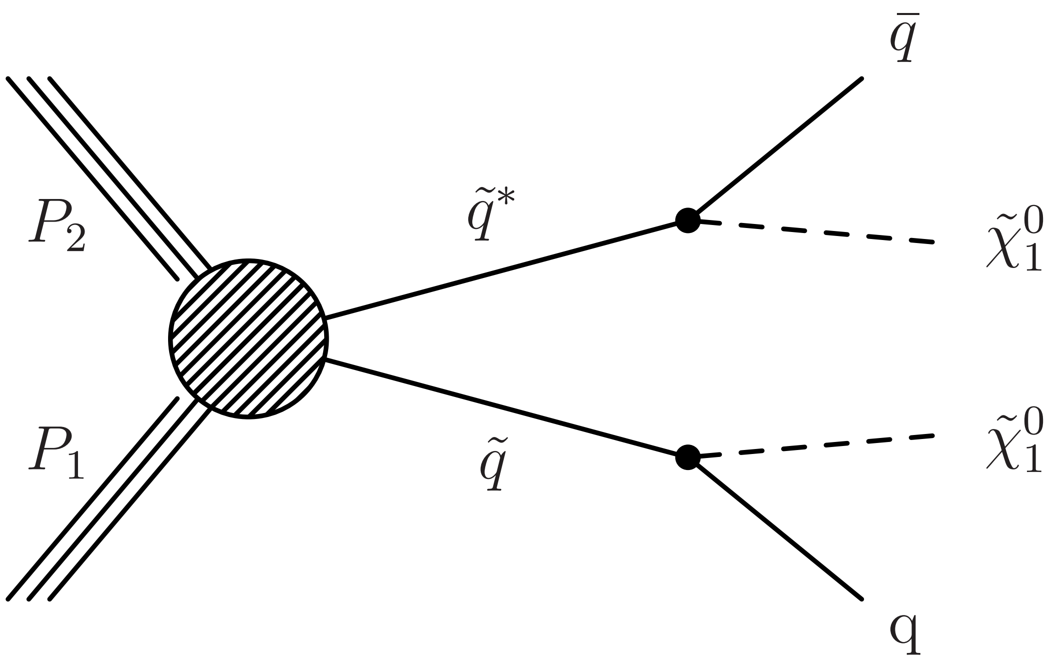
Frank Golf (UCSB),
on behalf of the CMS collaboration

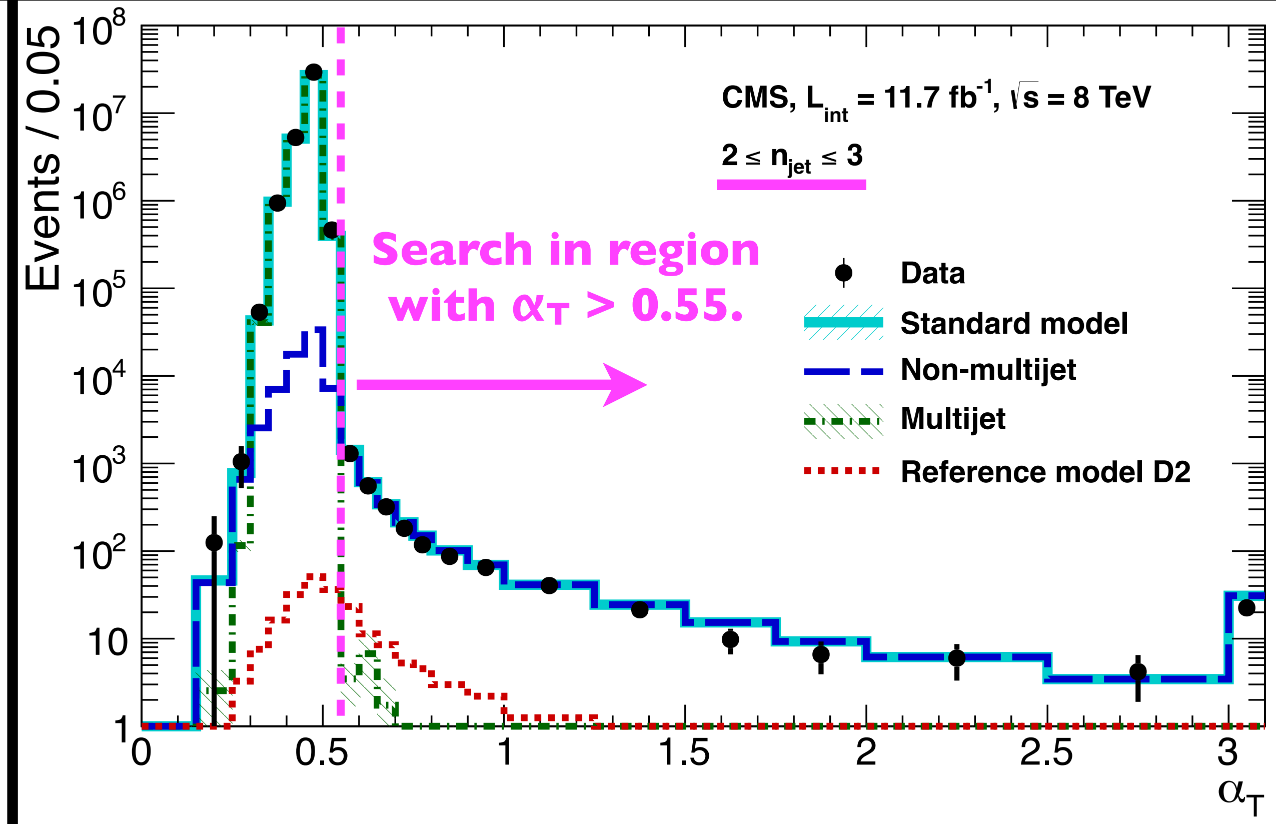
# Interpreting CMS SUSY Results

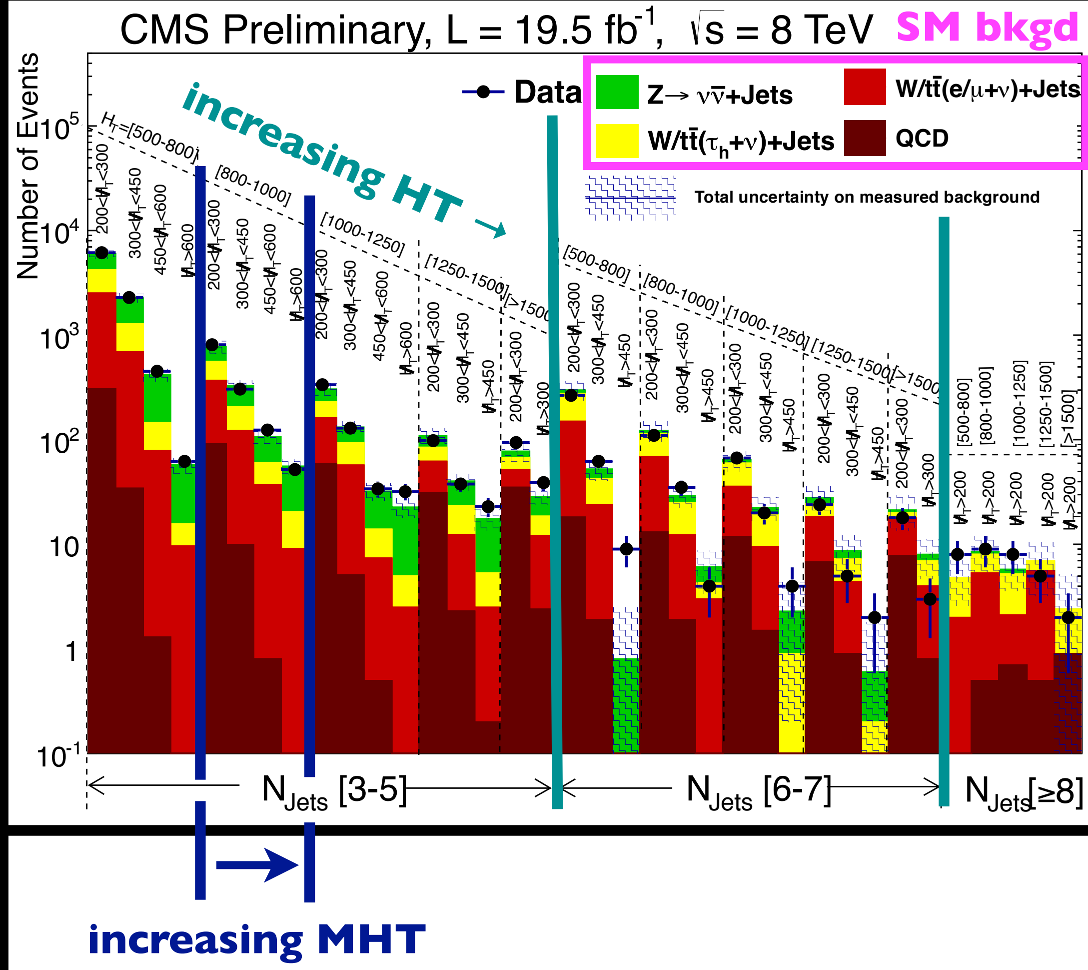
- Gradual evolution in how SUSY results are interpreted.
- Today: interpretation of SUSY searches in the context of simplified models.
  - Utility in simplicity, but also limitations....
- Moving beyond simplified models → phenomenological MSSM.
  - Addresses some of the limitations of SMS scenarios.
  - Allows us (experimentalists) to understand our results in a broader framework and discover signatures that our analyses may not be covering.
- The future: looking towards the next run of the LHC.

# Interpretation: Squark Pair Production

| Interpretation of SUSY Searches | $\alpha_T$ all-hadronic search (11.7 fb$^{-1}$) | HT+MHT all-hadronic search (19.5 fb$^{-1}$) |
|---|---|---|
| SUS-11-016, arXiv:1301.2175 | SUS-12-028, arXiv:1303.2985 | SUS-13-012 |




$\tilde{q}\tilde{q}^*$ production ($gg \to \tilde{q}\tilde{q}^*$ @ LO)
gluino decoupled $\Rightarrow$ no $pp \to \tilde{q}\tilde{q}$ @ LO
simplified model $\Rightarrow BR(\tilde{q} \to q\tilde{\chi}_1^0) = 1$
$m_{\tilde{u}_{L,R}} = m_{\tilde{d}_{L,R}} = m_{\tilde{s}_{L,R}} = m_{\tilde{c}_{L,R}}$

Reject multi-jet background using $\alpha_T$.

Use HT to suppress remaining SM bkgd.

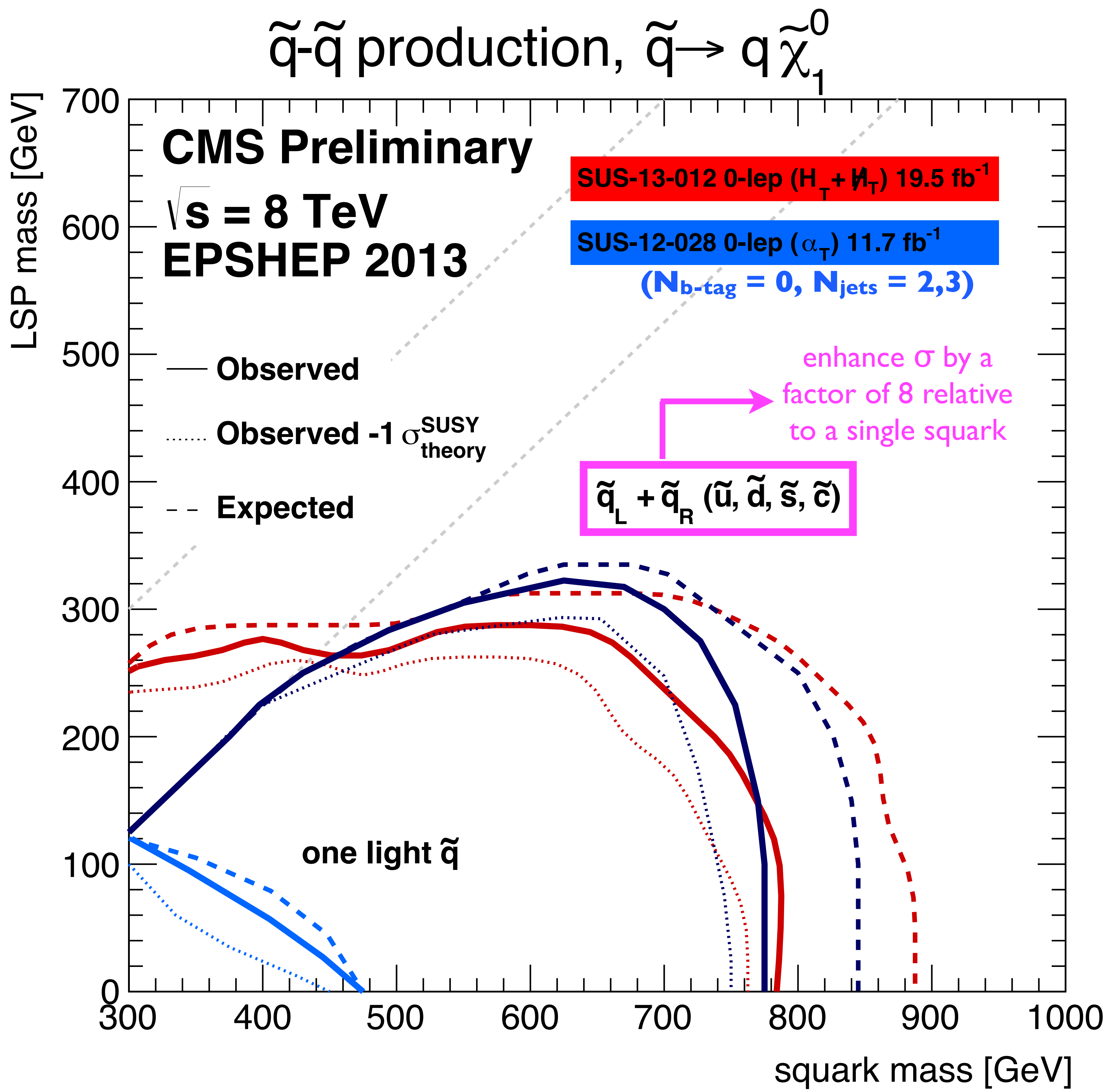
Search in bins of $N_{b\text{-tag}}$, $N_{jets}$, HT.

Search in bins of $N_{jets}$, HT, MHT.

$N_{jets} \geq 3 \Rightarrow$ at least 1 jet from ISR/FSR.

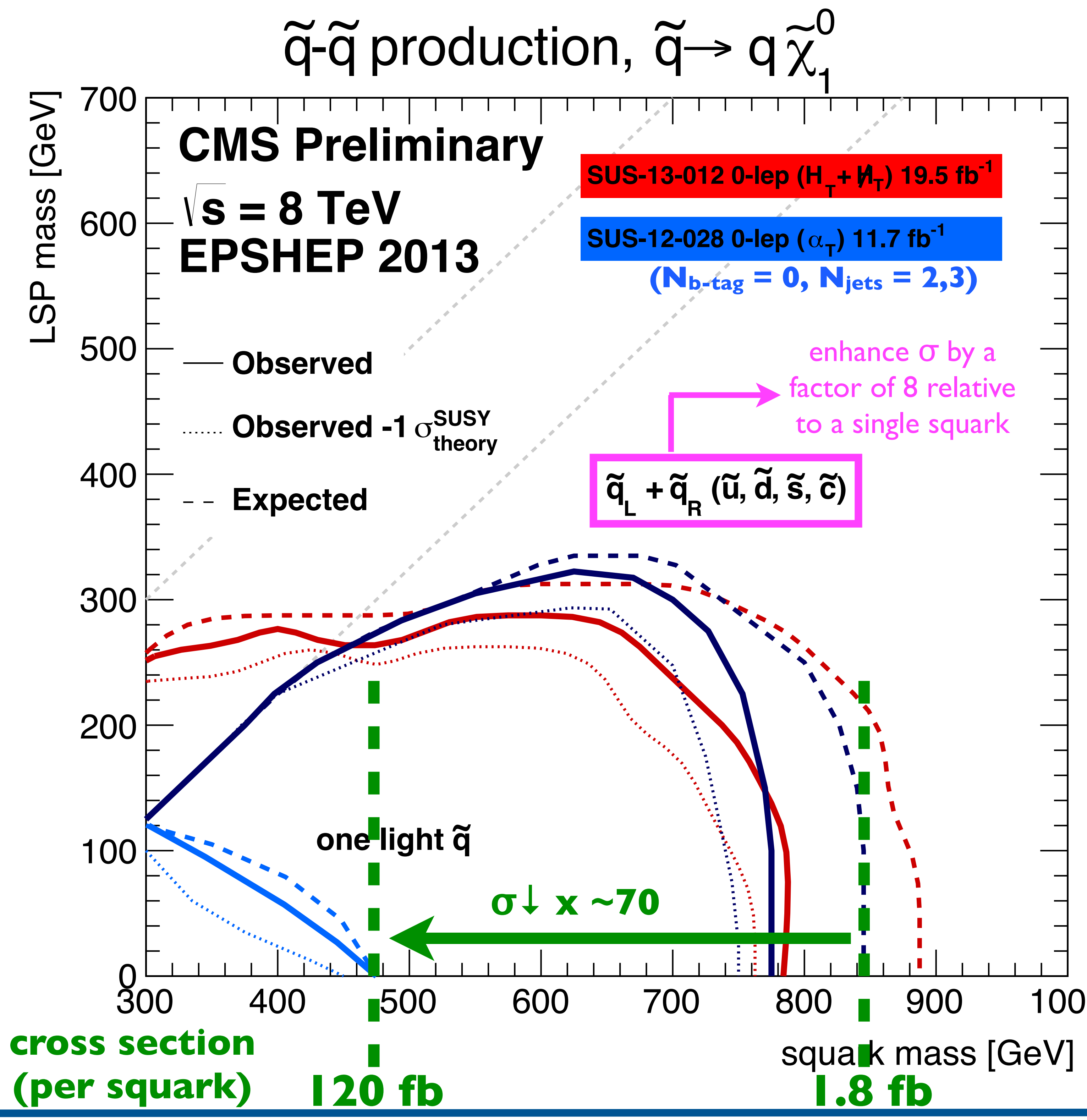
# Impact of Squark Degeneracy

- Squark degeneracy → increased production rate.



# Impact of Squark Degeneracy

- Squark degeneracy → increased production rate.
- For a scenario with a single light squark, the mass probed decreases from 850 GeV → 475 GeV.
  - This represents a factor of 70 decrease in the squark pair production cross section.



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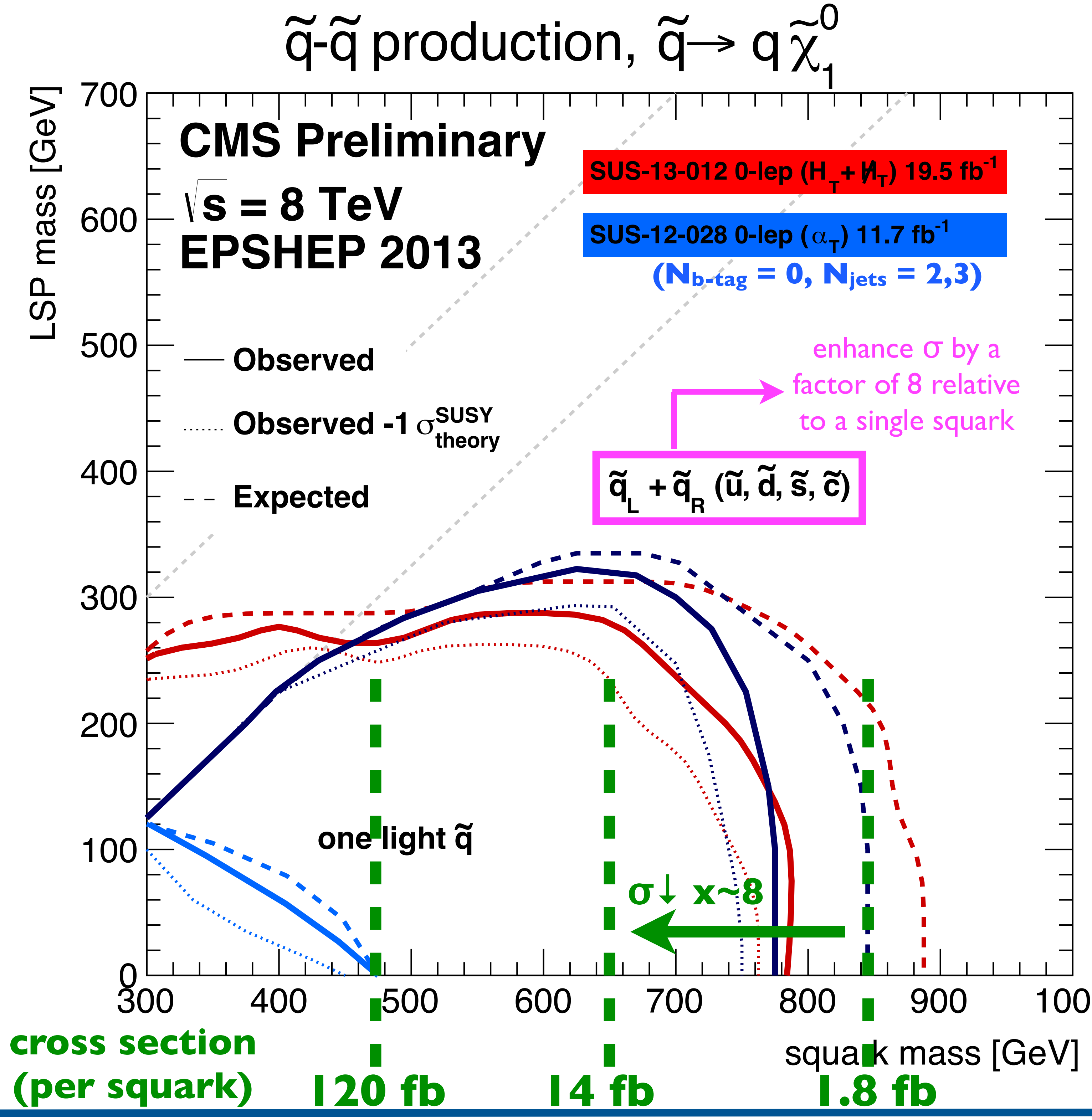

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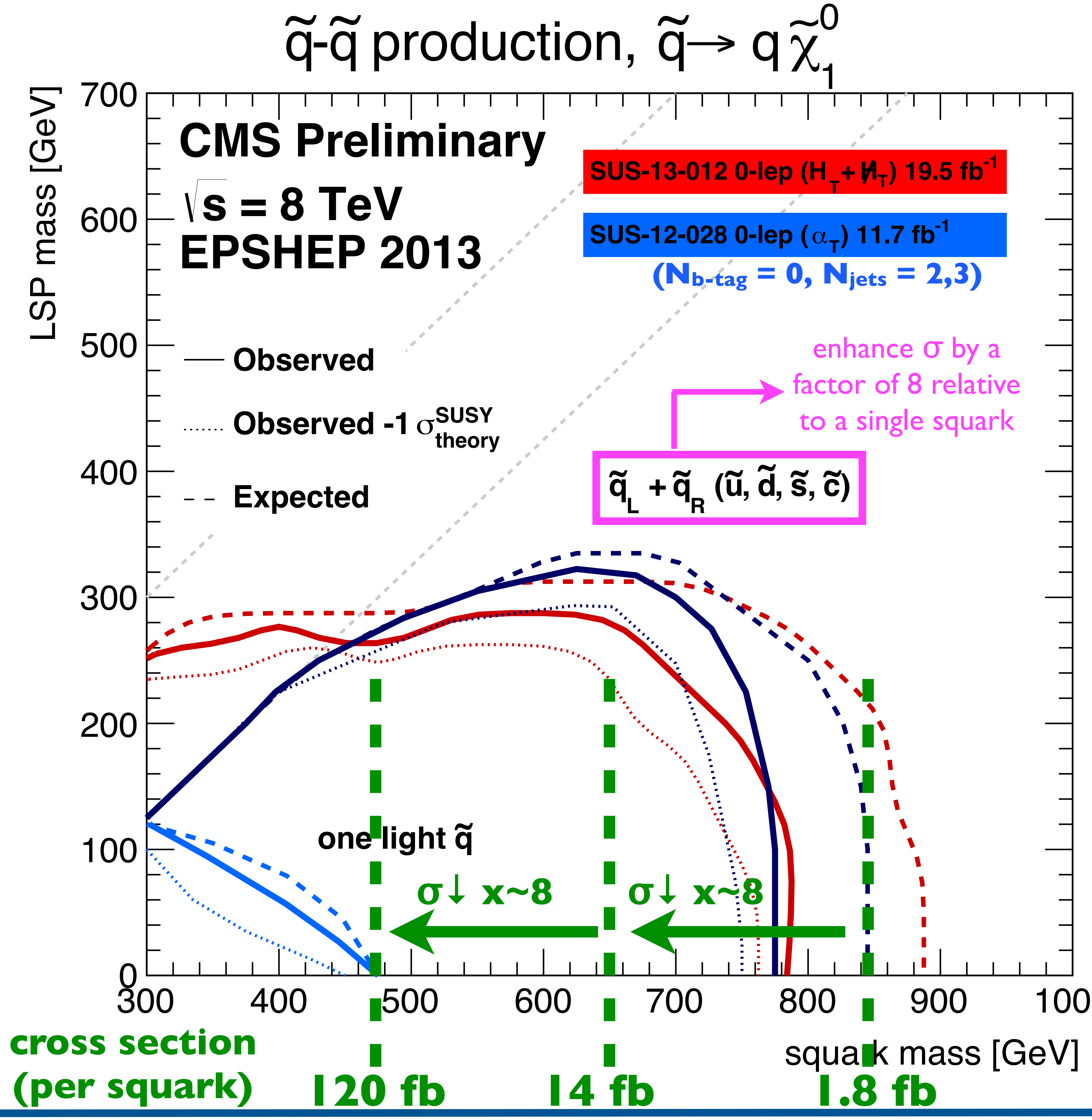
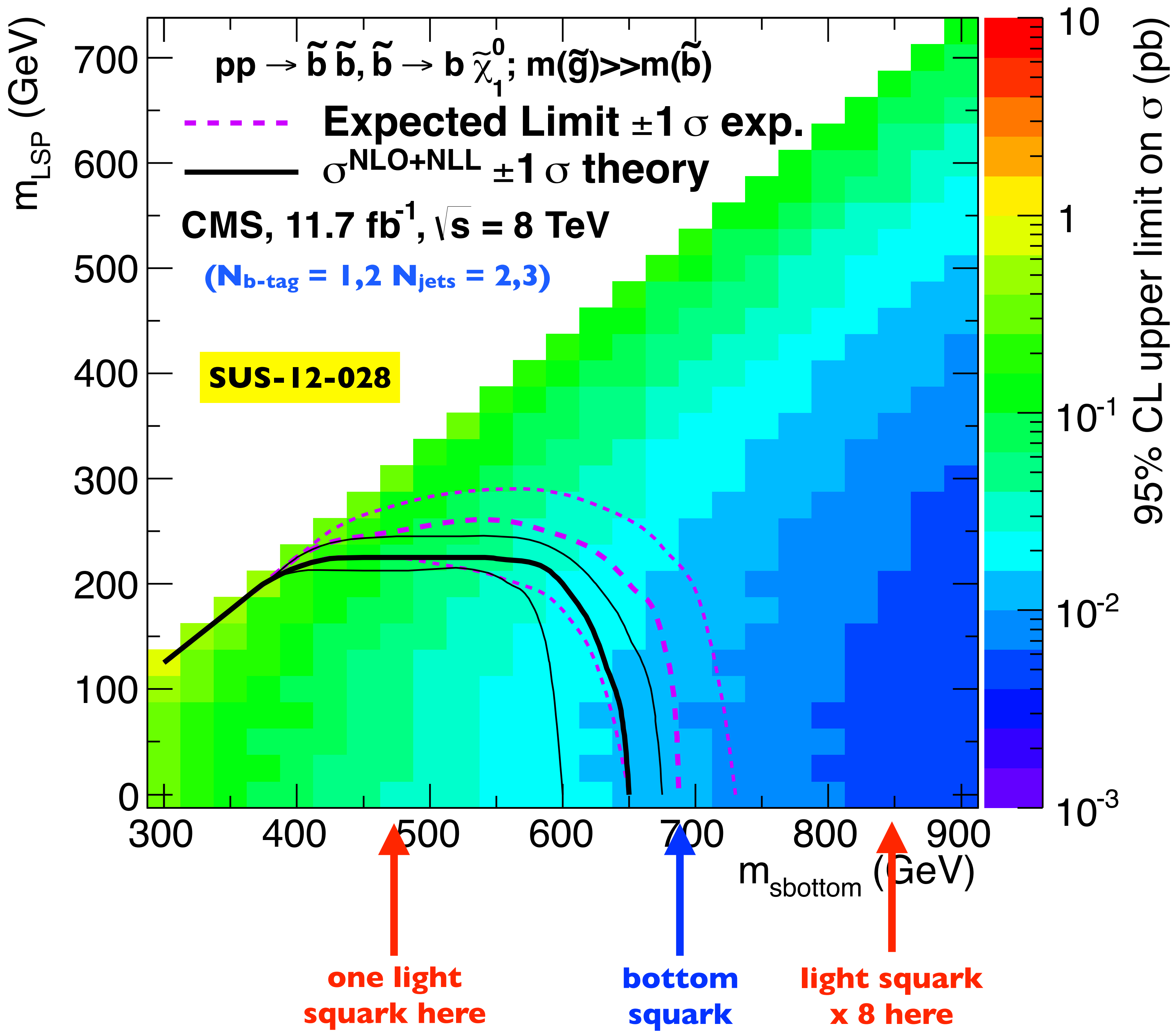
  - From theory, expect only a factor of 8 decrease in cross section sensitivity → probe mass of ~650 GeV.
  - Remaining decrease in sensitivity is experimental: lower squark mass → smaller boost to decay products → less MET and lower pt jets (smaller HT).
    - Either accept a decrease in signal efficiency or, if signal efficiency is maintained, an increase in SM backgrounds.



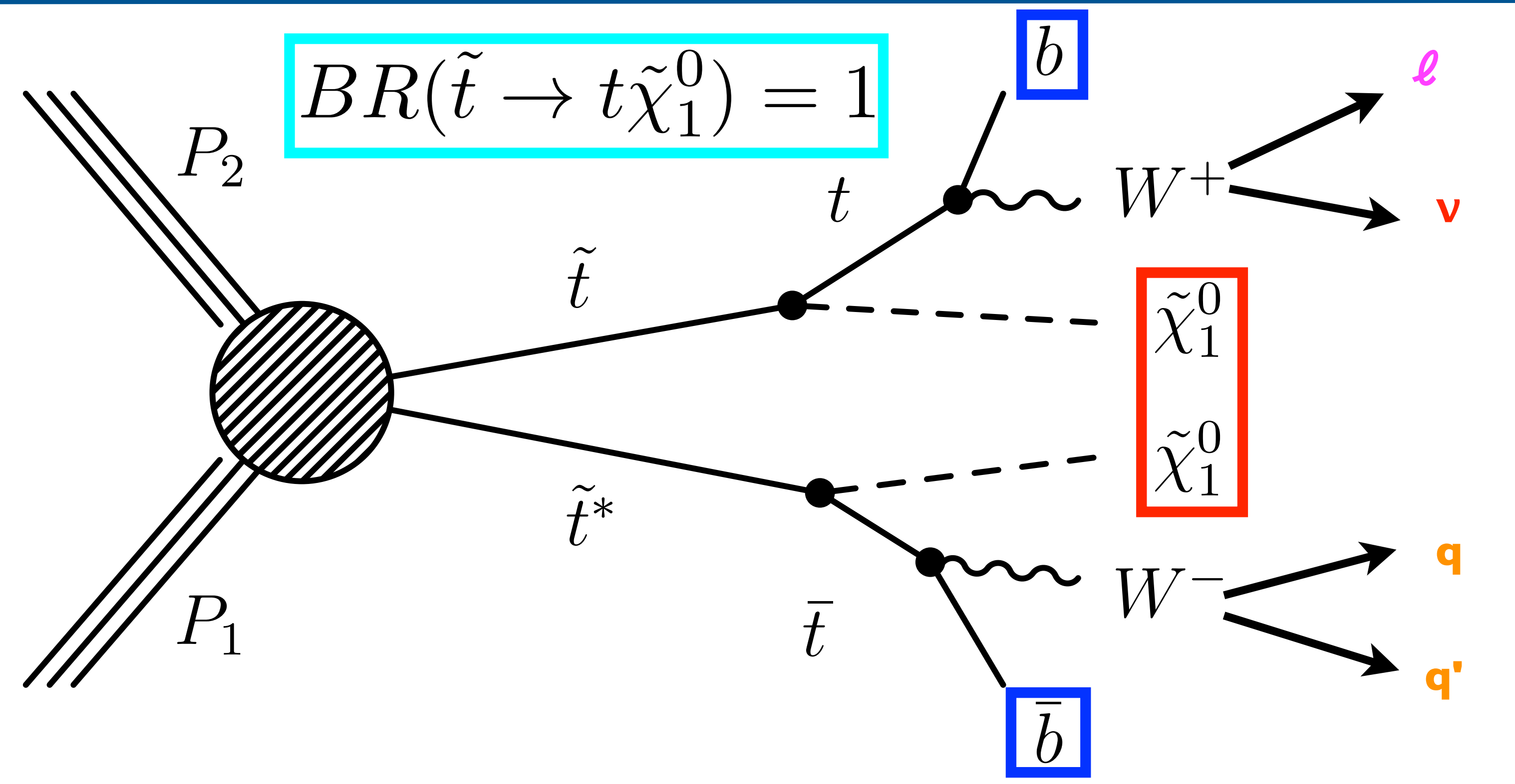
# Impact of Squark Flavor

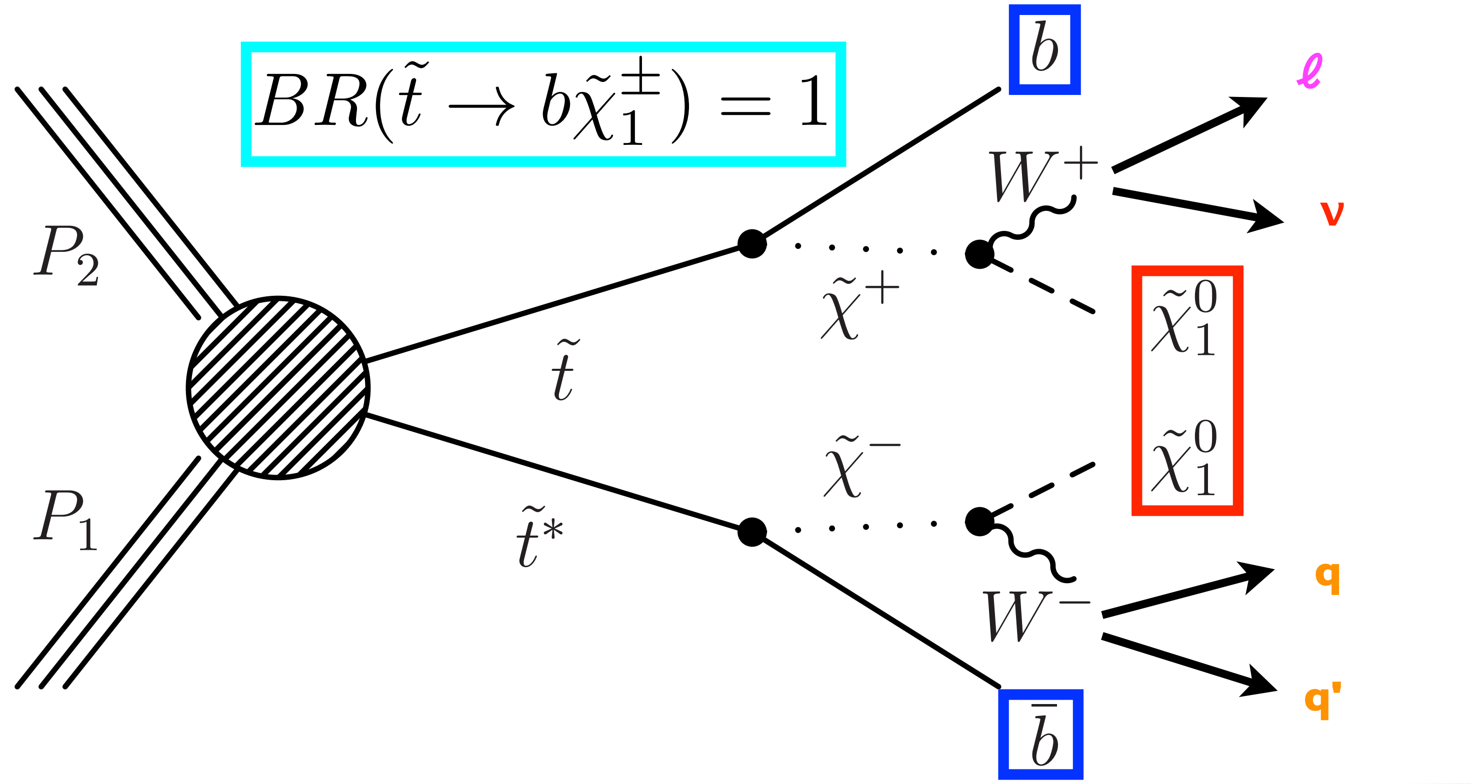



- Sensitivity to sbottom pair production is better than for a non-degenerate light squark, although the cross section is the same.
  - Requiring at least one b-tagged jet suppresses the SM background by a factor of ~5-7 for a small decrease (~15%) in signal efficiency.
- Generic statements about squarks, especially light squarks, are limited.

For more on hadronic searches, see talk by J. Thompson.

# Interpretation: Stop Pair Production




## Event Pre-selection

- One high-$p_T$, isolated e or μ.
- ≥ 4 jets with ≥ 1 b-tagged jet.
- Missing Transverse Energy.
- Veto events with a second lepton.

## Search Strategy

- Search in $M_T$ tail → $M_T(\ell, MET) \gg M_W$.
- Dominant backgrounds (ttbar, W+jets):
  - Take shape from simulation.
  - Data/MC scale factors from control regions.

# Limits on Stop Pair Production

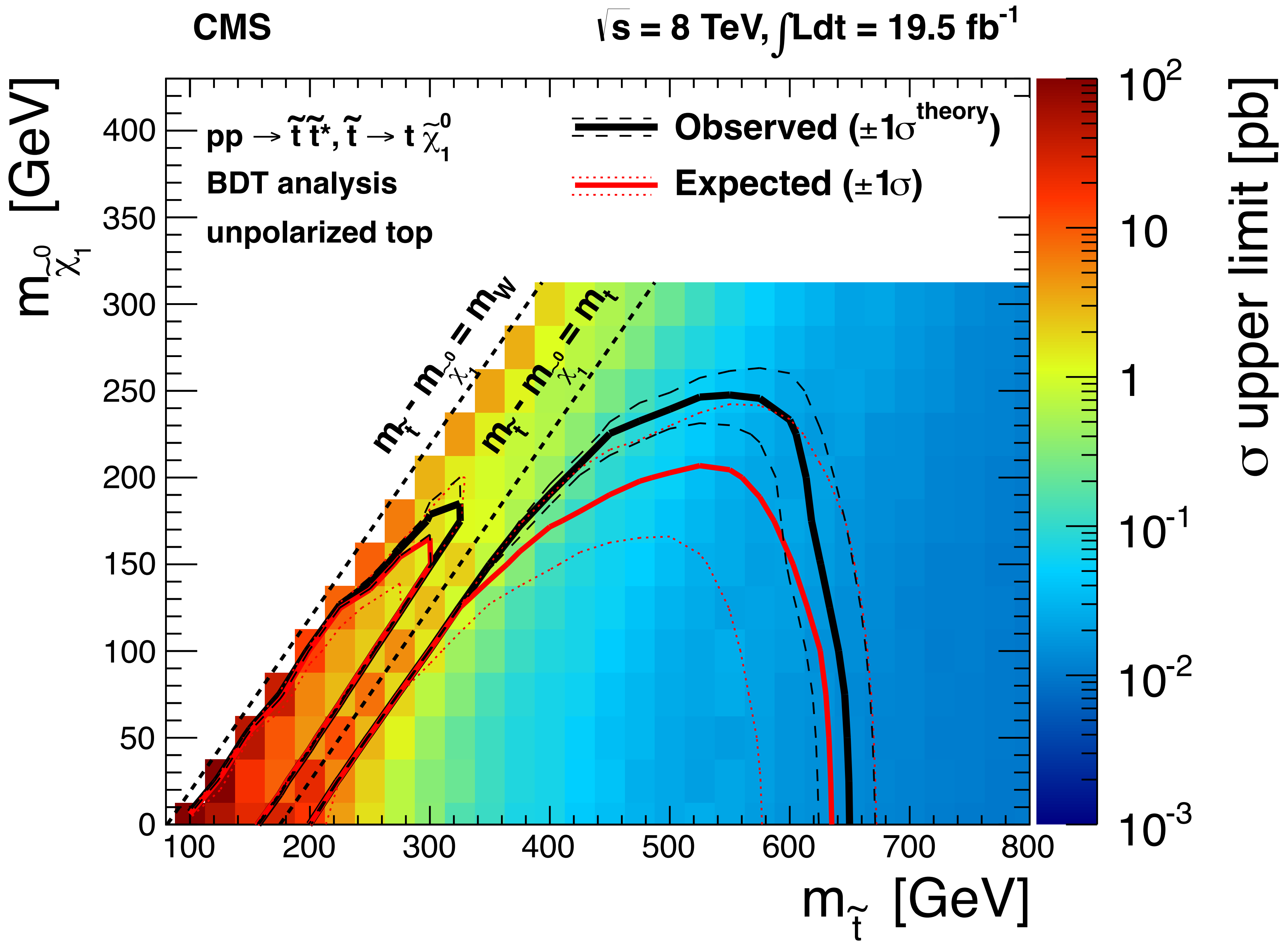
- Simplified models assume BR = 1.
- Actual BR depends on left-right stop mixture as well as chargino-neutralino mixture.
  - For example, if we have right-handed stops and pure-higgsinos, the BR depends only on kinematics and if both channels are allowed we can reasonably expect

$$BR(\tilde{t} \to t\tilde{\chi}_1^0) \sim BR(\tilde{t} \to b\tilde{\chi}_1^\pm)$$

- How are limits impacted if BR ≠ 1?

For more on stop searches, see talk by M. D'Alfonso.

SUS-13-011
arXiv:1308.1586

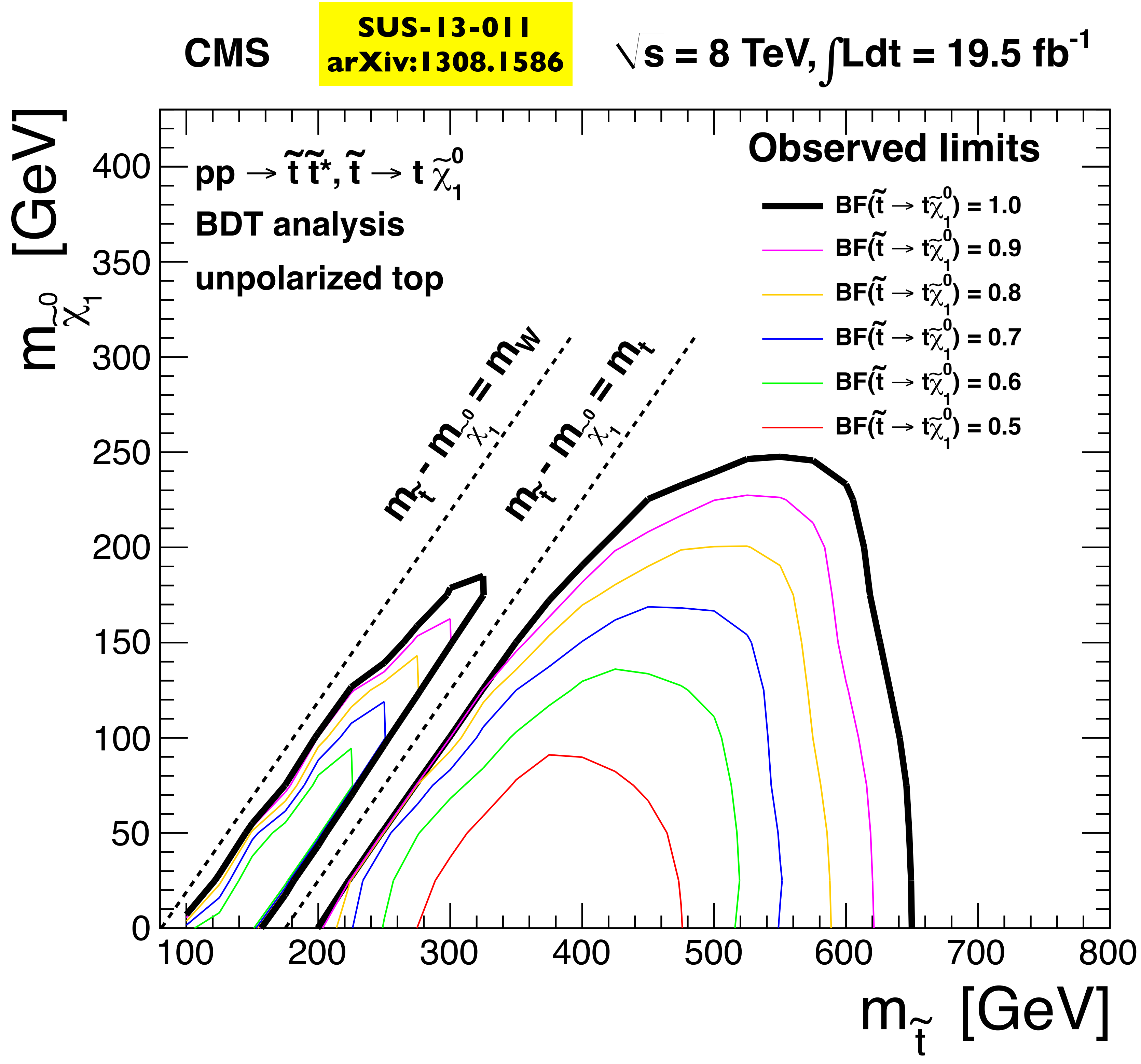


# Impact of Branching Ratio

- Consider a "natural" scenario, where

$$\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \ll M_W$$

- Small $\Delta$m → W decay products not reconstructed.
  - Two less jets in final state → fails analysis selection.
- Only select events where both stops decay to tops.
  - Signal efficiency reduced by $BR(\tilde{t} \to t\tilde{\chi}_1^0)^2$ relative to SMS scenario.
- Generic statements about stops are limited.



# Phenomenological MSSM Interpretation

## Definition of pMSSM

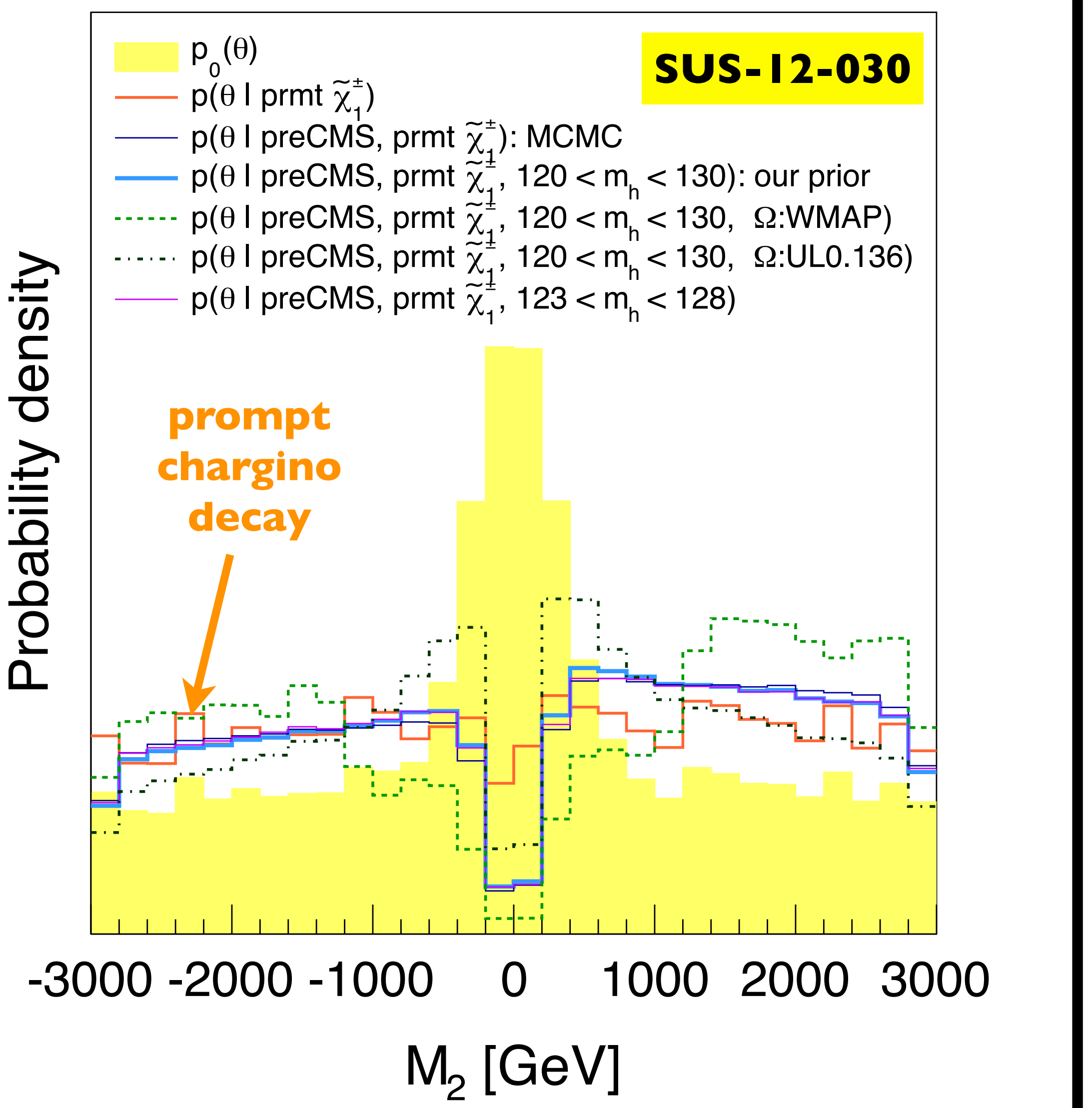
- Subset of MSSM with 19 free parameters.
  - Experimental constraints on CP violation, FCNC.
- RPC with lightest neutralino as LSP.
- Degeneracy amongst first two generations.
- Only consider sub-space accessible to LHC.

- Perform Bayesian analysis
- Flat initial prior - all points equally likely.

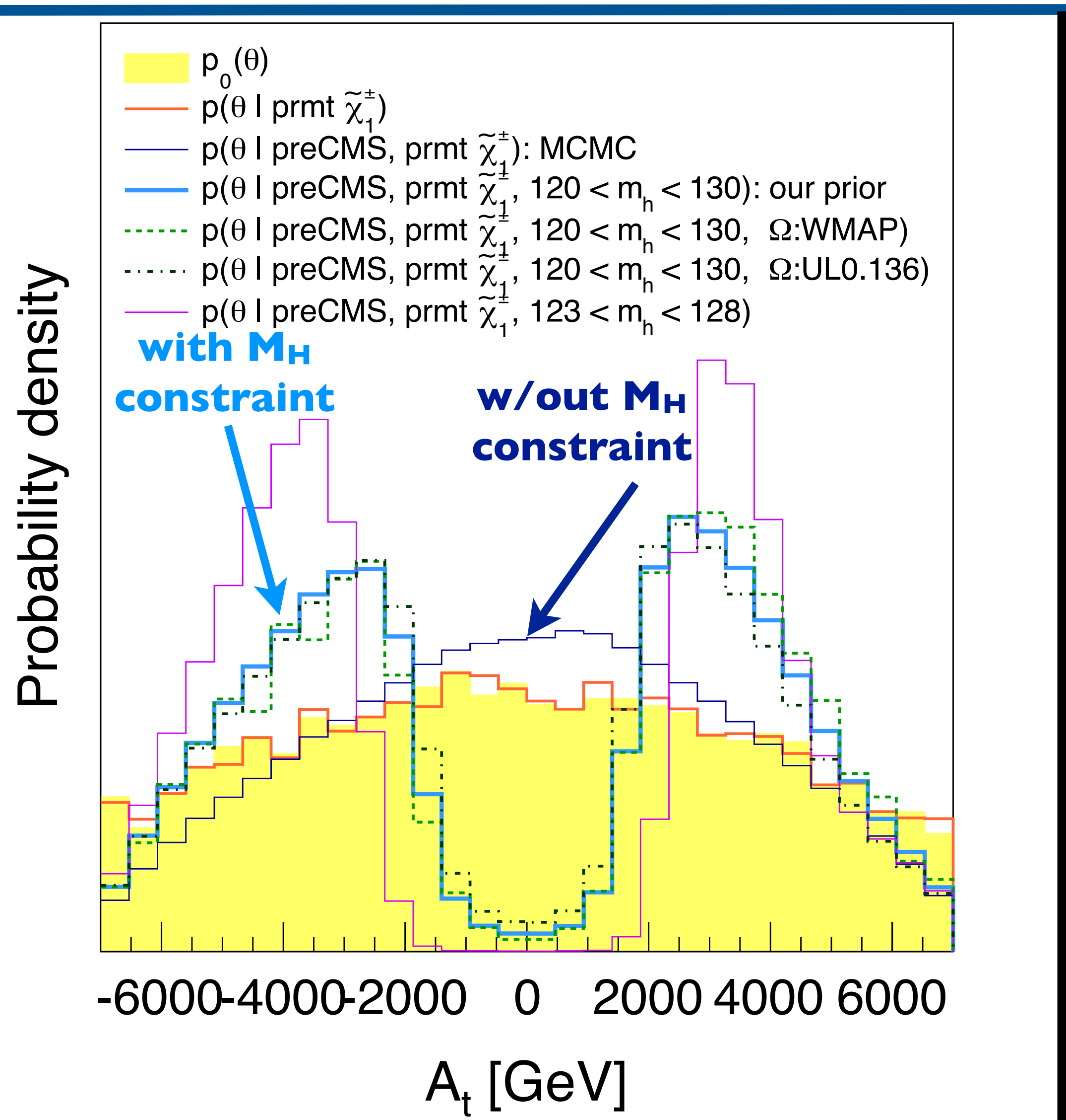
## preCMS Constraints

- Select a representative subset of pMSSM space subject to experimental constraints on:
  - $b \rightarrow s\gamma$, $B \rightarrow \tau\upsilon$, $B_s \rightarrow \mu\mu$
  - $M_t$, $M_b$, $M_h$, sparticle masses
  - $\alpha_s$, $\Delta a_\mu$
  - prompt chargino ($c\tau < 10$ mm)

# Impact of preCMS constraints

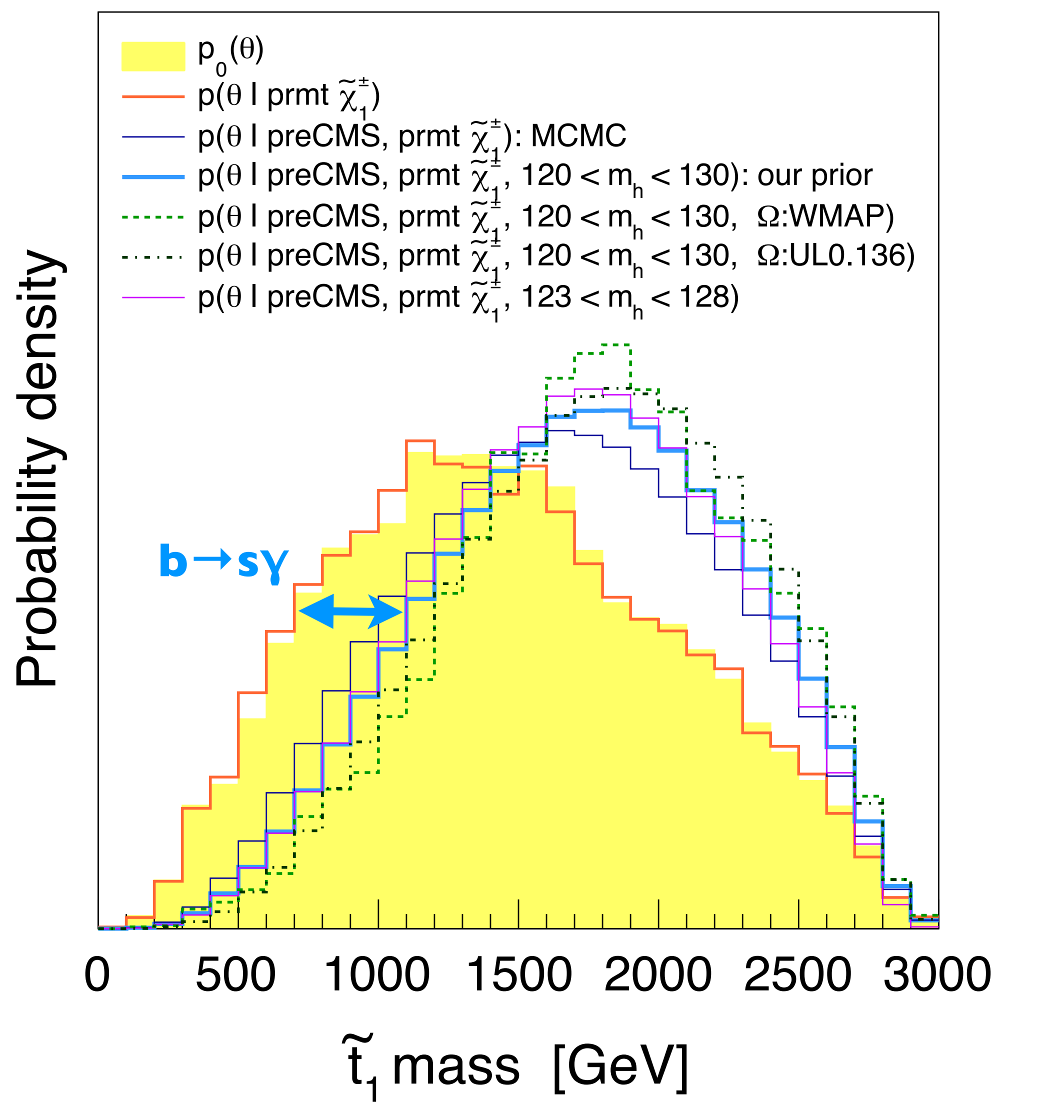



Requiring prompt chargino decays leads to larger $M_2$ resulting in somewhat larger mass splittings as wino-like $\tilde{\chi}_1$ are less preferable.




Higgs mass constraint prefers larger values of $|A_t|$ which contributes to radiative correction to Higgs mass.

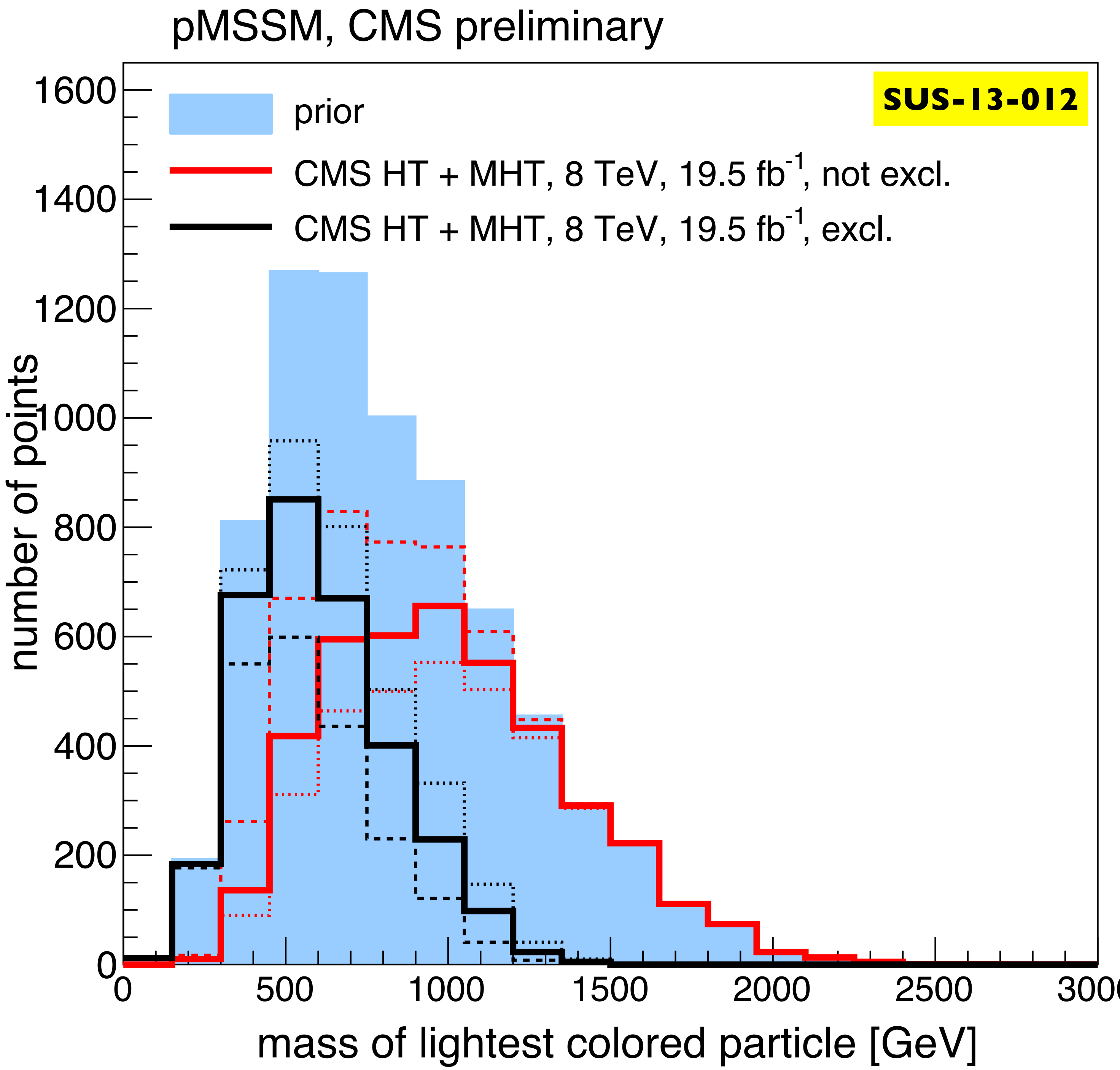
See talk by D. Shih regarding $M_H$ and $A_t$.




Indirect constraints on stop mass from loop mediated $b \to s\gamma$ decay. Measurement consistent with SM expectation prefers heavier stop.

# Impact of Current Results on pMSSM

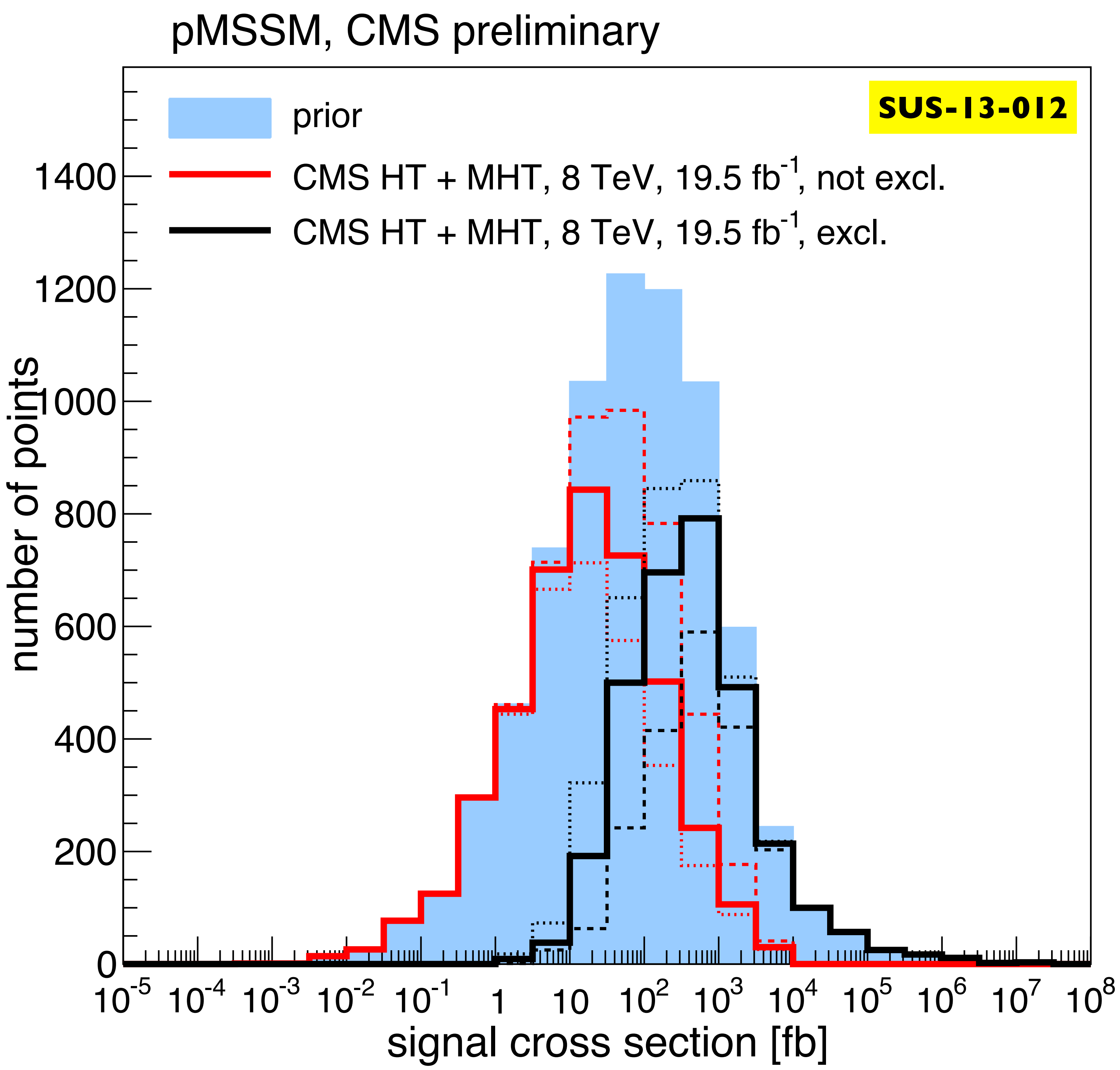
- Favor colored particles with mass above TeV.
- Significant improvement upon preCMS results.



# A Generic Look at the pMSSM

- A "global" analysis of 7 TeV CMS results already began to push the $\sigma_{total}$ well below 1 pb.

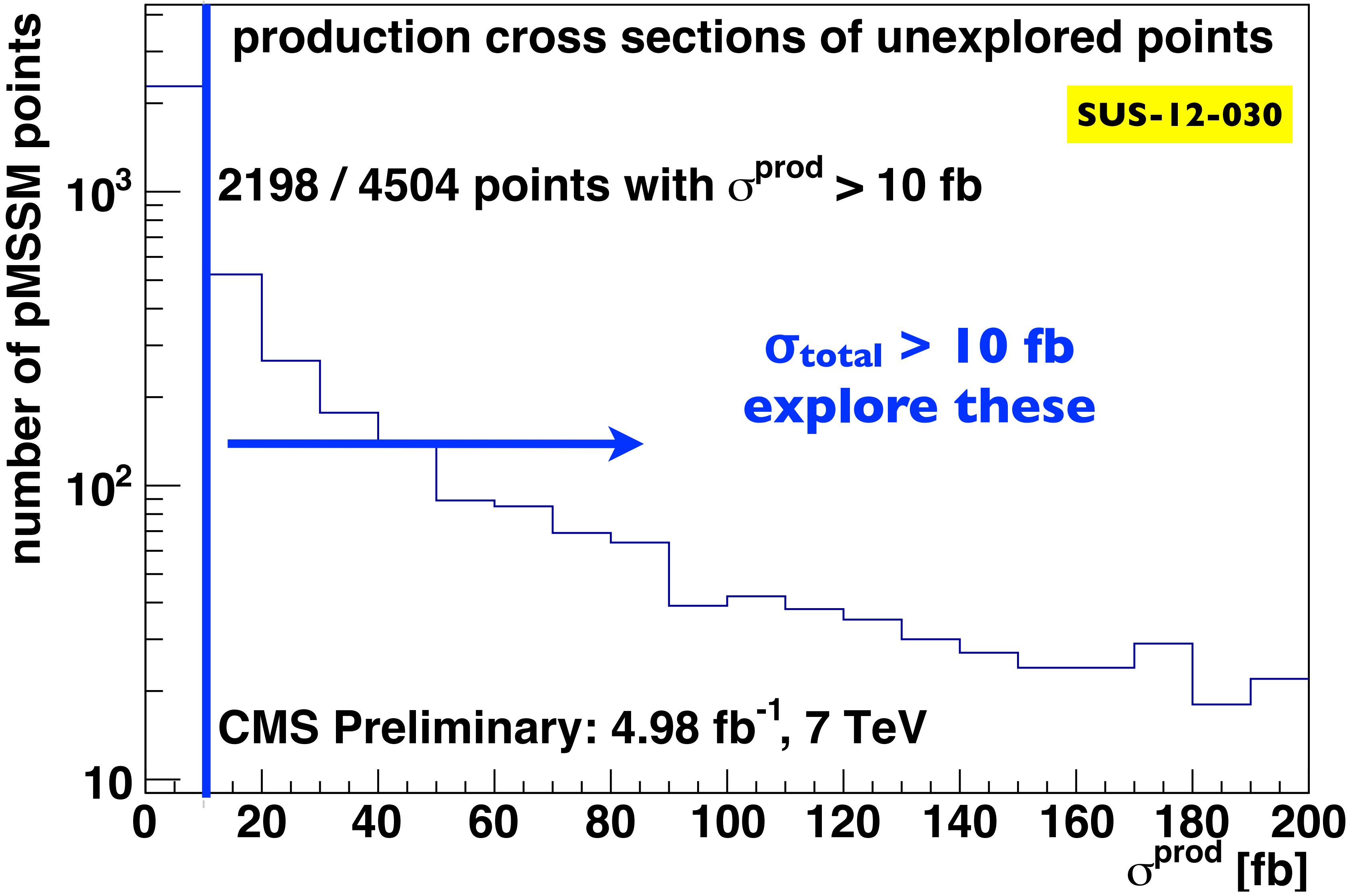
- No similar study of 8 TeV results has been performed yet, but a look at the most sensitive analysis (HT+MHT) continues to push $\sigma_{total}$ down.




**(total pMSSM cross section)**

# Exploring the Unexplored

- As part of the 7 TeV study, a comprehensive survey was made of the non-excluded points.
  - A bit over half of the non-excluded points had $\sigma_{total}$ < 10 fb → some of these will be probed by the 8 TeV analyses.
  - Remaining had $\sigma_{total}$ > 10 fb → interesting to look at these in more detail.




(total pMSSM cross section)

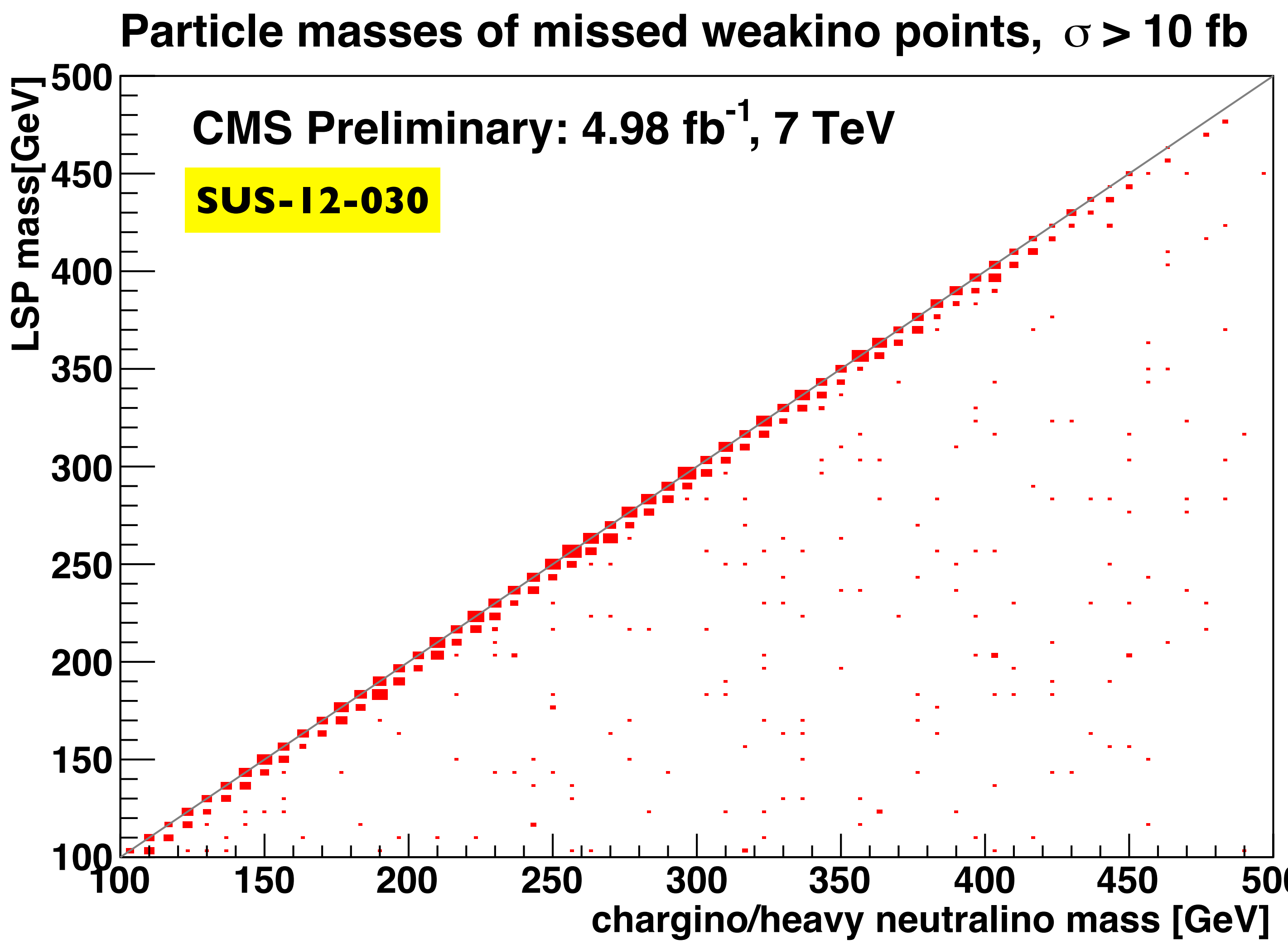
# Breakdown of the Unexplored

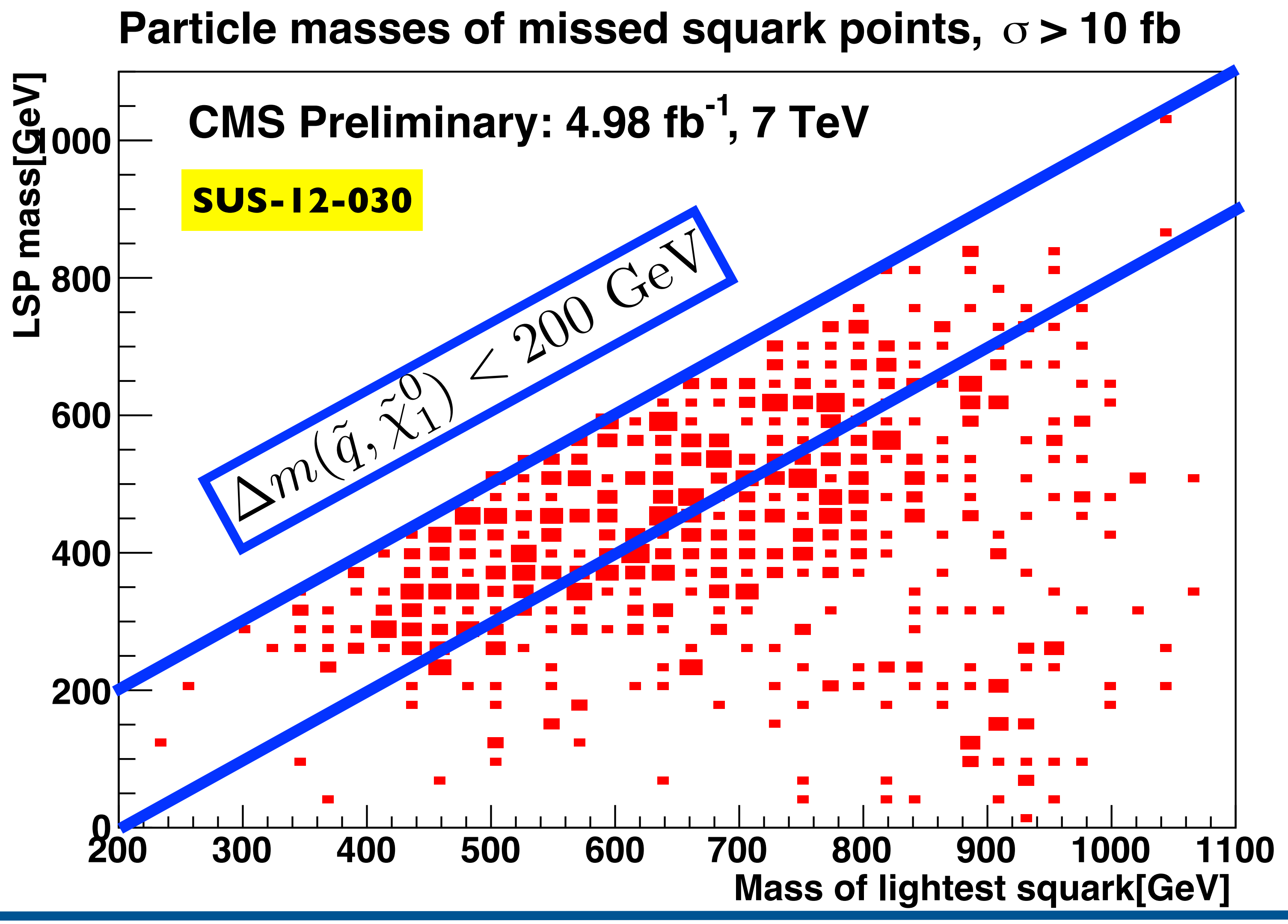
- Over half of un-probed points are dominated by the production of a pair of electroweak particles.
- Another third involves the production of a pair of squarks.

| SUS-12-030 channnel | Fraction of pMSSM points [%] for which channel contributes ... $> 90\%$ | $50$ - $90\%$ | $10$ - $50\%$ | $< 10\%$ |
|---|---|---|---|---|
| $\tilde{\chi}_i\tilde{\chi}_j$ | 40.4 | 14 | 11.8 | 33.8 |
| $\tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*$ | 11.9 | 18.1 | 12.8 | 57.2 |
| $\tilde{g}\tilde{g}$ | 1.5 | 2.1 | 2.6 | 93.9 |
| $\tilde{q}\tilde{g}$ | 0.0 | 0.6 | 6.1 | 93.3 |
| $\tilde{\chi}\tilde{q}$ | 0.0 | 0.3 | 6.3 | 93.4 |
| $\tilde{t}\tilde{t}^*$ | 0.3 | 0.5 | 1.8 | 97.4 |
| $\tilde{\ell}\tilde{\ell}^*$ | 0.1 | 0.1 | 1.6 | 98.2 |
| $\tilde{\chi}\tilde{g}$ | 0.0 | 0.0 | 0.3 | 99.7 |

# Compressed Spectra

- Most unexplored points with large cross sections have a compressed spectrum.
- Two scenarios predominate: those with small $\sigma_{total}$ will be helped by an increase in luminosity. Those with a compress spectrum require dedicated searches.



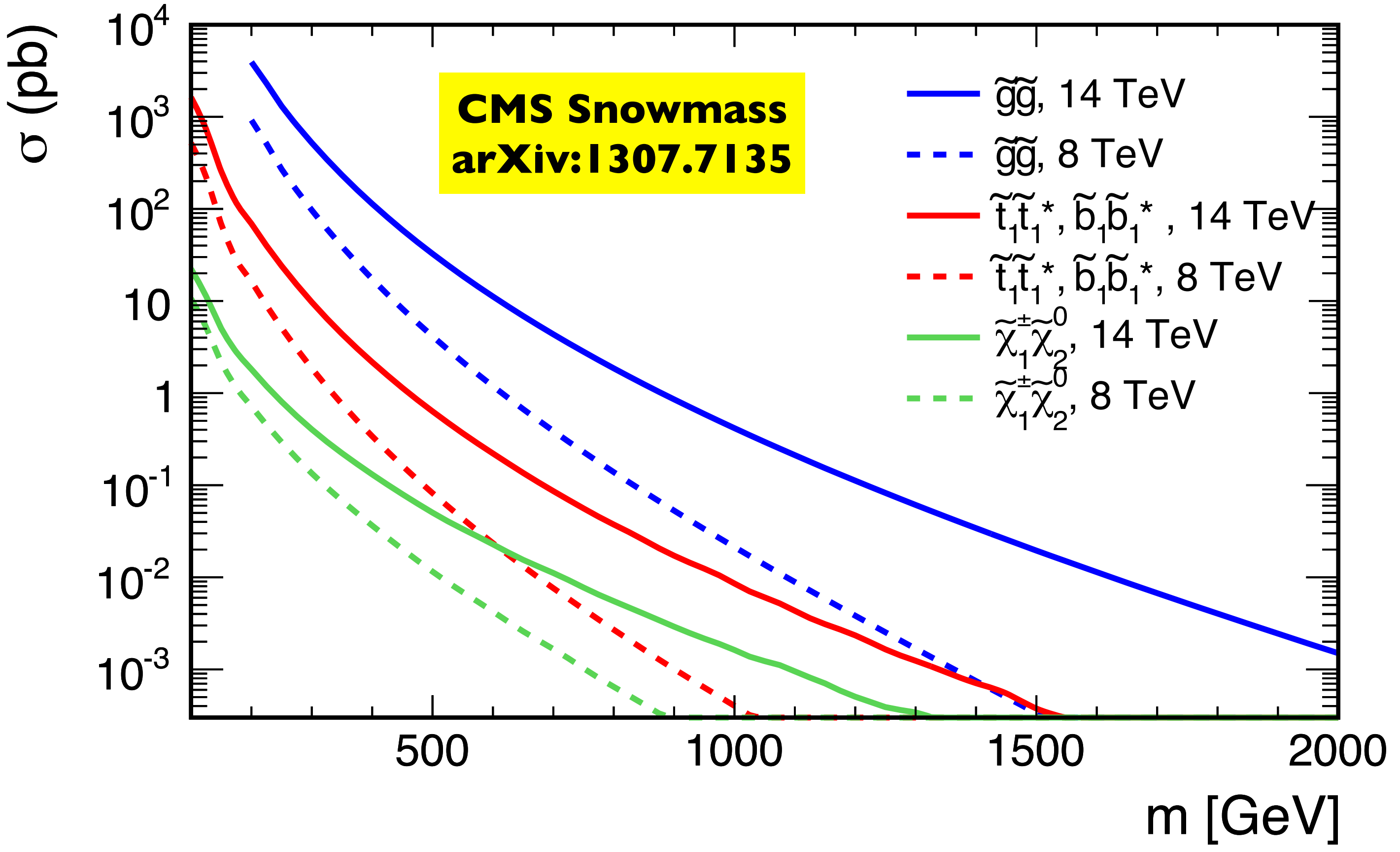



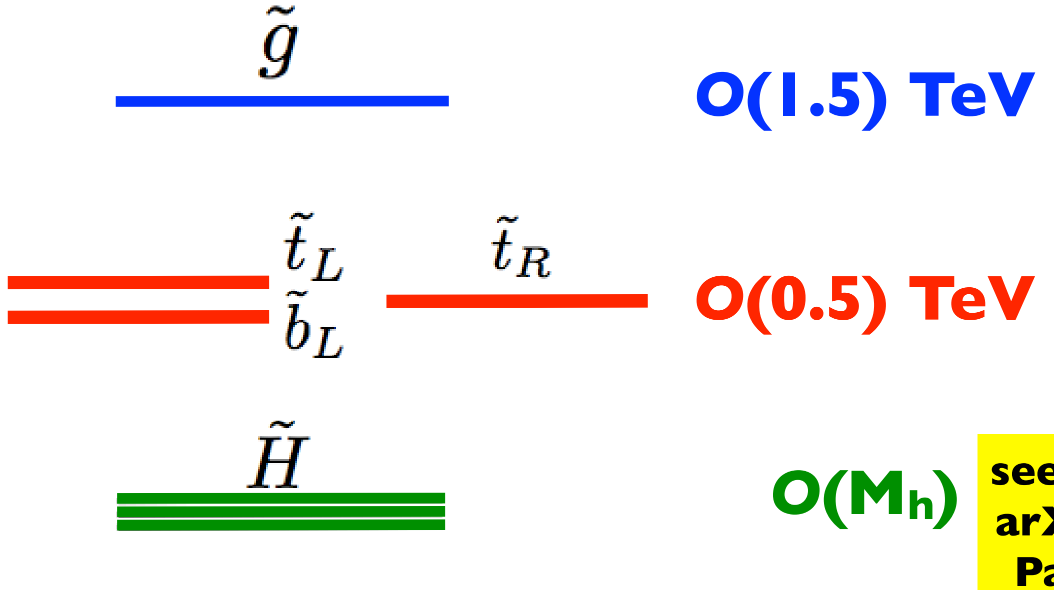
# Looking to the Future

- We're rather limited in the conclusions that we can draw about natural SUSY, in particular, and SUSY in general from the existing data.

- **This should be a source of excitement about the next run of the LHC.**
  - We're only beginning to probe the interesting physics.
  - Significant cross section enhancement for sparticle production.

- **A 14 TeV run with O(100) fb$^{-1}$ will allow us to expand our investigation of natural SUSY.**




**see for example: arXiv:1110.6926 Papucci, et. al.**

**example natural SUSY spectrum**

# Disclaimer


"The [horse manure] problem did indeed seem intractable. The larger and richer that cities became, the more horses they needed to function. The more horses, the more manure. Writing in the Times of London in 1894, one writer estimated that in 50 years every street in London would be buried under nine feet of manure."

[1] http://www.fee.org/files/docLib/547_32.pdf

**It is difficult to predict the future...**

# Snowmass Projections

- Scale signal and background by cross section ratios ($\sigma_{14\,\text{TeV}}/\sigma_{8\,\text{TeV}}$) and luminosity (300/20 ~ 15).
- Estimate 5$\sigma$ discovery reach for two scenarios:
  - **Scenario A (conservative)**: Scale background uncertainty by ratio of $\sigma$ x L.
  - **Scenario B (optimistic)**: Reduced background uncertainty relative to conservative scenario.
- **Caveat emptor**: Projections assume constant performance. We have not attempted any optimization nor accounted for potential degradation due to effects such as increased pile-up.

| Process | Decay | Search | Current (TeV) | Scenario A (TeV) | Scenario B (TeV) |
|---|---|---|---|---|---|
| $pp \to \tilde{g}\tilde{g}$ | $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ | $\ell + b + \not{E}_T$ | 1.1 TeV | 1.9 TeV | – |
| | $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ | $b + \not{E}_T$ | 1.1 TeV | 1.9 TeV | – |
| $pp \to \tilde{b}\tilde{b}^*$ | $\tilde{b} \to t\tilde{\chi}_1^- \to tW^-\tilde{\chi}_1^0$ | $\ell^\pm\ell^\pm + b + \not{E}_T$ | 0.45 | 0.6 | 0.75 |
| $pp \to \tilde{t}\tilde{t}^*$ | $\tilde{t} \to t\tilde{\chi}_1^0$ | $\ell + b + \not{E}_T$ | 0.25-0.5 | 0.75 | 0.95 |
| $pp \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0$ | $WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ | $3\ell + \not{E}_T$ | 0.25 | 0.45 | 0.6 |
| | $WH\tilde{\chi}_1^0\tilde{\chi}_1^0$ | $\ell + b + \not{E}_T$ | 0.2 | 0.4 | >0.5 |

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- As an example, let's consider the stop projection in more detail.

| Process | Decay | Search | Current (TeV) | Scenario A (TeV) | Scenario B (TeV) |
|---|---|---|---|---|---|
| $pp \to \tilde{g}\tilde{g}$ | $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ | $\ell + b + \not{E}_T$ | 1.1 TeV | 1.9 TeV | – |
| | $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ | $b + \not{E}_T$ | 1.1 TeV | 1.9 TeV | – |
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| | $WH\tilde{\chi}_1^0\tilde{\chi}_1^0$ | $\ell + b + \not{E}_T$ | 0.2 | 0.4 | >0.5 |

See talk by B. Hooberman for EWK SUSY searches, including new results on SUSY→Higgs.

# Stop Projection

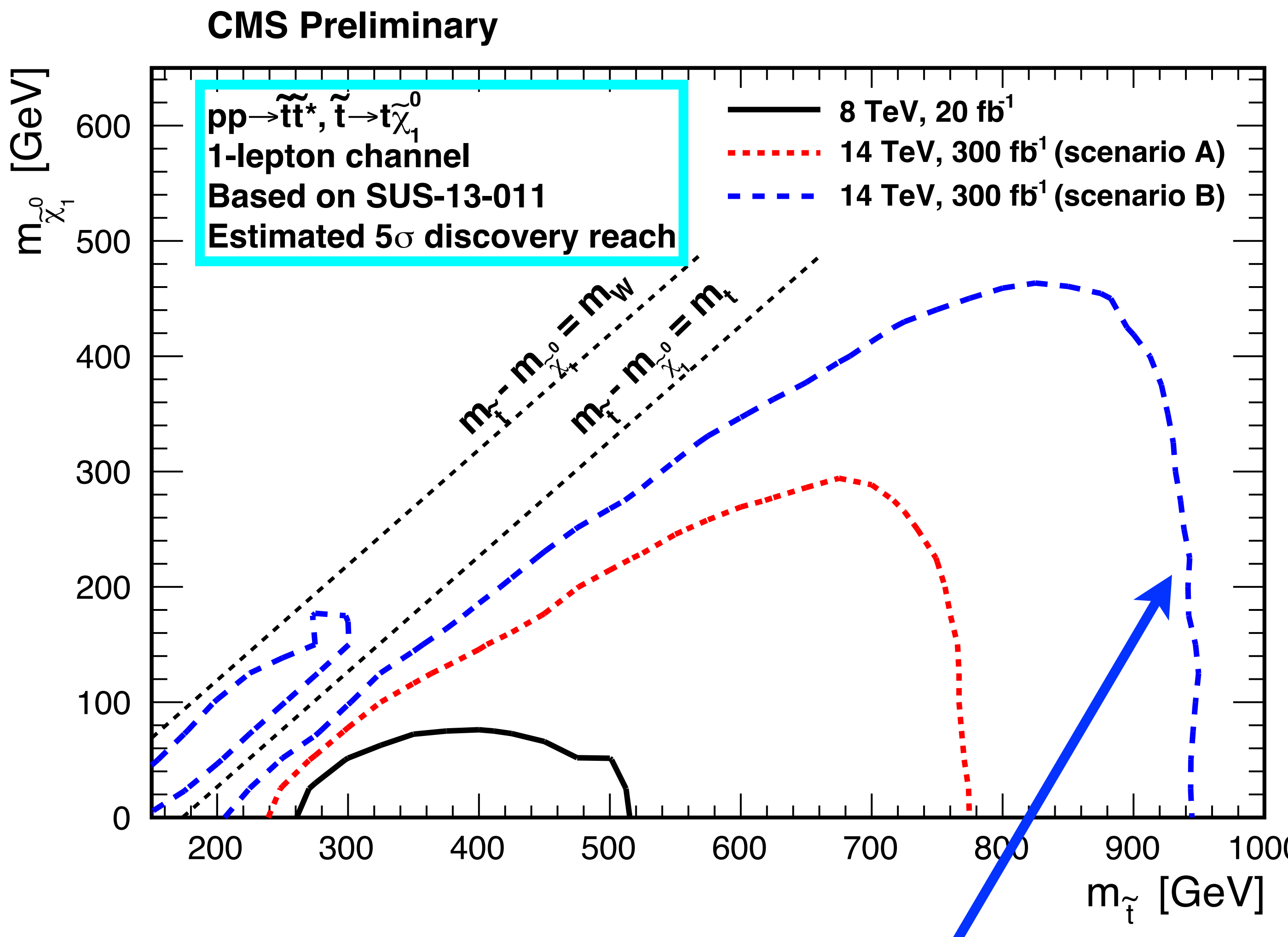
Significance = $\dfrac{N_{sig}}{\sqrt{N_{bkgd} + \sigma^2_{bkgd}}}$

Bkgd scaling: $R_{bkgd} = \left(\dfrac{300\ \mathrm{fb}^{-1}}{20\ \mathrm{fb}^{-1}}\right) \times \boxed{\dfrac{\sigma_{t\bar{t}}(14\ \mathrm{TeV})}{\sigma_{t\bar{t}}(8\ \mathrm{TeV})}}$

$$= 15 \times \left(\frac{965\ \mathrm{fb}}{249\ \mathrm{fb}} \sim 3.9\right) = 60$$

Signal scaling: $R_{sig} = \left(\dfrac{300\ \mathrm{fb}^{-1}}{20\ \mathrm{fb}^{-1}}\right) \times \boxed{\dfrac{\sigma_{\tilde{t}\tilde{t}^*}(14\ \mathrm{TeV})}{\sigma_{\tilde{t}\tilde{t}^*}(8\ \mathrm{TeV})}}$

= 15 x (~4-20 for $M_{stop}$ of 0.2-1 TeV) = 60-300



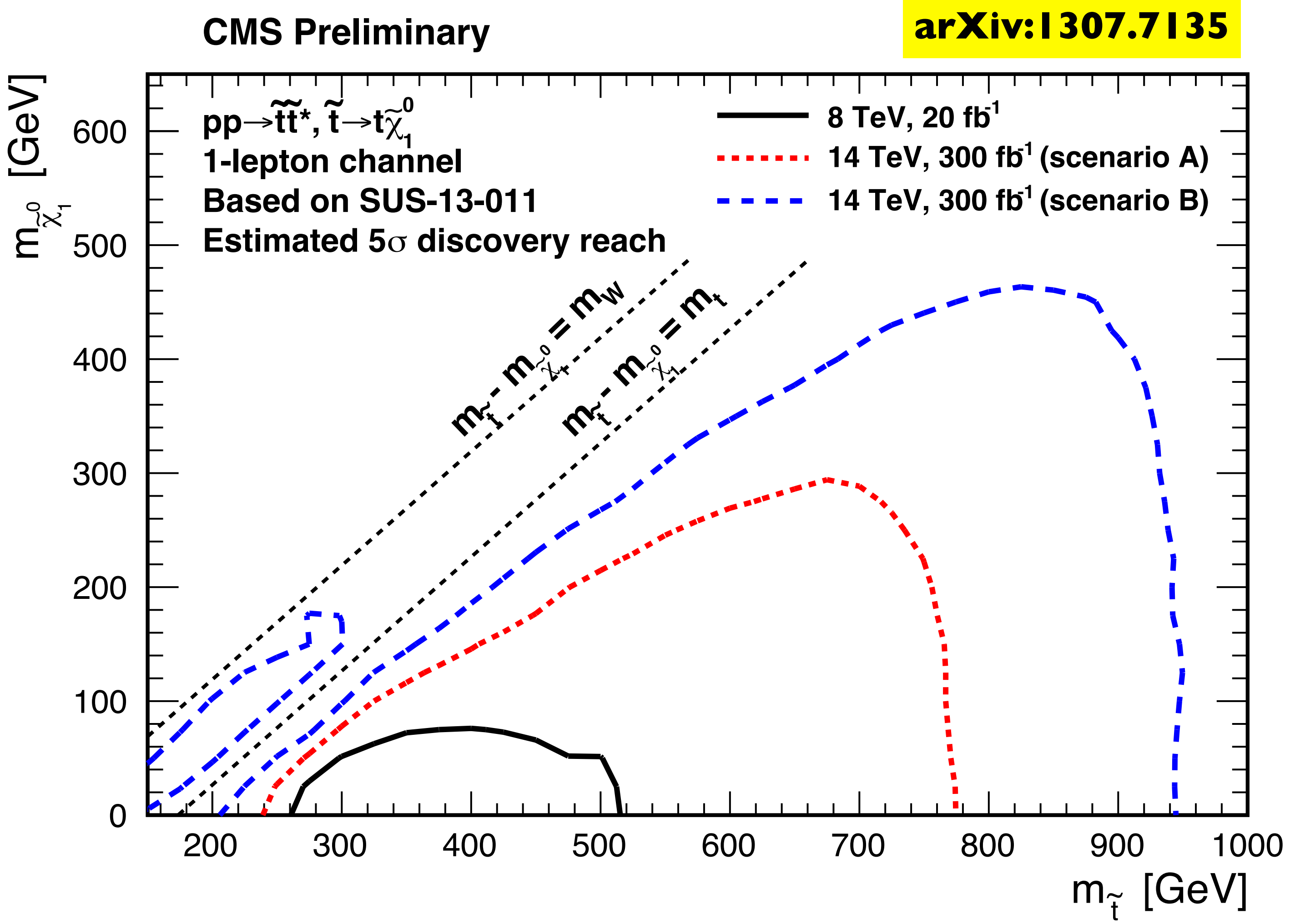

**Reduce background uncertainty by $\sqrt{R_{bkgd}}$ relative to Scenario A.**

# Interpreting Stop Projections

## Projections are too optimistic because:

- Increased pile-up.
  - Degradation of MET, $M_T$ resolution means more tt→ $\ell$ +jets and W+jets background survives the $M_T$ cut.
  - Additional jets means more tt→2 $\ell$ background.
  - Reduced lepton efficiency (eg. isolation).
- Increased trigger thresholds.
- Boosted stops and tops.

CMS Snowmass
arXiv:1307.7135

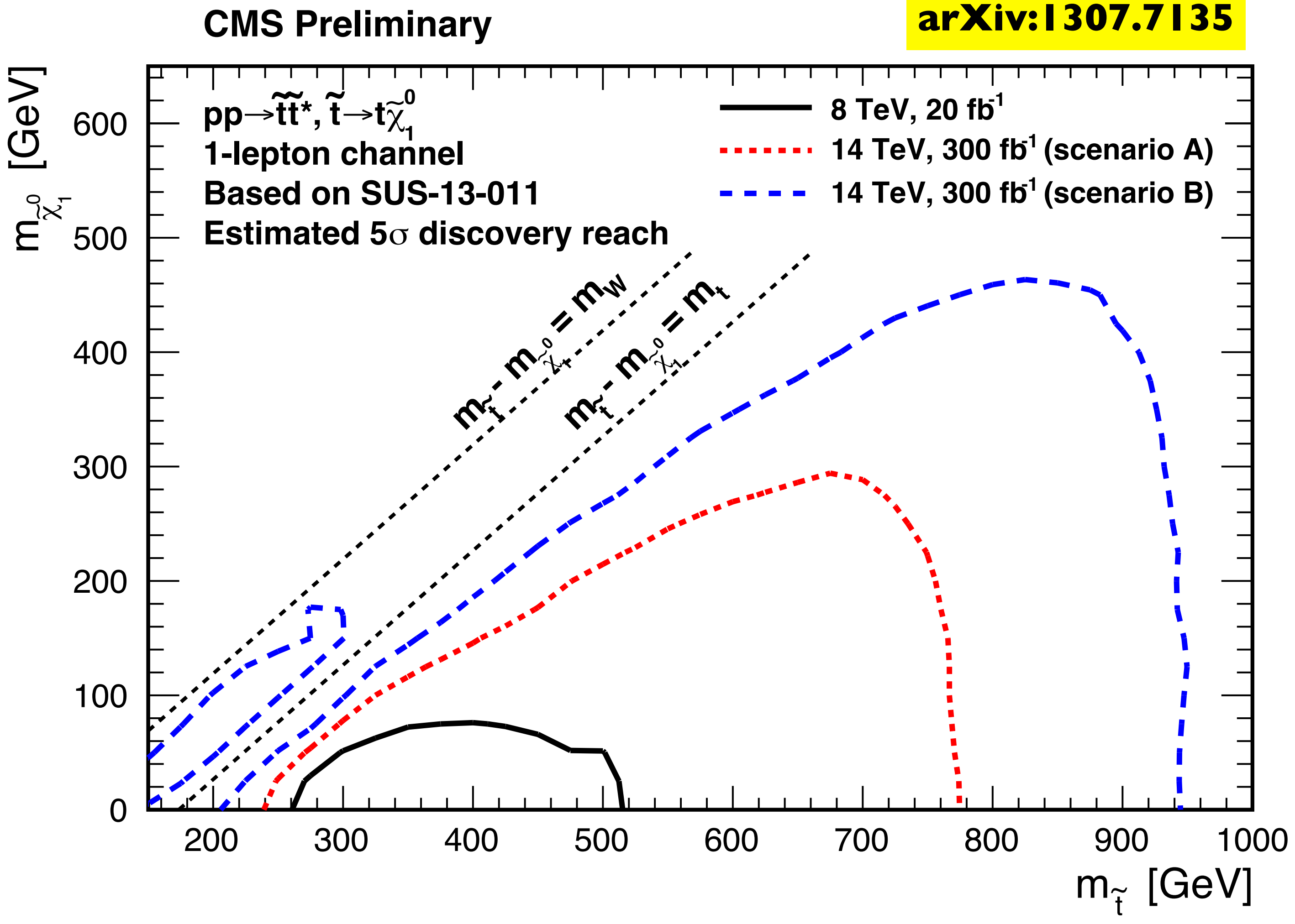


# Interpreting Stop Projections

## Projections are too pessmistic because:

- Scaling assumes no re-optimization of signal regions.
- The tightest signal region has:
  - $N_{bkgd}$ ~ 3 estimated from 8 TeV data.
  - $N_{bkgd}$ ~ 170 extrapolated to 14 TeV and 300 fb$^{-1}$.
- Can improve sensitivity by adding tighter signal regions.

CMS Snowmass
arXiv:1307.7135



# Summary

- CMS interprets a broad range of SUSY searches in a variety of SMS and pMSSM scenarios.
- We've significantly improved upon previous constraints on SUSY from direct searches.
- Limits from direct searches are beginning to expand and improve upon those from indirect searches → the era of constraining SUSY from direct searches is beginning.
- We're all looking forward with excitement to the next run of the LHC.

Details of all publicly available CMS results are available online:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP

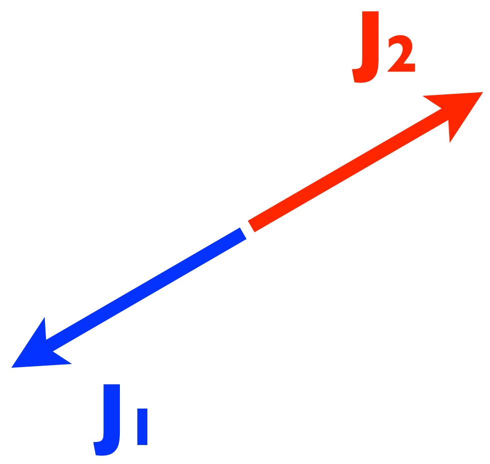
# Backup

# Overview of $\alpha_T$ (SUS-12-028)

- Search in bins of $N_{jets}$, $N_{b\text{-}tag}$, $H_T$.
- Use $\alpha_T$ to suppress multi-jet background.
- Dominant background depends on $N_{b\text{-}tag}$.
  - $N_{b\text{-}tag} = 0$: $Z(\nu\nu)$+jets, $W(\ell\nu)$+jets, $W(\tau\nu)$+jets
  - $N_{b\text{-}tag} > 0$: ttbar $\rightarrow$ $\ell$+jets
  - Estimated from simulation with data-MC scale factor measured in control region.

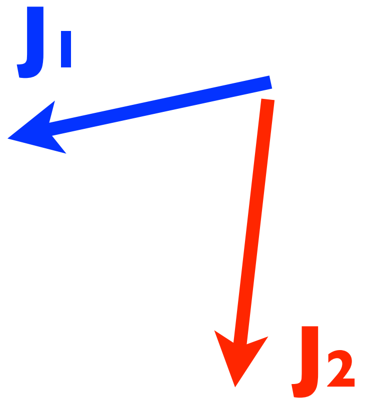
$$\alpha_T \equiv \frac{E_T^{J_2}}{M_T(J_1 J_2)} = \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{\sqrt{2(1-\cos\Delta\phi_{J_1 J_2})}}$$

**QCD**




$$\alpha_T \approx \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{2} \leq \frac{1}{2}$$

**SUSY**




$$\alpha_T \equiv \frac{1}{2} \times \frac{1-(\Delta H_T/H_T)}{\sqrt{1-(\not{H}_T/H_T)^2}}$$

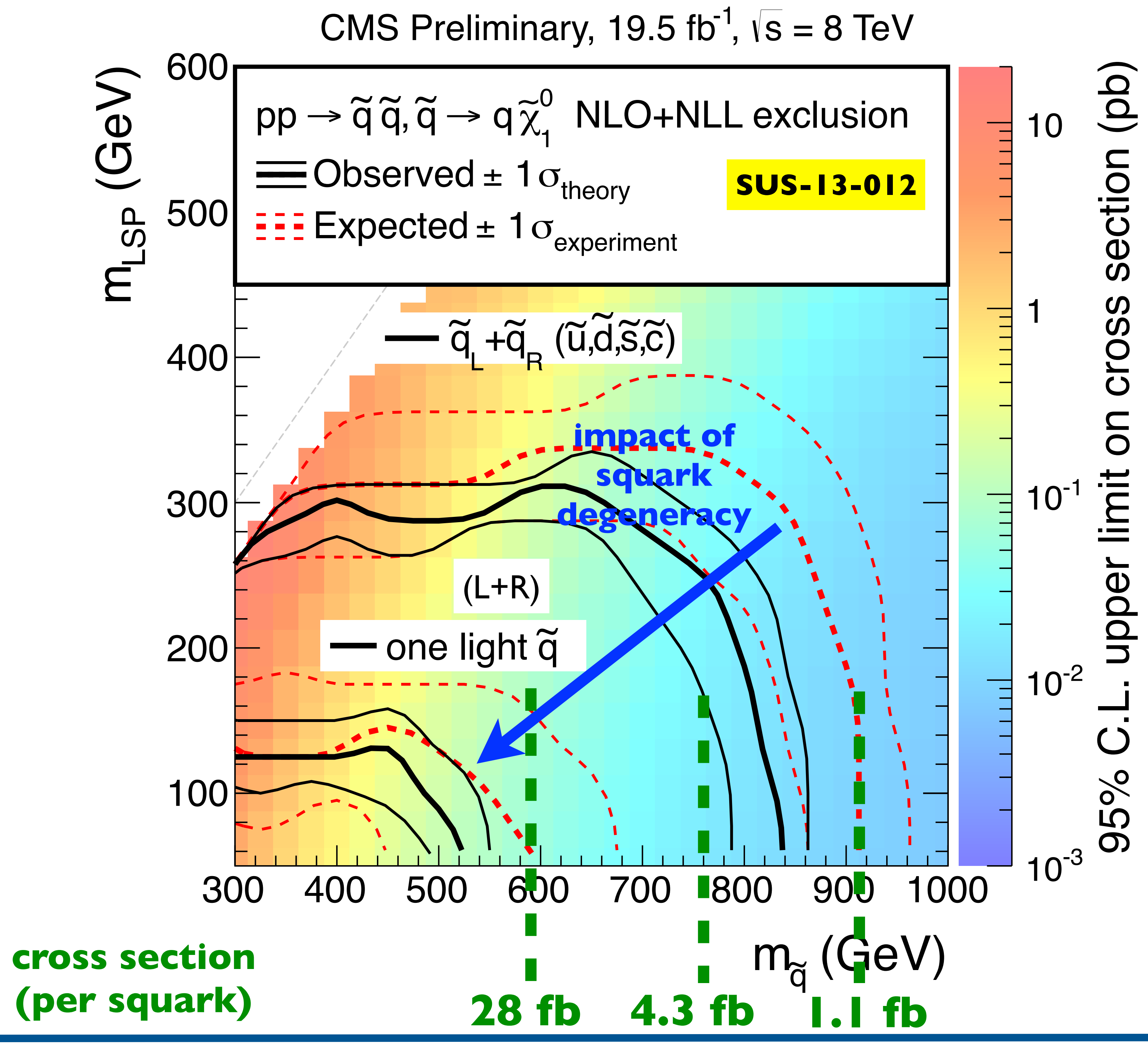
# Overview of HT+MHT (SUS-13-012)

- Counting experiment in exclusive bins of $H_T$, MHT and $N_{jets}$ (3-5, 6-7, ≥8).
  - Require at least three jets with $p_T$ > 50 GeV, no explicit b-tagging requirement.
  - Veto events with a lepton or where the MHT vector is aligned with any of 3 leading jets.

| **Backgrounds** | **Estimation Methods** |
| --- | --- |
| 1. Invisible decays: Z(νν)+jets. | 1. Estimate using γ+jets control sample. |
| 2. Lost lepton (ttbar, W+jets). | 2. Apply measured inefficiency to μ+jets control sample. |
| 3. Hadronic tau (ttbar, W+jets). | 3. Perform tau embedding using μ+jets control sample |
| 4. QCD multi-jet events. | 4. Rebalance and smear technique. |

# SUS-13-012: Squark Pair Production

- Loosest signal region requires at least 3 jets.
  - Sensitivity to squark pair production requires at least one additional jet from ISR/FSR.
- Impact of squark degeneracy.
  - SMS has implicit eightfold degeneracy. If there were only a single light squark (L+R), the production cross section decreases by a factor of 4, naively expect to probe squark masses up to 760 GeV.
  - Actual experimental sensitivity is only 590 GeV. Additional loss of sensitivity is experimental: lower squark mass → smaller boost to decay products → less MET and lower pt jets (smaller HT).



# SUS-13-012: Statistical Interlude

Slide courtesy of J. Richman. See SUSY plenary presentation in Wednesday session.

- The bin with $N_{jets}$ = 6 -7, $H_T$ = 500 - 800 GeV and MHT ≥ 450 GeV has an excess.
  - 9 events observed compared to an estimated background of 0.8 ± 1.7 events.
- If we ignore the uncertainty on the background, the probability for a Poisson with μ = 0.8 to fluctuate to at least 9 events is:
  - prob(n ≥ 9 | μ = 0.8) = 1.8 x 10-7. Have we discovered new physics?
- NO! The uncertainty is crucial!
  - prob(n ≥ 9 | μ = 0.8 ± 1.7) ≈ 0.15
  - **This example highlights the importance of quantifying the uncertainties on the SM backgrounds.**

# Overview of Stop Search (SUS-13-011)



SUS-13-011
arXiv:1308.1586

| | $\tilde{t} \to t\tilde{\chi}_1^0$ | | | $\tilde{t} \to b\tilde{\chi}_1^+$ | | |
|---|---|---|---|---|---|---|
| | | cut-based | | | cut-based | |
| Selection | BDT | Low $\Delta M$ | High $\Delta M$ | BDT | Low $\Delta M$ | High $\Delta M$ |
| $E_{\mathrm{T}}^{\mathrm{miss}}$(GeV) | yes | $>150, 200, 250, 300$ | $>150, 200, 250, 300$ | yes | $>100, 150, 200, 250$ | $>100, 150, 200, 250$ |
| $M_{\mathrm{T2}}^{\mathrm{W}}$ (GeV) | yes | | $>200$ | yes | | $>200$ |
| min $\Delta\phi$ | yes | $>0.8$ | $>0.8$ | yes | $>0.8$ | $>0.8$ |
| $H_{\mathrm{T}}^{\mathrm{ratio}}$ | yes | | | yes | | |
| hadronic top $\chi^2$ | (on-shell top) | $<5$ | $<5$ | | | |
| leading b-jet $p_{\mathrm{T}}$ (GeV) | (off-shell top) | | | yes | | $>100$ |
| $\Delta R(\ell,$leading b-jet) | | | | yes | | |
| lepton $p_{\mathrm{T}}$ | | | | (off shell W) | | |

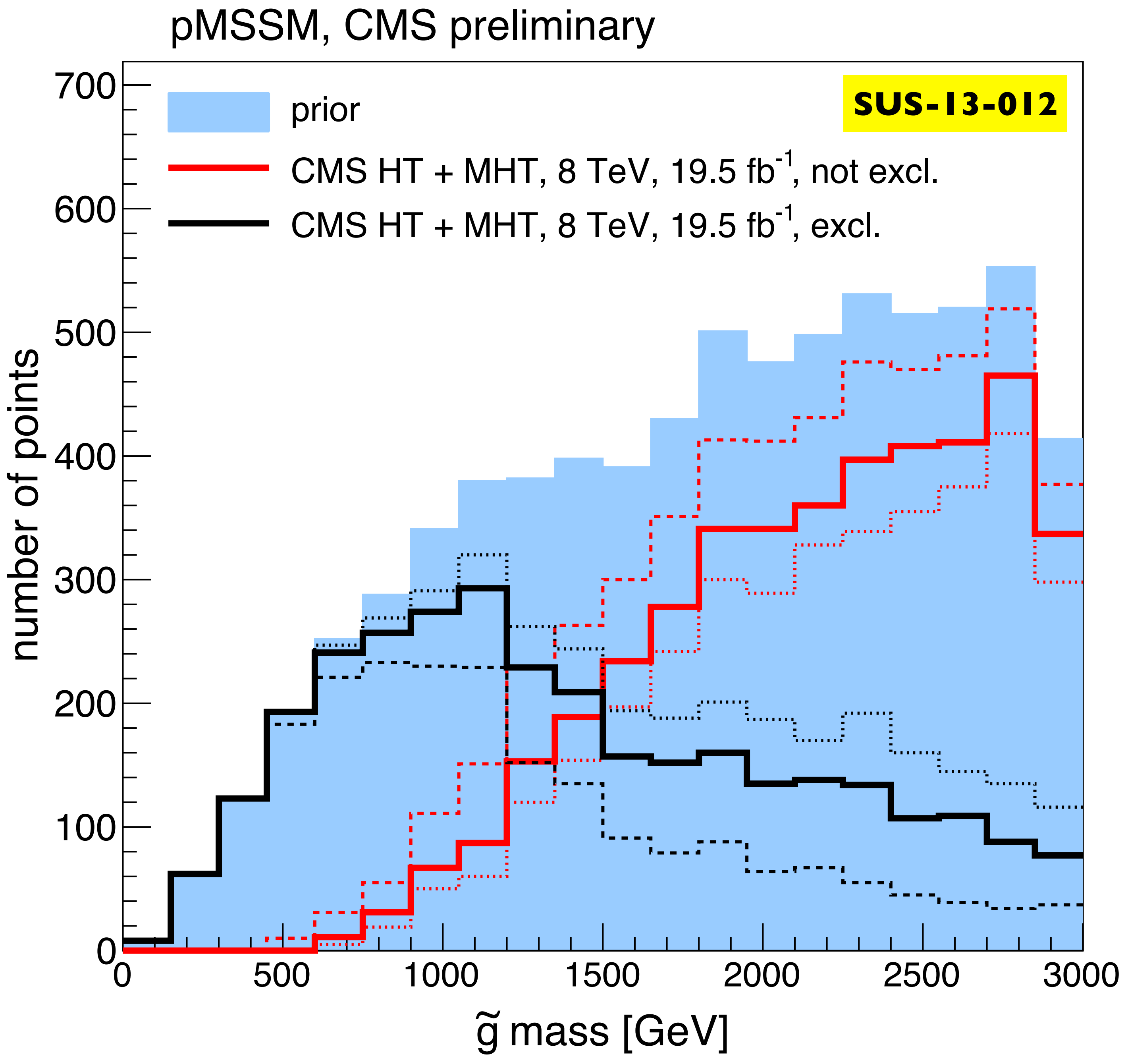
# pMSSM: preCMS constraints

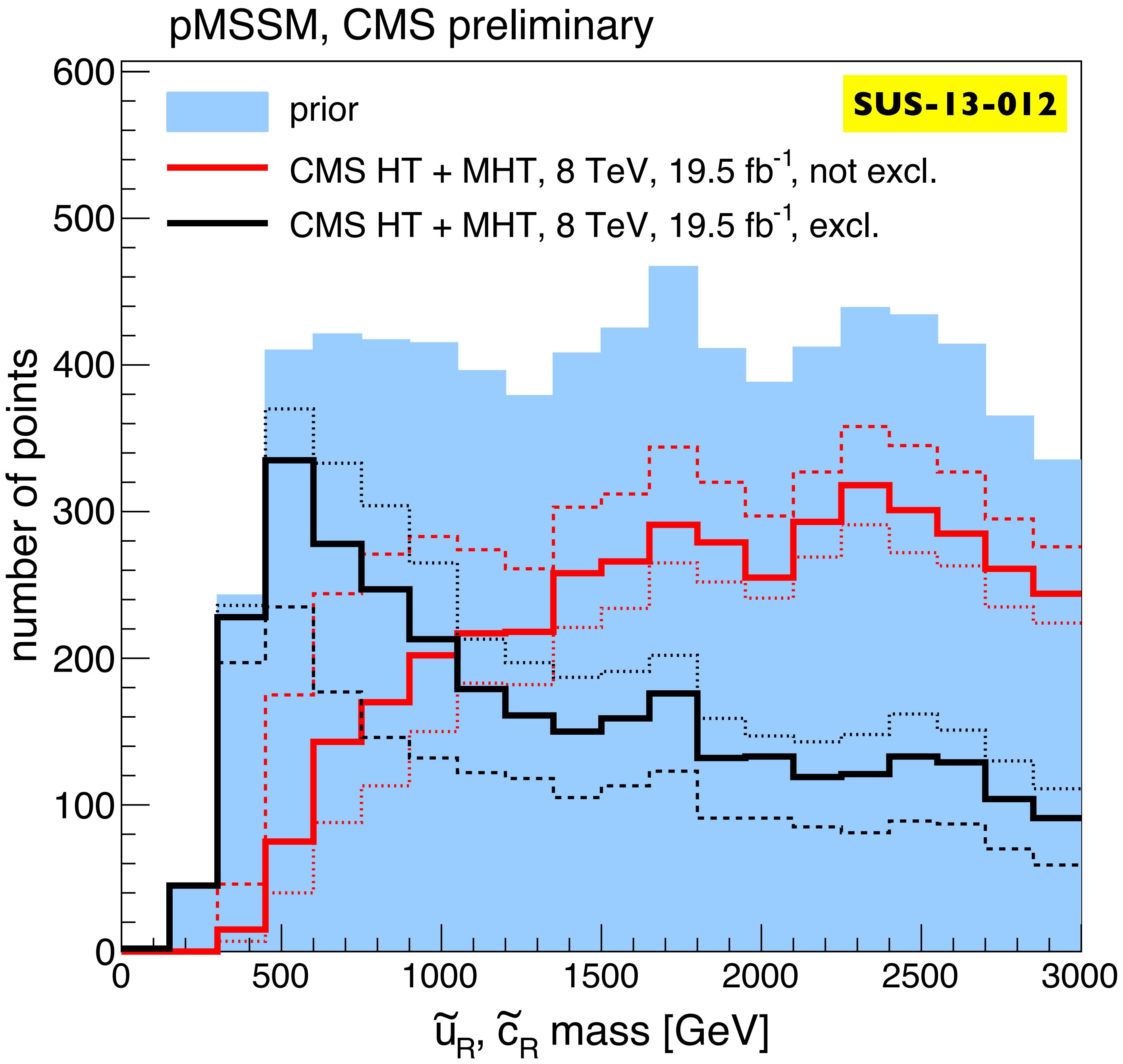
Table 1: The measurements that are the basis of our pMSSM prior $p^{\text{preCMS}}(\theta)$. All measurements except the measurement of $m_h$ at the LHC were used to sample points from the pMSSM parameter space via Markov Chain Monte Carlo (MCMC). The $m_h$ likelihood was imposed as a weight on the sampled points.

SUS-13-012

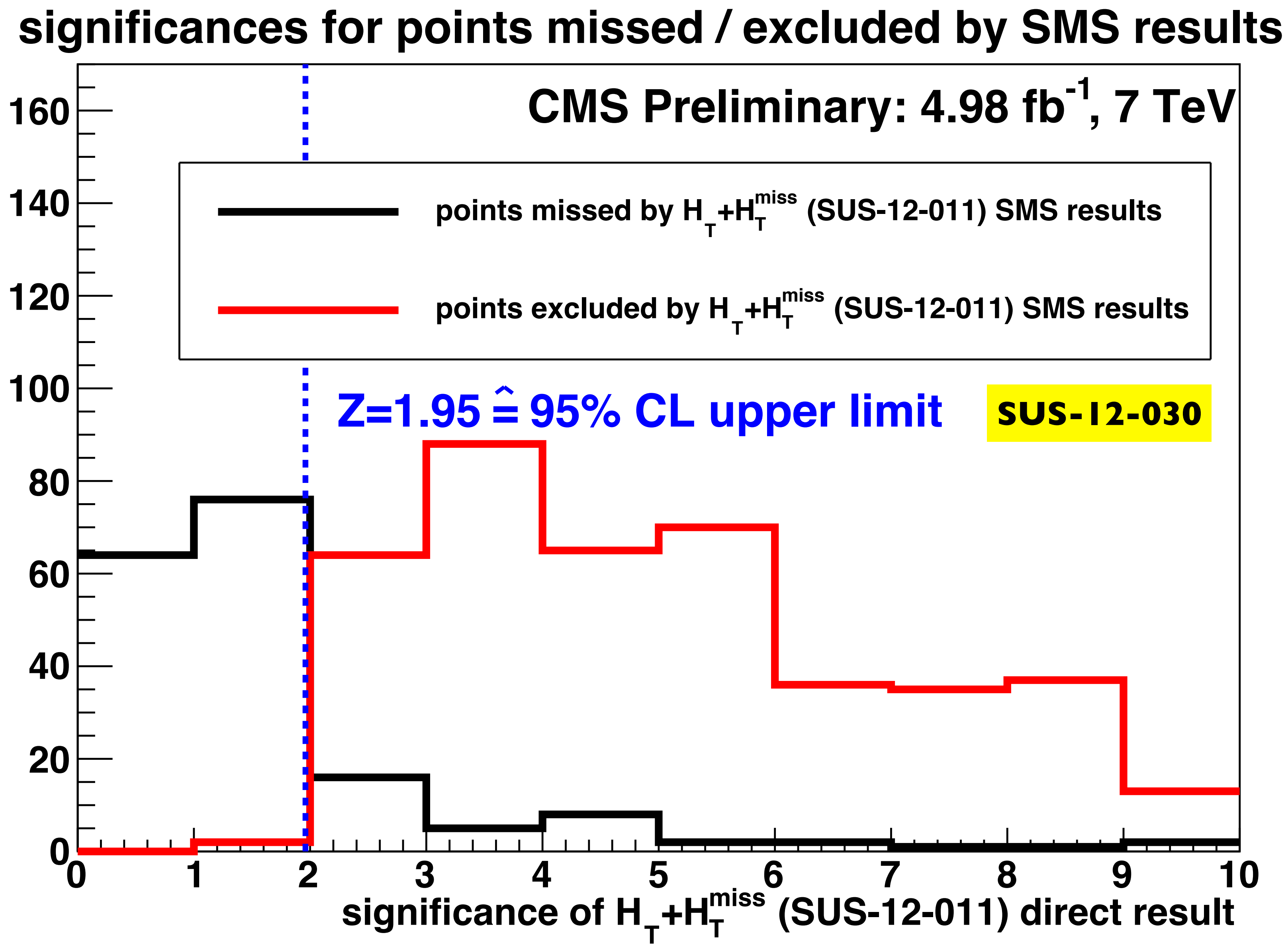
| $i$ | Observable $\mu_j(\theta)$ | Constraint $D_j^{\text{preCMS}}$ | Likelihood function $L(D_j^{\text{preCMS}}\|\mu_j(\theta))$ | MCMC / post-MCMC |
|---|---|---|---|---|
| 1 | $BR(b \to s\gamma)$ [28, 29] | $(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$ | Gaussian | MCMC |
| 2a | $BR(B_s \to \mu\mu)$ [30] | observed CLs curve from [30] | $d(1-CLs)/d(BR(B_s \to \mu\mu))$ | 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] | $1.63 \pm 0.54$ | Gaussian | MCMC |
| 4 | $\Delta a_\mu$ [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] | $0.1184 \pm 0.0007$ | Gaussian | MCMC |
| 8a | $m_h$ | pre-LHC: $m_h^{low} = 112$ | 1 if $m_h \geq m_h^{low}$<br>0 if $m_h < m_h^{low}$ | MCMC |
| 8b | $m_h$ | LHC: $m_h^{low} = 120$, $m_h^{up} = 130$ | 1 if $m_h^{low} \leq m_h \leq m_h^{up}$<br>0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$ | post-MCMC |
| 9 | sparticle masses | LEP [35] (via micrOMEGAs [23–25]) | 1 if allowed<br>0 if excluded | MCMC |
| 10 | prompt $\tilde{\chi}_1^\pm$ | $c\tau(\tilde{\chi}_1^\pm) < 10$ mm | 1 if allowed<br>0 if excluded | post-MCMC |

# Additional pMSSM Results

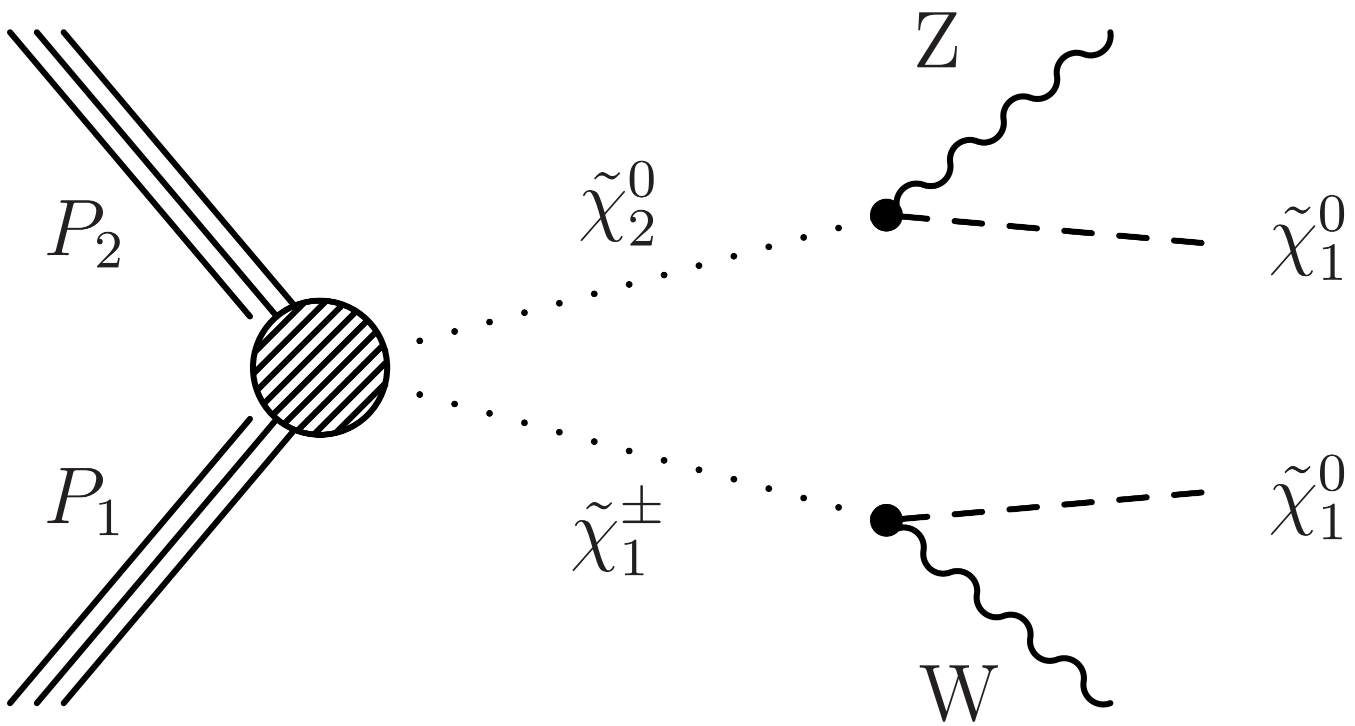


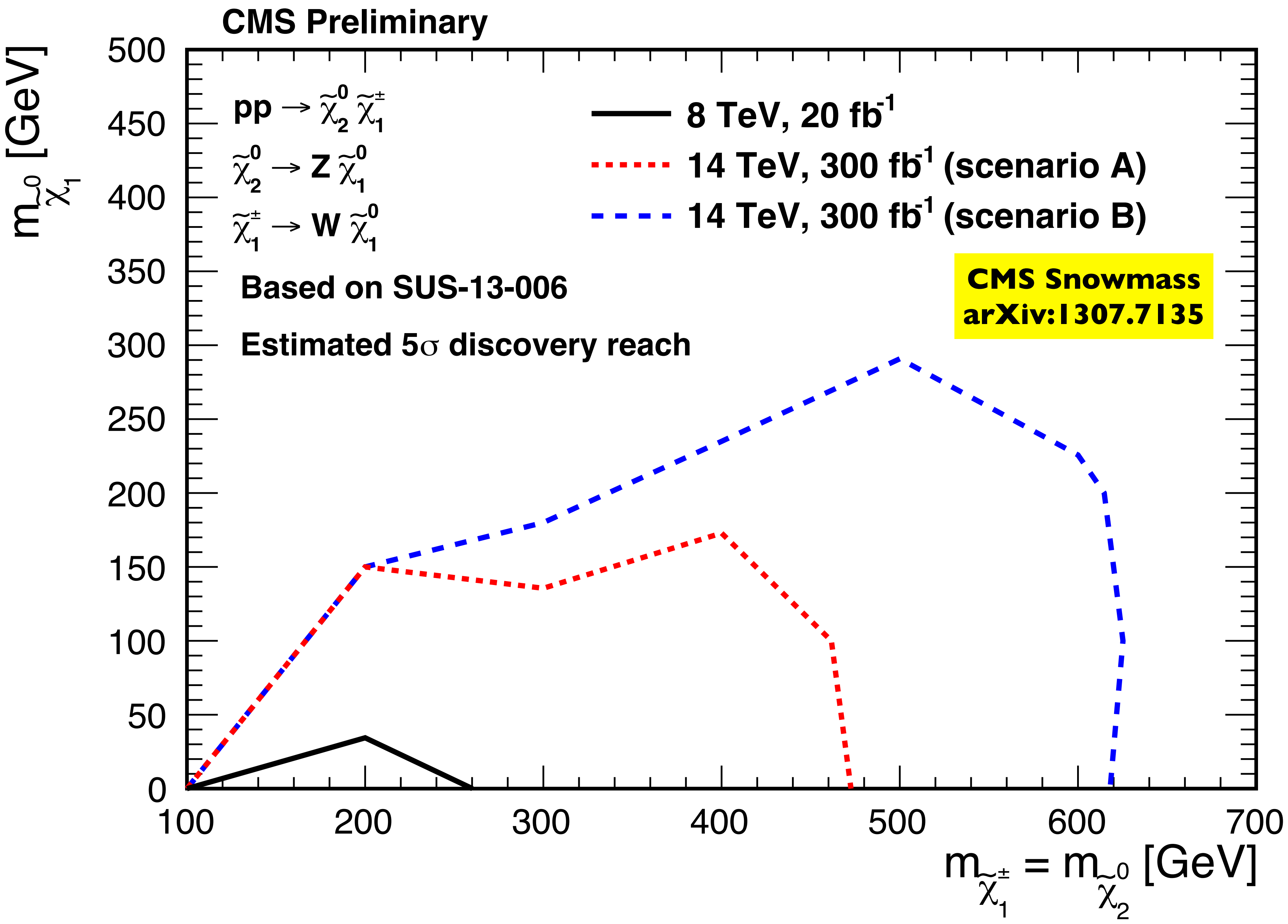



# Comparison of 7 TeV pMSSM with SMS




Cross check between pMSSM results and SMS results, for SUS-12-011. The histograms show the distributions of |Z| values, which are calculated through implementing the full analysis chain on each point. Points with Z > 2 are excluded whereas points with |Z| < 2 are unexplored (note that points with Z > 2 would point to discovery, however we do not have any such points in our list, therefore our set of points with |Z| > 2 fully consist of excluded points with Z < -2). The red histogram shows the |Z| distribution for points that are excluded by the SMSs, and the black curve shows the Z distribution for the points that are missed, or unexplored by the SMSs. The red histogram almost always has |Z|>2, which means that the points excluded by the SMSs are also excluded by the full analysis. The black histogram almost always has |Z|<2, which means that the points unexplored by the SMSs are also unexplored by the full analysis. A small part of the black histogram lies beyond |Z|>2, corresponding to points missed by the SMS results but excluded by the direct analysis.


Z
$P_2$
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
$P_1$
$\tilde{\chi}_1^\pm$
$\tilde{\chi}_1^0$
W


CMS Preliminary
$pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$
$\tilde{\chi}_2^0 \to Z \tilde{\chi}_1^0$
$\tilde{\chi}_1^\pm \to W \tilde{\chi}_1^0$
Based on SUS-13-006
Estimated $5\sigma$ discovery reach
8 TeV, 20 $fb^{-1}$
14 TeV, 300 $fb^{-1}$ (scenario A)
14 TeV, 300 $fb^{-1}$ (scenario B)
CMS Snowmass
arXiv:1307.7135
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^0}$ [GeV]
0
50
100
150
200
250
300
350
400
450
500
100
200
300
400
500
600
700