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 $\rightarrow$ 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 of SUSY Searches

$\tilde{q}\tilde{q}^*$ production ($gg \to \tilde{q}\tilde{q}^* \text{ @ LO}$)
gluino decoupled $\Rightarrow$ no $pp \to \tilde{q}\tilde{q} \text{ @ LO}$
simplified model $\Rightarrow BR(\tilde{q} \to q\tilde{\chi}_1^0) = 1$

$m_{\tilde{u}} = m_{\tilde{d}} = m_{\tilde{s}} = m_{\tilde{c}}$

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$m_{\tilde{u}} = m_{\tilde{d}} = m_{\tilde{s}} = m_{\tilde{c}}$
Impact of Squark Degeneracy

- Squark degeneracy $\rightarrow$ increased production rate.

![Graph showing the impact of squark degeneracy on production rates.](image)
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.

![Graph showing the impact of squark degeneracy on SUSY cross sections.](image)
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.

- From theory, expect only a factor of 8 decrease in cross section sensitivity → probe mass of ~650 GeV.

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CMS Preliminary
\( \sqrt{s} = 8 \) TeV
EPSHEP 2013

\( \tilde{q} \tilde{q} \) production, \( \tilde{q} \rightarrow q \tilde{\chi}_1^0 \)

- Observed
- Observed -1\( \sigma \)_SUSY theory
- Expected

\( \tilde{q}_L + \tilde{q}_R \) (\( \tilde{u}, \tilde{d}, \tilde{s}, \tilde{c} \))

Enhance \( \sigma \) by a factor of 8 relative to a single squark

- 19.5 fb
- 11.7 fb
- 1.8 fb

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\( \chi \sim q \rightarrow q \tilde{\chi} \) production,

- 120 fb
- 14 fb
- 1.8 fb

\( \sigma \downarrow \times 8 \)

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SUSY-13-012 0-lep (H\( \rightarrow \)g) 19.5 fb
SUS-12-028 0-lep (\( \rightarrow \)) 11.7 fb
\((N_{b-tag} = 0, N_{jets} = 2,3)\)

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Impact of Squark Degeneracy

- Squark degeneracy $\rightarrow$ increased production rate.

- For a scenario with a single light squark, the mass probed decreases from 850 GeV $\rightarrow$ 475 GeV.

- This represents a factor of 70 decrease in the squark pair production cross section.

- From theory, expect only a factor of 8 decrease in cross section sensitivity $\rightarrow$ probe mass of $\sim$650 GeV.

- Remaining decrease in sensitivity is experimental: lower squark mass $\rightarrow$ smaller boost to decay products $\rightarrow$ 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 \( \mu \).
- \( \geq 4 \) jets with \( \geq 1 \) b-tagged jet.
- Missing Transverse Energy.
- Veto events with a second lepton.

Search Strategy

- Search in \( M_T \) tail \( \rightarrow M_T(\ell, \text{MET}) \gg M_W \).
- 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

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

- How are limits impacted if $BR \neq 1$?

For more on stop searches, see talk by M. D’Alfonso.
Impact of Branching Ratio

- Consider a “natural” scenario, where
  \[ \Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \ll M_W \]

- Small \( \Delta m \to W \) decay products not reconstructed.

- Two less jets in final state \( \to \) 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.

\[ \sqrt{s} = 8 \text{ TeV}, \int L dt = 19.5 \text{ fb}^{-1} \]

**Observed limits**

- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 1.0 \)
- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 0.9 \)
- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 0.8 \)
- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 0.7 \)
- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 0.6 \)
- \( BF(\tilde{t} \to t\tilde{\chi}_1^0) = 0.5 \)
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:
  - $b \to s\gamma$, $B \to \tau\nu$, $B_s \to \mu\mu$
  - $M_t, M_b, M_h$, sparticle masses
  - $\alpha_s, \Delta a_\mu$
  - prompt chargino ($cT < 10 \text{ mm}$)
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 $\sigma_{\text{total}}$ 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 $\sigma_{\text{total}}$ down.
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 $\sigma_{\text{total}} < 10$ fb $\rightarrow$ some of these will be probed by the 8 TeV analyses.

- Remaining had $\sigma_{\text{total}} > 10$ fb $\rightarrow$ interesting to look at these in more detail.

2198 / 4504 points with $\sigma^{\text{prod}} > 10$ fb

CMS Preliminary: 4.98 fb$^{-1}$, 7 TeV

(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.

<table>
<thead>
<tr>
<th>channel</th>
<th>&gt; 90%</th>
<th>50 - 90%</th>
<th>10 - 50%</th>
<th>&lt; 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\chi}_i\tilde{\chi}_j$</td>
<td>40.4</td>
<td>14</td>
<td>11.8</td>
<td>33.8</td>
</tr>
<tr>
<td>$\tilde{q}\tilde{q}^*$</td>
<td>11.9</td>
<td>18.1</td>
<td>12.8</td>
<td>57.2</td>
</tr>
<tr>
<td>$\tilde{g}\tilde{g}$</td>
<td>1.5</td>
<td>2.1</td>
<td>2.6</td>
<td>93.9</td>
</tr>
<tr>
<td>$\tilde{q}\tilde{g}$</td>
<td>0.0</td>
<td>0.6</td>
<td>6.1</td>
<td>93.3</td>
</tr>
<tr>
<td>$\tilde{\chi}\tilde{q}$</td>
<td>0.0</td>
<td>0.3</td>
<td>6.3</td>
<td>93.4</td>
</tr>
<tr>
<td>$\tilde{t}\tilde{t}^*$</td>
<td>0.3</td>
<td>0.5</td>
<td>1.8</td>
<td>97.4</td>
</tr>
<tr>
<td>$\tilde{\ell}\tilde{\ell}^*$</td>
<td>0.1</td>
<td>0.1</td>
<td>1.6</td>
<td>98.2</td>
</tr>
<tr>
<td>$\tilde{\chi}\tilde{g}$</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
<td>99.7</td>
</tr>
</tbody>
</table>
Compressed Spectra

- Most unexplored points with large cross sections have a compressed spectrum.

- Two scenarios predominate: those with small $\sigma_{\text{total}}$ will be helped by an increase in luminosity. Those with a compressed spectrum require dedicated searches.

![Particle masses of missed weakino points, $\sigma > 10$ fb](Image)

CMS Preliminary: 4.98 fb$^{-1}$, 7 TeV

SUS-12-030

Chargino/heavy neutralino mass [GeV]

LSP mass [GeV]

![Particle masses of missed squark points, $\sigma > 10$ fb](Image)

CMS Preliminary: 4.98 fb$^{-1}$, 7 TeV

$\Delta m(\tilde{q}, \tilde{\chi}_1^0) < 200$ GeV

SUS-12-030

Mass of lightest squark [GeV]

LSP mass [GeV]
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.

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CMS Snowmass arXiv:1307.7135

example natural SUSY spectrum

see for example: arXiv:1110.6926 Papucci, et. al.
“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.”


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 $\sigma \times L$.
  - **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.

<table>
<thead>
<tr>
<th>Process</th>
<th>Decay</th>
<th>Search</th>
<th>Current (TeV)</th>
<th>Scenario A (TeV)</th>
<th>Scenario B (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \to \tilde{g}\tilde{g}$</td>
<td>$\tilde{g} \to \tilde{t}\tilde{\chi}_1^0$</td>
<td>$\ell + b + \not{E}_T$</td>
<td>1.1 TeV</td>
<td>1.9 TeV</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>$\tilde{g} \to \tilde{b}\tilde{\chi}_1^0$</td>
<td>$b + \not{E}_T$</td>
<td>1.1 TeV</td>
<td>1.9 TeV</td>
<td>–</td>
</tr>
<tr>
<td>$pp \to \tilde{b}\tilde{b}^*$</td>
<td>$\tilde{b} \to t\tilde{\chi}_1^- \to tW^*\tilde{\chi}_1^0$</td>
<td>$\ell^\pm \ell'^\pm + b + \not{E}_T$</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
</tr>
<tr>
<td>$pp \to \tilde{t}\tilde{t}^*$</td>
<td>$\tilde{t} \to t\tilde{\chi}_1^0$</td>
<td>$\ell + b + \not{E}_T$</td>
<td>0.25-0.5</td>
<td>0.75</td>
<td>0.95</td>
</tr>
<tr>
<td>$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0$</td>
<td>$WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$</td>
<td>$3\ell + \not{E}_T$</td>
<td>0.25</td>
<td>0.45</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>$WH\tilde{\chi}_1^0\tilde{\chi}_1^0$</td>
<td>$\ell + b + \not{E}_T$</td>
<td>0.2</td>
<td>0.4</td>
<td>&gt;0.5</td>
</tr>
</tbody>
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Snowmass Projections

- Scale signal and background by cross section ratios ($\sigma_{14\text{ TeV}}/\sigma_{8\text{ TeV}}$) and luminosity ($300/20 \sim 15$).

- Estimate $5\sigma$ discovery reach for two scenarios:
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- As an example, let's consider the stop projection in more detail.

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<tr>
<td>$pp \rightarrow \tilde{g}\tilde{g}$</td>
<td>$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$</td>
<td>$\ell + b + E_T$</td>
<td>1.1 TeV</td>
<td>1.9 TeV</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$</td>
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<td>1.1 TeV</td>
<td>1.9 TeV</td>
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<tr>
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<td>$\tilde{b} \rightarrow t\tilde{\chi}_1^- \rightarrow tW\tilde{\chi}_1^0$</td>
<td>$\ell^\pm \ell^\mp + b + E_T$</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
</tr>
<tr>
<td>$pp \rightarrow \tilde{t}\tilde{t}^*$</td>
<td>$\tilde{t} \rightarrow t\tilde{\chi}_1^0$</td>
<td>$\ell + b + E_T$</td>
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<td>0.75</td>
<td>0.95</td>
</tr>
<tr>
<td>$pp \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0$</td>
<td>$WZ\tilde{\chi}_1^0\tilde{\chi}_2^0$</td>
<td>$3\ell + E_T$</td>
<td>0.25</td>
<td>0.45</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>$WH\tilde{\chi}_1^0\tilde{\chi}_2^0$</td>
<td>$\ell + b + E_T$</td>
<td>0.2</td>
<td>0.4</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>

See talk by B. Hooberman for EWK SUSY searches, including new results on SUSY→Higgs.
Significance = \[ \frac{N_{\text{sig}}}{\sqrt{N_{\text{bkgd}} + \sigma_{\text{bkgd}}^2}} \]

Bkgd scaling:
\[ R_{\text{bkgd}} = \left( \frac{300 \text{ fb}^{-1}}{20 \text{ fb}^{-1}} \right) \times \frac{\sigma_{\tilde{t}\tilde{t}^*}(14 \text{ TeV})}{\sigma_{\tilde{t}\tilde{t}^*}(8 \text{ TeV})} \]

\[ = 15 \times \left( \frac{965 \text{ fb}}{249 \text{ fb}} \sim 3.9 \right) = 60 \]

Signal scaling:
\[ R_{\text{sig}} = \left( \frac{300 \text{ fb}^{-1}}{20 \text{ fb}^{-1}} \right) \times \frac{\sigma_{\tilde{t}\tilde{t}^*}(14 \text{ TeV})}{\sigma_{\tilde{t}\tilde{t}^*}(8 \text{ TeV})} \]

\[ = 15 \times (\sim 4-20 \text{ for } M_{\text{stop}} \text{ of } 0.2-1 \text{ TeV}) = 60-300 \]
Interpreting Stop Projections

Projections are too optimistic because:

- Increased pile-up.
- Degradation of MET, $M_T$ resolution means more $t\bar{t}\rightarrow \ell +$jets and $W+$jets background survives the $M_T$ cut.
- Additional jets means more $t\bar{t}\rightarrow 2\ell$ background.
- Reduced lepton efficiency (eg. isolation).
- Increased trigger thresholds.
- Boosted stops and tops.
Interpreting Stop Projections

Projections are too pessimistic because:

• Scaling assumes no re-optimization of signal regions.
• The tightest signal region has:
  • $N_{\text{bkgd}} \sim 3$ estimated from 8 TeV data.
  • $N_{\text{bkgd}} \sim 170$ extrapolated to 14 TeV and 300 $\text{fb}^{-1}$.
• Can improve sensitivity by adding tighter signal regions.
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 $N_{\text{jets}}, N_{\text{b-tag}}, H_T$.
- Use $\alpha_T$ to suppress multi-jet background.
- Dominant background depends on $N_{\text{b-tag}}$.
  - $N_{\text{b-tag}} = 0$: $Z(\nu\nu)+\text{jets}$, $W(\ell\nu)+\text{jets}, W(\tau\nu)+\text{jets}$
  - $N_{\text{b-tag}} > 0$: $t\bar{t} \rightarrow \ell + \text{jets}$
- Estimated from simulation with data-MC scale factor measured in control region.

\[
\alpha_T \equiv \frac{E_T^{J_2}}{M_T(J_1J_2)} = \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{2(1 - \cos \Delta \phi_{J_1J_2})}
\]

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

- QCD

\[
QCD \approx \frac{1}{2} \times \frac{1 - \Delta H_T/H_T}{\sqrt{1 - (H_T/H_T)^2}}
\]

- SUSY
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**

1. Invisible decays: $Z(\nu\nu)+$jets.
2. Lost lepton (ttbar, W+jets).
3. Hadronic tau (ttbar, W+jets).
4. QCD multi-jet events.

**Estimation Methods**

1. Estimate using $\gamma+$jets control sample.
2. Apply measured inefficiency to $\mu+$jets control sample.
3. Perform tau embedding using $\mu+$jets control sample.
4. Rebalance and smear technique.
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 $\rightarrow$ smaller boost to decay products $\rightarrow$ less MET and lower pt jets (smaller HT).
• The bin with $N_{\text{jets}} = 6-7$, $H_T = 500 - 800$ GeV and $\text{MHT} \geq 450$ GeV has an excess.

• 9 events observed compared to an estimated background of $0.8 \pm 1.7$ events.

• If we ignore the uncertainty on the background, the probability for a Poisson with $\mu = 0.8$ to fluctuate to at least 9 events is:

$$\text{prob}(n \geq 9 \mid \mu = 0.8) = 1.8 \times 10^{-7}.$$  Have we discovered new physics?

• NO! The uncertainty is crucial!

$$\text{prob}(n \geq 9 \mid \mu = 0.8 \pm 1.7) \approx 0.15$$

• This example highlights the importance of quantifying the uncertainties on the SM backgrounds.
Overview of Stop Search (SUS-13-011)

<table>
<thead>
<tr>
<th>Selection</th>
<th>$\tilde{t} \rightarrow t\tilde{\chi}_1^0$ cut-based</th>
<th>$\tilde{t} \rightarrow b\tilde{\chi}_1^+$ cut-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cut-based</td>
<td>cut-based</td>
</tr>
<tr>
<td></td>
<td>Low $\Delta M$</td>
<td>High $\Delta M$</td>
</tr>
<tr>
<td></td>
<td>$&gt; 150, 200, 250, 300$</td>
<td>$&gt; 150, 200, 250, 300$</td>
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<td></td>
<td>$&gt; 200$</td>
<td>$&gt; 200$</td>
</tr>
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<td>$&gt; 0.8$</td>
<td>$&gt; 0.8$</td>
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<tr>
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<td>$&lt; 5$</td>
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<tr>
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<td>yes</td>
</tr>
<tr>
<td>$M_W^{T2}$ (GeV)</td>
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<td>yes</td>
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<tr>
<td>min $\Delta \phi$</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>$H_T^{ratio}$</td>
<td>yes (on-shell top)</td>
<td>yes (off-shell W)</td>
</tr>
<tr>
<td>leading b-jet $p_T$ (GeV)</td>
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<td></td>
</tr>
<tr>
<td>$\Delta R(\ell, \text{leading b-jet})$</td>
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<td></td>
</tr>
<tr>
<td>lepton $p_T$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# 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.

| \( i \) | Observable \( \mu_i(\theta) \) | Constraint \( D_i^{\text{preCMS}} \) | Likelihood function \( L(D_i^{\text{preCMS}} | \mu_i(\theta)) \) | 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 |
| 2b    | \( BR(B_s \to \mu\mu) \) [31] | observed CLs curve from [30] \( 3.2^{+1.5}_{-1.2} \times 10^{-9} \) | \( d(1 - \text{CLs})/d(BR(B_s \to \mu\mu)) \) 2-sided Gaussian | MCMC post-MCMC |
| 3     | \( R(B_d \to \tau\nu) \) [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] | \( 173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}} \text{ GeV} \) | Gaussian | MCMC |
| 6     | \( m_b \) [32] | \( 4.19^{+0.18}_{-0.06} \text{ GeV} \) | Two-sided Gaussian | MCMC |
| 7     | \( \alpha_s(M_Z) \) [32] | \( 0.1184 \pm 0.0007 \) | Gaussian | MCMC |
| 8a    | \( m_h \) | pre-LHC: \( m_h^{\text{low}} = 112 \) | 1 if \( m_h \geq m_h^{\text{low}} \) \newline \( 0 \) if \( m_h < m_h^{\text{low}} \) | MCMC |
| 8b    | \( m_h \) | LHC: \( m_h^{\text{low}} = 120 \), \( m_h^{\text{up}} = 130 \) \newline 1 if allowed \newline 0 if excluded | \( 1 \) if \( m_h^{\text{low}} \leq m_h \leq m_h^{\text{up}} \) \newline \( 0 \) if \( m_h < m_h^{\text{low}} \) or \( m_h > m_h^{\text{up}} \) | MCMC |
| 9     | sparticle masses | LEP [35] (via micrOMEGAs [23–25]) | 1 if allowed \newline 0 if excluded | MCMC |
| 10    | prompt \( \tilde{\chi}_1^\pm \) | \( c\tau(\tilde{\chi}_1^\pm) < 10 \text{ mm} \) | 1 if allowed \newline 0 if excluded | MCMC |
Additional pMSSM Results

pMSSM, CMS preliminary

- Prior
- CMS HT + MHT, 8 TeV, 19.5 fb⁻¹, not excl.
- CMS HT + MHT, 8 TeV, 19.5 fb⁻¹, excl.

Mass [GeV]

0 500 1000 1500 2000 2500 3000

Number of points

0 100 200 300 400 500 600 700

pMSSM, CMS preliminary

- Prior
- CMS HT + MHT, 8 TeV, 19.5 fb⁻¹, not excl.
- CMS HT + MHT, 8 TeV, 19.5 fb⁻¹, excl.

Mass [GeV]

0 500 1000 1500 2000 2500 3000

Number of points

0 100 200 300 400 500 600 700

SUS-13-012
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.

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.
Snowmass: Electroweak Production

\[ \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0 \]

Based on SUS-13-006

Estimated 5\( \sigma \) discovery reach

CMS Preliminary

arXiv:1307.7135