Three searches for squarks and gluinos with the CMS detector using kinematic variables

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On behalf of the CMS Collaboration

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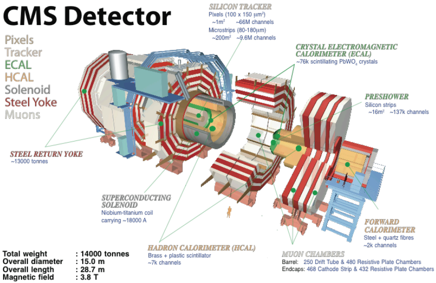
Introduction

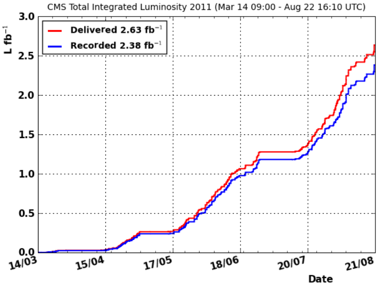
- CMS has a broad range of searches for events with escaping undetected particles from, e.g., SUSY with R-parity conservation. They are organized by numbers of leptons and photons required.

- Described here are three different searches which use primarily all-hadronic events: α_{T}, M_{T2}, Razor. Shared features include strong suppression of multi-jet backgrounds and variables related to mass scales. Substantial differences include triggers, signal selection, and background estimation methods.

- Results from analyzing 1.1/fb (35/pb) of data are presented and interpreted in both the CMSSM and "simplified models".

The CMS Detector





- Excellent performance and live-time in 2011.
- SUSY searches exercise every sub-detector!

The search using M_{T2}

- M_{T2} is a generalization of transverse mass to a system with two semi-invisibly decaying particles [Lester, Summers, 1999]:

$$M_{T2}(m_\chi) = \min_{p_T^{\chi(1)} + p_T^{\chi(2)} = p_T^{miss}} \left[\max\left(m_T^{(1)}, m_T^{(2)} \right) \right]$$

- Each m_T is the transverse mass of a sparticle decaying to a visible system and LSP; for the correct value of m_χ, M_{T2} has an endpoint at the parent sparticle mass.
- Assuming zero masses and no ISR or UTM, M_{T2} assumes a simple form: $(M_{T2})^2 = 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12}) \implies$ apparent that back-to-back visible systems have low M_{T2}
- For an n-jet system, two "pseudo-jets" are formed from reconstructed event hemispheres.

M_{T2} search: trigger, objects, vetoes

Trigger $H_{\mathrm{T}} > 550\ \mathrm{GeV}$

MET Built from reconstructed particles.

Jets Anti-k_T, $R = 0.5$; built from reconstructed particles; $|\eta| < 2.4$, $p_{\mathrm{T}} > 20\ \mathrm{GeV}$.

~~Leptons~~ Veto events with an iso. muon or electron with $p_{\mathrm{T}} > 10\ \mathrm{GeV}$.

~~Noise~~ Veto events with a jet which fails loose ID requirements.

Further:

- $|MHT - MET| < 70\ \mathrm{GeV}$, to protect against several low-p_{T} jets pointing in the same direction.
- $\min_j \Delta\phi(\mathrm{jet}, MET) > 0.3$ to protect against severely mis-mismeasured jets.

M_{T2} search: two signal selections

"High M_{T2}" selection

- $H_{\mathrm{T}} > 600\ \mathrm{GeV}$
- $N_{\mathrm{jets}} \geq 3$
- Leading two jets have $p_{\mathrm{T}} > 100\ \mathrm{GeV}$
- $M_{T2} > 400\ \mathrm{GeV}$

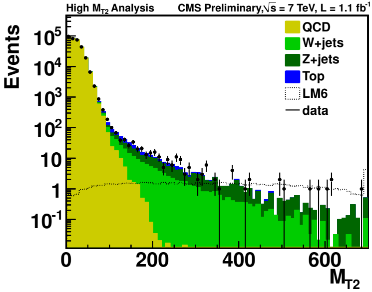
- Targets models with heavy sparticles.

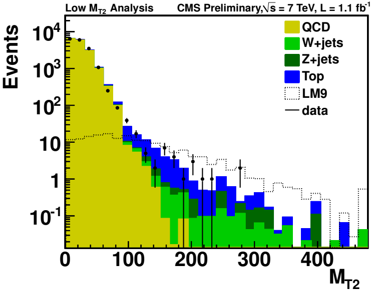
"Low M_{T2}" selection

- $H_{\mathrm{T}} > 650\ \mathrm{GeV}$
- $N_{\mathrm{jets}} \geq 4$; $N_{\mathrm{b\text{-}jets}} \geq 1$
- Leading (second) jet has $p_{\mathrm{T}} > 150(100)\ \mathrm{GeV}$
- $M_{T2} > 150\ \mathrm{GeV}$

- Targets models with large m_{squark} and small m_{gluino}.

M_{T2} search: observed distributions





[numbers are in GeV]

- signal region: $400 < M_{T2}$
- control region: $200 < M_{T2} < 400$

- signal region: $150 < M_{T2}$
- control region: $100 < M_{T2} < 150$

M_{T2} search: yields and background estimation

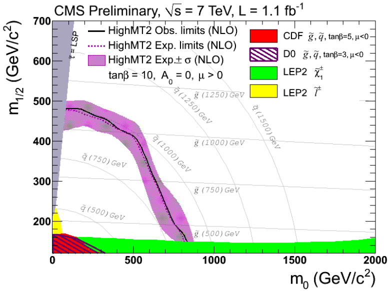
- The QCD background was estimated from a control region using the form $r(M_{T2}) = \frac{N(\Delta\phi_{min} \geq 0.3)}{N(\Delta\phi_{min} \leq 0.2)} = \exp(a - b \cdot M_{T2}) + c$, validated in MC, tested with variations of fit range and cut values, emulated catastrophic jet loss. Contribution found to be negligible for both analyses (< 1 event).

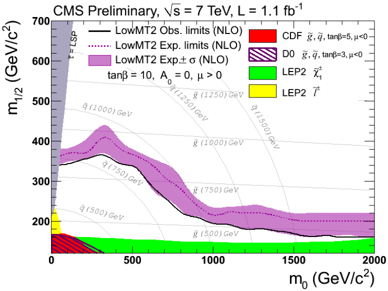
- $\mathrm{W} \to \mu\nu$ and $\mathrm{W} \to \mathrm{e}\nu$ samples were selected by inverting the lepton vetoes in the M_{T2} control region and used to predict:
  - W and $\mathrm{t\bar{t}}$ backgrounds from unobs. leptons (using loss probs.)
  - $\mathrm{Z} \to \nu\bar{\nu}$ background (using $\mathrm{t\bar{t}}$ subtraction; W-to-Z correction)

- Results (1.1/fb):

search	N_{obs}	data-driven pred.	MC pred.
High M_{T2}	12	$12.6 \pm 1.3(\text{stat.}) \pm 3.5(\text{syst.})$	11.0
Low M_{T2}	19	$10.6 \pm 1.9(\text{stat.}) \pm 4.8(\text{syst.})$	15.0

M_{T2} search: interpretation in the CMSSM

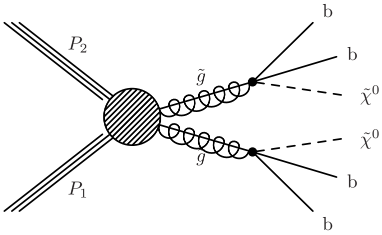


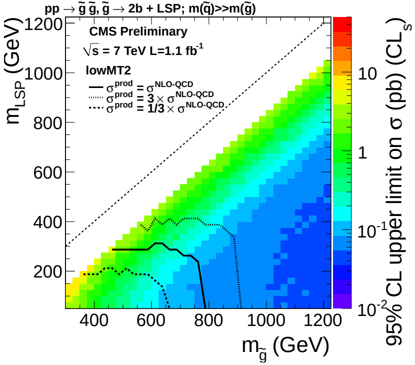


- The sensitivities complement each other.

M_{T2} search: interpretation in a simplified model

Two SUSY particles, b-enriched:





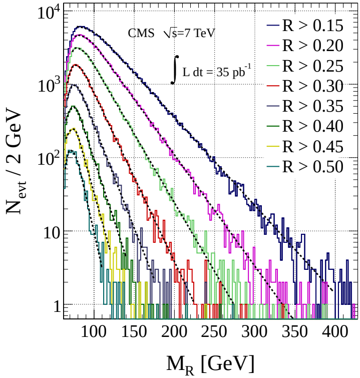
The search using Razor variables

$$M_R = 2\sqrt{\frac{(|\vec{p}|q_z - |\vec{q}|p_z)^2}{(p_z - q_z)^2 - (|\vec{p}| - |\vec{q}|)^2}}$$

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

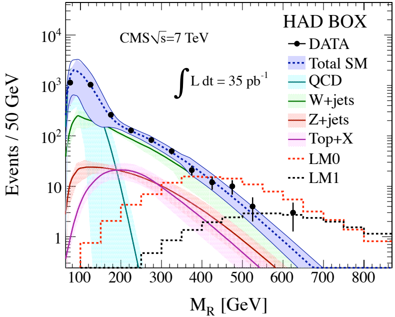
$$M_\Delta = \frac{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{q}}}$$

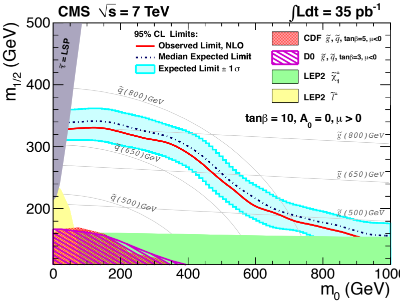
- The “Razor” variables R, M_R were designed to discover and characterize events with heavy pair-produced particles [Rogan, arXiv:1006.2727].
- Reconstructed objects are grouped into two hemispheres with 3-momenta $\vec{p}$, $\vec{q}$ ($\vec{M}$ denotes MET).
- M_R peaks at M_Δ, whereas M_T^R has a kinematic edge at M_Δ.
- $R \equiv \frac{M_T^R}{M_R}$ provides strong rejection of QCD multi-jet events:



Razor search: method and 35/pb results

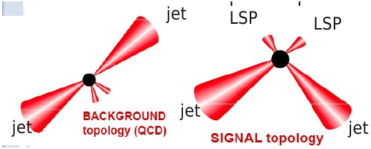
- Exponent of M_R distribution is measured as function of R cut
- Hadronic box with ≥ 2 jets and $R > 0.5$ has signal region at $M_R > 500\ \mathrm{GeV}$
- Muon and electron boxes:
  - provide EWK background prediction (using low M_R)
  - provide search sensitivity (at high M_R)
- Excellent sensitivity at 35/pb– stay tuned for 2011 results!



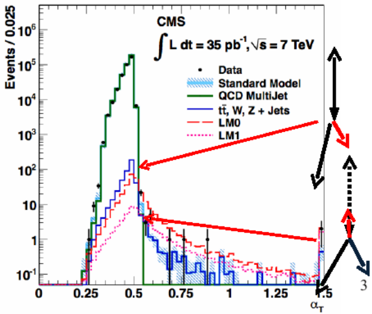


The search using α_{T}

- Inspired by the variable α [Randall, Tucker-Smith, 2008]
- For a di-jet system, $\alpha_{\mathrm{T}} \equiv \frac{E_{\mathrm{T}}{}^{\mathrm{jet2}}}{M_{\mathrm{T}}}$.
- QCD expectation $= 0.5$
- Jet mis-measurements cause $\alpha_{\mathrm{T}} < 0.5$
- Events with genuine MET can have smaller M_T, and hence $\alpha_{\mathrm{T}} > 0.5$



- For an n-jet system, form two "pseudo-jets" defined by balance in pseudo-jet $H_{\mathrm{T}} \equiv \sum_j E_T$
- $\alpha_{\mathrm{T}} \equiv \frac{1}{2}\frac{H_{\mathrm{T}} - \Delta H_{\mathrm{T}}}{M_{\mathrm{T}}}$.



α_{T} search: trigger, objects, vetoes

Trigger $H_{\mathrm{T}} > 250\ \mathrm{GeV}$ and $MHT > 90\ \mathrm{GeV}$.

MET Built from calorimeter towers.

Jets Anti-k_T, $R = 0.5$; built from calorimeter towers; $|\eta| < 3.0$, $p_{\mathrm{T}} > 50\ \mathrm{GeV}$. The thresholds are scaled at low H_{T} to preserve phase space:

H_{T} range	jet p_{T} threshold	leading 2 jets p_{T} threshold
$275 < H_{\mathrm{T}} < 325$	36.7	73.3
$325 < H_{\mathrm{T}} < 375$	43.3	86.7
$375 < H_{\mathrm{T}}$	50.0	100.0

~~Leptons~~ Veto events with an iso. muon or electron with $p_{\mathrm{T}} > 10\ \mathrm{GeV}$.

~~Photons~~ Veto events with an iso. photon with $p_{\mathrm{T}} > 25\ \mathrm{GeV}$.

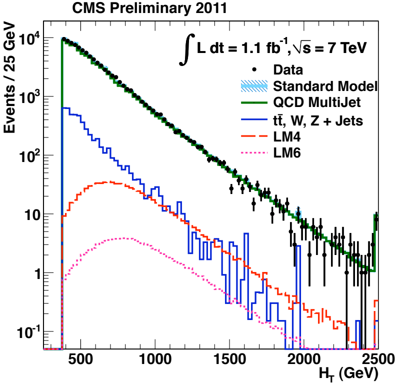
~~Forward~~ Veto events with a jet with $|\eta| > 3.0$.

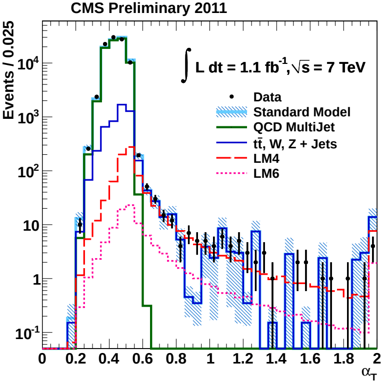
~~Noise~~ Veto events with a jet which fails loose ID requirements.

α_{T} search: hadronic (signal) selection

- $H_{\mathsf{T}} > 275\ \mathrm{GeV}$ (where trigger becomes fully efficient)
- $N_{\mathsf{jets}} \geq 2$
- Leading jet has $|\eta| < 2.5$.
- $\alpha_{\mathrm{T}} > 0.55$
- $MHT/MET < 1.25$, to protect against several low-p_{T} jets pointing in the same direction.
- $\Delta\phi^* \equiv \min_j \Delta\phi(\text{jet, MHT computed w/o the jet}) > 0.5$
  or
  $\min \Delta R(\text{jet}^*, \text{insensitive detector region}) > 0.3$
  to protect against severely mis-mismeasured jets due to instrumental inefficiency.

$\alpha_{\rm T}$ search: some distributions

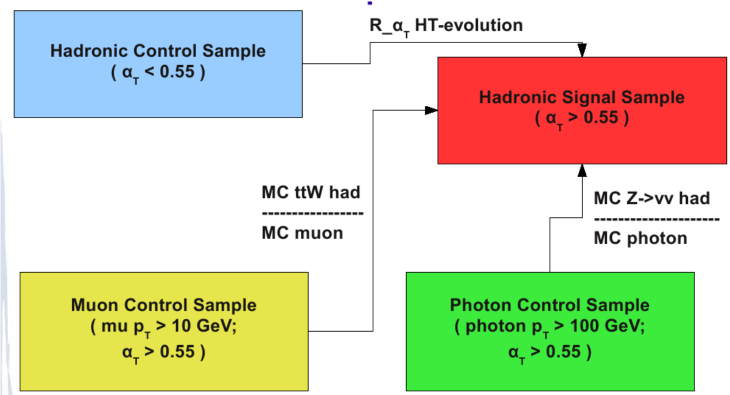




- Applied cuts: $H_{\rm T} > 375\ {\rm GeV}$, $MHT > 100\ {\rm GeV}$, $MHT/MET < 1.25$, where the trigger is fully efficient.
- Note: MC is shown simply for guidance; yields not used in the analysis. LM4 and LM6 are benchmark points in the CMSSM.

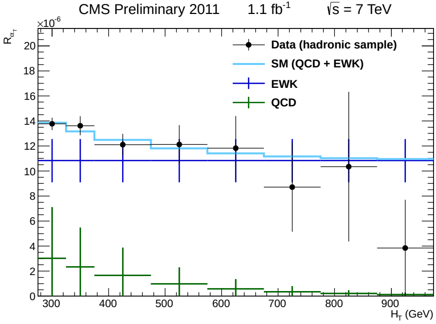
α_{T} search: background estimation

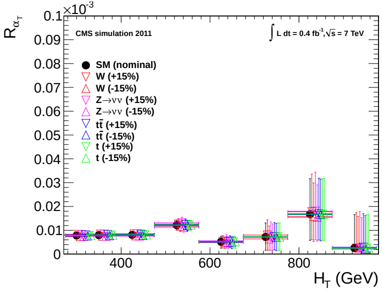
- All-Hadronic (signal) sample, already described
- Photon + jets sample, used to estimate Z $\rightarrow \nu\bar{\nu}$ background
- Muon + jets sample, used to estimate tt+W background
- QCD-dominated all-Hadronic sample (invert α_{T} cut) used to model H_{T} dependence



- MC used only for ratios of kinematically similar processes

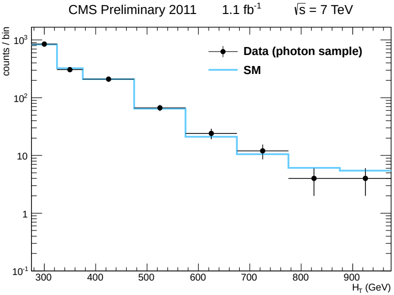
α_T search: evolution in H_T of yield ratio

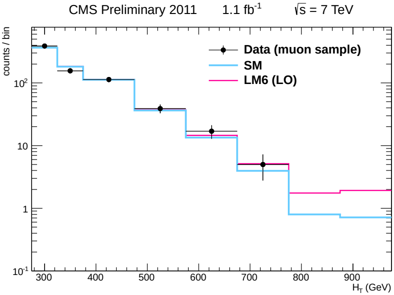




- $R_{\alpha_T} \equiv \frac{N_{\alpha_T > 0.55}}{N_{\alpha_T < 0.55}}$. Left: observed values and fit result.
- The contribution from EWK backgrounds is modeled as flat, as tested in MC (right).
- A possible contribution from QCD is modeled as exponentially falling, as tested with relaxed cuts (to greatly enrich QCD background). Fit contribution compatible with zero.
- A signal contribution is expected to rise.

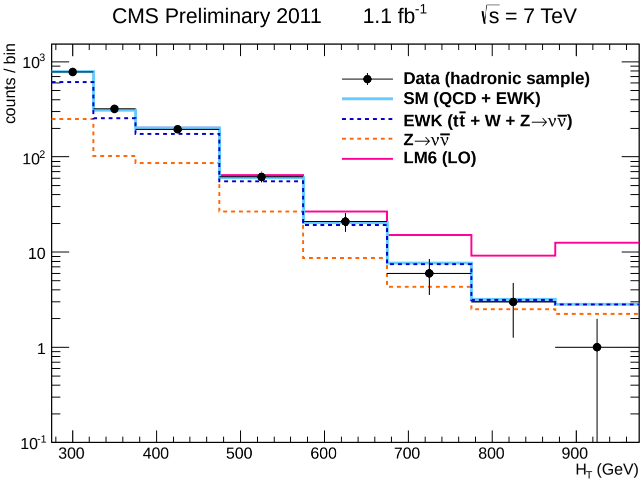
α_T search: observations and SM-fit in control samples





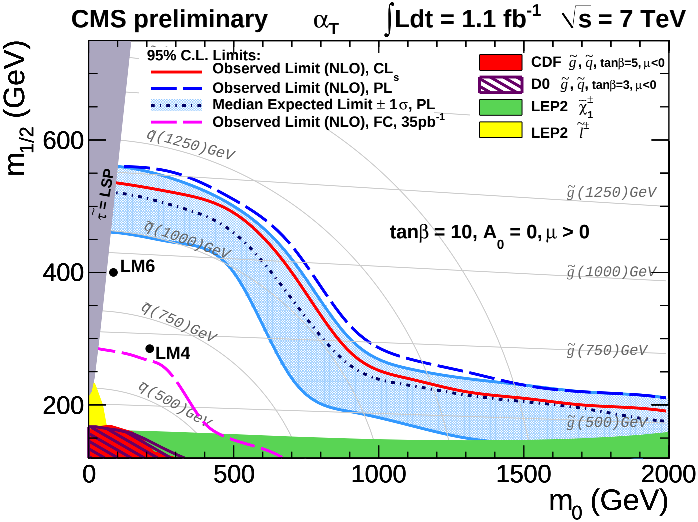
- The SM yields result from the simultaneous fit to the hadronic (signal) sample and these control samples.
- The control sample yields are connected via MC ratios to the background yields in the hadronic sample [O(30%) sys. unc.].

α_T search: observations and SM-fit in hadronic sample



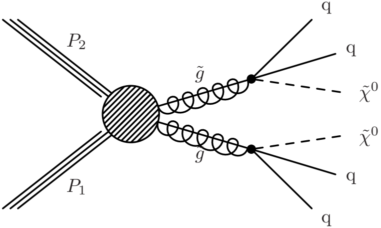
- The background model describes the data over three orders of magnitude in yield, from near the trigger threshold to O(1 TeV) of visible transverse energy.

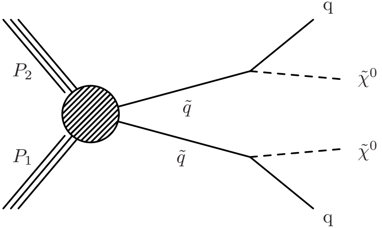
α_T search: interpretation in the CMSSM

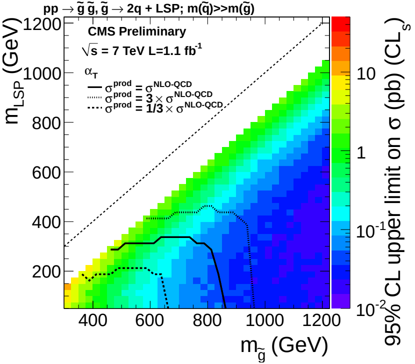


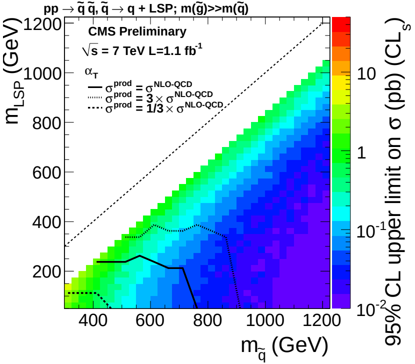
α_T search: interpretation in simplified models

Two models, each with only two SUSY particles:









Summary

- The outstanding performance of the LHC and CMS has enabled many complementary searches for events with undetected escaping particles.
- Presented are three searches which focus on all-hadronic events.
- The observed event yields are consistent with SM expectations.
- In the CMSSM slice considered, equal squark and gluino masses of 1.1 TeV are excluded at 95% C.L.
- Interpretation in simplified models is well underway.

- Where is SUSY hiding?