Search for new physics at CMS using the razor kinematic variables

Will Reece (CERN) for the CMS Collaboration
Introduction

- Presenting four analyses that use the Razor variables
  - All use the 2011 CMS 7TeV pp dataset

- **Razor Inclusive:** \(4.4 \times 10^{-1}\) fb: PAS-SUS-12-005
  - [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12005](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12005)

- **Razor-B:** \(4.6 \times 10^{-1}\) fb: PAS-SUS-11-024
  - [https://twiki.cern.ch/twiki/bin/view/CMSPublic/ResultSUS11024](https://twiki.cern.ch/twiki/bin/view/CMSPublic/ResultSUS11024)

- **Razor MultiJet:** \(5.0 \times 10^{-1}\) fb: PAS-SUS-12-009
  - [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12009](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12009)

- **Razor 3rd-Gen. Scalar LQ:** \(1.8 \times 10^{-1}\) fb: PAS EXO-11-030
  - [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11030](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11030)

*Previous Lumi normalization*
The Razor Variables

- No strong intuition in specifics of new physics models
  - Try to be model independent and inclusive

- Canonical example: R-parity conserving SUSY
  - New heavy states & LSP as DM candidate
  - High $p_T$ jets, leptons, and MET in final state
  - Also in SM background: must discriminate
The Razor Variables

\[ M_{\Delta} \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}} \]

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- We assume new physics is pair produced at the LHC
  - Reconstruct pseudo-dijet topology with hemispheres
  - Ignore some details of event; look just for high scale
- Use \( M_R \) to estimate scale event-by-event
  - For signal: Peaks at \( M_{\Delta} \); For QCD di-jets: falls as \( \sqrt{S} \)
  - Transverse boost to di-squark rest frame: \( |p_{h1}| = |p_{h2}| \)

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The Razor Variables

- Studying $M_R$ distribution not enough: QCD dominates
  - Consider additional variable: $M_T^R$
- Gives kinematic endpoint at $M_\Delta$
- $M_R$ and $M_T^R$ measure similar quantity
  - Use different information: transverse/global
- Dimensionless ratio $R$: Approximate range 0-1
  - $R$ very small for QCD; large for signal

$$M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{x}}^2}{M_{\tilde{q}}}$$

$$M_R \equiv \sqrt{(E_{j1} + E_{j2})^2 - (p_{z1} + p_{z2})^2}$$

$$M_T^R \equiv \sqrt{E_T^{miss}(p_T^{i1} + p_T^{i2}) - \frac{E_T^{miss}.(\bar{p}_T^{i1} + \bar{p}_T^{i2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}$$
The Razor Variables

- Each background has a own shape in plane
  - Defined by scale of process and intrinsic MET
  - \( M_R \) peak moves to right as scale increases

- Model shapes of SM background
  - See signal as bump on exponentially falling tail

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Inclusive Razor

- Very inclusive selection:
  - Razor triggers: hadronic + single lepton
  - Event quality filters, ≥2 jets (60 GeV)
  - Cut on offline $M_R/R$ to remove HLT turn-on
  - Standard lepton ID: tight & loose defines box

- Classify events into orthogonal Boxes:
  - EleMu, MuMu, EleEle, Mu, Ele, Had

- After $M_R/R$ cuts, QCD background negligible
  - Cross-check with shape from low $M_R$ control region

- Data control sample for shape of each background:
  - $t\bar{t}$: ≥1 b-tags; ≥ 1 lepton
  - $Z$+jets: 0 b-tags; ≥2 OS leptons; $Z$ mass window
  - $W$+jets: 0 b-tags; ≥1 lepton

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Inclusive Razor

2D shapes and normalization of SM background from ML fit

- Fit in low $M_R/R$ fit region; Extrapolate to signal region $\rightarrow$ SM prediction
- Box-by-box and then combine for best limit

\[ \mathcal{L}_b = \frac{e^{-\sum_{j\in SM} N_j}}{N!} \prod_{i=1}^{N} \left( \sum_{j\in SM} N_j P_j(M_{R,i}, R_i^2) \right) \]

$F_j(M_R, R^2) = \left[ k_j (M_R - M_{R,j}^0)(R^2 - R_{0,j}^2) - 1 \right] e^{-k_j(M_R-M_{R,j}^0)(R^2-R_{0,j}^2)}$

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Inclusive Razor

CMS Preliminary

$\sqrt{s} = 7$ TeV $\int L \, dt = 4.4$ fb$^{-1}$

Razor Inclusive
Hybrid CLs 95% C.L. Limits
- Median Expected Limit
- Expected Limit $\pm 1\sigma$
- Observed Limit
- HAD Observed Limit
- Leptons Observed Limit

- Model dependent result: Hybrid CLs with signal from MC
- Systematics included toy-by-toy

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Inclusive Razor with B-tag

- Natural extension to inclusive analysis: ≥1 b-tags (40 GeV)
- Dataset is a subset of the inclusive sample: same triggers & selection
- Background model simplified: V+jets & ttbar shapes from control regions

- Interpret model-dependent results in simplified models (SMS)
**Razor MultiJet:**

\[ M_\Delta = \sqrt{\frac{m_{\tilde{t}}^2 - (m_t + m_{\tilde{\chi}})^2}{m_{\tilde{t}}^2}} \]

- Complementary to inclusive analyses: Probe low R region
  - Use MultiJet triggers to select events: *No online MET cut*
  - Require \( \geq 6 \) jets (30GeV); \( \geq 1 \) b-tags; isolated lepton veto (inc. taus)

- Very high statistics measurement: 71k events in search (BJet) box

- Major backgrounds: QCD & ttbar: Shapes from control regions then float in BJet fit
  - QCD & ttbar hadronic: b-jet veto with loose tagger; Veto leptons as in BJet box
  - ttbar leptonic: b-jet veto with loose tagger; invert lepton veto \( \rightarrow W+\geq5 \) jets

Extract SM background shape in low \( M_R/R \) region

Predict background in signal region for limit
Razor Multijet

- **T1ttt**: Set limits on gluino pair production in SUSY

- **T2tt**: Set limits on $t'_0$ mass in SUSY (stop) & $t'_{1/2}$ in UED, 4th Gen, etc
  - Treat $t'_{1/2}$ and LSP masses as independent: Reweight SUSY $\sigma_{\text{NLO}}$ with LO k-factor

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3rd Generation Scalar LeptoQuarks

- Search for LQ pair production: $LQ \rightarrow b \nu_\tau$ (2b, 0 leptons, & MET)
  - Use data from razor HLT trigger suite: hadronic + leptonic
  - Require $\geq 2$ jets (60 GeV); 1,2 loose b-tags; lep. ID (e, $\mu$)
  - Classify events into Ele, Mu, & Had boxes

- Describe background shapes with 1D function:
  $$F(M_R) = e^{-(A_1 + B_1 \times R^2_{cut}) M_R} + f \times e^{-(A_2 + B_2 \times R^2_{cut}) M_R}$$

- Find $A_{1,2}, B_{1,2}$ for from control regions/MC
  - $V^+$ heavy flavour jets: Madgraph matched to pythia
  - $t\bar{t}$bar: $\geq 2$ b-tags; $\geq 1$ tight $\mu$; $R^2 > 0.14$
  - QCD Multijets with HF: $\geq 1$ b-tags; $\geq 1$ loose $\mu$; $R^2 > 0.14$

- Find scale factors from sidebands in Ele & Had boxes
  - Apply to Had box signal region to predict background
  - Cross-check in Ele box at high $R^2$ (>0.25)
3rd Generation Scalar LeptoQuarks

Assuming $\text{Br}(LQ \rightarrow b\nu_\tau)$ is 1

Br$(LQ \rightarrow b\nu_\tau)$ free to vary

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Summary

- The razor variables allow us to search inclusively for NP
  - Make assumptions about underlying kinematics
  - Get peaking signal on exponentially falling background

- Presented four analyses:
  - Inclusive Razor: Stringent limits on CMSSM
  - Razor-B: New limits on di-stop and di-gluino production
  - Razor MultiJet: Sensitivity to di-stop production expected for 2012
  - 3rd Generation LQ: Improves previous limits by 100 GeV

- Looking forward to new results in 2012
Backup Slides
Razor Cartoon

longitudinal boost (R-frame)

R-frame \sim CM frame
Model Dependent Results

example hypothesis test

\[ m_0 = 240, \quad m_{1/2} = 500, \quad \tan \beta = 10, \quad A_0 = 0, \quad \mu > 0 \]

\[ \lambda = \log Q = \log \left( \mathcal{L}_{s+b} / \mathcal{L}_b \right) \]
Model Dependent Results

Boxes are combined by adding the test-statistic (log-likelihood ratio)

\[
\lambda^{TOT} = \sum_{i \in \text{boxes}} \lambda^i
\]

\[
\mathcal{L}^{TOT} = \prod_{i \in \text{boxes}} \mathcal{L}^i \quad \lambda^i = \log Q^i = \log(\mathcal{L}^i_{s+b}/\mathcal{L}^i_b)
\]
**Razor Multijet: T1tttt 2D limits**

![Graph and table]

**Table 1:** Agreement between observed yield and expected background in the $S_i$ regions, obtained integrating numerically the background model (including shape uncertainties) with toy MC. The signal regions are shown in Fig. 1.

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Razor Multijet: T2tt 2D limits

Scaler t’ (SUSY)

Fermion inc t’ (UED, 4th Gen. etc)