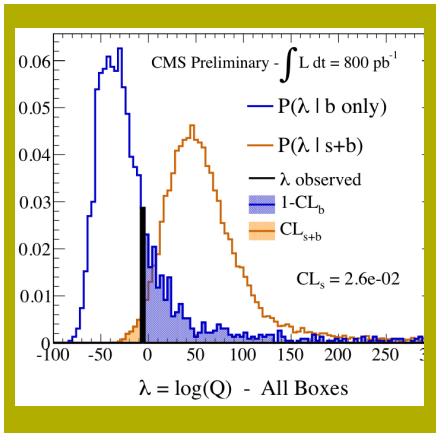
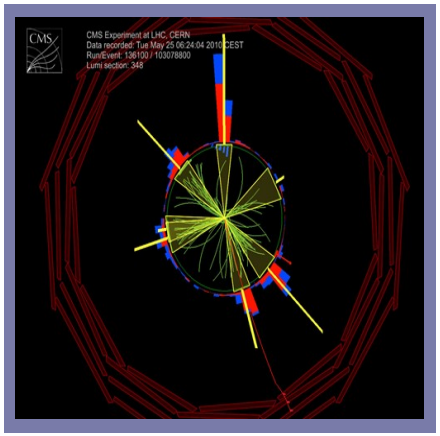
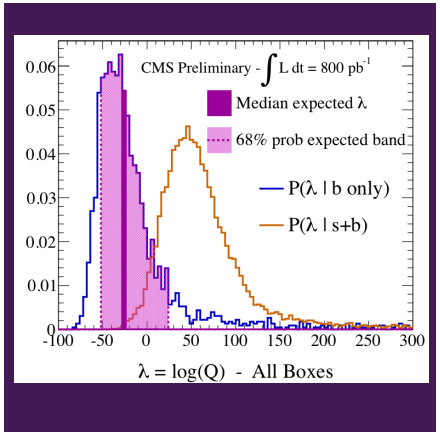






Search for new physics at CMS using the razor kinematic variables

Will Reece (CERN)
for the CMS Collaboration

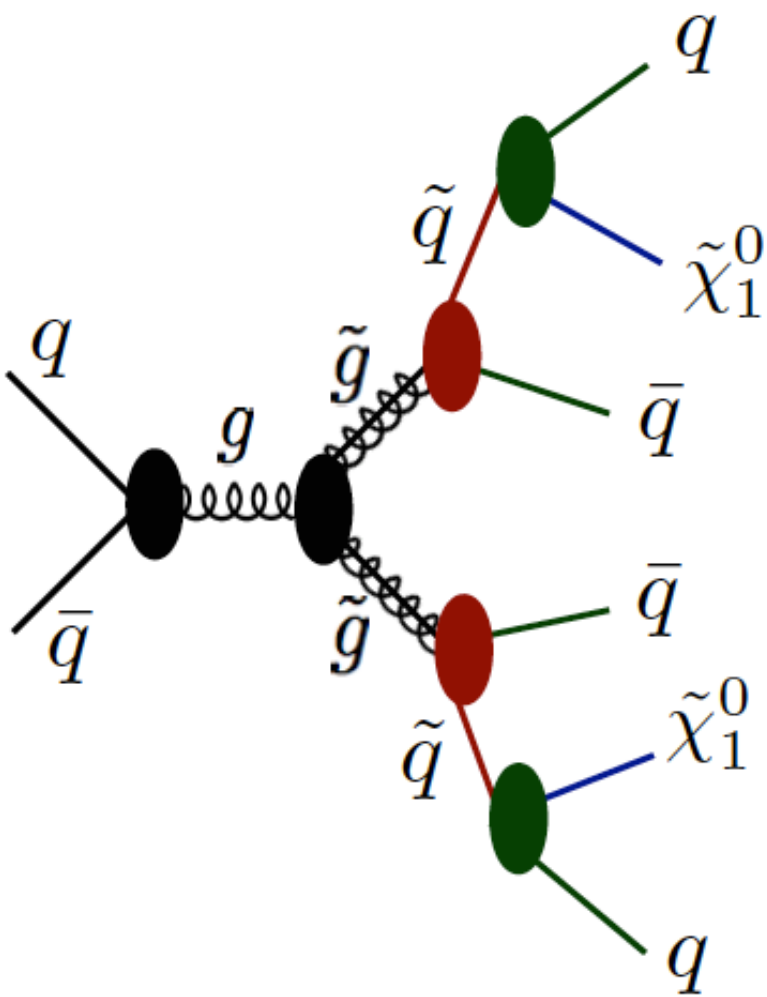
Introduction

- Presenting four analyses that use the Razor variables
  - All use the 2011 CMS 7TeV pp dataset
- Razor Inclusive: 4.4* fb^{-1}: PAS-SUS-12-005
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12005
- Razor-B: 4.6 fb^{-1}: PAS-SUS-11-024 NEW
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/ResultSUS11024
- Razor MultiJet: 5.0 fb^{-1}: PAS-SUS-12-009 NEW
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12009
- Razor 3rd-Gen. Scalar LQ: 1.8* fb^{-1}: PAS EXO-11-030
  - 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

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

- 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
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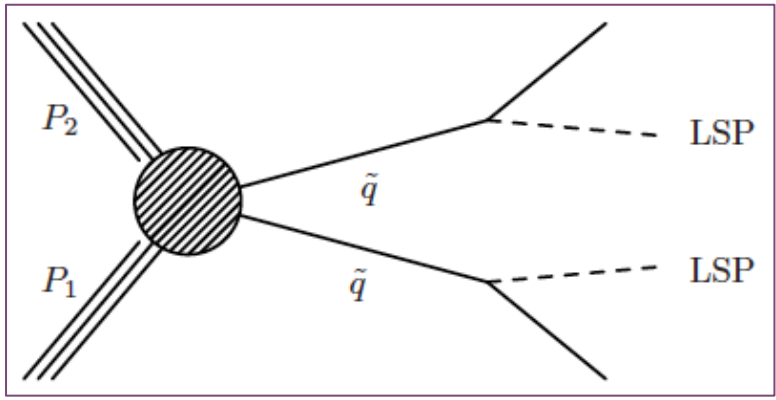
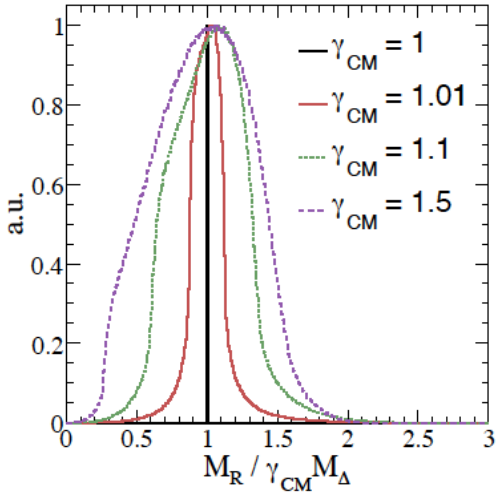
  - Also in SM background: must discriminate



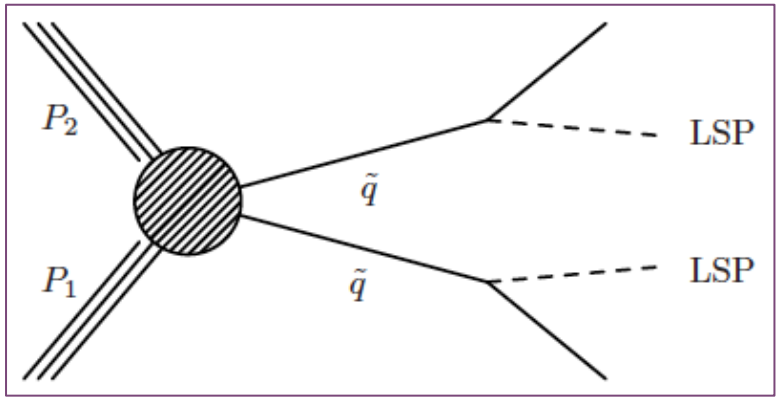
- We assume new physics is pair produced at the LHC
  - Reconstruct pseudo-dijet topology with hemispheres
  - Ignore some details of event; look just for *high scale*
- Use M_R to estimate scale event-by-event
  - For signal: Peaks at M_Δ; For QCD di-jets: falls as $\sqrt{\hat{s}}$
  - Transverse boost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



The Razor Variables

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

- Studying M_R distribution not enough: QCD dominates
  - Consider additional variable: M_T^R
- Gives kinematic endpoint at M_Δ
- 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

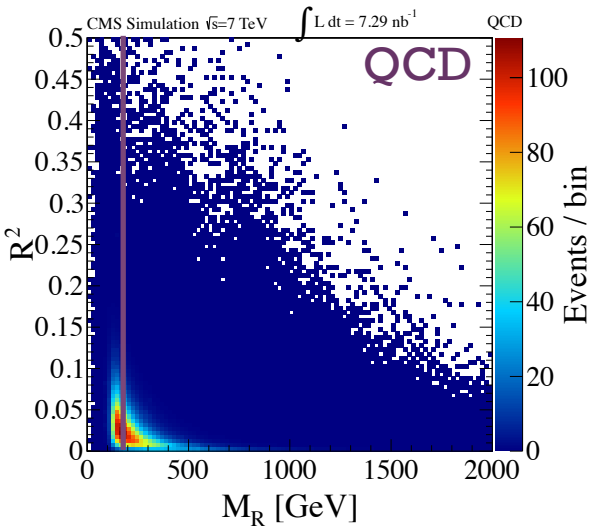


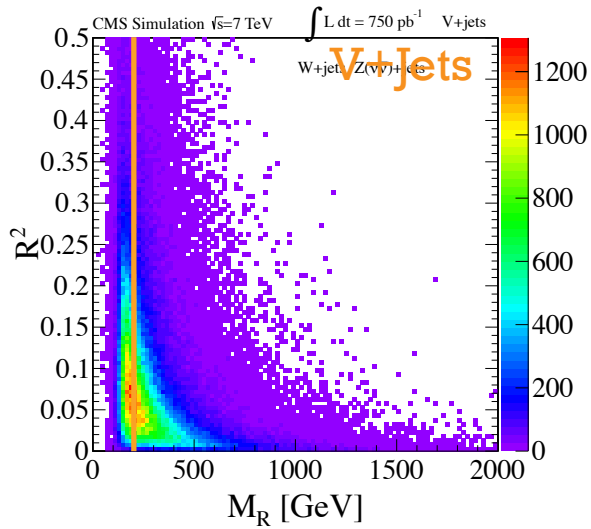
$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

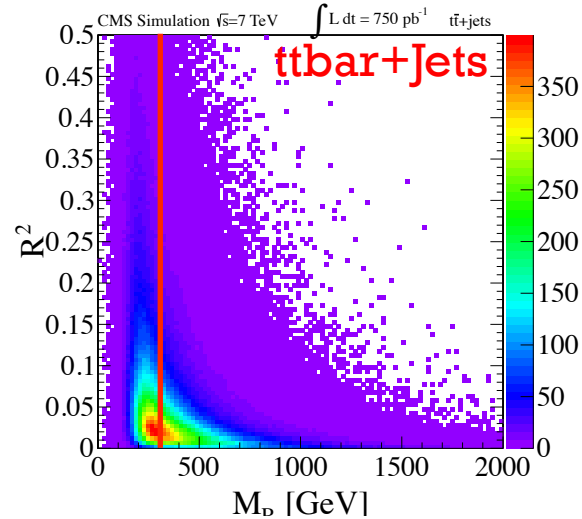
$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

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

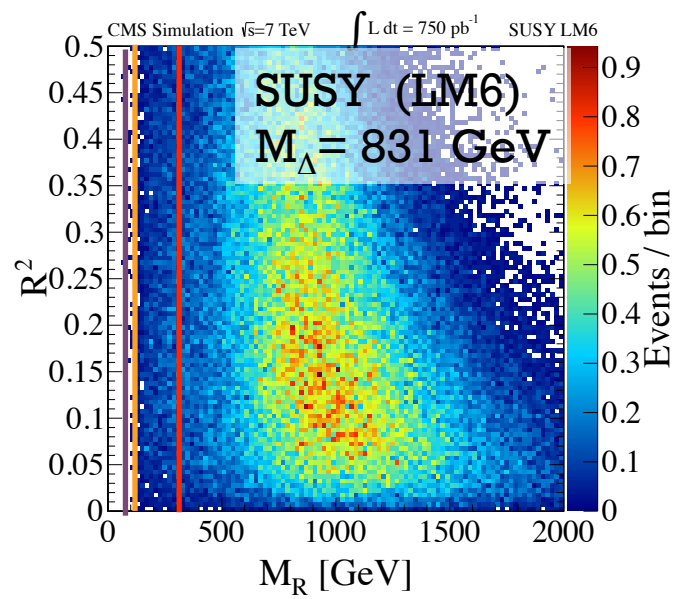
The Razor Variables





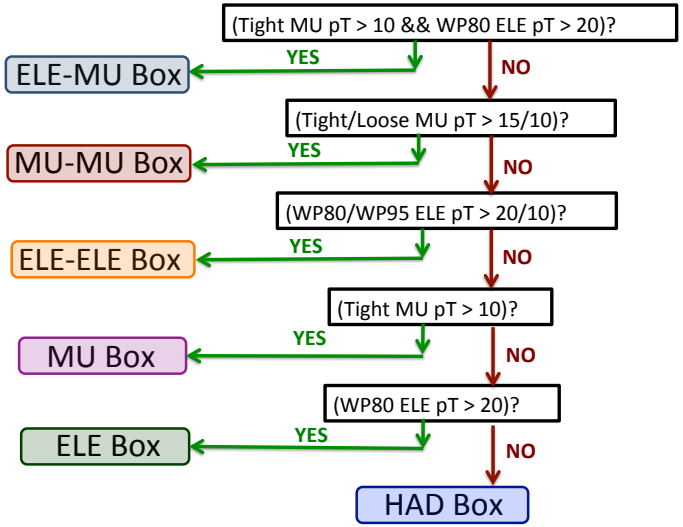


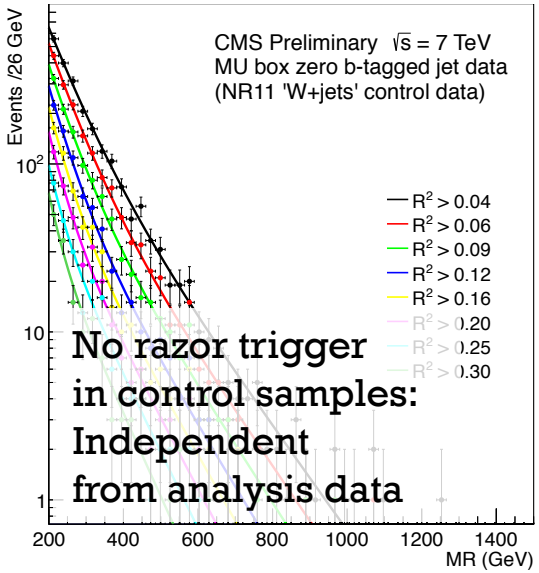
- Each background has a own shape in plane
  - Defined by scale of process and intrinsic MET
  - M_R peak moves to right as scale increases
- Model shapes of SM background
  - See signal as bump on exponentially falling tail



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:
  - ttbar: ≥1b-tags; ≥ 1 lepton
  - Z+jets: 0b-tags; ≥2 OS leptons; Z mass window
  - W+jets: 0b-tags; ≥1 lepton

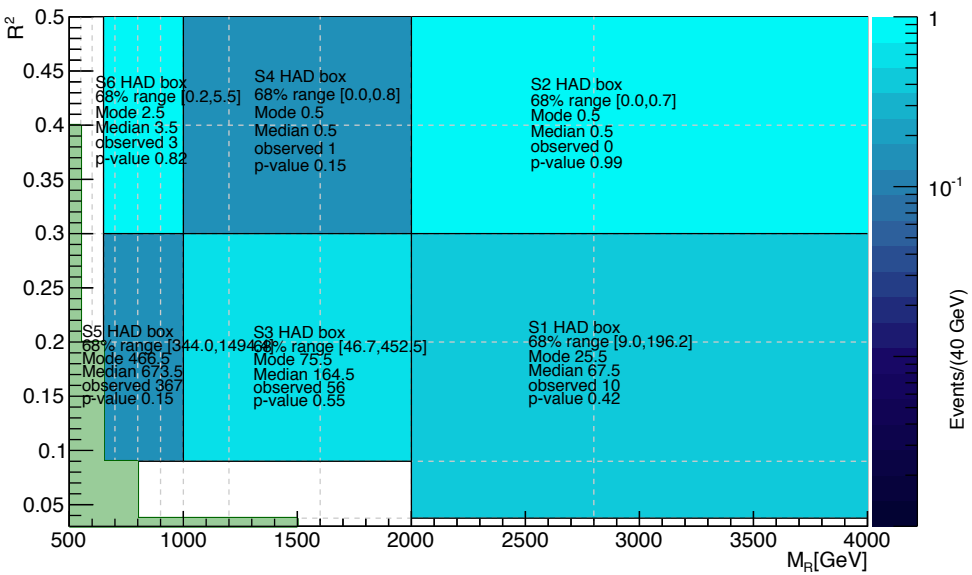


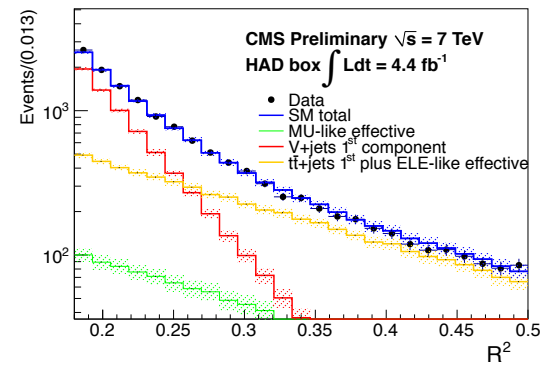


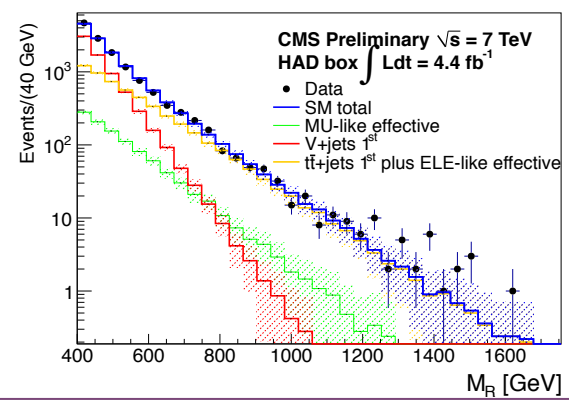
Inclusive Razor

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

- 2D shapes and normalization of SM background from ML fit
  - Fit in low M_R/R *fit region*; Extrapolate to signal region → SM prediction
  - Box-by-box and then combine for best limit



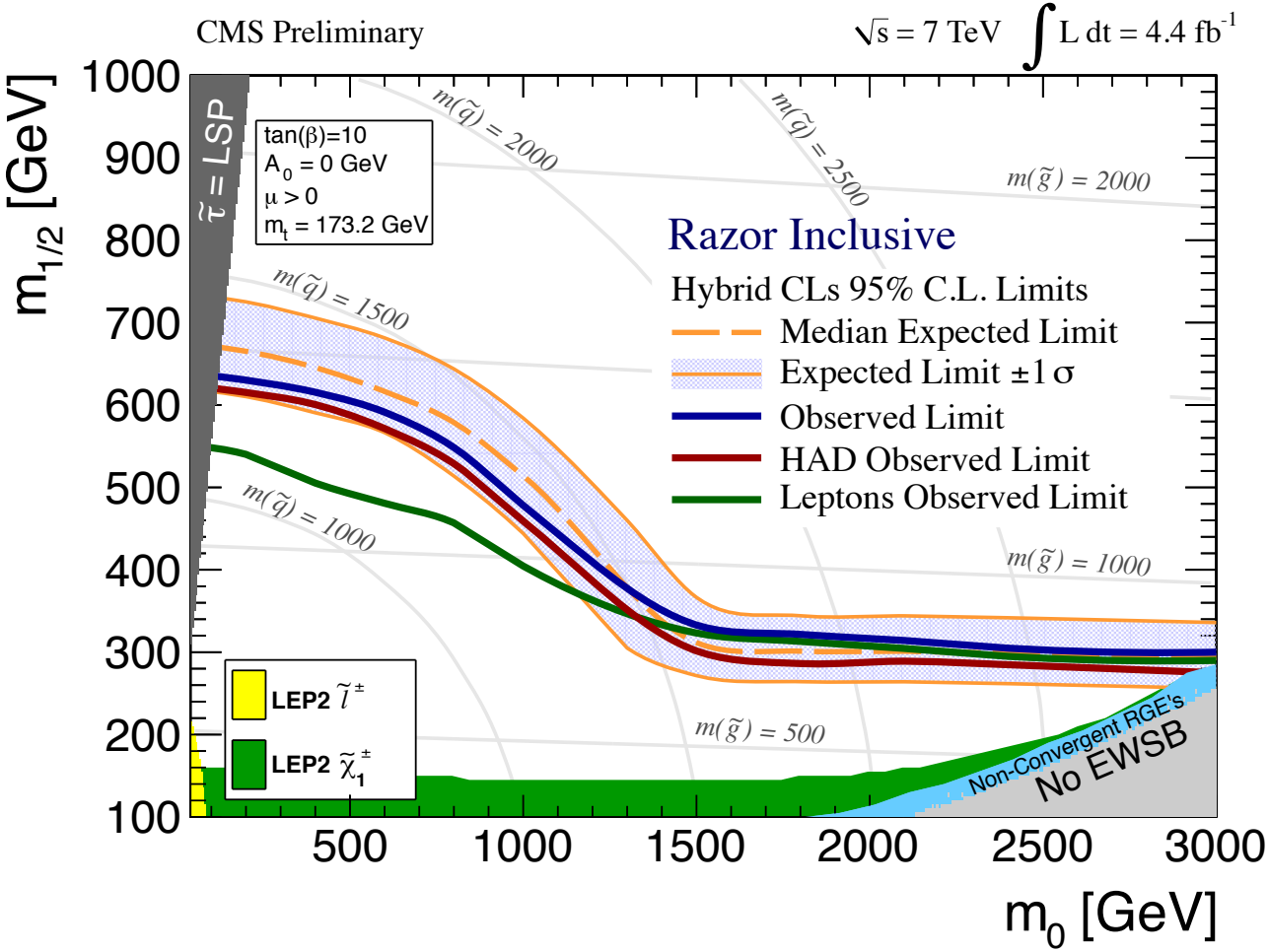




1D projections of 2D PDF

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

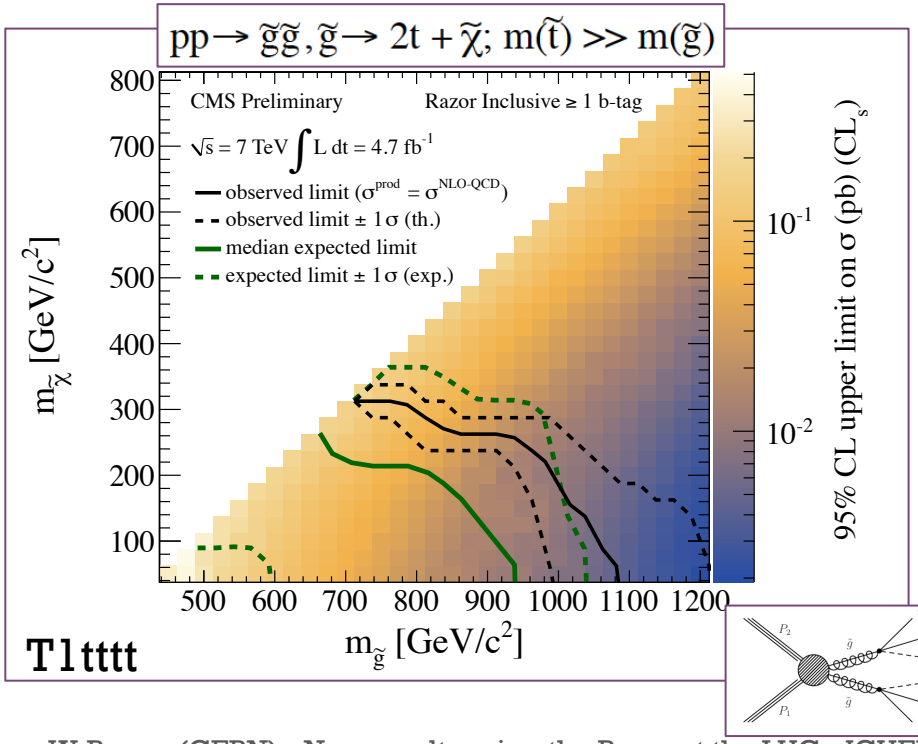
Inclusive Razor

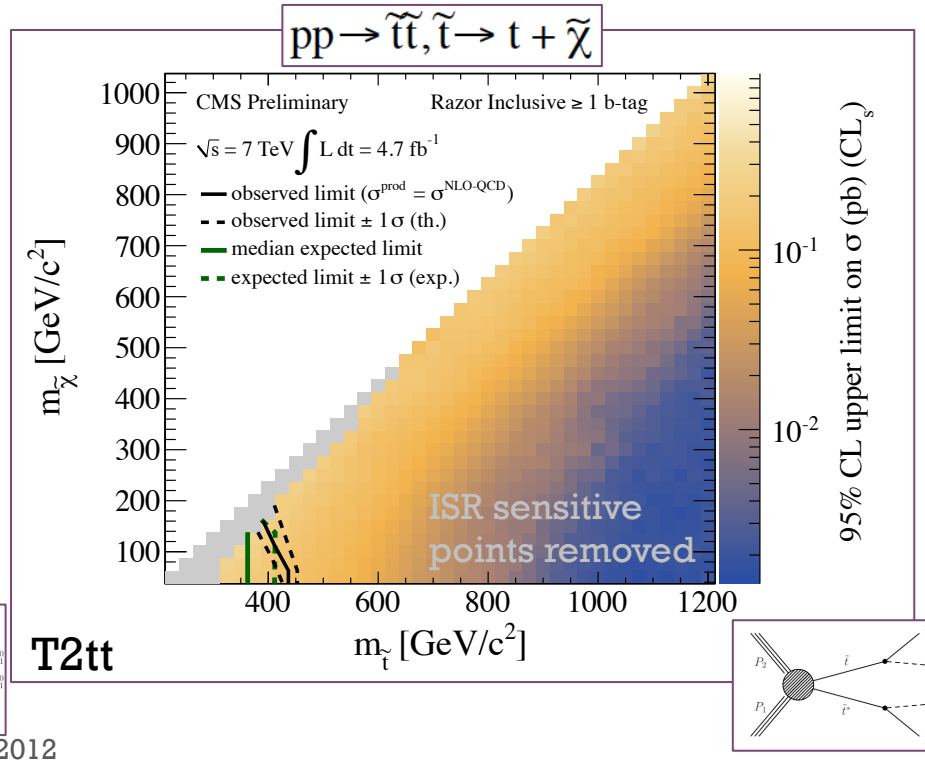


- Model dependent result: Hybrid CL_S with signal from MC
  - Systematics included toy-by-toy

Inclusive Razor with B-tag

- Natural extension to inclusive analysis: ≥1 b-tags (40GeV)
  - 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)



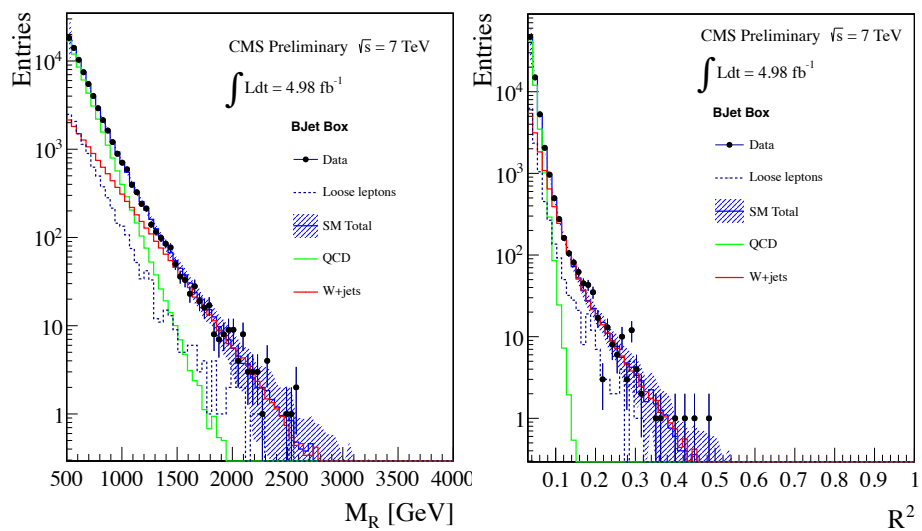


Razor MultiJet:

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

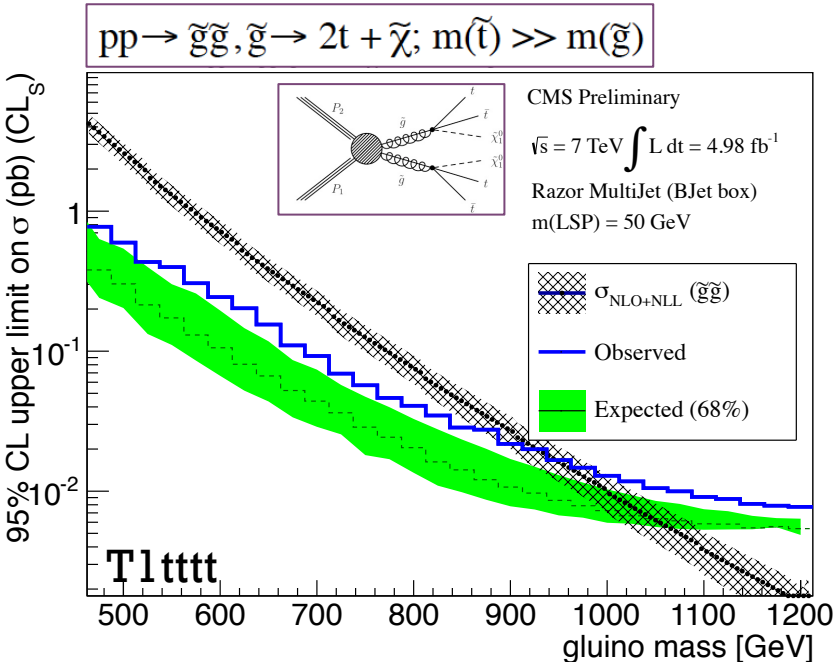
- Complementary to inclusive analyses: Probe low R region
  - Use MultiJet triggers to select events: *No online MET cut*
  - Require ≥ 6 jets (30GeV); ≥ 1 b-tags; isolated lepton veto (inc. taus)
- Very high statistics measurement: 71k events in search (BJet) box
- Major backgrounds: QCD & ttbar: Shapes 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 → W+≥5 jets

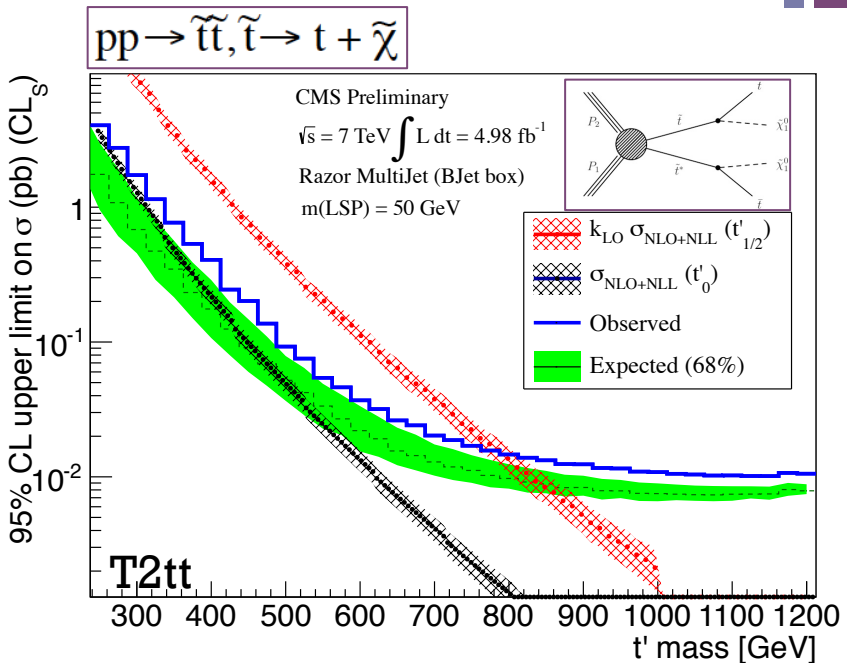
Extract SM background shape in low M_R/R region



Predict background in signal region for limit

Razor Multijet





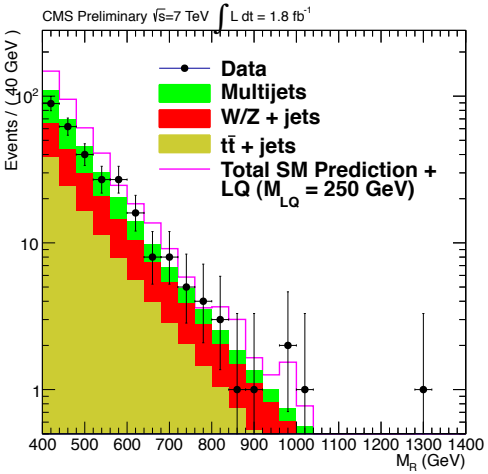
- T1tttt: Set limits on gluino pair production in SUSY
- T2tt: Set limits on t'_0 mass in SUSY (stop) & $t'_{1/2}$ in UED, 4th Gen, etc
  - Treat $t'_{1/2}$ and LSP masses as independent: Reweight SUSY σ_{NLO} with LO k-factor

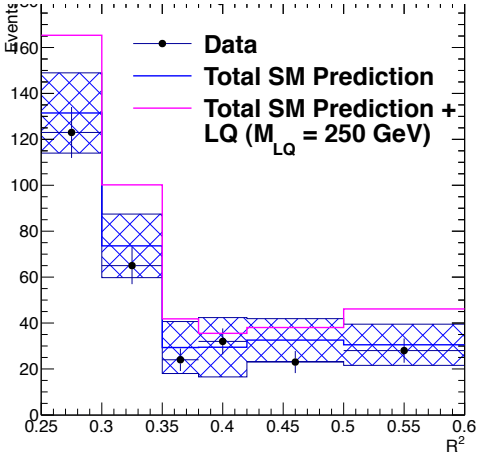
3rd Generation Scalar LeptoQuarks

- Search for LQ pair production: LQ→bν_τ (2b, 0 leptons, & MET)
  - Use data from razor HLT trigger suite: hadronic + leptonic
  - Require ≥2 jets (60 GeV); 1,2 loose b-tags; lep. ID (e,μ)
  - Classifly events into Ele, Mu, & Had boxes
- Describe background shapes with 1D function:

$$F(M_R) = e^{-(A_1+B_1\times R^2_{cut})M_R} + f \times e^{-(A_2+B_2\times R^2_{cut})M_R}$$

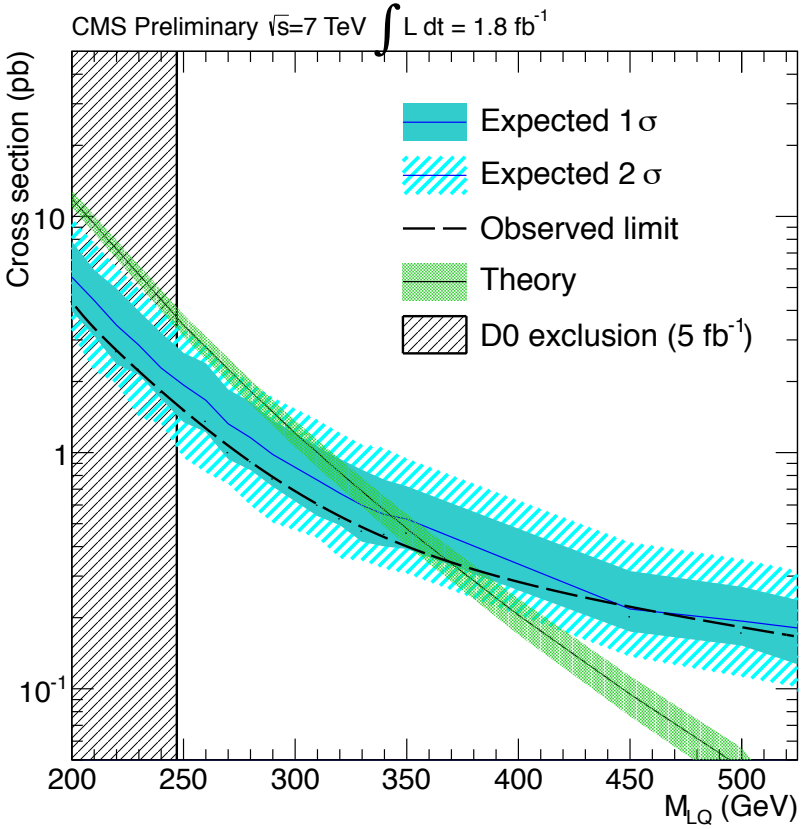
- Find $A_{1,2}$, $B_{1,2}$ for from control regions/MC
  - V+ heavy flavour jets: Madgraph matched to pythia
  - ttbar: ≥2 b-tags; ≥1tight μ; $R^2 > 0.14$
  - QCD Multijets with HF: ≥1 b-tags; ≥1loose μ; $R^2 > 0.14$
- Find scale factors from sidebands in Ele & Had boxes
  - Apply to Had box signal region to predict background
  - Cross-check in Ele box at high R^2 (>0.25)



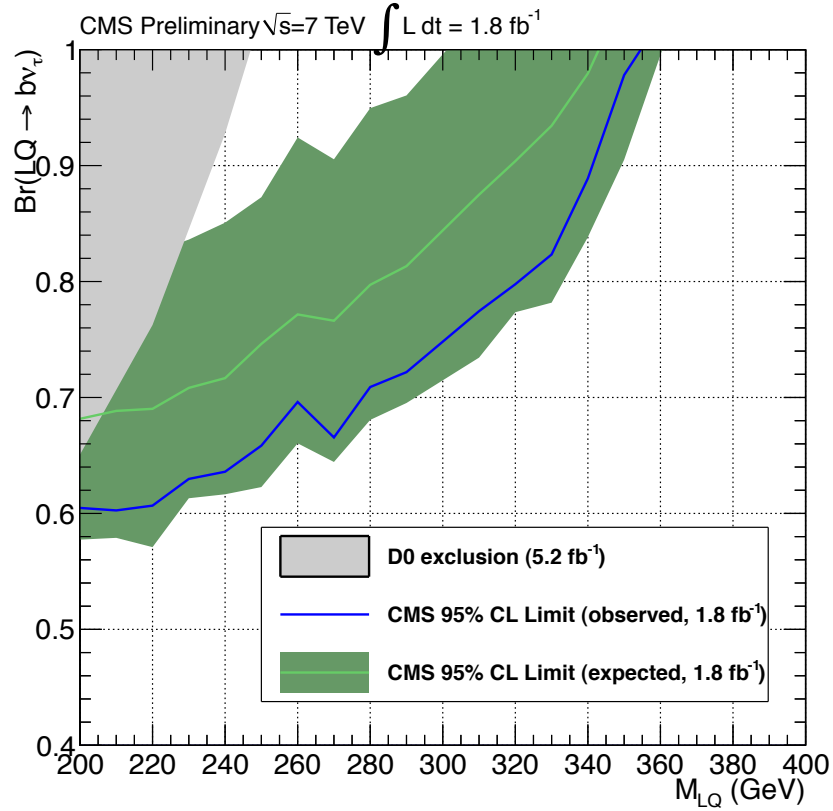


3rd Generation Scalar LeptoQuarks

Assuming Br(LQ→bν_τ) is 1



Br(LQ→bν_τ) free to vary

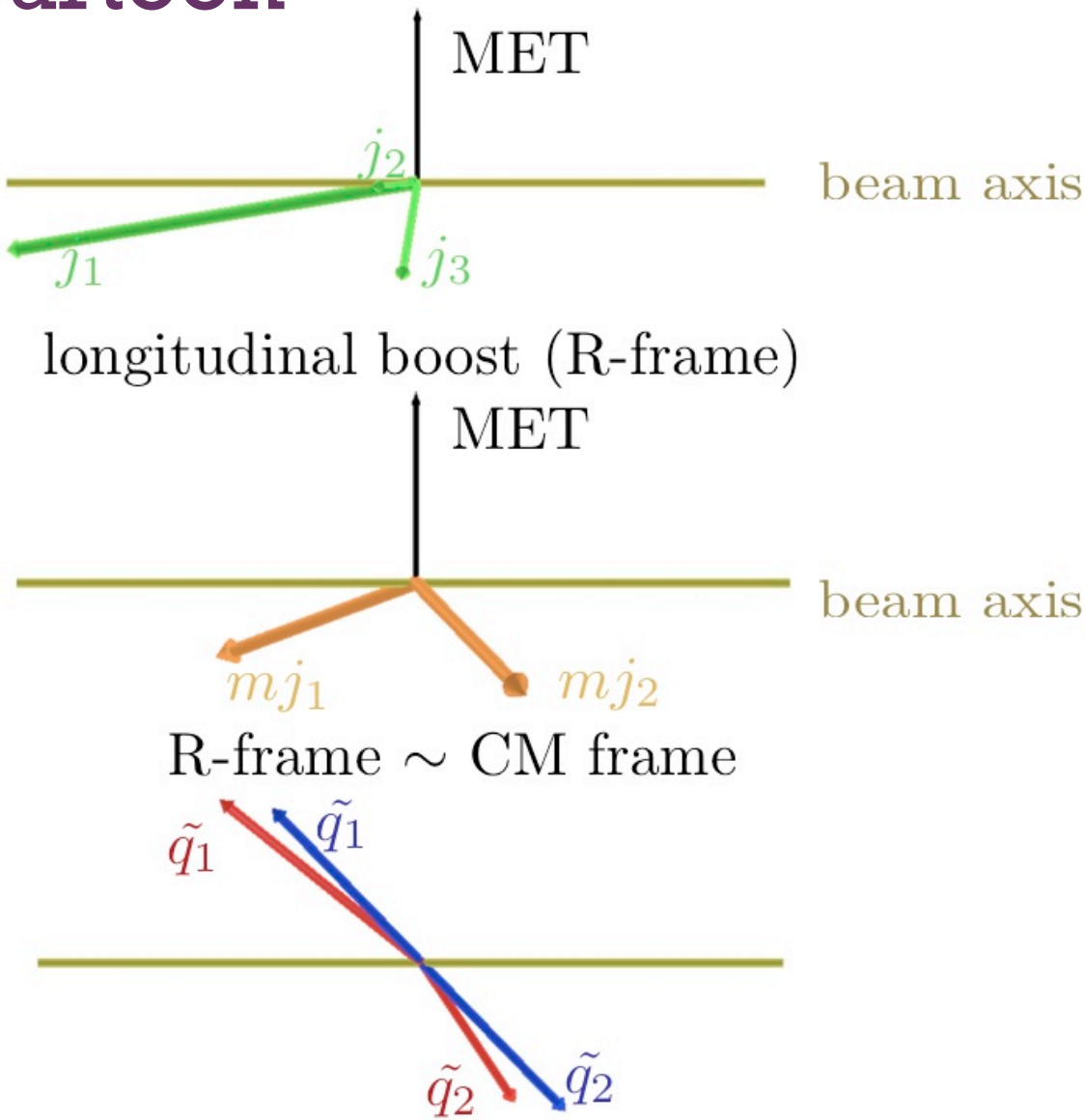


Summary

- 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

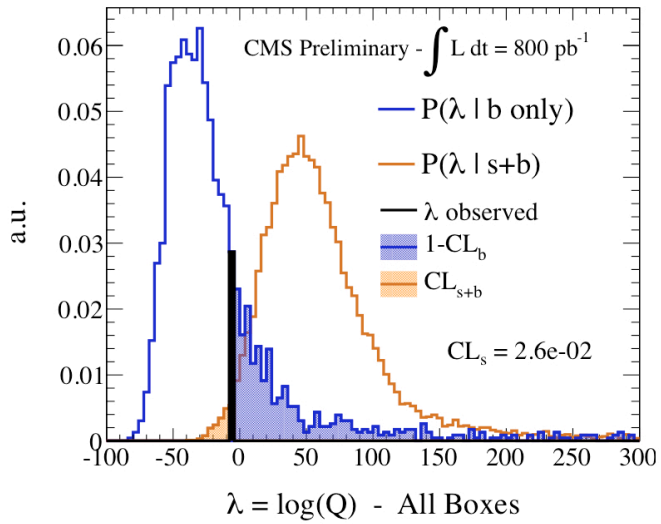
Razor Cartoon



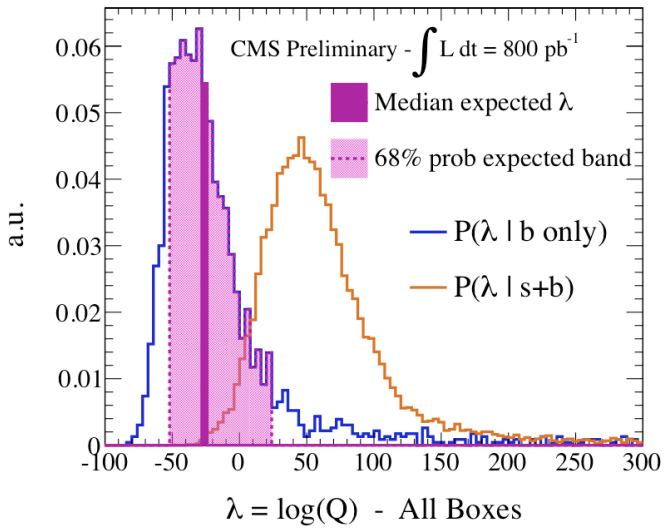
Model Dependent Results

example hypothesis test

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



observed

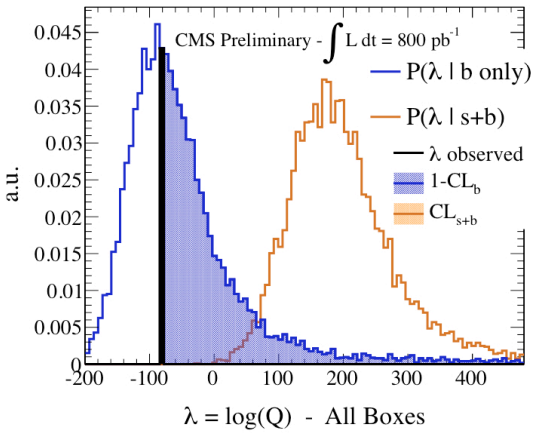


expected $\pm 1\sigma$

$$\lambda = \log Q = \log(\mathcal{L}_{s+b}/\mathcal{L}_b)$$

Model Dependent Results

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



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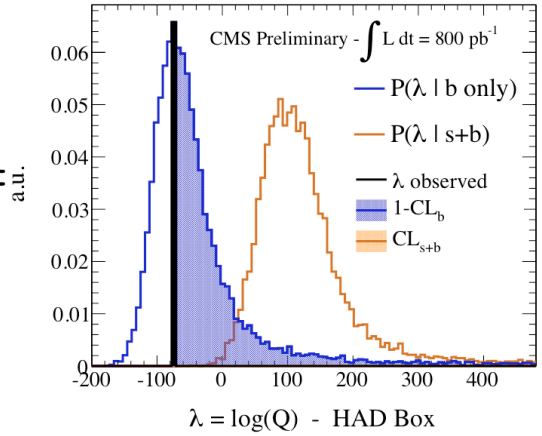

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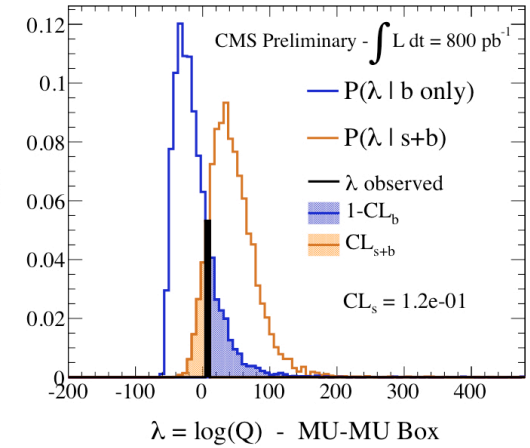
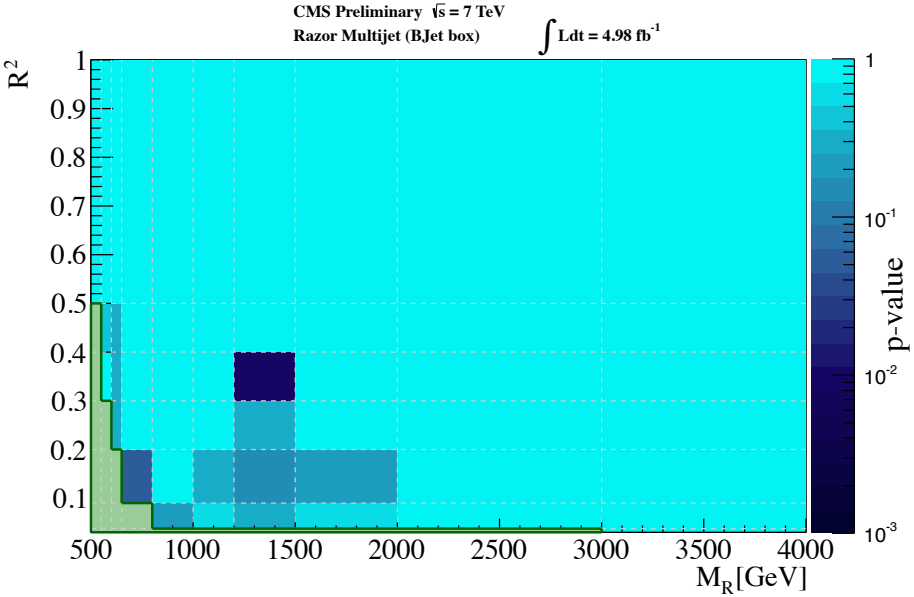


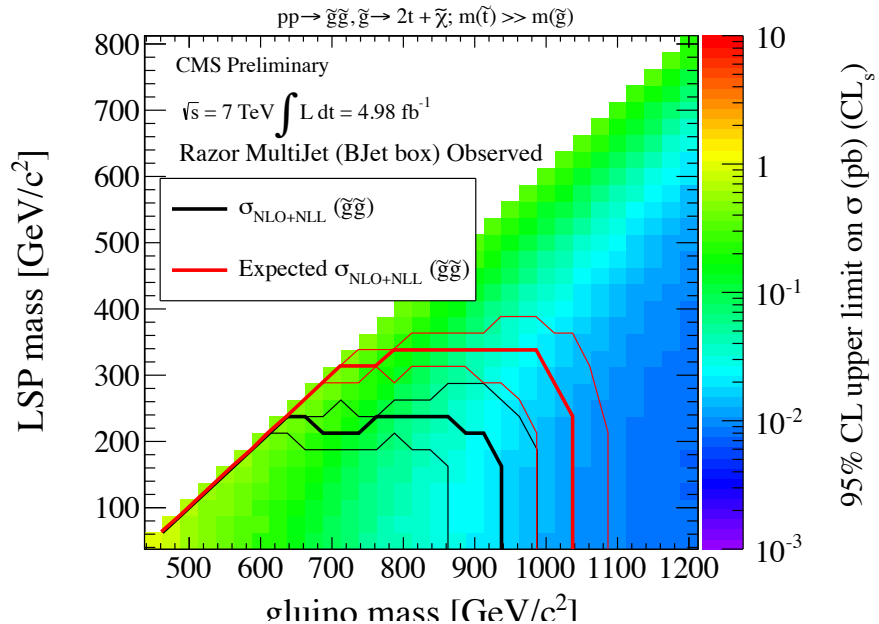
+ …

$$\lambda^{\mathrm{TOT}} = \sum_{i \in \mathrm{boxes}} \lambda^i$$

$$\mathcal{L}^{\mathrm{TOT}} = \prod_{i \in \mathrm{boxes}} \mathcal{L}^i \qquad \lambda^i = \log Q^i = \log(\mathcal{L}^i_{s+b}/\mathcal{L}^i_b)$$

Razor Multijet: T1tttt 2D limits

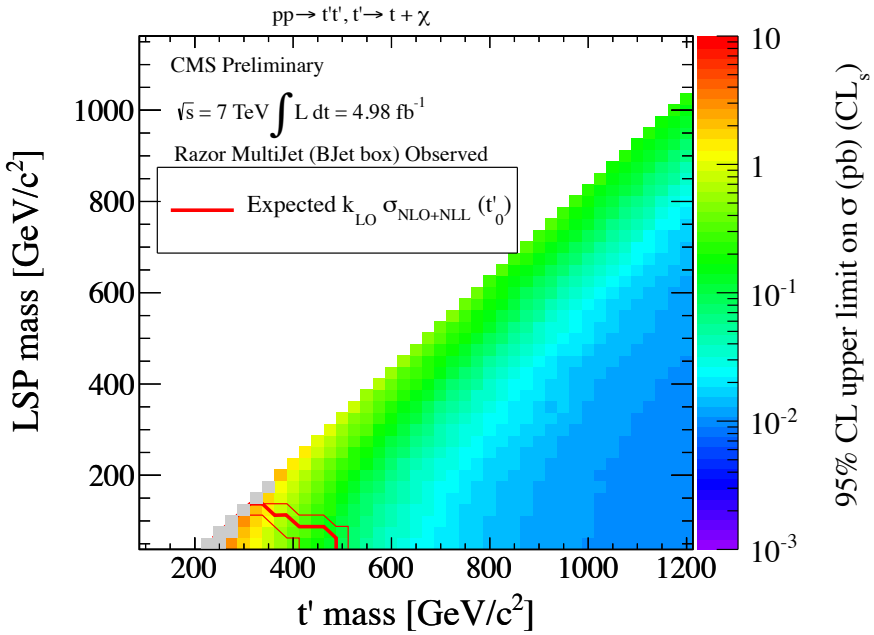




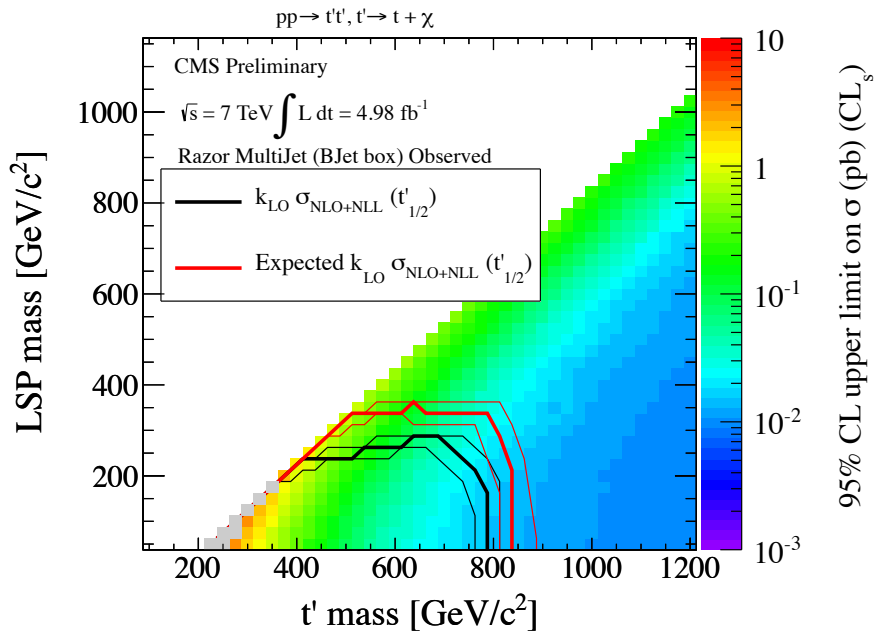
Region	M_R	R^2	Observed	Predicted Mode	Predicted Median	Predicted 68 Prob. Range	p-value
S_1	[3000, 4000]	[0.0300, 0.0375]	0	0.5	0.5	2.5 ± 2.5	0.99
S_2	[800, 4000]	[0.0375, 0.0900]	4328	4318.5	3709.5	4426.5 ± 718.5	0.40
S_3	[650, 4000]	[0.0900, 0.2000]	551	504.5	500.5	640.5 ± 140.5	0.43
S_4	[600, 4000]	[0.2000, 0.3000]	37	33.5	11.5	37.0 ± 27.0	0.84
S_5	[550, 4000]	[0.3000, 0.5000]	7	9.5	1.5	14.0 ± 14.0	0.70
S_6	[500, 4000]	[0.5000, 1.0000]	0	0.5	0.5	3.0 ± 3.0	0.99

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.

Razor Multijet: T2tt 2D limits



Scaler t' (SUSY)



Fermioninc t' (UED, 4th Gen. etc)