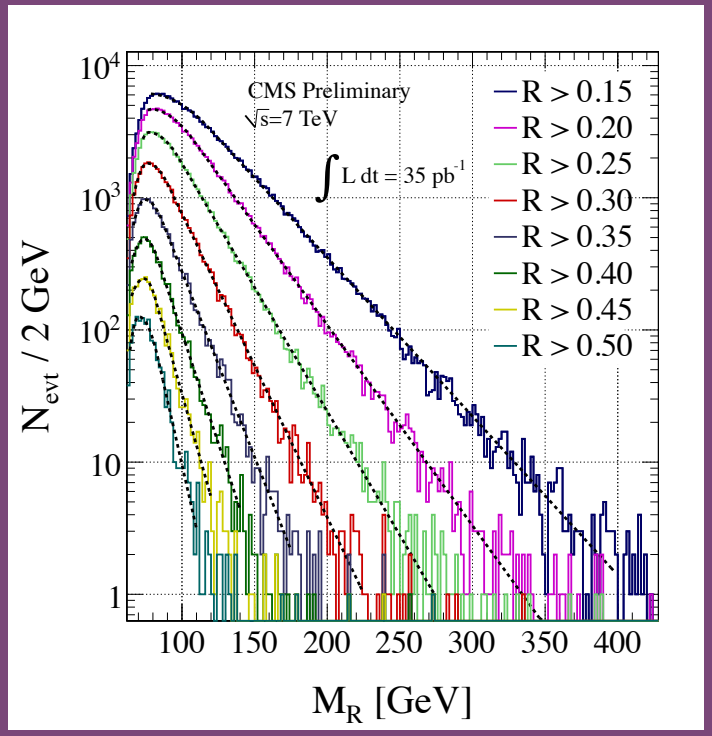
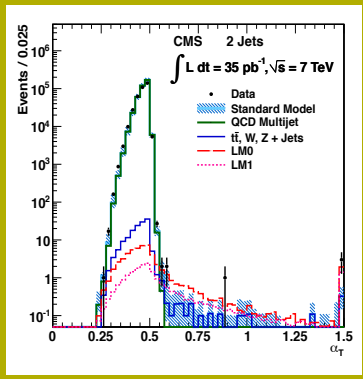
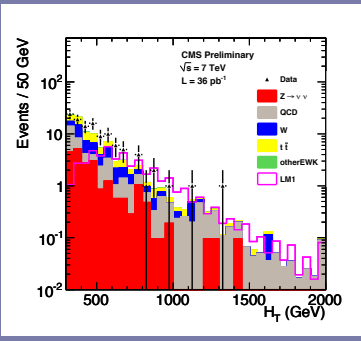
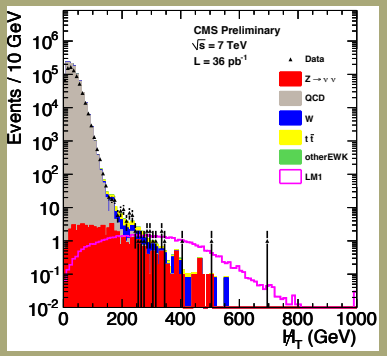
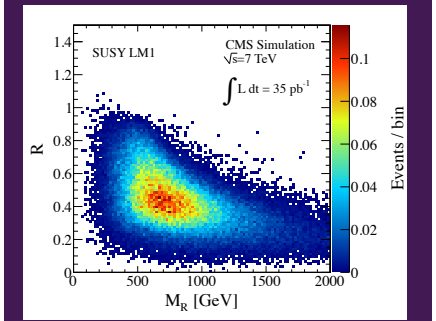










SUSY Searches in Jets + MET Final States

Christopher Rogan
California Institute of Technology
On behalf of the CMS collaboration

LPCC - Status of Higgs and BSM Searches at the LHC – April 13, 2011

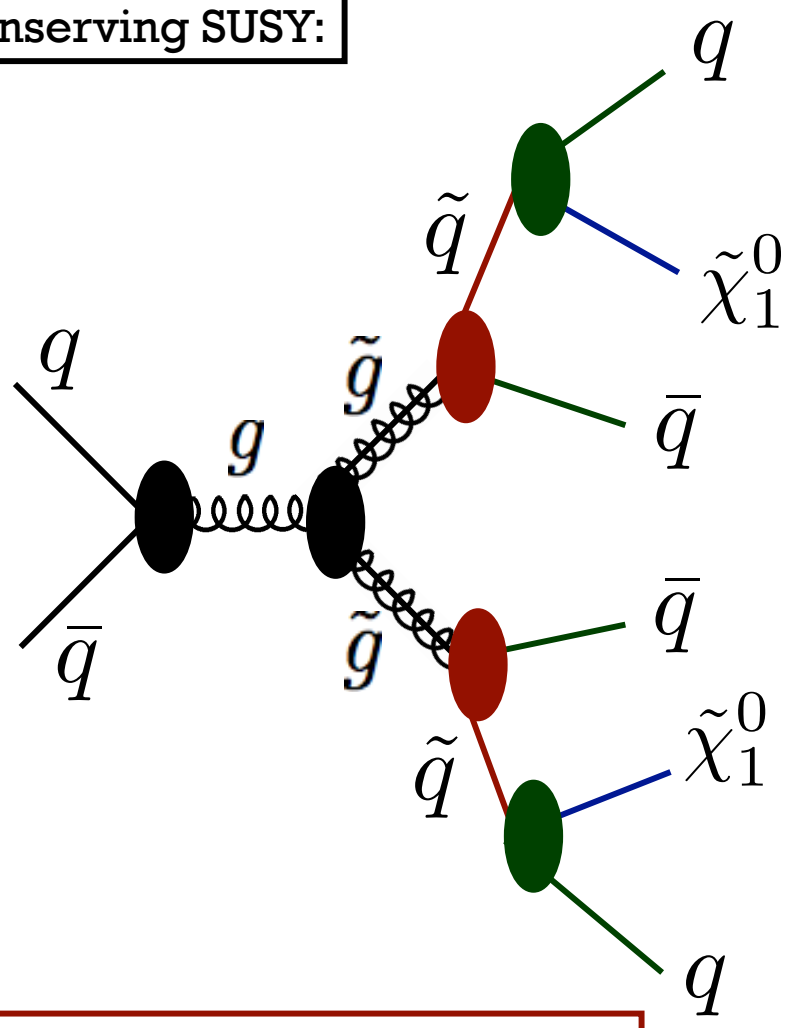
Outline

- SUSY Searches in Jets + MET Final States
  - Motivation for search topology
  - SUSY signatures
- CMS Jets+MET SUSY Searches
  - α_T and HT
  - MHT and HT
  - M_R and R (Razor)
- Results Interpretation with Simplified Topologies

+ SUSY in Jets + MET Final States

Consider R-parity Conserving SUSY:

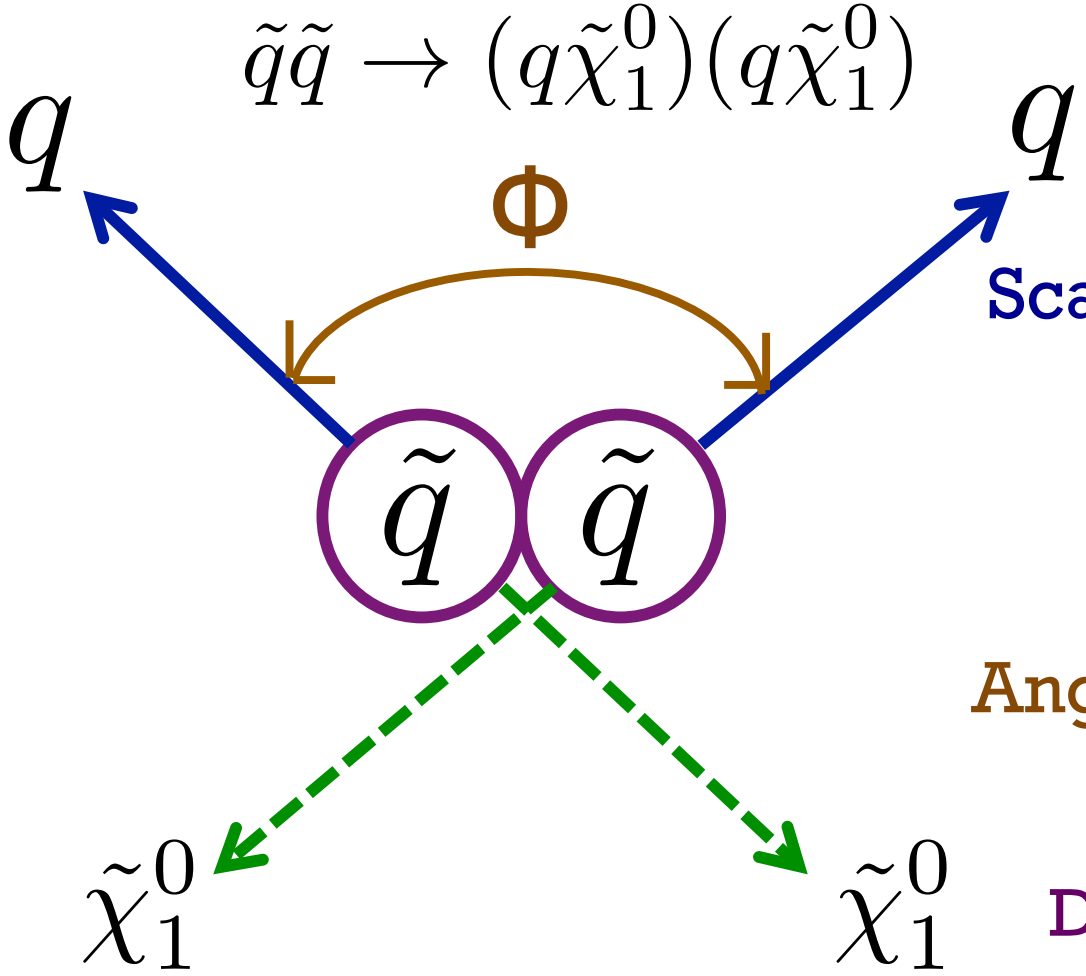
- Strongly interacting sparticles (squarks, gluinos) dominate production
- If heavier than sleptons, gauginos ⇒ cascade decays to LSP
- Long decay chains and large mass differences between SUSY states ⇒ Many high p_T objects (leptons, jets)
- R-parity conservation ⇒ LSP stable (DM candidate) and sparticles pair-produced ⇒ Large missing transverse momentum (MET)



MET + jets + X final states

+ SUSY in Jets + MET Final States

Consider 'canonical' di-squark ➔ 2 jets + MET:



SUSY Signatures:

Scale:

In squark rest frames, final state objects have momentum equal to:

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

Angle:

Coming from different decays, visible and invisible particles do not necessarily balance

Different searches exploit these considerations in different ways

+ Search with α_T + HT

Jets+MET final state search is challenging due to QCD multijet backgrounds: $\sigma \times \epsilon \approx \infty \times 0$

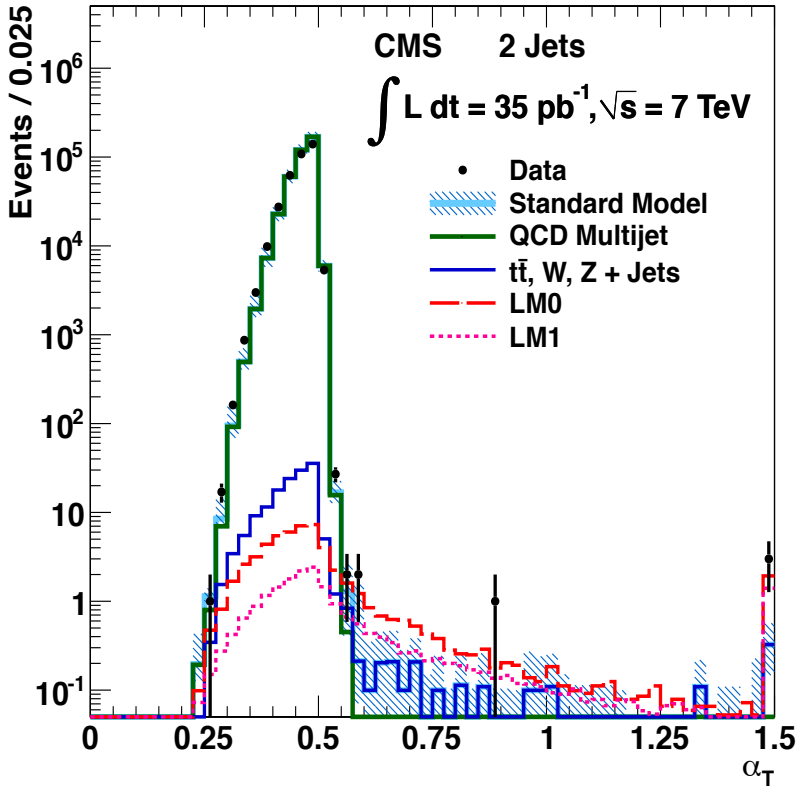
BUT QCD multi-jets' momentum must ~balance in transverse plane ➔ exploit angle between visible jets with α_T

Scale: $$H_T = \sum_{i}^{\text{jets}} |p_T^i|$$

For di-jets:

Angle: $$\alpha_T = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

$\alpha_T \leq 0.5$ for mis-measured QCD



+ Search with α_T + HT

Can generalize to ≥ 3 jet final states by assigning all jets to either one of two *pseudojets*, defined by minimizing

$$\Delta H_T = p_T^{\text{pseudojet 1}} - p_T^{\text{pseudojet 2}}$$

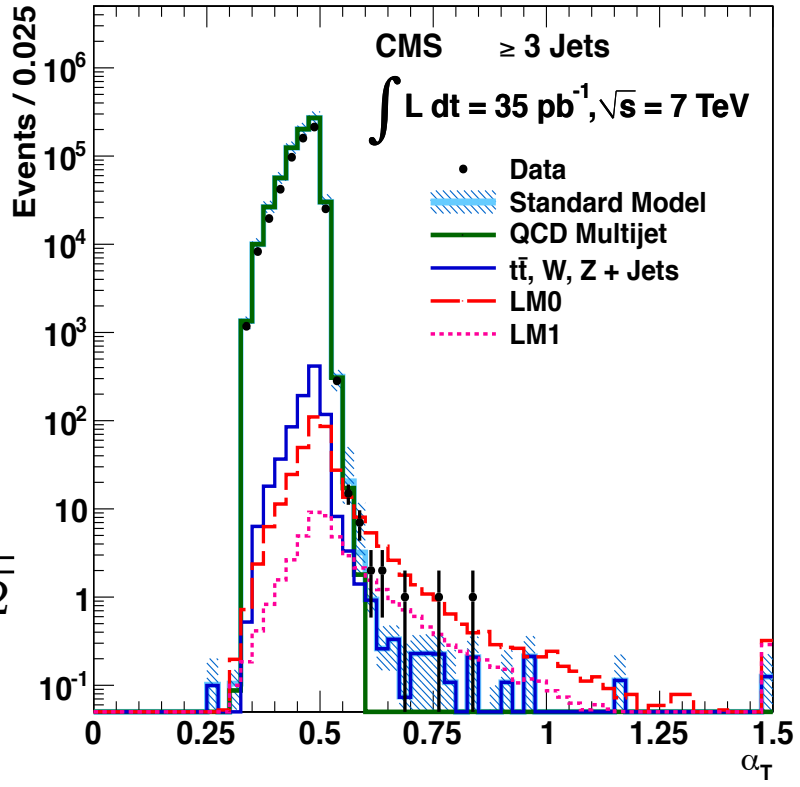
Scale:
$$H_T = \sum_i^{\text{jets}} |p_T^i|$$

In general:

Angle:
$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - MHT^2}}$$

$$MHT = |\sum_i^{\text{jets}} \vec{p}_T^{\,i}|$$

$\alpha_T \leq 0.5$ for mis-measured QCD



+ Search with α_T + HT

Search for high p_T jets, high HT and α_T>0.55

Selection:

At least 2 jets with:

$$p_T > 100\ \mathrm{GeV}/c \quad |\eta| < 2.5$$

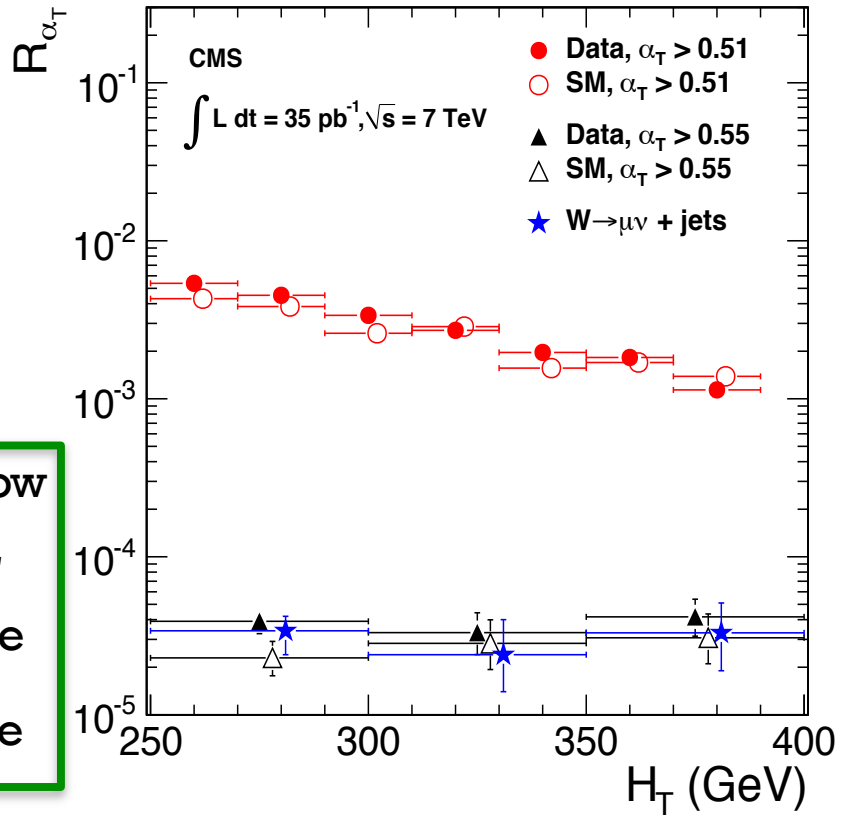
Include additional jets with:

$$p_T > 50\ \mathrm{GeV}/c \quad |\eta| < 3$$

Signal region defined by:

$$H_T > 350\ \mathrm{GeV} \quad \alpha_T > 0.55$$

$$R_{\alpha_T} = \frac{\int_{0.55}^{\infty} \frac{d\sigma}{d\alpha_T} d\alpha_T}{\int_{0}^{0.55} \frac{d\sigma}{d\alpha_T} d\alpha_T}$$



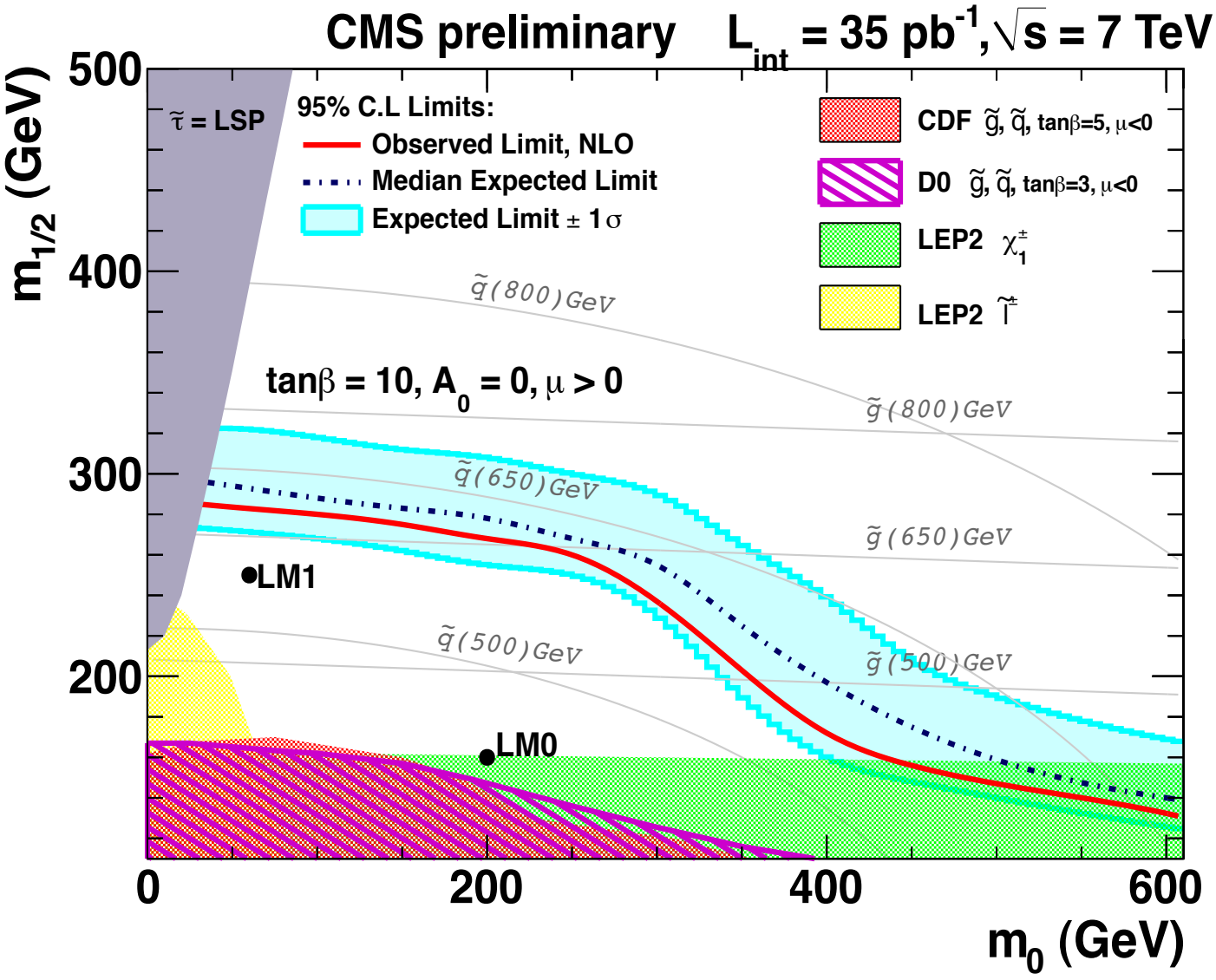
Background prediction:

QCD+All bkgs	Extrapolate yields from low HT to high HT using R_{α_T}
$W(\ell\nu) + \mathrm{jets}$, $t\bar{t}$	Use μ control sample
$Z(\nu\nu) + \mathrm{jets}$	Use γ +jets control sample

Predict: $9.4^{+4.8}_{-4.0}$ (stat) ± 1.0 (syst) events

Observe: 13 events

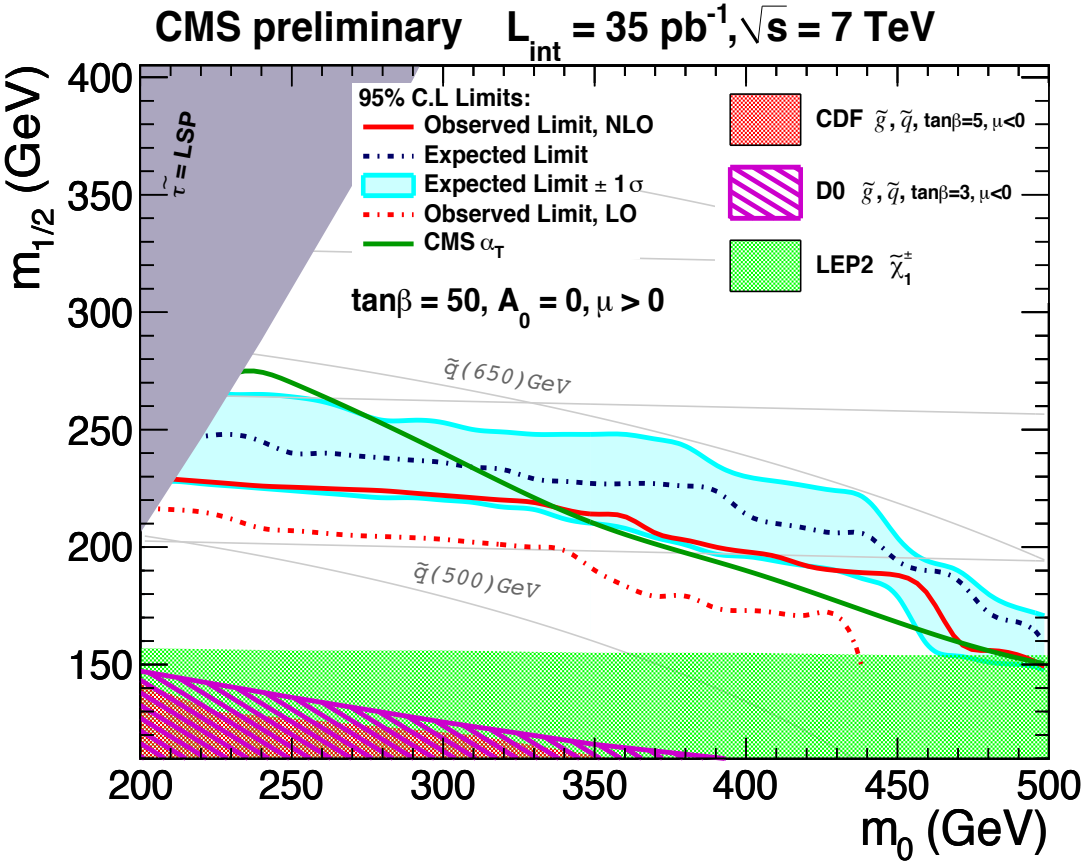
+ Search with α_T + HT



+ Search with α_T + HT + b-tag

α_T is a QCD killer; b-tagging is a EWK killer.
⇒ Enhance early discovery potential

Similar selection (+b-tag) and background prediction methods



Predict: $0.33^{+0.43}_{-0.33}$ (stat) ± 0.13 (syst) events
Observe: 1 event

+ Search with MHT + HT

Search for high p_T jets, high HT and high MHT

Scale:

$$H_T = \sum_{i}^{\text{jets}} |p_T^i|$$

Scale+Angle:

$$MHT = |\sum_{i}^{\text{jets}} \vec{p}_T^{\,i}|$$

Selection (baseline):

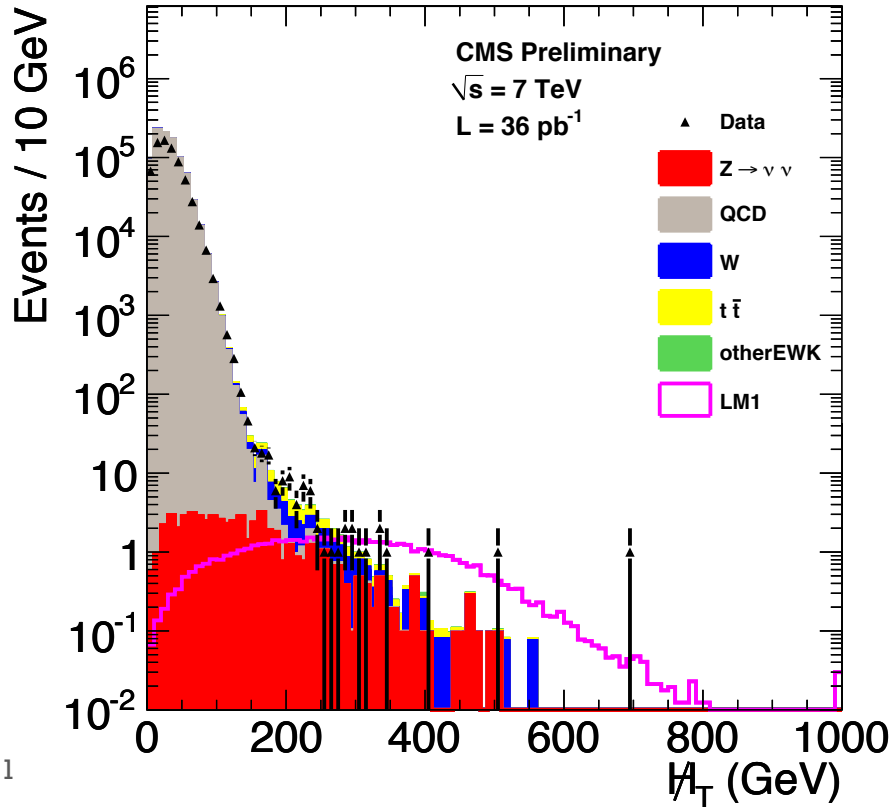
At least 3 jets with:

$$p_T > 50 \text{ GeV}/c \quad |\eta| < 2.5$$

Signal region defined by:

$$H_T > 350 \text{ GeV}$$

$$MHT > 150 \text{ GeV}$$



+ Search with MHT + HT

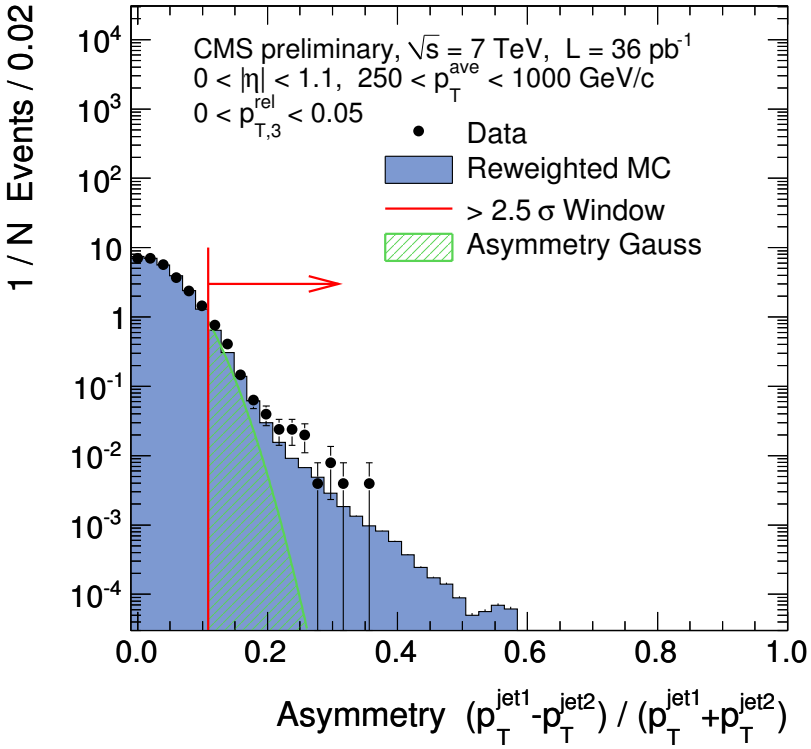
Background prediction:

QCD	Re-balance and smear
$W(\ell\nu) + \text{jets},\ t\bar{t}$	Use μ control sample
$Z(\nu\nu) + \text{jets}$	Use γ +jets and Z($\mu\ \mu$)+jets control samples

Search for high p_T jets, high HT and high MHT

QCD multi-jet events do not intrinsically populate the phase-space defined by our requirements on scale and angle -- BUT, mis-measurements of jets can result in large measured MHT

QCD multi-jet background predicted by 'smearing' balanced (no MHT) events with measured resolution functions



+ Search with MHT + HT

Search for high p_T jets, high HT and high MHT

Selection (baseline):

At least 3 jets with:

$$p_T > 50 \text{ GeV}/c$$
$$|\eta| < 2.5$$

Signal region defined by:

$$H_T > 350 \text{ GeV}$$
$$MHT > 150 \text{ GeV}$$

Background prediction:

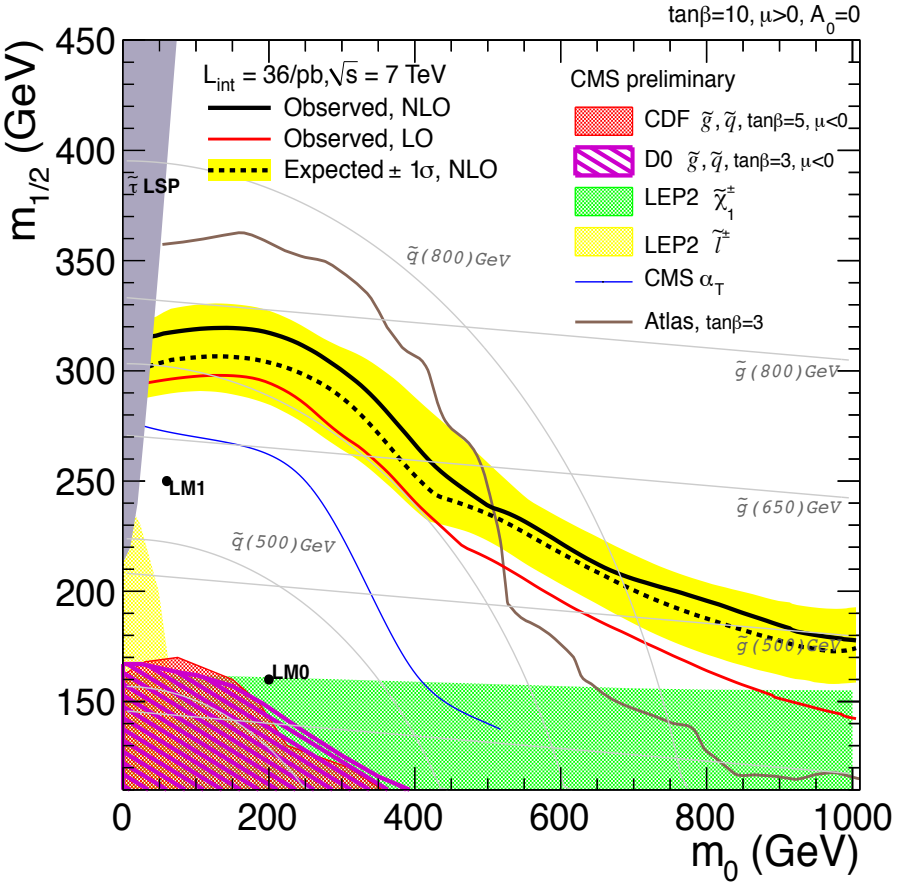
QCD — Re-balance and smear

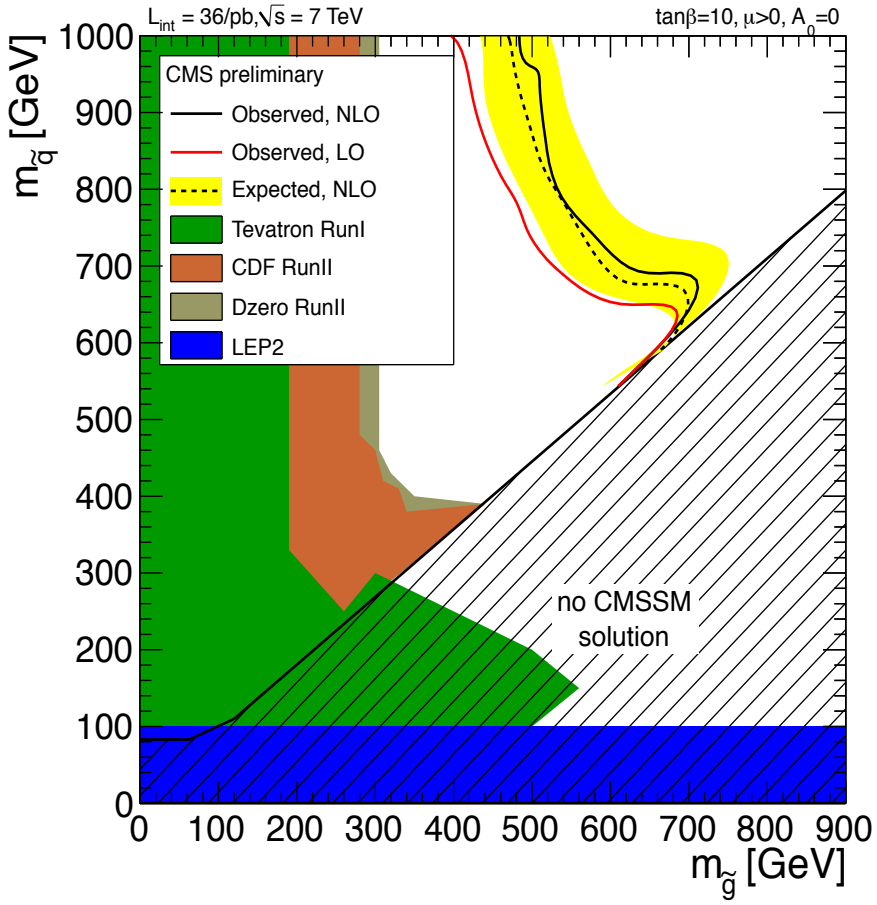
$W(\ell\nu) + \text{jets}, \; t\bar{t}$ — Use μ control sample

$Z(\nu\nu) + \text{jets}$ — Use γ +jets and Z($\mu\ \mu$)+jets control samples

Method	Baseline		High-$\not{H}_T$ ($\not{H}_T > 250$ GeV/c)		High-H_T ($H_T > 500$ GeV/c)	
$Z \to \nu\bar{\nu}$ from γ+jets	26.3	$\pm$4.8	7.1	$\pm$2.2	8.4	$\pm$2.3
$t\bar{t}/W \to e, \mu$+X lost-lepton method	33.0	$\pm$8.1	4.8	$\pm$1.9	10.9	$\pm$3.4
$t\bar{t}/W \to \tau_{hadr}$+X method	22.3	$\pm$4.6	6.7	$\pm$2.1	8.5	$\pm$2.5
QCD Rebalance+Smear method	29.7	$\pm$15.2	0.16	$\pm$0.10	16.0	$\pm$7.9
QCD factorization method	25.2	$\pm$13.4	0.4	$\pm$0.3	17.3	$\pm$9.4
Total data-driven background	111.3	$\pm$18.5	18.8	$\pm$3.5	43.8	$\pm$9.2
Observed in 36 pb^{-1} of data	111		15		40	
95% CL limit on signal events	40.4		9.6		19.6	

+ Search with MHT + HT





+ Search with M_R + R (Razor)

Introduce "Razor" variables, R and M_R, designed to discover and characterize massive pair-production

arXiv:1006.2727

Arranging all reconstructed objects into two hemispheres, with 3-momenta $\vec{p}$ and $\vec{q}$

$$\text{MET} = \vec{M}$$

Example: $\tilde{q}\tilde{q} \to (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$

Scale:

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

→ Peaks at $M_\Delta = \dfrac{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{q}}}$

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

→ Edge at $M_\Delta = \dfrac{m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{q}}}$

Angle:

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

+ Search with M_R + R (Razor)

Introduce "Razor" variables, R and M_R, designed to discover and characterize massive pair-production

arXiv:1006.2727

Arranging all reconstructed objects into two hemispheres, with 3-momenta $\vec{p}$ and $\vec{q}$

$\text{MET} = \vec{M}$

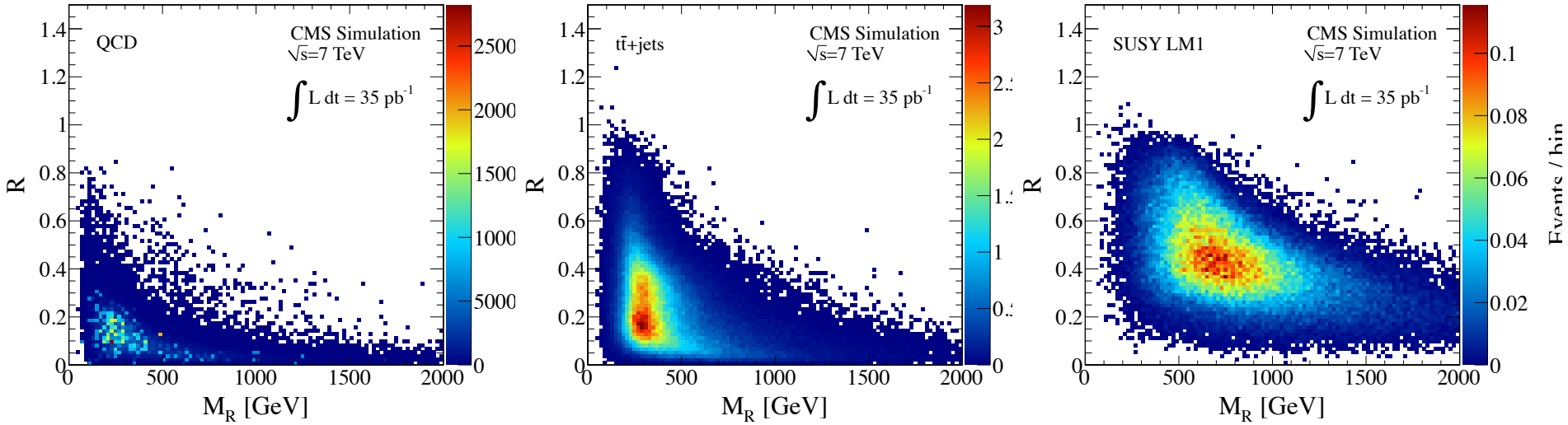
Scale:

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

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

Angle:

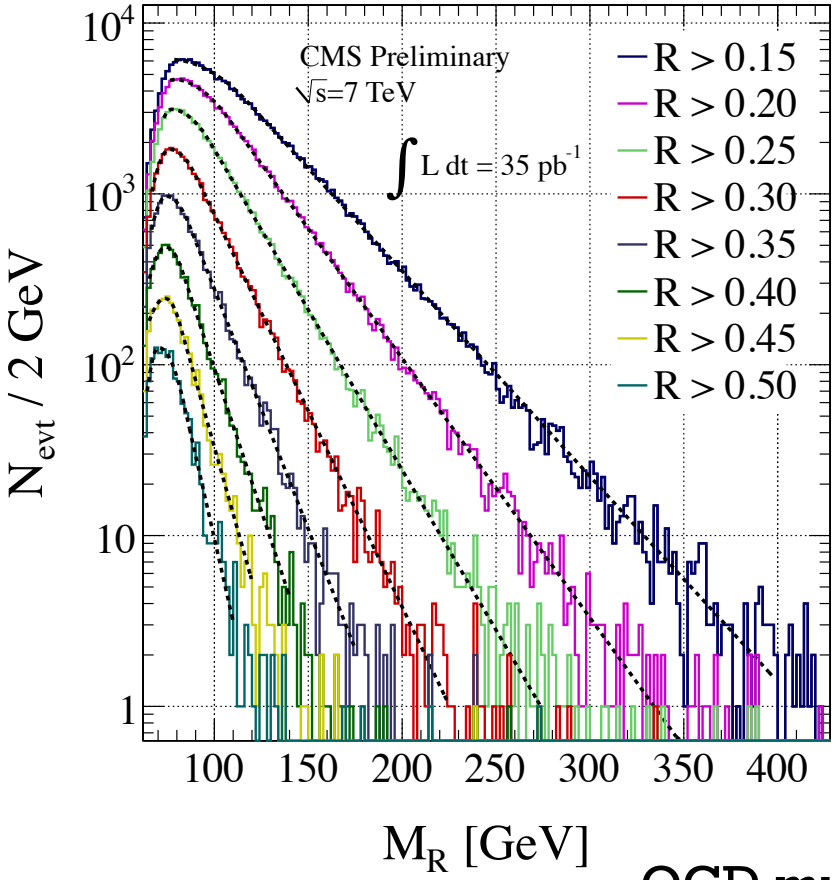
$$R = \frac{M_T^R}{M_R}$$

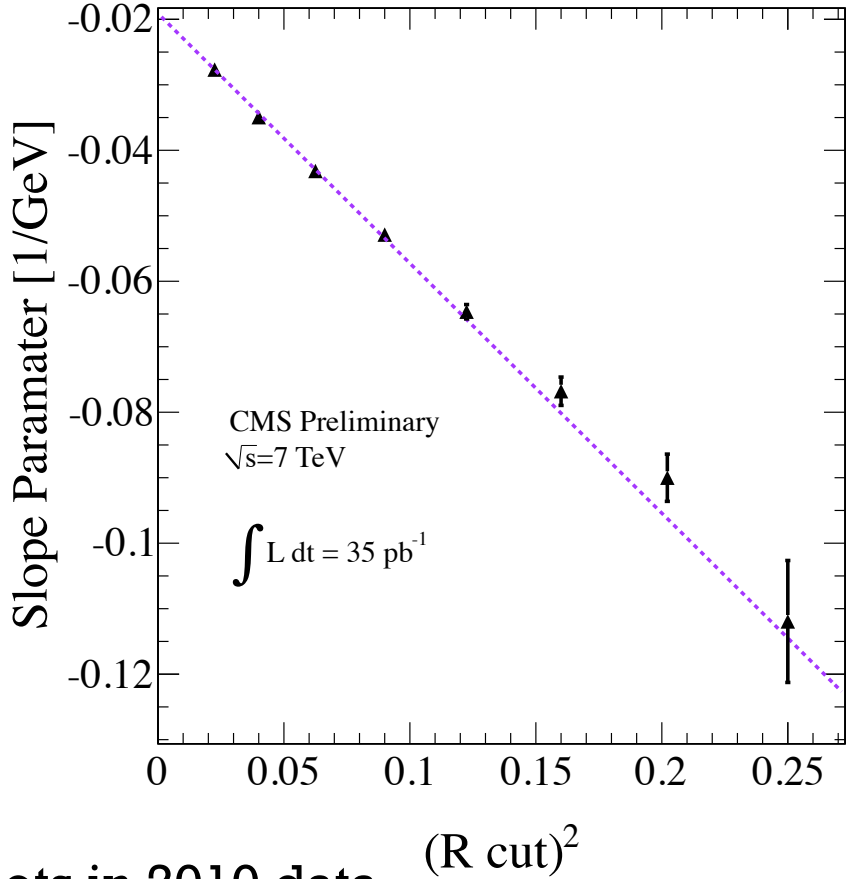


+ Search with M_R + R (Razor)

M_R distribution for QCD background falls exponentially, with slope dictated by cut on R

Exponential slopes scale linearly with $(R\ cut)^2$ – used to predict QCD background to high M_R search region



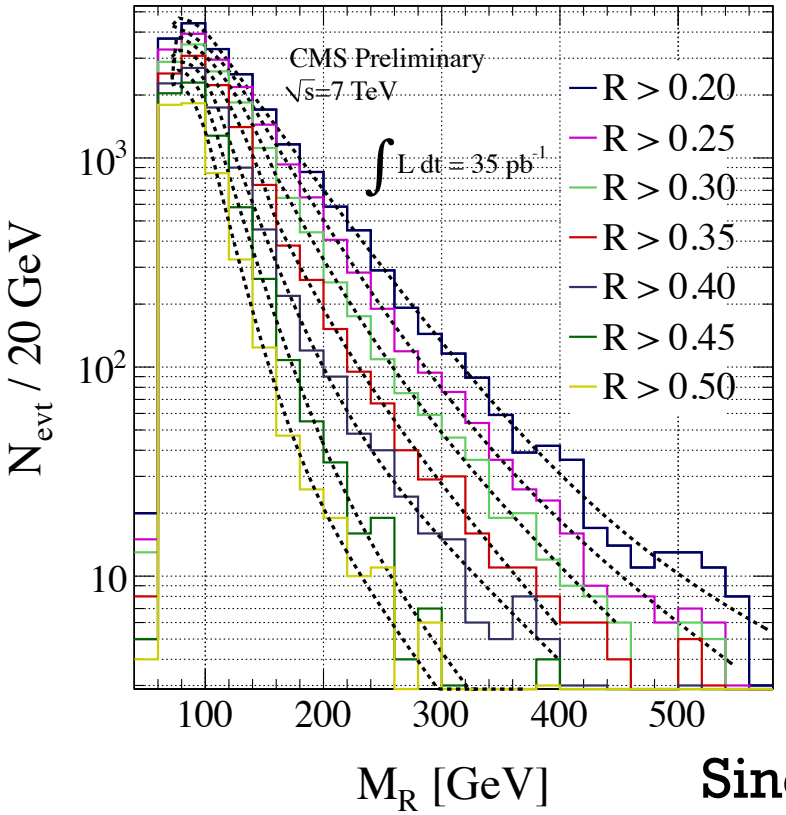


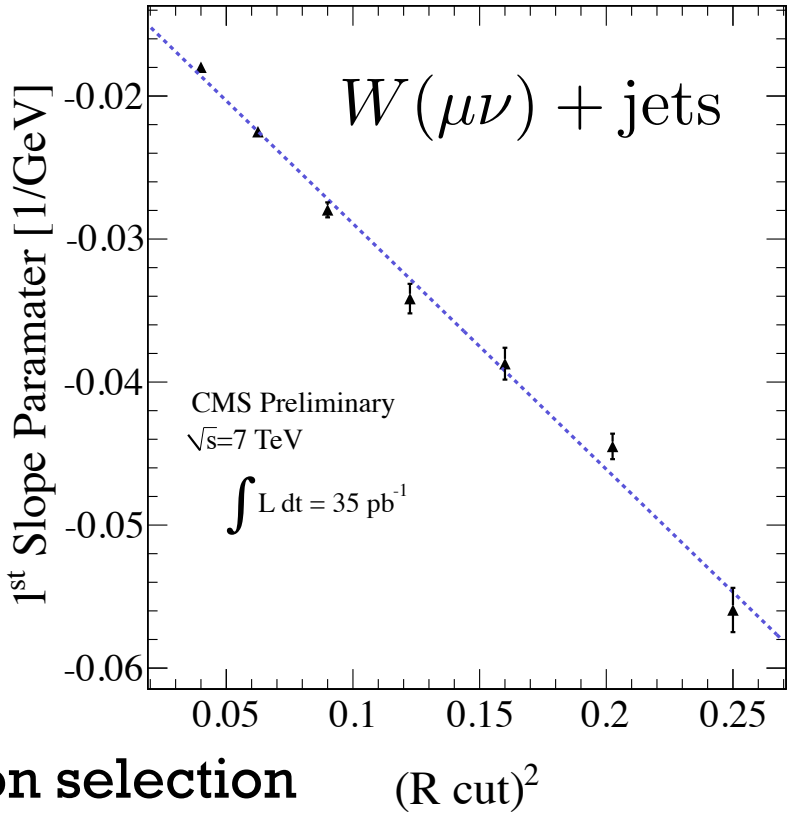
QCD multi-jets in 2010 data

+ Search with M_R + R (Razor)

Same exponential behavior in M_R and $(R\ cut)^2$ scaling observed in other backgrounds

Lepton control samples used to measure M_R slope evolution parameters for non-QCD backgrounds



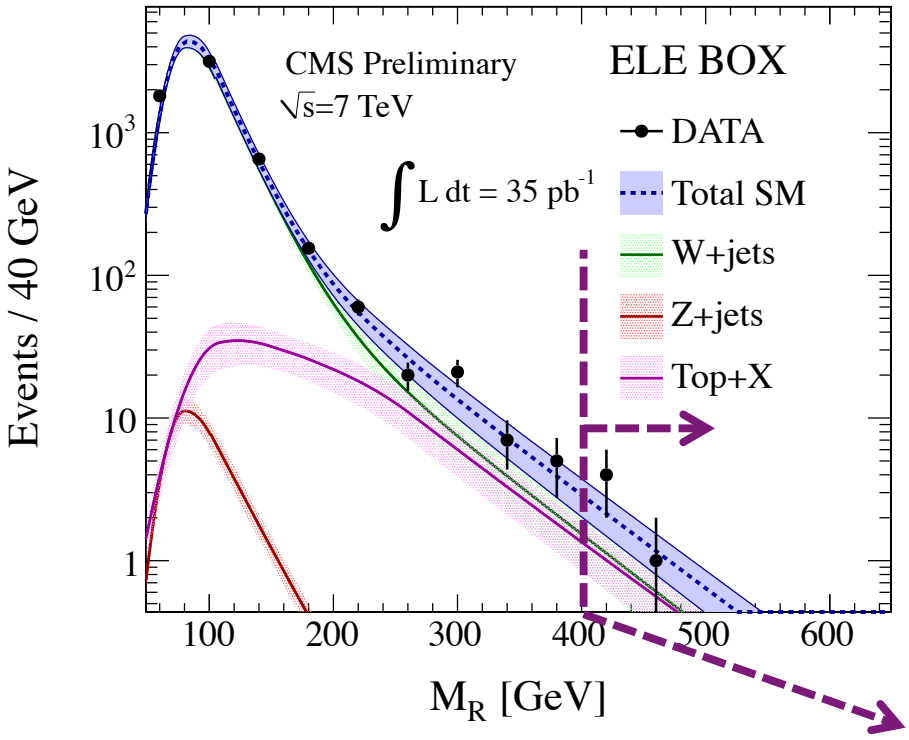


Single muon selection

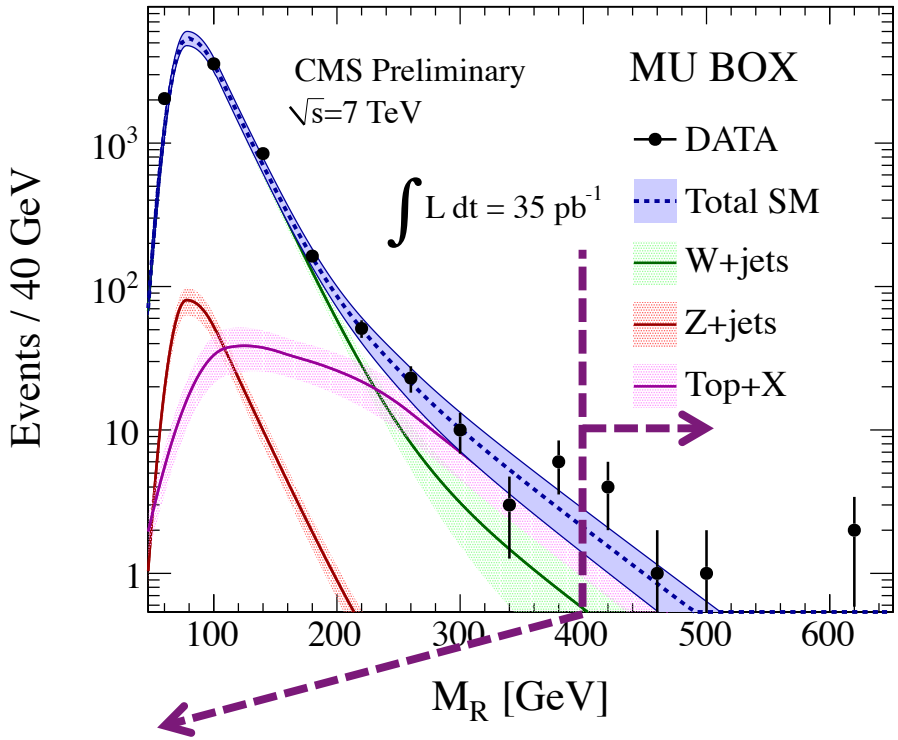
+ Search with M_R + R (Razor)

Low M_R regions in lepton samples (here, **R > 0.45**) are used to normalize background in jets+MET final state search

Single electron selection



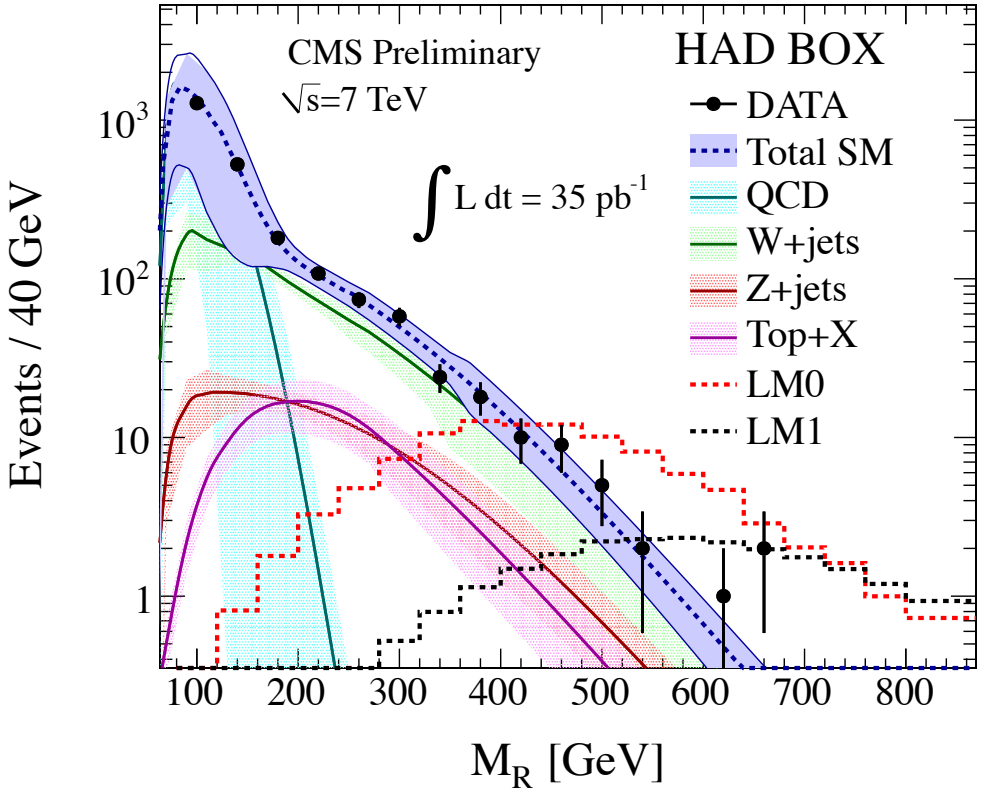
Single muon selection



High M_R regions are used to search for SUSY in single lepton analyses

+ Search with M_R + R (Razor)

Each background species' shape and normalization is measured in data using different control samples



Selection:

At least 2 jets with:

$$p_T > 30 \text{ GeV}/c$$
$$|\eta| < 3$$

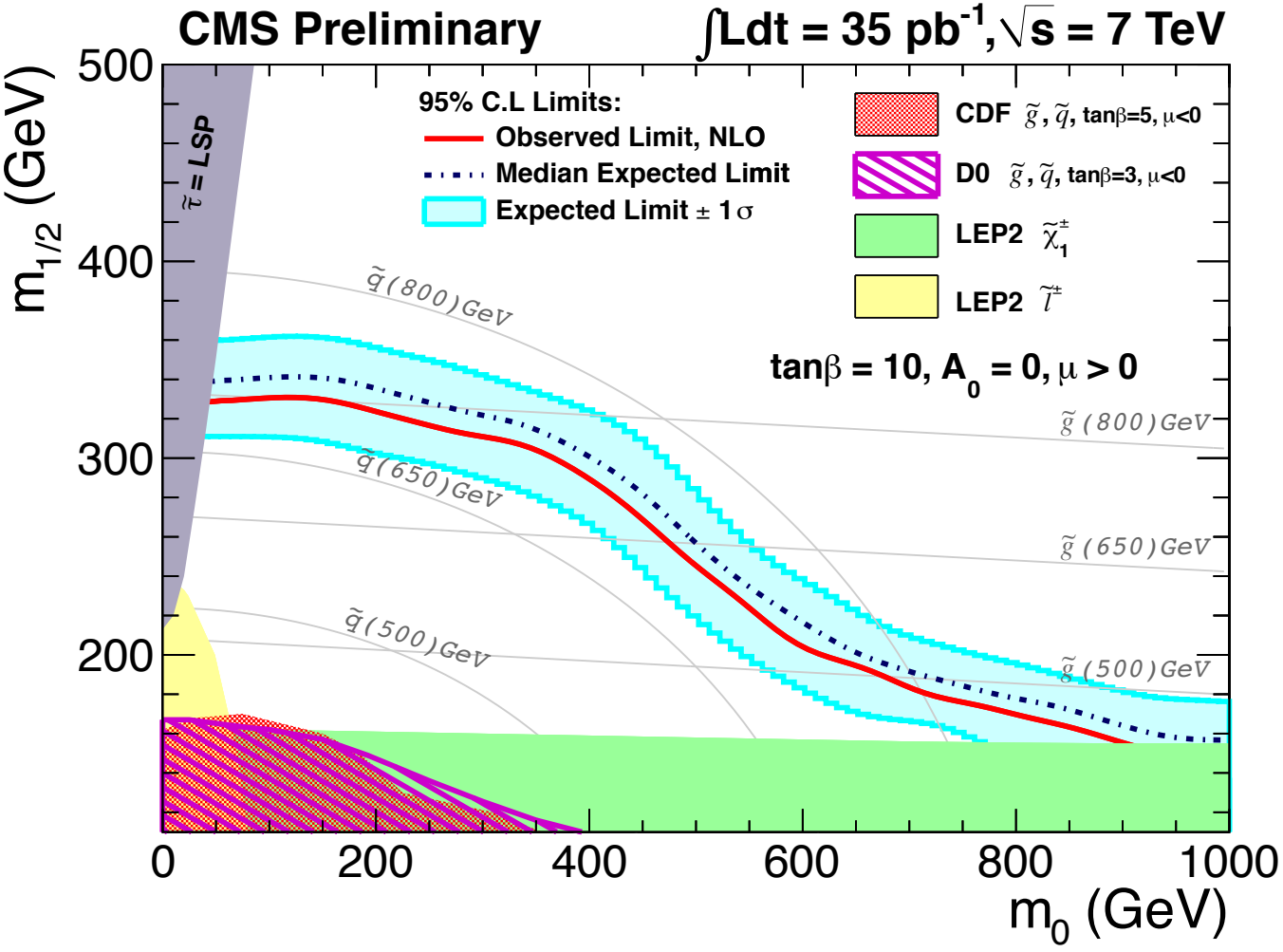
Signal region defined by:

$$R > 0.5$$
$$M_R > 500 \text{ GeV}$$

Predict: 5.5 ± 1.4 events

Observe: 7 event

+ Search with M_R + R (Razor)

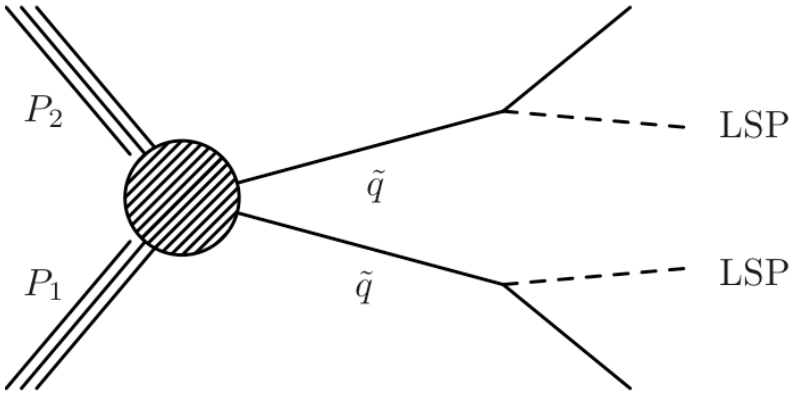


+ Simplified topology interpretation

http://www.lhcnewphysics.org

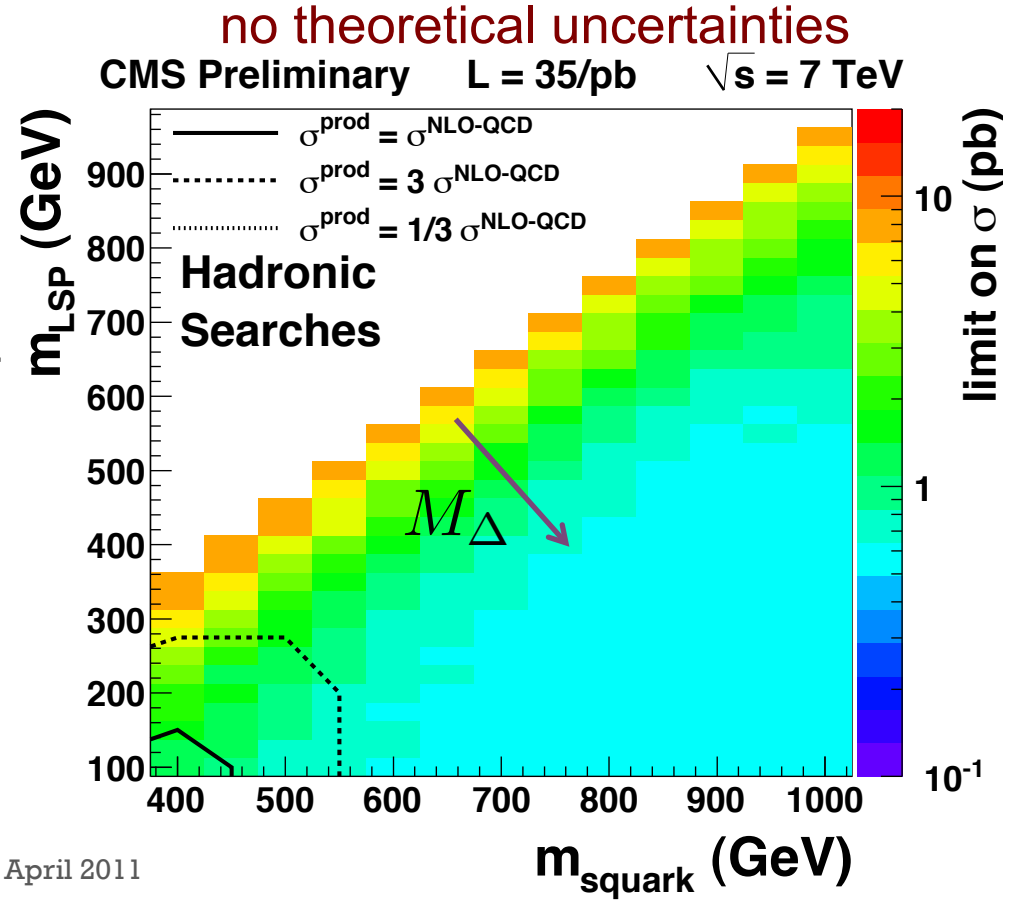
$$\tilde{q}\tilde{q} \rightarrow (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$$

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



Exclusion limits from jets+MET SUSY searches are interpreted in context of simplified SUSY spectrum with ONLY squarks and LSPs

Here, exclusion limits represent the union of parameter space excluded by the three analyses



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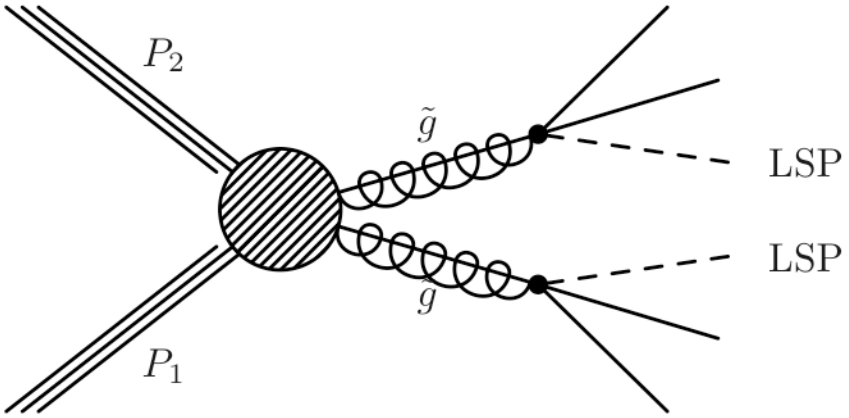
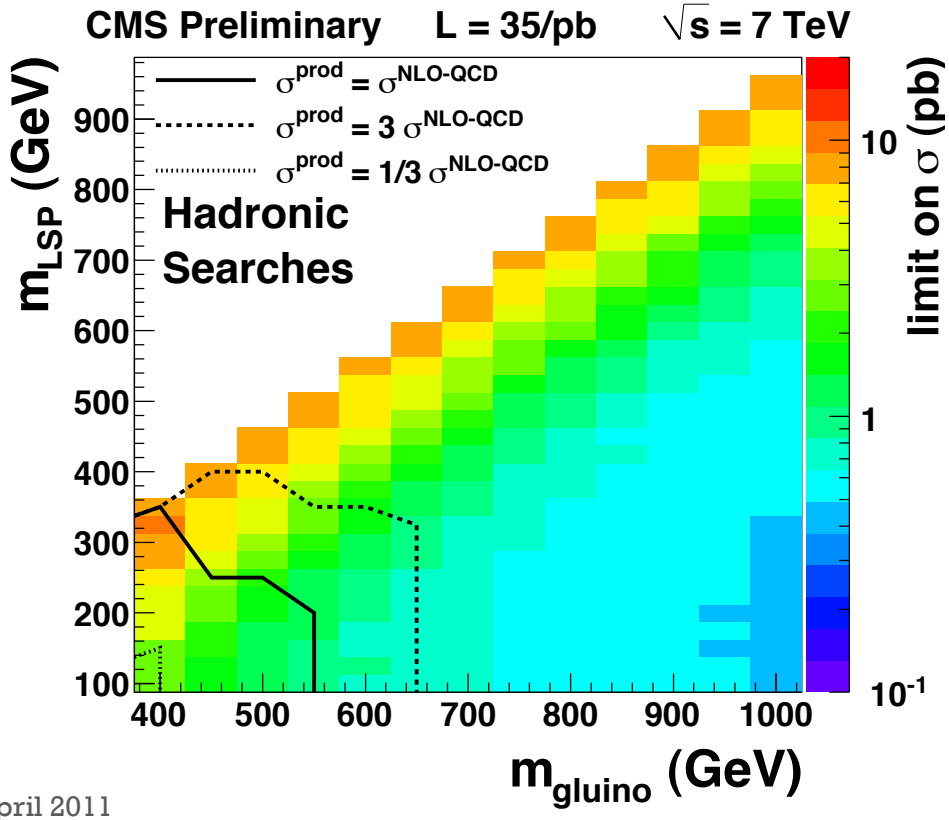


$$\tilde{g}\tilde{g} \rightarrow (qq\tilde{\chi}_1^0)(qq\tilde{\chi}_1^0)$$

Exclusion limits from jets+MET SUSY searches are interpreted in context of simplified SUSY spectrum with ONLY gluinos and LSPs

Here, exclusion limits represent the union of parameter space excluded by the three analyses

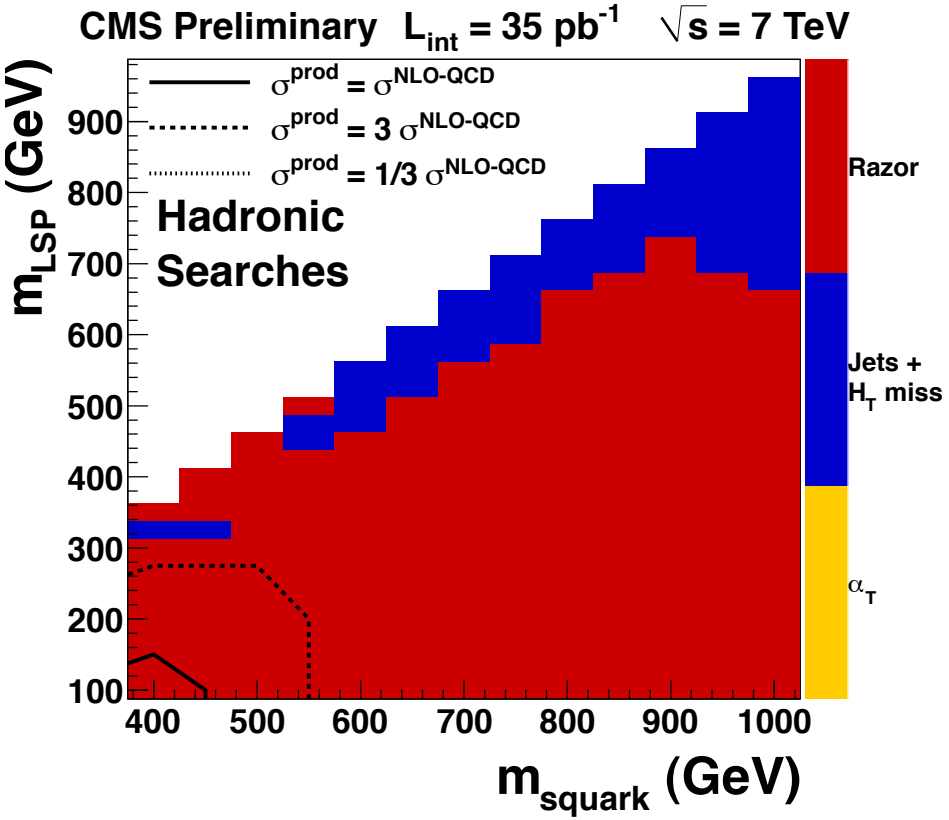
no theoretical uncertainties



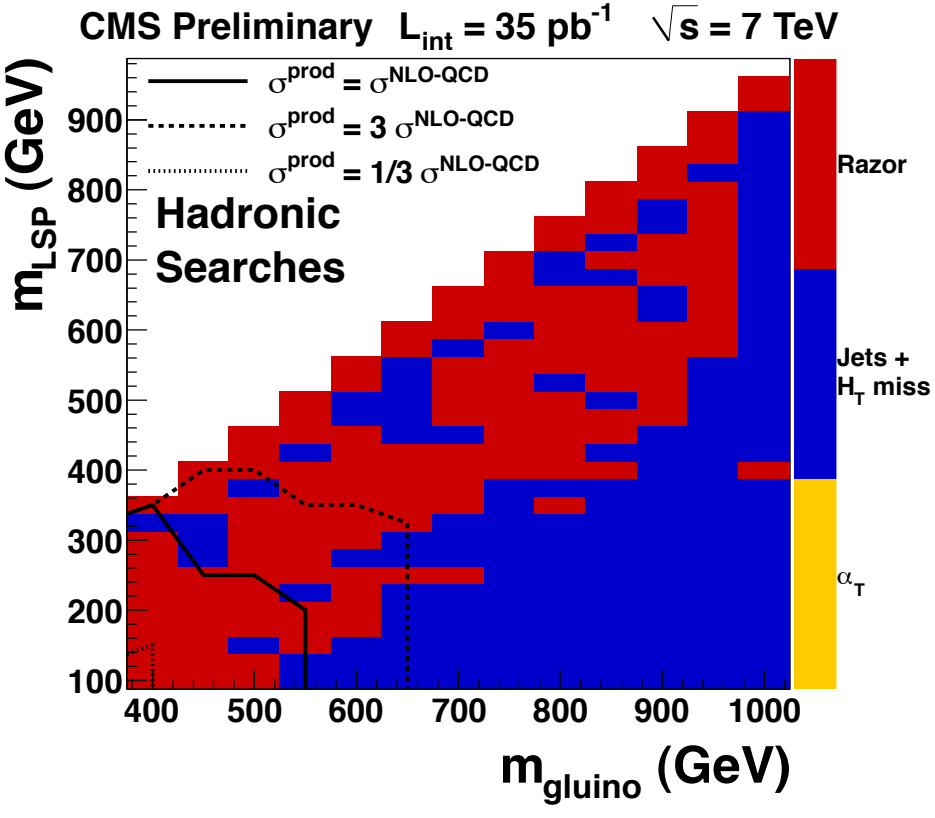
+ Simplified topology interpretation

Analysis resulting in most stringent limit for each model point

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



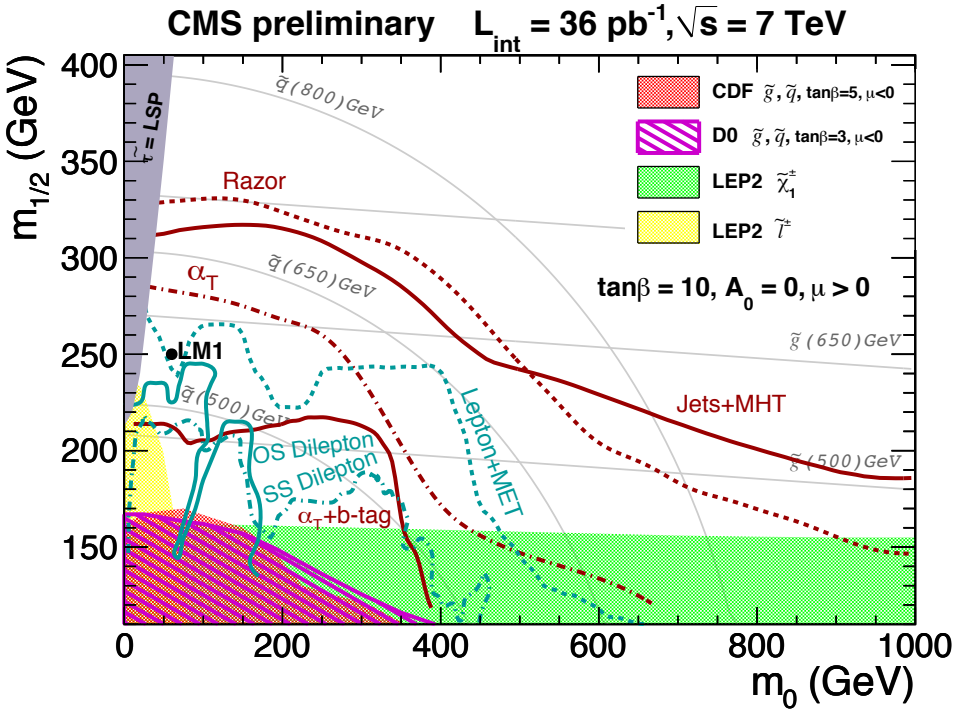
$$\tilde{g}\tilde{g} \rightarrow (qq\tilde{\chi}_1^0)(qq\tilde{\chi}_1^0)$$



Complementarity between analyses

Outlook

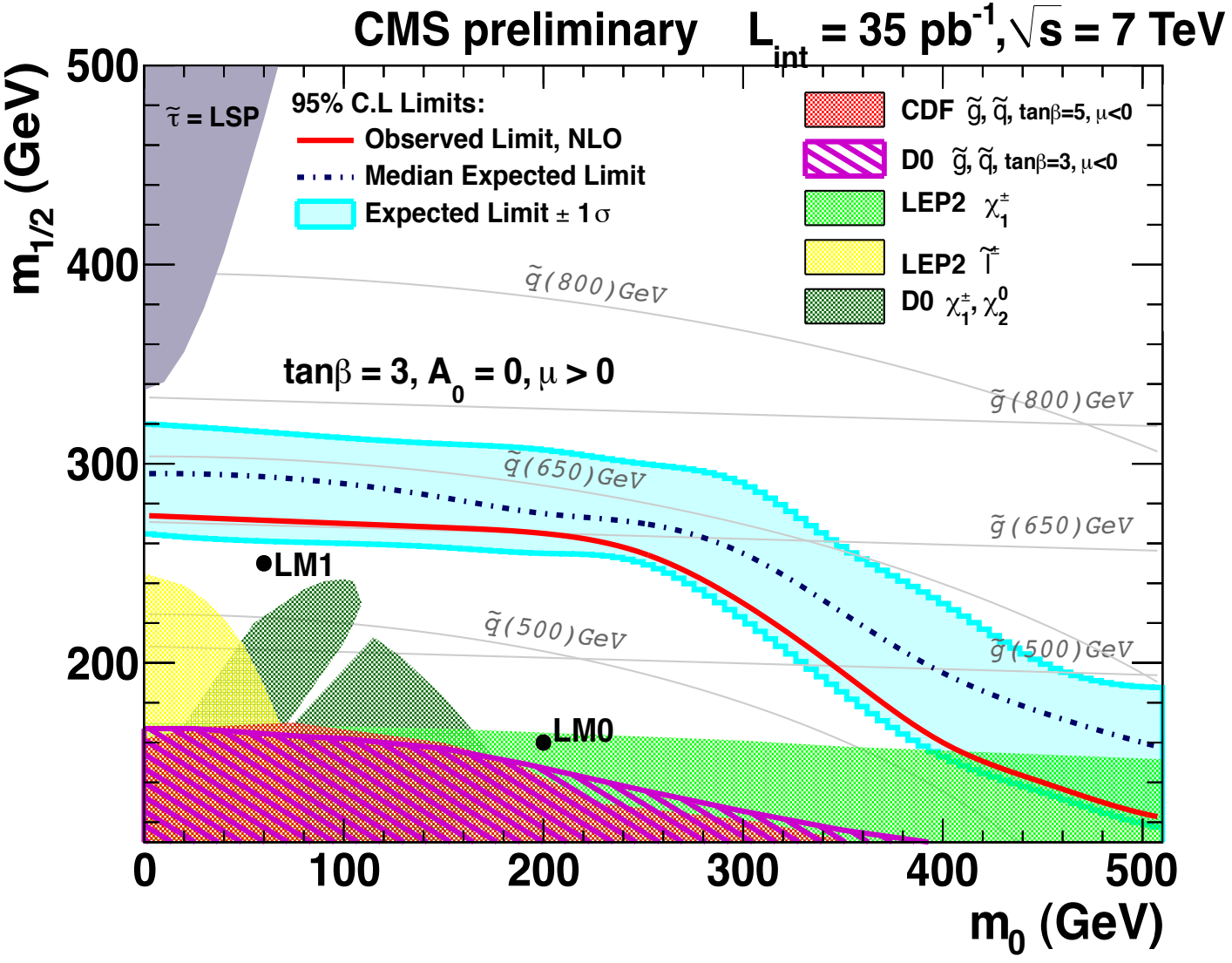
- CMS is searching for SUSY not only with a broad collection of final states, but also with different approaches within the jets+MET final state
- The analyses presented here, each with it's own data-driven background estimation techniques, provide not only robust x-checks, but also complementarity w.r.t. the signature space we are searching
- Looking forward to discovery



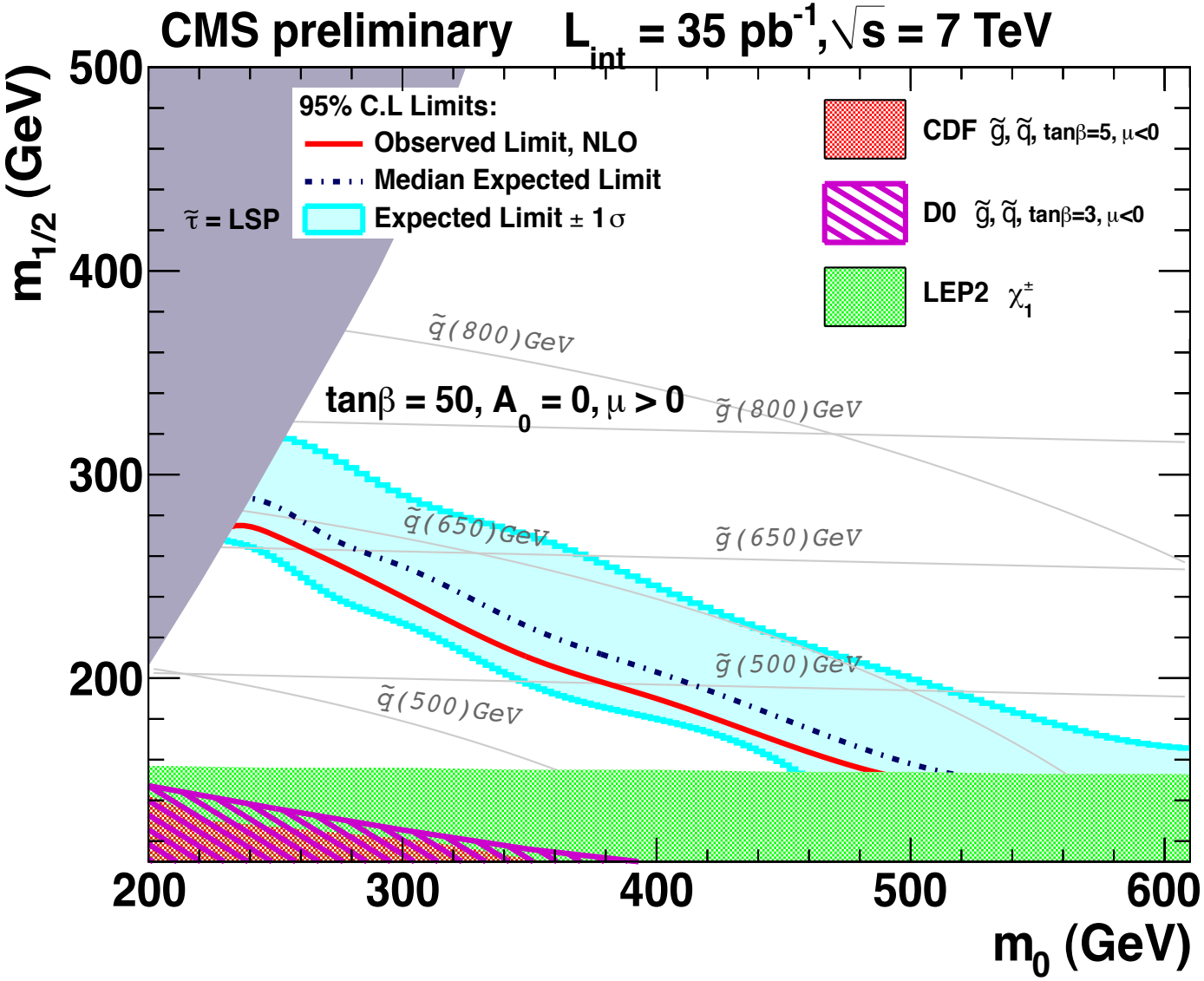
More details at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

BACKUP SLIDES

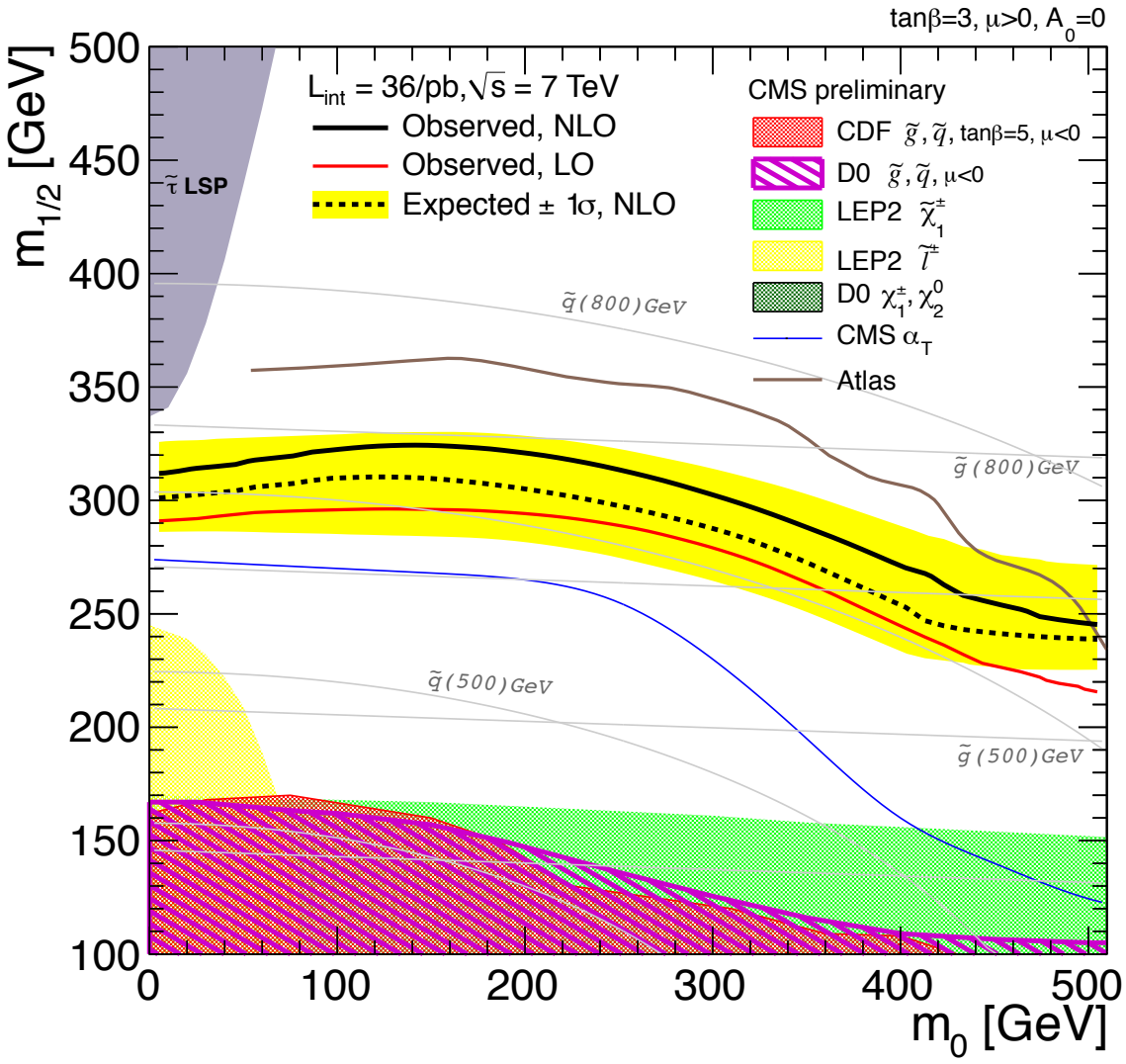
+ Search with α_T + HT



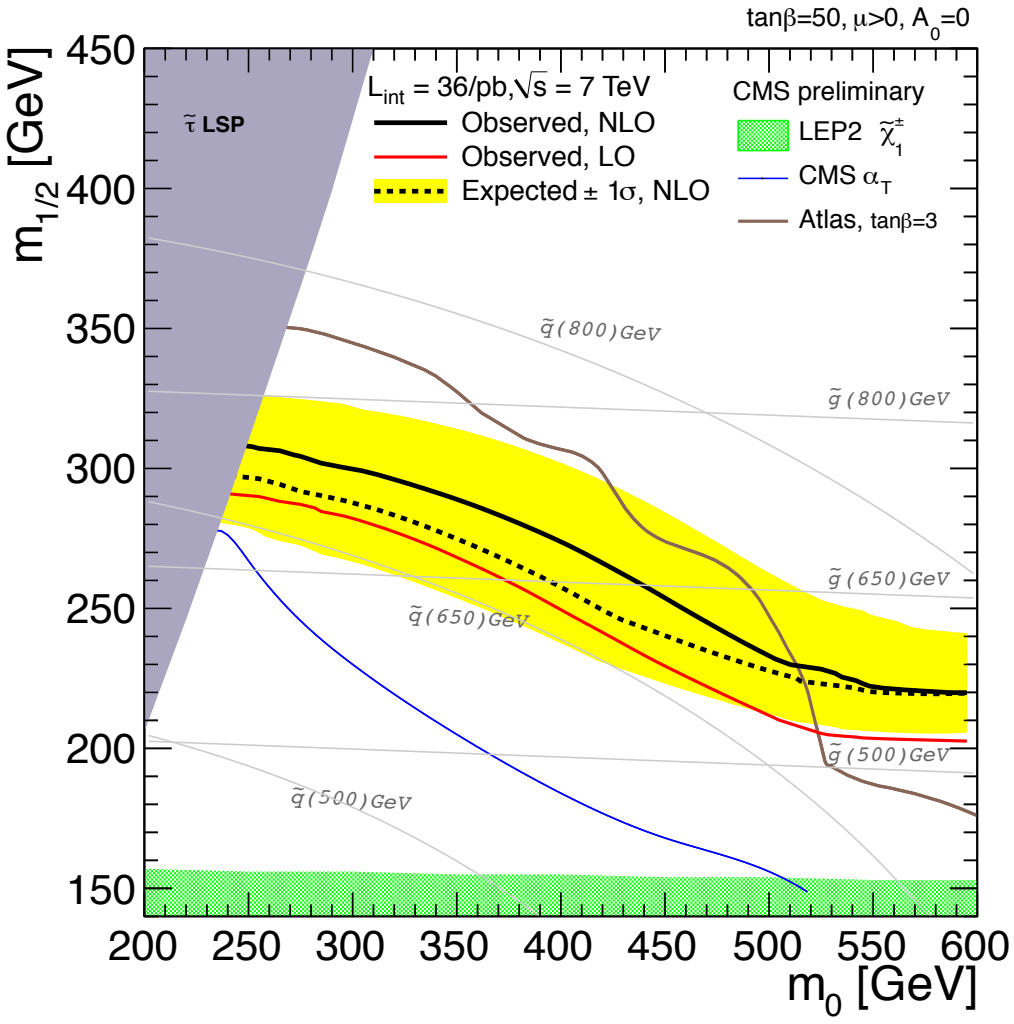
+ Search with α_T + HT



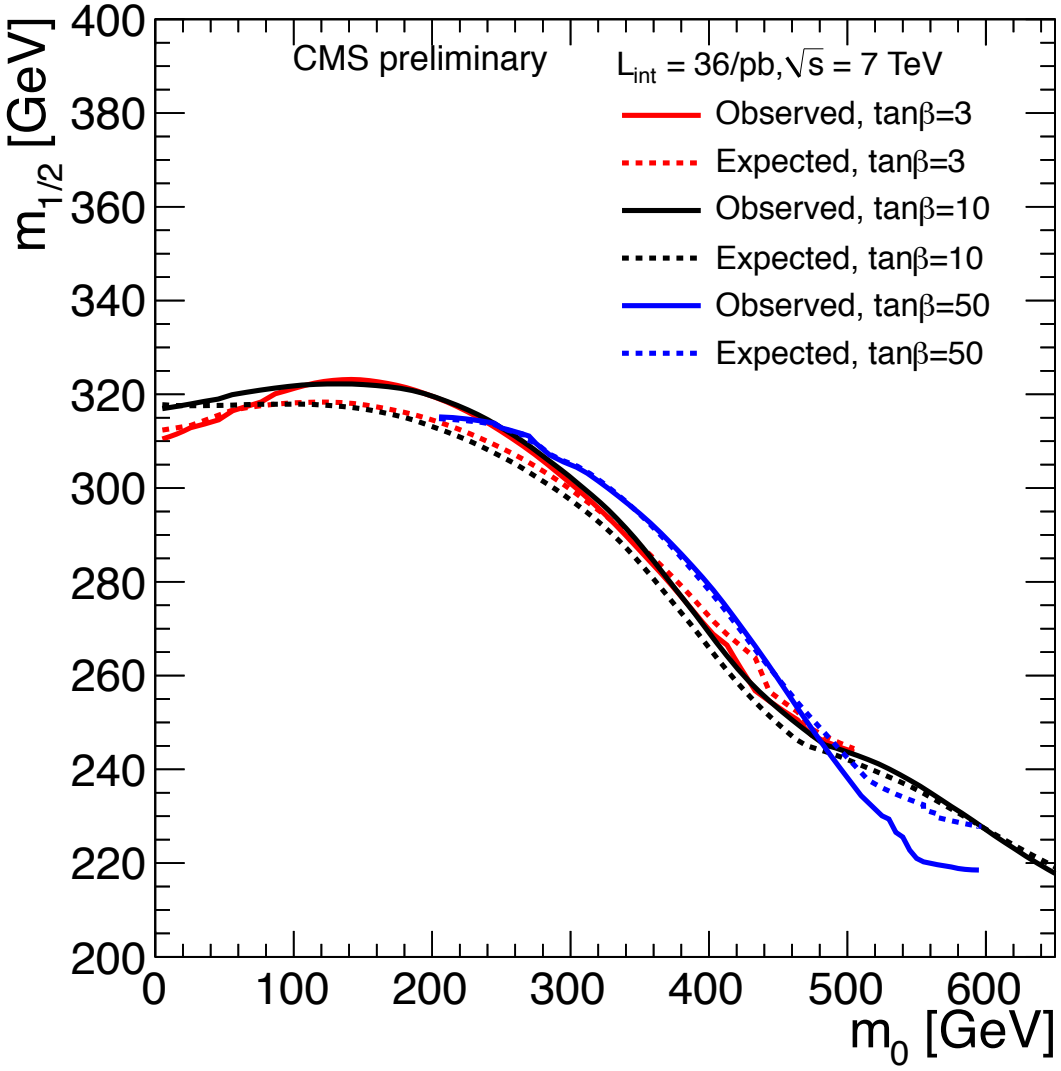
+ Search with MHT + HT



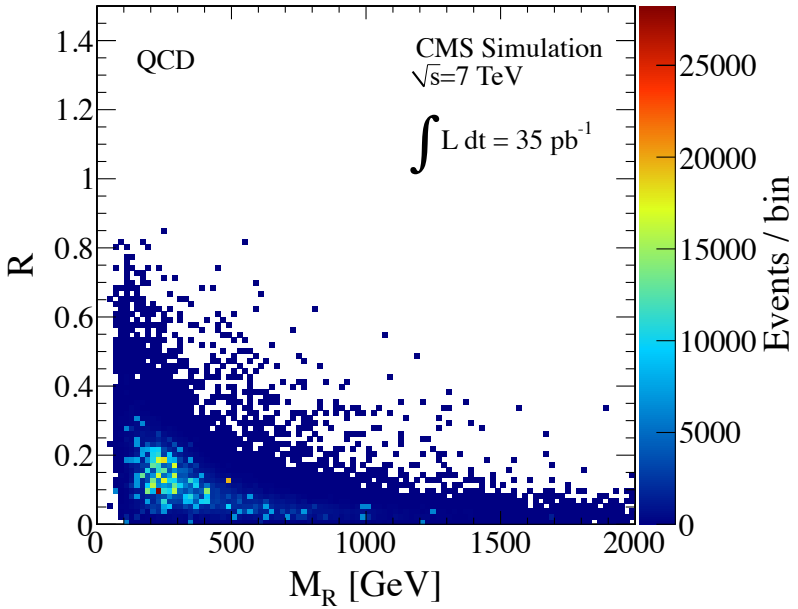
+ Search with MHT + HT

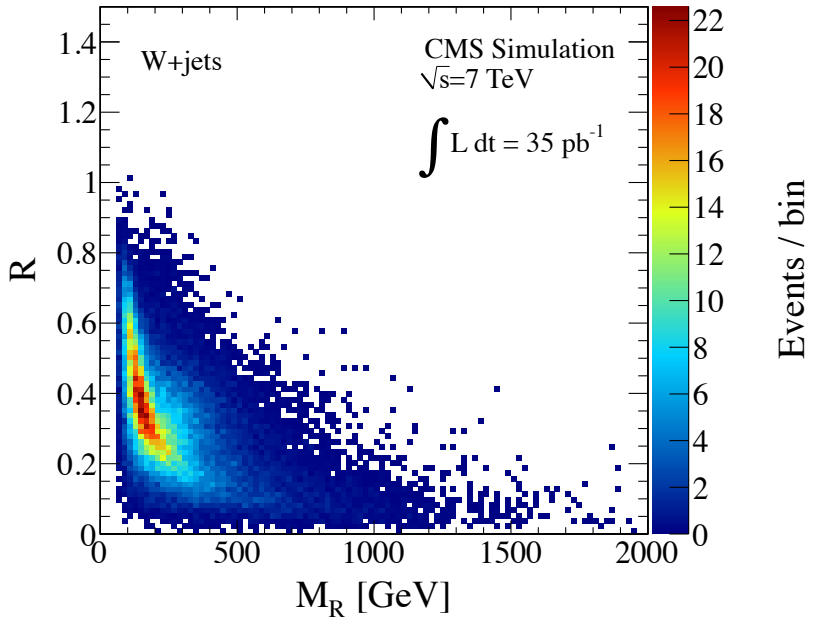


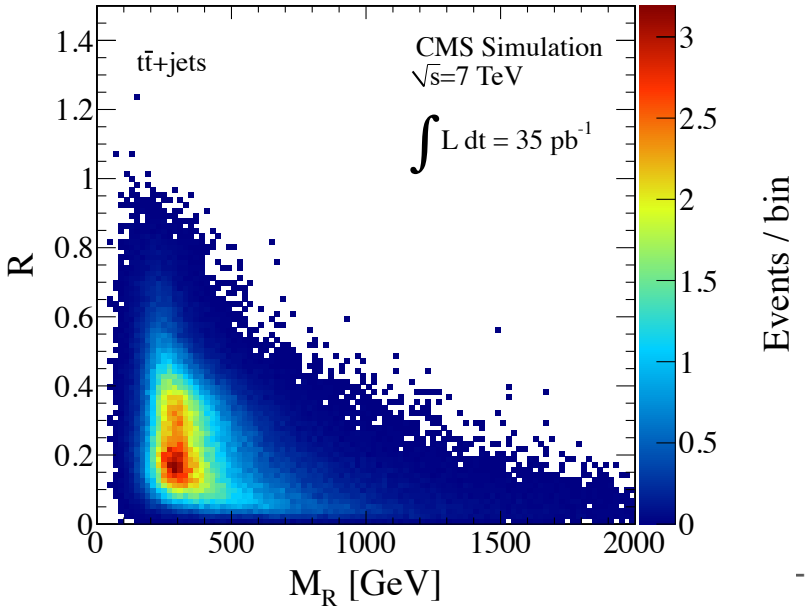
+ Search with MHT + HT

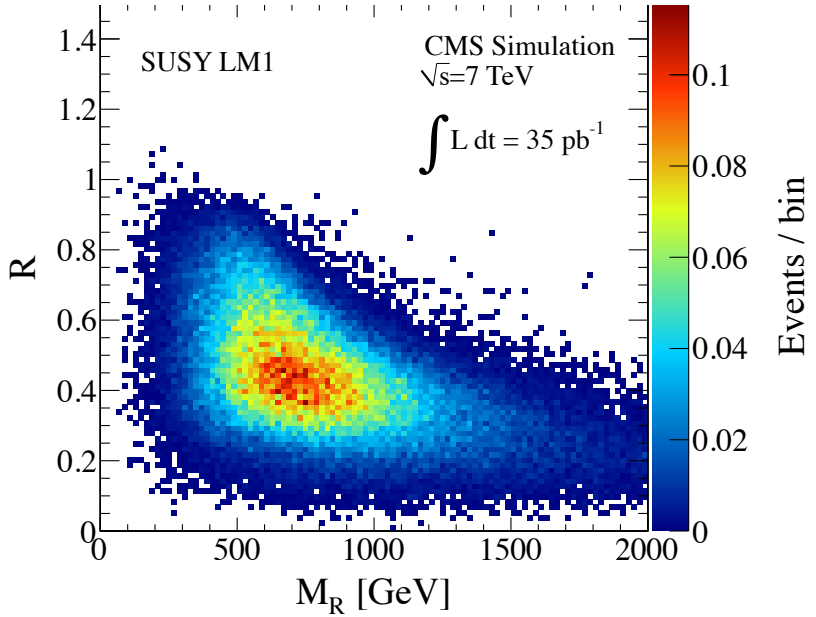


Search with M_R + R (Razor)



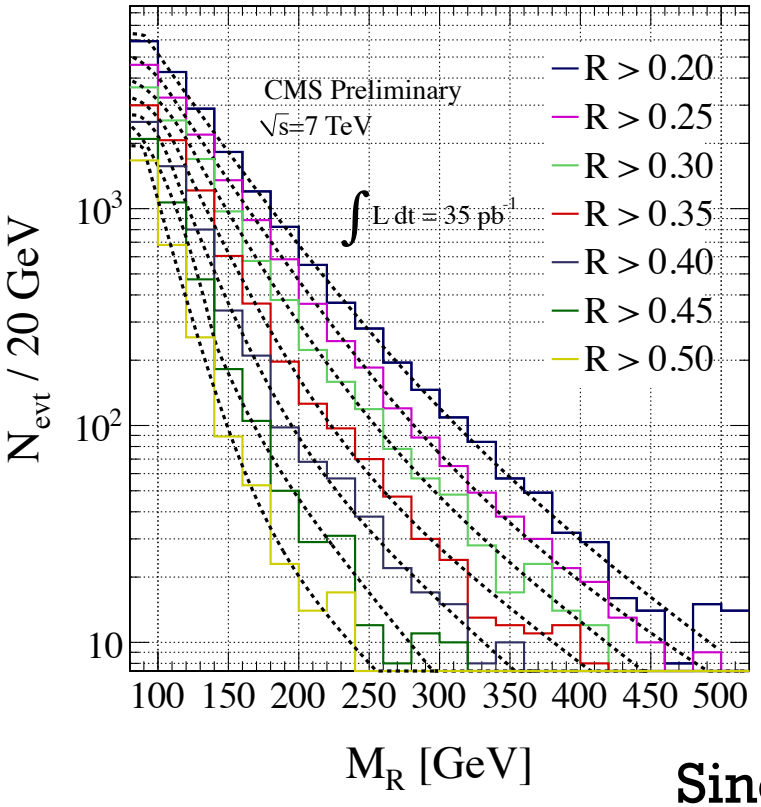




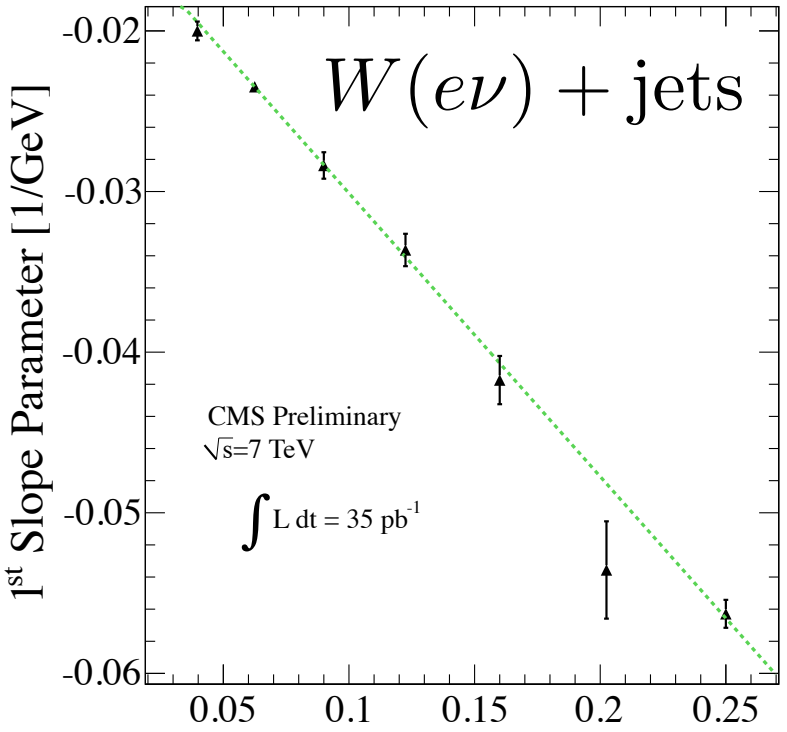


+ Search with M_R + R (Razor)

Same exponential behavior in M_R and $(R\ cut)^2$ scaling observed in other backgrounds

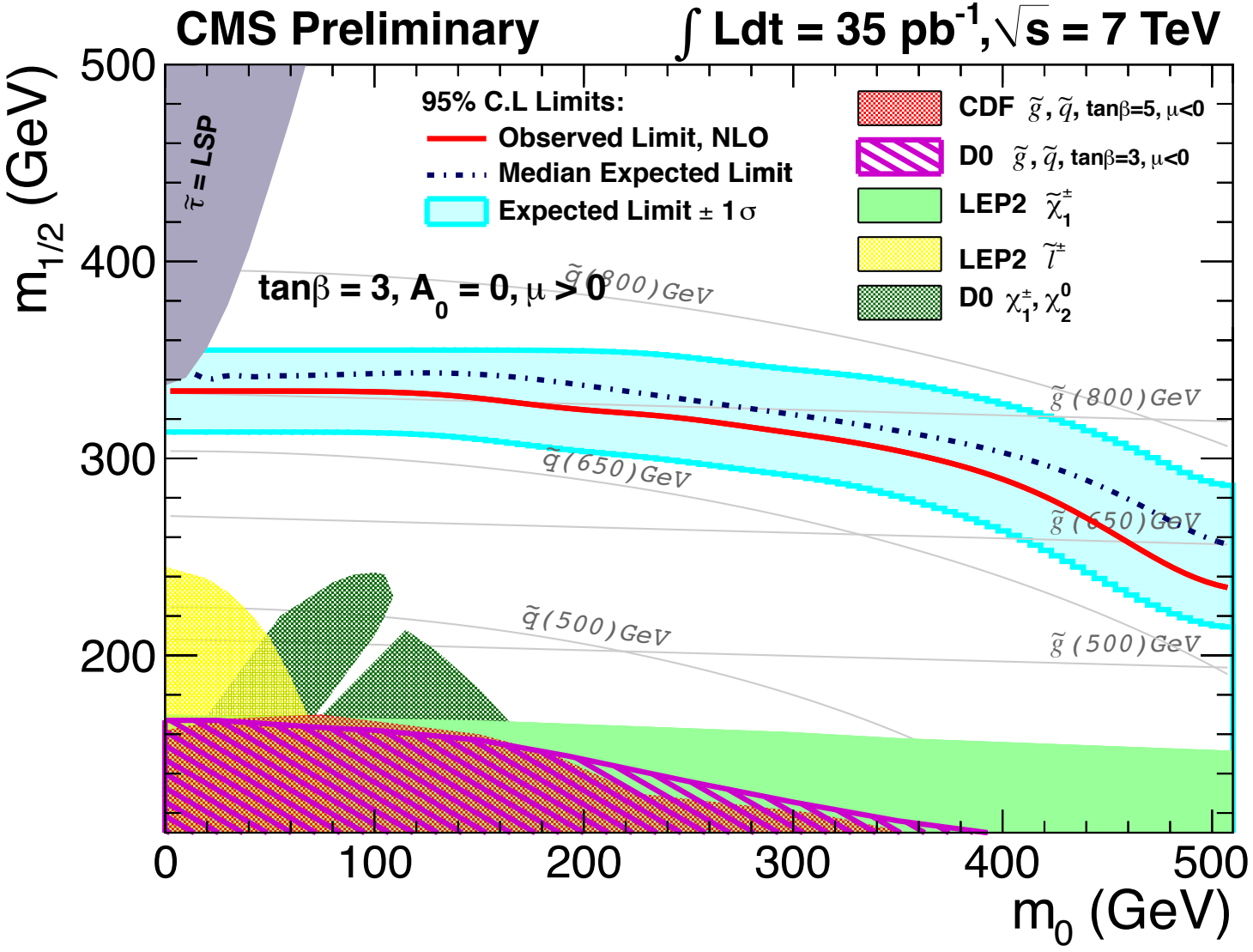


Lepton control samples used to measure M_R slope evolution parameters for non-QCD backgrounds



Single electron selection

+ Search with M_R + R (Razor)



+ Search with M_R + R (Razor)