CMS New Physics Searches with Jets

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For the CMS Collaboration

Workshop on Jet Reconstruction and Spectroscopy

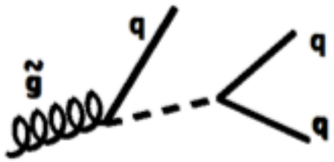
at Hadron Colliders

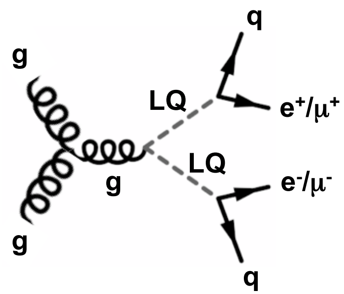
Pisa, Italy

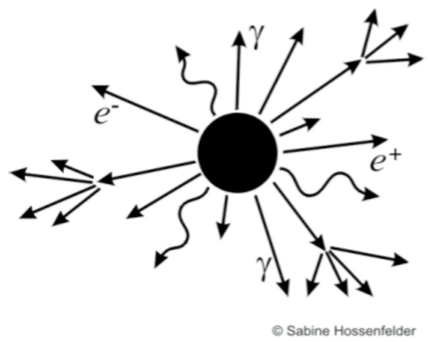
Introduction and Overview

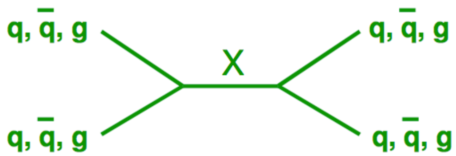
- **Final states containing jets are an integral part of searches for New Physics at CMS**

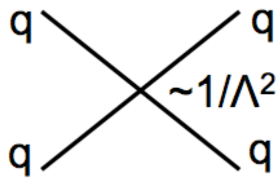
Many predicted New Physics outside the SM live in this sector:











- **Dedicated analyses with jets probe all of these final states using 2010 LHC data (up to 36 pb^{-1})**

***This talk highlights just a few of these searches. For a comprehensive list:**

 twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO


Black Holes
b'
Multi-Jets
Lepto-Quarks
Dijets
" The road to discovery "

New Physics in the Dijet Mass Spectrum

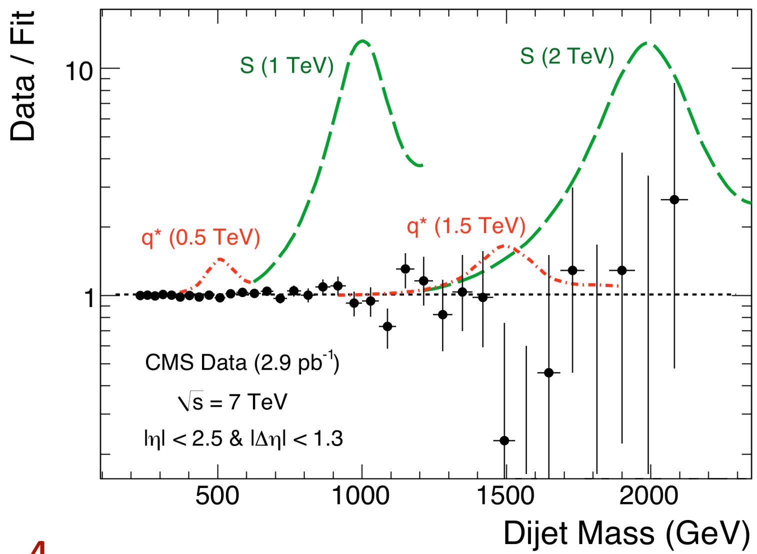
PRL **105** (2010), 211801

Signature Selection

Leading 2 jets in event :

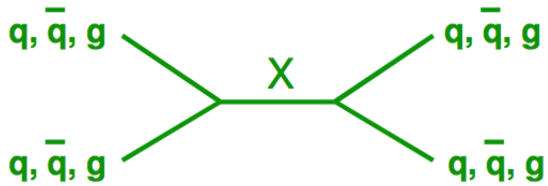
$M_{jj} > 220$ GeV

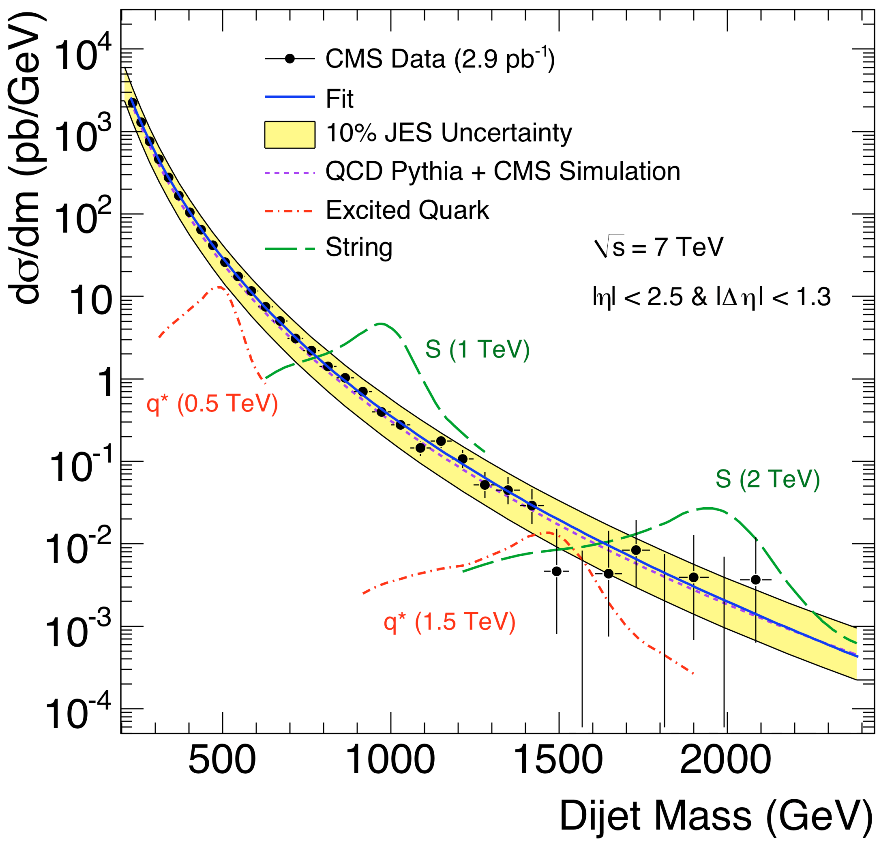
$|\eta_{1,2}| < 2.5$, $|\Delta\eta_{1,2}| < 1.3$



- **Narrow resonances decaying to dijets (3 initial-state models):**

Quark-quark, quark-gluon, gluon-gluon



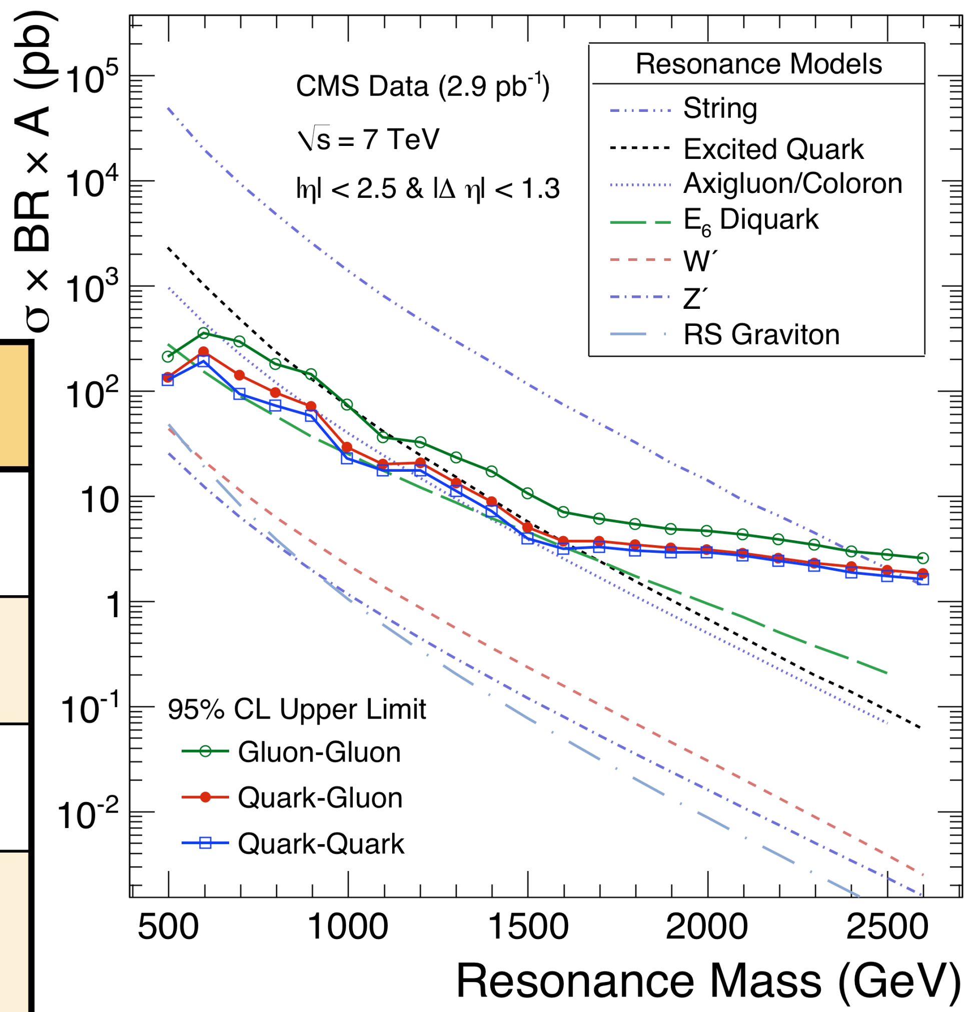


New Physics in the Dijet Mass Spectrum

Model-independent limits tested for 7 benchmark resonances

Bayesian approach is used to set separate limits for gg, qg and qq

Model	Exclusion regions [TeV]
String resonance (qg, $q\bar{q}$, gg)	0.50 – 2.50
Excited quark (qg)	0.50 – 1.58
Axigluon / Coloron ($q\bar{q}$ / $q\bar{q}$)	0.50 – 1.17 & 1.47 – 1.52
E_6 diquark (qq)	0.50-0.58, 0.97-1.08, & 1.45-1.60



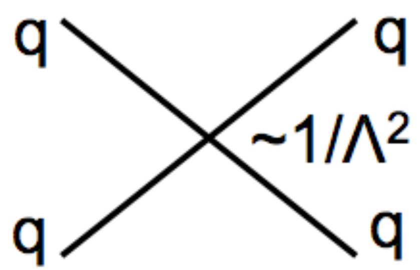
Quark Compositeness in Dijet Angular Distributions

- **New Physics in dijet angular distributions:**
  - χ is related to scattering angle θ* as

$$\chi = e^{2y^*} = \exp(|y_1 - y_2|)$$

  - Background from QCD is flat in χ
  - Isotropic new physics peaks at low χ

  Benchmark Model: quark compositeness



Signature Selection

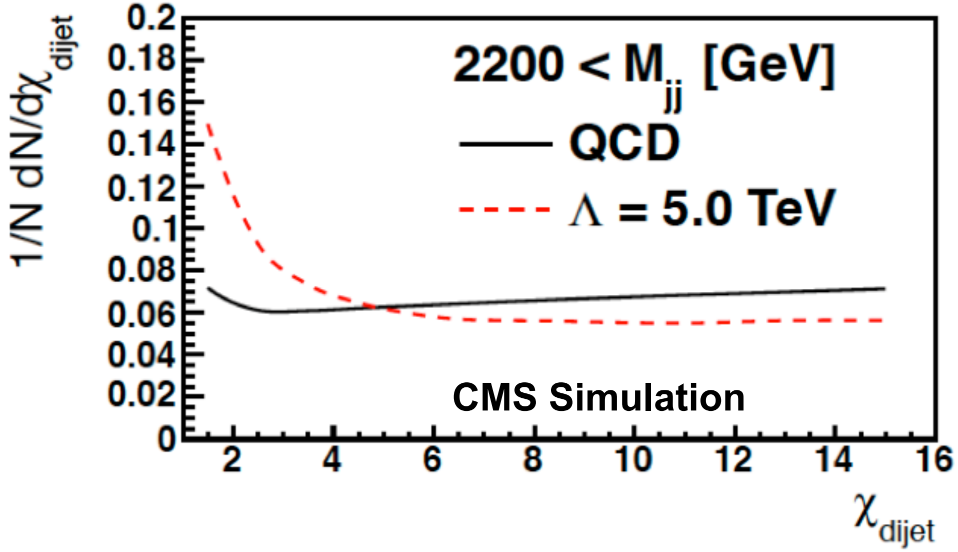
Leading 2 jets in event :

M_{jj} > 250 GeV

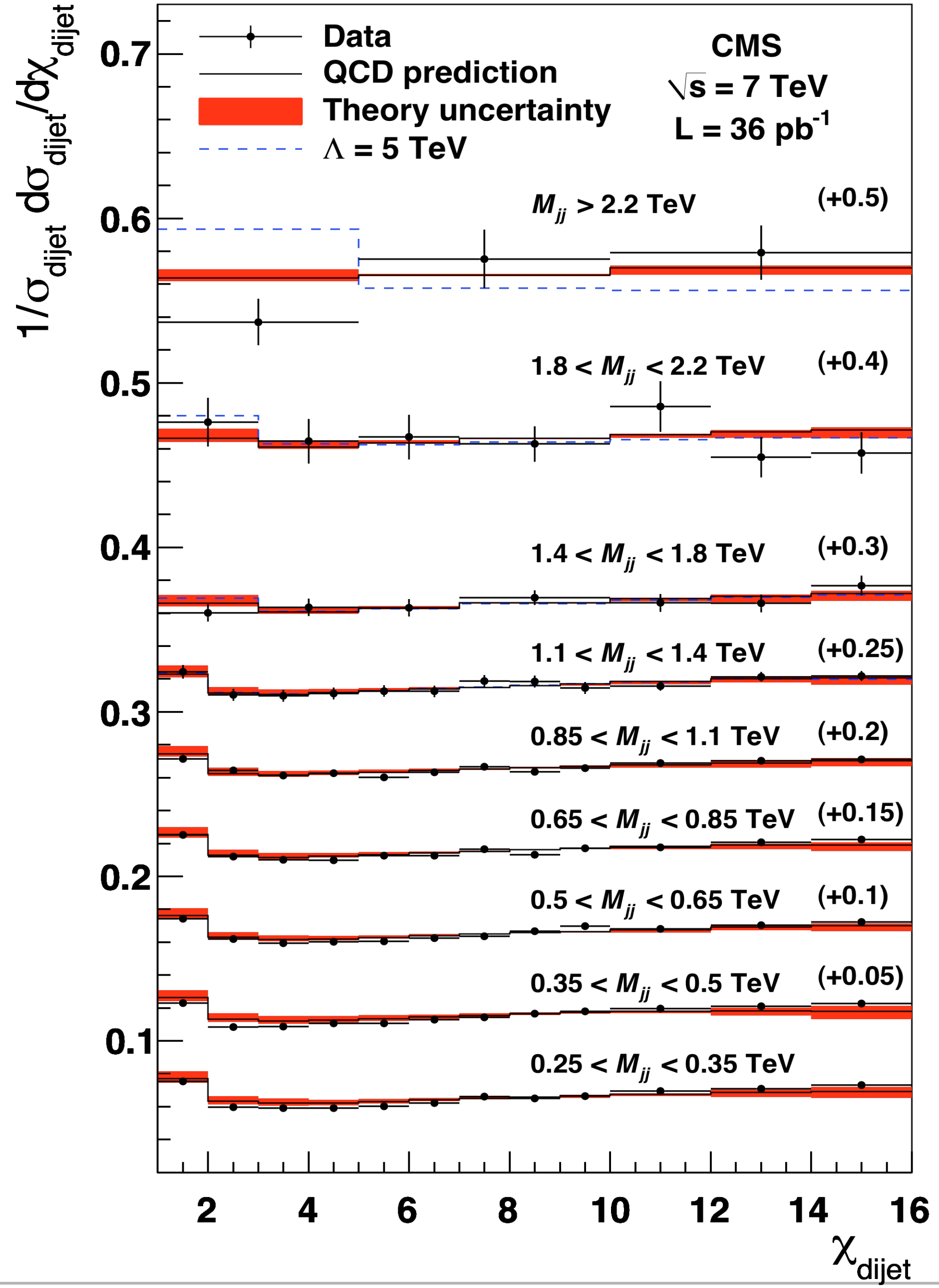
$|\eta_{1,2}| < 2.5$

$y_{BOOST} = ½ (y_1 + y_2) < 1.11$

$y^* = ½ |y_1 - y_2| < 1.39$



Dijet χ : Data and Limits

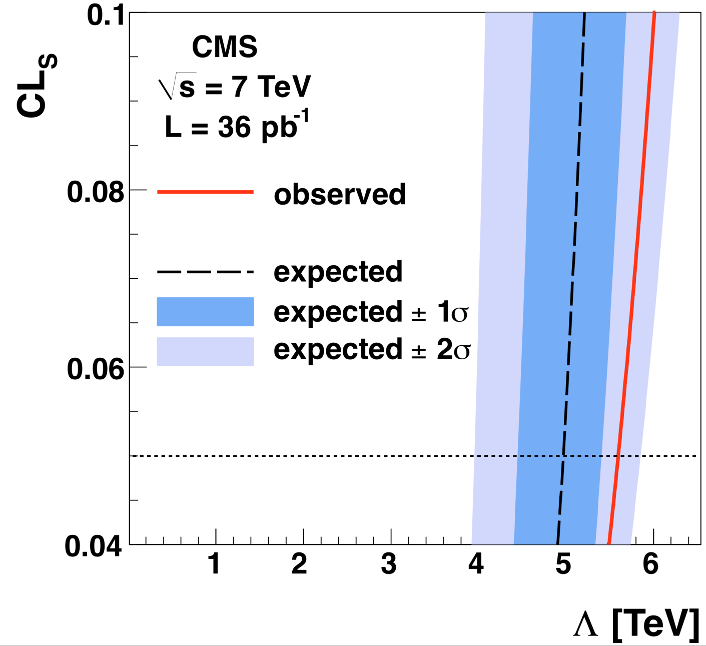


Good agreement between data and NLO QCD found

→ **Limits set using modified frequentist approach:**

$$CL_s = \frac{P_{QCD+CI}(Q \geq Q_{obs})}{1 - P_{QCD}(Q \leq Q_{obs})}$$

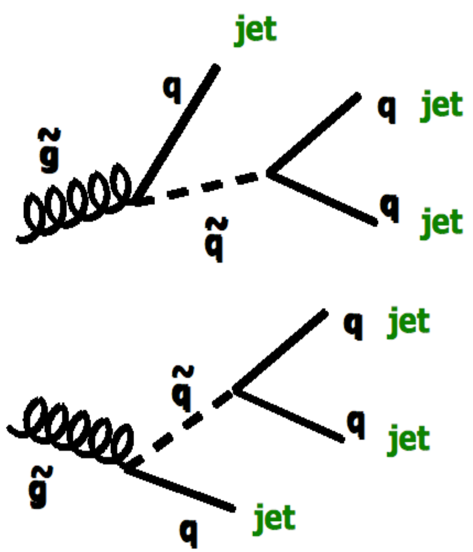
Observed limit: Λ > 5.6 TeV
Expected limit: Λ > 5.0 TeV



Three Jet Resonances in Multi-Jet Events

- **Searching for strongly coupled resonances decaying to three-jets**

  Benchmark model: R-parity violating gluino decays (pair-produced + strongly coupled to *uds* quarks)



Signature Selection

High Jet Multiplicity (≥ 6 Jets)

Large event scalar sum p_T (> 425 GeV)

No requirement on leptons or MET

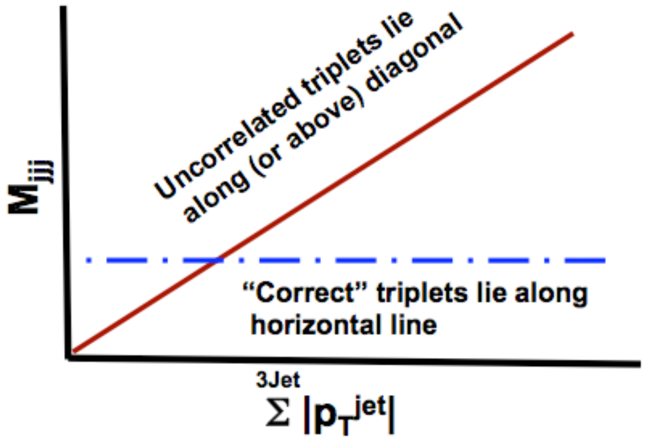
Construct Jet M_{jjj} Triplets (20 Combinations)

For all jet triplets, plot :

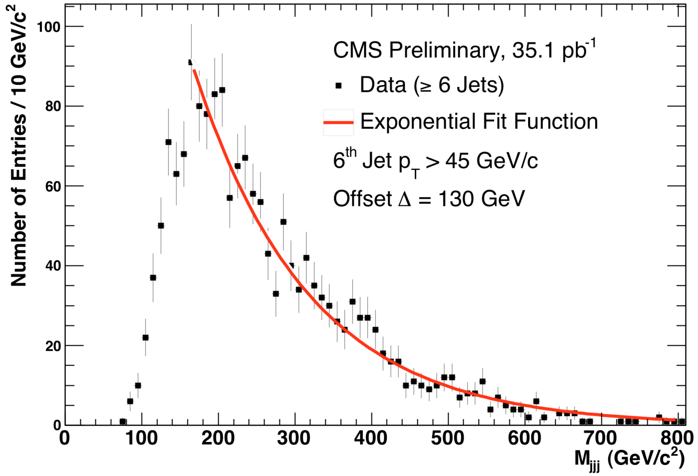
M_{jjj} vs. $\Sigma |p_T^{jet}|$

Require each to pass:

$M_{jjj} < \Sigma |p_T^{jet}| - \Delta$ (Offset)



Three Jet Resonances in Multi-Jet Events



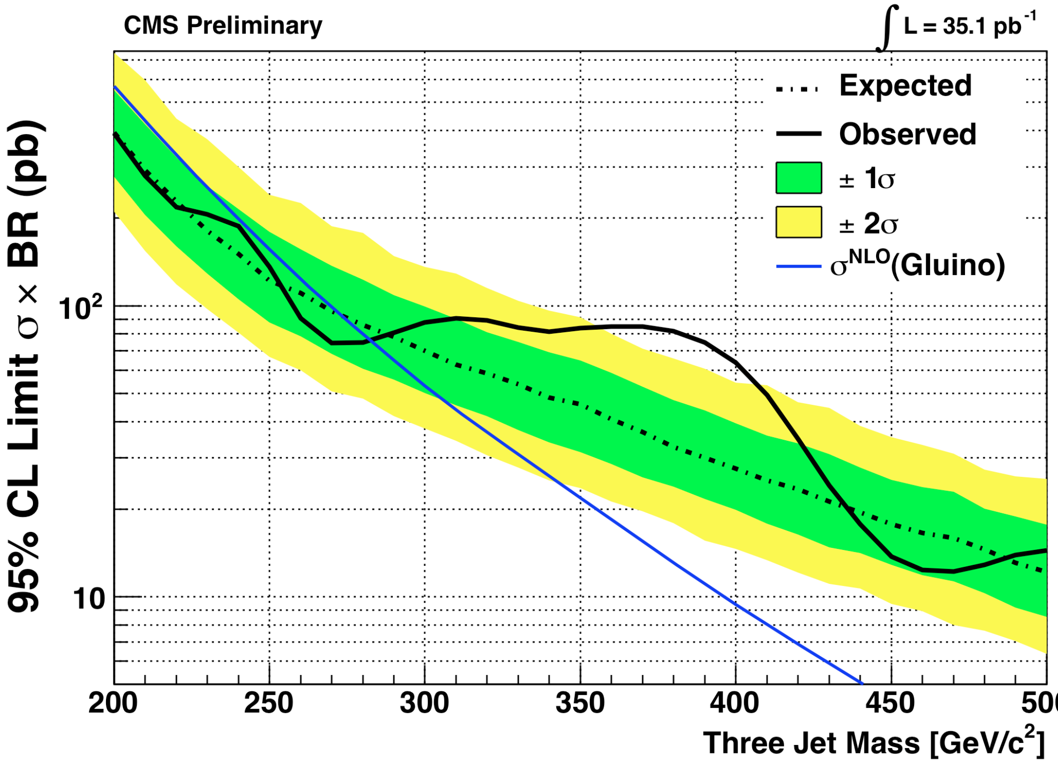
Exclusion for gluino RPV decay:

Observed: $200 < M_g < 280$ GeV/c^2

Expected: $200 < M_g < 270$ GeV/c^2

Largest excess seen at 390 GeV/c^2 → significance of 1.9σ (with look-elsewhere effect)

- **1st limits from the LHC**
- **Highest limits to date on gluino RPV decays!**



EXO-11-001

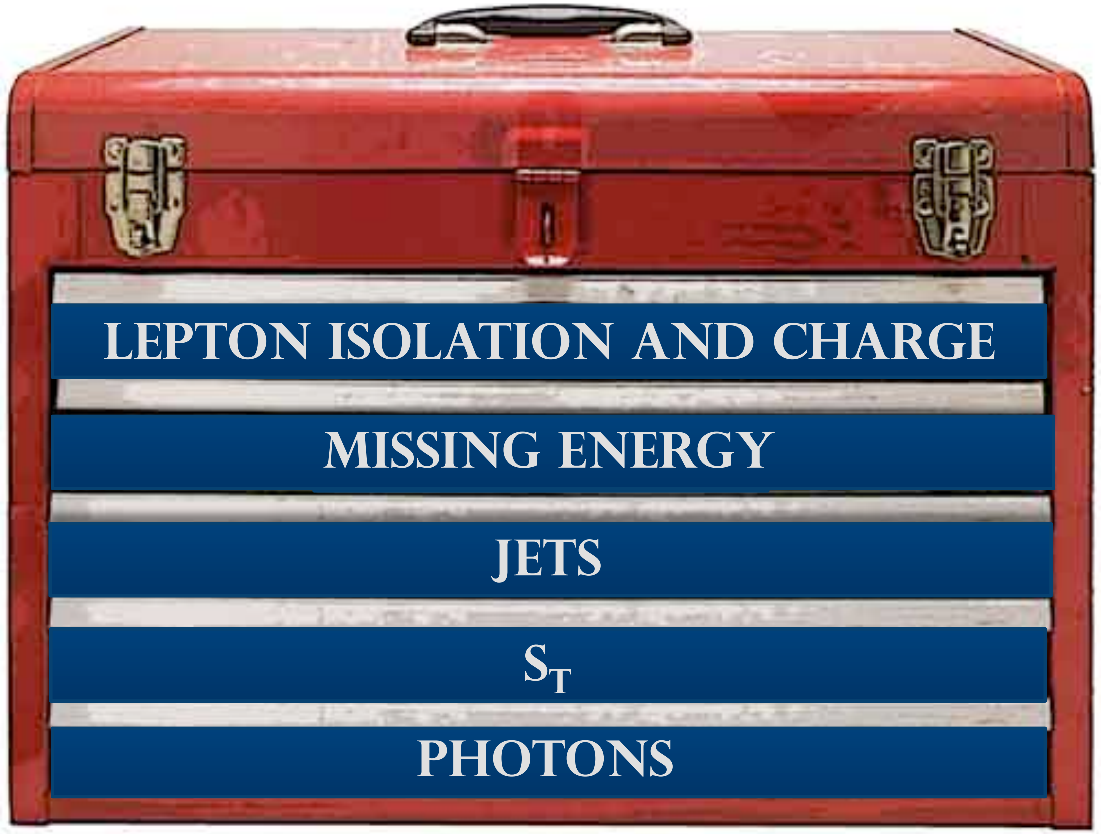
Expanding the toolbox

For searches past jet-only final states, we include additional objects for more discriminating power!

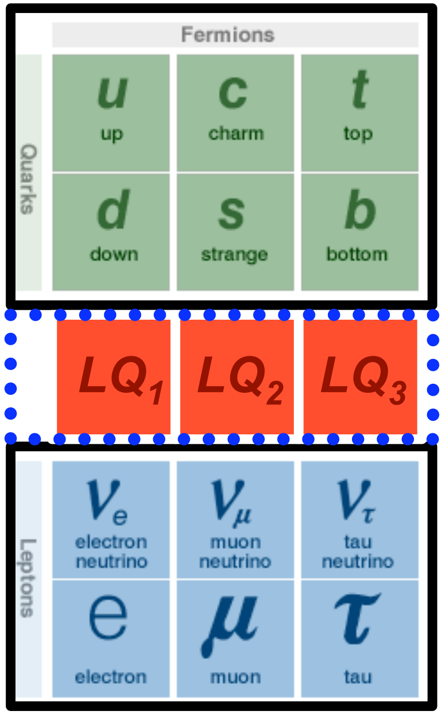
- **Define new variable S_T**

$$S_T = \sum_{\text{Selected Objects}} |p_T| + MET$$

- **Lepton requirements:**
  - Charge pairing of μ/e: Same-Sign (SS) and Opposite Sign (OS)
  - Isolation to reject QCD background
- **Large Missing E_T**



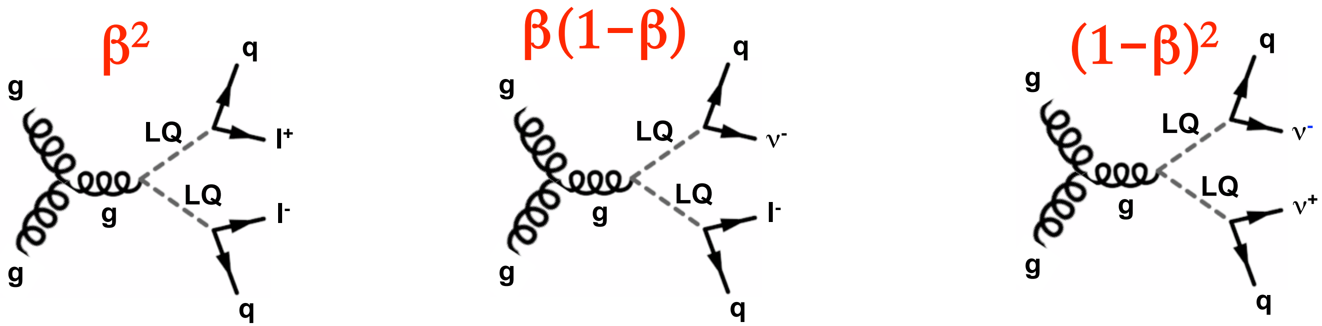
Searches for Leptoquarks



Leptoquarks

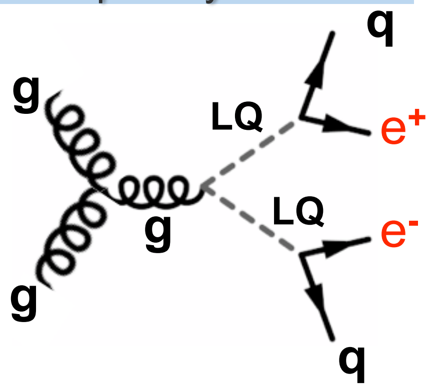
- Predicted by many extensions to the SM (TC, GUTs, and more)
- Couple to both quarks and leptons with interaction scale λ
- 3 types of final states possible through pair production: (llqq, lνqq, ννqq)

* β is the branching fraction Br(LQ → lq)



1st Generation Leptoquarks (e^+e^-jj)

arXiv:**1012.4031** (hep-ex)
Accepted by PRL

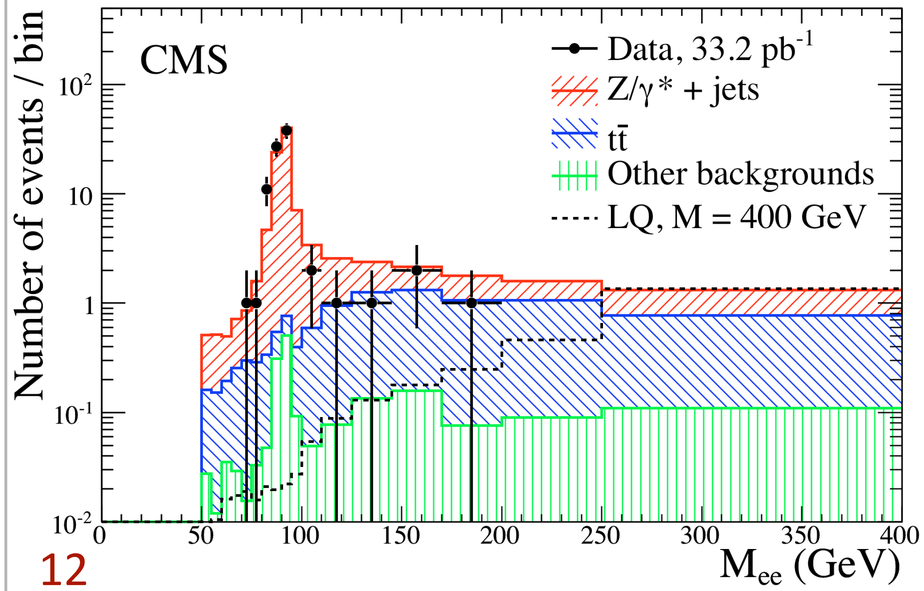


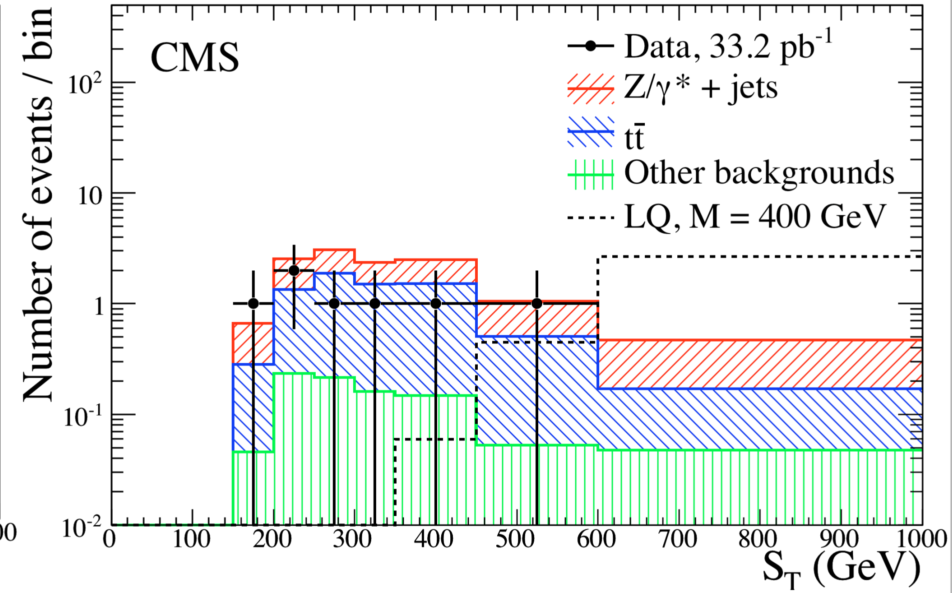
Pre-Selection

At least 2 isolated electrons, each p_T > 30 GeV
At least two jets, each p_T > 30 GeV
M_T(e,e) greater than 50 GeV
S_T (2 electrons, 2 jets, MET) > 250 GeV

Full Selection

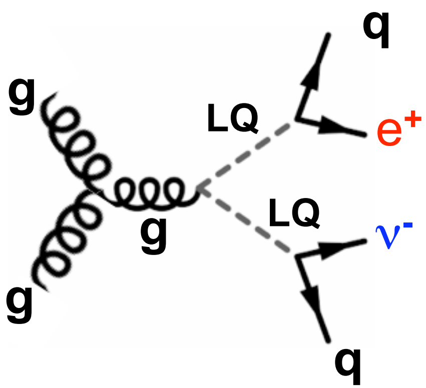
M_T(e,e) > 125 GeV
S_T > f(*x*), where *x* is LQ mass hypothesis





1^{st} Generation Leptoquarks ($e^+\nu^-jj$)

EXO-10-006

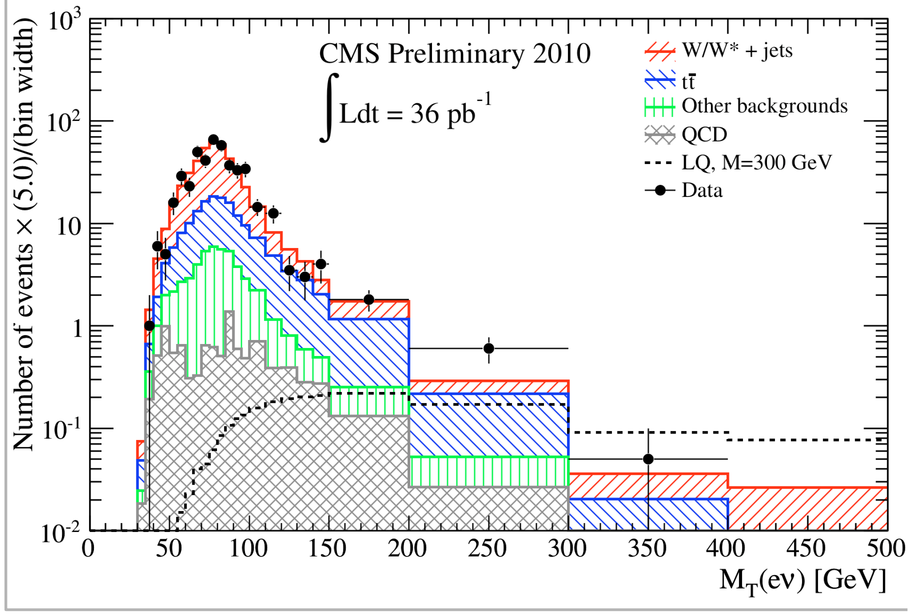


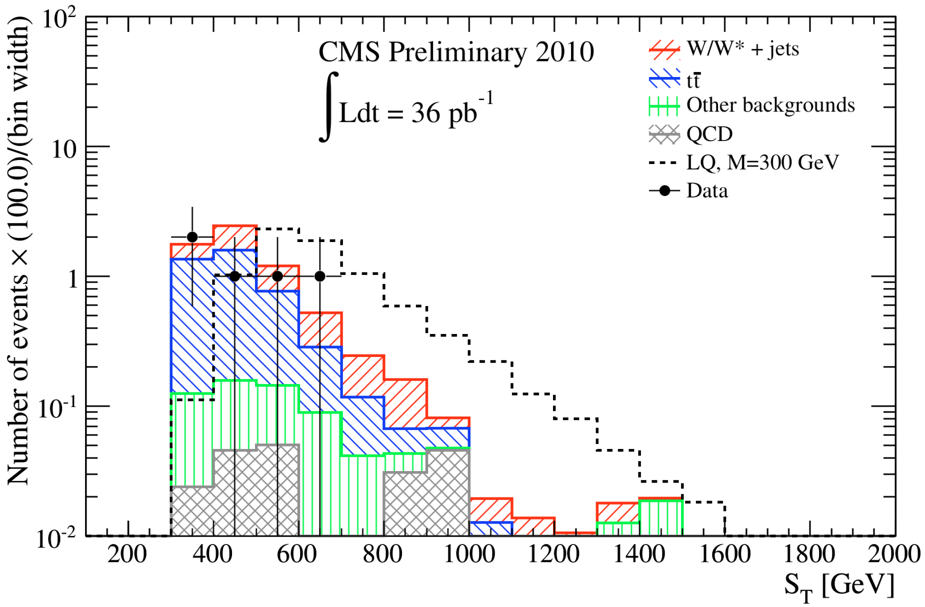
Pre-Selection

- Exactly 1 isolated electron with p_T > 35 GeV
- At least two jets, each p_T > 30 GeV
- Missing E_T greater than 45 GeV
- $|\Delta\Phi(MET,e)| > 0.8$ and $|\Delta\Phi(MET,jet_1)| > 0.5$
- No good muons with p_T > 10 GeV
- S_T (e, 2 jets MET) > 250 GeV

Full Selection

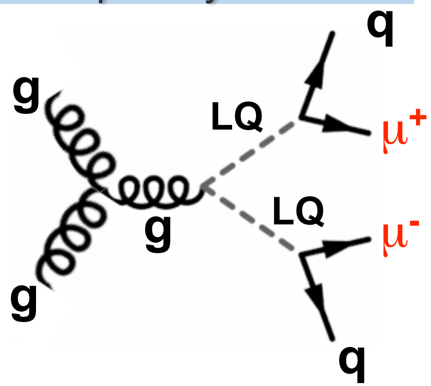
- M_T(e, MET) > 125 GeV
- min(p_T(e), MET) > 85 GeV
- $S_T > f(x)$, where x is LQ mass hypothesis





2^{nd} Generation Leptoquarks ($\mu^+\mu^-jj$)

arXiv:**1012.4033** (hep-ex)
Accepted by PRL

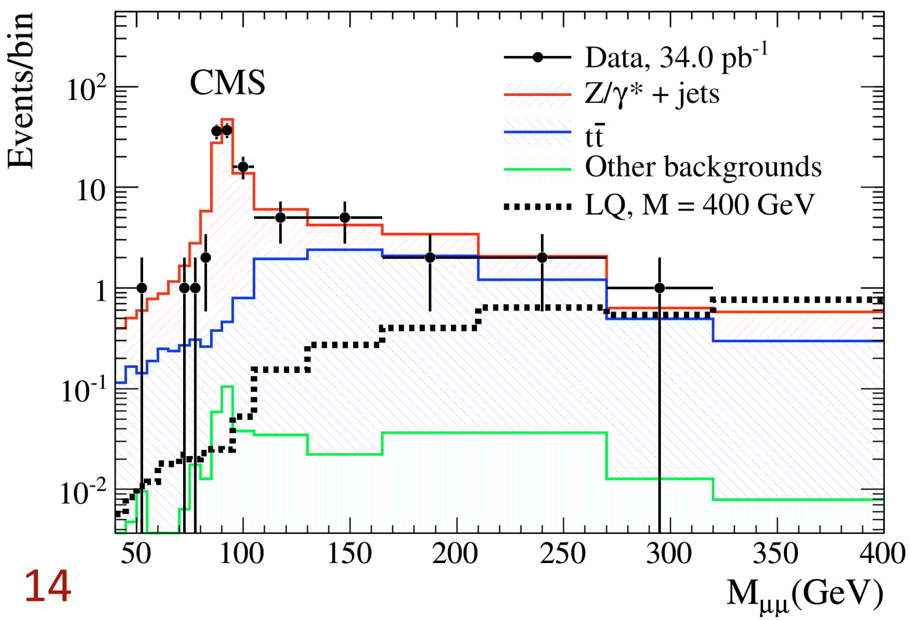


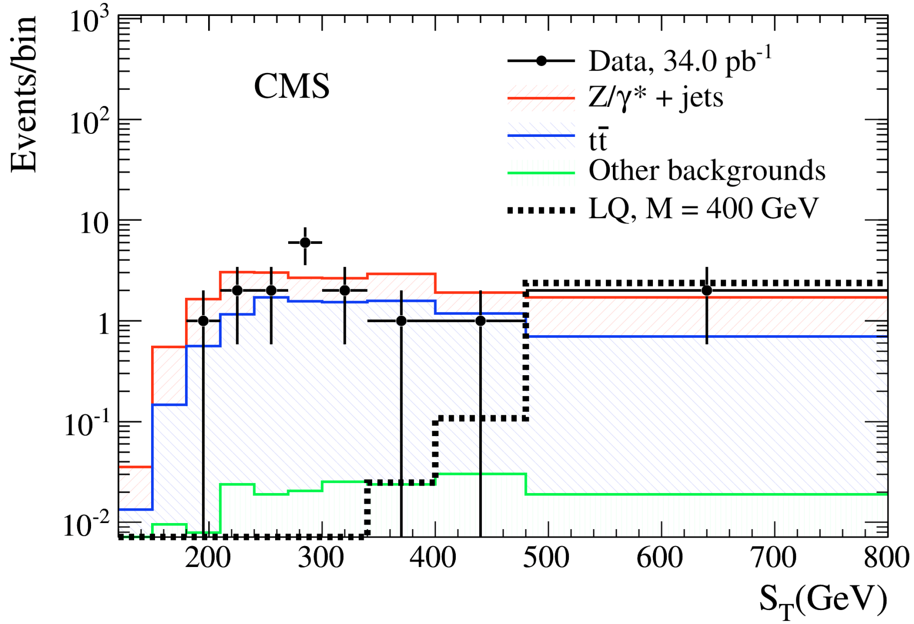
Pre-Selection

- At least 2 isolated muons, each p_T > 30 GeV
- At least two jets, each p_T > 30 GeV
- $M_T(\mu,\mu)$ greater than 50 GeV
- S_T (2 muons, 2 jets, MET) > 250 GeV

Full Selection

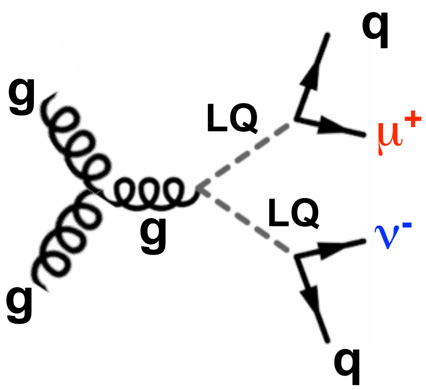
- $M_T(\mu,\mu)$ > 115 GeV
- S_T > f(*x*), where *x* is LQ mass hypothesis





2^{nd} Generation Leptoquarks ($\mu^+\nu^-jj$)

EXO-10-008

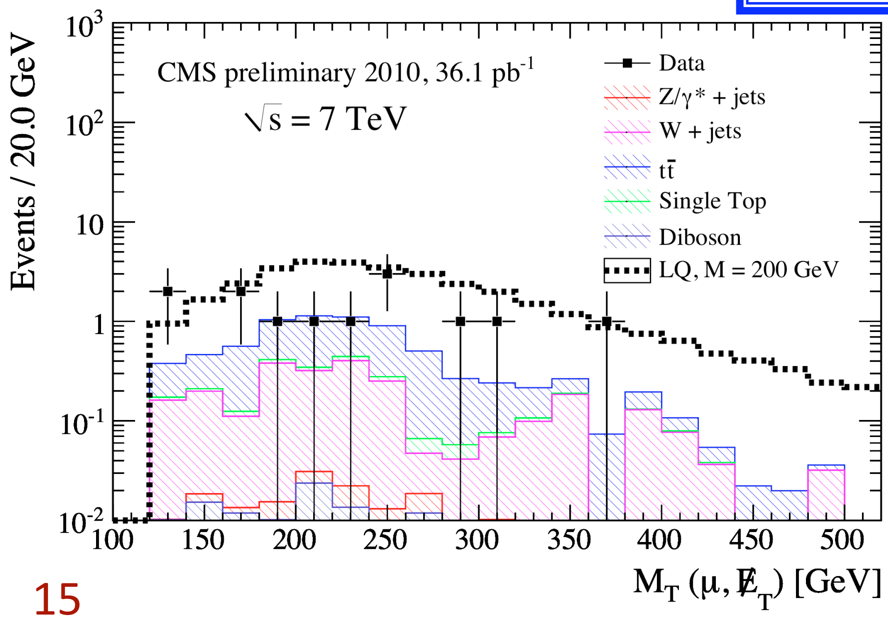


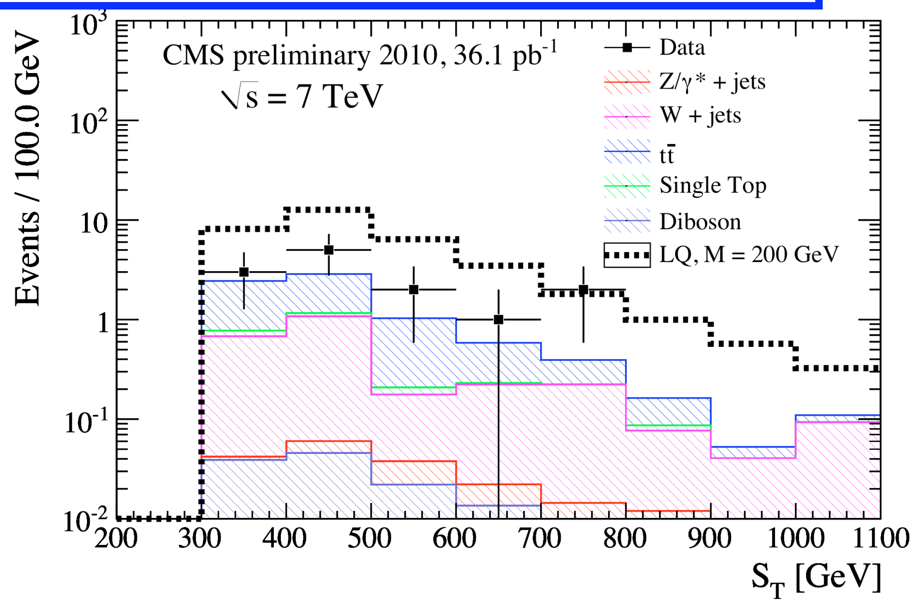
Pre-Selection

Exactly one muon with p_T > 35 GeV
At least two jets, each p_T > 30 GeV
Missing E_T greater than 45 GeV
No good electron with p_T > 15 GeV
S_T (muon, 2 jets MET) > 250 GeV

Full Selection

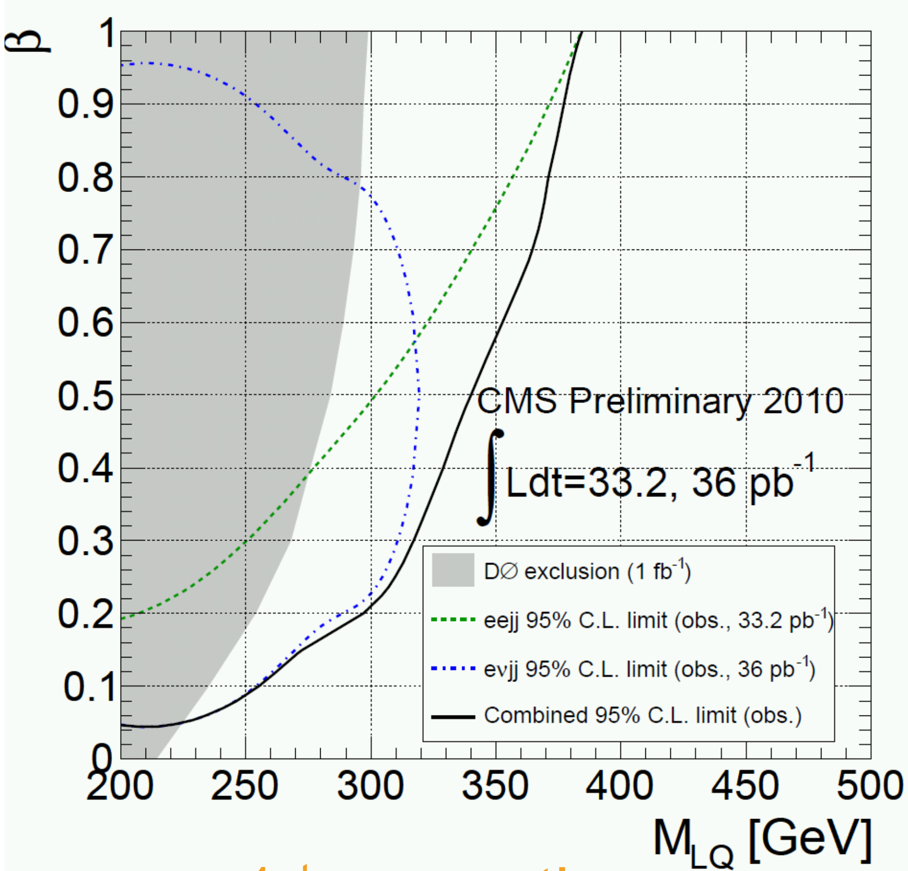
$M_T(\mu, MET)$ > 125 GeV
$\min(p_T(\mu), MET)$ > 85 GeV
S_T > f(*x*), where *x* is LQ mass hypothesis



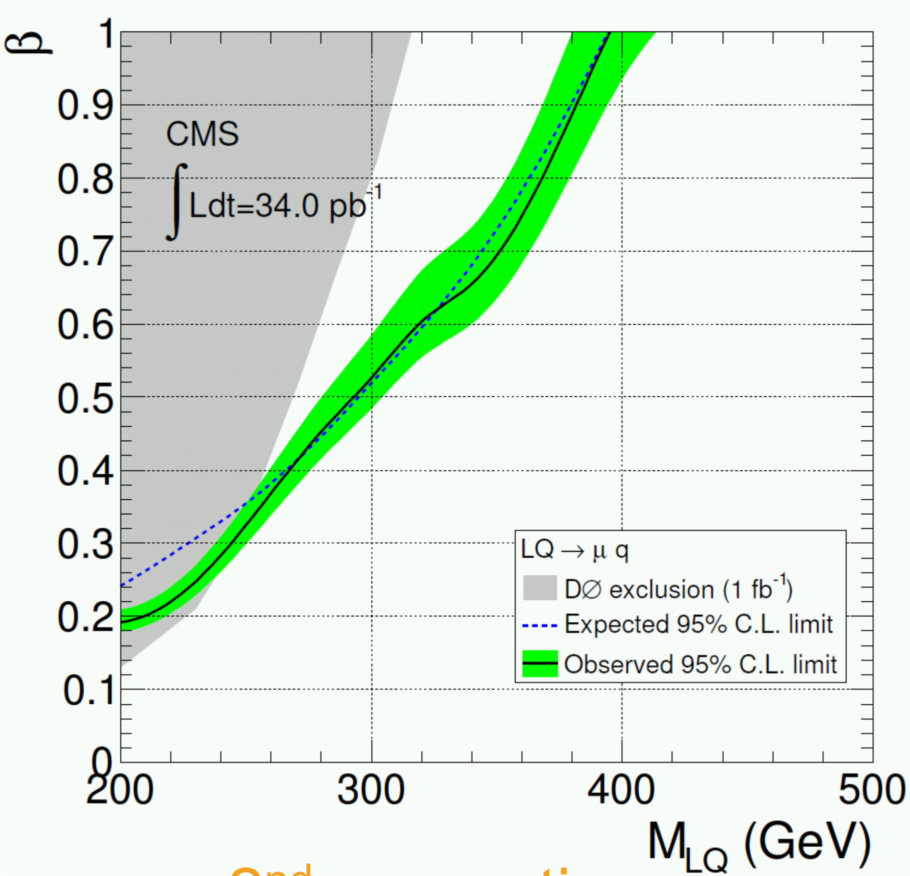


Leptoquark limits

Limits for both 1st and 2nd generation Leptoquarks outperform Tevatron limits for all but very low β



1st generation



2nd generation

New combined limits:
M_{LQ1} > 384, 340 GeV/c², β = 1, 0.5

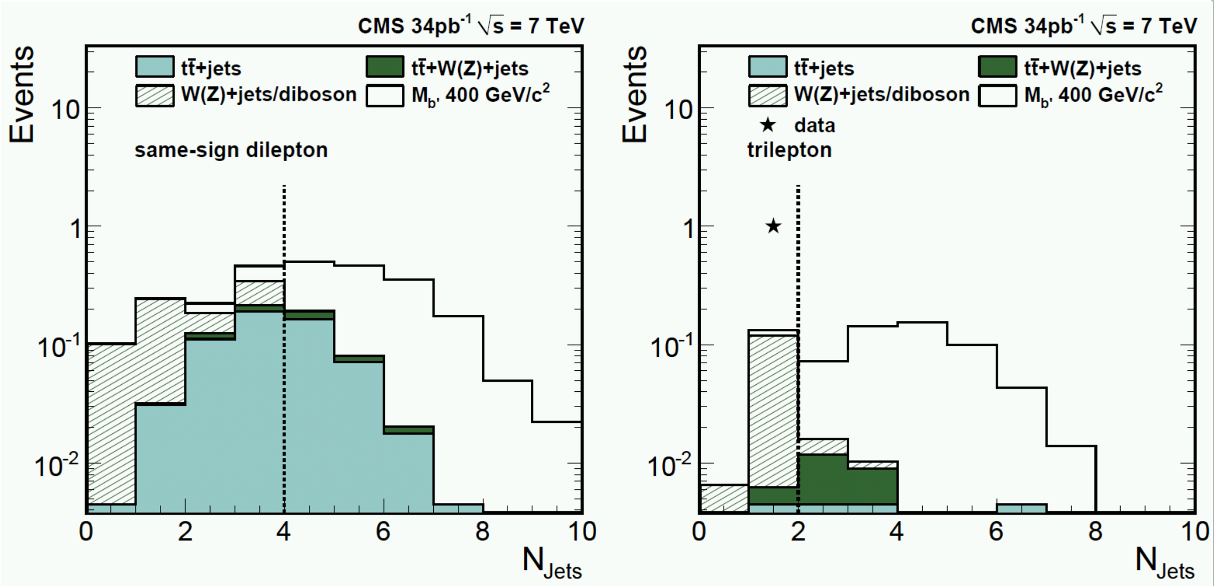
New limit from the μμjj channel:
M_{LQ2} > 394 GeV/c²

Search for b'

arXiv:1102.4746 (hep-ex)

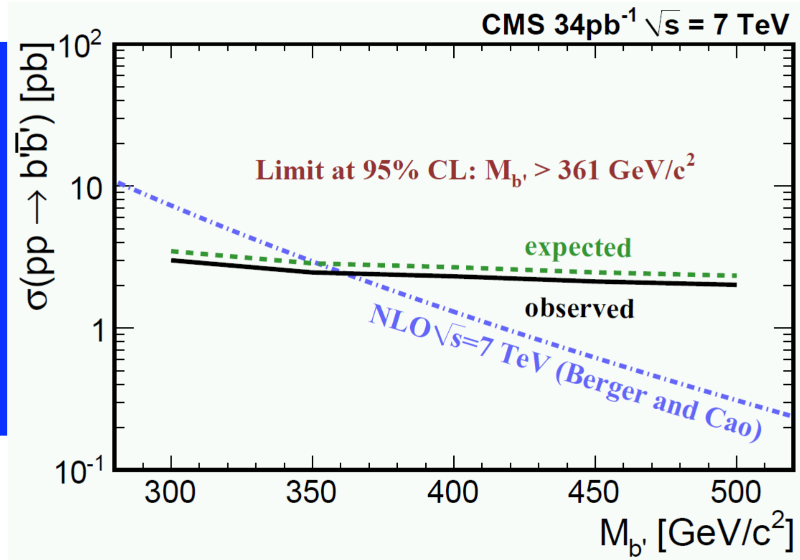
Pair produced 4th generation heavy quarks

b' → tW → bWW



Signature Selection

2 (3) Leptons with p_T	> 20 GeV
At least 2 (4) Jets with p_T	> 25 GeV
2 SS leptons (3 leptons: 2OS + 1 extra)	
Large Missing E_T	> 425 GeV
Large S_T	> 350 GeV



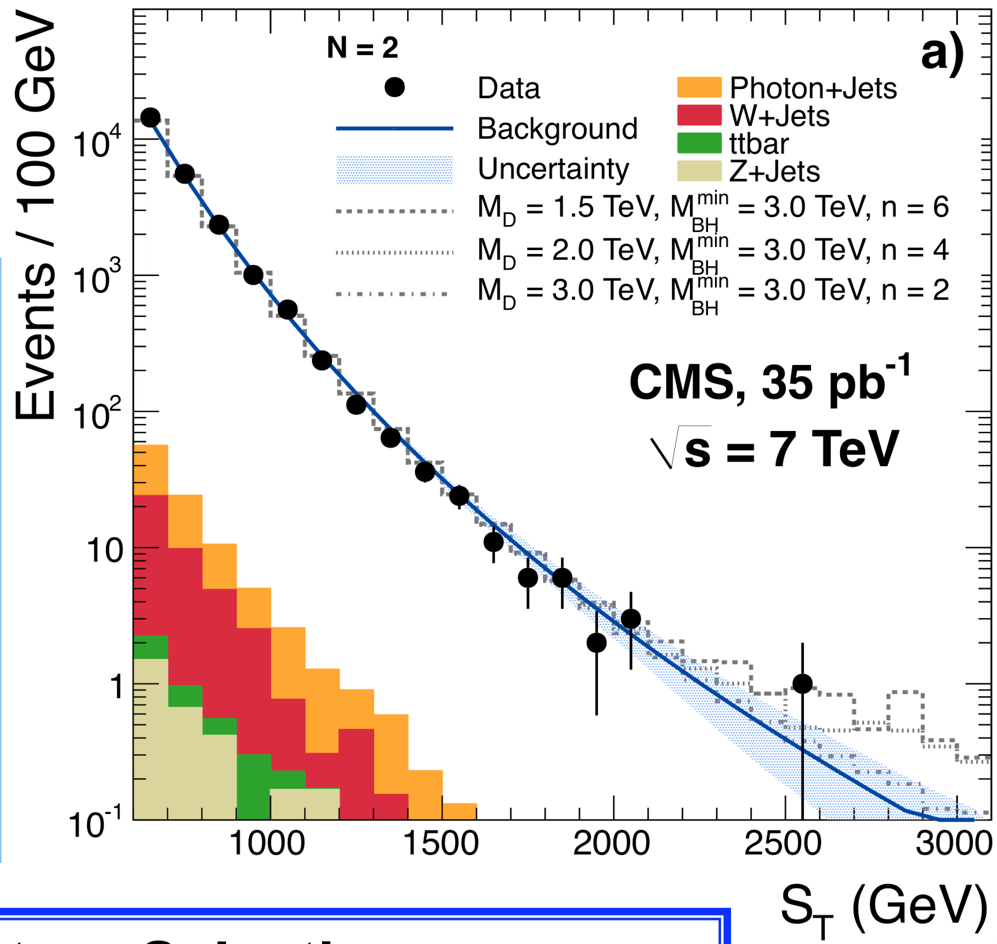
Closing in on Tevatron limit ($m_{b'}$ > 385 GeV) with just 34 pb^{-1}

Search for Black Holes

PLB **697** (2011), 434

Microscopic Black Holes

- Lifetimes of ~10^{-27} seconds
- Decays into wide range of particles
  - Mostly quarks and gluons
  - But also γ's, e's, μ's, W, Z and more
- Cross section proportional to $\pi \cdot R_S^2$
  - (R_S is the Schwartzchild Radius)
- And with extra dimensions (n > 0)
  - Cross sections accessible at LHC



Signature Selection

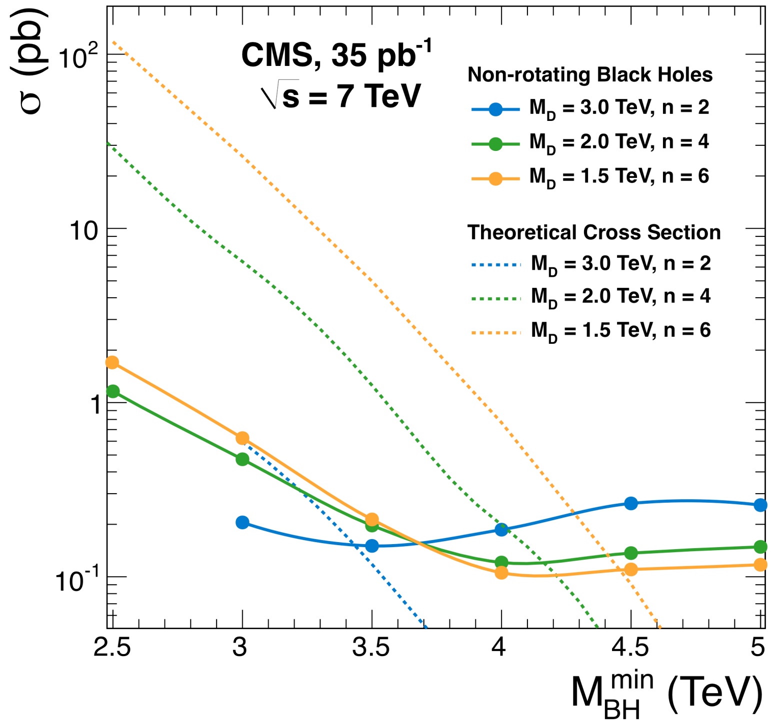
Large amount of total energy expected:

Construct S_T using all objects with

p_T > 50 GeV (jets and isolated $\gamma^0/e^\pm/\mu^\pm$)

Events divided into object multiplicity bins

Black Holes: Limits

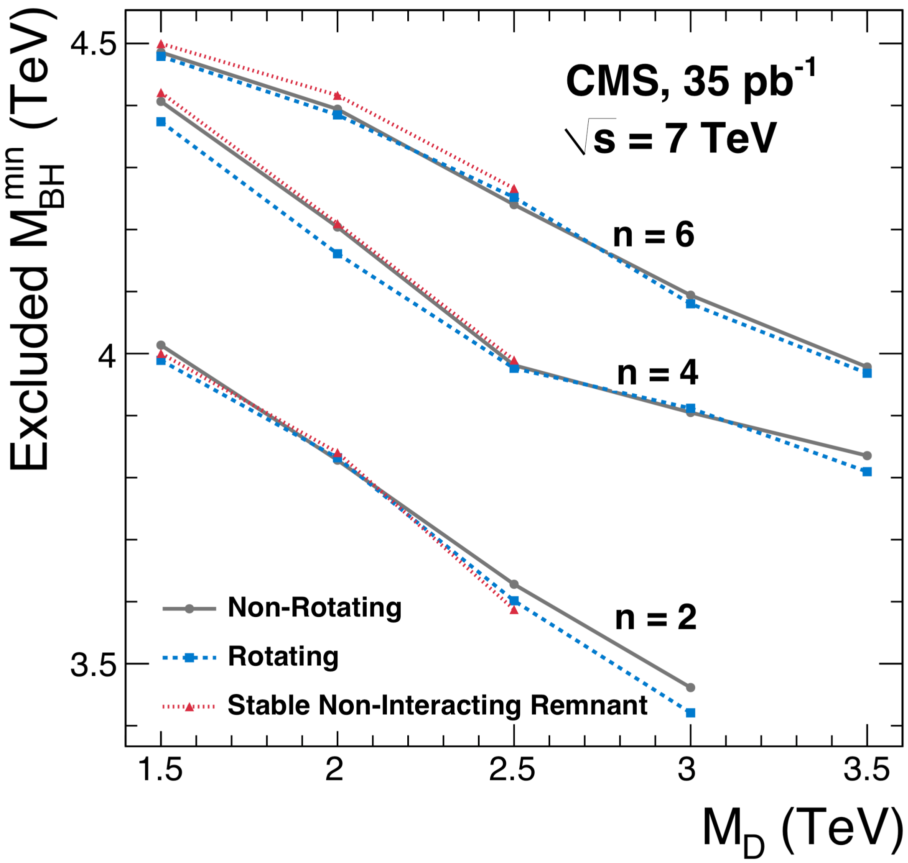


95% CL Black Hole Exclusion Limit

✓**Bayesian Technique with flat prior**

M_{BH} : from 3.5 – 4.5 TeV for

M_D : from 1.5 – 3.5 TeV



No excess observed in data

Limits are set based on:

- **Black Hole Mass (M_{BH})**
- **True Planck Scale (M_D)**

First direct limits on BH production at hadron colliders

- No discoveries yet for hadronic resonances using 2010 data, however…
  - Well understood backgrounds and data-driven techniques
  - Competitive limits are set in all analyses, and in many cases world's best limits are set
- Already plans for updating results with 2011 data and extending analyses into new channels

Potential for New Physics is right down the road!