Non-SUSY Searches @ CMS

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Introduction

This talk (Non-SUSY Searches @ CMS) describes

- some of early new physics searches we've performed
  - using 2010 pp data (~36 pb^{-1}) @ 7 TeV

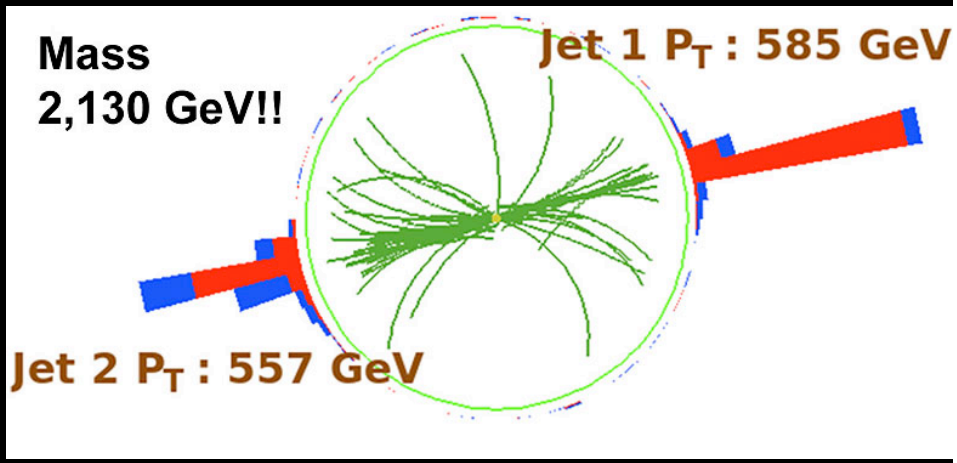
- some of the important theories we've tested so far
  - new heavy resonances
  - quark/lepton compositeness
  - extra dimensions & other exotic signatures

Many results are published or submitted/accepted for publication

~20 searches are detailed in:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Searches for
New Physics with Dijets & Multijets

- Bump search in the dijet spectrum
- Dijet centrality ratio
- Dijet angular distribution
- Multijet resonance



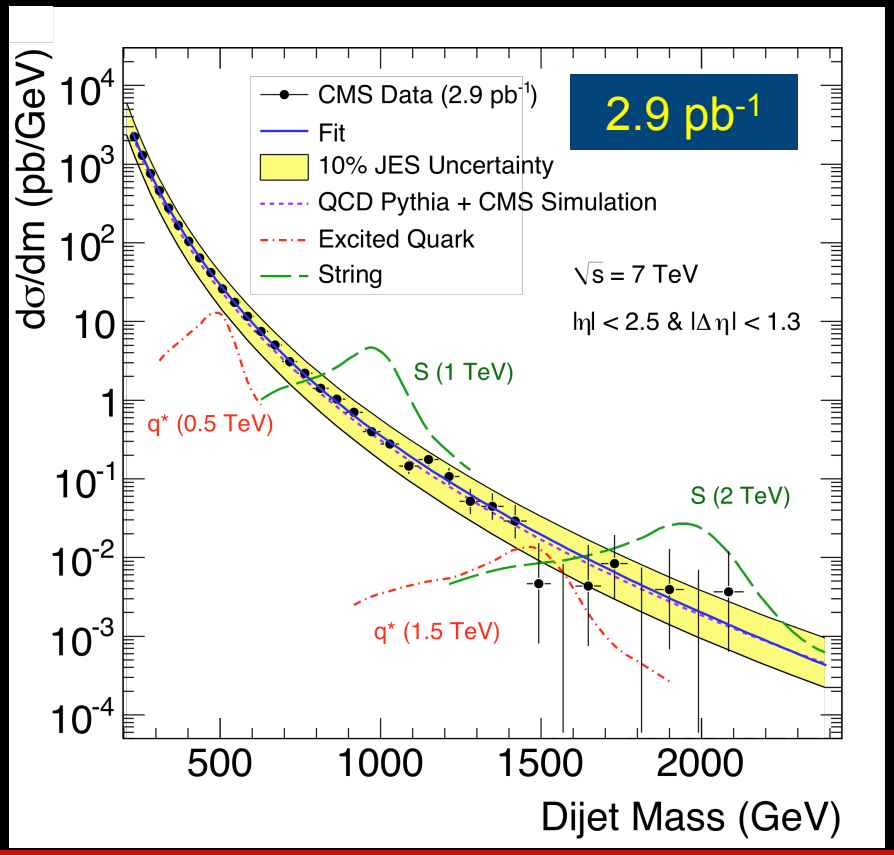
Dijet Mass Resonances

Select dijet in event with $|\eta_1,\eta_2| < 2.5$ & $|\Delta\eta| < 1.3$

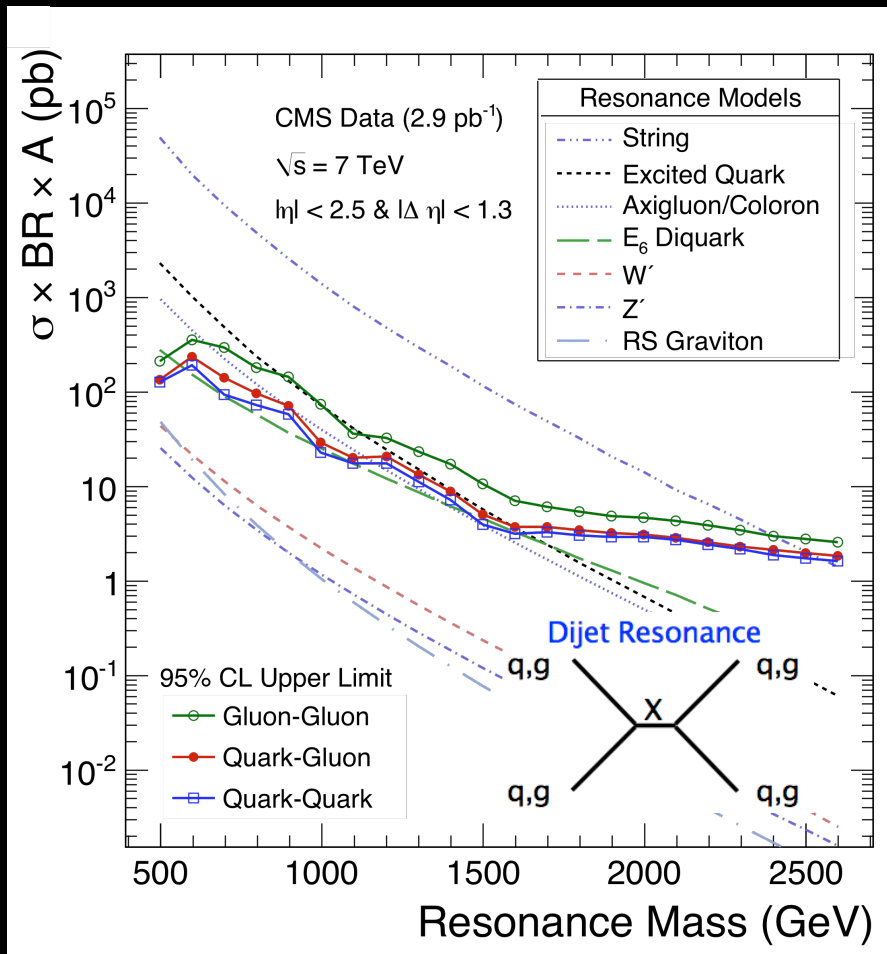
Look for bumps in dijet mass spectrum

- sensitive to the coupling of any new massive object to quarks and gluons.
- no resonance signal observed,

  set model-independent limits on 8 models



ATLAS limit: $0.6 < m(q^*) < 2.15$ (36 pb^{-1})



95% C.L. Mass Limit [TeV] (2.9pb^{-1})

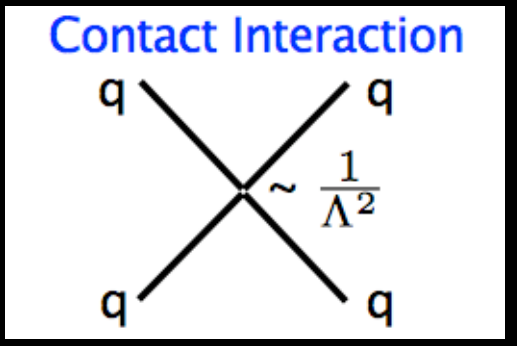
String	q*	Axigluon/ Coloron	E6 Diquark
0.5 – 2.5	0.5 – 1.58	0.50 – 1.17 1.47 – 1.52	0.50 – 0.58 0.97– 1.08 1.45 – 1.60

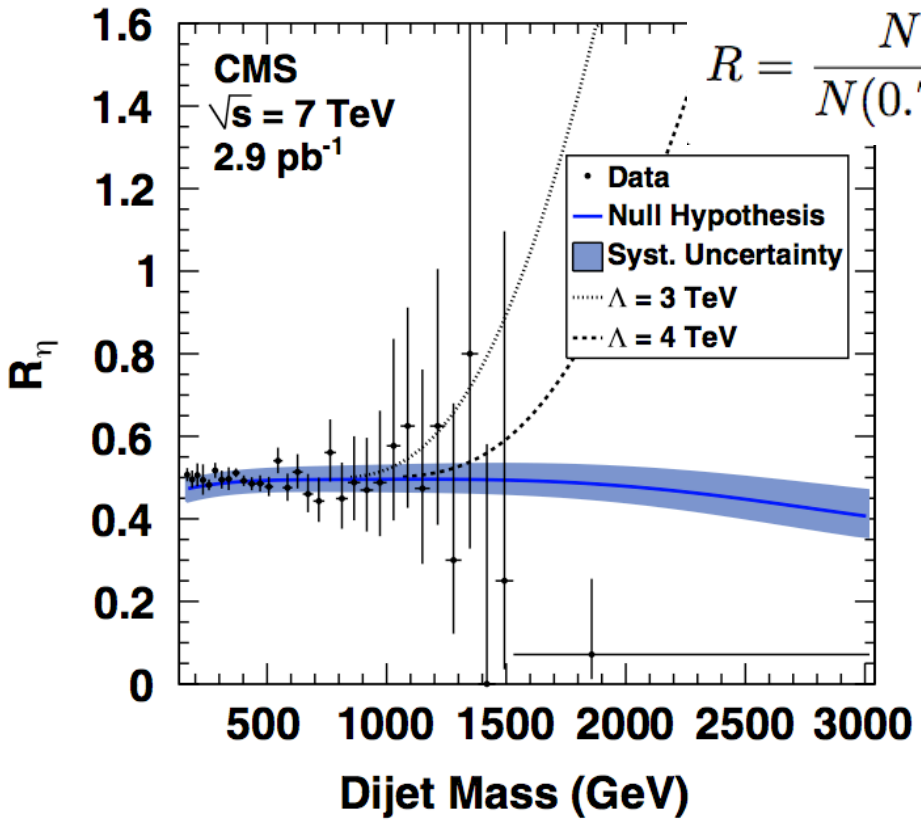
Dijet Centrality Ratio

Look for excess of central dijets compared to forward dijets

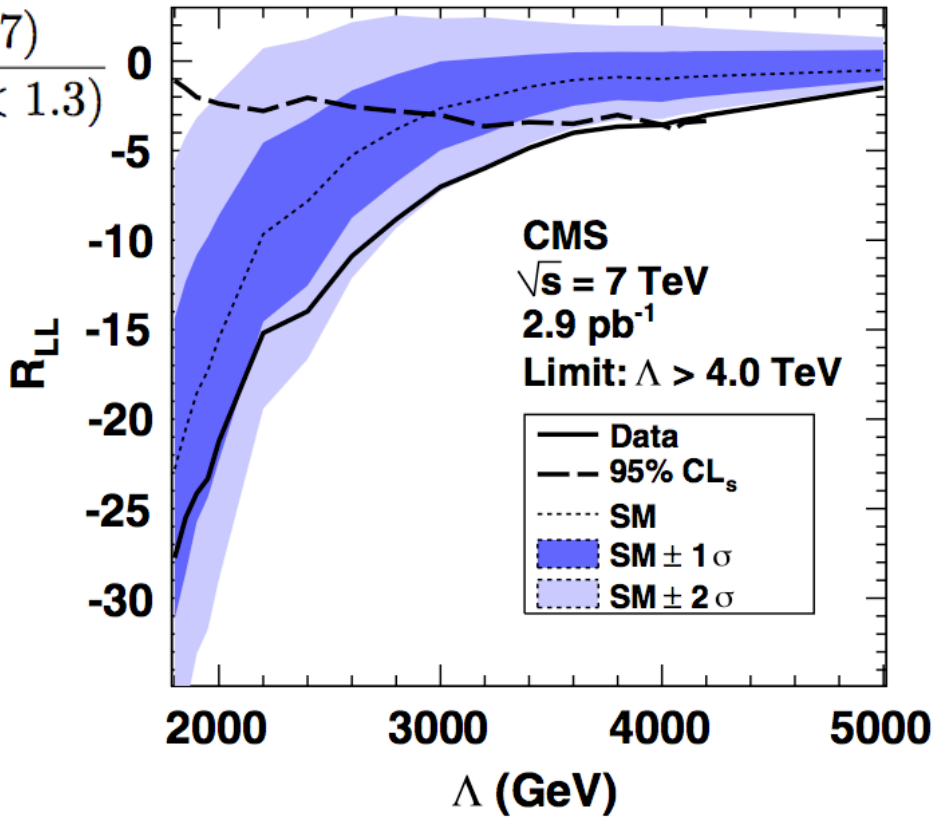
New physics tends to decay isotropically, but
QCD tends to be forward: deviation from flat is sign of NP

2.9 pb^{-1} data consistent with flat, set limit on $\Lambda > 4$ TeV





$$R = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)}$$



Dijet Angular Distribution

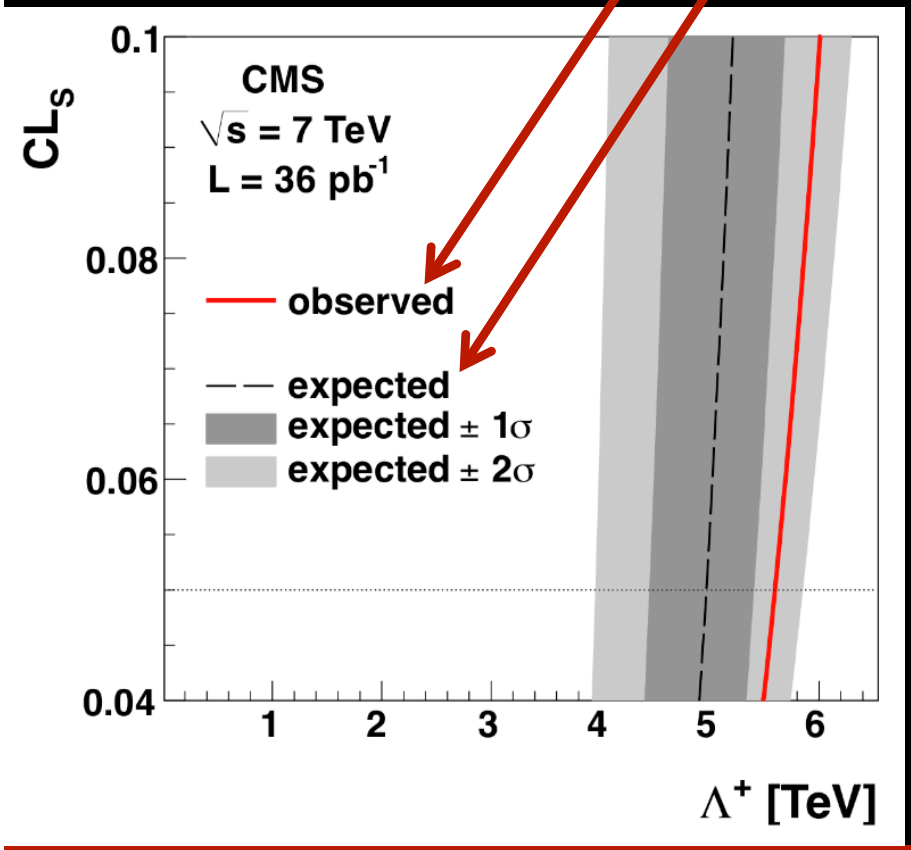
arXiv:1102.2020
accepted by PRL

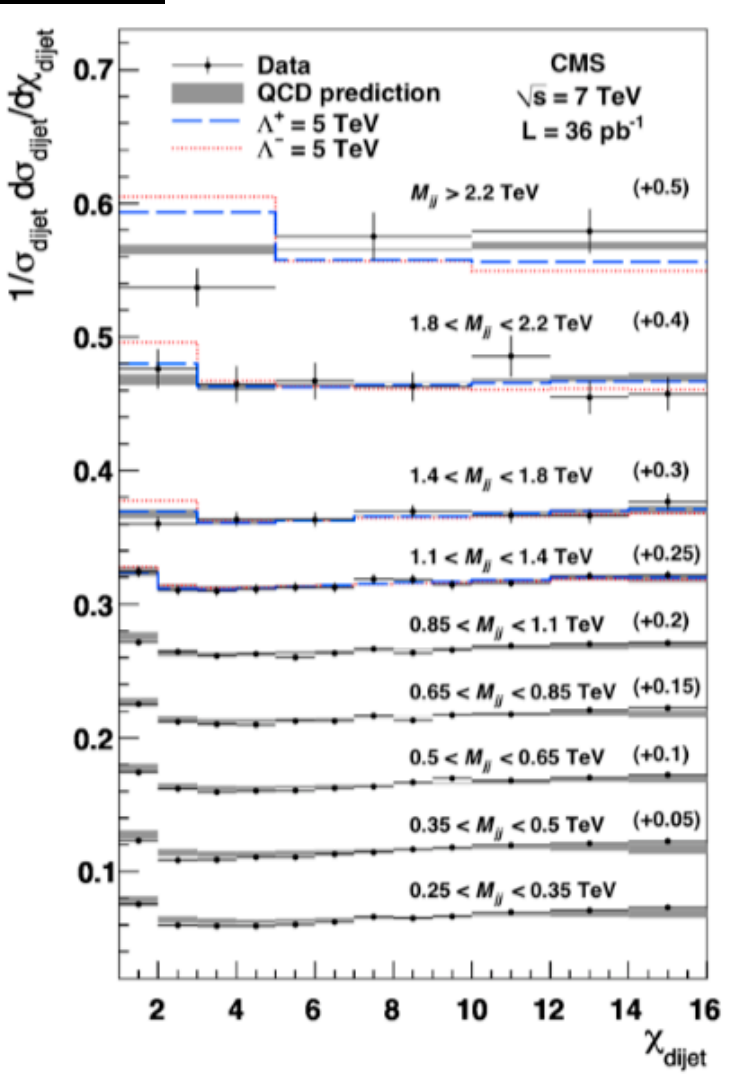
Look at dijet c.o.m scattering angle θ^* via χ variable →

$$\chi = e^{2y^*} = \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

Isotropic new physics peaks at low χ & QCD is flat in χ

Good agreement between data (36 pb^{-1}) & NLO QCD, set limit on C.I. scale $\Lambda^+ > 5.6$ (5.0)TeV, $\Lambda^- > 6.7$ (5.8)TeV (similar to ATLAS expected limit: $\Lambda^+ > 5.7$ TeV)

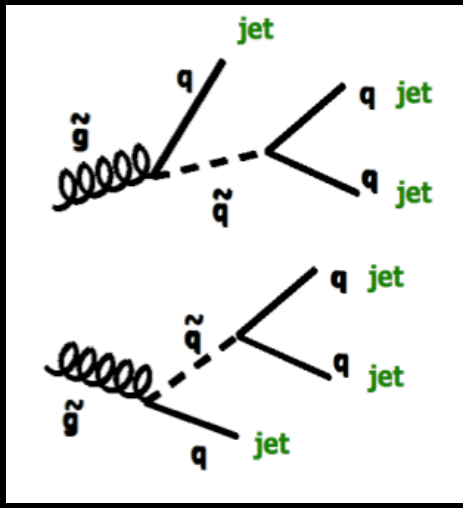




Three Jet Resonances

Searching for strongly coupled resonances decaying to 3-jets

- look for 3 jet resonances in 6 jet final states
- modeled with RPV $\tilde{g}$ decays

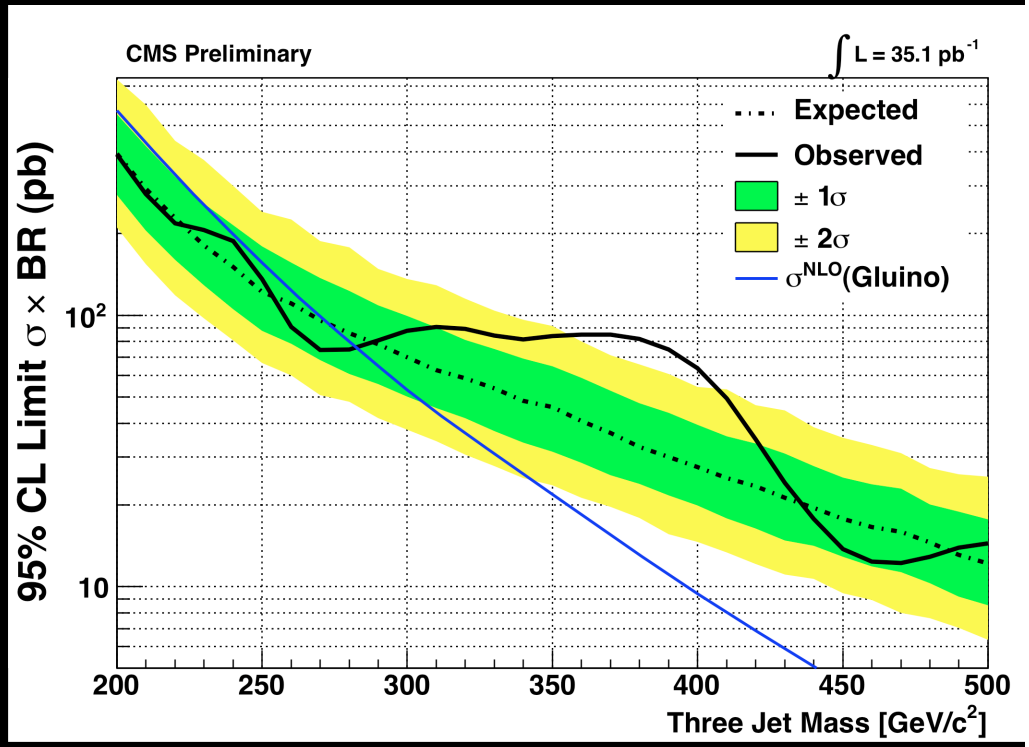


Signature Selection

- high Jet Multiplicity (≥ 6 Jets)
- large event scalar sum p_T (> 425 GeV)
- use an ensemble of jet combinations
- construct 20 jet triplet combinations (M_{jjj})

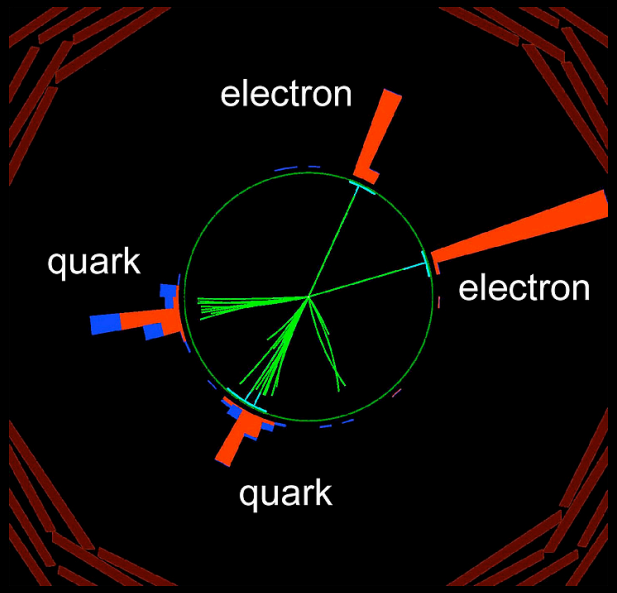
Limits set for RPV decaying gluinos

- excluding masses from 200 to 280 GeV
- highest limits to date, first pp limits
- largest excess seen @ 390 GeV → significant of 1.9 σ (look-elsewhere effect)



Searches for
Additional Gauge Bosons

- Di-lepton Resonances: W′, Z′
- Leptoquarks: LQ1, LQ2

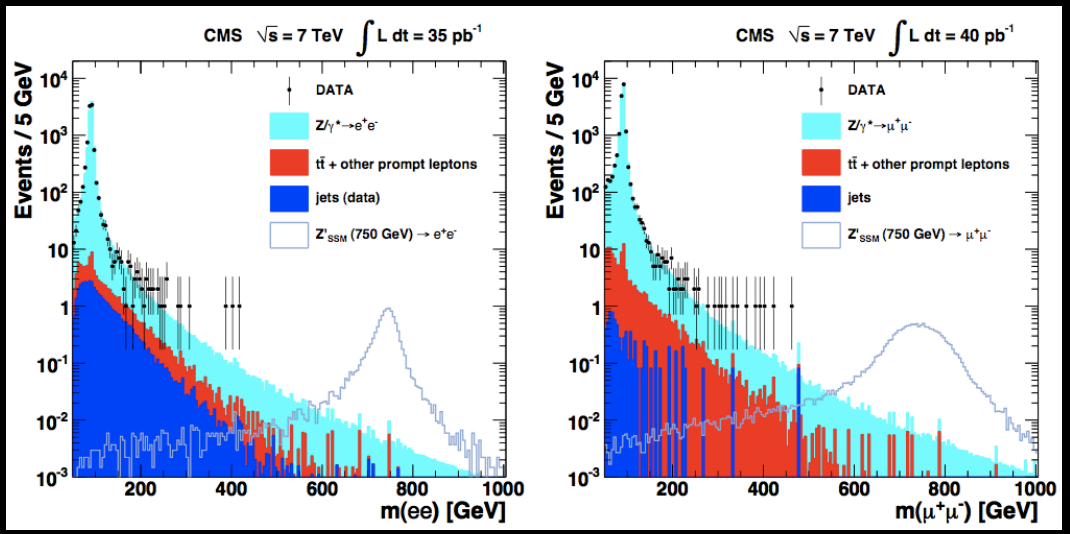


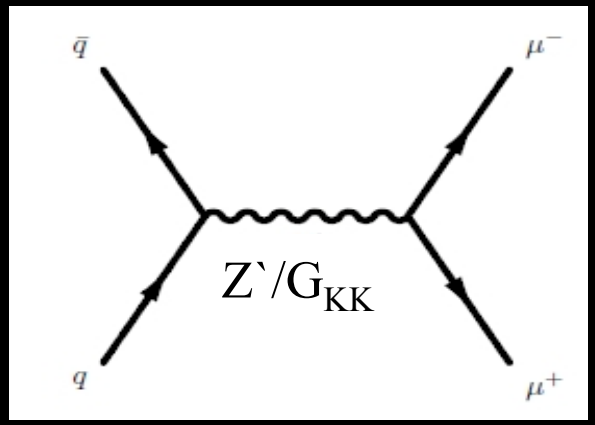
arXiv:1103.0981
accepted by JHEP

Dilepton Mass Resonances

Look for bump in dilepton mass spectrum

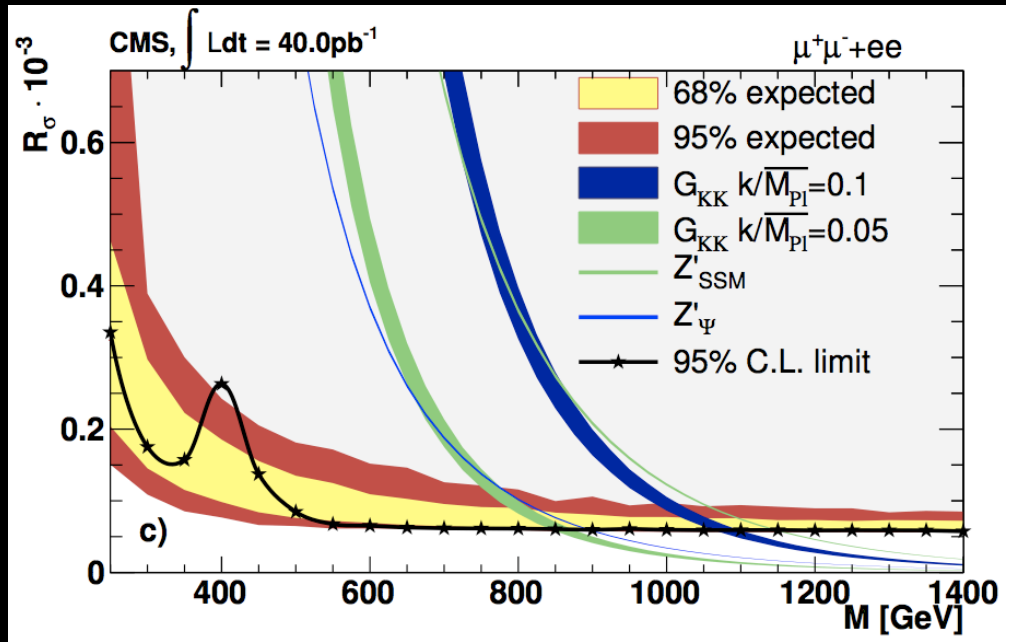
- Two central, isolated e(μ) with p_T > 25(20) GeV
- No deviation from SM (dominantly Drell-Yan)
- Set limits, most stringent limits to date





Express limit as a ratio b/w σ(Z') to the SM Z

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$



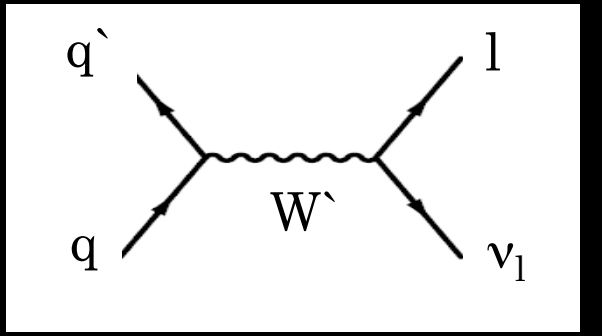
CMS limits (35 ~ 40 pb^{-1})

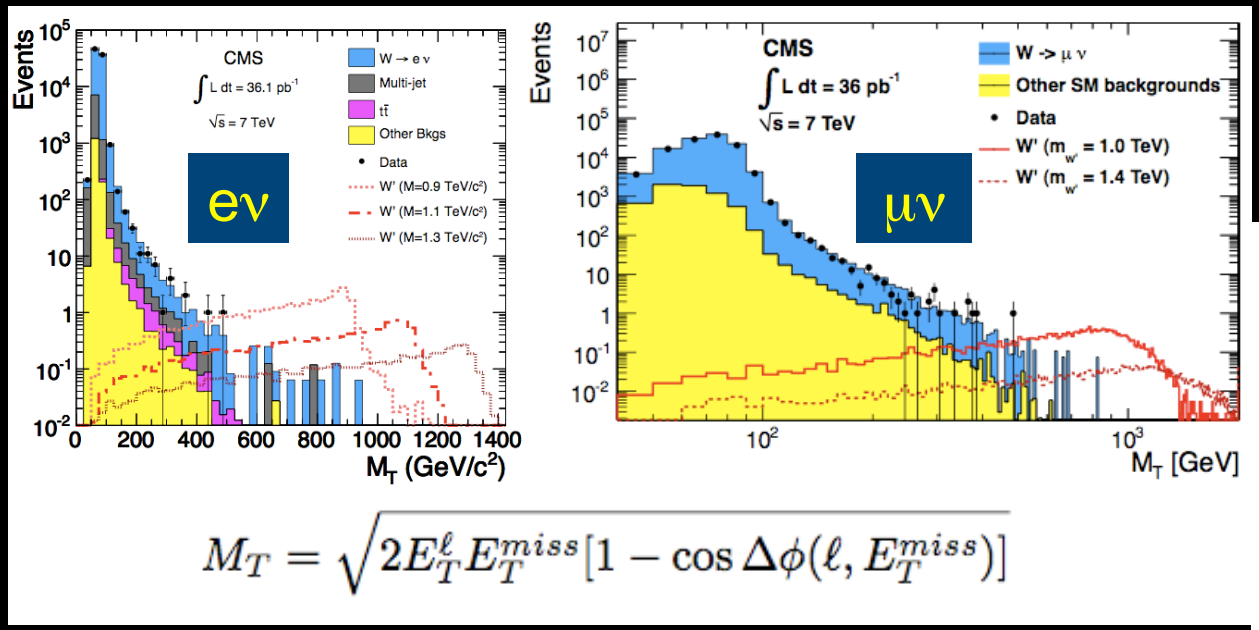
Channel	μμ	ee	Combined
Z_{SSM}	1027 GeV	958 GeV	1140 GeV
Z_ψ	792 GeV	731 GeV	887 GeV
G_{KK}, k/M_{Pl} = 0.05	778 GeV	729 GeV	855 GeV
G_{KK}, k/M_{Pl} = 0.10	987 GeV	931 GeV	1079 GeV

W' Searches

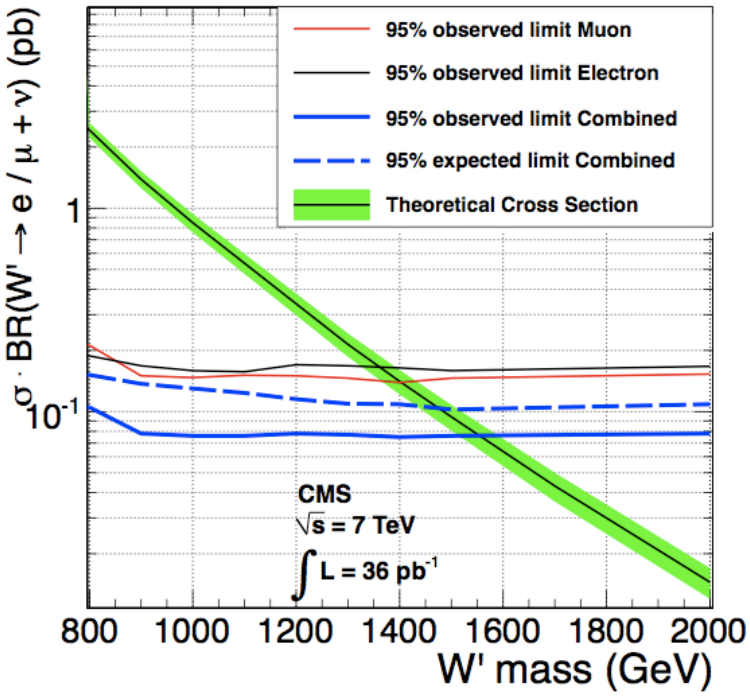
Look for Jacobian peak in M_T (eν) & M_T(μν) distribution

- A central, isolated e(μ) with $p_T > 30(25)$ GeV
- No significant deviation from SM
- Set limits, most stringent limits to date





$$M_T = \sqrt{2E_T^{\ell} E_T^{miss}[1 - \cos\Delta\phi(\ell, E_T^{miss})]}$$



CMS limits (36 pb^{-1})

eν	1.36 TeV
μν	1.40 TeV
eν+μν	1.58 TeV

ATLAS: 1.45 TeV
Tevatron: 1.1 TeV

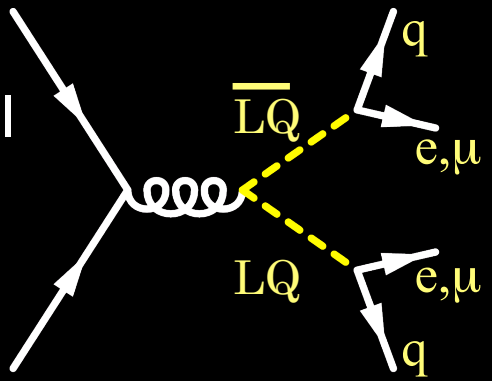
Leptoquarks

eejj: arXiv:1012.4031, accepted by PRL
eejj + eνjj: EXO-10-006

- LQs decays to lepton and quark. β = BR(LQ→lq), 1-β = BR(LQ→ νq)
- Search for 1st (e) and 2nd (μ) generation LQs, look for S_T (scalar sum of jet & lepton p_T)

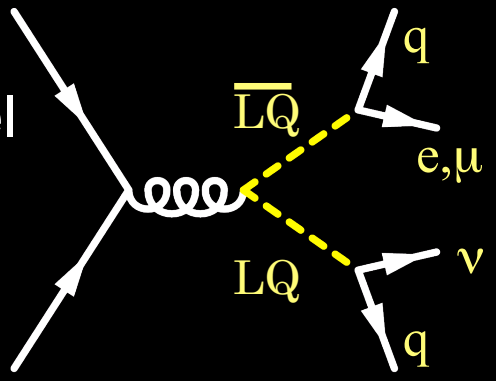
eejj/μμjj channel

BR: β^2

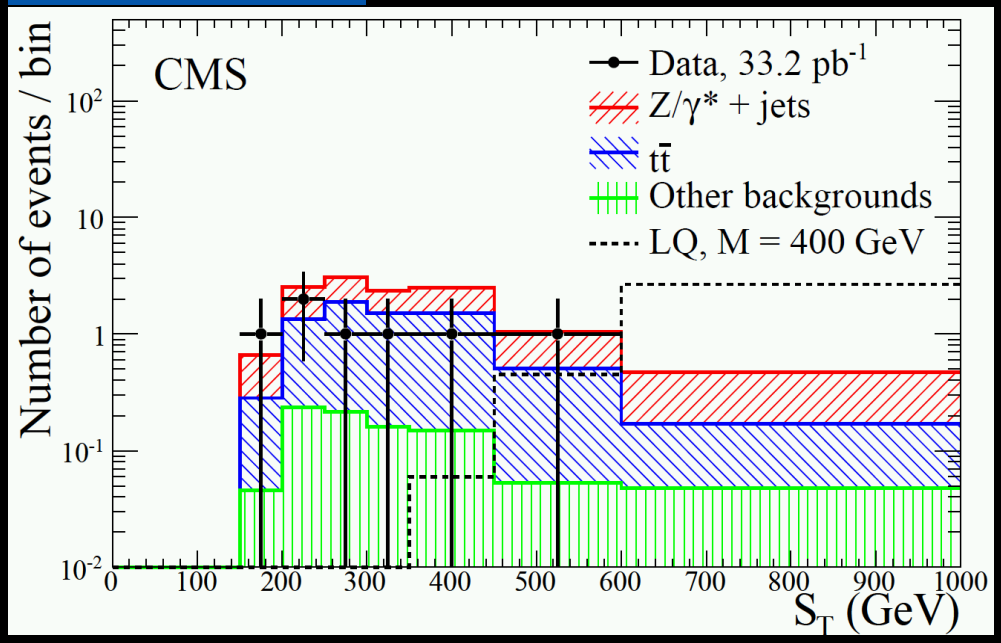


eνjj/μνjj channel

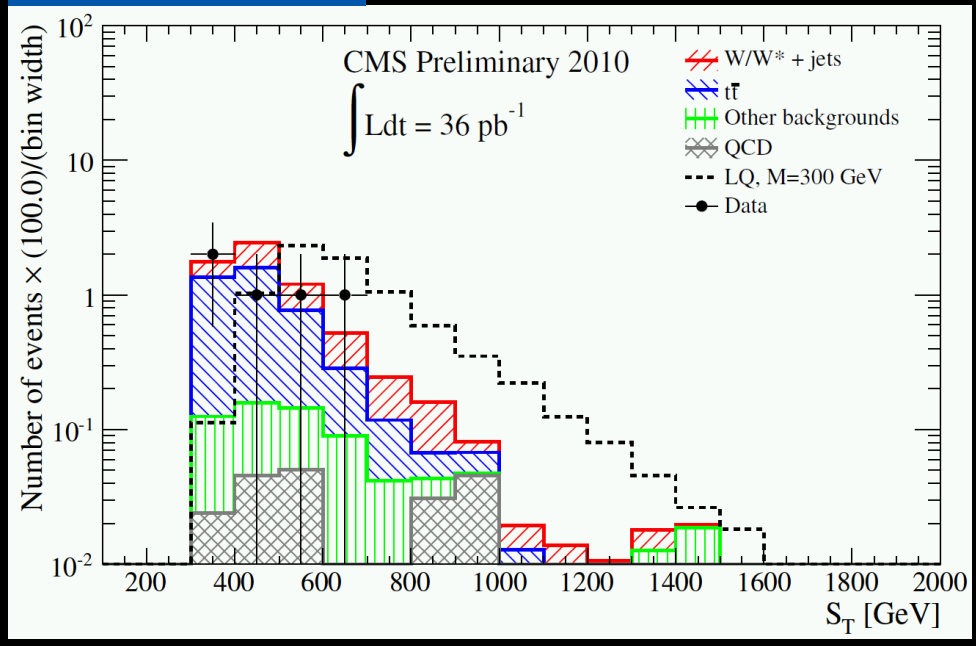
BR: $\beta(1-\beta)$



eejj channel

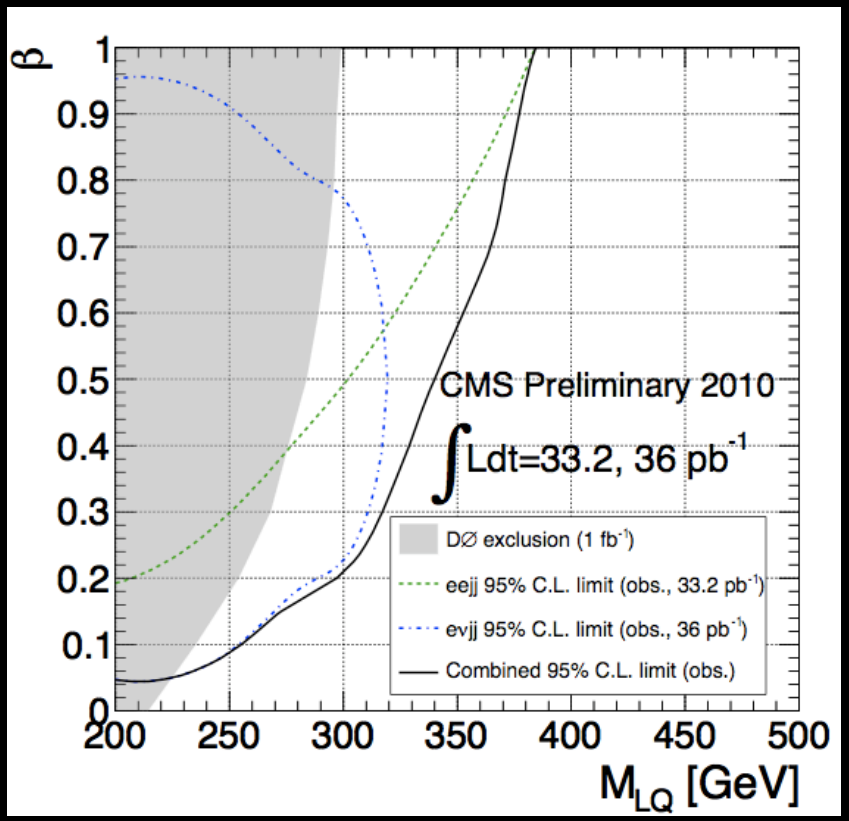


eνjj channel



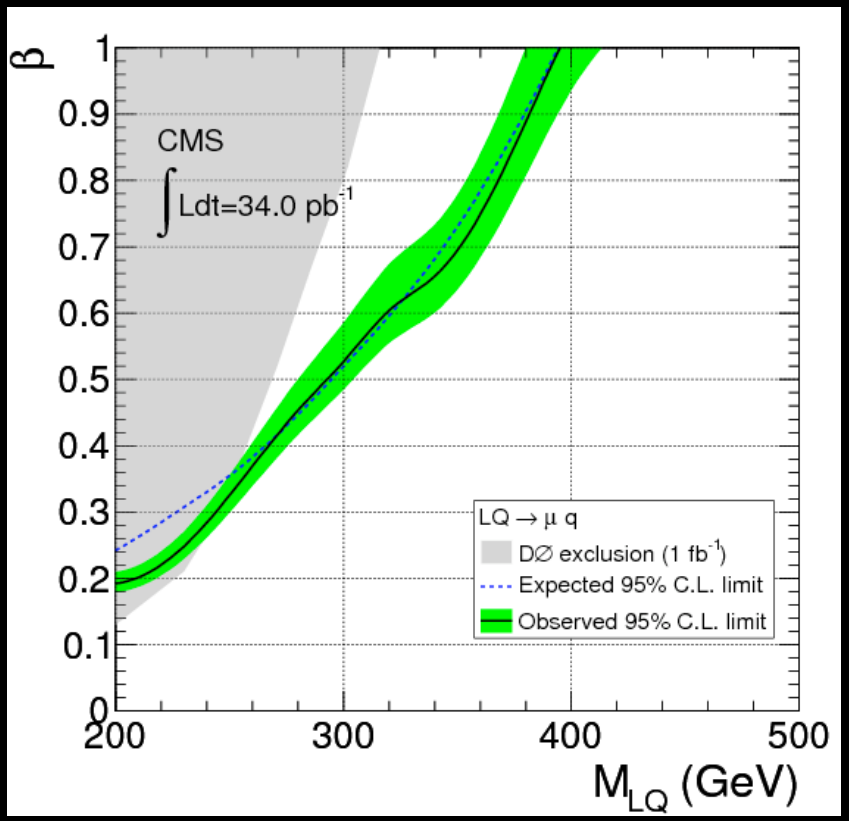
Leptoquarks

1st gen LQs – eejj+evjj channels



$M_{LQ} > 340, 384$ GeV for $\beta=0.5, 1$

2nd gen LQs – μμjj channel

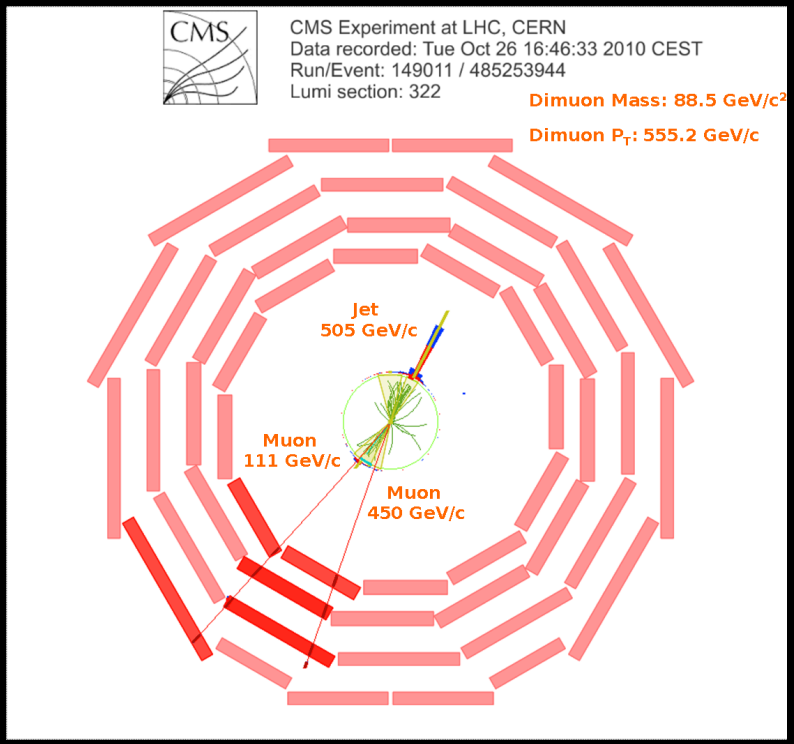


$M_{LQ} > 394$ GeV for $\beta=1$

- Exceed Tavatron limits for almost the entire β range (except @ very low β)
- Similar to ATLAS limit: $M_{LQ1} > 376$ GeV & $M_{LQ2} > 422$ GeV for $\beta = 1$

Searches for Compositeness

- Quark Compositeness
- Lepton Compositeness



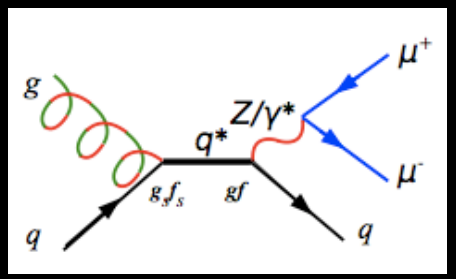
Highest dimuon p_T candidate event ~ 555 GeV

Quark Compositeness

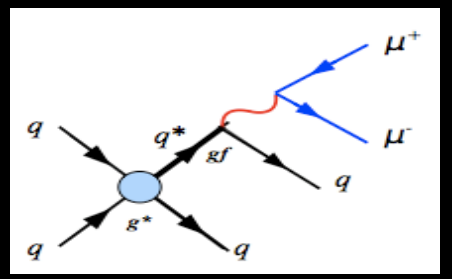
Weakly decaying excited quark
- $q^* \rightarrow qZ \rightarrow q\,\mu^+\mu^-$ ($\Lambda = m_{q^*}$ and $f = f' = 1$)
- complementary to $q^* \rightarrow jj$ decay channel

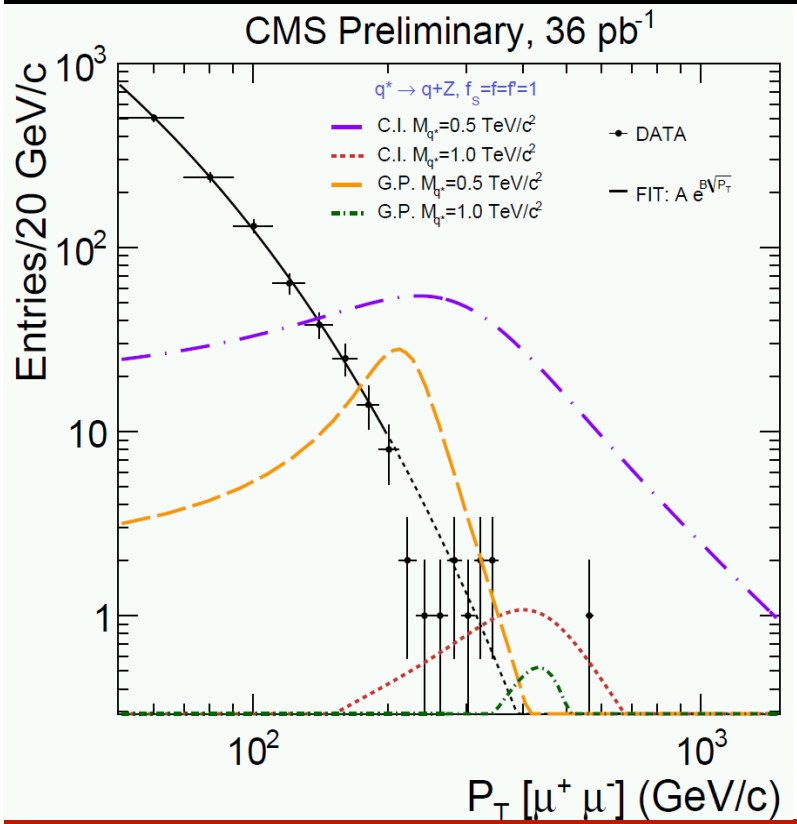
Searching for bump in Z p_T spectrum
- no deviation from SM predictions,
- set limits on M_{q^*}

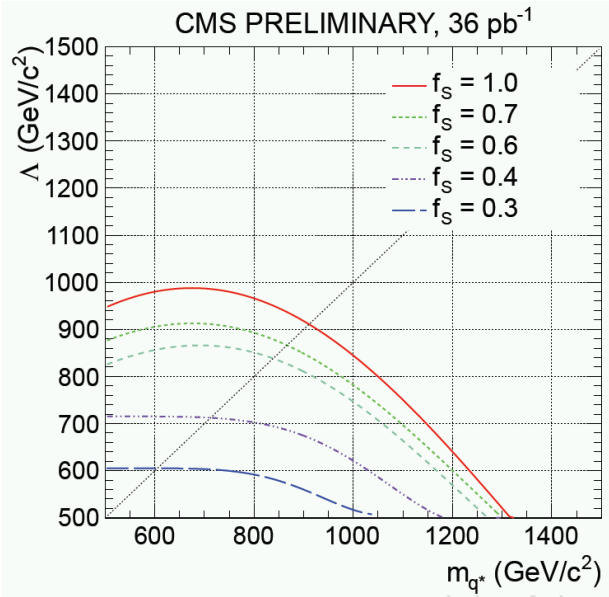
Gauge Interaction



Contact Interaction

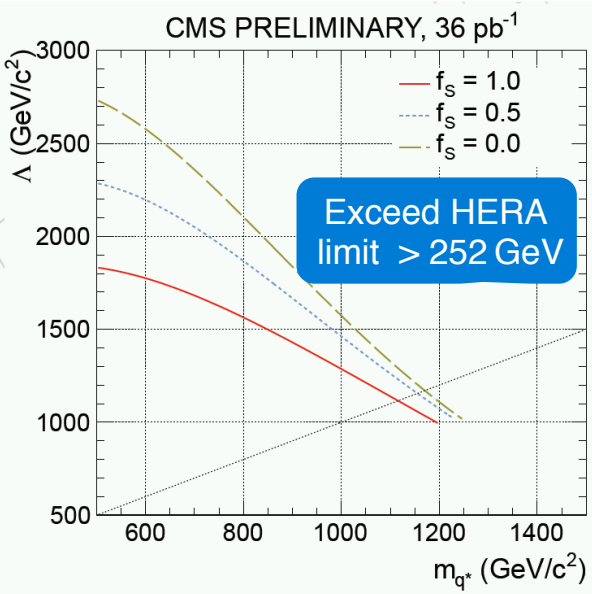






$M_{q^*} = \Lambda,\ f = f' = f_S = 1$

$M_{q^*} > 0.91$ TeV

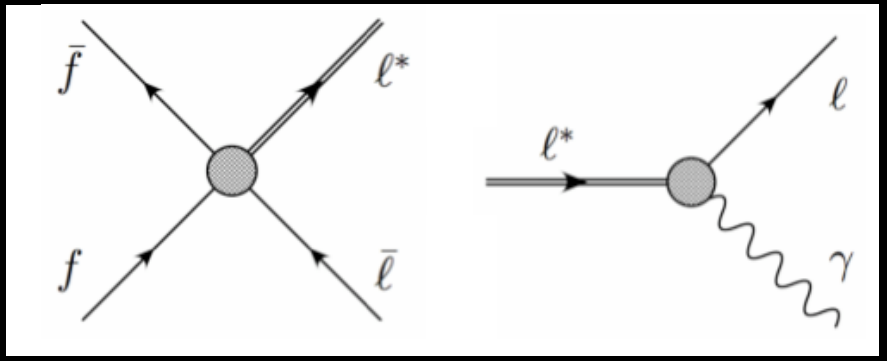


$M_{q^*} = \Lambda,\ f = f' = 1, f_S = 0$

$M_{q^*} > 1.17$ TeV

EXO-10-016

Lepton Compositeness



Production via new contact interaction

- $qq \rightarrow ee^* \rightarrow ee\gamma$
- $qq \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$

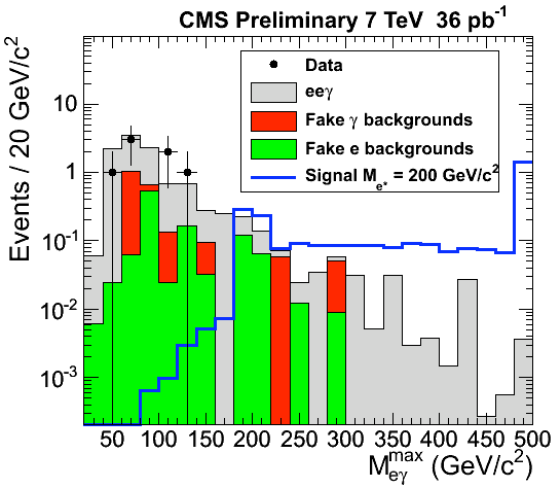
Experimental signature:

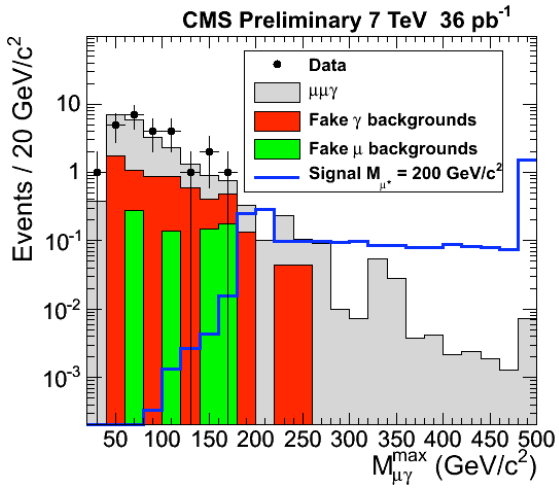
- 2 isolated e/μ of opposite charge
- isolated photon ($\Delta R(\gamma,l) > 0.5$)

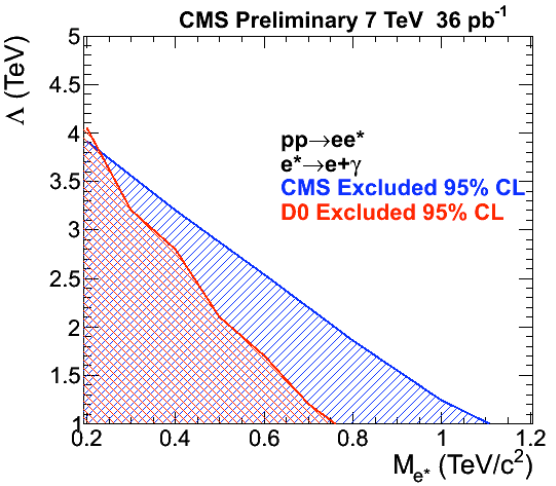
Searching for excess in data at high M(eγ) or M(μγ)

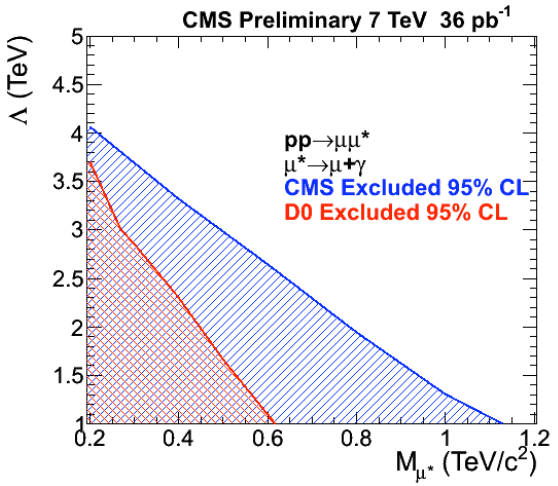
- 0 event observed, set limits on M(e*) > 760 GeV, M(μ*) > 785 GeV for $\Lambda = 2$ (exceed Tevatron result)

$qq \rightarrow ee^* \rightarrow ee\gamma$ $qq \rightarrow \mu\mu^* \rightarrow \mu\mu\gamma$



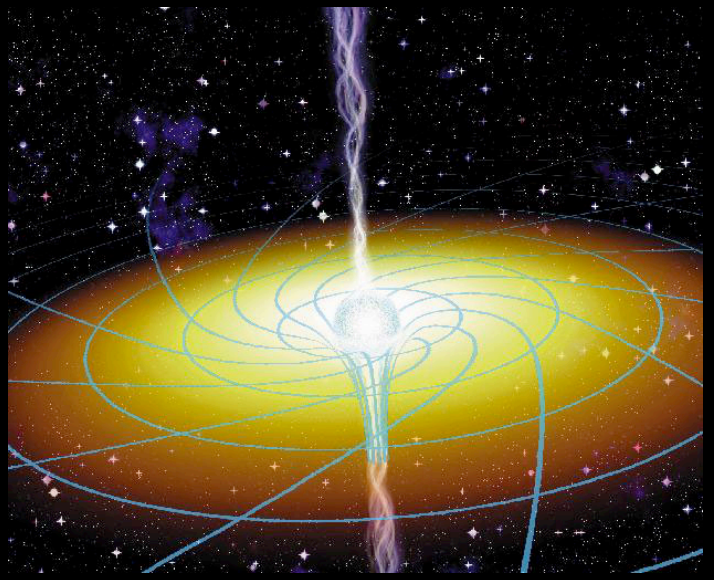






Searches for
TeV Scale Gravity

- RS Graviton
- Large Extra Dimension (ADD)
- Micro Black Holes



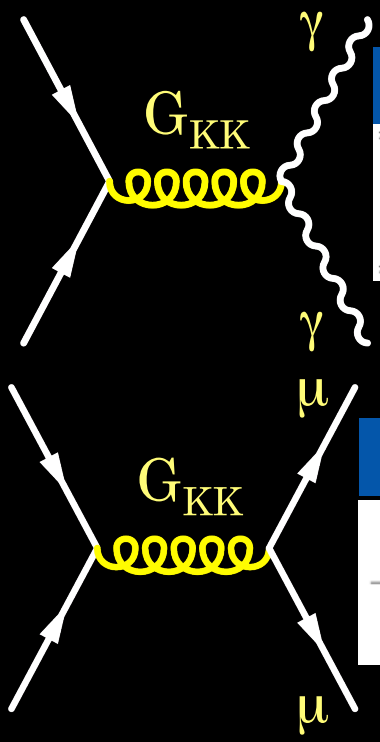
LED (γγ/μμ)

ADD Model

Looking for excess @ high mass in γγ/μμ spectrum

- no event observed with $M_{\gamma\gamma}(M_{\mu\mu}) > 500\ (600)$ GeV
- set limits on M_s vs n

  M_s = UV cut-off in σ, n = # of extra dimensions

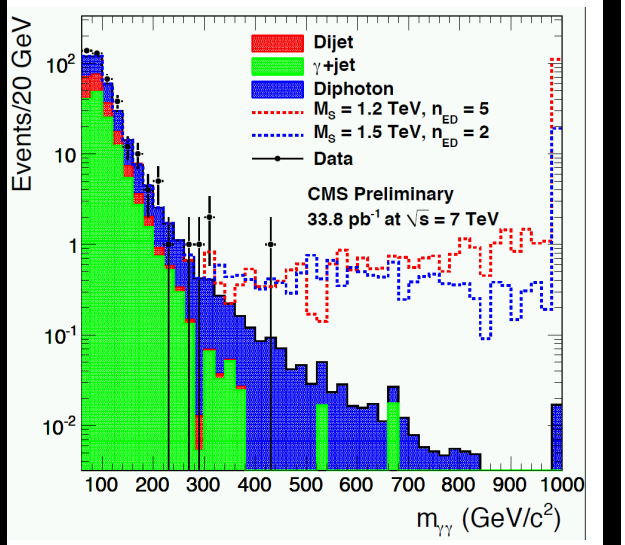


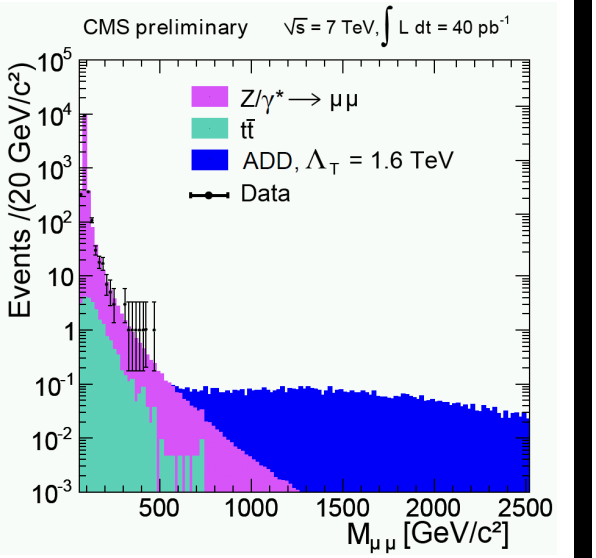
Limit on strength of ED effect / UV cut-off

	GRW	Hewett		HLZ					
		Pos.	Neg.	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
Full	1.94	1.74	1.71	1.89	2.31	1.94	1.76	1.63	1.55
Trunc.	1.84	1.60	1.50	1.80	2.23	1.84	1.63	1.46	1.31

Limit on Pheno. parameter Λ_T, n, M_S

	Λ_T [TeV] (GRW)	M_s [TeV/c^2] (HLZ)					
		$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
Full	1.80	1.75	2.15	1.80	1.63	1.52	1.43
Truncated	1.68	1.67	2.09	1.68	1.49	1.34	1.24





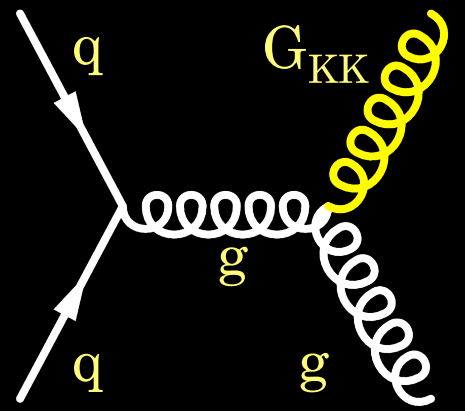
LED -Monojet

ADD Model

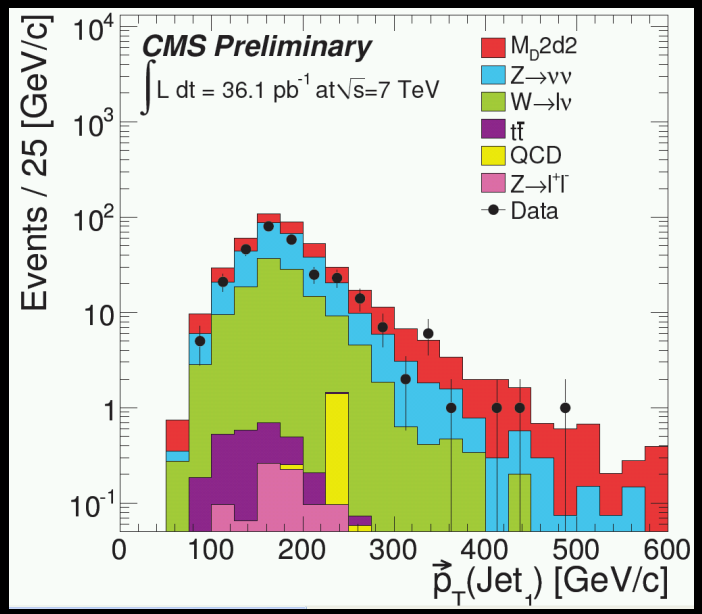
one high p_T jet + large MET (a.k.a. Mono-jet)

- veto on leptons, dijets, cosmics, beam halo, instrumental backgrounds
- data consistent with SM, set limits on M_D vs δ

  M_D = Planks scale, δ = # of extra dimensions



N_{DATA}	275
N_{BKG} (data-driven)	297 ± 45
$N_{SIGNAL}(M_D=2,\delta=2)$	115.2



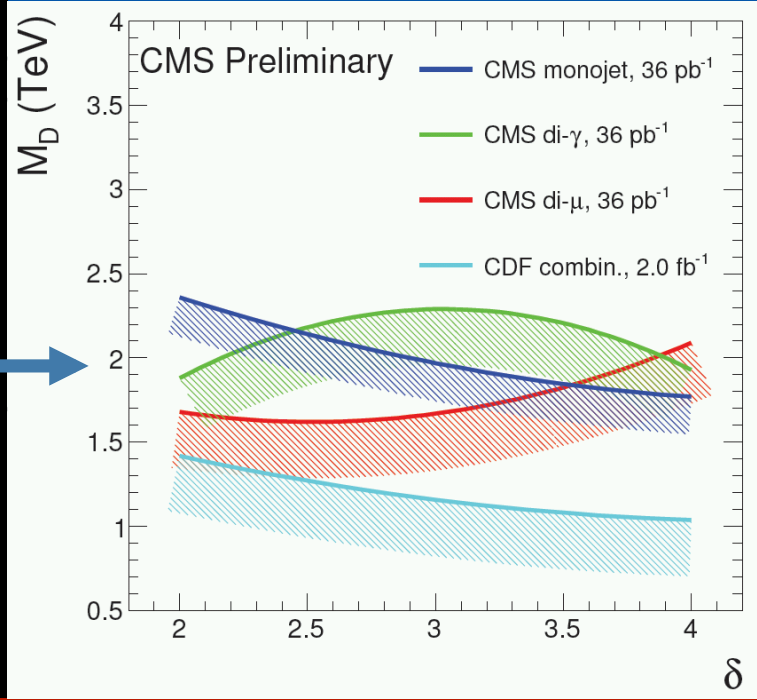
CMS limits on M_D (36 pb^{-1})

δ	with K-factor**
2	2.37 TeV
3	1.98 TeV
4	1.77 TeV

** = 1.5 (1.4) for δ=2,3 (4)

δ	CDF	LEP
2	1.40 TeV	1.6 TeV
3	1.15 TeV	1.2 TeV
4	1.04 TeV	0.94 TeV

Summary Plot

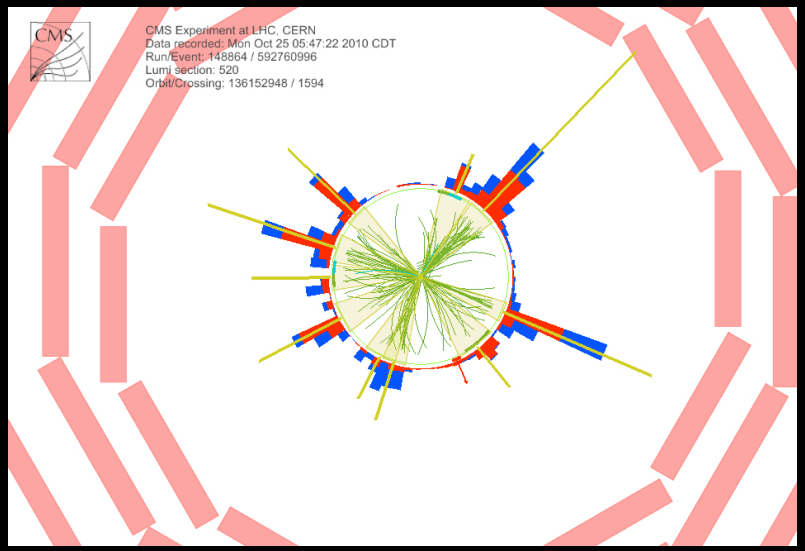


Black Holes

Smoking gun signature of TeV scale gravity

BH decay via Hawking radiation

- produce large number of energetic objects
- mostly quarks & gluons → jets



High multiplicity event

Search for deviation in S_T distribution in bins of object multiplicity (n; at least > 2)

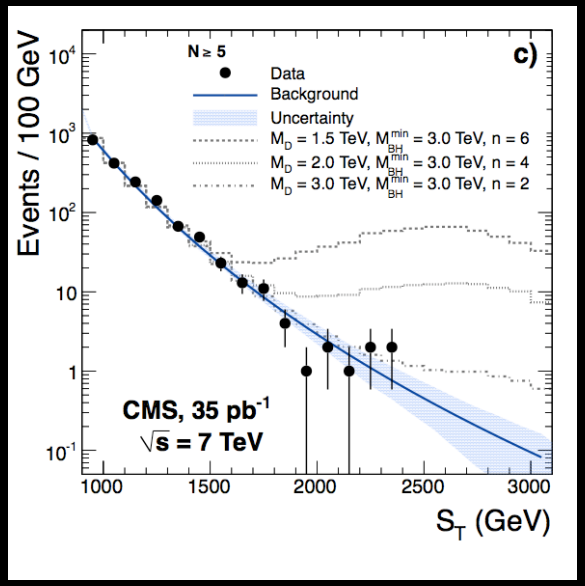
- S_T = scalar sum of all objects with p_T > 50 GeV

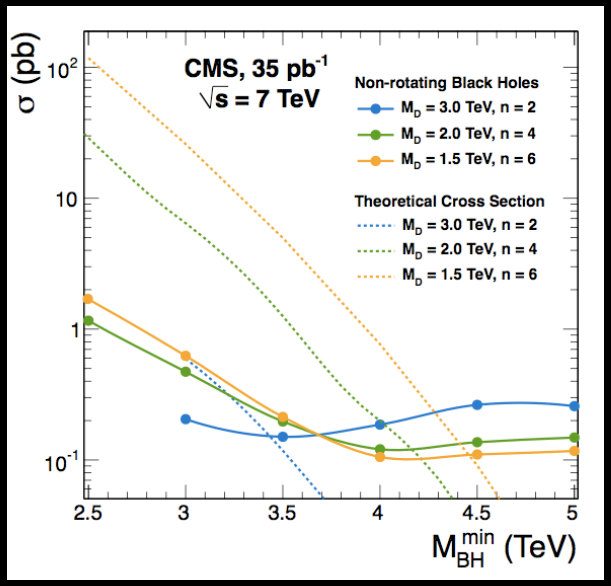
No excess observed in data

Set limit on the minimum BH mass of 3.5 – 4.5 TeV in semi-classical approximation

First direct BH limits

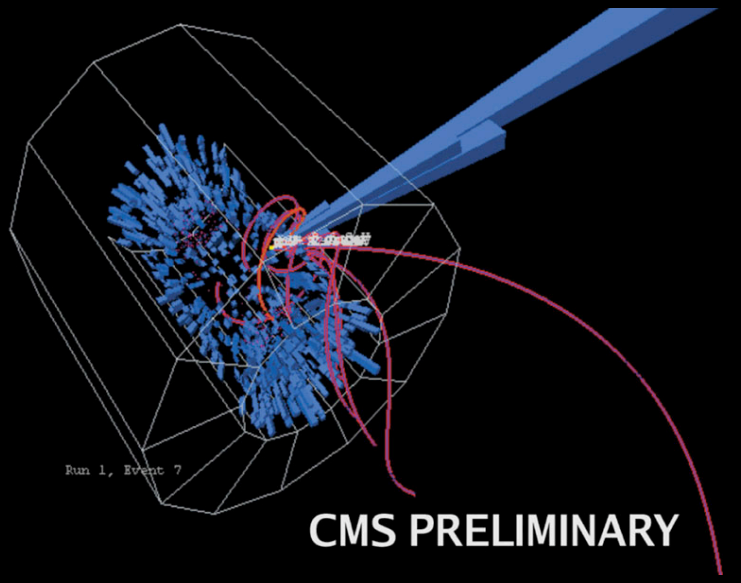
PLB 697, 434 (2011)





Searches for
Long-Lived Heavy Particles

- Heavy Stable Charged Particles
- Stopped Gluinos



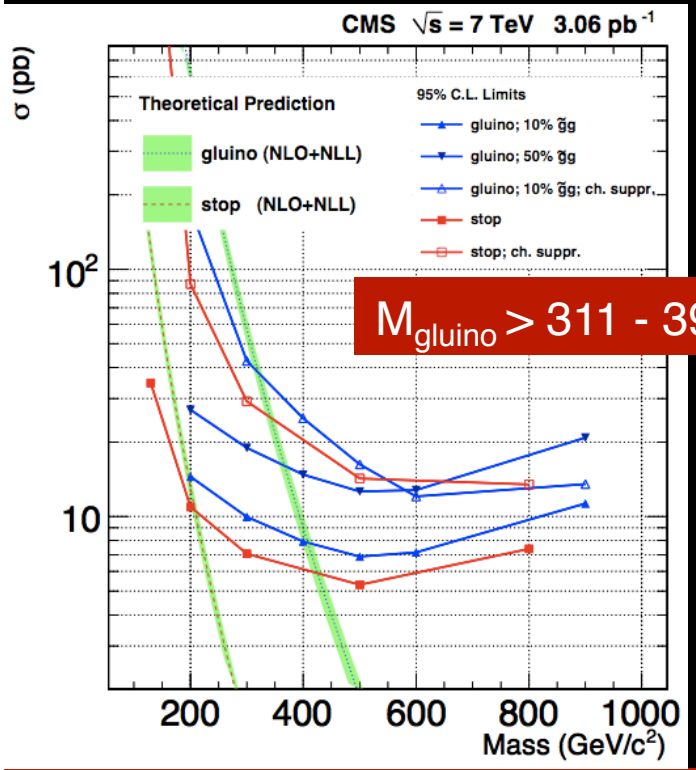
Long-Lived Particle

Long-Lived Heavy particles appear in many BSM (e.g. $\tilde{g}$ in split SUSY)

- Since massive they are slow ($\beta < 0.9$)
- Gluinos hadronize forming R-Hadrons

We've performed searches for 2 distinctive signatures of LLH particles

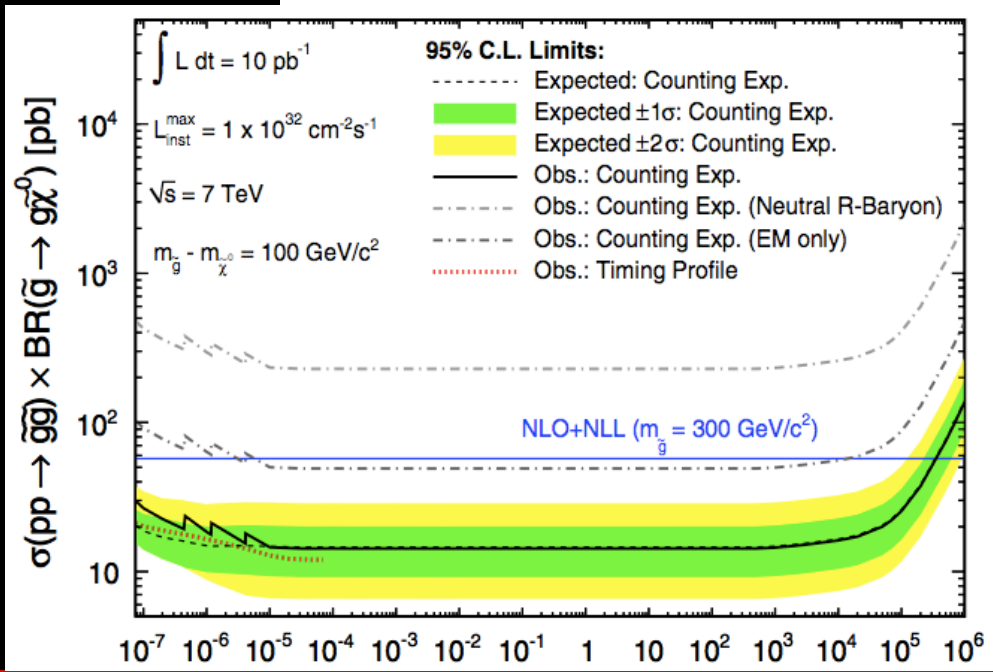
1. Large dE/dx due to larger ionization for slow moving particles
2. Out-of-Time decays of particles which have come to rest before exiting the detector



$M_{gluino} > 311 - 398$ GeV (3 pb^{-1})

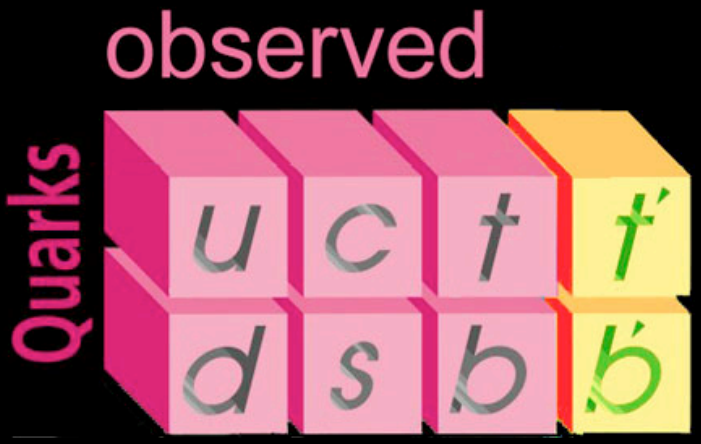
ATLAS limit:
$M_{gluino} > 586$ GeV
(34 pb^{-1})

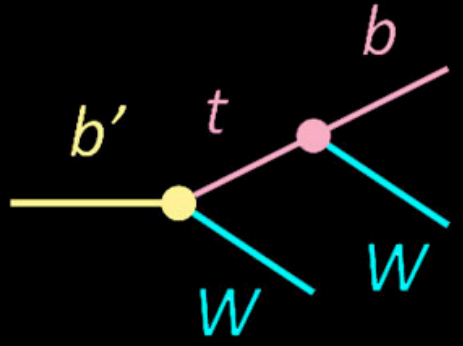
$M_{\tilde{g}} > 370$ GeV, $\tau = 10\ \mu s - 1000\ s$



Searches for
Forth Generation

- b'
- ttbar Resonances





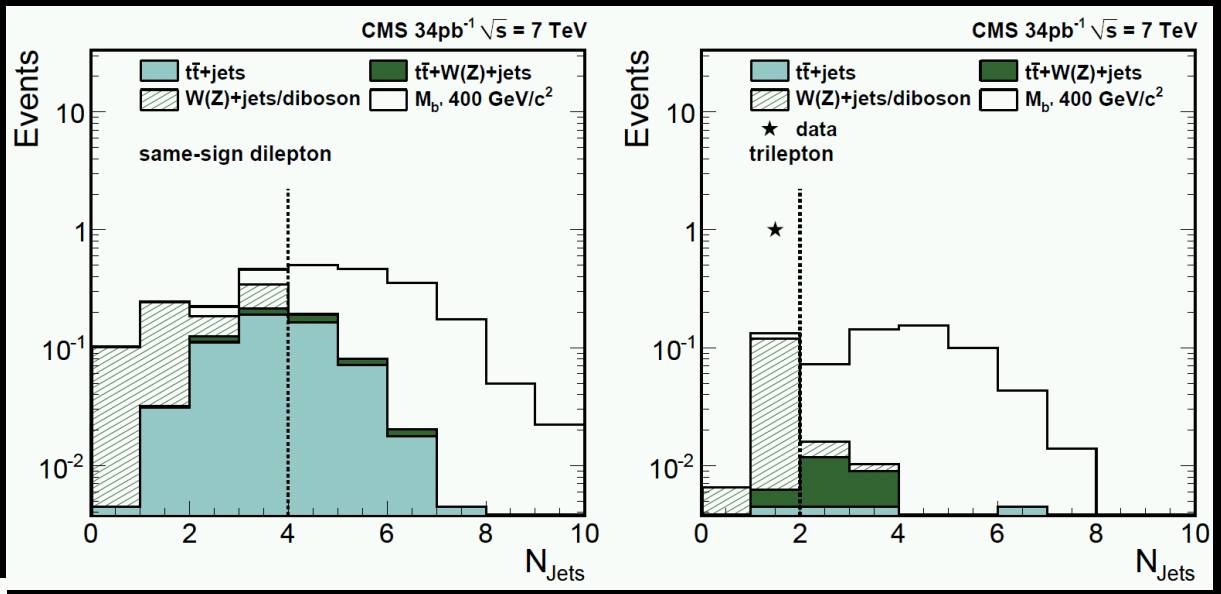
b' Search

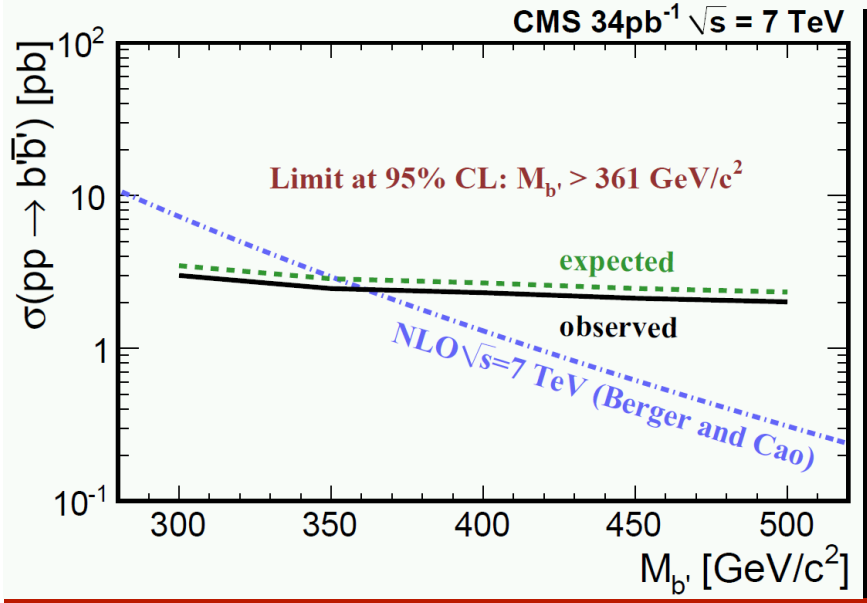
Pair produced 4th generation heavy quarks b'. each b' → tW → bWW

Like-sign dilepton & trileptopn (e,μ) decays + jets

Events selected based on leptons, N_{Jets}, large MET, &

$$S_T = \sum_{\text{jets}} p_T + \sum_{\text{leptons}} p_T + \not{E}_T$$





Like-sign dilepton & trilepton decays + 4(2) jets

N_{bgd} = 0.3 +/- 0.2 events

0 event observed

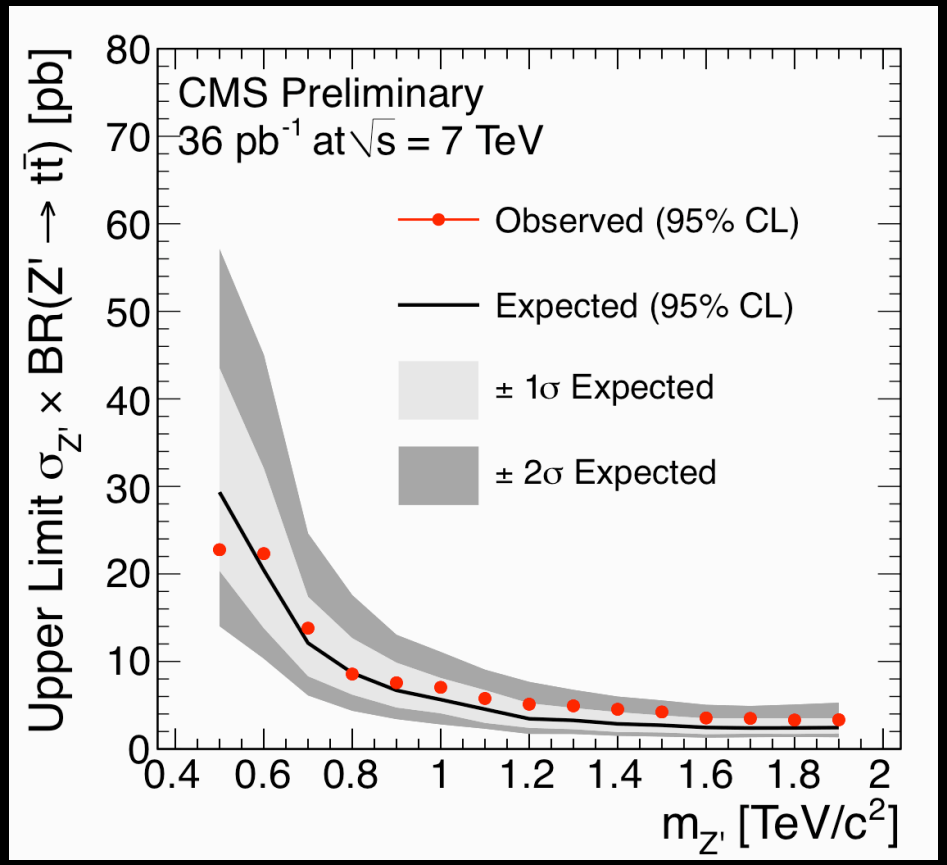
Limit @ 95% CL: $M_{b'} > 361$ GeV

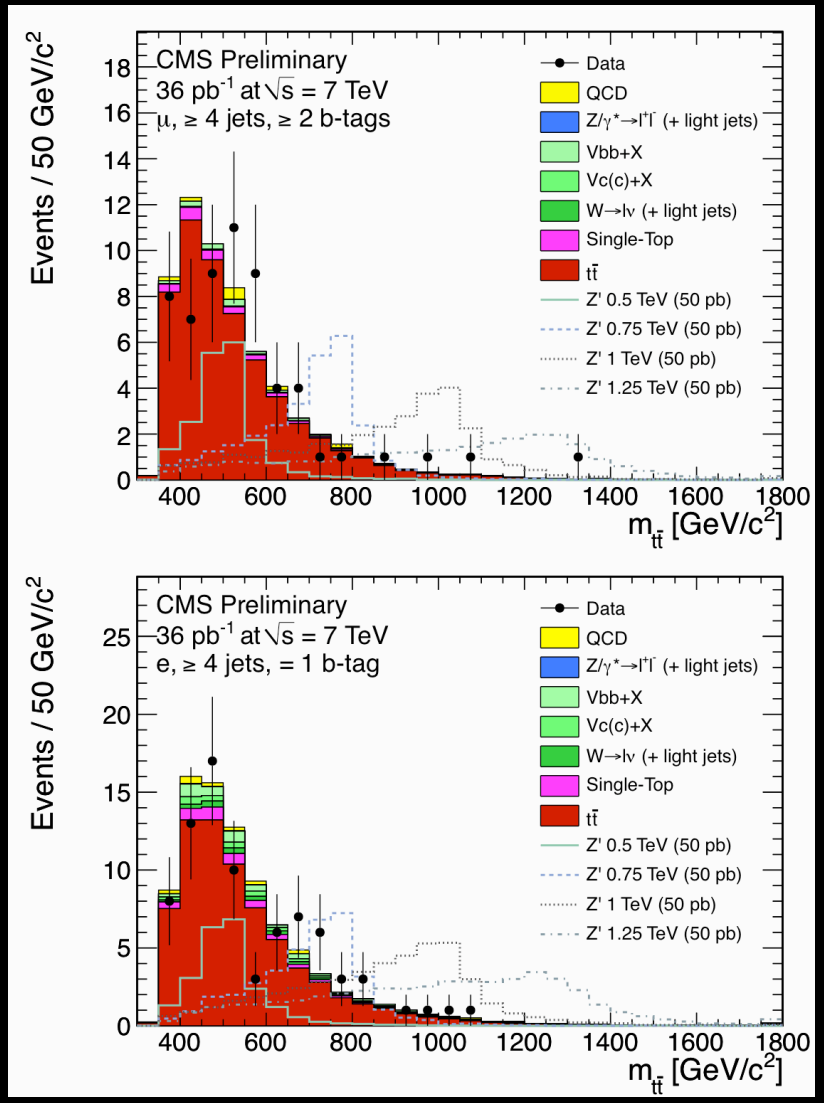
Similar to new Tevatron limit: $M_{b'} > 372$ GeV

Top Pair Resonances

Bump hunt in M(ttbar) spectrum

- Lepton + jets channels (e & μ)
- No significant excess of events above SM
- Set limit on the production cross section, competitive with Tevatron

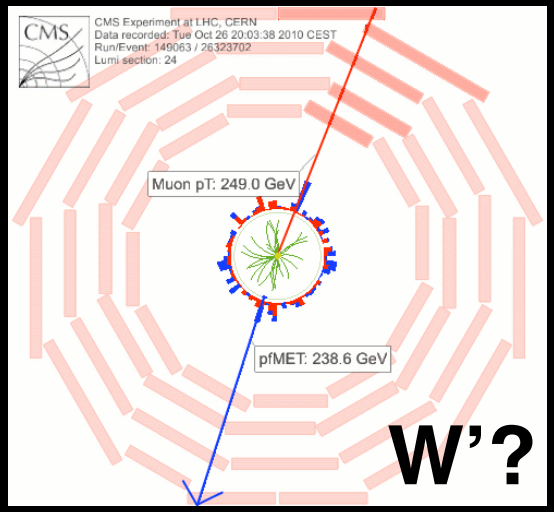


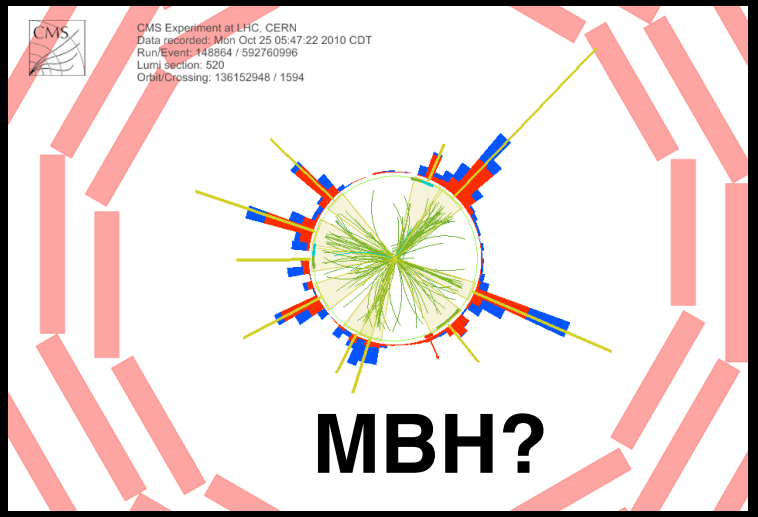


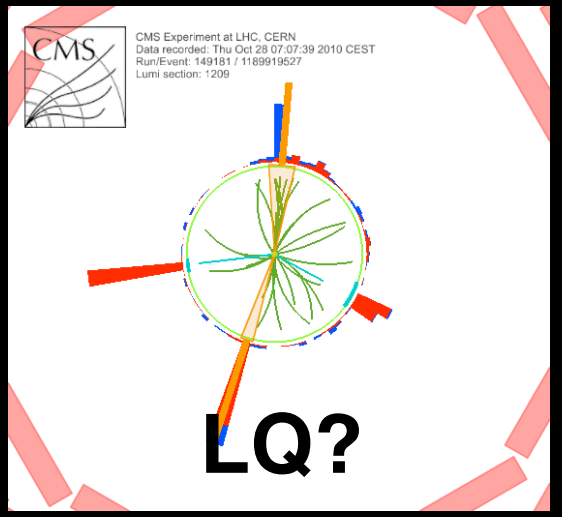
25 pb for $m_{z'}$ = 0.5 TeV, 7 pb for $m_{z'}$ = 1 TeV,
4 pb for $m_{z'}$ > 1.5 TeV

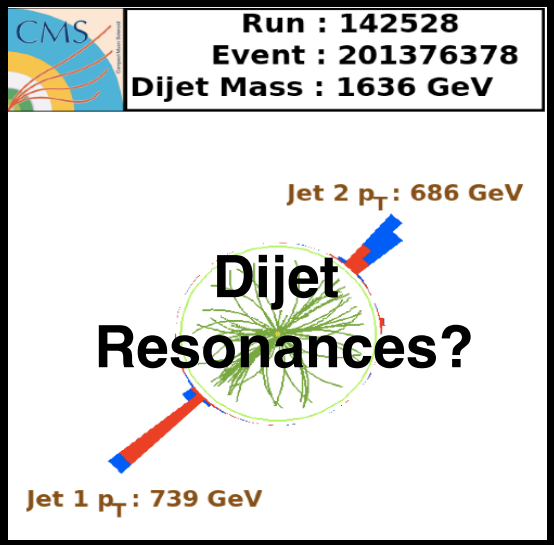
2011 and Beyond …

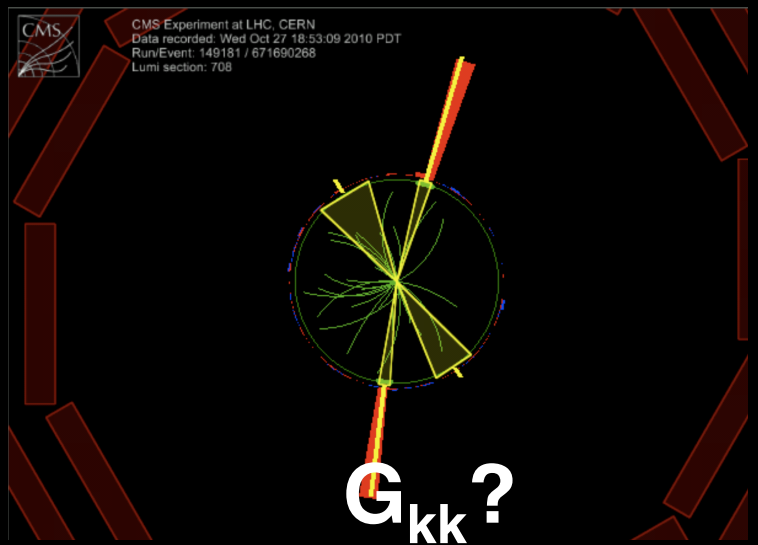
Looking forward to see more of these events…

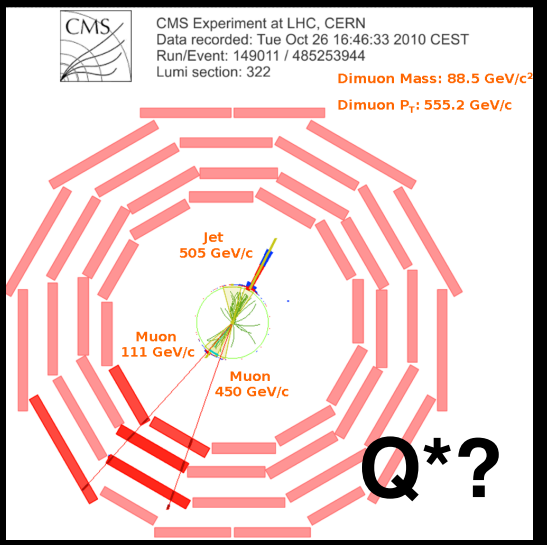












Conclusions

- CMS is searching for evidence of different models of new physics in several channels using the early LHC data & already exploring new territory beyond the Tevatron.

- Only recent results shown here.

  Many new physics searches are underway.

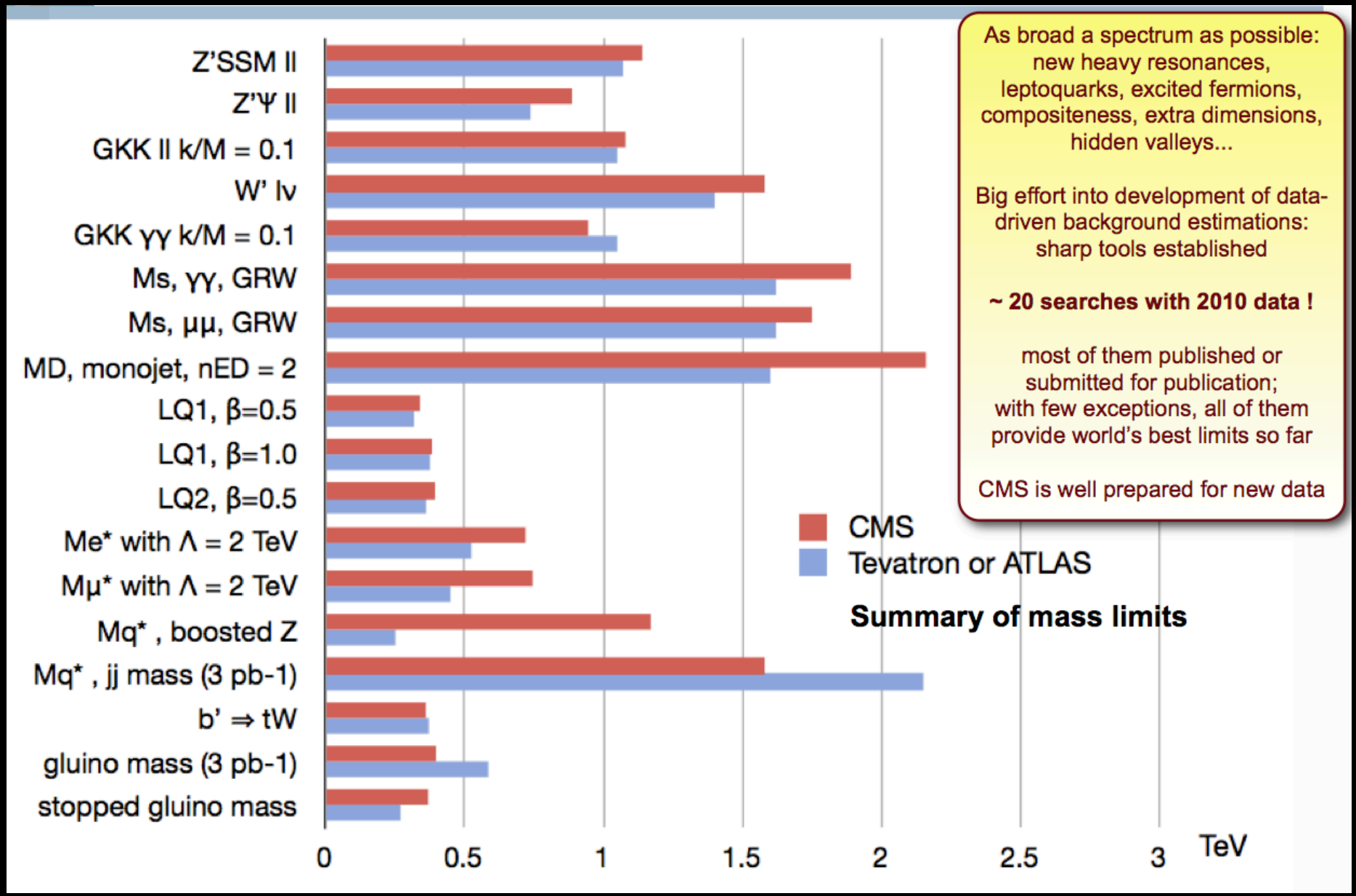
- No signals of the new physics observed in the early LHC data yet.

- More LHC data on the way;

  Analyses of ~230 pb^{-1} data samples just beginning.

  New exciting results are in the pipe-line. Stay tune!

Extra Slides


Z'SSM ll
Z'Ψ ll
GKK ll k/M = 0.1
W' lν
GKK γγ k/M = 0.1
Ms, γγ, GRW
Ms, μμ, GRW
MD, monojet, nED = 2
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
Me* with Λ = 2 TeV
Mμ* with Λ = 2 TeV
Mq* , boosted Z
Mq* , jj mass (3 pb-1)
b' ⇒ tW
gluino mass (3 pb-1)
stopped gluino mass
0
0.5
1
1.5
2
2.5
3
TeV
CMS
Tevatron or ATLAS
Summary of mass limits
As broad a spectrum as possible: new heavy resonances, leptoquarks, excited fermions, compositeness, extra dimensions, hidden valleys...
Big effort into development of data-driven background estimations: sharp tools established
~ 20 searches with 2010 data !
most of them published or submitted for publication; with few exceptions, all of them provide world's best limits so far
CMS is well prepared for new data