Searches for New Physics at CMS

Berkeley Workshop for
SUSY at the LHC
October 21, 2011

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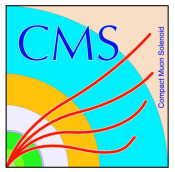
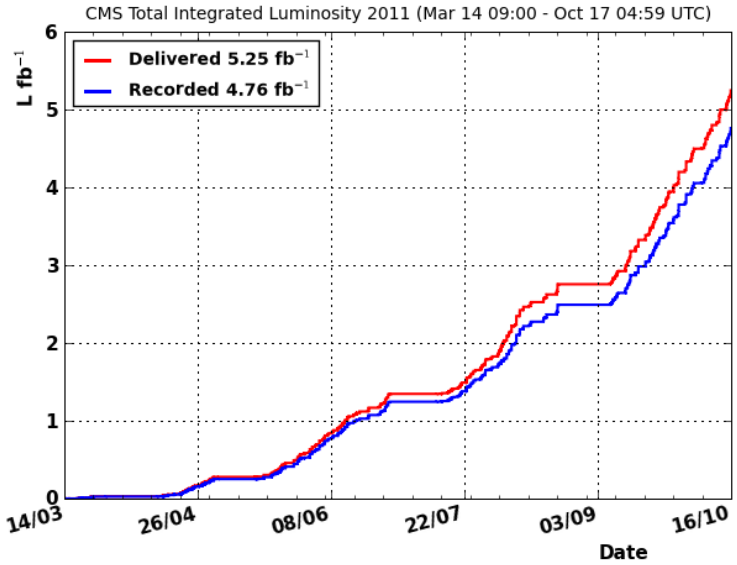
For the CMS Collaboration



Outline

- SUSY and Higgs results already covered
- I will cover “exotic” searches:
  - Heavy Resonances
    - dileptons, diphotons, dijets, trijets, l+MET, WZ, ttbar
  - Non-Resonant Signatures
    - mono-jet, mono-photon, black-holes
  - 4th Generation Quarks
    - b’, t’



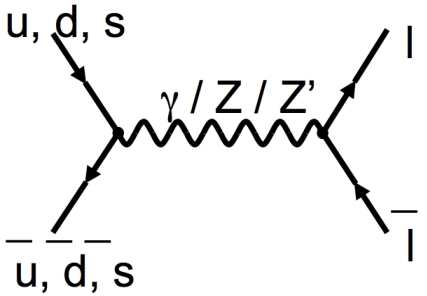
- 20 new physics results this summer with 2011 data
  - Impossible to cover everything
- **All CMS new physics results can be found at:**

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

Searches for Heavy Resonances

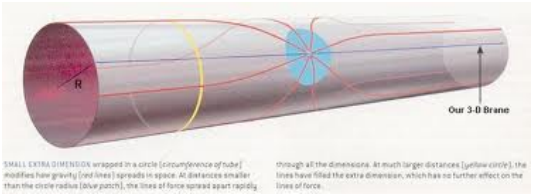
- Search for excesses in invariant mass spectra
  - Bump hunt
  - Generic, powerful and track record for discovery in the past
  - Predicted by several BSM models

  with extended gauge symmetries
    - Z' and W' with SM-like couplings
    - Kaluza-Klein excitations from RS model of extra dimensions
    - E6 models
    - Technicolor
    - ….



Searches for Non-Resonant Signatures

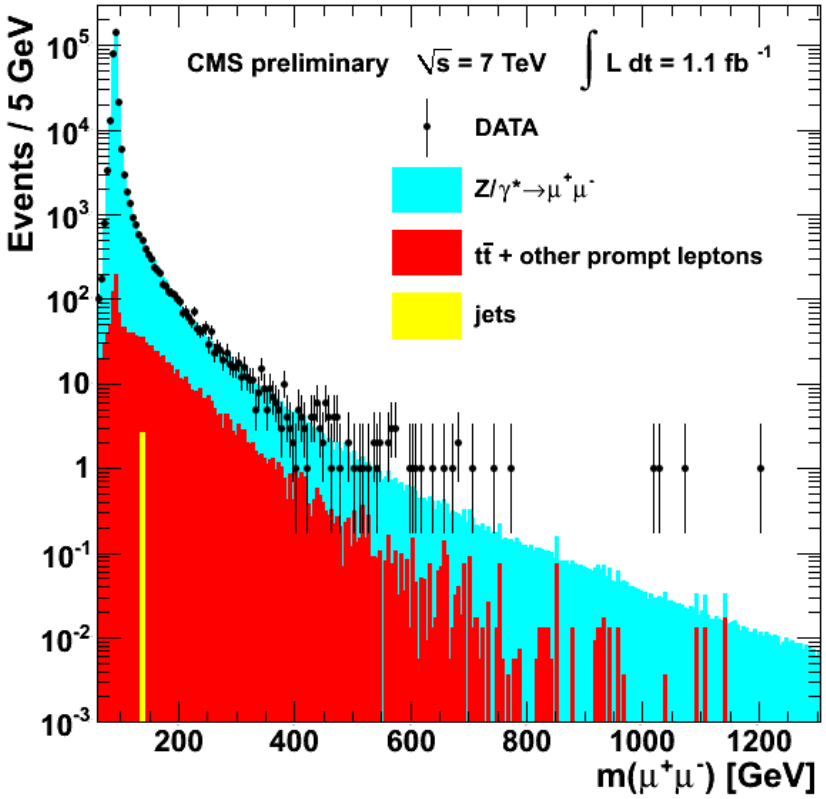
- Searches non-resonant excess in kinematic distributions and mass spectra
- Predicted by many Extra Dimension Models
  - Universal Extra Dimensions (UED)
    - All particles propagate the bulk
  - Large Extra Dimensions:
    e.g. ADD
    - Only Graviton propagates the bulk
  - Warped Extra Dimensions:
    e.g. Randall-Sundrum
    - Warped geometry



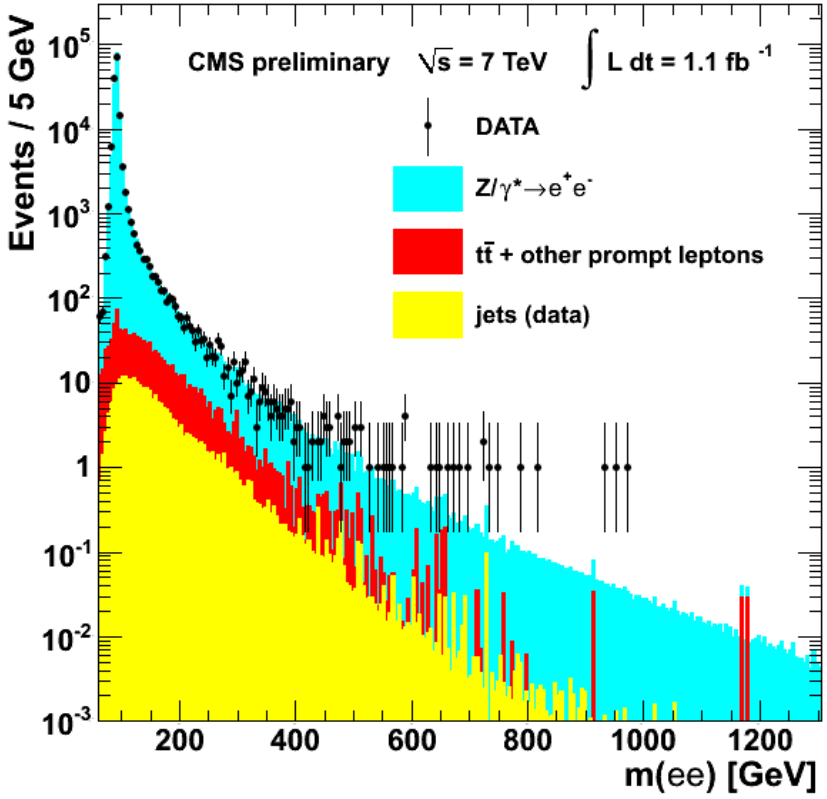
$$M_{Pl}^{2} \sim M_{D}^{2+n} R^{n}$$

Dilepton Resonances

di-muons

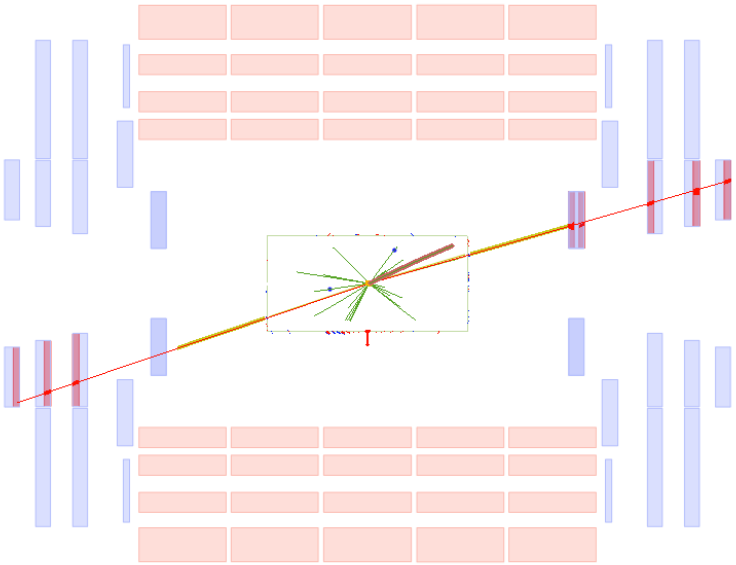


di-electrons

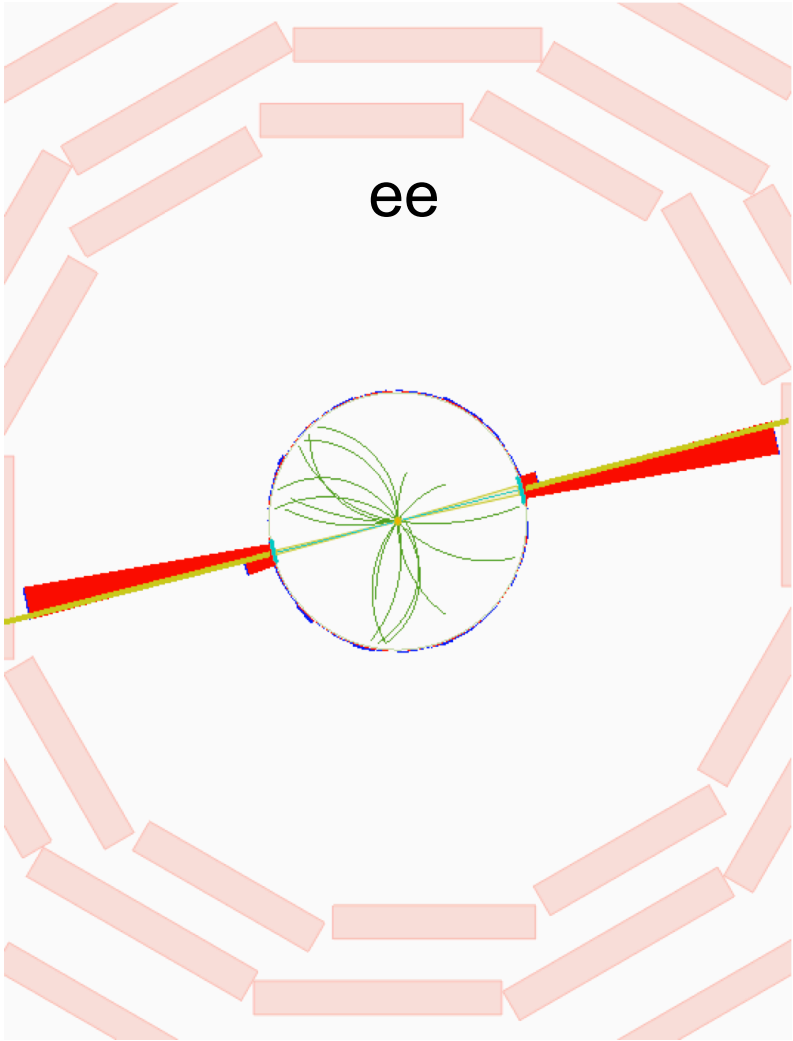


Displays of Highest Mass Events

μμ

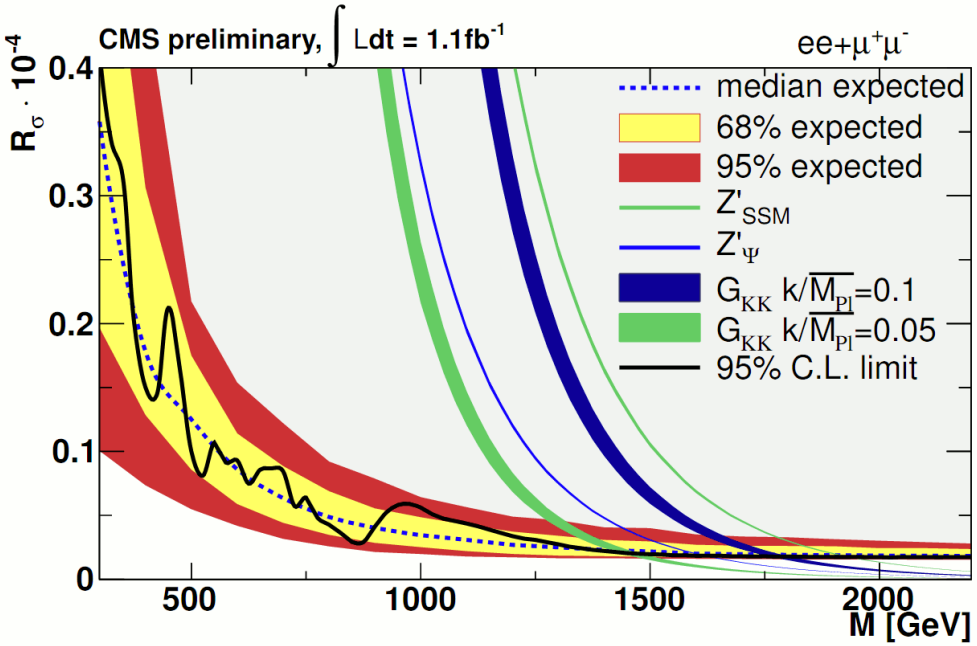


ee



CMS PAS-EXO-11-019

Dilepton Resonances

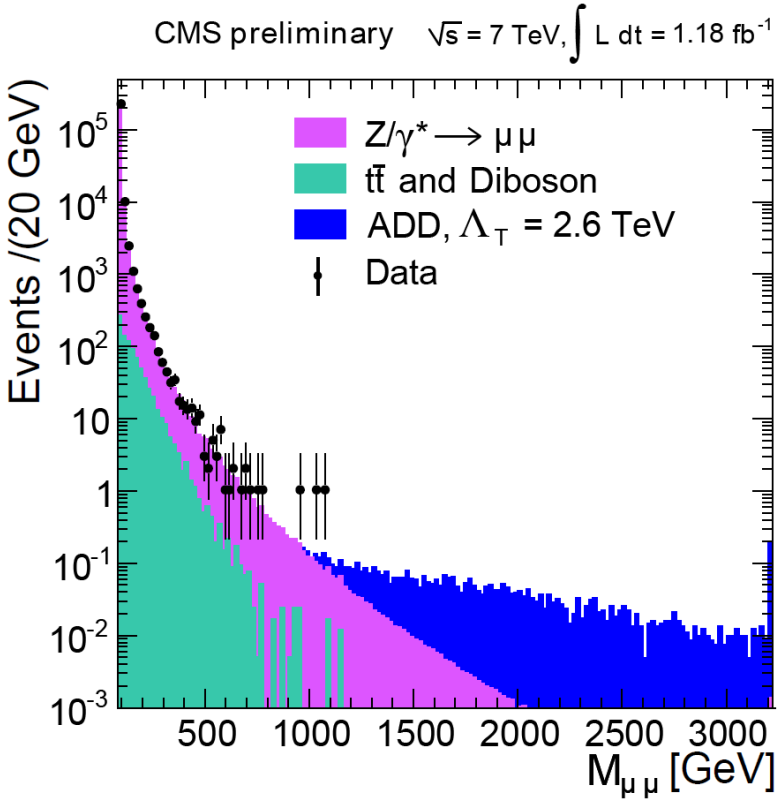


- Published ~40 pb^{-1} result
  - JHEP 05, 093 (2011)
- 1.1 fb^{-1} update
- Z' with SM-like couplings is excluded below 1.94 TeV

Z' SSM	Z' ψ	RS G* k=0.05	RS G* k=0.10
1.94 TeV	1.62 TeV	1.45 TeV	1.78 TeV

Dimuons

Search for non-resonant excess in $M_{\mu\mu}$



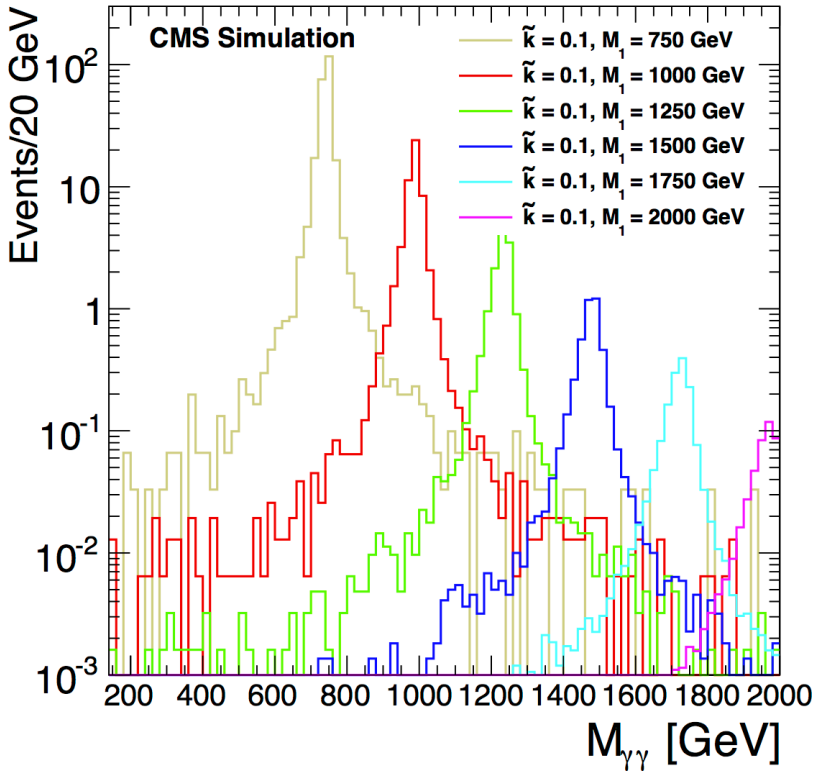
- Search for excess above 1.1 TeV
- Exclusion limits for ADD models for several parameters (2-3 TeV)

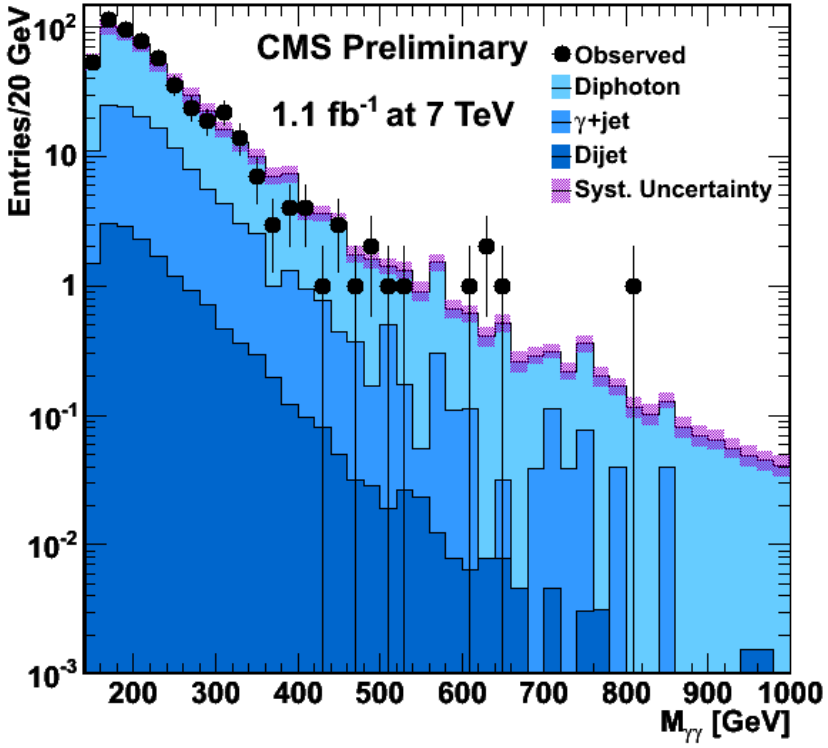
Limits on M_s (no k-factor)

n=2	n=3	n=4	n=5	n=6	n=7	
2.6	3.1	2.6	2.3	2.1	2.0	TeV

Diphotons

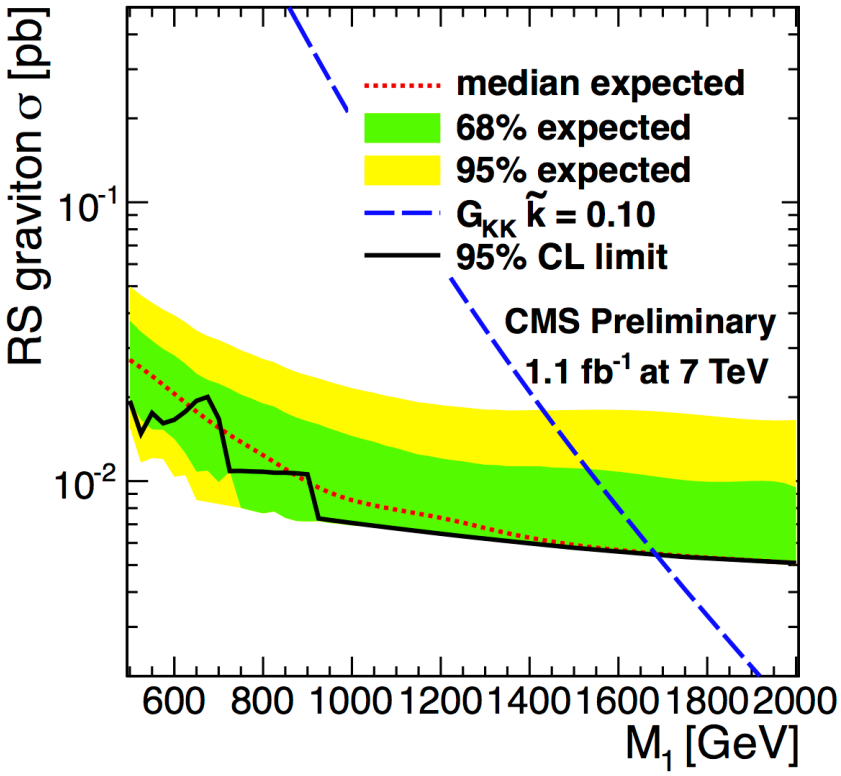
Search for resonant and non-resonant diphoton production





Search for excess above 0.8 TeV

Diphotons



Exclusion limits on RS gravitons (800-1800 GeV) and several ADD models (2.2-3.6 TeV)

Effective Planck scale (TeV) in ADD

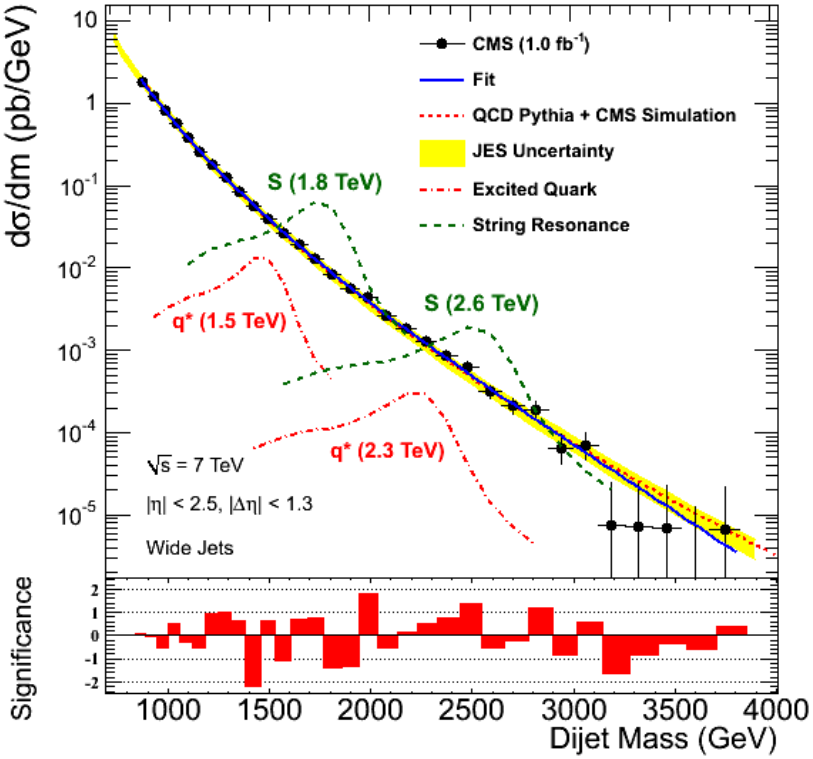
K factor	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
1.0	3.2	3.4	2.8	2.6	2.4	2.2
1.6	3.5	3.7	3.1	2.8	2.6	2.4

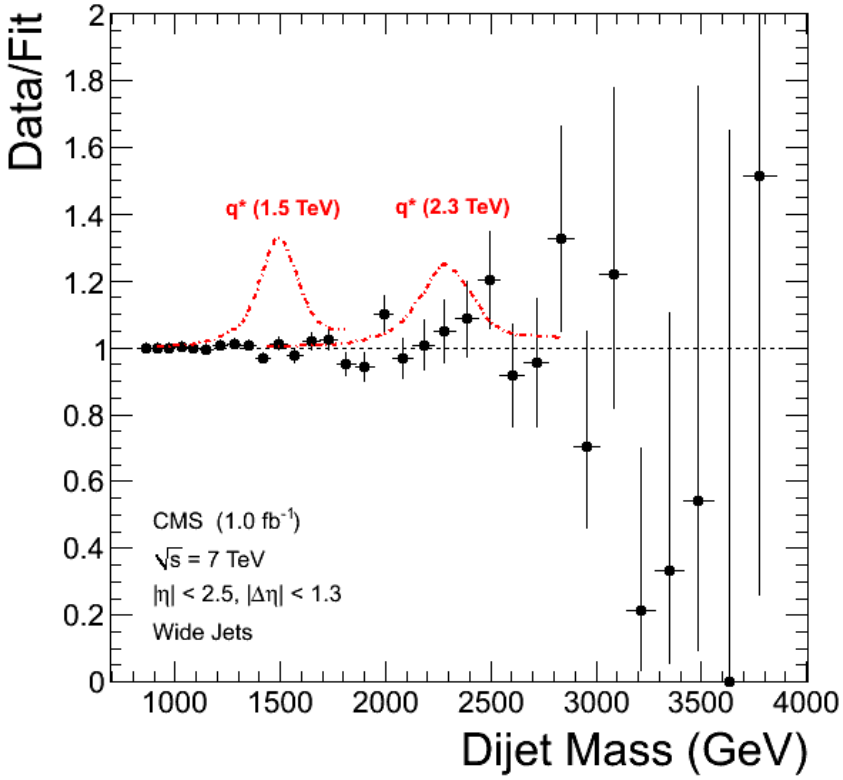
RS gravitons: Mass (TeV)

$\tilde{k}$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11
M_1 [TeV]	0.77	1.05	1.20	1.31	1.41	1.49	1.57	1.63	1.69	1.74	1.78

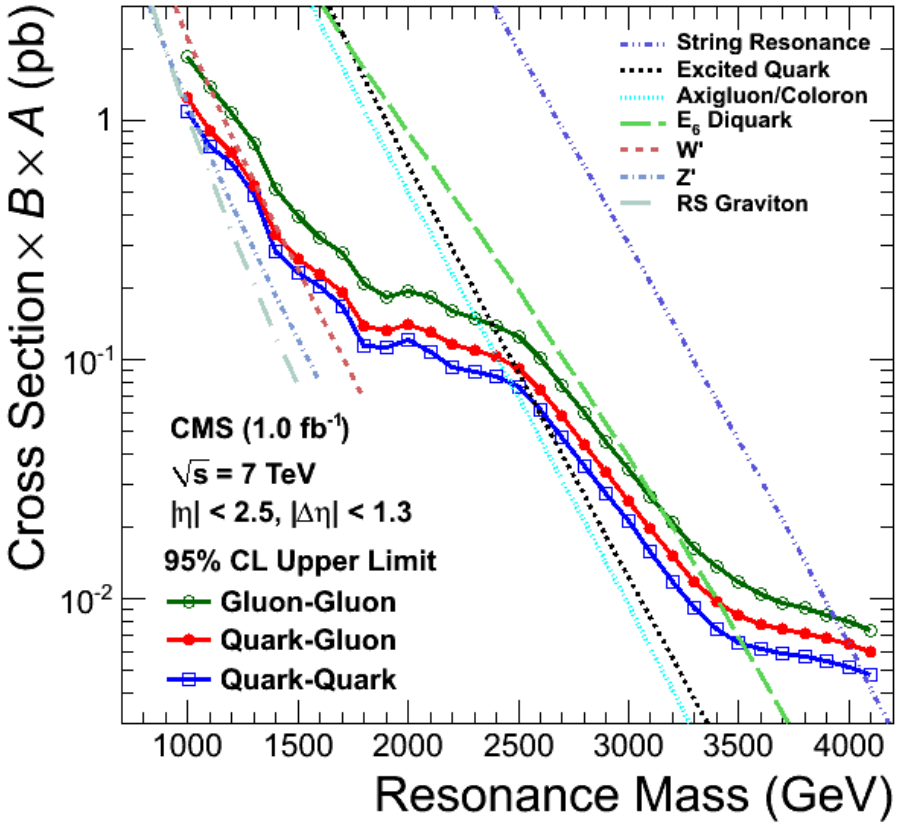
Dijet Resonances

High sensitivity to strongly produced new resonances decaying to pairs of jets predicted in numerous models:
string phenomena, excited quarks, colorons, diquarks





Dijet Resonances



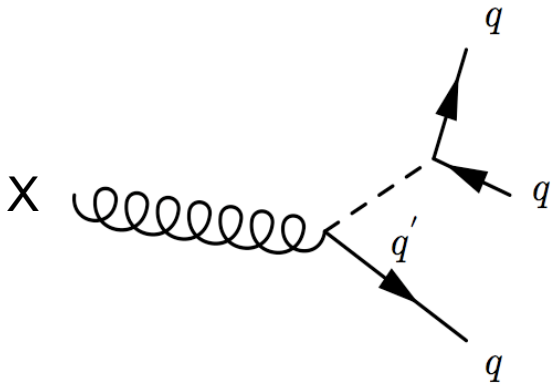
Mass limits up to 4 TeV

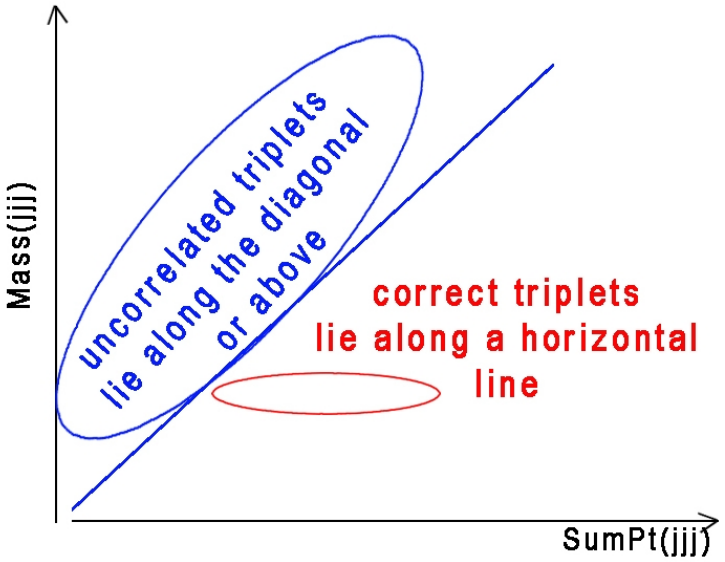
Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

1 fb^{-1} results published in:
PLB 704, 123 (2011)

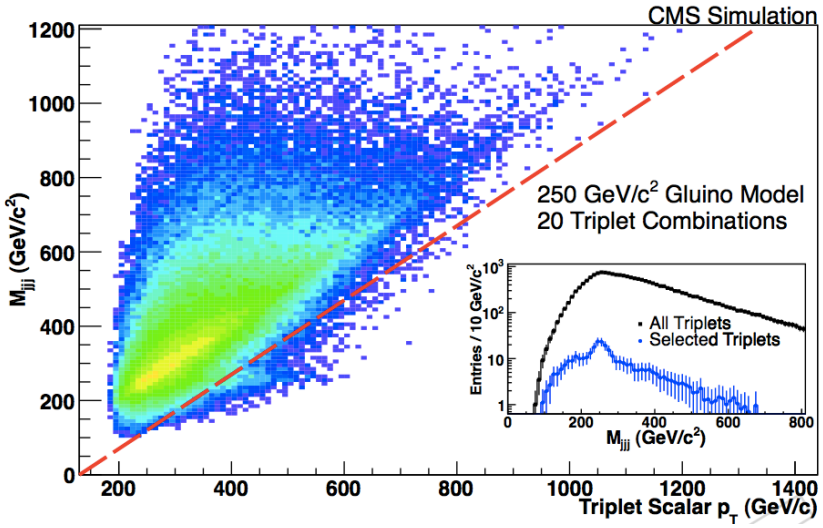
Trijet Resonances

- Model-independent search for:
  - $p\bar{p} \rightarrow X X'$, where $X, X' \rightarrow$ 3jets
    - 6 jet final state
    - Large QCD multijets background
- NEW Technique
  - Make use of kinematic features and an **ensemble** of jet combinations
    - Build triplets out of all final state jets and calculate
      - Invariant mass M_{jjj}
      - Scalar sum p_T $\Sigma|p_T|_{jjj}$
    - Plot one vs. the other for each combination (at least 20 combinations for each event)

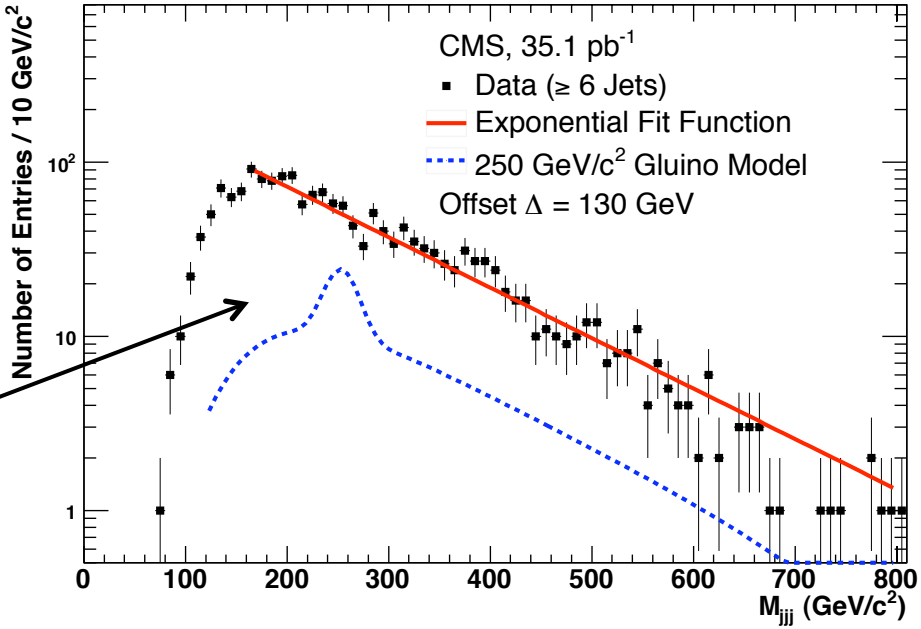




Trijet Resonances



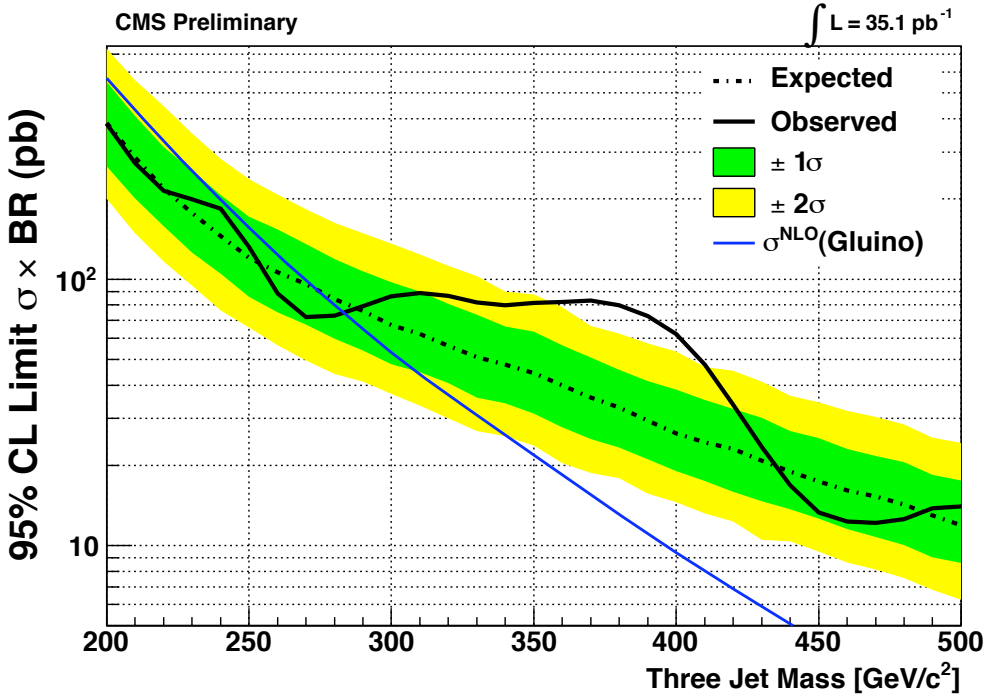
- Search M_{jjj} 200-500 GeV
- Interpretation:
  - RPV SUSY
  - gluino → 3jets



- Hypothetical gluino signal for mass 250 GeV shown, normalized to data
- No significant excess observed

Trijet Resonances

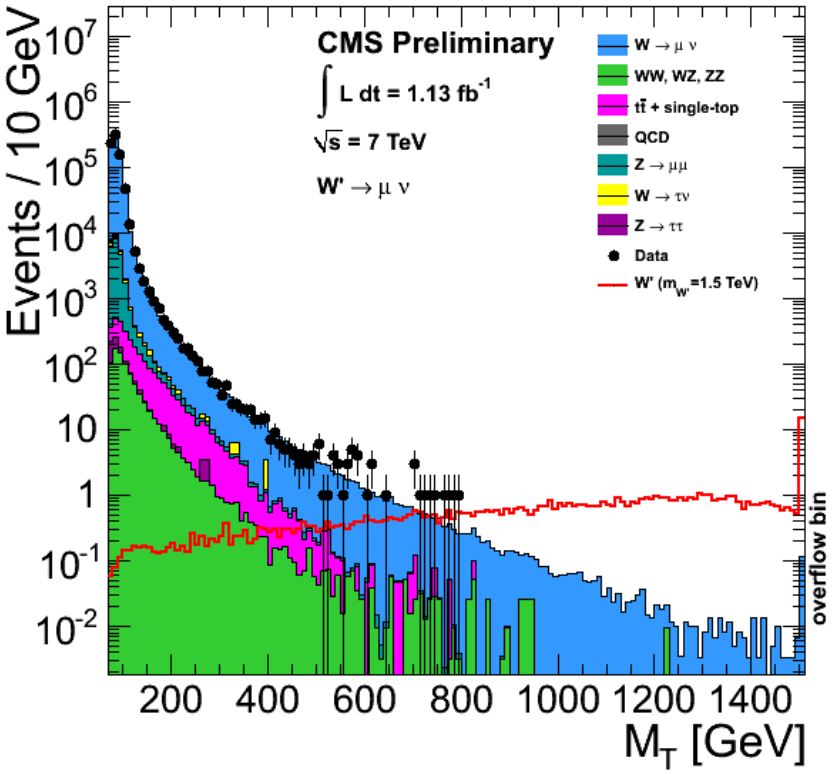
- Exclusion for masses
  $200 < M_{jjj} < 280$ GeV
- Largest excess seen at 390 GeV corresponding to 1.9σ (with "look-elsewhere effect")
- **1st search for 3-jet resonances at the LHC**
- **Highest limits to date**
- **Published in PRL**
  - Phys. Rev. Lett. 107, 101801 (2011)



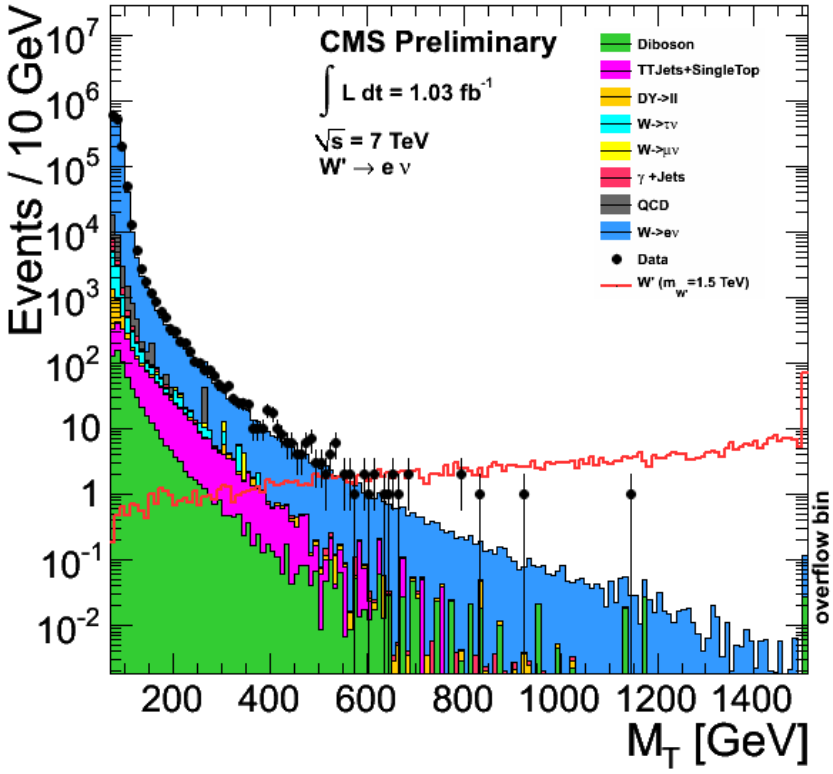
Lepton+MET

Look for an excess in the transverse mass spectrum

μ+MET

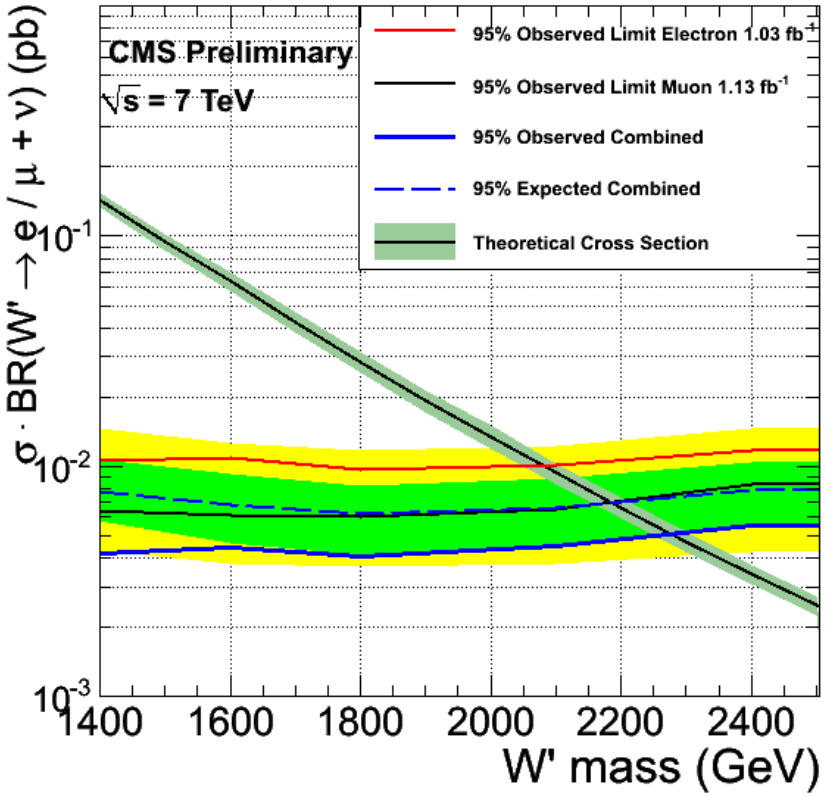


e+MET



$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

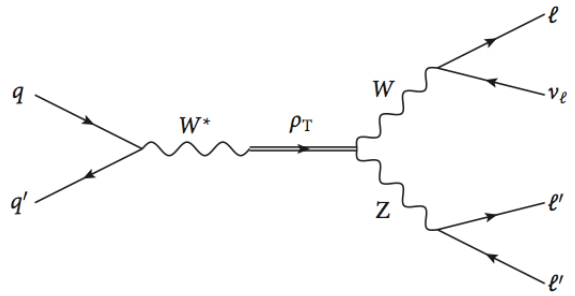
Lepton+MET

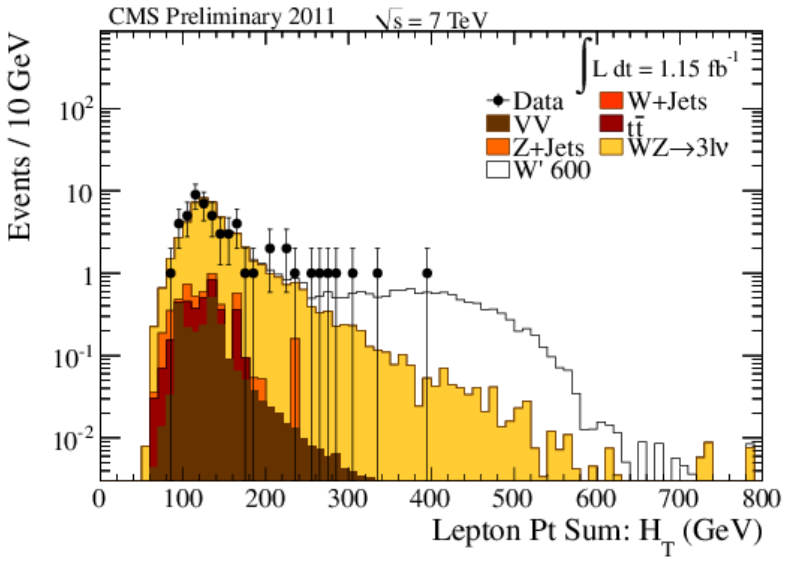


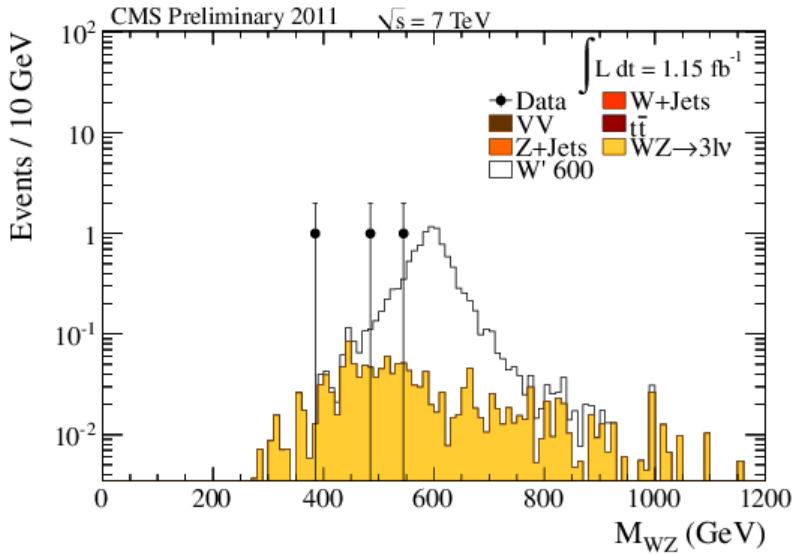
- Published ~36 pb^{-1} results
  - PLB 698, 21 (2011)
  - PLB 701, 160 (2011)
- ~1 fb^{-1} update
- W' with SM-like couplings is excluded below 2.4 TeV

WZ Resonances

Search for Gauge-Boson-like objects.
Predicted by many BSM models:
e.g. Extra dimensions, technicolor.
Search done in 3lepton+MET channel.





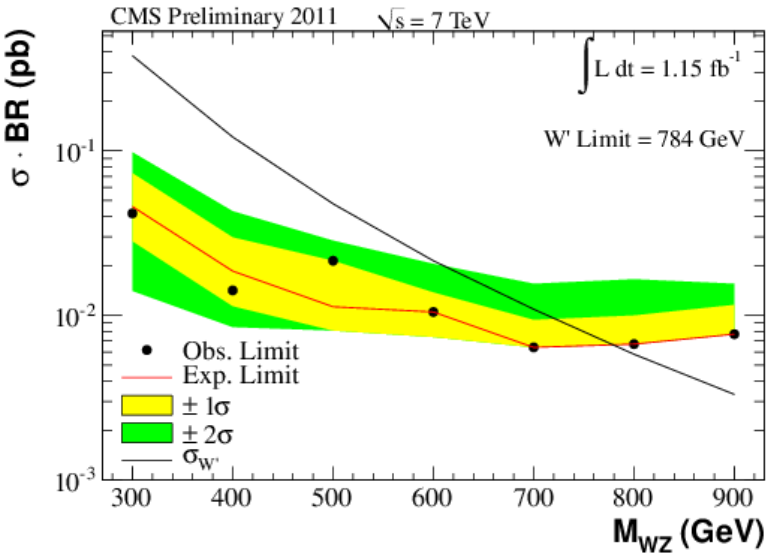


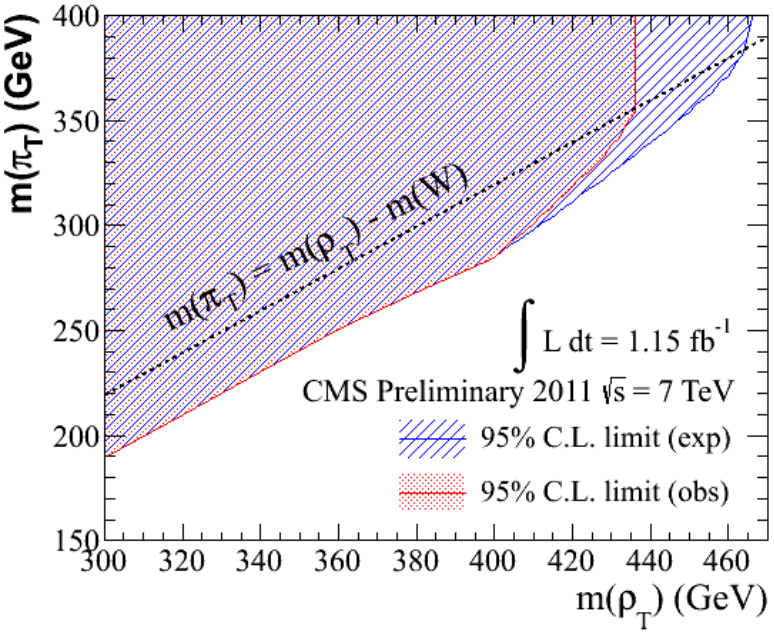
H_T (scalar sum of leptons) cut optimized for each mass point

CMS PAS-EXO-11-041

WZ Resonances

Limits on W' and technicolor production

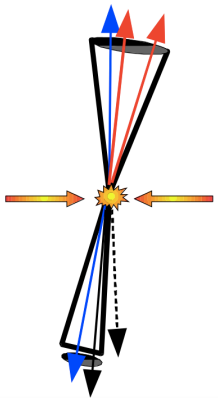




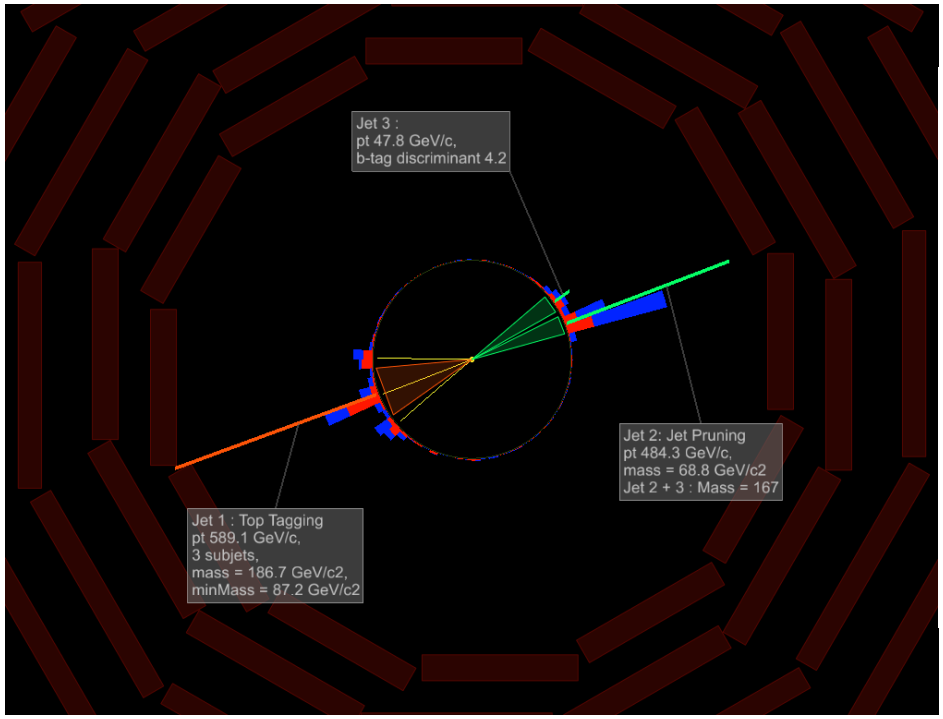
W' SSM	ρ_{TC} $M(\pi_{TC}) = \frac{3}{4} M(\rho_{TC}) - 25GeV$	ρ_{TC} $M(\rho_{TC}) < M(\pi_{TC}) + M_W$
784 GeV	382 GeV	436 GeV

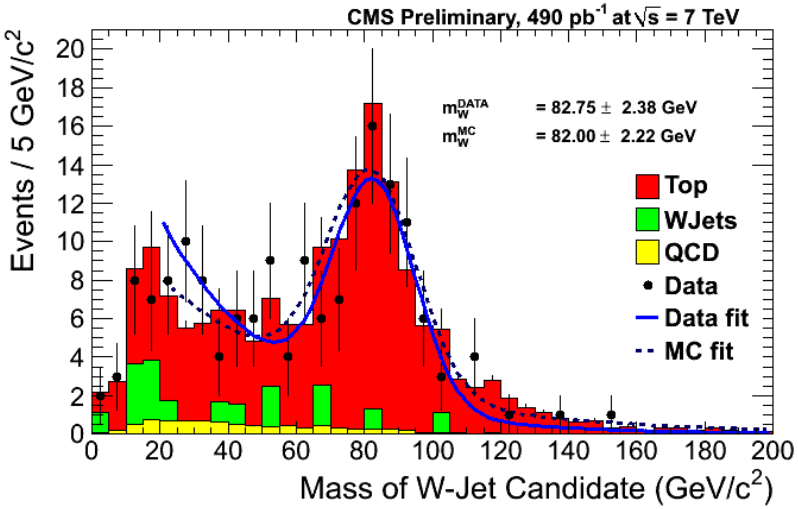
ttbar Resonances

CMS PAS-EXO-11-006



Boosted All-Hadronic State

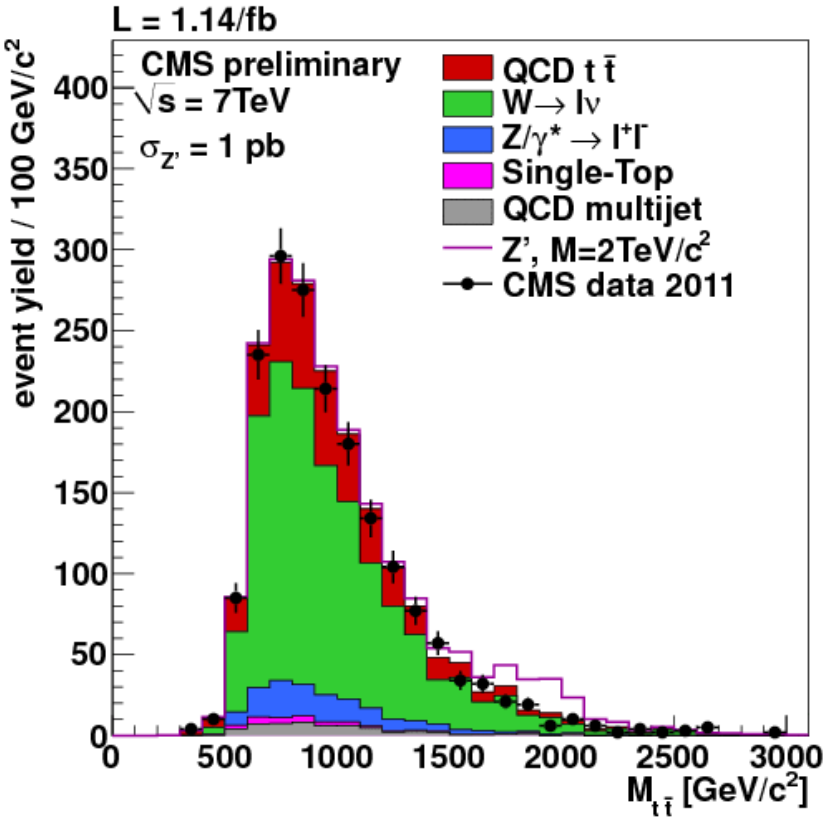




Top decay products either partially or fully merged into one jet.

Top-tagging tools using jet substructure with Cambridge-Aachen R=0.8 jets.

ttbar Resonances



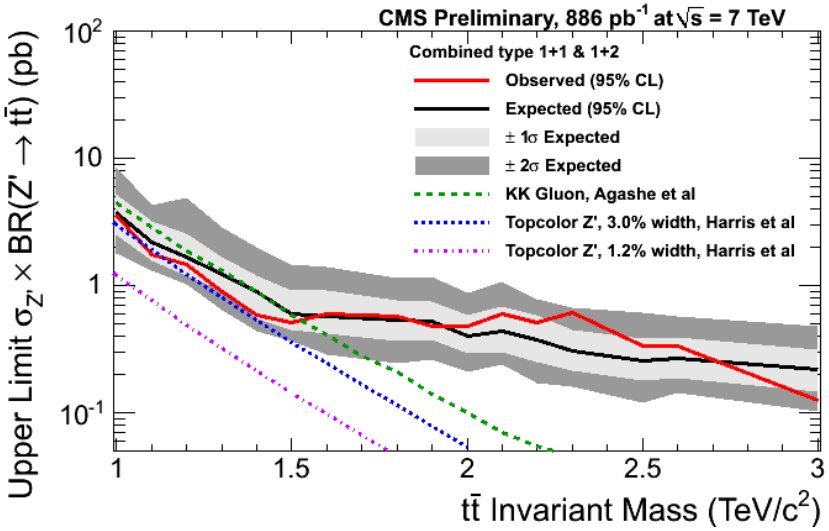
Boosted Semi-leptonic State

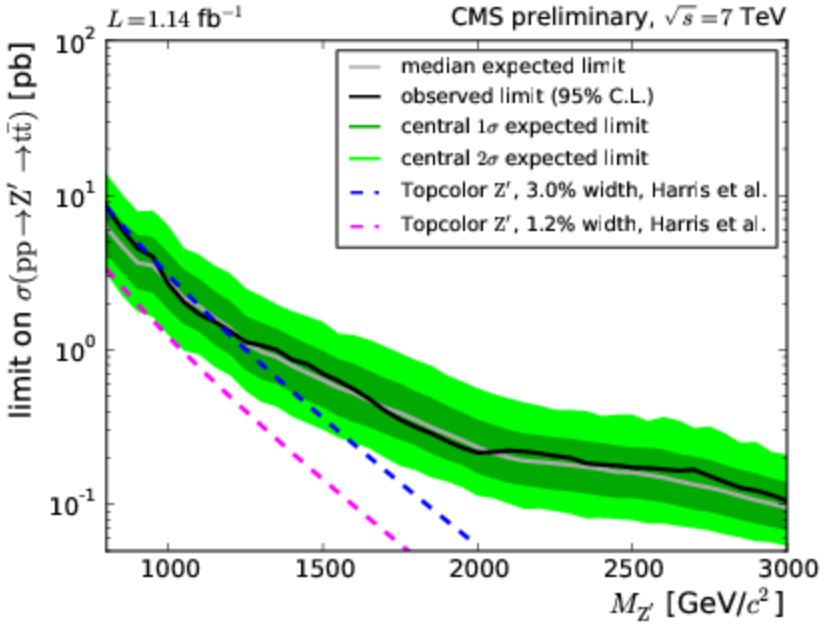
- Again, top daughter products are collimated
- Use μ + ≥ 2 jets + MET
- Kinematic variables used:
  - $H_{T,lep}$: scalar sum of muon p_T and MET
  - M_{ttbar}

ttbar Resonances

CMS PAS-EXO-11-006
CMS PAS-EXO-11-055

Exclusion limits on SSM, KK and topcolor models





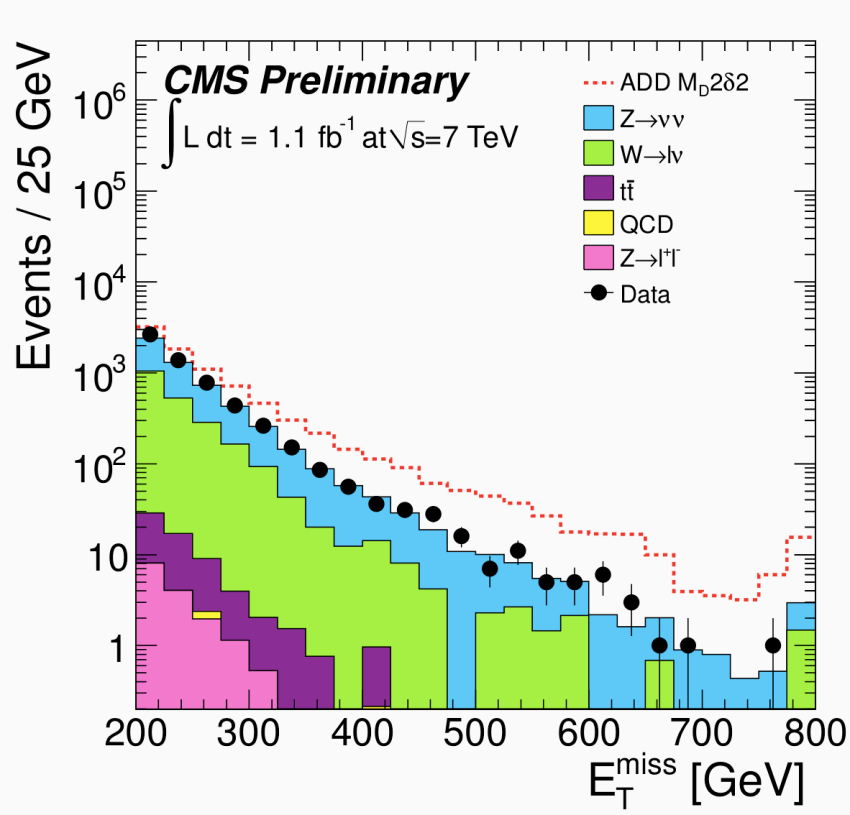
W' SSM	KK Gluon
1.1 TeV	1.0 < M < 1.5 TeV

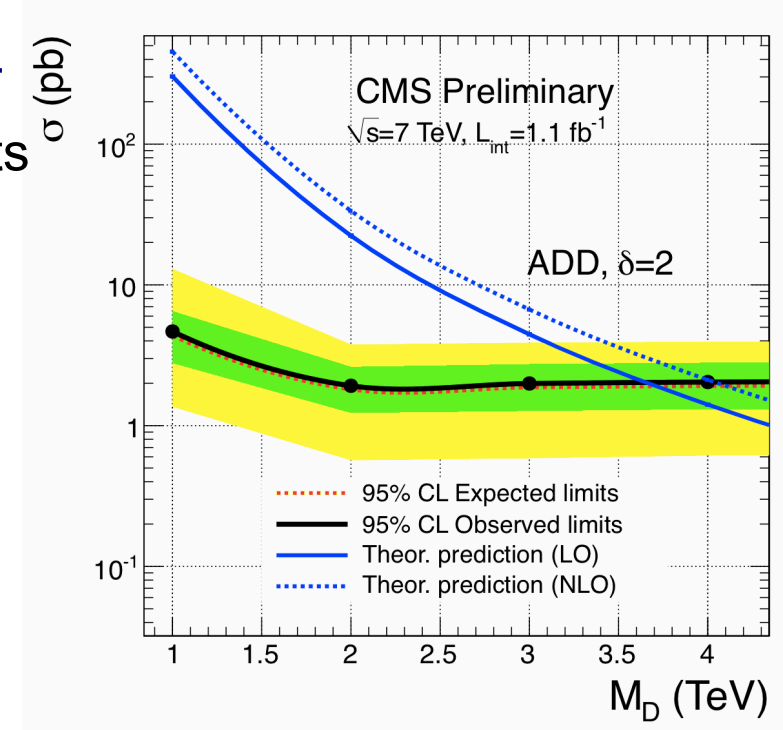
Topcolor Z'
850 < $M_{Z'}$ <935 GeV 960 < $M_{Z'}$ < 1060 GeV

Mono-jet + MET

Search for excess in events with 1 jet + MET

Irreducible background from Z(invisible) + jets





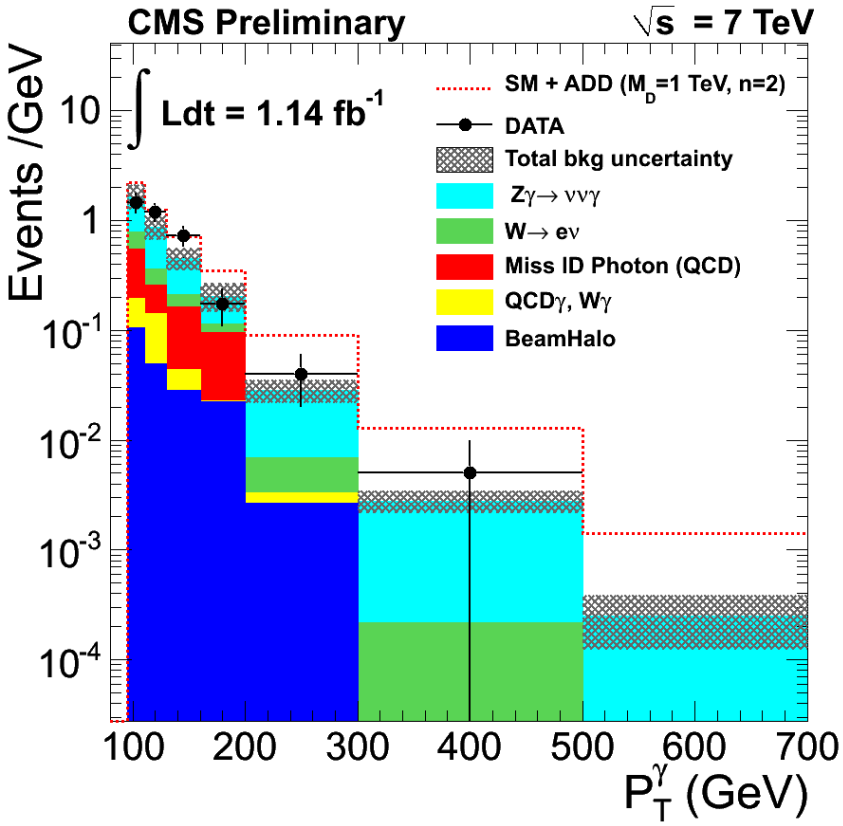
Limits on ADD models for several parameters

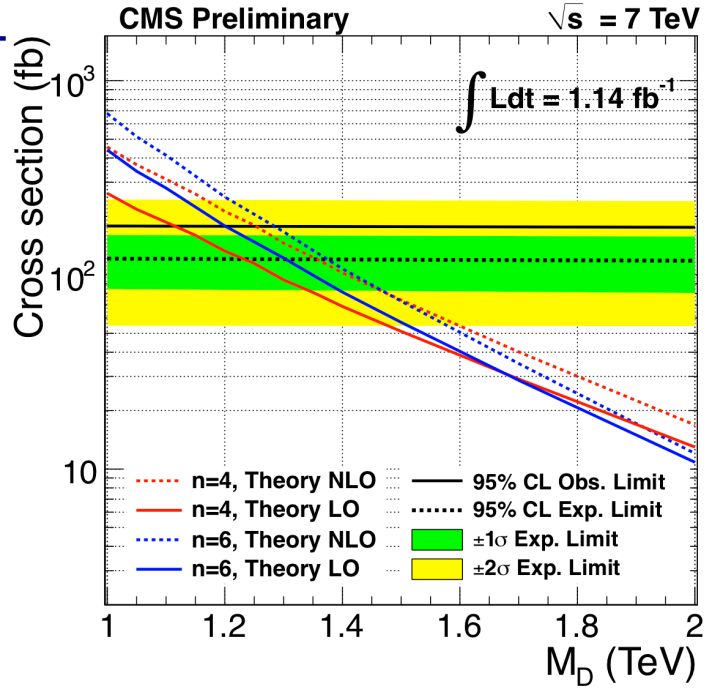
ADD K factor	M_D [TeV/c^2] $\delta=2$	$\delta=3$	$\delta=4$	$\delta=5$	$\delta=6$
LO: 1.0	3.67	2.96	2.66	2.41	2.25
NLO: 1.5	4.03	3.21			
1.4			2.80	2.55	2.36

Mono-photon + MET

Search for excess in events with 1 photon + MET

Similar challenges as in mono-jet + MET



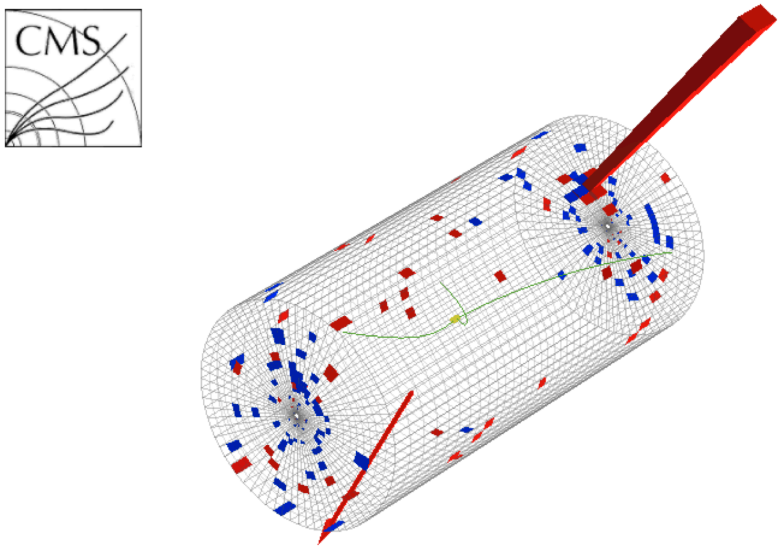


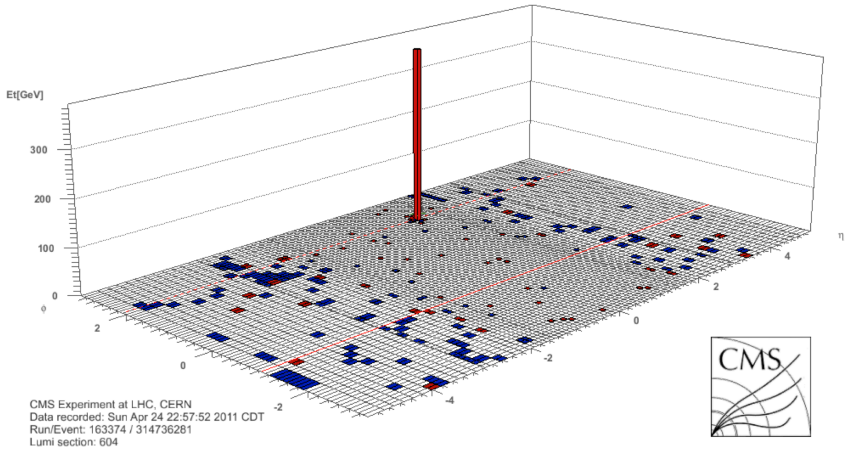
Limits on ADD models for several parameters

M_D (TeV) [no k-factor]

n=2	n=3	n=4	n=5	n=6
1.30	1.07	1.12	1.16	1.21

Highest Photon P_T Event



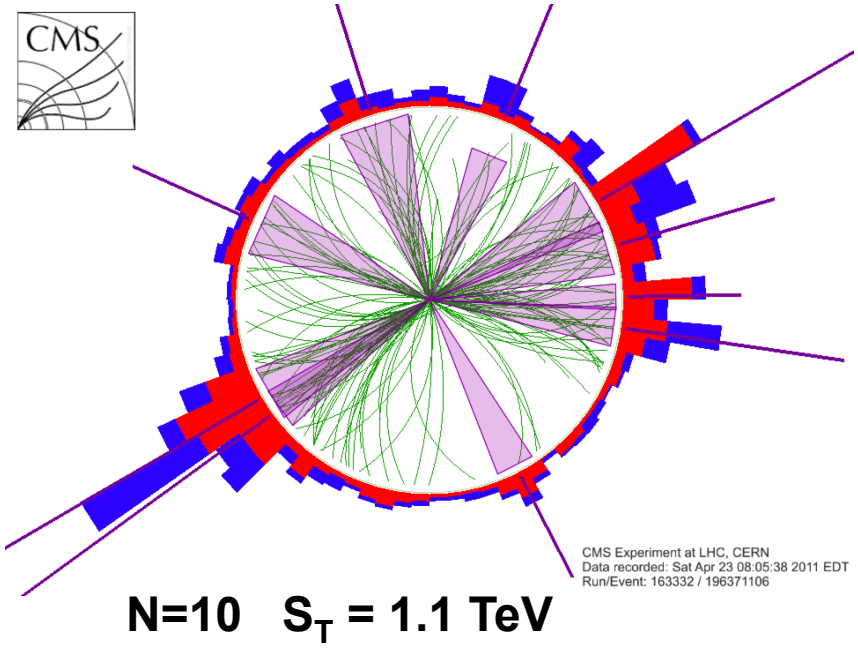


Black Holes

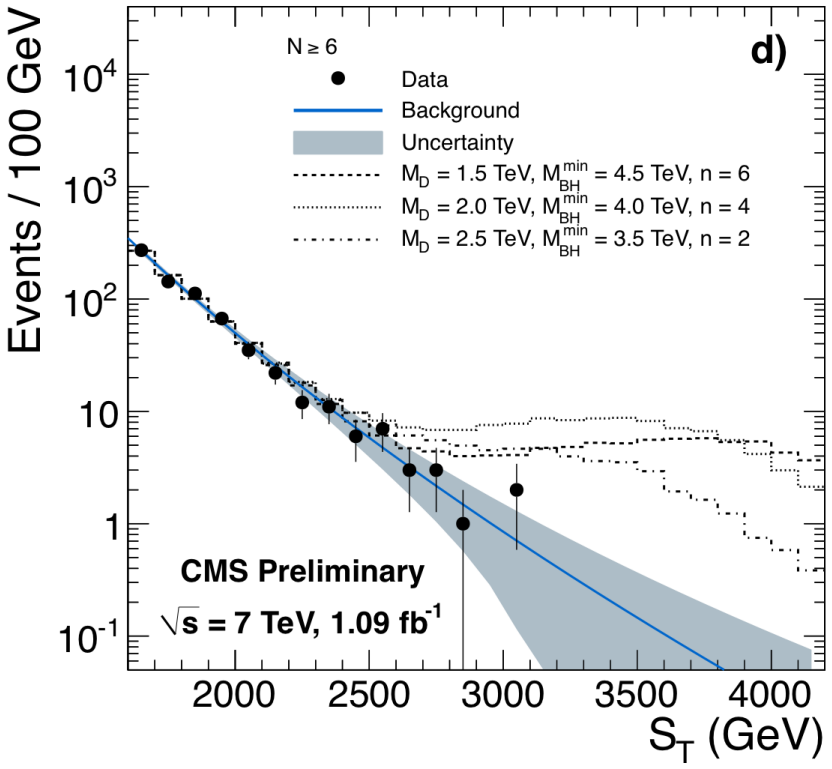
BH production in ADD model (large flat extra spatial dimensions)

- Democratic and isotropic decay
- High S_T events (total transverse energy)
- High total multiplicity (e.g. ≥4)

Use N=2, 3 for background model.



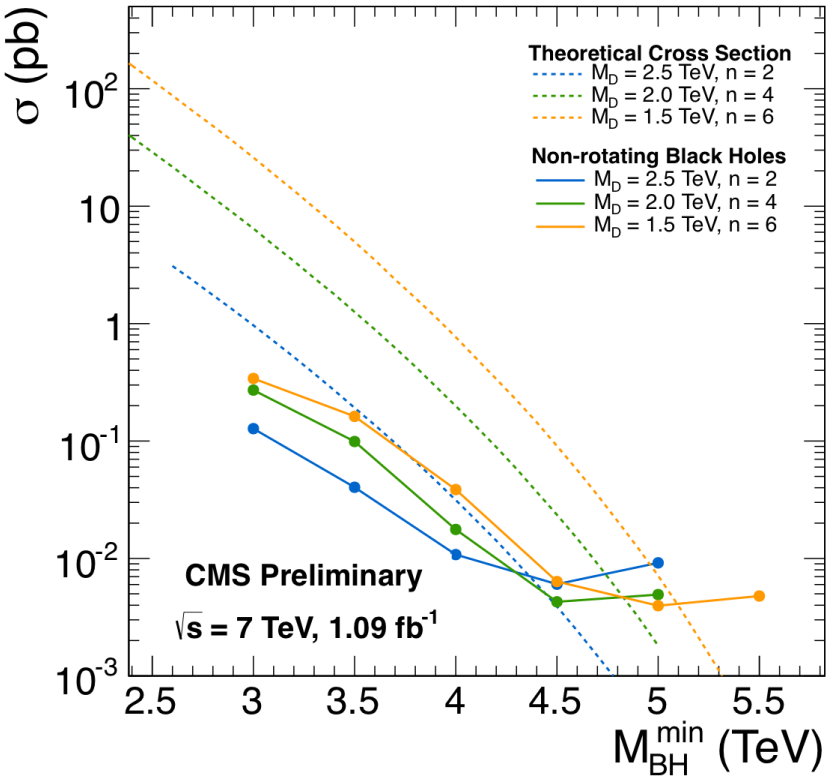
N=10 S_T = 1.1 TeV

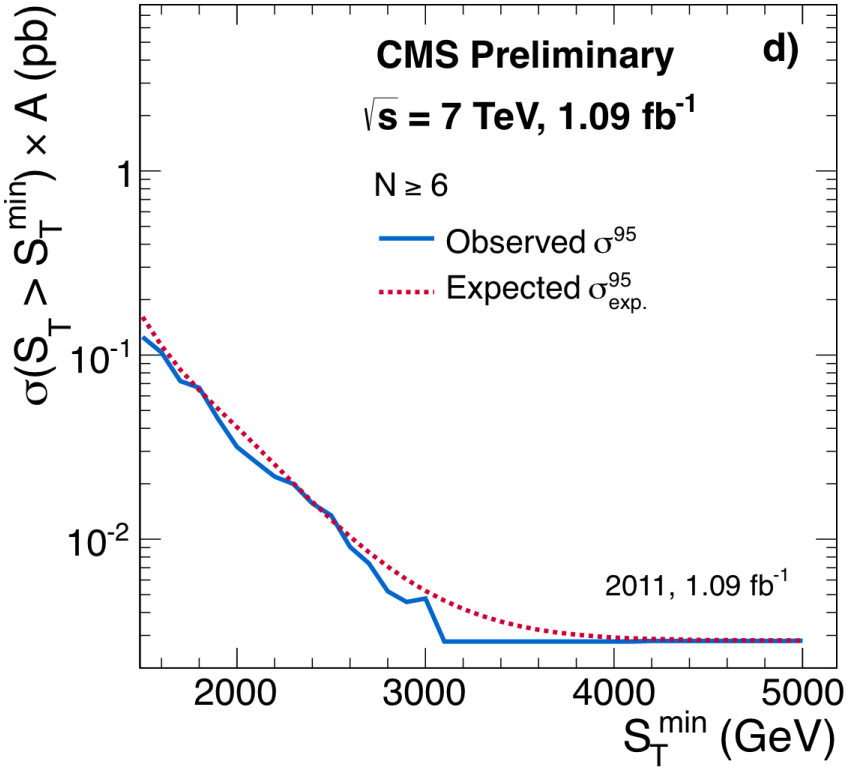


Black Holes

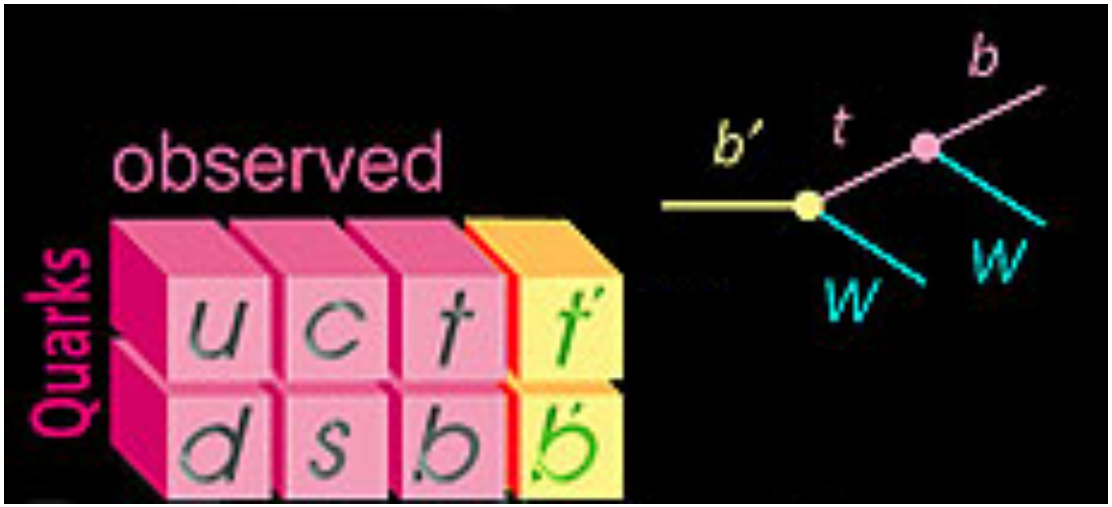
Model-specific limits on minimum black hole (ADD) and string balls masses
4 − 5 TeV range for large variety of model parameters

Also model-independent limits





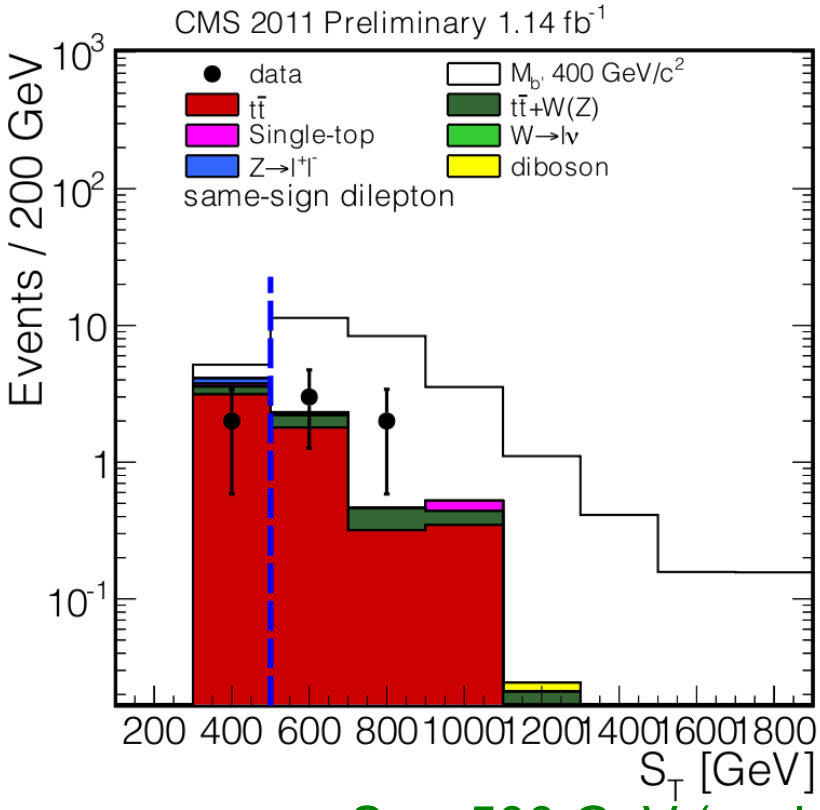
Searches for 4th Generation Quarks

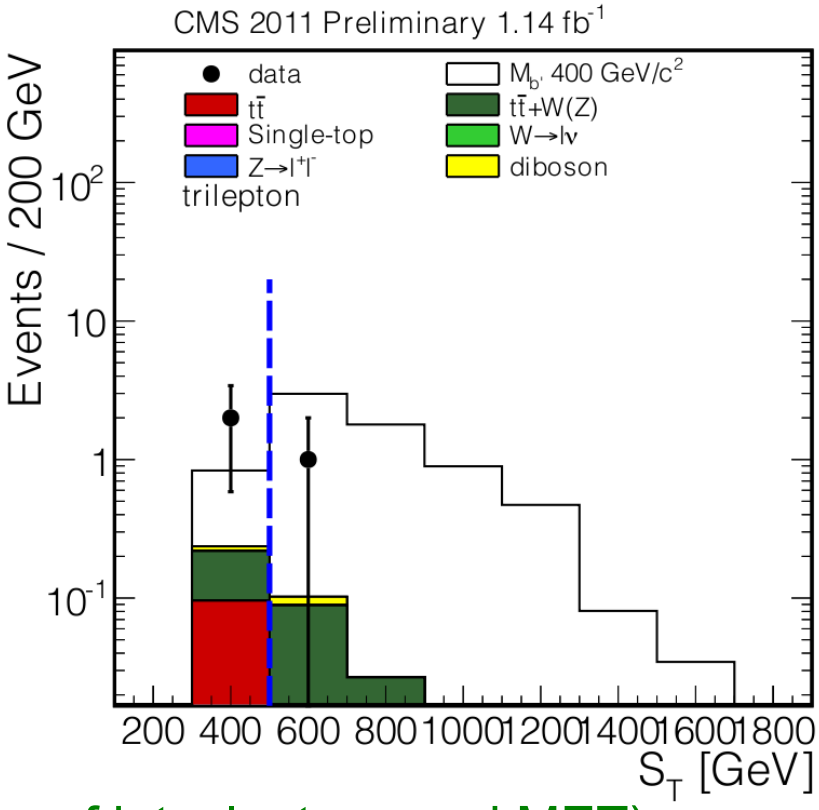


Heavy Bottom-like Quarks

Search for production of: $b'\bar{b}' \rightarrow tW^-\bar{t}W^+ \rightarrow bW^+W^-\bar{b}W^-\bar{W}^+$

Signatures: 3-lepton and same-sign dileptons + ≥ 1 bjet





S_T > 500 GeV (scalar sum of jets, leptons and MET)

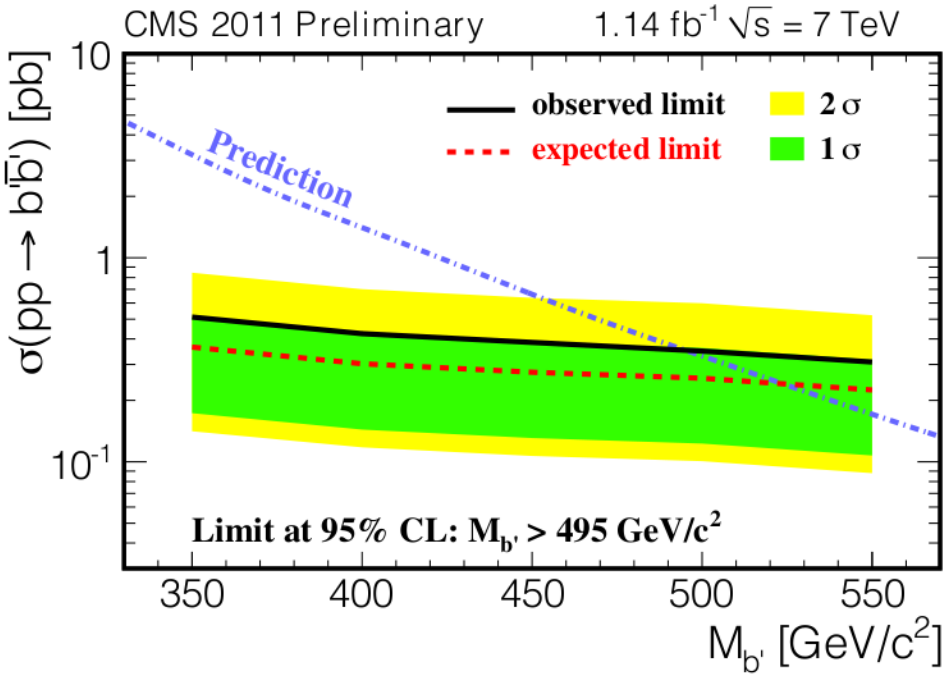
Heavy Bottom-like Quarks

Dilepton channel

Signal (400GeV)	Bkg	Data
22	4.4 ± 1.4	5

Trilepton channel

Signal (400GeV)	Bkg	Data
6.7	0.16 ± 0.09	1



b' excluded below 495 GeV

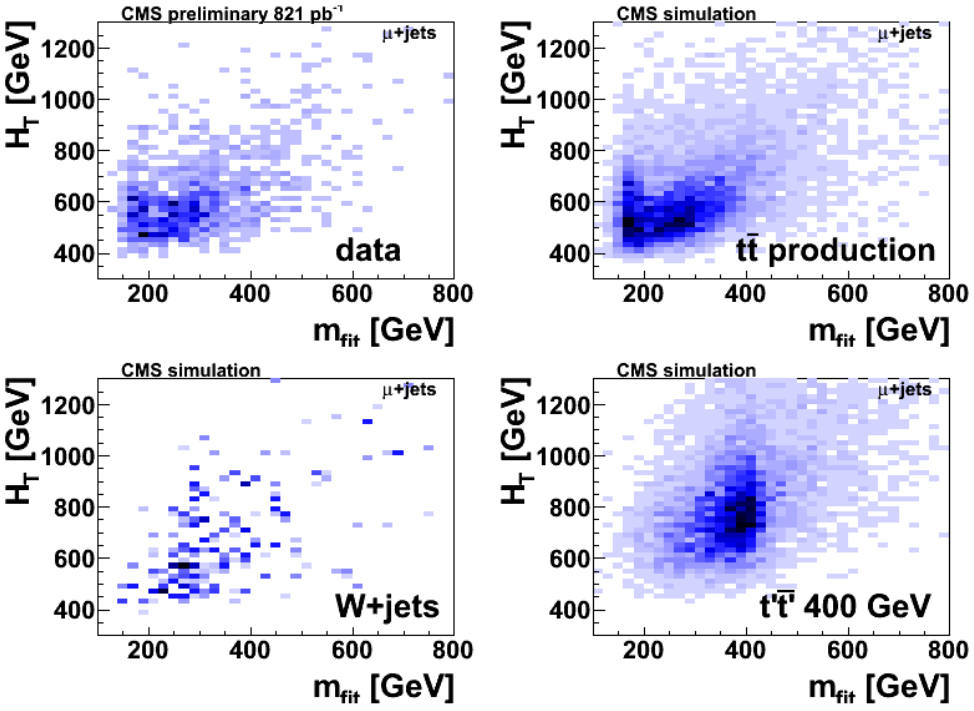
Significant improvement over 2010 analysis

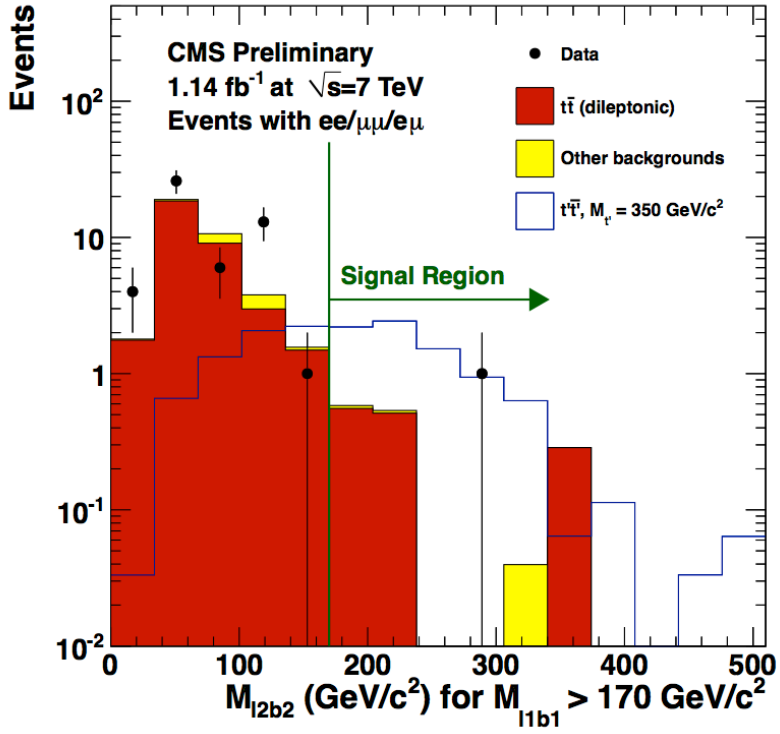
PLB 701, 204 (2011)

Heavy Top-like Quark

CMS PAS-EXO-11-050
CMS PAS-EXO-11-051

Search for production of: $t'\bar{t}' \rightarrow bW^+\bar{b}W^-$ in l+jets and dilepton channels





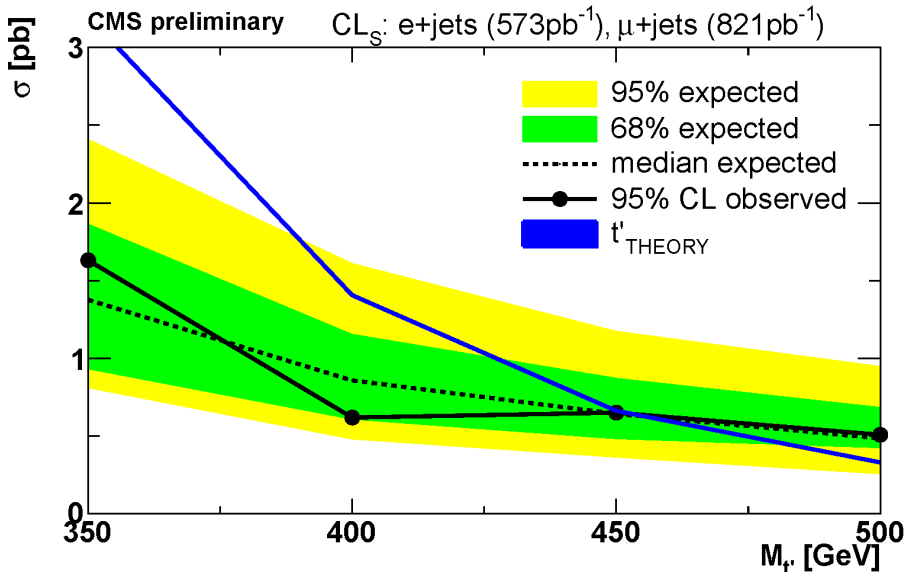
l+jets: Uses H_T and reconstructed mass

Dilepton: Uses M_{lb} (two combinations with smallest $\Delta R(l,b)$)

Heavy Top-like Quark

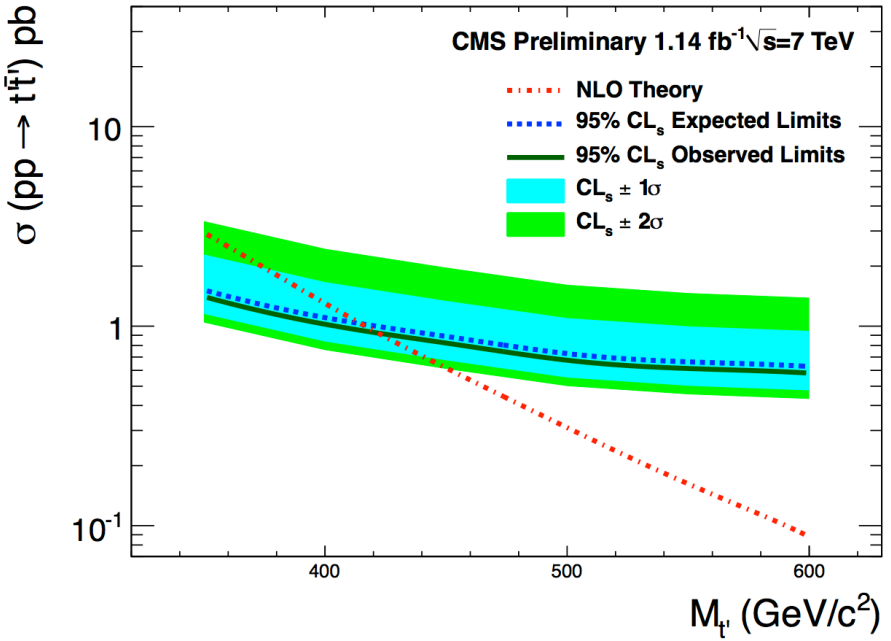
CMS PAS-EXO-11-050
CMS PAS-EXO-11-051

l+jets



t' excluded below 450 GeV

dileptons



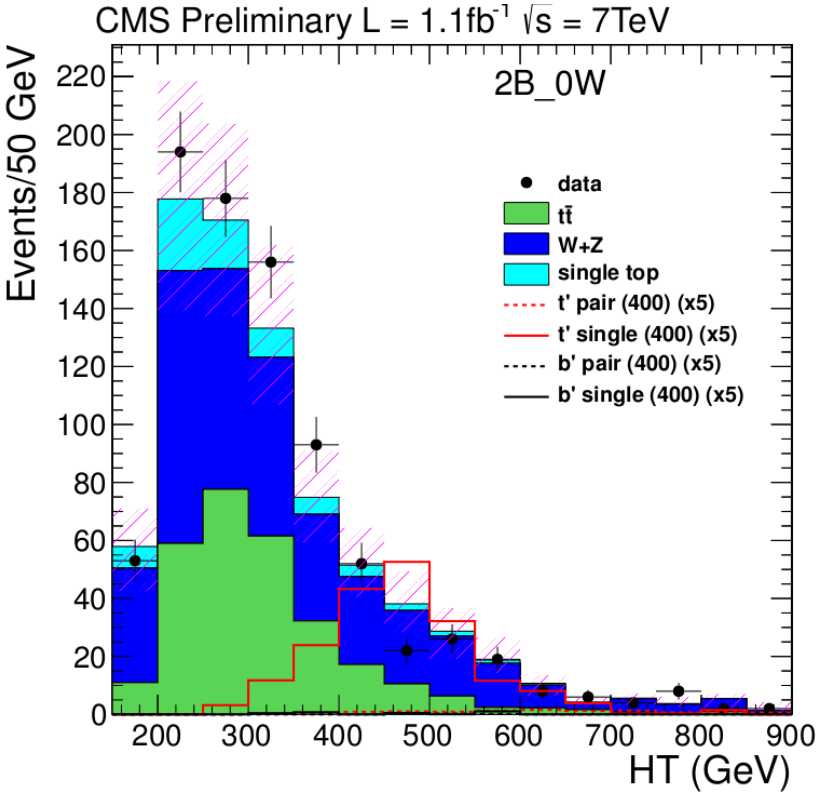
t' excluded below 422 GeV

CMS PAS-EXO-11-054

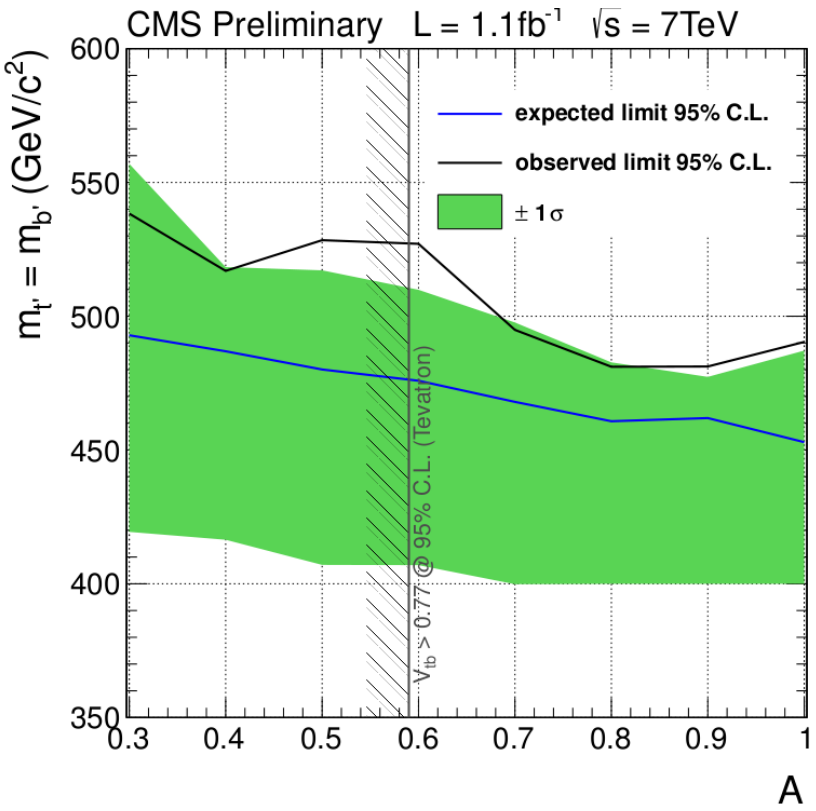
Inclusive Search for 4th Generation Quarks

Inclusive search for t′ and b′ quarks, produced singly or in pairs

- Muon + jets channel
  - Classify events according to:
    - Number of hadronically decaying W's
    - Number of b-tags
  - Discriminating variable H_T distribution
    - Scalar sum p_T of muon, MET, b-jets and W(jj)



Inclusive Search for 4th Generation Quarks



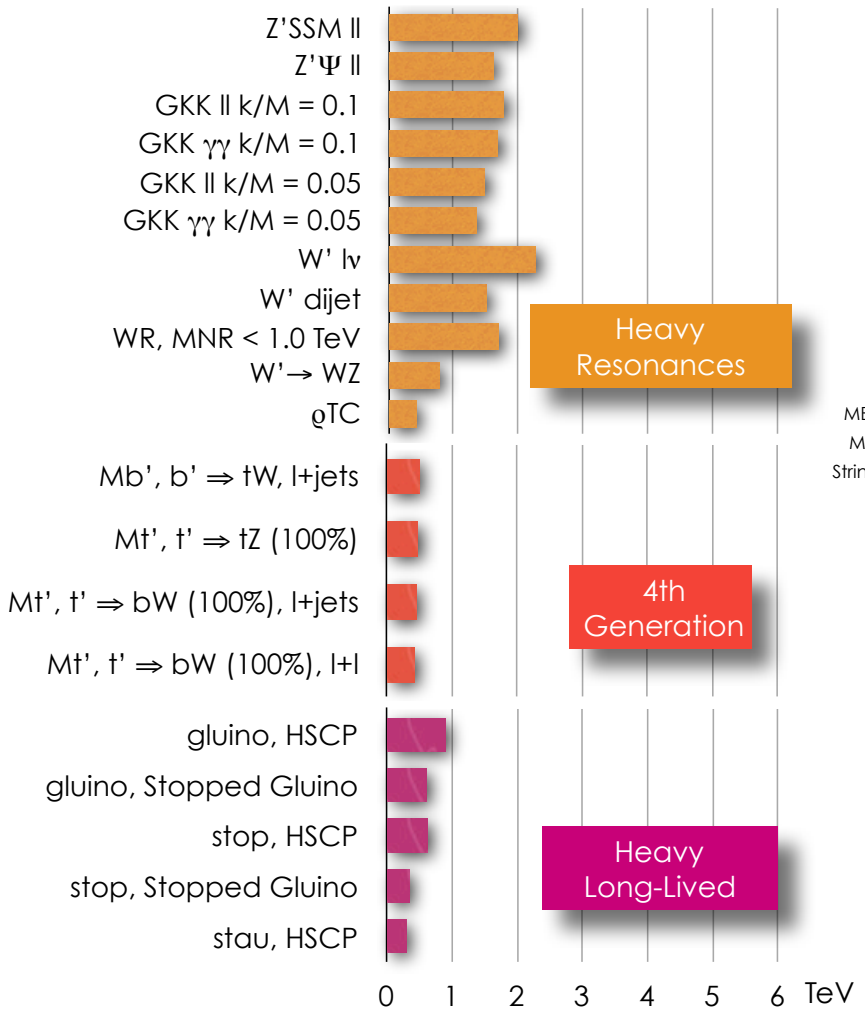
- Assume a simplified model, where t' and b' masses are degenerate and:

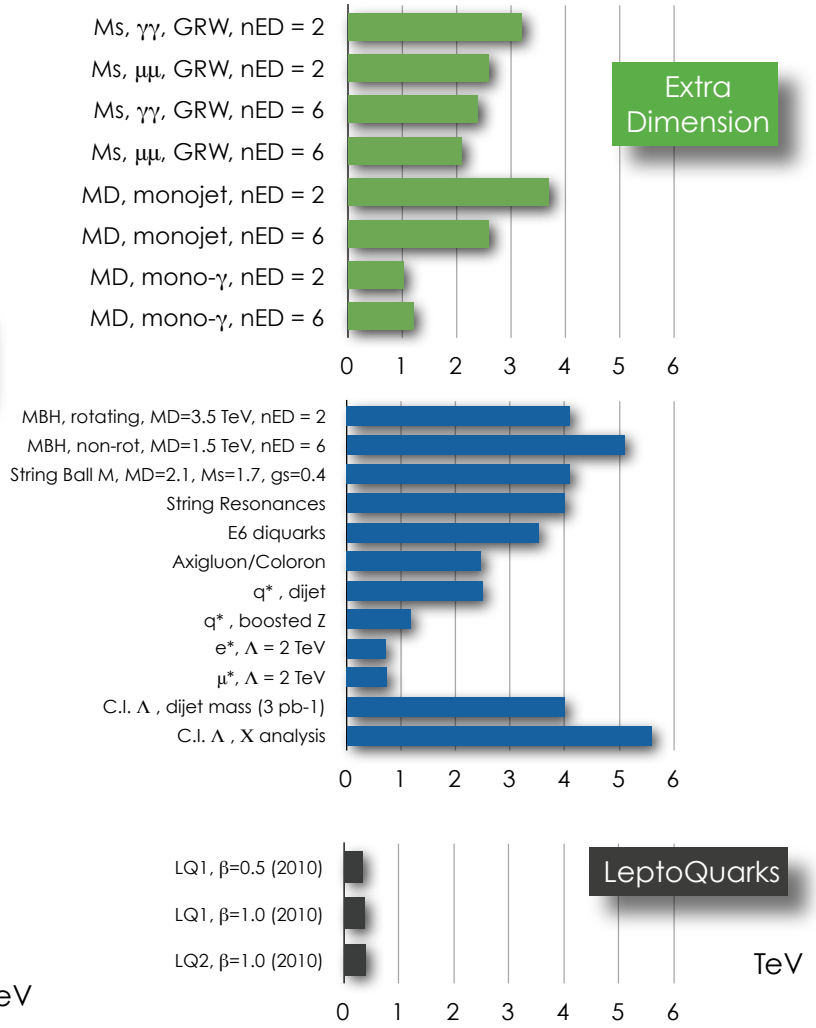
$$\text{CKM4} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \sqrt{A} & \sqrt{1-A} \\ 0 & 0 & \sqrt{1-A} & \sqrt{A} \end{pmatrix}$$

- Limits a function mass and parameter A.
- For minimal off-diagonal mixing (A ≈1) between 3rd and 4th generations, observed mass limit > 490GeV

CMS Grand Summary

As of PIC2011
Thanks to S. Rahatlou





Conclusions

- Rich program of searches for physics beyond the SM
- Many analyses performed with > 1 fb^{-1}
  - Lots more data in the can
- Advanced analysis techniques
- Stringent limits on many benchmark models
- No evidence of new physics yet
  - Keep looking until either we find something
  - **The exploration of Terascale physics has only just started!**

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