Beyond the Standard Model: Searches by ATLAS and CMS at the LHC

Recontres de Moriond: EW Interactions and Unified Theories

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BROOKHAVEN NATIONAL LABORATORY

Introduction

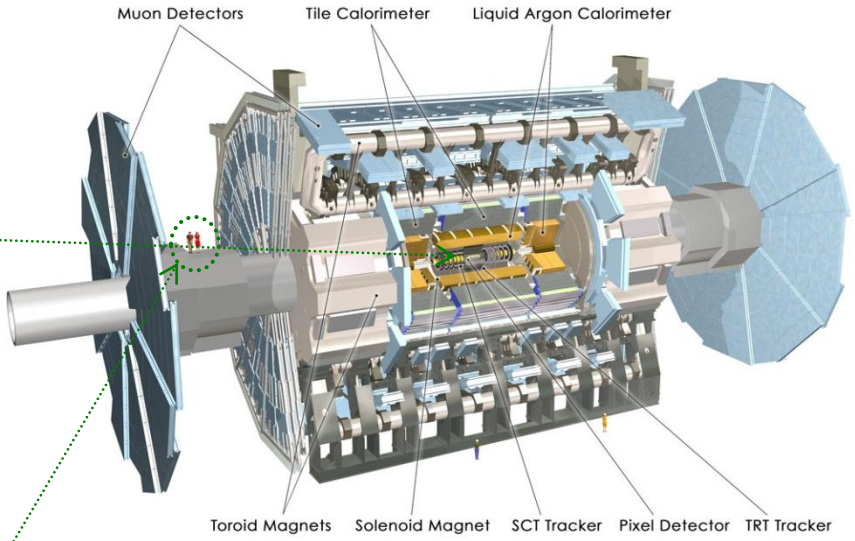
Standard Model has survived decades of experimental tests

- But there must be something more…
- The LHC provides access to a new energy frontier
- And so the opportunity to search for physics beyond the Standard Model (BSM)
- ATLAS and CMS are general-purpose detectors designed to carry out these searches

Detectors

ATLAS

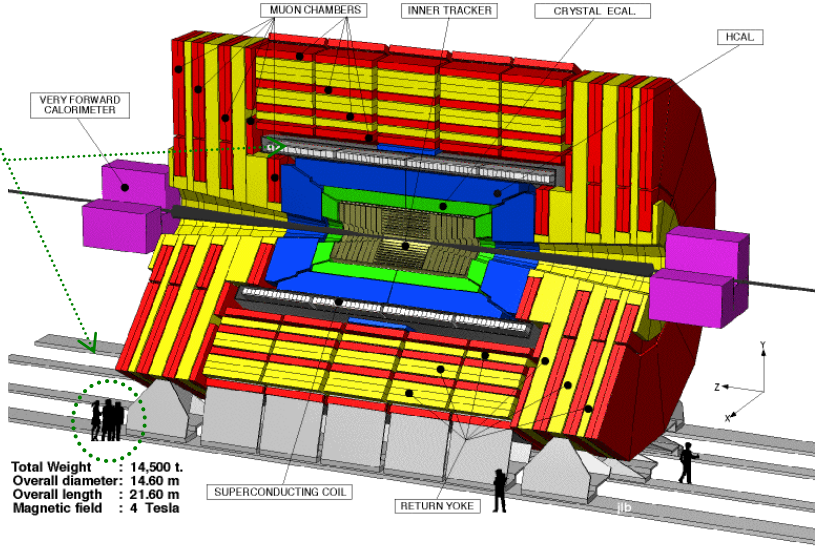
- r = 11 m, L = 45 m, 7 k tons
- 2 T central solenoid
- 3 outer toroids enable standalone muon reconstruction
- 3000 scientists
  - 1000 students



Different scales

CMS

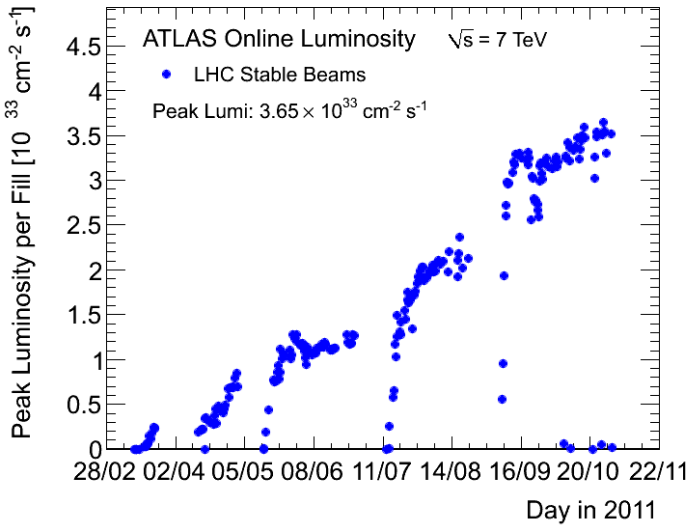
- r = 7.5 m, L = 29 m
- 4 T central solenoid
  - Calorimeter inside
- 2600 scientists
  - 850 students

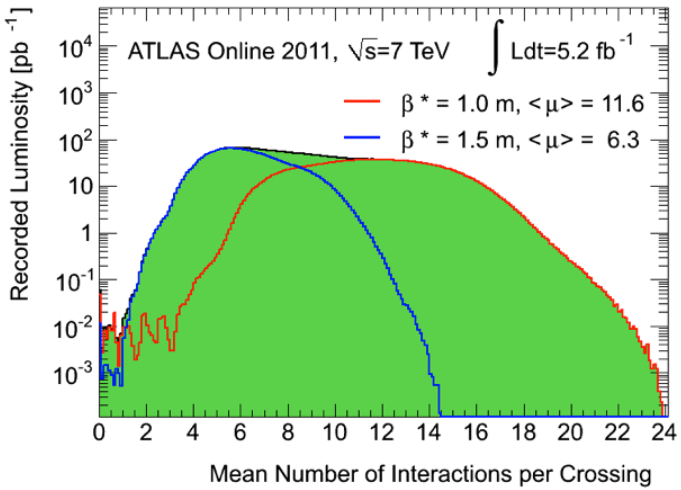


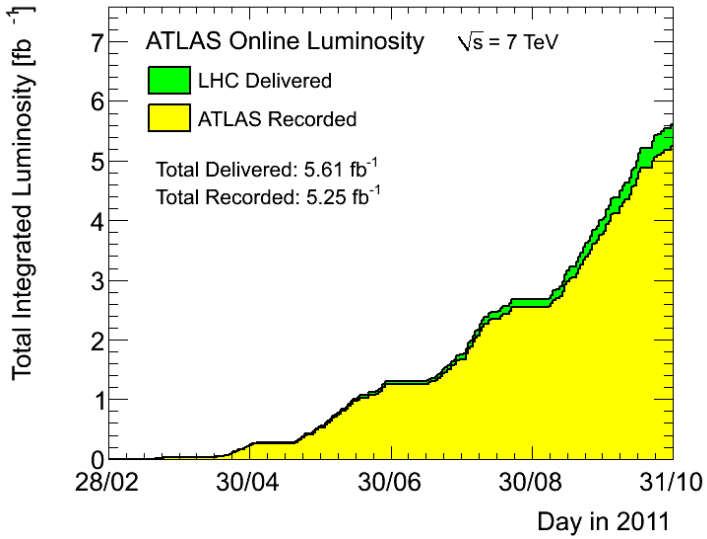
Beam conditions in 2011

ATLAS and CMS results shown here

- Mostly based on the 7 TeV collisions recorded taken in 2011
- More than 5 fb^{-1} for each experiment
- Luminosity increased during the year
  - Maximum was 3.5×10^{33} cm^{-2} s^{-1}
- Multiple interactions per beam crossing
  - Average more than 10
- Outstanding LHC performance

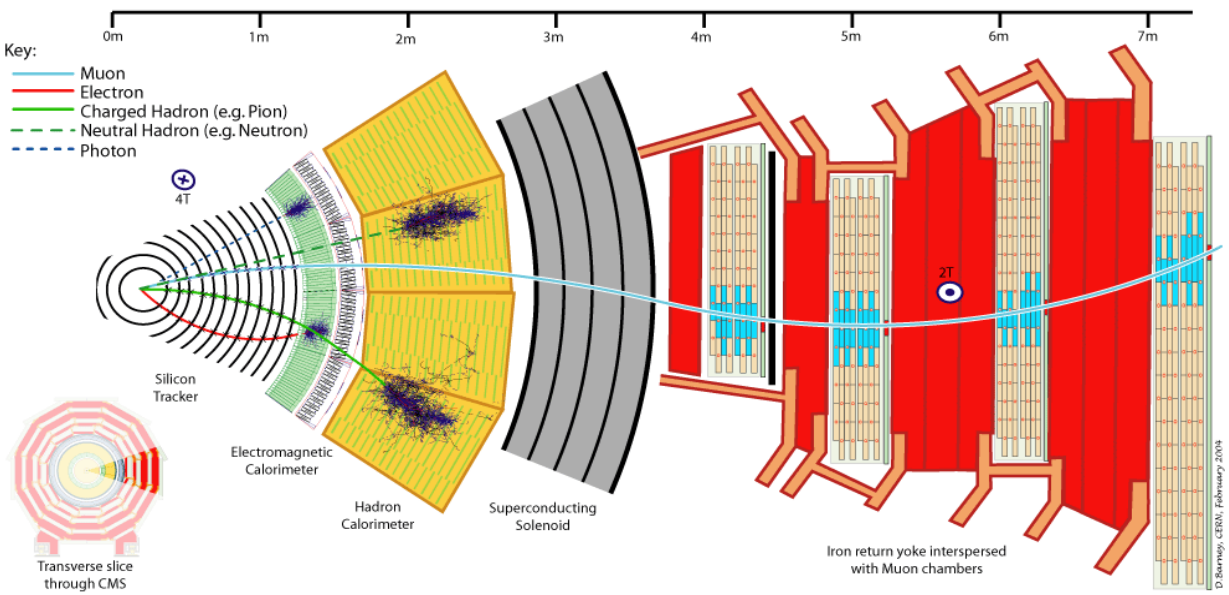






Physics objects

j	Jet	Cluster in EM and hadronic calorimeters (and inner tracker)
γ	Photon	EM cluster without matching track
e	Electron	EM cluster with matching track
μ	Muon	Matching tracks in inner and muon trackers
τ	Tau lepton	Narrow jet with matching track(s)
MET	Missing E_T	pT required to balance all of the above (and more)



Searching for BSM physics

List of physics objects is extended by combining the previous ones:

b	B-jet	Jet with displaced secondary vertex (or lepton tag)
W	W-boson	l+MET or dijet with m=80 GeV
Z	Z-boson	OS dilepton or dijet with m=90 GeV
t	Top quark	W+b, m=175 GeV

Either leptonic or hadronic channel. Boosted jets may be used for the latter.

Search for BSM physics signal

- Define event selection based on above objects and their kinematics
- Combine Monte Carlo prediction of signal with
- Monte Carlo and data-driven standard model BG estimates
- Observed data that is inconsistent with BG and consistent with BG+signal would be evidence for physics BSM, but…

No evidence for BSM physics is seen!

- Observed limits are not far (many sigma) above expected values

Limits typically set on σB or σBA

- Comparisons provided for specific models
- Usually possible for reader to constrain additional models—let us know if not…

Scope of this talk

Although relevant to BSM searches, the following are *not* included:

- Standard Model measurements
  - Jan Kretzschmar (Wednesday)
- Top quark properties
  - Pedro Ferreiera da Silva (Friday)
- B-physics results
  - Jochen Schieck (Tuesday)
- Search for the Higgs (by any name) and other scalar bosons
  - Sandra Kortner, Marco Pieri (Wednesday)
- Supersymmetry (including many long-lived particle searches)
  - Sridhara Dasu (Wednesday), Steven Lowette (Thursday)
- CDF jj resonance in Wjj (see backup)

Focus is on what both collaborations call Exotic physics

- New gauge bosons
- 4th generation quarks
- Composite objects
- Extra dimensions (graviton, black holes,…; notation in backup slides)
- And more…

Results

Results are summarized on the following pages

Organized by final state

- Latest results are shown from both ATLAS and CMS
- One or a few representative plots for each analysis
  - Typically the final limit plot
- Link provided to the paper or collaboration note describing the result

Mostly based on 2011 data

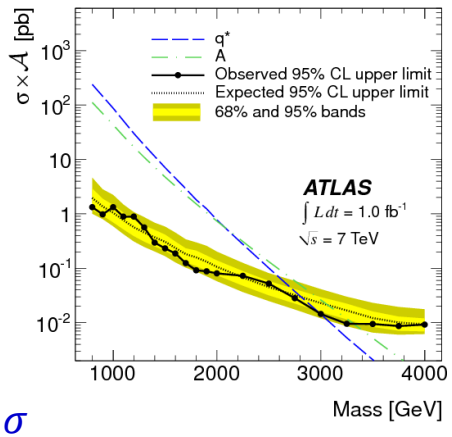
For details and more results, see the collaboration pages:

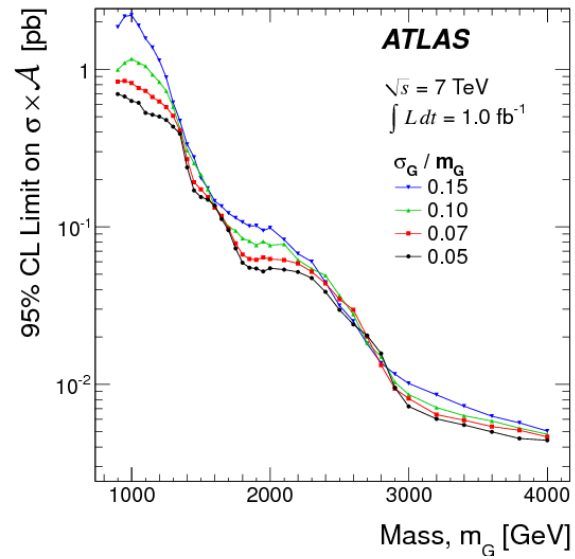
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- http://cms.web.cern.ch/org/cms-papers-and-results
- Or do a web search for “ATLAS results” or “CMS results” to find these pages

Dijet resonance

ATLAS and CMS search for dijet resonances

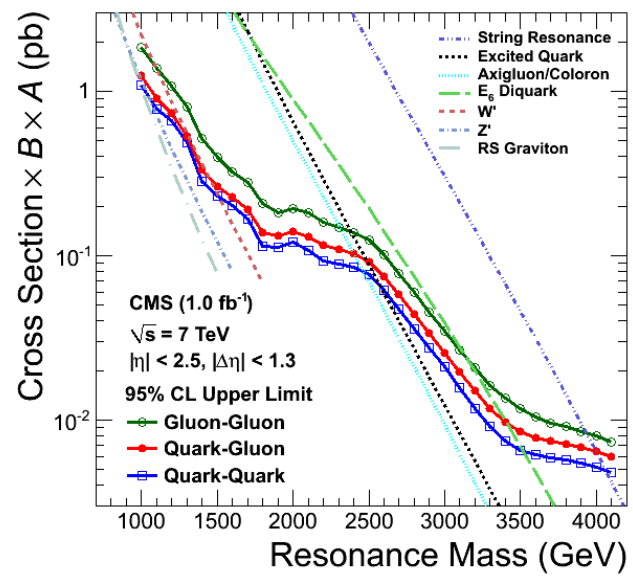
- Signature for many BSM models
  - string balls, GUT diquarks, excited quarks, axigluons, W', Z'





ATLAS search in 1.0 fb^{-1}

- Mass limits:
  - $m_{q*} > 2.99$ TeV
  - $m_{axigluon} > 3.32$ TeV
  - $m_{s8} > 1.92$ TeV
- Gaussian limits varying σ
- Phys. Lett. B 708, 37 (2012)



CMS search in 1.0 fb^{-1}

- Mass limits:
  - string resonance: $m > 4.00$ TeV
  - SSM: $m_{W'} > 1.51$ TeV
  - and many more…
- Phys. Lett. B **704**, 123 (2011)

Dijet angular distribution

Additional BSM sensitivity

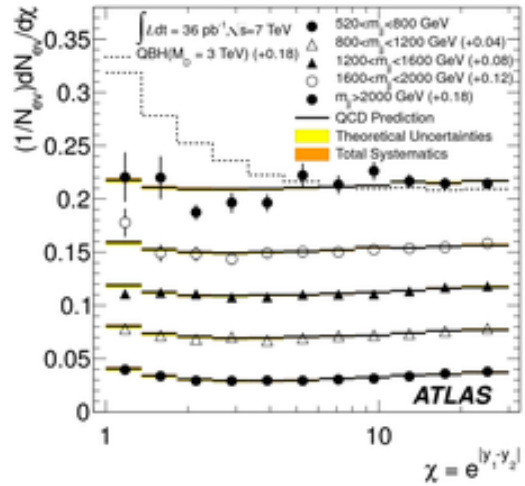
- BSM signals are typically central
- Search variable is $\chi = e^{|y_2 - y_1|}$: Flat for QCD, peaks at small values for BSM

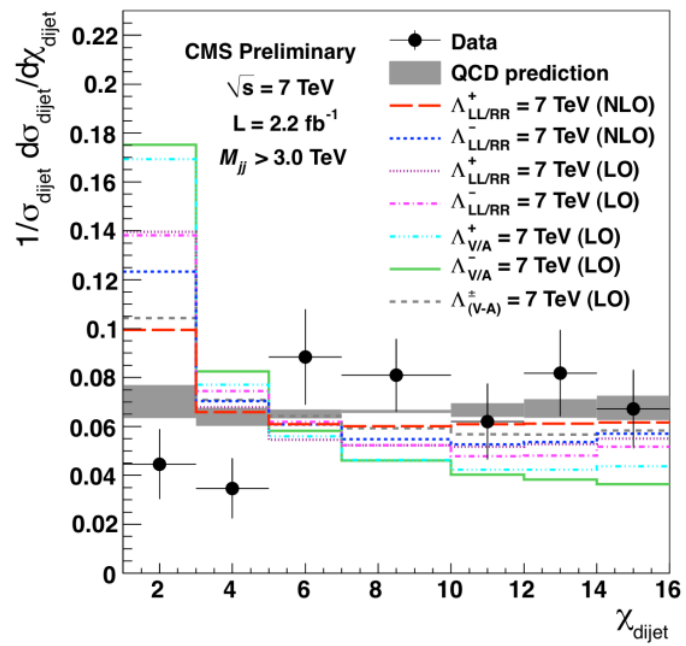
ATLAS search in 36 pb^{-1}

- 2010 data
- New J. Phys. **13**, 153044 (2011)

CMS results are based on 2.2 fb^{-1}

- CMS EXO-11-017
- arXiv:1202.5535 (submitted to JHEP)

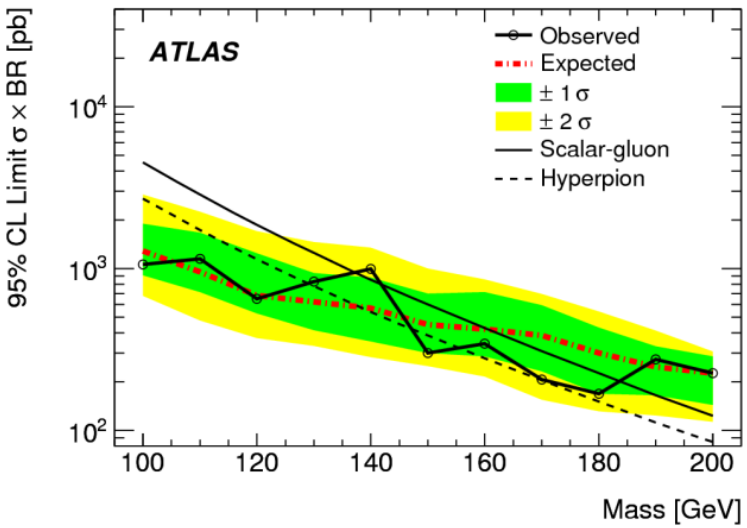




Dijet pairs

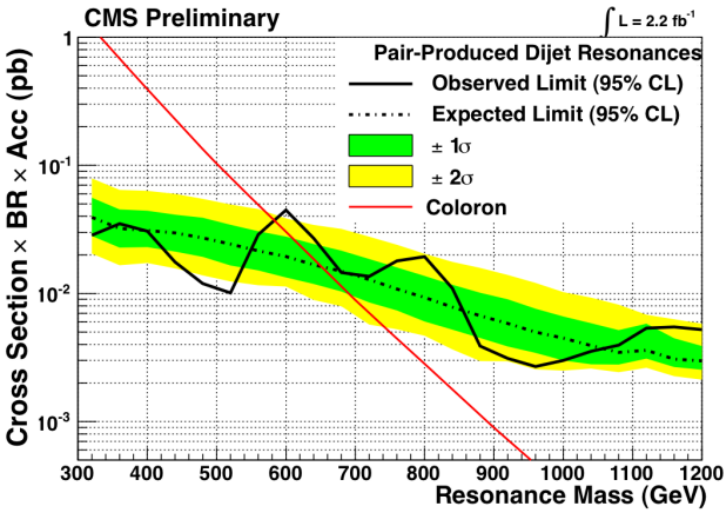
ATLAS search in 35 pb^{-1}

- 2010 data
- Excludes
  - Hyperpions for (100, 155) GeV
  - Scalar gluons (100, 185) GeV
  - Both except for window near 140 GeV
- EPJC **71**, 1828 (2011)



CMS search in 2.2 fb^{-1}

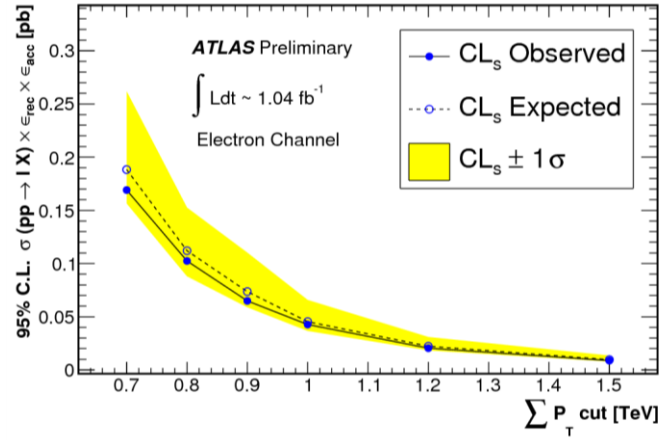
- Difference between jet $\sum p_T$ and average dijet mass is used to suppress QCD BG
- Trigger requires jet $\sum p_T > 200$ GeV or 4 jets with $p_T > 70$ GeV
  - Efficient for $m_{jj} > 320$ GeV
- Limit on σBA as function of m_{jj}
- Limit: coloron $m > 580$ GeV
- CMS PAS EXO-11-016



Transverse energy (scalar sum)

ATLAS and CMS look for events with large transverse energy

- Set limits on microscopic black holes or string balls (extra dimensions)
  - See papers for exclusion plots
- Model independent limits also provided

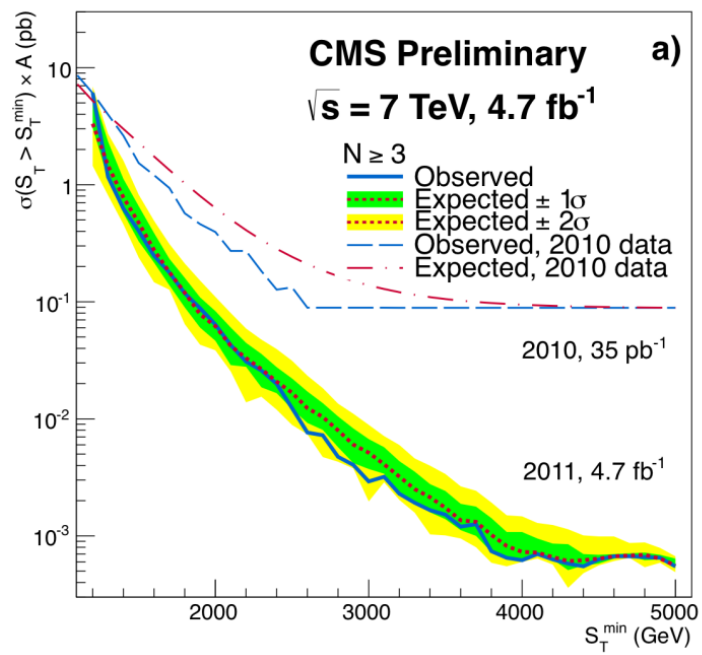


ATLAS search in 1.0 fb^{-1}

- Acceptance includes lepton trigger
- ATLAS-CONF-2011-147

CMS search in 4.7 fb^{-1}

- ADD limits
  - Black hole $m > 3.8 - 5.2$ TeV
  - String ball $m > 4.6 - 4.8$ TeV
- arXiv:1202.6396 (submitted to JHEP)



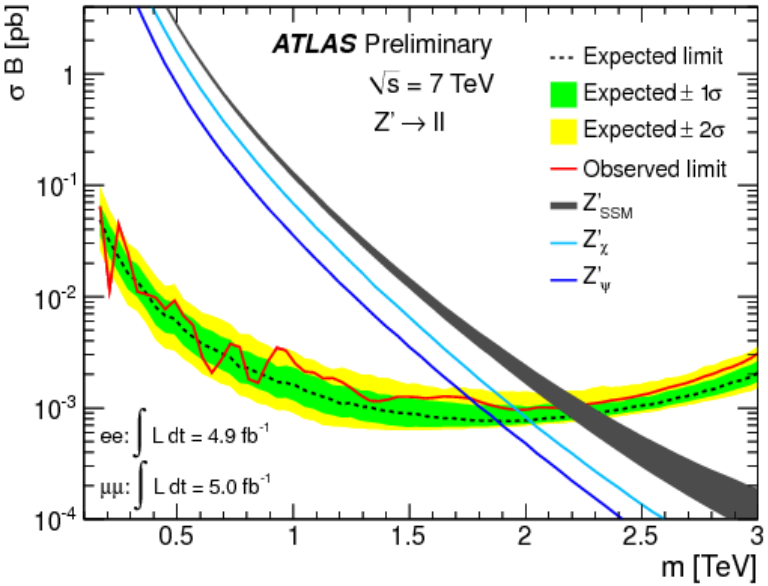
Dilepton resonance

ATLAS and CMS search for dilepton resonances

- BSM signatures include Z', gravitons and technihadrons

ATLAS search in 5.0 fb^{-1}

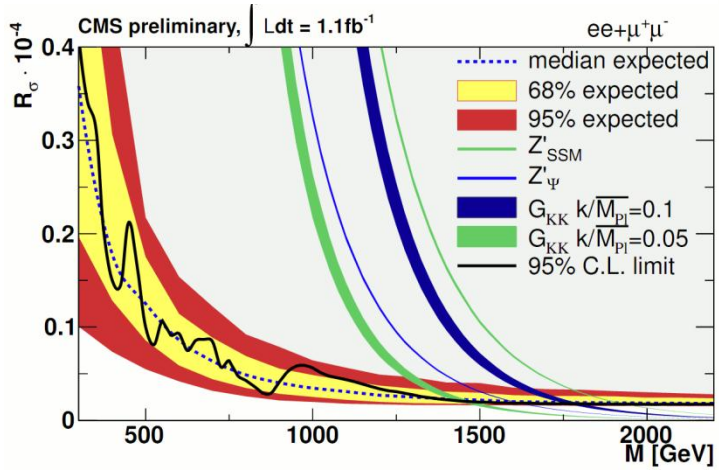
- Both ee and μμ channels
- Limits:
  - SSM: $m_{Z'} > 2.21$ TeV
  - RS1 graviton, $\frac{k}{M_{Pl}} = 0.1$: $m_G > 2.16$ TeV
- ATLAS-CONF-2012-007



CMS search in 1.1 fb^{-1}

- Both ee and μμ channels
- Limits:
  - SSM: $m_{Z'} > 1.94$ TeV
  - RS1 graviton, $\frac{k}{M_{Pl}} = 0.1$: $m_G > 1.98$ TeV
- CMS PAS EXO-11-019

$$\frac{(\sigma B)_{Z'}}{(\sigma B)_Z}$$



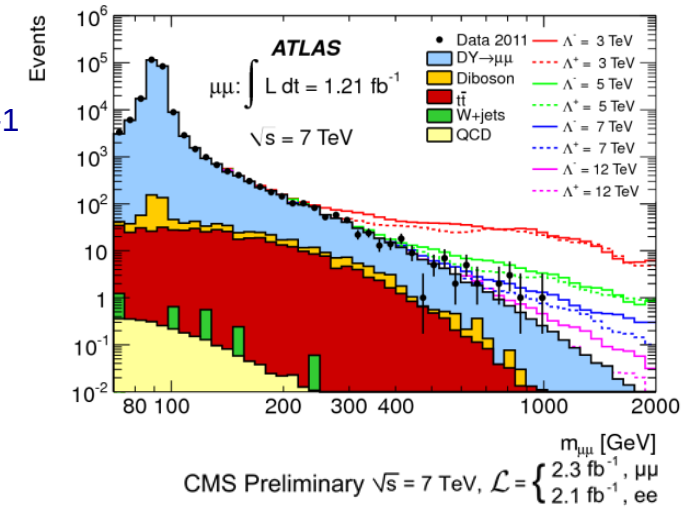
Dilepton high-mass tail

ATLAS and CMS look for non-resonant dilepton signals

- Excess at high mass is a BSM signature

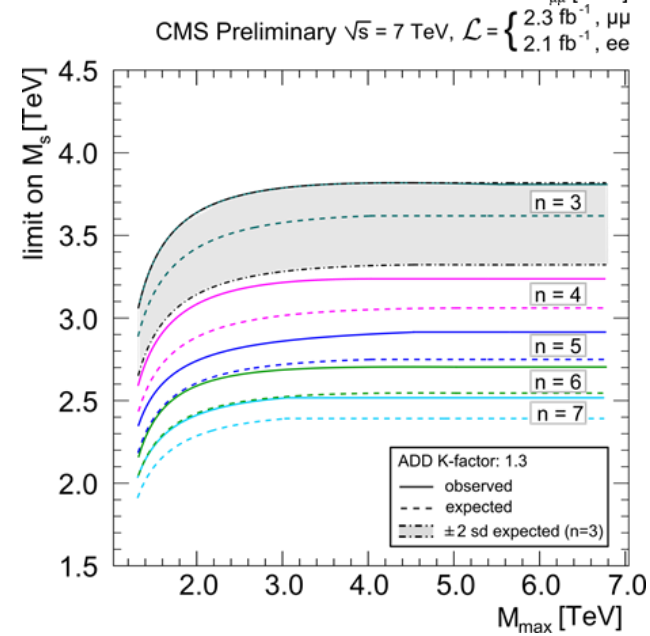
ATLAS has looked for contact interactions in 1.2 fb^{-1}

- If quarks and leptons are composite, then their interaction may be characterized by a compositeness scale Λ
- Limits Λ > 8-10 TeV are set separately in the ee and μμ channels, depending on the degree of interference with the SM interaction
- arXiv:1112.4462 (submitted to Phys. Rev. X)



CMS has searched for extra dimensions in 2.3 fb^{-1}

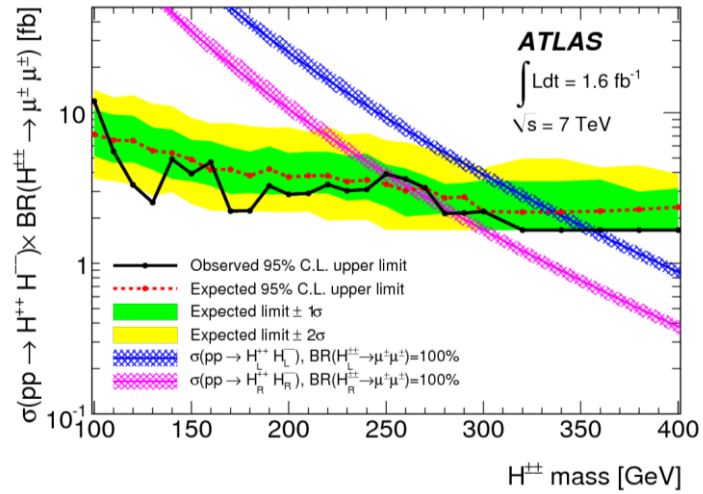
- Signal cross sections are evaluated in terms of
  - M_s - effective Planck scale
  - M_{max} - max $\sqrt{s}$ where the effective theory is valid
- ADD limit: M_s > 2.5-3.8 TeV
- arXiv:1202.3827 (submitted to Phys. Lett. B)



Same-sign leptons

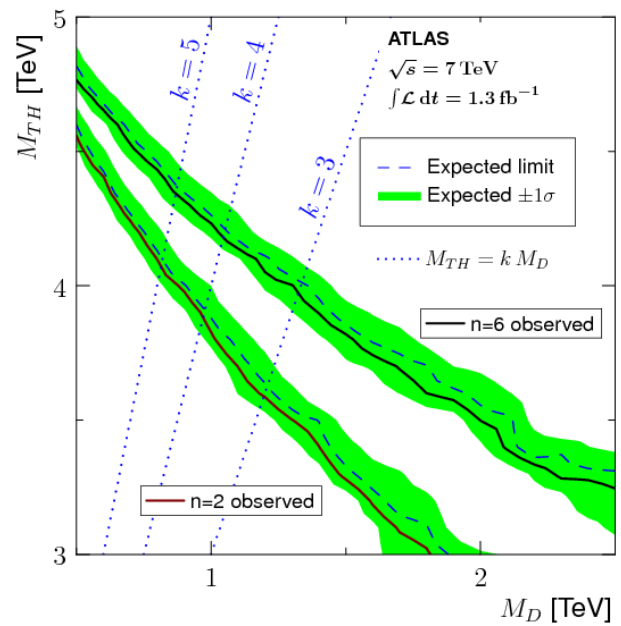
ATLAS search of same-sign dimuons in 1.6 fb^{-1}

- Limit set on doubly-charged Higgs Production
  - Limits up to $m > 355$ GeV
    - > depend on handedness and branching
- Also limits on same-sign top and SS generic
- arXiv:1201.1091 (accepted by Phys. Rev. D)



ATLAS search for black holes in 1.3 fb^{-1}

- Events require to have two like-sign muons
- Track multiplicity is used to discriminate BG
- 2D mass limits set on
  - M_{TH} = lower mass threshold for BH production
  - M_D = Planck scale in 4+n dimensions
- $\sigma < 0.018$ pb in defined signal region
- arXiv:1111.0080 (accepted by PLB)

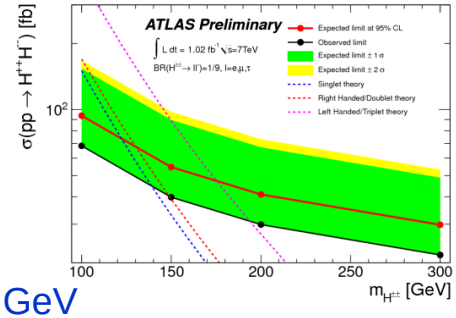


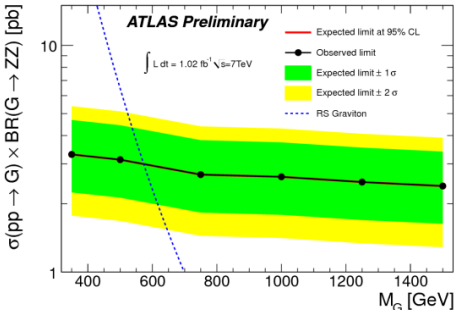
See also heavy quark searches, SUSY talk

Multilepton

ATLAS search of $4l$ events in 1 fb^{-1}

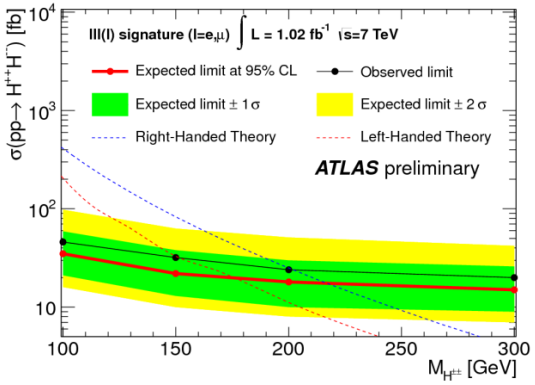
- Excluding Z, no events
  - $H^{++}\ H^{--} \rightarrow l\ l\ l\ l\ X$: $\sigma_{fid} < 4.7$ fb
- Requiring 2 Z's
  - RS graviton ($\frac{k}{M_{Pl}} = 0.1$): $M_G > 575$ GeV
- ATLAS-CONF-2011-144





ATLAS search of 3-lepton events in 1.0 fb^{-1}

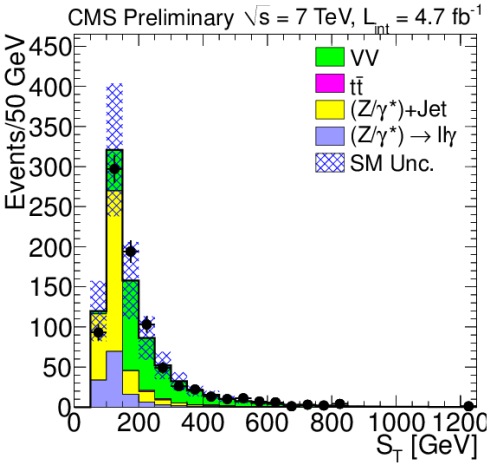
- Excluding Z-window
- Two $H^{++}H^{--}$ fiducial regions: $\sigma_{fid} < (38, 14)$ fb
- $\nu^*\nu^*$ production: $\sigma < (41, 34)$ fb for $m = (200, 300)$ GeV
- ATLAS-CONF-2011-158



CMS search of 3- and 4-lepton events in 4.7 fb^{-1}

- Events are classified by lepton flavor (including τ_h), multiplicity, and Z mass
- Example S_T distribution at right—many more distributions and exclusion plots available
- CMS EXO-11-045/SUS-11-013

Steven Lowette, Thursday



Diphoton

ATLAS and CMS search with diphotons

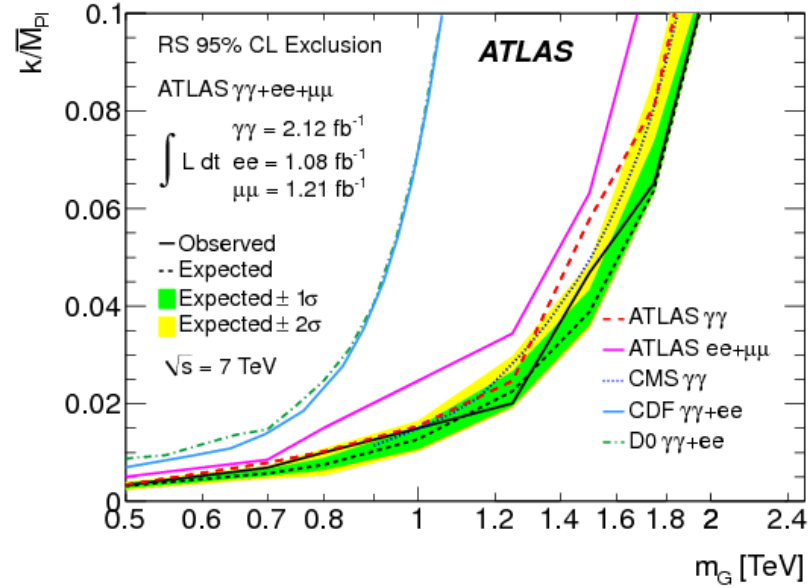
- Clean signal, modest SM BG
- $m_{\gamma\gamma}$ is signature for extra dimensions:
  - High-mass continuum for ADD
  - Resonance for RS models
- ATLAS Preliminary

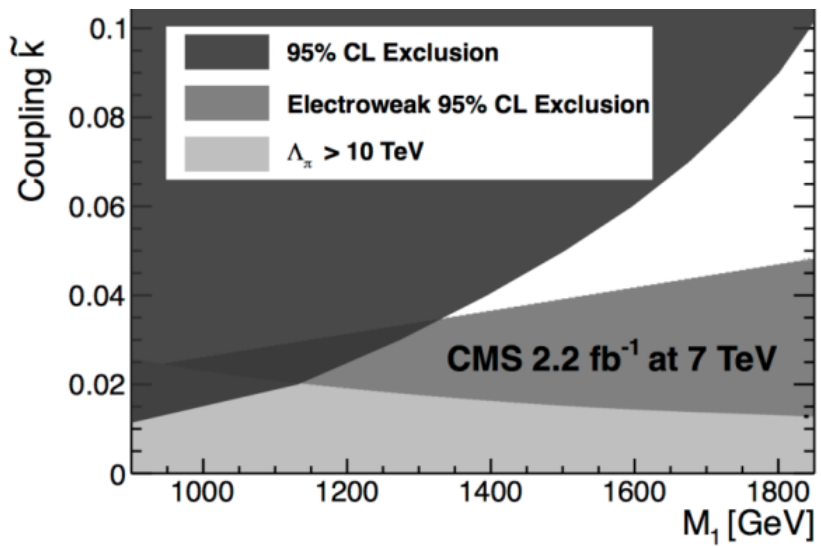
ATLAS result based on 2.1 fb^{-1}

- RS1: $M_G > 0.79$ - 1.75 TeV
- ADD: $M_D > 2.3$ - 3.5 TeV
- Results combined with dilepton
- arXiv:1112.2194 (submitted to PLB)

CMS result based on 2.2 fb^{-1}

- RS1: $M_G > 0.86$ - 1.84 TeV
- ADD: $M_S > 2.3$ - 3.8 TeV
- arXiv:1112.0688 (accepted by PRL)





Lepton + MET

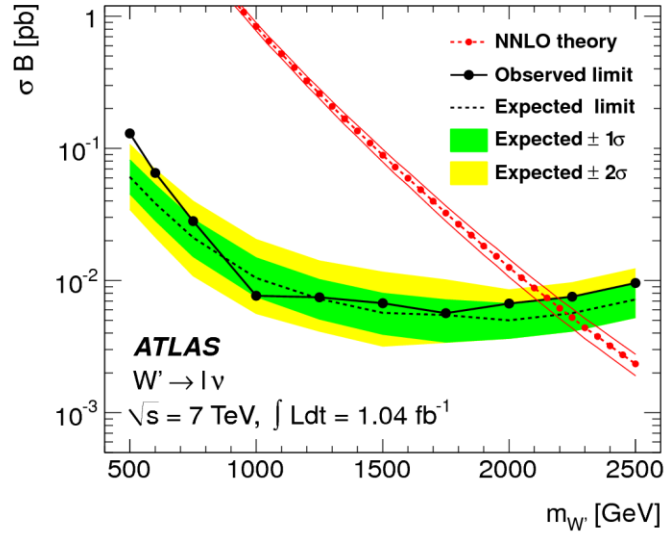
ALAS and CMS both search for $W' \rightarrow l\,\nu$

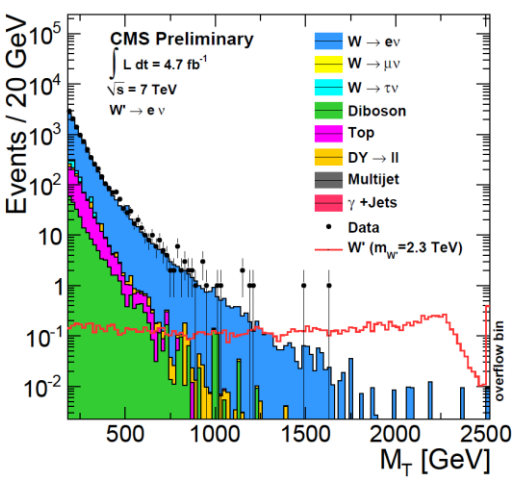
ATLAS result based on 1.0 fb^{-1}

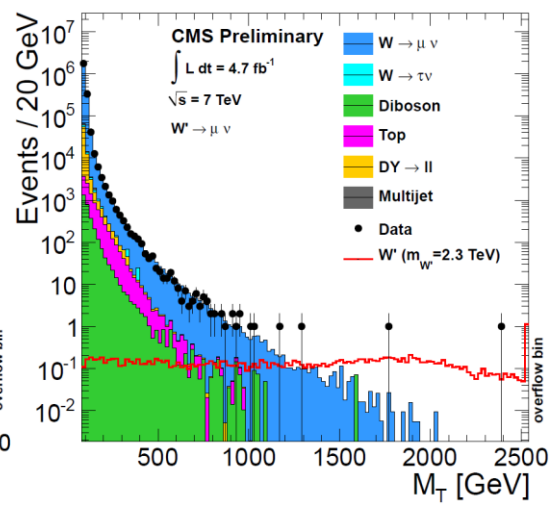
- SSM $m_{W'}$ > 2.2 TeV
- Phys. Lett. B **705**, 28 (2011)

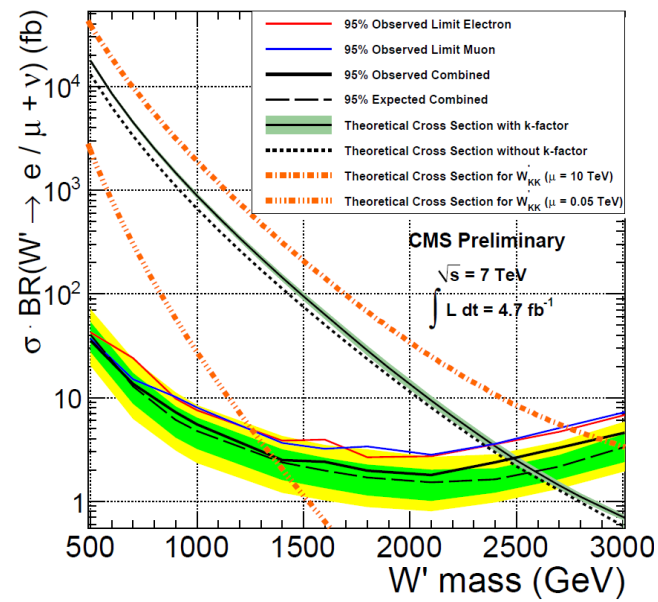
CMS result based on 4.7 fb^{-1}

- SSM $m_{W'}$ > 2.5 TeV
- CMS EXO-11-024 Winter 2012





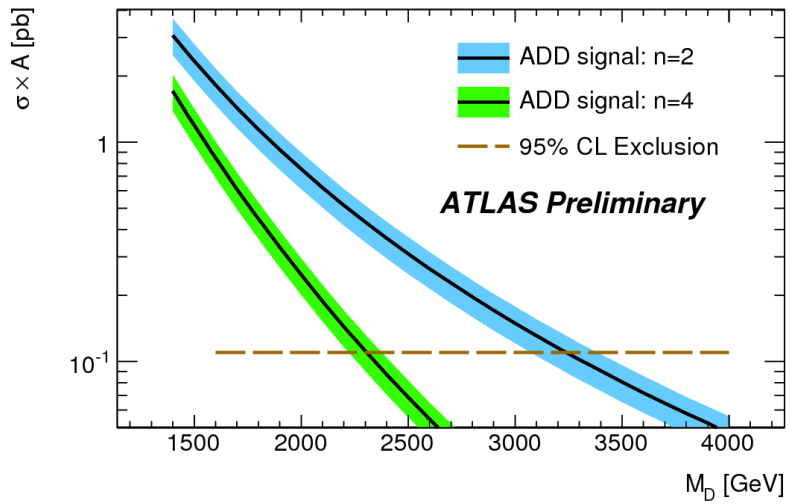




Monojet (jet + MET)

Monojet is a simple and striking signal

- High-p_T jet with no object to balance p_T
- Non-interacting particle created
- Main BG is $Z \rightarrow \nu\,\nu$
- BSM candidate here is ADD graviton
  - $qq \rightarrow gG$, $qg \rightarrow qG$, $gg \rightarrow gG$
  - Limits set on M_D, the Planck scale for n_{ED} extra dimensions

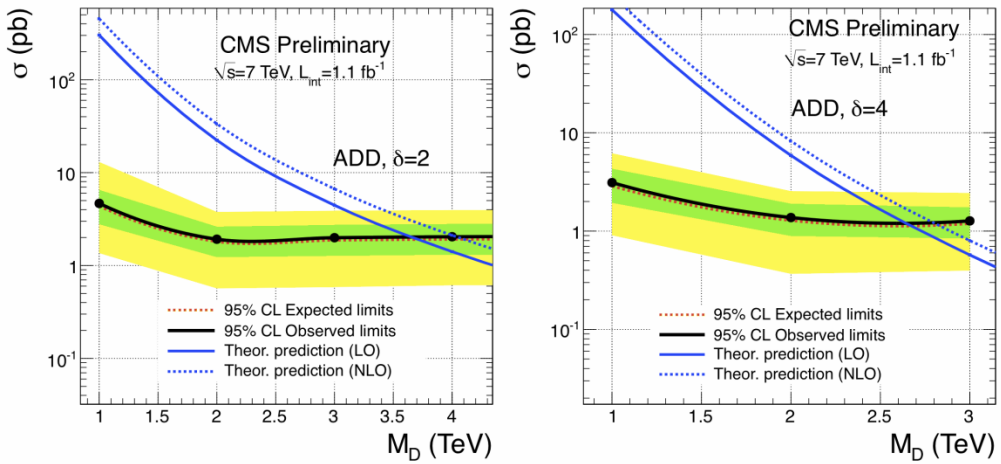


ATLAS result obtained with 1.0 fb^{-1}

- M_D > 3.4 TeV for n_{ED}=2
- M_D > 2.3 TeV for n_{ED}=4
- ATLAS-CONF-2011-096

CMS result obtained with 1.1 fb^{-1}

- M_D > 3.7 TeV for n_{ED}=2
- M_D > 2.7 TeV for n_{ED}=4
- Larger with NLO K-factor
- CMS PAS EXO-11-059

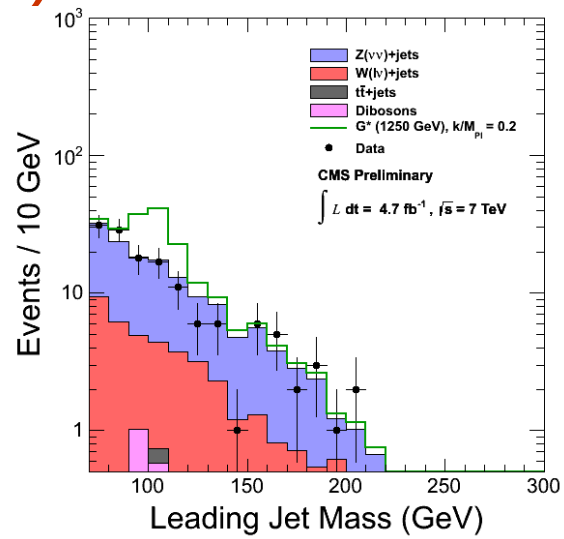


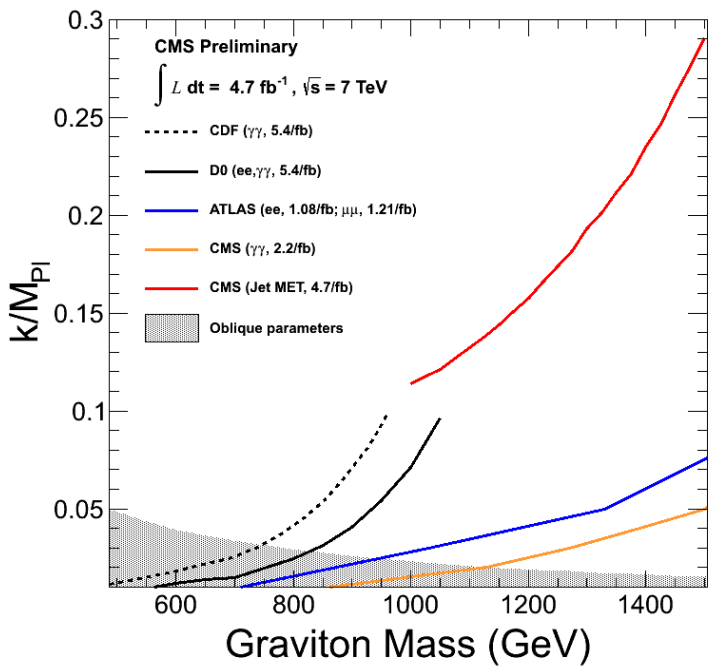
Update and DM interpretation described by Steven Worm on Thursday.

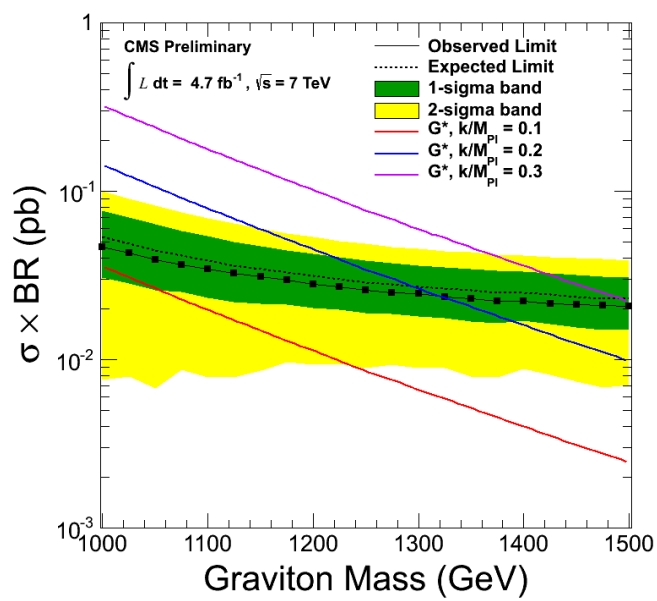
Z + MET (monojet)

CMS result with 4.7 fb^{-1}

- $ZZ \rightarrow (qq)(\nu\nu) \rightarrow J + MET$
- $m_{\text{jet}} > 70$ GeV, no isolated tracks
- RS limits for $G^* \rightarrow ZZ$ with $1.0 < m_{G^*} < 1.5$ TeV:
  - $\sigma B < 47$-21 fb
  - $k/M_{Pl} < 0.21$-0.29
- CMS PAS EXO 11-061



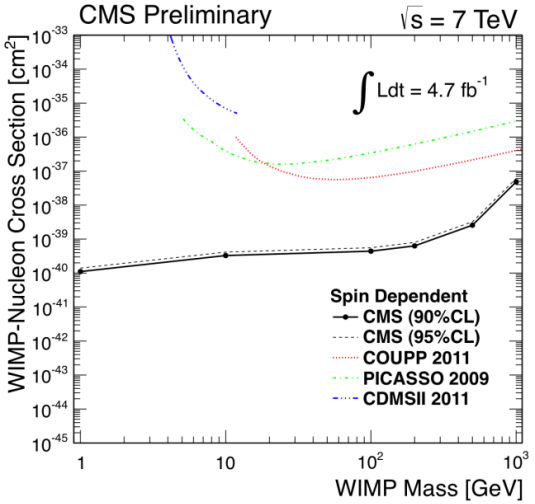




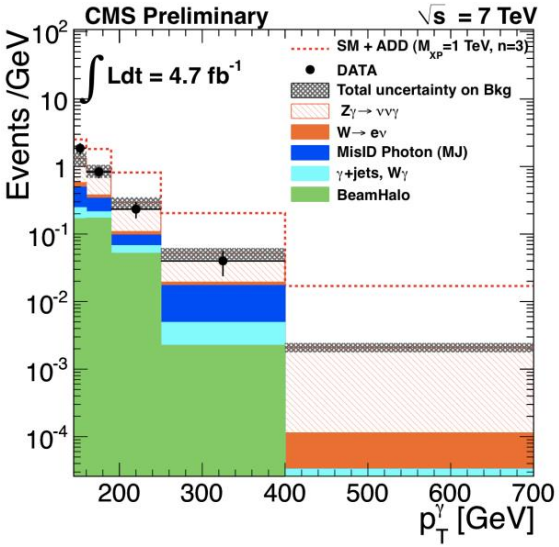
Monophoton (γ + MET)

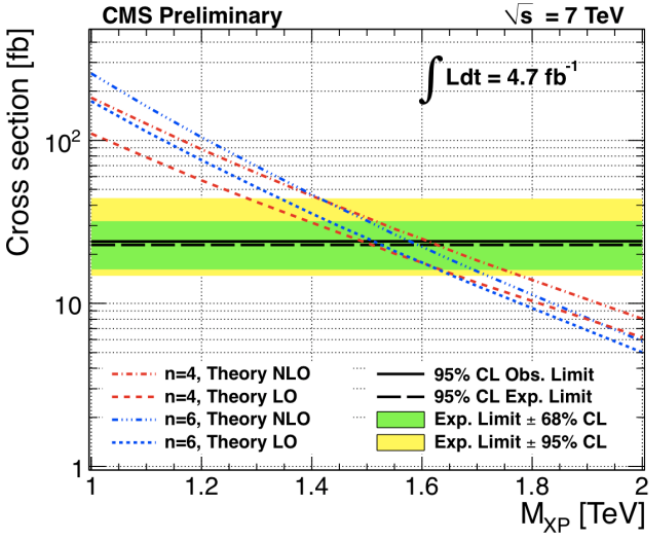
CMS search in 4.7 fb^{-1}

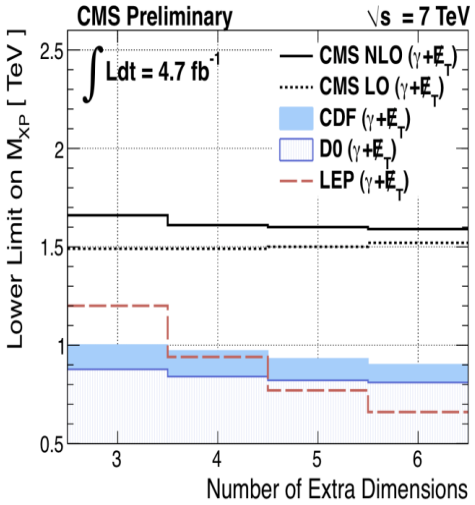
- High-p_T photon and not much else
- ADD limit ($qq \rightarrow G\gamma$):
  - $M_D \gtrsim 1.59 - 1.66$ TeV for $3 \leq n_{ED} \leq 6$
- Limits on WIMP-nucleon cross section:
  - $\sigma B <$ 16-18 fb for $1 < M_{\mathrm{DM}} < 1000$ GeV
- CMS EXO 11-096



Steven Worm on Thursday



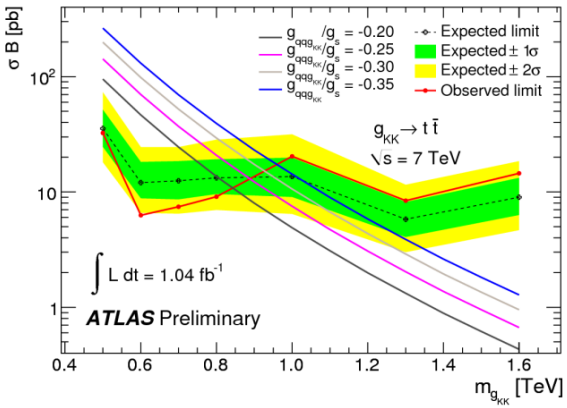




t-tbar resonance 1/3

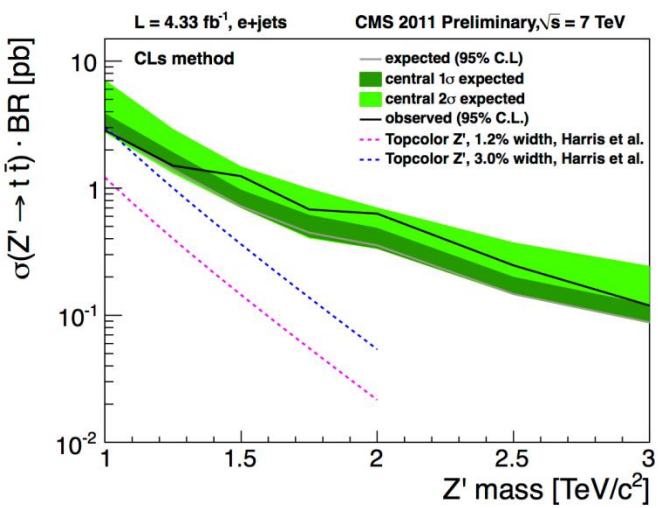
ATLAS search of the dilepton channel in 1.0 fb^{-1}

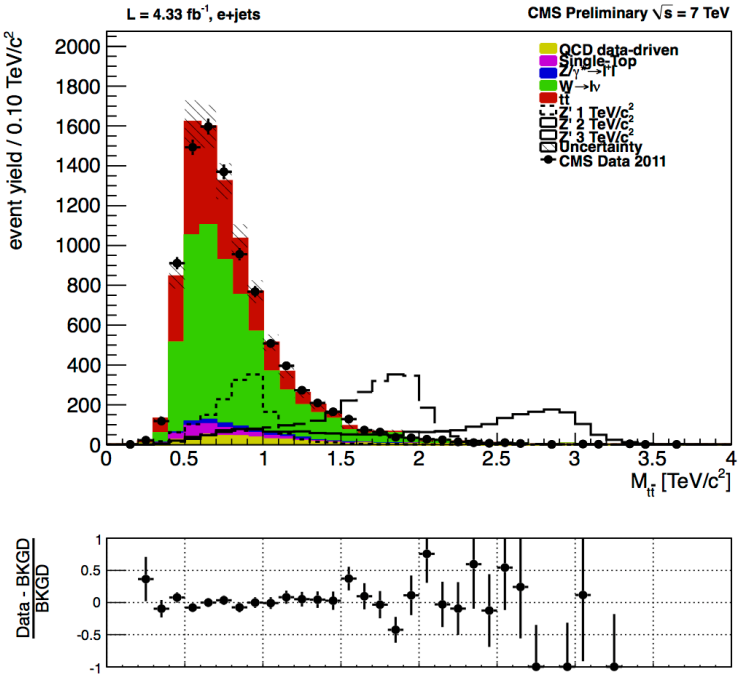
- Low mass—down to 400 GeV
- Limit near $m > 900$ GeV on the RS KK gluon
- ATLAS-CONF-2011-123



CMS search of the electron+jets channel in 4.3 fb^{-1}

- Model-independent limits for 1% width:
  - $\sigma B < 2.51$ pb for $m > 1$ TeV
  - $\sigma B < 0.62$ pb for $m > 2$ TeV
- CMS PAS EXO-11-092

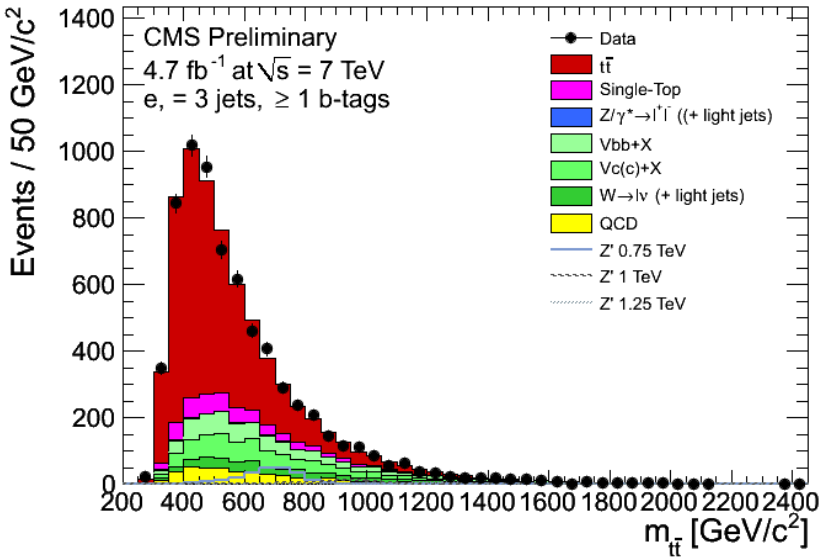


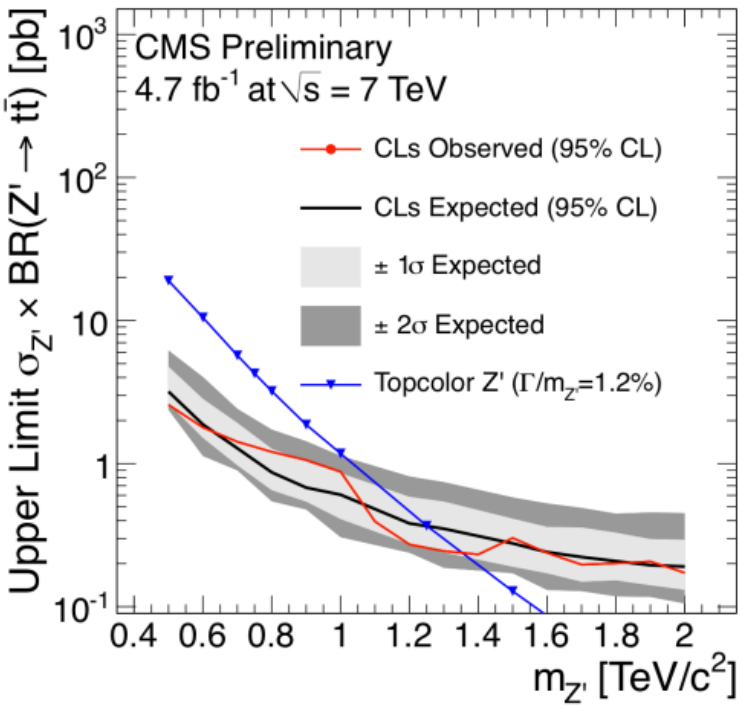


t-tbar resonance 2/3

CMS search of the lepton+jets channel in 4.7 fb^{-1}

- Leptophobic topcolor Z' limits:
  - $m_{Z'} > 1.3$ TeV for narrow resonance
  - $m_{Z'} > 1.7$ TeV for 10% width
- KK gluon: $m_{g_{KK}} > 1.4$ TeV
- CMS PAS TOP-11-009

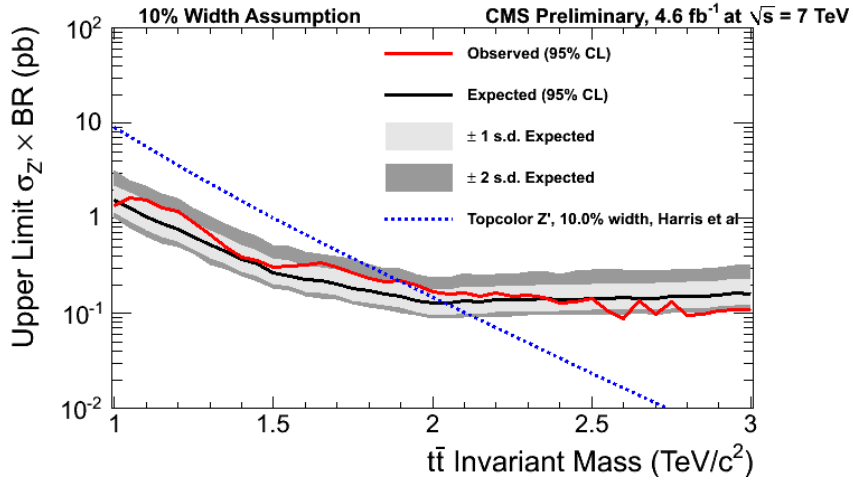


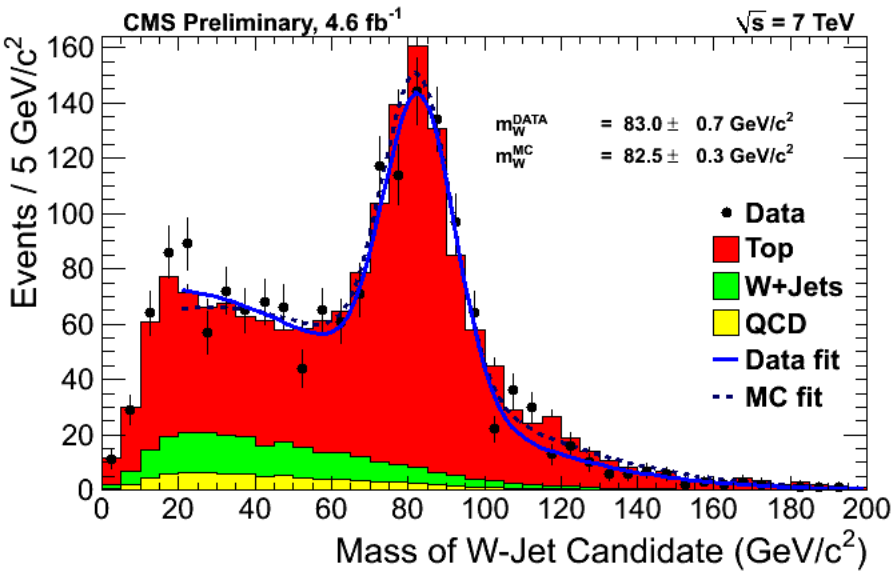


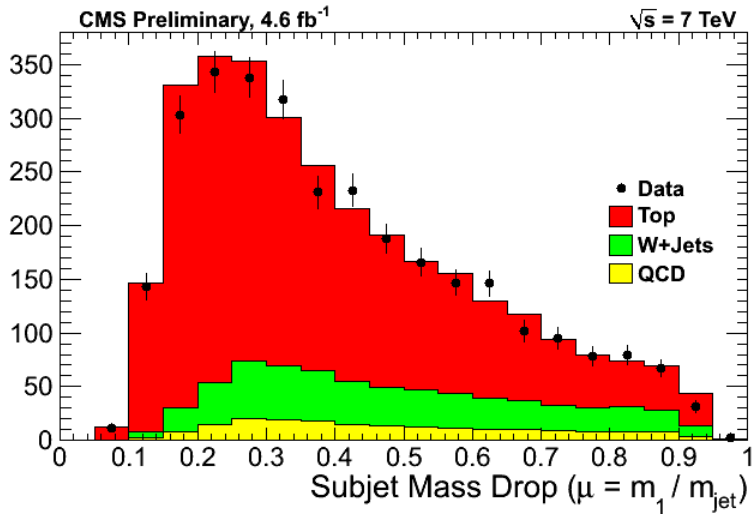
t-tbar resonance 3/3

CMS search of all-jets channel in 4.6 fb^{-1}

- Boosted jets with mass pruning
- Mass drop used in W-jet identification
- Leptophobic topcolor Z' limits varying the width (e.g. plot at right)
- KK gluon limit: $m_{g_{KK}} > 1.4$-1.5 TeV
- CMS EXO 11-006 Winter 2012



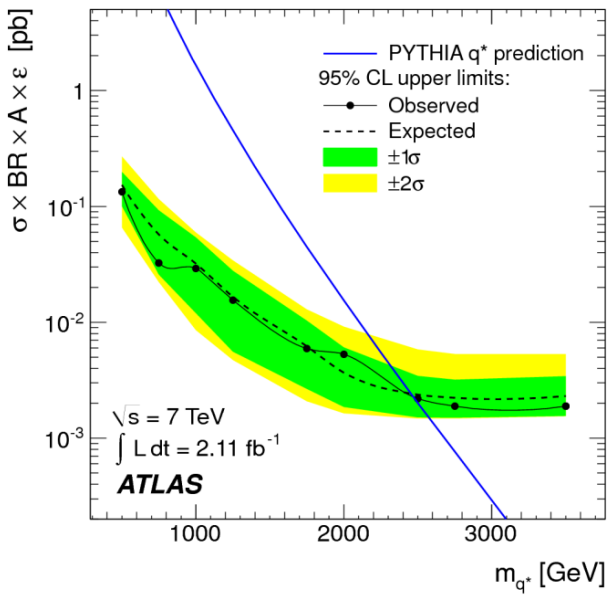


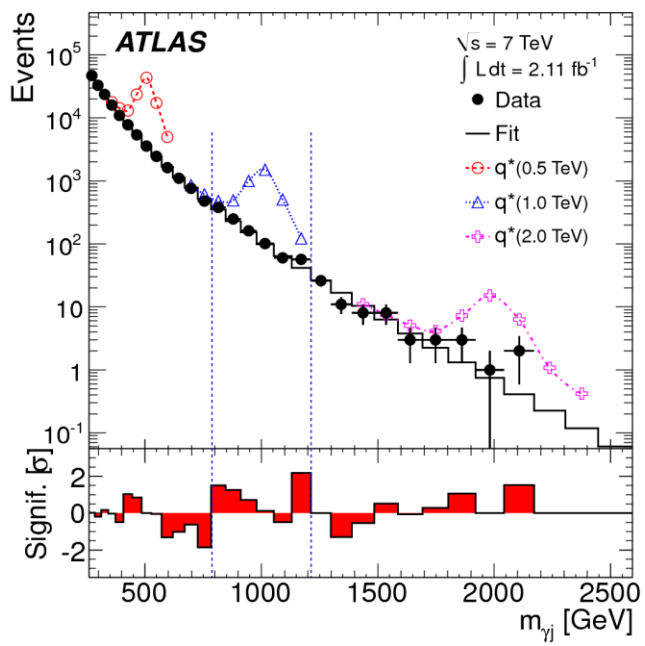


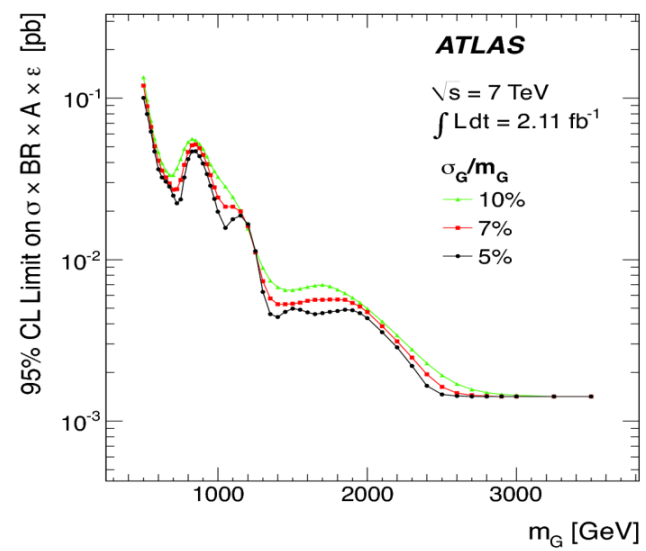
Photon-jet resonance

ATLAS search of the γ-jet channel in 2.1 fb^{-1}

- Excited quark: $m_{q^*} > 2.46$ TeV
- Generic Gaussian signal:
  - $\sigma BA < 5$ fb for $m = 2$ TeV
- arXiv:1112.3580 (submitted to PRL)







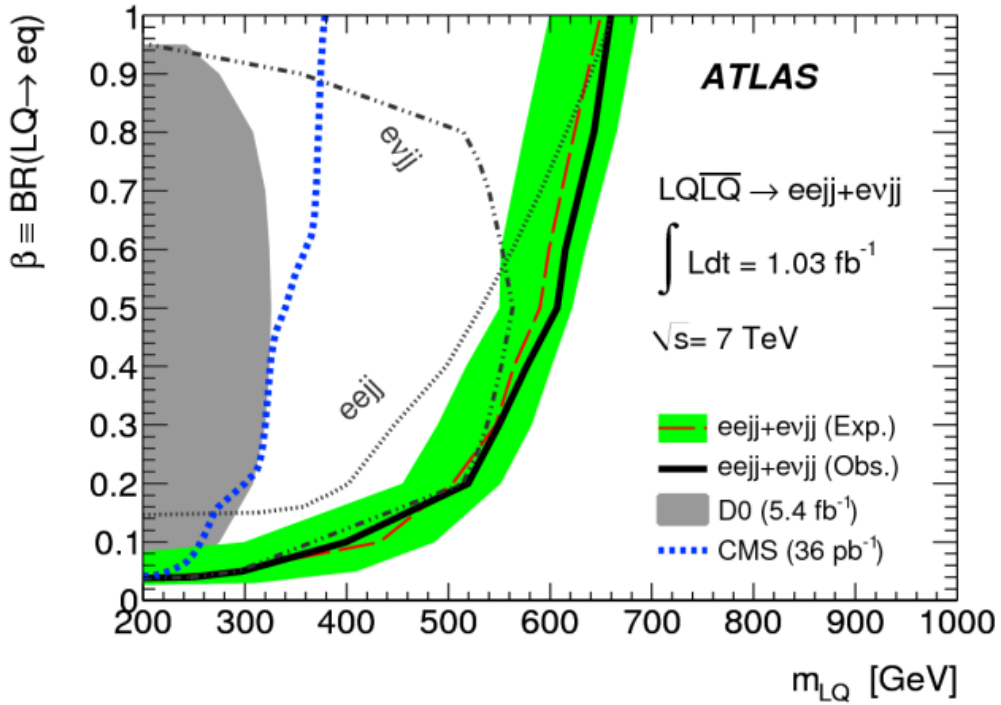
1st generation leptoquark

ATLAS and CMS search for leptoquarks

- Pair-produced particle that decays to lq or νq
  - Branching fractions respectively denoted β and $1-\beta$
- Search typically carried out in both $llqq$ and $l\nu qq$ channels
- Search typically restricted to one generation
  - E.g. $l = e$ for first generation search

ATLAS search in 1.1 fb^{-1}

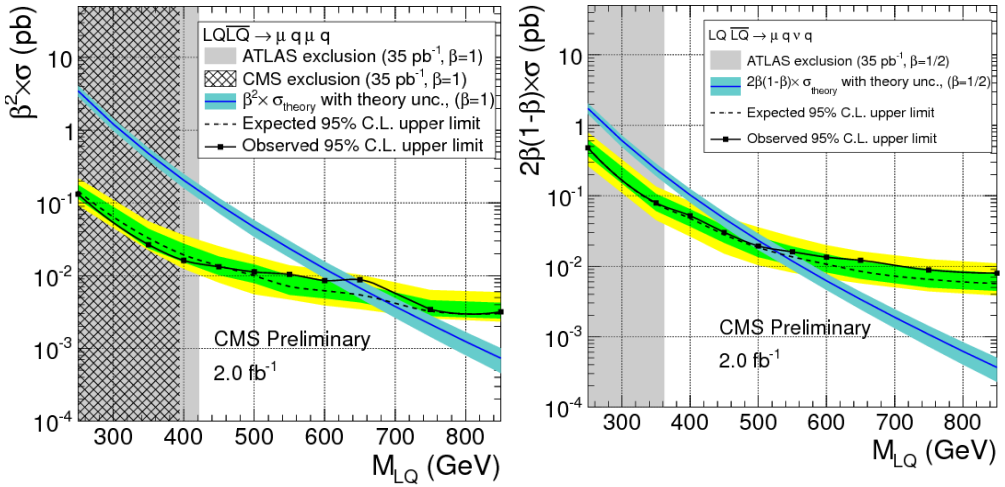
- Using $eejj$ and $e\nu jj$ channels
- Limits:
  - $m_{LQ} > 660$ GeV for $\beta = 1$
  - $m_{LQ} > 607$ GeV for $\beta = 0.5$
- Phys. Lett. B **709**, 158 (2012)



2nd generation leptoquark

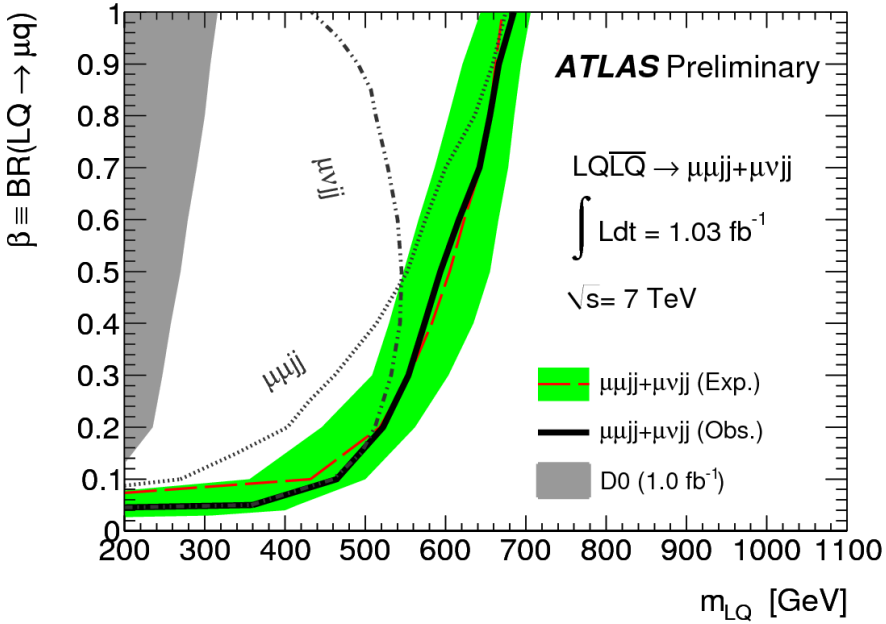
CMS search in 2.0 fb^{-1}

- Using $\mu\mu jj$ and $\mu\nu jj$ channels
- Limits:
  - $m_{LQ} > 632$ GeV for $\beta = 1$
  - $m_{LQ} > 523$ GeV for $\beta = 0.5$
- CMS PAS EXO-11-028



ATLAS search in 1.0 fb^{-1}

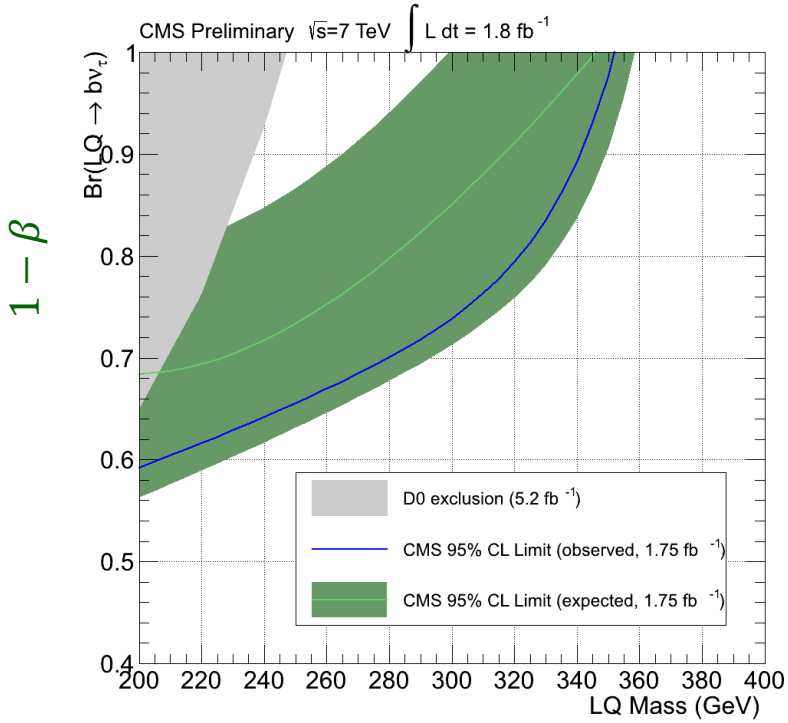
- Using $\mu\mu jj$ and $\mu\nu jj$ channels
- Limits:
  - $m_{LQ} > 685$ GeV for $\beta = 1$
  - $m_{LQ} > 594$ GeV for $\beta = 0.5$
- ATLAS Preliminary



3rd generation leptoquark

CMS search in 1.8 fb^{-1}

- Search channel is $bb\nu\nu$
- Uses *razor* variables
  - Designed to search for pairs of heavy particles
- Limit:
  - $m_{LQ} > 350$ GeV for $\beta = 0$
- CMS PAS EXO-11-030



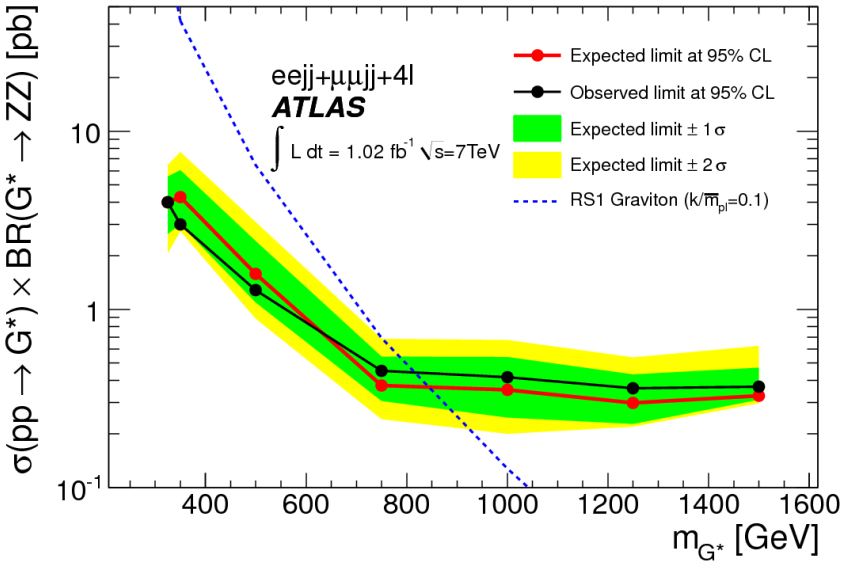
Diboson resonance (1/1)

ATLAS and CMS search for diboson resonances

- Possible decay channel for Z' and W'
  - Branching is quite small in the usual SSM
- Important signature for technicolor, e.g. $\rho_{TC} \rightarrow WZ$
- Also important channel for Graviton searches
- See also Z+MET, multilepton

ATLAS search for ZZ in 1.0 fb^{-1}

- $ZZ \rightarrow lll$ and $ZZ \rightarrow lljj$
- RS1 limits for $G^* \rightarrow ZZ$ $(k/M_{Pl} = 0.1)$
  - $m_{G^*} > 845$ GeV
- arXiv:1203.0718 (submitted to PLB)

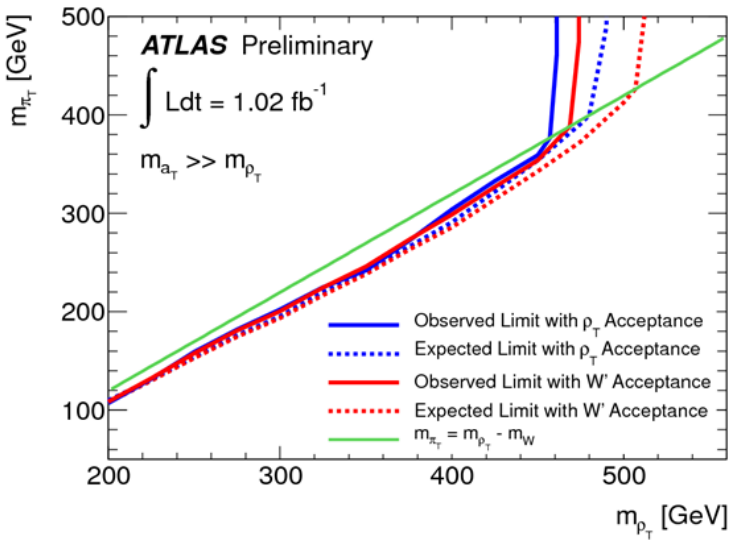


See CMS Z+MET search

Diboson resonance (2/2)

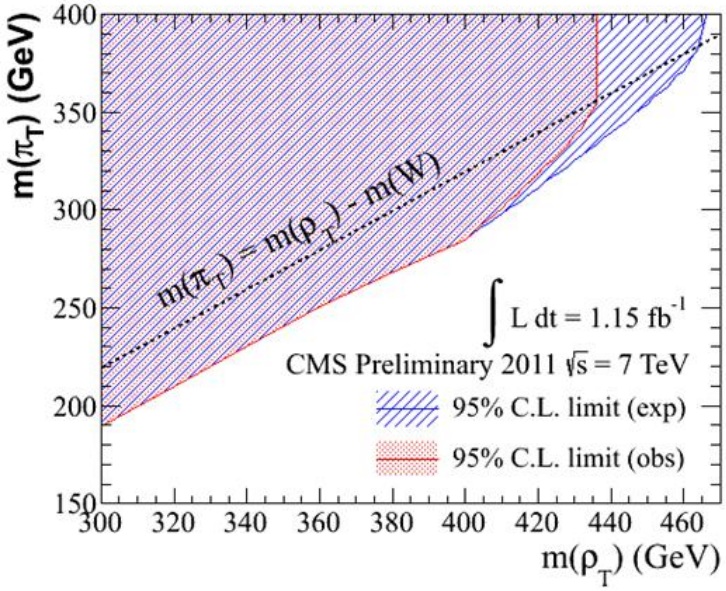
ATLAS search for $WZ \rightarrow lll\nu$ in 1.0 fb^{-1}

- Exclusion in m_{π_T}-m_{ρ_T} plane
- ATLAS Preliminary



CMS search for $WZ \rightarrow lll\nu$ in 1.1 fb^{-1}

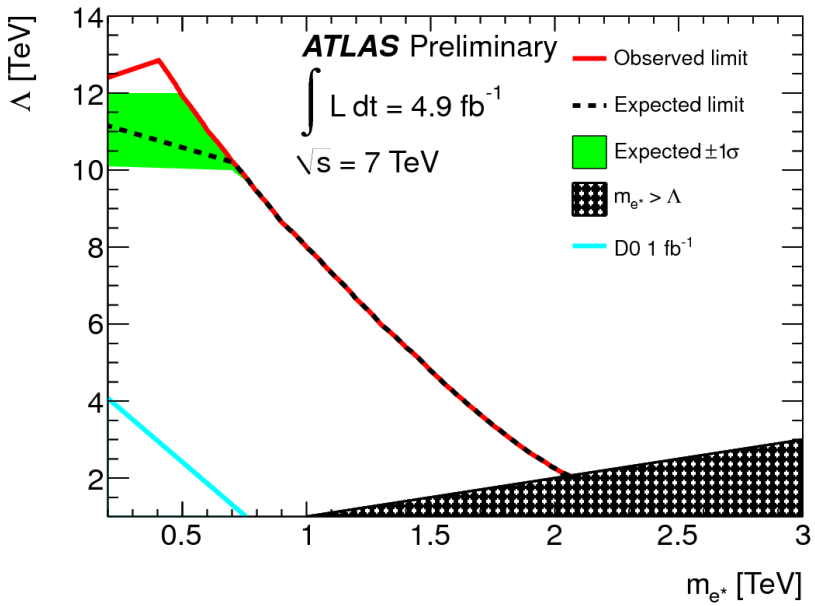
- SSM $m_{W'} > 784$ GeV
- Exclusion in m_{π_T}-m_{ρ_T} plane
- CMS PAS EXO-11-041

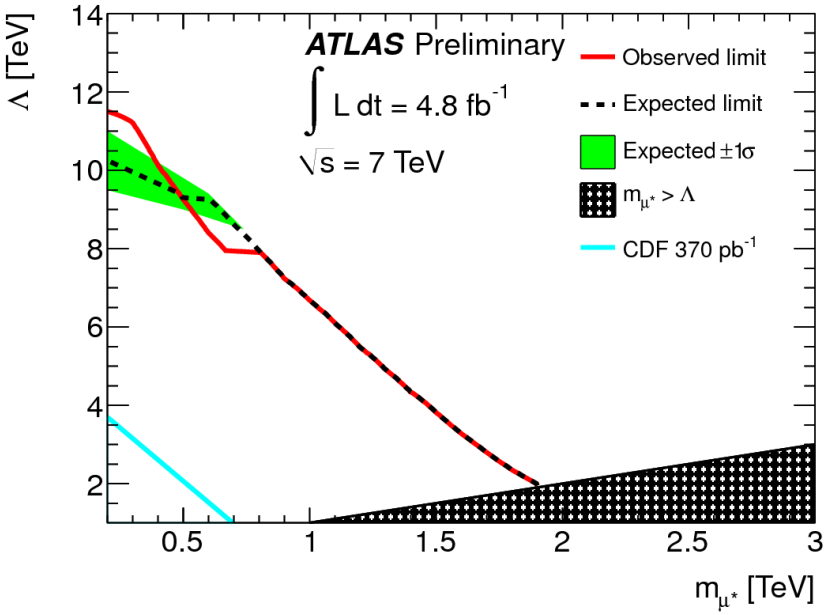


Excited leptons

ATLAS search in 4.9 fb^{-1}

- For $e\gamma$ resonance in $ee\gamma$ events or $\mu\gamma$ in $\mu\mu\gamma$ events
- Limits as a function of excited lepton mass m_{l^*} and compositeness scale Λ
- Limits for $\Lambda = m_{l^*}$: $m_{e^*} > 2.0$ TeV, $m_{\mu^*} > 1.9$ TeV
- ATLAS-CONF-2012-008





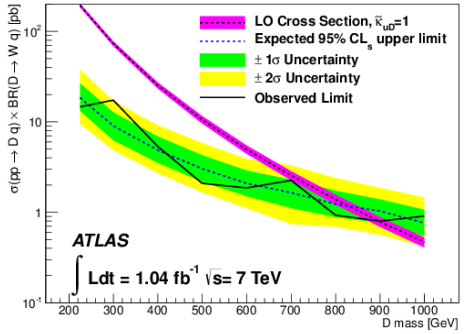
4th generation quarks (1/6)

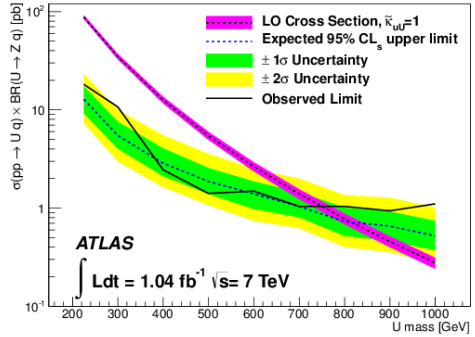
ATLAS and CMS carry out many searches for heavy quarks

- Here denoted T and B; or Q for either flavor
- Searches for $T \to Wb$, $B \to Wt$ and $T \to Zt$, $T \to A_0 t$, $B \to Zb$
  - 100% branching fraction assumed for mass limits
- Both single and pair production considered
  - Mechanism and cross section depend on Q nature (chiral, vector-like)
- Complicated final states, usually with bosons
- Many searches…

ATLAS search: $Qq \to Vqq'$ in 1.0 fb^{-1}

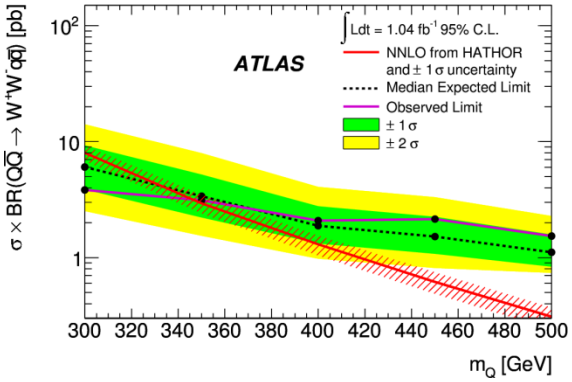
- Bosons decay leptonically
- Limits:
  - $Qq \to Wqq'$: $m_Q > 900$ GeV
  - $Qq \to Zqq'$: $m_Q > 760$ GeV
- arXiv:1112.5755 (submitted to PLB)





ATLAS search for $QQ \to (Wq)(Wq)$ in 1.0 fb^{-1}

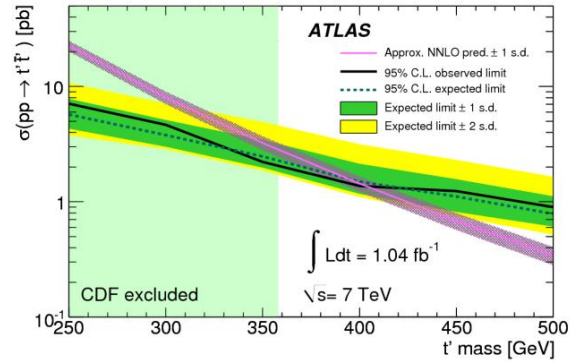
- Both W's decay leptonically
- Limit: $m_Q > 350$ GeV
- arXiv:1202.3389 (submitted to PRD)



4th generation quarks (2/6)

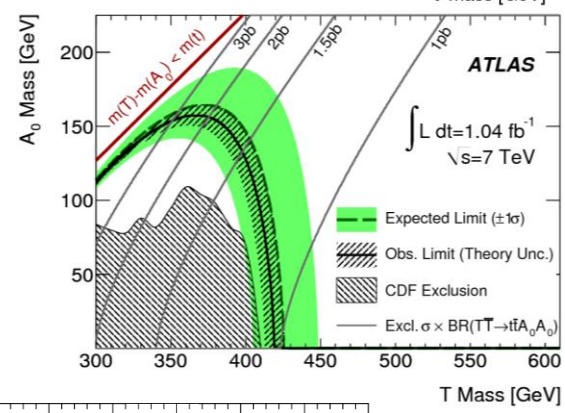
ATLAS search for $TT \rightarrow (Wb)(Wb)$ in 1.0 fb^{-1}

- One W decays leptonically
- One b is tagged
- Limit: $m_T > 404$ GeV
- arXiv:1202.3076 (submitted to PRL)



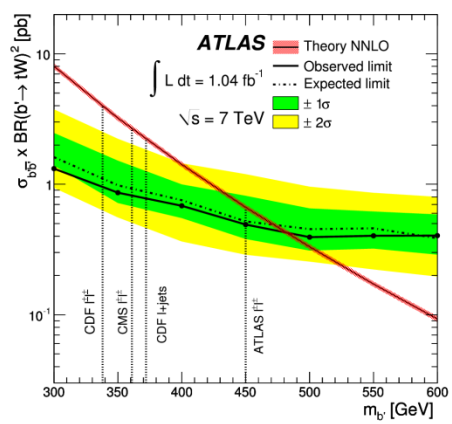
ATLAS search for $TT \rightarrow (tA_0)(tA_0) \rightarrow l\,X$ in 1.0 fb^{-1}

- A_0 is an undetected neutral particle
- Limit: m_T > 420 GeV for light A_0
- PRL **108**, 041805 (2012)



ATLAS search for $BB \rightarrow (Wt)(Wt)$ in 1.0 fb^{-1}

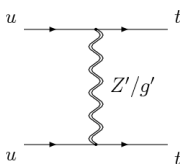
- Require 1 lepton, 6 jets, high MET
- Dijet mass used to identify W-bosons
- Analysis uses bins in jet and W multiplicities
- Limit: $m_B > 480$ GeV
- arXiv:1202.6540 (submitted to PRL)

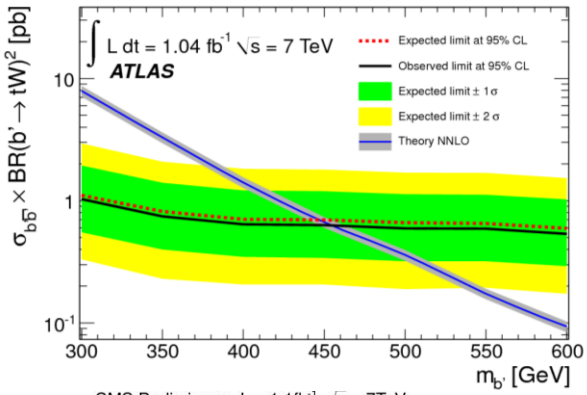


4th generation quarks (3/6)

ATLAS search for $BB \rightarrow (Wt)(Wt) \rightarrow llX$ in 1.0 fb^{-1}

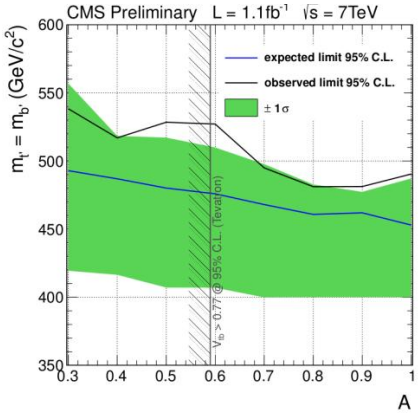
- 2 same-sign leptons, 2+ jets, high MET
- Limit: $m_B > 450$ GeV
- Also limits on same-sign tt production
- arXiv:1202.5520 (submitted to JHEP)





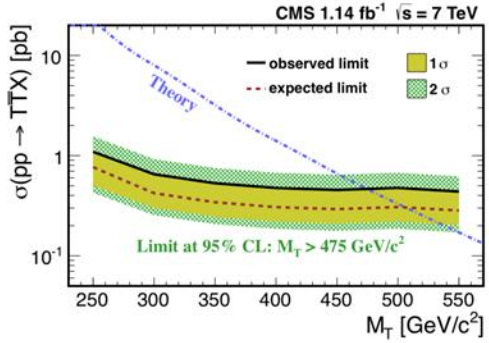
CMS inclusive search for chiral Q in 1.1 fb^{-1}

- Assume $m_T = m_B$, CKM4: $V_{TB} = V_{tb} \equiv \sqrt{A}$
- Require 1 muon (trigger) and 1 b-jet
- Classify events by b-tag and W multiplicities
- Limit set in $A - m_Q$ plane, $m_Q > 490$ GeV
- CMS PAS EXO-11-054



CMS search for $TT \rightarrow (Zt)(Zt)$ in 1.1 fb^{-1}

- Require 3 leptons (2 with Z mass), 2+ jets
- Limit: $m_T > 475$ GeV
- PRL **107**, 271802 (2011)

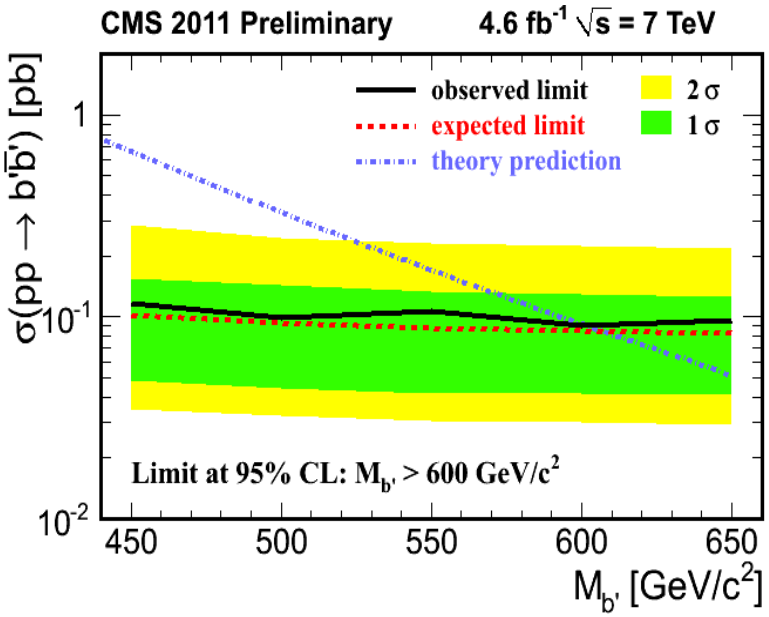


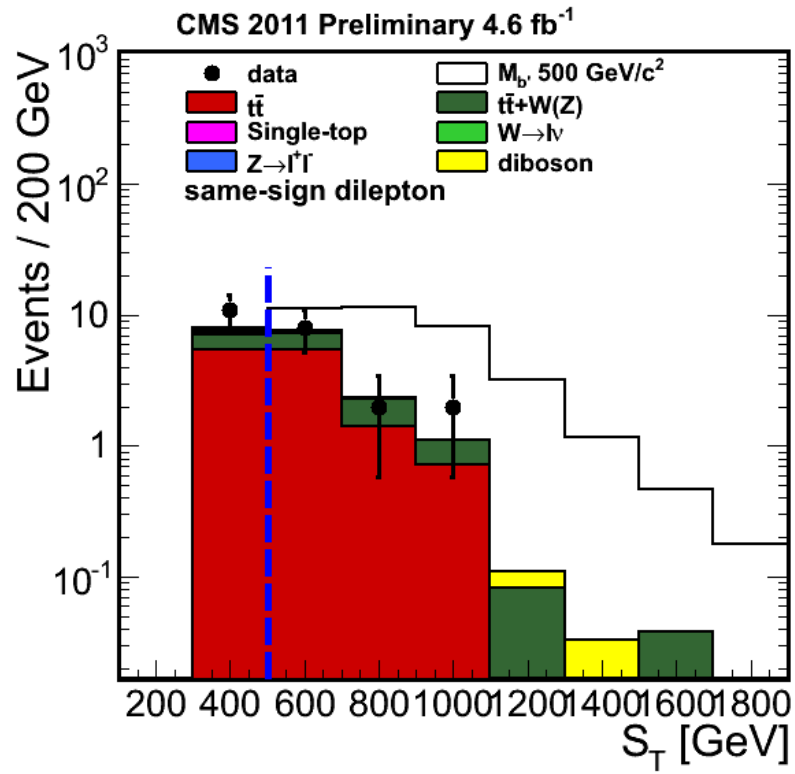
4th generation quarks (4/4)

There are a few searches with all the data

CMS search for $BB \rightarrow (Wt)(Wt)$ in 4.6 fb^{-1}

- 3 leptons or 2 same-sign leptons plus a b-jet
- Limit: $m_B > 600$ GeV
- CMS EXO-11-036 Winter 2012

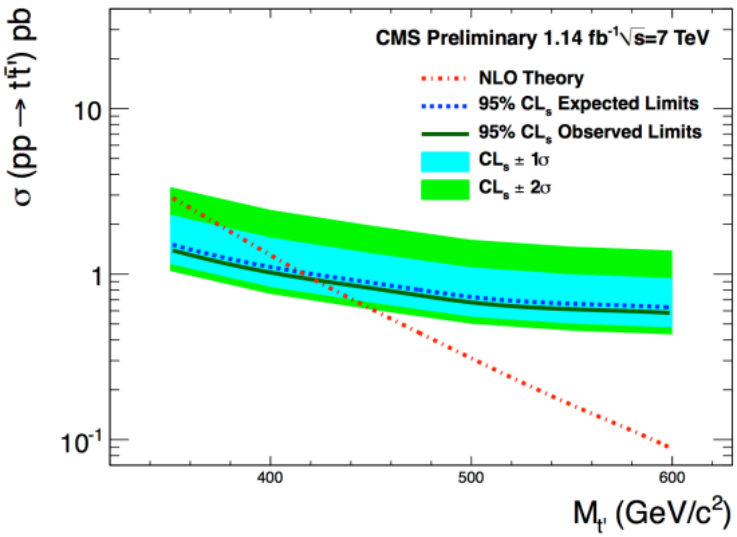


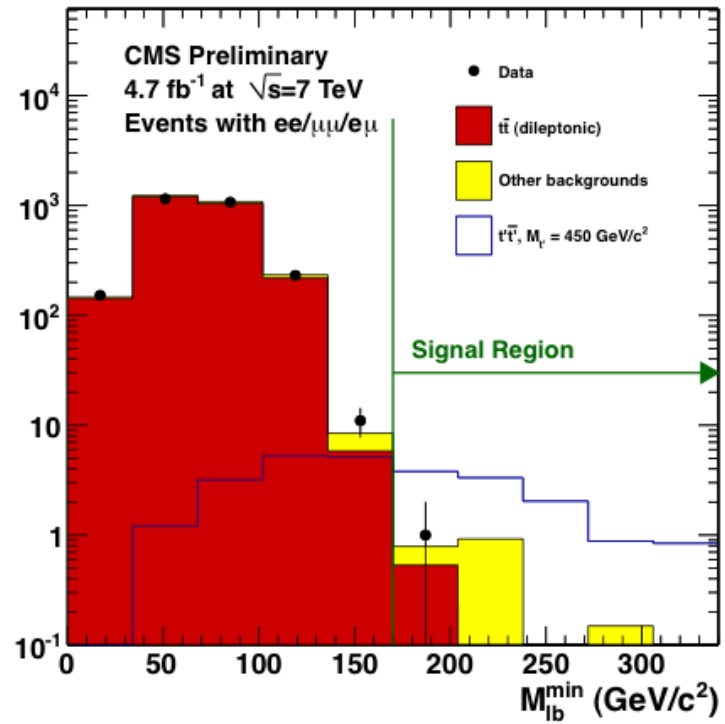


4th generation quarks (5/6)

CMS search for $TT \rightarrow (Wb)(Wb) \rightarrow llX$ in 4.7 fb^{-1}

- Require 2 leptons, 2+ jets, high MET
- Limit: $m_T > 552$ GeV
- CMS EXO-11-050 Winter 2012

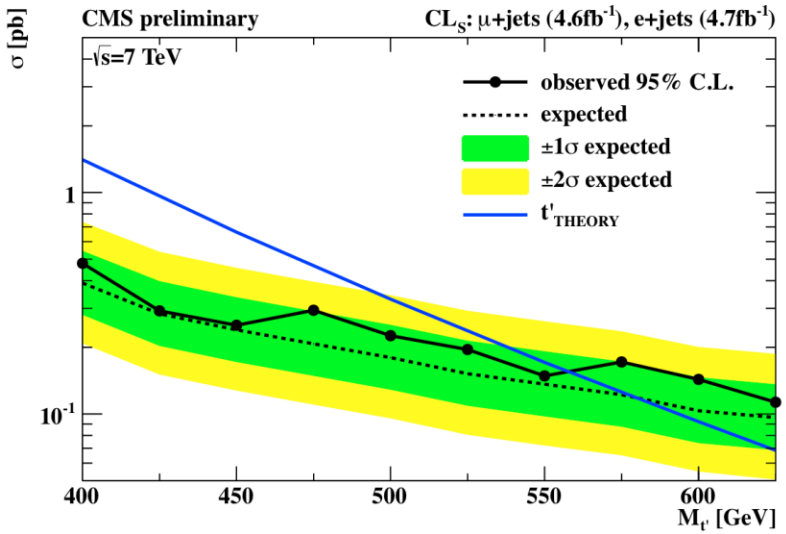


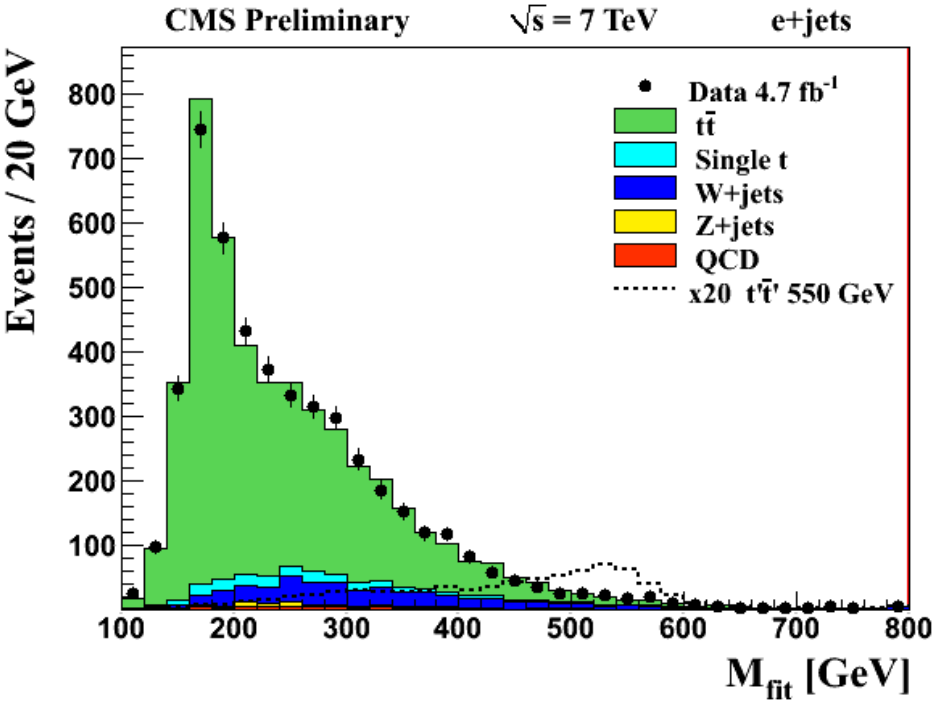


4th generation quarks (6/6)

CMS search for $TT \rightarrow (Wb)(Wb) \rightarrow lX$ in 4.7 fb^{-1}

- Require 1 lepton, 4 jets, 1 b-tag and MET
- Limit: $m_T > 560$ GeV
- CMS PAS EXO-11-099





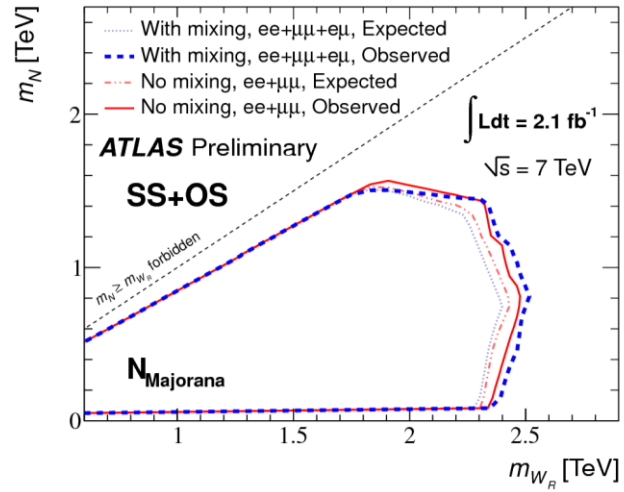
4th generation quarks: Summary

Exp.	Channel	$\int L\,dt$ [fb^{-1}]	Mass limit
ATLAS	$Qq \to Wqq'$	1.0	$m_Q > 900$ GeV
ATLAS	$Qq \to Zqq'$	1.0	$m_Q > 760$ GeV
ATLAS	$QQ \to (Wq)(Wq)$	1.0	$m_Q > 350$ GeV
CMS	chiral $Q \to WbX$	1.1	$m_Q > 490$ GeV
ATLAS	$TT \to (Wb)(Wb)$	1.0	$m_T > 404$ GeV
ATLAS	$TT \to (tA_0)(tA_0) \to l\,X$	1.0	$m_T > 420$ GeV
CMS	$TT \to (Wb)(Wb) \to llX$	4.7	$m_T > 552$ GeV
CMS	$TT \to (Wb)(Wb) \to lX$	4.7	$m_T > 560$ GeV
CMS	$TT \to (Zt)(Zt)$	1.1	$m_T > 475$ GeV
ATLAS	$BB \to (Wt)(Wt) \to ljjjjjjX$	1.0	$m_B > 480$ GeV
ATLAS	$BB \to (Wt)(Wt) \to llX$ (SS l)	1.0	$m_B > 450$ GeV
CMS	$BB \to (Wt)(Wt)$	4.6	$m_B > 600$ GeV

Heavy neutrinos

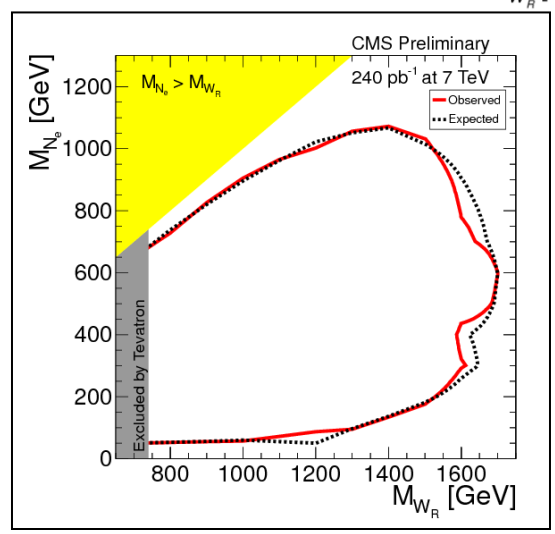
ATLAS and CMS search for heavy neutrinos

- In LRSM, these appear as right-handed partners of the light neutrinos
- $qq \rightarrow W_R \rightarrow Nl \rightarrow W_R{}^{*}ll \rightarrow lljj$
- Leading to a mass resonance both ljj and $lljj$



ATLAS search in 2.1 fb^{-1}

- Assume similar masses for N_e and N_μ
- Limit: $m_{W_R} > 2.3$ TeV
  - for $(m_{W_R} - m_N) < 300$ GeV
- Separate limits for Dirac and Majorana
  - But very similar results.
- Limits also set on an effective operator model
- ATLAS Preliminary



CMS search in 240 pb^{-1}

- Limits extend to about $m_{W_R} > 1.6$ TeV
- Separate limits for e and μ
  - Similar results for the two flavors
- CMS PAS EXO-11-002

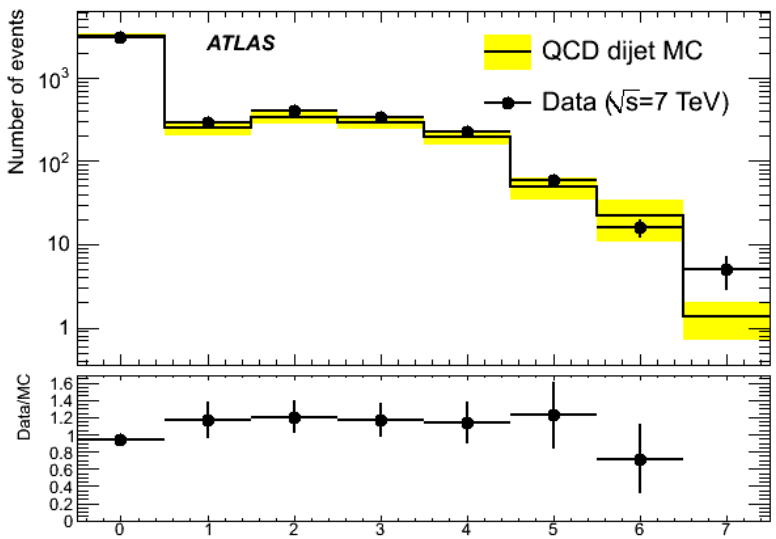
New stable particles (1/2)

ATLAS and CMS search for new stable particles

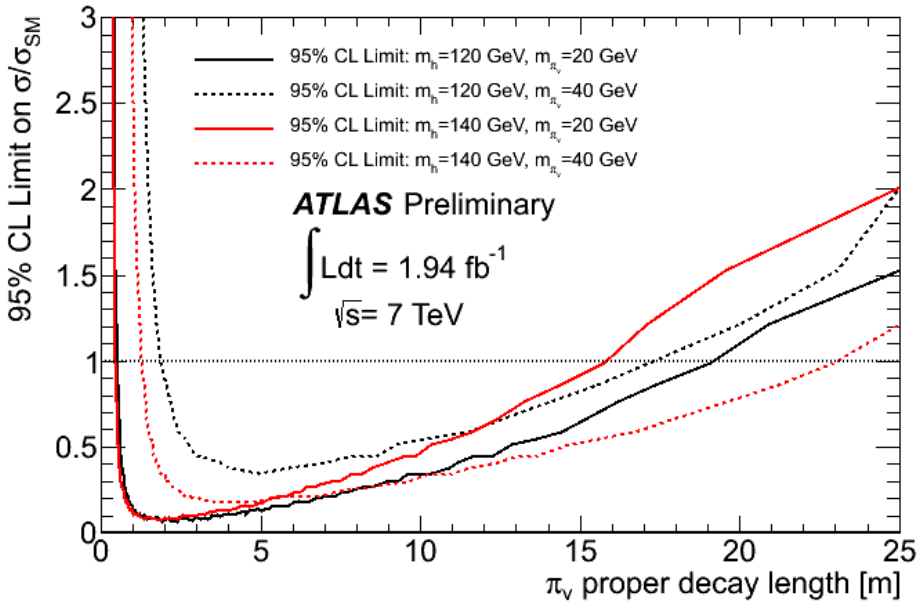
- Decay far from the interaction point or unusual signatures in the detector
- See SUSY talk (Steven Lowette on Thursday) and pages for more searches

ATLAS search in 1.9 fb^{-1}

- Search for pairs of back-to-back particles decaying in the muon spectrometer
- Signature of $h^0 \rightarrow \pi_v \, \pi_v$ where π_v is a weakly-interacting pseudoscalar decaying to heavy fermions
- arxXiv:1203.1303 (submitted to PRL)



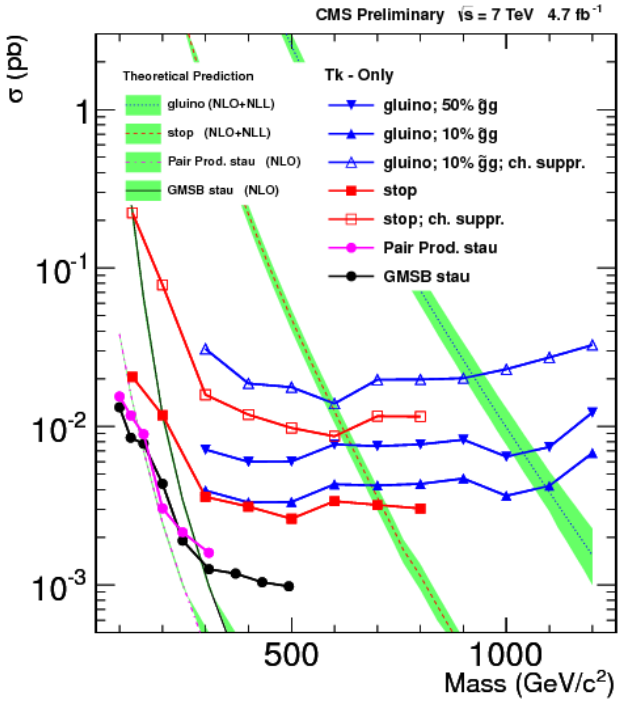
 # muon ROI

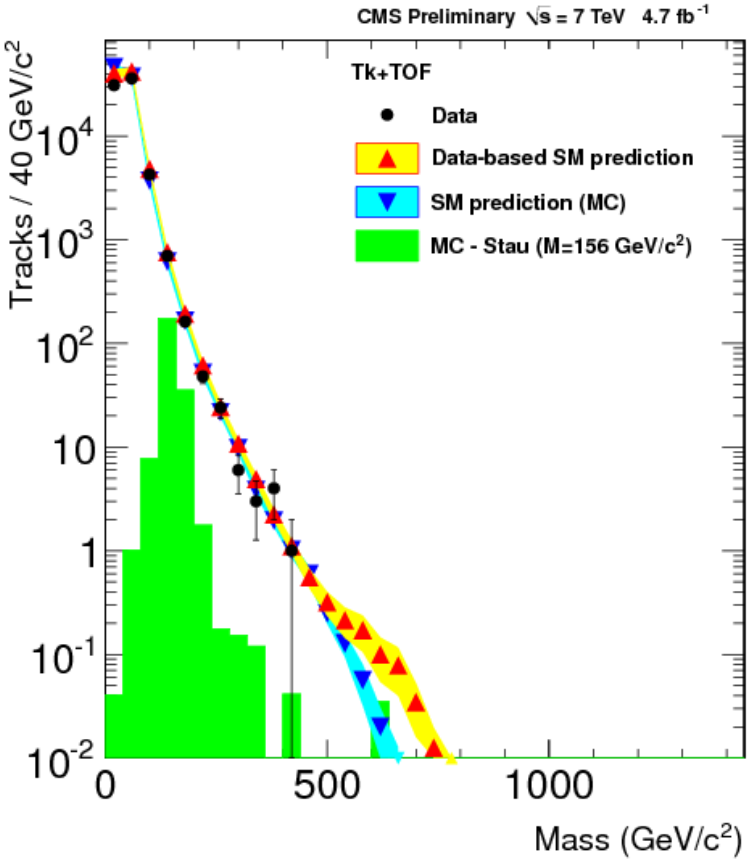


New stable particles (2/2)

CMS HSCP search in 4.7 fb^{-1}

- Use momentum-ionization in the tracker to identify heavy stable charge particles
- Mass limits of 200-900 GeV set on a variety of SUSY particles
- CMS EXO-11-022 Winter 2012





Summary

2011 run at the LHC was very successful

- Both ATLAS and CMS have 5 fb^{-1} of 7 TeV data

ATLAS and CMS are quickly analyzing these data

- Long list of BSM results presented here based on 2011 data
  - Most on the first 1-2 fb^{-1} but a few analyses already use the full dataset
- No BSM physics (yet)

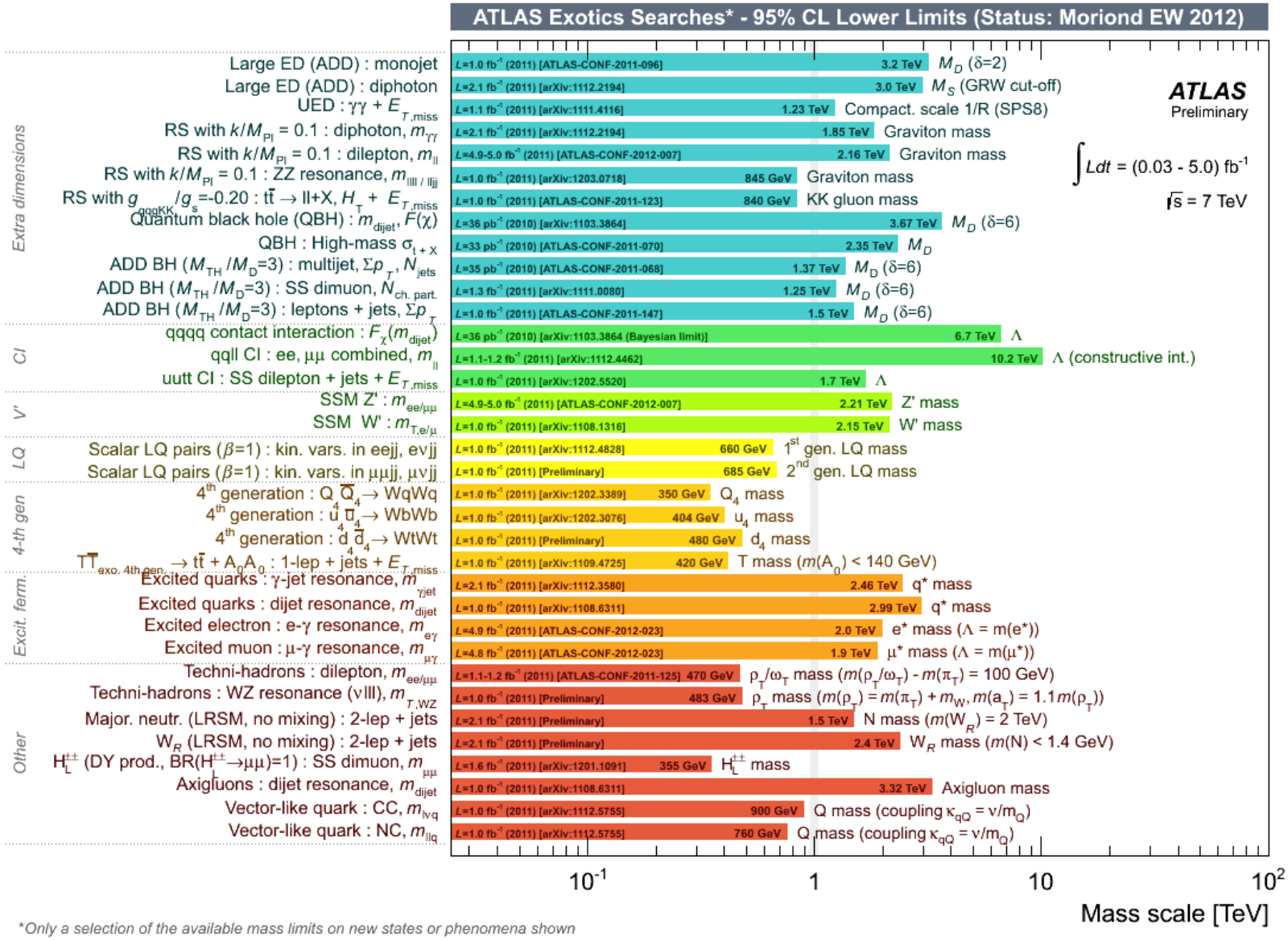
Acknowledgements

- Thanks to ATLAS and CMS for the honor to represent them.
- Thanks to conference organizer and support staff for the interesting program and the enjoyable week.

Extras

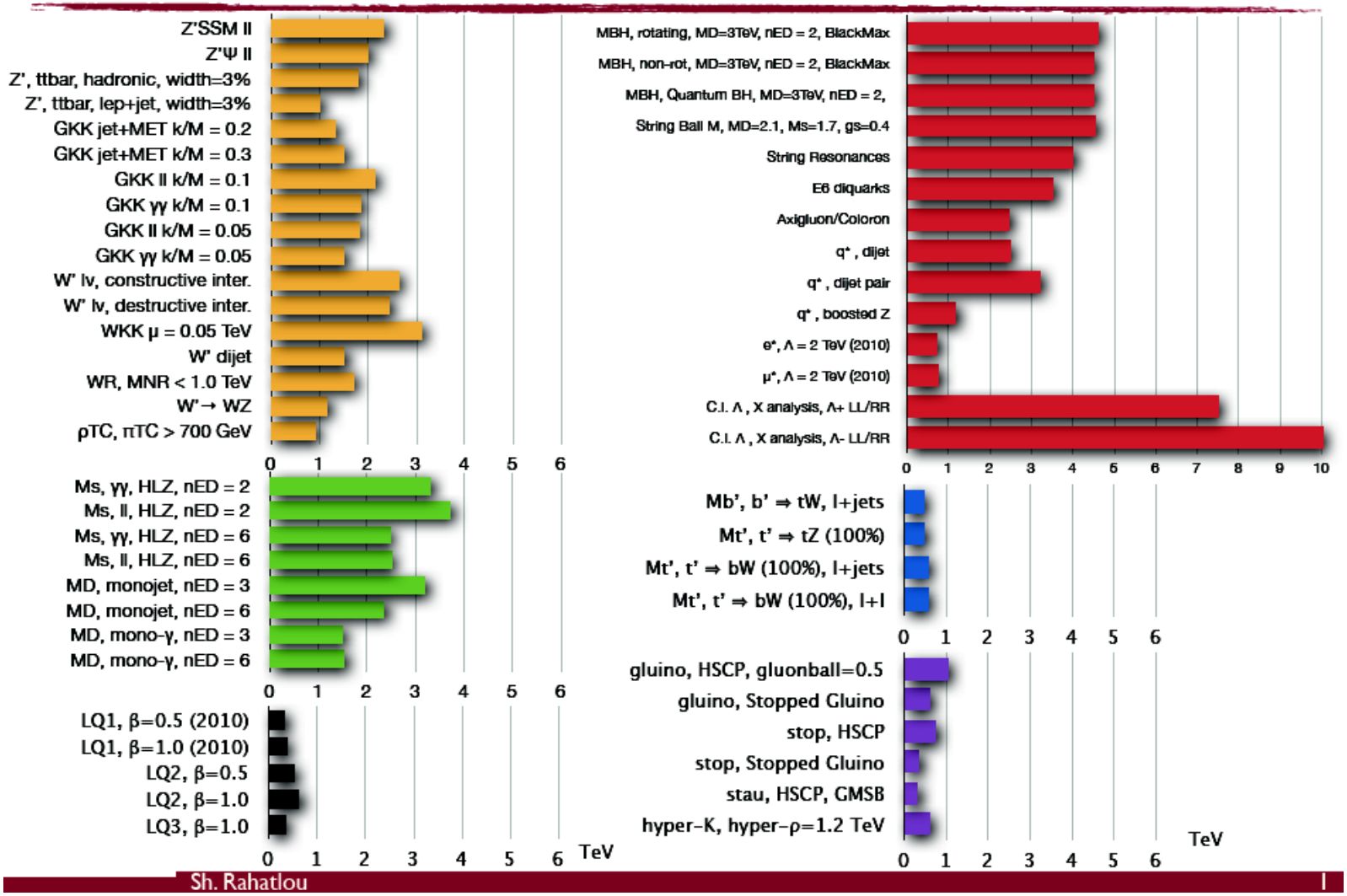
Backup slides follow…

ATLAS search summary



CMS search summary

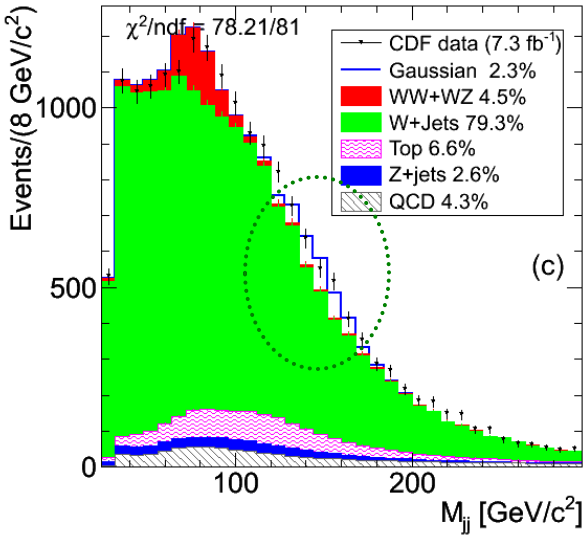
GRAND SUMMARY MORIOND 2012



CDF W-associated dijet resonance

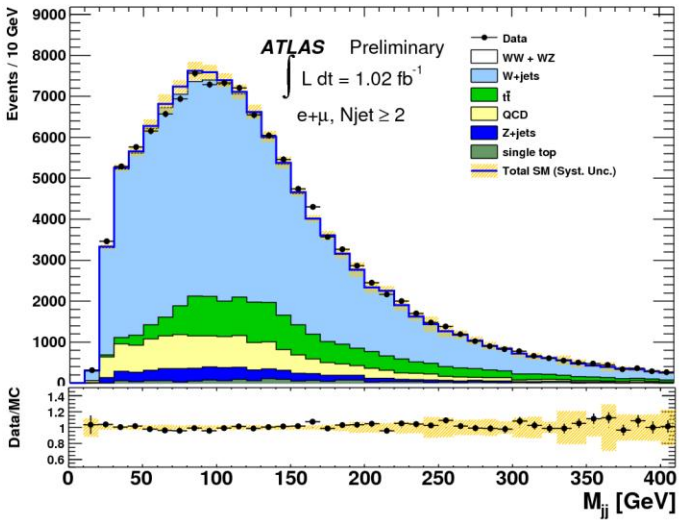
CDF has reported a dijet resonance

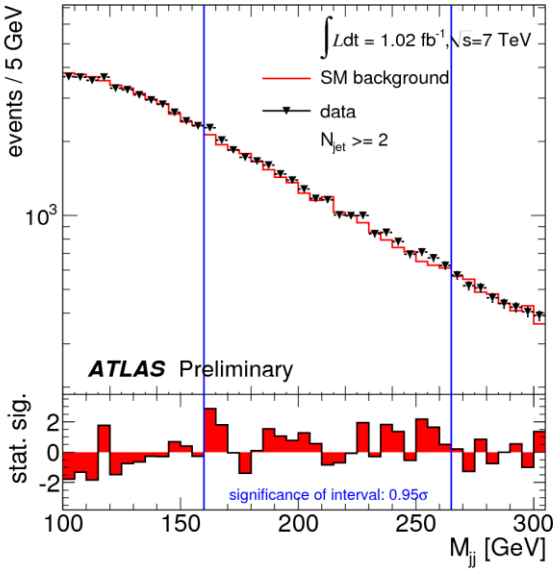
- In events containing W-bosons
- Updated to 7.3 fb^{-1}
- Significance is 4.1 sigma
- PRL **106**, 171801 (2011), CDF update to 7.3 fb^{-1}



ATLAS has performed a similar search with 1.02 fb^{-1}

- No evidence for an excess
- ATLAS-CONF-2011-097





Extra dimensions: RS model

Extra dimensions

- Models with compact extra dimensions can resolve the hierarchy problem
  - The Planck mass M_{Pl} in the SM (3+1) dimensions is naturally much larger than the fundamental Planck mass in the bulk
- Two models are considered: RS and ADD
- Search for graviton or other KK excitations
  - Graviton decay to fermions suppressed w.r.t. boson because of spin

RS model

- The Randall-Sundrum (RS or RS1) model posits the existence of a 5th dimension bounded by two (3+1) branes with SM fields localized on the TeV brane
  - PRL 83, 3370 (1999)
- Gravitons appear as well-separated KK states, i.e. distinct resonances: m_G, …
- Strength of the coupling to the SM is parameterized by the dimensionless warp factor k/M_{Pl} where k is the curvature scale (warp factor)
  - Experimentally $0.01 \lesssim k/M_{Pl} \lesssim 0.1$ (precision EW data, perturbativity)
- Limits on m_G depend on k/M_{Pl}

Extra dimensions: ADD model

ADD model

- SM is confined to a (3+1) brane in a space with n_{ED} extra dimensions while gravity propagates through the bulk (full $4 + n_{ED}$) dimensions)
  - Phys. Lett. B 429, 263 (1998), Phys. Rev. D 59, 086004 (1999)
- M_D denotes the Planck scale in the bulk (M_{Pl} in the SM brane)
  - Fundamental Planck scale
- Gravitons appear as a series of closely spaced KK excitations
  - Experimental decay spectrum will be a continuum
- UV scale M_S is introduced to keep the cross section from diverging
  - Effective Planck scale
  - Three conventions for this: GRW, Hewett and HLZ
- Limits on M_D or M_S depend on convention and n_{ED}