Searches for new physics at ATLAS and CMS

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on behalf CMS and ATLAS Collaboration

Disclaimer

- CMS and ATLAS searches hundreds of new physics models
- Today, I will only show some personal collections

Complete information about all results:

- ATLAS
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- CMS
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Introduction

The Standard Model is a (very) effective theory that breaks down at a certain scale

→ Hierarchy:quadratic divergence of the Higgs mass, extremely fine-tuned

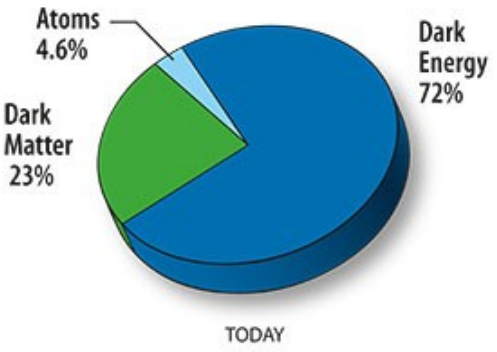
→ What is the underlying nature of EWSB?

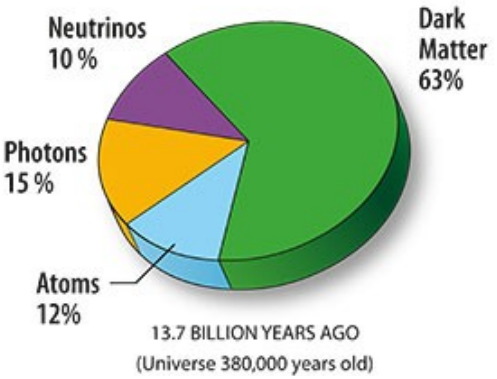
Dark Matter

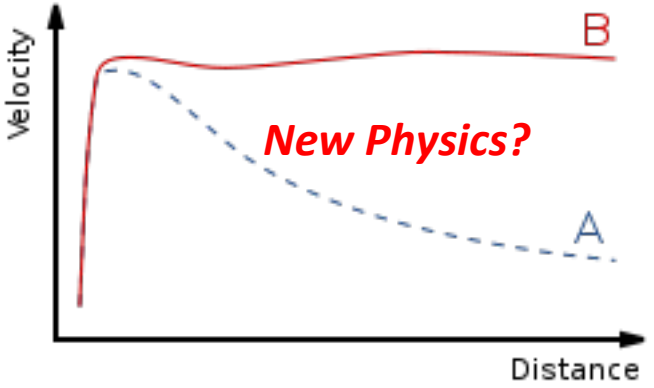
→ cannot be explained by SM

Neutrinos have mass

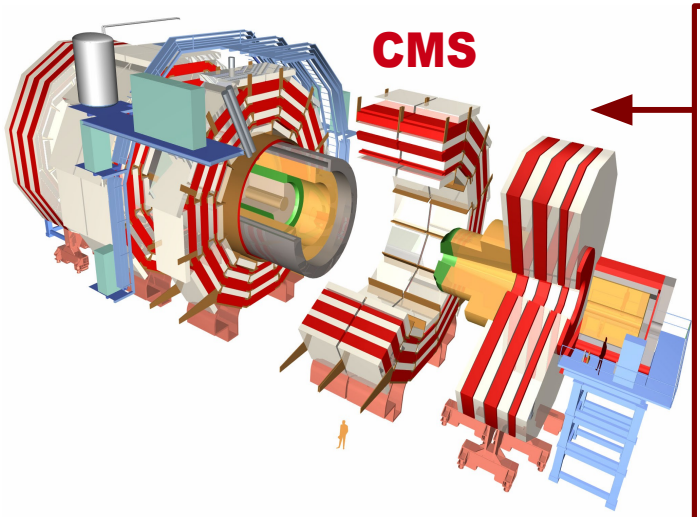
→ where are the right-handed neutrinos?





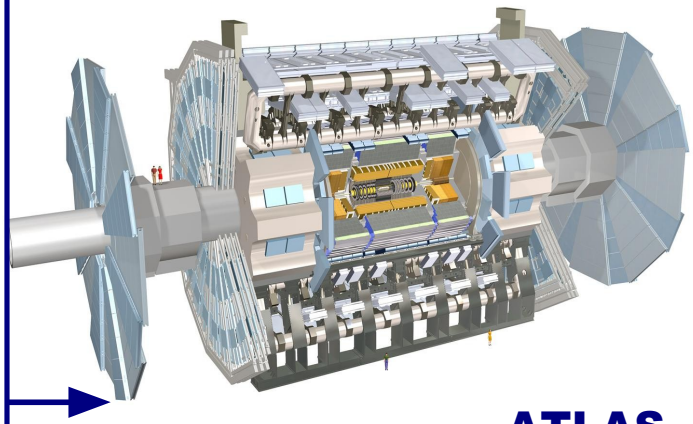


CMS and ATLAS



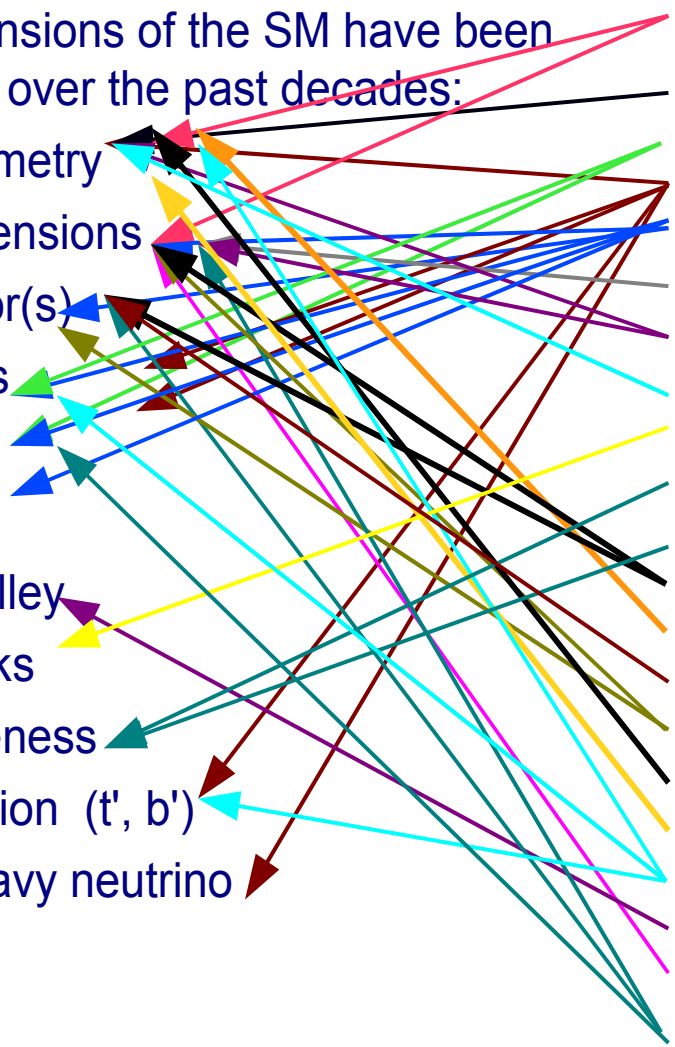
- 3.8T solenoid containing calorimeters
- Silicon tracker: $\sigma(p_T)/p_T \sim 15\%$ at 1TeV
- EM cal: homogeneous Lead-Tungstate crystal, $\sigma_E/E \sim 3\%/\sqrt{E[GeV]} \oplus 0.5\%$
- HAD cal: Brass-scint., $\geq 7\lambda_0$
  $\sigma_E/E \sim 100\%/\sqrt{E[GeV]} \oplus 5\%$
- Iron return yoke muon spectrometer

- 2T solenoid inside calorimeters
- Silicon+TRT tracker + electron ID
- EM cal: Longitudinally segmented Lead-Ar:
  $\sigma_E/E \sim 10\%/\sqrt{E[GeV]} \oplus 0.7\%$
- HAD cal: Fe-scint + Cu-Ar, $\geq 11\lambda_0$
  $\sigma_E/E \sim 50\%/\sqrt{E[GeV]} \oplus 3\%$
- Air-toroid muon sp.: $\int \sqrt{B}.dl$ = 1 to 7 T.m



More models more fun

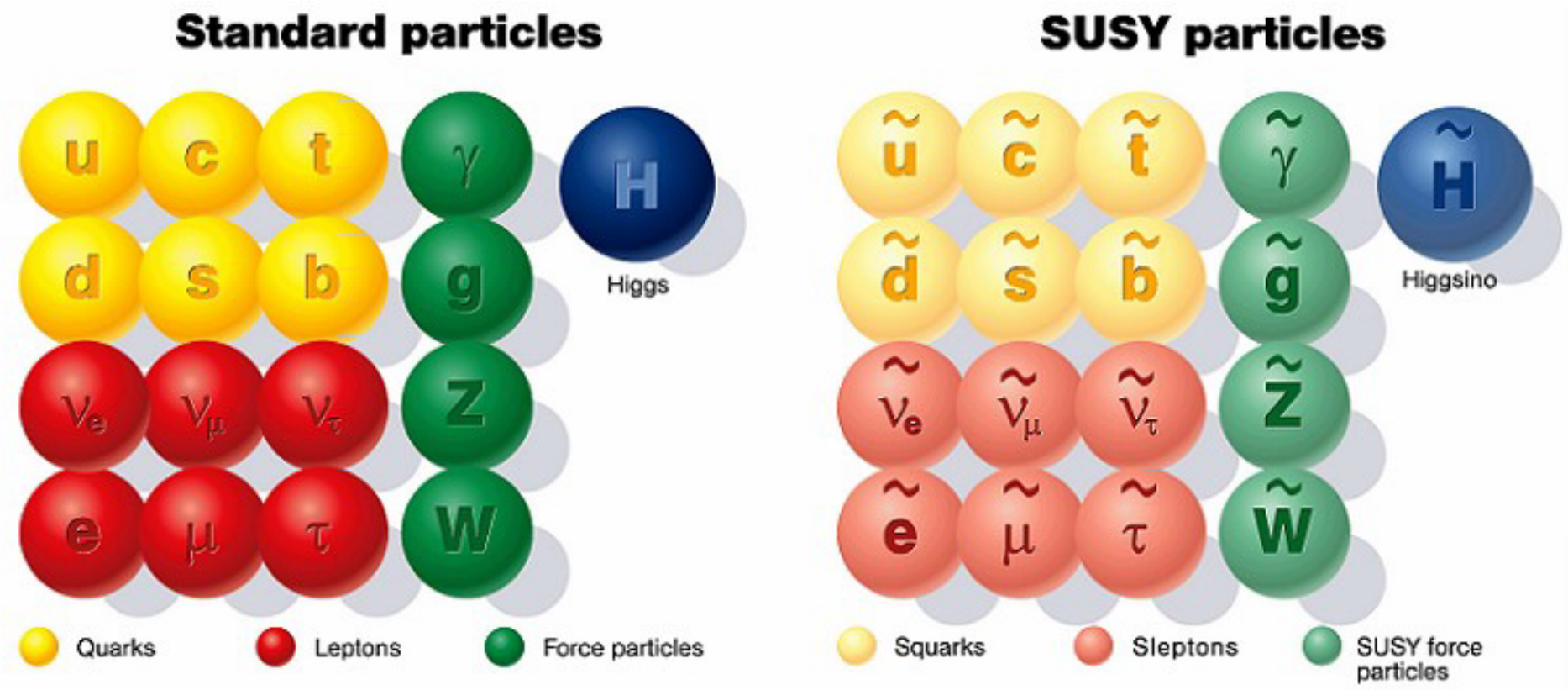
- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4^{th} generation (t', b')
- LRSM, heavy neutrino
- etc...



- 1 jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign di-lepton
- Dilepton resonance
- Diphoton resonance
- Diphoton + MET
- Multileptons
- Lepton-jet resonance
- Lepton-photon resonance
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+Gamma resonance
- Top-antitop resonance
- Slow-moving particles
- Long-lived particles
- Top-antitop production
- Lepton-Jets
- Microscopic blackholes
- Dijet resonance
- etc...

(for illustration only)

Supersymmetry



- Supersymmetry links fermions and bosons
- Elegant solution to the hierarchy problem
- Unification of the gauge couplings

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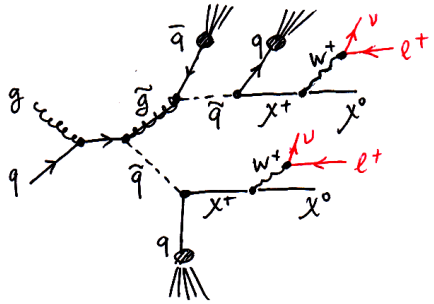
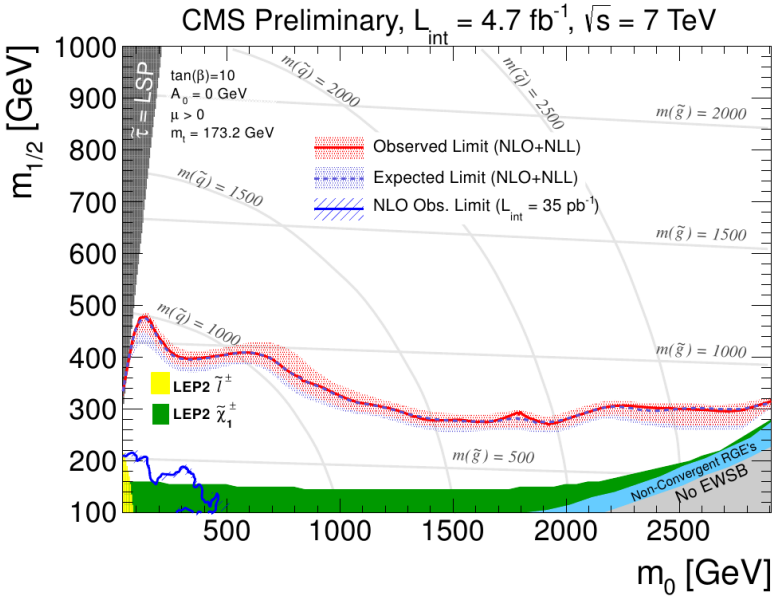
Same sign dilepton

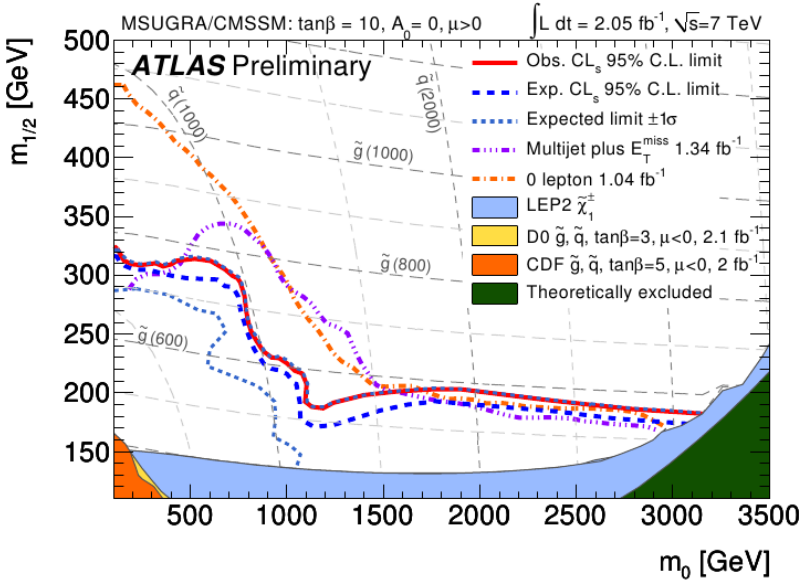


SS dilepton can arise from e.g. gluino squark production

CMS-SUS-11-010

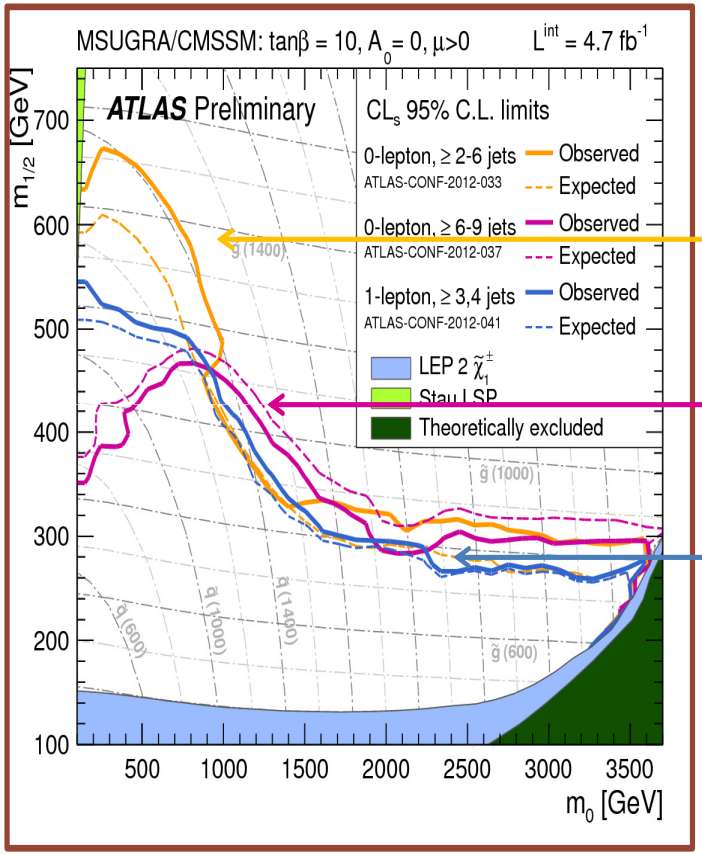


ArXiV:1203.5763



Results in some benchmark models

- search for squark/ gluino production in final states with jets, missing E_T , and 0/1 lepton
- Sensitive to final states from squarks mass scale



ATLAS-CONF-2012-033 (4.7 fb^{-1})
Up to 6 jets + E_T^{miss}

ATLAS-CONF-2012-037 (4.7 fb^{-1})
Up to 9 jets + E_T^{miss}

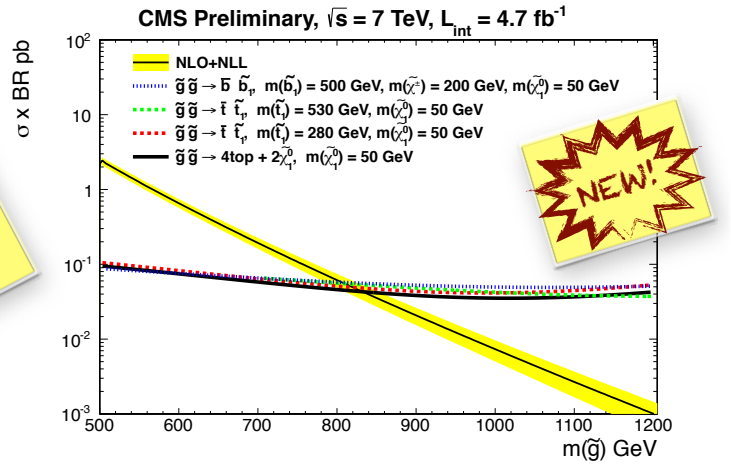
ATLAS-CONF-2012-041 (4.7 fb^{-1})
1 lepton + jets + E_T^{miss}

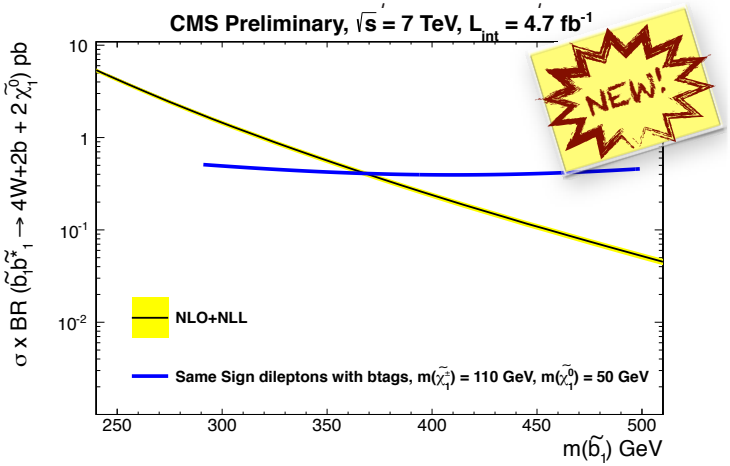
Same sign dilepton with bjet

SS Dileptons + 2b-jets

- Similar to SS dilepton analysis: just add 2 b-tagged jets
- Fake lepton background from b's dramatically smaller!
- top contribution expected to decrease by factor of 2!
- More exclusive search
  - Same-sign top production
  - SUSY 4 top final states
  - SUSY sbottom pair production
  - SUSY 4b4W final states

SUS-11-020



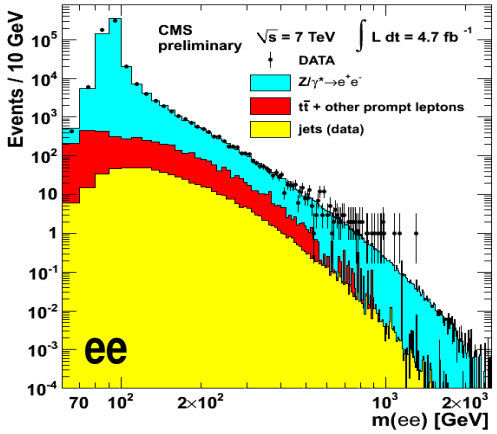


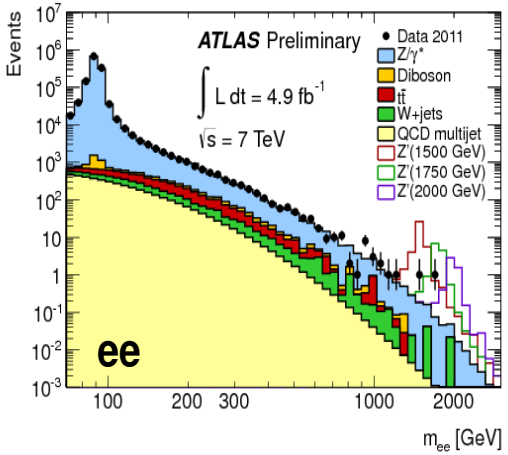
R. Cavanaugh
Chicago 2012, May 2nd, 2012

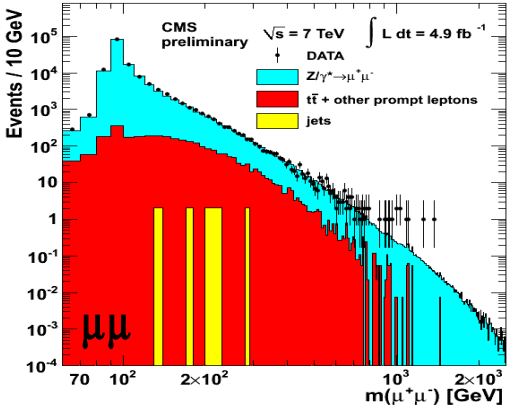
Dilepton Resonances 1/3
Mass Spectrum

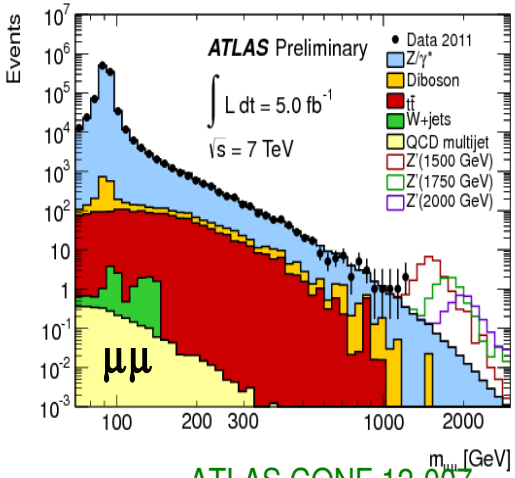
Expected in many new physics models:

- Z’
- gravitons
- Technicolor









CMS EXO-11-019

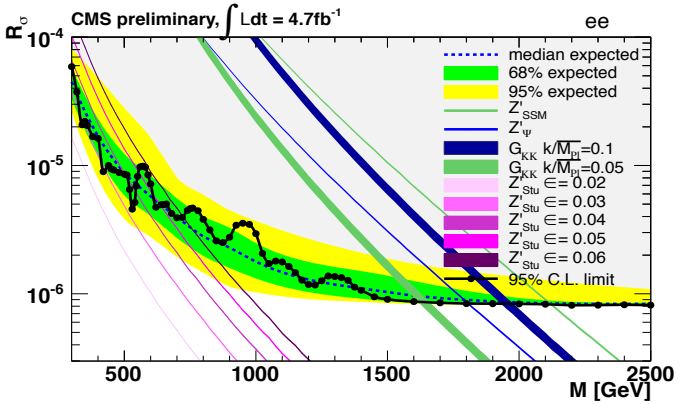
ATLAS CONF 12-007

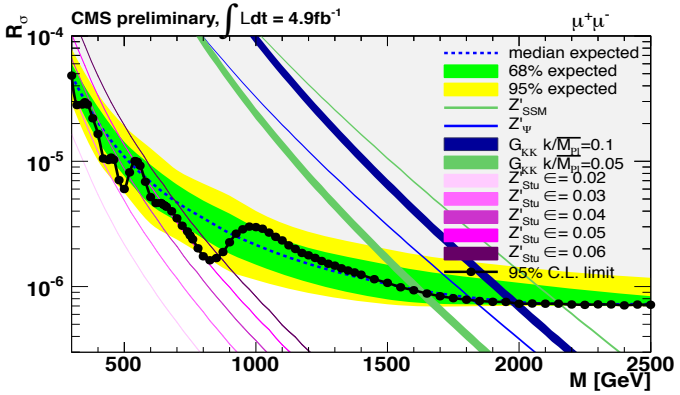
Dilepton resonance 2/3

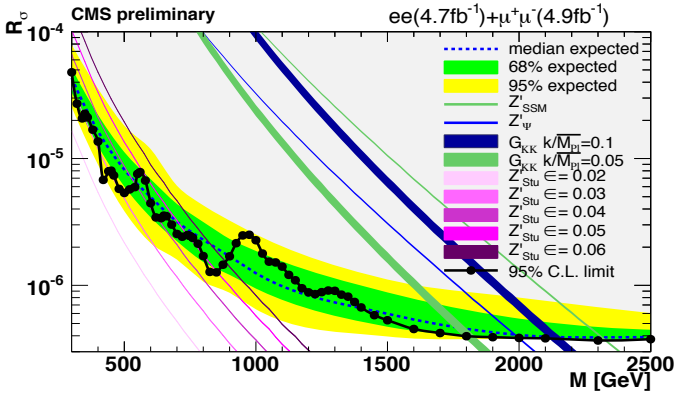
CMS search in 4.7 fb^{-1}

- μμ and ee channels
- $Z'_{SSM} > 1.94$ TeV
- $Z'_{\psi} > 1.62$ TeV
- RS1 graviton
  - $k/M_{Pl} = 0.05$: $m_G > 1.45$ TeV
  - $k/M_{Pl} = 0.10$: $m_G > 1.78$ TeV

CMS PAS EXO-11-019





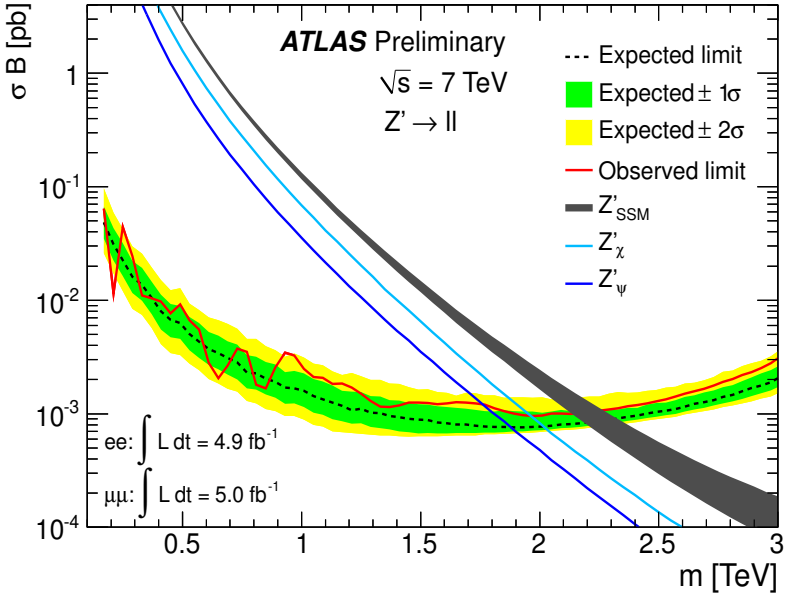


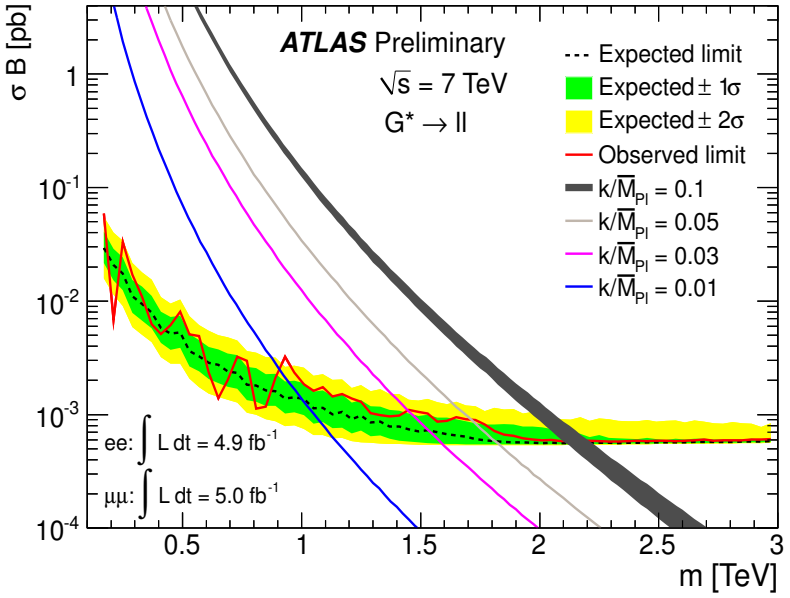
Dilepton Resonance 3/3

ATLAS search in 5 fb^{-1}

- μμ and ee channels
- $Z'_{SSM} > 2.21$ TeV
- $Z'_{\psi} > 1.76$ TeV
- RS1 graviton
  - $k/M_{Pl} = 0.05$: $m_G > 1.71$ TeV
  - $k/M_{Pl} = 0.10$: $m_G > 2.16$ TeV

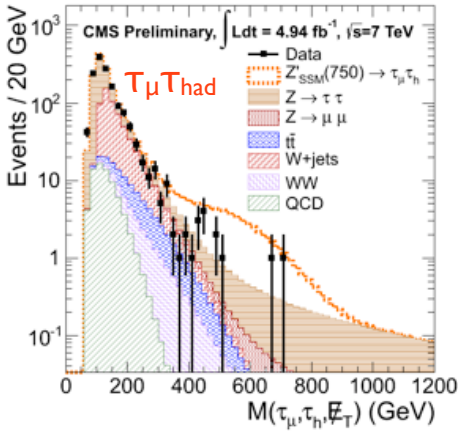
ATLAS-CONF-2012-007

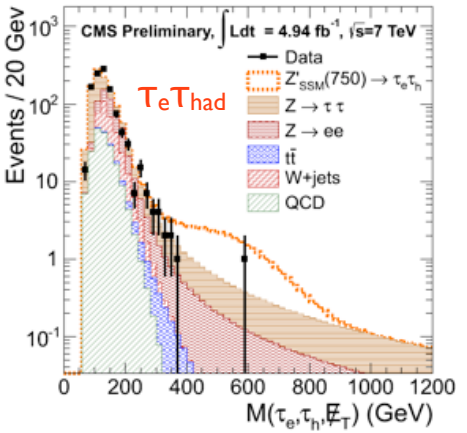


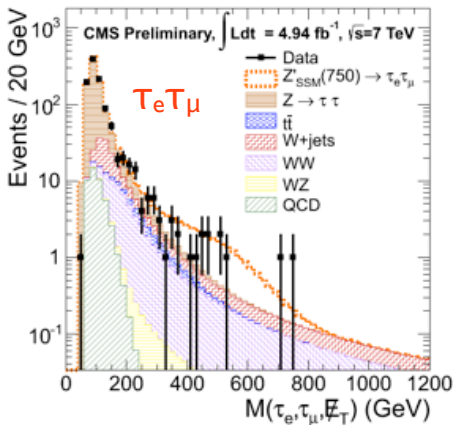


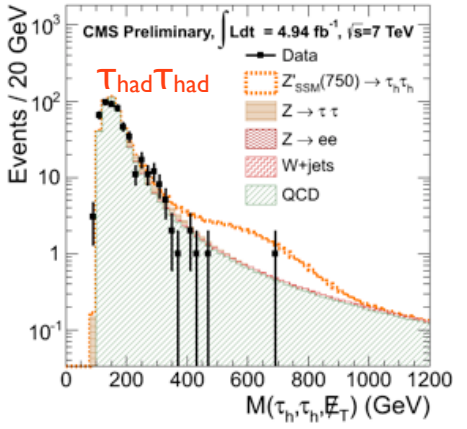
$\tau^+\tau^-$

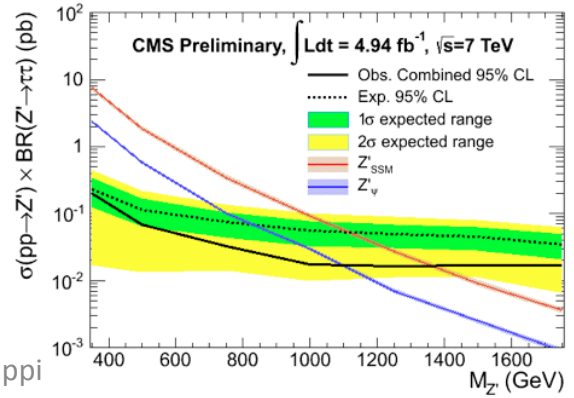
- Searching for a Z' decaying into $\tau^+\tau^-$ pair
- All 4 channels consistent with SM background estimates
- 95% CL limits
  - $Z_{SSM'} > 1.36$ TeV,
  - $Z'_{\psi} > 1.10$ TeV











Dijet resonance

Signature of some new physics models

- String balls
- GUT
- Diquark
- Excied quarks
- Axigluons
- W'
- Z'

CMS search in 1 fb^{-1}

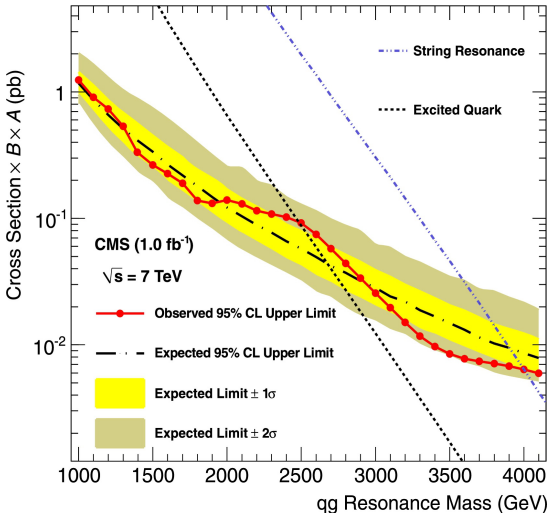
Mass limits:

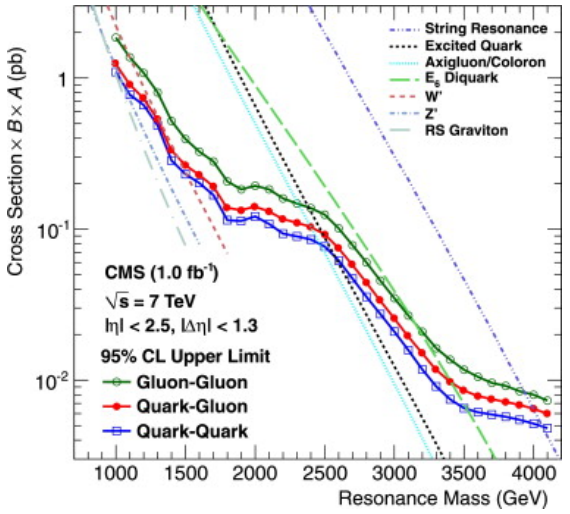
- String resonance: m > 4.00 TeV
- SSM: $m_{W'}$ > 1.51 TeV
- Phys. Lett. B **704**, 123 (2011)

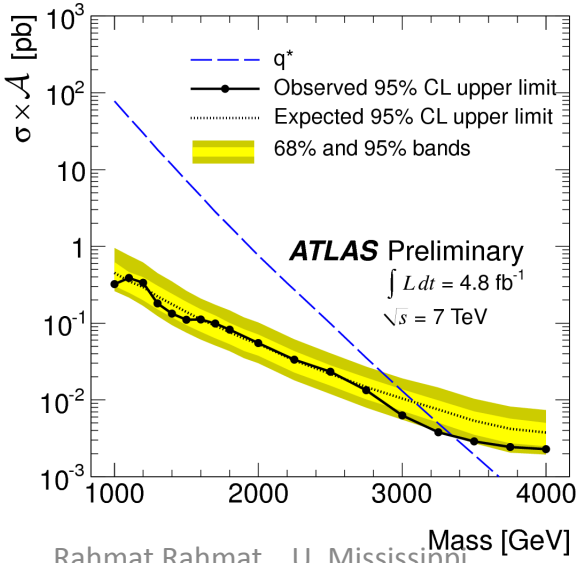
ATLAS search in 4.8 fb^{-1}

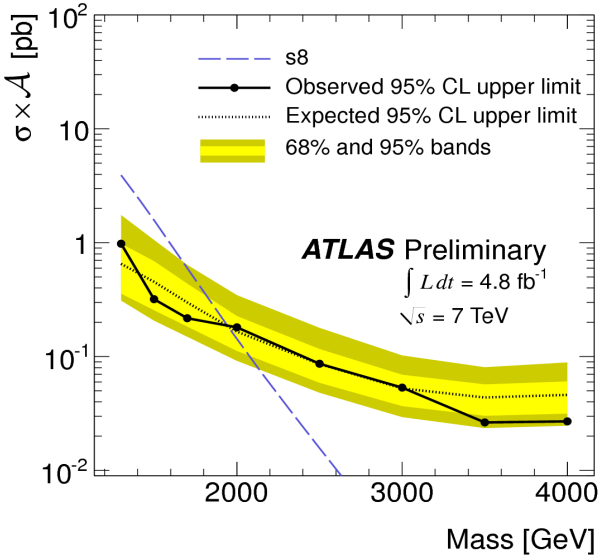
Mass limits:

- m_{q^*} > 3.35 TeV
- m_{s8} > 1.94 TeV
- ATLAS-CONF-2012-038



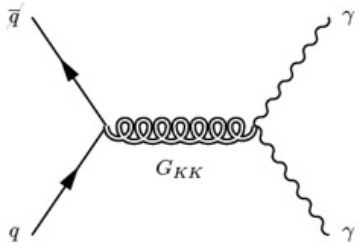


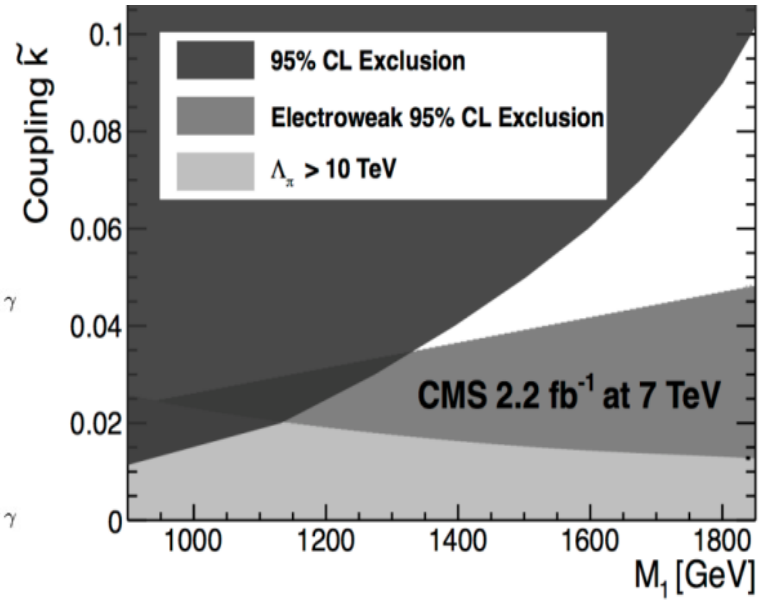




Diphoton

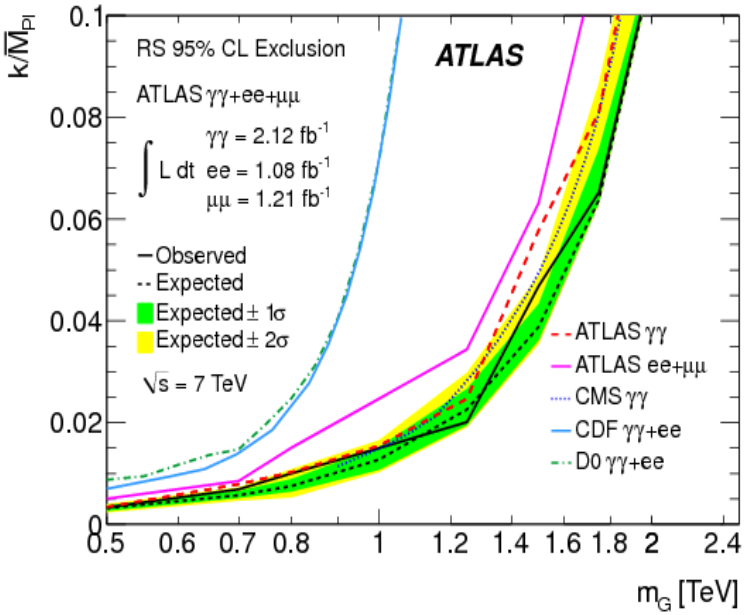
Signature for extra dimension $m_{\gamma\gamma}$





CMS search in 2.2 fb^{-1}

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



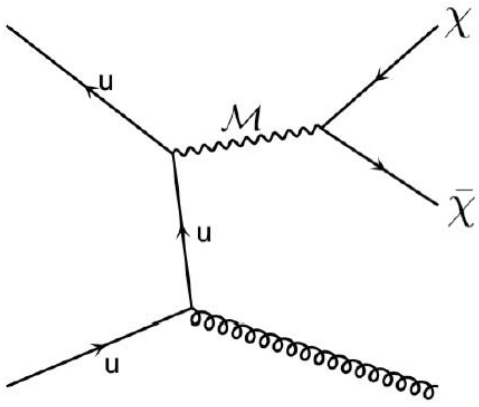
ATLAS search in 2.1 fb^{-1}

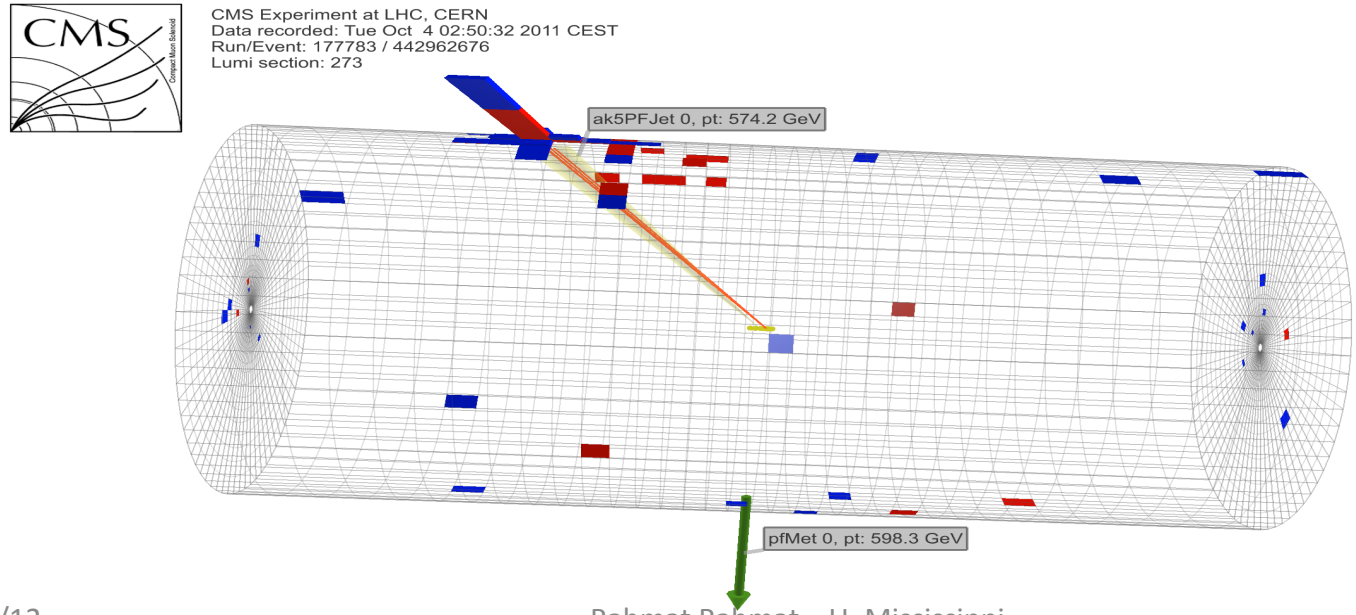
- RS1 M_G > 0.79 – 1.75 TeV
- ADD M_D > 2.3 – 3.5 TeV
- Result combined with dilepton
- arXiv:1112.2194 (submitted to PLB)

Monojet

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→νν
- 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





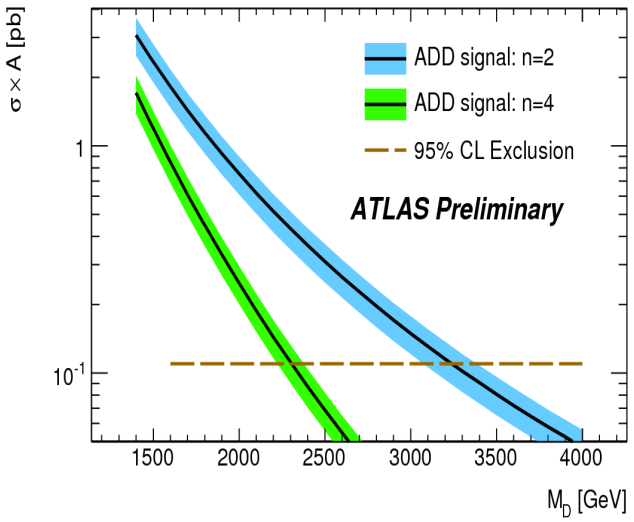
Monojet

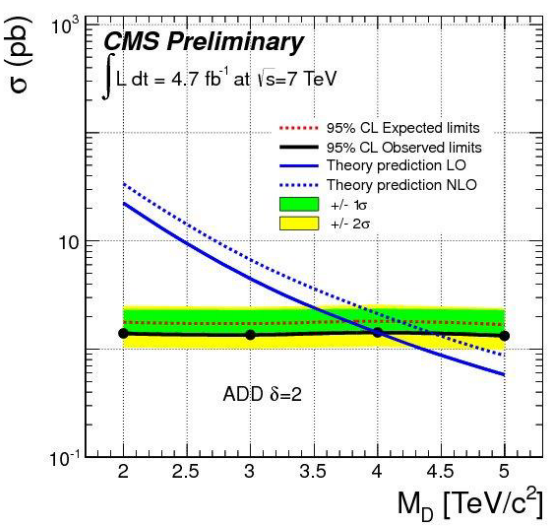
ATLAS result obtained with 1.0 fb^{-1}

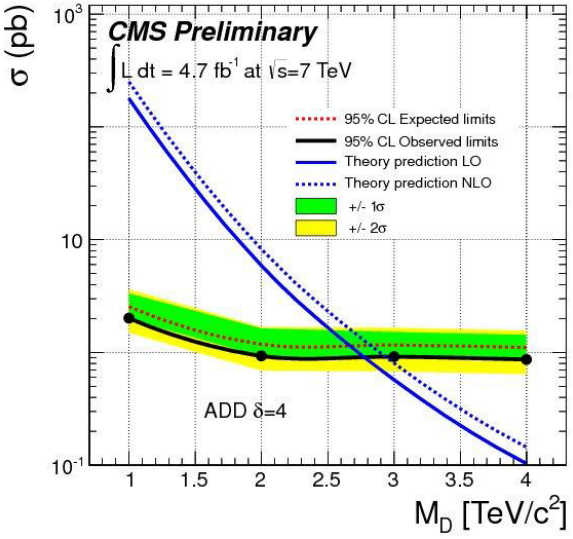
- M_D > 3.4 TeV for n_{ED}=2
- M_D > 2.3 TeV for n_{ED}=4
- ATLAS-CONF-2011-096

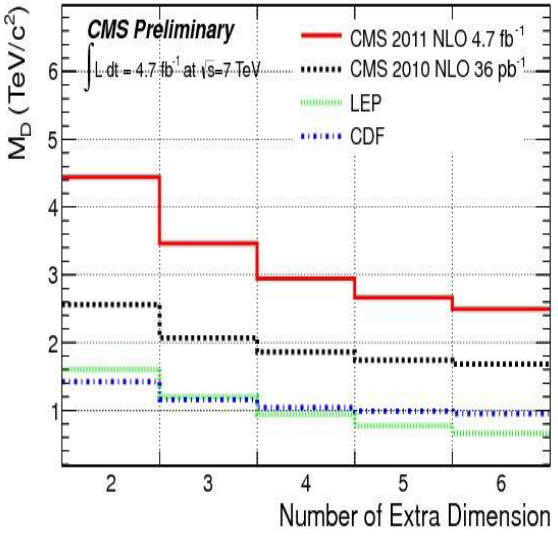
CMS result obtained with 4.7 fb^{-1}

- M_D > 4.44 TeV for n_{ED}=2
- M_D > 2.94 TeV for n_{ED}=4
- Larger with NLO K-factor
- CMS PAS EXO-11-059





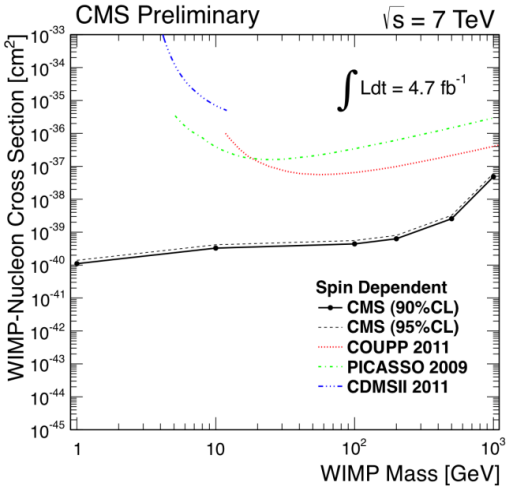


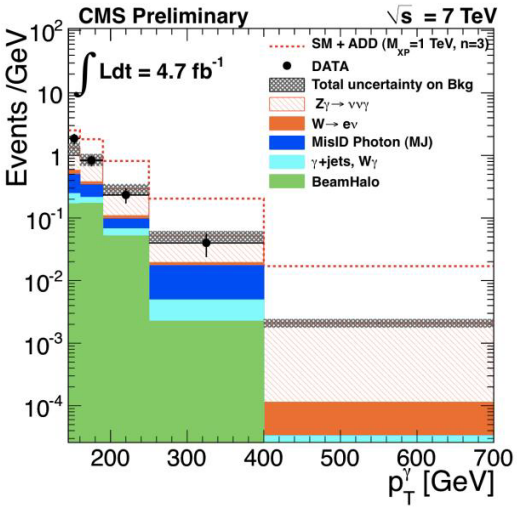


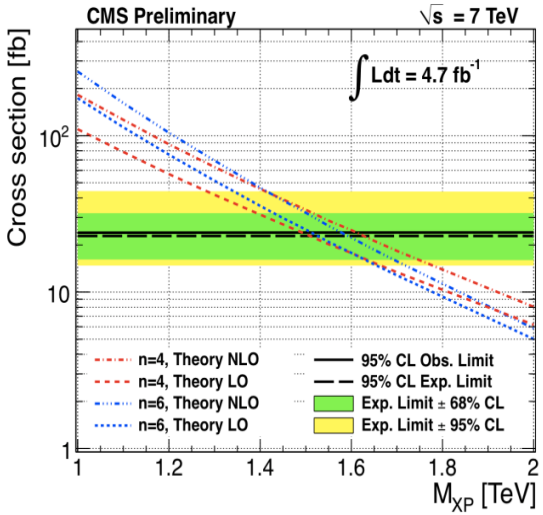
Monophoton

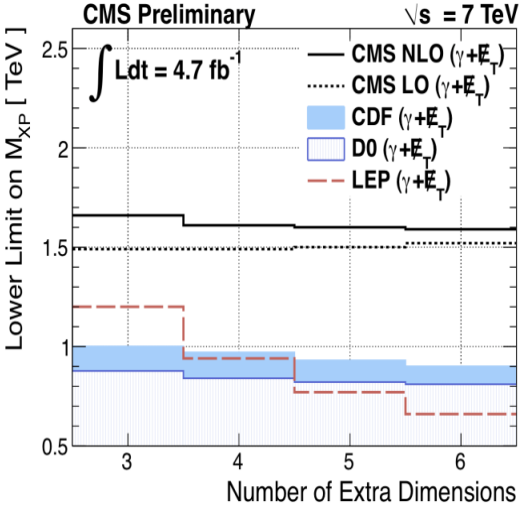
CMS search in 4.7 fb^{-1}

- 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 $1 < M_{DM} <$ 1000 GeV
- CMS EXO 11-096

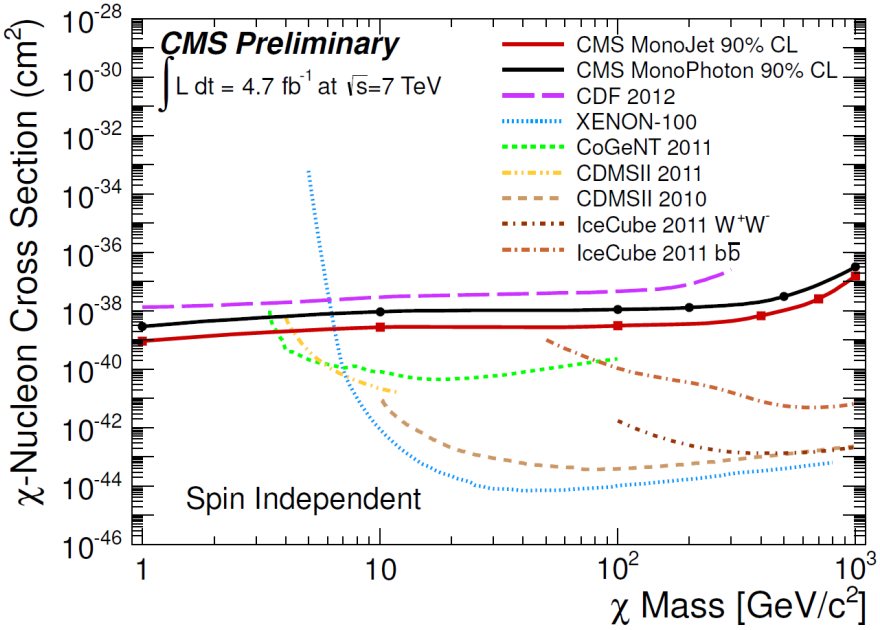


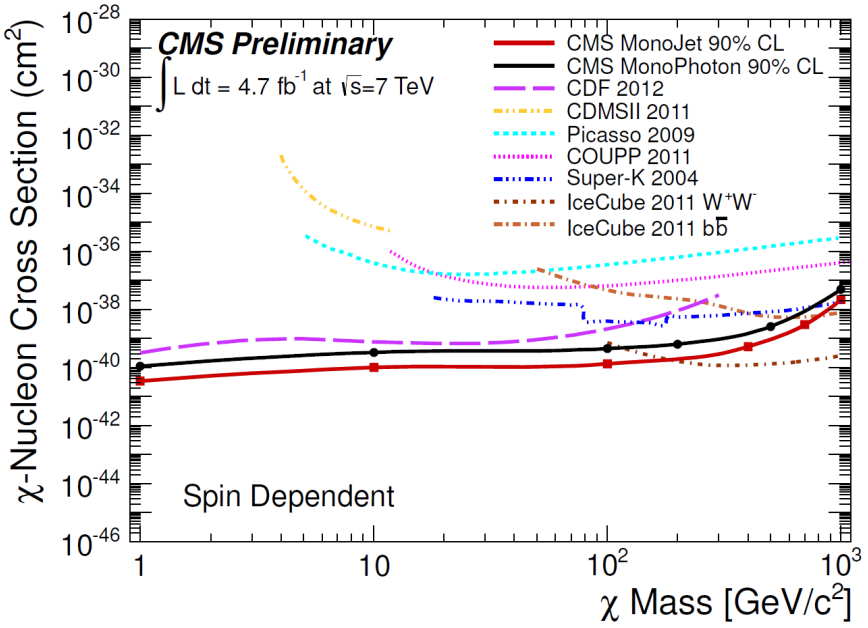






Monojet and Monophoton Results





Best Limit for Dark Matter Mass < 3.5 GeV a region as Unexplored
By Direct Detection Experiments

Lepton+MET

Search for $W' \rightarrow l\,\nu$ ($\ell = e, \mu$)
Calculate mass transverse:

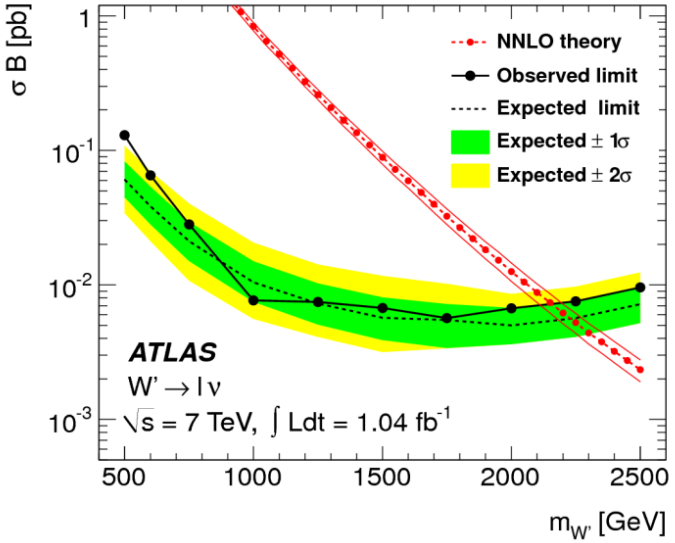
$$M_T = \sqrt{2 \cdot (p_T^{\mu} \cdot c) \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\mu,\nu})}$$

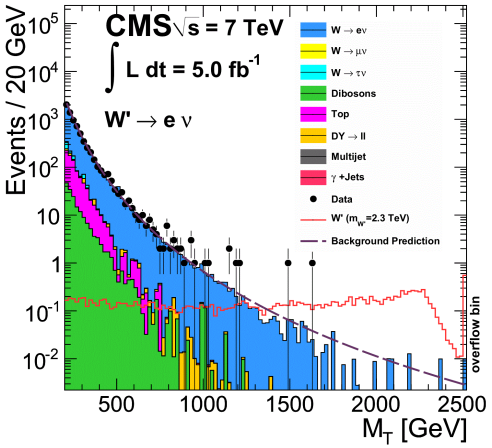
ATLAS result based on 1.0 fb^{-1}

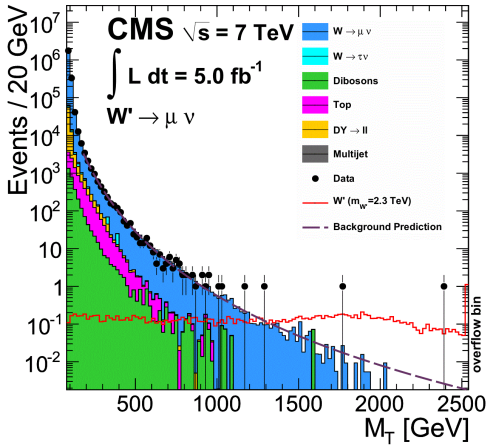
- SSM $m_{W'}$ > 2.2 TeV
- Phys. Lett. B **705**, 28 (2011)

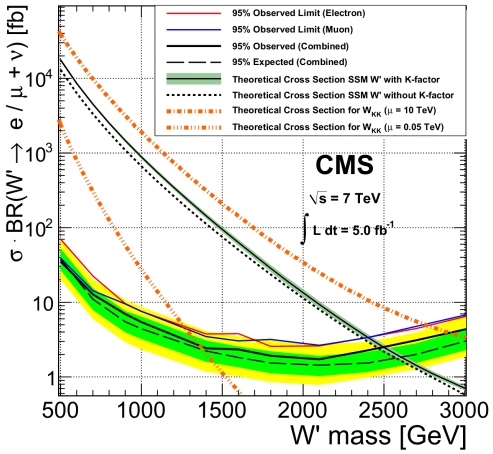
CMS result based on 4.7 fb^{-1}

- SSM $m_{W'}$ > 2.5 TeV
- Submitted to JHEP arXiv: 1204.4764









Leptoquark Search

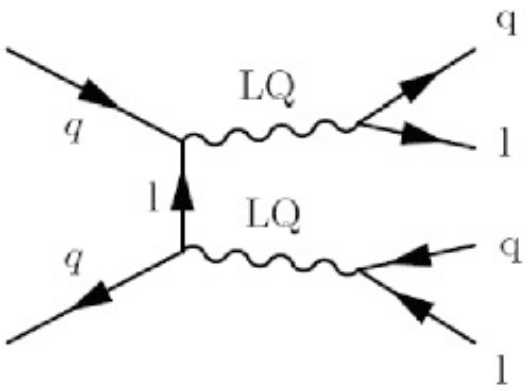
✦ Possibility of a fundamental relationship between quarks and leptons through leptoquarks

- ✤ they are colored and have fractional charge
- ✤ couples to quarks and leptons with coupling λ
- ✤ branching fractions are denoted as: β(lq) and 1- β (**ν**q)

✦ CMS and ATLAS search for all 3 generation of leptoquarks with following final states:

- ✤ llqq (β =1) where l = e, μ
- ✤ l**ν**qq (β =0.5)
- ✤ bb**νν**

✦Limits are set on mass of leptoquarks (M_{LQ})

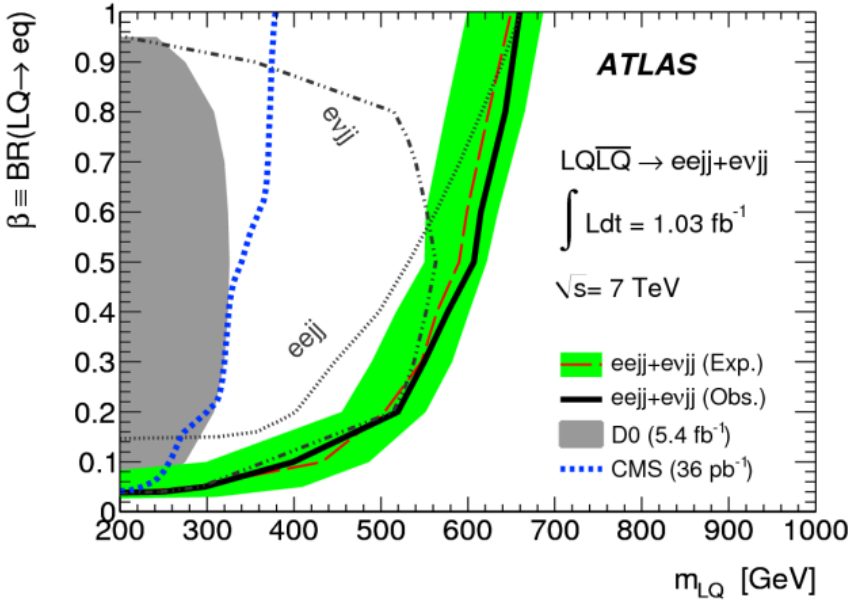


First generation leptoquark

- Pair produced particle decay to νq or lq
- Search both llqq and lνqq channels

ATLAS search in 1.1 fb^{-1}

- Using eejj and eνjj channels
- Limits:
  - m_{LQ} > 660 GeV for β=1
  - m_{LQ} > 607 GeV for β=0.5
- Phys. Lett. B **709**, 158 (2012)



Second generation leptoquark

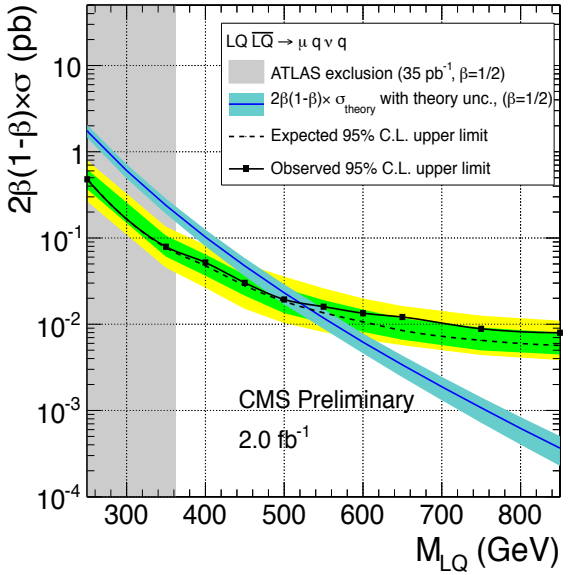
CMS search in 2.0 fb^{-1}

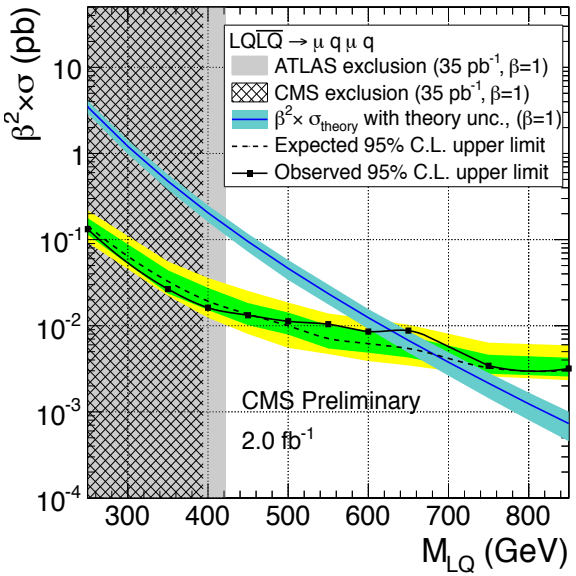
Using $\mu\mu jj$ and $\mu\nu jj$ channels

Limits:

- m_{LQ} > 632 GeV for β = 1
- m_{LQ} > 523 GeV for β = 0.5

CMS PAS EXO-11-028





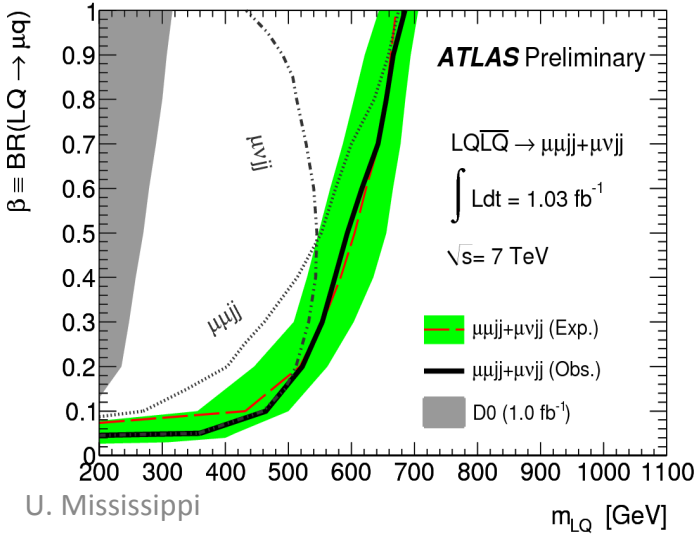
ATLAS search in 1.0 fb^{-1}

Using $\mu\mu jj$ and $\mu\nu jj$ channels

Limits:

- m_{LQ} > 685 GeV for β = 1
- m_{LQ} > 594 GeV for β = 0.5

ATLAS Preliminary



Third generation leptoquark

CMS search in 1.8 fb^{-1}

- Search channel is $bb\nu\nu$
- Uses *razor* variables $R \equiv \frac{M_T^R}{M_R}$

$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

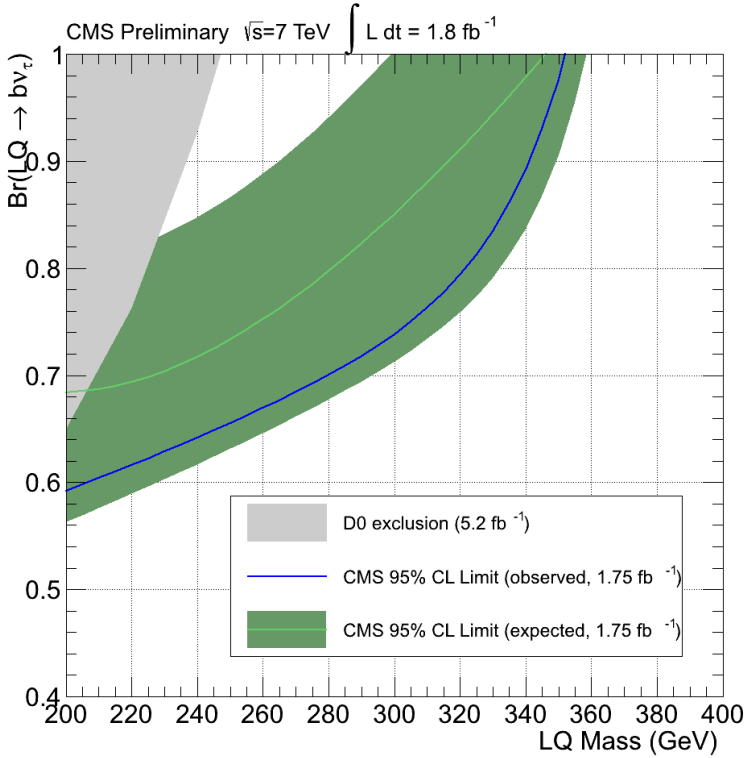
$$M_T^R \equiv \sqrt{\frac{\not{E}_T(p_T^{j1} + p_T^{j2}) - \not{\vec{E}}_T \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

Designed to search for pairs of heavy particles

Limit:

- m_{LQ} > 350 GeV for β = 0

CMS PAS EXO-11-030

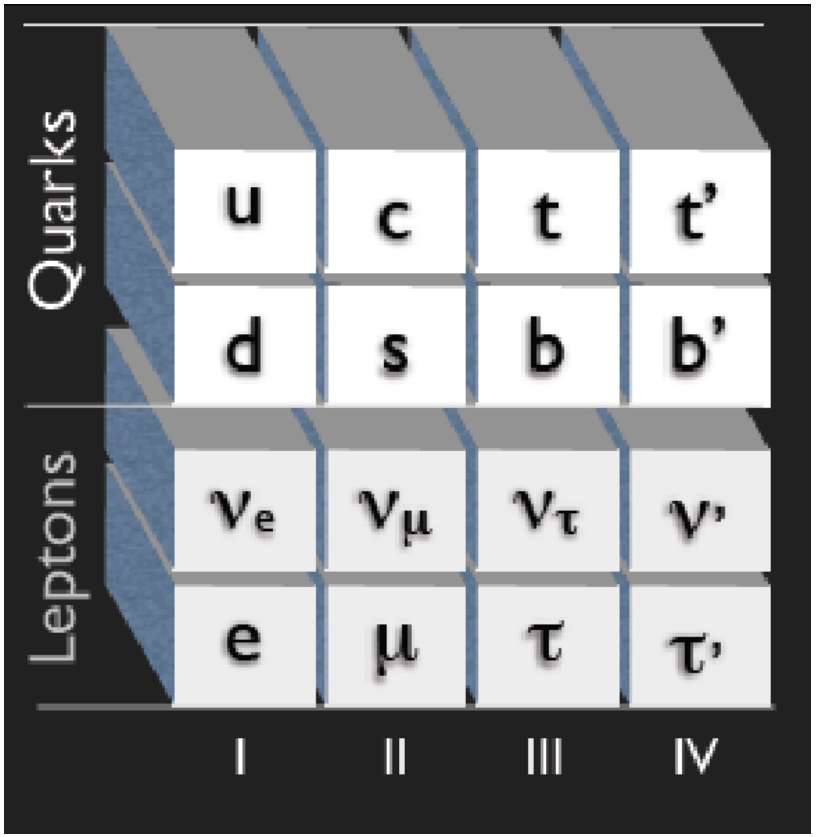


Are you ready to upgrade your plan?

Welcome to 4G

✦ SM Extension: Adding one more generation of quarks is an obvious extension of SM and is also not fully excluded by electroweak precision data

✦ Due to heaviness of this new generation of quarks the CP violation can be boosted by large factor and could resolve the matter-antimatter asymmetry in the universe can provide enough CP violation to explain matter-dominated universe



Fourth generation quarks 1/4

CMS and ATLAS search for heavy quarks

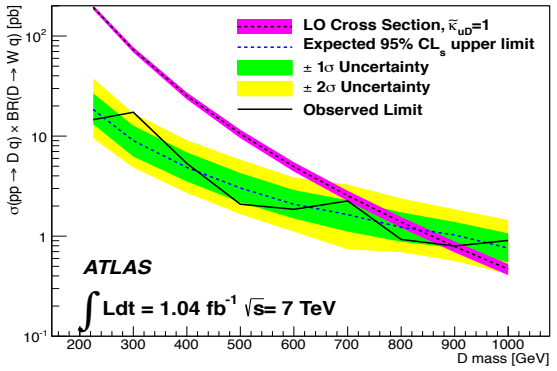
- Here denoted T and B; or Q for either flavor
- Searches for $T \to Wb$, $B \to Wt$ and $T \to Zt$, $T \to A_0 t$, $B \to Zb$
  - –100% branching fraction assumed for mass limits
- Both single and pair production considered
  - –Mechanism and cross section depend on Q nature (chiral, vector-like)
-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

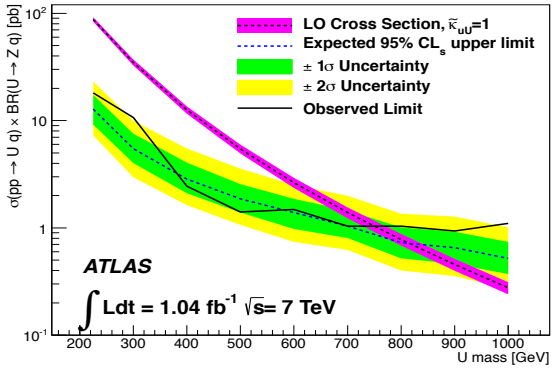
ATLAS search: $Qq \to Vqq'$ in 1.0 fb^{-1}

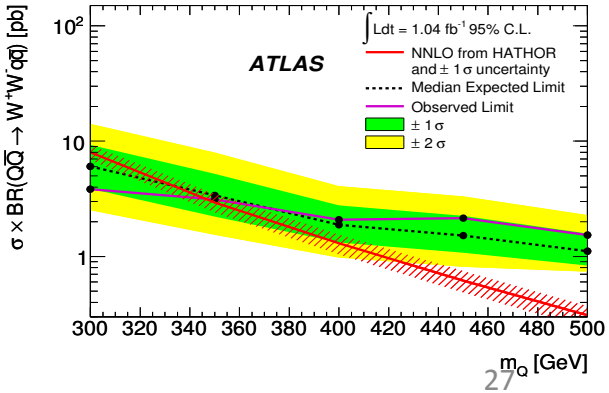
- Bosons decay leptonically
- Limits:
  - $Qq \to Wqq'$: $m_Q > 900$ GeV
  - $Qq \to Zqq'$: $m_Q > 760$ GeV
- arXiv:1112.5755 (submitted to PLB)

ATLAS search for $QQ \to WqWq$ in 1.0 fb^{-1}

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







Fourth generation quarks 2/4

ATLAS search for $TT \rightarrow WbWb$ in 1.0 fb^{-1}

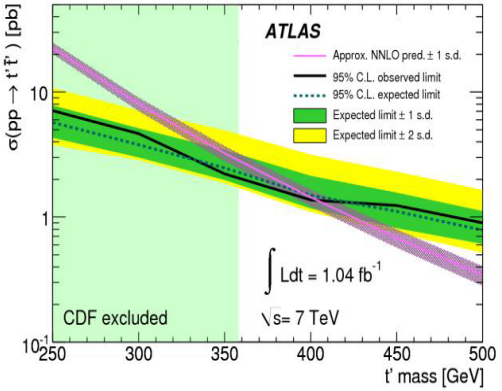
- One W decays leptonically
- One b is tagged
- Limit: m_T > 404 GeV
- arXiv:1202.3076 (submitted to PRL)

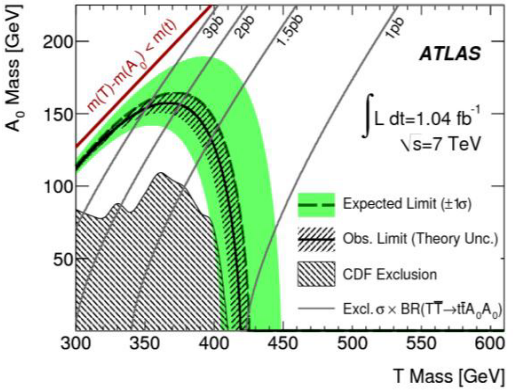
ATLAS search for $TT \rightarrow tA_0tA_0 \rightarrow l\ X$ in 1.0 fb^{-1}

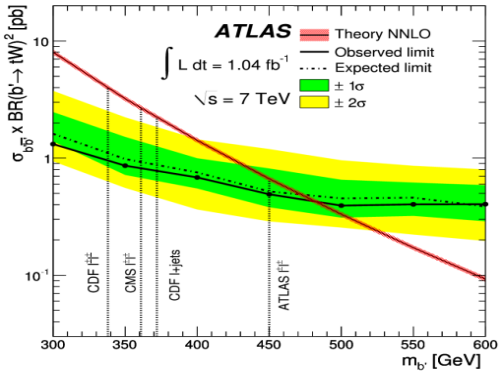
- A_0 is an undetected neutral particle
- Limit: m_T > 420 GeV for light A_0
- PRL **108**, 041805 (2012)

ATLAS search for $BB \rightarrow WtWt$ 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 3/4

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

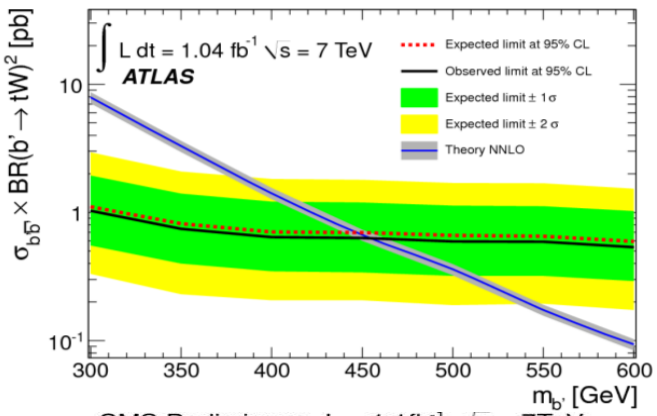
- 2 same-sign leptons, 2+ jets, high MET
- Limit: $m_B > 450$ GeV
- Also limits on same-sign tt production
- arXiv:1202.5520 (submitted to JHEP)

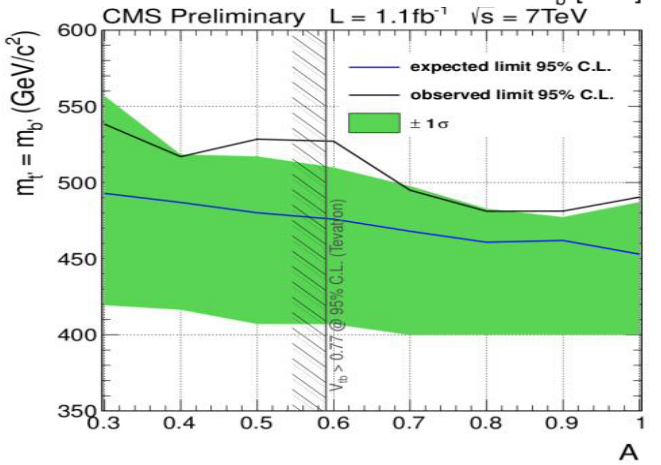
CMS inclusive search for chiral Q in 1.1 fb^{-1}

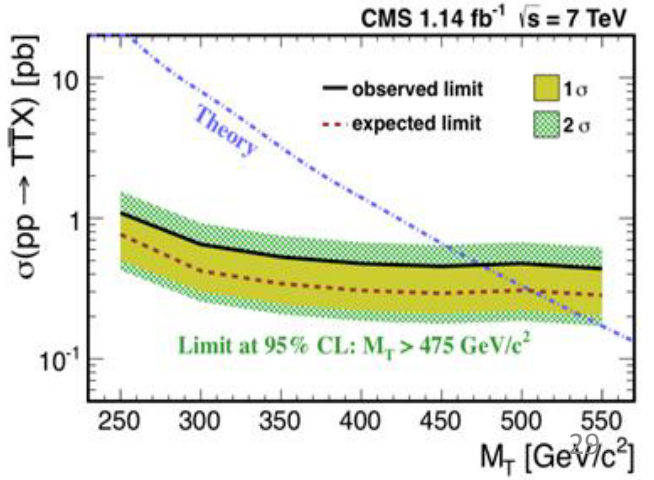
- Assume $m_T = m_B$, CKM4: $V_{TB} = V_{tb} \equiv A$
- Require 1 muon (trigger) and 1 b-jet
- Classify events by b-tag and W multiplicities
- Limit set in A–m_Q plane, $m_Q > 490$ GeV
- CMS PAS EXO-11-054

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

CMS search for $BB \rightarrow WtWt$ in 4.6 fb^{-1}

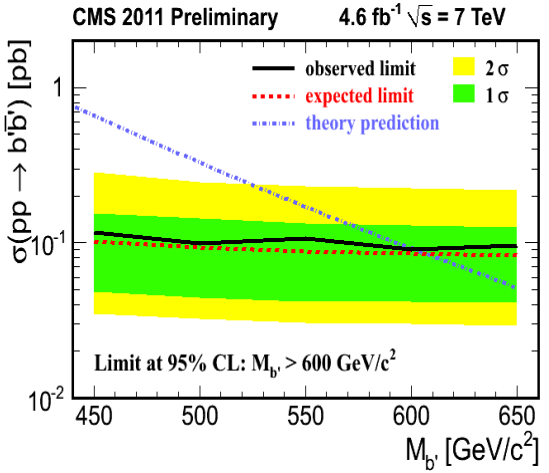
- 3 leptons or 2 same-sign leptons plus a b-jet
- Limit: $m_B > 600$ GeV
- CMS EXO-11-036 Winter 2012

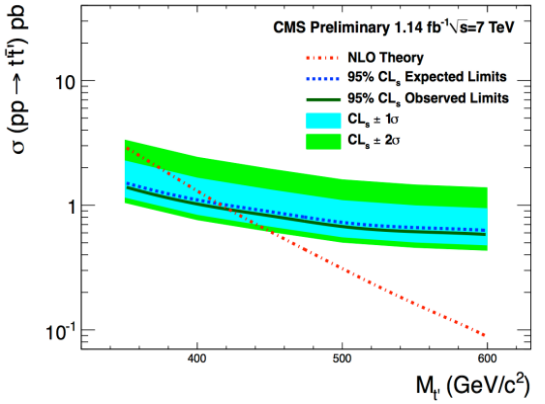
CMS search for $TT \rightarrow WbWb \rightarrow llX$ in 4.7 fb^{-1}

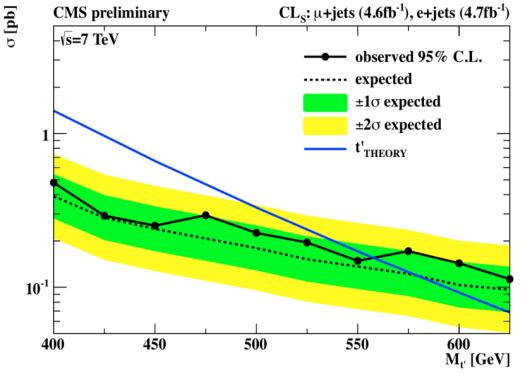
- Require 2 leptons, 2+ jets, high MET
- Limit: $m_T > 552$ GeV
- CMS EXO-11-050 Winter 2012

CMS search for $TT \rightarrow WbWb \rightarrow lX$ 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



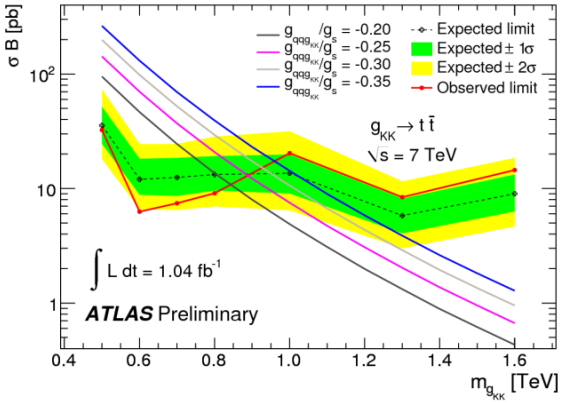




ttbar resonance

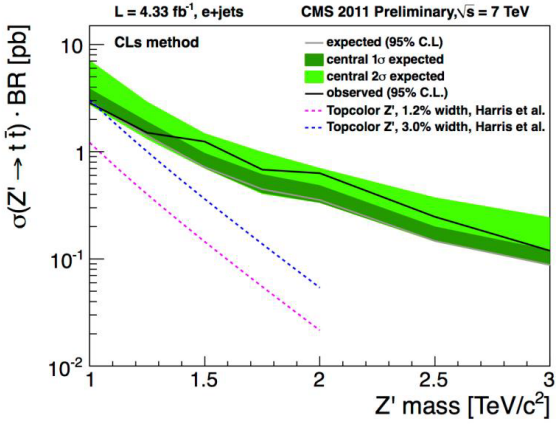
ATLAS search of the dilepton channel in 1.0 fb^{-1}

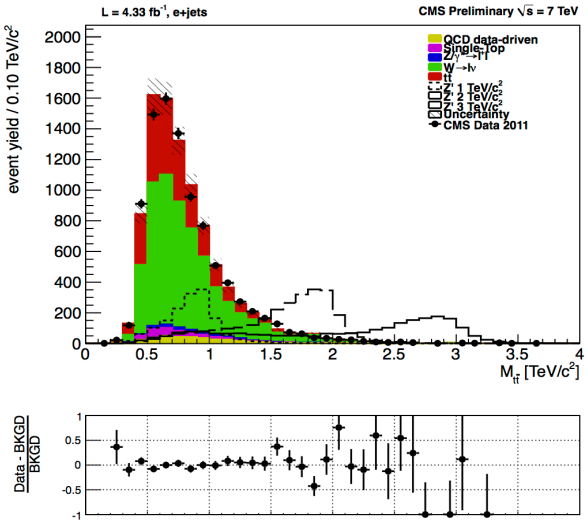
- Low mass—down to 400 GeV
- Limit near m > 900 GeV on the RS KK gluon
- ATLAS-CONF-2011-123



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

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





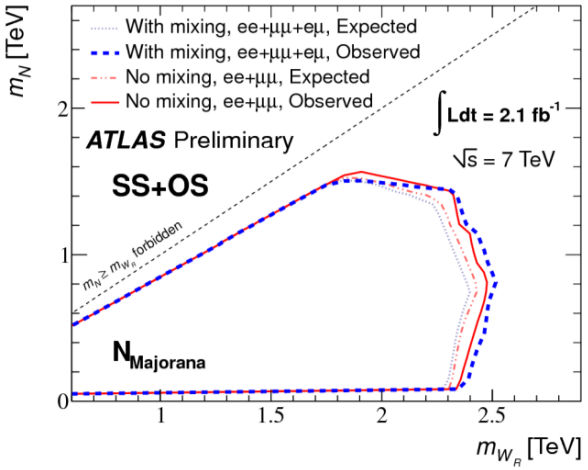
Heavy Neutrinos

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 $lljj$

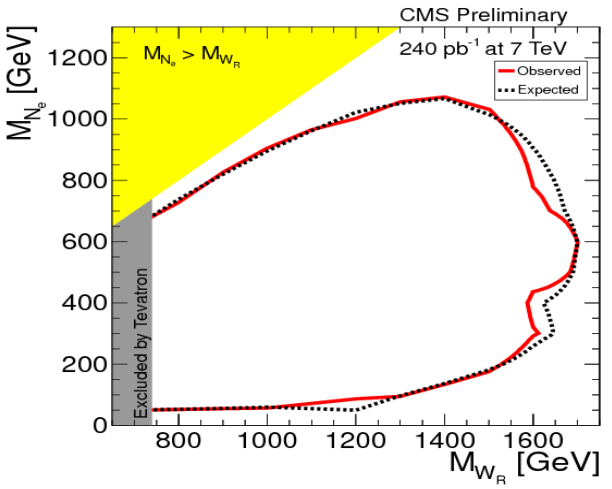
ATLAS searched in 2.1 fb^{-1}

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



CMS searched in 240 pb^{-1}

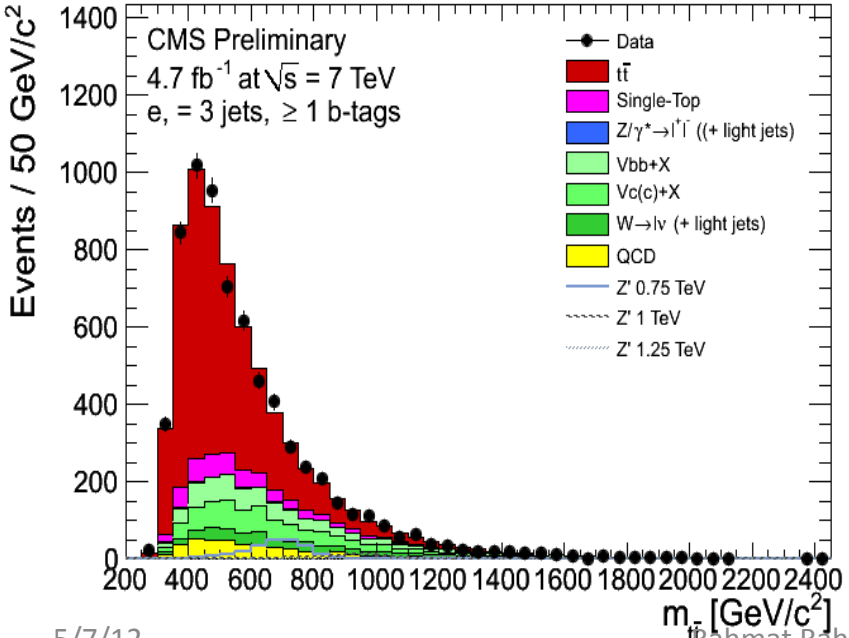
- Limits extend to about $m_{WR} > 1.6$ TeV
- Separate limits for e and μ
  - –Similar results for the two flavors
- CMS PAS EXO-11-002

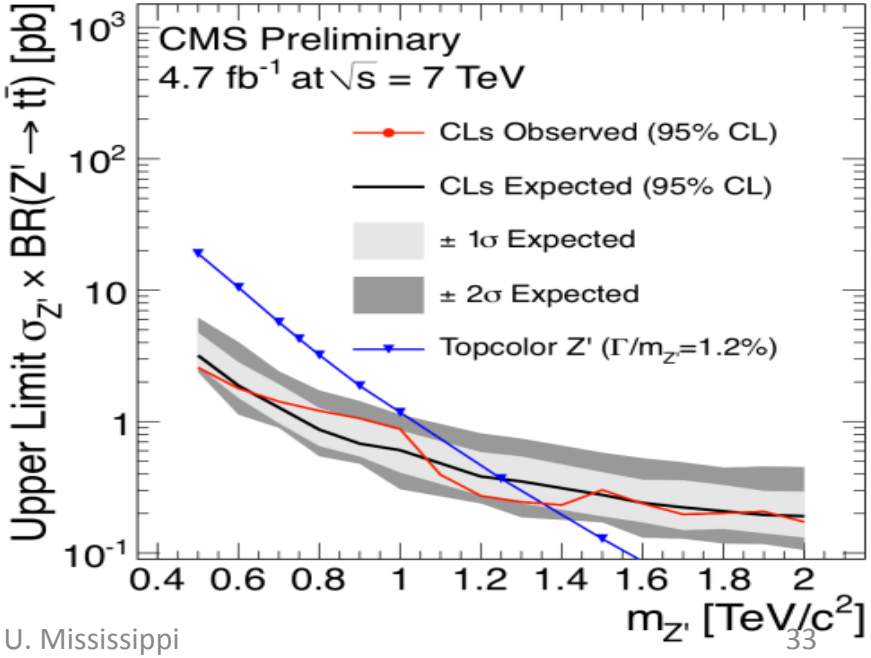


ttbar l+jets

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_{gKK} > 1.4 TeV
- CMS PAS TOP-11-009



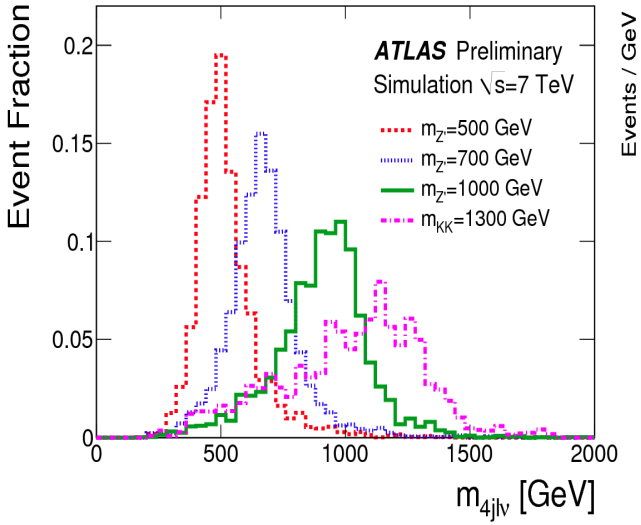


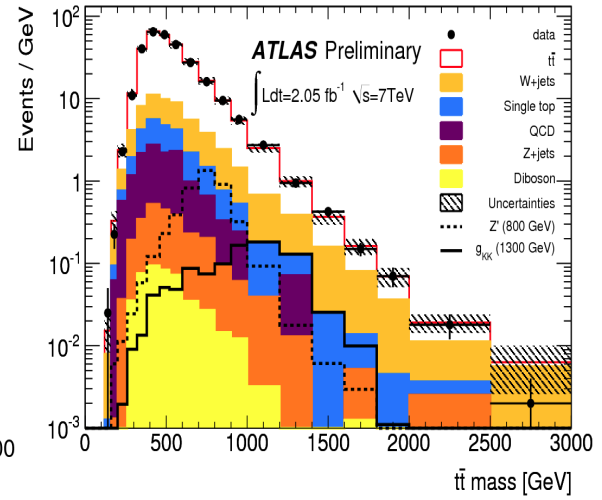
ttbar l+jets ATLAS

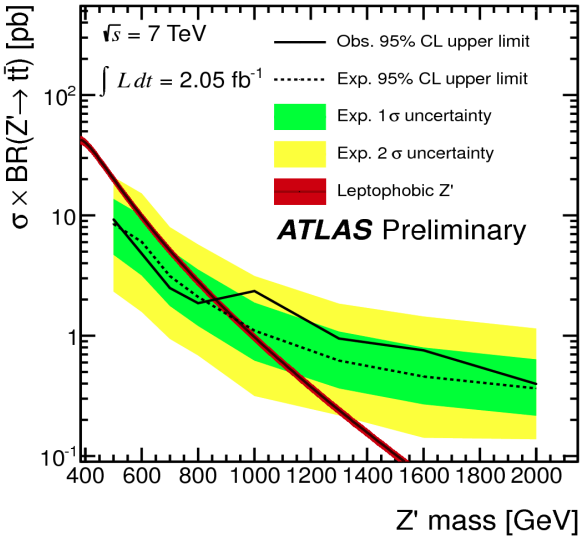
RS model:
m(KK gluon) > 1025 GeV

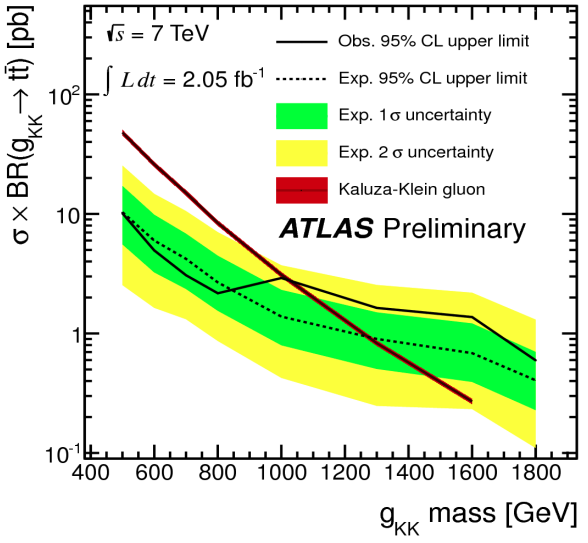
Leptophobic top color Z':
$m_{Z'} > 860$ GeV

Preliminary





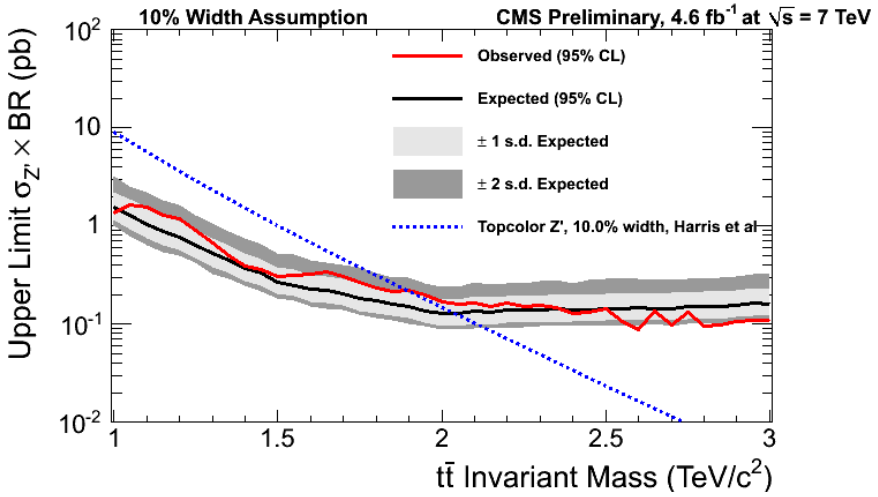


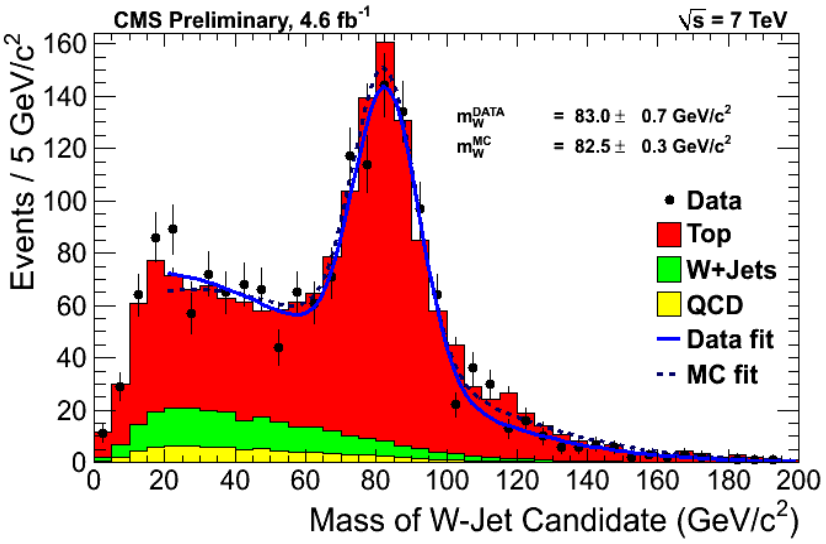


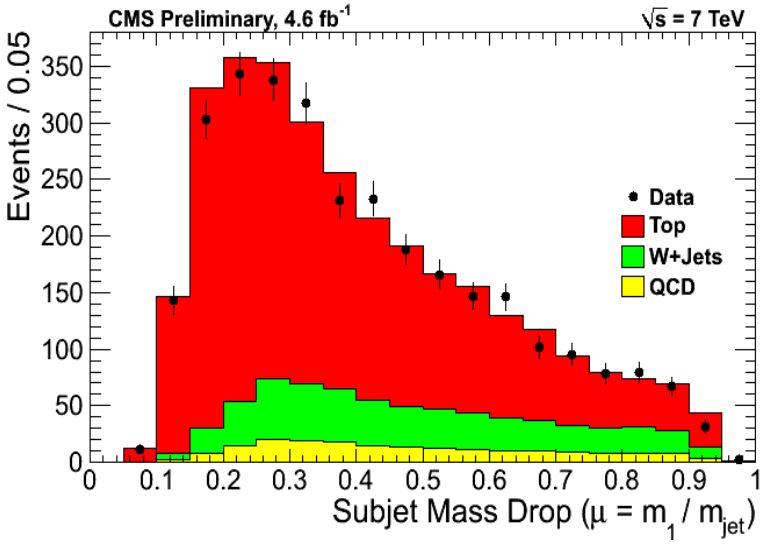
ttbar resonance all-jets

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_{gKK} >1.4 - 1.5 TeV
- CMS EXO-11-006



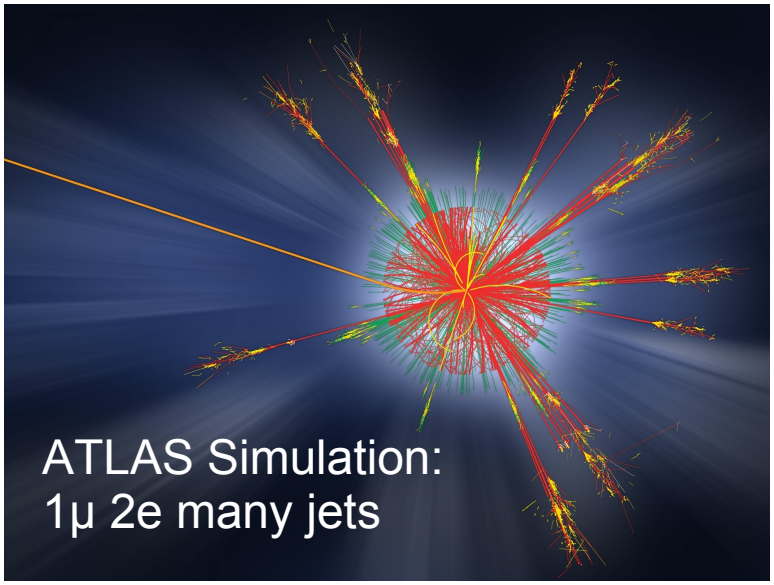


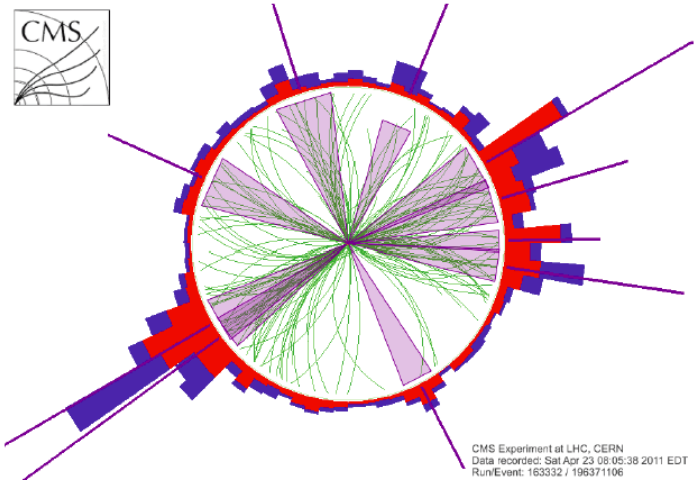


Many objects

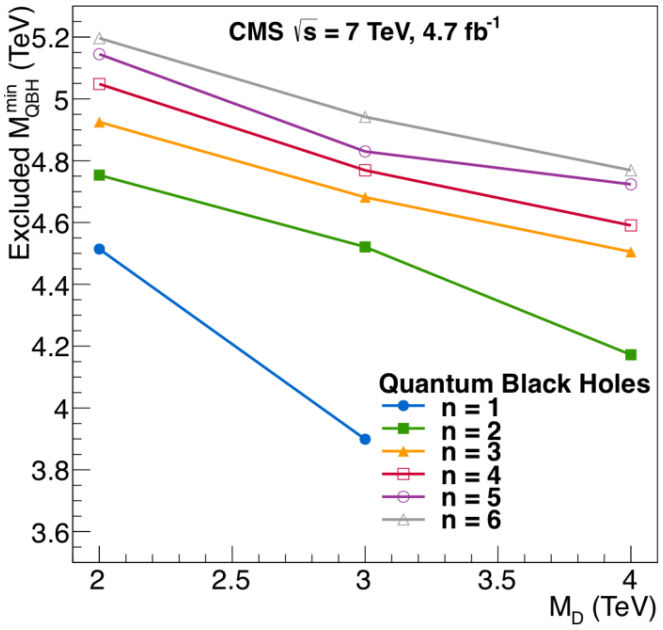
Microscopic black-holes decaying through Hawking Radiation

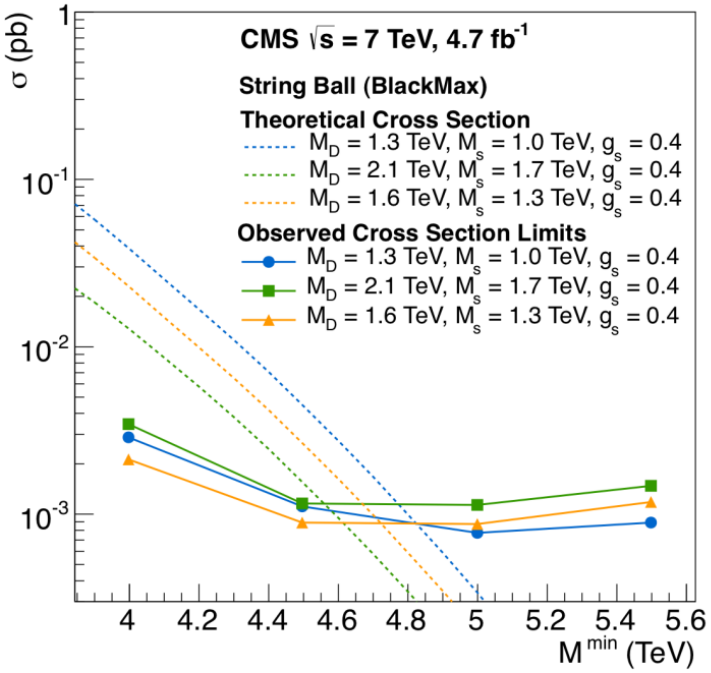
The decay is democratic and isotropic.
Likely large multiplicity of particles → look for (many) jets and leptons at high mass
Inclusive search: sum energy of all objects (e, μ , jets)





CMS Limits





Quantum Black Holes: 3.8 − 5.2 TeV

String Balls: 4.6 − 4.8 TeV

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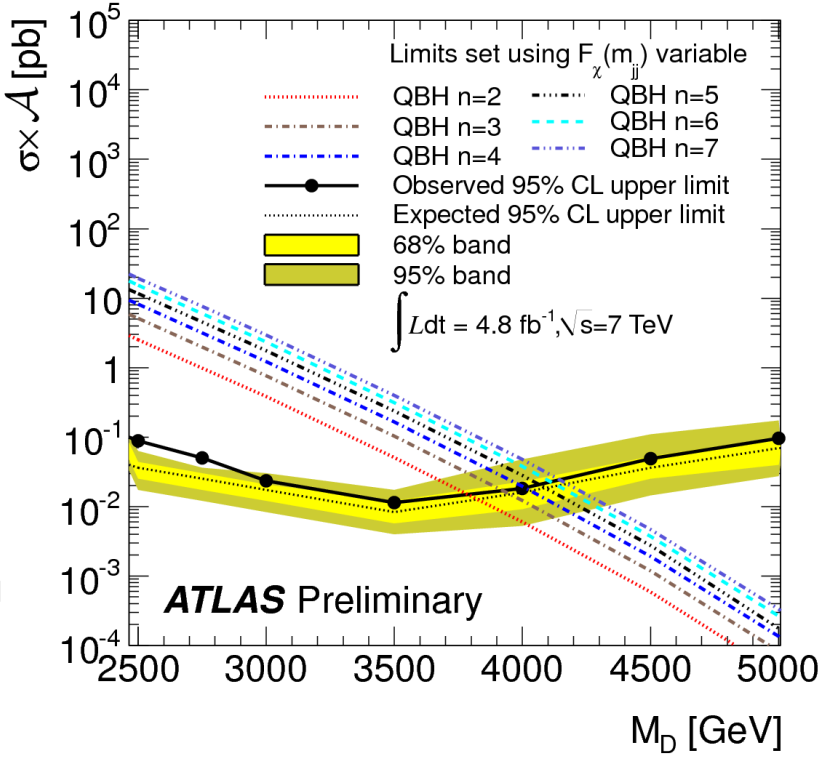
Lower limits at 95% C.L. on M_D of the QBH model with n=2 to 7 extra dimensions.

n extra dimensions	Expected limit (TeV)	Observed limit (TeV)
2	3.82	3.79
3	3.95	3.93
4	4.03	4.01
5	4.09	4.06
6	4.14	4.11
7	4.18	4.15



The 95% C.L. upper limits on σ × A as function of the reduced Planck mass M_D of the QBH model using $F_\chi(m_{jj})$ (black filled circles). The black dotted curve shows the 95% C.L. upper limit expected from Monte Carlo and the light and dark yellow shaded bands represent the 68% and 95% contours of the expected limit, respectively. Theoretical predictions of σ × A are shown for various numbers of extra dimensions.

Summary

- We have many new results!
- Excellent performance of CMS and ATLAS
- No evidence of new physics yet
- **It's only the beginning**
- CMS and ATLAS are expected to have ~30 fb^{-1} combined from 8 TeV Collision by the end of 2012 and as of today, we have started to have some fun with more than 2 fb^{-1} at 8 TeV
- We are very productive producing new results even our universe needs to expand

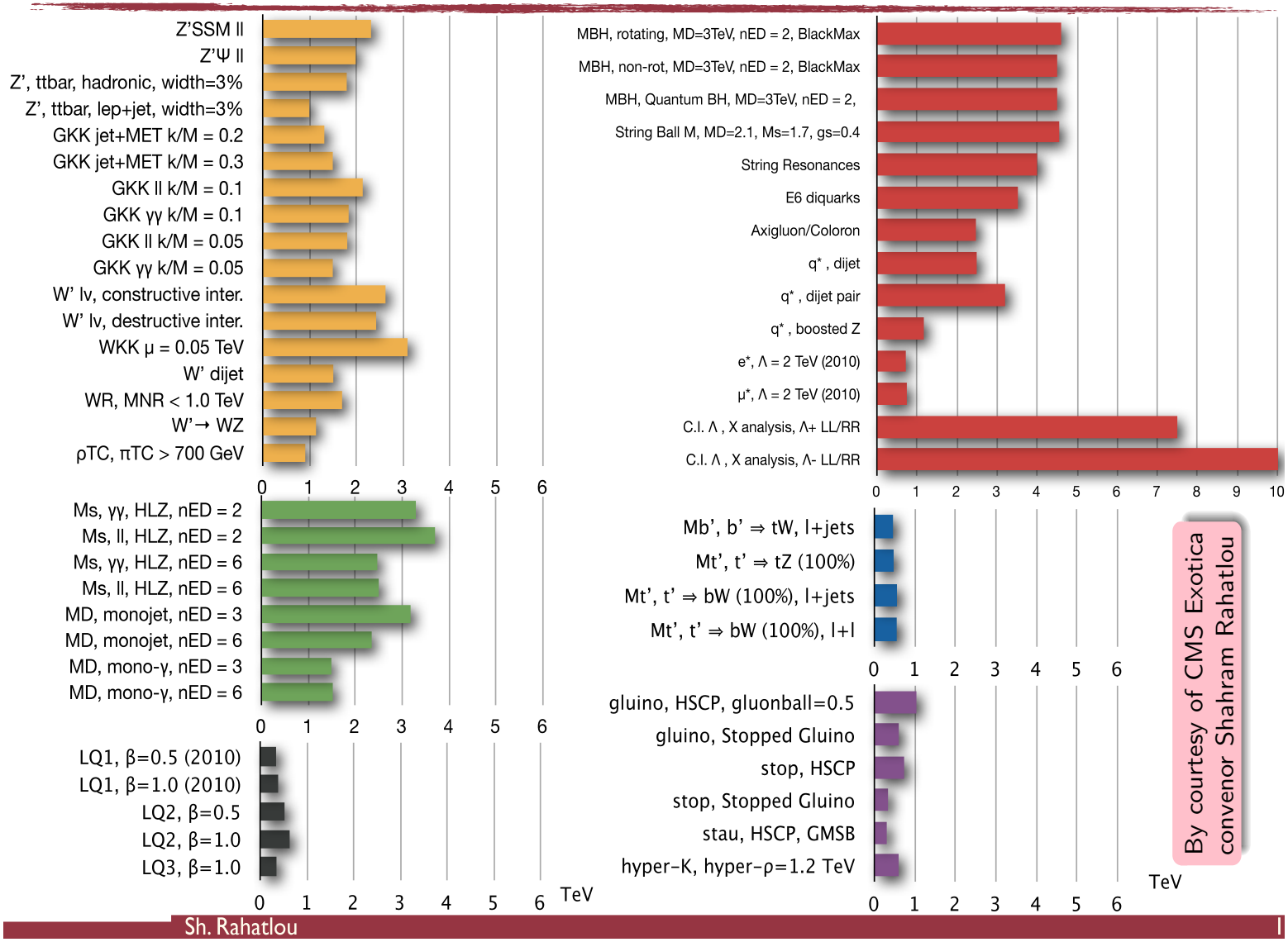
More talks about New Physics at Pheno 2012 (CMS)

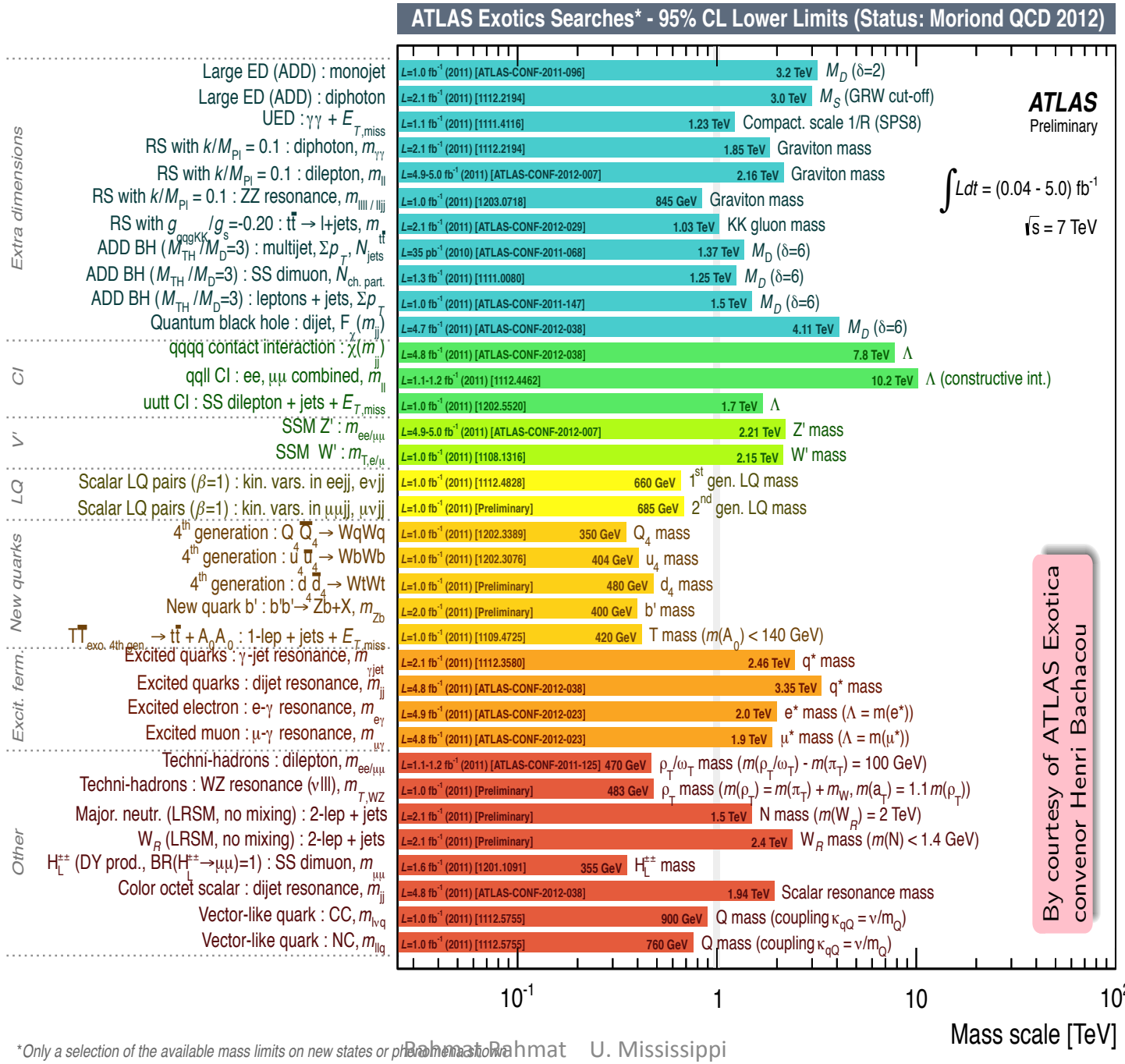
- Search for Heavy Stable Charged Particles at CMS Speaker: Venkatesh Veeraraghavan (Florida State Univ.)
- Recent results from a search for Dark Matter production in the CMS experiment Speaker: Shruti Shrestha (Kansas State Univ.)
- Diboson physics at CMS Speaker: Irakli Svintradze (Kansas State Univ.)
- Measurement of Drell-Yan Cross Section Speaker: Alexey Svyatkovskiy (Purdue Univ.)
- Search for Fourth Generation Top-Like Quarks at CMS Speaker: Michael Luk (Brown Univ.)
- Study of the di-jet mass spectrum in association with a W boson Speaker: Jake Anderson (FNAL.)
- Search for Supersymmetry in Events with Photons and Missing Transverse Energy Speaker: Yueh-Feng Liu (Carnegie Mellon Univ.)
- Search of new physics in the top quark sector Speaker: Victor Eduardo Bazterra (Univ. of Illinois at Chicago)
- Search for contact interactions in the dimuon final state at CMS Speaker: Sowjanya Gollapinni (Wayne State)
- A Search for New Physics in Events with Jets and Missing Energy in pp Collisions at 7 TeV Speaker: Hongxuan Liu (Baylor University)

More talks about New Physics at Pheno 2012 (ATLAS)

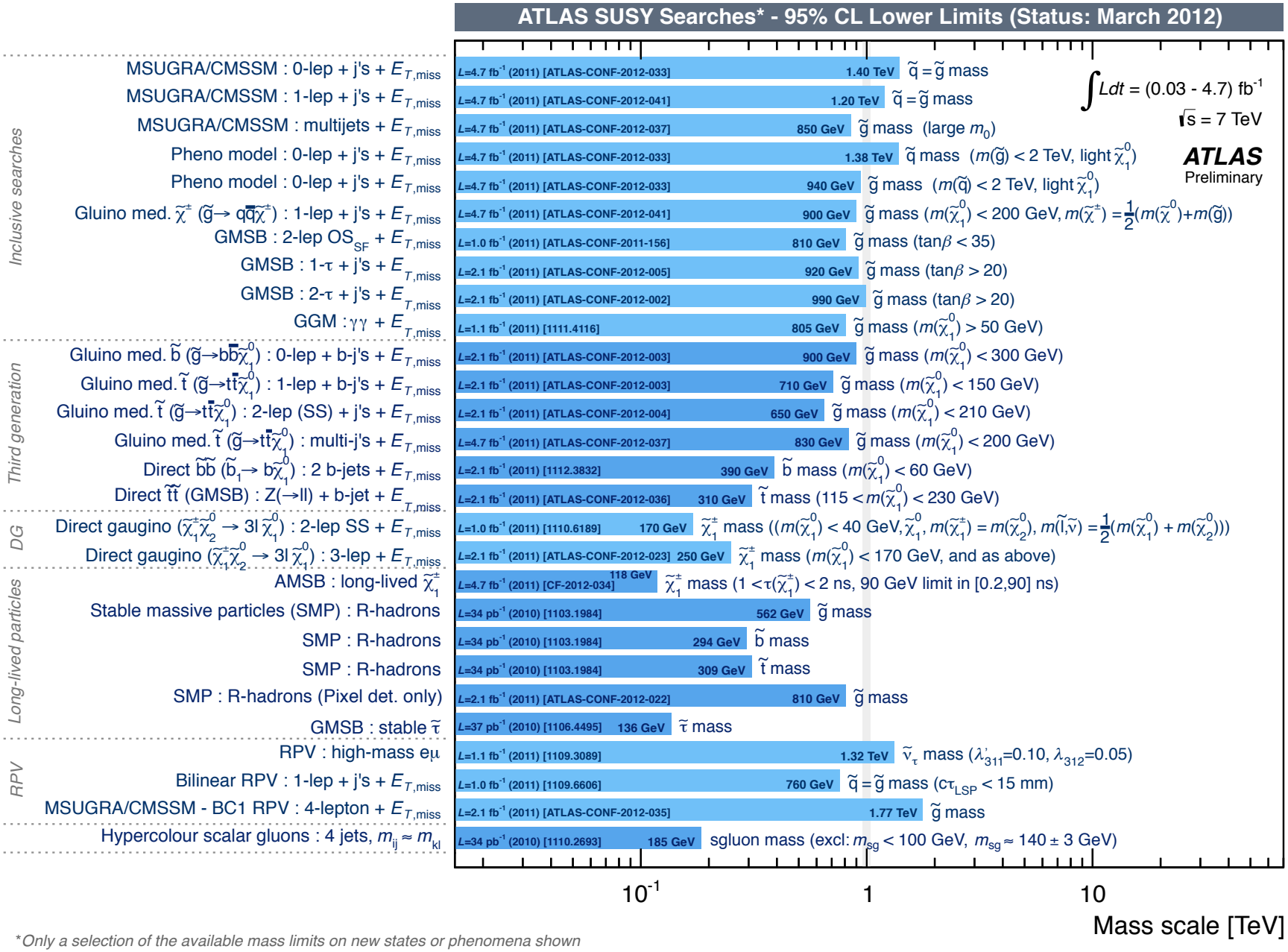
- **BSM Higgs searches at ATLAS** GOUSSIOU, Anna
- **Jet Production Measurements with ATLAS** FAROOQUE, Trisha
- **Diboson production and TGCs from ATLAS** JEANTY, Laura
- **Direct Photons at ATLAS** CAPUTO, Regina
- **Inclusive searches for supersymmetric signatures with the ATLAS detector** HARPER, Devin
- **Searches for third generation squarks with the ATLAS detector** BUTLER, Bart
- **Search for long-lived massive particles with the ATLAS detector** MARINO, Christopher
- **Top quark pair production cross-section with ATLAS** Mr. URBANIEC, Dustin Henry
- **Physics with Tau Lepton Final States in ATLAS** MORGENSTERN, Marcus Matthias
- **Top Quark Pair Properties** with ATLAS Dr. KAUSHIK, Venkat
- **Searches for direct supersymmetric gaugino production and R-parity violation in final states with leptons with the ATLAS** detector OKAWA, Hideki

GRAND SUMMARY MORIOND 2012





*Only a selection of the available mass limits on new states or phenomena shown



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