Searches for Physics Beyond the Standard Model with the ATLAS Detector

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TRIUMF

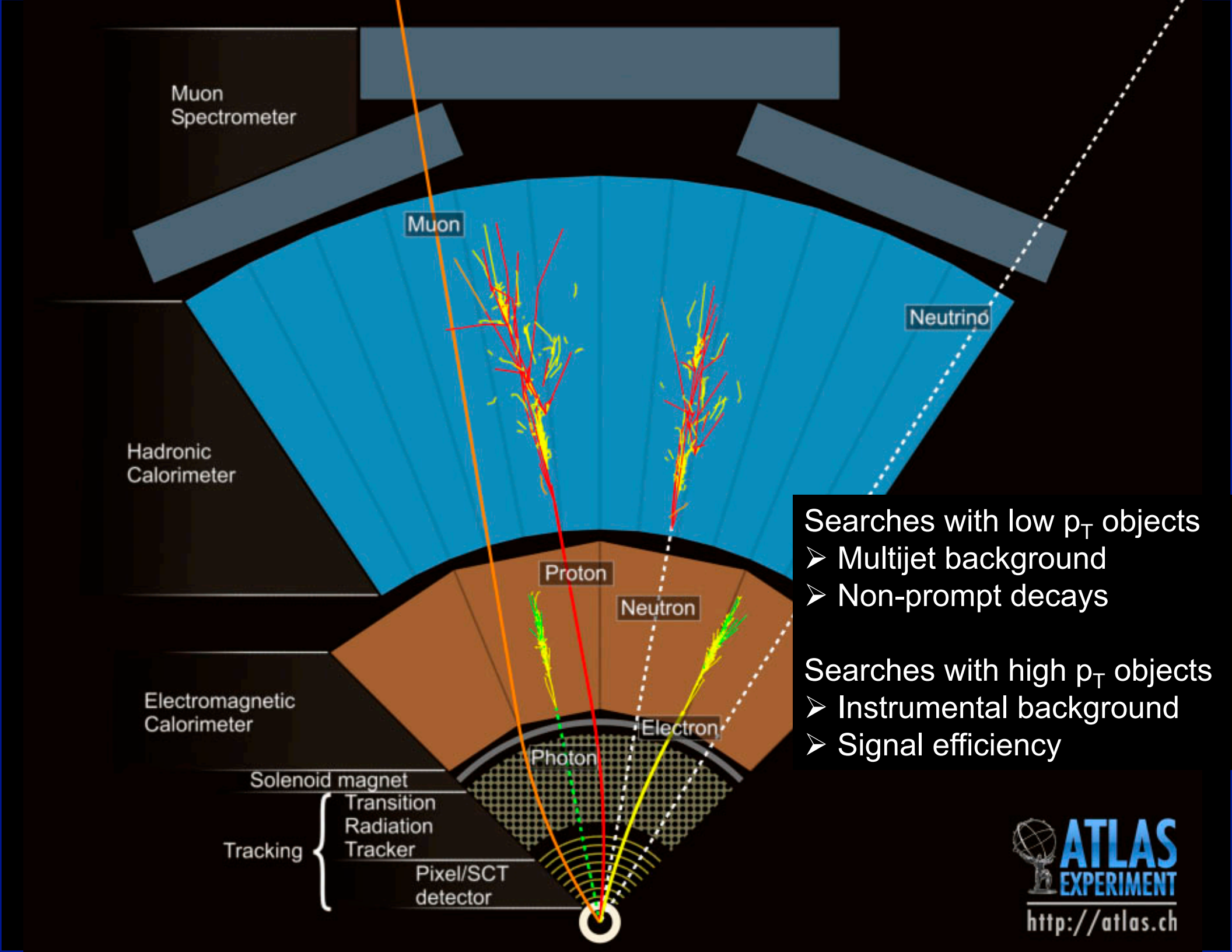
On behalf of the ATLAS Collaboration

XXVI Rencontres de Physique de la Vallée d'Aoste

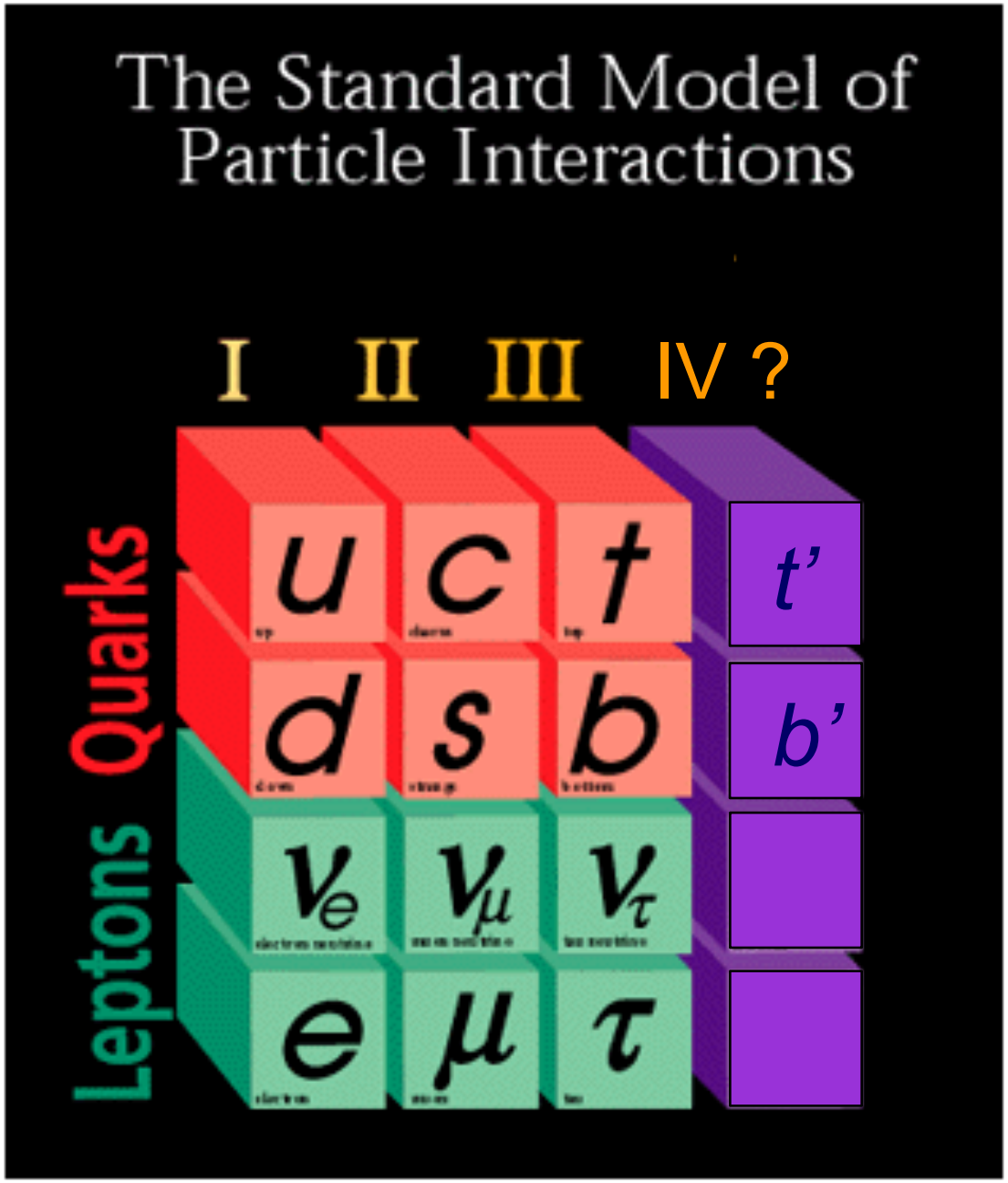
La Thuile, Feb 26th – March 3rd, 2012

Why search for physics beyond the SM ?

- BSM models: to address questions left unanswered by the SM
- Past year has been very exciting and productive at ATLAS
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- Will present most recent results from exotic searches for:
  - 4^{th} generation / heavy quarks:
    - b', t'
    - Generic heavy quark search
  - Compositeness:
    - Excited leptons and quarks
    - Contact interactions
  - New heavy bosons:
    - Z'
    - RS gravitons
    - Leptoquarks
    - W_R
- No results older than mid-December
  - Two new results approved last night


Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Searches with low p_T objects
➢ Multijet background
➢ Non-prompt decays
Searches with high p_T objects
➢ Instrumental background
➢ Signal efficiency
ATLAS EXPERIMENT
http://atlas.ch

Search for 4th generation / heavy quarks



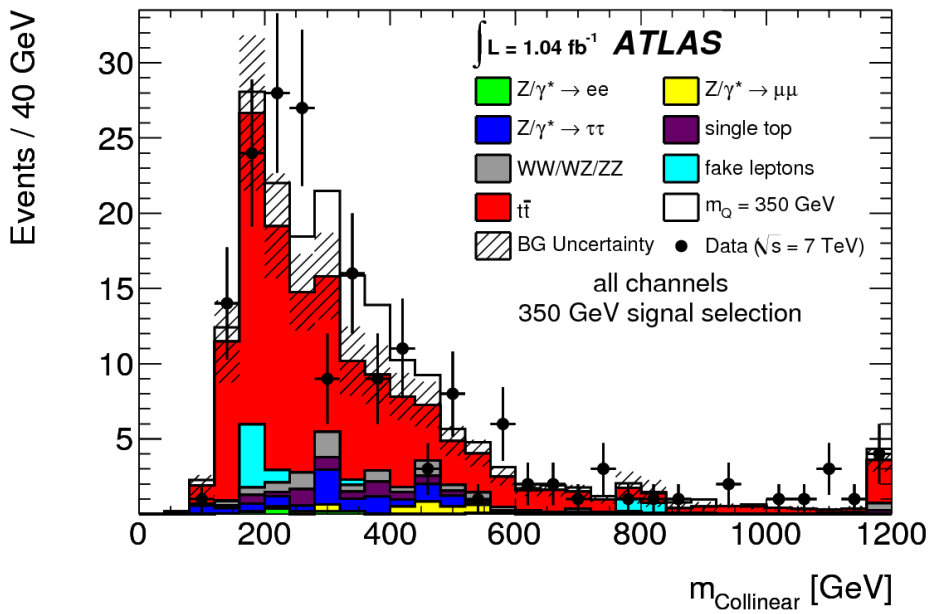
New

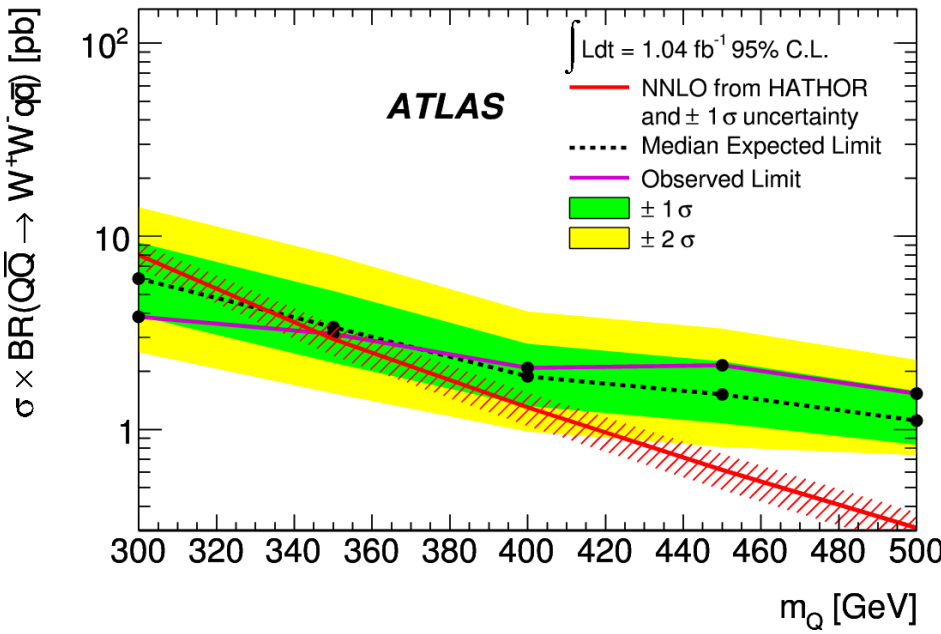
Search for heavy quarks: generic Q (1.04 fb^{-1})

- Generic search for heavy quarks Q
  - Pair produced: QQ → WqWq → llvvqq
- Signature:
  - 2 OS lepton + MET + $N_{jets} \geq 3$
- Backgrounds:
  - **Top pair decays**
  - Z and W+jets / diboson events
- Average m_Q used as discriminating variable
- No excess observed in any of the channels
  - $m_Q > 0.35$ TeV @ 95%

Submitted to Phys. Rev. D

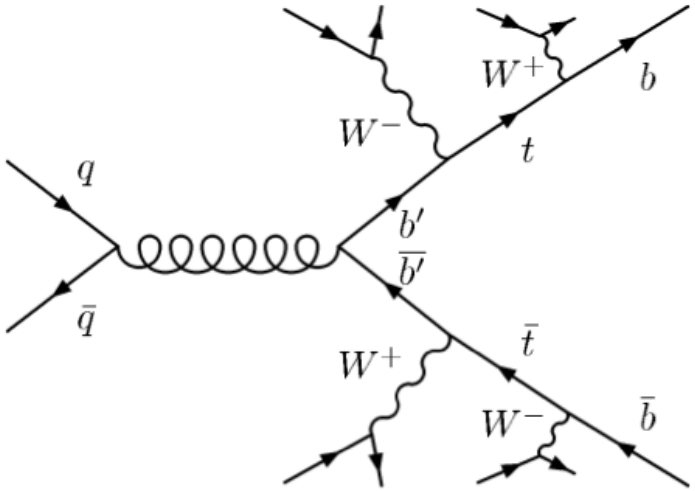
arXiv:1202.3389

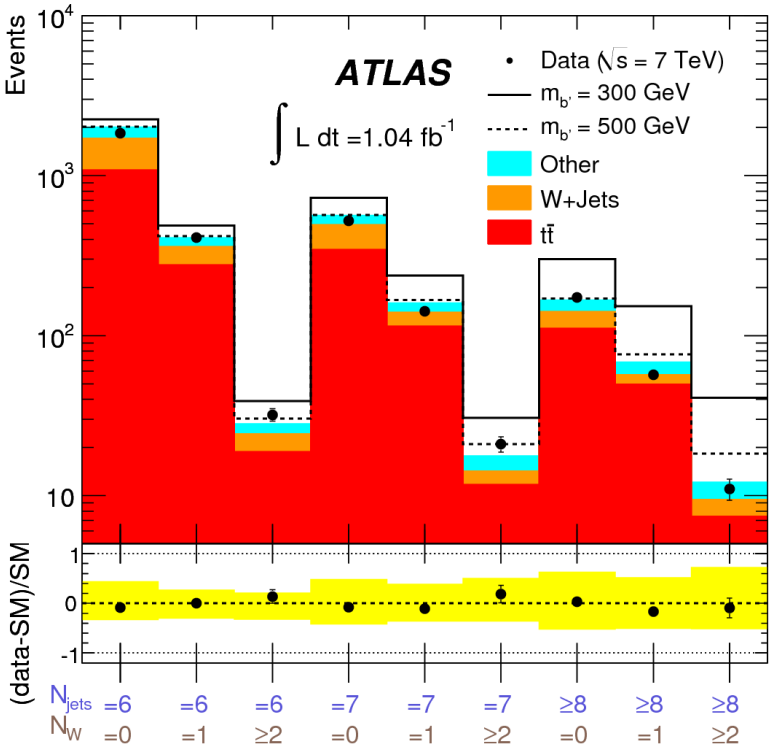


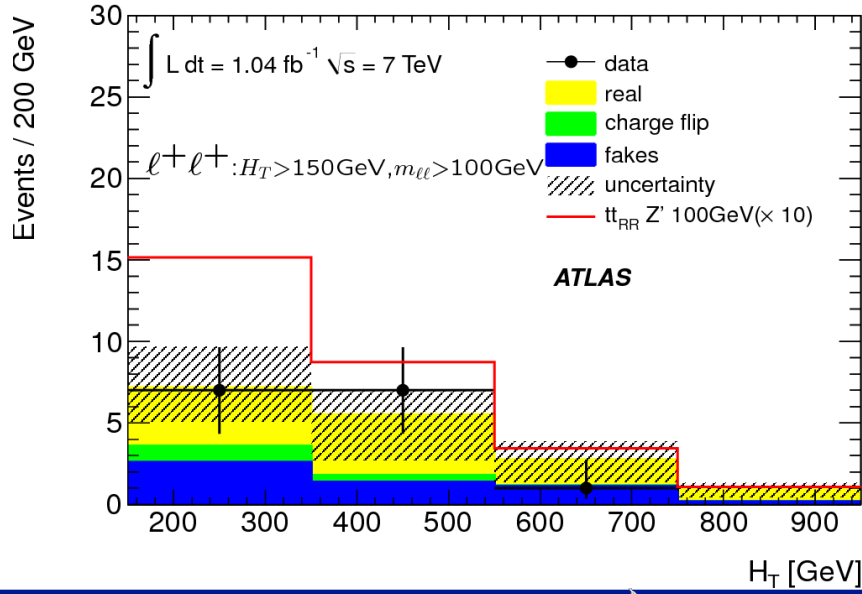


New

Search for 4th generation quarks: b' (1.04 fb^{-1})



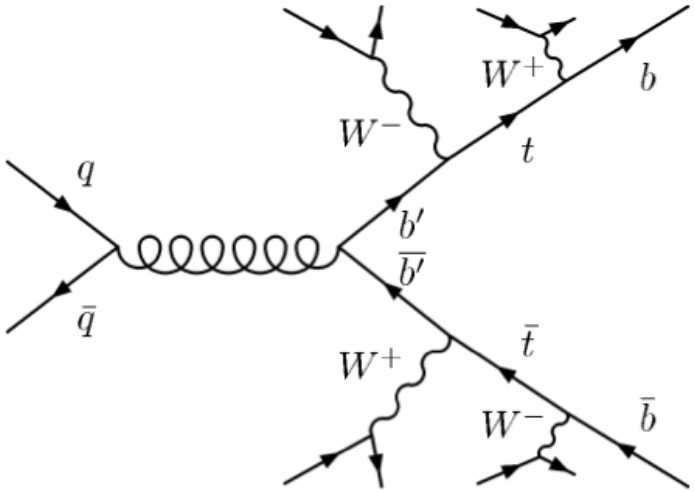


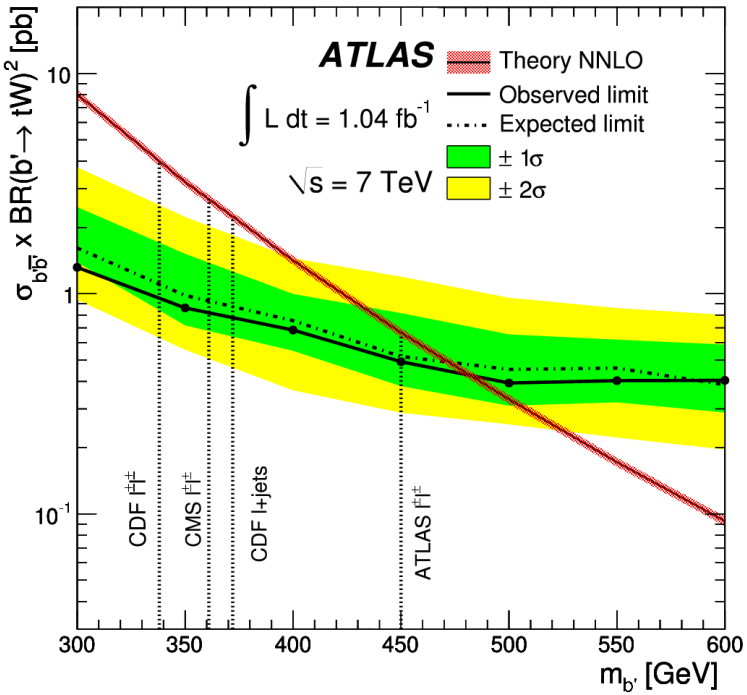


- Assume b' mass > mass top + W
- Signature for b'b' → WtWt
  - 1 lepton + MET + $N_{jets} \geq 6$
    - Count # of jets
    - Count # semi-boosted W
  - 2 same-sign leptons + MET + $N_{jets} \geq 6$
    - Use scalar sum of jet + lepton p_T = H_T

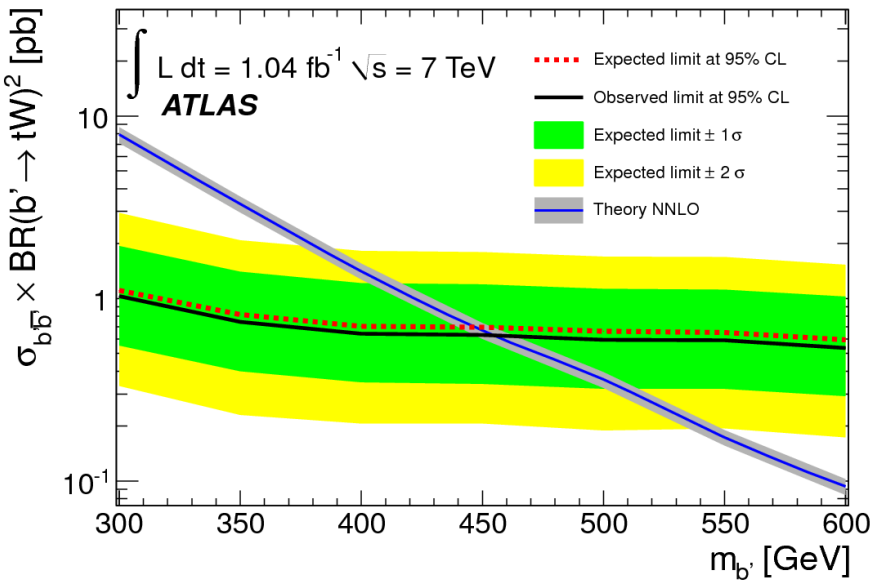
New

Search for 4th generation quarks: b' (1.04 fb^{-1})



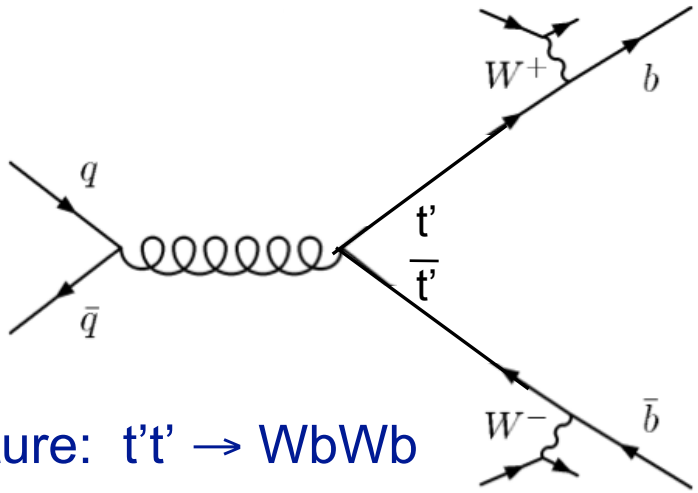


- No excess observed in either channels
  - Single lepton: $m_{b'} > 0.48$ TeV @ 95%
    Submitted to Phys. Rev. Lett.
    arXiv:1202.6540
  - SS dilepton: $m_{b'} > 0.45$ TeV @ 95%
    Submitted to JHEP
    arXiv:1202.5520



New

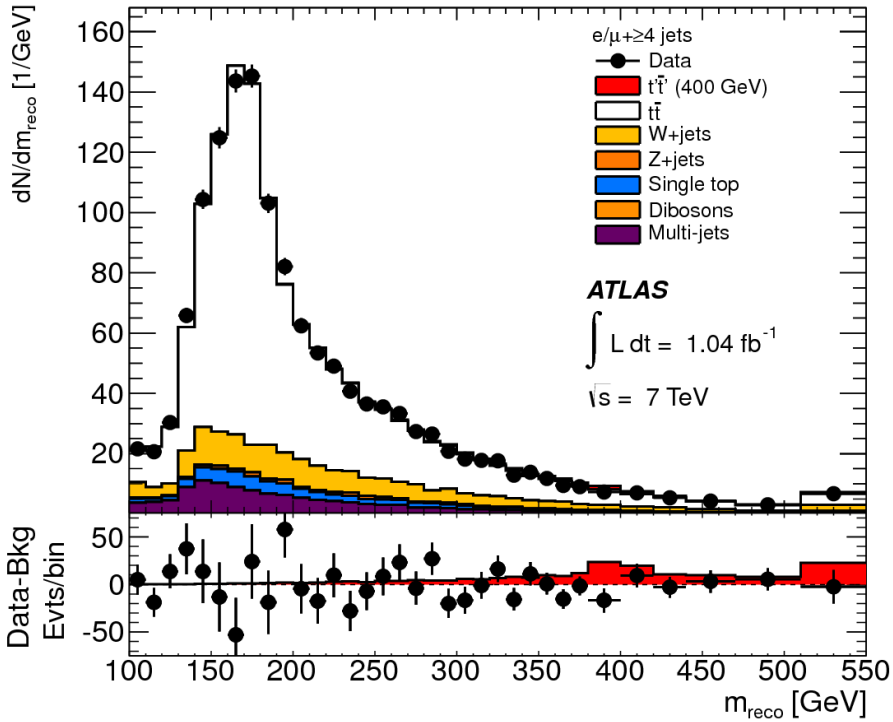
Search for 4th generation quarks: t' (1.04 fb^{-1})

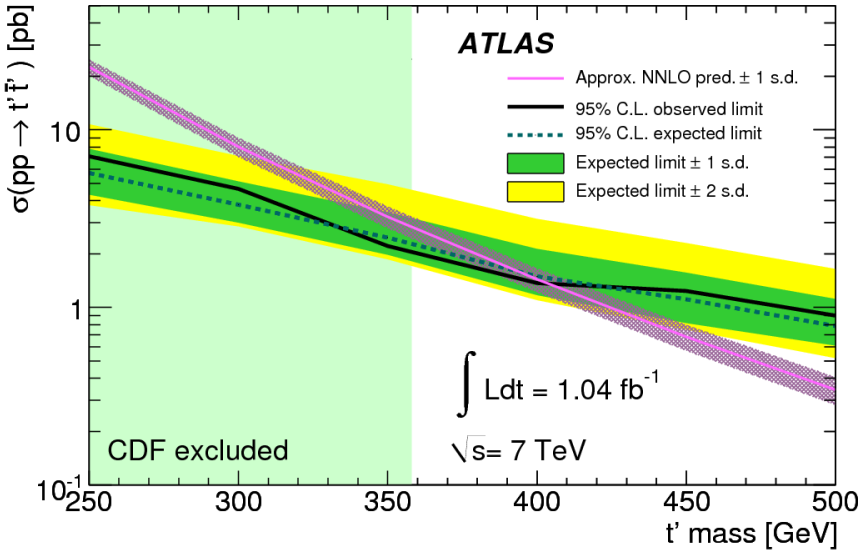


- Signature: t't' → WbWb
  - 1 lepton + MET + $N_{jets} \geq 3$ (1 b-jet)
- Separate analyses for
  - Lepton flavor e or μ
  - $N_{jets} = 3$ and $N_{jets} \geq 4$
- No excess observed in any of the channels
  - $m_{t'} > 0.40$ TeV @ 95%

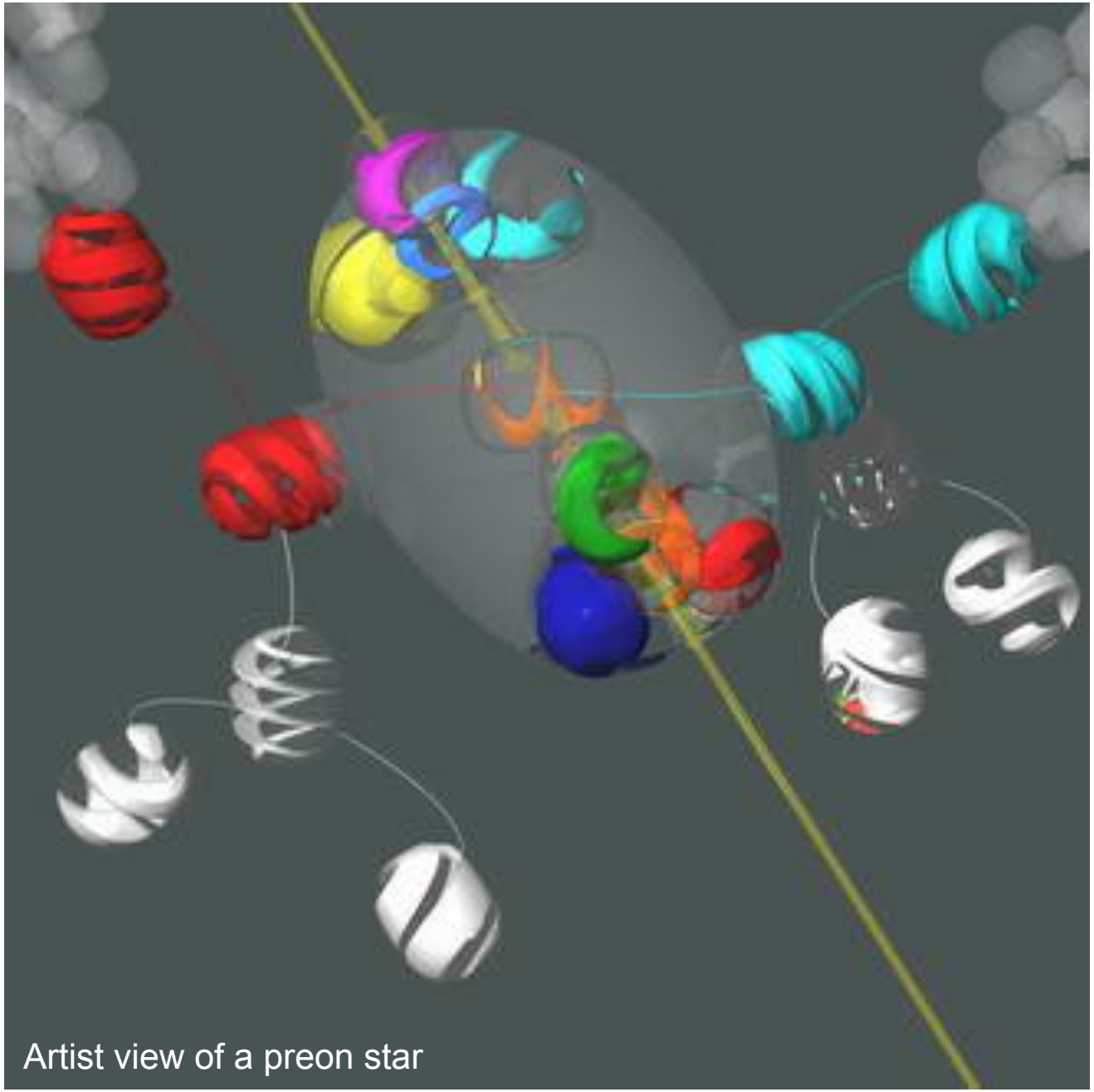
Submitted to Phys. Rev. Lett.

arXiv:1202.3076





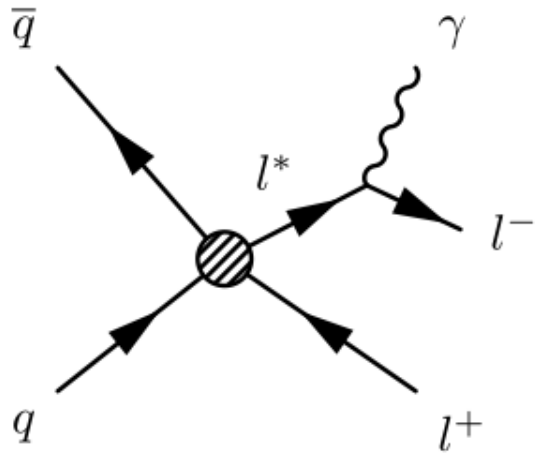
Searches for compositeness



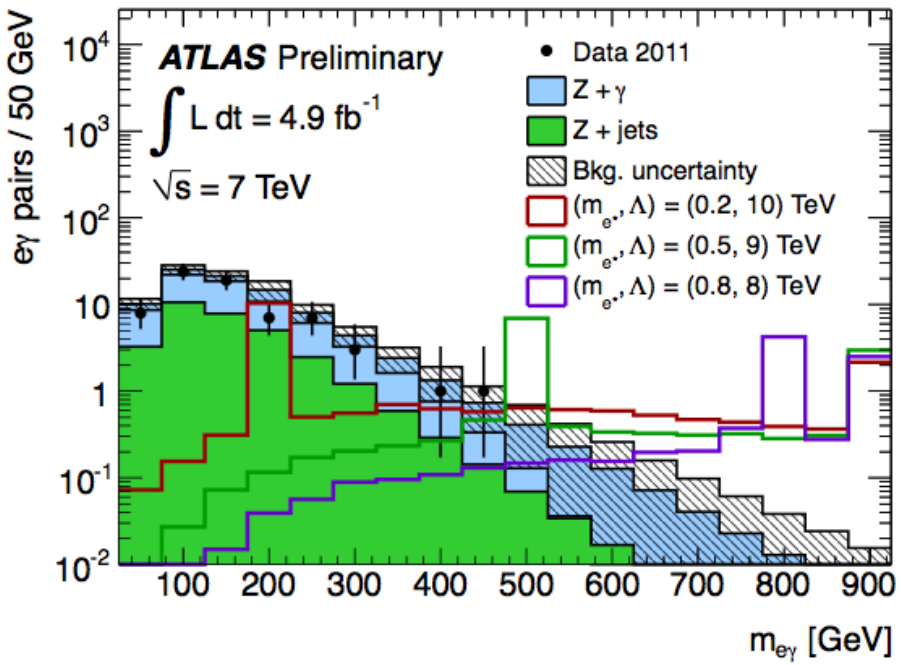
Artist view of a preon star

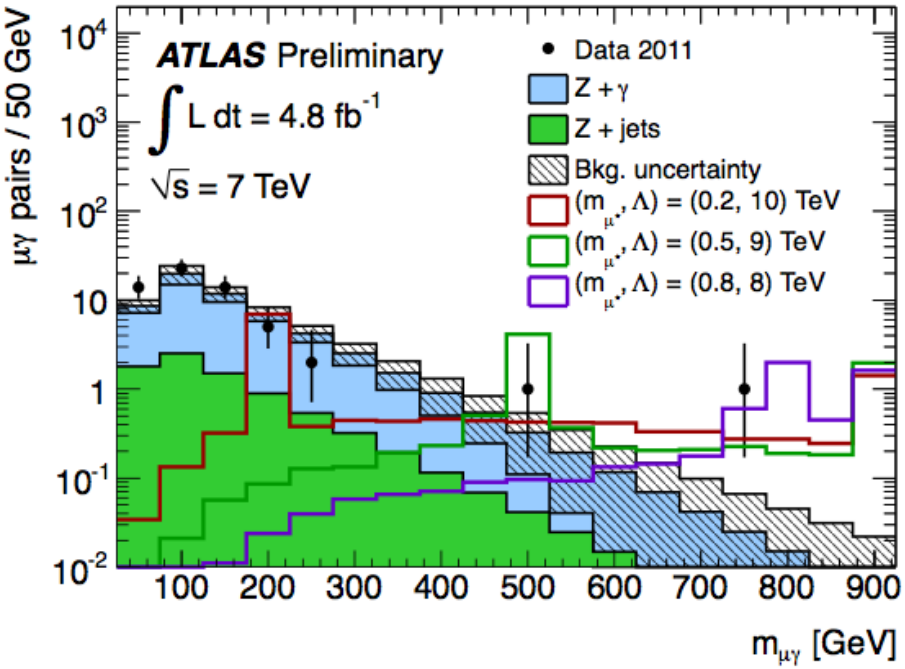
New

Search for excited leptons (5 fb^{-1})



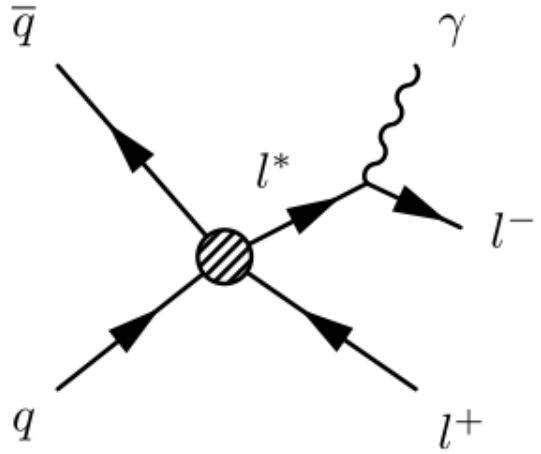
- Benchmark: compositeness model
  - Predicts existence of excited fermions
- Very clean signature:
  - Bump in lepton-photon invariant mass
  - Caveat:
    which of the lepton to associate to l* ?



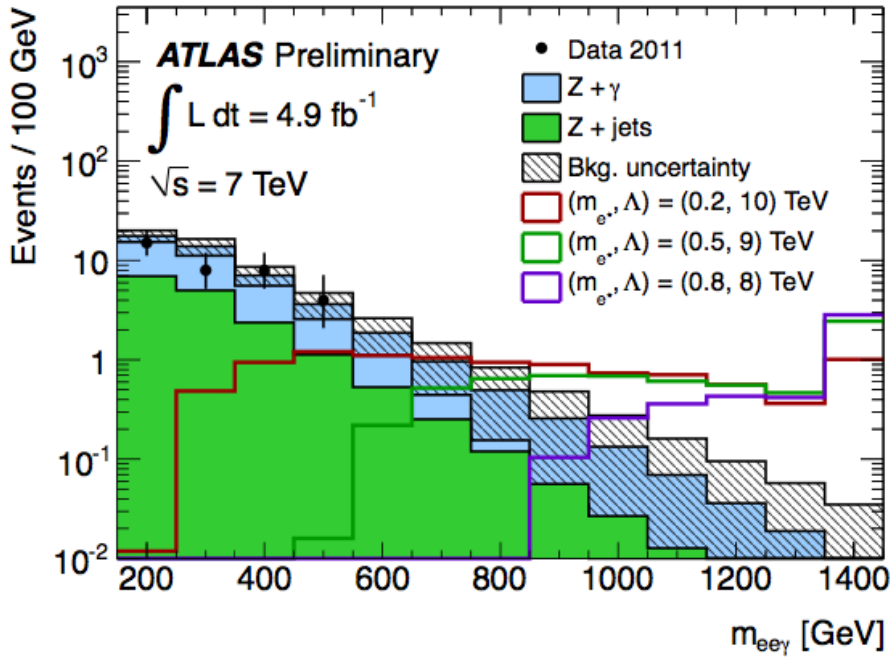


New

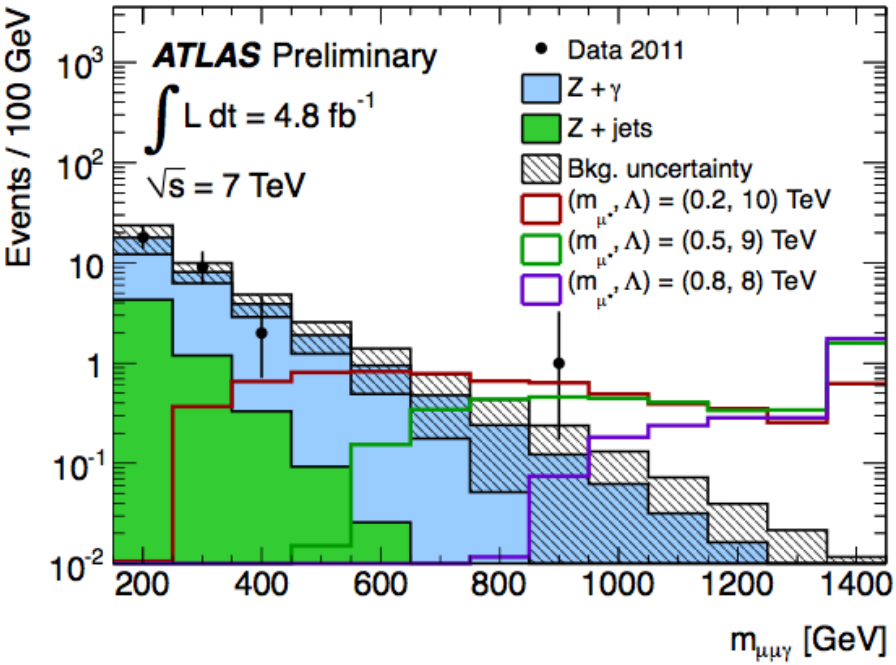
Search for excited leptons (5 fb^{-1})



→ **look at 3-body invariant mass**

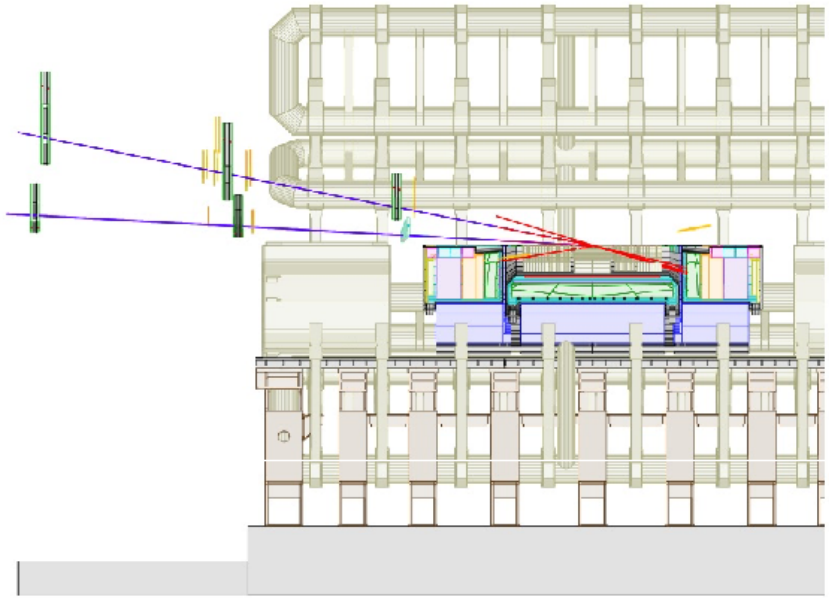


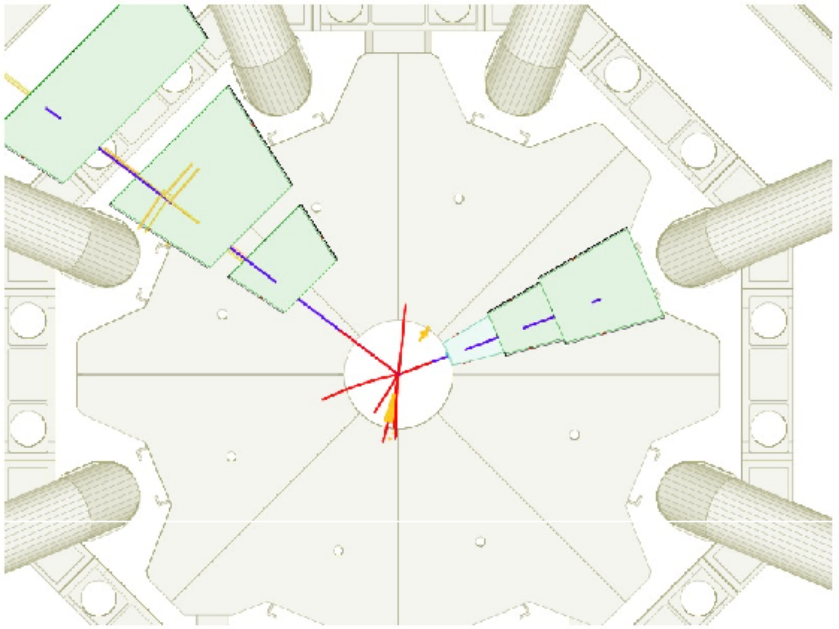
- SM backgrounds:
  - DY associated with ISR/FSR photon
  - DY + jets → tune to data
- Suppress backgrounds
  - 2 isolated leptons + isolated photon
  - Veto Z's at end of analysis to suppress DY

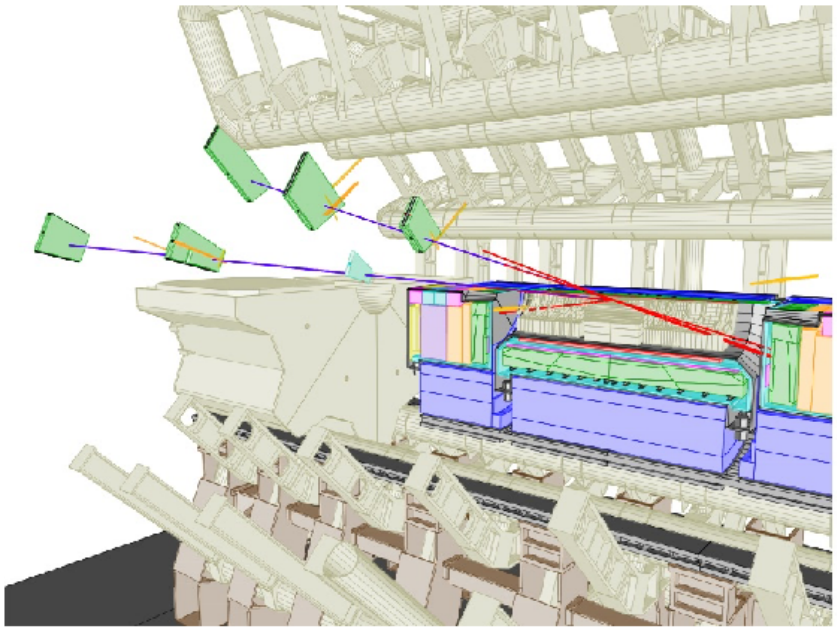


New

Search for excited leptons (5 fb^{-1})







ATLAS EXPERIMENT

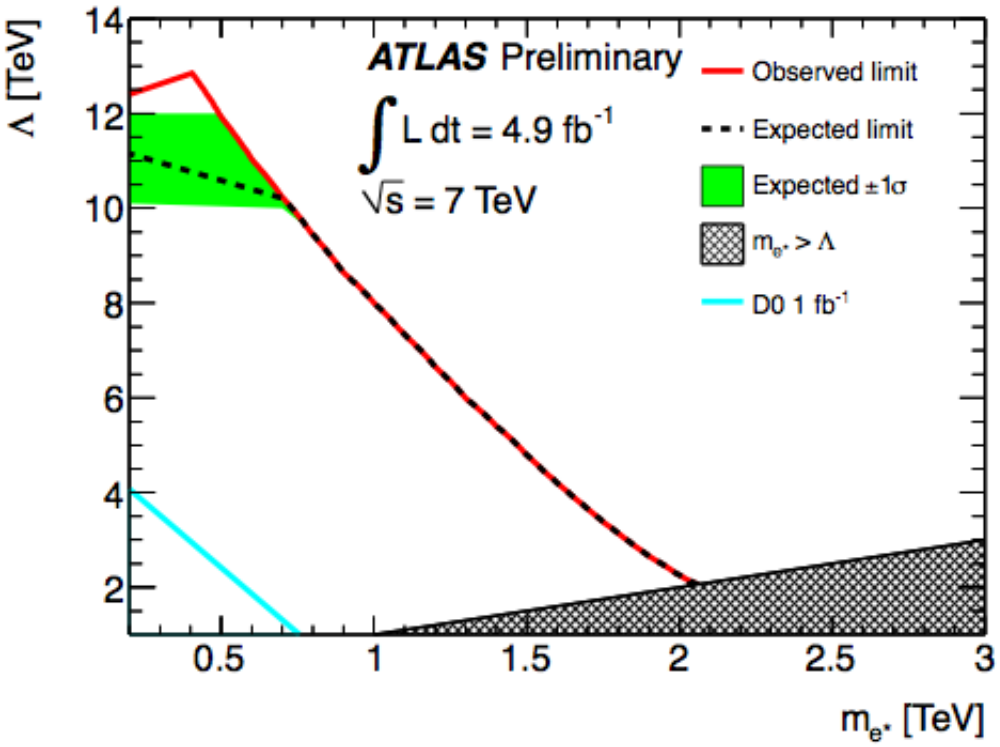
Run Number: 186169,
Event Number: 33317424
Date: 2011-07-23, 03:55:27 CET

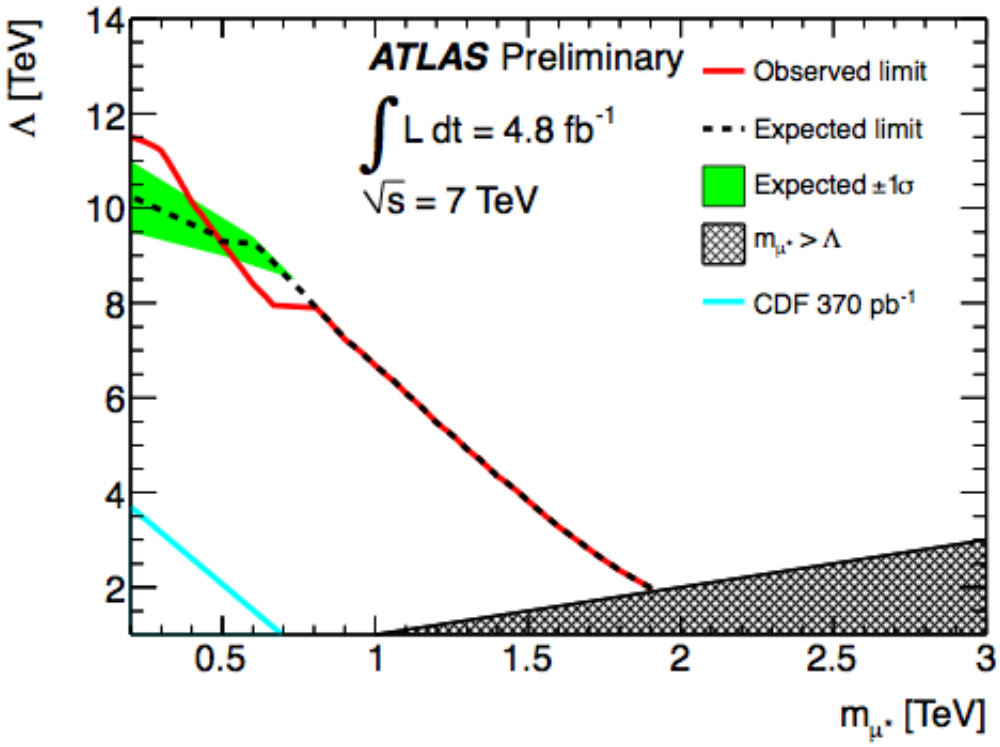
Cells: Tiles, EMC

$M_{\mu\mu\gamma}$ = 890 GeV
$M_{\mu\mu}$ = 165 GeV
$M_{\mu 1\gamma}$ = 720 GeV
$M_{\mu 2\gamma}$ = 490 GeV

New

Search for excited leptons (5 fb^{-1})





- For $m_{l^*} > 800$ GeV
  - $\sigma B(e^*) < 1.0$ fb
  - $\sigma B(\mu^*) < 1.9$ fb

ATLAS-CONF-2012-008

- Scan for compositeness scale and excited lepton mass
  - Exclude all e* masses for $\Lambda < 2.0$ TeV @ 95% C.L.
  - Exclude all μ* masses for $\Lambda < 1.9$ TeV @ 95% C.L.

2 fb^{-1} paper:

Submitted to Phys. Rev. D

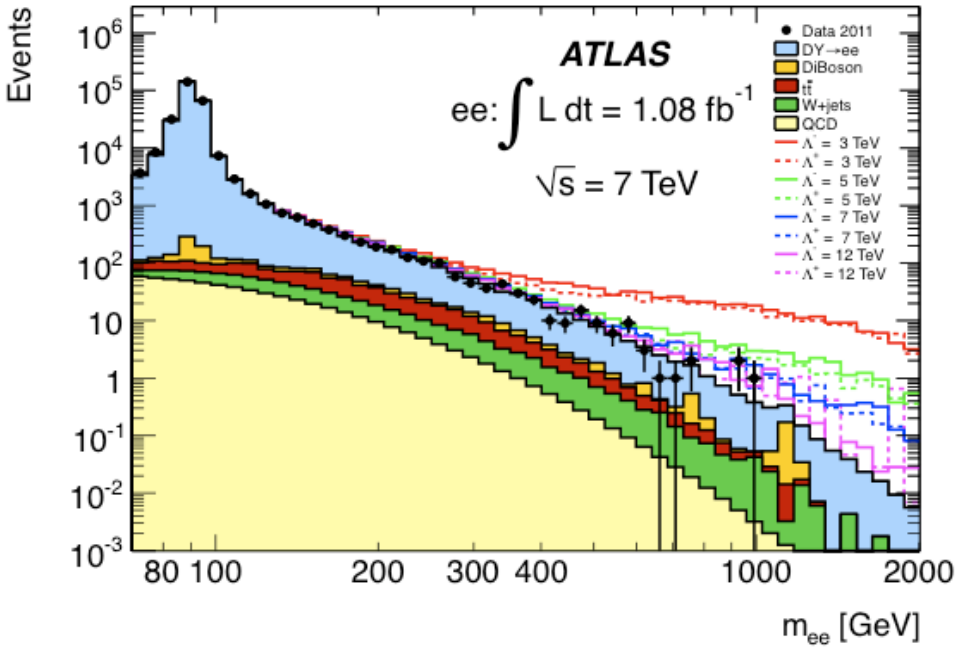
arXiv:1201.3293

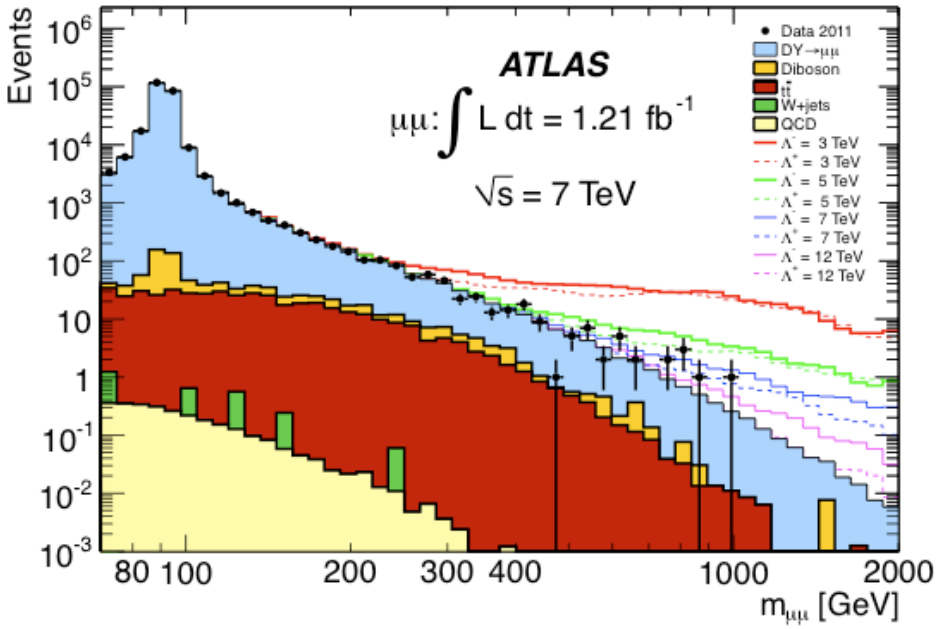
Search for contact interactions with dileptons (1.1-1.2 fb^{-1})

- Contact interactions
  - Large extra dimensions (ADD)
  - Compositeness models
- Constructive or destructive interference with
  - Investigate both possibilities
- Same analysis as Z', different interpretation
  - Set limit on minimum scale Λ for contact interactions ~ Λ > 9 TeV

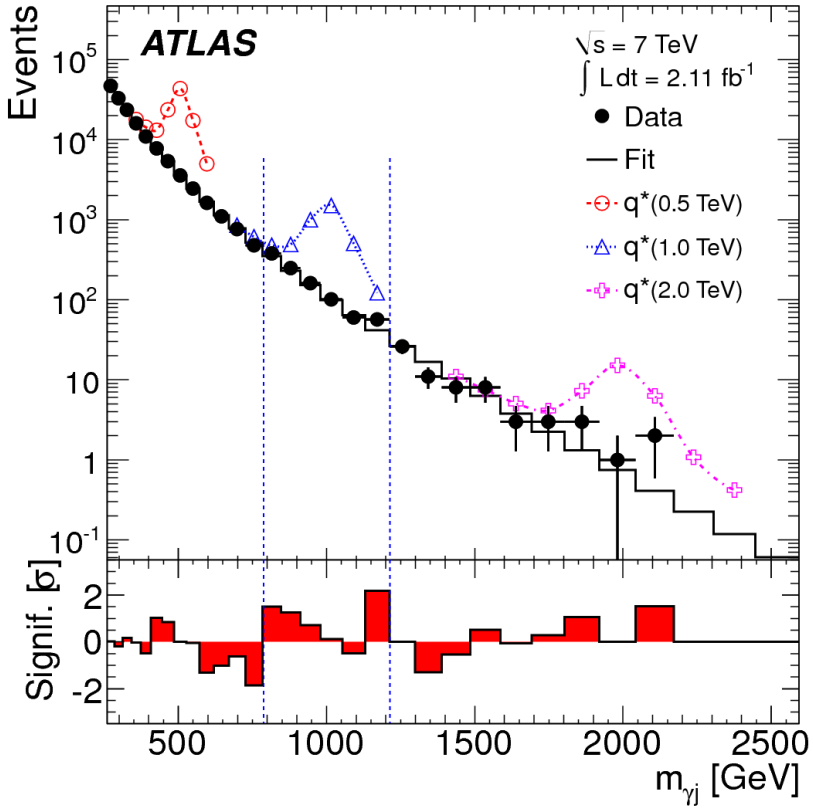
	Expected limit (TeV)		Observed limit (TeV)	
	Constr.	Destr.	Constr.	Destr.
e^+e^-	9.6	9.3	10.1	9.4
$\mu^+\mu^-$	8.9	8.6	8.0	7.0
Combined	10.4	10.1	10.2	8.8

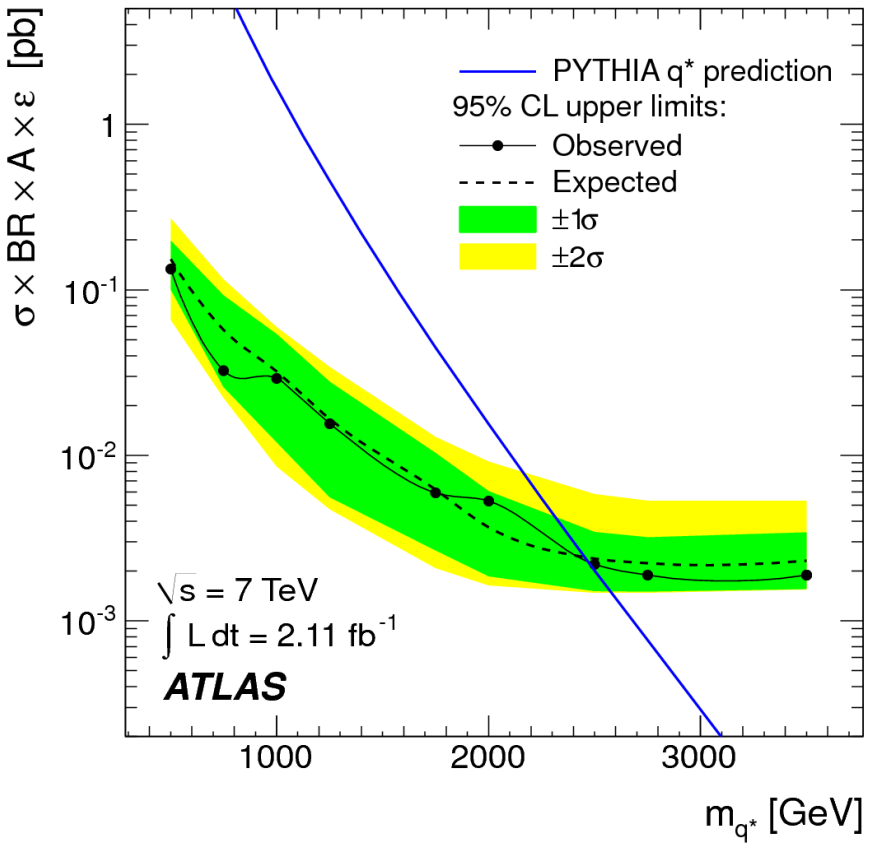
Submitted to Phys. Lett. B
arXiv:1112.4462





New Search for excited quarks: photon + jet (2.11 fb^{-1})



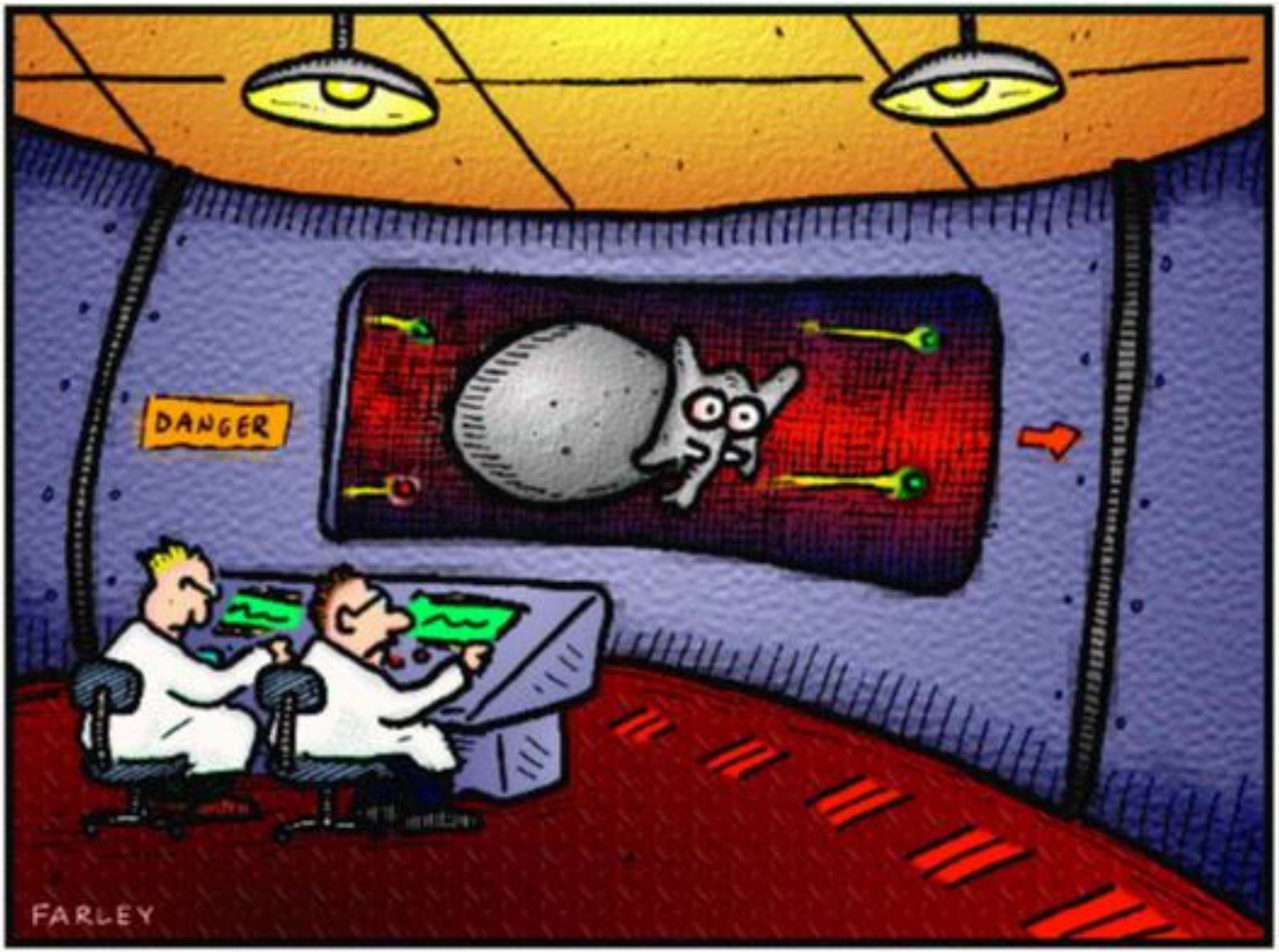


- Benchmark model:
  - Search for excited quark q* → qγ
- Signature
  - High p_T photon + jet → search for bump in photon-jet mass spectrum
- Scan for compositeness scale and excited lepton mass
  - Exclude all q* masses for Λ < 2.46 TeV @ 95% C.L.

Submitted to Phys. Rev. Lett.

arXiv:1112.5755

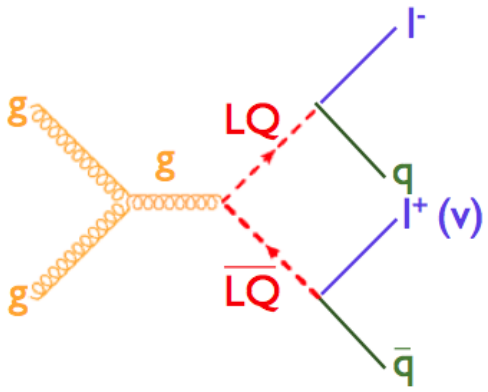
Search for New Heavy Bosons



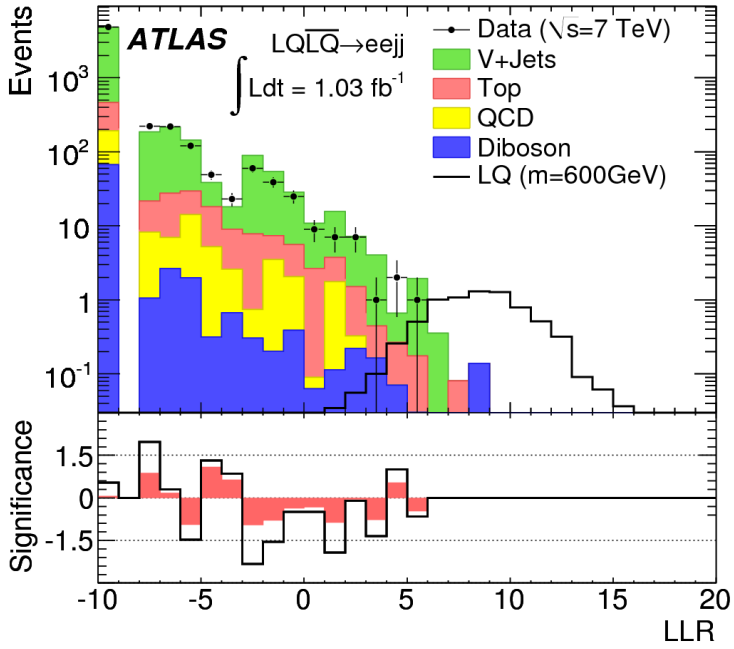
Deep within the atomic supercollider, the search continues for the elusive elephantino.

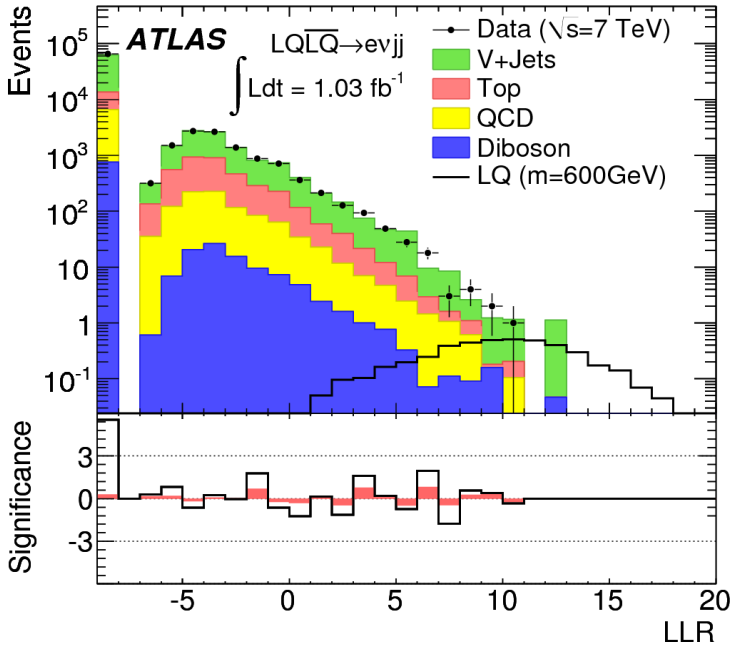
New

1st and 2nd generation Leptoquark (1.03 fb^{-1})



- Benchmark
  - Pair production of LQ in effective Lagrangian
- Signature
  - 2l + 2 jets
  - l + MET + 2 jets iff FCNC allowed
- Dominant backgrounds:
  - Z+jets and W+jets
  - Top quark decays
- LLR discriminant to maximize sensitivity:
  - avg LQ mass, S_T, m_T





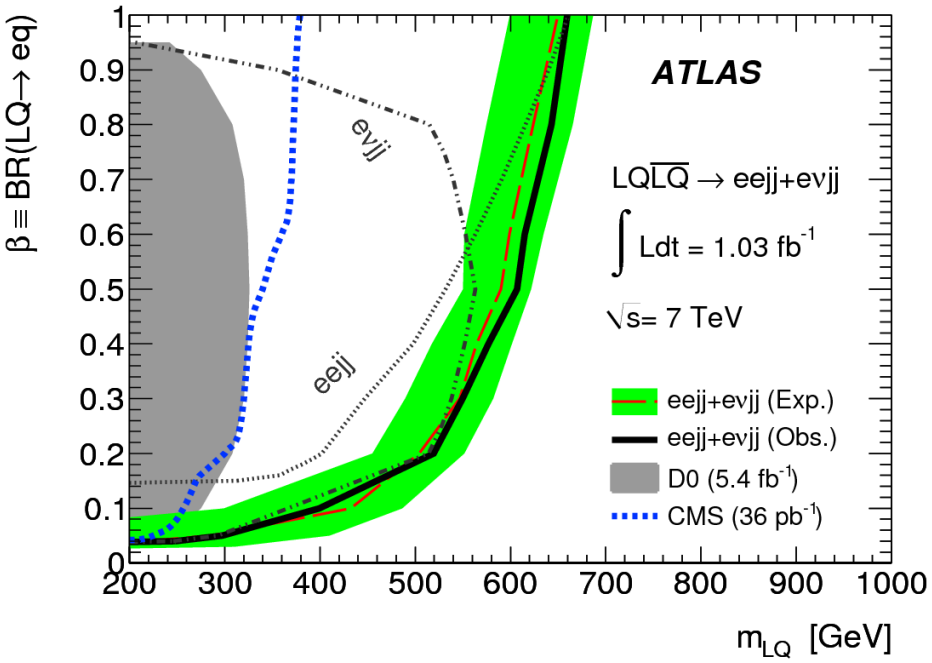
New

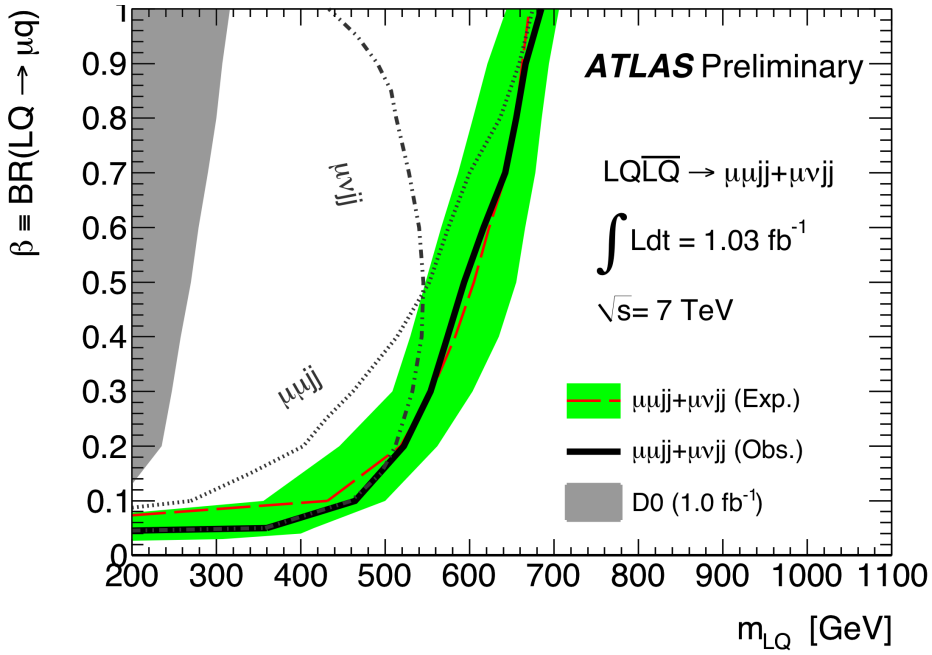
1st and 2nd generation Leptoquarks (1.03 fb^{-1})

- No excess found for either searches
- Limits on 1st generation LQ
  - m_{LQ} > 0.66 TeV @ 95% for β = 1.0
  - m_{LQ} > 0.61 TeV @ 95% for β = 0.5
- Limits on 2nd generation LQ
  - m_{LQ} > 0.69 TeV @ 95% for β = 1.0
  - m_{LQ} > 0.59 TeV @ 95% for β = 0.5

1st generation: *Submitted to Phys. Lett. B*
arXiv:1112.4828

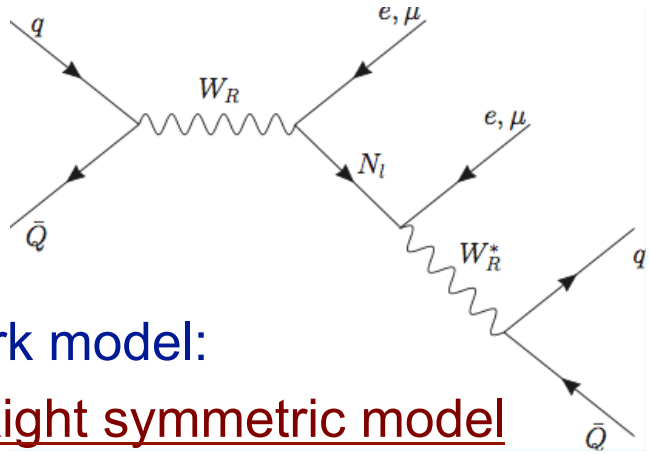
2nd generation: final internal review process



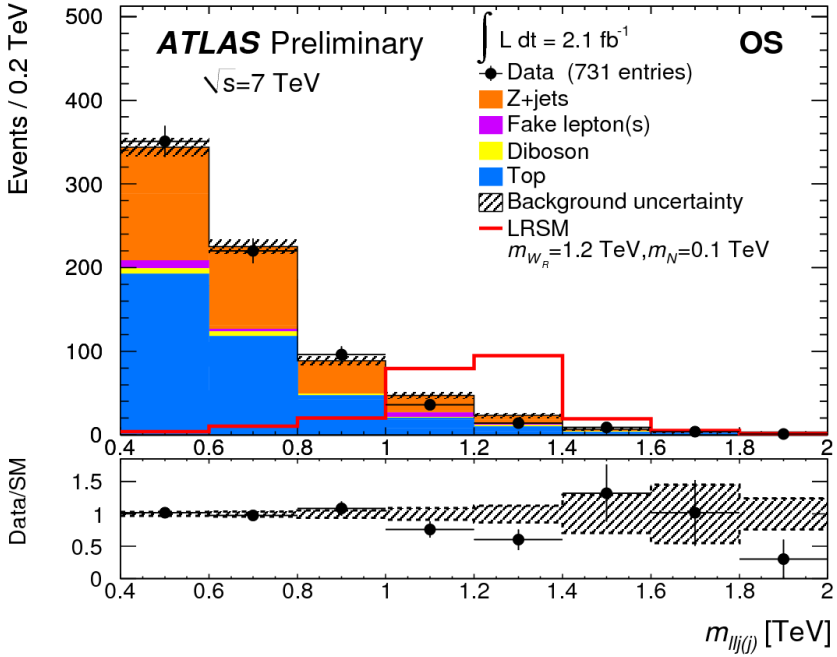


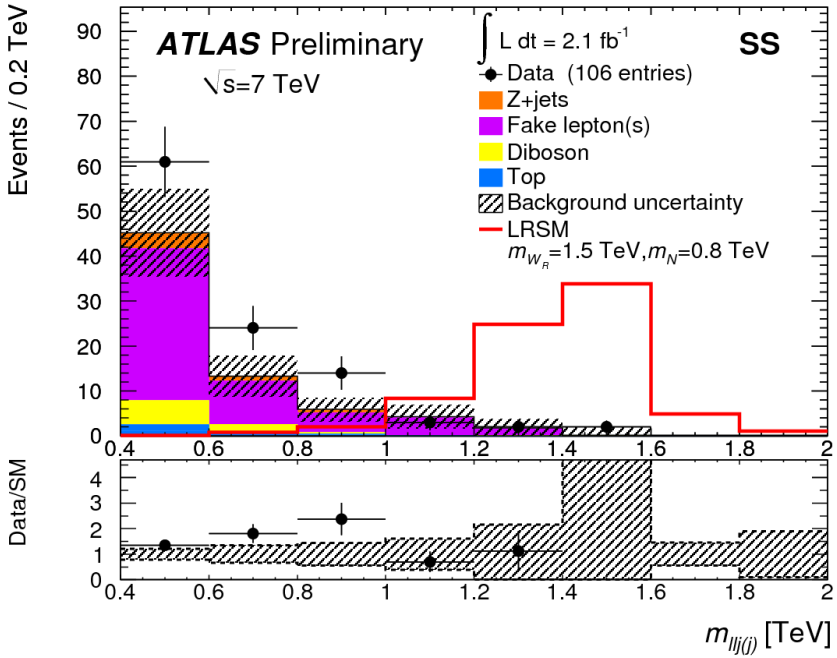
New

Search for W_R and heavy neutrinos (2.1 fb^{-1})



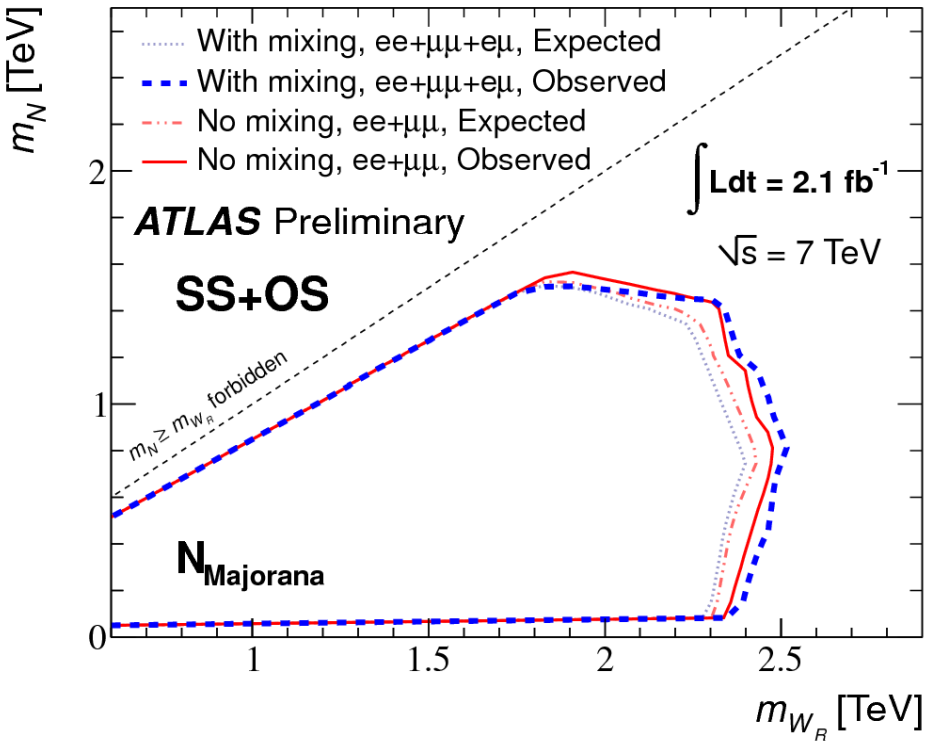
- Benchmark model:
  - Left-Right symmetric model
- Signature:
  - ee, μμ, or eμ + 2 jets
    - OS (Dirac + Majorana) / SS (Majorana)
- Backgrounds:
  - Z+jets, ttbar, diboson
  - Fake leptons → data-driven
- Observable:
  - Invariant mass of 2 leptons+jet (+jet) = m_{WR}

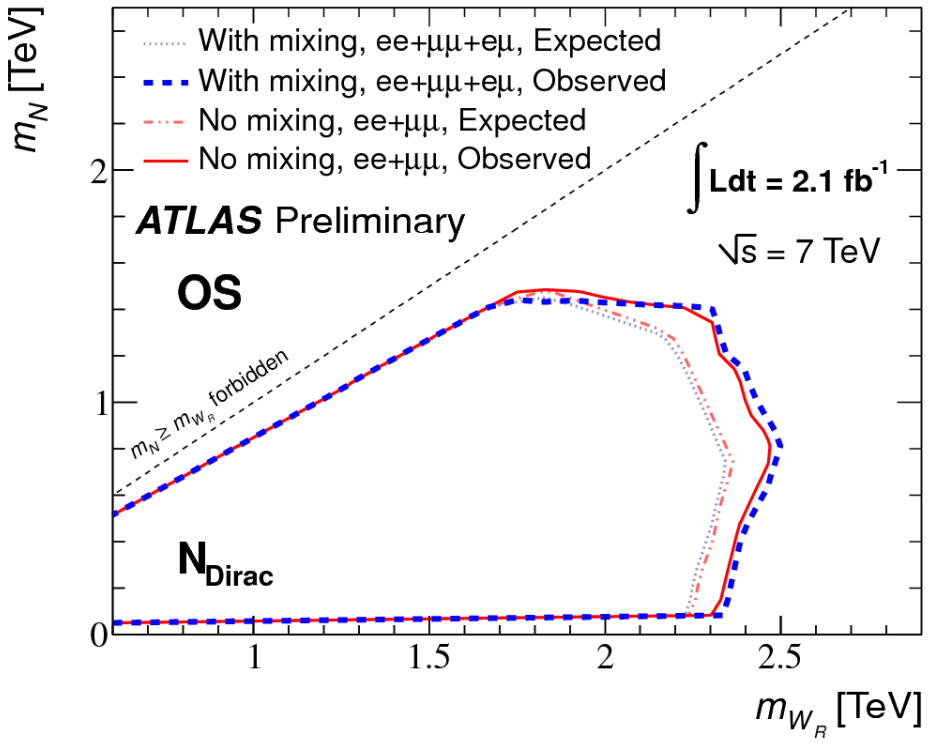




New

Limits for W_R and heavy neutrinos (2.1 fb^{-1})





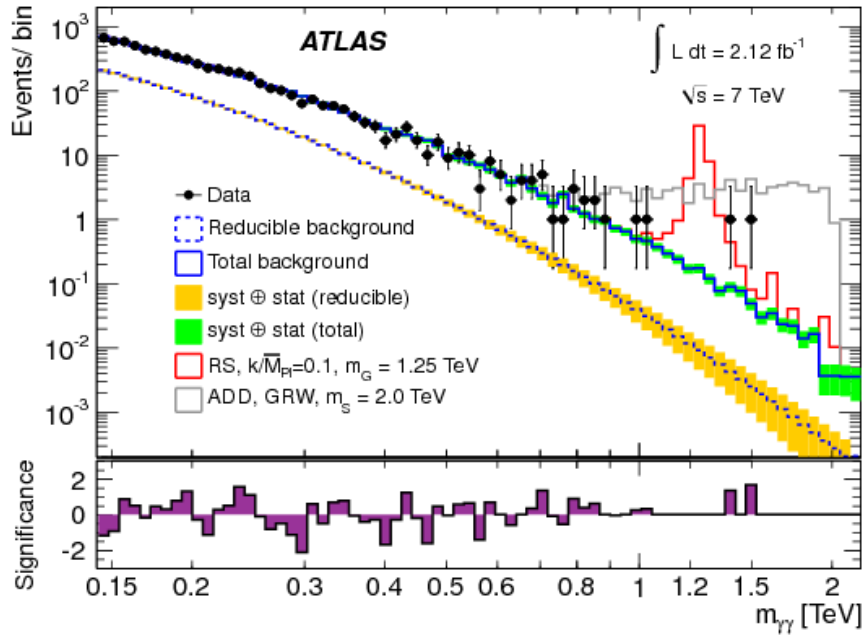
LRSM:

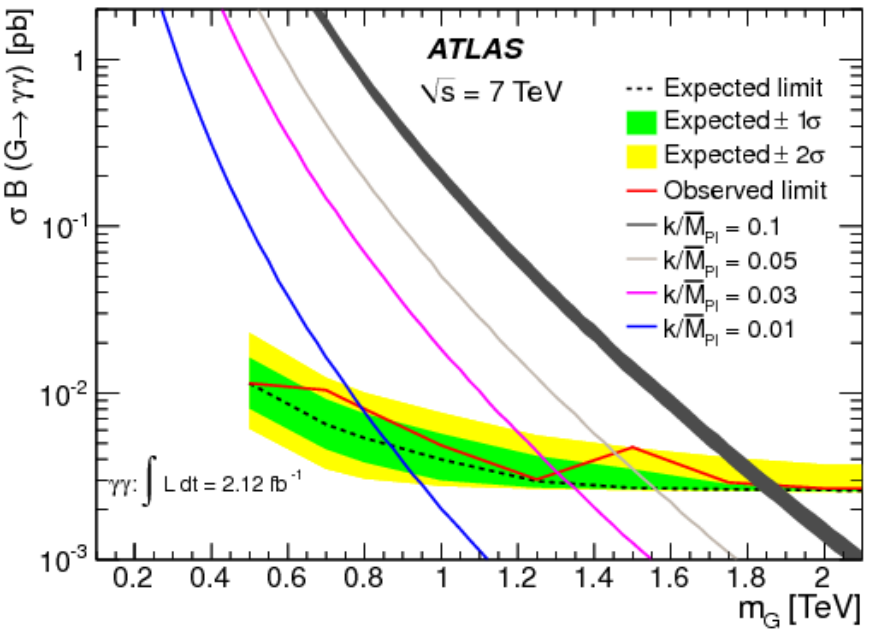
In model, assume $m_N < m_{WR}$

For many m_N, set limits on righ-handed W mass of $m_{WR} < 2.3$ TeV @ 95% C.L.

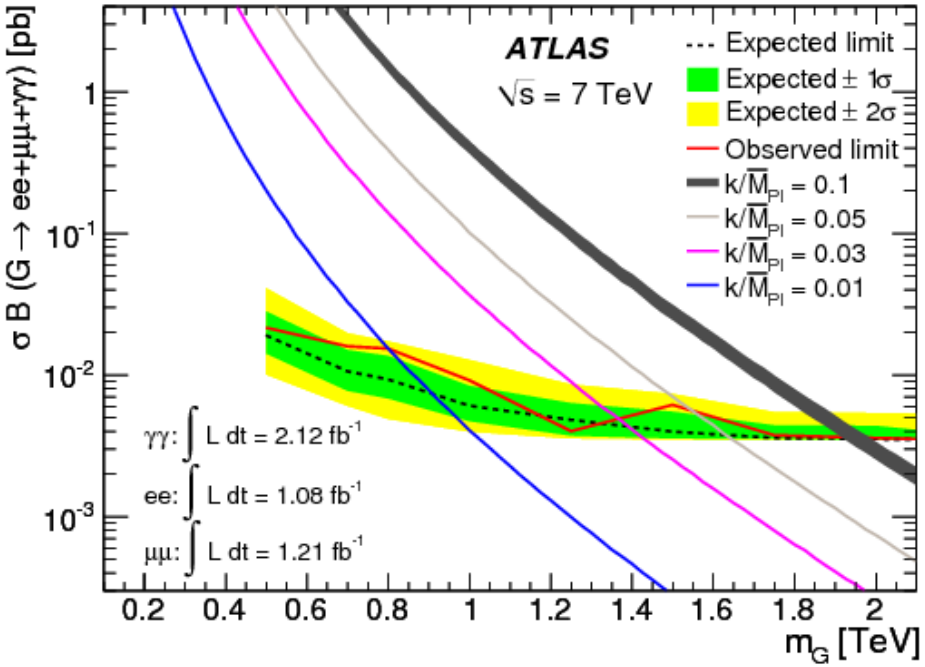
RS Graviton: diphoton (2.12 fb^{-1})

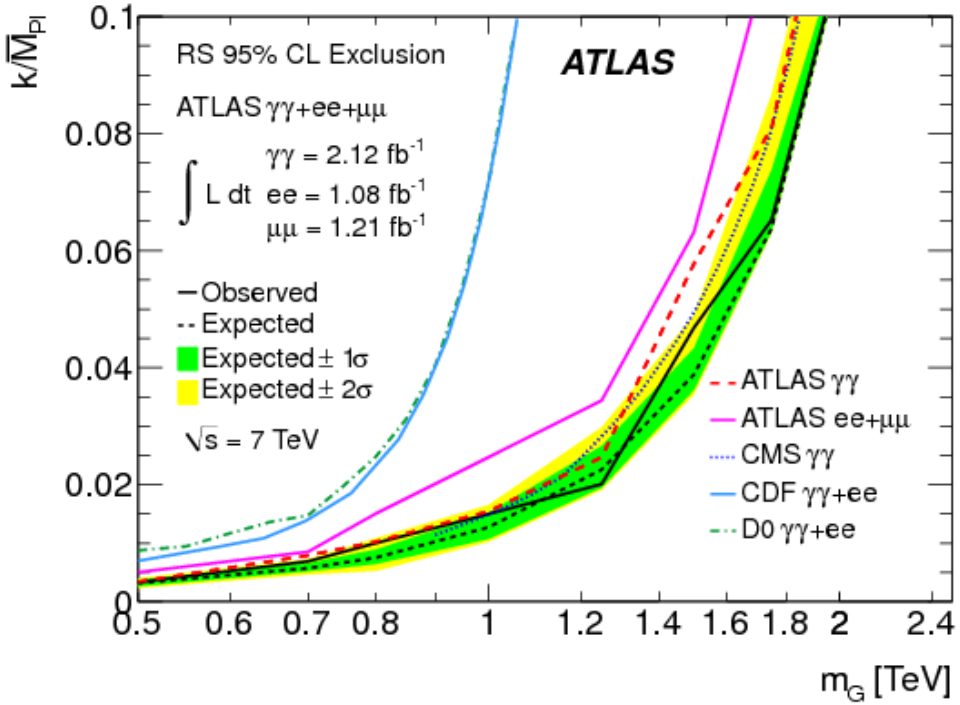
- Benchmark: RS G*
  - mass and coupling are free parameters
- Very clean signature:
  - Bump in diphoton invariant mass
- Backgrounds:
  - Irreducible SM γγ
  - Reducible γ+jet, jet+jet → from data
- Suppress reducible backgrounds
  - Use tight photon selection + isolation
  - Remove Z→ ee candidates
- No excess found
  - $m_{G^*} > 1.85$ TeV @ 95% for $k/M_{Pl} = 0.1$
  - $m_{G^*} > 0.79$ TeV @ 95% for $k/M_{Pl} = 0.01$





RS Graviton: diphoton (2.12 fb^{-1})





- Produce combined limits for G*
  - Reinterpret dilepton G* @ NLO
- Probe 2D phase space in terms of G* mass and coupling to SM fields

k-Factor Value	Channel(s) Used	95% CL Limit [TeV] $k/\bar{M}_{Pl}$ Value			
		0.01	0.03	0.05	0.1
1	$G \to \gamma\gamma$	0.78	1.26	1.38	1.80
	$G \to \gamma\gamma/ee/\mu\mu$	0.76	1.32	1.47	1.90
1.75	$G \to \gamma\gamma$	0.80	1.30	1.43	1.85
	$G \to \gamma\gamma/ee/\mu\mu$	0.80	1.37	1.55	1.95

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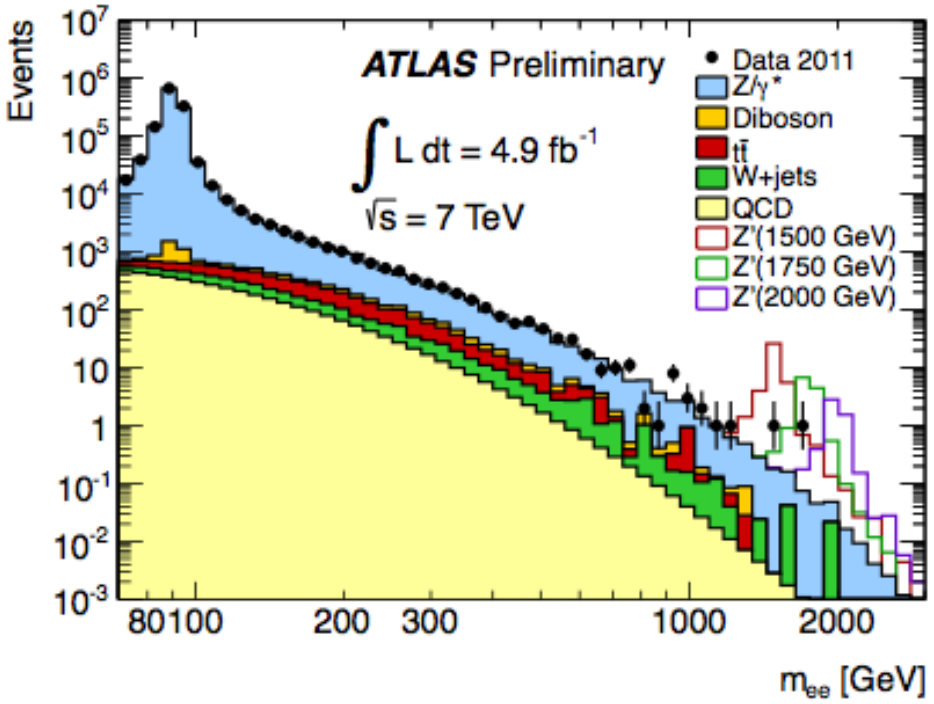
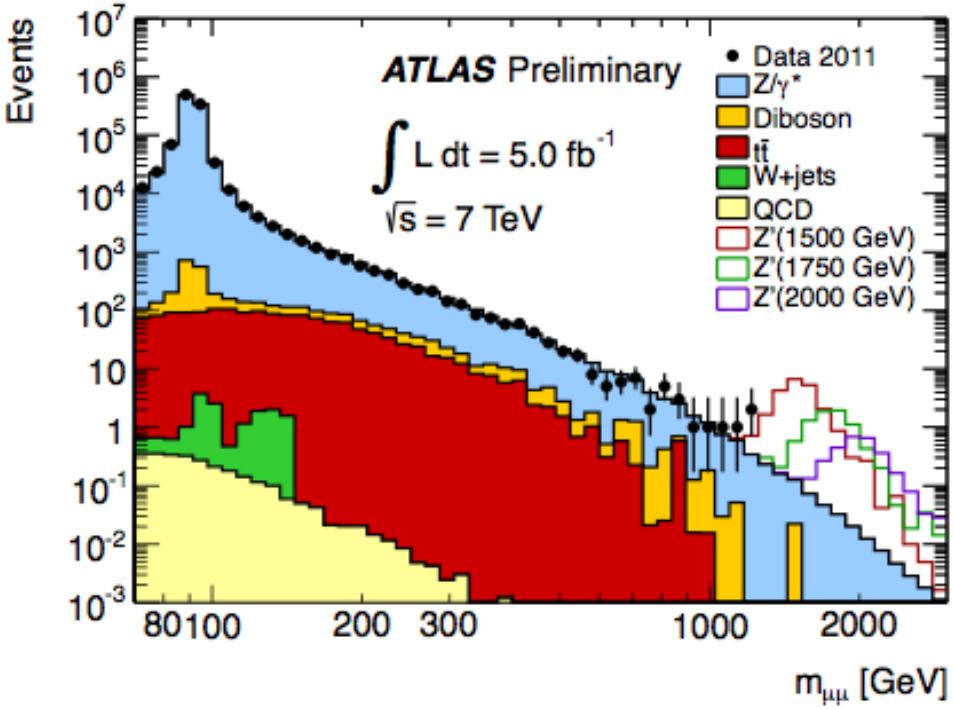
New

Z' and RS Graviton: dilepton (5 fb^{-1})

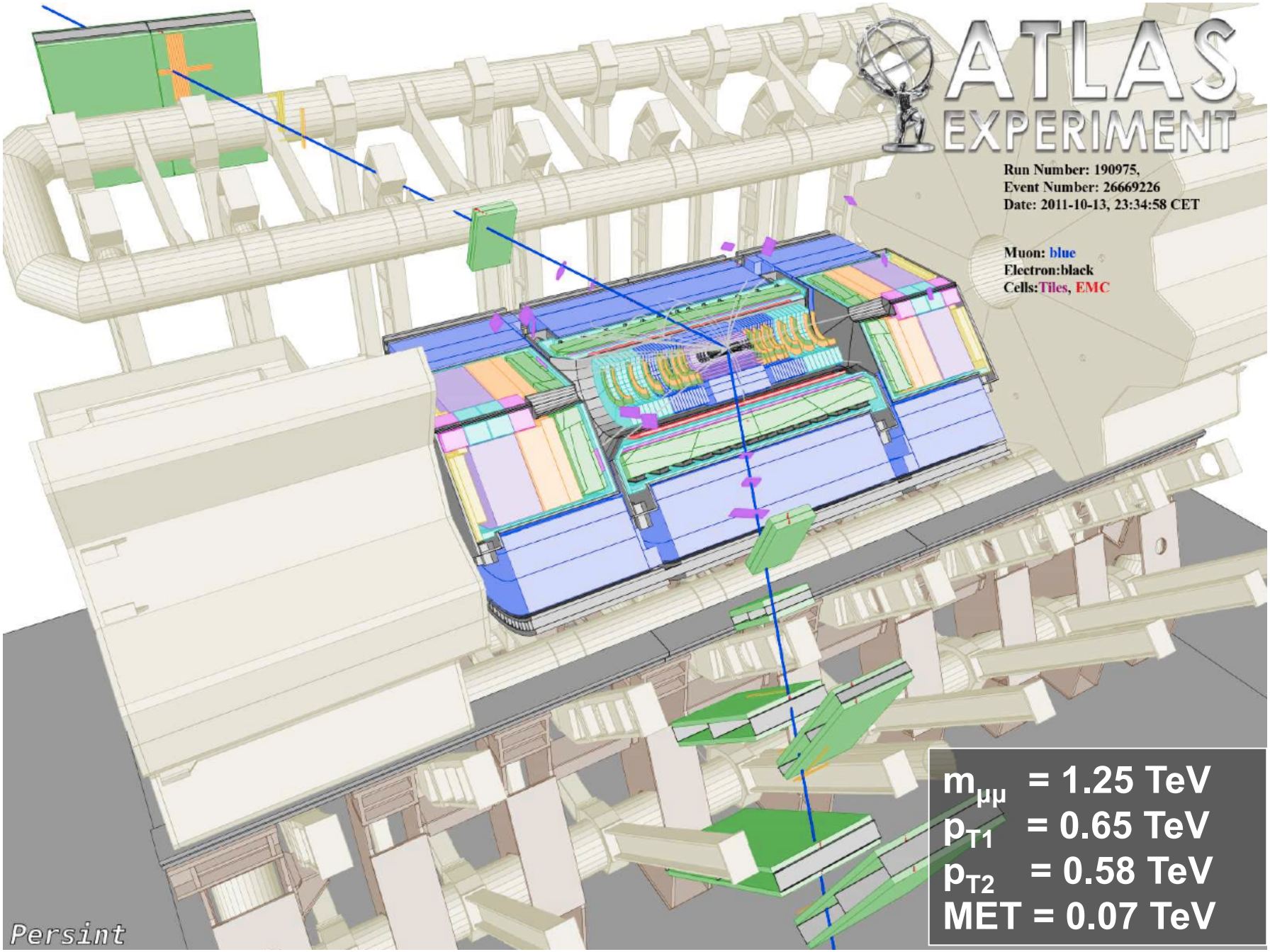
- Very clean signatures:
  - 2 isolated high p_T ee or μμ
- SM backgrounds:
  - **$Z/\gamma \rightarrow ll$ (NNLO)**
- Dominant uncertainties:
  - Theoretical: 20%
  - Experimental: 4 to 6%
- Consistent with background only
  - p-values of 13% (ee) and 82% (μμ)





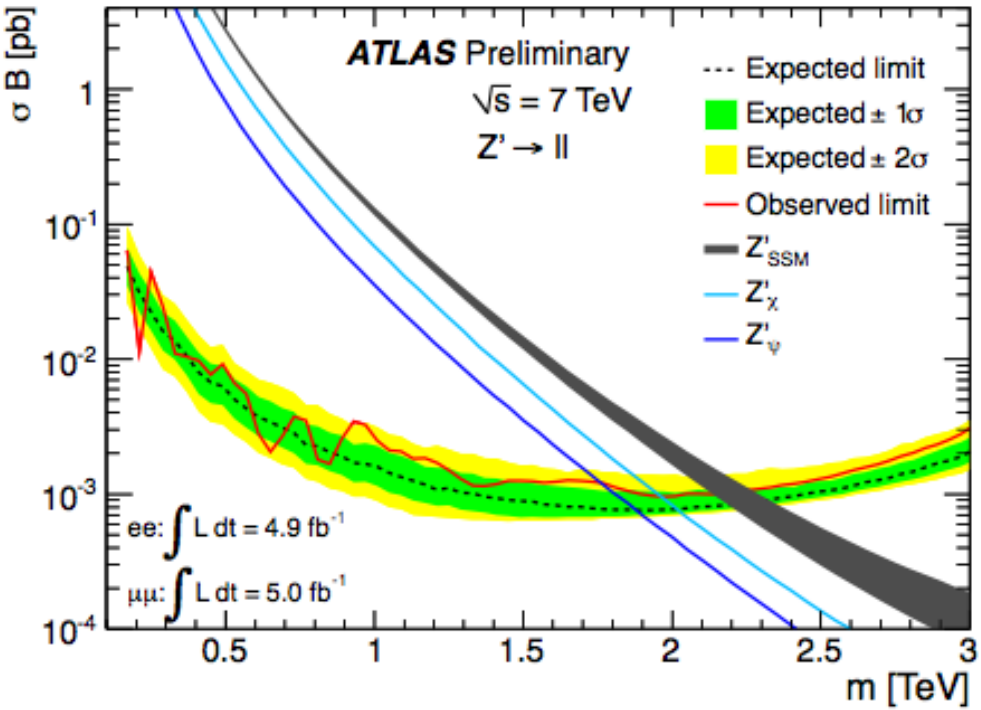
New

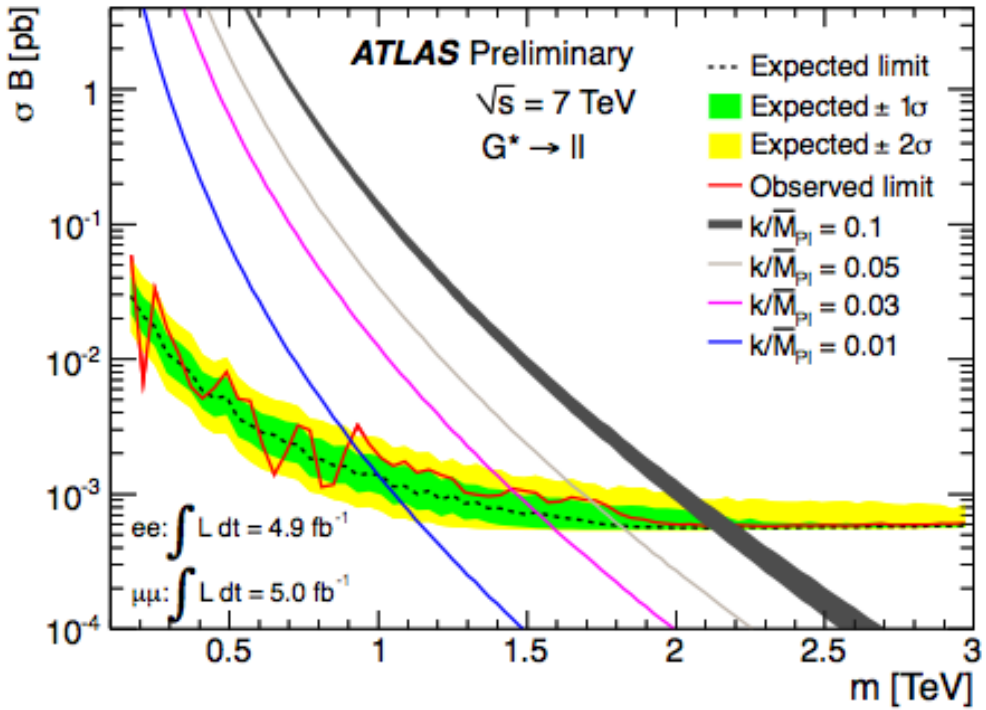
Z' and RS Graviton: dilepton (5 fb^{-1})



New

Z' and RS Graviton: dilepton (5 fb^{-1})



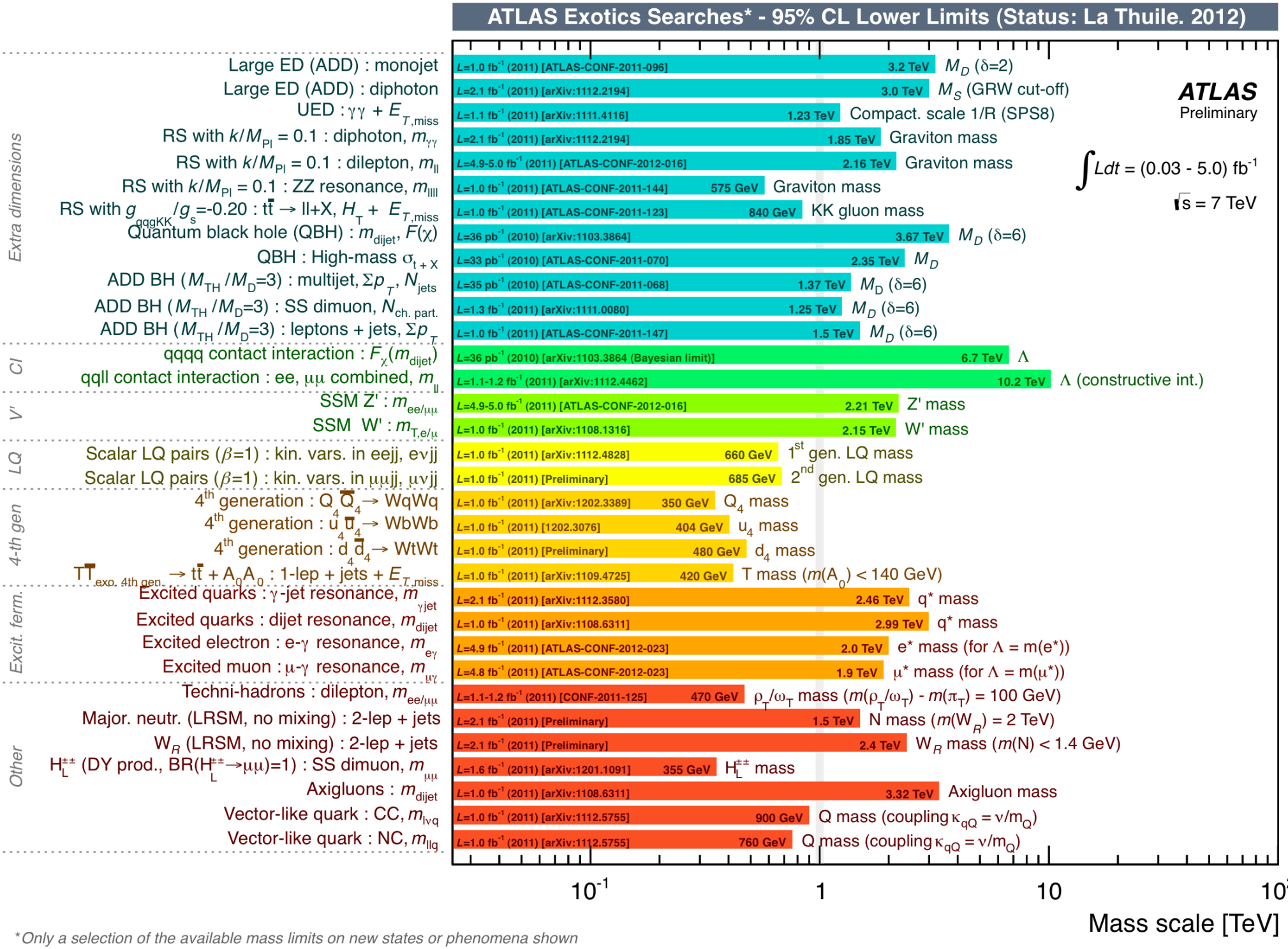


- Observed mass limits in TeV:
  - $m_{Z'} > 2.21$ TeV @ 95%
  - $m_{G^*} > 2.16$ TeV @ 95% for $k/M_{Pl} = 0.1$

Model	Mass limit [TeV]		
	e^+e^-	$\mu^+\mu^-$	$\ell^+\ell^-$
Z'_{SSM}	2.07 (2.14)	1.99 (2.01)	2.21 (2.26)
G^*	2.03 (2.05)	1.90 (1.92)	2.16 (2.17)

ATLAS-CONF-2012-007

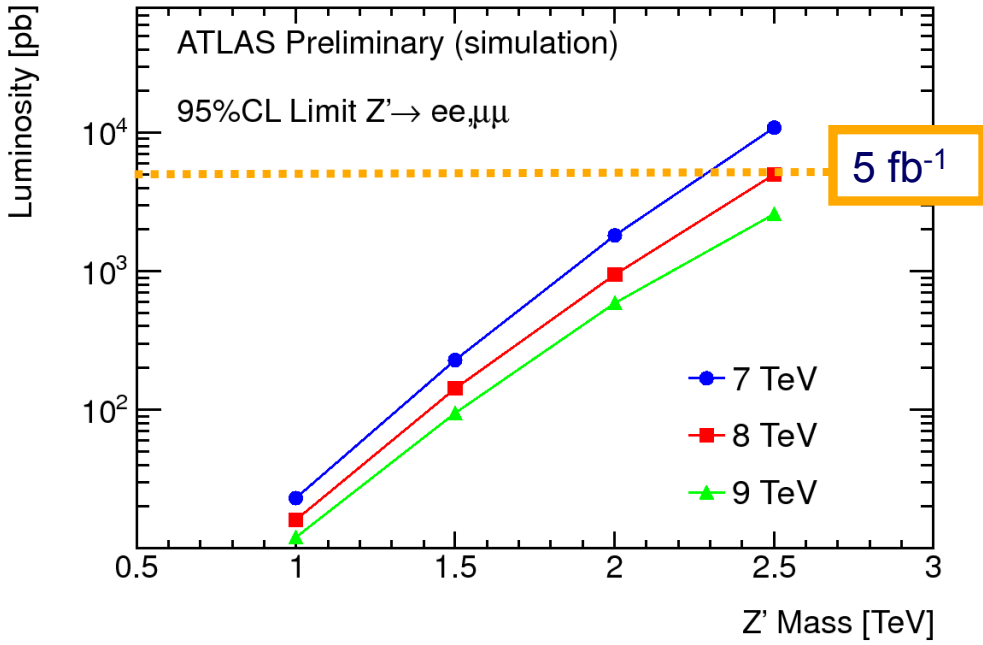
	E_6 Z' models						RS graviton			
Model/Coupling	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ	0.01	0.03	0.05	0.1
Mass limit [TeV]	1.76	1.78	1.84	1.84	1.90	1.96	0.91	1.45	1.71	2.16

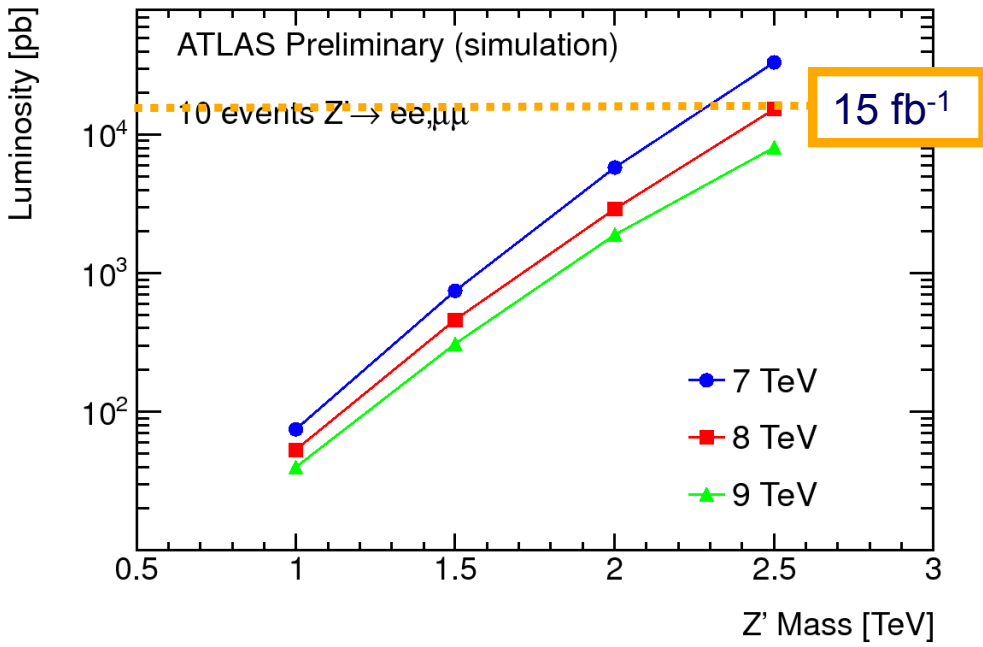


*Only a selection of the available mass limits on new states or phenomena shown

Outlook

- Past 18 months have been very productive
  - Many results from ATLAS
  - Many new searches under way
- Effective gain of factor 2 in production rate for Z' ~ 2.5 TeV by going to 8 TeV collisions
  - Parton luminosity
- Another exciting year ahead !

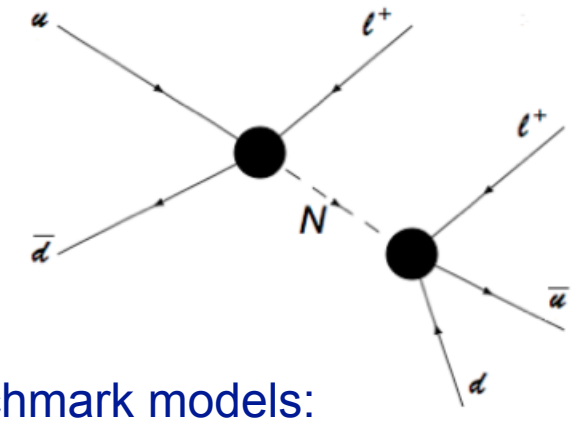




Extra slides

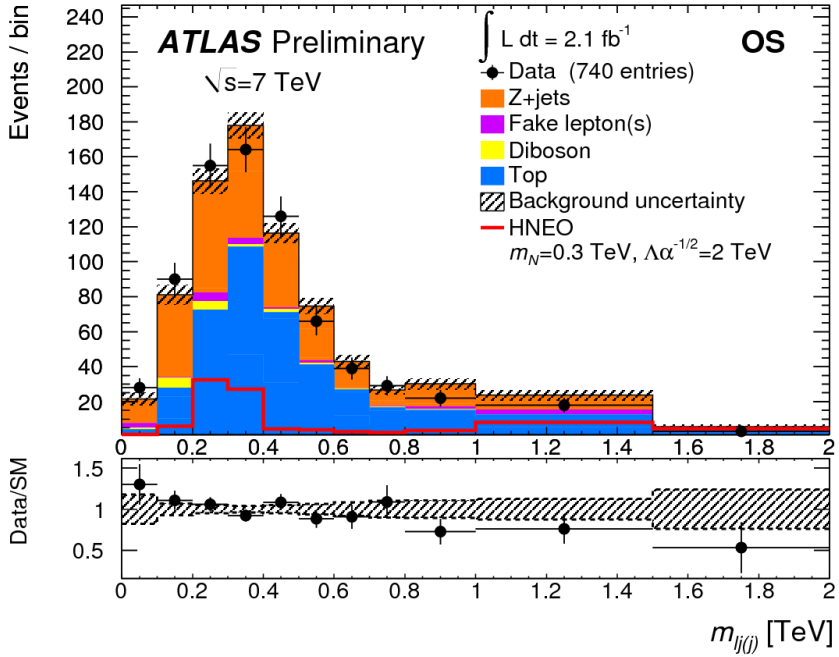
New

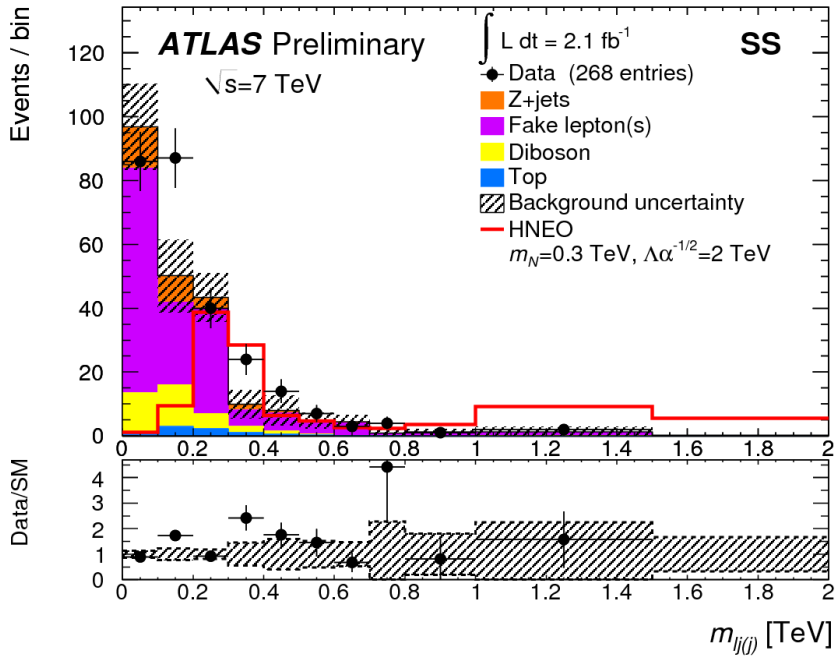
Search for heavy neutrinos (2.1 fb^{-1})



- Benchmark models:
  - Lagrangian of effective operators (HNEO)
  - Scan parameter-space for m_N, Λ, and α
- Same signature and backgrounds
- Observable:
  - Invariant mass lepton+jet (+jet) = m_N

No significant excess found





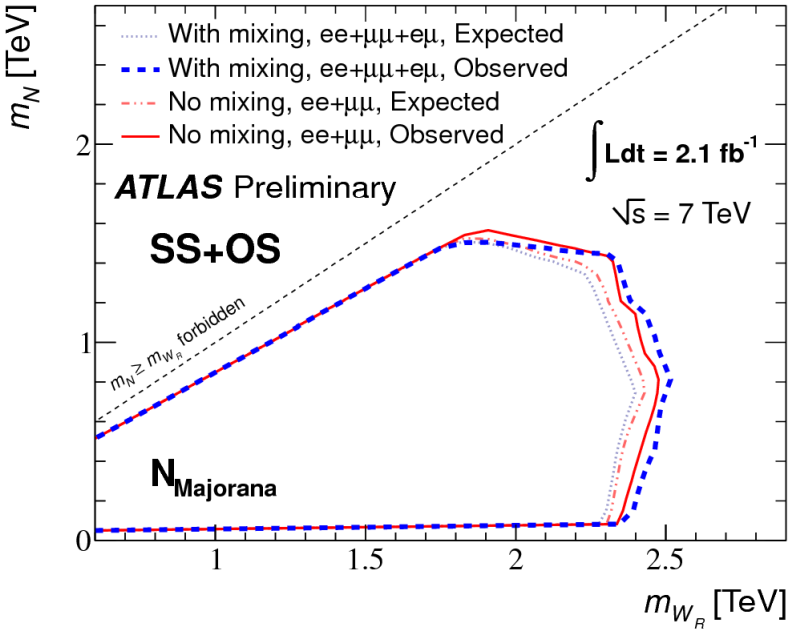
New

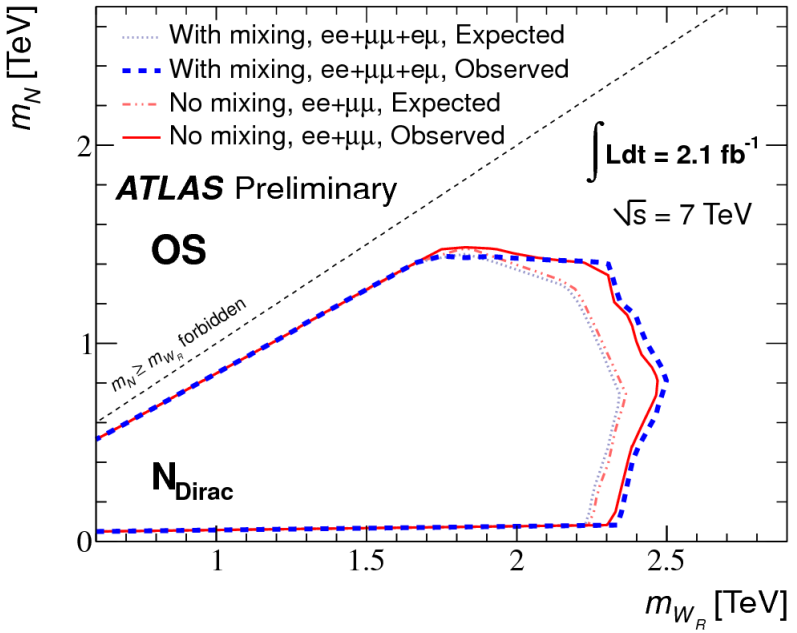
Limits for W_R and heavy neutrinos (2.1 fb^{-1})

LRSM:

$m_N < m_{WR}$

$m_{WR} < 2.3$ TeV

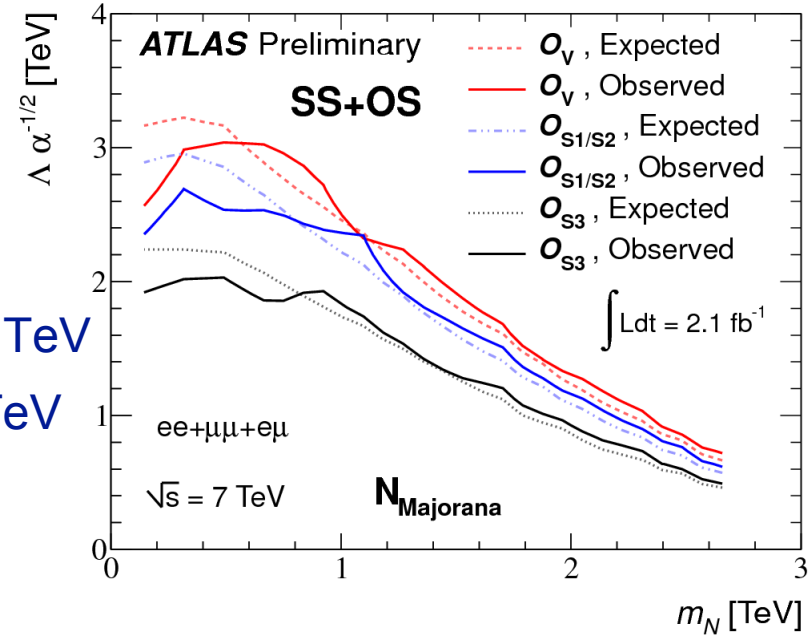


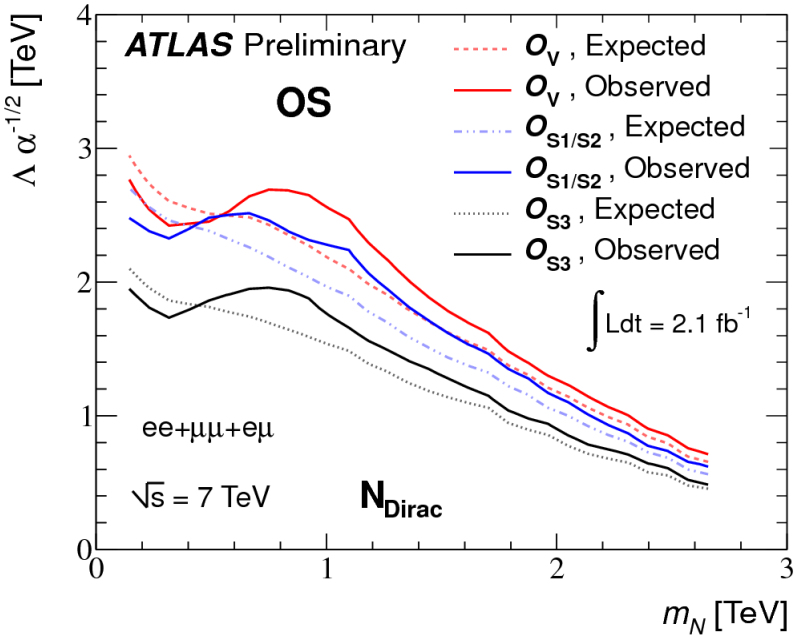


HNEO:

$0.7 < \Lambda\alpha^{-½} < 2.5$ TeV

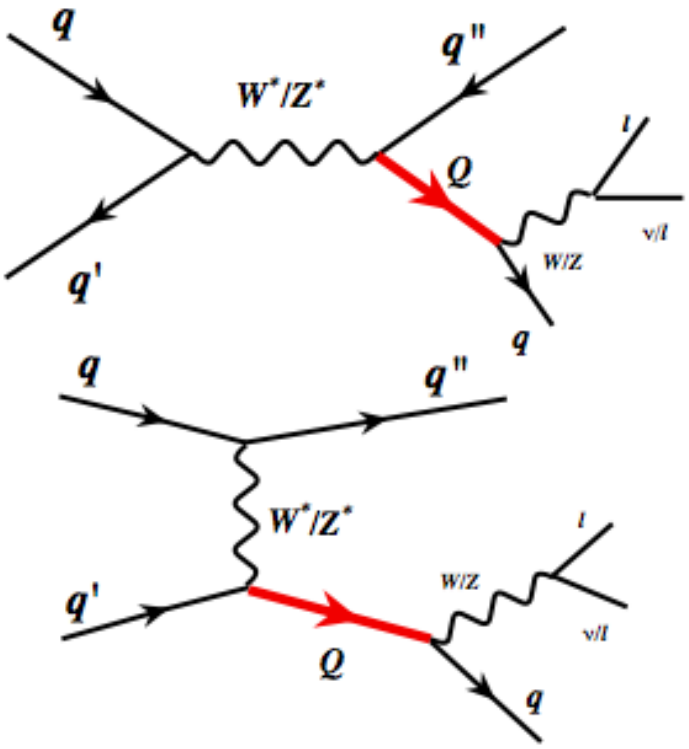
$0.1 < m_N < 2.7$ TeV

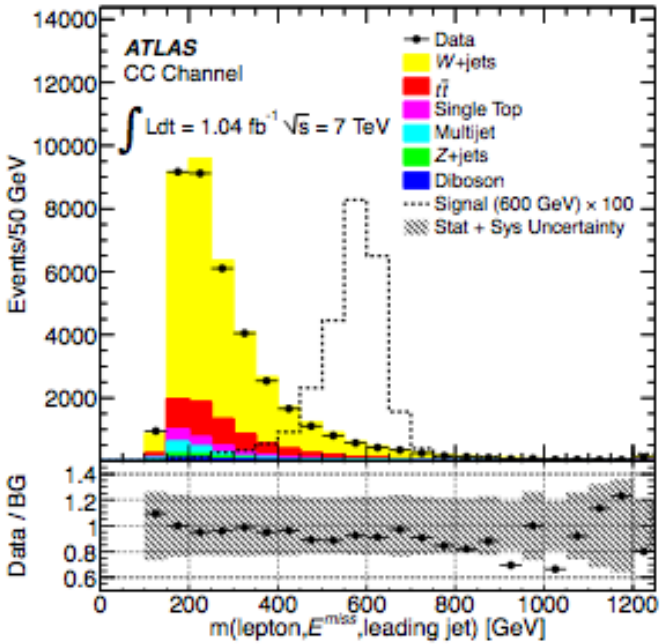


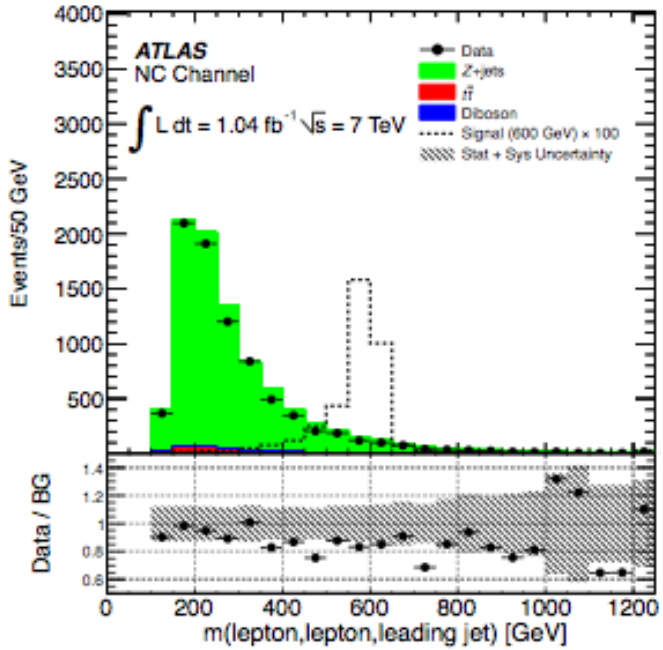


Search for heavy vector-like quarks (1.04 fb^{-1})

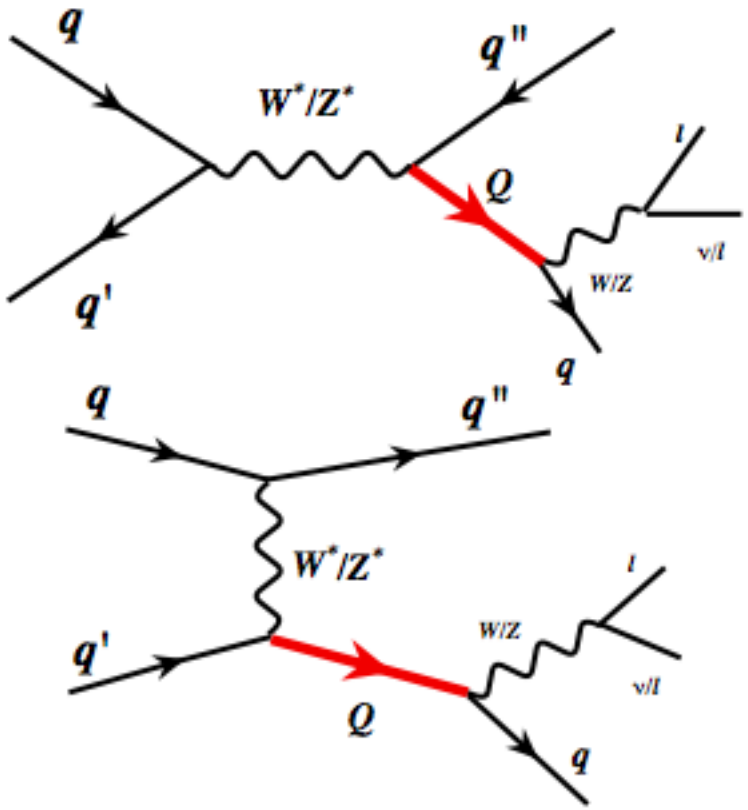
- Benchmark model:
  - Assume coupling to light quarks
  - Single production dominates
- Signature: VLQ → Vq
  - CC: l + MET + jet
  - NC: 2l + jet
- Backgrounds
  - Z and W+jets
  - Top + diboson events
- Observable
  - VLQ invariant mass

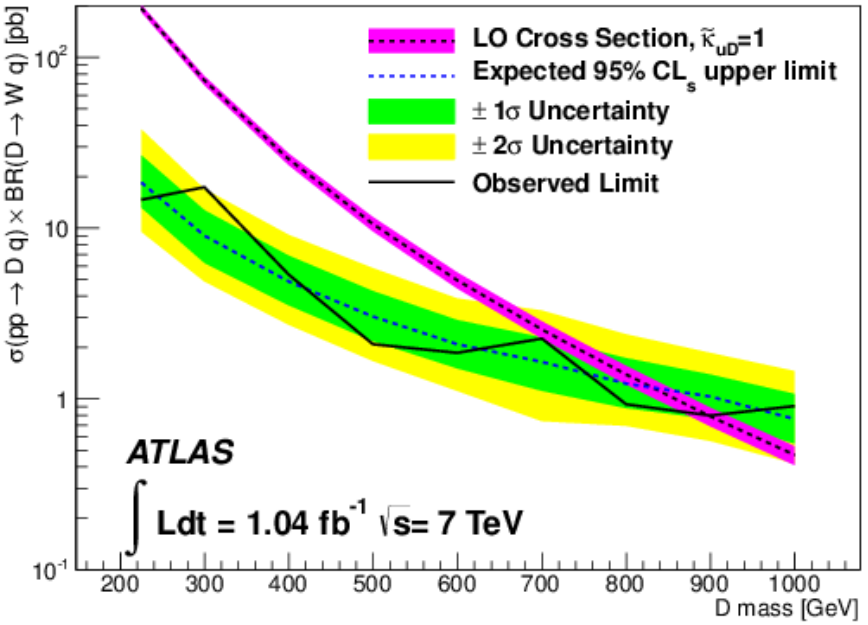


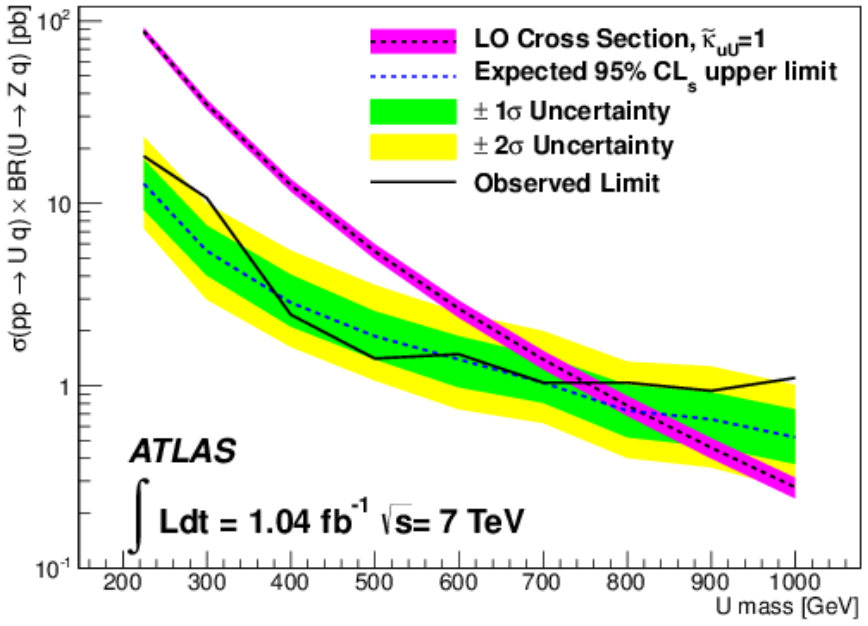




Search for heavy vector-like quarks (1.04 fb^{-1})







- No excess observed in either channels
  - CC: $m_{VLQ} > 0.90$ TeV @ 95%
  - NC: $m_{VLQ} > 0.76$ TeV @ 95%

Submitted to Phys. Lett. B

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