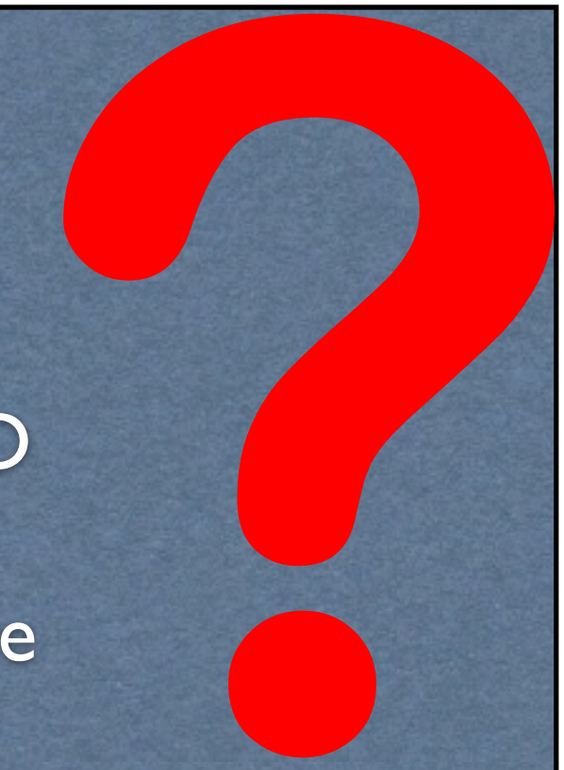
BSM Physics?

Hierarchy / fine tuning problem
Fermions mass structure
Matter vs. Antimatter
Cosmology -> Dark M & Dark E
Unification of electroweak (EW) & QCD
Number of generations
Neutrinos are Massive



(Non SUSY)
Searches for New Particles and Interactions

Hierarchy / fine tuning problem
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Number of generations
Neutrinos are Massive

LHC is a discovery machine!

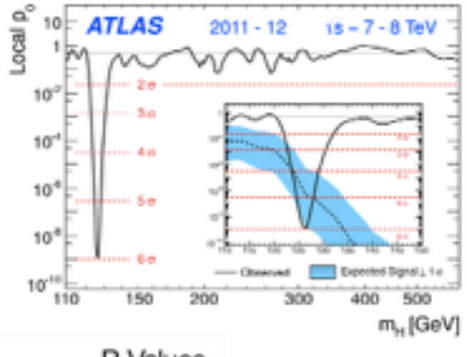
XXVIth Recontres de Blois
Particle Physics & Cosmology

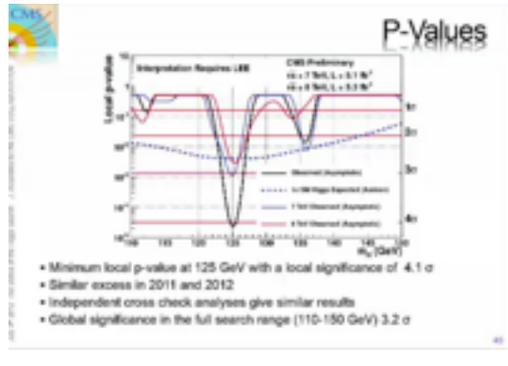
18th-23rd May 2014

Erez Etzion, Tel Aviv University
For the ATLAS and CMS collaborations

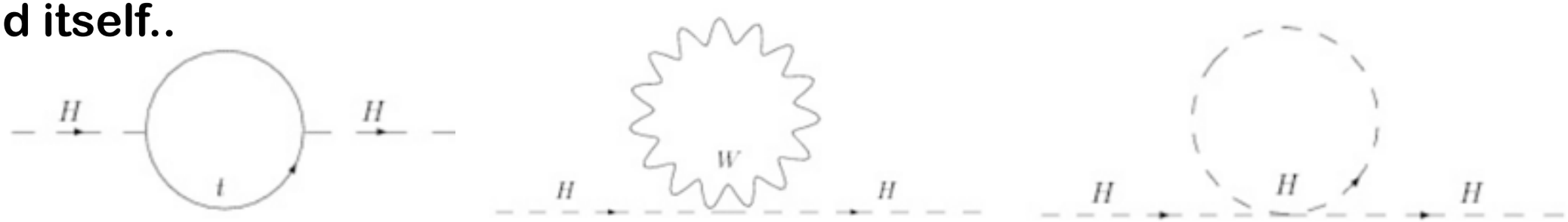
A new era for BSM searches?

- Impact of 125 H on our search for BSM strategy?
- SM Higgs related measurements:
  - Measure its mass, width and BR to SM particles
  - Look for other decay channels and measure their BR
  - Measure its spin (angular distributions)
- Exotics decays, does it couple to new particles??
  - ➡ Invisible Higgs→(MonoX analyses..)
  - ➡ Higgs to Exotics objects, e.g. Hidden valley to dark photons (LLP or lepton jets)
  - ➡ Other Higgses? might be more than one (SUSY)



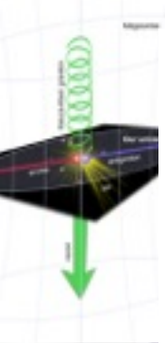


- Technicolor and SM4 are less likely, however other models including SUSY live well with a light Higgs.
- As the Higgs acquires mass from loops of fermions (tops!), Gauge bosons and itself..



- ➡ New physics may appear close to the Higgs mass
- ➡ Look for new physics in top related, or diboson physics.

(partial) List of Exotic Models



Extra dimensions:

RS Kaluza Klein (KK) Graviton (dibosons, dileptons, diphotons)

RS KK gluons (top antitop)

ADD (monojets, monophotons, dileptons, diphotons)

KK Z/gamma boosns (dileptons)

Grand Unification (GUT) symmetries (dielectons, dimuons, ditaus)

Leptophobic topcolor Z' boson (top antitop to dileptons, l+j, all had)

S8- color octet scalars (dijets)

String resonance (dijets,)

Benchmark Sequential SM (SSM) Z', W'

W' (lepton+MET, dijets, tb)

W* (lepton+MET, dijets)

Quantum Black Holes (dijet, l+j)

Black Holes (l+jets, same sign leptons)

Technihadrons (dileptons, dibosons)

Dark Matter

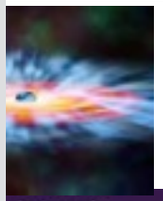
WIMPs (monojet, monophotons,monoX..)

Excited fermions

q*, Excited quarks (dijets, photon+jet)

l*, excited leptons (dileptons+photon)

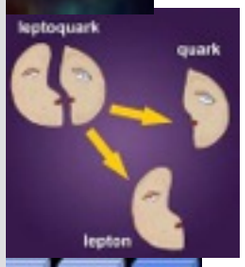
Leptoquarks (1st, 2nd, 3rd generations)



higgs -> hidden sector (displaced vertices, lepton jets)

Contact Interaction

llqq CI



4q CI (dijets)

Doubly charged Higgs (multi leptons, same sign lepton

4th generation

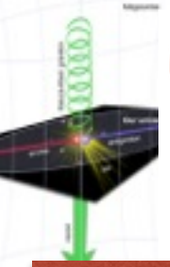
t'->Wb, t'->ht, b'-Zb, b'->Wt (dileptons, same sign leptons, l+J)

VLQ-Vector Like quarks

Magnetic Monopols (and HIP)

Heavy Majorana neutrino and RH W

(partial) List of Exotic Models



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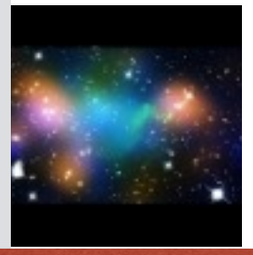
(dibosons, dileptons, diphotons)



Dark Matter

WIMPs (monojet, monophotons,monoX..)

Excited fermions

Complementary talks:

Searches for BSM in final states with 3rd Generation Particles - F. Blekman

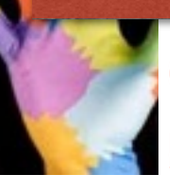
SUSY searches - P. Pralavorio

Detailed talks this afternoon:

L. Thomas (Heavy resonances), I. Tomalin (LLP), I. Vivarelli (DM & ED)

C. Contreas (heavy quarks and multi leptons)

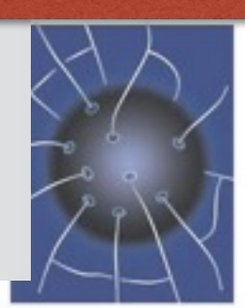
TBD ? (surprises?)



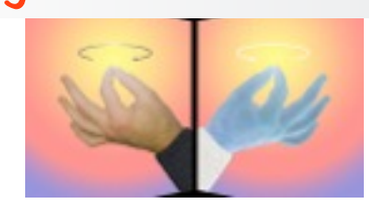
Quantum Black Holes (dijet, l+j)

Black Holes (l+jets, same sign leptons)

Technihadrons (dileptons, dibosons)



Heavy Majorana neutrino and RH W



Search for heavy resonances

- There are famous precedents
- Theoretical challenges: predicted by numerous BSM extensions
  - GUT, ED, Technicolor ..
  - Benchmark model Sequential SM (Z^0, $W^{+/-}$ couplings)
- Experimental challenges:
  - Detector effects (trigger, resolution, efficiency) at high E.
  - Reach the TeV scale - a few CRs, extrapolate from low E, MC
  - However expect clean signal

Search for heavy resonances

- Strategy
  - Search in tails of the SM distributions (lower mass excluded ? hidden by SM “BG”?)
  - S-channel - easy to detect, higher cross section, but high BG
  - Pair production - clearer signal but lower cross section
  - BG estimate - main BG data driven techniques, smaller BG with MC
  - Acceptance and efficiency - model dependent
  - Sometime start with SM cross section measurement
  - Alway start with SEARCH phase!!
  - Plan B, turn to limits on typical benchmarks
  - and / or “model independent” limit
  - Blind analyses

Jet + X

- JETS, thats what we have at LHC ..
- The signatures: resonances or angular distributions of dijets, multijets or γ + jet, single-jet / γ
- Exotics model considered are:
  - ED (ADD)
  - DM, (and SUSY signals)
  - TeV-scale gravity
  - Contact Interaction
  - Model independent searches

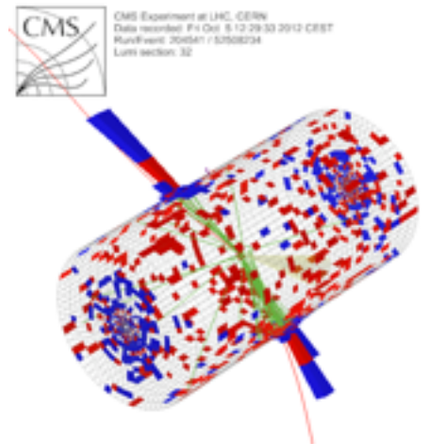
- QCD like signal: (excited quarks, axigluons..) usually couple to jets, the EW BG is small but has irreducible Jets BG calculated at NLO or fit the data in control regions (CR)

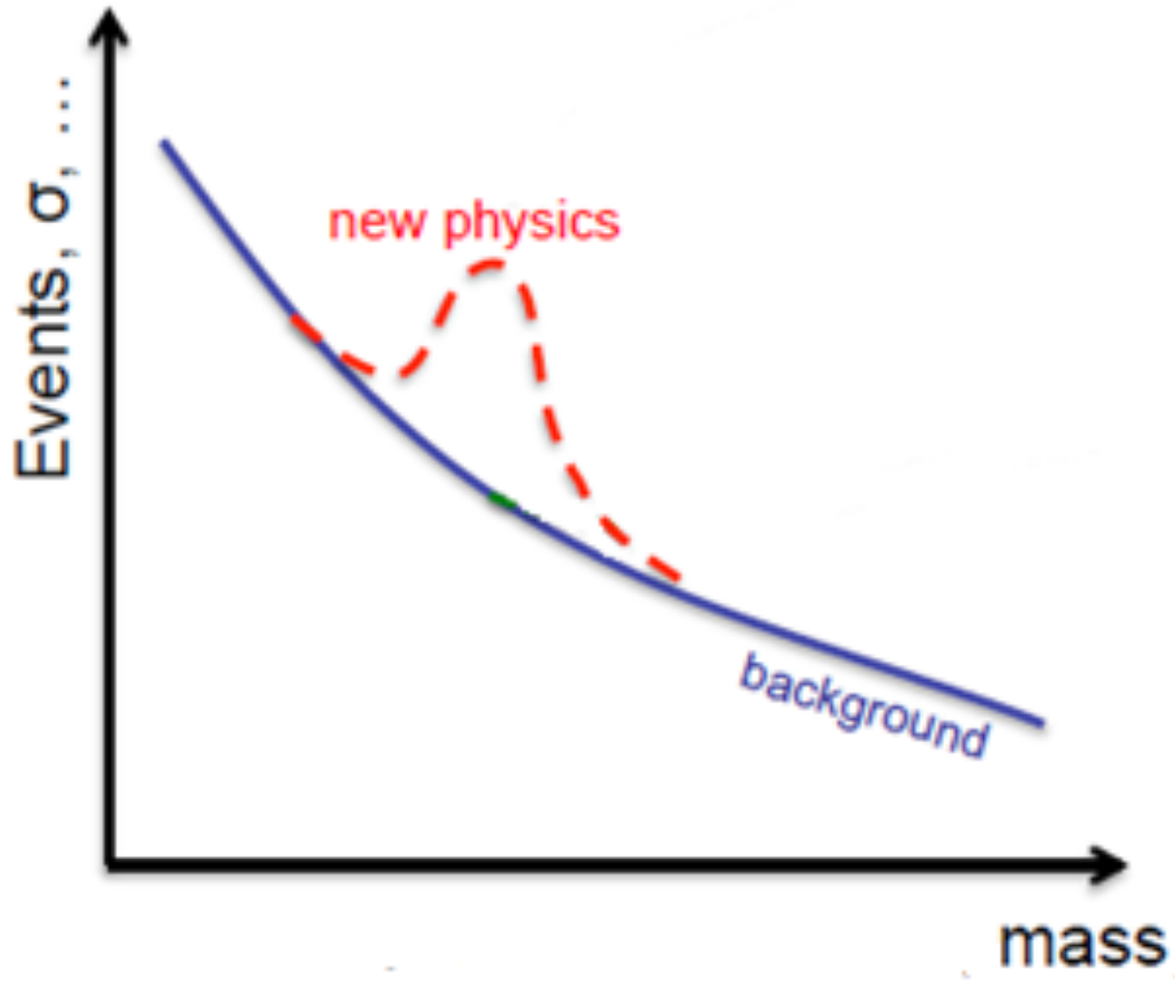
Search for heavy resonance: dijets

- Models: excited quarks, strong gravity, contact interaction..
- Large statistics
- However high background (QCD) level
- Looks for resonance above phenomenological fit of the data

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

$$x \equiv m_{jj}/\sqrt{s}$$





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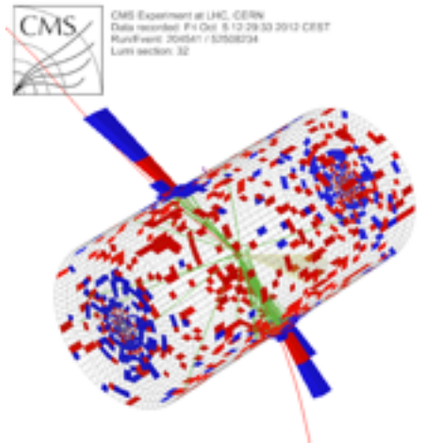
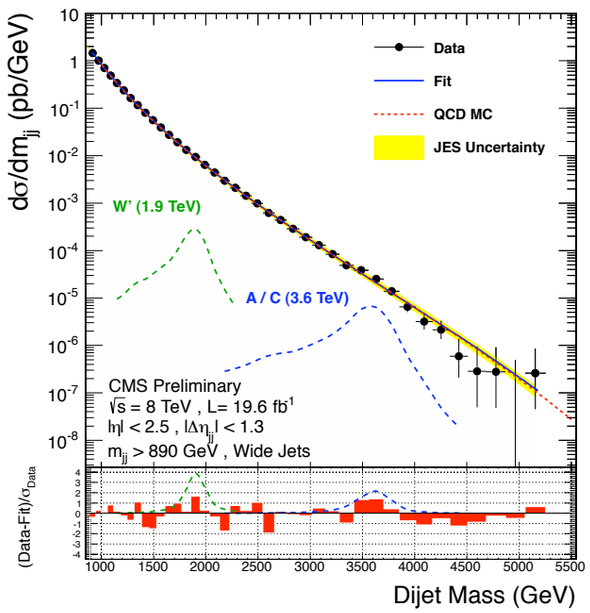
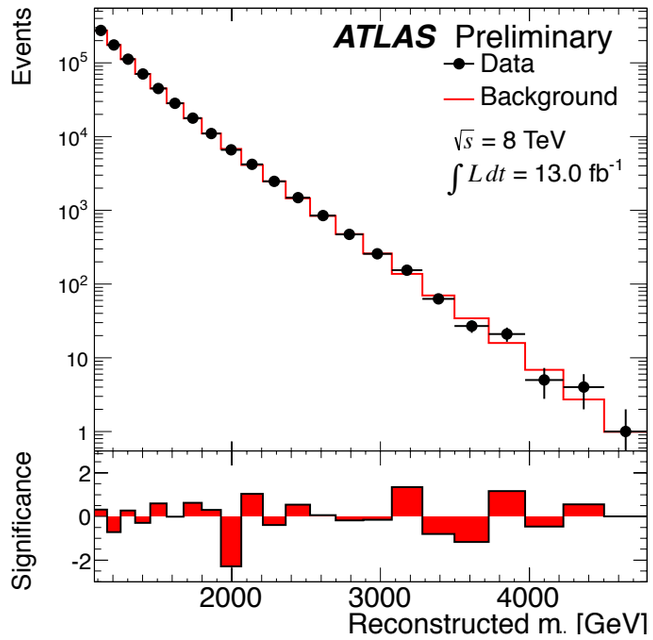


CMS EXO-12-059



ATLAS-CONF-2012-088



M(q*) 95% CL	Luminosity	Expected	Observed
ATLAS 2011	4.8	> 3.09 TeV	> 3.55 TeV
CMS 2011	5.0	> 3.27 TeV	> 3.05 TeV
ATLAS 2012	13.0	> 3.70 TeV	> 3.84 TeV
CMS 2012	19.6	> 3.75 TeV	> 3.50 TeV

Resonance in X→HH→bbbb

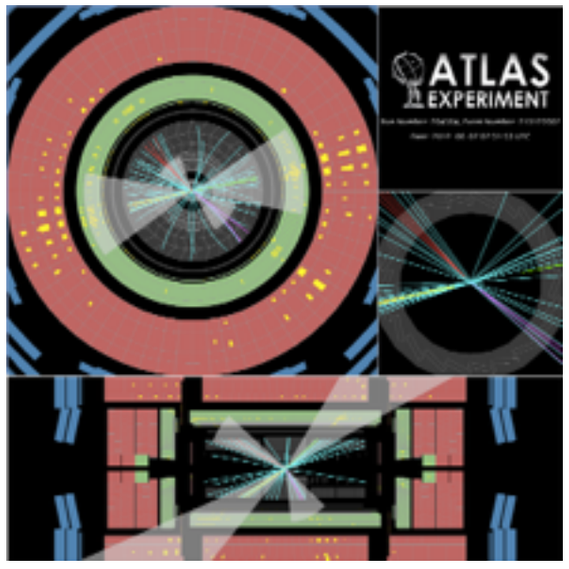
TeV scale resonances decaying via two SM Higgs to 4 b jets

Event selection

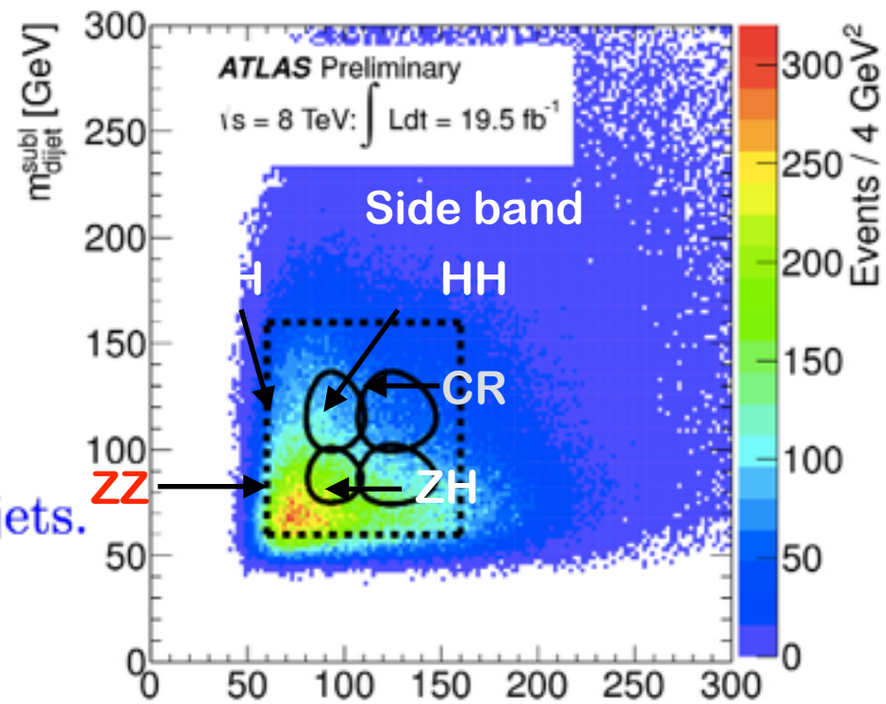
- 2 pairs of b-tagged jets, jet $p_T > 40$ GeV,
- Δ R(jets)< 1.5, Dijets $p_T > 200$ GeV
- $t\bar{t}$ veto $\sqrt{(\frac{m_W-80.4}{0.1m_w})^2 + (\frac{m_t-172.5}{0.1m_t})^2} > 3.2$
- HH ellipse: $\sqrt{(\frac{m_1-124}{0.1m_1})^2 + (\frac{m_2-115}{0.1m_2})^2} < 1.6$; $m_{1(2)}$ leading dijets.

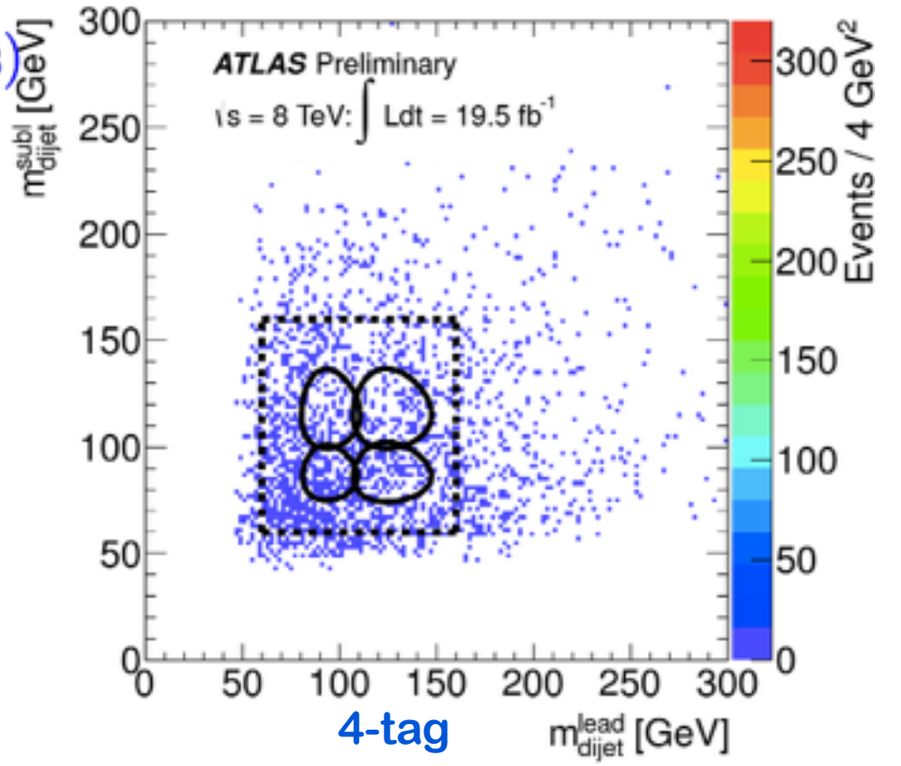
Background multijets (90%) and $t\bar{t}$ (10%)

- multijets compare "2-tag" data (only one b-tag) to "4-tag"
- regions to normalise, re-weight and test (exclude H-Z regions)
- $t\bar{t}$ shape: MC, normalise to "4-tag" data with failed $t\bar{t}$

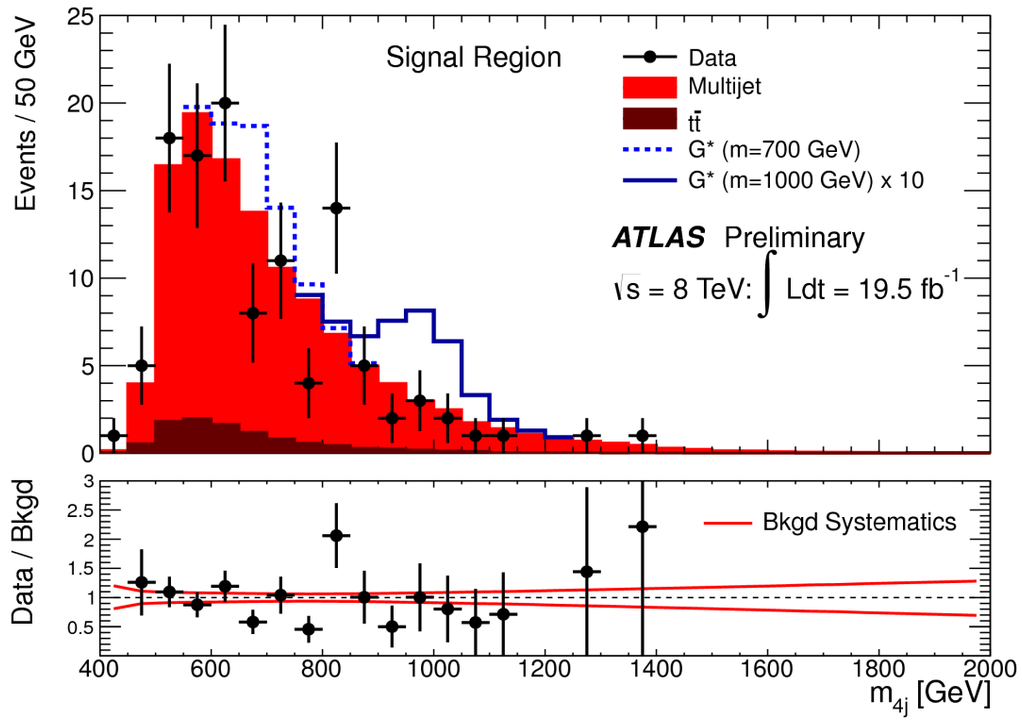


ATLAS-CONF-2014-005





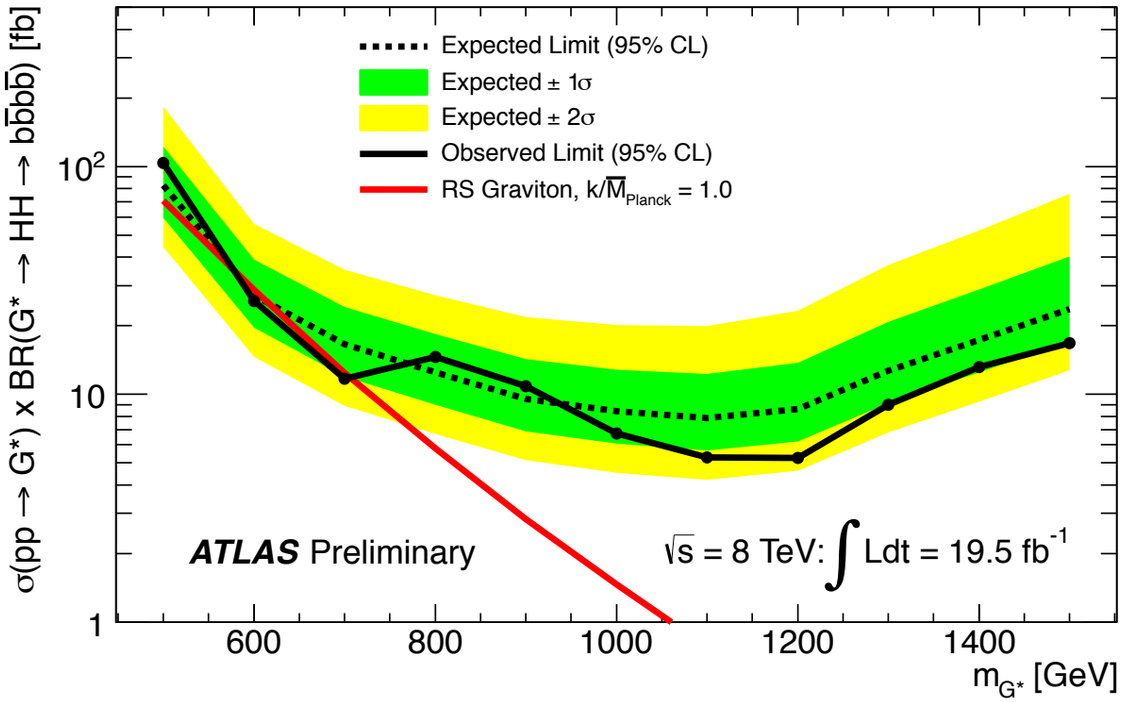
Resonance in X→HH→bbbb



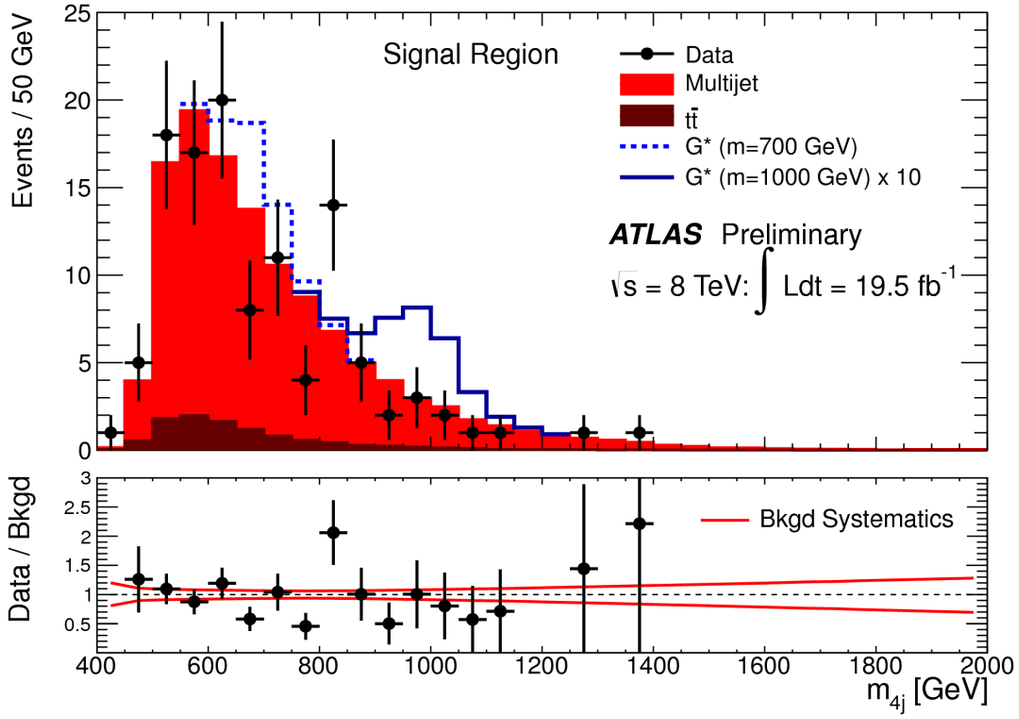
ATLAS-CONF-2014-005

Type	Sideband Region	Control Region
Multijet	903 ± 3	935 ± 3
$t\bar{t}$	19.0 ± 0.2	26.7 ± 0.3
Z+jets	11 ± 1	17 ± 1
Total Bkgd	933 ± 3	979 ± 3
4-tag Data	933	933
G^* (m_{G^*} = 500 GeV)	0.75 ± 0.10	3.9 ± 0.2
G^* (m_{G^*} = 700 GeV)	0.48 ± 0.04	3.0 ± 0.1

- Benchmark spin-2 KK RS graviton(G*)
- Data compatible with SM hypothesis
- Set upper limit $\sigma(pp \to G*)$ $\times BR(G* \to HH \to b\bar{b}b\bar{b})$ as function of m_{G*}
- Exclude for $590 < m_{G*} < 710$ GeV at 95% CL



Resonance in X→HH→bbbb



ATLAS-CONF-2014-005

Type	Signal Region
Multijet	109 ± 5
$t\bar{t}$	10 ± 6
Z+jets	0.7 ± 0.2
Total Bkgd	120 ± 8
Data	114
G^* (m_{G^*} = 500 GeV)	12.5 ± 0.4
G^* (m_{G^*} = 700 GeV)	12.5 ± 0.2

- Benchmark spin-2 KK RS graviton(G*)
- Data compatible with SM hypothesis
- Set upper limit $\sigma(pp \to G*)$ $\times BR(G* \to HH \to b\bar{b}b\bar{b})$ as function of m_{G*}
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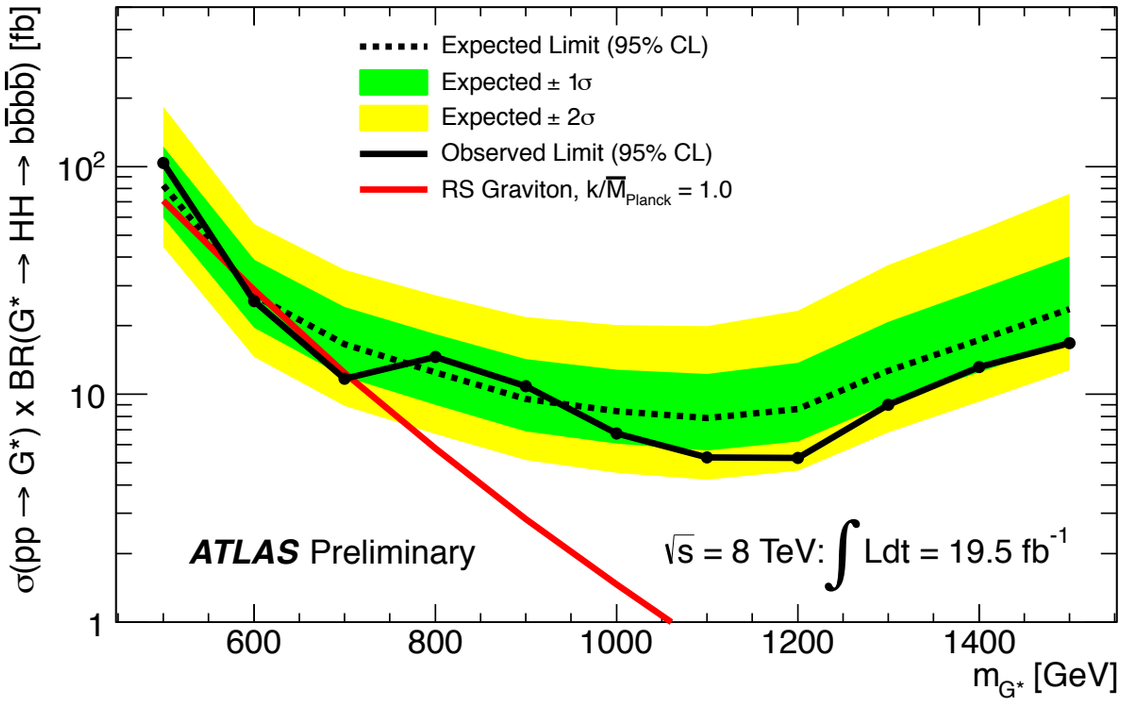
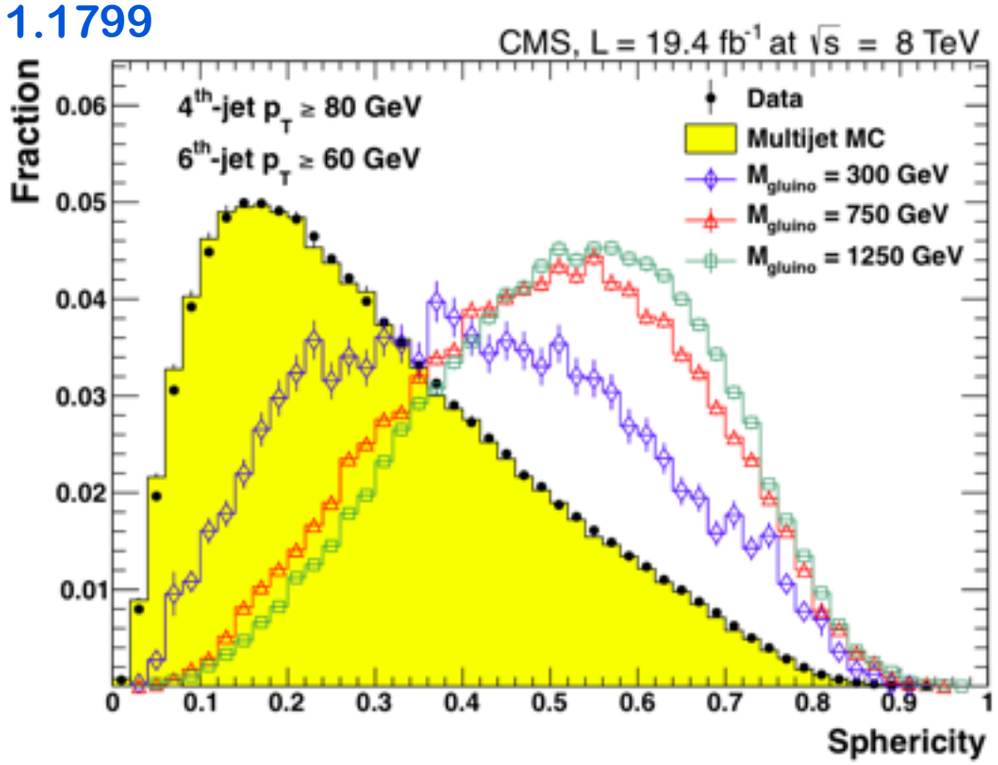
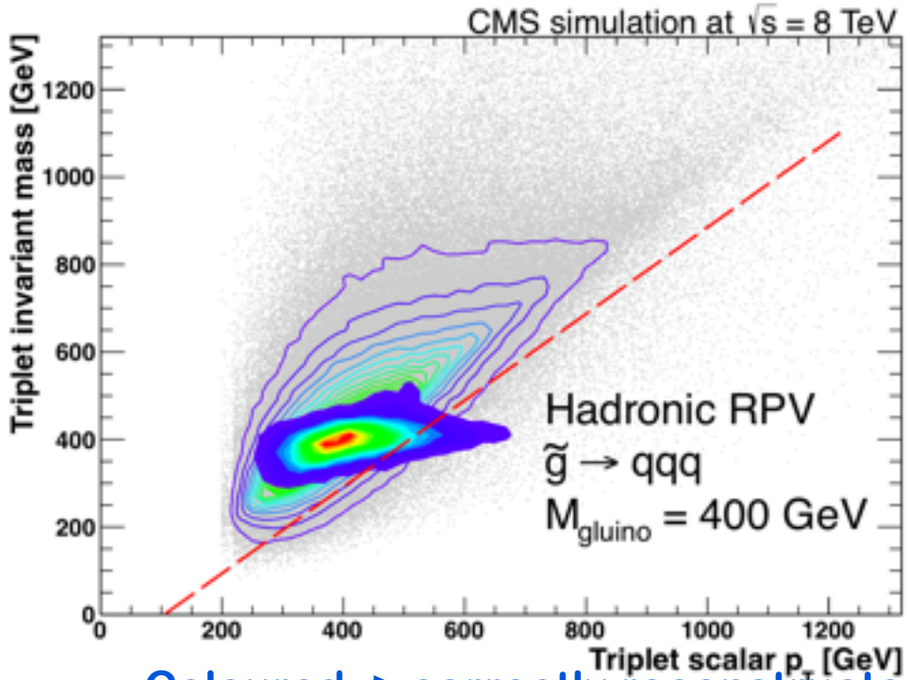
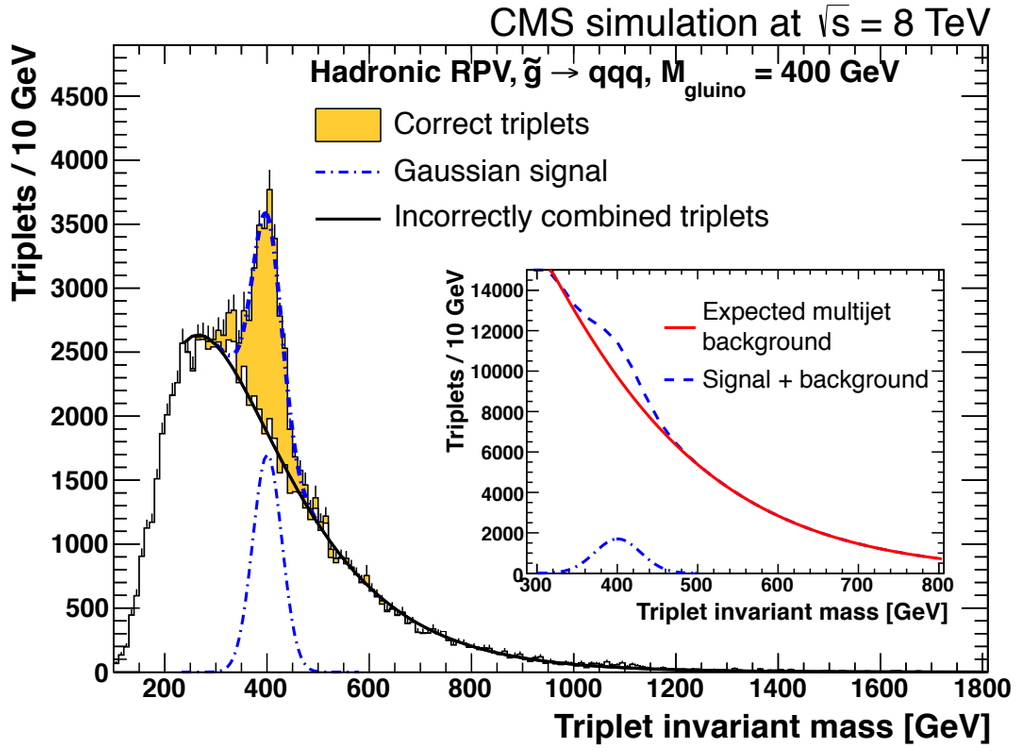


Pair produced three jets resonances

- Search strongly coupled resonances decaying each to 3-jets arXiv: 1311.1799
- Benchmark model pair production of gluino decaying to 3-jets through RPV couplings
- Event selection:
  - ≥ 6 jets; 1-4 jets (5-6) $> 80(> 60)$ GeV
  - Supress bg at high mass with sphericity
  - Use b-tagging for gluino $\rightarrow$ udb/csb cases
- Try 20 unique triplet combinations of the 6 highest p_T jets
- Suppress wrong combinations and QCD by requiring $m_{3j} < \sum_{i=1}^{3} |p_T|_i - \Delta; \Delta = 110$ GeV



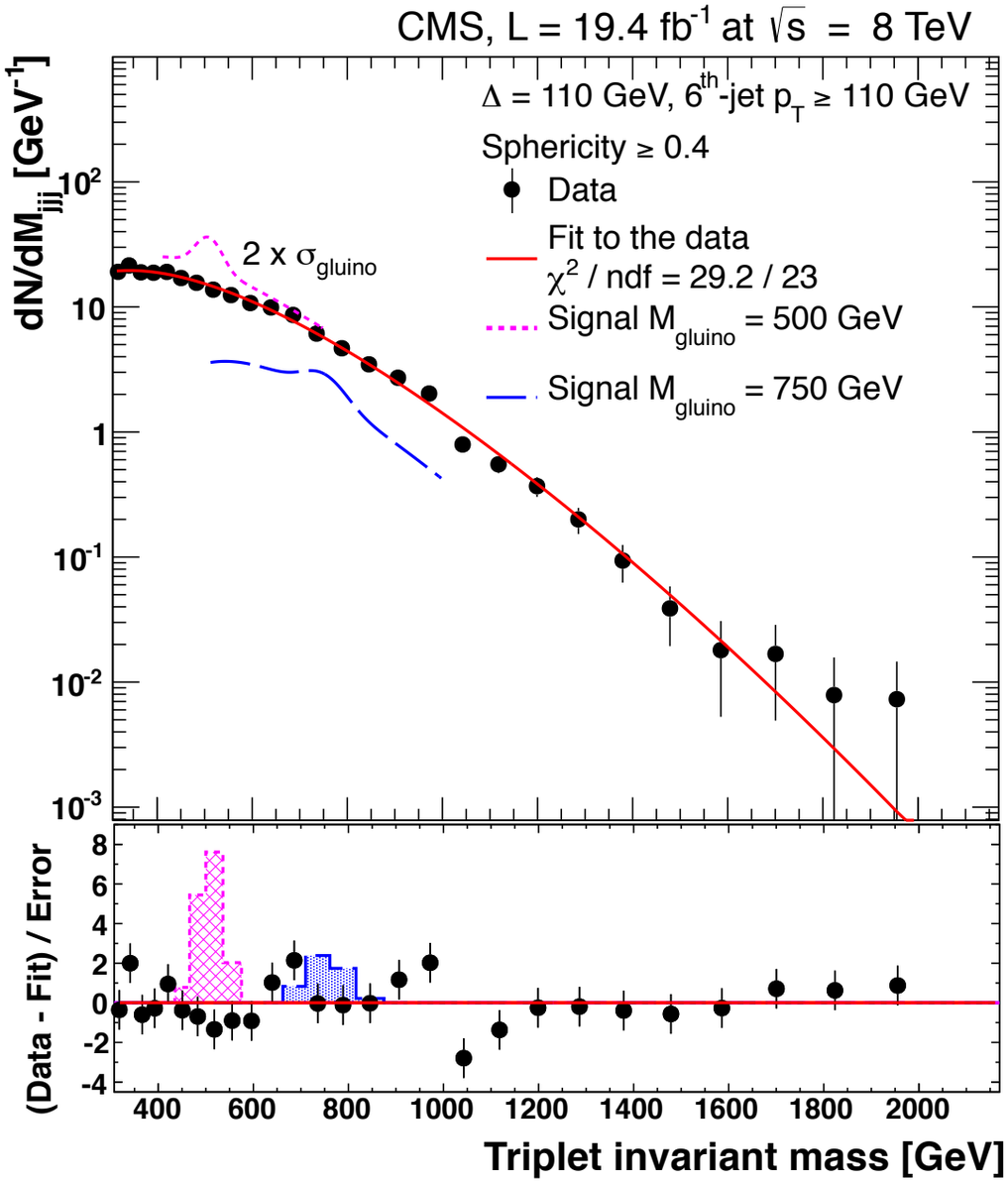




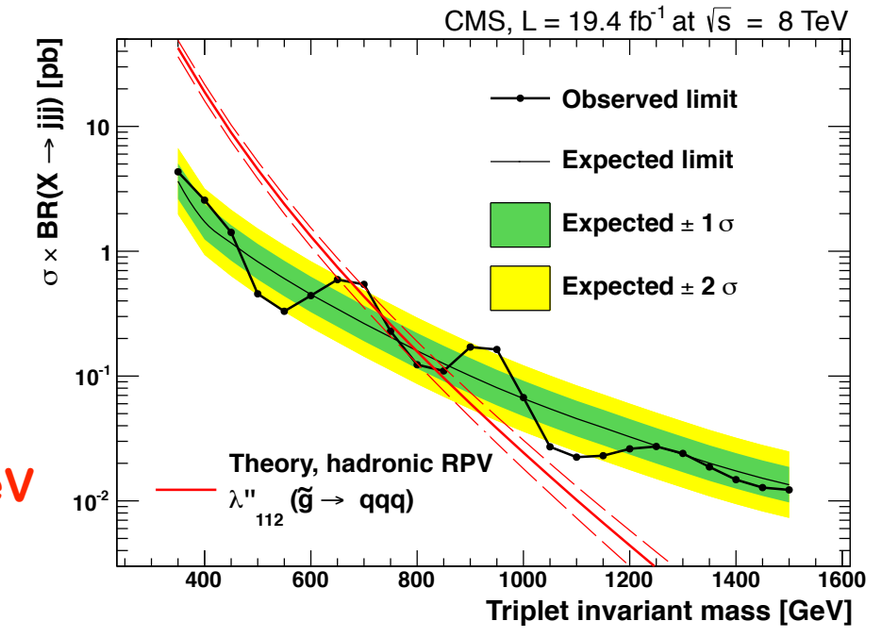
Coloured -> correctly reconstructed triplets, contour lines and points -> incorrectly combined triplets. Dashed line -> Δ=110 GeV

Pair produced three jets resonances

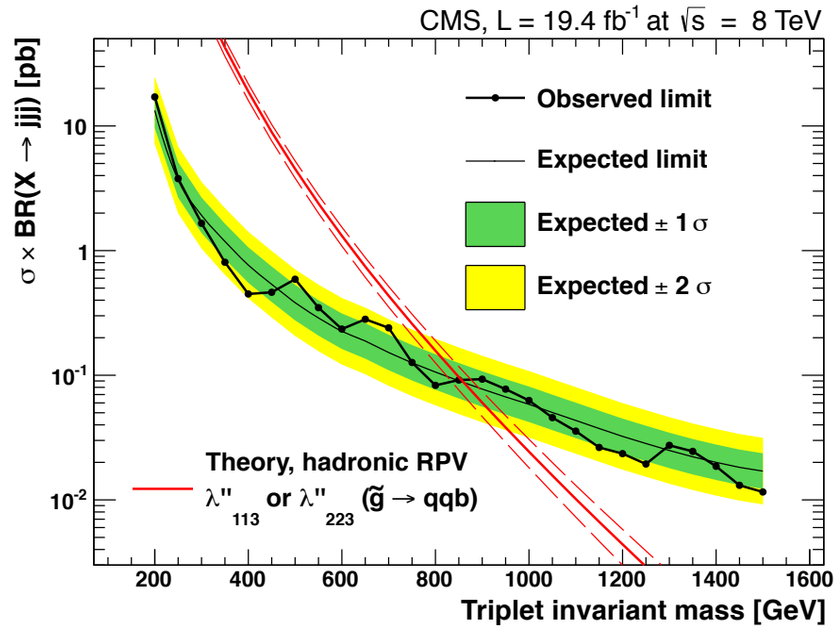
- **Search for 3 jet resonance in falling spectrum** arXiv: 1311.1799
  - Model independent search
  - Signal model: RPV SUSY gluino pair decay to light jets or light+heavy jets.
  - For b-tagged results, QCD shape from b-vetoed data



Previous limits:
CDF: 144 GeV
CMS (7 TeV) 460 GeV
ATLAS (7 TeV) 666 GeV



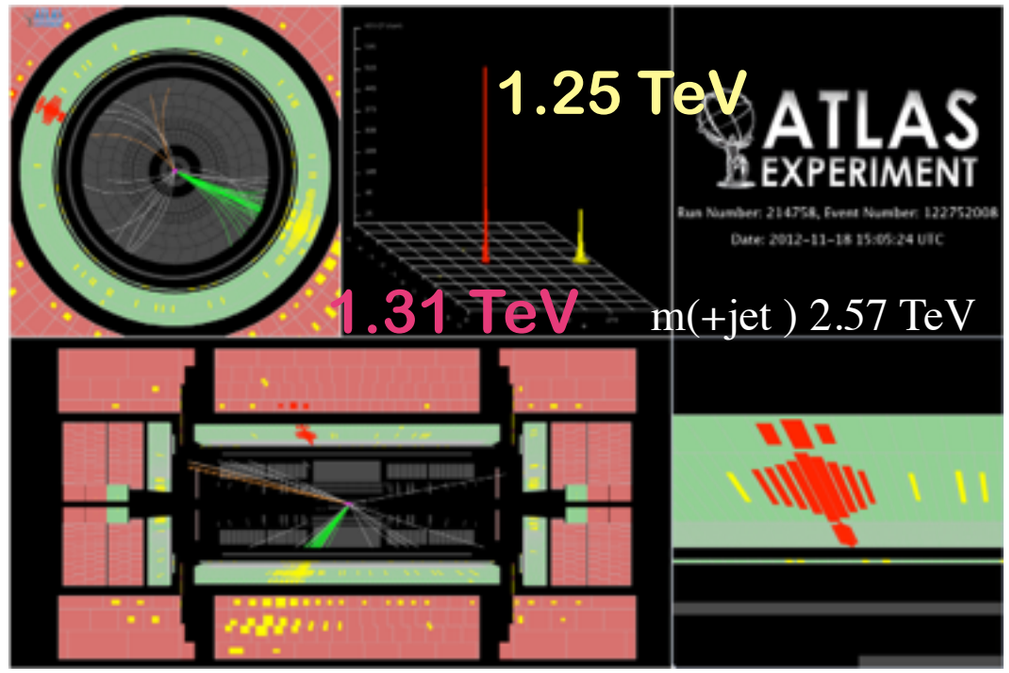
Exclude RPV gluinos< 650 GeV (light quarks - extend the 460) and between 200 to 835 GeV (heavy quarks)

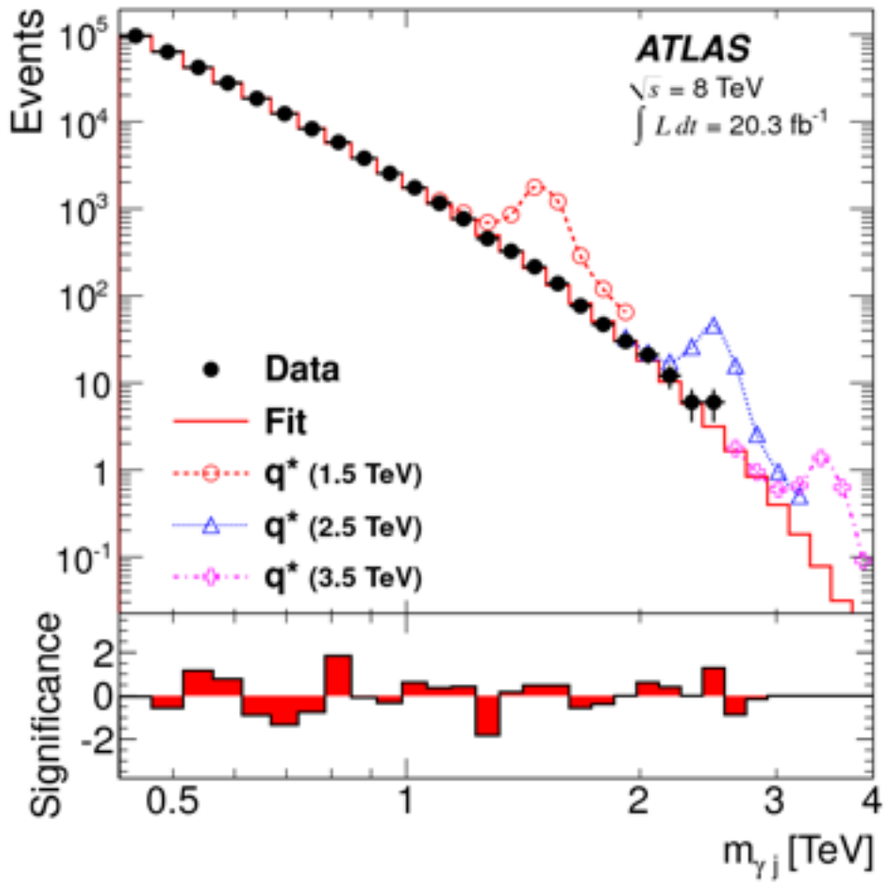


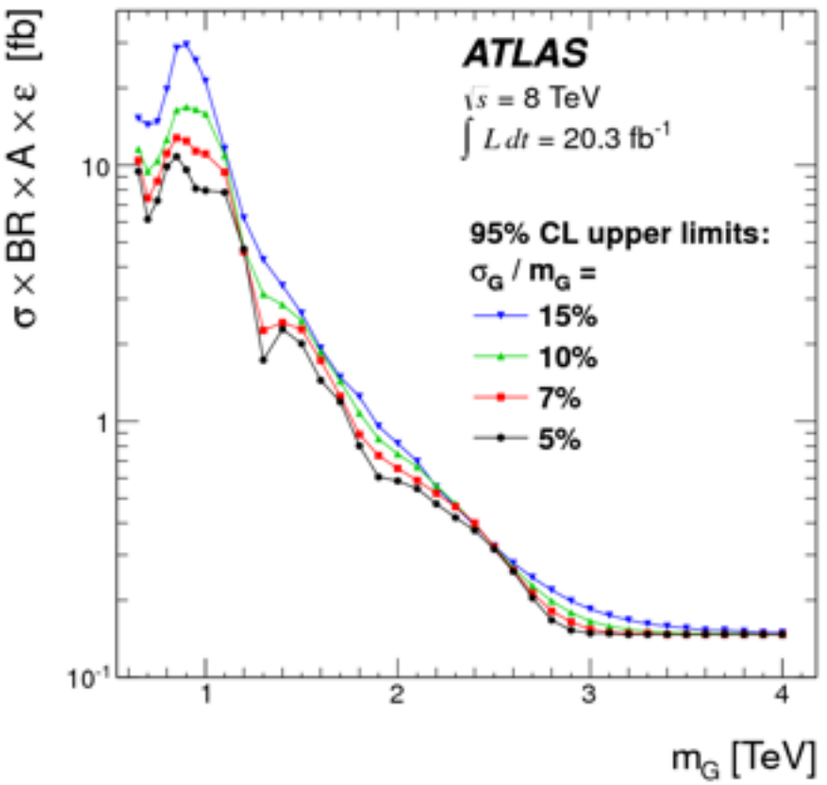
Search for heavy resonance: γ +jet

- Complementary analysis study fermion compositeness in γ+jet events
- Select high p_T jet and γ in central events $|\eta_j - \eta_\gamma| < 1.6$
- Smooth fit to data $p_1(1-x)^{p_2}x^{p_3+p_4 lnx}$
- Set limit on q^*, QBH and Gaussian like resonance

arXiv:1309.3230





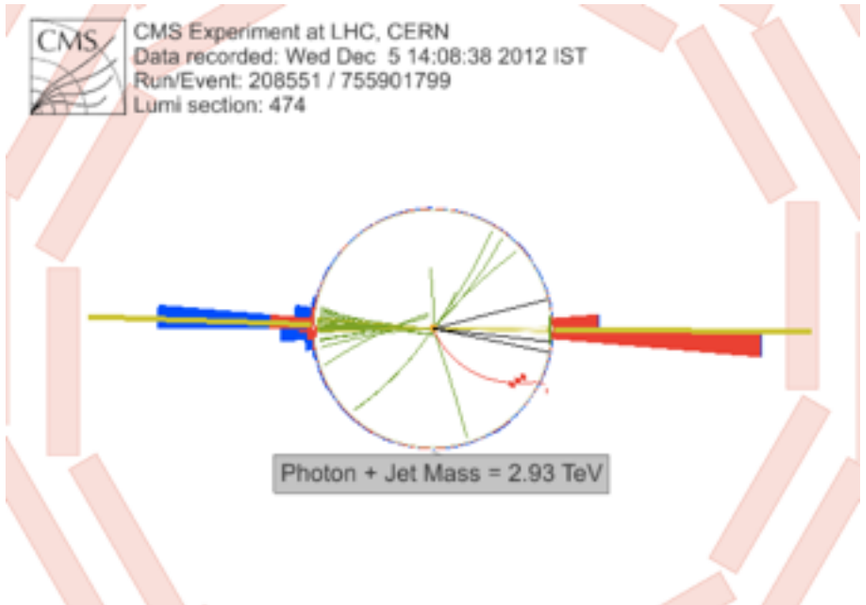


Exclude
- **q* bellow 3.5 TeV**
- **QBH bellow 4.6 TeV**

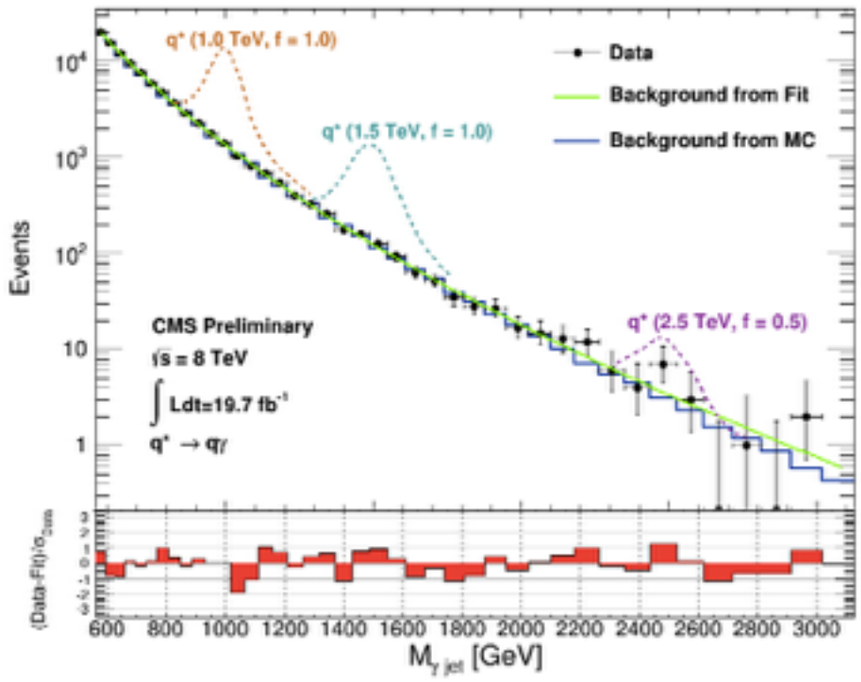
Search for heavy resonance: γ +jet

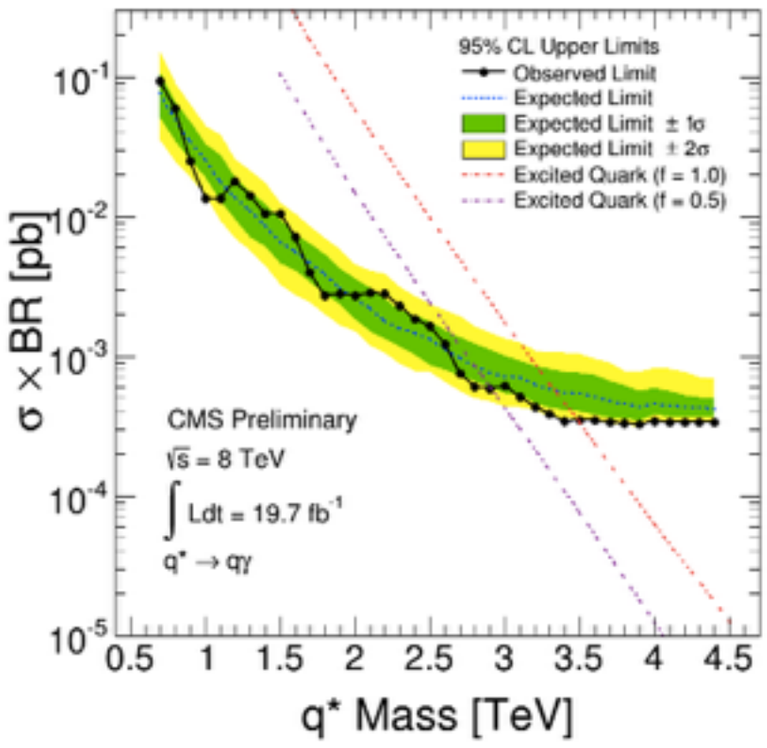
EXO-13-003

- Complementary analysis study fermion compositeness in γ+jet events
- Select high p_T jet and γ in central events $|\eta_j - \eta_\gamma| < 2.0$
- Smooth fit to data $p_1(1-x)^{p_2}x^{p_3+p_4 lnx}$
- CMS set limit on q^* also as function of the couplings versus mass



Exclude
- **0.7 <q*< 3.5 TeV**
- **Exclude coupling vs q* mass**





Search for heavy resonance: γ +jet

NEW!

EXO-13-003

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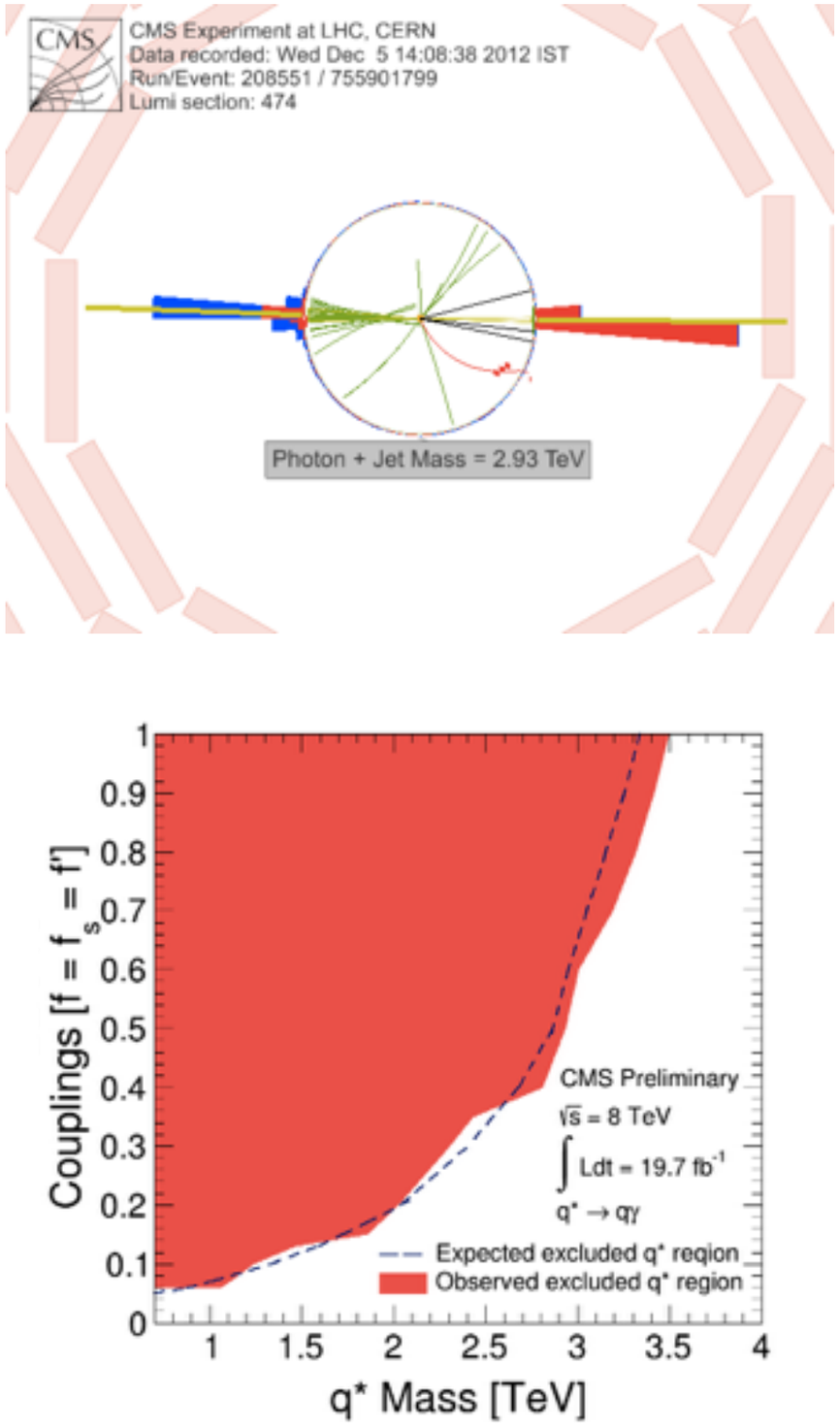

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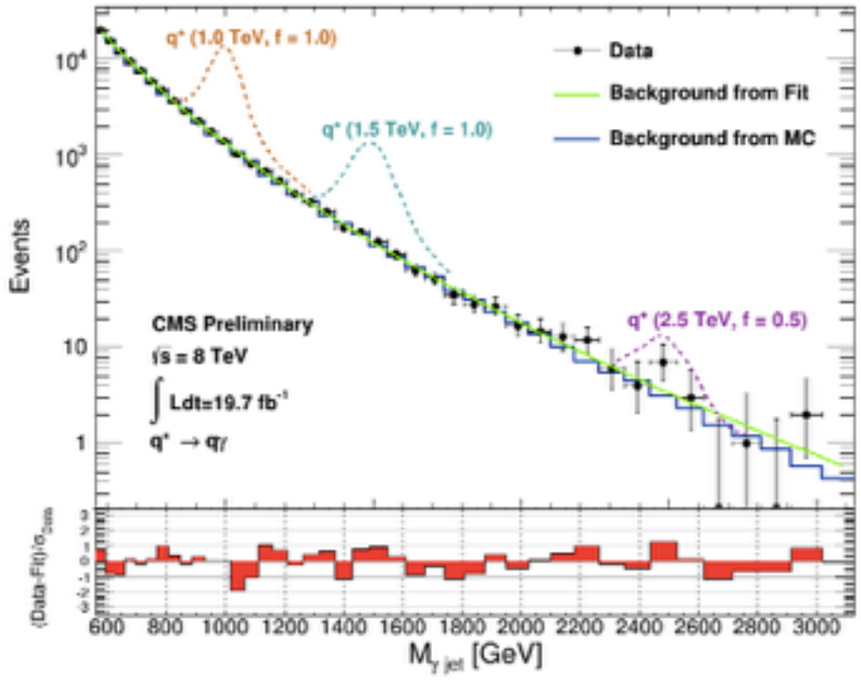
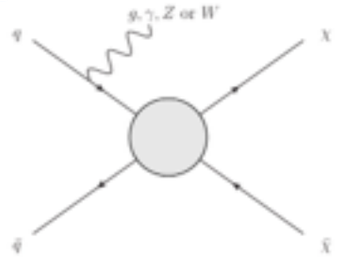
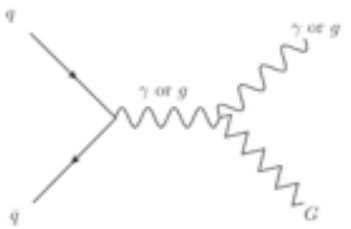
- **0.7 <q*< 3.5 TeV**
- **Exclude coupling vs q* mass**

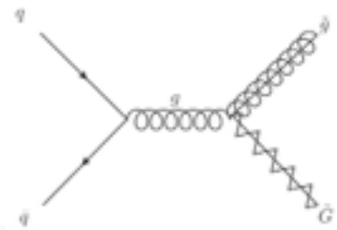


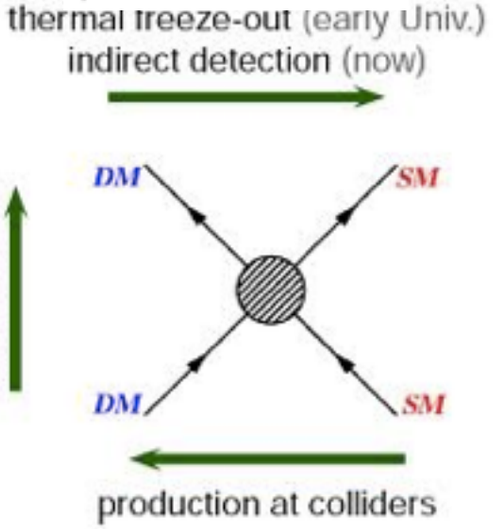
Single objects + missing transverse energy

- Motivation
  - Galaxies rotation velocities, Gravitational lensing, CMB -> DM cover 25% of universe? may have complex physics.
  - Graviton in ED
  - Gluino (squark) to gluon (q) +gravitino
  - H->invisible

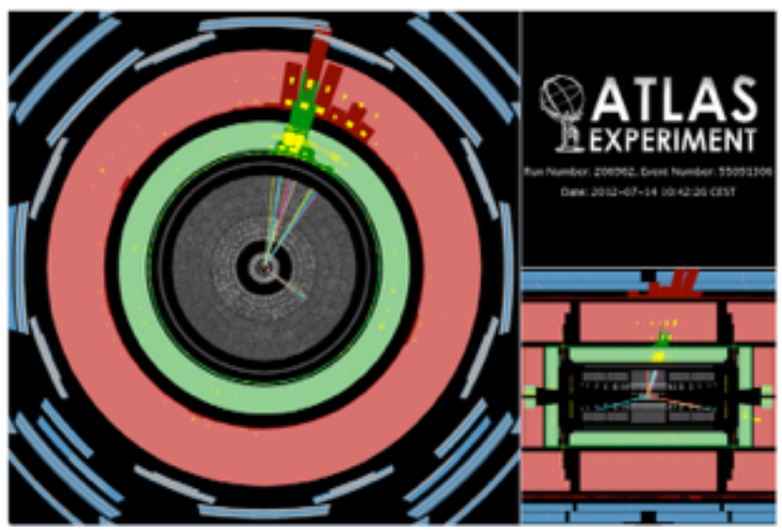


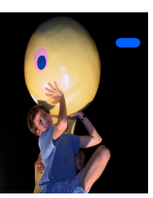






- Searches for SM<->DM
  - Direct detection: (XENON, LUX, DaMa, CDMS..)
  - Indirect detection: (AMS, LAT, AMANDA, IceCube..)
  - Production: LHC (complimentary at low masses)
- Simple final state, known EWK BG
- Reject:
  - ➡ Events with identified lepton (EWK BG)
  - ➡ More than 1 extra jet (top or multijet BG)
  - ➡ MET pointing toward 2nd jet (mis-measured jets)
- Data driven BG estimate:
  - Z(->νν)+X (irreducible)
  - W(->lν)+X or Z with 1 undetected l
  - multijets, γ+jets with fake MET
  - non-collision data
  - top, dibosons and γγ (MC based rejection)





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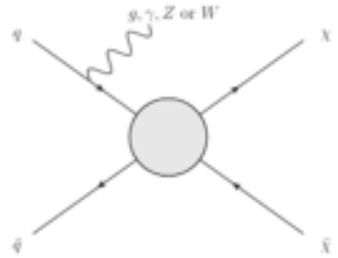

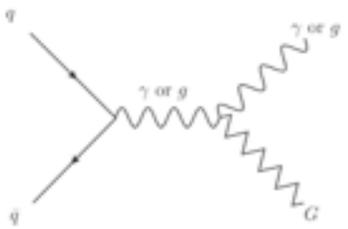

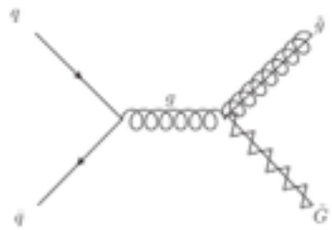

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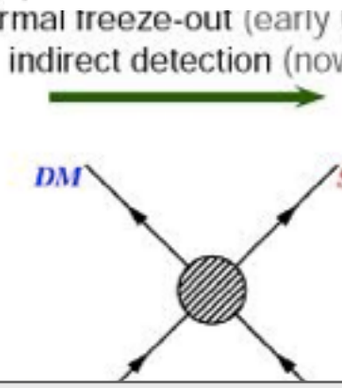
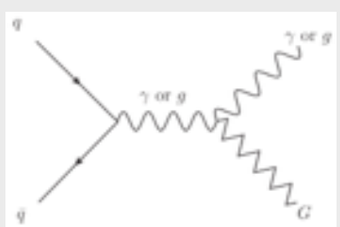
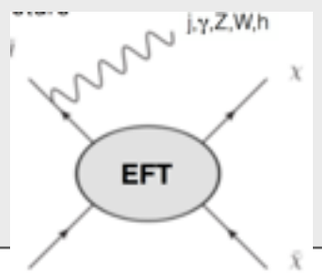
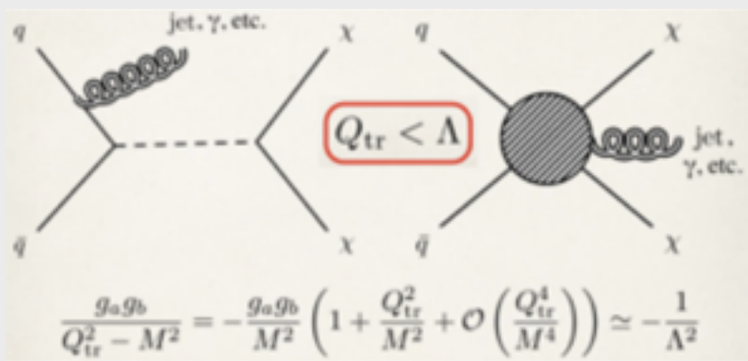


- **DM Interpretations**
-
-

Large ED	EFT	Simplified models
● If MD<< the energy scale, particle may interact via gravity ● ED -> KK graviton tower ● Gravitons can escape detection	Contact interaction with mediator too heavy to be generated Suppression scale $M^* \approx \frac{M}{\sqrt{g_\chi \times g_{SM}}}$ where M^* is the mediator mass and g_χ and g_{SM} are the DM and SM couplings	● EFT has limited validity when mediator mass is light ● UV- theories - valid everywhere ● Use ad-hoc fields, interactions to model the possible DM





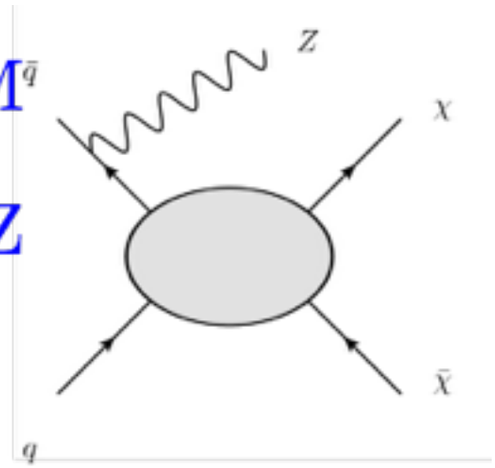


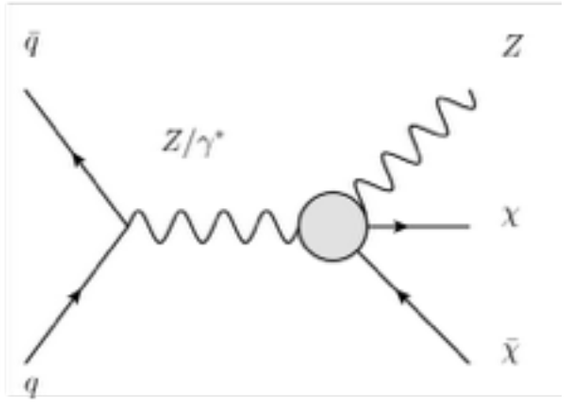
Mono Z (-> dileptons)

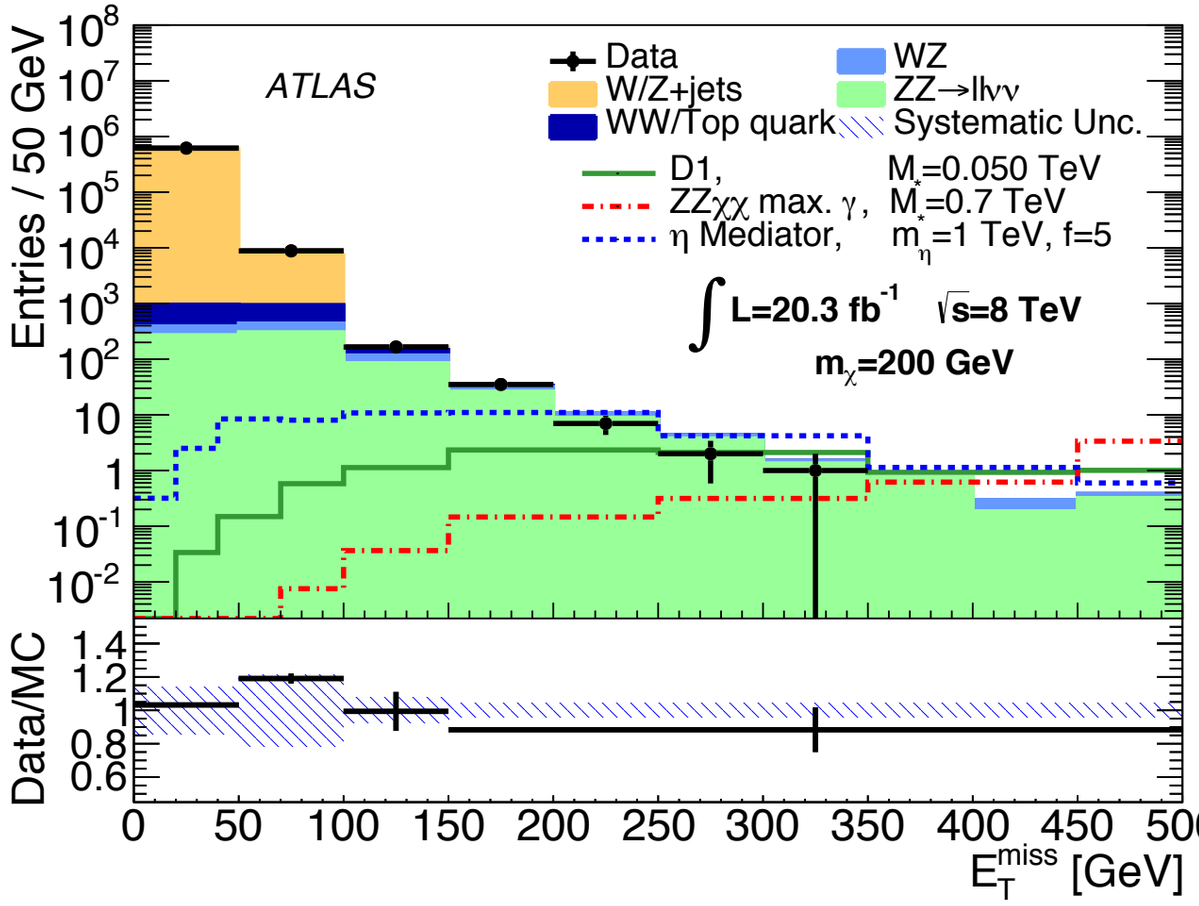
arXiv:1404.0051 [hep-ex]

NEW!

- Appears as ISR Z or Z couples to the DM
- Look for OS ee or $\mu\mu$ with mass around Z
- No E_T^{miss} from mismeasured jet:
  $\Delta\phi(E_T^{miss}, p_T^{ll}) > 2.5, |\eta^{ll}| < 2.5,$
  $|p_T^{ll} - E_T^{miss}|/p_T^{ll} < 0.5$
- No 3^{rd} lepton and no jets
- SR: $E_T^{miss} > 150, 250, 350, 450$ GeV
- Dominant BG $Z \to l^+l^-\nu\nu$
- Main BG uncertainty: 35-43% (depending on SR)



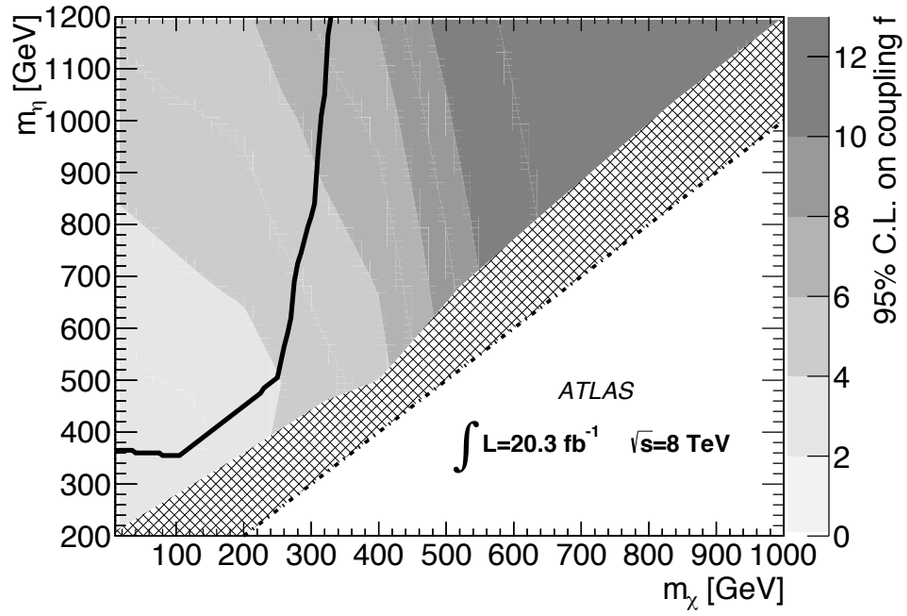




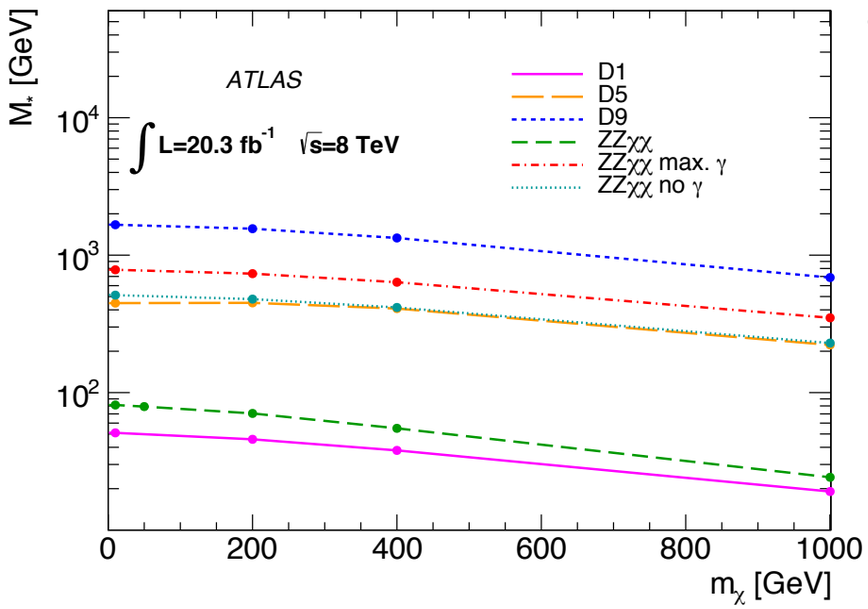
Mono Z (-> dileptons)

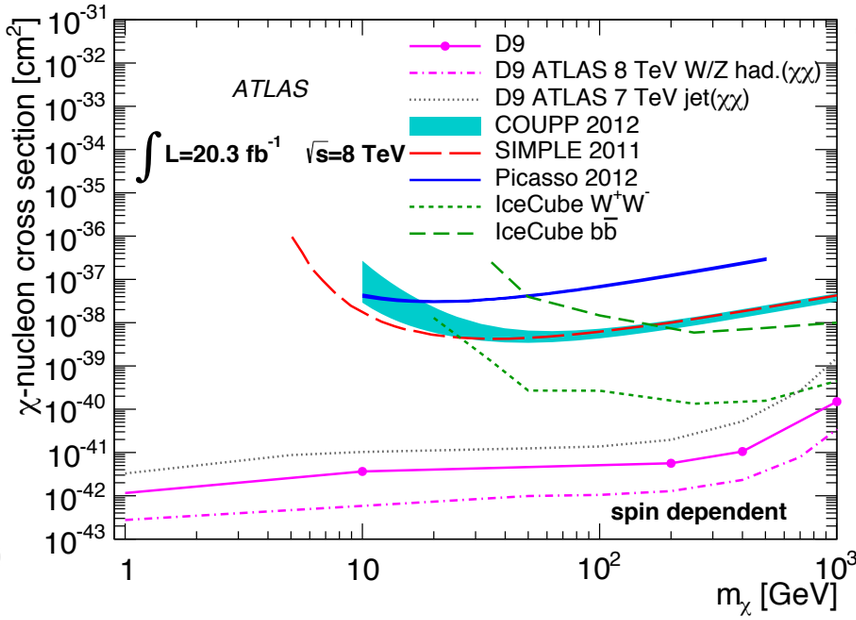
arXiv:1404.0051 [hep-ex]

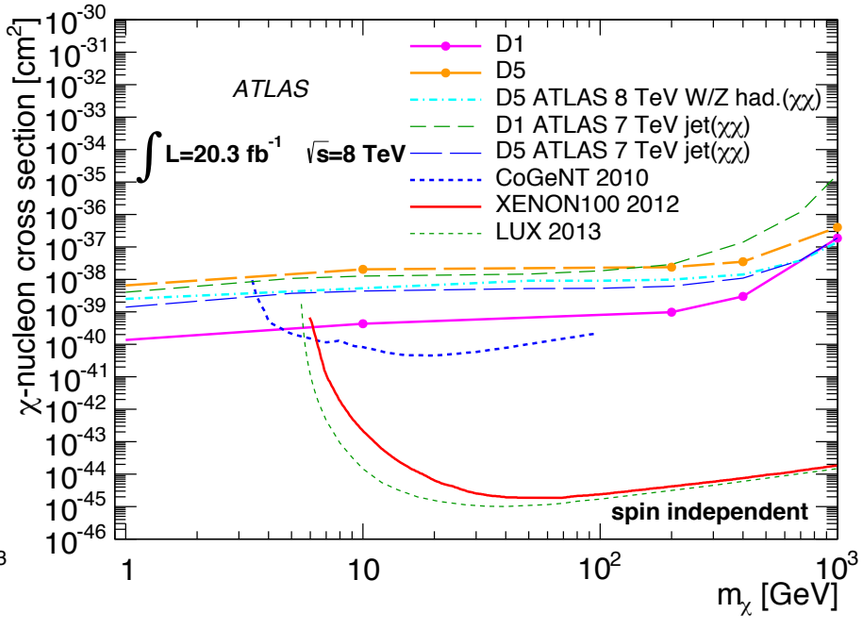
- 95% C.L. upper limits on $\chi\eta$ coupling, f, as a function of m_χ and the mediator mass, m_η. The cross-hatching shows the theoretically accessible region outside the analysis coverage. The white region is phase space beyond the model's validity. Above the black line smaller than lower limit from our relic abundance calculations.



- Below: limits on EFT scale and upper bounds on $\sigma(\chi - N)$







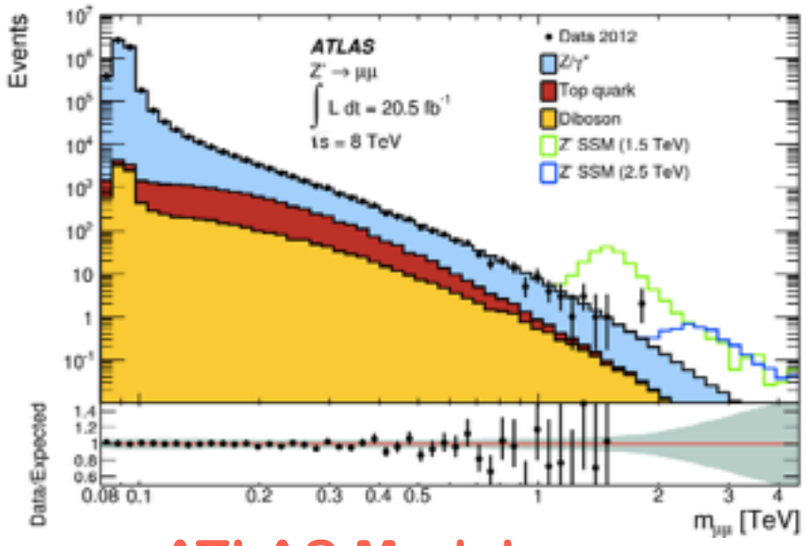
Leptons + X

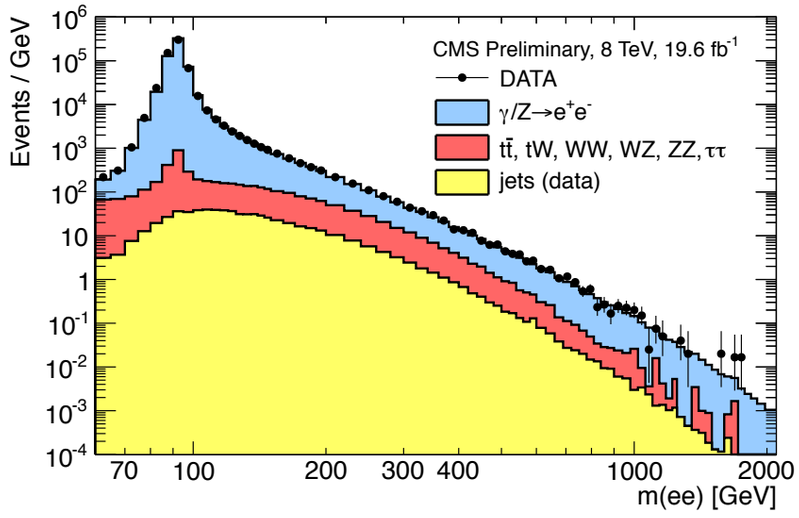
- We have fewer leptons, but they are easy to trigger and measure
- Signatures include: pairs of e, μ, τ, γ, l+jet and l+MET
- Models include:
  - ➡ Extra dimensions (ADD and RS)
  - ➡ GUT E6 heavy bosons (Z',)
  - ➡ Benchmark models SSM ...
  - ➡ Excited leptons
  - ➡ Leptoquarks
  - ➡ Tev Gravity
  - ➡ Quantum Black Holes

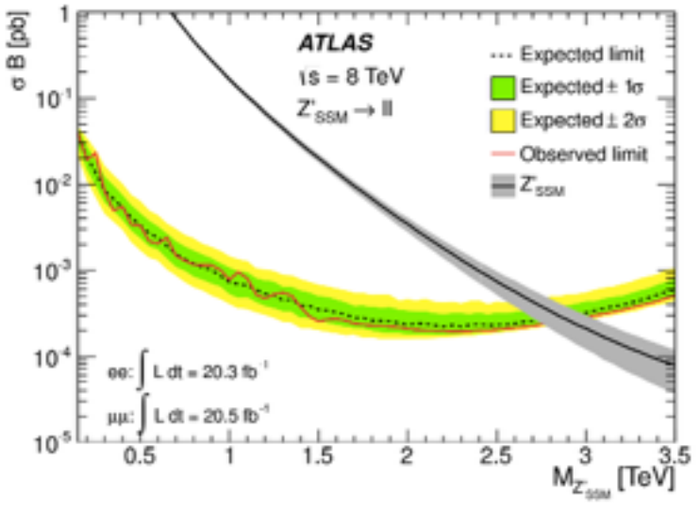
- **Multileptons**
  - Signatures are 3+, 4+ leptons, like-sign leptons
  - Inclusive searches and interpretations in models like:
    - ➡ Doubly charged Higgs
    - ➡ Heavy Neutrino
    - ➡ Seesaw models
    - ➡ Higgs to Dark Z
  - EW like signal: usually leptonic final states, dominated by irreducible EW BG calculated at (N)NLO or fit the data in CR

arXiv:1405.4123 [hep-ex]

Search for heavy resonance: dileptons







- **ATLAS Models**
  - Z', E6 motivated and SSM Z', RS graviton, Minimal Walking Technicolor, Z*, QBH, minimal Z'
  - Dominant BG: DY
- Signal and BG evaluated with MC and rescaled using known Xsect
- Jets BG in e estimated with data
- QCD shape from loose selection extrapolated to high ET, normalized using data in CR
- NNLO k-factors correct the LO MC
- Calculate p-value of observed vs expected events

- **CMS preliminary results from 8 TeV full data set in ee and μμ channels**
- No excess seen; exclude variety of narrow resonances (Z'SSM, Z'ψ, etc.)
- Event selection
  - CMS: E_T (e1,e2) > 35 GeV, p_T (μ1,μ2) > 45 GeV, plus isolation criteria
  - ATLAS: E_T (e1,e2)> (40,30) GeV, p_T (μ1,μ2) > 25 GeV, plus isolation criteria

M(Z'	expected	observed
CMS	> 2.96 TeV	> 2.96 TeV
ATLAS	> 2.87 TeV	> 2.90 TeV

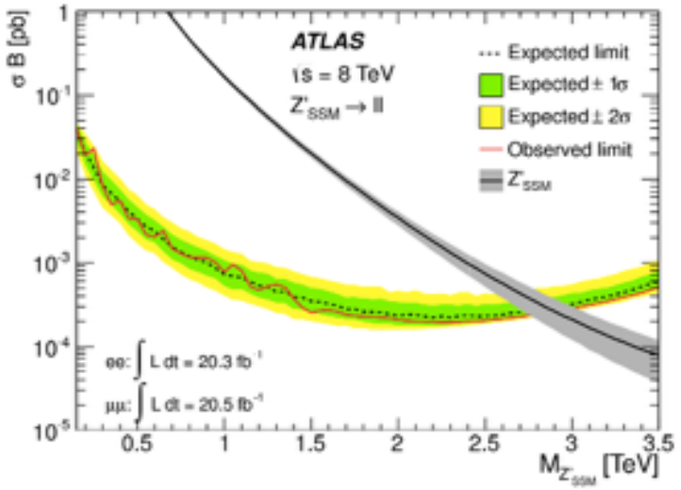
But more on the comparison in the text!

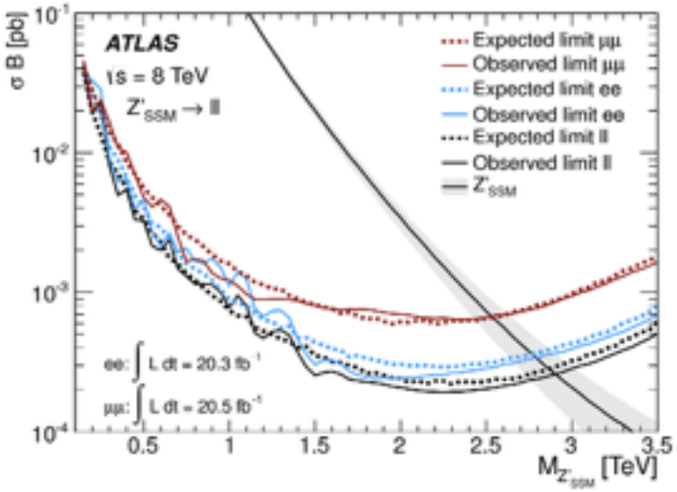
arXiv:1405.4123 [hep-ex]

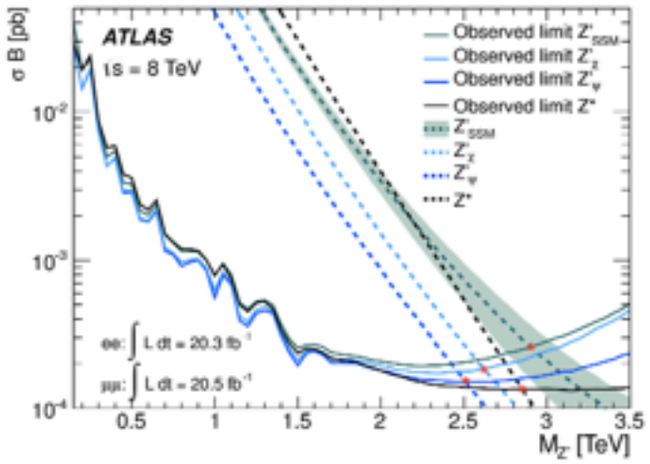
NEW!

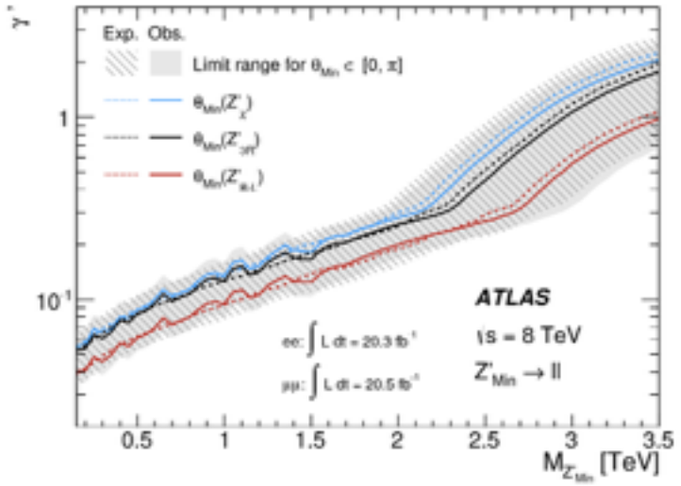
Search for heavy resonance: dileptons

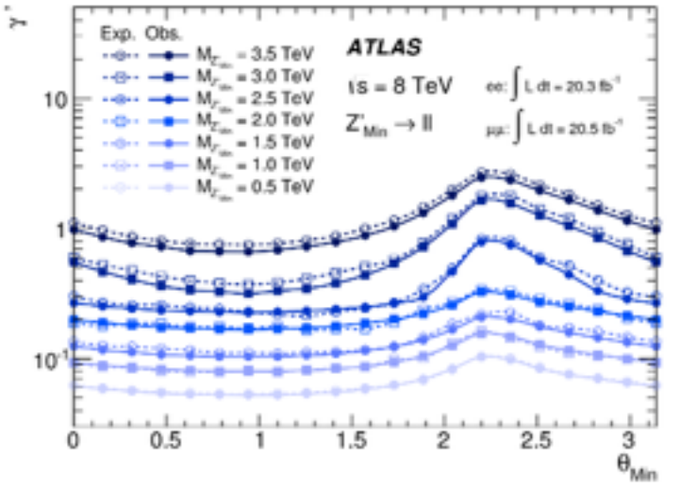
	σB [fb]		
Model	$M = 1$ TeV	$M = 2$ TeV	$M = 3$ TeV
$Z'_{\rm SSM}$	170	3.4	0.21
Z'_{χ}	93	1.5	0.062
Z'_{ψ}	47	0.87	0.032
Z^*	300	4.0	0.076
G^*, $k/\overline{M}_{\rm Pl}$=0.1	190	1.8	0.044
RS QBH	56	0.40	0.0065
ADD QBH	11000	96	1.8
MWT, $\tilde{g} = 2$	31	0.17	N/A

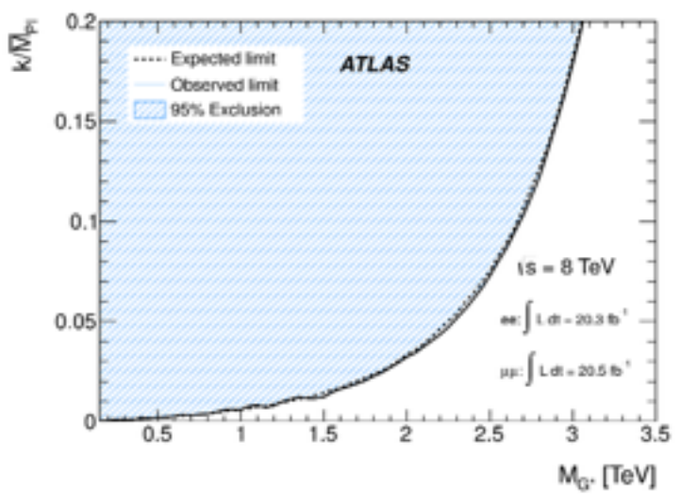


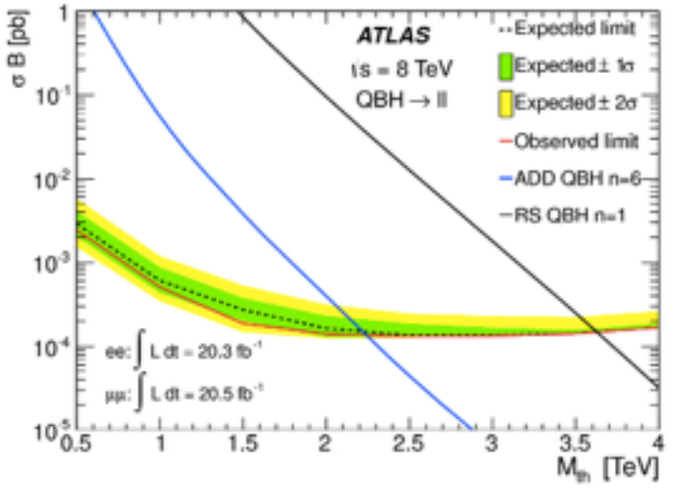


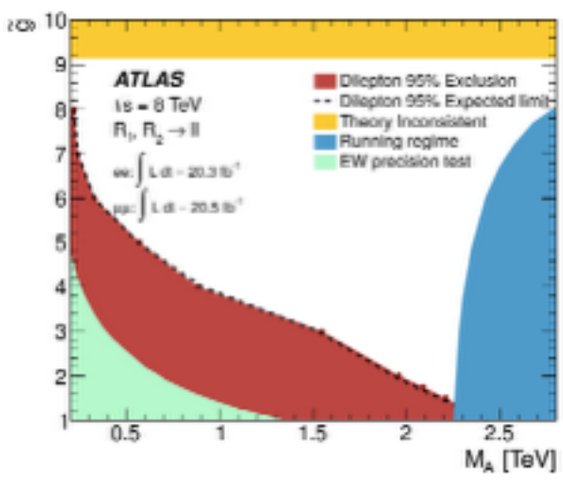










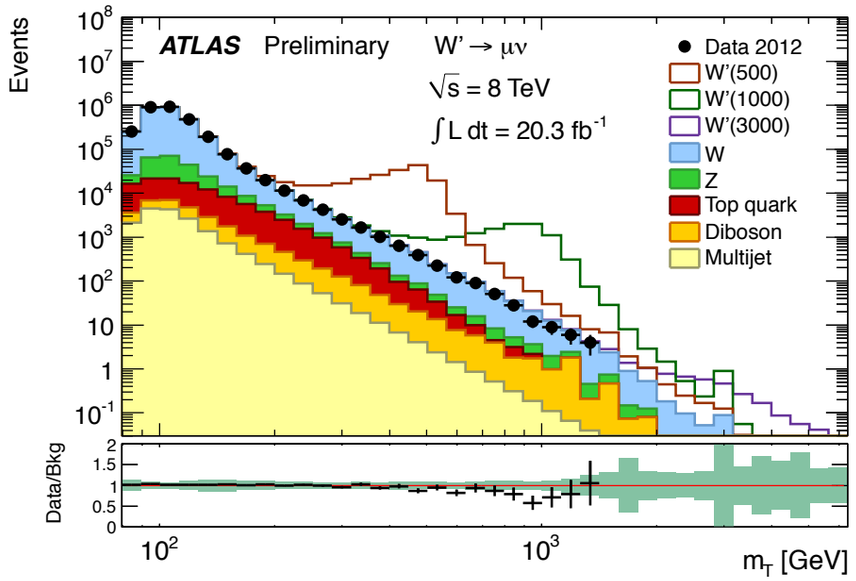


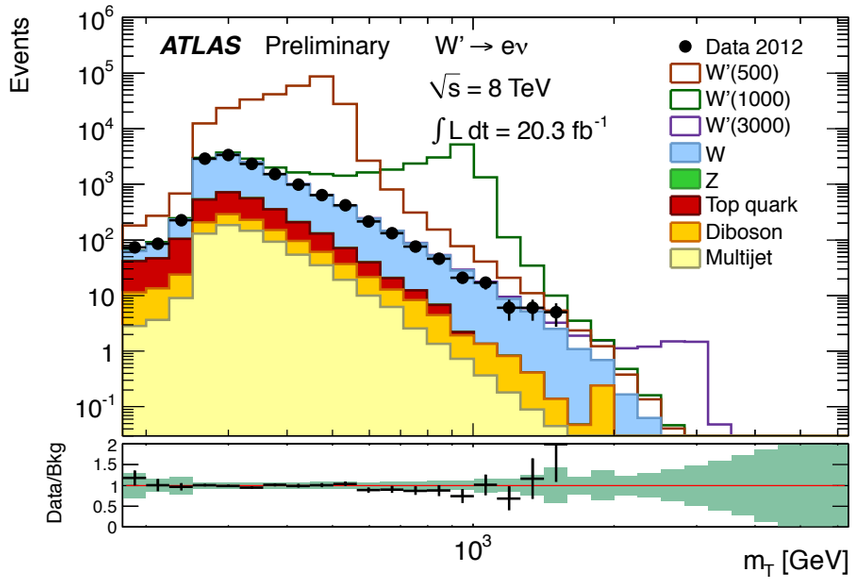
Searches in single lepton states

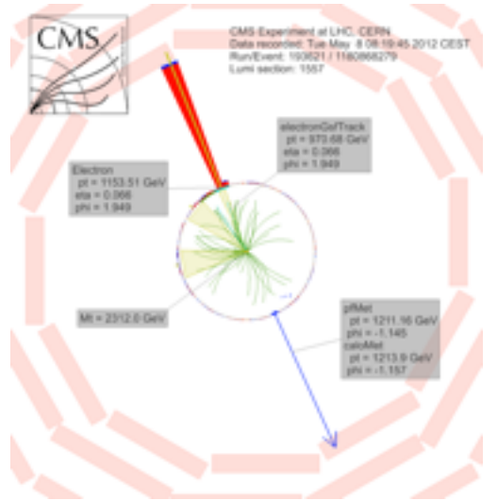
- Search for excess in transverse mass of e or μ with low mass neutrino
- Interpret as SSM W' (no interference with SM W)
- Interpret also as excited chiral boson (W*) with equivalent couplings

ATLAS-CONF-2014-017

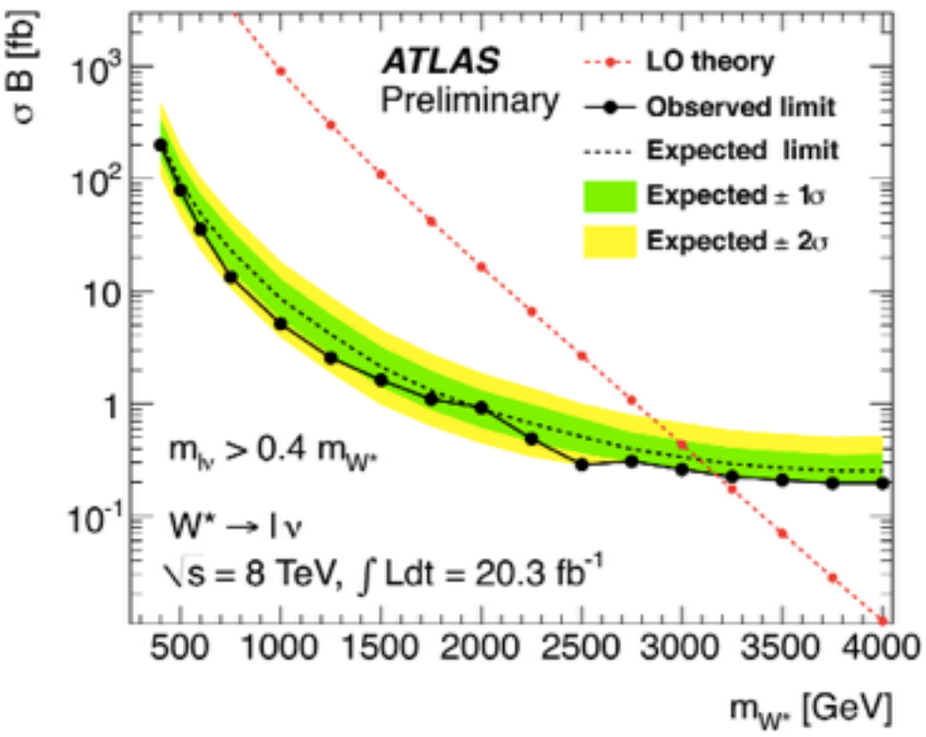
[CMS EXO-12-060]







$$M_T = \sqrt{2 \cdot P_T^l \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{l,E_T^{miss}})}$$



	$m_{W'}$ [TeV]		m_{W^*} [TeV]	
decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	3.15	3.15	3.04	3.04
$\mu\nu$	2.98	2.98	2.80	2.80
both	3.19	3.27	3.08	3.17

M(W'	expected	observed
CMS	> 3.40 TeV	> 3.35 TeV
ATLAS	> 3.19 TeV	> 3.27 TeV
ATLAS 7 TeV		> 2.55TeV

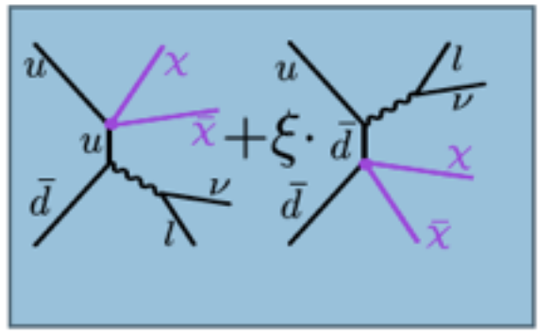
Searches in single lepton states

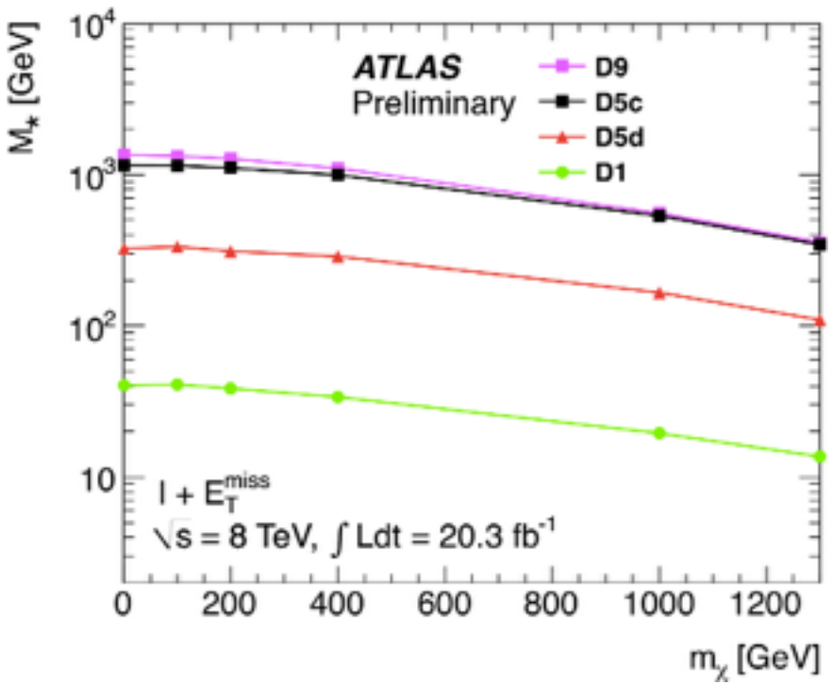
NEW!

- New interpretation: MONO W recoiling against pair produced DM
- Consider three couplings, interference
  - D1 Scaler, D5 -Vector (cont/dest interference) and D9 tensor couplings
  - Unlike mono jets, affected by interference effects
  - Interference parametrised by ξ (see diagram)
  - M* Scale of unknown mediating interaction

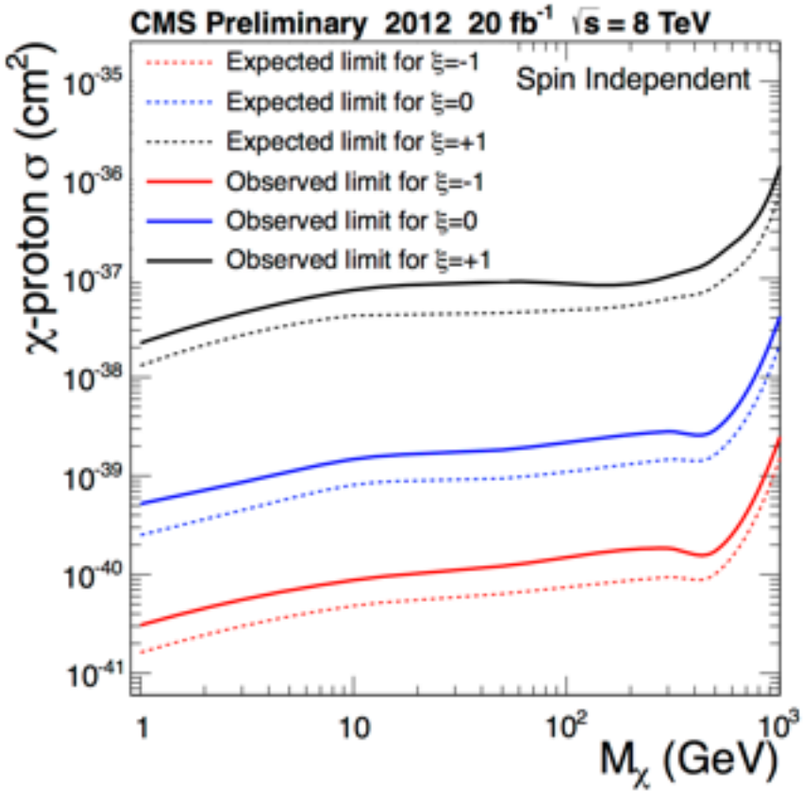
ATLAS-CONF-2014-017

[CMS EXO-13-004]

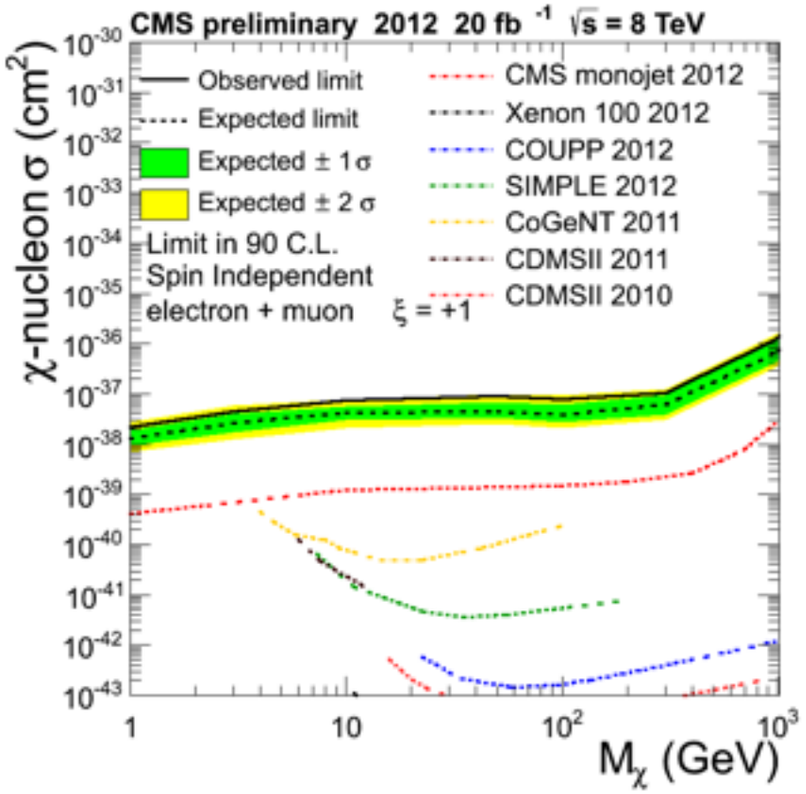




Observed limit on M* as a function of the mass of DM particle (m_χ)



Excluded nucleon-DM cross section for vector-like and $\xi = 0, \pm 1$

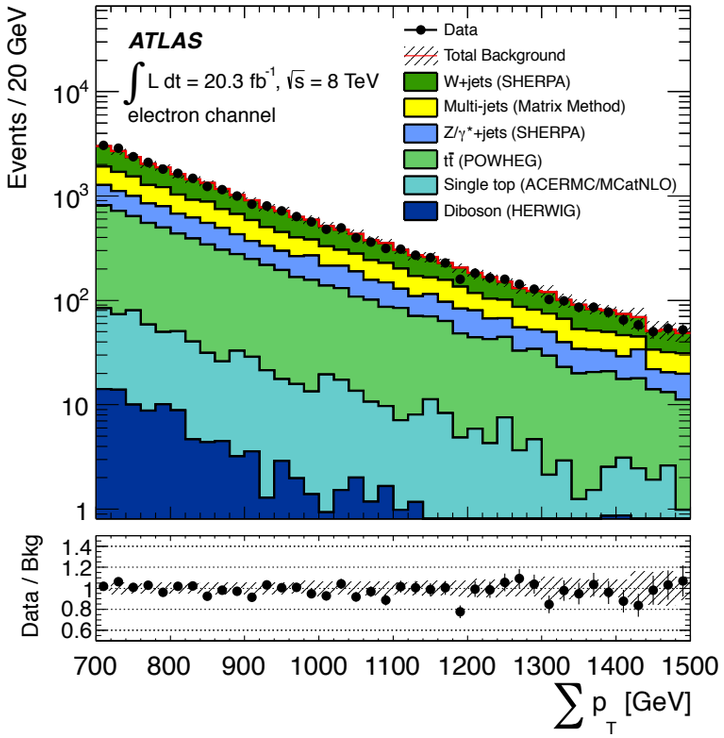


Exclude proton-DM cross-section vector-like (spin independent)

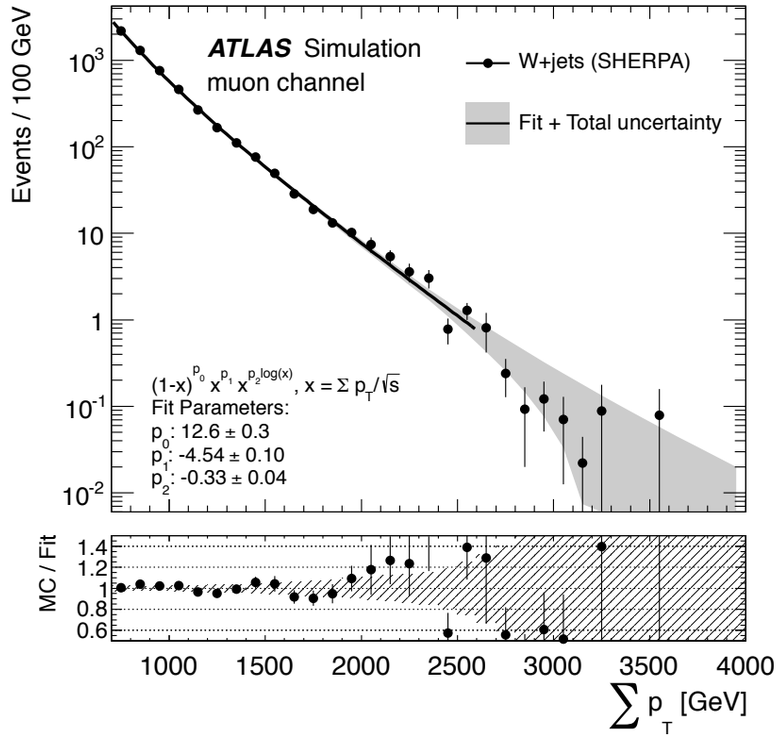
Microscopic BH & string balls in leptons + jets

arXiv:1405.4254

- ED with low scale gravity (ADD) allow prod of strong gravitational states decaying via Hawking radiation
- BH - high mass, high object multiplicity (reasonable BF to leptons)
- Require at least 3 high p_T objects (jets + leptons)
- Construct scalar p_T sum of selected objects
- Main BG W/Z+jets, ttbar, Multijets (to the e channel)
- Shape and relative fraction of BG with MC
- Derive scale factors for dominant BG in CR
- Fit each BG component to "dijets" function, systematics - choice of fit function



∑p_T distribution for electron channel Pre-selection region.



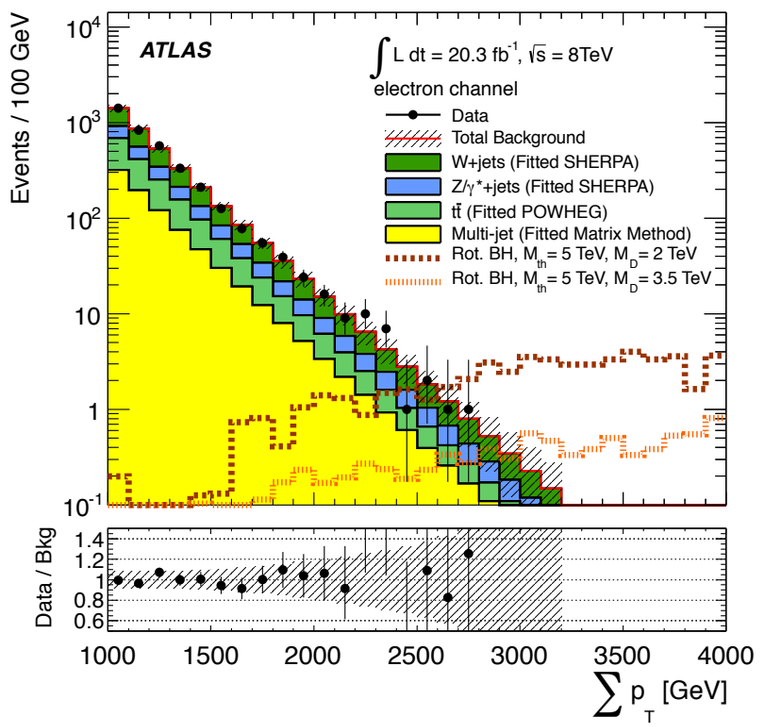
Fit to ∑p_T distribution, muon channel, W+jets background.

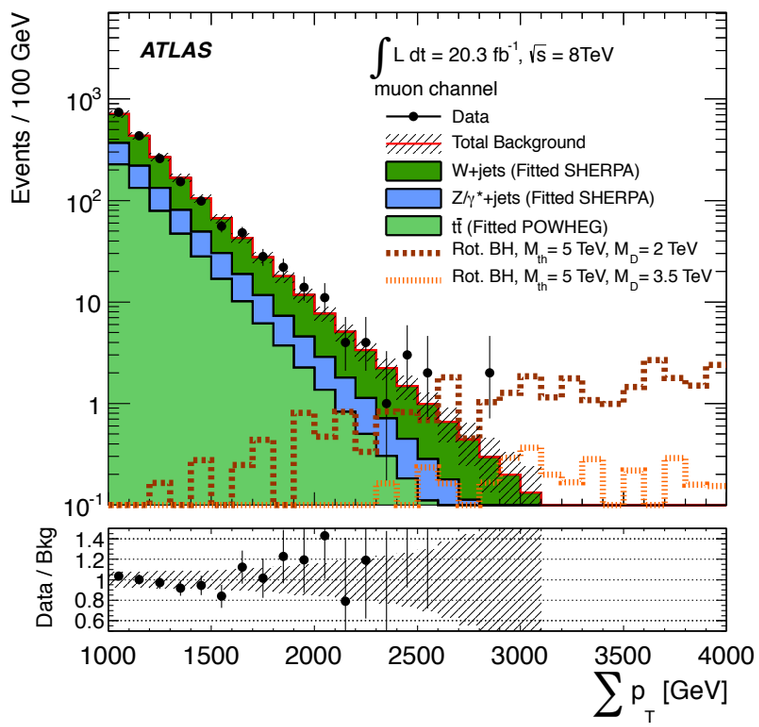
Microscopic BH & string balls in leptons + jets

NEW!

arXiv:1405.4254

- Combine shapes from fit with relative fractions of each background for final estimate
- Slice signal region in order to be sensitive to wide range of signal phenomenologies
  - Model independent limits on signal cross-section.
  - Limits on 11 Black Hole/String Ball models.



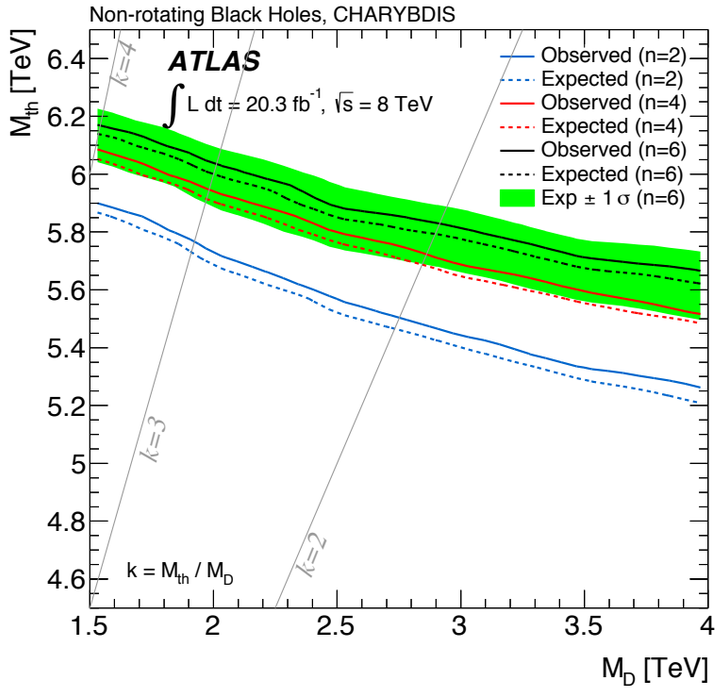


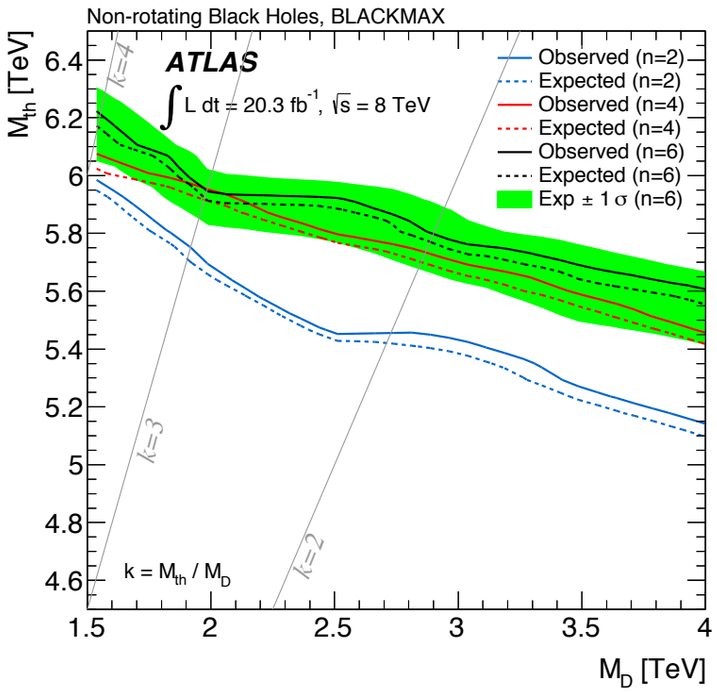
Previous searches

CMS multiplicity vs sum pT [arXiv:1303:5338, EXO-12-009]

ATLAS SS muons + jets

arXiv:1308.4075

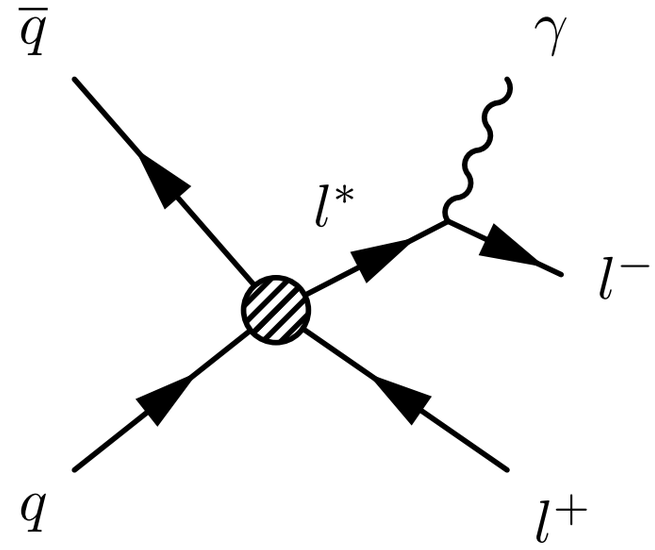


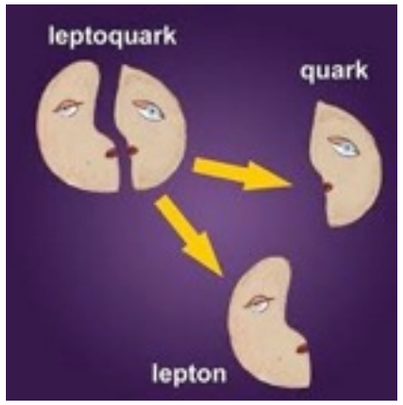


The exclusion limits in the M{th} -M{D} plane

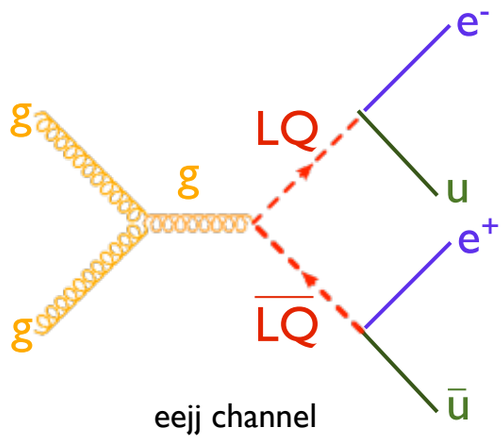
Exotics new particles

- **Excited leptons,**

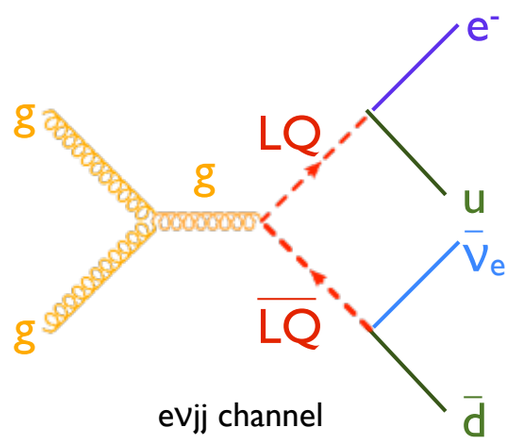




- **LeptoQuarks**



eejj channel

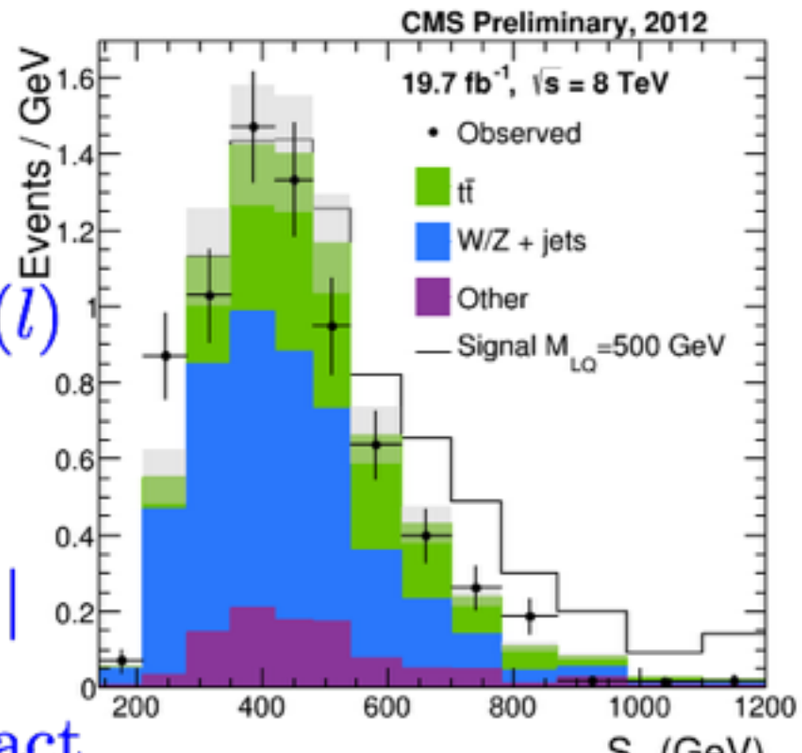


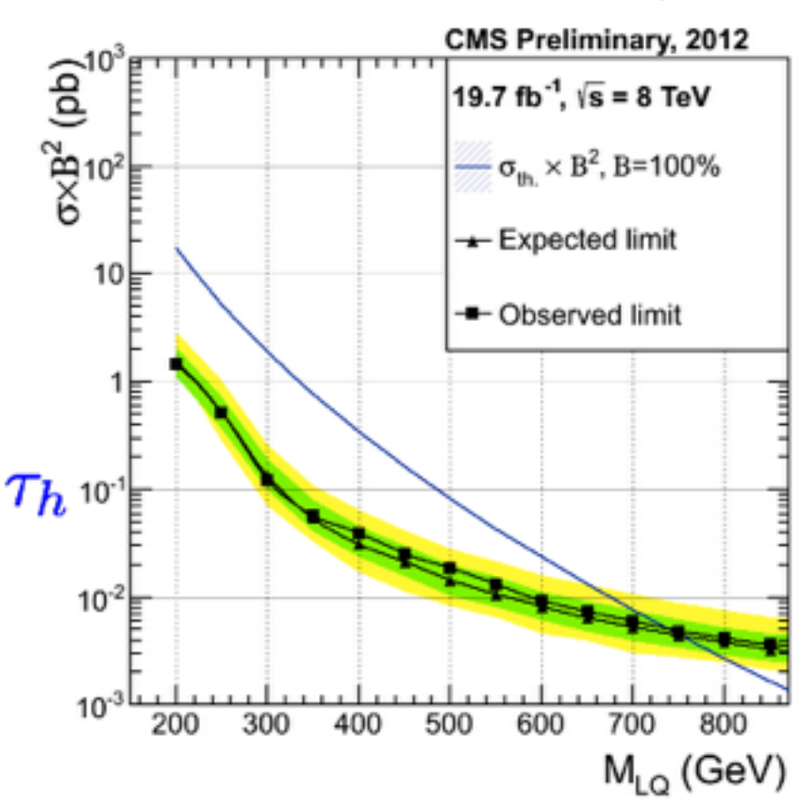
eνjj channel

Search for scalar LQ3

EXO-12-032

- Search for scalar LQ pair each decaying to τ and b
- One τ decays hadronically (τ_h) and one leptonically (l)
- Require two jets at least one tagged as b-jet
- Pair to minimise the difference $|M(\tau_h, j_m) - M(l, j_n)|$
- As no excess is found use the S_T distribution to extract limits on leptoquark (as well as stop scenarios)
- $S_T^{LQ} = p_T(l) + p_T(\tau_h) + p_T(b\text{-jet}) + p_T(jet)$
- Major irreducible BG $t\bar{t}$ decaying to τ_h and τ_l
- Major reducible BG events with jet misidentified as τ_h





LQ3 with masses bellow 740 GeV (and stops with masses below 576 GeV) is excluded at 95% CL

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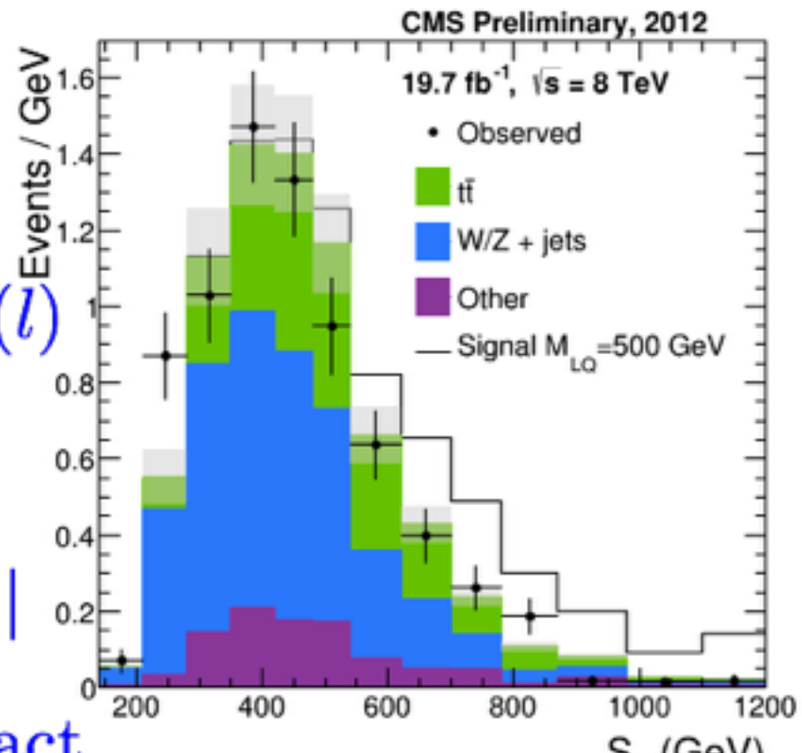
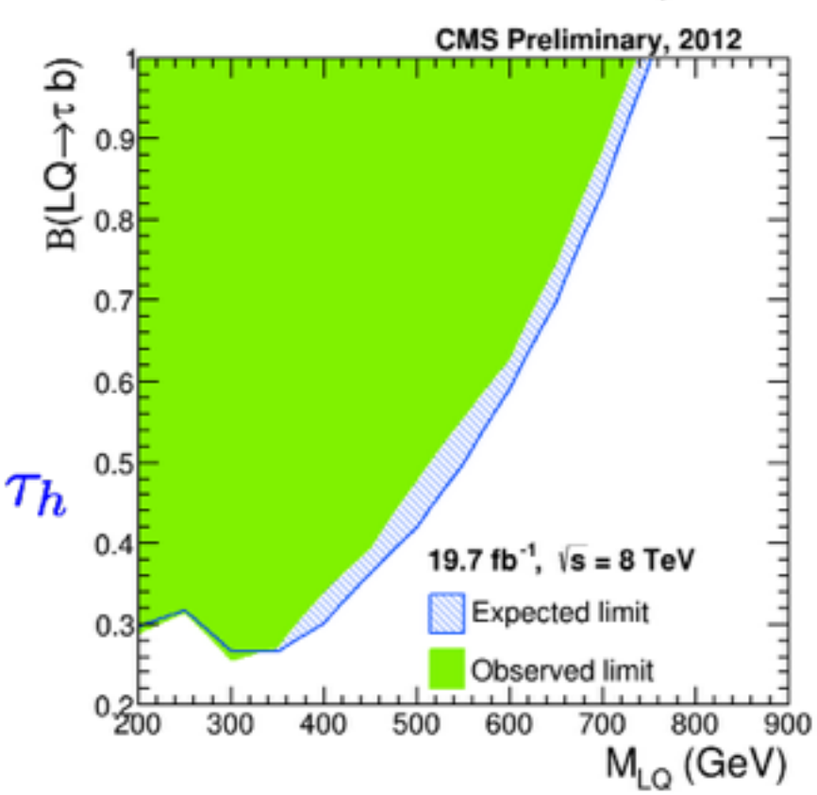




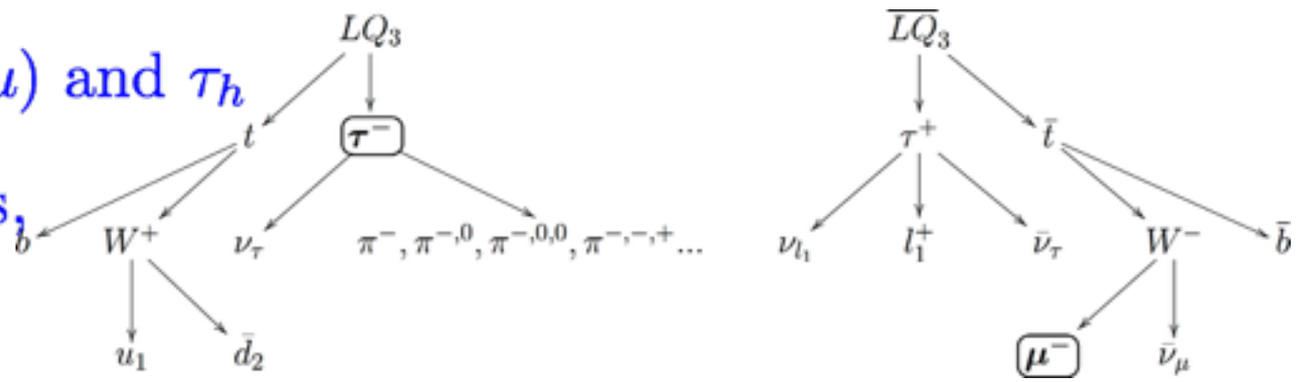
LQ3 with masses bellow 740 GeV (and stops with masses below 576 GeV) is excluded at 95% CL

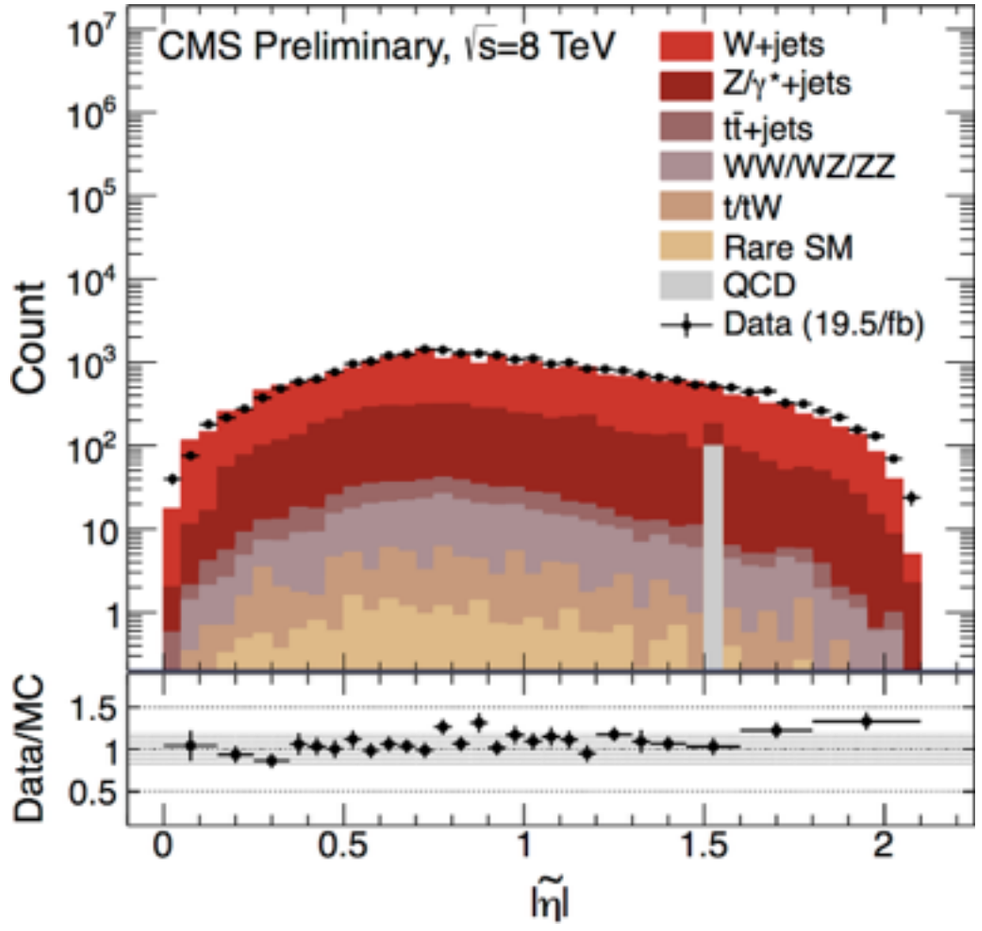
Search for LQ3 -> to top tau pairs

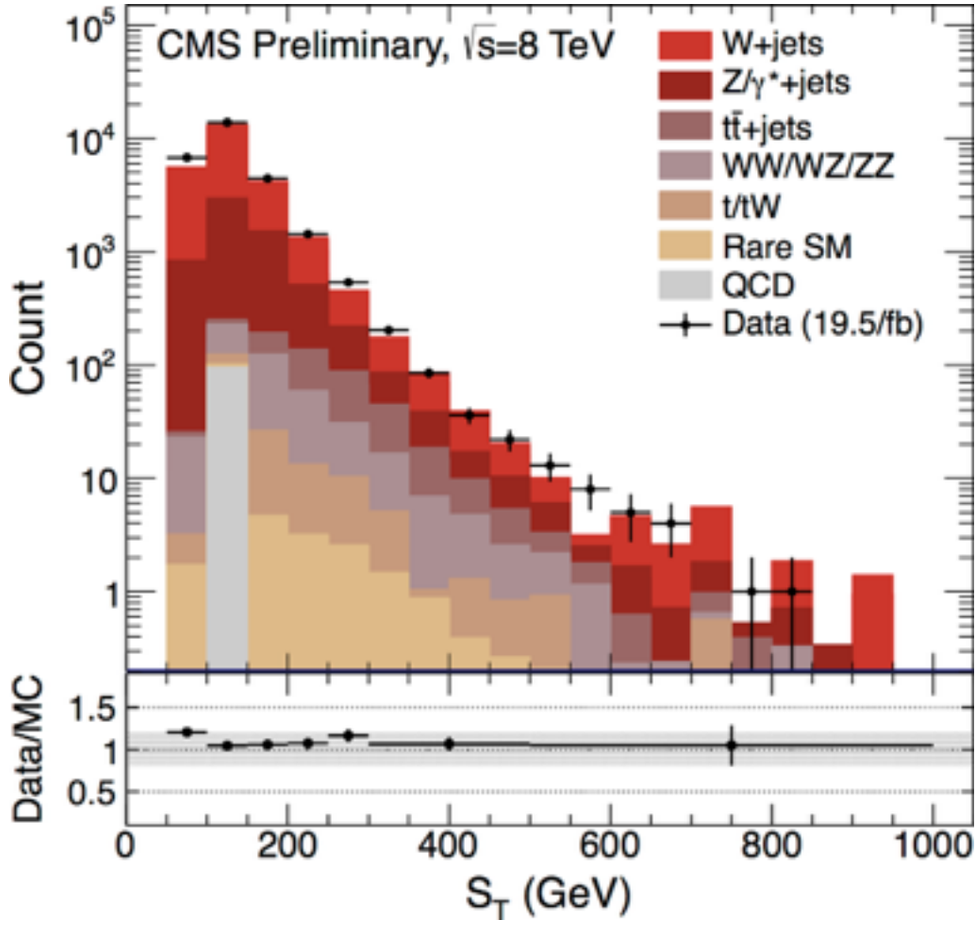
NEW!

- Search for scalar LQ pair each decaying to τ and top
- The signature is like sign W (decaying to μ) and τ_h
- Require $S_T > 400$ GeV, additional two jets, reject dimuon around Z mass
- Centrality $|\tilde{\eta}|$ - average of all e, μ, τ in the event split to central (forward) $|\tilde{\eta}| < 0.9$ (> 0.9) events

EXO-12-030







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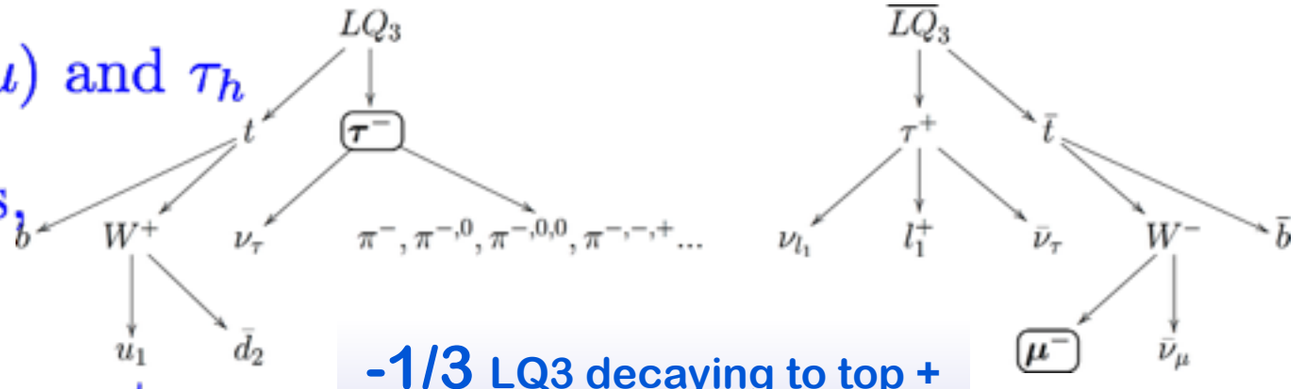
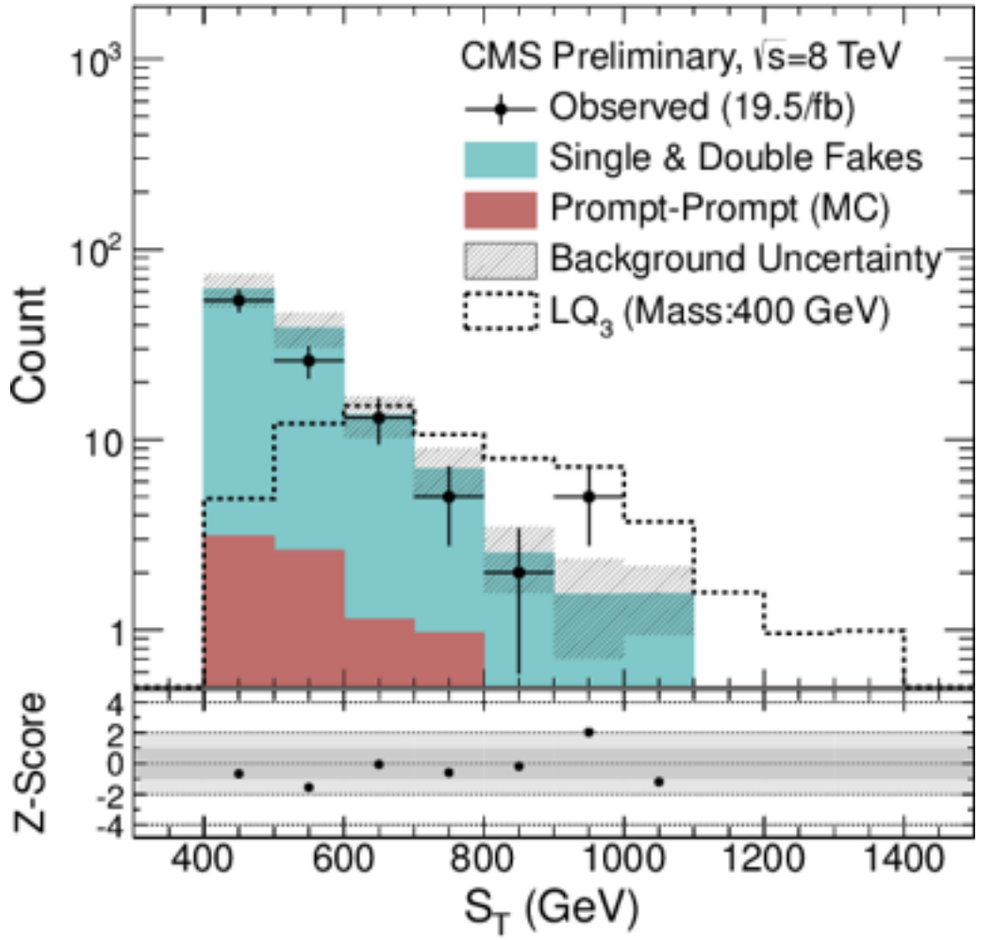
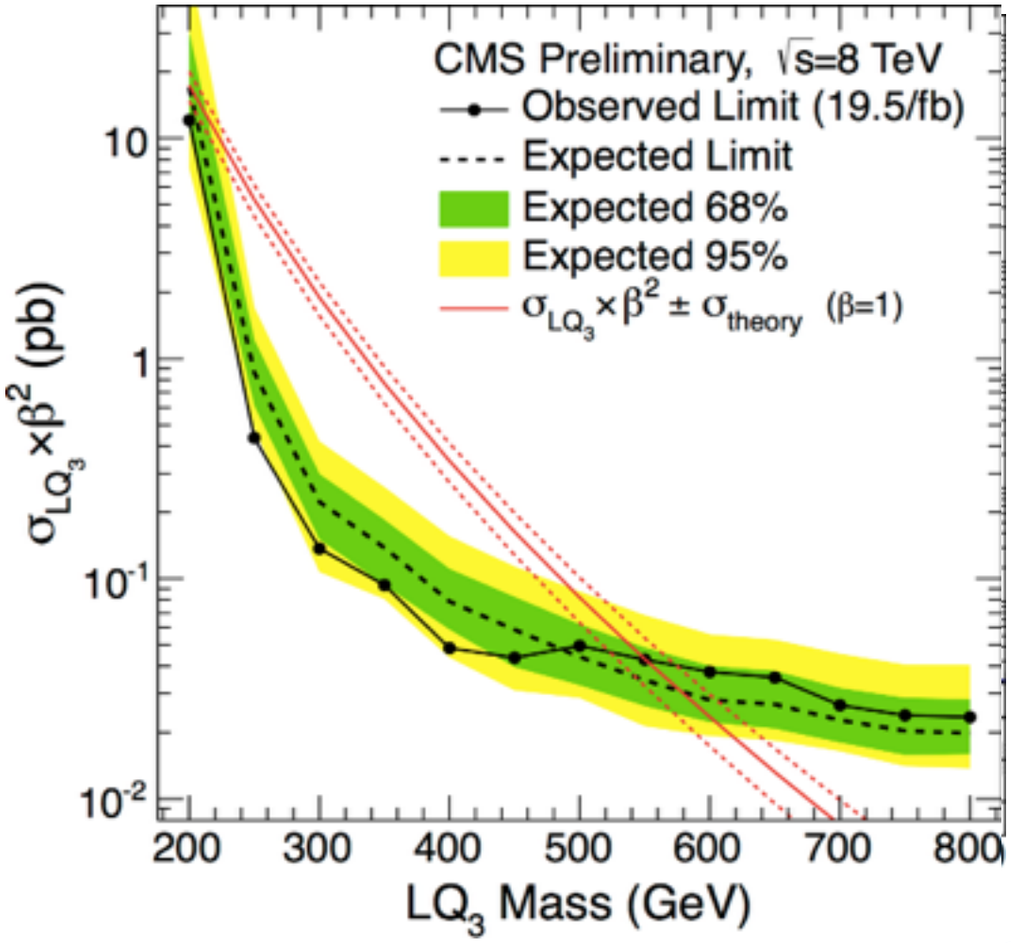
EXO-12-030



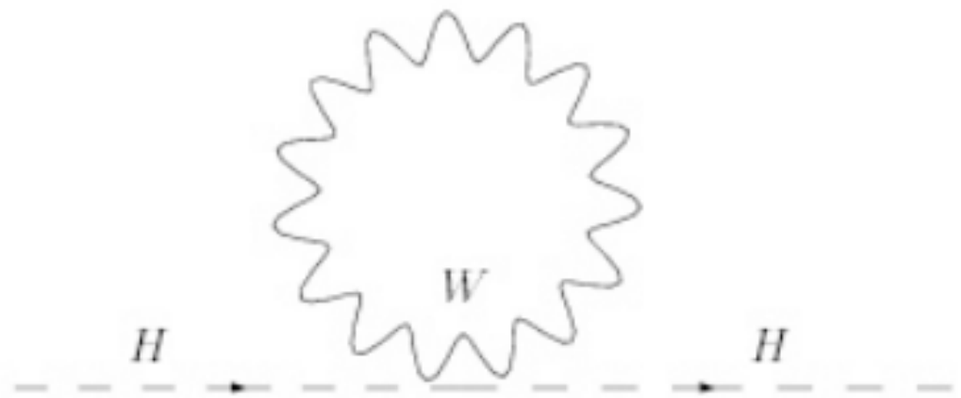
-1/3 LQ3 decaying to top + tau with mass bellow 550 GeV is excluded at 95% CL

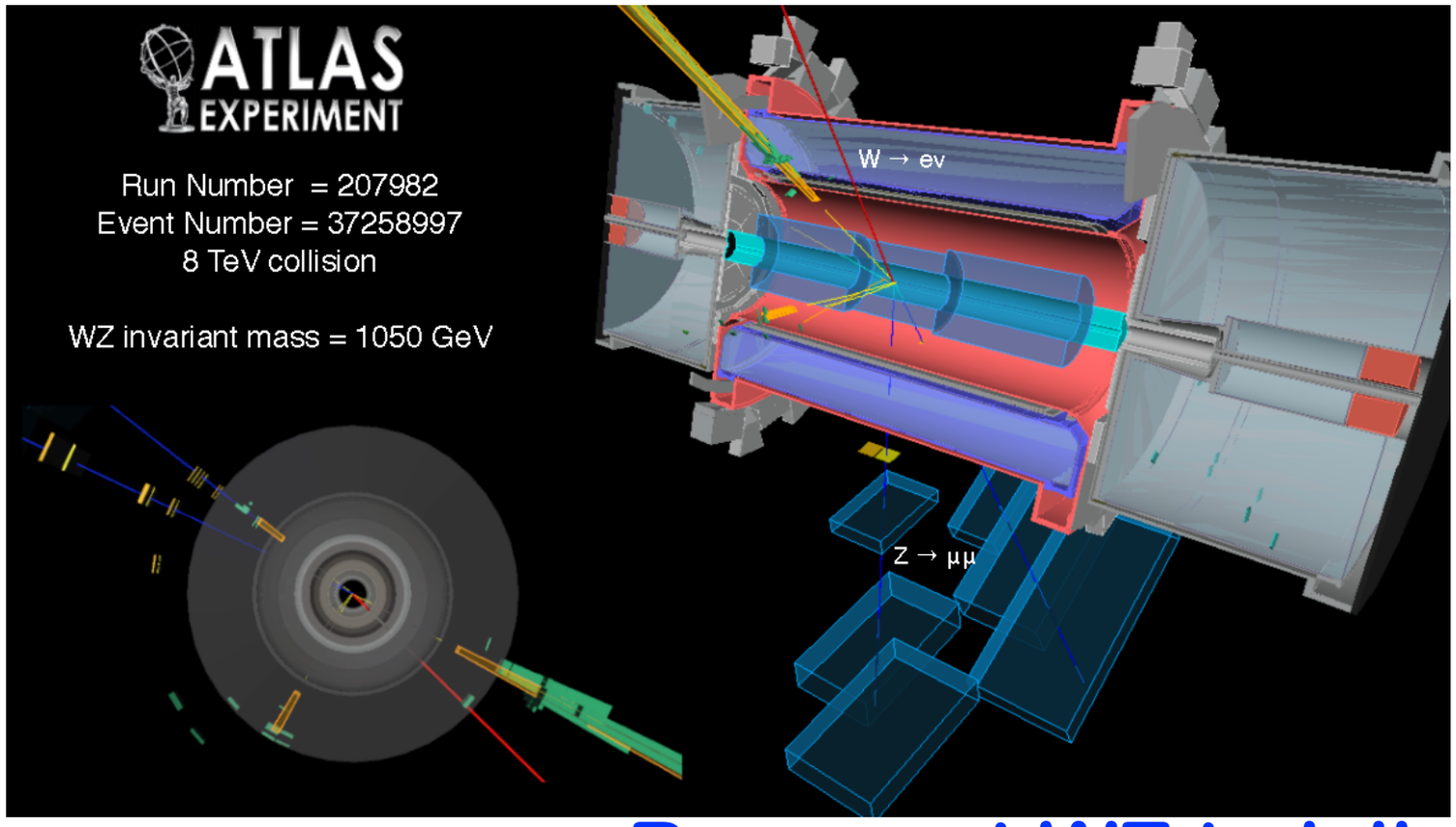




Dibosons

- **Dibosons**
  - Search for new Physics with two or more EW bosons
  - Signatures are various combinations of diboson: lljj, lvjj, lvll, lvlv, W/Z +photon,jjjj and JJ, monoZ
  - Main Physics interests are:
    - ➡ New heavy Gauge bosons
    - ➡ RS gravitons
    - ➡ Composite Higgs
    - ➡ Extended Guage Model (EGM)



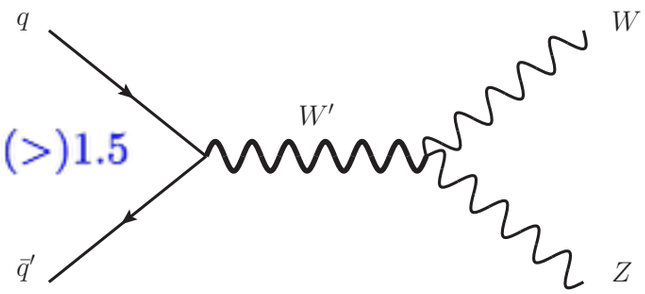


Resonant WZ to lvll

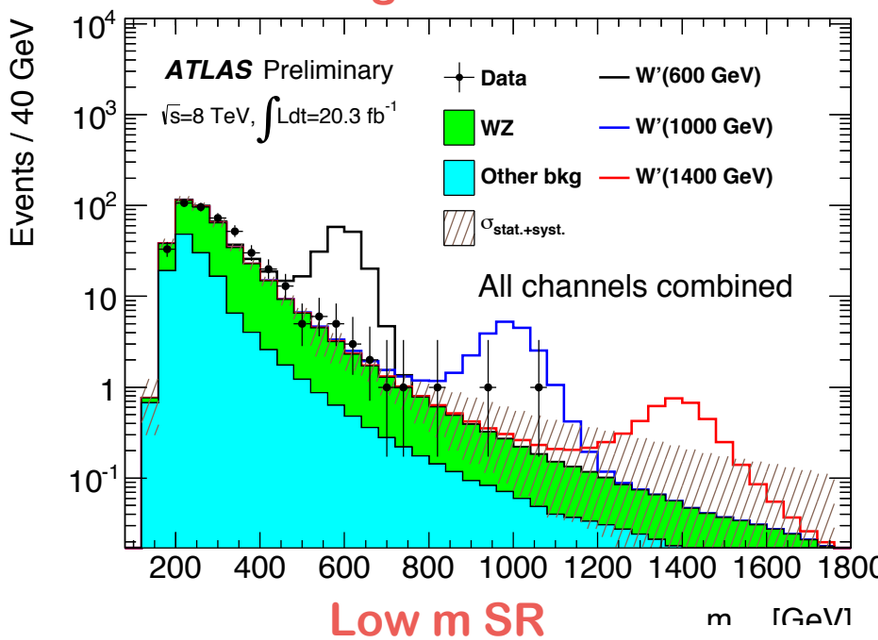
Resonant WZ to lνll

- Event Selection
  - Exactly 3 leptons
  - 2 OS SF $|m_{ll} - m_Z| < 20$ GeV
  - $E_T^{miss} > 25$ GEV
  - $\Delta y(W, Z) < 1.5$
  - High (low) mass region $\Delta\phi(l^W, E_T^{miss}) < (>)1.5$
- Reconstruct m_{WZ} using $m(l^W, E_T^{miss}) = m_W$
- Background estimation
  - Prompt BG, 3 or more prompt leptons, MC: WZ, ZZ (Powheg), $t\bar{t} + W/Z$ (Madgraph)
  - Non prompt BG: photon conversion MC $Z\gamma$ (Sherpa), where leptons from hadron decays Data driven: ll+jets, ($t\bar{t}$, single t, Z+jets)

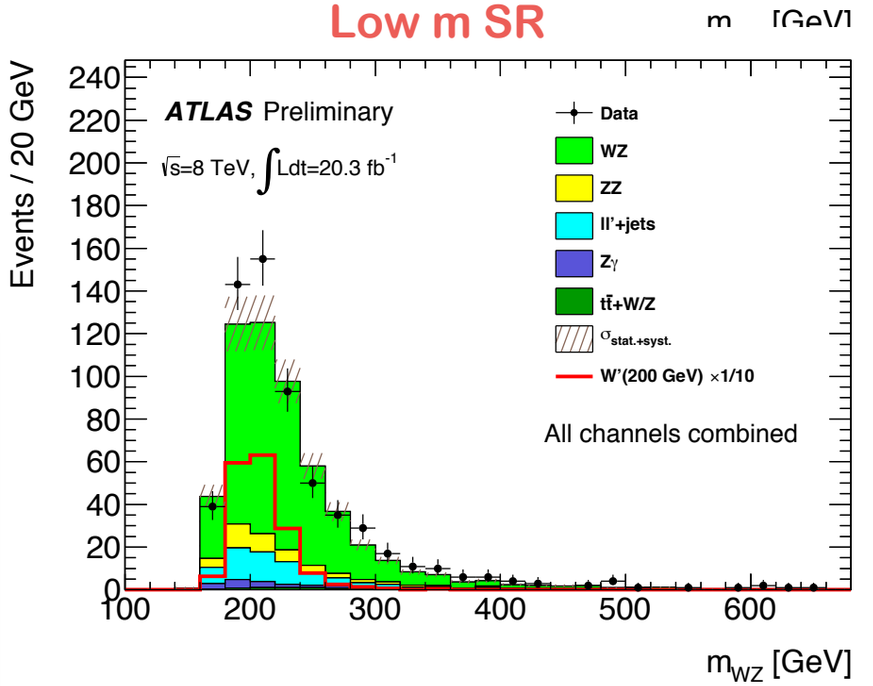
ATLAS-CONF-2014-015



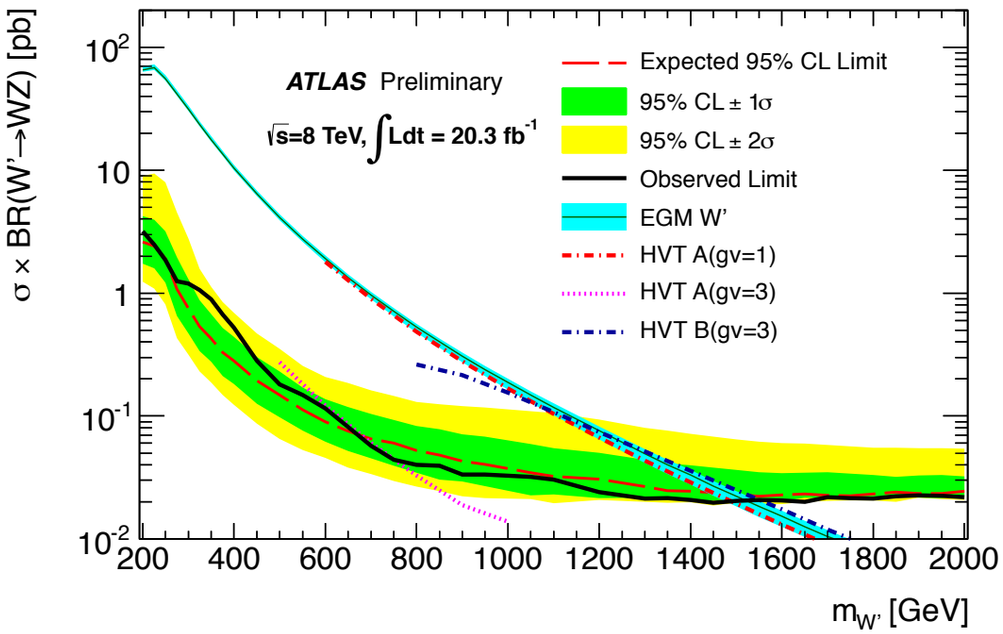
High m SR



Low m SR



Limits are set on the signal σ × BR(WZ) using CLs method for the EGM W′ and heavy vector triplets (HVT) models.



Related searches 8 TeV:
CMS:
WZ -> lνll EXO-12-025

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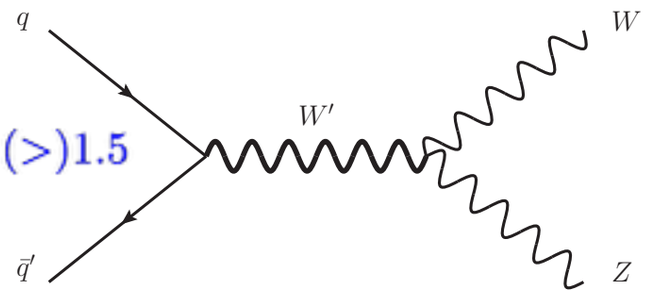
ATLAS-CONF-2014-015



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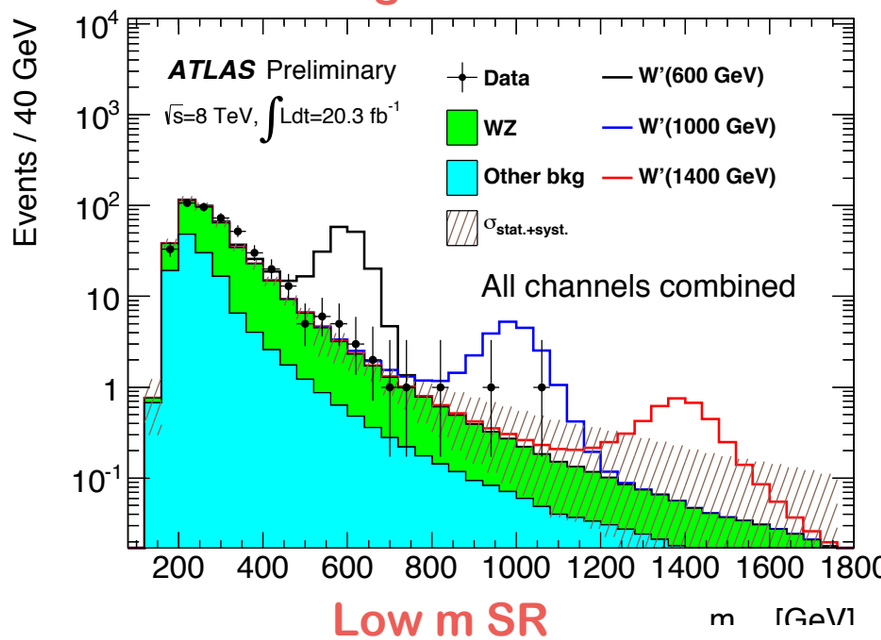

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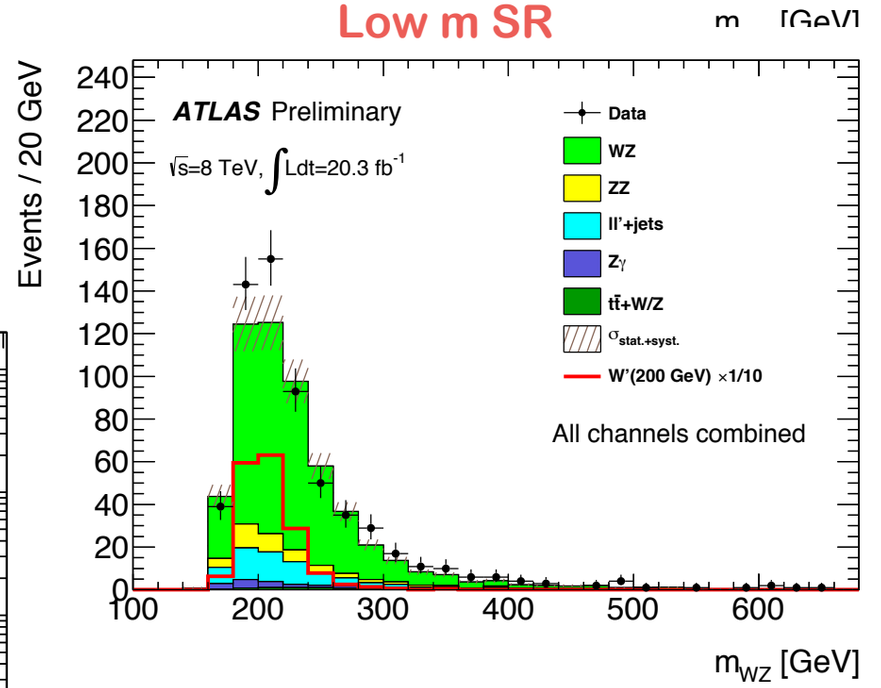

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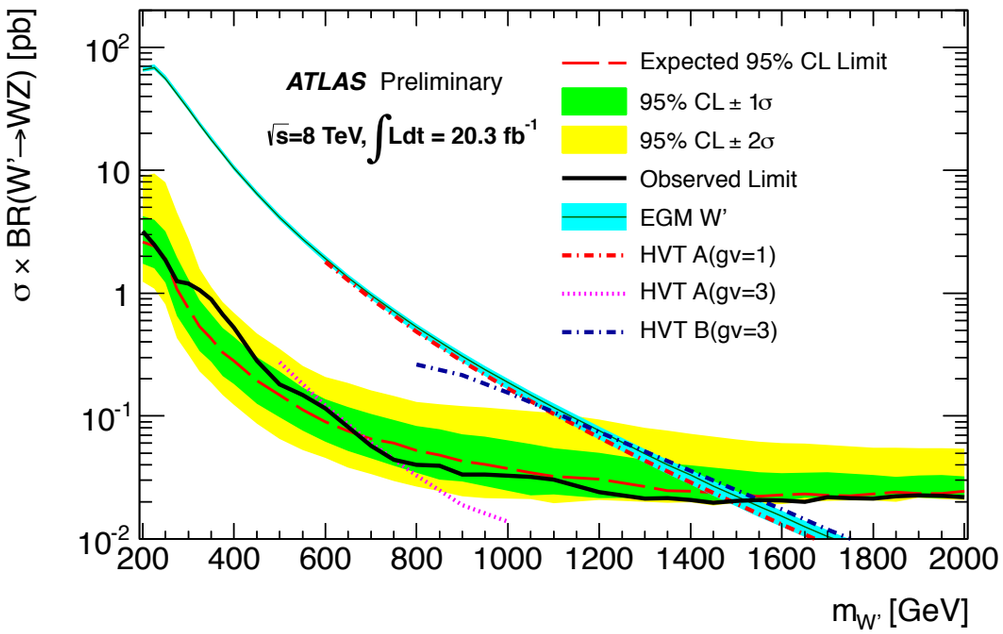


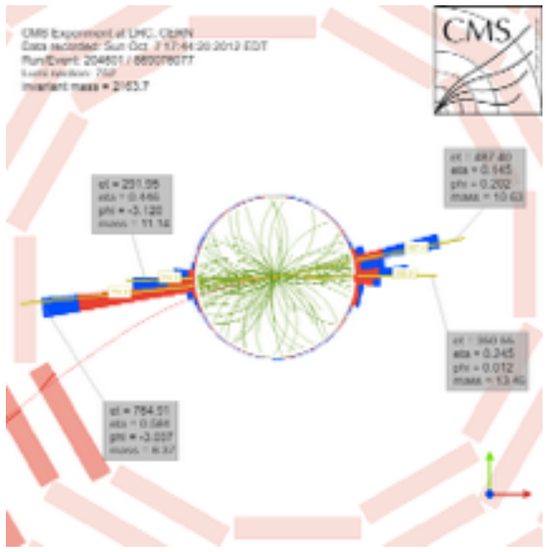
Related searches 8 TeV:
CMS:
WZ -> lνll EXO-12-025

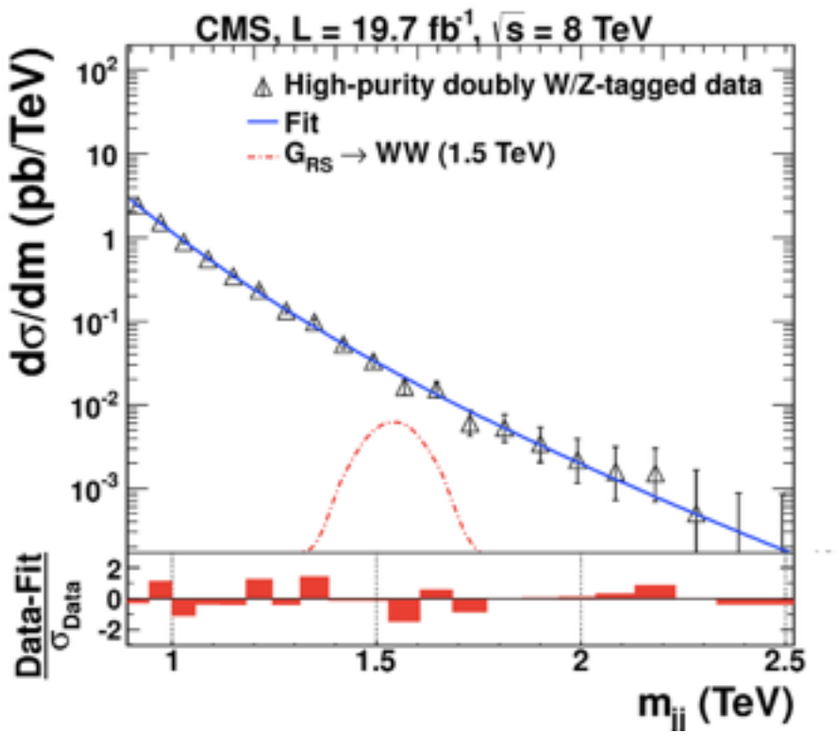
Lower limit on W' is 1.52 (observed 1.49) TeV

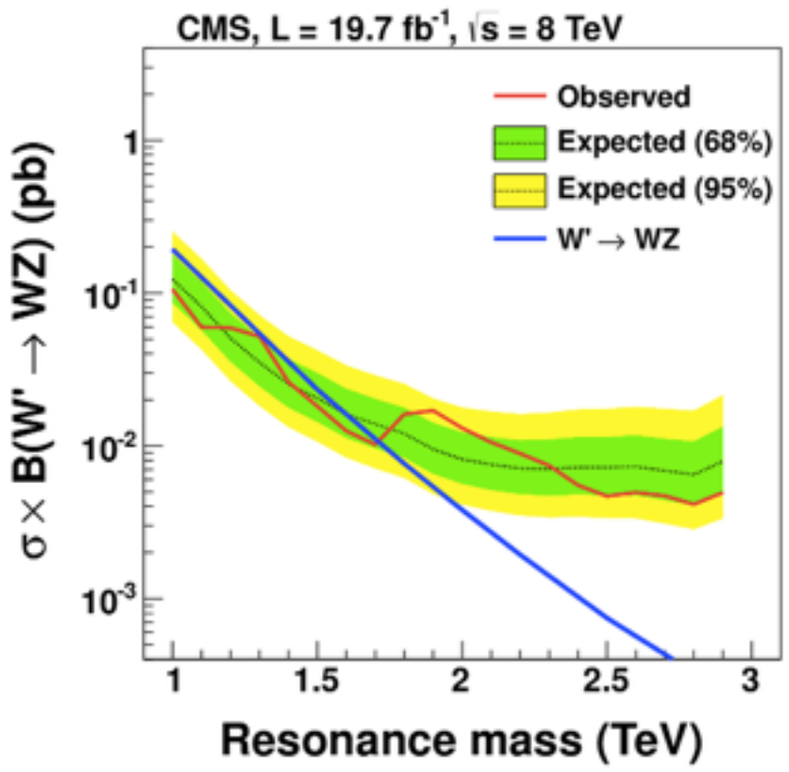
CMS: exclude between 0.17 to 1.45 TeV

Resonance->boosted dibosons

- Search for massive resonances decaying into pairs of boosted bosons in semi-leptonic final states - (llqq, lvqq) - arXiv:1405.3447
- Search for massive resonances decaying into pairs of boosted bosons in all-hadronic final states - arXiv:1405.1994 (qW, qZ, WW, WZ, ZZ)







Related searches 8 TeV:
ATLAS
ZZ -> lljj CONF-2012-150

Long lived particles and Lepton jets

- What if the BSM Physics is there, but hidden behind a large barrier?
- Searches for decays in the detector, heavily ionizing particles ..
- Signatures: prompt or displaced lepton jets, displaced jets, high TRT ionization, high p_T "muons" with high dE/dx, or tracks with anomalous ionization and bending
- Physics model include

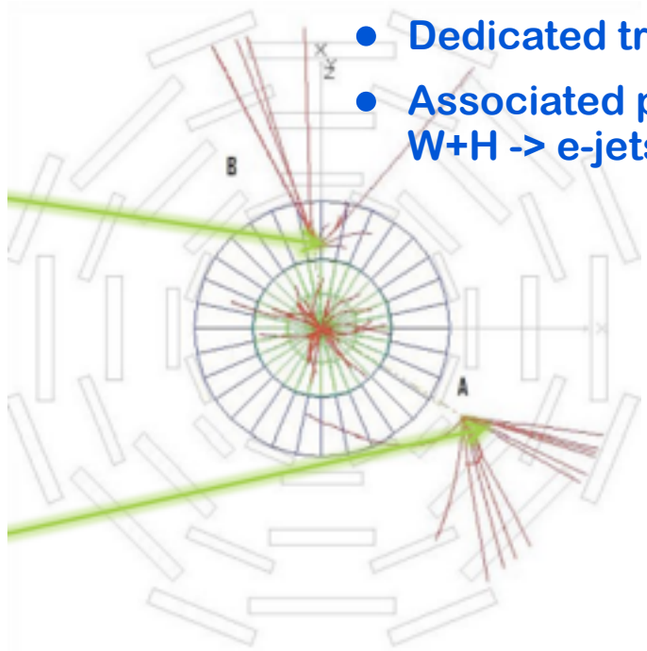
➡ Higgs & Z' decays -> hidden valley particles

➡ Monopoles

➡ High charges

➡ Quirks

➡ Associated production of W/Z & H to l-jets:



- Dedicated triggers and tracking
- Associated production e.g. W+H -> e-jets

- WIMP-like DM
- Predicts massive dark photon (γ_d) decay to pairs of e, mu or pions.
- Appear as collimated sets of leptons (pions) at LHC.
- The strength of the SM and γ_d mixing determines the vertex distance
- ATLAS set limits on Sigma X BR of Higgs to prompt e-jets as well as to prompt and displaces mu-jets and LLP pseudoscalar dark pions, π_v and on SUSY lepton-jets production.

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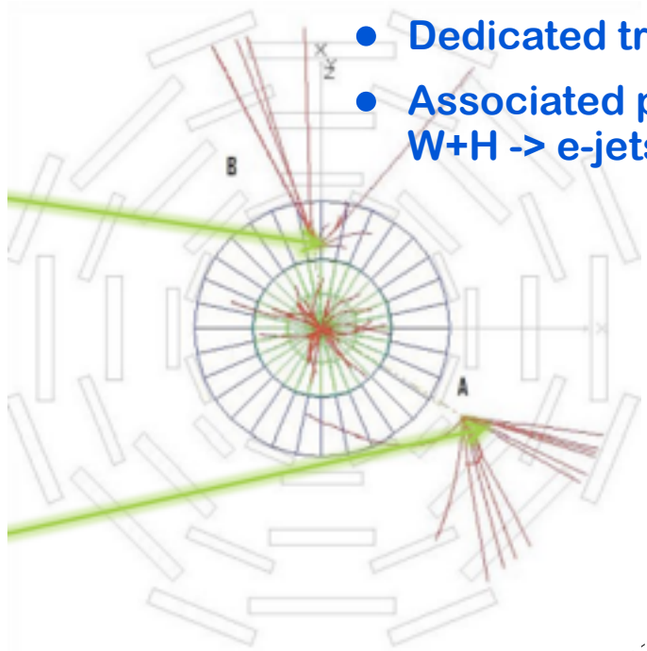

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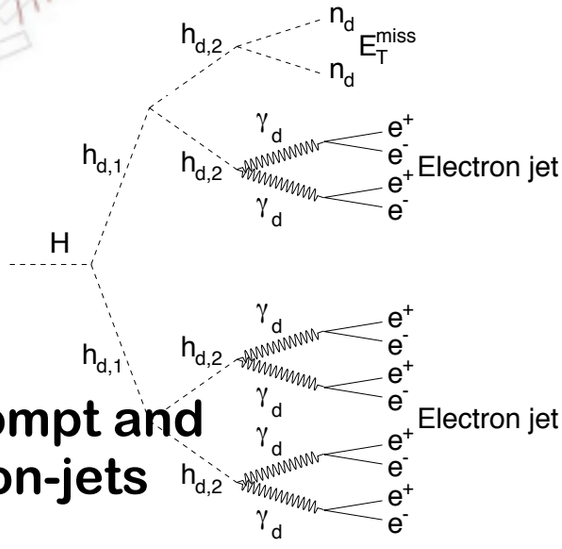
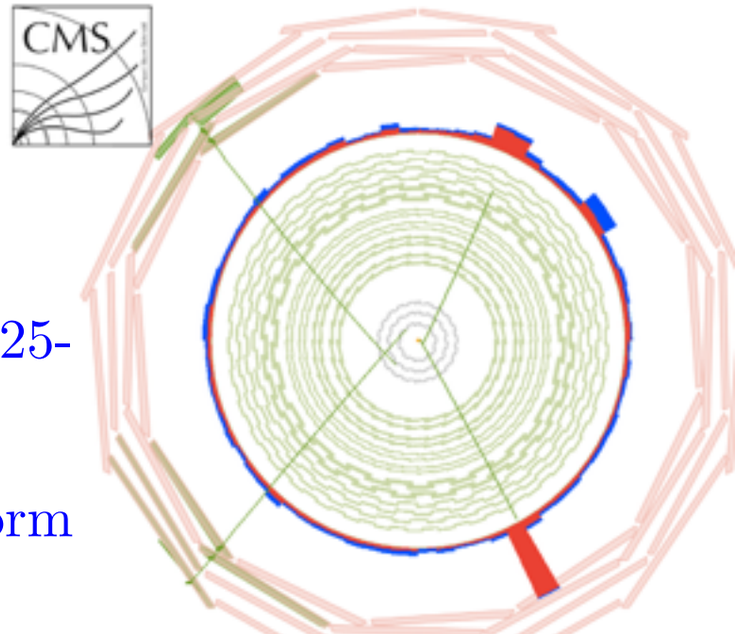


Search for displaced dilepton pairs

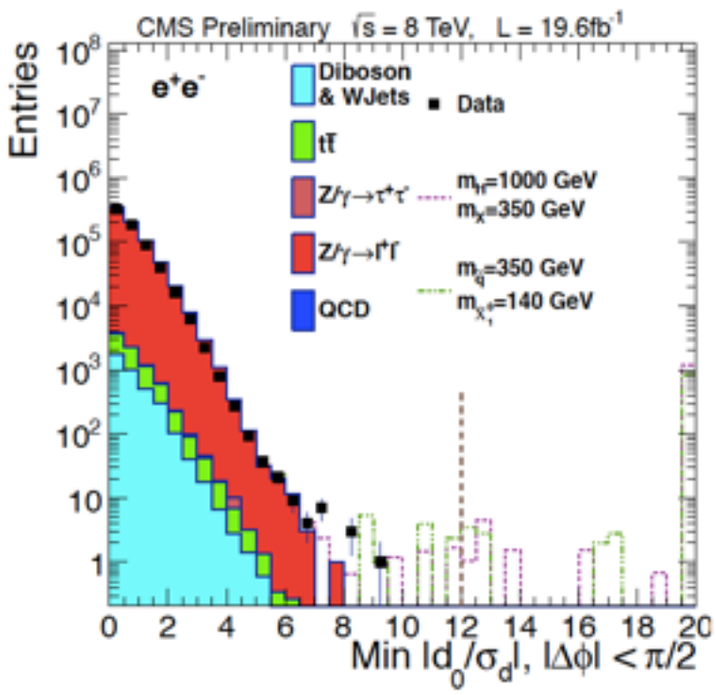
NEW!

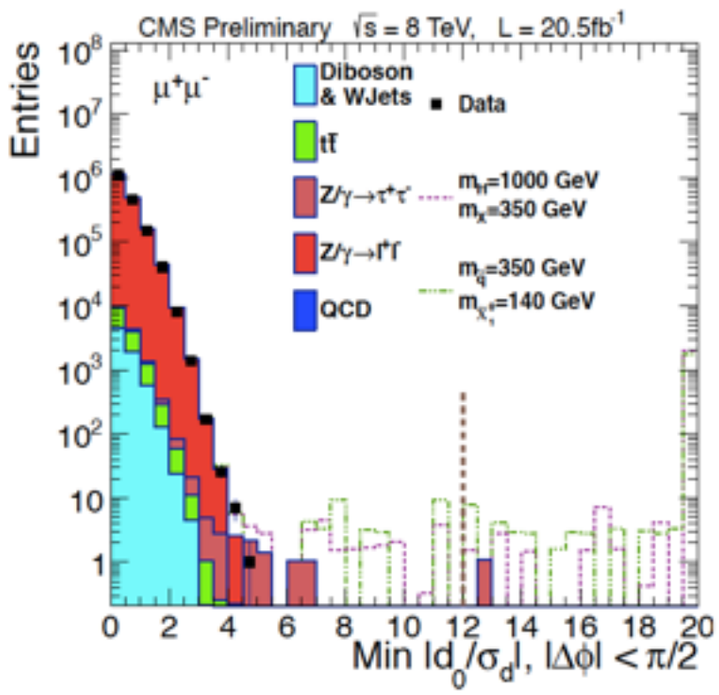
EXO-12-037

- Search for massive long-lived particles (LLP)decaying to leptons
- Predicted e.g. by split or RPV SUSY, hidden valley, Z' with LLP ν's
- Look for BSM Higgs $H^0 \to \chi\chi, \chi \to l^+l^-$ or
  squark pair production $\tilde{q} \to q\tilde{\chi}^0$ RPV $\tilde{\chi}^0 \to l^+l^-\nu$
- Signal MC H^0 (masses 125-1000 GeV) decaying to LLP with masses 25-350 GeV.
- Isolated lepton tracks (with significant transverse impact parameter) form good secondary vertex with mass > 15 GeV.



- $\delta\phi$ between the dilepton vertex and their momentum sum vector is $< \pi/2$





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EXO-12-037

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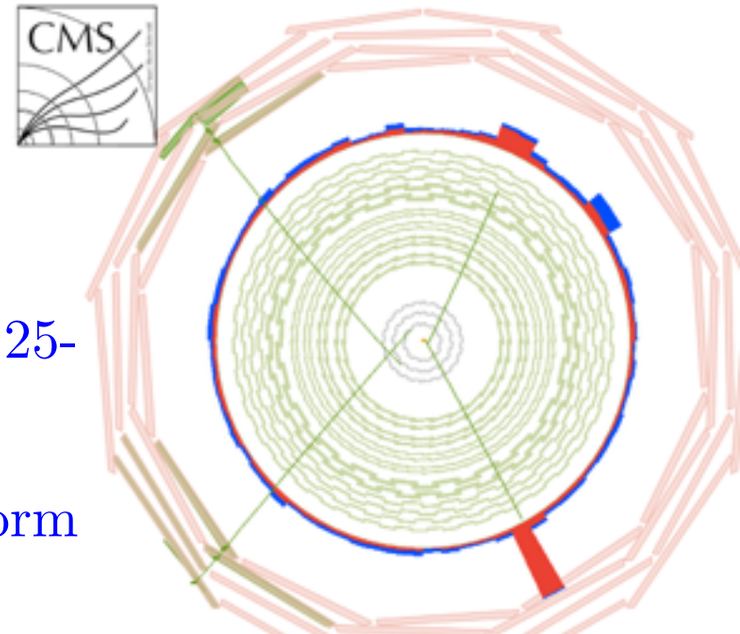

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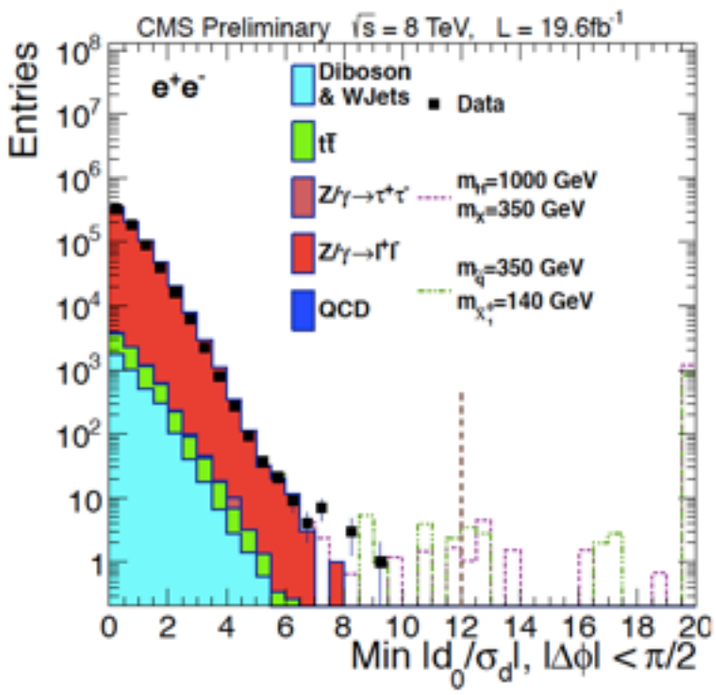
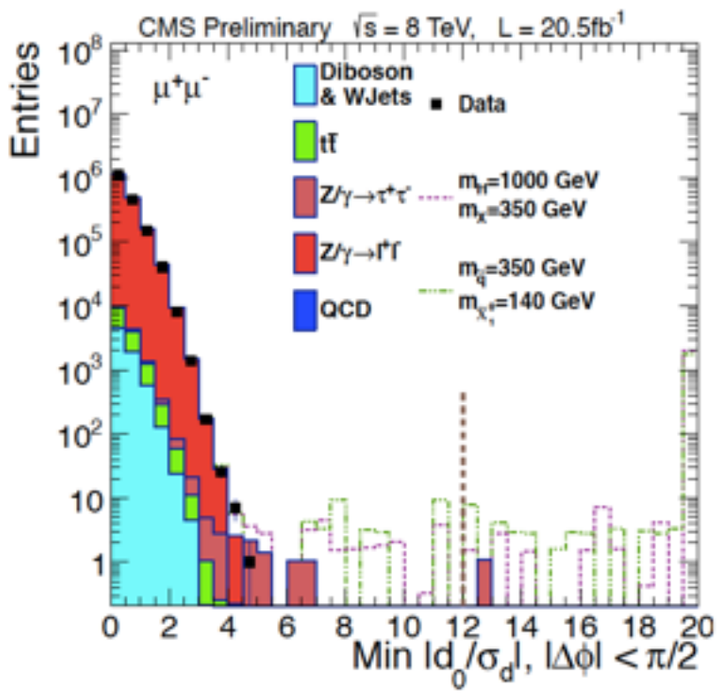
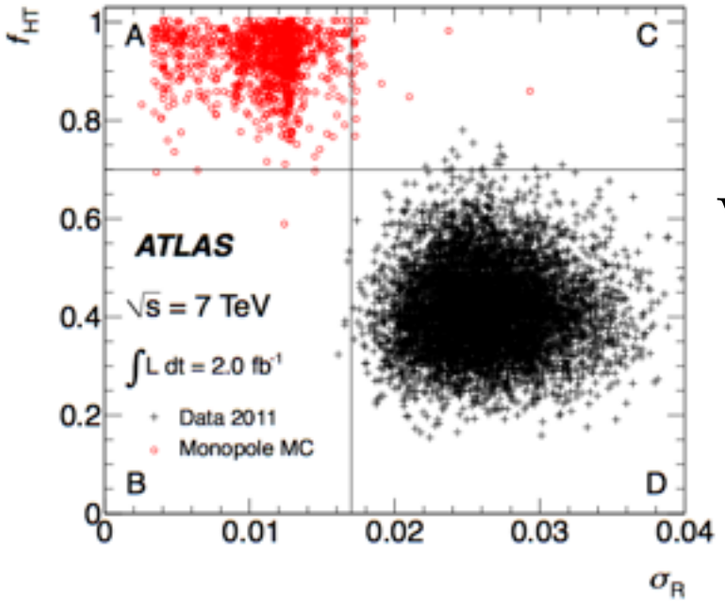




A Higgs boson, m_H =125 – 1000 GeV decays to pair of 20–350 GeV X bosons, decaying to dileptons.
The upper limits are between 0.1 – 5 fb for lifetimes of $0.01 < ct < 100$ cm, weaken to 5 – 50 fb for m_H=125 GeV

Other exotics searches

- **Magnetic monopoles and highly ionizing particles**



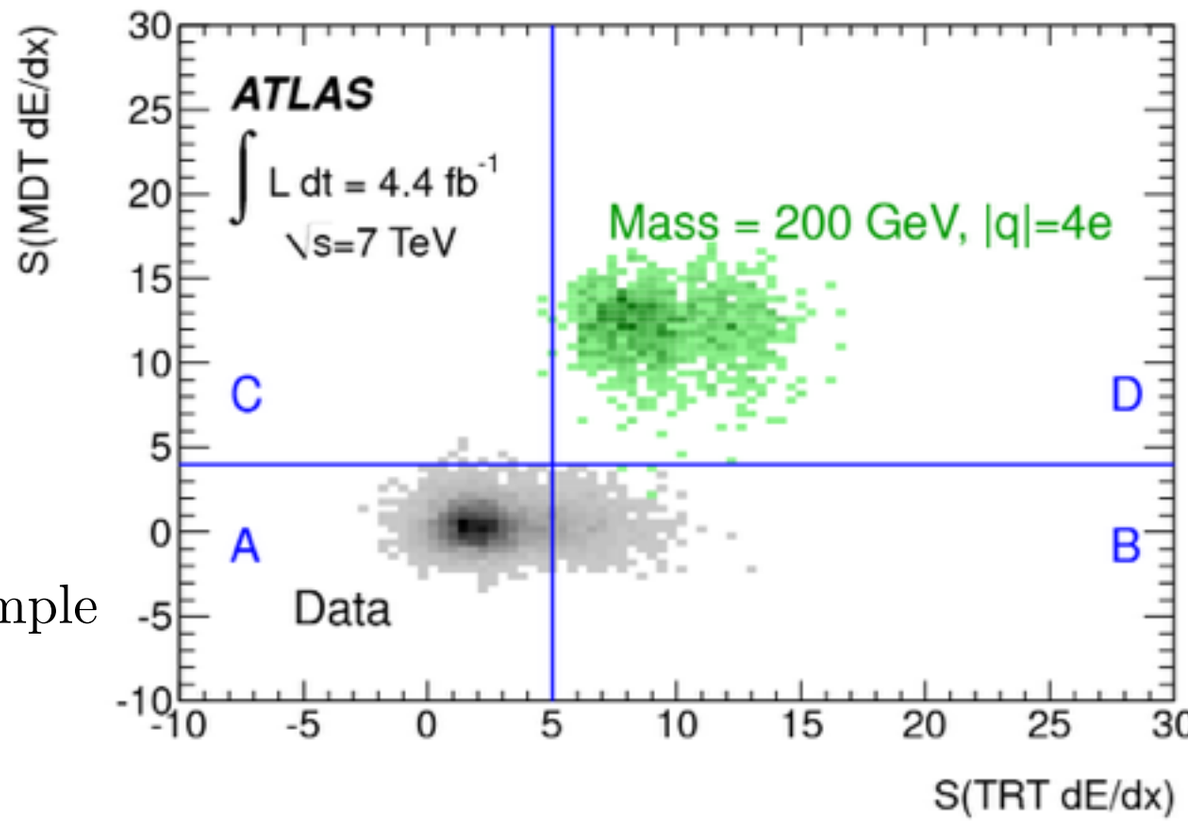
PRL 109 (2012) 261803

High-threshold TRT hit fraction, f_{HT}, versus EM cluster dispersion, σ_R

- **Multi-charges**

PLB 722, 305 (2013)

The plane of TRT and MDT dE/dx significances after the $|q| > 2e$ selection.
The distributions of the 2011 data and the signal sample (mass of 200 GeV and $|q| = 4e$)



More on Ian Tomalin's talk- (parallel session)

Model-independent generic search

ATLAS-CONF-2014-006

- Not optimised for specific signal
- Provides comprehensive investigation for new physics
- Study topologies with isolated e's, μ's, γ's, Jets, b-jets, MET
- Search in 697 classes with SM expectation greater than 0.1 events
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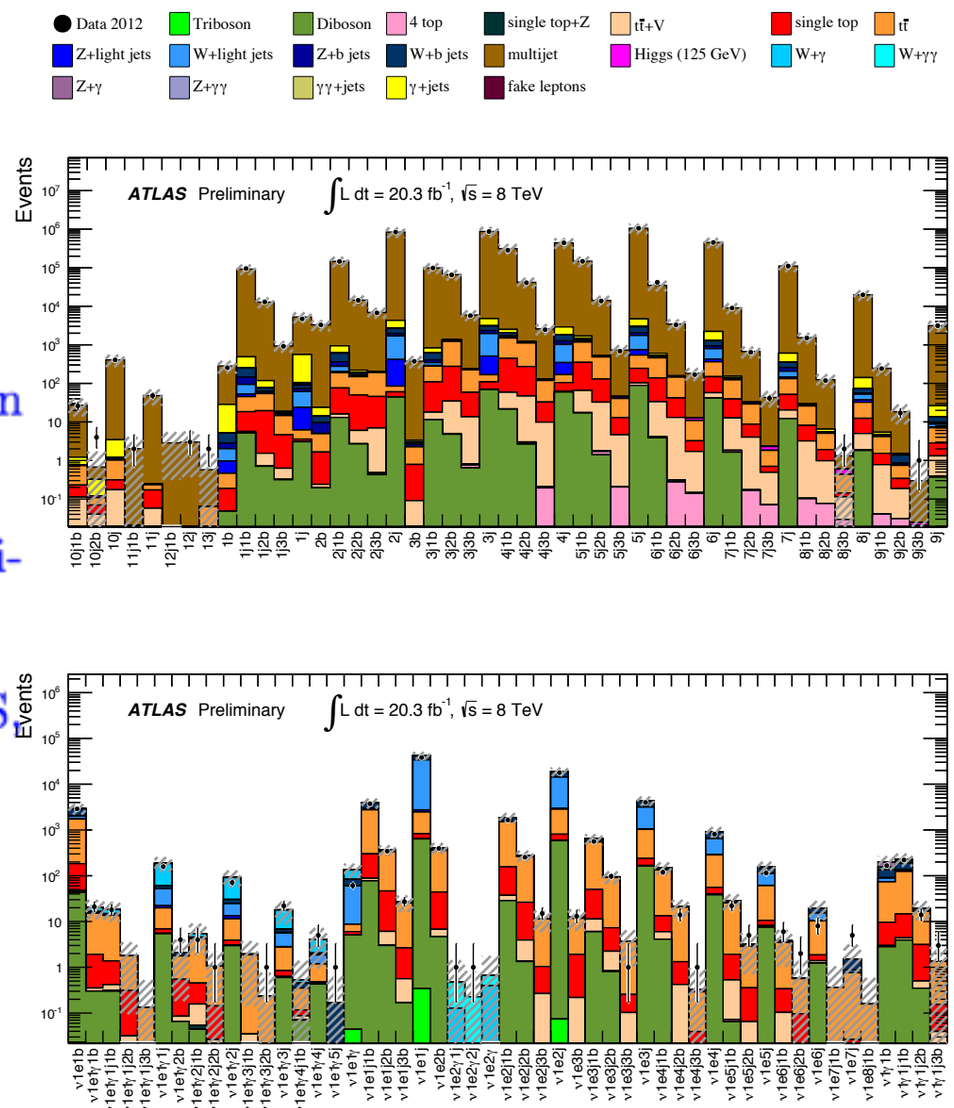
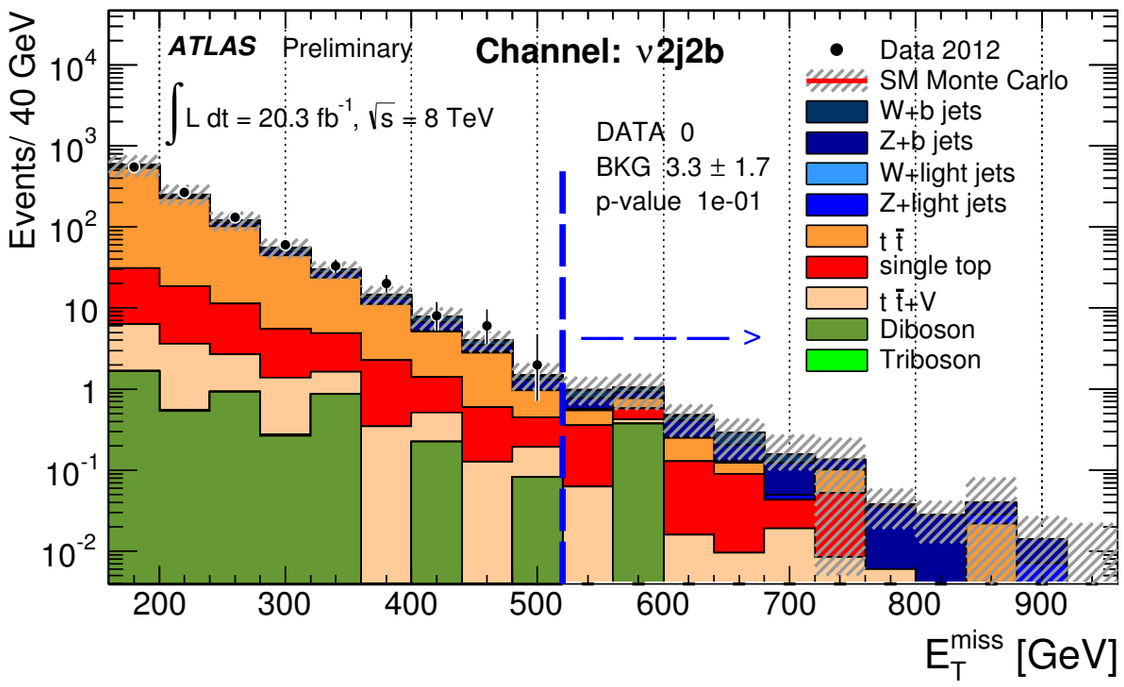


MET for the class with (nu2j2b). The dashed vertical line indicate the region with the smallest p-value (0.097) for this class.



Model-independent generic search

ATLAS-CONF-2014-006

- Not optimised for specific signal
- Provides comprehensive investigation for new physics
- Study topologies with isolated e's, μ's, γ's, Jets, b-jets, MET
- Search in 697 classes with SM expectation greater than 0.1 events
- BG estimated with MC, except for single fake leptons using data driven ("ABCD" method)
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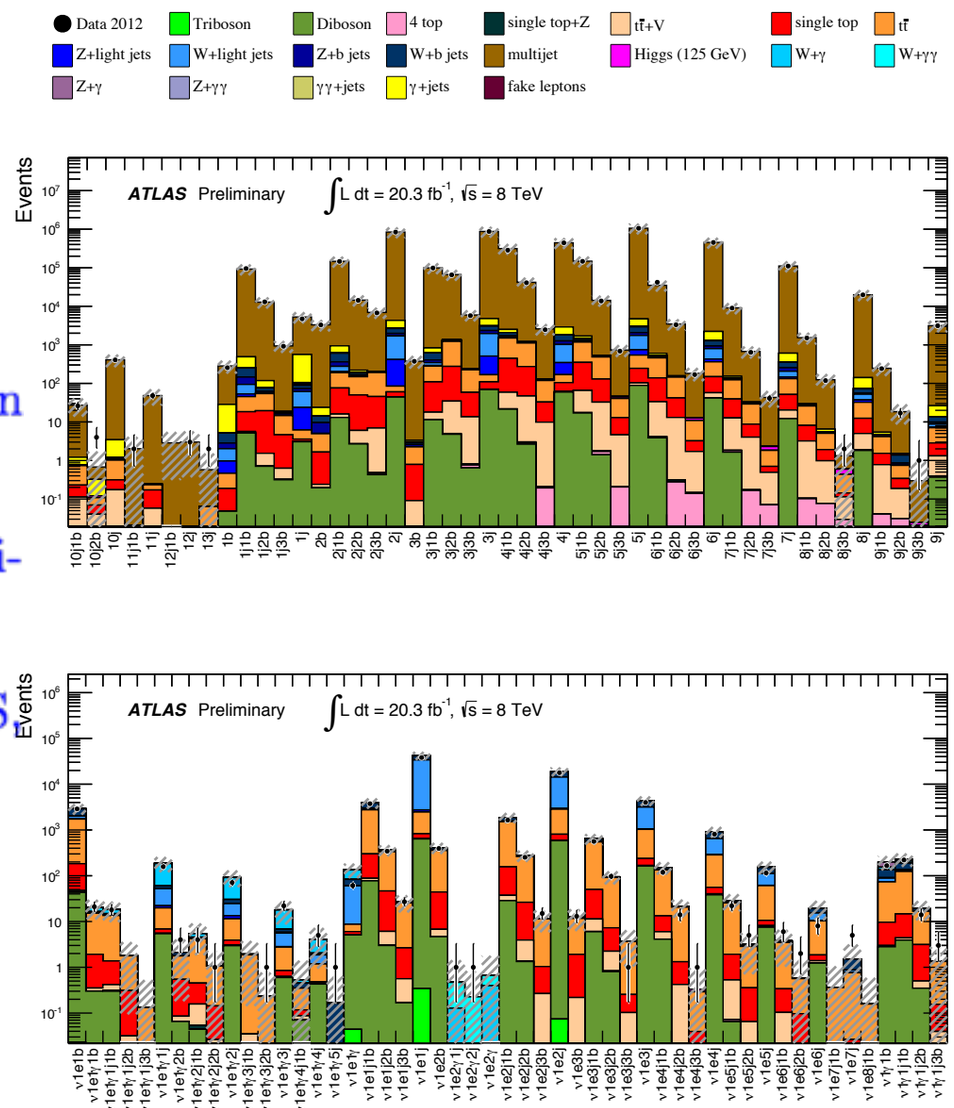

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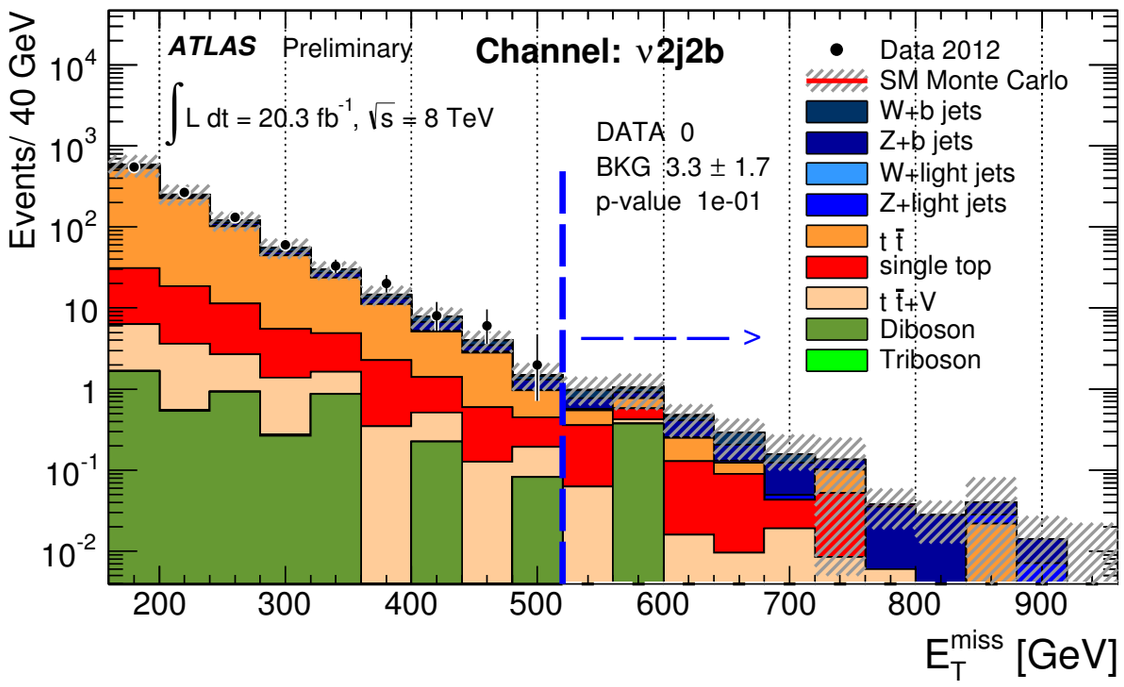


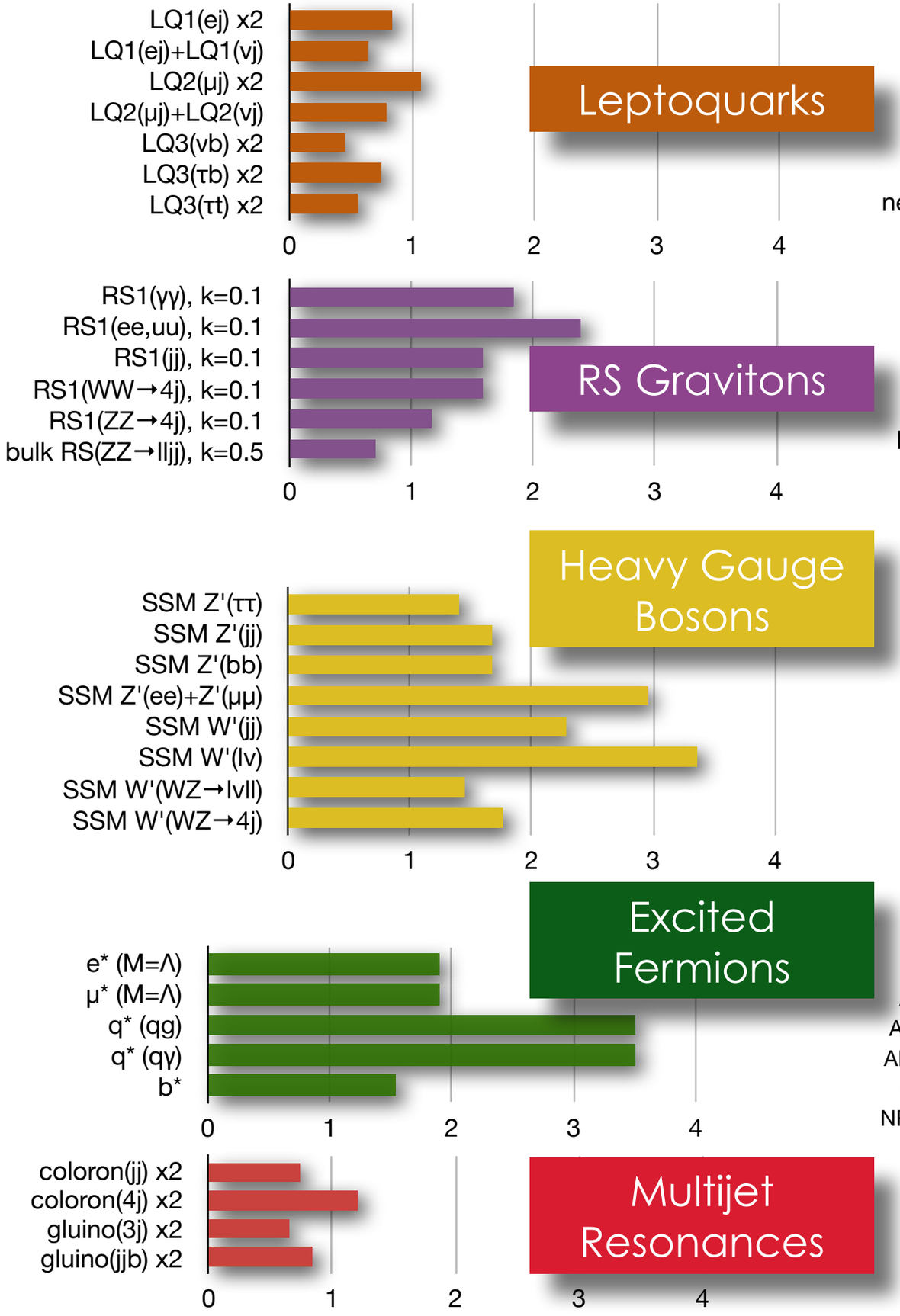
No excess in all search regions
A clear demonstration of our MC precision

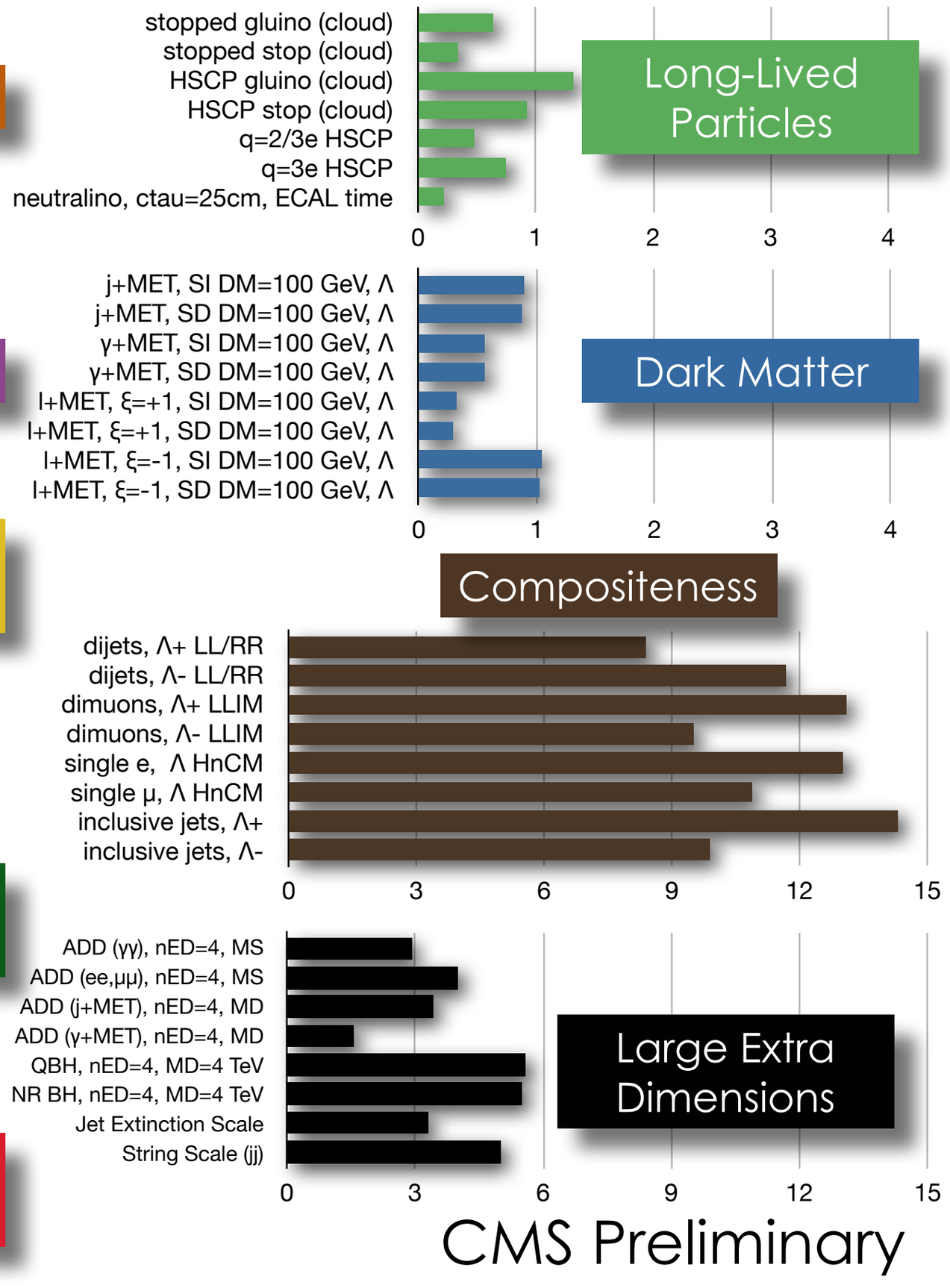
Summary

- 125 Higgs: Do we understand the theory of particle Physics?
- Large number of NEW! BSM searches results in various topologies and theoretical scenarios.
- Excellent (too good?) data/MC agreement.
- No hint for new physics.
- Supersede previous exclusions, reach a few TeV scale!
- Some models less favoured (RS1->Bulk RS, 4th generations->VLQ, technicolor..). Some get more attention (Exotics+Higgs, DM)
- Large fraction of the data has been investigated… surprises hiding in the rest ?
- Challenges for the new run (boosted objects, higher pile up..) and… new energy frontier !

ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

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





CMS Preliminary

CMS Exotica Physics Group Summary – March, 2014

ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 2014

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (1.0 - 20.3) fb^{-1} $\sqrt{s}$ = 7, 8 TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell/\gamma\gamma$	2γ or 2e, μ	–	–	4.7	M_S 4.18 TeV	$n = 3$ HLZ NLO	1211.1150
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq$ 1 e, μ	$\geq$ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	ATLAS-CONF-2014-016
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.47 TeV	$k/\overline{M}_{Pl} = 0.1$	ATLAS-CONF-2013-017
	RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell\ell qq/\ell\ell\ell\ell$	2 or 4 e, μ	2 j or –	–	1.0	G_{KK} mass 845 GeV	$k/\overline{M}_{Pl} = 0.1$	1203.0718
	RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	1 e, μ	$\geq$ 1 b, $\geq$ 1J/2j	Yes	14.3	g_{KK} mass 0.5-2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.86 TeV		ATLAS-CONF-2013-017
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\,\ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		ATLAS-CONF-2014-015
	LRSM $W'_R \rightarrow t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	5.0	Λ 13.9 TeV	$\eta_{LL} = -1$	1211.1150
	CI $uutt$	2 e, μ (SS)	$\geq$ 1 b, $\geq$ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C\rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator	–	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator	–	1 J, $\leq$ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	$\geq$ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	$\geq$ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$	1 e, μ	$\geq$ 2 b, $\geq$ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	1 e, μ	$\geq$ 1 b, $\geq$ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $BB \rightarrow Zb + X$	2 e, μ	$\geq$ 2 b	–	14.3	B mass 725 GeV	B in (B,Y) doublet	ATLAS-CONF-2013-056
	Vector-like quark $BB \rightarrow Wt + X$	2 e, μ (SS)	$\geq$ 1 b, $\geq$ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \rightarrow qg$	–	2 j	–	13.0	q^* mass 3.84 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2012-148
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e\rvert$=0.055, $\lvert V_\mu\rvert$=0.063, $\lvert V_\tau\rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \rightarrow \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q\rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

10^{-1} 1 10 **Mass scale [TeV]**

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