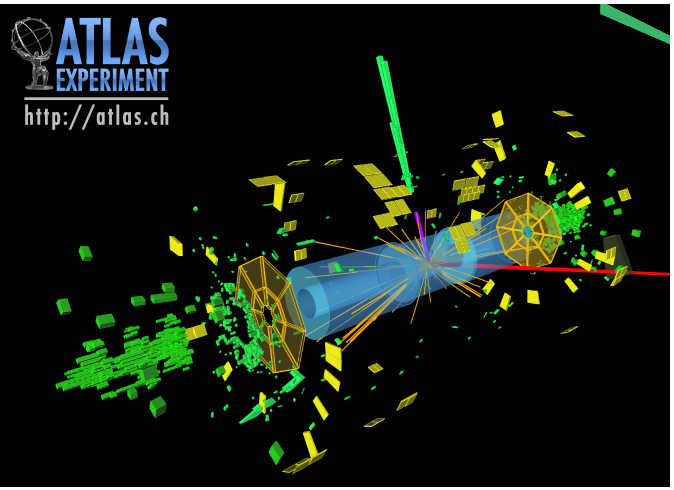
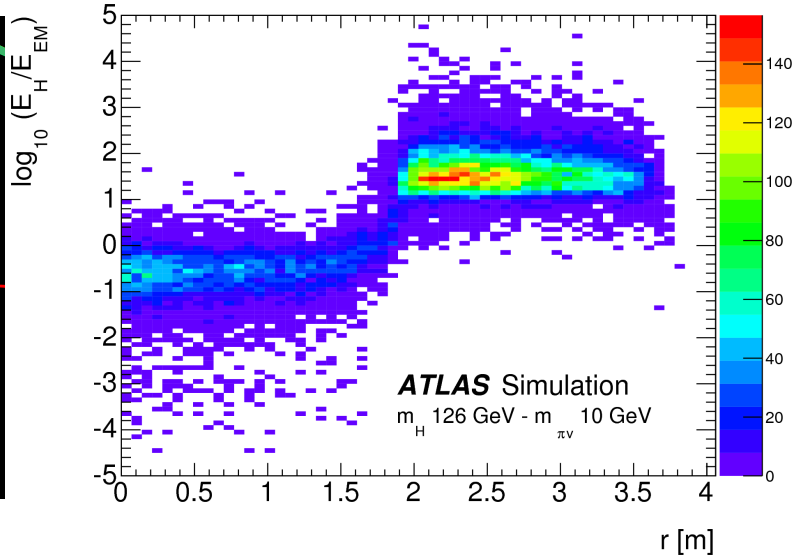
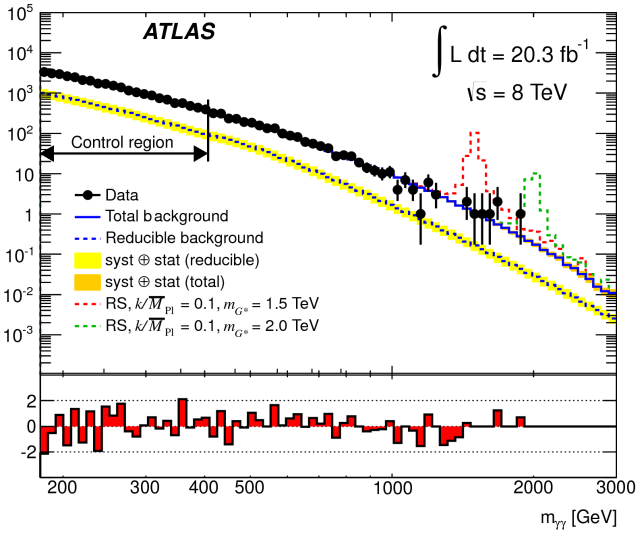
ATLAS Exotics Results & MC Generation Overview

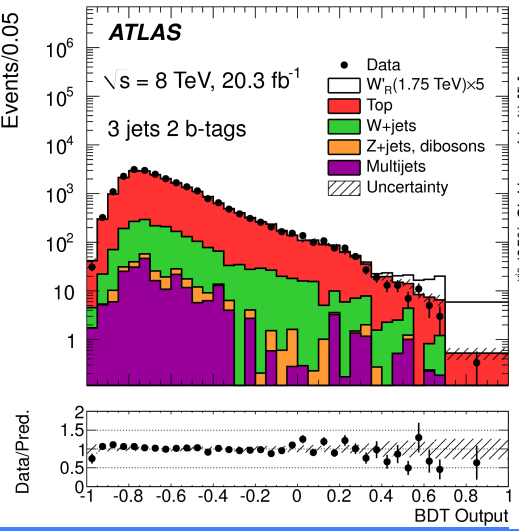


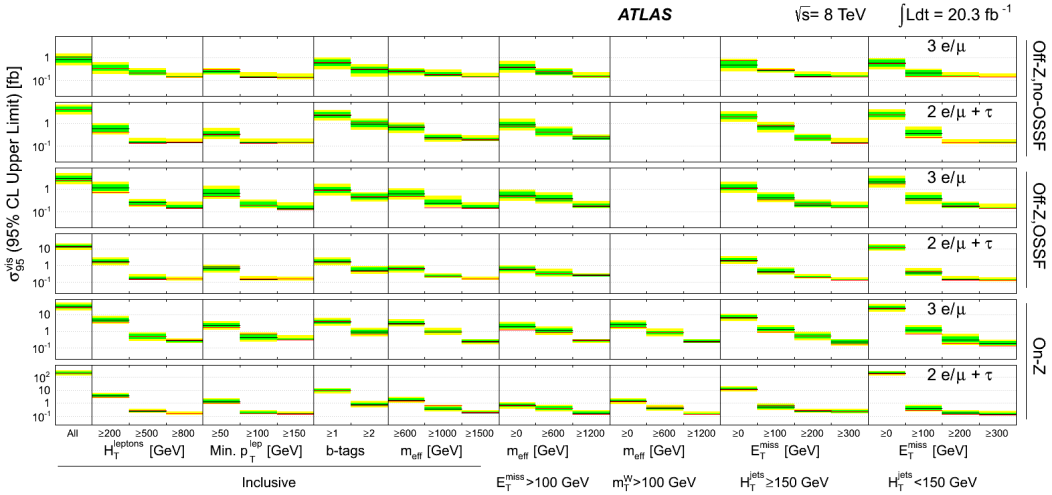


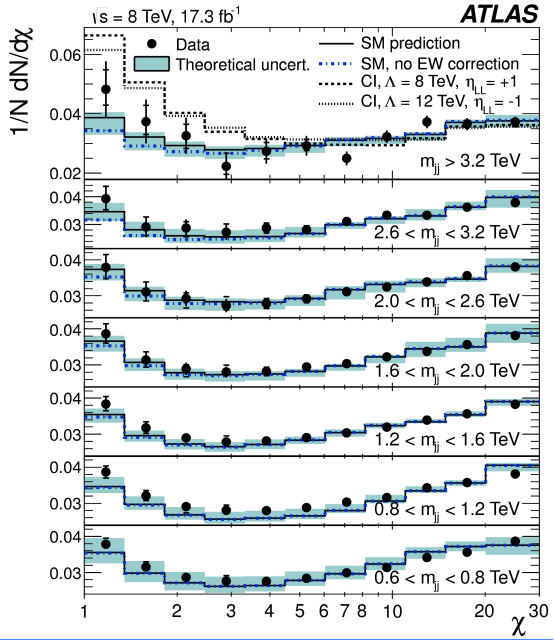


Stéphane Willocq (U. Massachusetts)
On behalf of ATLAS Collaboration

MC4BSM @ Fermilab
18-20 May 2015





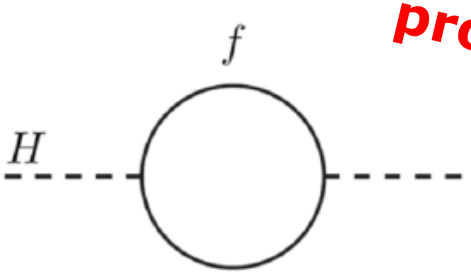


Beyond the Standard Model

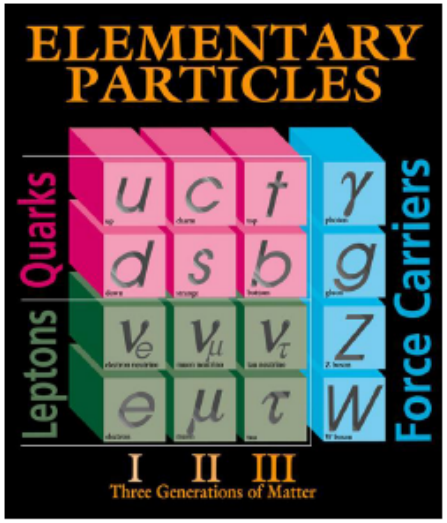
- **Many unanswered questions**
  - **Hierarchy between Electroweak scale and Planck scale**
    - **Lower Planck scale with extra spatial dimensions?**
  - **Discovery of light Higgs boson**
    → why so light?
    - **SUSY or vector-like (top) quarks?**
    - **New interactions / particles at TeV scale?**

    → Fundamental or composite Higgs?

Naturalness problem

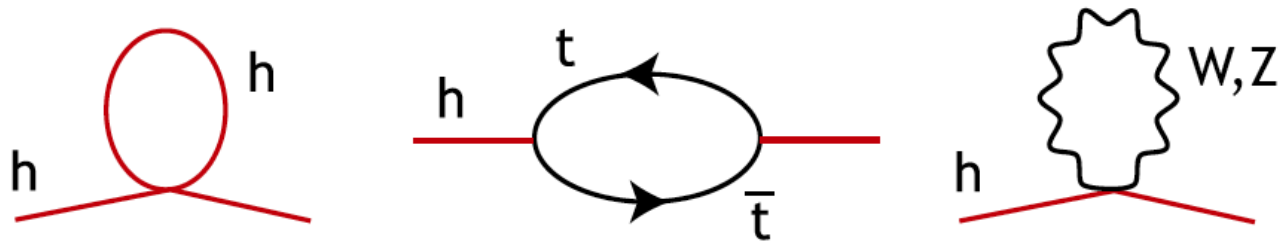


  - **Unification of forces, are there other fundamental forces?**
    Do GUTs exist?
  - **Flavor puzzle**
    Why 3 generations? Lepto(n)-quark symmetry?
    Composite leptons and quarks?
    Pattern of fermion masses and mixing?
  - **Matter-antimatter asymmetry / baryogenesis**
  - **Dark matter opportunity**



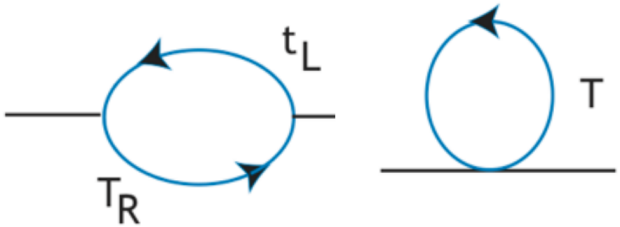
Hierarchy / Naturalness Problem

- **Electroweak Symmetry Breaking**
  - **Quadratic divergences in the Higgs mass**



M. Peskin

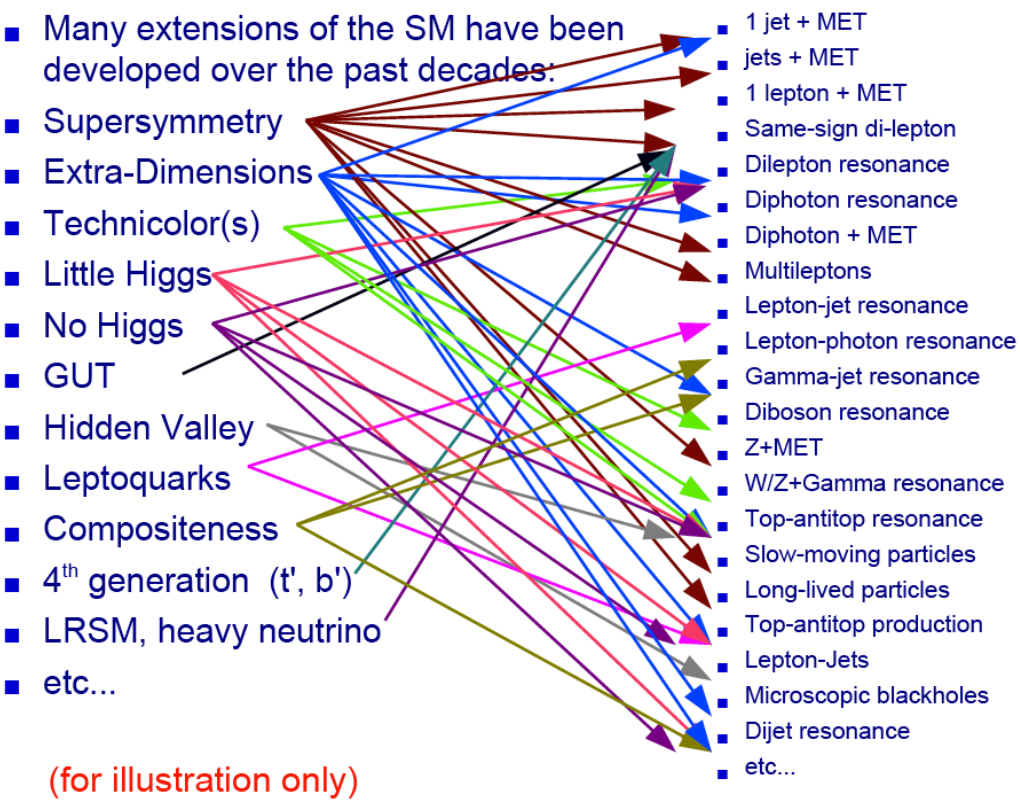
  - **Addressed by invoking additional symmetry**
    - **Supersymmetry → SUSY**
    - **Global symmetry → Little Higgs**
    - **Extra dimensions / Strong dynamics**
- **Solutions imply new particles at ~ TeV scale to avoid large amount of fine tuning**
  - **Search for fermionic top quark partners → vector like T quarks**
  - **Search for new heavy W, Z, γ, g → e.g. KK excitations in warped ED models**



Exotics Matrix

- **Many different experimental signatures are studied**
- **Important to cast a wide net**
- **Each signature provides a different window into the high energy regime at the LHC**
- **Exotics search program attempts to be both agnostic and focused on model hot spots**

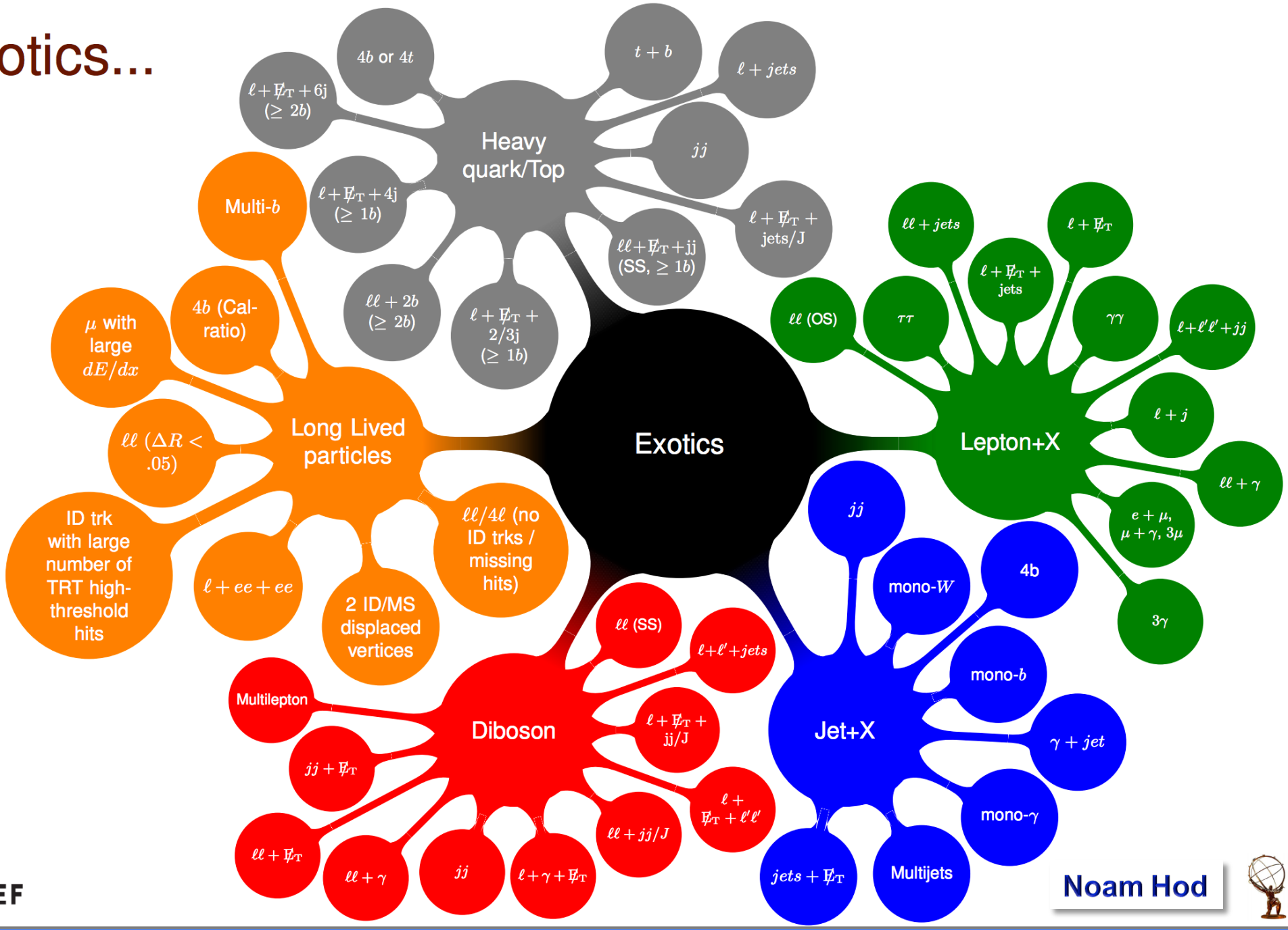
→ recent highlights shown



(for illustration only)

Signatures / Subgroups

Exotics...



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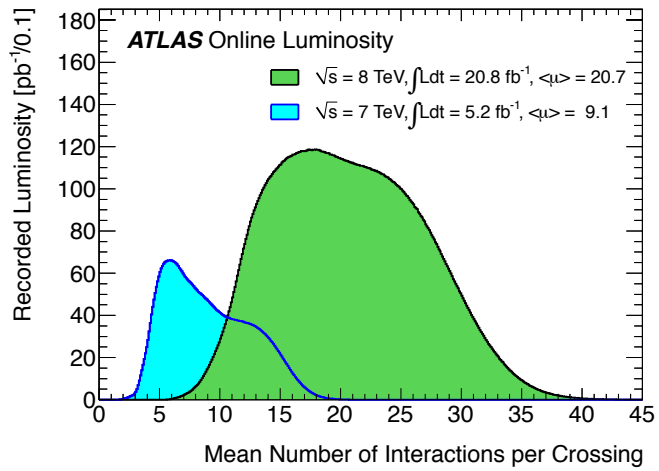
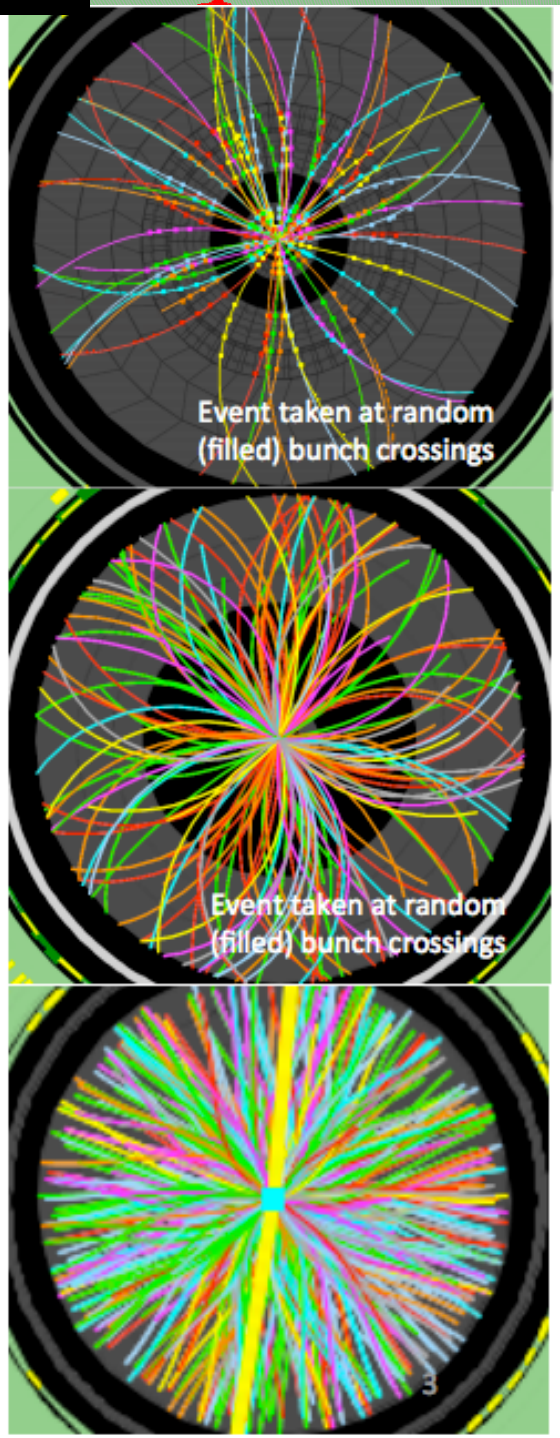
Exotics Analysis Challenges

- **High LHC luminosity**
  - Increased pileup
  - Higher trigger thresholds or including isolation

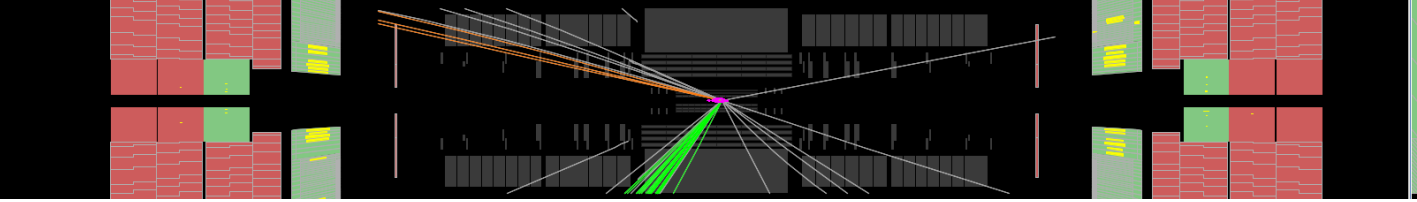


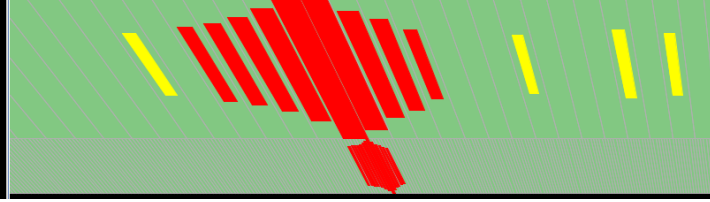
- **Physics objects**
  - **Search for high-mass new states**
    - ➔ high-pT decay products
    - ➔ limited statistics for calibration → extrapolate
  - **New techniques developed for boosted objects**
    - Jet substructure (tagging of b, t, W, Z, H jets)
    - Dilepton isolation
  - **Unconventional signatures**
    - Displaced vertices
    - Lepton-jets
    - Highly-ionizing particles



Event Generators for Searches

- **Event generators for signal processes**
  - CalcHep, MadGraph5, Pythia8, Sherpa
  - BlackMax, Charybdis, Herwig, HVMC, QBH, Protos
  - Re-weighting of background process with full cross section computation in some cases (instead of using signal event generator)
    → reduces number of signal MC samples to be produced
- **Event generators for background processes**
  - Alpgen, Herwig(++), MC@NLO, Powheg, Pythia8, Sherpa
- **Parton distribution functions for signal processes**
  - MSTW2008LO, CTEQ6L1, CT10
- **Higher order corrections?**
  - Most models computed at leading order
  - Cross sections adjusted to NLO or NNLO when available (mostly for background processes)
  - Some with K-factors computed with other tools (e.g. FEWZ) and applied as a function of kinematical variables (e.g. mass)





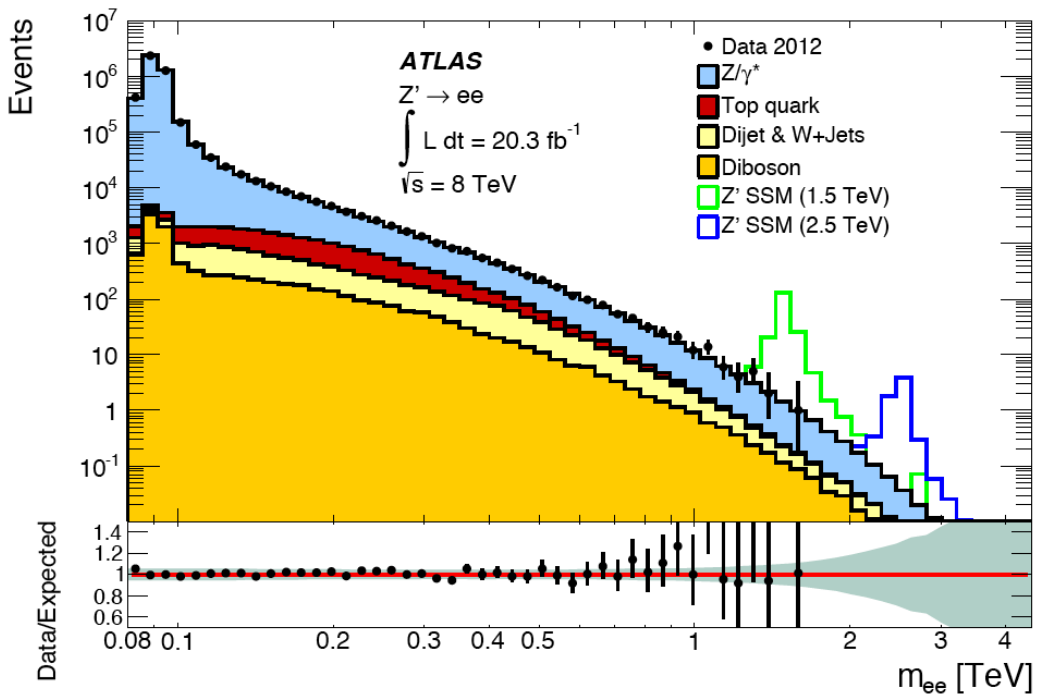
Heavy Resonances

Dielectron & Dimuon Resonances

arXiv: 1405.4123

- **Many extensions of the SM predict new resonances**
  - **Heavy gauge bosons W' and Z' from additional symmetries**
  - **KK excitations of vector bosons**
- **Clean decay channels**

  $Z' \rightarrow e^+e^-$ or $\mu^+\mu^-$



Main event generators / PDF sets	
signal	background
Z': Pythia 8 / MSTW2008LO	**DY**: Powheg+Pythia 8 / CT10 HOC: FEWZ / MSTW2008NNLO
Z*: CalcHEP / MSTW2008LO	**tt, Wt**: MC@NLO+Herwig / CT10
G_{KK}: Pythia 8 / CTEQ6L	**Diboson**: Herwig++ + Herwig / CTEQ6L1

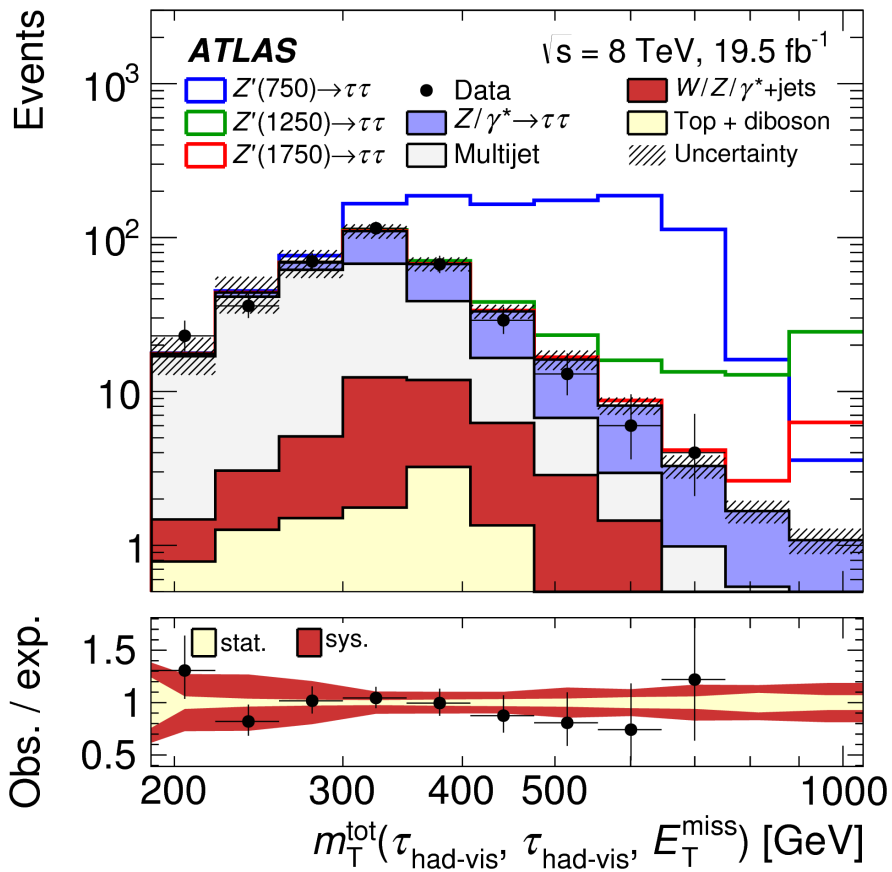
Model	Width [%]	Observed Limit [TeV]	Expected Limit [TeV]
Z'_{SSM}	3.0	2.90	2.87
Z'_{χ}	1.2	2.62	2.60
Z'_{ψ}	0.5	2.51	2.46
Z^*	3.4	2.85	2.82

- **Higher order corrections (HOC) include QCD, EW and photon-induced ($\gamma\gamma \rightarrow ll$) effects**

Ditau Resonances

arXiv: 1502.07177

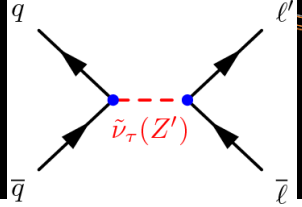
- **Heavy gauge bosons with non-universal coupling to 3rd gen fermions**
- **$Z' \rightarrow \tau^+\tau^-$ τ reco with leptonic decays / 1- or 3-prong hadronic decays**



Main event generators / PDF sets	
signal	background
Z': Pythia 8 DY reweighted w/ TauSpinner	**DY**: Pythia 8 / CTEQ6L1 HOC: FEWZ / MSTW2008NNLO
	tt, Wt: MC@NLO+Herwig / CT10
	Diboson: Herwig++ + Herwig / CTEQ6L1

Model / 95% CL lower mass limits	
Z' SSM	2.02 TeV
G(221)	1.3—2.1 TeV

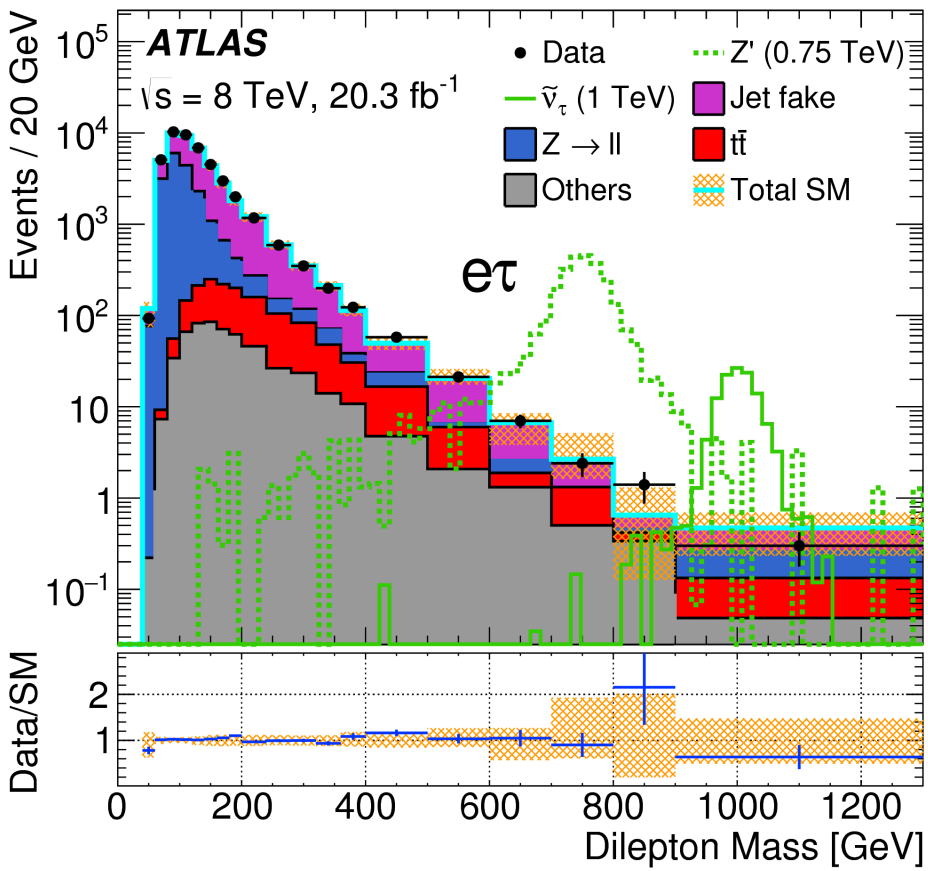
- **Pythia8 DY @ LO reweighted for various signals**
- **TauSpinner correctly accounts for spin effects in tau decays**
- **Higher order corrections (HOC) include QCD, EW effects**



LFV Leptonic Resonances

arXiv: 1503.04430

- **Heavy gauge bosons/RPV SUSY scalars with lepton-flavor violating coupling**
- **Z' → eμ, eτ, μτ τ reco with 1-prong hadronic decays**

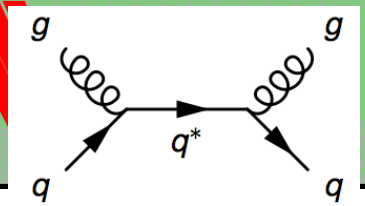


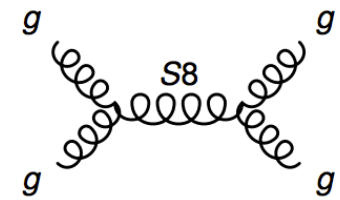
Main event generators / PDF sets	
signal	background
Z': Pythia 8 / MSTW2008LO	**DY**: Alpgen / CTEQ6L1
$\tilde{\nu}_\tau$: Herwig	**tt, Wt**: MC@NLO+Herwig / CT10
	Diboson: Herwig / CTEQ6L1

Model / 95% CL lower mass limits [TeV]	eμ	eτ	μτ
Z' SSM	2.0	1.7	1.7
$\tilde{\nu}_\tau$ RPV SUSY	2.5	2.2	2.2

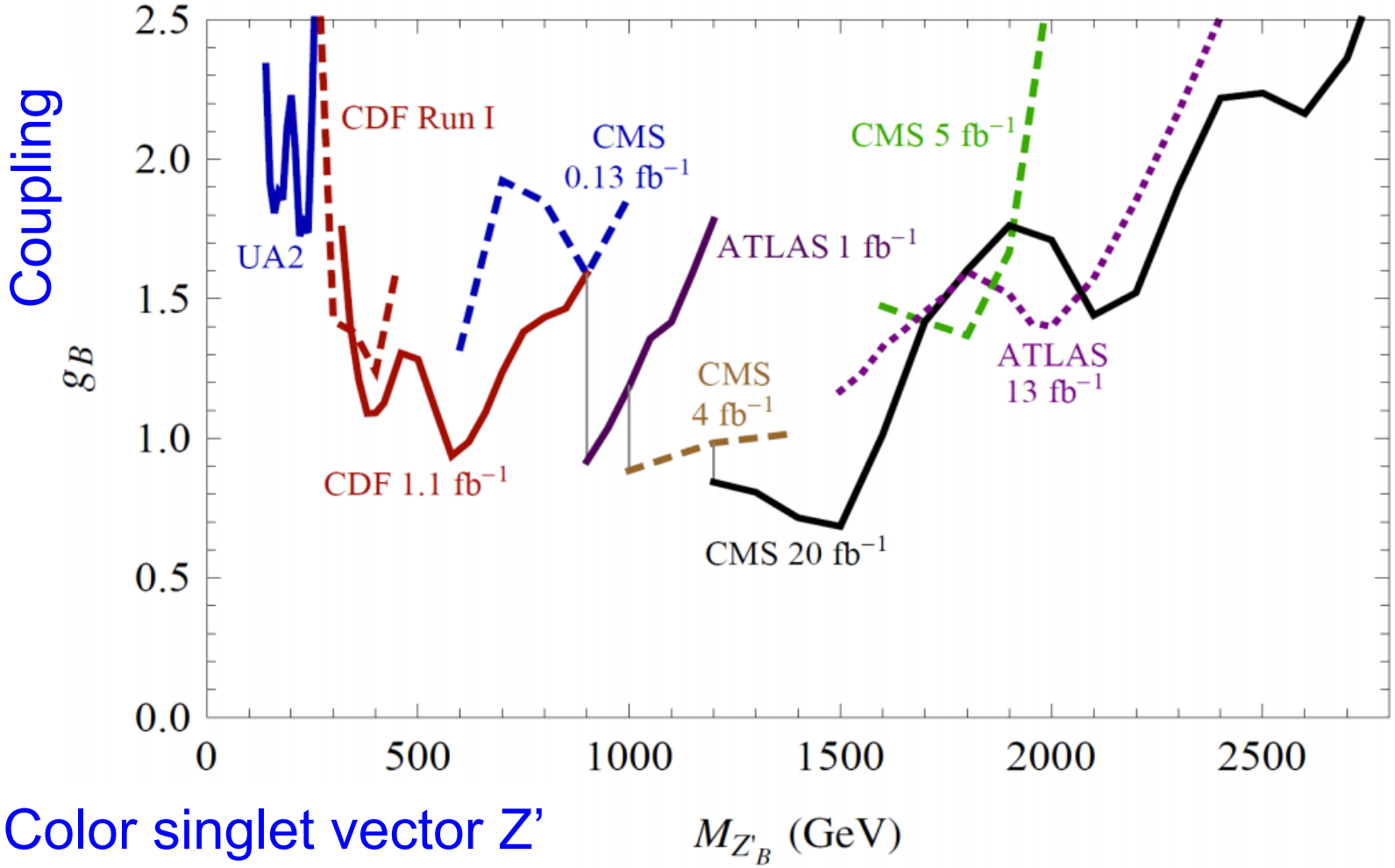
- **W+jets and multijet background estimated from data control regions**

Dijet Resonances





- **Dijet resonances :** resonance → q q, q g, gg
  - **B. Dobrescu and F. Yu, arXiv:1306.2629**



Color singlet vector Z'

Trigger limitation: thresholds rising with sqrt(s) & lumi
→ need to also push sensitivity at lower resonance mass

Dijet Resonances

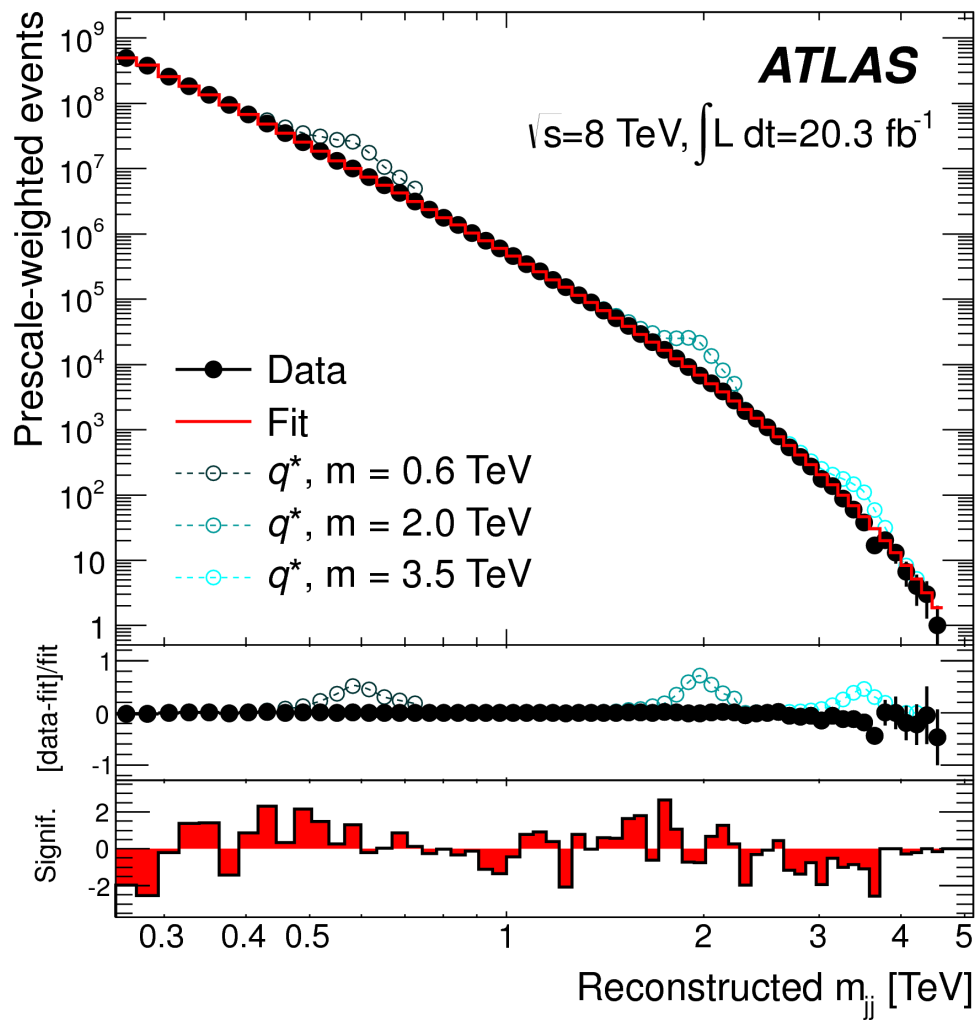
arXiv:1407.1376

- **Extend search to masses below mass of 1 TeV with 8 TeV data**
  - **Add delayed stream + prescaled triggers**
- **Bump hunting**
  - **Background does not rely on MC → Fit mass spectrum with func.**

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

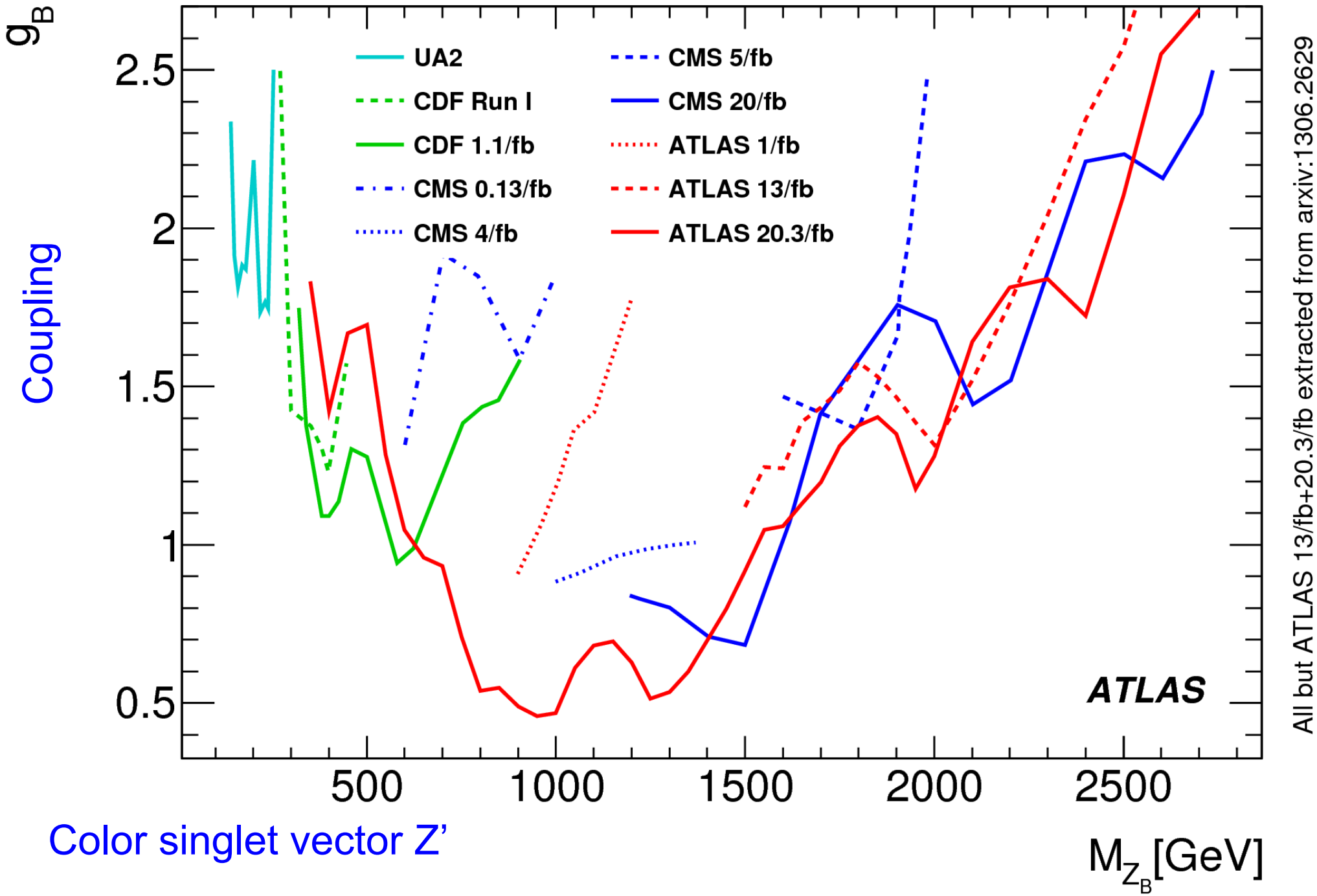
$$x \equiv m_{jj}/\sqrt{s}$$

Model and Final State	95% CL Limits [TeV] Expected	Observed
$q^* \to qg$	3.99	4.09
$s8 \to gg$	2.83	2.72
$W' \to q\bar{q}'$	2.51	2.45
Leptophobic $W^* \to q\bar{q}'$	1.93	1.75
Leptophilic $W^* \to q\bar{q}'$	1.67	1.66
QBH black holes (q and g decays only)	5.82	5.82
BLACKMAX black holes (all decays)	5.75	5.75

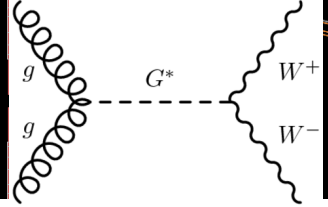


Global Analysis of Dijet Searches

arXiv:1407.1376

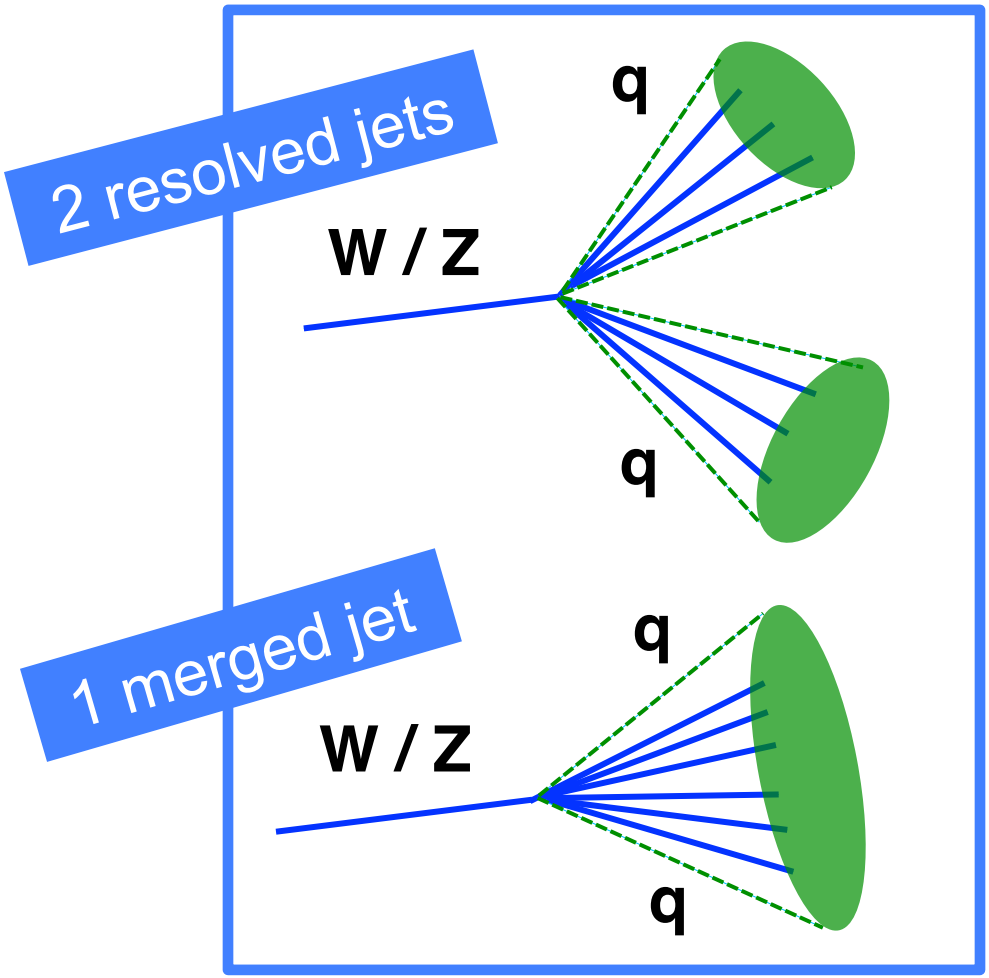


Color singlet vector Z'



Diboson (VV) Resonances

- **Heavy gauge bosons, extra dimensions, composite Higgs**
  - **VV final state with V =** W → qq, eν, μν **or** Z → qq, ee, μμ
  - **Jets from V → qq become merged for high-mass resonances**

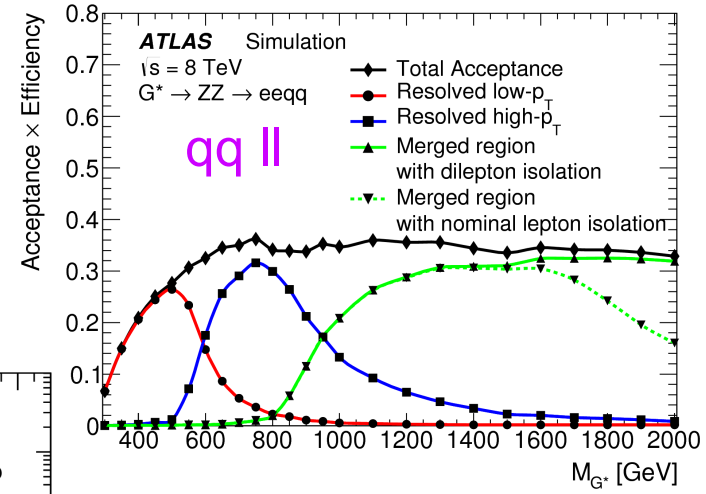


- **$\Delta R \approx 2\ M / p_T$**
  ➔ $\Delta R < 0.4$ if p_T (W) > 400 GeV
- **Use large-R jet**
- **Apply substructure techniques to mitigate impact of pileup and identify hard sub-jets**

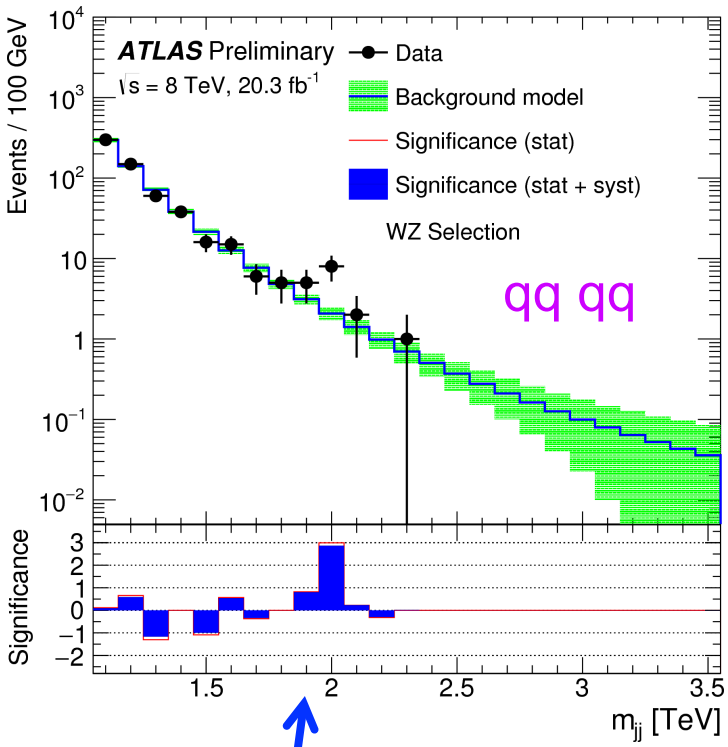
Main event generators / PDF sets	
signal	background
W': Pythia 8 / MSTW2008LO scale to NNLO w/ ZWPROD	**W/Z+jets**: Sherpa / CT10 massive b and c
G_{KK}: CalcHEP / CTEQ6L1	**tt, Wt**: MC@NLO+Herwig / CT10
	Diboson: Herwig / CTEQ6L1

Diboson (VV) Resonances

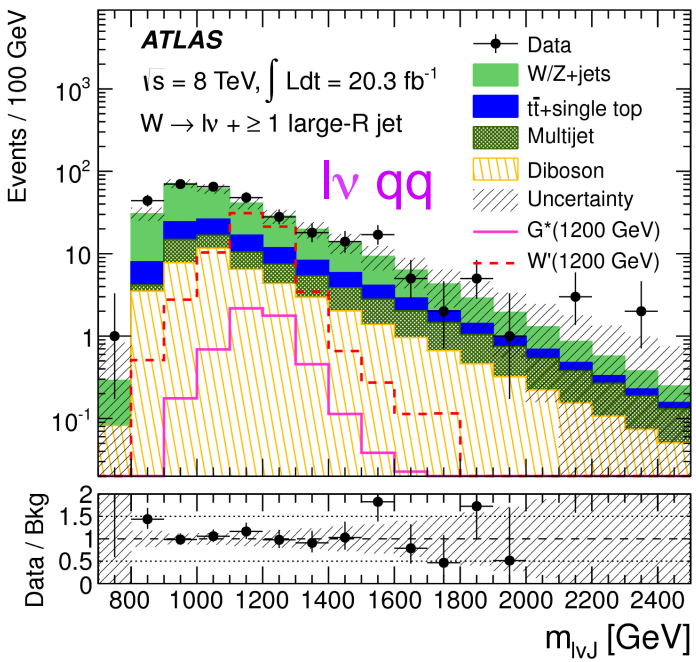
- **Analyses optimized separately for resolved and merged regions**
- **High-p_T boson ➔ relax lepton isolation for Z → ll**
- **Background model: smooth analytical function or smoothed background MC**



arXiv:1409.6190



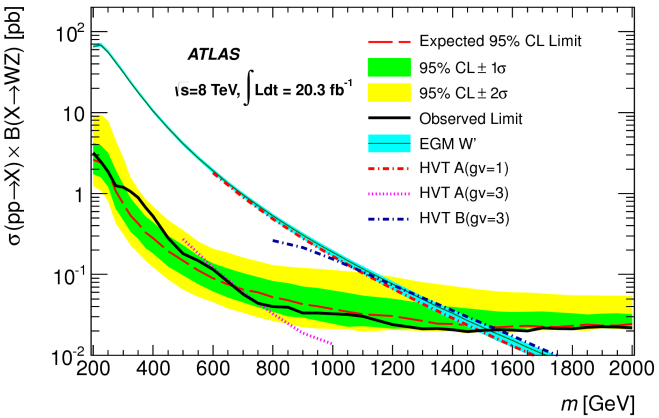
arXiv:1503.04677



- **Data excess in qq qq channel near M = 2 TeV: Global significance = 2.5 sigmas**

arXiv:1406.4456

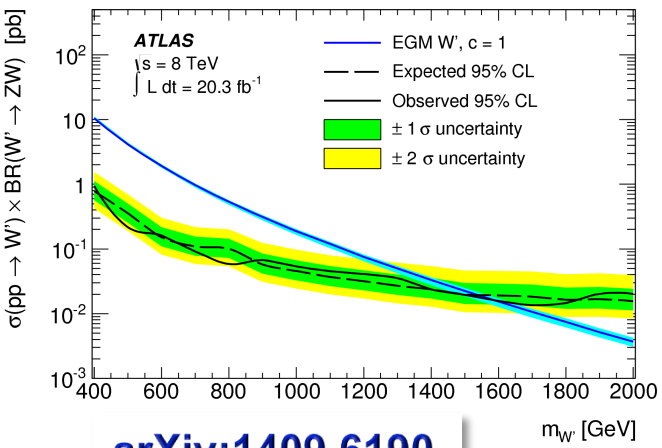
Diboson (VV) Resonances

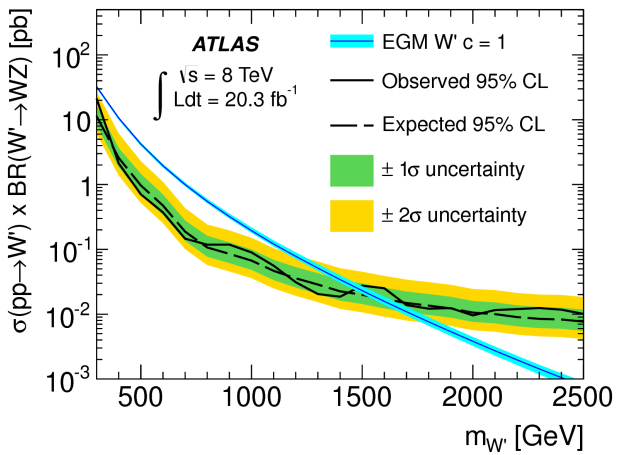


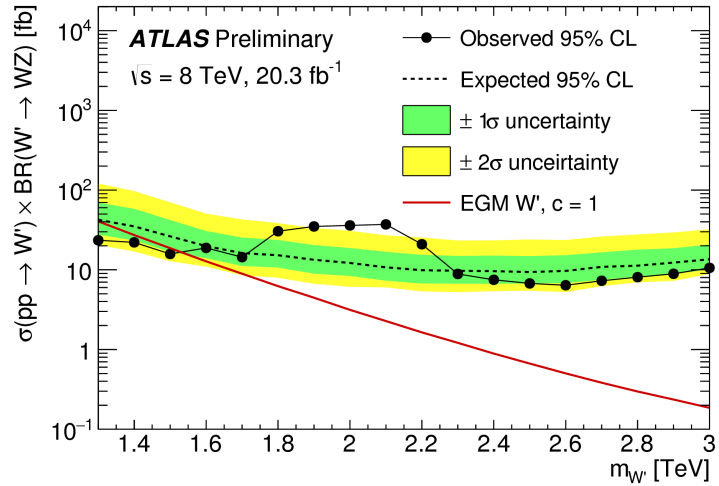
Most sensitive at low, intermediate, high mass: lν ll, qq ll & lν qq, qq qq

Model / 95% CL lower mass limits [TeV]	lν ll	qq ll	lν qq	qq qq
W′ EGM	1.52	1.59	1.49	1.5
G_{KK} Bulk RS	—	0.74	0.70	—

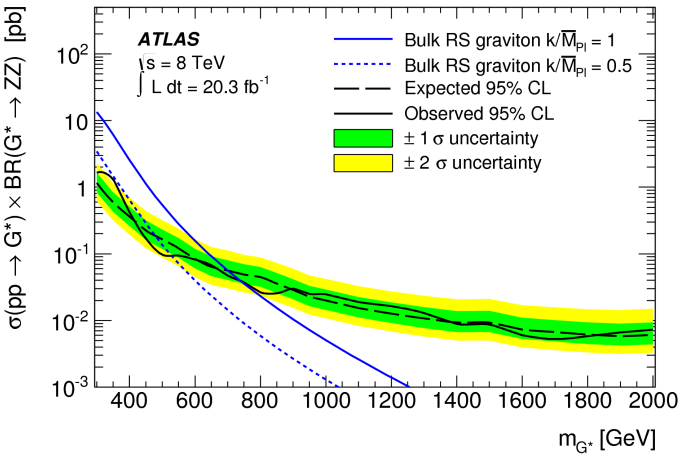
arXiv:1503.04677

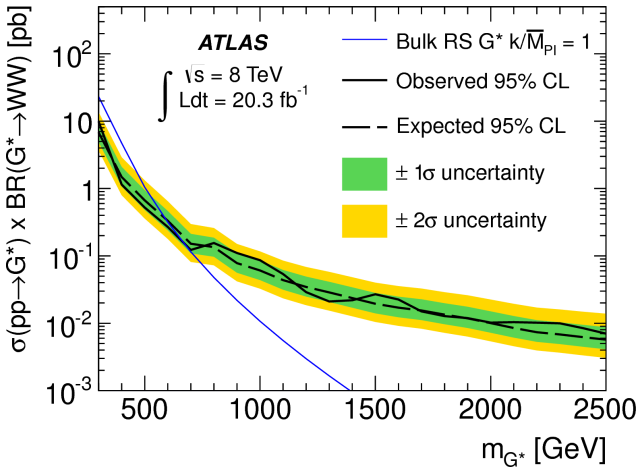


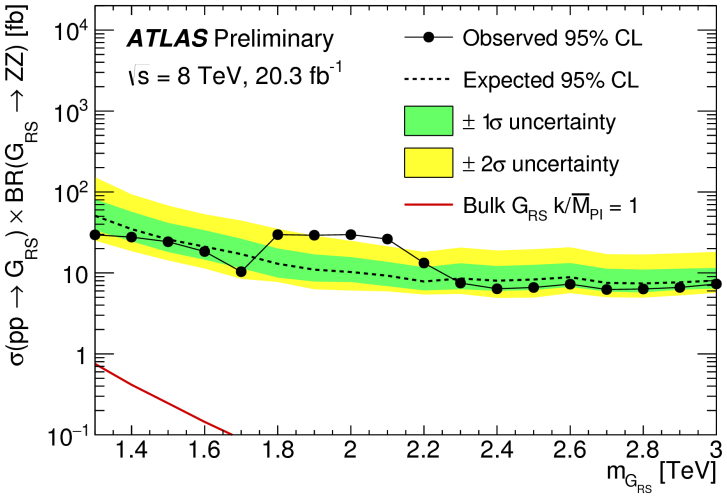




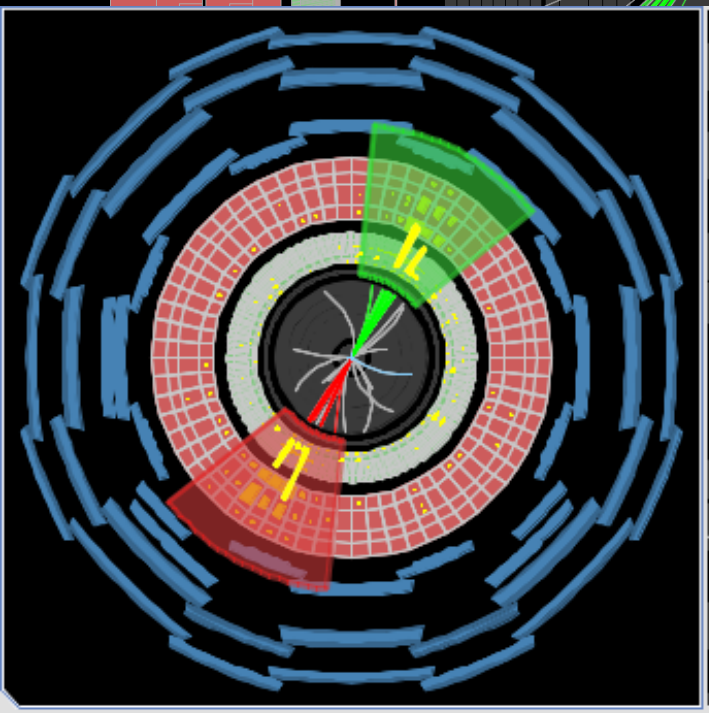
arXiv:1409.6190

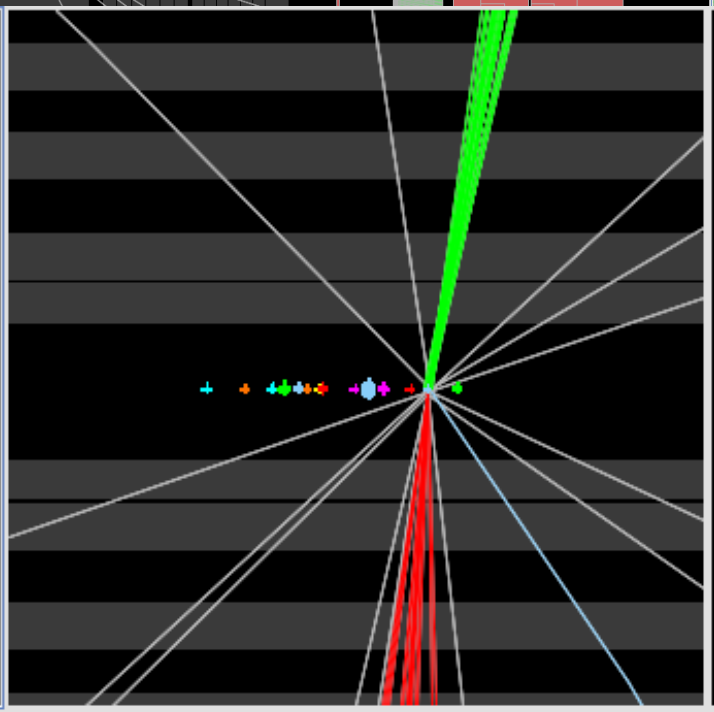






Diboson (VV) Resonances



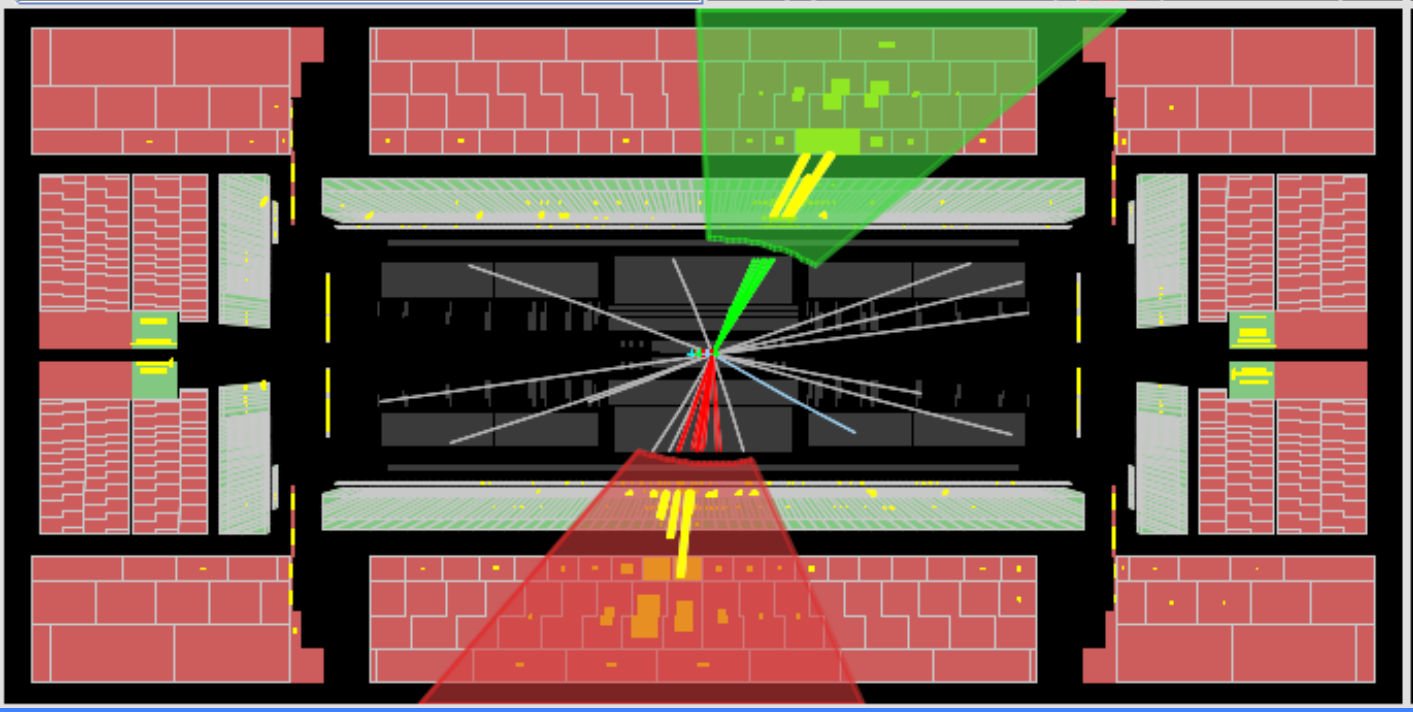


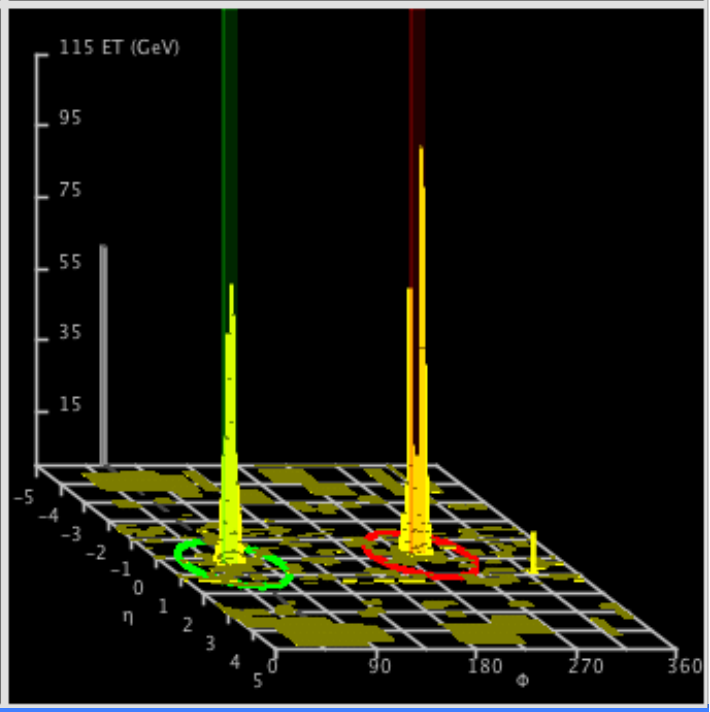
ATLAS EXPERIMENT

Run Number: 207749, Event Number: 36414089

Date: 2012-07-31 01:30:57 CEST

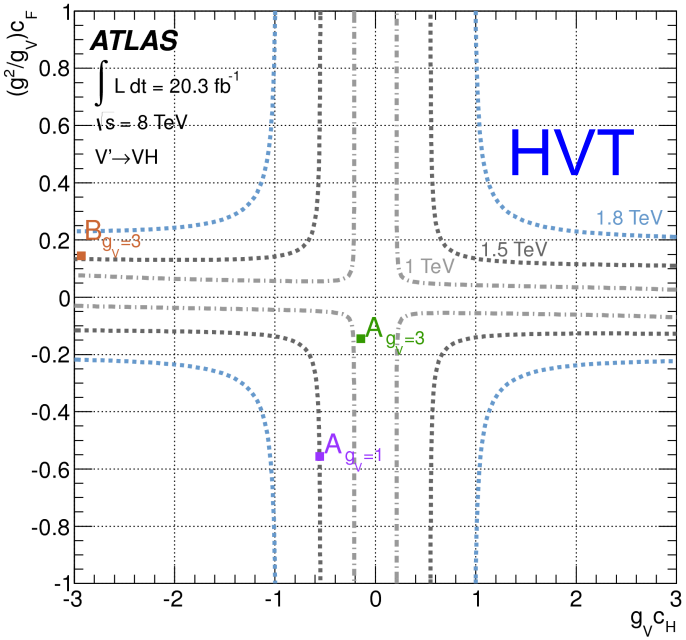
Jet p_T = 1.1 and 1.1 TeV
Jet m = 104 GeV and 71 GeV
Dijet m = 2.26 TeV



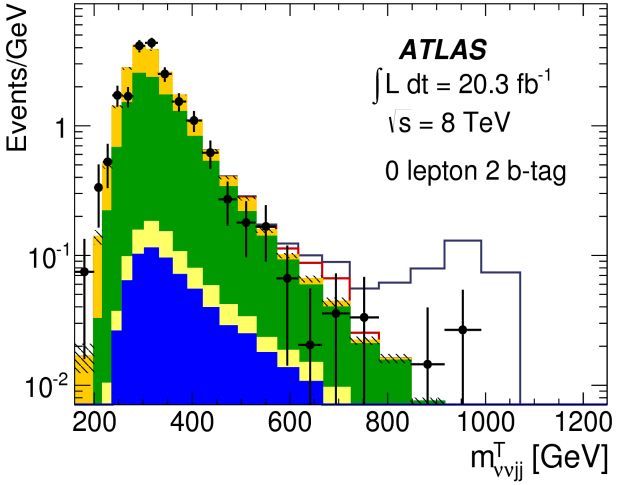


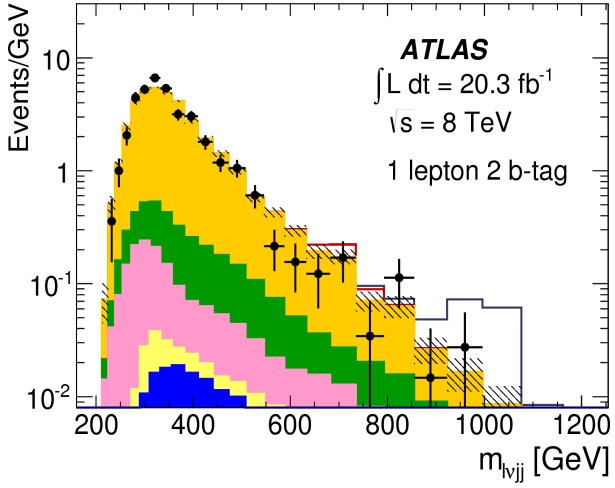
Diboson (VH or HH) Resonances

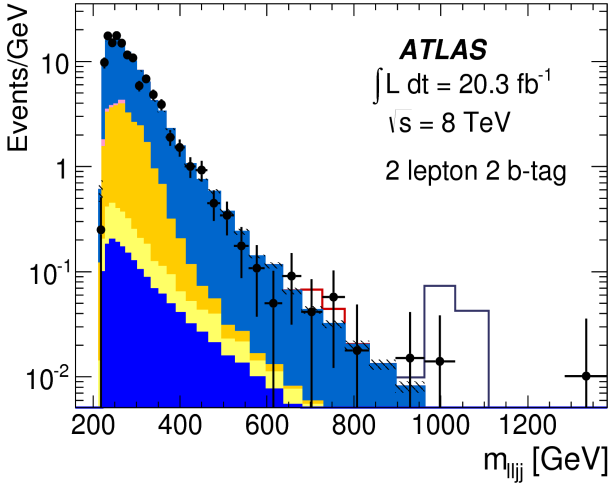
- **Extended scalar sector, extra dimensions, composite Higgs**
- **Higgs boson as a discovery tool**
  - **Exploit large BR for H → bb (57%)**
- **VH analysis: vv / lv / ll + bb**
  - **Signal (MWT, HVT) with MadGraph5 + Pythia8**
  - **Categories: 0, 1, 2 leptons & 1 or 2 b-tags**



arXiv:1503.08089

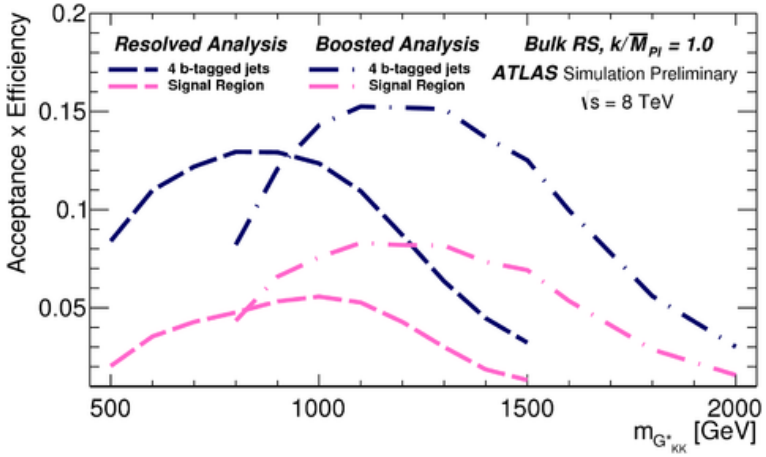


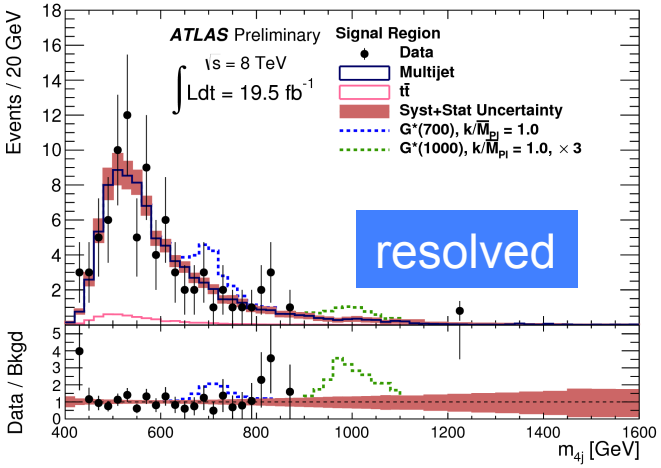




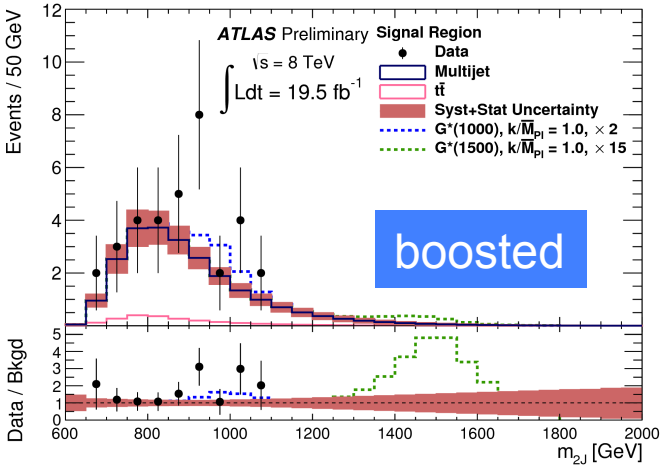
Diboson (VH or HH) Resonances

- **HH analysis: Jet substructure for boosted H → bb + b-tagging on smaller-R track jets**
  - **Resolved: 4 b-tagged R=0.4 calo jets**
  - **Boosted: 2 R=1.0 calo jets with 2 b-tagged R=0.3 track jets associated with each**
  - **Signal MC: Bulk RS G_{KK} → hh**
    2HDM H → hh
    MadGraph5 + Pythia8

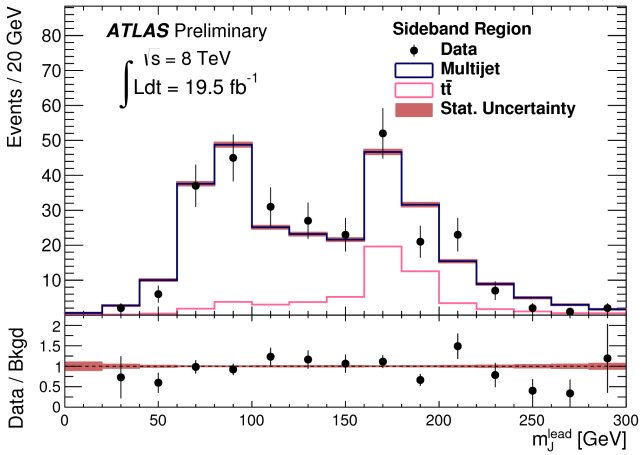




m_{4j}



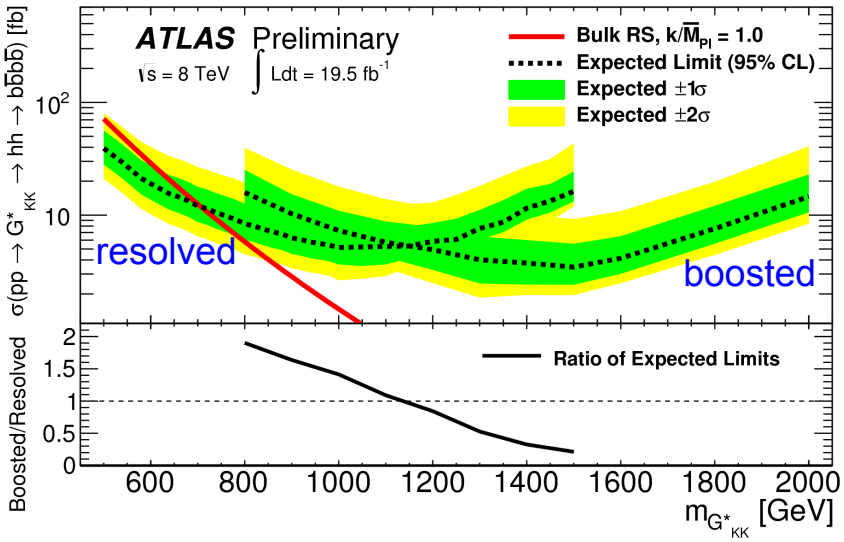
m_{2J}

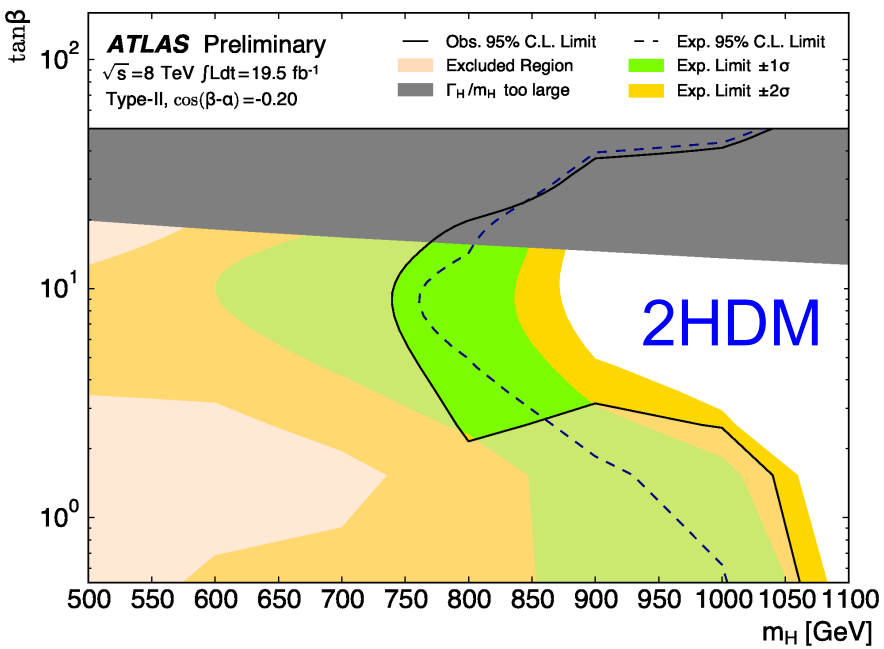


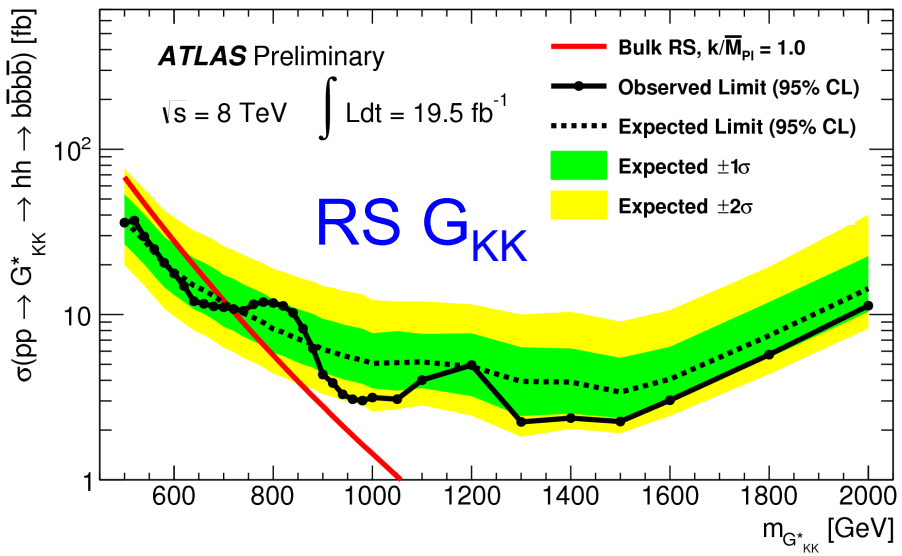
m_J

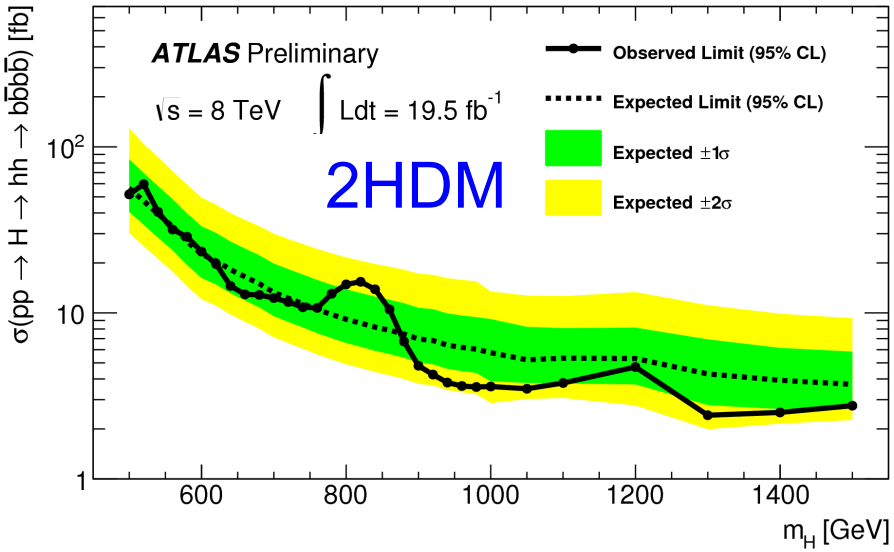
Diboson (VH or HH) Resonances

- **HH → 4b analysis:**

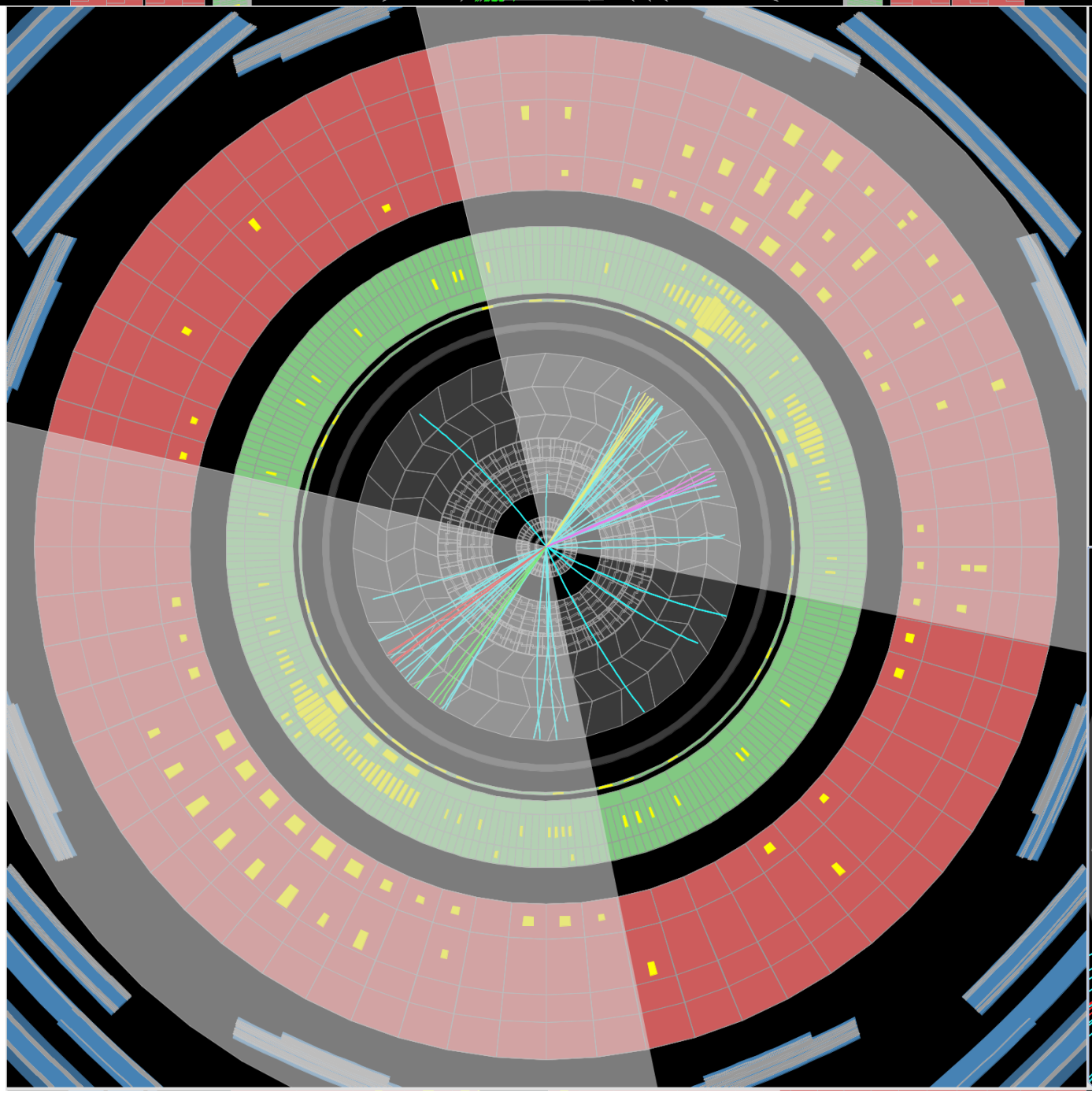








HH → 4b Candidate Event



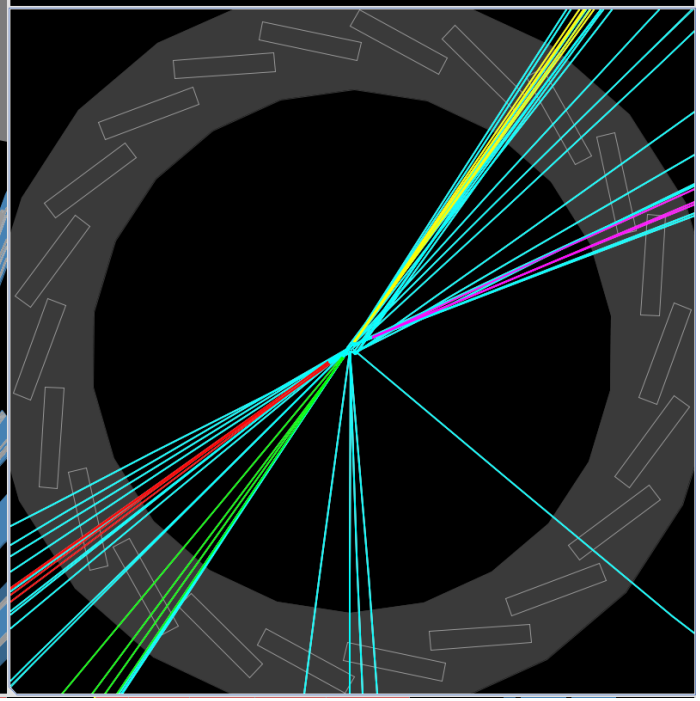
ATLAS EXPERIMENT

Run Number: 214216, Event Number: 127778116

Date: 2012-11-09 05:37:12 CET

Jet p_T = 0.45 and 0.44 TeV

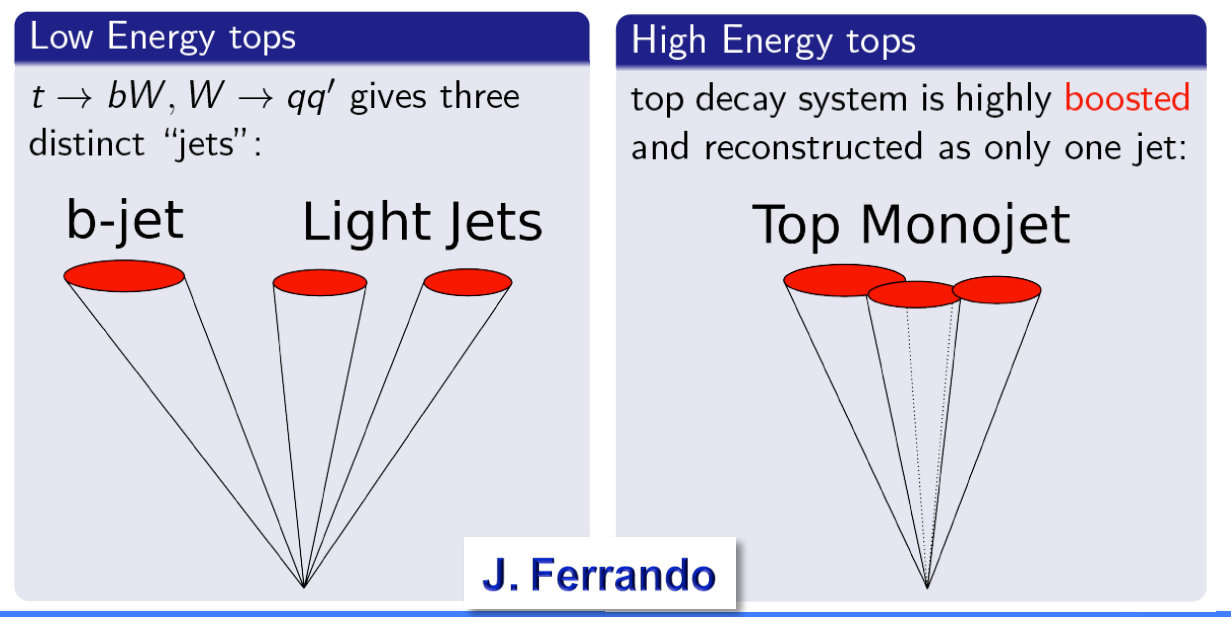
Dijet m = 1.03 TeV



$t\bar{t}$ Resonances

- **Models**
  - **H → $t\bar{t}$ in 2HDM**
  - **Z' → $t\bar{t}$ in Topcolor Z'**
  - **g_{KK} → $t\bar{t}$ in RS extra dimensions**
- **Channel $t\bar{t}$ → bW $\bar{b}$W → bqq $\bar{b}$lnu**
- **Selection**
  - **No b-tag required for hadronic top**
  - **Boosted t → bqq with jet substructure**
    - **Anti-kt jets with radius parameter R = 1.0**
    - **Require large jet mass and last kt splitting scale sqrt(d_{12}) > 40 GeV**
  - **Reconstruct m_{tt} with**
    - **Hadronic top**
    - **Lepton**
    - **$E_T$miss**
    - **anti-kt (R=0.4) jet nearest lepton**

Main event generators / PDF sets	
signal	background
g_{KK}: MadGraph5 + Pythia8 / MSTW2008LO	**W/Z+jets**: Alpgen + Pythia6 / CTEQ6L1
G_{KK}: MadGraph5 + Pythia8 / CTEQ6L1	**tt, Wt**: Powheg+Pythia6 / CT10 (hdamp = 172.5 GeV)
Z': Pythia8 / MSTW2008LO	**ttV**: MadGraph5 + Pythia6
ϕ: MadGraph aMC@NLO / CTEQ6L1	**Diboson**: Sherpa / CT10

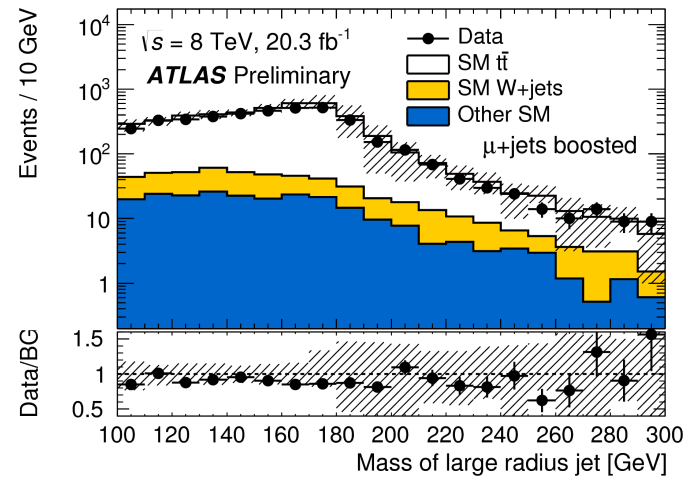


J. Ferrando

$t\bar{t}$ Resonances

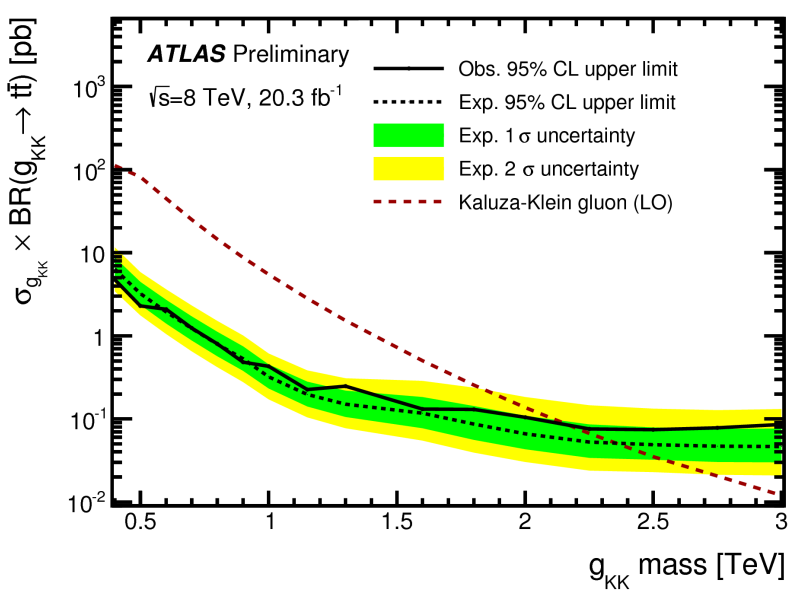
- **Boosted top selection optimized for high-mass $t\bar{t}$ pairs**
  → outperforms "standard" analysis

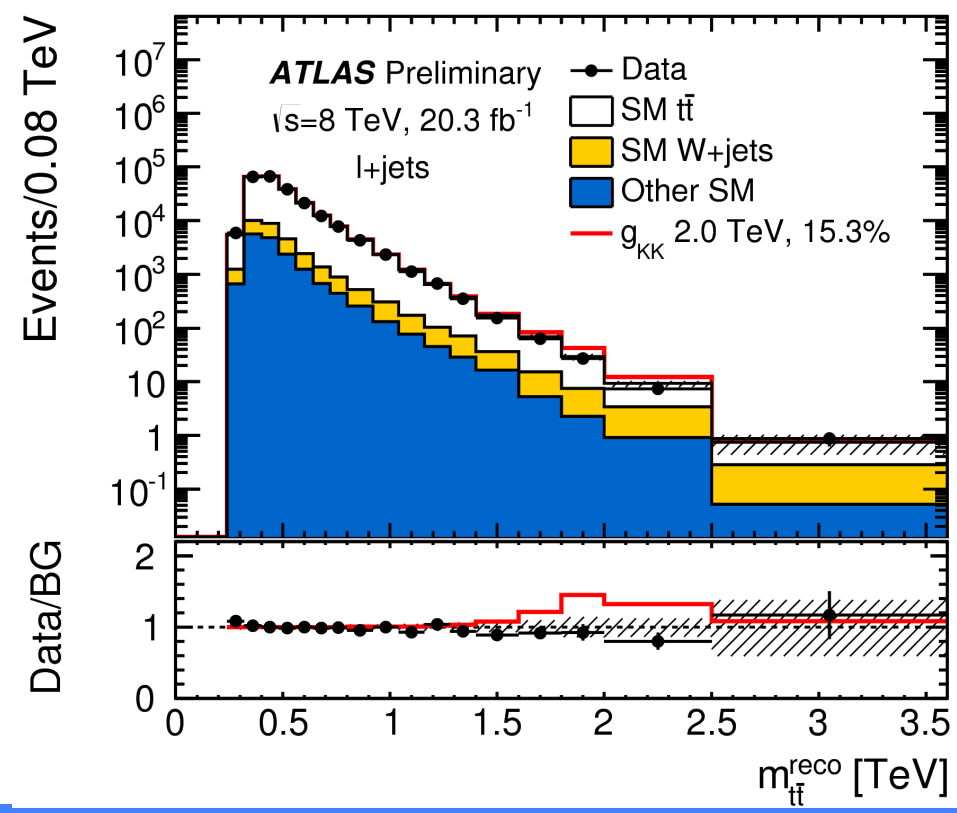
Model / 95% CL lower mass limits	
Topcolor Z'	1.8 TeV
RS KK gluon	2.2 TeV

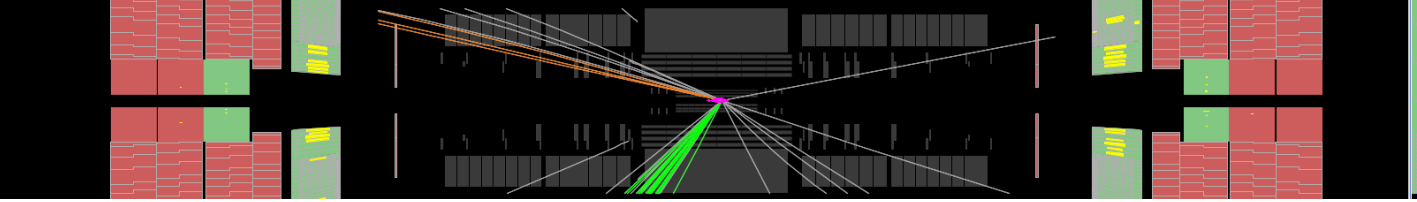


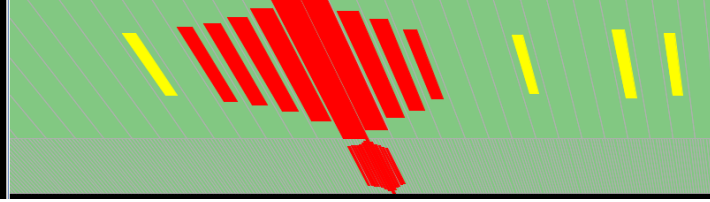
ATLAS-CONF-2015-009

Broader resonance Γ/M ~15%







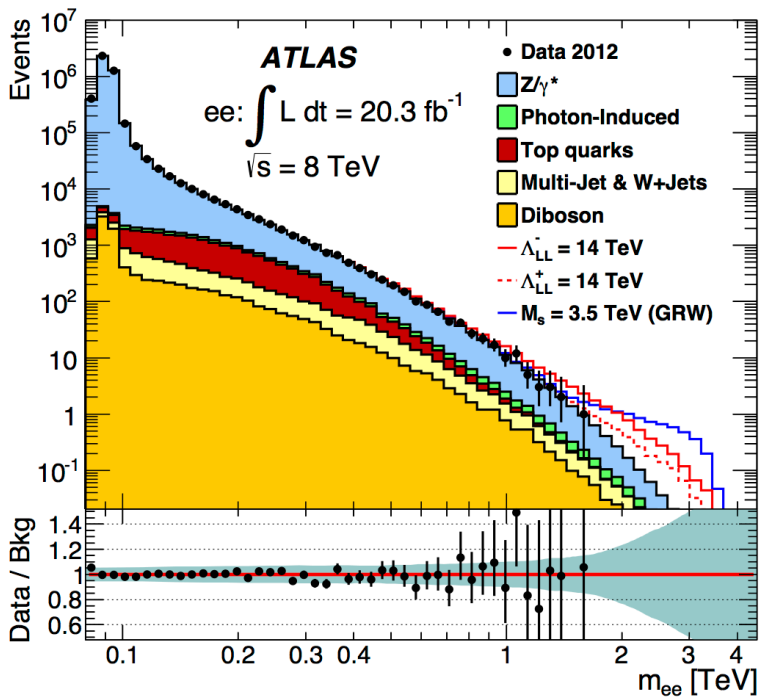


Non-resonant signatures

Non-resonant Dilepton

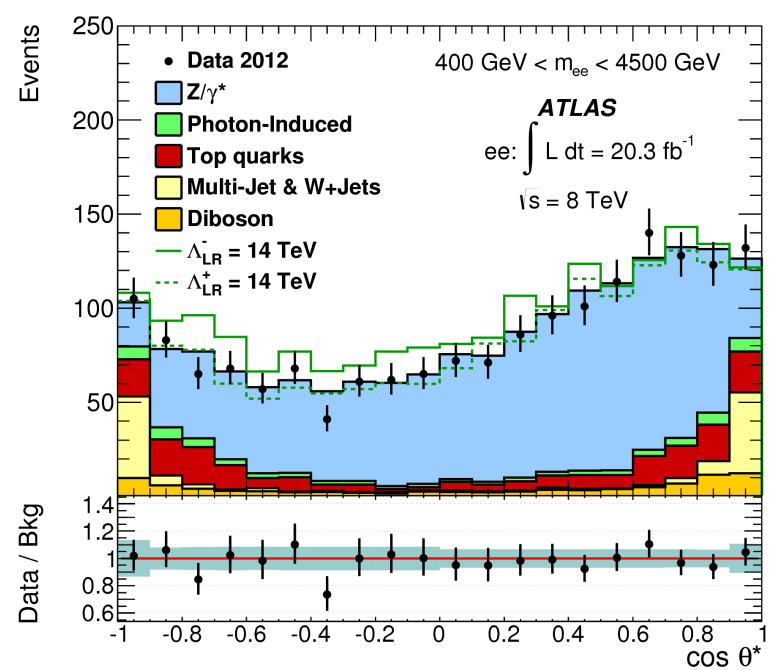
arXiv: 1407.2410

- e^+e^- or $\mu^+\mu^-$ interpretations
  - Contact interactions
  - ADD large extra dimensions
- **Note:** Change in default μ_F from m_{ll} to $p_T j$ in Sherpa ADD for pp → ll+1j matrix element had large impact on high-m XS



- **Photon-induced (γγ → ll) correction estimated with Pythia 8 / MRST2004qed**

Main event generators / PDF sets	
signal	background
CI: Pythia 8 / MSTW2008LO	**DY**: Powheg+Pythia 8 / CT10 HOC: FEWZ / MSTW2008NNLO
ADD: Sherpa / CTEQ6L1	**tt, Wt**: MC@NLO+Herwig / CT10
	Diboson: Herwig++ + Herwig / CTEQ6L1

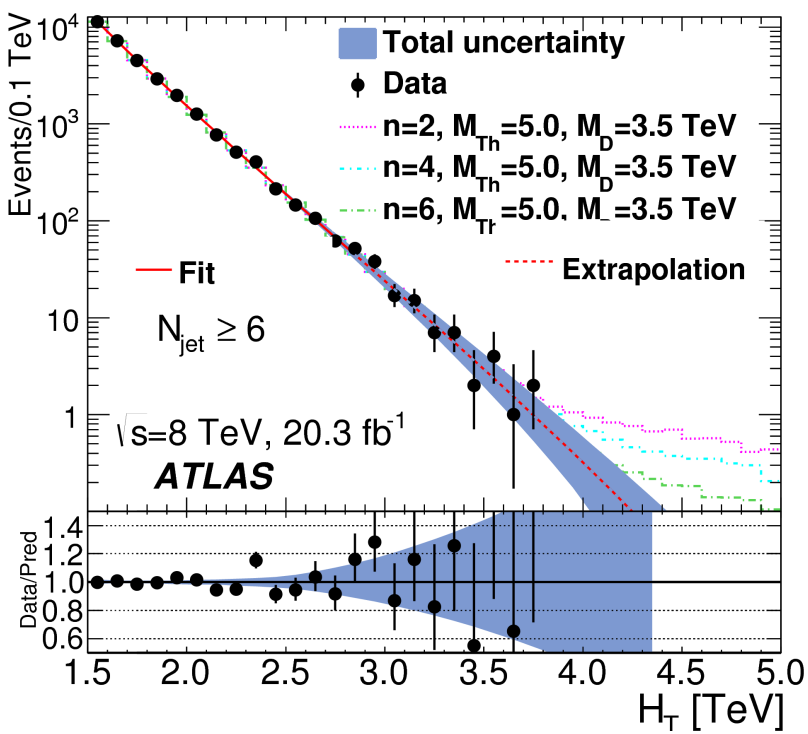


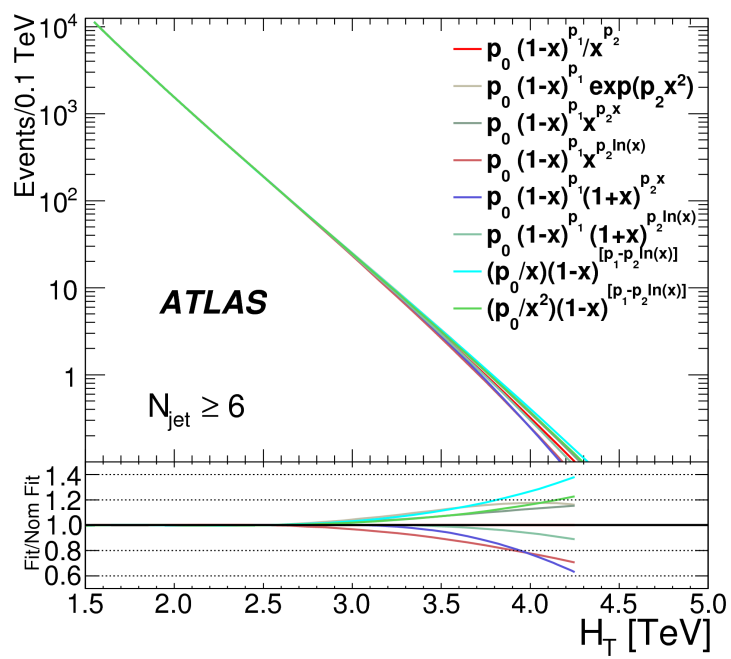
TeV Gravity

arXiv: 1503.08988

- **Extra dimensions**
  - **Black holes or string balls**
- **Multijet final state**
  - **Empirical fits to H_T distribution**
  - **Normalization: $1.5 < H_T < 2.9$ TeV**
  - **Tests with Pythia8, Herwig++, Alpgen**
  - **Many functional forms**

Main event generators / PDF sets	
signal	background
BH: Charybdis + Pythia8 / MSTW2008LO	**Multijet**: Pythia 8 / CT10
BH: BlackMax + Pythia8 / MSTW2008LO	**Multijet**: Herwig++ / CTEQ6L1
	Multijet: Alpgen + Pythia6 / CTEQ6L1



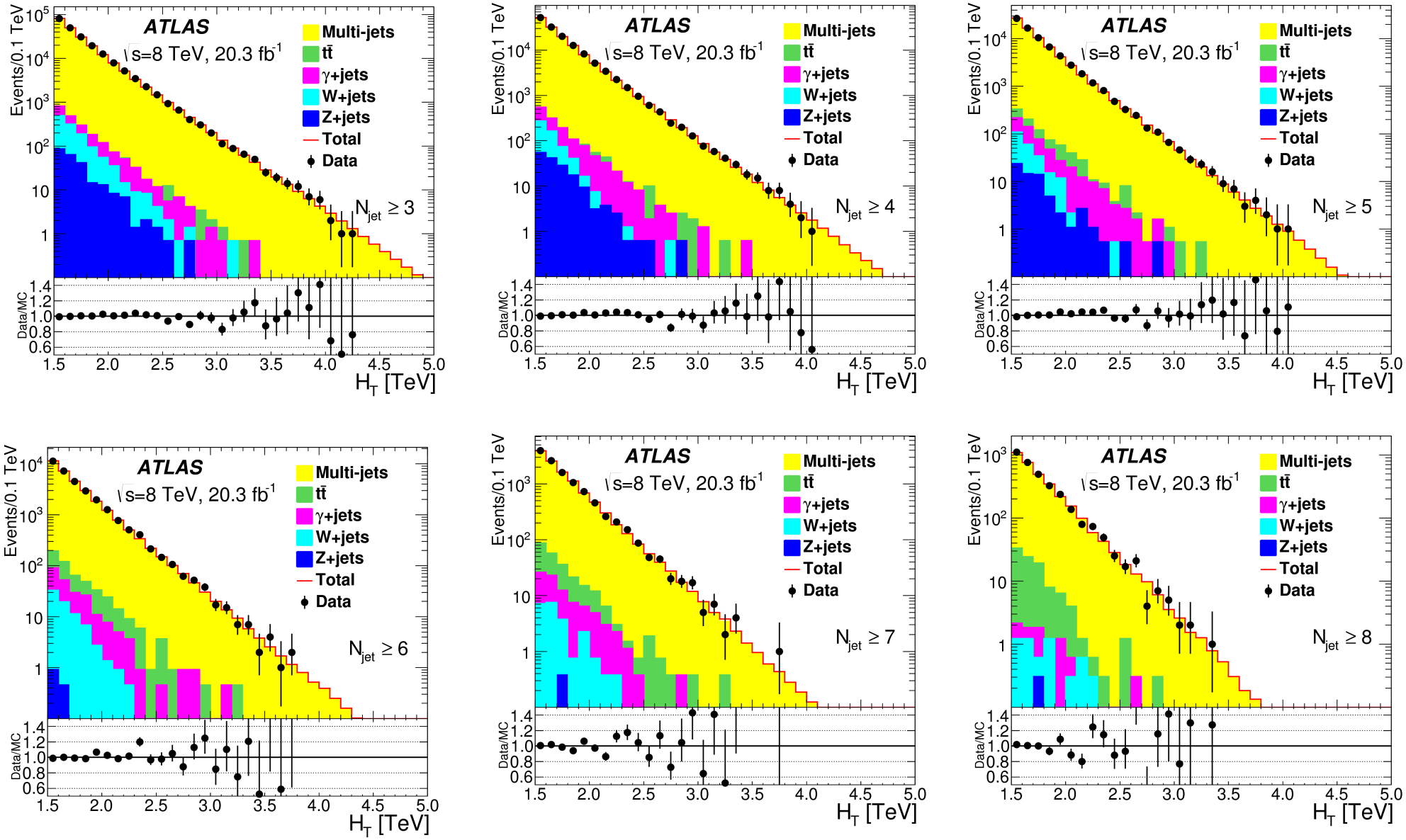


$M_{th} > 5.8$ TeV @ 95% CL for n = 6, $M_D = 3$ TeV, non-rot BH

TeV Gravity

arXiv: 1503.08988

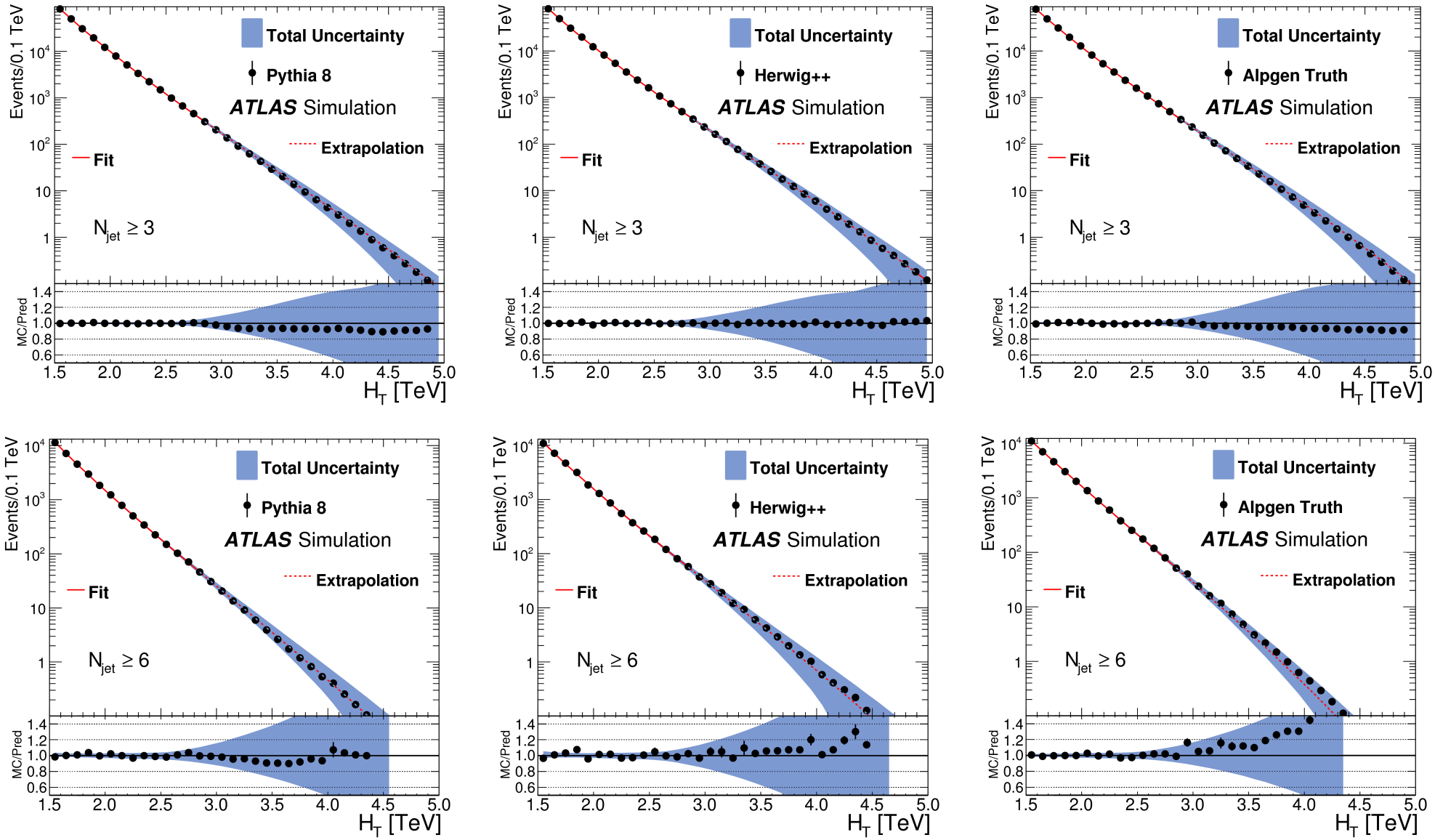
- **Data vs. Pythia8 MC**



TeV Gravity

arXiv: 1503.08988

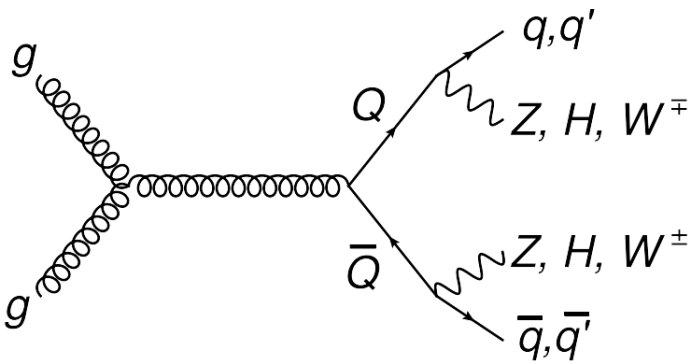
- **Multijet MC with Pythia8, Herwig++, Alpgen**



Differences between event generators are small

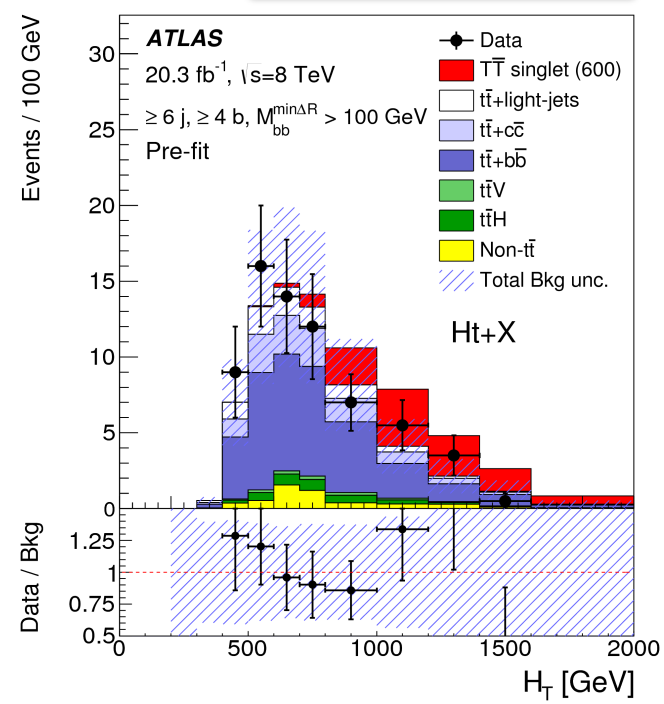
Vector-Like Quarks

- **Production & decay**
  - Pair-production dominant up to m(Q) ≈ 1 TeV
  - T → Wb, Zt, Ht
  - B → Wt, Zb, Hb



- **Lepton+jets analyses**
  - All require 1 e/mu + $E_T$miss and/or M_T(W)
  - Wb+X : ≥ 4 jets, ≥ 1 b-tag, Reco W→had, test m(Wb)
  - Ht+X : ≥ 5 jets, ≥ 2 b-tags, test H_T(all)
  - Wt+X : ≥ 6 jets, ≥ 1 b-tag, H_T > 600 GeV, BDT
  - Hb+X : ≥ 5 jets, ≥ 2 b-tags, test H_T(all)
- **Multi-lepton+jets analyses**
  - Zt/b+X : Z→ll, high p_T(Z), ≥ 2 b-tags, test m(Zb)
  - Same-sign dileptons : SS leptons, $E_T$miss, ≥ 2 jets, ≥ 1 b-tag, large H_T(all), count

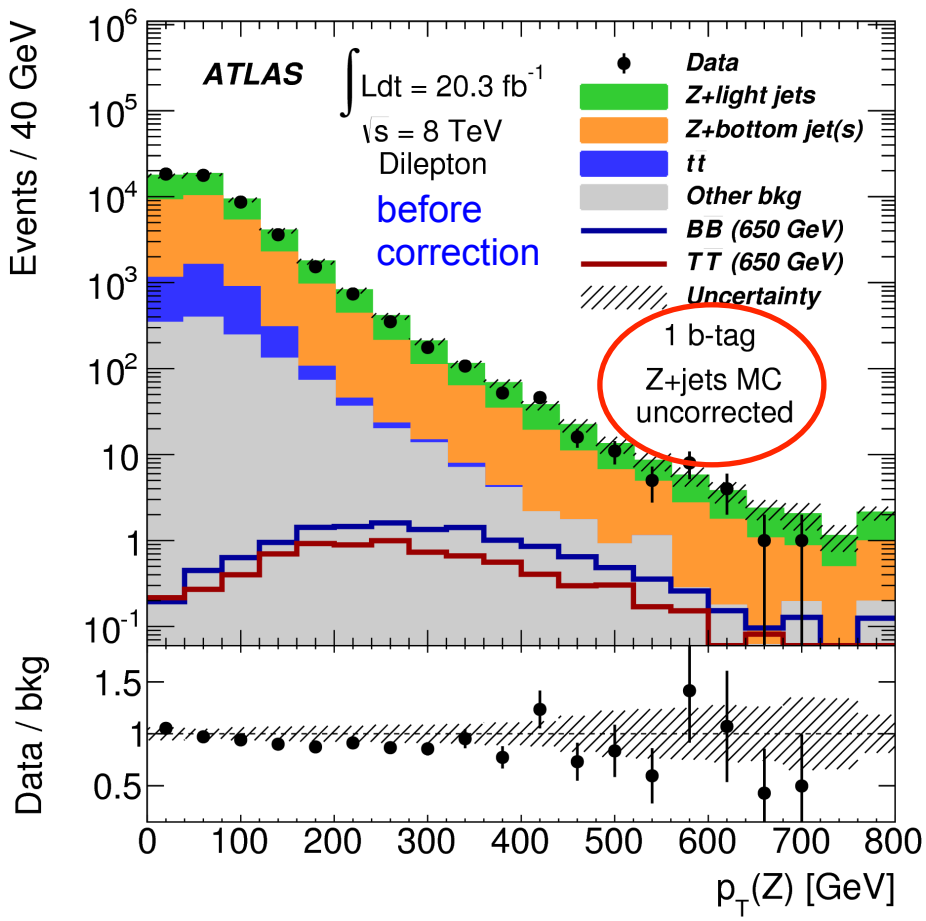
arXiv:1505.04306

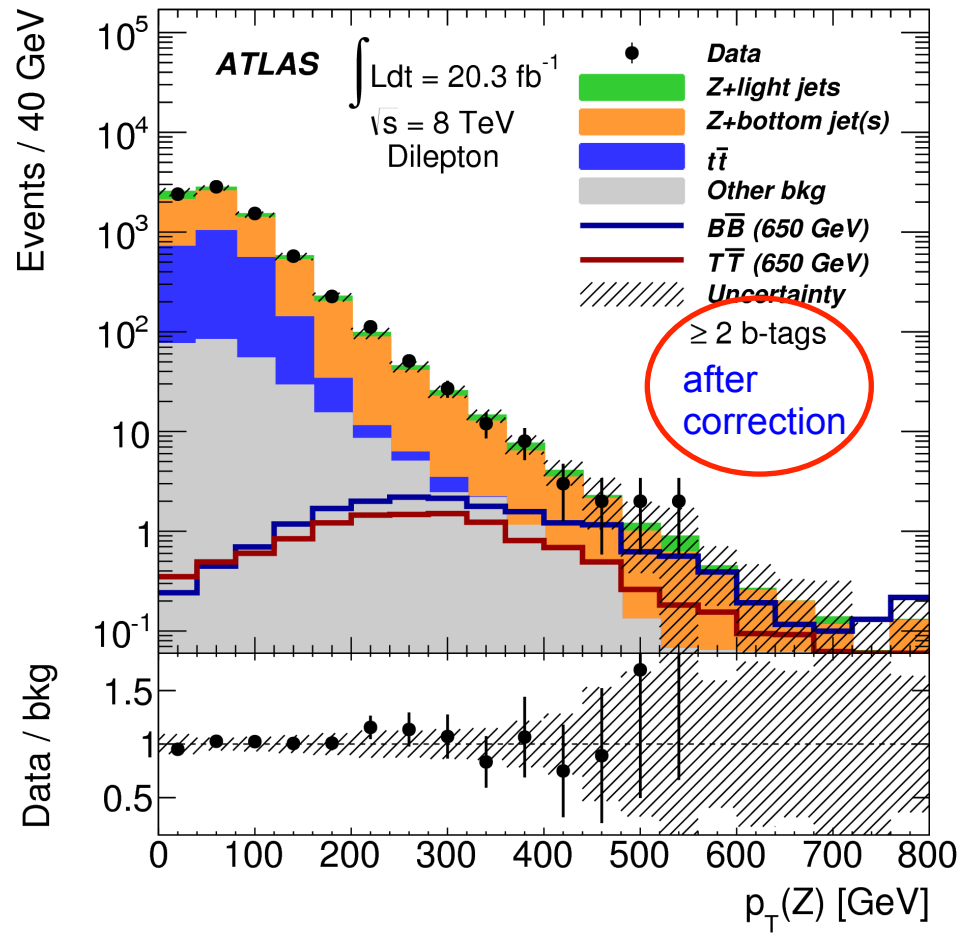


Vector-Like Quarks

arXiv: 1409.5500

- **Zt/b+X : Z→ll, high $p_T(Z)$, ≥ 2 b-tags**
  - **Test of Z+jets background modeling shows $p_T(Z)$ distribution too hard in Sherpa (as well as Alpgen) ➔ Use 1 b-tag CR to correct $p_T(Z)$ distribution**
  - **Impact: 9% (7%) decrease in Z+jets predicted by Sherpa (Alpgen) in high $p_T(Z)$, ≥ 2 b-tags SR**

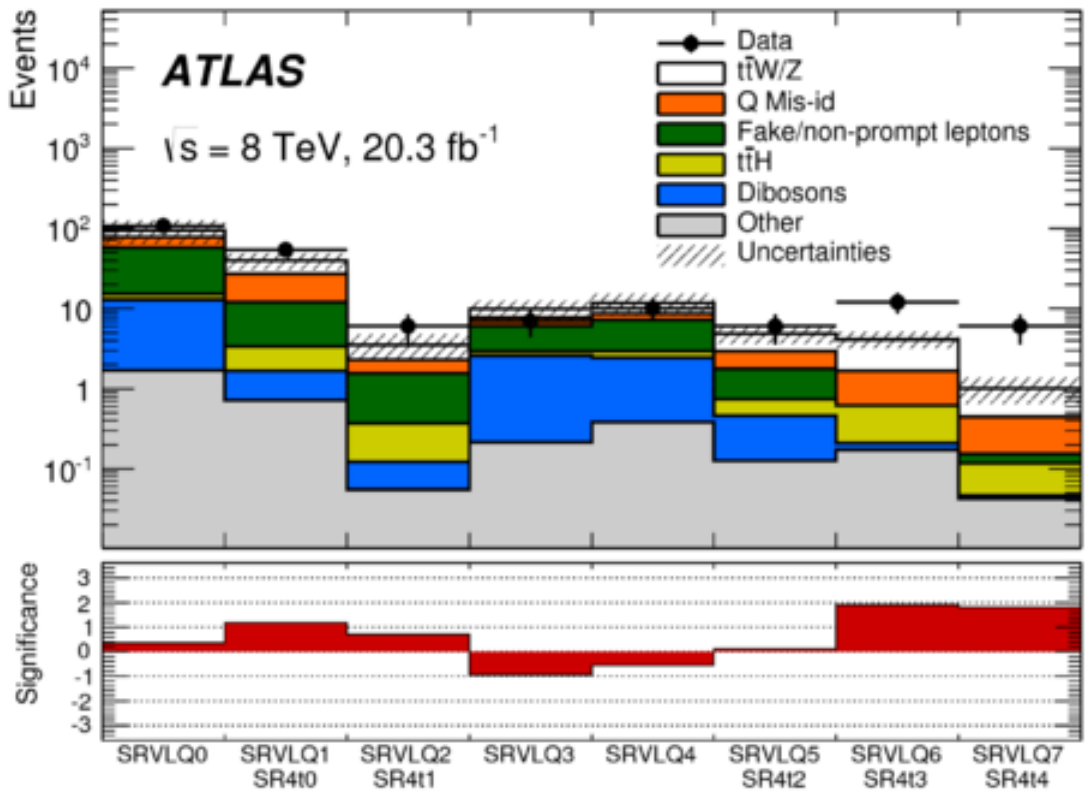




Vector-Like Quarks

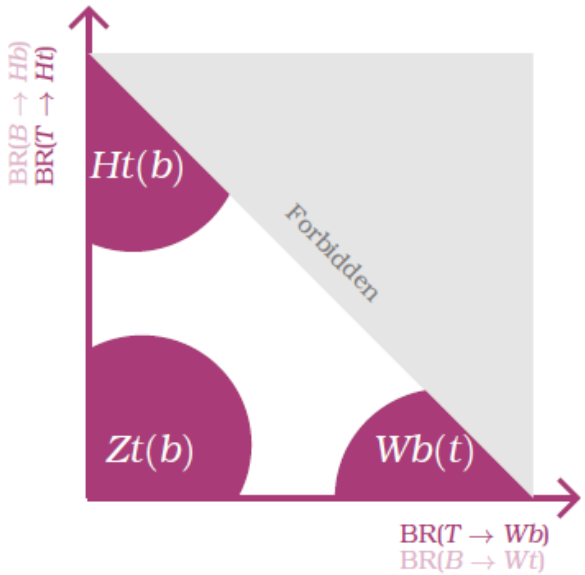
arXiv: 1504.04605

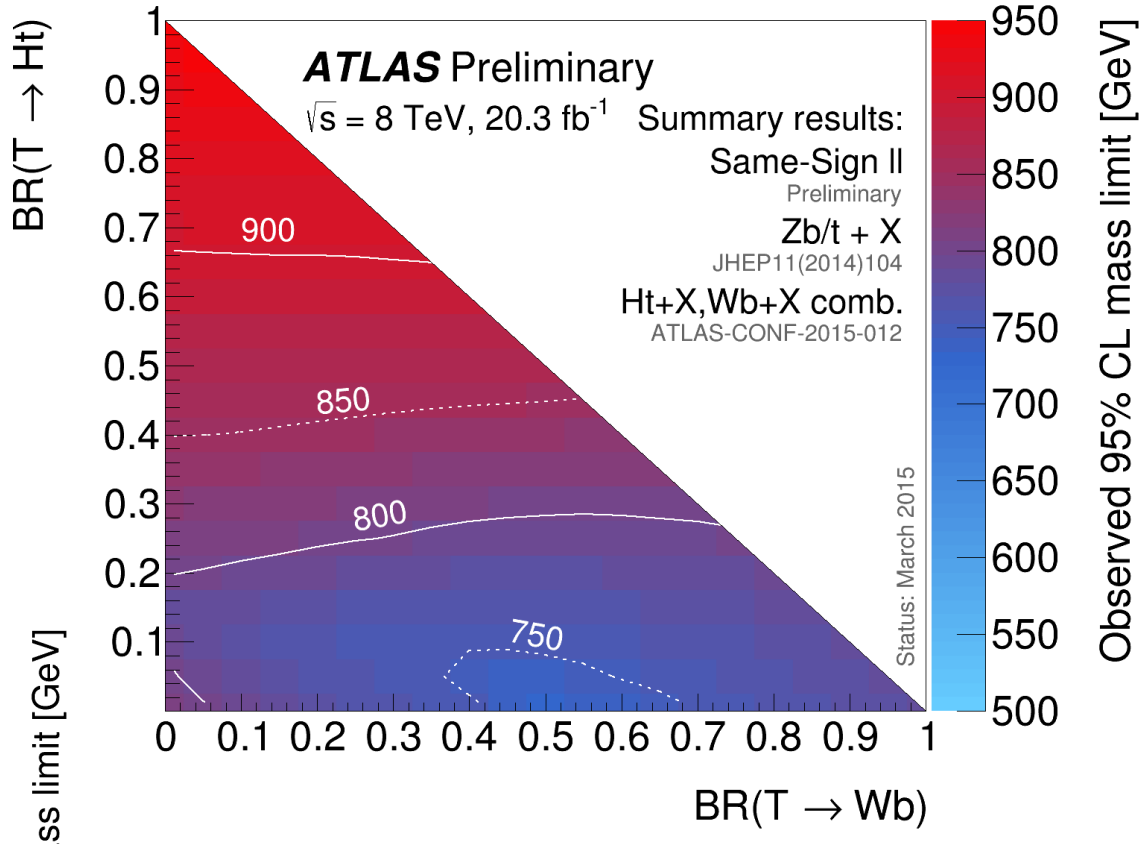
- **Same-sign dileptons :** SS leptons, $E_T$miss, ≥ 2 jets, ≥ 1 b-tag, large H_T(all), **cut-and-count**
  - Includes tri-lepton channel
  - Fairly inclusive selection ➔ sensitive to many different new phenomena
  - Complements other approaches targeting specific decay channels

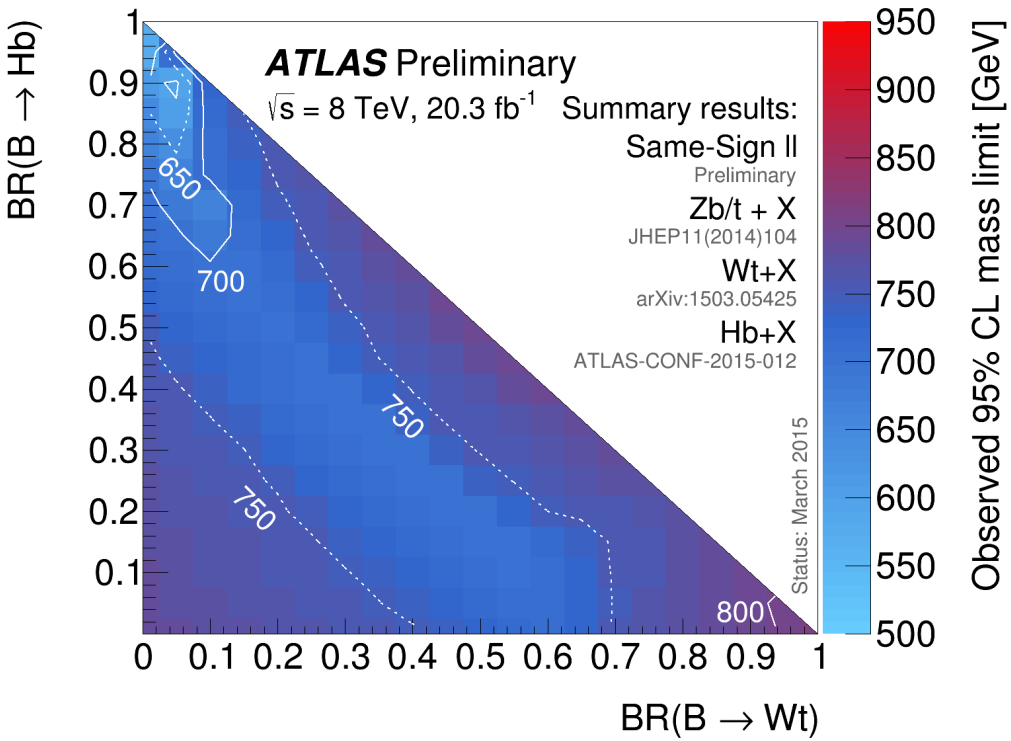


- 8 signal regions dep. on # b-tags, E_T^{miss}, H_T
- Excess signif. ~2.5 σ in SR with ≥ 2 b-tags, high E_T^{miss} and H_T

Vector-Like Quarks Summary

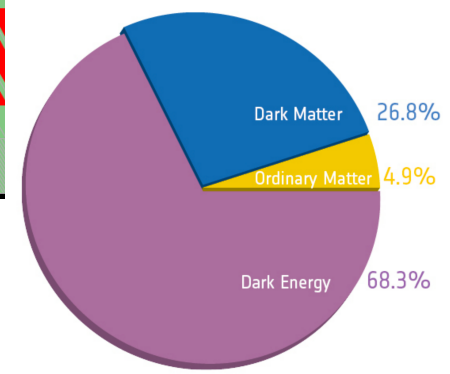




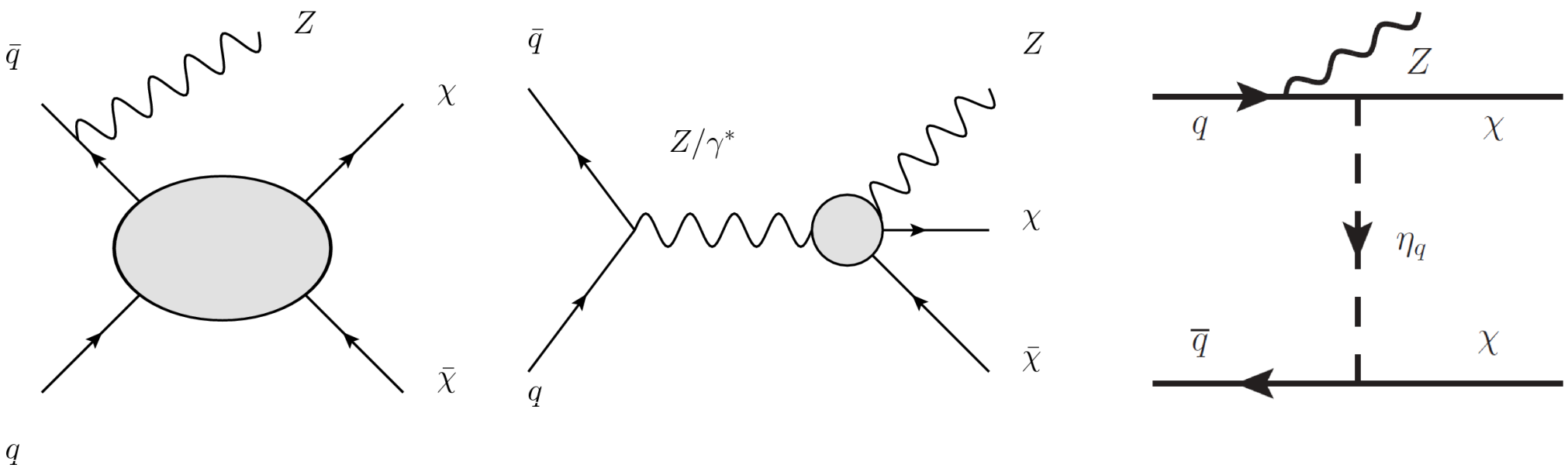


- **VLT (VLB) excluded in all models up to mass of ~700 (550) GeV**
- **Strongest exclusion ~950 (800) GeV**
- **Naturalness under stress**
- **Single production limits also set in Zt+X analysis**

Dark Matter



- **Mono-X program**
  - **Assumption:** Sensitive to dark matter WIMPs via initial state radiation or direct coupling via a mediator particle
  - **Challenge:** Type of interaction and coupling to SM particles are unknown → look for dark matter in many different final states
  - Final state = WIMP + WIMP + X, with X = jet, photon, W, Z, H, b(b), t(t)

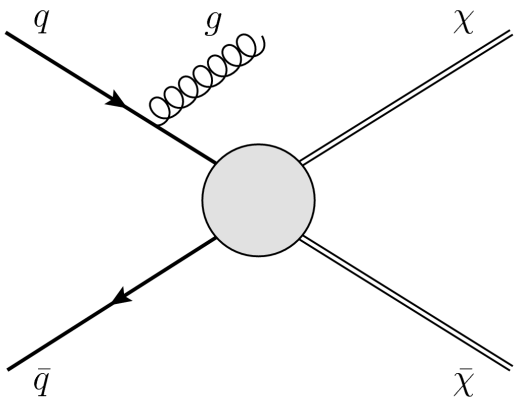


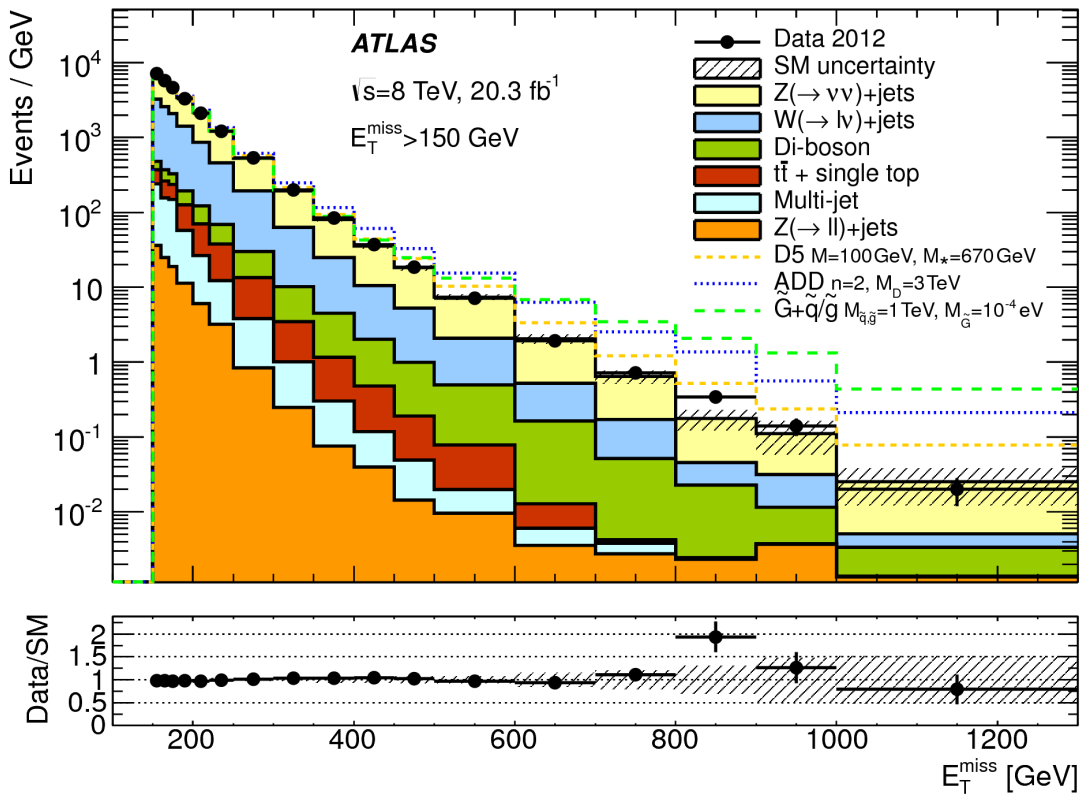
Example diagrams for production of Z + WIMP pairs

Dark Matter

arXiv: 1502.01518

- **"Mono"-jet**
  - **$E_T$miss > 150 GeV**
  - **Leading jet p_T > 120 GeV, p_T / $E_T$miss > 0.5**
  - **Additional jets allowed**
  - **Z → νν & W → μν background derived from CR**
  - **Powerful signature for compressed SUSY as well**



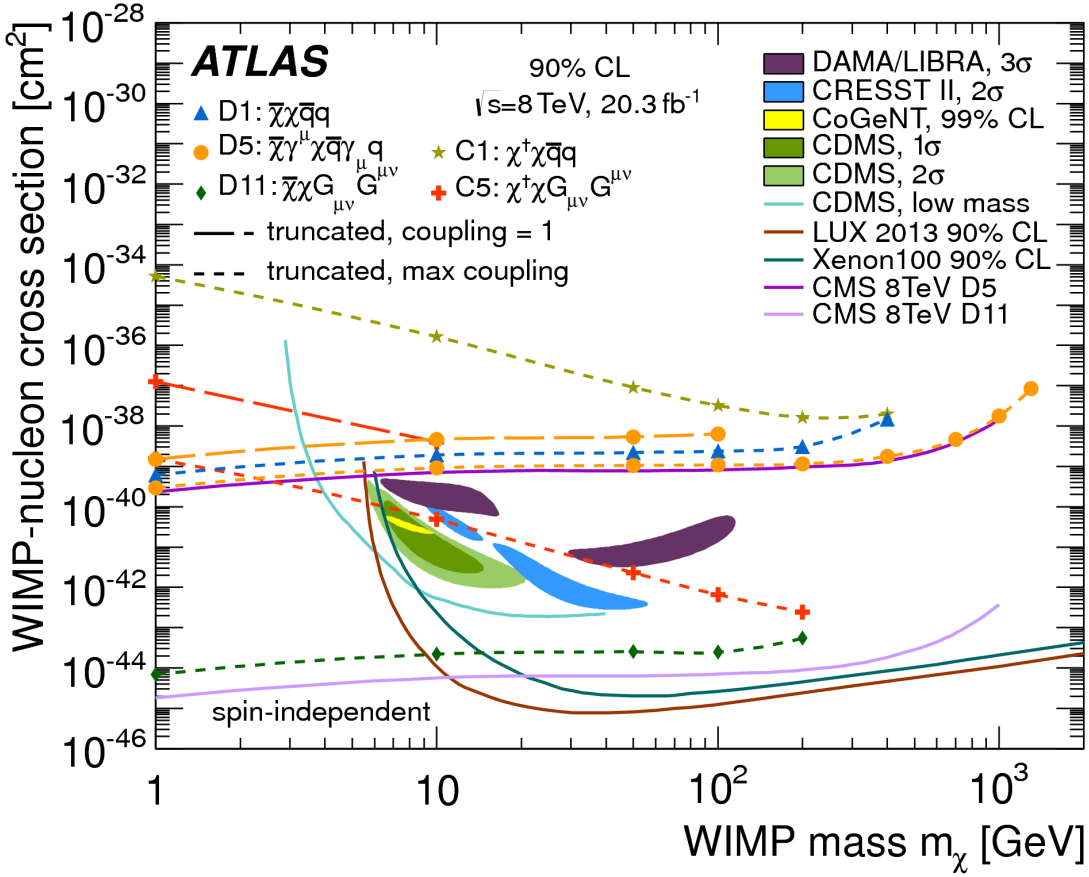


Main event generators / PDF sets	
signal	background
WIMP: MadGraph5 + Pythia6 / MSTW2008LO	**W/Z+jets**: Sherpa / CT10 HOC: DYNNLO / MSTW2008NNLO
ADD: Pythia8 / CT10	**tt, Wt**: MC@NLO+Herwig / CT10
	Multijet, γ+jet: Pythia8 / CT10
	Diboson: Sherpa / CT10

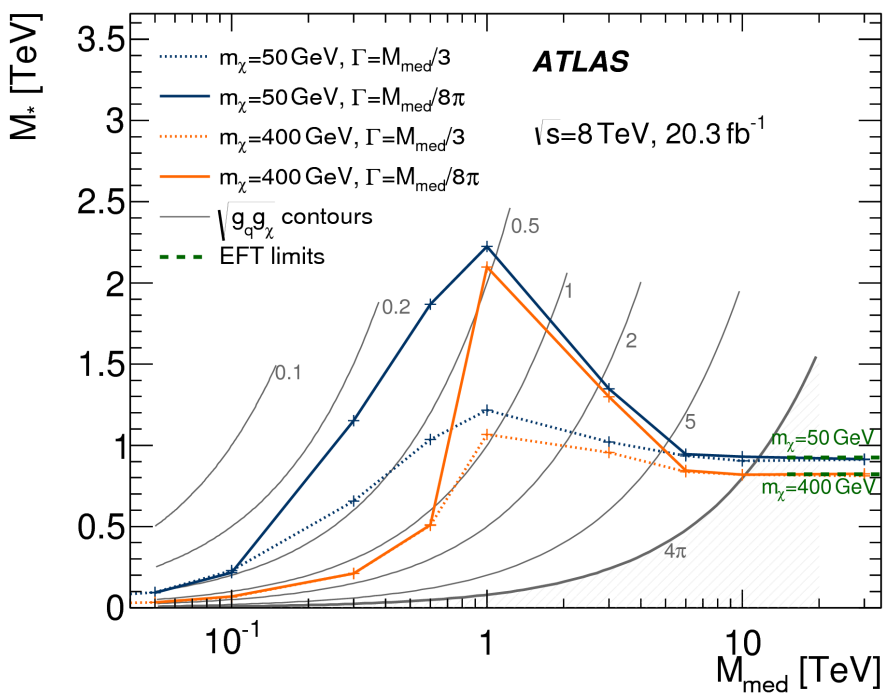
Mono-jet Dark Matter

arXiv: 1502.01518

- **Excellent sensitivity at low WIMP mass (compared with direct detection)**
- **Various truncations studied to remain within EFT validity**
- **Simplified models examined to contrast against EFT**



Simplified Z' model for vector interaction

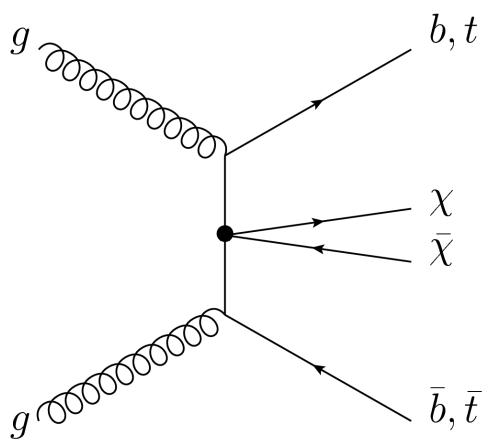


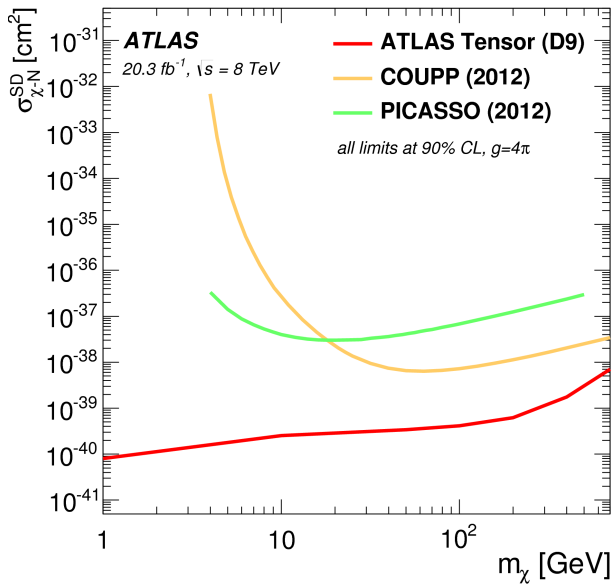
Mono-HF and Mono-γ Dark Matter

arXiv: 1410.4031

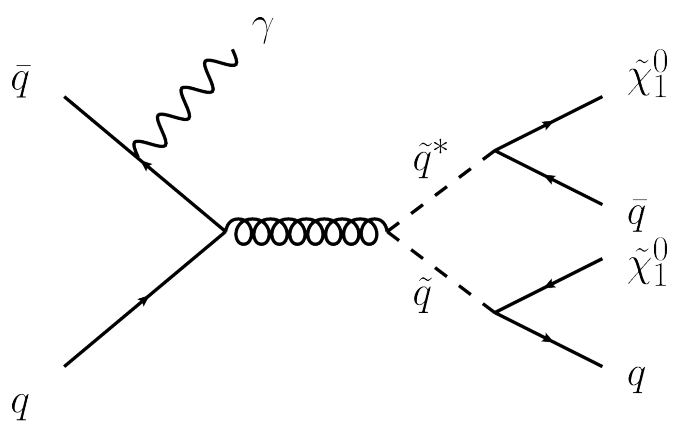
arXiv: 1411.1559

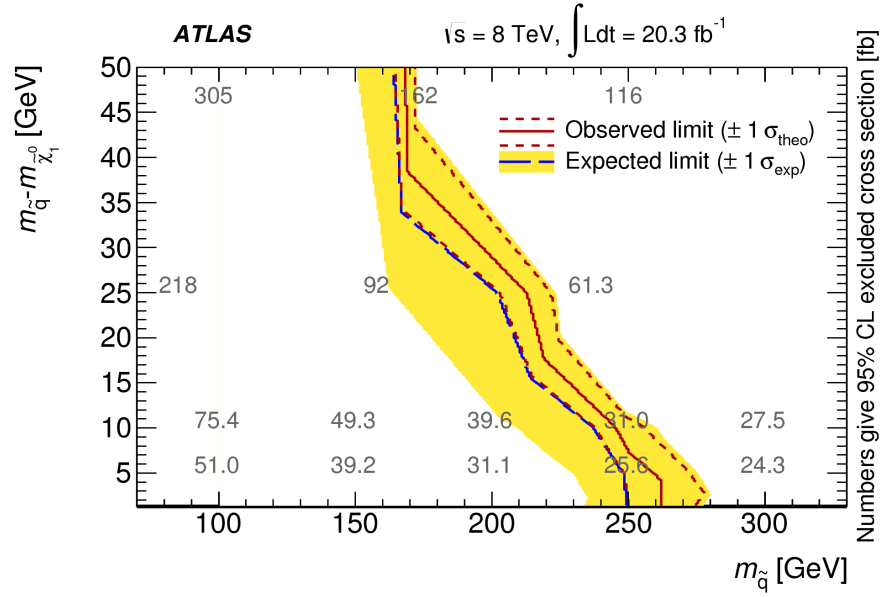
- **Other "X" particles used in various mono-X searches**
  - **May be important since we do not know the WIMP – SM coupling**

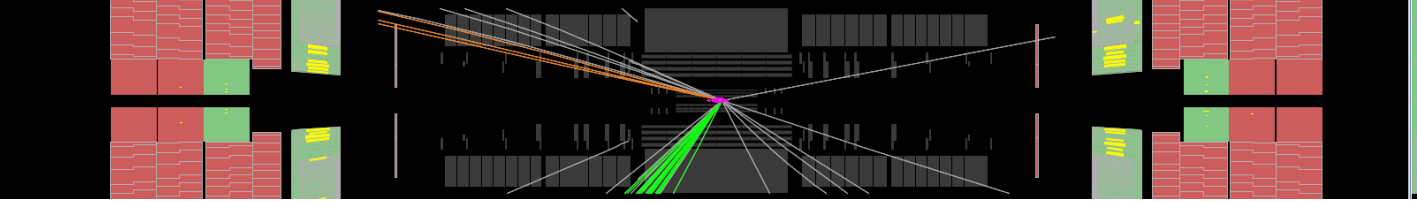


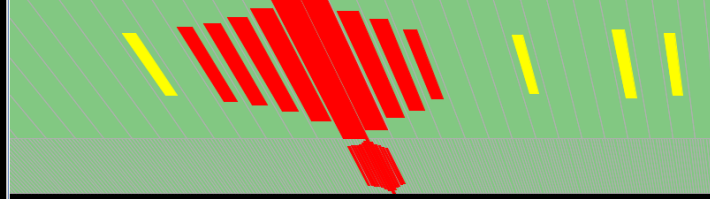


  - **Sensitive to SUSY compressed scenarios**



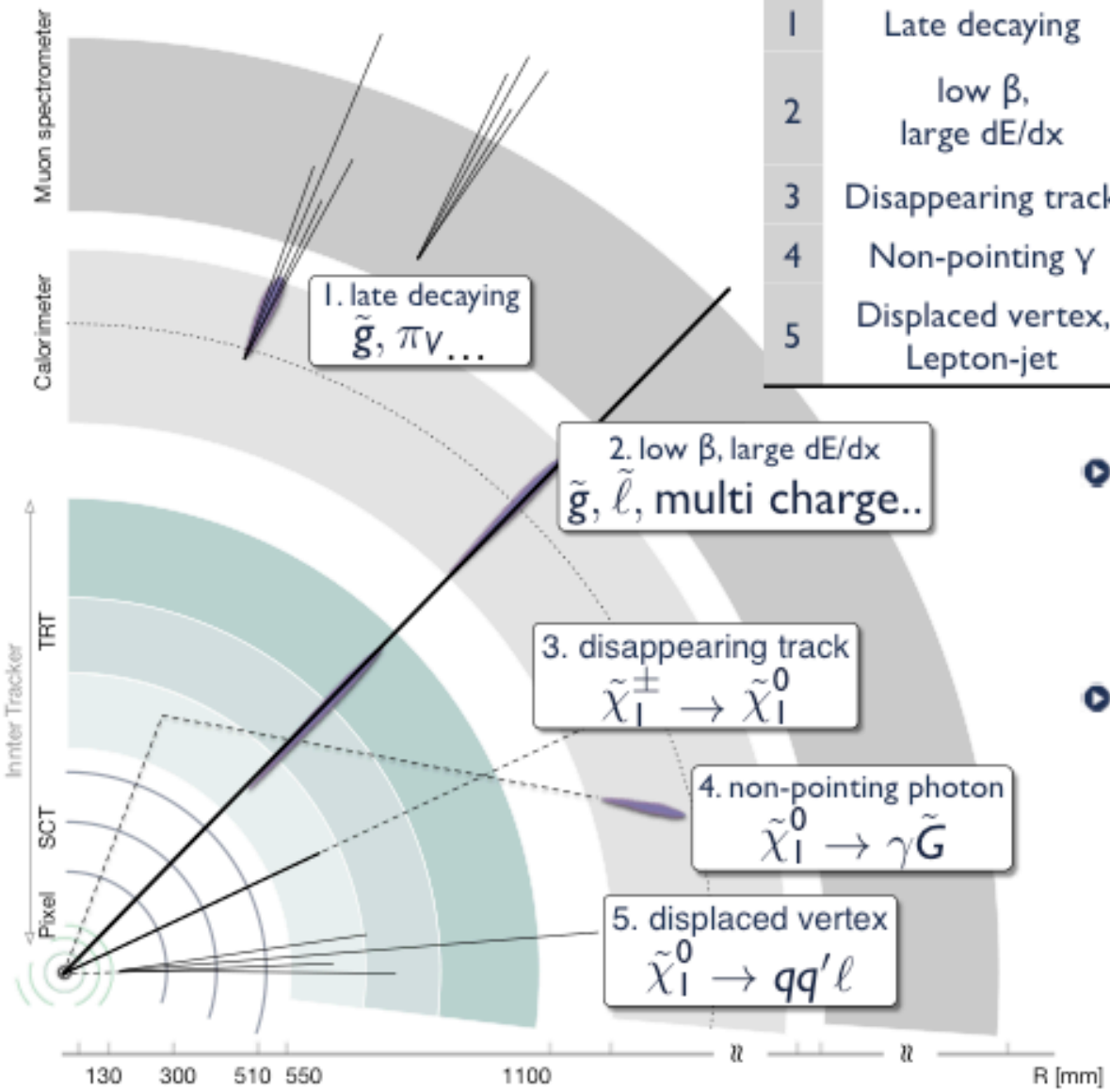






Unconventional signatures

Unconventional Signatures



	Signature	Scenario	decay-length sensitivity
1	Late decaying	split SUSY, Hidden Valley	—
2	low β, large dE/dx	GMSB, Split-SUSY, Stealth SUSY, Multi-charged	>1000mm
3	Disappearing track	AMSB (wino-LSP)	O(100-1000)mm
4	Non-pointing γ	GMSB	O(100-1000)mm
5	Displaced vertex, Lepton-jet	RPV, GMSB, Hidden Valley	O(10-100)mm

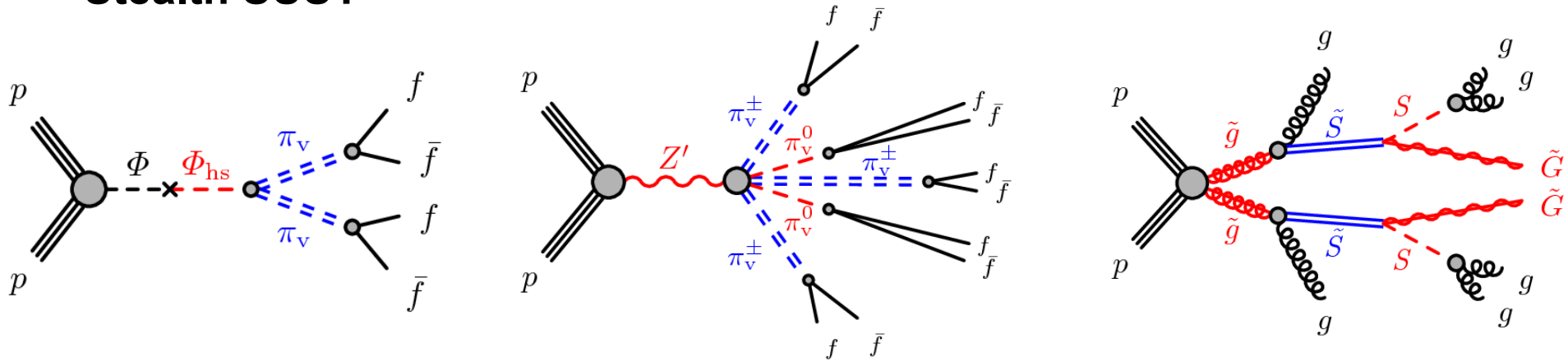
- Comprehensive searches in ATLAS, covering almost all possible experimental signatures with innovative analysis techniques.
- Few SM background process in general, but instrumental background dominates. The searches require full understanding of
  - material effects
  - alignment
  - timing calibration
  - non-collision background

Shimpei Yamamoto @ LHCP 2014

Displaced Hadronic Vertices

arXiv: 1504.03634

- **Models**
  - **Hidden sector communicating with SM via Higgs or vector portals**
  - **Stealth SUSY**



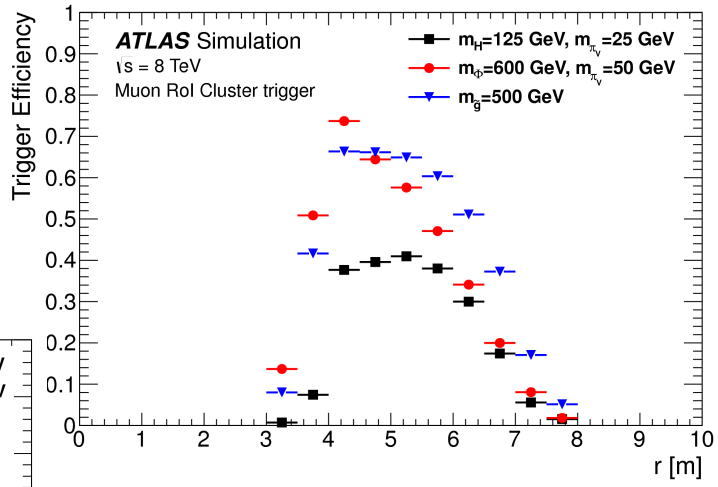
- **Backgrounds**
  - **Multijet events**
  - **Estimated primarily from data**

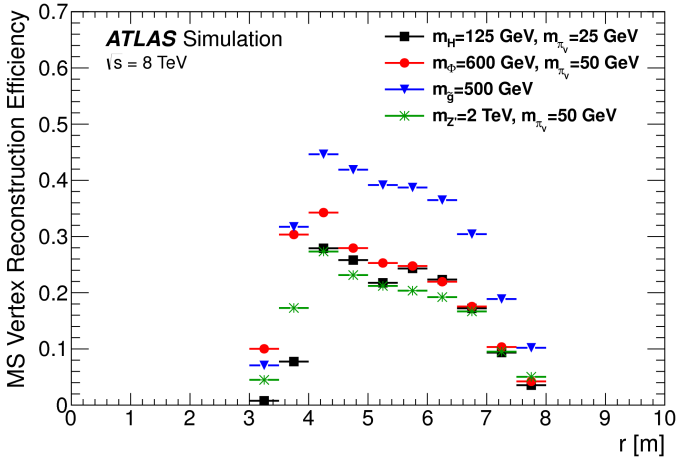
Main event generators / PDF sets	
signal	background
Scalar ϕ: Pythia8 / MSTW2008LO	**Multijet**: Pythia8 / CT10
Z': HVMC + Pythia8 / MSTW2008LO	
Stealth SUSY: MadGraph5 + Pythia8 / CTEQ6L1	

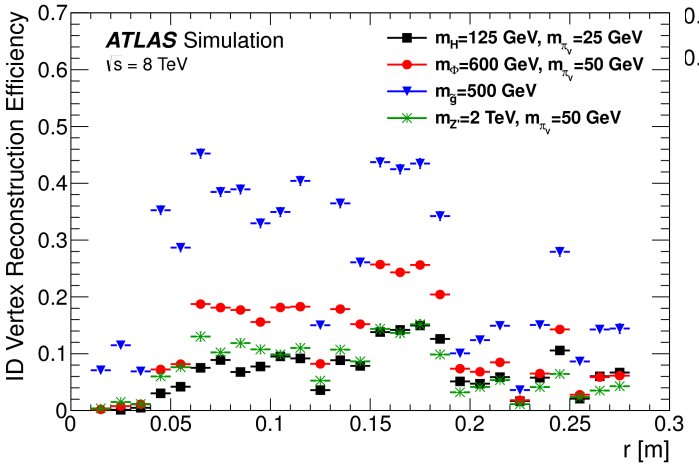
Displaced Hadronic Vertices

arXiv: 1504.03634

- **Signature**
  - Displaced vertices (2 vtx / evt) in Tracker and/or Muon Spectrometer
  - Dedicated Muon RoI trigger
    - Cluster of MuonSp RoIs in ΔR = 0.4 cone
    - Little upstream activity in Tracker or Calo
  - Dedicated tracking and vertexing







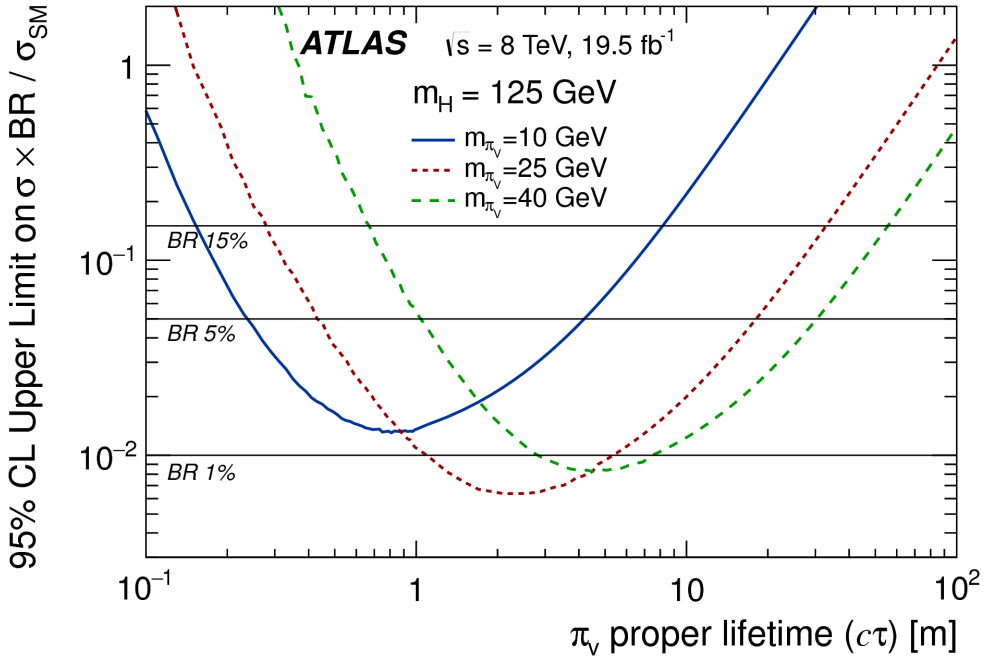
- **Results**
  - No signif. data excess

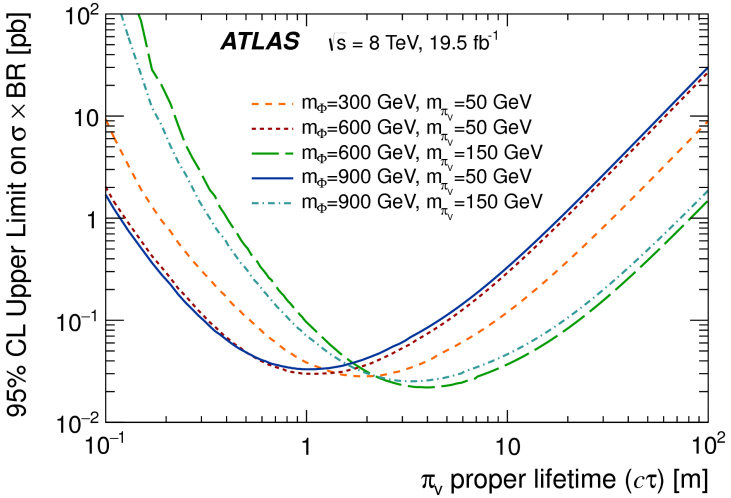
Topology	m_{π_v} [GeV]	Expected events: Signal	Expected events: Background	Observed events
IDVx+MSVx	10	1.9 ± 1.4	2.0 ± 0.4	0
	25	62 ± 8		
	40	41 ± 6		
2 MSVx	10	234 ± 15	$0.4^{+0.3}_{-0.2}$	2
	25	690 ± 26		
	40	313 ± 18		

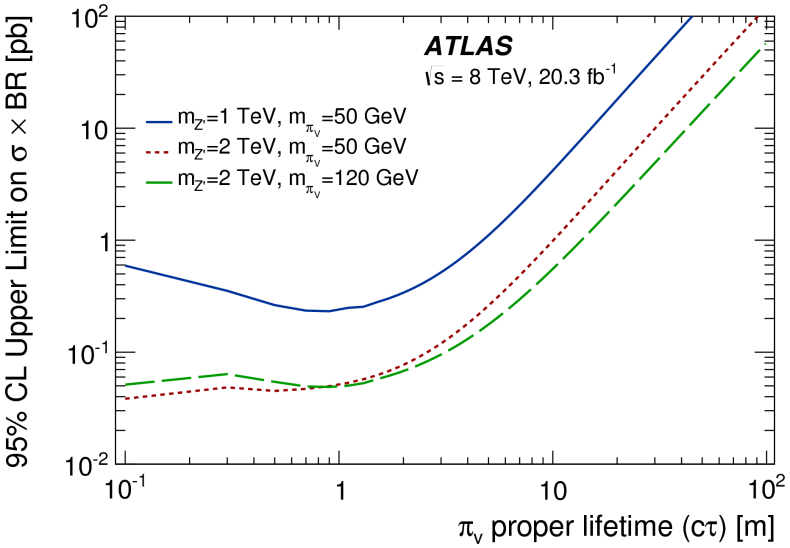
Displaced Hadronic Vertices

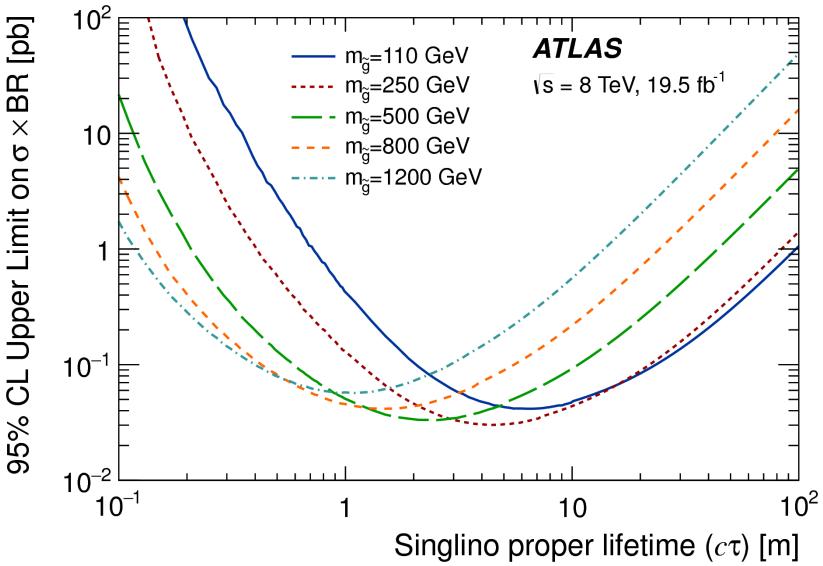
arXiv: 1504.03634

- **Significant constraint on Higgs boson decay rate to LLP**





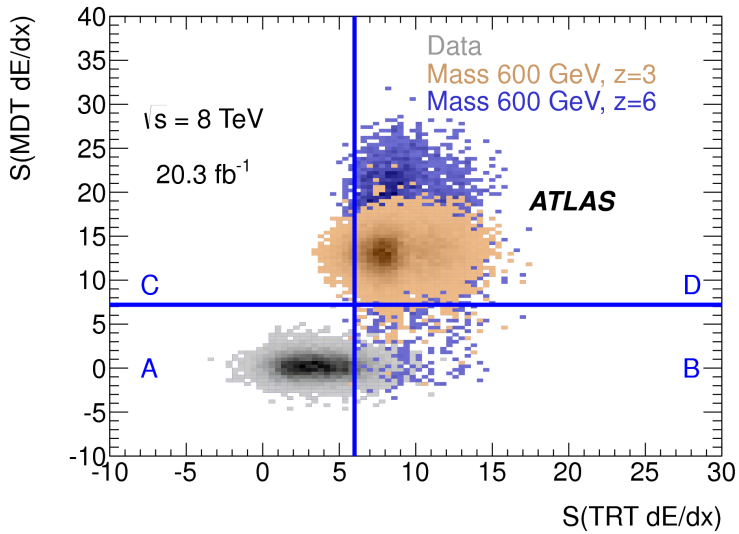


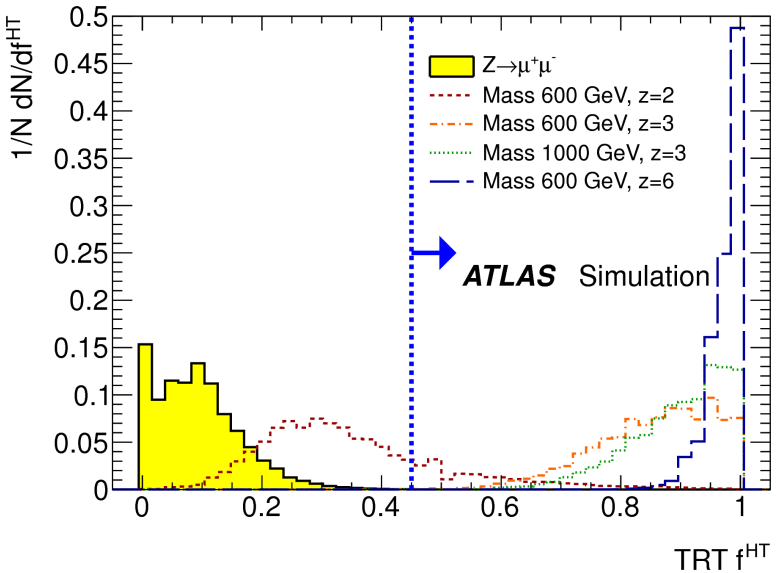


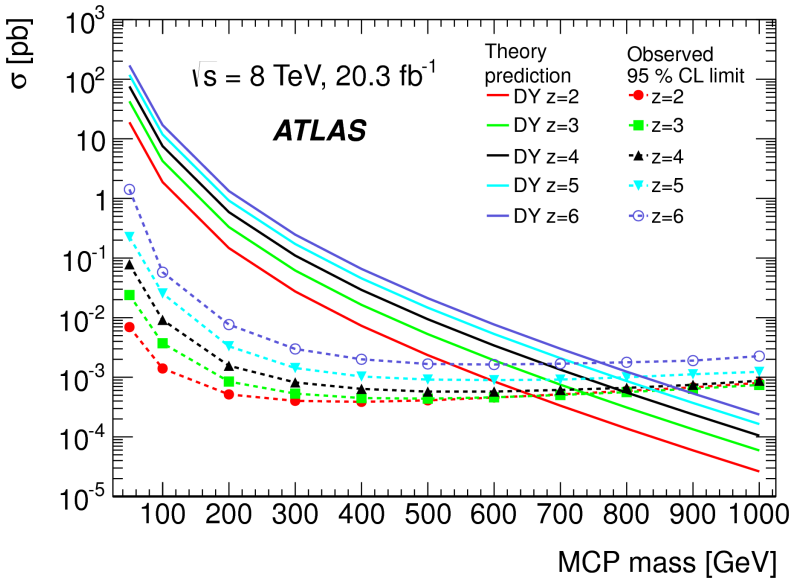
Long-lived Multi-charge Particles

arXiv: 1504.04188

- **Signature**
  - **Models: composite dark matter, doubly-charged Higgs**
  - **Drell-Yan pair production of particles with charge |q| = ze (with z = 2, 3, 4, 5, 6) → highly ionizing signature**
  - **Require large fraction of high-threshold hits in TRT**







- **No data excess**
- **Exclude multi-charge particles up to mass of 785 GeV**

ATLAS Exotics Long-lived Particle Searches* - 95% CL Exclusion

Status: March 2015

ATLAS Preliminary

$\int \mathcal{L}\, dt = (19.5 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8$ TeV

	Model	Signature	$\int \mathcal{L}\, dt [\mathrm{fb}^{-1}]$	Lifetime limit		Reference
Higgs BR = 10%	Hidden Valley $H \to \pi_v \pi_v$	2 low-EMF trackless jets	20.3	π_v lifetime 0.41-7.57 m	$m(\pi_v) = 25$ GeV	1501.04020
	Hidden Valley $H \to \pi_v \pi_v$	2 ID/MS vertices	19.5	π_v lifetime 0.31-25.4 m	$m(\pi_v) = 25$ GeV	Preliminary
	FRVZ $H \to 2\gamma_d + X$	2 $e-, \mu-, \pi-$jets	20.3	γ_d lifetime 14-140 mm	$H \to 2\gamma_d + X$, $m(\gamma_d) = 400$ MeV	1409.0746
	FRVZ $H \to 4\gamma_d + X$	2 $e-, \mu-, \pi-$jets	20.3	γ_d lifetime 15-260 mm	$H \to 4\gamma_d + X$, $m(\gamma_d) = 400$ MeV	1409.0746
Higgs BR = 5%	Hidden Valley $H \to \pi_v \pi_v$	2 low-EMF trackless jets	20.3	π_v lifetime 0.6-5.0 m	$m(\pi_v) = 25$ GeV	1501.04020
	Hidden Valley $H \to \pi_v \pi_v$	2 ID/MS vertices	19.5	π_v lifetime 0.43-18.1 m	$m(\pi_v) = 25$ GeV	Preliminary
	FRVZ $H \to 4\gamma_d + X$	2 $e-, \mu-, \pi-$jets	20.3	γ_d lifetime 28-160 mm	$H \to 4\gamma_d + X$, $m(\gamma_d) = 400$ MeV	1409.0746
Φ 300 GeV	Hidden Valley $\Phi \to \pi_v \pi_v$	2 low-EMF trackless jets	20.3	π_v lifetime 0.29-7.9 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	1501.04020
	Hidden Valley $\Phi \to \pi_v \pi_v$	2 ID/MS vertices	19.5	π_v lifetime 0.19-31.9 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	Preliminary
Φ 900 GeV	Hidden Valley $\Phi \to \pi_v \pi_v$	2 low-EMF trackless jets	20.3	π_v lifetime 0.15-4.1 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	1501.04020
	Hidden Valley $\Phi \to \pi_v \pi_v$	2 ID/MS vertices	19.5	π_v lifetime 0.11-18.3 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	Preliminary
Other	GMSB	non-pointing or delayed γ	20.3	χ_1^0 lifetime 0.08-5.4 m	SPS8 with $\Lambda = 200$ TeV	1409.5542
	Stealth SUSY	2 ID/MS vertices	19.5	$\tilde{S}$ lifetime 0.12-90.6 m	$m(\tilde{g}) = 500$ GeV	Preliminary
	HV Z'(1 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	π_v lifetime 0.1-4.9 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	Preliminary
	HV Z'(2 TeV) $\to q_v q_v$	2 ID/MS vertices	20.3	π_v lifetime 0.1-10.1 m	$\sigma \times$BR = 1 pb, $m(\pi_v) = 50$ GeV	Preliminary

0.01 0.1 1 10 100 $c\tau$ [m]

$\sqrt{s} = 8$ TeV

*Only a selection of the available lifetime limits on new states is shown.

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

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 j	Yes	20.3	M_D 5.25 TeV	$n = 2$	1502.01518
	ADD non-resonant $\ell\ell$	$2e, \mu$	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	$1\ e, \mu$	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	1407.1376
	ADD BH high N_{trk}	$2\ \mu$ (SS)	–	–	20.3	M_{th} 4.7 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1405.4254
	ADD BH high multijet	–	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	Preliminary
	RS1 $G_{KK} \rightarrow \ell\ell$	$2\ e, \mu$	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	$2\ \gamma$	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	Preliminary
	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell\ell$	$2\ e, \mu$	2 j / 1 J	–	20.3	G_{KK} mass 740 GeV	$k/\overline{M}_{Pl} = 1.0$	1409.6190
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1\ e, \mu$	2 j / 1 J	Yes	20.3	W' mass 700 GeV	$k/\overline{M}_{Pl} = 1.0$	1503.04677
	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 $g_{KK} \rightarrow t\bar{t}$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	ATLAS-CONF-2015-009
	2UED / RPP	$2\ e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	KK mass 960 GeV		Preliminary
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2\ e, \mu$	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \rightarrow \tau\tau$	$2\ \tau$	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	SSM $W' \rightarrow \ell\nu$	$1\ e, \mu$	–	Yes	20.3	W' mass 3.24 TeV		1407.7494
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\ \ell'\ell'$	$3\ e, \mu$	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \rightarrow WZ \rightarrow qq\ell\ell$	$2\ e, \mu$	2 j / 1 J	–	20.3	W' mass 1.59 TeV		1409.6190
	HVT $W' \rightarrow WH \rightarrow \ell\nu bb$	$1\ e, \mu$	2 b	Yes	20.3	W' mass 1.47 TeV	$g_V = 1$	Preliminary
	LRSM $W'_R \rightarrow t\bar{b}$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow t\bar{b}$	$0\ e, \mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	17.3	Λ 12.0 TeV	$\eta_{LL} = -1$	Preliminary
	CI $qq\ell\ell$	$2\ e, \mu$	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	1407.2410
	CI $uutt$	$2\ e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.35 TeV	$\lvert C_{LL}\rvert = 1$	Preliminary
DM	EFT D5 operator (Dirac)	$0\ e, \mu$	≥ 1 j	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9 operator (Dirac)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	$2\ e$	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	$2\ \mu$	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	$1\ e, \mu, 1\ \tau$	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	VLQ $TT \rightarrow Ht + X$, $Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 3 j	Yes	20.3	T mass 785 GeV	isospin singlet	ATLAS-CONF-2015-012
	VLQ $TT \rightarrow Zt + X$	$2/\geq 3\ e, \mu$	$\geq 2/\geq 1$ b	–	20.3	T mass 735 GeV	T in (T,B) doublet	1409.5500
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3\ e, \mu$	$\geq 2/\geq 1$ b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $BB \rightarrow Wt + X$	$1\ e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	B mass 640 GeV	isospin singlet	Preliminary
	$T_{5/3} \rightarrow Wt$	$1\ e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		Preliminary
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	$1\ \gamma$	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	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1407.1376
	Excited quark $b^* \rightarrow Wt$	1 or $2\ e, \mu$	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	$2\ e, \mu, 1\ \gamma$	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
	Excited lepton $\nu^* \rightarrow \ell W, \nu Z$	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1\ e, \mu, 1\ \gamma$	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	$2\ e, \mu$	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2\ e, \mu$ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	$1\ e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	Preliminary
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

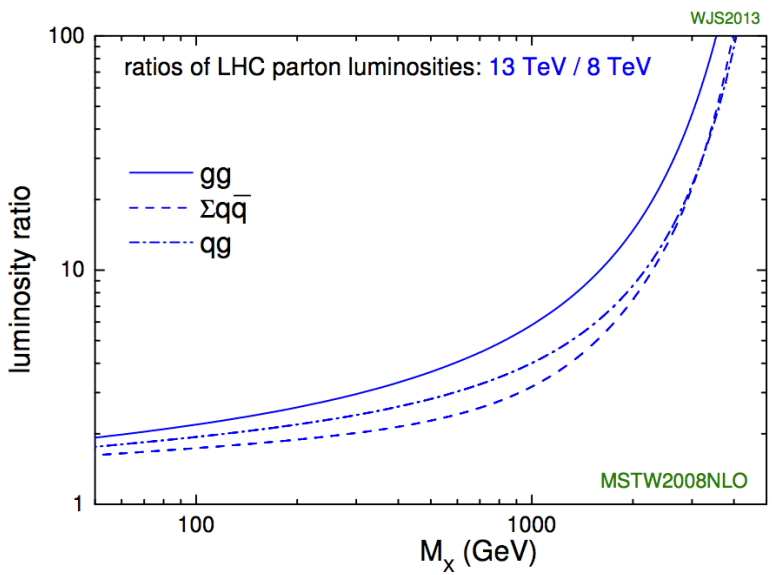
$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

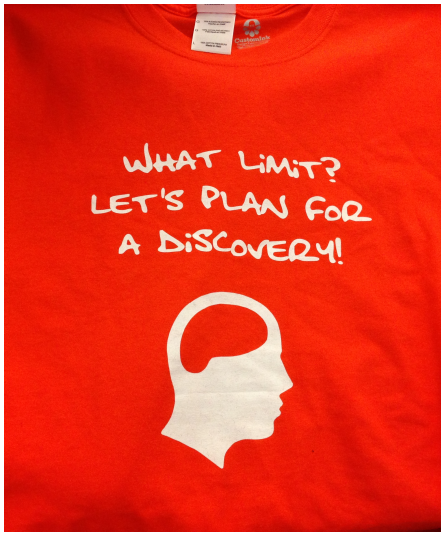
10^{-1} 1 10 Mass scale [TeV]

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

Exotics Summary & Outlook

- **Wide range of signatures explored**
- ***8 TeV data analyses mostly completed***
- **All public results available at**
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- **Discovery reach significant in Run 2**





- **Remember our goal is discovery!**