ATLAS Run II Exotics Results

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on behalf of ATLAS collaboration

Exotics search motivation

There are a lot of questions beyond of Standard Model

Questions

- What is the dark matter?
- Is the Higgs boson solely responsible for electroweak symmetry breaking and the origin of mass?
- Are fundamental parameters finely tuned?
- What is the origin of the matter-antimatter asymmetry?
- What is the origin of quark, lepton, and neutrino mass hierarchies and mixing angles?
- Are there new fundamental forces in nature?
- Are 'elementary' particles in fact composite?
- How to include quantum gravity to the SM?

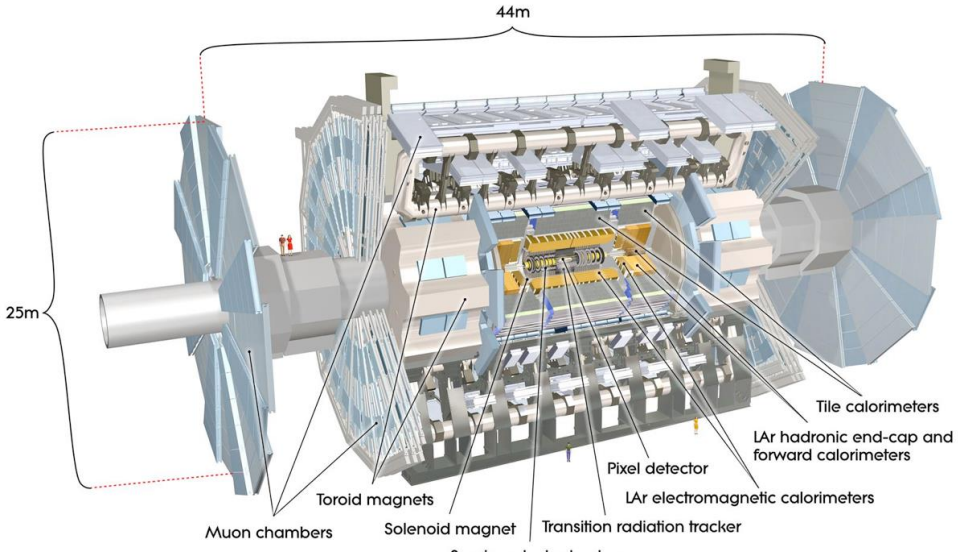
What can help to answer

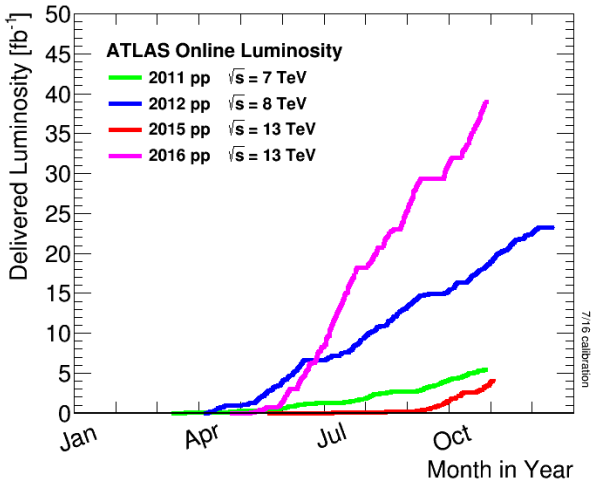
- Supersymmetry
- Extra dimensions and compositeness
- Unification of forces
- Top partners
- Additional Higgs bosons
- WIMP
- New gauge bosons (W'/Z')

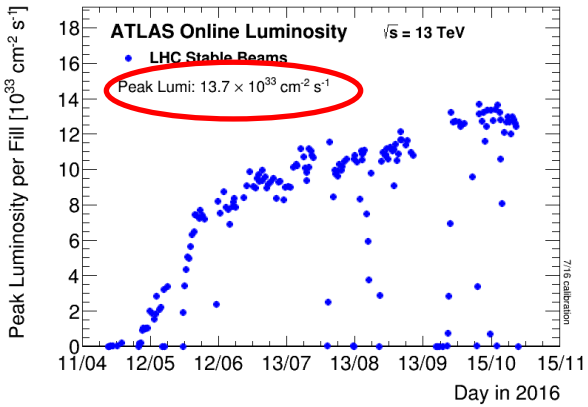
ATLAS has an extensive search program to prove or discard models

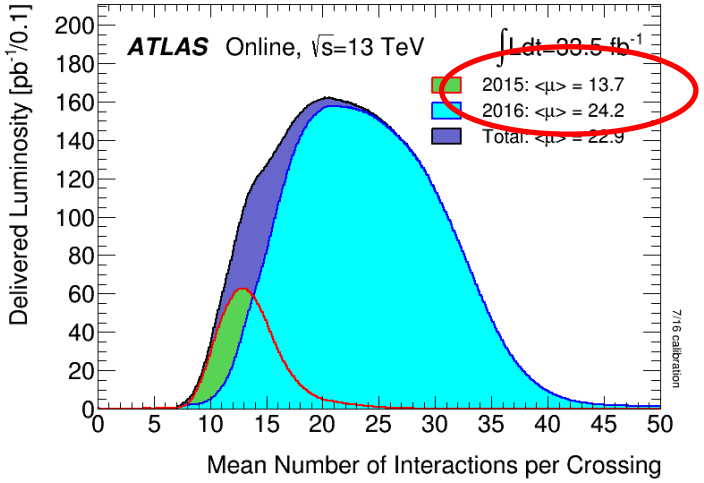
Only few of them will be discussed here

Data sets and conditions









Total collected good data 36.5 fb^{-1}(3.2 fb^{-1} in 2015, and 33.3 fb^{-1} in 2016) with efficiency > 90%

Results presented here are based on full 2015 data set and partial 2016 data set (from 10 fb^{-1} to 15 fb^{-1})

highest-mass di-electron event

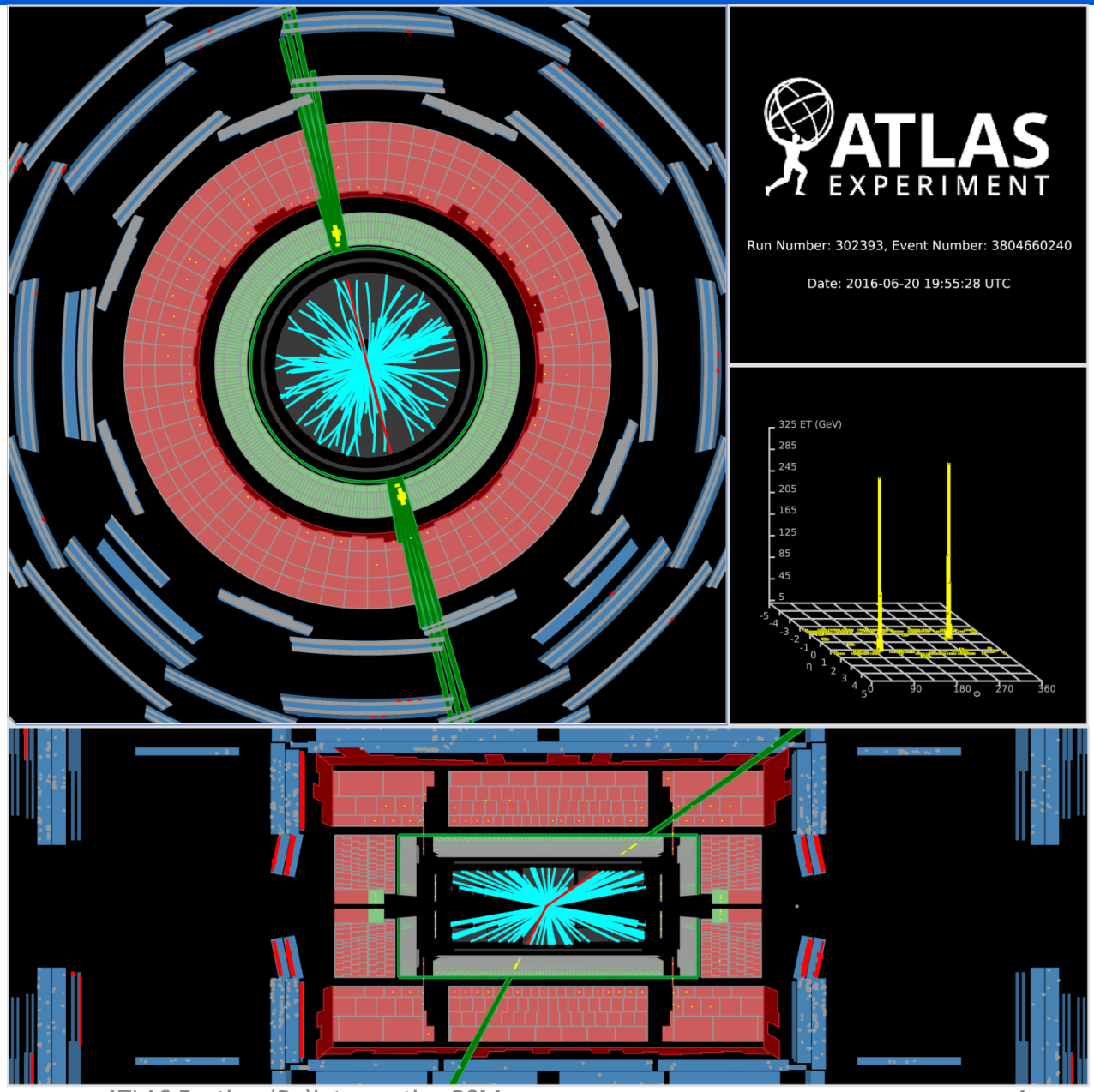
Candidate leptons with E_T > 30 GeV are displayed.

Leading electron: E_T = 889 GeV

Subleading electron:

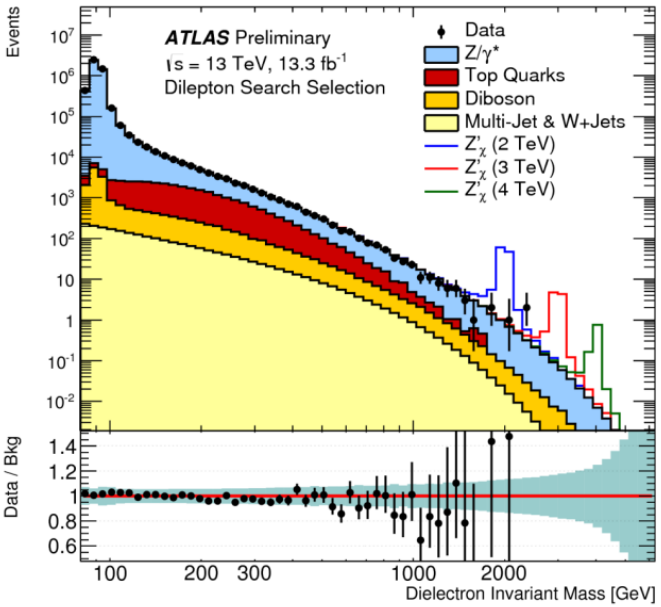
E_T = 868 GeV

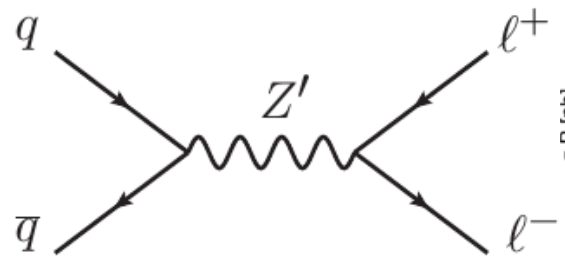
The invariant mass of the pair is 2.38 TeV.



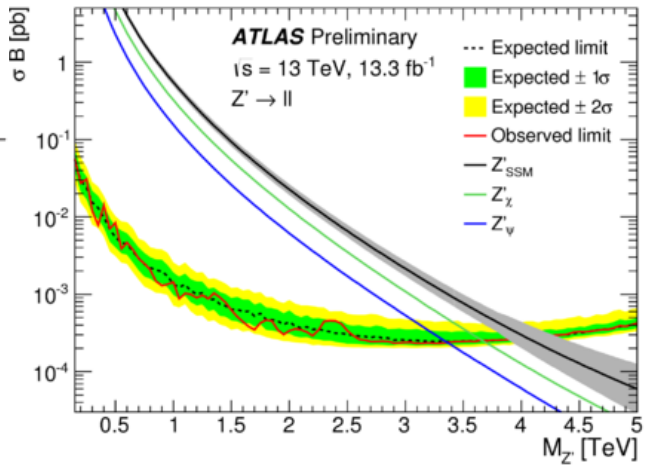
Di-lepton resonances

NC:[ATLAS-CONF-2016-045]

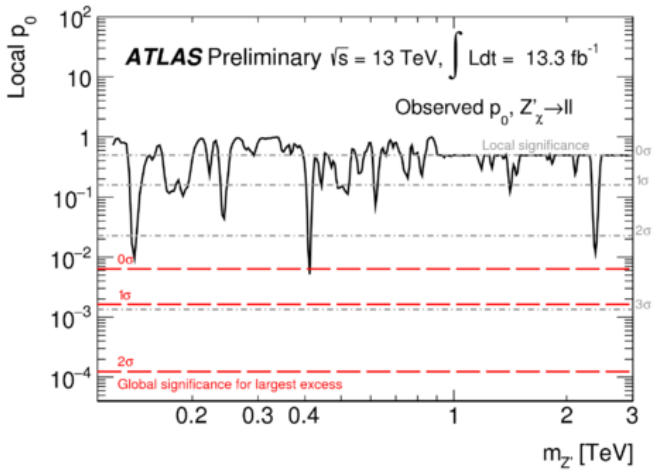


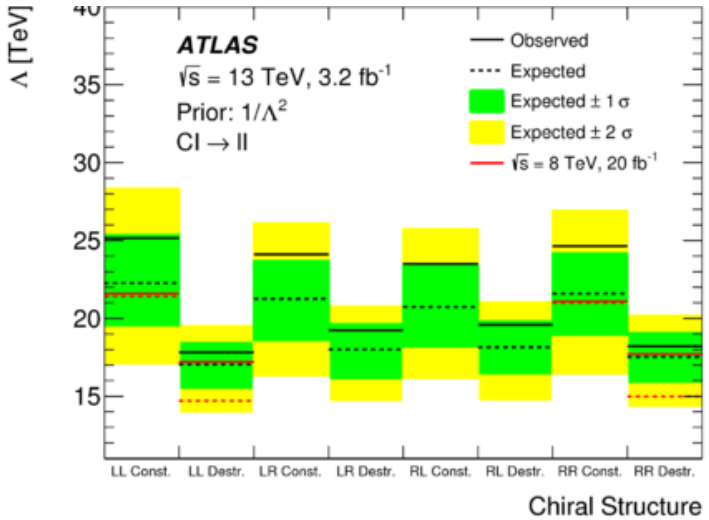


Z'_{SSM} mass limit: 4.05 TeV
Z'_{ψ} mass limit: 3.36 TeV



$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_L\gamma^\mu\ell_L) + \eta_{RR}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_R\gamma^\mu\ell_R) + \eta_{LR}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_R\gamma^\mu\ell_R) + \eta_{RL}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_L\gamma^\mu\ell_L)\right]$$

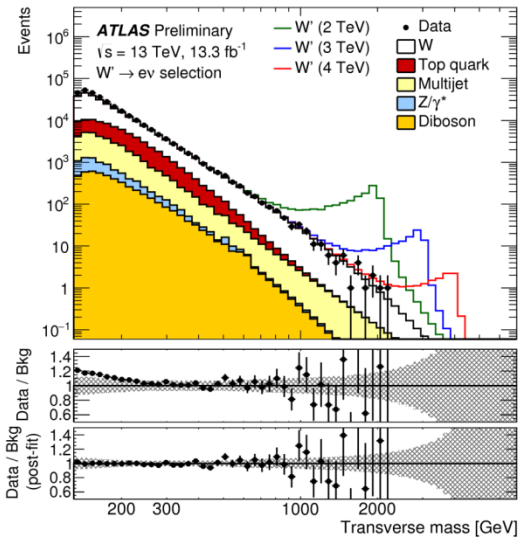


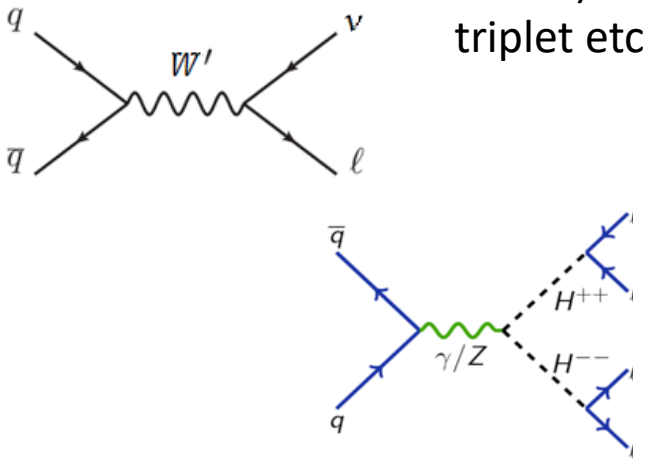


Phys. Lett. B 761 (2016) 372-392

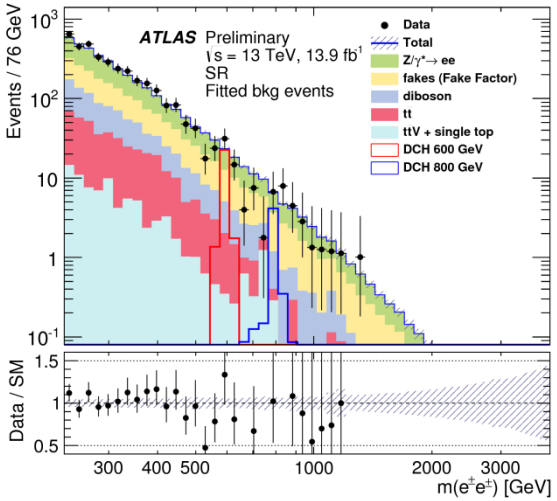
Lepton resonances

CC:ATLAS-CONF-2016-061



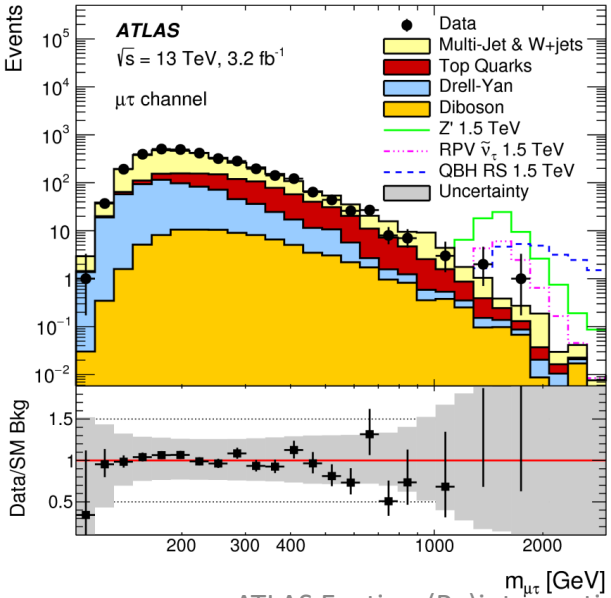


SS: DCH (Double-charged Higgs Boson) from LRSM, Little Higgs, Higgs triplet etc. ATLAS-CONF-2016-051



DCHR-mass > 420 GeV
DCHL-mass > 570 GeV

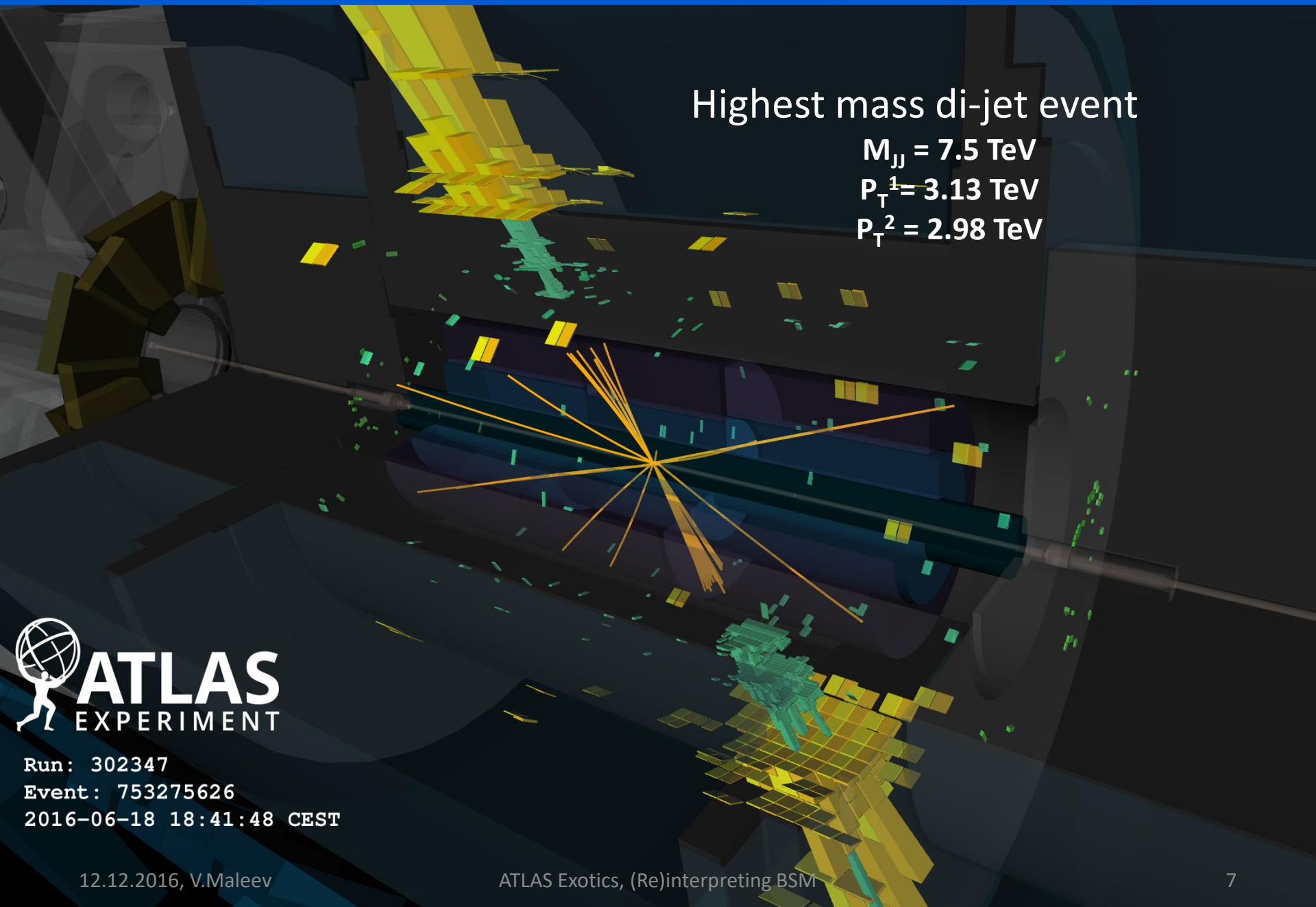
W'_{SSM} mass limit: 4.74 TeV



LFV: Z', QBH…
Eur. Phys. J. C76 (2016) 541

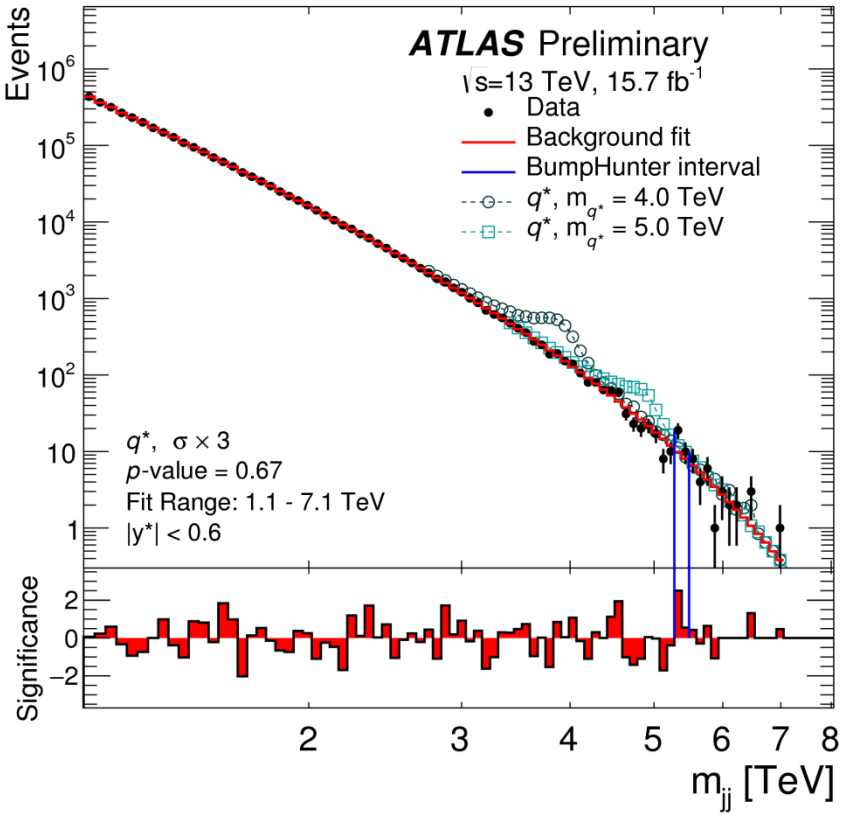
Model	Expected Limit [TeV]			Observed Limit [TeV]		
	$e\mu$	$e\tau$	$\mu\tau$	$e\mu$	$e\tau$	$\mu\tau$
Z'	3.2	2.7	2.6	3.0	2.7	2.6
RPV SUSY $\tilde{\nu}_\tau$	2.5	2.1	2.0	2.3	2.2	1.9
QBH ADD $n = 6$	4.6	4.1	3.9	4.5	4.1	3.9
QBH RS $n = 1$	2.5	2.2	2.1	2.4	2.2	2.1

Di-jet analysis



High-mass di-jet analysis(ATLAS-CONF-2016-069)

$$f(z) = p_1(1-z)^{p_2} z^{p_3}$$

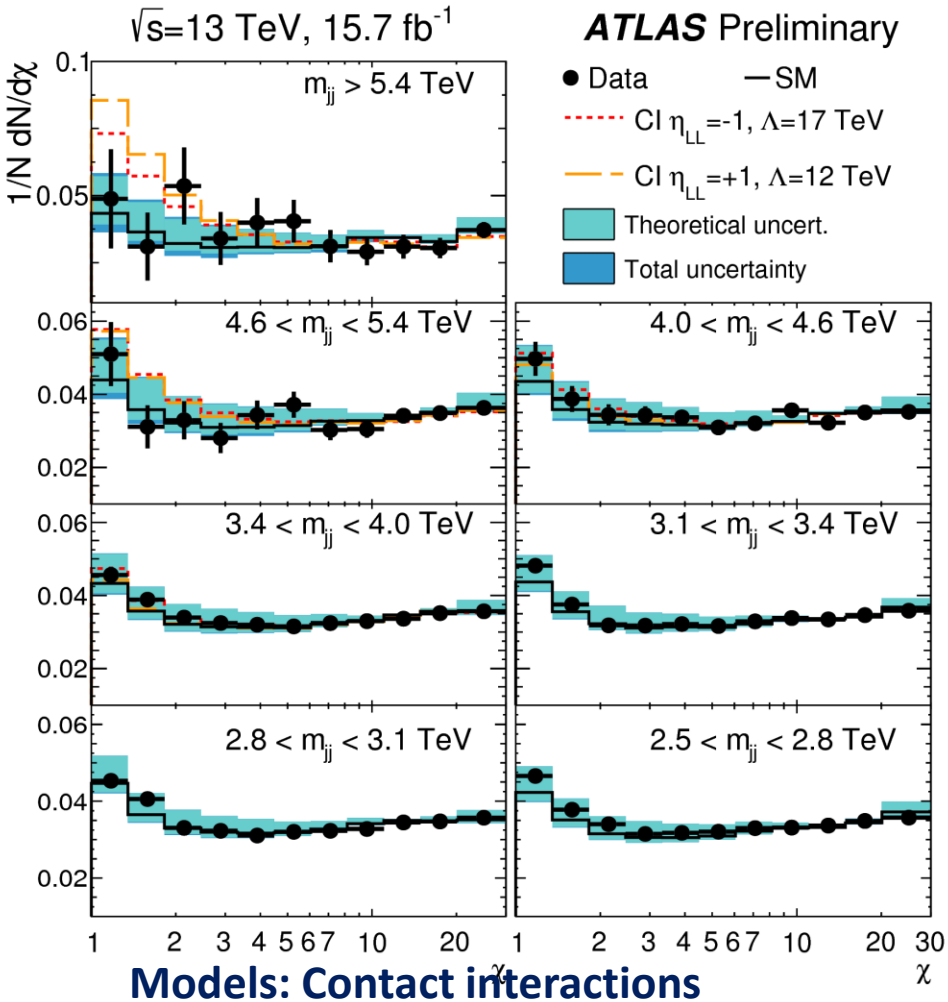


Models: Excited quarks, QBH, W', Z'

Limit on q* mass – 5.6 TeV

$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

$$|y^*| = |y_1 - y_2|/2$$



Models: Contact interactions

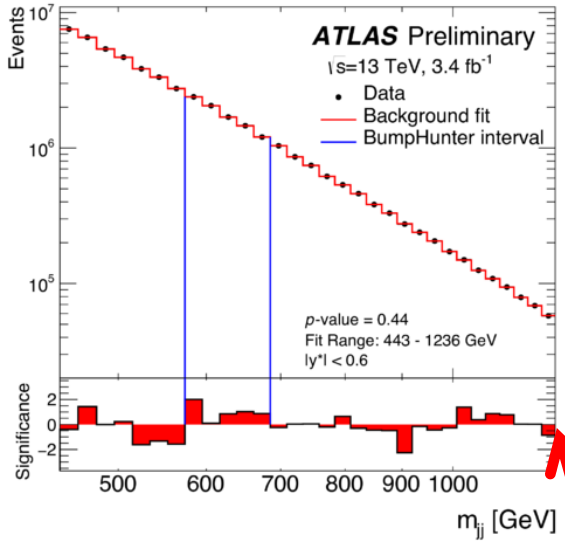
Limit: Λ > 12.6 TeV for DI and

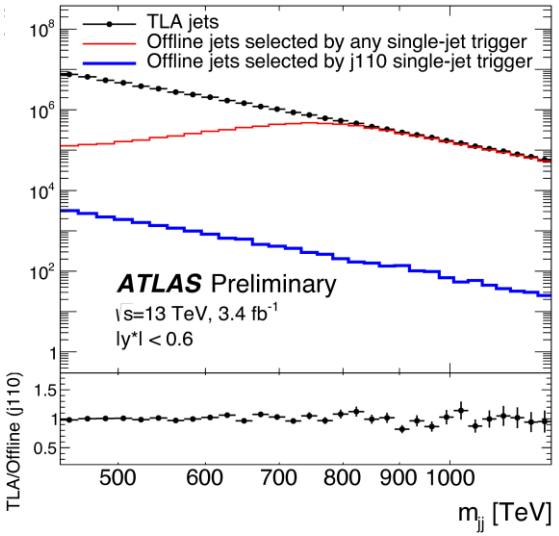
Λ > 19.9 TeV for CI

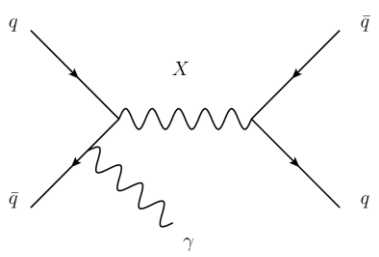
Low-mass di-jet searches

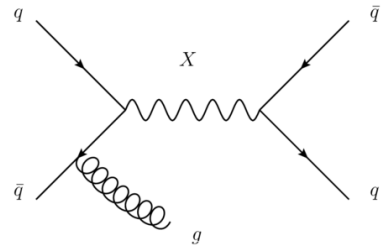
Trigger Level Analysis (TLA): ATLAS-CONF-2016-030 Di-jets + ISR: ATLAS-CONF-2016-070

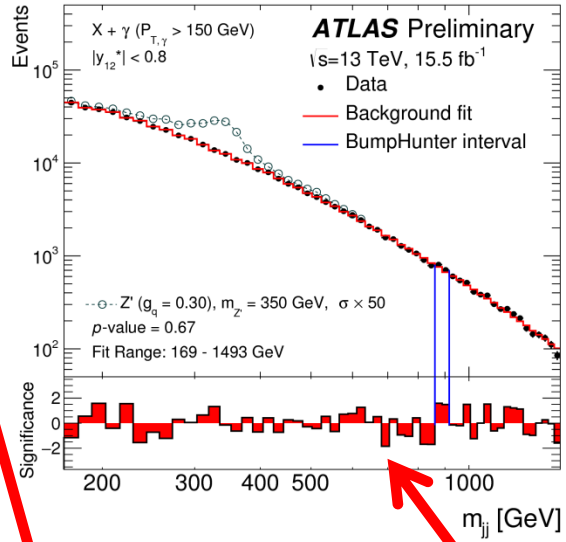
$|y^*| = |y_1 - y_2|/2$

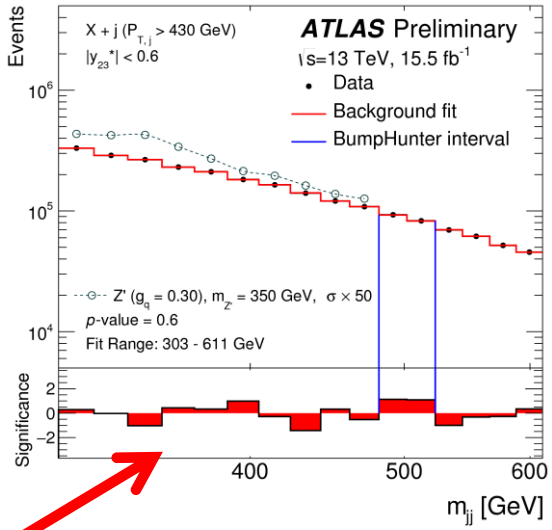












$$f(z) = c_1 (1-z)^{c_2} z^{c_3 + c_4 \ln z}$$

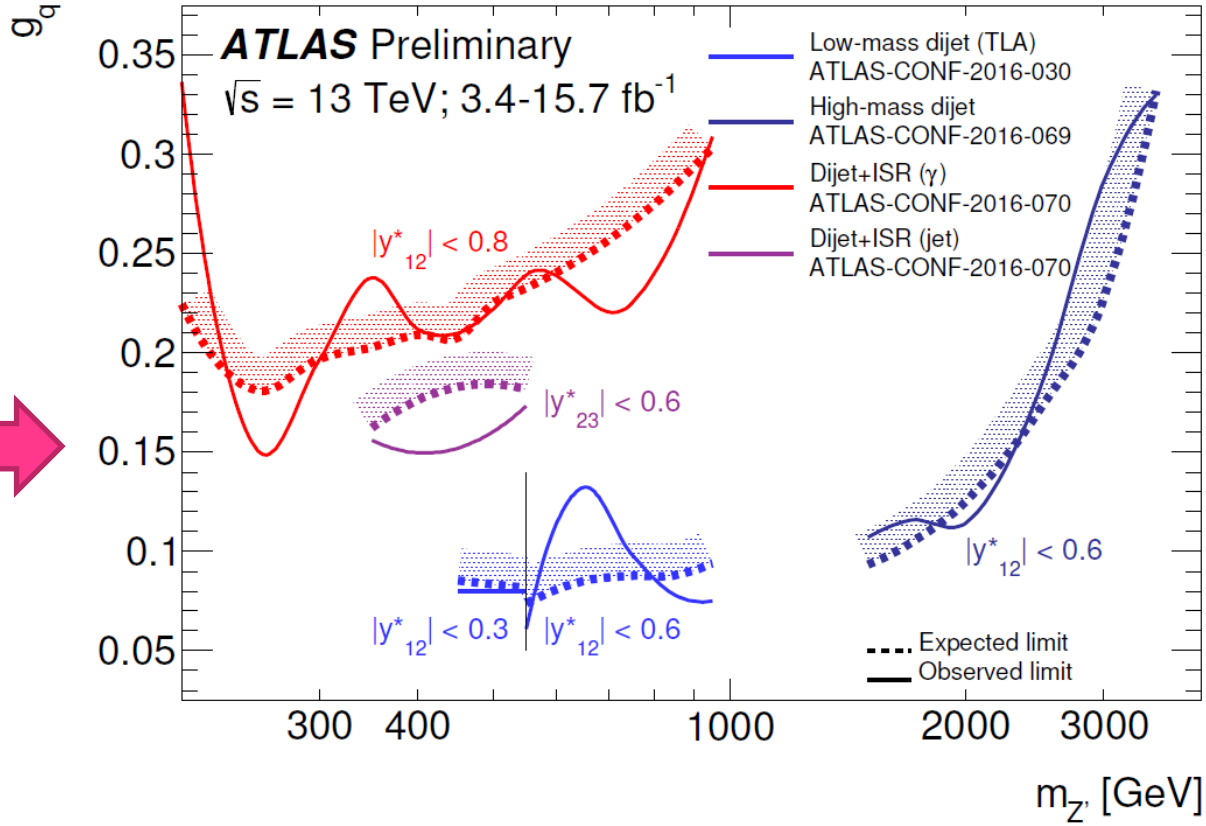
$$f(z) = \frac{p_1}{z^{p_2}} e^{-p_3 z - p_4 z^2}$$

Di-jets summary

Model	95% CL exclusion limit Observed	Expected
Quantum black holes, ADD (BlackMax generator)	8.7 TeV	8.7 TeV
Excited quark	5.6 TeV	5.5 TeV
W'	2.9 TeV	3.3 TeV
W^*	3.3 TeV	3.3 TeV
Contact interactions (η_{LL} =+1)	12.6 TeV	13.7 TeV
Contact interactions (η_{LL} =-1)	19.9 TeV	23.7 TeV

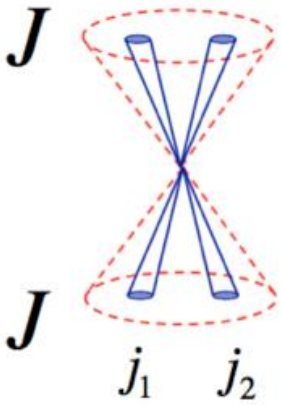
High-mass di-jet search result

Combination of different di-jet searches in various mass ranges for leptophobic Z' model [arXiv:1507.00966]

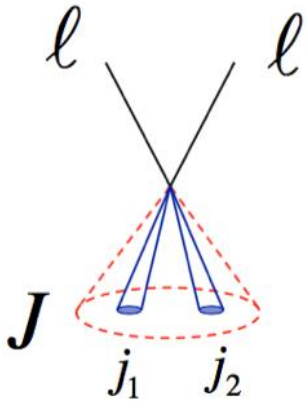


Di-boson resonances

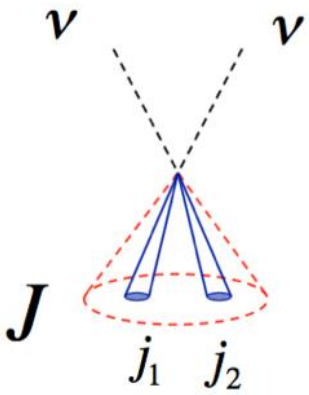
VV to **JJ**



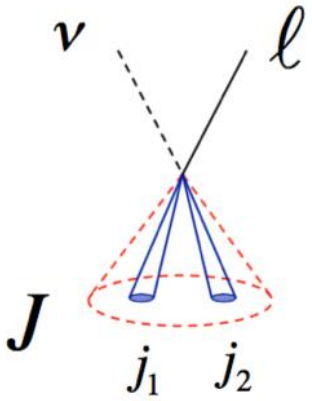
ZV (with Z to **dilepton**)



ZV (with Z to **vv**)



WV (with W to **lv**)



Boosted (J) or Resolved (j_1,j_2) technique used depending on boson P_T

Spin-0:

Scalar CP-even singlet S/G*→WW/ZZ

Scalar CP-odd Higgs (2HDM) A→Zh

Spin-1:

Heavy weakly coupled vector triplet (HVT) $V^{\pm}$→WZ/Zh or V^0→WW/ZZ

Spin-2:

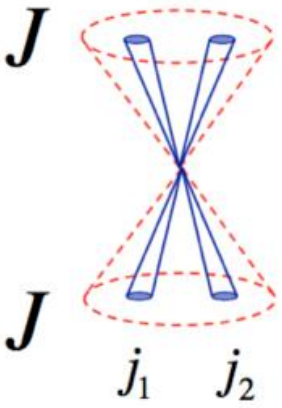
Randall-Sundrum Graviton G*→WW/ZZ

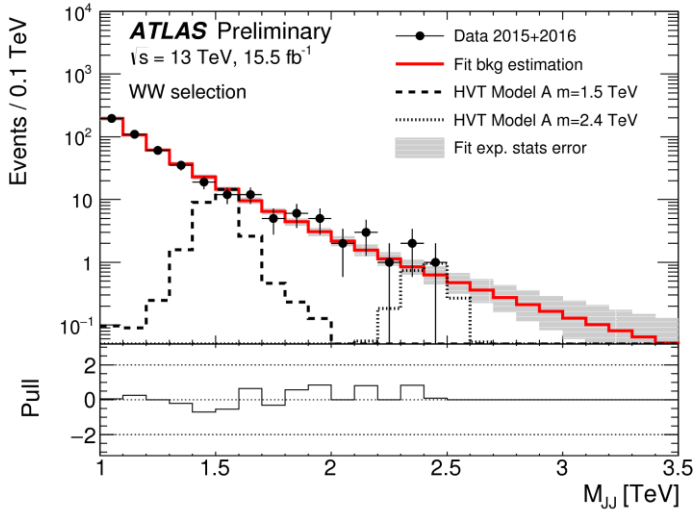
Analyses not presented here:

Vh resonances: semi-leptonic https://arxiv.org/abs/1607.05621 and hadronic ATLAS-CONF-2016-083 (first time done in ATLAS!)

HH resonances ATLAS-CONF-2016-049

Di-boson resonanses

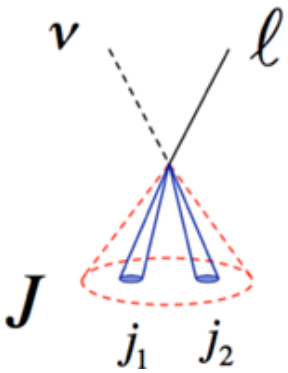


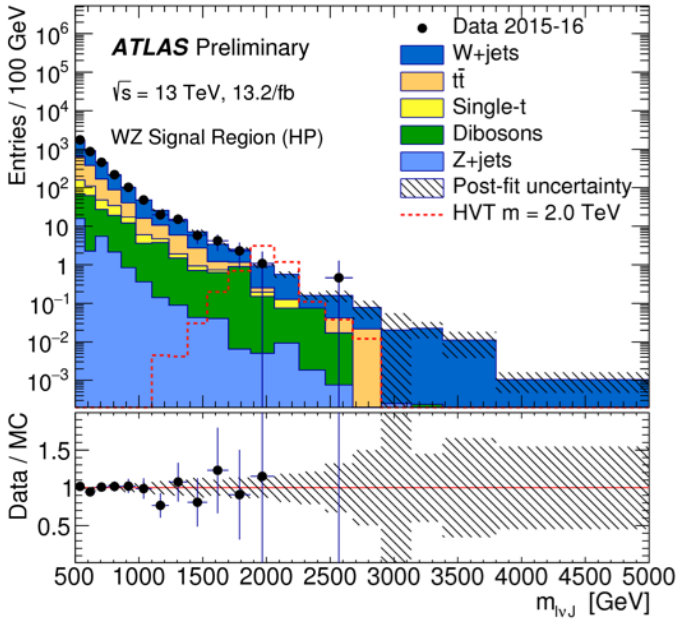


Fully hadronic:

- RSG, HVT, S decaying to WW/ZZ/WZ→qqqq
- Boosted jet tagged to Z or W
- Background from fit

ATLAS-CONF-2016-055



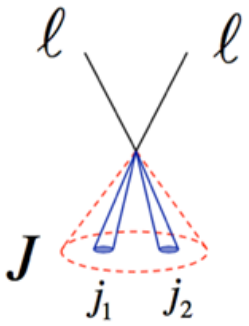


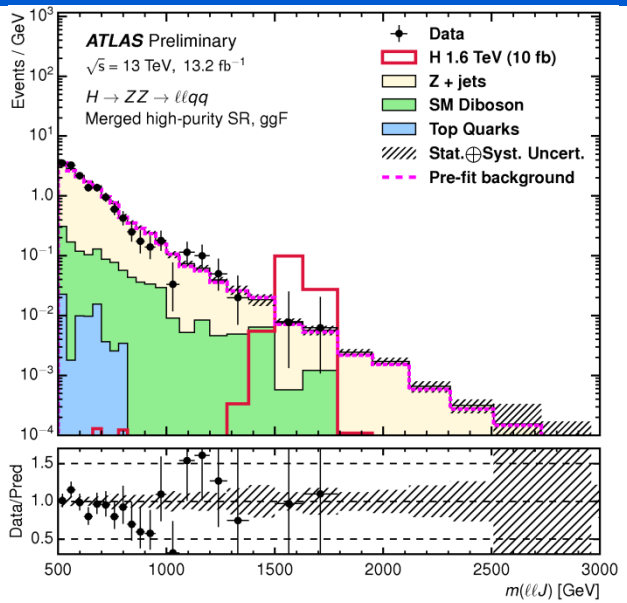
WV with W→ℓν

- jet tagged to Z or W + 1 lepton + MET>100 Gev
- Background from MC checked in CR

ATLAS-CONF-2016-062

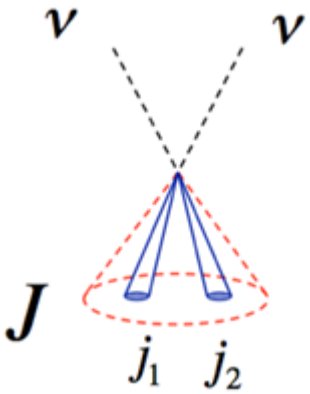
Di-boson resonanses

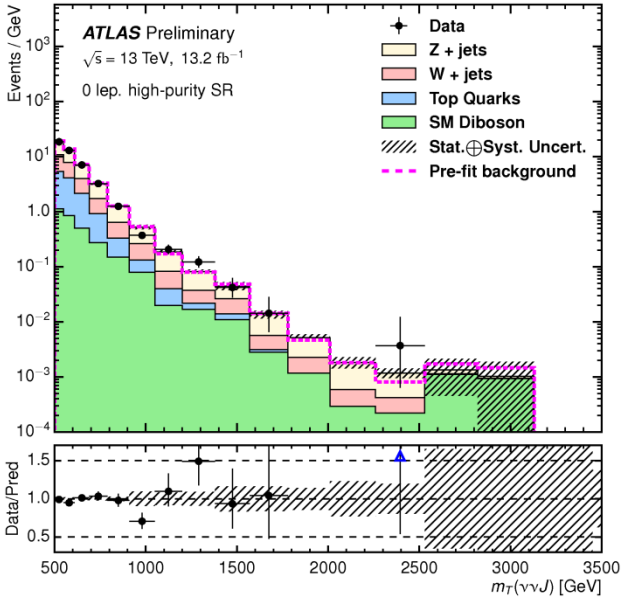




- ZV with Z→ℓℓ
- jet tagged to Z or W and 2 leptons giving Z-mass

ATLAS-CONF-2016-082





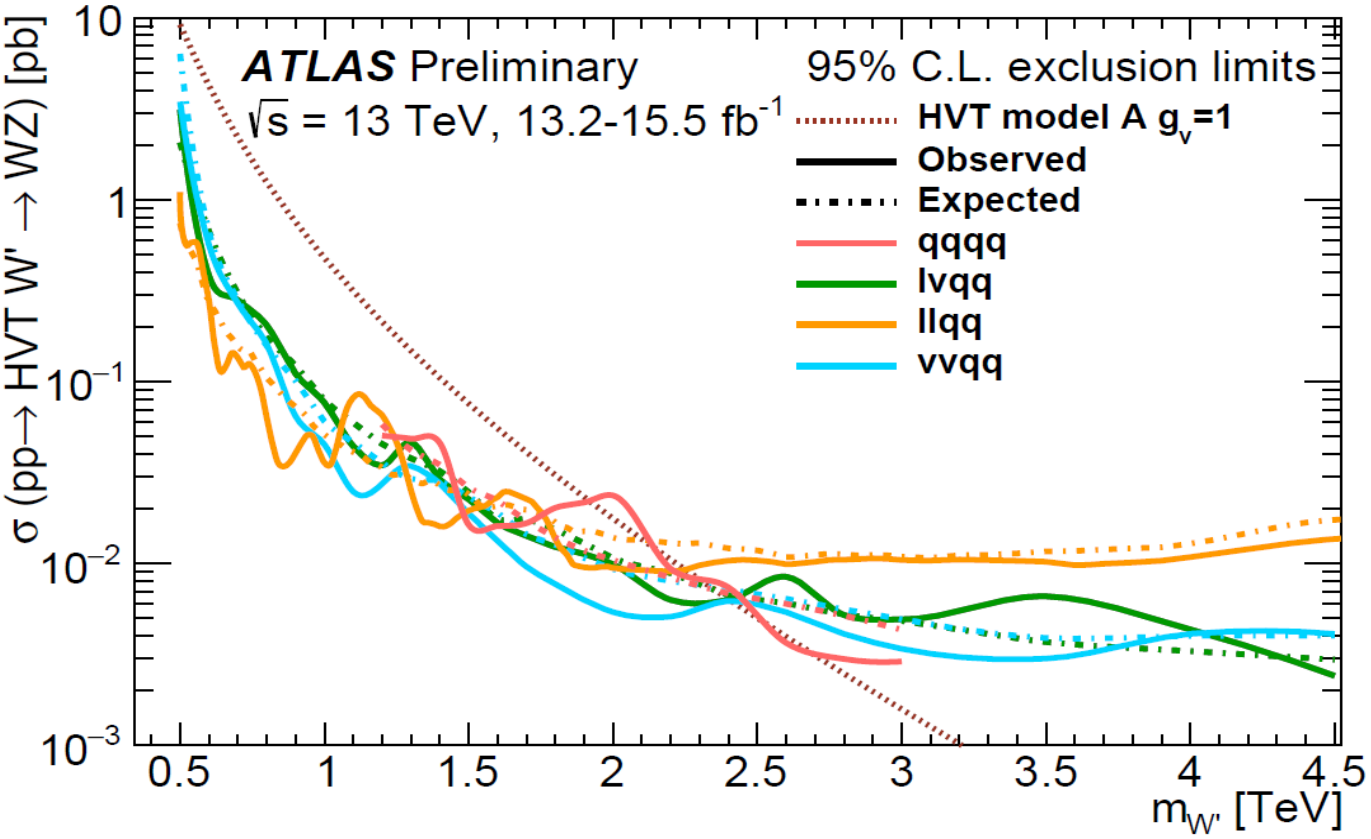
- ZV with Z→νν
- jet tagged to Z or W and MET > 200 GeV

- Background estimated from MC and checked in CR

Di-boson result summary

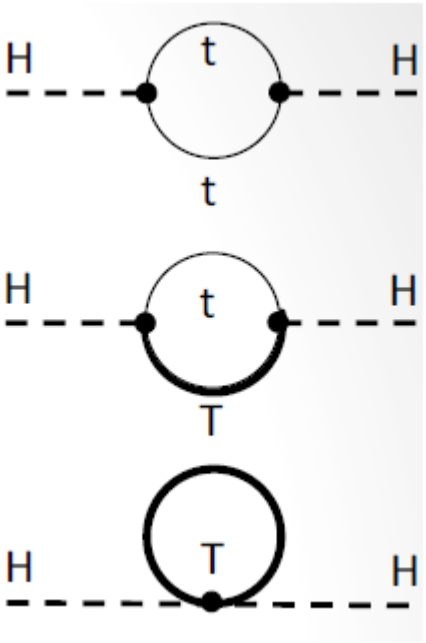
RSG excluded up to 2 TeV

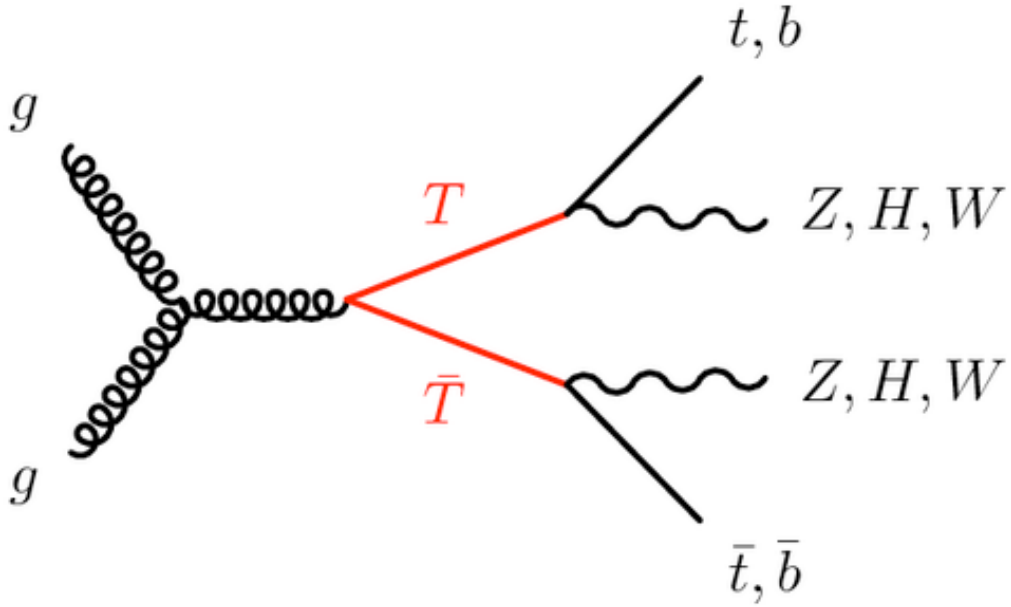
HVT W' excluded up to 2.4 TeV



- Expected and observed limits on the cross section times branching fraction to WZ for a new heavy vector boson W' at √s=13 TeV. The different limit curves correspond to different decay modes for the W and Z bosons.

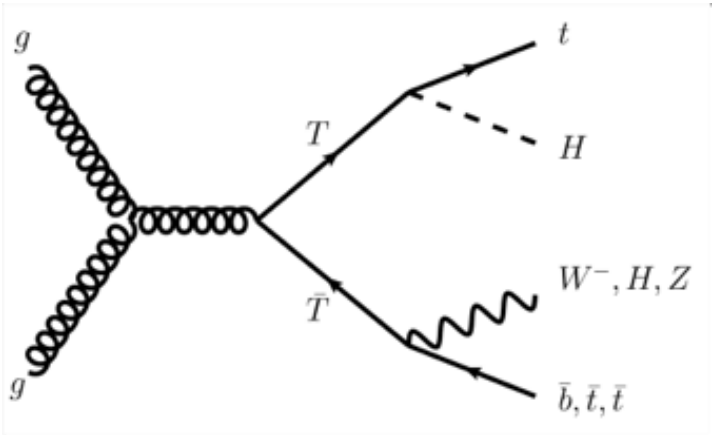
Vector-Like Quarks (VLQ)





- Vector-like partner quark predicted by Little Higgs models, Composite Higgs models etc.
- spin-1/2, colored, same transformation for left and right chirality, couples to third generation
- t-partners searches are presented here, but ATLAS searches for b-partners and for light quark partners also

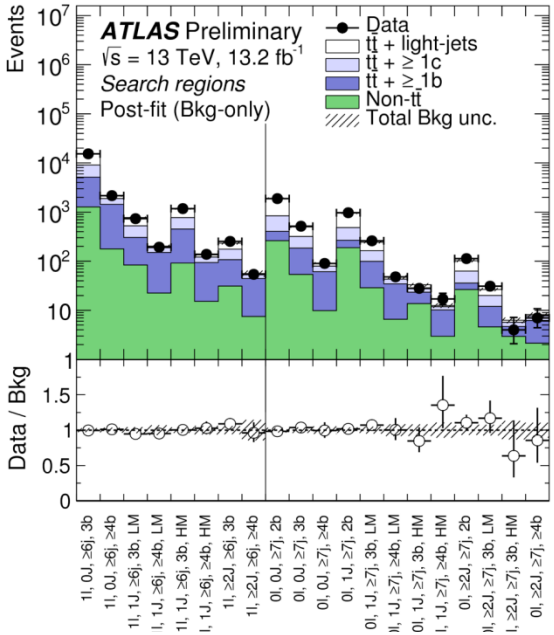
Vector-Like Quarks

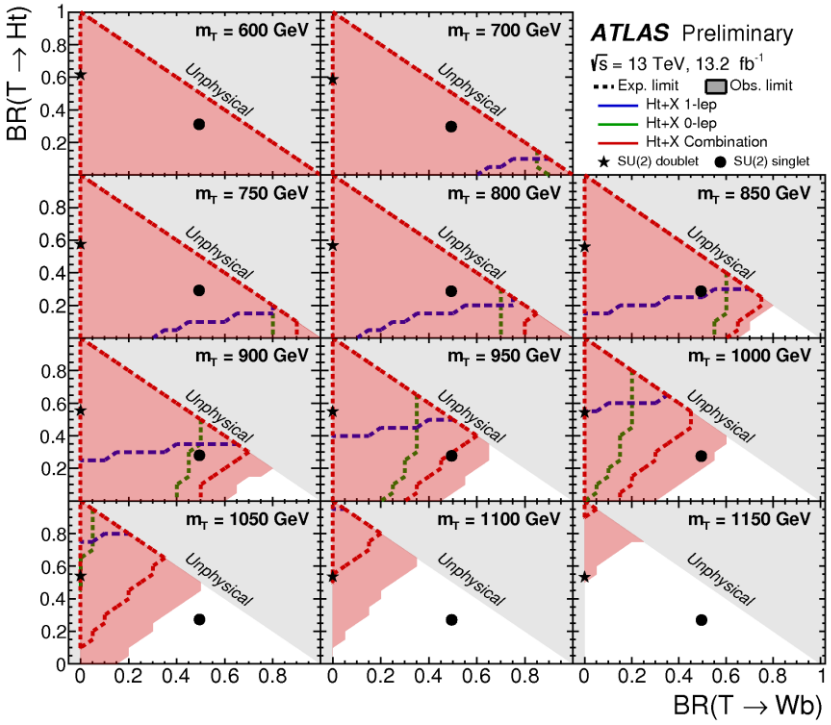


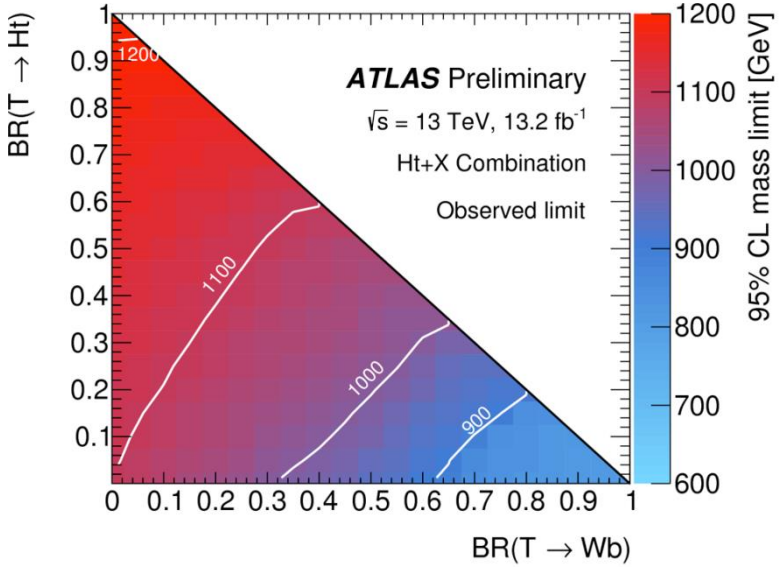
T→Ht

ATLAS-CONF-2016-104

Model-independed limit in 2D BR plane

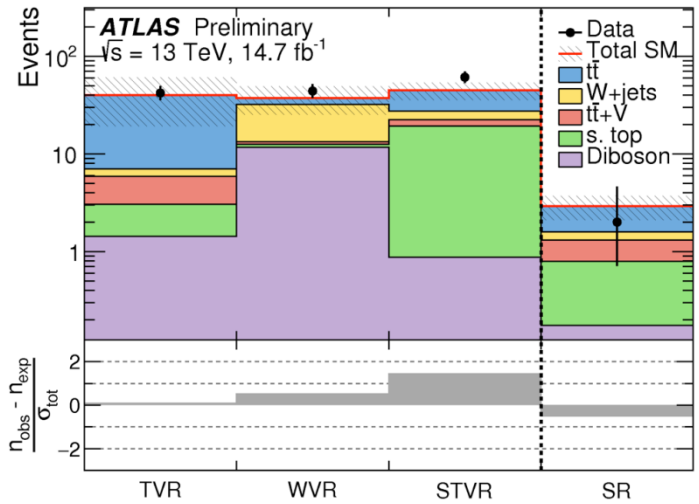


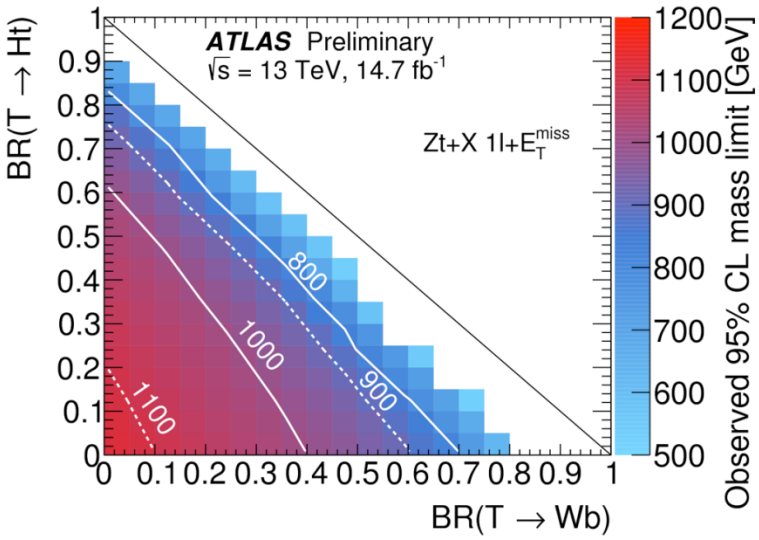




Vector-Like Quarks

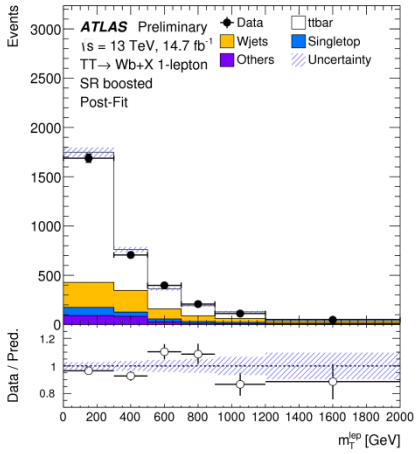
T→Zt

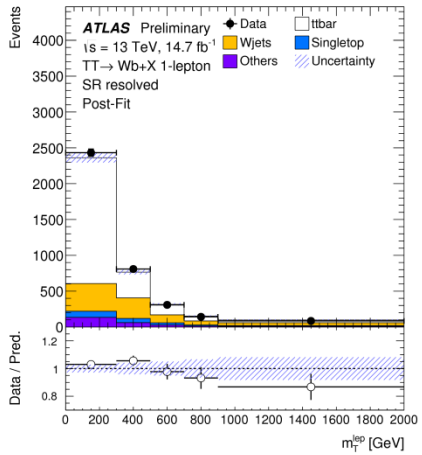


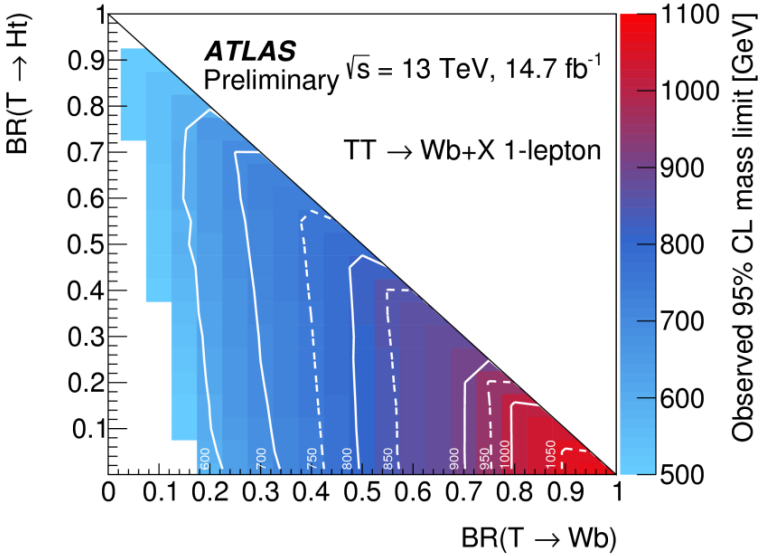


[ATLAS-CONF-2016-101]

T→Wb

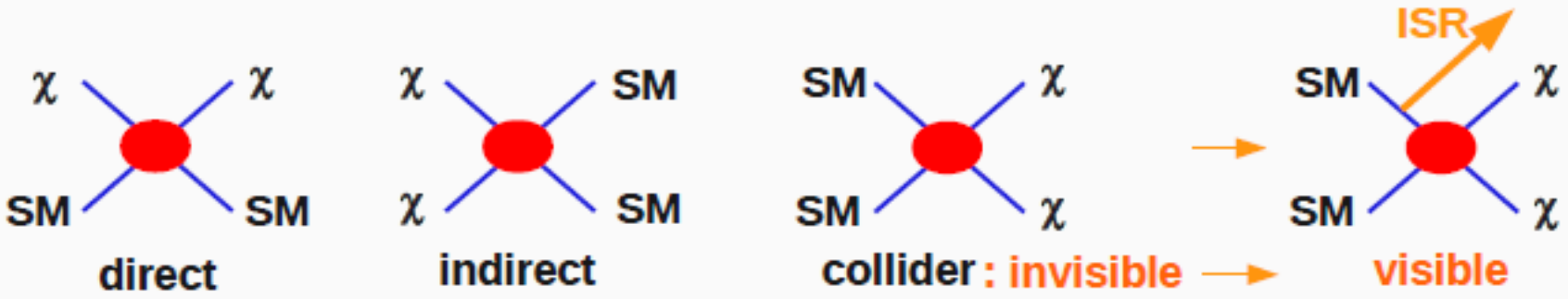




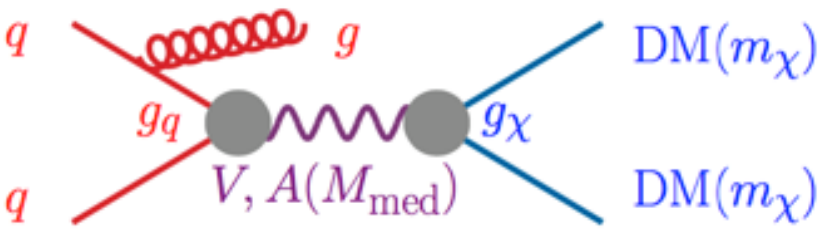


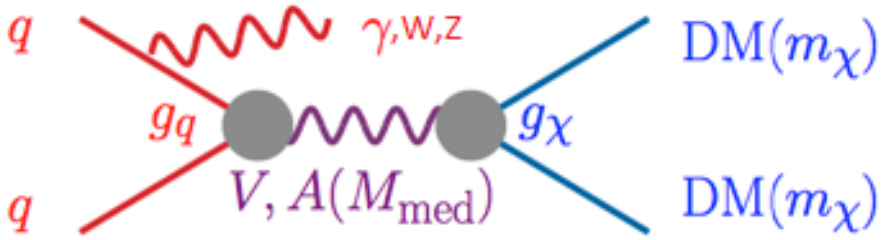
[ATLAS-CONF-2016-102]

Dark matter searches



- LHC has some advantages over direct searches
  - Probes higher energy scale
  - Can search DM particles with very low mass

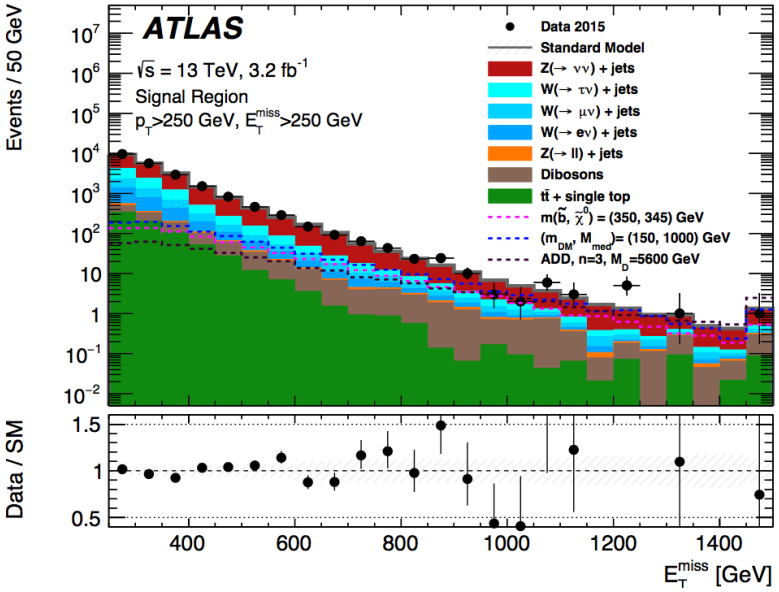




- using Simplified Models for Run II result interpretation

Mono-X searches

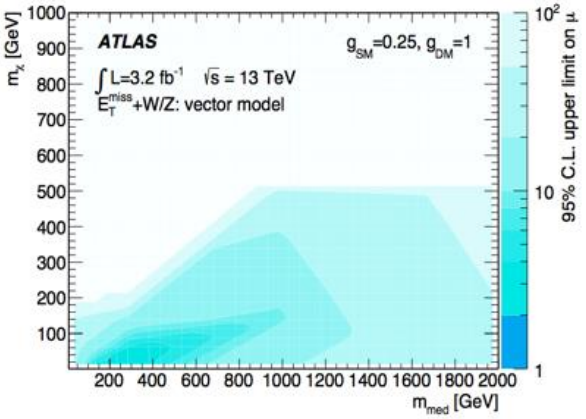
Mono-Jet [PRD 94 (2016) 032005]



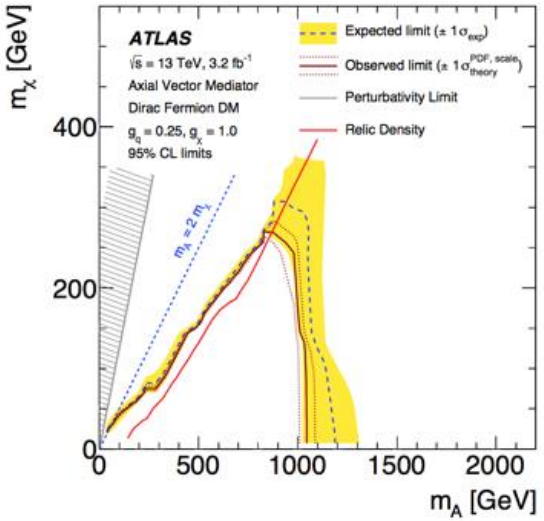
Mono-W/Z (hadronic)

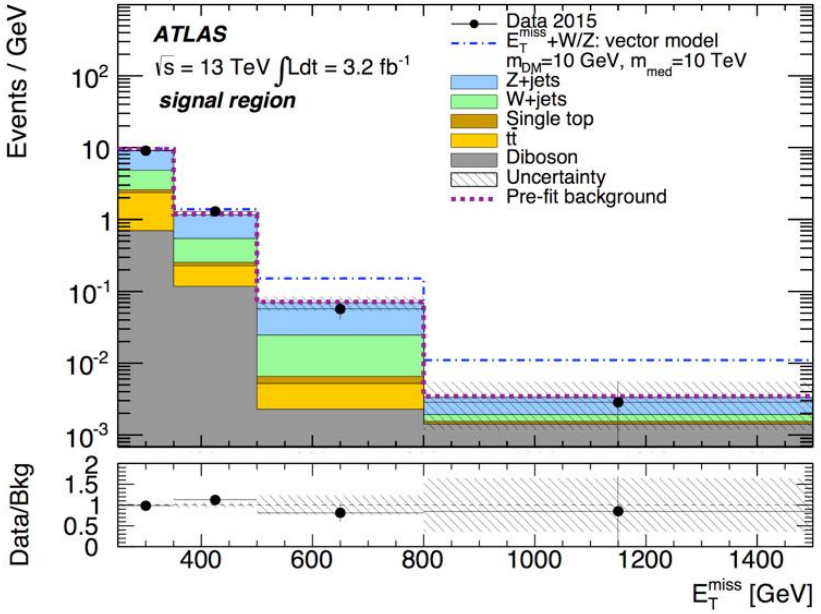
[Phys. Lett. B 763 (2016) 251]

W/Z targeted jet
+ MET> 200 GeV



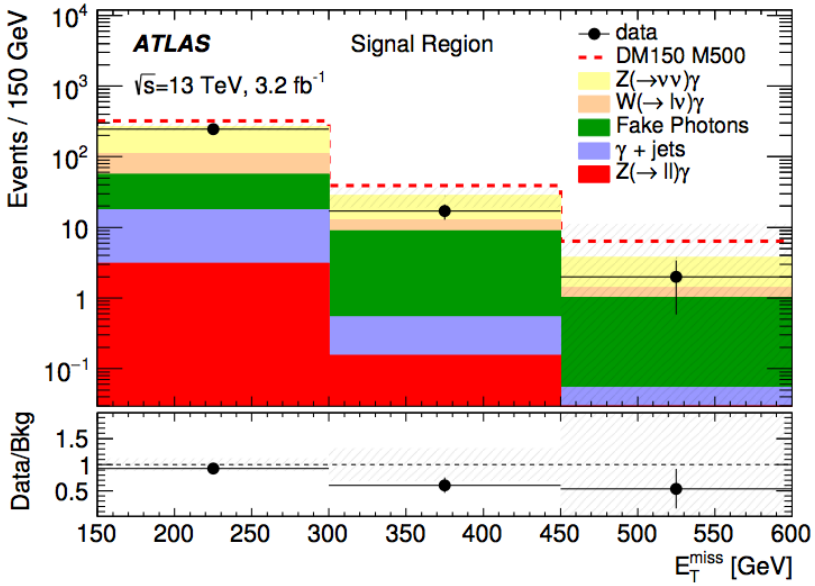
Jet+MET
both > 250 GeV
Highest rate

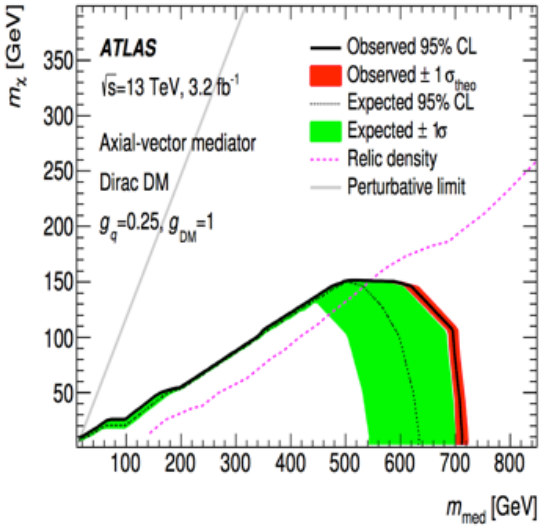




Mono-X searches

Mono-Photon [JHEP 06 (2016) 059]





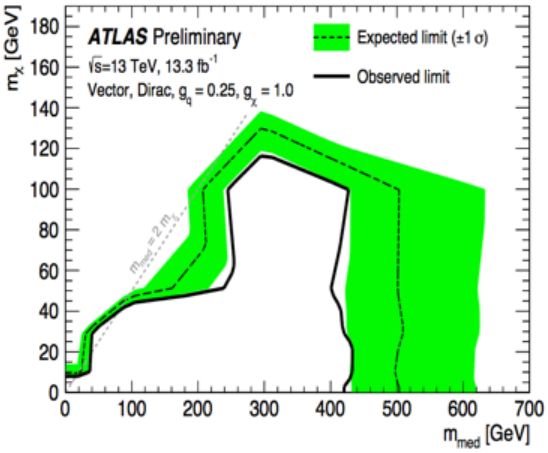
Gamma + MET > 150 GeV

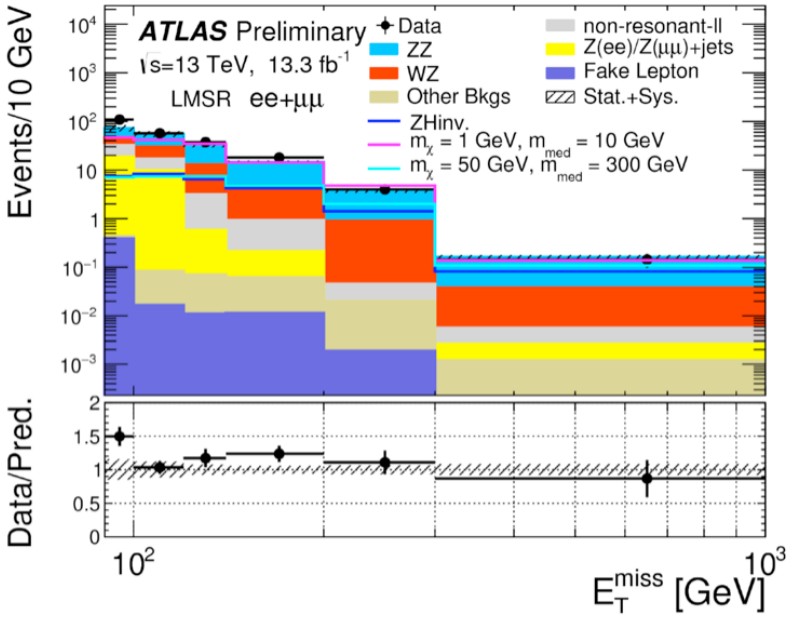
Clean final state

Mono-Z→ℓℓ [ATLAS-CONF-2016-056]

2 leptons + MET > 100 GeV

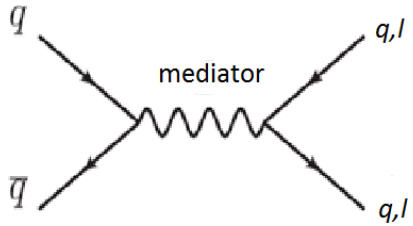
Cleanest final state



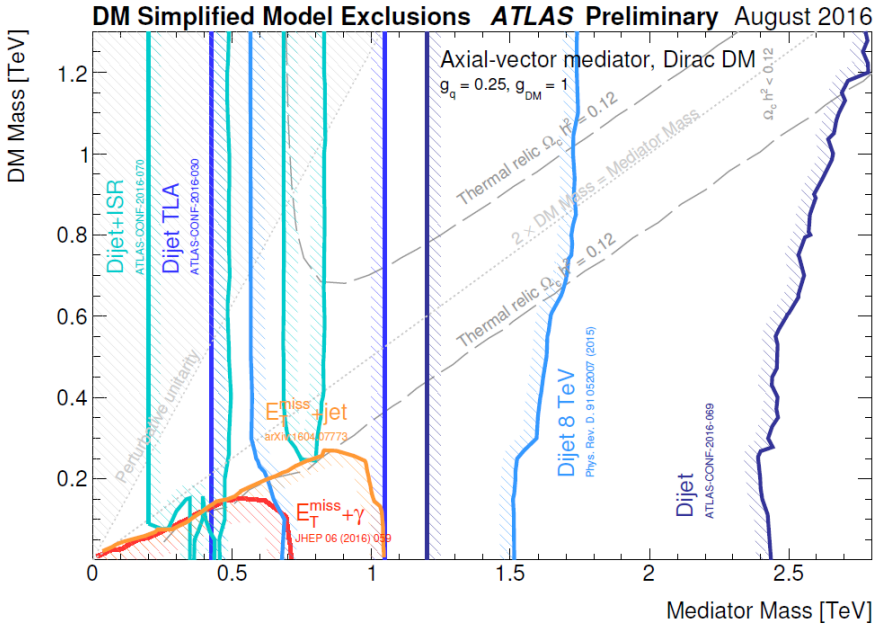


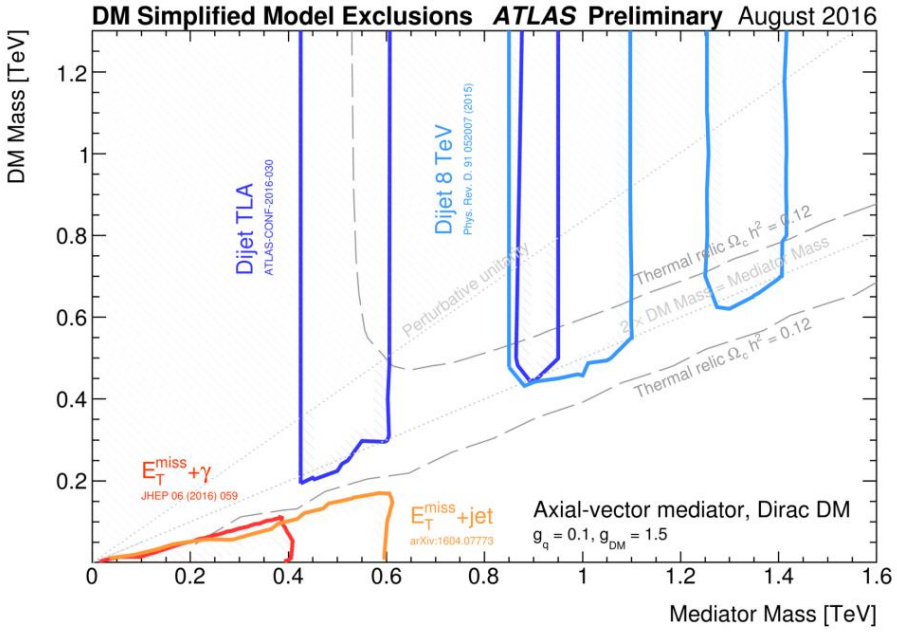
DM re-interpretation

- If DM mediator produced in annihilation of SM particles, it can decay to them



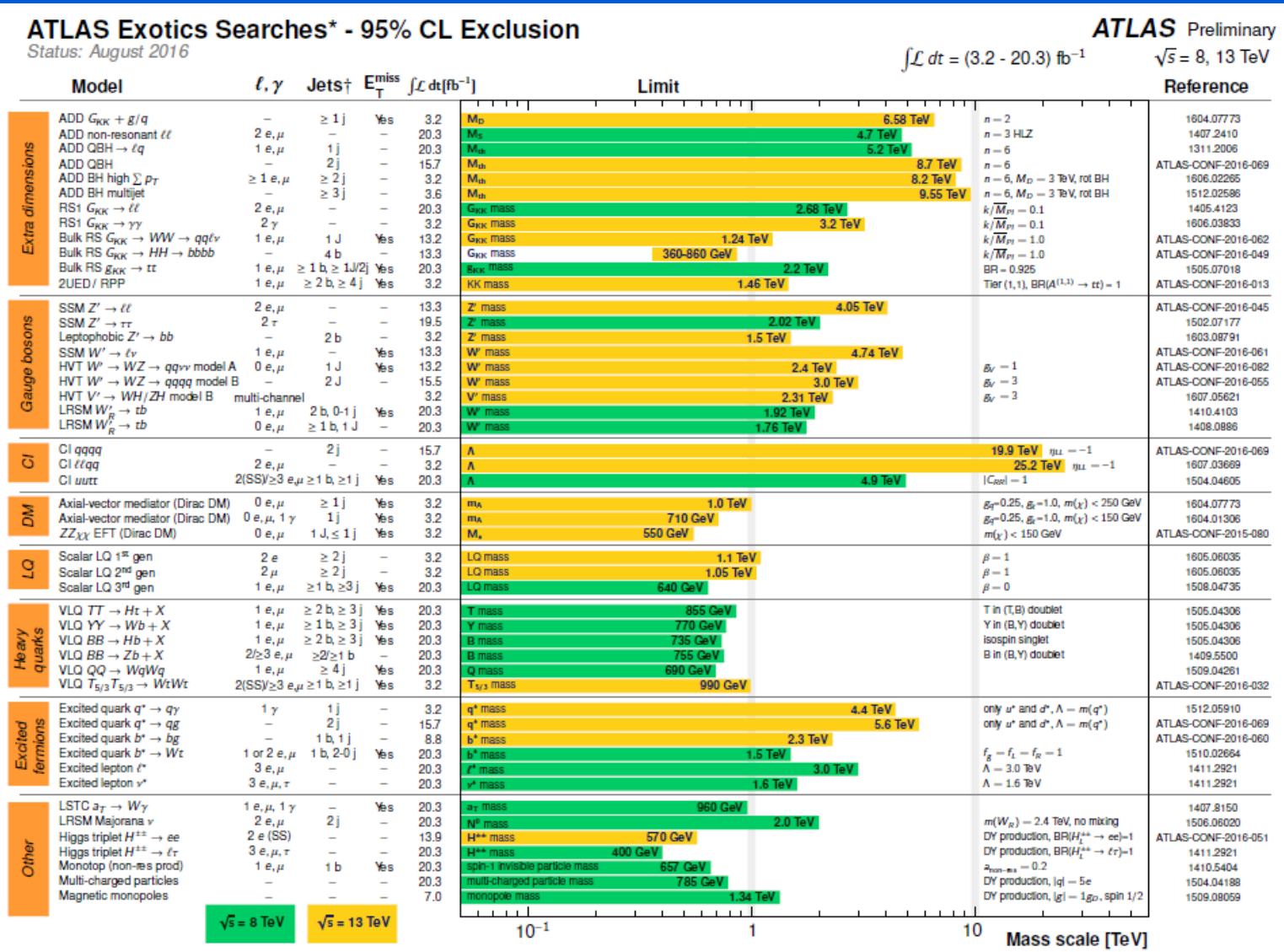
- Di-jet searches already used to probe DM mediator production





- We are working on adding of di-lepton to these plots

Exotics results



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

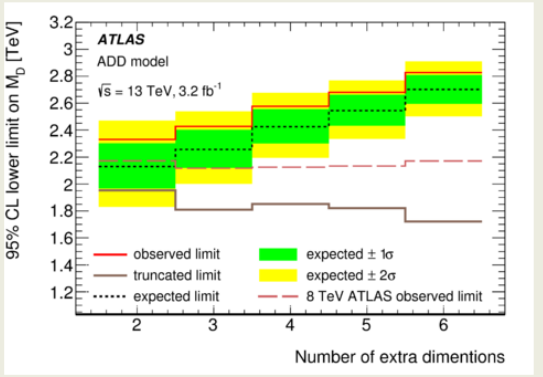
Result presentation

- **From ATLAS Public Result**

Search for new phenomena in events with a photon and missing transverse momentum in pp collisions at √s = 13 TeV with the ATLAS detector	Published in JHEP	Plots and more Info (+ HepData); arxiv:1604.01306, JHEP 06 (2016) 059	3.2/fb	Apr 2016

reaction keywords: [P P --> GRAVITON GAMMA X]
observable keywords: [EXCLUSION, LIMIT, M]

SQRT(S)	13000.0 GeV	
Number of extra dimentions	95% CL lower limit on M_D (untruncated) IN TeV	95% CL lower limit on M_D (truncated) IN TeV
2.	2.33196	1.954
3.	2.4264	1.809
4.	2.57671	1.853
5.	2.67995	1.822
6.	2.82594	1.722
	Plot SelectPlot	Plot SelectPlot



RE	P P --> Z(muon muon) + jets	
SQRT(S)	8000.0 GeV	
	Data	Background
E_T^{miss} IN GEV		Events
100.0 – 120.0	0.0	0.0 ± 0.0 (stat) ± 0.0 (sys)
120.0 – 130.0	0.0	0.0 ± 0.0 (stat) ± 0.0 (sys)
130.0 – 140.0	0.0	0.0 ± 0.0 (stat) ± 0.0 (sys)
140.0 – 150.0	0.0	0.0 ± 0.0 (stat) ± 0.0 (sys)
150.0 – 160.0	3339	3380.01 ± 26.45 (stat) ± 209.21 (sys)
160.0 – 170.0	2910	2831.27 ± 22.07 (stat) ± 170.29 (sys)
170.0 – 180.0	2274	2340.75 ± 19.28 (stat) ± 166.61 (sys)
180.0 – 200.0	3483	3473.36 ± 21.91 (stat) ± 231.83 (sys)
200.0 – 220.0	2454	2366.96 ± 17.68 (stat) ± 150.77 (sys)
220.0 – 250.0	2240	2191.48 ± 16.85 (stat) ± 156.35 (sys)
250.0 – 300.0	1736	1732.2 ± 13.83 (stat) ± 116.1 (sys)
300.0 – 350.0	691	755.76 ± 7.98 (stat) ± 46.14 (sys)
350.0 – 400.0	313	332.55 ± 5.21 (stat) ± 24.28 (sys)
400.0 – 450.0	160	165.93 ± 3.65 (stat) ± 13.08 (sys)
450.0 – 500.0	65	79.16 ± 2.28 (stat) ± 7.64 (sys)
500.0 – 600.0	61	66.13 ± 1.34 (stat) ± 4.75 (sys)
600.0 – 700.0	16	20.14 ± 0.65 (stat) ± 1.95 (sys)
700.0 – 800.0	2	6.65 ± 0.34 (stat) ± 0.50 (sys)
800.0 – 900.0	2	2.57 ± 0.25 (stat) ± 0.36 (sys)
900.0 – 1000.0	0.0	0.76 ± 0.09 (stat) ± 0.08 (sys)
1000.0 – 1300.0	0.0	0.33 ± 0.05 (stat) ± 0.11 (sys)
	Plot SelectPlot	Plot SelectPlot

- **Get any plot with data points**
- **Or histogram content with errors**

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https://arxiv.org/abs/1609.04572

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High Energy Physics - Experiment

Search for dark matter in association with a Higgs boson decaying to b-quarks in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

ATLAS Collaboration

(Submitted on 15 Sep 2016)

A search for dark matter pair production in association with a Higgs boson decaying to a pair of bottom quarks is presented, using 3.2 fb^{-1} of pp collisions at a centre-of-mass energy of 13 TeV collected by the ATLAS detector at the LHC. The decay of the Higgs boson is reconstructed as a high-momentum $b\bar{b}$ system with either a pair of small-radius jets, or a single large-radius jet with substructure. The observed data are found to be consistent with the expected backgrounds. Results are interpreted using a simplified model with a Z' gauge boson mediating the interaction between dark matter and the Standard Model as well as a two-Higgs-doublet model containing an additional Z' boson which decays to a Standard Model Higgs boson and a new pseudoscalar Higgs boson, the latter decaying into a pair of dark matter particles.

Comments: 36 pages in total, author list starting page 20, 4 figures, 2 tables, submitted to Phys. Lett. B. All figures including auxiliary figures are available at this https URL
Subjects: **High Energy Physics - Experiment (hep-ex)**
DOI: 10.1016/j.physletb.2016.11.035
Report number: CERN-EP-2016-181
Cite as: arXiv:1609.04572 **[hep-ex]**
(or arXiv:1609.04572v1 **[hep-ex]** for this version)

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https://atlas-web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2015-23/

Search for dark matter in association with a Higgs boson decaying to b-quarks in pp collisions at sqrt(s) = 13 TeV with the ATLAS detector

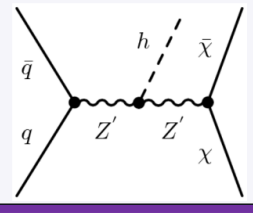
15 September 2016

Contact: ATLAS Exotic conveners

Content	Preview
e-print arXiv:1609.04572	pdf from arXiv
Inspire record	-
Figures, Tables and Auxiliary Material	-

Figures

Figure 1a:
Diagrams showing the simplified models where (a) a Z^{8}prime; decays to a pair of DM candidates χanti-χ after emitting a Higgs boson h, and where (b) a Z^{8}prime; decays to a Higgs boson h and the pseudoscalar A of a two--Higgs--doublet model, and the latter decays to a pair of DM candidates χanti-χ.



png (4kB), pdf (24kB)

- From arXive page with this link all plots and auxiliary data on ATLAS Public Result page are available
- If you need you can easy contact ATLAS Exotics conveners

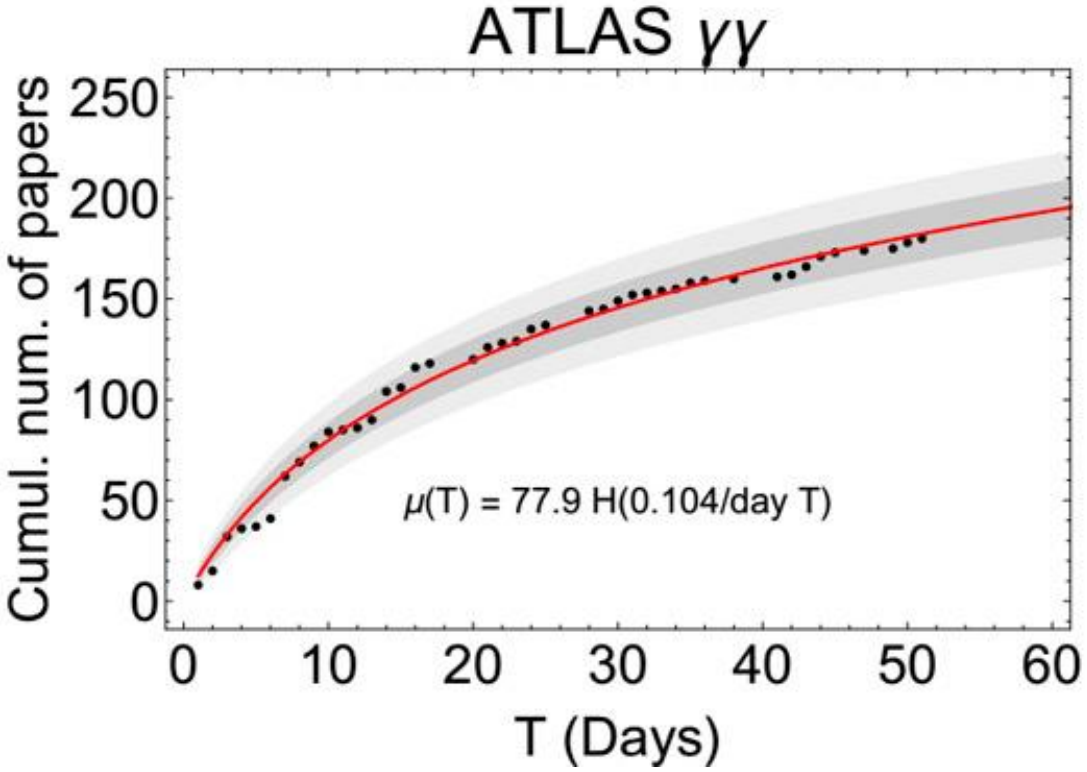
CONCLUSION

- Excellent operation of LHC allow ATLAS significantly improve sensitivity for Beyond Standard Model searches in Run II
- Search program was extended to new signatures and scenarios
- No BSM hint found ☹
- But 1/3 of 2016 dataset is used
- More results coming early next year
- ATLAS is doing best to present results as useful as possible and always in touch with CMS and theorists within joint working groups such as Dark Matter Working Group (https://arxiv.org/abs/1507.00966) or New Particles Working Group (https://arxiv.org/abs/1311.0299)

THANK YOU

Result and interpretation

https://arxiv.org/pdf/1603.01204v1.pdf



- ~100 papers in 15 days after di-photon excess announced