Jet searches with ATLAS: first results in Run 2

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LUND
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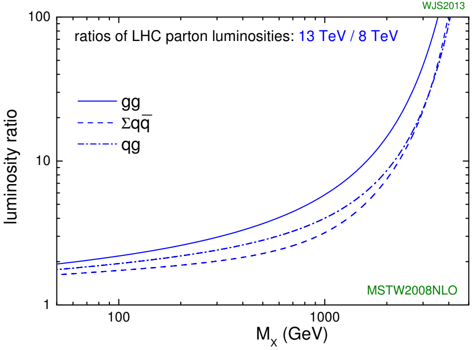
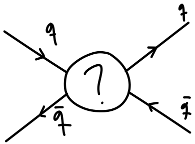
Why jets, and why now?



LHC Run2 = energy upgrade:
$\sqrt{s} = 8 \rightarrow 13$ TeV



- Hadron collider: processes couple to partons
- Access to energy frontier
  - highest mass reach
  - smallest scales

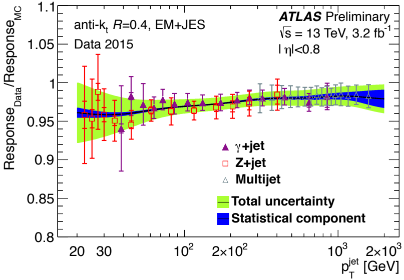
Some recent results involving jets

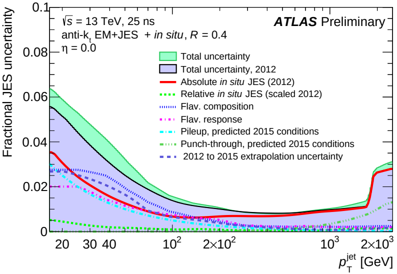
All info here

Search for...	Reference	Int. luminosity
... new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	PLB 754 (2016) 302-322	3.6/fb
... strong gravity in multijet final states produced in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC	arxiv:1512.02586 (JHEP)	3.6/fb
... new phenomena with photon+jet events in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	arxiv:1512.05910 (JHEP)	3.2/fb
... diboson resonances in the $\nu\nu qq$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-068	3.2/fb
... diboson resonances in the $\ell\ell qq$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-071	3.2/fb
... resonances with boson-tagged jets in 3.2/fb of pp collisions at $\sqrt{s} = 13$ TeV collected with the ATLAS detector	ATLAS-CONF-2015-073	3.2/fb
... new resonances decaying to a W or Z boson and a Higgs boson in the $\ell\ell b\bar{b}$, $\ell\nu b\bar{b}$, and $\nu\nu b\bar{b}$ channels in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-074	3.2/fb
... WW/WZ resonance production in the $\ell\nu qq$ final state at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-075	3.2/fb
... dark matter produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-080	3.2/fb
... TeV-scale gravity signatures in high-mass final states with leptons and jets with the ATLAS detector at $\sqrt{s} = 13$ TeV	ATLAS-CONF-2015-046	80/pb

$\Rightarrow$ Jets are everywhere!

Understanding jets





Jet conditions very similar between Run 1 and 2

- MC-based calibration, validated *in situ* using p_T balance with reference objects
- Cover 2 orders of magnitude in p_T
- Different beam and detector conditions in 2015, mostly affect low p_T
- Small differences at high p_T, predominantely jet punch-through

⇒ based on Run 1 experience, we can do jets with early 2015 data!

Plots available here

Results discussed in this talk

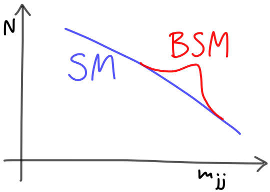
All info here

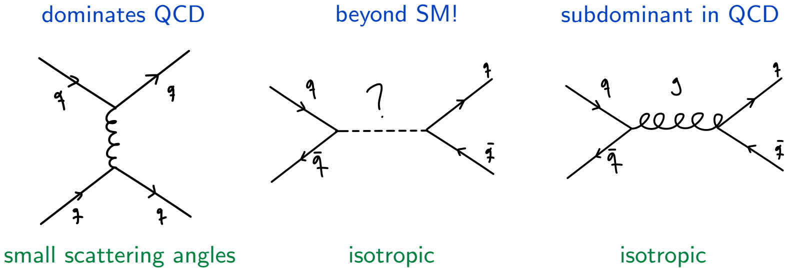
Search for...

	Reference	final state
... new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	PLB 754 (2016) 302-322	jets
... strong gravity in multijet final states produced in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC	arxiv:1512.02586 (JHEP)	more jets
... new phenomena with photon+jet events in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	arxiv:1512.05910 (JHEP)	something more than jets
... new resonances in events with one lepton and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-063	
... diboson resonances in the $\nu\nu qq$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-068	
... diboson resonances in the $\ell\ell qq$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-071	
... resonances with boson-tagged jets in of pp collisions at $\sqrt{s} = 13$ TeV collected with the ATLAS detector	ATLAS-CONF-2015-073	
... new resonances decaying to a W or Z boson and a Higgs boson in the $\ell\ell b\bar{b}$, $\ell\nu b\bar{b}$, and $\nu\nu b\bar{b}$ channels in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector	ATLAS-CONF-2015-074	
... WW/WZ resonance production in the $\ell\nu qq$ final state at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-075	
... dark matter produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-080	
... TeV-scale gravity signatures in high-mass final states with leptons and jets with the ATLAS detector at $\sqrt{s} = 13$ TeV	ATLAS-CONF-2015-046	

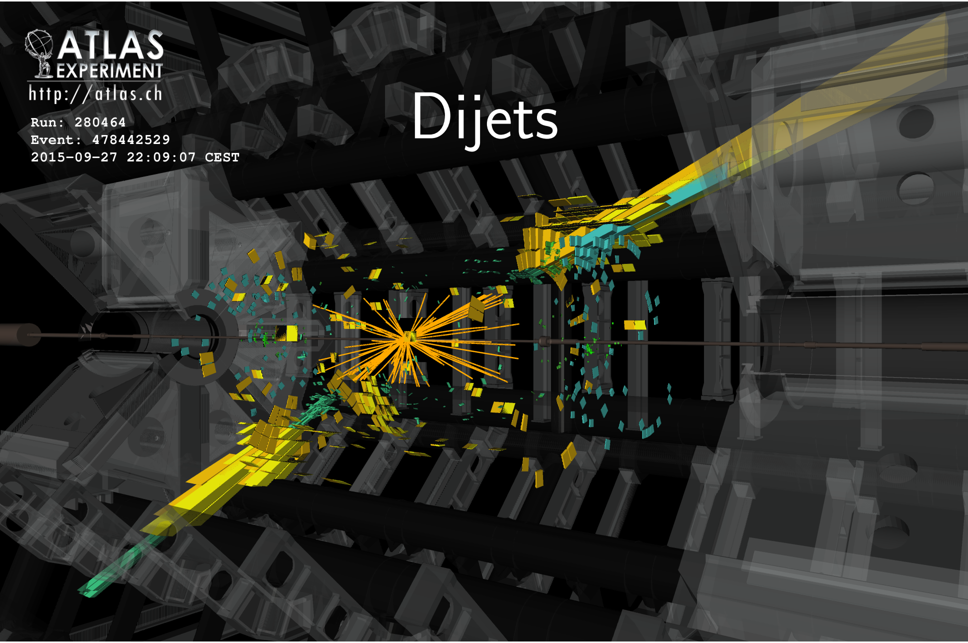
Common logic (dijet example)

- The invariant mass of outgoing objects probes the scale of the process
- No new scales in SM (smooth)





Dijets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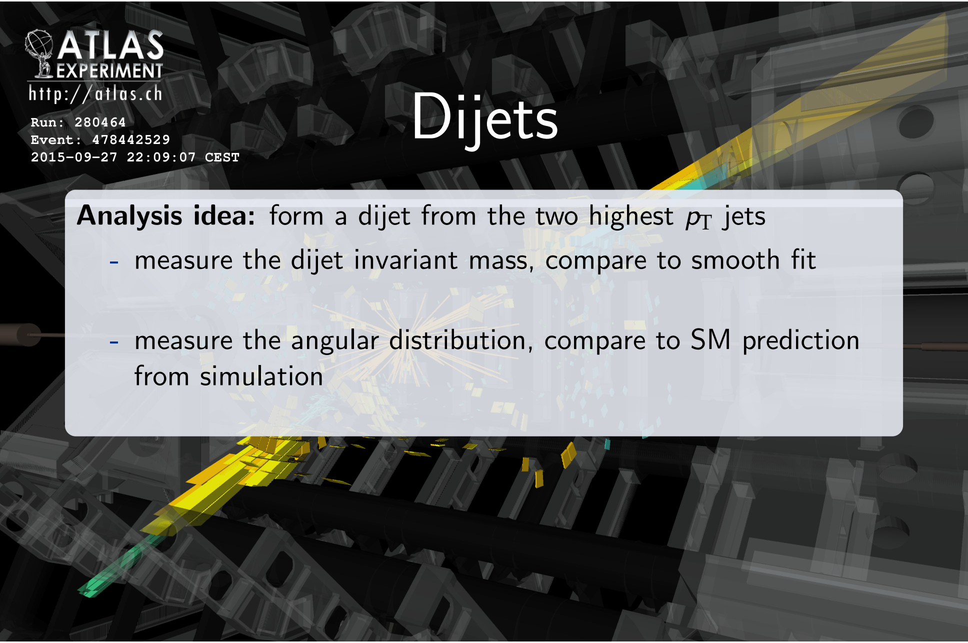
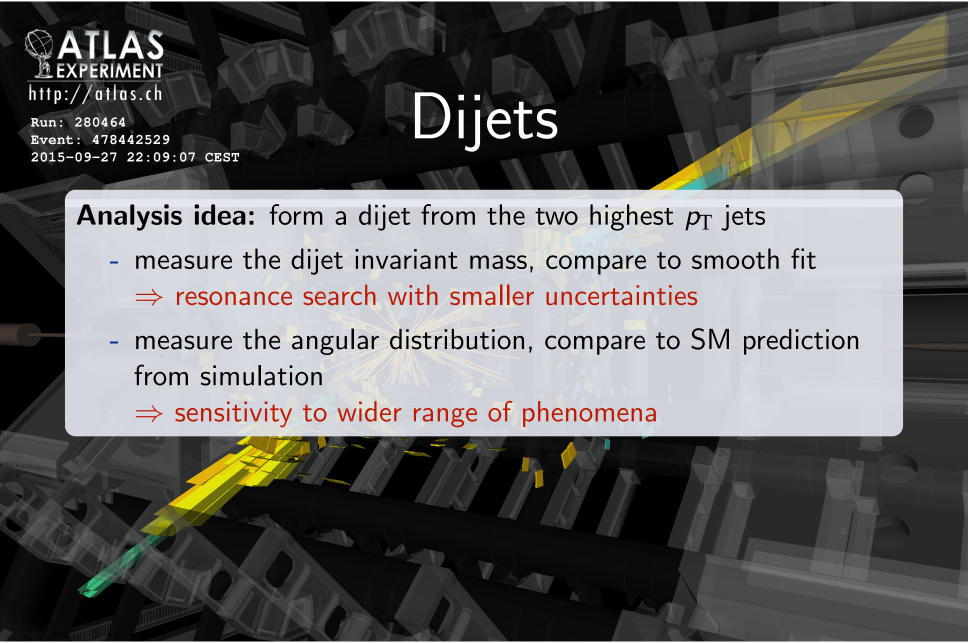
Run: 280464
Event: 478442529
2015-09-27 22:09:07 CEST

Dijets



Analysis idea: form a dijet from the two highest p_{T} jets

- measure the dijet invariant mass, compare to smooth fit
- measure the angular distribution, compare to SM prediction from simulation

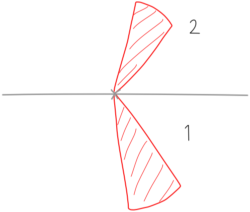


Dijets

Analysis idea: form a dijet from the two highest p_{T} jets

- measure the dijet invariant mass, compare to smooth fit
  $\Rightarrow$ resonance search with smaller uncertainties
- measure the angular distribution, compare to SM prediction from simulation
  $\Rightarrow$ sensitivity to wider range of phenomena

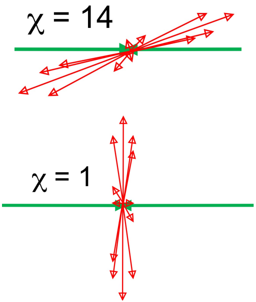
large Δy: more QCD-like



$$y = \ln\left(\frac{E+p_z}{E-p_z}\right)$$

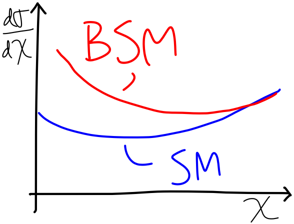
$$y^* = \frac{y_1 - y_2}{2}$$

$$\chi = e^{2|y^*|} = e^{|\Delta y|}$$

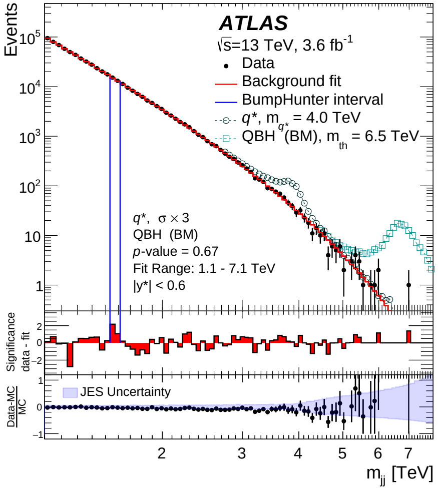


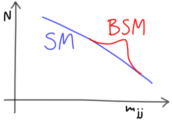
small Δy: more BSM-like

- The distribution in χ (or y^*): isotropy measure
  - we can cut on, or, measure it!
- The distribution in m_{jj}: scale measure
  - measure, or, bin in it!



Dijet mass distribution

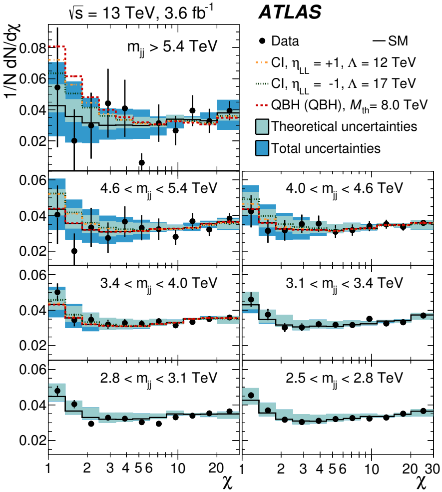


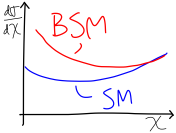


- $|y^*| < 0.6$ (suppress QCD)
- data m_{jj} compared to smooth fit: $f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\log(x)}$, where $x = m_{jj}/\sqrt{s}$
- hypothesis testing to choose the number of non-zero parameters
  - 3 parameters sufficient
- BumpHunter excludes any significant deviations and refits

No significant excess seen

Dijet angular distributions





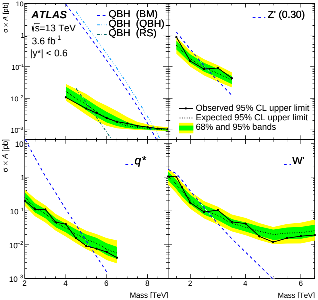
- $|y^*| < 1.7$ – *measure* isotropy
- QCD NLO and EW corrected PYTHIA prediction normalised to data integral
  - normalisation greatly reduces uncertainty (esp. PDF)
- largest systematic uncertainties:
  - theoretical: renormalisation and factorisation scale choice
  - experimental: jet energy scale uncertainty
- combined fit of MC to data in four highest m_{jj} regions

No significant excess seen

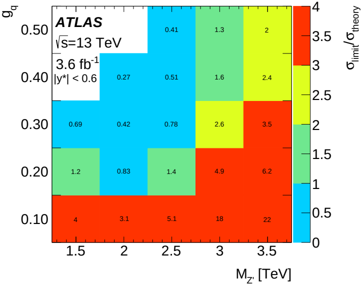
New limits: models + generic Gaussian signal

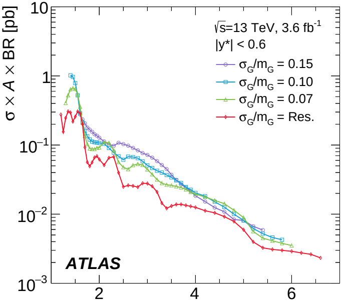
model details

Resonant models

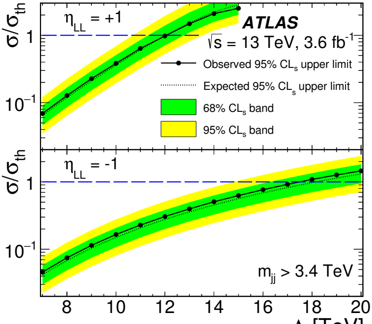


Dark matter model



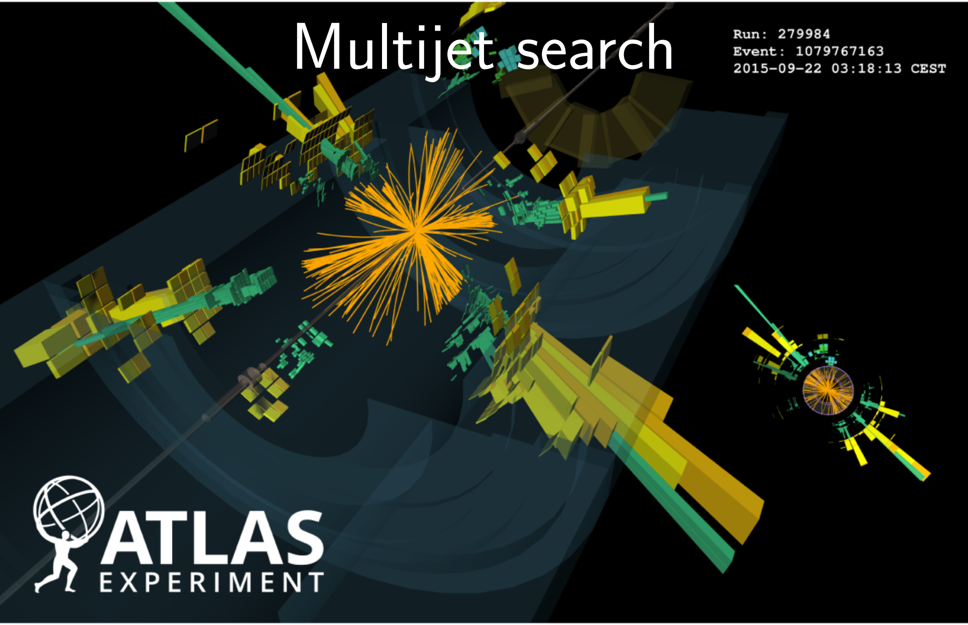


Generic Gaussians for recast

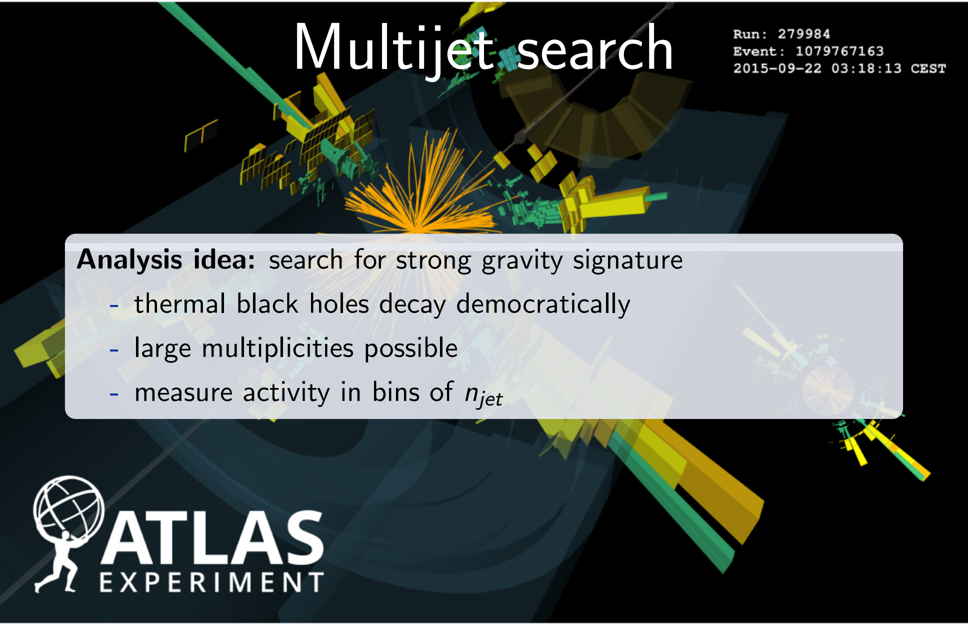


Non-resonant Contact Interaction

Multijet search



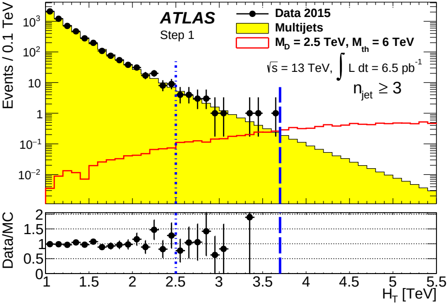
Multijet search



Analysis idea: search for strong gravity signature

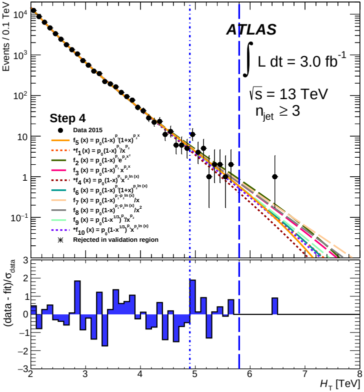
- thermal black holes decay democratically
- large multiplicities possible
- measure activity in bins of n_{jet}

ATLAS EXPERIMENT



- Capture overall large activity in $H_T = \sum_{jets \in \{p_T^{jet} > 50 \text{ GeV}\}} |p_T|$
- Define Control, Validation and Signal Region (CR, VR, SR) based on signal expectation
  - given by signal strength at previous limit
  - bootstrap: re-define regions and search in incrementally larger data sets

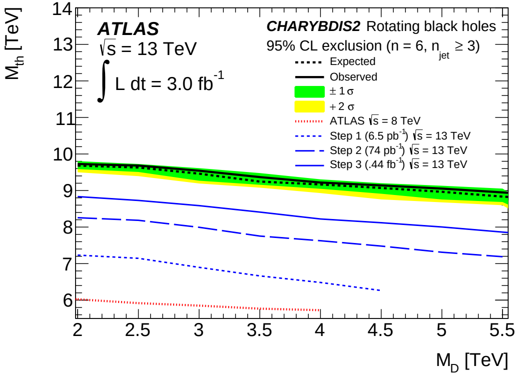
- Smooth fit to data (10 functions tested)
  - assess fit quality in low-H_T CR
  - check extrapolation in VR
  - analyse data agreement with baseline function in SR (highest H_T)
- Systematic uncertainty from non-baseline functions



No significant excess seen

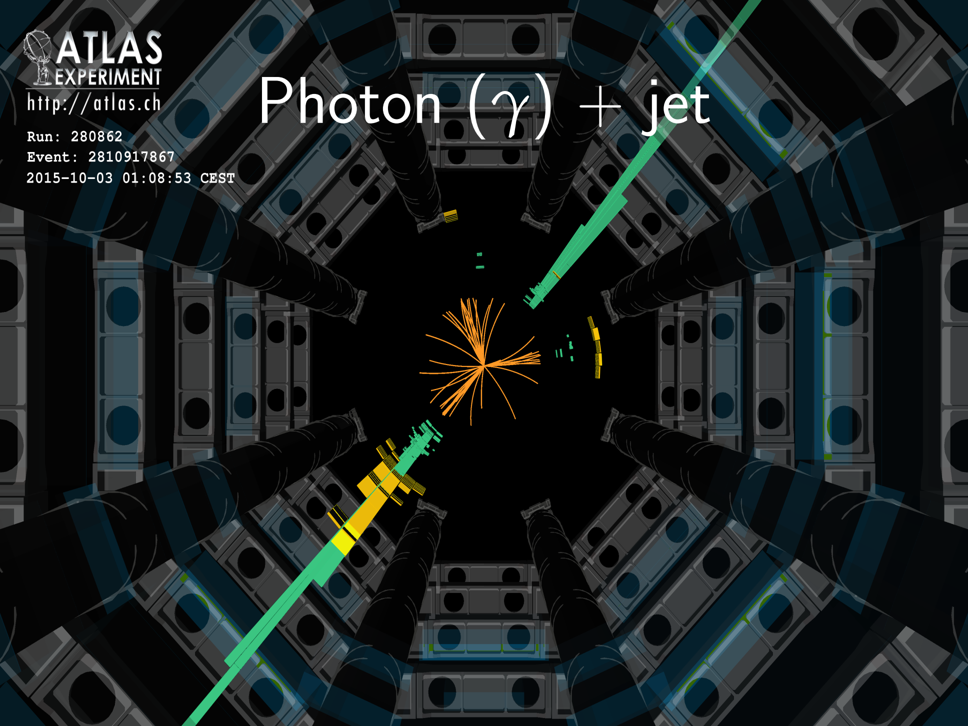
Multijet limits

model details



- rotating thermal black holes in an ADD scenario, 6 extra dimensions
- black hole production threshold mass M_{th} and fundamental Planck scale M_D
- limits at incremental stages shown

ATLAS 8 TeV result here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http://atlas.ch
Run: 280862
Event: 2810917867
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Photon (γ) + jet

ATLAS EXPERIMENT
http://atlas.ch

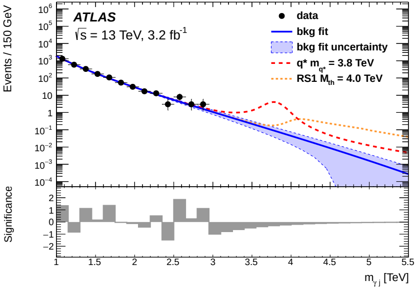
Run: 280862
Event: 2810917867
2015-10-03 01:08:53 CEST

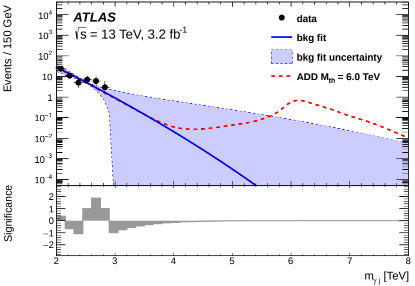
Photon (γ) + jet

Analysis idea: similar to dijet philosophy, but one jet $\rightarrow \gamma$

- invariant mass spectrum of γ + jet from QCD Compton scattering background
- search for s-channel resonance
- excited quark decays $q^* \rightarrow q\gamma$, non-thermal black holes with low multiplicity

γ + jet



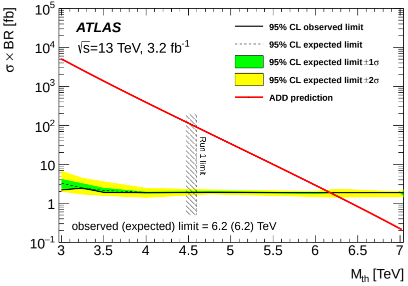


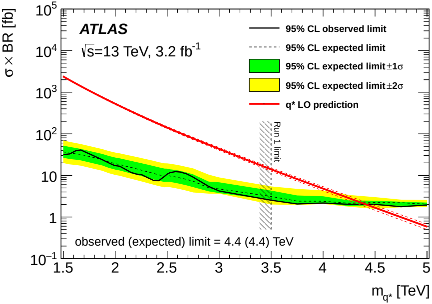
- $\mathcal{O}(100)$ suppressed by smaller coupling
- suppress QCD: cut on $|\Delta\eta| \leq 1.6$
- data $m_{\gamma j}$ compared to smooth fit: $f(x) = p_1(1-x)^{p_2}x^{-p_3-p_4\log(x)}$, where $x = m_{\gamma j}/\sqrt{s}$
- model dependent fit, range achieving sufficient sidebands

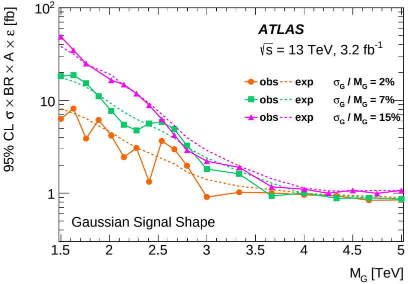
No significant excess seen

γ + jet limits: on models + generic Gaussians

model details







- Model-dependent limits (Quantum black holes, excited quarks) improved over Run 1
- Somewhat weaker limits than dijets but complementary final state
- Generic Gaussians for theory recasts with finer width

ATLAS 8 TeV result here

Conclusions

- Jets probe the collider energy frontier
- Jet searches benefit greatly from increased beam energy
- I have shown results from analyses entering new phase space
- We see no significant excesses
  - narrow down parameter space for a range of models
  - generic Gaussians provided for recast of resonant models

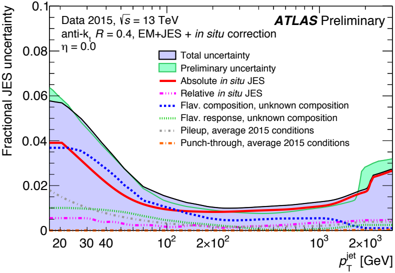
Just beginning to explore the energy regime opened up with LHC in Run2!

Coming soon: evolutions of the dijet search from ATLAS.

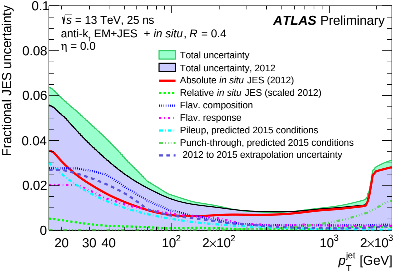
Backup

Understanding JES

green: pre-recommendation (winter) 2015 JES
blue: final **2015** JES



green: pre-recommendation (winter) 2015 JES
blue: final **2012** JES



Pre-recommendation: conservative, especially punch-through

Comparing final 2012 and 2015:

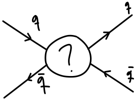
- Small increase at low p_{T}: pile-up
- Decrease at high p_{T}: reduced statistical uncertainty!

$\Rightarrow$ the energy frontier will only get better!

Details on event selection (all jets: anti-k_t, $R = 0.4$)

- dijets
  - trigger: single jet, $p_\mathrm{T} > 360$ GeV
  - leading jet $p_\mathrm{T} > 440$ GeV ($> 99.5\%$ efficient trigger)
  - two or more jets (second jet $p_\mathrm{T} > 50$ GeV)
  - y^* cut: $|y^*| \equiv \frac{|y_1 - y_2|}{2} < 0.6$ for mass, $|y^*| < 1.7$ for angular distributions
  - y_B cut: $|y_B| \equiv \frac{|y_1 + y_2|}{2} < 1.1$ for angular distributions
  - m_{jj} cut for unbiased kinematics: $m_{jj} > 1.1$ TeV for mass, 2.5 TeV for angular distributions
- multijet
  - H_T trigger, at least one jet with $p_\mathrm{T}^{jet} > 200$ GeV, $H_T > 0.85$ TeV
  - $H_T > 1$ TeV (fully efficient trigger)
  - H_T is the scalar p_T sum of all jets with $p_\mathrm{T}^{jet} > 50$ GeV, within $|\eta| < 2.8$
- γ + jet
  - trigger: $p_\mathrm{T}^{\gamma} > 140$ GeV, loose photon identification criteria
  - $p_\mathrm{T}^{jet} > 150$ GeV, $m_{\gamma j} > 1$ TeV
  - $|\Delta\eta(\mathrm{jet}, \gamma)| < 1.6$

Signal models I

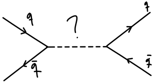


back to dijets

- Contact Interactions (CI)
  - effective four-point interaction model
  - characterised by compositeness scale Λ
  - and by destructive or constructive interference with the QCD process $q\bar{q} \rightarrow q\bar{q}$
  - Run 1 limits: 9.0 (CMS) and 12.0 TeV, respectively

    ATLAS 8 TeV result here
  - 2015 limits: 12.0 and 17.5 TeV (both ATLAS), respectively
  - generated together with QCD in PYTHIA8 and brought to NLO using CIJET
- (non-thermal) Quantum Black Holes
  - ADD scenario with fundamental quantum gravity scale $M_D = M_{th}$ (threshold mass), $n = 6$
  - also a RS scenario with $n = 1$
  - two generators: BLACKMAX and QBH
  - Run 1 limits: 5.6 and 5.7 TeV, respectively ATLAS 8 TeV result here
  - 2015 limits: 8.1 and 8.3 TeV, respectively
  - different modelling but final distributions mostly differ by cross section

Signal models II



back to $\gamma+$ jet

- leptophobic Z' boson
  - axial-vector couplings to SM quarks and a Dirac fermion dark matter candidate
  - decays to dark matter set negligible $\rightarrow$ rate to dijets depend on SM coupling g_q and mass $M_{Z'}$
  - no interference modelled
- W' boson
  - decays restricted to quark-antiquark pairs (all six flavours)
  - $V - A$ SM couplings
  - Run 1 dijet limit: 2.5 TeV ATLAS 8 TeV result here
  - 2015 dijet limit: 2.6 TeV
- q^*
  - excited quark decays to a gluon and up- or down-type quark, or
  - excited quark decays any flavour $q + \gamma$
  - compositeness scale set to m_{q^*}
  - SM like gauge interactions
  - coupling multipliers $f_s = f = f' = 1$
  - Run 1 dijet limit: 4.1 TeV ATLAS 8 TeV result here
  - 2015 dijet limit: 5.2 TeV

Signal models III

back to multijet

- rotating thermal micro black holes, and string balls
  - number of extra dimensions $n = 2, 4$ or 6
  - also a RS scenario with $n = 1$
  - implemented in CHARYBDIS
  - limits in the plane of $4 + n$-dimensional fundamental Planck scale M_D and M_{th}, string scale M_S and coupling g_S respectively
  - different modelling but final distributions mostly differ by cross section