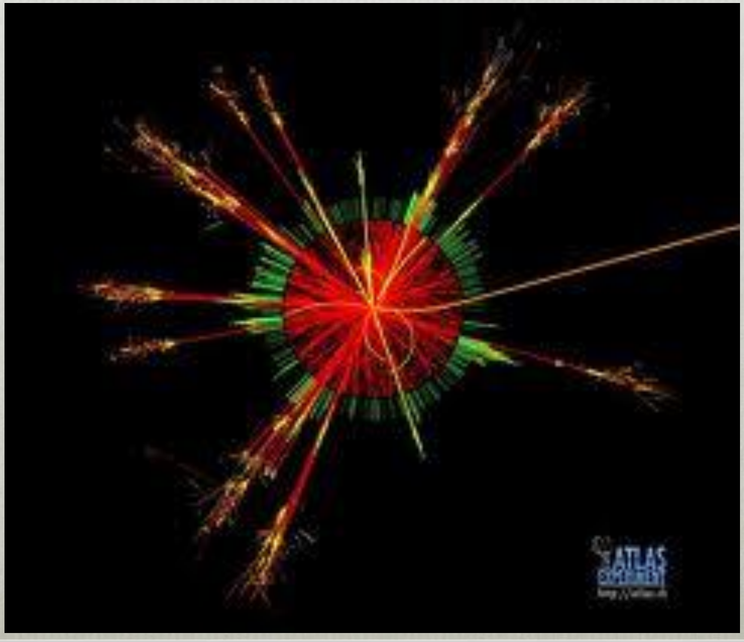
Boston Jets Workshop 2014

Jets in ATLAS Searches



Prof. Pierre-Hugues Beauchemin
Tufts University
Thu Jan 23th 2014

Objectives of this talk

- The objective is not to give a comprehensive list of searches with results and limits, but to see examples of searches using jets differently, to show:
    - What type of searches can be done (have been done) with jets;
        - Also indicates what is missing
    - What are the experimental and theoretical limitations coming from jets in the physics results of the analyses,
        - in comparison to other sources;

Searches to discuss

- Searches for new phenomena are mostly signature-based:
  - Gathered in different by which jets are used

- Phase space selections for events containing jets:
  - Monojet (Dark Matter, LED), large jet multiplicity and E_T^{miss} (stop and gluino production)

- Resonances:
  - Dijet, photon+jets

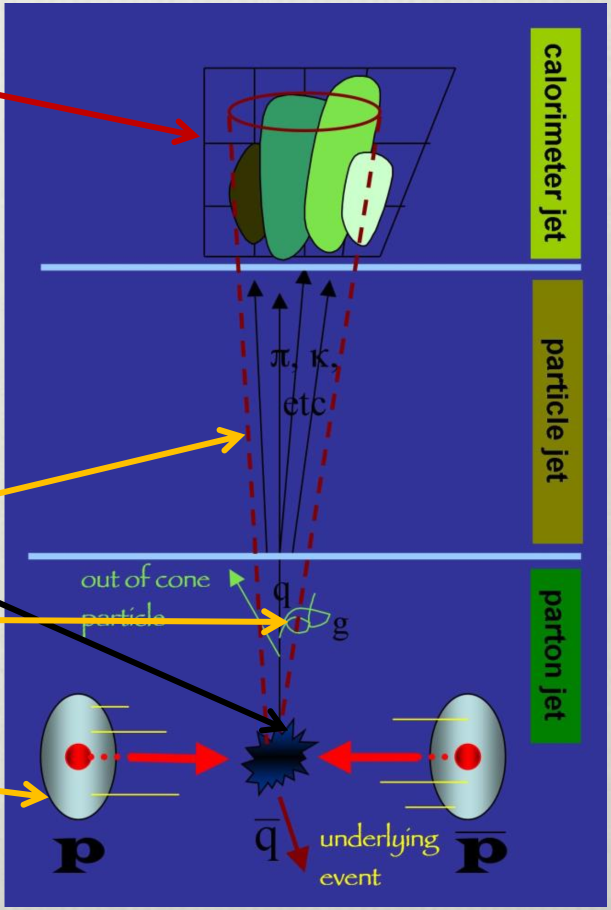
- Non-resonance invariant mass searches:
  - Quantum black-hole (lepton+jet)

Sources of uncertainties

Theory & simulations are used to estimate production rate and to model detector effects on select or background selections

⇒ Syst. uncertainty from approx. and inaccuracy in modeling of:

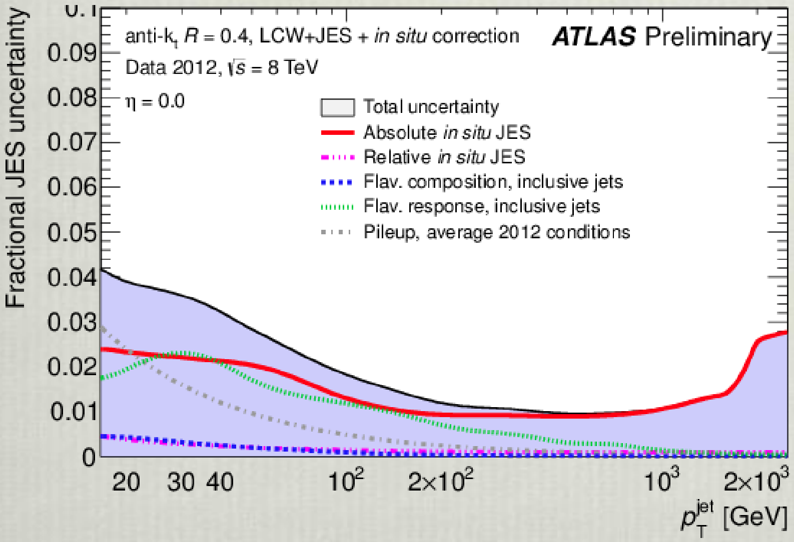
- **Modeling of detector effects on jets**
  - **Jet energy scale and resolution, jet selection efficiencies**
- **Production rate**
  - **Renorm./fact. scale uncertainties**
- **Modeling of strong interaction effects at (or in transition to) large distance**
  - **PDF, hadronization, parton shower, etc**
- **Others**
  - **Background normalization assumptions**
  - **Luminosity, lepton and trigger efficiencies**

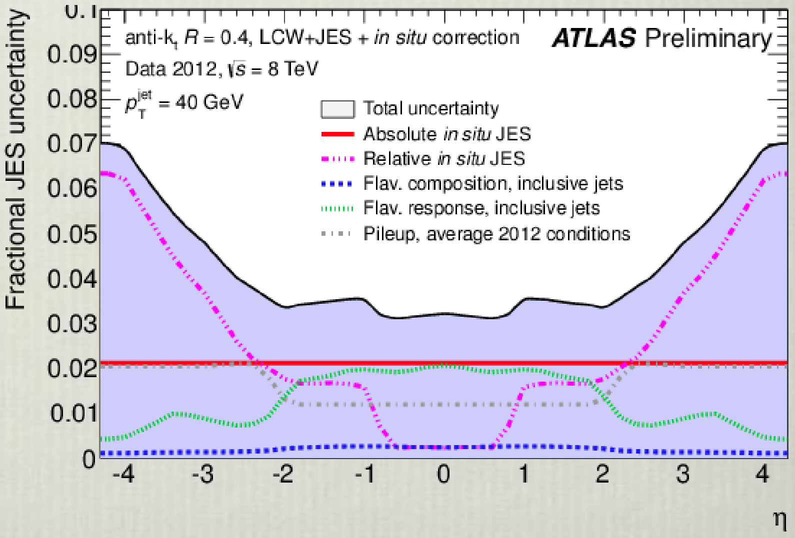


Example: Jet Energy Scale

- The uncertainty on the jet energy calibration is typically the largest experimental uncertainty affecting jets

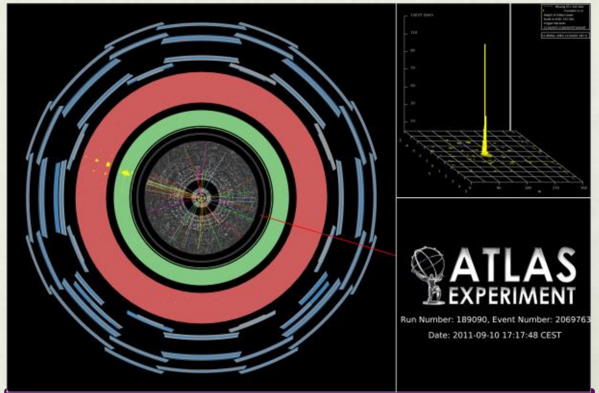
- The impact on the overall background estimate **can** be up to 2-3 times larger than the actual JES uncertainty
  - Affect jet veto more than 200 GeV - 1 TeV jets,
  - Larger uncertainty for forward jets…





https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetEtmissApproved2013JESUncertainty

Monojet search



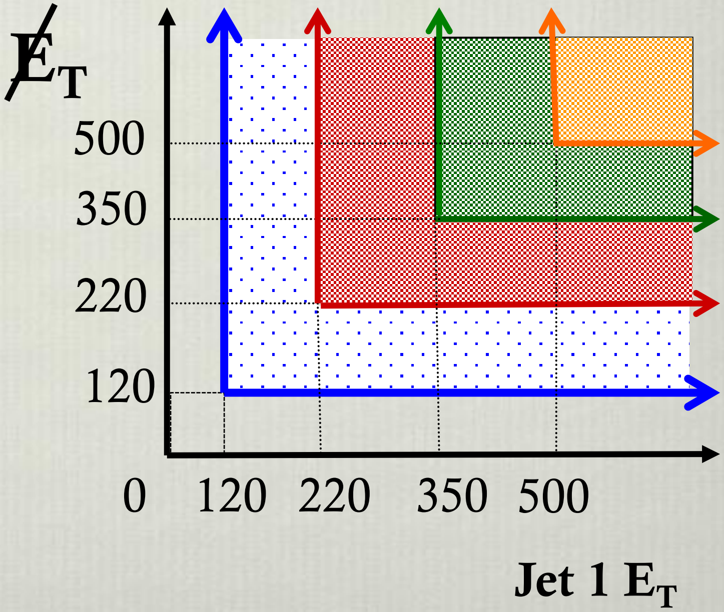
- **JHEP 04 (2013) 075**
- **ATLAS-CONF-2012-147**

- Published: 7 TeV, 4.7 fb^{-1} of data
  Preliminary: 8 TeV, 20.3 fb^{-1} of data

- Sensitive to a broad class of new physics:
  - Generic dark matter production, invisible Higgs, large extra dimensions, gravitino+squark/gluino production in gauge-mediated SUSY breaking, unparticles

- Cut on jets P_T and on E_T^{miss} to define multiple signal regions in which SM contribution must be estimated and compared to data
  - Sensitivity in a given kinematic region varies with models

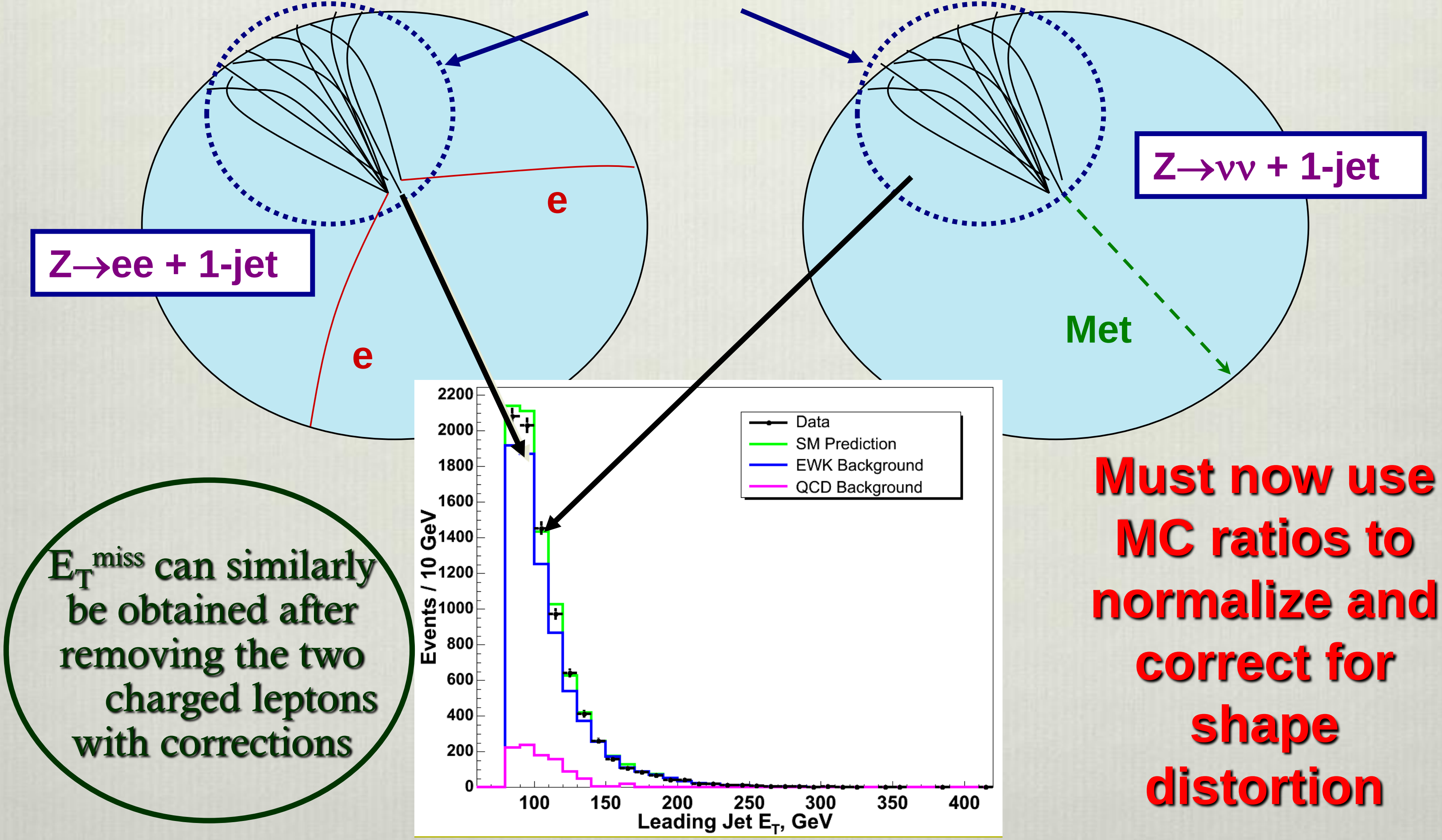
    ⇒ Ensure some model-independence
  - Other jet cuts to reduce reducible bkg
    - Eg: $\Delta\phi(E_T^{miss}$-jet) to suppress multijet



Data-driven estimate

- Reduce syst. uncertainty by replacing MC distribution with well understood data distribution similar to the process of interest

Jets observables present similar distributions



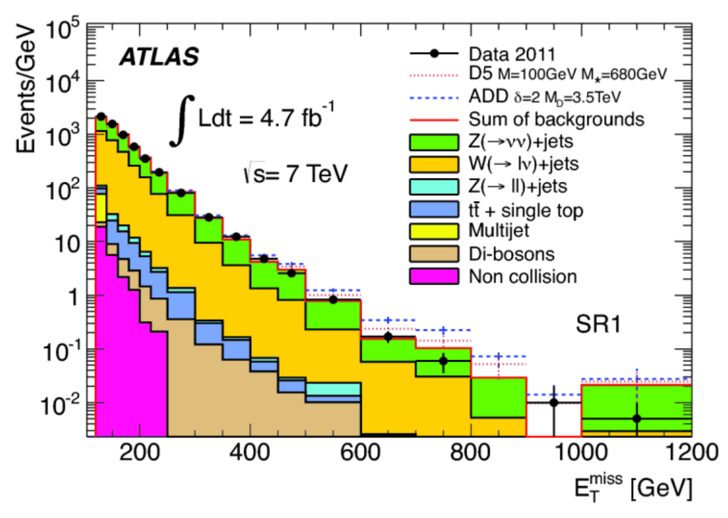
E_T^{miss} can similarly be obtained after removing the two charged leptons with corrections

Must now use MC ratios to normalize and correct for shape distortion

Monojet results

- Predictions are consistent with observations, regardless of the jet P_T and E_T^{miss} selections

	SR1	SR2	SR3	SR4
$Z \to \nu\bar{\nu}$+jets	63000 ± 2100	5300 ± 280	500 ± 40	58 ± 9
$W \to \tau\nu$+jets	31400 ± 1000	1853 ± 81	133 ± 13	13 ± 3
$W \to e\nu$+jets	14600 ± 500	679 ± 43	40 ± 8	5 ± 2
$W \to \mu\nu$+jets	11100 ± 600	704 ± 60	55 ± 6	6 ± 1
$t\bar{t}$ + single t	1240 ± 250	57 ± 12	4 ± 1	-
Multijets	1100 ± 900	64 ± 64	8^{+9}_{-8}	-
Non-coll. Background	575 ± 83	25 ± 13	-	-
$Z/\gamma^* \to \tau\tau$+jets	421 ± 25	15 ± 2	2 ± 1	-
Di-bosons	302 ± 61	29 ± 5	5 ± 1	1 ± 1
$Z/\gamma^* \to \mu\mu$+jets	204 ± 19	8 ± 4	-	-
Total Background	124000 ± 4000	8800 ± 400	750 ± 60	83 ± 14
Events in Data (4.7 fb^{-1})	124703	8631	785	77
σ_{vis}^{obs} at 90% [pb]	1.63	0.13	0.026	0.0055
σ_{vis}^{exp} at 90% [pb]	1.54	0.15	0.020	0.0064
σ_{vis}^{obs} at 95% [pb]	1.92	0.17	0.030	0.0069
σ_{vis}^{exp} at 95% [pb]	1.82	0.18	0.024	0.0079



No disagreement in the shape too

- **Amazing precision of 3.2% on bkg prediction (high stats region)**

⇒ **Tight constraints on new physics**

Background systematics

- If we breakdown the total systematic uncertainty into the various sources presented above we have, for the high stat kinematic region:

Systematic source	**Uncertainty**
Jet and E_T^{miss} energy scale and resolution	2-4 % on transfer factors
Lepton identification efficiencies	1-3 % on transfer factors
Non-electroweak backgrounds	Less than 1 % on total background
Parton shower and hadronisation modelling of simulation samples	3 % on total background

- A few comments:
  - Jet or QCD systematics still dominate, but have been very conservatively estimated and are comparable to other uncertainties
  - Important to keep the multijet background to a very low level

Examples of limits

- Typical efficiency for jets and Met selection: ~83%
  - Similar for Zvv, and ADD and general dark matter model

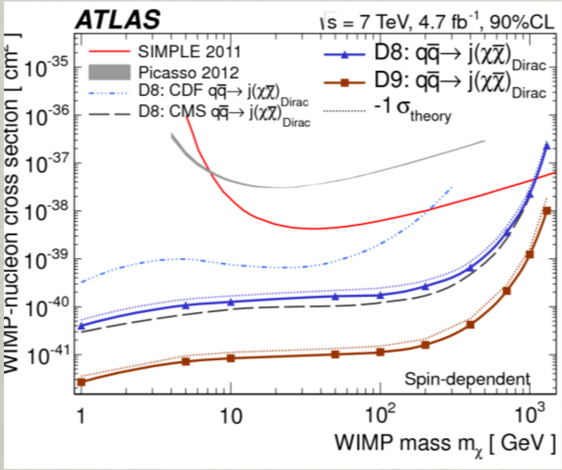
- Can set model-independent limit on visible cross section (σ×A×ε)

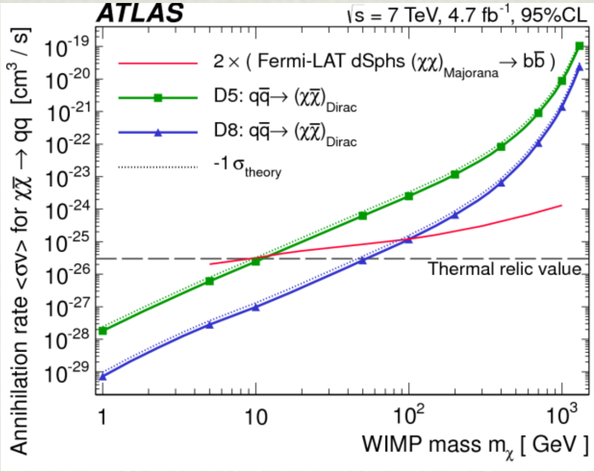
	SR1	SR2	SR3	SR4
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ at 90% [pb]	1.63	0.13	0.026	0.006
$\sigma_{\mathrm{vis}}^{\mathrm{exp}}$ at 90% [pb]	1.54	0.15	0.020	0.006
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ at 95% [pb]	1.92	0.16	0.030	0.007
$\sigma_{\mathrm{vis}}^{\mathrm{exp}}$ at 95% [pb]	1.82	0.17	0.024	0.008

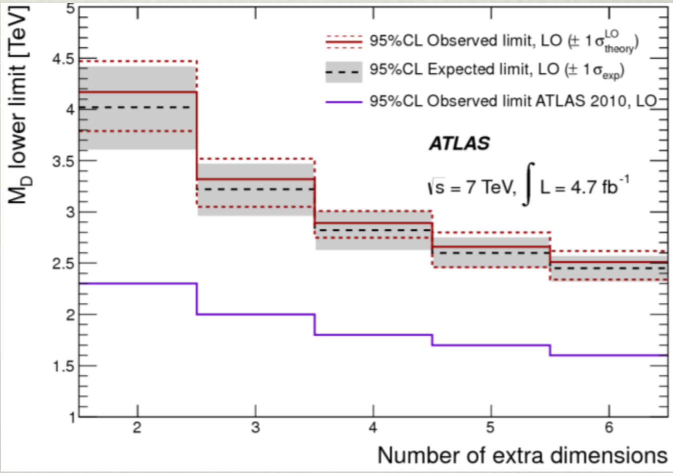
Limits on WIMPs σ_{scatt} (for various M_{WIMP})

Limits on WIMPs $\sigma_{\mathrm{annihil}}$ (for various M_{WIMP})

Limits on M_D (for various Ndim)







Other contexts

- The large virtue of data-driven techniques as employed in the monojet analysis relies on:
  - Large statistics in control regions
  - Limited biases between control and signal region

    ⇒ works well for searches that try to dig out a signal from large bkg
- Many searches are made in very low background regions or don't have very similar control regions (to avoid signal)
  - Typically takes shapes from MC which can lead to substantial discrepancies or uncertainties
  - Normalize MC in multiple control region to suppress the scale uncertainty

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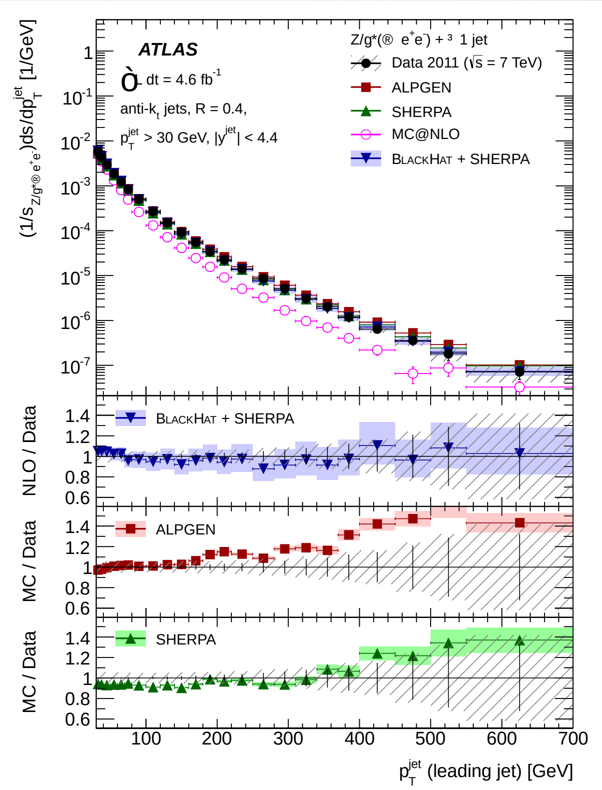

An example: large N and E_T^{miss}

- An example of such other context consists in the search for new physics in large number of jets and large ETmiss
  - Typically used to constraint squark and gluino pair production each dacaying to a pair of top quarks and a neutralino
  - Expected to contain B-jets
- Two complementary analysis streams separated in 19 signal regions:
  - The number of jets (≥7-≥10) and the number of B-jets (0, 1, ≥2)
  - The number of jets (≥8-≥10) and the mass of fat jets (>340, >420)
    - Fat jets are defined as all the antikt4 jets clustered by an antikt10 algo
  - The stats is low in each region (from 1 to 50 events expected)
- Dominated by multijet background (from 50% to 90%)

large N and E_T^{miss} (c'tn)

- Bkg is estimate from Met significance template for N=6 jets
  - ~independent of N_{jets} and M_J and is ~signal free for Sig(E_T^{miss})<1.5
  - For multijet bkg, a template is obtained from data and converted to signal region prediction using MC ratios after ewk subtraction
  - The ewk bkg templates is obtained from MC but normalized to data in a CR defined by an upper cut on MT

- Suffer from large systematic uncertainties because of the dependence on MC shape, or the difference between CR and SR
  - JER+JES uncertainty on transfer factor and EWK contamination of the multijet prediction and on the ewk bkg template: 20-30%
  - Total theory uncertainty on the same factors: 25-40%
  - Additional btag uncertainty: 10-25%
  - Multijet prediction non-closure in various validation regions (5-15%, with some cases up to 50%)

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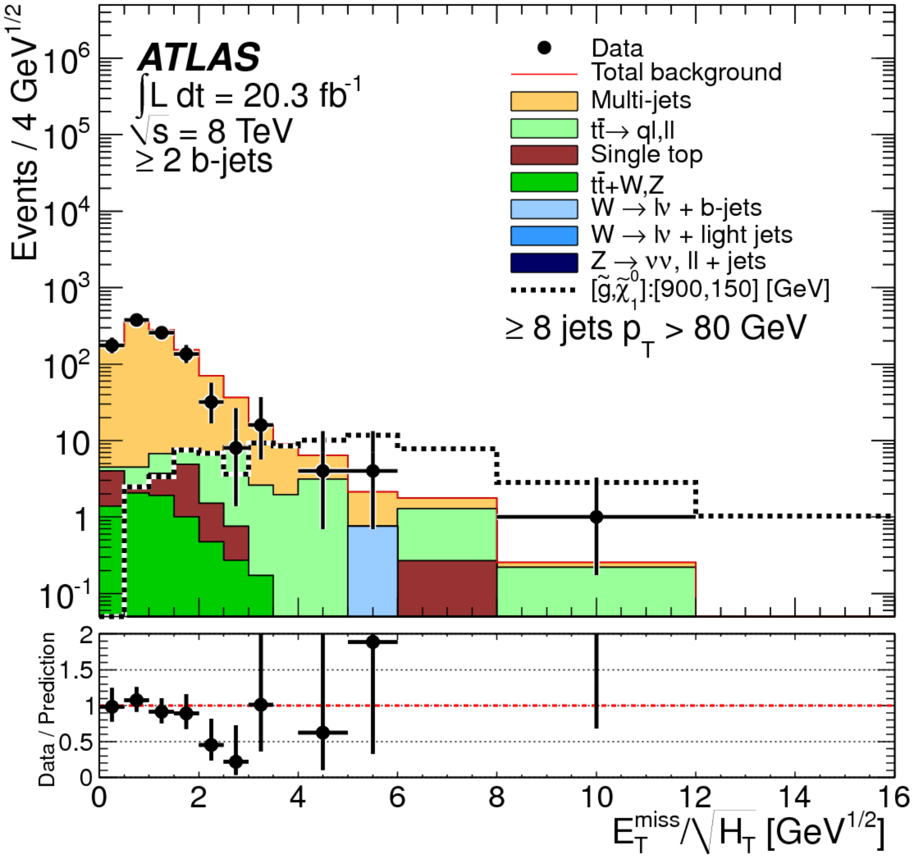
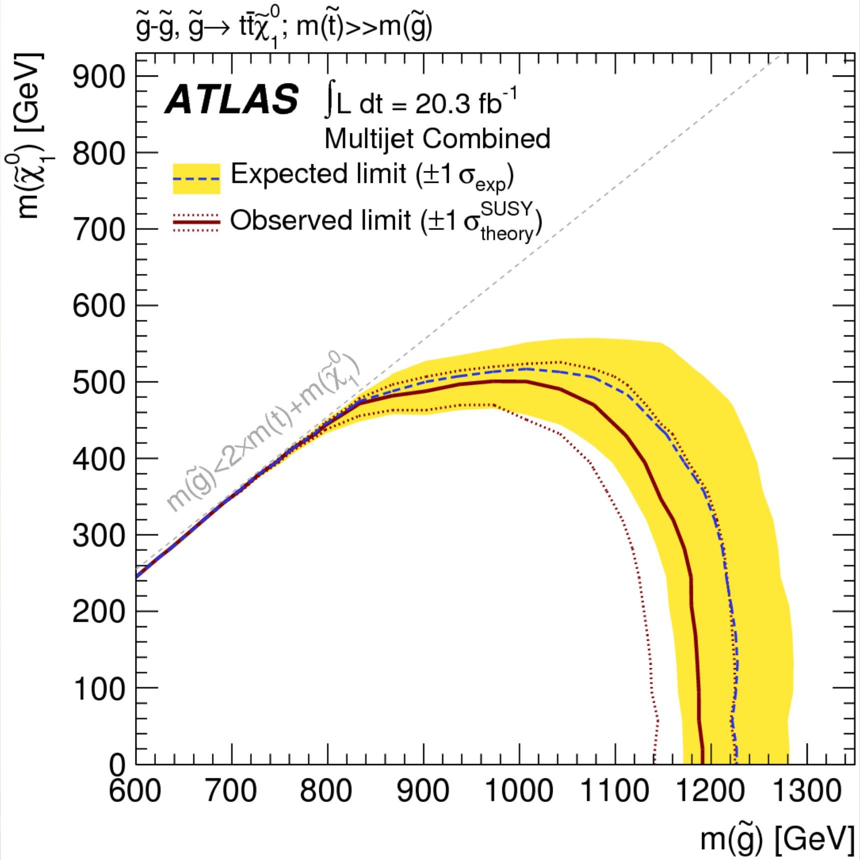
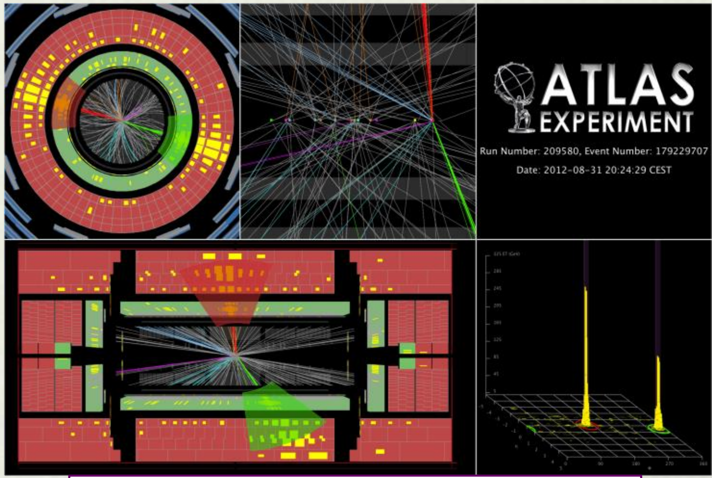
Stop and gluino limits

- Example of predictions and limits on stop and gluino production
  - The experimental uncertainty is larger, but comparable to the theory uncertainty on the signal modeling





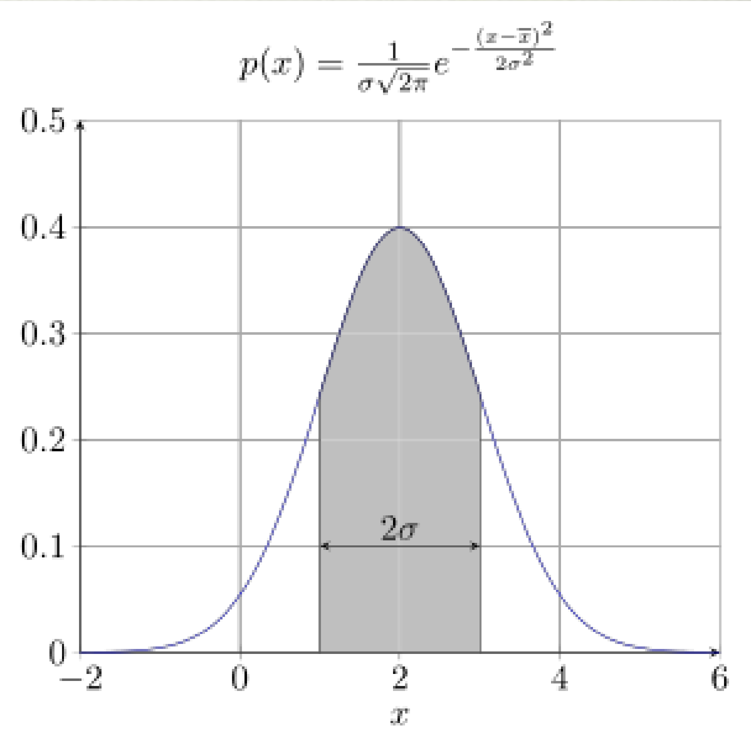
Dijet resonances



- **ATLAS-CONF-2012-148**
- **JHEP 01 (2013) 029**

- Probe new physics at the highest energy accessible at the LHC
- Sensitive to a large range of new physics model
  - E.g.: Excited quarks, axigluons, wrapped extra dimensions, Regge excitations of string theory, etc.
- Performed model independent searches for resonances using Gaussian mass peak model

➔ **Constraints from such generic model can be applied to your favorite resonance scenario!**



Analysis strategy

- Analysis strategy similar for all resonance searches:

1) Quality object selections, clean-up and jet kinematic cuts enhancing the sensitivity to new physics (eg: angular cuts) are first applied

2) Invariant mass reconstructed above a certain threshold

3) Fit mass spe nass distribution

$$f(x \equiv \frac{m}{\sqrt{s}}) = p_1(1-x)^{p_2} x^{-p_3-p_4 \ln x}$$

➔ greatly reduce the effect of JES on the bkg prediction

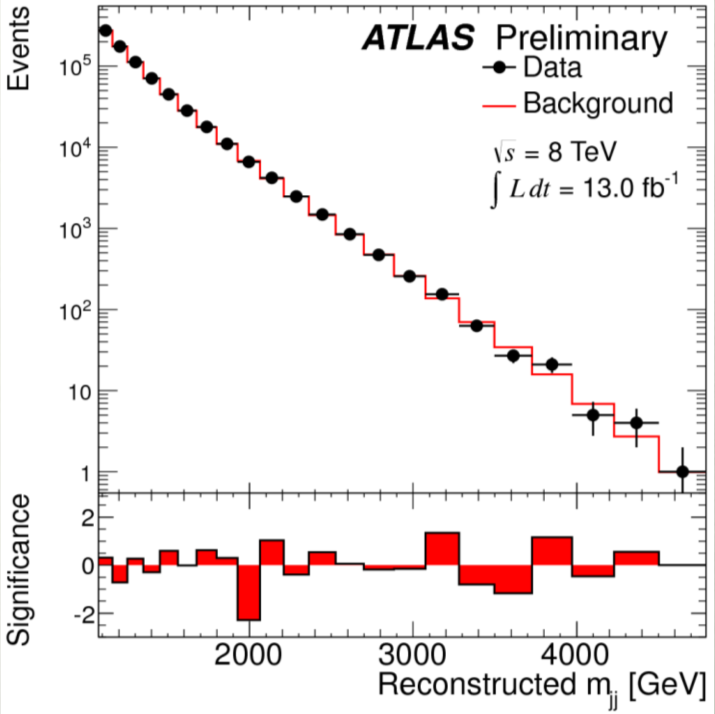
4) Choose binning
   - Optimal when bin size = 1σ, i.e. half resolution width

5) Run Bump hunter algorithm

6) Set limits

Bump Hunting

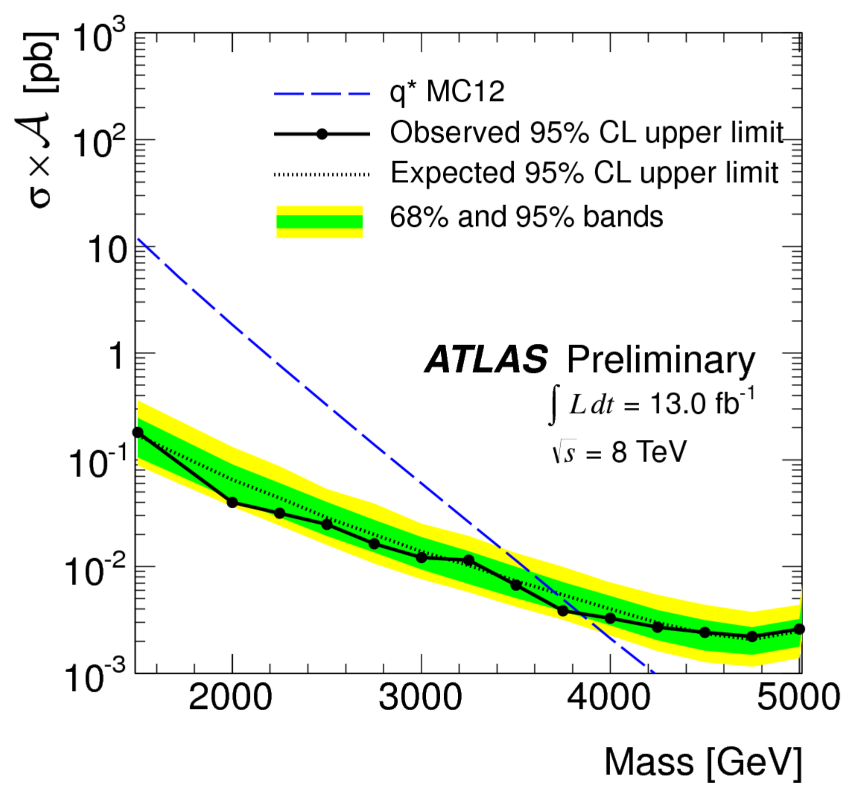
- BumpHunter algorithm is used to scan through the mass distribution between 1.0 and 4.7 TeV
  - Look for most significant deviation from null hypothesis,
  - Use window mass of progressively increasing width
    - From 2 bins, to N/2 bins
  - Largest deviation = smallest probability of coming from bkg fluctuation
  - Algorithm accounts for “look elsewhere effects”
- χ^2/ndf of the fit for background modeling is 15.5/18=0.86
- 75% of the chance to have a larger excess than the most discrepant bins from background-only hypothesis



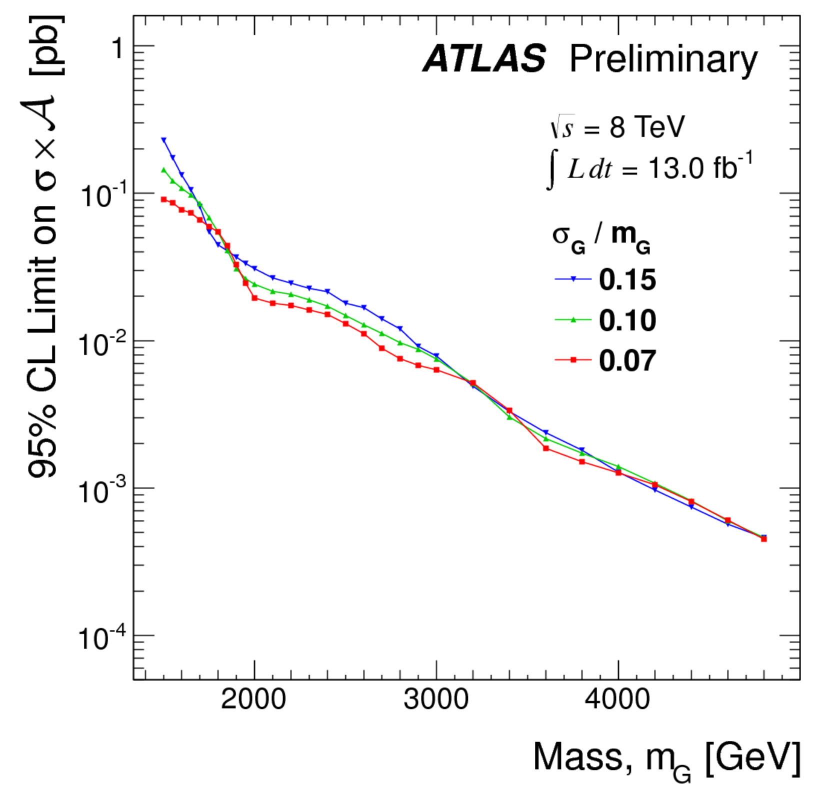
Limits

- 95% CL limits are set on σ×A for an hypothetical narrow particle decaying to dijet using Bayesian approach.
  - Excited quark model
  - Model-independent gaussian resonance of mean m_G and width σ_G

Excited quarks (q*)



Gaussian



For your model

- If you want to use general results and apply them to your model, you must:

1) Generate MC sample at mass M
2) Apply selection cuts
3) Smear signal mass according to detector resolution
    - For ATLAS: σ_M/M = 5% for 1 TeV, 4.5% at 2 TeV, asymptotically reaching 4% at 5 TeV
4) Suppress the tail of your "reco" Mass because Gaussian hypothesis
    - Keep m between 0.8M and 1.2M
5) Compute acceptance
6) Check quoted limit on σ x A in published tables for m_G=M
    - Use quoted value for $\sigma_G = (1.2M - 0.8M)/5$

Uncertainties

- The only sources of uncertainty affecting this search comes from:
  - JES: shifts resonance peak by less than 4%
  - JER: found to be negligible in this analysis
  - Luminosity: shift the signal yield in the likelihood function used in the Bayesian test by +/- 3.6%
  - Fit parametrization: parameter values changed when the χ^2/ndf of the fit varies by +/- 1
    - Bypass all QCD errors on bkg predictions, but depends on stats
- Error incorporated as nuisance parameters in the likelihood function and marginalized by integrating the posterior prob.
  - Yield the 1σ and 2σ uncertainty band on the limit plot

Uncertainty ~0.14 TeV for ~3.5% for q*: small and well-controlled!

Gamma+jet resonance

Phys. Rev. Lett. 108, 211802

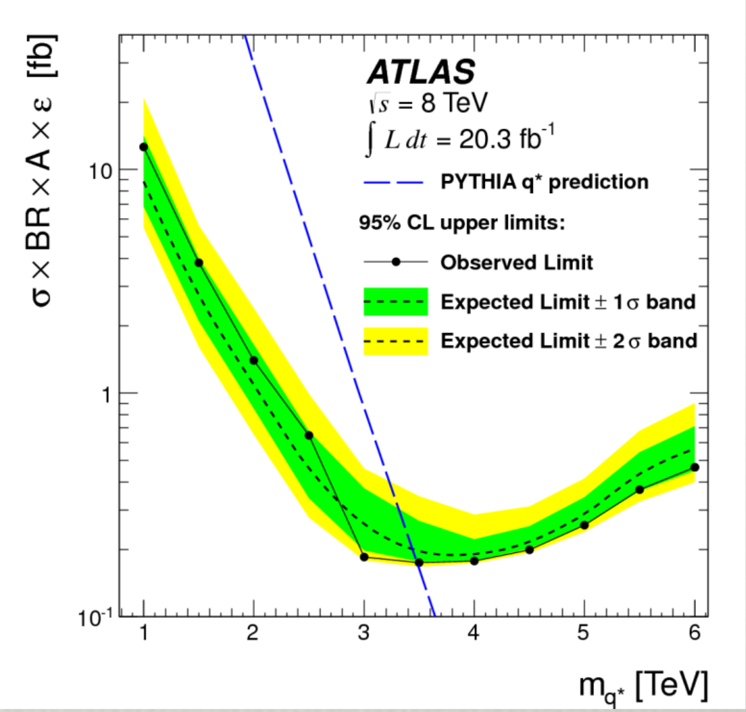
- Models predicting dijet resonances also often predic gamma+jet resonances

- Exact same analysis strategy as for dijet (search region of m > 426 GeV)
  - Largest deviation in 2-bins interval [785-916] GeV with p_{val}=61%

- Diff in uncertainties with dijet:
  - Smaller bkg, smaller impact of JES, new photon efficiency systematics
  - Similar impact on the measurement:

    q* uncertainty of 0.1 TeV for 2.9%
  - M_{q*} limits comparable to dijet:

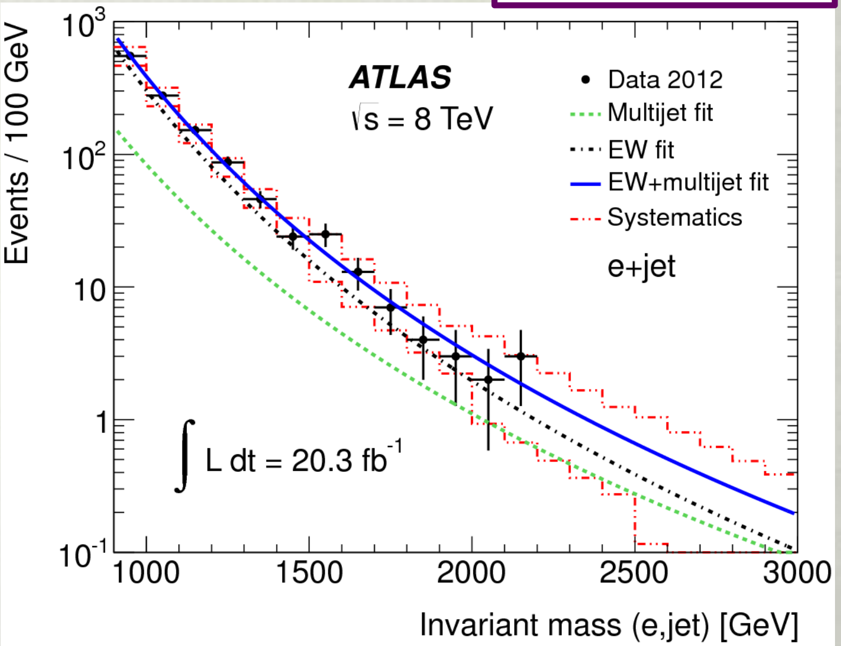
    3.5 TeV vs 3.8 TeV



Lepton+jet invariant mass

- Very massive (a few TeV) quantum black-holes are expected to decay to a lepton and a jet, violating lepton and baryon numbers
- Signal expected where there is essentially no background so a strategy different than for dijet or photon+jet must be used
  - Electroweak background mass distribution is obtained from MC
  - QCD multijet mass distribution is obtained from data
  - To normalize: templates are fitted to E_T^{miss} data distribution in the control region $400<M_{inv}<900$ geV
  - To extrapolate: distributions are fitted to the function used for dijet bkg model
  - Predictions are compared to data

arXiv:1311.2006

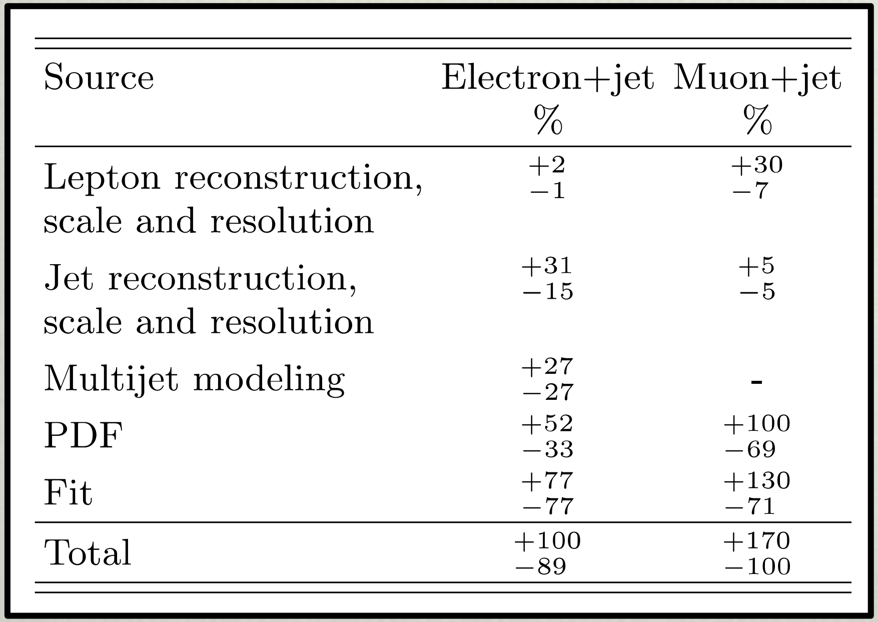


Limits and limitations…

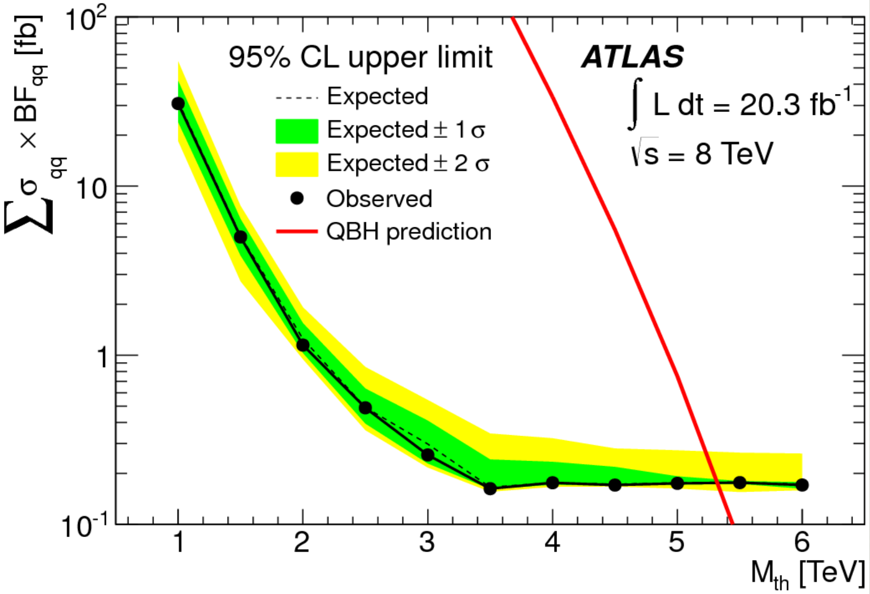
- Since the shape of the background invariant mass is obtained from MC and then extrapolated to high mass region, this predictions is sensitive to all the QCD and jet systematics
  - Extra uncert. on fit function, lepton efficiencies and fake templates

⇒ Very large uncertainty affecting the sensitivity (more than 100%)!

⇒ Yield a limit of 5.2 TeV, much beyond data reach in this channel



Source	Electron+jet %	Muon+jet %
Lepton reconstruction, scale and resolution	$^{+2}_{-1}$	$^{+30}_{-7}$
Jet reconstruction, scale and resolution	$^{+31}_{-15}$	$^{+5}_{-5}$
Multijet modeling	$^{+27}_{-27}$	-
PDF	$^{+52}_{-33}$	$^{+100}_{-69}$
Fit	$^{+77}_{-77}$	$^{+130}_{-71}$
Total	$^{+100}_{-89}$	$^{+170}_{-100}$



Summary

- Jets are used in various way in searches for new physics at the LHC
  - Specify a final state and a kinematic region probed for new physics
  - Jets+X resonance searches
  - Jet kinematic observable to be compared to predictions
- A large number of limiting systematic uncertainties due to jet measurements or QCD underlying physics can severely affect the sensitivity to new physics
- Many searches benefits from very power control region or background determination techniques to strongly suppress these jet related systematics and provide optimal sensitivity to new physics.

These techniques can be used to find something new in early run2 data!!!

Back-up