UCL

Search for Resonances in the Mass Spectrum of Events with *b*-Tagged Jets with the ATLAS Detector at 13 TeV

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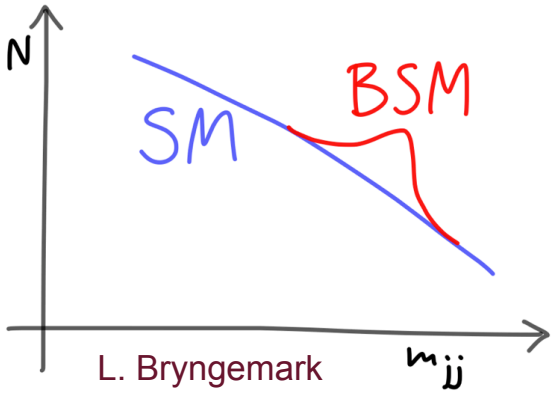
Exotics Plenary Meeting

27 November 2015

- b-Tagged di-jet resonance search
- **Aiming for a paper for Moriond**
- Documentation in Place
  - CDS Entry
  - SVN Area
- Ed Board Assembled
  - A. Glazov (Chair), F. Parodi, L. Tompkins
  - First Ed Board Meet - 11th November
  - Agenda can be found here
- Plots shown today are still preliminary

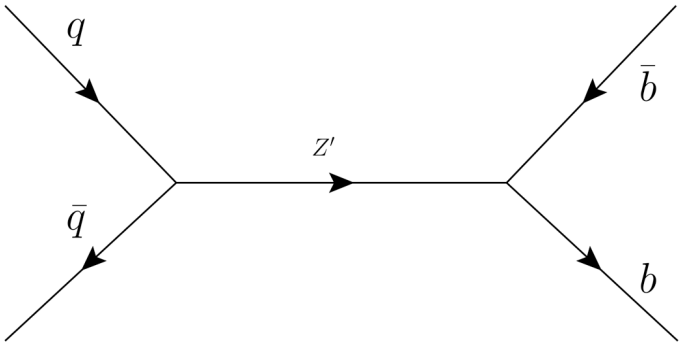
- Follow similar analysis strategy to inclusive di-jet analysis.
  - **Search for resonance in invariant mass spectrum**.
  - Fit QCD background using smoothly falling function.
  - Same event selection as di-jet search.
  - This allows us to share much of the framework.

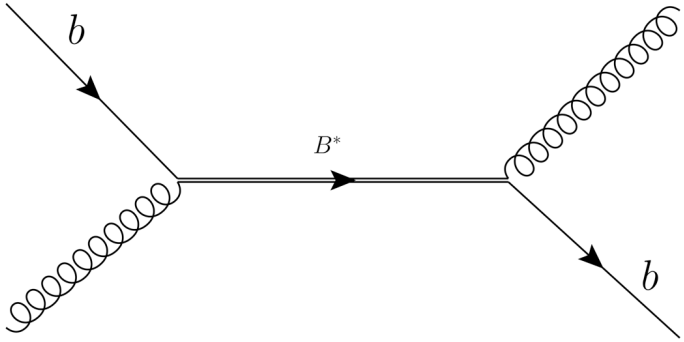


L. Bryngemark

- **In addition, b-tagging is applied.**
  - Three categories - 0, 1 and 2 b-tags

- Search for generic di-jet resonance
  - Gaussian with width similar to benchmark models.
  - Two Benchmark models, which we will set limits on.
    1) Z' => bb, double b-jet final state.
    2) b* => bg, single b-jet final state.

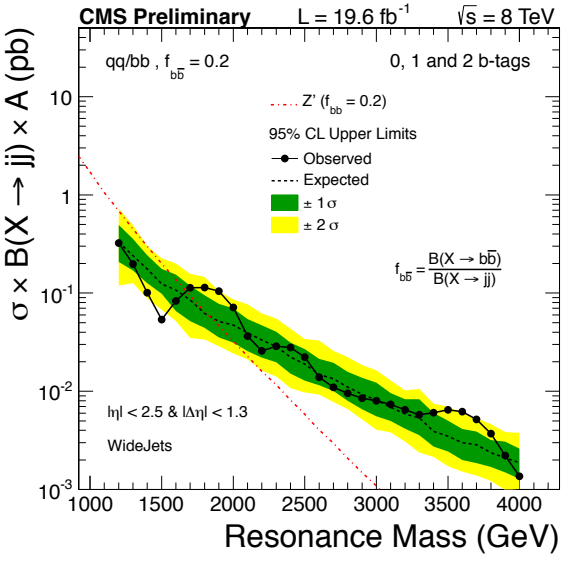




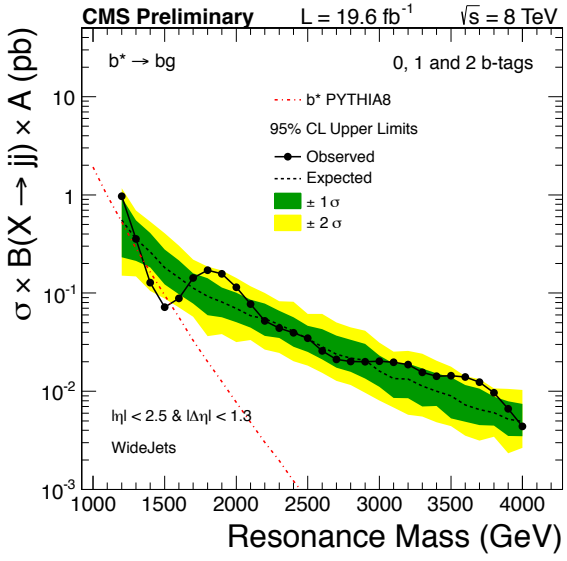
- Many BSM models predict heavy particles that decay into bb or bg.
  - Z', b*, RS Graviton...
  - b-Tagging can be used to reduce light dominated QCD background
  - Hence increased sensitivity to these models.

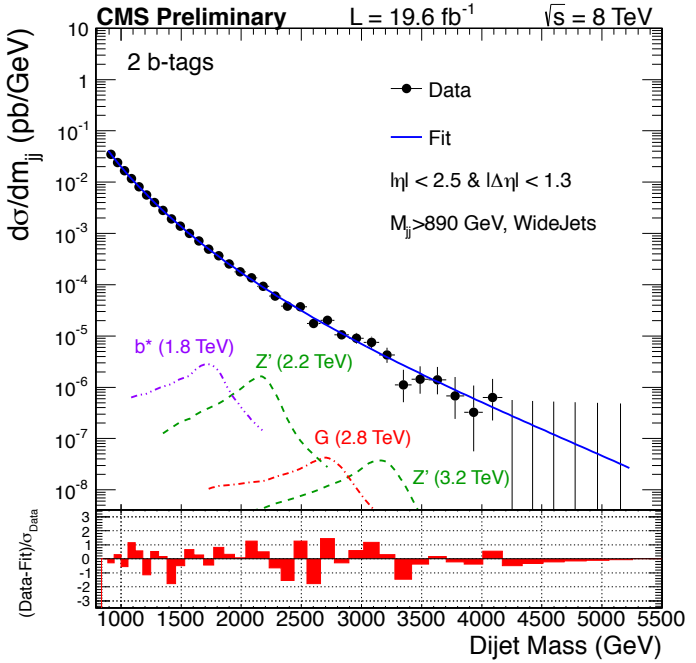
- Generic search performed searching for high mass resonance decaying to b-tagged jets.
  - Performed at CDF and CMS - (*CMS-PAS-EXO-12-023*)
  - No ATLAS result from Run-1

Z' excluded at 1.7 TeV



b excluded at 1.5 TeV*





Data and Event/Jet Selection

- **Data Used**
  - 25ns data with luminosity of **3.27 fb^{-1}** (Periods D-J)
  - Exclude runs with IBL Off - Due to huge drop in b-tagging performance.
  - GRL: *data15_13TeV.periodAllYear_DetStatus-v70-pro19-04_DQDefects-00-01-02_PHYS_StandardGRL_All_Good_25ns.xml*

- **Trigger**
  - **HLT_j360**, lowest unprescaled single jet trigger

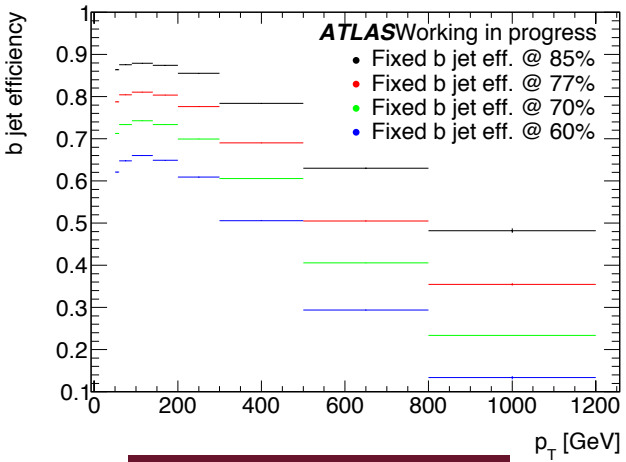
- **Event Selection**
  - Reject events with problematic calo. reconstruction (LAr, Tile and Core Errors)
  - At least two jets.
  - **Leading-jet p_T > 440 GeV**, Subleading jet p_T > 50 GeV
  - **m_{jj} > 1100 GeV**, such that we are on the trigger plateau.
  - **$|y^*| < 0.6$**, where $y^*=0.5*(y_1 - y_2)$
    - Central region more sensitive to BSM physics.

- **Jet Selection**
  - Standard jet calibration (with JES correction applied)
  - 2015 loose jet quality cuts applied.

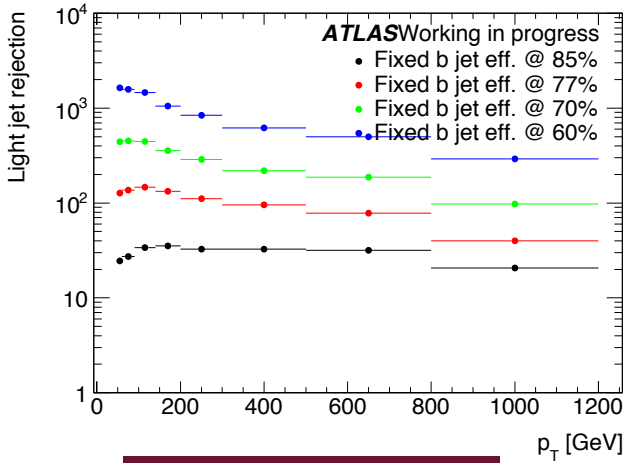
- **MV2c20** - **Fixed cut 85% efficiency working point**
  - MV2c20 > -0.7887
  - Calibrated and supported by flavour tagging group
  - Loose WP provides best sensitivity compared to others.

- b-jet efficiency ~ 50% at jet-p_T ~ 1 TeV
- Light-jet rejection ~ 30
  - Approximately flat, good for background modelling.

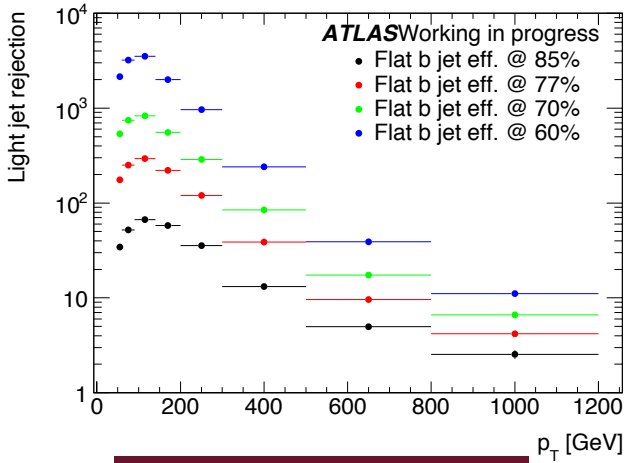
- Flat b-jet efficiency also being considered.
  - Shows promise of improving signal sensitivity of high mass resonances
  - Need to understand background modelling for this as not flat light-jet rej.



b-jet eff. - Fixed WPs



light rej. - Fixed WPs



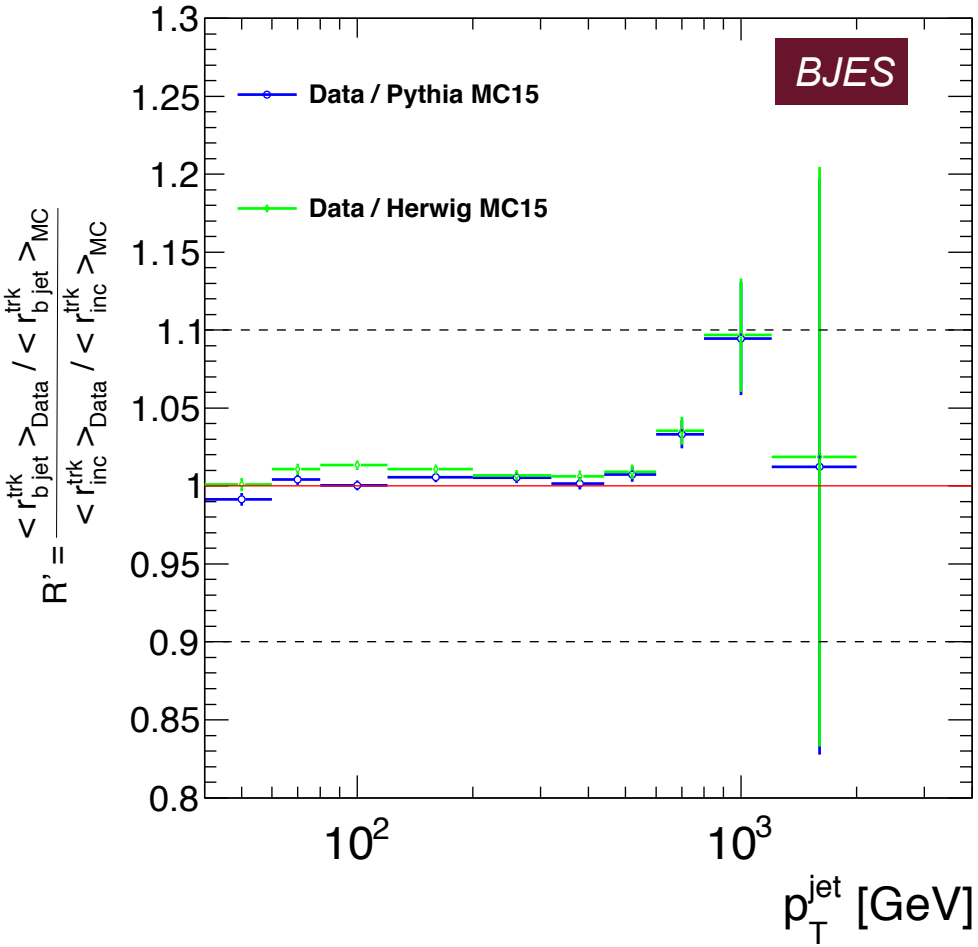
light rej. - Flat Eff. WPs

b-Jet Energy Scale

- Calculate using ratio of tracks within jet cone to reconstructed calo jet.
  - Use a double ratio between b-tagged jets and inclusive jets
- Below 1% on top of JES for $p_T < 600$ GeV
  - Then increases to ~10% as p_T increases.
- Ongoing study
  - Further work required
  - Study in to if there is a component in bJES due to tracks not entering the ratio.
- Regularly presented in JES/JER Meetings

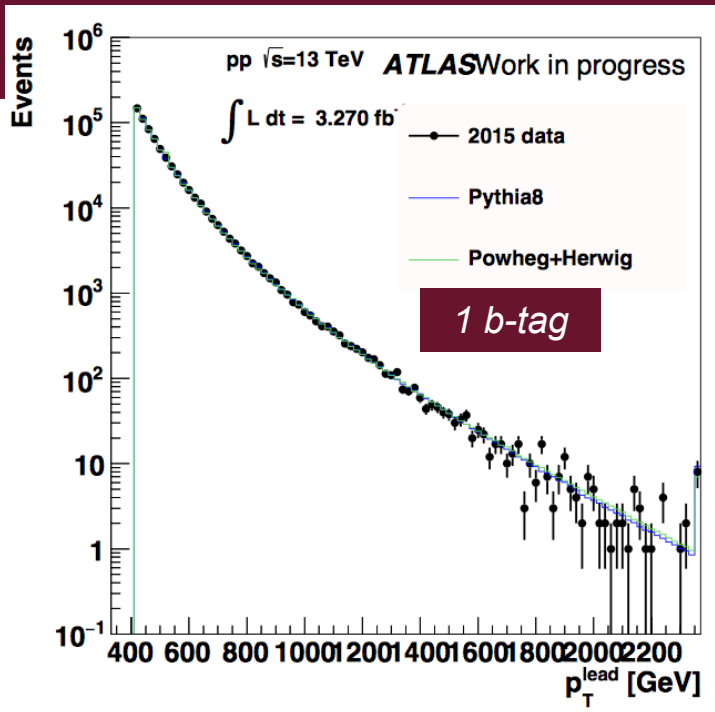
$$R' = \frac{< r^{trk}_{bjet} >_{Data} / < r^{trk}_{bjet} >_{MC}}{< r^{trk}_{inc} >_{Data} / < r^{trk}_{inc} >_{MC}}$$

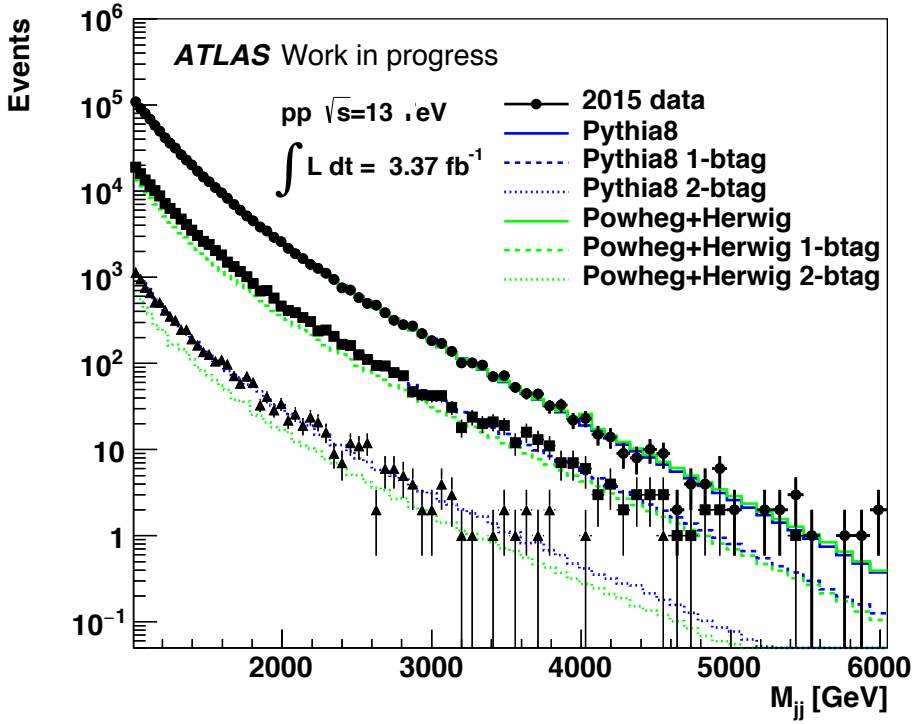
where $r^{trk} = \frac{\sum \vec{p_T}^{trk}}{p_T^{jet}}$

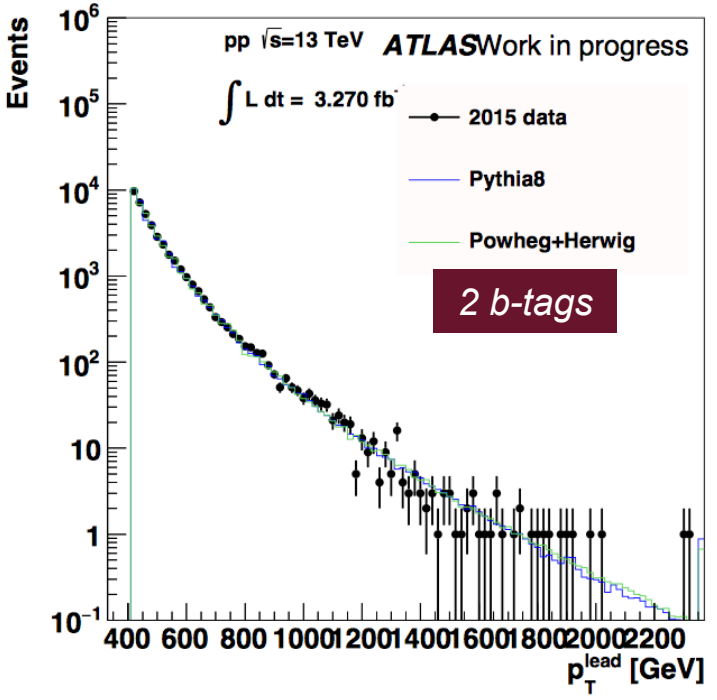


Data/MC Comparisons

- Compare Data to Monte Carlo
  - Pythia8 and Powheg+Herwig
- Scale factors still to be applied
  - Expect better agreement after SFs applied
- Good shape agreement with Pythia8 for...
  - Leading and Subleading Jet p_T
  - m_{jj} distributions
  - In both one *b*-tag and two *b*-tags







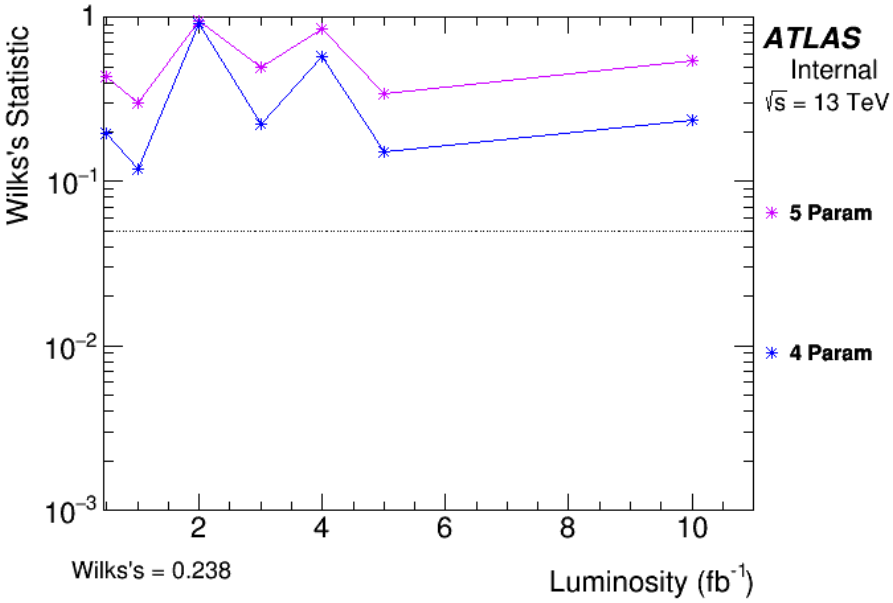
Background Modelling

- Fit to background using smoothly falling function:

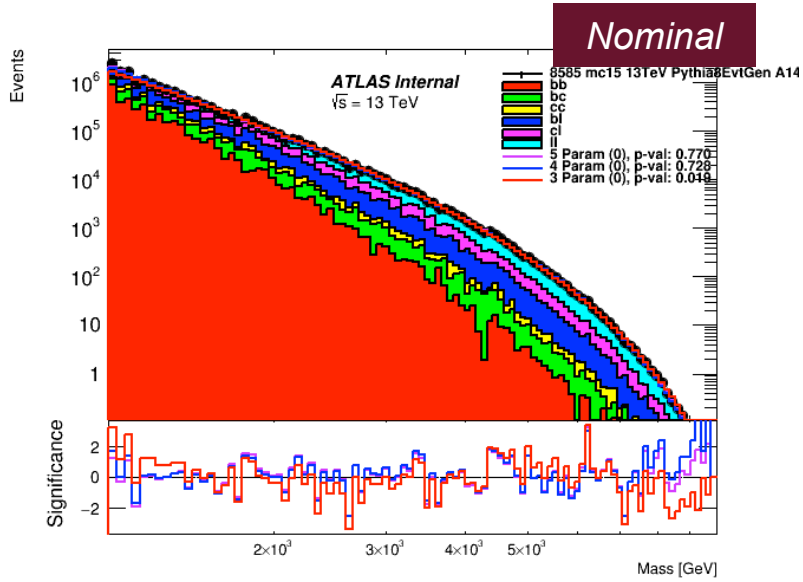
$$f(x) = p_1(1-x)^{p_2}(x)^{p_3+p_4\ln x+p_5\ln x^2}$$

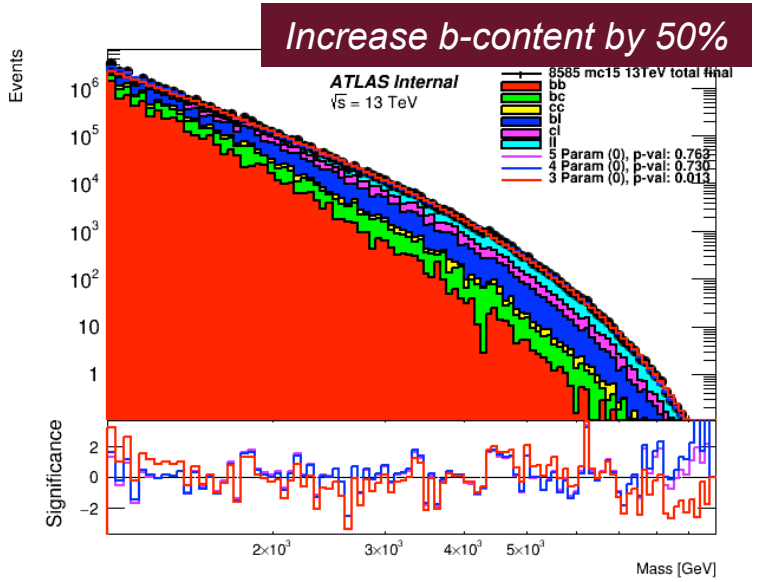
where, $x = m_{jj}/\sqrt{s}$

- Default option is 3 parameter (p_4, p_5 = 0)
  - Use Wilks' statistic to determine if we need to change to 4-parameter fit
  - 3 Parameter sufficient to 10 fb^{-1} with MC



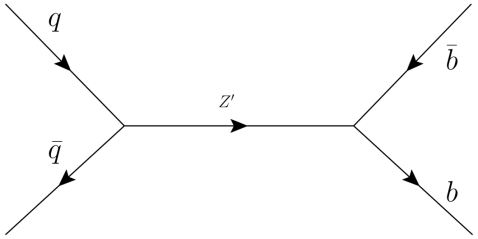
- Performing cross-checks confirming that we are robust to changes in flavour fraction
  - At high mass background is dominated by lights.



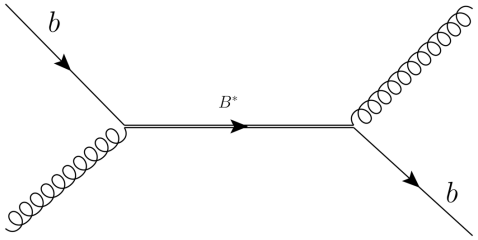


Signal Models

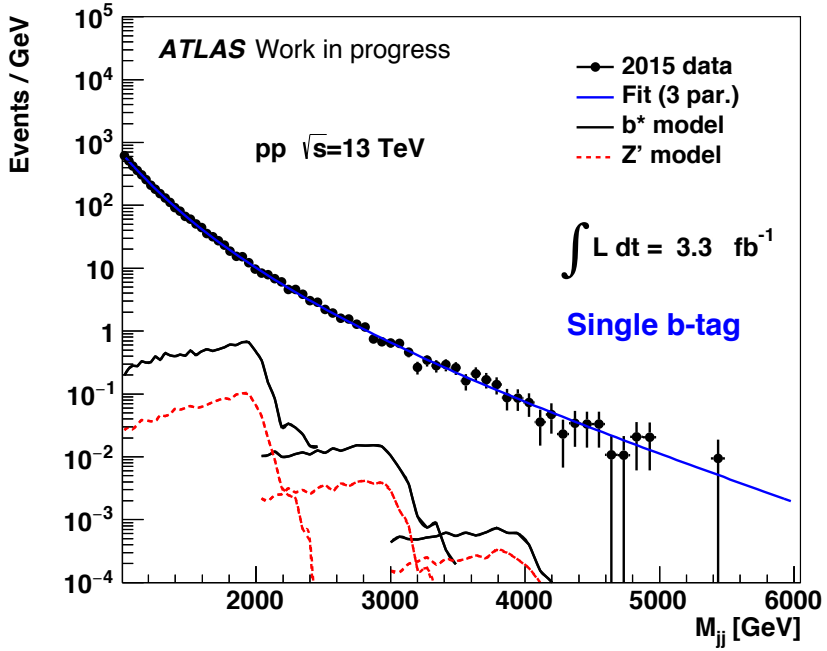
- Two benchmark models - We can set limits here.
  - **Z' => bb** - 1.25, 2, 3 and 4 TeV
  - **b* => b+X** - 1.25, 2, 3, 4 and 5 TeV
  - Templates taken from MC samples

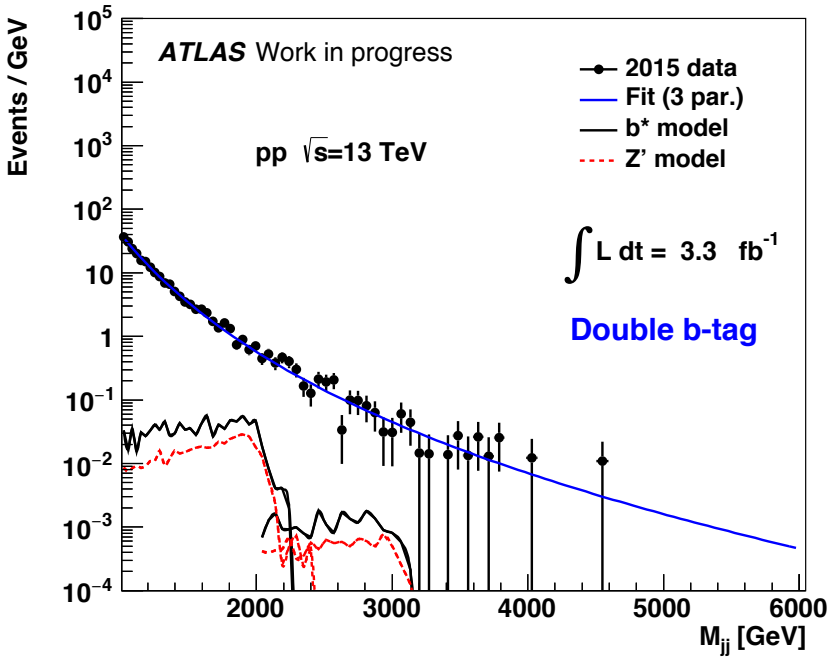


- One cross-check channel
  - **q*** - 2.5, 3, 3.5 and 4.5 TeV



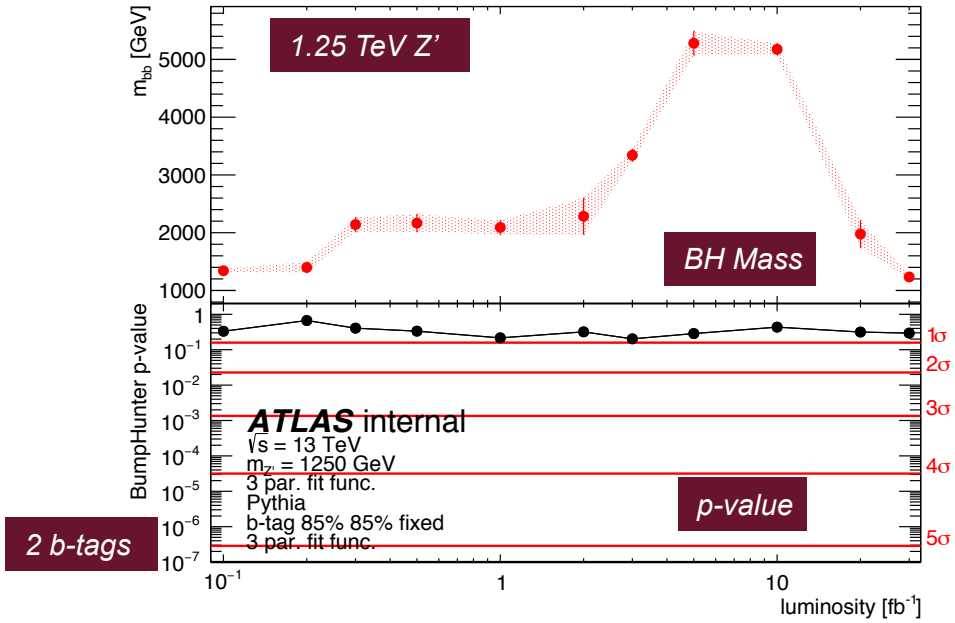
- Generic search performed for a Gaussian signal.
  - Resonance width taken from the benchmark



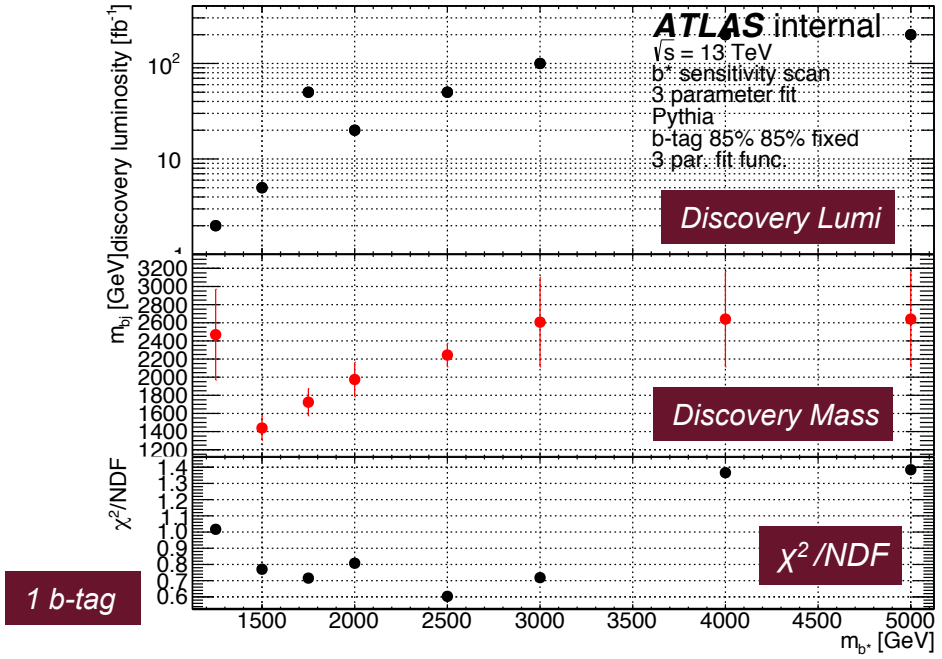


Sensitivity Studies

- **Low sensitivity to Z'**
  - Low cross section
  - Search for 1.25 TeV Z' slowly converging towards signal value at 30 fb^{-1}
  - Also want to include *Z'* => *cc* and *Z'* => *light-jet* signals.



- **Discovery potential for b***
  - Larger cross-section than Z'
  - Fit is stable for single b-tag
  - Sensitivity curve is not smooth
  - Under investigation

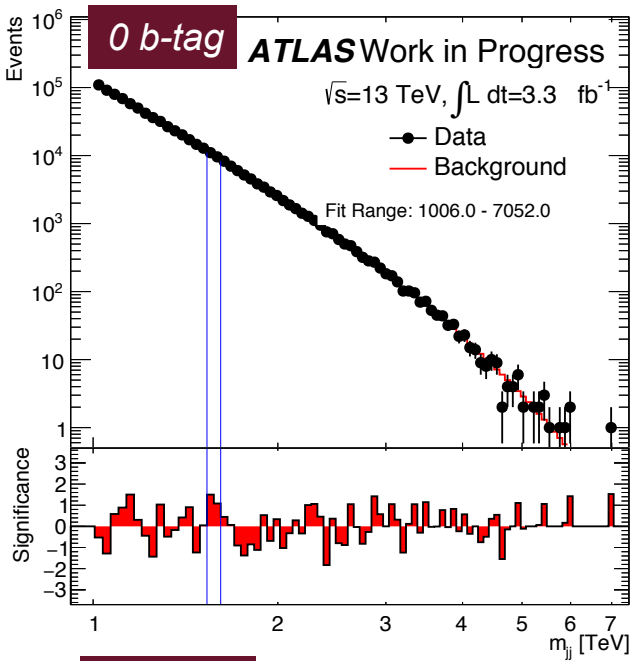


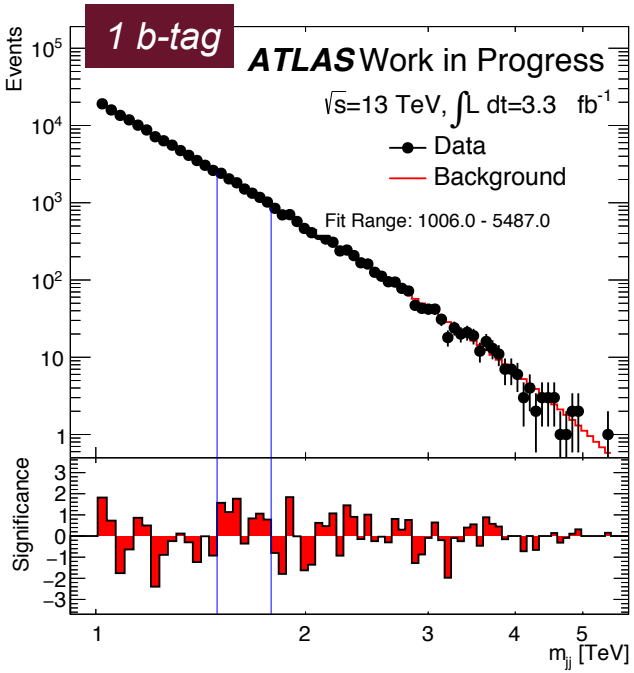
Results - Bump Hunter

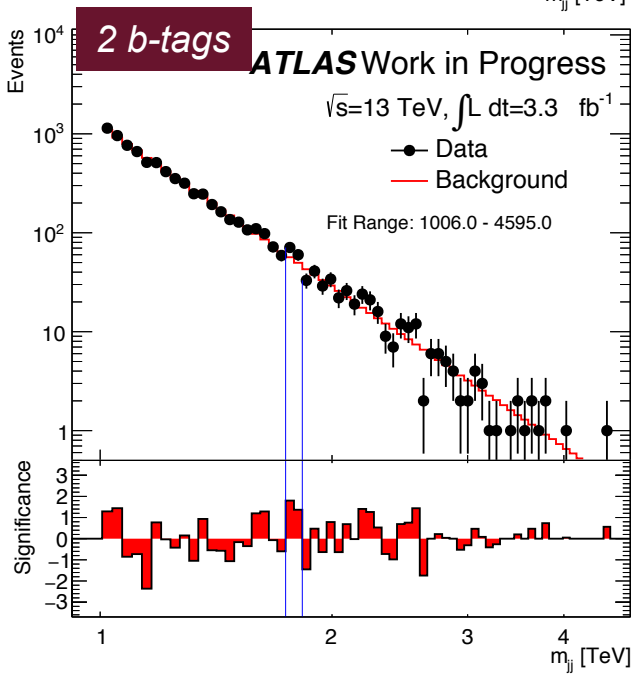
- Mass spectra in three tag categories
  - 3.27 fb^{-1} of data, full data set.
  - Background fitted with 3 parameter function.

- Bump Hunter searches for resonances
  - Looks for a Gaussian signal
  - Searches for statistically significant deviations.

- **No deviation found more significant than 2σ**

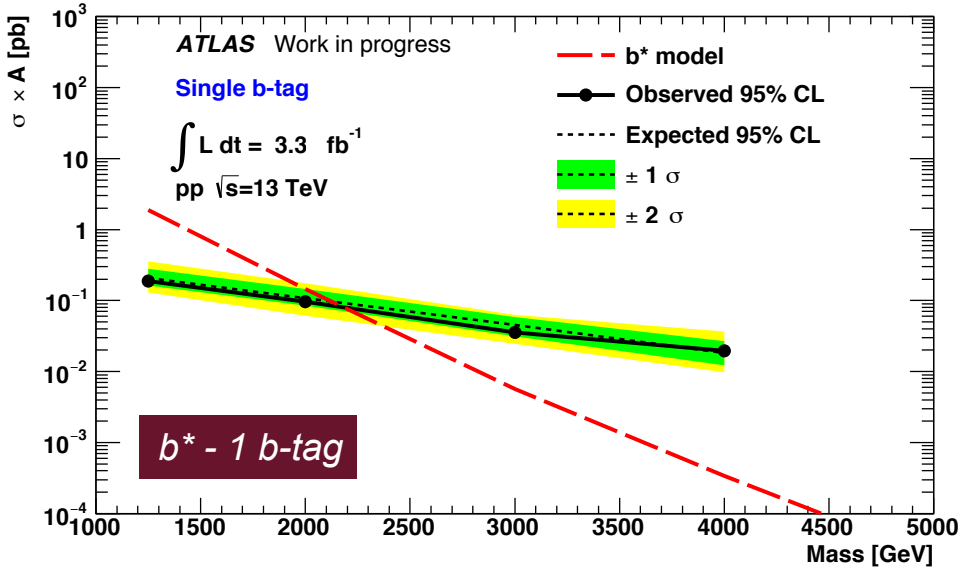


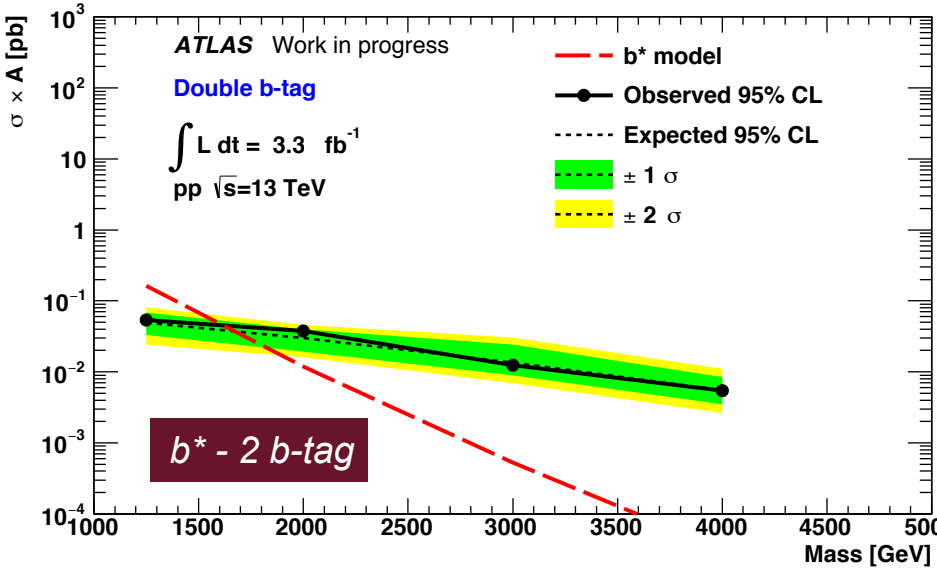




Limit Setting - b*

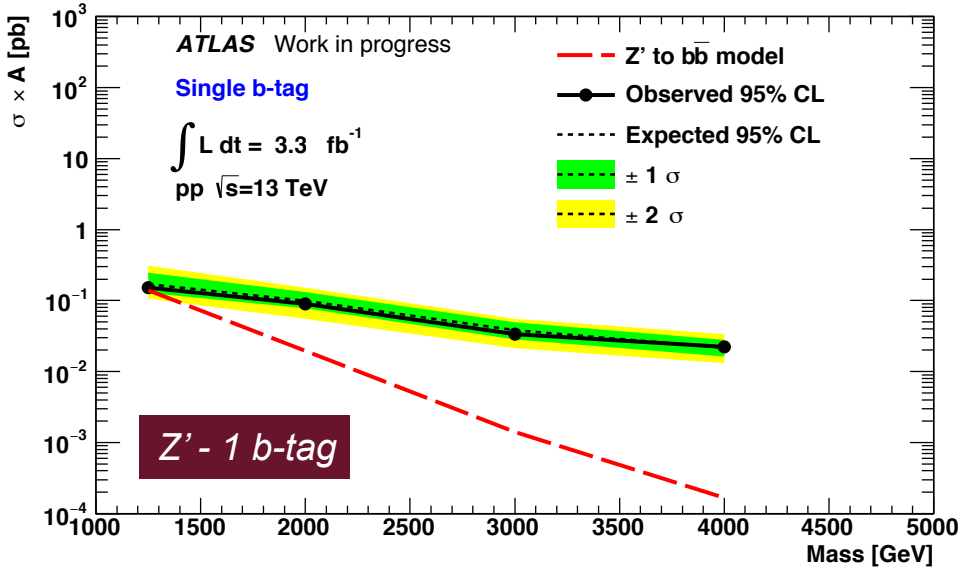
- Machinery up and running, using Di-jet statistical package
  - Deviations found by bump-hunter, test statistics by running pseudo-experiments.
  - 95% C.L. upper limiting
  - Use Bayesian approach for limit setting.
  - No Correction for acceptance.
- Systematics: Some still need to be added to the limit setting program.
  - ✓ Luminosity uncertainty - 9%
  - ✓ JES uncertainty - 1σ up and down
  - ✓ JER uncertainty - 1σ up and down
  - ➡ BJES uncertainty - to be added
  - ➡ B-tagged scale factor uncertainties - to be added

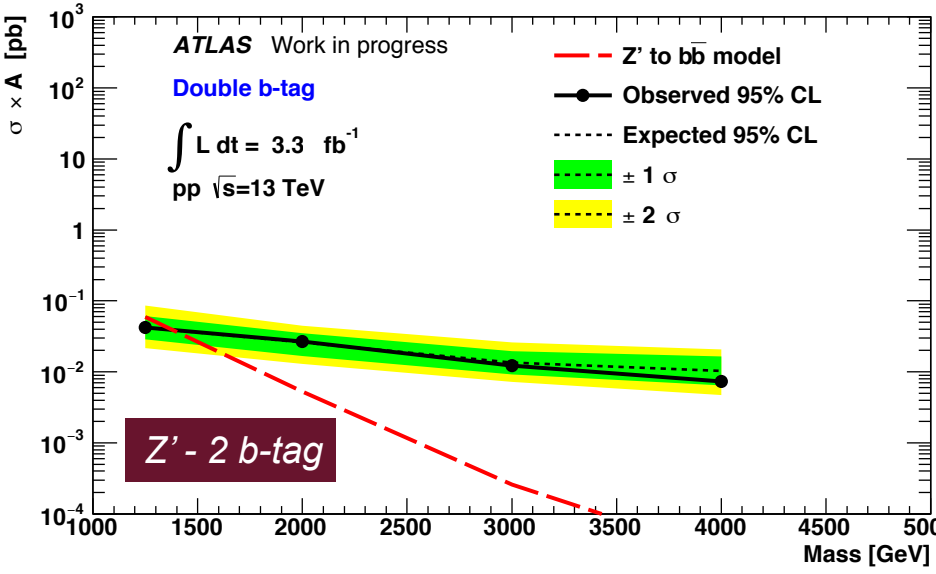




Limit Setting - Z'

- Machinery up and running, using Di-jet statistical package
  - Deviations found by bump-hunter, test statistics by running pseudo-experiments.
  - 95% C.L. upper limiting
  - Use Bayesian approach for limit setting.
  - No Correction for acceptance.
- Systematics: Some still need to be added to the limit setting program.
  - ✓ Luminosity uncertainty - 9%
  - ✓ JES uncertainty - 1σ up and down
  - ✓ JER uncertainty - 1σ up and down
  - ➡ BJES uncertainty - to be added
  - ➡ B-tagged scale factor uncertainties - to be added





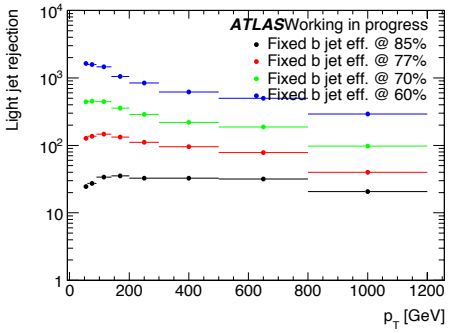
Summary

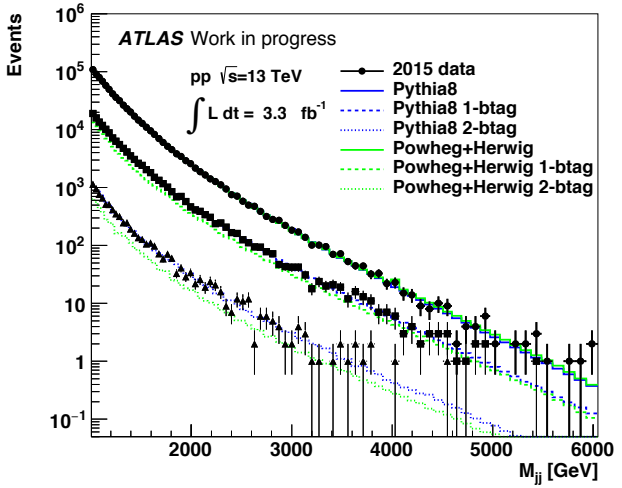
- b-tagged di-jet search following di-jet analysis
  - Shared cuts and framework
  - In addition applying b-tagging (1 b-tag and 2 b-tags)

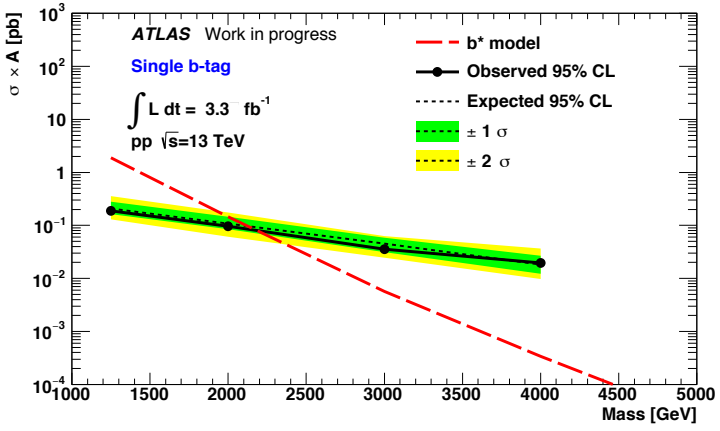
- 3.27 fb^{-1} of data used for this analysis.
  - Show good agreement with QCD MC
  - We find no deviations from the background fit with significance greater than 2σ.
  - 95% C.L. upper limits set for b* and Z'
    - No acceptance correction
    - Some systematics need to be added

- Many studies ongoing...
  - Further sensitivity studies
  - Robustness of fit to flavour fraction
  - More systematic studies (b-tag. uncertainties)
  - BJES finalisation.
  - Inclusion of *Z'* => *cc* and *light.* (Ready to request)

- On course for Moriond!
  - Ed. board and documentation in place.







Backup!

Systematics

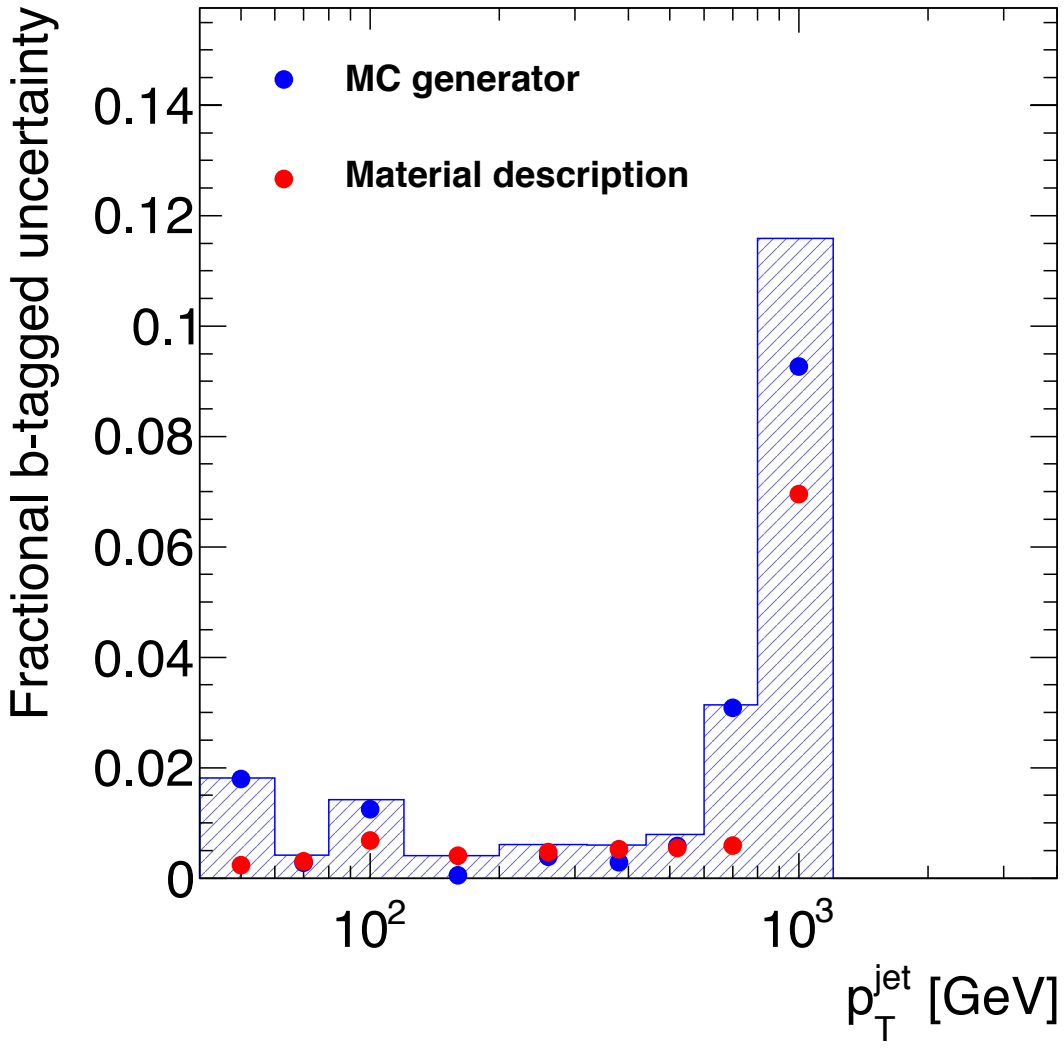
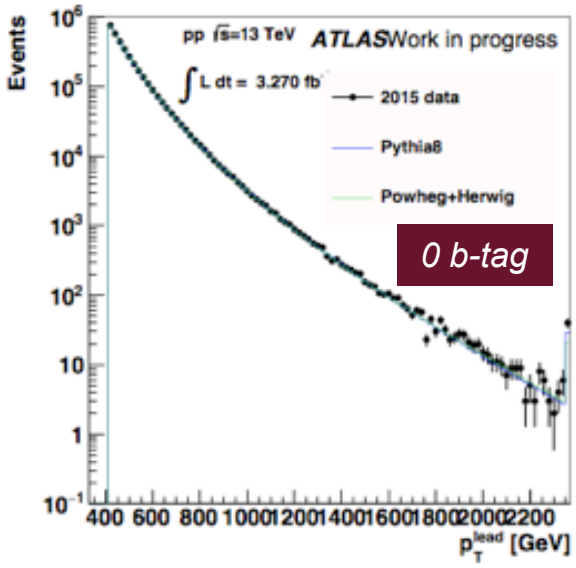
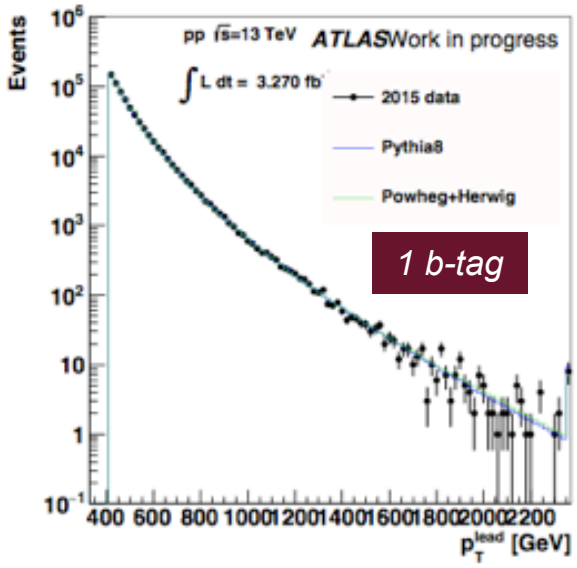
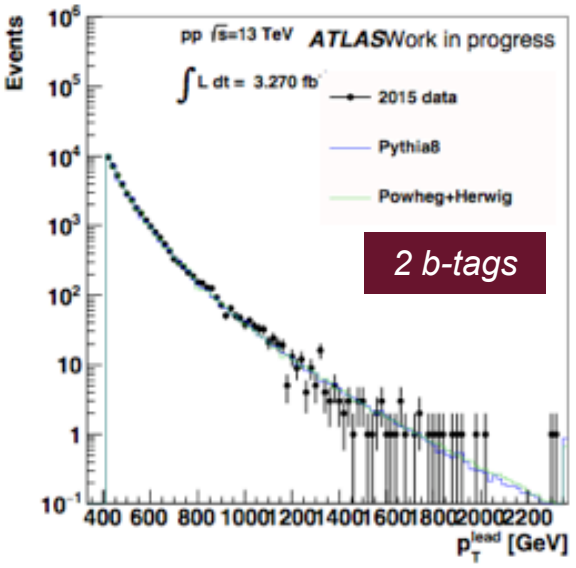
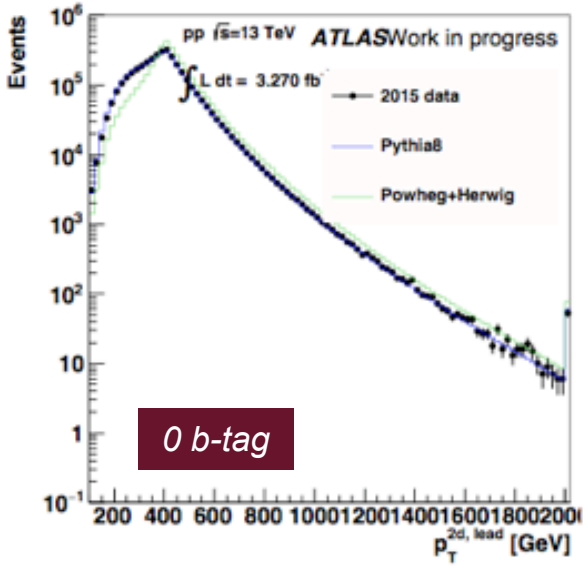
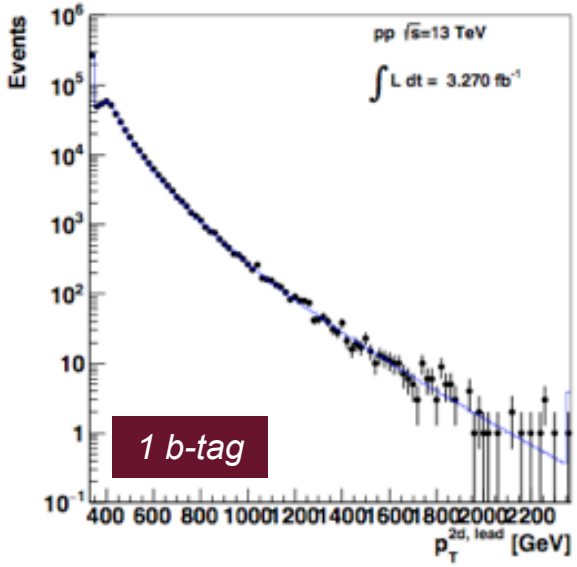
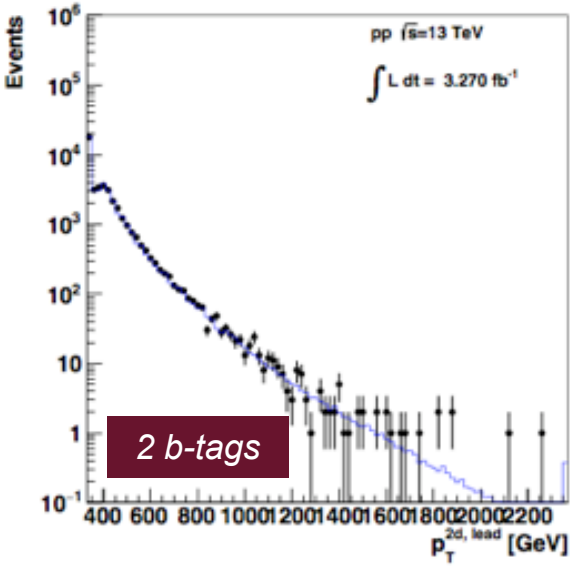
- Luminosity - 9% uncertainty

- Background
  - Fit function and fit parameters

- Signal
  - JES Uncertainty
    - Branches available in analysis nTuple
    - < 4%
  - JER Uncertainty
    - Assume to be negligible
  - JER Uncertainty
    - Studies performed, large for high p_T jet (p_T > 800 GeV)
  - B-tagging scale factor uncertainty

- Studies to be carried out
  - Then will be added to limit setting procedure.

BJES Uncertainty



Data/MC Jet pT Comparison