Search for Resonances in the Mass Distribution of Jet Pairs with One or Two Jets Identified as *b*-Jets in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector

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UCL Meeting

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Outline

- **Analysis Overview**
  - Analysis Status
  - Motivation
  - Search Strategy
  - Results

- **Flavour Fraction Studies**
  - Background flavour composition
  - Robustness to flavour fraction studies
  - Spurious signal tests.

Analysis Status

- **b-Tagged di-jet resonance search**
- **Aiming for a paper for Moriond**
- **Progress:**
  - Open Presentation - 29/02/2016
  - ATLAS Circulation - 03/02/2016
  - Open Presentation - 14/03/2016 (?)
- **Documentation**:
  - Paper Draft: ATLAS-EXOT-2015-22
  - INT Note: ATL-COM-PHYS-2015-1324

ATLAS Paper Draft

Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

EXOT-2015-22

Version: 2.0

To be submitted to: Phys. Lett. B

Supporting internal notes

ATL-COM-PHYS-2015-1324 https://cds.cern.ch/record/2062417

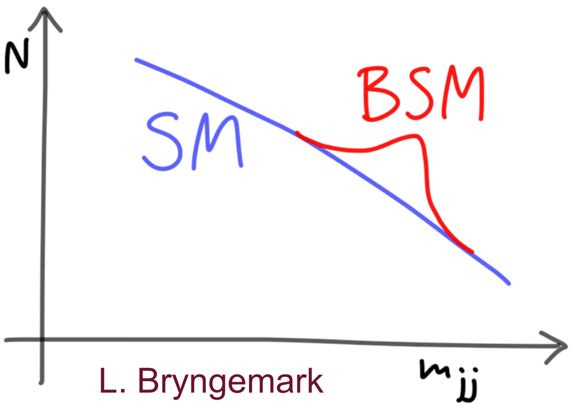
Comments are due by: 10 March 2016

Abstract

Searches for high-mass resonances in the dijet invariant mass spectrum with one or two jets identified as a b-jet are performed using an integrated luminosity of 3.2 fb^{-1} of proton–proton collisions with a centre-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the Large Hadron Collider. The dijet events are divided into categories with one or two jets identified as containing a b-hadron. No evidence of anomalous phenomena is observed in these two categories and upper limits are obtained on the production cross section of narrow resonances in the mass range considered 1.1–5 TeV. For a benchmark model calculated at leading order QCD, excited b^* quarks are excluded with masses below 2.1 TeV and leptophobic Z' bosons are excluded with masses below 1.5 TeV at 95% credibility level. Contributions of a Gaussian signal shape with effective cross sections ranging from approximately 0.3–0.001 pb are also excluded in the mass range 1.5–5 TeV.

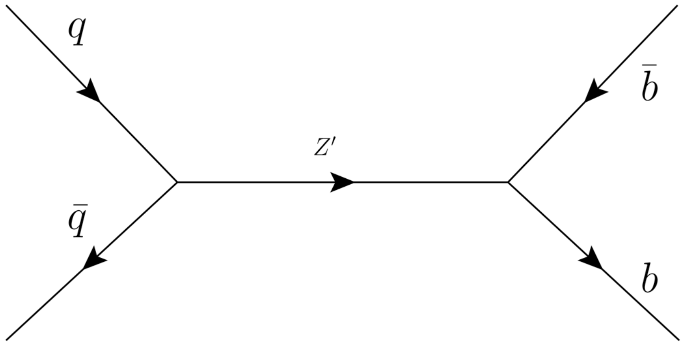
Analysis Strategy

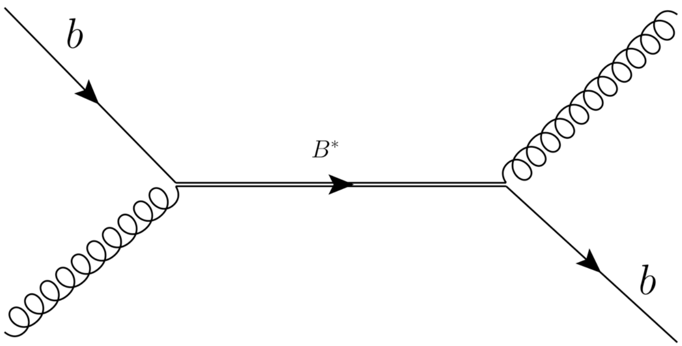
- Follow similar analysis strategy to inclusive di-jet analysis.
  - **Search for resonance in invariant mass spectrum**.
  - Fit QCD background using smoothly falling function.



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

- **Search for generic di-jet resonance**
  - Gaussian with width similar to benchmark models.
  - Two Benchmark models
    1) **Z' => bb**, double b-jet final state
       - We look at both a SSM Z' and a Leptophobic Z'
    2) **b* => bg**, single b-jet final state
  - Set limits on Z', b* and Gaussian signal



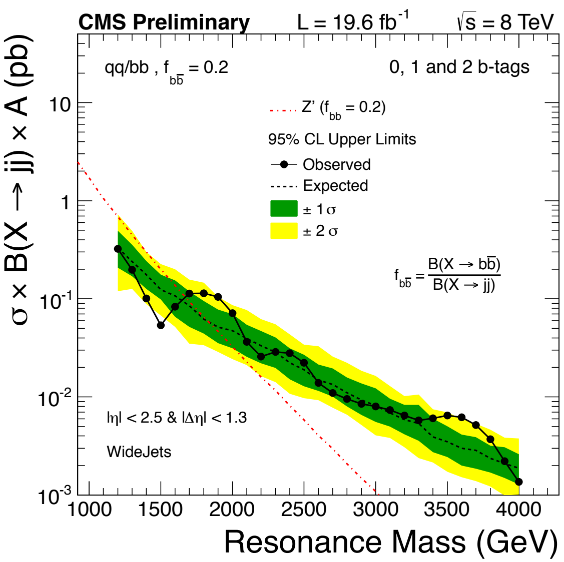


Motivation

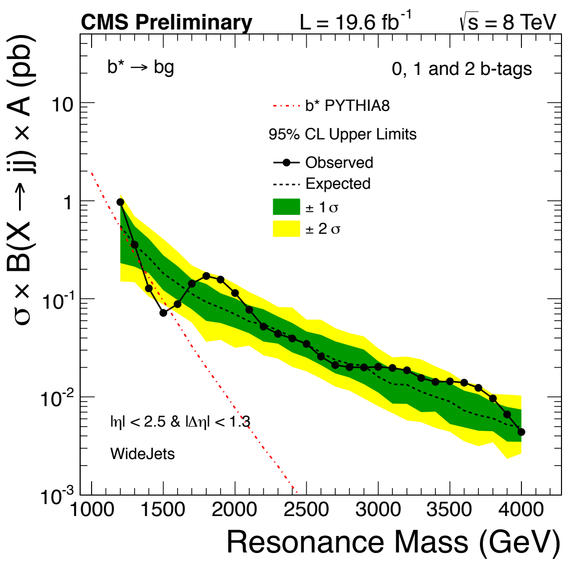
- Many BSM models predict heavy particles that decay into bb or bg.
  - Z', b*, RS Graviton...
  - b-Tagging can be used to reduce light dominated QCD background
  - Hence increased sensitivity to these models.

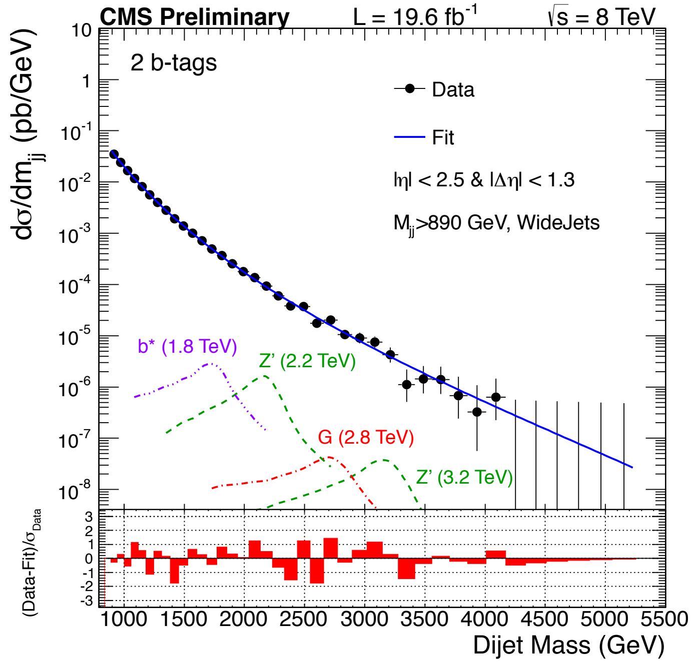
- Generic search performed searching for high mass resonance decaying to b-tagged jets.
  - Performed at CDF and CMS - (*CMS-PAS-EXO-12-023*)
  - No ATLAS result from Run-1

Z' excluded at 1.7 TeV



b excluded at 1.5 TeV*





Data and Event/Jet Selection

- **Data Used**
  - 3.2 fb^{-1} of data.
  - Excluding runs with IBL Off
  - **HLT_j360**
    - Unprescaled single jet trigger
- **Jet Selection**
  - Anti-Kt EM Topo Jets, R=0.4
  - Jet Cleaning Applied
  - $p_T > 50$ GeV
  - **$|\eta| < 2.4$**, in tracking volume.
- **Event Selection**
  - At least two jets.
  - **$m_{jj} > 1.1$ TeV**, on the trigger plateau.
    - Leading-jet $p_T > 440$ GeV
  - **$|y^*| < 0.6$**, where $y^*=0.5^*(y_1 - y_2)$
    - More sensitive to BSM physics.
- **b-Tagging** (Next Slide)

Data

Selection criteria	N_{events}	Remain (%)	Rel. remain (%)
All	3.31478e+07	100%	100%
LAr	3.30707e+07	99.77%	99.77%
tile	3.30675e+07	99.76%	99.99%
NPV(+SCT)	3.30635e+07	99.75%	99.99%
Trigger	2.1681e+07	65.41%	65.57%
Jet selection	2.13722e+07	64.48%	98.58%
Trigger efficiency	1.16798e+07	35.24%	54.65%
Jet cleanning	1.16738e+07	35.22%	99.95%
Leading jet	4.66451e+06	14.07%	39.96%
Jet η	4.50223e+06	13.58%	96.52%
y*	2.52035e+06	7.60%	55.98%
m_{jj} >1.1 TeV	633885	1.91%	17.69%
Inclusive one *b*-tag	113124	0.34%	17.85%
Exclusive one *b*-tag	106743	0.32%	94.36%
Two *b*-tag	6381	0.02%	5.98%

Z' => bb: 1.5 TeV

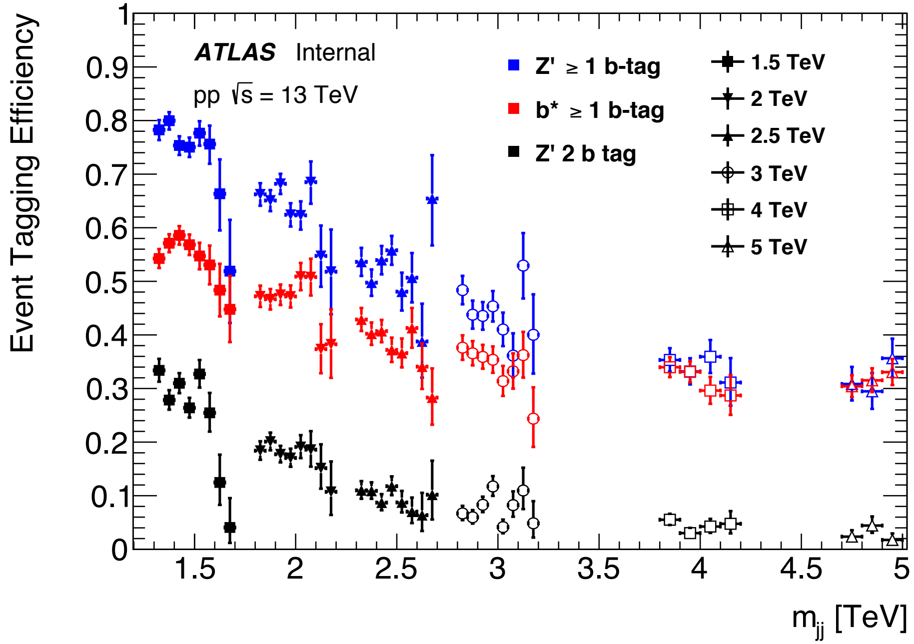
Selection criteria	N_{events}	Remain (%)	Rel. remain (%)
All	15000	100%	100%
Trigger efficiency	11394	75.96%	78.06%
Jet cleaning	11394	75.96%	100%
Leading jet	9692	64.61%	85.06%
Jet η	9592	63.95%	98.98%
y*	6367	42.45%	66.38%
m_{jj} >1.1 TeV	4596	30.64%	72.18%
Inclusive one *b*-tag	3522	23.48%	76.64%
Exclusive one *b*-tag	2253	15.02%	63.95%
Two *b*-tag	1270	8.47%	56.37%

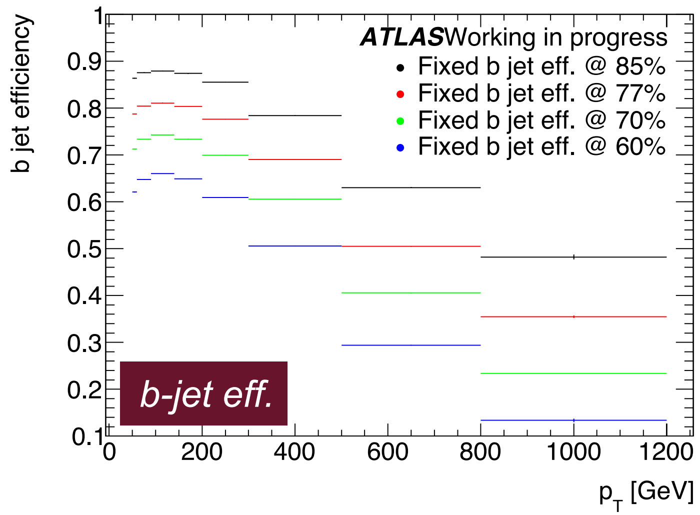
B-Tagging Strategy

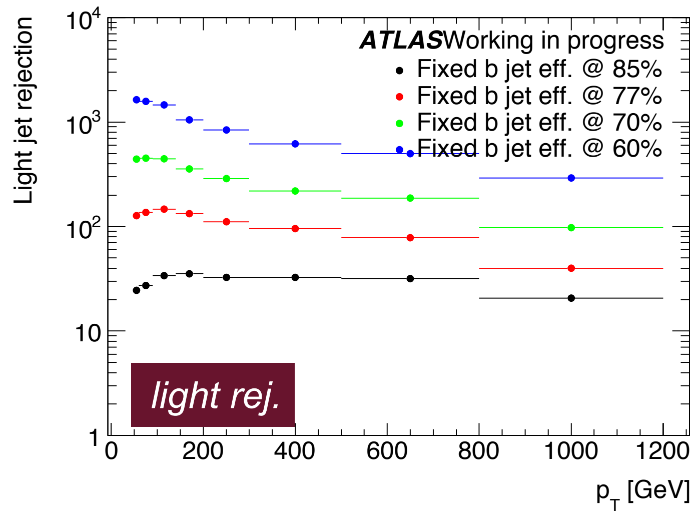
- **MV2c20** - **Fixed 85% Eff. WP**
  - MV2c20 > -0.7887
  - Calibrated and supported
  - Good sensitivity

- b-jet eff. ~ 50% at jet-p_T ~ 1 TeV
- Light-jet rejection ~ 30
  - Approximately flat
  - Good for background modelling.

- Two Categories
  - "1b" = ≥ 1 b-tag
  - "2b" = 2 b-tags





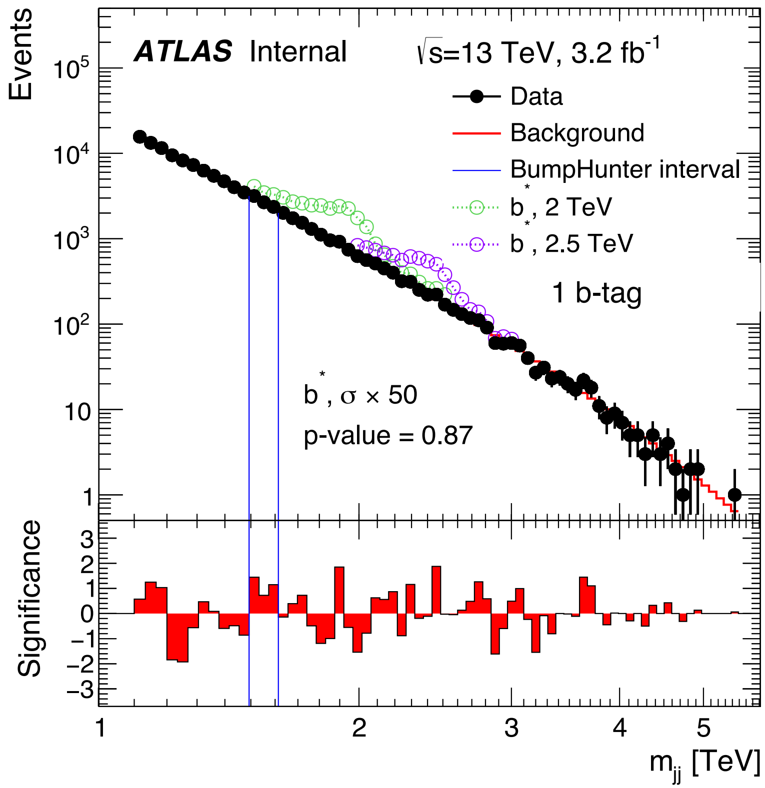


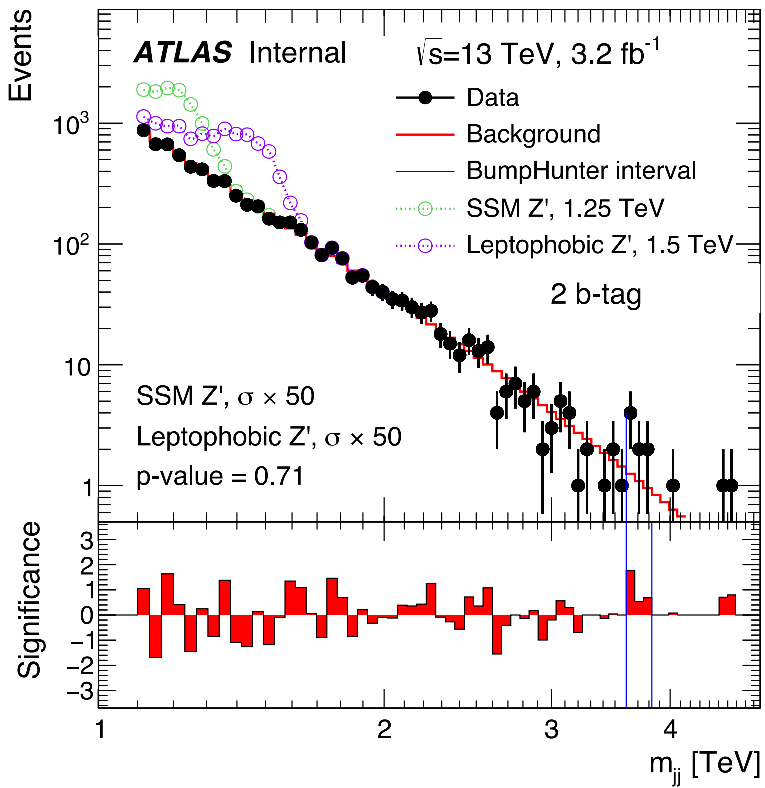
Data - Bump Hunter

- **Mass spectra in two b-tag categories**
  - 3.2 fb^{-1} of data, full data set
  - Background fitted with smoothly falling function

$$f(z) = p_1(1-z)^{p_2} z^{p_3}$$
$$\text{where} \quad z = m_{jj}/\sqrt{s}$$

- **BumpHunter searches for excesses**
  - Searches for statistically significant deviations.
  - Consecutive bins with smallest probability from background fluctuations
- **No excess found more significant than 3σ**



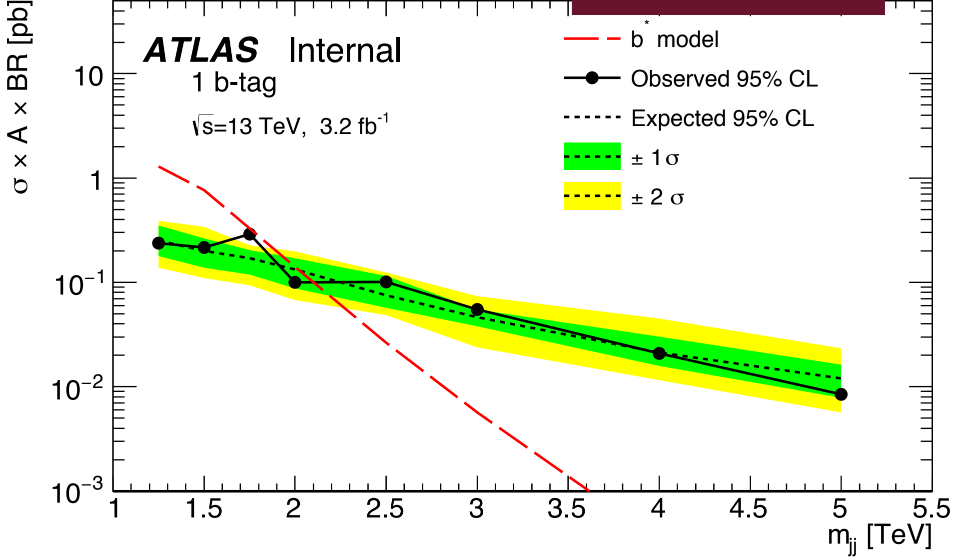


Limit Setting - b* and Z’

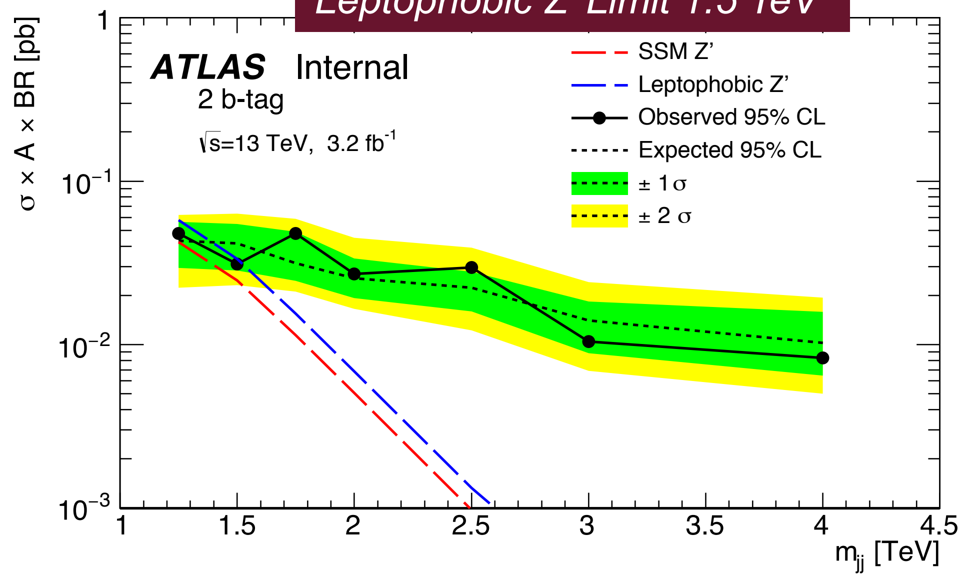
- **95% C.L. upper limits set for *b** and *Z’***
  - Use bayesian approach for limit setting
  - No correction for acceptance

- **Systematics:**
  - Luminosity uncertainty - 5% - From luminosity group
  - Background uncertainty
    - Uncertainties on fit function choice and fit parameters
  - Signal uncertainties
    - JES and bJES Uncertainties = Combined 6%
    - An additional BJES uncertainty < 2%
    - *b*-tagged scale factor uncertainty - 20-50% for masses 1.1-5 TeV

b Limit 2.1 TeV*



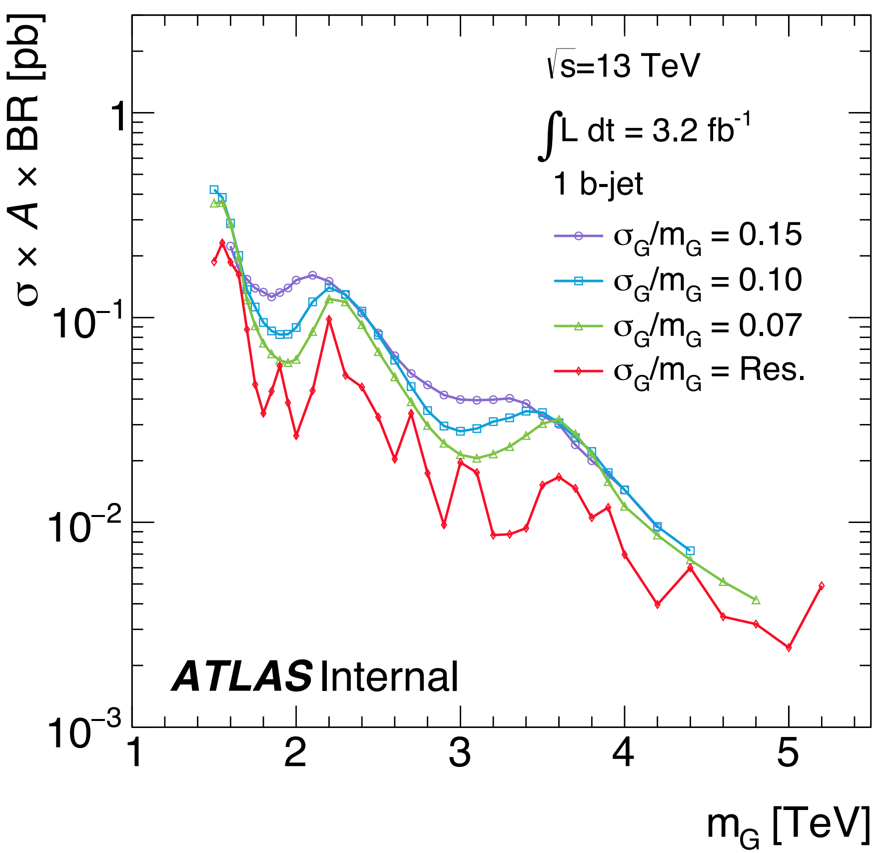
Leptophobic Z’ Limit 1.5 TeV

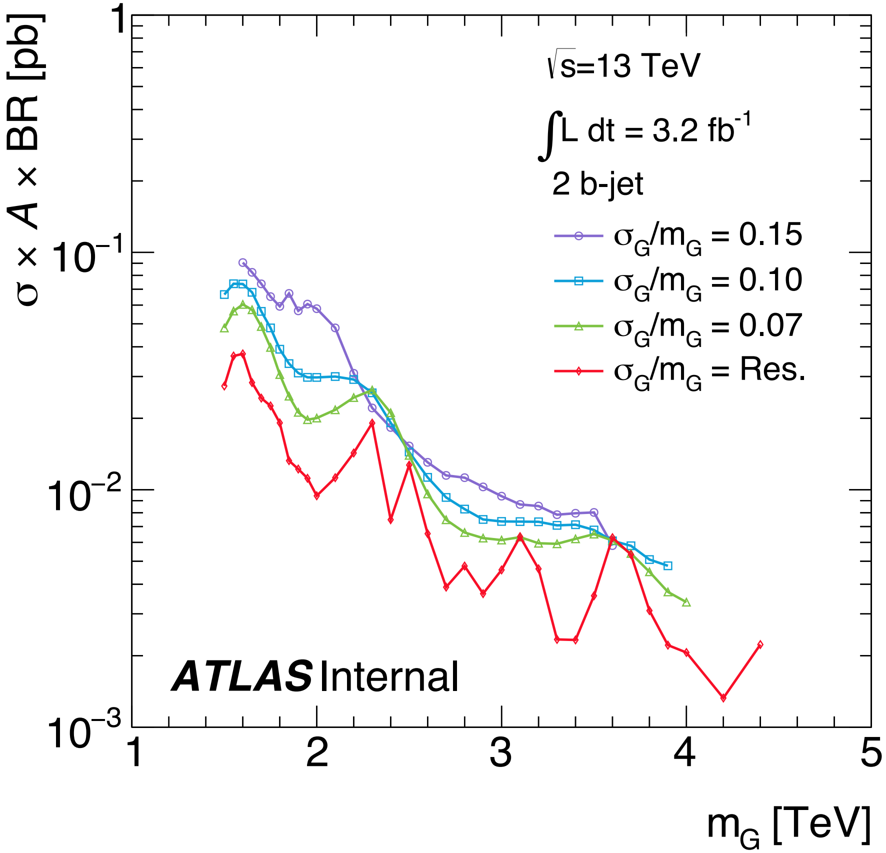


Limit Setting - Gaussian Signal

- **95% C.L. upper limits set for Gaussian Signal**
  - Use bayesian approach for limit setting
  - No correction for acceptance

- **Gaussian Signal Shape**
  - Varied signal width: From detector resolution to 15% of resonance
  - Exclusion on effective cross section: 0.3 - 0.001 pb in mass range 1.5 - 5 TeV

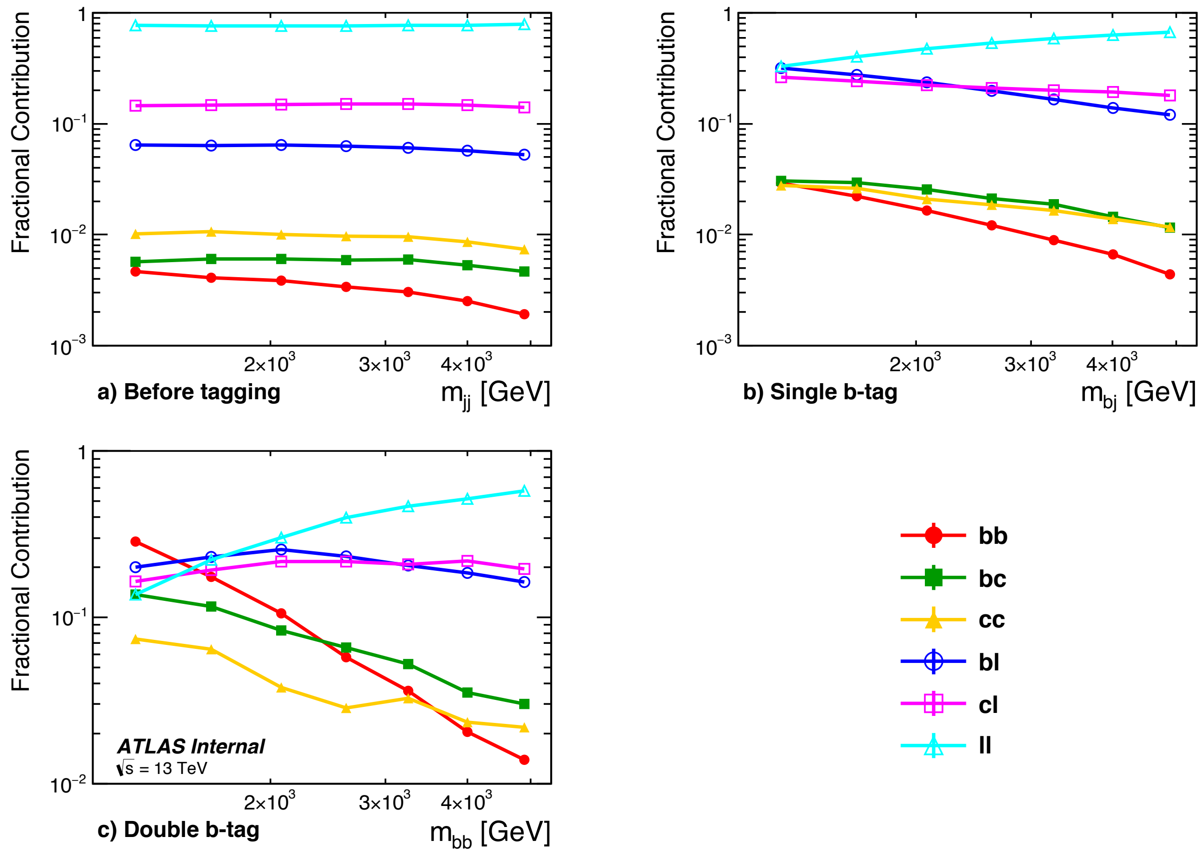




Flavour Composition Studies

Getting the Flavour Fractions

- Flavour composition of the single b-tag and double b-tag changes as a function of mass.
  - This is due to b-tagging efficiency dependance on jet-pT



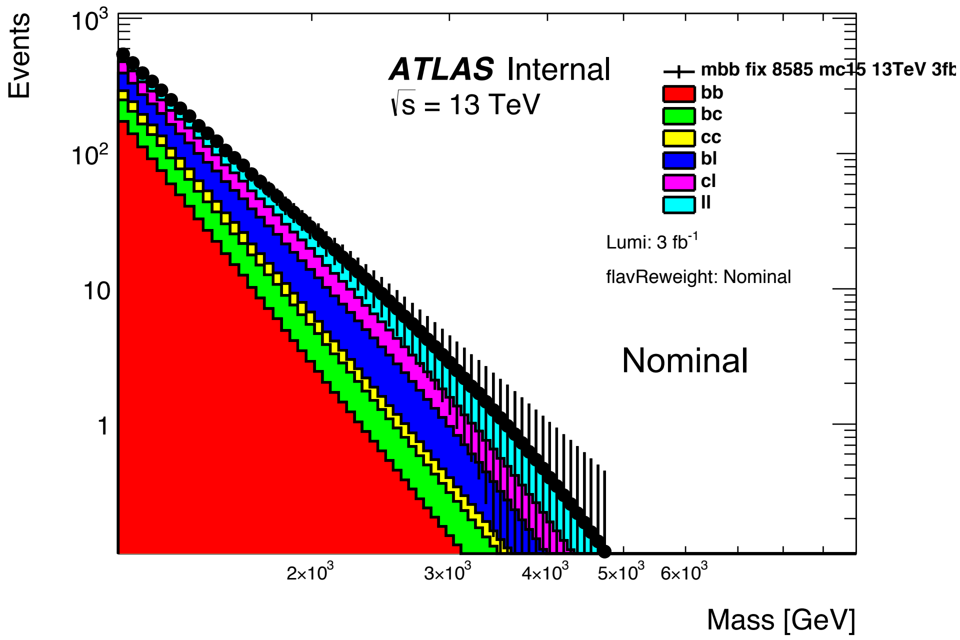
- We want to understand how varying the flavour composition will affect the fitting function.
  - Are the fitting functions robust to changes flavour composition?
  - Do we need an additional systematic for this?

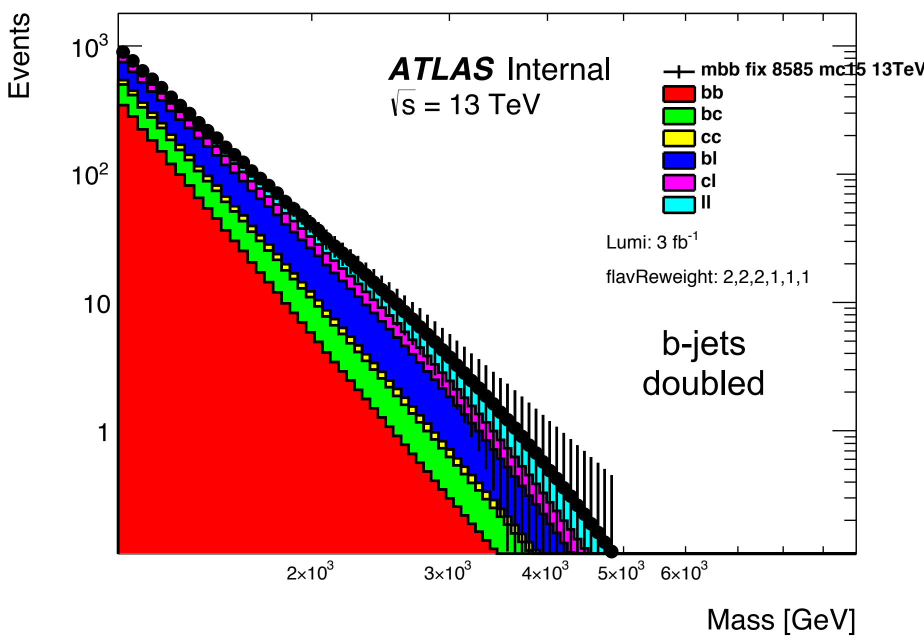
- Vary the amount that different flavour combinations contribute and fit.

Stacking the Flavour Fractions

- Take mass spectrum of each flavour combination from MC (bb, bc, cc, bl, cl, ll)
  - Fit to each spectrum scaled to 20ifb using our fitting function.
  - Use the fit each combination as a template.

- Create new scaled like distributions.
  - Adding templates from fits to 20 fb^{-1} scaled to 3 fb^{-1}
  - Adding the fractions in different ways to produce various spectra

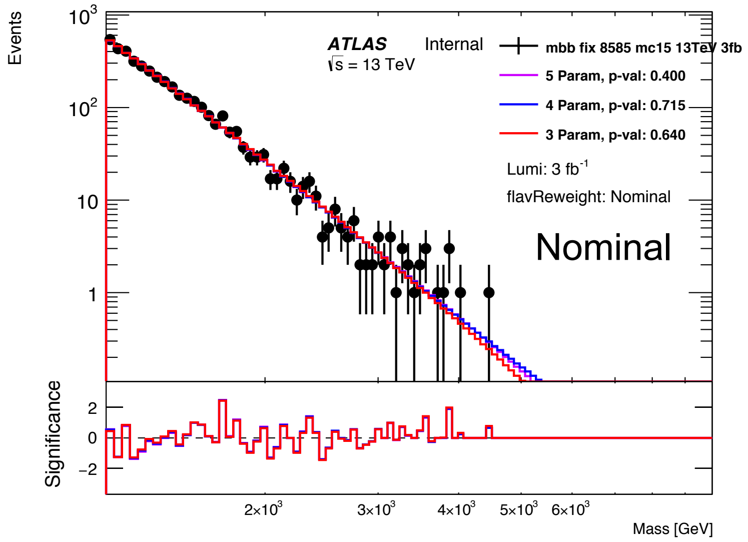


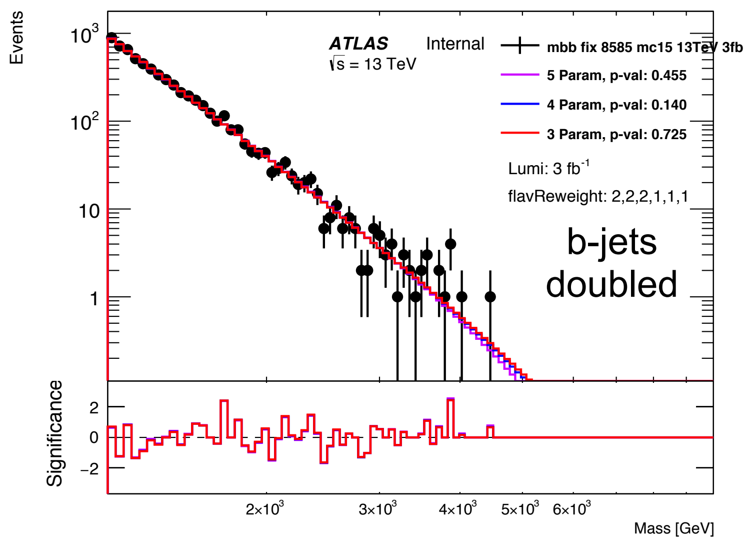


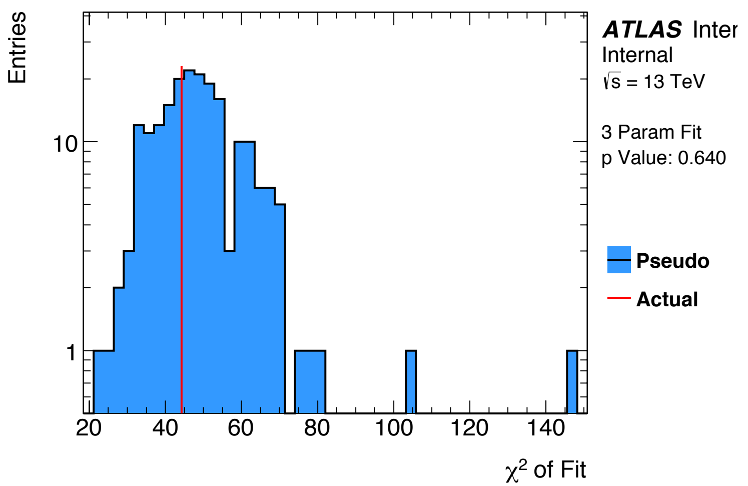
Data-Like p-Values

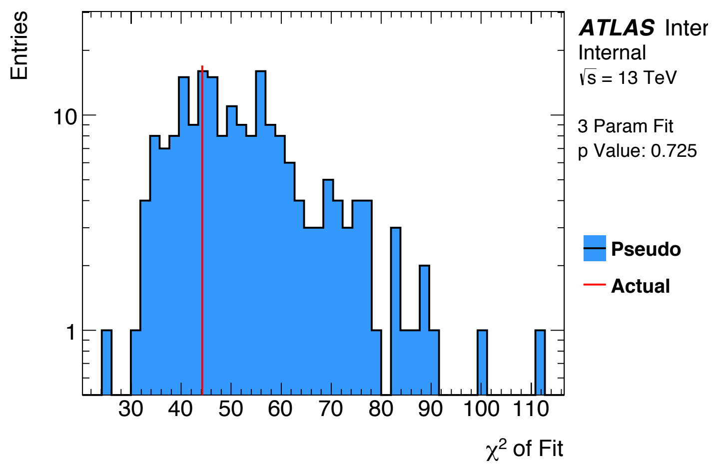
- By applying poisson fluctuations we can create 'data-like' distribution
- These are fitted using the 3, 4 and 5 parameter fit function
- Fitting function:

$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln x + p_5 (\ln x)^2}, \quad \text{with } x \equiv m_{jj}/\sqrt{s}$$



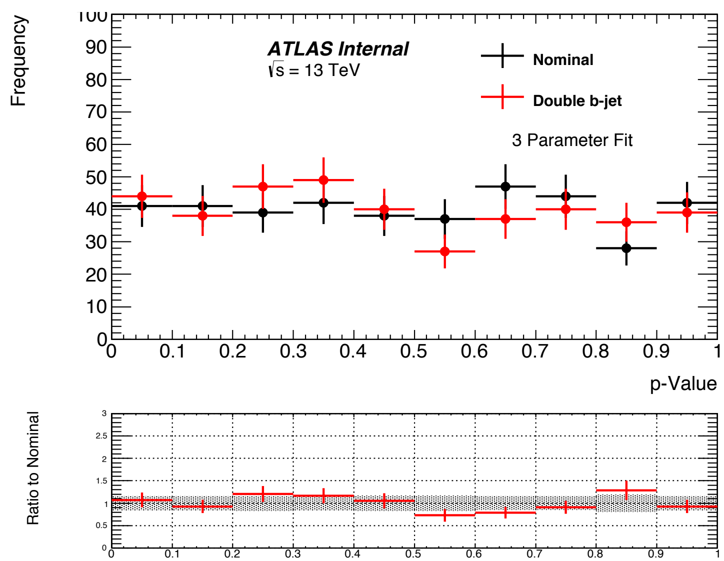


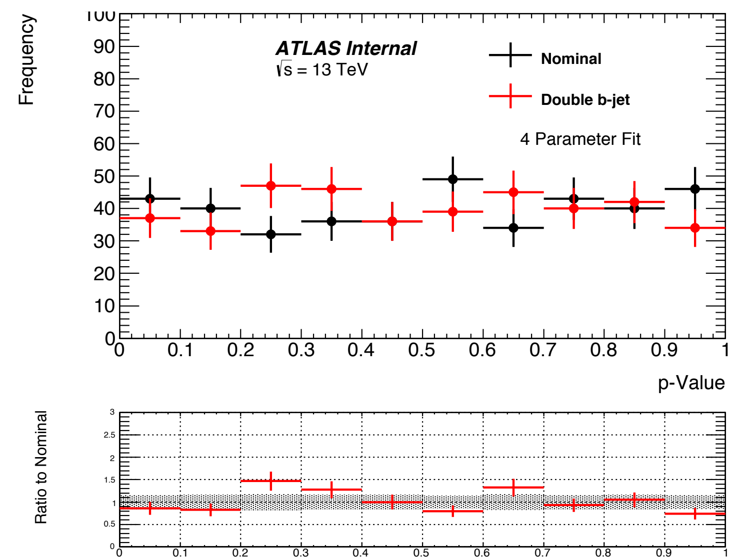




p-Value studies

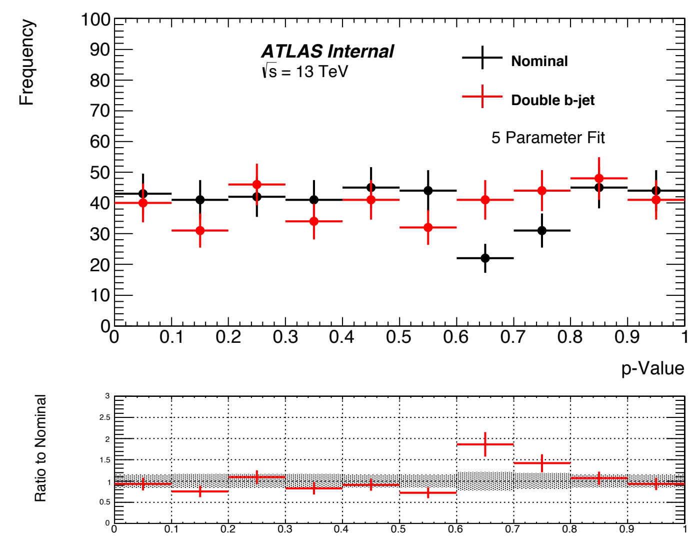
- Different sets of poisson fluctuations means a different ‘data-like’ spectrum
- Each ‘data-like’ dist. can be fitted to, giving a different p-value for each fit variation.
- 400 different data-like distributions have been studied





Mean p-values

	3-Para. Fit	4-Para. Fit	5-Para. Fit
Nominal	0.492 +/- 0.014	0.508 +/- 0.015	0.488 +/- 0.015
b-jet Doubled	0.478 +/- 0.014	0.495 +/- 0.014	0.514 +/- 0.022



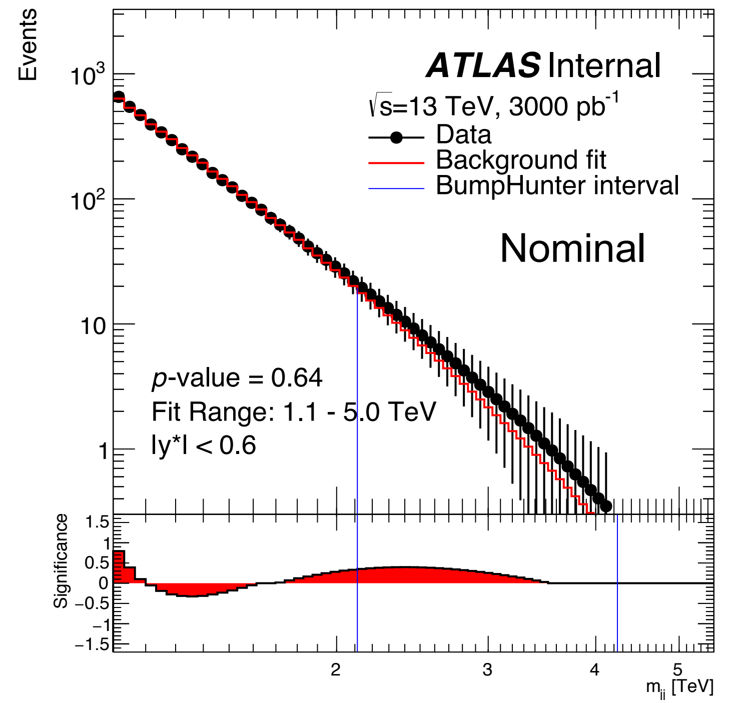
16 Spurious Signal

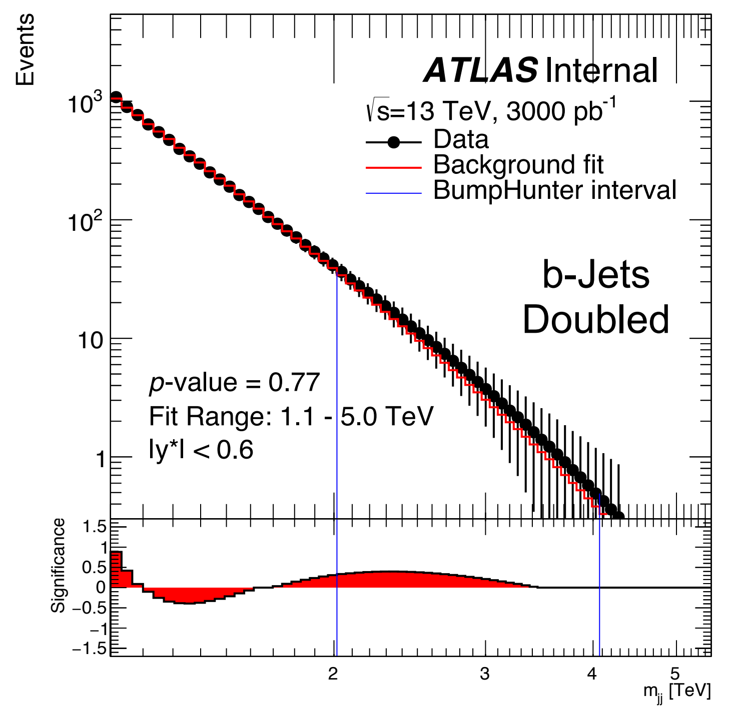
- Spurious signal
  - If there is discrepancy between fit and data then this can be mistaken as signal

- Test for spurious signal
  - Use scaled spectra before Poisson noise
  - Fit to this spectra using fit function
  - BumpHunter will identify discrepant region
  - BH then can calculate p-value

- Mass Range of Fit
  - 1.1 - 5 TeV
  - Larger than mass range in data.

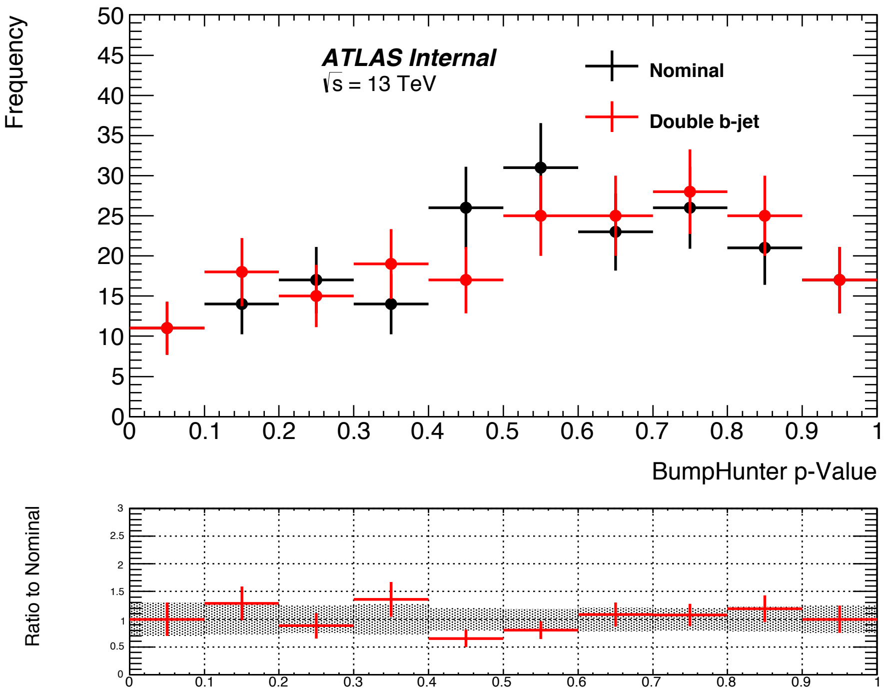
- No significant spurious signal found.
- Consistent p-Value in both flavour composition cases
- Wide discrepant region
  - Unlike benchmark models



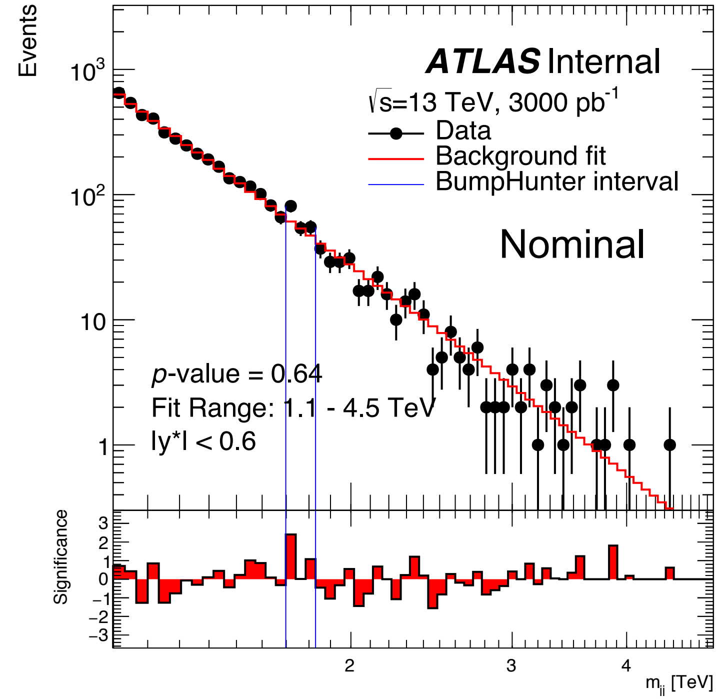


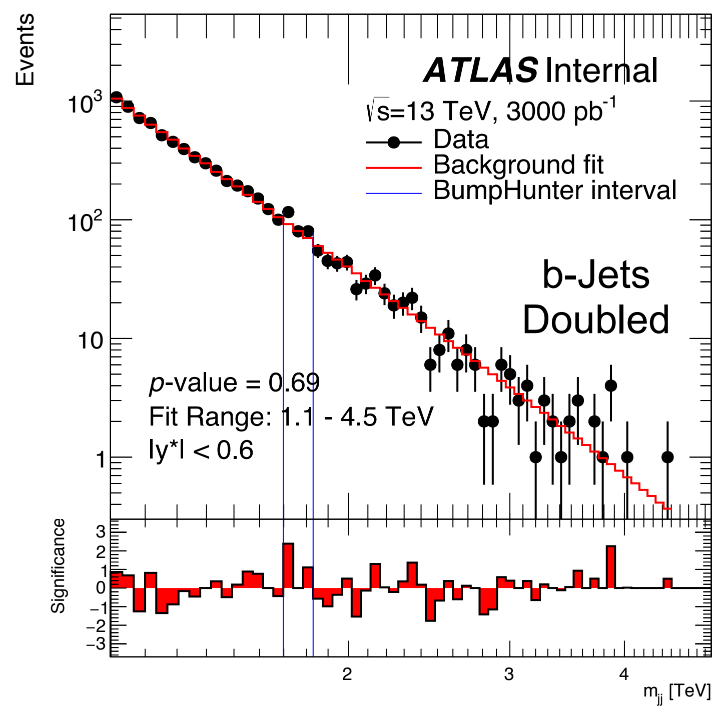
Spurious Signal - Data Like

- Test for spurious signal in data-like distributions
  - Repeat process after poisson fluctuations
  - Try 200 different set of poisson fluctuations.



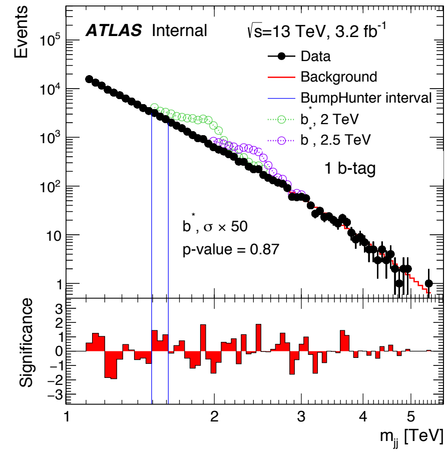
- No clear bias in p-value
  - No large ‘false alarm’ rate
  - Poisson fluctuations dominate discrepancy
- Consistent for both flavour composition cases

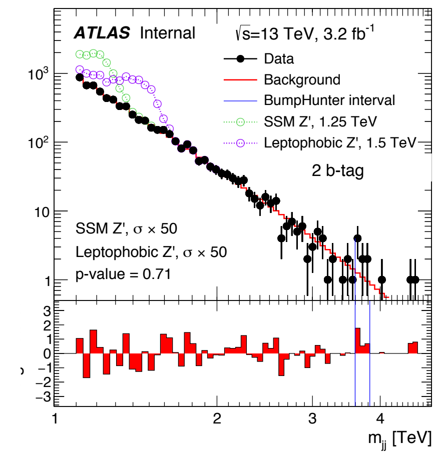


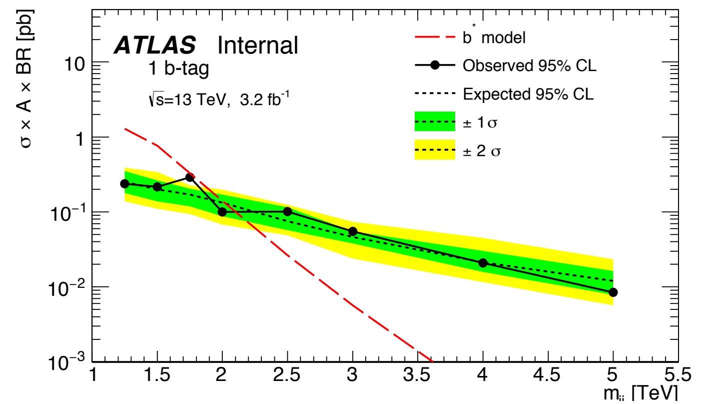


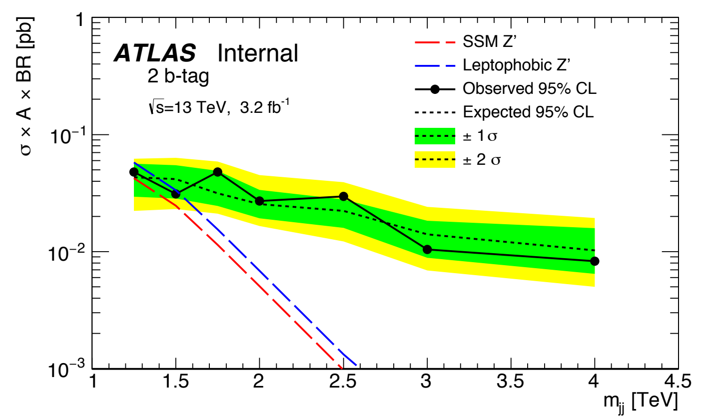
Summary

- **b-Tagged di-jet search**
  - First such analysis at ATLAS
  - Similar strategy to inclusive di-jet analysis
  - Use of very high pT b-tagging
- **Searched 3.2 fb^{-1} of data**
  - Inclusive 1 b-tag and 2 b-tag spectra
  - No significant excess observed
  - Limits set on b* and leptophobic Z'
  - Also set limit on generic Gaussian signal
- **Fit robust to changes in flavour composition**
  - Fit p-value consistent when flavour comp. is changed
  - No need for additional systematic.
  - No spurious signal introduced.
- **On course for Moriond paper!**
  - Paper and INT Note written
  - Comment from Open Presentation Addressed
  - In circulation now!









Backup!

b-Jet Energy Scale

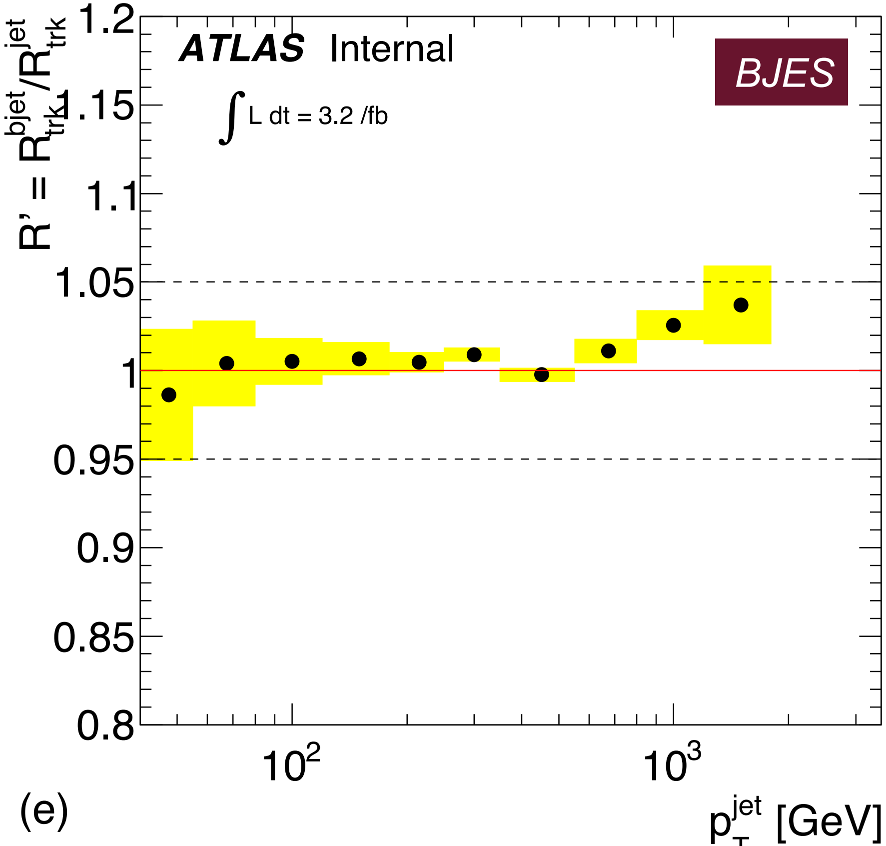
- Calculate using ratio of tracks within jet cone to reconstructed calo jet.
  - Use a double ratio between b-tagged jets and inclusive jets

- Additional bJES uncertainty < 2.6 for pT range
  - Applied on top of normal JES of 1-5%
  - Total b-Jet uncertainty of 6% assigned.

- Approved in JES/JER Meetings

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

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



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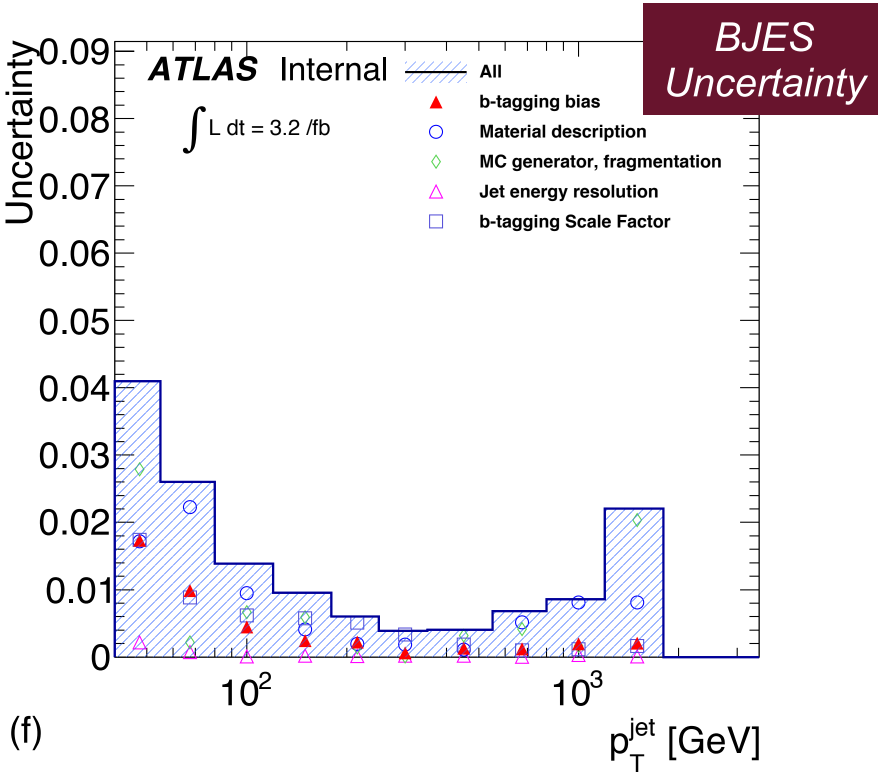

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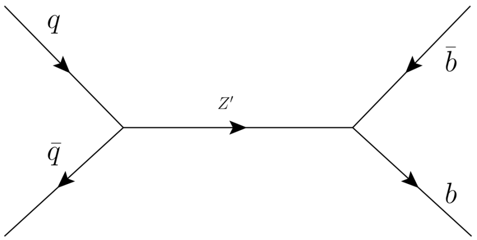
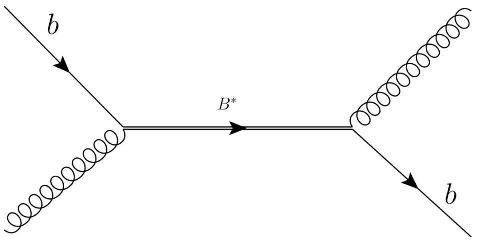
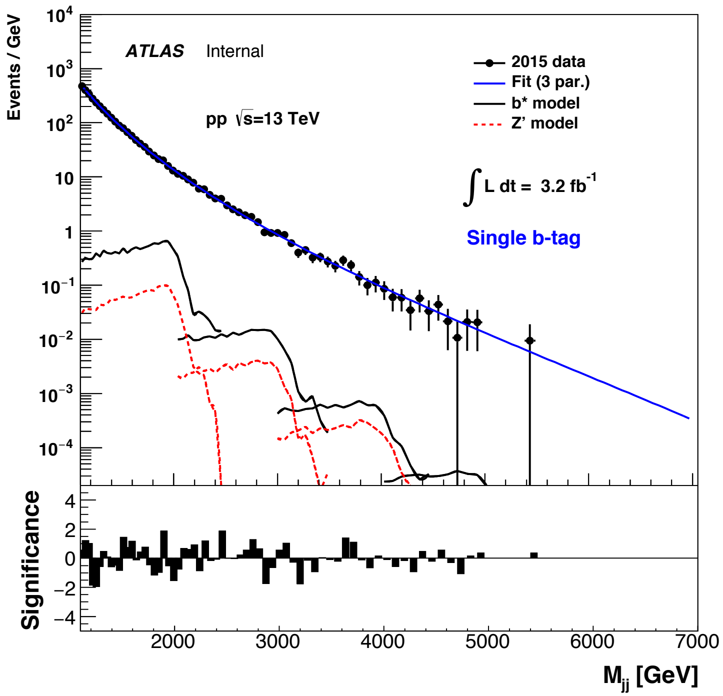
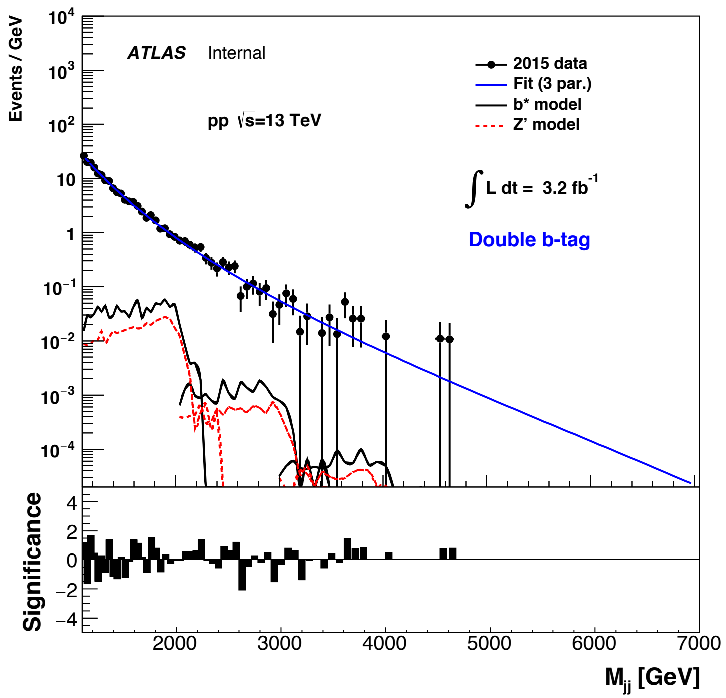
Signal Models

- Benchmark models - We can set limits here.
  - **Z' => bb** - 1.25, 2, 3 and 4 TeV
    - SSM => BR(bb) = 13.8%
    - Leptophobic => BR(bb) = 18.9%
  - **b* => b+X** - 1.25, 2, 3, 4 and 5 TeV
    - BR(bg) = 85%
  - **Generic Gaussian**
  - Templates taken from MC samples



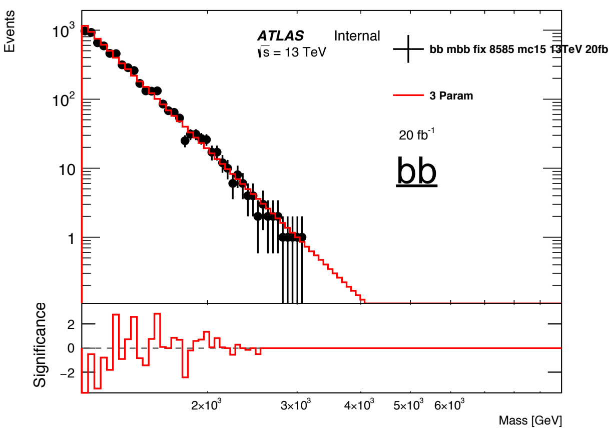


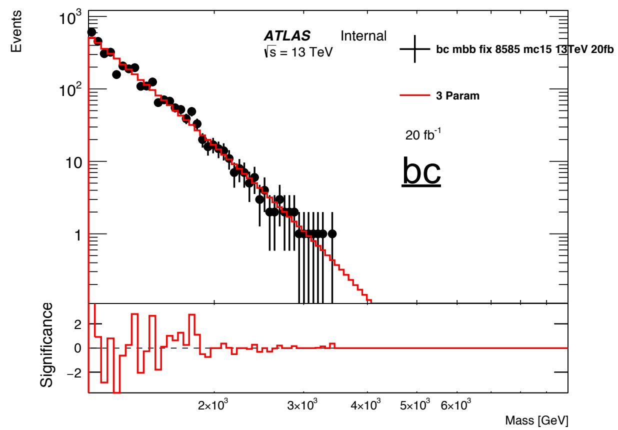


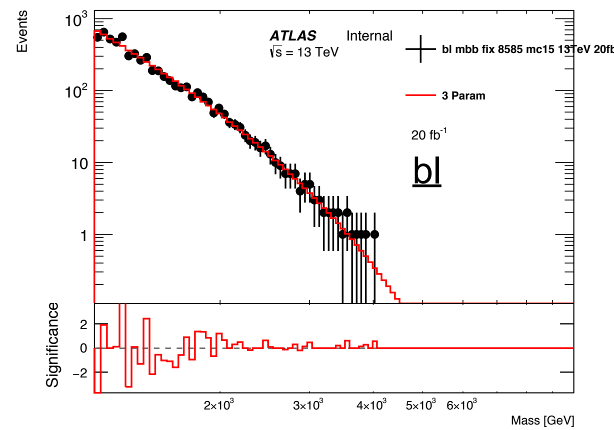


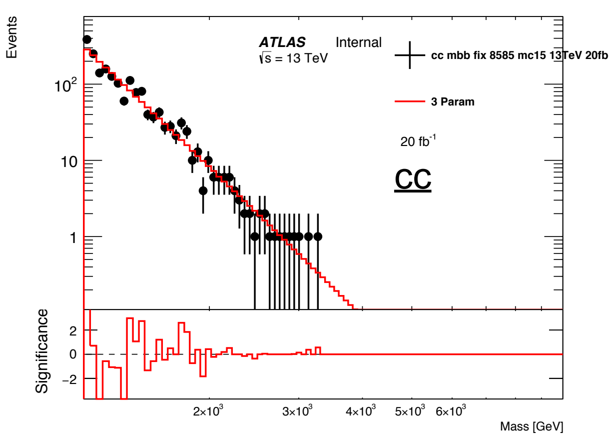
Getting the Flavour Fractions

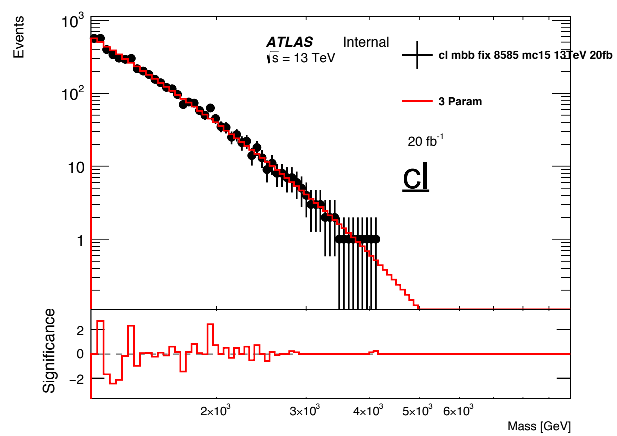
- Flavour fractions are extracted from MC using truth information
- The dijet mass spectrums for these flavour fractions are then scaled to $20fb^{-1}$
- The dijet mass spectrums are fitted to using the **3-parameter** fit function.

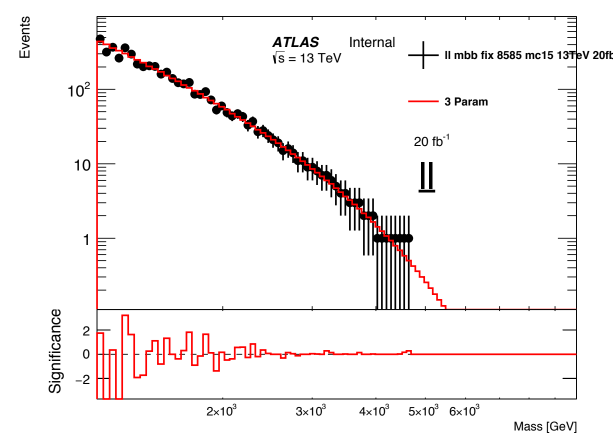






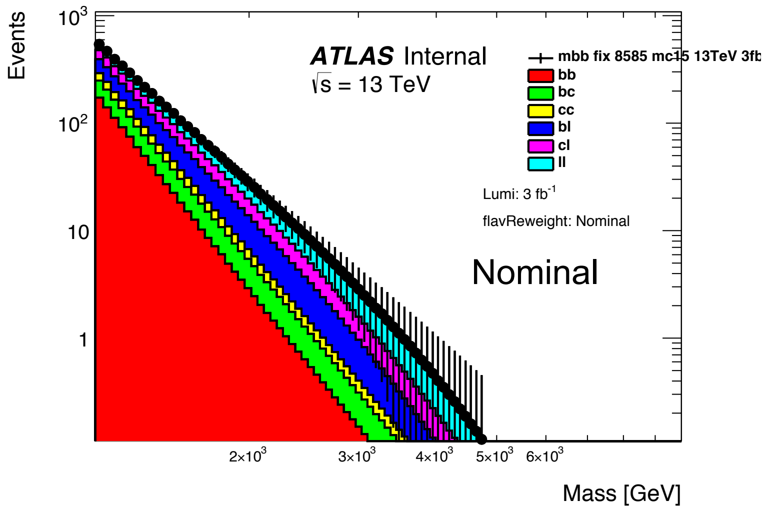


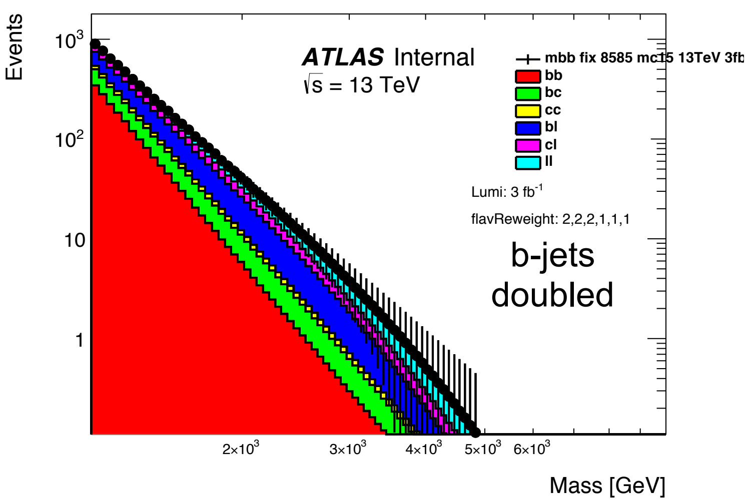


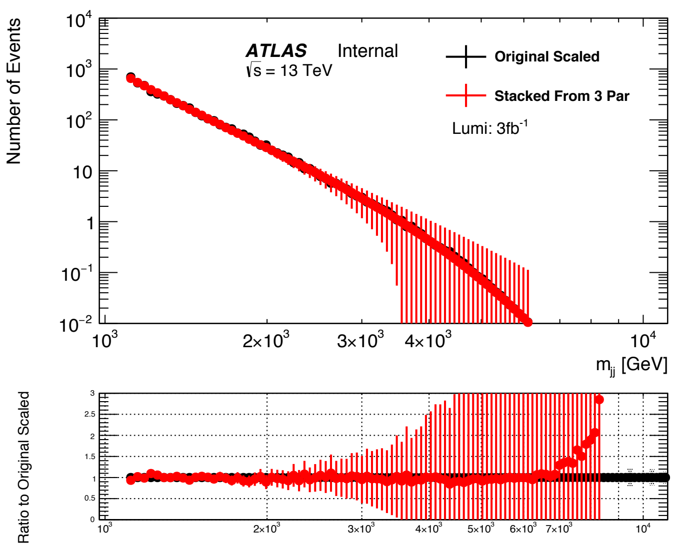


Stacking the Flavour Fractions

- Creates new scaled like distributions.
  => Adding templates from fits to 20 fb^{-1} scaled to 3 fb^{-1}
  => Adding the fractions in different ways to produce various spectra

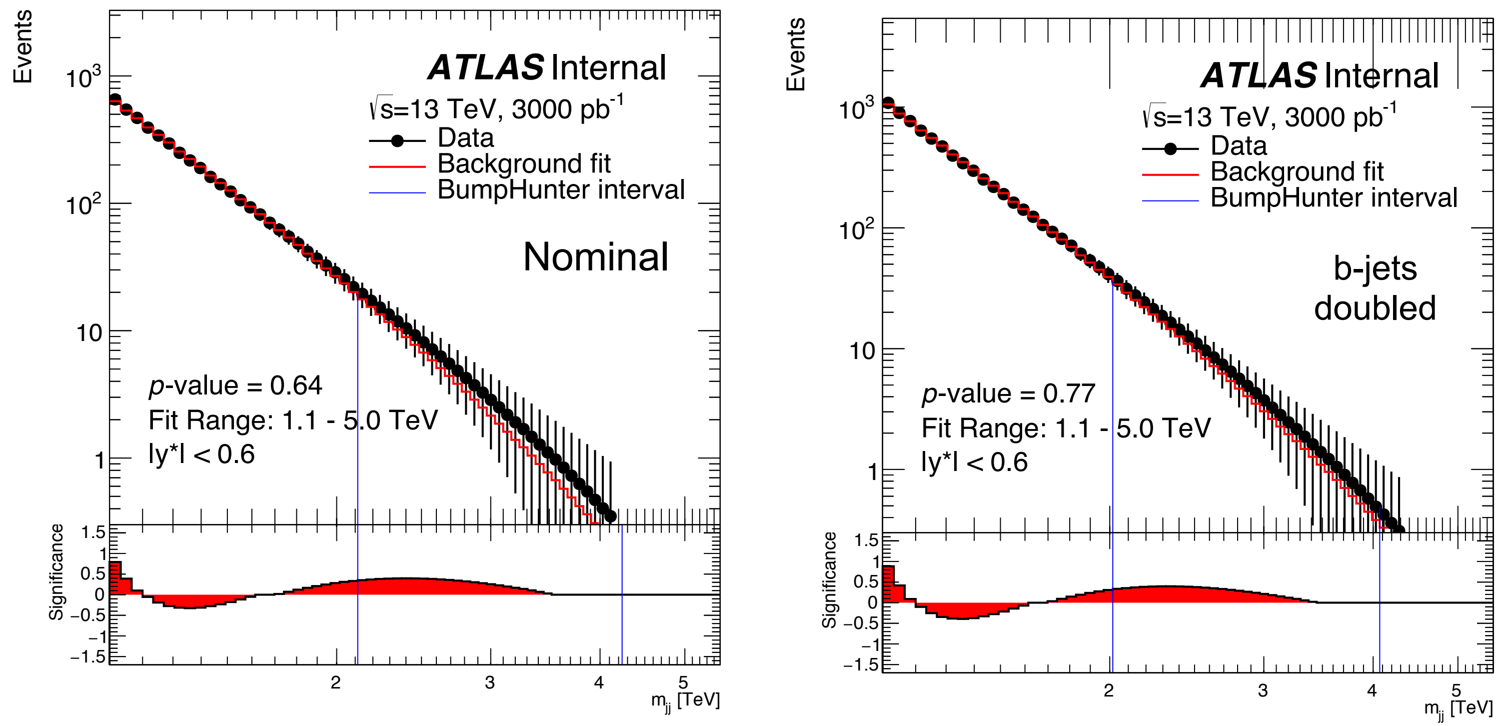


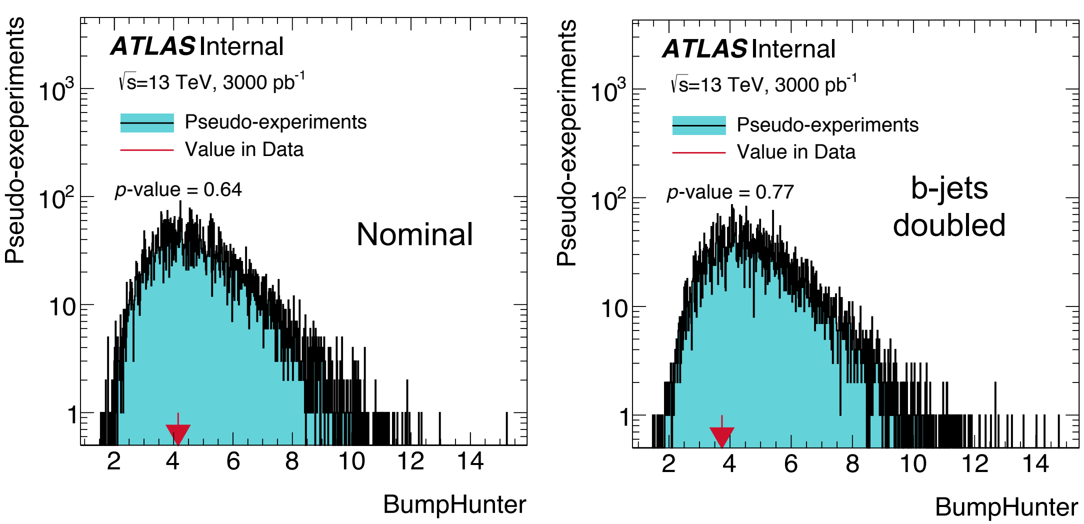




- Able to reproduce MC up to large masses.
- We conclude that the procedure of fitting to flavour fractions then stacking is appropriate.

Test for Spurious Signal - Results





- No significant spurious signal found.
- Consistent p-Value in both flav. composition cases
- Wide discrepant region => Unlike benchmark models