



Search for Resonances Below 1 TeV in the Mass Distribution of jet pairs with Two Jets Identified as b-Jets in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

Laurie McClymont,
for the di-b-jet analysis team

JDM Approval
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**Search for resonances below 1 TeV in the mass distribution of jet pairs
with two jets identified as b -jets in proton-proton collisions at $\sqrt{s}=13$
TeV with the ATLAS detector.**

J. Alison^a, L. Beresford^b, S. Chekanov^c, A. Coccaro^d, J. Dandoy^d, F. Guescini^d, G. Facini^d,
T. Golling^d, Y. Kim^a, A. Korn^e, K. Krizka^a, T. LeCompte^c, J. Love^c, L. McClymont^e,
J. Proudfoot^c, S. Ryu^c, M. Shochet^a, R. Wang^c, N. Zhou^f, N. Nishu^f

^a*University of Chicago, Enrico Fermi Institute*

^b*Department of Physics, Univ. of Oxford*

^c*HEP Division, Argonne National Laboratory*

^d*Section de Physique, Universite de Geneve*

^e*University College London*

^f*Tsinghua University*

Abstract

Searches for mass resonances in the b -tagged dijets invariant mass spectrum below 1 TeV have been performed with the ATLAS detector at the LHC. The dijet mass distribution from 0.5 TeV to 1.2 TeV is studied. The sensitivity was optimized considering a 750 GeV narrow resonance. The 2015 proton-proton collision data at $\sqrt{s} = 13$ TeV is used, corresponding to an integrated luminosity of 3.2 fb^{-1} . Conclusions will be added once the full mass spectrum has been unblinded.

INT Note in CDS - [Here](#)

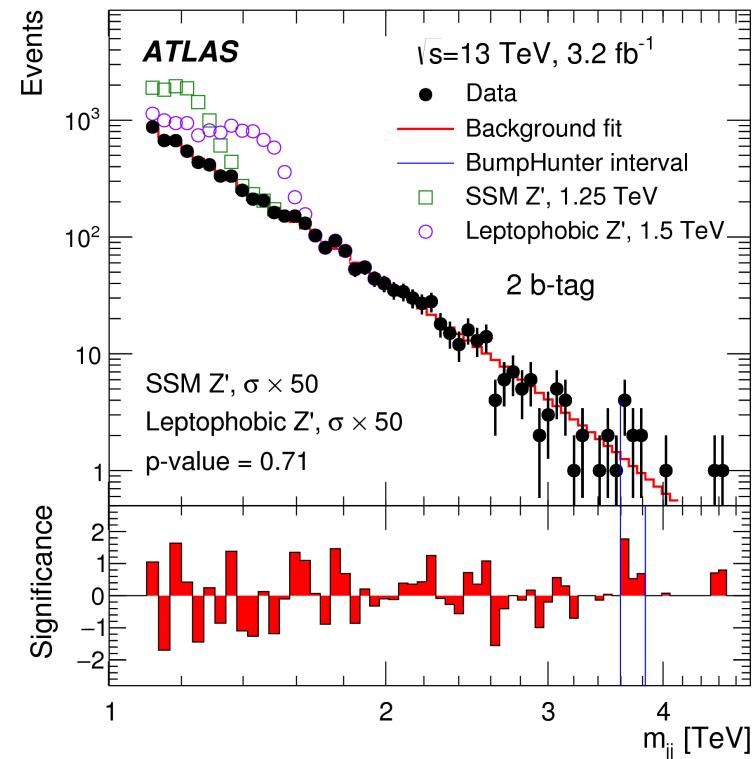
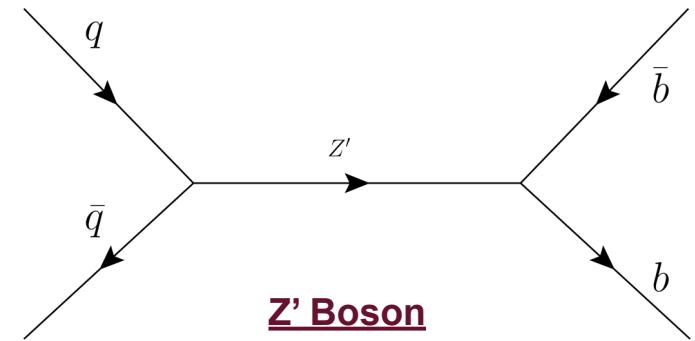
Conf Note working draft - [Here](#) - Updated Today!



- 1) Introduction**
- 2) Event and Jet Selection**
- 3) Description of b-Jet Triggers**
- 4) Kinematic Distributions**
- 5) Statistical Techniques**
- 6) Systematic Uncertainties**
- 7) Search Result**
- 8) Conclusions**

- Many BSM models predict resonances that decay to b-quark(s)
 - E.g. Z' Boson
- b-Tagging Increases Sensitivity
 - Large QCD background
 - Dominated by light jets
 - (*light = u, d, s and gluon*)
 - Increased sens. to these models
- Perform Resonance Search
 - Similar strategy as inclusive dijet
 - Fit using smoothly falling function
 - Use BumpHunter to find excesses
- Moriond High Mass Paper
 - $m_{jj} > 1.1 \text{ TeV}$
 - ≥ 1 b-tag and 2 b-tag category
 - No significant excesses found

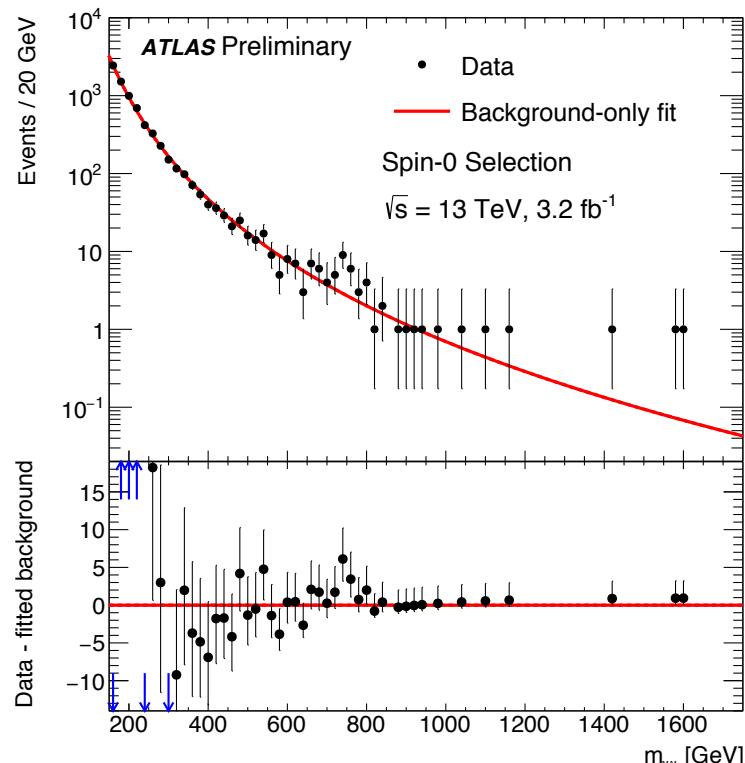
[arXiv:1603.08791](https://arxiv.org/abs/1603.08791)





5 Introduction: Low Mass Analysis

- **Motivation to go to lower masses**
 - Cross over between $\gamma\gamma$ and bb ?
 - Assume scalar couples to bb and $\gamma\gamma$ only
 - Estimate $\sigma_{\gamma\gamma}$ and Γ from diphoton
 - Theorists calculate σ_{bb} , ([arXiv:1512.04933](#))
 - $\sim 0.4 \text{ pb}$ @ 8 TeV
 - $\sim 2.1 \text{ pb}$ @ 13 TeV
- **Weak limits on BSM at low mass**
 - Limits on above model are weak
 - $< 1 \text{ pb}$ @ 8 TeV, ([arXiv:1506.08329](#))
 - No limits @ 13 TeV
 - We should study this region...
- **New Trigger Strategy Required**
 - Last time limited by trigger turn on
 - **HLT_j360** (*Unprescaled single jet trigger*)
 - We can use b-jet trigger
 - **HLT_j175_bmedium_j60_bmedium**
 - $500 < m_{jj} < 1200$



- **Can be done in 2015 data**
- **CONF Note for LHCP**



6 Event and Jet Selection

- **Trigger and Data**
 - **3.2 fb⁻¹**, excluding IBL off data
 - **Double b-jet trigger:**
HLT_j175_bmedium_j60_bmedium
- **Jet Selection**
 - Anti-k_T EM Topo Jets, R=0.4
 - **Leading Jet, p_T > 200 GeV***
 - **Sublead. Jet p_T > 80 GeV**
 - Both jets, |η| < 2.4
- **Event Selection**
 - **500* < m_{jj} < 1200 GeV**
 - *Currently blinding 700-800 GeV*
 - **|y*| < 0.6, y* = 0.5 * Δy**
 - *Central region more sensitive to BSM*
- **Offline b-Tagging**
 - **MV2c20 @ 70% WP**
 - Online tagging limits b-jet eff.
 - Gain Light jet rej. from offline

Data - Full 3.2 fb⁻¹

| Selection criteria | N _{events} | Remain (%) | Rel. remain (%) |
|---------------------------|---------------------|------------|-----------------|
| All | 95022224 | 100 | 100 |
| GRL, Evt cleaning | 94082176 | 99.01 | 99.01 |
| Trigger | 2829596 | 2.98 | 3.01 |
| Jet η | 2698350 | 2.83 | 95.36 |
| b-tag 1st jet | 1351809 | 1.42 | 50.10 |
| b-tag 2nd jet | 726938 | 0.77 | 53.78 |
| jet ₀ >200 GeV | 436913 | 0.46 | 60.10 |
| jet ₁ >80 GeV | 429133 | 0.45 | 98.22 |
| y* | 252086 | 0.27 | 58.74 |

MC Z' - m_{Z'} = 800 GeV

| Selection criteria | Remain (%) | Rel. remain (%) |
|---------------------------|------------|-----------------|
| All | 100 | 100 |
| GRL, Evt cleaning | 96.00 | 96.00 |
| Jet η | 79.77 | 83.09 |
| b-tag 1st jet | 51.00 | 63.94 |
| b-tag 2nd jet | 30.17 | 59.16 |
| Trigger SF | 20.64 | 68.41 |
| jet ₀ >200 GeV | 14.18 | 68.70 |
| jet ₁ >80 GeV | 14.17 | 99.89 |
| y* | 0.10 | 77.34 |

* Not fixed - see slide 19

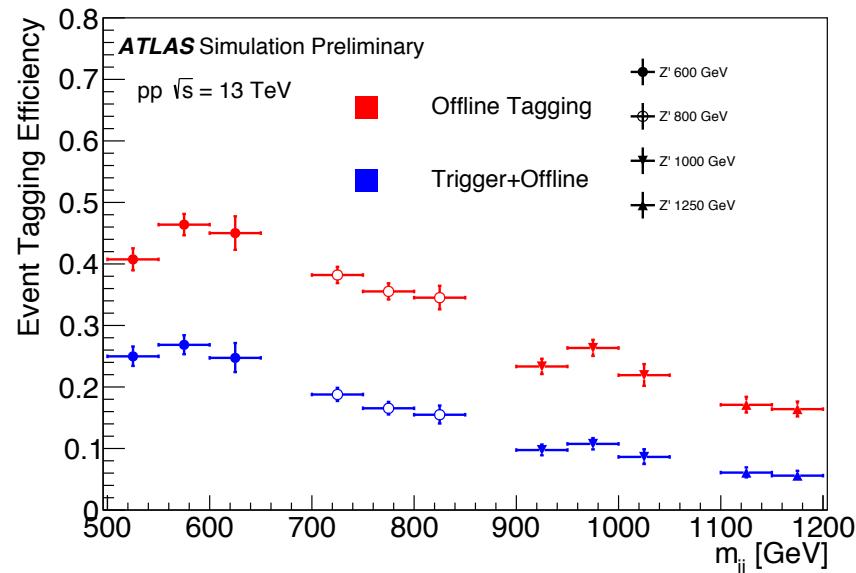
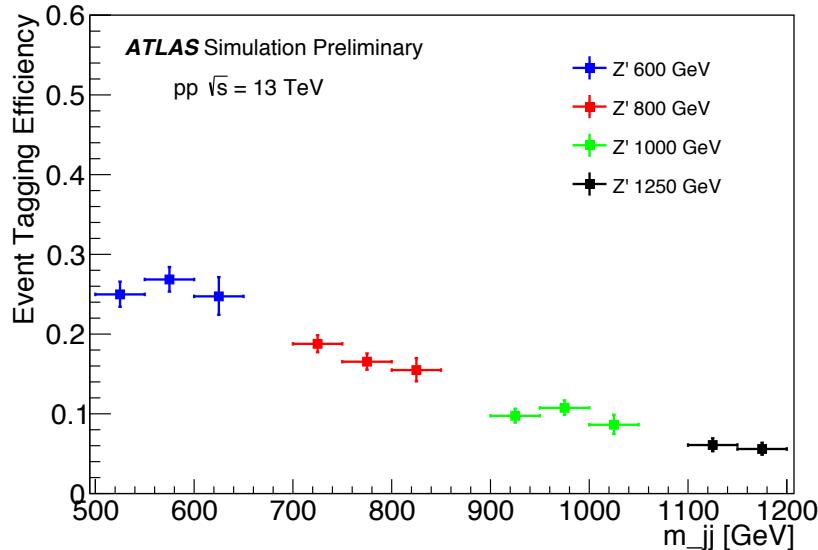


7 Event and Jet Selection - Extras

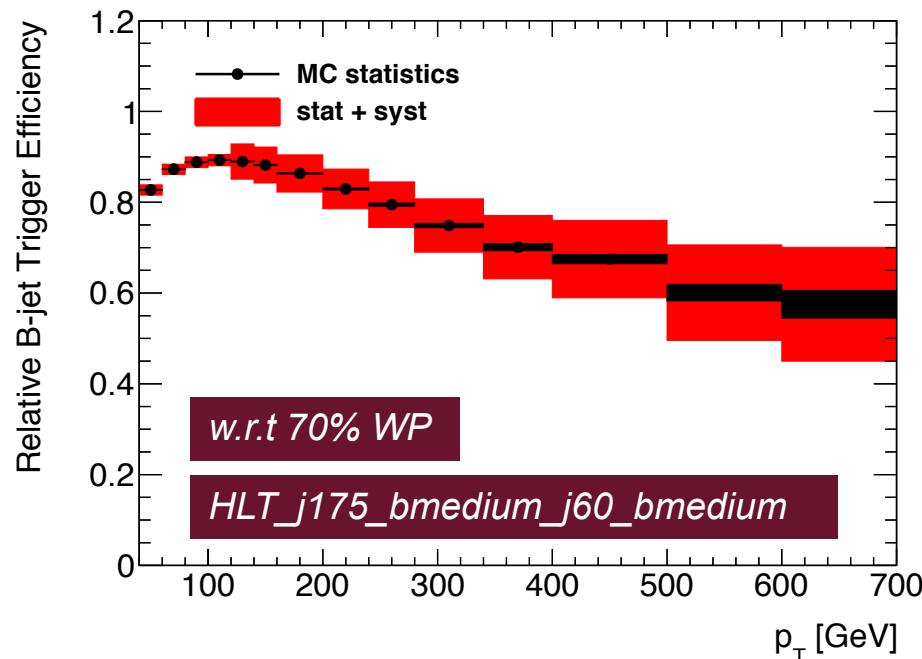
- **Offline b-Tagging**
 - MV2c20 @ 70% WP
 - Online tagging limits b-jet eff.
 - Gain Light jet rej. from offline
- **Working Point Selection**
 - Various b-tagging OP
 - Acceptance efficiency of Z'
 - $m_{Z'} = 800$ GeV
 - Emulating trigger efficiency
 - Expected # events from sideband fit
 - Expected Gaussian limits
 - Width 10% of mass

| b-tag OP | Eff (%) | N_{evt}^{exp} (bkg) in SR | Exp limit (pb) |
|----------|---------|-----------------------------|----------------|
| 85 | 9 | 8800 | 1.2 |
| 77 | 9 | 6000 | 1.0 |
| 70 | 8 | 4400 | 1.0 |
| 60 | 6 | 2800 | 1.1 |

Signal Tagging Efficiency



- **b-Jet Triggers to get to low masses**
 - 2015 data: IP3D+SV1 Algorithm
- **HLT_j175_bmedium_j60_bmedium**
 - bMedium WP
 - Tighter than 70% eff. WP
 - Cut in MC doesn't match Data
- **b-Jet Trigger Strategy**
 - Derive b-Jet Trigger Efficiencies
 - Data driven technique
 - Details on the next slide
 - Efficiencies are applied to signal samples to emulate trigger
 - Not required for background - Exact light-jet and c-jet rejections not needed
 - Use fit to model background rather than MC

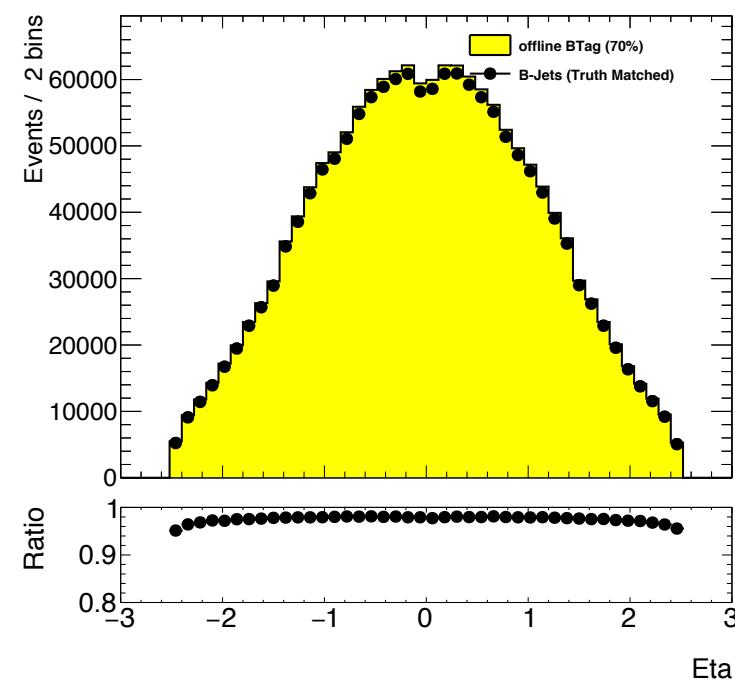
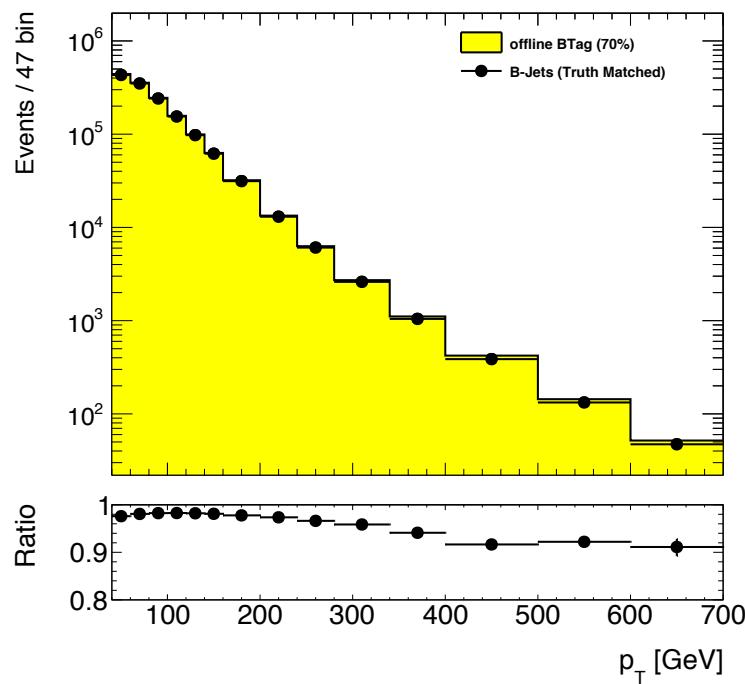


$$\text{b-Jet Trig Eff.}_{\text{wrt offline}} = \frac{\# \text{ b-Jets pass offline and online b-tagging}}{\# \text{ b-Jets offline b-tagging}}$$



9 b-Jet Triggers: Event Selection

- **High purity b-jet sample: Di-lepton tt selection**
 - **Single lepton bperf trigger:** *HLT_(mu26_imedium/e26_tight_iloose/e26_lhtight_iloose)_2j35_bperf*
 - Calculate online b-tagging algorithms on all jets with $p_T > 35 \text{ GeV}$
 - **1 medium electron & 1 medium muon** ($p_T > 30 \text{ GeV}$)
 - **2 b-tagged jets**, MV2c20 @ 70% ($p_T > 30 \text{ GeV}$, $|\eta| < 2.4$)
- **Testing the b-jet purity**
 - Use truth matching to estimate impurities in sample
 - High purity (>95%) at low p_T , decreases to ~90% at 700 GeV

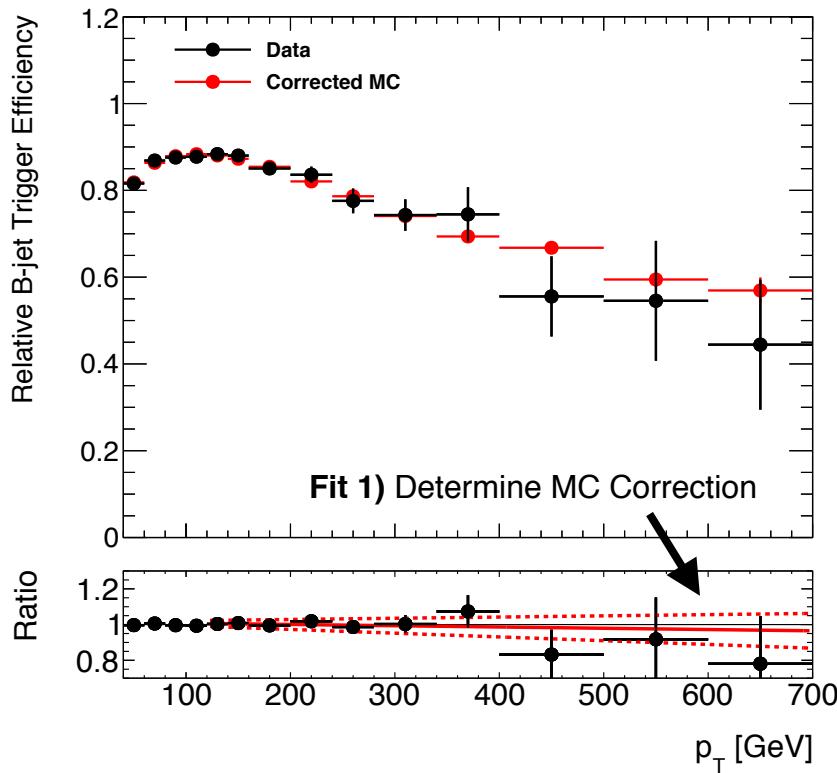




10 b-Jet Triggers: Estimating Efficiency

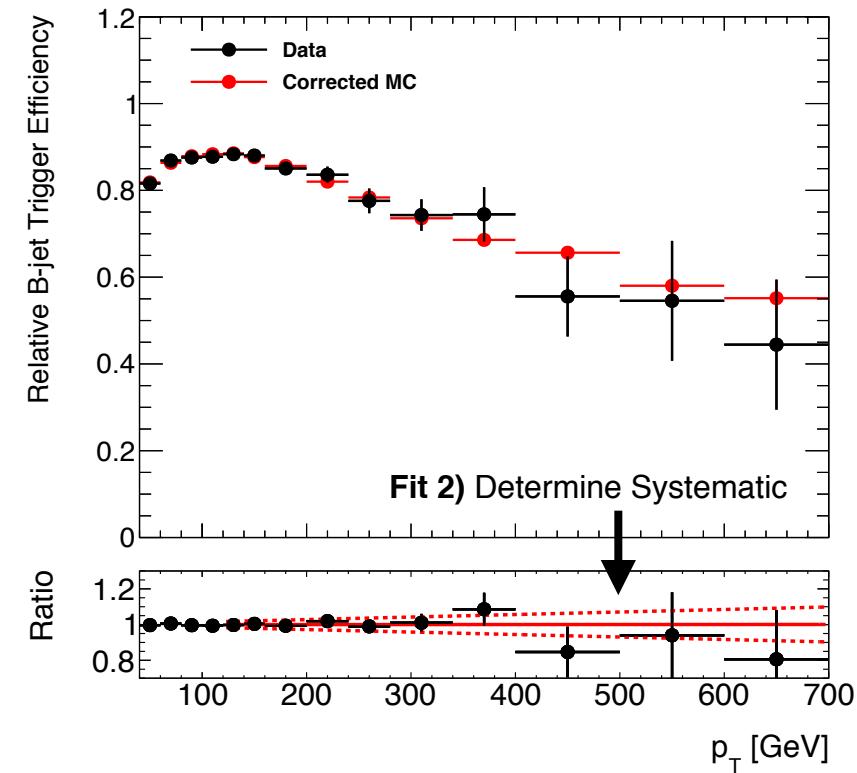
Jet $p_T < 120 \text{ GeV}$

- Data Eff. taken as central value
- Data/MC difference taken as syst.
- Precision of data also as syst.



Jet $p_T > 120 \text{ GeV}$

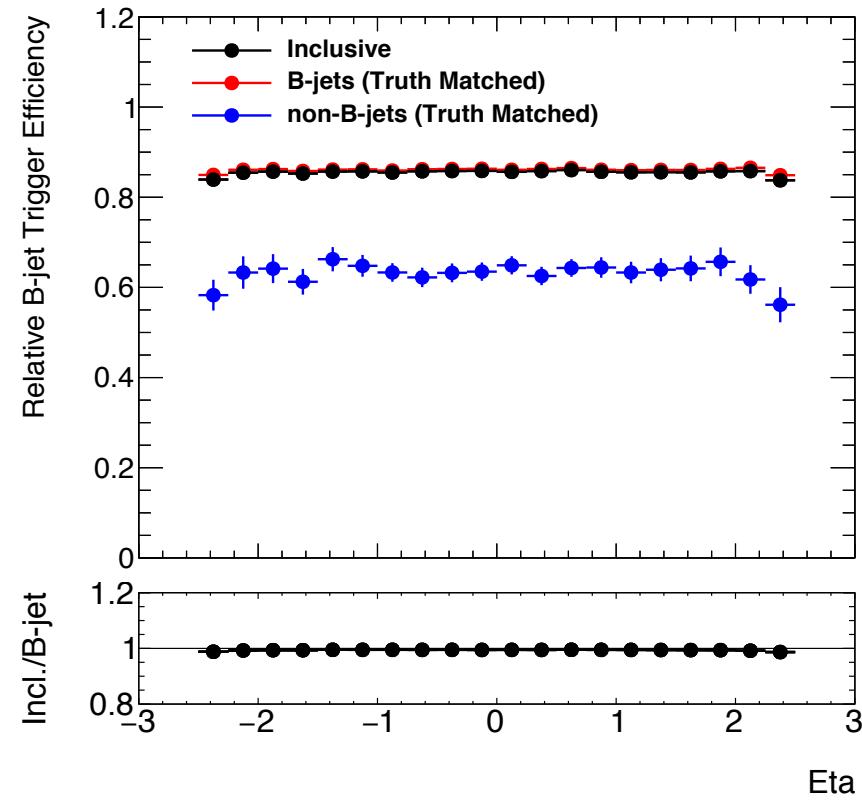
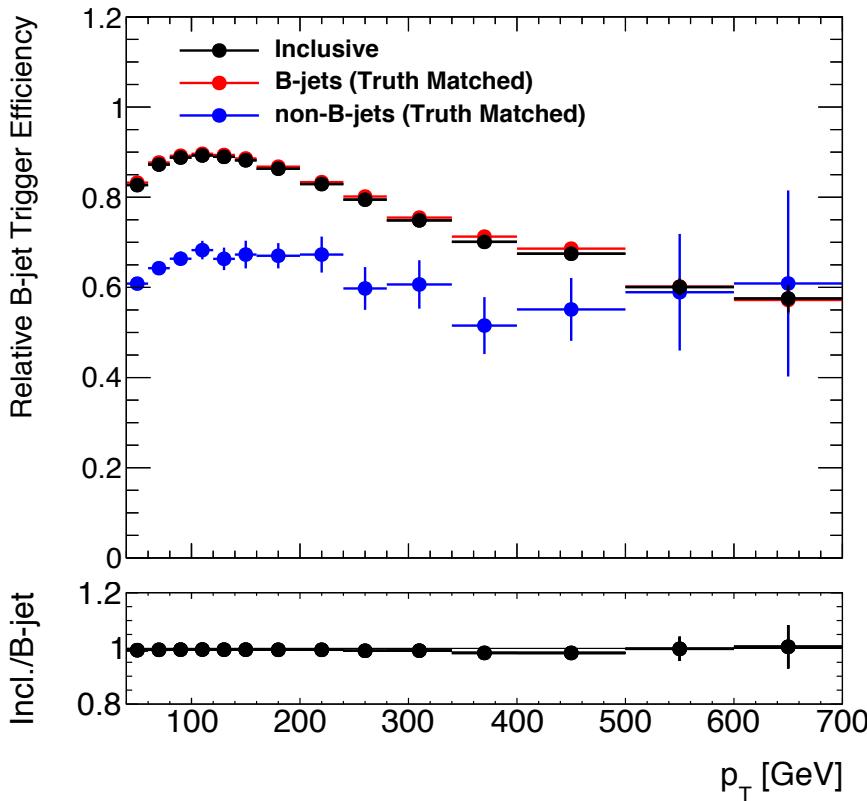
- 1) **Linear fit to Data/MC eff. ratio**
 - Used to correct tail in MC eff.
 - This gives central value
- 2) **Linear fit to Data/Corrected MC ratio**
 - Errors are taken from this fit
 - Symmetric systematic





11 b-Jet Triggers: Sample Dependence Syst.

- We know that we are not 100% pure in b-jets
 - High purity (>95%) at low p_T , decreases to 90% at 700 GeV
- Systematic to account for impurities derived from MC
 - Truth match b-jets and non-b-jets (*light, c*)
 - Ratio of inclusive and truth matched b-jets taken as systematic





- Following discussion with Ed. Board
- Additional systematics to deal with MC mismodelling of;

1) The initial light flavour composition

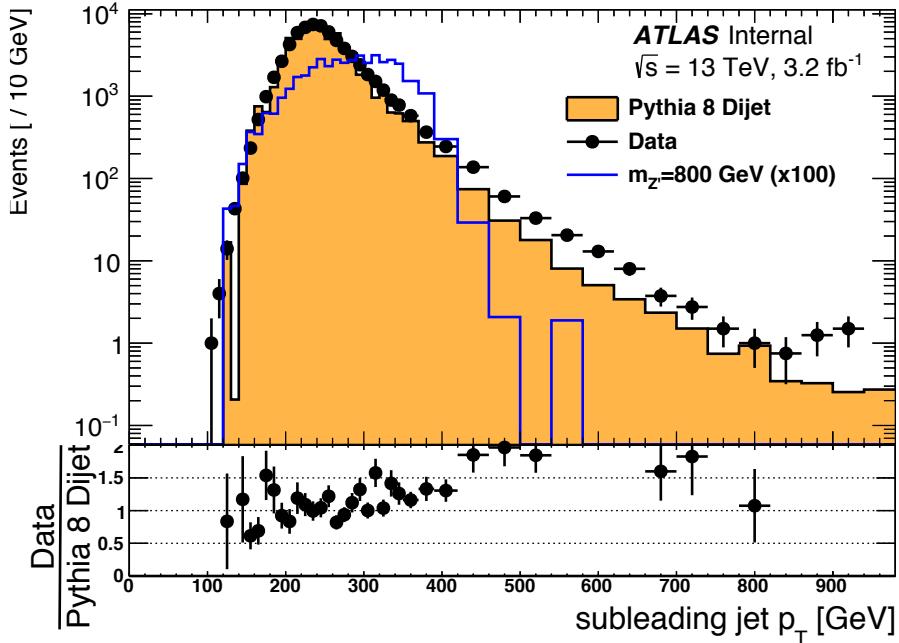
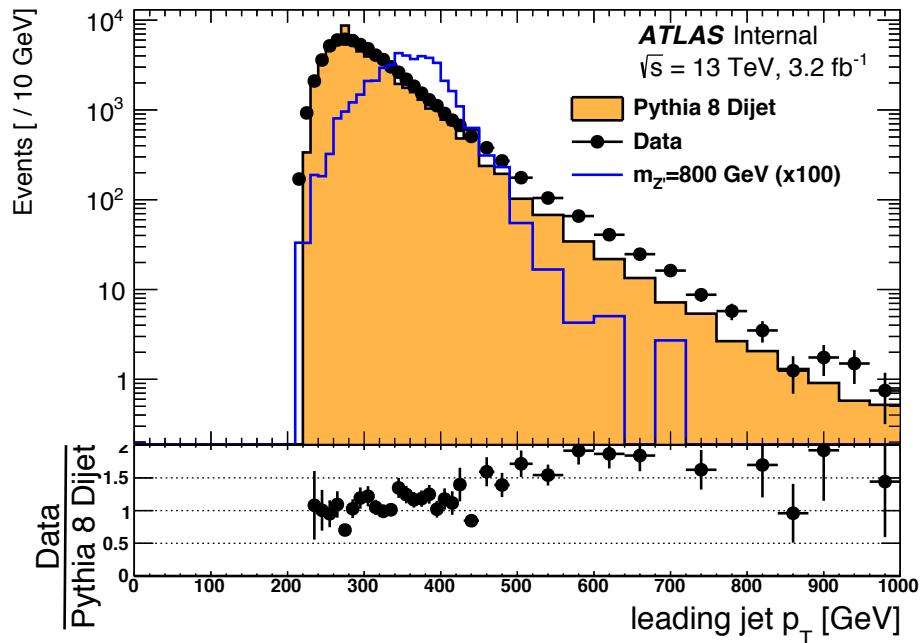
- => Vary the non-b-jet component of the tt sample by +/- 100%
- => Difference in calculated b-jet trigger efficiency taken as a systematic

2) The light-jet efficiency of the trigger

- => Vary light-jet trigger efficiency from 0 to 1
- => Difference in calculated b-jet trigger efficiency taken as systematic

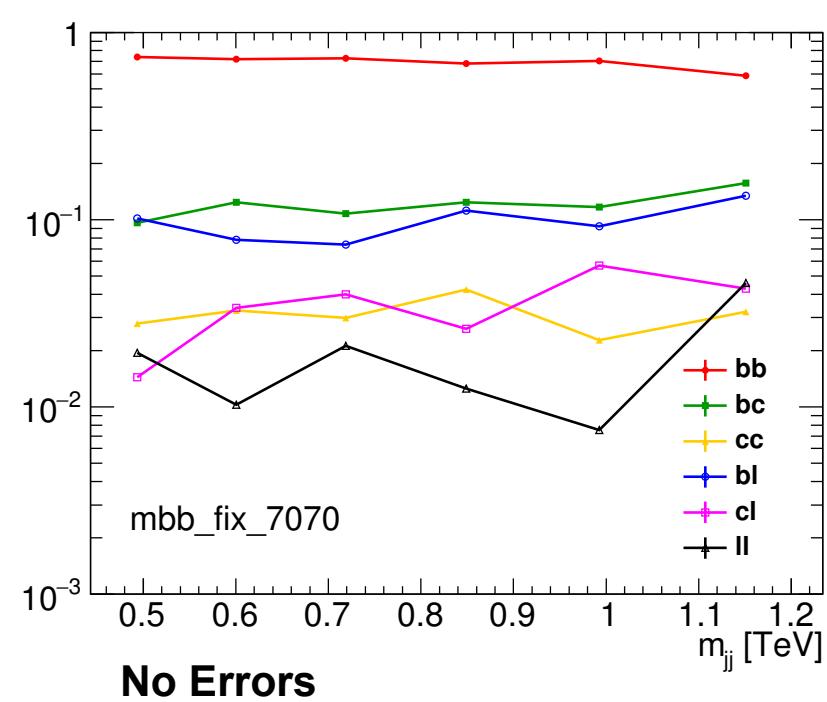
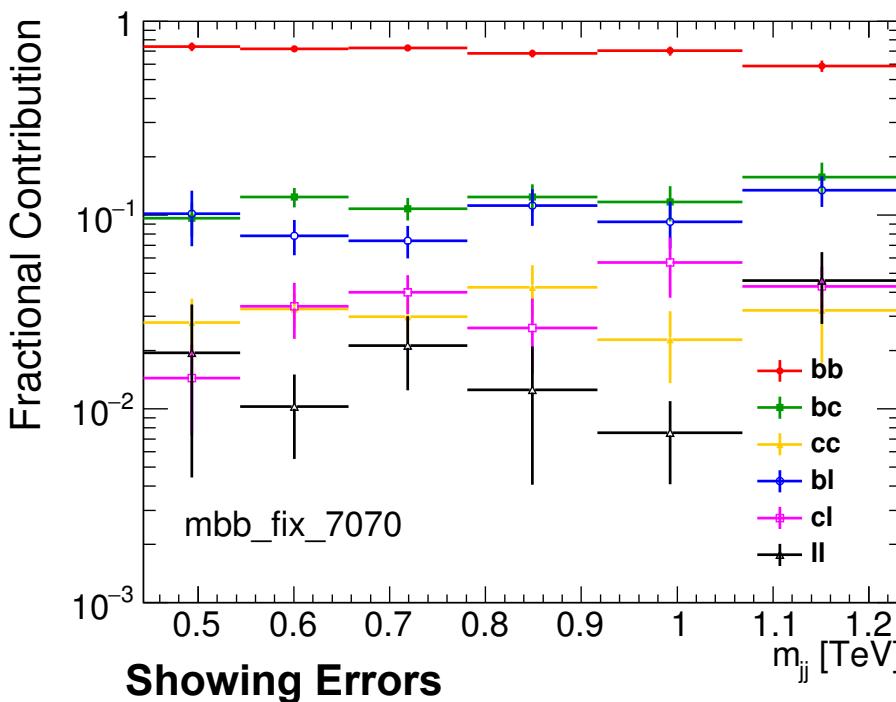
- MC/Data comparison plots for tt selection

13 Kinematics: Validation Plots



- **Emulating online b-tagging**
 - Light/Charm online b-tagging efficiencies not known
 - Thus some mismodelling expected
- **Many more validation plots available**
- **Z' with $m_Z = 750 \text{ GeV}$ being simulated now**

- **Flavour Composition from MC**
 - Applying b-tagging, emulating online b-tagging
- **Emulating online b-tagging**
 - Light/Charm online b-tagging efficiencies not known
 - Estimated from fit to non-b-jet efficiencies (slide 10)



- Dominated by bb
- Flavour fractions are changing smoothly



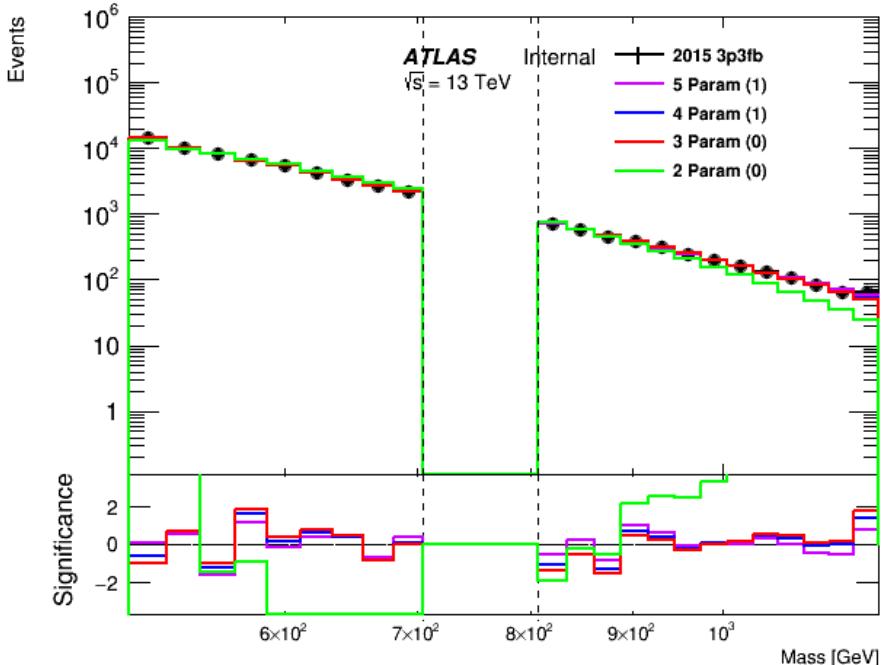
- **Using Dijet Fitting Procedure**

- Used in high-mass inclusive dijet and b-tagged dijet search
- 5 Par Dijet Function :
 - => 3 par; $p_4 = p_5 = 0$
 - => 4 par; $p_5 = 0$

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

- **Function Choice; Wilks' Statistic**

- Begin with by choosing the 3 parameter function.
- Use Wilks' test statistic to compare 3 to 4, if it drops below a threshold switch to 4
- Repeat for 4 to 5.



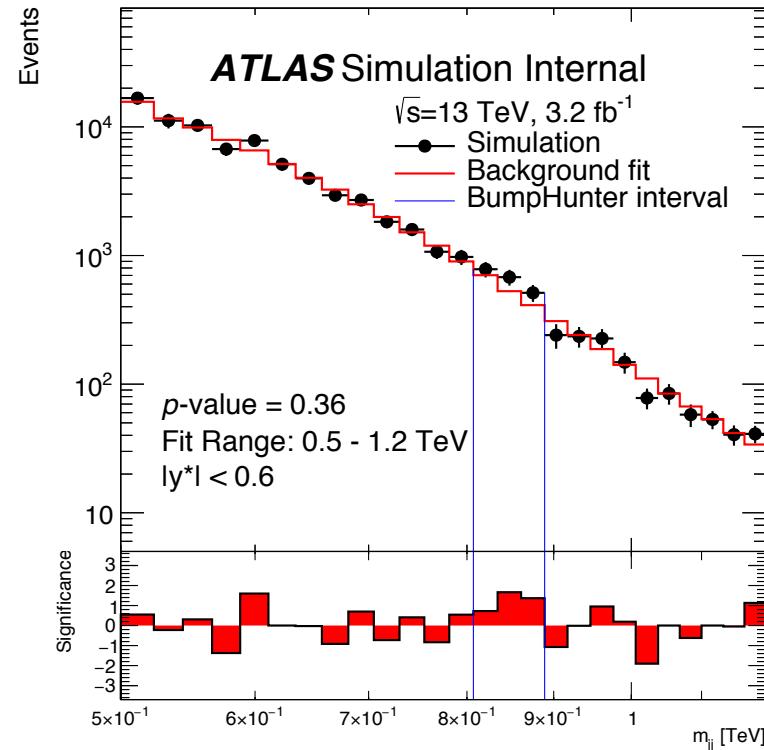
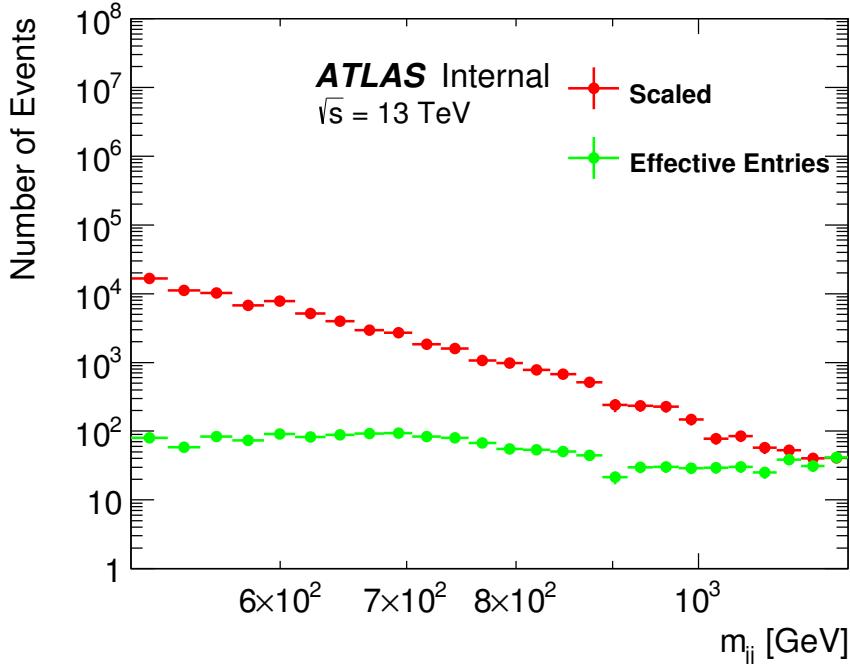
- **Blinded data**

- Data blinded 700-800 GeV
- Wilks' procedure chooses 4 parameter
- This may change when we unblind...



16 Statistics: Spurious Signal - MC

- **Confirm that fits discrepancies are not significantly occurring**
 - A fit discrepancy may fake or disguise signal
 - Fits performed to a representative background only data set can test fit function
- **Monte Carlo**
 - Pythia8 Dijet Sample, same cuts as in data
 - Except trigger, emulated using p_T dependant b-jet and non b-jet efficiencies (slide 10)
 - Problems with statistics, Effective Entries < Scaled Entries
=> Not poisson-like errors



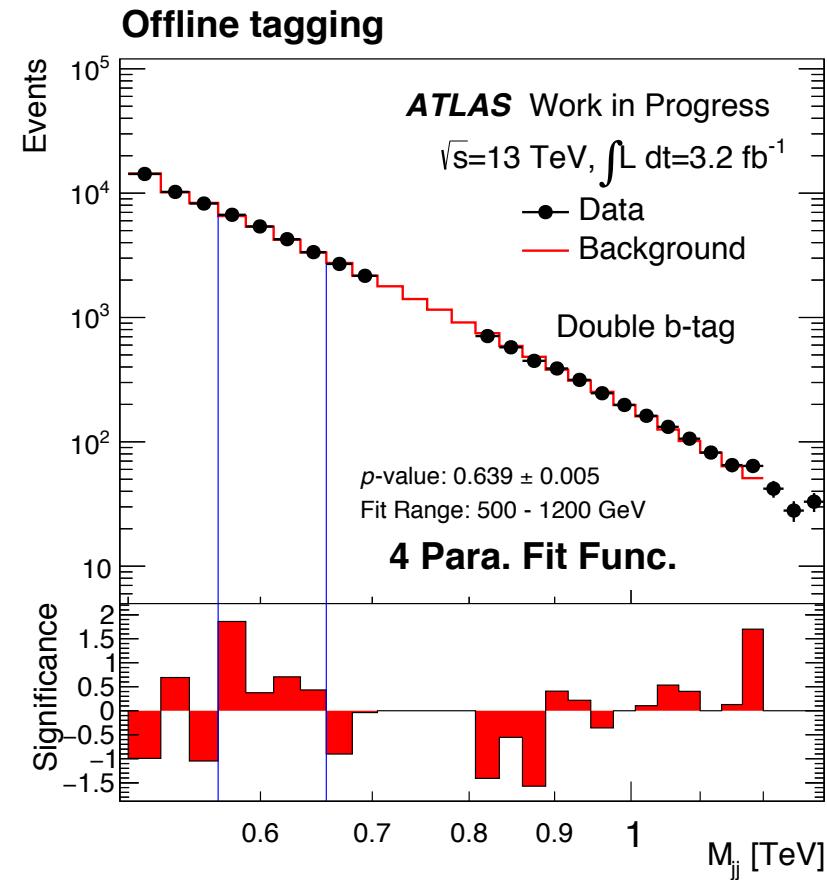
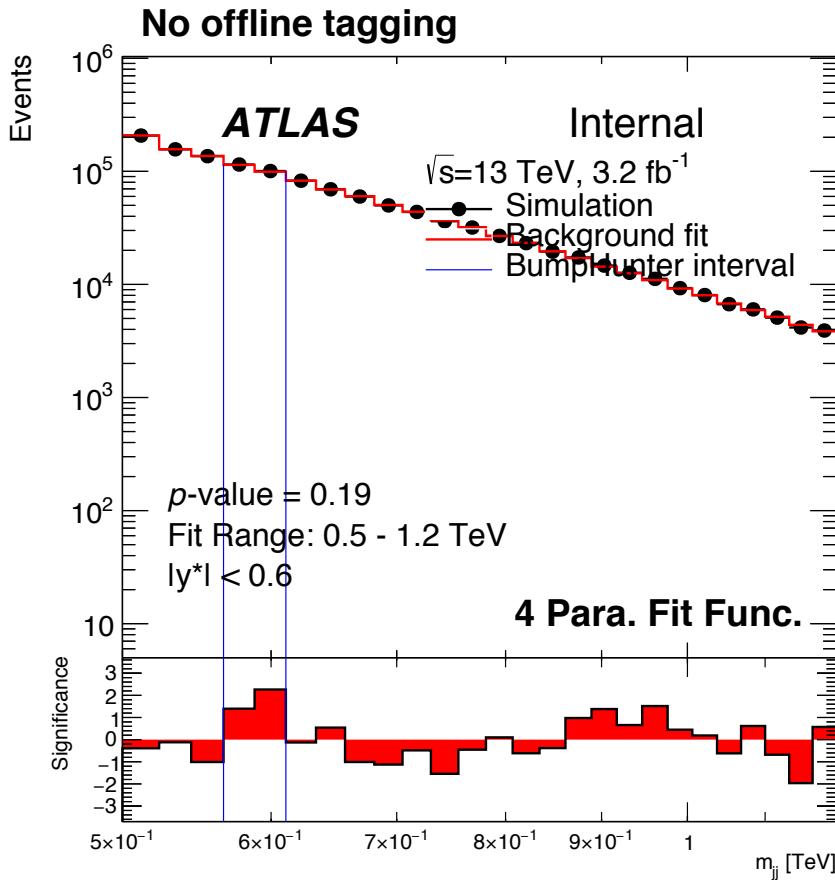


- **Fit to Data with Trigger Applied**

- b-Tagging not applied, so we are not blinded.
- Dominated by bl, but this give us a similar, but different control region to test fitting

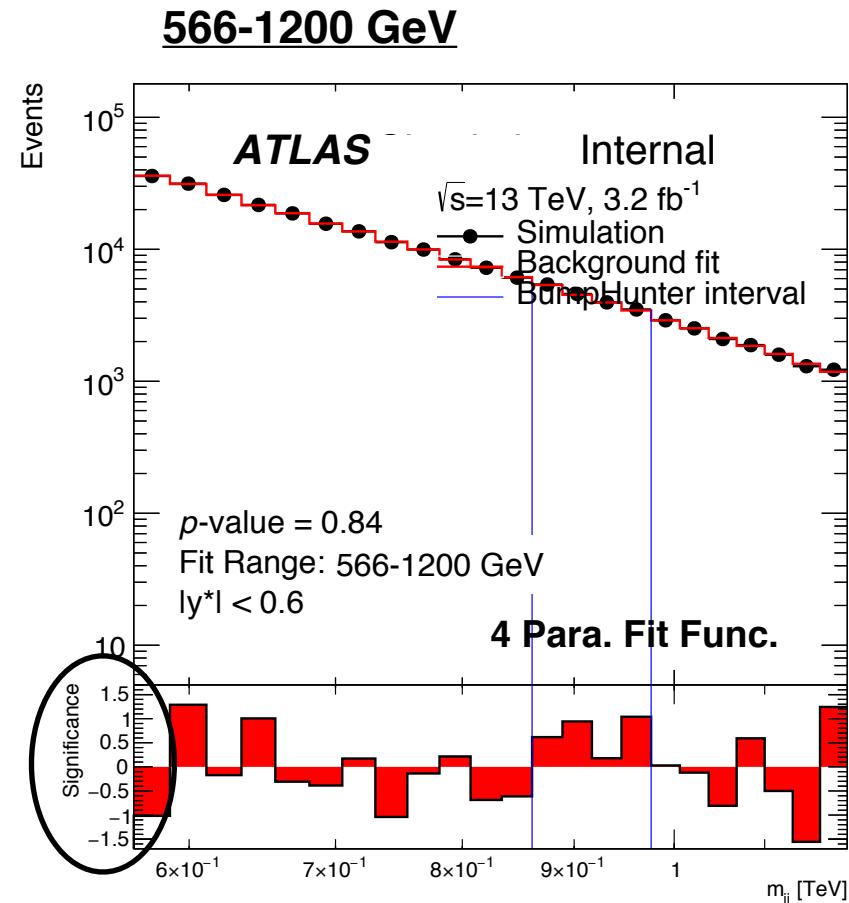
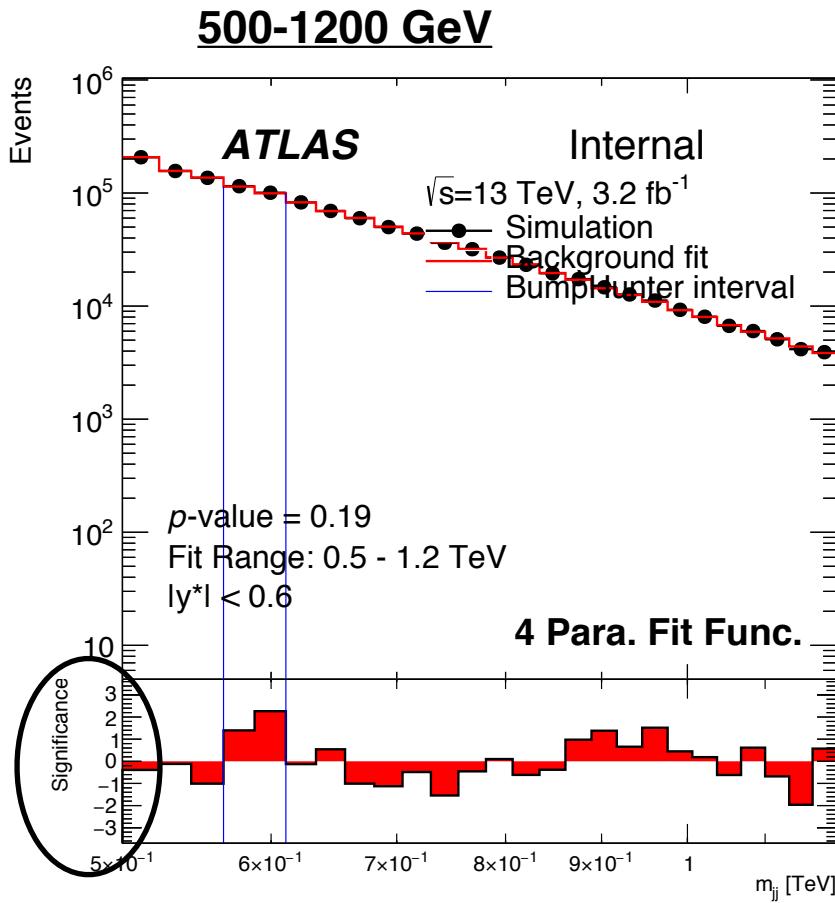
- **Fit quality**

- Periodic structure, seen in ratio plot.
- Also hints of this in blinded double b-tag spectrum

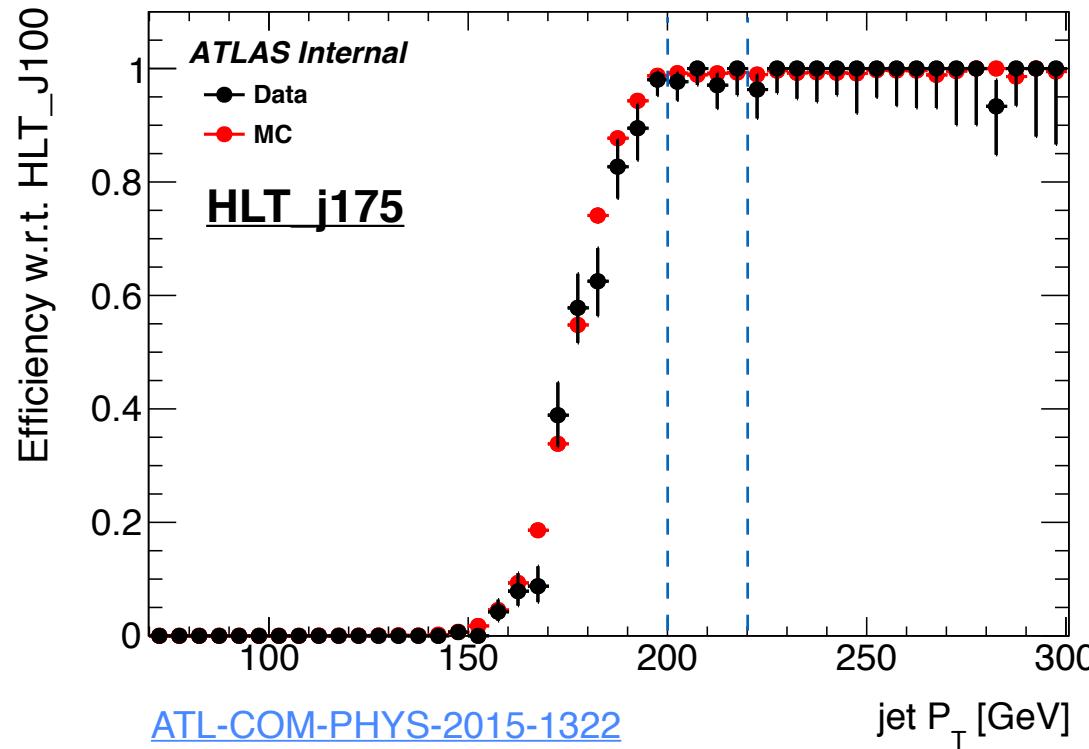


- **Changing Fit Range**

- We tried removing lower bins, fit quality improves
- Find that for the range 566-1200 we get an improved fit
- Note change of axis in significance



- **Leading Jet P_T Cut**
 - Possible cause of misfit is from trigger turn on effect
 - Cut on P_T too close!



- Proposed change: Leading Jet $P_T > 220$ GeV
- m_{jj} cut to be determined again



- **Additional Checks**

- We want to understand this fit better!

- **Check if statistical fluctuation at 566 GeV**

- This may cause fit issues (even if not actually significant)
 - Removing up to stat edge allows fit to adjust
 - **Plan: Remove bin and refit**

- **Check if number of stats is causing issue**

- Much higher stats in control sample
 - Smaller errors, less room for fit to adapt
 - **Plan: Scale down to post tag, refit**

- **New Signal Samples**

- Scalar dark matter mediator signal being considered
 - Same signature as the Z' benchmark but better motivated
 - Decays to uu , dd , ss , cc and bb ; dominant decay is bb

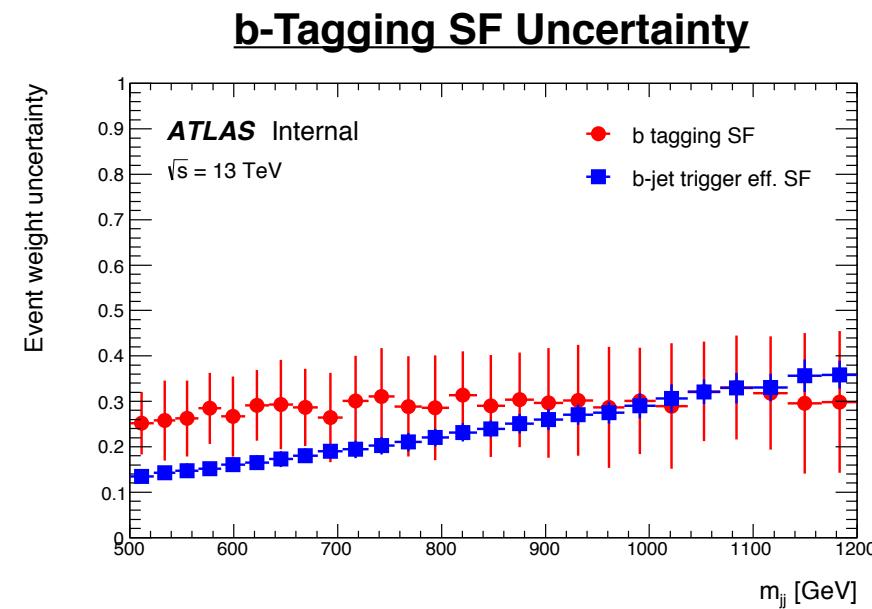
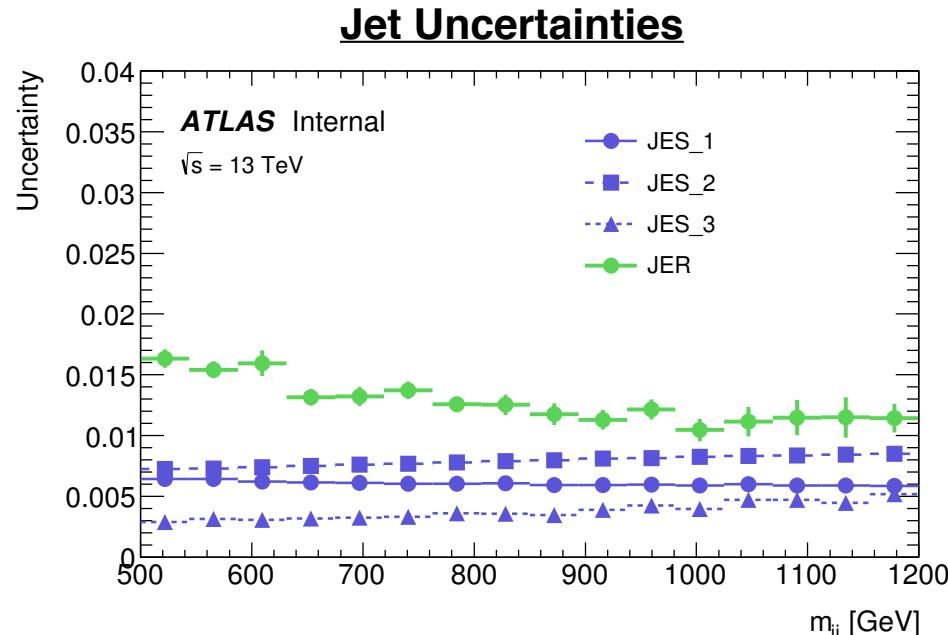
- **Production Details**

- Generation with MadGraph, showering with Pythia
- Dark matter width calculator used
- Dark matter mass set to 10 TeV to remove dependance on it
- Jobs finished! - [JIRA ticket](#) - [Production Link](#)

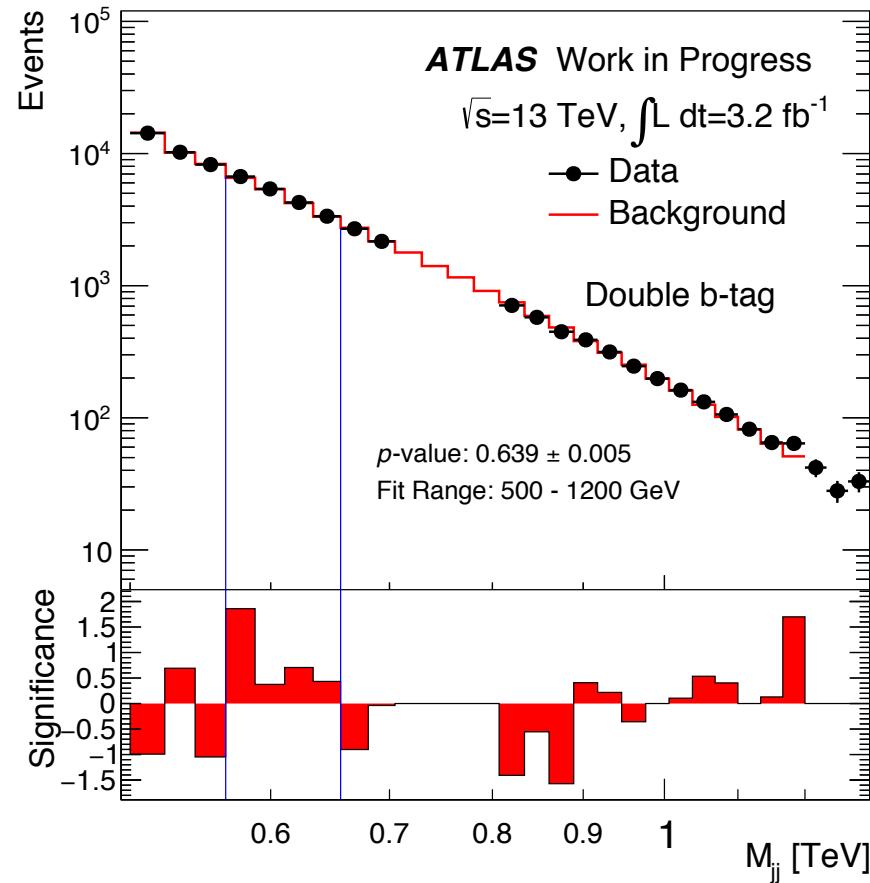
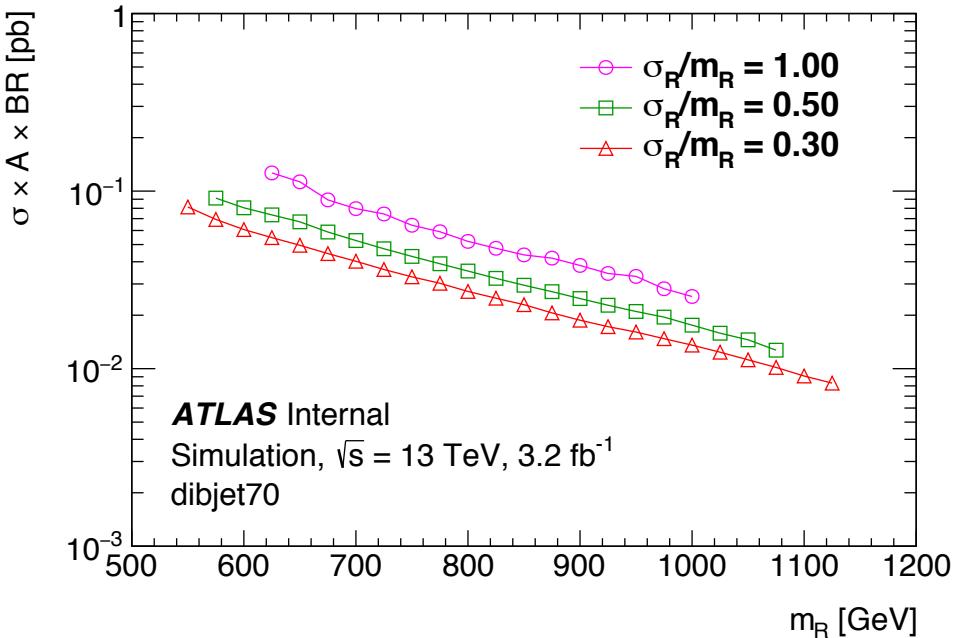
| dmS mass [GeV] | gQ | width [GeV] | xsec [pb] | gQ | width [GeV] | xsec [pb] |
|----------------|-----|-------------|-----------|------|-------------|-----------|
| 600 | 1.0 | 19.35 | 9.72e-7 | 1.37 | 36.33 | 1.95e-6 |
| 750 | 1.0 | 31.00 | 2.67e-7 | 1.21 | 45.39 | 4.19e-7 |
| 800 | 1.0 | 34.71 | 1.89e-7 | 1.18 | 48.33 | 2.78e-7 |
| 1000 | 1.0 | 48.90 | 5.35e-8 | 1.11 | 60.25 | 7.10e-8 |
| 1200 | 1.0 | 62.38 | 1.90e-8 | 1.08 | 72.76 | 2.42e-8 |

- **Monte-Carlo (Signal)**
 - Luminosity (5%)
 - JES - Reduced 3NP (<4%)
 - JER - Reduced 1NP (<2%)
 - **b-tagging SF (~30%)**
 - **b-Jet trigger Efficiency (~10-30%)**
- **Background**
 - Fit function choice
 - Comparison to alt. function (5 par.)
 - Uncertainty on fit parameters
 - Taken from pseudo-experiments

| <i>Rec. mass (GeV)</i> | <i>JES (para1/para2/ para3)</i> | <i>JER</i> | <i>b-tagging SF</i> | <i>b-jet trigger eff. SF</i> |
|----------------------------|-------------------------------------|-------------|-------------------------|----------------------------------|
| 600 | 2.5% / 2% / 1.3% | 1.6% | 30% | 16% |
| 800 | 2.4% / 2% / 1.1% | 1.3% | 30% | 20% |
| 1000 | 2% / 1.9% / 1% | 1.1% | 30% | 30% |



- **Currently Looking at Fitting to Sidebands**
 - 4 Parameter Fit Function
 - **Use BumpHunter Algorithm**
 - Finds most discrepant excess
 - Calculate p-values of discrepancy
 - 10,000 pseudo-exp.
- **Generic Gaussian Expected Limits**
 - We do well compared to 2.1pb theory
 - ~20% acceptance at 750 GeV



No significant discrepancy, yet...

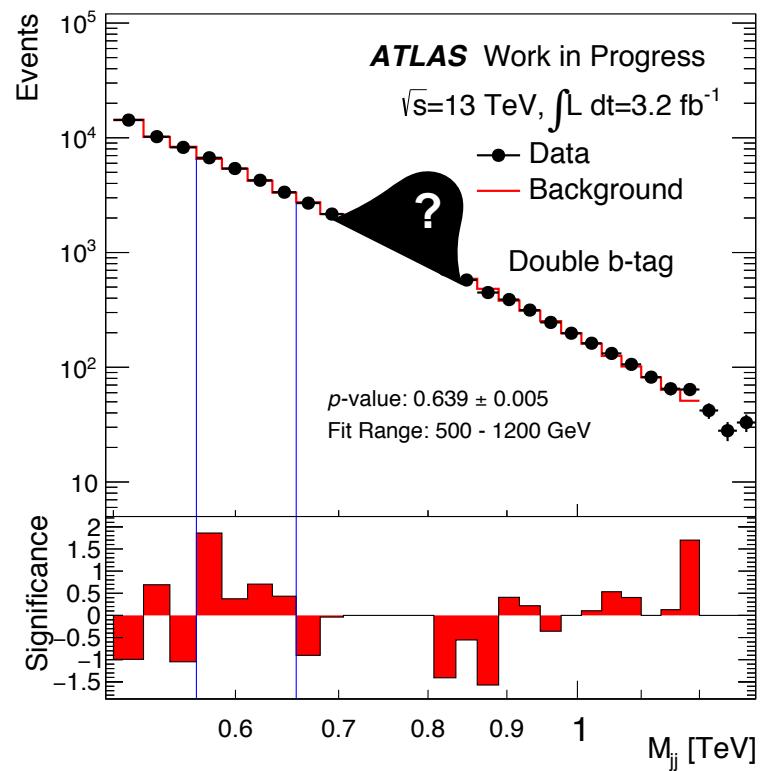
Will be run on full range
when unblinded

330 **9 Conclusions**

331 Doing science

We probably need to update
Conclusion section in note...

- **Low Mass b-Tagged Analysis**
 - Weak limits in bb at 750 GeV
 - Gaussian limits and Z' dark matter model
- **Use b-Triggers to get to low mass**
 - b-Jet efficiency measured
 - Systematics being studied
- **Fit quality being tested**
 - Tested with data and in MC
- **Systematics ready to go!**
 - b-tagging and b-jet trigger eff. dominant
- **We are ready to unblind...**

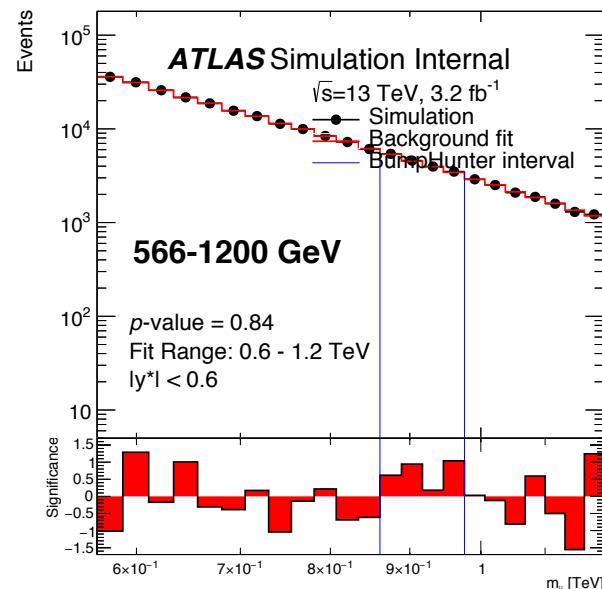
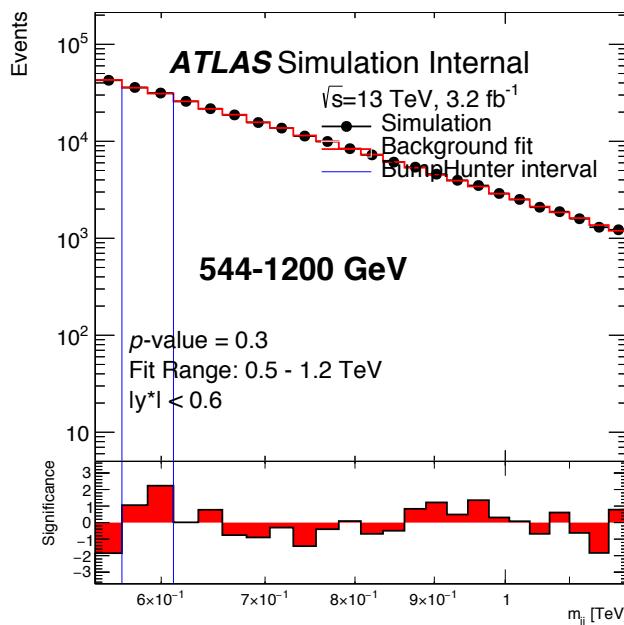
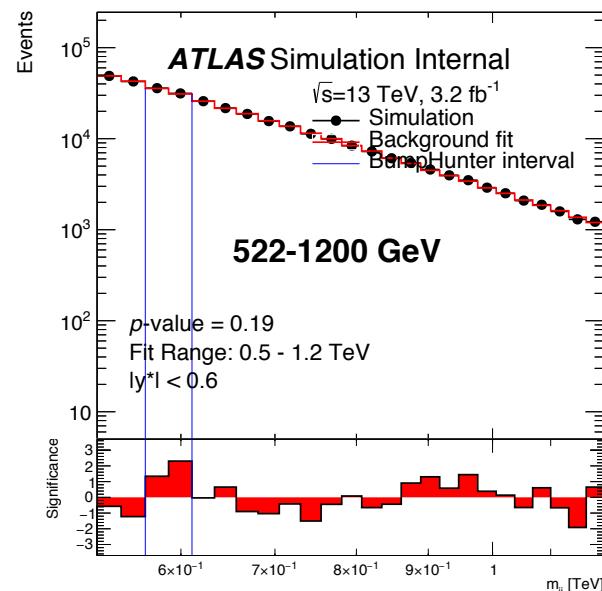
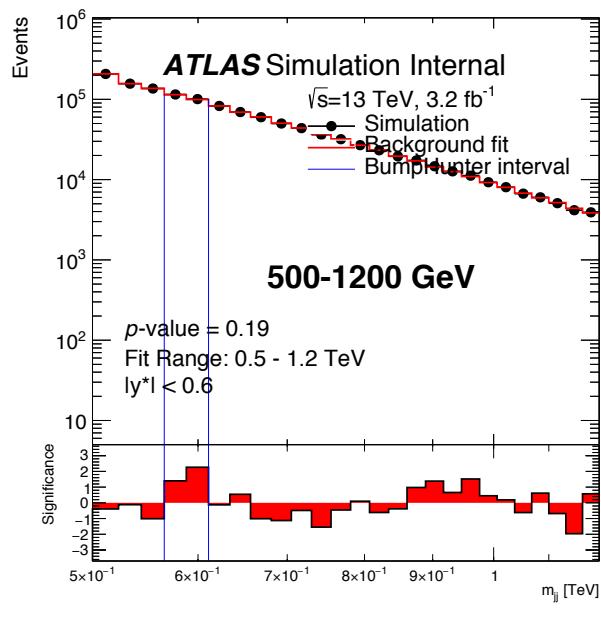




Backup!



26 Spurious Signal: Full Set of Ranges





| | Request EB (latest) | First EB meet (latest) | Support note to JDM & EB | JDM Approval | Sup. Note to Exotics | Exotics Approval | Conf to ATLAS | Approval Meeting | Start of Conference |
|----------------|---------------------|------------------------|--------------------------|--------------|----------------------|------------------|---------------|------------------|---------------------|
| LHCP Jun 13-18 | April 20 | May 4 | May 4 | May 11 | May 18 | May 25 | June 1 | June 8 | June 13 |

