# Dark Matter Searches with two jets at ATLAS: dijet and mono-V(jj)

Nishu, Bibhuti Parida, Ning Zhou

CLHCP 2016

2016-12-18, PKU

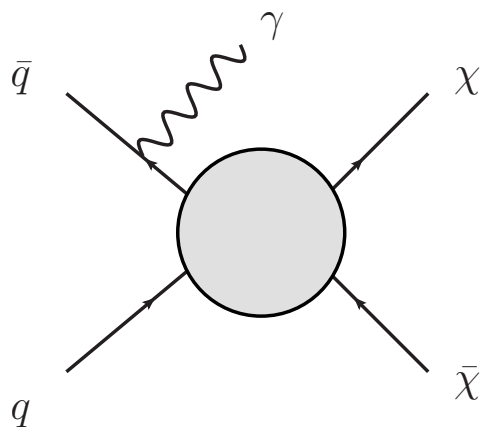
# Outline

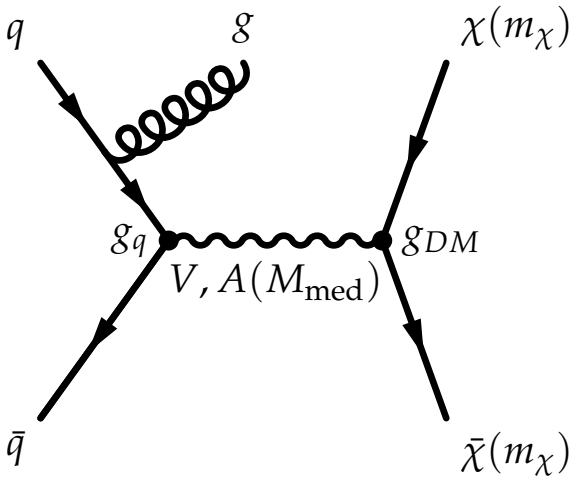
- Dark matter production at collider
- Di-bjet resonance: DM-SM mediator search
- Di-jet + Missing ET: DM search in association with W/Z(jj)

# Dark matter production: from EFT to simplified model

- Keep the mediator information
  - Mass, spin, coupling, width, etc

LHC DM forum
arXiv:1507.00966



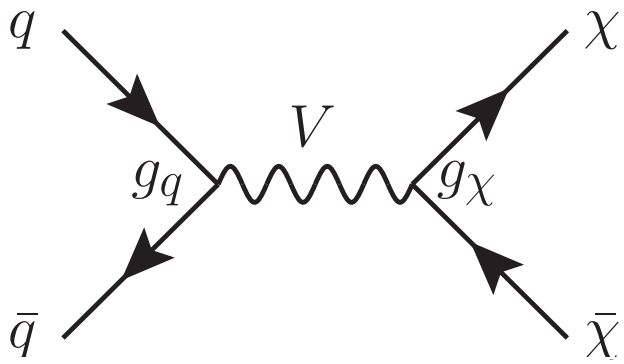

- Simplified model:
  - Starting point to build complete theories
  - Colliders can search for the mediator directly
  - Benchmark model @ Run II

$$\mathcal{L}_{\mathrm{vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$

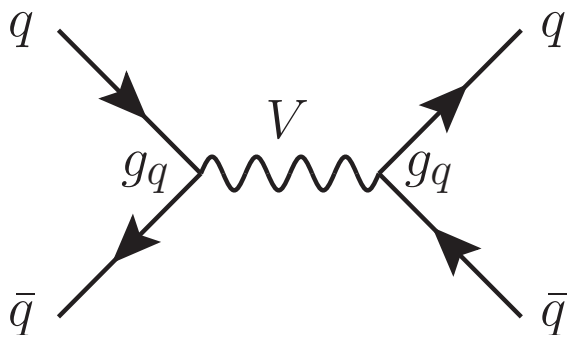
$$\mathcal{L}_{\mathrm{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu\gamma^5 \chi$$

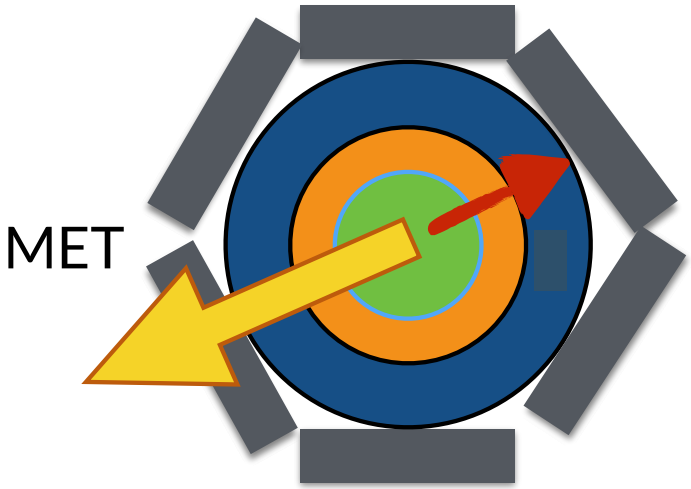
# Dark matter search at collider

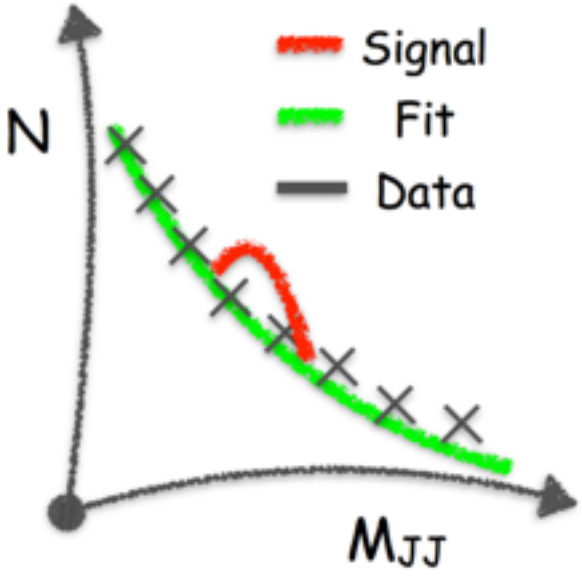
- Search for produced DM



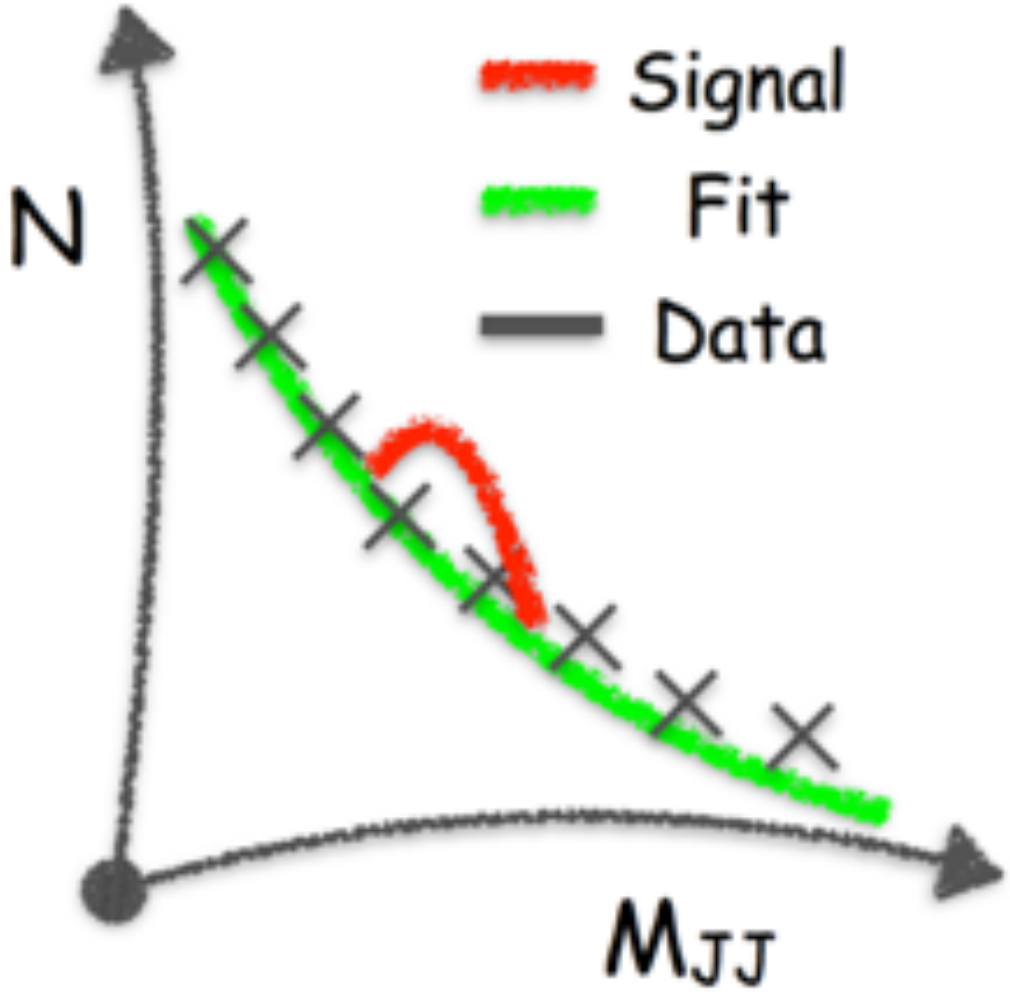

- Search for DM-SM mediator



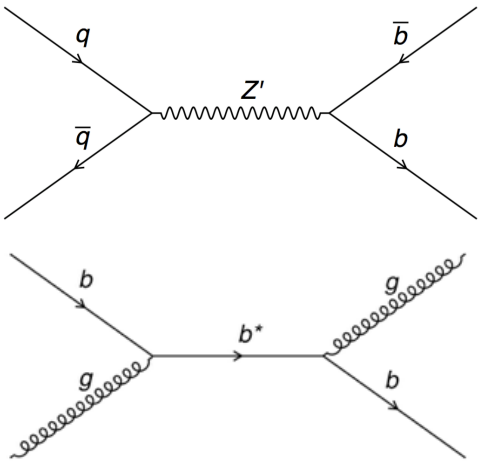



# Search for DM-SM Mediator

- 

# Di-jet resonance with b-tagging

- Search for mediator itself
  - Many BSM predicts mediator connecting SM and DM
  - The mediator may couple to heavy quarks
- Signature
  - two jet resonance with one or both b-tagged




- Main Updates at Run II
  - Di-bjet resoannce search in High mass region (above 1.1TeV) with 2015 data.
    - Analysis divided into inclusive one b-tag (>=1 b-tag) and 2 b-tag categories
    - Moriond paper in Phys. Lett. B.759 (2016) 229-246 (with 3.2 fb-1 of 2015 data)
  - Di-bjet resonance search in Low mass region (600 GeV- 1.1 TeV) with 2015 data
    - 2 b-tag category (using di-bjet trigger)
    - ATLAS-CONF-2016-031 note in LHCP (with 3.2 fb-1 of 2015 data)
  - Di-bjet resonance search in High mass region with 2015+2016 data (13.3 fb-1)
    - Inclusive one b-tag and 2 b-tag
    - ATLAS-CONF-2016-060 note in ICHEP (with 3.2 fb-1 of 2015 + 10.1fb-1 of 2016 data)

# Event Selection

- **High Mass analysis:** 1 b-tag and 2 b-tag categories

- Single jet trigger: HLT_j380

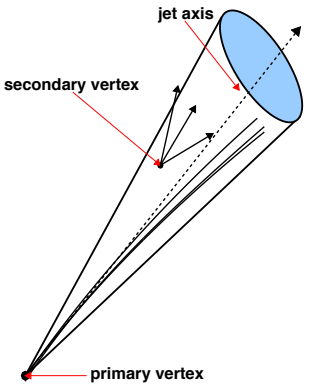
- Jet Selection: Anti-$k_T$ EM Topo Jets, R=0.4
  - Leading jet pT > 430 GeV
  - Sub-leading jet pT > 60 GeV
  - Both jets $|\eta| < 2.4$

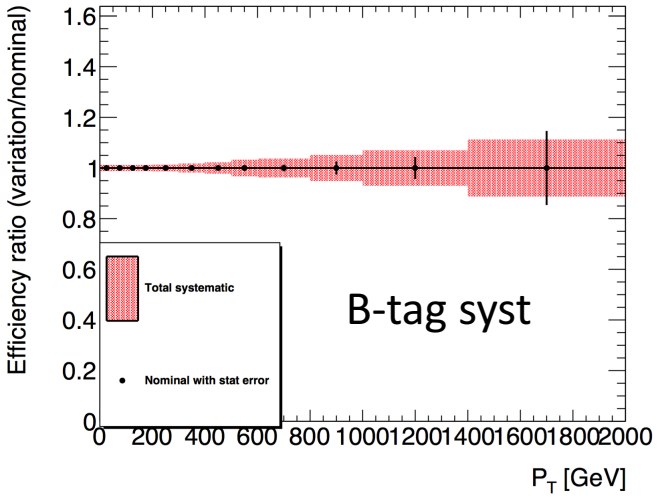
- Event Selection:
  - $|y^*| < 0.6$ , $y^* = 0.5\ \Delta y$
  - mjj >1.38 TeV

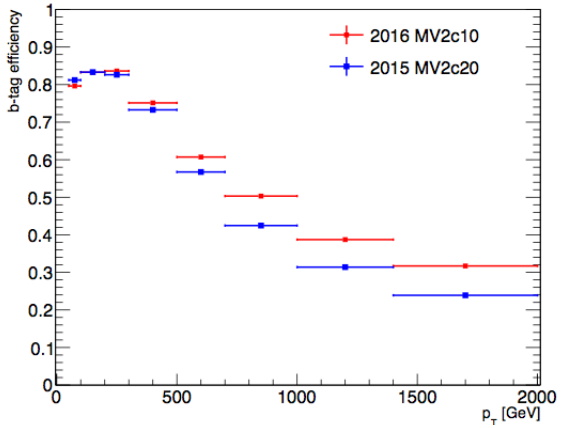
- Offline b-tagging: b-tagging fix cut 85% OP MV2c10

# B-tagging Performance

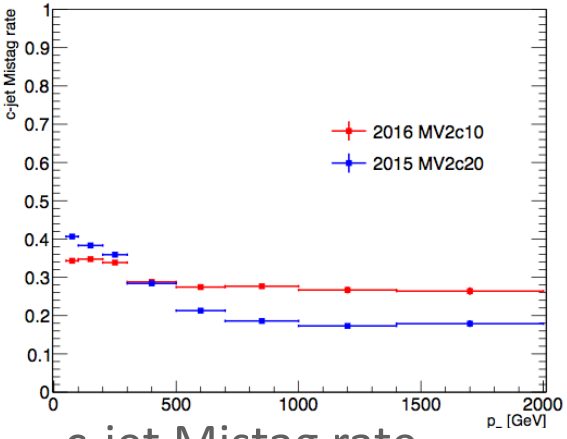
- B-jet tagging
  - 85% fixed b-jet efficiency WP
  - Use recommended tagger: MV2c10
- Tagging efficiency study
  - Using ttbar, b* and Z' samples
  - Efficiency drops at high pT
  - Systematics studies



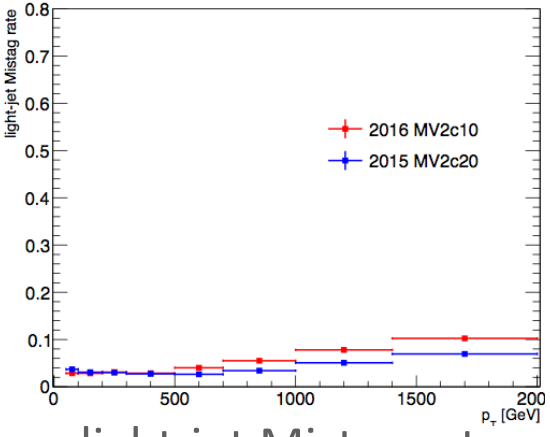




b-tag efficiencies



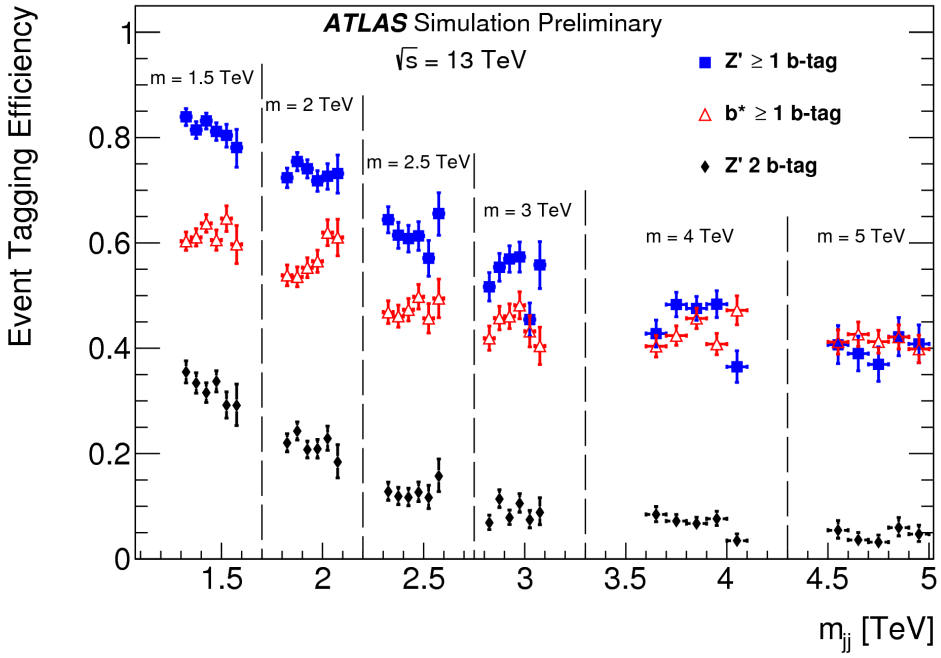

c-jet Mistag rate



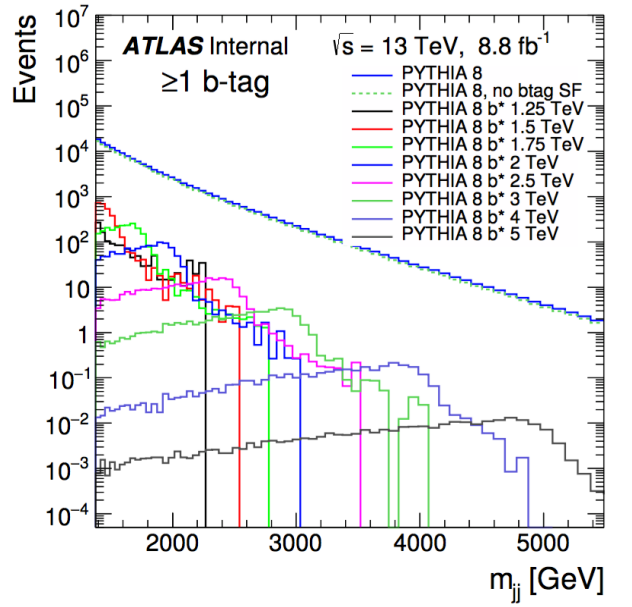

light-jet Mistag rate

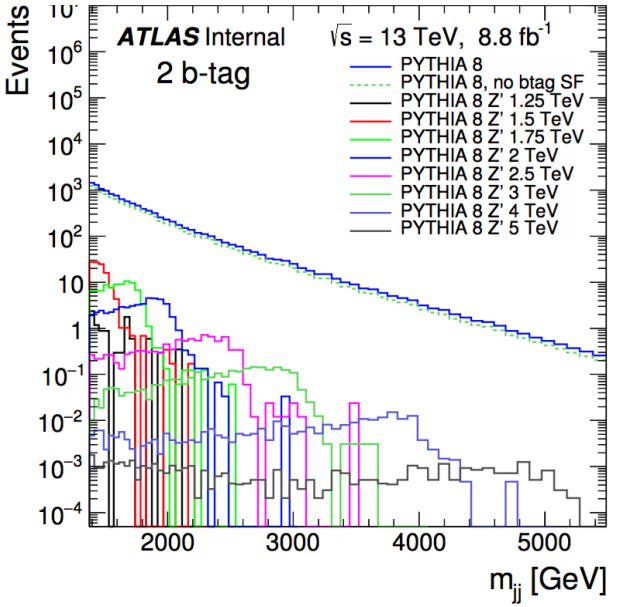
# Signal Shape

- Resonance in di-jet invariant mass



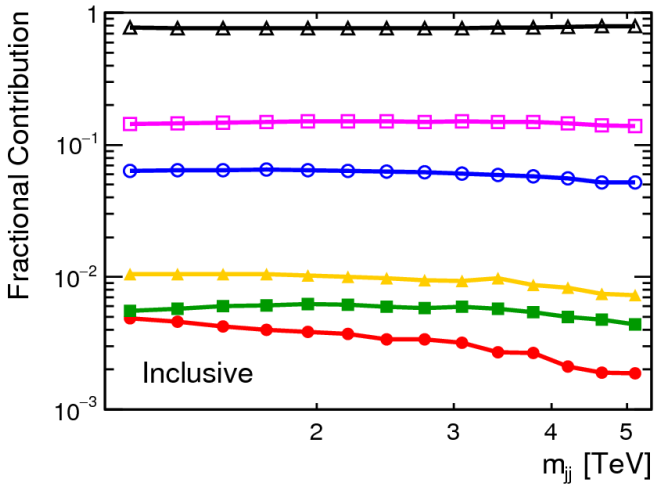

Per-event tagging efficiency as a function of reconstructed mass

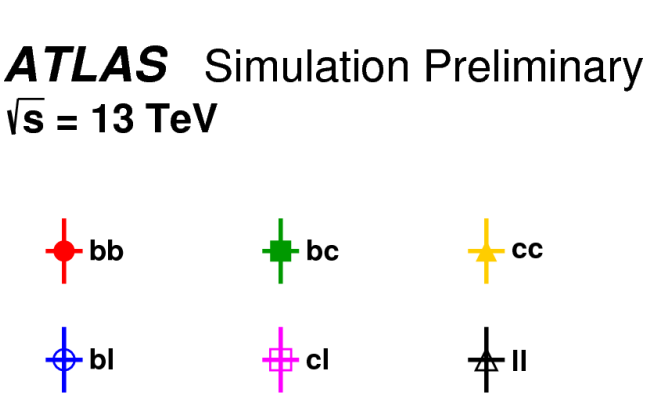


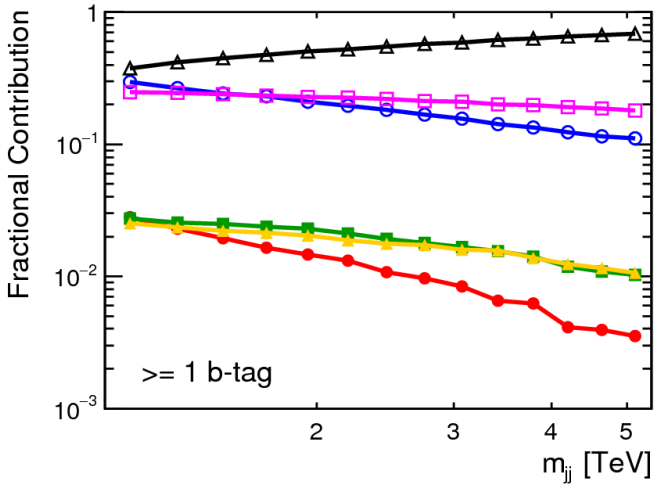



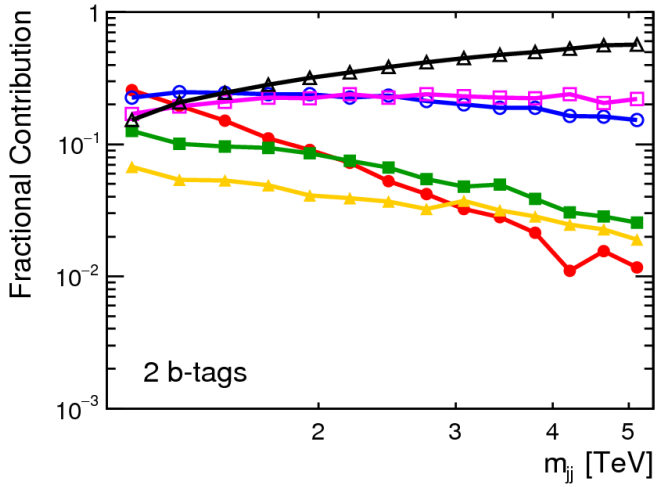
# Background Composition

- Background is dominated by mis-tagged light-jet
- Dijet mass spectrum is affected by the non-flat tagging efficiency



# Background Estimation

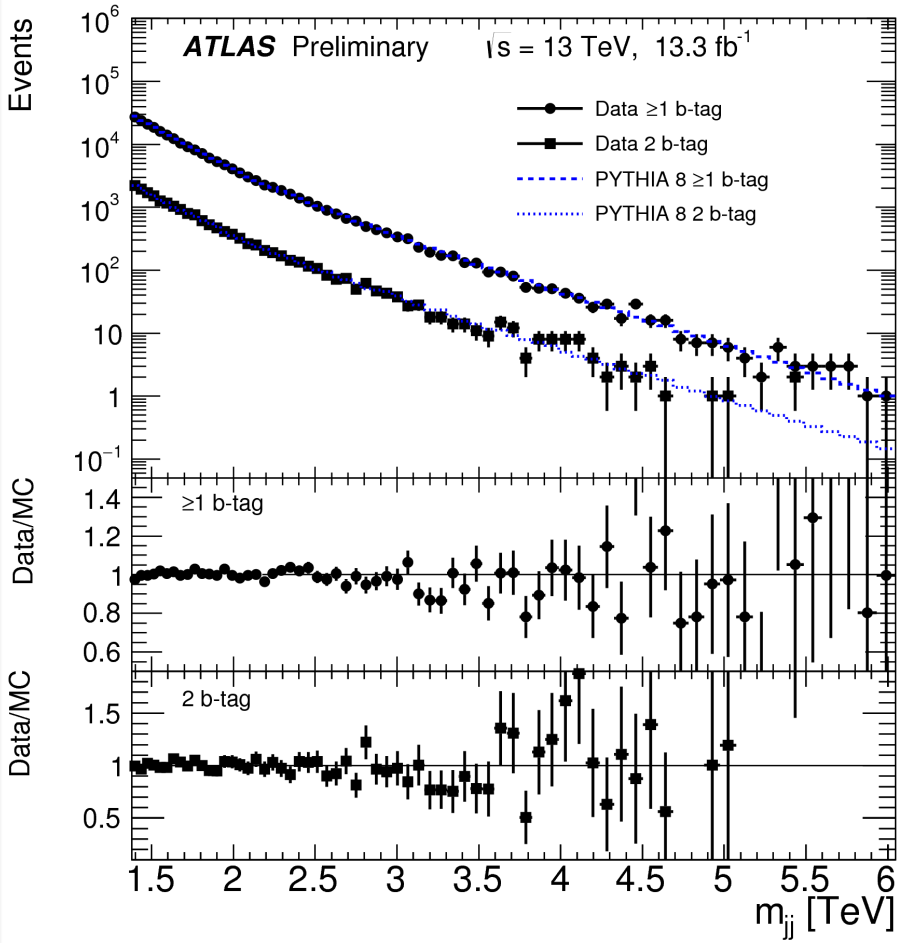
## Bump-Hunter:

- Background estimated from fitting the data spectrum directly
- Looking for the most significant deviation from the background

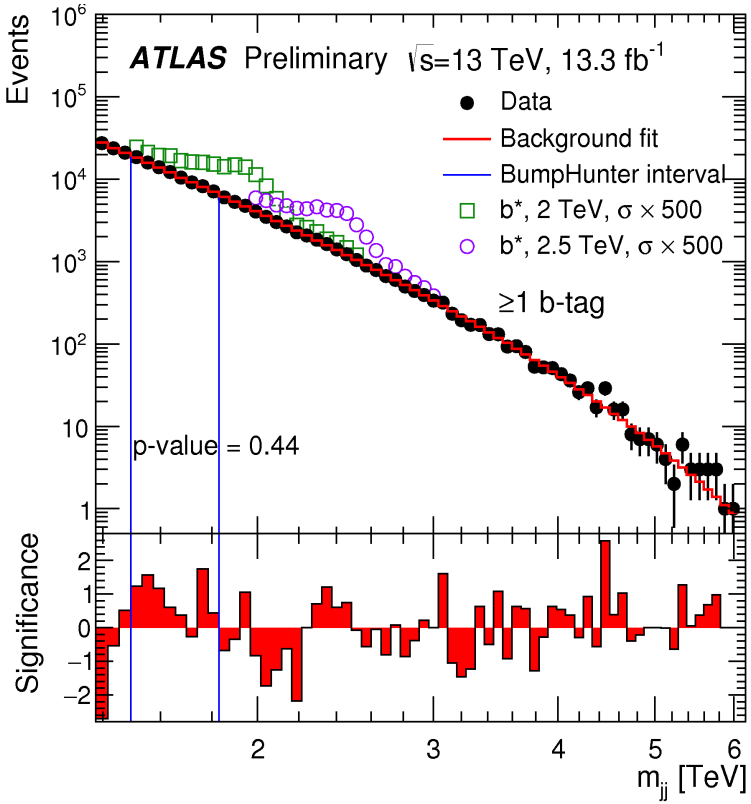
$$f(x) = p_1(1-x)^{p_2}(x)^{p_3+p_4\ln x+p_5(\ln x)^2},$$

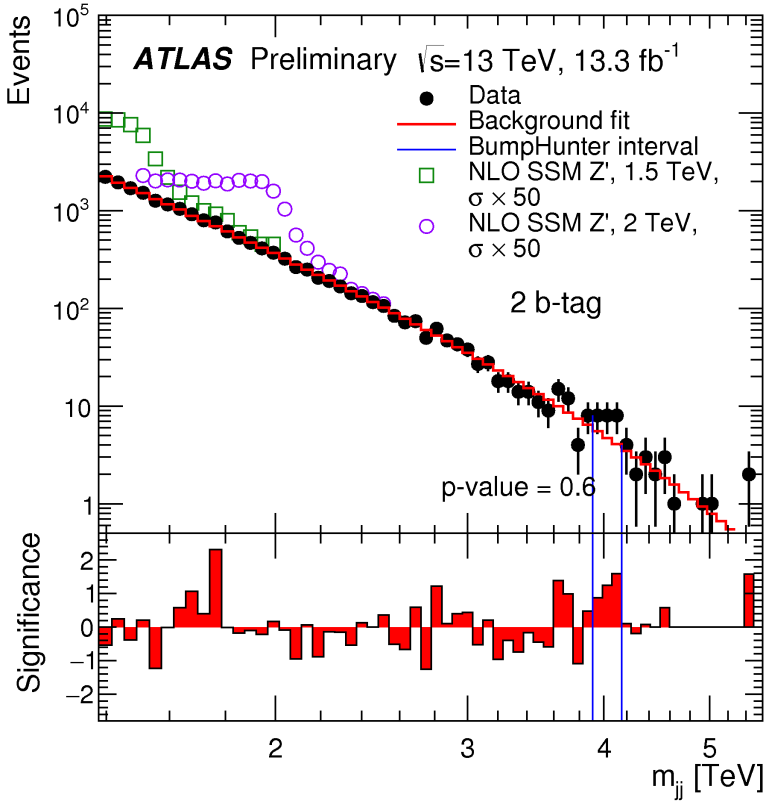
$$x = m_{jj}/\sqrt{s}$$

**The 3 parameter fit function is found to describe accurately the present amount of data.**



# Bump-Hunter Results



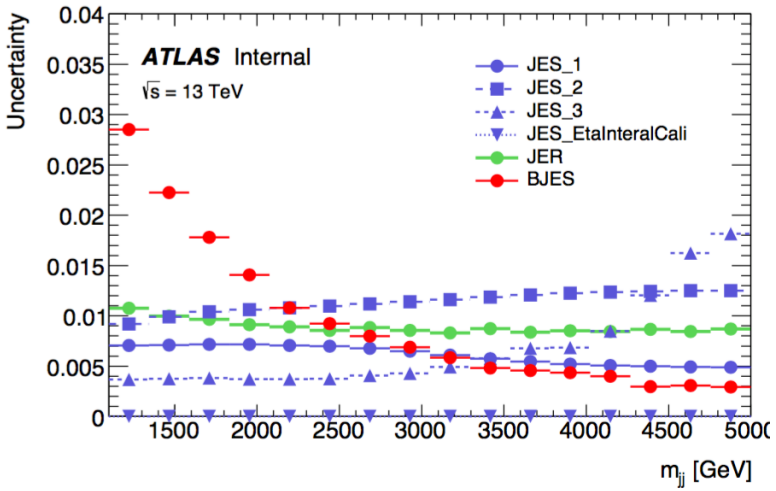

- No 3sigma excess, p-value with 10k pseudo-experiments: 0.44 and 0.6 for 1 b-tag and 2-btag categories respectively.

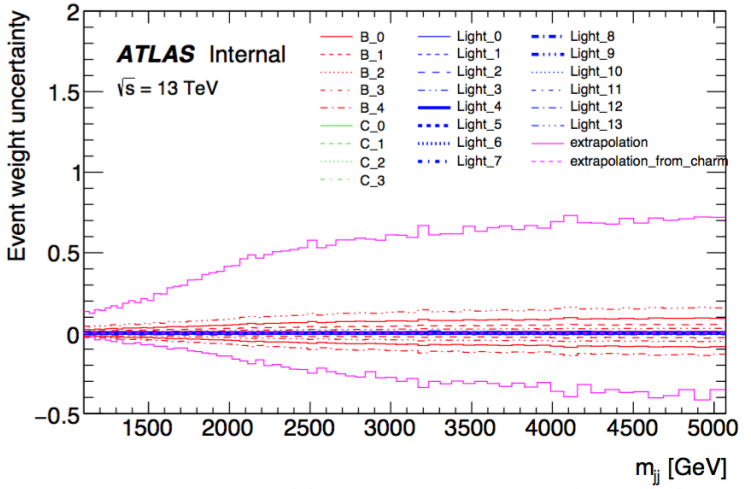
# Systematics

- Background modeling
  - Fit function : from alternate function
  - Fit parameter : obtained by fitting the nominal function to the 10K of pseudo experiments
- Signal modeling
  - Luminosity : 2.1%
  - JES/bJES/JER : Updated with ICHEP recommendation

| Rec. mass (GeV) | JES (para1 / para2 / para3) | JER | bJES | $b$-tagging SF ($b^*/Z'$) |
|---|---|---|---|---|
| 1.25 | 0.7% / 0.9% / 0.4% | 1.1% | 2.9% | 20% / 10% |
| 3 | 0.6% / 1.2% / 0.4% | 0.9% | 0.7% | 50% / 60% |
| 5 | 0.5% / 1.3% / 1.8% | 0.9% | 0.3% | 50% / 70% |

  - b-tagging
    - b* model : 20% to 50%
    - Z' model : 10% to 70%
  - pdf uncertainty : 1%

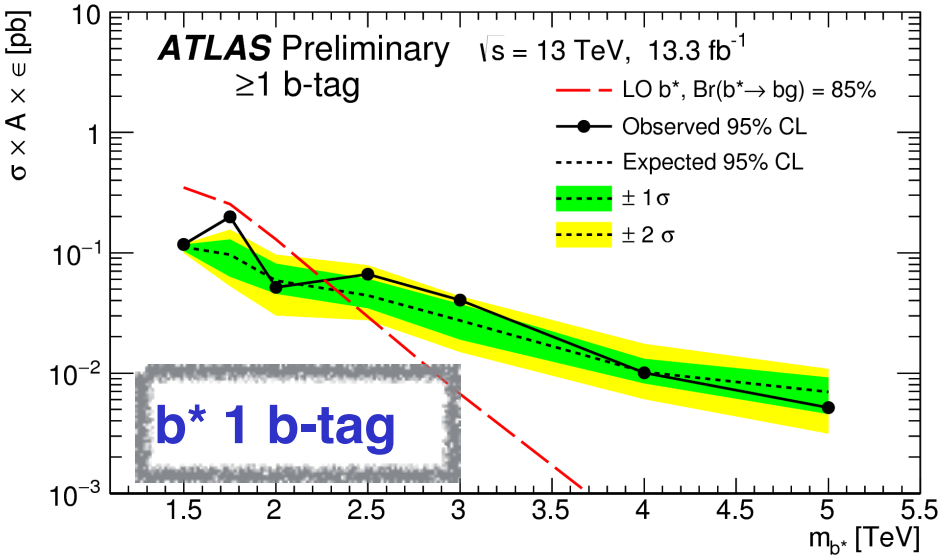



uncertainty of b-tagging SF on Z' model

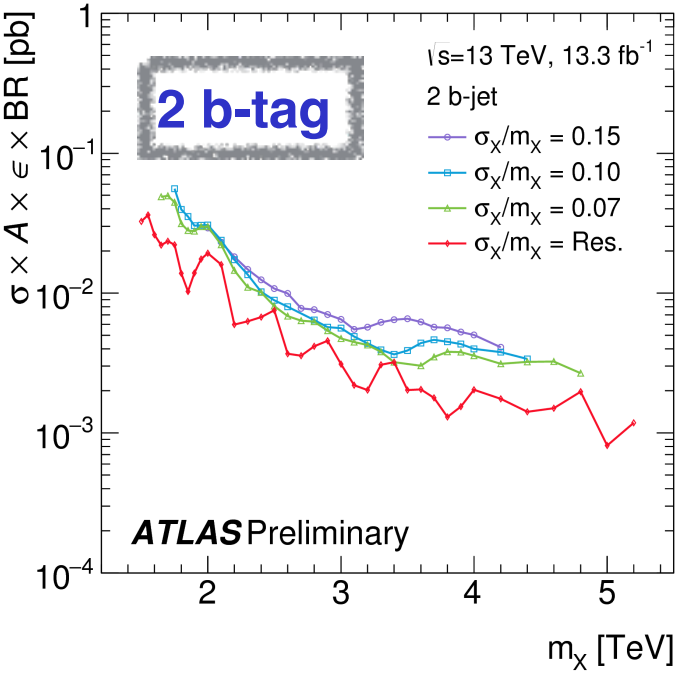
# Exclusion Limits

- Bayesian approach to set 95% upper limit on Acceptance × ∈ x cross section:
  - **b* model excluded up to 2.3 TeV for >= 1 b-tag**



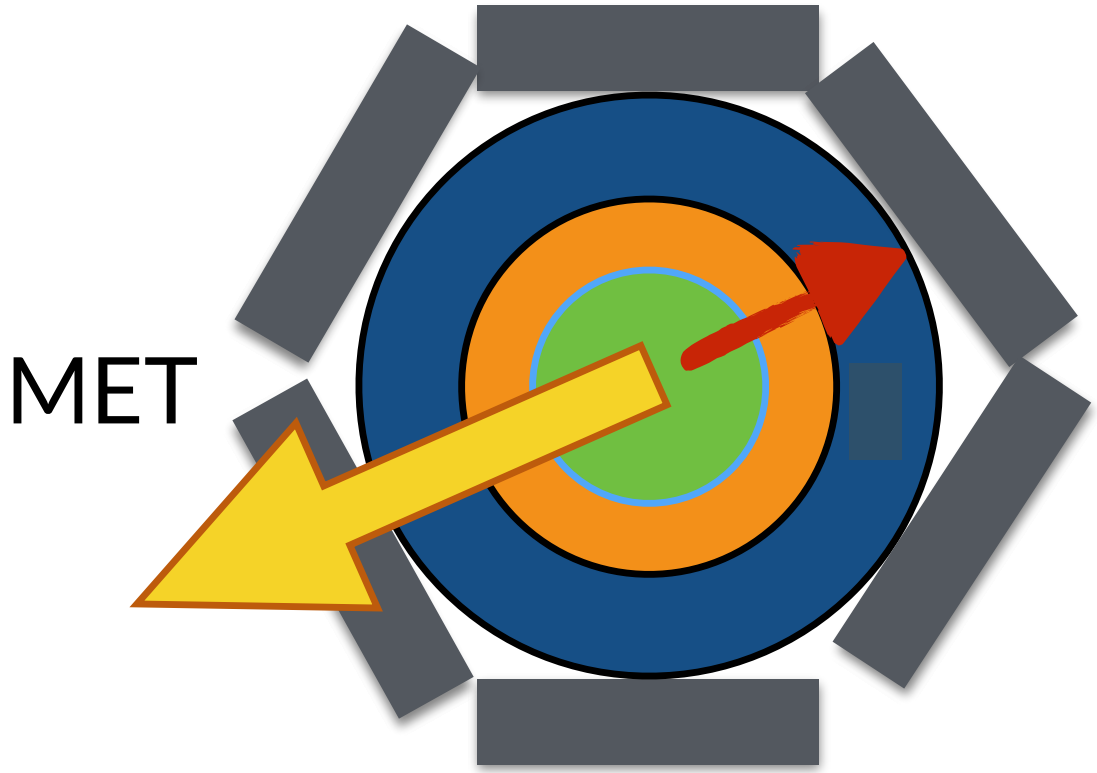

**Gaussian with different width to set 95% C.L. upper limits:**

**Exclude Gaussian contributions with effective cross sections ranging from approximately 0.2 – 0.001 pb in the mass range 1.4 – 5.5 TeV**



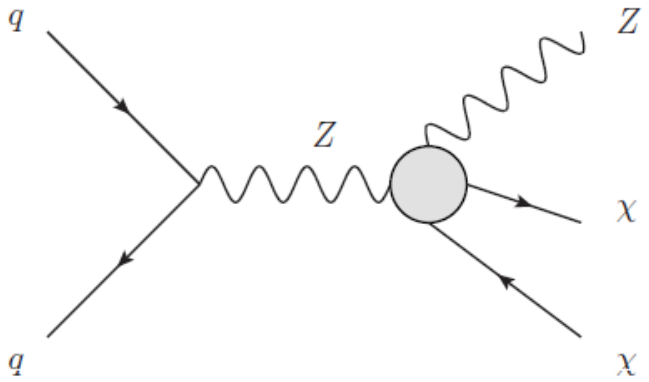
# Search for DM+W/Z(jj)

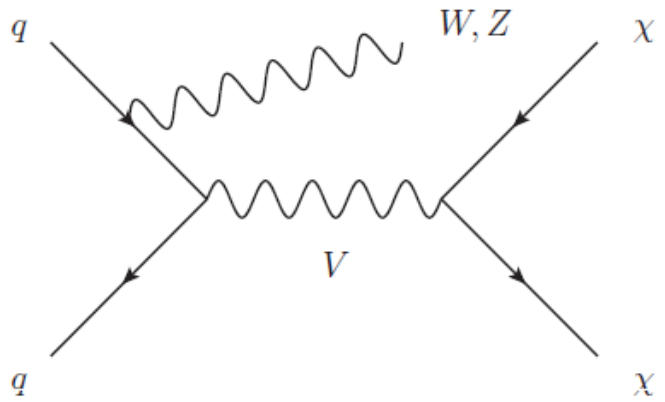
- 



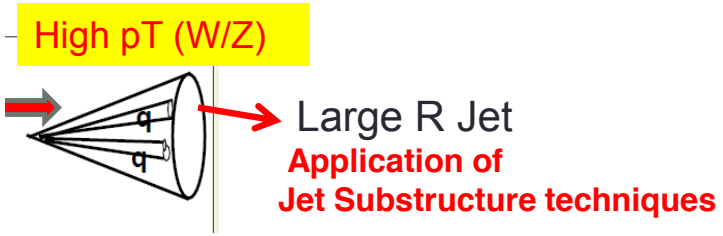
# DM + W/Z

- Mono-V (jj) channel:
  - Search for dark matter production in association with a hadronically decaying W or Z boson



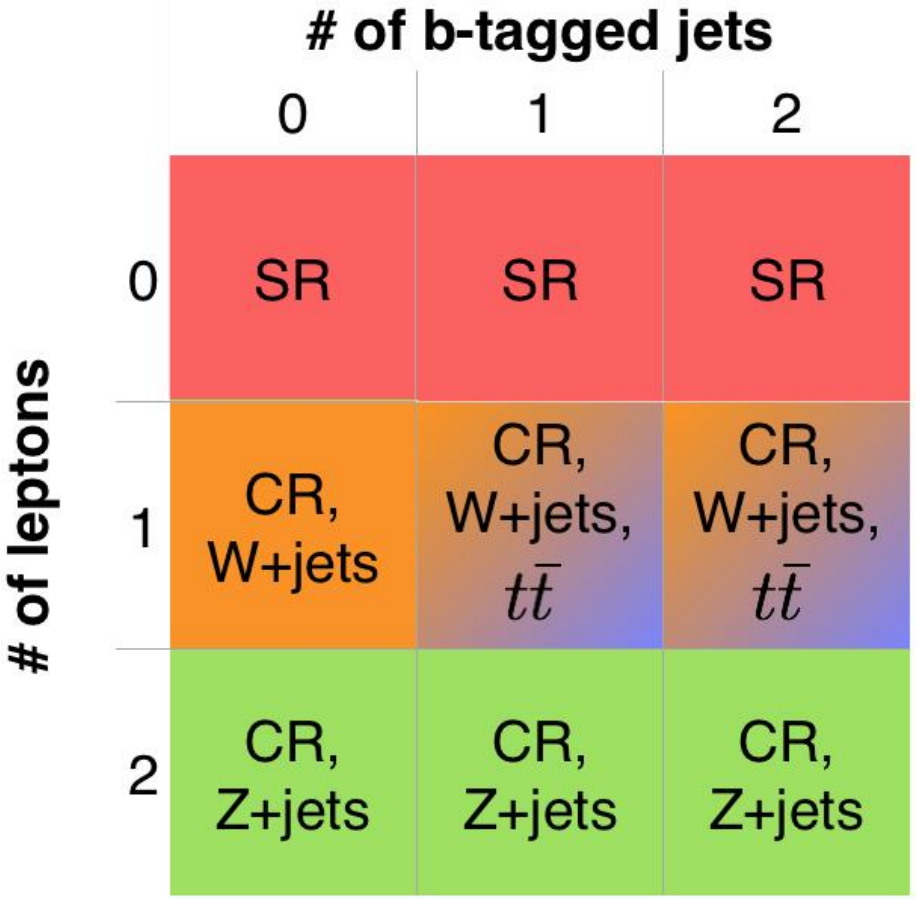




- Merged analysis
  - High MET region: MET > 250 GeV
- Resolved analysis
  - Low MET region: 150 < MET < 250 GeV
- B-tag splitting to improve signal sensitivity

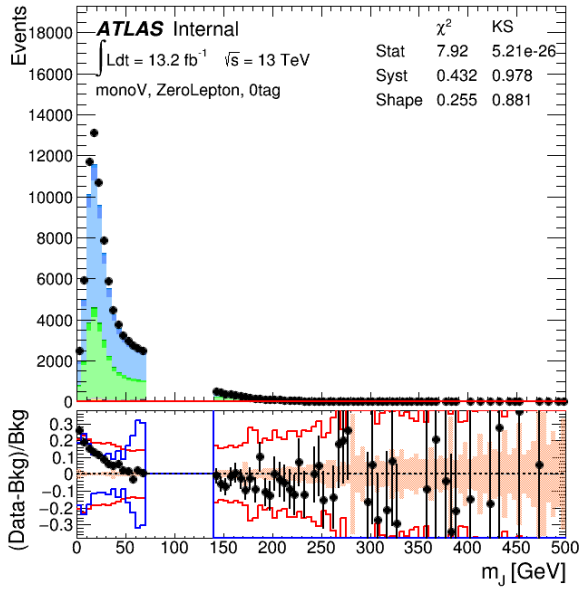


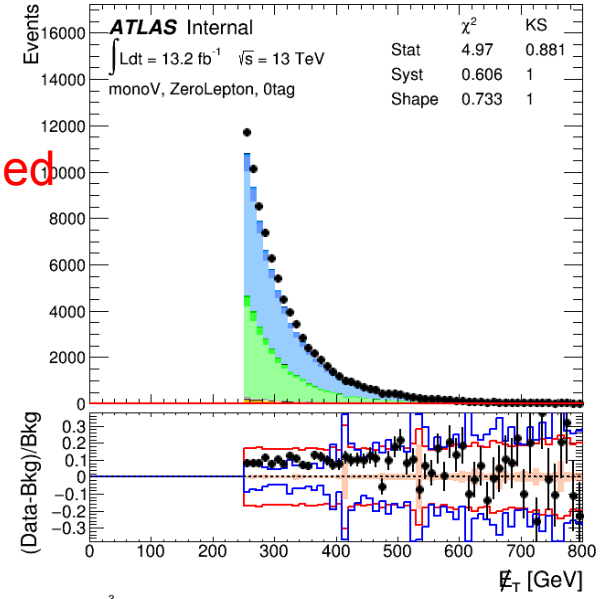
# Signal region and control region

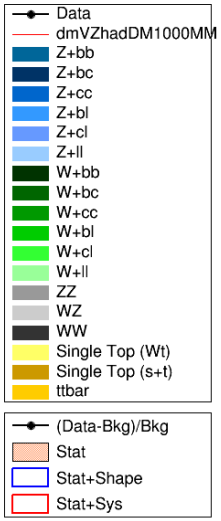
- Dominant backgrounds: Z(vv)+jets, W(lv)+jets, ttbar

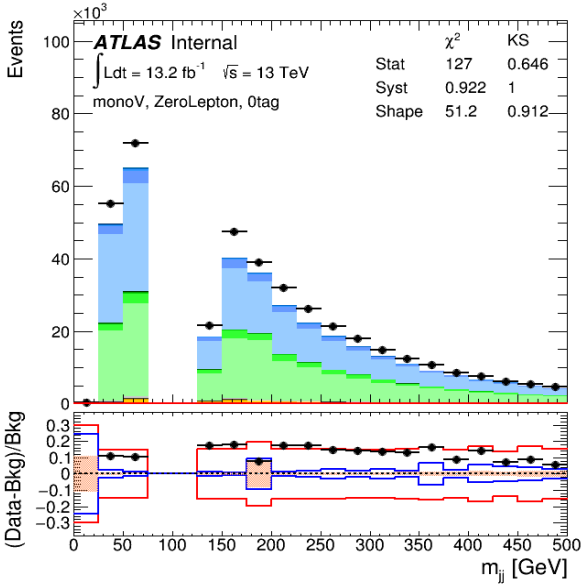


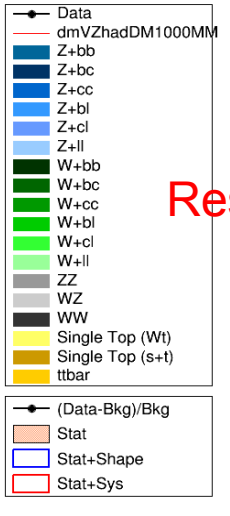
# Data/MC

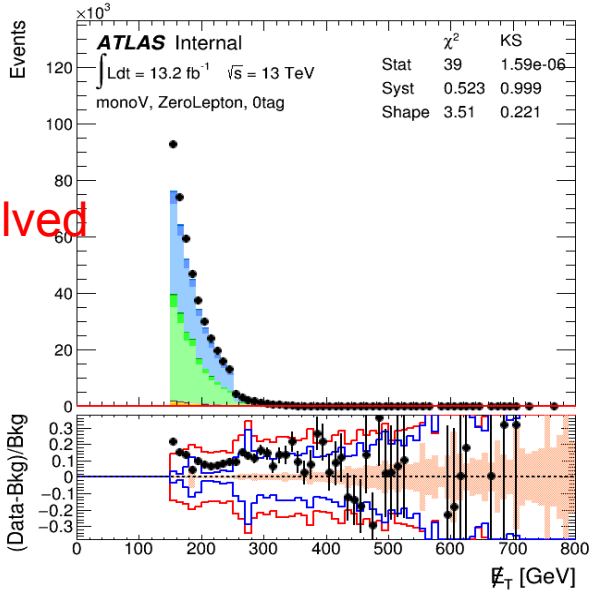
- 

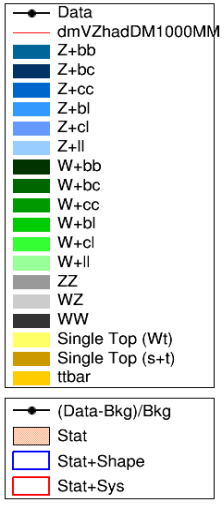
Merged








Resolved




# Strategy and Plan

- Global fitting the SR and CRs to constrain the background estimation
- Currently analyzing the ICHEP dataset of 13.2 fb-1
- Plan to look at full 2015+2016 dataset of 36.5 fb-1

# Summary

- Collider search may tell us about the nature of WIMP
  - Trying to cover every possibility

- We are performing searches from dijet final states (w and w/o MET, w and w/o b-tagging)

- Mediator search: dijet with b-tagging

- WIMP production: mono-W/Z(jj)

- Stay tuned!