Dark Matter Search at ATLAS
di-jet with b-tagging and mono-V

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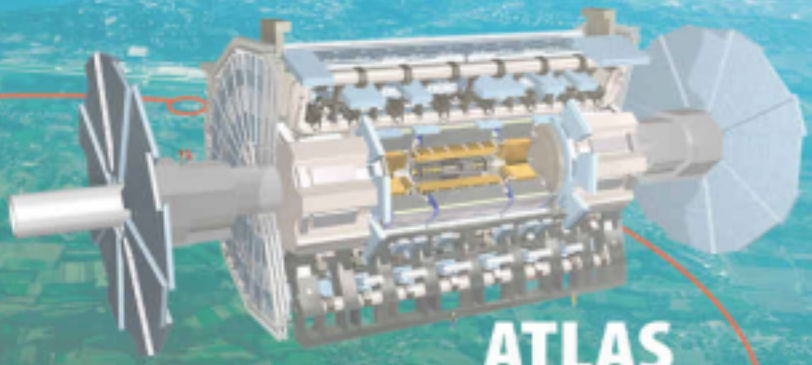
第十二届全国粒子物理学术会议 ・合肥
2016年8月

Searching for WIMP @LHC

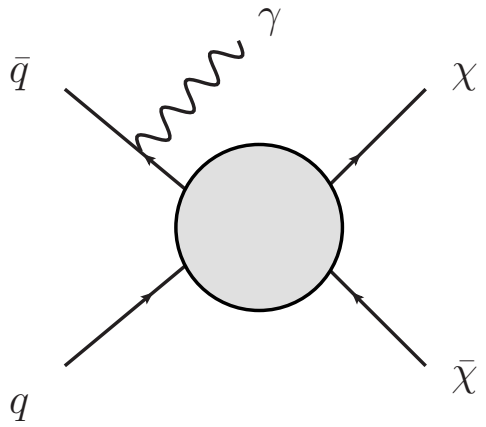
- **Collider searches**
  - **DM production from collisions: independent searches**
  - **Sensitive to small mass WIMPs**
  - **May reveal the nature of WIMPs**
- **LHC @ CERN**
  - **7/8 TeV, with 5/20 fb^{-1}**
  - **13 TeV in 2015, with 2.3-3.2fb^{-1}**
  - **13 TeV in 2016, data-taking**

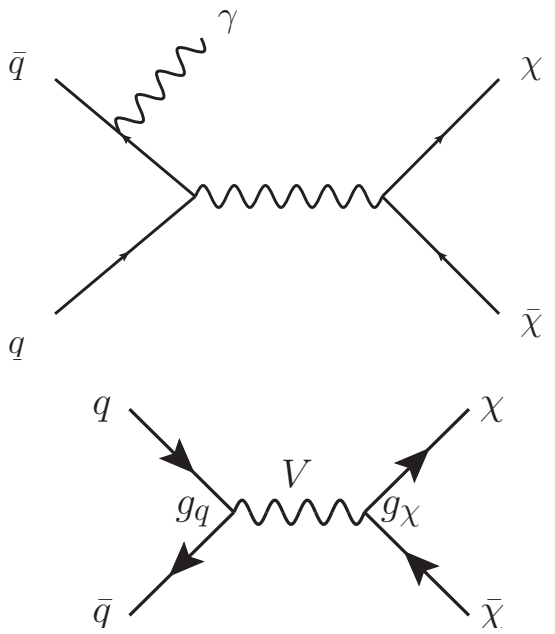


DM: From EFT to Simplified Model

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

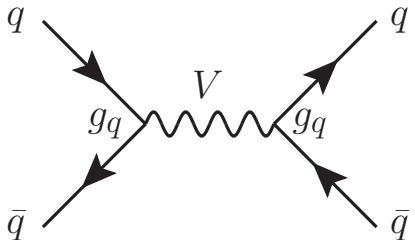
LHC DM forum
arXiv:1507.00966





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

Search for WIMP

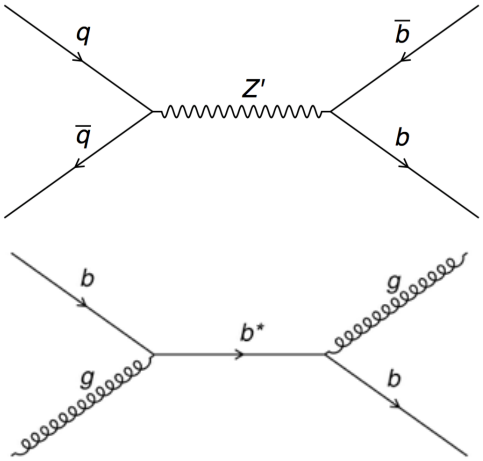


Search for WIMP-SM mediator

- DM production mechanism: Mediator Search

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

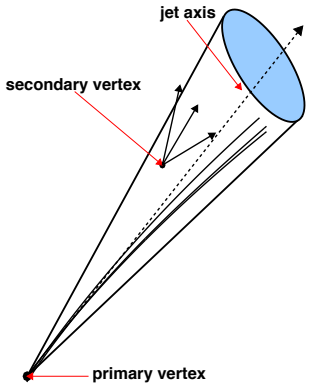


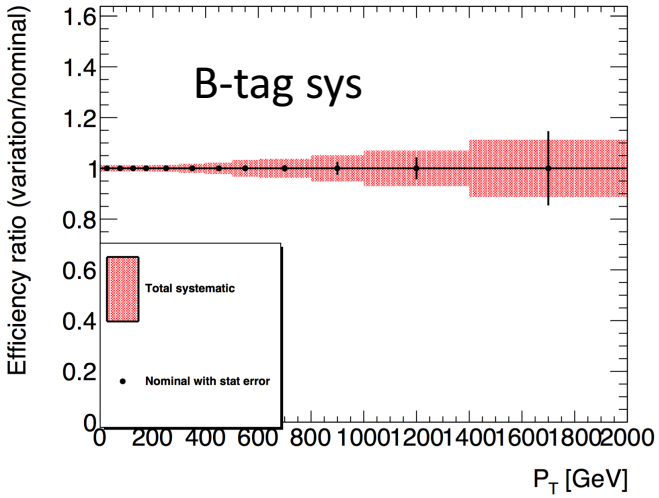
- Main Updates at Run II
  - Di-bjet resoannce search in High mass region (above 1.1TeV) with 2015 data.
    - Analysis divided into inclusive one b-tag (>=1 b-tag) and 2 b-tag categories
    - Moriond paper in Phys. Lett. B. (with 3.2 fb-1 of 2015 data)
  - Di-bjet resonance search in Low mass region (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)

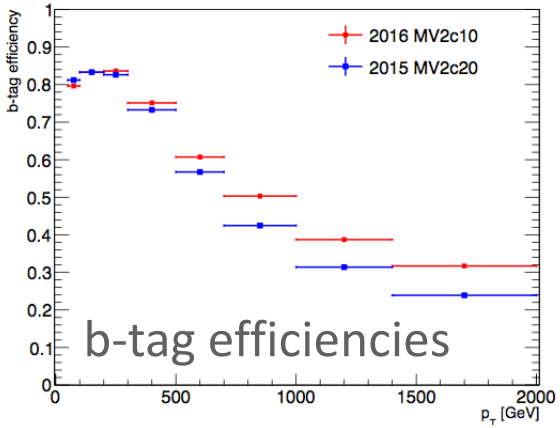
- Approval talk for Moriond (Contact Editor) and ICHEP analyses

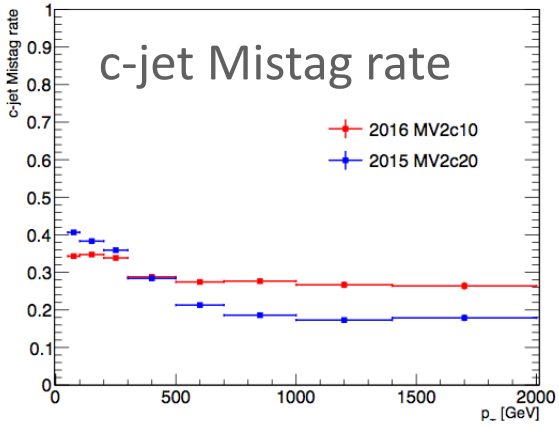
B-tagging Performance

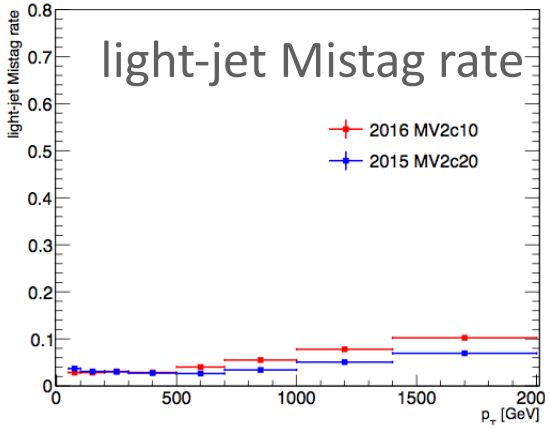
- B-jet tagging
  - 85% fixed b-jet efficiency WP
  - Use recommended tagger: MV2c10
- Tagging efficiency study
  - Using ttbar, b* and Z' samples
  - Efficiency drops at high pT
  - Systematics studies







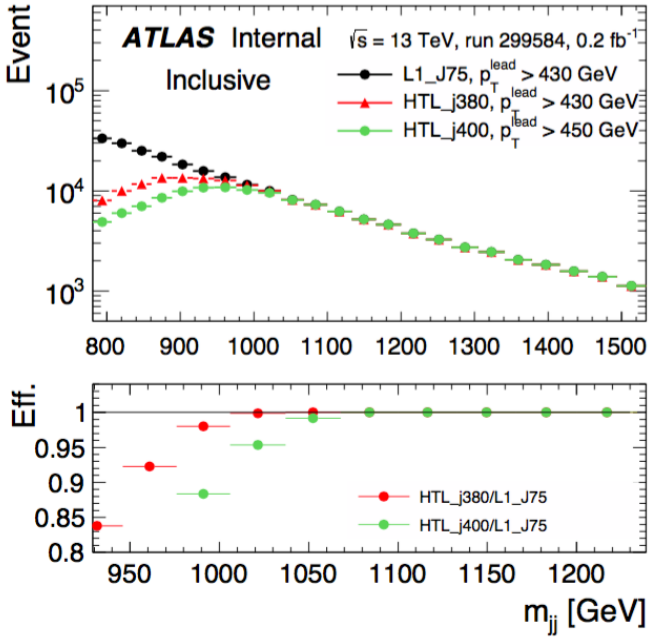




Presentation at Flavor Tagging Plenary in ATLAS P&P week 2016
Presentation at ATLAS Flavour Tagging Workshop in Germany 2016

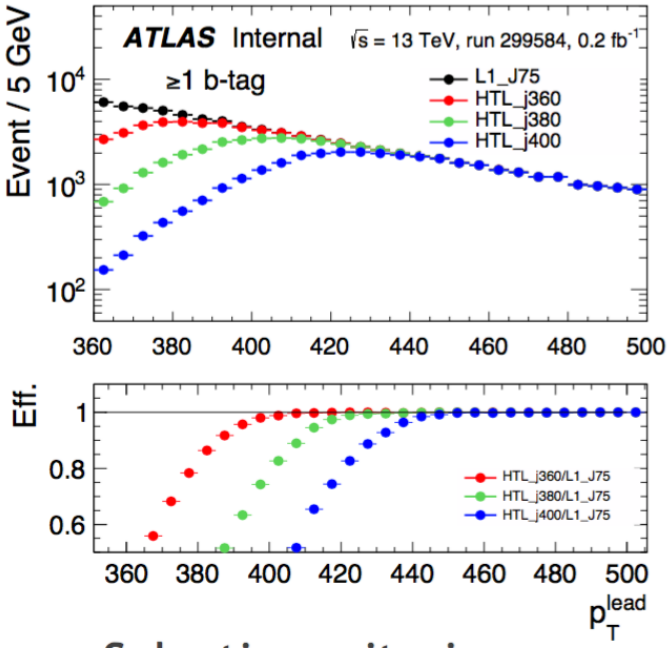
Data and Selection

- Data: 3.2 fb-1 (2015) + 10.5 fb-1 (2016)
- Event Selection



- Single Jet trigger
  - HLT_j360 (2015)
  - HLT_j380 (2016)
- Full efficiency at m_{jj} = 1.1TeV

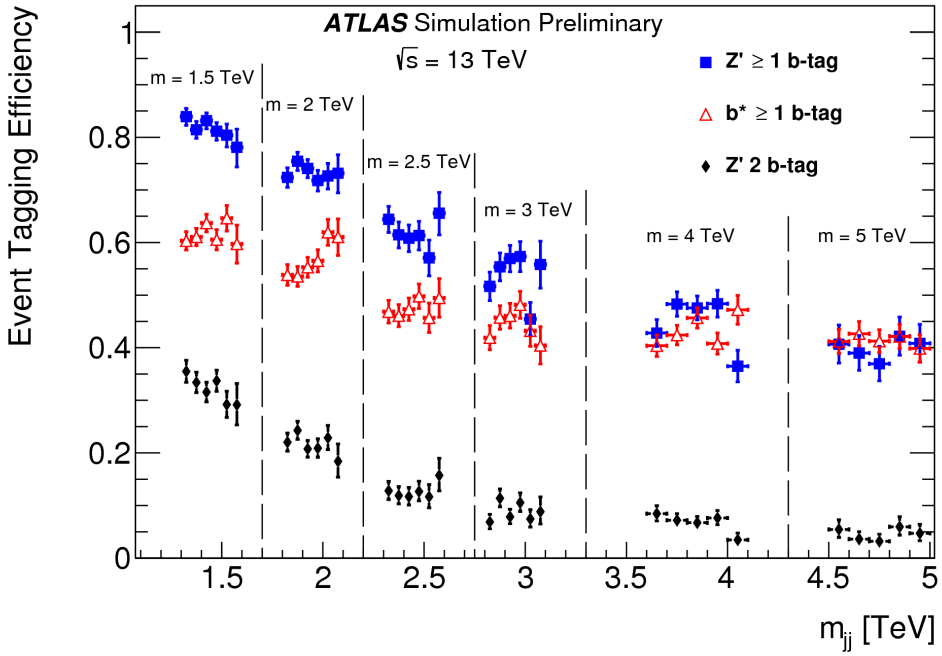
Updated value: mjj > 1.38 TeV (fit function studies)



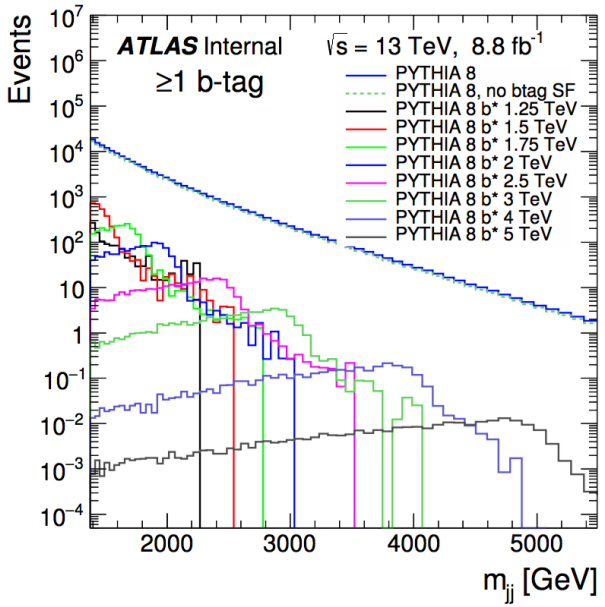
- Selection criteria
  - 1st jet pT > 430 GeV
  - 2nd jet pT > 60 GeV
  - |η| < 2.4
  - |y*| < 0.6
  - b-tagging 85% OP
    - MV2c10 tagger

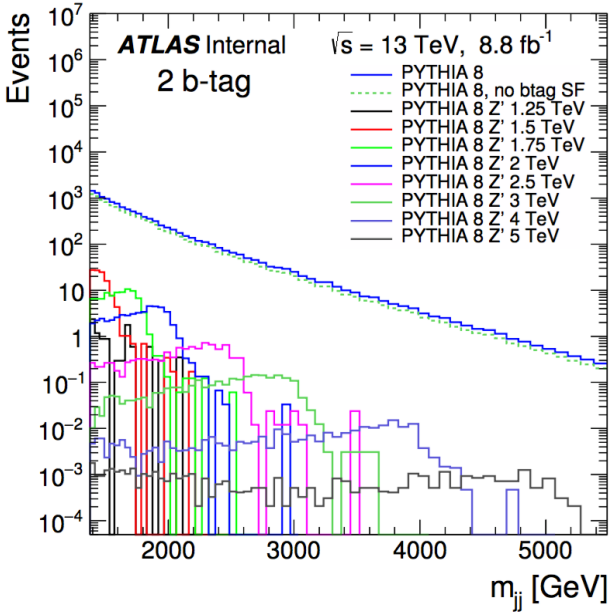
Signal Shape

- Resonance in di-jet invariant mass



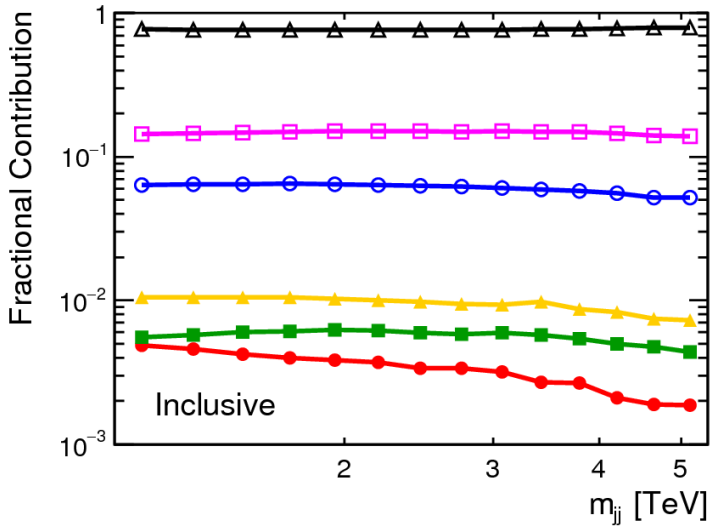
Per-event tagging efficiency as a function of reconstructed mass

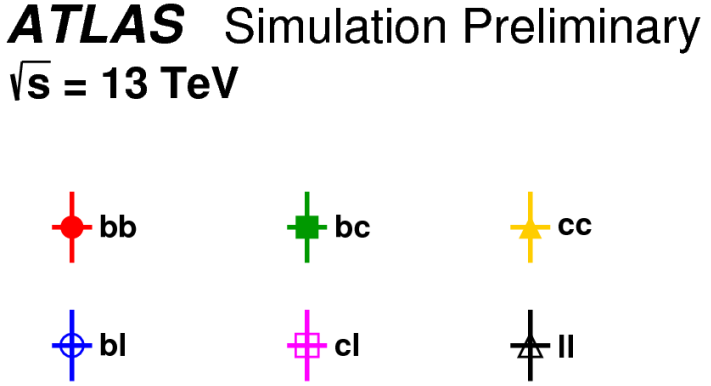


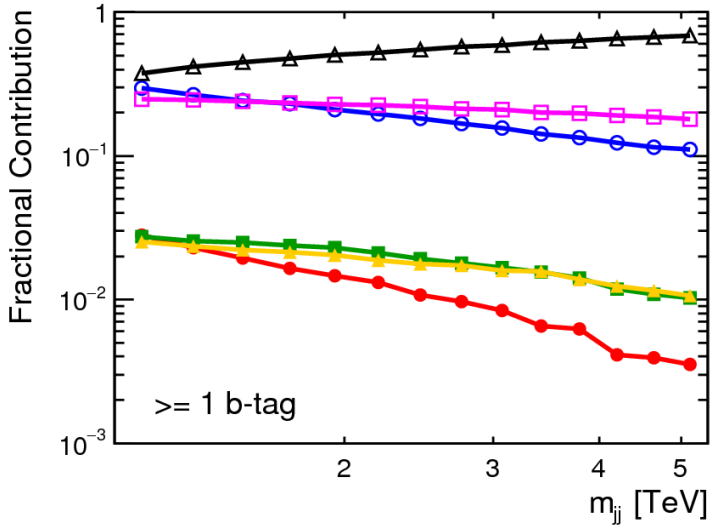


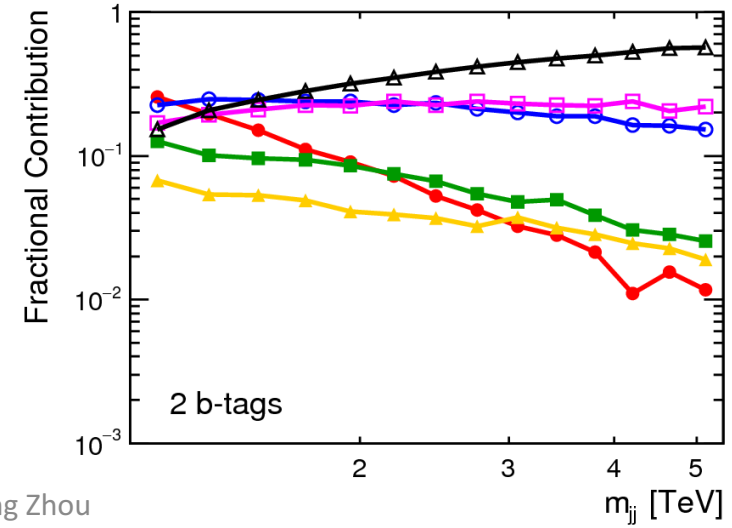
Background Composition

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









Background Estimation

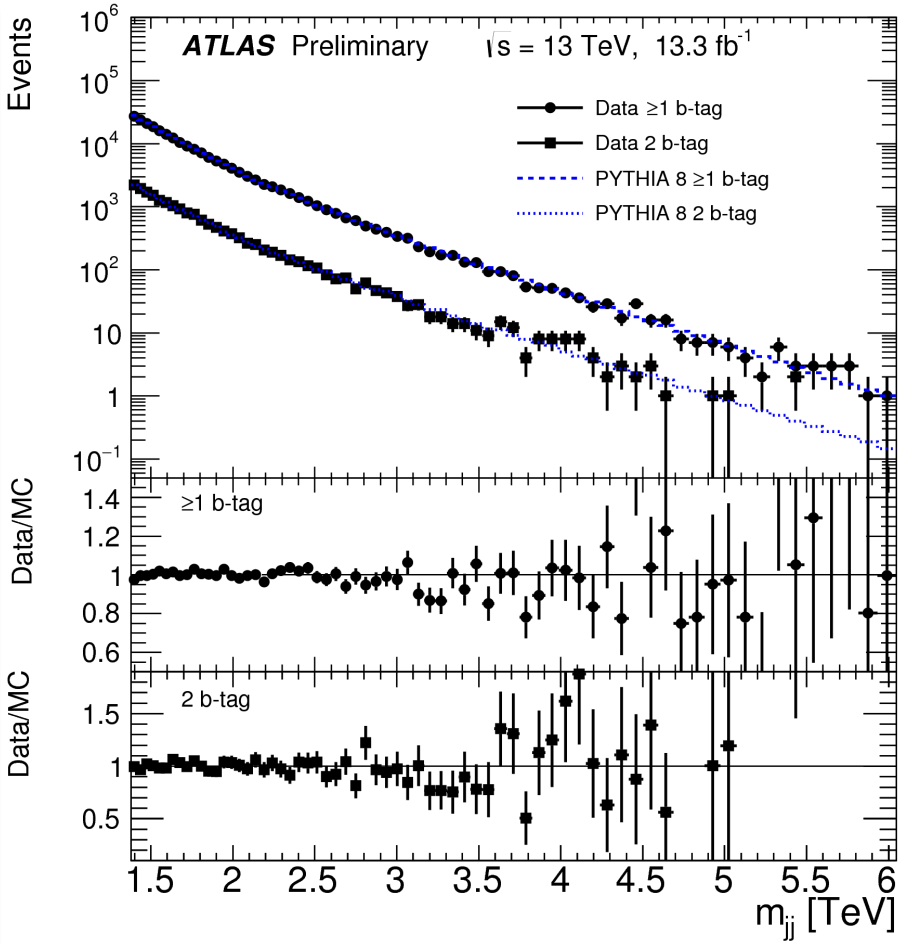
Bump-Hunter:

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

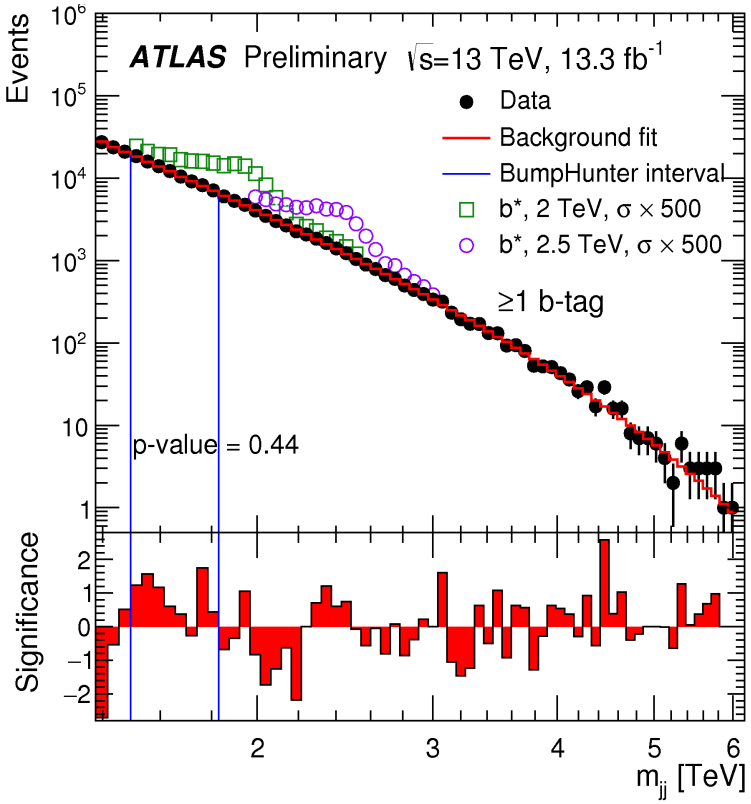
$$f(x) = p_1(1-x)^{p_2}(x)^{p_3+p_4\ln x+p_5(\ln x)^2},$$

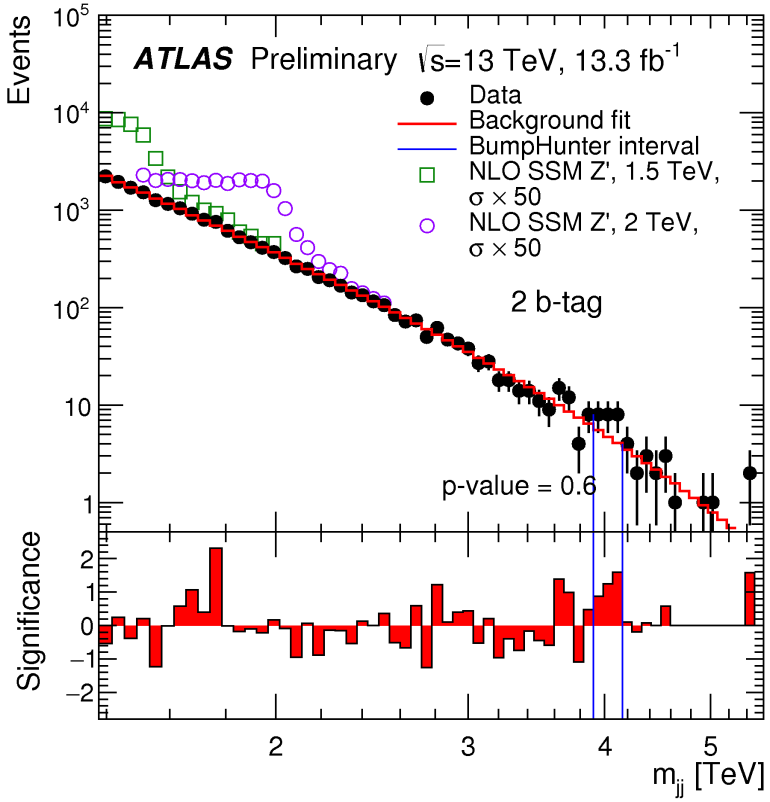
$$x = m_{jj}/\sqrt{s}$$

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



Bump-Hunter Results





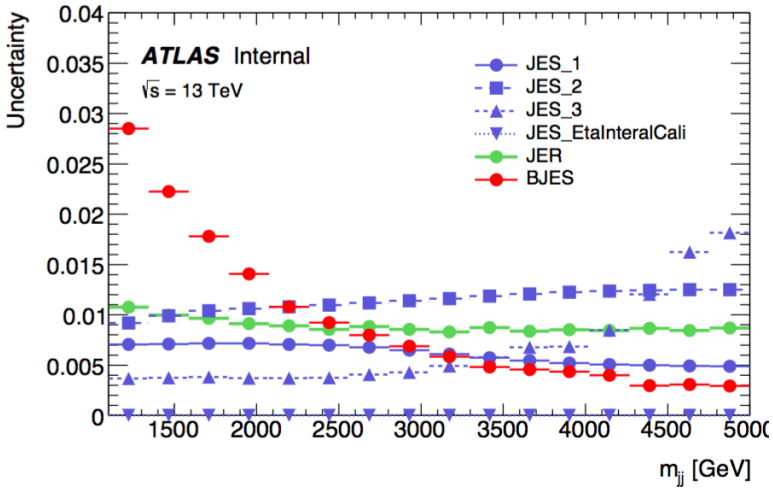
- No 3sigma excess, p-value with 10k pseudo-experiments: 0.44 and 0.6 for 1 b-tag and 2-btag categories respectively.

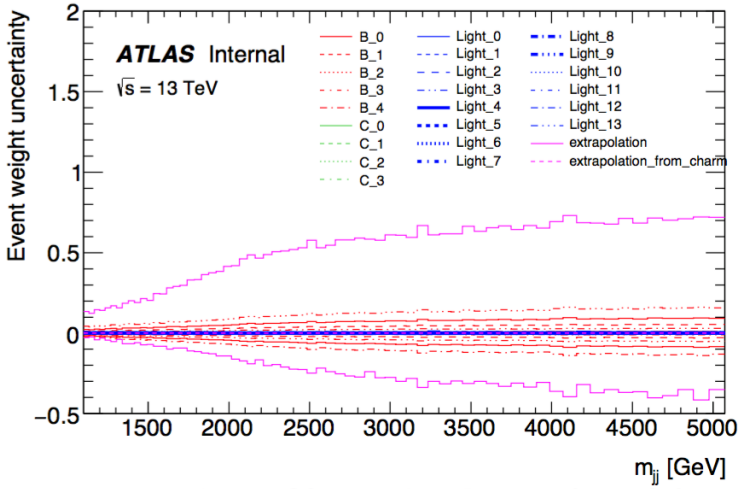
Systematics

- 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%



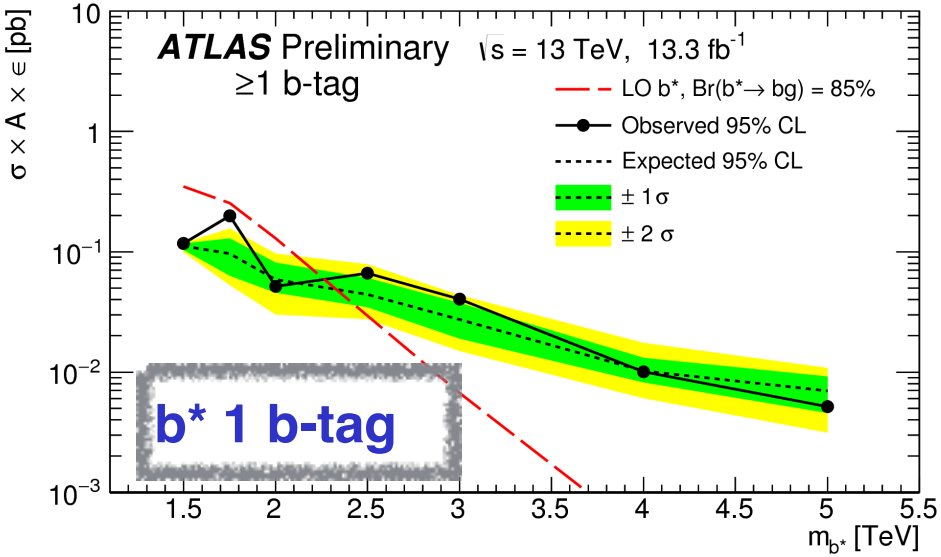


uncertainty of b-tagging SF on Z' model

Exclusion Limits

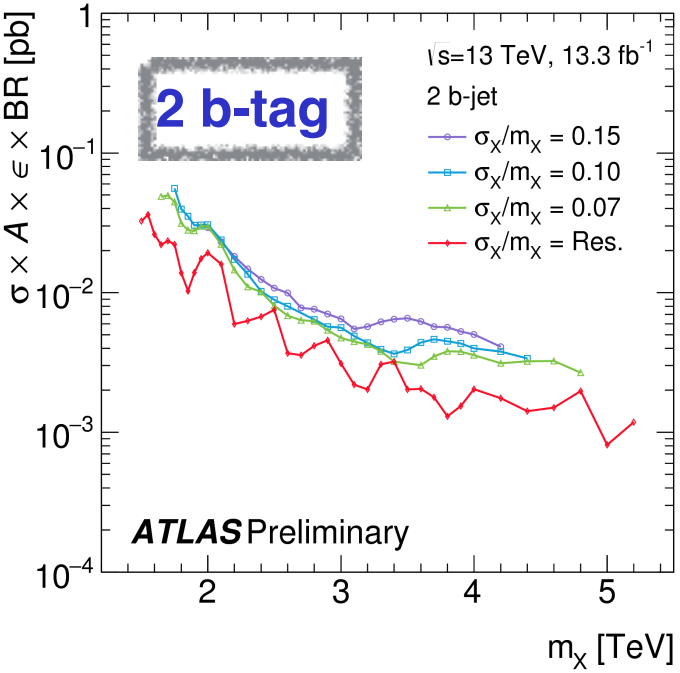
Bayesian approach to set 95% upper limit on Acceptance × ∈ x cross section:

- **b* model excluded up to 2.3 TeV for >= 1 b-tag**



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

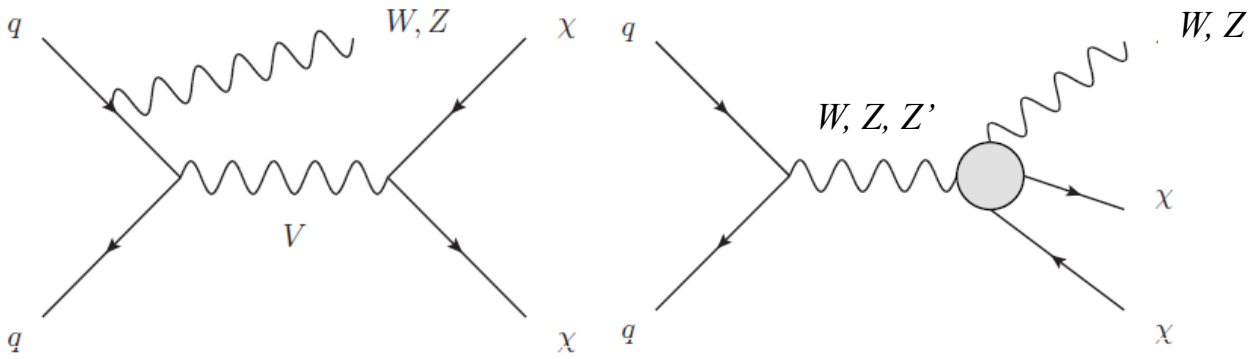
Exclude Gaussian contributions with effective cross sections ranging from approximately 0.2 – 0.001 pb in the mass range 1.4 – 5.5 TeV

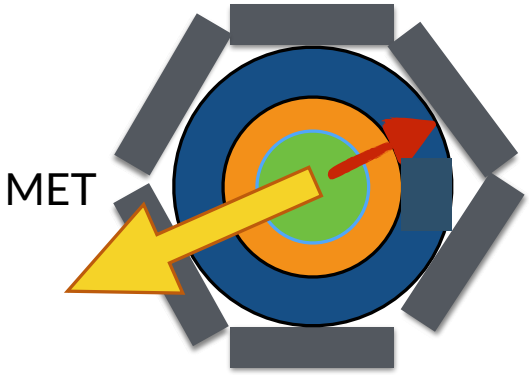


- DM produced in association with vector boson (hadronic decay)

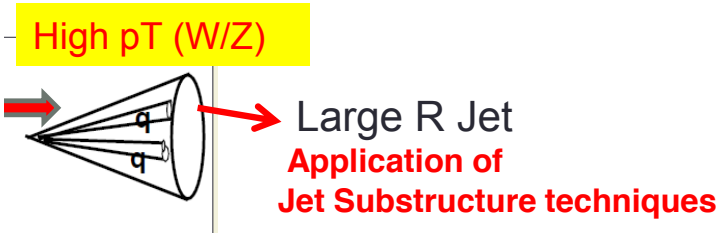
Mono-V

- Invisible WIMP produced with visible W/Z

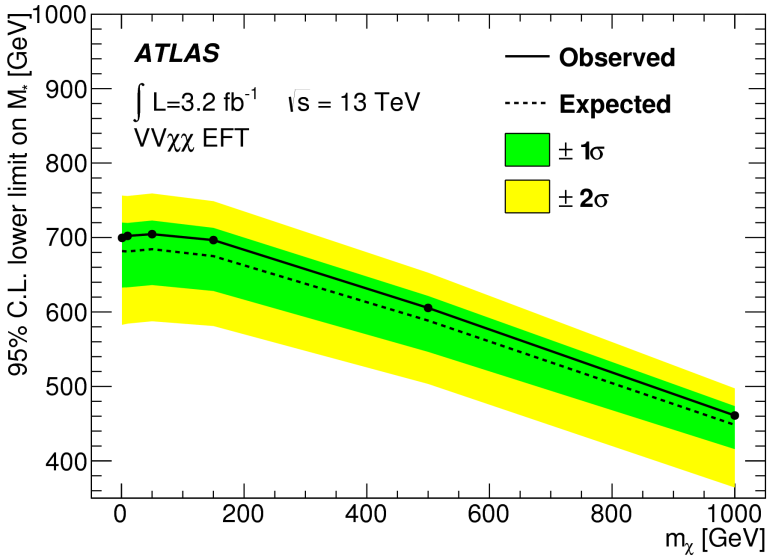




- Jet substructure to reconstruct W/Z hadronic decay



- Run-I result published at PRL
- 2015 3.2fb-1 data result submitted to PLB
- 2016 data analysis is work-in-progress



Event Selection

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Leptons

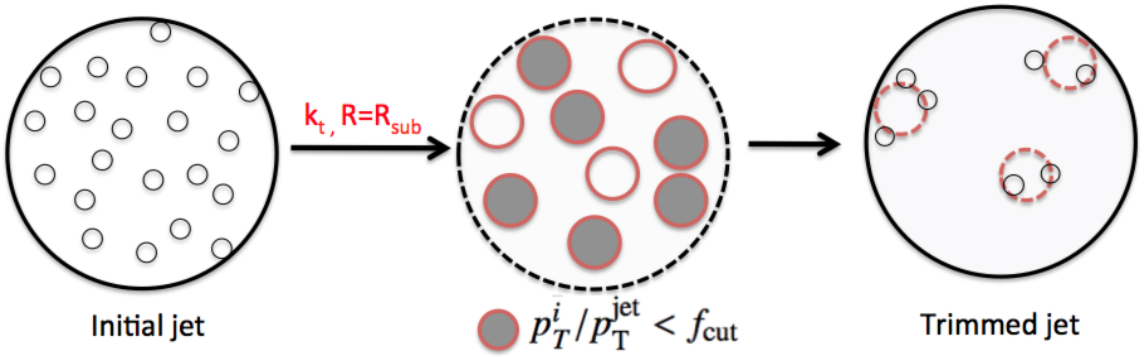
	0-Lepton	1-Lepton	2-Lepton
Electron	0 “Loose” electrons, pT>7GeV, $\|\eta\| < 2.47$, LooseTrackOnly iso, LooseLH	No additional “Loose” electrons	-
Muons	0 “Loose” muons, pT > 7GeV, $\|\eta\| < 2.7$, LooseTrackOnly iso, Loose	1 “Signal” muon pT> 25GeV and Medium No additional “Loose” muons	2 “Signal” muons pT > 25GeV, $\|\eta\| < 2.5$ Loose

Jets

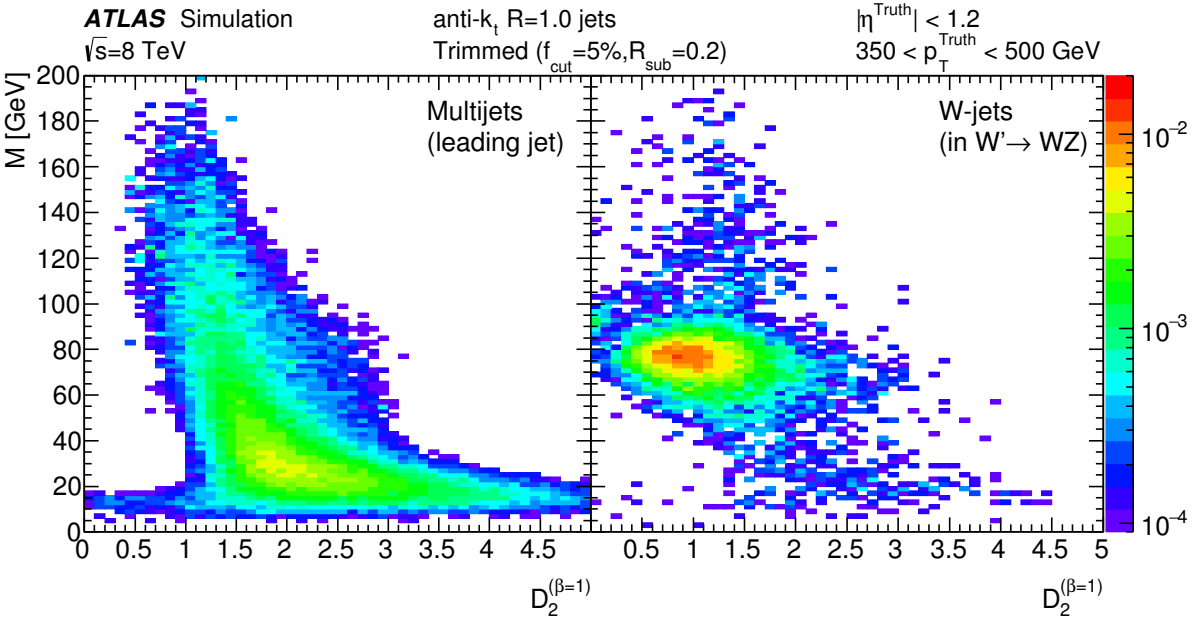
R = 0.2 Track jets	pT> 10 GeV, $\|\eta\| < 2.5$ >= 2 track-jets ghost associated to the leading large-R jet
R= 0.4 Small-R jets	Central: pT >20 GeV, $\|\eta\| < 2.5$ Forward: pT> 20GeV, $2.5< \|\eta\| < 4.5$ JVT > 0.59 for jets!= pT < 60GeV, $\|\eta\| < 2.4$
R= 1.0 Large-R jets	Anti-Kt R = 1.0 Large-R jet (trimmed with $R_{sub} = 0.2$, $f_{cut} = 0.05$) pT > 200 GeV $\|\eta\| < 2.0$
Boson Tagging	WZ-tagger: medium WP D2(pT) cut ~<1 M(jet) ~m(W/Z) +- 15GeV

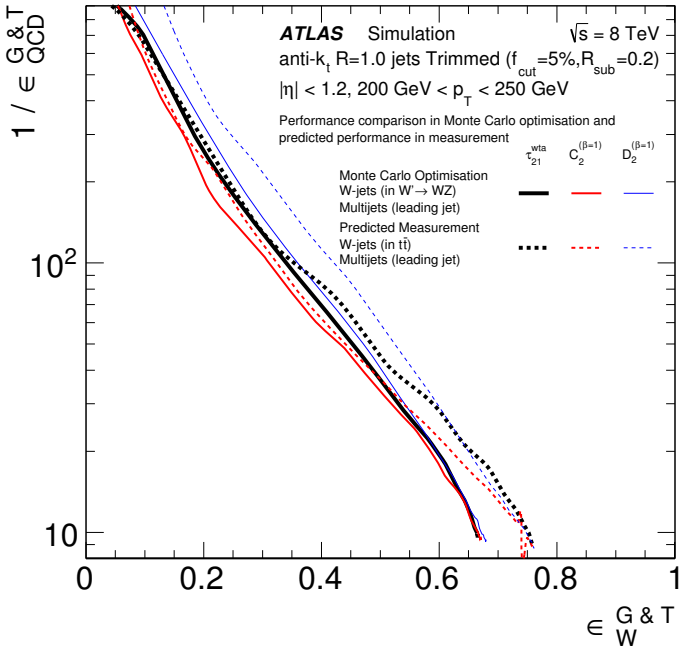
W Tagger

- Jet substructure
- Anti-kT 1.0 jet Trimming
  - fcut=5%
  - R_subjet = 0.2



- pT dependent cuts on jet mass and D2 variable (energy correlation ratio)

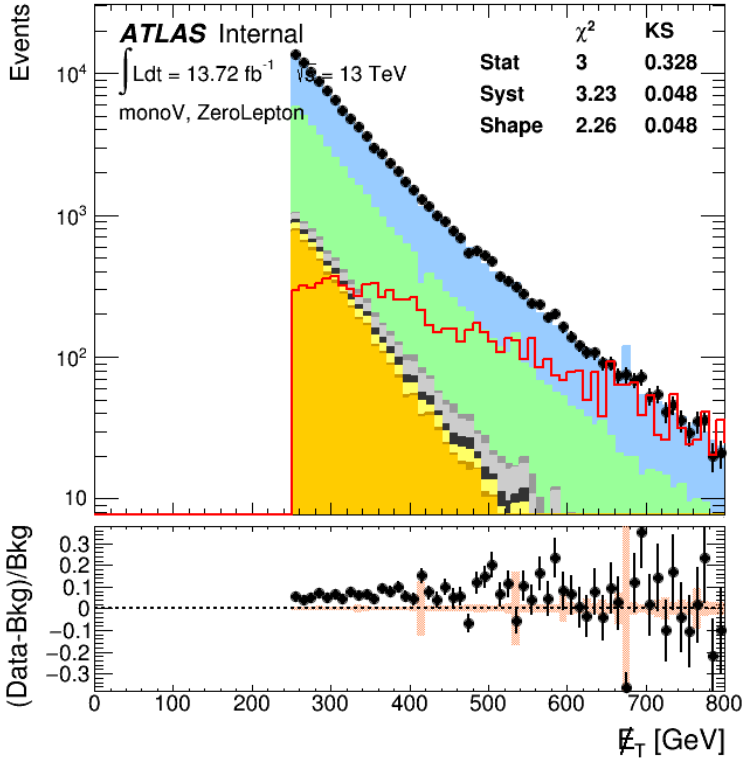


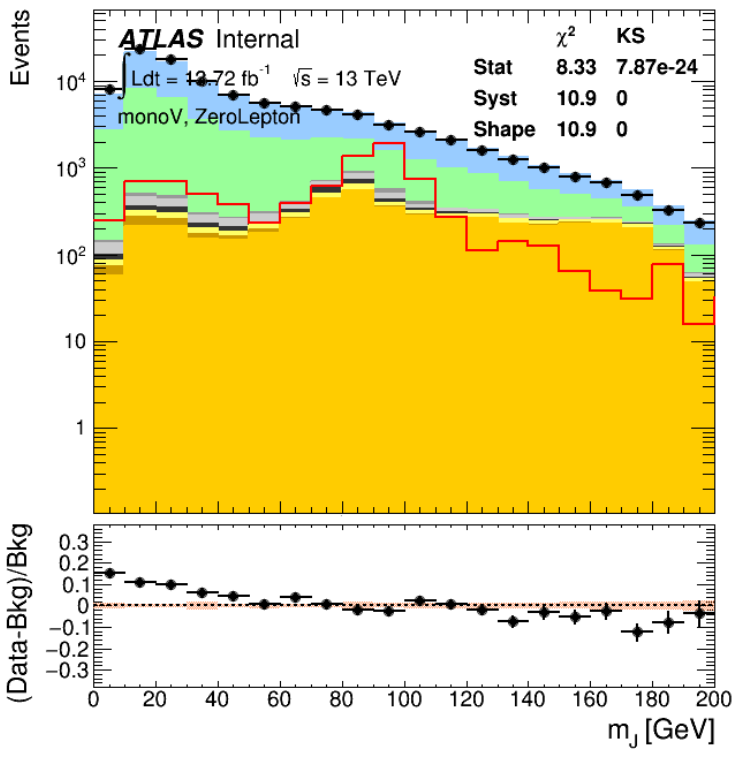


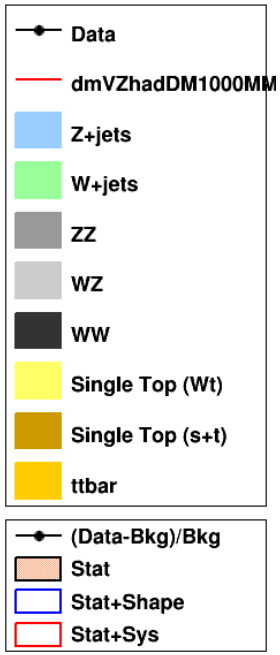
Signal and Background

- 0-lepton control region
  - No W-tagger

- Goal: paper with the full 2016 data







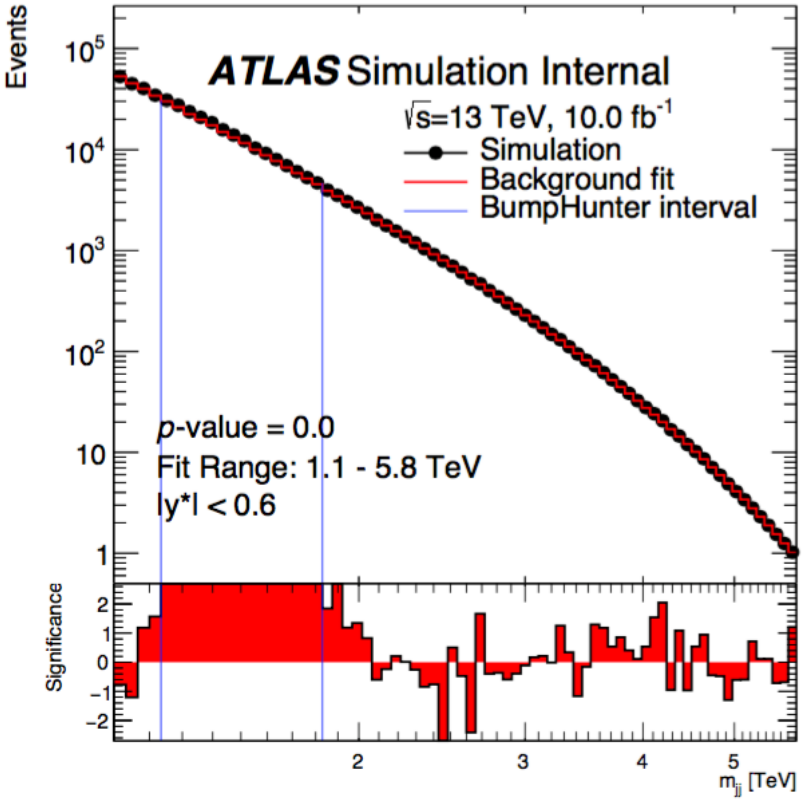
Summary

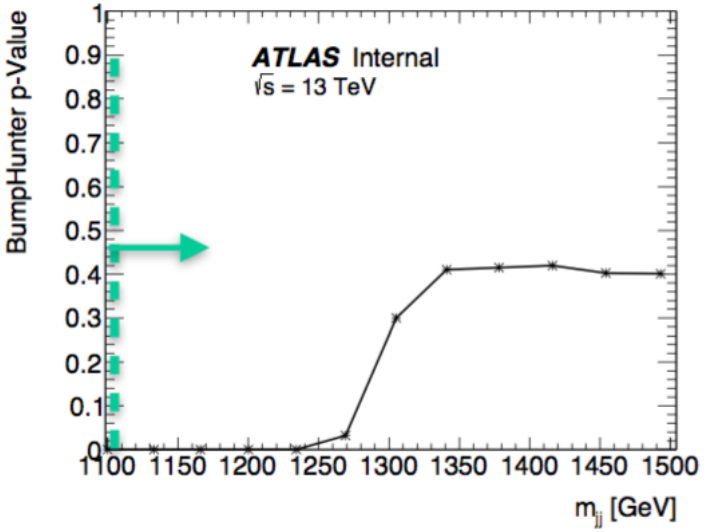
- Collider search may tell us about the nature of WIMP
  - Trying to cover every possibility
- Mediator search: dijet with b-tagging
- WIMP production: mono-W
- Stay tuned!

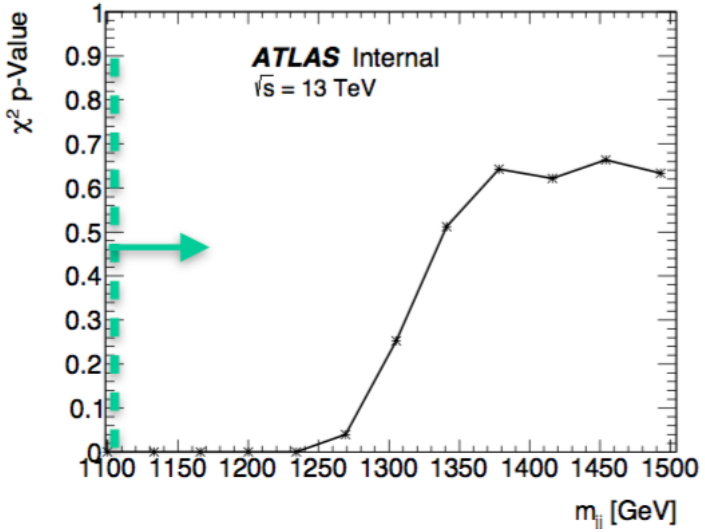
Backup

di-bjet Fit function Study (I)

- Lower bound of the fit range at 1.1 TeV is not sufficient to describe background shape of 1 b-tagged sample
- **Scan lower bound from 1.1 to 1.5 TeV**

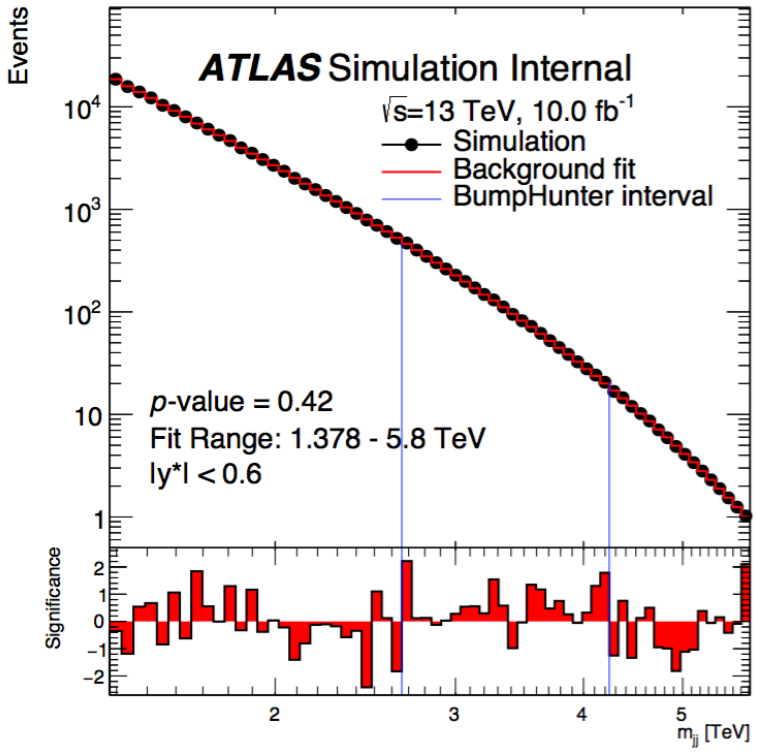


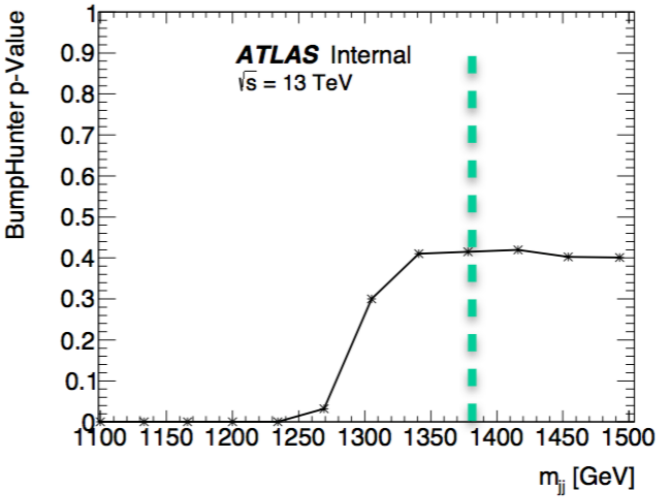


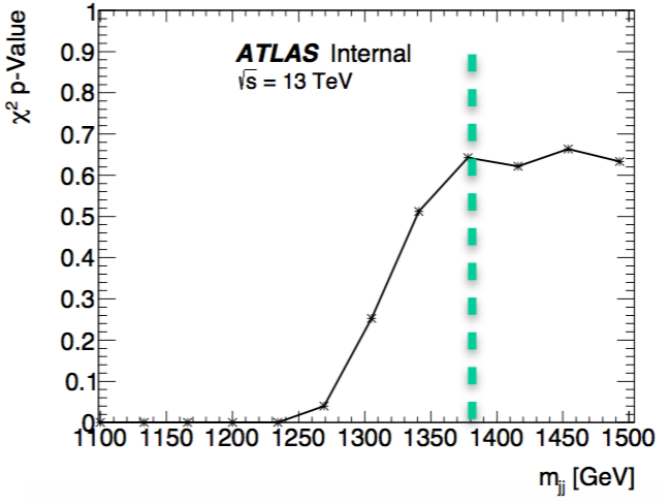


di-bjet Fit function Study (II)

- Trigger-efficient dijet mass point is 1.1 TeV
- Lower bound of fit at 1.1 TeV is not sufficient to describe the background shape of 1 b-tagged sample
- Scan lower bound from 1.1 to 1.5 TeV
- **Starting at 1.38 TeV is sufficient**







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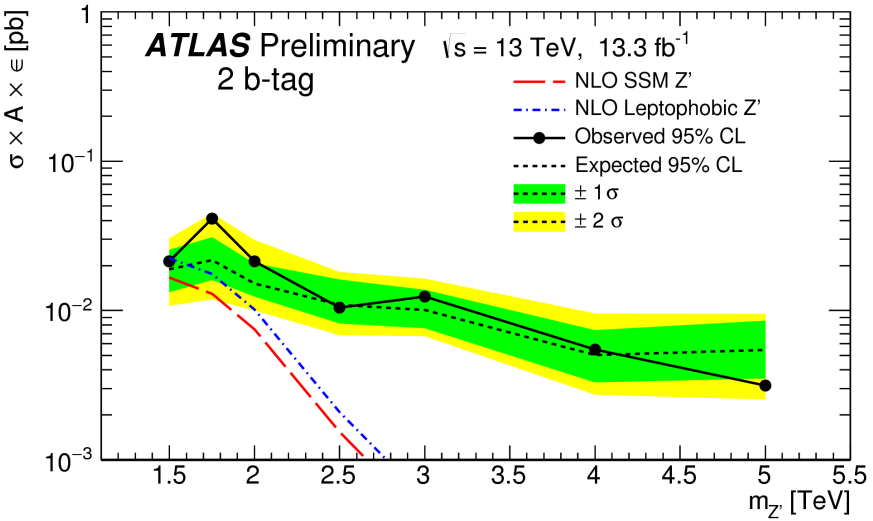
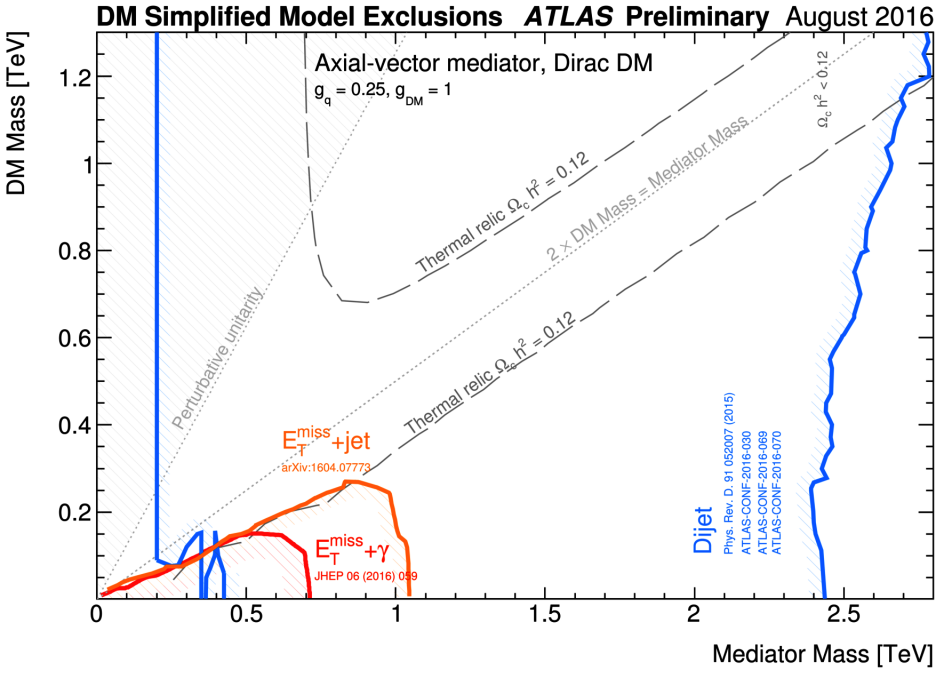
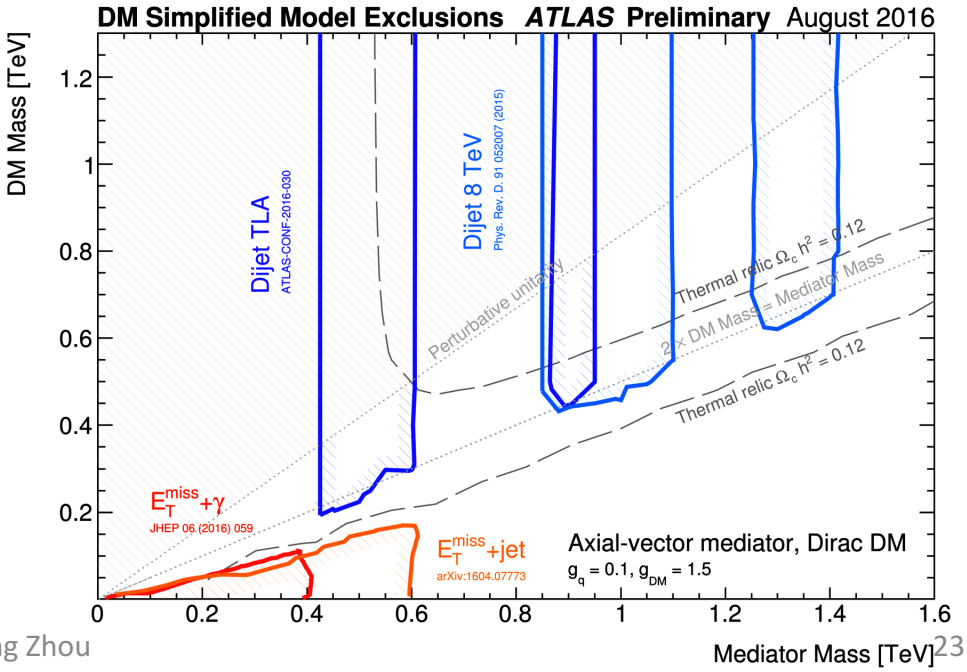
Z' 2 b-tag


ATLAS Preliminary
2 b-tag
√s = 13 TeV, 13.3 fb-1
NLO SSM Z'
NLO Leptophobic Z'
Observed 95% CL
Expected 95% CL
± 1σ
± 2 σ
σ × A × ∈ [pb]
mZ' [TeV]


DM Simplified Model Exclusions ATLAS Preliminary August 2016
Axial-vector mediator, Dirac DM
gq = 0.25, gDM = 1
Thermal relic Ωc h2 = 0.12
2 × DM Mass = Mediator Mass
Ωc h2 < 0.12
Perturbative unitarity
Thermal relic Ωc h2 = 0.12
ETmiss+jet
arXiv:1604.07773
ETmiss+γ
JHEP 06 (2016) 059
Dijet
Phys. Rev. D. 91 052007 (2015)
ATLAS-CONF-2016-030
ATLAS-CONF-2016-069
ATLAS-CONF-2016-070
DM Mass [TeV]
Mediator Mass [TeV]


DM Simplified Model Exclusions ATLAS Preliminary August 2016
Dijet TLA
ATLAS-CONF-2016-030
Dijet 8 TeV
Phys. Rev. D. 91 052007 (2015)
Perturbative unitarity
Thermal relic Ωc h2 = 0.12
2 × DM Mass = Mediator Mass
Thermal relic Ωc h2 = 0.12
ETmiss+γ
JHEP 06 (2016) 059
ETmiss+jet
arXiv:1604.07773
Axial-vector mediator, Dirac DM
gq = 0.1, gDM = 1.5
DM Mass [TeV]
Mediator Mass [TeV]