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Search for Dark Matter in association with a hadronically decaying vector boson

DPF Conference
August 1st, 2017

Introduction

Motivation

Dark matter (DM) compose large part of the mass-energy of the universe.
If the DM particle couples to the SM, it may be produced in a particle collider and be observed in experiment.

Search for dark matter pair production in association with a W/Z boson with 2015 + 2016 data at $\sqrt{s} = 13$ TeV with the ATLAS detector, 36.1 fb^{-1}

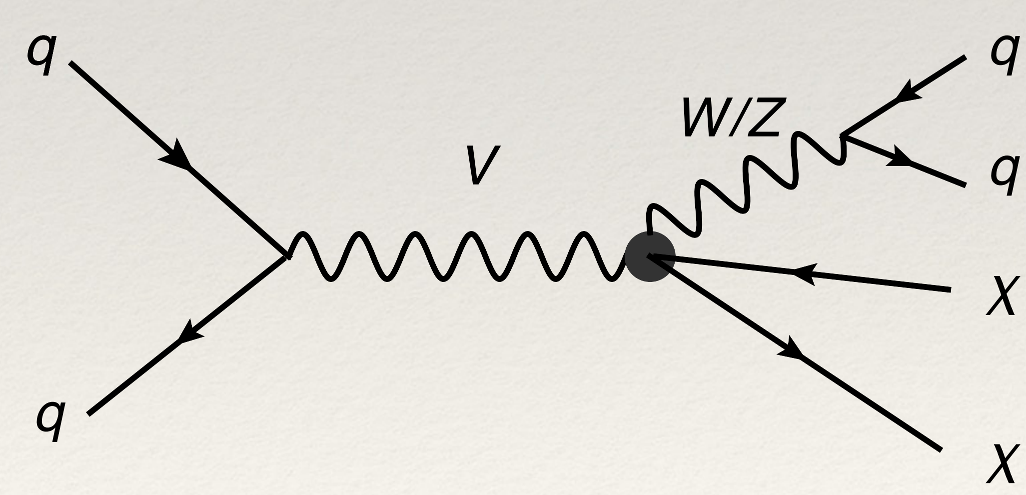
The Experimental Final State

Large Missing transverse momentum and a quark pair decayed from the vector boson

W/Z—> qqbar

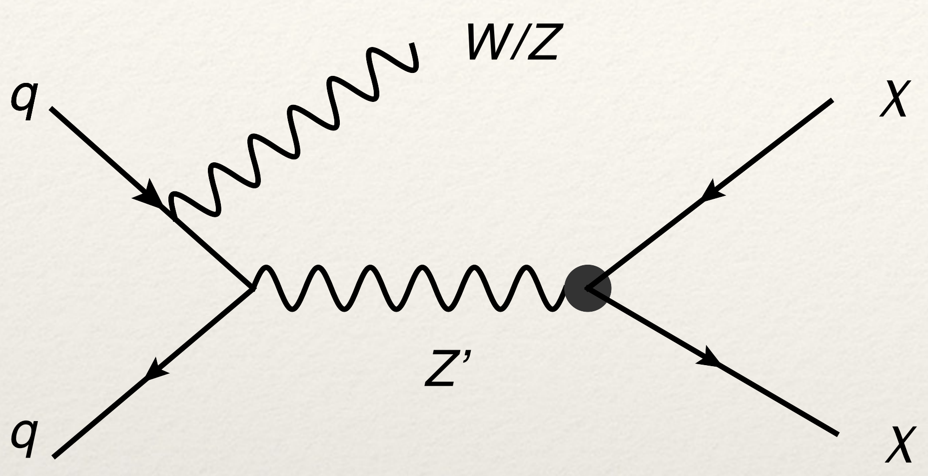
merged reconstruction: decaying from a high mass resonance, the quark pair is more efficiently reconstructed as a single large-radius jet (large-R jet)

resolved reconstruction: 2 small-R jets



Signal models used in the analysis

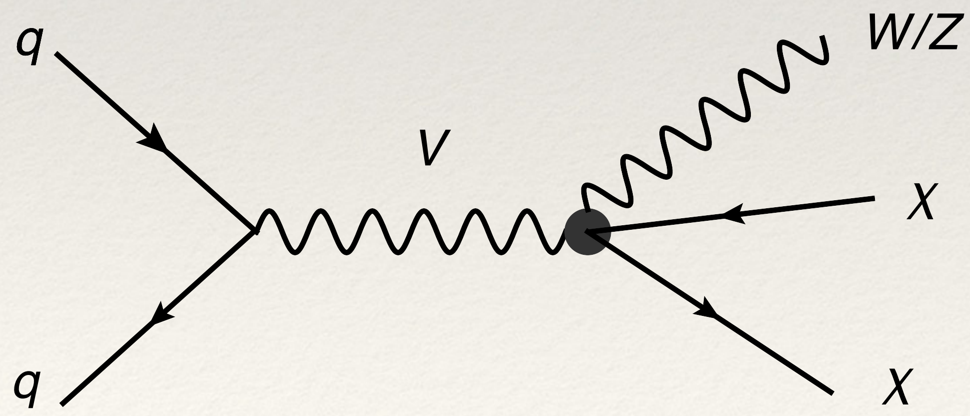
Example of simplified model diagram



The simplified vector mediate models and the Vvxx effective field theory are considered

Simplified models have a particle mediating the interaction between Standard Model (SM) particles and Dark Matter (DM)

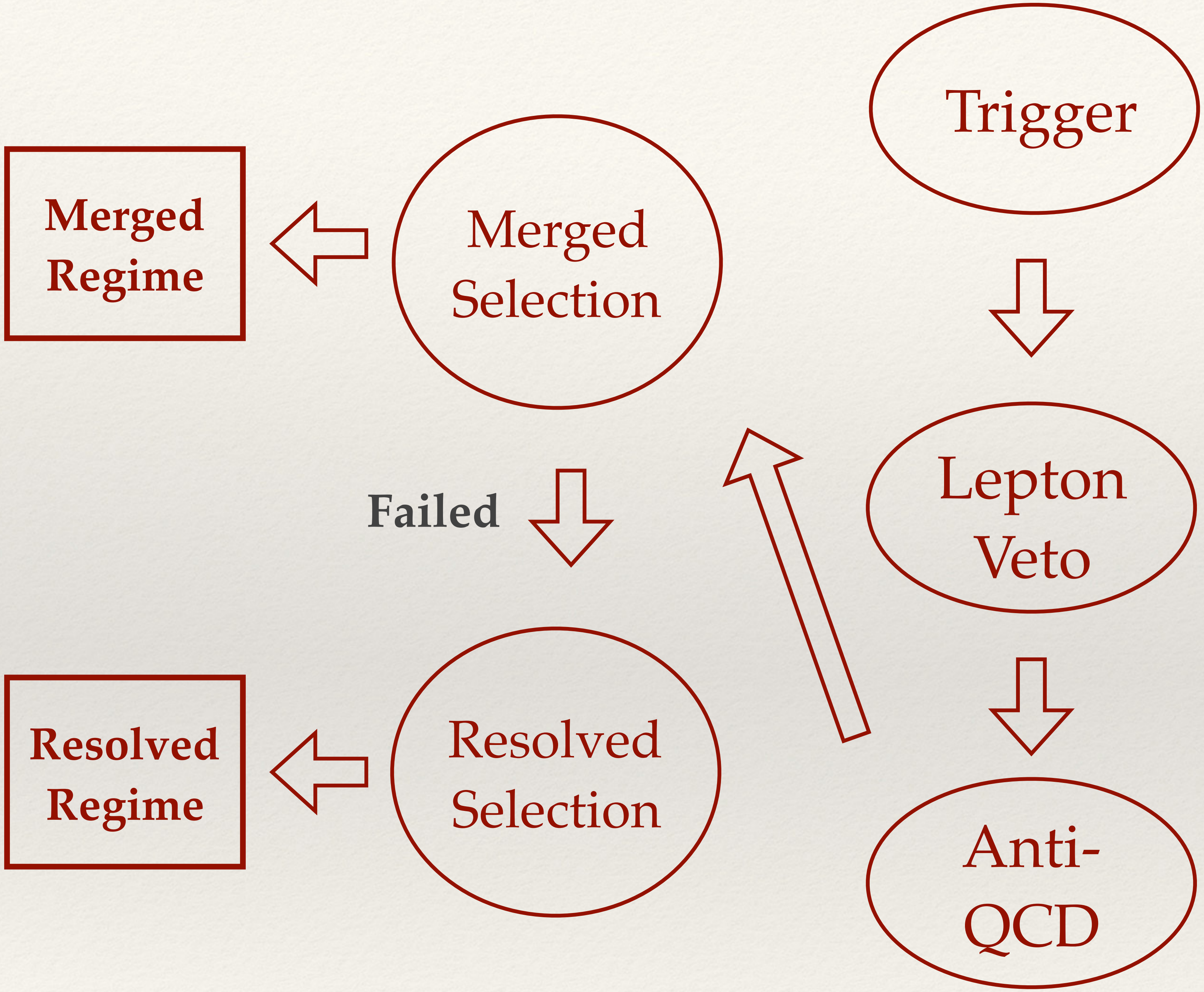
Example of Vvxx diagram



EFTs integrate out the mediator removing degrees of freedom and leading to a generic model.

In this analysis
g_x (coupling of the DM to the mediator) = 0.25,
g_q (coupling of the SM to the mediator) = 1

Event Selection



MET Triggers

70-110 GeV
depends on the luminosity

No loose leptons
(electrons or muons)

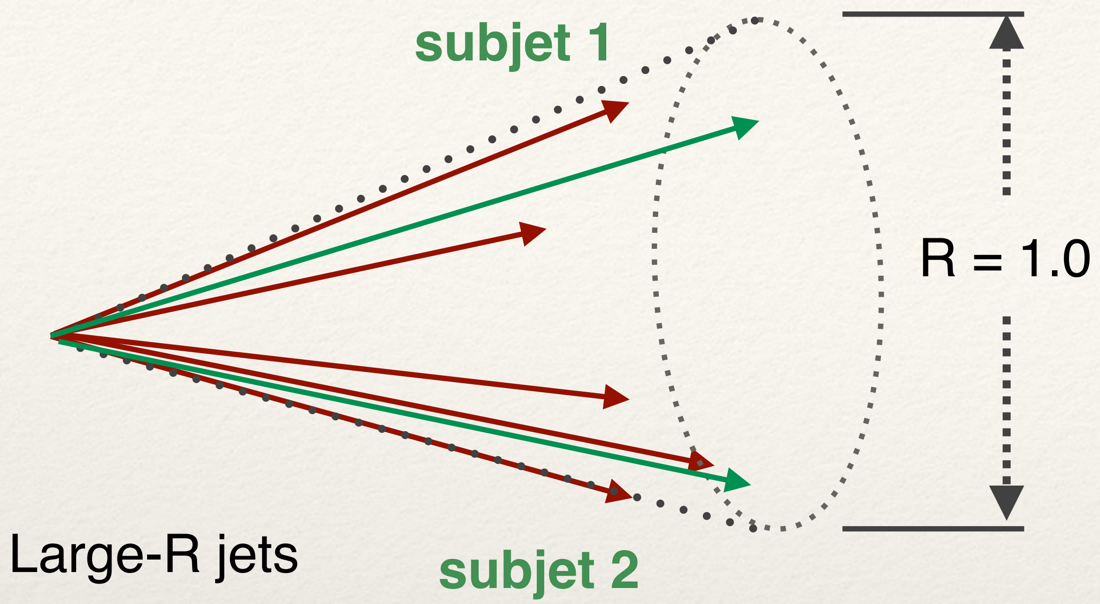
Track-MET > 30 GeV

min(Δϕ(MET, jets)) > 20°

Δϕ(MET, Track-MET) < 90°

Δϕ(MET, J/jj) > 120°

Merged Regime



Requirements:

MET > 250 GeV

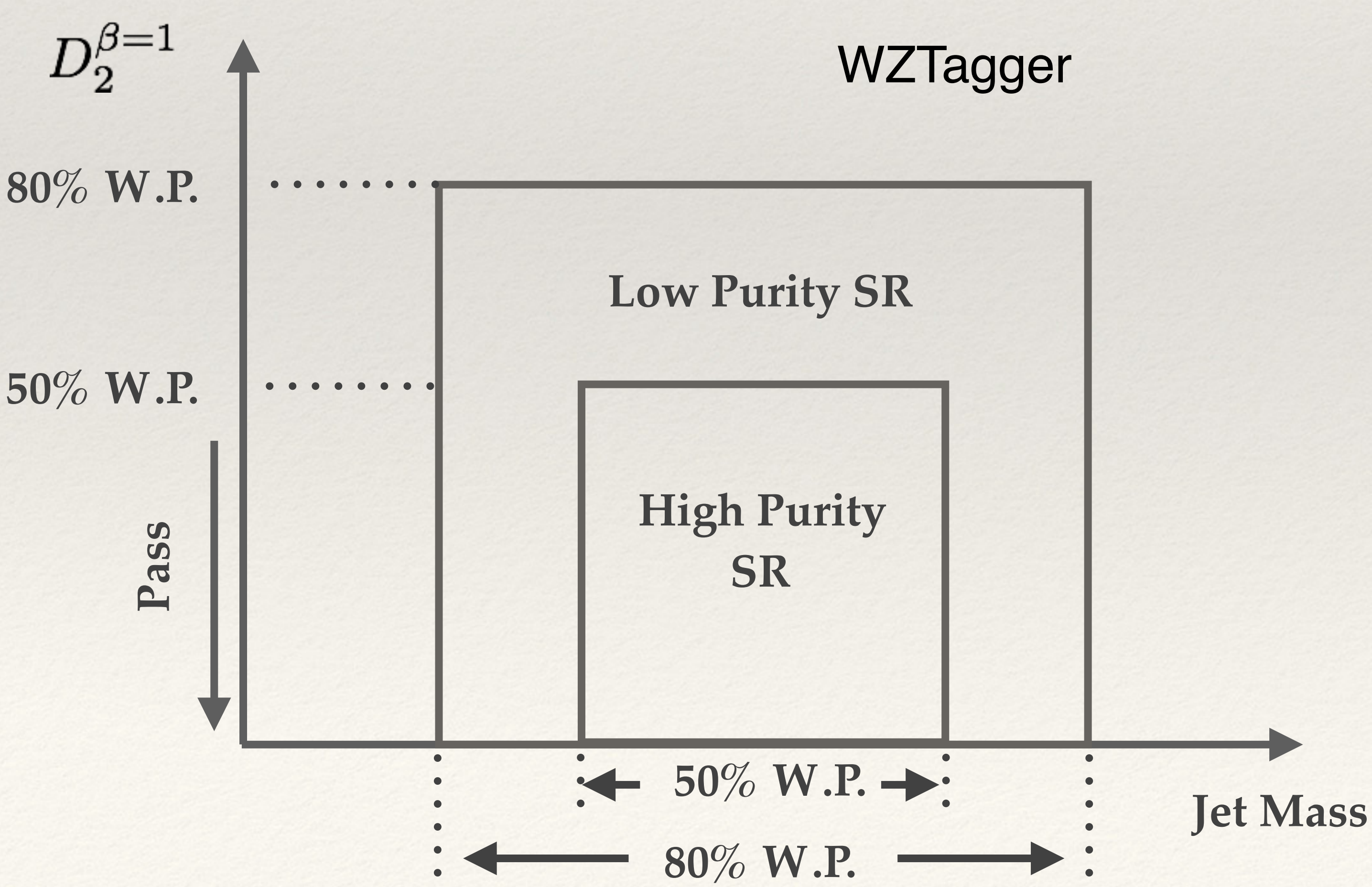
1 Large-R jet

Boson-tagging:

0 b-jet category* — WZTagger

1 b-jet category — WZTagger

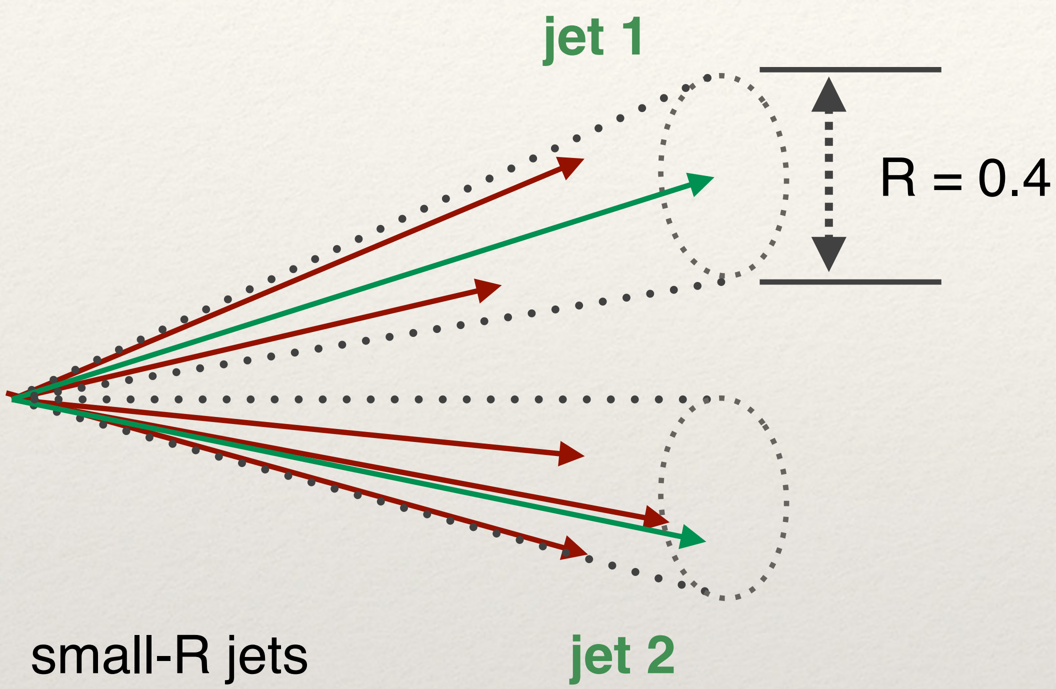
2 b-jet category: m_J: [75, 100] GeV



* b-jet categories

track jets b-tagging at 70% w.p.

Resolved Regime



Requirements:

MET >150 GeV

2-3 central small-R jets

no forward small-R jets

leading jet p_T > 45 GeV

$\Delta\phi$(jet, jet) > 140°

$p_{T,sum}$(jets) > 120/150 GeV (2/3 jets)

m(leading 2 jets):
[65, 105/100] GeV (01/2 bjets category)

* b-jet categories: small-R jets b-tagging at 70% w.p.

Control Regions

Major backgrounds: Z+jets, W+jets, ttbar

Replacing the lepton veto by requiring two lepton control regions, the rest event selections are the same as signal region

One lepton control region — constrain W+jets and ttbar backgrounds

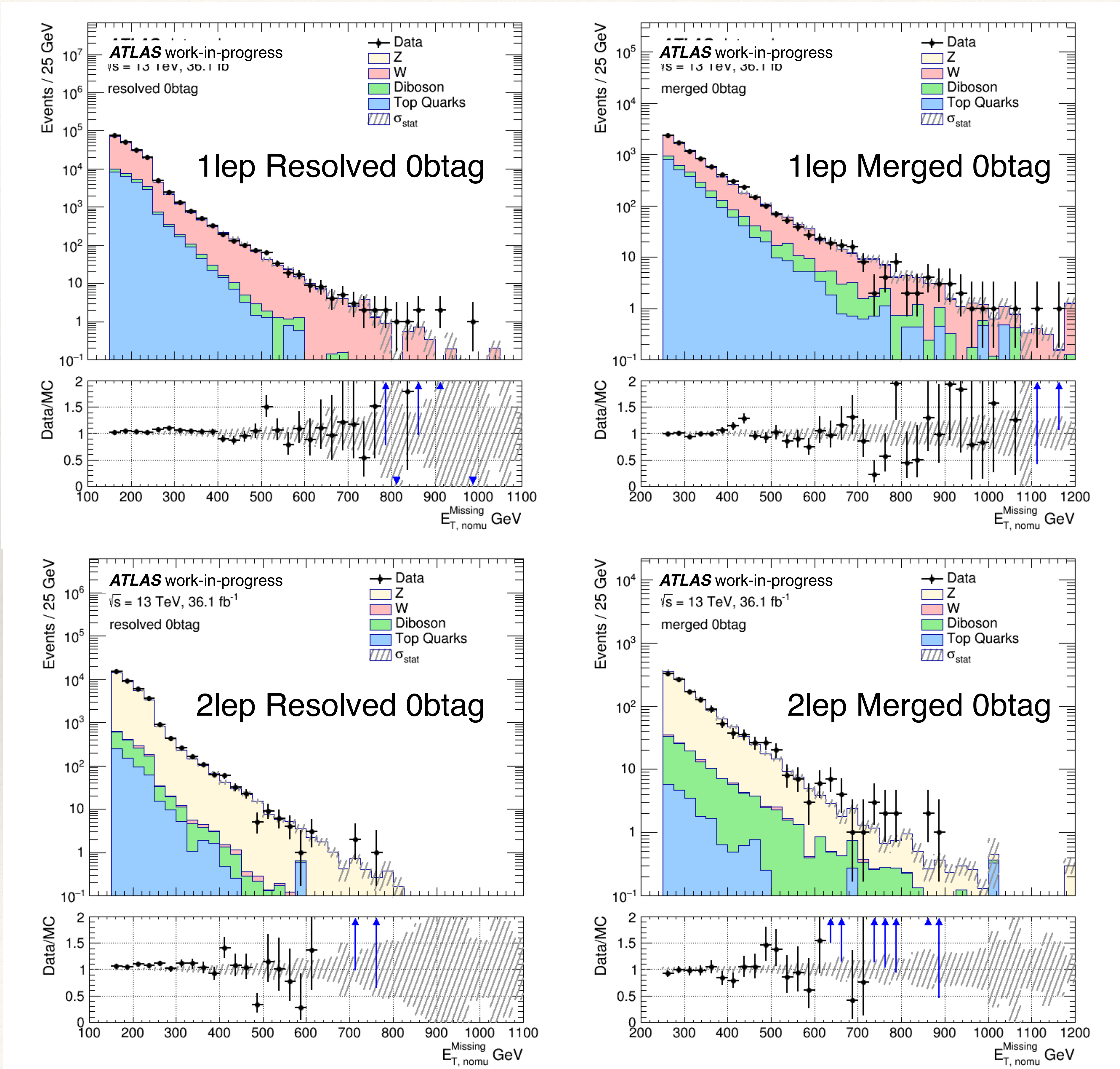
- required 1 tight muon

Two lepton control region — constrain Z+jets backgrounds

- required 2 same flavor leptons (>=1 medium lepton).
- dilepton mass: [66, 116]

*In control regions, METmod ($\overrightarrow{MET} + \overrightarrow{p_{T,lep}}$) is defined to mimic the SR MET for event selections

METmod Distributions in Control Regions

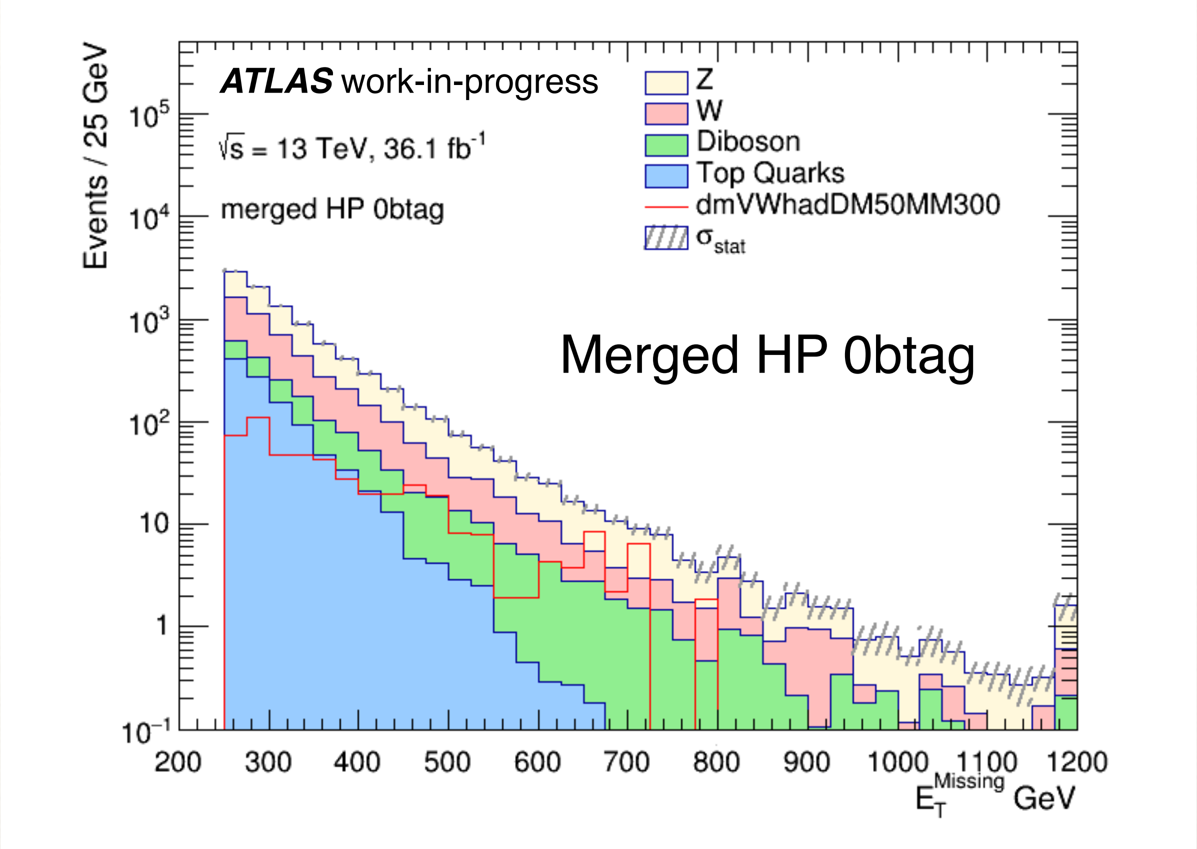


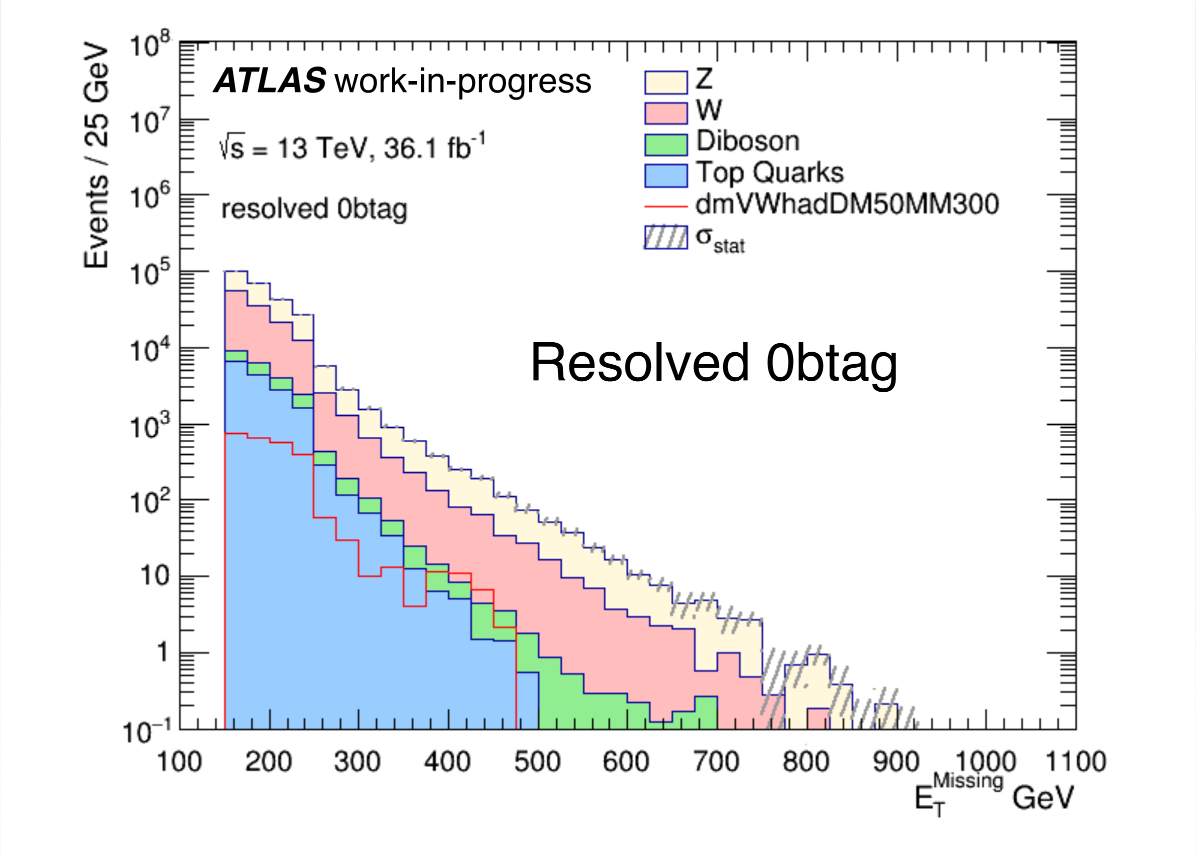
Distributions in 0 b-tag categories are shown as examples

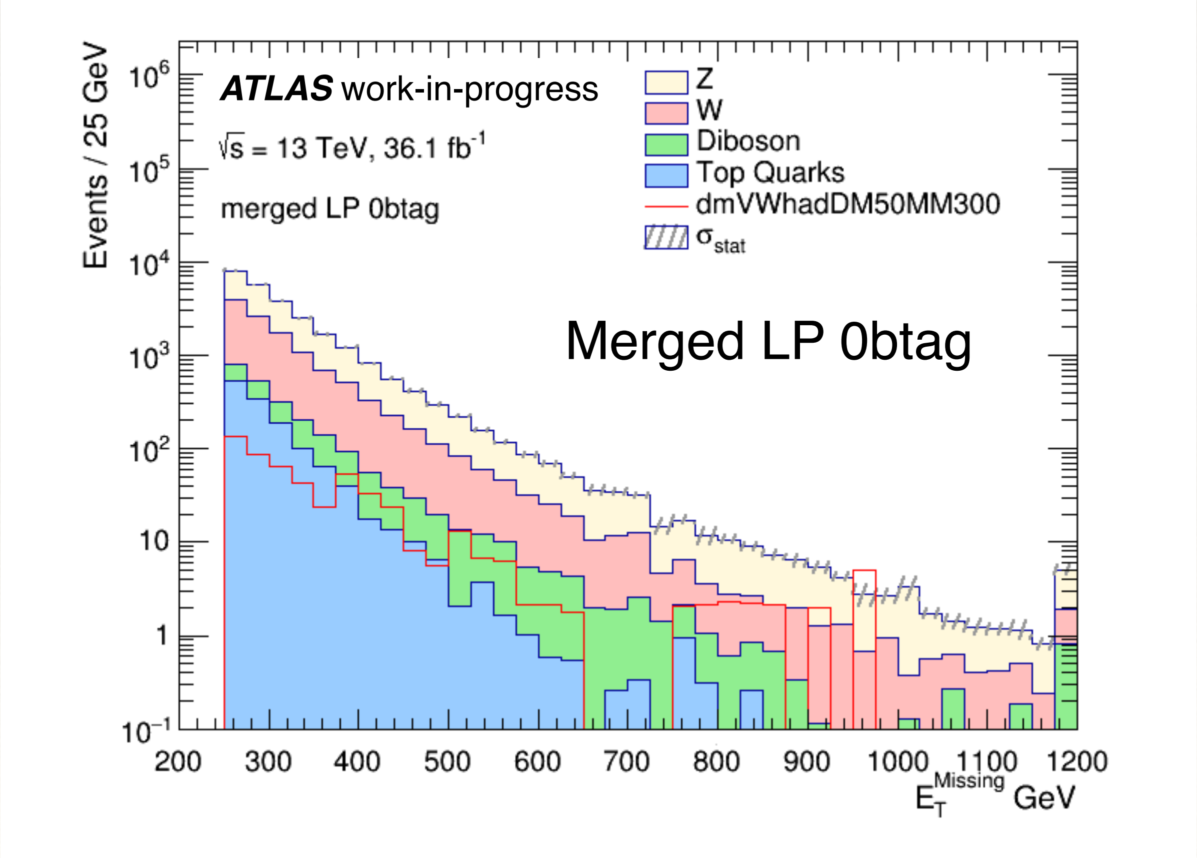
The Data are consistent with the expected background in control regions

MET Distributions in Signal Regions

Signal:
W boson hadronic decay,
mediator mass = 300 GeV,
dark matter mass = 50 GeV

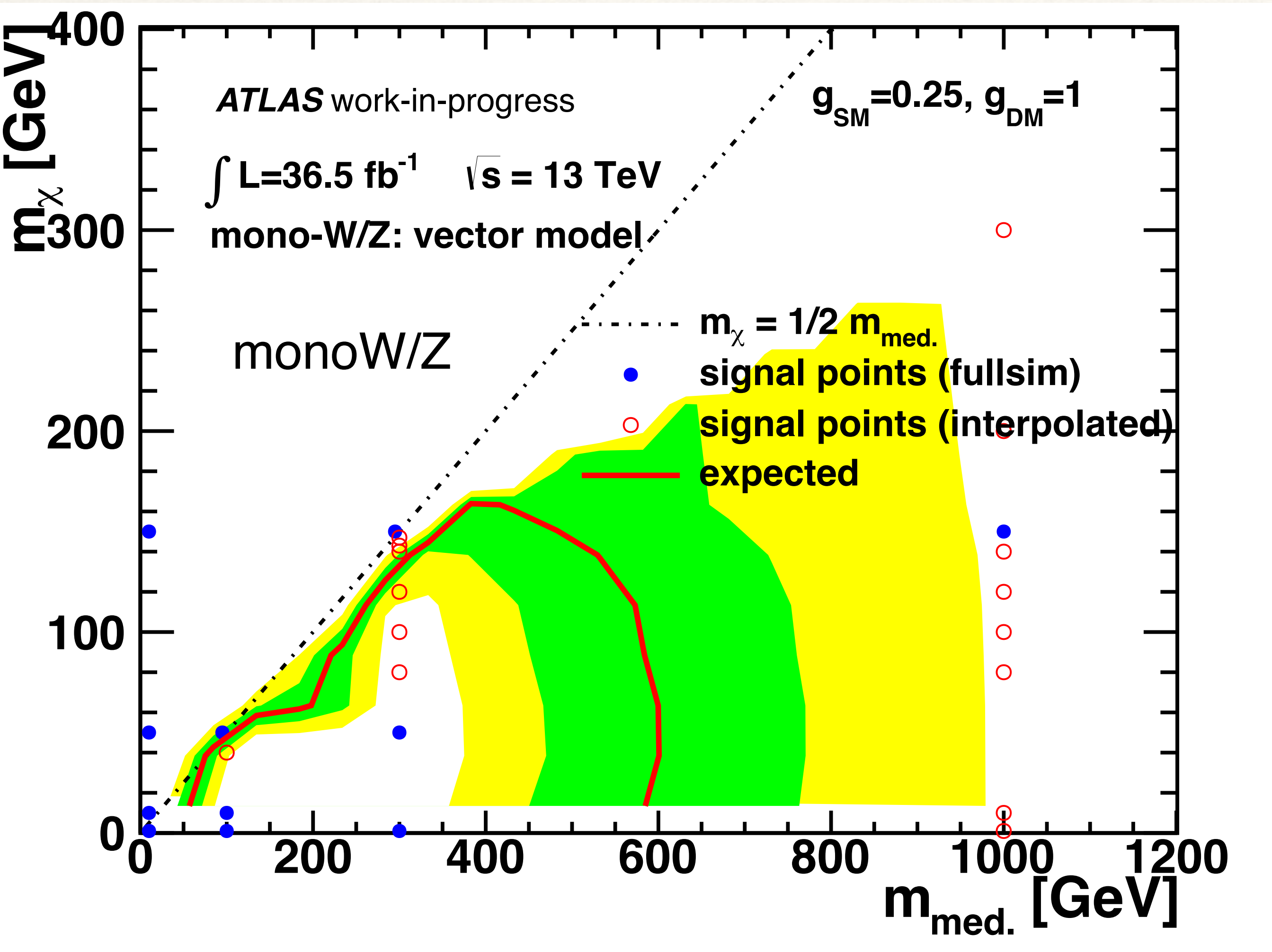


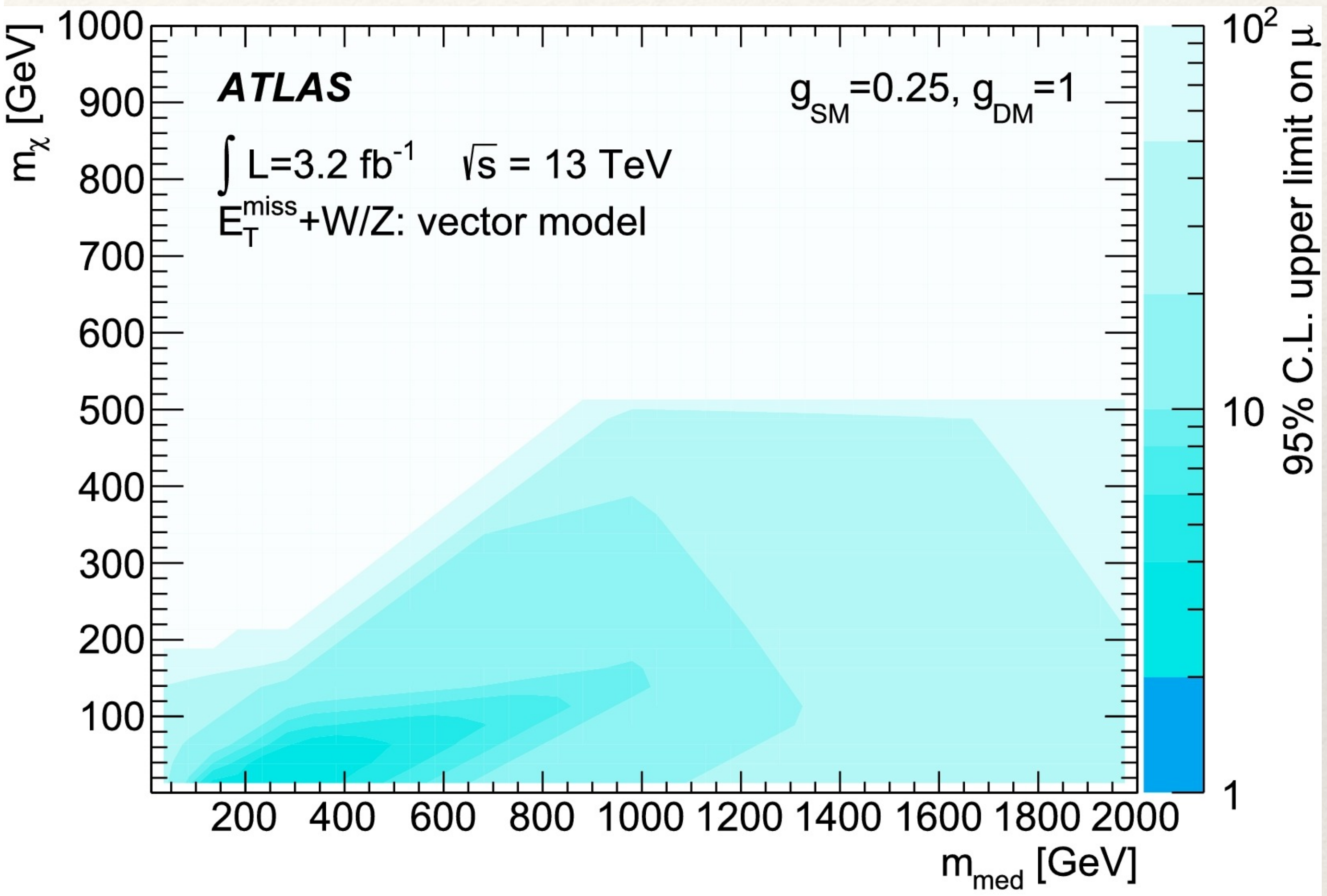




Limits – DM simplified model exclusions

All limits at 95% C.L.





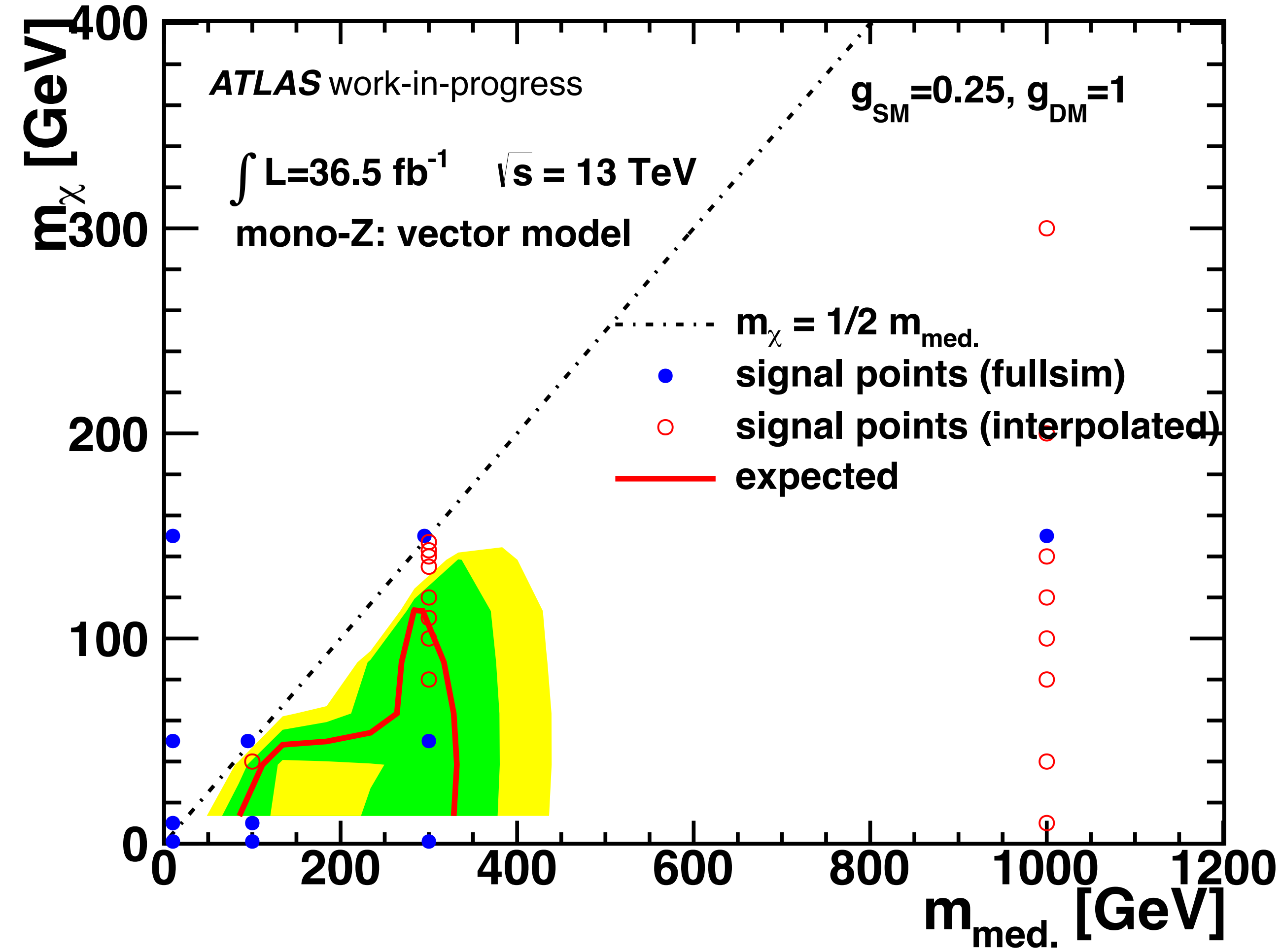
Limits with 2015 data

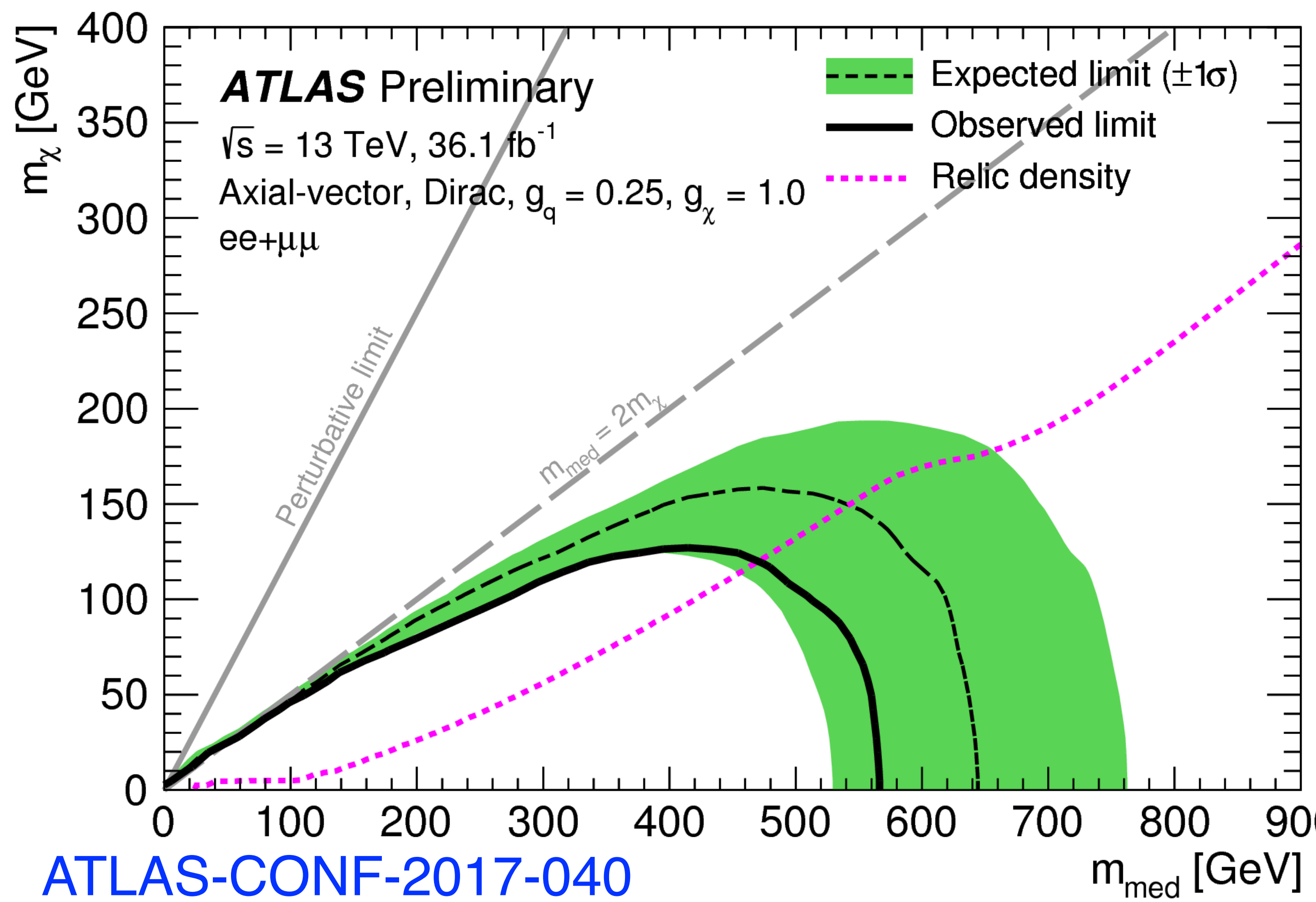
Limits with new data improves previous results.

Phys. Lett. B 763 (2016) 251

Limits – Comparison to the leptonic analysis

MonoZ channel, All limits at 95% C.L.





ATLAS-CONF-2017-040

the leptonic decay channel gives out better limits in the monoZ channel.

Summary

Search for DM with monoZ and monoW is performed with large missing energy and dijet final state at 13TeV with 36.1 fb^{-1} data;

Changes to the 2015 analysis:

- Inclusion of a resolved regime
- Using b-tagging in SR and all CRs to improve the sesititity
- New selections and optimizing
- Using new W/Z tagger and combined mass for large-R jets

The limits with simplified vector mediator model exclusions are shown at 95% C.L, which improves previous results.

Back Up

Objects Used in Analyses

Loose Muon
$p_T > 7$ GeV
$|\eta| < 2.7$
Loose quality
$|z_0 * \sin\theta| < 0.5$
$|d_0$ significance$| < 3$
isolation: LooseTrackOnly

Medium Muon
LooseMuon
$P_T > 25$ GeV
$|\eta| < 2.5$

Tight Muon
Medium Muon
Tight Isolation

Loose Electron
$p_T > 7$ GeV
$|\eta| < 2.47$
LooseLH
$|z_0 * \sin\theta| < 0.5$
$|d_0$ significance$| < 5$
isolation: LooseTrackOnly
Quality: isGoodOQ

MET/trk-MET
MET: MET_TST
trk-MET: negative vectorial sum of pT in of
(trk-)METmod:
$\overrightarrow{\text{(trk-)MET}} + \vec{p}(T, \text{lep})$

Large-R Jet
AntiKt10LCTopoTrimmedPtFrac5SmallR20Jets
$|\eta| < 2.0$
$p_T > 200$ GeV

Small-R Jet
AntiKt4EMTopoJets
central jets: $|\eta| < 2.5$, $p_T > 30$ GeV
forward jets: $2.5 < |\eta| < 4.5$: $p_T > 30$ GeV
if $p_T < 60$GeV and $|\eta| < 2.4$: JVT > 0.59
b-Tagging: 70% W.P.

Track jets
AntiKt2PV0TrackJets
$|\eta| < 2.5$
$p_T > 10$ GeV
b-Tagging: 70% W.P.

Signal Models

Simplified models and effective field theories (EFT)

Simplified models have a particle mediating the interaction between Standard Model (SM) particles and Dark Matter (DM)

EFTs integrate out the mediator removing degrees of freedom and leading to a generic model.

E.g. the cross-section of the s-channel exchange of vector mediator

$$\sigma \propto \frac{g_\chi^2 g_q^2}{(Q^2 - M^2)^2 + M^2\Gamma^2} \approx \frac{g_\chi^2 g_q^2}{M^4} = \frac{1}{M_\star^4},$$

g_x: coupling of the DM to the mediator

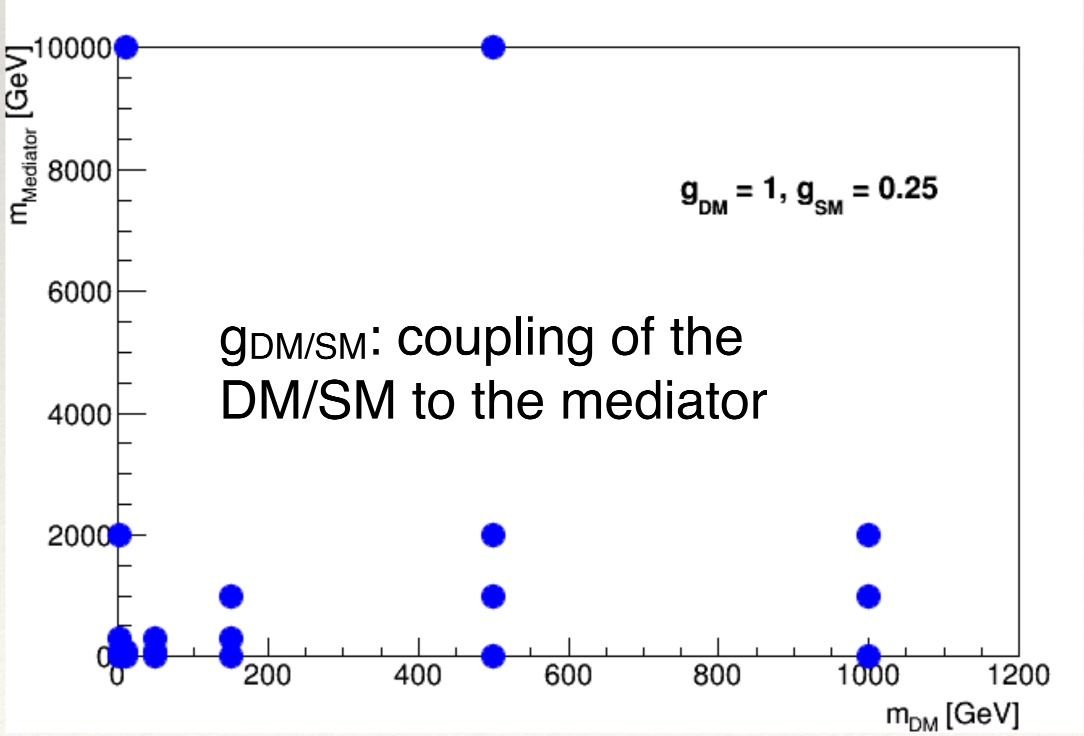
g_q: coupling of the SM to the mediator

Q: momentum transfer

M: Mass of the mediator

Γ: width of the mediator

Grid of generated signal mass point for simplified model



Combined Mass

The combined mass is defined as the simple linear combination of the calorimeter jet mass and the track assisted mass definitions. It is expected to have better mass resolution and a reduction of the systematic uncertainties.

The calorimeter jet mass is defined using the collection of topo-clusters in the calorimeter and corrects with an MC-based calibration the reconstructed jet-mass to the particle level. It is defined as

$$m^{\text{calo}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \boldsymbol{p}_i\right)^2}.$$

The track assisted (TA) mass is defined as the mass of the tracks reconstructed by the inner detector and weighted by the ratio of the transverse momenta measured by the calorimeter and the inner detector. It is defined as

$$m^{\text{TA}} = m^{\text{track}} \cdot \frac{p_{\text{T}}^{\text{calo}}}{p_{\text{T}}^{\text{track}}}.$$

FatJet Substructure – C_2 & D_2

N-Points Energy Correlation Functions (ECF)

$$ECF(N,\beta) = \sum_{i_1<i_2<\ldots<i_N\in J} \left(\prod_{a=1}^{N} p_{T_{i_a}}\right)\left(\prod_{b=1}^{N-1}\prod_{c=b+1}^{N} R_{i_b i_c}\right)^{\beta}$$

where $R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$

Loop over all particles in the system J.

If a jet has fewer than N constituents then ECF(N,β) = 0

$$\mathrm{ECF}(0,\beta) = 1,$$

$$\mathrm{ECF}(1,\beta) = \sum_{i\in J} p_{T\,i},$$

$$\mathrm{ECF}(2,\beta) = \sum_{i<j\in J} p_{T\,i}\, p_{T\,j} (R_{ij})^{\beta},$$

$$\mathrm{ECF}(3,\beta) = \sum_{i<j<k\in J} p_{T\,i}\, p_{T\,j}\, p_{T\,k} (R_{ij} R_{ik} R_{jk})^{\beta},$$

$$\mathrm{ECF}(4,\beta) = \sum_{i<j<k<\ell\in J} p_{T\,i}\, p_{T\,j}\, p_{T\,k}\, p_{T\,\ell} (R_{ij} R_{ik} R_{i\ell} R_{jk} R_{j\ell} R_{k\ell})^{\beta}.$$

FatJet Substructure – C_2 & D_2

Dimesionless variables

$$e_n^{(\beta)} = \frac{ECF(n,\beta)}{(ECF(1,\beta))^n}$$

$$C_2^{(\beta)} = \frac{e_3^{(\beta)}}{(e_2^{(\beta)})^2} = \frac{ECF(3,\beta) \times ECF(1,\beta)}{ECF^2(2,\beta)}$$

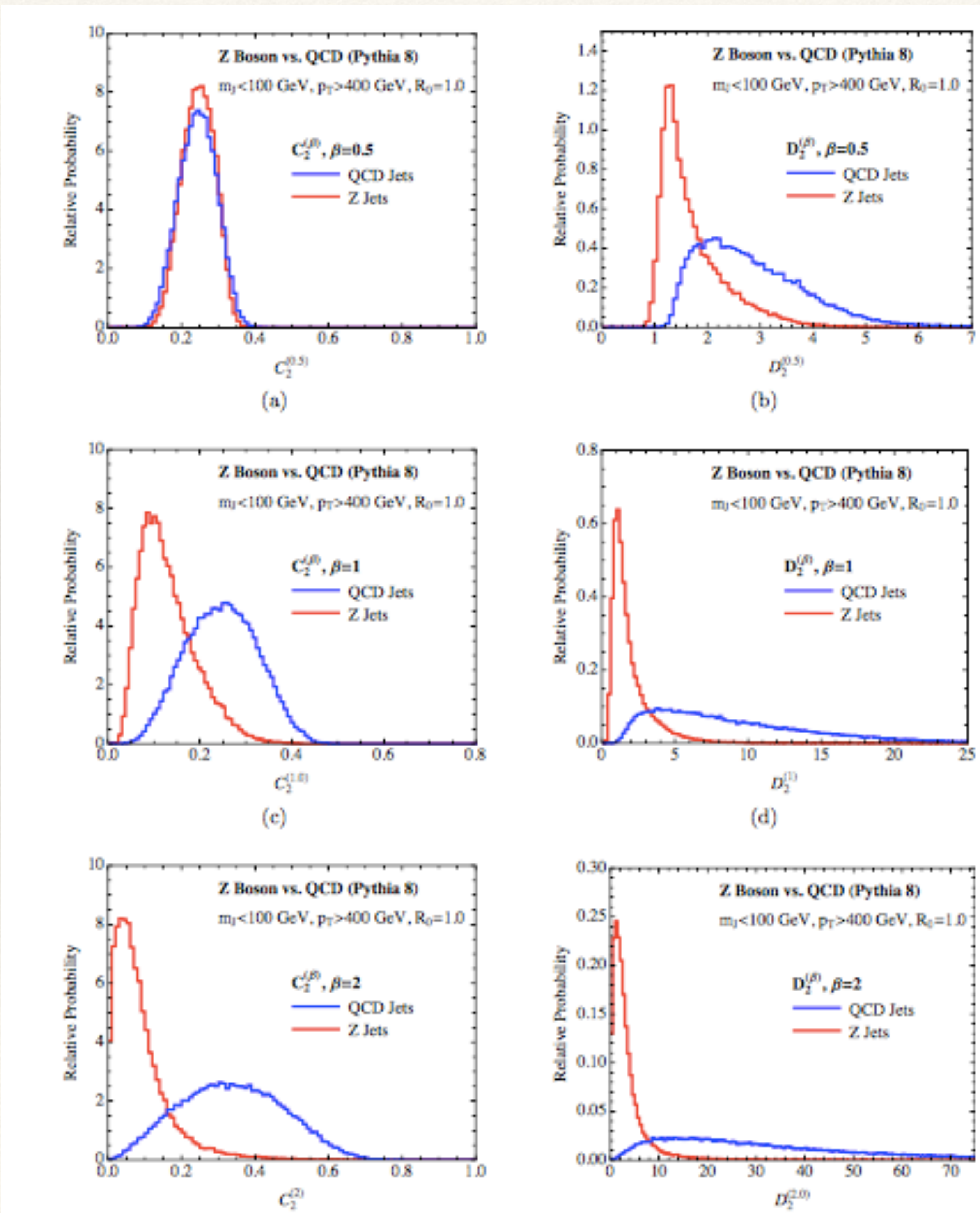
A study of e_2 and e_3

1-prong jet (QCD jets) $(e_2)^3 \lesssim e_3 \lesssim (e_2)^2$

2-prong jet (boosted Z) $0 < e_3 \ll (e_2)^3$

⇨ **boundary $e_3 \sim (e_2)^3$** ⇨ $D_2^{\beta} = \dfrac{e_3^{\beta}}{(e_2^{\beta})^3}$

FatJet Substructure – C_2 & D_2



C2 and D2

with different index (beta)