Search for hadronic Mono-V + $E_{\mathrm{T}}^{\mathrm{miss}}$

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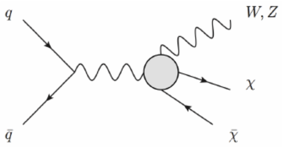
Content

Mono-V analysis overview

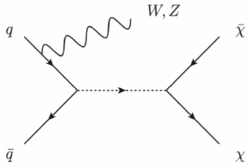
Search for dark matter with hadronically decaying Z/W boson in the channels

- large-R jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ (merged)
- pair of small$R$-jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ (resolved)

using $13.2\,\mathrm{fb}^{-1}$ of 2015 + 2016 data, interpreted in terms of



Effective Field Theory



Simplified Models

Mono-V analysis overview

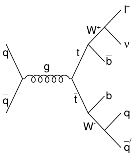
Signal signature and dominant backgrounds

Signal signature (0lep)

- large-R jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ (merged)
- pair of small$R$-jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ (resolved)

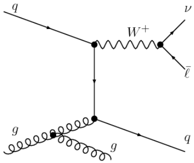
Dominant backgrounds

$t\bar{t}$ (1lep)



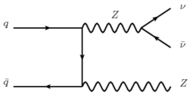
ℓ not detected

$W +$ jets (1lep)



ℓ not detected

$Z \to \nu\bar{\nu}$ (2lep)



estimated with $Z \to \mu\bar{\mu}$

Event selection

Merged region

0 leptons	1 lepton	2 leptons
HLTxe70, HLTxe90	lepton triggers	lepton triggers
0 loose e + μ	1 tight μ	1 loose μ, 1 medium μ

- MET > 250 GeV
- MPT > 30 GeV
- $n_{\text{large-}R\text{ jet}} > 0$
- $\min \Delta\phi(j, E_{\mathrm{T}}^{\mathrm{miss}}) > 20^{\circ}$
- $\Delta\phi(\mathrm{MET}, \mathrm{MPT}) < 90^{\circ}$
- $\Delta\phi(\text{large-}R\text{ jet}, \mathrm{MET}) > 120^{\circ}$

use b-tagging (0tag, 1tag, 2tag)
discriminate between $W+$jets (0tag)
and $t\bar{t}$ (1tag)

$$\mathrm{MET} := E_{\mathrm{T}}^{\mathrm{miss}} + \sum p_{\mathrm{T}}^{\mu}$$
$$\mathrm{MPT} := p_{\mathrm{T}}^{\mathrm{miss}} + \sum p_{\mathrm{T}}^{\mu}$$

Event selection

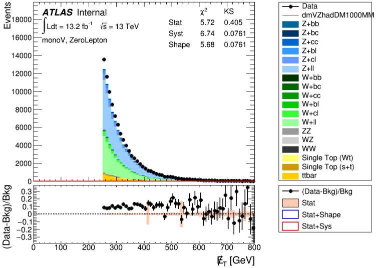
Resolved region

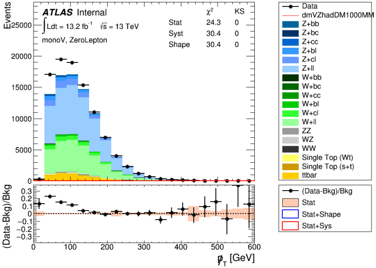
0 leptons	1 lepton	2 leptons
HLTxe70, HLTxe90	lepton triggers	lepton triggers
0 loose e + μ	1 tight μ	1 loose μ, 1 medium μ

- MET > 150 GeV
- $p_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV
- $n_{\text{central jet}} = 2$ or 3
- $n_{\text{forward jet}} = 0$
- $p_{\text{leading jet}} > 45$ GeV
- $p_{\mathrm{T}}^{j1} + p_{\mathrm{T}}^{j2} > 120$ GeV or $p_{\mathrm{T}}^{j1} + p_{\mathrm{T}}^{j2} + p_{\mathrm{T}}^{j3} > 150$ GeV
- $\min \Delta\phi(j, E_{\mathrm{T}}^{\mathrm{miss}}) > 20^\circ$
- $\Delta\phi(\mathrm{MET}, \mathrm{MPT}) < 90^\circ$
- $\Delta\phi(\mathrm{dijet}, \mathrm{MET}) > 120^\circ$
- $\Delta\phi(\mathrm{jet}_1, \mathrm{jet}_2) > 140^\circ$

Pre-fit distributions

0 lep, merged region, 0+ b-tags

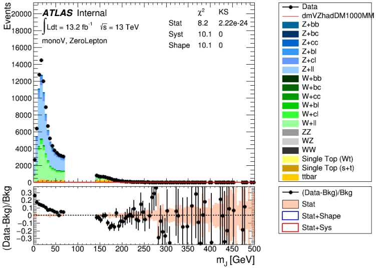


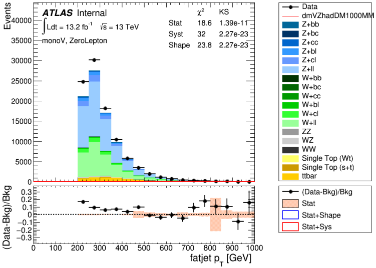


- Poor modeling of low $p_{\mathrm{T}}^{\mathrm{miss}}$ values
- Overall reasonable data/MC agreement

Pre-fit distributions

0 lep, merged region, 0+ b-tags



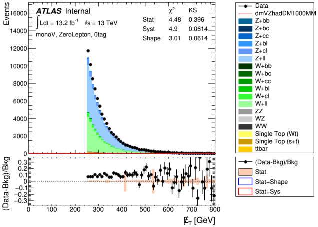


- Blinding harmonised between mono-H and mono-V search

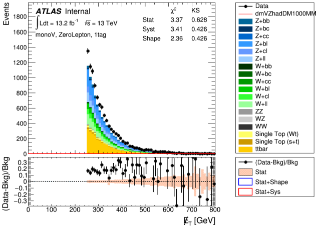
Pre-fit distributions

0 lep, merged region, split in b-tag regions

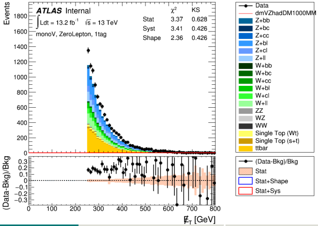
0 b-tags



1 b-tag



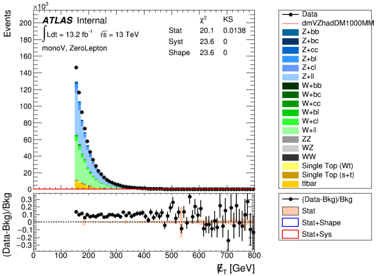
2+ b-tags

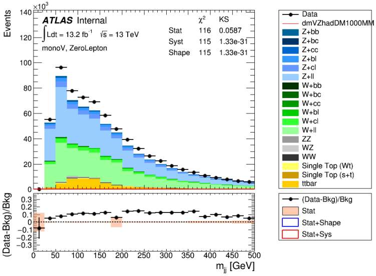


- B-tagging now included in mono-V search
- good discrimination of $t\bar{t}$

Pre-fit distributions

0 lep, resolved region, 0+ b-tags



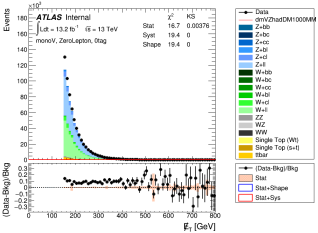


- Moderate data/MC agreement, multi-jet contribution not included yet

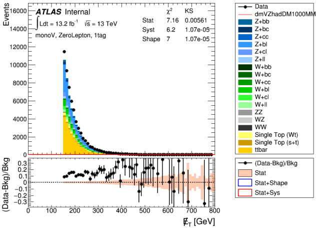
Pre-fit distributions

0 lep, resolved region, split in b-tag regions

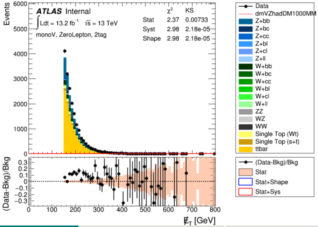
0 b-tags



1 b-tag



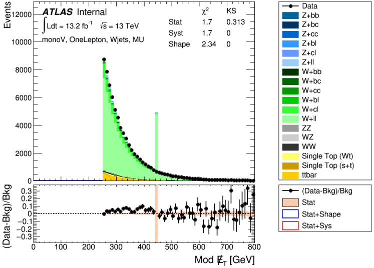
2+ b-tags

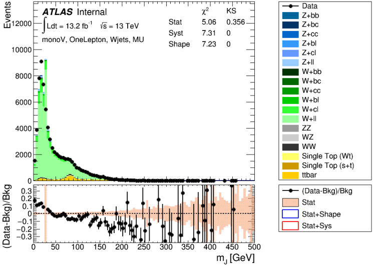


- B-tagging now included in mono-V search
- good discrimination of $t\bar{t}$

Pre-fit distributions

1 lep, merged region: W+jets (0 b-tags)

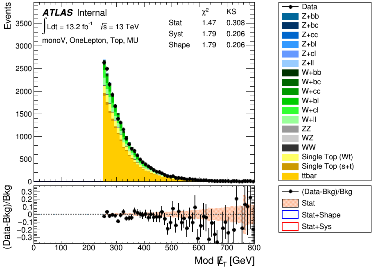


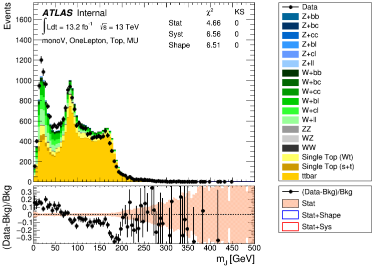


- moderate data/MC agreement
- slope in large-R jet shape

Pre-fit distributions

1 lep, merged region: $t\bar{t}$ (1+ b-tags)

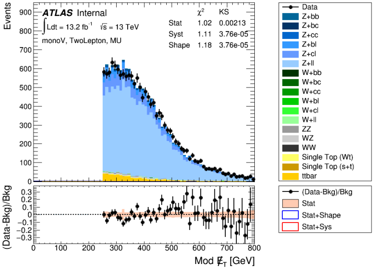


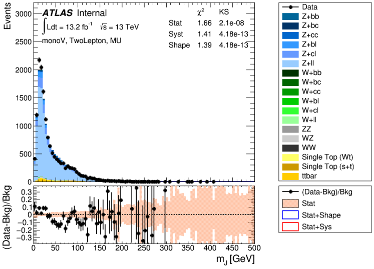


- reasonable data/MC agreement
- slope in large-R jet shape

Pre-fit distributions

2 lep, merged region: $Z \to \mu\bar{\mu}$, 0+ b-tags



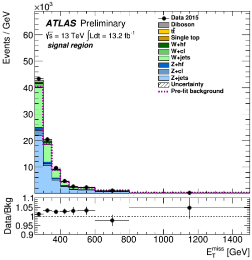


- resonable data/MC agreement
- high purity in Z+jets

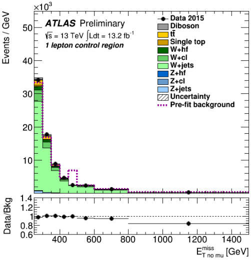
Post-fit distributions

merged region, 0 b-tags

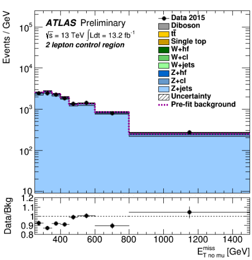
signal region (0lep)



CR W+jets (1lep)



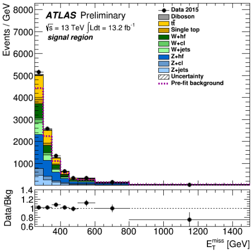
CR $Z \to \nu\nu$ (2lep)



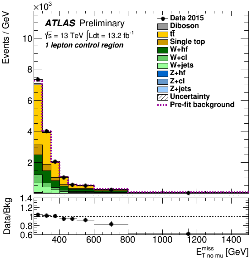
Post-fit distributions

merged region, 1 b-tag

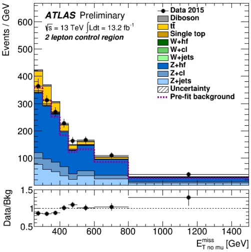
signal region (0lep)



CR $t\bar{t}$ (1lep)



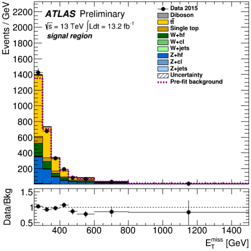
CR $Z \to \nu\nu$ (2lep)



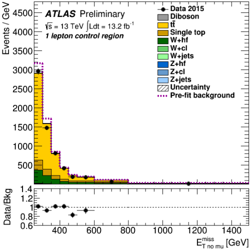
Post-fit distributions

merged region, 2 b-tags

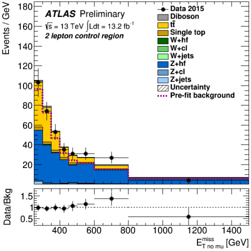
signal region (0lep)



CR $t\bar{t}$ (1lep)



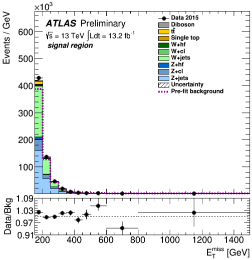
CR $Z \rightarrow \nu\nu$ (2lep)



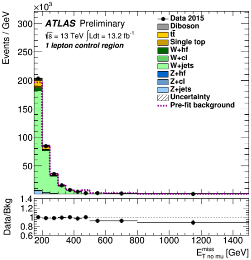
Post-fit distributions

resolved region, 0 b-tags

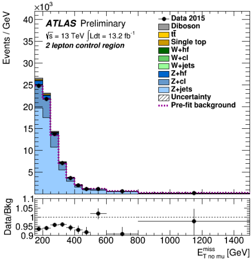
signal region (0lep)



CR W+jets (1lep)



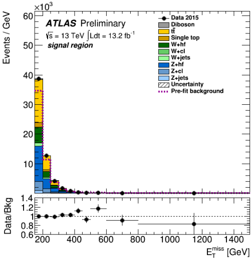
CR $Z \rightarrow \nu\nu$ (2lep)



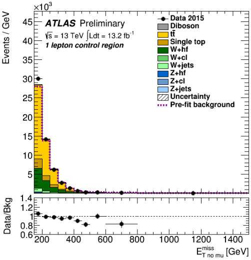
Post-fit distributions

resolved region, 1 b-tag

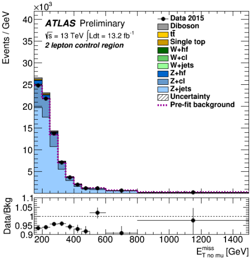
signal region (0lep)



CR $t\bar{t}$ (1lep)



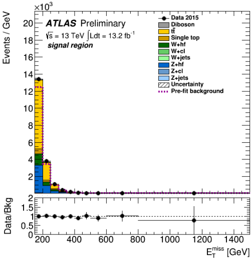
CR $Z \to \nu\nu$ (2lep)



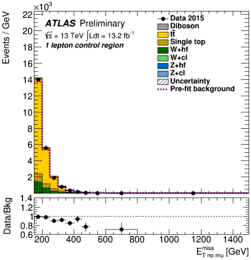
Post-fit distributions

resolved region, 2 b-tags

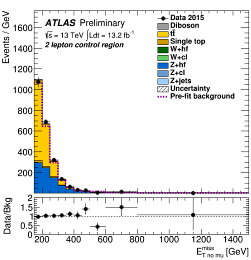
signal region (0lep)



CR $t\bar{t}$ (1lep)



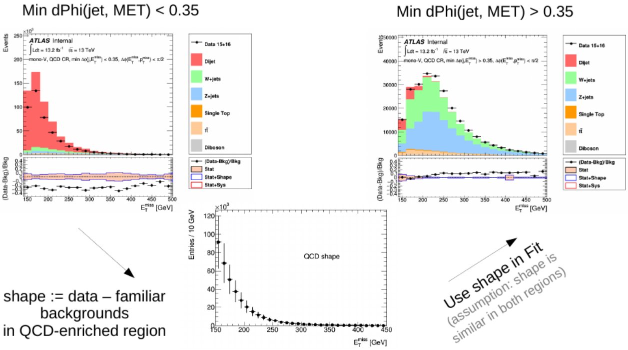
CR $Z \to \nu\nu$ (2lep)



Multi-jet background estimation in 0lep, merged

in 0lep, merged, still very preliminary

- define QCD-enriched region by lowering requirement on MET > 150 GeV
- divide events in QCD and signal-like region by inversion of min $\Delta\phi(j, \text{MET}) > 20^\circ$ requirement

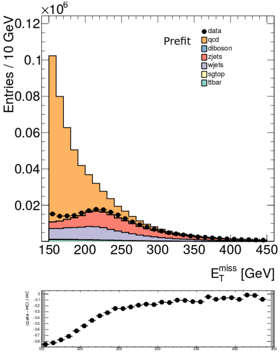


Multi-jet background estimation

in 0lep, merged, still very preliminary

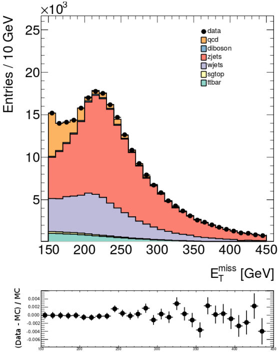
[t]

Pre-fit



$\rightarrow$

Post-fit



- profile-likelihood fit for QCD shape normalisation: 0.058 ± 0.014

pulls	α_{VV}	α_t	$\alpha_{t\bar{t}}$	$\alpha_{\text{W+jets}}$	$\alpha_{\text{Z+jets}}$
σ	-0.037 ± 0.994	-0.028 ± 0.994	-0.093 ± 0.993	-1.880 ± 0.406	1.718 ± 0.253

Multi-jet estimation

Aim for closure tests

- Take a QCD template of another variable, e.g. $m_{\text{large-}R\text{ jet}}$ in the QCD region
- Apply the QCD normalisation factor derived from the QCD template fit in MET distribution
- Use the resulting QCD distribution in the signal-like region and check if the model describes the data

Multi-jet estimation

Questions to JDM

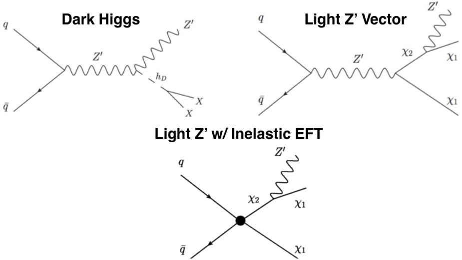
- Overall opinion on this approach?
- For MET $> 250\,\text{GeV}$ the QCD event fraction appears to be small. What is small enough to be allowed to neglect it?
- If we don't neglect it, how should we derive QCD templates used in the final fit?
  - Note: the current study is based on blinded data.
  - Should we estimate the QCD contribution as presented here and rescale it to the expected normalisation given the unblinded data?
  - How should we estimate the uncertainy of the QCD template? Use the uncertainty of the QCD template fit? What about double counting of uncertainties then?

mono-Z' status

same set-up (trigger, object definitions, SR, CRs) as in mono-V

interpretation in terms of

- Dark Higgs model
- light Z' vector simplified model
- light Z'/Inelastic EFT models

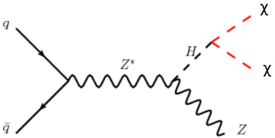


Signal samples are in production(see JDM talk)

- Event generation details
- JIRA ticket
- PANDA production page

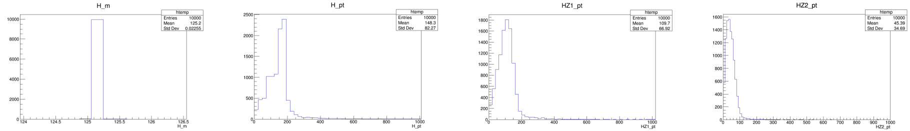
$H \to$ invisible status

same set-up (trigger, object definitions, SR, CRs) as in mono-V

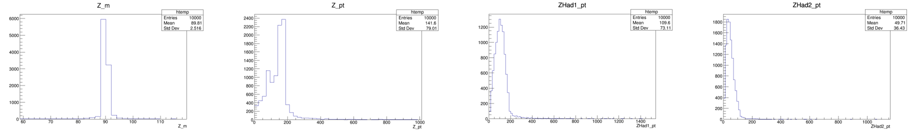


Signal production in progress, first validation plots created

$\rightarrow$ for H truth particle



$\rightarrow$ for Z truth particle



Conclusion and next steps

mono-V

- added b-tagging to analysis for improved sensitivity
- mono-V QCD estimate strategy on good way, mono-H might benefit
- working on fit and sensitivity estimate with $13\,\mathrm{fb}^{-1}$

mono-Z'

- signals are being produced

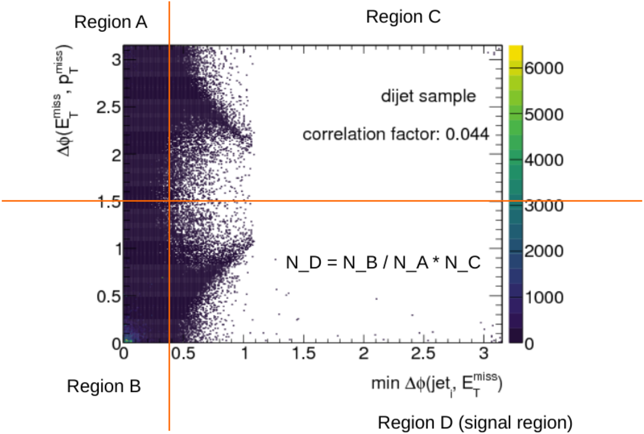
$H \rightarrow$ invisible

- working on signal production

Additional material

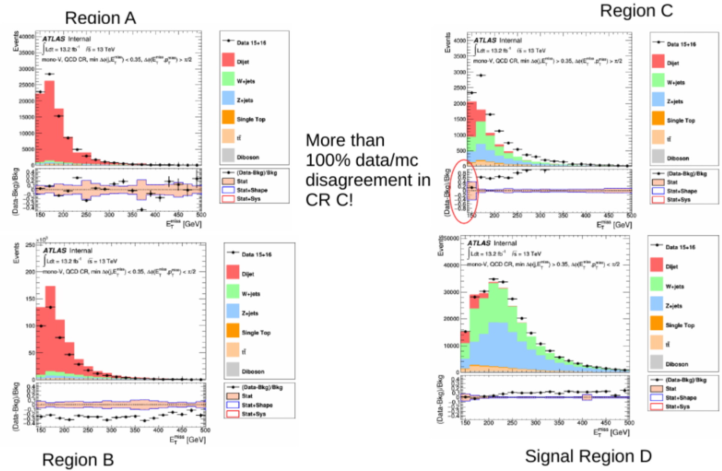
Multi-jet estimation

Why not the ABCD method?



Multi-jet estimation

Why not the ABCD method?



More than 100% data/mc disagreement in CR C!

- ABCD method unreliable for poor data/mc agreement