BSM Interpretation of MET+jet ratio cross section measurement

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Exotics Jet plus Dark Matter Meeting

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Introduction

- This analysis is measuring the production cross section ratio: $\frac{\sigma(\mathrm{MET+j(j)})}{\sigma(\mathrm{Z}\rightarrow l^{+}l^{-}+\mathrm{j(j)})}$ as a function of various kinematic variables.
  - Effectively a measurement of: $\frac{\sigma(\mathrm{Z}\rightarrow\nu\bar{\nu}+\mathrm{j(j)})+\sigma(\chi\bar{\chi}+\mathrm{j(j)})}{\sigma(\mathrm{Z}\rightarrow l^{+}l^{-}+\mathrm{j(j)})}$
  - Many theoretical and experimental uncertainties will cancel in the ratio.

- The final state of MET+j(j) studied in two different phase spaces:
  - $\geqslant 1$ jet : Similar to a standard monojet analysis selection.
  - VBF : MET+jj selection with high dijet invariant mass and central jet veto.

- Differences to existing MET+j(j) analyses (In addition to the ratio):
  - This result will be corrected for detector effects and so can be easily compared to any future models.
  - Corrected distributions of various variables in various phase spaces will be published, with correlation information.

Fiducial cuts

Cuts on both (MET+j(j)) and (Z$\rightarrow l^+ l^-$+j(j)):

Phase Space	Jet 1 p_T	Jet 2 p_T	$\mid \eta \mid$	mjj	$\Delta\Phi$(dilepton,jet)	$\not{E}_T$ / Dilepton p_T
VBF	$>$80GeV	$>$50GeV	$<$4.4	$>$200	$>$0.4	$>$200GeV
$\geqslant$ 1 jet	$>$120GeV	n/a	$<$2.4	n/a	$>$0.4	$>$200GeV

Cuts on denominator (Z$\rightarrow l^+ l^-$+j(j)) only:

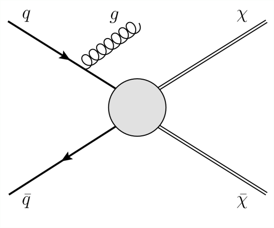
Lead lepton p_T	Sublead lepton p_T	$\mid \eta \mid$	M_{ll}	ΔR(jet, lepton)
$>$80GeV	$>$7GeV	$<$2.5	$>$66GeV + $<$116GeV	$<$0.2

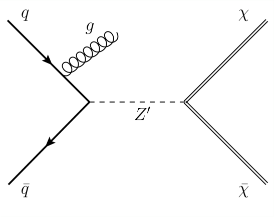
Reco level and particle level cuts are identical, but the dilepton p_T cut is a MET cut for all three channels (Z$\rightarrow \nu\nu$, Z$\rightarrow \mu\mu$, Z$\rightarrow$ ee) with leptons marked invisible.

Dark matter interactions and sensitivity

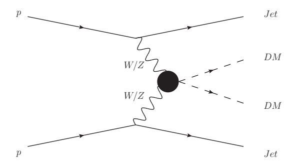
This measurement is sensitive to two DM interactions

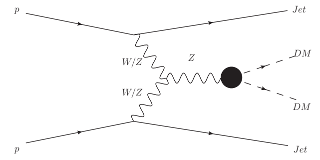
Quark/Gluon - DM interactions ($\geqslant$ 1 jet Topologies)

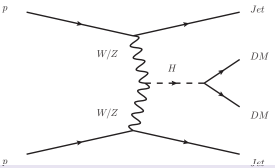




Electroweak Boson - DM interactions (VBF Topologies)







Planned Models

Monojet Models:

- Plan to run any existing monojet models through our analysis and limit setting code.
- Are there any suggestions any other Monojet MCs or simplified models that should be looked at?

VBF Models:

- Again, plan to run over any existing MC models through our analysis and limit setting code.
- Happy to run over simplified models for VBF, if they exist?
  - Currently only aware of EFT implementation [PRD 88 116009 (2013)].
  - Using this EFT model to validate our analysis and limit setting framework, but will be straight forward to replace with any other model.
- Any other thoughts/models?

Idea of this measurement

- EFT models mentioned in the previous slide are only providing a benchmark, and any model will be comparable to our published data using our rivet analysis code after publication.
- Difference from existing VBF and monojet searches:
  - Measure corrected differential ratio as a function of various observables (Mjj, jet1pt, deltaphijj,)
  - Publish alongside paper:
    - Cross section ratio in each bin
    - Statistical and systematic correlations between bins
    - Rivet routine for post-publication model analysis
- This analysis approach is not optimised for specific searches (like H$\rightarrow$invisible) so have tradeoff of reduced sensitivity to these specific models for improved sensitivity to other general production modes.
- Next slides show details of DM in the EFT models.

MadGraph simulation using VBF EFT models

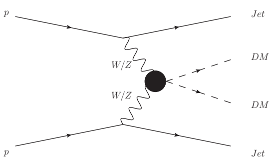
MadGraph implemenation discussed in [PRD 88 116009 (2013)]

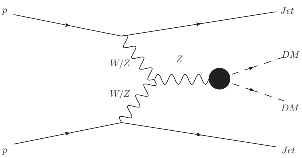
Name	Operator
D5a	$\mathcal{L} = \frac{1}{\Lambda}\bar{\chi}\chi\left[\frac{Z_\mu Z^\mu}{2} + W^+_\mu W^{-\mu}\right]$
D5b	$\mathcal{L} = \frac{1}{\Lambda}\bar{\chi}\gamma^5\chi\left[\frac{Z_\mu Z^\mu}{2} + W^+_\mu W^{-\mu}\right]$
D5c	$\mathcal{L} = \frac{g}{2\cos\theta_W \Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\left[\delta_\mu Z_\nu - \delta_\nu Z_\mu\right]$
D5d	$\mathcal{L} = \frac{g}{2\cos\theta_W \Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\epsilon^{\mu\nu\sigma\rho}\left[\delta_\rho Z_\sigma - \delta_\sigma Z_\rho\right]$
D6a	$\mathcal{L} = \frac{g}{2\cos\theta_W \Lambda^2}\bar{\chi}\gamma^\mu\delta^\nu\chi\left[\delta_\mu Z_\nu - \delta_\nu Z_\mu\right]$
D6b	$\mathcal{L} = \frac{g}{2\cos\theta_W \Lambda^2}\bar{\chi}\gamma_\mu\delta_\nu\chi\epsilon^{\mu\nu\sigma\rho}\left[\delta_\rho Z_\sigma - \delta_\sigma Z_\rho\right]$
D7a	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\chi W^{i,\mu\nu}W^i_{\mu\nu}$
D7b	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi W^{i,\mu\nu}W^i_{\mu\nu}$
D7c	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\chi\epsilon^{\mu\nu\sigma\rho}W^{i,\mu\nu}W^i_{\rho\sigma}$
D7d	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi\epsilon^{\mu\nu\sigma\rho}W^{i,\mu\nu}W^i_{\rho\sigma}$

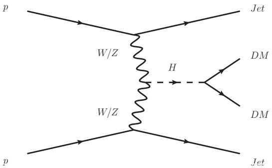
Original publication tested unitarity validity in VBF processes for mass-EFT scale probed in this analysis.

MadGraph simulation using EFT models

- Currently only generating exclusively two jets ($\chi\bar{\chi}jj$), but are in the process of interfacing these to a parton shower, so results very preliminary.
  - Also generating other minor contributing processes: ($\chi\bar{\chi}l\nu$, $\chi\bar{\chi}ll$, $\chi\bar{\chi}lljj$)







EFT scale constraints from SM measurements

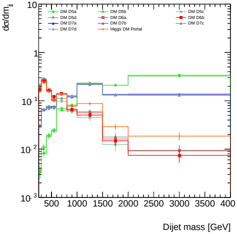
- The different dimensions that have the higher EFT scale constraints result in some dimensions with vastly reduced rates due to the Z invisible width.

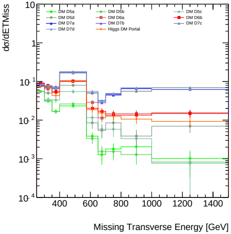
$$\Gamma(Z \to \chi\bar{\chi}) = \frac{2\alpha m_Z^3}{3\Lambda^2 \cos^2\theta_W \sin^2\theta_W}\left(1+\frac{8m_\chi^2}{m_Z^2}\right)\sqrt{1-\frac{4m_\chi^2}{m_Z^2}}$$

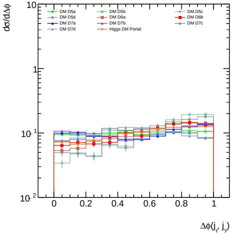
Name	Operator	Minimum EFT Scale (GeV)
D5a	$\mathcal{L} = \frac{1}{\Lambda}\bar{\chi}\chi\left[\frac{Z_\mu Z^\mu}{2} + W_\mu^+ W^{-\mu}\right]$	100
D5b	$\mathcal{L} = \frac{1}{\Lambda}\bar{\chi}\gamma^5\chi\left[\frac{Z_\mu Z^\mu}{2} + W_\mu^+ W^{-\mu}\right]$	100
D5c	$\mathcal{L} = \frac{g}{2\cos\theta_W\Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\left[\delta_\mu Z_\nu - \delta_\nu Z_\mu\right]$	3300
D5d	$\mathcal{L} = \frac{g}{2\cos\theta_W\Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\epsilon^{\mu\nu\sigma\rho}\left[\delta_\rho Z_\sigma - \delta_\sigma Z_\rho\right]$	6600
D6a	$\mathcal{L} = \frac{g}{2\cos\theta_W\Lambda^2}\bar{\chi}\gamma^\mu\delta^\nu\chi\left[\delta_\mu Z_\nu - \delta_\nu Z_\mu\right]$	230
D6b	$\mathcal{L} = \frac{g}{2\cos\theta_W\Lambda^2}\bar{\chi}\gamma_\mu\delta_\nu\chi\epsilon^{\mu\nu\sigma\rho}\left[\delta_\rho Z_\sigma - \delta_\sigma Z_\rho\right]$	330
D7a	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\chi W^{i,\mu\nu}W^i_{\mu\nu}$	100
D7b	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi W^{i,\mu\nu}W^i_{\mu\nu}$	100
D7c	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\chi\epsilon^{\mu\nu\sigma\rho}W^{i,\mu\nu}W^i_{\rho\sigma}$	100
D7d	$\mathcal{L} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi\epsilon^{\mu\nu\sigma\rho}W^{i,\mu\nu}W^i_{\rho\sigma}$	100

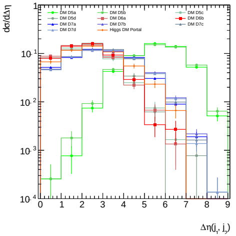
Model Kinematics: Distinguishing DM operators

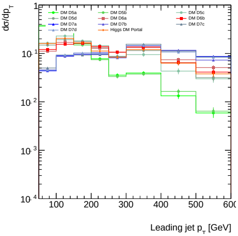
- Plots show unit normalised DM distributions for DM mass = 100GeV











Discrimination between models varies with observable studied: Motivation to measure multiple observables.

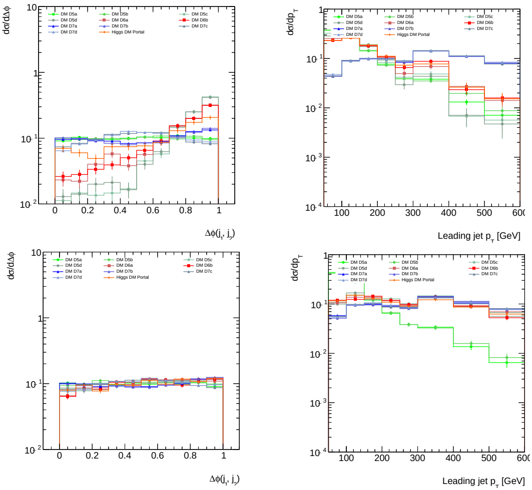
Model Kinematics: Distinguishing DM Mass

- Plots show unit normalised DM distributions for leading jet p_T and $\Delta\phi$

ΔΦ | Jet 1 pT

1GeV

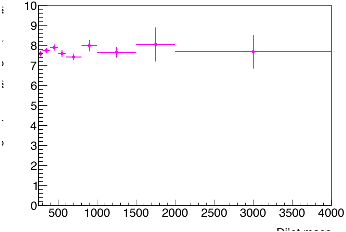
1TeV



- These observables are also sensitive to the mass of the dark matter.
- Can also exploit correlations between distributions for increased sensitivity.

From DM kinematics to Ratio

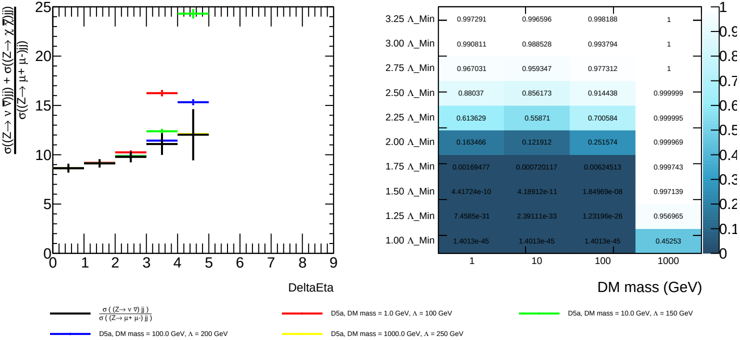
- Previous slides show DM production rate kinematics
- We measure the ratio $\frac{\sigma(\mathrm{Z}\rightarrow\nu\bar{\nu}+\mathrm{j(j)})}{\sigma(\mathrm{Z}\rightarrow l^{+}l^{-}+\mathrm{j(j)})}$ in data, so DM presence causes modification to shape and normalisation of this ratio
- SM expectation is flat value of approx. 6 $\rightarrow$, modified in measured data due to acceptance differences in numerator and denominator



- Next slides will show modification of this ratio with DM present

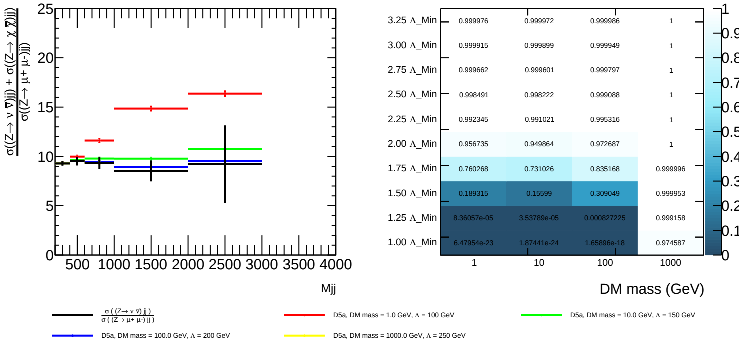
Example of ratio modification with DM

Effective Operator D5a : $\Delta\eta$: $\Lambda_{Min} = 100\text{GeV}$: 2% statistical uncertainty : P-value of chi2 stat. test.



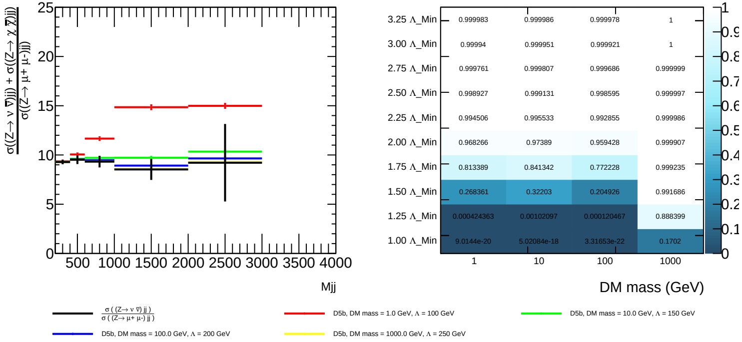
- Ratio plot shows $\frac{\sigma((Z\to\nu\nu)jj)+\sigma((Z\to DMDM)jj)}{\sigma((Z\to\mu^+\mu^-)jj)}_{(EWK+QCD)}$
- p-value from a χ^2-test comparing the DM model to the SM background ratio of $\frac{\sigma((Z\to\nu\nu)jj)}{\sigma((Z\to\mu^+\mu^-)jj)}$, for a range of DM masses and EFT scales.

Effective Operator D5a : Mjj : $\Lambda_{Min} = 100$GeV : 2% statistical uncertainty : P-value of chi2 stat. test.



Example of ratio modification with DM

Effective Operator D5b : Mjj : $\Lambda_{Min} = 100\text{GeV}$: 2% statistical uncertainty : P-value of chi2 stat. test.



- This is currently a work in progress as we are validating the implementation of the models. PS and CJV also not yet present.

Summary and To Do

- Differential measurement of $\frac{\sigma(\mathrm{MET+j(j)})}{\sigma(\mathrm{Z} \to l^+ l^- + \mathrm{j(j)})}$ sensitive to both quark/gluon and electroweak boson couplings to DM
- Set up framework to test presence of DM models against SM expectation in variety of fiducial regions and for various observables
- Currently running on VBF EFT model as a benchmark, plan to now extend to process existing Monojet/VBF DM signal MCs
  - Simplified models for VBF? Who to contact?
- Plan to publish Rivet routine with ratios and correlation information so new models can be easily compared to data also after publication
- Next steps:
  - Continue validation of models and analysis framework
  - Interface parton showering to Madgraph EFT implementation
  - Process existing Monojet/VBF MCs (and any other new models?)
  - Quantify sensitivity gains from correlations between differential ratios