First look at EFT DM model kinematics and rates with VBF/Monojet selections

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November 27, 2015

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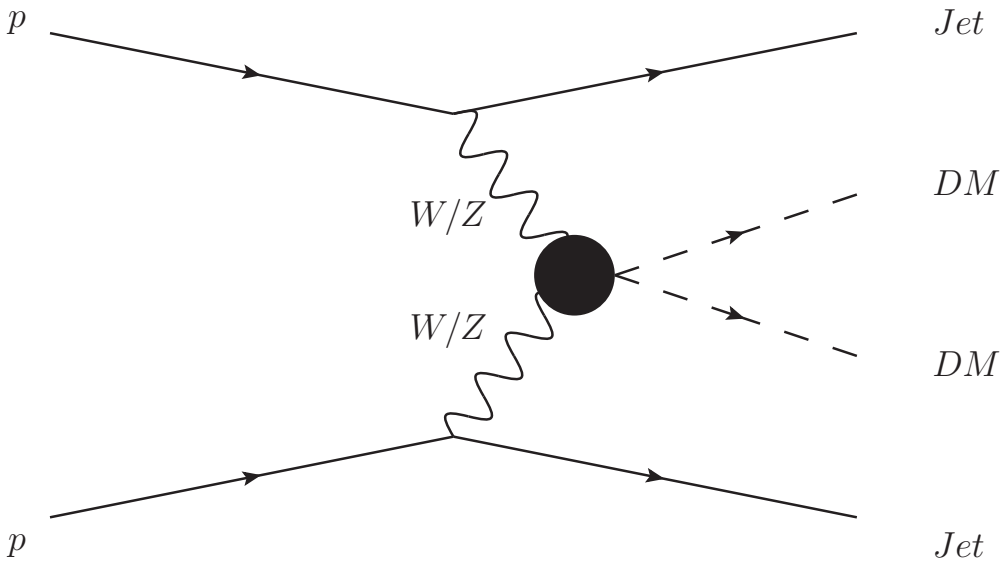
Effective field theory Model Introduction



- Dimension BSM Operator and Tensor Structure
- Dark Matter Mass
- Mass of Mediating Particle (EFT Scale)
  - Affects the production rate (σ scales with $\Lambda^{-2(D-4)}$)

Introduction to MadGraph Models

- Models were originally discussed in Phys. Rev. D88 116009 (2013)
- Had to start from scratch from the general lagrangian:

$$(\text{ Mathematica} \rightarrow \text{FeynRules }) \rightarrow \textbf{MadGraph}$$

generate p p $\rightarrow$ chi chi j j

- Pythia (Not using yet)
- Rivet Analysis:
  - Basic selection cuts
  - Kinematic distributions
  - Based on Atlas VBF Z/W + jets Analysis

Outline of Different Operators

$$\mathcal{L}_{\mathrm{D5a}} = \frac{1}{\Lambda}\bar{\chi}\chi\left[\frac{Z_\mu Z^\mu}{2} + W_\mu^+ W^{-\mu}\right]$$

$$\mathcal{L}_{\mathrm{D5b}} = \frac{1}{\Lambda}\bar{\chi}\gamma^5\chi\left[\frac{Z_\mu Z^\mu}{2} + W_\mu^+ W^{-\mu}\right]$$

$$\mathcal{L}_{\mathrm{D5c}} = \frac{g}{2\cos\theta_W \Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\left[\partial_\mu Z_\nu - \partial_\nu Z_\mu\right]$$

$$\mathcal{L}_{\mathrm{D6a}} = \frac{g}{2\cos\theta_W \Lambda^2}\bar{\chi}\gamma^\mu\partial^\nu chi\left[\partial_\mu Z_\nu - \partial_\nu Z_\mu\right]$$

$$\mathcal{L}_{\mathrm{D6b}} = \frac{g}{2\cos\theta_W \Lambda^2}\bar{\chi}\gamma_\mu\partial_\nu chi\epsilon^{\mu\nu\sigma\rho}\left[\partial_\sigma Z_\rho - \partial_\rho Z_\sigma\right]$$

$$\mathcal{L}_{\mathrm{D7a}} = \frac{1}{\Lambda^3}\bar{\chi}\chi W^{i,\mu\nu}W^i_{\mu\nu}$$

$$\mathcal{L}_{\mathrm{D7b}} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi W^{i,\mu\nu}W^i_{\mu\nu}$$

$$\mathcal{L}_{\mathrm{D7c}} = \frac{1}{\Lambda^3}\bar{\chi}\chi\epsilon^{\mu\nu\rho\sigma}W^i_{\mu\nu}W^i_{\rho\sigma}$$

$$\mathcal{L}_{\mathrm{D7c}} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi\epsilon^{\mu\nu\rho\sigma}W^i_{\mu\nu}W^i_{\rho\sigma}$$

- DM Mass and Lagrangian term influences the rates and kinematics.
- Currently using baseline $\Lambda = 100\mathrm{GeV}$ for all values, scaling as $\Lambda^{-2(D-4)}$.
- Can study Higgs 'dark portal' where the interactions are the same as the BSM EFT:
  - Plan to do so soon
  - Cross-check results with existing models in programs such as Sherpa.

Phasespace Selection Cuts

VBFZ Baseline: Jet1PT >55 GeV; Jet2PT >45 GeV; NumJets $\geq$ 2.

VBFZ HighMass: Mjj >1000 GeV; Jet1PT >55 GeV; Jet2PT >45 GeV; NumJets $\geq$ 2.

VBFZ Search: Mjj >250 GeV; Jet1PT >55 GeV; Jet2PT >45 GeV; NumJets $\geq$ 2.

VBFDM:

Mjj >250 GeV; Jet1PT >55 GeV; Jet2PT >45 GeV; NumJets $\geq$ 2; abseta <4.4; MET >150 GeV.

Monojet: Mjj >250 GeV; Jet1PT >45 GeV; NumJets $\geq$ 1; abseta <4.4; MET >150 GeV.

VBFDM OR Monojet: VBFDM; Monojet.

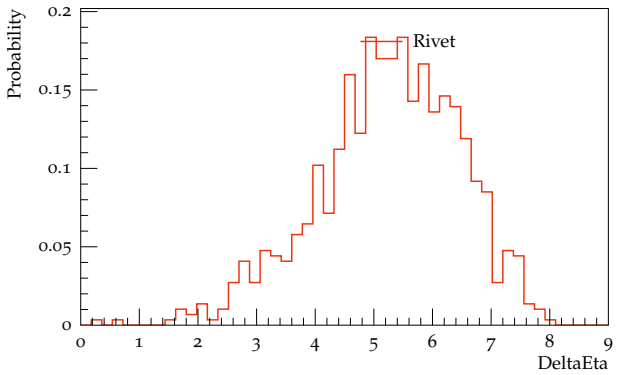
Distributions of interest:

Main distributions that have been produced:

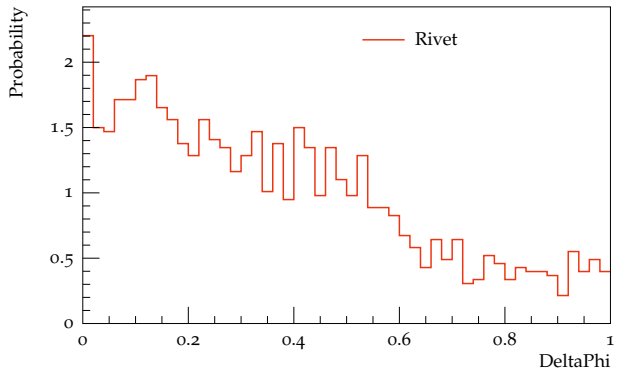
- Transverse Momentum of Jets, $P_T(j1)$ and $P_T(j2)$.
- Dijet Mass, M_{jj}.
- Missing Transverse Energy, $\not{E}_T$.
- Difference in Jet Angle $\Delta\phi$.
- Difference in Jet Pseudorapidity, $\Delta\eta$.

Distributions for D5a, VBFDM Selection, 10 GeV

DeltaEta



DeltaPhi



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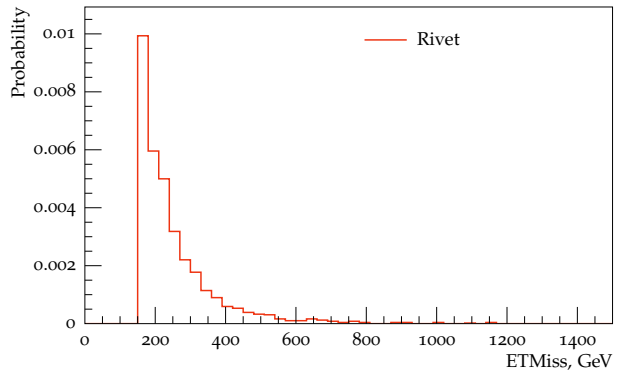
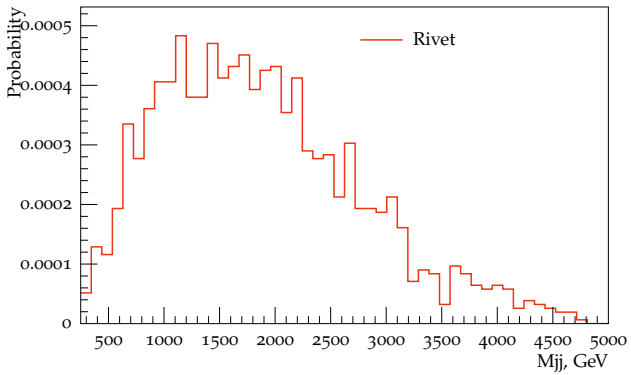
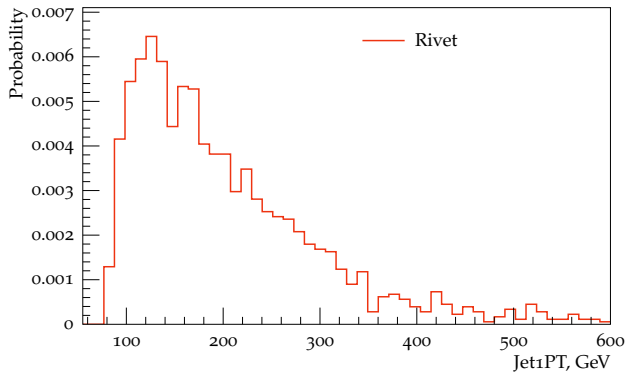


Mjj



Jet1PT



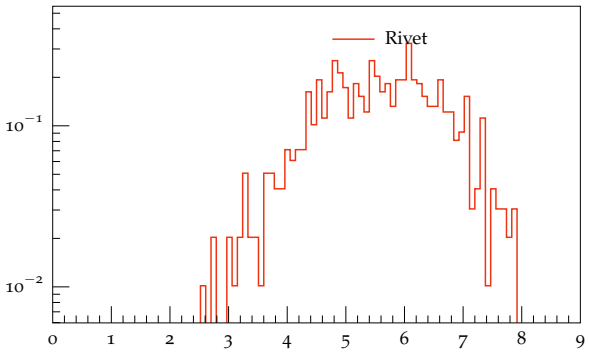
Cross-section, $\sigma = 102$ pb

Acceptance $= 26\%$

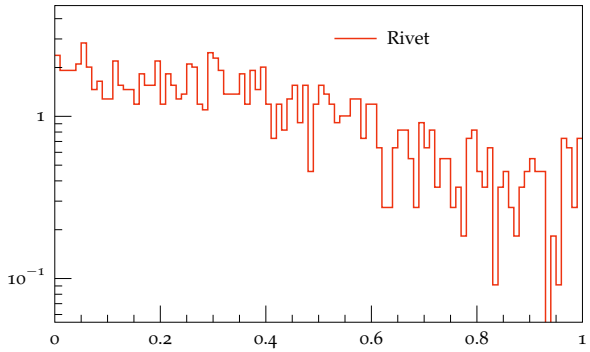
- DeltaPhi spectrum peaks

Distributions for D5a, VBFDM Selection, 1000 GeV

DeltaEta



DeltaPhi



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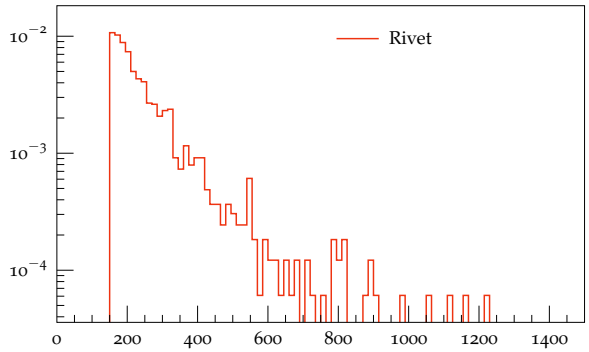
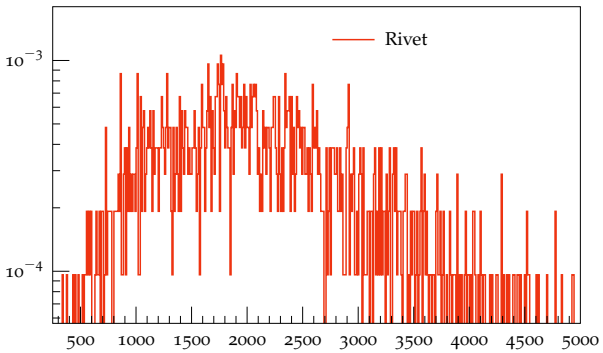
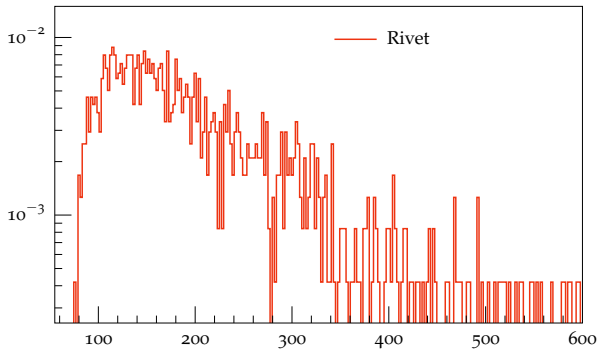


Mjj



Jet1PT

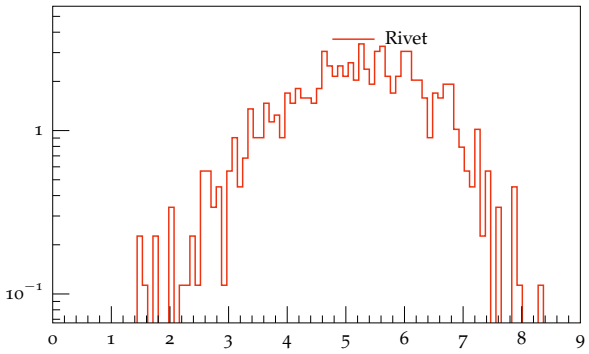


Cross-section, $\sigma = 9.1$ pb

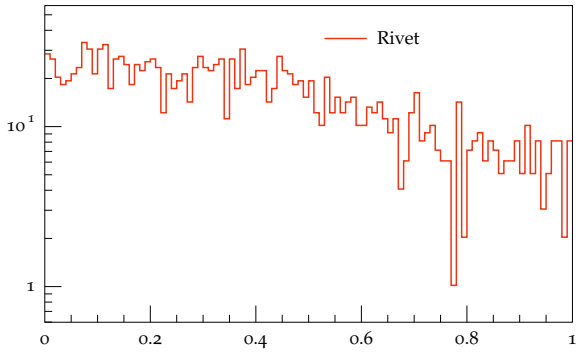
Acceptance $= 20\%$

Distributions for D5b, VBFDM Selection, 10 GeV

DeltaEta



DeltaPhi



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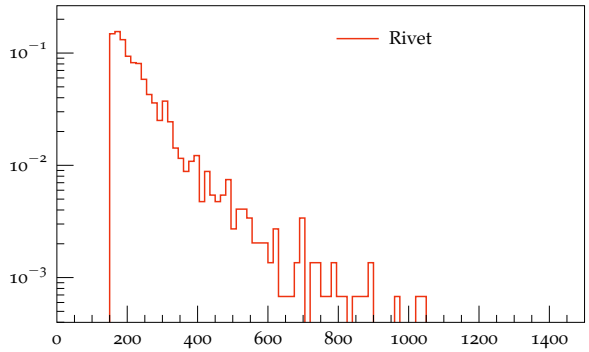
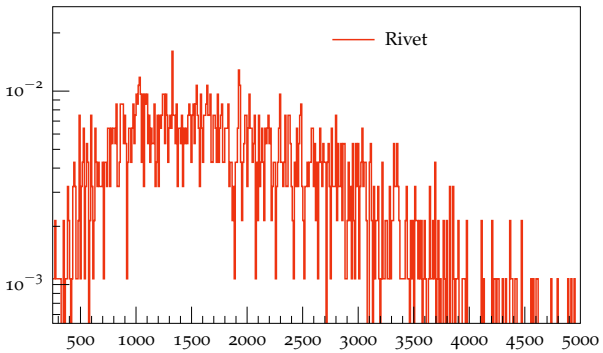
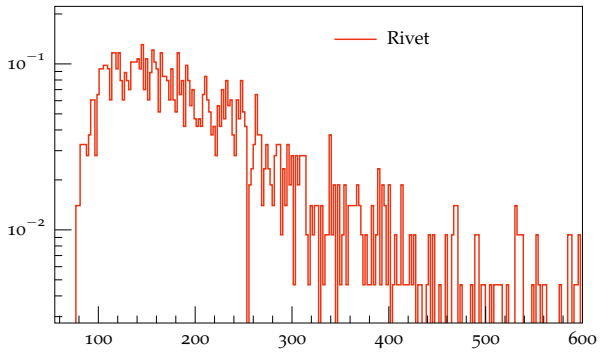


Mjj



Jet1PT

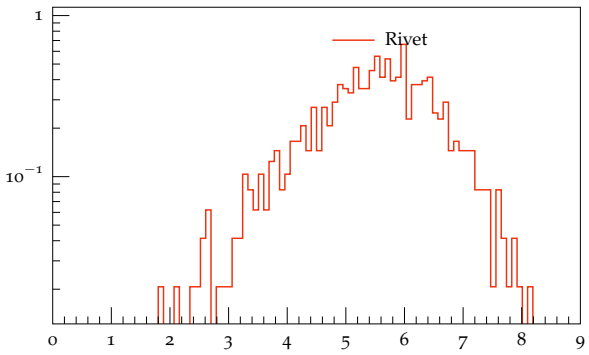


Cross section, $\sigma = 102$ pb

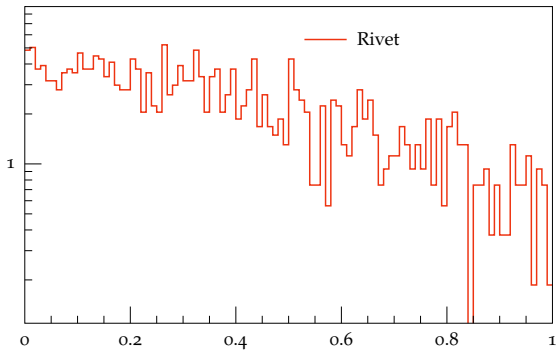
Acceptance $= 25\%$

Distributions for D5b, VBFDM Selection, 1000 GeV

DeltaEta



DeltaPhi



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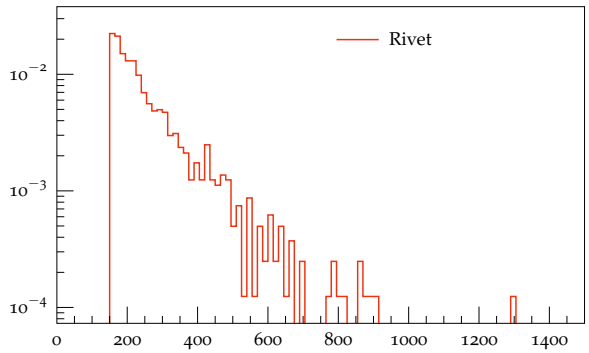
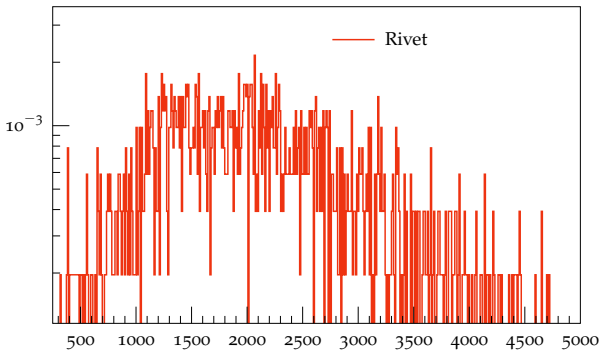
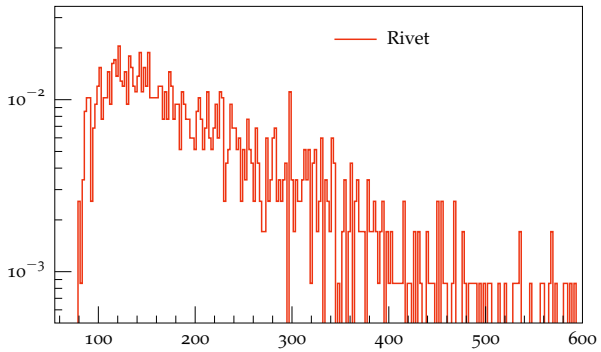


Mjj



Jet1PT

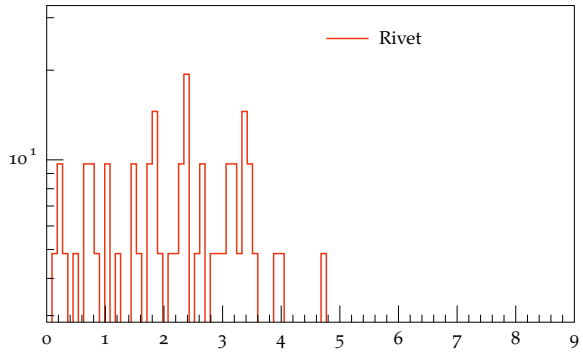


Cross section, $\sigma = 18$ pb

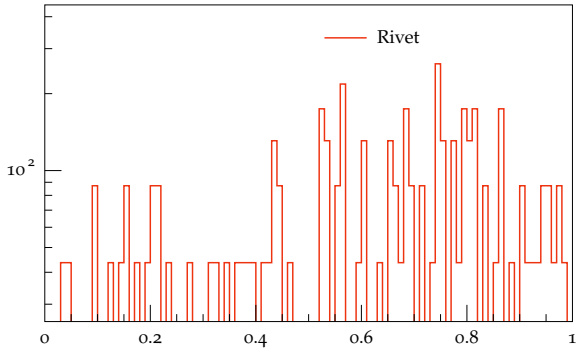
Acceptance $= 21\%$

Distributions for D5c, VBFDM Selection, 10 GeV

DeltaEta



DeltaPhi



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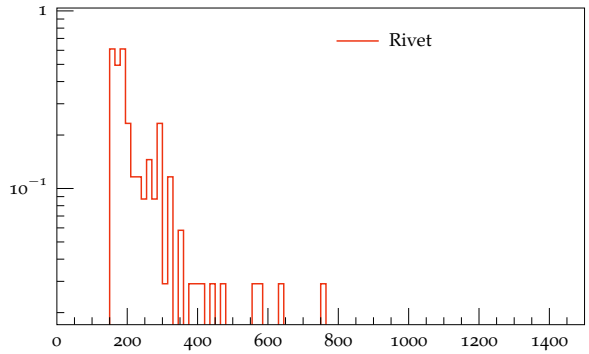
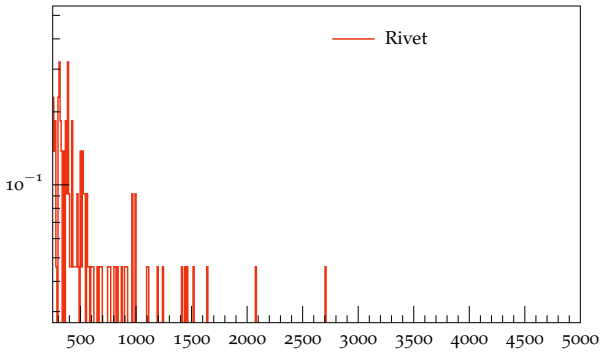
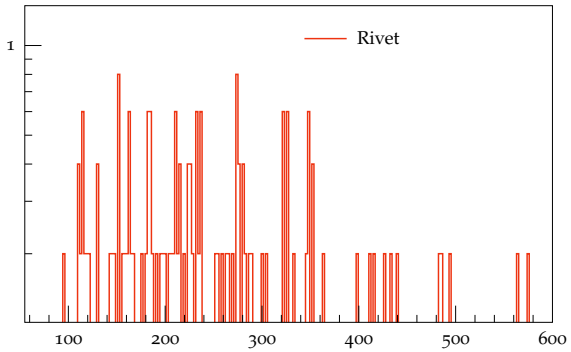


Mjj



Jet1PT



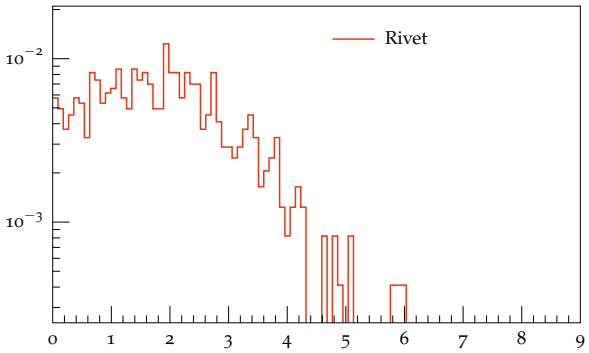
Cross section, $\sigma = 4360$ pb

Acceptance $= 4\%$

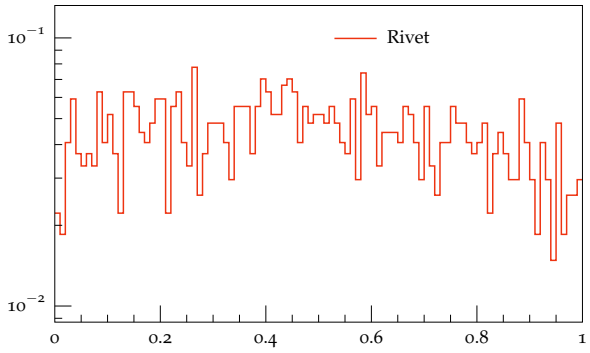
- The interaction would allow a new Z decay channel, which creates an invisible Z width constraint of Λ >3.3 TeV.

Distributions for D5c, VBFDM Selection, 1000 GeV

DeltaEta



DeltaPhi



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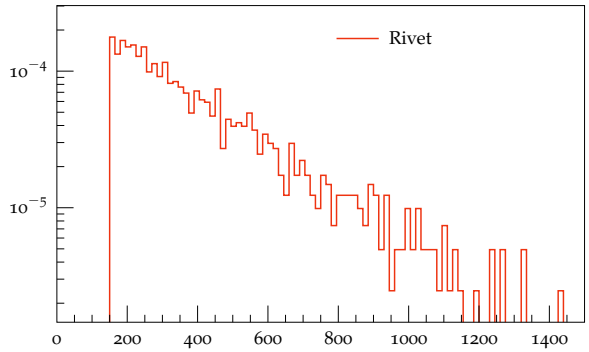
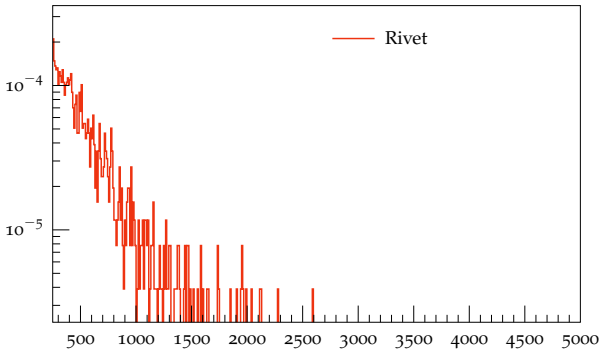
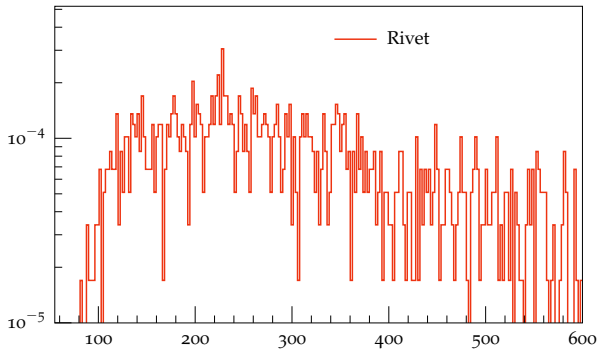


Mjj



Jet1PT

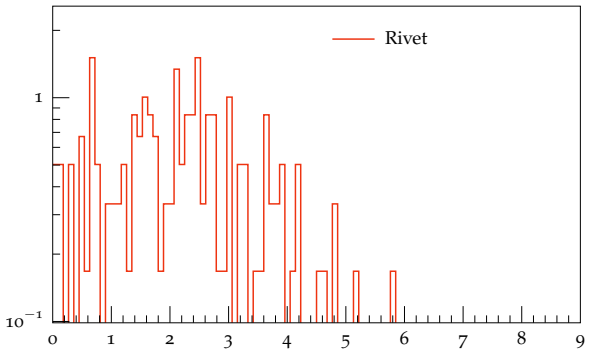


Cross section, $\sigma = 37$ pb
Acceptance $= 42\%$

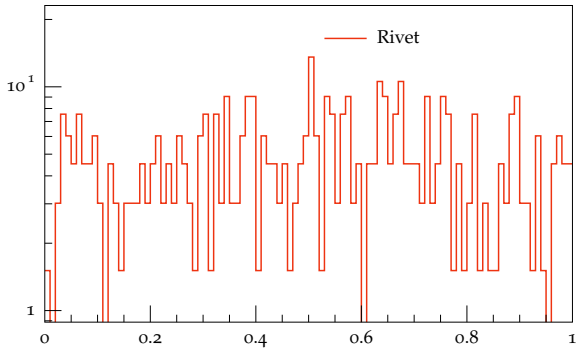
- Invisible Z width constraint of Λ >6.6 TeV. This gives a very high suppression factor: 4.5×10^3.

Distributions for D6a, VBFDM Selection, 10 GeV

DeltaEta



DeltaPhi



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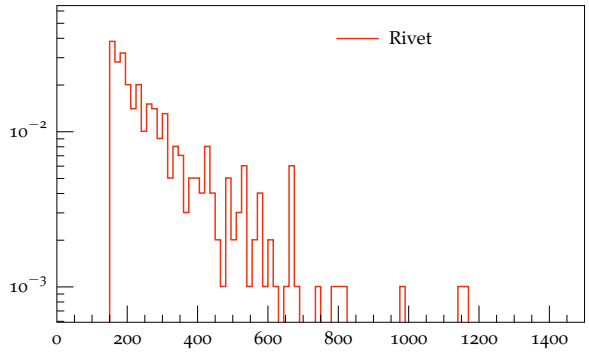
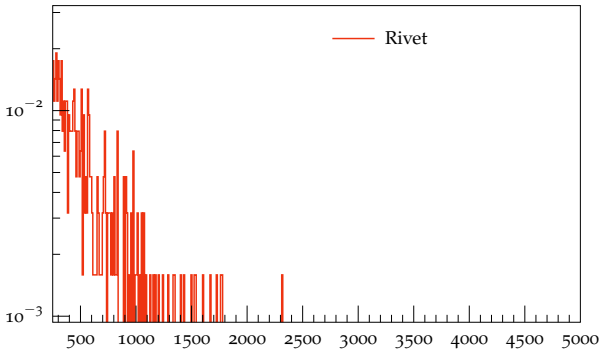
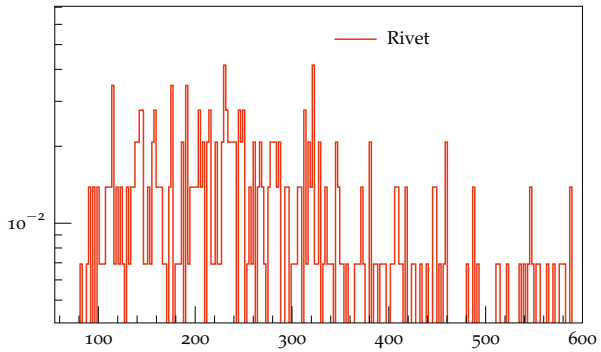


Mjj



Jet1PT



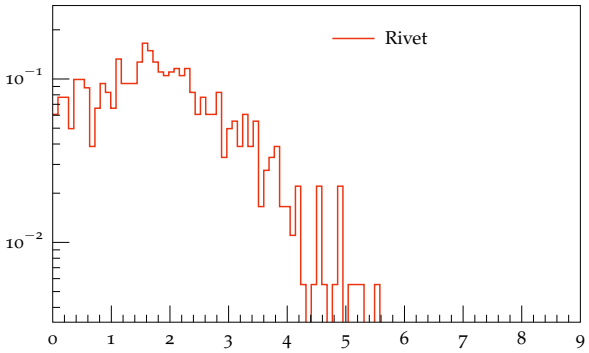
Cross section, $\sigma = 151$ pb

Acceptance $= 11\%$

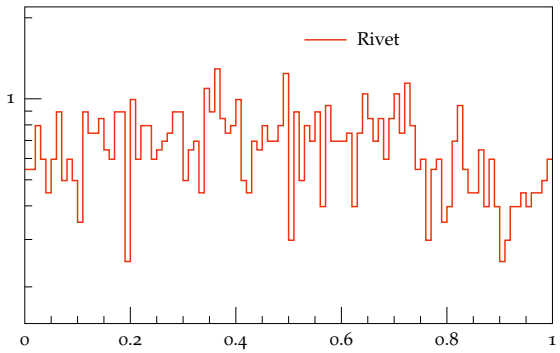
- Invisible Z width constraint of $\Lambda >$230GeV. This gives a very high suppression factor: 30.

Distributions for D6a, VBFDM Selection, 1000 GeV

DeltaEta



DeltaPhi



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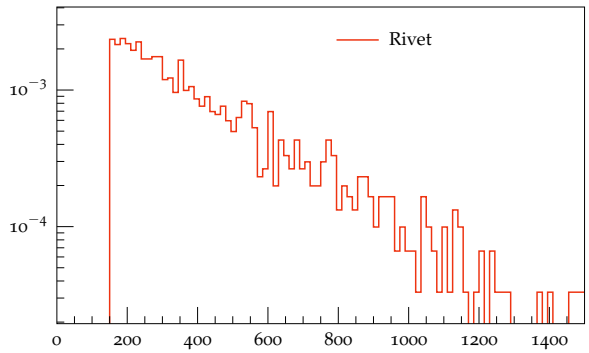
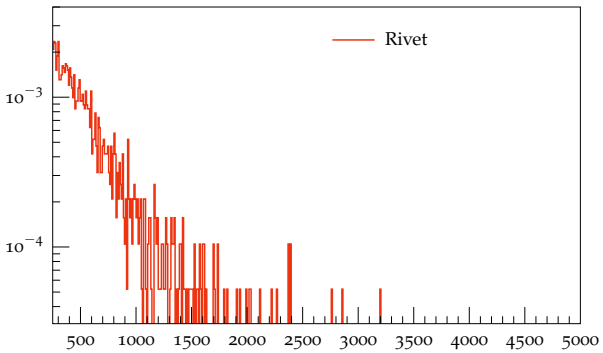
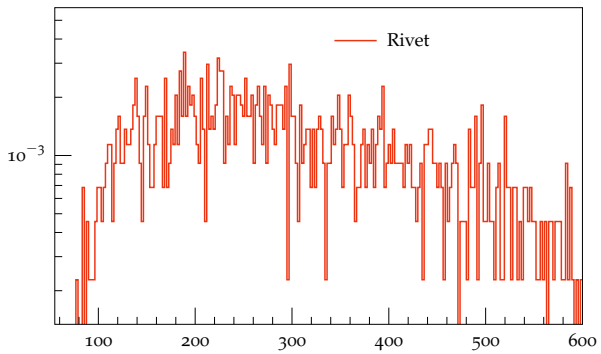


Mjj



Jet1PT



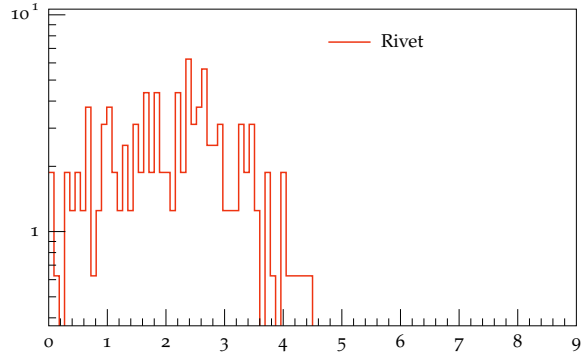
Cross section, $\sigma = 4.96$ pb

Acceptance $= 42\%$

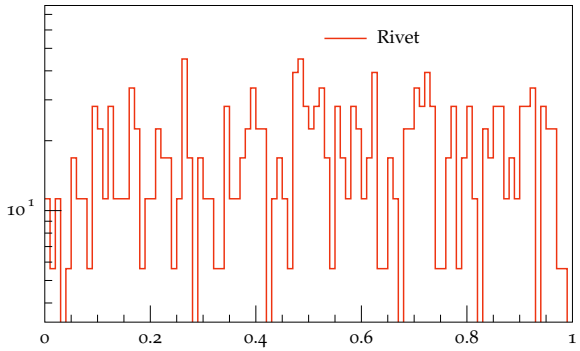
- DeltaEta distribution is quite low.
- DeltaPhi distribution is flat compared to the rest.

Distributions for D6b, VBFDM Selection, 10 GeV

DeltaEta



DeltaPhi



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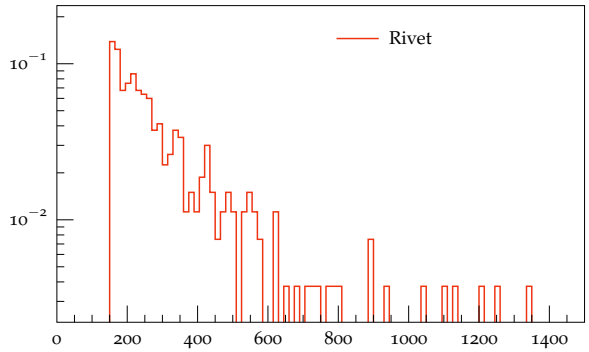

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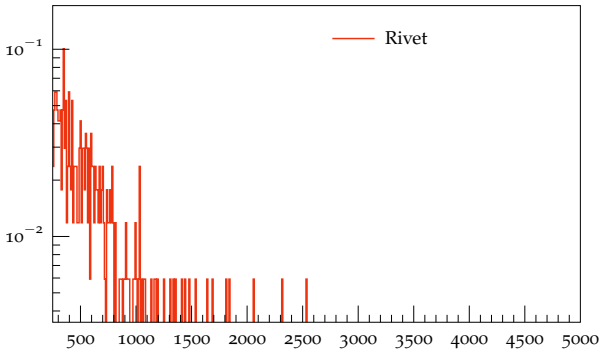
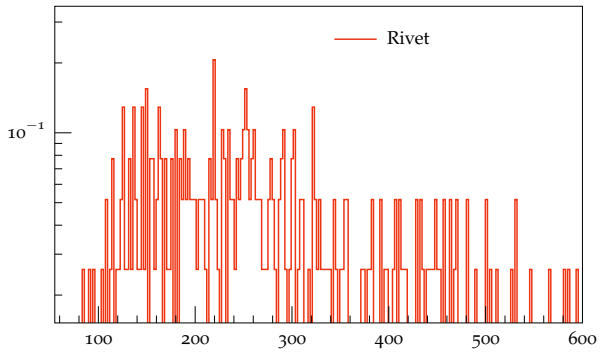


Jet1PT



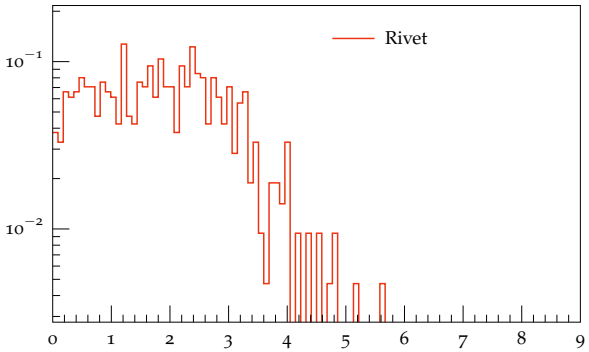
Cross section, $\sigma = 562$ pb

Acceptance $= 13\%$

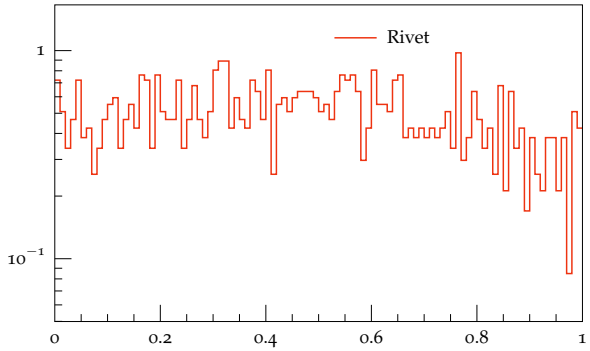
- Invisible Z width constraint of Λ >330GeV. This gives a very high suppression factor: 120.

Distributions for D6b, VBFDM Selection, 1000 GeV

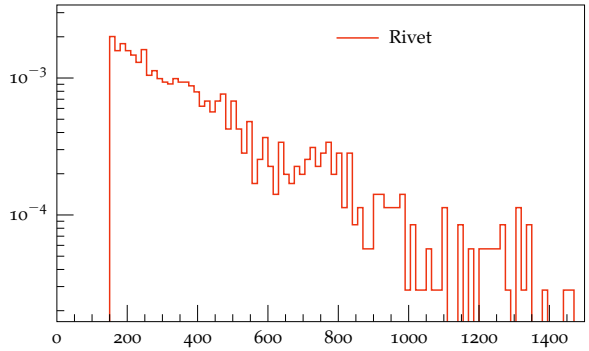
DeltaEta



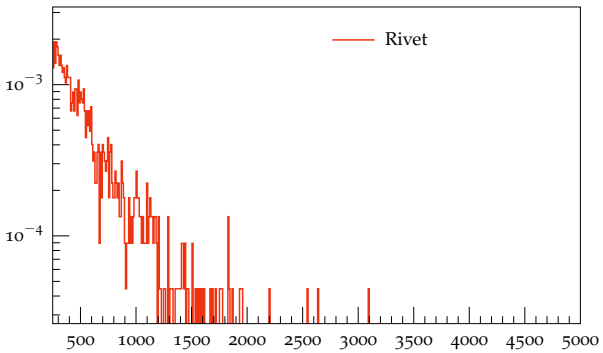
DeltaPhi



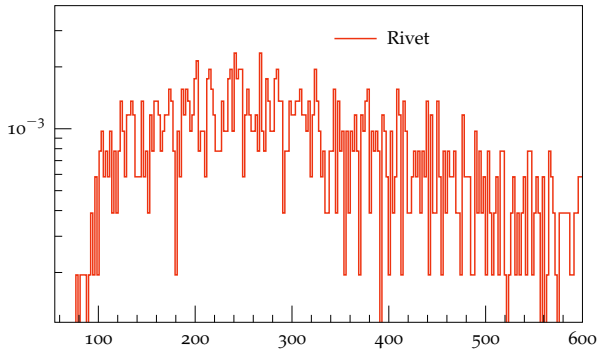
ETMiss



Mjj



Jet1PT



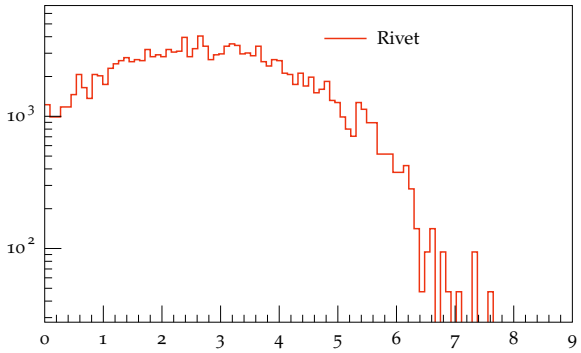
Cross section, $\sigma = 4.2$ pb

Acceptance $= 42\%$

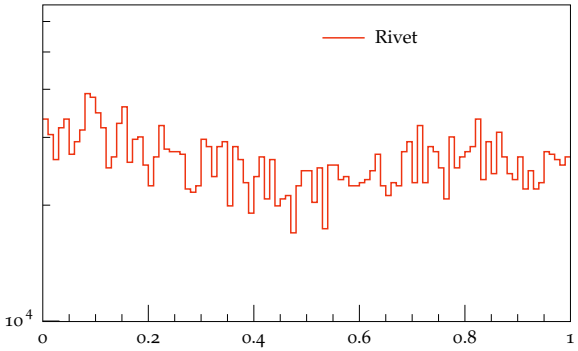
- Very flat Jet P_T spectrum.

Distributions for D7a, VBFDM Selection, 10 GeV

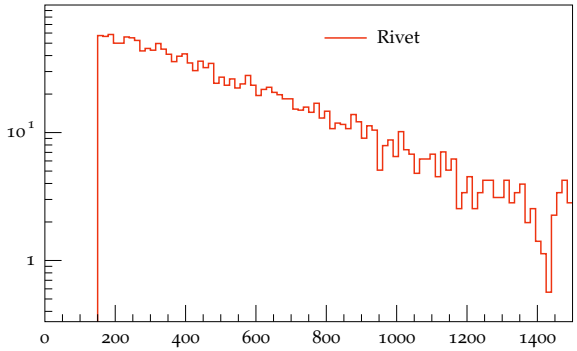
DeltaEta



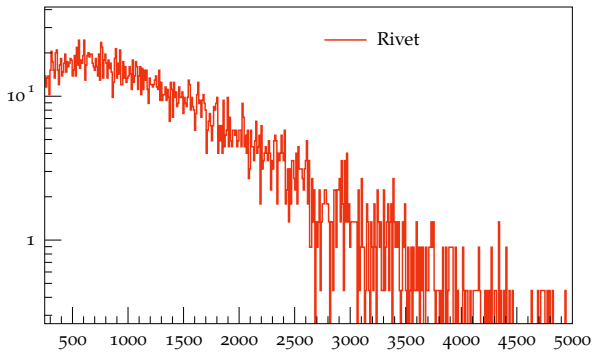
DeltaPhi



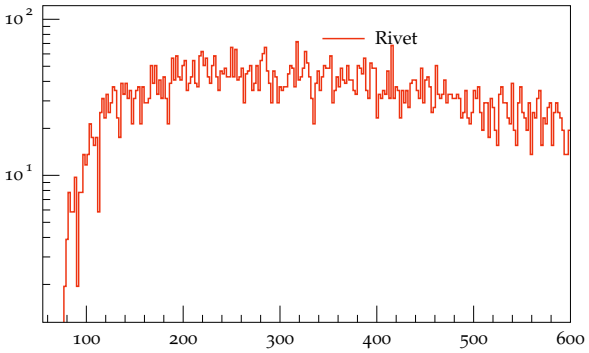
ETMiss



Mjj



Jet1PT



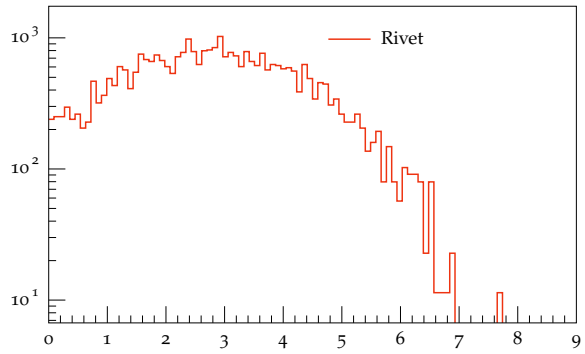
Cross section, $\sigma = 4240$ pb

Acceptance $= 78\%$

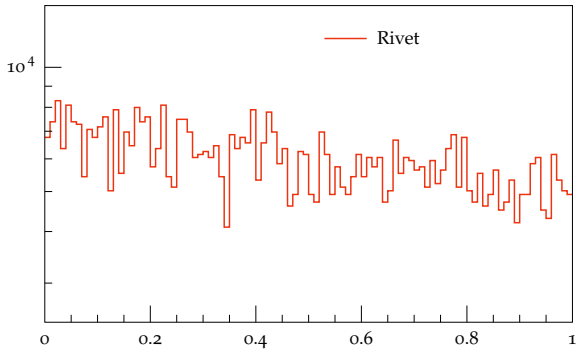
- DeltaEta distribution is very broad.
- Perhaps some modulation in DeltaPhi?

Distributions for D7a, VBFDM Selection, 1000 GeV

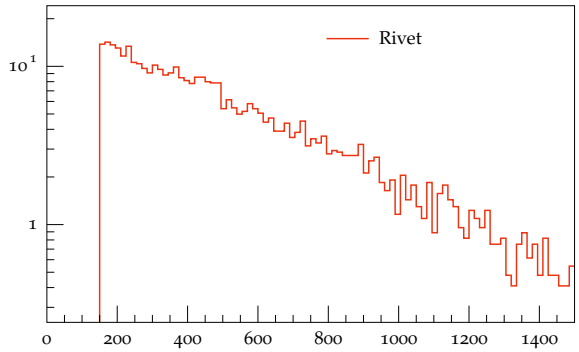
DeltaEta



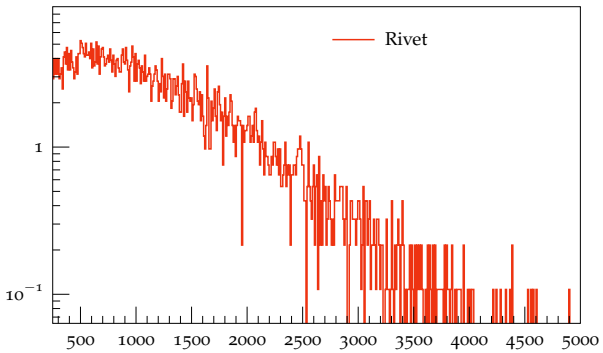
DeltaPhi



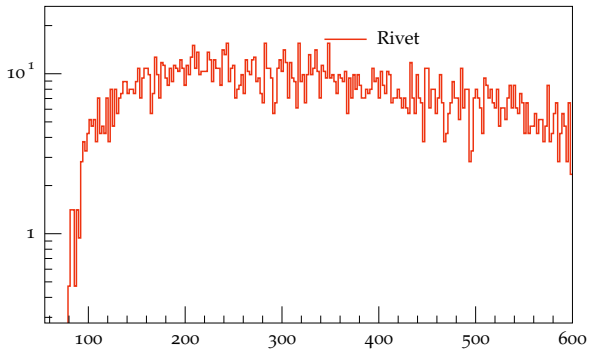
ETMiss



Mjj



Jet1PT

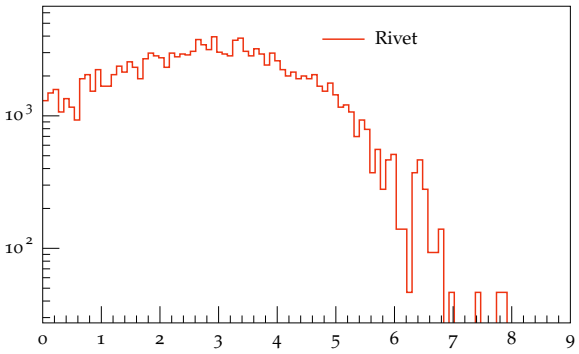


Cross section, $\sigma =$ 10200 pb

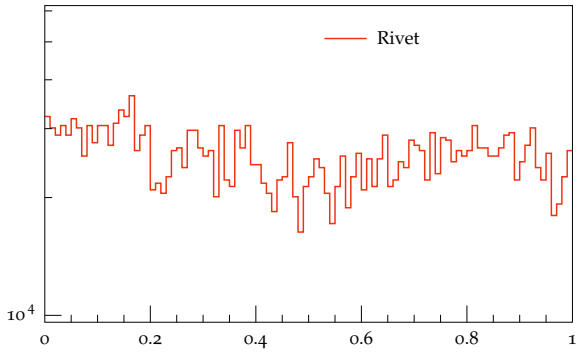
Acceptance $= 75\%$

Distributions for D7b, VBFDM Selection, 10 GeV

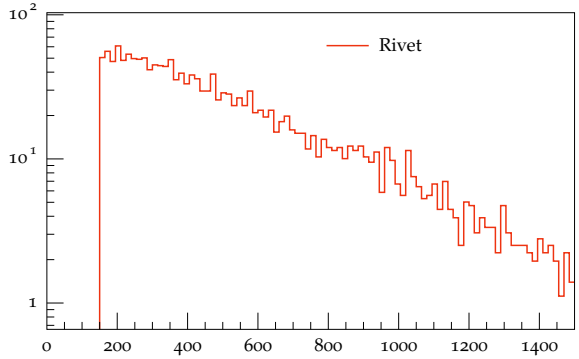
DeltaEta



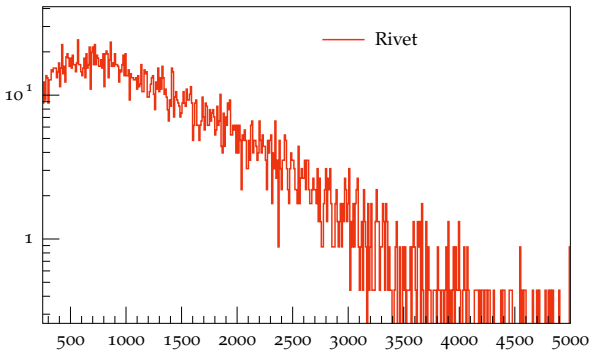
DeltaPhi



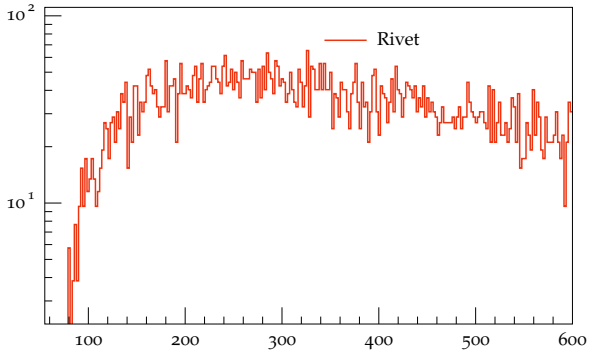
ETMiss



Mjj



Jet1PT

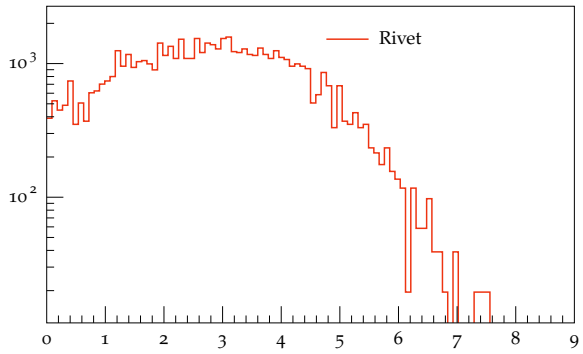


Cross section, $\sigma =$ 41900 pb

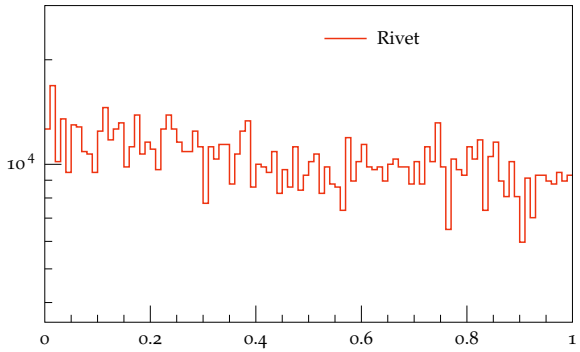
Acceptance $= 78\%$

Distributions for D7b, VBFDM Selection, 1000 GeV

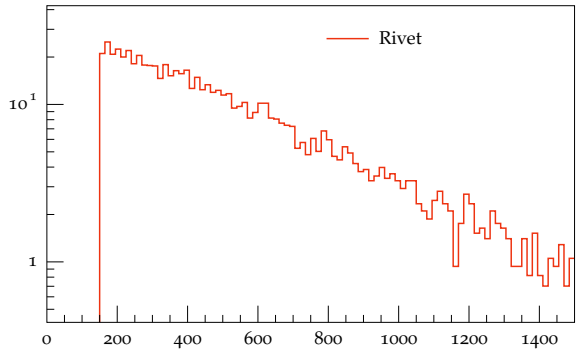
DeltaEta



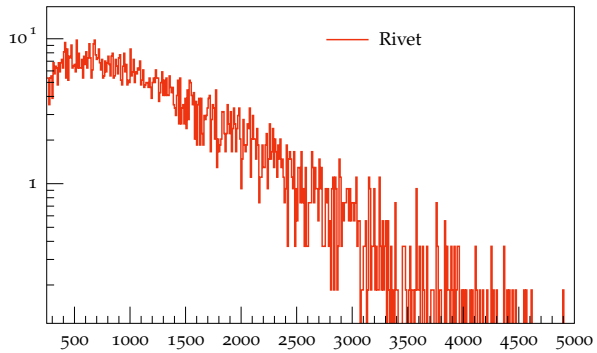
DeltaPhi



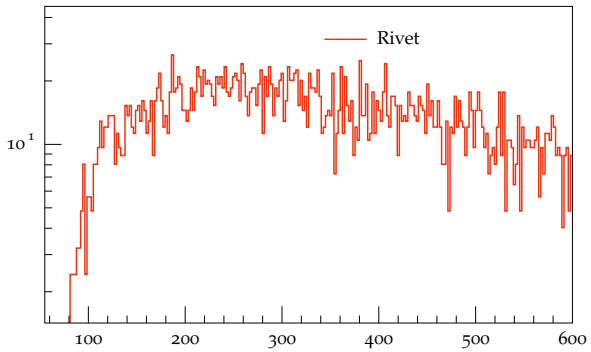
ETMiss



Mjj



Jet1PT

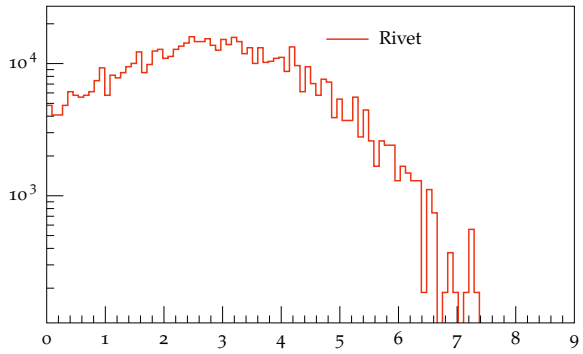


Cross section, $\sigma =$ 17600 pb

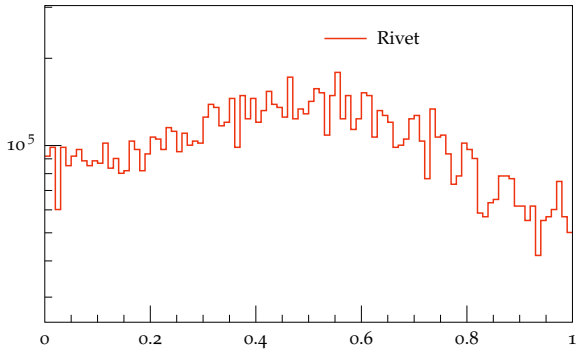
Acceptance $= 76\%$

Distributions for D7c, VBFDM Selection, 10 GeV

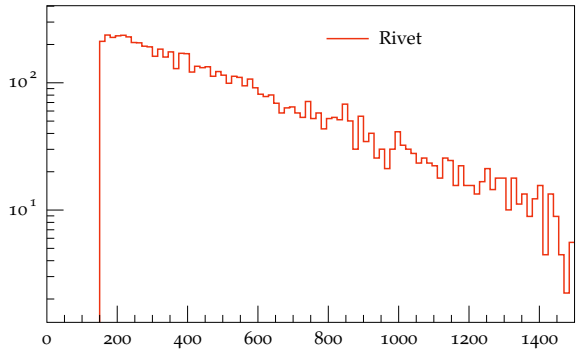
DeltaEta



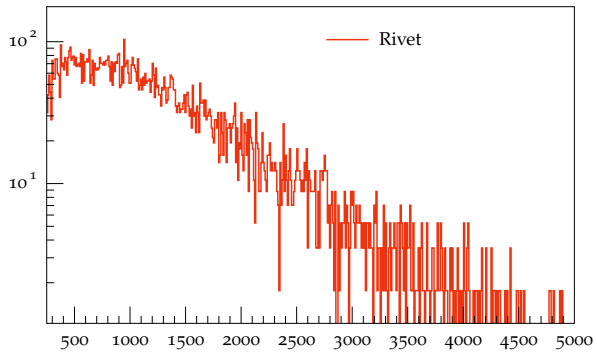
DeltaPhi



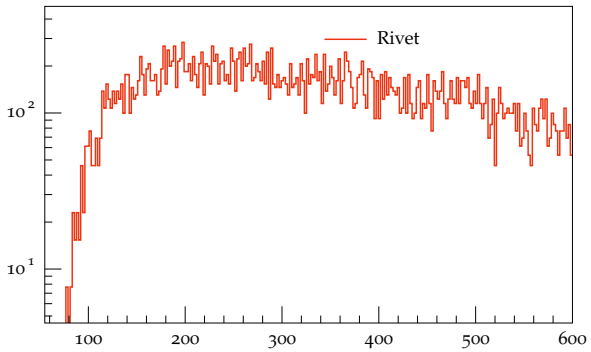
ETMiss



Mjj



Jet1PT

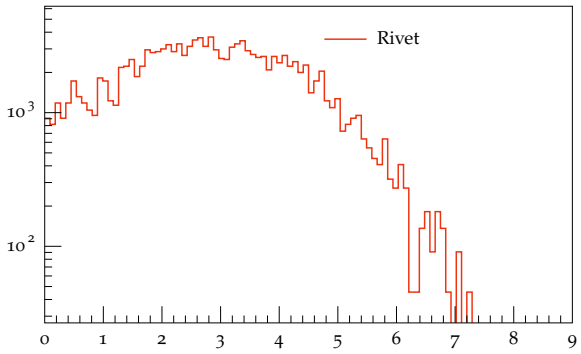


Cross section, $\sigma =$ 167000 pb

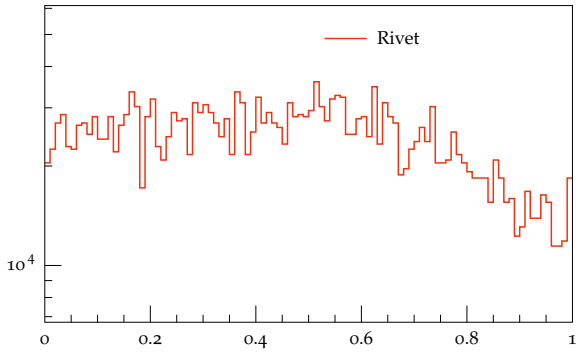
Acceptance $= 80\%$

Distributions for D7c, VBFDM Selection, 1000 GeV

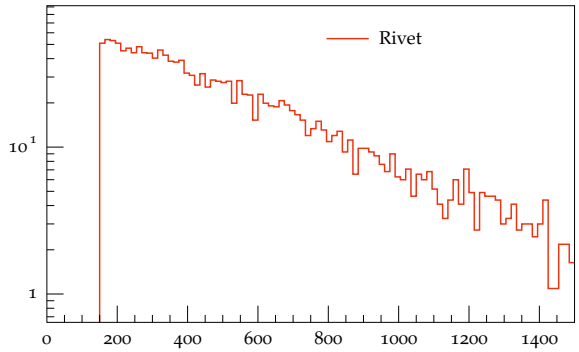
DeltaEta



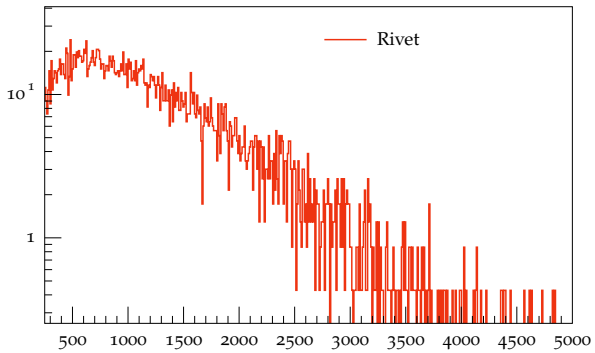
DeltaPhi



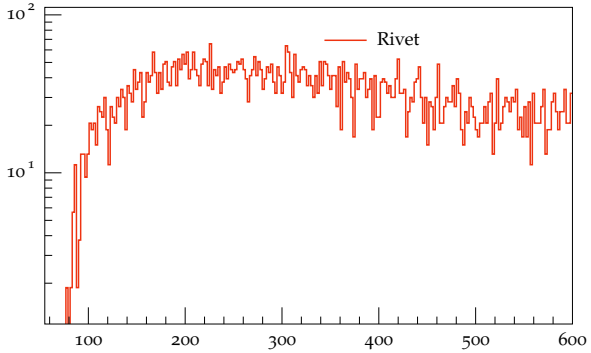
ETMiss



Mjj



Jet1PT

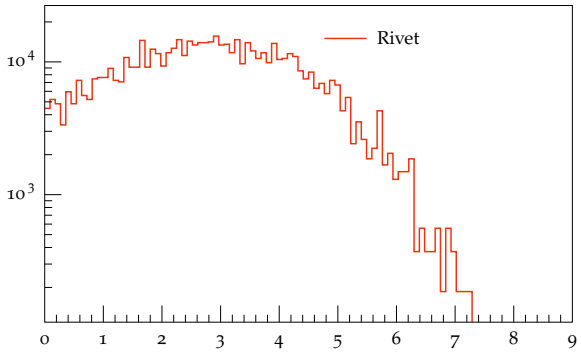


Cross section, $\sigma =$ 40900 pb

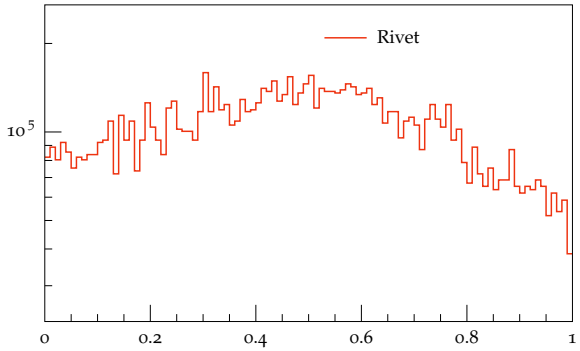
Acceptance $= 78\%$

Distributions for D7d, VBFDM Selection, 10 GeV

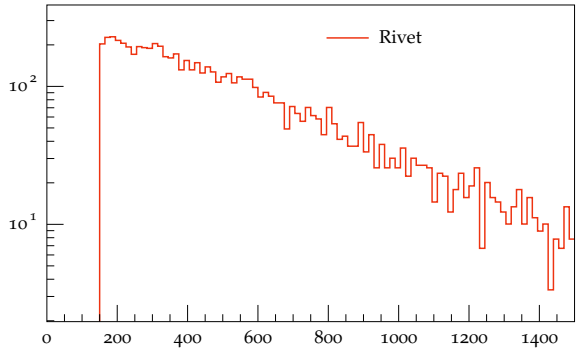
DeltaEta



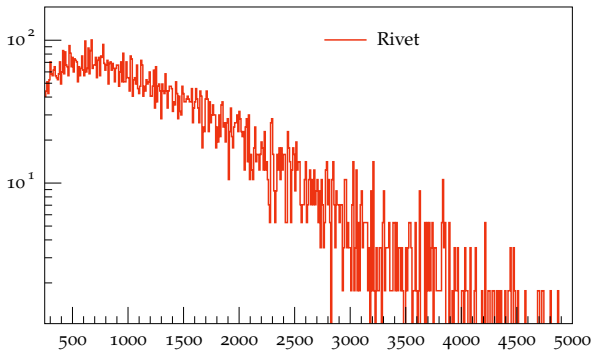
DeltaPhi



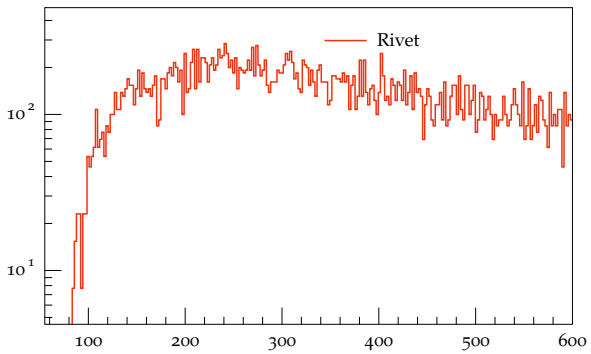
ETMiss



Mjj



Jet1PT

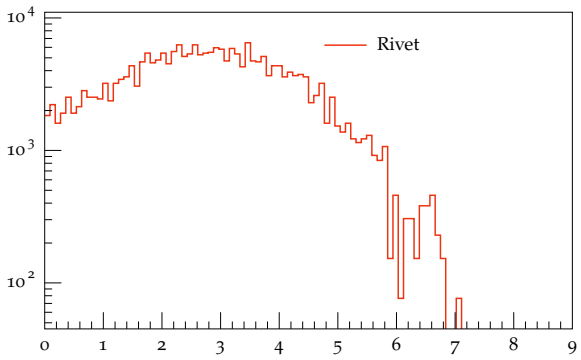


Cross section, $\sigma =$ 168000 pb
Acceptance $= 79\%$

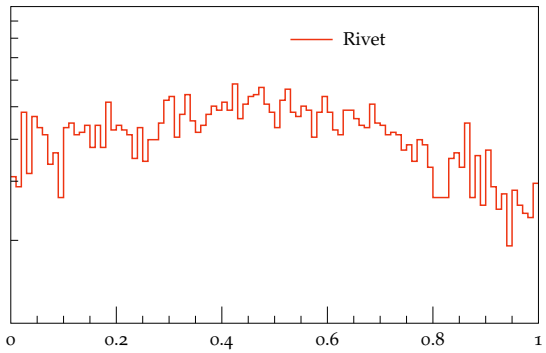
- DeltaPhi again has different structure.

Distributions for D7d, VBFDM Selection, 1000 GeV

DeltaEta



DeltaPhi



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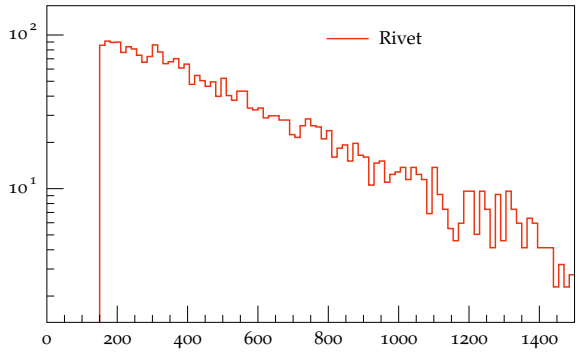
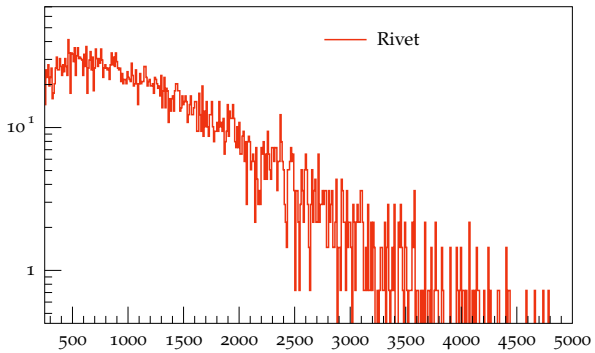
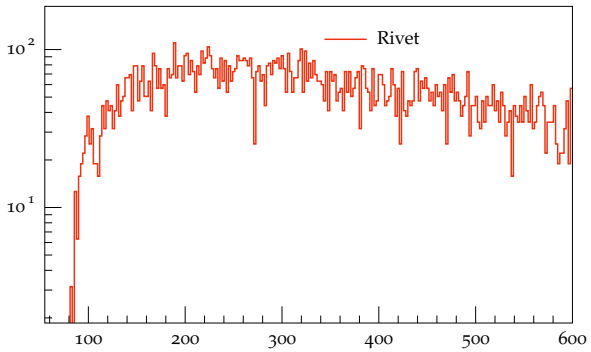


Mjj



Jet1PT



Cross section, $\sigma =$ 68800 pb

Acceptance $= 78\%$

Next Steps:

- Overlays of distributions for various operators/masses.
- Automation of current run through, as well as looking at:
  - Any other distributions of interest.
  - Any other phase spaces (Any gains from relaxed requirements?)
  - Scan all mass/dimension parameter space.
- Look at invisible Higgs validation of Sherpa.
- Add three jet contributions later.
- Indicative simulated sample through Atlas production system.
- Check regions of differential distributions for EFT validity.
- Run through Rivet routine with background processes to compare to signal kinematics.
  Mainly SM($Z \rightarrow \nu\ \bar{\nu}$) + j j.
- Any other thoughts?