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Comparison of W/Z+jets and W/Z+$b\bar{b}$+jets Processes for Different Matrix-Element MC Generators

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(for the lepton+jets working group)

Abstract

This note is a follow up to CDF note 6063, in which we defined a standard set of generator parameters, cuts, and processes in order to coordinate the comparisons between several of the available leading-order (LO) Matrix Element Monte Carlo (ME-MC) generators. Here we present results of ME level comparisons between `ALPGEN`, `GR@PPA`, `MadGraph`, and LO `MCFM`. We show total cross sections for W+jets, Z+jets, $Wb\bar{b}$+jets and $Zb\bar{b}$+jets, as well as some kinematical distributions.

1 Introduction

Several Matrix-Element Monte Carlo event generators exist today. These are extremely important tools, as they can be used interfaced with parton showering programs and detector simulations to generate MC samples used in physics analyses. Since the leading-order matrix element processes are theoretically well understood, it is expected that, given a common set of inputs, these generators should give consistent results. The comparisons presented in this note are the result of an iterative process. A few significant discrepancies were found initially, and they were traced to differences in the CKM matrix and coupling constants, rapidity *vs* pseudorapidity cuts, E_T *vs* P_T cuts, quark masses, and factorization scale, to name some examples. In most cases the authors themselves had to intervene to implement the exact inputs and cuts needed. The numbers presented here correspond to the state of the MC generators as of January of 2003. We stress that the comparisons are at the leading-order, matrix element level only. Parton shower and simulation effects are not considered for the moment.

Documentation for the various programs can be found at the following sites:

- `MCFM`: `http://theory.fnal.gov/people/ellis/mcfm.html`
- `ALPGEN`: `http://home.cern.ch/mlm/alpgen`
- `MadGraph`: `http://madgraph.physics.uiuc.edu/`
- `GR@PPA`: `http://atlas.kek.jp/physics/nlo-wg/index.html`

These sites contain links to the relevant hep-ph preprints, the latest version of the code, and examples of how-to-use. Other useful links can be found on the dilepton and lepton+jets WG sites. The comparisons shown in this note are part of an ongoing effort, and as such, more programs and more comparisons are likely to be reported in future revisions. `MCFM` is a Next-to-Leading (NLO) program, but for the purpose of these comparisons we report only its leading order calculations. The generator inputs and cuts used are described in detail in CDF note 6063 [1].

2 Cross Section Comparisons

In this section we concern ourselves with total rate predictions of the different LO ME generators for four different types of processes: W+jets, Z+jets, $Wb\bar{b}$+jets and $Zb\bar{b}$+jets. All numbers were kindly provided via private communications by the authors of the different generators: Michelangelo Mangano for `ALPGEN`, Soushi Tsuno for `GR@PPA`, Tim Stelzer and Fabio Maltoni for `MadGraph`, and John Campbell for `MCFM`(LO). All uncertainties quoted are the statistical.

2.1 W+Jets

Table 1 and figure 1 (upper left) show the cross sections for $W \to e\nu + nj$ reported by leading-order ME-MC event generators. There is good agreement between most processes generated. Some differences seem significant relative to the statistical uncertainties, but the maximum differences observed are well below 1% except for the case of $W + 3$ jets, in which `GR@PPA` seems slightly lower than the others.

Table 1: Cross sections (in pb) for $W \to e\nu + nj$. Uncertainties are statistical.

Process	W+0j	W+1j	W+2j	W+3j	W+4j	W+5j
ALPGEN	2046 ± 1	522.6 ± 0.6	146.1 ± 0.3	41.5 ± 0.2	11.55 ± 0.07	3.13 ± 0.02
GR@PPA	2042 ± 4	525.4 ± 0.6	146.8 ± 0.3	40.2 ± 0.3		
MadGraph	2044 ± 5	525.4 ± 0.6	146.1 ± 0.3	41.75 ± 0.12		
MCFM(LO)	2044 ± 1	526.3 ± 0.5	147.2 ± 0.3	41.8 ± 0.2		

2.2 Z+Jets

Table 2 and figure 1 (upper right) show the cross sections for $Z \to e\nu + nj$ reported by leading-order ME-MC event generators. All results are in good agreement, with

Table 2: Cross sections (in pb) for $Z \to e\nu + nj$. Uncertainties are statistical.

Process	Z+0j	Z+1j	Z+2j	Z+3j	Z+4j	Z+5j
ALPGEN	198.0 ± 0.2	53.72 ± 0.06	14.76 ± 0.05	4.09 ± 0.02	1.13 ± 0.01	0.292 ± 0.002
GR@PPA	198.1 ± 0.2	54.02 ± 0.06	15.07 ± 0.02			
MadGraph	198.9 ± 0.7	53.5 ± 0.2	14.70 ± 0.04	4.079 ± 0.009		
MCFM(LO)	198.2 ± 0.1	53.80 ± 0.05	14.79 ± 0.03	4.11 ± 0.02		

GR@PPA values only slightly higher but always within about 1% of the rest.

2.3 $Wb\bar{b}$+Jets

Table 3 and figure 1 (lower left) show the cross sections for $W \to e\nu + b\bar{b} + nj$ reported by leading-order ME-MC event generators. The largest difference is 1% in

Table 3: Cross sections (in fb) for $W \to e\nu + b\bar{b} + nj$. Uncertainties are statistical.

Process	Wbb+0j	Wbb+1j	Wbb+2j	Wbb+3j
ALPGEN	1170 ± 2	596 ± 2	253 ± 2	100 ± 1
GR@PPA	1178 ± 3			
MadGraph	1175 ± 8	602 ± 2	251.1 ± 0.7	
MCFM(LO)	1175 ± 3			

the bb+1j bin, but reasonable given the statistical uncertainties. All other results agree to better than 1% and are statistically consistent.

2.4 $Zb\bar{b}$+Jets

Table 4 and figure 1 (lower right) show the cross sections for $Z \to e\nu + b\bar{b} + nj$ reported by leading-order ME-MC event generators. All results are statistically consistent and

Table 4: Cross sections (in fb) for $Z \to e\nu + b\bar{b} + nj$. Uncertainties are statistical.

Process	Zbb+0j	Zbb+1j	Zbb+2j	Zbb+3j
`ALPGEN`	181.7 ± 0.4	93.5 ± 0.5	37.6 ± 0.4	12.8 ± 0.6
`GR@PPA`				
`MadGraph`	182.5 ± 1.2	92.7 ± 0.4		
`MCFM`(LO)	182.2 ± 0.5			

agree to better than 1%.

3 Kinematical Distributions

In addition to predicting the overall rates for any given process, it is also expected that the ME generators produce comparable differential distributions with respect to kinematical variables. In this section we present energy and angular distributions of jets and leptons for `ALPGEN`, `GR@PPA` and `MadGraph`. Soushi Tsuno provided us with 10K `GR@PPA` samples, and we generated 10K samples using `MadGraph` and `ALPGEN`. The `MCFM` Monte Carlo is not an event generator and therefore kinematical distributions cannot be obtained from it.

3.1 $W + 2$ Jets

Figures 2,3,4,5,6,7,8,9 show several unit normalized kinematic distributions for the process $W \to e\nu + 2j$. No significant differences are observed. We note that figure 9 is of special importance, since the ΔR distribution is related to the collinear singularity, and the jet-jet invariant mass distribution is related to the mass singularity. These distributions are therefore particularly sensitive to the method which is used to perform the unweighting of the generated events. If the maximum weight used is very different from the true maximum weight, one would expect to see differences between the generators.

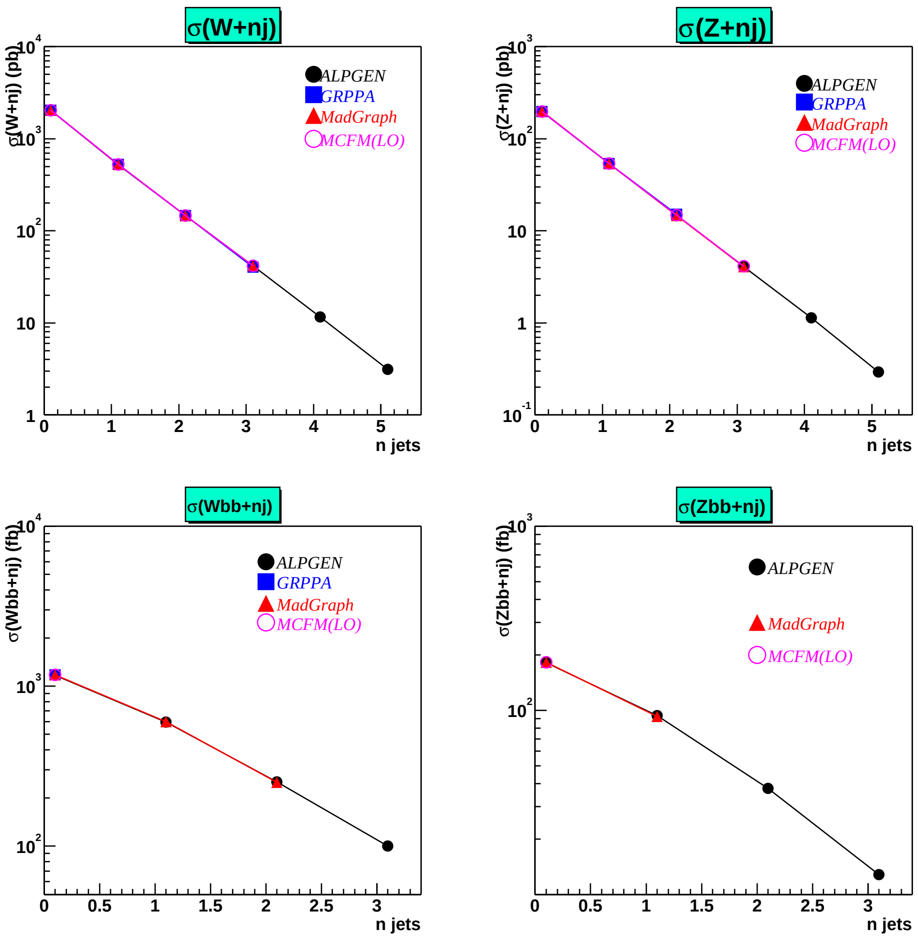

Figure 1: Cross sections for the different processes and for the different MC generators, corresponding to tables 1,2,3,4.

3.2 $Wb\bar{b} + 2$ Jets

Figures 10,11,12,13,14,15,16,17 show several unit normalized kinematic distributions for the process $W \to e\nu + b\bar{b}$. No significant differences are observed. Again we note that the distributions of figure 17 are particularly sensitive to the method used to perform the unweighting of the generated events.

4 Conclusions

After a few iterations in which the generator inputs and cuts were correctly implemented, we find that there is good agreement (at Matrix Element level) between cross section predictions by `ALPGEN`, `MadGraph`, `GR@PPA` and `MCFM`(LO) for W/Z+jets and $W/Z + b\bar{b}$+jets processes. All predictions agree to $\approx 1\%$ or better except for

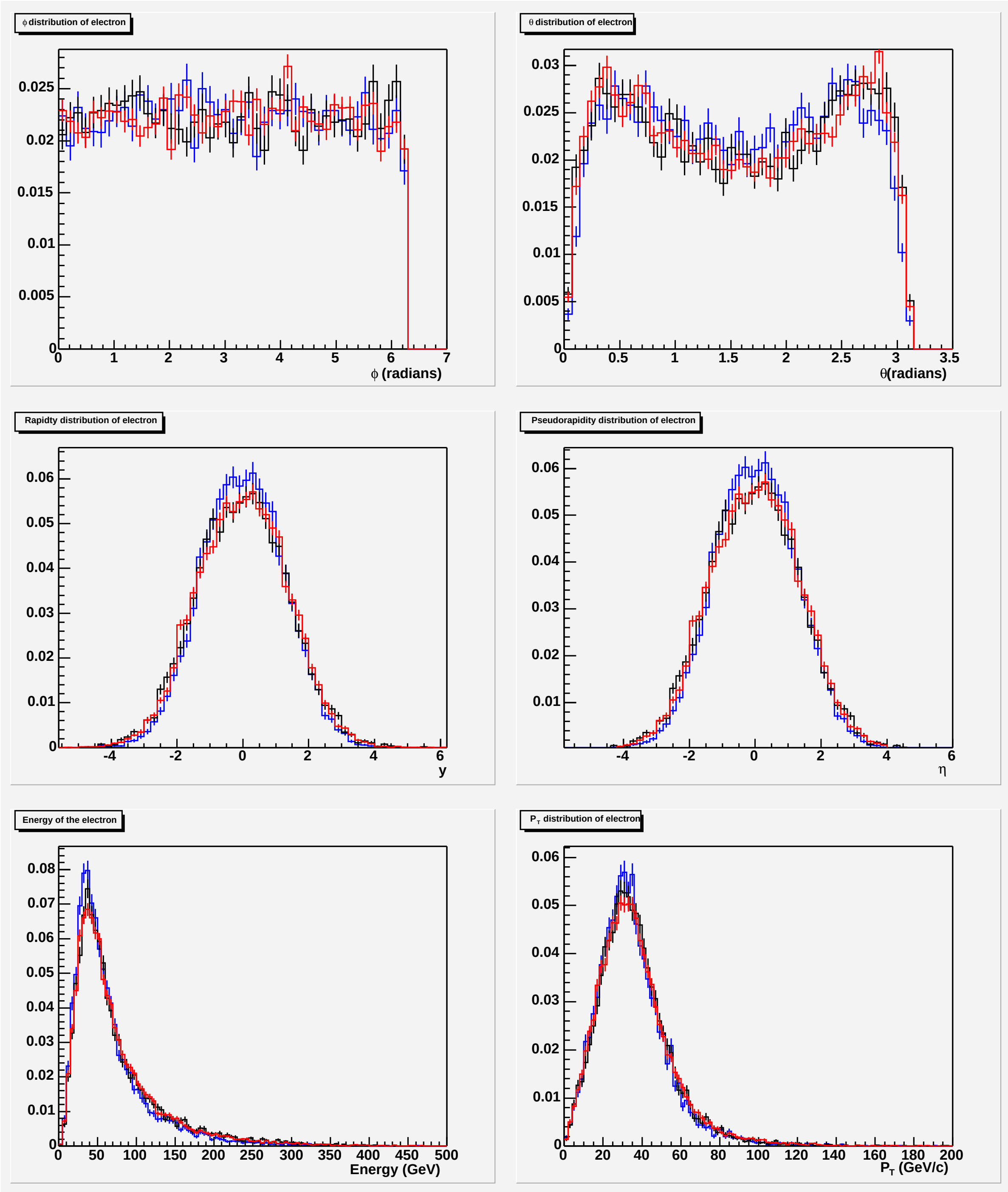

Figure 2: Electron ϕ, θ, y, η, E and P_T distributions for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

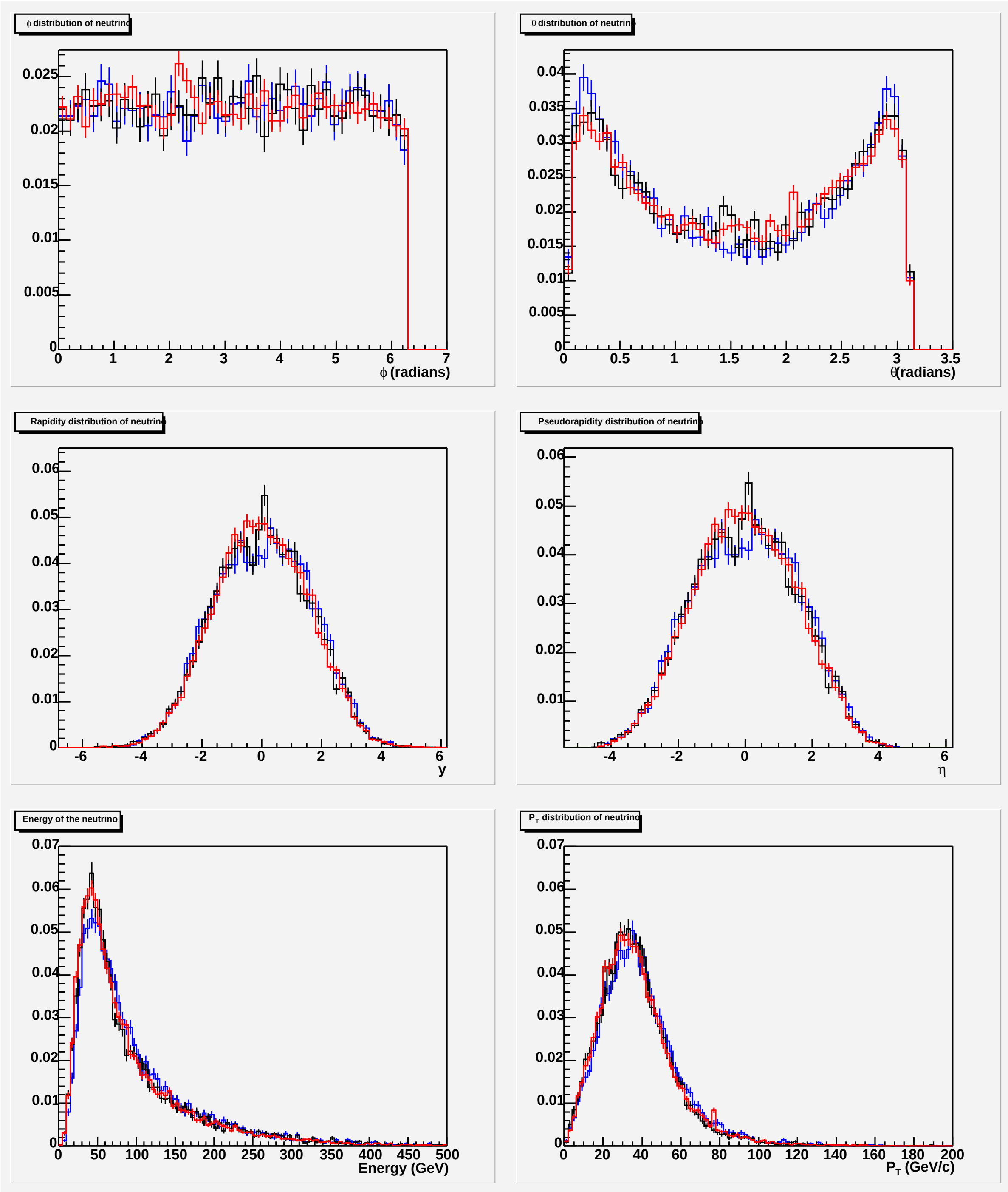

Figure 3: Neutrino ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

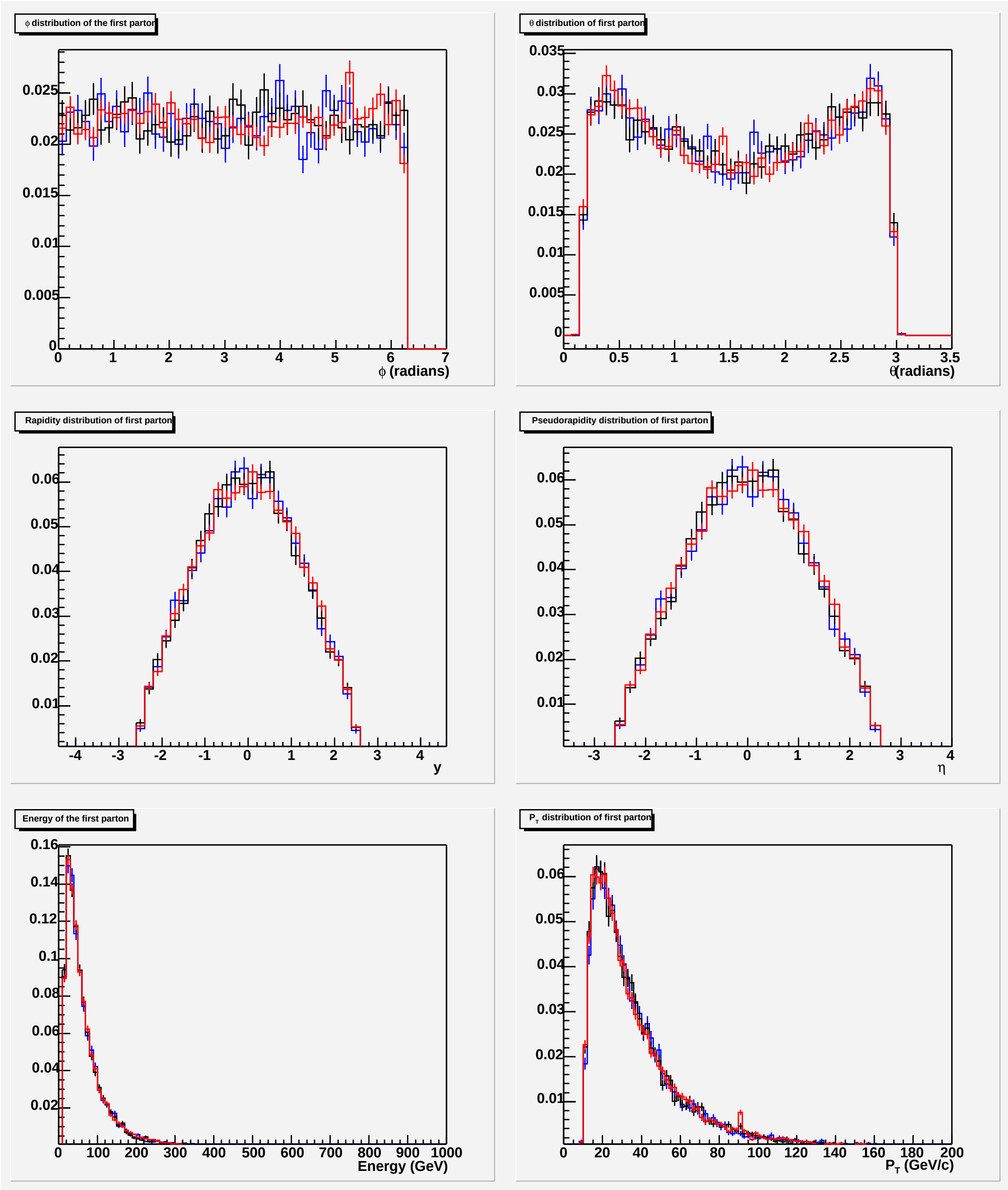

Figure 4: ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for the highest energy parton for $W \to e\nu + 2j$. Black=ALPGEN, red=MadGraph, blue=GR@PPA. All histograms are unit normalized.

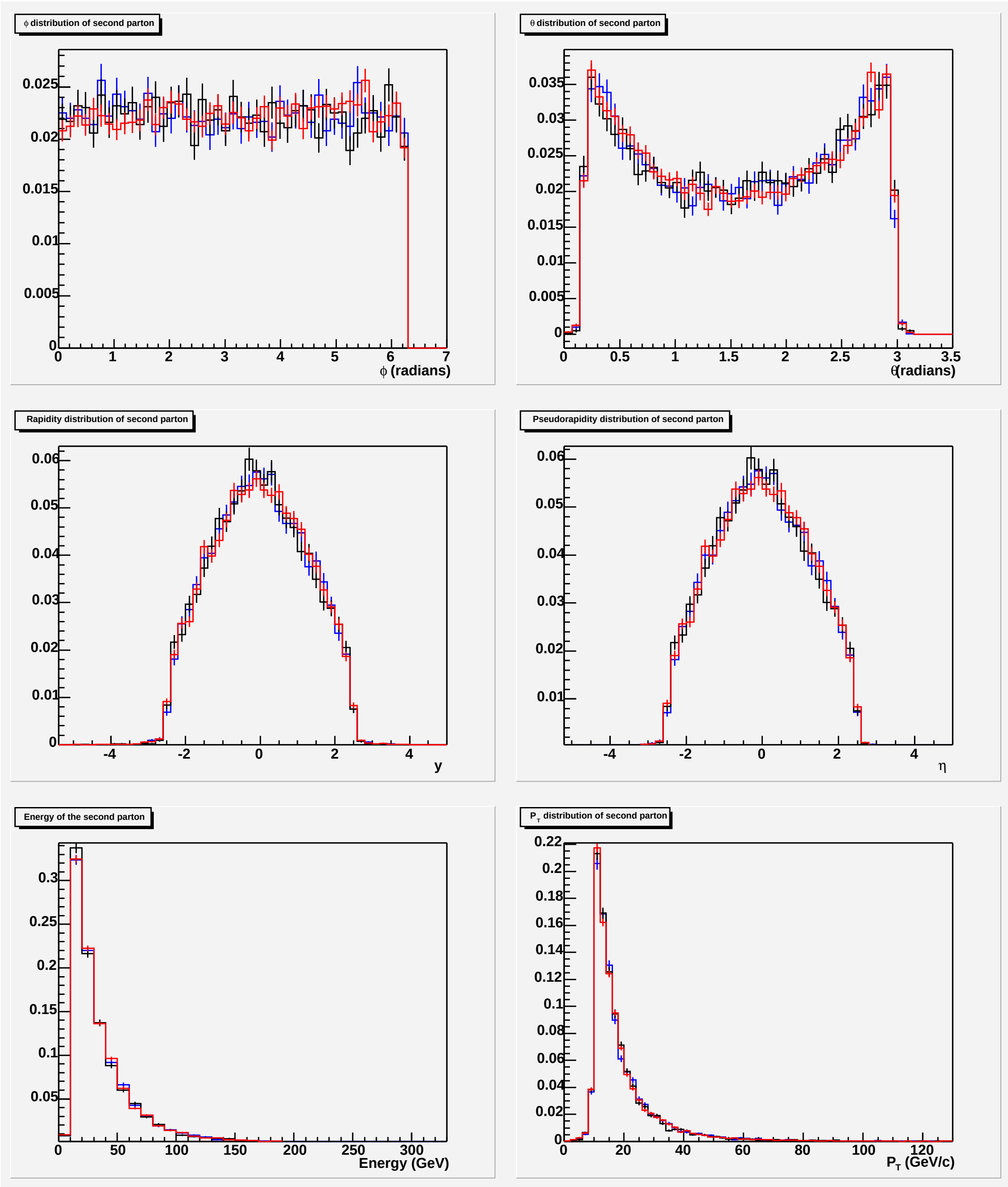

Figure 5: ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for the second highest energy parton for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

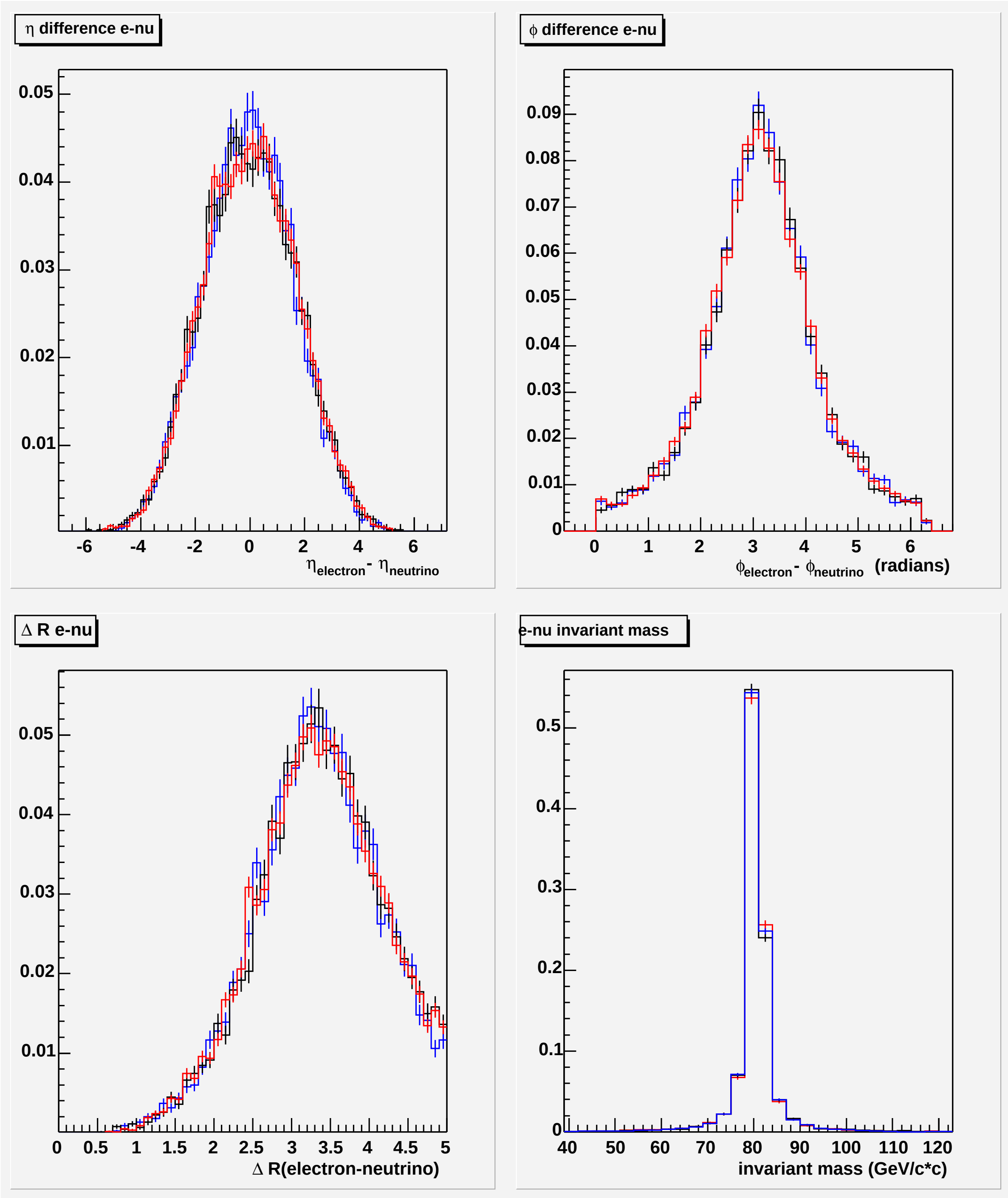

Figure 6: $\Delta\eta, \Delta\phi, \Delta R$ and invariant mass distributions for electron-neutrino for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

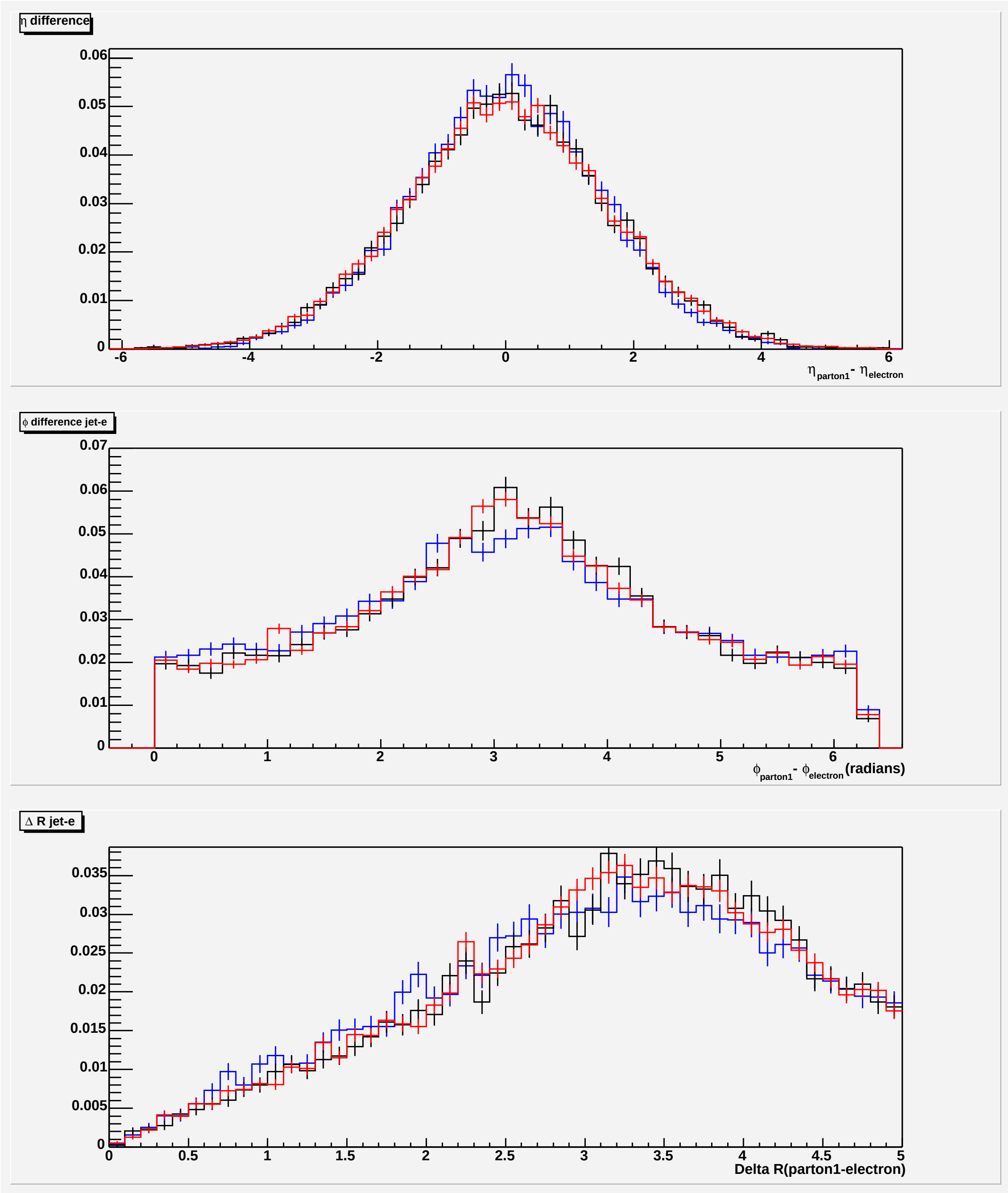

Figure 7: $\Delta\eta, \Delta\phi, \Delta R$ distributions for electron and highest energy parton for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

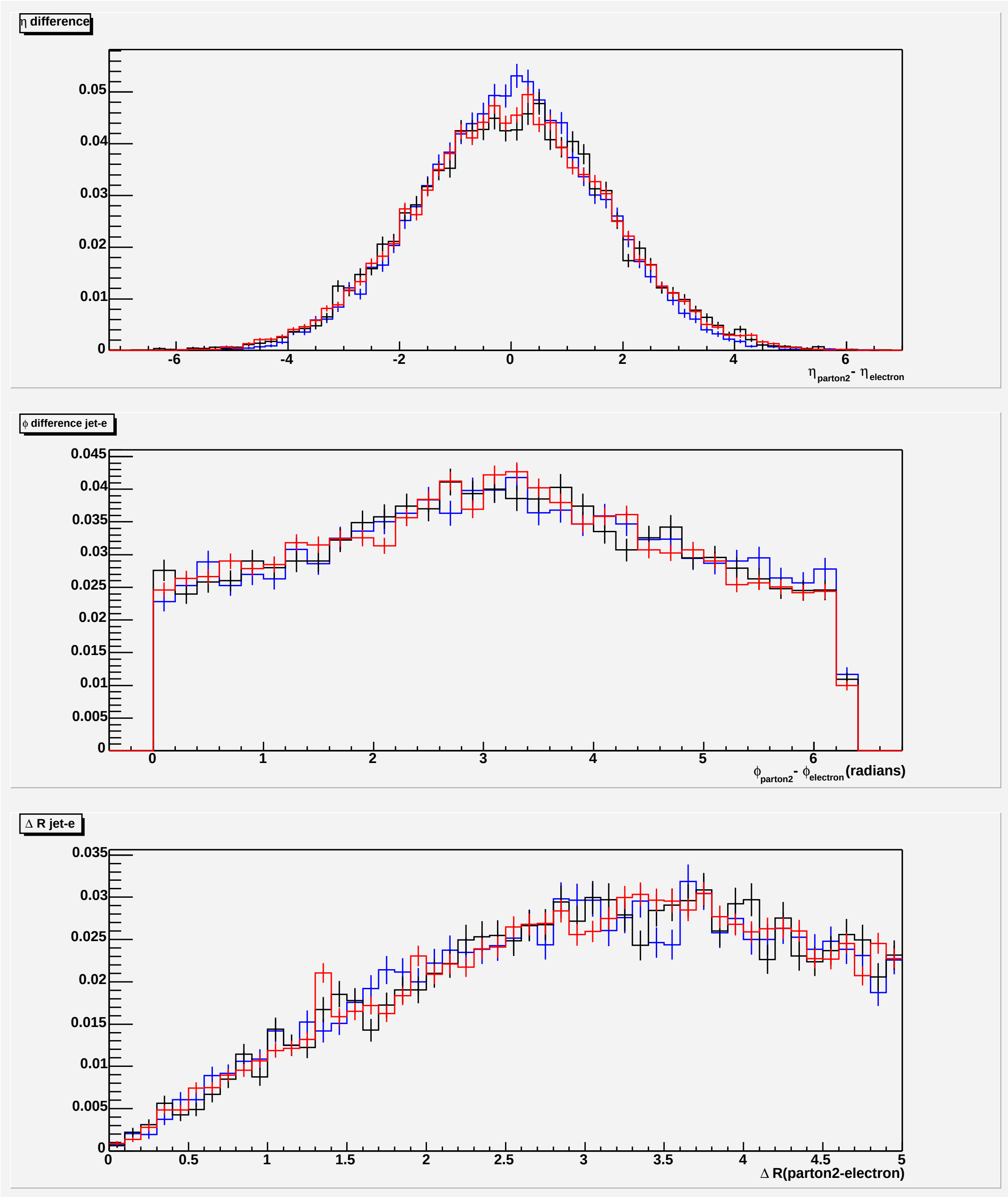

Figure 8: $\Delta\eta, \Delta\phi, \Delta R$ distributions for electron and second highest energy parton for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

GR@PPA $W + 3j$ which is $\approx 3\%$ low. In addition to overall rate agreement, several kinematic distributions were compared and no significant differences are found.

Acknowledgements

We thank Michelangelo Mangano, Soushi Tsuno, John Campbell, Keith Ellis, Steve Mrenna, Tim Stelzer and Fabio Maltoni for their continuous help and availability.

References

[1] CDF Note Number: CDF/PHYS//PUBLIC/6063. *Standardized Comparison of Matrix Element Monte Carlo Event Generators.* (Aug. 1, 2002)

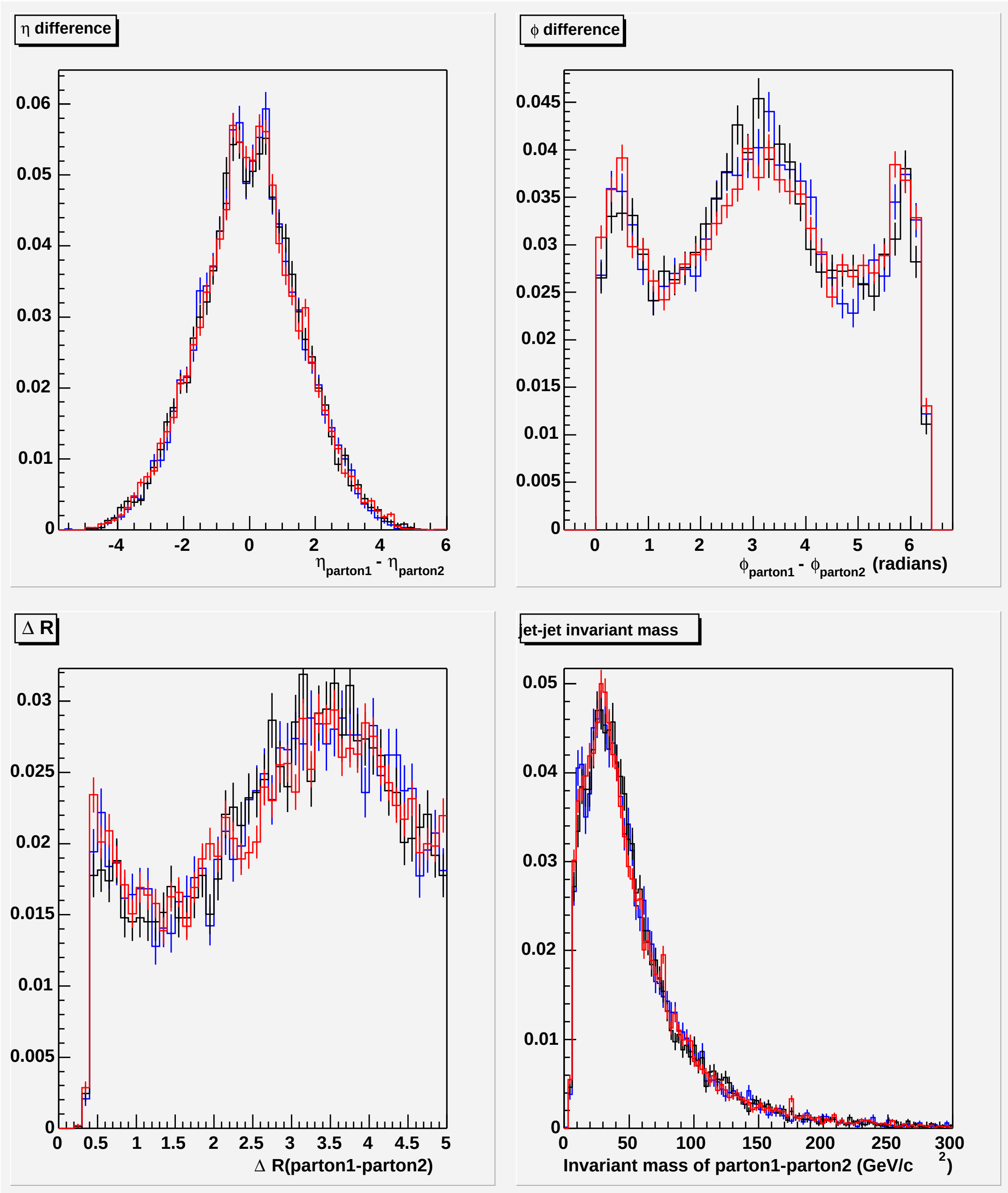

Figure 9: $\Delta\eta$, $\Delta\phi$, ΔR and invariant mass distributions for highest and second highest energy partons for $W \to e\nu + 2j$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

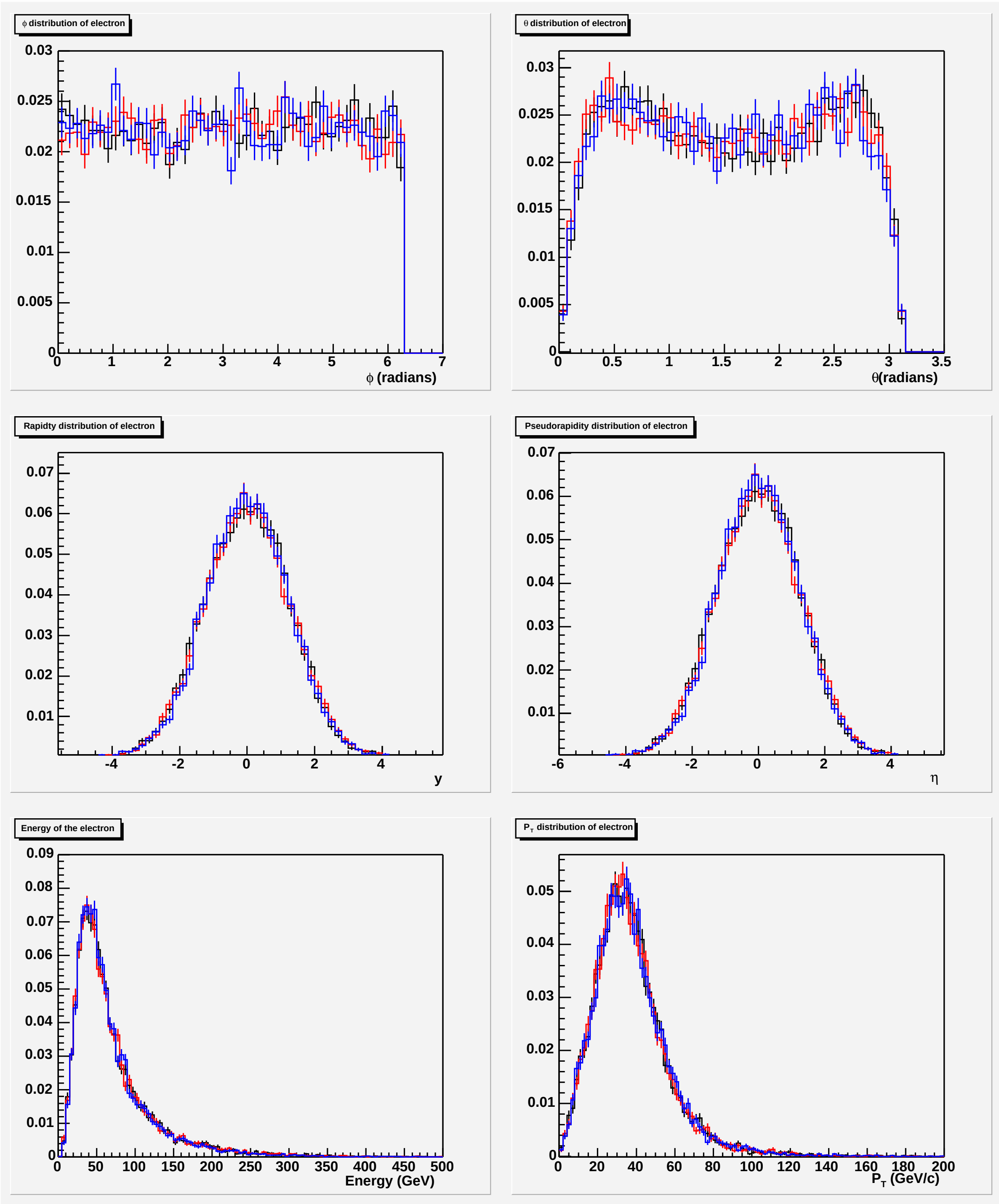

Figure 10: Electron ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for $W \to e\nu + b\bar{b}$. Black=ALPGEN, red=MadGraph, blue=GR@PPA. All histograms are unit normalized.

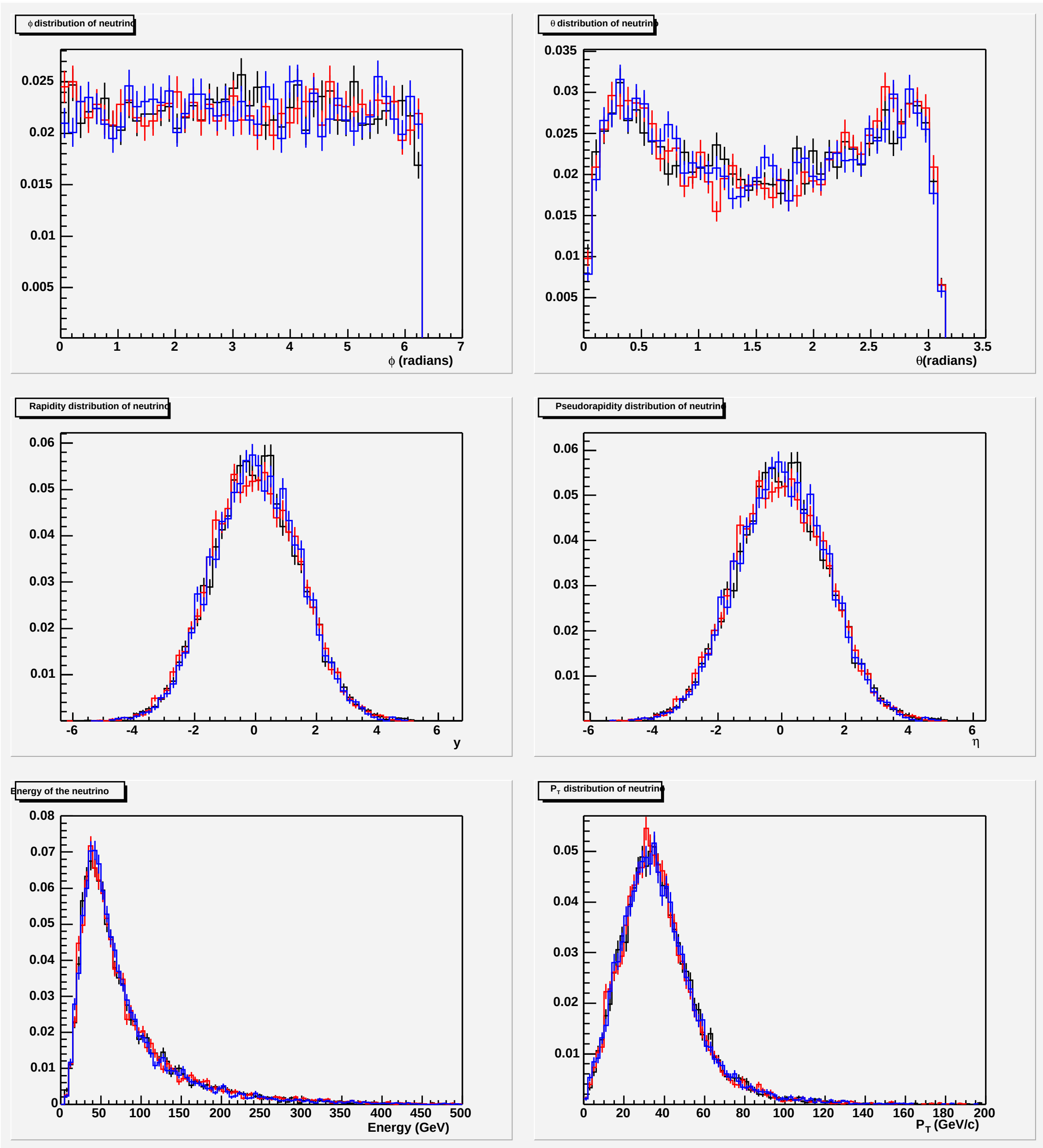

Figure 11: Neutrino ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

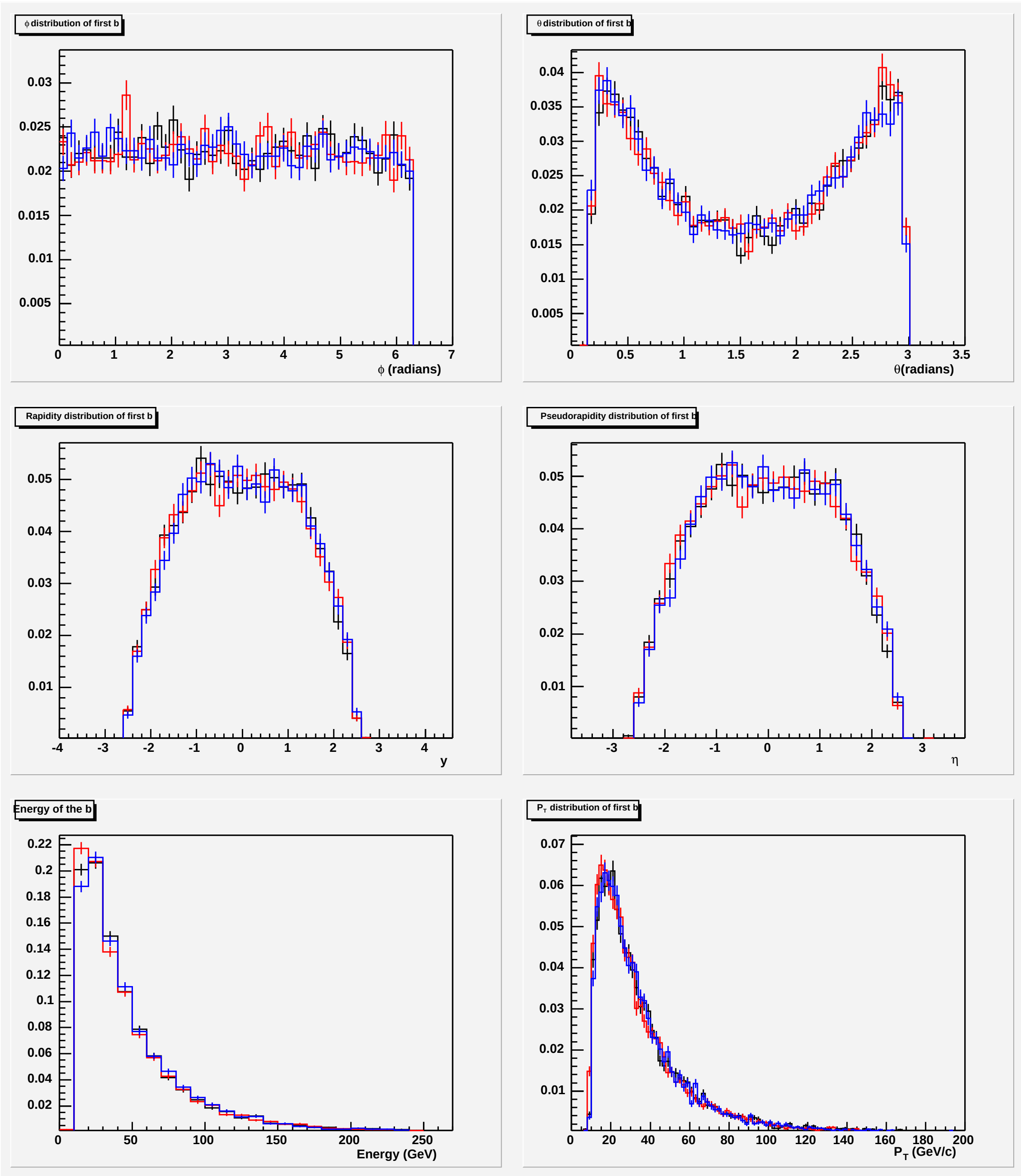

Figure 12: ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for the highest energy parton for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

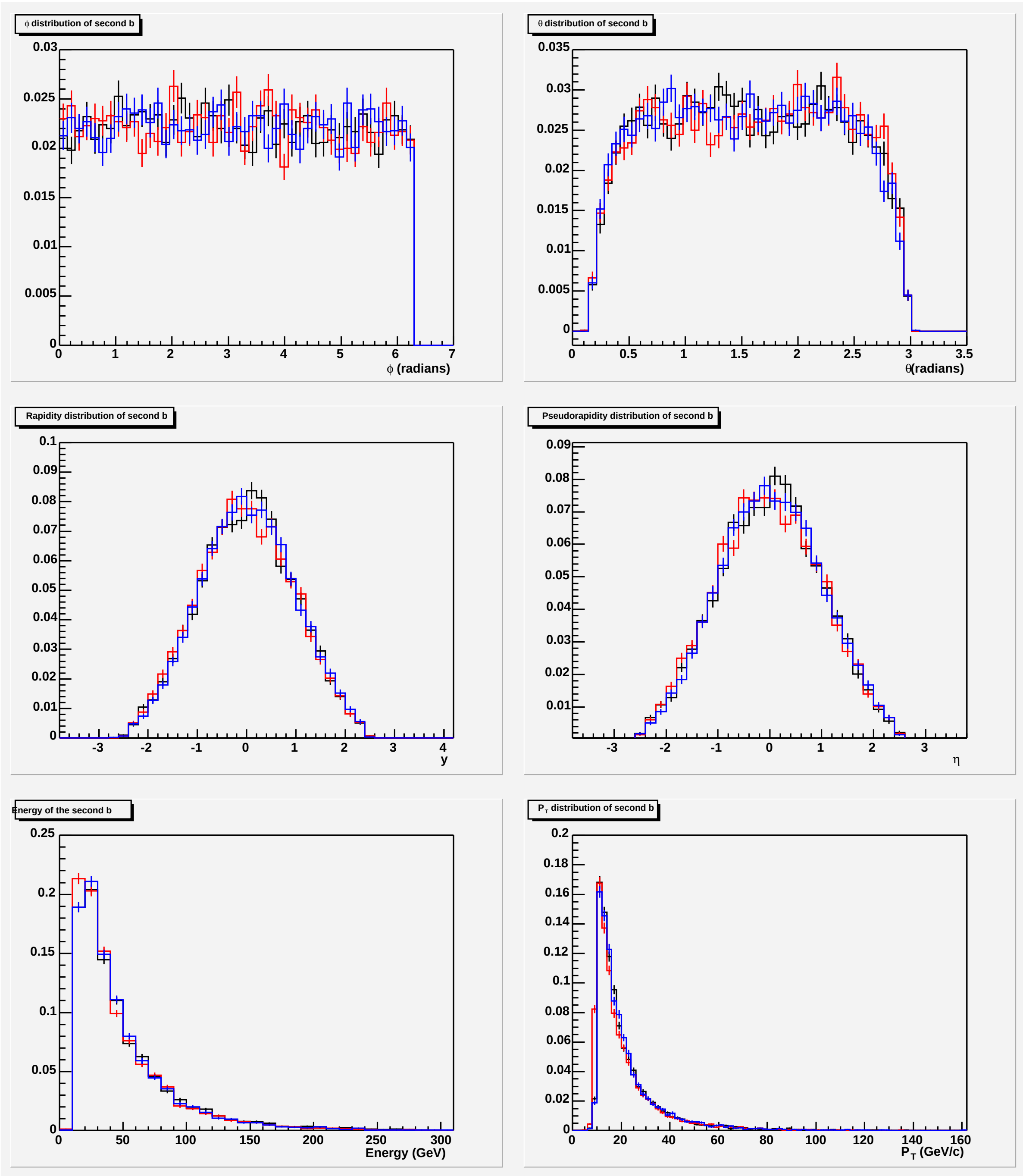

Figure 13: ϕ, θ, y, η, E and $\mathrm{P_T}$ distributions for the second highest energy parton for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

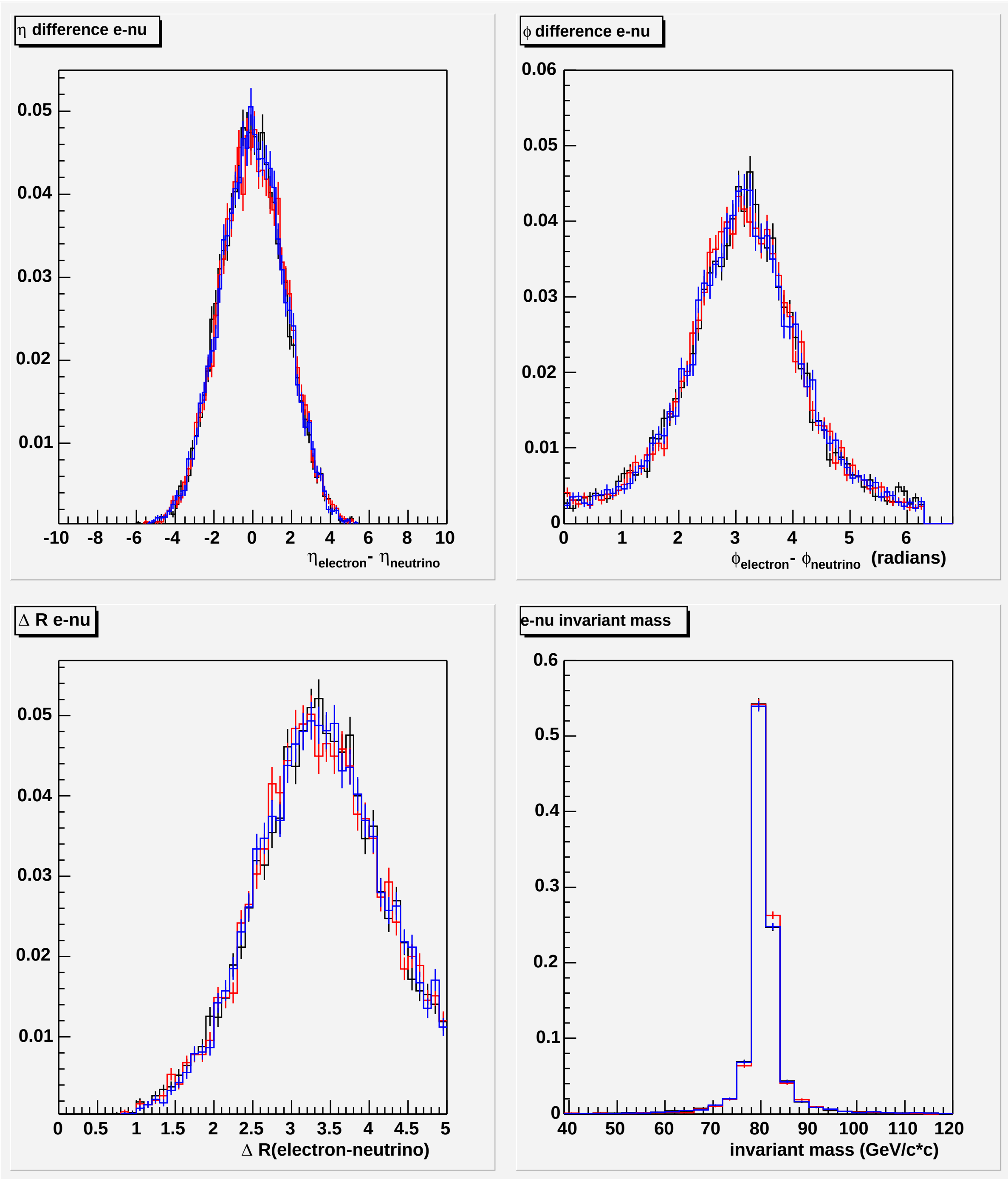

Figure 14: $\Delta\eta, \Delta\phi, \Delta R$ and invariant mass distributions for electron-neutrino for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

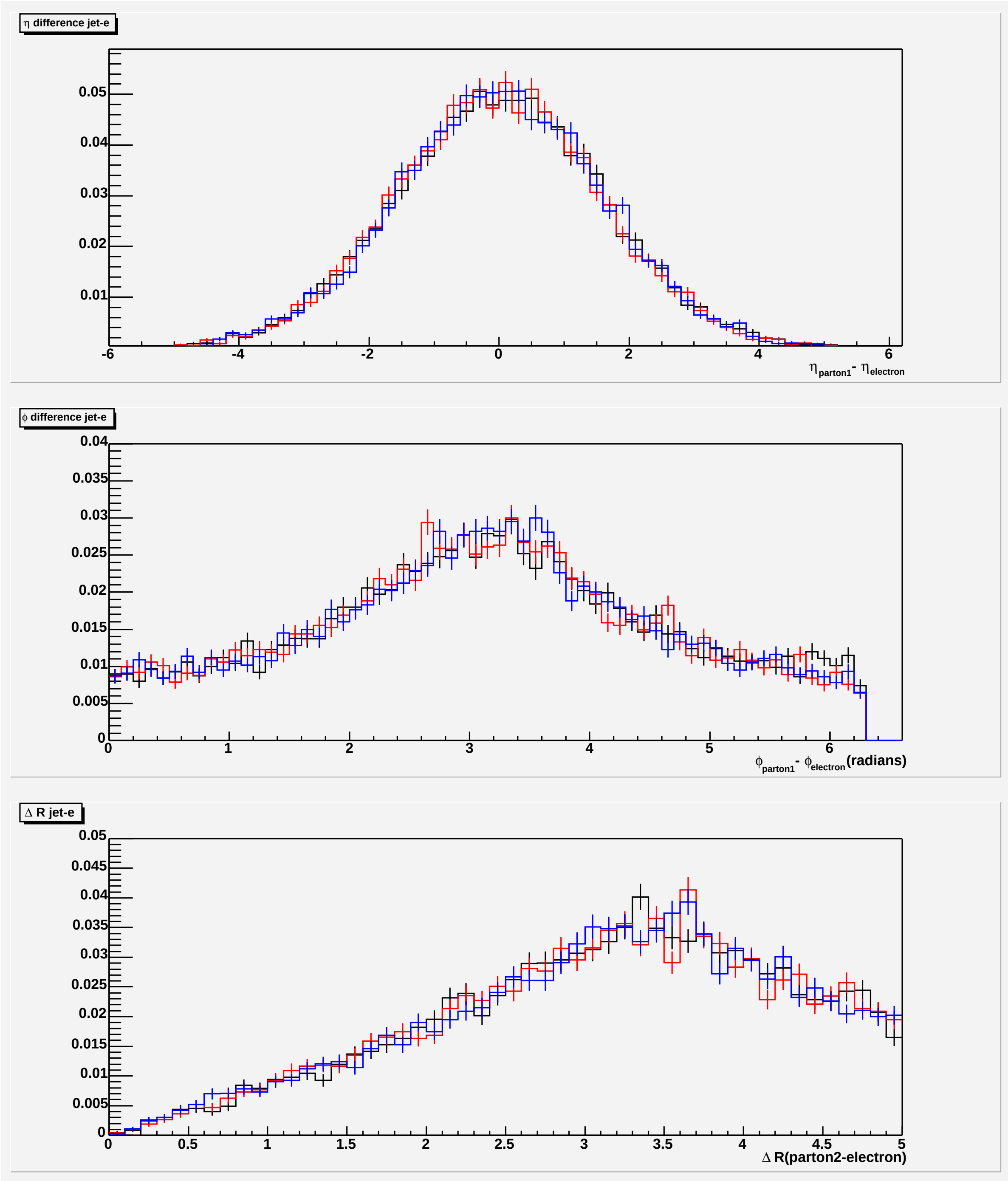

Figure 15: $\Delta\eta, \Delta\phi, \Delta R$ distributions for electron and highest energy parton for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

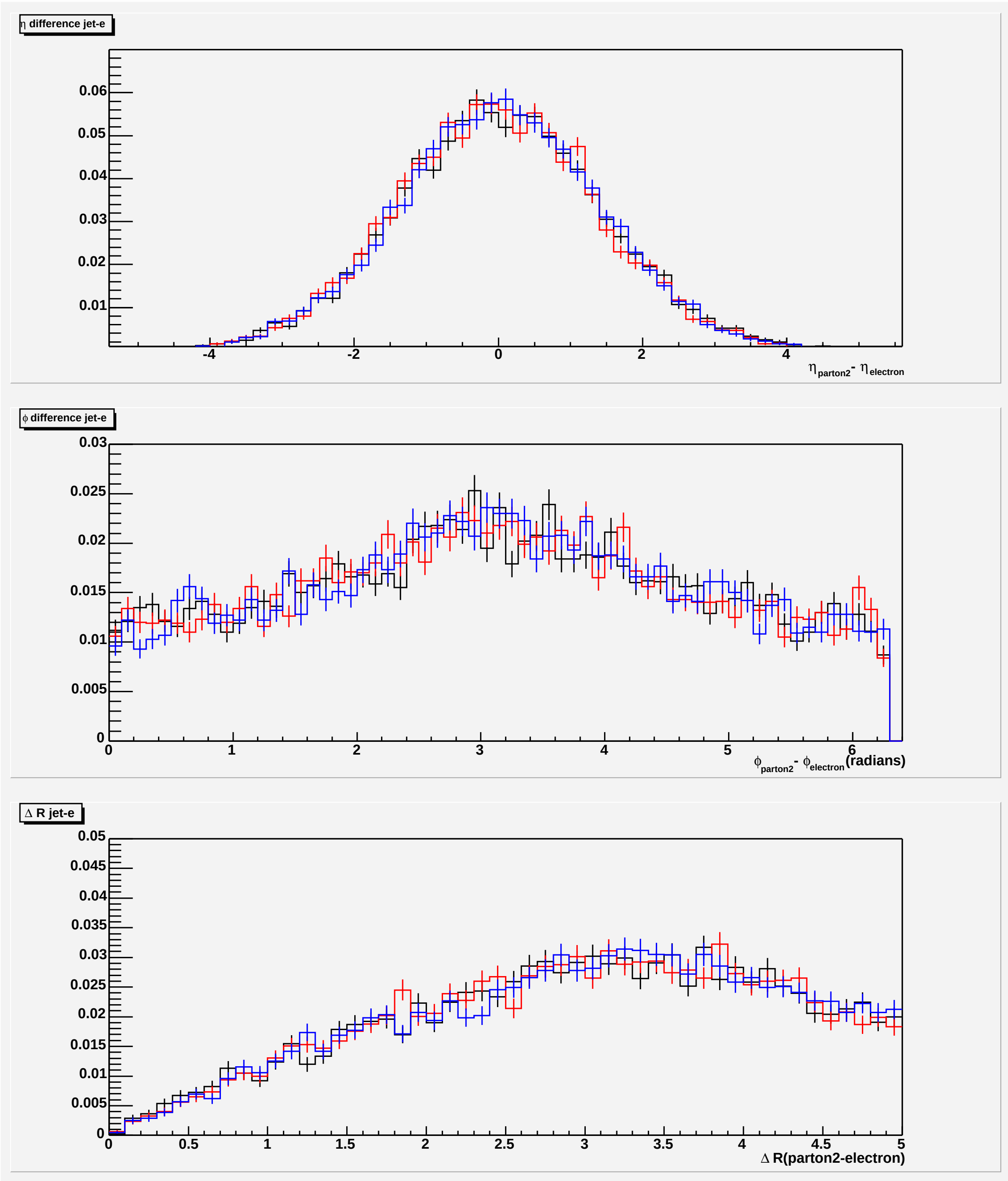

Figure 16: $\Delta\eta, \Delta\phi, \Delta R$ distributions for electron and second highest energy parton for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.

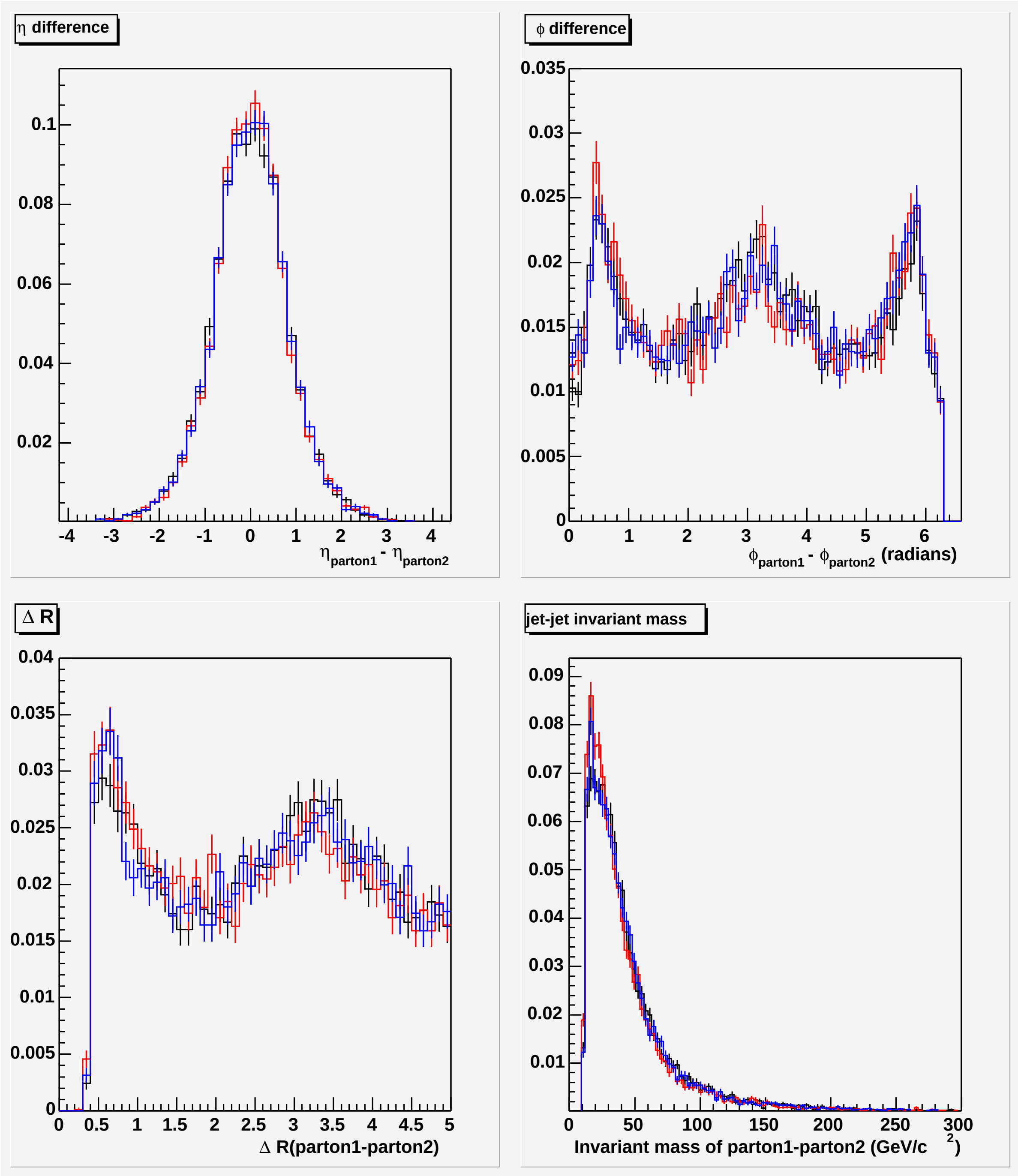

Figure 17: $\Delta\eta$, $\Delta\phi$, ΔR and invariant mass distributions for highest and second highest energy partons for $W \to e\nu + b\bar{b}$. Black=`ALPGEN`, red=`MadGraph`, blue=`GR@PPA`. All histograms are unit normalized.