Analysis of W+jets background to WW production

DESY Summer Student Programme, 2014

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Abstract

A new method to determine the W+jets background to WW production in proton proton collision is analyzed. The study is performed at the centre of mass energy of 8 TeV with the ATLAS experiment at the LHC and it takes advantage of the W boson charge asymmetry. ALPGEN and SHERPA Monte Carlo are compared and a cross check to data is performed. Different parton distribution function sets are used to reweight the distributions and evaluate systematic errors.

Contents

1 Introduction

During this DESY summer school I had the opportunity to join the ATLAS group working on the WW production at the LHC. WW production is an interesting process to study, bucause of its high sensitivity to the electroweak coupling. So far, the W+jets background has only been determined from MC, there was not really any cross check from data available. My work here consisted indeed in the investigation of the W+jets background through the analysis of charge asymmetry in W boson production arising from proton proton collisions. In particular, I compared different Monte Carlo and different parton distribution function sets.

2 The ATLAS experiment

The Large Hadron Collider (LHC), located near Geneva, Switzerland, is the world's largest particle collider. It accelerates and collides protons with unprecedented energies, allowing physicists to test the predictions of different particle physics theories.

ATLAS[1] (A Toroidal LHC Apparatus, Fig. 1) is one of the seven particle detector experiments at the LHC, the largest in size. It is intended to investigate many different physics phenomena that might become detectable in the energetic collisions of the LHC. Some of these are confirmations or improved measurements of the Standard Model, while many others are possible clues for new physical theories.

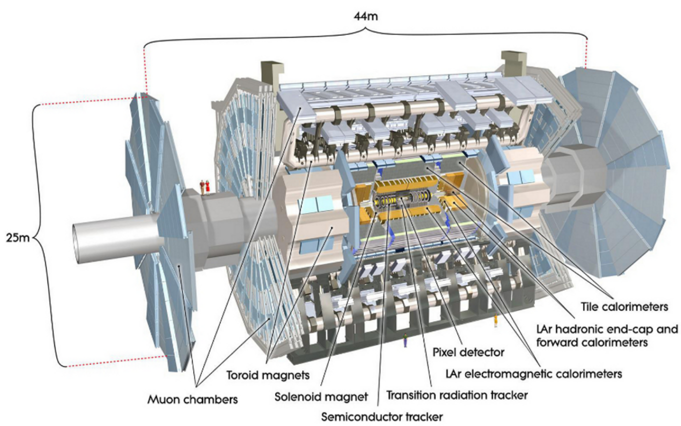

Figure 1: The ATLAS detector, image courtesy of ATLAS Experiment ©2012 CERN

The ATLAS detector is assembled in several layers around the nominal interaction point and symmetric in backward and forward direction along the beam pipe with respect to the interaction point. The detector consists of four main components: the inner detector measures the momentum of charged particles, the calorimiter measures the energies carried by the particles, the muon spectrometer identifies and measures the momenta of muons and the magnet system bends charged particles for momentum measurement. A right-handed coordinate system has the origin in the interaction point, the z-axis in the beam direction, the y-axis pointing upwards and the x-axis pointing towards the centre of the LHC ring; measuring these coordinates, it is easy to calculate the polar angles ϕ and θ. It is often useful to define[2] the pseudo-rapidity as

$$\eta = -\ln \tan \frac{\theta}{2}$$

and the distance ΔR in the η-ϕ space, that is

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

3 WW production

The aim of the analysis of the ATLAS group I worked in here in DESY is the measurement of WW production (Figure 2).

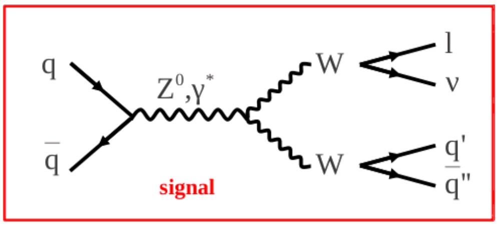

Figure 2: One of the possible processes that could lead to WW production

Indeed, the precise measurement of WW production is important since this kind of process is very sensitive to electroweak coupling: this enables having a better understanding of the Standard Model. Moreover, becouse of triple gauge couplings, these measurements could lead to the discovery of some new physical processes beyond the SM[3]. The main background processes are QCD, single top production and W+jets, which gives the largest contribution to the background. Thus, this analysis enables us to understand better the W+jets processes.

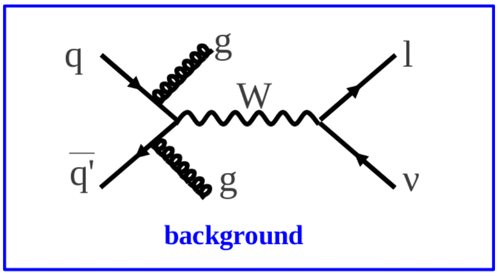

Figure 3: background (W+2jets)

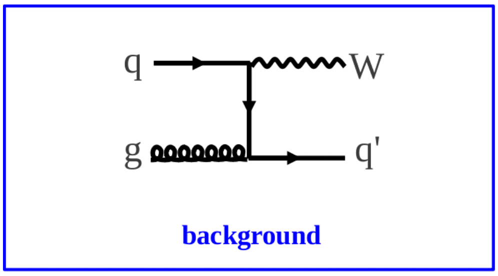

Figure 4: background (W+1jet)

Some examples of background processes are shown in Fig. 3 and Fig. 4. Specifically, the process in Fig. 3 may perfectly mimic the process shown in Fig. 2, since both of them have in the final state two jets, one charged lepton and missing energy. The difference is in the m_{jj} distribution, that is the invariant mass of the two leading jets, since for the signal there should be a peak around the W mass.

4 W+jets background

In this chapter charge asymmetry and its relation with the parton distribution function will be introduced. Then the concepts introduced are used for Monte Carlo and data analyses.

4.1 Charge Asymmetry in W boson production at LHC

The aim of this summer student project is the validation of MC and the analysis of the W+jets background distributions. For these analyses, the charge asymmetry in W boson production is a useful tool (charge asymmetry is defined as $A_W = \frac{N_{W^+} - N_{W^-}}{N_{W^+} + N_{W^-}}$)[4]. At pp colliders, the W^+ is most often made by an up and an antidown quark (depending on the PDF product $u(x_1)\bar{d}(x_2)$), while the W^- is most often made by an antiup and a down quark (depending on the PDF product $d(x_1)\bar{u}(x_2)$). A charge asymmetry in the production rate arises, since in protons there are two valence up quarks and only one valence down quark in a sea of quark-antiquark pairs and gluons. Thus, more positive W bosons are produced compared to negative W bosons. At LHC the cross section for W boson production can be expressed at leading order in QCD as:

$$\sigma_{pp\to W} = \sum_q \sum_{\bar{q}'} \int \mathrm{d}x_1 \mathrm{d}x_2 f_q(x_1, Q^2) f_{\bar{q}'}(x_2, Q^2) \sigma_{q\bar{q}'\to W}(x_1 x_2)$$

where $f_q(x_1, Q^2)$ is the parton distribution function (PDF) for quark q, x_1 and x_2 are the longitudinal momentum fractions of the partons, $\sigma_{q\bar{q}'\to W}$ is the partonic cross section and the sums run over all quark and antiquark flavours[1].

Charge asymmetry can be determined by counting the number of W^+ bosons and W^-. Actually, for this project, only W bosons dacaying in muons have been considered, therefore $N_{W^\pm} = N_{\mu^\pm}$. This is simply because muons are good tags for W bosons, while electrons have a higher mismatch probability.

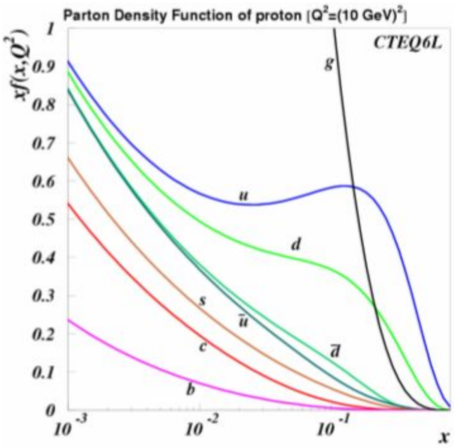

Figure 5: Parton distribution functions

4.2 Monte Carlo analysis

The first step was looking at the asymmetry in the m_{jj} distributions[2] obtained with different Monte Carlo event generator (ALPGEN and SHERPA). For ALPGEN, Np0, Np1, Np2, Np3 and Np4 samples [3] have been included, while for SHERPA only the cjet-veto b-veto sample was considered, because of some problems with the luminosity weight in the other SHERPA samples. Later also POWHEG samples for single top and ttbar background have been included. As can be seen in Fig. 6, there is no asymmetry in the $t\bar{t}$ sample which is, as expected, charge symmetrical. Also the single top seems to have a negligible asymmetry. It is a reasonable assumption that Z+jets and QCD backgrounds are charge symmetrical. ALPGEN and SHERPA asymmetries seems to have the same shape, even if they are shifted: this is because the two MCs use different PDF sets, obtained from different data sets. Anyway, we are interested in the shape of the asymmetries: in the following calculations, I shifted all the correction factor, so that they have the same value in the first bin, in other words I assume that they are consistent with the data I will use in the analysis. Referring to Eq.4.2, asymmetry is used to compare MCs with each other and with data calculating:

- the difference $(N_{W^+} - N_{W^-})$, token from data,
- a correction factor, that is the inverse ratio of the asymmetry, obtained for each MC,

[1] Actually the sums run over gluons too. At leading order this is negligible
[2] m_{jj} is the invariant mass of the two leading jets.
[3] where "Npi" means that in that sample there are i jets

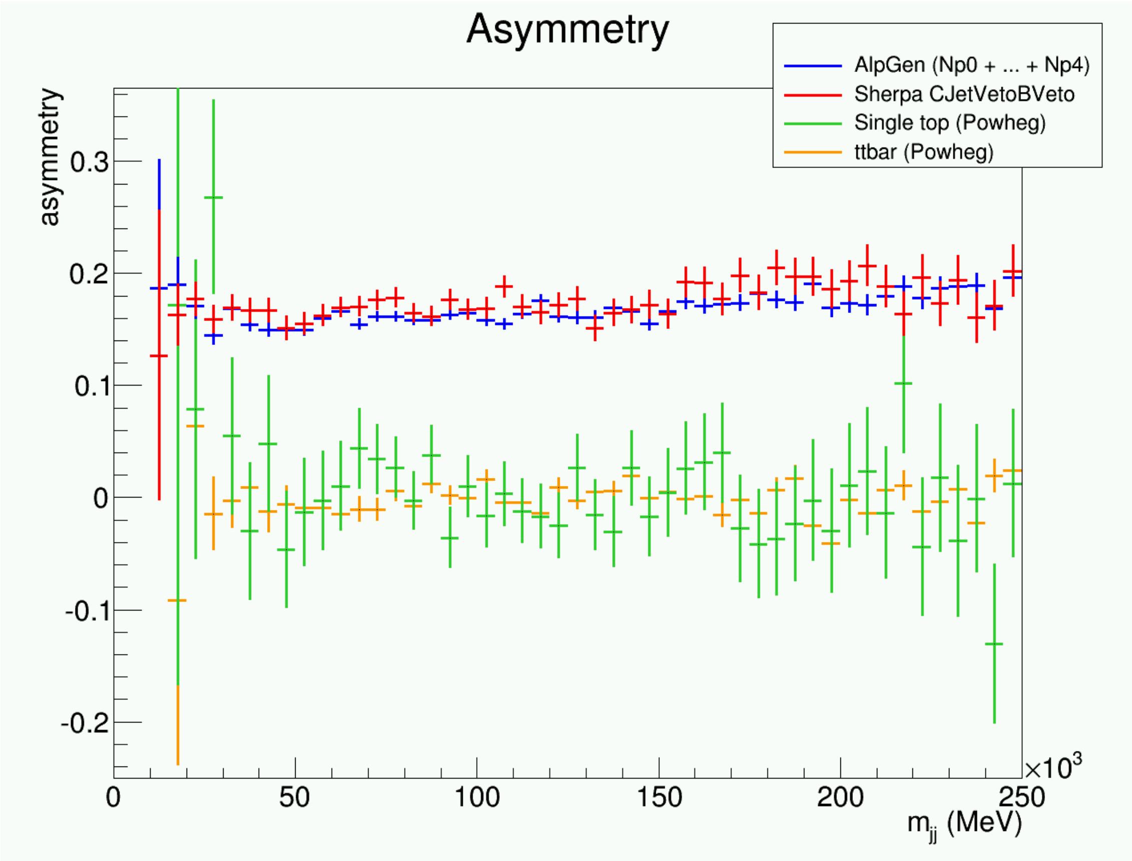

Figure 6: Asymmetry as function of m_{jj} for the different event generators.

With these two items we can calculate the sum $(N_{W^+} + N_{W^-})$ for each correction factor and compare it to the sum obtained from data.

$$\underbrace{N_{W^+} + N_{W^-}}_{\text{Total W+jets production}} = \underbrace{\left(\frac{N_{W^+} + N_{W^-}}{N_{W^+} - N_{W^-}}\right)}_{\text{Correction Factor (W+jets MCs)}} \cdot \underbrace{(N'_{W^+} - N'_{W^-})}_{\text{Measure from data}}$$

In Fig.7 is shown the comparison between the data corrected with ALPGEN and with SHERPA and the corrisponding MC distributions.

In addition to m_{jj}, other variables have been examined, such as the ΔR and the $\Delta\phi$ of the two leading jets. In Fig.8 is shown the ΔR for ALPGEN and SHERPA, while in Fig.9 the $\Delta\phi$'s for ALPGEN and SHERPA are compared to data. In Fig.10 are shown the asymmetries as functions of $\Delta\phi$ calculated for ALPGEN and SHERPA.

It is useful to have a look at the ratio between the asymmetries obtained with ALPGEN and SHERPA (Fig.**??**, so that potential differences are amplified.

5 PDF reweighting

The last part of this work concerns the analysis of different PDF sets. Specifically, the m_{jj} distribution have been reweighted in respect to different PDF sets (n.b. this analysis have been applied only to the SHERPA sample). The PDF sets used[5][6] are:

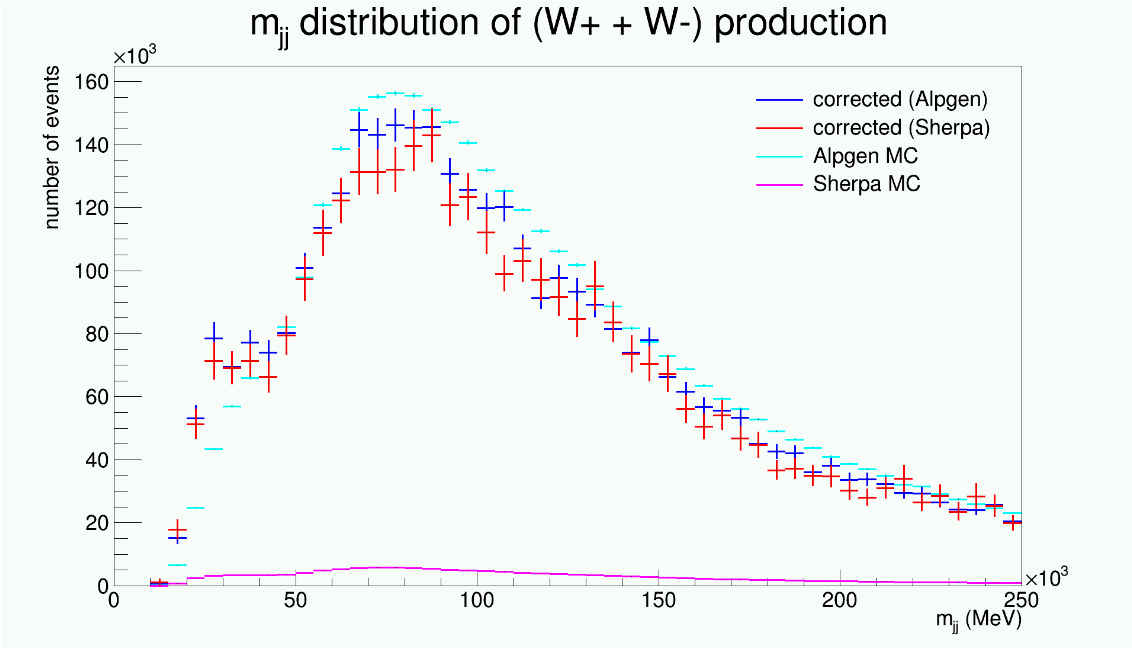

Figure 7: Total W+jets production distribution as function of m_{jj}, corrected with ALPGEN and with SHERPA.

- CT10,
- MSTW 2008,
- HERA PDF 1.5,
- NN PDF 2.3.

A parton distribution function $f_i = f_i(x_i, Q^2)$ is defined as the probability density for finding the i-flavour parton with momentum fraction x_i at resolution scale Q^2. We define:

$$\sigma_{CT10} = \sigma_{i,j}(x_i, x_j, Q^2) f_i f_j$$

$$\sigma_P = \sigma_{k,l}(x_k, x_l, Q^2) f'_k f'_l$$

where P can be MSTW2008, HERAPDF15 or NNPDF23, and i, j, k, l identify the parton.

The reweighting is done in the following way:

$$\sigma_P = \sigma_{CT10} \left(\frac{f'_k f'_l}{f_i f_j} \right)$$

This is possible because, even if in the next-to-leading order the functions don't factorize, the non-factorizing term is negligible compared to the PDF reweighting errors. In the histograms plotted in Fig.11,12,13,14 it is shown the m_{jj} distribution reweighted with respect to the different PDF sets considered in this analysis. After this reweighting, we can compare the original asymmetry with the reweighted ones. This is what is done in Fig.15,16,17: in the left hand plots, the original asymmetry as function of m_{jj} is compared to the asymmetry reweighted to an other PDF set, while in right hand the ratio between these two asymmetries is plotted.

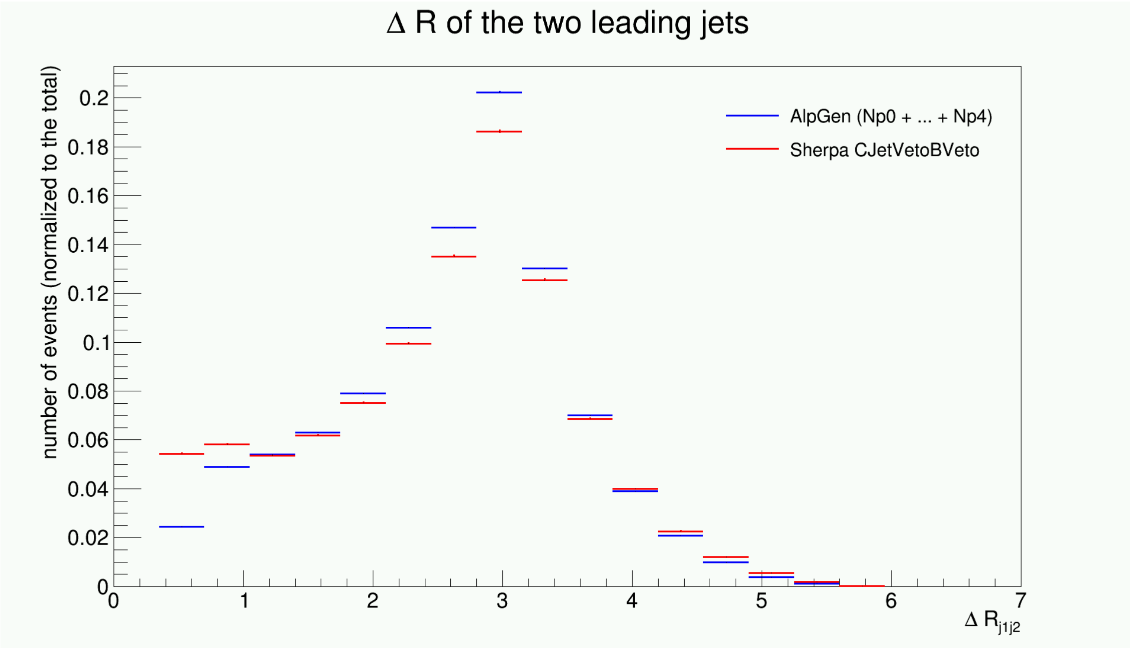

Figure 8

6 Conclusion

Two main noteworthy results of this projects are:

- ALPGEN and SHERPA show some discrepancy sometimes, because they are different implementation of the same leading order calculations. Still comparing them to data, they show the same decent agreement, so it is reasonable to use both of them in the analyses.
- different PDF sets lead to slightly different m_{jj} distribution, in particular HERAPDF 1.5 seems to show the biggest difference. This should be taken into account in the analysis of the W+jets background.

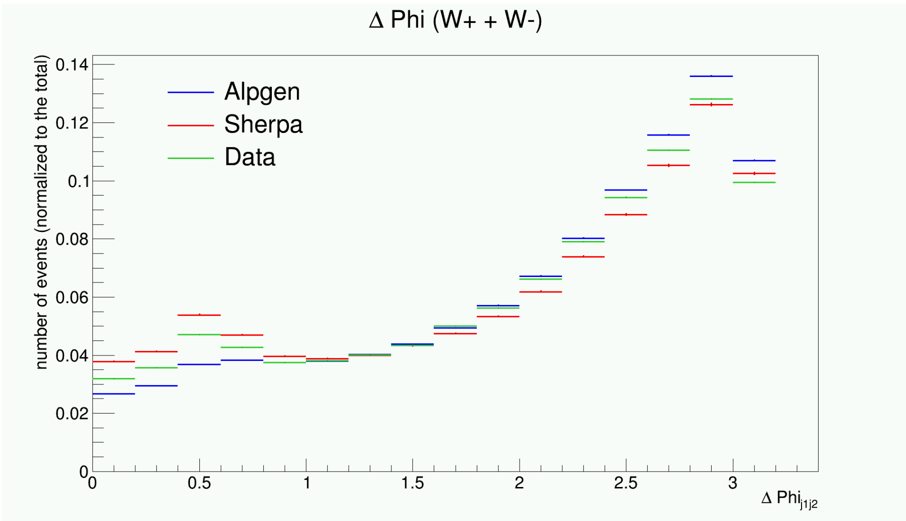

Figure 9: $\Delta\phi$ distribution obtained from data, compared with the same distribution obtained from ALPGEN and SHERPA.

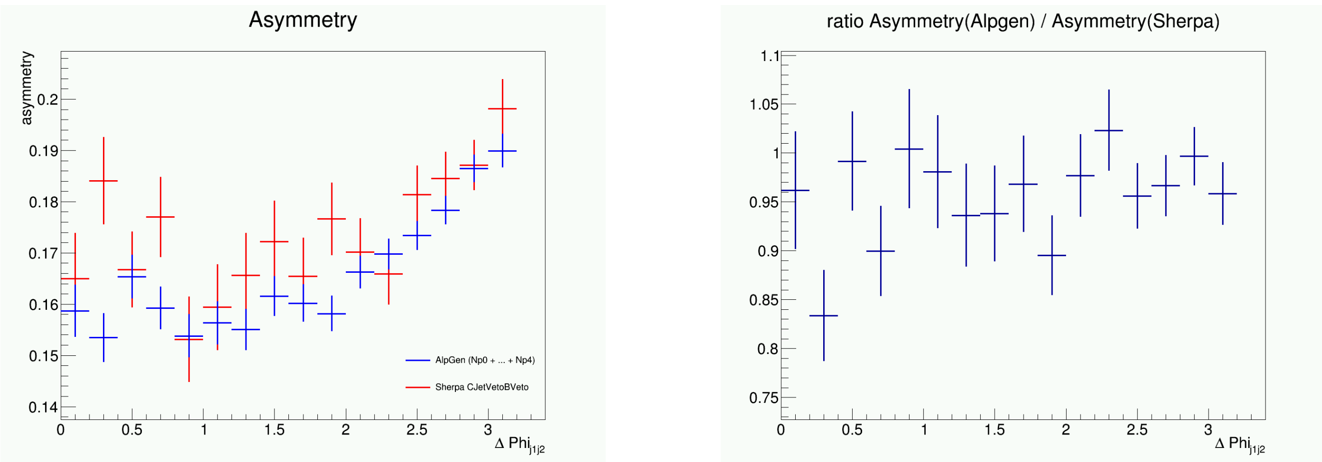

Figure 10: Left side: asymmetry as function of $\Delta\phi$ for ALPGEN and SHERPA. Right side: ratio of ALPGEN asymmetry to SHERPA asymmetry as function of the $\Delta\phi$ of the two leading jets.

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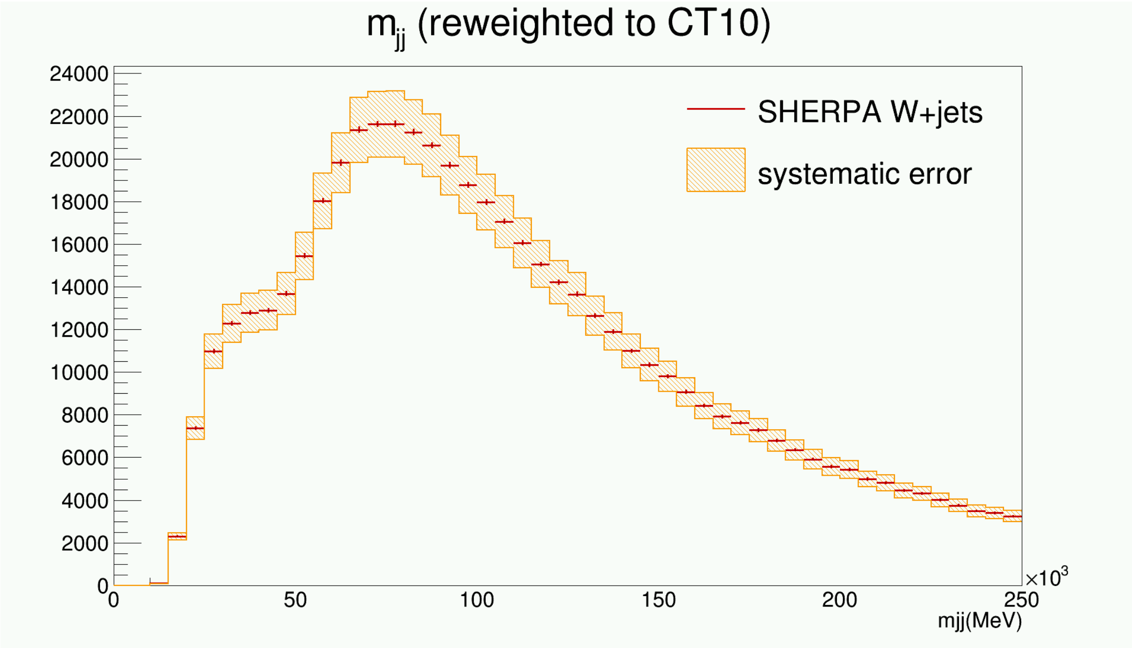

Figure 11

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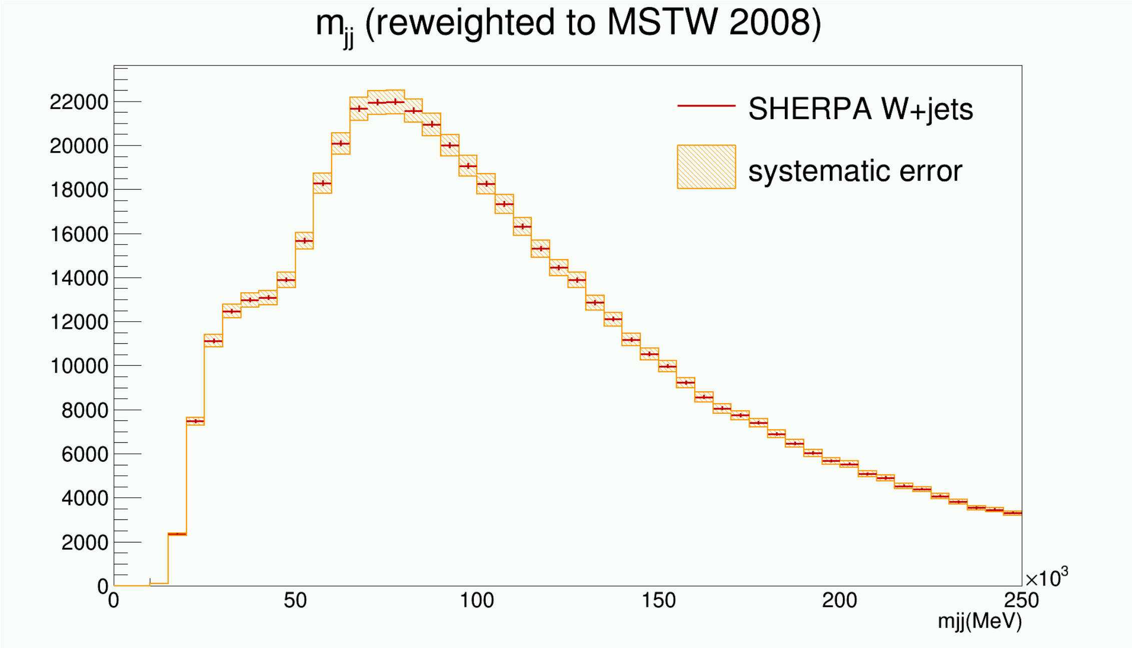
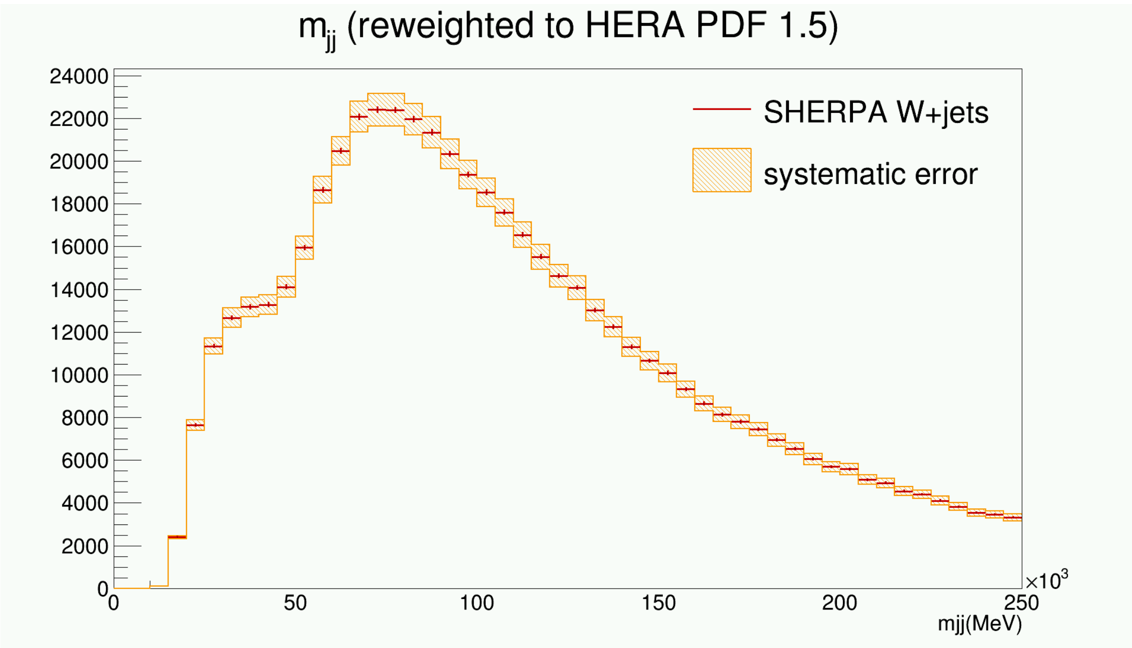


Figure 12



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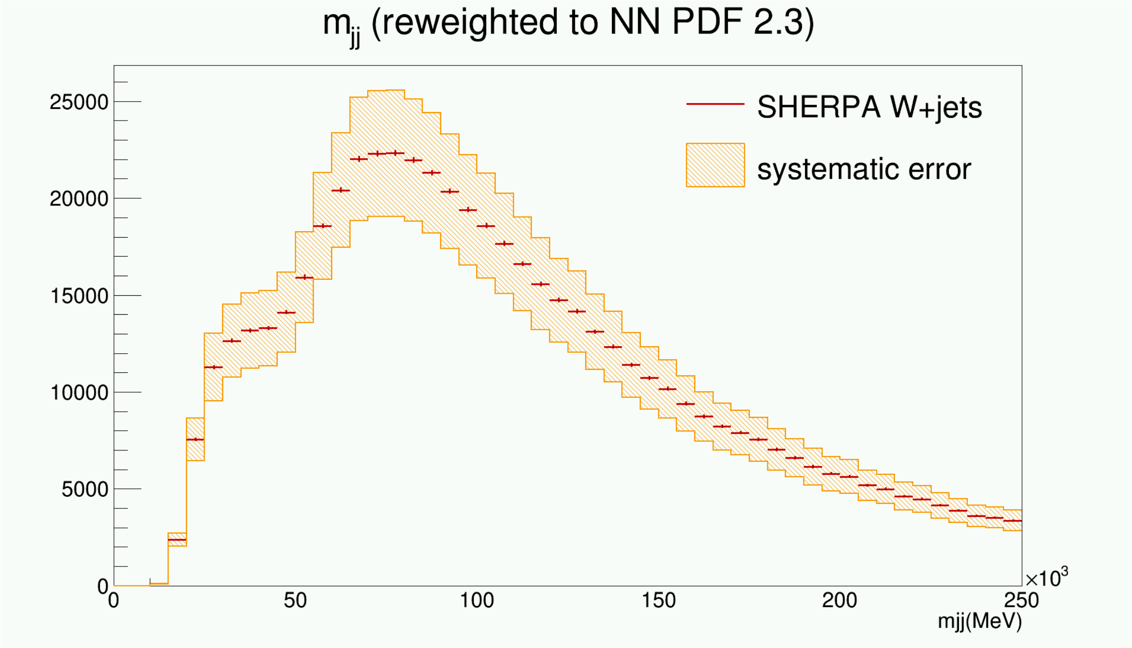

Figure 14

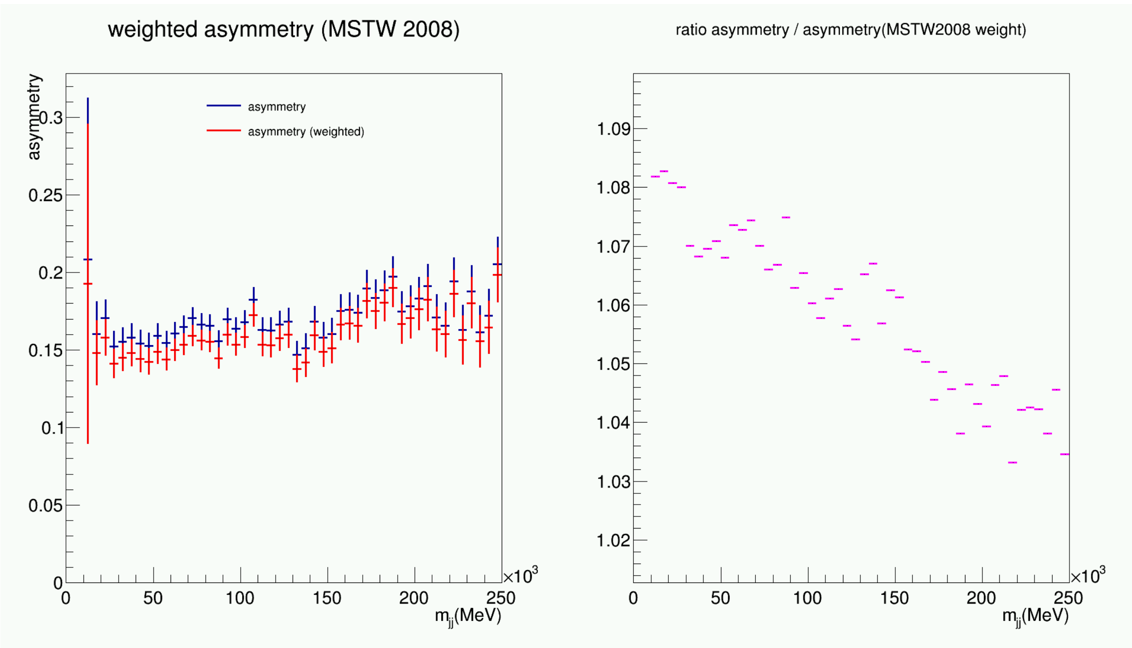

Figure 15

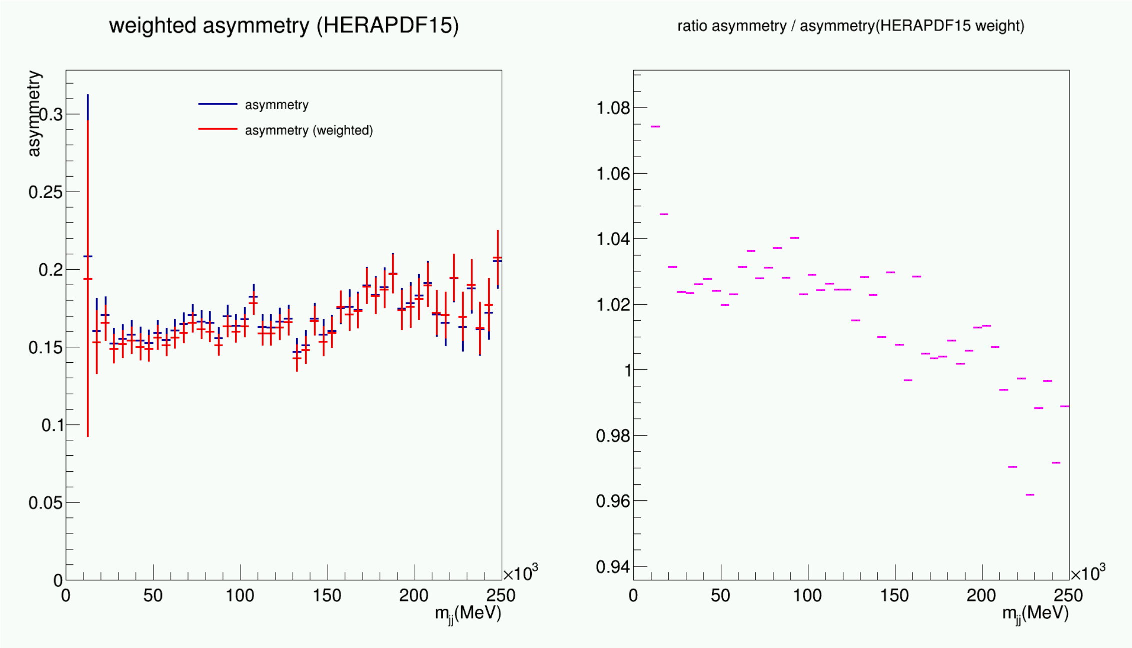

Figure 16

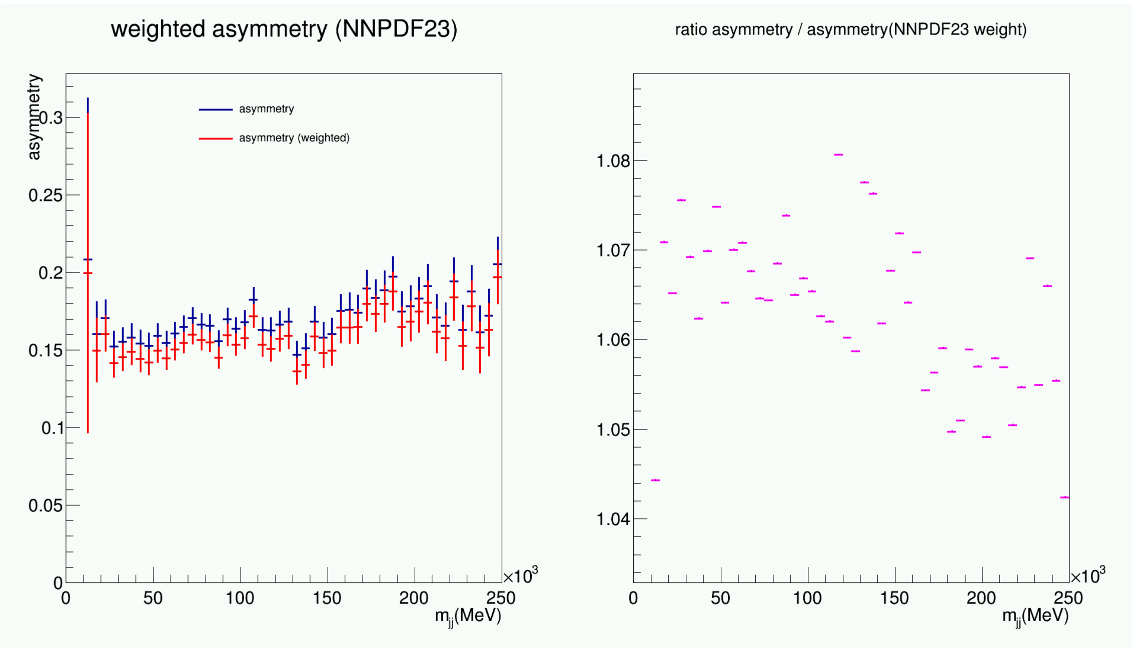

Figure 17