PROCEEDINGS OF SCIENCE

Dijet angular distributions at $\sqrt{s} = 14$ TeV

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We present a Monte Carlo study of dijet angular distributions at $\sqrt{s} = 14$ TeV. First we perform a next-to-leading order QCD study; we calculate the distributions in four different bins of dijet invariant mass and investigate the systematic uncertainties coming from the choice of the parton distribution functions and the renormalization and factorization scales. In the second part, we present the effects on the distributions coming from a model including gravitational scattering and black hole formation in a world with large extra dimensions.

The 2009 Europhysics Conference on High Energy Physics,
July 16 - 22 2009
Krakow, Poland

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1. Introduction

Jet production is the most dominant hard process in hadron collision experiments. While jets are background for many new physics searches, jets can also be used as a signal, both for probing QCD and for physics beyond the Standard Model. Because of their rich abundance, many jet studies can be performed with little integrated luminosity.

The dijet angular distribution between the two hardest jets in the event has proven to be a very useful measurement [1, 2, 3, 4]; at low integrated luminosity it is a good tool to probe QCD, while with more statistics, a search for new physics, such as effects coming from large extra dimensions, becomes possible.

This paper is about dijet angular distributions at $\sqrt{s} = 14$ TeV. First, we will perform a QCD study; we will calculate the distributions up to NLO and make an estimate of the systematic uncertainties. In the second part, we present the effects on the distributions coming from a model including gravitational scattering and black hole formation in a world with large extra dimensions.

2. Dijet angular distributions

The study of the angular behavior is done using the variable $\chi = \exp(|\eta_1 - \eta_2|)$, with η_1 and η_2 the pseudorapidities of the two hardest jets. The dijet angular distribution is the cross section $\mathrm{d}\sigma/\mathrm{d}\chi$ vs χ in bins of dijet invariant mass (M_{jj}), which is almost flat for QCD. On the other hand, new physics processes often generate more isotropic events, which causes the dijet angular distributions to peak at low χ. More precisely, $\mathrm{d}\sigma/\mathrm{d}\cos\hat{\theta} \sim$ flat, with $\hat{\theta}$ the scattering angle in the center of mass frame, transforms as $\mathrm{d}\sigma/\mathrm{d}\chi \sim 1/(\chi+1)^2$.

The following four mass bins were chosen for this study at $\sqrt{s}$=14 TeV: $0.5 < M_{jj} < 1$ TeV, $1 < M_{jj} < 2$ TeV, $2 < M_{jj} < 3$ TeV and 3 TeV $< M_{jj}$. Furthermore we require $|\eta_1 + \eta_2| < 1.5$.

3. QCD calculations

Two programs are available for NLO jet calculations: JETRAD [5] and NLOJET++ [6]. It was found that the programs are consistent with each other. Fig. 1 compares a calculation at the Born level with NLO calculations, done with JETRAD, for the four different mass bins and for $\chi < 600$. Two different jet algorithms are used; a seeded cone algorithm with radius R = 0.7, and an inclusive k_T algorithm with radius parameter R = 1.0. Note that in a LO parton level calculation, the outgoing partons are back-to-back, so that a jet algorithm is redundant. The NLO angular distributions with the two different jet algorithms tend to have the same shape, but differ in absolute normalization. The angular distributions at NLO are more flat than the Born calculations, especially at large values of χ ($\chi > 100$), which is mainly caused by the fact that the running of α_s has less effect on NLO than on LO calculations.

Uncertainties coming the choice of renormalization (μ_R) and factorization (μ_F) scale and from parton distribution functions (PDFs) will contribute to a systematic error. The PDF uncertainties are provided by the CTEQ66 PDF error members [7], and the error coming from the scales is obtained by varying (μ_R) and (μ_F) independently around the central value $\mu_R = \mu_F = p_T$ of the hardest jet in the range 0.5, 1.0 and 2.0 $\times p_T$. The quadratic sum is displayed as an error band in

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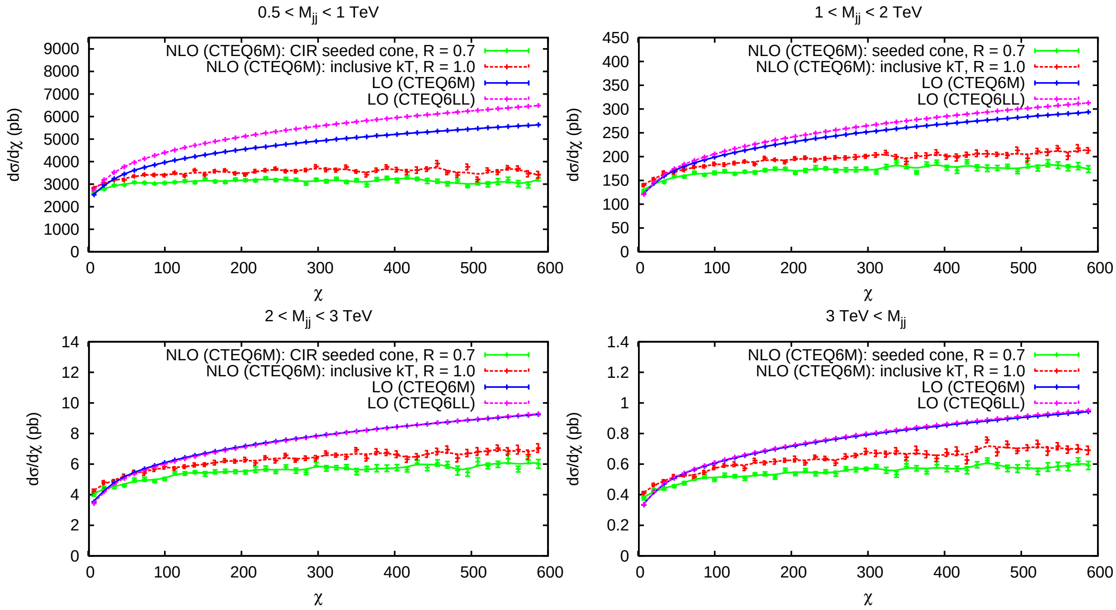

Figure 1: LO and NLO angular distributions calculated with JETRAD for 4 different mass bins. The NLO calculations are done with two different jet algorithms: a seeded cone algorithm with radius R = 0.7, and an inclusive k_T algorithm with radius parameter R = 1.0.

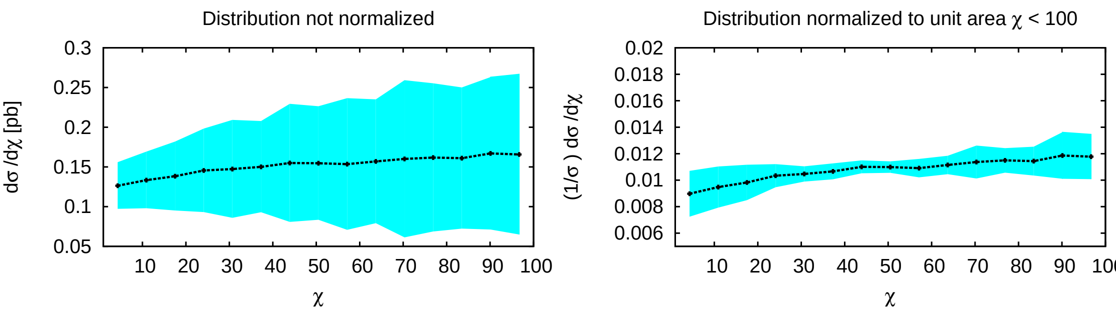

Figure 2: Black line: calculation done with the central member of the CTEQ66 PDF and $\mu_R = \mu_F = p_T$ of the highest jet, both without (left plot) and with (right plot) normalization to unit area $\chi < 100$. Blue band: error band from combining the uncertainties coming from the choice of renormalization and factorization scale, together with the intrinsic uncertainty from the CTEQ66 PDF.

Fig. 2 for the mass bin $1 < M_{jj} < 2$ TeV, both for the distributions without (left plot) and with (right plot) normalization to unit area $\chi < 100$. In both cases, the renormalization scale introduces the major uncertainty.

4. Gravitational scattering and black hole formation in large extra dimensions

The ADD model [8] assumes the existence of large extra spatial dimensions in which gravity

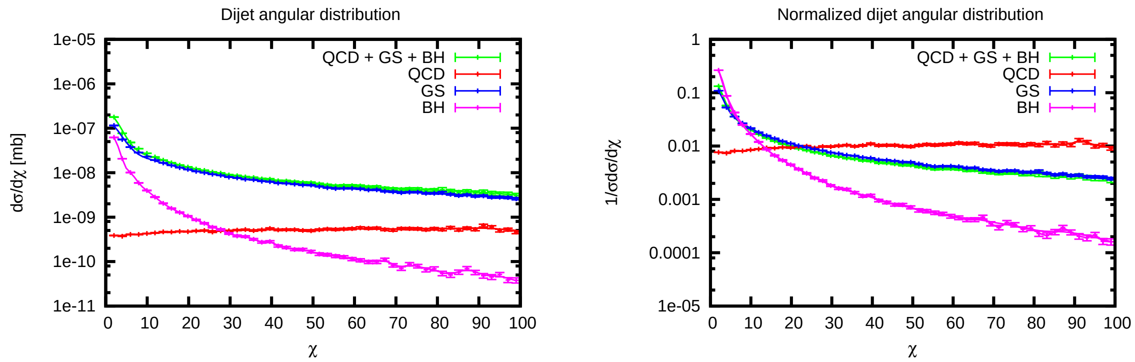

Figure 3: Expectations for the mass bin 3 TeV $< M_{jj}$, for a scenario with 6 extra dimensions and $M_P \approx 1$ TeV. Left: cross section in mb, right: cross section normalized to unit area $\chi \leq 100$.

is allowed to propagate, while the SM fields are confined to a four-dimensional membrane, which causes the fundamental Planck scale M_P to be much smaller than the observed 4-dimensional one.

For a fundamental Planck scale of around 1 TeV, the ADD model predicts the production of extra dimensional black holes at the LHC. Besides black holes, also processes involving the exchange of virtual Kaluza-Klein (KK) modes, with gravitational scattering of hard partons as dominant process, will be present.

Gravitational scattering in hadron collisions was studied in [9, 10, 11] by means of an effective field description. This was implemented in the PYTHIA 6.410 [12] event generator and combined with the CHARYBDIS [13] black hole generator, in a similar way as in [14]. Fig. 3 shows the parton level expectations for the mass bin 3 TeV $< M_{jj}$, both on the distributions without (left plot) and with (right plot) normalization to unit area $\chi \leq 100$, for a scenario with 6 extra dimensions and $M_P \approx 1$ TeV. The different contributions —gravitational scattering (GS), black holes (BH) and QCD— are plotted separately, as well as their sum. The QCD cross section is scaled with the so-called K-factor which is defined as the ratio $(d\sigma_{\mathrm{NLO}}/d\chi)/(d\sigma_{\mathrm{LO}}/d\chi)$. New physics effects are clearly visible.

5. Conclusions

We have discussed dijet angular distributions at $\sqrt{s} = 14$ TeV in the context of QCD and new physics.

NLO QCD calculations in four bins of dijet invariant mass were presented, as well as the systematic uncertainty coming from the renormalization and factorization scale and from parton distribution functions.

For a fundamental Planck scale of about 1 TeV, effects from gravitational scattering and black hole formation in large extra dimensions are expected to be visible in the higher dijet mass bins.

A detailed study can be found in [15].

Acknowledgments

The author wishes to thank Torbjörn Sjöstrand, Torsten Åkesson and Leif Lönnblad for the many useful discussions.

References

[1] UA1 Collaboration: G. Arnison *et al.*, *Phys. Lett.*, **B136** (1984) 294; G. Arnison *et al.*, *Phys. Lett.*, **B158** (1985) 494; G. Arnison *et al.*, *Phys. Lett.*, **B177** (1986) 244.

[2] UA2 Collaboration: P. Bagnaia *et al.*, *Phys. Lett.*, **B144** (1984) 283.

[3] CDF Collaboration: F. Abe *et al.*, *Phys. Rev. Lett.*, **62** (1989) 3020; *Phys. Rev. Lett.*, **69** (1992) 2896; *Phys. Rev. Lett.*, **77** (1996) 5336.

[4] D0 Collaboration, B. Abbott *et al.*, *Phys. Rev. Lett.*, **80** (1998) 666–671; arXiv.org:0906.4819(2009).

[5] W. T. Giele, E. W. Glover and D. A. Kosower, *Nucl. Phys.*, **B403** (1993) 633.

[6] Z. Nagy, *Phys. Rev.*, **D68** (2003) 094002 [hep-ph/0307268].

[7] P. M. Nadolsky, H.-L. Lai, Q.-H. Cao, J. Huston, J. Pumplin, D. Stump, W.-K. Tung and C.-P. Yuan, *Phys. Rev.*, **D78** (2008) 013004.

[8] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, *Phys. Lett.*, **B429** (1998) 263, N. Arkani-Hamed, S. Dimopoulos and G. Dvali, *Phys. Rev.*, **D59** (1999) 086004.

[9] T. Han, J. D. Lykken and R.-J. Zhang, *Phys. Rev.*, **D59** (1999) 105006 [hep-ph/9811350].

[10] G. F. Giudice, R. Rattazzi, and J. D. Wells, *Nucl. Phys.*, **B544** (1999) 3–88 [hep-ph/9811291].

[11] M. Sjödahl and G. Gustafson, *EPJ*, **C53** (2008) 109 [hep-ph/0608080].

[12] T. Sjöstrand, S. Mrenna and P. Skands, *JHEP*, **0605** (2006) 026 [hep-ph/0603175].

[13] C. M. Harris, P. Richardson and B. R. Webber, *JHEP*, **0308** (2003) 033 [hep-ph/0307305].

[14] L. Lönnblad and M. Sjödahl, *JHEP*, **0610** (2006) 088 [hep-ph/0608210].

[15] N. Boelaert, T. Åkesson, (2009) [arXiv.org:0905.3961].