Coloron Limits using the DØ Dijet Angular Distribution

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Abstract

The DØ dijet angular distribution is used to place limits on a coloron model. Models with $M_{\mathrm{c}}/\cot\theta >$ 759 GeV/c^2 are excluded at the 95% CL.

A flavor-universal coloron model [1] has been proposed to explain the excess in the inclusive jet spectrum as measured by CDF [2] without contradicting other experimental data. The model is minimal in its structure, in that it involves the addition of one new interaction, one new scalar multiplet, and no new fermions. The QCD gauge group is extended to $SU(3)_1 \times SU(3)_2$, with gauge couplings ξ_1 and ξ_2 respectively, with $\xi_1 \gg \xi_2$. All quarks are assigned to triplet representations of strong group $SU(3)_2$. The symmetry is broken to its diagonal subgroup at a scale f by introducing a scalar boson Φ which transforms as a $(3, \bar{3})$ under the two $SU(3)$ groups. As described in [1], the Lagrangian for this process can be written as:

$$\mathcal{L} = -g_3 \cot\theta J^{\mathrm{a}}_{\mu} C^{\mu\mathrm{a}}, \tag{1}$$

where J^{a}_{μ} is the color current and $\tan\theta = \xi_1/\xi_2$. g_3 is identified with the QCD coupling constant and has a value of approximately 1.2 (corresponding to $\alpha_3(M_{\mathrm{Z}}) \approx 0.12$). In terms of these parameters the mass of the coloron is

$$M_c = \left(\frac{g_3}{\sin\theta\cos\theta}\right) f. \tag{2}$$

Below the scale M_{c}, coloron–exchange can be approximated by the effective four-fermion interaction

$$\mathcal{L}_{\mathrm{eff}} = -\frac{g_3^2 \cot^2\theta}{2!M_{\mathrm{c}}^2} J^{\mathrm{a}}_{\mu} J^{\mu\mathrm{a}}, \tag{3}$$

This interaction can be rewritten in terms of a compositeness mass scale Λ:

$$\Lambda\sqrt{\alpha_s} = \frac{M_c}{\cot\theta} \tag{4}$$

The phenomenology of the coloron has been studied [3] and limits have been placed on M_c and $\cot\theta$. Constraints on the size of the weak-interaction ρ parameter require $M_c/\cot\theta > 450$ GeV and a direct search for colorons in the dijet mass spectrum at CDF exclude colorons with mass below 1 TeV for $\cot\theta \lessapprox 1.5$.

As with compositeness ([4, 5]) this model will lead to an excess of events at small values of χ in the dijet angular distribution. Predictions of the dijet angular distribution with colorons are available at leading order (LO). To simulate a next–to–leading order (NLO) prediction of the effects of the coloron LO predictions for several values of $M_c/\cot\theta$ are generated. The fractional difference between the angular distribution with $M_c/\cot\theta = \infty$ and the distribution with a finite value of $M_c/\cot\theta$ are then measured. The coloron NLO order prediction of the dijet angular distribution is obtained by multiplying a NLO QCD prediction obtained using the JETRAD program [6] by the LO fractional differences obtained above. The results are shown in Figure 1.

Also show in Fig. 1 is dijet angular distribution as measured by DØ [7] for $M_{JJ} > 635$ GeV/c^2. Limits on the coloron mass are calculated using $R_\chi = N(\chi < 4)/N(4 < \chi < \chi_{\max})$, the ratio of the number of events with $\chi < 4$ to the number of events between $4 < \chi < \chi_{\max}$ which removes the point to point to point correlated errors.Table 1 shows the experimental ratio R_χ for the different mass ranges with their statistical and their systematic uncertainties, which are fully correlated in mass.

Mass Range GeV/c^2	R_χ	Stat Error	Sys Error
260-425	0.191	0.0077	0.015
425-475	0.202	0.0136	0.010
475-635	0.342	0.0085	0.018
635-	0.506	0.0324	0.028

Table 1: The dijet angular ratio R_χ and its statistical and systematic uncertainty.

The method chosen to obtain a compositeness limit is using Bayesian statistics. The compositeness limit is determined using a Gaussian likelihood function for R_χ as a function of dijet mass.

The likelihood function is defined as

$$P(\xi) = \frac{1}{|S|2\pi^2} exp(-1/2[d - f(\xi)]^T S^{-1}[d - f(\xi)]) \tag{5}$$

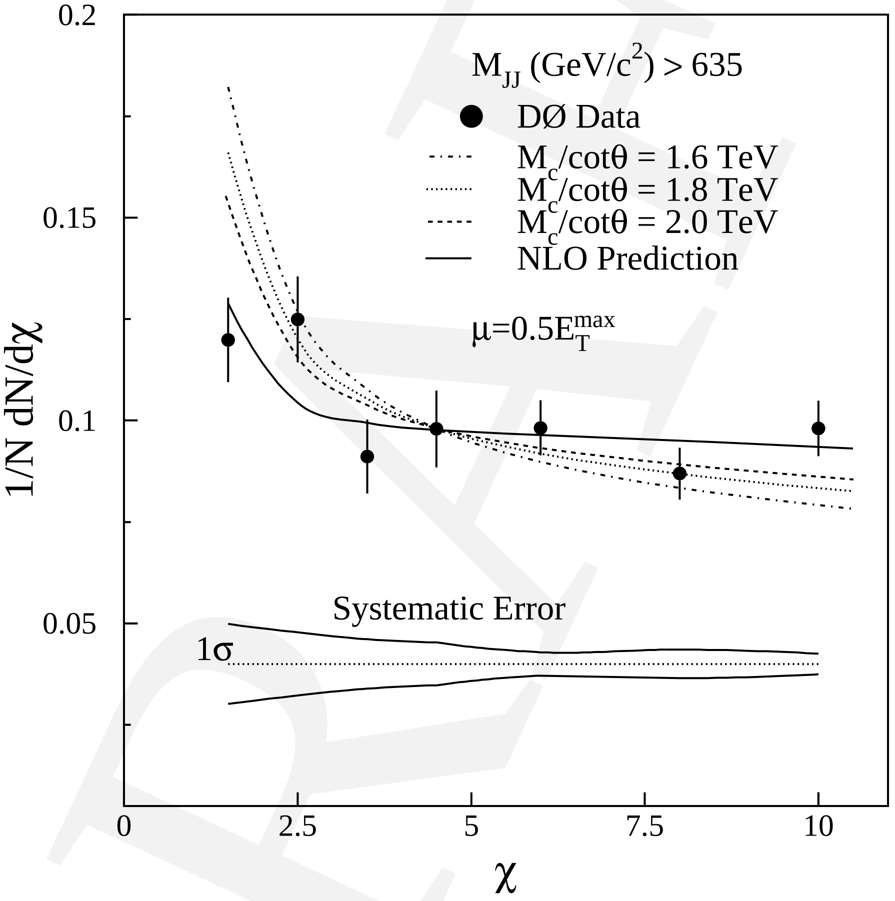

Figure 1: Data compared to theory for different values of $M_c/\cot\theta$. See text for how the coloron distributions are calculated. The errors on the points are statistical and the band represents the correlated $\pm$ 1 σ systematic uncertainty.

Where d is a vector of data point for the different mass bins, f(ξ) is a vector of theory points for the different mass bins for different values of ξ where ξ=1/Λ^n, and S^{-1} is the inverse of the covariance matrix.

The compositeness limit depends on the choice of the prior probability distribution, $P(\xi)$. Motivated by the form of the Lagrangian, $P(\xi)$ is assumed to be flat in ξ=1/$(\Lambda)^2$. Since the dijet angular distribution at NLO is sensitive to the renormalization scale, each renormalization scale is treated as a different theory. The likelihood function has the form $P(R_\chi|\xi) = e^{-\chi^2/2}$. To determine the 95% confidence limit in Λ, a limit in ξ is first calculated by requiring that $Q(\xi) = \int_0^\xi P(R_\chi|\xi')P(\xi')d\xi'$ = 0.95 of $Q(\infty)$. The limit in ξ is then transformed back into a limit in Λ. If a renormalization scale, $\mu = E_{\mathrm{T}}^{\mathrm{max}}$ is chosen and $\alpha_s = 0.12$ then the 95% CL on the coloron mass is $M_{\mathrm{c}}/\cot\theta >$ 759 GeV/c^2. If a renormalization scale of $\mu = 0.5E_{\mathrm{T}}^{\mathrm{max}}$ is assumed then the 95% CL is 786 GeV/c^2.

In conclusion, the dijet angular distribution as measured by DØ can be used to exclude coloron models with $M_{\mathrm{c}}/\cot\theta$ below 859 GeV/c^2 at the 95% CL.

References

[1] R.S. Chivukula, A.G. Cohen and E.H. Simmons, Phys.Lett. **B380** 92, (1996)

[2] F.Abe *et al.*, (CDF Collaboration), Phys. Rev. Lett., **77** 438 (1996).

[3] E.H. Simmons, Phys. Rev. **D55**, 1678 (1997)

[4] E. Eichten, K. Lane, and M. Peskin, Phys. Rev. Lett. **50**, 811 (1983).

[5] K. Lane, BUHEP-96-8, hep-ph/9605257 (1996).

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

[7] DØ Collaboration, B. Abbott, et al. Phys. Rev. Lett. **80**, 666 (1998)

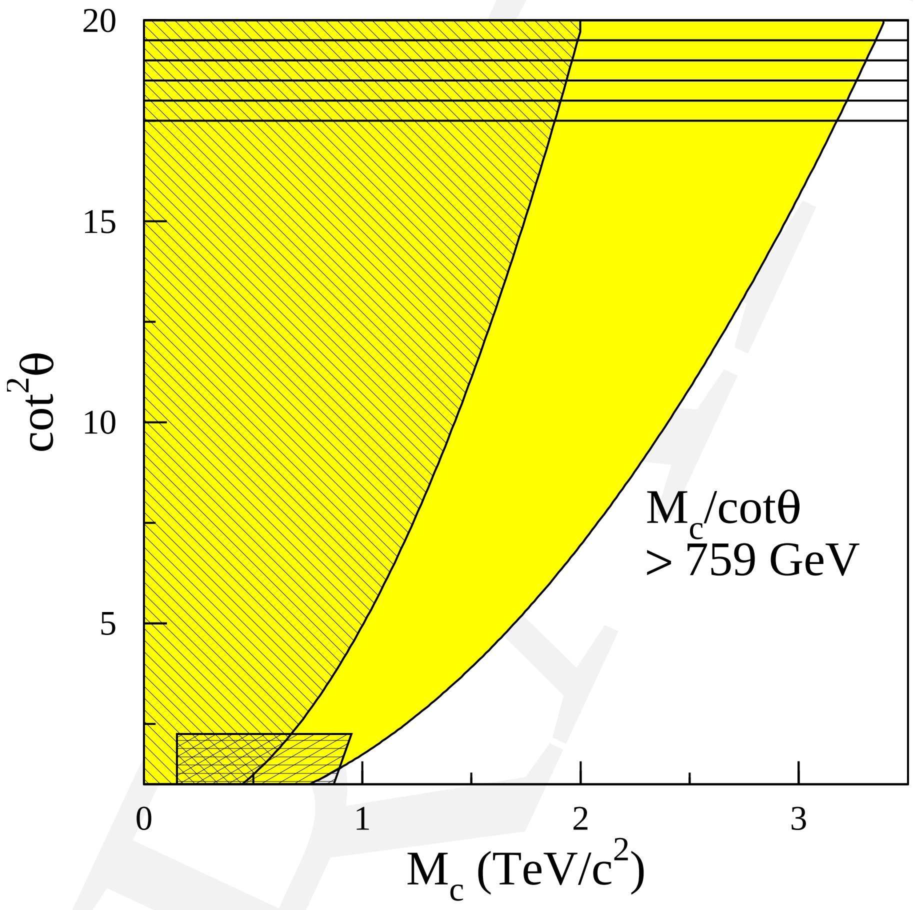

Figure 2: Limits on the coloron parameter space: $M_{\rm c}$ vs mixing parameter $\cot\theta$. The shaded region shows the 95$\%$ exclusion region for the dijet angular distribution measurement ($M_{\rm c}/\cot\theta >$ 759 GeV/c^2). The horizontally hatched region at large $\cot^2\theta$ is not allowed in this model. The diagonally hatched region shows the region excluded by the ρ parameter ($M_{\rm c}/\cot\theta >$ 450 GeV/c^2). The cross–hatched region is excluded by the CDF search for new particles decaying to two–jets.