Search for Compositeness at LHC

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Abstract. If leptons and quarks are composite objects built from more fundamental constituents, it may be possible to explore contact interactions at the LHC. We report on the discovery potential for such interactions in processes with dijet and with dimuon final states.

Introduction
If fermions are composite particles made up of more basic constituents, characteristic phenomenological effects could be observable at the LHC. If the scale of compositeness is sufficiently low, narrow resonant states of excited fermions could be produced on shell. If, however, the compositeness scale (Λ) is much larger than the centre of mass energy of the colliding partons, √s, the manifestation of compositeness will be an effective 4-fermion contact interaction (CI). In a commonly used model, the CI is described as an interaction between two left-handed quark currents [1]:

\[ \mathcal{L}_{ffff}(\Lambda) = \frac{\eta g^2}{2(\Lambda L)^2} \bar{\Psi}^L_L \gamma^\mu \Psi^L_f \bar{\Psi}^L_f \gamma^\mu \Psi^L_L, \]

where \( \eta = \pm 1 \) is a constructive or destructive interference sign. Λ is defined in such a way that \( g^2/4\pi = 1 \). Note that, the possible discovery of contact interaction alone is not enough to prove compositeness because other possible new phenomena \(^1\) can be described by a CI lagrangian.

Early measurements of both jet \( p_T \) and dijet mass distributions at the Tevatron showed an excess in the rate above QCD expectations [2, 3]. These effects were eventually explained by larger than expected high-x tail in the gluon PDF[4]. After these measurements, less PDF-sensitive studies based on ratio of cross sections and angular distributions have been developed in ATLAS and CMS to search for CI in the dijet and dimuon channels.

1. Dijet final state
Quark compositeness would manifest itself as something hard within the quark, producing more hard scattering than expected, and more jets perpendicular to the beam. This admittedly simplistic picture leads one to expect deviations from QCD predictions in the form of an excess of high energy jets in the central region of the detector. Dijet angular distributions benefit from much smaller systematic uncertainties than dijet mass or jet \( p_T \) distributions because they are less sensitive to uncertainties from the jet energy scale, K-factors and PDFs and because the angle of the jet is well measured by finely segmented calorimeters.

\(^1\) Exchange of a new heavy boson is an example of an interaction which can be described by a 4-fermion contact interaction at low energy.
Figure 1. Left: shape of the dijet angular distribution showing the QCD prediction and the effect of different quark compositeness scales in ATLAS, $\chi_{\text{cut}}=2.7$ is shown with the vertical line. Right: dijet ratio in CMS from QCD (solid curve) is compared with QCD plus a quark contact interaction at a scale $\Lambda$ of 15 TeV (dashed), 10 TeV (dotted) and 5 TeV (dot-dashed).

Table 1. ATLAS Preliminary: The required luminosity to achieve a sensitivity of $3\sigma$ using dijet angular distributions.

| $\Lambda$(TeV) | 3    | 5    | 10   | 20   | 40   |
|----------------|------|------|------|------|------|
| Luminosity    | $<1$ pb$^{-1}$ | 6 pb$^{-1}$ | 0.7 fb$^{-1}$ | 34 fb$^{-1}$ | 426 fb$^{-1}$ |

The ATLAS study of the CI effect [5] uses the dijet angular distribution. The quantity $\chi$ is defined as $\chi = e^{-|\eta_1-\eta_2|}$, where $\eta_{1,2}$ are the pseudorapidities of the two leading jets. The distribution of the $\chi$ variable is presented in Fig. 1:left for different values of $\Lambda$ for jets with $p_T > 1$ TeV and for dijet invariant mass $>4$ TeV. The CI affects the large $\chi$ region and one defines the ratio of events $R_{\chi_{\text{cut}}} = N(\chi<\chi_{\text{cut}})/N(\chi>\chi_{\text{cut}})$. The corresponding sensitivity is estimated using the formula $S = R_{\chi_{\text{cut}}}(\Lambda) - R_{\chi_{\text{cut}}}(\text{SM}) \sqrt{\sigma_\Lambda^2 + \sigma_{\text{SM}}^2}$. The luminosity required to achieve a $3\sigma$ sensitivity is presented in Table 1 for different values of $\Lambda$. A luminosity of 700 pb$^{-1}$ is enough to probe the scale $\Lambda = 10$ TeV.

The CMS study [6] uses a ratio of the number of dijet events in which both jets have $|\eta| < 0.5$ to the number of dijet events in which both jets have $0.5 < |\eta| < 1$. This ratio is presented in Fig. 1:right as a function of the dijet mass. This ratio is a simple measure from the most sensitive part of the angular distribution. Scales up to 6.2 TeV can be excluded at 95% CL with a luminosity of 100 pb$^{-1}$ and a significance of $5\sigma$ is reached for $\Lambda = 8$ TeV with a luminosity of 1 fb$^{-1}$.

2. Dimuon final state

CMS has studied CI’s in the dimuon final state [7]. A double ratio method has been developed in order to reduce the systematic uncertainties from the K factors and the luminosity. $R_{\text{data}}^{D} = \frac{N_{\text{J}}^{D}}{N_{\text{J}}^{0}} = \frac{\sigma_{\text{J}}^{D}}{\sigma_{\text{J}}^{0}} \frac{\epsilon_{\text{J}}^{D}}{\epsilon_{\text{J}}^{0}}$ is defined as a ratio of the number of observed events in the dimuon mass bin “i” to the number of observed events in a normalization bin “0”. $\sigma$ is the cross section and $\epsilon$ is the experimental efficiency. The normalization bin is chosen to be between 250-500 GeV.
Figure 2. Left: double ratio in the dimuon channel for contact interactions with a scale of $\Lambda = 20$ TeV. $\Lambda^+$ and $\Lambda^-$ refer to the constructive and destructive interferences respectively. Right: 5$\sigma$ discovery reach of contact interactions in the dimuon channel versus luminosity.

above the $Z$ pole and in a region well measured by the Tevatron where the Standard Model predictions have been confirmed. $R_{\text{data}}^i$ is normalized to the template ratio $R_{\text{MC}}^i$ extracted from Monte Carlo studies to define the double ratio $DR_i = \frac{R_{\text{data}}^i}{R_{\text{MC}}^i}$. In the case of perfect theory understanding and detector modelling, $DR_i$ would be equal to 1. $DR_i$ is plotted as a function of the dimuon mass for a scale of $\Lambda = 20$ TeV in Fig. 2. The 5$\sigma$ discovery reach using the double ratio is shown on the same figure.

3. Conclusion
The angular distributions and rates of high $p_T$ dijets and dimuons allow to probe fermion compositeness at the LHC. With a few hundred pb$^{-1}$, the ATLAS and CMS experiments will be sensitive to contact interactions at a compositeness scale of $\approx 5$ TeV. It will remain to determine that the observed deviations from SM expectations are indeed due to compositeness.

References
[1] E.J. Eichten, K.D. Lane, and M.E. Peskin, Phys. Rev. Lett. 50, 811 (1983).
[2] CDF Collaboration (F. Abe et al.), Phys.Rev.Lett.77:438-443,1996, hep-ex/9601008.
[3] CDF Collaboration (T. Affolder et al.), Phys.Rev.D61:091101 (2000), hep-ex/9912022.
[4] J. Pumplin et al., JHEP 07 (2002) 012, hep-ph/0201195.
[5] L. Pribyl, LHC Days in Split, October 2006, Split.
[6] S. Esen and R.M. Harris, CMS NOTE-2006/071, (2006).
[7] D. Bourilkov, CMS NOTE-2006/085, (2006).