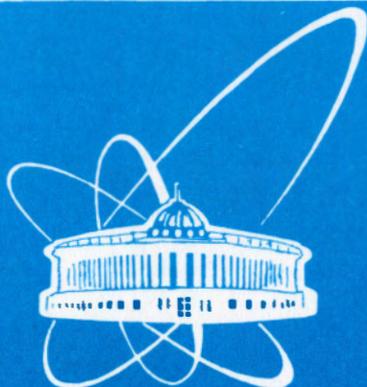


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A SEARCH FOR QUARK COMPOSITENESS
AT THE LHC.
TRANSVERSE ENERGY DISTRIBUTIONS OF JETS

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Поиск структуры кварков на LHC.

Анализ распределений поперечной компоненты энергии струй

Рассмотрены эффекты, по которым может быть обнаружена структура кварков на LHC. Приведены предсказания для распределений поперечной энергии струй на установке ATLAS. Изучено влияние функции распределения кварков и нелинейности отклика калориметра на эффекты, связанные со структурой кварков. Приведены оценки значений константы связи кварков, которые могут быть достигнуты в эксперименте.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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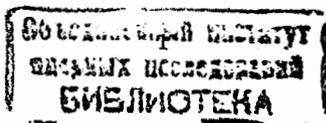
A Search for Quark Compositeness at the LHC.
Transverse Energy Distributions of Jets

The paper considers the quark substructure effects that will manifest themselves at LHC energies. The inclusive jet transverse energy spectrum as would be seen by ATLAS detector is investigated. The influence of the parton distribution function choice and calorimeter non-linearity to the compositeness effect is studied. The data sensitivity to the quark compositeness scale for low and high LHC luminosity is discussed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

The test of QCD predictions provides a useful tool to probe the underlying dynamics and to search for new physics such as quark compositeness, the existence of axiguons or other new particles. Measuring the inclusive jet cross section and studying the dijet mass spectrum and angular distributions open a new window to this field. The connection between jets and partons has been clearly demonstrated in the high statistic LEP , $Tevatron$ and $HERA$ experiments. The existence of a quark substructure would appear as an excess of the high P_T jets compared to the level predicted by QCD or with dijet angular distributions more isotropic than what is expected from a point-like quark theory. Dijet angular distributions have been studied by the CDF [1] and $D0$ [2] experiments at a center-of-mass(CM) energy of $1.8 TeV$. The highest E_T reached so far at the $Tevatron$, $440 GeV$, corresponds to a distance scale of order $10^{-17} cm$. The experimental data have been compared with QCD predictions including compositeness. No evidence of quark substructure was found. Previous studies of dijet invariant mass spectrum reported by $UA1$ [3], $UA2$ [4] at $\sqrt{s} = 630 GeV$ and by CDF [5] have also shown the data that were consistent with QCD predictions. The CDF [6] and $D0$ [7] results on high-mass Drell-Yan cross-section measurement sets lower limit on the quark-electron compositeness scale about $5.5 TeV$. From the ratio of charged current to neutral current cross-section measurement in the CCFR fixed target neutrino experiment[8] at $Tevatron$ limit on $\Lambda \sim 8 TeV$ was achieved.

In future hadron colliders, the search for quark substructure will continue. Here we investigate the effect of quark compositeness as would be seen by $ATLAS$ [12] at the LHC . To simulate a scenario with quark substructure the event generator $PYTHIA-5.7$ [9] has been used. This has allowed to use a simple phenomenological approach of contact interactions between quark constituents with a compositeness scale Λ [10], where the sign of the *effective Lagrangian* for a flavor diagonal definite chirality current is positive (destructive interference) or negative (constructive interference). The data simulated in the framework of *Standard Model (SM)* are compared with those obtained assuming quark compositeness. The sim-



ulated event sample included the following hard-scattering subprocesses: qq , qg , gg , $g\gamma$, $q\gamma$, $\gamma\gamma$. The γ^*/Z , W , tt production subprocesses also enabled. To get a sufficiently large number of events with high P_T jets in a reasonable *CPU* time, a cut on the transverse momentum of the hard scattering subprocess was set to 1000 and 1200 *GeV* for low and high luminosity, respectively. Initial and final state *QCD* and *QED* radiation, fragmentation and decay of partons and particles, multiple interactions were enabled. First-order running α_S calculations were applied. The Λ_{QCD} value is chosen according to the parton distribution functions (pdf) parametrizations, used in *PYTHIA*. For the Q^2 scale in the hard scattering $2 \rightarrow 2$ process, $Q^2 = (m_{T1}^2 + m_{T2}^2)/2$ was used. The detector performance was simulated using the *ATLFAST*[11] package which provides a reliable estimate of the detector response to hadronic jets. Jets were reconstructed with *ATLFAST* using the standard procedure of summing the energy deposited in a cone of radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$. All calorimeter cells with $E_T > 1.5$ *GeV* are taken as possible initiators of clusters. The total E_T summed over all cells in a cone ΔR should be larger than 15 *GeV*. Jets are reconstructed down to $|\eta| \leq 5.0$.

Figure 1 and *Figure 2* show the effect of compositeness on the inclusive jet energy spectrum for 30 fb^{-1} of integrated luminosity. The case of constructive interference is shown; the destructive case is similar. Only events with two jets of $E_T > 400$ *GeV* are included. The deviation from *Standard Model* prediction assuming that all quarks are composite is shown. This figure emphasises that the deviation is significant for the largest values of E_T . *Figure 3* and *Figure 4* show the effects on the jet E_T distribution for 300 fb^{-1} of integrated luminosity and larger values of Λ .

The effects of compositeness could be masked by uncertainties in the pdf's. *Figure 5* shows a band corresponding to the results obtained with all the pdf's in *PYTHIA*-5.7 (except for *DO1* and *EHLQ1* which have large inconsistencies with present data). For this case $\Lambda_{all}^- = 15000$ *GeV*.

The non-linear response of the hadron calorimeter can affect the observed difference between the *SM* and compositeness scenario, or fake a

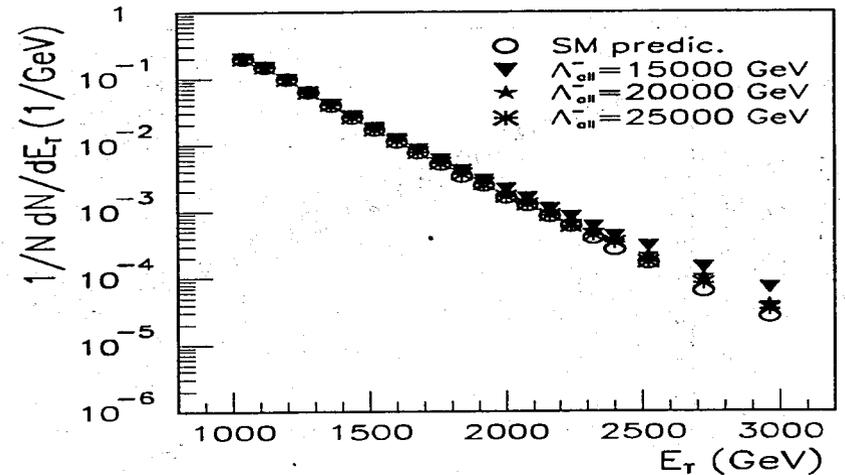


Figure 1: E_T distribution for two leading jets showing the Standard Model prediction (open circles) and the effect of quark compositeness to the scales indicated. 30 fb^{-1} of integrated luminosity assumed.

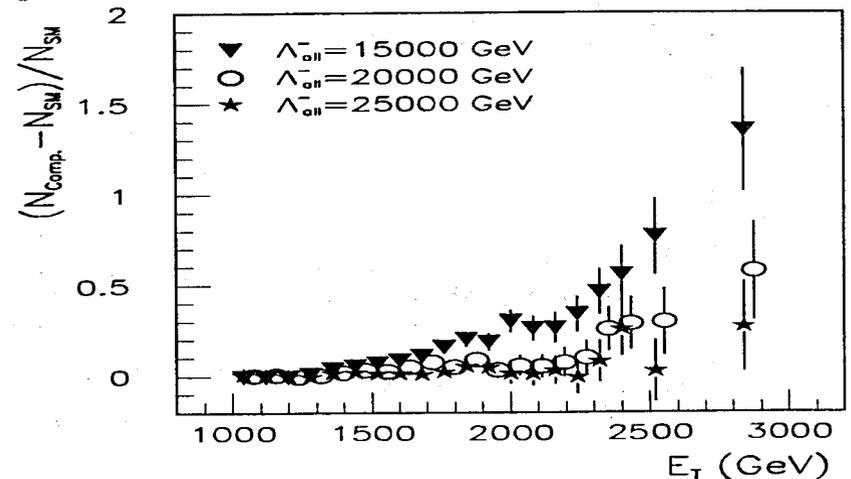


Figure 2: Difference of the Standard Model prediction and the effect of compositeness on the jet E_T distribution, normalised to the Standard Model rate. The errors correspond to 30 fb^{-1} .

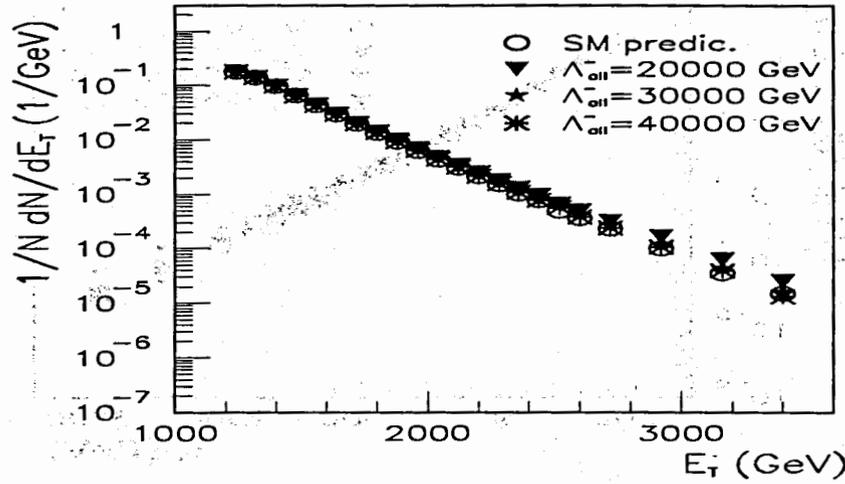


Figure 3: The same as in Figure 1, but for an $L = 300 \text{ fb}^{-1}$.

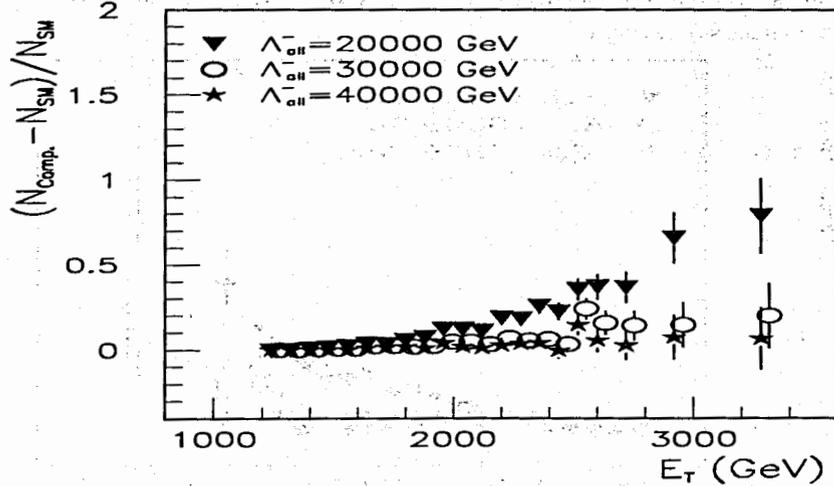


Figure 4: The same as in Figure 2, but for an $L = 300 \text{ fb}^{-1}$.

compositeness signal. To study this effect, we considered a non-linearity of the jet E_T scale according the relation[13]:

$$E_T(\text{meas}) = E_T \cdot \frac{1}{c(1 + (e/h - 1) \cdot 0.11 \cdot \ln E_T)} \quad (1)$$

where $E_T(\text{meas})$ and E_T are measured and true jet transverse energy, respectively; $e/h = 1.36$ and c is adjusted such that at 500 GeV the scale is unchanged. The parameter b controls the size of calorimeter non-linearity. After correction the residual uncertainty can be parametrised by this formula with $b = 0.025$ and corresponds to a 1.5% non-linearity at 3 TeV . If no correction is made then $b = 0.11$ and there is a 5% non-linearity at 3 TeV .

The effect of non-linearity shown in Figure 6. The figure shows the fractional deviation of the transverse energy spectrum as measured by a non-linear calorimeter to that expected from a linear one. The rates are normalised to be equal at 1.20 TeV . Two cases are shown corresponding to $b = 0.025$ and $b = 0.11$. It can be seen by comparing this plot to that of Figure 4 that, in the worse case, the effect of a non-linearity is similar in magnitude to that due to a composite scale of 20 TeV , and that if the 1.5% non-linearity can be achieved then it is comparable to the 30 TeV case. The points in Figure 5 are shown calorimeter non-linearity affected distributions.

In order to estimate the calorimeter non-linearity part in the effect we construct the variable:

$$R = \frac{R_n^{\text{nonlin.}} - R_n^{\text{lin.}}}{R_n^{\text{lin.}}},$$

where

$$R_n = \frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \Big|_{\text{Comp.}} / \frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \Big|_{\text{SM}}$$

and $N(E_T > E_T^0)$ ($N(E_T < E_T^0)$) is the number of events with $E_T > E_T^0$ ($E_T < E_T^0$). From the Figure 7 where we demonstrate R versus Λ_{all}^- it can be observed that the effect almost twice bigger at $\Lambda_{\text{all}}^- = 6000 \text{ GeV}$

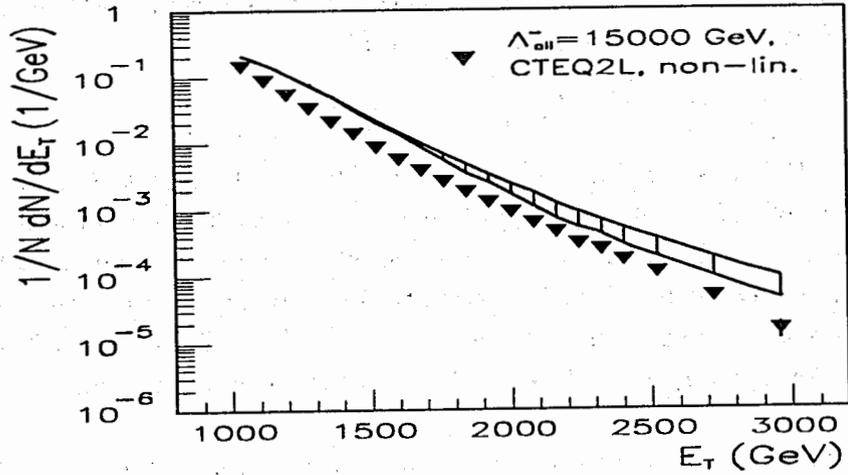


Figure 5: The jet E_T spectrum showing the uncertainty from present parton distribution functions; $30 fb^{-1}$ assumed. The points are shown for calorimeter non-linearity resulting predictions. $\Lambda_{all}^- = 15000 GeV$.

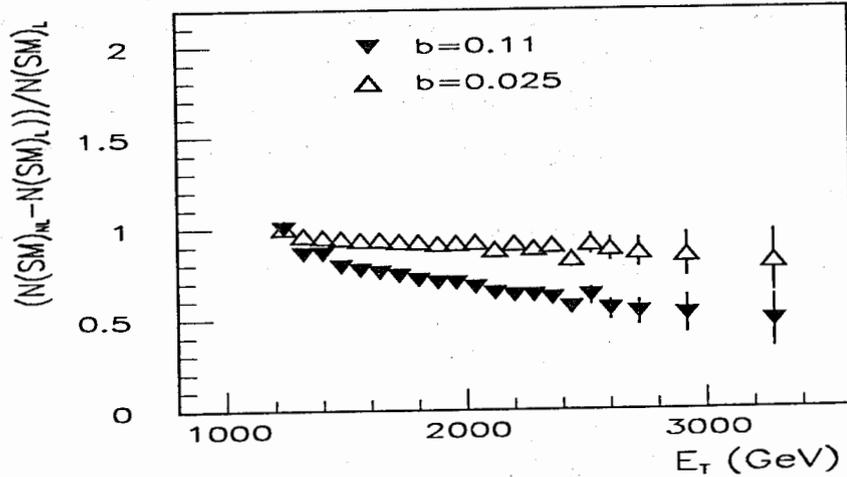


Figure 6: The fractional difference between the E_T spectrum measured by a linear and non-linear calorimeter. The curves are normalised at $1.20 TeV$.

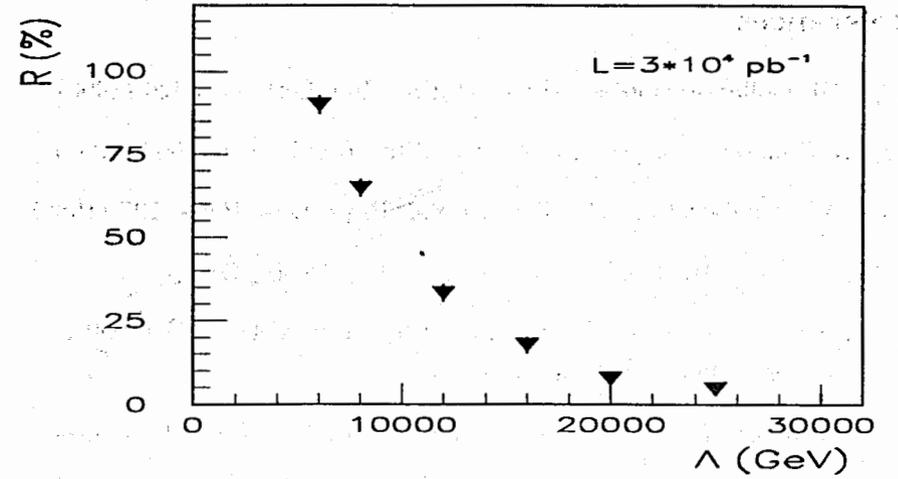


Figure 7: The R versus compositeness scale Λ_{all}^- (see the text). $30 fb^{-1}$ of integrated luminosity assumed.

resulting from non-linear response of calorimeter. We choose $b = 0.11$ and $E_T^0 = 1500 GeV$.

In conclusion, the effects due to quark compositeness has good chance to be observed by ATLAS at LHC. High transverse energy jet production at a center-of-mass energy of $14 TeV$ can give bounds of quark compositeness scale Λ above $\sim 25(40) TeV$ for integrated LHC luminosity of $30(300) fb^{-1}$. We can note that Λ limits estimation using inclusive jets E_T spectrum is very sensitive to calorimeter non-linearity effects and parton distribution function choice.

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