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Contact Interactions at the LHC

Mónica Vázquez Acosta

CERN, Geneva, Switzerland

on behalf of the ATLAS and CMS Collaborations

Abstract

Contact interactions offer a general framework for describing a new interaction with a scale above the energy scaled probed. These interactions can occur if the Standard Model particles are composite or if new heavy particles are exchanged. The discovery potential of contact interactions at the LHC in dimuon and dijet final states at startup and the asymptotic reach are presented.

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1 Introduction

Quark compositeness or new interactions mediated by a new massive particle can be approximated by a contact interaction, when the center-of-mass energy of the partons initiating the interaction, $\sqrt{s}$, is below the scale Λ [1, 2]. This is analogous to the effective four-fermion interaction which can describe the weak force at low energies.

2 Dijet final state

Quark compositeness in dijet events has been studied assuming a CI Lagrangian formed by the product of left-handed quark currents: $\mathcal{L} = \frac{2\pi A}{\Lambda^2} \sum_{i,j=1}^{6} (\bar{q}_i \gamma^\mu q_{iL})(\bar{q}_j \gamma^\mu q_{jL})$, where $A = \pm 1$ which can give constructive or destructive interference with the Standard Model (SM).

Contact interactions will produce an increase in the event rate relative to QCD at high mass. Observation of CI in mass distributions requires a precise understanding of QCD dijet cross sections, due to the large uncertainties in the jet energy scale and in the parton distribution functions (PDF) at high mass. CI are expected to be more isotropic than the QCD background, since QCD is dominated by the t-channel scattering and produces jets predominantly in the forward region. Angular distributions have much smaller systematic uncertainties than cross sections measurements versus dijet mass.

2.1 ATLAS Contact interaction sensitivity

ATLAS has studied the effect of compositeness in the PTDR [3]. New preliminary results with the ATLAS fast simulation have been produced, which include more recent PDFs. The p_t distribution of the two leading jets has been studied (Fig. 1-left). An uncertainty of 1% is enough to hide CI scales of $\Lambda = 20$ TeV (Fig. 1-right). The uncertainties on the PDFs (Fig. 2-left) and calorimeter non linearity (Fig. 2-right) are large in the dijet cross section distributions.

The effect of CI in the dijet angular distribution versus $\chi = e^{|\eta_1 - \eta 2|}$, where $\eta_{1,2}$ are the pseudorapidities of the two leading jets has been studied (Fig. 3). For the $2 \to 2$ parton scattering, it is related to the centre-of-mass scattering angle θ^* as follows: $\chi = \frac{1+|cos\theta^*|}{1-|cos\theta^*|}$. If one defines R_χ as the fraction of events with $R_\chi = \frac{N(\chi<\chi_{\rm cut})}{N(\chi>\chi_{\rm cut})}$ and the sensitivity as $R_1 = \frac{R_\chi(\Lambda) - R_\chi(SM)}{\sqrt{\sigma_\Lambda^2 + \sigma_{SM}^2}}$, the luminosity required to achieve a sensitivity of $R_1 = 3$ is presented in Table 1. The value of $\chi_{\rm cut} = 2.8$ maximizes the sensitivity. Systematic uncertainties are expected to be much smaller than in the $d\sigma/dp_t$ case.

Table 1: ATLAS Preliminary: Luminosity to achieve a contact interaction sensitivity of $R_1 = 3$ in dijet angular distributions. Systematic uncertainties are not included.

Λ(TeV)	3	5	10	20	40
Lumi	< 1 pb^{-1}	6 pb^{-1}	0.7 fb^{-1}	34 fb^{-1}	426 fb^{-1}

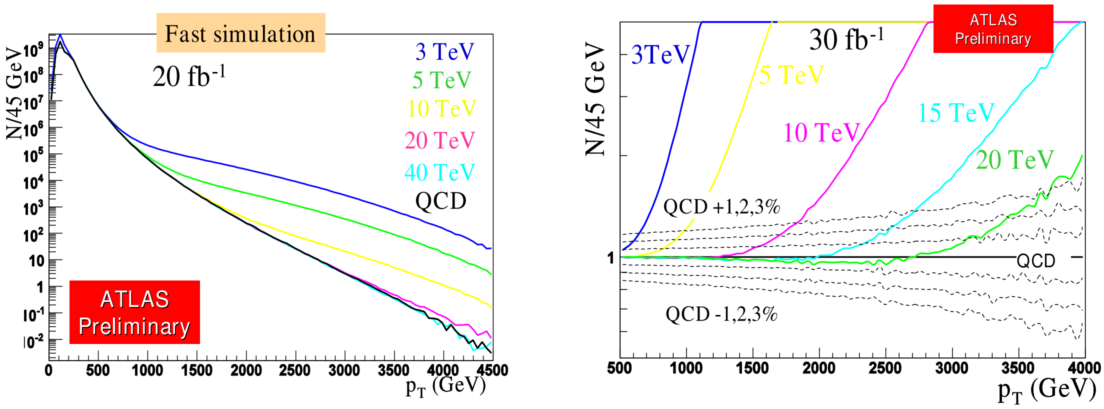

Figure 1: p_t distribution of the two leading jets showing the QCD prediction and the effect of different quark compositeness scales (left). Ratio of the p_t distribution of the two leading jets for different compositeness scales to the QCD prediction (right).

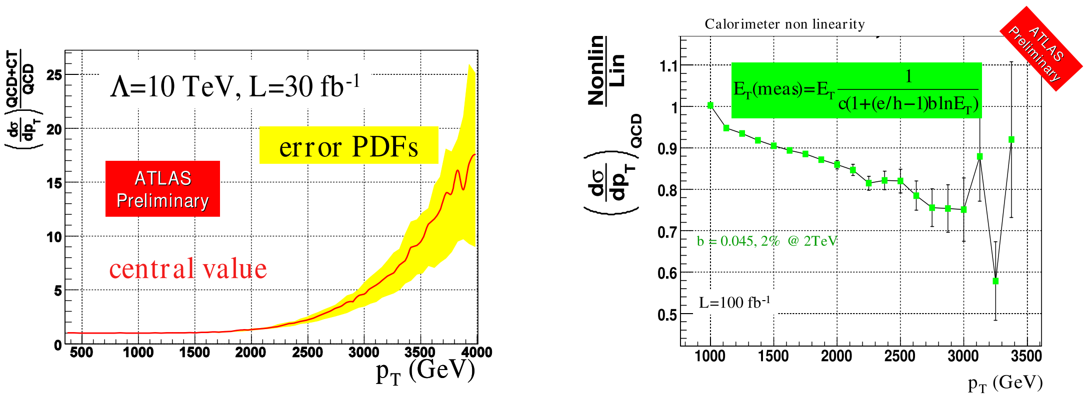

Figure 2: PDF uncertainty in the ratio of the p_t distribution of the two leading jets for a contact interaction scale of $\Lambda = 10$ TeV to the QCD prediction (left). Effect of calorimeter non linearities in the QCD dijet cross section (right).

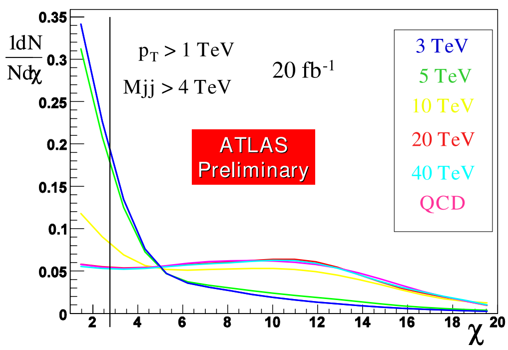

Figure 3: Dijet Angular distribution showing the QCD prediction and the effect of different quark compositeness scales

2.2 CMS Contact interaction sensitivity

CMS has studied the effects of compositeness [4, 5] in the dijet cross section as a function of the dijet mass (Fig. 4-left). It is expected that a jet energy scale uncertainty of $\pm 5\%$ is achievable, which can produce changes in the dijet mass cross section of $30 - 70\%$ (Fig. 4-right).

The ratio of the number of dijets in which both jets have $|\eta| < 0.5$ to the number of dijets in which both jets have $0.5 < |\eta| < 1$ as function of the dijet mass, is a simple measure of the most sensitive part of the angular distribution. The effects of CI in the dijet ratio have been studied (Fig. 5-left) and the systematic uncertainties (Fig. 5-right) have been to be much smaller than in the case of the dijet mass cross section. The CI scales that can be excluded at 95% confidence level or can be discovered with a significance of 5σ are shown in Table 2 for a luminosity of 100 pb^{-1}, 1 fb^{-1} and 10 fb^{-1}. Scales up to 6.2 TeV can be excluded with a luminosity of 100 pb^{-1}. The D0 experiment has excluded scales up to 2.7 TeV [6] with an analysis that uses the same dijet ratio and a luminosity of 100 pb^{-1}.

Table 2: CMS: Contact interaction 95% CL exclusion limits and 5σ discovery reach in dijet events, with the inclusion of statistical uncertainties only and with all systematic uncertainties taken into account

Luminosity		100 pb^{-1} Λ(TeV)	1 fb^{-1} Λ(TeV)	10 fb^{-1} Λ(TeV)
95% CL Exclusion	Stat Only	6.4	10.6	15.1
	All Syst	6.2	10.4	14.8
5σ Discovery	Stat Only	4.7	8.0	12.2
	All Syst	4.7	7.8	12.0

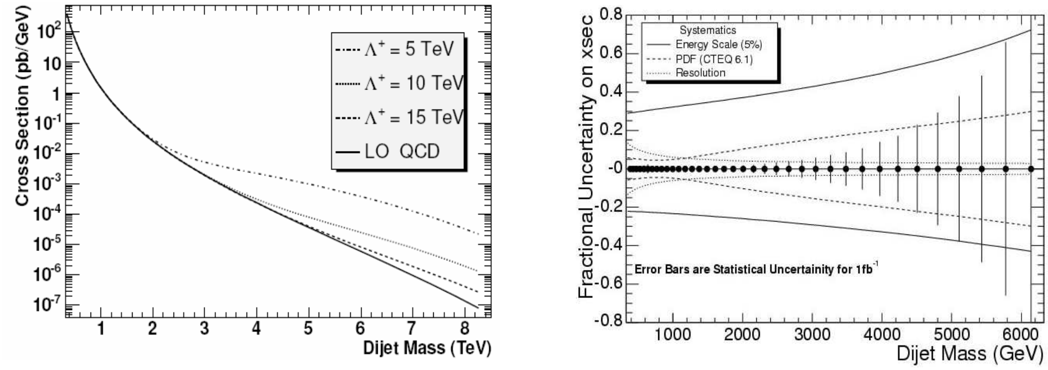

Figure 4: CMS: Dijet mass cross section of the two leading jets showing the QCD prediction and the effect of different contact interaction scales (left). Systematic uncertainties on the Dijet Mass cross section (right).

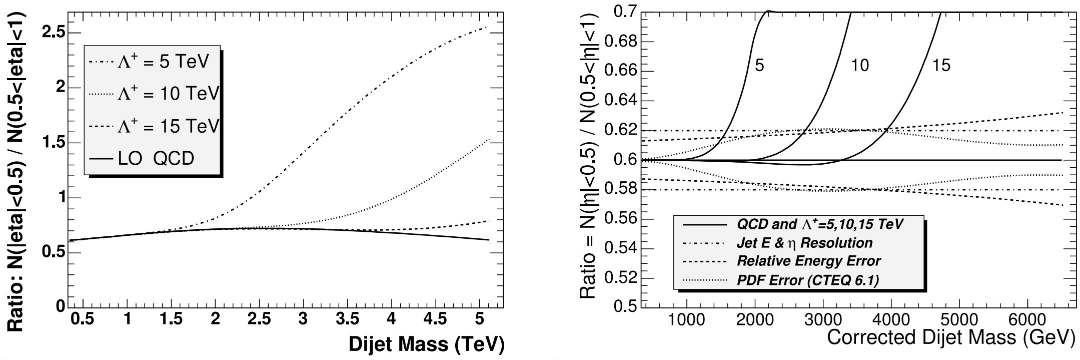

Figure 5: CMS: Dijet ratio showing the QCD prediction and the effect of different contact interaction scales as a function of the dijet mass (left). Systematic uncertainties on the Dijet Ratio (right).

3 Dimuon final state

Contact interaction in the dimuon final state have been studied assuming a non-parity conserving LL model. Contact interactions are expected to produce deviations from the Drell-Yan spectrum at high dimuon invariant mass.

3.1 CMS Contact interaction sensitivity

CMS has studied the sensitivity to contact interaction in the dimuon final state [4, 7]. A double ratio method has been developed to reduce systematic uncertainties. The ratio of the number of observed events in the dimuon mass bin i and a zeroth normalization bin $R_i^{\rm data} = \frac{N_i^D}{N_0^D} = \frac{\sigma_i^D \epsilon_i^D}{\sigma_0^D \epsilon_0^D}$ is defined, where σ is the cross section and ϵ is the experimental efficiency. The normalization bin is chosen to be between 250-500 GeV, above the Z pole and in a region well covered by the Tevatron where the standard model has been seen to be valid. In this region the u quark PDF is dominant which has the smallest uncertainties. A similar ratio is defined for the Monte Carlo simulation $R_i^{MC} = \frac{N_i^{MC}}{N_0^{MC}} = \frac{\sigma_i^{MC} \epsilon_i^{MC}}{\sigma_0^{MC} \epsilon_0^{MC}}$. The double ratio $DR_i = \frac{R_i^{\rm data}}{R_i^{MC}}$ is studied versus dijet mass and is shown for a scale of $\Lambda = 20$ TeV in Fig. 6. In the case of perfect theory understanding and detector modelling, a value of $DR_i = 1$ is expected.

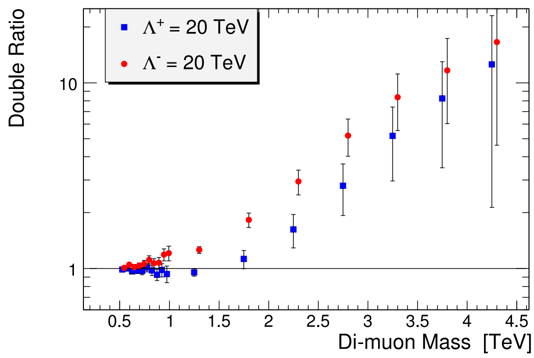

Figure 6: CMS: Double ratio in the dimuon channel for contact interactions with a scale of $\Lambda = 20$ TeV

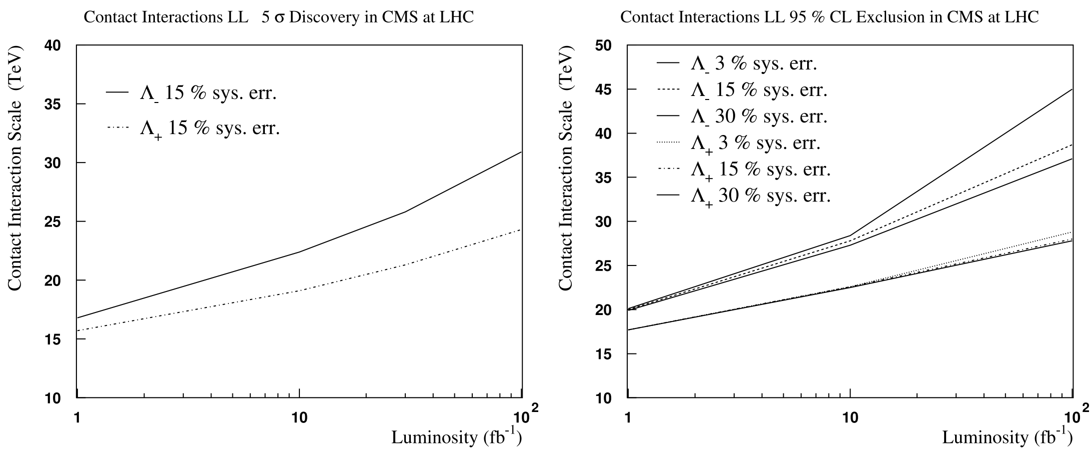

Figure 7: CMS: 5σ discovery reach of contact interactions in the dimuon channel versus luminosity (left). 95% CL exclusion limit of contact interactions in the dimuon channel versus luminosity.

The 5σ discovery reach (Fig. 7-left) and the 95% CL exclusion limit (Fig. 7-right) for contact interactions in the dimuon channel have been studied as a function of the luminosity. Up to a luminosity of 10 fb^{-1} the measurements are dominated by statistical uncertainties. Systematic uncertainties of up to 30% have a small impact in the discovery potential.

4 Conclusions

Contact interaction at a scale Λ can be observed before any new exchanged particle is directly seen. Many techniques have been developed to study compositeness and show promising results with low systematic effects. The sensitivity of the ATLAS and CMS experiments to contact interactions has been investigated. The first hundred pb^{-1} of data will allow the discovery of contact interactions with a scale up to $\Lambda = 5$ TeV. A luminosity of 100 fb $^{-1}$ will allow the discovery of compositeness up to $\sim$ 30 TeV.

References

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