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Hunting for wide resonances in the dijet mass spectrum at CMS

Dimitrios Karasavvas*
On behalf of the CMS Collaboration
National and Kapodistrian University of Athens
E-mail: dimitrios.karasavvas@cern.ch

Results from the dijet resonance search using 35.9 fb^{-1} of pp collision data collected with the CMS experiment at the LHC in 2016 running will be shown. Emphasis is placed on wide resonances, for resonance masses above 1.6 TeV, and focusing on simplified models of dark matter for the interpretation of the experimental results.

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*Speaker.

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1. Introduction

Quantum chromodynamics (QCD) predicts that the production of high transverse momentum (p_T) partons in proton-proton collisions results in a dijet mass (m_{jj}) spectrum which falls smoothly as the dijet mass increases. Several models of physics beyond the standard model, predict the existence of new particles (colorons, excited quarks, Randall-Sundrum gravitons, etc. [1–3]) that couple to quarks and gluons and hence can be detected as a narrow or wide resonance in the dijet mass spectrum. Wide resonances are defined as the ones with natural width larger than the experimental resolution, and would result in a a broad enhancement in the invariant dijet mass distribution above the main standard model (SM) QCD background. In the current article, we search in general for vector and axial vector resonances but emphasize a specific simplified dark matter (DM) model, in which dark matter particles and quarks couple through a DM mediator, that can decay to either a pair of jets or a pair of DM particles, and therefore can be observed as a dijet resonance [4].

2. Jet reconstruction and event selection

Jets used in the high-mass dijet analysis are reconstructed offline using the particle-flow algorithm, described in detail [5], with anti-k_T as the clustering algorithm [6, 7] with a distance parameter 0.4. Such jets are denoted as AK4 jets. Events are selected with the CMS detector at the CERN LHC, described in detail in [8], using a two-tier trigger system. A dijet mass threshold at 1.25 TeV is used in order for the trigger to be fully efficient, and a pseudo-rapidity separation between the two leading wide-jets of $|\Delta\eta| < 1.3$ is required in order to suppress the main standard model background from QCD, while keeping the majority of the signal. AK4 jets that are neighboring in the $\eta - \phi$ plane within a radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 1.1$ are combined into *wide jets* and used to determine the dijet mass. This technique was used in all previous CMS dijet resonance searches [9–12]. The wide-jet algorithm, designed for dijet resonance event reconstruction, reduces the analysis sensitivity to gluon radiation from the final-state partons.

3. Wide resonance introduction

Searching for broad dijet resonances, i.e with the width (Γ) up to 30% of the resonance mass M, allows us to be sensitive to more models and larger couplings compared to the narrow resonance search. The shape of a broad resonance depends on the relationship between the width and the resonance mass, which in turn depends on the resonance spin and the decay channel. The subprocess cross section for a resonance with mass M as a function of di-parton mass m is described by a relativistic *Breit-Wigner* function (e.g. Eq. (7.47) in Ref. [13]):

$$\sigma \propto \frac{\pi}{m^2} \frac{\Gamma_M^i \Gamma_M^f}{(m^2 - M^2) + (\Gamma_M)^2} \tag{3.1}$$

where Γ_M is the total width and $\Gamma_M^{(i,f)}$ are the partial widths for the initial state i and final state f. We consider explicitly the shapes of spin-1 resonances in the quark-quark channel and the shape of spin-2 resonances in the quark-quark and gluon-gluon channels. Spin-0 resonances coupling

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directly to pairs of gluons or to pairs of gluons through fermion loops will have a similar shape as a spin-2 resonance in the gluon-gluon channel. Spin-0 resonances coupling to quark-quark will have a similar shape as a spin-1 resonance in the quark-quark channel.

4. Dijet mass spectrum and fit

We describe the main QCD background by performing a fit of the dijet mass spectrum with an empirical functional form shown below:

$$\frac{d\sigma}{dm_{jj}} = \frac{p_0(1-m_{jj}/\sqrt{s})^{p_1}}{(m_{jj}/\sqrt{s})^{p_2+p_3 log(m_{jj}/\sqrt{s})}} \tag{4.1}$$

where p_0, p_1, p_2 and p_3 are four freely floating nuisance parameters, and the chi-squared per number of degrees of freedom of the fit is χ^2/NDF = 38.9/39. Figure 1 shows the dijet mass spectra, defined as the observed number of events in each bin divided by the integrated luminosity and the bin width, with predefined bins of width corresponding to the dijet mass resolution [14].

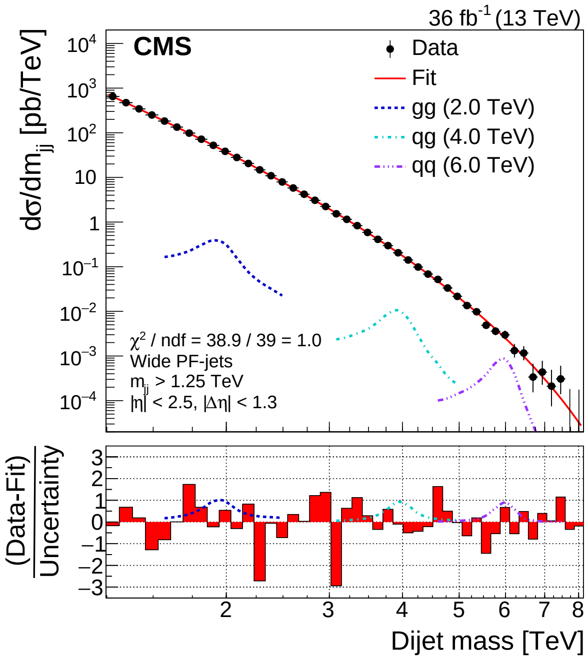

Figure 1: Top: Differential cross section as a function of dijet mass for data (black points) along with the empirical parametric fit (red line) performed in the range $1246 < m_{jj} < 8152\ GeV$. Resonance signal shapes for different resonance masses are shown, normalized to the excluded cross section for each resonance type, with blue, cyan and magenta lines. Bottom: Pulls of the fitted distribution, defined in each bin as the yield difference between the data and the fit divided by the data uncertainty [11].

5. Results

Wide resonance shapes are produced using Monte Carlo techniques setting the standard quark coupling $g_q = 1.0$, $g_{DM} = 1.0$ and m_{DM} = 500 GeV, for natural widths 1%, 10%, 20%, 30% and masses up to 8 TeV. Figure 2 shows the 95% confidence level (CL) upper limits on vector dark matter mediator decaying to qq for different values of Γ/M (left). The cross section limits in Fig. 2

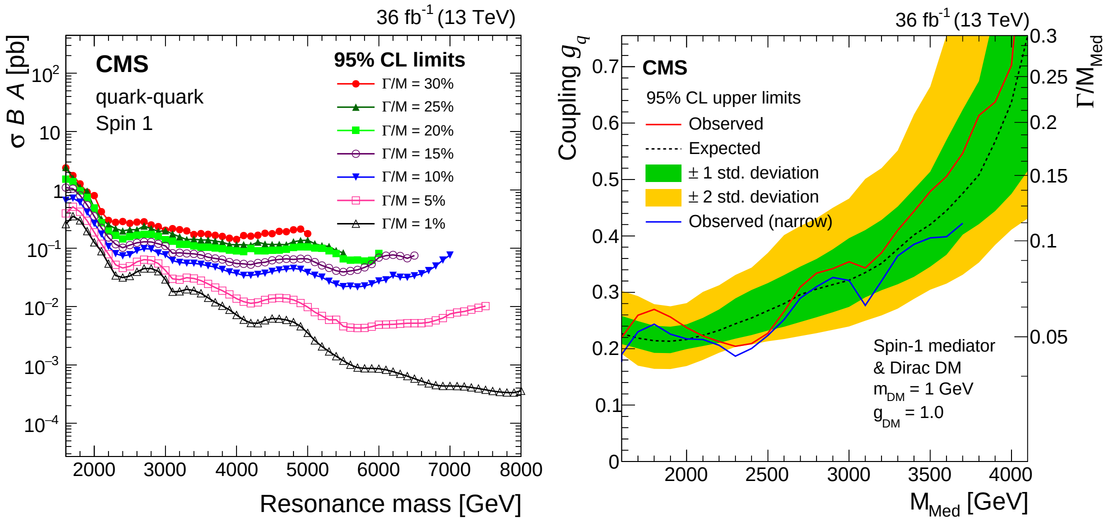

Figure 2: Left: The observed 95 % CL upper limits on the product of the cross section, branching fraction, and acceptance for quark-quark spin-1 resonances. Right: The 95 % CL upper limits on the quark coupling g_q as a function of resonance mass for a vector mediator. The observed limits (solid), expected limits (dashed) and their variation at the 1 and 2 standard deviation levels (shaded bands) are shown [11].

(quark-quark Spin-1 resonances) have been used to derive constraints on a DM mediator. The cross section for mediator production for m_{DM}= 1 GeV and g_{DM} = 1 is calculated at leading order using MasGraph5_ aMC@NLO version 2.3.2 [15] for mediator masses within the range $1.6 < M_{Med} < 4.1$ TeV in 0.1 TeV steps, and for quark couplings within the range $0.1 < g_q < 1.0$ in 0.1 steps. For these choices the relationship between the width and g_q given in Refs. [16] and [17] simplifies to:

$$\Gamma_{Med} \approx \frac{(18g_q^2+1)M_{Med}}{12\pi} \tag{5.1}$$

for both vector and axial-vector mediators. Figure 2 (right), shows the 95% CL upper limits on the universal quark coupling g_q as a function of resonance mass for a vector mediator of interactions between quarks and DM particles.

6. Conclusions

Results from the dijet resonance search using 35.9 fb^{-1} of pp collision data collected with the CMS experiment at the LHC in 2016 are presented with emphasis on wide resonances. Limits on the coupling of vector dark matter mediators as a function of the mediator mass are presented for simplified models of interactions between quarks and dark matter.

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