CMS Physics Analysis Summary

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Search for Mono-Jet Final States from ADD Extra-Dimensions at $\sqrt{s}$=10 TeV

The CMS Collaboration

Abstract

The missing transverse energy + single-jet signature has been investigated with the CMS detector, as a probe for the discovery of large extra dimensions in the framework of the ADD model. Signal and background samples have been simulated and analyzed. Techniques to estimate the background contributions via data-driven methods are discussed. The discovery reach is studied for the 2009/2010 running conditions of the LHC pp collider ($\sqrt{s} = 10$ TeV, O(100) pb^{-1}) taking into account systematic uncertainties. It is shown that a significant improvement to the current limits of the model can be obtained even in this very early stage.

1 Introduction

This note describes analysis procedures for the search of large extra dimensions from a signature with missing transverse energy plus a single jet, using the Compact Muon Solenoid (CMS) detector. The description of the detector performance and the simulated samples of events correspond to those expected for the 2009-2010 run at 10 TeV center-of-mass energy, for an integrated luminosity of up to 200 pb^{-1}. This analysis is an update of the study in Ref. [1], where conditions for a later stage with $\sqrt{s} = 14$ TeV were addressed.

The phenomenological ADD model [2] aims to solve the hierarchy problem between the electroweak and Planck scales by introducing a number δ of extra spatial dimensions, which in the simplest scenario are compactified over a torus and all have the same radius R. The fundamental scale M_D is related to the effective 4-dimensional Planck scale M_{Pl} according to the formula $M_{Pl}^2 \sim M_D^{\delta+2} R^\delta$. Current experimental constraints allow a scenario with $\delta \geq 2$, corresponding to extra dimensions sizes below $5 \cdot 10^{-2}$ mm if the fundamental scale M_D is of the order of TeV.

This study is focused on the production of a graviton G balanced by a energetic hadronic jet via the $q\bar{q} \to gG$, $qg \to qG$, and $gg \to gG$ processes.

Searches in both the jet+$E_{\mathrm{T}}^{\mathrm{miss}}$ and the $\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$ channels have been performed by CDF (1.1 fb^{-1} and 2.0 fb^{-1} of data respectively, [3]), DØ ($\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$, 1.05 fb^{-1}, [4] and jet+$E_{\mathrm{T}}^{\mathrm{miss}}$ in Run I with 78.8 pb^{-1}, [5]), and LEP experiments [6]. The best 95% confidence limits on M_D are 1.400(1.040) TeV for the extra dimensions scenario with $\delta = 2(4)$.

It has been shown [1] that with $\sqrt{s}$ =14 TeV a 95% confidence limit of 4.61(3.46) TeV for δ =2(4) can be achieved after 100 pb^{-1}. In this note we demonstrate that the current limits can be significantly improved also at $\sqrt{s}$ =10 TeV with a similar data size.

2 Signal and background generation and reconstruction

The new physics signature considered in this study is simple: a high-transverse-momentum ($p_{\mathrm{T}} > 100 \div 200$ GeV) jet in the central region of the detector, recoiling back-to-back in the transverse plane with a $E_{\mathrm{T}}^{\mathrm{miss}}$ of similar magnitude.

The process of Z+jets production, with Z decaying to neutrinos, leads to invisible energy recoiling against jets and is described by the same signature as the signal, thus the contribution from this "irreducible" background needs to be estimated in the best possible way. Other important background sources are W+jets with a leptonic W decay (if the charged lepton is not reconstructed), QCD di-jets (when one or more jets are mismeasured and a significant amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ is produced), and top-pair and single-top quark production, especially for events with few of collimated jets where leptons are not identified. A minor contribution is expected also from $ZZ/WW/ZW$+jets processes, that may have many events with large $E_{\mathrm{T}}^{\mathrm{miss}}$, thus contributing despite the relative low cross-section.

A variable discriminating signal from background is constructed as the vectorial sum of jets transverse momenta $\vec{p}_T(\mathrm{jet})_{\mathrm{i}}$ above a threshold p_{T}^0. This quantity (MHT) is defined as:

$$MHT = \left| \sum_{p_{\mathrm{T}}(\mathrm{jet})_{\mathrm{i}} > \mathrm{p}_{\mathrm{T}}^0} \vec{p}_T(\mathrm{jet})_{\mathrm{i}} \right|$$

and has been proven to be remarkably larger in signal than in QCD events. In this analysis

p_{T}^{0}=30 GeV was chosen. All the jets with $|\eta| < 5$ were included.

The ADD-model signal was produced with the SHERPA Monte Carlo generator [7] version 1.1.2. In order to scan the sensitivity in a large parameter space, different samples with M_D ranging from 1 to 3 TeV and δ from 2 to 6 were generated. Since the model is considered an effective theory that holds for energies well below M_D, the cut $\sqrt{\hat{s}} < M_D$ (with $\sqrt{\hat{s}}$ center-of-mass energy of the partonic interaction) was imposed in the generation step. A p_{T} cut-off on the parton recoiling against the graviton was introduced, by requiring $\hat{p}_T$ >150 GeV [1]. The CTEQ61L Parton Density Functions (PDF) [8] were used. With these production parameters, the signal cross sections at leading-order were calculated by SHERPA for the 15 samples and ranges from 279 pb (for M_D =1 TeV, $\delta = 2$) to 0.58 pb (for M_D =3 TeV, $\delta = 6$). For each subsample with a given (M_D, δ), $2 \cdot 10^4$ events were produced. The graviton transverse momentum, the jet multiplicity and the event shape do not show any striking dependence on δ; a larger M_D will only result in more energetic parton and graviton.

A set of background processes were generated with a sample size corresponding to an integrated luminosity larger than 200 pb^{-1} (with the exception of $\hat{p}_T$ >80 GeV and $\hat{p}_T$ >170 GeV QCD samples), then processed by a full simulation of the CMS detector. All the boson+jets and top pair samples were produced with MADGRAPH [9], based on a leading-order calculation of the matrix element. The large QCD backgrounds (here referred also as 'multi-jet events') were generated by PYTHIA 6.409 [10], in slices of $\hat{p}_T$ lower cuts. The MC@NLO generator [11] was used for inclusive single-top production.

The hadronization and fragmentation of quarks and gluons (along with the underlying event) were performed using PYTHIA with the MLM shower matching prescription [12] to avoid double counting due to the parton showering. Jets were defined using an iterative cone (IC) algorithm with $\Delta\mathrm{R} = 0.5$ [13], with the jet energy scale obtained by applying a Monte Carlo-based energy correction. This includes the relative corrections, which produce a uniform response along η, and the absolute corrections, which bring the jet energy back to the generator particle level [14].

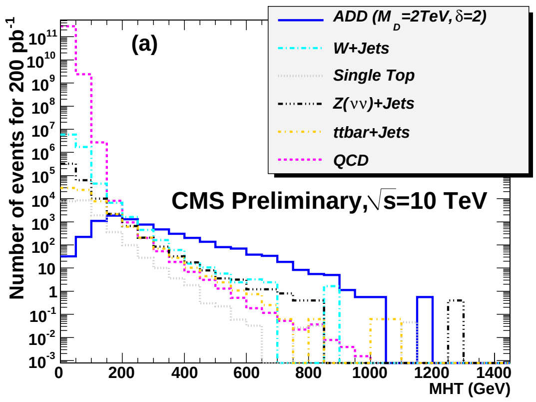
3 Signal and background analysis

The analysis procedure closely resembles the one in Ref. [1]. In this study we opted for a different trigger, replaced the $E_{\mathrm{T}}^{\mathrm{miss}}$ by MHT, and lowered the p_{T} cuts, following the beam energy reduction. The choice of thresholds was determined by looking for a high $N_S/\sqrt{N_B}$ ratio (with $N_S(N_B)$ number of signal(background) events after the selection); relative improvements obtained by further adjusting the cuts were found to be negligible.

At trigger level, a simple single jet stream designed for a phase with a $10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ luminosity is proposed here. It requires at least one jet with $p_{\mathrm{T}} > 70$ GeV at Level 1 (L1) and at least one jet with $p_{\mathrm{T}} > 110$ GeV at High Level Trigger (HLT). The multi-jet rate at the HLT is expected to be of 8.1 ± 1.1 Hz.

As shown in Fig. 1(a), the signal leads to a long tail in the MHT distribution, hence a cut MHT >250 GeV was imposed at the preselection level. In this region the trigger efficiency of the signal is expected to be close to 100% .
To reduce the impact of objects not coming from hard interaction, only jets with transverse momenta larger than 50 GeV within the hadronic calorimeter acceptance $|\eta| < 3$ were considered.

[1] Hereafter, $\hat{p}_T$ stands for as the transverse momentum of the outcoming parton in jet production (gluon or quark).



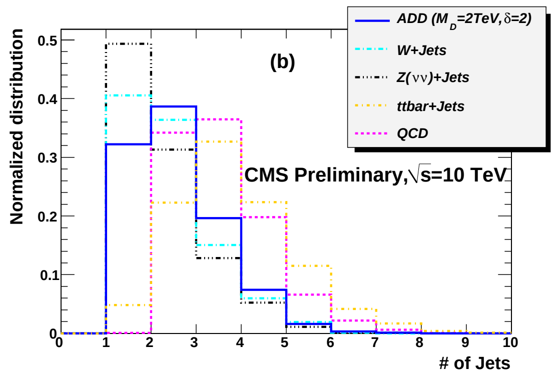


Figure 1: (a) MHT distributions for ADD signal ($M_D = 2$ TeV, $\delta = 2$) and relevant backgrounds before any selection, after 200 pb^{-1} (b). Number of jets for signal and relevant backgrounds, for $MHT > 250\,\text{GeV}$ and jets with transverse momenta larger than 50 GeV and $|\eta| < 3$. Histograms are overlaid and normalized to the same area.

The data sample was then cleaned from leptonic events using the "Indirect Lepton Veto" approach, where two variables are exploited:

- Jet Electromagnetic Fraction ($JEMF$), defined as the fraction of jet energy collected by the electromagnetic calorimeter over the total energy in electromagnetic and hadronic calorimeter. High-energy electrons and photons can be rejected by requiring a $JEMF$ lower than 0.9. Instrumental background (as noise in calorimetric cells, beam halo events or cosmic rays), that may lead to fake jets, was reduced with a cut $JEMF > 0.1$;
- Track Isolation Veto (TIV). A hollow cone 0.02< ΔR <0.3 was defined around each track with $p_T > 10$ GeV. The sum of the transverse momenta p_T^j of all the tracks inside the cone with $p_T > 1$ GeV was calculated and the TIV variable defined as:

$$TIV = \frac{1}{p_T(\text{tk}\,1)} \sum_{R \in \Delta R} p_T^j \quad ,$$

  where $p_T(\text{tk}\,1)$ is the highest transverse momentum of tracks in the cone and the cone lower bound excludes the track itself. Rejecting tracks with $TIV < 0.1$ resulted in a reduction of $W(\mu\nu)$+jets and top pair events by factors 9 and 5, respectively.

In order to suppress cosmic background, at least one vertex coming from the interaction point and at least two tracks with $p_T > 5\,\text{GeV}$ inside the leading jet cone were requested.

To improve the background rejection, the most energetic jet in the event (leading jet, jet 1) was

	$t\bar{t}$	$Z(\nu\nu)$+j	QCD	$W(e\nu)$+j	$W(\mu\nu)$+j	$W(\tau\nu)$+j	single-t
Trigger	28,970	11,390	$143 \cdot 10^6$	31,320	19,320	20,600	4460
MHT >250 GeV	318	358	288	90	391	230	44
$0.1 < JEMF < 0.9$ TIV >0.1	52.5	305	214	31.9	38.5	90.9	7.2
$p_{\mathrm{T}}(\mathrm{jet}\,1) > 200$ GeV $\lvert\eta(\mathrm{jet}\,1)\rvert$ <1.7	37.4	245	187	24.6	24.6	72.1	4.5
numb. jets<3	8.2	205.6	70.9	18.8	22.9	59.8	2.8
$\Delta\phi(\mathrm{jet}\,1, MHT)$ >2.8 $\Delta\phi(\mathrm{jet}\,2, MHT) > 0.5$	6.4	182.5	0.2	17.2	19.7	46.7	2.3

Table 1: Number of selected events for each group of cuts in the relevant background samples, normalized to 200 pb^{-1}.

required to have $p_{\mathrm{T}}(\mathrm{jet}\,1) > 200$ GeV and $|\eta(\mathrm{jet}\,1)|$ <1.7. After this selection, the signal jet multiplicity (Fig. $1(b)$,) is peaked around $1 \div 2$ and rapidly decreases for higher number of jets. Events with more than two jets were vetoed.
Since in the events with $E_{\mathrm{T}}^{\mathrm{miss}}$+1 jet the direction of $E_{\mathrm{T}}^{\mathrm{miss}}$ is ideally aligned with the MHT vector, the angle in the transverse plane between MHT and leading jet is expected to be close to π. When events with an angular difference in the transverse plane $\Delta\phi(\mathrm{jet}\,1, MHT) > 2.8$ are selected, processes where missing energy does not recoil with jets are suppressed. The rejection is largely enhanced by requiring in addition $\Delta\phi(\mathrm{jet}\,2, MHT) > 0.5$, that further reduces multi-jet events by two orders of magnitude.

After the complete set of selections was applied ,only one Monte Carlo event from QCD background was found, corresponding to 0.2 events after normalizing to an integrated luminosity of 200 pb^{-1}. QCD is therefore expected to contribute to the total background at the per-mille level. A factorization approach to verify this estimate is provided in the Appendix A: it proves that it is possible to evaluate a selection efficiency that is within a factor ~ 3 of the value from Monte Carlo. A systematic uncertainty of 300% on the number of multi-jet events was therefore introduced.

Besides the irreducible $Z(\nu\nu)$+jets background, the only significant sources of background are those with a muon or an electron from W (or from τ from W) decay; the W can be directly produced or coming from a top quark. These leptons are not identified by the Indirect Lepton Veto either because they are outside the pseudorapidity acceptance, or too close to a high-p_{T} jet.

The MHT distributions for signal and background after all selections are shown in Fig. 2. The signal shows up as an excess of events in addition to the dominant $Z(\nu\nu)$+jets background.

The effect of each group of cuts is reported in Tab. 1 for all the Standard Model processes and in Tab. 2 for some benchmark signals. The absolute expected number of selected events (assuming 200 pb^{-1} of data) along with the relative efficiency of the cuts are quoted. The behavior of simulated $ZZ/WW/ZW$+jets processes is not shown here, because their impact on the final selection is negligible.

Events from the machine-induced background and cosmic rays were not simulated, but we are confident that the set of cut reduces this kind of effects to a negligible level. In fact, the beam halo is expected to be removed by the jet electromagnetic fraction lower cut. The requirement of at least one track from interaction point and the cut on number of tracks inside jets was observed not to reduce the signal more than 1%: therefore, the proposed procedure allows

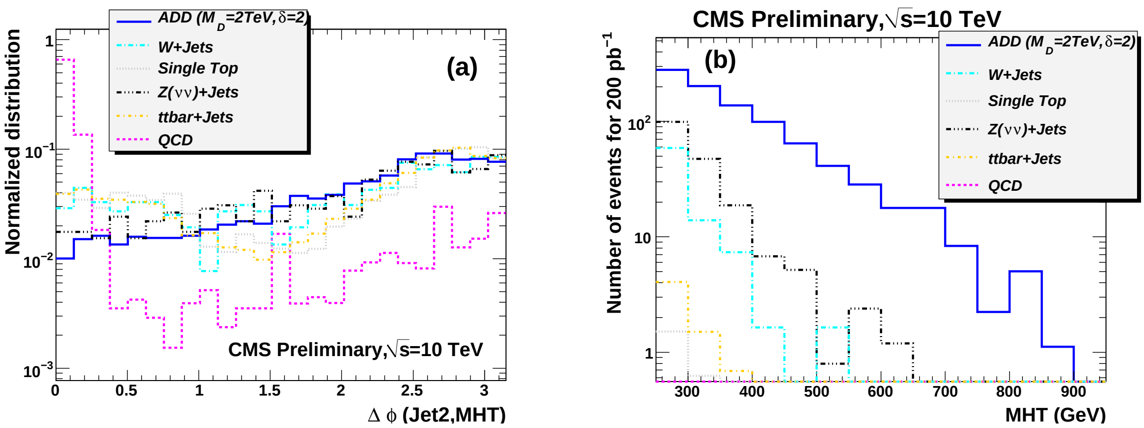


Figure 2: (a) Azimuthal angle in the transverse plane between the MHT and a possible second jet, after MHT cuts. Histograms are overlaid and normalized to the same area. (b) MHT distribution after all selections are applied. Histograms are overlaid and number of events correspond to 200 pb^{-1}.

	$\delta = 2$			$\delta = 4$	
	$M_D = 1$ TeV	$M_D = 2$ TeV	$M_D = 3$ TeV	$M_D = 2$ TeV	$M_D = 3$ TeV
Trigger	51,000	6180	1370	2010	301
MHT >250 GeV	11,140	2123	498	753	133
$0.1 < JEMF < 0.9$ TIV >0.1	9572	1825	426	641	113
$p_T(\text{jet}\,1) > 200$ GeV $\lvert\eta(\text{jet}\,1)\rvert$ <1.7	6785	1368	314	487	88.4
number of jets<3	5605	1044	401	374	64.4
$\Delta\phi(\text{jet}\,1, MHT)$ >2.8 $\Delta\phi(\text{jet}\,2, MHT) > 0.5$	4934	906	206	322	55.8
Total Efficiency (%)	8.8 ± 0.1	13.7 ± 0.4	14.1 ± 0.4	13.2 ± 0.4	17.7 ± 0.4

Table 2: Number of selected events for each group of cuts in five signal subsamples, normalized to 200 pb^{-1}. The final efficiencies are quoted with statistical uncertainties.

to select jets coming from genuine collision events, while objects that are displaced from the interaction point (as cosmic rays) do not contaminate the sample.

4 Impact of systematic effects

Systematic uncertainties play an important role in this analysis where no mass peak is expected. In the next section, it will be shown how the most relevant background processes can be estimated in a control region with real data: therefore, systematic effects on background normalization have little relevance here. Only effects on efficiency ratios will be considered and reported in the next section.
The most important uncertainties related to theoretical signal modeling are:

- cross section sensitivity to the renormalization and factorization scale $Q = \sqrt{\hat{s}}$. The scale was varied from $Q/2$ to $2Q$ in the SHERPA generation step for different PDF choices. Results indicate that a $^{+7.5\%}_{-6.7\%}$ uncertainty has to be considered;
- uncertainties on the parton density function. They were evaluated using the reweighting technique and Master Equation on the CTEQ61M model set [8], as described in [15]. We found a $^{+11.5\%}_{-9.5\%}$ cross section variation for the signal, with little dependence on the specific ADD point.

Uncertainties associated to energy, direction, and calibration of jets are the most relevant systematic instrumental effects. In this analysis, the following mismeasurements of jets have been emulated:

- jet energy resolution and direction uncertainties. Transverse momenta and ϕ angle of all jets were smeared by a Gaussian function, accounting for a 10% resolution in p_{T} and a (conservative) 0.1 rad resolution in angle;
- jet energy scale, emulated by shifting the jet 4-vector with a common $(1 \pm \alpha)$ factor. For this early LHC stage, $\alpha = 10\%$ was assumed irrespective of the jet energy.

These uncertainties were applied to both the HLT and off line-corrected jets. Their relative shift from the value with no systematic effect depends on the ADD points, ranging from 10% to 16%. The value of instantaneous luminosity, that is assumed to have a $\pm$10% uncertainty, was incorporated.

5 Data-driven background estimation

Since the present analysis is tailored to the very early data-taking, evaluating the background from early data instead of simulations is important. In the following, the irreducible $Z(\nu\nu)$+jets ("invisible Z" background) and $W(e/\mu/\tau\nu)+$ jets backgrounds are estimated following the same strategy as used for the 14 TeV analysis.

5.1 $Z(\nu\nu)+$jets background estimation

In Ref. [1], it has been shown that the Z invisible background can be derived from sample of events containing a high-p_{T} $W(\rightarrow l\nu)$+jets boson.
The selection defining the control region maintains the same cuts as for the $E_{\mathrm{T}}^{\mathrm{miss}} + 1$ jet signal, except for the muon requirement. The strategy consists of different steps:

- the event was triggered by the single-jet stream adopted for the signal;
- a sample with muons was selected, with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ and $|\eta| <2.4$;
- the muon was required to fulfill tracker and calorimeter isolation requirements. The muon isolation variable is defined as the the sum of the transverse momenta of the tracks in a cone of $\Delta\mathrm{R} = 0.3$ around the muon track direction, excluding the muon

track: $\mu_{Iso} = \sum_{trk}^{\Delta R} p_T(\mathrm{trk})$ (in the calorimeters, $p_T(\mathrm{trk})$ is replaced by E_T deposit in the cone). It was considered isolated when μ_{Iso} was less than 3 GeV in the tracker and 1 GeV in the calorimeter. Only events with one isolated muon were retained;

- jets closer than a $\Delta R = 0.5$ distance from the isolated muon direction were ignored;
- the resulting sample underwent the same set of selections as the signal region, but excluding from TIV the track which is associated to the single muon.

This procedure allowed to reproduce the same kinematic region that was designed for the signal, but having one hard isolated muon, for which the hypothesis of coming from W is highly probable. The only systematic effects are those associated to the muon selection.
The number of $W(\mu\nu)$+jets selected for 200 pb^{-1} is $164 \pm 11(\mathrm{MC})^2$. Different processes with at least one isolated muon and jet are prone to pass the selection. The most significant backgrounds were found to be $W(\tau\nu)$+ jets (39.8 $\pm$ 5.2), top pair (18.3 $\pm$ 1.0), and single top (8.7 $\pm$ 0.6) events.

In order to verify that the contamination from QCD can be neglected also in this case, an independent cross-check was performed by using a factorization method. The selection on control region was split in single muon selection (with trigger, kinematical and isolation requirements) and full selection without muon cuts. Since it can be assumed that the two sets of cuts are not correlated, the rejection for multi-jet can be obtained by multiplying the two rejection factors separately. The efficiency for the stand-alone single muon selection is $(5.35 \pm 0.01) \cdot 10^{-3}$, while the full set of cuts but those on the muon retains a fraction equal to $(2.5 \pm 0.4) \cdot 10^{-9}$. The total efficiency amounts to $(1.3 \pm 0.2(\mathrm{MC})) \cdot 10^{-11}$: after 200 pb^{-1}, this corresponds to less than 0.01 surviving events.
Since this analysis is specifically aimed to a very early data-taking, no b-tagging techniques were introduced to veto the b-jets from top. As long as it is not possible to identify a region where top pair and single top events are separable from W production, their contribution should be evaluated from Monte Carlo. Recent studies in the 10 TeV regime demonstrate that both processes can be observed in a very early stage with reasonable precision: for the single top, 35% statistic and 11% systematic errors on the cross section is expected [16] at 200 pb^{-1}, while for $t\bar{t}$ the result in Ref. [17] can be scaled to 3.35%(10%) statistic (systematic) error. Therefore, it can be assumed that the expected cross sections will be normalized in data with those uncertainties: $N(t\bar{t})^{Contr} = 18.3 \pm 0.6$ (stat.) $\pm$ 1.8 (syst.), $N(\mathrm{single}-\mathrm{t})^{Contr} = 8.7 \pm 3.0$ (stat.) $\pm$ 1.0 (syst.).
The distribution of MHT is similar between $W(\tau\nu)$+ jets and $W(\mu\nu)$+ jets within few percent and all events from $W(\tau\nu)$ events entering the region have a muon from τ decay. Therefore, the composition of the control region can be written as

$$N^{Contr} = [1 + Br(\tau \to \nu\nu\mu)]\, N(W(\mu\nu) + \mathrm{jets})^{Contr} + N(\mathrm{others})^{Contr} \quad ,$$

where $N(\mathrm{others})$ includes contributions from top pair and single top. With $Br(\tau \to \nu\nu\mu) = 0.1736 \pm 0.0005$ [18], the method produces the number of events in the control region $N(W(\mu\nu) + \mathrm{jets})^{Contr} = 172.9 \pm 13.1$ (stat.) $\pm$ 13.4 (syst.), which is consistent with the Monte Carlo result. Subtracting this value from the control region leads to a $N(W(\tau\nu) + \mathrm{jets})^{Contr} = 30.0 \pm 2.3$ (stat.) $\pm$ 2.3 (syst.), to be compared with the result mentioned above.
To reproduce the number of $Z(\nu\nu)$+jets background, the amount of selected $W(\mu\nu)$+jets has to be rescaled for the following factors:

[2] Notation MC refers to the counting error due to the limited number of generated Monte Carlo events (or the error induced by this source through error propagation).

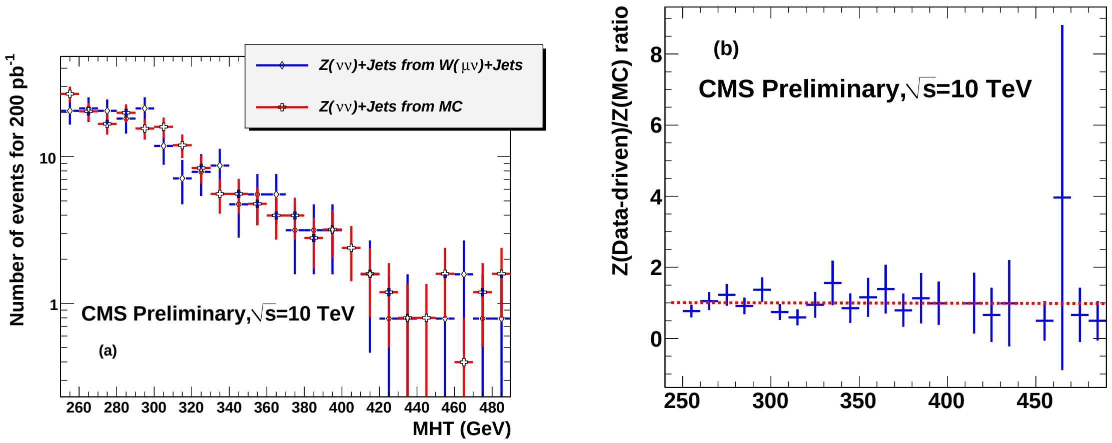


Figure 3: Selected $Z(\nu\nu)+$jets events from Monte Carlo and estimated from $W(\mu\nu)+$jets procedure (a) and their ratio (b). Within error bars from Monte Carlo statistic, the ratio is consistent with 1 (red dashed line).

- ratio between $W(\mu\nu)$+jets and $Z(\nu\nu)$+jets production cross sections. The ratio between two MHT spectra was found to be constant up to high energies in the hard interaction, and equal to $1.314 \pm 0.008\,(\mathrm{MC}) \pm 0.013\,(\mathrm{PDF})$;
- muon reconstruction and isolation efficiency. In this control region, it was determined to be $0.760 \pm 0.079\,(\mathrm{MC}) \pm 0.015$ (syst.), where the systematic error includes a fit on the muon efficiency and the effects listed in the previous section.

The number of invisible Z events in the signal region was found to be $N(Z(\nu\nu)+\mathrm{jets})^{Sign} = 163 \pm 22$ (stat.) ± 13 (syst.) ± 17(MC) (to be compared with $N(Z(\nu\nu)+\mathrm{jets})^{MC} = 182 \pm 13$ (stat.)). In Fig. 3(a) the Z background MHT distributions taken directly from Monte Carlo and from our data-driven method are displayed, along with their ratio in Fig. 3(b). The two shapes are consistent and confirm that even in an early scenario, the $Z(\nu\nu)+$jets background can be estimated from data, with a $\sim 10\%$ uncertainty and relying on robust reconstructed objects.

5.2 Other background sources

The same region designed for invisible background estimation can be used to measure the $W(\tau\nu)$+jets contribution in the signal region. The Monte Carlo simulations demonstrate that the muon efficiency for the $W(\tau\nu)$+jets process is reproduced by the value determined above from the $W(\mu\nu)$+jets sample, scaled by the efficiency of the TIV cut. Therefore, the simplest approach is to rescale the $N(W(\tau\nu)+\mathrm{jets})^{Contr}$ by muon reconstruction and isolation efficiencies measured in the control region. This results in $N(W(\tau\nu)+\mathrm{jets})^{Sign} = 39 \pm 5$ (stat.) $\pm$ 3 (syst.) ± 4 (MC) with 200 pb^{-1}.

To evaluate the number of surviving events for the other W channels, the ratio between the dif-

	$\delta = 2$			$\delta = 4$	
	$M_D = 1$ TeV	$M_D = 2$ TeV	$M_D = 3$ TeV	$M_D = 1$ TeV	$M_D = 2$ TeV
95% C.L.	0.2	1.1	10	0.5	4.9
5σ	1.7	14	160	6.0	68

Table 3: Minimum integrated luminosity (pb^{-1}) needed for a 95% C.L. exclusion or a 5σ discovery, for different ADD points.

ferent W decay channels predicted by Monte Carlo in the signal region was taken into account, along with its systematic uncertainty. This produced $N(W(\mu\nu) + \text{jets})^{Sign} = 16.7 \pm 2.2$ (stat.) $\pm$ 3.0 (syst.) $\pm$ 4.4 (MC) and $N(W(e\nu) + \text{jets})^{Sign} = 14.5 \pm 2.0$ (stat.) $\pm$ 2.2 (syst.) $\pm$ 4.0 (MC). All these estimates are consistent with the result from simulations in Tab. 1. The estimate of the top contributions takes the prediction from Monte Carlo as the central value, but using the precision expected to be reached for the actual observation of top, leading to $N(t\bar{t})^{Sign} = 6.4 \pm 0.2$ (stat.) $\pm$ 0.6 (syst.), $N(\text{single} - \text{t})^{Sign} = 2.3 \pm 0.8$ (stat.) $\pm$ 0.2, (syst.).

6 Discovery potential and exclusion limits

Combining the results from the previous section, the total background N_B can be estimated as:

$$N_B = 243 \pm 23 \text{ (stat.)} \pm 13 \text{ (syst.) events}$$

for 200 pb^{-1} of integrated luminosity. All the correlations between uncertainties on different background sources were accounted for.
In the absence of an excess over the dominant invisible background, an upper limit on the M_D parameter can be calculated in the 200 pb^{-1} dataset. The Profile Likelihood approach [19] was chosen, where the likelihood function was derived from a Poisson distribution for the total number of observed events, multiplied by a Gaussian with N_B as mean and the total background uncertainty as sigma. The 95% C.L. limit was found by scanning the parameter space to minimize the negative Log Likelihood. Scanning was repeated for 5 different benchmark points for ADD and the minimum integrated luminosity needed is quoted in Tab. 3. When different M_D, δ are interpolated, the exclusion plot in Fig. $4(a)$ can be derived.
A significance estimator based again on Profile Likelihood was used to measure the amount of data needed for a 5σ discovery, and results are reported in Tab. 3. When results from different signal points are interpolated, the plot in Fig. $4(b)$ is obtained, that represents the sensitivity for a discovery after 200 pb^{-1}.

These results indicate that the current exclusion limits from Tevatron experiments can be matched at LHC with the first physics run. After 200 pb^{-1}, M_D can be excluded for masses below 3.8(3.2) TeV for $\delta = 2(4)$; also early discoveries for $\delta = 2(4)$ scenarios are possible, if M_D is below 3.1(2.3) TeV, respectively.

7 Conclusions

A simulation study of the ADD model in the G+jet channel has been performed with the CMS detector. The previous analysis for a center of mass energy of 14 TeV has been updated to the machine conditions expected for 2009/2010 LHC run ($\sqrt{s}$=10 TeV) and extended to 200 pb^{-1} of data.

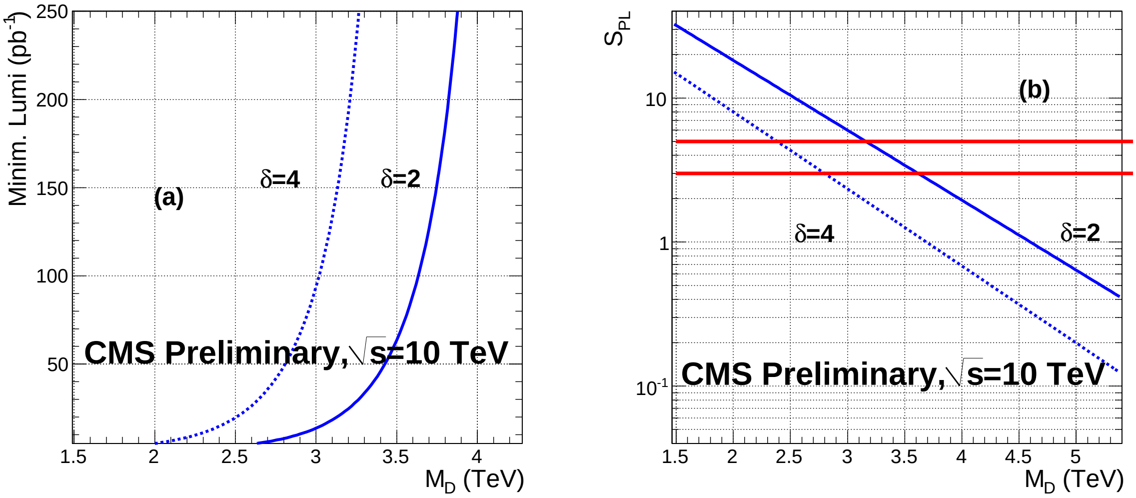


Figure 4: (a): Exclusion plot at 95% C.L., showing the minimum luminosity necessary to exclude a given value of M_D. (b): Discovery potential of the analysis as a function of M_D and δ after 200 pb^{-1}. The horizontal thick lines correspond to 3σ and 5σ significance level. In both cases, sensitivity is plotted for two different extra dimension scenarios.

Unlike the former analysis, based on a standard missing energy measurement from the calorimeter system, here the vectorial sum of corrected jets was exploited. Selection criteria were chosen to maximize rejection for the Standard Model reducible backgrounds (top production, multi-jet, and $W(l\nu)+$jets). For the irreducible $Z(\nu\nu)+$jets, the usage of a control region with $W(\mu\nu)+$jets events was demonstrated to work.
An ADD parameter scan was performed in order to calculate the CMS sensitivity to the studied model. A 5σ discovery for a $E_{\mathrm{T}}^{\mathrm{miss}}+1$jet signal can be obtained for values of the fundamental scale M_D lower than 3.1(2.3) TeV for $\delta = 2(4)$, while 95% C.L. exclusion limits for $M_D = 3$ TeV, $\delta = 2$, $M_D = 2$ TeV, $\delta = 4$ can be reached after only 11 pb^{-1} and 5.0 pb^{-1}, respectively.

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A Factorization method for QCD events

The value of the QCD events rejection factor was further checked with a factorization approach. The signal region was divided in two sets of cuts:

1. events with $MHT > 250\,\mathrm{GeV}$, leptons removed with the Indirect Lepton Veto, and cut on $|\eta(\mathrm{jet}\,1)|$;
2. events with $|p_{\mathrm{T}}(\mathrm{jet}\,1)|$ cut, veto for more than 2 jets, and azimuthal cuts. To have a sufficient number of QCD events to compute efficiencies, the leading jet momentum cut was lowered to 150 GeV: therefore, the final estimate should be an upper bound.

	$\hat{p}_T > 80\,\text{GeV}$	$\hat{p}_T > 170\,\text{GeV}$	$\hat{p}_T > 300\,\text{GeV}$	$\hat{p}_T > 470\,\text{GeV}$
Number of events after ϵ_1	< 0.6	16 ± 8	97 ± 5	98 ± 2
Efficiency after ϵ_2 (10^{-3})	1.06 ± 0.02	5.02 ± 0.04	0.777 ± 0.018	$(7.2 \pm 0.6) \cdot 10^{-2}$
QCD_{fact} (10^{-3})	< 0.65	80 ± 40	75.4 ± 4.3	7.1 ± 0.6

Table 4: Number of events (second row) and efficiency (third row) for the two sets of cuts explained in the text, when measured on four QCD bins. The two set have been checked to be not correlated to a good approximation, so the total number of selected events can be estimated as the product QCD_{fact} in the fourth row. Uncertainties come from size of Monte Carlo samples.

The linear correlation coefficient ρ among all the jet-related variables was evaluated and these two sets were demonstrated to be the ones with smallest correlation ($\rho < 0.15$, mostly due to correlation between leading jet and MHT). Therefore, the total efficiency for multi-jet in the control region can be reproduced by the product of the two efficiencies to a good approximation. The number of multi-jet events surviving the first set (ϵ_1), together with the efficiency of the second set (ϵ_2), is reported in Tab. 4. Combining together all the $\hat{p}_T$ samples, the number of multi-jet after 200 pb^{-1} (QCD_{fact}) is expected not to be larger than 0.2, confirming that QCD processes do not introduce sizable uncertainties in our knowledge of the background and can be ignored in the total background.