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Exotic searches at the Tevatron

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Summary. — This paper is intended to briefly expose the latest exotic physics results from the Tevatron experiments, focusing on non-supersymmetry searches.

PACS 13.85.Rm – Limits on production of particles.

1. – Introduction

Despite its great success the Standard Model (SM) leaves several questions still open, like: it does not include gravity and it has no explanation of the origin of dark energy and matter, nor why fundamental parameters like particles masses and coupling constants have exactly the values we observe; last but not least, we still have no explanation of the large difference between the Planck scale (10^{16} TeV) and the weak scale. These are just some of the reasons why theoretical physicists are exploring many other possibilities, in terms of extensions of the Standard Model. One of the most popular theories is Supersymmetry (SUSY), but since there is no experimental evidence of new physics yet, there is no truly compelling argument for any given model. This work reports the latest experimental results performed at the Tevatron experiments, CDF and D0, in the search for new physics. In particular we will cover exotic searches with 1–2.9 fb^{-1}, not including SUSY.

Exotic searches may be conducted so that event selection is mainly driven by an *a priori* chosen signature, interpreting the results in terms of specific models only at the very end of the analyses. These are what we call signature-based searches. In this work we will consider three signatures: di-lepton/photon resonances, di-boson resonances and jets plus missing transverse energy.

2. – Di-lepton/photon resonances

Lepton-antilepton pair signatures have been historically a leading discovery channel for new particles, representing also particularly clean and then powerful signature at hadron colliders where we are overwhelmed by QCD processes. In addition to this, many models beyond the SM predict the presence of new heavy particles that can potentially be

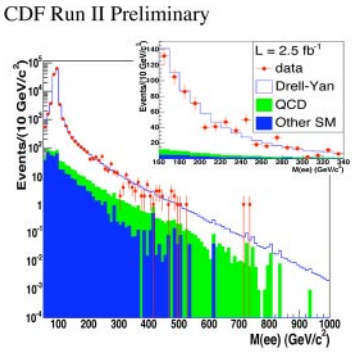

Fig. 1. – CDF di-lepton resonances searches: the di-electron invariant mass.

observed as narrow resonances in the invariant mass spectra of high transverse momentum objects.

CDF performed two searches looking for di-electron and di-muon events.

In the first search, events are required to have two isolated electrons with $E_T > 25\,\mathrm{GeV}$, one in the central region ($|\eta| < 1.1$) and the other one either in the central or the plug ($1.1 < |\eta| < 2.0$) one. The dominant background is the Drell-Yan production of electron-positron pairs, which is irreducible. In this search a data excess is observed at about $240\,\mathrm{GeV}/c^2$ in the di-lepton invariant mass (fig. 1). The probability of observing an equal or greater excess anywhere in the considered mass range (150–$1000\,\mathrm{GeV}/c^2$) is 0.6%. The 95% CL limits on $\sigma \times \mathrm{BR}(\mathrm{X} \to \mathrm{e}^+\mathrm{e}^-)$ obtained for new particles foreseen in new Gauge interactions models (Z′) and Randall-Sundrum (RS) models (G) are presented in [1].

In the CDF di-muon search, events are selected with two muons of $p_T > 30\,\mathrm{GeV}/c$. Similarly to the di-electron search, the main source of background comes from the Drell-Yan production. In this analysis, instead of the usual di-muon invariant mass $m_{\mu\mu}$, the $1/m_{\mu\mu}$ distribution is considered since at high mass the $m_{\mu\mu}$ resolution is dominated by the track resolution, resulting in an approximately constant resolution in $\delta(1/m_{\mu\mu})$. This distribution (fig. 2) shows good agreement between data and expected backgrounds. The 95% CL limits on $\sigma \times \mathrm{BR}(\mathrm{X} \to \mu^+\mu^-)$ obtained for new particles foreseen in new

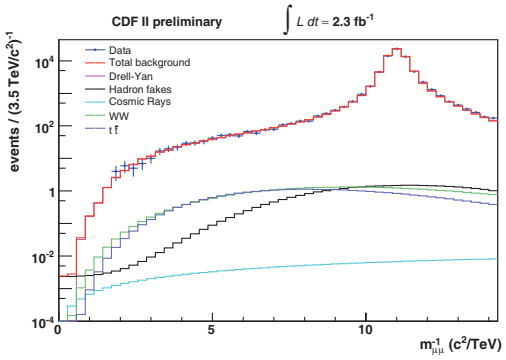

Fig. 2. – CDF di-lepton resonances searches: the $1/m_{\mu\mu}$ distribution.

TABLE I. – *D0 limit results in the* $Z\gamma$ *resonances search.*

$\sigma \times \mathrm{BR}(X \to Z\gamma)$	$< 0.19\,\mathrm{pb}$	with $M_{X\,\mathrm{scalar}} = 140\,\mathrm{GeV}/c^2$
	$< 2.5\,\mathrm{pb}$	with $M_{X\,\mathrm{scalar}} = 600\,\mathrm{GeV}/c^2$
$\sigma \times \mathrm{BR}(X \to Z\gamma)$	$< 0.2\,\mathrm{pb}$	with $M_{X\,\mathrm{vector}} = 140\,\mathrm{GeV}/c^2$
	$< 3.1\,\mathrm{pb}$	with $M_{X\,\mathrm{vector}} = 600\,\mathrm{GeV}/c^2$

Gauge interactions models and Randall-Sundrum models are presented in [2]. This search provides the most stringent constraints on Z′ and G.

D0 performed a similar search for narrow resonances in the di-electron and di-photon mass spectra with $1\,\mathrm{fb}^{-1}$ of integrated luminosity. Since both electrons and photons result in electromagnetic showers with very similar signatures, an inclusive selection of both final states was defined. Events are required to have two clusters of $E_T > 25\,\mathrm{GeV}$ in the central calorimeter ($|\eta| < 1.1$) with electromagnetic energy depositions consistent with the expected shower profile and having less than 3% of their energy in the hadronic calorimeter. To accept both electrons and photons no matching track was required. The $ee/\gamma\gamma$ invariant mass shows good agreement between data and expected backgrounds. Limits for the $\sigma \times \mathrm{BR}(X \to e^+e^-/\gamma\gamma)$ of RS gravitons were set at 95% CL and are presented in [3].

3. – Di-boson resonances

Studies of di-boson production could lead to a potential discovery of resonances predicted in some SM extensions.

D0 performed a search [4] with $1\,\mathrm{fb}^{-1}$ of integrated luminosity for $Z\gamma$ resonances in the narrow resonance approximation, *i.e.* the total width of the resonance must be smaller than the detector resolution. The specific final state of interest is constituted by two leptons (electrons or muons) of opposite charge and a photon, where the two leptons come from the leptonic decay of the Z boson. D0 found no significant excess and set a limit at 95% CL on the cross-section times branching ratio for the production of a new massive particle X (scalar or vector) that decays into a $Z\gamma$ pair (see table I).

CDF performed two searches with $2.9\,\mathrm{fb}^{-1}$ of integrated luminosity: the first one searches for WW/WZ resonances [5] and the second one for a massive particle X decaying into a ZZ pair [6].

In the WW/WZ analysis the first W boson is considered in its leptonic decay to $e\nu$, while the second boson (W or Z) is selected in its hadronic decay to two quarks. Thus the signature is constituted by an electron, some missing transverse energy and two jets. The choice of looking at W/Z boson hadron decay was driven by its high branching ratio (68/70%), but it has the drawback of increasing backgrounds coming from QCD events. In this analysis no significant excess was observed and lower limits were set for the mass of potential new gauge bosons and RS gravitons (see table II).

The CDF search for anomalous production of Z pairs through a new massive resonance X focused on all leptonic final states (4 electrons or 4 muons) and 2 leptons (e or μ) plus two jets final states. CDF observed no excess setting a limit on the production cross-section of RS gravitons decaying via two Z bosons which resulted in a limit on the graviton mass set at $M_G > 491\,\mathrm{GeV}/c^2$ ($k/M_p = 0.1$).

TABLE II. – *CDF limit results in the di-boson searches.*

$M_{W'}$	$\notin [285, 515]$ GeV/c^2
$M_{Z'}$	$\notin [247, 545]$ GeV/c^2
M_G	> 607 GeV/c^2 $(k/M_p < 0.1)$

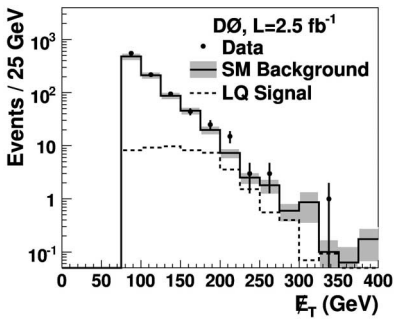

Fig. 3. – D0 di-jet plus missing energy search: the missing transverse energy distribution.

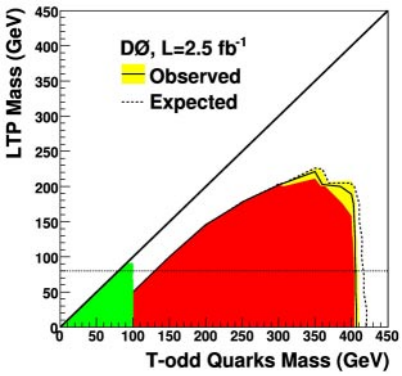

Fig. 4. – D0 di-jet plus missing energy search: expected and observed 95% CL excluded regions in the $\tilde{Q} - \tilde{A}_h$ mass plane.

4. – Jets plus missing transverse energy topology

The experimental signature constituted by exactly two jets plus some missing transverse energy is interesting for several exotic models involving the production of new colored particles. D0 performed a search for this topology of events [7] with 2.5 fb^{-1} of integrated luminosity. The main irreducible SM background is given by the $Z(\to \nu\bar{\nu}) +$jets process. Also $W(\to l\nu) +$jets events present the missing energy in the signature, but can be reduced by rejecting events with an isolated electron or muon. The number of events observed are in good agreement with the standard model expectations as illustrated in fig. 3. The result of this search has been used to set a lower mass limit at 205 GeV/c^2 on the mass of a scalar leptoquark when this particle decays exclusively into a quark and a neutrino. In the framework of the Little Higgs model with T-parity, limits were also obtained on the T-odd quark $\tilde{Q}$ mass as a function of the T-odd photon $\tilde{A}_h$ mass (fig. 4).

5. – Conclusions

CDF and D0 have many exotic searches on-going and a few recent results (1–2.9 fb^{-1} integrated luminosity used) were presented here. Several models have been tested and limits set. Twice as much data is already at disposal to update these results and better analysis techniques are expected soon.

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