Searching for physics beyond the Standard Model with High Energy Colliders

Carmine Elvezio Pagliarone
Università di Cassino & INFN Trieste, Italy
E-mail: pagliarone@fnal.gov

Abstract. In this paper we review a selection of recent results obtained in the area of experimental searches for physics beyond the Standard Model performed at present high-energy physics colliders. In particular we illustrate searches for squarks and gluinos, searches for scalar top and scalar bottom in different scenarios, searches for large extra dimensions, and more in general signature based searches. As no evidence for new physics have been found so far, 95% Confidence Level limits have been set for all the theoretical scenarios that have been investigated by present high energy colliders.

1. Introduction
The Standard Model of Particle Physics (SM) represents the simplest and most economical theory, which is able to describe jointly weak and electromagnetic interactions. At present it continues to survive all experimental tests, providing a remarkably successful description of known phenomena; some precision observable tests it at $10^{-3}$. In spite of that, there are plenty of aspects that we do not understand yet and that may suggest the SM to be most likely, a low energy effective theory of spin-$1/2$ matter fermions interacting via spin-$1$ gauge bosons. As matter of fact, the SM leaves many important questions unanswered. It is also widely acknowledged that, from the theoretical standpoint, the SM must be part of a larger theory, “beyond” the SM (BSM), which is yet to be experimentally confirmed.

2. Supersymmetry
An excellent candidate of a new theory, able to describe physics at arbitrarily high energies, may be the Supersymmetry. Supersymmetry (SUSY) is a larger space-time symmetry, which relates bosons to fermions so that, in the vast space of all viable physics theories, SUSY is not simply a point. Almost any theory can be supersymmetrized and the large array of choices, for spontaneous SUSY breaking (SB), just enhances these possibilities. A comprehensive SUSY search is almost impossible: i.e. the most general Minimal Supersymmetric extension of the SM (MSSM) counts 124 truly independent parameters [1]. The strategy is then to search for signals suggested by particular models in which

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1 To whom any correspondence should be addressed.
theoretical assumptions are also adopted to reduce the number of free parameters to a few. Even if we don't have direct experimental evidences of SUSY, there are remarkable theoretical properties that provide ample motivation for its study. SUSY describes electroweak data equally well as SM but, in addition, allows the unification of the gauge couplings constants, the unification of the Yukawa couplings and do not require the incredible fine tuning, endemic to the SM Higgs sector. Naturally, SUSY cannot be an exact symmetry of the nature, as none of the predicted spin 0 partners of the quarks or leptons and none of the spin 1/2 partners of the gauge bosons have been observed so far. In Supersymmetry, fermions can couple to a sfermion and a fermion, violating lepton and/or baryon number. To avoid this problem, a discrete multiplicative quantum number, the R-parity was introduced: \( R \equiv (-1)^{B+L+2S} \). SUSY models can be constructed assuming either conservation (RP) or violation of this quantum number (RPV). The assumption of R-parity conservation has, for example, deep phenomenological consequences: SUSY particles can only be pair produced; the Lightest Supersymmetric Particle (LSP) does exist and it is stable and interacts very weakly with the ordinary matter, leading to a robust missing transverse energy signature \( E_T \) [2]; the LSP may be a natural candidate for the dark matter. However, SUSY does not R-parity conservation and viable R-parity violating models can be built, for example, by adding explicitly B-violating and/or L-violating couplings to the SUSY Lagrangian. SUSY signals are of particular interest, as they provide a natural explanation for the Dark Matter, known to pervade our universe, and help us to understand the fundamental connection between particle physics and cosmology. A large amount of theoretical effort has been spent trying to understand the mechanism for soft Supersymmetry Breaking (SB) that produces the desired properties in the superpartner masses and interactions. The three most extensively studied mechanisms are: the Gravity Mediated Supersymmetry Breaking, the Gauge Mediated Supersymmetry Breaking and the Anomaly Mediated Supersymmetry Breaking.

2.1. Gravity Mediated Supersymmetry Breaking Models
Gravity Mediated Supersymmetry Breaking is a method of communicating supersymmetry breaking to the supersymmetric Standard Model through gravitational interactions. It was the first method...

**Figure 1**: a) Schematic layout of the CDF-II and b) DO Experiments.
Figure 2: a) Results on the searches for squark and gluinos at Tevatron. a) Results coming from the CDF-II experiment, b) results from the DØ collaboration.

proposed to communicate supersymmetry breaking. In gravity mediated supersymmetry breaking models, there is a part of the theory that only interacts with the MSSM through gravitational interaction. This hidden sector of the theory breaks supersymmetry. Through the supersymmetric version of the Higgs mechanism, the gravitino, the supersymmetric version of the graviton, acquires a mass. After the gravitino has a mass, gravitational radiative corrections to soft masses are incompletely cancelled beneath the gravitino mass. It is currently believed that it is not generic to have a sector completely decoupled from the MSSM and there should be higher dimension operators that couple different sectors together with the higher dimension operators suppressed by the Planck scale. These operators give as large of a contribution to the soft supersymmetry breaking masses as the gravitational loops; therefore, today people usually consider gravity mediation to be gravitational sized direct interactions between the hidden sector and the MSSM. Between these models there are so called minimal supergravity (mSUGRA). This theoretical scenario is one of the most widely investigated models of particle physics due to its predictive power requiring only 4 input parameters and a sign, to determine the low energy phenomenology from the scale of Grand Unification.

2.2. Gauge Mediated Supersymmetry Breaking Models

The theories with gauge-mediated Supersymmetry breaking (GMSB) provide an interesting alternative scenario. In GMSB, for instance, the dynamical Supersymmetry breaking (DSB) is mediated by gauge interactions. In recent years, many mechanisms for DSB have been found and realistic models have been constructed. This class of models assumes that Supersymmetry is broken with a scale $\sqrt{F}$ in a sector of the theory, which contains heavy non-Standard-Model particles. This sector then couples to a set of particles with Standard Model interactions, called messengers, which have a mass of order M. The mass splitting, between the superpartners in the messenger multiplets, depends by $\sqrt{F}$ and the SUSY particles get their masses via gauge interactions, so there is no flavor changing neutral currents (FCNC). These theories have very distinctive phenomenological features. The typical SUSY spectra is
Figure 3: CDF search for scalar top in the case in which $\tilde{t}_1$ is the next-to-LSP: $pp \rightarrow \tilde{t} \tilde{t}_1 \rightarrow c \tilde{\chi}^0_1 c \tilde{\chi}^0_1$.

different from those predicted in the SUGRA models; the LSP is the gravitino $\tilde{G}$, the next lightest supersymmetric particle (NLSP) has a lifetime that can vary strongly from model to model ($1 \mu < \tau < $ several km) and decays into a $\tilde{G}$.

2.3. Anomaly Mediated Supersymmetry Breaking Models

The Anomaly Mediated Supersymmetry Breaking is a special type of gravity mediated supersymmetry breaking that results in supersymmetry breaking being communicated to the supersymmetric Standard Model through the conformal anomaly.

2.4. Experimental searches for SUSY at Tevatron

The Tevatron collider is a circular particle accelerator at the Fermi National Accelerator Laboratory (FNAL) close to Batavia, Illinois (USA). This machine has been built in order to accelerate beams of protons and anti-protons and make them collide at center of mass energy of 1.80, during the Run I (1992-1996) and 1.98 TeV, during the Run II (2001-2011) [2]. Two experiments have been equipped in order to study the collision products: the CDF-II detector and the DØ detector. In Fig. 1.a and in Fig. 1.b we give a schematic layout of both these Tevatron experiments. A particle leaving the interaction point (IP) will see first a set of silicon detectors, mainly used to tag jets originated by the $b$-quarks, and a bigger tracking volume. Both these tracking detectors are immersed in a magnetic field to avoid charge and momentum measurement. An electromagnetic and hadronic calorimeter follows the internal silicon and conventional trackers. Outside the magnetic field there are a set of muon detectors. In order to suppress the strong background, coming from QCD processes, and to be able to collect only those events that may be considered of interest, dedicated trigger systems have been developed in both the experiments, for the different channels under investigation.

2.4.1. Searches for squarks and gluinos

The search for squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) is one of the most relevant SUSY searches at Tevatron. As matter of fact, squarks and gluinos are expected to be copiously produced via strong interaction.
Due to the large production cross-sections, the inclusive production of squarks and gluinos have always been considered one of the most promising discovery channels for SUSY. Squarks and gluinos are produced at Tevatron trough one of the following three processes: 

\[ p\bar{p} \rightarrow q\bar{q} \rightarrow q\tilde{\chi}^0 q\tilde{\chi}^0 + X, \]

\[ p\bar{p} \rightarrow gq \rightarrow q\tilde{\chi}^0 q\tilde{\chi}^0 + X \] and \[ p\bar{p} \rightarrow gg \rightarrow q\tilde{\chi}^0 q\tilde{\chi}^0 + X. \]

Because of the presence of two neutralinos (\( \tilde{\chi}^0 \)) in the final states, neutralino that behaves from an experimental point of view as a neutrino, the signature for these searches is 2 or 4 jets plus a large amount of missing transverse energy (\( E_T \), MET) produced by the two neutralinos. The limits obtained by the CDF-II [3] and by the DØ experiment [4] are given in Figure 2.a and in Figure 2.b. The CDF-II experiment, by using a total integrated luminosity of 2 fb\(^{-1}\), have been able to excludes, at 95% Confidence Level, gluinos with masses below 208 GeV/c\(^2\), for any value of the squark masses. DØ performed a similar analysis based on a data set of 2.1 fb\(^{-1}\). In this case gluino masses below 308 GeV/c\(^2\) have been excluded at 95% CL for all squark masses. Both CDF-II and DØ ruled out the existence of squarks with masses below 380 GeV/c\(^2\) for all gluino masses. In mSUGRA, region that was not accessed by LEP experiments have been also excluded by these two experiments.

### 2.4.2. Searches for scalar top

Search for scalar top (\( \tilde{t} \)) is particularly relevant since, in many SUSY models the top-squark mass eigenstate \( \tilde{t} \) is expected to be the lightest squark viable in nature. As matter of fact, the strong Yukawa coupling, between top/stop and Higgs fields gives rise to potentially large mixing effects and large mass splitting between the two scalar to mass eigentates: \( \tilde{t}_1 \) and \( \tilde{t}_2 \) returning the following mass hierarchy: \( m_1 < m_2 \). The CDF-II collaboration has performed a search for scalar top (\( \tilde{t}_1 \)), in the case in which the stop is next to Lightest Supersymmetric Particle. In this specific scenario the decay channel \( pp \rightarrow \tilde{t}_1 \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 c\tilde{\chi}_1^0 \) is open. The results for such a search are given in Figure 3. The analysis have

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**Figure 4**: Search for scalar top decaying in two leptons: CDF-II (a) and DØ (b) results.
Figure 5: a), b), c) DØ limits in terms of the 3-dimensional space: $M_{t}\times M_{\tilde{\chi}^{\pm}} \times M_{\tilde{\chi}^{0}}$; d) CDF-II limits in the $M_{t}$ versus $M_{\tilde{\chi}^{0}}$ plan for two different chargino masses and $Br(\chi_{1}^{\pm}\rightarrow \chi_{1}^{0}\nu\ell)$.

been performed by using a total integrated luminosity of about 2.6 fb$^{-1}$ and represented as an exclusion region in the stop mass versus neutralino mass plane (see Fig. 3).

2.4.3. Searches for scalar top in the dilepton channel
If sneutrino is lighter than the stop, the dominant decay channel is: $\tilde{t}_{1} \rightarrow b\ell \bar{\nu}$ with $\bar{\nu} \rightarrow \nu \tilde{\chi}_{1}^{0}$. In this case the final states are quite similar to the ones that is possible to have in the top dilepton decay. Even if the signature is similar, anyhow the kinematics is different and leptons show up to be softer. The results obtained by searching for the scalar top in the dilepton channel are given in Fig. 4.a [5] and in Fig. 4.b [6].

2.4.4. Searches for scalar top in top-like events
In the case in which chargino is lighter than the stop ($M_{\tilde{\chi}^{\pm}}<M_{t}$), the dominant stop decay becomes the following: $\tilde{t}_{1}\rightarrow b\tilde{\chi}^{\pm}$ giving rise to a top-like decay scalar top decay: $pp \rightarrow t\bar{t} \rightarrow b\bar{b} \tilde{\chi}^{\pm} \tilde{\chi}^{-}$. As charginos decay in one the two following ways: $\tilde{\chi}^{\pm}\rightarrow \ell^{\pm} \tilde{\chi}_{1}^{0}$ or $\tilde{\chi}^{\pm}\rightarrow q\bar{q} \tilde{\chi}_{1}^{0}$ we end up with the same $t\bar{t}$ finals states: dilepton, lepton + jets, all hadronic. This SUSY scenario has been studied from both the Tevatron experiments. DØ searched for scalar top in the lepton + jets channel [7]. CDF-II studied the stop decay in the dilepton channel. [8] The results of both the analysis are shown from Fig. 5.a to Fig. 5.d.
DØ extracted the limits in terms of the 3-dimensional space: $M_t \times M_{\tilde{e}_l} \times M_{\tilde{\chi}^0_1}$ (see Fig. 5.a, Fig. 5.b and Fig. 5.c). The CDF-II results are expressed in the $M_t$ versus $M_{\tilde{\chi}^0_1}$ plan, for two different chargino masses and $Br(\tilde{\chi}^\pm_1 \rightarrow \tilde{\chi}^0_1 \nu \ell)$.

2.4.5. Searches for scalar bottom

At large $\tan(\beta)$, the scalar bottom ($\tilde{b}$) may be the lightest colored particle. Such sbottom quark can decay as follow: $\tilde{b} \rightarrow b \tilde{\chi}^0_1$ giving rise to final states containing two b-jets and large missing transverse energy ($pp \rightarrow \tilde{b} \tilde{b} \rightarrow b b \tilde{\chi}_1^0 \tilde{\chi}_1^0$). The limits, coming from both the Tevatron searches can be seen in Figure 6.a and in Figure 6.b [9, 10]. Both the analysis has excluded sbottom masses up to 250 GeV/c^2.

2.4.6. GMSB Models searches at Tevatron

In the gauge mediated SUSY breaking (GMSB) scenario, the gravitino is the LSP and the next-to-lightest SUSY particle (NLSP) may be the lightest neutralino, which decays to a gravitino and a photon: $\chi^0_1 \rightarrow \gamma \tilde{G}$. At Tevatron, pair production of SUSY particles decaying to a neutralino NLSP with negligible lifetime would therefore lead to final states with two acoplanar photons and missing transverse energy. Both CDF and DØ Collaborations have performed searches for such events. No excess was found in the data [11]. The process is then used to set a limit on the GMSB scale $\Lambda$, which also gives the scale of the gaugino masses. For a $\tilde{\chi}^0_1$ lifetime of 0 ns, neutralino masses below 149 GeV/c^2 have been excluded.

2.5. Higgsless Models

Since the Higgs mechanism was first introduced, in early 1960s by Peter W. Higgs, there have been several alternatives proposed. All of the alternative mechanisms use strongly interacting dynamics to produce a vacuum expectation value that breaks electroweak symmetry. A partial list of these alternative mechanisms includes: Technicolor models, Extra-dimensional Higgsless models, Models of composite W and Z vector bosons, Top quark condensate and several other models.
2.6. Models with Extra Dimensions

In the Standard Model we assume, commonly, that effects of gravity can be neglected, because the scale where such effects become large is the Planck Scale. The question of why the 4-dimensional Planck Scale, $G_{\text{Pl}}^{1/2} \approx 10^{19}$ GeV, is much larger than the electroweak (EWK) scale, $G_{\text{Pl}}^{1/2} \approx 10^{19}$ GeV, is an outstanding problem in contemporary physics. The hierarchy problem is in the essence the difficulty to explain the large disparity between these two numbers. Motivated in part by naturalness issues, numerous scenarios have emerged recently, that address the hierarchy problem within the context of the old idea that some part of the physical world (i.e. the SM-world) is confined to a brane in a higher dimensional space. Although Supergravity theories were formulated up to 11 dimensions and Superstring theories in 10 dimensions were known since the 70’s, the idea to extend this extra spatial dimension paradigm (ESD) to other contexts, received a new impulse in the recent past years.

As we don’t experience in our everyday world, more then 3 spatial dimensions, we have to assume that any possible ESD is hidden. There is a simple and elegant way to hide possible extra spatial dimensions: the compactification. The result is achieved by assuming, for example, that the extra dimensions form, at each point of the 4-dimensional space, a torus of volume $2\pi R_1 R_2 \ldots R_D$.

In this way, it is possible to allow the gravity to live in the $D$ large extra dimensions, the bulk, while the SM fields will lie on a $3-D$ surface, the brane. In presence of a compactified extra spatial dimension $y$, a field $\phi(x, y)$ of mass $m_0$ is periodic over $y$ and can be Fourier developed as follow:

$$\phi(x, y) = \sum_{k=-\infty}^{\infty} e^{i k y} \phi^{(k)}(x)$$  \(\text{(1)}\)

where $R$ is the radius of the compact ESD. The 4D terms $\phi^{(k)}(x)$ are the Kaluza-Klein states ($\text{KK}$) also called modes or excitations. The mass of each $\text{KK}$ mode is then expressed by the formula:

$$m_k^2 = m_0^2 + k^2/R^2$$  \(\text{(2)}\)

If $M_F$ is the actual fundamental scale of gravitational interactions and if $V_{\text{extra}}$ is the volume of the extra dimensional $D$-fold, then, by Gauss’s law, at distances larger than the inverse mass of the lightest $\text{KK}$ mode in the theory, the gravitational force will follow an inverse square law with an effective coupling of:

$$M_{\text{Pl}}^{-2} = M_F^{-2} V_{\text{extra}}^{-1}$$  \(\text{(3)}\)

We see indeed that gravity becomes strong in the full $4+D$-dimensional space at a scale $M_F$ of few TeV, which is far below the conventional Planck Scale ($M_{\text{Pl}}^2 = M_F^{D+2} V_{\text{extra}}$). At the present there are many models, which assume the existence of extra spatial dimensions predicting the appearance of new physics signatures that can be probed at energy scale above 1 TeV. Most of the models fall, between the others, into one of the three following classes: Large Extra Dimension scenario (LED), $\text{KK}$ gauge bosons, warped extra spatial dimensions. The large extra dimension scenario (LED) started with the works of Arkani-Hamed, Dimopoulos and Dvali (ADD). In this model the SM particles live on a 3+1-dimensional space (3-brane) while the gravity is free to propagate in higher-dimensional space, extra dimensions. This model predicts essentially the emission and exchange of large Kaluza-
Figure 7: Searches for Large Extra Dimension at Tevatron; a) DØ indirect search, b) and c) results coming from the CDF-II Experiment.

Klein towers of gravitons that are finely spaced in mass. The ADD model was first proposed to solve the hierarchy problem by requiring the compactified dimensions to be of very large size. A second possibility comes from all those models where the extra spatial dimensions are of TeV scale size. In these classes of models there are $\text{KK}$ excitations of the SM gauge fields with masses of the order a TeV, which can show up in collider experiments as resonances. Another approach, for extra spatial dimensions, has been proposed by L. Randall and R. Sundrum (RS models or WED). In this scenario two $4D$ branes with tension $V$ and $V'$ are situated in the position, $y = 0$ and $y = \pi r_c$, of a $5D$ bulk with cosmological constant $\lambda$, where the gravitation lives. One of the interesting consequence of this assumptions is the fact that the fundamental mass scale, on the brane at $y = 0$ is then red-shifted by a factor $e^{-2k}\lambda$ (warp factor) on the other brane at $y = \pi r_c$. In this way the EWK scale ($\mathcal{O}(1 \text{ TeV})$ can be produced from the Planck Scale. In the RS models the $4D$ Planck mass may be expressed as follow:

$$M_{P}^2 = M_5^2 \frac{1}{k l^2} \left[1 - e^{-2k\lambda l}ight]$$  \hspace{1cm} [4]$$

2.6.1. Experimental searches for Extra Dimension at Tevatron

The experimental limits coming from Tevatron experiments are given both for direct and indirect LED searches in Figure 7 [12, 13].
2.7. Black Hole production and related signatures
Black holes (BH) have always been considered, since their introduction, objects of great interest both in theoretical physics both in astrophysics. In the last decade the interest for BH production and observation have been extensively studied in the context of collider experiments. As a matter of fact, BH can be produced in particle collisions if the center of mass energy is above the Planck Scale ($\sqrt{s} > M_{\text{Pl}}$). In LED models the Planck Scale can be effectively $O(1 \text{ TeV})$, opening up the interesting possibility of producing and studying BH using collider experiments. The observability of such BH at future colliders will depend on the value of the fundamental Planck Scale. At Hadron colliders, where it is possible to reach the highest center of mass energies, compared to other machines, the BH production cross section can be written as follow:

$$\sigma_{\text{pp} \rightarrow \text{BH}}(M_{\text{min}}, s) = \sum_{i,j} \int_{\tau_{i}}^{1} d\tau \int_{x}^{1} F_{i}(x) F_{j}(\tau/x) \sigma_{ij} \rightarrow \text{BH}(\tau s)$$

where $i$ and $j$ are the two colliding partons, $x$ and $\tau/x$ are the momentum fractions of $i$ and $j$ and $F$ are the parton distribution functions. If we assume the Thorne’s hoop conjecture, that states that horizons form when and only when a mass $M$ is compacted into a region whose circumference in every directions is less than $2\pi R_{\text{BH}}(M)$, we obtain the important result that the black hole production cross section is:

$$\sigma_{ij} \rightarrow \text{BH}(s) \approx \pi R_{\text{BH}}^{2}(\sqrt{s})$$

The precise mass of the BH, formed in a collision, depends on the amount of energy and matter, which becomes trapped behind the event horizon. If the scale of gravity is the TeV scale, BH production could be a dominant process at hadron colliders beyond LHC. For example for $M_{\text{Pl}} = 1 \text{ TeV}$ and $D = 10$, at a Very Large Hadron Collider (VLHC) where center of mass energy is supposed to be 100 TeV assuming an integrated luminosity per year of 100 $fb^{-1} yr^{-1}$, black halls, of mass around 10 TeV, should be produced with a rate of 1 kHz.

Once produced black holes decay. The decay process is rather complex and occurs in several stages. A Balding phase, in which there is emission of gauge and gravitational radiation that will settle down the BH to a symmetrical rotating object with a growing horizon. A Spin-down phase, in which the BH Hawking radiates, emitting quanta, having angular moment $\ell \approx 1$. A Schwarzschild-Hawking Evaporation phase in which the spin-down phase leaves a Schwarzschild black hall that continues to radiate Hawking radiation. Instant quanta are emitted with a thermal spectrum around Hawking temperature (TH). A Planck phase in which, once the BH reach the Planck mass $M \approx M_{\text{Pl}}$, the black hall completely decays emitting few quanta with energies $O(M_{\text{Pl}})$. Because of the large cross section, multiplicity and visible energy, black halls, at hadron colliders, give rise to very spectacular events. The BH production and decay is characterized by the following specific signatures: suppression of hard perturbative scattering processes at energy in which the BH production start to dominate; very large production cross sections that grows with the energy; high multiplicity events (for $M_{\text{BH}} \approx 10 \text{ TeV}$, $D = 10$ the expected multiplicity is around 50) with visible transverse energy of the order of $\sim 1/3$ of the total energy; high sphericity events because of the small BH boost: $\langle \gamma \beta \rangle < 1$; a ratio of $\sim 1/5$ between leptonic and hadronic activity, because of the
Schwarzschild- Hawking evaporation phase.

2.8. Technicolor
Between the theories beyond the SM, another interesting theory as to why matter has mass is the Technicolor theory. In this class of theoretical scenarios, instead of introducing elementary Higgs bosons, Technicolor models hide electroweak symmetry and generate masses for the W and Z bosons through the dynamics of new gauge interactions. Although asymptotically free at very high energies, these interactions must become strong and confining (and hence unobservable) at lower energies that have been experimentally probed. Technicolor differs from Supersymmetry in several ways. It only has two particles, called Techniparticles, or Techniquarks, that are bound together by a new force called Technicolor. Technicolor does not require the multitude of new particles that SUSY does. Technicolor may be simpler than Supersymmetry but it is not without flaws: the theory fails to explain why the forces unit at high energy. Technicolor theories naturally contain dark matter candidates. Almost certainly, models can be built in which the lowest-lying technibaryon, a technicolor-singlet bound state of technifermions, is stable enough to survive the evolution of the universe.

2.9. Compositeness
Quarks may not be fundamental particles, but rather an agglomeration of smaller constituents called preons. These features are visible above a characteristic energy scale, the so called compositeness scale \( \Lambda \), below which, quarks appear to be point like. The parameter \( \Lambda \) characterizes both the strength of the preon coupling and the physical size of the composite scale. If fermions are composite particles made up of more basic constituents, characteristic phenomenological effects could be observable at the particle colliders. If the scale of compositeness is sufficiently low, narrow resonant states of excited fermions could be produced on shell. If, however, the compositeness scale is much larger than the center of mass energy of the colliding partons, the manifestation of compositeness will be an effective 4-fermion contact interaction. In a commonly used model, the contact interaction is described as an interaction between two left-handed quark currents:

\[
L_{\text{int}}(\Lambda) = \frac{g^2}{2(\Lambda^2)} \eta \bar{\psi}_{i'} \gamma_{\mu} \psi_{i'} \bar{\psi}_{i''} \gamma_{\mu} \psi_{i''}
\]

where \( \eta = \pm 1 \) is a constructive or destructive interference sign. \( \Lambda \) is defined in such a way that \( g^2/4\pi = 1 \). Note that, the possible discovery of contact interaction alone is not enough to prove compositeness because other possible new phenomena can be described by a contact interaction Lagrangian. Early measurements of both jet \( p_T \) and dijet mass distributions at the Tevatron showed an excess in the rate above QCD expectations. These effects were eventually explained by larger than expected high-x tail in the gluon Parton Distribution Function (PDF). After these measurements, less PDF-sensitive studies based on ratio of cross sections and angular distributions have been developed by LHC experiments in order to be able to search for contact interactions both in the dijet and in the dimuon channel.

2.10. Global Model independent searches
The search for physics beyond the SM can be widely performed by searching for anomalies in the data sets classified by their final states. Then event classes are created according to the number and types of objects detected in the final states. A comparison is then performed between the numbers of events in each class and the expected one coming from purely SM processes. In Figure 8 we give a couple of
example of such a searches where the dijet mass and the inverse di-muon mass \((M_{\mu^+\mu^-}^{-1})\) is compared with the SM expectations [14, 15].

3. Conclusions

This paper reviewed some of the aspects discussed, in the plenary talk, on physics beyond the Standard Model at present colliders. A selection of recent results, obtained in the area of experimental searches, for physics beyond the Standard Model, has been given. Despite of the intensive searches performed on data, there are no evidence yet, no convincing signs, of physics beyond the SM at the energy scale that have been possible to explore so far. Tevatron have been testing, in the last two decades, models with increasing sensitivity. A new era, the LHC era is finally started and very soon we may get closer to the understanding which direction we have to take to further increase our knowledge on the Nature.

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