0.0.1 Physics beyond the Standard Model

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RHIC-Spin potential for uncovering new physics beyond the Standard Model (SM) has been explored in a number of last decade publications. Our purpose in this section is to illustrate this new potentiality by means of a few specific examples.

The non-SM modifications of parity-violating helicity asymmetry $A_L = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$ for one-jet production in collisions of the longitudinally polarized protons at unpolarized has been studied in Refs. [1, 2]. In the A_L definition above, σ^+ and σ^- are for the cross sections[1] with the positive and negative helicities of the initial protons, respectively. In the SM, inclusive jet production is dominated by the pure QCD gg, gq, and qq scattering which conserve a parity. However the existence of electroweak interactions through the $W^\pm$ and Z gauge bosons gives a small contribution to A_L. Consequently, the A_L is expected to be nonzero from the QCD-electroweak interference (as shown in Fig. 1). Additionally, a small peak near $E_T = M_{W,Z}/2$ is seen, which is the main signature of the purely electroweak contribution. The existence of new parity-violating interactions could lead to large modifications of this SM prediction [4].

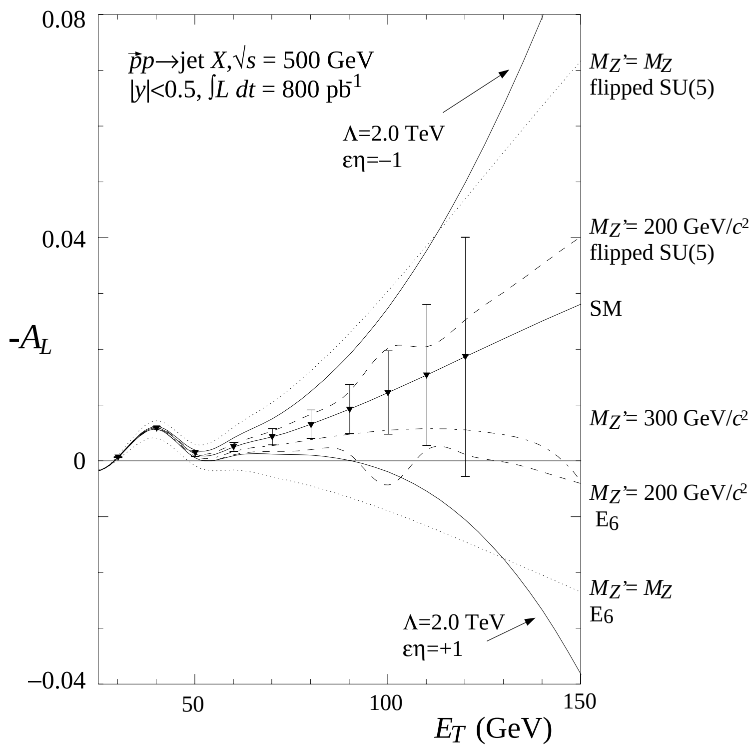

Figure 1: A_L, for one-jet inclusive production in $\vec{p}p$ collisions versus transverse energy, for $\sqrt{s} = 500$ GeV. The solid curve with error bars represents the SM expectations. The error bars show the sensitivity at RHIC for 800 pb^{-1}, for the STAR detector. The other solid curves, labeled by the product of $\epsilon\eta$, correspond to the contact interaction at $\Lambda = 2$ TeV [1]. The dashed and dotted curves correspond to different leptophobic Z' models. The calculations are at the leading order.

[1] Or differential cross sections.

The modifications due to the presense of quark substructure have been analyzed in Ref. [1] in the framework of an effective Lagrangian approach. Such effects are generally realized as quantum effects of new physics where new heavy particles are considered to be decoupled. The non-SM Lagrangian could be represented in terms of new quark-quark contact interactions[2] under the form:

$$\mathcal{L}_{qqqq} = \epsilon \frac{g^2}{8\Lambda^2} \overline{\Psi}\gamma_\mu(1-\eta\gamma_5)\Psi \cdot \overline{\Psi}\gamma^\mu(1-\eta\gamma_5)\Psi \quad , \tag{1}$$

where Ψ is a quark doublet, g is a non-standard coupling, Λ is a compositeness scale, and $\epsilon = \pm 1$. If parity is maximally violated, $\eta = \pm 1$. Fig. 1 shows how the SM prediction will be affected by such a new interaction, assuming $\Lambda = 2$ TeV, which is close to the present limit obtained for example by the DØ experiment at the Tevatron [5]. The statistical errors shown are for RHIC luminosity of 800 pb^{-1}, and for the jets with rapidity $|y| < 0.5$, and include measuring A_L using each beam, summing over the spin states of the other beam. Due to the parity-violating signal's sensitivity to new physics, RHIC is surprisingly sensitive to quark substructure at the ∼2-TeV scale and is competitive with the Tevatron, despite the different energy range of these machines. Indeed, a parity-violating signal beyond the SM at RHIC would definitely indicate the presence of new physics [4].

RHIC-Spin would also be sensitive to possible new neutral gauge bosons [2, 3]. A class of models, called leptophobic Z', is poorly constrained up to now. Such models appear naturally in several string-derived models [6] (non-supersymmetric models may be also constructed [7]). In addition, in the framework of supersymmetric models with an additional Abelian $U(1)'$ gauge, it has been shown [8] that the Z' boson could appear with a relatively low mass ($M_Z \leq M_{Z'} \leq 1$ TeV) and a mixing angle with the standard Z close to zero. The effects of different representative models are also shown in Fig. 1 (see Ref. [2] for details). RHIC covers some regions of parameters space of the different models that are unconstrained by present and forthcoming experiments, and RHIC would also uniquely obtain information on the chiral structure of the new interaction. In Ref. [3], it has been suggested to extend this study to the collisions of polarized neutrons, which could be performed with colliding at RHIC polarized ^3He nuclei [9]. The authors argue that, in case of a discovery, a compilation of the information coming from both polarized $\vec{p}\vec{p}$ and $\vec{n}\vec{n}$ collisions should constrain the number of Higgs doublets and the presence or absence of trilinear fermion mass terms in the underlying model of new physics.

The study of the production cross sections for squarks and gluinos in collisions of longitudinally polarized hadrons has been undertaken in Ref. [10]. The resulting asymmetries are evaluated for the polarized proton collider RHIC, as well as for hypothetical polarized options of the Tevatron and the LHC. These asymmetries turned out to be sizable over a wide range of supersymmetric particle masses. Once supersymmetric particles are discovered in unpolarized collisions, a measurement of the spin asymmetries would thus potentially help to establish the properties of the newly discovered particles and open a window to detailed sparticle spectroscopy at future polarized colliders. Although non-observation of squark and gluino signatures at the Tevatron thus turns into the stringent limits on the squark and gluino masses in a frame of MSSM[3] [11]: $m_{\tilde{q}} >$ 250 GeV, $m_{\tilde{g}} >$ 195 GeV, these limits are substantially weakened if more complicated supersymmetric models are considered. RHIC energy up to $\sqrt{s} =$ 500 GeV is not sufficient to produce the MSSM sparticles; however they could be within its reach if supersymmetry is realized in a more exotic scenario. Some results of "scanning" the space of squark and

[2] It is assumed here that only quarks are composite.

[3] Minimal Supersymmetric Standard Model.

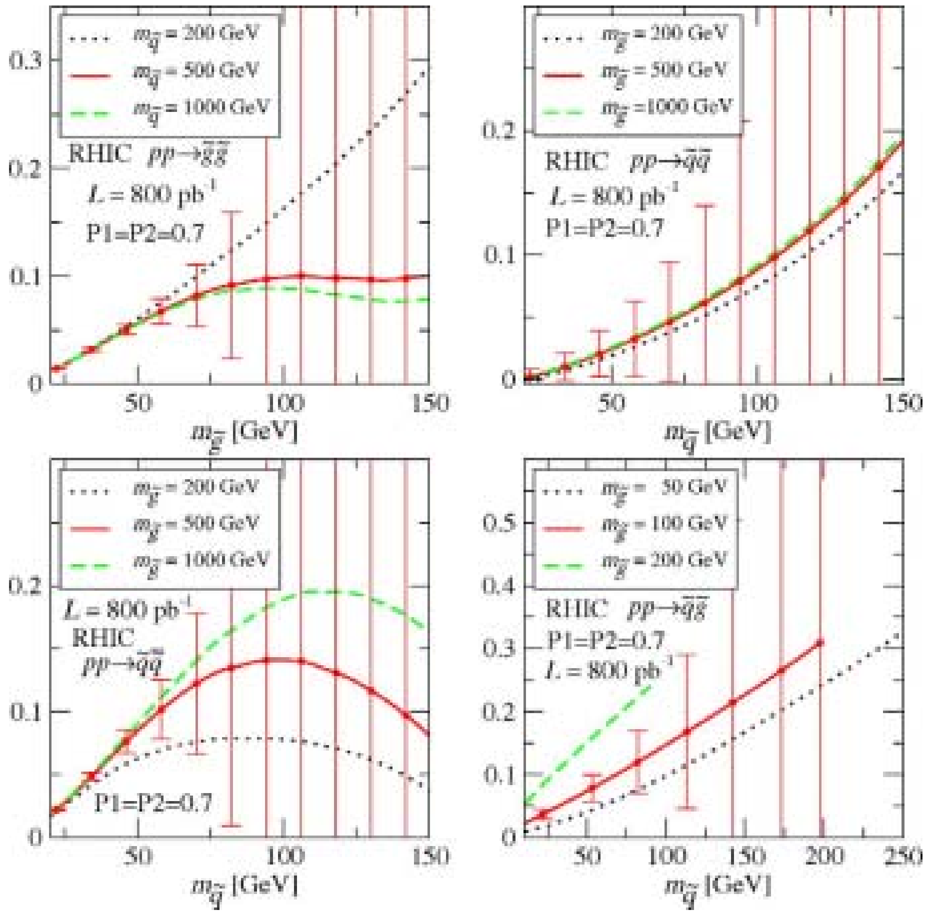

Figure 2: The leading order A_L predictions for sparticle production at RHIC (see Ref. [10] for details). Using the full-scale high-energy physics detector of $\sim 4\pi$ acceptance, similar to, for example, the one proposed in Ref. [12], with the capability of measuring multi–jet events and missing transverse energy is assumed.

gluino mass parameters at RHIC are shown in Fig. 2. One can observe that, in the low mass region, the asymmetry A_L measurements at RHIC for $\tilde{q}\overline{\tilde{q}}$ and $\tilde{q}\tilde{g}$ production could be sensitive to gluino mass, although in $\tilde{q}\overline{\tilde{q}}$ process, the gluino appears only as an exchange particle. The authors of Ref. [10] conclude that, assuming the design luminosities and beam polarization of 70%, the asymmetries are statistically measurable for sparticle masses up to 75 GeV at RHIC, 350 GeV at the Tevatron and well above 1 TeV at LHC, provided experimental uncertainties on them can be kept under control.

The similar study for slepton production in polarized hadron collisions has been recently presented in Ref. [13]. However, this channel might not be accessible at RHIC, because, even in the most optimistic scenarios, the cross section is not expected to exceed 1 fb.

In the examples above, it is assumed that the polarized parton distribution functions (pol-PDFs) of initial longitudinally polarized hadrons would be known at a sufficient accuracy for being able to detect A_L deviations from the SM predictions[4]. Another venue (The best place? -

[4]Presumably, the pol-PDFs will be well measured as a part of the mainstream RHIC-Spin program discussed in the previous sections, as well as at the other facilities.

J. Soffer et al. [16]) to look for a new physics beyond the SM, which does not rely this much on the precise pol-PDF knowledge, is in the observables that either vanish or are very suppressed in the SM. The good representatives of such observables are transverse spin asymmetries – single or double – for $W^\pm$ and Z^0 productions, since these are expected to be extremely small in the SM [14, 15, 16]. Non-vanishing contributions could arise here for example in the form of higher-twist terms, which would be suppressed as powers of $M^2/M^2_{W,Z}$, where M is a hadronic mass scale and $M_{W,Z}$ is the $W^\pm$ or Z^0 mass. Other possible contributions were demonstrated in Ref. [15] to be negligible as well. New physics effects, on the contrary, might generate asymmetries at leading twist.

In Ref. [16], the authors have argued that the existence of *R*-parity violating MSSM interaction would generate the single-spin azimuthal dependences[5] of the charged lepton production via $W^\pm$ in collision of transversely polarized protons at unpolarized: $p^\uparrow p \to W^\pm X \to e^\pm \nu X$ or $\mu^\pm \nu X$ or $\tau^\pm \nu X$. The results of [16] show that, in this particular extension of the SM, the asymmetries are likely to be small and, at best, could be just marginally detectable at RHIC. Nevertheless, this does not exclude that other non-standard mechanisms produce larger effects.

One more mechanism of generating non-zero A_N and A_T asymmetries in leptoproduction via $W^\pm$ and Z^0 decays is due to anomalous electroweak dipole moments of quarks [16, 17, 18]. Phenomenologically, the presence of anomalous dipole moments could be described as a combination of tensor and (pseudo)scalar $q\overline{q}W$ and $q\overline{q}Z$ couplings additional to the standard *V* and *A* couplings. The nonzero A_N and A_T arise from the interference of these additional couplings with the SM's *V* and *A* couplings. The SM predictions for anomalous dipole moments of u and d quarks, which provide the main contribution to the $W^\pm$ and Z^0 production at RHIC, are extremely small, and their effects are much below the RHIC sensitivity. On the other hand, the current experimental limits on anomalous dipole moments of quarks[6] are still far above the SM expectations. The most stringent experimental constraints, applicable to *CP*-conserving components of quark dipole moments, come from the analysis [19] of electroweak data from high energy colliders. In this analysis, it has been considered that theories beyond the SM, emerging at some characteristic energy scale above W/Z mass, have effect at low energies $E \leq M_{W,Z}$, and can be introduced by taking account of an effective Lagrangian that extends the SM Lagrangian $\mathcal{L}_{SM}$: $\mathcal{L}_{eff} = \mathcal{L}_{SM} + \delta\mathcal{L}$. To preserve the consistency of the low energy theory, it has been assumed that the non-SM Lagrangian $\delta\mathcal{L}$ is $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge invariant. The $W^\pm$ and Z^0 productions in $p^\uparrow p$ collisions at RHIC is expected to have a good sensitivity on $\mathcal{L}_{SM}$–$\delta\mathcal{L}$ interference at the parton level due to strong correlations between the proton spin and polarization of high-x valence quarks, that participated in gauge boson production [20]. As it has been estimated in Ref. [18], the measurements at RHIC, carried out with transversely polarized proton in the context of the physics discussed in the previous sections, would improve the current experimental limits [19] on electroweak dipole moments of u and d quarks by a factor of ~5–10. But a non-zero result would be a direct indication of a new physics beyond the SM.

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