Asymptotic Helicity Conservation in SUSY

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Abstract

We summarize the extensive work started in [1], according to which total helicity is conserved for any two-to-two process, at $\sqrt{s} \gg M_{\text{SUSY}}$ and fixed angles, in any SUSY extension of SM. Asymptotically the theorem is exact. But it may also have important implications at lower energies $\sqrt{s} \gtrsim M_{\text{SUSY}}$. Up to now, these have been investigated to 1loop electroweak (EW) order for the processes $ug \rightarrow dW^+\tilde{\chi}_i^+$; as well as the 17 $gg \rightarrow HH'$, and the 9 $gg \rightarrow VH$ processes, where $H, H'$ denote Higgs or Goldstone bosons, and $V = Z, W^\pm$.

Some years ago it has been established, to all orders in MSSM perturbation, that for any two-to-two process

\begin{equation}
a_{\lambda_a} + b_{\lambda_b} \rightarrow c_{\lambda_c} + d_{\lambda_d},
\end{equation}

where $\lambda_j$ denotes the particle helicity, all amplitudes satisfying

\begin{equation}
\lambda_a + \lambda_b - \lambda_c - \lambda_d \neq 0,
\end{equation}

vanish exactly at asymptotic energies and fixed angle [1]. This property, which is also true to any non-minimal supersymmetric extension of SM, has been termed asymptotic Helicity Conservation (HCns) [2]. The amplitudes obeying (2), are called below helicity violating (HV) amplitudes; while those satisfying $\lambda_a + \lambda_b - \lambda_c - \lambda_d = 0$, which are the only
ones that can be non-vanishing asymptotically, are termed as helicity conserving (HC) amplitudes.

HCns is an impressive SUSY property, drastically reducing the number of the asymptotically non-vanishing amplitudes, independently of the softly breaking sector. Because of this, it may well be considered at the same level as the best SUSY beauties, like the smooth ultraviolet behavior, the gauge coupling unification and existence of dark matter candidates [2].

If no external vector bosons appear in (1), HCns is merely a consequence of the chiral structure of the fields in SUSY. As a result, it is valid at a diagram-by-diagram level, to all orders in perturbation theory.

When external gauge bosons are involved in (1) though, huge cancelations among the various diagrams are essential for establishing HCns [1]. This may easily be seen at the Born level, but it should much more impressive at higher order [1]. In constructing the general proof in this case, a crucial role was played by the fact that the SUSY transformation for "gauge ↔ gaugino", when projected to single particle states, only involves particles with helicities of the same sign [1]. Thus, the structure of the amplitudes involving external gauginos, was used to study those involving external gauge bosons.

As a first example we quote the complete 1loop calculations of the processes $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow \gamma Z$ or $\gamma\gamma \rightarrow ZZ$, where all HV amplitudes obeying (2) were found to tend asymptotically to non-vanishing constants in SM, while vanishing in MSSM [3]. Thus, the SM and the sfermion-loop contributions to all HV amplitudes for these processes go asymptotically to opposite constants, exactly canceling each other in SUSY [3].

Moreover, in the 1loop study of $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma Z$, $ZZ$ [3], it has been observed that the HC amplitudes were asymptotically much larger that the HV ones, also in SM. Thus, HCns for these processes, appears approximately true in SM also. A similar property is also observed for $ug \rightarrow dW$ in [4].

HCns is not a general property of SM though. Thus for the 1loop EW computations of $gg \rightarrow H^0H^0$, $W^+G^-$, $ZG^0$, $G^+G^-$ (where $G$ denotes goldstone bosons), we have found a strong violation of HCns in SM ; while, of course, it is respected in all MSSM gluon-fusion processes to a pair of spin=1 or spin=0 bosons [2]. Such examples indicate that HCns is a genuine SUSY property.

The dominance of the HC amplitudes at asymptotic energies allows the construction of simple relations among the differential cross sections of various processes, which become exact at high energies, but may be also useful at the LHC range, provided the SUSY scale is not too high. One such example is obtained using

$$\frac{d\hat{\sigma}(ug \rightarrow \tilde{d}_L\tilde{\chi}^+)}{d\cos\theta} = \frac{\beta'_{\tilde{\chi}}}{3072\pi s} \sum_{\lambda_\alpha\lambda_\beta\lambda_{\tilde{\chi}}} |F_{\lambda_\alpha\lambda_\beta\lambda_{\tilde{\chi}}}^\tilde{\chi}|^2,$$

$$\frac{d\hat{\sigma}(ug \rightarrow dW^+)}{d\cos\theta} = \frac{\beta'_{W}}{3072\pi s} \sum_{\lambda_\alpha\lambda_\beta\lambda_{d}\lambda_W} |F_{\lambda_\alpha\lambda_\beta\lambda_{d}\lambda_W}^W|^2,$$
The energy (left panel) and angular (right panel) dependencies of the left part of (6) (dash line with circles), are compared to the right part for $\tilde{\chi}_1^+$ (full line) and $\tilde{\chi}_2^+$ (dash line with squares) production, using the benchmark model SPS1a' [7].

$$\beta'_{\tilde{\chi}_i} = \frac{2p'_{\tilde{\chi}_i}}{\sqrt{s}}, \quad \beta'_{W} = 1 - \frac{m_W^2}{s}, \quad a_{\tilde{\chi}_i,W} = \frac{\alpha}{4\pi} \frac{(1 + 26c_W^2)}{72s^{-2}c_W^2} \ln \frac{M_{\text{SUSY}}^2}{m_Z},$$

with $p'_{\tilde{\chi}_i}$ being the c.m. momentum of the produced chargino $\tilde{\chi}_i$. HCns then implies the asymptotic relation [5]

$$\frac{d\hat{\sigma}(ug \to dW^+)}{d\cos\theta} \simeq \frac{1}{R_{iW}} \frac{d\hat{\sigma}(ug \to \tilde{d}_L\tilde{\chi}_i^+)}{d\cos\theta}.$$  

As shown in Fig.1, this relation is quite accurate even at the LHC energy range, provided the SUSY masses are close to those of the SPS1a’ benchmark [7].

In [2], the gluon-gluon fusion process to two colorless scalars, or a scalar and vector were considered, which most stringently test HCns, since they receive no Born contribution. Many asymptotic relations were then derived, one set of which is

$$R_1 \Rightarrow \tilde{\sigma}(gg \to G^0G^0) \simeq \frac{\tilde{\sigma}(gg \to G^0A^0)}{R_{a1}} \left(\frac{R_{a2}}{R_{a2}}\right)^2 \simeq \frac{\tilde{\sigma}(gg \to A^0A^0)}{R_{a1}} \left(\frac{R_{a2}}{R_{a2}}\right)^2 \simeq \frac{\tilde{\sigma}(gg \to H^0H^0)}{R_{a1}} \left(\frac{R_{a1}}{R_{a3}}\right)^2 \simeq \frac{\tilde{\sigma}(gg \to H^0H^0)}{R_{a1}} \left(\frac{R_{a1}}{R_{a3}}\right)^2 \simeq \frac{\tilde{\sigma}(gg \to Z^0G^0)}{R_{a1}} \left(\frac{R_{a1}}{R_{a2}}\right)^2 \simeq \frac{\tilde{\sigma}(gg \to Z^0A^0)}{R_{a1}} \left(\frac{R_{a1}}{R_{a2}}\right)^2,$$

where $\tilde{\sigma}(gg \to HH', VH)$ are differential cross sections from which kinematical factors have been removed, and $R_{aj}$ are numerical constants depending on the mixing angles of the Higgs-sector [2]. If the SUSY masses are close to those in SPS1a’, some of the relations (7) are approximately true even at energies close to the LHC range. Work is in progress for extending this study to include the processes $gg \to VV'$, $\tilde{\chi}_i^+\tilde{\chi}_j^-$, $\tilde{\chi}_i^0\tilde{\chi}_j^0$. 

Figure 1: The energy (left panel) and angular (right panel) dependencies of the left part of (6) (dash line with circles), are compared to the right part for $\tilde{\chi}_1^+$ (full line) and $\tilde{\chi}_2^+$ (dash line with squares) production, using the benchmark model SPS1a’ [7].
In conclusion we emphasize that HCns is a genuine SUSY property, which strongly simplifies the asymptotic 2-to-2 amplitudes. It solely depends on the symmetry; not on its breaking! And it is this symmetry that guarantees the cancelation of the strong divergencies between the fermion and the boson loops, which creates HCns and the SUSY beauties recapitulated at the beginning.

HCns provides many asymptotic relations among various subprocess cross sections. If the SUSY scale is not too high, these may be useful for LHC, or a future higher energy machine.

Codes for the amplitudes of the 1loop EW process used in this work, are available in http://users.auth.gr/gounaris/ FORTRANcodes.

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[6] The FORTRAN codes together with a Readme file explaining its use, are contained in gghhcode.tar.gz and ggVhcode.tar.gz, which can be downloaded from http://users.auth.gr/gounaris/FORTRANcodes. All input parameters in the code are at the electroweak scale.

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