Helicity Conservation (HC) in 2-body scattering, at high energy

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based on hep-ph/0501046, in collaboration with F.M. Renard.
Its background contains a long series of papers where J. Layssac and P. Porfyriadis have also collaborated

What is **HC** ?

At very large (s,|t|, |u|) , all asymptotically ≠0 2-body amplitudes should satisfy:

$$F(a_{\lambda_1} b_{\lambda_2} \to c_{\lambda_3} d_{\lambda_4}) \Leftrightarrow \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4$$

In addition, if both initial or final particles are fermions, and the rest bosons, we also have:

$$\lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 = 0$$

Curious: They have been known as MHV, at tree QCD, where multibody final states are also considered (Glover SUSY05).

Outline: I will try to show that

SM: HC is valid in LL to 1-loop, for: $s, |t|, |u| \gg m_w^2$

SUSY: HC should be valid to all orders in the gauge couplings of SU(3) ×SU(2)×U(1) for: $s, |t|, |u| \gg M_{SUSY}^2$

In particular: Before **EW** breaking:

constant (non-log) 1-loop terms usually **violate** HC in **SM**,

while in **SUSY**, they always **respect** it, to all orders.

For amplitudes involving fermions and scalars only,

HC means that the asymptotically $\neq 0$ amplitudes obey:

$$F(f^{(1)}_{\lambda_1} f^{(2)}_{\lambda_2} \to f^{(3)}_{\lambda_3} f^{(4)}_{\lambda_4}) \quad \Leftrightarrow \quad \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 \ ,$$

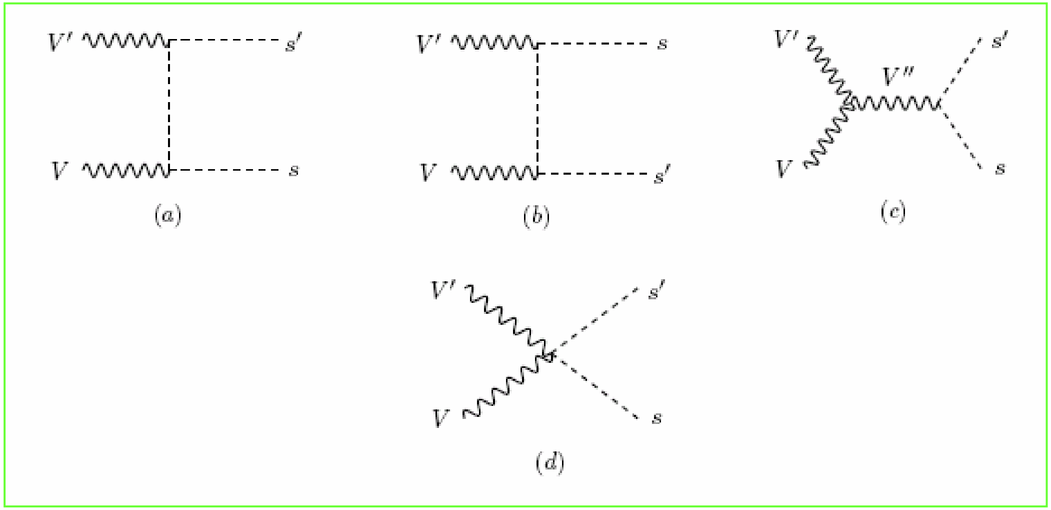
$$F(f_\lambda s \to f'_\lambda s') \ , \ F(f_\lambda f'_{-\lambda} \to s s')$$

It is satisfied to all orders, at a **diagram by diagram** basis, because of the helicity conserving γ_μ gauge coupling. No cancellations among diagrams required.

The Yukawa SM interactions, do not upset these rules; since they always contribute in hermitian conjugate pairs, respecting HC.

Renormalazability needed. True also in SUSY.

Born: HC for transverse gauge and scalars



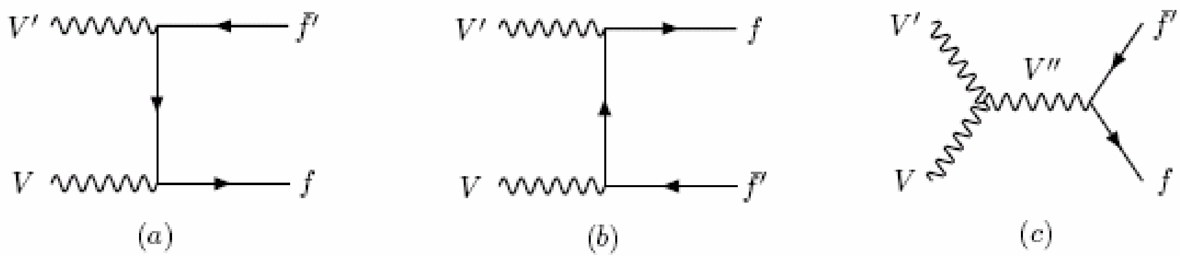
For (s, |t|, |u|) ≫ all intermediate masses, the only **≠0** amplitudes are:

$$F(V_{\lambda_V} V'_{-\lambda_V} \to s s') \ ,$$

$$F(V_{\lambda_V} s \to V'_{\lambda_V} s') \ ,$$

HC assumes renormalizable gauge-scalar couplings. Large **cancellations** among the various diagrams are crucial for establishing it. Valid in both, SM and SUSY.

Born: HC for transverse gauge and fermions



For (s, |t|, |u|) ≫ all intermediate masses, the only **≠0** amplitudes are:

$$F(V_{\lambda_V} V'_{-\lambda_V} \to f_{\lambda_f} f'_{-\lambda_f}) \ ,$$

$$F(V_{\lambda_V} f_{\lambda_f} \to V'_{\lambda_V} f'_{\lambda_f}) \ ,$$

Again renormalizable gauge-fermion couplings are needed, and large cancellations among the diagrams are instrumental. Valid in both, SM and SUSY.

Born: HC for purely transverse gauge amplitudes

Denoting: $$F(V^1_{\lambda_1} V^2_{\lambda_2} \to V^3_{\lambda_3} V^4_{\lambda_4}) \equiv F_{\lambda_1\lambda_2\lambda_3\lambda_4} \quad ,$$

and allowing renormalizable gauge couplings **only**,
we find for (s, |t|, |u|) ≫ the W and H masses:

$$F_{+++-} = F_{++-+} = F_{+-++} = F_{-+++} = F_{---+}$$
$$= F_{--+-} = F_{-+--} = F_{++--} = F_{--++} = 0$$

Valid in both:
SM and SUSY.

Non renormalizable (anomalous) interactions, although preserving SU(3) ×SU(2)×U(1), will violate HC;

like e.g. $O_W = \frac{1}{3!}(\vec{W}_{\mu\nu} \times \vec{W}^{\nu\lambda}) \cdot \vec{W}_\lambda{}^\mu$

1-loop gauge involving amplitudes in SM

- For Born≠0 processes, **HC** remains valid, at the level of the 1-loop $\ln^2$ and $\ln$ terms for $(s,|t|,|u|) \gg (m_w^2, m_H^2)$

We have checked it explicitly at $\mathbf{e^- e^+ \to \gamma\gamma, ZZ, \gamma Z}$ using the exact 1-loop computations, and at $\mathbf{e^- e^+ \to W^- W^+}$ calculated at the $\ln^2$, $\ln$ level.

- For Born=0 processes, **HC** is valid at 1-loop LL, for all the processes we have checked: $\gamma\gamma \longrightarrow ZZ, \gamma Z, ZZ.$

- **Constant** terms in SM, usually **violate HC.**

Could these gauge cancellations leading to HC be valid to all orders? May be in SUSY ?

We work in an exact MSSM model, with all soft breaking and the μ terms vanishing. All fields are massless.

Step 1: All terms (except the fermion Yukawa vertices) respect a U(1)-symmetry.

$$\psi_L, \psi_R, \tilde{\chi}_L \rightarrow Q_U = \lambda$$
$$\tilde{\psi}_L, \tilde{\psi}_R \rightarrow Q_U = 2\lambda$$
$$V_\mu \rightarrow Q_U = 0$$

Step 2: Diagrams containing hermitian conjugate fermion Yukawa vertices, also respect this U(1). Such are those for the 2-body amplitudes containing even numbers of transverse gauge, Higgs (Goldstone), and Higgsinos.

In this massless model we have exact HC for fermions and scalars; i.e. the only ≠0 such amplitudes are:

$$F(f^{(1)}_{\lambda_1} f^{(2)}_{\lambda_2} \to f^{(3)}_{\lambda_3} f^{(4)}_{\lambda_4}) \quad \Leftrightarrow \quad \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 \ ,$$

$$F(f_\lambda s \to f'_\lambda s') \ , \ F(f_\lambda f'_{-\lambda} \to s s')$$

Step 3: In this exactly SUSY model, the amplitudes containing 4 external gauginos, respect the HC structure.

Applying then a SUSY transformation, an incoming gaugino of a definite helicity, is transformed to an incoming gauge, carrying a helicity of the same sign.

Thus, HC for gauginos, implies HC for transverse gauge. The only ≠0 gauge amplitudes then are:

$$F(V^1_{\lambda_1} V^2_{\lambda_2} \to V^3_{\lambda_3} V^4_{\lambda_4}) \Leftrightarrow \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 \ ,$$

$$F(V_{\lambda_V} f_{\lambda_f} \to V'_{\lambda_V} f'_{\lambda_f}) \ , \quad F(V_{\lambda_V} V'_{-\lambda_V} \to f_{\lambda_f} f'_{-\lambda_f}) \ ,$$

$$F(V_{\lambda_V} s \to V'_{\lambda_V} s') \ , \quad F(V_{\lambda_V} V'_{-\lambda_V} \to s s') \ ,$$

Step 4: In our massless SUSY model, HC holds exactly, implying that the only ≠0 amplitudes satisfy

$$F(a_{\lambda_1} b_{\lambda_2} \to c_{\lambda_3} d_{\lambda_4}) \Leftrightarrow \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4$$

Realistic HC: Introducing EW and SUSY breaking, and using Eqivalence theorem, the same structure describes all asymptotically ≠0 amplitudes, involving physical vector bosons, scalars and fermions, provided that

$$(s, |t|, |u|) \gg M_{SUSY}^2$$

Can non-log terms, involving ratio of masses, violate HC? This is not the case in $\gamma\gamma \to \gamma Z, ZZ$. We plan to further investigate it…

The HC structure is very simple

All asymptotically $\neq 0$ amplitudes should satisfy:

$$F(a_{\lambda_1} b_{\lambda_2} \to c_{\lambda_3} d_{\lambda_4}) \Leftrightarrow \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4$$

In case only the initial or final particles are fermions, we also have:

$$\lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 = 0$$

SM: HC is valid in LL to 1-loop, for: $s, |t|, |u| \gg m_w^2$

Constants are generally small and violate HC.

SUSY: HC valid to all orders in the gauge couplings of the SU(3) ×SU(2)×U(1) theory, for $(s, |t|, |u|) \gg M_{SUSY}^2$
Constants respect it also. SUSY somehow **knows** the gauge cancellations, leading to simple amplitude structures.

Observability: It may be possible to test **HC** by measuring polarizations, or comparing differential cross sections for processes like

SM: $s, |t|, |u| \gg m_w^2$

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$q\bar{q} \to gg\,,\ g\gamma\,, gZ\,, gW\,, \gamma\gamma\,, \gamma Z\,,$
$ZZ\,, W^+W^-\,, \gamma W\,, ZW$

$gq \to gq\,, \gamma q\,, Zq\,, Wq$

$gg \to gg\,, q\bar{q}$

$e^-e^+ \to \gamma\gamma\,, \gamma Z\,, ZZ\,, W^-W^+$

$\gamma e \to \gamma e\,, Ze\,, W\nu$

$\gamma\gamma \to f\bar{f}\,, \gamma\gamma\,, \gamma Z\,, ZZ\,, W^-W^+$

MSSM: $s, |t|, |u| \gg M_{SUSY}^2$

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$gg \to \tilde{g}\tilde{g}\ ,\ \tilde{q}\bar{\tilde{q}}\ ,$

$e^-e^+ \to \tilde{f}\bar{\tilde{f}}\,,\ \tilde{\chi}^-\tilde{\chi}^+\,,\ H^-H^+\,,\ H^0H'^0$

$\gamma\gamma \to \tilde{f}\bar{\tilde{f}}\,,\ \tilde{\chi}^-\tilde{\chi}^+\,,\ H^-H^+\,,\ H^0H'^0$

Hard to separate SM from SUSY on the basis of **HC**.