Search for Sphalerons in Proton-Proton Collisions

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Theoretical overview

Two non-perturbative solutions of the electroweak sector in the SM

• an **instanton** is a tunneling process
• a **sphaleron** is a classical transition

nontrivial vacuum structure with an infinite number of ground states

Perturbation theory $\rightarrow$ Baryon and Lepton number **CONSERVATION**

Non-perturbative theory $\rightarrow$ Baryon and Lepton number **VIOLATION**
Advantages and perspectives

Baryon-antibaryon symmetric early Universe

Sphaleron processes during electroweak phase transition

Standard Model extensions

Baryon asymmetry
Sphaleron \leftrightarrow \text{ an unstable configuration of fields, which, after a small perturbation, decays to the vacuum by emission of many particles.}

The sphaleron energy is

$$E \sim \frac{m_W}{\alpha_W} \sim 9 \text{ TeV}$$

High energy proton-proton collisions \( (E \sim E_{sp}) \rightarrow \text{sphaleron-induced transitions} \)
Instantons $\rightarrow$ quantum tunneling - exponentially suppressed!!!

Low energies ($E \ll E_{sp}$): $\sigma_{inst} \sim e^{-4\pi/\alpha_W} \sim 10^{-150}$

Higher energies ($m_W \ll E \ll E_{sp}$) $\rightarrow$ $\sigma_{inst}$ grows exponentially with collision energy and number of bosons

The cross section for sphaleron events is absolutely unknown!!!

LARGE boson multiplicity $n_B \geq 30$

BUT: Theory breaks down as the energy approaches sphaleron energy $E_0 \sim 10$ TeV

The optimistic view: it will be possible to detect sphaleron processes in proton-proton collisions at high energies (30 – 100 TeV)
Sphaleron process simulation
Monte Carlo event generator simulates sphaleron processes generating multiple parton scattering.
Main principles of HERBVI generation

1. Sphaleron process: \( u + d \rightarrow 7 \bar{q} + 3 \bar{\ell} + n_B W(Z) + n_H H \)

2. \( \Delta B = \Delta L = -3 \) (the transition between closest vacua, \( \Delta N = -1 \))

3. Flat parton level cross section

\[
\sigma = \frac{1}{2s} \int |M|^2 \, d\Pi_n(\sqrt{s})
\]

constant

4. Gauge boson multiplicity \( n_B \): fixed number OR leading order expectation (energy dependent)

5. Generation of the main background process – B- and L-conserving multi-W production:

\[ q_1 + q_2 \rightarrow q_3 + q_4 + n_B W(Z) + n_H H \]
HERBVI RESULTS: BLNV events analysis

Fixed number of bosons $n_B = 30 \sim \frac{1}{\alpha_W}$ → large number of produced Z and W bosons
HERBVI RESULTS: BLNV events analysis

We expect a large number of leptons and jets due to the tops and large number of bosons produced in sphaleron process.
A) Fixed value: $n_B = 30 \sim \frac{1}{\alpha_W}$

B) Normal distribution with mean value depending on energy:

$$n_B \sim \frac{3}{2} \frac{\pi}{\alpha_W} \left( \frac{E}{E_{sp}} \right)^{4/3}$$
Background expectations

Multi-W process

While the number of W-bosons is still not very large it is possible to calculate the cross sections within the perturbation theory.

Madgraph leading order results

Integrated luminosity = 3000 $fb^{-1}$

tops+Ws production process

We expect a zero background for number of bosons $n_B \geq 6$ (14 TeV) and 10 (33-100 TeV)
Conclusions

• Sphalerons provide a great interest for future collider physics, since they can only be observed in high energy proton-proton collisions. **If these sphaleron processes are detected**, we’ll get:
  ✓ a truly remarkable breakthrough in understanding non-perturbative EW dynamics
  ✓ clarification of baryogenesis.

• We tested the sphaleron generator HERBVI, examined different running modes, studied the influence of parton and boson distributions on the sphaleron decay products.
• The output was modified to the format common for collider physics (HepMC), hence it is easy to continue detector simulation and further statistical analysis of the HERBVI results.
• The background simulation was performed in order to estimate sensitivity limits (our next step).
• The qualitative analysis of sphaleron process was carried out; the magnitude of the sphaleron cross section, however, remains undefined!