Search for Sphalerons in Proton-Proton Collisions

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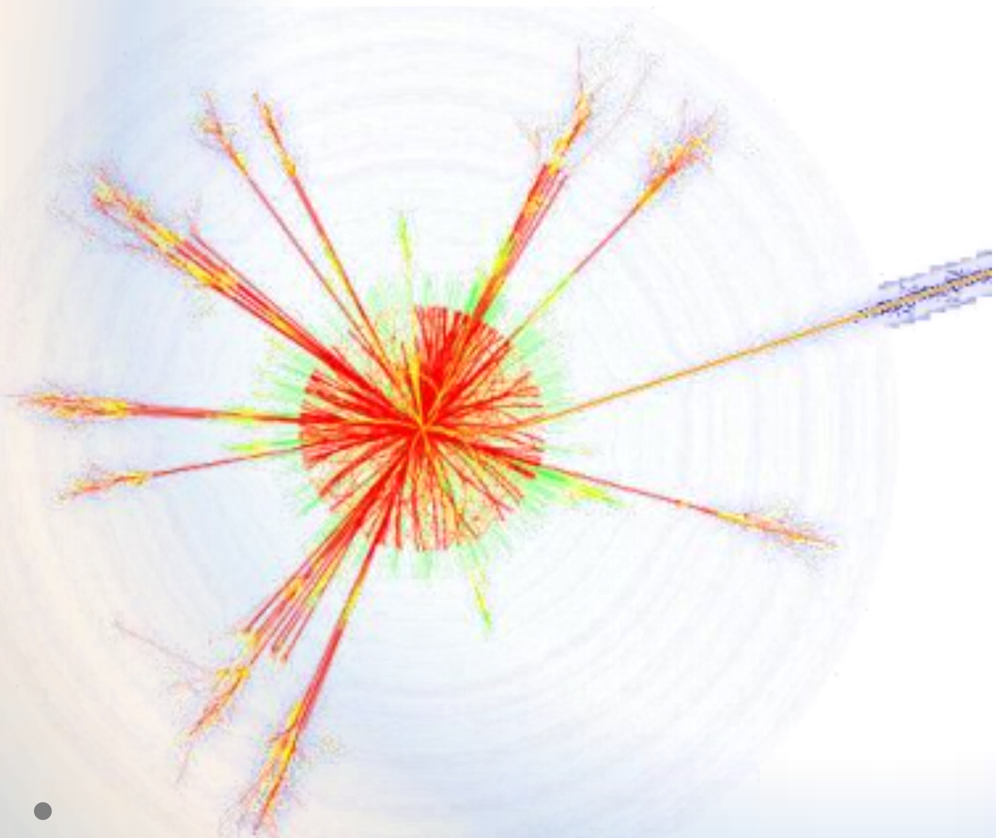
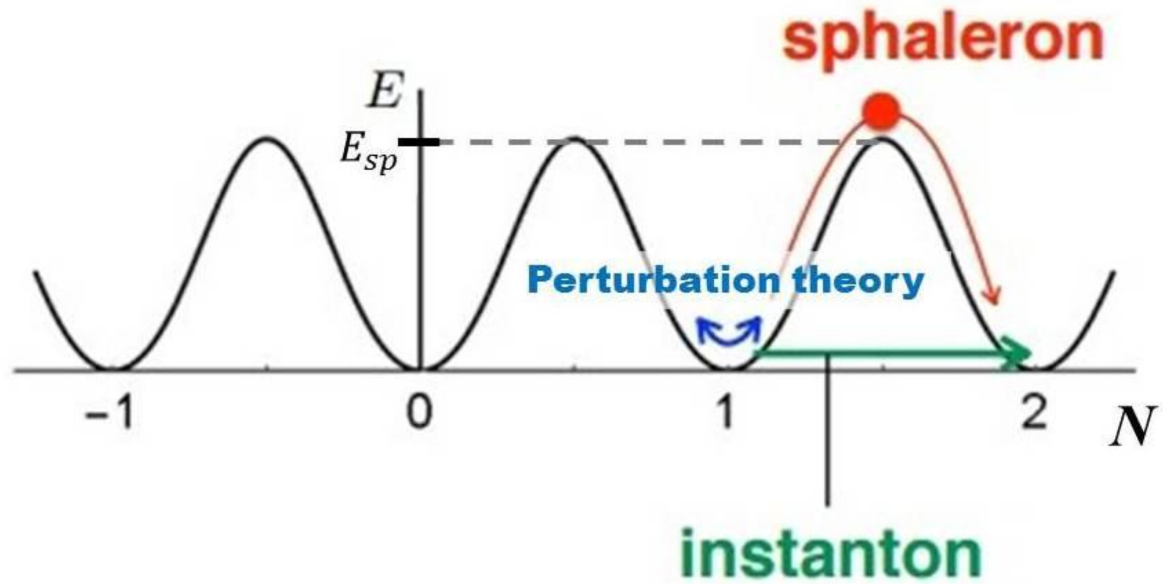


Theoretical overview

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 → Baryon and Lepton number CONSERVATION

VS

Non-perturbative theory → Baryon and Lepton number VIOLATION

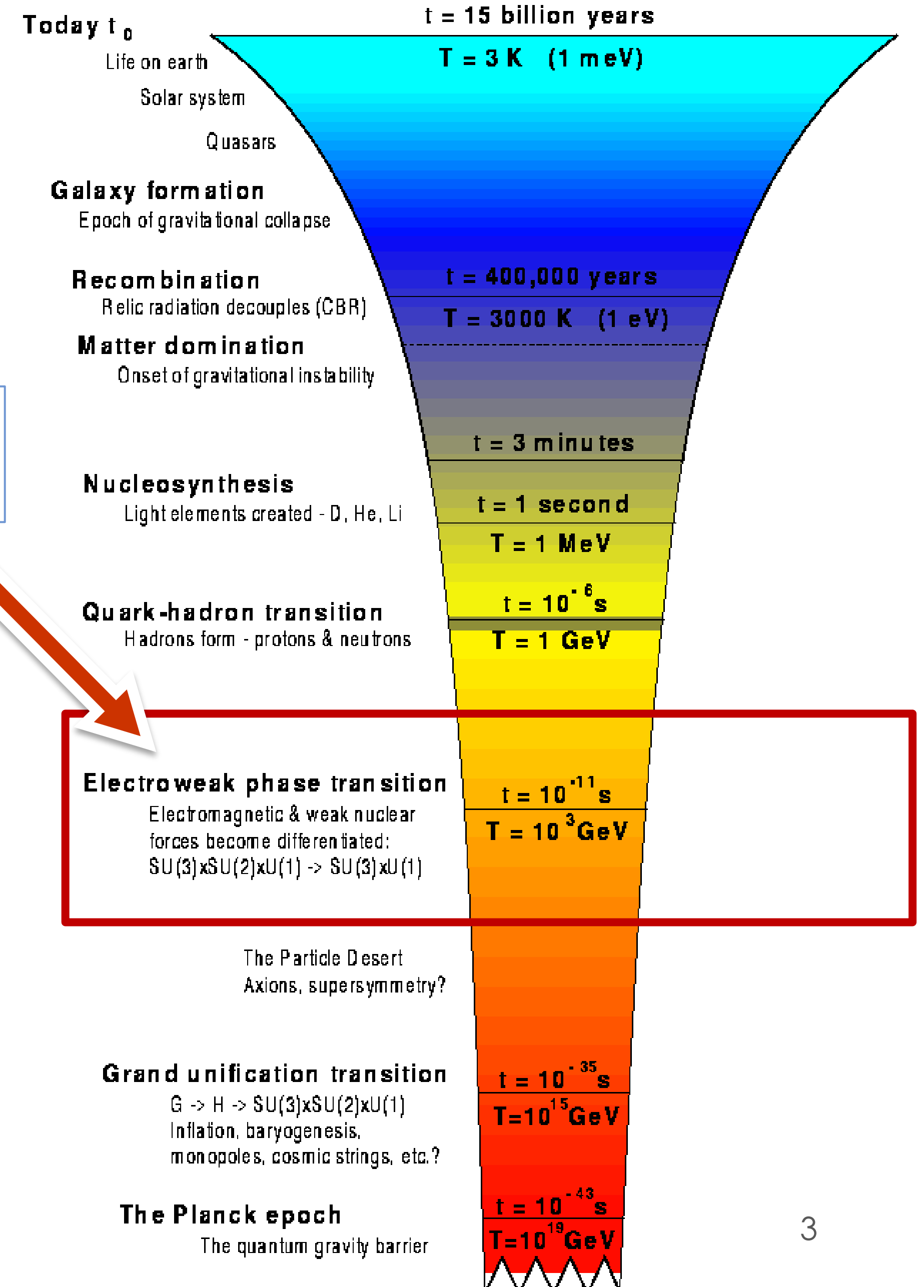
Advantages and perspectives

Baryon-antibaryon symmetric early Universe

Sphaleron processes during electroweak phase transition

Standard Model extensions

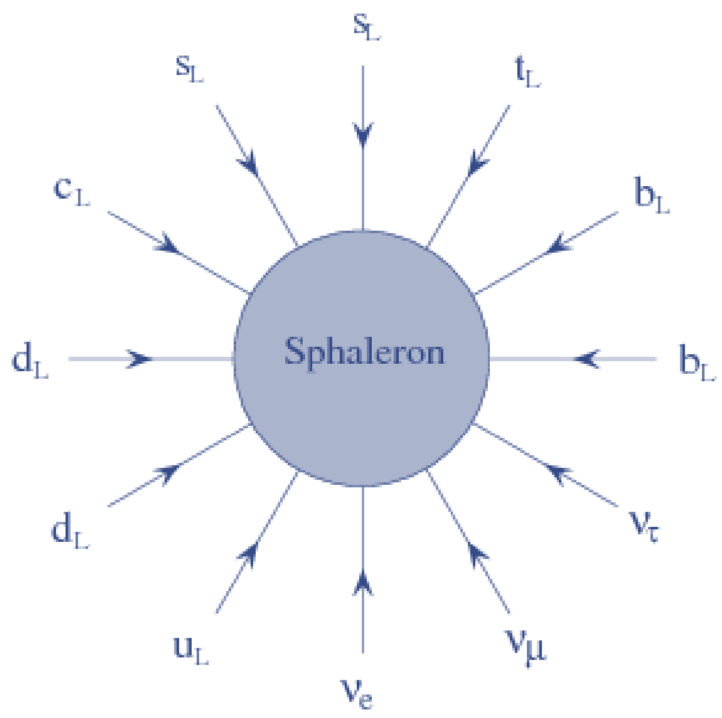
Baryon asymmetry



Sphaleron ←→ an unstable configuration of fields, which, after a small perturbation, decays to the vacuum by emission of many particles.

The sphaleron energy is

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



High energy proton-proton collisions (E ~ E_{sp}) → sphaleron-induced transitions

??? σ ???

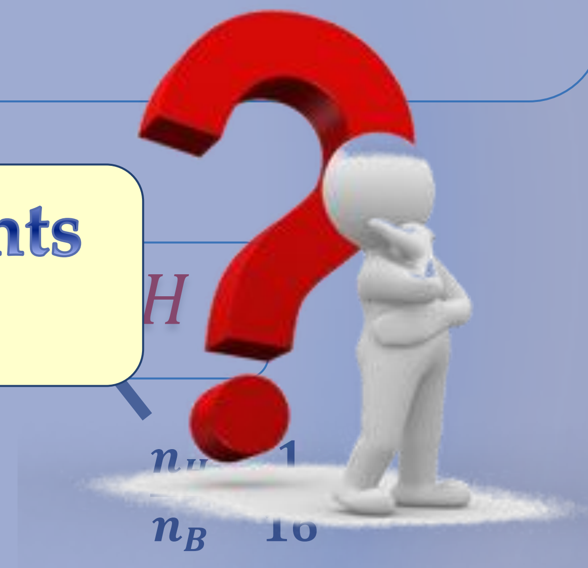
Sphaleron (instanton approach)

Instantons → quantum tunneling - <u>exponentially suppressed</u>!!!

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

Higher energies (m_W<< E << E_{sp}) → σ_{inst} grows exponentially with collision energy and number of bosons

The cross section for sphaleron events is absolutely <u>unknown</u>!!!



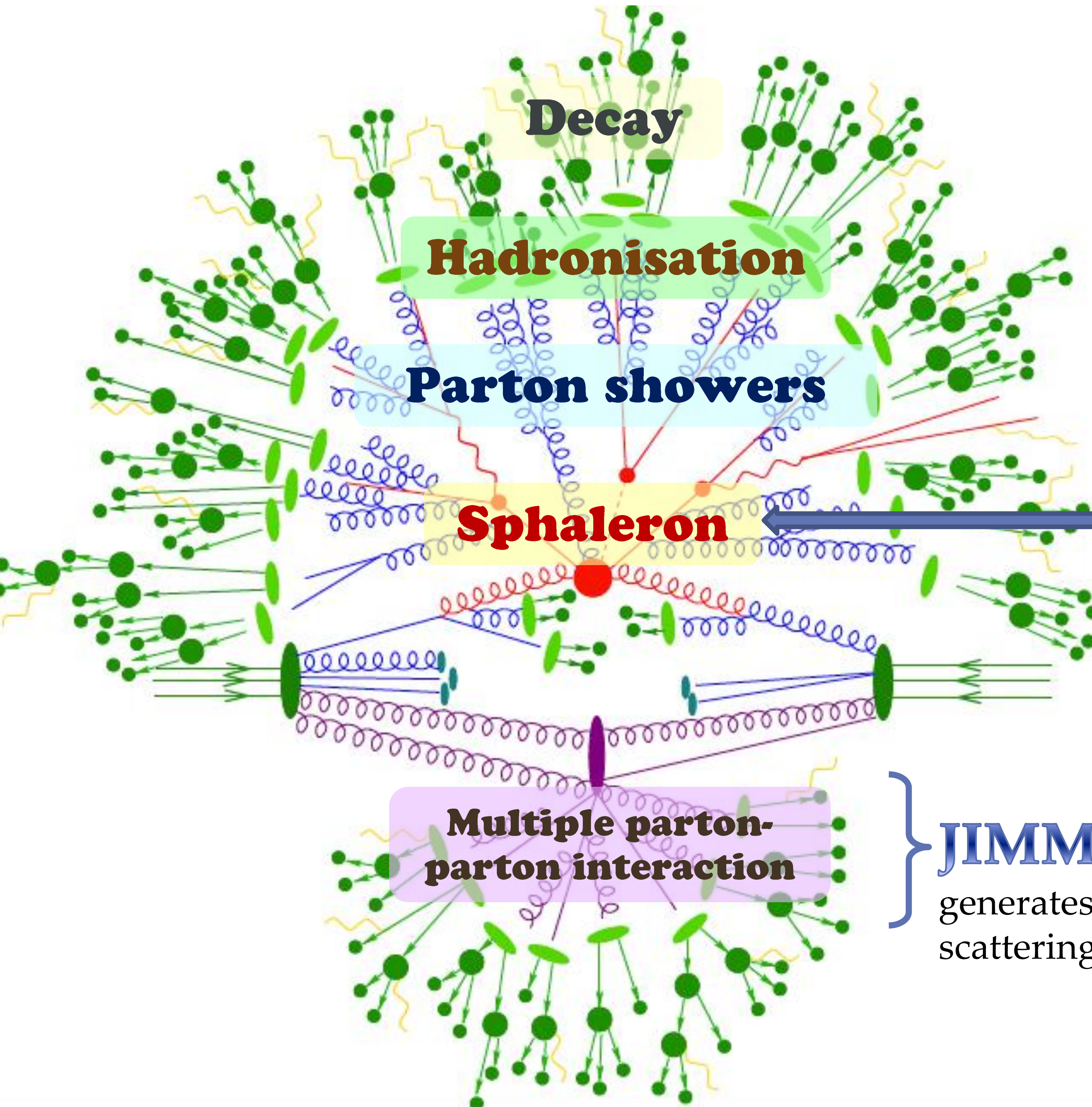
LARGE boson multiplicity $n_B \geq 30$

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

<u>**The optimistic view:**</u> it will be possible to detect sphaleron processes in proton-proton collisions at high energies (30 – 100 TeV)

FCC hh ee he

Sphaleron process simulation



HERWIG

Monte Carlo event generator

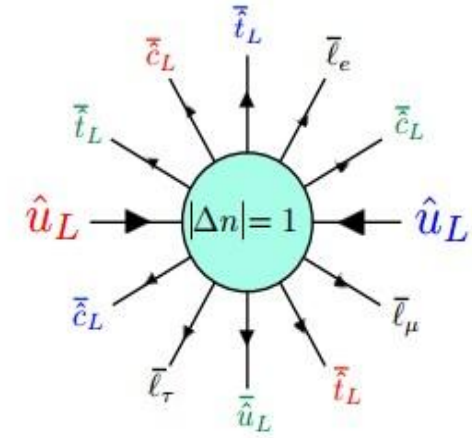
HERBVI

simulates sphaleron processes

JIMMY

generates multiple parton scattering

Simulation of sphaleron process with HERBVI



Main principles of HERBVI generation

1. Sphaleron process: $\mathbf{u + d \to 7\bar{q} + 3\bar{l} + n_B W(Z) + n_H H}$

2. **ΔB = Δ L = - 3** (the transition between closest vacua, ΔN = -1)

3. Flat parton level cross section

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

constant

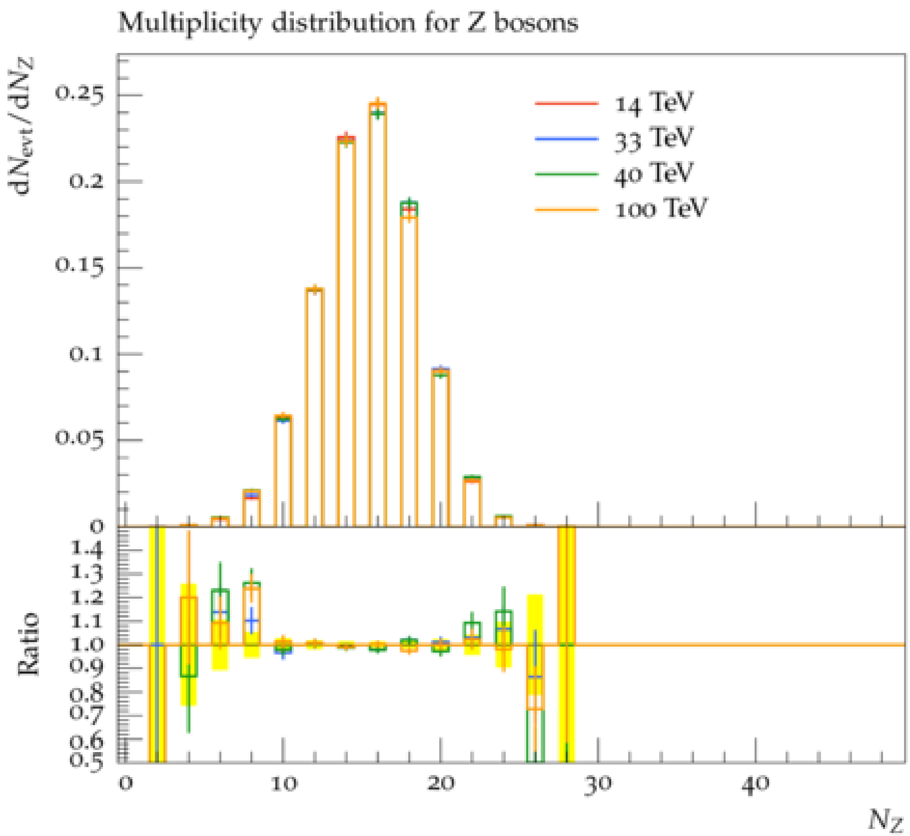
4. Gauge boson multiplicity n_B : fixed number OR leading order expectation(energy dependent)

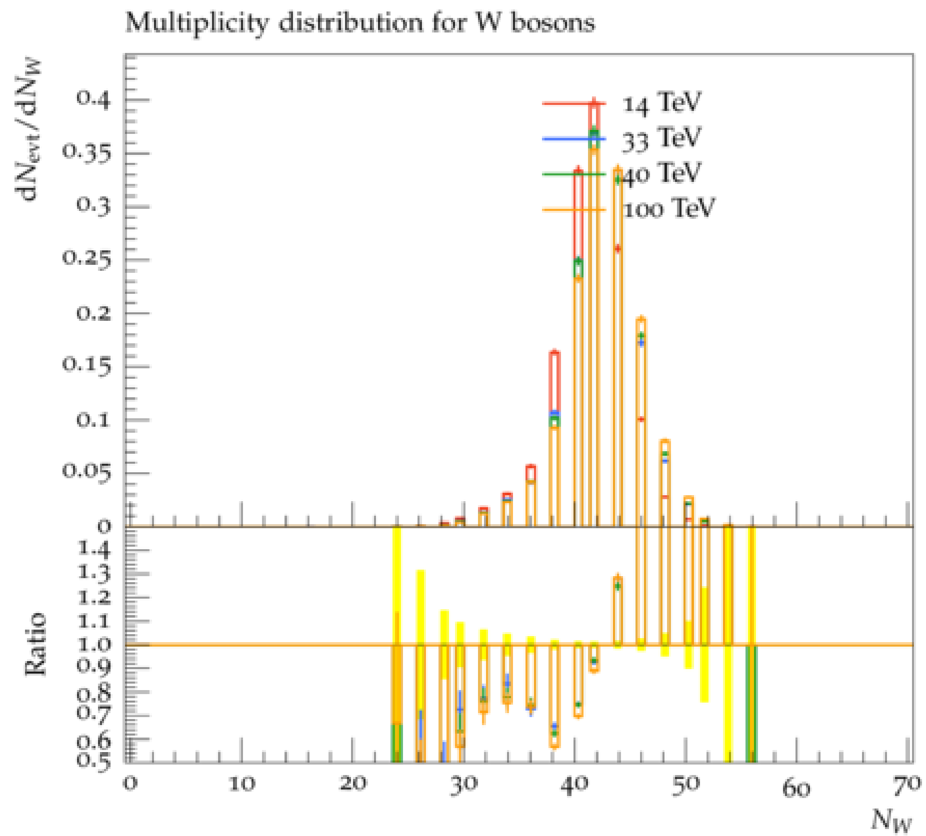
5. Generation of the main background process – B- and L-conserving multi-W production:

$$q_1 + q_2 \to q_3 + q_4 + n_B W(Z) + n_H H$$

HERBVI RESULTS: BLNV events analysis

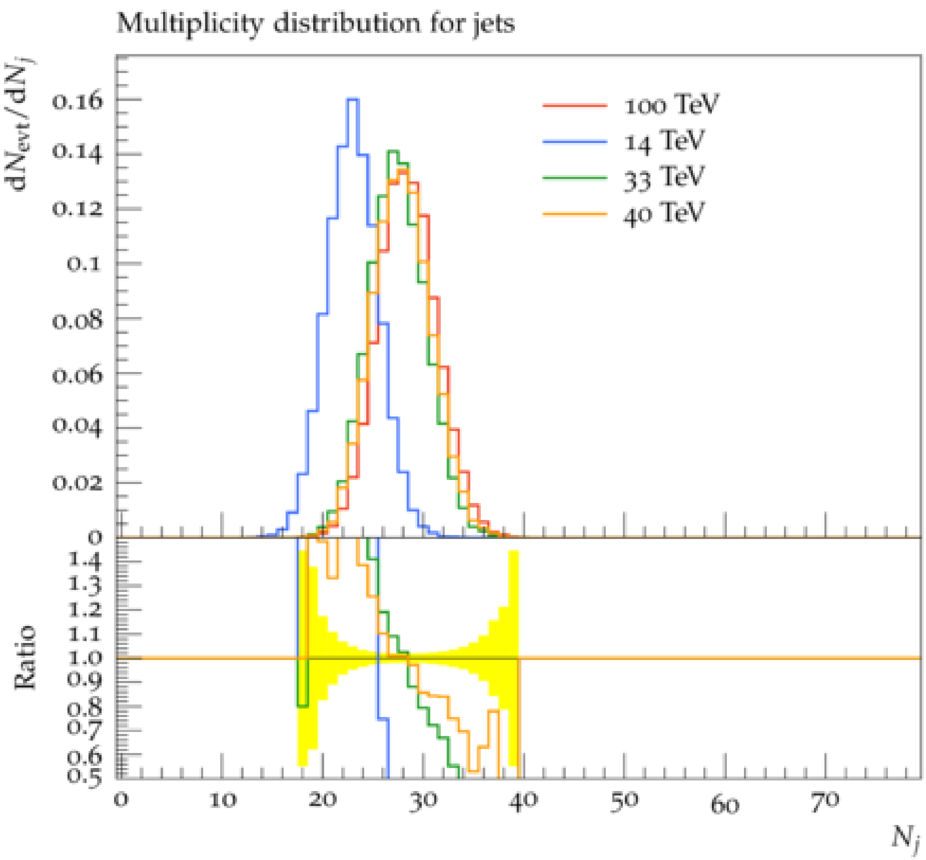
Fixed number of bosons $n_B = 30 \sim \frac{1}{\alpha_W}$ → large number of produced Z and W bosons

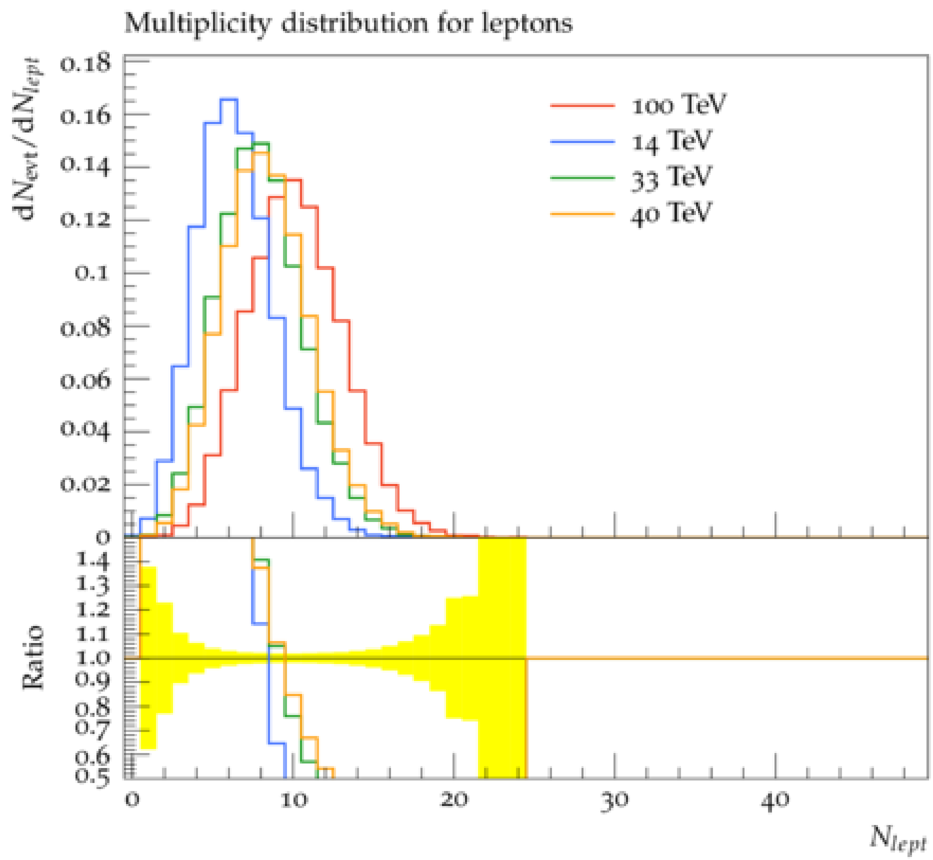




HERBVI RESULTS: BLNV events analysis

We expect a large number of leptons and jets due to the tops and large number of bosons produced in sphaleron process



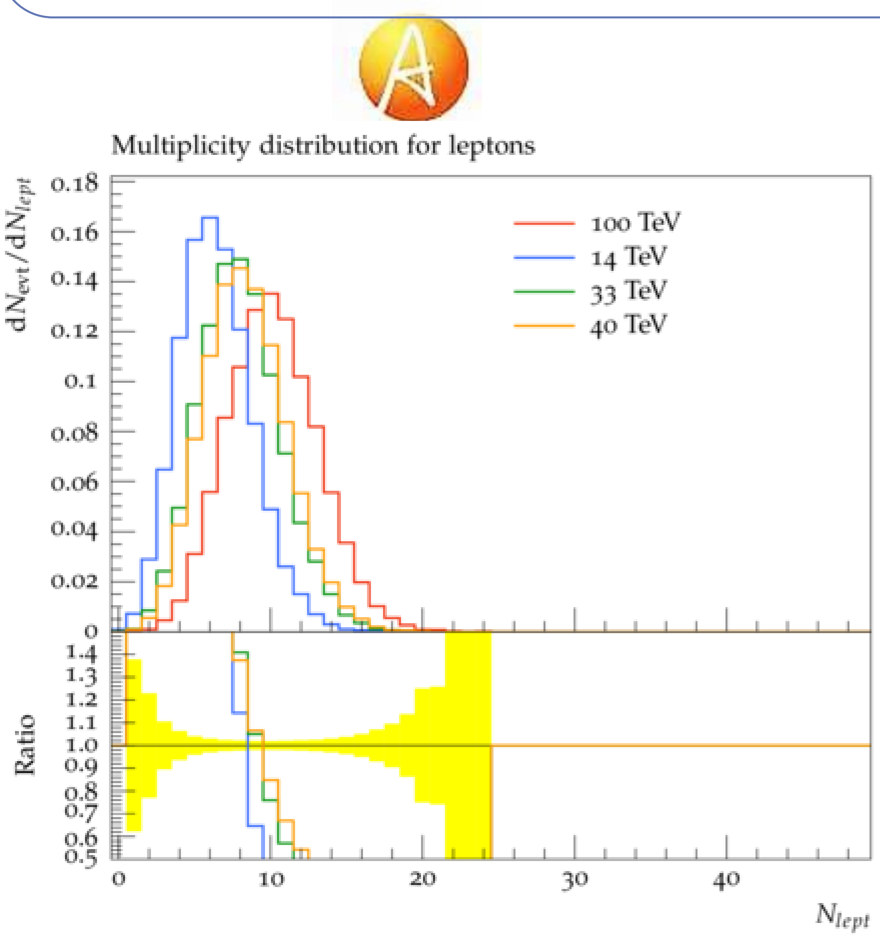


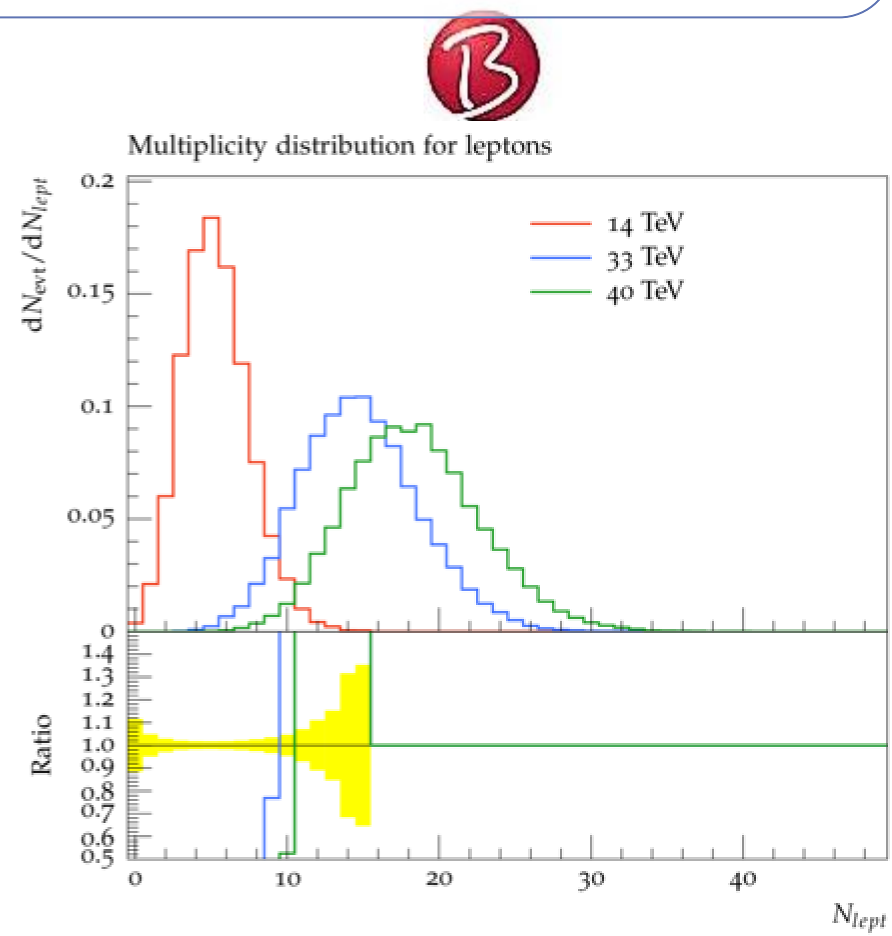
HERBVI RESULTS: boson multiplicity models

A) Fixed value: $n_B = 30 \sim \frac{1}{\alpha_W}$

B) Normal distribution with mean value depending on energy:

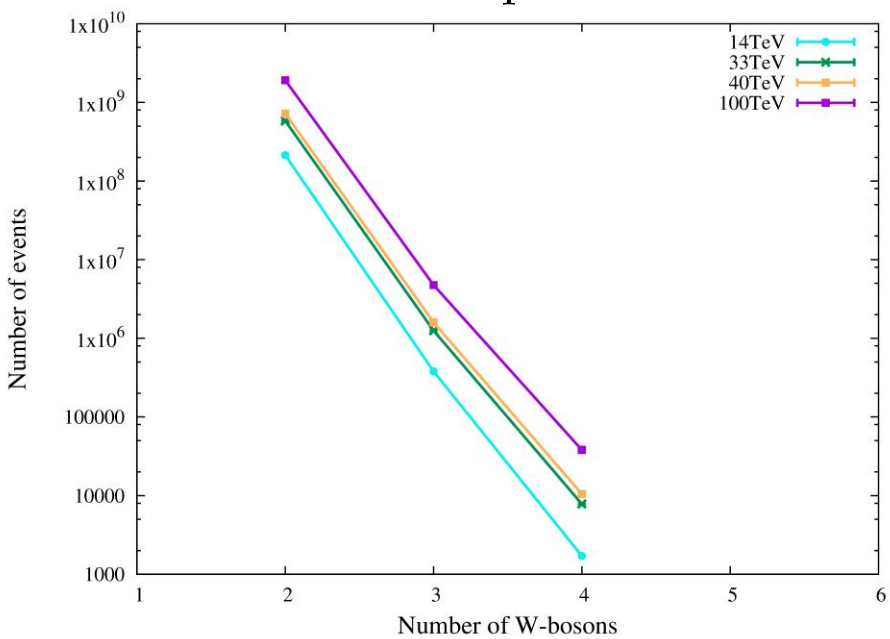
$$n_B \sim \frac{3}{2}\frac{\pi}{\alpha_W}\left(\frac{E}{E_{sph}}\right)^{4/3}$$





Background expectations

Multi-W process

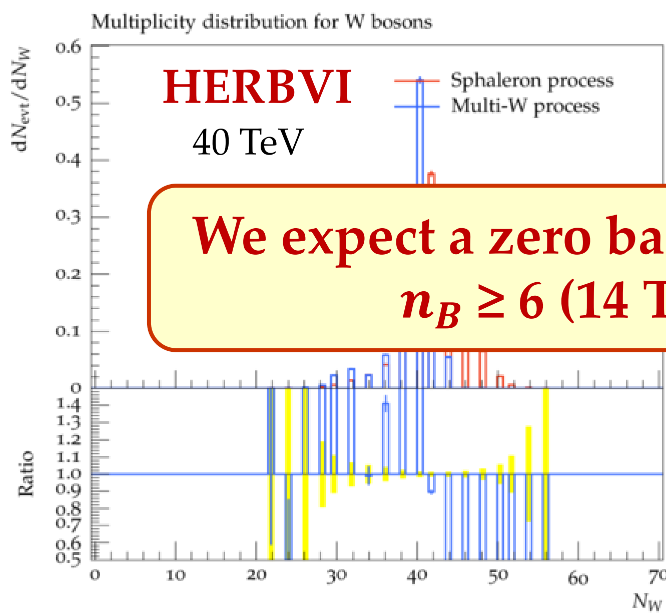


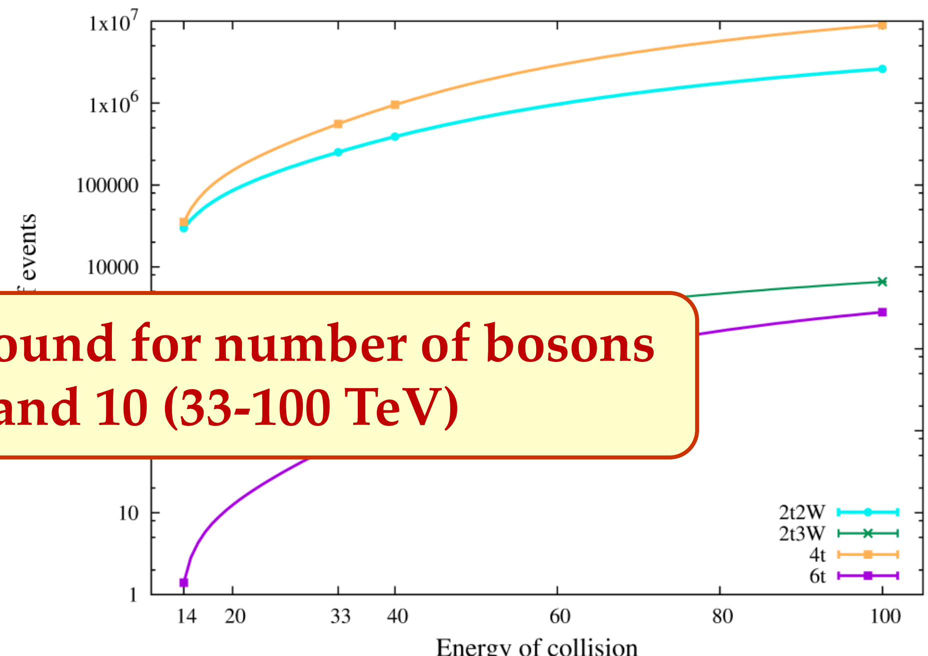
While the number of W-bosons is still not very large it is possible to calculate the cross sections within the perturbation theory

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!