Discovery potential of LHC for extended gauge symmetries

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Overview

- LHC & ATLAS & CMS
- extended gauge theories
- experimental searches for:
  - $W'$
  - $Z'$
  - heavy majorana neutrinos, $W^R$
  - 2nd generation Leptoquarks
- conclusions
LHC schedule/luminosities

- 1st run at 14 TeV: July 2008
- $\int L \, dt$ in 1st month (August 2008): a few pb\(^{-1}\)
- $\int L \, dt$ until end of 2008: up to 1fb\(^{-1}\)
The Detectors

ATLAS

Diameter
15 m

Length
21.5 m

Magnetic field
4 T

Overall weight
12500 t

CMS

Diameter
25 m

Barrel toroid length
26 m

End-cap end-wall chamber span
46 m

Overall weight
7000 Tons
Extended Gauge Symmetries

• Many extensions of the Standard Model rely on larger symmetry groups → Extended Gauge Symmetries:

  • Left-right-symmetric models (LRSM)
    → \( Z', W_R' \), heavy majorana neutrinos etc.

  • Sequential standard model
    → \( Z', W' \) etc.

  • Superstring inspired \( E_6 \)-models
    → \( Z', \) Leptoquarks etc.

  • Grand-Unifying-Theories (GUTs)
    → \( \) Leptoquarks etc.

  • Little Higgs Model
    → \( Z' \) etc.
W' in the sequential Standard Model:

- W' is an additional heavy gauge boson
- W' has same couplings with left-handed fermions like W;
  no interaction with other heavy gauge bosons (W, Z, Z')
- lower bound on W' mass (direct searches): ~ 1 TeV

studied channel at ATLAS:  \( W' \rightarrow \mu + \nu_{\mu} \)

Standard model backgrounds considered:

- \( W \rightarrow \mu_{\mu} + X \)
- \( Z \rightarrow \mu_{\mu} + X \)
- QCD (dijet processes)

W' signature: high energy muon accompanied by missing energy allows easy separation of signal and background reactions
Expected luminosity needed for a 5σ discovery (likelihood ratio method)

ATLAS Preliminary

"Recent results on W’ observability" Z. Ropas

| W' mass (TeV) | Luminosity (pb⁻¹) |
|--------------|-------------------|
| 1            | 3.0 ± 0.3         |
| 1.5          | 14.6 ± 1.4        |
| 2            | 84 ± 9            |
| 2.5          | 283 ± 31          |

assumed sys. uncertainties:
- signal 5%
- background 20%
- same channel studied as in ATLAS:
  \[ W' \rightarrow \mu + \nu_\mu \]
  
  → same background channels and same \( W' \) signature as in ATLAS

- number of events for signal and background after selection cuts

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**discovery limits for \( W' \)**

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**CMS PTDR 2006**
• $Z'$ is an additional heavy gauge boson, predicted in many extended gauge theories, excluded mass: $\sim 1$ TeV (direct searches)

| Model       | $\Gamma/M$ \% | $Z' \rightarrow \mu^+\mu^-$ BR in \% | $\sigma^{LO} \cdot \text{Br, full interference, fb}$ (PYTHIA) |
|-------------|----------------|---------------------------------------|---------------------------------------------------------------|
|             |                |                                       | $1$ TeV/c$^2$ | $3$ TeV/c$^2$ | $5$ TeV/c$^2$ |
| $Z_{SSM}$   | 3.1            | 3.0                                   | 610           | 2.8           | 0.050         |
| $Z_\psi$    | 0.6            | 4.0                                   | 340           | 1.7           | 0.032         |
| $Z_\eta$    | 0.7            | 3.4                                   | 370           | 1.8           | 0.035         |
| $Z_\chi$    | 1.3            | 5.7                                   | 500           | 2.2           | 0.038         |
| $Z_{LRM}$   | 2.2            | 2.3                                   | 500           | 2.3           | 0.040         |
| $Z_{ALRM}$  | 1.6            | 8.6                                   | 740           | 3.7           | 0.077         |

- $Z_{SSM}$ within the sequential standard model
- $Z_\eta$, $Z_\psi$, $Z_\chi$ arising in $E_6$ (and SO(10)) GUT groups
- $Z_{LRM}$ and $Z_{ALRM}$ arising in the framework of the so-called “left-right” and “alternative left-right” models ($g_R = g_L$ chosen)

k-factor used: 1.35 (mass-independent)
- Decay channels (assumption: no exotics channels opened):
  - \( Z' \rightarrow \mu^+\mu^- \) promising
  - \( Z' \rightarrow e^+e^- \) promising
  - \( Z' \rightarrow \tau^+\tau^- \) instrumental background from QCD
  - \( Z' \rightarrow \) hadrons instrumental background from QCD

- \( Z' \) signal:
  - high invariant mass peak above Drell-Yan line shape

- studied channel (ATLAS):
  - \( Z' \rightarrow e^+e^- \)

- dominant and irreducible background:
  - \( pp \rightarrow \gamma/Z^0 \rightarrow e^+e^- \)

studied channel: \( Z' \rightarrow \mu^+\mu^- \) (CMS)(assumption: no exotic channels opened)

- overall efficiency (incl. acceptance, trigger, reconstruction) for \( Z' \rightarrow \mu^+\mu^- \) events at CMS:
  - 75%-85%
Z' (CMS)

- dominant and irreducible background: $pp \rightarrow \gamma/Z^0 \rightarrow \mu^+\mu^-$
- other backgrounds negligible (after signal-selection criteria)

luminosity needed to discover Z' in $Z' \rightarrow \mu^+\mu^-$ channel with 5$\sigma$ significance

- bands correspond to predictions with ±1$\sigma$ theoretical uncertainty

- discovery potential with 1 fb$^{-1}$:
  \[ Z_{\text{SSM}}^{\psi} (2.6 \text{ TeV}), Z_{\eta} (2 \text{ TeV}), Z_{\psi} (1.95 \text{ TeV}), Z_\chi (2.5 \text{ TeV}), Z_{\text{LRM}} (2.5 \text{ TeV}) \text{ and } Z_{\text{ALRM}} (2.7 \text{ TeV}) \]
Heavy Majorana neutrinos, $W_R$ (CMS)

- LRSM model ($SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$) incorporates three additional heavy gauge bosons $W_R$, $Z'$ and the heavy right-handed Majorana neutrino states $N$.

- The Ns can be partner of light neutrino states and can provide their non-zero masses through the see-saw mechanism.
- assumption: $g_R = g_L$
- studied channel: $pp \rightarrow W_R \rightarrow eN$ (cross-section for this channel is 10 times higher than for $pp \rightarrow Z' \rightarrow N\bar{N}_e$)

- **$W_R$ signal**: 2 leptons + 2 jets
- **$N$ signal**: 1 lepton + 2 jets

- main backgrounds: $Z$+jets and $ttbar$
Scalar Leptoquarks (ATLAS)

- Leptoquarks (LQ) are particles which carry both lepton- and baryon-numbers. LQ interactions conserve the lepton- and baryon-numbers separately.

- 1\textsuperscript{st} Assumption: LQ couple only to one generation of quarks and to one generation of leptons of the standard model → 3 generations of LQ

- 2\textsuperscript{nd} assumption: LQ interactions are chiral

- With these assumptions there are 14 kinds (mBRW model) of LQ

- only pair production of scalar LQ considered here → single production depends on the unknown Yukawa (q-ℓ-LQ) coupling
Scalar Leptoquarks

• 2nd generation LQ

\[ \sigma(pp \rightarrow \text{LQ+LQ+X}) \ [\text{pb}] \]
\[ \sqrt{s} = 14 \ \text{TeV} \]

“Pair production of scalar leptoquarks at the LHC”
M. Krämer et al.

• main background channels:

| process                              | \( \sigma \times \text{BR (in pb)} \) |
|--------------------------------------|--------------------------------------|
| \( Z /\gamma^* (\mu\mu)+\text{jets} \) \( p_T^\text{jet} > 20 \text{GeV} \) | 313                                   |
| \( tt (\mu\nu \mu\nu) \)            | 9.5                                   |
| \( ZZ (\mu\mu \ jj) \)              | 1.2                                   |
| \( ZW (\mu\mu \ jj) \)              | 1.2                                   |
| \( WW (\mu\nu \mu\nu) \)            | 1.1                                   |

• 2nd generation Leptoquark decay channels: \( \text{LQ} \rightarrow q + \mu \) or \( \text{LQ} \rightarrow q + \nu_\mu \)

• assumed: 100% of 2nd generation LQ decays: \( \text{LQ} \rightarrow q + \mu \)

• excluded mass for 2nd generation LQ (so far): ~ 250 GeV

• signal: 2 high energetic jets, 2 high energetic muons

ATLAS Preliminary

| Leptoquark mass | Expected Luminosity for exclusion with 95% C.L. |
|-----------------|-----------------------------------------------|
| 300 GeV         | 2.8 pb\(^{-1}\)                              |
| 400 GeV         | 6.6 pb\(^{-1}\)                              |
| 600 GeV         | 40 pb\(^{-1}\)                               |
| 800 GeV         | 220 pb\(^{-1}\)                             |
Conclusions

• presented a selection of analyses on particles predicted by extended gauge theories

• LHC with ATLAS and CMS provides a powerful tool to discover or exclude many particles predicted by extended gauge theories

• many particles can be discovered or excluded already in the early phase of the LHC

• exciting years ahead