LHeC and Physics Beyond the Standard Model

Emmanuelle Perez
CERN

• Sensitivity to new physics in ep collisions at 1.4 TeV: quark radius, leptoquarks, SUSY, eeqq contact interactions. Complementarity w.r.t. pp.

• LHeC w.r.t. the interpretation of LHC discoveries: are there limitations due to our limited knowledge of high x pdfs? See also M. Cooper-Sarkar and C.P.Yuan talks
LHeC: a future DIS experiment at the LHC?

J.B. Dainton, M. Klein, P. Newman, F. Willeke, EP

Consider the feasibility of pursuing the DIS programme using the 7 TeV LHC proton (A) beam and bringing it in collision with a 70 GeV electron beam in the LHC tunnel: LHeC.

\[ \sqrt{s} = 1.4 \text{ TeV} \text{ i.e. } Q^2 \text{ up to } 2 \times 10^6 \text{ GeV}^2 \]

\[ \text{Lumi} \sim 10^{33} \text{ cm}^{-2} \text{ s}^{-1}, \text{ i.e. integrated luminosities of about 10 fb}^{-1} \text{ per year can be considered.} \]

\[ \text{Polarised e}^{-} \text{ beam.} \]

See talks of M. Klein and P. Newman at this session.
Assign a finite size $< r >$ to the EW charge distributions:

$$d\sigma/dQ^2 = SM_{\text{value}} \times f(Q^2)$$

$$f(Q^2) = 1 - \frac{< r^2 >}{6} Q^2$$

Global fit of PDFs and $< r >$ using $d\sigma/dxdQ^2$ from LHeC simulation, 10 fb$^{-1}$ per charge, $Q^2$ up to 500000 GeV$^2$:

$$< r_q > < 8 \times 10^{-20} \text{ m}$$

One order of mag. better than current bounds.
Apparent symmetry between the lepton & quark sectors?
Exact cancellation of QED triangular anomaly?

- LQs appear in many extensions of SM
- Scalar or Vector color triplet bosons
- Carry both L and B, frac. em. charge

LQ decays into (lq) or (νq):

<table>
<thead>
<tr>
<th></th>
<th>ep</th>
<th>pp</th>
</tr>
</thead>
<tbody>
<tr>
<td>eq</td>
<td>νq</td>
<td>lllq</td>
</tr>
<tr>
<td>NC DIS</td>
<td>CC DIS</td>
<td>Z/DY + jj</td>
</tr>
<tr>
<td>QCD</td>
<td>QCD</td>
<td>QCD</td>
</tr>
</tbody>
</table>

LHC could discover eq resonances with a mass of up to 1.5 - 2 TeV via pair production.

Quantum numbers? Might be difficult to determine in this mode.
Determination of LQ properties

**pp, pair production**

- **Fermion number**
  
  \[ q \rightarrow g ightarrow LQ \bar{LQ} : \]
  angular distributions depend on the structure of \( g-LQ-LQ \). If coupling similar to \( \gamma WW \), vector LQs would be produced unpolarised...

- **Scalar or Vector**

  \[ q \bar{q} \rightarrow g \rightarrow LQ \bar{LQ} : \]
  
  \[ \cos(\theta^*) \]
  distribution gives the LQ spin.

- **Chiral couplings**

  \[ ? \]
  Play with lepton beam polarisation.

**ep, resonant production**

- Compare \( \sigma \) with \( e^+ \) and \( e^- \):
  
  \[ F=0 \text{ LQs : } \sigma(e^+) \text{ higher} \]
  
  \[ F=2 \text{ LQs : } \sigma(e^-) \text{ higher} \]
Single LQ production at LHC

Scalar LQ, $\lambda=0.1$, single production

Single LQ production also possible at the LHC.

γ → ee followed by eq → LQ not considered yet. Not expected to change much the results shown here (Tevatron).

Smaller x-section than at LHeC. And large background from $Z + 1$ jet.

Can be used in principle to determine the LQ properties in pp.
Single LQ production at LHC to determine the LQ properties?

Example: Fermion number:

Look at signal separately when resonance is formed by \((e^+ + \text{jet})\) and \((e^- + \text{jet})\):

\[
\sigma(e^+) > \sigma(e^-)
\]

Sign of the asymmetry gives \(F\), but could be statistically limited at LHC. Easier in ep!

Idem for the simultaneous determination of coupling \(\lambda\) at \(e^-q\)-LQ and the quark flavor \(q\).

If LHC observes a LQ-like resonance, \(M < 1\) TeV, with indications (single prod) that \(\lambda\) not too small, LHeC would solve the possibly remaining ambiguities.
Supersymmetry

\tan \beta = 10, M_2 = 380 \text{ GeV}, \mu = -500 \text{ GeV}

Pair production via $t$-channel exchange of a neutralino.

Cross-section sizeable when $\Sigma M < 1 \text{ TeV}$ i.e. if squarks are “light”, could observe selectrons up to $\sim 500 \text{ GeV}$.

- Could extend a bit over the LHC slepton sensitivity
- Possible information on couplings by playing with $e^+ / e^- / L / R$
The interpretation of discoveries in AA at Alice may require direct measurements on pdfs in A - not covered.

Here, focus on ATLAS & CMS discoveries: highest masses $\rightarrow$ highest $x$. Constraints on $d$ and $g$ at high $x$ still limited:

\[ Q^2 = 10000 \text{ GeV}^2 \]
Current high $x$ uncertainties and NP processes at LHC: quark-quark processes

Example: squark production

\[ d \quad \cdots \quad \tilde{d} \]
\[ d \quad \tilde{g} \quad \tilde{d} \]

(Shown uncertainties: from CTEQ 6.1 sets)

\[ \delta(pdf) \] on the relevant partonic luminosities instead of that on the $\sigma$ of a given BSM process.

\[ \text{partonic luminosity} \]
\[ dd \rightarrow X X \]

\[ \text{uncertainty on part. lum.} \]

\[ \text{M}(X) \text{ (GeV)} \]

Estimated LHC sensitivity (SUSY)

For a process involving high $x$ $d$ quarks, pdf uncertainty $\sim 20\%$ at the corner of the LHC phase space.

Could be $\sim 50\%$ with extended sensitivity (e.g. LHC upgrade)
Quark-antiquark processes

Example: new $W'$, resonant slepton production in RpV SUSY

$\begin{align*}
&d \bar{u} \rightarrow X \\
&\text{partonic luminosity}
\end{align*}$

$\begin{align*}
&\text{reach for a } W' \text{ with SM like couplings} \\
&40\% \text{ uncertainty on part. lum. For a 6 TeV } W'. \\
&\rightarrow g(W')?
\end{align*}$

RpV SUSY: reach would depend on the strength of the coupling $\lambda'$. With sea quarks involved, uncertainties large already well below the kinematical limit. Would make the measurement of the coupling difficult.
Example: new Z' boson, KK gravitons in Randall-Sundrum models etc.. Signal = a mass peak.

Partonic luminosities can be “normalised” to the side-bands data if enough stat.

But close to the discovery limit, couplings of a Z' boson may not be measured accurately.
Quark-antiquark: DY mass spectrum

NP in Drell-Yan spectrum might not manifest itself as a mass peak... e.g. large extra-dimensions, interference with very heavy boson etc...

Effective “contact-term” Lagrangian:

$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \varepsilon_{ij} \frac{4\pi}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

$$d\sigma/ds = SM_{value} + ... \varepsilon s/\Lambda^2 + ... (s/\Lambda^2)^2$$

LHeC sensitivity (10 fb\(^{-1}\) e- & e+):
25 – 45 TeV

depending on the model

Similar to the expected sensitivity at LHC.

(\text{GeV}^2)
“eeqq” contact-term in DY and DIS

- LL model, $\Lambda = 30$ TeV, sign = -1: effect in DY can be “absorbed” in pdf unc.
- In some cases, may be difficult to determine the sign of the interference of the new amplitude with SM.

- At LHeC, sign of the interference can be determined by looking at the asym. between $\sigma/\sigma_{SM}$ in $e^-$ and $e^+$. Polarisation can further help disentangle various models.
Some NP models predict deviations in dijet mass spectrum at high mass. Example: some extra-dimension models. See A. Cooper-Sarkar, SF-2

Due to pdf uncertainties, sensitivity to compactification scales reduced from 6 TeV to 2 TeV in this example.
Conclusions

For "new physics" phenomena "coupling" directly electrons and quarks (e.g. leptoquarks, eeqq contact interactions) : LHeC has a sensitivity similar to that of LHC.

The further study, in ep, of such phenomena would bring important insights : leptoquark quantum numbers, structure of the "eeqq" new interaction. These studies may be difficult, if possible at all, in pp.

LHC sensitivity to new (directly produced) particles not much limited by our pdf knowledge. "Contact-interactions" deviations may be more demanding (both on theo. and on exp. side).

However, the interpretation of discoveries at LHC may require a better knowledge of the high x pdfs : e.g. determination of the couplings of a W' or Z' if "at the edge".