1995-96 HERA WORKSHOP
BEYOND THE STANDARD MODEL GROUP
SUMMARY

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Abstract: We summarize the work done in the “Beyond the Standard Model” group of the 1995-96 HERA Workshop. Of the various proposed HERA upgrades, the luminosity improvement is the most important for this physics. With an integrated luminosity of 1 fb\(^{-1}\), collected by 2005, HERA will remain a competitive and potentially fruitful facility for new physics searches.

1 Summary Statement

The goal of the 1995-96 HERA Workshop was to work out the implications for physics with the proposed upgrades to HERA. Since, by construction, the Beyond the Standard Model group must study highly speculative topics (most, if not all, known extensions to the Standard Model are certainly wrong), we studied whether potentially interesting physics could be made more accessible by the upgrades.

Of the proposed upgrades, the luminosity enhancement is \textit{a priori} the most important for this physics. Without substantially enlarging the data set in relatively short periods of time, exotic physics searches stall. In addition, the competition from other facilities, in particular LEP and the Tevatron, is stiff. The results of our studies indicate that a luminosity upgrade is essential if the HERA program is to remain interesting and competitive in this area.

Since we are going beyond the Standard Model, the topics we studied may be organized by how far beyond the Standard Model they lie, as follows. The individual contributions can be found in full at: [http://ucosun.desy.de/~heraws96/proceedings/beyondSM/](http://ucosun.desy.de/~heraws96/proceedings/beyondSM/)

1.1 Higgses

We start by revisiting searches for Higgs bosons. Standard Model Higgs physics has been deemed hopeless at HERA, mainly due to the small production cross-section\[1\]. (With an integrated luminosity of 1 fb\(^{-1}\), HERA might actually produce a few Standard Model Higgs
bosons in currently allowed mass ranges, but isolating these few events from the background still looks hopeless.) Plausible non-standard Higgs sectors offer more possibilities. Many models, including the minimal SUSY extension to the Standard Model, include two Higgs doublets, generating five physical particle degrees of freedom: two neutral scalars ($H^0$ and $h^0$), a neutral pseudoscalar ($A$), and two charged scalars ($H^\pm$); and introducing two parameters that modify the couplings: a mixing angle for the neutral scalars ($\alpha$) and the ratio of the vacuum expectation values for the two doublets ($\tan \beta$). In Minimal SUSY these parameters are constrained to regions that keep these light Higgses out of HERA’s reach, when taking the LEP bounds into account. However, there is good reason to look anyway. The LEP program is steadily eating away the remaining allowed regions and, SUSY aside, non-minimal Higgs sectors have been proposed as mechanisms for a wide variety of phenomena, e.g., electroweak CP violation, the suppression of strong CP violation, and neutrino mass generation. Such a search is well-motivated.

Maria Krawczyk has studied the phenomenology of a general two-doublet model. She found that there are regions of ($\alpha, \beta$) that are not ruled out by LEP, even for very light Higgs massless of a few GeV. Such Higgses can be produced at HERA via photoproduction. The resolved process, $gg \rightarrow h$, results in a $b\bar{b}$ final state (or a $\tau^+\tau^-$ final state for very light $h$), while the direct process $\gamma g \rightarrow b\bar{b}h$ results in an enticing four-$b$ final state (or a $b\bar{b}\tau^+\tau^-$ final state for very light $h$). The success of these searches will depend on how well the signals can be isolated from the backgrounds. Krawczyk and Ritz are producing 1 generators to study these processes. There may, after all, be a Higgs for HERA, in photoproduction.

1.2 Contact Interactions and Compositeness

Moving somewhat further beyond the Standard Model, the study of contact interactions provides a model-independent way to parametrize the sensitivity to new physics. Jason Gilmore has studied the sensitivity to $eeqq$ contact interactions, as well as to finite quark radii. He concludes that integrated luminosities of order 200-500 $pb^{-1}$ in both $e^-p$ and $e^+p$ are necessary to probe distances shorter than $10^{-16} cm$ and contact interaction scales comparable to those accessible at the Tevatron.

1.3 Lepton Flavor Violation

With the relatively clean HERA environment, lepton flavor violating process can be probed in a straightforward and general manner: a high $Q^2$ DIS-like final state is sought with a $\mu$ or $\tau$ replacing the scattered lepton beam particle. There are already results from ZEUS[2] and H1[3]. Frank Sciulli and Songhoon Yang have extended their original analysis of leptoquarks with 2nd and 3rd generation couplings to the 1 $fb^{-1}$ case, and show that HERA will have the world’s best sensitivity to many types of these particles.

1.4 Heavy Neutral Leptons

Frank Sciulli and Larry Wai have studied an interesting case for HERA: a neutral right handed lepton with moderate mass may have escaped detection if it is more massive than the associated

\footnote{Consult the web page for details.}
right-handed $W_R$ boson. In that case, the $W_R$ will decay only to a pair of jets with no missing momentum, and the existing experimental limits are not valid for $W_R$ masses below 100 GeV. Again, high luminosities allow a significant discovery potential.

1.5 Supersymmetry

Supersymmetry is the most widely studied extension of the Standard Model. Members of our group have focused on three distinct models of supersymmetry: (a) the minimal supersymmetric standard model (MSSM) with conserved R-parity and a gluino mass above the Tevatron bound of 140 GeV; (b) R-parity violation through the $LQ\bar{D}$ operator, and (c) the light gluino scenario where $M_{\text{gluino}} \lesssim 1\text{GeV}$.

1.5.1 $R_p$ Conserving

In the MSSM we considered the two processes

\begin{align*}
e^− + q & \rightarrow \bar{e}^- + \bar{q} \quad (1) \\
e^− + q & \rightarrow \bar{e}^- + \chi^0_1 + q \quad (2)
\end{align*}

where $\chi^0_1$ is the lightest neutralino.

For the first process, studied by Peter Schleper, the present bound from LEP1.3 are comparable to those from HERA. The overall sensitivity with 500 pb$^{-1}$ is comparable to LEP2. Therefore the sooner we obtain the upgrade the more likely HERA can remain in competition. Optimistically, if LEP2 discovers this process then HERA can also access this physics. Pessimistically, if one applies the model-dependent scalar quark bounds from the Tevatron then HERA is not competitive. The second process was investigated by Massimo Corradi. Unfortunately, LEP1.3 has already excluded the region of parameter space to which HERA can ever be sensitive in this particular model.

1.5.2 $R_p$ Violating

R-parity violation has several Yukawa couplings beyond those of the MSSM which violate either lepton number or baryon number. HERA is particularly sensitive to a subset of the lepton number-violating couplings, denoted $LQ\bar{D}$ since they lead to resonant scalar quark production:

\begin{equation}
e^− + q \rightarrow \bar{q} \rightarrow q' + \tilde{\chi} \quad (3)
\end{equation}

where $\tilde{\chi}$ represents a general gaugino (neutralino or chargino). This has been studied in much greater detail by Dreiner, Perez, and Sirois, extending the scalar squark decays to the entire supersymmetric spectrum. HERA remains the best machine for this process.

Previously, Dreiner and Morawitz studied the process

\begin{equation}
e^− + q \rightarrow \bar{e}^- + \bar{q}, \quad (\bar{q}, \bar{e}) \rightarrow (q, e) + \chi^0_1. \quad (4)
\end{equation}

HERA is sensitive to the case when the $\chi^0_1$ decays via lepton number-violating operators $L_3Q\bar{D}$ or $L_3Q\bar{E}$. These lead to tau-lepton final states. HERA is the best machine to test these operators.
1.5.3 Light Gluino

The exclusion of a light gluino with mass below 5-10 GeV is debated within the supersymmetry community. If a light gluino exists it should be copiously produced in photoproduction at HERA [8], and will likely hadronize as a long-lived, electrically neutral particle [9]. Marc David has studied the possibilities of detecting such processes using topologies of energy deposits in the H1 calorimeter.

For multi-jet processes in DIS involving a light gluino, Graudenz et al. confirm that extracting a signal from the very large QCD background would require more clever analyses than jet-angle variables alone.

It is worth noting that a recent reanalysis [10] of OPAL data may have closed the light gluino window definitively.

1.6 Other New Particles

With general scaling rules, Uli Martyn has extended previous workshop results and existing HERA results to the $1 \text{ fb}^{-1}$ domain. Topics include exotic leptons, excited leptons, excited quarks, leptoquarks, leptoglueons, new vector bosons, compositeness, and quark form factors. With an integrated luminosity of 1 $\text{ fb}^{-1}$, HERA will remain an excellent facility to search for most of these extensions to the Standard Model.

We also have a contribution from Blümlein et al. explicitly considering scalar and vector leptoquark pair production. The advantage here is that leptoquark couplings to gauge particles are determined, in contrast to the more familiar single leptoquark production case where the Yukawa coupling is a free parameter. In this mode, HERA is likely to be most competitive, if at all, in searches for leptoquark pairs that decay to 3rd generation states ($b, \tau$).

2 Conclusions

With a substantial luminosity upgrade HERA will continue to have good discovery potential for most of the topics we have studied. In addition to the amount of integrated luminosity, when that luminosity is delivered also matters. Table [I] shows luminosity profiles in different scenarios. The numbers represent only our best guesses, but they illustrate a point: as the annual integrated luminosity asymptotes, the time required to acquire substantially increased statistics grows. One figure of merit is the time to double the existing data sample. If HERA asymptotes to 35 $\text{ pb}^{-1}/y$, it will be difficult to wait to accumulate even 250 $\text{ pb}^{-1}$. By contrast, if the asymptotic value is 170-200 $\text{ pb}^{-1}/y$, integrated delivered luminosities in the neighborhood of 1 $\text{ fb}^{-1}$ can be accumulated in a timely manner, with substantial new data sets each year to maintain an exciting program. Finally, since plans for the Tevatron indicate an integrated luminosity of 33 $\text{ fb}^{-1}$ by that same time, HERA must certainly upgrade to be of interest for physics beyond the Standard Model.
| Year | Annual-35 | Int | 2yr ratio | Annual-170 | Int | 2yr ratio |
|------|-----------|-----|-----------|------------|-----|-----------|
| 1993 | 1         | 1   | 1         | 1          | 1   | 1         |
| 1994 | 6         | 7   | 1         | 6          | 7   | 1         |
| 1995 | 12        | 19  | 19        | 12         | 19  | 19        |
| 1996 | 15        | 34  | 4.9       | 15         | 34  | 4.9       |
| 1997 | 30        | 64  | 3.4       | 30         | 64  | 3.4       |
| 1998 | 35        | 99  | 2.9       | 50         | 114 | 3.4       |
| 1999 | 35        | 134 | 2.1       | 100        | 214 | 3.3       |
| 2000 | 35        | 169 | 1.7       | 125        | 339 | 3.0       |
| 2001 | 35        | 204 | 1.5       | 150        | 489 | 2.3       |
| 2002 | 35        | 239 | 1.4       | 170        | 659 | 1.9       |
| 2003 | 35        | 274 | 1.3       | 170        | 829 | 1.7       |
| 2004 | 35        | 309 | 1.3       | 170        | 999 | 1.5       |
| 2005 | 35        | 344 | 1.3       | 170        | 1169| 1.4       |

Table 1: Two versions of the future. Luminosity profiles for a machine that asymptotes to $35 \text{ pb}^{-1}/y$ (first set of columns) and $170 \text{ pb}^{-1}/y$ (second set of columns). In each group of columns, the first gives the delivered luminosity that year, the second gives the running total collected since turn-on, and the third gives the ratio of the running total of that year to that amount two years earlier. When this ratio falls below 2, we have failed to double our statistics within two years (see text). The running total at that point is given by the bold numbers for the two scenarios.

References

[1] Proc. ‘Physics at HERA’, Eds. W. Buchmüller, G. Ingelman, DESY Hamburg 1992

[2] ZEUS Collaboration, DESY96-161, submitted to Z.Phys.C.

[3] H1 Collaboration, Phys.Lett. B369 (1996)173.

[4] J. Butterworth and H. Dreiner, Nucl. Phys. B397 (1993)3.

[5] H. Dreiner and P. Morawitz, Nucl. Phys. B428(1994)31.

[6] H1 Collaboration, Phys.Lett.B380(1996)461.

[7] P. Maettig, Plenary talk, 28th ICHEP, Warsaw, Poland, July, 1996; Aleph Coll., CERN-PPE/96-083, Delphi Coll., CERN-PPE/96-110, L3 Coll., CERN-PPE/96-29, and Opal Coll., Phys Lett B 377 (1996) 181.

[8] S. Mrenna, http://sgi2.hep.anl.gov:8001/index.htm, and links therein.

[9] Glennys R. Farrar, Phys.Rev.Lett.76(1996)4111, and references therein.

[10] Andre de Gouvea and Hitoshi Murayama, LBL-39030, Jun 1996, e-Print Archive: hep-ph/9606449.