Tr. J. of Physics
22 (1998) , 607 – 610.

International Workshop on Linac-Ring
Type ep and γp Colliders

Physics at future ep, γp (linac–ring) and μp colliders

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Abstract

The physical problems for the enumerated colliders are discussed. It is taken into account that all these machines can work only after corresponding parental colliders.

1. Basic points

In our discussion we should take into account the fact that all discussed colliders will work (if will?) only AFTER basic e^+e^- / γe / $\gamma\gamma$ and pp or $\mu\mu$ colliders. Therefore, the question under discussion is:

what news can be obtained here AFTER studies at basic colliders.

Let us consider from beginning the main features of discussed machines.

Linac–Ring colliders

The proposed luminosities $\mathcal{L}$ are low for discussed generation of colliders, $\mathcal{L} \lesssim \mathcal{L}_{HERA}$ [1]. The sources of real news in comparison with HERA and "parental" colliders are

1. Higher energy.
2. Longitudinal polarization of e^- or γ.
3. New type of collisions — γp.

The additional physical potential is not too high here.

μp collider

It was noted recently that in the frame on the $\mu^+\mu^-$ project one can develop with relatively small additional efforts μp collider with $\sqrt{s} = 4$ TeV and[2] $calL \approx 3 \cdot 10^{35}$ cm^{-2}s^{-1}. It will be really new machine with high potential supplemented strongly to that of other colliders of next generation.

2. Linac—Ring colliders

Hadron physics and QCD

Modern studies continuation.

The studies at HERA can be continued here with going to higher $\hat{s}$ and smaller x (*structure functions, etc.* – cf. [3]).

The study of *hard diffractive processes* provides opportunity to test pQCD and to investigate perturbative Pomeron and Odderon in reactions

$$\gamma p \to \rho^0 + ..., \;\; \gamma p \to (q\bar{q}) + ..., \;\; \gamma p \to \gamma + ..., \gamma p \to \pi^0 + ... \textit{with rapidity gap.} \quad (1)$$

The growth of structure functions at small x can give opportunity to test pQCD validity at large enough $p_\perp$ and with the better *signal/background* ratio (see e.g. [4]).

Real news.

⊙ Using higher energy than in HERA and longitudinal polarization of electrons, one will study in detail **axial (Z) current interaction with hadron**. Until now we have only the calculations in the parton model here.

To this goal we consider standard DIS experiment with polarized electrons. Let σ^L and σ^R are the cross sections for light–hand polarized and right–hand polarized electron. Taking into account only the diagrams with photon and Z boson exchanges (other diagrams contribute negligibely) one can connect these cross sections with contributions of vector current M_V and axial current M_A. The last obliged by interaction with photon (J^γ) and Z (J^Z):

$$M_V = \frac{1}{Q^2} J^\gamma + \frac{1/4 - \sin^2\Theta_W}{Q^2 + M_Z^2} J_V^Z; \quad M_A + \frac{1}{Q^2 + M_Z^2} J_A^Z. \quad (2)$$

(We see that in the good approximation $M_V \propto J^\gamma$.)

With these notations

$$\sigma_{L,R} \propto |M_V \pm M_A|^2;$$
$$\sigma^L - \sigma^R \propto Re(M_V^* M_A), \quad \sigma^L + \sigma^R \propto |M_V|^2 + |M_A|^2. \quad (3)$$

The difference $\sigma^L - \sigma^R$ should be not small in comparison with separate cross sections σ^L and σ^R at $Q^2/M_Z^2 \gg 0$, for example at $Q^2 > (1 \div 3) \cdot 1000$ GeV^2. Therefore, the reliable accuracy in the extraction of axial contribution is possible here.

⊙⊙ In the γp mode one can study **the charged current interaction with hadrons**. Until now we have here only calculations in the parton model with very rough testing.

To this goal we should consider inclusive process $\gamma p \to W + ...$ with recording of W. The main contribution here is determined by the W exchange diagram. The necessary basic calculations are in progress.

⊙ ⊙ ⊙ One can study the polarized gluon density in the $\gamma_\uparrow p_\uparrow \to c\bar{c} + ...$ (cf. [5]). In the case when $c\bar{c}$ system energy is close to that of initial electron, the cross section of this process is dominated by diagram with gluon exchange. The cross section of

$g\gamma \to c\bar{c}$ subprocess depends strong on the product of photon and gluon helicities (circular polarizations) and of mass of pair. So, with variation of sign of photon helicity we cam measure polarized gluon density in proton.

One should note the relatively low range of validity of such approach, obliged by large radiative corrections. For example the events with rapidity gap between $c\bar{c}$ system and other hadrons should be described with two–gluon (Pomeron) exchange with the other polarization dependence.

New particles, etc.

If modern results of HERA will be confirmed as discovery of leptoquark, new directions in new field of energies should be reconsidered strong for all colliders. We consider below more conservative point that receive some traditional explanation of above results will be found.

For me, the discovery of leptoquark in the discussed experiments is very difficult task inn the main of models. Indeed, the *"natural"* estimate for the coupling of leptoquark with the known matter is

$$g_{\ell q}^2 \sim \left(\frac{m_\ell + m_q}{v}\right)^2 |S_{\ell q}|^2 \text{ with } v = 1\sqrt{/}G_F\sqrt{2} \approx 250 \text{ GeV}. \tag{4}$$

It seems to be natural that the mixing between generations is small, and the masses of electron and u or d quarks are summed here. Therefore, the expected rate of "electro-quarks" is very low, and the discovery of such leptoquark seems to be hardly probable.

Certainly, the less natural models with not too small $g^{\ell q}$ can not be excluded and the search of leptoquark should be continued here.

3. μp colliders

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The program of this collider will be substantial supplement to those of LHC and linear colliders due to

- other set of constituents produces good other set of new particles;
- the energy of constituents here is close (roughly) to that for LHC.

This collider will have **no new potential in gauge boson/ Higgs physics**, BUT

1. It will be useful to study new particles (SUSY, etc.). The simple example provide us the reaction

$$\gamma g \to \tilde{\gamma}\tilde{g} \tag{5}$$

with very high potential for the gluino discovery.

The corresponding list is large enough.

2. Leptoquark $((\ell q) \equiv (\mu s),\ (\mu c), ...)$ production is expected here to be much more probable than in *ep* collisions since the *natural* estimate gives here much more coupling constant (see (4)).

3. This colliders provides new fields for testing of QCD:
   (a) The region of covered parameters in the standard studies become much more wide.
   (b) One can study in detail Z^*p scattering via reactions with polarized μ, as it was written above. One can study in detail Wp scattering via reaction $\mu p \to \mu W + ...$ similar to that discussed for γp collider above.
   (c) One can study the breaking of factorization in the production of high $p_\perp$ events at LHC via much more precise measurements of structure functions at μp collider.
   (d) One can test good pQCD in studies of processes (1) related to perturbative Pomeron and Odderon.

4. Conclusions

1. To consider potential of linac—ring machines in more detail their luminosity should be high enough:

   For γp machine one should have luminosity $\mathcal{L} > 10^{30}$ cm$^{-2}s^{-1}$.

   For *ep* machine one should have luminosity $\mathcal{L} > 10^{31}$ cm$^{-2}s^{-1}$.

   If (ℓq) discovery will be confirmed, the *ep* machines should be built even with low luminosity.

2. The μp machine has high physics potential. It should be considered in more detail in nearest future.

This work is supported by grants INTAS – 93–1180 ext and RFBR – 96–02–19114.

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