ON INCREASING THE HERA COLLIDER E-P INTERACTION REGION LUMINOSITY

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Abstract

Since September 1995 a working group has been considering ways to significantly increase the specific luminosity at the HERA e-p interaction points within the context of "Future Physics at HERA." Means have been found to increase luminosity a factor of 3.5 beyond the current design limit without exceeding standard tune-shift and chromaticity limits. Experimental and machine upgrade options and constraints are discussed.

1 INTRODUCTION

High luminosity is particularly important to study electroweak effects and to search for new phenomena. A meaningful physics goal is an integrated luminosity of $\approx$ 1 fb^{-1}. It is found that for the detector the following goals and associated compromises are appropriate:

- Provide capability for polarized e^+ and e^- beams.
- Minimize shadowing below 100 mrad for good acceptance at high $Q^2 > 50{,}000$ GeV^2 for the electrons.
- Rebuild most of the detector parts near beampipe.
- Design new synchrotron radiation masks.
- Expect about 10$\times$ more synchrotron radiation reaching central trackers and chambers.
- Expect blurring of machine-detector interface (with machine elements inside detector).
- Expect loss of some forward/backward physics at very low Q^2 due to machine elements (but anticipate that this physics is completed before luminosity upgrade).
- Expect luminosity measurement to be more difficult; however high luminosity opens up other ways (i.e. Compton scattering) to measure luminosity in central detector.

Also it is understood that while providing polarized protons may be important for some physics goals, there are largely unknown machine implications (which are however being studied by another working group).

For evaluating machine performance the reference point for the luminosity upgrade study is the present HERA lattice (see Fig. 1) at design intensity with parameters as shown on Table 1. The luminosity limitations for HERA become evident when one examines the luminosity formula written as

$$L = \frac{I_e^{\rm Total} \cdot N_p \;\; \gamma_p}{4\pi e \;\; \epsilon_{p\rm N} \cdot \sqrt{\beta_x^p \beta_y^p}\sqrt{\epsilon_{yp}/\epsilon_{xp}}}$$

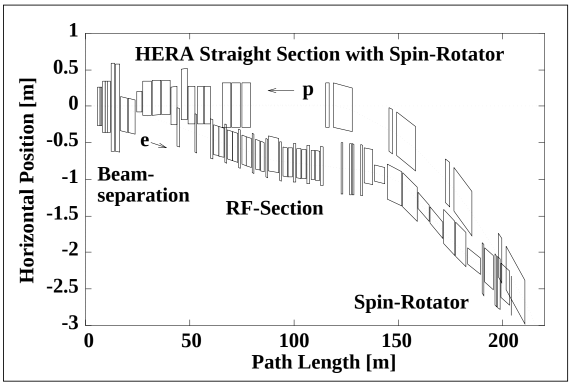

Figure 1: Present HERA e-p IR design layout (plan view) with spin-rotator.

Reference point for luminosity study is the present HERA lattice at design intensity with 174 colliding bunches	
E_p = 820 GeV $N_p = 10^{11}$ β_{xp} = 7 m β_{yp} = 0.7 m	E_e = 30 GeV I_e = 58 mA β_{xe} = 1 m β_{ye} = 1 m
$\hat{L}_{\rm Max} = 2 \times 10^{31} {\rm cm}^{-2}{\rm s}^{-1}$	

Table 1: HERA Reference Design Parameters.

where

- $I_e^{\rm Total}$ is limited by rf-power
- $N_p/\epsilon_{p\rm N}$ is limited in injector chain
- $\epsilon^*_{p\rm N}$ is limited by beam-beam interaction parameterized via horizontal and vertical tune shifts as

$$\Delta\nu_{px} = \frac{r_p}{2\pi}\,\frac{N_e}{\epsilon_{p\rm N}}$$
$$\Delta\nu_{py} = \frac{r_p}{2\pi}\,\frac{N_e}{\sigma_x \gamma_p}\sqrt{\frac{\beta_y^p}{\epsilon_{p\rm N}}}$$

- β_{xp}, β_{yp} are limited by interaction region aperture.

The degrees of freedom we are then left with are to:

- Change the injector chain to reduce proton vertical emittance
- Change the IR Lattice to get a smaller β_p at the IP

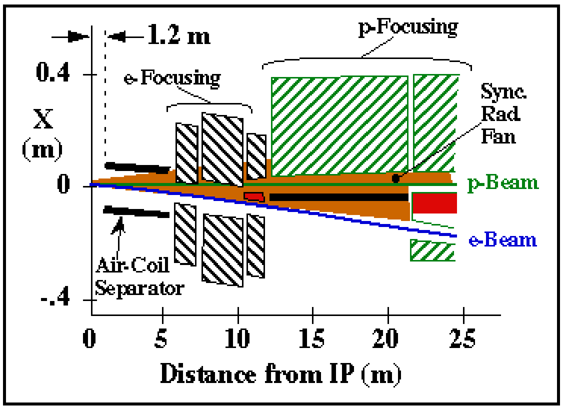

Figure 2: Example of early separation via weak air-coil dipole integrated inside detector. Separate p-focusing starts at 12.5 m using special quadrupoles.

2 EMITTANCE IMPROVEMENTS

A separate group has investigated increasing the proton beam density and they started from the assumption that the present limitation comes about via space charge effects in DESY III. To this end there was work to:

- Make new measurements of emittance-blowup in DESY III.
- Study feasibility of upgrading LINAC III to inject into DESY III with higher energy (conceptual design study done by INR, Moscow [1]).
- Start feasibility study for adding prebooster between LINAC III and DESY III (in collaboration with IHEP, Protvino).

While raising the injection energy into DESY III above its present 50 MeV level would seem an admirable goal, at present the cost-benefit tradeoff is unclear.

3 REDUCING THE IR β^*

The current HERA IR layout is shown in Fig. 1. The detector free of accelerator magnets is $\pm$5.8 m. Electrons are focused via a triplet quadrupole configuration. The first proton focusing elements (protons little affected by e-focusing elements due to 30:1 rigidity ratio) start at 27 m with strings of resistive quadrupoles arranged in a doublet configuration.

Paths to an improved IR layout for smaller β_p^* and large luminosity include:

- Use stronger separation fields.
- Use earlier separation fields, i.e. inside the detector.
- Achieve more effective focusing via dedicated quadrupole design.
- Develop special new quadrupole septum magnets.

By using a combination of the above we find that the luminosity can be increased by a factor of 3.5. An example of one such configuration is shown in Fig. 2. Here we use:

- An early separation field given by a weak air-coil dipole (see Fig. 3), integrated in the detector, with bending radius ρ=550 m (as compared to the present separation value of ρ = 1360 m).
- A new septum quadrupole composed of a half quadrupole with a specially cut mirror plate (see Fig. 4).
- A special quadrupole with a septum coil very much like PEP-II design[2] (see Fig. 5).

A less aggressive approach which does not put an accelerator magnet in the experiment is also possible, but such an approach only achieves an approximate $\times 2$ increase.

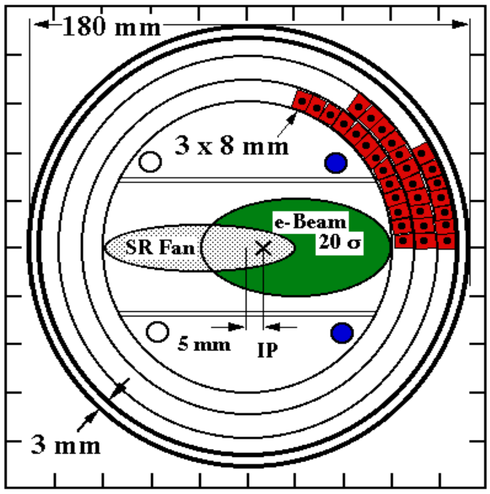

Figure 3: Air-coil separator magnet with B = 0.187 T (E_{crit} = 109. keV).

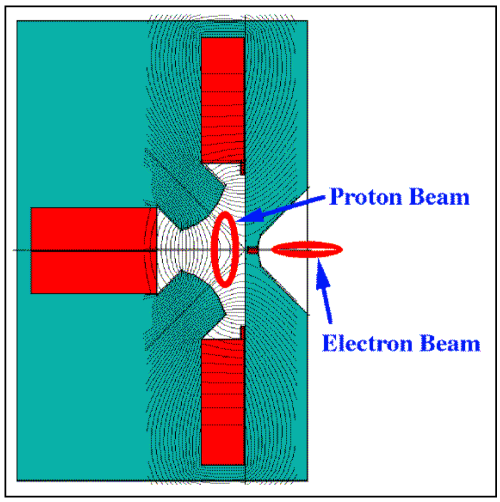

Figure 4: Beam separation schematic at magnetic septum quadrupole with R_{pole} = 40 mm and 20 T/m gradient.

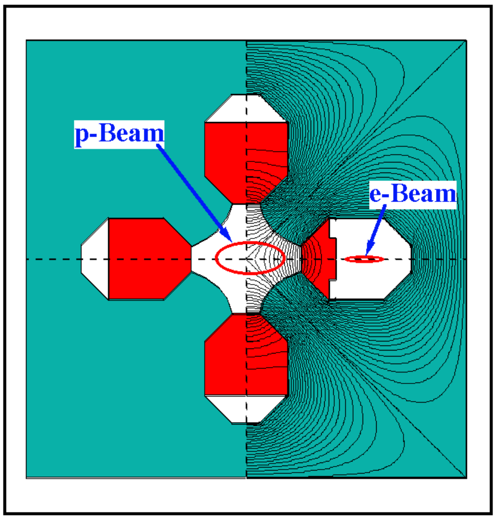

Figure 5: Beam separation schematic at current septum quadrupole.

4 SYNCHROTRON RADIATION SHIELDING ISSUES

A critical issue for the performance of the detector is to ensure that only a tolerably low level of synchrotron radiation reaches elements of the central detector. For scenarios like that shown in Fig. 6, where the separation elements start inside the detector, sufficient aperture must be maintained to pass all synchrotron radiation completely through the IR, and the major part travels at least 15 m before being intercepted on tungsten absorbers with multiple coating layers. The multiple coatings are important because with total primary fluxes reaching $\approx 3\times 10^{18}$ photons/s the backscattered radiation (with $E_\gamma > 10$ keV) is still significant (so getting every additional reduction factor possible is important). For instance we see in Fig. 7 that a tungsten absorber with thin copper and silver coating sends back $\frac{1}{5}$ as much radiation as an uncoated absorber. This is especially important for the absorber that is needed in front of the first quadrupole septum at 12.5 m.

In Fig. 6 we see that along with an absorber for the septum there are also extra backscatter collimators to provide additional backscatter suppression. With a properly optimized system it seems possible to limit the flux to less than 20 gammas per bunch crossing with energies $\approx$109 keV on the central beam pipe; however, this is still an order of magnitude greater than that experienced so far (i.e. during 1995 running).

Another challenge concerns luminosity measurement. With reduced βs at the IP, the divergence of the photons coming from the IP is greater, and the present luminosity counter $\approx$100 m from the IP would see a smaller fraction of the total flux. Also the planned stronger bends nearer to the IP send a harder spectrum of synchrotron radiation into the luminosity counter. Some remedies are:

- Add a soft bend in front of the separator dipole (but separator field then has to increase).
- Provide additional absorber material upstream of the luminosity counter (degrading its resolution).

5 CONCLUSIONS

We see that while a factor 3.5$\times$ increase in peak luminosity beyond the current HERA design limit is possible, it will not be easy. There will be plenty of pain to share between the experiments and the machine. Also one should keep in mind that HERA is still in a consolidation phase towards reaching the original design goal. Nevertheless a significant upgrade, in support of new physics goals, should be possible.

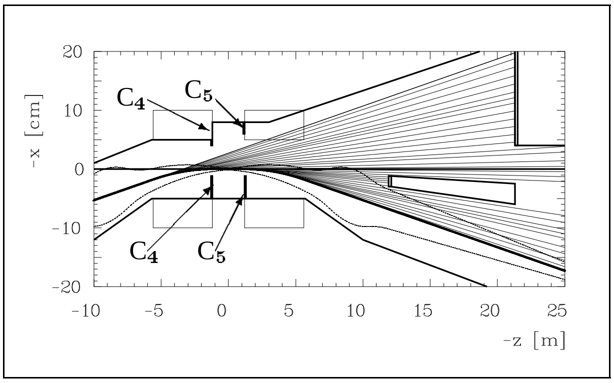

Figure 6: Synchrotron radiation fan from air-coil separator. γ-flux actually striking absorber protecting the septum is 2×10^{17}/s. Collimators C_4, C_5 are placed inside detector to catch backscatter.

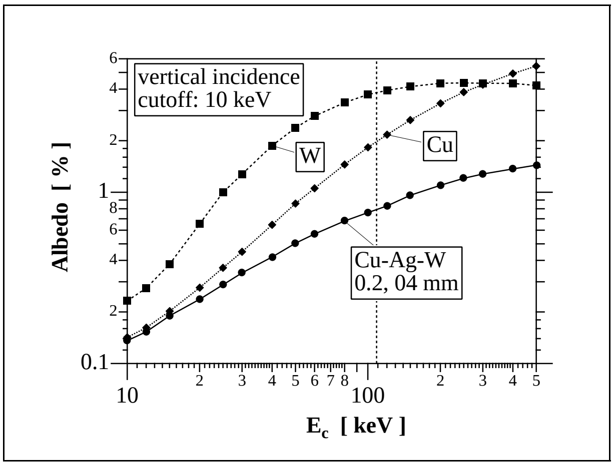

Figure 7: Comparison of backscattered synchrotron radiation albedo for coated and uncoated tungsten absorber.

6 REFERENCES

[1] "DESY III Linac III Upgrade: Conceptual Design," to be published.

[2] "PEP-II Conceptual Design Report," Chapter 5, Lawrence Berkeley Lab. PUB-5379, 1993.