4 ELFE: The Electron Laboratory For Europe

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Contents

4.1 ELFE

ELFE –the acronym stands for Electron Laboratory For Europe– is planned to be a European center for fundamental research on the quark structure of matter. It is the European machine initiative proposed as the optimum experimental tool to probe the structure of the nucleons and nuclei by exclusive and semi-exclusive electron scattering. It will deliver an electron beam with: *i)* an energy in the 20–30 GeV range; *ii)* a large duty cycle; *iii)* a high intensity, guaranteeing a luminosity $\geq 10^{35}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$; *iv)* a good energy resolution, of the order of 10^{-3}; *v)* a large longitudinal beam polarization, well above 60 %. The beam energy allows a virtuality Q^2 up to 20 GeV^2, or a momentum transfer t up to 20 GeV^2, to be reached at a reasonable scattering angle of the electron. The high luminosity and duty factor are needed to face the low probability of exclusive processes and to avoid a prohibitively large number of accidental events. The good energy resolution is mandatory to clearly identify exclusive channels. A highly longitudinally polarized beam allows the spin structure of the various amplitudes to be accessed. No other facilities, either planned or existing, provide such beam characteristics. In this energy range, their beam is either pulsed or the intensity is too low by more than two orders of magnitudes.

ELFE would not only make a new class of exclusive processes dubbed *Deeply Virtual Exclusive Scattering* (DVES) processes accessible, but would also allow one to pursue a rich program for inclusive and semi-inclusive experiments on nucleons and nuclei under ideal conditions. In particular high statistics experiments would allow a detailed decomposition of the (*transverse*) spin-flavour structure of parton distributions and fragmentation functions by utilizing the azimuthal dependencies of the cross sections of polarized semi-inclusive experiments.

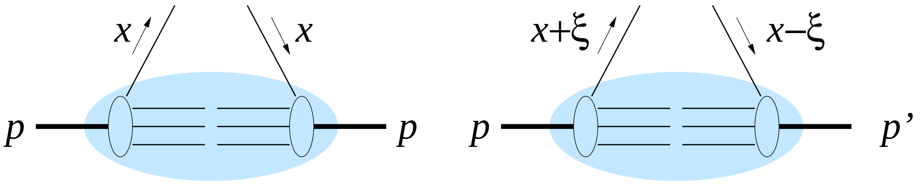
Such a new experimental facility would attract a large fraction of the broad community of nuclear and particle physicists who are now investigating the structure of hadrons at high energy laboratories, like CERN, DESY and FNAL or lower energy facilities, like MAMI, GRAAL, ELSA and TJNAF. The consensus is that ELFE is the natural and necessary facility for the long term future of hadronic physics in Europe and that it will allow to understand the interplay between particle and nuclear physics. ELFE would be a large scale international facility, in the tradition of HERA, CERN and TJNAF.

This note is a short summary of comprehensive studies on the Physics Case and Detectors [1], as well as Machine Designs [2, 3, 4] which have been done over the past few years and completed during the last year of the XX^{th} century. We refer the reader to these reports for a more detailed account.

4.2 The Physics Programme

The boundary between particle and nuclear physics remains a challenging scientific field representing one of the frontiers in contemporary nuclear physics. Quantum Chromodynamics has to come up with an explanation of e.g. confinement, the basic simplicity of the constituent quark model and the pattern of chiral symmetry breaking including the role of the vacuum and its fluctuations. While certain input is expected to come from lattice calculations, experiment will remain the main guiding line for the development of a predictive theory.

The electromagnetic interaction provides one with a unique tool to address these issues. It is a well understood probe and it provides one with a formidable microscope, with a resolution that can be varied from the size of the largest nuclei down to distances much smaller than the size of a single proton.



forward scattering

usual parton distributions

off forward scattering

skewed parton distributions

Figure 4.2.1: *The relation between SPDs and usual distribution functions*

The detailed investigation of exclusive processes induced by energetic electrons on hadrons, which is the main mission of ELFE, will allow us to measure properties of the hadronic wave functions which were hitherto unaccessible. The orbital angular momentum of quarks in a hadron or the spin structure of unstable particles are examples for the potential of this approach. A recent theoretical breakthrough, namely the description of DVES by means of so called *skewed parton distributions* (SPDs) [5, 6, 7], makes it possible to achieve this goal in a theoretically controlled manner. SPDs are a generalization of the well-known parton distributions and interpolate between parton densities and form factors. While the usual parton distributions are related to hadronic forward matrix elements, SPDs are related to the off-forward matrix elements. As depicted in Fig. 4.2.1, a parton is emitted with a certain fraction $x+\xi$ of the momentum $(p+p')/2$ of the nucleon and reabsorbed with a different fraction $x-\xi$. Factorisation theorems have been derived that put the description of DVES on a firm theoretical ground [8]. Radiative corrections were calculated up to next-to-leading order [9], twist-3 corrections were studied in detail [10], and the relationship to hadronic wave functions was exploited [11]. In sum, the theoretical level of understanding of SPDs approaches that of the usual distribution functions. This will allow one to study new universal hadron properties with *controllable accuracy*.

As illustrated in Fig. 4.2.2, SPDs describe a variety of different reactions. In the forward limit, i.e. when the proton momenta p and p' become equal, one recovers the usual parton distributions, which thus provide boundary conditions for the SPDs. Via sum rules, i.e. equations fulfilled by integrals over the momentum fraction x, they are also connected to elastic nucleon form factors like F_1 and F_2 (Pauli and Dirac form

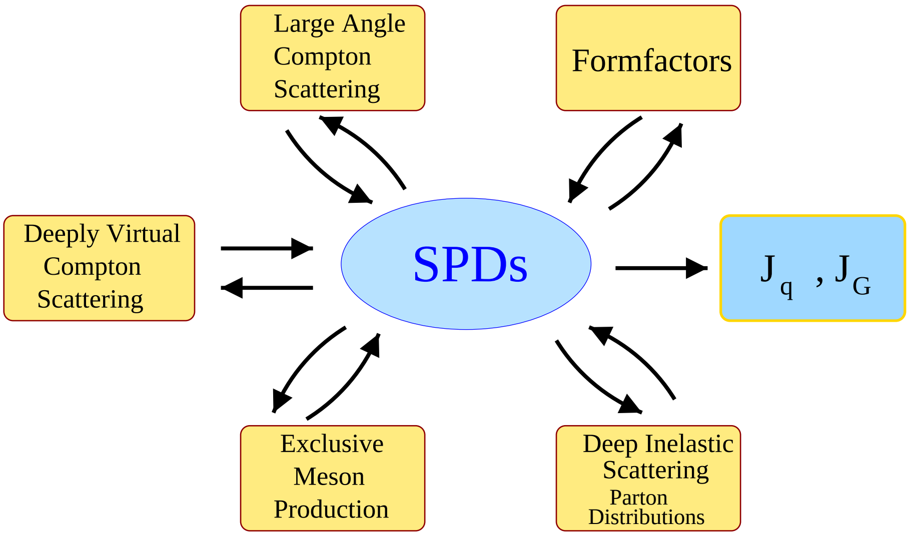


Figure 4.2.2: *Skewed Parton Distributions provide one with a unifying description of many reaction channels, which may lead to the determination of the total angular momentum of quarks,* J_q*, and gluons,* J_G*.*

factors). Thus they relate the two types of quantities which so far have been the prime sources of our knowledge of hadron structure: parton distributions, which tell us about the longitudinal momentum structure of a fast-moving nucleon, and form factors, which contain information on its transverse structure, such as its charge radius.

In inclusive reactions, when only the scattered electron is detected and the hadronic final state remains unobserved, the interaction of the hit parton with the hadronic remnants can effectively be neglected. The theoretical description can therefore avoid the complicated question of the final state interaction and reduces the information to one-parton densities.

In elastic scattering processes described by form factors, the struck quark must recombine with the spectators to form the original hadron. This process favours rare configurations where there are no sea quarks and gluons altogether. These special states are simpler than the hadron wave functions as a whole, and a theoretical description again becomes possible.

The physics aspects probed in the two cases are very different and the DVES processes fill the gap between these extremes. In that sense, SPDs interpolate between parton densities and form factors. They involve rich nonperturbative dynamics and give rise to a variety of novel sum rules. For example, the distribution of angular momentum among nucleon constituents can only be accessed through SPDs. Models of SPDs are available and allow one to estimate the experimental accuracy which will be obtainable by ELFE. Lattice-QCD allows one to calculate some leading moments of SPDs and will in the near future further constrain these models.

In addition to the situation shown in Fig. 4.2.1, where a parton is extracted from the nucleon with a certain momentum fraction $x+\xi$ and returned with a different one $x-\xi$, SPDs also have a region in x where a quark-antiquark or a gluon pair is emitted from the initial proton, changing its momentum from p to p', see [12, 13, 14]. This illustrates again how SPDs combine information from different processes. As in the case of form factors, SPDs can also describe the transition between different hadrons, allowing one to probe the overlap of their respective wave functions. This opens the way to study baryons not available as beam particles. Prominent examples of transition SPDs appear for the reactions $ep \to e\Delta^+\gamma$ and $ep \to en\pi^+$.

Various constraints based on fundamental symmetries give helpful guidance for the modeling of SPDs. On the other hand the dynamics they contain is extremely diverse. This diversity is reflected in the notable conceptual differences between current models, ranging from constituent quarks and the bag models to studies based on chiral solitons and the instanton vacuum of QCD [11], [15]-[19]. Experimental data on SPDs will elucidate the relationship between these models. The great advantage of SPDs is, generally speaking, that their large information content allows one to connect different observables and to determine quantities of physical interest which cannot be extracted directly from individual observables. The most prominent of these quantities is the total angular momentum of quarks, J_q and of gluons, J_G. For instance, J_q can be expressed as an integral

$$\frac{1}{2}\left[\int_{-1}^{1} dx\ x\ [H_q(x,\xi,\Delta^2) + E_q(x,\xi,\Delta^2)]\right]_{\Delta^2\to 0} = J_q$$

of the quark SPDs $H_q(x,\xi,\Delta^2)$ and $E_q(x,\xi,\Delta^2)$, defined by

$$\begin{aligned}\int \frac{d\lambda}{2\pi} e^{i\lambda x}\langle p'|\bar{\psi}(-\lambda n/2))\gamma^\mu\psi(\lambda n/2)|p\rangle &= H_q(x,\xi,\Delta^2)\bar{U}(p')\gamma^\mu U(p) \\ &+ E_q(x,\xi,\Delta^2)\bar{U}(p')\frac{i}{2M_N}\sigma^{\mu\nu}\Delta_\nu U(p)\end{aligned} \quad (4.2.1)$$

Here ψ, $\bar{\psi}$ are quark fields at the space-time points $\pm\lambda n/2$, n is a 4-vector defined such that $n\cdot(p+p')/2 = 1$ and $n^2 = 0$, and $\Delta_\nu = p'_\nu - p_\nu$ is the momentum transferred to the proton.

Up to now only the spin content of the nucleon originating from quark and gluon spins could be studied. Combining such results with the knowledge of J_q and J_G would determine also the orbital angular momentum contributions and thus provide an essential part for the complete experimental determination of the nucleon spin structure.

Detailed measurements of DVES processes represent the core of the physics programme at ELFE. The interest in DVES, underscored by the rapid theoretical development, originates from the fact that these processes bridge a gap between two different regimes in which the QCD description of hadronic reactions has been successful in the past. In both cases the electromagnetic probe transfers a large momentum via a highly virtual photon to a single parton inside a hadron. This programme includes [1] the study and determination of:

- Deeply Virtual Compton Scattering (DVCS) cross sections;

- Deeply Virtual Meson Production (DVMP) cross sections;
- Meson form factors;
- Exclusive reaction cross sections at large angles.

Current experiments like HERMES, H1 and ZEUS at DESY or planned experiments at CERN and TJNAF are exploring their capacity to address these new observables. The few pioneering results seem to confirm the expectations about their size and symmetries [20]. However, since these experiments either lack luminosity or energy resolution or they fall short in their kinematical range, a quantitative controlled analysis is not possible.

The proposed experimental facility ELFE will overcome these limitations. It has a luminosity of $10^{35} - 10^{38}$ cm^{-2}s^{-1} (depending on the detector set-up) and a beam energy of more than 25 GeV. Its energy resolution of about 0.1%, required by the smallness of the pion mass, allows one to separate individual exclusive channels including the most interesting one – deeply virtual Compton scattering. It can access the range of $x > 0.02$ and reach a "partonic" resolution of $Q^2 \approx 10$ GeV^2 at $x \approx 0.2$. A much higher energy would increase the kinematical range in the direction of smaller x at the expense of energy resolution. A lower energy would reduce the lever arm in Q^2 in the important region of x around 0.1 to 0.2 to unacceptably low values which would not allow one to verify scaling.

In addition, ELFE obviously will contribute significantly also to refine our understanding of other fields.

In the past twenty years experiments at CERN, FNAL, DESY and SLAC have tried to determine and refine parton distributions through the study of hard inclusive processes. The theoretical foundations are solid and the calculations are mostly under control. The obtained information is vital for the use of hadrons as quark-gluon beams at the high energy particle physics frontier. This program is advanced but still incomplete since it lacks detail about distributions of (transverse) spin, flavour and gluons. A new generation of semi-exclusive (where the undetected final state is partially constrained) and semi-inclusive (where the undetected final state is unknown) experiments, aiming to decipher the complete spin, flavour and transverse-momentum structure of nucleons and hadrons, will fill these gaps of our knowledge. More specifically, the physics programme at ELFE will involve [1]:

- The precise determination of inclusive parton distribution at medium to large x;
- The flavour and valence-sea decomposition of parton distributions;
- The access to the transverse (spin and momentum) degrees of freedom;
- The access to the spin properties of distribution and fragmentation functions.

Finally, the use of the nucleus as a "femto-detector" will allow one to determine the space time structure of elementary processes, providing further constraints on the interplay between hard and soft mechanisms at large momentum transfer. Examples are [1]:

- Propagation and interaction of compact rare configurations of hadrons (Colour Transparency);
- Quark propagation and hadronization;
- Rare multiquark configurations in nuclei;
- Charm production near threshold.

In summary, ELFE would indeed be a unique facility, well suited for the study of the structure of hadrons and the dynamics of confinement by means of

- the determination of new parton distributions and quark distribution amplitudes through the measurement of exclusive and semi-exclusive reactions at high momentum transfer;
- an accurate determination of hadron structure functions (parton distribution functions, quark–gluon correlations and parton fragmentation functions) especially at large and medium-large x in inclusive and semi-inclusive measurements;
- the study of hadron propagation in nuclei, which will select compact hadron configurations, and the study of hadronization, which can be tuned to take place either inside or outside a nuclear target.

4.3 Detector

The measurement of exclusive processes in deeply inelastic electron scattering puts rather high requirements on the beam and detector quality. The smallness of the exclusive cross sections demands high luminosities of more than about $L = 10^{35}$ cm^{-2} s^{-1} and a high duty factor to avoid pile up with intense backgrounds. A limit is set by the production of hadrons from the absorption of quasi-real photons by the target nucleons. The detector must be fast enough to assign an observed signal unambiguously to a single scattering event. This does not mean that all parts of the detector must have a time resolution in the 100 ps range. A coarse grained coverage with fast detectors however will be necessary to assign an event time to signals from slower detectors. The acceptance for the coincident observation of the electron and at least (n-1) final state particles from the hadronic system has to be much larger than 10% to assure efficient running. In fact a large forward dipole spectrometer, as it is used by HERMES [21] and recent muon scattering experiments, can achieve efficiencies close to 100% for some simple cases like exclusive charged meson (π, K) production. This is due to the predominance of small transverse momenta of the produced hadrons relative to the virtual photon direction. At beam energies around 30 GeV a horizontal acceptance of $\Theta \approx 3Q/E = 25°$ appears sufficient to cover the kinematical region up to momentum transfers of $Q^2 = 25$ GeV^2. Although focusing spectrometers would offer a momentum resolution of better than $\delta p/p \approx 10^{-4}$ for charged particles, their small acceptance would be adequate in a few cases only (see for instance Ref. [22]). For a large acceptance spectrometer on the other hand it is a very challenging task to obtain a momentum resolution of about $\delta p/p \approx 10^{-3}$. This resolution would be necessary to assure the exclusivity of an event by the reconstruction of missing masses. The smallness of the pion mass as compared to the beam energy sets this scale. It is very important that the energy spread of the beam does not exceed 10^{-3} since this would then degrade the missing mass resolution. The limiting accuracy of the measurement of momenta of charged particles in a forward dipole is set by the amount of multiple scattering between the particles origin and its final detection after having traversed some magnetic field. In principle the two extreme positions can be measured or experimentally defined to any accuracy. For the determination of the particle momentum at least one intermediate measurement is necessary. This unavoidably introduces multiple scattering. The combined requirement of high spatial resolution together with fast response and low mass appears presently to be met best with a scintillating fiber detector. A procedure for operating such a detector in vacuum has been worked out. Together with a 5 Tm dipole a momentum measurement with 10^{-3} resolution is achievable.

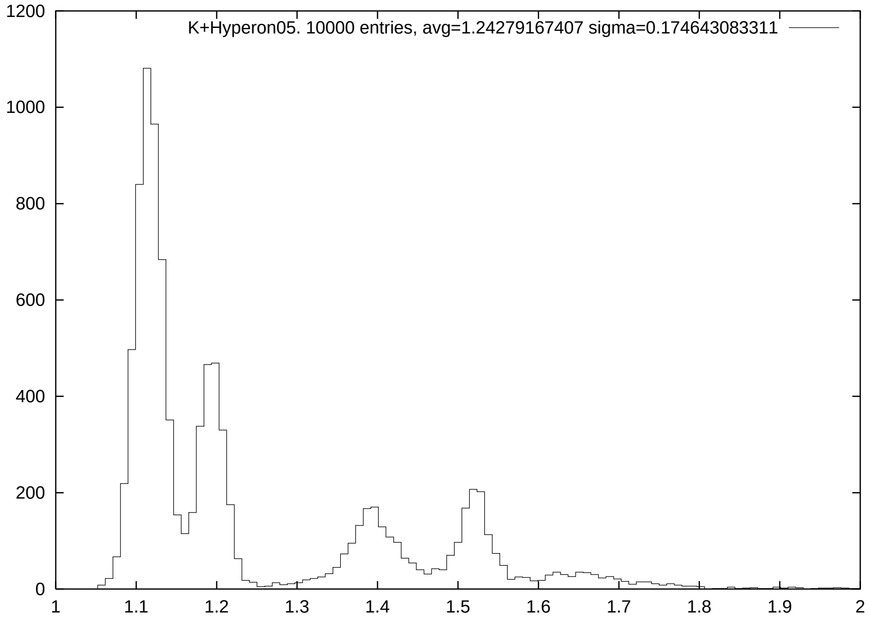


Figure 4.3.1: *Missing mass spectrum for exclusive* K^+ *production at x=0.2,* Q^2*=4 GeV*^{2} *simulated for the apparatus shown in figure 4.3.2. With the assumed energy width of the 25 GeV electron beam of* $\sigma_E/E = 5\cdot10^{-4}$ *the missing mass resolution is* $\sigma_M = 16$ *MeV. A beam energy width of* $\sigma_E/E = 10^{-3}$ *degrades the mass resolution to 21 MeV. The relative cross sections for the different hyperon states were taken from recent CEBAF data at 4 GeV beam energy. The natural width are taken from the Particle Data Group compilation.*

Figure 4.3.1 shows a simulated missing mass spectrum for the K^+ electroproduction at 25 GeV beam energy with the proposed forward detector. The simulation assumes the presence of a performant particle identification system. A large dual radiator RICH is part of the proposed detector. With the use of a thin target and a well defined beam diameter the origin of the particle track can be sufficiently constrained in order not to worsen the mass resolution. For extended targets and particles originating from secondary vertices an additional vertex detector can be introduced which then determines the origin of a particle track before entering the spectrometer. It turns out that the loss of angular resolution of the primary track by multiple scattering in the target or the vertex detector is not as severe as a loss of resolution in the absolute momentum. For the exclusive measurement of deeply virtual Compton scattering a forward spectrometer alone can not provide the desired separation from events where the target is excited. A fine grained calorimeter as foreseen for the ELFE detector can detect the photon with good angular resolution and an energy resolution of about $\delta p/p \approx 3 \cdot 10^{-2}/\sqrt{p[GeV]}$. While the spatial resolution will help to detect π^0 and thus provide means for background subtraction, the energy resolution is insufficient for the separation of inelastic channels via a missing mass determination. The obvious solution is the detection of the recoiling proton. A minimum momentum of typically 100-200 MeV/c is necessary for its detection. This momentum is directly related to the minimum transverse momentum of the real photon relative to the virtual photon accessible to measurement. The addition of a recoil detector with a very low momentum threshold is another necessary feature of the proposed spectrometer. The massive production of Moeller electrons in the forward and backward direction sets limits to the detector acceptance. While at forward angles these electrons can be removed by cutting out a “Moeller-parabola” from the acceptance, causing only mild losses of good events, at backward angles an axial field will curl up the abundant low momentum electrons. The biggest cross sections will occur for purely radiative events. By not instrumenting the median plane of the forward dipole spectrometer the radiative photons as well as the electrons can leave the detector without further interaction. The exclusive production of unstable mesons decaying in or close to the target, like $\eta, \eta', \rho, \omega, \phi$ and K_s^0, poses an acceptance problem to the spectrometer. The lower momentum charged mesons from their decays can not pass the spectrometer. Instrumenting the inner side faces of the dipole recovers these particles with sufficient resolution. The recoil detector will also serve to detect decay mesons at larger angles ($\Theta > 25^\circ$).

Figure 4.3.2 shows a view of the proposed detector system including the recoil detector. The cost of such a detector will be of the order of 25-50 MEUR.

A particular difficult problem is represented by exclusive measurements with polarized proton or deuterium targets. Target materials which can maintain a high degree of polarization at beam currents of 100 nA have been used at SLAC. Useful targets are typically one cm thick and require a field of 5 T for continuous polarization build up and methods to distribute the heat load over a larger volume. It appears feasible to integrate such targets into the spectrometer without compromising acceptance and resolution too much.

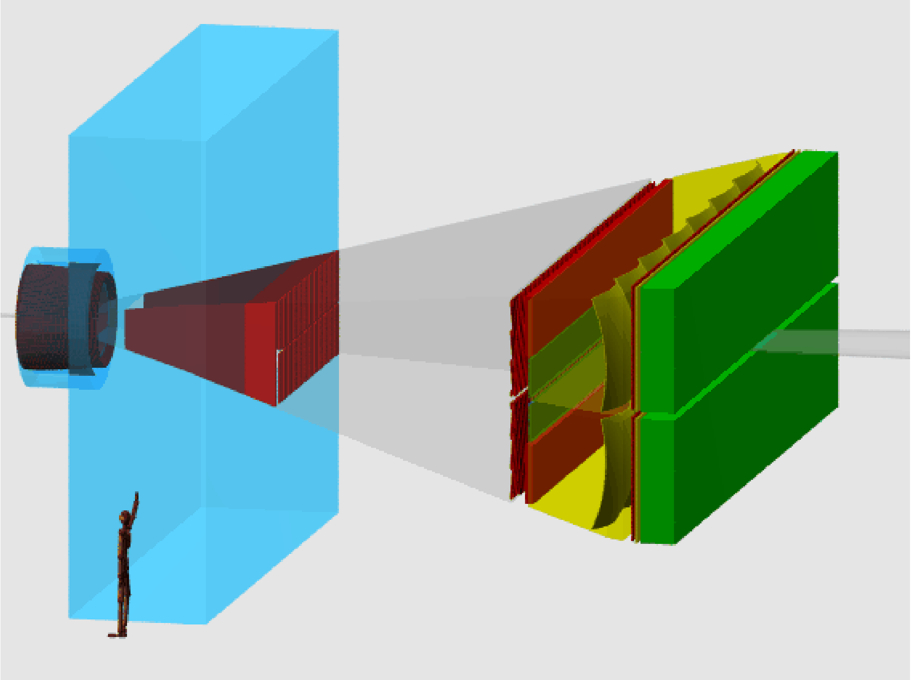


Figure 4.3.2: *View of the ELFE spectrometer. The beam enters from the left. The total length is about 10 m. It consists of a dipole magnet (blue) equipped with three fibre trackers (red), a particle identification section with a RICH (yellow), a TRD, an hodoscope/TOF (red) and a calorimeter (green). The cylinder in front of the dipole is the recoil detector.*

4.4 The ELFE@DESY Project

A proposal of incorporating ELFE into an extended TESLA project (ELFE@DESY) was presented in 1995 [2]. It consists in using only a fraction of the TESLA linac (a 27 GeV linac) together with the HERA electron ring as a pulse stretcher. The proposal is based on the fact that the superconducting linac, that is operated at low duty-cycle (about 0.4%) for e^+e^- collider mode, is available for other tasks during the time between collider pulses. A fraction of the beam pulses produced by TESLA could be injected into the HERA ring until the ring is filled. Then, the principle of ELFE@DESY is the following:

- Short pulses are produced at low frequency (10 Hz) by TESLA and accumulated in the HERA ring until they fill the ring.

- The stored beam is then slowly extracted from the ring over the time period between the accelerator pulses by switching on nonlinear lenses in the ring that induce a controlled beam instability (resonant growing of particle oscillation amplitudes).

- When the ring is empty, new pulses from the linac are stored and the extraction process start again.

In 1996 a group of accelerator physicists from Bonn, DESY, Frascati, Grenoble, NIKHEF and Saclay has explored the possibility of combining TESLA and HERA to produce a beam for the ELFE physics program. The group has concentrated the efforts on the following problems:

- Modification of the HERA e-ring lattice for the needs of slow extraction.
- Beam extraction: analysis of possible extraction methods, simulation of the extraction process, definition of the extraction channel.
- Beam injection: optics and hardware.
- New RF system in HERA and multi-bunch instabilities.
- Time structure of the injected beam, compensation of beam-loading in the injection linac.

Solutions have been found for all these problems. For the repetition rate to fill HERA a compromise must be chosen between a high peak current in the ring and the stronger requirements for the linac RF-system to accommodate more frequent pulses. A repetition rate of 10 Hz has been assumed for the ELFE mode, twice the TESLA design value. Since the same linac section is also used to generate the drive beam for the Free-Electron Laser facility at a rate of 5 Hz, this means that the part of the TESLA linac used as the injector for the stretcher ring will be pulsed at a rate of 20 Hz, which seems feasible with moderate modifications of the pulsed RF-power sources. For an extracted beam intensity of 30 μA, the current stored in the HERA ring is 150 mA, which appears possible both from the point of view of RF-system requirements and instabilities in the stretcher ring. The design linac beam pulse length of 800 μs is matched by using a multiturn injection scheme in the ring. The bunch-train consists of 38 batches of 220 bunches, spaced by the HERA revolution time ($T_{rev} = 21.1$ μs) plus 50 ns to account for the kicker gap (see Figure 4.4.1). The bunch spacing is chosen as three times the linac bucket spacing, consistent with a 433 MHz RF-system in the ring.

For using HERA in stretcher-mode all the elements for e-p collisions have to be removed, sextupoles have to be inserted into the lattice at suitable positions with respect to the extraction septum, optical functions have to be properly defined because of their influence on extraction parameters and the horizontal tune must be close to a third-order resonance. The achievable performances of the extracted beam have been calculated assuming that the effects of machine imperfections could be corrected. The results of the feasibility study are reported in the ref. [3]: they demonstrate that it is possible to extract electrons from HERA used as a stretcher ring and produce a high luminosity quasi continuous beam suitable for exclusive experiments. A possible scheme of the linac arrangement with respect to the HERA ring is illustrated in Figure 4.4.2. The TESLA source is not far from the HERA ring, one end of the roughly 32 km long linear collider is close to the experimental West Hall, with the linac being exactly tangential to the HERA West straight section. Then, the injector linac for ELFE

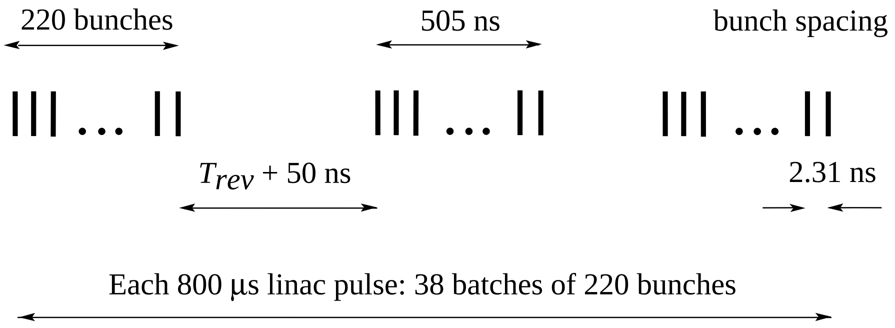


Figure 4.4.1: *Beam pulse structure in the TESLA injector linac*

points away from the DESY site and the beam has to be extracted approximately 2 km downstream and transported back to HERA. A return loop is used to send the beam back to HERA by using the TESLA tunnel. This return loop could be installed in the tunnel planned for the damping ring.

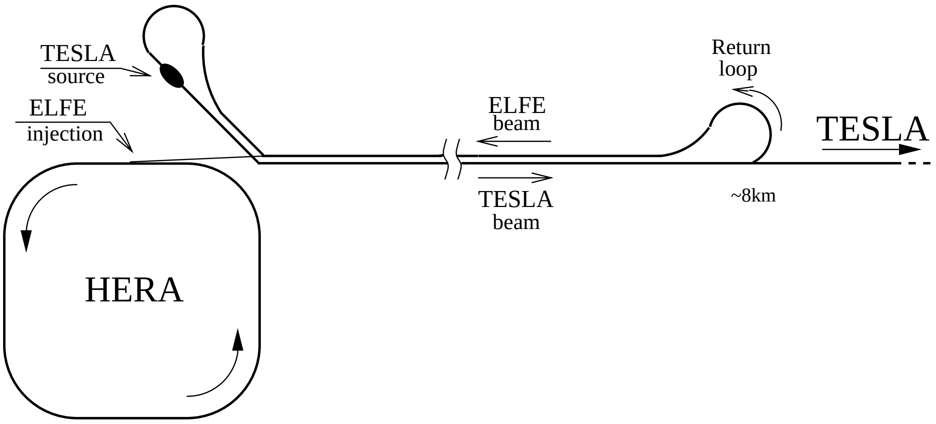


Figure 4.4.2: *Possible scheme of the beam transport.*

The expected performances of the machine are given in the Table 4.4.1. For unpolarized electrons the energy will range from 15 to 27 GeV. If the spin rotators are kept insise the ring as it is now, polarized electrons will be available at 27 GeV only. The nominal intensity of the extracted beam, 30 μA, is large enough to make possible experiments with high luminosities, in the range 10^{35} cm^{-2}s^{-1} (with large acceptance detectors) to 10^{38} cm^{-2}s^{-1} (with well shielded magnetic spectrometers). The large duty factor will enable coincident experiments which are excluded otherwise.

Table 4.4.1: *Expected performances of ELFE@DESY.*

Energy range	15-27 GeV
Maximum current	30 μA
Duty-factor	88 %
Bunch spacing (433.33 MHz)	2.3 ns
Horizontal emittance (90% of the particles)	4 mmμrad at 15 GeV
	12 mmμrad at 25 GeV
Energy spread (FWHM)	1.2 10^{-3} at 15 GeV
	2.2 10^{-3} at 25 GeV

Bibliography

[1] M. Anselmino et al., NuPECC Report (*in press*);
http://www-dapnia.cea.fr/Sphn/Elfe/Report/ELFE_phys.pdf

[2] R. Brinkmann, DESY Internal Report DESY-TESLA-95-14.

[3] R. Brinkmann et al., Nucl. Phys. A622 (1997) 187c.

[4] K. Aulenbacher et al., CERN Report 99-10, December 1999.

[5] X. Ji, J. Phys. G 24 (1998) 1181;
Phys. Rev. Lett. 78 (1997) 610.

[6] A. Radyushkin, Phys. Lett. B 380 (1996) 417.

[7] M. Vanderhaeghen, P. Guichon and M. Guidal, Phys. Rev. D60 (1999) 094017.

[8] J.C. Collins, L. Frankfurt and M. Strikman, Phys. Rev. D56 (1997) 2982;
J.C. Collins and A. Freund, Phys. Rev. D59 (1999) 074009.

[9] A.V. Belitsky, D. Müller, L. Niedermeier, A. Schäfer, Phys. Lett. B474 (2000) 163;
Nucl. Phys. B546 (1999) 279.

[10] A.V. Radyushkin and C. Weiss, hep-ph/0010296;
N. Kivel, M.V. Polyakov, A. Schäfer, and O.V. Teryaev, hep-ph/0007315.

[11] M. Diehl, T. Feldmann, R. Jakob and P. Kroll, Eur. Phys. J. C8 (1999) 409.

[12] L. Mankiewicz, G. Piller and A. Radyushkin, Eur. Phys. J. C10 (1999) 307.

[13] L. L. Frankfurt, P. V. Pobylitsa, M. V. Polyakov and M. Strikman, Phys. Rev. D60 (1999) 014010.

[14] M. V. Polyakov and C. Weiss,Phys. Rev. D60 (1999) 114017.

[15] X. Ji and W. Melnitchouk, Phys. Rev. D56 (1997) 5511.

[16] L. Mankiewicz, G. Piller and T. Weigl, Eur. Phys. J. C5 (1998) 119.

[17] I.V. Musatov and A.V. Radyushkin, Phys. Rev. D61 (2000) 074027.

[18] M.V. Polyakov and C. Weiss, Phys. Rev. D60 (1999) 114017.

[19] M. Penttinen, M.V. Polyakov and K. Goeke, hep-ph/9909489.

[20] M. Amarian for the HERMES Coll., Proc. of SPIN 2000, XIV Int. Spin Physics Symposium. Oct. 18-21, 2000, Osaka, Japan.

[21] HERMES Coll., K. Ackerstaff et al., Nucl. Instr. and Meth. A417 (1998) 230.

[22] O. Bing et al., Conference Proceedings of the Italian Physical Society, 44 (1992) 475.