THERA - Electron-Proton Scattering at $\sqrt{s} \simeq 1$ TeV

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summary of a talk given at Snowmass 01 in M5/E4

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THERA is the name for an ep collider using polarized leptons ($e^{\pm}$) from TESLA scattered off protons, or nuclei, accelerated in the HERA proton ring. With energies of $E_e = 250-800$ GeV and $E_p = 300-1000$ GeV, THERA reaches c.m.s. energies of 1 TeV and beyond, which compares well with a 250-400 GeV e^+e^- collider and with the LHC. Thus there exists a realistic opportunity to study ee, pp and ep collisions in the TeV range of energies. In the past this triple coexistence has been vital for understanding lepton and parton interactions and in establishing the standard model of electroweak and strong interactions.

Lepton probes represent the cleanest way to test the inner structure of matter. THERA will allow to access dimensions as small as 10^{-19} m, a factor of 1000 below the level at which partons were observed in deep inelastic scattering. Lepton-nucleon scattering is the cleanest testing ground for strong interaction physics and QCD in particular, a most beautiful theory which nonetheless is not understood most beautifully yet. For example, the strong interaction constant α_s is measured to only 2% accuracy while the electroweak mixing angle and the Fermi constant have been measured by far more accurately.

"The Higgs particle is certainly not, despite much loose talk to the contrary, the origin of mass... Most of the mass of ordinary matter is concentrated in protons and neutrons.. Their mass mostly arises from pure energy, associated with the dynamics of confinement in QCD" F.Wilczek, hep-ph/0101187. The physics at low x and the exploration of the transition between the physics at small distances (large Q^2, deep inelastic scattering) and larger distances (small Q^2, photoproduction) are directly related to the puzzle of confinement of quarks.

With THERA, the behaviour of parton distributions at low x can be probed, deeper than at HERA, where the rise of the proton structure function F_2 and of the gluon momentum distribution towards low x was discovered. Extension of the range towards even lower x is crucial since due to unitarity limits and the abundance of gluons, non-linear gluon interaction effects are expected which may lead to a taming of the observed rise. This will lead to the development of QCD for high density matter, and it affects the rates measured at the LHC as well as neutrino astrophysics in which high energy neutrinos from AGN's or gamma ray bursts occur with uncertain cross sections at x values as low as 10^{-8}. The low x programme at THERA, as has become obvious at HERA, requires precision measurements of the inclusive cross section, of hard diffraction, of vector meson production and of electron-nucleus interactions in order to establish a coherent theoretical understanding of these phenomena.

THERA represents a unique facility for testing QCD. For example, the role of heavy flavours (charm and beauty) in strong interactions, despite interesting developments inspired by HERA, has not been clarified yet. The beauty production cross section is mysteriously high, the hypothesis of intrinsic heavy flavour in the proton has not been investigated and the theoretical description of c and b production near threshold has not been settled. With a transverse vertex extension of about $20\mu m$ and a small pipe radius, THERA is an ideal place for heavy flavour physics.

A particularly interesting process at THERA is forward jet production in DIS which promises to reveal the mechanism of gluon emission in the ep interaction, i.e. departures from the conventional evolution equations in QCD and perhaps the existence of hot spots of partons in the proton. The "Thomson model" of continuously distributed partons in the proton may be wrong.

The huge range in momentum transfer Q^2 and x and the high accuracy in measuring the inclusive neutral and charged current cross sections lead to crucial tests of the Q^2 evolutions of parton distributions up to $Q^2 = 1\mathrm{TeV}^2$ and to a most accurate measurement of α_s to within 4 per mille uncertainty. If new particles exist within the range up to masses of 1 TeV, their properties can be well studied at a new ep collider. An impressive example are leptoquarks which can be spectroscopied because of the ability to prescribe the incoming lepton charge and polarisation state as well as using the measurement of the angular distribution of the scattered lepton.

Similar to the complementarity of HERA and LEP in the investigation of photon structure, THERA and TESLA will lead this field into a new region where the gluon and heavy flavour content of the photon will be explored. In this regard the real photon-proton scattering option of THERA is of interest.

Polarization of leptons and of protons extends the fixed target spin physics into the unexplored range of low x and large Q^2. This will resolve the question of the gluon spin at low x and permit the flavour decomposition of spin using NC and CC cross sections, respectively.

It is clear that the deep inelastic physics at the TeV scale may be investigated at any ep collider. This particular study has been pursued within the framework of the TESLA Technical Design Report (TDR) at DESY Hamburg. THERA appears as the natural successor of HERA taking advantage of the huge experience accumulated in ep physics and experimentation over the last 15 years. With TESLA at DESY, THERA appears to be cost effective, and it may coexist with the $e^{\pm}$ collider.

TESLA, as a superconducting LC with standing wave type cavities, allows both arms to be used for lepton acceleration towards the proton ring. With its about 300 ns bunch separation it fits to the HERA proton bunch separation of presently 96 ns. A design of the interaction region, for E_e/E_p ratios between 1/4 and 1, leads to estimated annual luminosities between 40 and 250 pb^{-1}. This assumes electron cooling of the proton phase space in the PETRA preaccelerator which is supposed to enhance the luminosity by a factor of about 2.

A long defocussing quadrupole separates the beams by orbit. There is no upstream synchrotron radiation which allows the beam pipe radius to be made as small as about 2 cm. This limits the detector extension in lepton beam direction to 5-10 m, i.e. enables the detection of scattered leptons in the region of low $Q^2 > 1$ GeV^2 and low $x > 10^{-6}$. While the kinematics at low x for the rather symmetric E_e to E_p energy ratio is a solvable challenge, it is of much advantage at high Q^2 since the whole final state is scattered rather centrally into the detector. This allows parton distributions to be measured near to $x \simeq 1$, for $Q^2 \sim 10^4$ GeV^2, and focusing magnets to be placed very close to the interaction point in the high Q^2 phase of experimentation at THERA.

A feasible design is presented for a THERA detector to be located in the West area of HERA, on site at DESY. The central and forward dimensions of such a detector resemble H1 and ZEUS since they are determined by the HERA proton beam energy.

In the past every significant step in the increase of energy in lepton scattering experiments has lead to new insight into the structure of matter. This is true for the discovery of the proton formfactor in elastic ep scattering at a few 100 MeV, the discovery of parton substructure in deep inelastic ep scattering at a few GeV, the exploration of the valence and sea quark structure in subsequent neutrino experiments, the development of QCD in precision μp scattering at 200 GeV and finally for the wealth of new phenomena discovered at HERA, which were summarised in the talk. While one is able to extrapolate the current wisdom to the THERA range, only experimentation in the new energy domain will testify this wisdom and undoubtedly lead to new insight.

For further information see:

- http://www.ifh.de/thera
- The web page contains copies of all talks delivered at the THERA meetings during the year 2000 and elsewhere, and the contributions to the THERA book, to appear.
- TESLA TDR, DESY 2001-011, Part VI, March 2001