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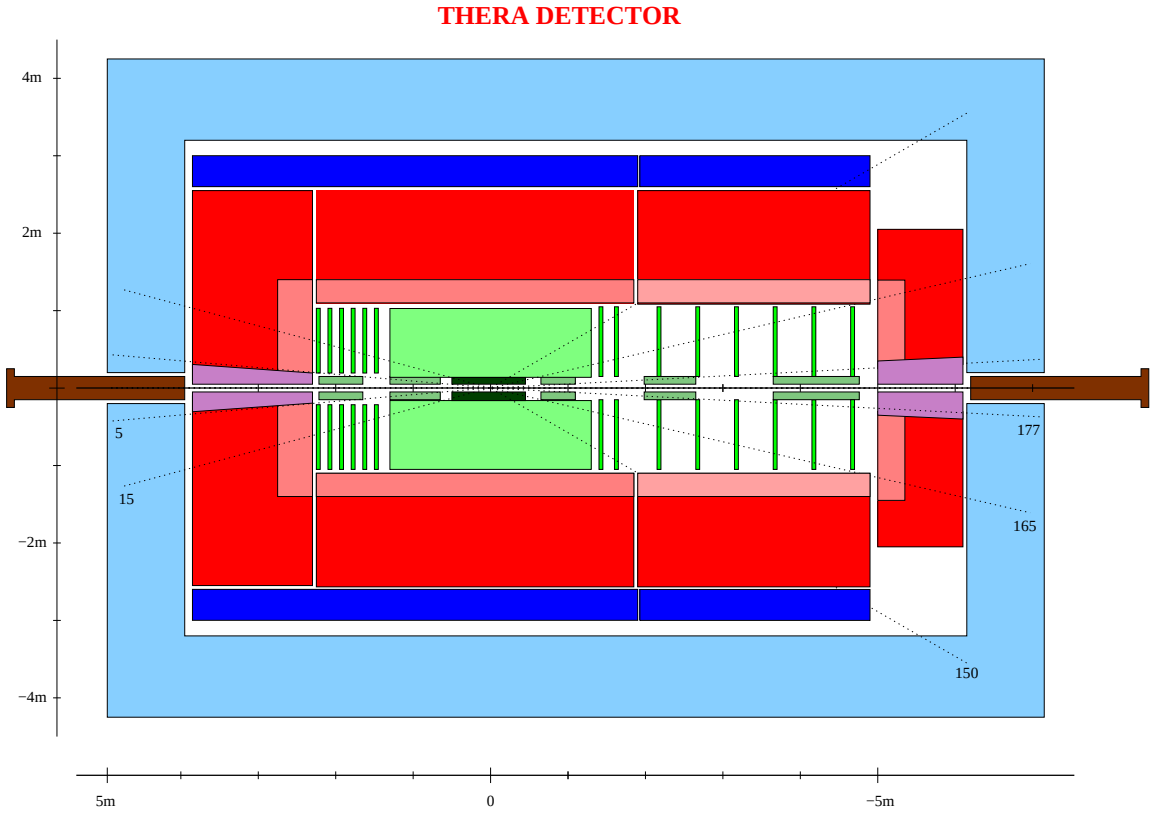
Volume 4: The THERA Book. Electron–Proton Scattering at $\sqrt{s} \sim 1$ TeV



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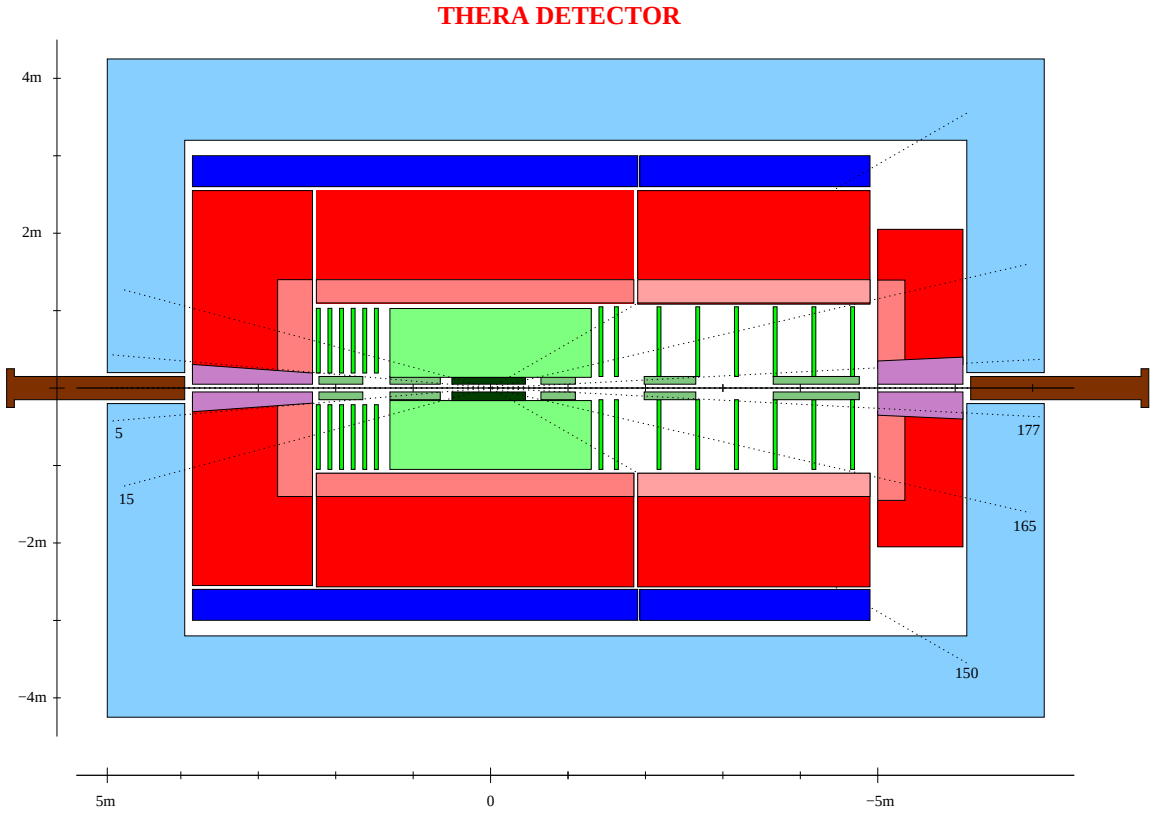

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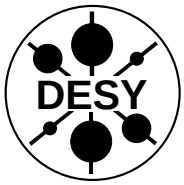

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The picture on the front page shows a version of
the low-x THERA detector with an extended coil.

This volume collects original contributions for THERA, a future electron-nucleon collider operating in the TeV energy range, which can be realised combining the $e^{\pm}$ linear accelerator TESLA with the proton ring accelerator HERA at DESY. The material presented here has been worked out during the preparation of the TESLA Technical Design Report in the years 2000 and 2001. The THERA option was discussed in a series of meetings involving about 100 physicists. These meetings are documented on `http:/www-zeuthen.desy.de/thera`.

Working Groups and Convenors:

Low x and Diffraction	E Levin (U Tel Aviv) A Levy (U Tel Aviv) P Newman (U Birmingham)
Tests of QCD and MC Simulation	H Jung (U Lund) L Lönnblad (U Lund) H Spiesberger (U Mainz)
Heavy Flavours	K Daum (U Wuppertal) L Gladilin (U Hamburg, Moscow)
Photon Structure	J Butterworth (UC London) M Krawczyk (U Warsawa) S Söldner-Rembold (CERN/U Freiburg)
High Q^2 and BSM	M Kuze (KEK) K Long (IC London) E Perez (Saclay)
Detector and Machine	J Crittenden (U Bonn) U Katz (U Bonn/ U Erlangen) M Klein (DESY Zeuthen) D Pitzl (DESY Hamburg) S Schlenstedt (DESY Zeuthen) U Schneekloth (DESY Hamburg) F Willeke (DESY Hamburg)
eA Scattering	M Strikman (Penn State)
Real Photon-Proton Interactions	S Sultansoy (Ankara)
Polarisation	A Deshpande (Yale U) E Rondio (U Warsawa)

Contents

1 Introduction to the THERA Book

This document is a result of a study within the TESLA Technical Design Report at DESY, Hamburg. It was carried out during the years 2000/01 with the aim of investigating the feasibility and the physics interest of an *ep* collider, THERA, which scatters polarized leptons ($e^{\pm}$) from TESLA off protons, or nuclei, accelerated in the HERA proton ring. With lepton energies of $E_e = 250{-}800\,\mathrm{GeV}$ and proton energies of $E_p = 300{-}1000\,\mathrm{GeV}$, THERA can reach center-of-mass energies of 1 TeV and beyond. Estimated annual luminosities between 40 and $250\,\mathrm{pb}^{-1}$, for energy ratios E_e/E_p between 1/4 and 1, respectively, would allow THERA to complement the TeV-scale exploration with the next generation of $\mathrm{e^+e^-}$ and *pp* colliders. THERA is a natural successor of the HERA collider, extending the kinematic limits of the photon virtuality, Q^2, up to more than $10^6\,\mathrm{GeV}^2$, and that of the Bjorken x variable down to 10^{-7}.

Lepton probes represent the cleanest way to explore the structure of matter. THERA will allow to access dimensions as small as $10^{-19}\,\mathrm{m}$, a factor of thousand below the scale where partons were first observed in deep inelastic scattering and five times smaller than resolved at HERA.

In the past, lepton–nucleon scattering has been an excellent ground for investigating strong-interaction physics and for developing Quantum Chromodynamics (QCD). The HERA collider greatly improved our understanding of QCD, especially in the low-x region. However, the current experimental and theoretical assessment of QCD is far from complete. QCD predicts the existence of a variety of as yet unknown new forms of hadron matter, such as quark-gluon plasma, or color superconductivity, which are all related to large-distance QCD interactions. In order to fully establish QCD as one of the cornerstones in our picture of fundamental interactions, further research is necessary which should help to elucidate intricate features of QCD and also to find qualitatively new QCD phenomena. Investigating small-x *ep* reactions at THERA, where the coherence length is about $10^4\,\mathrm{fm}$ and the parton densities are high will be a major step in this direction.

Physics at THERA leads far beyond the low-x domain. In this book, many aspects of the exciting physics at THERA are described. These include the role of heavy flavors in strong interactions and the very high Q^2 region and searches for physics beyond the Standard Model, such as quark compositeness and leptoquarks. Extremely important options are high energy physics with real photons, deep inelastic lepton scattering on nuclei, and *ep* collisions with polarized beams.

While one can try to extrapolate the current wisdom to the THERA range, only experimental data in this new kinematic domain will substantiate the view on this physics and will undoubtedly lead to new insights. This book presents the foundations of a new *ep* machine in the TeV range.

We gratefully acknowledge the enthusiastic, ingenious work and contributions of many theorists and experimentalists to this THERA book, and we thank the DESY directorate for encouragement and support.

U. Katz, M. Klein, A. Levy and S. Schlenstedt, editors