Introduction to DESY

Welcome Summer Students 2008

Frank Lehner
DESY

Frank Lehner, July 2008
Deutsches Elektronen-Synchrotron

DESY - Deutsches Elektronen Synchrotron
- founded 1959 -

Mission: Development, construction, operation and scientific exploitation of accelerators

Provide access and services for national and international users

Internationally used, nationally funded Research Institute

<table>
<thead>
<tr>
<th>Base-Budget:</th>
<th>183 MEuro (2007)</th>
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<tbody>
<tr>
<td>Funding source:</td>
<td>90% federal, 10% state</td>
</tr>
<tr>
<td>Staff:</td>
<td>~1600 FTE in Hamburg and Zeuthen</td>
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<tr>
<td>Users:</td>
<td>~3000 (1500 from abroad) from 45 nations</td>
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<td></td>
<td>920 in particle physics, 2100 in photon science</td>
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Frank Lehner, July 2008
Research Centers: 15

Employees: ~ 24 000

Funding (Bill. Euro) ~ 2.2

Research Areas:
- Health
- Environment and Earth
- Energy
- Traffic and Space
- Structure of Matter
- Key Technology

Programme oriented funding:
Five year program planning, strategic review -> funding
DESY in Hamburg und Zeuthen

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DESY

• DESY has a long successful history in three areas of basic science and high tech:
  - **Particle physics** (one of 5 laboratories worldwide),
  - **Research with Photons** (synchrotron radiation sources and Free-Electron Lasers) and
  - **Accelerator development**.

• These topics **stimulate each other**, are **unique** in their combination in Europe and constitute the basis for the future of the laboratory.

• DESY develops, builds and operates accelerators for research
  - about 70% of budget for operation of accelerators and to provide services for 3000 external users/year
DESY - Research

- Research at DESY spans many orders of magnitude in scale
- Investigate the structure of matter from macroscopic to atomic scales with photons
- Investigate the building blocks of matter and their forces (discovering the quantum universe)
- theory of particle physics & cosmology
- astroparticle physics with neutrinos (experiments at Southpole)
- Accelerator & Detector R&D
DESY Management Structure and Advisory Boards

Scientific Council

Directorate
GD, FH, FS, M, V

Admin. Council

**PRC: Particle Physics Research Committee**

**MAC: Machine Advisory Committee**

**PSC: Photon Science Committee**

**Exp. & Theor. Particle Physics**

**Accelerators + Development**

**Research with Photons SR, FEL**

PRC, PSC, and MAC review the respective fields, advise the Directorate and inform the ESC.
DESY RESEARCH

Particle and Astroparticle physics
- HERA
- LHC
- ILC
- Theory
- Detectors
- Icecube

Accelerator R&D and operation
- DESY+Pre-Inj.
- DORIS
- FLASH
- PETRA III
- PITZ
- XFEL
- ILC (SCRF)

Research w/ Photons
- DORIS
- FLASH
- PETRA III
- CFEL (XFEL)
- Detectors

Frank Lehner, July 2008
DESY operated until recently 16 km of accelerators for:
- Particle physics
- Photon science
Accelerator Development

Strategy:

• Further strengthening of know-how in accelerators, driven by science needs:
  - Accelerator technology development (superconducting RF, electron sources)
  - Operation of synchrotron light sources
  - Development and operation of Linac driven Light sources (FLASH, XFEL)
  - International Linear Collider development

• Exploiting the synergy between projects and technologies
Superconducting RF-structures were developed in many countries

TESLA Collaboration (55 Institutes from 12 countries), centered at DESY, bundled ~ worldwide know-how and achieved significant progress:

>30-fold improvement of acceleration/cost performance over 10 years

Of large relevance for future accelerators such as XFELs and others
TESLA Technologie
The heart of the accelerator

Developed for applications in particle physics

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Niobium
1.9 K
TESLA Collaboration

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Research with Photons at DESY

**Structural biology:**
Outstations of
EMBL
MPG

**Materials science:**
Outstations of
GKSS
GFZ

DORIS III

FLASH

PETRA III

XFEL
1895 Discovery of X-Rays (W.C. Röntgen)
X-Rays can penetrate matter
Applications in medicine, life science, natural science and in engineering sciences

The Wavelength of X-Rays fits to the distance of atoms in Matter
“Position of atoms”
Applications in basic applied science

accelerated electrons generate radiation (Bremsstrahlung)
Synchrotron Radiation

Since 1960, sources became stronger by a factor of 1000 every 10 years, leading to substantial progress in science.

Undulators:
- Line spectrum
- Higher intensity
- Focused in narrow cone

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Some Applications:

Die “Proteinfabrik”

Knee of a Spider

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Examples for Research at DORIS

8 keV at BW2

**Volume rendering of the head and thorax of the sawfly Tenthredo vespa.**


**Painting: van Gogh**

Boerin, Janssens et al. (submitted, 2008)
Strategy for Research with Photons

Strategy:
- Make leading edge research possible in physics, chemistry, material science, biology etc. through unique light sources:
  - Synchrotron light sources
    - DORIS
    - PETRA III
  - Linac driven light sources
    - VUV-FEL - FLASH
    - Participation in European XFEL
  - FLASH, PETRA and the XFEL are or will be unique facilities on a world scale
In 2006 at Hasylab:
German Users: 928
Internat. Users: 771
No. of Nations: 40
Distribution among Research Fields (biology included)

Distribution corresponds roughly to "number of experiments performed", it does not scale to allocated beam time.

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PETRA III

- Originally built for particle physics end of 1970ies
  - Discovery of gluon
  - Later, injector für HERA
- now being refurbished to world best source for hard X-ray
  - PETRA III
    - very high brilliance
    - very low emittance
- a new high performance light source for European users, nationally financed

1/8 of ring completely new assembled
7/8 of ring refurbished
14 beamlines (some of them together w/ other institutes, e.g. EMBL)
PETRA III

• begin construction: July 2007
• laying of founding stone: September 2007
• roof construction: November 2007
• monolithic concrete slab (280 m long, 24 m wide) poured: December 2007
• Expect user operation mid 2009
PETRA III

Status July 2008:

• PETRA III-Hall
  - Outside finished
  - Installation of equipment/beam line in hall has started

• Refurbishment of PETRA ring finished

• Expect user operation mid 2009

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Principle of a Free-Electron laser

- Free-Electron Laser FEL is very long undulator so radiation field is strong enough to introduce periodic microbunches inside bunch and hence a resonance with undulator.

The “Supertandem”: “all move in sync”
Properties of FEL radiation

- X-ray FEL radiation (0.2 - 14.4 keV)
  - ultrashort pulse duration \(<100\) fs (rms)
  - extreme pulse intensities \(10^{12}-10^{14}\) ph
  - coherent radiation \(x10^9\)
  - average brilliance \(x10^4\)

- Spontaneous radiation (20-100 keV)
  - ultrashort pulse duration \(<100\) fs (rms)
  - high brilliance

FELs deliver in 10 Femtoseconds so much light as today's best X-ray sources in 1 second.
Diffraction: From Static to Dynamics

Realtime holograms of motion of atoms, molecules and electrons on nature’s time scale

incident X-ray beam

sample

detector

beam stop
The **FLASH** FEL as Prototype for the XFEL

FLASH:
VUV free electron laser

- **electron energy:** 1 GeV
- **wavelength:** 6.5-47 nm
- **average pulse energy:** 2-70 μJ
- **peak pulse energy:** 170 μJ
- **pulse duration:** 10-25 fs
- **average power (700 pulses / s):** 20 mW
- **peak power:** 3-10 GW
- **peak brilliance:** $1 \cdot 10^{20}$
- **divergence (@13nm):** 90 μrad
- **spectral width:** 0.7-1%
FLASH - lasing towards shorter wavelength

Lasing at 6.5 nm 10/2007 @ 1 GeV
Lasing at 25 nm 12/2005
Lasing at 32 nm 1/2005

FEL at TTF 1 (1999 - 2002)
Proof-of-Principle for SASE in the VUV

Courtesy: Sigfried Schreiber
Ultrashort times

Light takes about 1 second from earth to moon.

Light travels a distance of 30 micrometers in 100 femtoseconds.

That is about the thickness of a human hair.

Key processes in nature proceed on such ultra-short time scales.
First X-ray imaging of biological cells (free fall)

Image of Picoplankton (most abundant photosynthetic cells) recorded with ~10 fs light pulse at FLASH, wave length 13.5 nm.

Image reconstructed using Shrinkwrap

Ostreococcus TEM section
(Wenche Eikrem and Jahn Throndsen, University of Oslo)

J. Hajdu, I. Andersson, M. Svenda, M. Seibert (Uppsala)
S. Boutet (SLAC)
M. Bogan, H. Benner, U. Rohner, H. Chapman (LLNL)
Ultrafast coherent diffraction at 32 nm

FEL-Pulse at FLASH:
30 fs, 32 nm, $3 \times 10^{13}$ W/cm²
$10^{12}$ photons/s in one pulse
Probe heats up to 60’000C and evaporates
Take single shot image before probe gets destroyed

H. Chapman, J. Hajdu et al.
The European XFEL Project

Schenefeld (Pinneberg district)

3.4km

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Status of the European XFEL Project

• 14 countries have signed Memorandum of Understanding for the preparatory phase
• Construction Phase officially launched on 5 June 2007

• Prep. Phase support by European Funds
• 12 countries ready to sign convention
• Funding of phase 1 assured

Civil construction tenders out

First Beam: 2013
Complete Operation with up to 10 Exp. Stations: 2015
XFEL – Official Launch

- XFEL Launch on 5 June 2007

First beam in 2013, all beamlines operational in 2015
Approach to FEL science in Germany

Center for Free-Electron Laser Science (CFEL)
MPG, DESY, and University of Hamburg

In 2010 a new building available for ~300 people, annual budget ~15 M€

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What do we know about Particle Physics?

The elementary particles:

- Electromagnetic forces
- Strong forces
- Higgs field?

Understanding of the elementary particles and interactions
Particle Physics – open questions?

What generates Mass?
Search for the "Higgs".

Do we understand the Universe?

Is the world made out of "Strings"?

Is there a „shadow world“ of new particles?

In how many dimensions do we live?

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String theory

STRING THEORY SUMMARIZED:

I just had an awesome idea.
Suppose all matter and energy
is made of tiny, vibrating "strings."

Okay, what would
that imply?

I dunno.
Particle Physics as telescope to the early universe

Particle physics at highest energies, at the 'Energy Frontier' (LHC, ILC)
Expect breakthrough in understanding of mikrocosmos and of early universe (Physics at the Terascale)

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Particle/Astroparticle Physics
- rich program pursued at DESY -

**HERA**
unique ep-facility, leading physics analyses, combined results, HERA -> LHC HERA Analysis centre at DESY

**LHC**
involvement in ATLAS and CMS, commissioning and physics, detector R&D towards possible upgrade (sLHC)

**Linear Collider**
central role in all aspects and through all phases towards Technical Design Phase in 2012

**IceCube**
complete installation, R&D on acoustic detectors, leading analysis contributions (→ multimessenger), prepare for the future (CTA)

**Theory**
keep balanced excellence in phenomenology, string theory, cosmology and astroparticle physics, lattice gauge theory (incl. hardware)

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HERA: Microscope - unique world-wide - with a resolution of 1/1000 of proton radius (10^{-18} m)

Questions:

• How big are electron and quark
• What is the proton made of
• Which properties do the fundamental forces have
• What is the origin of spin
• Are there new phenomena

First collisions in 1992
End of Operation 30 June 2007
About 900 scientists from 33 countries (snapshot in 2006)

DESY has ended HERA Programme to make room for new projects

More than 1,000 Physiker
~ 1,000 Ph.D.’s
~ 400 publications
DESY in post-HERA era - participation at LHC

- expect scientific breakthroughs
- strong link to HERA program
- preparation of ILC
Large Hadron Collider LHC

- Large Hadron Collider LHC at CERN/Geneva
- Circular machine
  - 27 km circumference
- Proton-proton collisions at 14 TeV energy
  - 800 million quark/gluon collisions per second
  - 15 Petabyte of data/year (GRID)
- LHC will start by mid 2008 and is our essential tool to explore the Terascale

HERA results are vital for LHC predictions

Frank Lehner, July 2008
HEP in Germany - Future Challenges

- End of HERA: -> turning point for HEP in Germany
- Particle physics at the energy frontier is becoming global in all its areas
- Stay competitive with high impact → restructure HEP in D

Join all forces of complementary excellence in all areas (analysis, computing, detector, accelerator) in a long-lasting structure and strong sustained infrastructures:

**Alliance:** a Network of complementary excellence between

- 2 Helmholtz Centres
- 17 Universities
- 1 Max Planck Institute

**Key Elements**

- Physics Analysis
- Detector Development
- GRID Computing
- Accelerator Science

Frank Lehner, July 2008
Physics at the Terascale

- Start July 2007 for 5 years duration
  - all structures set up and most positions filled
  - Analysis Centre and Virtual Theory Institute constituted
  - NAF prototype operational
  - lecture and school programme in full swing, e.g.:

  Kick-off workshop
  ≈ 350 participants

  Accelerator school
  ≈ 35 students

  Monte Carlo school
  ≈ 85 students

  Heraeus seminar
  ≈ 60 students

- Planned:
  - Sep 2008 Statistical Methods
  - Nov 2008 Parton Density
  - Dec 2009 Annual Workshop (Aachen)
International Linear Collider

- International consensus: Linear Collider as next large-scale facility in particle physics
- Worldwide technology decision in 2004: TESLA (SCRF) Technology
- „Baseline“ Design Configuration
  - Many elements of the Main Linac correspond to the XFEL design (except gradient)
  - FLASH and XFEL experience and future work (industrialization)
- DESY actively involved in ILC Global Design Effort
- Reference Design Report including costs were presented in February 2007
- Now strong international effort towards engineering design to be completed by 2012
Which ILC questions are answered by XFEL?

• how to build a 100 accelerator module linac using superconducting RF (SCRF) Technology

• how to industrialize the SCRF on a 5% ILC scale

• how to extrapolate from FLASH by a factor of 20
  Remark: ILC ~ 20 × XFEL

• how to start and organize an international project based on in-kind contributions
Strategy:

Experimental Scientific Focus: Origin of high energy cosmic rays, through neutrino messengers

- Analysis of data from Baikal and Amanda
- deployment of Icecube until 2011

New: Combination of neutrino and high energy photon signals (multi-messenger principle)

Close collaboration with German universities

Experimental astroparticle activities are presently mainly located in Zeuthen
**Neutrino Astrophysics**

ICECUBE will in 2010 have an active volume of 1 km$^3$ of Antarctic ice to detect neutrinos.

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<th>Year</th>
<th>Strings</th>
<th>Icetop</th>
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<tr>
<td>2005</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2006</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>2007</td>
<td>12-14</td>
<td>10</td>
</tr>
<tr>
<td>2011 Sum</td>
<td>70-80</td>
<td>70-80</td>
</tr>
</tbody>
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ALPS – „Axion like particle search“

Elementary particle physics at very low energies:

• Search for particles which are 1.000.000 times lighter than electrons. Hints from:
  - Masses of neutrinos,
  - Dark energy

• New very light particles can be easily integrated in extensions of the SM

• Experimental searches for light particles would
  - test String-Theories,
  - Provide indirect access to extremely high energies
  - Complement experiments at LHC and ILC.
The ALPS-Experiment at DESY

DESY, Hamburger Sternwarte, Laser Zentrum Hannover, MPI für Gravitationsphysik (Albert Einstein Institut)

search for „Light shining through the wall“.

\[ \gamma \rightarrow \phi \rightarrow \gamma, B \times \gamma^* \rightarrow \phi \rightarrow B \times \gamma^* \]

Skivie 1983, Ansel’m 1985, Van Bibber et al. 1987
The ALPS-Experiment

Measurement using old HERA-Dipole magnet
50 Years of DESY

in 2009:
we celebrate 50 years of DESY

start planning for
a series of events, from spring 2009 onwards

First operation of DESY in 1964

Minister Balke    Max Brauer

18.12.1959

Frank Lehner, July 2008
The scientific focus of the research at DESY is the understanding of the structure of matter at different length and time scales.

In its three areas of key competence DESY is a world leading institution.

Science driven technology developments have led to a major new research possibilities for photon science and particle physics, such as FLASH, XFEL and ILC.
Finally …

Enjoy your stay at DESY and in Hamburg …