Introduction

Science

A Forward Look

Accelerating Science and Innovation
Introduction

Accelerating Science and Innovation
The Mission of CERN

- **Push back** the frontiers of knowledge
  
  E.g. the secrets of the Big Bang …what was the matter like within the first moments of the Universe’s existence?

- **Develop** new technologies for accelerators and detectors
  
  Information technology - the Web and the GRID
  Medicine - diagnosis and therapy

- **Train** scientists and engineers of tomorrow

- **Unite** people from different countries and cultures
CERN was founded 1954: 12 European States
"Science for Peace"
Today: 20 Member States

~ 2300 staff
~ 1000 other paid personnel
> 11000 users
Budget (2013) ~1000 MCHF

Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom
Candidate for Accession: Romania
Associate Members in Pre-Stage to Membership: Israel, Serbia
Applicant States for Membership or Associate Membership: Brazil, Cyprus (awaiting ratification), Pakistan, Russia, Slovenia, Turkey, Ukraine
Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO
Science is getting more and more global

**Distribution of All CERN Users by Location of Institute on 14 January 2013**

**MEMBER STATES**
- Austria: 128
- Belgium: 152
- Bulgaria: 52
- Czech Republic: 197
- Denmark: 71
- Finland: 103
- France: 918
- Germany: 1316
- Greece: 111
- Hungary: 62
- Italy: 1422
- Netherlands: 177
- Norway: 88
- Poland: 220
- Portugal: 125
- Slovakia: 60
- Spain: 354
- Sweden: 93
- Switzerland: 379
- United Kingdom: 803

**CANDIDATE FOR ACCESSION**
- Romania: 88

**ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP**
- Israel: 63
- Serbia: 31

**OTHERS**
- Chile: 7
- China: 114
- Colombia: 69
- Croatia: 24
- Cuba: 3
- Cyprus: 7
- Egypt: 11
- Estonia: 17
- Georgia: 10
- Iceland: 4
- Iran: 23
- Ireland: 8
- Korea: 96
- Lithuania: 13
- Malta: 1
- Mexico: 41
- Montenegro: 1

**OBSERVERS**
- India: 146
- Japan: 238
- Russia: 883
- Turkey: 94
- USA: 1757

**CANDIDATE FOR ACCESSION**
- Argentina: 19
- Armenia: 15
- Australia: 32
- Azerbaijan: 2
- Belarus: 22
- Brazil: 107
- Canada: 168

**OTHERS**
- China (Taipei): 69
- Colombia: 10
- Croatia: 24
- Cuba: 3
- Cyprus: 7
- Egypt: 11
- Estonia: 17
- Georgia: 10
- Iceland: 4
- Iran: 23
- Ireland: 8
- Korea: 96
- Lithuania: 13
- Malta: 1
- Mexico: 41
- Montenegro: 1

**OBSERVERS**
- Morocco: 10
- New Zealand: 9
- Pakistan: 22
- Peru: 2
- Saudi Arabia: 3
- Slovenia: 30
- South Africa: 25
- South Korea: 26
- Tunisia: 1
- Ukraine: 25
- Venezuela: 1

**Total Users:** 6831

**Total Observers:** 3118

**Total Others:** 959
Survey in March 2009

They do not all stay: where do they go?

Today:
~2500 PhD students in LHC experiments
CERN: Particle Physics and Innovation

- Interfacing between fundamental science and key technological developments

- CERN Technologies and Innovation

  - Accelerating particle beams
  - Detecting particles
  - Large-scale computing (Grid)
CERN Technologies and Innovation
Example: Medical applications
Combining Physics, ICT, Biology and Medicine to fight cancer

Hadron Therapy
- Detecting particles
  - Accelerating particle beams
    - ~30'000 accelerators worldwide
    - ~17'000 used for medicine
  - >70'000 patients treated worldwide (30 facilities)
  - >21'000 patients treated in Europe (9 facilities)
- Imaging
  - Protons light ions
  - X-ray
  - Protons
- PET Scanner
  - Clinical trial in Portugal for new breast imaging system (ClearPEM)
  - Leadership in Ion Beam Therapy now in Europe and Japan

Brain Metabolism in Alzheimer's Disease: PET Scan
Main emphasis: High energy frontier, i.e. LHC and beyond
But: rich program of accelerator based particle physics

LHC: 27 km circumference
The Particle Physics Landscape at CERN

**High Energy Frontier**

**LHC**

**Hadronic Matter**
- deconfinement
- non-perturbative QCD
- hadron structure

**Low Energy**
- heavy flavours / rare decays
- neutrino oscillations
- anti-matter

**Non-accelerator**
- dark matter
- astroparticles

**Multidisciplinary**
- climate, medicine

**Non-LHC Particle Physics** = $o(1000)$ physicists / $o(20)$ experiments

---

In the past few years

**Several breakthroughs !**

**Steady progress of other programs**

**New mid-term and long-term projects started or in discussion**
Antiproton Physics

Cold antiprotons
("manufacturing anti-matter")
1. PS $p \rightarrow pp \ 10^{-6}$/collision
2. AD deceleration + cooling stochastic + electron
3. Extraction @ ~ 0.1c
4. Produce thousands of anti-$H$

Anti-$H$ annihilations detected
ATHENA ($\rightarrow$ ALPHA)

$anti-H (pe^+)$ + matter $\rightarrow \pi^+\pi^- + \gamma\gamma$

Neutrino Physics

CERN NEUTRINOS TO GRAN SASSO

Data taking now terminated

Silicon micro strips
CsI crystals

511 keV $\gamma$

Fixed Target Physics
Breakthroughs... ALPHA
First successful trapping of Anti-Hydrogen atoms
Trapping times of more than 15mn regularly achieved

Breakthroughs... ASACUSA

Antiproton mass measurement

- van Dyck 86 / CODATA 86
- Farnham 95
- Beier 02
- Verdu 04
- CODATA 02 average
- This work

CODATA 2010
\[ \rho = 1836.15267245(75) \]
\[ \bar{\rho} = 1836.1526736(23) \]

First $\nu_\tau$ Candidate

Muonless event 9234119599, taken on 22 August 2009, 19:27 (UTC)
(as seen by the electronic detectors)
Nucleation depends on traces of organic vapors (tertiary process) and is sensitive to cosmic rays ionization. Atmospheric nucleation rates however not reproduced with $\text{H}_2\text{SO}_4 + \text{NH}_3$ only, other (yet unknown) organic compounds needed.

More studies ongoing at lower temperature.
Glion Colloquium / June 2009

Accelerating Science and Innovation

Energy Frontier

LHC
Past few decades

“Discovery” of Standard Model

through synergy of

hadron - hadron colliders (e.g. Tevatron)
lepton - hadron colliders (HERA)
lepton - lepton colliders (e.g. LEP)
Test of the SM at the Level of Quantum Fluctuations

indirect determination of the top mass

possible due to
• precision measurements
• known higher order electroweak corrections

\[ \propto \left( \frac{M_t}{M_W} \right)^2, \ln \left( \frac{M_h}{M_W} \right) \]
Key Questions of Particle Physics

- origin of mass/matter or origin of electroweak symmetry breaking
- unification of forces
- fundamental symmetry of forces and matter
- where is antimatter
- unification of quantum physics and general relativity
- number of space/time dimensions
- what is dark matter
- what is dark energy
For all proposed solutions:
new particles should appear
at \textbf{TeV} scale or below
\rightarrow \textbf{territory of the LHC}

\textbf{Stand. Model}

\begin{itemize}
  \item \textit{Supersymmetry}:
    \begin{itemize}
      \item New particles at $\approx$ TeV scale, light Higgs
      \item Unification of forces
      \item Higgs mass stabilized
      \item No new interactions
    \end{itemize}
  \item \textit{Extra Dimensions}:
    \begin{itemize}
      \item New dimensions introduced
      \item $m_{\text{Gravity}} \approx m_{\text{ew}}$ $\Rightarrow$ Hierarchy problem solved
      \item New particles at $\approx$ TeV scale
    \end{itemize}
  \item \textit{Technicolor}:
    \begin{itemize}
      \item New (strong) interactions produce EWSB
      \item Extensions of the SM gauge group: Little Higgs / GUTs / ...
    \end{itemize}
\end{itemize}
2010: a New Era in Fundamental Science

Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions
at $E_{CM}$ up to 14 TeV
2010: a New Era in Fundamental Science

Exploration of a new energy frontier
Proton-proton and Heavy Ion collisions at $E_{CM}$ up to 14 TeV

LHC ring: 27 km circumference

ALICE
LHCb
CMS
LHCf
TOTEM
MOEDAL
ATLAS
LHC Experiments → complementary

- CMS
- ATLAS
- LHCb
- ALICE

Specialised detector to study b-quarks → CPV

General purpose detectors

Specialised detector to study heavy ion collisions
LHC Experiments → complementary

Overlap in physics reach

Key feature: reconstruct secondary vertex

CMS

LHCb

ATLAS

ALICE

LHCb Preliminary
EVT: 49700980
RUN: 70684
LHC Experiments → complementary

Overlap in physics reach

Key feature: reconstruct > 20’000 charged tracks in one event

Overlap in physics reach
Versatility of LHC & complementarities of experiments make the whole of LHC a more powerful instrument than the sum of its parts
Basic processes at LHC

Proton 1 $p_1$

$fa(x_1, Q^2)$

Proton 2 $p_2$

$fb(x_2, Q^2)$

$q$

$q'$

Jet

Jet
Di-jet event recorded by ATLAS on 9 April 2012 at $\sqrt{s}=8$ TeV

Leading jet $p_T$:

1.96 TeV = 1 Tevatron !!

$p_T (j,j)= 1.96, 1.65$ TeV, $M (jj) = 3.6$ TeV
Basic processes at LHC

Proton 1 $p_1$

Proton 2 $p_2$

$g$

$f_b(x_2, Q^2)$

$g$

$W/Z$

$W/Z$

$f_a(x_1, Q^2)$
“Well known” processes. Don’t need to keep all of them ...

New Physics!!
We want to keep!!
Evolution of Integrated Luminosity 2012
The Worldwide LHC Computing Grid

Tier-0 (CERN): data recording, reconstruction and distribution

Tier-1: permanent storage, re-processing, analysis

Tier-2: Simulation, end-user analysis

WLCG:
An International collaboration to distribute and analyse LHC data

Nearly 160 sites, 35 countries
~250’000 cores
173 PB of storage
> 2 million jobs/day
10 Gb links

Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists
Physics Objectives for 2010-2012 LHC Run I

- Integrated Luminosity
  - 1 nb
  - 1 pb
  - 1 fb

Physics = f(Time)

We are here!

- W & Z Observation
- Di-jets
- Min. bias
- W/Z Measurements
- Di-top Observation
- W/Z + N jets
- WZ Observation
- WW Measurements
- ZZ Observation

Higgs ?
SUSY ?
Z'
A tiny part of our measurements

- Experiments have about completed their journey through the Standard Model ...
- and have started to take us into new territories ...

- **B⁺ → J/ψ(→μμ)K⁺** production (2011 data)

- **ZZ → 4ℓ** (20 fb⁻¹ @ 8 TeV)

- **WZ → 3ℓv** (13 fb⁻¹ @ 8 TeV)
The study of LHC data will allow us to answer some of the key questions ...

Will we understand the **primordial state of matter** after the Big Bang before protons and neutrons formed?

Have we found the **Higgs particle** that is ‘responsible for giving mass’ to all particles?

Will we find the reason why **antimatter and matter** did not completely destroy each other?

Will we find the **particle(s)** that make up the **mysterious ‘dark matter’** in our Universe? And what’s ‘dark energy’?
Low $p_T$ direct photons $\rightarrow$ a direct thermometer for the temperature of the fireball

Integrated over fireball history: $T = 304$ MeV
initial temperature $> 450$ MeV
highest temperature ever measured in the laboratory

around $3.5 \times 10^{12}$ K

$0$-$40\%$ Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV
Correlations

- Correlations for pairs of trigger and associated particles, $p_{T,\text{trig}} > p_{T,\text{assoc}}$, as $f(\Delta \phi, \Delta \eta)$, defined as associated yield per trigger particle.

Low multiplicity event class

- Qualitatively similar to CMS ridge

High multiplicity event class

- Excess on both near-side (NS) and away-side (AS) going from p-p/low multiplicity -> high multiplicity events

Projection on $\Delta \phi$ – pPb and pp data

Subtracting the low-mult from the high-mult

- A double-ridge structure appears, with remarkable properties:
  - Shape of the distributions decomposed into a Fourier series, in terms of the coefficients $v_n$ of the corresponding single particle azimuthal distributions:
    - $v_2$ is the dominant component
    - $v_2$ and $v_3$ increase with $p_T$ and $v_2$ also with multiplicity
  - Same yield near and away side for all classes of $p_T$ and multiplicity:
    - Suggest common underlying process
  - Width independent of yield
  - Possible explanations? CGC?? Flow??

Huge amount of information, opening a new window in the field

Also observed by ATLAS
- Smooth pA/Ap LHCb run (data on both directions, and with magnet UP & DOWN)
- 2/nb collected (x10 what expected)
- Analyses started: particle multiplicities, resonances (D, J/ψ, Υ) as probes of DY process in a low (x, Q²) area specific of LHCb only

J/ψ → μμ

from B decays
The study of LHC data will allow us to answer some of the key questions ...

Will we understand the **primordial state of matter** after the Big Bang before protons and neutrons formed?

Have we found the **Higgs particle** that is ‘responsible’ for giving mass to all particles?

Will we find the reason why **antimatter and matter** did not completely destroy each other?

Will we find the **particle(s)** that make up the mysterious ‘**dark matter**’ in our Universe? And what’s ‘**dark energy**’?
Dark Matter

Astronomers & astrophysicists over the next two decades using powerful new telescopes will tell us how dark matter has shaped the stars and galaxies we see in the night sky.

Only particle accelerators can produce dark matter in the laboratory and understand exactly what it is.

Composed of a single kind of particle or more rich and varied (as the visible world)?

LHC may be the perfect machine to study dark matter.
Supersymmetry

- Unifies matter with forces for each particle a supersymmetric partner (sparticle) of opposite statistics is introduced.

- Allows to unify strong and electroweak forces:
  \[ \sin^2\theta^\text{SUSY}_W = 0.2335(17) \]
  \[ \sin^2\theta^\text{exp}_W = 0.2315(2) \]

- Provides link to string theories.

- Provides Dark Matter candidate (stable Lightest Supersymmetric Particle)
Beyond the Higgs Boson

Supersymmetry: A New Symmetry in Nature

Candidate Particles for Dark Matter
⇒ Produce Dark Matter in the lab

SUSY particle production at the LHC

... but potential for discovery of SUSY particles sizeable in the coming years

3 isolated leptons
+ 2 b-jets
+ 4 jets
+ \( E_{t\text{miss}} \)
LHC results should allow, together with dedicated dark matter searches, first discoveries in the dark universe. Around 73% of the Universe is in some mysterious “dark energy”. It is evenly spread.

Challenge:
get first hints about the world of dark energy in the laboratory
The Higgs is Different!

All the matter particles are spin-1/2 fermions.
All the force carriers are spin-1 bosons.

Higgs particles are spin-0 bosons (scalars).
The Higgs is neither matter nor force.
The Higgs is just different.
This would be the first fundamental scalar ever discovered.

The Higgs field is thought to fill the entire universe.
Could it give some handle of dark energy (scalar field)?

Many modern theories predict other scalar particles like the Higgs.
Why, after all, should the Higgs be the only one of its kind?

LHC can search for and study new scalars with precision.
Search for the Higgs-Boson at the LHC

Production rate of the Higgs-Bosons depends on its mass as well as its decay possibilities.

\[ \sqrt{s} = 7 \text{TeV} \]

Production rate of the Higgs-Bosons depends on its mass as well as its decay possibilities.
SM Higgs
4 July 2012: CERN scientific seminar
“CERN experiments observe particle consistent with long-sought Higgs boson”
A historical day: 4th July 2012

Observation of a new particle consistent with a Higgs Boson (but which one...?)

Historic Milestone but only the beginning

Global Implications for the future
S/B Weighted Mass Distribution

- Sum of mass distributions for each event class, weighted by S/B
- B is integral of background model over a constant signal fraction interval

![Graph showing S/B weighted mass distribution with data points and fitted curves for CMS Preliminary with statistics on luminosity and energy.]
Evolution of the excess with time
But what kind of Higgs is it?
- 5 main channels shown at right
  - All are determined at $m=125$ GeV except for the ZZ channel which uses the best fit $m_{ZZ}=125.8$
  - Full combination with best combined mass value will result in different signal strengths than those seen here.
- Consistent with SM
- But can’t rule out a BSM Higgs!

New significance values:
- $H \rightarrow ZZ \rightarrow 4l$: $6.7 \sigma$ (7.2 exp.)
- $H \rightarrow WW$: $4.1 \sigma$ (5.1 exp.)
- $H \rightarrow \gamma \gamma$: $3.2 \sigma$ (4.2 exp.)
- $H \rightarrow \tau \tau$: $2.9 \sigma$ (2.6 exp.)

New mass values
- ZZ: $m_H = 125.8 \pm 0.5$ (stat.) $\pm 0.2$ (syst.)
- $\gamma \gamma$: $m_H = 125.4 \pm 0.5$ (stat.) $\pm 0.6$ (syst.)
- $\tau \tau$: $m_H = 120^{+9}_{-7}$ (stat+syst) GeV

It has the properties of a Higgs boson
... but that’s only the beginning!
What’s next?

... it is a Higgs Boson!
... is it the Higgs Boson (of the Standard Model)?
or one of several?

... its properties could give information
on Dark Matter
... its properties could give first hints
on Dark Energy

Physics programme at the LHC
beyond 2030
The Couplings roadmap

Test Higgs boson couplings depending on available L:

- Total signal yield tested at 10-20%
- Couplings to Fermions and Vector Bosons tested at 20-30%
- Loop couplings tested at 40%
- Custodial symmetry W/Z Couplings tested at 30%
- Test Down vs Up fermion couplings
- Test Lepton vs Quark fermion couplings
- Top yukawa direct measurement $t\bar{t}H: \kappa_t$
- Test second generation fermion couplings: $\kappa_\mu$
- Higgs self-couplings couplings $HHH: \kappa_H$

Looking only at the studies of the Higgs Boson
There is much more physics beyond the Higgs

LHC Upgrade
14 TeV
~ 3000 fb⁻¹

~ 30 fb⁻¹
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle’s properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

*Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*
Around 2022 the Present Triplet magnets reach the end of their useful life (due to radiation damage) ...and will anyway need replacing.

In addition the Luminosity of the LHC will saturate by then

Time for an upgrade: HL-LHC
The LHC roadmap to fully exploit the physics potential

- **2009**
  - LHC startup, $\sqrt{s} = 900$ GeV

- **2010**
  - $\sqrt{s} = 7\sim 8$ TeV, $L = 6 \times 10^{33}$ cm$^{-2}$ s$^{-1}$, bunch spacing 50 ns

- **2011**
  - Go to design energy, nominal luminosity

- **2012**
  - $\sqrt{s} = 13\sim 14$ TeV, $L = 1 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, bunch spacing 25 ns

- **2013**
  - LS1

- **2014**
  - Injector and LHC Phase-1 upgrade to ultimate design luminosity

- **2015**
  - $\sqrt{s} = 14$ TeV, $L = 2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, bunch spacing 25 ns

- **2016**
  - LS2

- **2017**
  -

- **2018**
  - LS3

- **2019**
  - HL-LHC Phase-2 upgrade, IR, crab cavities?

- **2020**
  - $\sqrt{s} = 14$ TeV, $L = 5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, luminosity levelling

- **2021**
  -

- **2022**
  -

- **2023**
  - ...

- **2030?**
  - $\sim 3000$ fb$^{-1}$
LHC and Injectors 2013/14

- LS1 ongoing as planned
- Restart of accelerator chain in 2014
  - mid June PSB, Isolde
  - mid July east area
  - mid October SPS
- Restart LHC 2015 (commissioning, then physics)
Key message

There is a program with the LHC for at least 20 years:
7 and 8 TeV, 14 TeV design luminosity, 14 TeV high luminosity (HL-LHC)

Upgrades to accelerator complex, detectors, and computing Grid are vital to fully exploit the physics potential of LHC
beyond LHC?
Road beyond Standard Model

At the energy frontier through synergy of

hadron - hadron colliders (LHC, (V)HE-LHC?)

hadron - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (ILC or CLIC) ?)
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. **CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.**

This covers all colliders mentioned before, albeit with different priority
High Energy Hadron – Hadron Colliders
HE – LHC and VHE-LHC

Study of New Physics Phenomena

main challenge: High-Field Magnets
HE-LHC – LHC modifications

HE-LHC >2030
SPS+, 1.3 TeV, >2030
2-GeV Booster
Linac4

July 23, 2011
HE-LHC

- HE-LHC dipole design will piggy back on the high gradient quadrupole R&D needed for HL-LHC
  - Would allow an increase in energy by factor of 2-2.5
Beyond High Energy LHC

- First studies on a new 80 km tunnel in the Geneva area
  - 42 TeV with 8.3 T using present LHC dipoles
  - 80 TeV with 16 T based on Nb$_3$Sn dipoles
  - 100 TeV with 20 T based on HTS dipoles

Figure 9. Two possible location, upon geological study, of the 80 km ring for a Super HE-LHC (option at left is strongly preferred)
Such a large tunnel would also allow $e^+e^-$ and $e^-p$ collisions in addition to $pp$ collisions.
HE-LHC and VHE-LHC

• VHE-LHC needs a (at least) 80km tunnel
  In conjunction with the high field magnets would allow a factor of \((2-2.5) \times \frac{80}{27} = 6-7.5\) times LHC (42- 52 TeV/beam)

• HE-LHC \rightarrow VHE-LHC
  (“80 km” study together with TLEP)

Logic (“roadmap”): exploit synergy effects between HL-LHC, HE-LHC, VHE-LHC (and TLEP), in particular high field magnet development
Lepton – Lepton Colliders
Both projects are global endeavours and at CERN part of the LC effort.

Wide range of Physics topics, e.g.
- Higgs couplings, in particular self coupling
- precision studies of Z, W, and Top
- new physics phenomena

Very interesting after the discovery of a Higgs Boson
Conceptual Design Report published

→ R&D continues (accelerator and detector) in the framework of the CLIC collaboration (e.g. high gradient accelerating structures)
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

1. There is a strong scientific case for an electron-positron collider, complementary to the Large Hadron collider, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.

2. CERN ILC efforts will continue in the framework of the LC efforts.
After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

Decision to be taken in the framework of the next 5-years plan for the neutrino sector.

**CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.**
Fixed Target Program (examples)

- HIE-Isolde as approved and ongoing
- AD and ELENA as approved; extension for GBAR and addition of a storage ring under consideration
- n-TOF (with EAR2) as approved

- CNGS terminated

- high gradient accelerator R&D (“AWAKE”)
Program at the energy frontier with the LHC for at least 20 years

R&D, Studies for the next projects ongoing

Global collaboration vital