INTERNATIONAL SCHOOL OF SUBNUCLEAR PHYSICS
14 June to 23 June 2016

The LAA Project

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Courtesy Tim Peake: Pictures taken from ISS Ref Spiegel ONLINE.
The school presented several highlight talks about LHC including ..... The LAA impact on technology R&D: from past to future. with slights on detector upgrades for LHC Run2 and a time line for LHC programs
The LAA Project

history - achievements - and what next …
CERN’s first 30 years: from fixed targets to the first colliders
The Synchrocyclotron (SC) -
The CERN Proton Synchrotron (CPS) -
The Intersecting Storage Rings (ISR) -
The Super Proton Synchrotron (SPS) & Experimental Areas -
The Proton–Antiproton Collider
1927, Eugene Wigner formalized the principle of conservation of parity

1956 Tsung-Dao Lee and Chen-Ning Yang realized: no experimental evidence for parity conservation in weak interactions

1957 Chien-Shiung Wu testing the directional properties of beta decay in cobalt-60
Mirror plane

Original arrangement

Mirror-reversed arrangement

Preferred direction of beta ray emission

Cobalt-60 nuclei

Direction of electron flow through the solenoid coils

Predicted direction of beta emission if parity were conserved

Observed direction of beta emission in mirror-reversed arrangement
from original ideas
to experimental evidence for the Standard Model

At the end of the 1950's weak interactions were well described by the V-A theory.

Citation Dieter Haidt

Drawback of the V-A theory for weak interactions was a bad high energy behaviour, which initiated various ideas to cure the problem of infinities. Guided by QED as a gauge theory, attempts were made in the 60's to construct a gauge theory of weak interactions. The intermediate vector boson (W) - existence not yet known - was complemented with a neutral intermediate vector boson to achieve the required cancellations.
The Brout-Englert-Higgs mechanism solved the problem of a
gauge theory and massive mediators of weak interactions.

The progress gained by Glashow, Salam and Weinberg was
completed by the work of Veltman & 't Hooft demonstrating
the renormalizability of the theory.

So, at the turn from 1971 to 1972 a viable theory of weak
interactions claiming weak neutral currents as crucial
ingredient was proposed and experiment was prompted to
answer by yes or no whether weak neutral currents existed
or not. In fact, two neutrino experiments were running, the
Gargamelle bubble chamber experiment at CERN and the
HPWF counter experiment at NAL (now FNAL). Both were
confronted with this challenge without preparation.
EXAMPLE: neutral currents

Fig. 1: one-dimensional model used in estimating the neutron-induced contribution to the neutral-current candidates.
November 1974 SLAC and BNL discovery, now "called the J/psi, that helped verify the existence of the charmed quark. This was the breakthrough for the theoretical picture of the Standard Model.

This was followed in 1984 by the experimental evidence for the intermediate vector bosons in UA1 and UA2.
an important recommendations of the ..

ECFA – LEP Working Group
Progress Report

Chairman: A ZICHICHI

which paved the way to build a 27km tunnel for

LEP & LHC
CERN’s second 30 years: the LEP and LHC and other experiments
The Large Electron Positron Collider (LEP)
The Large Hadron Collider (LHC)
The excavation of the LEP tunnel (27 km) was the most formidable civil-engineering venture in the history of CERN and Europe's largest civil-engineering project prior to the Channel Tunnel (50 km - train) and the Gotthard Basis tunnel (57 km - train).
and when CERN then entered the LEP era

Unlike previous CERN projects such as BEBC, the ISR and the SPS, in the case of LEP the large-scale infrastructure, the 27 km tunnel and the collider itself, had all to be planned and constructed without project funding in addition to the regular budget.
from 1980 to 1989 the CERN resources were mainly dedicated to SPSpp_{bar} and to the LEP project. Not much was left for other activities, the ISR, all bubble chambers etc. had to be closed to free resources for LEP construction.
The timeline illustrates the evolution of various Large Hadron Collider (LHC) projects from 1980 to 2040:

- **LEP (1980-2000)**: Construction, Physics, Upgrade.
- **FCC (2030-2040)**: High Luminosity LHC.

Each phase represents a significant advancement in particle physics research, with a focus on high-energy collisions and the pursuit of new physics.
The LAA Project was initiated by Prof. A. Zichichi, funded by the Italian government and implemented at CERN in 1986.

The goal of the project was to prove the feasibility of new detector technologies that could be used in a future multi-TeV hadron collider.
THE LAA PROJECT

- 5 - SUBNUCLEAR MULTICHANNEL INTEGRATED DETECTOR TECHNOLOGIES
- 6 - DATA ACQUISITION AND ANALYSIS

≈ 30 m long

= 30000 tons detector

Low B - large volume

p (10+100 TeV)

High B

p (10+100 TeV)

≈ 20 m diameter

1 - HIGH PRECISION TRACKING

2 - CALORIMETRY

3 - LARGE AREA DEVICES

7 - SUPERCOMPUTERS AND MONTECARLO SIMULATION

4 - LEADING PARTICLE DETECTION

8 - VERY HIGH MAGNETIC FIELDS

9 - SUPRACONDUCTIVITY AT HIGH TEMPERATURE

10 - RADIATION HARDINESS

Fig. 5 - The ten components of the LAA Project.
All aspects of an LHC detector layout were considered in the project and, in view of the demands of the machine, special attention was paid to hermeticity, radiation hardness, rate capability, and momentum resolution of the detector assemblies.

Although the solutions adopted for the LHC may differ from those studied at the LAA, the LAA work had a great influence and measurable impact on the design of the present LHC detectors.
LAA was established by the CERN Council in 1986

Recruitment of > 40 LAA staff-members (technicians-engineers-physicists) & over 80 unpaid scientists worked for the project.
The LAA Project consisted of 11 sub-projects:

https://indico.cern.ch/event/318730/contributions/737335/

High precision tracking
Calorimetry
Large area muon detection devices
Leading particle detection
Data acquisition and analysis

The LAA project was open to all physicists and engineers. The project was presented in an open presentation at CERN in June 1987 and subsequently to CERN’s Research Board.

The main achievements were described in a CERN report (CERN/LAA/91-1).
The impact of LAA on the LHC Detectors
Has been outlined in the books ....
In 1962, A. Zichichi’s group developed the PAPLEP (Proton-AntiProton into LEpton Pairs) experiment at the CERN Proton Synchrotron (PS). This NBC Non Bubble Chamber Detector introduced techniques such as pre-shower, punch through, time-of-flight... was the beginning of the search for the 3rd sequential lepton family.

For a complete history see Wu et al. (1997). The idea was to look for lepton pairs of opposite sign.
IL NUOVO CIMENTO
rivista internazionale di fisica
fondata a Pisa nel 1885 da C. Matteucci e R. Peria
dal 1897 Organo della Società Italiana di Fisica
pubblicata sotto gli auspici del Consiglio Nazionale delle Ricerche
a cura del Direttore
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e del Vicedirettori
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A. ZICHICHI — Project Leader

Advances in Technology for High-Energy Subnuclear Physics.
Contribution of the LAA Project.

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Further details are contained in the «Guide for the Authors», which will be sent free on request.
LAA achievements
LAA R&D activities described in > 350 publications
LAA R&D groups participation in 8 major proposals approved by the CERN DRDC

Impact of LAA works on LHC technology:
multi-drift chambers, scintillation fibre trackers, GaAs microstrip precision tracking and read-out electronics, IPSA tube (Imaging Silicon Pixel Array) silicon pixels detectors...CMOS chips and ASIC/VLSI chip detector read-out

LAA participated in several CERN R&D program 1990 to 1996 e.g.: RD 8 GaAS collaboration, RD 9 Demonstrator for analog signal processing in SOI-CMOS technology, RD19 Hybrid and monolithic silicon micropattern detectors.....
LAA engineers, physicists, technicians help LHC experiments till today.

A **sustainable impact of LAA** has been and is still in the technology domains of silicon detectors and micro-electronics. ...

It allowed to build-up the know-how at CERN via recruitment of electronic engineers

It allowed to finance hardware & software tools required for the development/design of microelectronics, silicon strip, pixel detectors
LEP vertex detector timeline

1989, ALEPH & DELPHI
install prototype modules

1990, ALEPH & DELPHI
install first complete barrels
ALEPH read rz coordinate with “double sided” detectors

1991, all
Beampipes go from Al with r=8 cm to r=5.3 cm Be
DELPHI installs three layer vertex detector
OPAL construct and install detector in record speed

1992, L3
2 layer double sided vertex detector

1993, OPAL
install rz readout with back to back detectors

1994, DELPHI
double sided detectors and “double metal” readout

1996, DELPHI
install “LEP II Si Tracker” with μstrips, ministrips & pixels
“.. the design of custom chips for silicon detector readout was started at SLAC in 1981 and at CERN in 1986 via LAA”. The basis for the CERN micro-electronics group goes back to the implementation of the LAA project.
1st component in LAA project
Si detector with AMPLEX chip

HERMETIC PAD DETECTORS UA2

~5 mm THICK CILINDER
ONLY POSSIBLE with "AMPLEX" CHIP DESIGN Pierre Jarron

1986 – 1988 FIRST Si DETECTOR in COLLIDER
FIRST operating Si DETECTOR with IC CHIP READOUT

DETECTOR CYLINDER CURRENTLY IN U. DORTMUND by Claus Gößling

16 CHANNELS COLLABORATION IMEC LEUVEN
2nd component in LAA project
micropattern pixel detector

First design in collaboration with EPFL

Krummenacher et al.
NIM A288(1990)176
(presented at Munich Symp Feb 1989)

Chip ready
Summer 1989
published at IEEE Nucl Sc Symp 1989

Campbell et al. NIM A290 (1990) 149
results including spectra taken with radioactive sources

Chip layout  Dec 1988
Krummenachher & Enz  EPFL
PROGRESS REPORT 1988–1989

DEVELOPMENT OF INTEGRATED CMOS CIRCUITS AND SILICON PIXEL DETECTORS IN THE CERN–LAA PROJECT

F. Anghinolfi, P. Aspell, M. Campbell, E.H.M. Heijne, P. Jarron and G. Meddeler
CERN, EF-Division, Geneva, Switzerland

Ch.C. Enz and F. Krummenacher
LEG–EPFL, Lausanne, Switzerland

L. Moult and P. Sharp
Rutherford Appleton Laboratory, Chilton-Didcot, UK

A. Olsen
Senter for Industriforskning, Oslo, Norway

Abstract
Microelectronics at CERN

The start of the LAA project in 1986 propelled electronics at CERN into the era of microelectronics, and laid crucial foundations for the success of the LHC experiments.

The start of the LAA project led directly to the build-up of know-how within CERN’s Experimental Physics Facilities Division, with the recruitment of young and creative electronic engineers. It also enabled the financing of hardware and software tools, as well as the training required to prepare for the future. By 1988, an electronics design group had been set up at CERN, dedicated to the silicon technology that now underlies many of the high-performing detectors at the LHC and in other experiments. Miniaturization to sub-centimeter scale and in particular the replacement of wires by chip-to-chip connections, and the use of sophisticated computer tools, were vital ingredients of this success.
from infancy to maturity

The LAA

The LAA programme, proposed by Antonino Zichichi and financed by the Italian government, was launched as a comprehensive R&D project to study new experimental techniques for the next step in hadron-collider physics at multi-tera-electron-volt energies. The project provided a unique opportunity for Europe to take a leading role in advanced technology for high-energy physics. It was open to all physicists and engineers interested in participating. A total of 40 physicists, engineers and technicians were recruited, and more than 80 associates joined the programme. Later in the 1990s, during the operation of LEP for physics, the programme was complemented by the activities overseen by CERN's Detector R&D Committee.

years 1984–1985 Heijne was seconded to the University of Leuven, where the microelectronics research facility had just become the Interuniversity MicroElectronics Centre (IMEC). It soon became apparent that CMOS technology was the way ahead, and the experience with IMEC led to Jarron's design of the AMPLEX.

(Earlier, in 1983, a collaboration between SLAC, Stanford University Integrated Circuits Laboratory, the University of Hawaii and Bernard Hyams from CERN had already initiated the design of the "Microplex" - a silicon-microstrip detector read-out chip using nMOS, which was eventually used in the MARK II experiment at SLAC in the summer of 1990. The design was done in Stanford by Sherwood Parker and Terry Walker. A newer iteration of the Microplex design was used in autumn 1989 for the microvertex detector in the DELPHI experiment at LEP.)

Heijne and Jarron were keen to launch chip design at CERN, as was Alessandro Marchioro, who was interested in developing digital signal processing. However, a major obstacle for the group of

the group, and from Jim Virdee, who is one of the founding fathers of the CMS experiment at the LHC. Together, they recalled the birth and gradual growth to maturity of microelectronics at CERN.

The beginning

2 to fit a silicon-pad detector (bottom left) in the 9 mm gap around the beam pipe in WA97 in the mid-1990s. By 2002, CERN had developed a silicon pad detector produced in the nearby beam dump during the first injection tests (right).
Silicon Detectors: 60 years of innovations by Erik Heijne (Czech Technical University (CZ))
CERN presentation 16 June 2016

https://indico.cern.ch/event/537154/
Silicon Detectors: 60 years of innovations
HEIJNE, E. (Czech Technical University (CZ))

The first demonstration of a semiconductor particle detector in 1944 was followed by intense efforts, exploiting the rapidly evolving materials purification technologies. About 10 years later the first practical silicon devices were used for energy measurement of ionizing nuclear particles. From then on, during 60 years a succession of innovations in materials, geometry, processing technology, system architecture and signal readout electronics has led to widespread use of silicon detectors in experiments, materials analysis and medical imaging.

Belatedly, thanks to innovations at CERN and by other teams in elementary particle physics worldwide, the segmented silicon pixel and micro-strip detectors now made their comeback in the LHC, allowing 40 million frames per second to be recorded, 7 orders of magnitude more than in the ~1975 bubble chambers.
How can we get Intelligent Systems Close to Experiments?

R.K. Bock, Y. Ermolin, W. Krischer, Ch. Ljuslin, S. Lone, A. Marchioro, K. Zografos

CERN, Geneva, Switzerland

(presented at the Snowmass Summer Study, July 5 – 7 1988)

Abstract

For the high data rates expected at future multi-TeV hadronic colliders like the SSC, it is of utmost importance to take decisions in real time on partial data and as fast as possible. At a first level and shortest timescale, some customized electronics will reduce the rates. In a second phase, decisions have to use concepts closer to physics and hence imply the presence of some intelligence in the trigger. We consider various parallel computer or computer-like systems for their possibilities to be embedded as critical active elements in future detectors. We also discuss the present activities and the pilot systems being built up as part of the LAA project at CERN. These activities aim at a better understanding of existing commercial systems, their design, and their limits of performance. The ultimate aim is to integrate suitable system designs in a flexible way into the data acquisition electronics of future detectors, most likely in VLSI technology.

The Data Acquisition Environment
LAA spin-off to recent developments

two examples
Technology Transfer

Medipix success story

Timepix + Si

University of Canterbury, Christchurch, New Zealand
CEA, Paris, France
CERN, Geneva, Switzerland
DESY-Hamburg, Germany
Albert-Ludwigs-Universität Freiburg, Germany
University of Glasgow, Scotland, UK
Leiden University, The Netherlands
NHETC, Amsterdam, The Netherlands
Mid Sweden University, Sundsvall, Sweden
IEAP, Czech Technical University, Prague, Czech Republic
ESRF, Grenoble, France
Universität Erlangen-Nurnberg, Erlangen, Germany
University of California, Berkeley, USA
USA VTT, Information Technology, Espoo, Finland
ISS, Forschungszentrum Karlsruhe, Germany
University of Houston, USA
Diamond Light Source, Oxfordshire, England, UK
Universidad de los Andes, Bogota, Colombia
University of Bonn, Germany
AMOLF, Amsterdam, The Netherlands
ITER, Cadarache, France
Technical University of Munich, Germany

Carlos Granja Institute of Experimental and Applied Physics
Czech Technical University in Prague

DEVELOPMENT OF INTEGRATED CMOS CIRCUITS AND SILICON PIXEL

E. Anghinolfi, P Aspell, M Campbell, E.H.M. Reine, P. Taron, G Meddever, C. Olsen

CERN Accelerating science

Description
The Medipix2 ASIC is a high spatial, high contrast resolving CMOS pixel read-out chip working in single photon counting mode. It can be combined with different semiconductor sensors which convert the X-rays directly into detectable electric signals. This represents a new solution for various X-ray and gamma-ray imaging applications.

The core concept of the Medipix2 chip was originally invented for pattern recognition in tracing of particles in the LHC. Since then the technological platform has evolved and is being developed for different application specific directions.

Area of expertise
Electronics
Applications
Life Sciences
Digital Art/Music
Astrophysics
Medical Imaging and gamma-ray Imaging applications

ESA/ ISS
THE MULTIGAP RESISTIVE PLATE CHAMBER (MRPC) – the base of the ALICE TOF – is an outstanding example of a very successful LAA R&D proposal.
The very good time resolution of MRPCs is due to the strong uniform electric field, which provokes the avalanche process immediately after primary ionization is deposited in the gas volume.

Resistive plates are physical barriers to stop the avalanche growing too big, but they are invisible for fast signals; the readout signal is the sum of the signals induced in each gap.

Time resolution is determined mainly by the avalanche statistics $\sigma \approx 1/(\alpha_{\text{eff}} v_D)$.

Very tiny gaps allow to have intense electric field preventing avalanches to develop sparks.

In this regime the development of the avalanche is strongly dominated by space-charge effect. Space-charge field inside the avalanche reaches the same magnitude as the applied electric field, stopping the exponential development of the avalanche (saturated avalanche mode).

A series of many gas gaps guarantees a high efficiency.

Typical parameter for ALICE MRPCs are, assuming $\Delta V \approx 13\text{kV}$ and standard gas mixture:
- Electric field $E \approx 100 \text{kV/cm}$
- Effective Townsend coefficient $\alpha_{\text{eff}} \approx 100 \text{mm}^{-1}$
- Drift velocity $v_D \approx 200 \text{\mu m/ns}$
ALICE Time-of-Flight ASIC: NINO front end

NINO 8-channels

- an ultra-fast, low-power, front-end amplifier discriminator for the Time-Of-Flight experiment in ALICE
- 3 Ghz preamplifier bandwidth
- Measure timing with 20 ps resolution
- 25,000 chips for ALICE TOF Pion-Kaon identification
NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber

F. Anghinolfi, P. Jarron, A.N. Martemiyanov, E. Usenko, H. Wenninger, M.C.S. Williams, A. Zichichi

EP Division, CERN, Geneva, Switzerland
Institute for Theoretical and Experimental Physics, Moscow, Russia
Institute for High Energy Physics, Protvino, Russia
Sezione INFN, Bologna, Italy
Dipartimento di Fisica dell’Università, Bologna, Italy

Available online 28 July 2004

Abstract

For the full exploitation of the excellent timing properties of the Multigap Resistive Plate Chamber (MRPC), front-end electronics with special characteristics are needed. These are (a) differential input, to profit from the differential signal from the MRPC (b) a fast amplifier with less than 1 ns peaking time and (c) input charge measurement by Time-Over-Threshold for slewing correction. An 8-channel amplifier and discriminator chip has been developed to match these requirements. This is the NINO ASIC, fabricated with 0.25 µm CMOS technology. The power requirement at 40 mW/channel is low. Results on the performance of the MRPCs using the NINO ASIC are presented. Typical time resolution σ of the MRPC system is in the 50 ps range, with an efficiency of 99.9%.

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PACS: 29.40.Ci; 84.30.—c; 84.30.Lq; 84.30.Qi

Keywords: Resistive plate chambers; ALICE; Time-of-flight; Fast amplifier; Discriminator; ASIC; CMOS technology
An interesting educational spin-off
Detectors R&D (TOF and electronics)

The « NINO ASIC » amplifier/discriminator for the signals from the MRPCs
Time-of-Flight array for ALICE

LAA group under Crispin Williams responsible for this R&D works

EEE project

6/22/2016 H.Wenninger ERICE 2011 50
EEE planar chambers

180 cm

90 cm

24 strips

6 gas gaps of 300 μm

after slewing corrections

Entries / 25 ps

σ = 160 ps

σ = 72 ps

no corrections

crispin.williams@cern.ch
EXAMPLE: BEH

Brout-Englert-Higgs (BEH) mechanism published in the 1960\textsuperscript{th} Experimental result - LHC experiments in 2012 some 50 years later
### Experiment Status

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous Lumi [(ub.s)^{-1}]</td>
<td>4068.586</td>
<td>1.758</td>
<td>3911.502</td>
<td>310.850</td>
</tr>
<tr>
<td>BRAN Luminosity [(ub.s)^{-1}]</td>
<td>3982.0</td>
<td>1.8</td>
<td>3766.8</td>
<td>266.2</td>
</tr>
<tr>
<td>Fill Luminosity (nb)^{-1}</td>
<td>325554.125</td>
<td>102.701</td>
<td>311254.000</td>
<td>19081557</td>
</tr>
<tr>
<td>Beam 1 BKGD</td>
<td>1.424</td>
<td>1.181</td>
<td>0.243</td>
<td>0.002</td>
</tr>
<tr>
<td>Beam 2 BKGD</td>
<td>1.716</td>
<td>0.045</td>
<td>0.293</td>
<td>0.040</td>
</tr>
</tbody>
</table>

### LHCb VELO Position

- **Status:** IN
- **Gap:** -0.0 mm
- **Status:** STABLE BEAMS
- **Status:** STANDBY

### Performance over the last 24 Hrs

- **Updated:** 08:59:06

![Graph showing performance over the last 24 hours](image-url)
### STABLE BEAMS

<table>
<thead>
<tr>
<th>Luminosity ((\text{ub.s})^{-1})</th>
<th>Fill Lumi ((\text{nb})^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATLAS</strong></td>
<td>4065.96</td>
</tr>
<tr>
<td><strong>ALICE</strong></td>
<td>1.73</td>
</tr>
<tr>
<td><strong>CMS</strong></td>
<td>3908.95</td>
</tr>
<tr>
<td><strong>LHCb</strong></td>
<td>309.58</td>
</tr>
</tbody>
</table>

ALICE Target Instantaneous Lumi = 1.7 Hz/ub

LHCb Target Instantaneous Lumi = 312.98645 Hz/ub
EXAMPLE: beyond the standard model?
CERN Council last week
message to the CERN members from to CERN DG, Fabiola Gianotti
Another important topic this week was the formal approval of the HL-LHC “High Luminosity LHC” project.

This comes as extremely good news not only for CERN, but also for particle physics globally. HL-LHC is the top priority of the European Strategy for Particle Physics in its 2013 update, and is part of the 2016 roadmap of the European Strategy Forum on Research Infrastructures, ESFRI.

It was also identified as a priority in the US P5 strategy process, and in Japan’s strategic vision for the field. It secures CERN’s future until 2035, and ensures that we will achieve the maximum scientific return on the investment in the LHC.

The Finance Committee passed some HL-LHC contract adjudications this week, allowing construction work to begin without delay.
and what next ...

quadrupole-hl-lhc-test
CERN Circular Colliders + FCC


Constr.  Physics  LEP  Design  Proto  Construction  Physics  LHC  Design  Construction  Physics  HL-LHC

EU FP7 Projects

Venue:

Courtesy: Zimmermann
BE/ABP Group Meeting
CERN, 21 May 2015

6/22/2016  ISSP 2016  H. Wenninger  59
https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=215087.

CERN Courier  Mar 28, 2013

**Accelerating innovation**

A workshop on the technology of particle accelerators and detectors marked the revival of an EPS group focusing on innovative areas and potential spin-offs.
Sixth Framework Programme 2003-2006
FP6 is the Union’s main instrument for the funding of research in Europe

EU FP6 Projects: EURISOL - EGEE Publications & Technical Reports (106)

Seventh Framework Programme 2007 - 2013
FP7 was the European Union's Research and Innovation funding programme

The current programme is Horizon 2020 but there are many projects funded under FP7 which are still running.

EU FP7 Projects
UNILHC TIARA SUPERFIELDS MassTeV HiLumi LHC AIDA Helix Nebula EuCARD-2 EuCARD ENVISION ARDENT
Neville Reeve and Jean-Emmanuel Faure
European Commission
provided details about the **Horizon 2020** programme at this ERICE EPS-TIG workshop 2012

It was stressed during the workshop that transnational collaborations between research and industry are required and, indeed favoured, within this forthcoming programme. Projects similar to the model of CERN openlab or the ATTRACT initiative of the ATLAS collaboration are clearly in line with these requirements, allowing the distribution and management of related Horizon 2020 funding on behalf of the EU as part of its efforts to externalize funding.
FUTURE will depend on outcome of LHC experiments
FCC Study Status & Summary of FCC Week 2015

Frank Zimmermann
BE/ABP Group Meeting
CERN, 21 May 2015

gratefully acknowledging input from Michael Benedikt & Johannes Gutleber

Work supported by the European Commission under Capacities 7th Framework Programme project EuCARD-2, Grant Agreement 312453, and the HORIZON 2020 project EuroCirCol, Grant Agreement 654305
**Historical studies in Europe**

**Eloisatron** *Eurasiatic Long Intersecting Storage Accelerator* proposed by Antonino Zichichi

C.M Energy ~200 TeV, circumference 300 km, 13.5 T magnets, fitting inside Sicily

INFN study started in 1979, still ongoing

The Eloisatron Project: Physics at the Energy Frontier

Supercolliders Superdetectors: Proceedings of the 19th and 25th Workshops of the INFN Eloisatron Project

Courtesy CERN FCC team
SUBNUCLEAR PHYSICS

THE FIRST 50 YEARS: HIGHLIGHTS FROM ERICE TO ELN

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Edited by
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World Scientific
The second annual meeting of the Future Circular Collider (FCC) design study took place from 11 to 15 April in Rome.
Collaboration Status

• 55 institutes
• 20 countries
• EC participation

Courtesy. CERN FCC team
Study time line towards Conceptional Design Report

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<td>Study plan, scope definition</td>
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<td>Explore options “weak interaction”</td>
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<td>FCC Week 2015: work towards baseline</td>
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<td>conceptual study of baseline “strong interact.”</td>
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<td>FCC Week 2016 Progress review</td>
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<td>FCC Week 17 &amp; Review Cost model, LHC results → study re-scoping?</td>
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<td>FCC Week 2018 contents of CDR</td>
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6/22/2016

ISSP 2016 H. Wenninger
EC Funded Scope

Arc Design
Lead: CEA
A. Chancé
Co-Lead: CERN
D. Schulte

EIR Design
Lead: JAI
A. Seryi
Co-Lead: CERN
D. Schulte

Cryo Beam Vacuum
Lead: CELLS
F. Perez
Co-Lead: CERN
P. Chiggiato

High Field Magnet
Lead: CERN
L. Bottura
Co-Lead: n.n.
AIDA-2020

The AIDA-2020 project brings together the leading European research infrastructures in the field of detector development and testing and a number of institutes, universities and technological centers, thus assembling the necessary expertise for the ambitious programme of work.

Who is involved?

In total, 19 countries and CERN are involved in a coherent and coordinated programme in line with the priorities of the European Strategy for Particle Physics.
See also talk by P. Collins on the Future of Silicon Vertex Detectors
.... and possible upgrades

[Diagram showing various particle physics experiments and their upgrades, including COMPASS (TGEM, micromegas upgrade), CMS (GEM), TOTEM (GEM), ALICE (GEM or....), LHCb (GEM), NA48 (micromegas), GLACIER (LEM), LHCb (GEM), CAST (micromegas), CAST (InGrid), ATLAS (micromegas), and other proposals in progress for future upgrades.]

... and other proposals in progress for future upgrades
The GEM consists of a thin, metal-clad polymer foil, chemically pierced by a high density of holes. With a potential difference between the two electrodes, electrons released by radiation in the gas on one side of the structure drift into the holes, multiply and transfer to a collection region.

In a Micromegas detector, the gas volume is divided in two by a metallic micro-mesh placed between 25 μm and 150 μm of the readout electrode. This allows for a high gain $10^4$ and a fast signal 100 ns.

**Georges Charpak – a true man of science**


http://cerncourier.com/cws/article/cern/44361

Nov 30, 2010 by Ioannis Giomataris, CEA-Saclay.
Past and Future of Microelectronics in HEP

A roadmap for R&D in microelectronics for Detector Builders

A. Marchioro
CERN/PH-ESE
Timeline of significant innovations

- **Node**
  - 180, 130, 90, 65, 45, 32, 22, 14 [nm]

- **Innovations**
  - Cu metalization
  - SOI
  - Strained Silicon
  - High K-metal gate
  - Wet litho
  - FinFET

- **Years**
EXPLORER (CERN) a cryogenic resonant-mass gravitational wave detector.

VIRGO a 3-km long interferometer built in the framework of a French-Italian collaboration. EGO (European Gravitational Observators) with the Netherlands, Poland and Hungary.
from original ideas to experimental evidence requires enabling technologies

1997: CERN Conference organized by Gabriele Veneziano et al. at CERN with people such as Kip Thorne, **Richard H. Price**, Barry Barish et al. on Gravitational waves.

**BLACK HOLES AND GRAVITATIONAL WAVES**

**R.H. Price**

*Department of Physics, University of Utah, Salt Lake City, UT 84112, USA*

Gravitational wave detectors will be a new form of telescope, sensitive to previously unseen astrophysical phenomena. At present, attention has shifted to black hole (BH) coalescences as perhaps the most likely source of detectable signals; they are certainly among the most exciting. An introduction is given here of the arguments for BH processes as powerful sources of gravitational waves, of the nature of such processes, and of characteristics of the waves produced. A more detailed discussion is then given of the phases of black hole coalescence, with special emphasis on theoretical questions that remain to be answered if we are to have an approximate understanding of such sources.
Gravitational waves emitted by the merger of two black holes have been detected, setting the course for a new era of observational astrophysics.

For a second time, scientists from the LIGO and VIRGO collaborations saw gravitational waves from the merger of two black holes.
“Big” science and advanced technology are known to cross-fertilize each other. This book emphasizes the interplay between particle physics and technology having led to breakthroughs in research and technology throughout the 50-year of CERN. The context, which led to outstanding technological innovations at CERN, often obtained by individuals or by small teams, and its impact on research, is illustrated with selected highlights, covering advances in accelerator and experimental technologies. The book presents the framework and conditions prevailing at CERN, enabling many spectacular technological advances, propelling this European organization into the league of leading research laboratories in the world.

While the book provides information of interest to more expert readers, it specifically aims at the technically interested public. References are given for readers who wish to further explore a topic.
The interaction between research in physics and technological development in the field of particle detectors and accelerators electronics and computing forms the main theme of the book.

By 1986, the ideas for a proton–proton collider to be built in the same tunnel infrastructure had become much more concrete, making a long-term R&D programme mandatory. CERN’s participation in this programme, at a time when all of its resources were committed to the construction phase of LEP, was made possible through the LAA project. This special programme, initiated and financed by Italy, approved by CERN Council, and implemented and executed at CERN, allowed for a broad detector R&D activity. In addition, LAA funds helped to recruit experts and propelled electronics at CERN into the era of microelectronics and silicon detectors, laying crucial foundations for the success of the next generation of experiments at the Large Hadron Collider (LHC).