«ETTORE MAJORANA» FOUNDATION AND CENTRE FOR SCIENTIFIC CULTURE

INTERNATIONAL SCHOOL OF SUBNUCLEAR PHYSICS

24 June to 3 July 2015

This year's school will present several highlight talks about LHC

Sergio Bertolucci will talk about LHC
Peter Jenni will lecture about the Roadmap at LHC to the Higgs boson and beyond
We will hear presentations about CMS – ALICE - LHCb
Lucio Rossi will present the High-Luminosity LHC Project

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INTERNATIONAL SCHOOL OF SUBNUCLEAR PHYSICS

24 June to 3 July 2015

The LAA impact on technology R&D: from past to future.

Horst Wenninger, CERN

References:

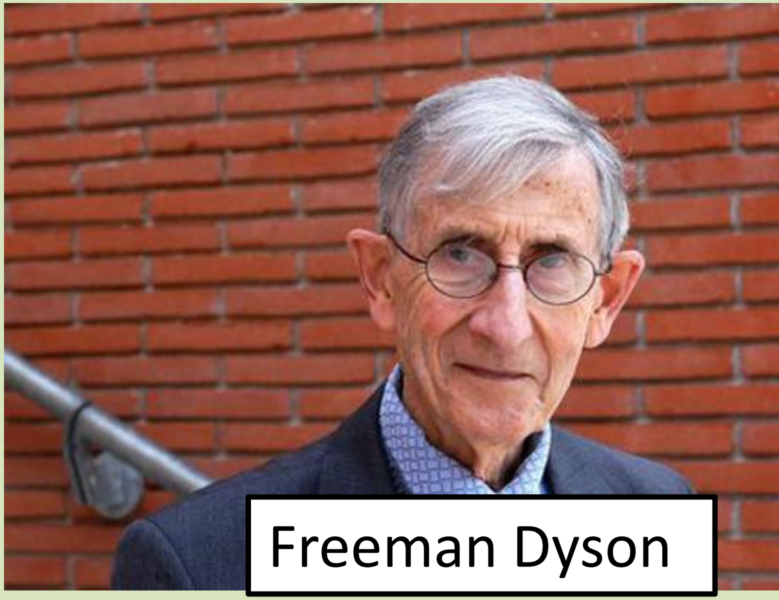
CERN Photo Library (copy rights) , CERN webpages, CERN current long-term plan, CERN lecture programs, LHCC meetings, AB talks , ISSP2013 (ERICE), EPS Technology & Innovation Workshop (ERICE 2012) private communications CERN staff and many more ….

On Tools and Instrumentation

"New directions in science are launched by new tools much more often than by new concepts.

The effect of a concept-driven revolution is to explain old things in new ways.

The effect of a tool-driven revolution is to discover new things that have to be explained"



unification of the three versions of quantum electrodynamics
Feynman, Schwinger and Tomonaga
65 Nobel Prize

Courtesy: Werner Riegler CERN lecture

The LAA impact on technology R&D: from past to future.

LAA project was implemented to prepare
“a tool-driven revolution
to discover new things that have to be explained”

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/87–122
July 14th, 1987

The LAA Project

by

A. Zichichi
CERN – Geneva
Switzerland

Geneva, 14 July 1987

Abstract.

A comprehensive R & D project to study new experimental techniques for the next step in multiTeV hadron collider physics is described.

(to be published in ICFA - INSTRUMENTATION BULLETIN)

This project represents a unique opportunity for Europe to have a leading role in the advanced technology for High Energy Physics.

It is open to all physicists and engineers who are interested in participating.

LAA was the first **special** program at CERN dedicated to prepare the future beyond the ongoing CERN LEP construction program 1980 to 1989

Unlike all previous CERN projects
(PS, BOOSTER, BEBC, ISR, SPS)
LEP approval: conditional to stay within the CERN budget level

\- **priorities required** –

Facilities and many experiments closed to free resources
for LEP construction + the proton-antiproton runs

The idea behind LAA

develop tools (technologies / detectors) for experiments
in view of a high intensity proton-proton collider in the LEP tunnel
as discussed at least since 1984

Use LAA funds to hire dedicated staff
(physicist, engineers, technicians)
and form collaborations supported by LAA
to prepare the future beyond LEP

40 **LAA staff and 80 unpaid scientist** worked together for 6 years
LAA activities are published in over 350 papers and journals

after LEP start during the1990th the **CERN DRDC** complemented **LAA**

R&D CERN 2015

PLAFOND	Platform for Developing Neutrino Detectors
RD-18	CRYSTAL CLEAR R&D on scintillation materials for novel ionizing radiation detectors for HEP, medical imaging and industrial applications
RD39	Cryogenic Tracking Detectors
RD42	Development of Diamond Tracking Detectors for High Luminosity Experiments at the LHC
RD50	Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders
RD51	**Development of Micro-Pattern Gas Detectors**
RD52	**Dual-Readout Calorimetry for Energy Measurements**
RD53	Development of pixel readout integrated circuits for extreme rate and radiation

GEMs & MICROMEGAS

MICROMEGAS
Narrow gap (50-100 µm) PPC with thin cathode mesh
Insulating gap-restoring wires or pillars

GEM
Thin metal-coated polymer foils
70 µm holes at 140 mm pitch

The **RD51** collaboration involves ~ 450 authors, 75 Universities and Research Laboratories from 25 countries in Europe, America, Asia and Africa.

more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operational stability and radiation hardness.

Y. Giomataris et al, Nucl. Instr. and Meth. A376(1996)239

F. Sauli, Nucl. Instr. and Methods A386(1997)531

RD 52

Richard Wigmans

Dual (triple) readout method

Basic principle:

- •Measure EM shower component separately
- •Measure HAD shower component separately
- •Measure Slow Neutron component separately

(The first two items are bracketed as **Dual**; all three as **Triple**.)

EM-fraction=> electrons => highly relativistic => Cherenkov light emission as well as Scintillation signal

HAD-fraction=> “less” relativistic => Scintillation signal only

Slow neutrons => late fraction of the Scintillation signal

Lucie Linssen 22/7/2009

Why is the title of the talk:

LAA impact on technology R&D: from past to future:

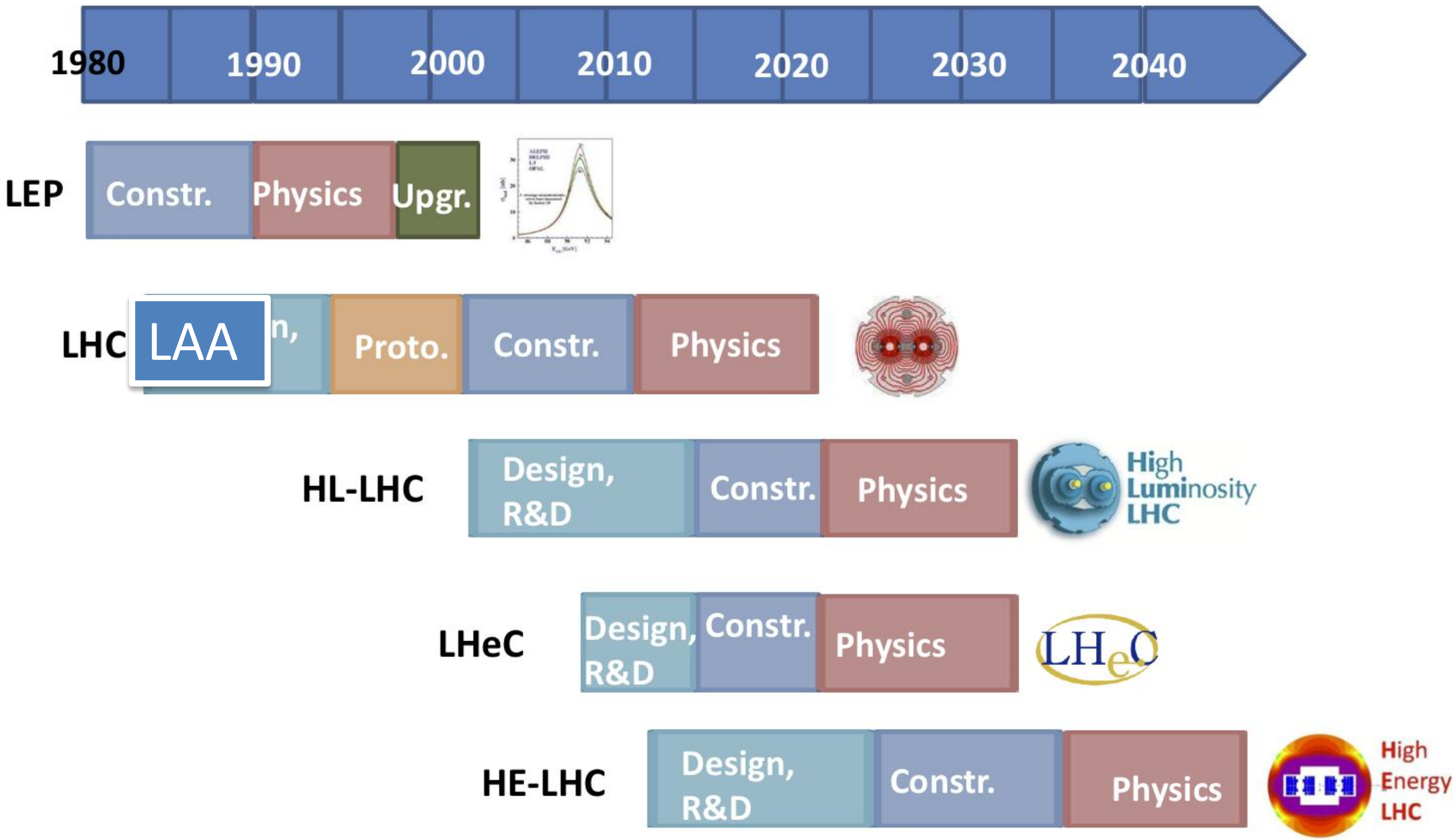
What is the importance of a special programme and R&D fund provided by Italy to CERN

implemented by the CERN Council in 1986 at CERN

Project Leader Prof. A. Zichichi.

Why should this have an impact not only on past

but even on present & future activities?



Courtesy: CERN lecture

Examples of LAA R&D topics: the spaghetti electromagnetic calorimeter, calorimetry, multi-drift chambers, scintillation fibre trackers, micro-strip detectors, precision tracking and read-out electronics, IPSA tube GaAs crystals (Imaging Silicon Pixel Array), silicon pixels detectors, CMOS chips and ASIC/VLSI chips - RPCs

LAA impact on LHC: through people
engineers, physicists, technicians, recruited for the LAA activities, helped LHC experiments and participate in the experiments still today.

LAA impact on LHC: through technology, in particular: built-up of competences in micro-electronics , CMOS chips, ASIC/VLSI chips, micro-strip-, silicon pixel development …

LAA spin-offs – one example: Medipix 1st phase

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EF 89–14
CERN/LAA/SD 89–11
13 September 1989

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

CERN has often been the incubator for the development of innovative technologies but very few people know about the **capacitive touch screens** invented for the consoles of the SPS Control Room in 1973. The inventor, Bent Stumpe, who also developed the CERN **tracker ball and the computer-programmable knob.**

Courtesy: CERN library and copy rights

Courtesy: CERN library and copy rights

Available online at www.sciencedirect.com

SCIENCE DIRECT

Nuclear Instruments and Methods in Physics Research A 533 (2004) 183–187

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber ☆

F. Anghinolfi[a], P. Jarron[a], A.N. Martemiyanov[b], E. Usenko[c], H. Wenninger[a], M.C.S. Williams[d,*], A. Zichichi[d,e]

[a] EP Division, CERN, Geneva, Switzerland
[b] Institute for Theoretical and Experimental Physics, Moscow, Russia
[c] Institute for High Energy Physics, Protvino, Russia
[d] Sezione INFN, Bologna, Italy
[e] 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%.

PACS: 29.40.Cs; 84.30.−r; 84.30.Le; 84.30.Qi

Keywords: Resistive plate chambers; ALICE; Time-of-flight; Fast amplifier; Discriminator; ASIC; CMOS technology

The original idea of the LAA project
to perform technology R&D

**as an independent research program
with its own, independent funding**

has meanwhile been adopted
for present and future R&D initiatives

LONG TERM ACCELERATOR R&D AS INDEPENDENT RESEARCH FIELD

R. Brinkmann, DESY, D-22607 Hamburg, Germany
Proceedings of IPAC2014, Dresden, Germany

Efforts and progress to perform accelerator R&D as an independent research program with its own, independent funding are described for the example of the Helmholtz ARD program in Germany.

Links to efforts in other countries are discussed and an outlook to future accelerator research is given."

How to fund physics using the wisdom of crowds

Grant applications are reviewed by expert scientists and funding policies are shaped by bureaucrats and politicians. This inevitably leads to mountains of paperwork, and Jackson argues that this wastes valuable time that could be spent on actually doing research.

His solution is for physicists to appeal directly to the public for research money by using Fiat Physica, which he launched late last year.

Physics world.com eventswire   May 25 2015

EU Framework programs /in future Horizon 2020

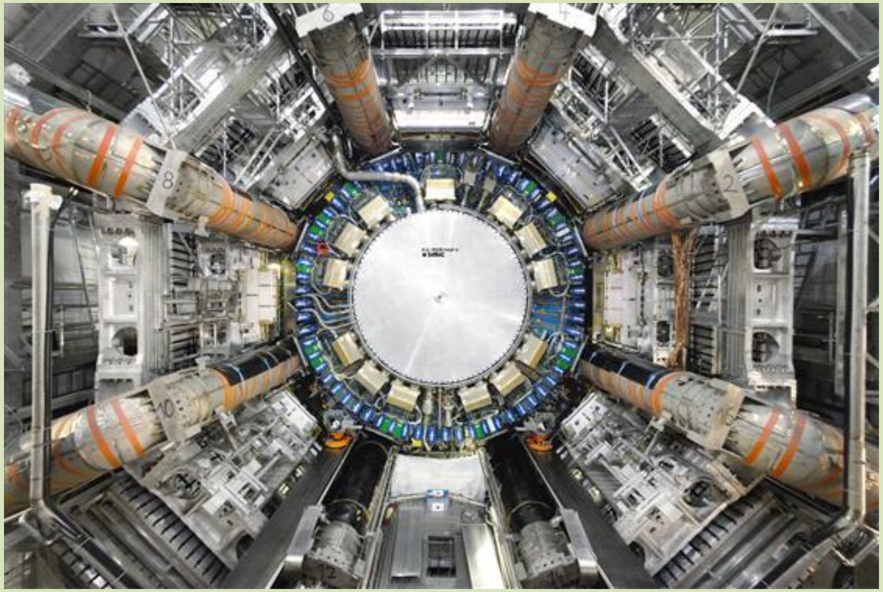
are also providing funds for joint R&D
science - industry – society

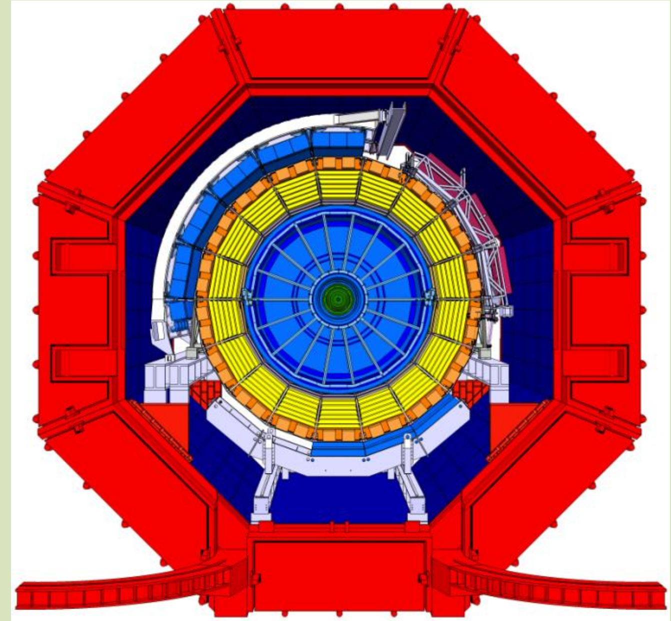
Today, accelerator and detector development projects are often organized in large world-wide collaborations and funded by the EU Framework programs. This creates overheads and inefficiencies but also competition and challenges.

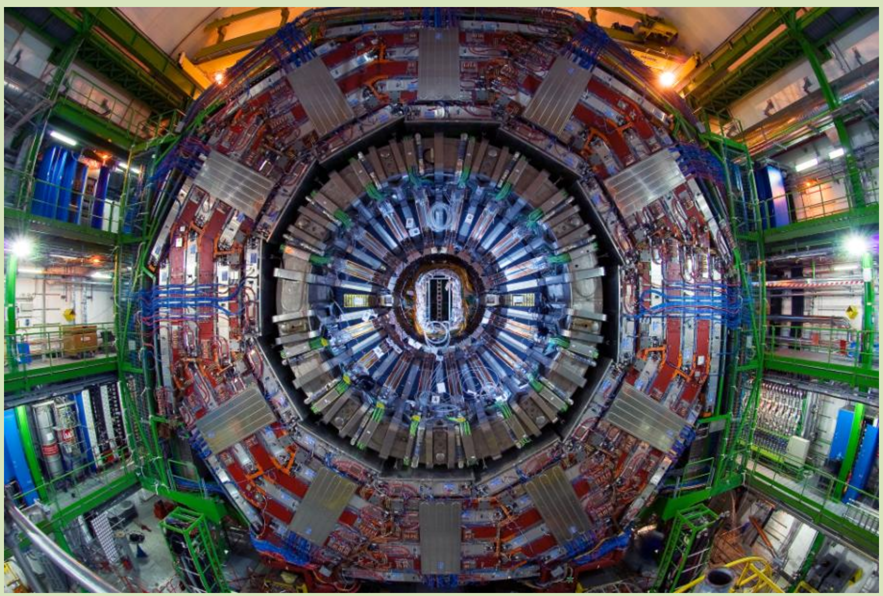
LAA and DRDC programs were CERN specific collaborations
peer-reviewed by CERN committees
and implemented with minimal bureaucracy

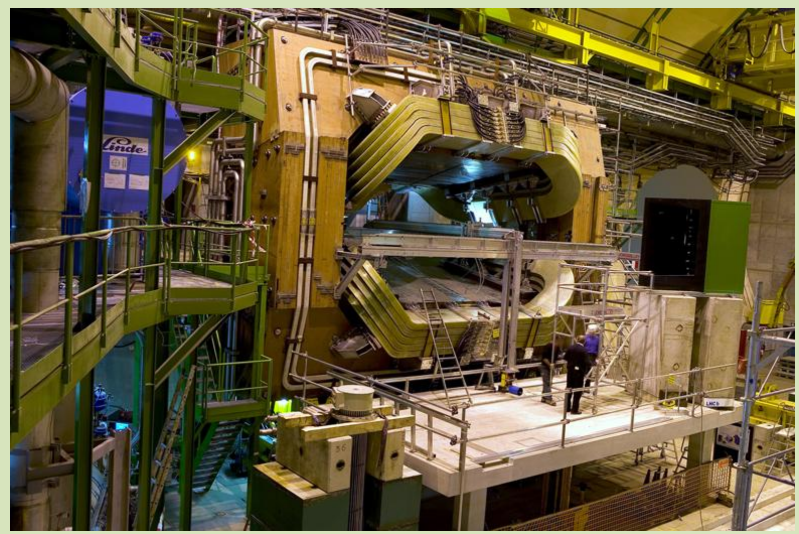
… back to particle physics technologies and R&D

LHC TOOLS installed for 1^{st} RUN









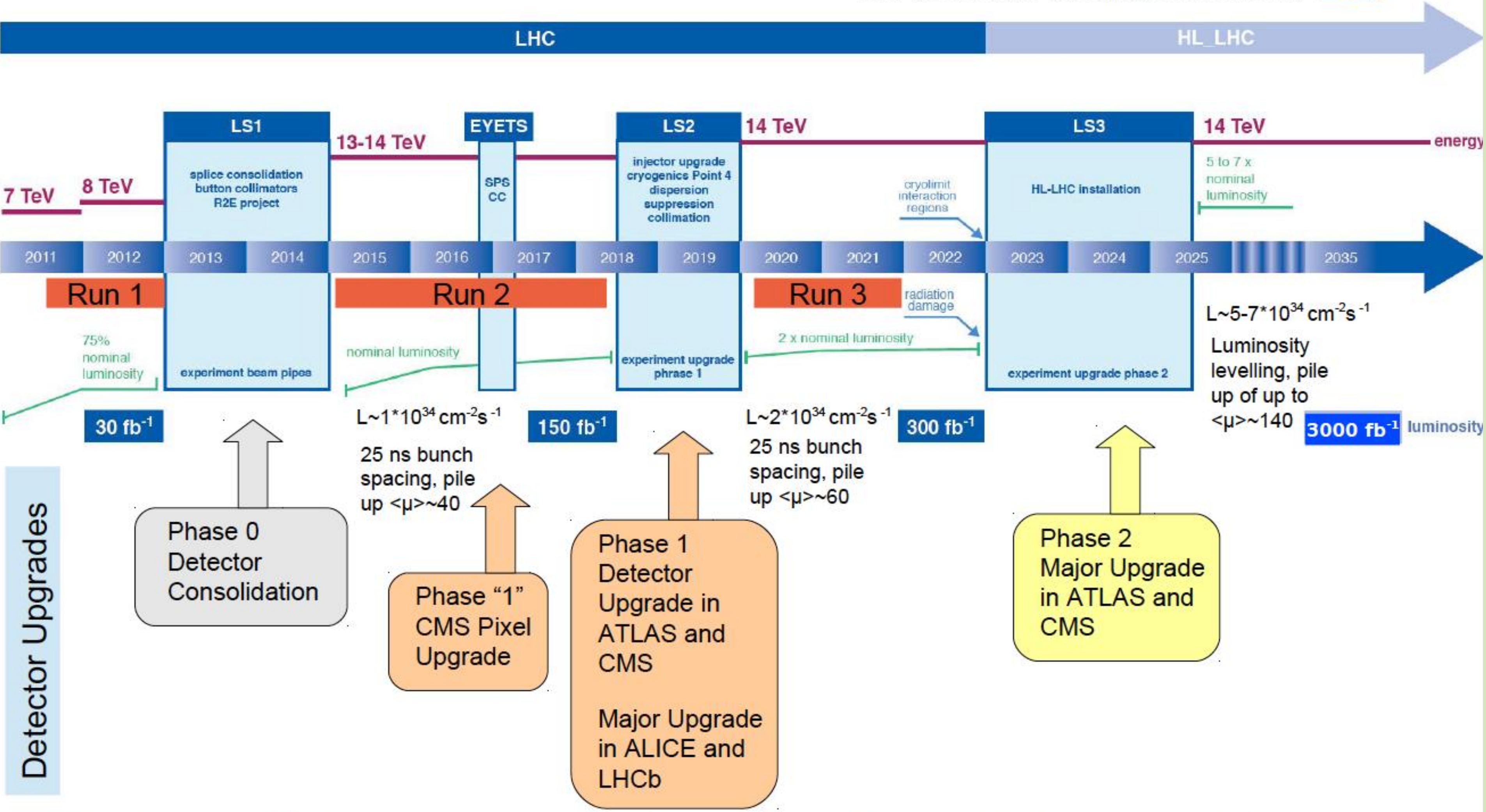
Courtesy CERN FOTOLIBRARY

ERICE ISSP2012

No Higgs without tools

From LHC to HL-LHC

LHC/ HL-LHC Plan (last update 24.09.2014)



Requires right balance between revolutionary approaches and technology evolution, based on physics potential and cost-effectiveness.

2013 – 2014: LS1

Primary aim: consolidation for 6.5 to 7 TeV

- Measure all splices and repair the defective ones
- Consolidate interconnects with new design (clamp, shunt)
- Finish installation of pressure release valves (DN200)
- Magnet consolidation - exchange of weak cryo-magnets
- Consolidation of the DFBAs
- Measures to further reduce SEE (R2E):
  - relocation, redesign, shielding…
- Install collimators with integrated button BPMs (tertiary collimators and a few secondary collimators)
- Experiments consolidation/upgrades

Courtesy: Mike Lamont


25R7 / 27R7
metabo
Courtesy CERN FOTOLIBRARY


Courtesy CERN FOTOLIBRARY

Challenges of high energy

- Quenches
  - Less margin to critical surface
- Protons have higher energy
  - acceptable loss level is reduced (losses in ramp, UFOs…)
  - set-up beam limit reduced
- Magnets run into saturation
  - field quality (although this is modelled)
- Hardware nearer limits
  - Power converters, beam dump (higher voltages), cryogenics (synchrotron radiation…)

Courtesy: Mike Lamont

50 versus 25 ns

	50 ns	25 ns
GOOD	• Lower total beam current • Higher bunch intensity • Lower emittance	• **Lower pile-up**
BAD	• **High pile-up** • Need to level • Pile-up stays high • High bunch intensity – instabilities…	• More long range collisions: larger crossing angle; higher beta* • Higher emittance • Electron cloud: need for scrubbing; emittance blow-up; • Higher UFO rate • Higher injected bunch train intensity • Higher total beam current

Courtesy: Mike Lamont

Expect to move to 25 ns because of pile up…

LHC and Detector upgrades

LHC TOOLS installed for 2^{st} RUN which just started

LHC Season 2: Major work at the experiments for Run 2

http://press.web.cern.ch/sites/press.web.cern.ch/files/file/backgrounder/2015/05/ls1_workexperiments.pdf

ATLAS

https://cds.cern.ch/journal/CERNBulletin/2014/18/News%20Articles/1696879?ln=en

CMS

http://cds.cern.ch/journal/CERNBulletin/2014/18/News%20Articles/1696880

ALICE

https://cds.cern.ch/journal/CERNBulletin/2014/16/News%20Articles/1694094?ln=en

LHCb

https://cds.cern.ch/record/1694095?ln=en

Detector preparation for Run 2

ATLAS

- Insertable B-layer (pixel layer) cooled with CO_2
- New cooling plant for pixel + SCT
- New Al/Be beam pipe
- Replaced all LV power supplies of calorimeter
- Increased acceptance in muon spectrometer
- Upgrade of L1 Calo (L1 trigger)
- Add neutron shielding
- ...

CMS

- Upgrade HCAL photo detectors
- Increased acceptance in muon system
- Thinner and centered beam pipe
- Repair of shorts in pixel detector barrel
- Installed pilot system for future upgrades
- Consolidation work to complete original detector
- Start upgrade for high pile-up
- ...

LHCb

- New Forward shower detector
- RICH detector
- Trigger system to allow offline analysis at 12.5kHz
- ...

ALICE

- DCAL installation
- Additional TRD modules
- Augmented trigger hardware and software
- ...

Short intermezzo


ATLAB, as an organized effort to support detector R&D in ATLAS
Erice
October 22nd, 2012
Marzio Nessi CERN & University of Geneva
Markus Nordberg CERN
ATLAS EXPERIMENT

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	…	2030
	Phase 0			LS1		Phase I,II			LS2	Phase II			LS3			

"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$L_{inst} \simeq 1 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 27.5$)
$\int L_{inst} \simeq 50\ fb^{-1}$

"Phase-I" upgrades:
ultimate luminosity
$L_{inst} \simeq 2\text{-}3 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 55\text{-}81$)
$\int L_{inst} \gtrsim 350\ fb^{-1}$

"Phase-II" upgrades:
$L_{inst} \simeq 5 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 140$) w. leveling
$\simeq 6\text{-}7 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 192$) no level.
$\int L_{inst} \simeq 3000\ fb^{-1}$

ATLAS has devised a 3 stage upgrade program to optimize the physics reach at each Phase

- New Insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation of detector elements (e.g. calorimeter power supplies)
- Add specific neutron shielding
- Finish installation of EE muon chambers staged in 2003
- Upgrade magnet cryogenics

- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

M. Nessi (29 October 2012 RRB)
https://indico.cern.ch/conferenceOtherViews.py?confId=204539&view=lhcrrb&showDate=all&showSession=1&detailLevel=contribution

European Commission

Horizon 2020

The EU Framework Programme for Research and Innovation

2014-2020

Neville Reeve
DG RTD A3

What's new

- **A single programme** bringing together three separate programmes/initiatives*
- **Coupling research to innovation** – from research to retail, all forms of innovation
- **Focus on societal challenges** facing EU society, e.g. health, clean energy and transport
- **Simplified access**, for all companies, universities, institutes in all EU countries and beyond.

*The 7th Research Framework Programme (FP7), innovation aspects of Competitiveness and Innovation Framework Programme (CIP), EU contribution to the European Institute of Innovation and Technology (EIT)

ATTRACT – From Open Science to Open Innovation

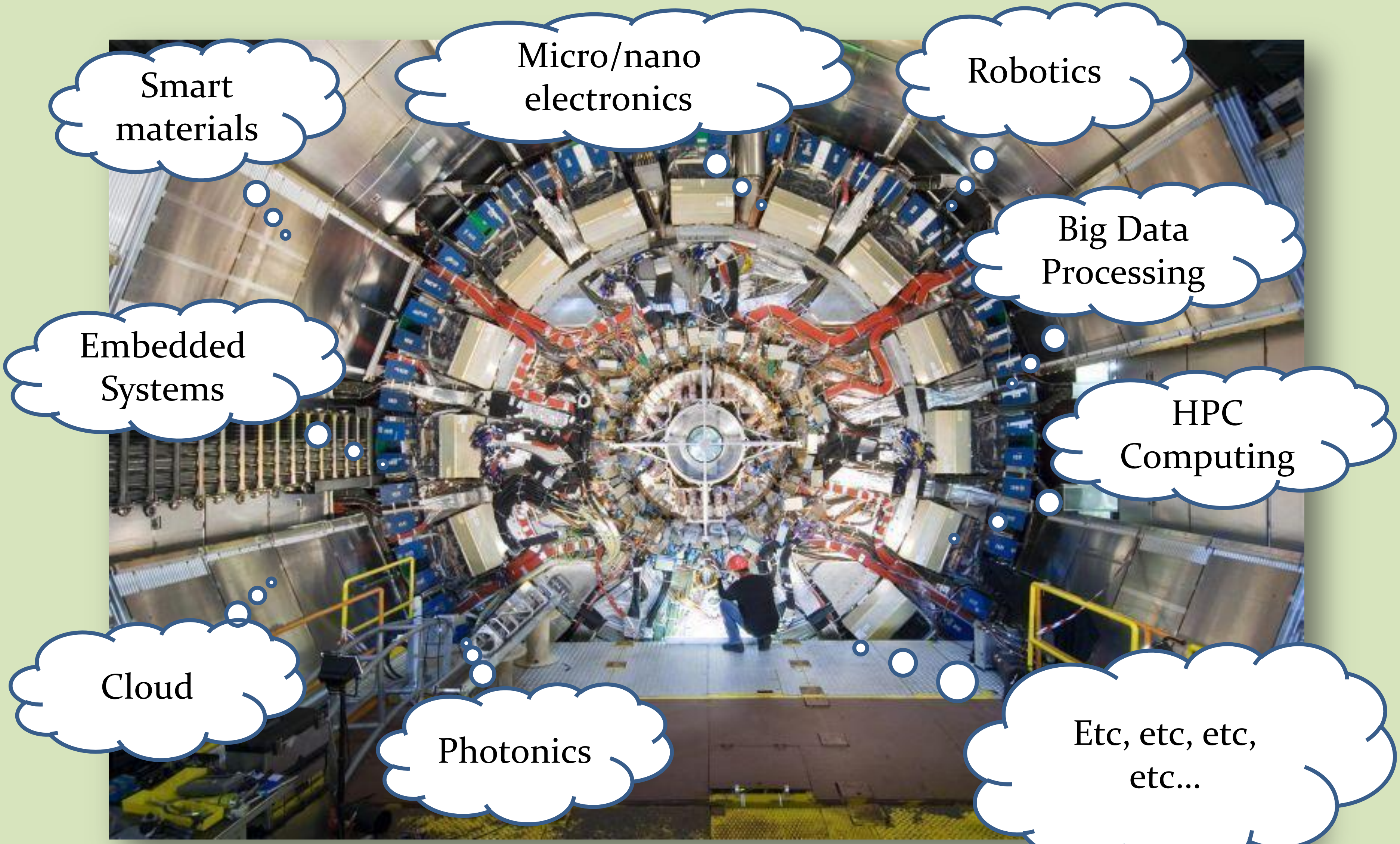
Information Sharing Meeting
Brussels, June 19, 2014
Markus Nordberg (CERN)
Development and Innovation Unit (DG-DI-DI)

Industrial and Societal value of Detection and Imaging Technology

Pablo Tello, CERN, Knowledge Transfer

ATTRACT meeting, Brussels June 19th 2014

When we talk about Detection and Imaging Technologies… what do we talk about?



Example ATLAS Detector

Courtesy: CERN library and copy rights

ATTRACT Is About an Ecosystem…

New Scientific Instruments, Products, Services, Entrepreneurs, Jobs	Contributing to …
Innovation Management Platform	Connecting through …
Cross-disciplinary MSc-Student Teams	Engaging …
Industry (special attention to on SMEs)	Co-developing with …
Sensor & Imaging R&D Community With Ambitious Goals and Projects	Being driven by …

Detection and Imaging Technologies

MEDIPIX Chip technology

has been applied in X-ray CT, in prototype systems for digital mammography, in CT imagers for mammography and for beta and gamma autoradiography of biological samples.

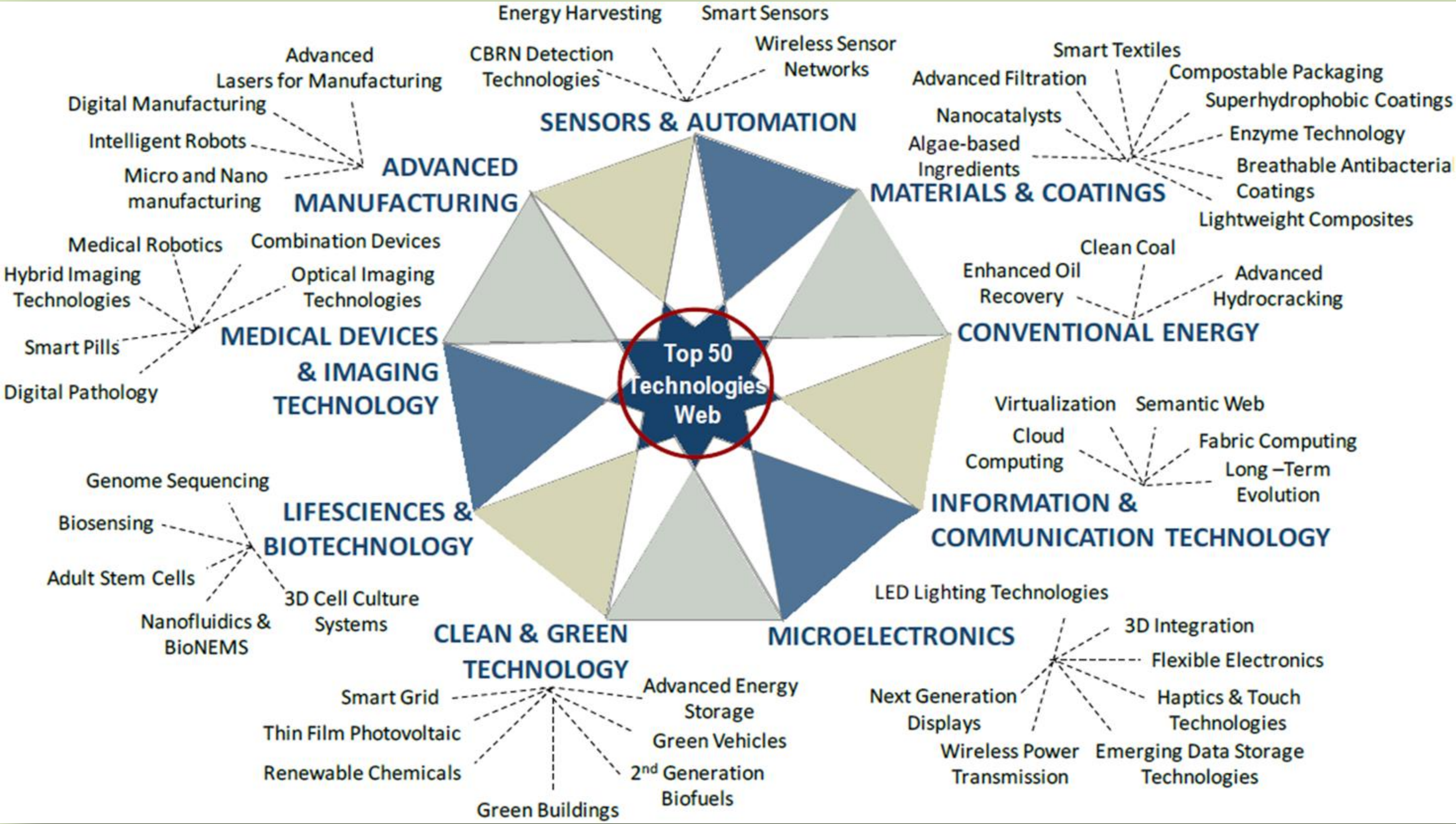
Radiation hard ASICS and FPGA technology developed at ESA, DESY, etc, can be one of the keys.

Hardware (i.e. micro-cooled ASICS) and software

(i.e. cloud computing) technologies developed for large RI instruments can be put to work for reducing global CO_2 footprint.

Optoelectronics sensing technology developed for fundamental research allows for innovative real time in flight aircraft health structure monitoring.

Difficult to think on a technology not in connection with Detection and Imaging

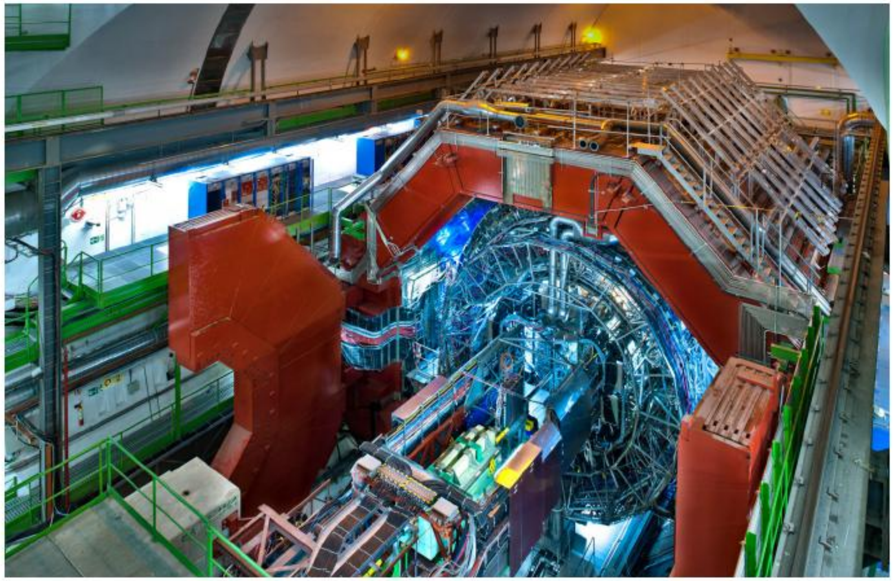


Source: Frost & Sullivan, Megatrends in Technology Convergence

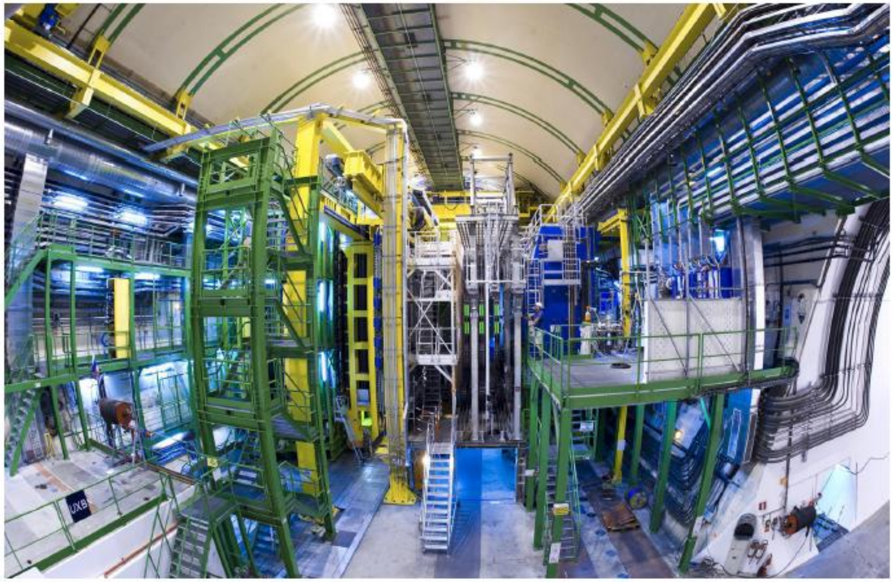
… back to particle physics technologies and R&D

LHC TOOLS installed for 2nd RUN

LHC Season 2: Major work at the experiments for Run 2



ALICE: A LARGE ION COLLIDER EXPERIMENT



LHCB: LARGE HADRON COLLIDER BEAUTY

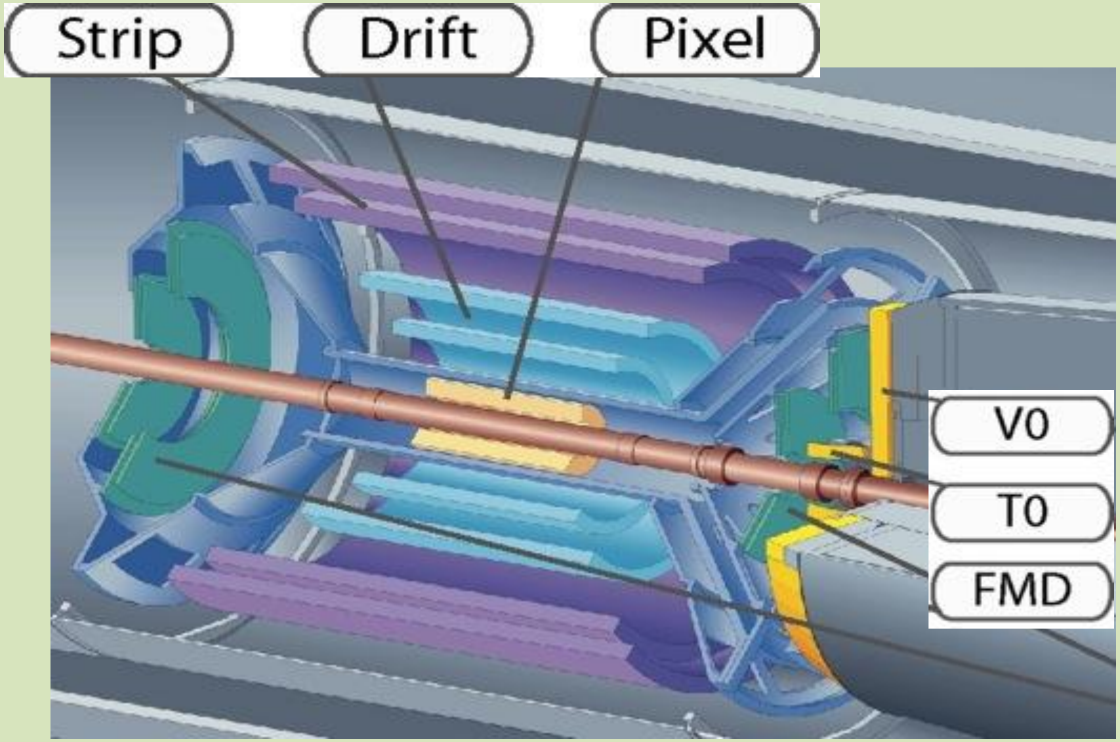
LONG SHUTDOWN 1 - ALICE

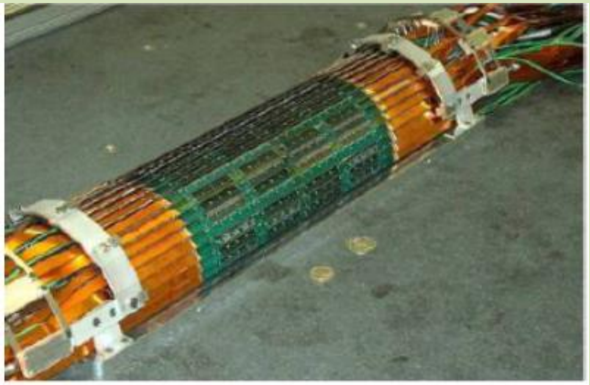
Among the consolidation and improvements to its 19 sub-detectors, they installed a **new calorimeter (DCAL)** extending the range covered by the electromagnetic calorimeter (EMCAL).

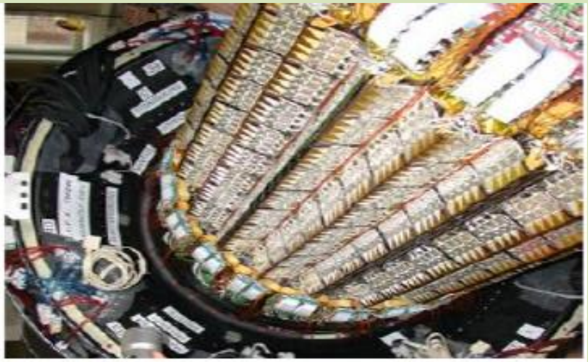
The EMCAL now covers a wider angle, allowing measurements of the energy of the photons and electrons over a larger area.

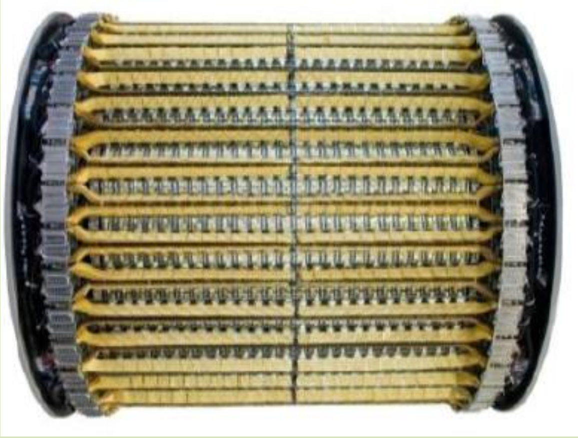
The TRD (**Transition Radiation Detector**) that detects particle tracks and identifies electrons has also been completed with **the addition of 5 more modules**

The Current ALICE Inner Tracking System









Current ITS 6 concentric barrels,

- 2 layers of silicon pixel (SPD)
- 2 layers of silicon drift (SDD)
- 2 layers of silicon strips (SSD)

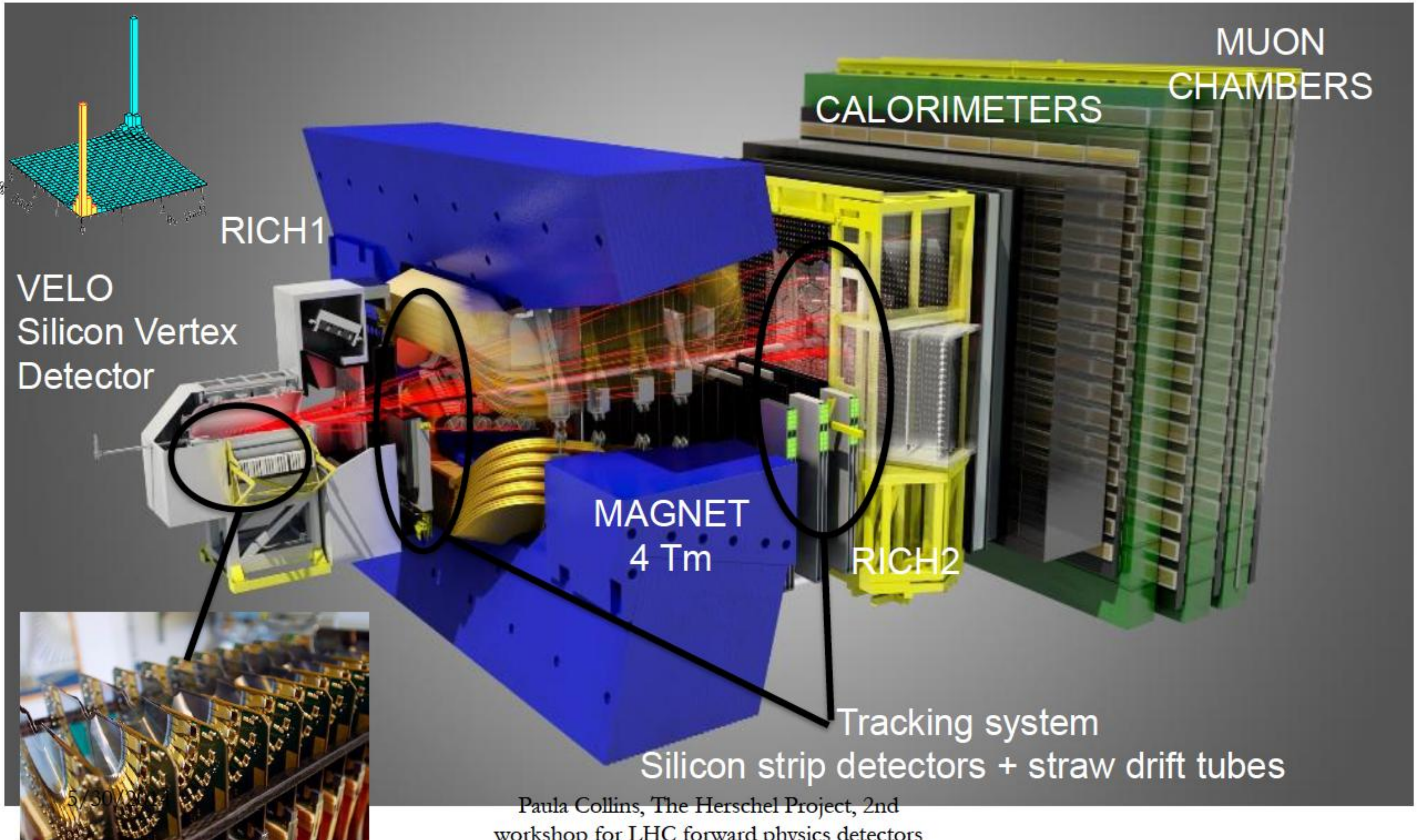
LONG SHUTDOWN 1 – LHCb

Installation of the new **HeRSCheL** detector to distinguish rare processes in which particles are observed in the detector but not along the beampipe.

A section of the beryllium beam pipe replaced.

LHCb Detector

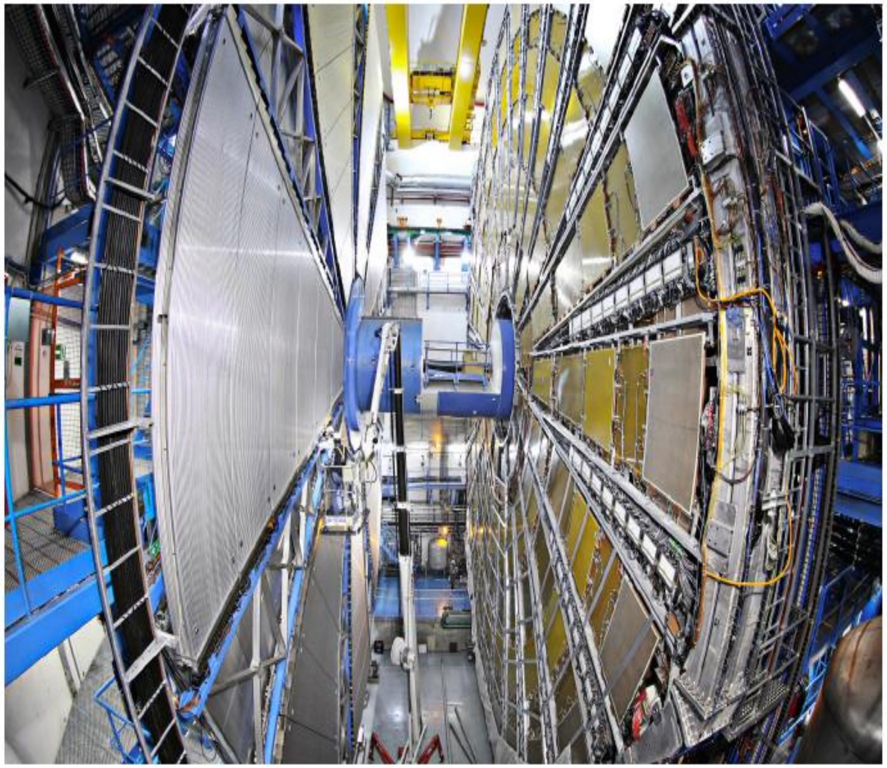
Single arm forward spectrometer dedicated to precision flavour physics

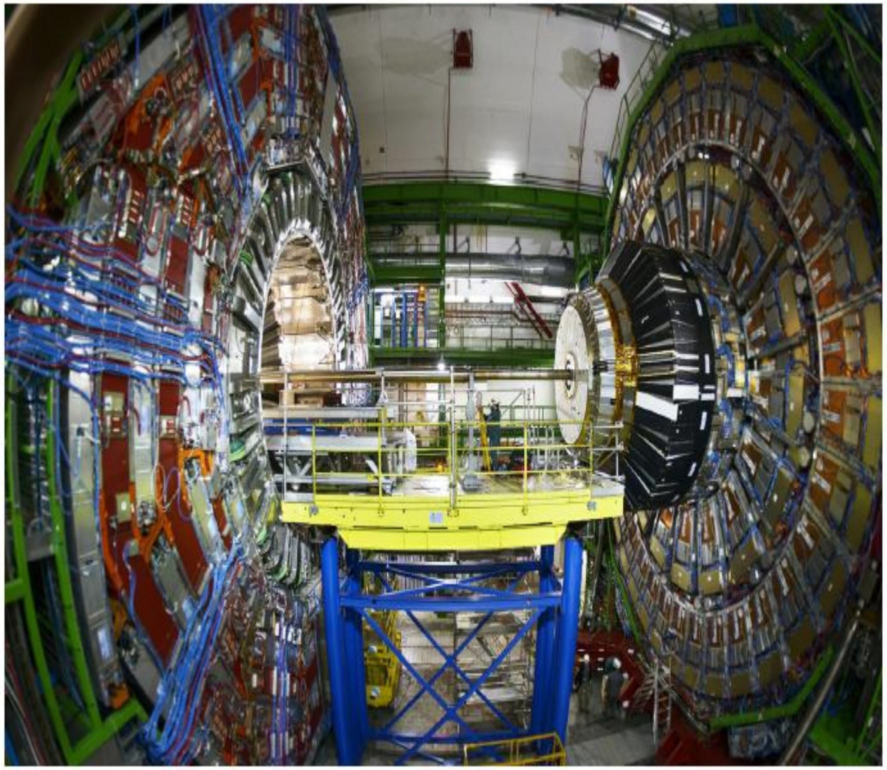


ATLAS: A TOROIDAL LHC APPARATUS / CMS: COMPACT MUON SOLENOID

WHAT IS ATLAS? WHAT IS CMS?

The ATLAS and CMS detectors have a broad physics programme including investigating the recently discovered Higgs Boson, searching for extra dimensions and particles that could make up dark matter, as well as continuing systematic studies of the Standard Model.





LONG SHUTDOWN 1 – ATLAS

The ATLAS pixel detector was improved with the insertion of a fourth and innermost layer that will provide the experiment with better vertex identification, essential to distinguish interesting collisions.

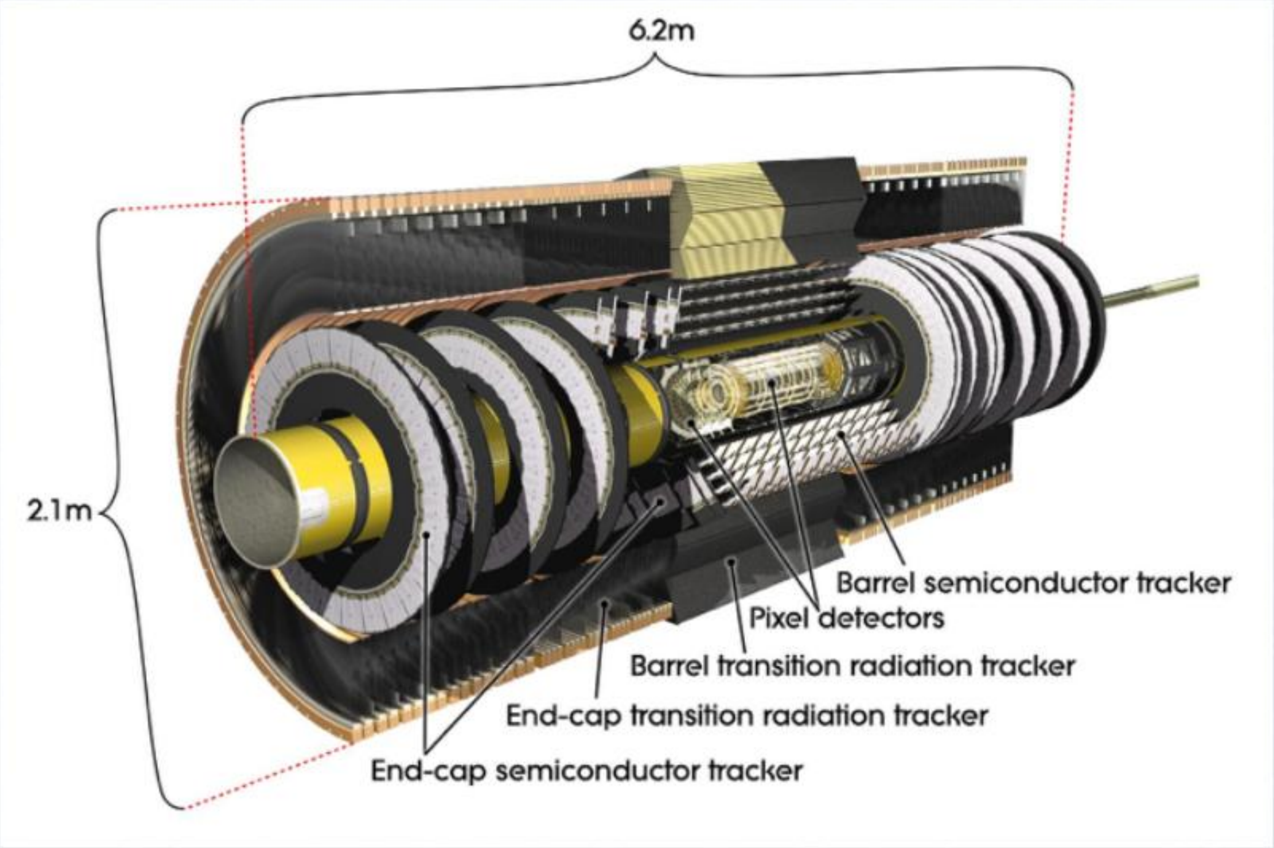
Improvement of general ATLAS **infrastructure**, including electrical power, cryogenic and cooling systems.

The gas system of the TRT, which contributes to the identification of electrons as well as track reconstruction, was modified significantly to minimise losses.

ATLAS Inner Detector OVERVIEW

ATLAS ID
RUN1-RUN2
D.Dobos

3



- located in 2T solenoid magnetic field
- 3 main detectors:
  - 350k channel Transition Radiation Tracker (TRT)
  - 6M Channel Silicon microstrips (SCT)
  - 80M channel Silicon Pixel Detector

- 4th Pixel layer with planar & 3D silicon sensors (3.27 cm radius) - 12M pixels of 50 × 250 μm^2 Radiation tolerance: 2.5 MGy / 5 x 10^{15} n_{eq} cm^{-2}

LONG SHUTDOWN 1 – ATLAS

New chambers were added in the **muon spectrometer** and the calorimeter readout consolidated.
The **forward detectors** were upgraded to provide a better measurement of the LHC luminosity
A new aluminium beam pipe to reduce the background.

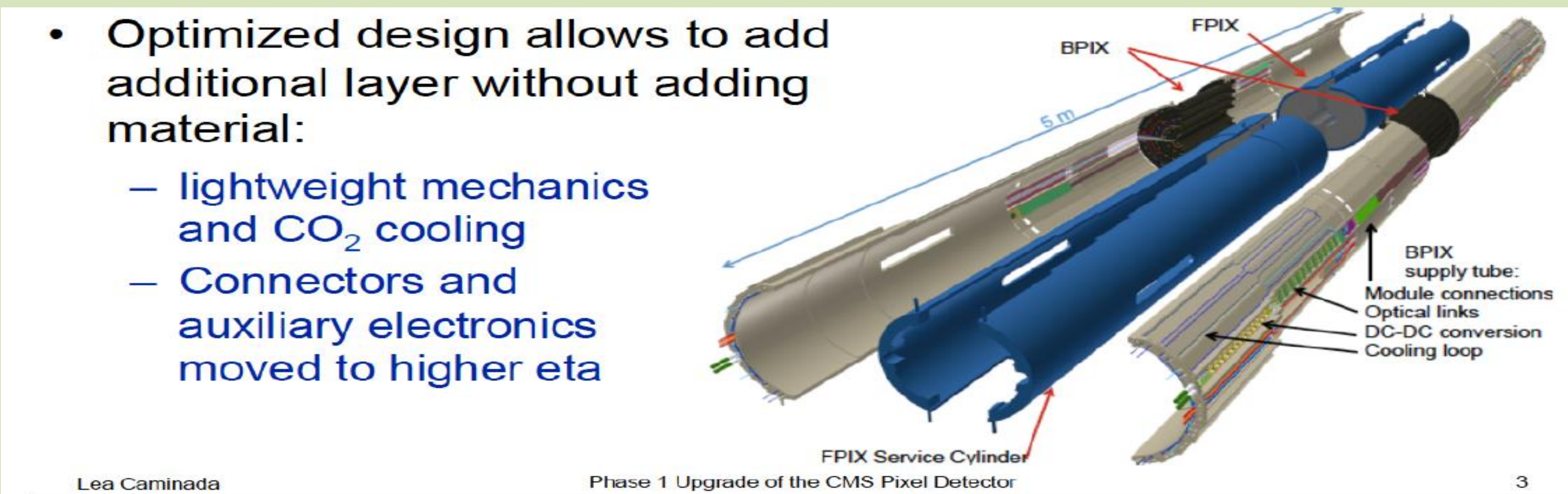
The whole **detector readout system** was improved to be able to run at 100 KHz and all data acquisition software and monitoring applications were re-engineered.
The trigger system was redesigned, going from 3 levels to 2 while implementing smarter and faster selection algorithms.

A very ambitious upgrade of simulation, reconstruction and analysis software was completed, and a new generation of data management tools on the GRID was implemented.

LONG SHUTDOWN 1 – CMS

Priority was to mitigate the effects of radiation on the performance of the Tracker, by equipping it to operate at low temperatures (down to -20°C).

This required **changes to the cooling plant**, and extensive work on the environment control of detector and cooling distribution to prevent condensation or icing.



LONG SHUTDOWN 1 – CMS

A fourth measuring station was added to each **muon endcap**, in order to maintain discrimination between low-momentum muons and background as the LHC beam intensities increase. Complementary to this installation at each end of the detector of a 125-tonne composite shielding wall to reduce neutron backgrounds.

A luminosity-measuring device, the Pixel Luminosity Telescope, was installed on either side of the collision point around the beam-pipe.

Other major activities included replacing photo-detectors in the hadron calorimeter with better-performing designs, moving the **muon readout** to more accessible locations for maintenance, installation of the first stage of **a new hardware triggering system** and consolidation of the solenoid's magnet cryogenic system and of the power distribution.

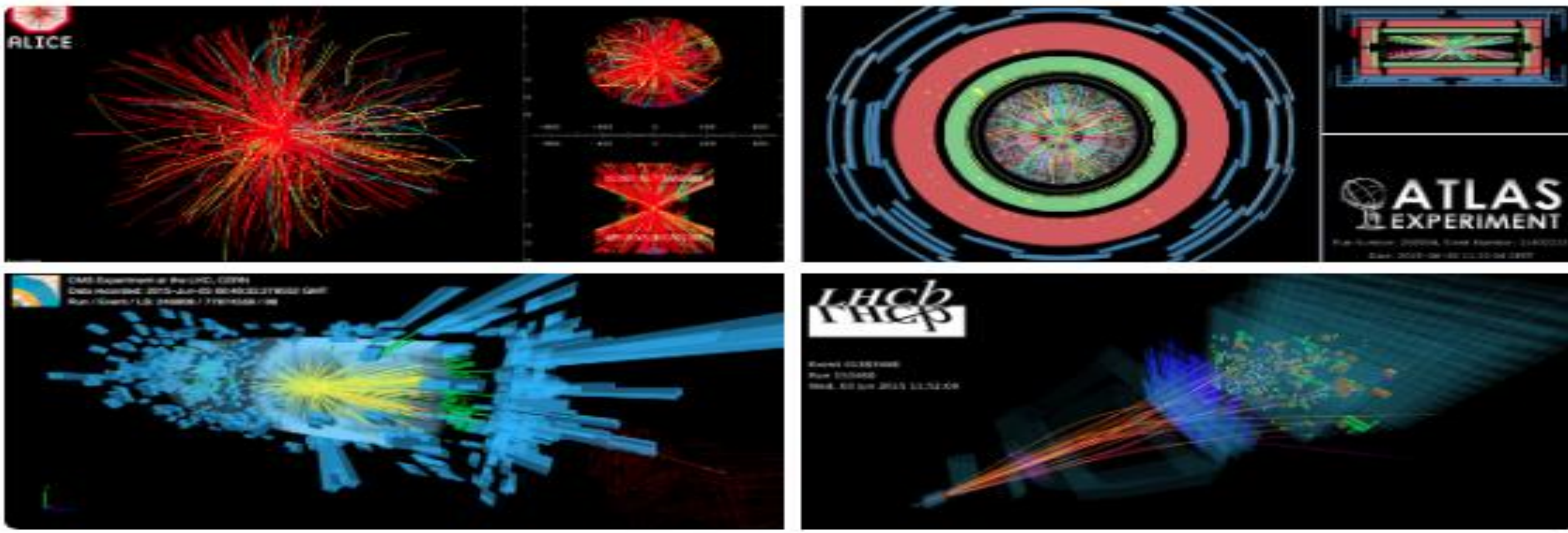
The software and computing systems underwent a significant overhaul during the shutdown to reduce the time needed to produce analysis datasets.

CERN
@CERN

Following

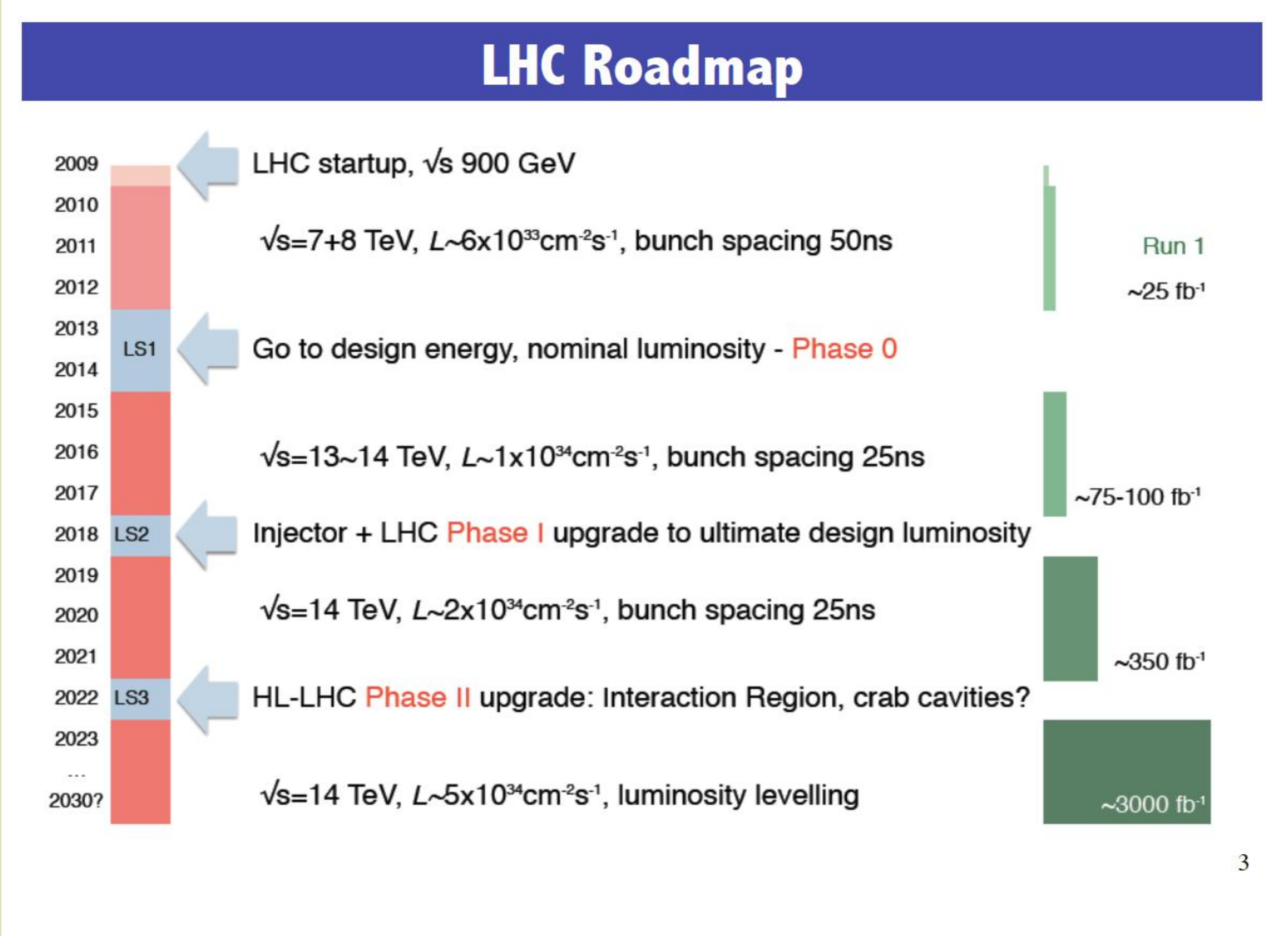
The LHC experiments are back in business with record energy collisions of #13TeV: cern.ch/go/D7z6

You, CERN, CERN en français and 5 others



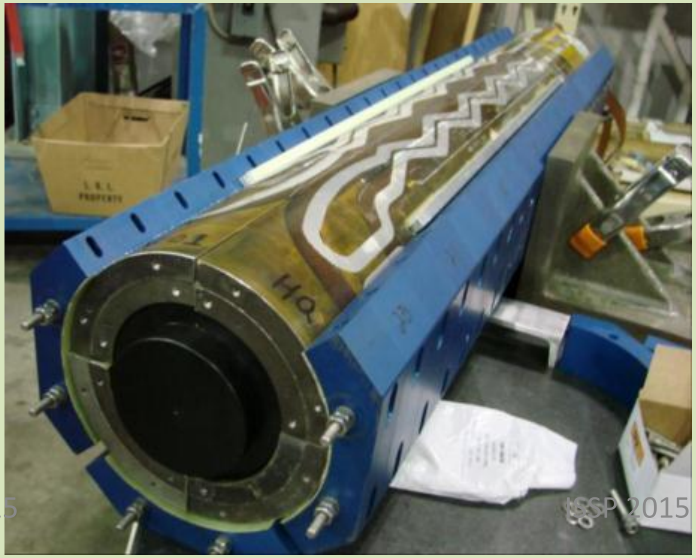
RETWEETS 815   FAVORITES 525

12:41 PM - 3 Jun 2015

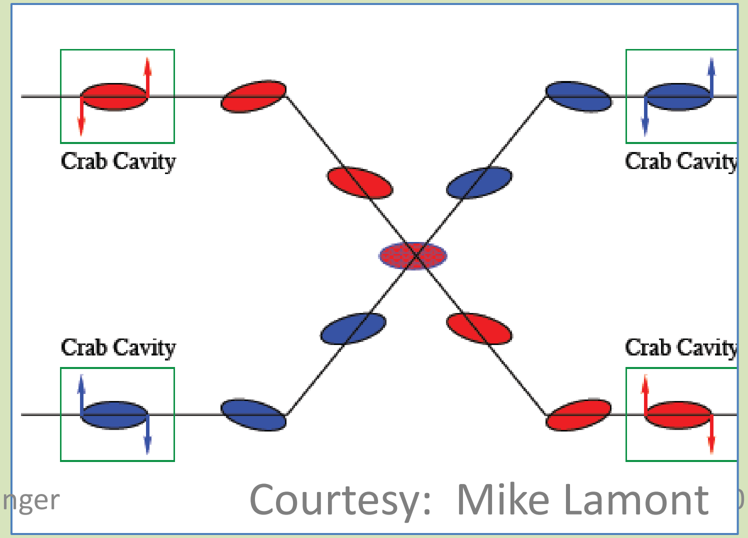

LHC Roadmap
2009
2010
2011
2012
2013
LS1
2014
2015
2016
2017
2018 LS2
2019
2020
2021
2022 LS3
2023
...
2030?
LHC startup, √s 900 GeV
√s=7+8 TeV, L~6x10³³cm⁻²s⁻¹, bunch spacing 50ns
Go to design energy, nominal luminosity - Phase 0
√s=13~14 TeV, L~1x10³⁴cm⁻²s⁻¹, bunch spacing 25ns
Injector + LHC Phase I upgrade to ultimate design luminosity
√s=14 TeV, L~2x10³⁴cm⁻²s⁻¹, bunch spacing 25ns
HL-LHC Phase II upgrade: Interaction Region, crab cavities?
√s=14 TeV, L~5x10³⁴cm⁻²s⁻¹, luminosity levelling
Run 1
~25 fb⁻¹
~75-100 fb⁻¹
~350 fb⁻¹
~3000 fb⁻¹
3

HL-LHC: main thrusts

- Wide aperture Nb_3Sn triplet quadrupoles
  - Optics and layout: beta* = 15 cm
- 11 T Nb_3Sn dipoles
  - Used to make room for collimation in dispersion suppression region
- Large Aperture NbTi separator magnets
  - First twin aperture magnets near interaction
- Crab cavities
  - Reduce the effect of the crossing angle
- Enhanced collimation for 500 MJ beams



LARP: HQ02



Courtesy: Mike Lamont

ECFA HL-LHC: Concluding Remarks & Future Workshops

D. Contardo, P. Allport
Aix-les-Bains: 3rd October

https://indico.cern.ch/conferenceDisplay.py?confId=252045

Existing areas of common detector R&D, potential future areas and synergies [4]

It is anticipated that 3-4 years of R&D and prototyping, followed by 5-6 years of construction, are needed to complete the largest upgrades.

Funding Agencies will need to invest now in targeted R&D to develop costeffective technical solutions, which CERN can help facilitate, and this needs to proceed rapidly and with adequate resources.

- There are existing forums for interaction between the machine and the experiments but it is always helpful to provide updates on this to a larger forum to be sure key parameters are understood across experiments.

From LHC design to ultimate luminosity:

- problems: pile-up, particle density, radiation damage
- performance loss : pixel tracker, trigger, end-caps, electronics

General Survival & Improvement Concepts

- pile-up 20 → 140...200
  - association of tracks and calorimeter energies to individual vertices (up to high eta)
  - particle flow reconstruction
- particle densities x5-10 (ATLAS+CMS: 6'000 primary tracks per event)
  - finer granularity → more channels
- data rates (particles per event) x5-10
  - higher band-width (analogue→digital links)
- increased trigger rates (at fixed thresholds) due to degraded resolution and ambiguities
  - improve resolution of pt and E measurement at trigger level
  - use topological information
  - provide tracking information to L1 trigger
  - increase latency and acceptable trigger rates (LHCb: no trigger at all: 40 MHz read-out)
- radiation damage x10
  - more radiation hard detection elements (silicon, crystals)
- increased front-end power consumption
  - ASIC technology scaling 250nm → 130 nm → 65 nm to reduce power per transistor
  - improved powering and cooling
- reduce material budget inside detector volume
- changes to a running system
  - test new systems as early as possible (e.g. run new triggers in parallel to old ones, run pilot systems inside detectors)

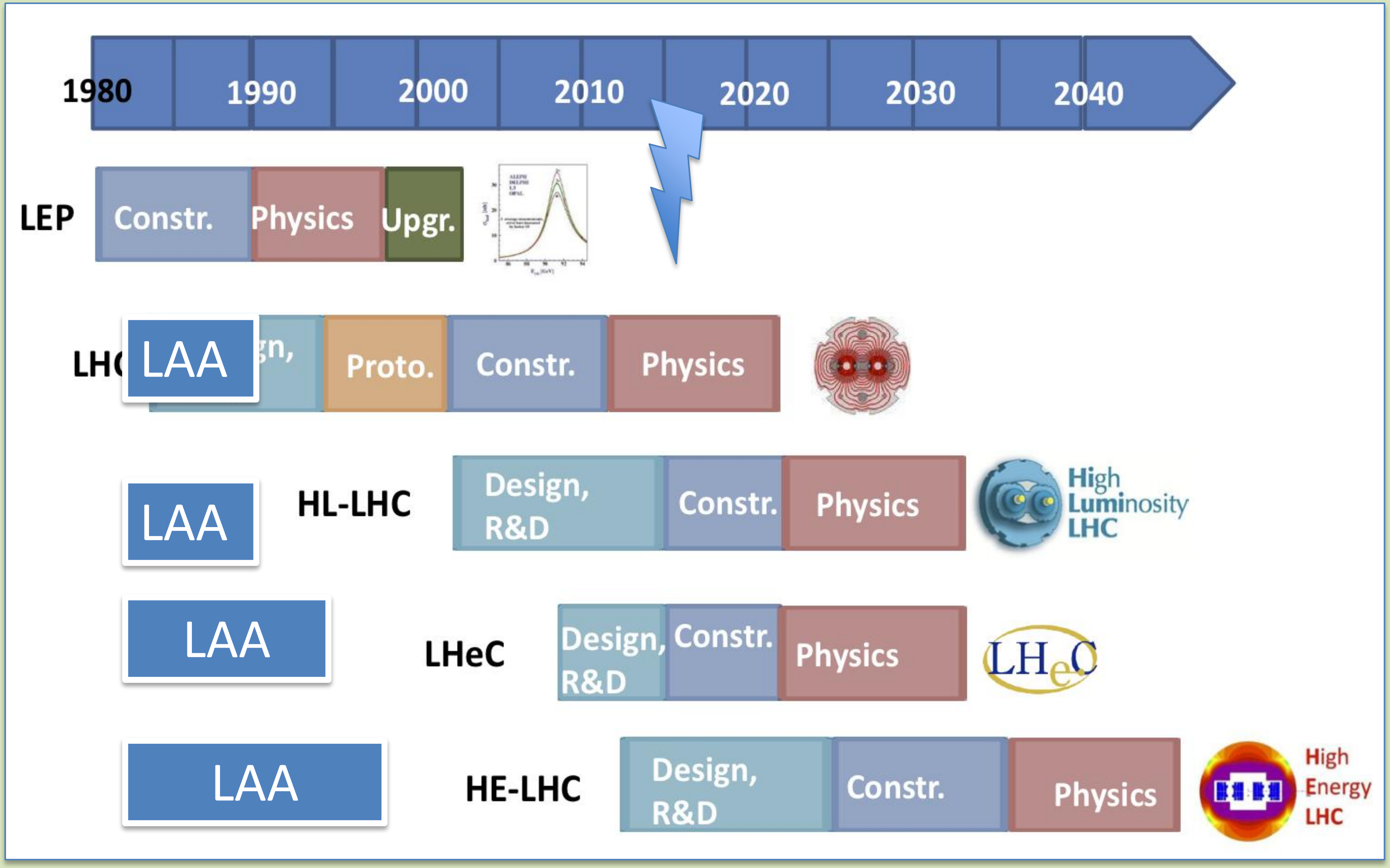
new technologies needed
+ keep what works well
+ cost-effective solutions
+ keep logistics in mind (ALARA)

Courtesy: Lutz Feld

4

General Remarks

Systems	R&D collaborations and Groups
• Tracking Systems	• RD 50 collaboration (rad. hard semiconductors) • Cooling: PH-DT and ext. collaborators
• Calorimetry	• RD52 collaboration (Dual-Readout Calorimetry) • CALICE collaboration (Calo. for linear coll.)
• Muon Systems	• RD 51 collaboration Micro-Pattern Gas Detectors Technologies
• Electronics & • Readout Systems	• Common Electronics Projects, ACES • RD 53 collaboration (Dev. of Pixel Readout IC)
• Trigger/DAQ/Offline/ Computing	• TDAQ teams of the experiments • PH-SFT group and ext. collaborators


1980
1990
2000
2010
2020
2030
2040
LEP
Constr.
Physics
Upgr.
LHC
LAA
Proto.
Constr.
Physics
LAA
HL-LHC
Design,
R&D
Constr.
Physics
High
Luminosity
LHC
LAA
LHeC
Design,
R&D
Constr.
Physics
LHeC
LAA
HE-LHC
Design,
R&D
Constr.
Physics
High
Energy
LHC

Not all is negative with 

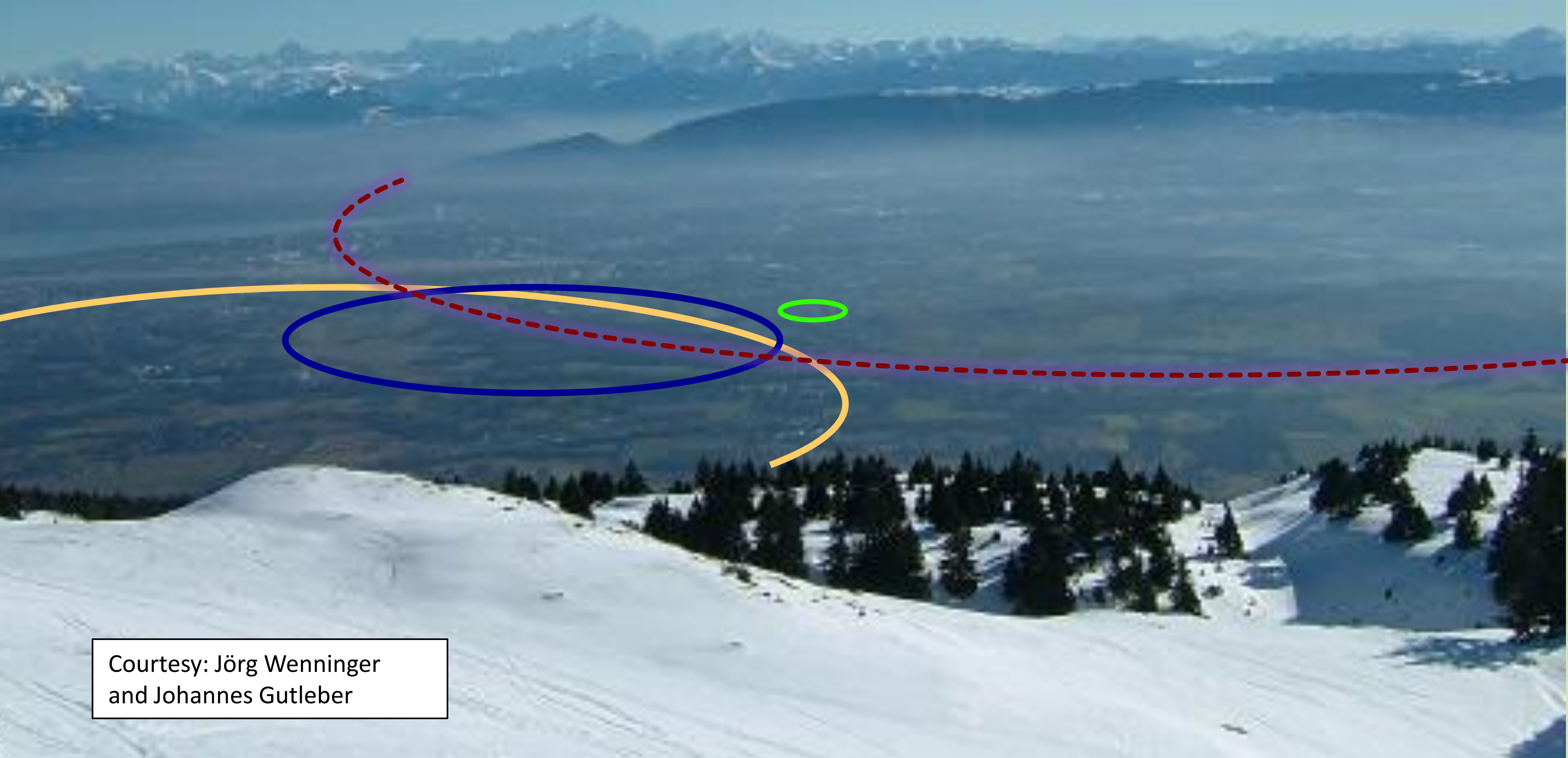
Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly € 80 billion of funding available over 7 years (2014 to 2020)

In addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market.

Science	24 441 M €
Industry	17 016 M €
Society	29 679 M €

FCC-hh Workshop: 26-28 May
Introduction

Fabiola Gianotti (CERN PH)



Courtesy: Jörg Wenninger
and Johannes Gutleber

Main areas for design study

Preparatory group for a kick-off meeting => Steering committee

See talk by M.Benedikt's

Machines and infrastructure conceptual designs	Technologies R&D activities Planning	Physics experiments detectors
Infrastructure	High-field magnets	Hadron physics experiments interface, integration
Hadron collider conceptual design	Superconducting RF systems	$e^+ e^-$ coll. physics experiments interface, integration
Hadron injectors	Cryogenics	e^- - p physics and integration aspects
Lepton collider conceptual design	Specific technologies	
Safety, operation, energy management environmental aspects	Planning	

PP-131007-MBE_FCC Design Study

The EuroCirCol kick-off event at CERN on 2-4 June brought together 62 participants to constitute governance bodies, commit to the project plan and align the organisation, structures and processes of 16 institutions from 10 countries.

The goal of the project is to conceive a post-LHC research infrastructure around a 100 km circular energy-frontier hadron collider capable of reaching 100 TeV collisions. The project officially started on 1 June and will run for four years. The total estimated budget of 11.2 million Euros includes **a 2.99 million Euro contribution from the Horizon 2020 programme** on developing new world-class research infrastructures.

EuroCirCol is a building block in the globally coordinated strategy of the FCC study to produce a global design for a global machine.

What is 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 of NAs, TAs and JRAs, fully in line with the priorities of the European Strategy for Particle Physics.

What benefits does AIDA-2020 offer?

AIDA-2020 aims to advance detector technologies beyond current limits **by offering well-equipped test beam and irradiation facilities** for testing detector systems under its Transnational Access programme.

Common software tools, micro-electronics and data acquisition systems are also provided. **This shared high-quality infrastructure will ensure optimal use and coherent development, thus increasing knowledge exchange between European groups and maximising scientific progress.** The project also exploits the innovation potential of detector research by engaging with European industry for large-scale production of detector systems and by developing applications outside of particle physics, e.g. for medical imaging.

AIDA-2020 will lead to enhanced coordination within the European detector community, leveraging EU and national resources. The project will explore novel detector technologies and will provide the ERA with world-class infrastructure for detector development, benefiting thousands of researchers participating in future particle physics projects, and contributing to maintaining Europe's leadership of the field.

AIDA-2020

AIDA-2020

General meetings	1 event	
Governing Board	empty	
WP1 (MGT) Project management and coordination	4 events	
WP2 (NA1) Innovation and outreach	empty	
WP3 (NA2) Advanced software	1 event	
WP4 (NA3) Micro-electronics and interconnections	1 event	
WP5 (NA4) Data acquisition system for beam tests	1 event	
WP6 (NA5) Novel high voltage and resistive CMOS sensors	empty	
WP7 (NA6) Advanced hybrid pixel detectors	1 event	
WP8 (NA7) Large scale cryogenic liquid detectors	1 event	

AIDA-PUB-2015-006

AIDA

Advanced European Infrastructures for Detectors at Accelerators

Journal Publication

Development of front-end electronics for LumiCal detector in CMOS 130 nm technology

Firlej, M (AGH-UST) *et al*

European Commission

AGA – Annotated Model Grant Agreement

Version 2.0.1
12 May 2015

Document with 634 pages

Cost – Benefit - Analysis
mandatory for any EU grant > 50 M€

CBA is widely endorsed by governments (recent review by the OECD): transport, environment, energy, water, industry, health, education, cultural heritage, more recently climate change remedial actions, but very little progress on scientific projects

strongly advocated by international organizations: mandatory for any EU grant beyond 50 million Euro (ERDF), five edition of EC CBA GUIDE (last one 2014), regularly performed by World Bank, EIB, ADB, etc.

the core of the theory and applications is how to identify and forecast project inputs, outputs and their 'shadow prices'

our research (3 years) is sponsored by the EIB after a competition for a grant: they asked to universities to develop and test a CBA model for research, development and innovation projects. We proposed to develop a new method and to test it on LHC and CNAO (Hadrontherapy).

Courtesy: CERN colloquium and copy rights

COST-BENEFIT ANALYSIS OF THE LHC TO 2025 AND BEYOND: Was it Worth it ?

Massimo Florio
Università degli Studi di Milano

with

Stefano Forte
Università degli Studi di Milano

Emanuela Sirtori
CSIL Centre for Industrial Studies

The present value of use-benefits PV_{B_u} is the sum of the economic value of:

KNOWLEDGE OUTPUT
(S)

HUMAN CAPITAL FORMATION
(H)

TECHNOLOGICAL EXTERNALITIES
(T)

CULTURAL EFFECTS
(C)

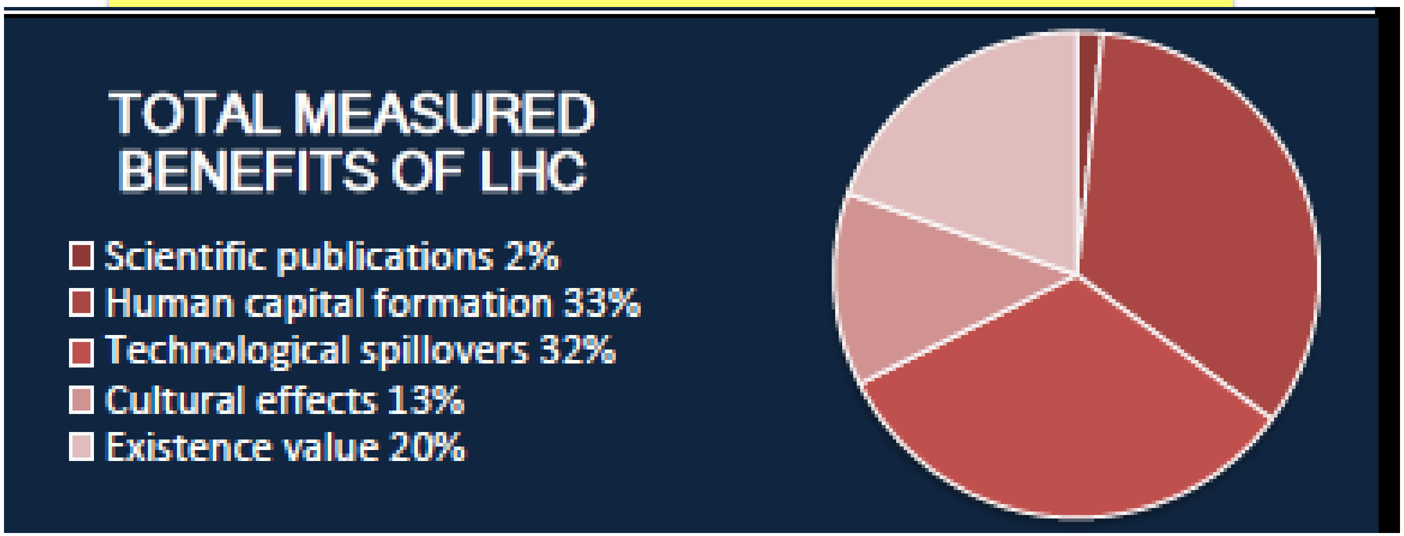
Courtesy Prof. Massimo Florio

Cost Benefit Analysis of Research Infrastructure LHC

The CBA model for pure and applied research infrastructures turns into the following equation:

PUBLICATIONS (S) | TECHNOLOGY (T) | EDUCATION (H) | OUTREACH (C) | PUBLIC GOOD (B_n) | COSTS

$$NPV_{RI} = \left[\left(\sum_{i=1}^{n}\sum_{t=1}^{T}\frac{s_t \cdot P_{it}}{k_{it}} + \sum_{i=0}^{n}\sum_{t=1}^{T} s_t \cdot Q_{it}\right) + \left(\sum_{j=1}^{J}\sum_{t=0}^{T}\frac{\Pi_{jt}}{(1+r)^t}\right) + \left(\sum_{z=1}^{z}\sum_{t=\varphi}^{T}\frac{I_{zt}}{(1+r)^t}\right) + \left(\sum_{g=1}^{G}\sum_{t=1}^{T}\frac{W_{gt}}{(1+r)^t}\right)\right] + (QOV_t + EXV_o) - \left[\sum_{t=0}^{T}\frac{(k_t + l_{st} + l_{ot} + \varepsilon_t)}{(1+r)^t}\right]$$



Courtesy Prof. Massimo Florio

Setting to zero any until now unpredictable economic value of discovery of the Higgs boson (or of any new physics), we compute a probability distribution for the net present value of the LHC through Monte Carlo simulation of 19 input, output and valuation variables and show that there is currently 92% probability that social benefits of the LHC exceed its costs

Courtesy Prof. Massimo Florio

60 years of CERN

Microelectronics at CERN: from infancy to maturity

Two decades of microelectronics at CERN enabled by the LAA project.

In 1988, the AMPLEX multiplexed read-out chip used in UA2

Hybrid pixel devices, with a read-out chip “bump bonded” to the detector, were used in WA97 in the mid-1990s.

By 2002, CERN had developed a bump-bonded 8000-channel pixel for the ALICE silicon-pixel detector at the LHC.

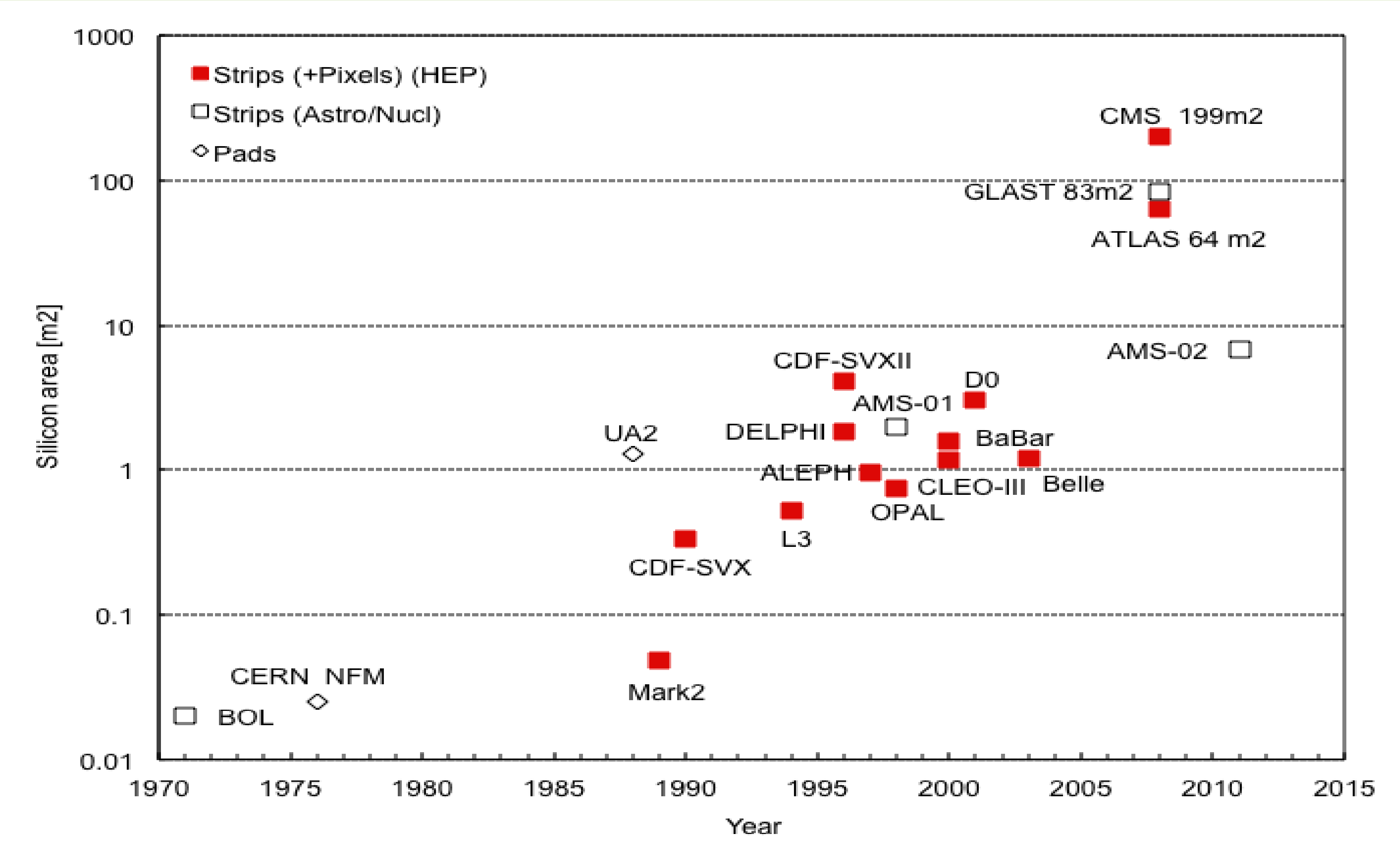
CERN Courier March 2014

The silicon age: micrometer precision at 40 million shots per second

At CERN a first MPW was designed in 1986, in collaboration with the IMEC laboratory in Leuven. This led to the production of the AMPLEX chip for silicon pad detectors, and the founding of a dedicated microelectronics design activity at CERN. Then finally the idea of a matrix of parallel, microscopic sensor elements could be implemented, now commonly called pixel detector.

CERN collaborated with circuit design specialists from EPFL in Lausanne on a CMOS chip with a 12x9 matrix of cells that each contained a contact, amplifier and following functions.

This project was supported by Italian-funded LAA project.



Evolution over time of the surface area of silicon detector systems in particle physics and in recent, space-based experiments. **Source Yoshinobu Unno, KEK.**

Thanks for listening to learn about the LAA