The Higgs Discovery at CERN - the impact of science without borders

Dreiländertagung der Medizinischen Physik
Universität Zürich
7 – 10 September 2014

Felicitas Pauss
ETH Zurich

How it all started .... science without borders

1946: first linear accelerators;
today also used for radiotherapy

1946: first electron synchrotron;
today used for light sources

1950: first proton synchrotrons;
hadron beams for cancer treatment

~1960: First storage rings

today: LHC (d ~ 10 km)

1931: first cyclotron (d ~ 0.1 m);
today to produce radioactive isotopes for medical application

SLS@PSI

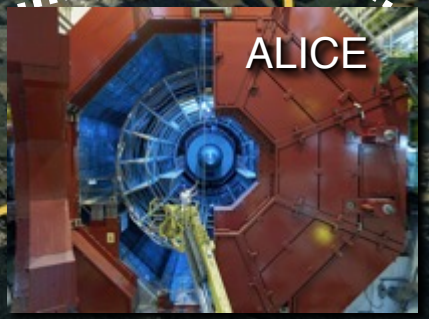
LHC@CERN

Ernest Lawrence

A New Era in Fundamental Science

One of the most ambitious project in science

Since March 2010 ... ation of a new energy frontier ... nd Pb-Pb collisions

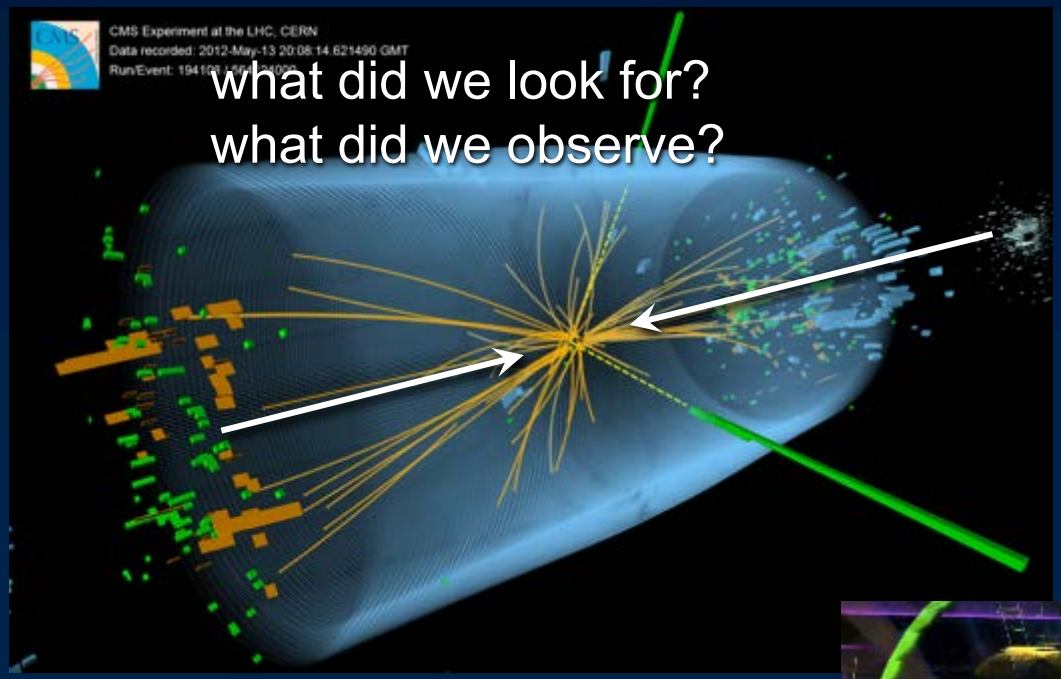


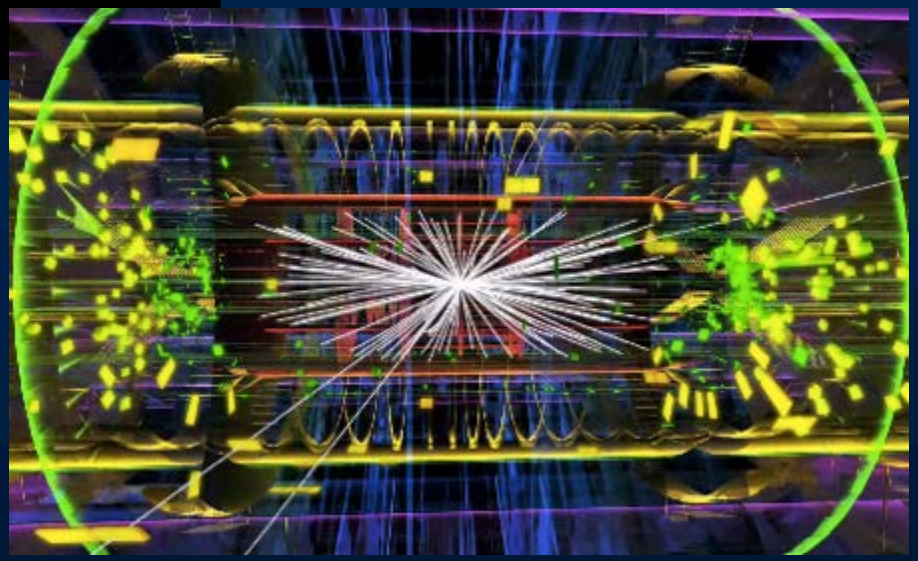
Challenge:
very high-tech ... detectors, ... nced
comput... ...tructure,
very la... ...ternational
collaborations

LHC challenge:
~1200 SC magnets of 8.3T
(7600km NbTi cables),
operated at 1.9K

4 July 2012: CERN press conference

"CERN experiments observe particle consistent with long-sought Higgs boson"





one Higgs → 4e produced in 10^{13} pp collisions

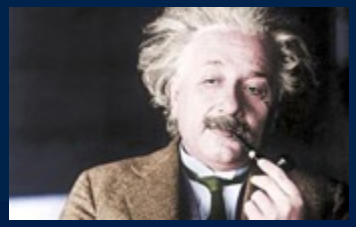
~4 Billion events registered, expected ~ 200 Higgs events (in 130 GeV Mass range)

4 July 2012: CERN press conference

"CERN experiments observe particle consistent with long-sought Higgs boson"

Why was this discovery important?

Newton: weight proportional to mass



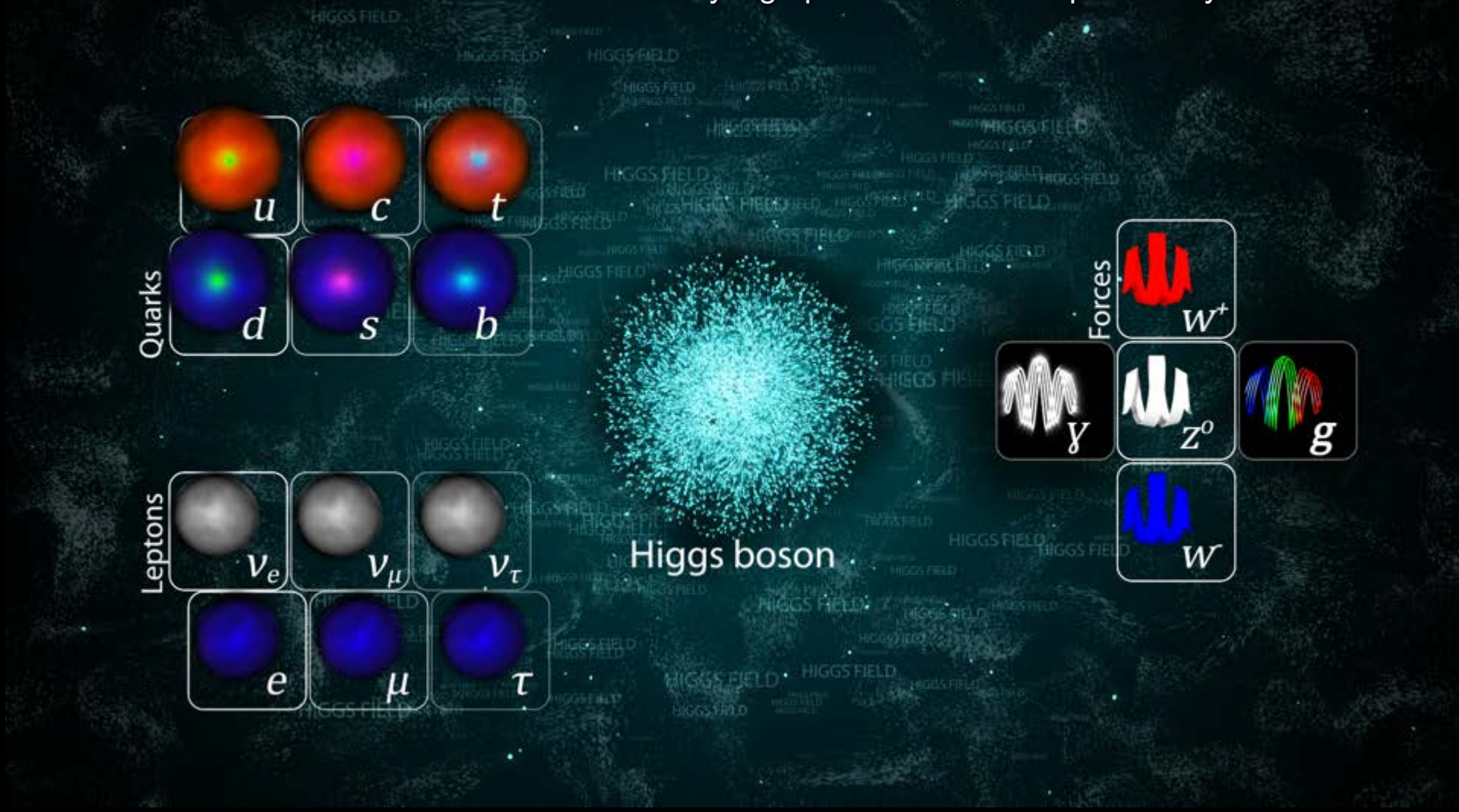
Einstein: Energy related to mass

No explanation of origin of mass

Where does mass come from?
Is it related to the Higgs Boson?

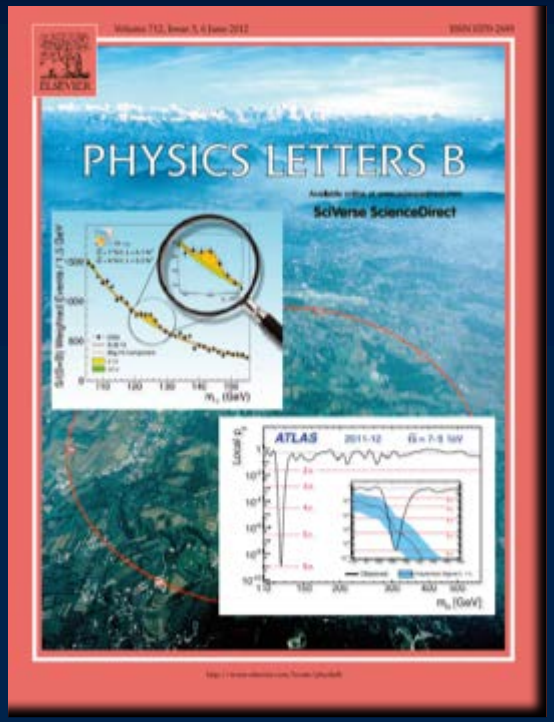
The Standard Model of Particle Physics

very successfully describes the interactions between the fundamental building blocks of matter.
Predictions have been tested with very high precision over the past ~40 years



4 July 2012: CERN press conference

"CERN experiments observe particle consistent with long-sought Higgs boson"



"The highlight of a remarkable year 2012"

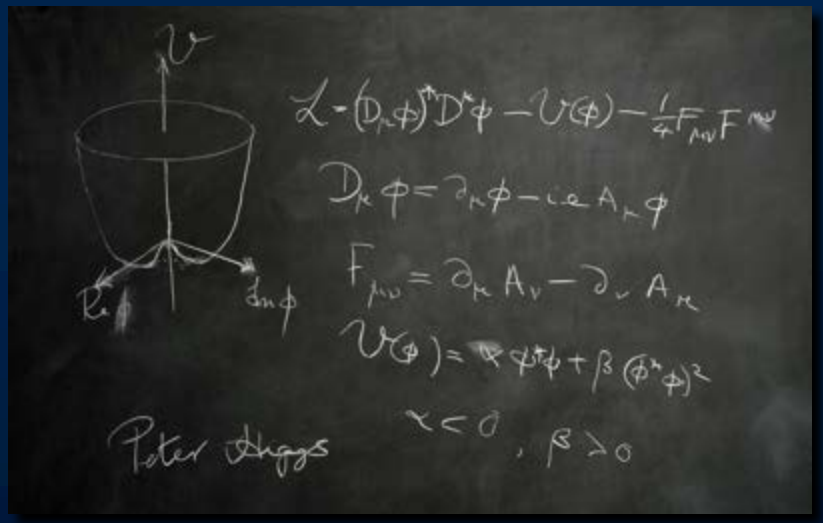
A historic milestone – but only beginning of a full exploitation of LHC physics potential

2013 Nobel Prize in Physics

to François Englert & Peter Higgs

"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

CERN, July 2012



Next Scientific Challenge:
understand the very first moments of our Universe after the Big Bang

LHC@CERN: ~ 10^{-12} seconds

Big Bang

WMAP

13.7 billion years

today

10^{28} cm

Experiments in Astrophysics & Cosmology

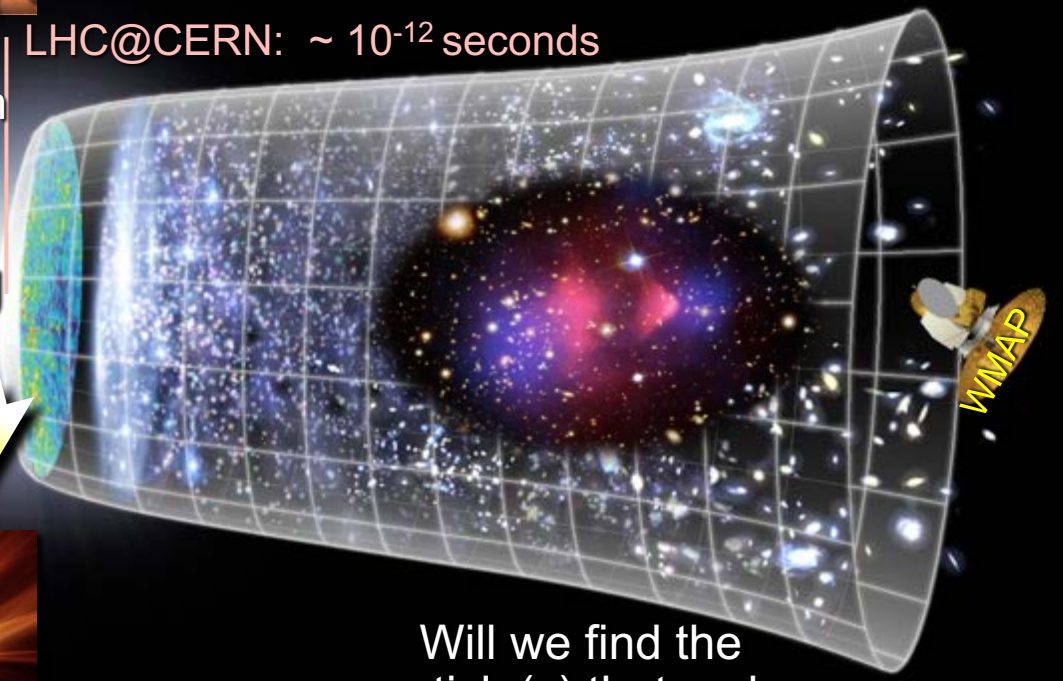
~380‘000 years

Next Scientific Challenge:
understand the very first moments of our Universe after the Big Bang

Start data taking in 2015 at close to design energy of 14 TeV

LHC@CERN: ~ 10^{-12} seconds

Big Bang



Will we find the particle(s) that make up the mysterious 'dark matter' in our Universe?

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

Next Scientific Challenge:
understand the very first moments of our Universe after the Big Bang

Start data taking in 2015 at close to design energy of 14 TeV

LHC@CERN: ~ 10^{-12} second

Big Bang

Learn about our Universe with technologically most advanced instruments

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?

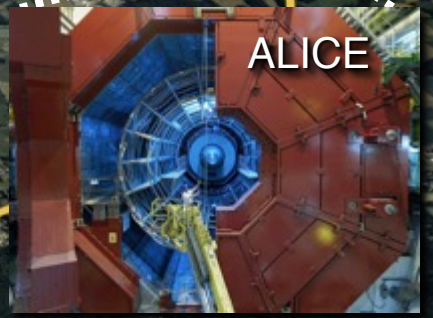
LHC and experiments are masterpieces of technology!

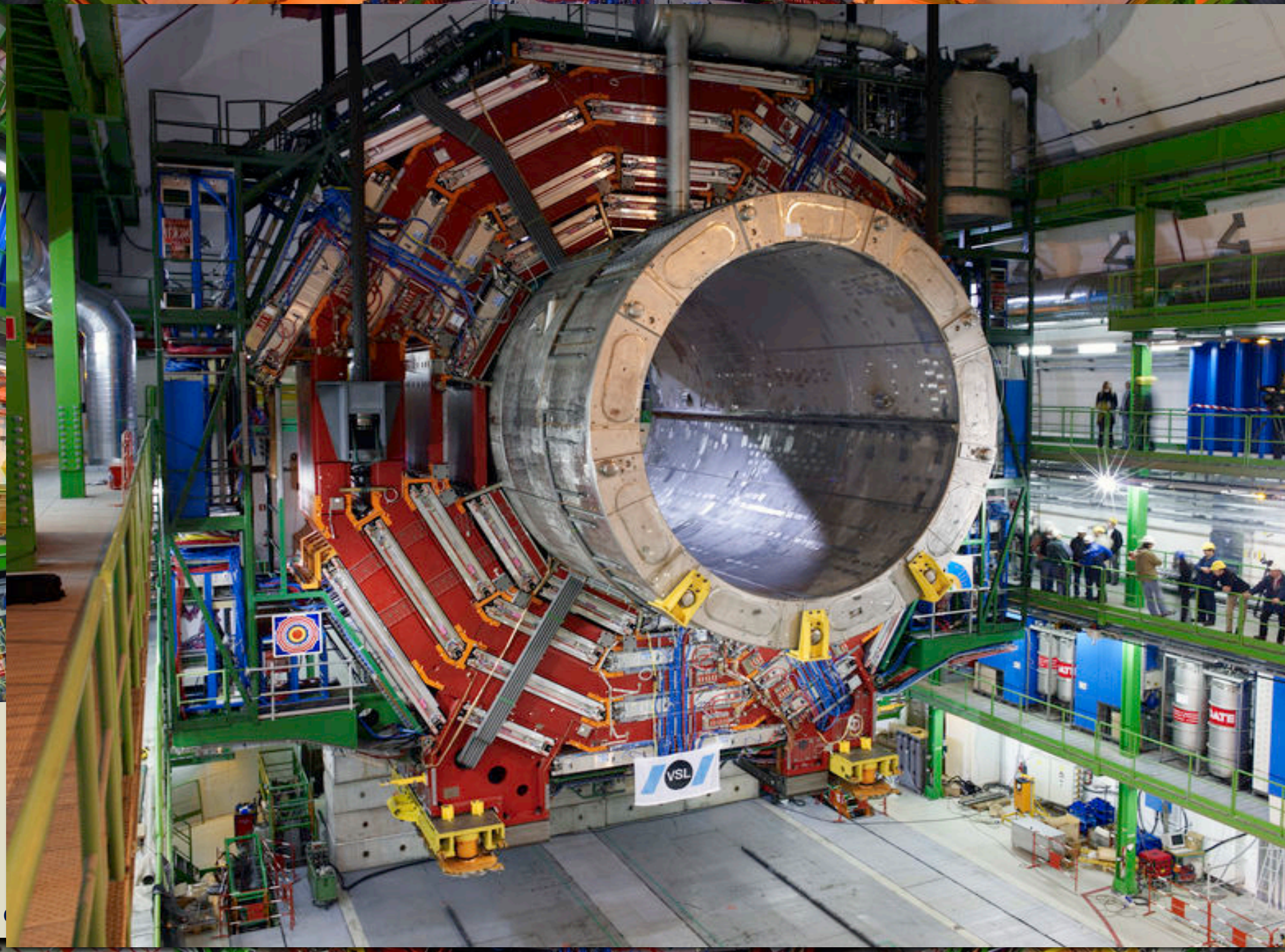
Project started in beginning of 1990's

Many years of R&D

Construction lasted for ~ 8 years

Innovative technologies developed




VSL

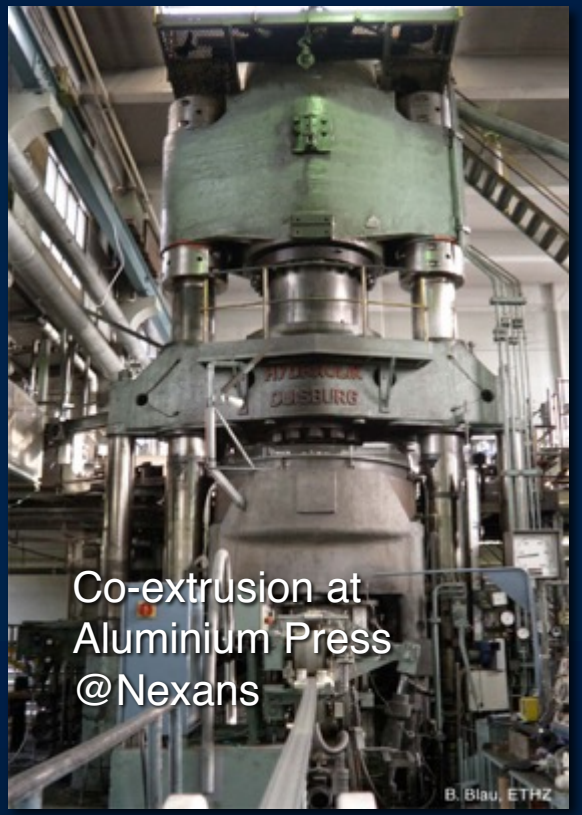
CMS SC Magnet

The challenge:
Develop a reliable superconductor which is able to create a 4 T field in a volume of 360m^3

current: 19'140 A
stored energy: 2.5 GJ


Cabling Machine @ Brugg Cables

End production:
spring 2003


Co-extrusion at Aluminium Press @Nexans

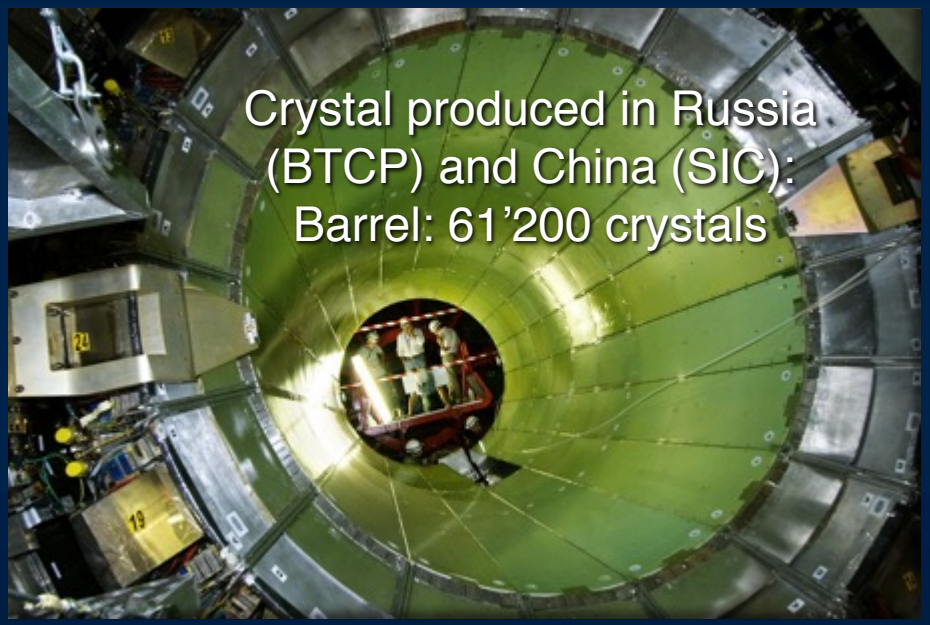
non-stop production time of 32 hours to produce one 2600 m long conductor unit; total 20 + 1 (prototype) conductor units

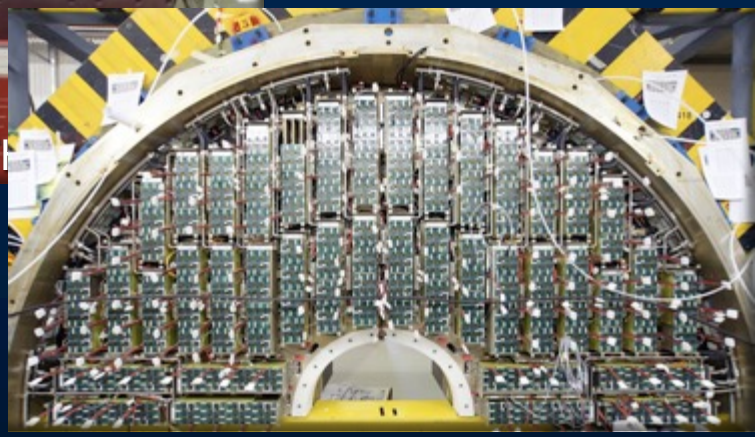
CMS crystal calorimeter

ETH Institute for Particle Physics

The challenge:

Construct a very high performance calorimeter (~76'000 $PbWO_4$ crystals of same characteristics) and complex readout electronics which operates under harsh LHC conditions





First Supermodule (1700 crystals) finished in Sept 2004; in July 2007 Barrel Installation terminated (36 SM):
28 dead/noisy channels out of 61200
Endcap construction started in 2007; in August 2008 installation terminated

Particle Physics and Innovation

- Interfacing between fundamental science and key technological developments

- Technologies and Innovation

Accelerating particle beams

Detecting particles

Large-scale computing (Grid)

How it all started .... science without borders

In 1946 B. Wilson proposes to use protons, helium and carbon ions for medical application

1946: first linear accelerators;
today also used for radiotherapy

1946: first electron synchrotron;
today used for light sources

1950: first proton synchrotrons;
hadron beams for cancer treatment

~1960: First storage rings

today: LHC (d ~ 10 km)

1931: first cyclotron (d ~ 0.1 m);
today to produce radioactive isotopes for medical application

Ernest Lawrence

Hadron Therapy Patients Statistics

Facilities in operation end of 2013

1954 – Dec 2013: > 120'000 patients (~80%protons, ~11% Carbon Ions)

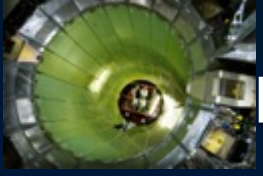
10 new facilities expected to be in operation by end of 2014

Adapted from M. Jermann (2014), Int J Particle Ther

Facilities in operation end of 2013

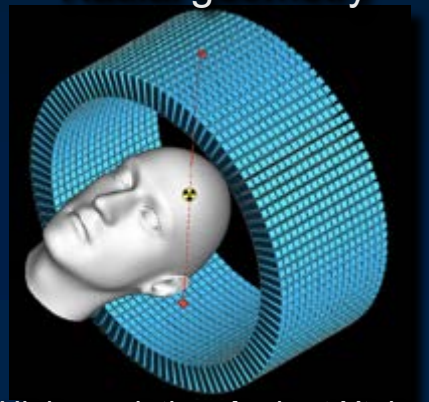
Proton therapy
C ion therapy

Canada	175	Germany	6'026	Russia	6'701		
China	1291	Italy	474	South Africa	521	Switzerland	1'581
Czech Rep.	140	Japan	24'975	South Korea	1'266	UK	2'446
France	11'368	Poland	39	Sweden	1'356	USA	44'362



From CMS Crystal Calorimeter to new PET project (AXPET)

Radial geometry

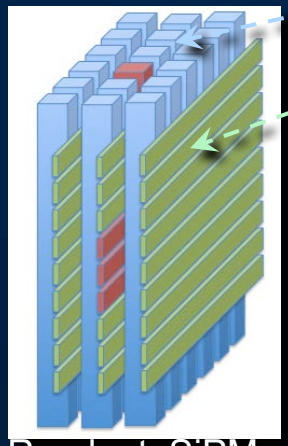


High resolution → short Xtals
High sensitivity → long Xtals

Axial geometry

Motivation:
decouple spatial resolution and sensitivity
→ optimize both together

→ Axial geometry:
- ❖ High resolution → small Xtal cross-section
- ❖ High sensitivity → several Xtal layers



LYSO Xtals (3x3x100 mm³ each)

WLS strips behind each Xtal layer

- ❖ Spatial resolution:
  < 2mm FWHM (all 3 dimensions)
- ❖ Energy resolution:
  ~ 12% FWHM (at 511 keV)

Readout: SiPM

reconstructed image of a rat injected with fluorine-18

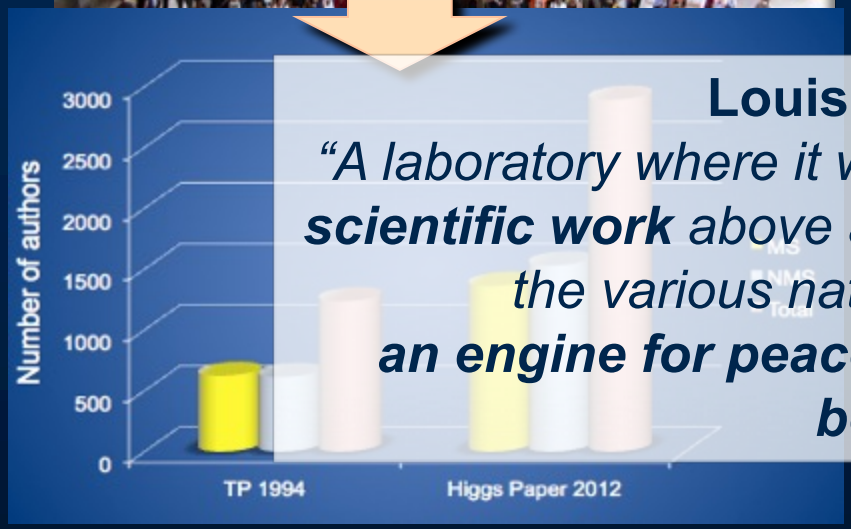
https://twiki.cern.ch/twiki/bin/view/AXIALPET/WebHome

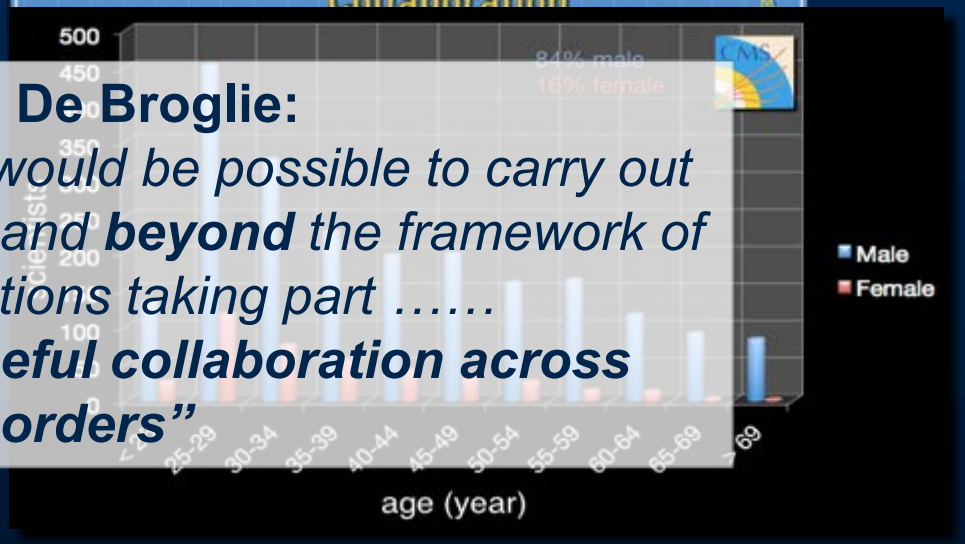
Unite people from different countries and cultures

Higgs discovery: success of a truly global scientific project

Each collaboration: ~3000 scientists, ~40 countries, ~200 institutes

Sir Ben Lockspeiser (1st president of CERN Council):
*"Scientific research lives and flourishes in an **atmosphere of freedom** – freedom to **doubt**, freedom to **enquire** and freedom to **discover**. These are the conditions under which this new laboratory has been established."*



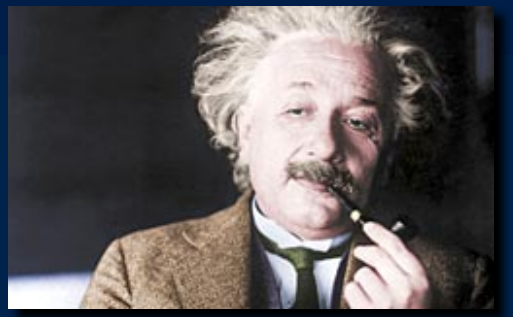


Louis De Broglie:
*"A laboratory where it would be possible to carry out **scientific work** above and **beyond** the framework of the various nations taking part ……*
an engine for peaceful collaboration across borders"

CERN: today world's largest Particle Physics Laboratory

Uniting people from different countries and cultures

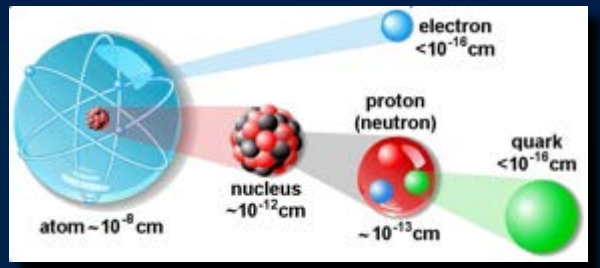
“Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world.”



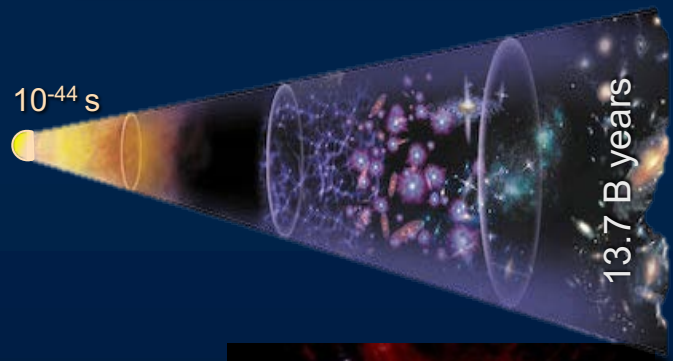
Imagination .....

There are more atoms in your fingertip than stars in the whole Universe

Atoms are almost empty space – without that empty space you would compress into a tiny volume (cube with length ~0.02 mm)



The components of your body are truly ancient: Protons we are made of were formed about 3 minutes after the Big Bang i.e. we all are about "13.7 billion years old"



The heaviest element (e.g. iron), which exists in our body, was formed via fusion in dying stars ……. i.e. we all are made of stardust


SGSMP
SSRPM
SSRFM
50th Anniversary
Swiss Society of Radiation Biology
and Medical Physics