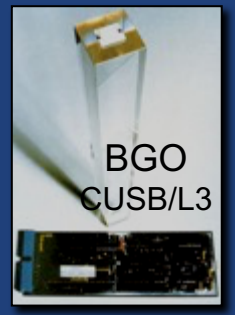
WELCOME
TO THE FAREWELL
LECTURE OF

FELICITAS PAUSS

... a bit of history ...


my 3rd office
ETH zürich
CERN
Singen (Hohentwiel)
Schaffhausen
Basel
Mülhausen
Belfort
Vesoul
Lure
Besançon
La Chaux-de-Fonds
Pontarlier
Yverdon-les-Bains
Bern
Freiburg
Thun
Interlaken
Grindelwald
Lauterbrunnen
Lausanne
Parc Jura vaudois
Montreux
Thonon-les-Bains
Annemasse
Sitten
Zermatt
Matterhorn
Chamonix-Mont-Blanc
Mont Blanc
Annecy
Saint-Vincent
Aosta
Zug
Luzern
Liechtenstein
St. Gallen
Kempten (Allgäu)
Oberstdorf
Bad Ragaz
Chur
Davos
St. Moritz
Parc Ela
Luwin
Sulden
Parco Nazionale dello Stelvio
Ischgl
St. Anton am Arlberg
Locarno
Domodossola
Lugano
Sünders
Tirano
Parco delle Orobie Bergamasche
Lecco
Como
Väris
Google

Scientific highlights (1978 – 2016)



- Cornell (1980-1983): Beauty physics & novel detectors technologies:
  Crystals and photo sensors → L3, CMS, FACT and PET application

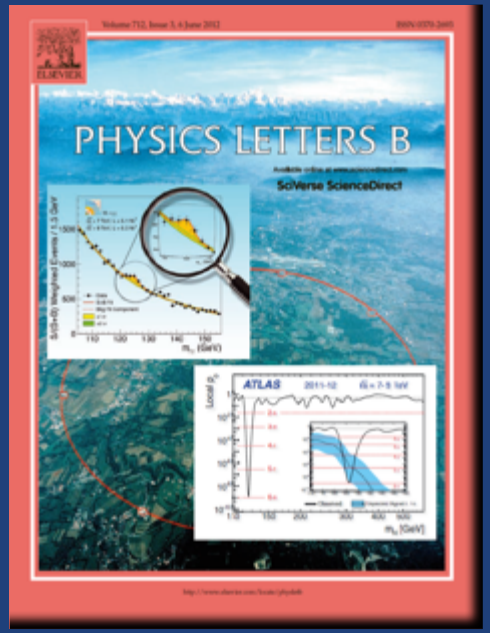
- CERN (since March 1983 at high-energy colliders):
  1983 discovery of the W/Z particle (UA1 experiment)
  → NP in 1984 to spokesperson (Carlo Rubbia)

- CERN: Nov 2009: recording first pp collisions with CMS at LHC
  July 2012: discovery of the Higgs Boson
  → NP to theorists in 2013 (Englert, Higgs)

- La Palma (Canary Islands, since 2004):
  Oct 2011: "first light" with novel camera for Cherenkov telescopes

4 July 2012: CERN press conference

“CERN experiments observe particle consistent with long-sought Higgs boson”



“The highlight of a remarkable year 2012”

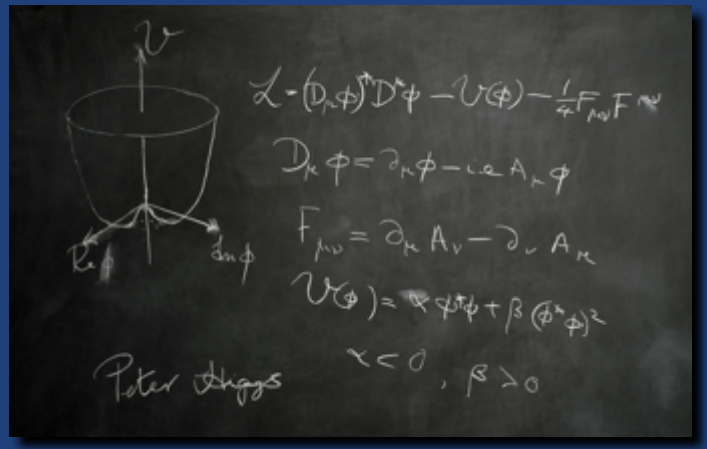
A historic milestone – but only the beginning of a full exploitation of LHC physics potential

2013 Nobel Prize in Physics

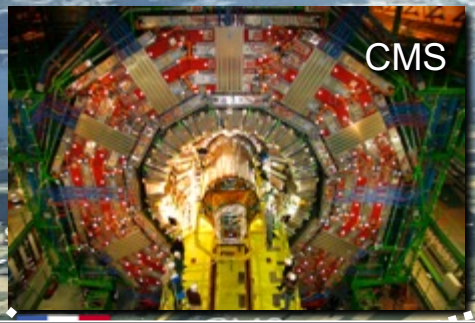
to François Englert & Peter Higgs

"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



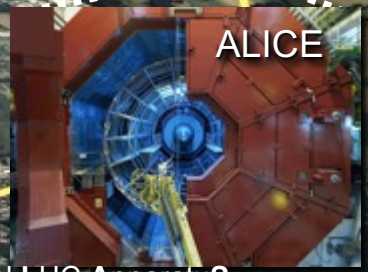
The challenges on the way to the Higgs discovery ...



One of the most ambitious project in science on the global scale

Experiments challenges:
very high-tech, complex detecto
very advanced computing infra
very large international c

LHC challenge:
~1200 SC magnets of 8.3T
operated at 1.9K (-271°C)



ATLAS **A** **T**oroidal **L**HC **A**pparatu**S**
CMS **C**ompact **M**uon **S**olenoid
LHCb **L**arge **H**adron **C**ollider **b**eauty
ALICE **A** **L**arge **I**on **C**ollider **E**xperiment

The LHC Project: how it all started ….

1984 Lausanne workshop official starting point for work at the LHC: E_{cm}= 18TeV ?, L = 10^{33} cm^{-2} s^{-1} ?

1987 La Thuile workshop: comparison of LHC, CLIC (e^+e^-), e-p option

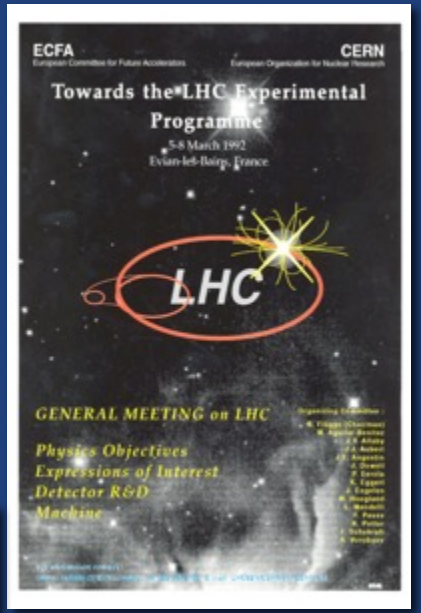
LHC: E_{cm} = 16TeV, L = 10^{33} cm^{-2} s^{-1} → 10^{34} cm^{-2} s^{-1} , e-p: 1.3 - 1.8TeV, CLIC: 2TeV

End 1980's the first collaborations started

1990 Aachen workshop: LHC physics and instrumentation

E_{cm} ~ 16 TeV, L = 10^{34} cm^{-2} s^{-1}

1992 Evian workshop presentation of EoI (in March)
proto-collaborations
LoI presentation at CERN (in October)



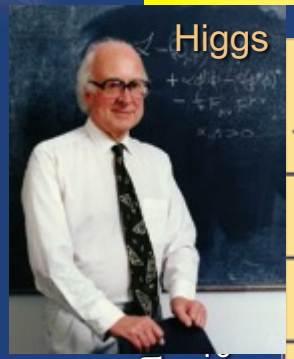
1995 LHC conceptual design: 14 TeV, L = 10^{34} cm^{-2} s^{-1}

1993 SSC cancelled (87 km, 40 TeV)

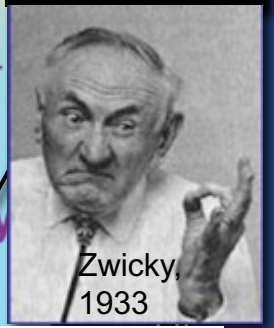
Physics motivation / goals – as in the late 1980's

before the start of LEP in 1989

Particle masses?



Dark Matter?



?

Quarks and Leptons

Hadrons
p/n

Nuclei

Extrapolation

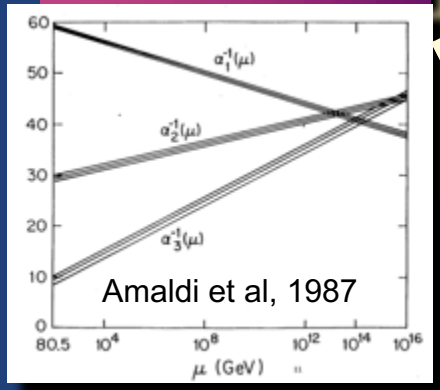
today

LHC ⇨ Answers to open questions
new physics is required

10^{-10} s 10^{-6} s 3 min

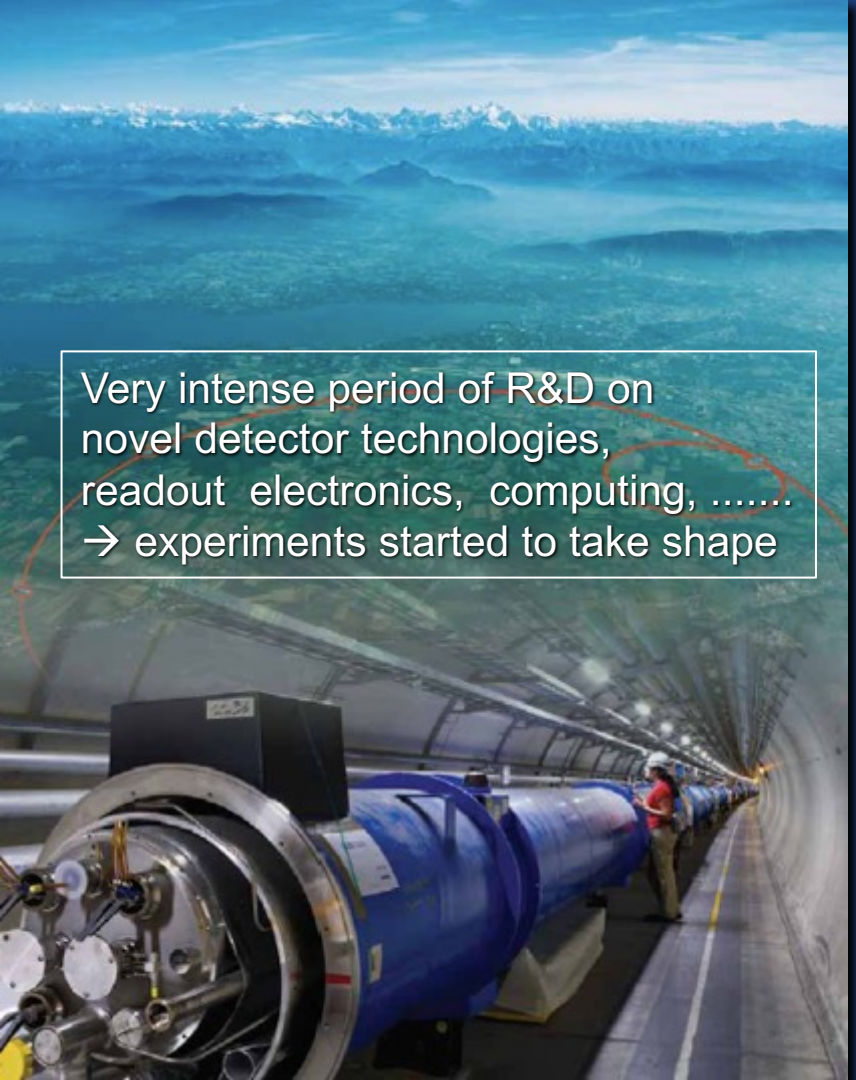
Time after

Unification of forces?



Amaldi et al, 1987

Matter-Antimatter Asymmetry?



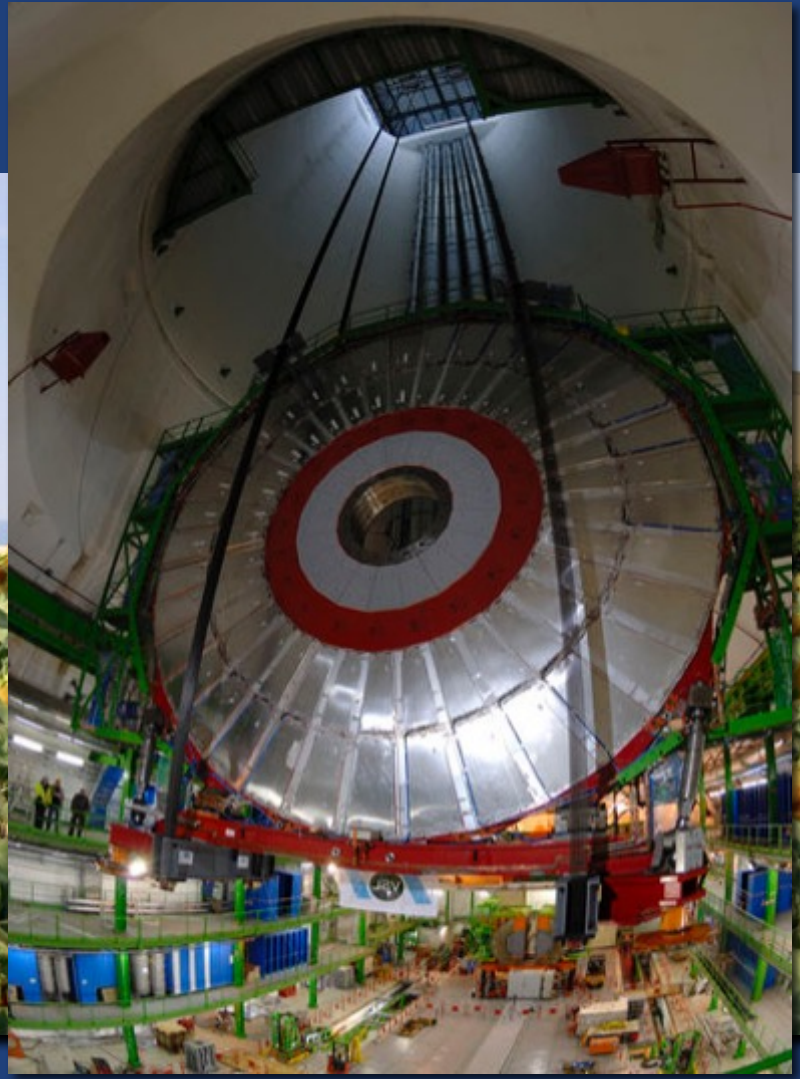
Very intense period of R&D on novel detector technologies, readout electronics, computing, ...
→ experiments started to take shape

Approval of the LHC experimental programme by CERN Council middle of the 1990's:

- a clear scientific vision and an excellent discovery potential
- tying together human and financial resources from around the globe for a common scientific goal
- realization of long-term project requires strong and steady support from all CERN Member States and the participating institutions in the experiments

→ Funding commitment for the next ~30 years!!
→ However: be realistic about the time schedule!

Construction of CMS



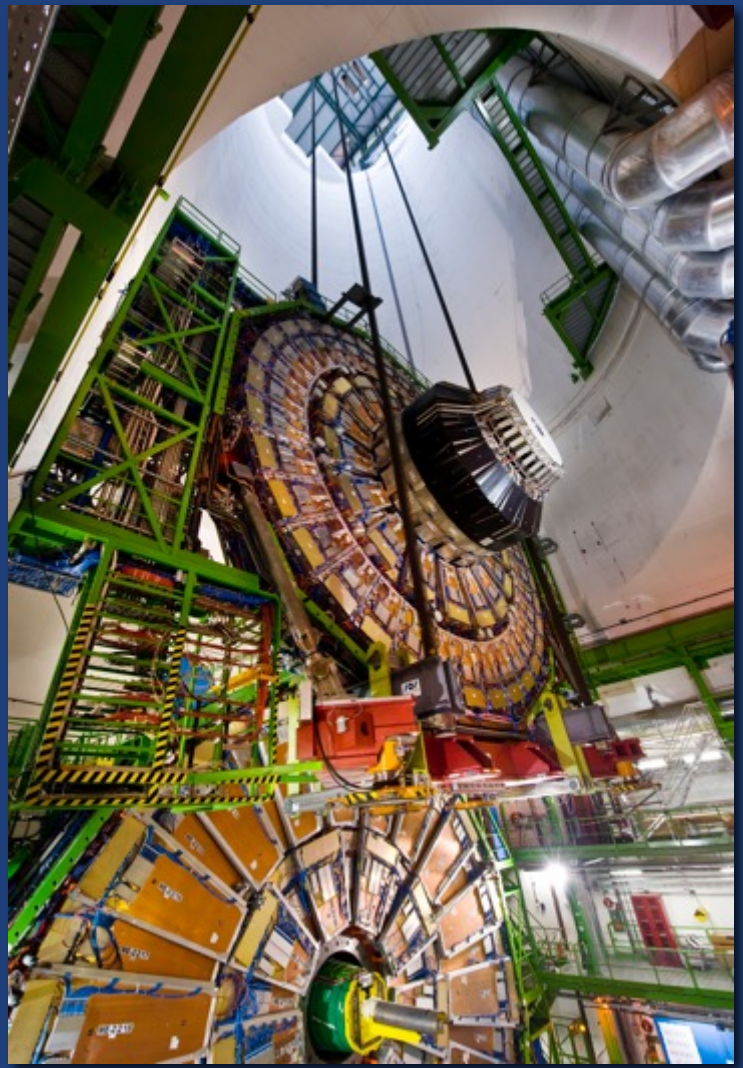
Surface building
in 2006

Lowering of first heavy element:
Nov 2006

Lowering of central and heaviest element (~ 2000 t) on 28/02/2007

~10 cm clearance between detector and balcony barrier

weight of ~5 Jumbo jets, or 3.5 Airbus380-planes….



Lowering of the last heavy element on
22 January 2008

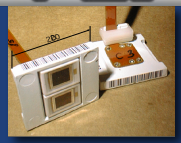
$PBWO_4$ crystal calorimeter: 76'000 crystals (from Russia and China)

July 2007: Barrel (61'200 Xtals) installation completed

28 dead/noisy channels out of 61'200!!

ETH Institute for Particle Physics

PAUL SCHERRER INSTITUT PSI



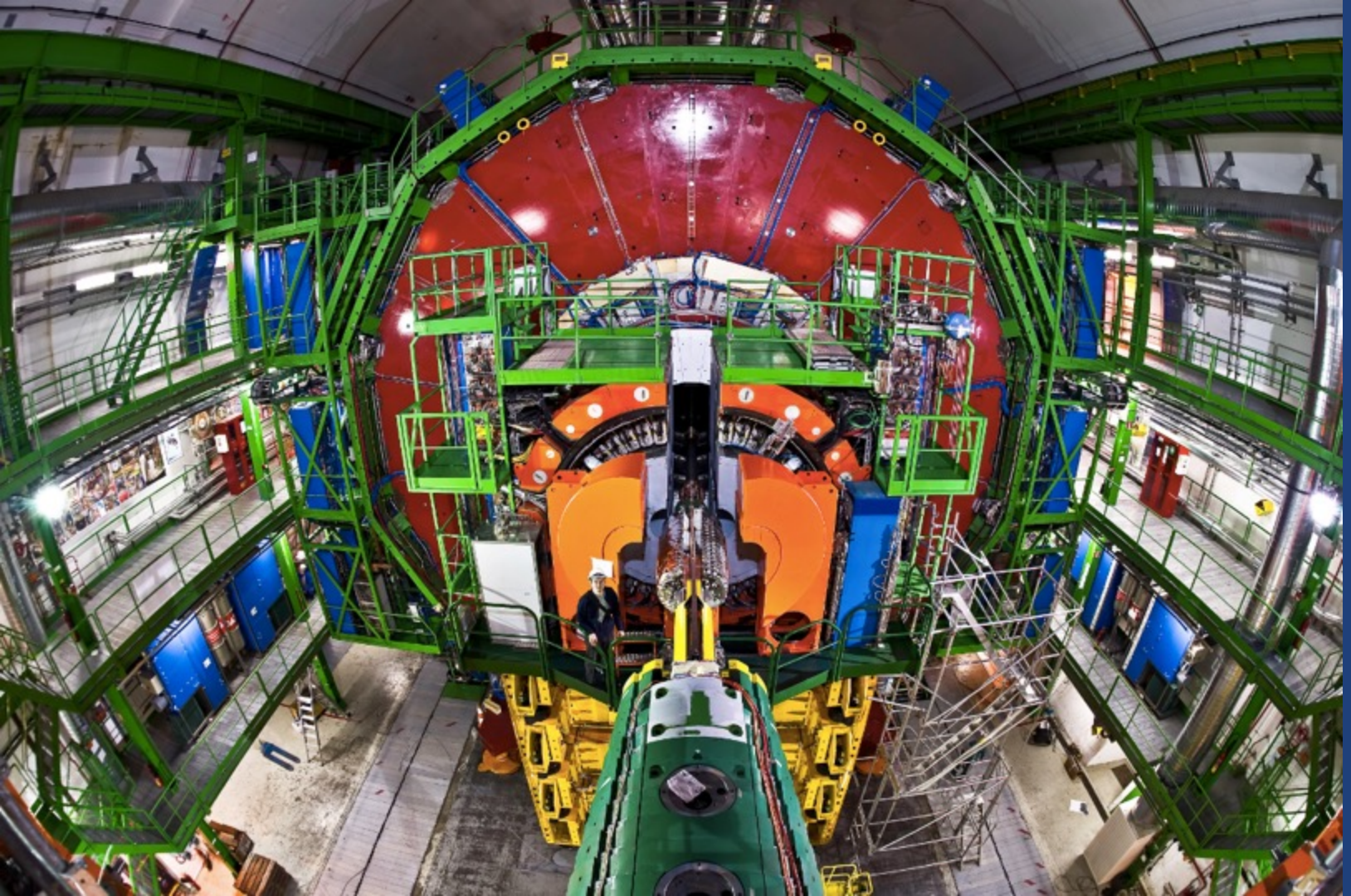
July 2008:
Pixel detector installation

PAUL SCHERRER INSTITUT
PSI

ETH Institute for Particle Physics

Universität Zürich[UZH]

Closing CMS to be ready for collisions



Gigantic digital camera

ETH Institute for Particle Physics

PAUL SCHERRER INSTITUT PSI

Universität Zürich[UZH]

CMS Detector

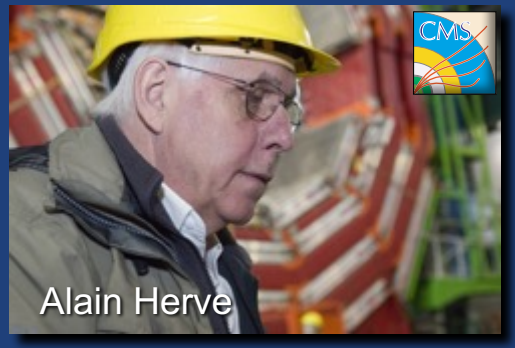
Weight: 12’500 t
Diameter: 15 m
Length: 21.6 m
Magnetic field: 4 T

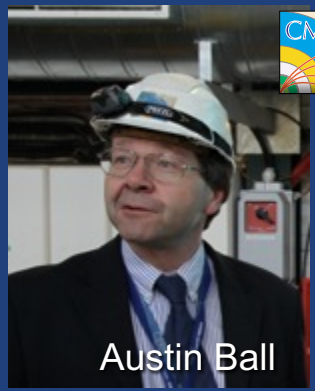
~ 100M individual detecting elements


DWE
ETH Zurich

Other success factors .....

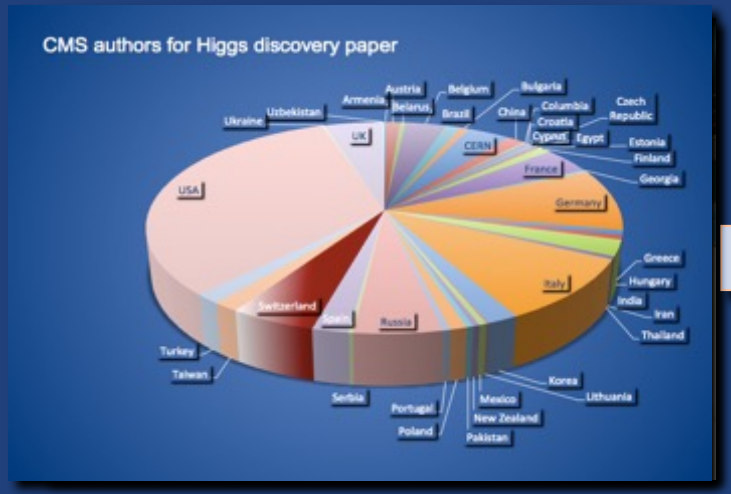
- Technical Coordination, Trigger/DAQ, ...



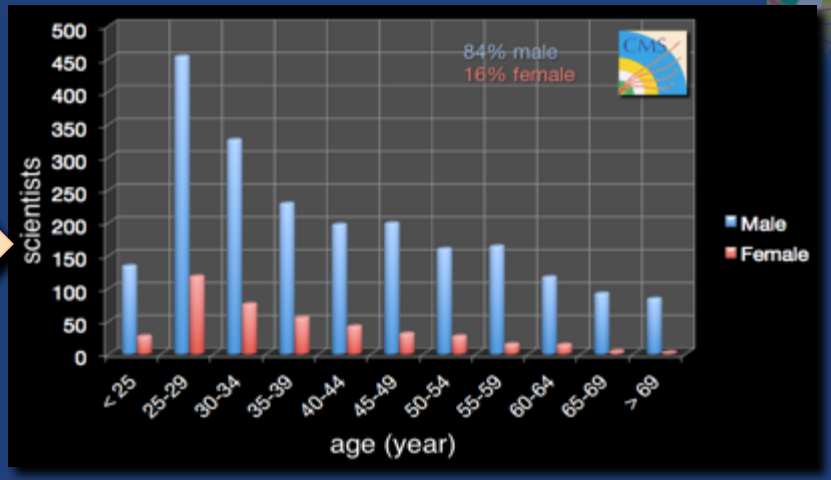


- Evaluation procedures based on peer review (LHC-Committee)
  LHCC: follows experiments (milestones, ...) till end of project
  any major technical change needs to be evaluated by the LHCC
  ("CERN model")

CMS: a truly global scientific project



CMS: ~3000 scientists, ~40 countries, ~200 institutes



Impact of large international collaborations:

- a place where people learn how to work together
- cooperation and competition are the path to success
- open access and sharing results allows everyone to participate and contribute to new developments

.... you learn how to collaborate / to manage ...

Timeline of the experiments

Daily Mail

7/09/2008

"Meet Evans the Atom, who will end the world on Wednesday"

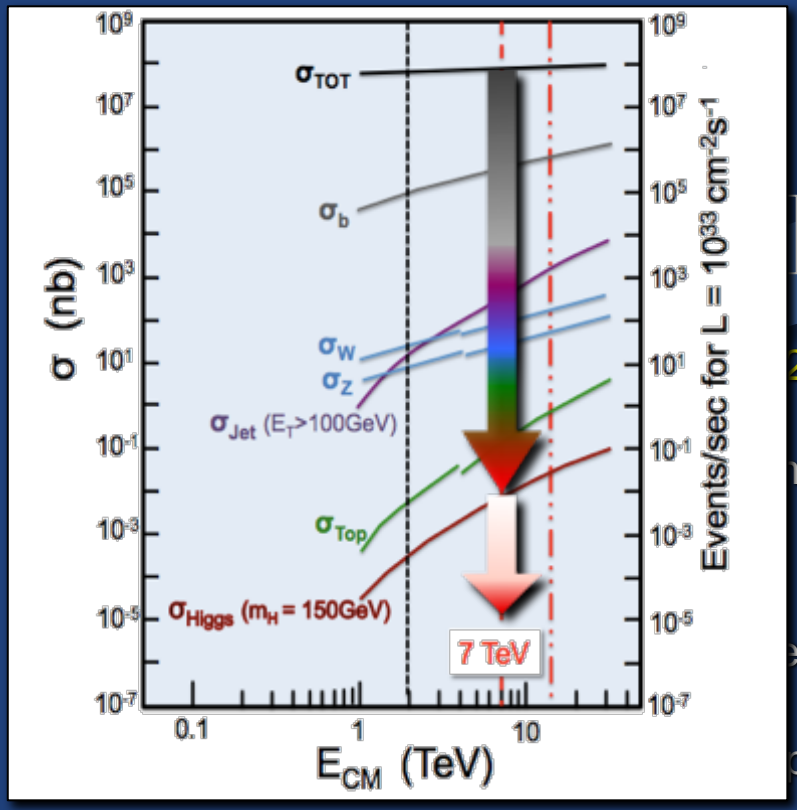
Sept 2008 → first protons circulating → 9 days later: incident in sector 3/4

Le Canard enchaîné

Journal satirique paraissant le mercredi

"A cause d'une soudure mal faite, la fin du Monde est reportée à l'an prochain"

Timeline of the experiments



2015 – 2018: 13 TeV (→14TeV)

2010: 7 TeV → 2012: 8 TeV → Higgs discovery

s circulating (E_{cm}=2.16 TeV)

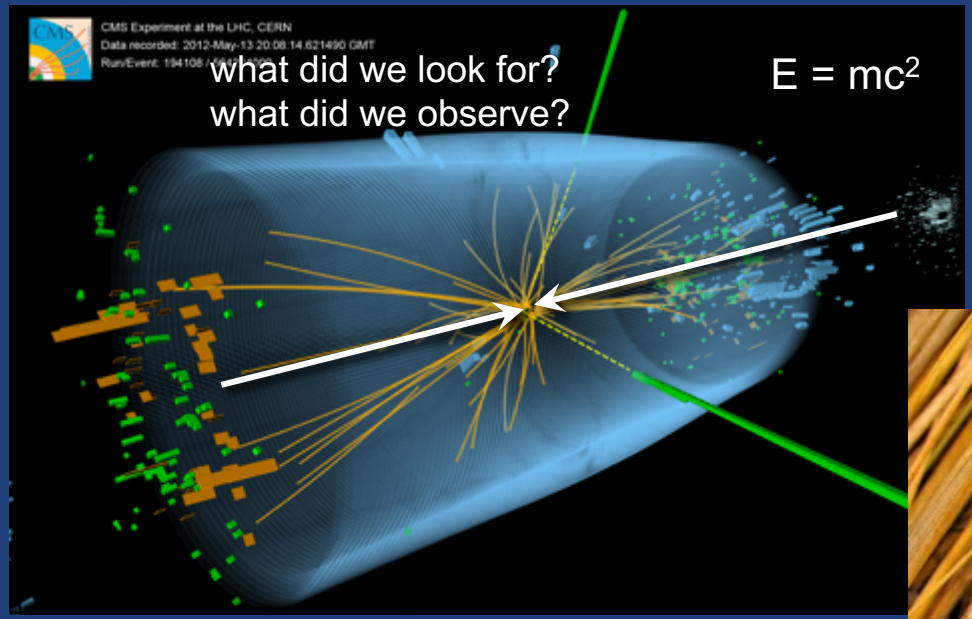
circulating → 9 days later: incident in sector 3/4

eriments → 2008 ready to take data

pproved (many years of R&D)

4 July 2012: CERN press conference

“CERN experiments observe particle consistent with long-sought Higgs boson”

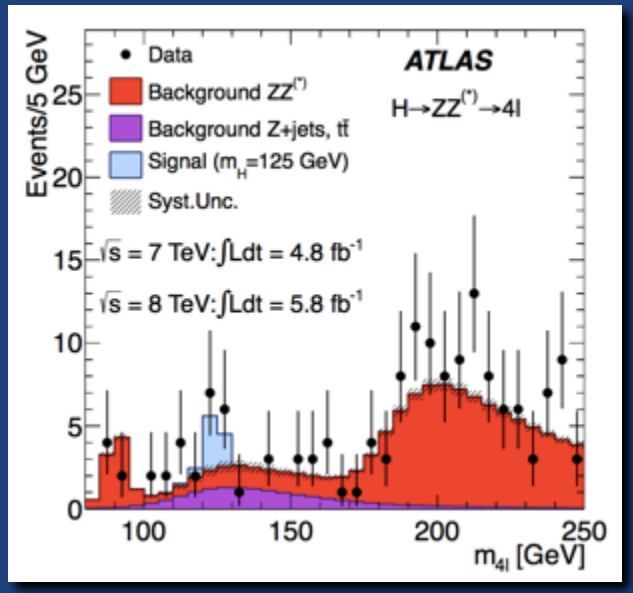


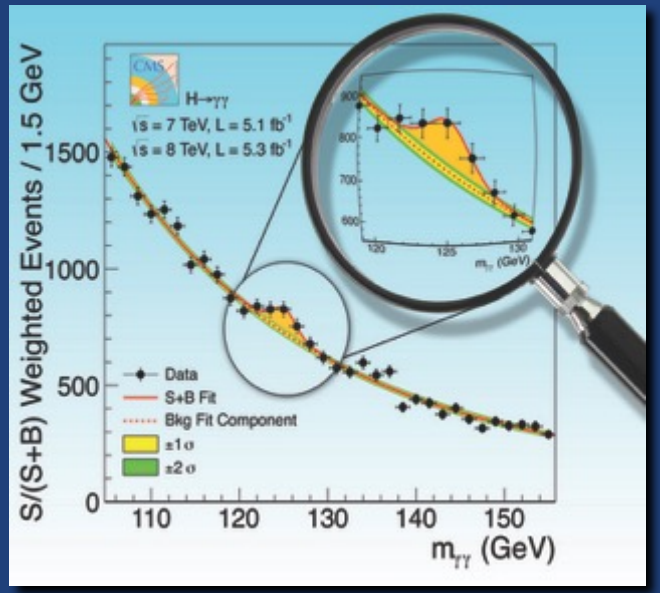
Challenge:

~ 200 Higgs events in ~ 4 Billion events recorded

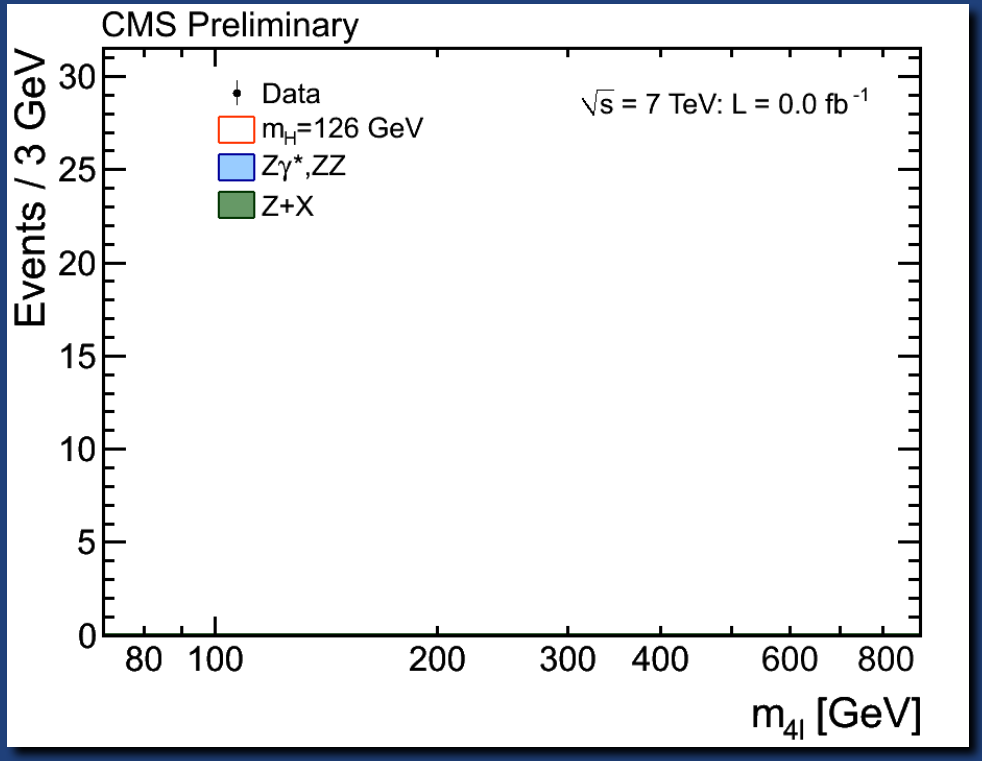
4 July 2012: CERN press conference

“CERN experiments observe particle consistent with long-sought Higgs boson”





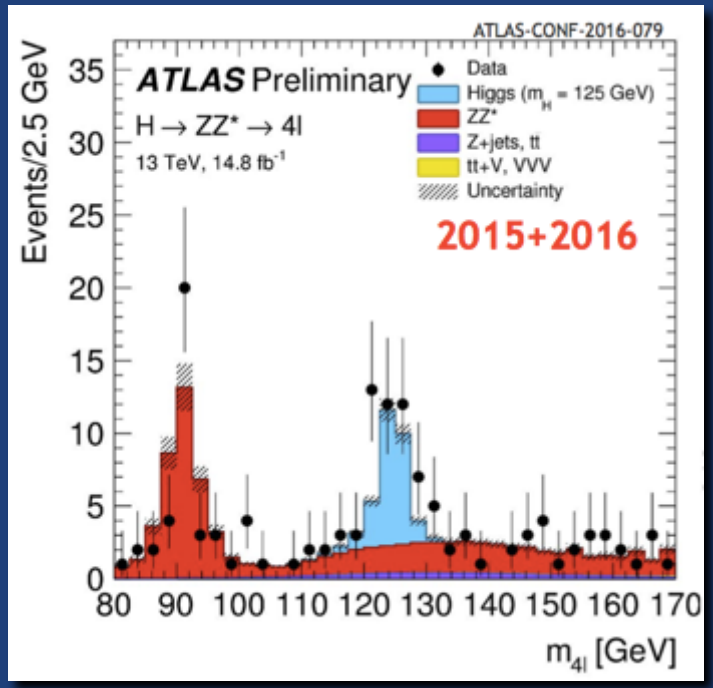
More data by end of 2012 .....

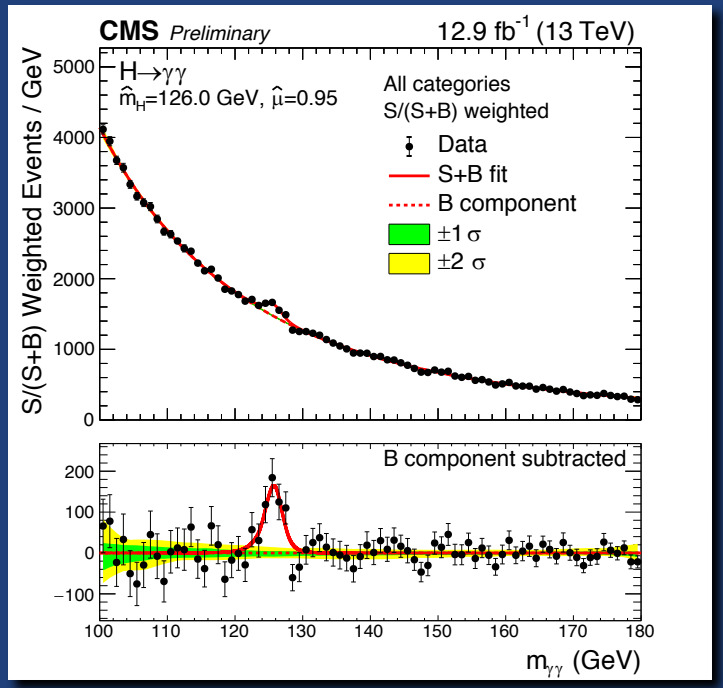


Shown in Stockholm when the physics NP was announced in Oct 2013

The 13 TeV data (2015/2016).....

August 2016: ICHEP 2016





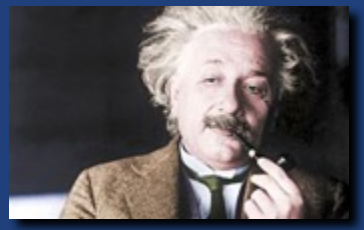
m(Higgs) = 125.09 ± 0.24 GeV (0.2% precision)

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



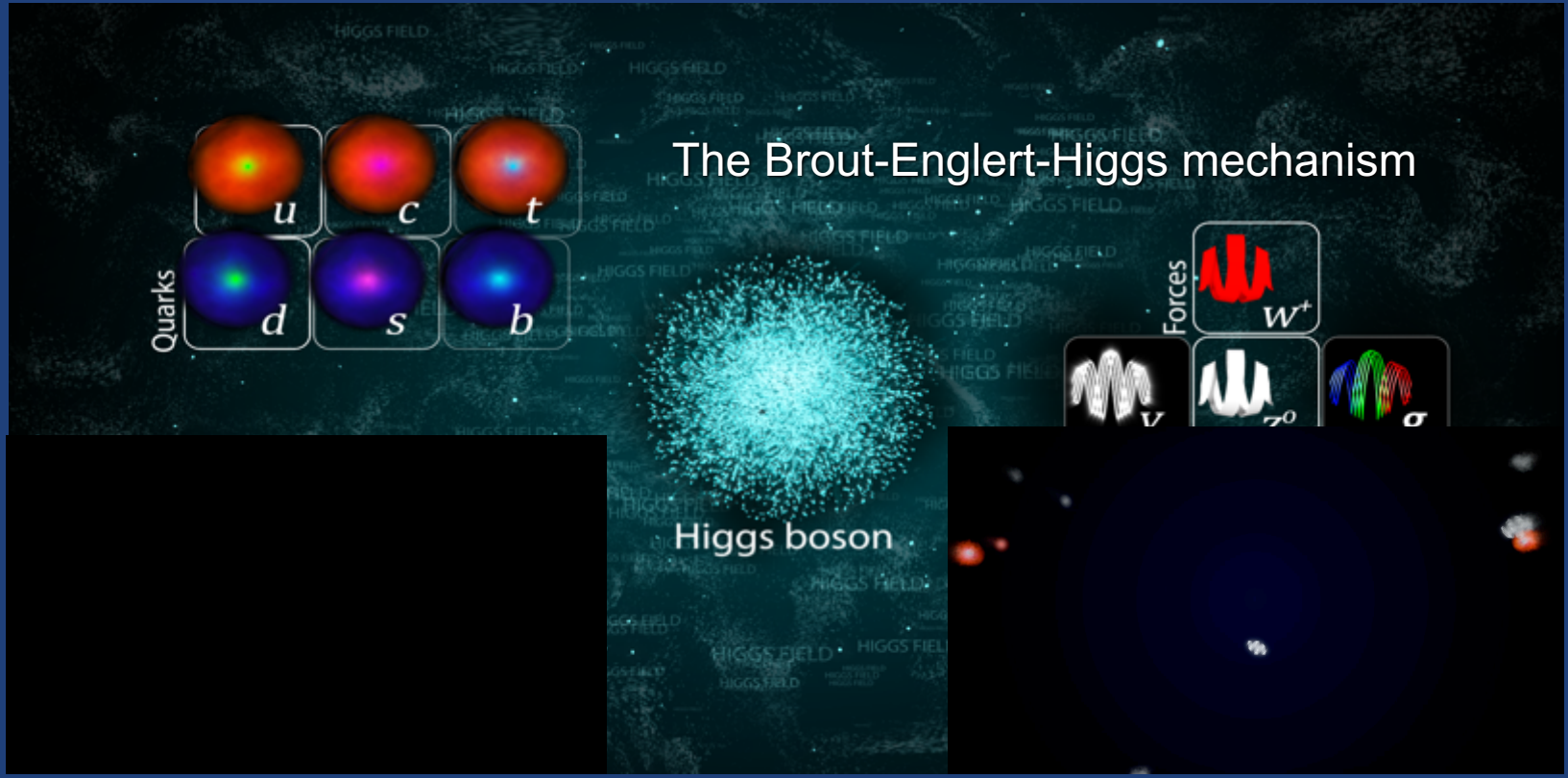
Einstein: Energy related to mass

No explanation of origin of mass

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

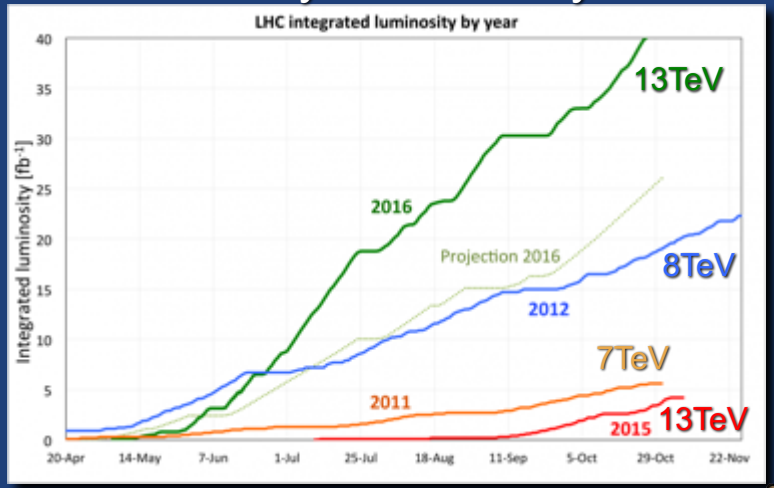
The Standard Model of Particle Physics

very successfully describes the interactions between the fundamental building blocks of matter, built on the powerful principle of gauge theories.



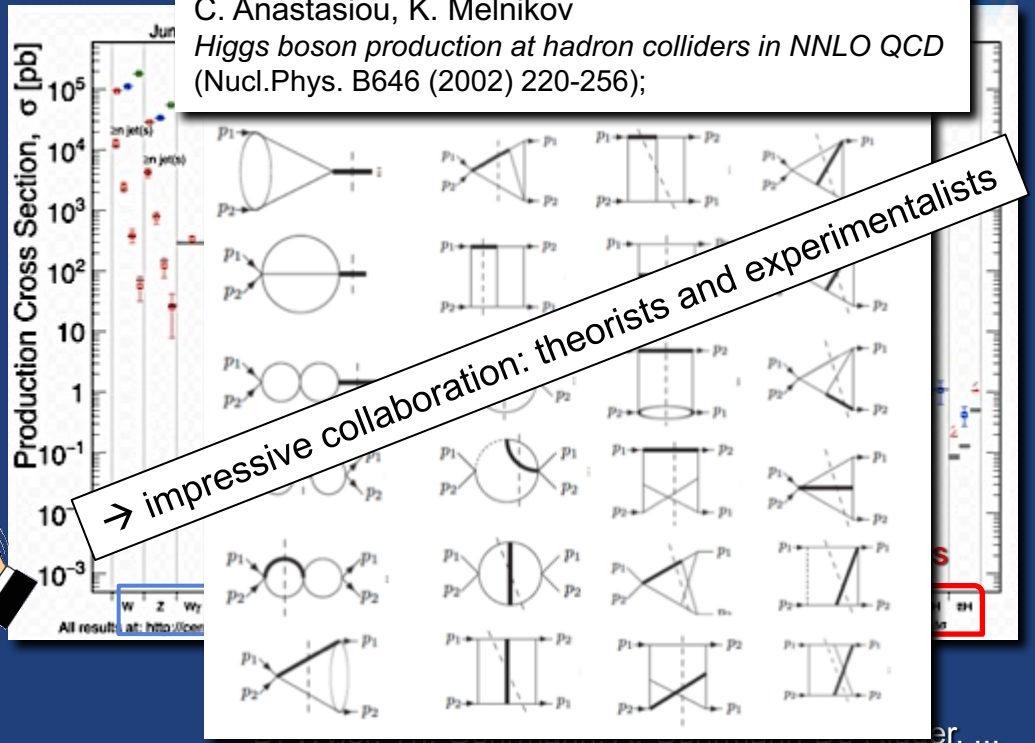
Impressive scientific output from CMS @ LHC

Luminosity delivered by LHC



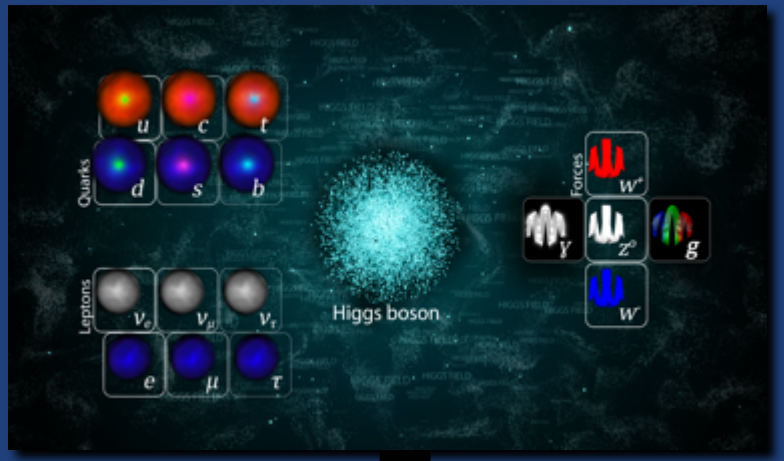
2016: CMS data taking efficiency: 93%

CMS recorded so far ~ 6×10^{11} events, requiring a storage capacity of 20 PB



The Standard Model (SM) of Particle Physics

... indeed a highly successful theory , but .....



Why is the Higgs boson so light?

What about Dark Matter?
a new form of matter must exist → what is it?

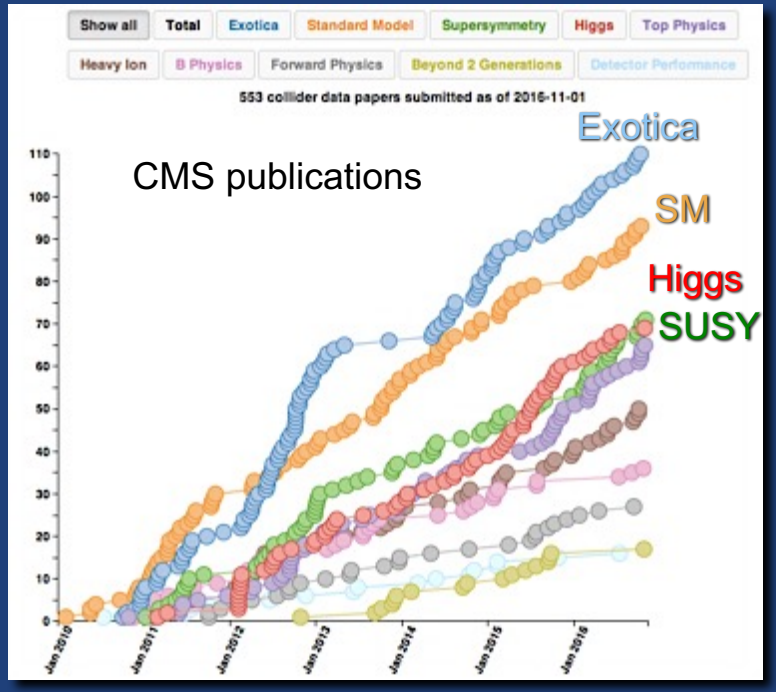
Is there a unification of forces?

.....

Beyond the SM

- Supersymmetry
- Extra Dimensions
- New symmetry groups, new interactions, substructure

Since the start of LHC we have searched for new physics ....

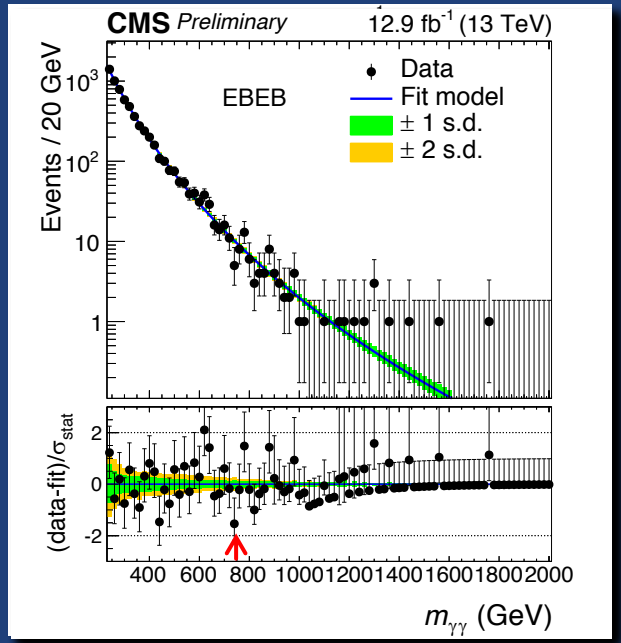


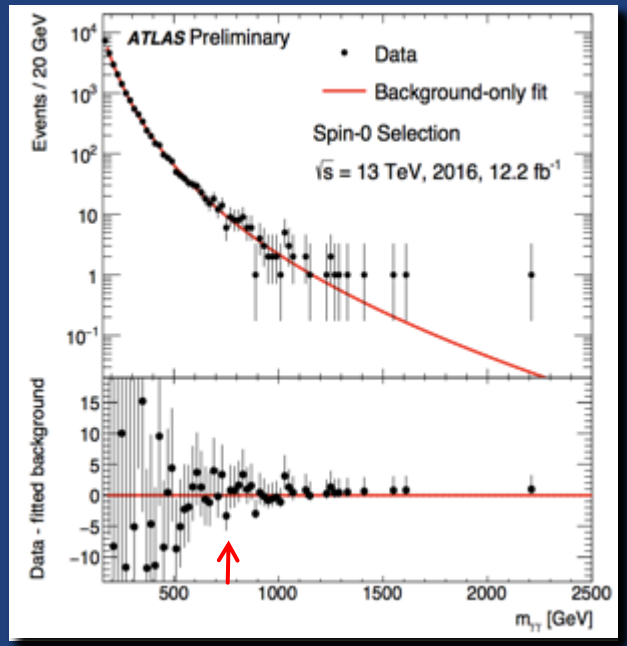
No physics signals beyond the SM (yet)

Similar Plot for ATLAS

Statistical fluctuations – the 750 GeV Story

2015 data: some excess observed by both experiments around 750 GeV .....





2016 data:
not confirmed
(ICHEP2016)

→ ~ 400 papers written ..... many press articles .....

.... one should not do this too often .....

Timeline of the experiments

Intense R&D programme necessary for upgrade of LHC and detectors

HL-LHC 2026 – 2035: 14 TeV: 3000fb^{-1}

RUN 3 2021 – 2023: 14 TeV (2x$L_{nominal}$): 300fb^{-1}

RUN 2 2015 – 2018: 13 TeV (→14TeV)

RUN 1 March 2010: 7 TeV → 2012: 8 TeV → Higgs discovery

Oct 2009:

Sept 2008 → first

~ 1999 start construction

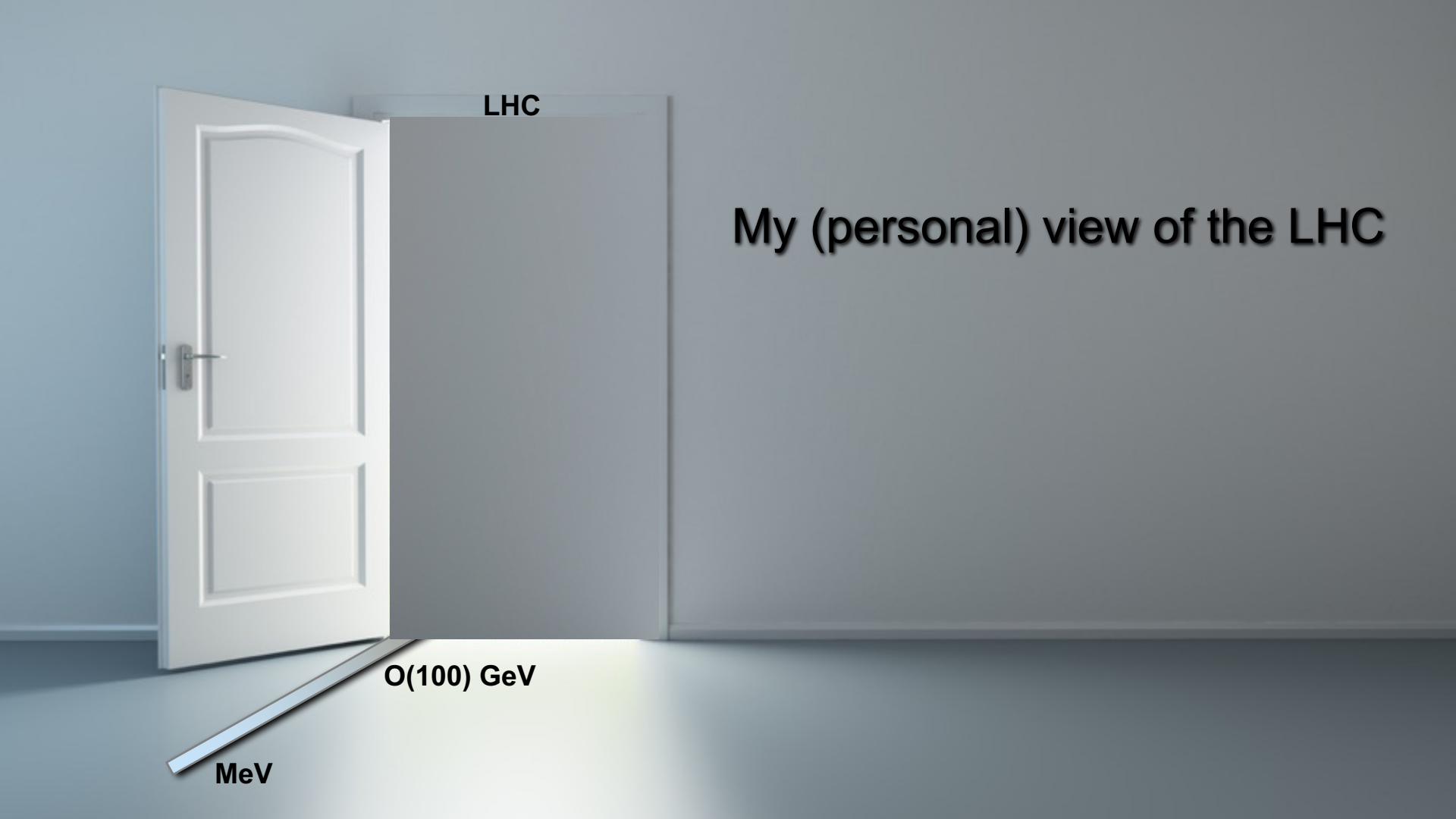
1992: EoI & LoI → 1994 TP →

?

Recall:
So far we have accumulated ~1% of luminosity we expect by the end of the HL-LHC!

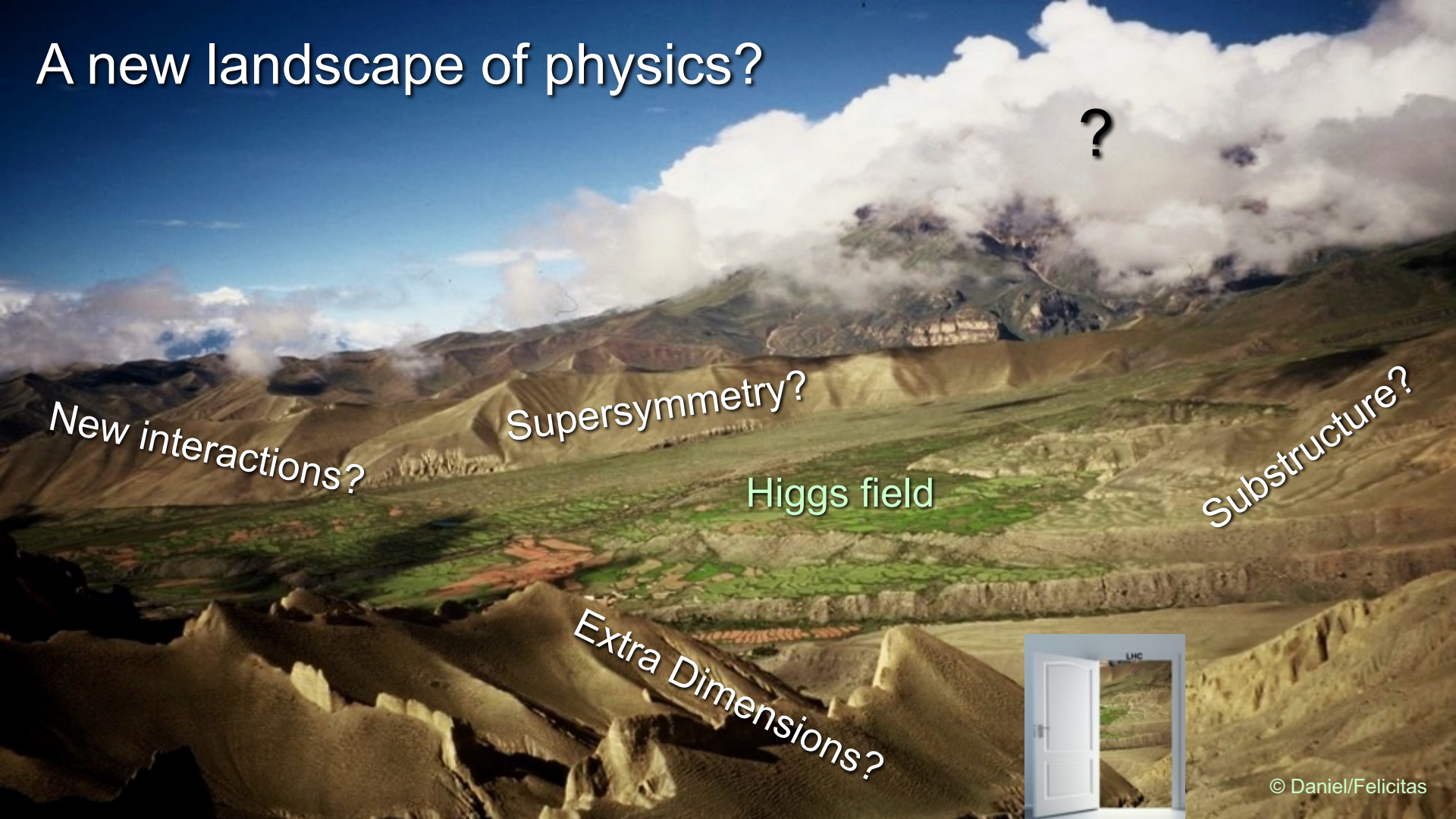
/4

M. Mangano: *"Claiming now that the LHC is useless, is like stopping a soccer game after 54 seconds, just because there was no goal yet....."*

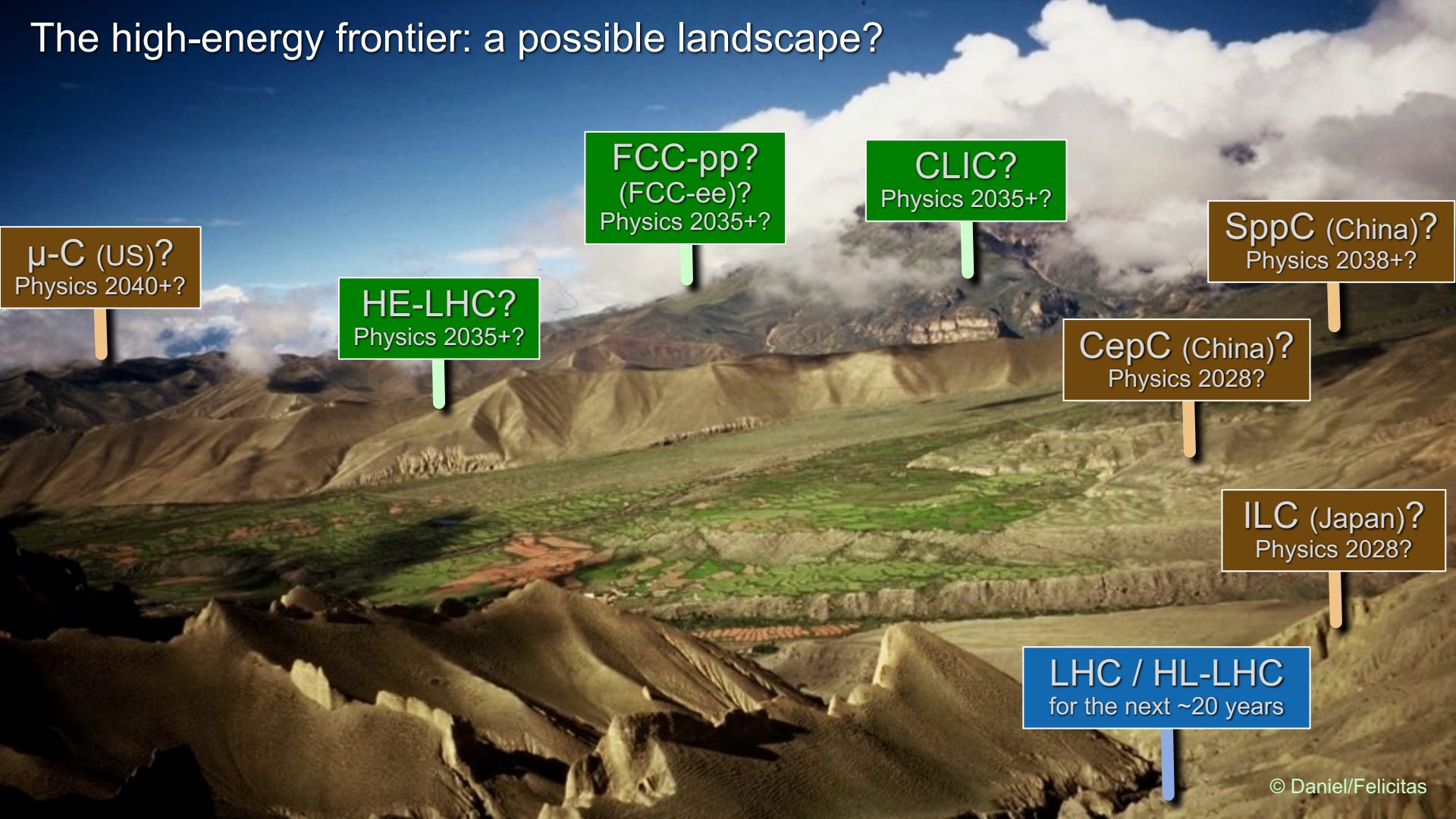


My (personal) view of the LHC

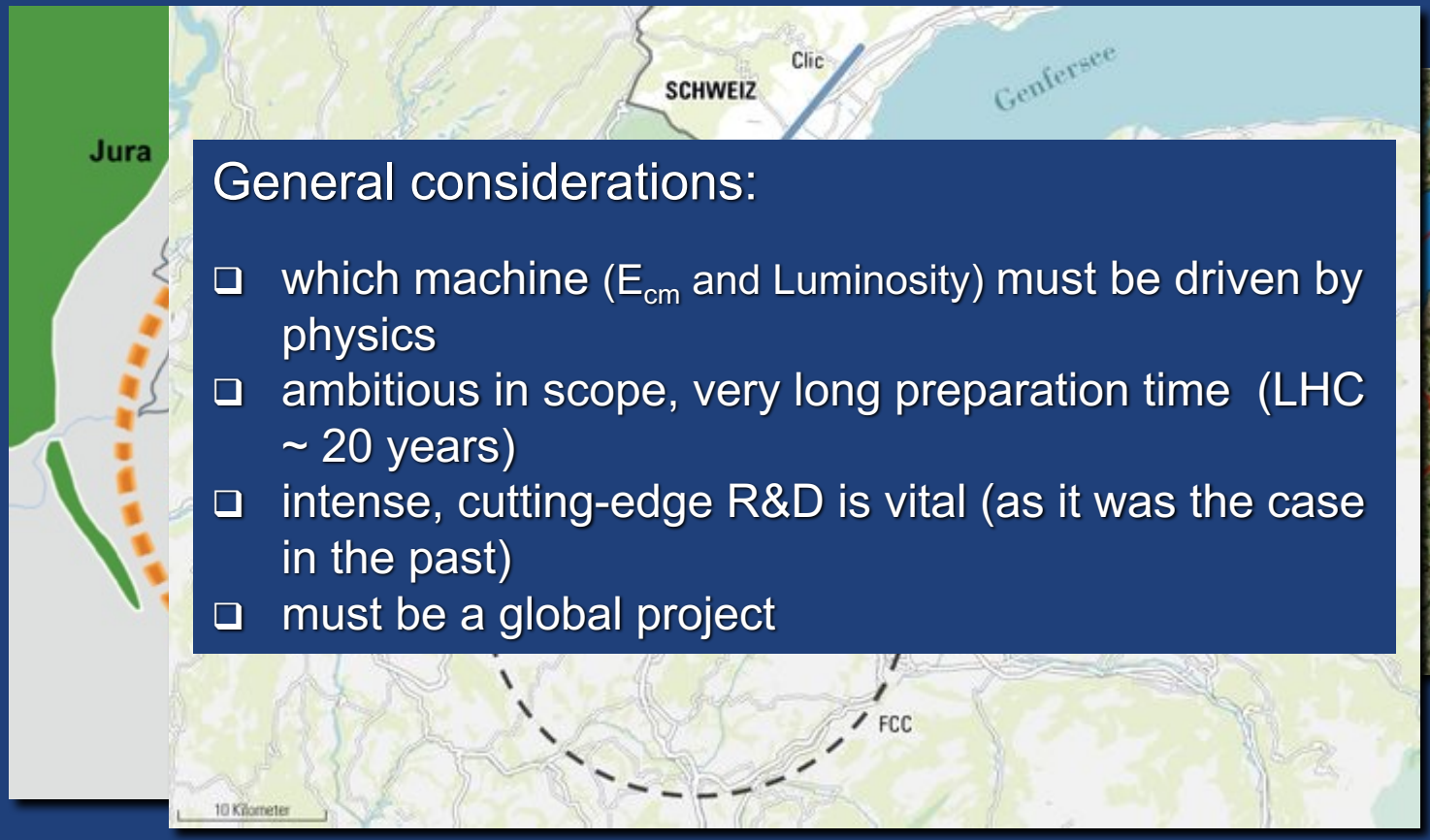
A new landscape of physics?



The high-energy frontier: a possible landscape?



The high-energy frontier: a possible landscape?

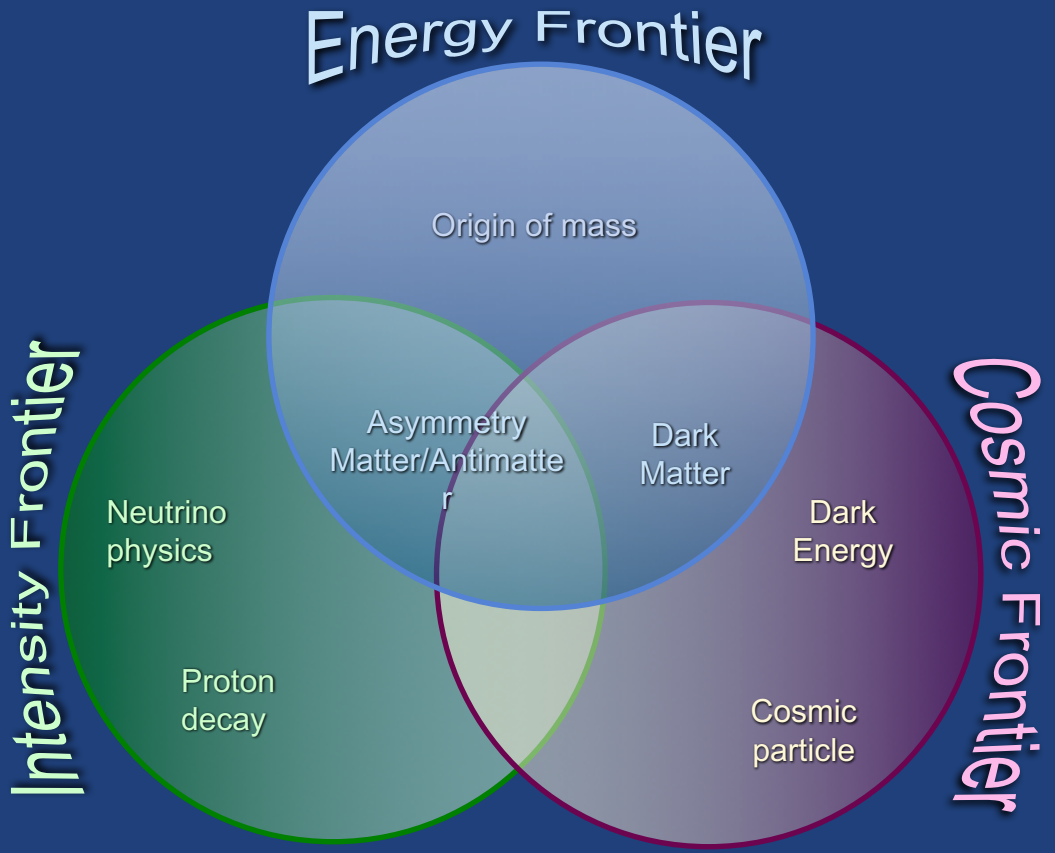


General considerations:

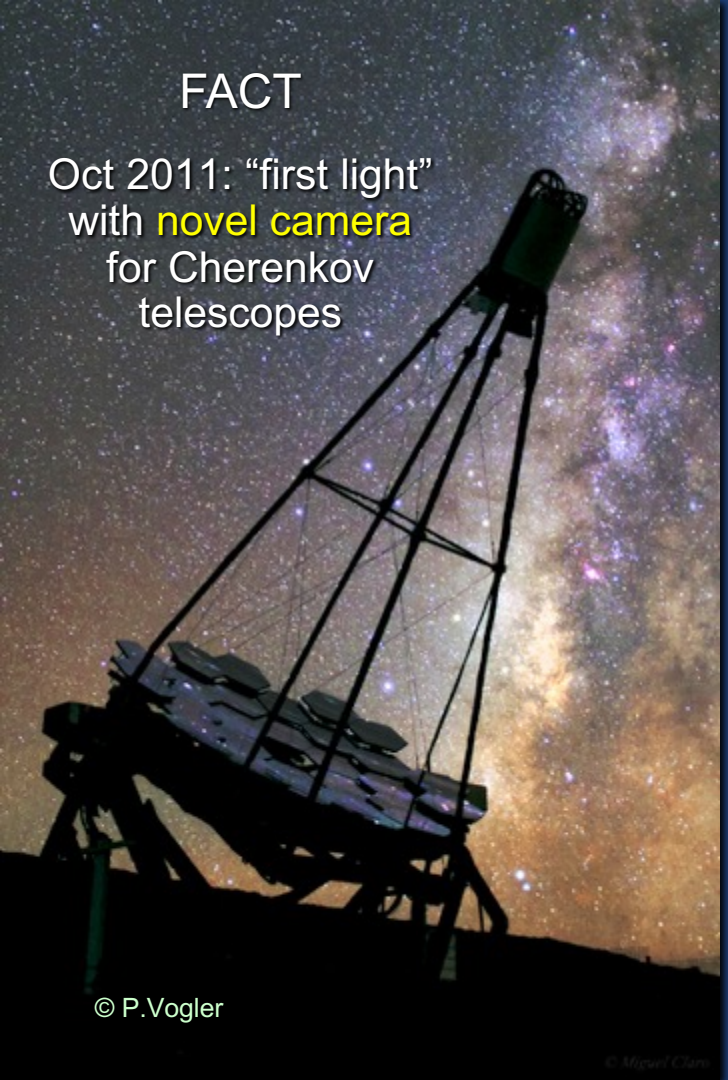
- which machine (E_{cm} and Luminosity) must be driven by physics
- ambitious in scope, very long preparation time (LHC ~ 20 years)
- intense, cutting-edge R&D is vital (as it was the case in the past)
- must be a global project

The Frontiers of Particle Physics

High precision physics at low energy at the PSI (nEDM, $\mu \rightarrow e^+e^+e^-$, ..)



The Cosmic Frontier



Based on the success of FACT:
> 50% of future CTA telescopes will have a G-APD/SiPM based camera


FACT
Spokes-
person


© P.Vogler


CERN

2005:
150th anniversary of ETH Zurich

Thank you very much !!!