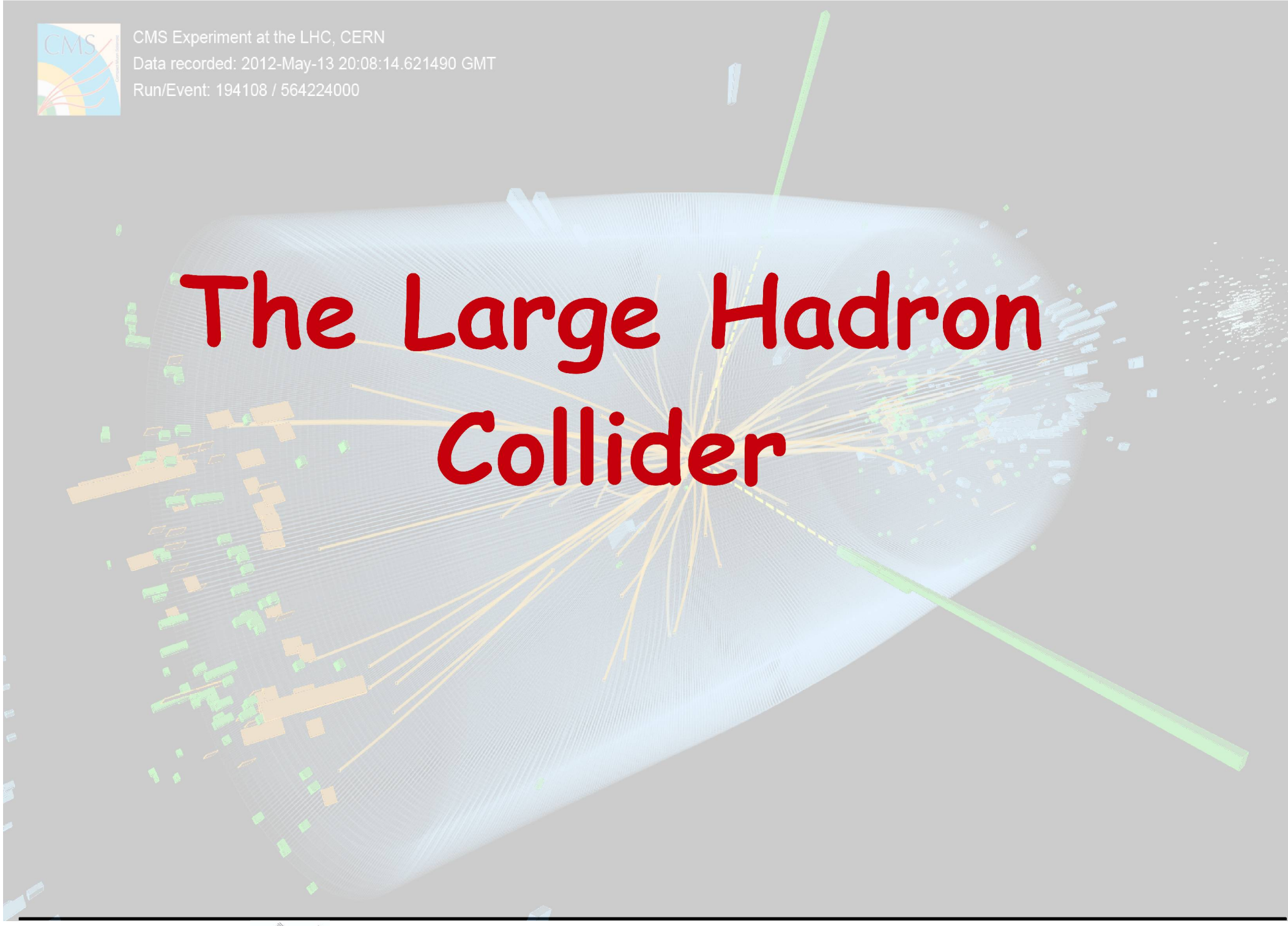
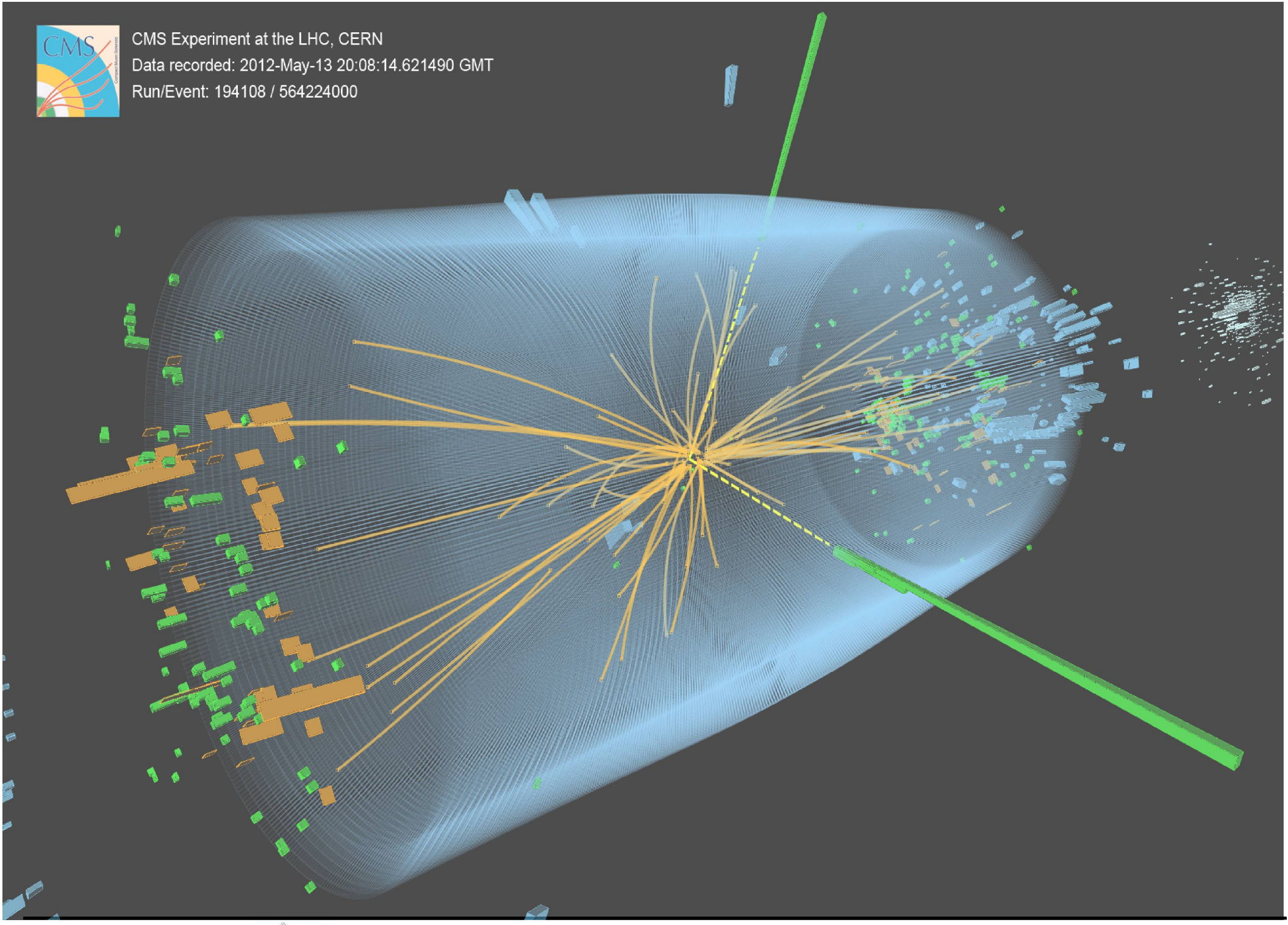
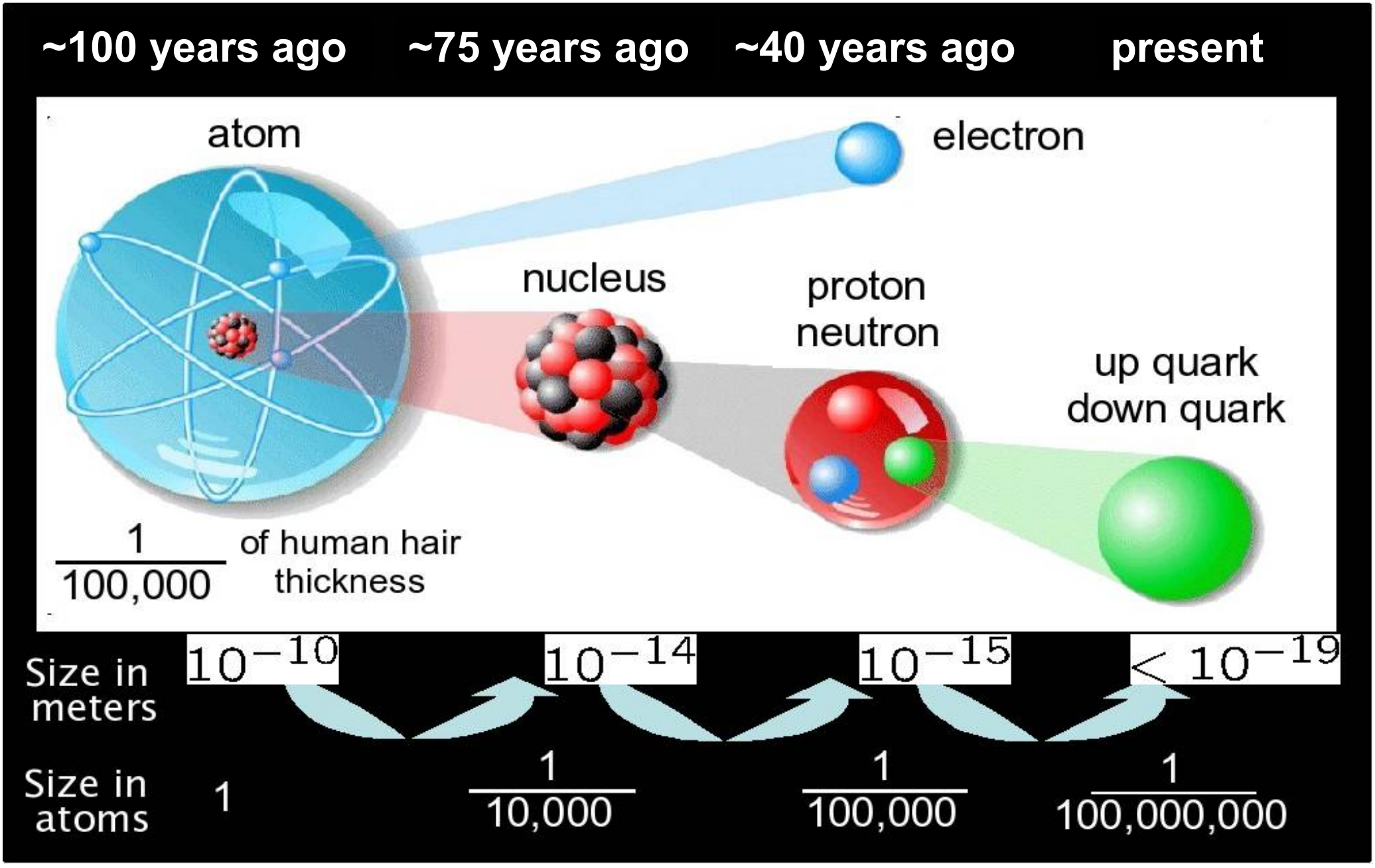


The Large Hadron Collider


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

Brief History of Particle Physics



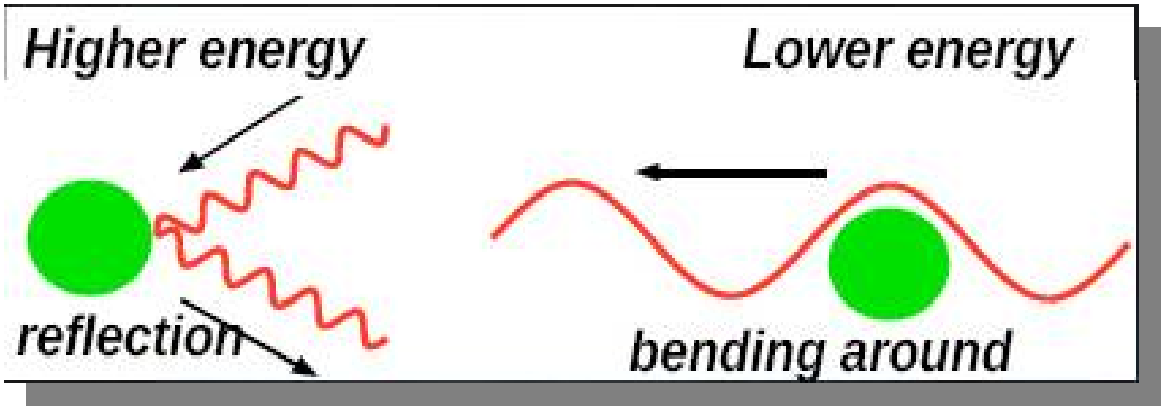
Why do we need High Energy to resolve small scale?

$$E = \frac{hc}{\lambda}$$

Energy ~ 1/[Wave-length]

Why do we need High Energy to resolve small scale?

$$E = \frac{hc}{\lambda}$$



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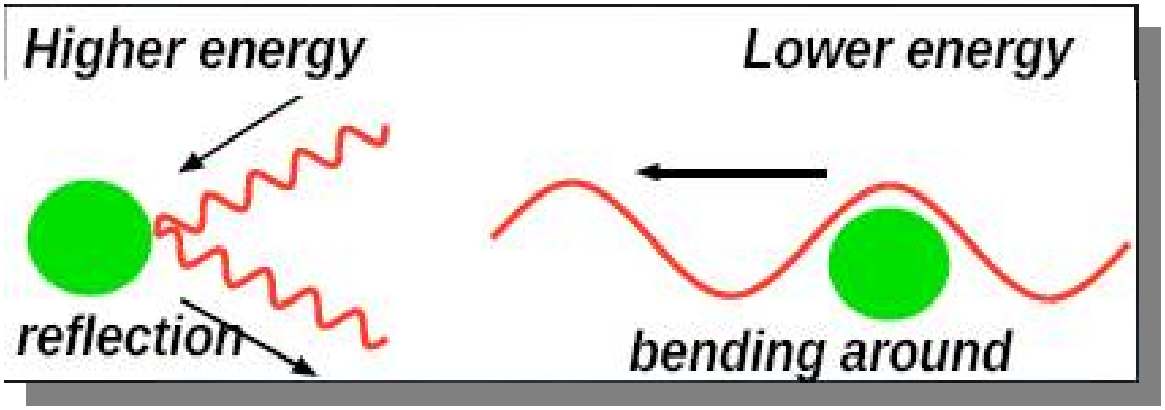
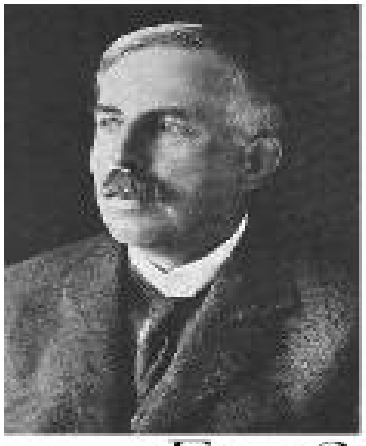
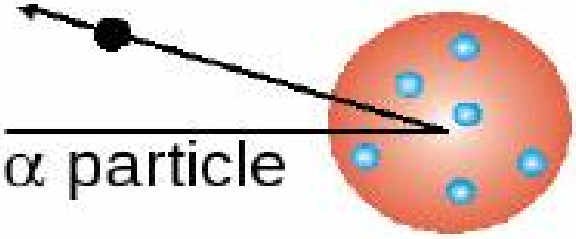
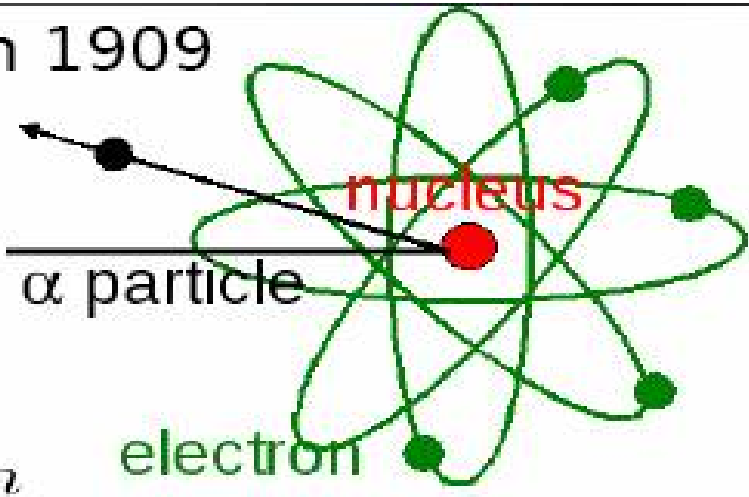




Rutherford's Experiment in 1909

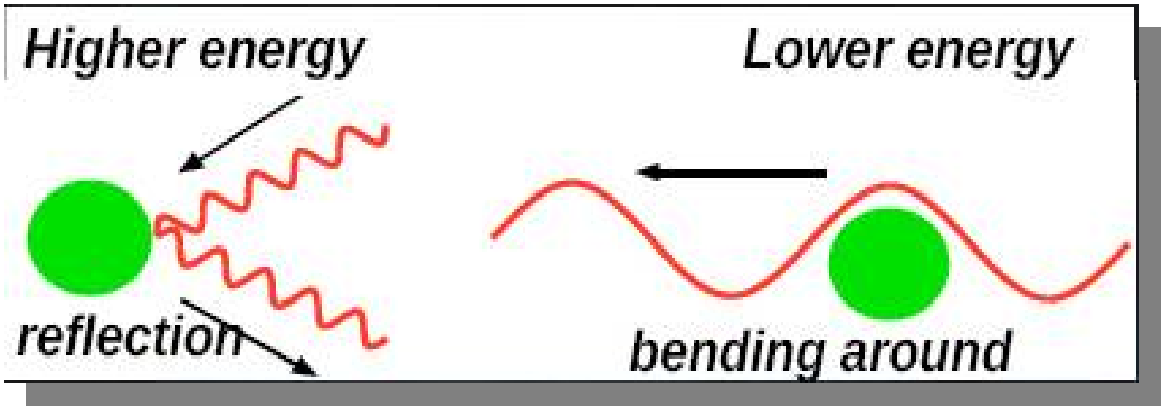


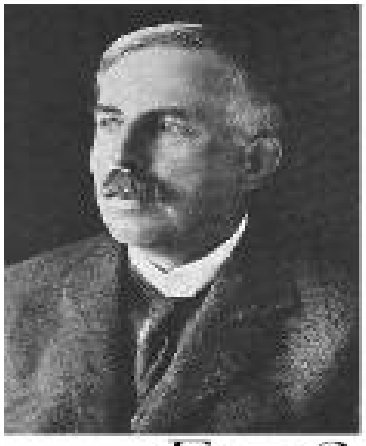


$E = 2.8 \times 10^6 eV, \lambda = 4.4 \times 10^{-13} m$

Why do we need High Energy to resolve small scale?

$$E = \frac{hc}{\lambda}$$





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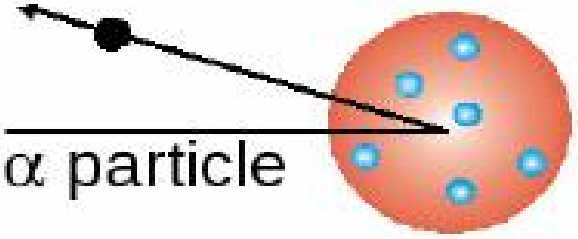
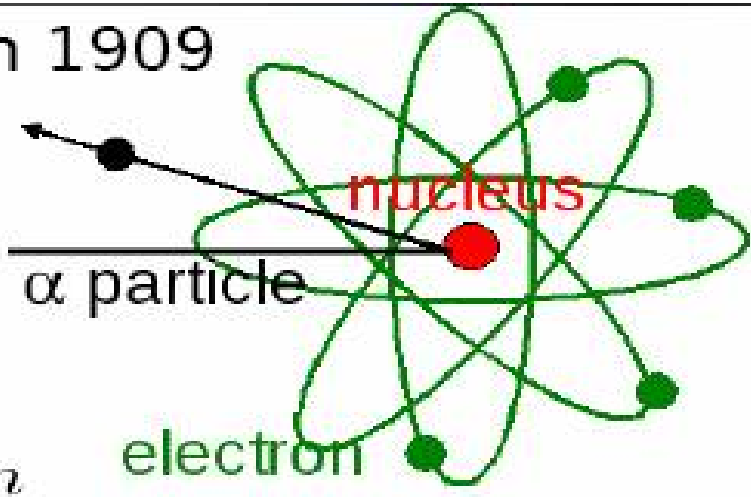
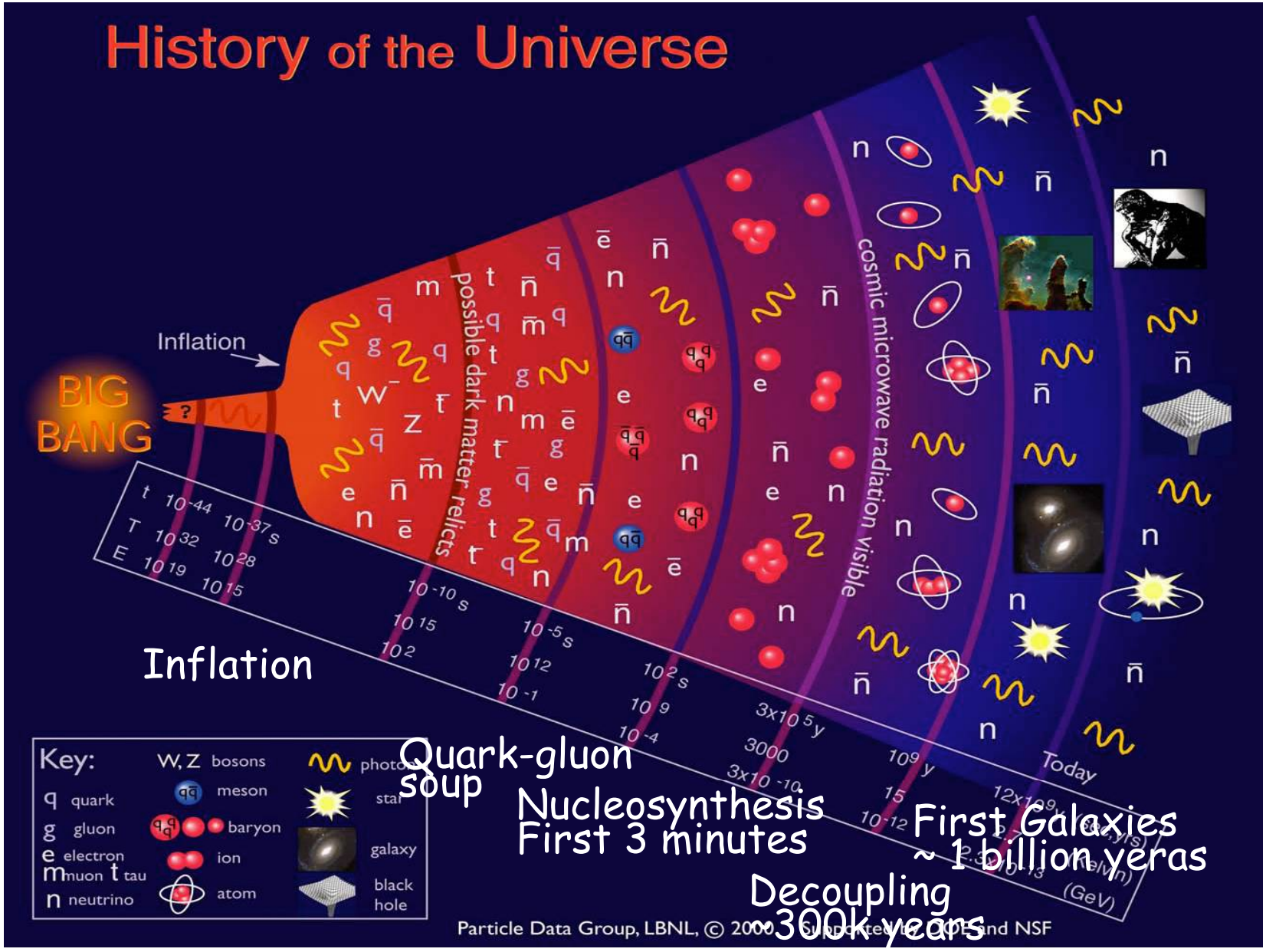




$E = 2.8 \times 10^6 eV, \lambda = 4.4 \times 10^{-13} m$

We need accelerators to resolve the structure of matter!

Brief History of Our Universe in connection to the LHC: E=kT



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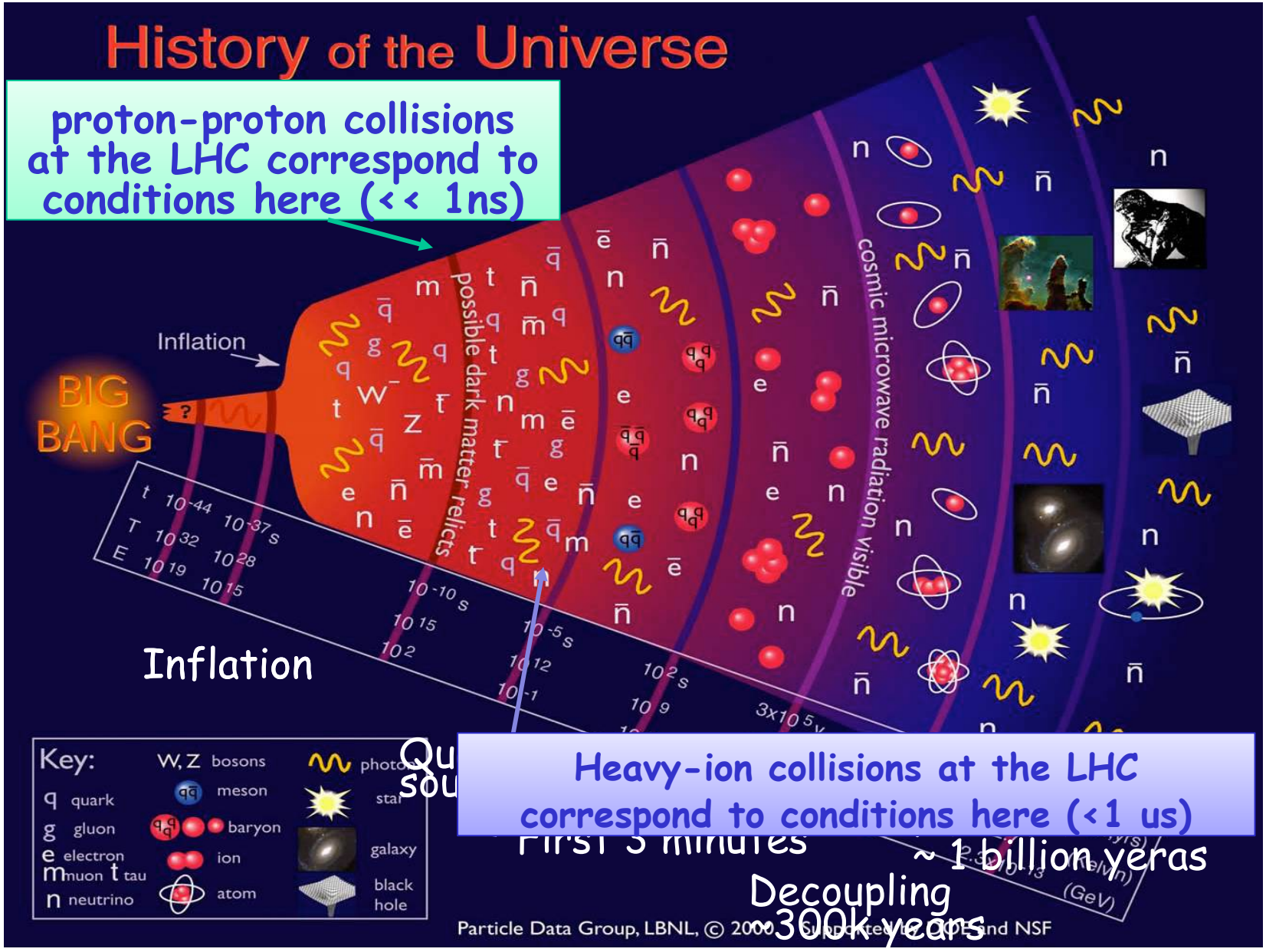
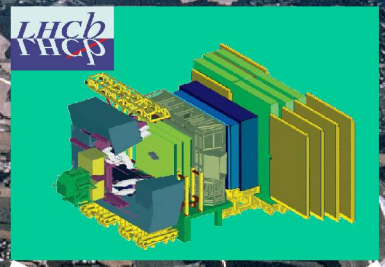


Large Hadron Collider

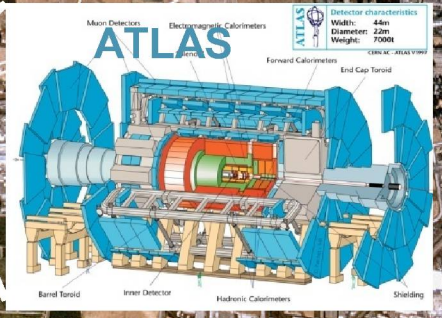
1992 General Meeting on LHC Physics and Detectors, Evian les Bains
1993 **Letters of Intent** (ATLAS and CMS selected by LHCC)
Technical Proposals Approved
1996 Approval to move to **Construction** (materials cost of 475 MCHF)
Memorandum of Understanding for Construction Signed
1998 Construction Begins (after approval of Technical Design Reports)
2000 ATLAS and CMS assembly begins above ground. LEP closes
2008 **ATLAS & CMS ready for First LHC Beams**
2009 First proton-proton collisions
2012 **A new heavy boson discovered with mass ~125 × mass of proton**

Main Experiments on the LHC

General-purpose (ATLAS and CMS) studying origin of mass, SUSY, …
Dedicated (LHCb) studying origin of matter-antimatter asymmetry,…
Dedicated (ALICE) studying general properties of quark-gluon fluid,…



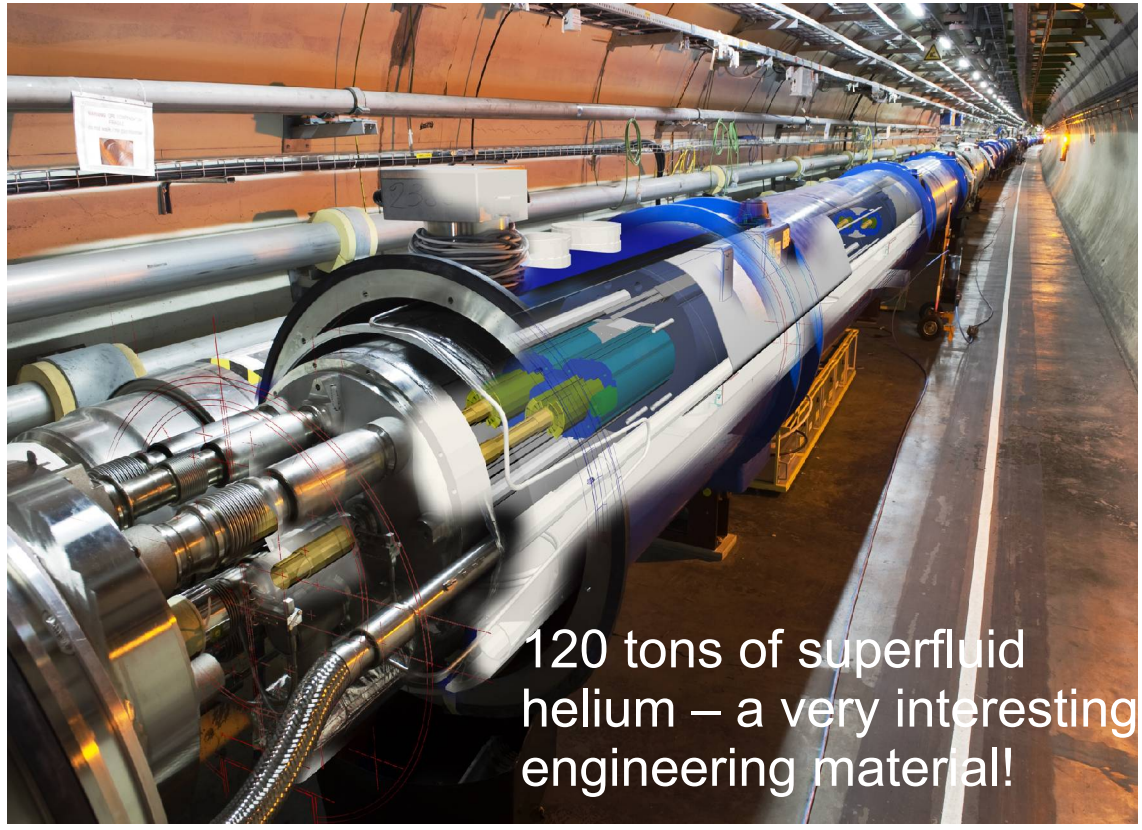
Exploration of a new energy frontier
Proton-proton collisions at ECM = 7-8 - 14 TeV
Lead-lead ion collisions at ECM = 2.76 - 5.4 TeV



The LHC Accelerator

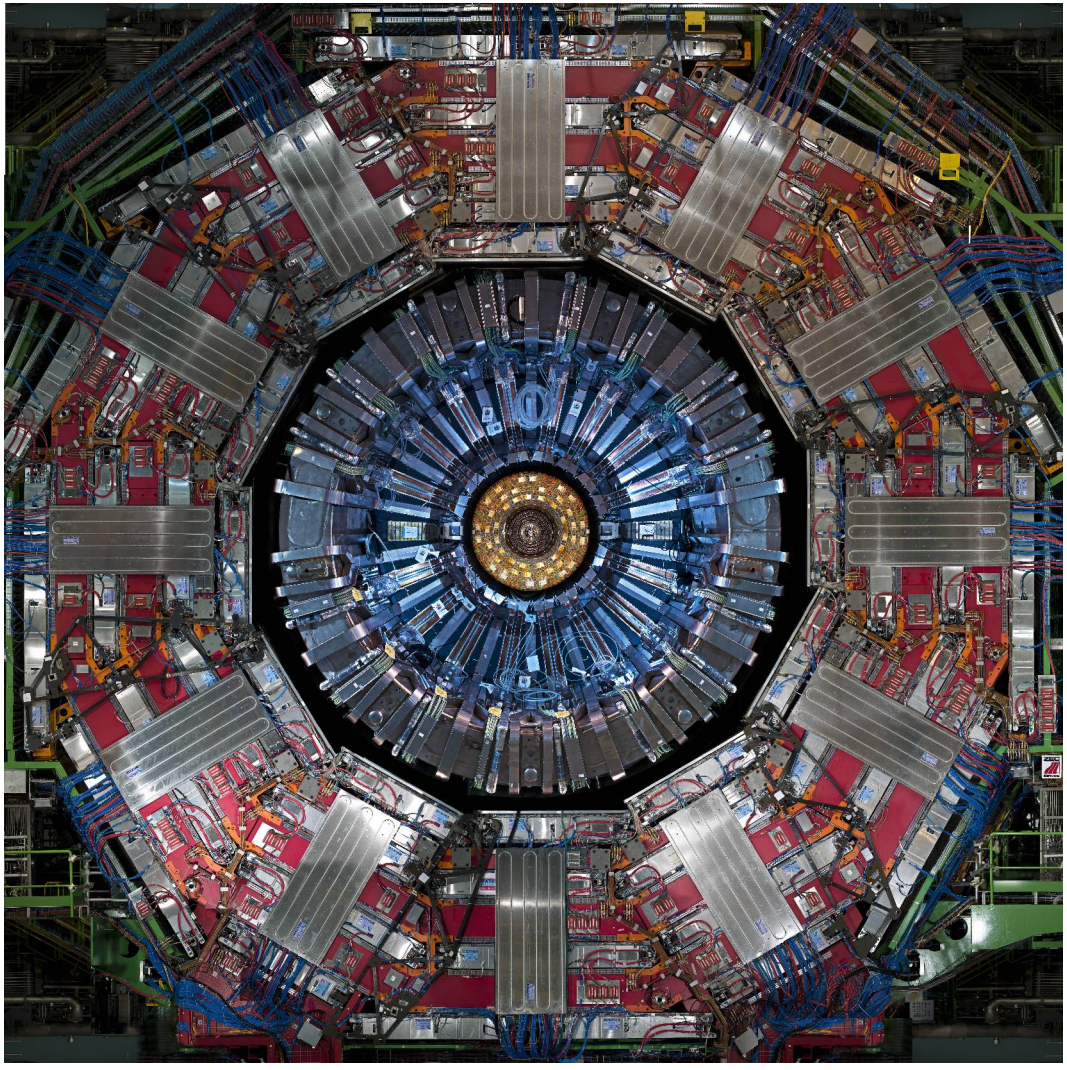
Protons are accelerated by powerful electric fields to very (very) close to the speed of light **(superconducting r.f. cavities)**
And are guided around their circular orbits by powerful **superconducting dipole magnets**.

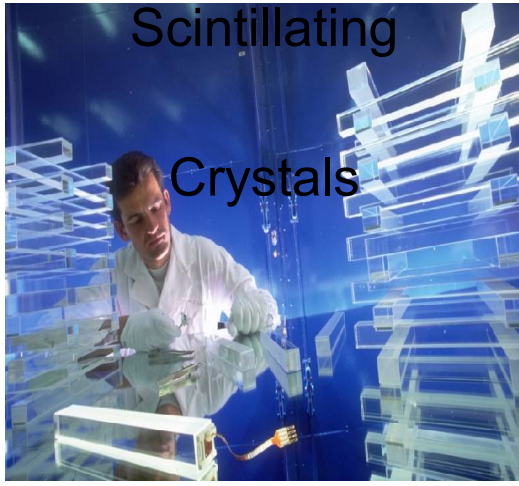
The dipole magnets operate at 8.3 Tesla (200'000 x Earth's magnetic field) & 1.9K (-271°C) in **superfluid helium**.
Protons travel in a tube which is under a better vacuum, and at a lower temperature, than that found in inter-planetary space.



CMS Concept to Data Taking – took 18 Years!

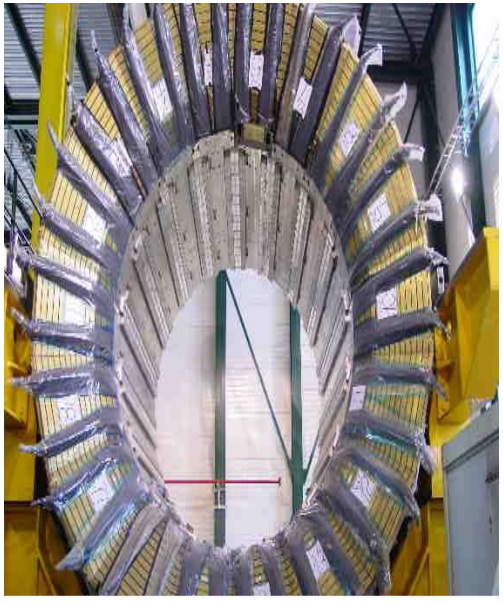
3000 scientists from 40 countries





Gas ionization chambers

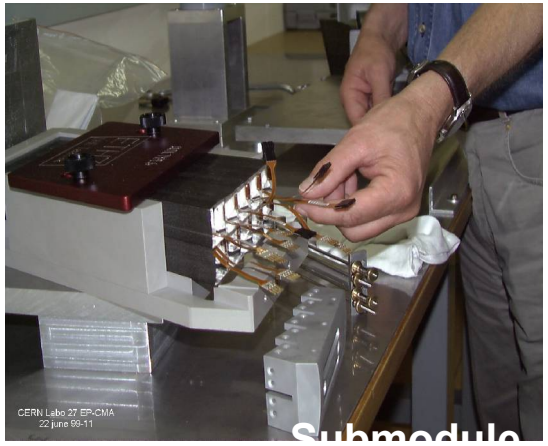
CMS cut in mid-plane

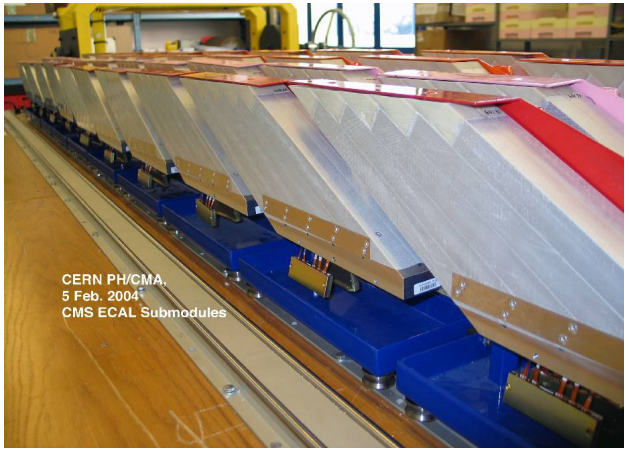


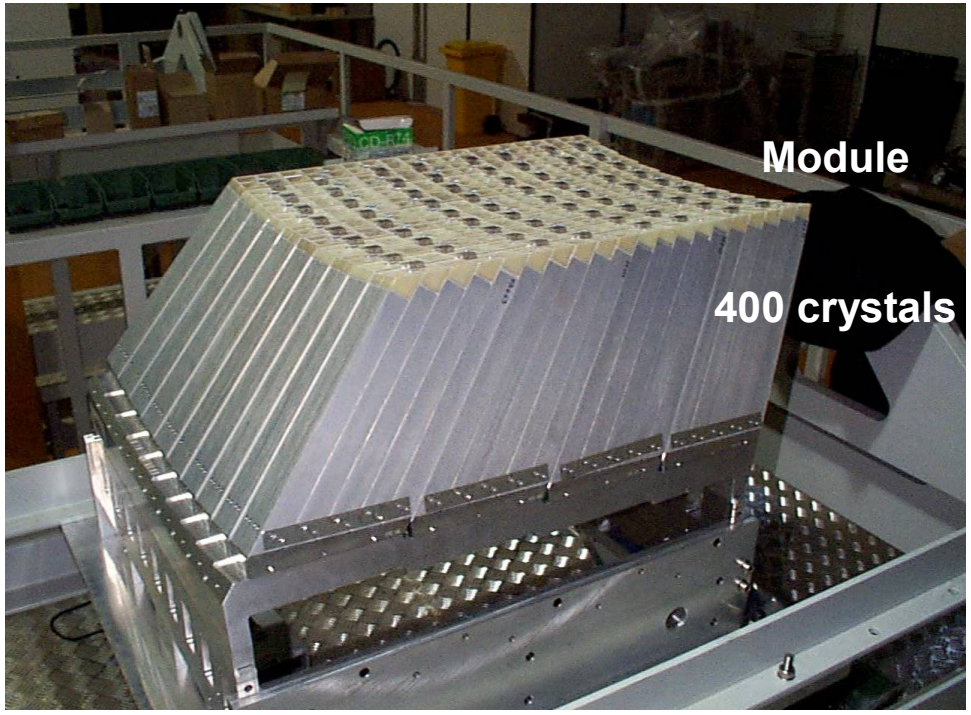
Brass plastic scintillator

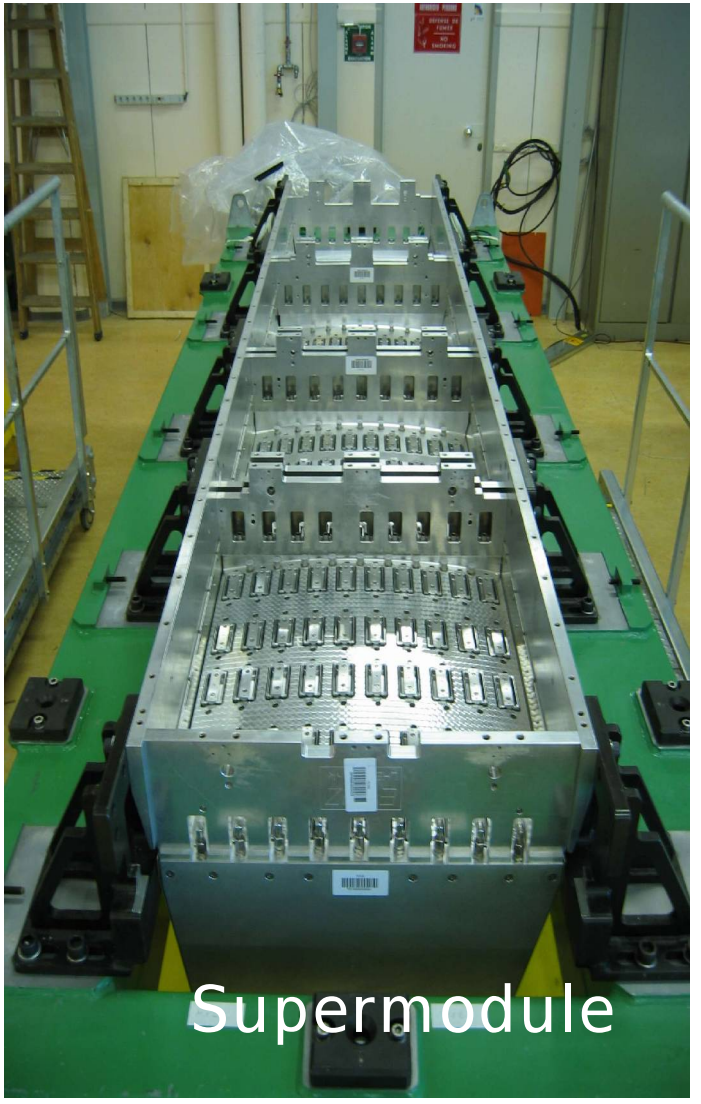
A glimpse of the construction of LHC experiments e.g. the CMS crystal calorimeter

Assembling the Calorimeter



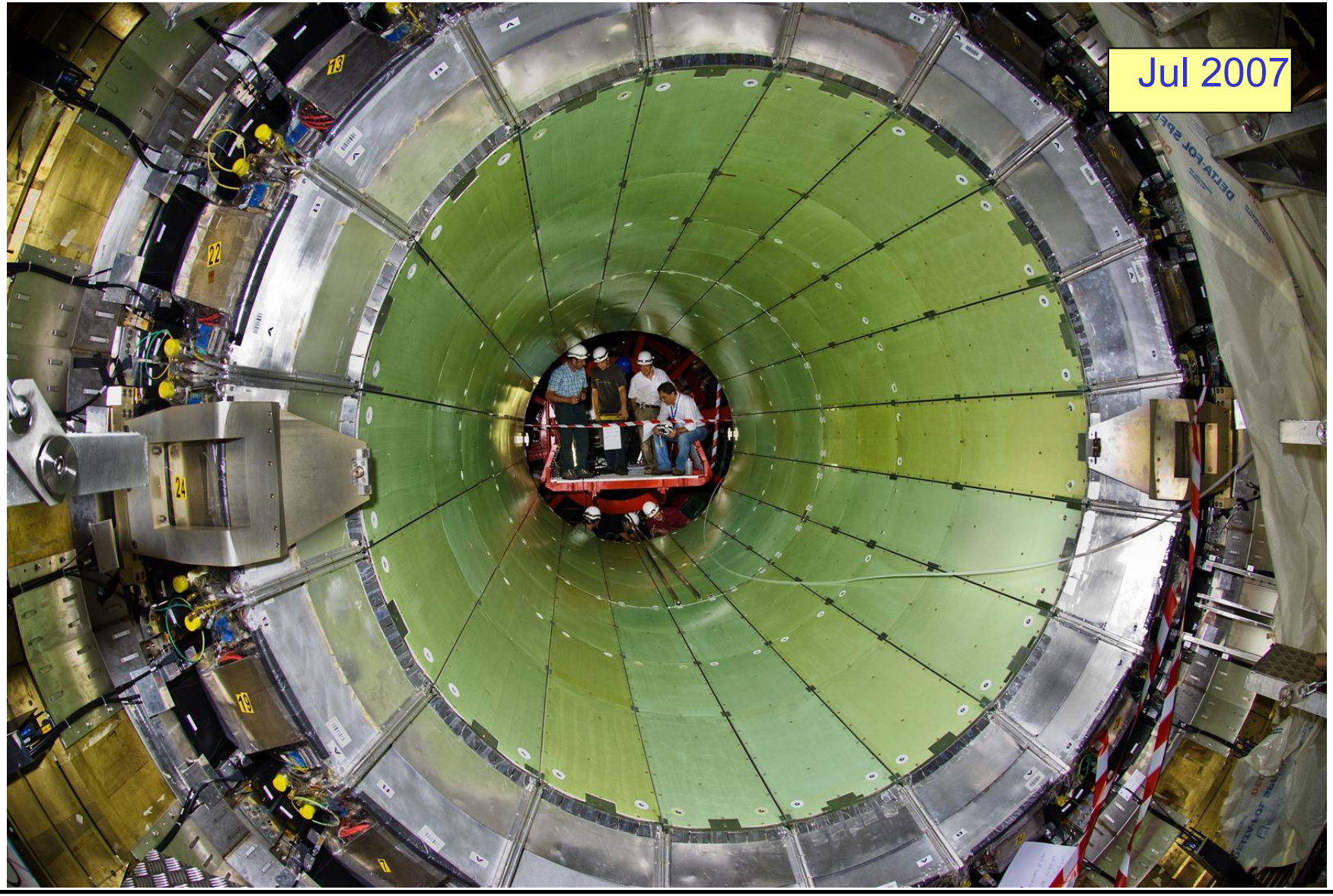




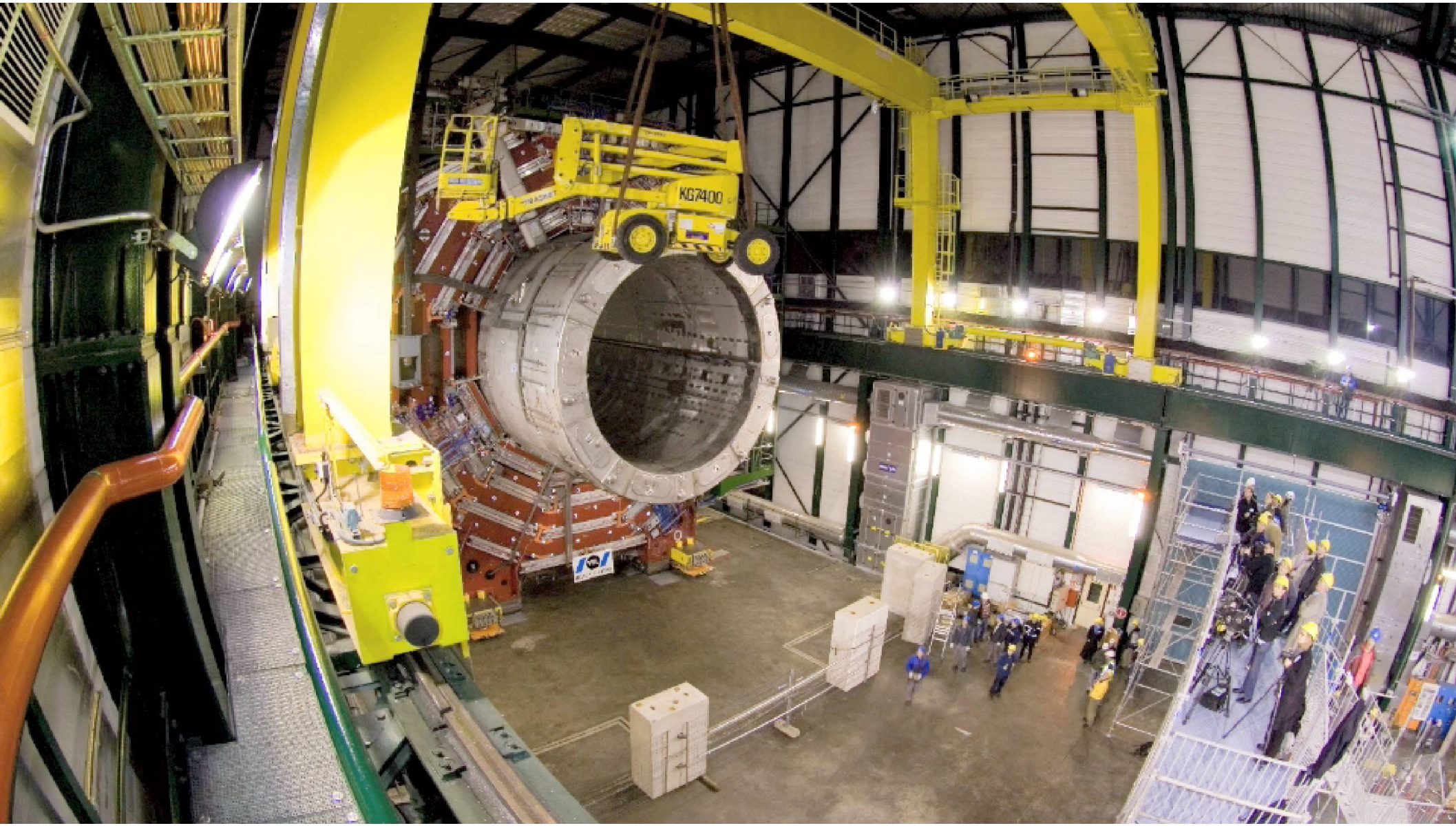


Total 36 Supermodules

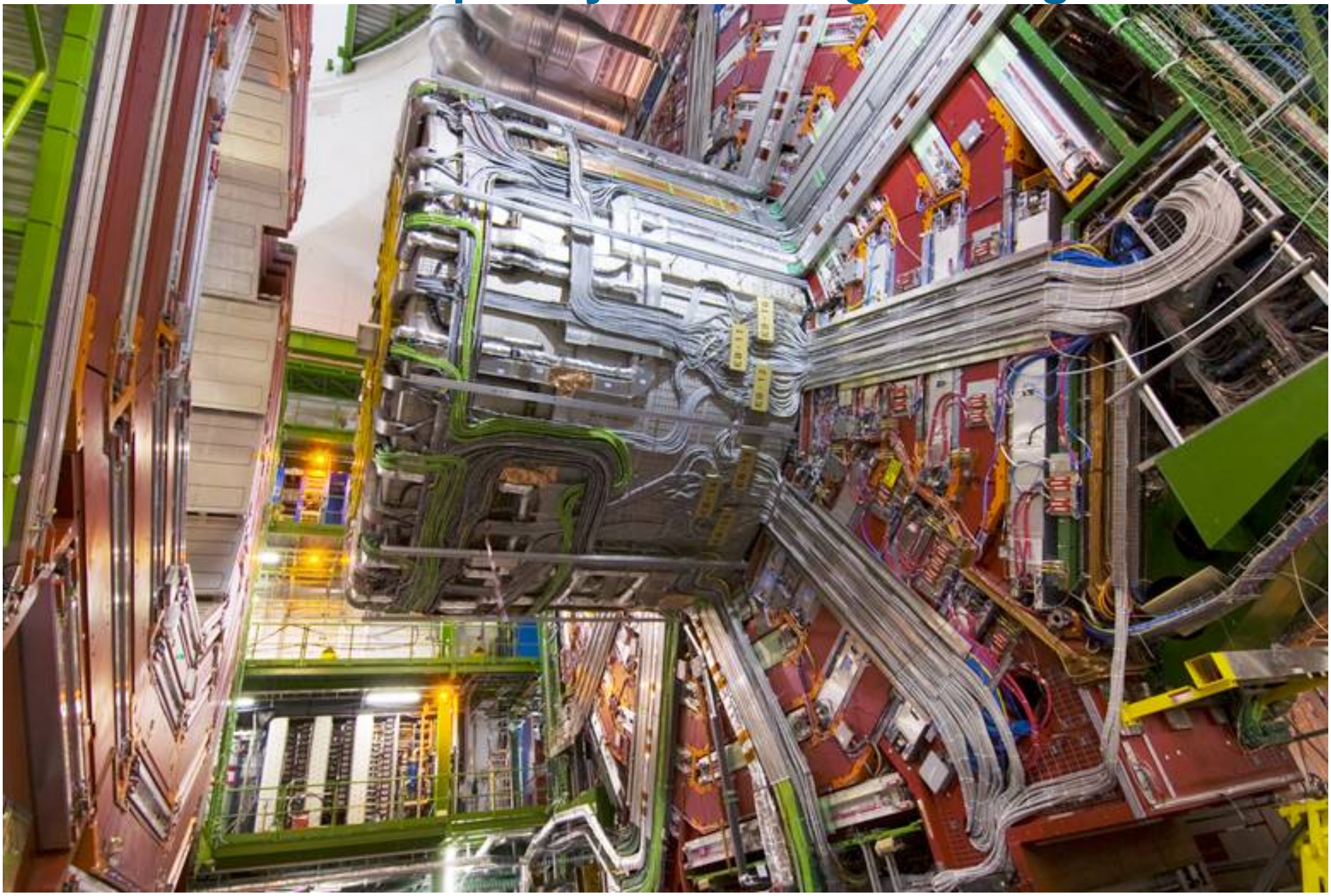
Installation of Barrel ECAL



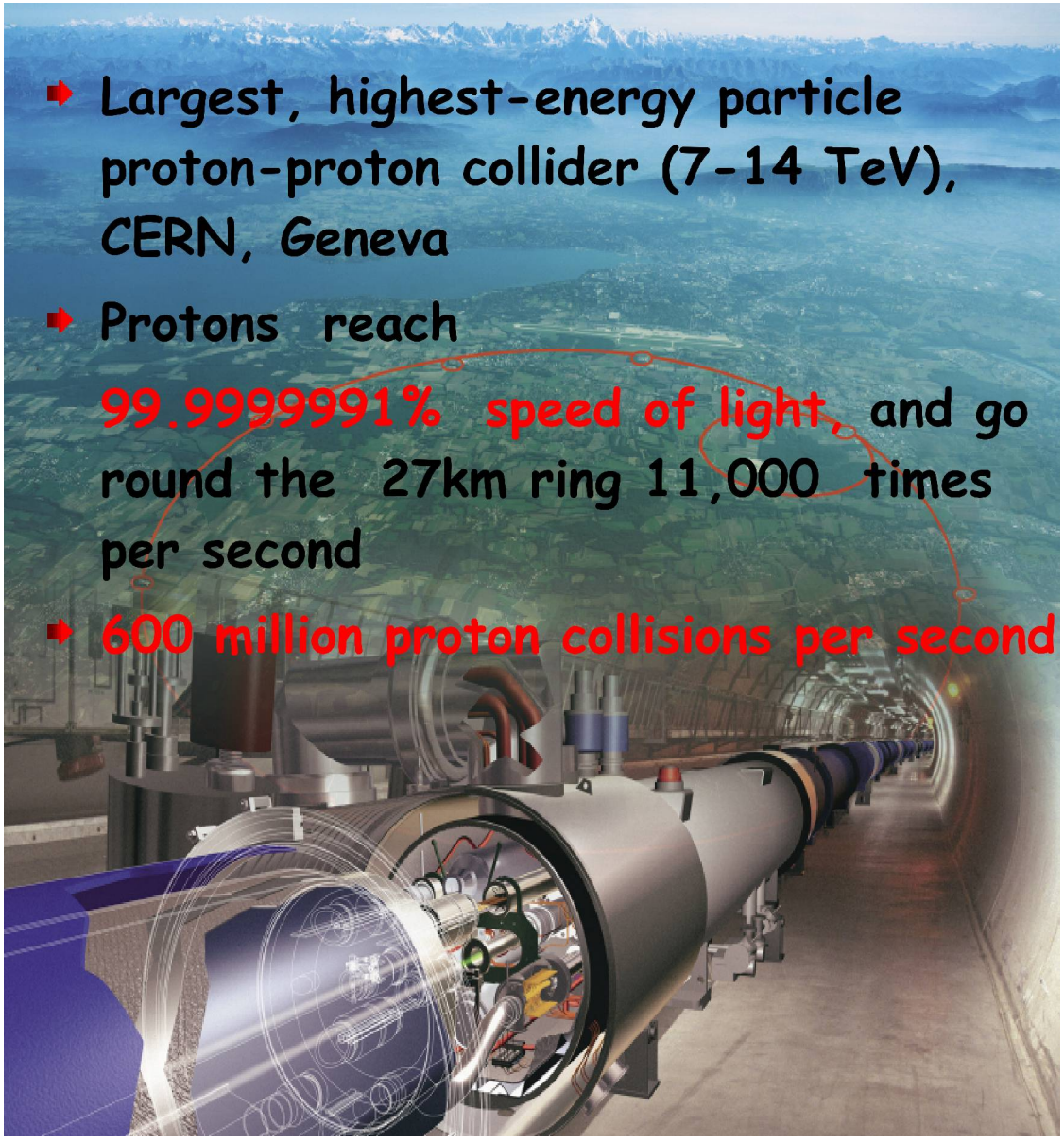
Spectacular Operations (Feb. 2007)



The Complexity of the Engineering!



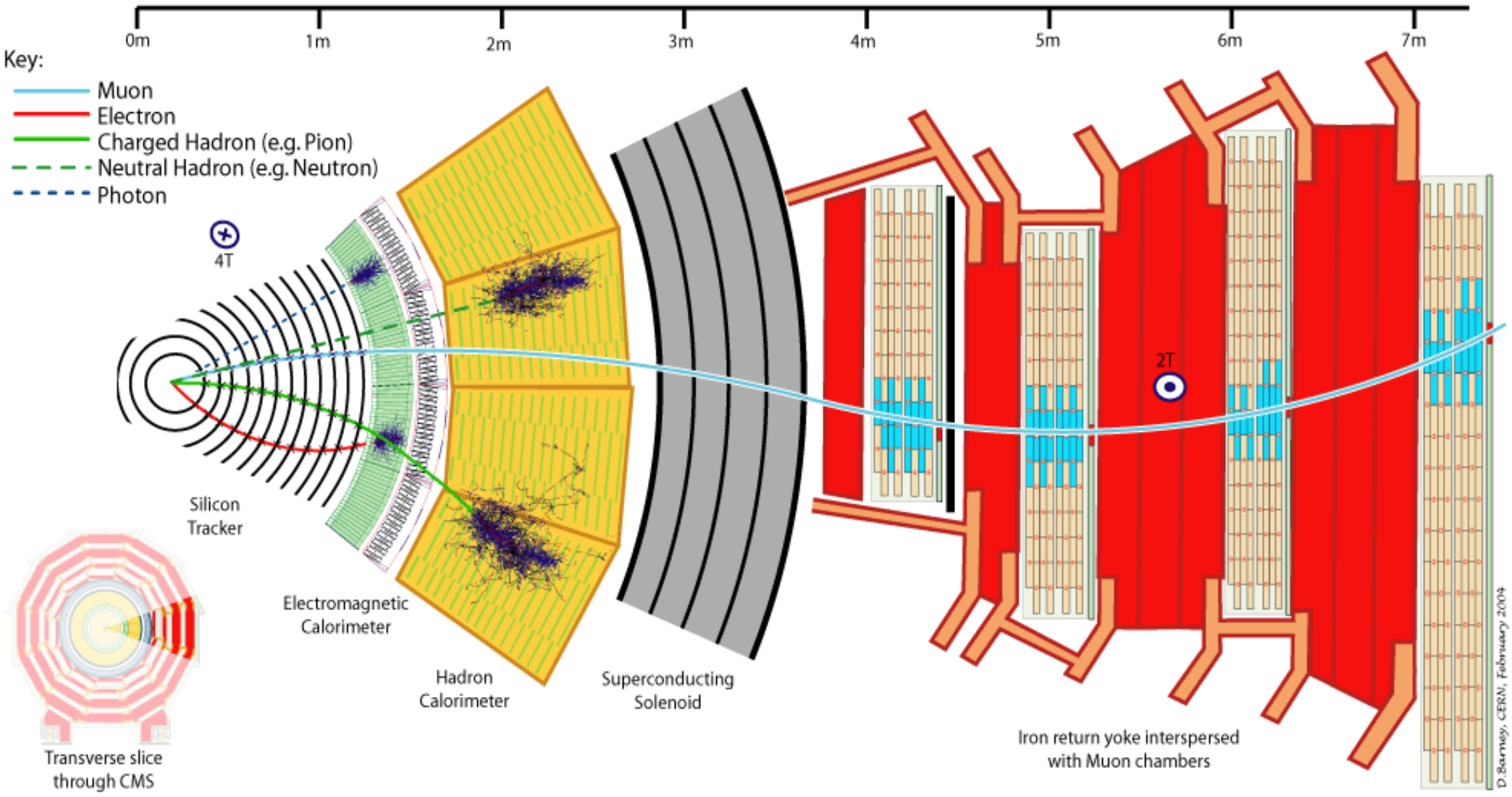
Large Hadron Collider at glance



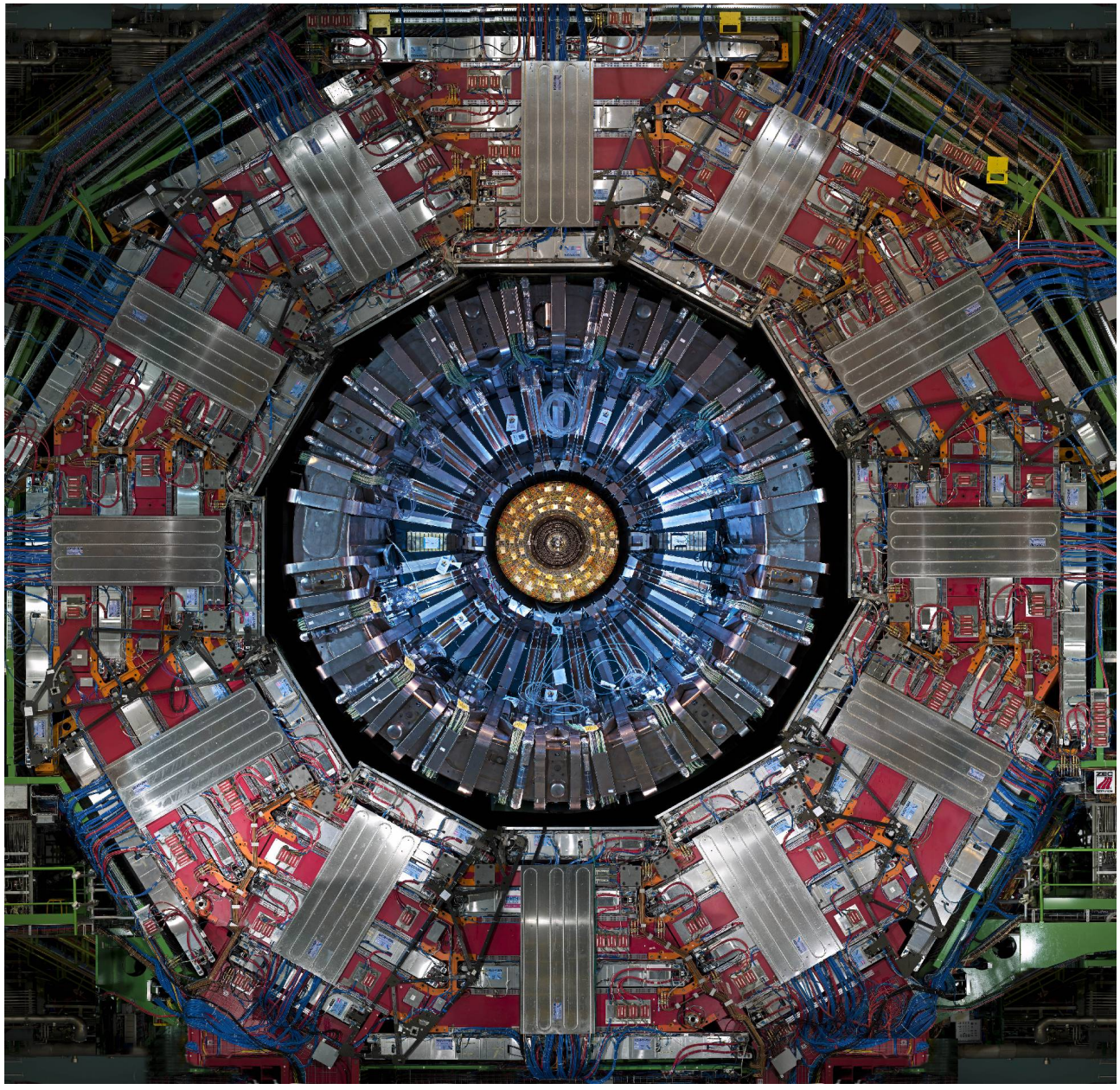
- Largest, highest-energy particle proton-proton collider (7-14 TeV), CERN, Geneva
- Protons reach 99.9999991% speed of light, and go round the 27km ring 11,000 times per second
- 600 million proton collisions per second

- generates temperature 1000 million times hotter than the heart of the sun
- Corresponding time is 10^{-13} second after Big Bang!
- probes 10^{-20} meters scale!
- Produced Higgs boson
- Has a great potential to produce Dark Matter candidates and probe related new symmetries
- generates new cutting edge technologies (e.g. WWW was born at CERN!)

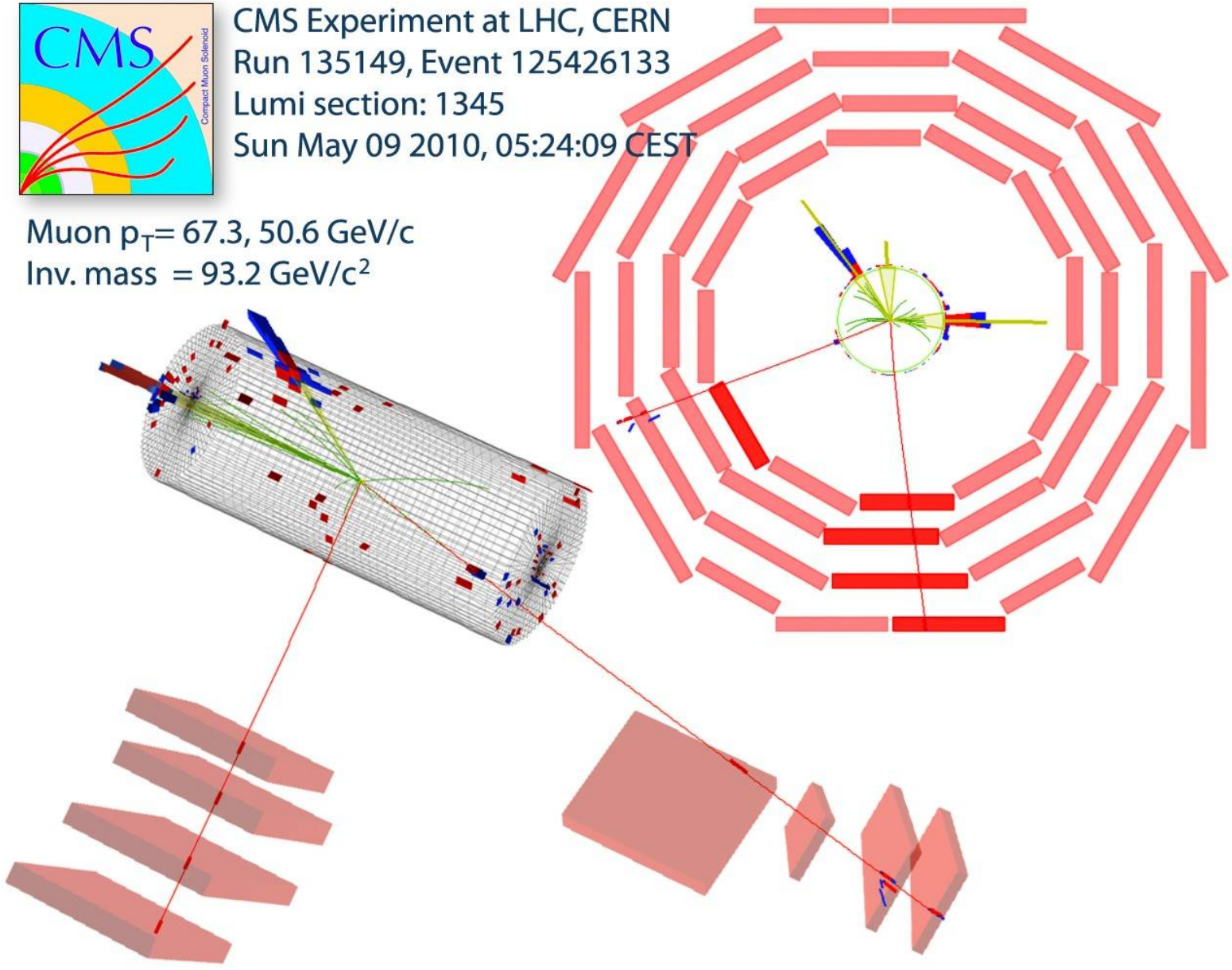
Measuring & Identifying Particles



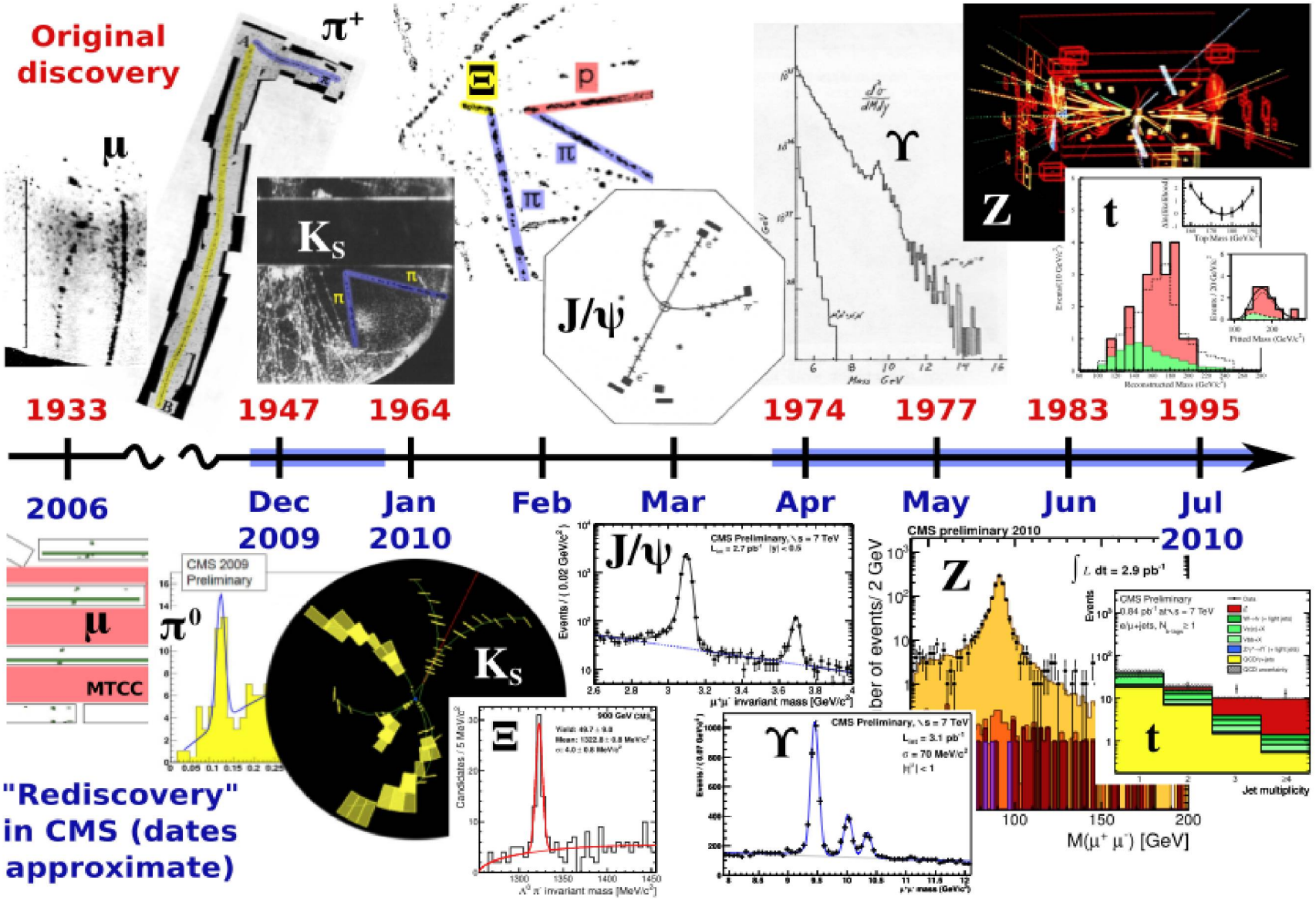
Measuring & Identifying Particles



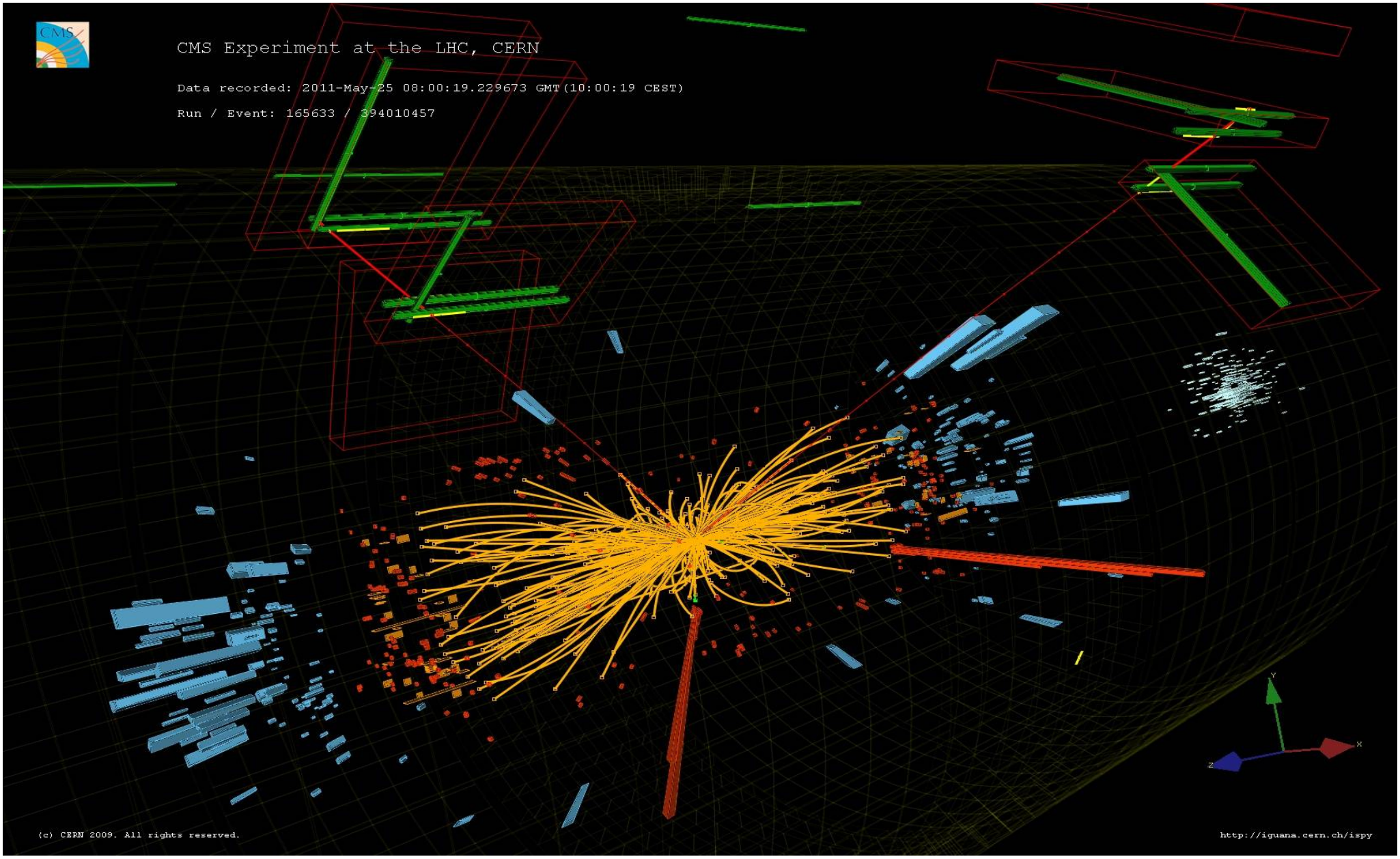
A Z boson decaying into $\mu^+\mu^-$ pair



Re-discovering the Standard Model at 7TeV
... in about half a year!



How do we look for the Higgs boson?



How do we look for the Higgs boson?

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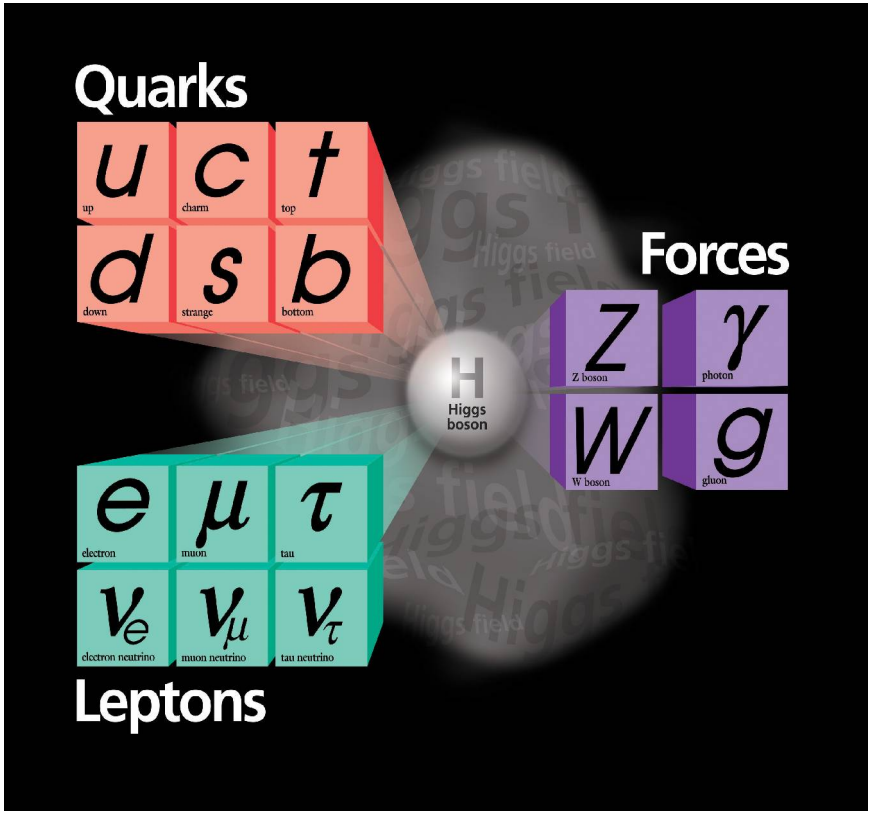


Higgs lifetime (125 GeV): 10^{-22} s

Will only see decay products

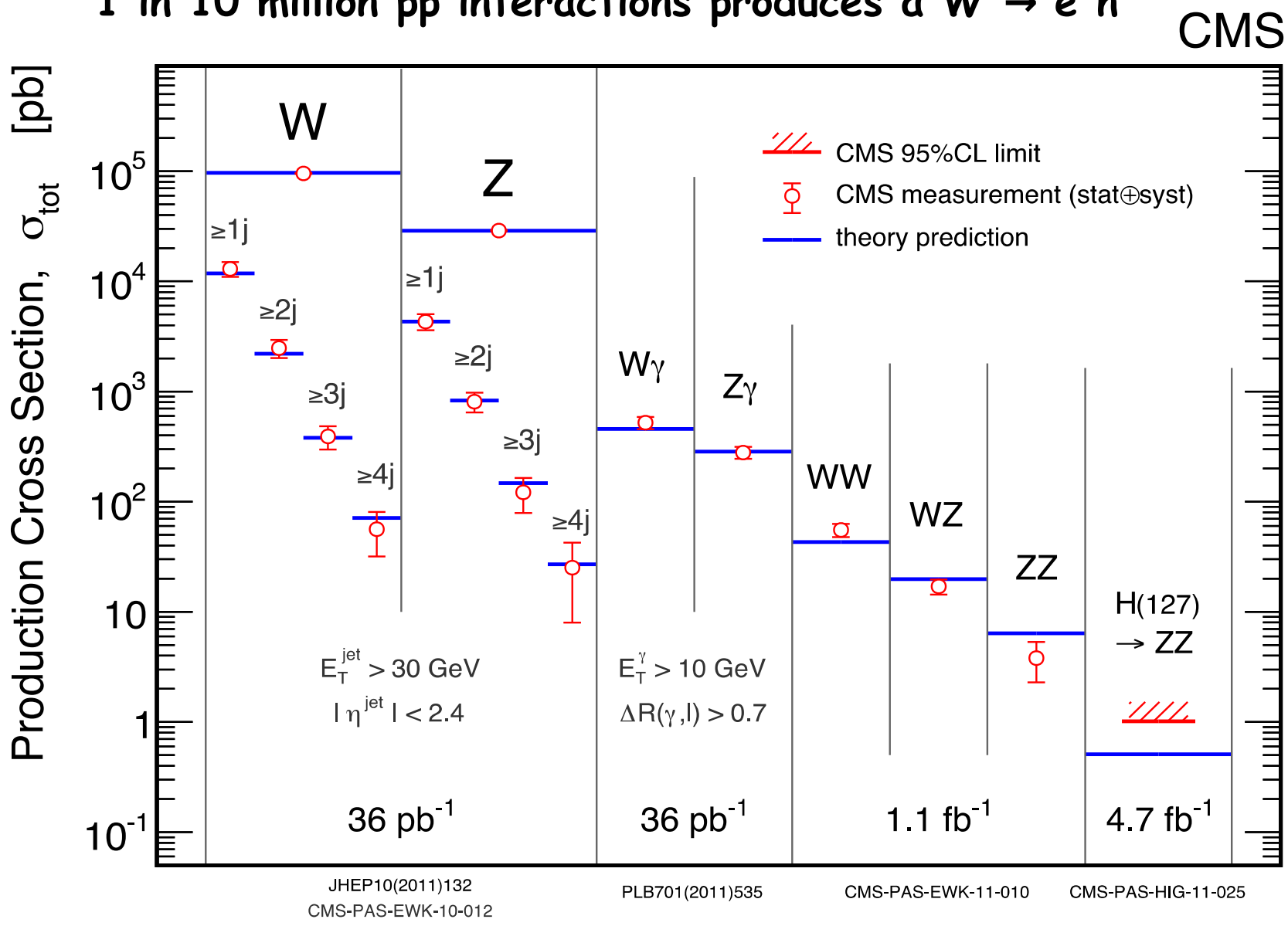
Higgs couples to mass:

Coupling to fermions ~ m_f

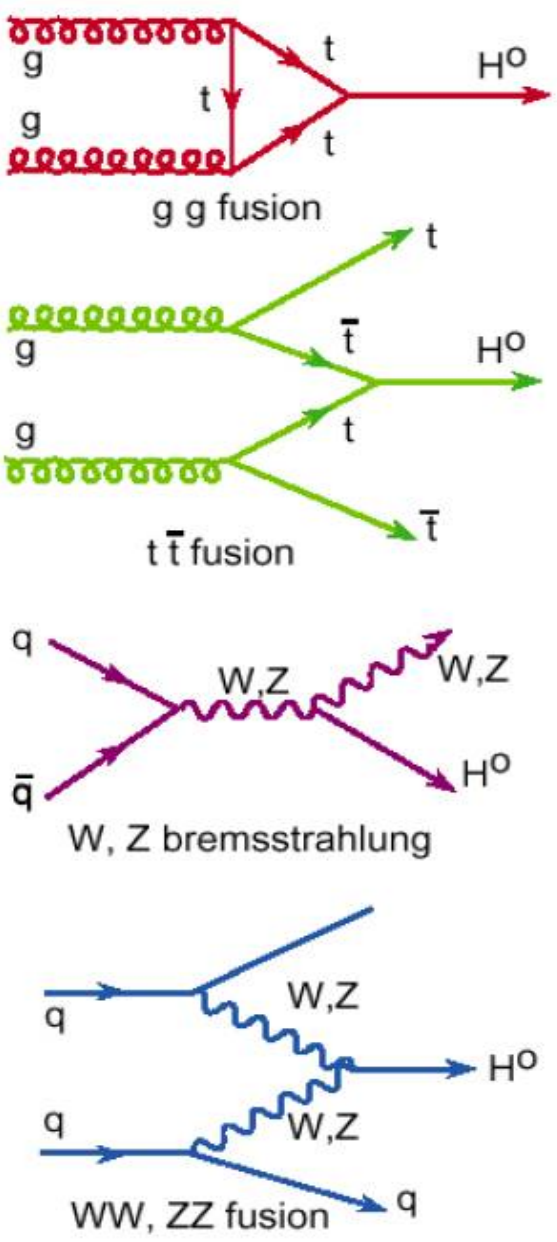
Coupling to bosons ~ M_V

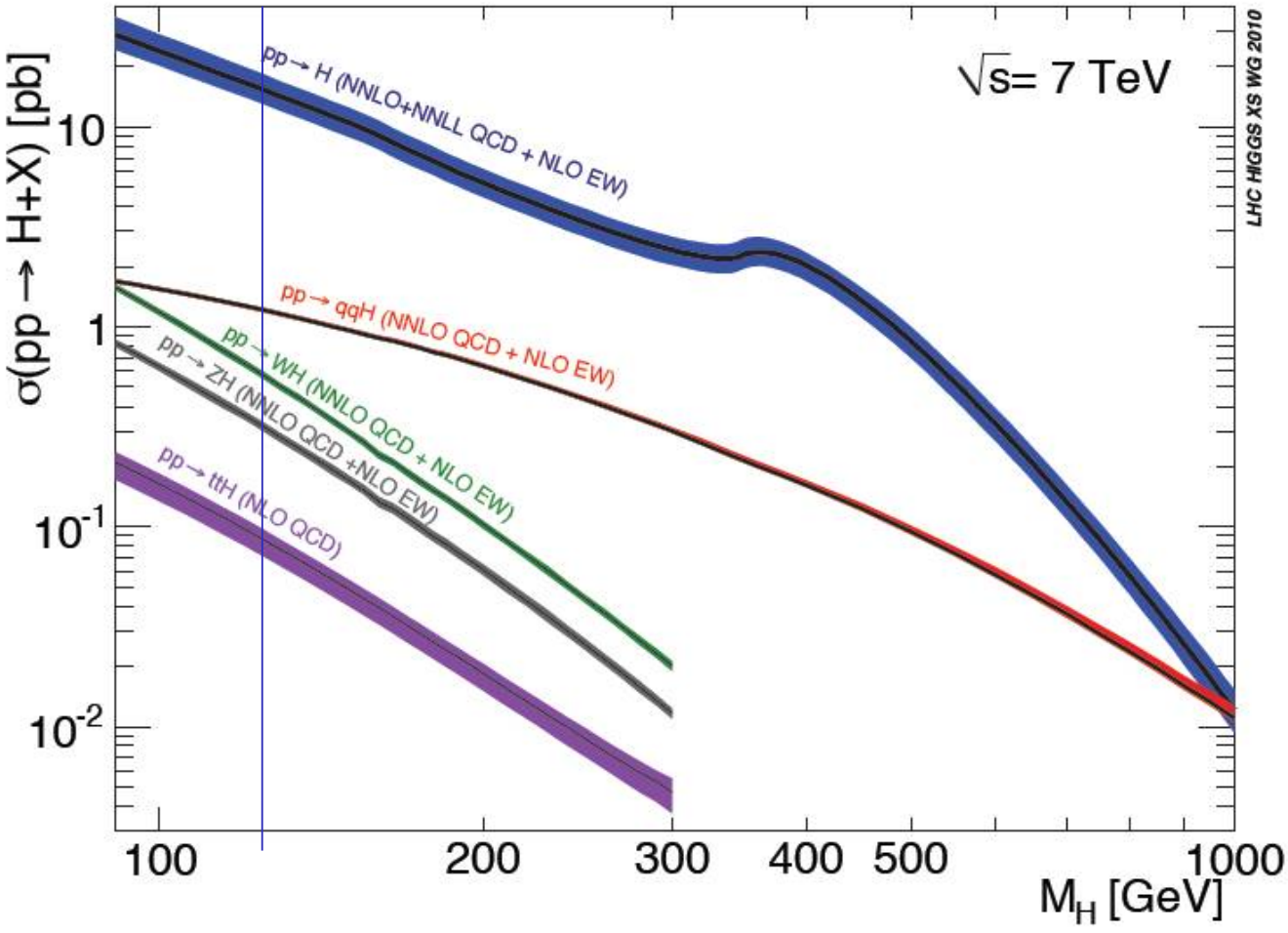
Standard Model EW Measurements/Rates

1 in 10 million pp interactions produces a W → e n



SM Higgs Boson Production





Integrated Luminosity

~5 fb-1 at $\sqrt{s}$=7TeV and ~ 20fb-1 at $\sqrt{s}$=8TeV

~2000 trillion pp collisions examined

And potentially produced

~500k SM Higgs bosons (m_H=125 GeV)

SM Higgs Decay

Optimal decay channel depends on M_H

Need detectors that measure and identify as much as possible in the event!

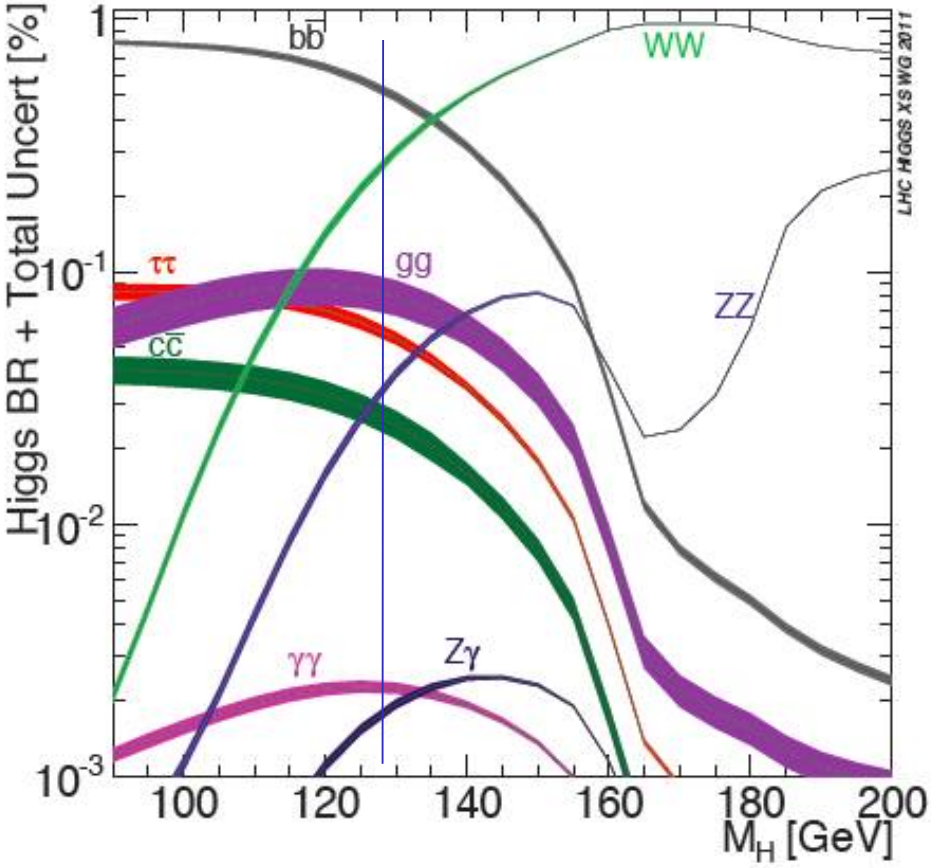
Natural Width: GH ~ few MeV
The best instrumental mass resolution achievable is ~1GeV

Only two channels have such a resolution with decay Branching Fractions:

$\gamma\gamma$ is 2 per mille

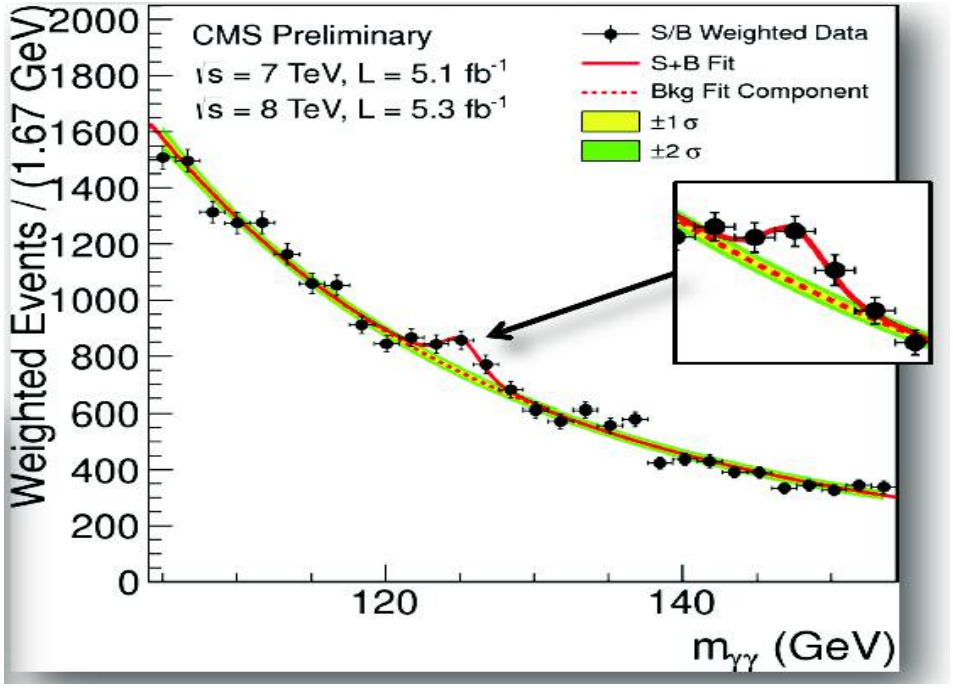
$ZZ \rightarrow 4l$ is $\sim 10^{-4}$

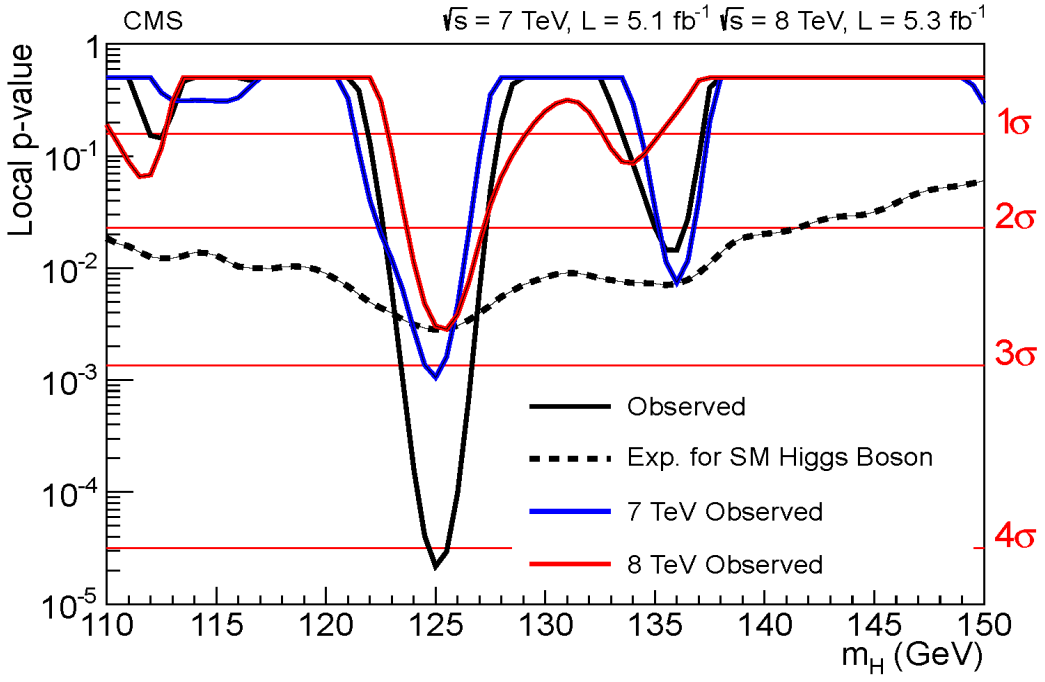
decay branching fractions

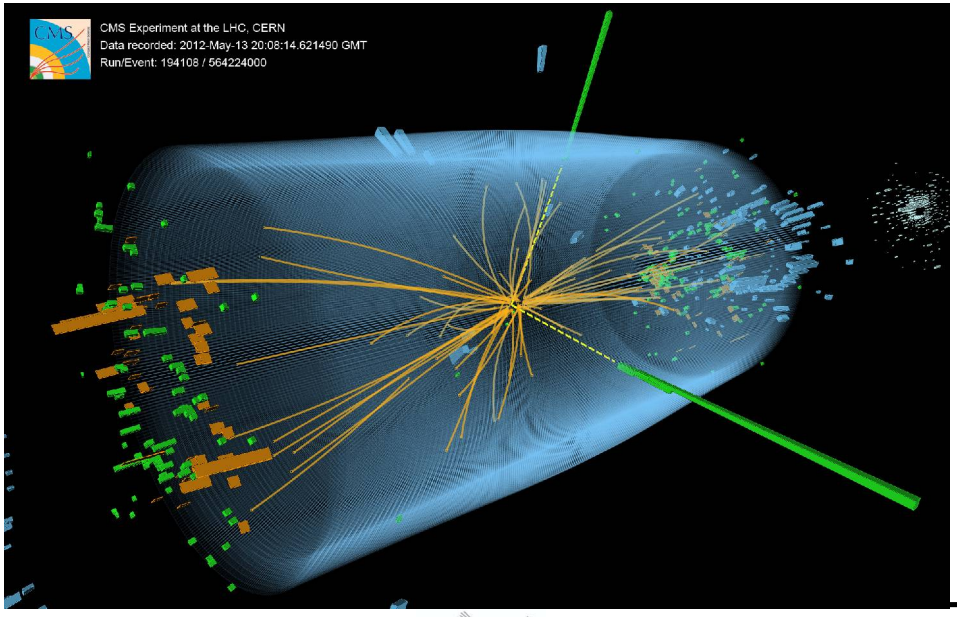


At $m_H \sim 125$ GeV many decay modes are detectable!

γγ Mass Distribution from CMS

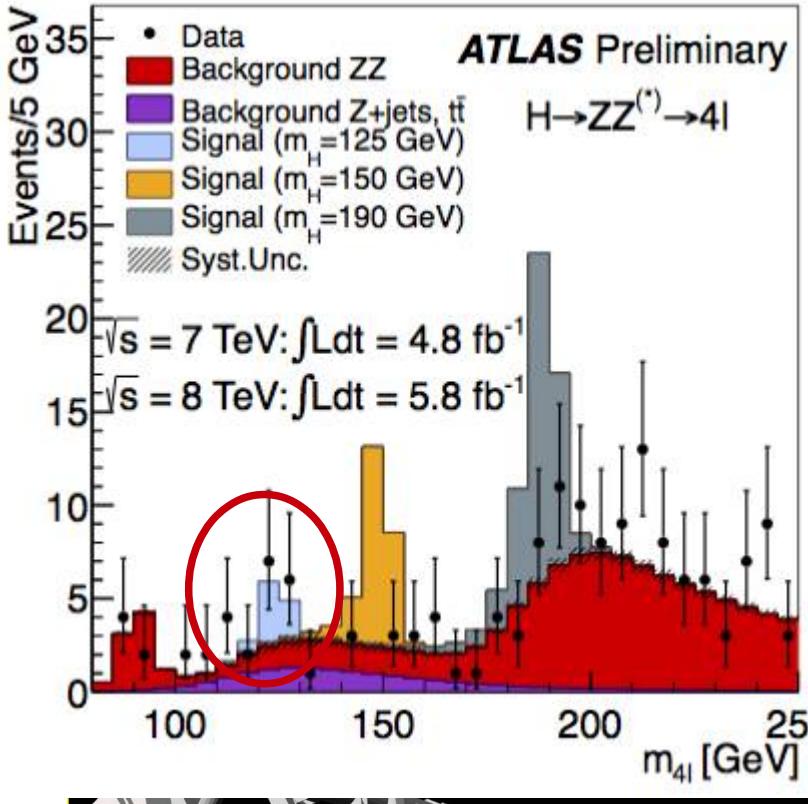


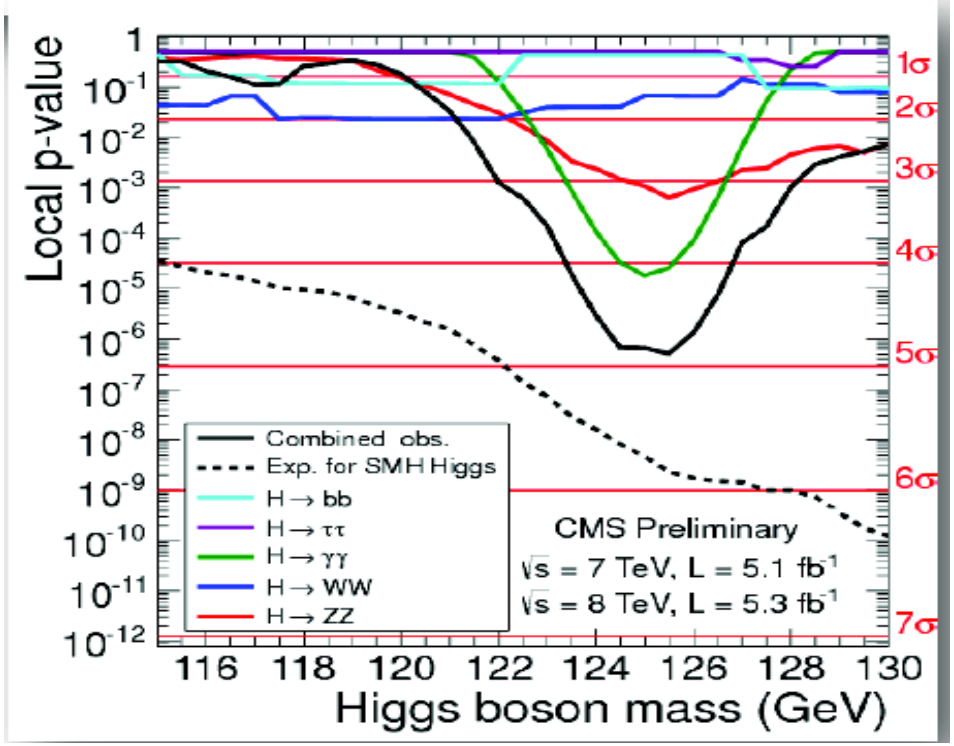


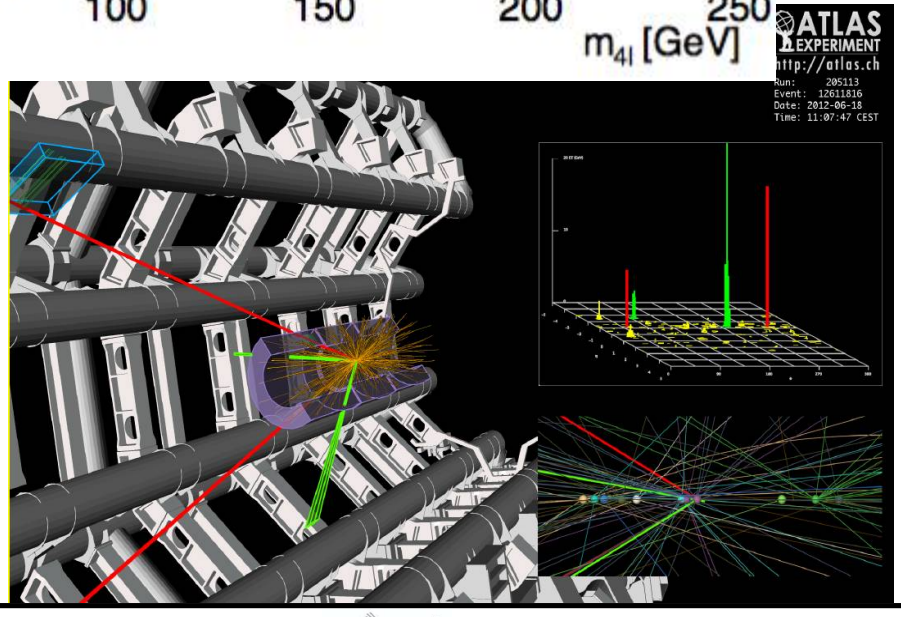


H –> γγ candidate

4-leptom invariant mass from ATLAS

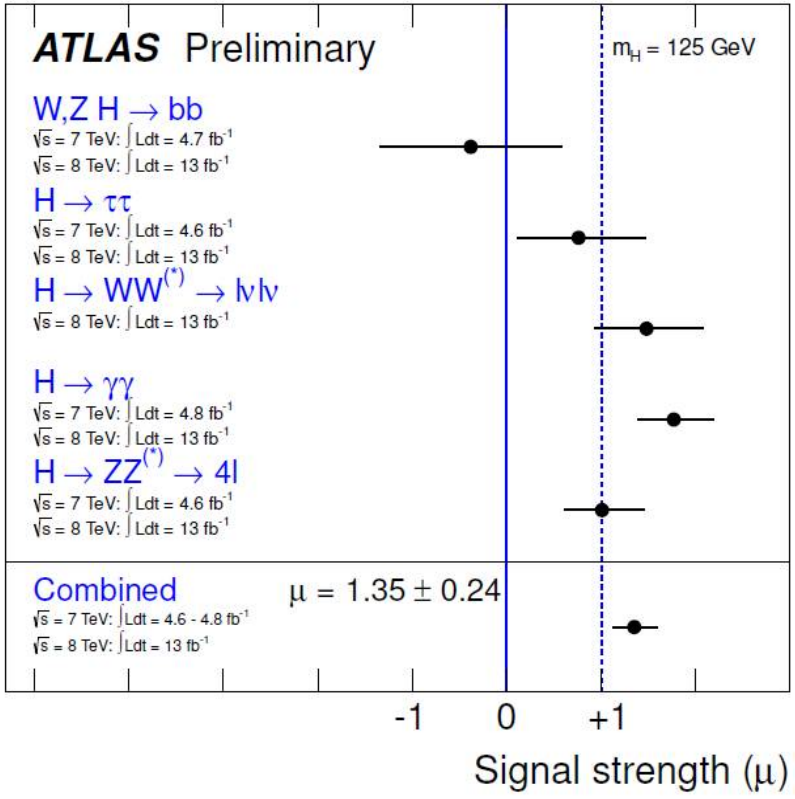






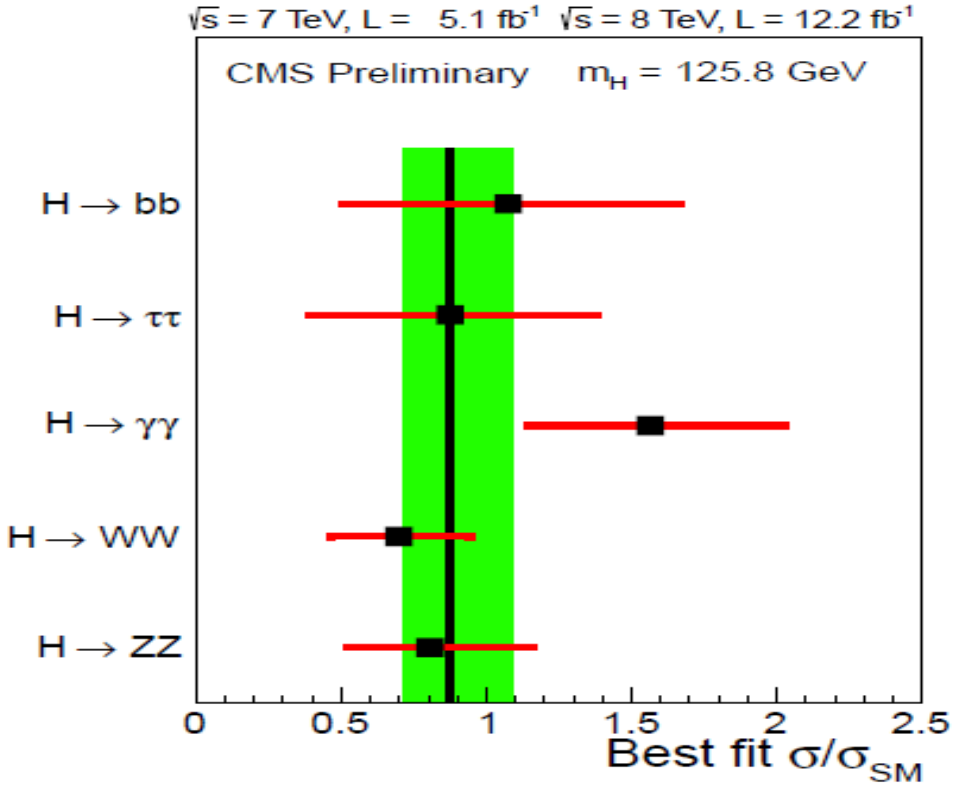
H -> ZZ* ->2μ2e candidate

Combined Higgs boson analysis from ATLAS and CMS



ATLAS-CONF-2012-170

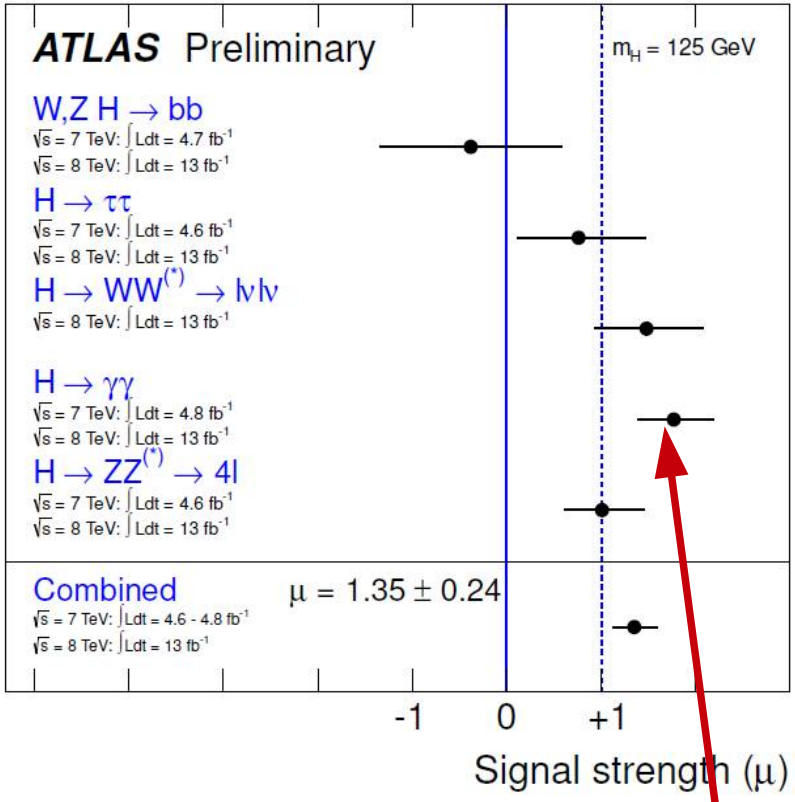
December 14 2012



CMS PAS HIG-12-045

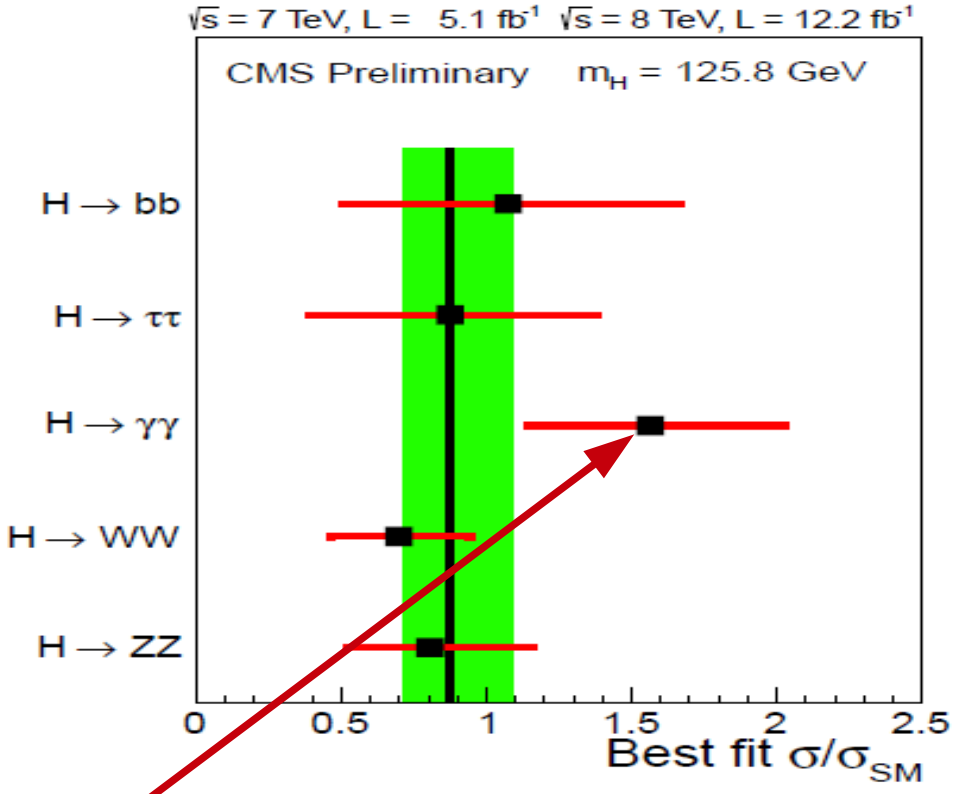
2012/11/16

Combined Higgs boson analysis from ATLAS and CMS



ATLAS-CONF-2012-170

December 14 2012

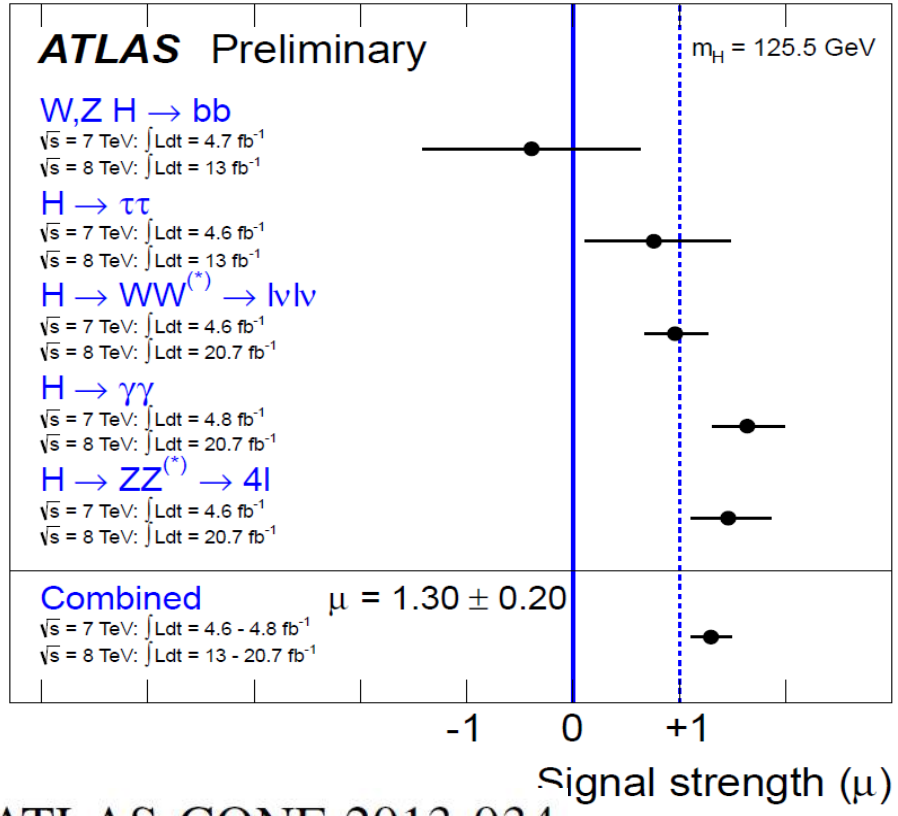


CMS PAS HIG-12-045

2012/11/16

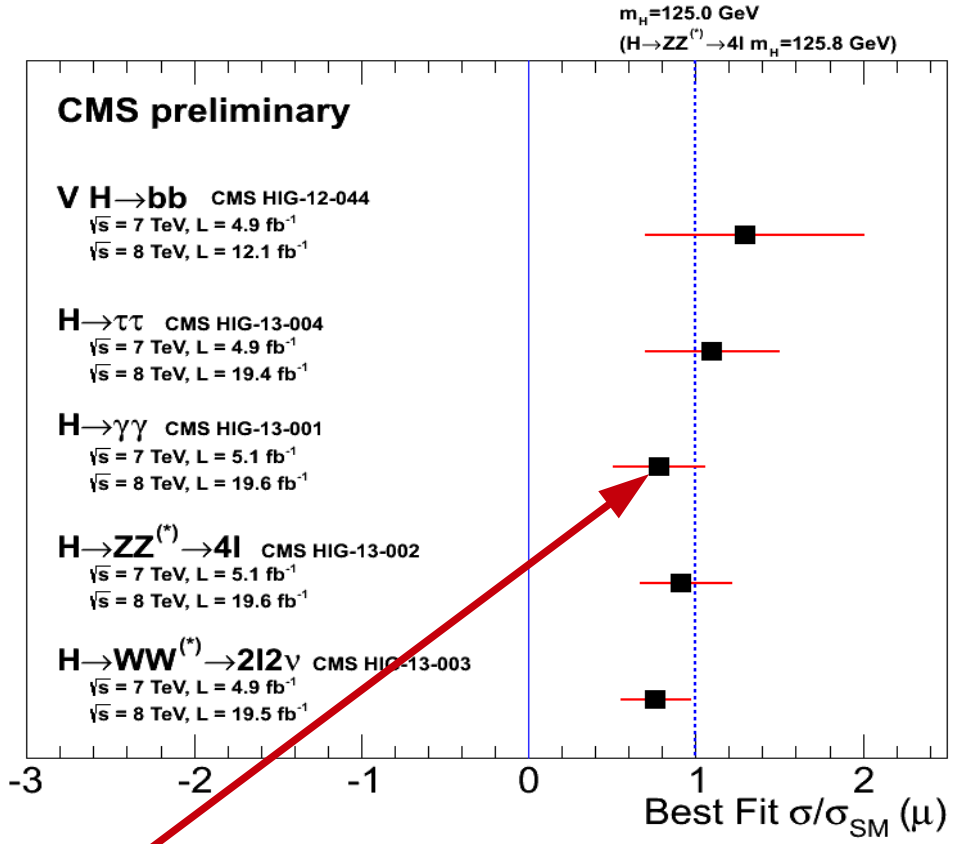
New physics?! Dozens of papers have been written to explain this ...

Combined Higgs boson analysis from ATLAS and CMS



ATLAS-CONF-2013-034

March 13, 2013



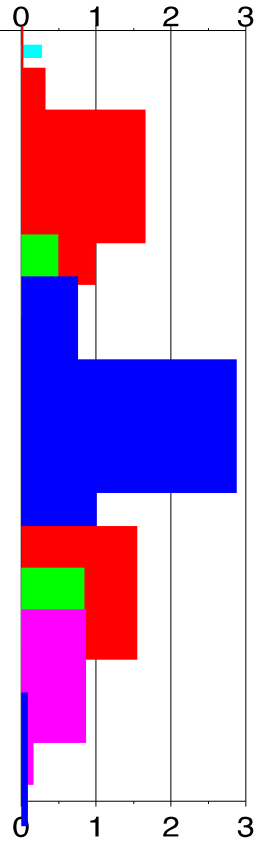
Moriond, CMS talk at QCD session, mid of March 2013

New physics?! Really?!

It is too early to claim anything, errors are still quite large!

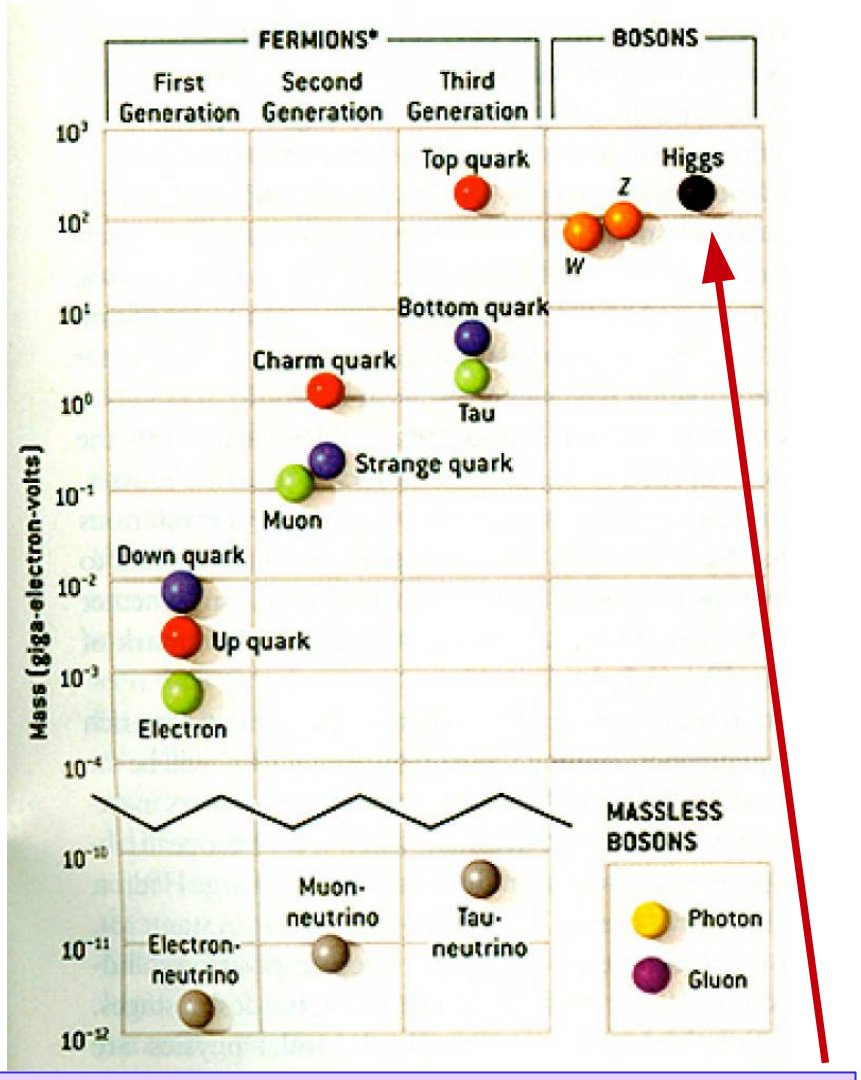
The Status of the Standard Model

	Measurement	Fit	$\lvert O^{meas} - O^{fit} \rvert / \sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.479	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.399 ± 0.023	80.379	
Γ_W [GeV]	2.085 ± 0.042	2.092	
m_t [GeV]	173.3 ± 1.1	173.4	



July 2010

Confirmed to better than 1% precision by 100's of precision measurements



The last missing particle - Higgs boson with ~125 GeV mass is found