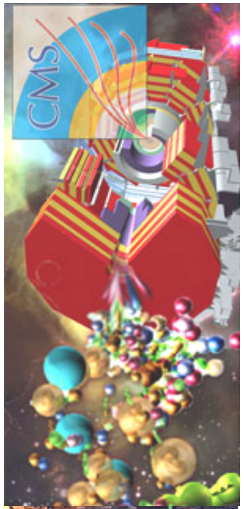
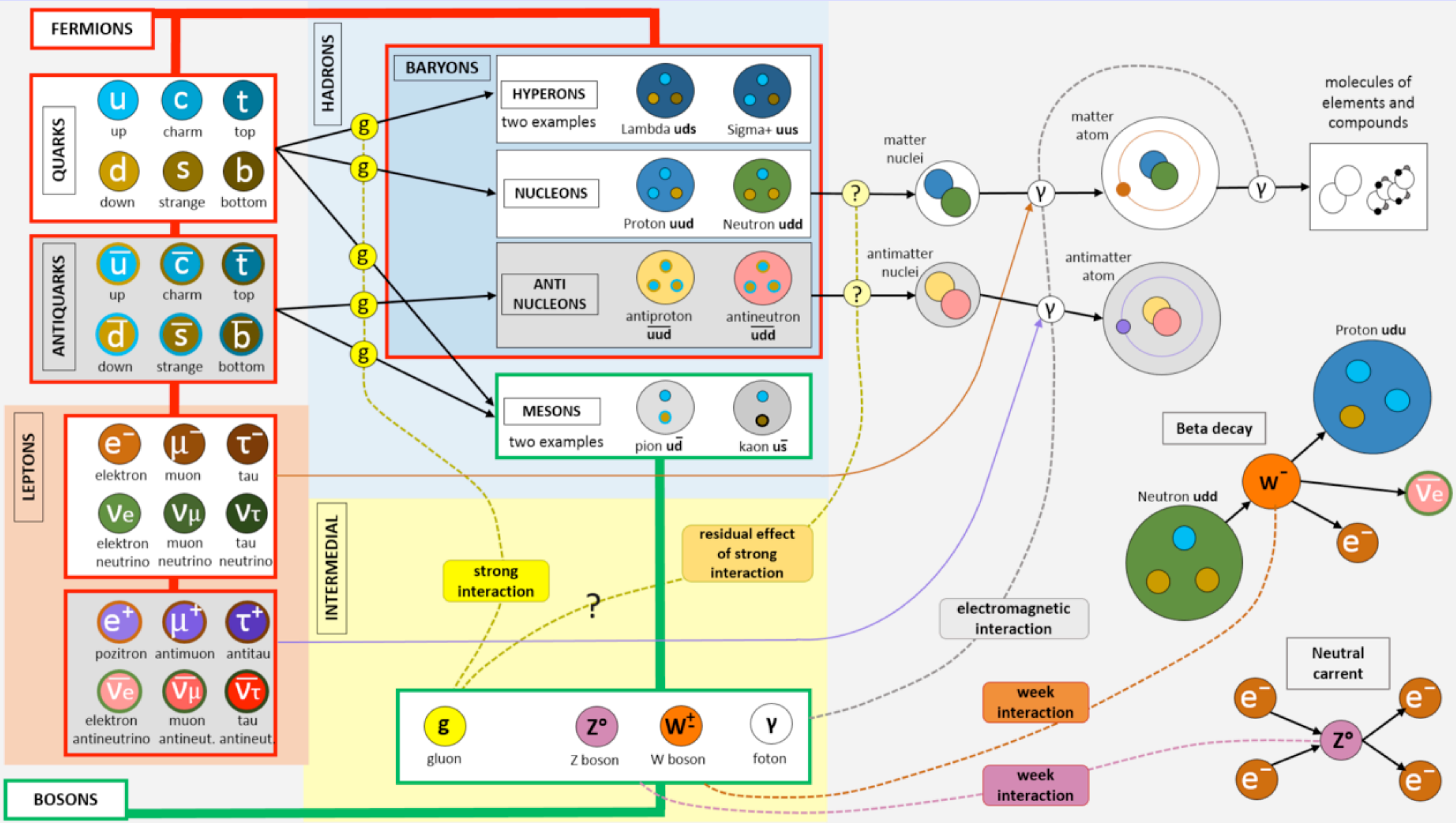


Standard Model probing at the LHC

Nicola De Filippis

Politecnico di Bari and INFN

The Standard Model

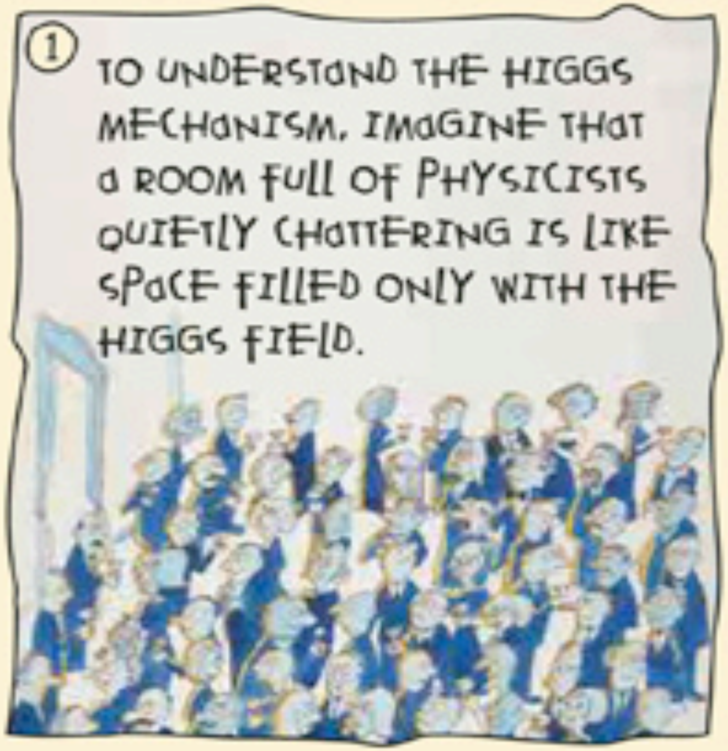


STANDARD MODEL OF ELEMENTARY PARTICLES

04/07/2012

the Higgs boson has been found !

THE HIGGS MECHANISM



A WELL KNOWN SCIENTIST, ALBERT EINSTEIN, WALKS IN, CREATING A DISTURBANCE AS HE MOVES ACROSS THE ROOM, AND ATTRACTING A CLUSTER OF ADMIRERS WITH EACH STEP.

THIS INCREASES HIS RESISTANCE TO MOVEMENT – IN OTHER WORDS, HE ACQUIRES MASS, JUST LIKE A PARTICLE MOVING THROUGH THE HIGGS FIELD.

IF A RUMOUR CROSSES THE ROOM ...

IT CREATES THE SAME KIND OF CLUSTERING, BUT THIS TIME AMONG THE SCIENTISTS THEMSELVES. IN THIS ANALOGY, THESE CLUSTERS ARE THE HIGGS PARTICLES.

Looking for the Higgs: Large Hadron Collider

The LHC project started at the initiative (and with the daring!!) of C. Rubbia

The Aachen Conference in October 1990 marked the start-up, since then work on the collider and magnets, various detector designs and understanding physics issues went on without let-up

➡ Scientific-diplomatic trips in 1990/91/92 to Japan, India, Russia, USA, Canada etc

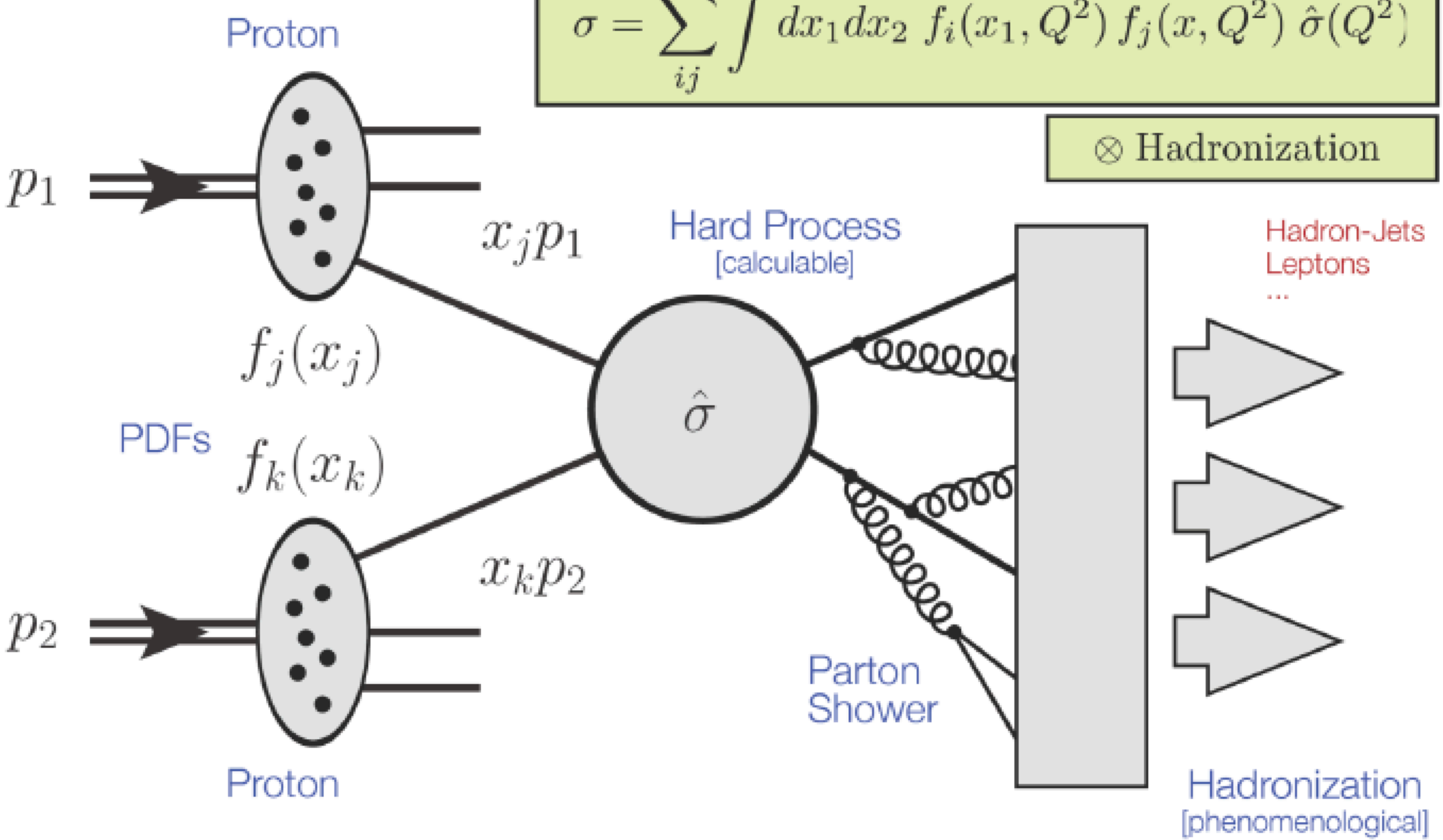
LHC vs SSC: Rubbia's arguments: savings!

- existing LEP tunnel ~1 GCHF
- existing infrastructure at CERN (PS. SPS, etc) ~ 1 GCHF
- "two-in-one" scheme for dipoles saves ~ half the cost of magnet ~ 0.7 to 1 GCHF
  thus overall LHC cost ~ 3 GCHF
- will be ready by 1998 - 2000 !!

Proton-proton scattering @ LHC

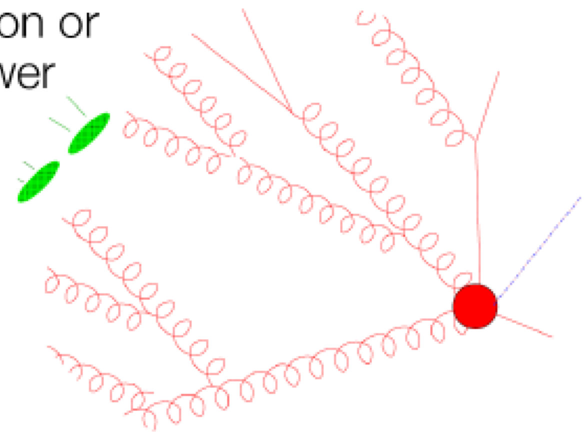
$$\sigma = \sum_{ij} \int dx_1 dx_2 \, f_i(x_1, Q^2) \, f_j(x, Q^2) \, \hat{\sigma}(Q^2)$$

$\otimes$ Hadronization



From Partons to Jets

From partons to
color neutral hadrons:



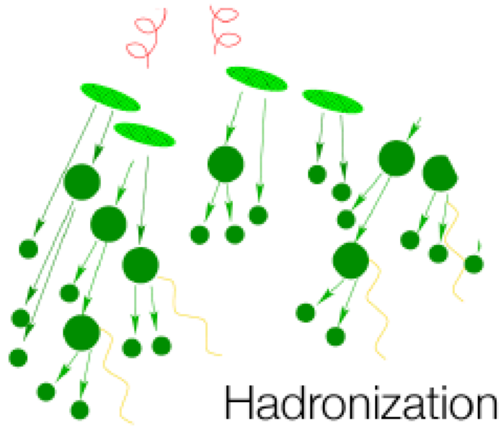
Fragmentation:

Parton splitting into other partons
[QCD: re-summation of leading-logs]
["Parton shower"]

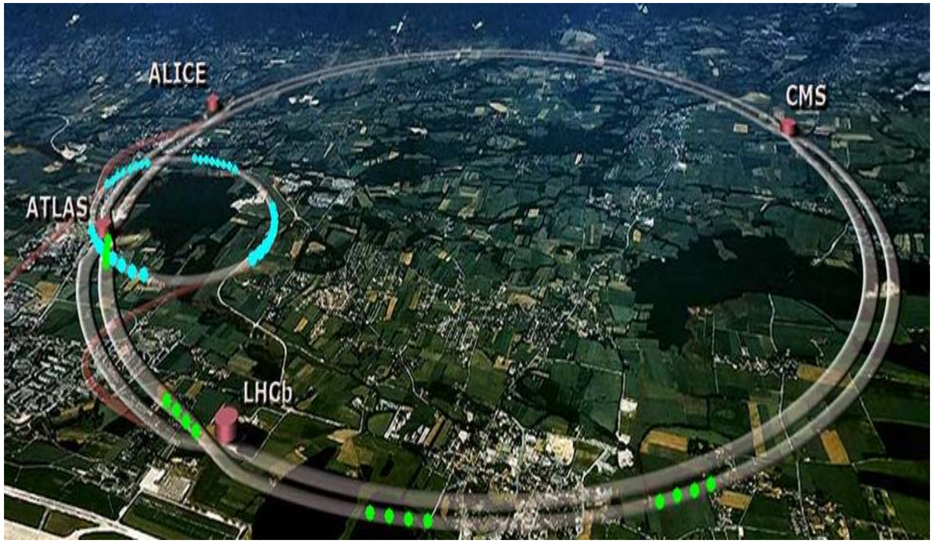
Hadronization:

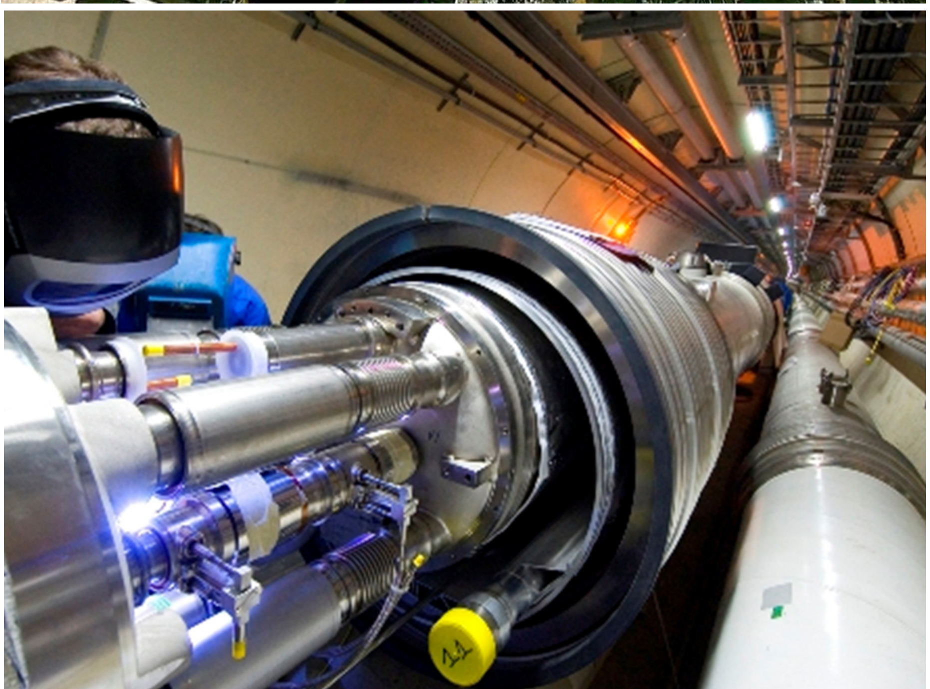
Parton shower forms hadrons
[non-perturbative, only models]

Decay of unstable hadrons
[perturbative QCD, electroweak theory]



The LHC machine





Circumference (km)	26.7
Number of superconducting Dipoles	1232
Length of Dipole (m)	14.3
Dipole Field Strength (Tesla)	8.4
Operating Temperature (K)	1.9
Current in dipole sc coils (A)	13000
Beam Intensity (A)	0.5
Beam Stored Energy (MJoules)	362
Number of particles per bunch	1.15×10^{11}
Number of bunches per beam	2808
Crossing angle (μrad)	285
Bunch length (cm)	7.55
Norm transverse emittance (μm rad)	3.75
Beta function at IP 1,2,5,8 (m)	0.55,10,0.55,10

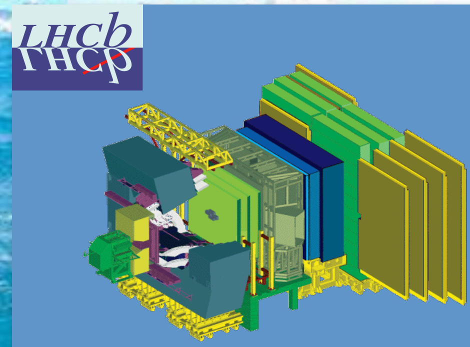
$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \varepsilon_n \beta *} F$$

N_b = number of proton per bunch
n_b = number of bunches

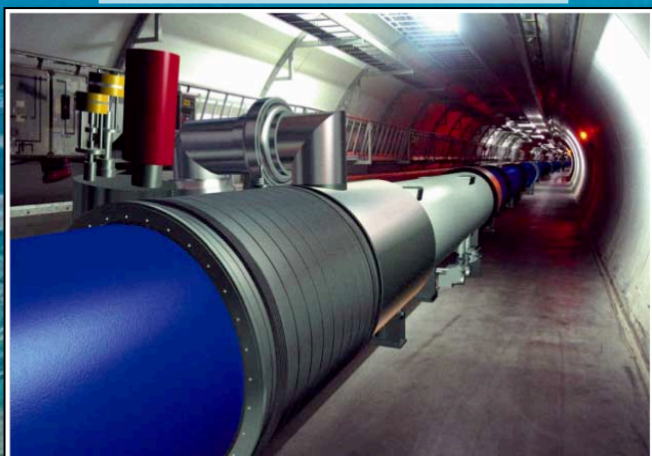
f_{rev} = rotation frequency (~ 11Hz)
F = crossing angle factor

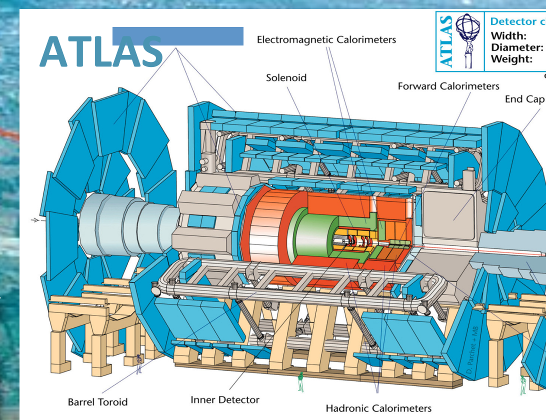
Rms transverse beam size $= \sqrt{\varepsilon \beta / \gamma}$
ε_n = renorm. transverse emittance
$\beta *$ = optics at beam crossing (m)
γ_r = relativistic factor

pp, B-Physics,
CP Violation

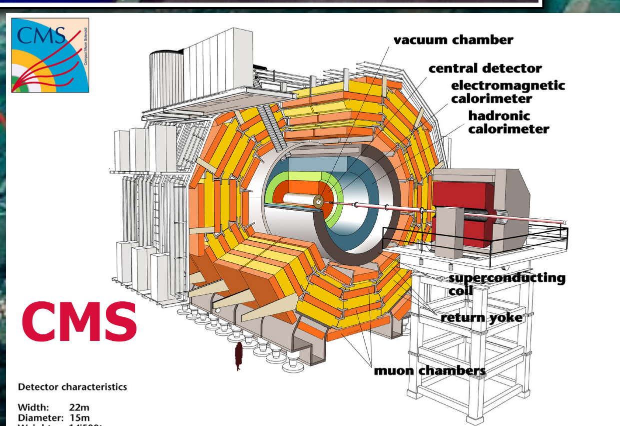


LHC : 27 km long
100m underground



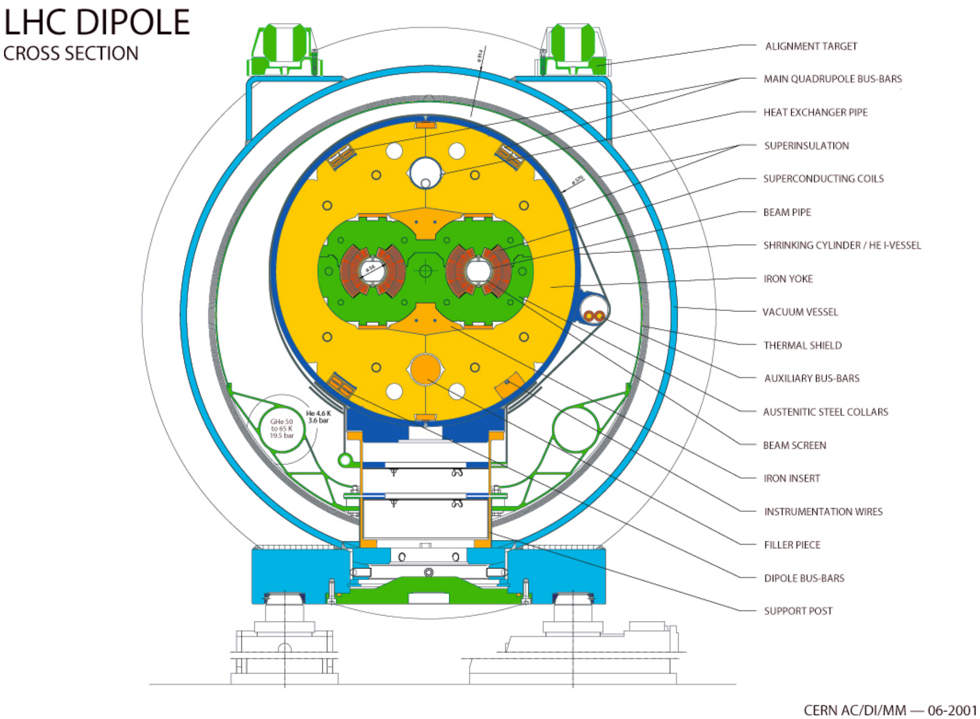


General Purpose,
pp, heavy ions



Heavy ions, pp

LHC Magnets



9300 Superconducting Magnets

1232 Dipoles (15m), 448 Main Quads, 6618 Correctors.

Operating temperature: 1.9° K

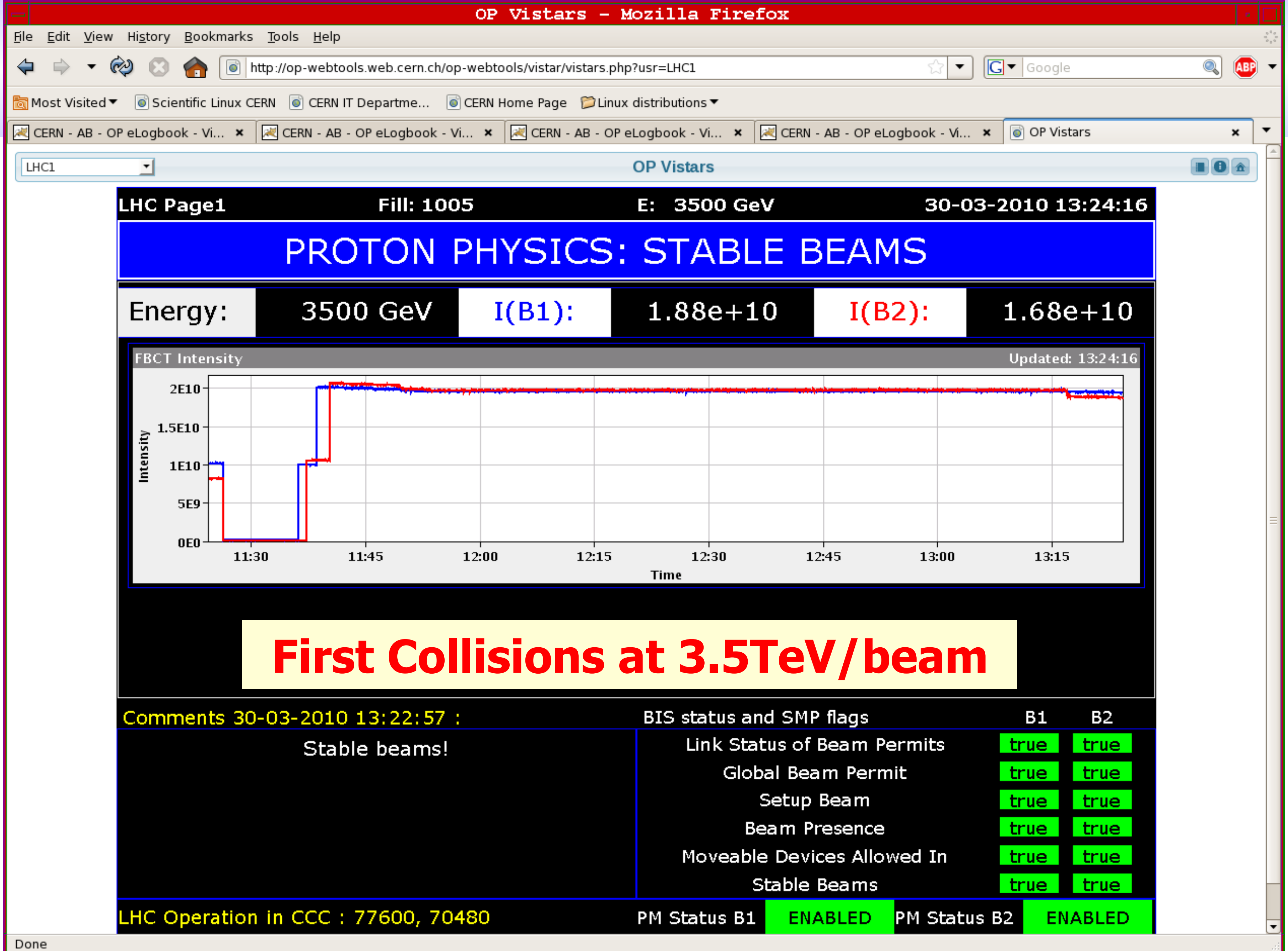
26.7 km tunnel

LHC magnets

Lowering one of the 1232
15m long dipoles 100m down into the LHC
There are another 8000 magnets of different types as well
1st magnet lowered in March 2005

The last dipole magnet makes its descent towards its final destination in the LHC tunnel.

18 | CERN


OP Vistars - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://op-webtools.web.cern.ch/op-webtools/vistar/vistars.php?usr=LHC1
Most Visited
Scientific Linux CERN
CERN IT Departme...
CERN Home Page
Linux distributions
CERN - AB - OP eLogbook - Vi...
OP Vistars
LHC1
OP Vistars
LHC Page1
Fill: 1005
E: 3500 GeV
30-03-2010 13:24:16
PROTON PHYSICS: STABLE BEAMS
Energy:
3500 GeV
I(B1):
1.88e+10
I(B2):
1.68e+10
FBCT Intensity
Updated: 13:24:16
2E10
1.5E10
1E10
5E9
0E0
Intensity
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
Time
First Collisions at 3.5TeV/beam
Comments 30-03-2010 13:22:57 :
Stable beams!
BIS status and SMP flags
B1
B2
Link Status of Beam Permits
Global Beam Permit
Setup Beam
Beam Presence
Moveable Devices Allowed In
Stable Beams
true
LHC Operation in CCC : 77600, 70480
PM Status B1
ENABLED
PM Status B2
ENABLED
Done

Basic principles of the detectors

Need "general-purpose" experiments covering as much of the solid angle as possible ("4π") since we don't know how New Physics will manifest itself

$\rightarrow$ detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….

Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) are measured in central tracker (Silicon layers).

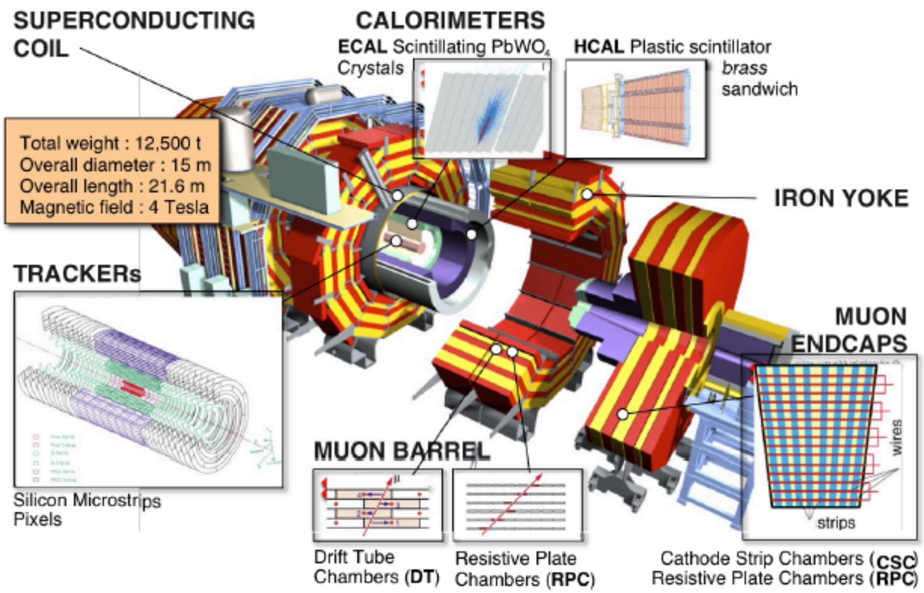
Energy and positions of electrons and photons measured in electromagnetic calorimeters (+central tracker).

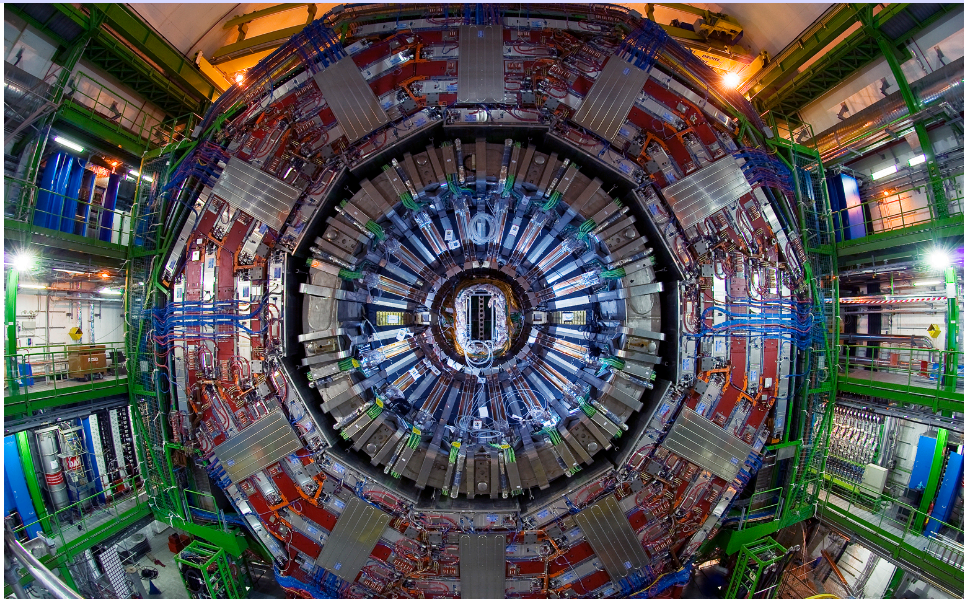
Energy and position of hadrons and jets measured mainly in hadronic calorimeters (+central tracker for charged hadrons).

Muons identified and momentum measured in external muon spectrometer (+central tracker).

Neutrinos "detected and measured" through measurement of missing transverse energy (**ET^{miss}**) in calorimeters (+central tracker).

CMS in a nutshell





|η|<2.5 : Tracker

$\sigma/p_T \approx 10^{-4} p_T \oplus 0.005$

|η|<4.9 : EM Calorimeter

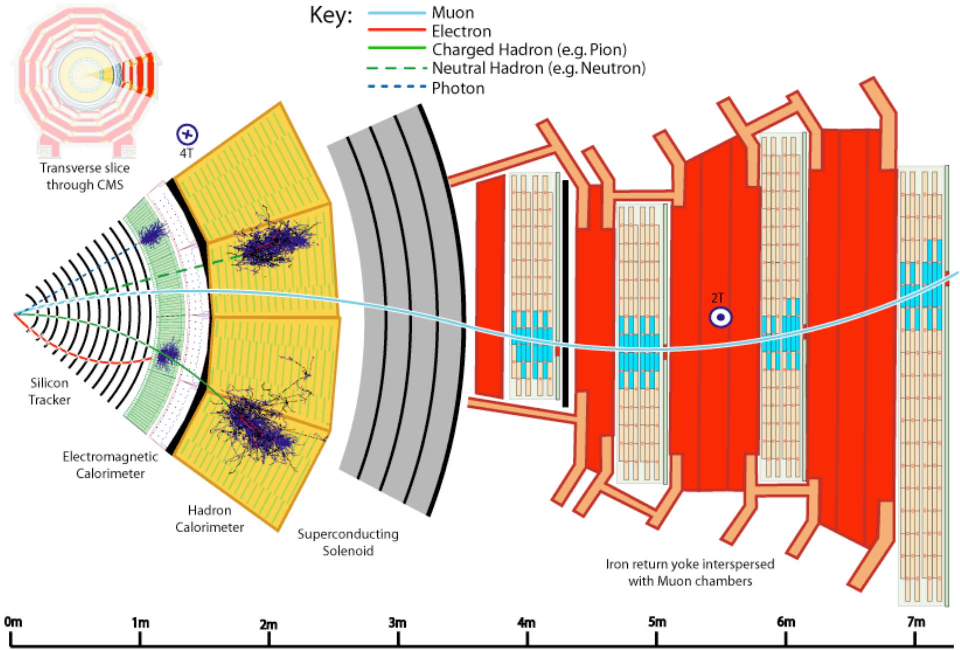
$\sigma/E \approx 0.03/\sqrt{E} + 0.003$

|η|<4.9 : HAD Calorimeter

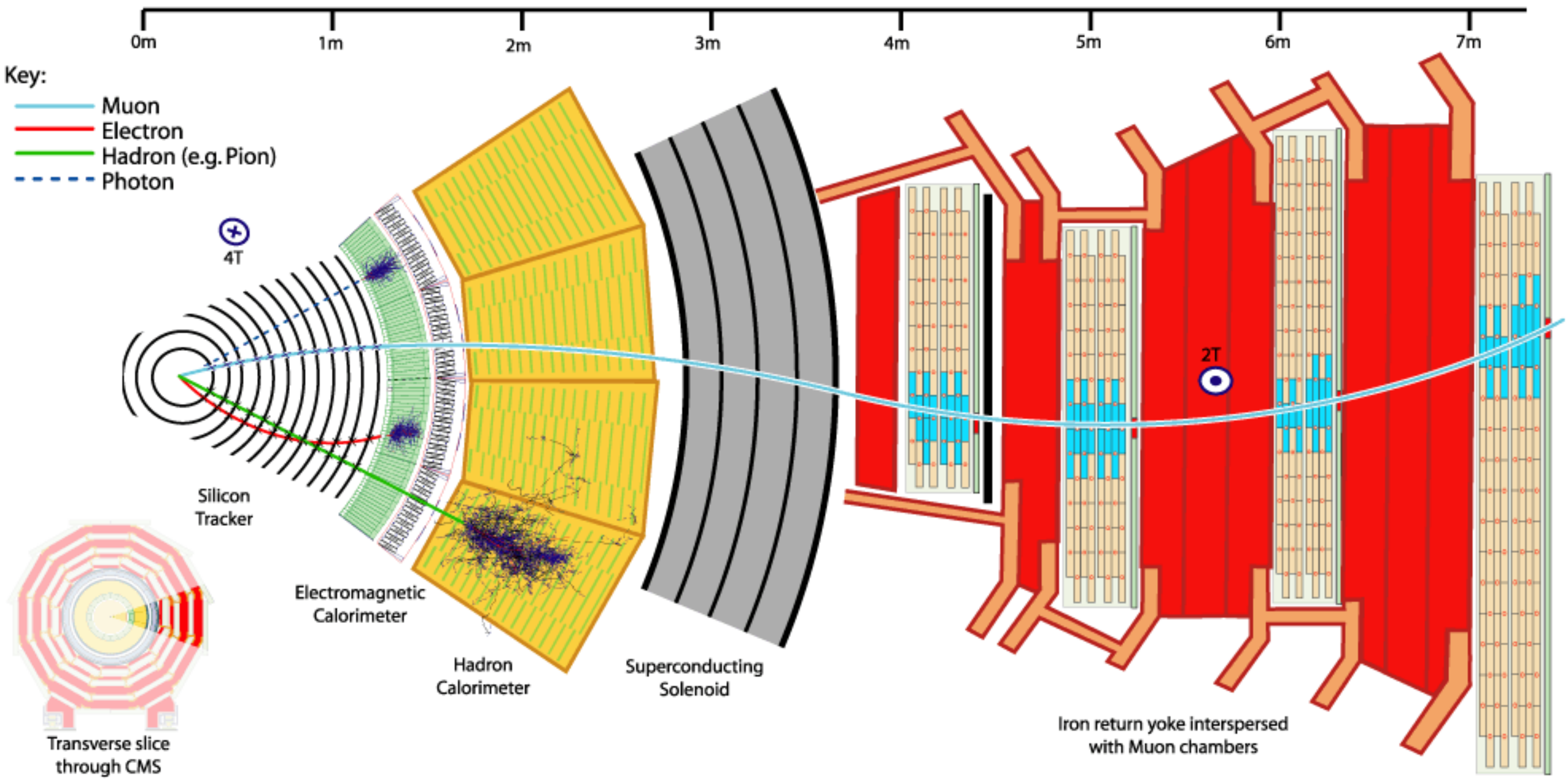
$\sigma/E \approx 1.0/\sqrt{E} + 0.05$

|η|<2.4 : Muon spectrometer

$\sigma/p_T \approx 0.10$ (1TeV muons)



Particles as seen in CMS



The CMS story

Work for escavation at "Point 5"

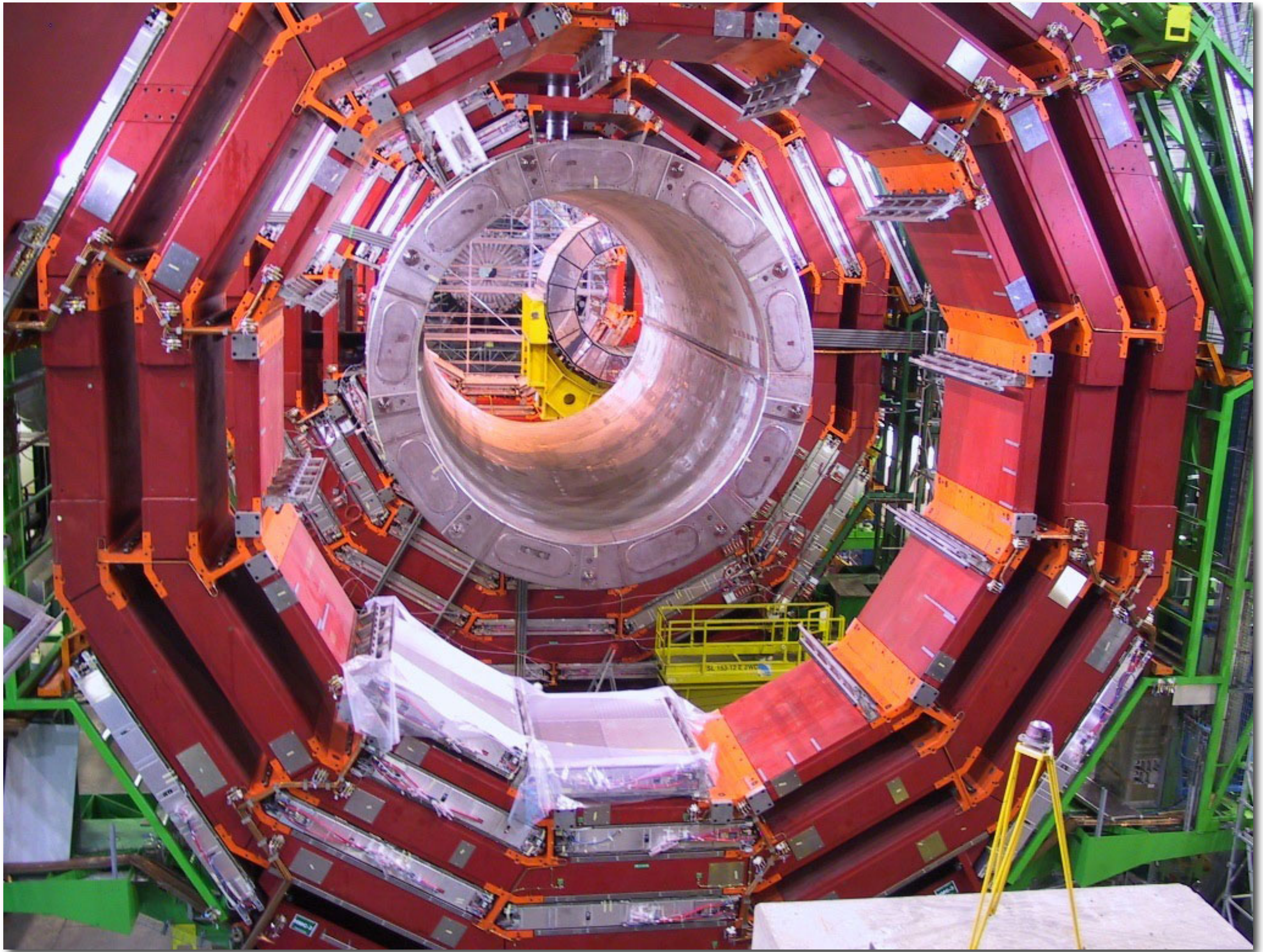
Point 5 - Excavation of pillar - November 22, 2000 - CERN ST-CE

Point 5 - Installation ventilation in PM54 - September 18, 2000 - CERN ST-CE

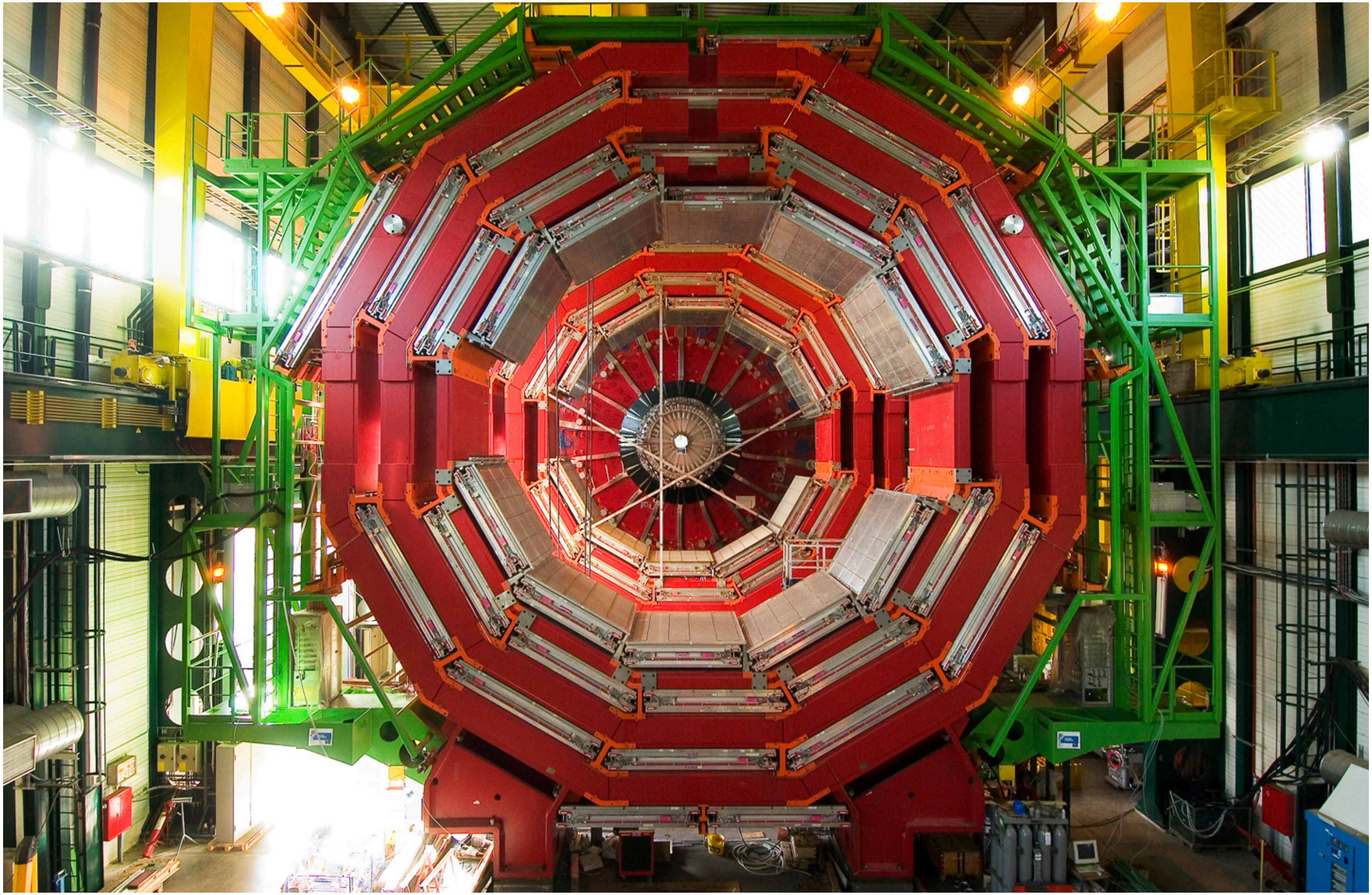
UXC/USC5: CMS caverns

Delivered to the experiment on February 1-st 2005.

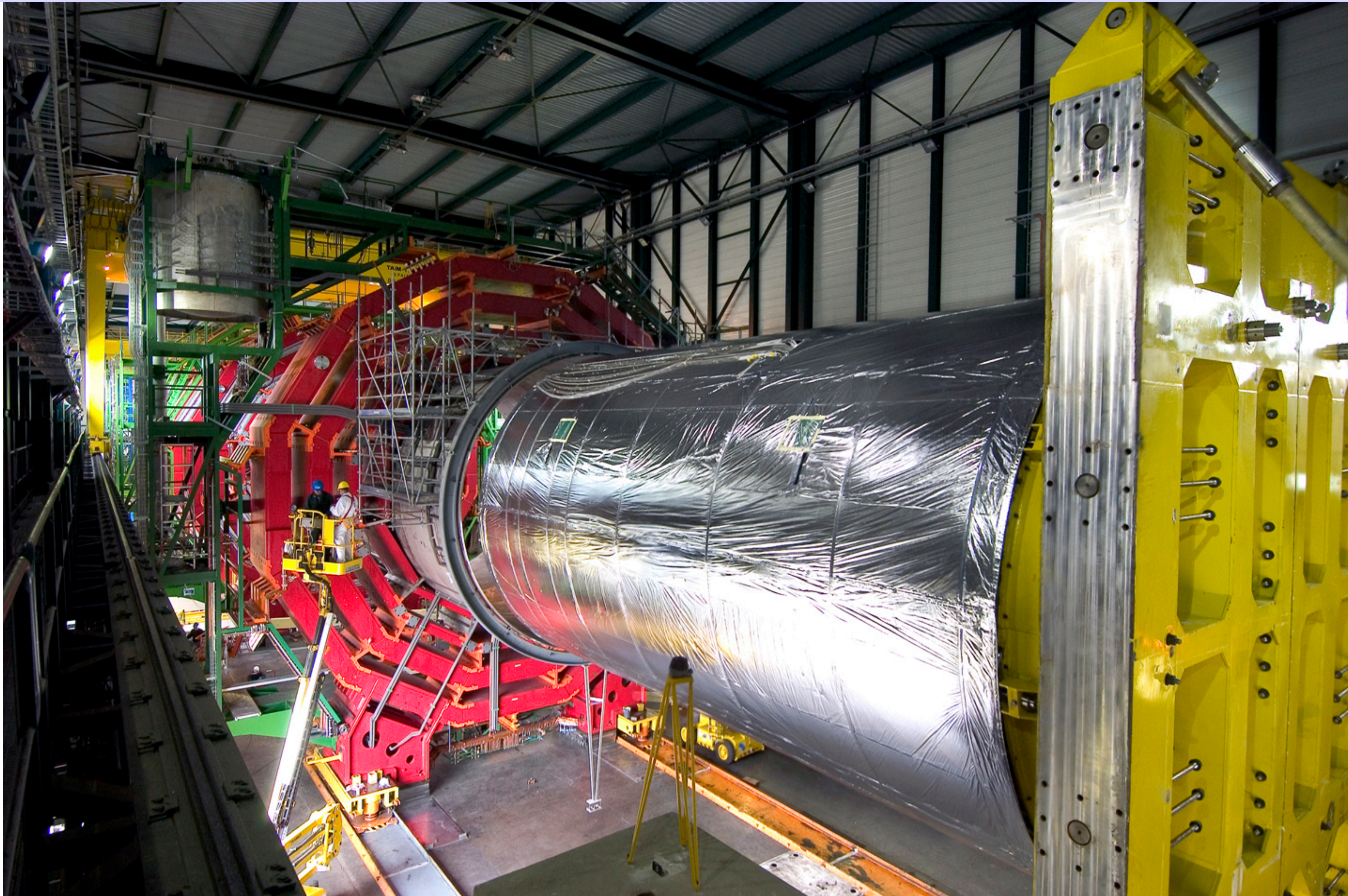
CMS Surface Hall in Feb 2006



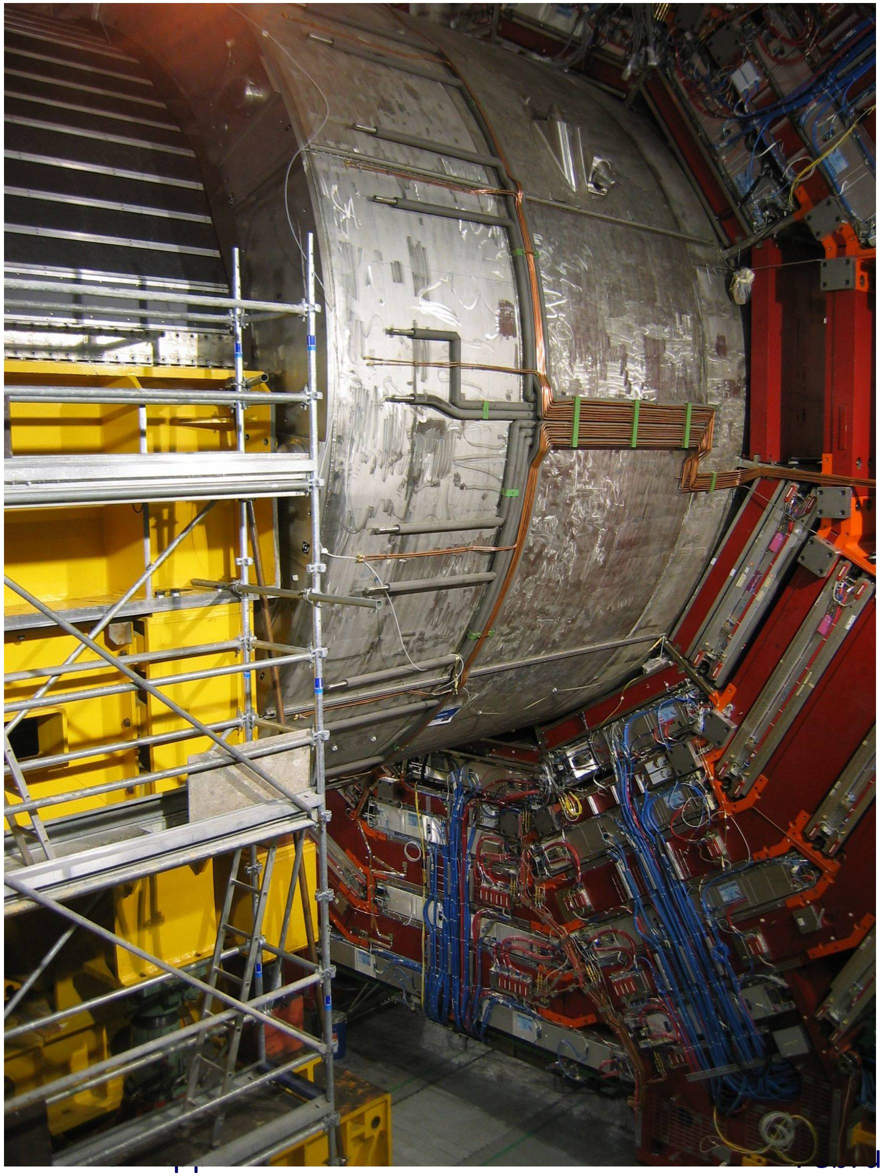
Surface Hall: Barrel Muons

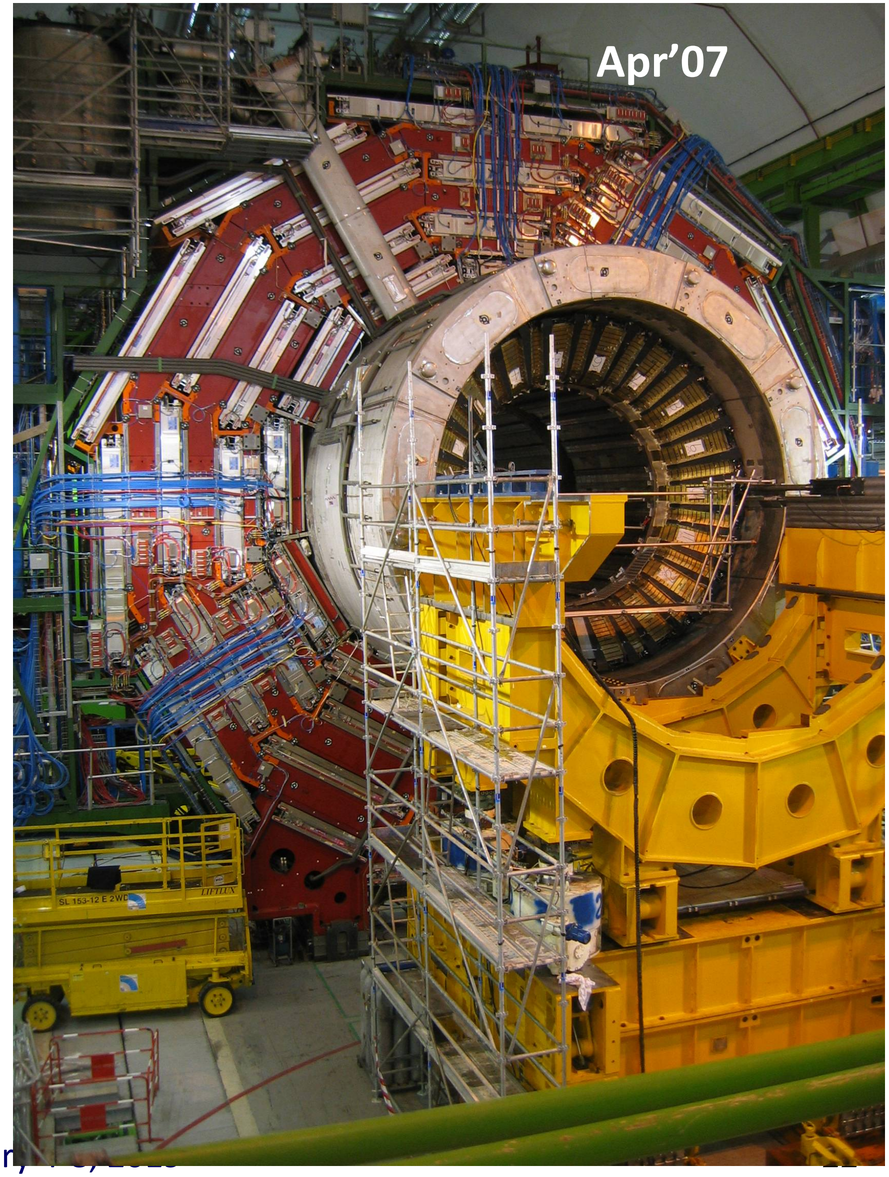


Assembly of the Coil

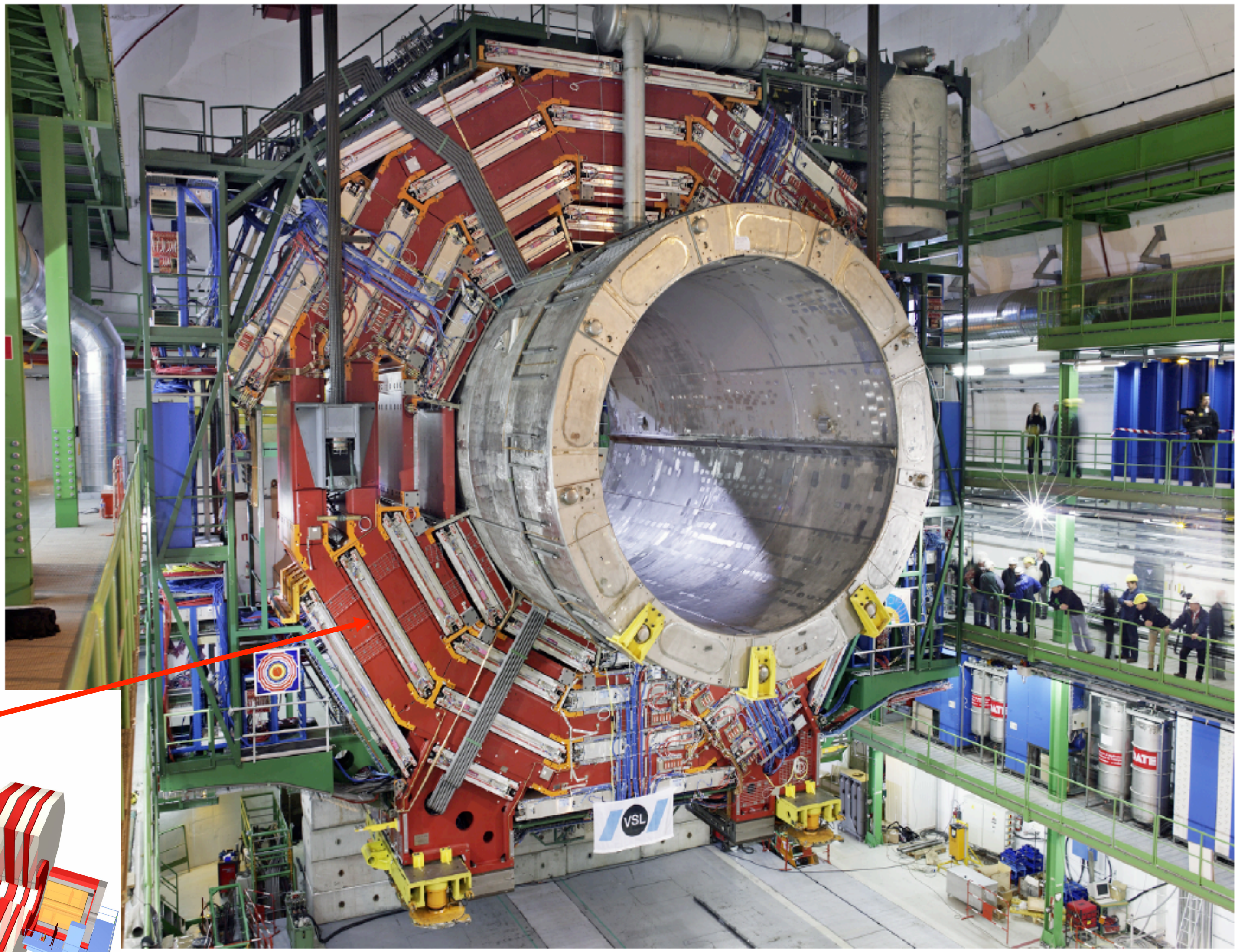


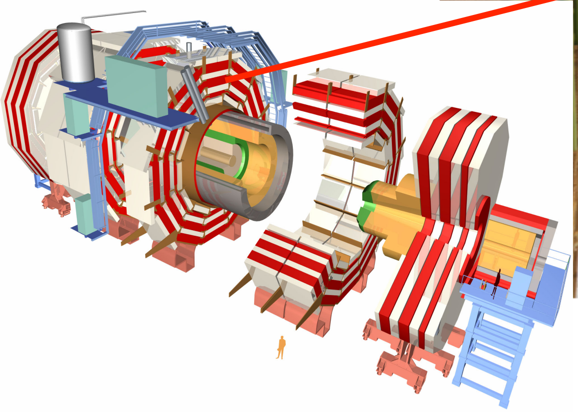
Insertion of HCAL Barrel





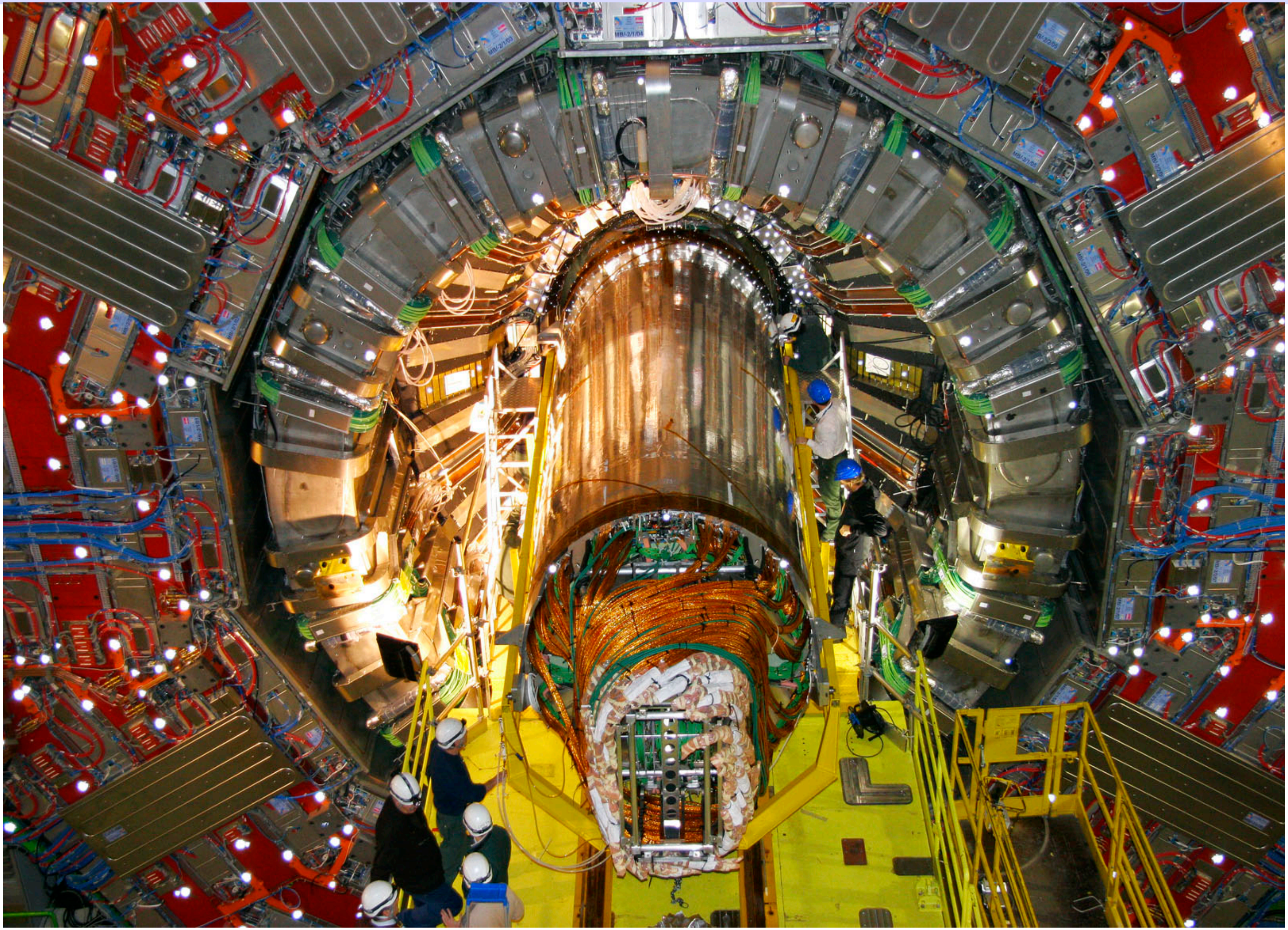
Lowering of Heavy Elements

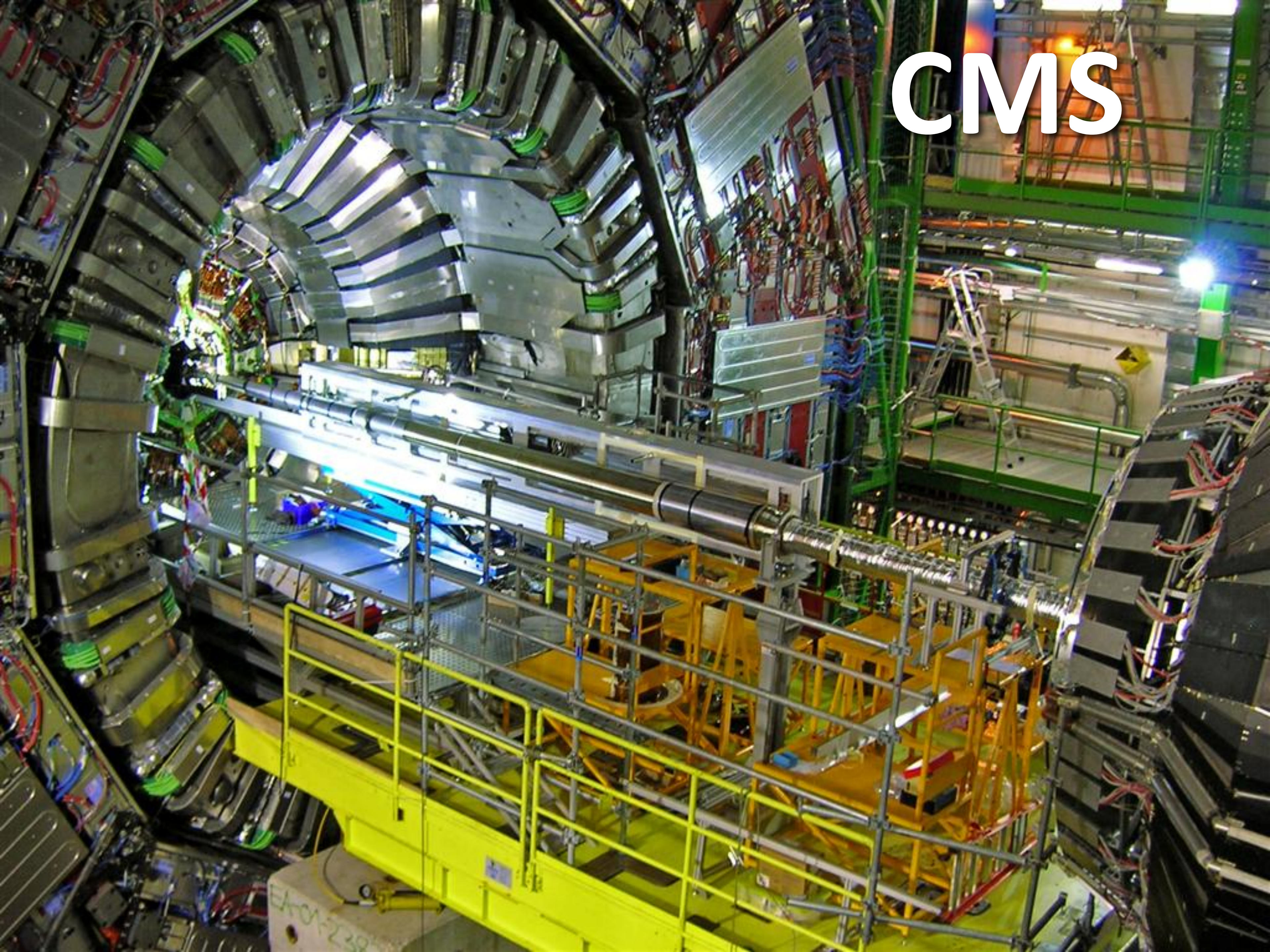




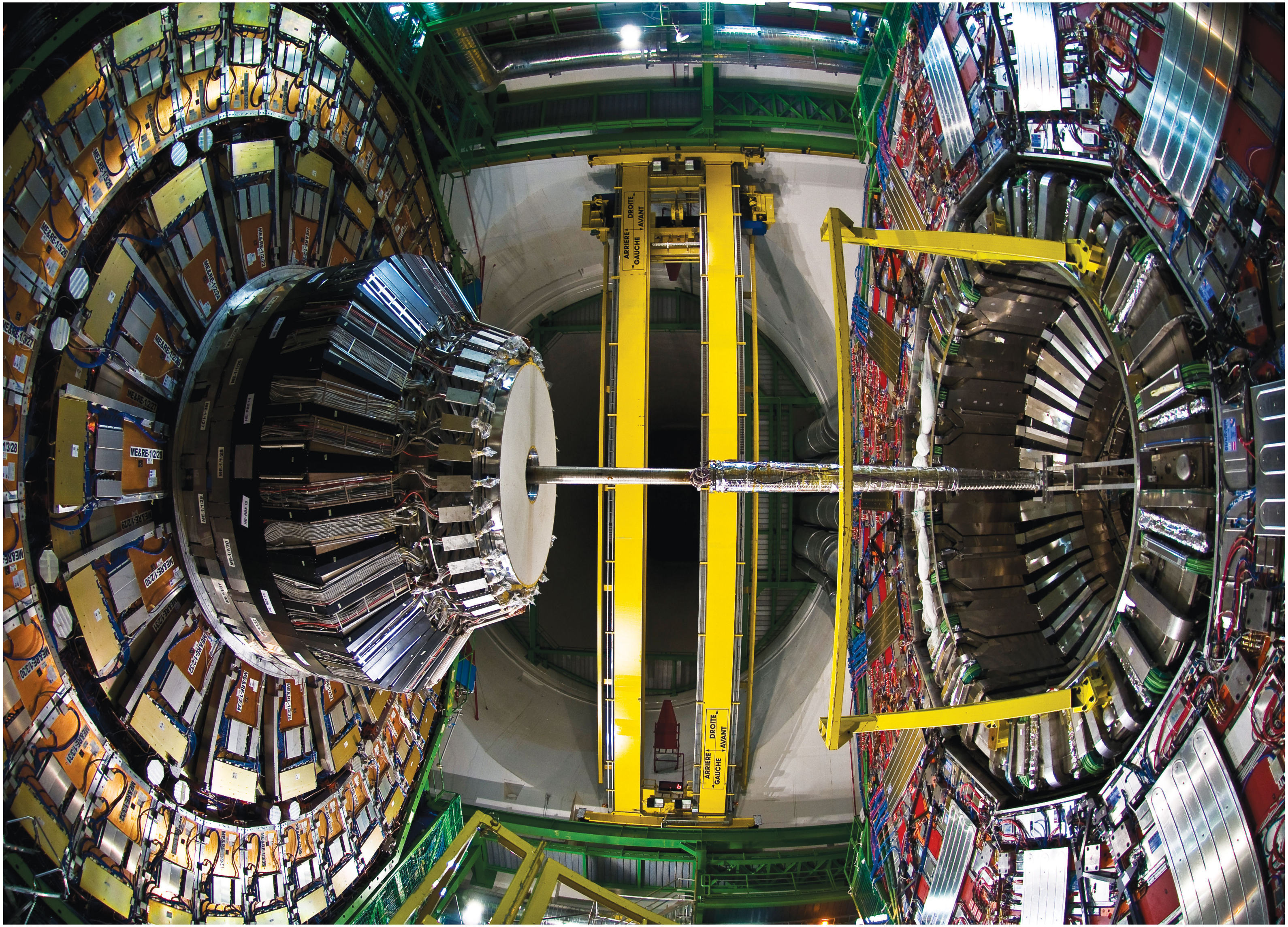
YB0 landing in the CMS experiment hall

Tracker insertion

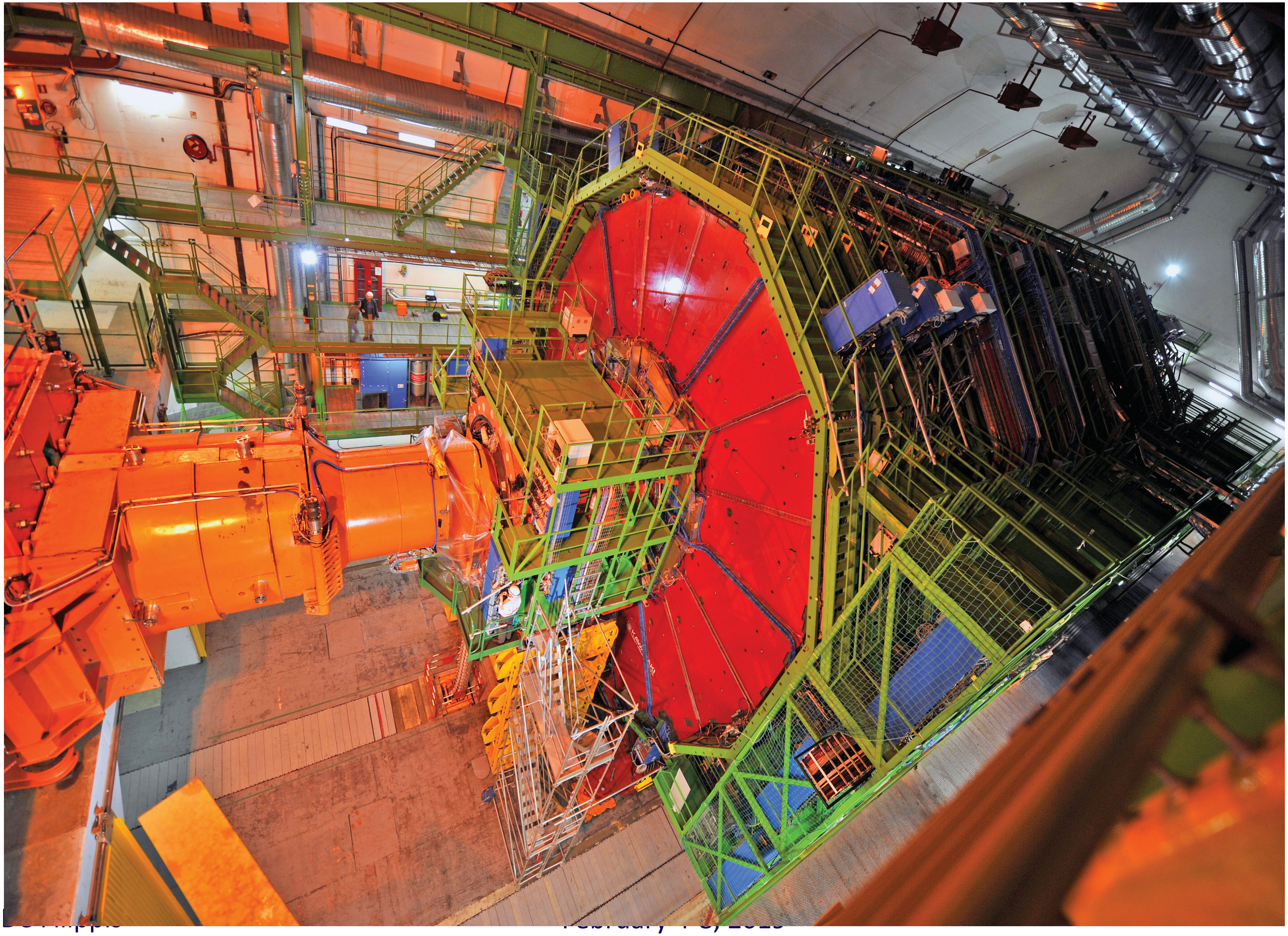



CMS

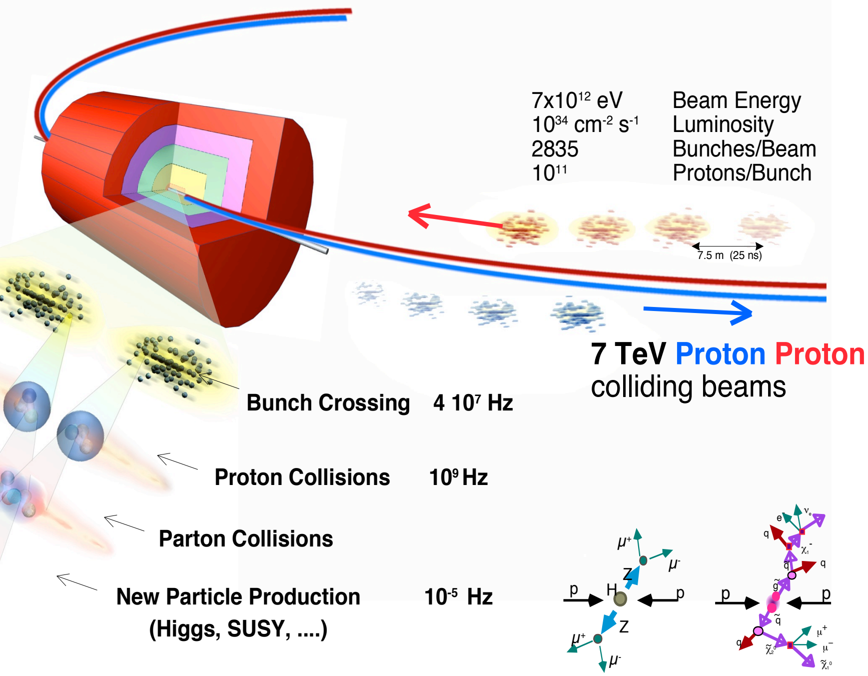
Beam Pipe installation



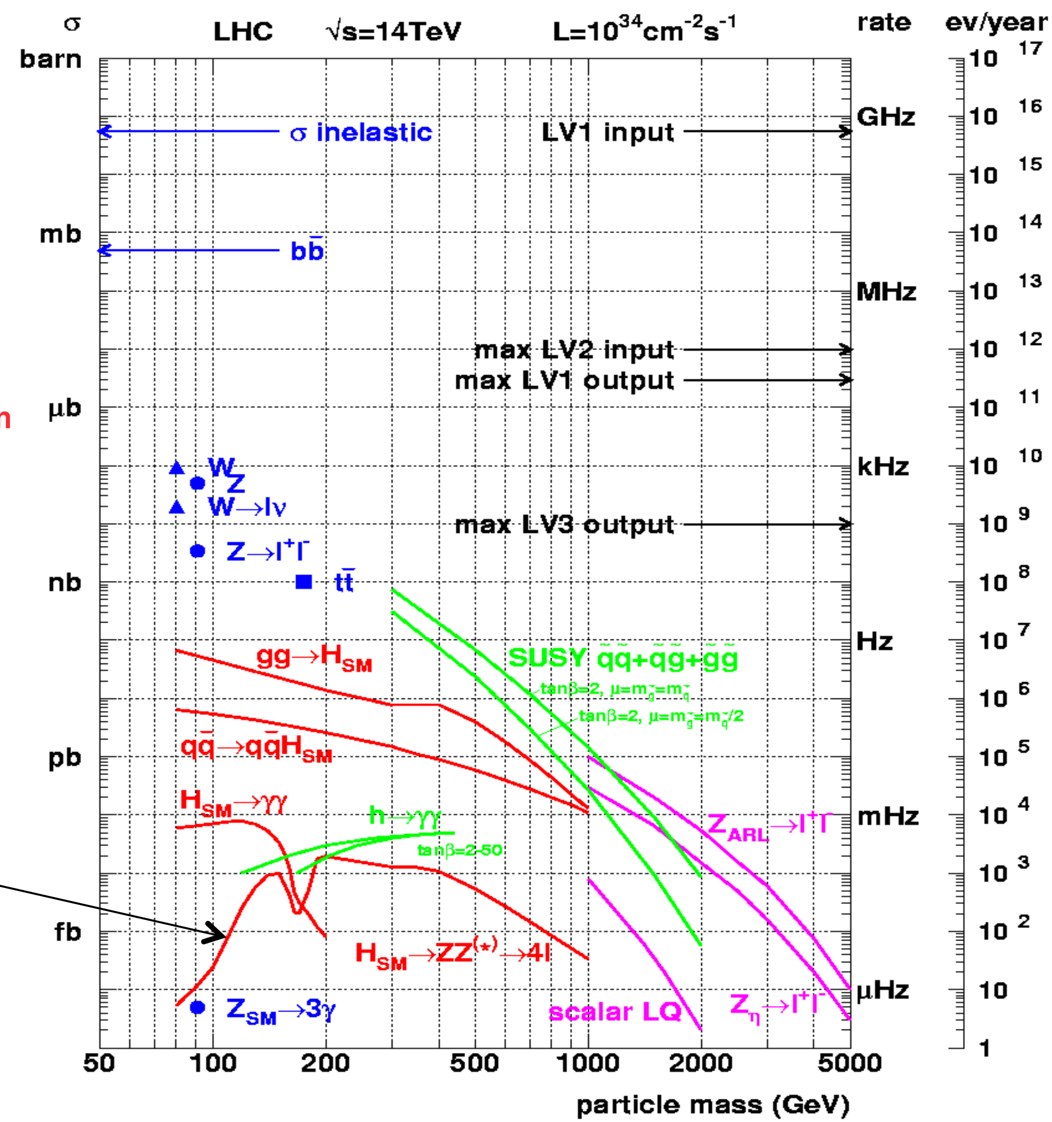
CMS closed and ready for data



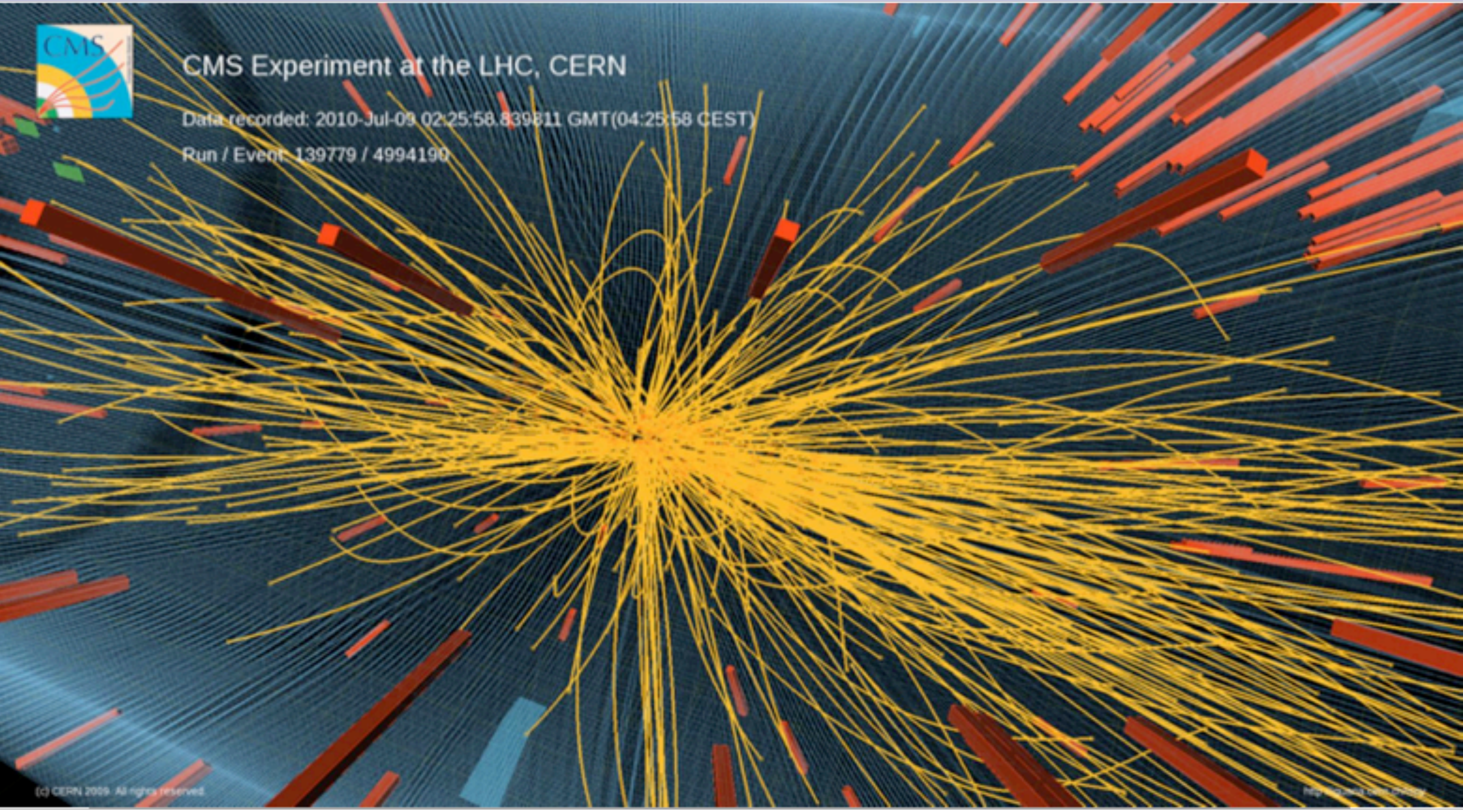
Proton-proton collisions at LHC



Selection of 1 event in 10,000,000,000,000

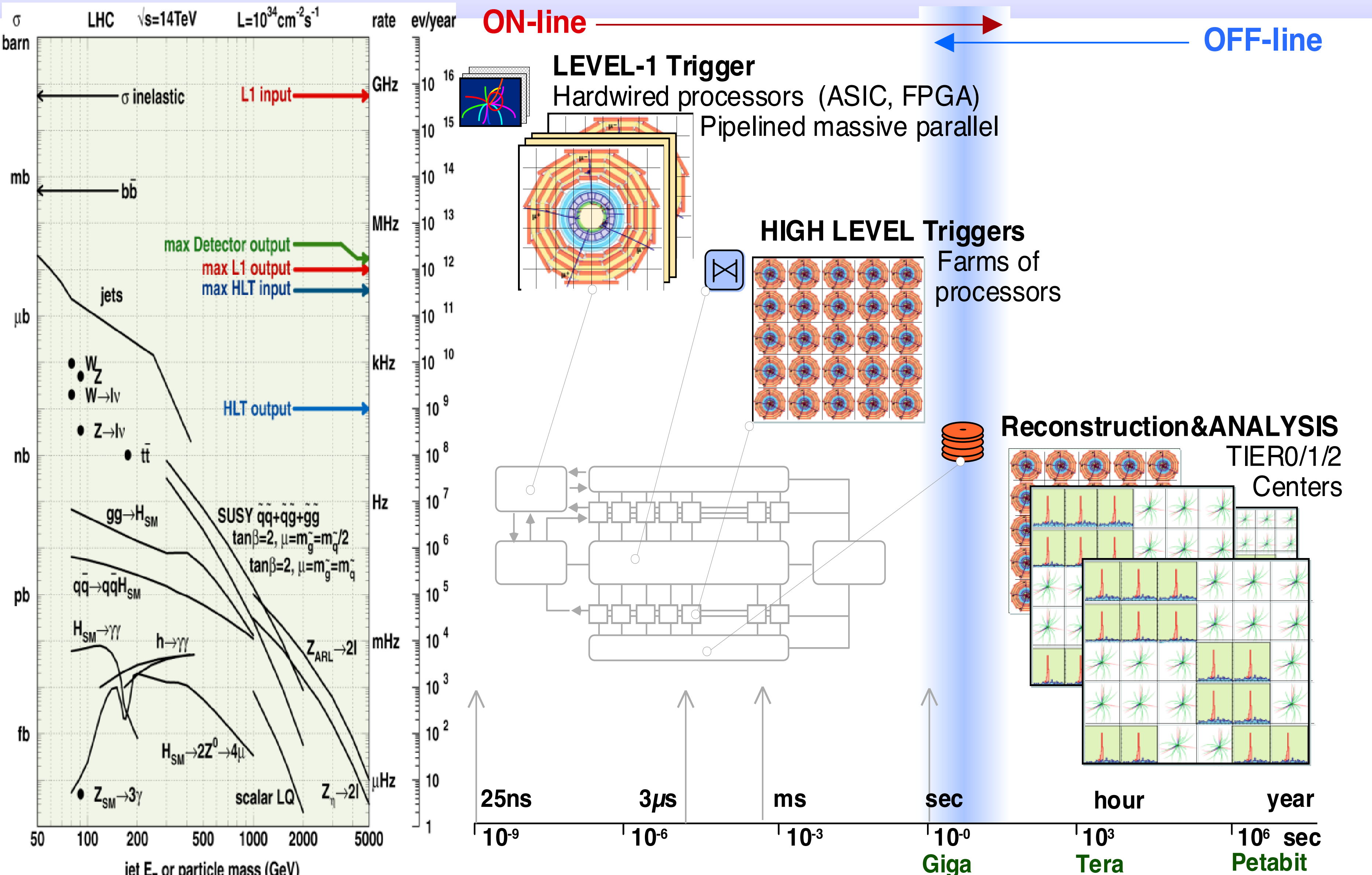


A typical pp collision at the LHC

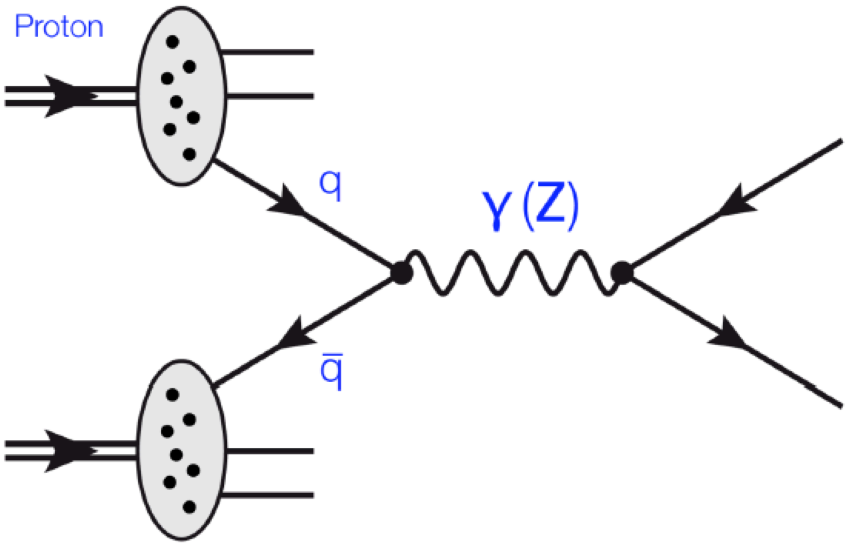


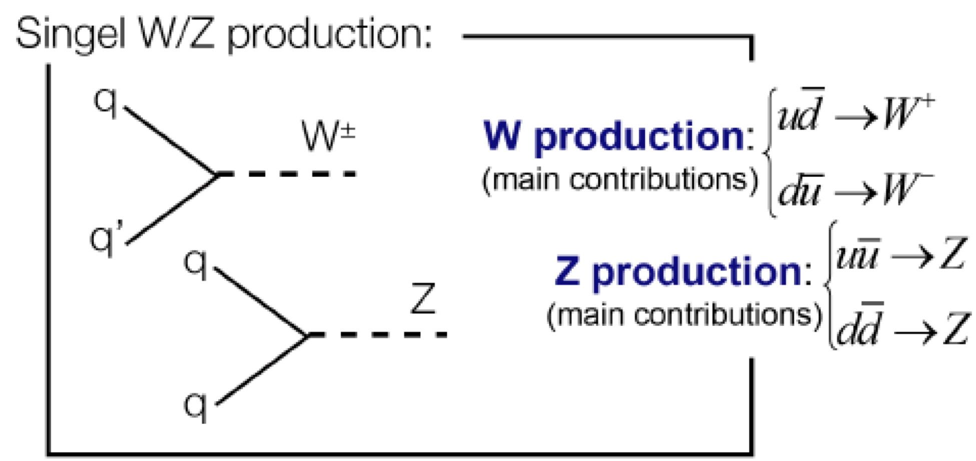
Expected Higgs boson production rate is less than one in a billion pp colisions!

Event selection stages



Drell-Yan process

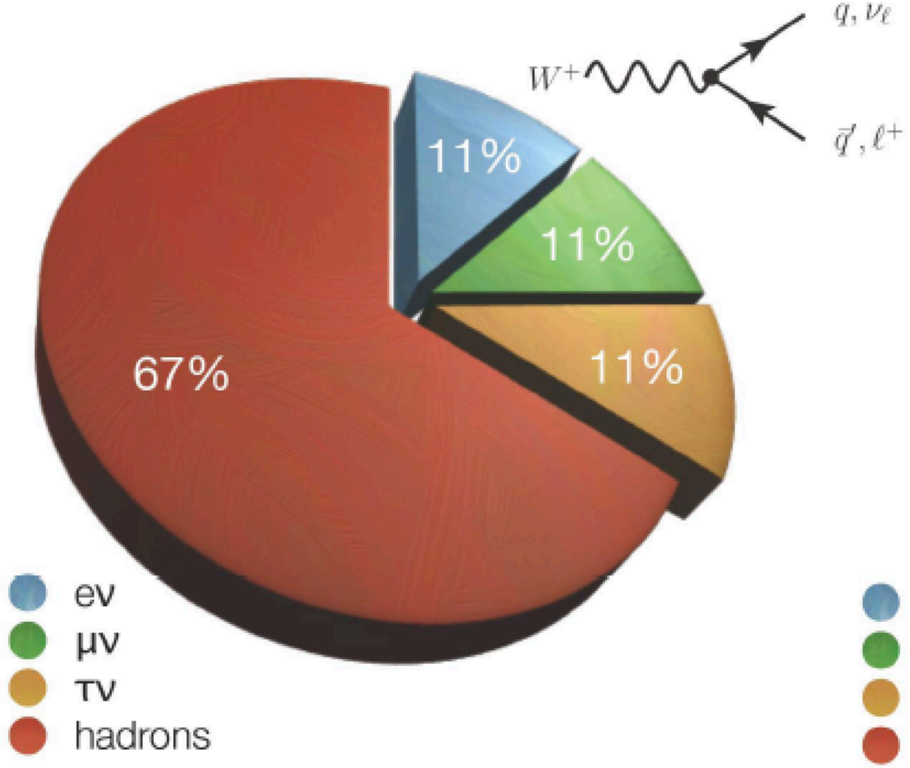


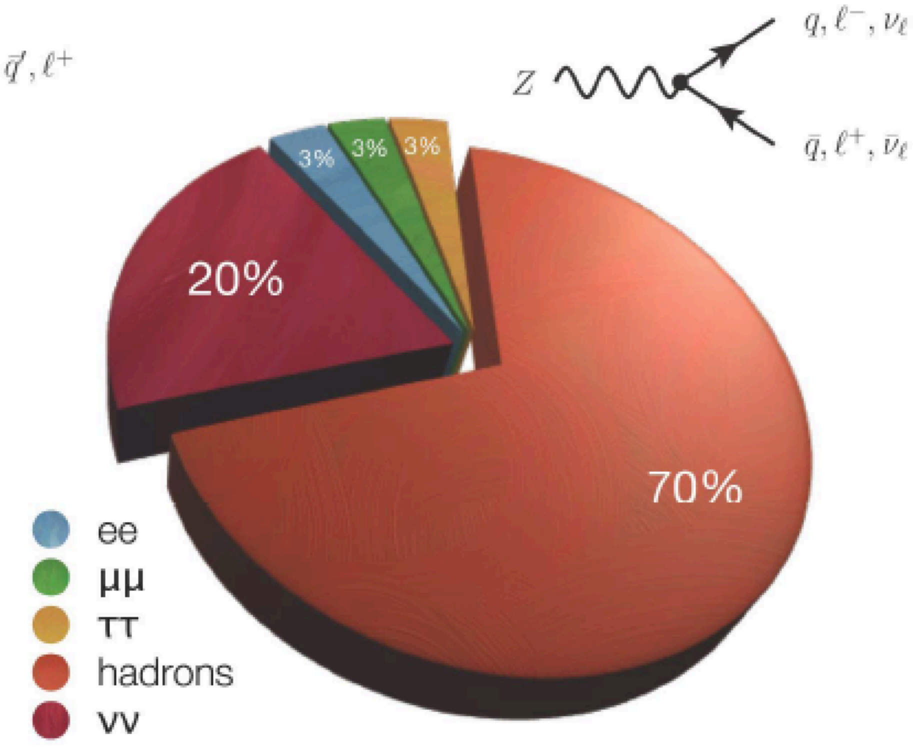


High rate at the LHC

- ✓ provides statistic to study inclusive and differential distributions
- ✓ Good understanding of the detectors allow for precision measurements
- ✓ Test p-QCD and PDF in different regimes
- ✓ Developments and testing of new MC generators and techniques

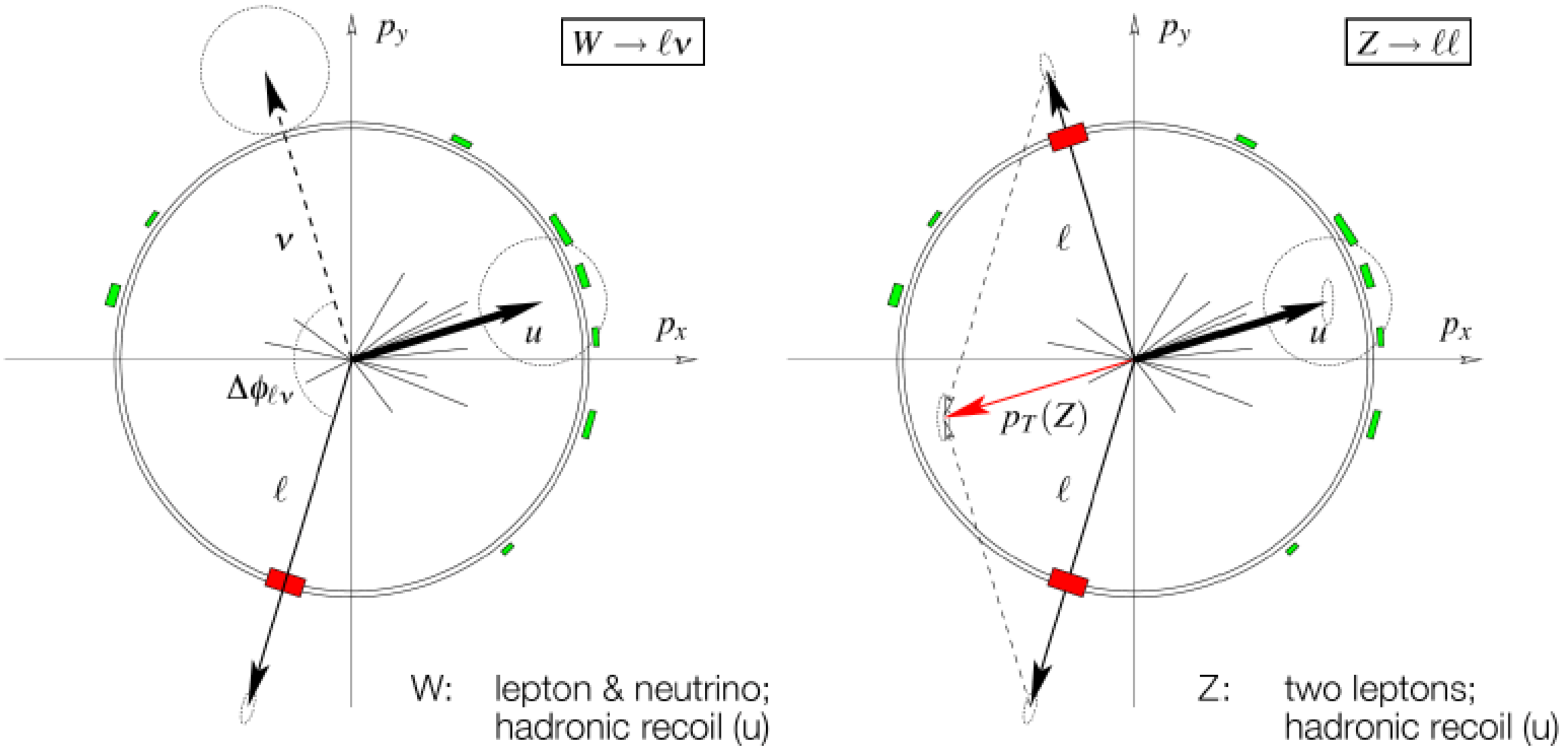
W and Z decay





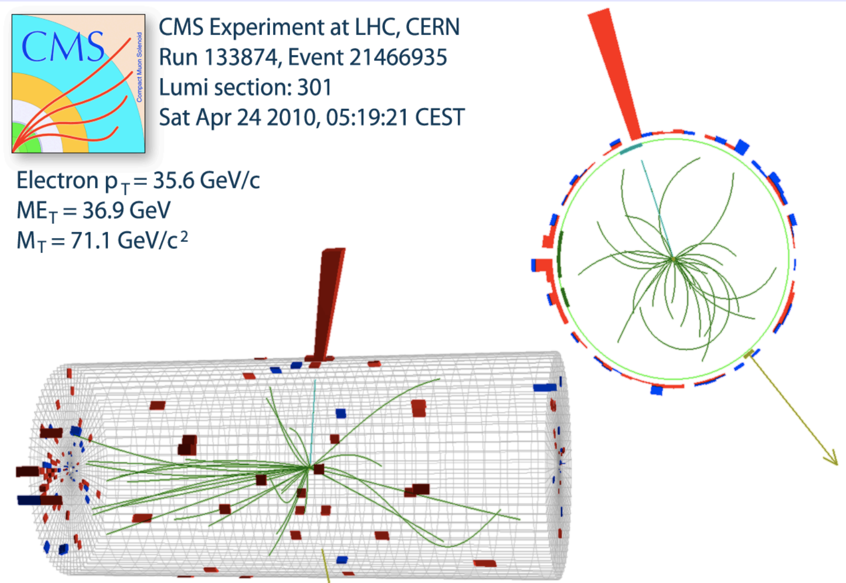
Leptonic decays (e/μ): very clean, but small(ish) branching fractions
Hadronic decays: two-jet final states; large QCD dijet background
Tau decays: somewhere in between…

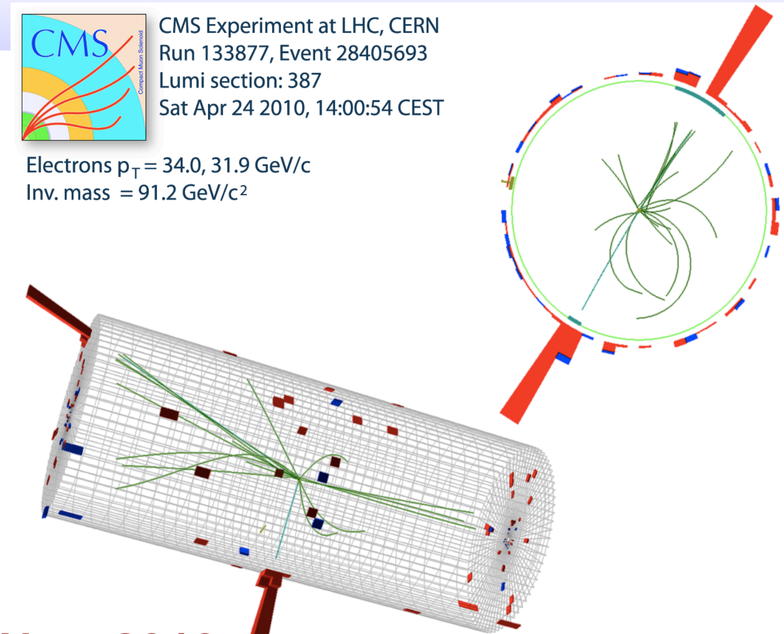
W and Z signatures



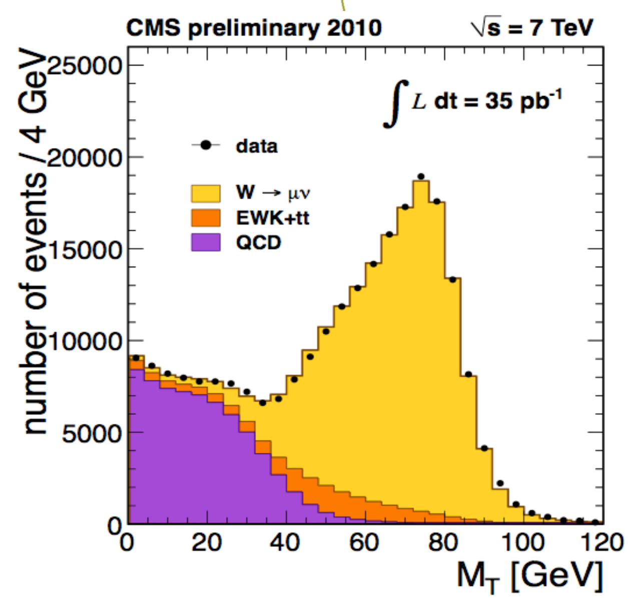
Additional hadronic activity ➤ recoil, not as clean as e^+e^-
Precision measurements: only leptonic decays

First W → eν and Z → e^+e^- events in LHC, April 2010



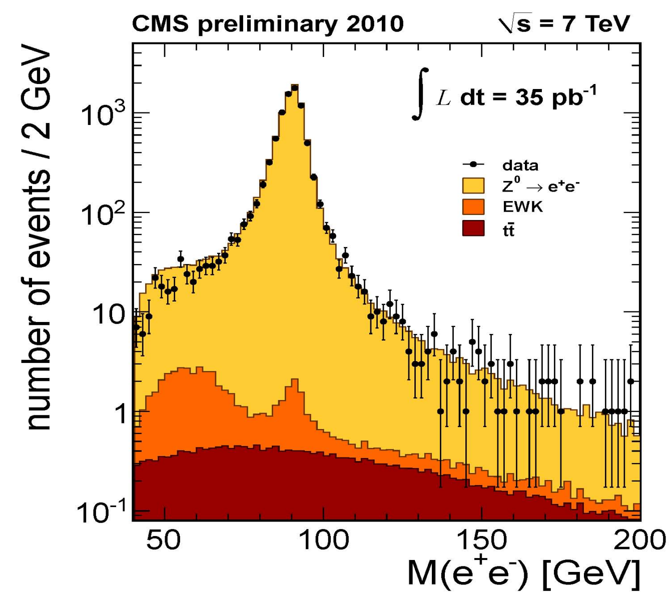


W and Z spectra in CMS, Nov. 2010

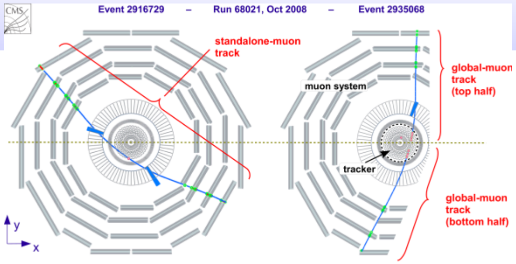


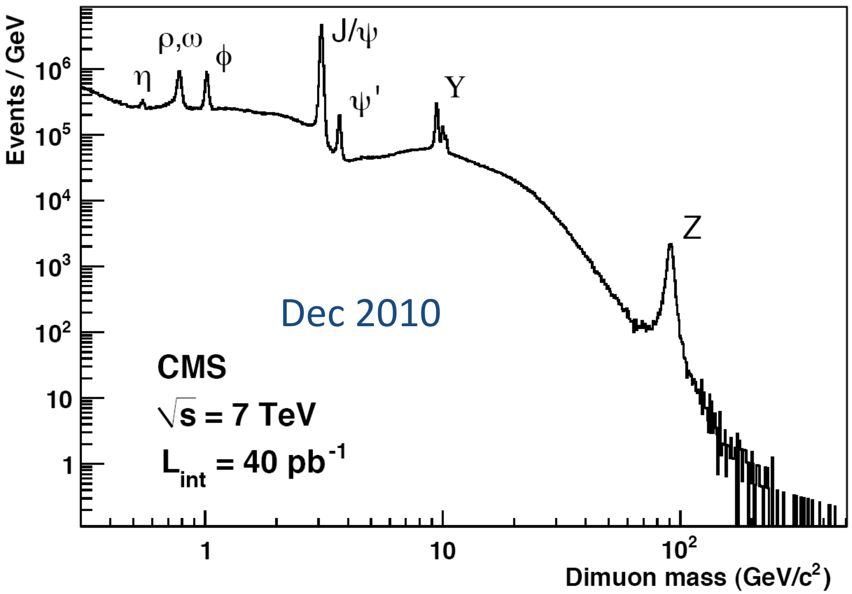
By end-2012 we had ~150.000.000 W and ~15.000.000 Z decaying leptonically!!

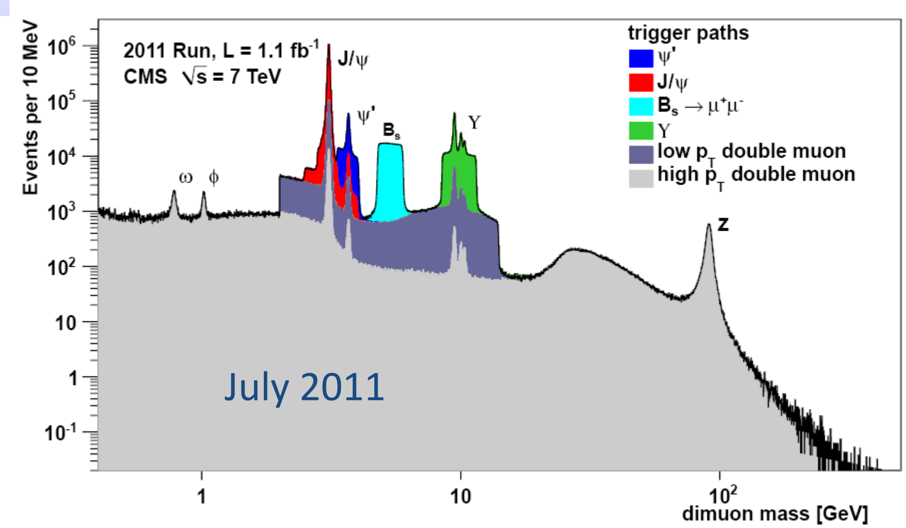
$$M_T = \sqrt{2E_T^{\mu} E_T^{miss}(1-\cos\Delta\phi_{e,miss}}$$

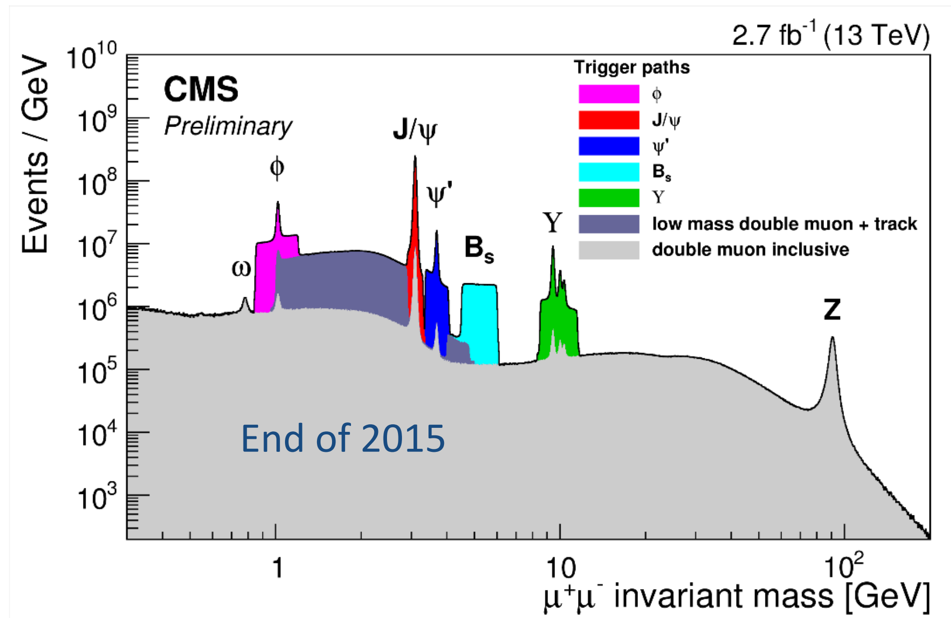


Di-muon resonances







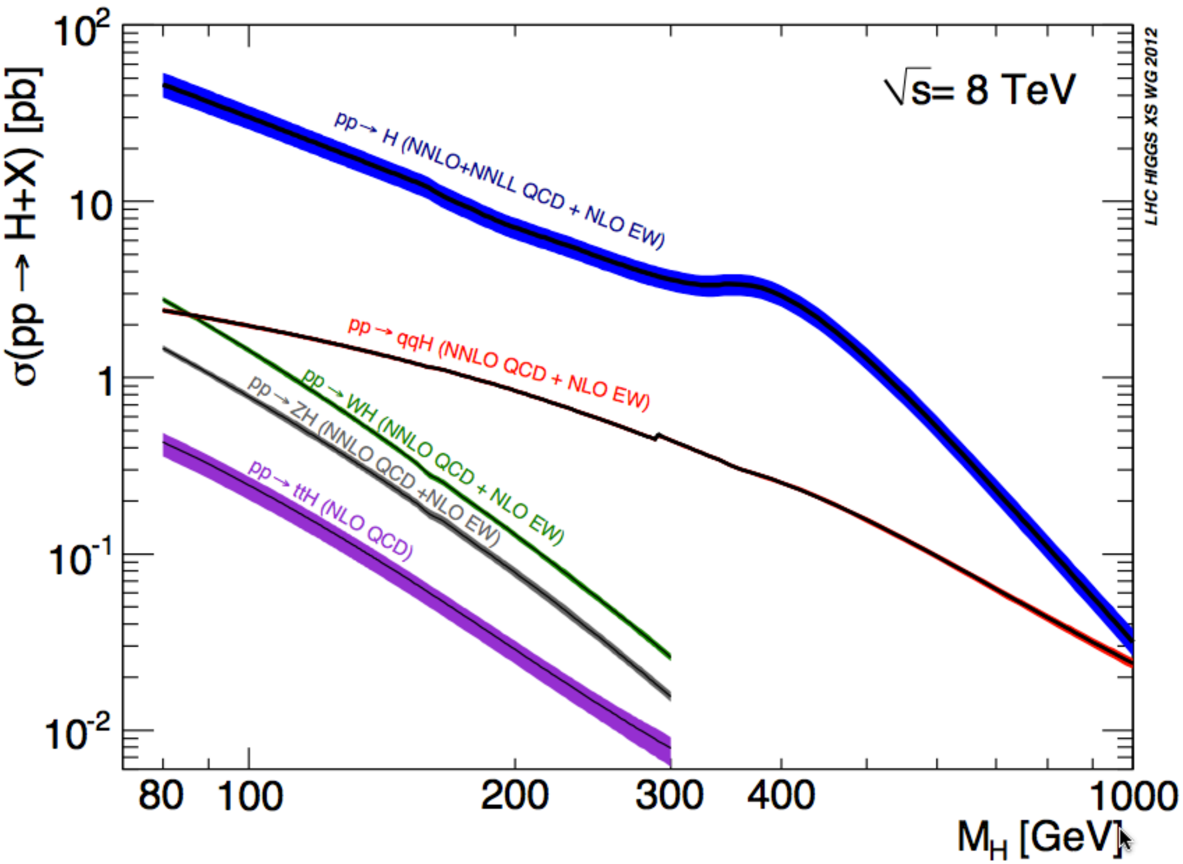


CMS shows a excellent performance to detect different signals

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsMUO

Higgs discovery

SM Higgs production at LHC

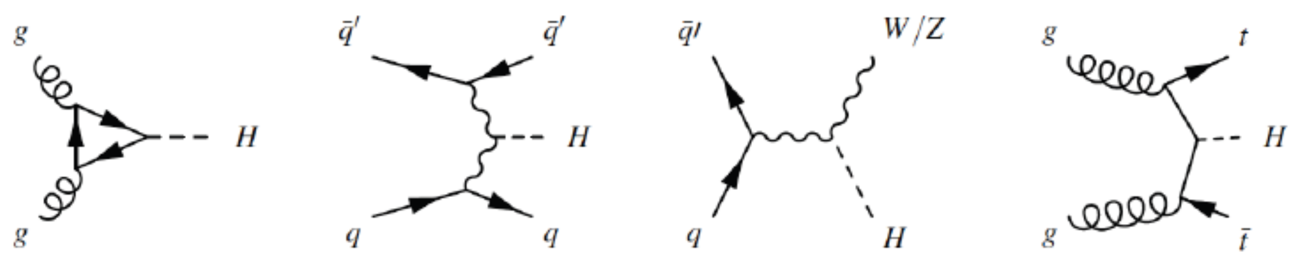


Gluon-gluon fusion:

→ radiative corrections at:

- NLO QCD
- NNLO QCD
- NNLL QCD
- NLO EW

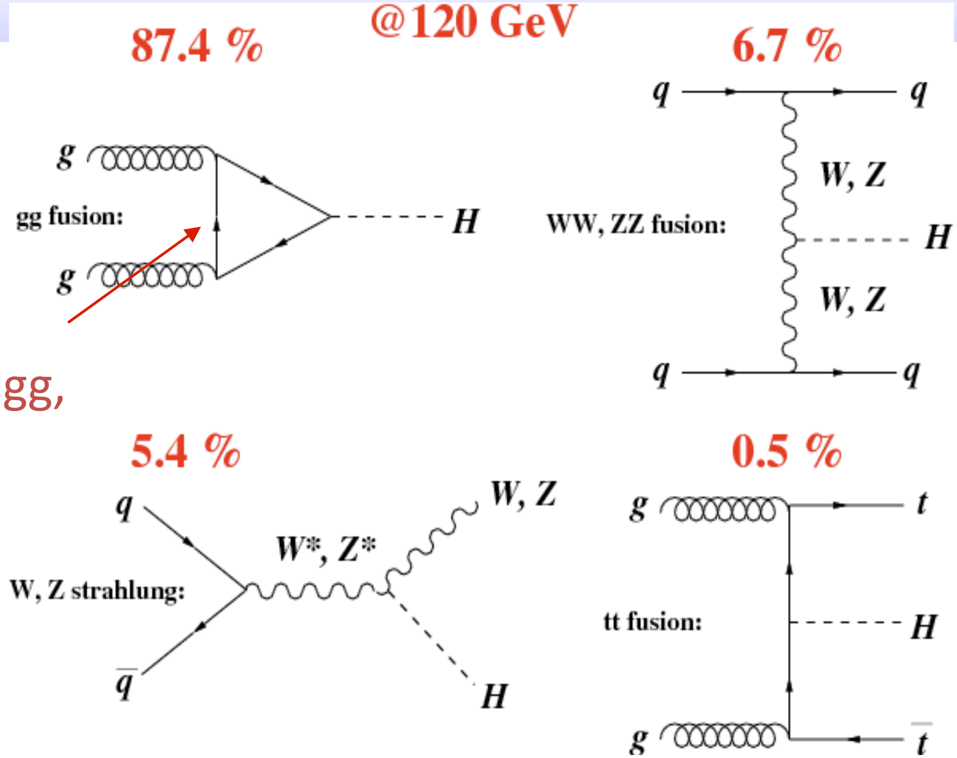
	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+a_s	Total error
ggF	+25% (+100%)	+12% -7%	±8%	+20 -15%
VBF	<1% (+5-10%)	±1%	±4%	±5%
WH/ ZH	+2-6% (+30%)	±1%	±4%	±5%
ttH	- (+5-20%)	+4% -10%	±8%	+12 -18%



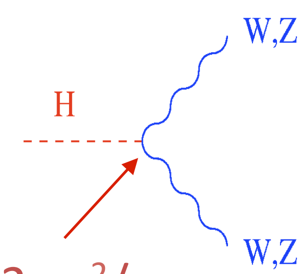
(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

LHC Higgs Xsection WG

Higgs production mechanisms and decay modes

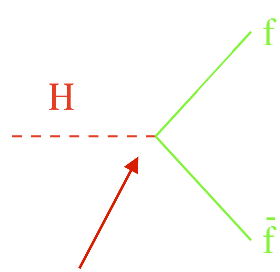


indirect coupling to gg,
top in the loop

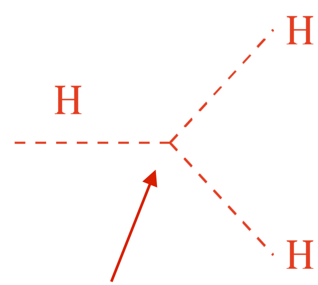


$g_{HVV} = 2m_V^2/v$

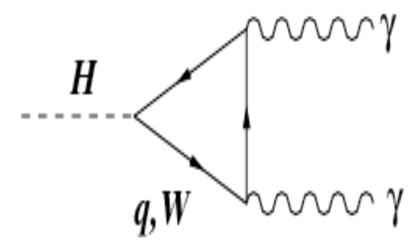
$g_{HWW} = g\ m_W$



$g_{Hff} = m_f/v$

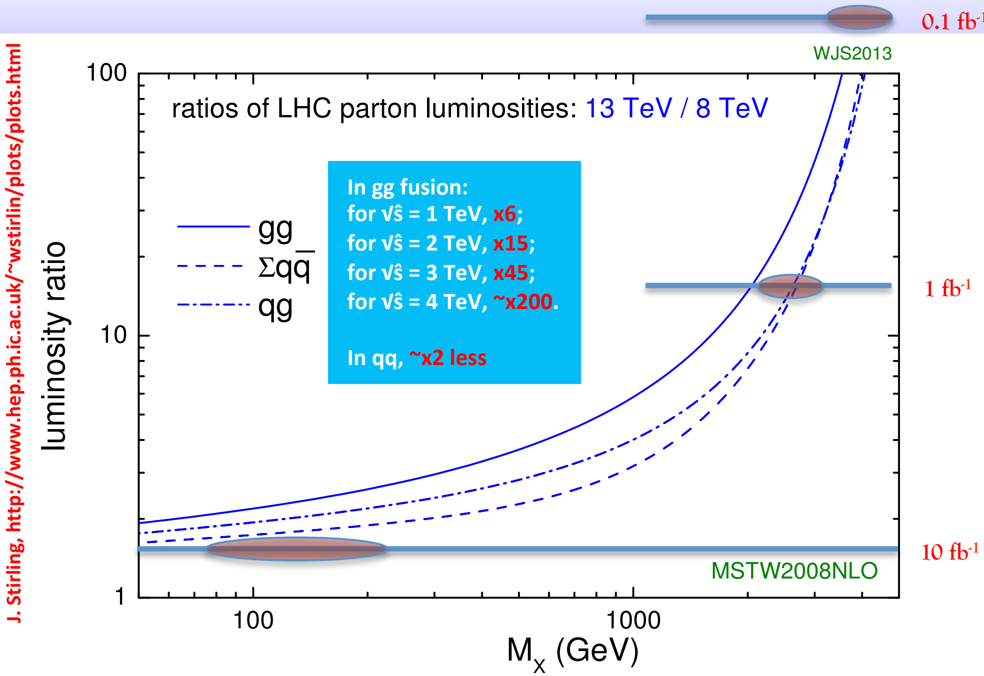


$g_{HHH} = 3m_H^2/v$

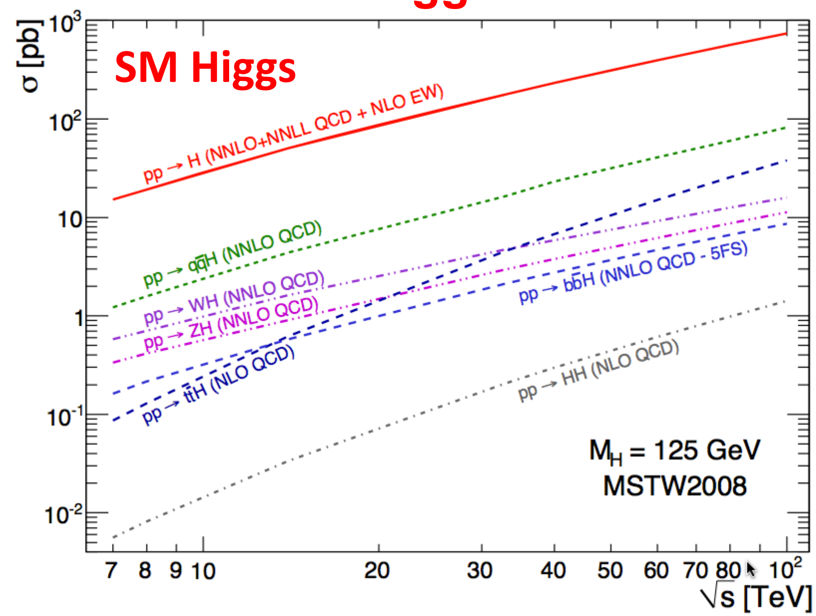


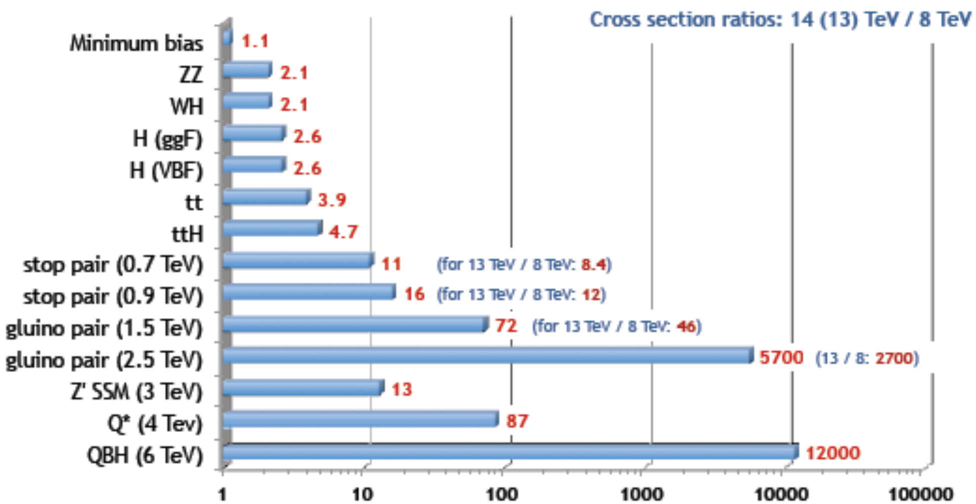
indirect coupling to $\gamma\gamma$

8 TeV → 13 TeV: What does it change ?



LHC Higgs Xsection WG

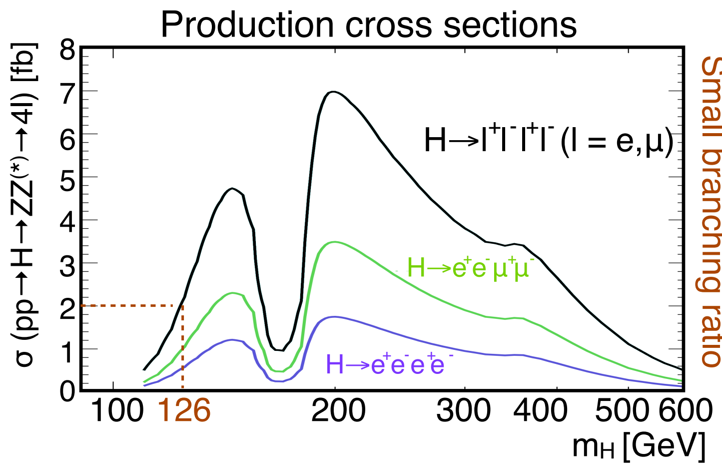




- SM Higgs is light, so the gluon fusion cross section doesn't get that much boost (x2, 19.1 → 43.6 pb)
- **Background cross sections increase too**

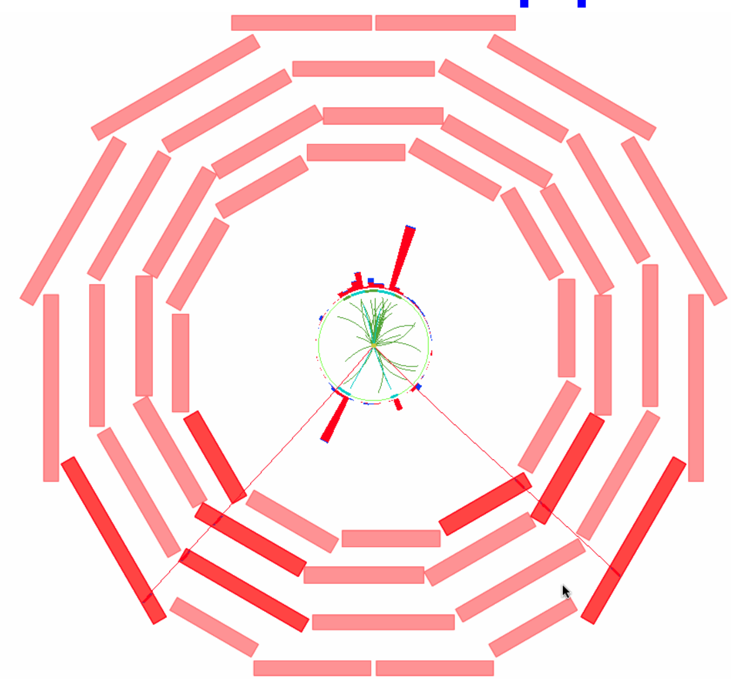
H→ZZ→4l in a nutshell

- Signatures: **4e, 4μ and 2e2μ** final state
  - clean but extremely demanding channel for requiring the **highest possible efficiencies (lepton Reco/ID/Isolation)**.
  - s x BR small ≈ few fb

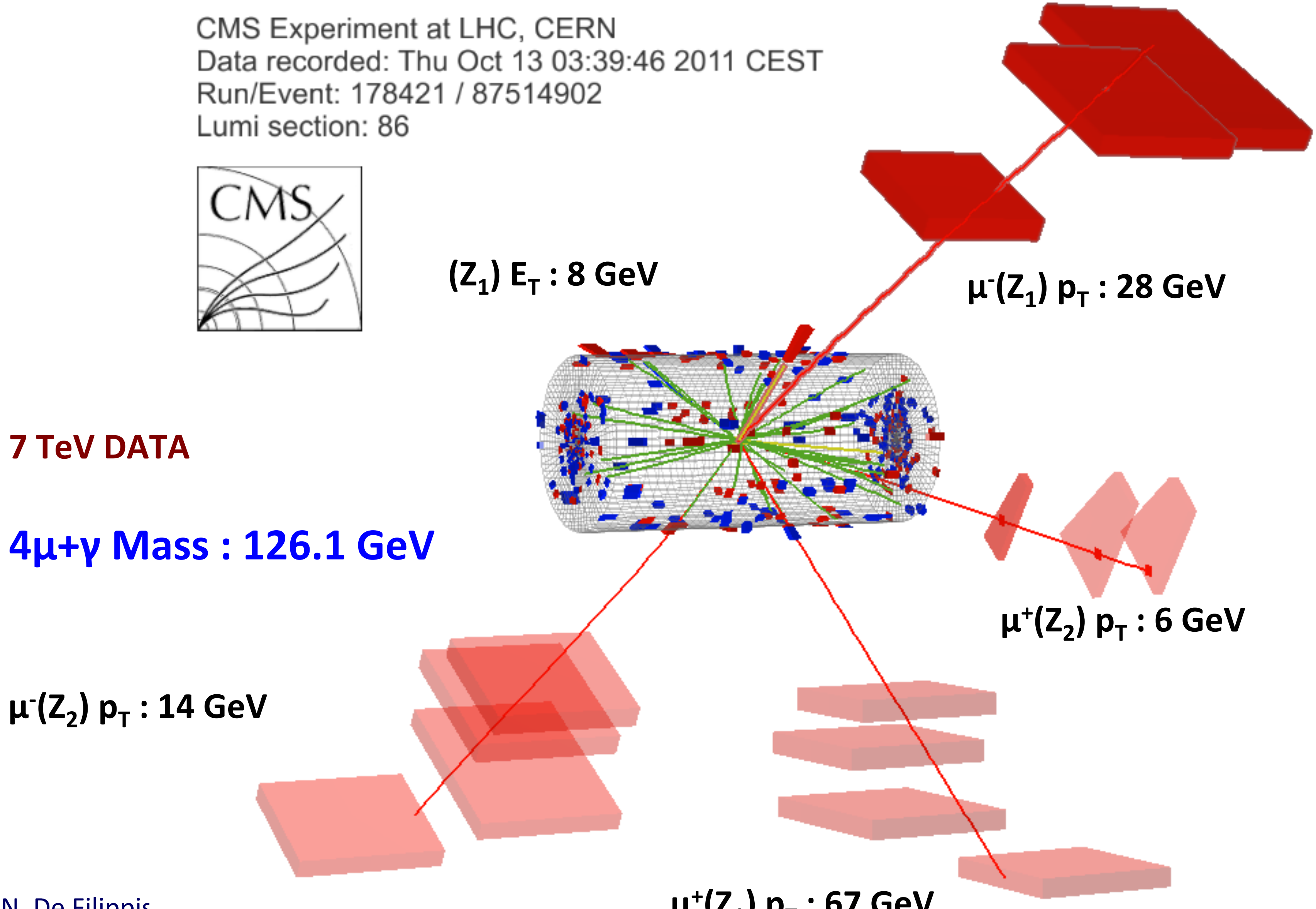


- Backgrounds:
  - Irreducible: ZZ*
  - Reducible: Zbb, tt+jets, Z+light jets, WZ+jets

H → ZZ* → e+e-μ+μ-

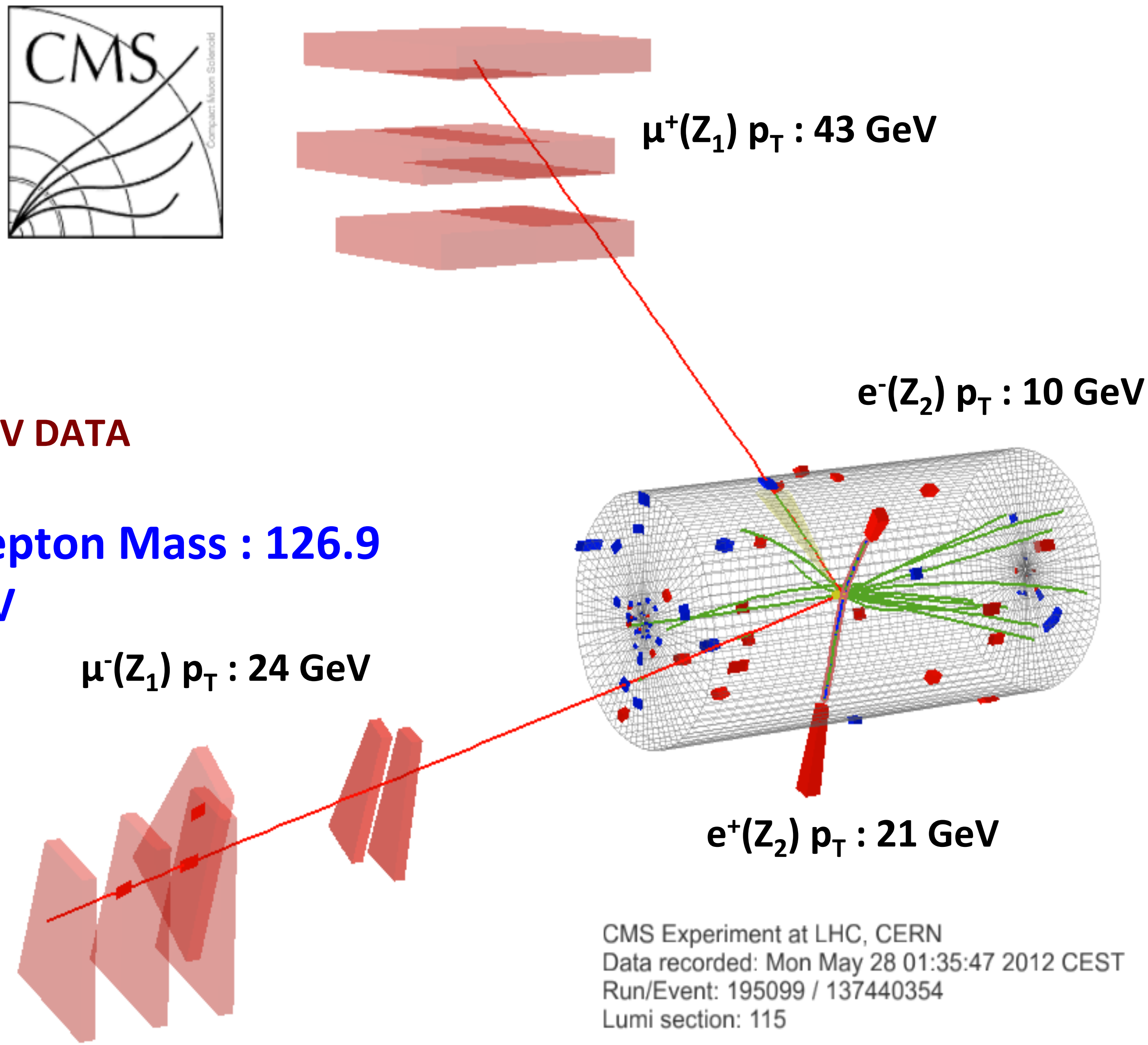


- Sensitivity: 115 < m_H < **1000** GeV
- Selection strategy:
  - triggering on double leptons
  - applying reco, id and isolation of leptons
  - recovery of FSR photons
  - use of impact parameter
  - m_Z and m_{Z*} constraint
  - kinematical discriminant / scalarity of the Higg

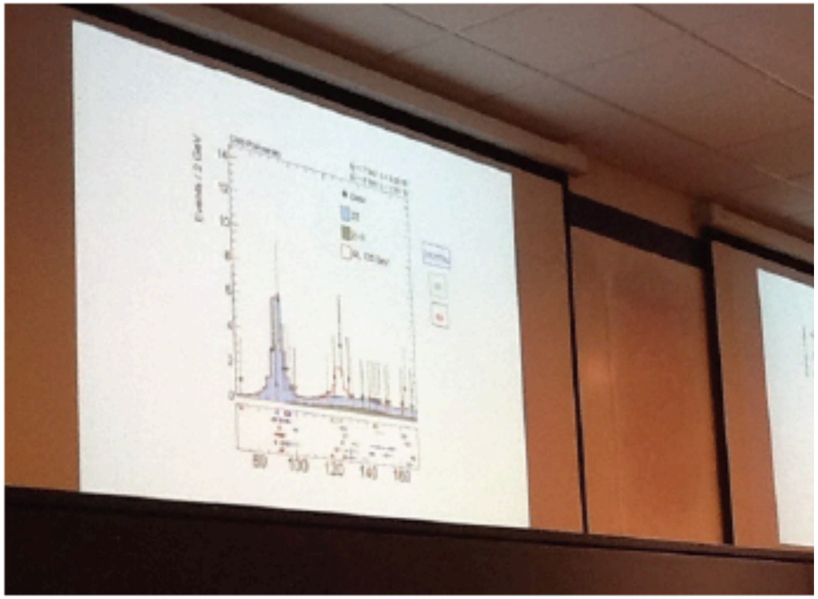

CMS Experiment at LHC, CERN
Data recorded: Thu Oct 13 03:39:46 2011 CEST
Run/Event: 178421 / 87514902
Lumi section: 86
CMS
(Z_1) E_T : 8 GeV
$\mu^-(Z_1)$ p_T : 28 GeV
7 TeV DATA
4μ+γ Mass : 126.1 GeV
$\mu^+(Z_2)$ p_T : 6 GeV
$\mu^-(Z_2)$ p_T : 14 GeV
$\mu^+(Z_1)$ p_T : 67 GeV

8 TeV DATA

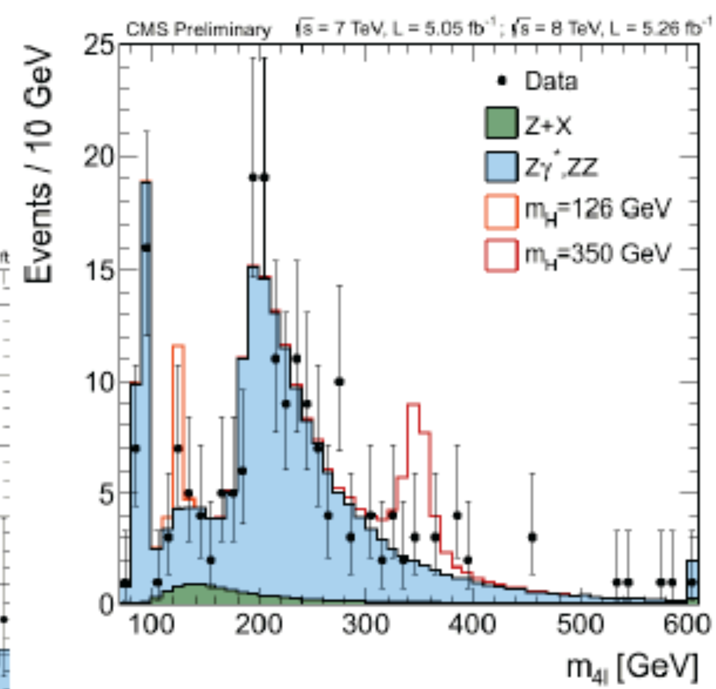
4-lepton Mass : 126.9 GeV

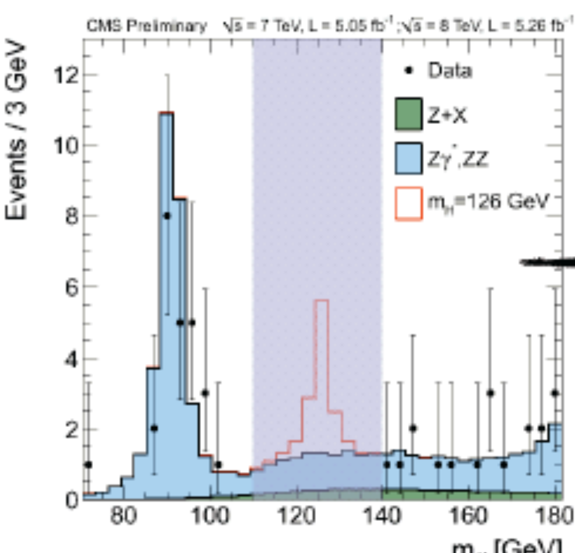


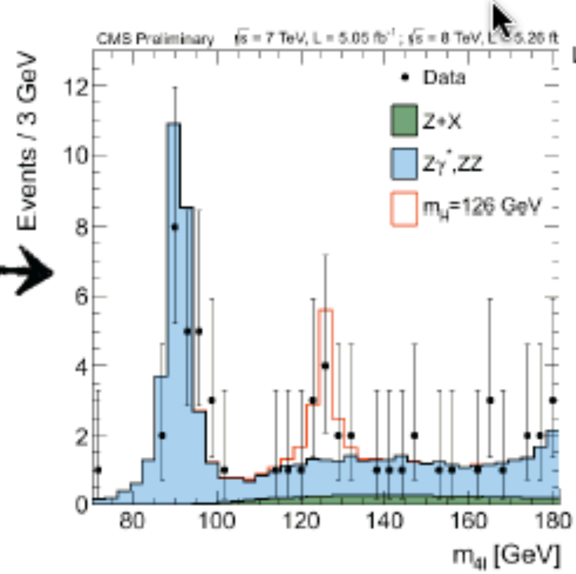
June 2012:



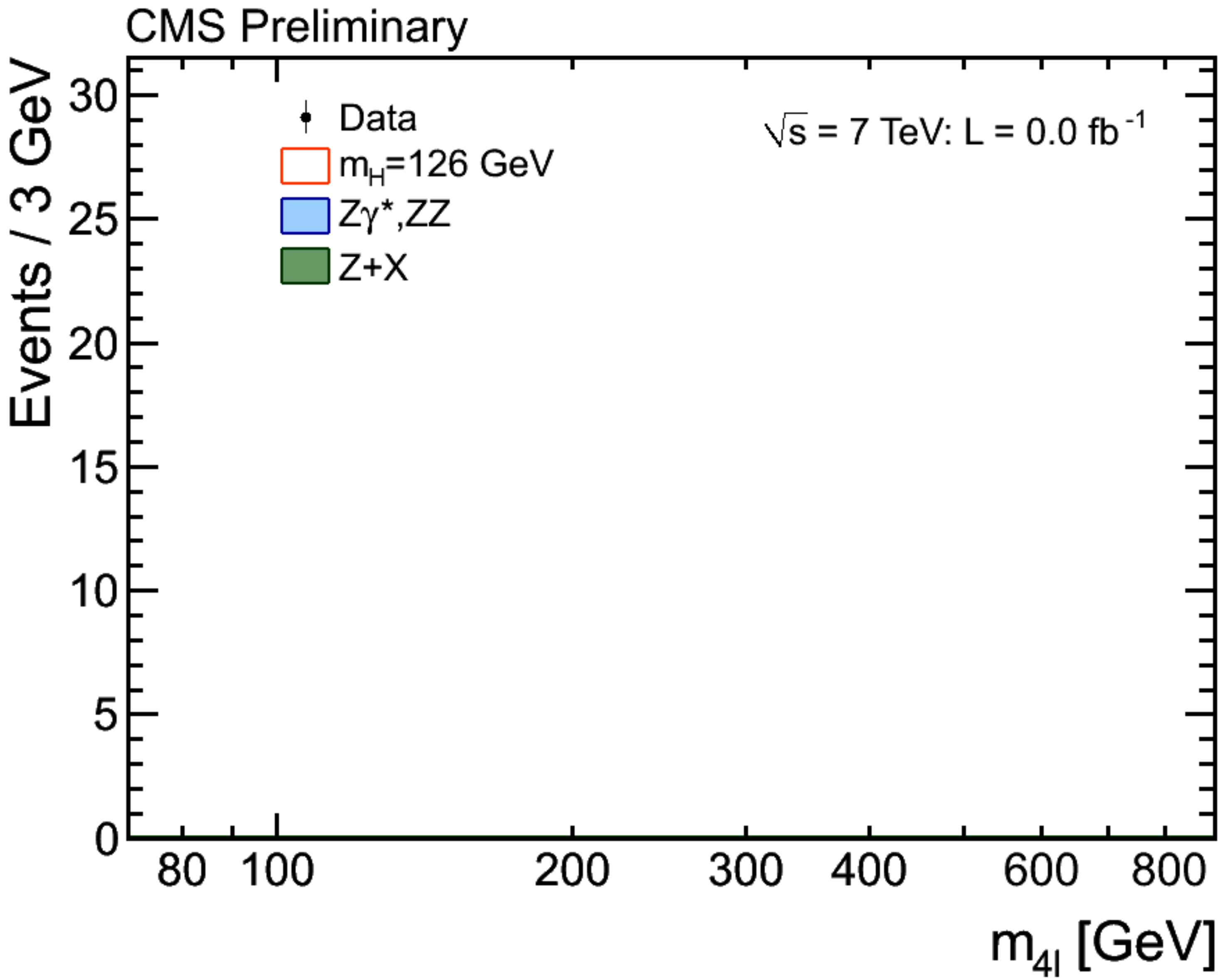
14/6/2012: Approval of **H→ZZ→4l** analysis



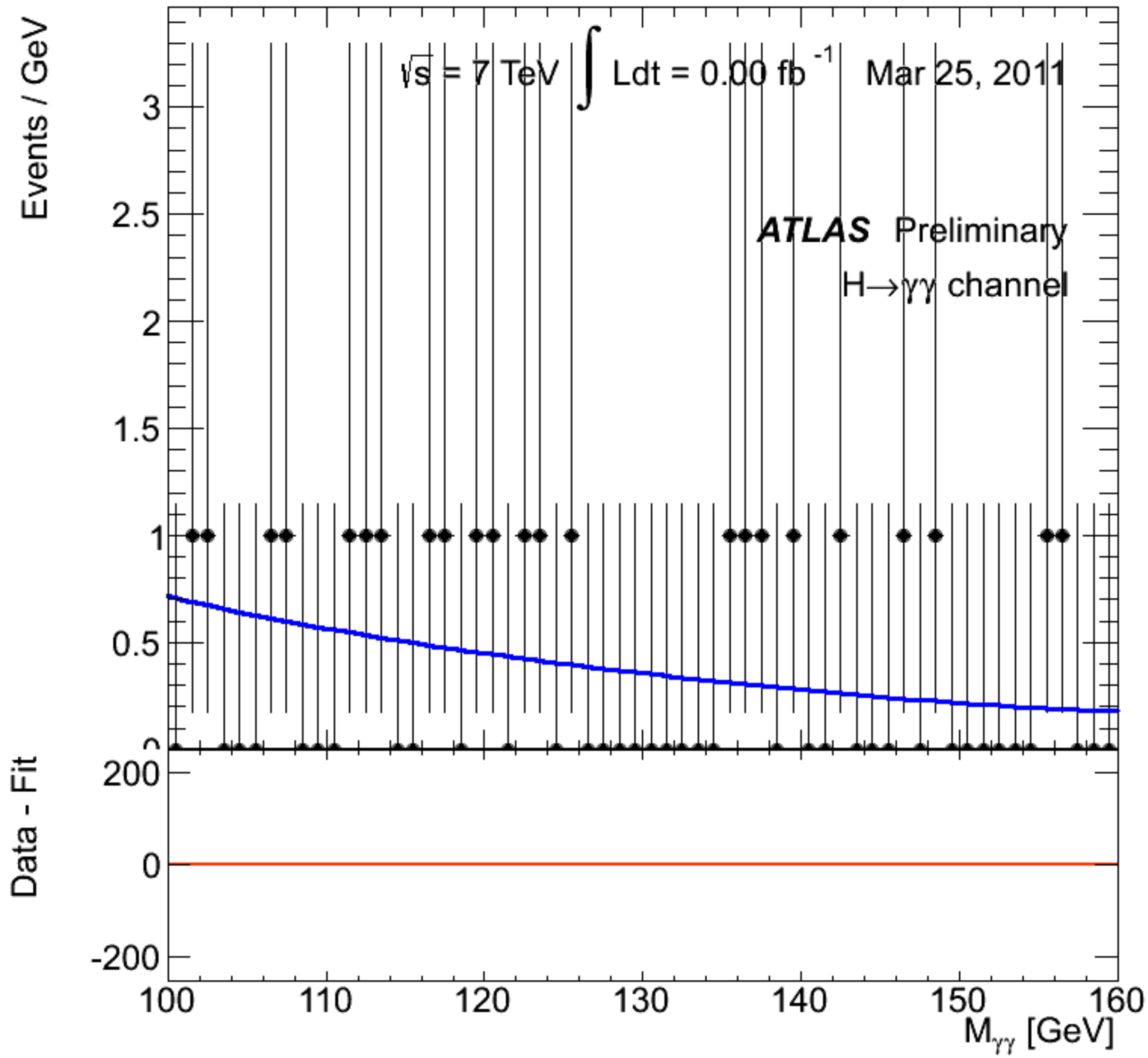




4-lepton mass: H→ZZ→4l, July 4 2012



Di-photon mass: H→γγ, July 4 2012



October 8 2013: Nobel prize

Nobel Prizes and Laureates

Physics Prizes 2013

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- Advanced Information
- Popular Information
- Greetings

▶ François Englert

▶ Peter Higgs

All Nobel Prizes in Physics

All Nobel Prizes in 2013

The Nobel Prize in Physics 2013

François Englert, Peter Higgs

The Nobel Prize in Physics 2013

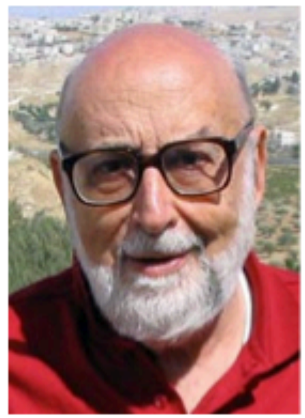

Photo: Pnicolet via Wikimedia Commons

François Englert

Photo: G-M Greuel via Wikimedia Commons

Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. 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"*