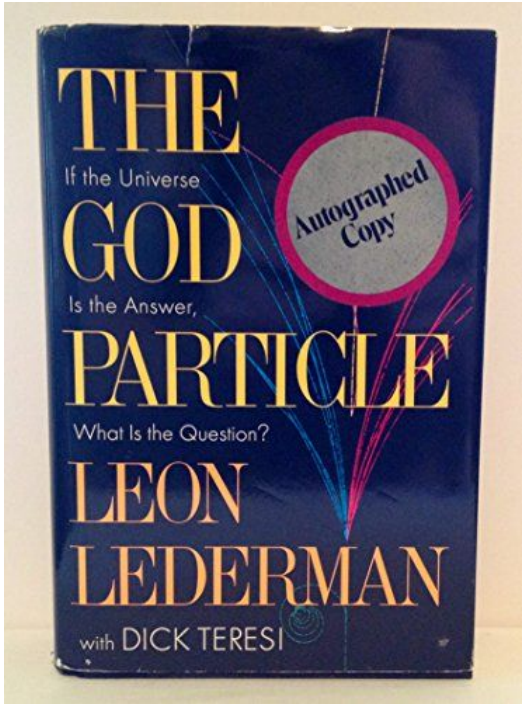
All about the Higgs

Dr. Dominik Duda

04-12-2025

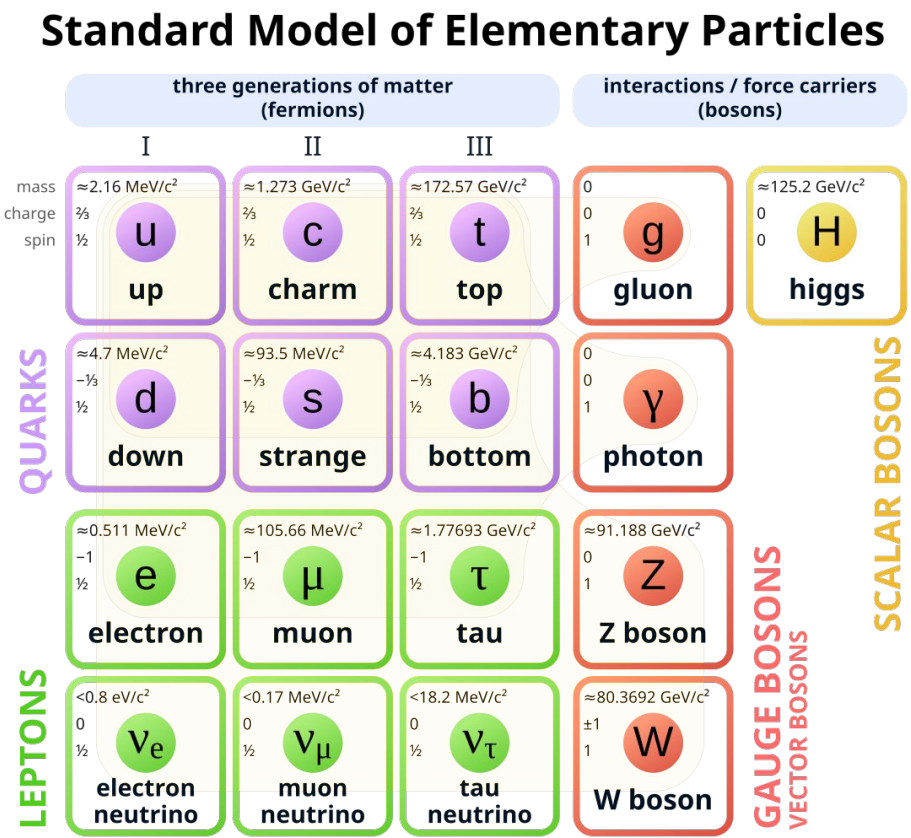
What is the Higgs Boson and why do we care ?

A God Particle ?!?



This boson is so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive, that I have given it a nickname: the God Particle. Why God Particle? Two reasons. One, the publisher wouldn't let us call it the Goddamn Particle, though that might be a more appropriate title, given its villainous nature and the expense it is causing. And two, there is a connection, of sorts, to another book, a *much* older one...

Particle Content of the Standard Model



The Standard Model of Particle Physics

$$\mathcal{L}_{SM} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$
$$+ i\bar{\psi} \not{D} \psi + h.c.$$
$$+ \psi_i y_{ij} \psi_j \phi + h.c.$$
$$+ |D_\mu \phi|^2 - V(\phi)$$

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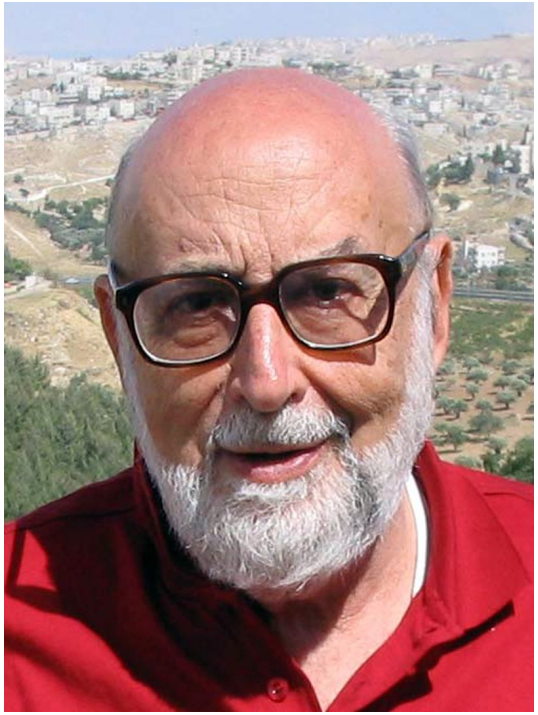
Introduced in 1964

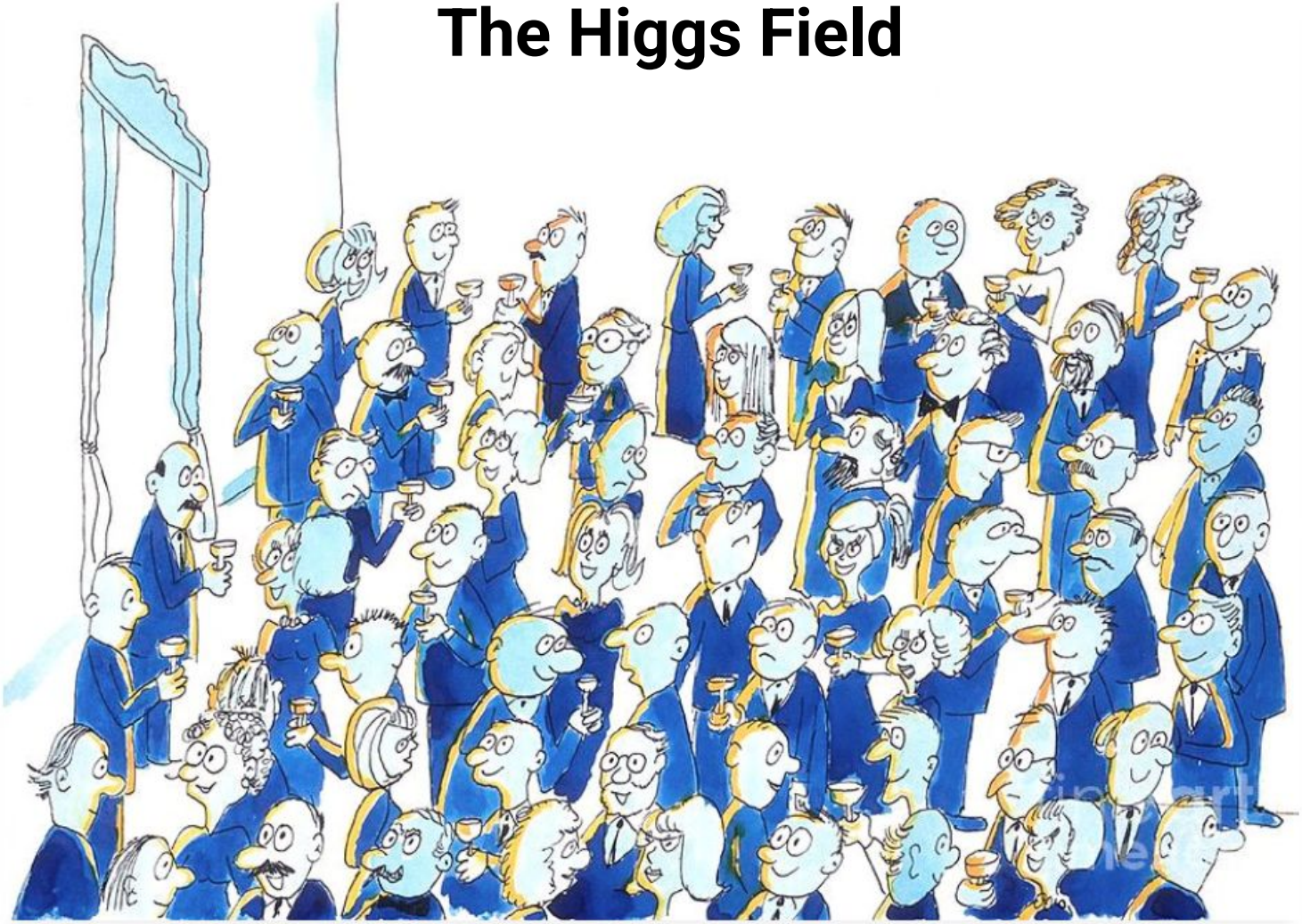
Brout-Englert-Higgs Mechanism

Peter Higgs

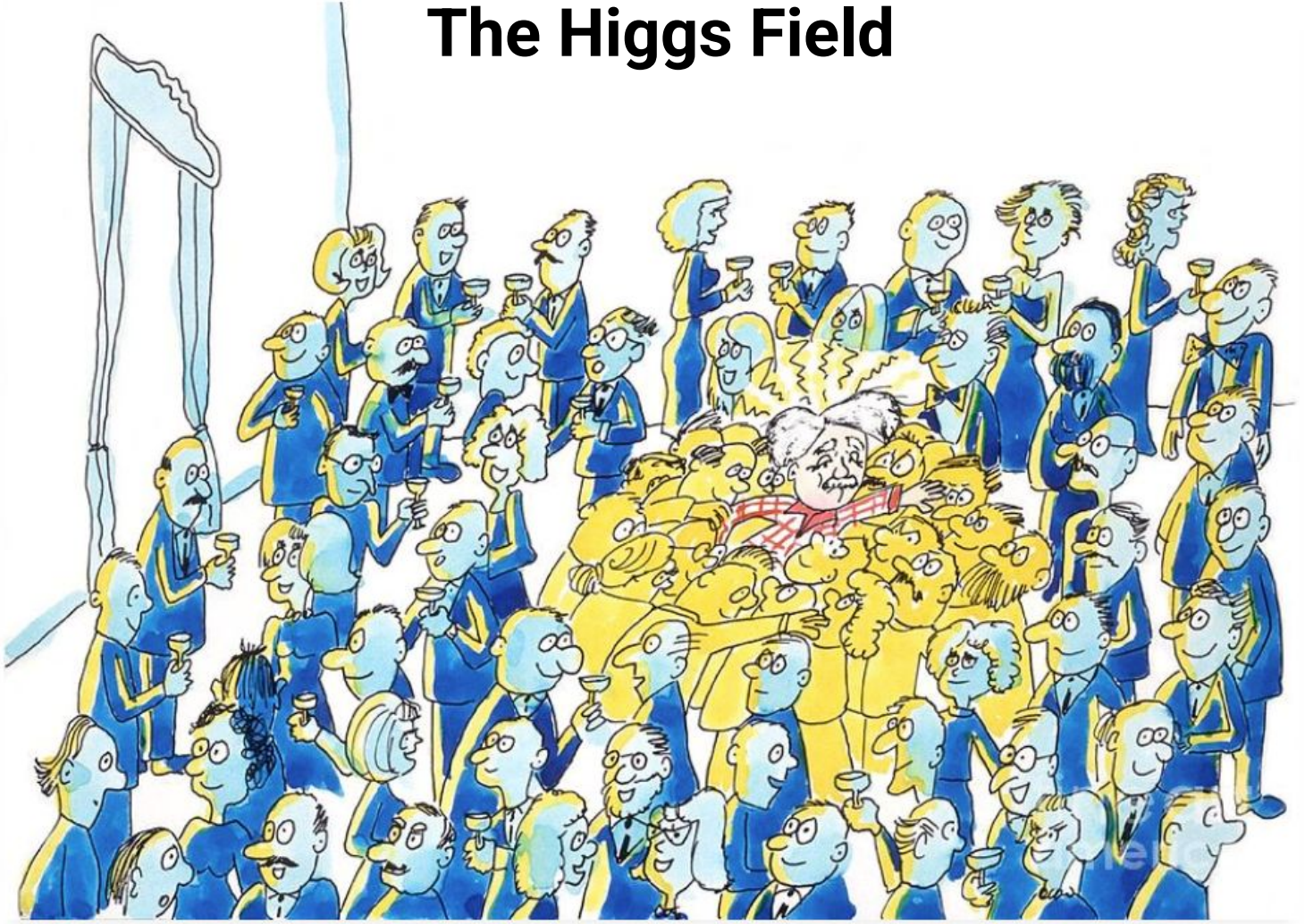


François Englert

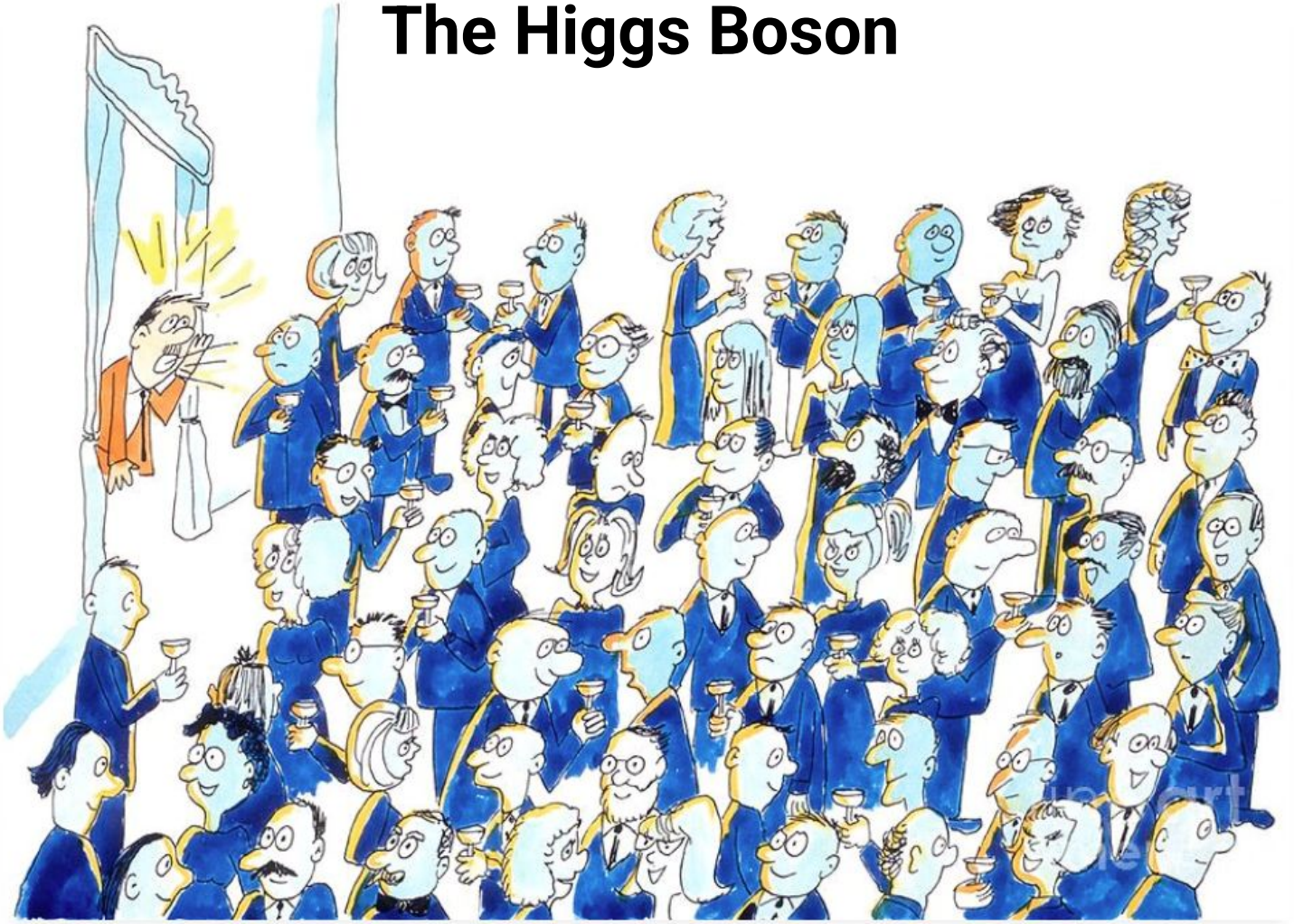
The Higgs Field



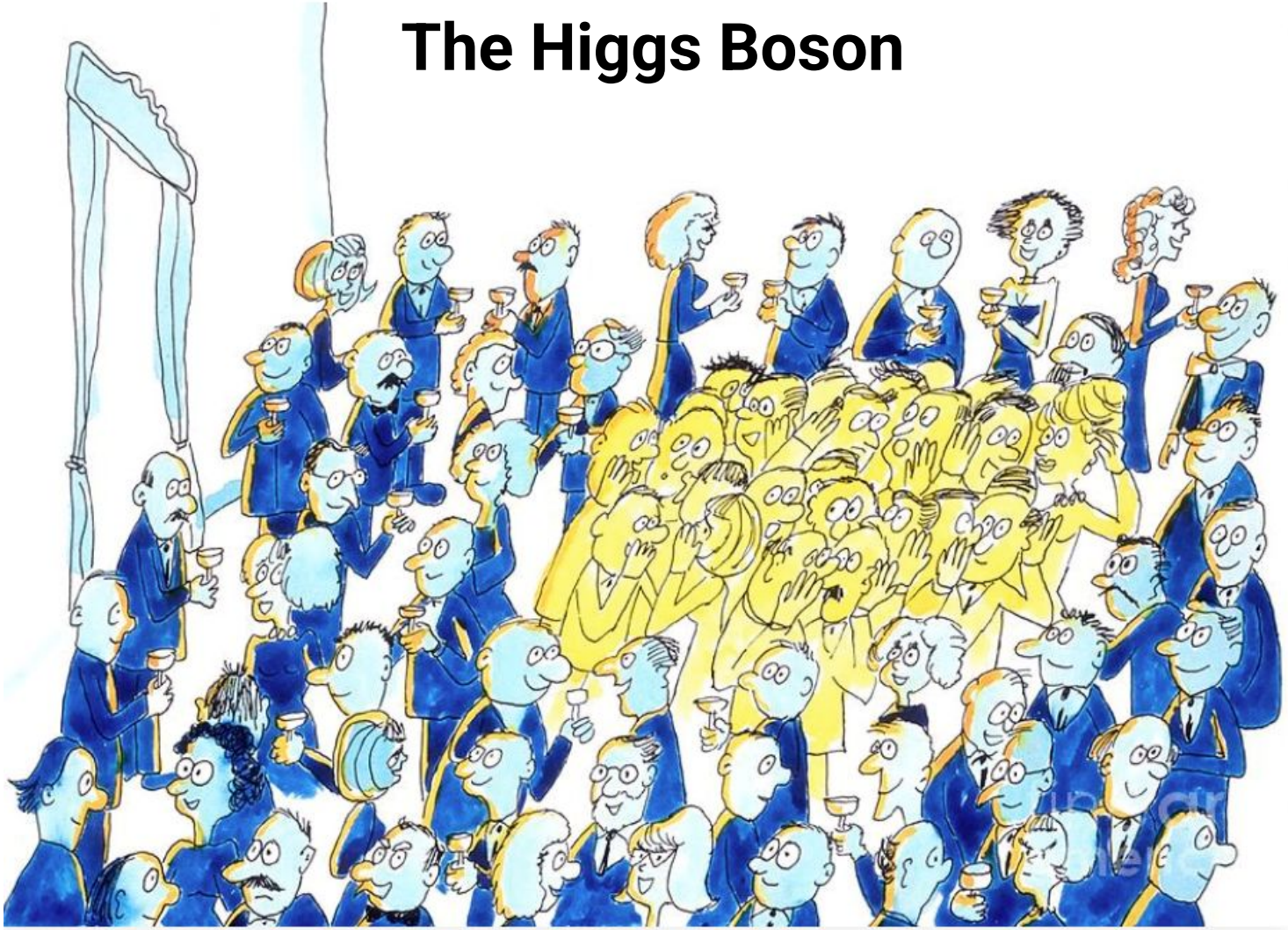
The Higgs Field



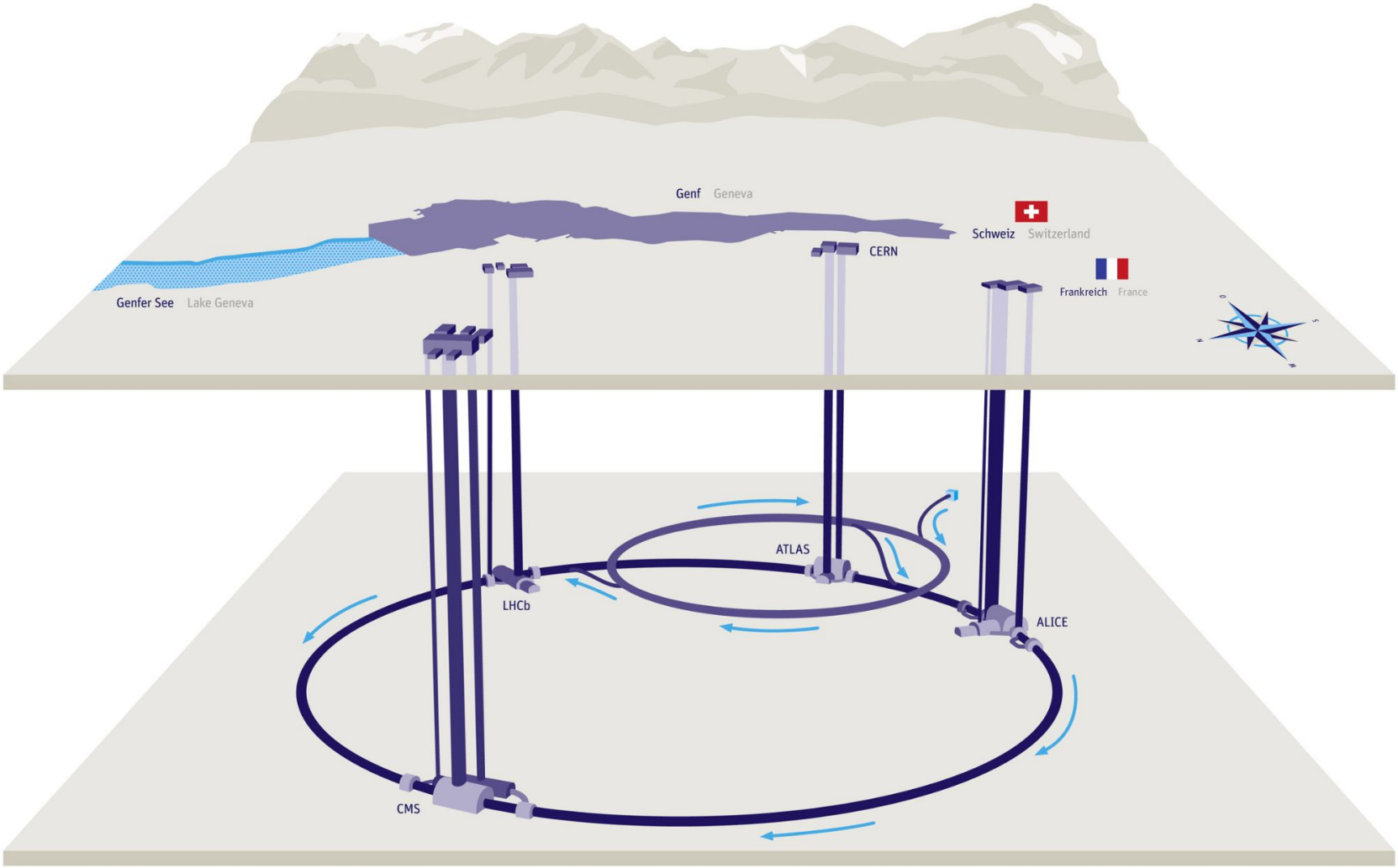
The Higgs Boson



The Higgs Boson

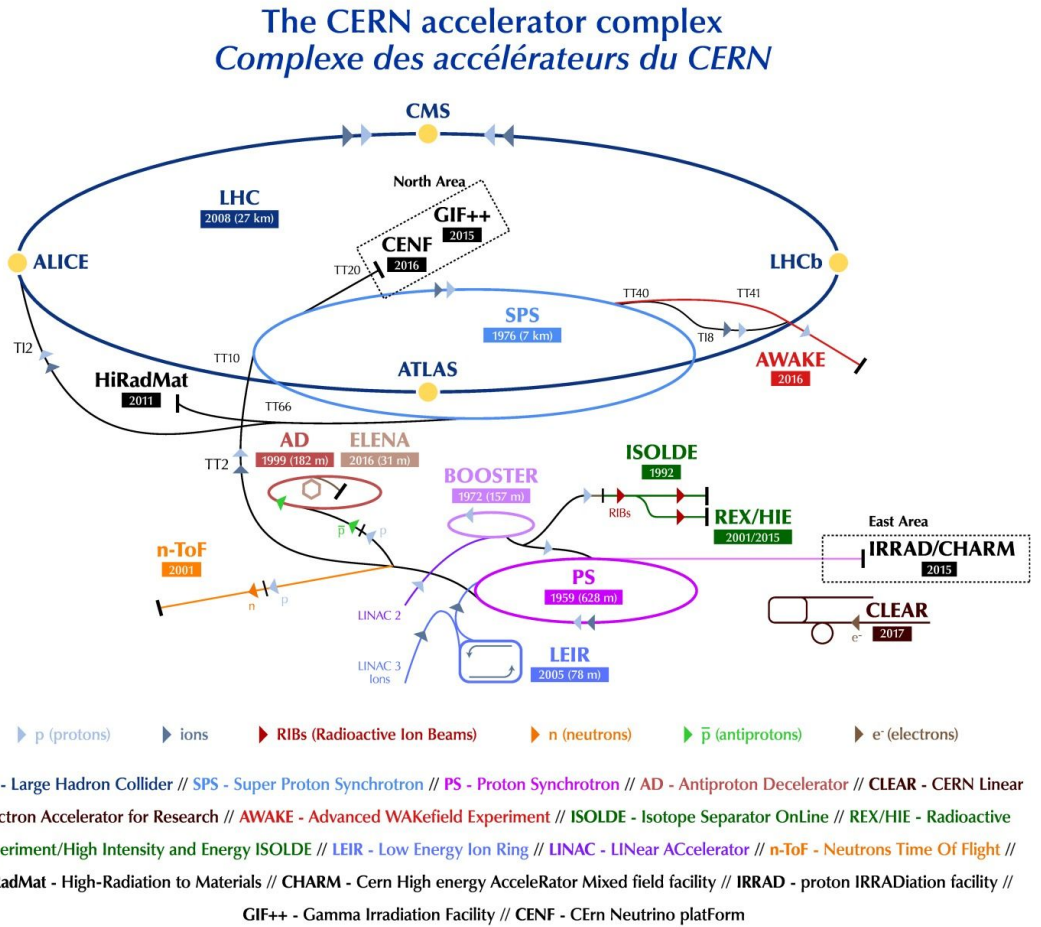


How we found the Higgs Boson


Genf Geneva
Schweiz Switzerland
CERN
Frankreich France
Genfer See Lake Geneva
ATLAS
LHCb
ALICE
CMS

Velocity of Protons: 99.999999% of speed of light

11000 cycles per second



LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n-ToF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // CHARM - Cern High energy AcceleRator Mixed field facility // IRRAD - proton IRRADiation facility // GIF++ - Gamma Irradiation Facility // CENF - CErn Neutrino platForm

Where do the protons come from ?

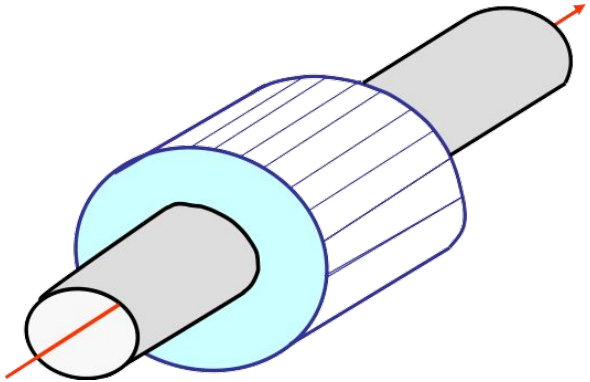
Proton source of the LHC

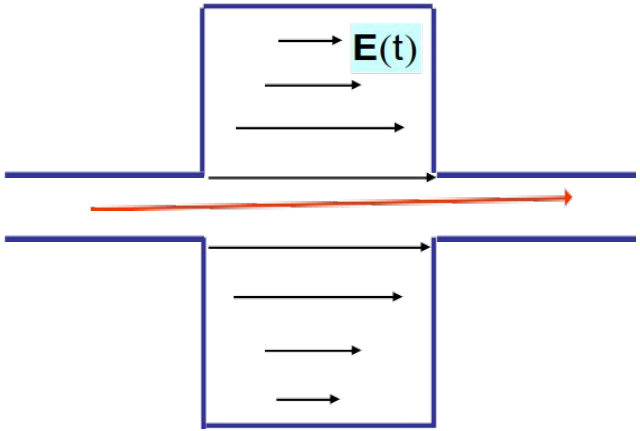
Taken from: http://cdsweb.cern.ch/record/1157734#04


LHC

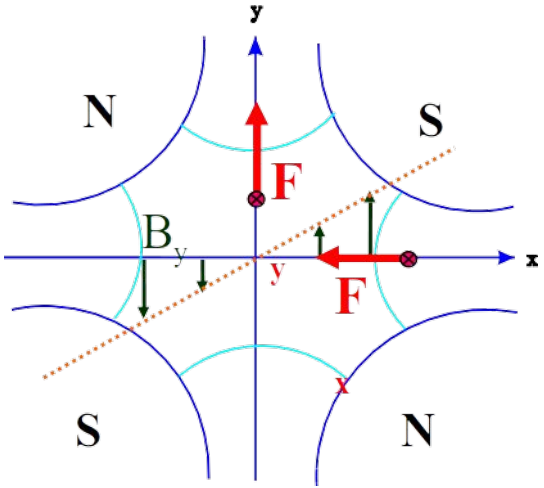
Acceleration

- At the LHC. radiofrequency (RF) cavities are used to accelerate particles:
  - RF cavities are basically resonators tuned to a selected frequency.
  - Charged particles injected into the electromagnetic field of these cavities receive an electrical impulse that accelerates them.
  - To accelerate a proton to 7 TeV, a 7 TV potential must be provided to the beam:
    - In circular accelerators the acceleration is done in small steps, turn after turn.
    - At the LHC the **acceleration** from 450 GeV to 7 TeV lasts ~20 minutes, with **an average energy gain of** ~0.5 MeV on each turn.

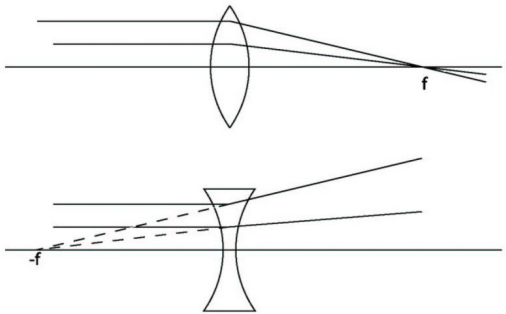




Magnets

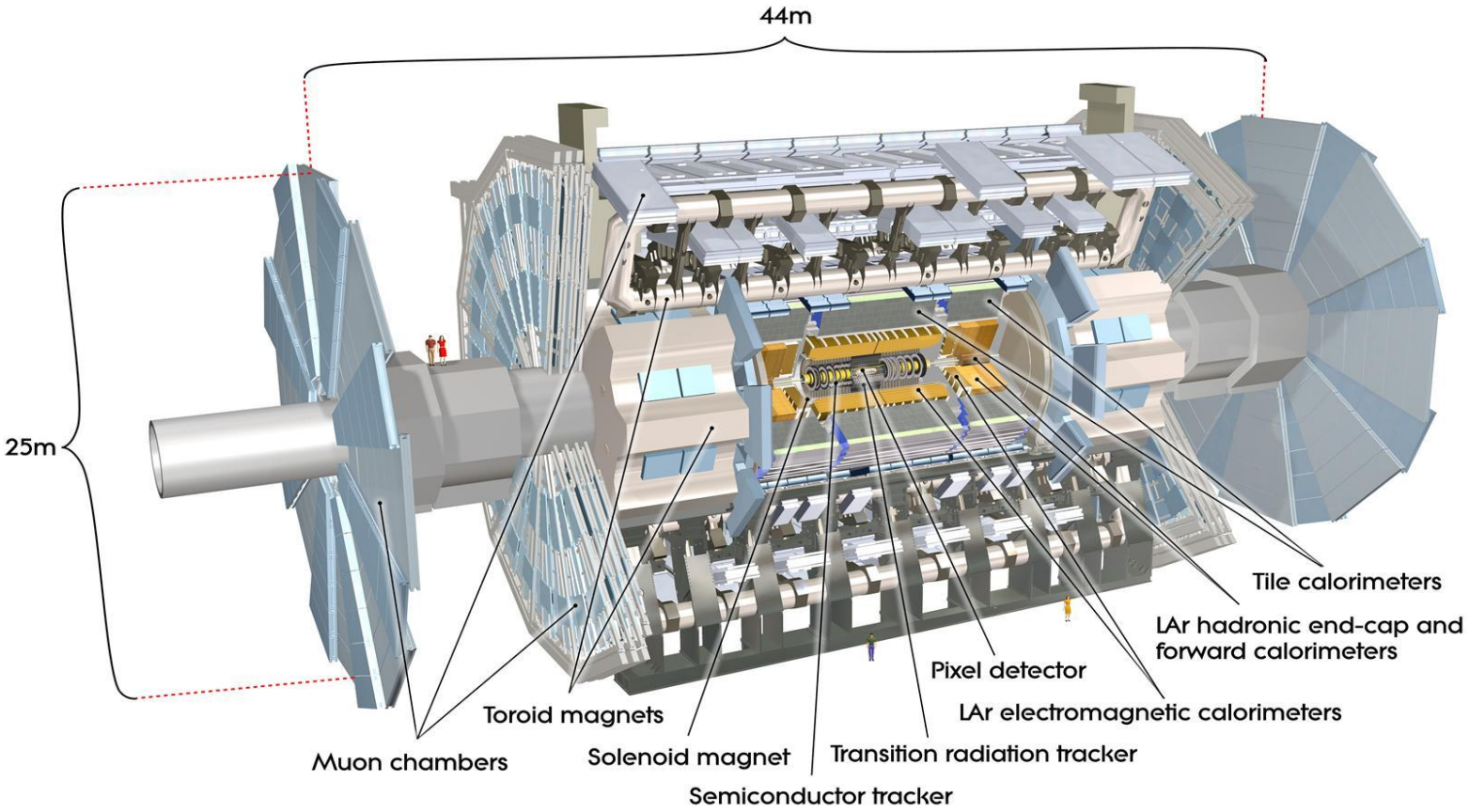


- At the LHC **superconducting dipole magnets** are operated at B-field strength of 8.3 T over their full length
  - Forcing the particle beams to follow the circular pipes

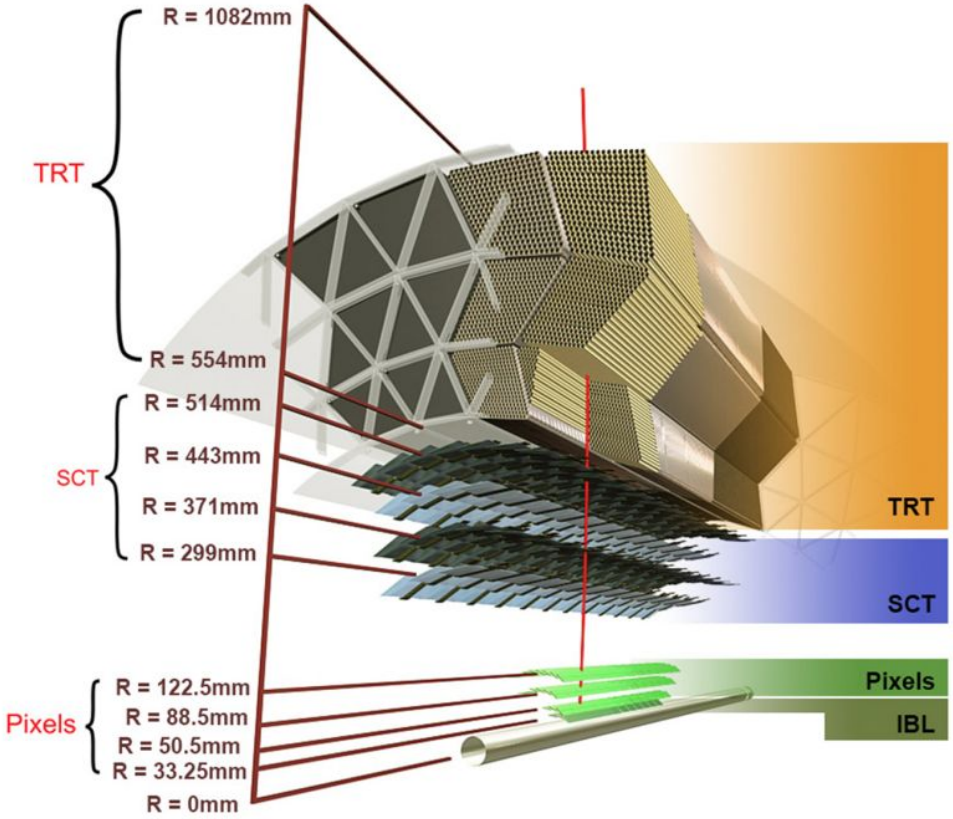


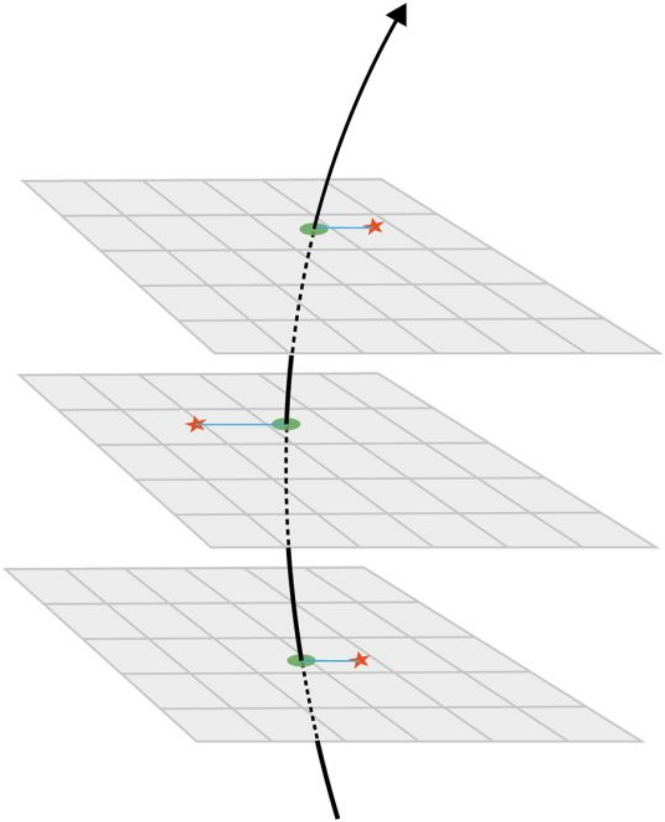
- **Quadrupole magnets** are used to focus the beams (as they act on the beam like an optical lens).
  - Focusing in one plane, de-focusing in the other!

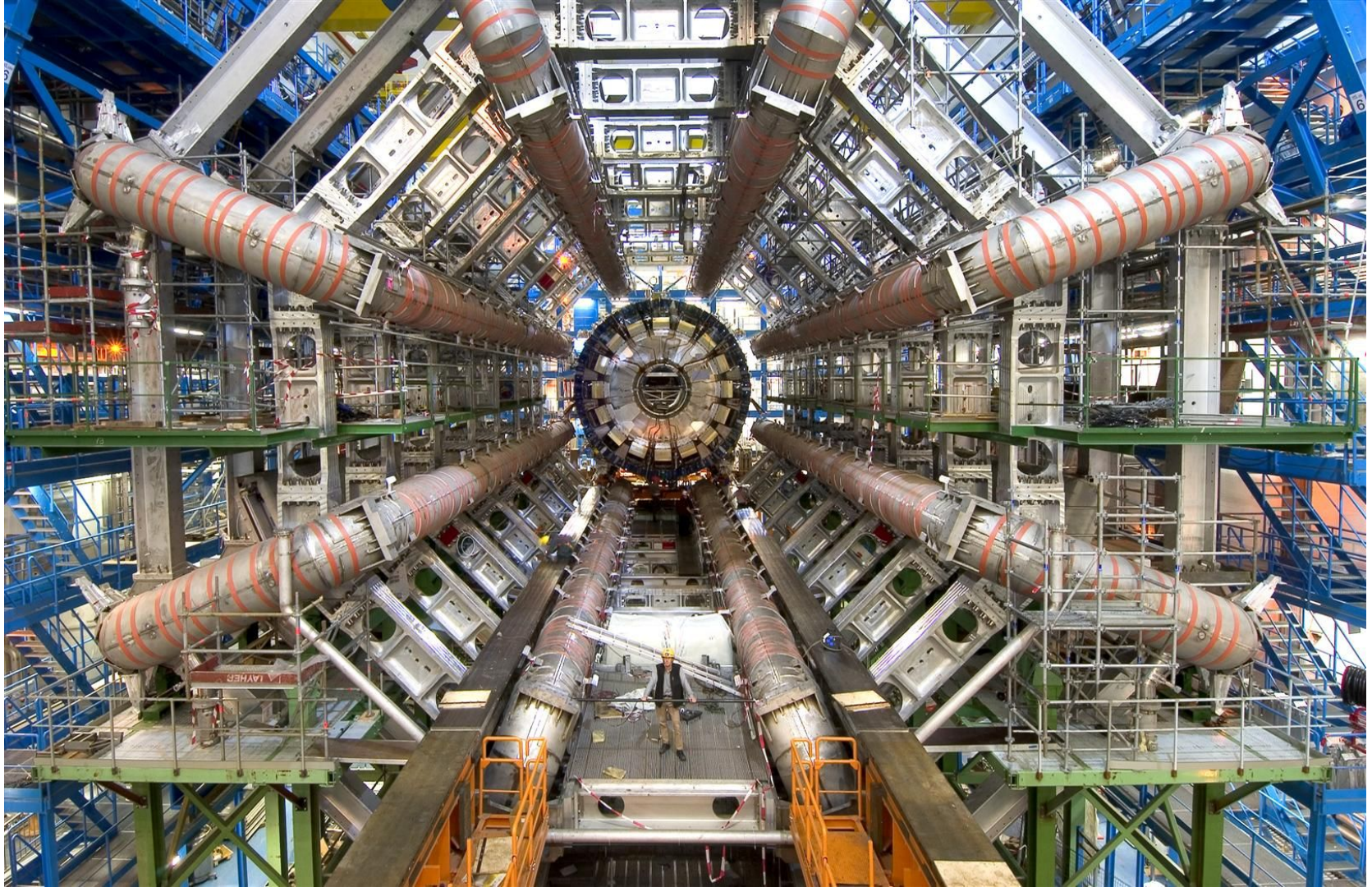
The ATLAS Detector

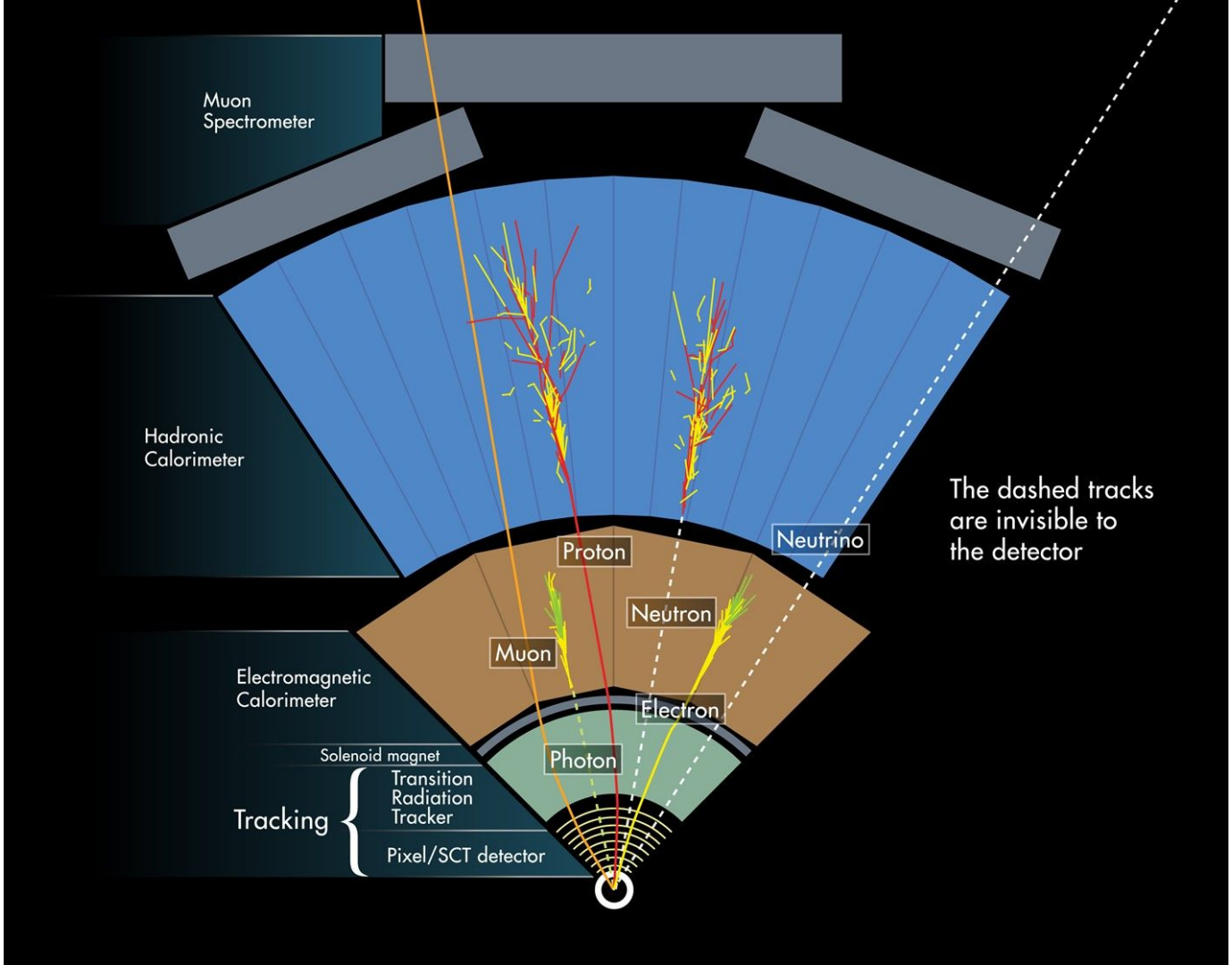


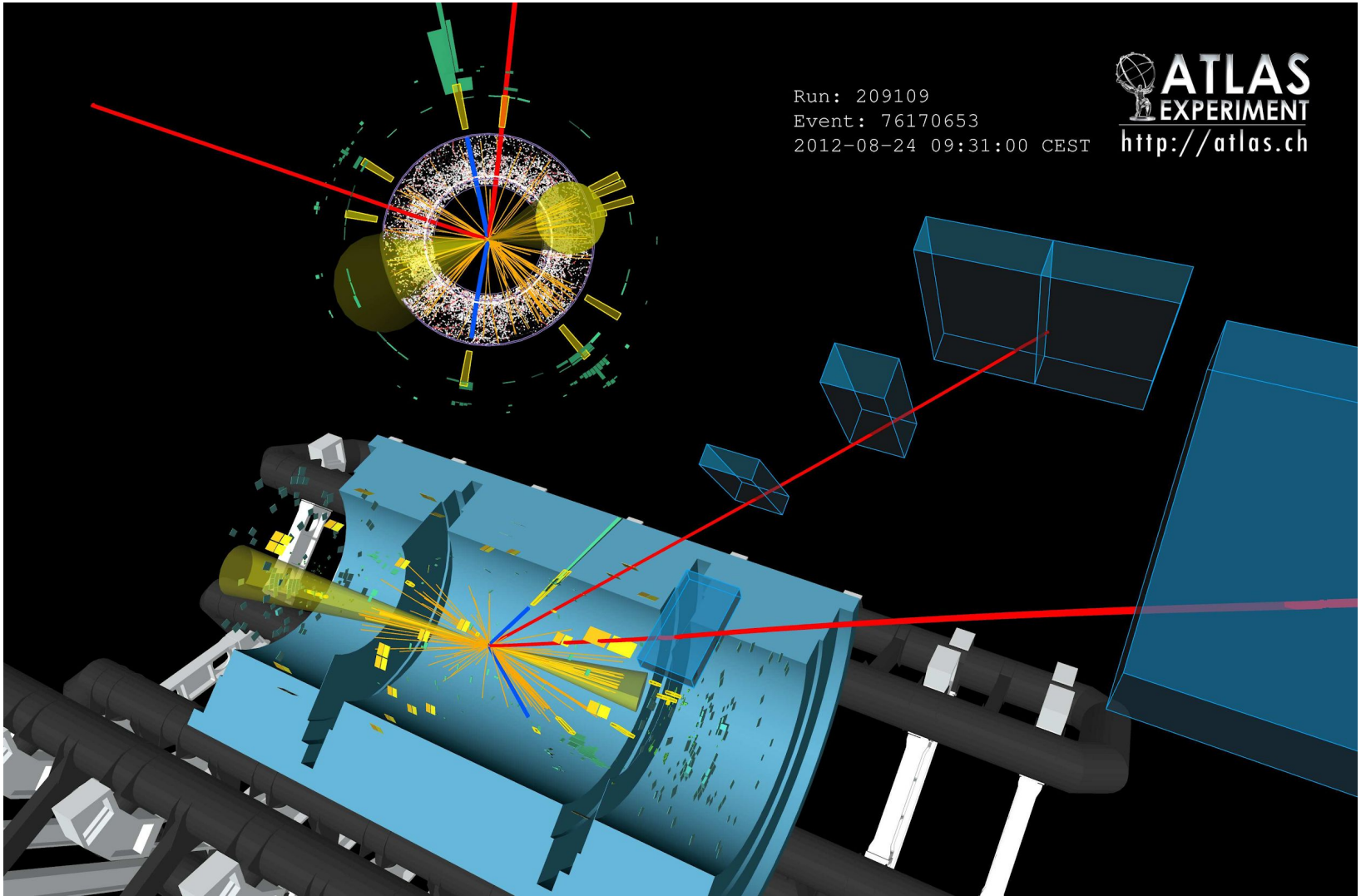
The ATLAS Inner Tracking Detector








Muon
Spectrometer
Hadronic
Calorimeter
Electromagnetic
Calorimeter
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT detector
Proton
Neutrino
Neutron
Muon
Electron
Photon
The dashed tracks
are invisible to
the detector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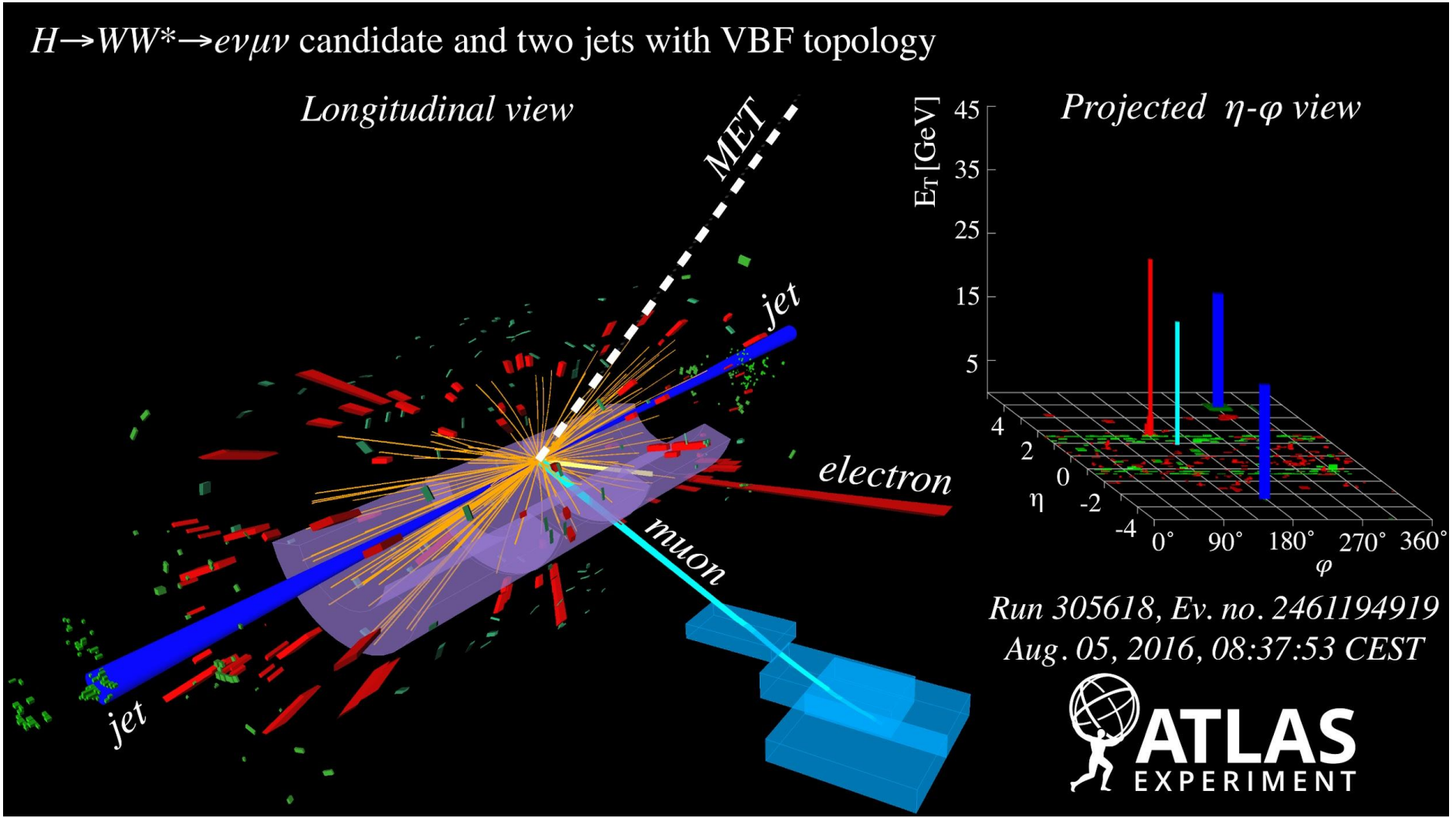
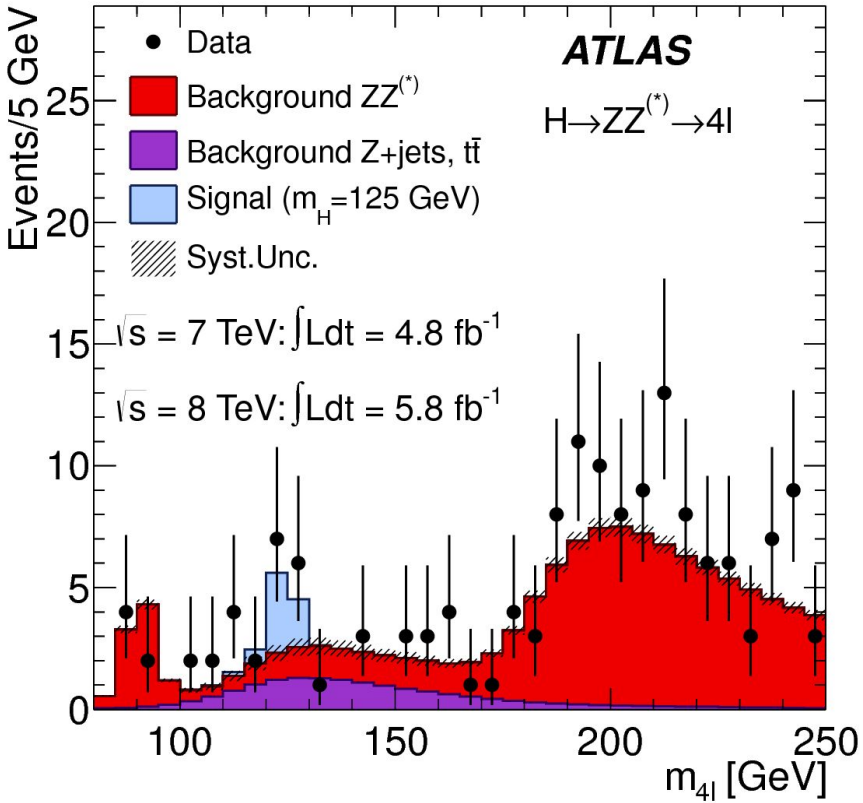
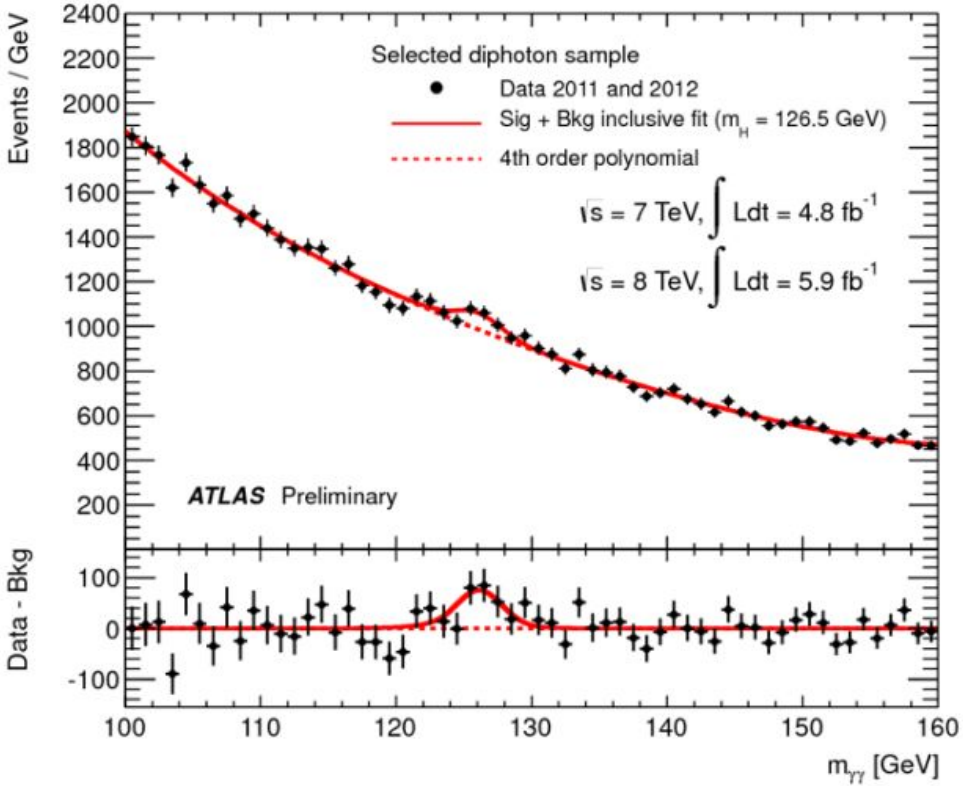
Event: 76170653
2012-08-24 09:31:00 CEST
ATLAS
EXPERIMENT
http://atlas.ch

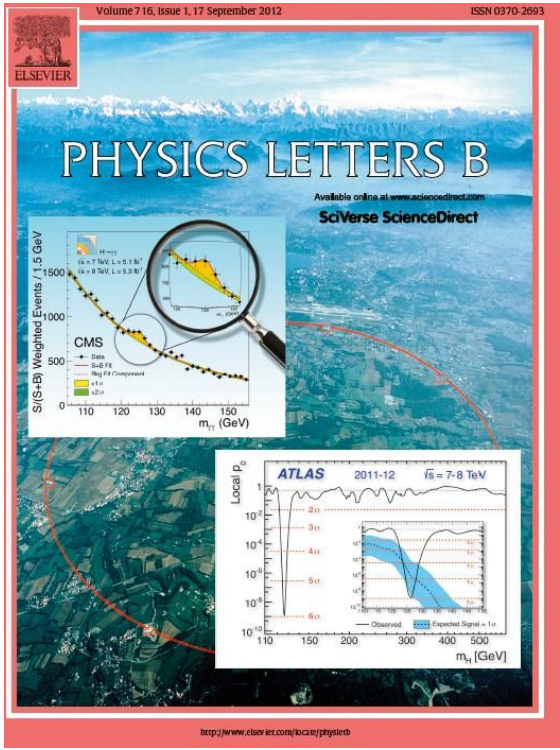

$H \rightarrow WW^* \rightarrow e\nu\mu\nu$ candidate and two jets with VBF topology
Longitudinal view
MET
jet
electron
muon
jet
Projected η-φ view
E_T [GeV]
45
35
25
15
5
4
2
0
-2
-4
η
0°
90°
180°
270°
360°
φ
Run 305618, Ev. no. 2461194919
Aug. 05, 2016, 08:37:53 CEST
ATLAS
EXPERIMENT

Discovery of the Higgs Boson



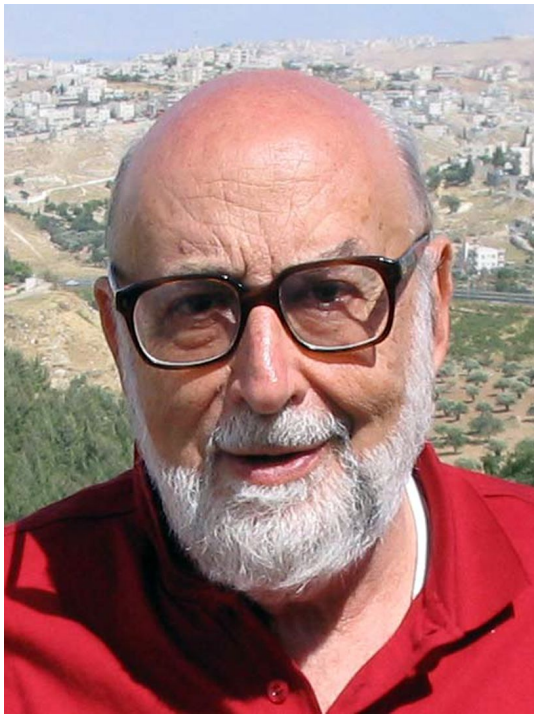


The Higgs Boson Discovery



Nobel Price for Physics in 2013

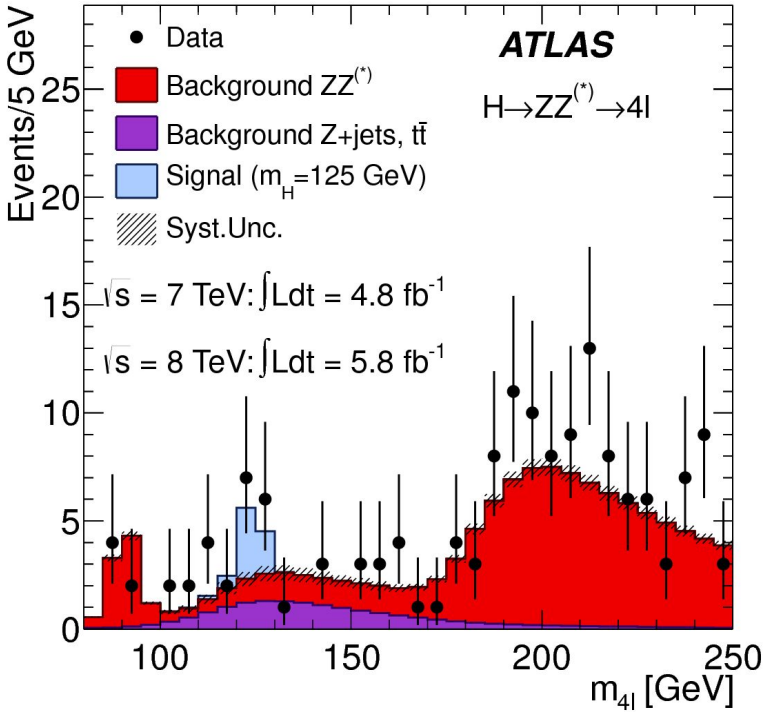
Peter Higgs



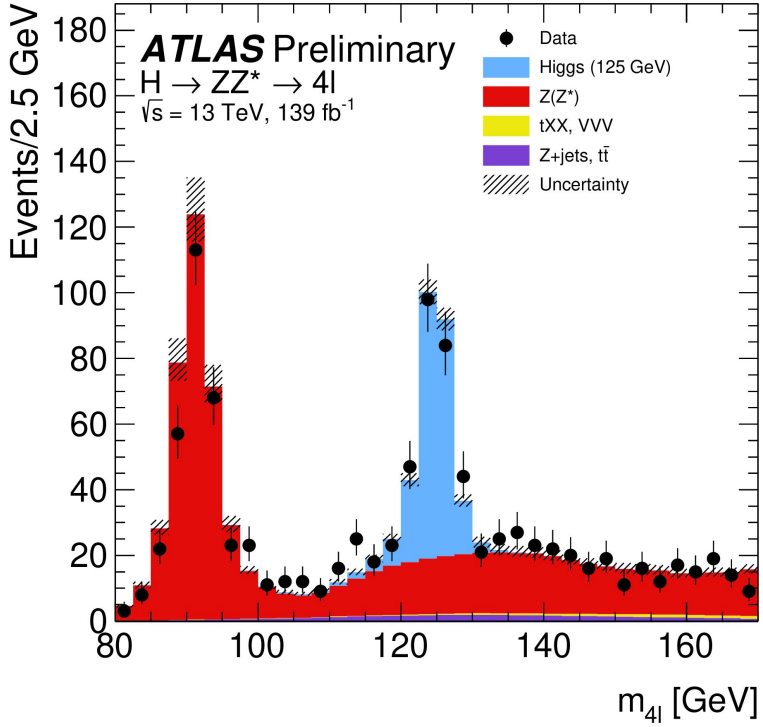
François Englert

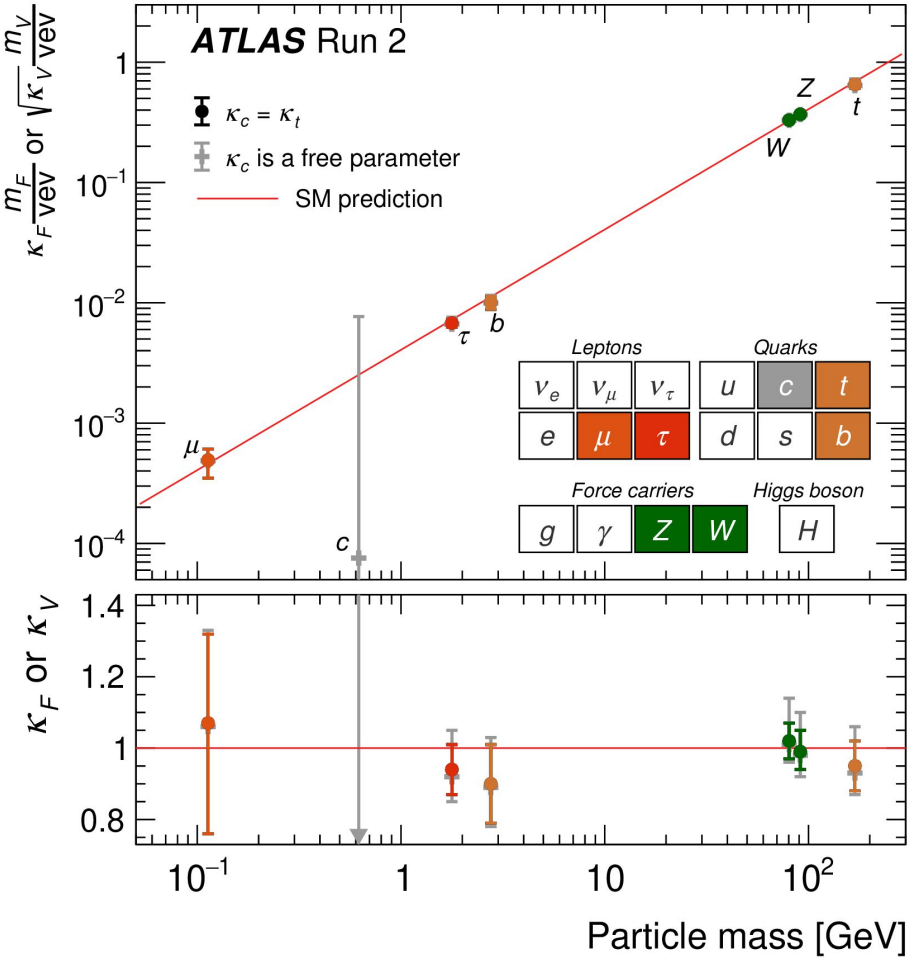
What we do nowadays

Then


Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Syst.Unc.
ATLAS
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Events/5 GeV
m4l [GeV]

Now


ATLAS Preliminary
H → ZZ* → 4l
√s = 13 TeV, 139 fb-1
Data
Higgs (125 GeV)
Z(Z*)
tXX, VVV
Z+jets, tt̄
Uncertainty
Events/2.5 GeV
m4l [GeV]


ATLAS Run 2
$\kappa_c = \kappa_t$
κ_c is a free parameter
SM prediction
$\frac{m_F}{\kappa_F \text{vev}}$ or $\sqrt{\frac{m_V}{\kappa_V \text{vev}}}$
κ_F or κ_V
Particle mass [GeV]
Leptons
Quarks
Force carriers
Higgs boson
ν_e ν_μ ν_τ
e μ τ
u c t
d s b
g γ Z W
H
μ
c
τ
b
W
Z
t

Search for heavy Higgs Bosons