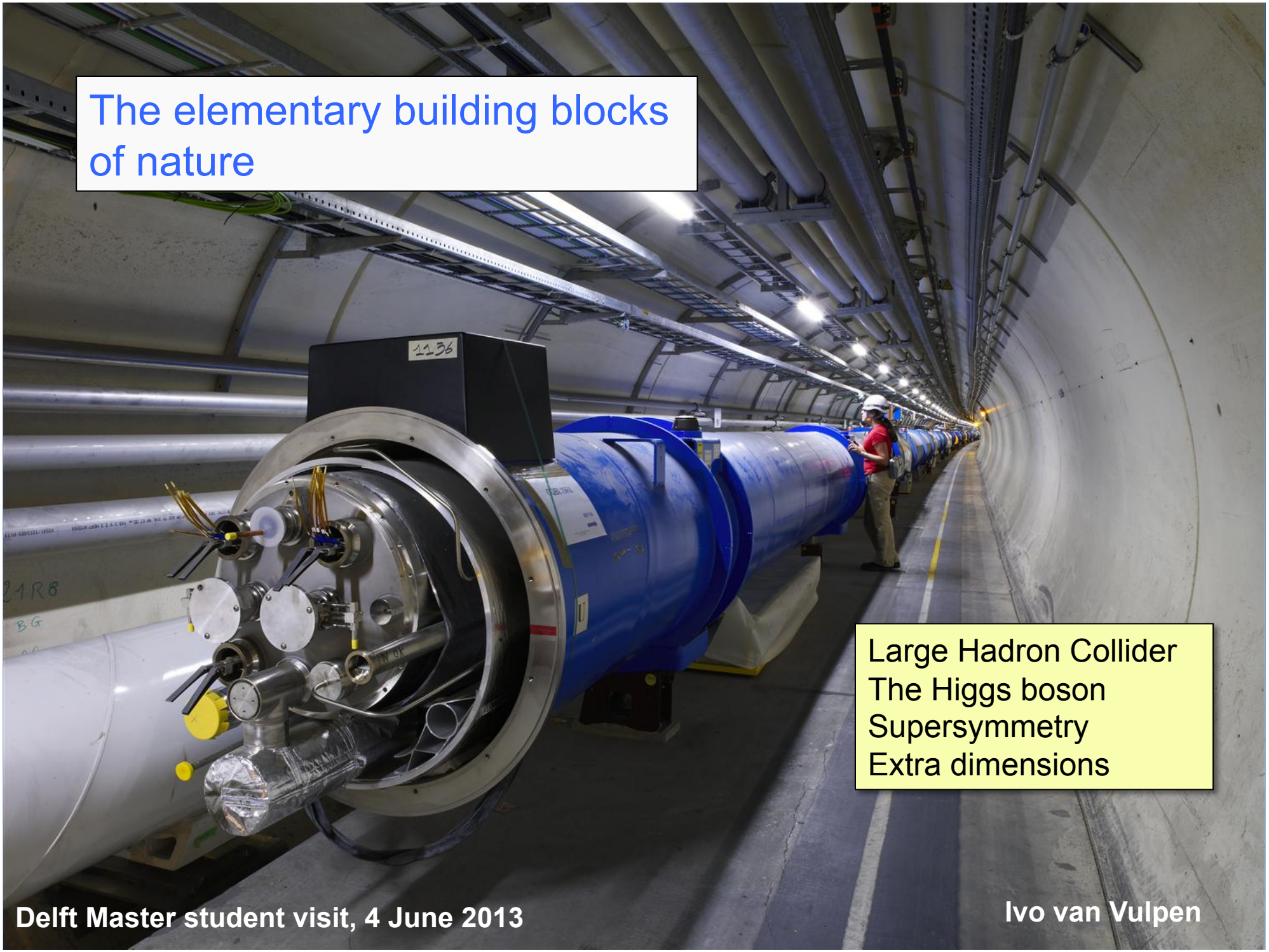
The elementary building blocks of nature

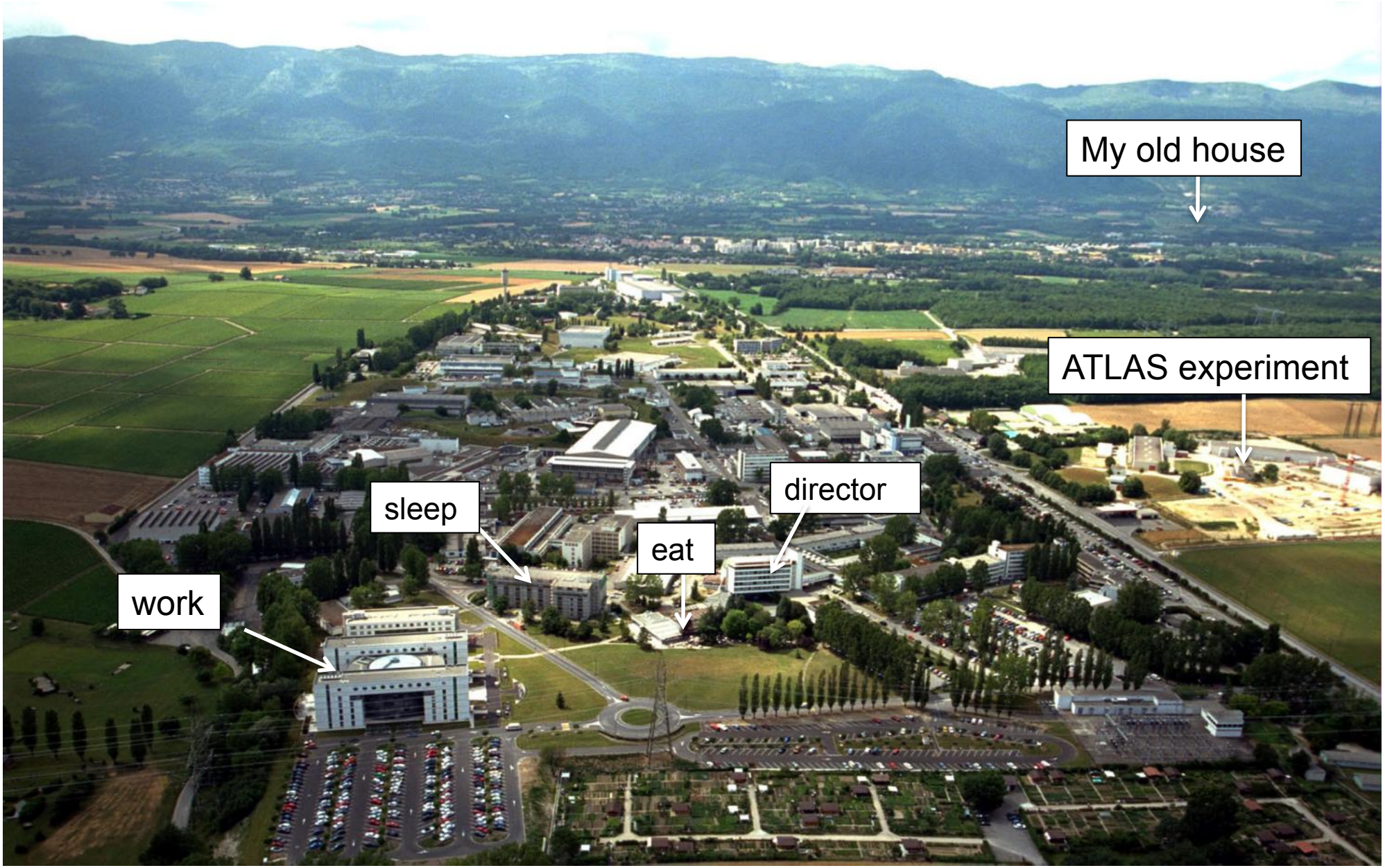


Large Hadron Collider
The Higgs boson
Supersymmetry
Extra dimensions

Delft Master student visit, 4 June 2013

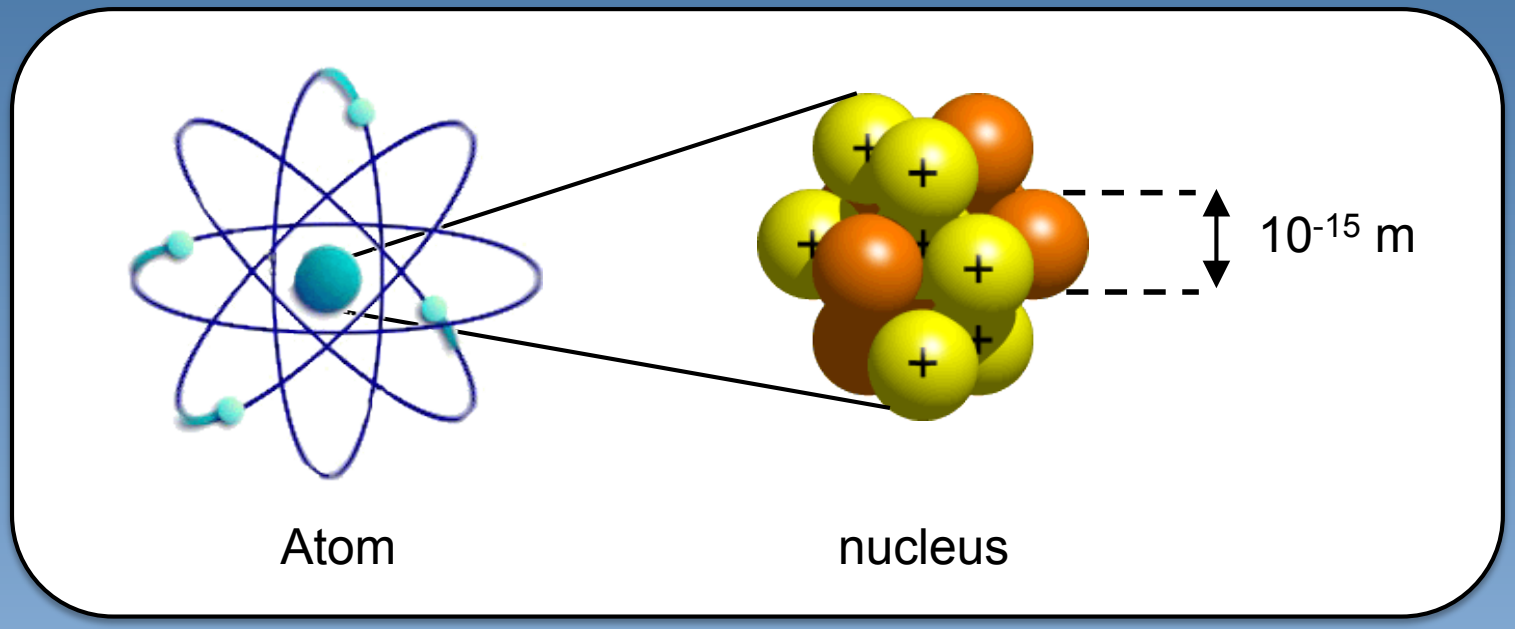
Ivo van Vulpen

CERN in Genève, Zwitserland



Particle Physics

Studies nature at distance scales < 10^{-15} m

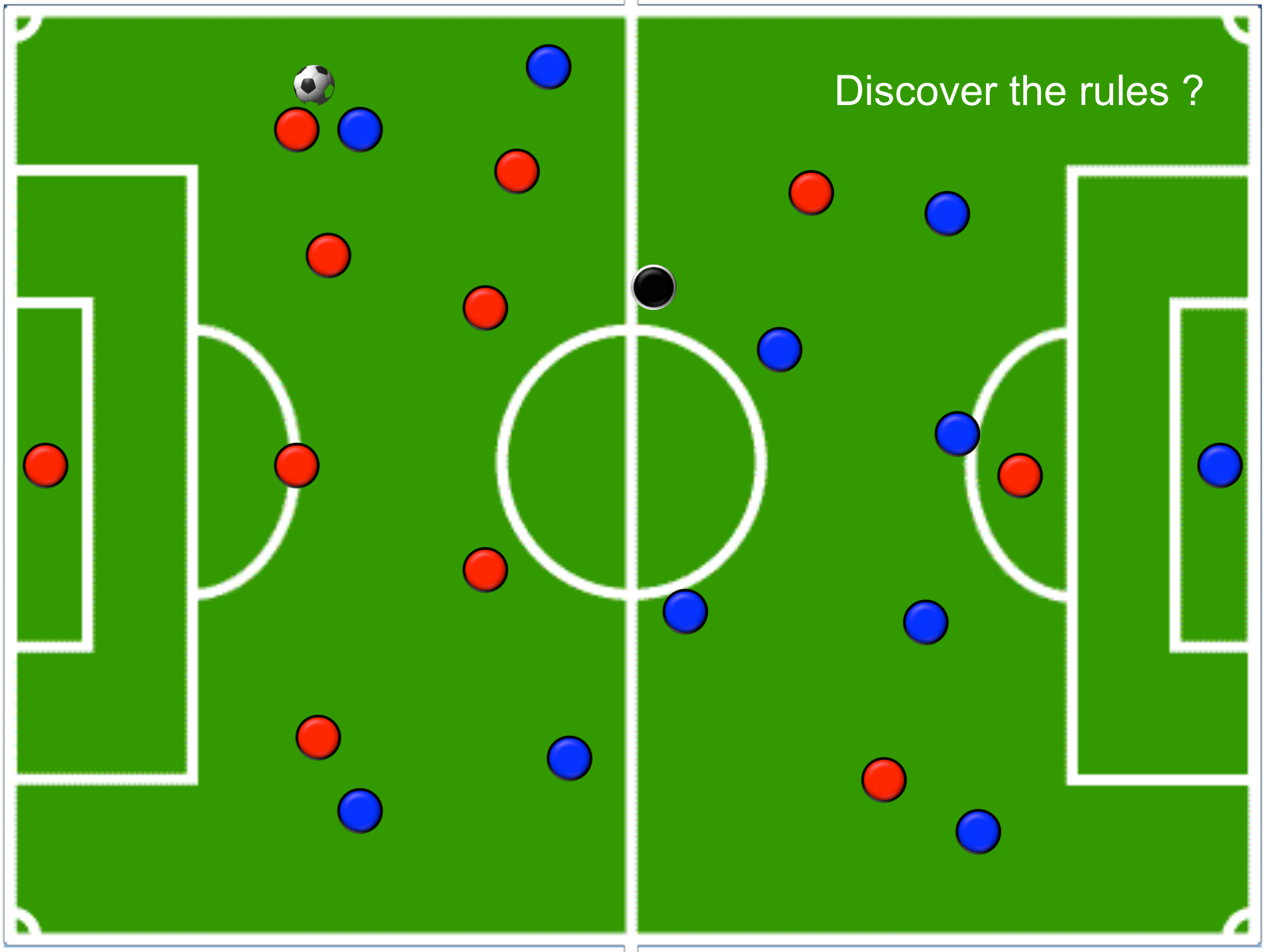



Harry van der Graaf


Paul de Jong


Niels Tuning

Standard Model:
Quantumfield theory that describes phenomena down to 10^{-19} m


Discover the rules ?

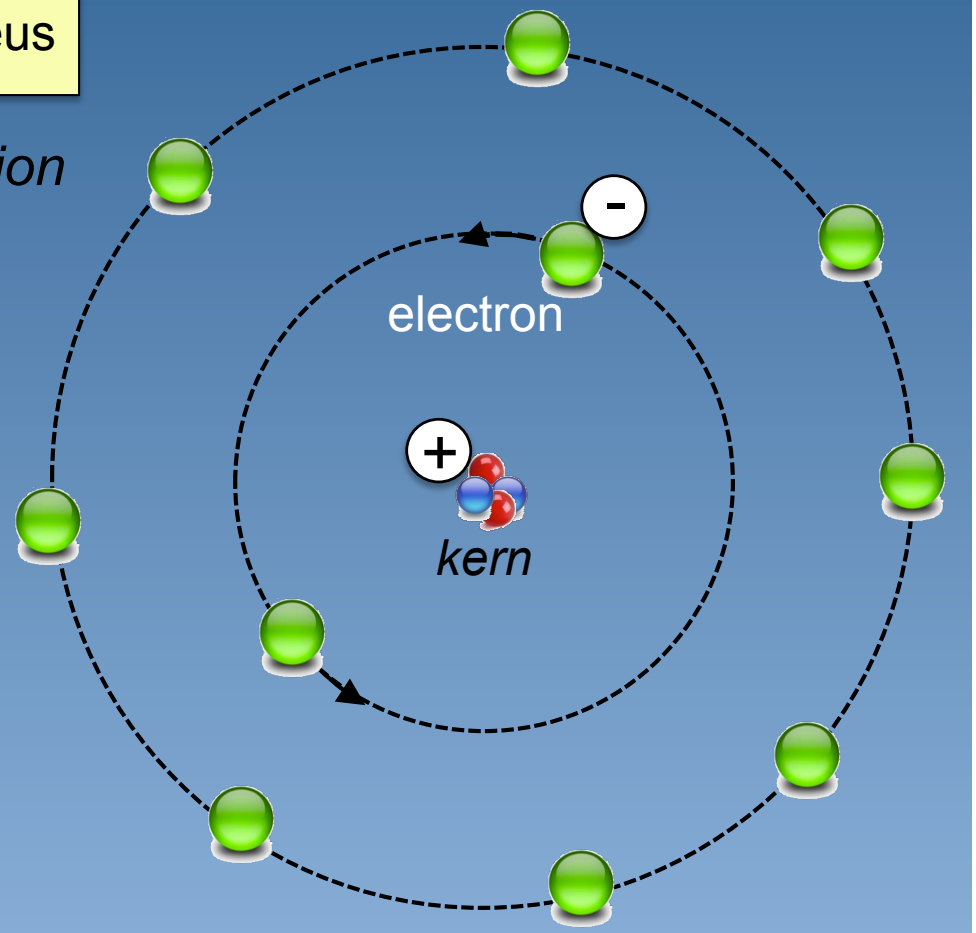
The atomic world

1) Electrons do not fall onto the nucleus

<u>Laws of physics</u>*: quantisation*

2) Protons and Neutrons stick together

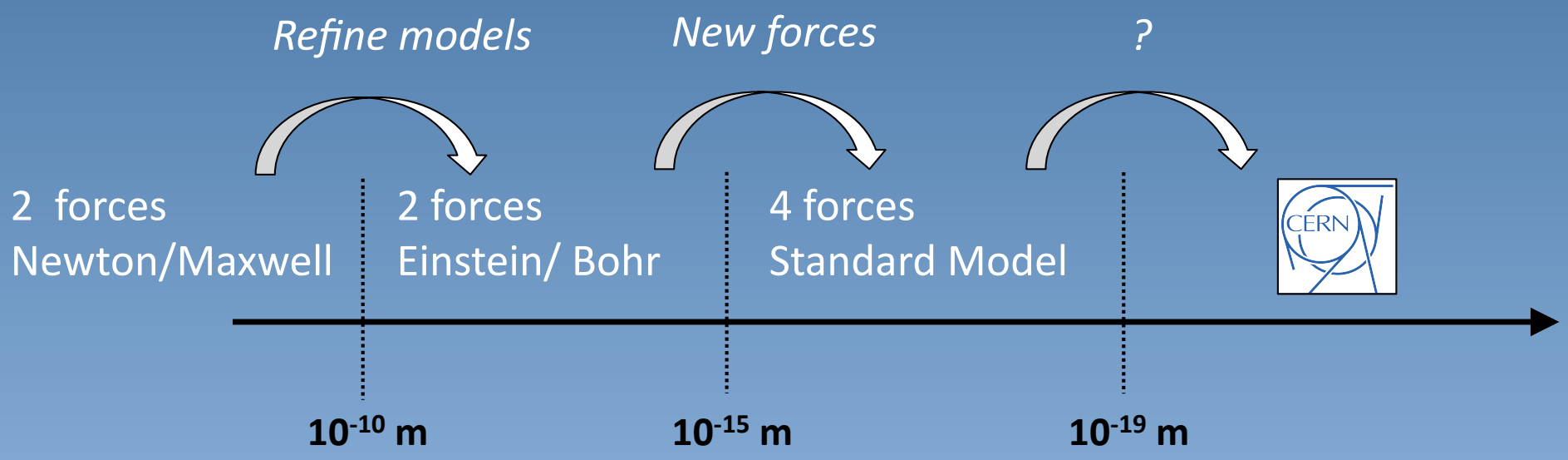
<u>Force</u>*: weak & strong*



3) Pattern in # electrons per orbit

<u>Properties</u>*:* spin

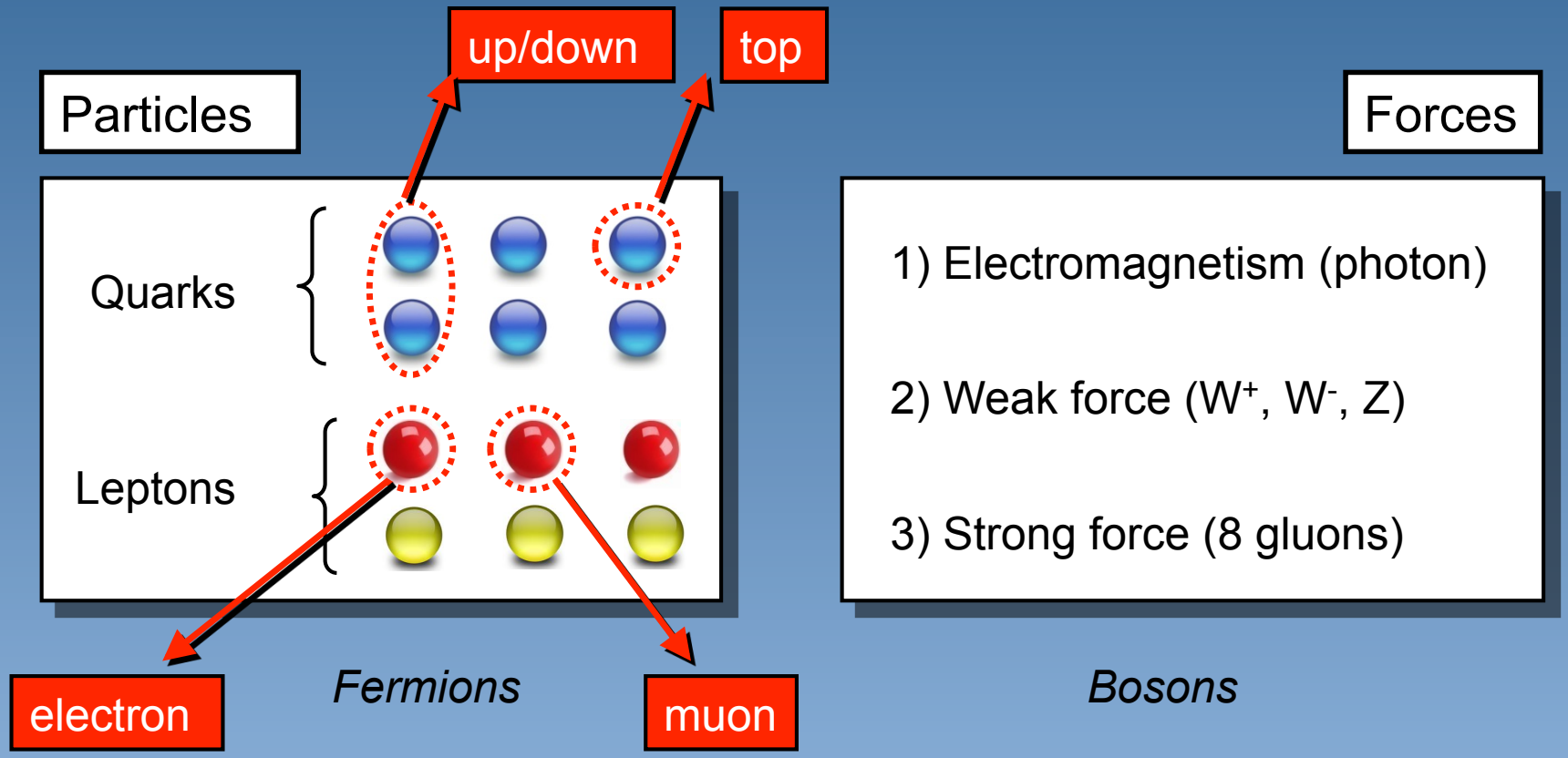
New phenomena, new forces ?



Where are we on March 1st 2013 ?

http:// pdg.lbl.gov

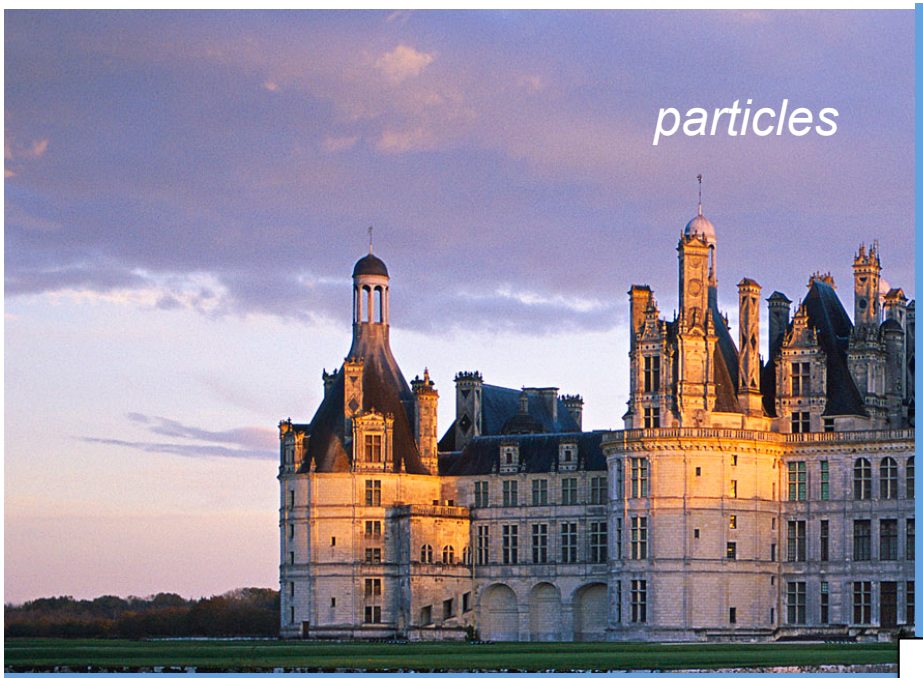
The Standard Model



The Standard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

Weak iso-spin, hypercharge, colour



The Standard Mod

Paar 'kleine' dingetjes:

1. 96% of the energy in the universe is unknown
   → dark matter (24%) what is that ?
   → dark energy (72%) what is that ?

2. Where did all the anti-matter go ?

3. How do particles acquire mass ? Higgs boson

4. Why is gravity so weak ?

Theory

The Standard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

Describes all phenomena

Massive (force-)particles

Reality

$\neq$

Massive (force-)particles

Theory

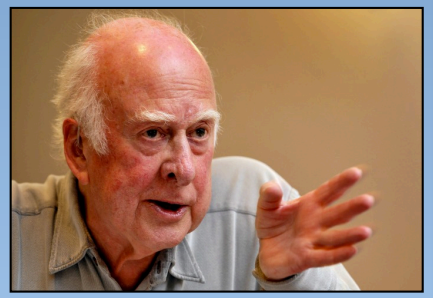
Reality

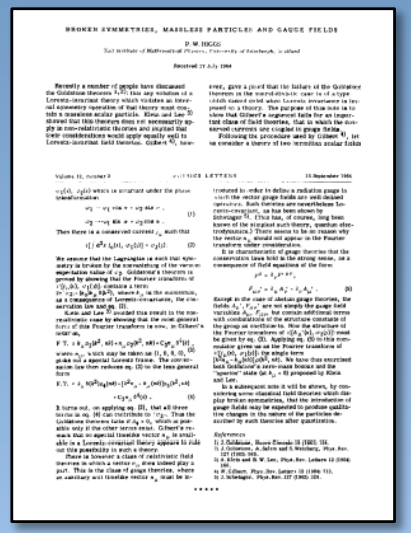
The Standard Model

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_C$$

=

Massive (force-)particles





BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS

- September 1964 -

The Higgs mechanism

Higgs field in the vacuum

"If I am right there should be a new particle in nature: ***the Higgs boson****"*


The last missing piece

(In)famous Higgs boson

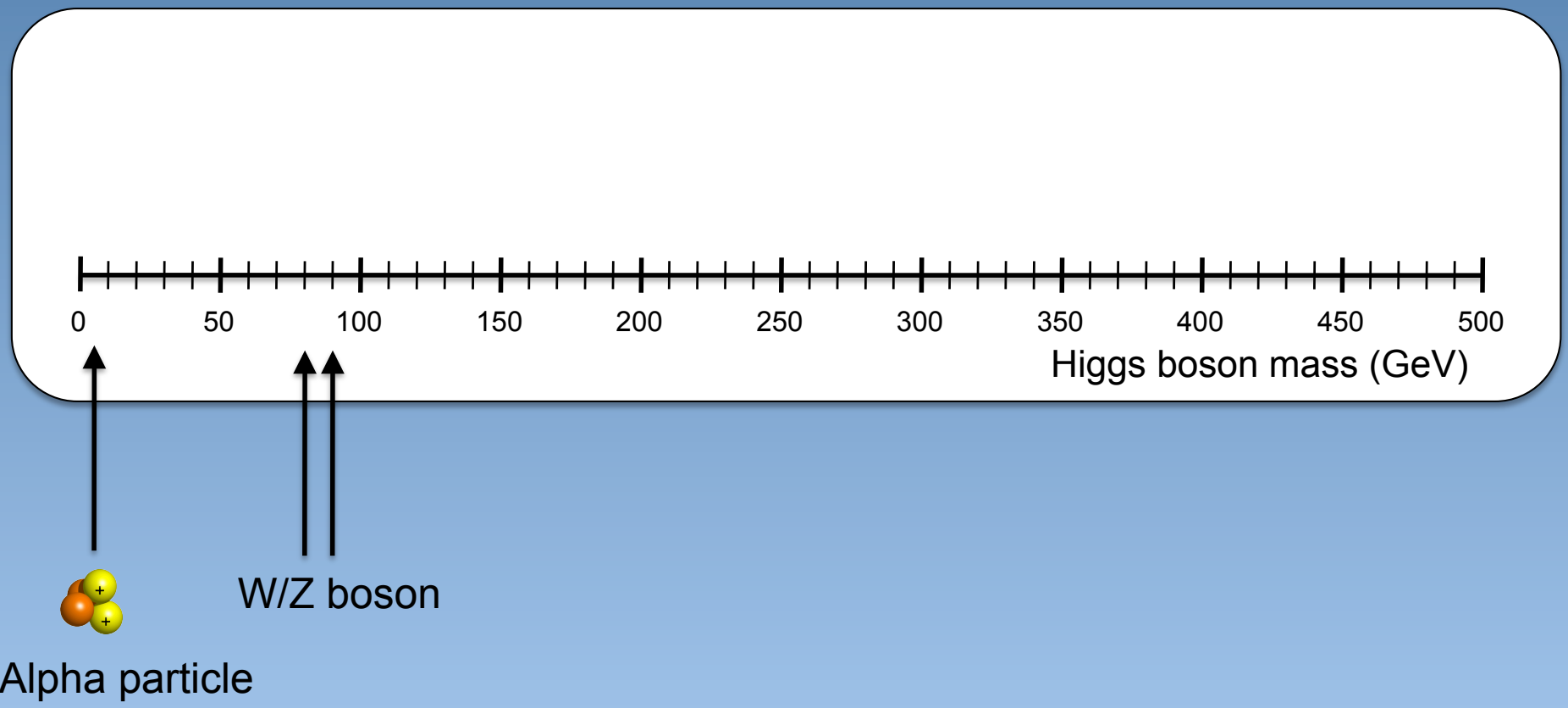
The Higgs boson

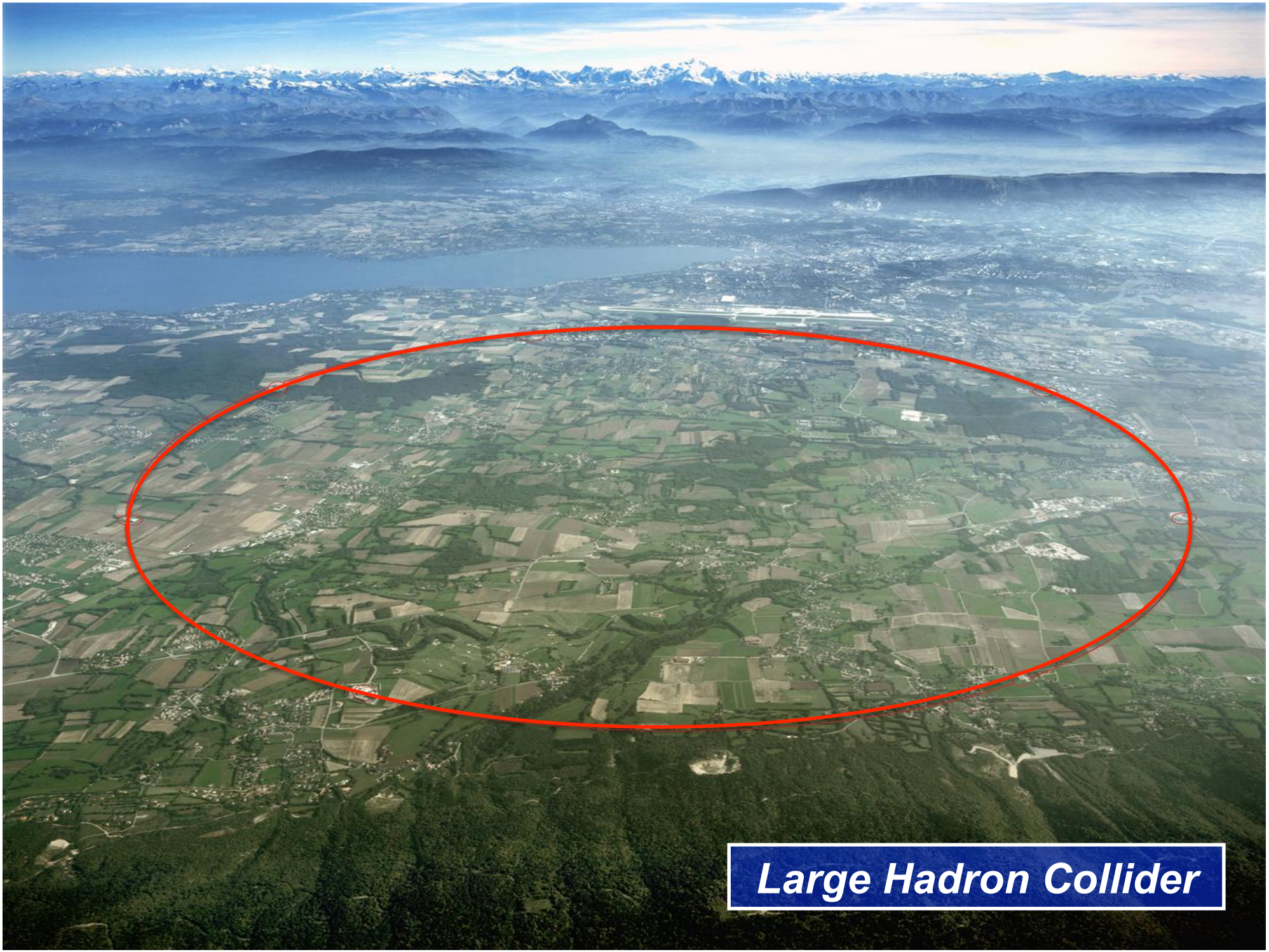
Paris Hilton

Being famous is not the same as being important

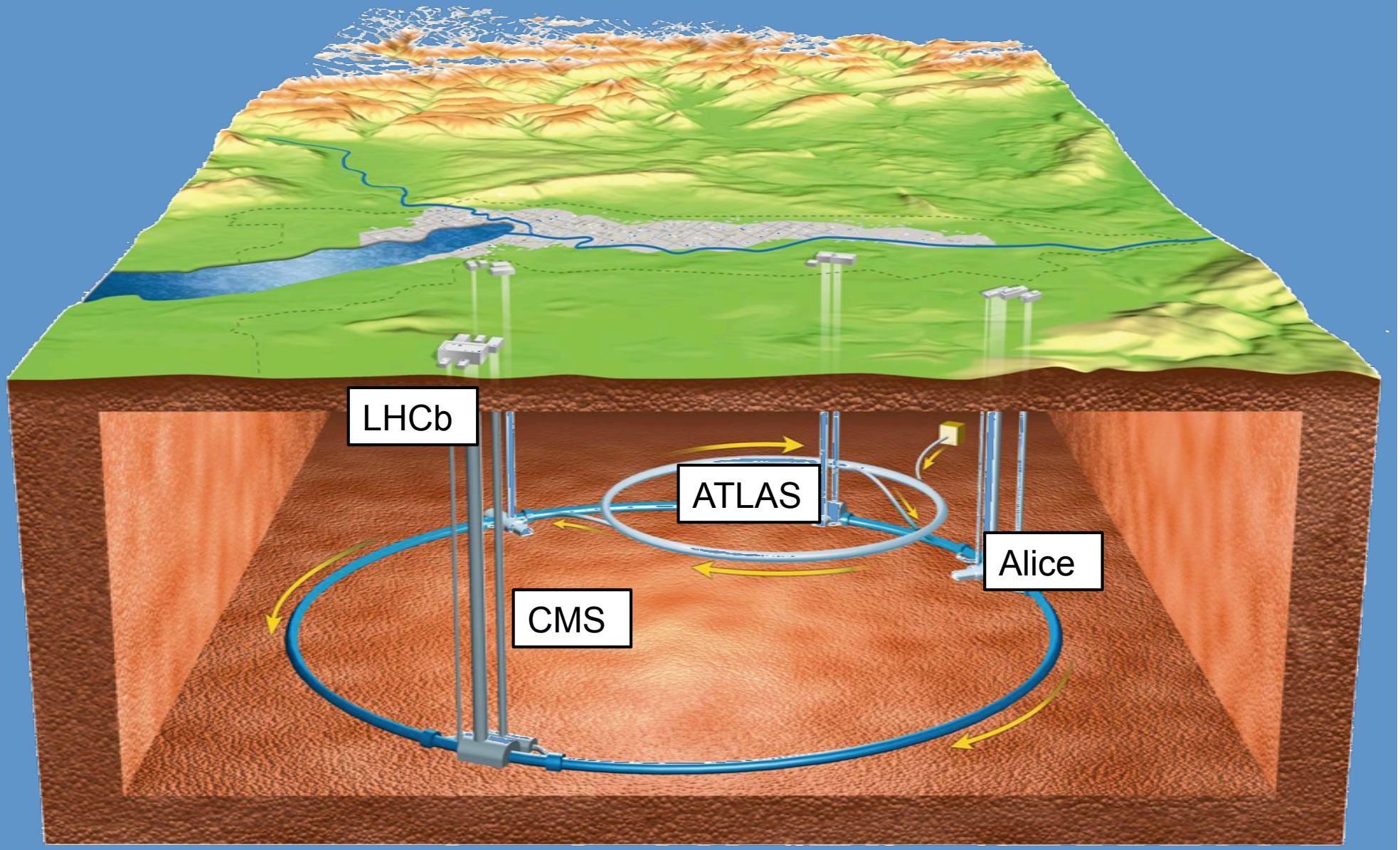
The mass of the Higgs boson

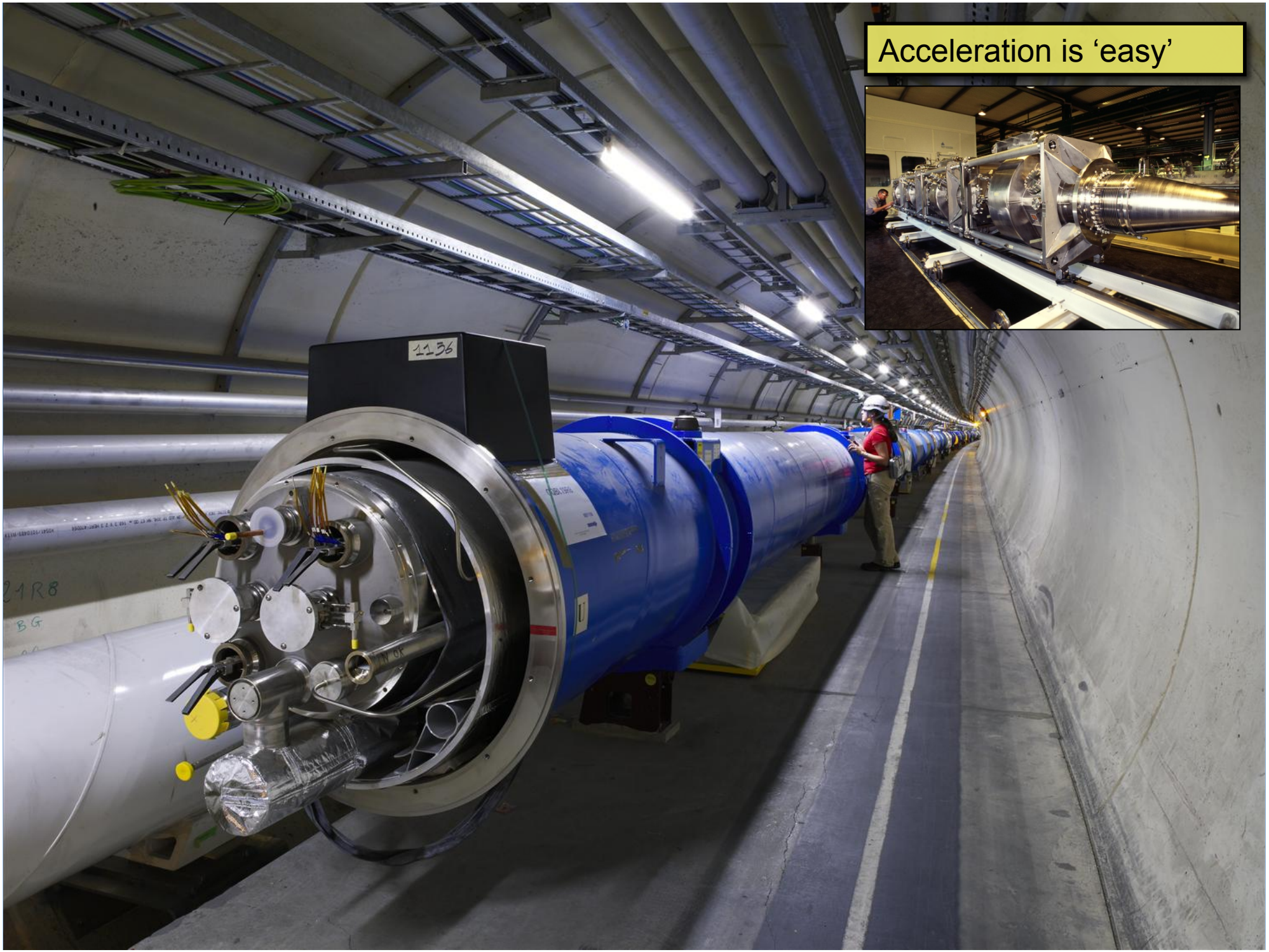
Properties of the Higgs boson are known … as a function of it's ***unknown*** *mass*




Large Hadron Collider

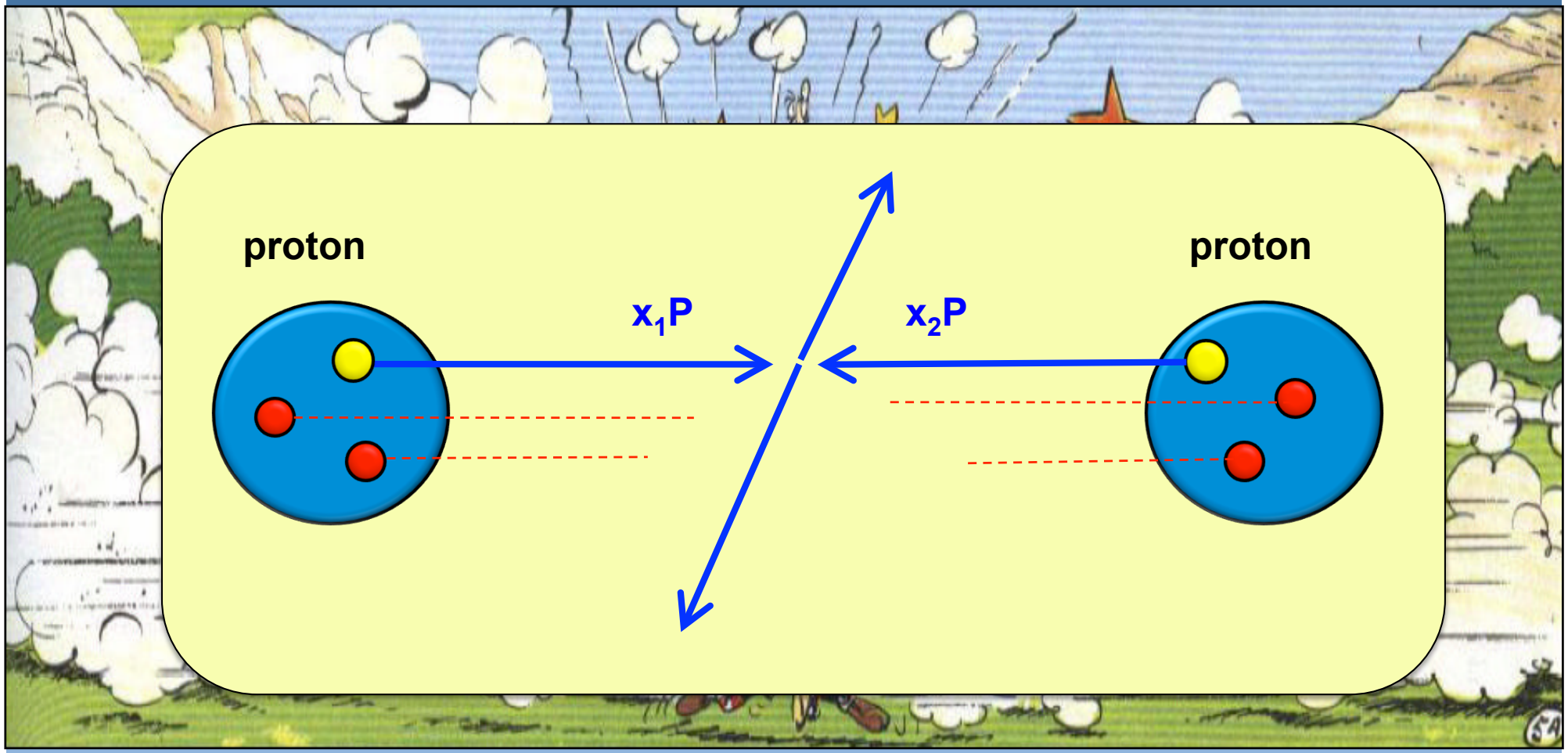
The Large hadron collider




Acceleration is ‘easy’
1136

Phenomenology of proton-proton collisions

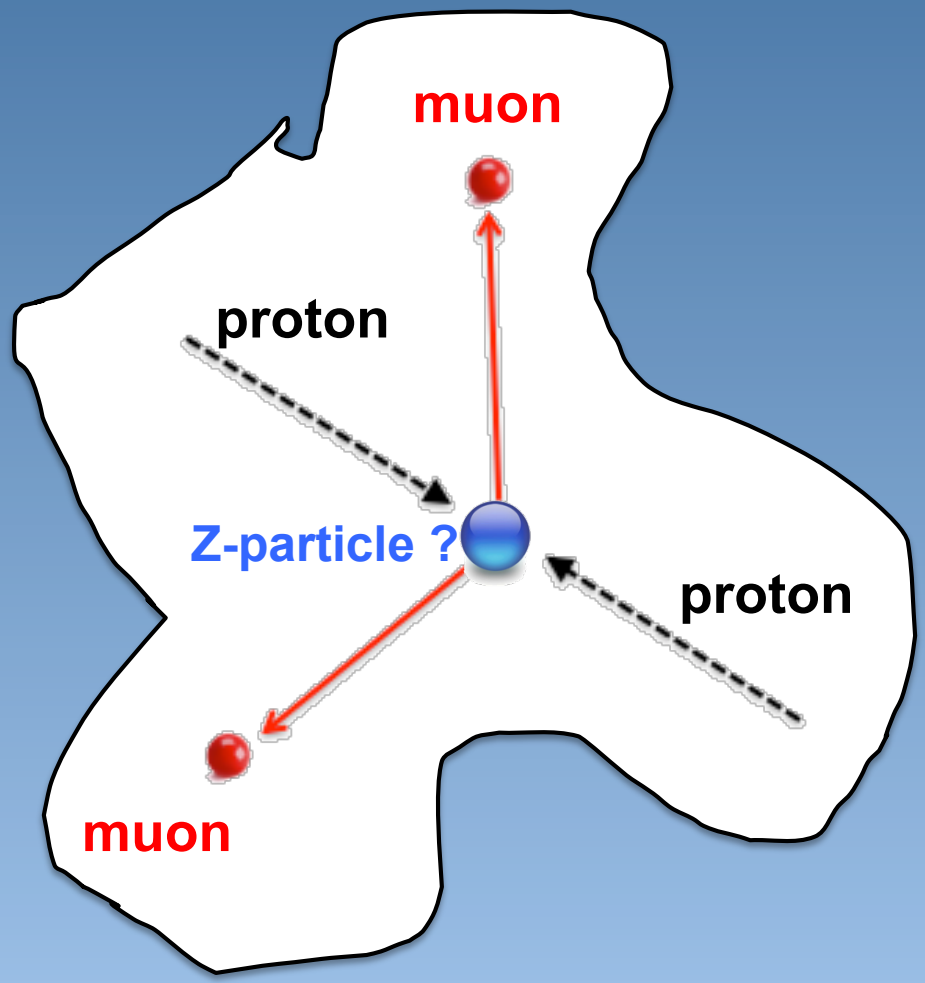
"Proton is a bag full of (anti-)quarks and gluons"



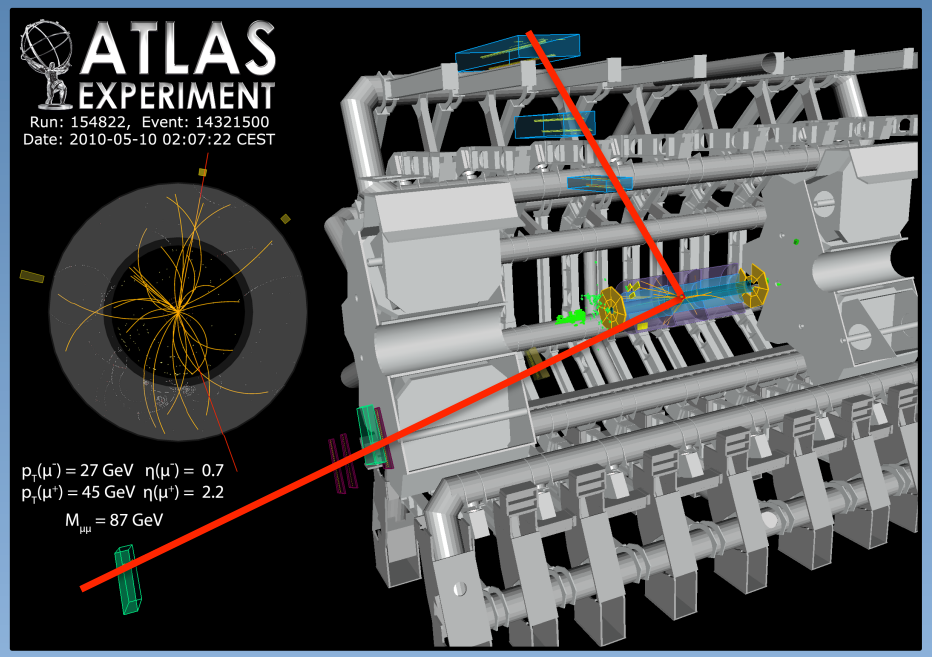
Only a fraction of the collision energy available for 'hard' interaction

How do you discover a Z particle ?

Deviations from the prediction without a Z boson



2-muons as seen in the ATLAS detector

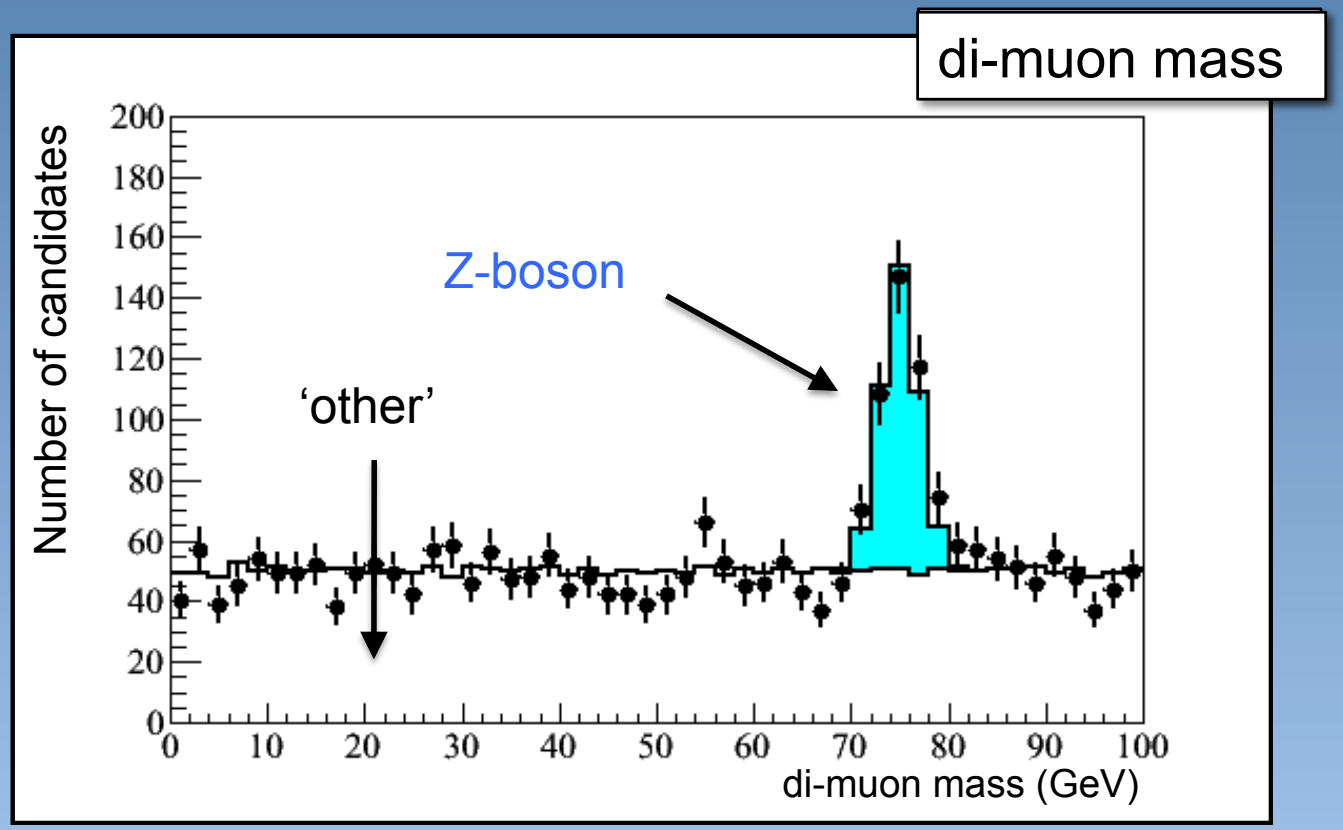


What is the fingerprint of the Z particle:
→ the di-muon mass

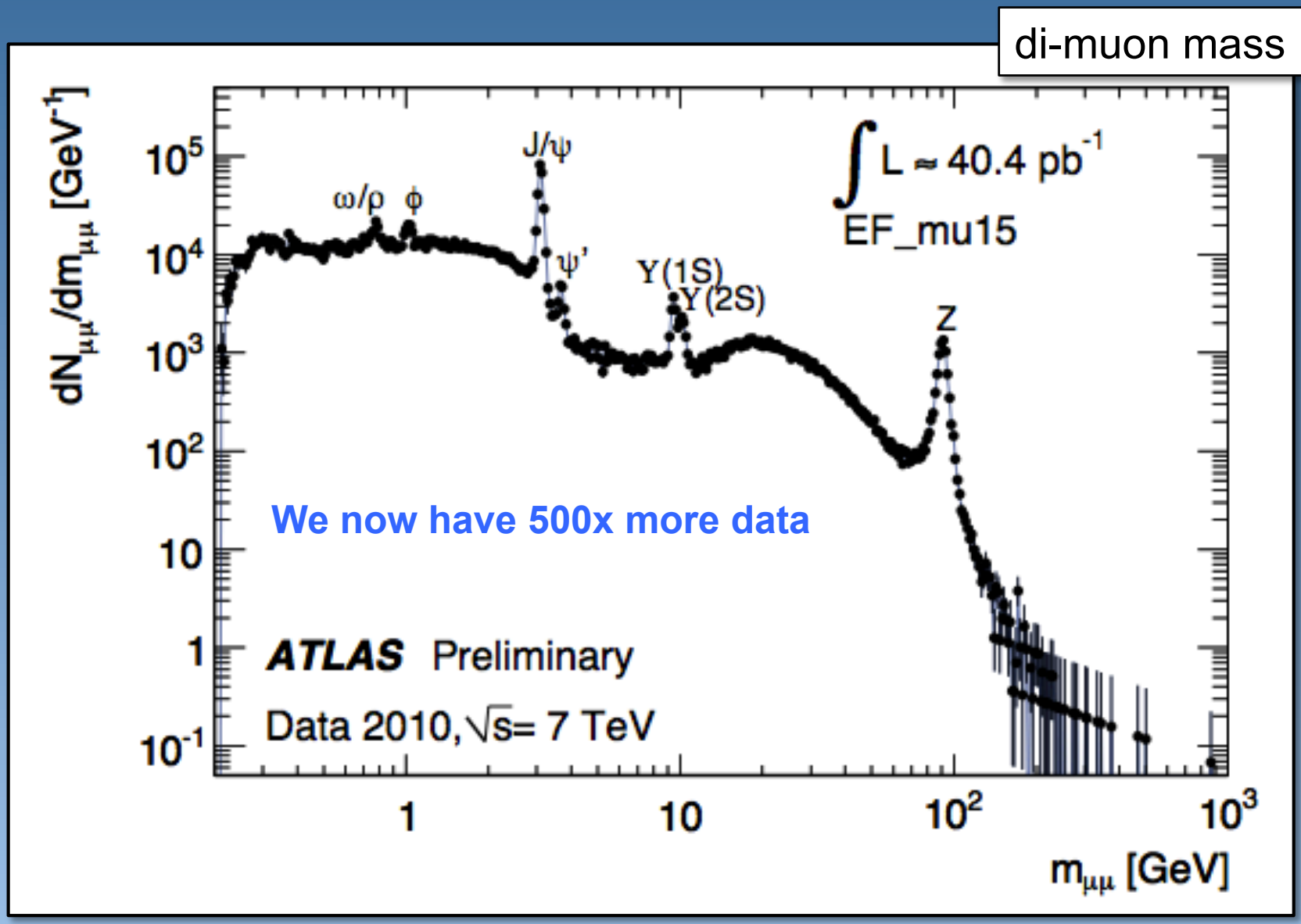
di-muon mass

‘other’: no preference/structure

Z-boson: Breit-Wigner ⊗ resolution

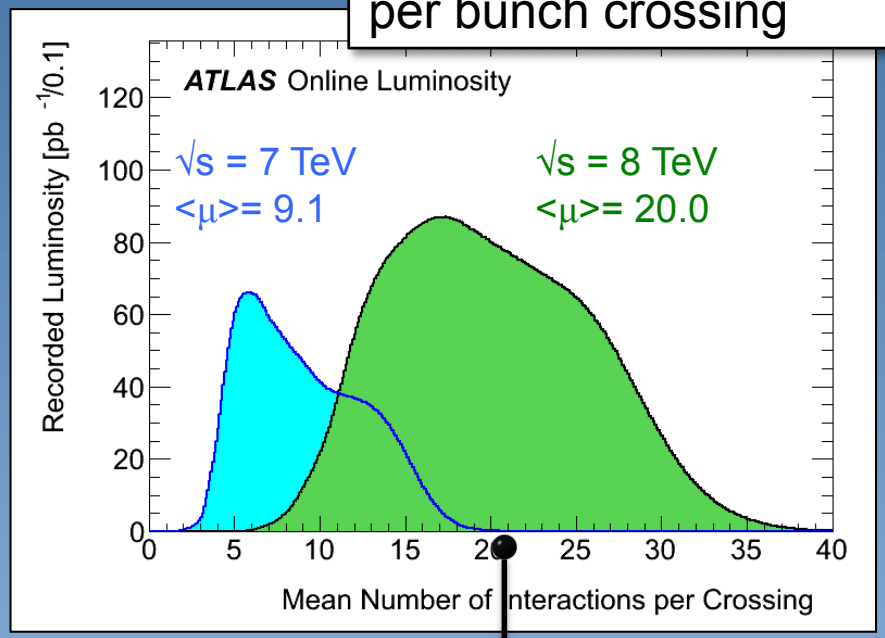


Di-muon resonances seen at the LHC

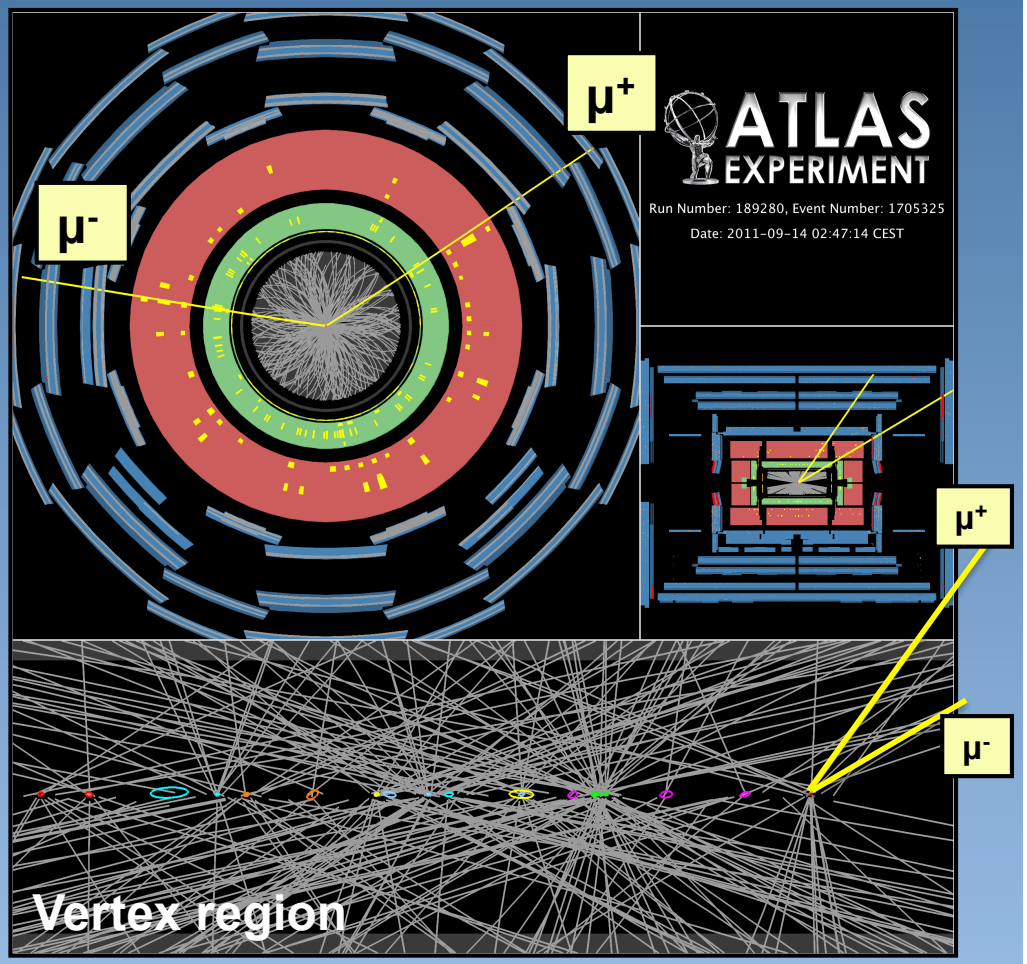


LHC is not a quiet environment

Number of interactions per bunch crossing



$Z \rightarrow \mu^+\mu^-$ event with 20 vertices

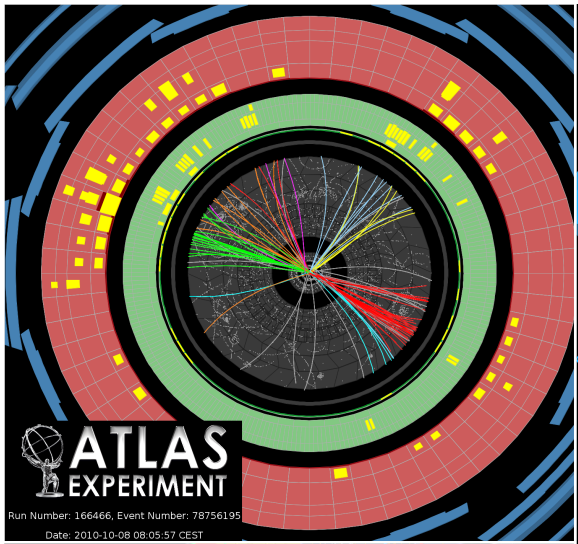


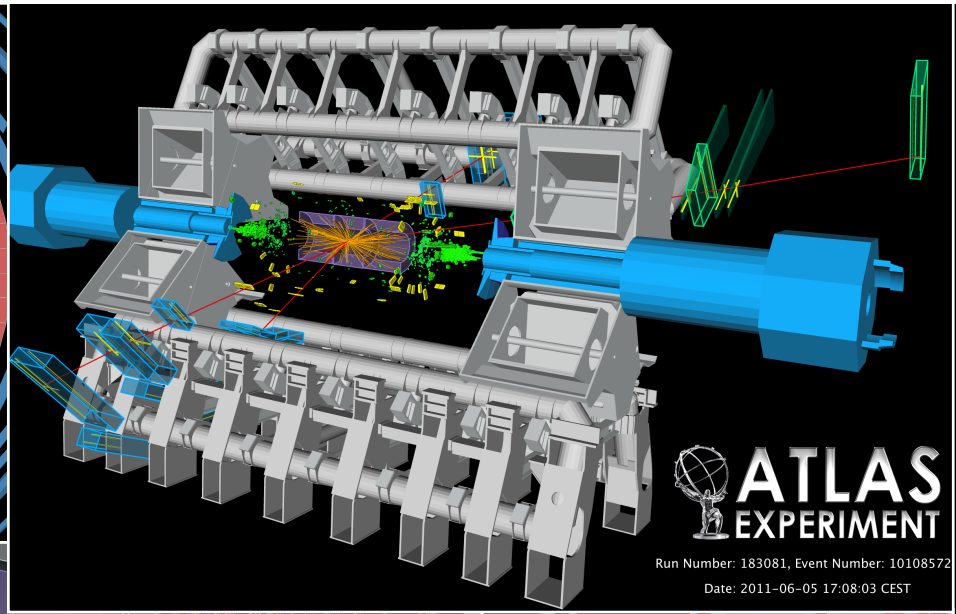
Trigger:
From 40 MHz (LHC) to a few hundred Hz

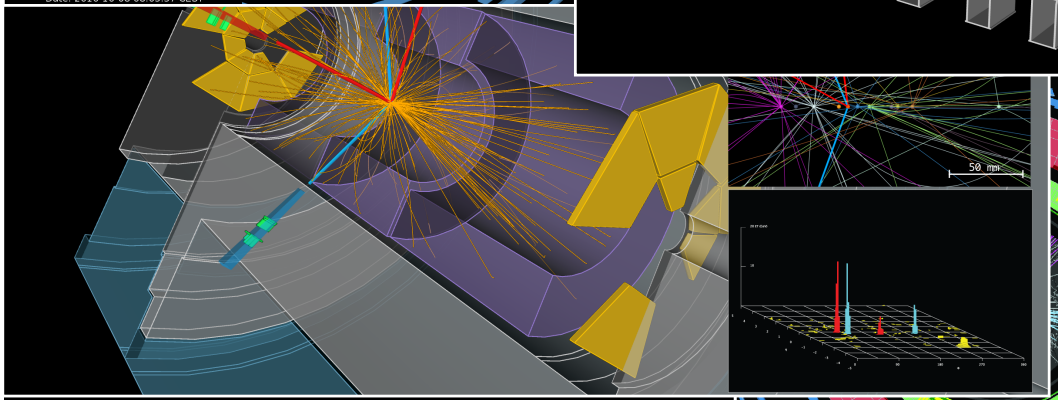
↓

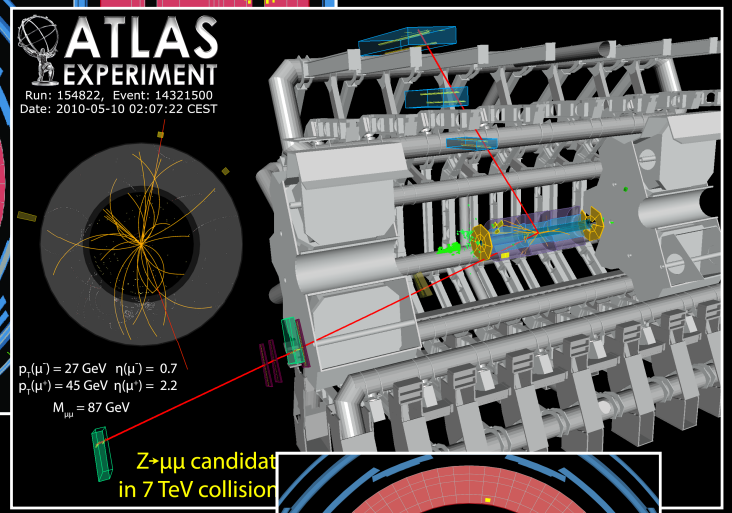
Bottleneck: disk space

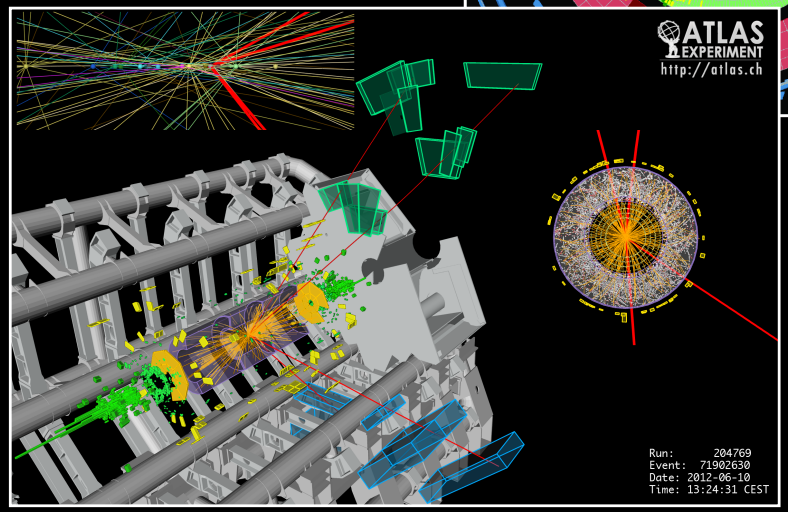
Selecting interesting physics from an e-nor-mous background

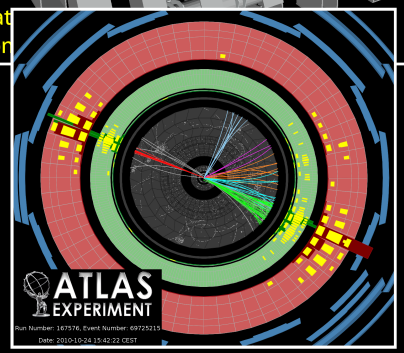

ATLAS
EXPERIMENT
Run Number: 166466, Event Number: 78756195
Date: 2010-10-08 08:05:57 CEST


ATLAS
EXPERIMENT
Run Number: 183081, Event Number: 10108572
Date: 2011-06-05 17:08:03 CEST

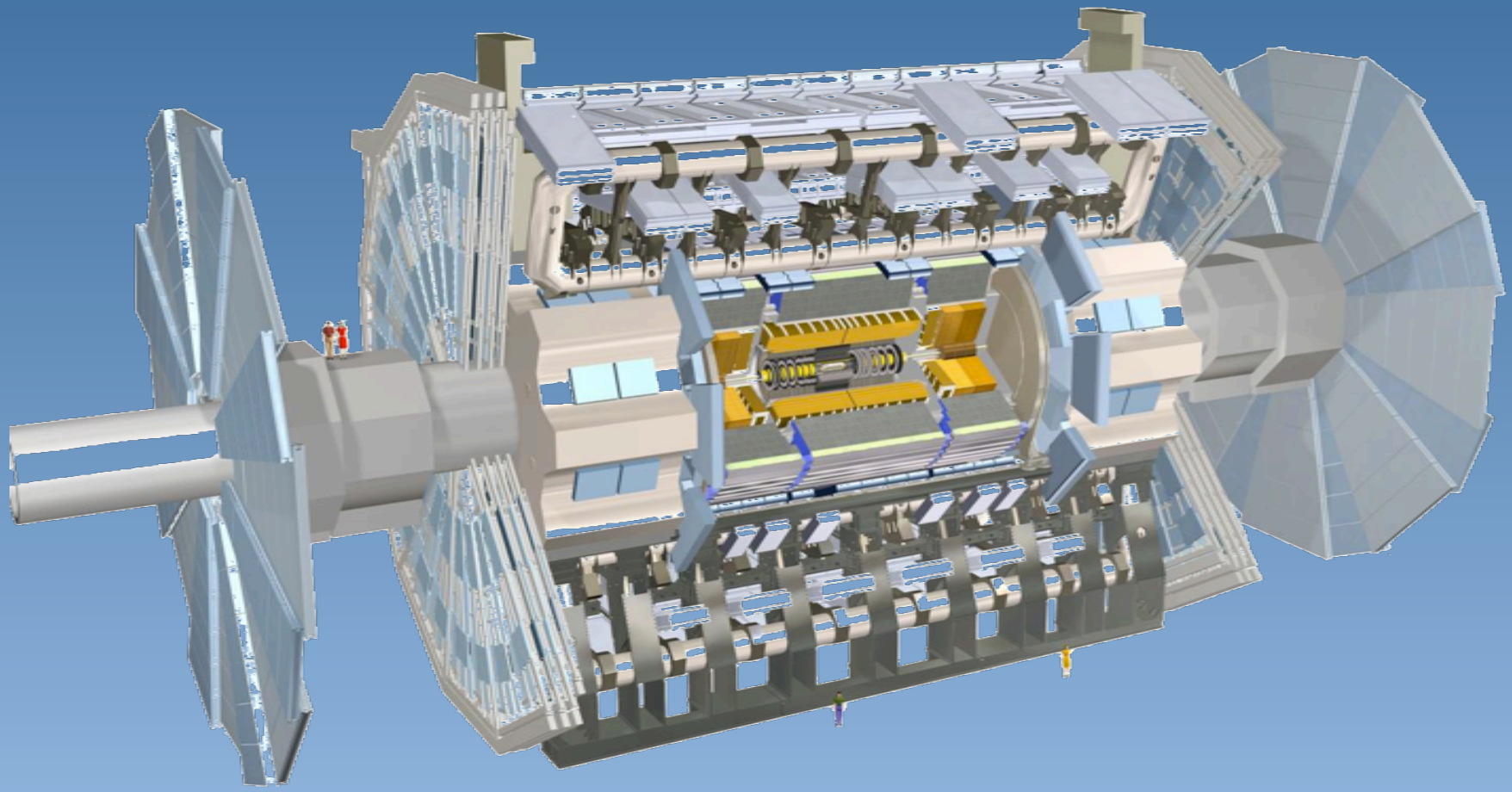

50 mm


ATLAS
EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidat
in 7 TeV collision

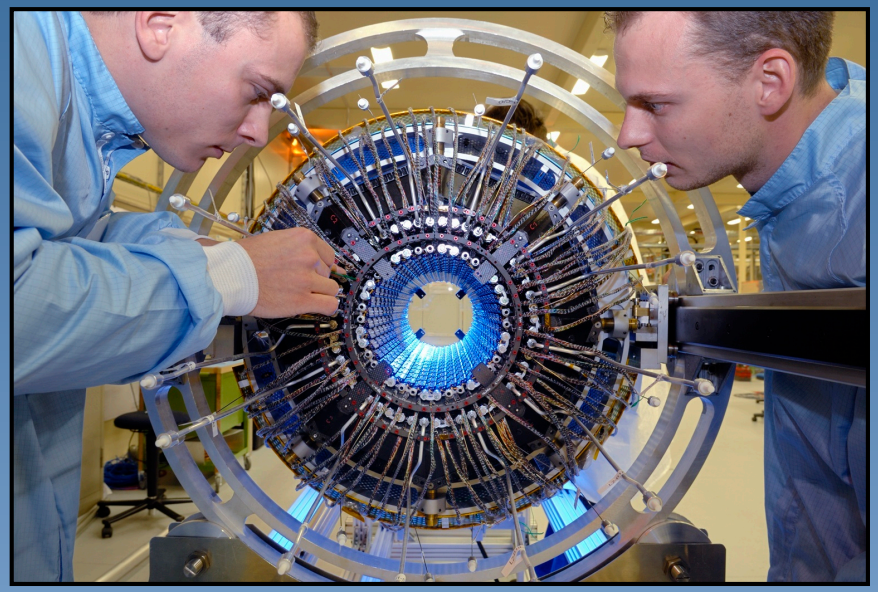

ATLAS
EXPERIMENT
http://atlas.ch
Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

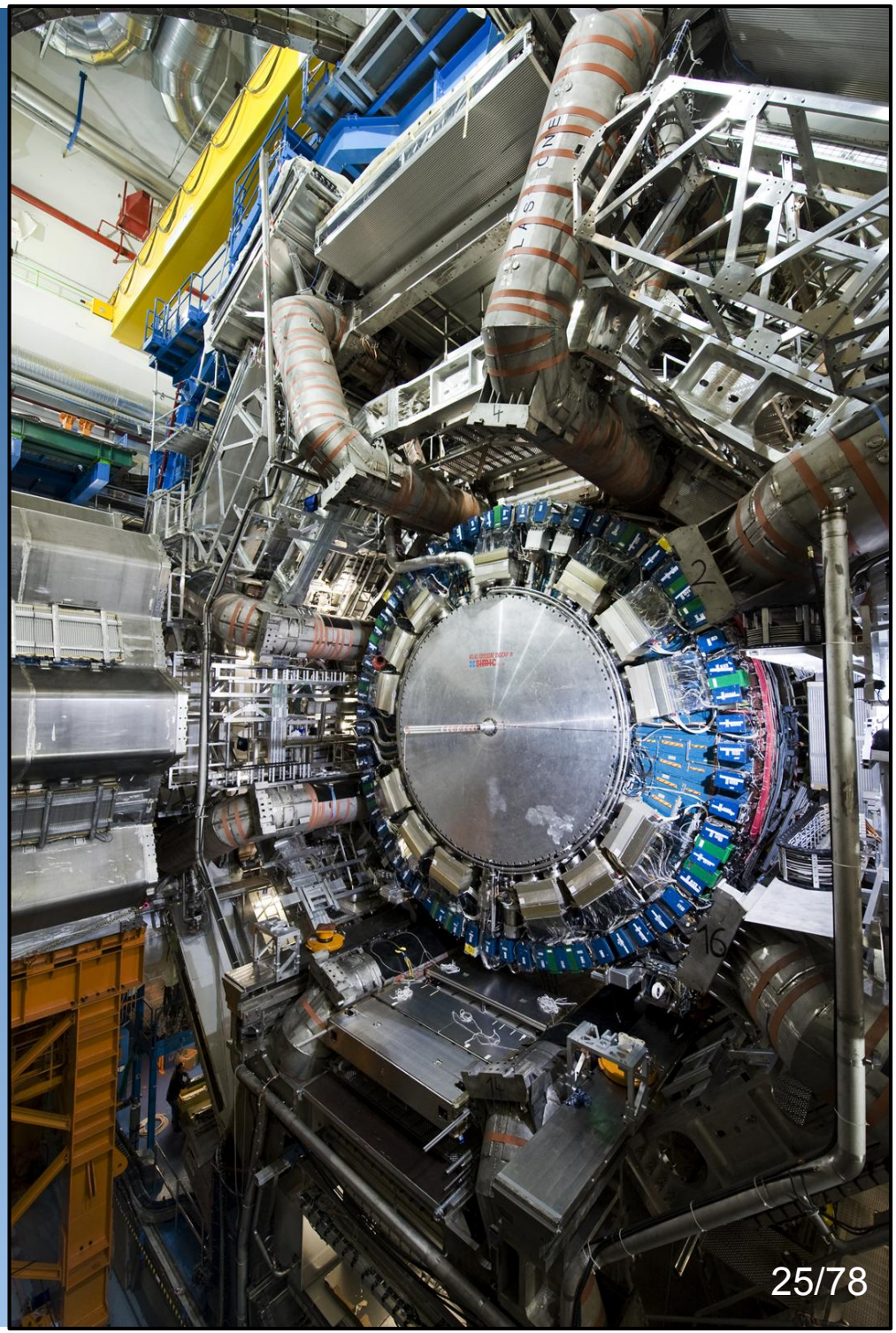

ATLAS
EXPERIMENT

The ATLAS detector
(as a computer model)

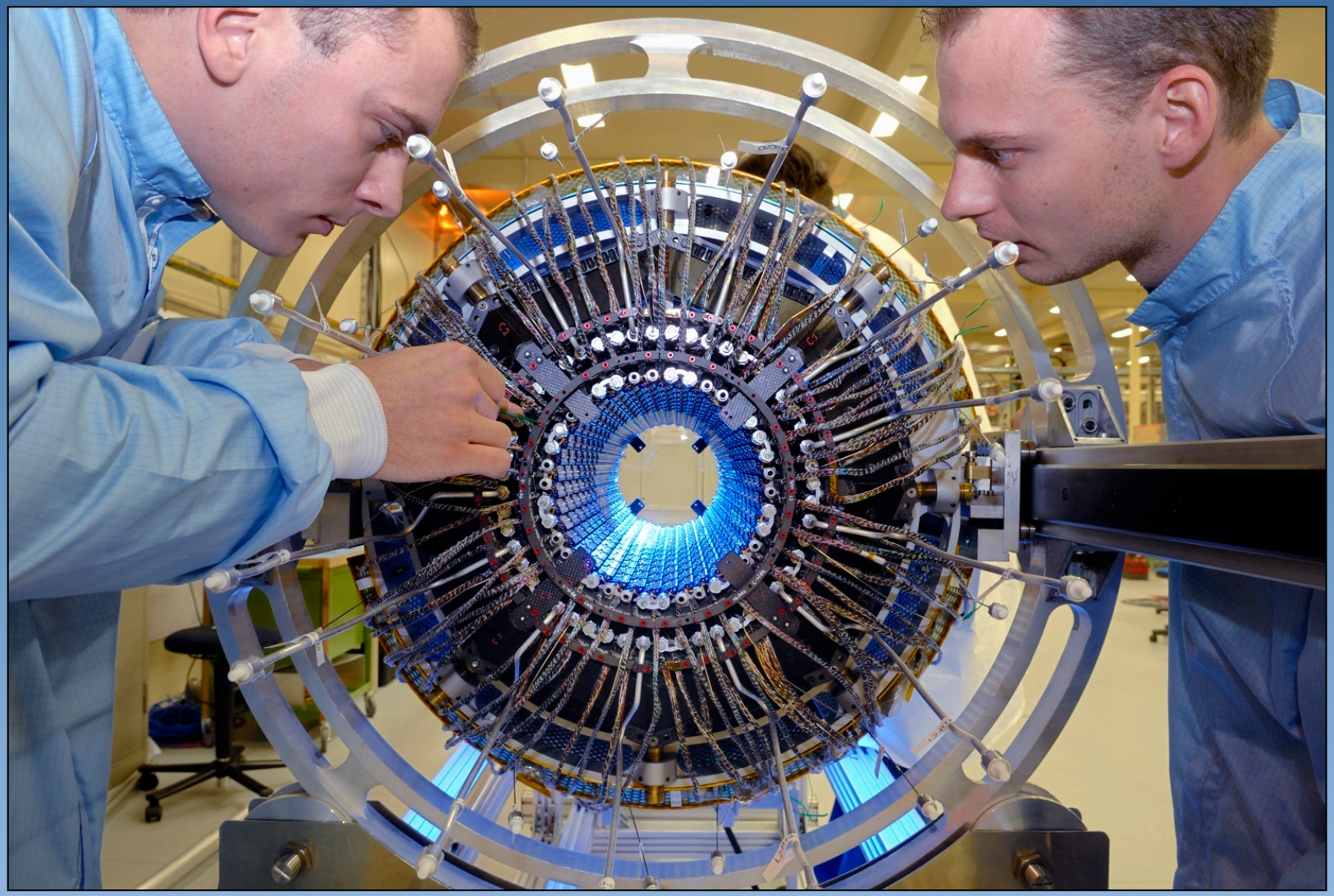


The ATLAS detector
(in real life)



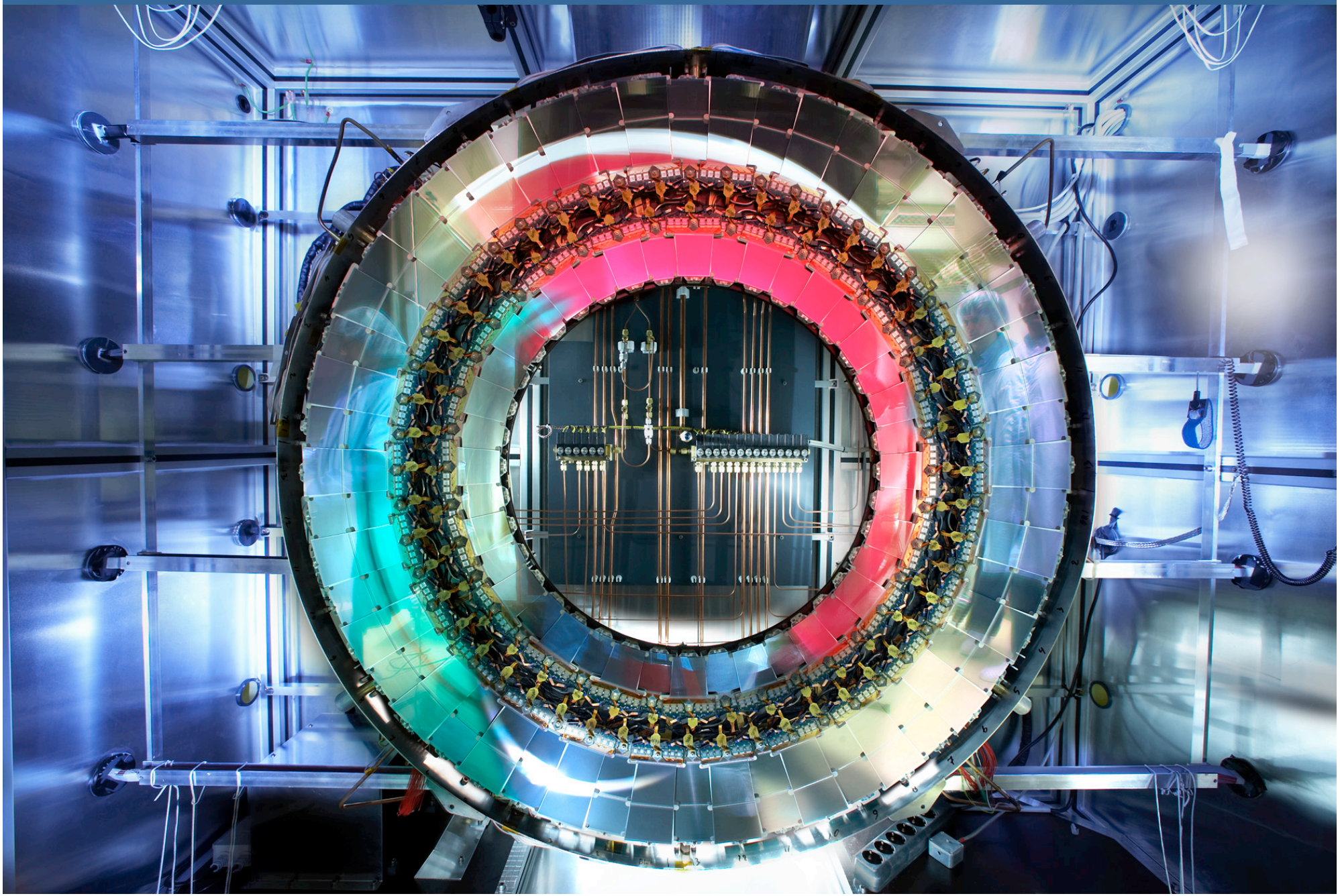


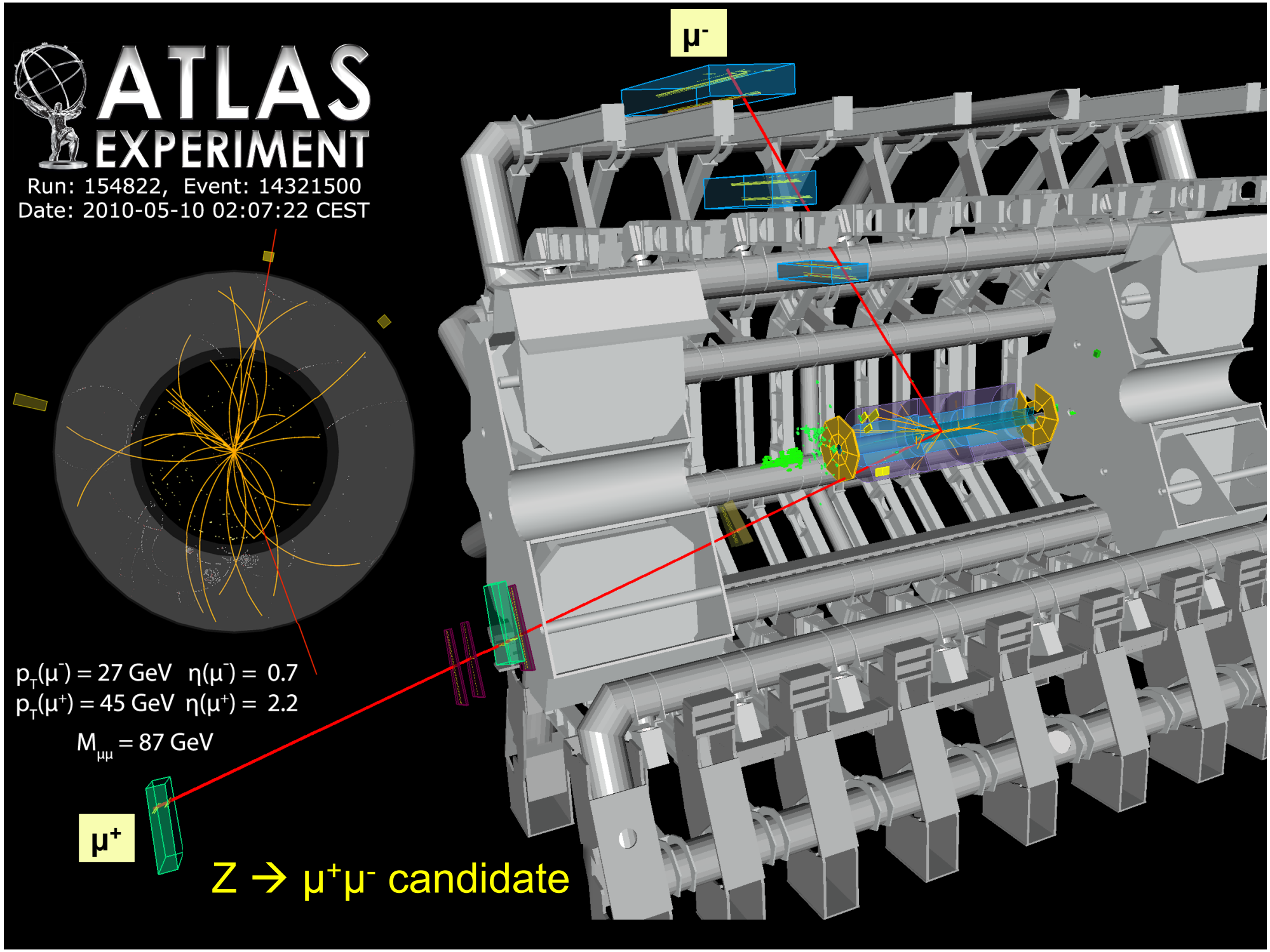
The Atlas pixel detector



80 MegaPixel camera 40.000.000 pictures per second

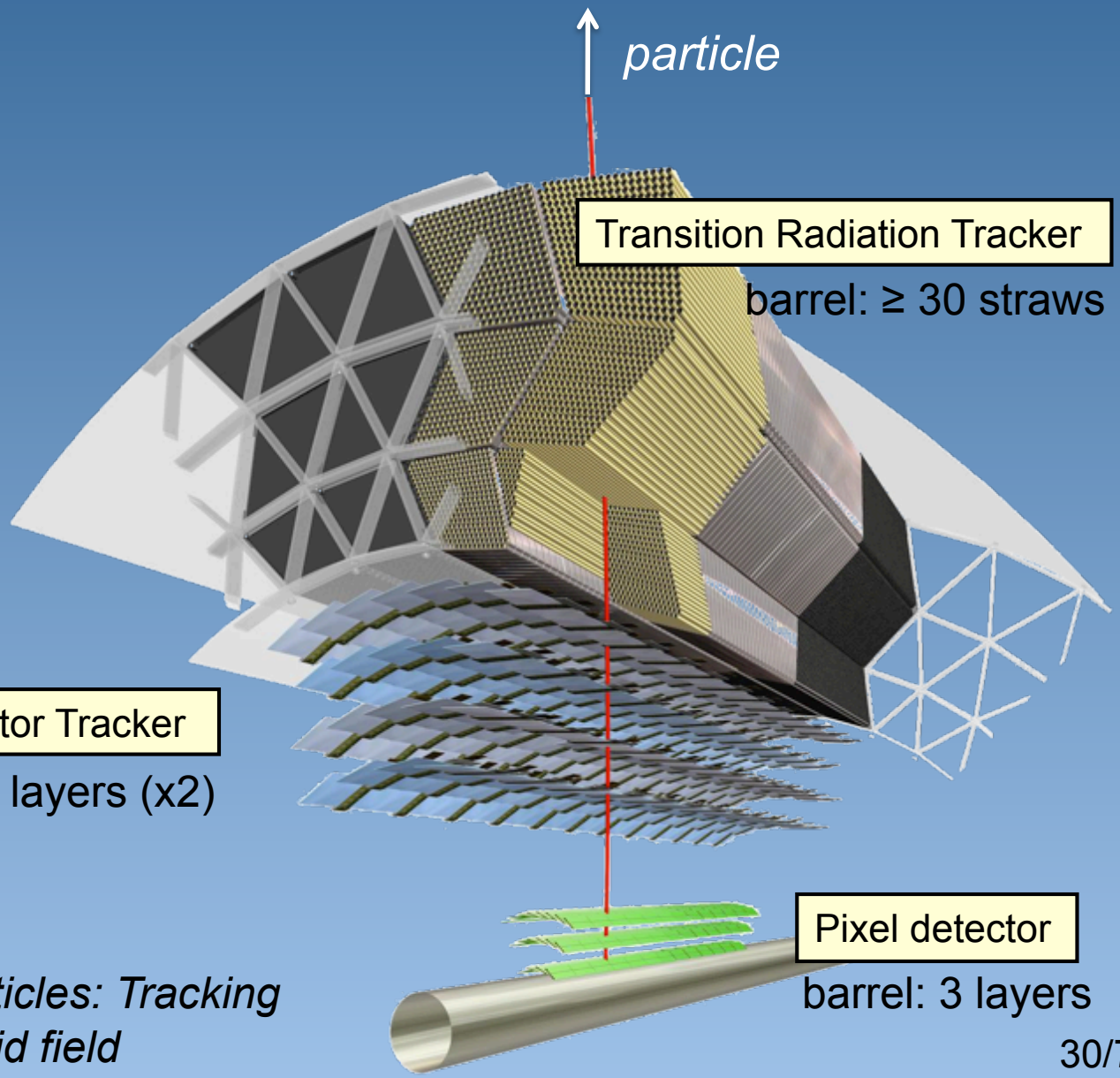
Part of the ATLAS detector has been designed and built at Nikhef




ATLAS
EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
μ-
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
μ+
Z → μ+μ- candidate

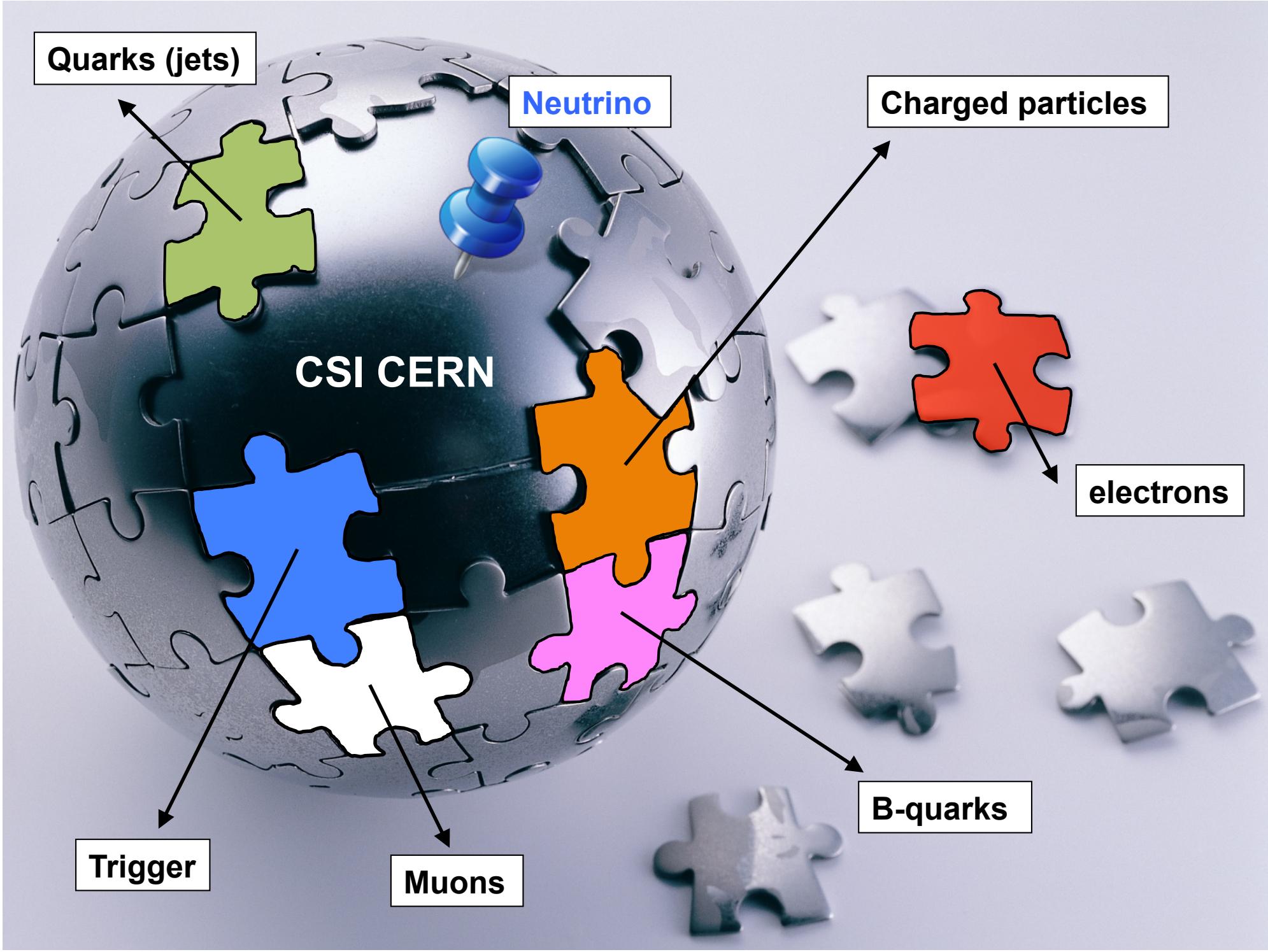
Complex structure ATLAS detector ?

Wide range of particle types / characteristics

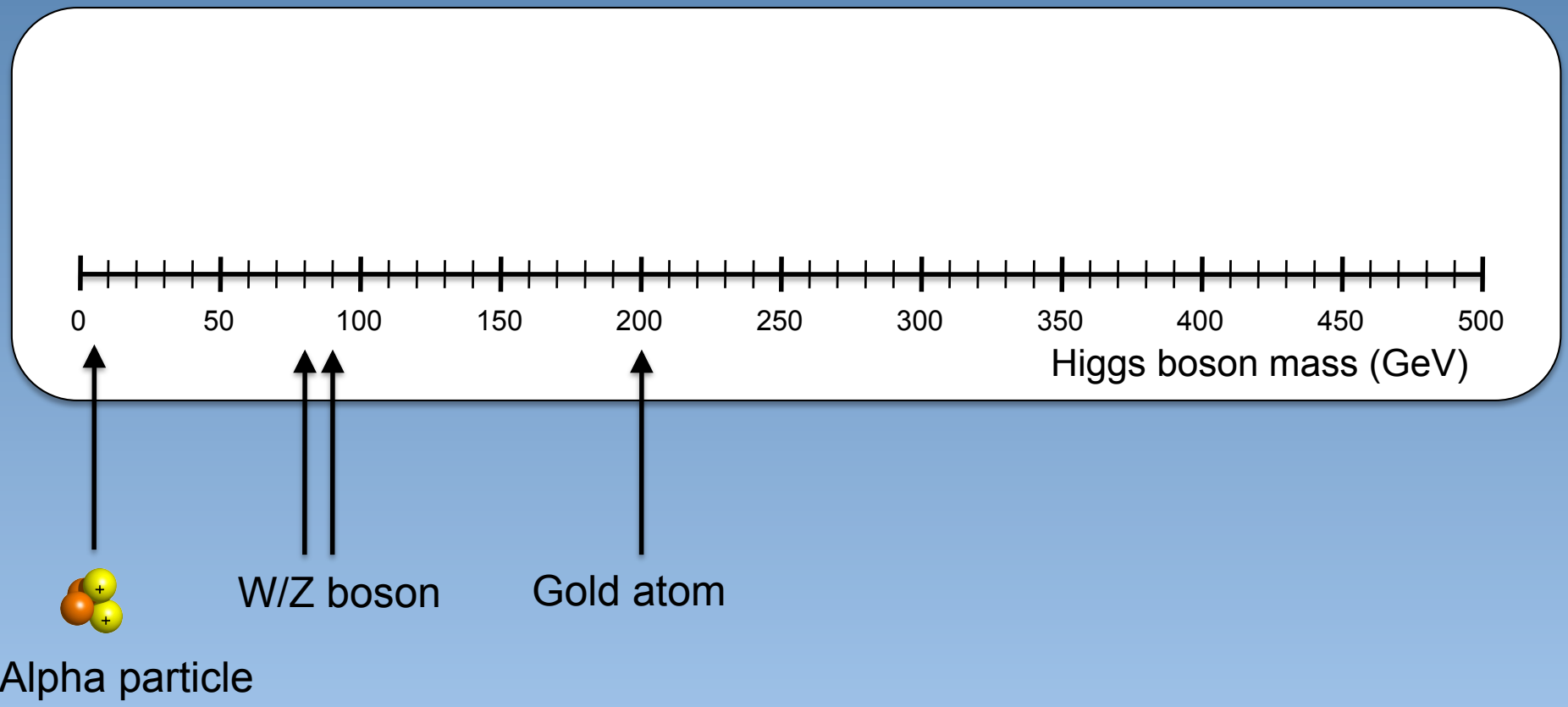


Momentum charged particles: Tracking detectors in a 2T solenoid field

Rabbit, car or human ?


Quarks (jets)
Neutrino
Charged particles
CSI CERN
electrons
B-quarks
Trigger
Muons

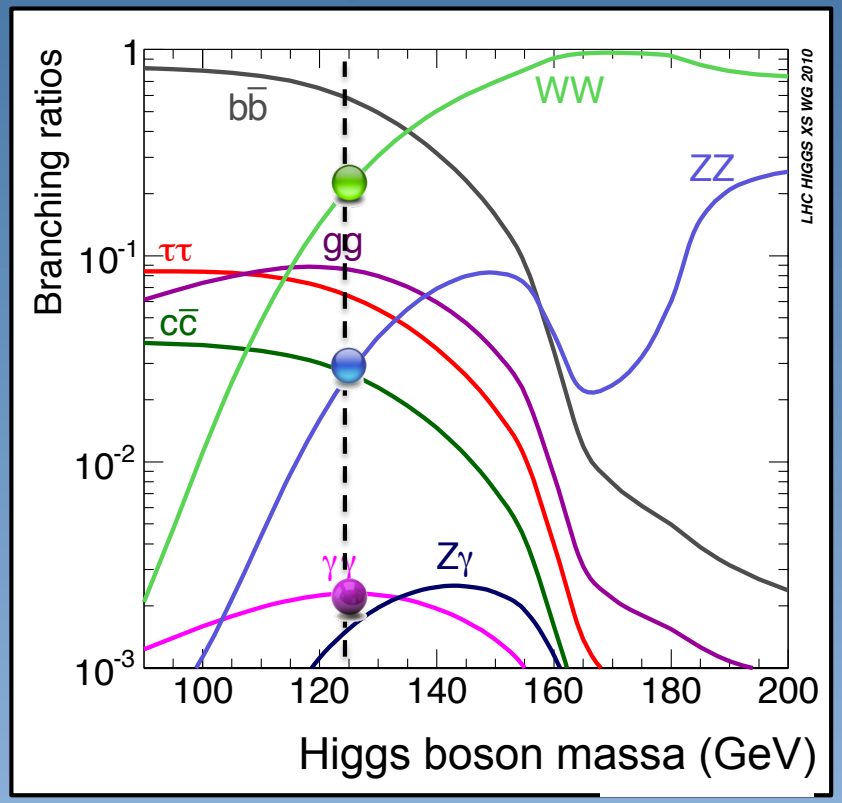
The mass of the Higgs boson

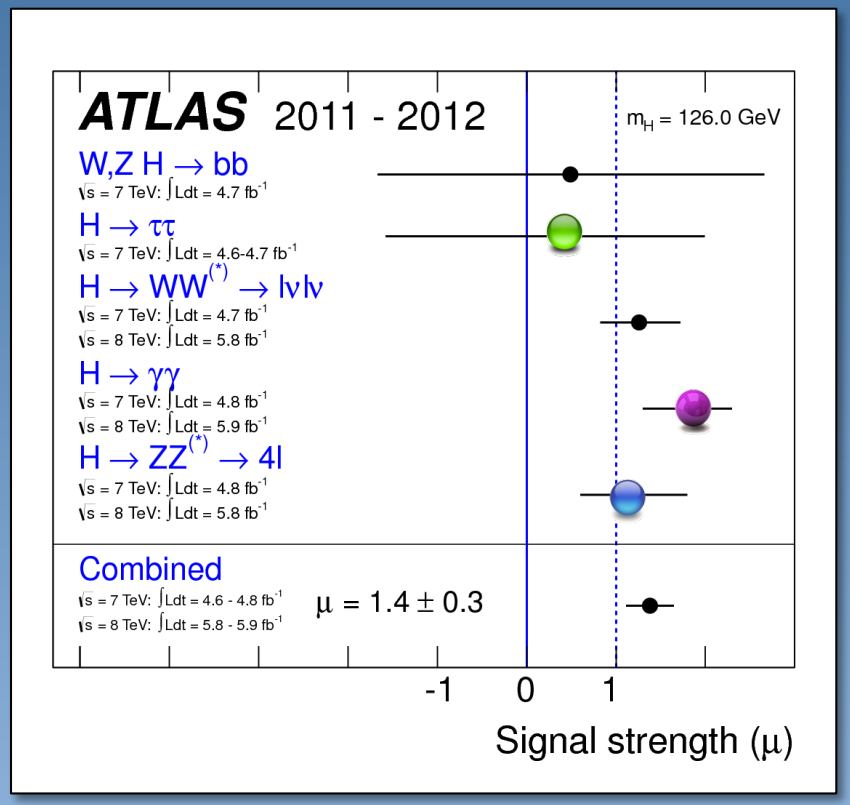


Kloppen Higgs' eigenschappen ?

m_h=125 GeV

Standaard Model



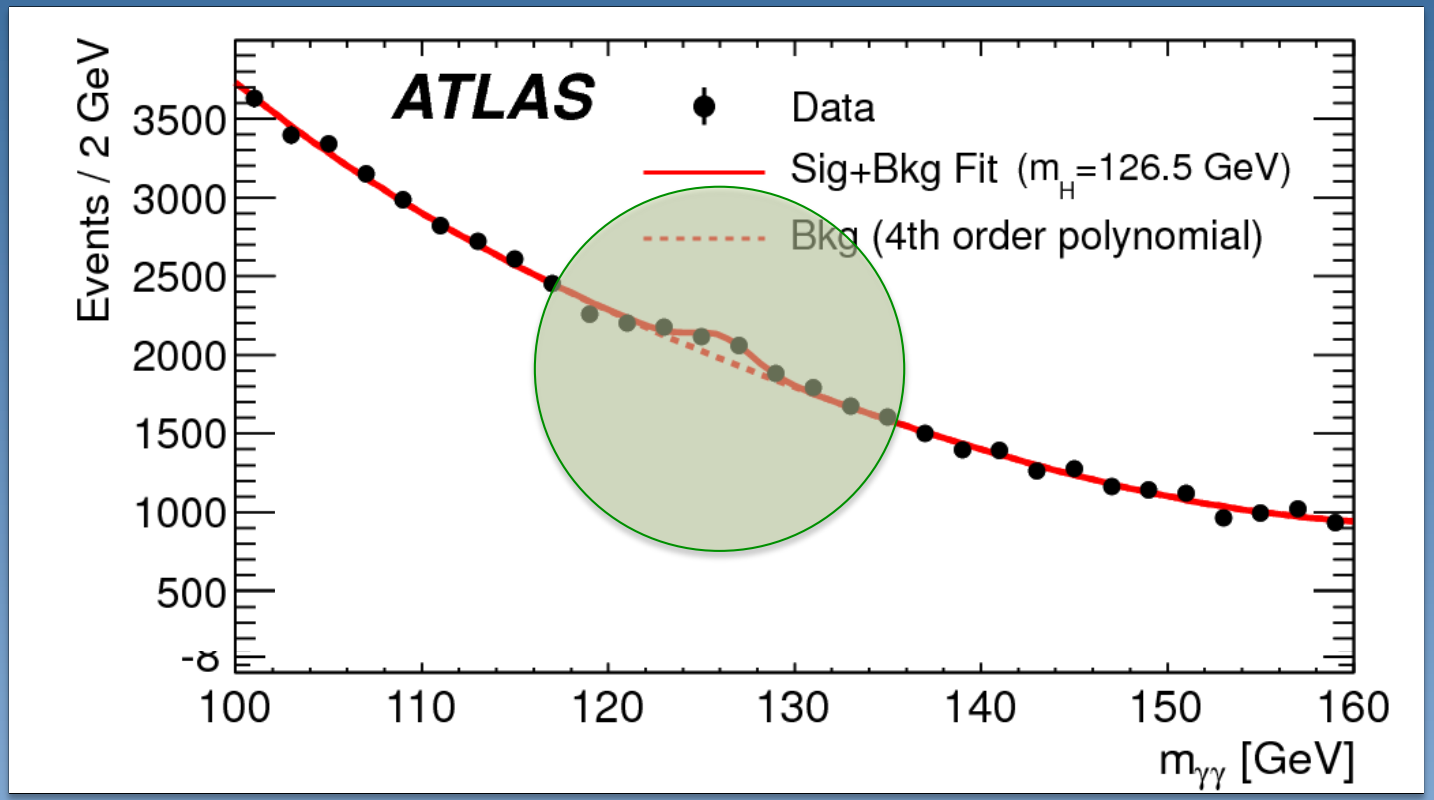


voorspelling

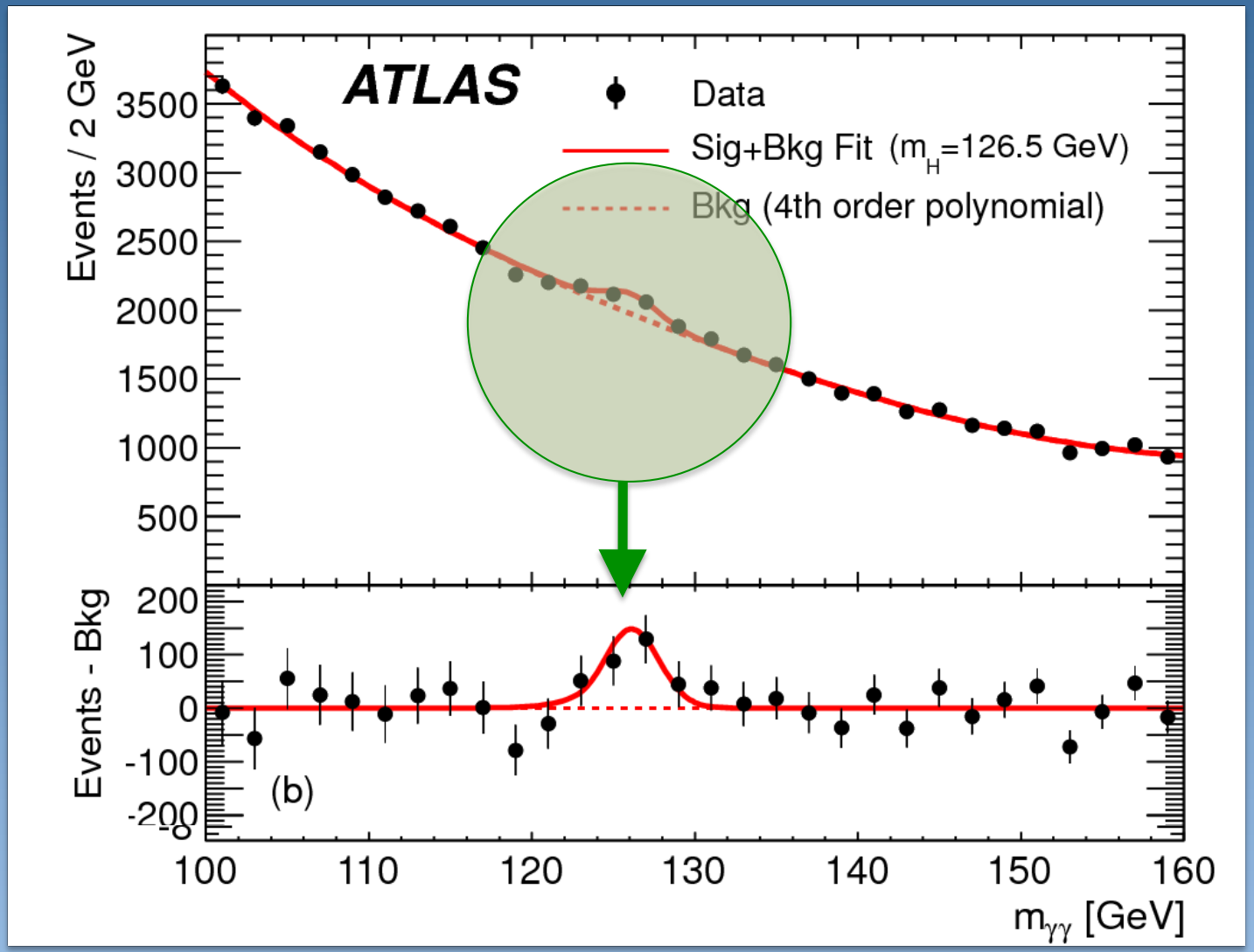
meting

Higgs boson verval naar 2 fotonen

The ATLAS data



The ATLAS data

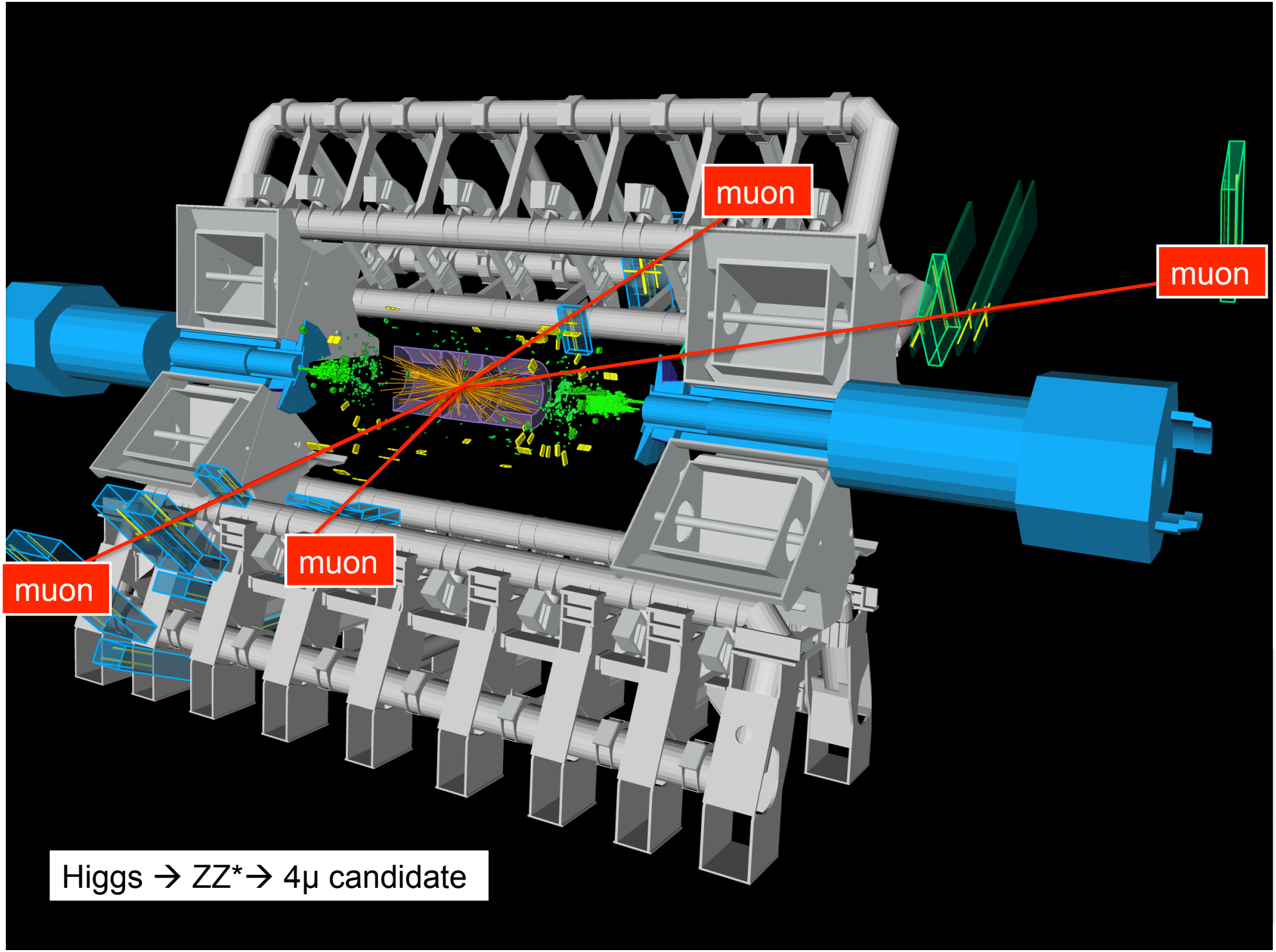


Quantify the significance ?

Combine the evidence

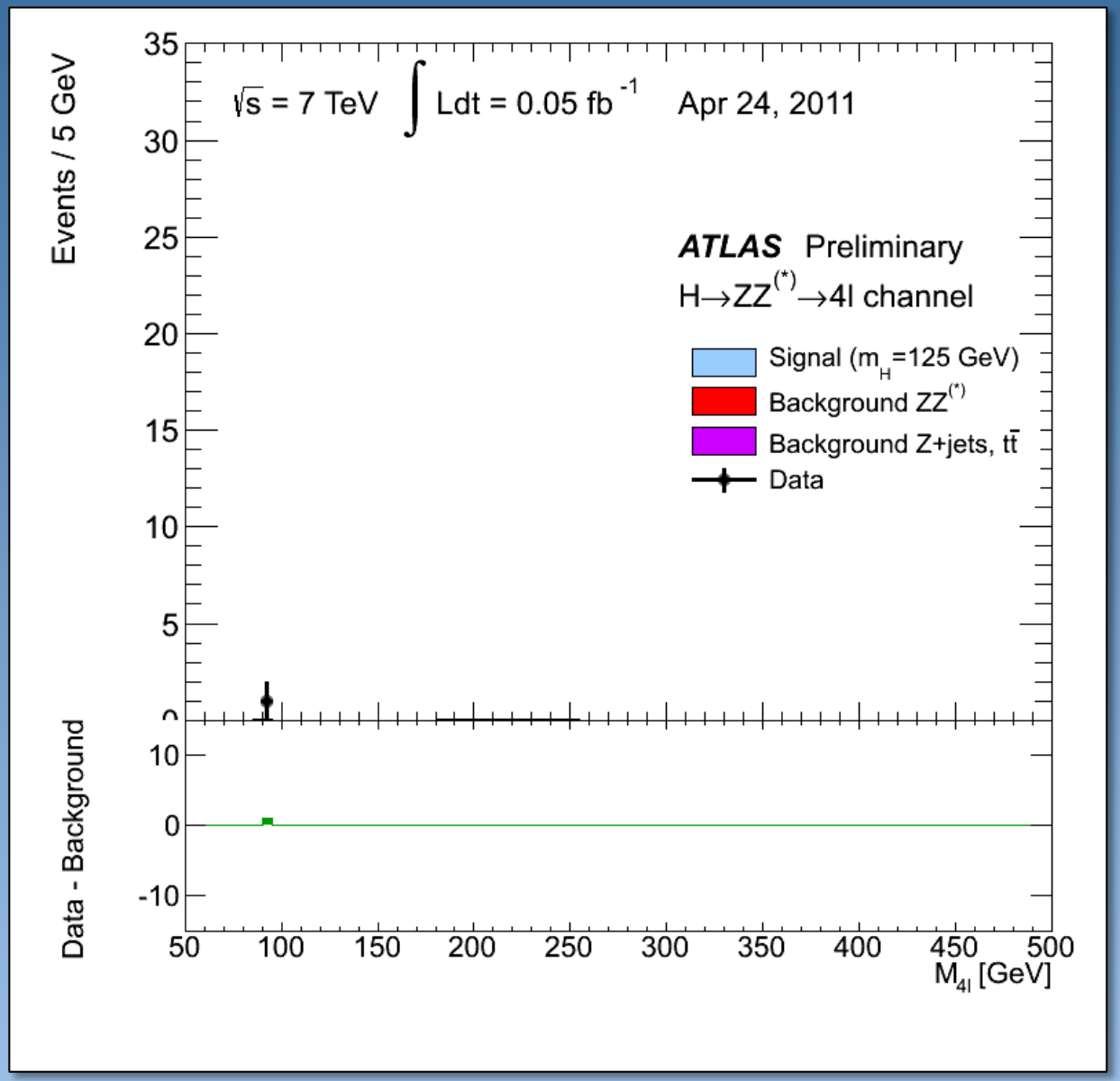
$h \rightarrow \gamma\gamma$, $h \rightarrow ZZ^*$ and $h \rightarrow WW^*$

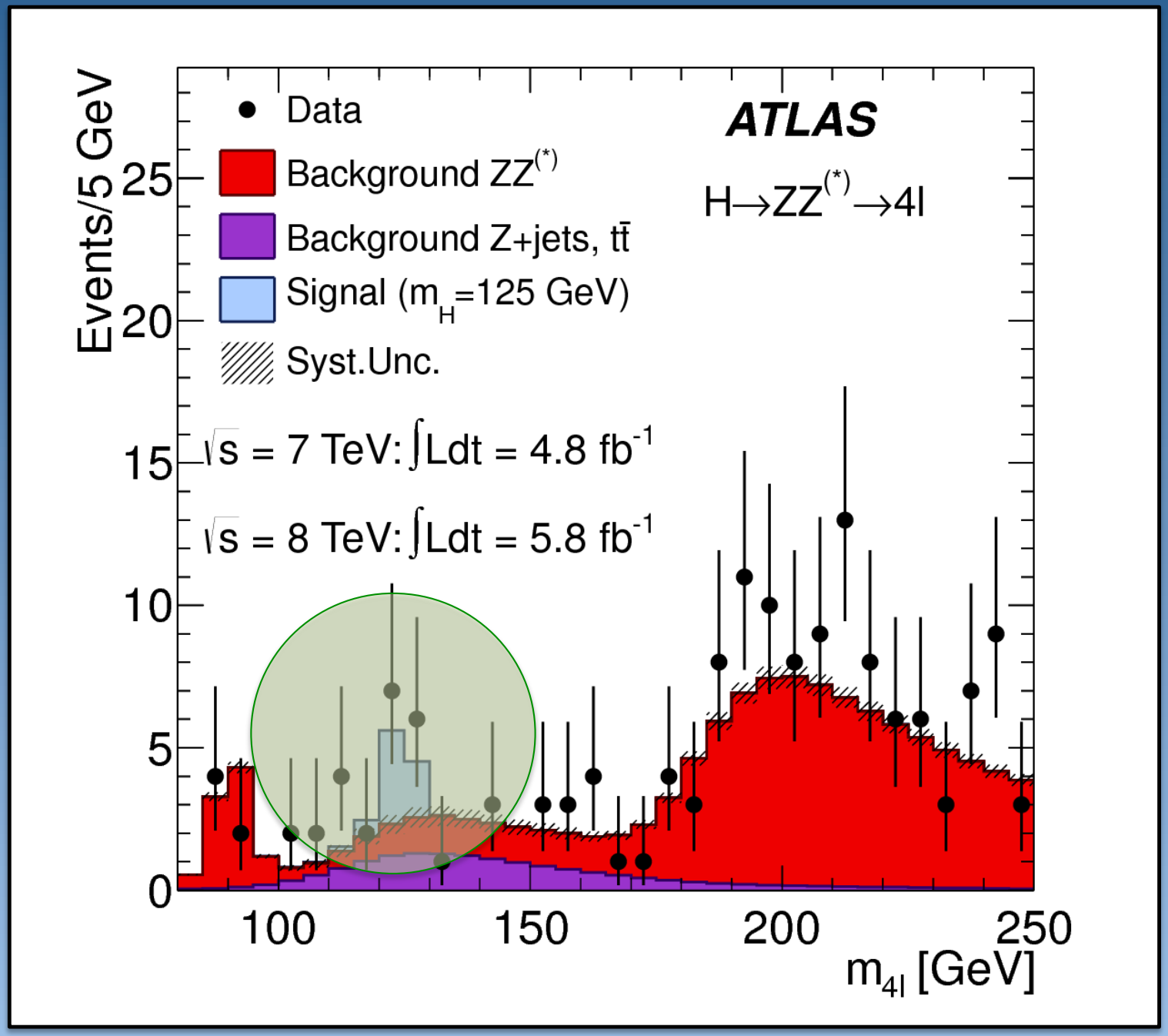
Higgs boson verval naar 4 muonen



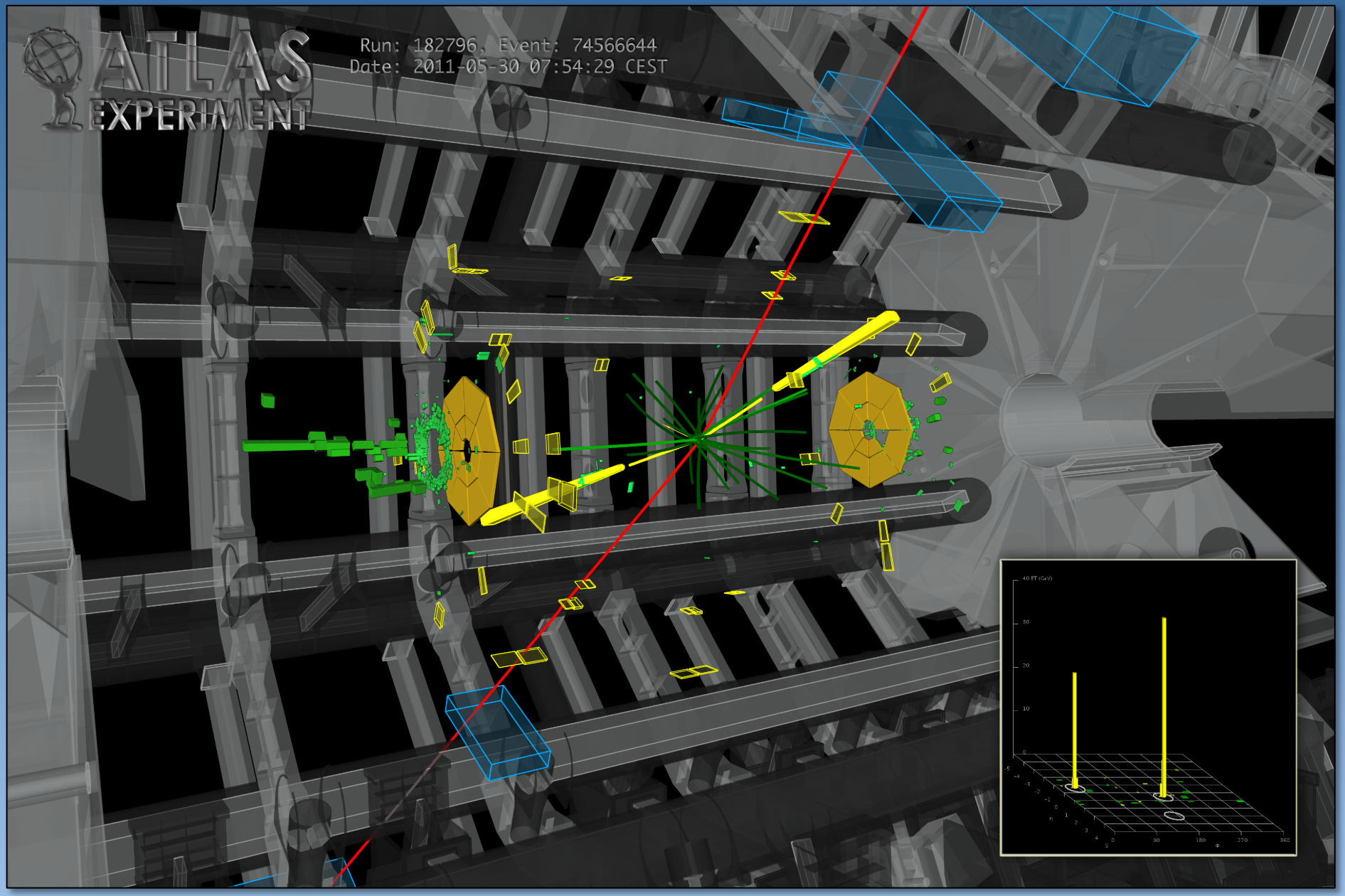
Higgs → ZZ*→ 4μ candidate

Look here (m_h = 125 GeV)



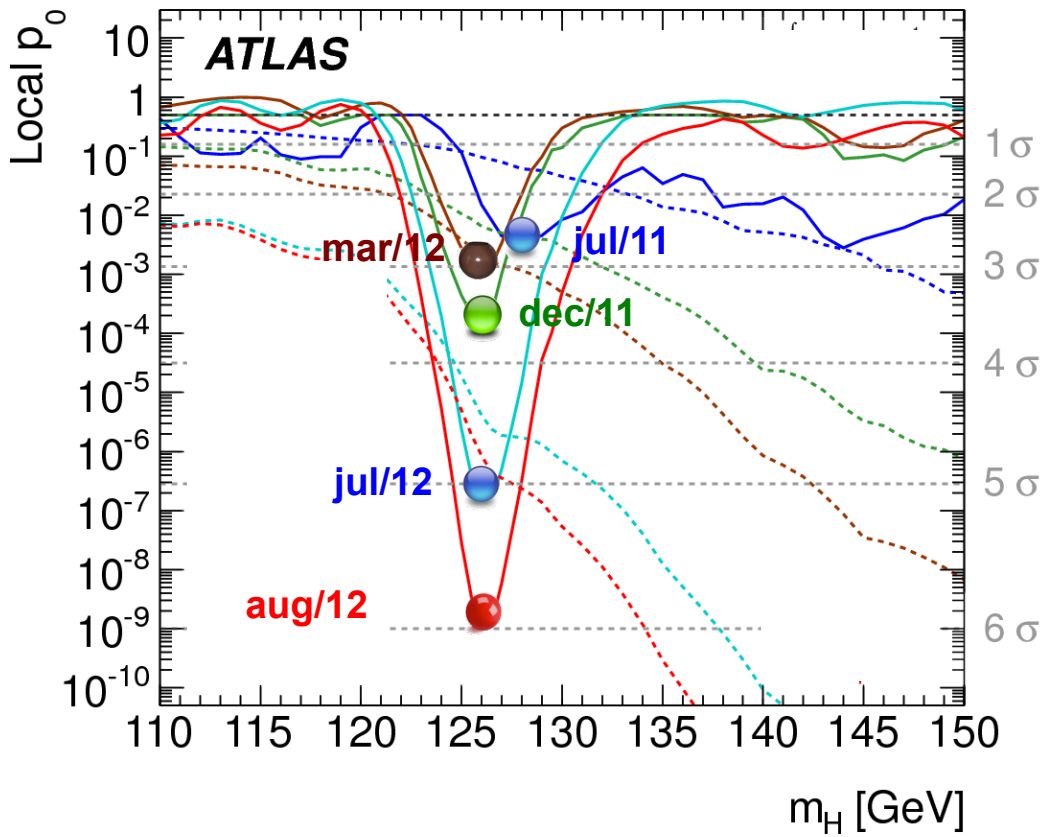

Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (mH=125 GeV)
Syst.Unc.
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
ATLAS
H→ZZ(*)→4l
Events/5 GeV
0
5
10
15
20
25
100
150
200
250
m4l [GeV]

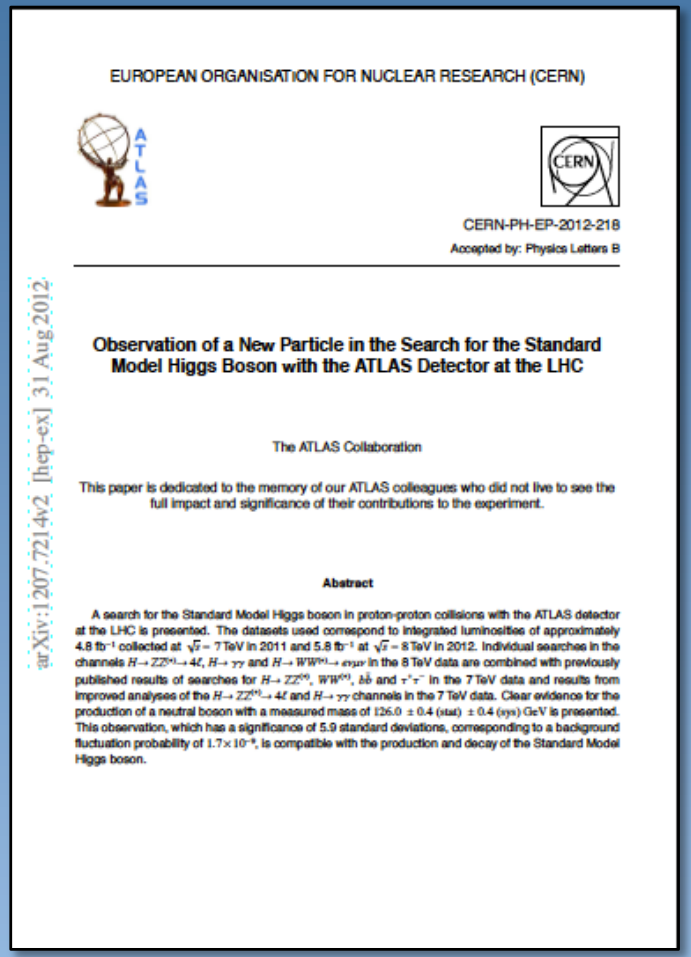
Another Higgs candidate: 2 electrons and 2 muons



A discovery in slow-motion

Time-line higgs discovery





EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

arXiv:1207.7214v2 [hep-ex] 31 Aug 2012

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4\,(\mathrm{stat}) \pm 0.4\,(\mathrm{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

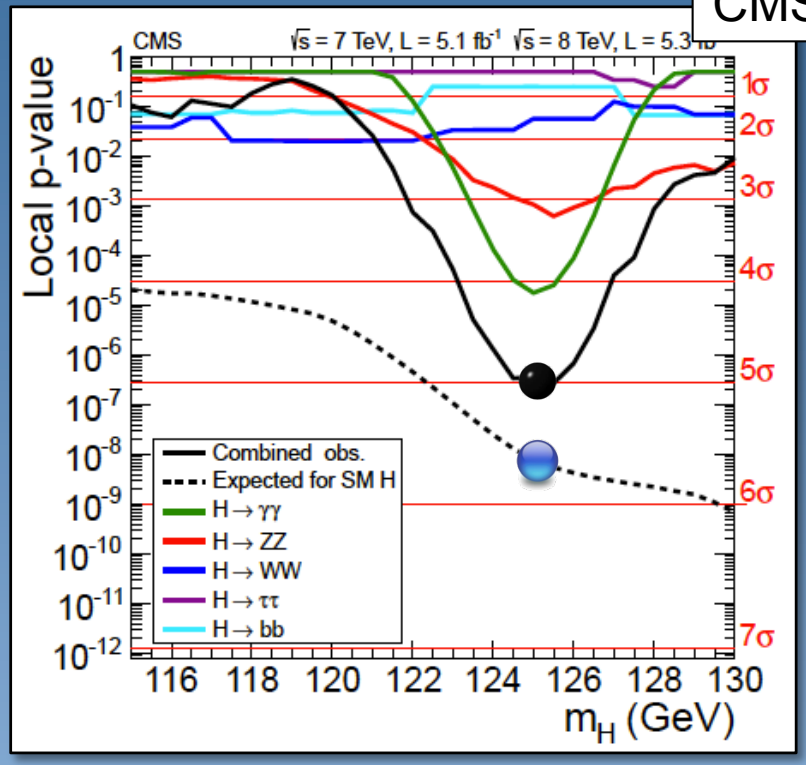
$m_h = 126.0 \pm 0.4$ (stat) ± 0.4 (syst) GeV

‘Are you sure Ivo ?’
‘Yes Diederik, we’re pretty sure’

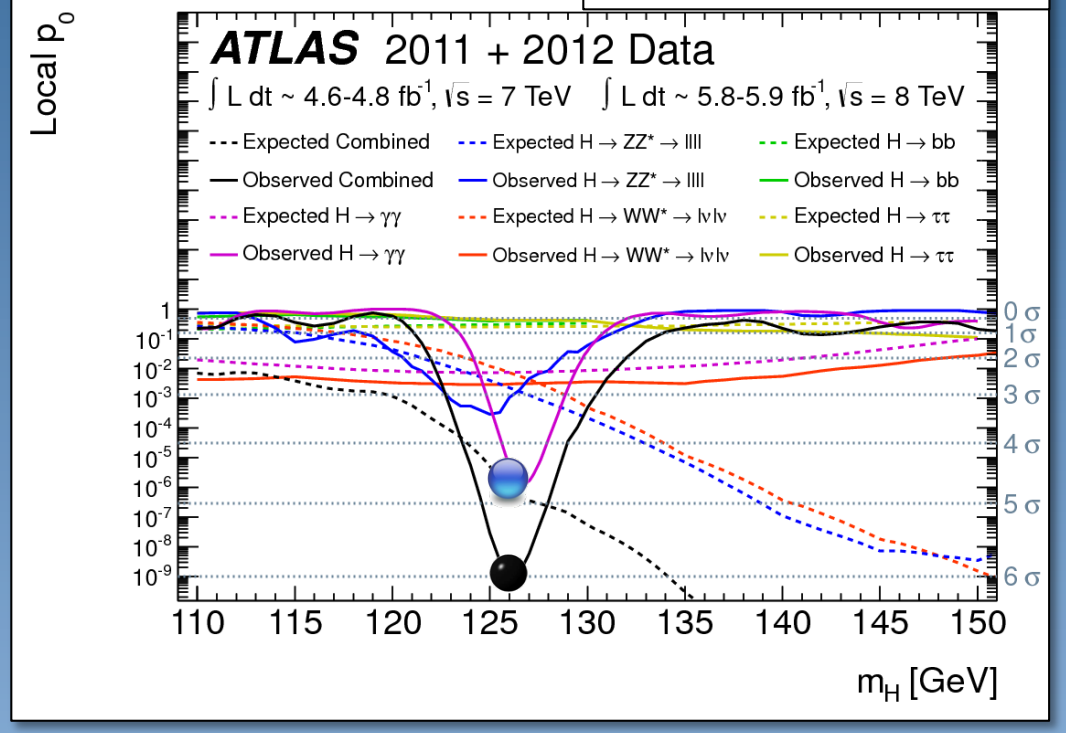
‘Independent cross-check ?’ ‘ Yep!’

Comparison results from ATLAS and CMS experiments

CMS



ATLAS experiment

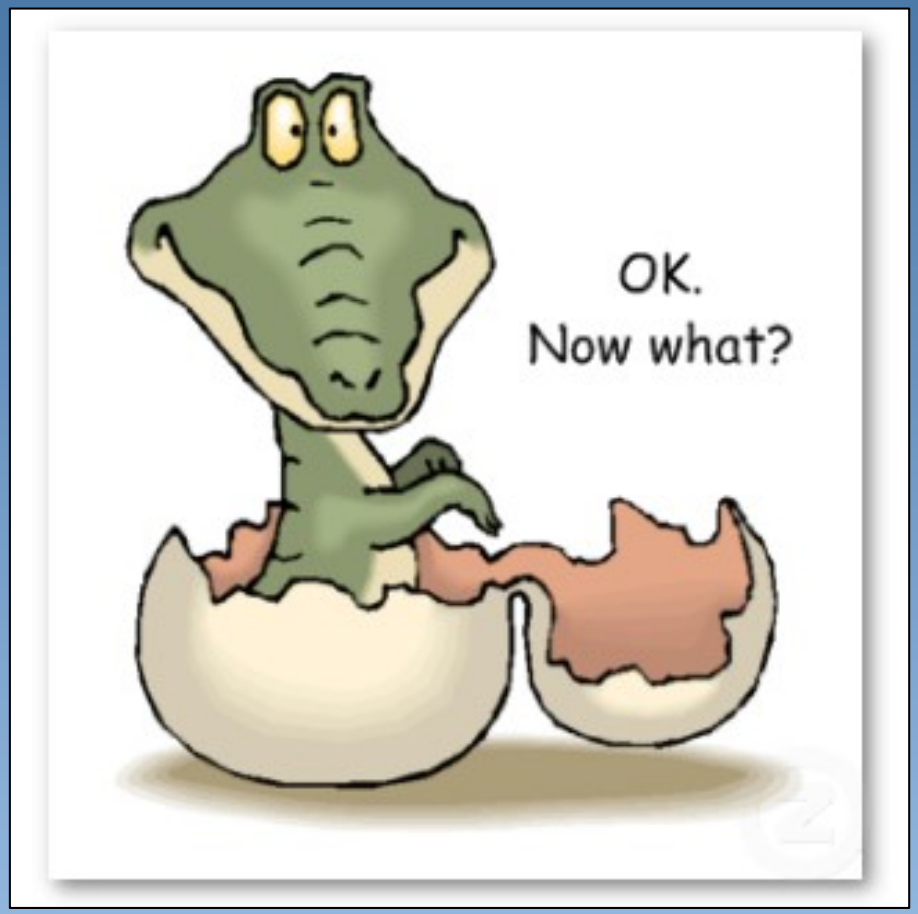


Conclusion (in July):

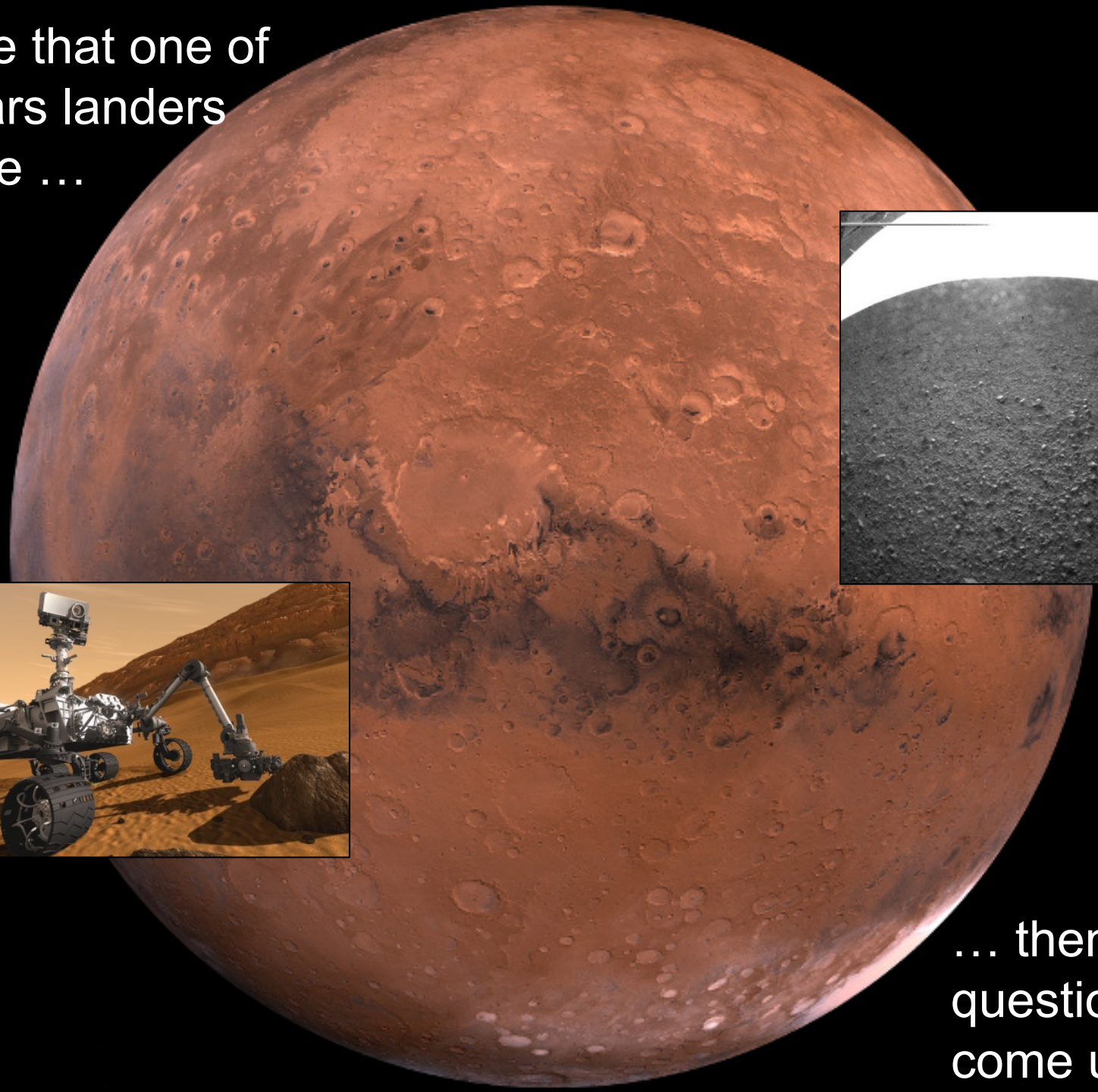
- 2 experiments observe new particle
- CMS more sensitive than ATLAS
  … but ATLAS was lucky
  ATLAS had highest observed significance

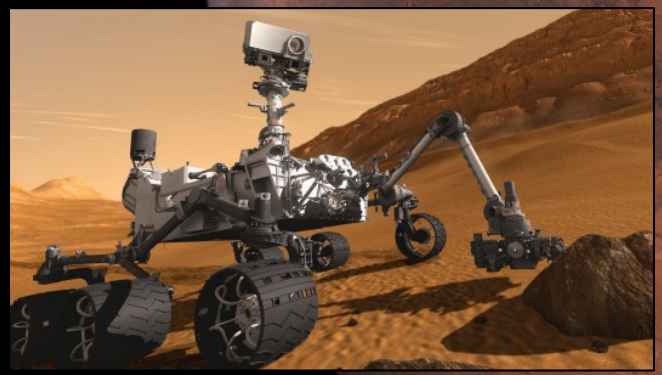
Presentation CMS en ATLAS experiment: Higgs boson discovery

5 juli 2012: ok now what ?



Imagine that one of the mars landers finds life …



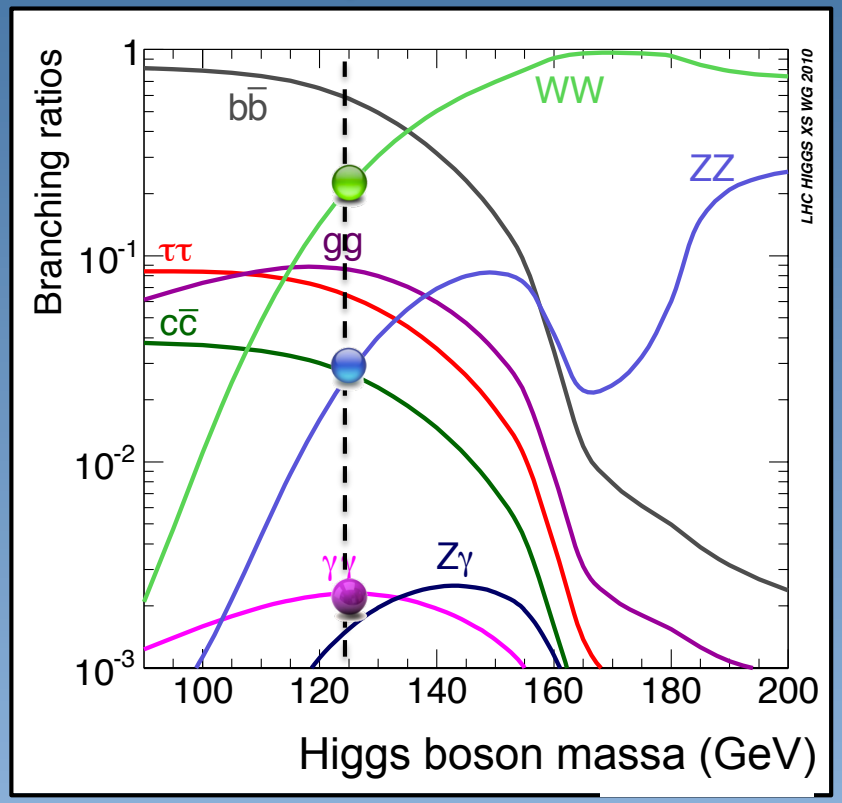


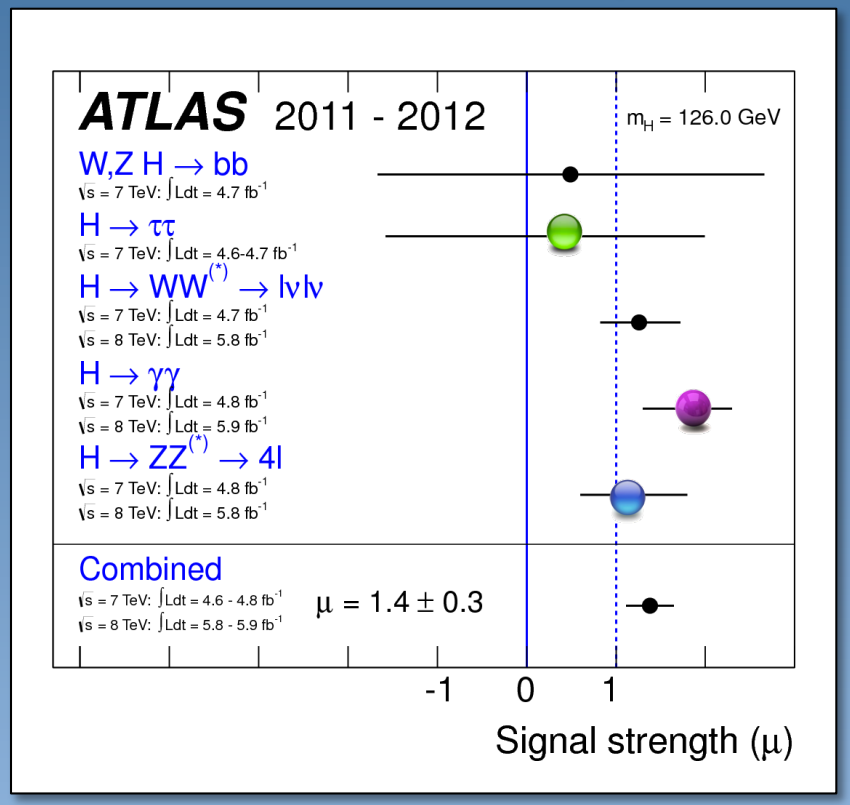
… then 1000 questions come up

Kloppen Higgs' eigenschappen ?

m_h=125 GeV

Standaard Model





voorspelling

meting

Some ‘tiny’ issues in a world with a Higgs field:

- Higgs does not give any hint to particle masses or dark matter

- Contribution to $\rho^{vac}_{Higgs}\ (\Omega_\Lambda)$ factor 10^{54} off

Why is the universe larger than a football ?

What are the remaining mysteries ?

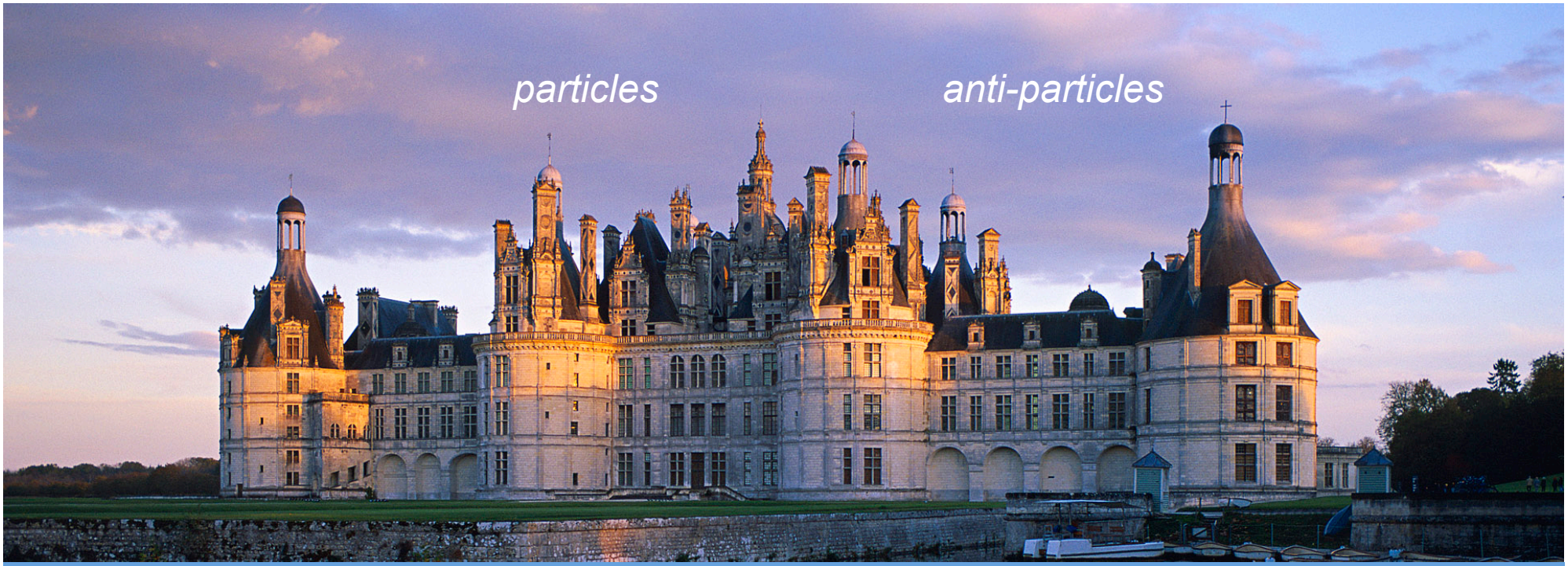
Paar 'kleine' dingetjes:

1. 96% of the energy in the universe is unknown
   → dark matter (24%) what is that ?
   → dark energy (72%) what is that ?

2. Where did all the anti-matter go ?

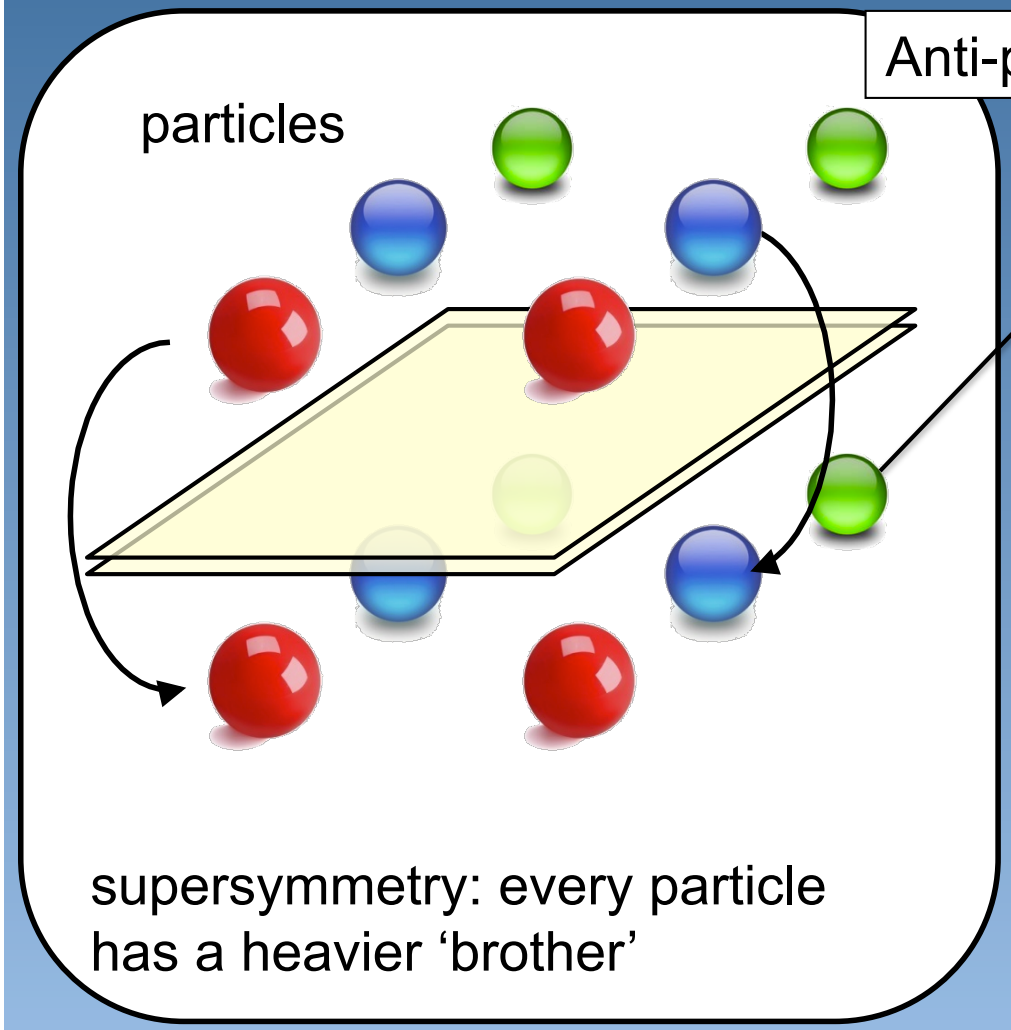
3. How do particles acquire mass ? Higgs boson ✔

4. Why is gravity so weak ?


particles
anti-particles

Dark Matter

Theoretical idea: supersymmetry:



Lightest one = dart matter ?

- Produce it yourself **(LHC)**
- Look for collisions in earth (**Xenon**) ?
- Signatures in space (**Fermi**)

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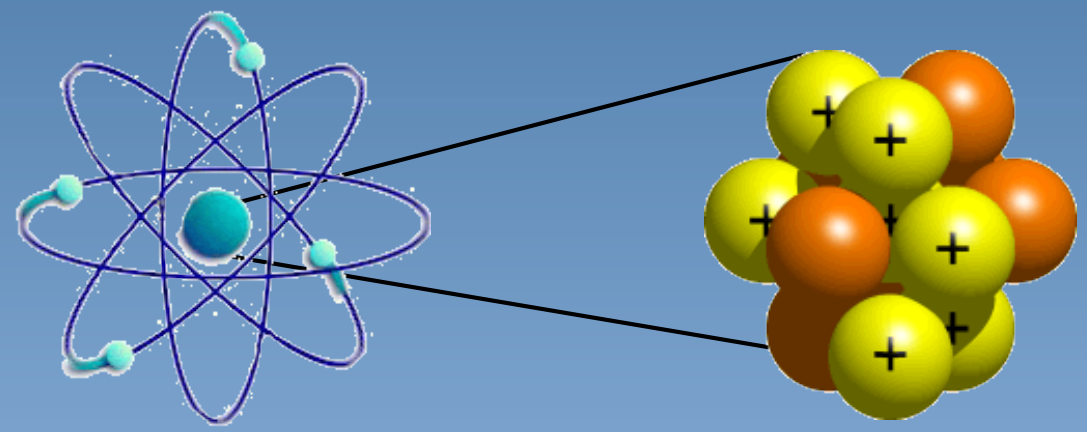
Is de zwaartekracht echt wel zoveel zwakker dan de andere 3 natuurkrachten ?

- Within a nucleus, all forces (except gravity) are equally strong
  … and *quantum* theories



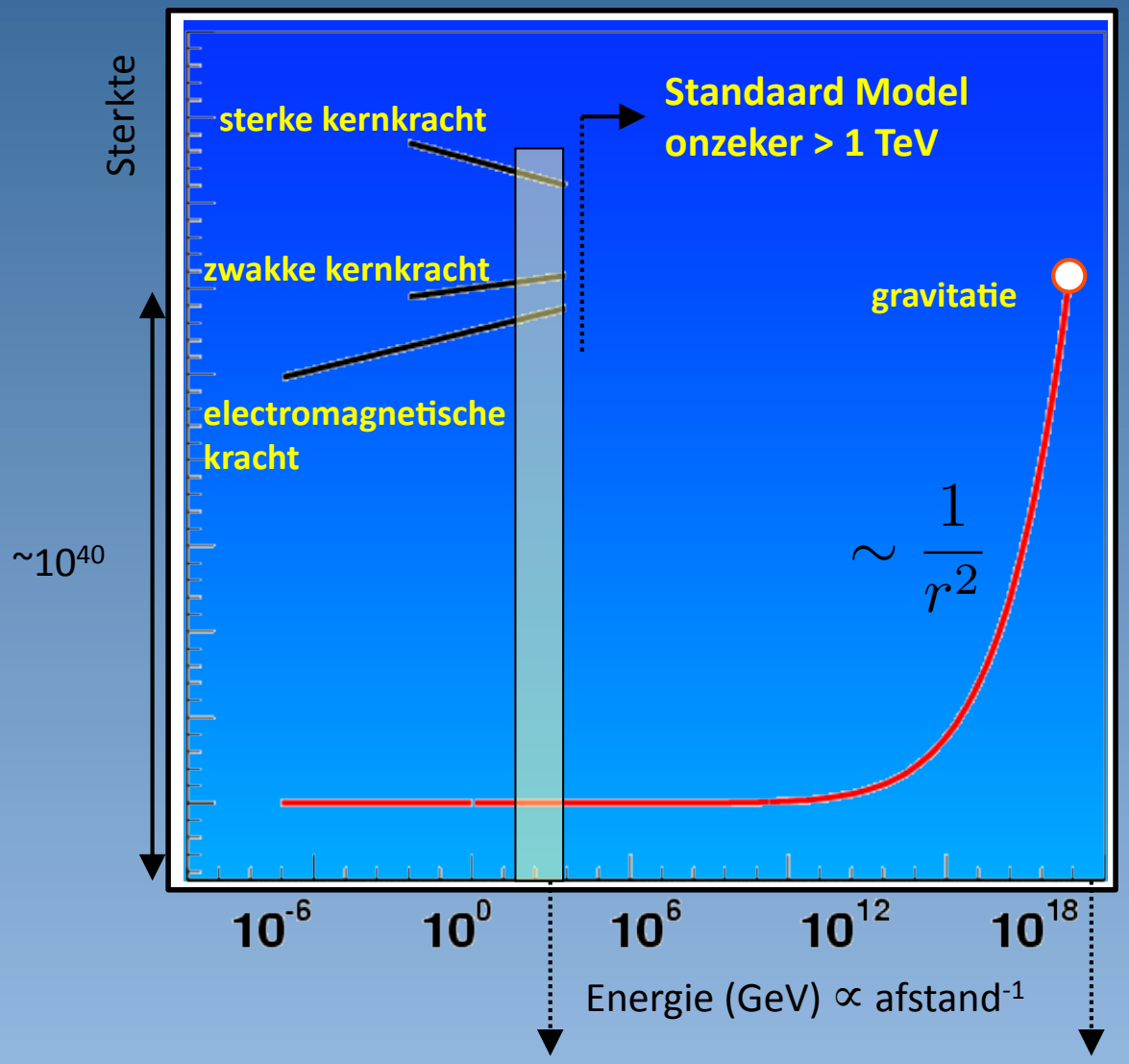
gravity ~10^{40} times smaller

- New theory: 1) Gravity is as strong as the other forces, but it only *appears* weak because of the presence of **extra space-dimensions**

  2) Around 10^{-20} m gravitaty is as strong as the other forces

De 3+1 forces of nature

quantum theories



no quantum theorie
string theorie?

Electrozwakke schaal

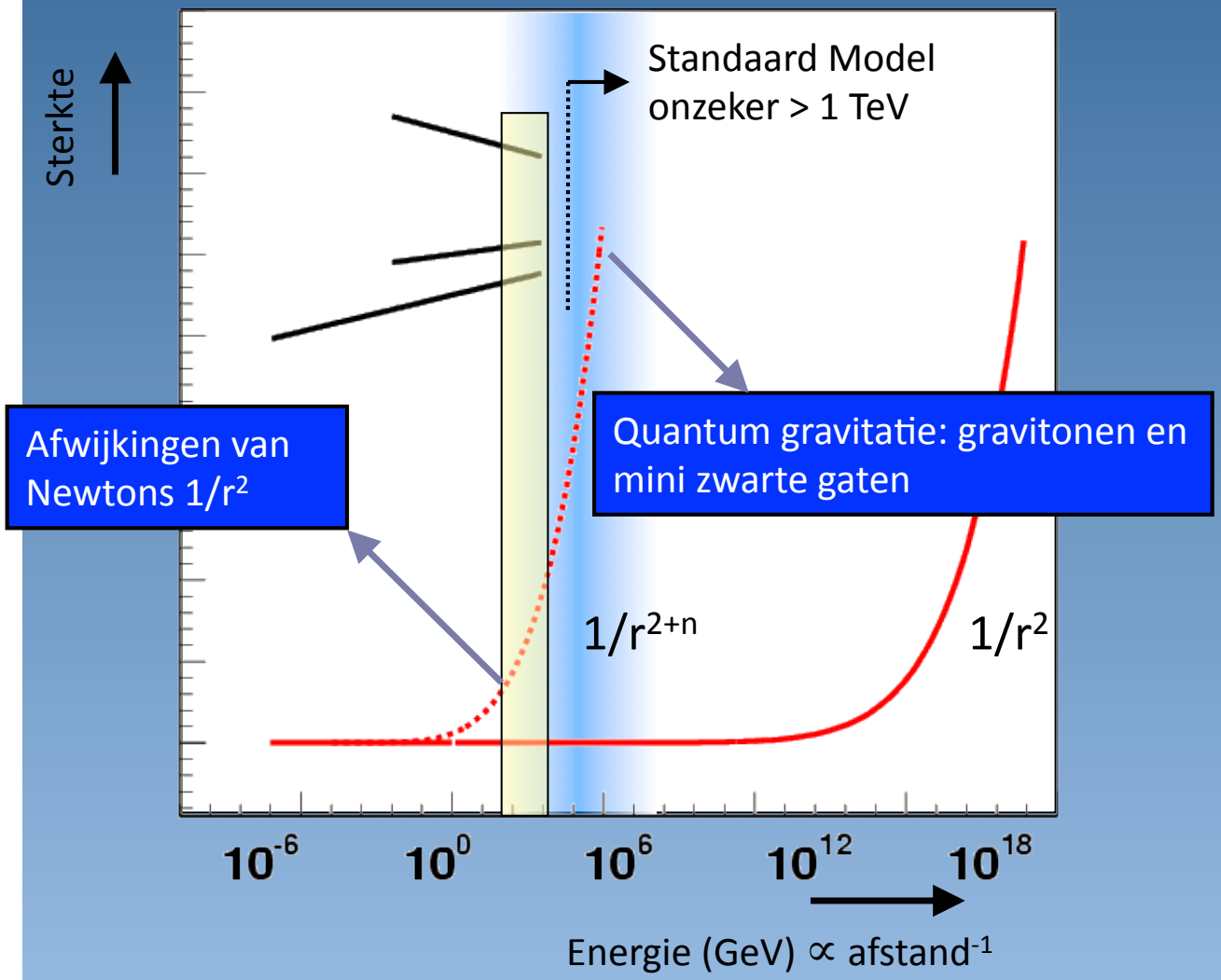
100 GeV ~10^{-18} m

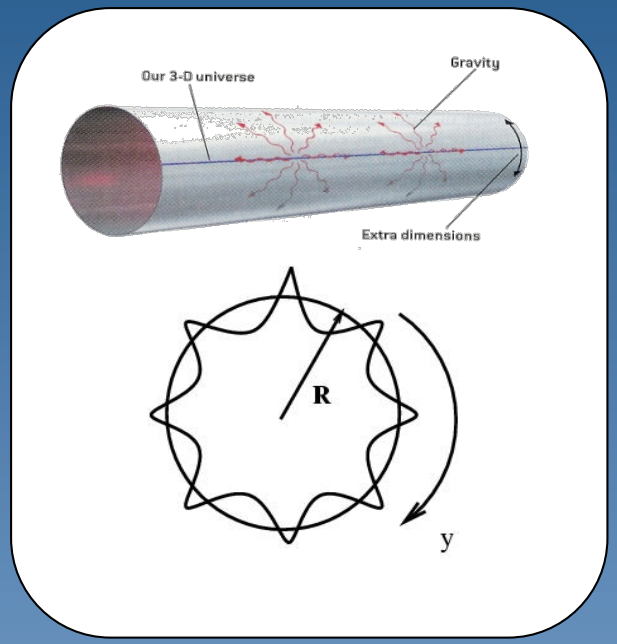
Planck schaal

10^{19} GeV ~ 10^{-35} m

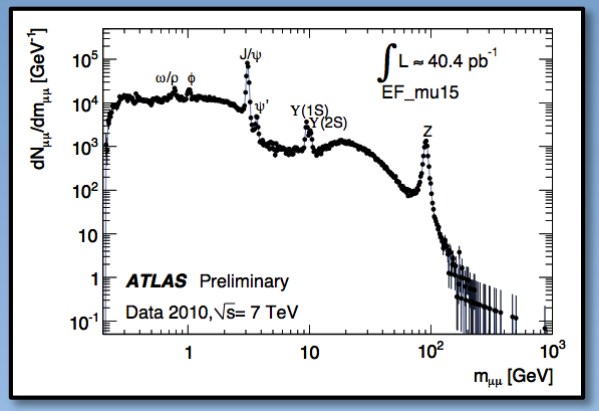
The 4 forces of nature

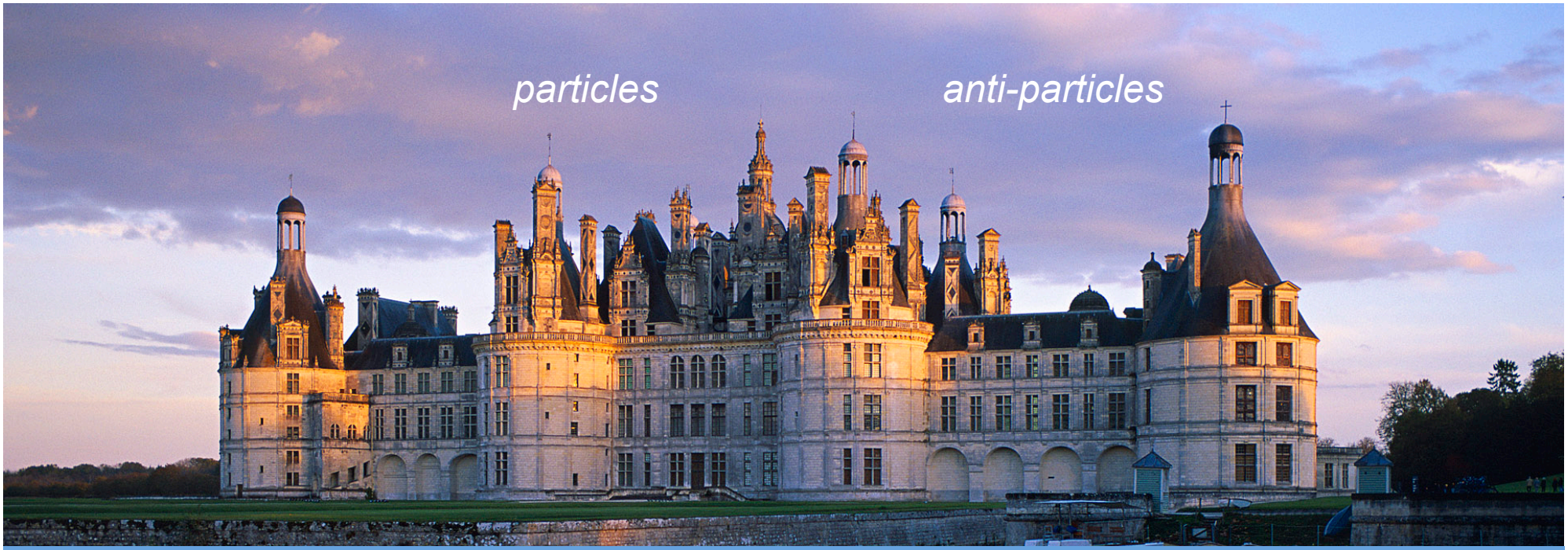
LHC experimenten





Gravitonen zien eruit als piekjes in de 2-muon massa





Wat do we know

Nature moves in mysterious ways

LHC works beautifully!

Standard Model. Doing just fine!

The Higgs boson exists

What do we not know:

Why the large spread in masses

What is dark matter made of ?

Why does gravity behave so different ?

Where did all the anti-matter go ?

Great adventure the coming years !

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