New Physics at the Large Hadron Collider

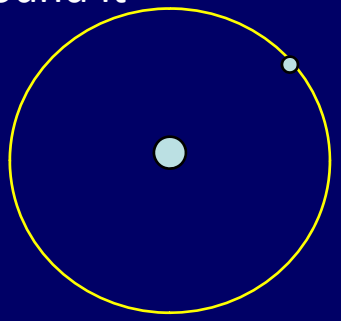
a brief introduction

Jos Engelen

CERN

The Structure of Matter

A hydrogen atom:
proton plus electron orbiting around it



towards complex structures:
heavier atoms Carbon, Oxygen, ...
molecules ... proteins ... DNA

0.000 000 1 mm
100,000 times smaller

at least another
10,000 times smaller:
'pointlike'

towards smaller distance scales
and the elementary constituents:
fundamental particles and fields and their interactions

in the beginning there were only fundamental particles and fields

Various very different fields: electromagnetic (between proton and electron); strong (inside proton); weak (very short range)

High Energy

A particle accelerated to high energy E can probe interactions down to distances 1/E: $\lambda = 1/E$
so probing sub-atomic distances requires high energy

High energy E is also required to produce new elementary particles with large mass M: $E = Mc^2$

If you understand these two equations you understand practically all of modern physics – I don't mean to say it is easy, it is hard

Is there still something new to be discovered at smaller distance scales and at higher energies or have we seen it all?

We definitely have not seen it all and the LHC will allow the next step into new territory: new physics 'must' show up →

The 'Standard Model'

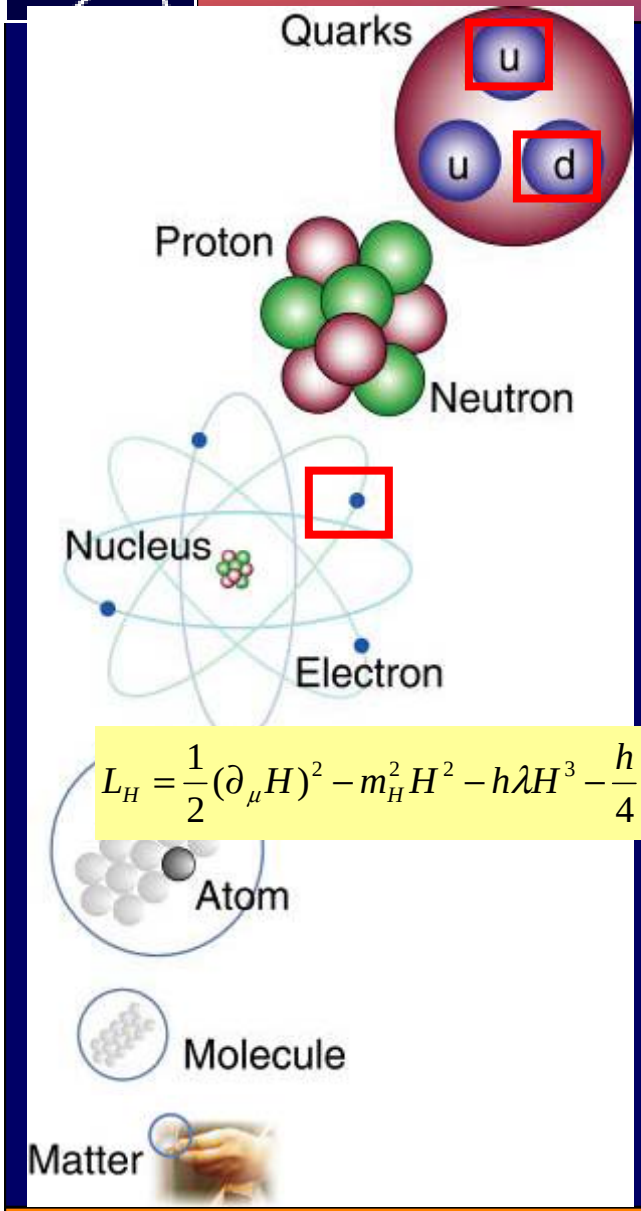
We have a wonderful model for describing the fundamental particles and fields and their interactions, it provides a quantitative description of all experimental results so far, but:

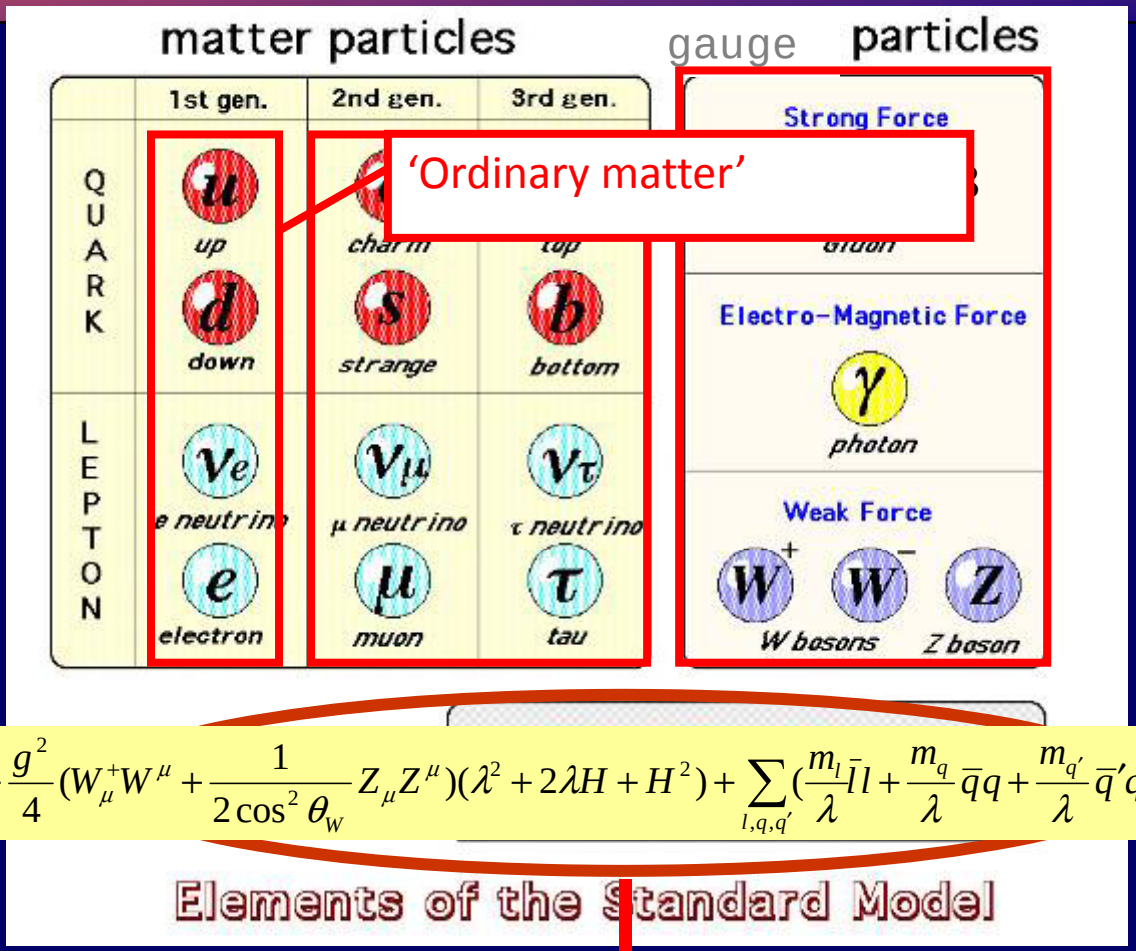
- the model invokes a mechanism for dealing with mass: it is an empirical fact that certain field particles (W, Z bosons) carry mass, incorporating this in the theory is highly non-trivial – it requires the introduction of a new field (Higgs field) and corresponding particle ('the Higgs'): this particle has never been found by an experiment → **it will be at the LHC**
- the model would 'go wrong' at high energy without the Higgs particle (or other 'new physics')
- 'unification of forces' at very high energy could be revealed by a new trend setting in at LHC energy: 'supersymmetry'

‘The Terascale’

Based on ‘extrapolations’ from our present understanding and on quite general theoretical insights we expect the ‘new physics’ to manifest itself at an energy around or below
1 Tera-electronVolt = 10^{12} electronVolt, i.e.
at the Terascale
accessible at the LHC for the first time
(and only at the LHC for years to come!)

The 'Standard Model'

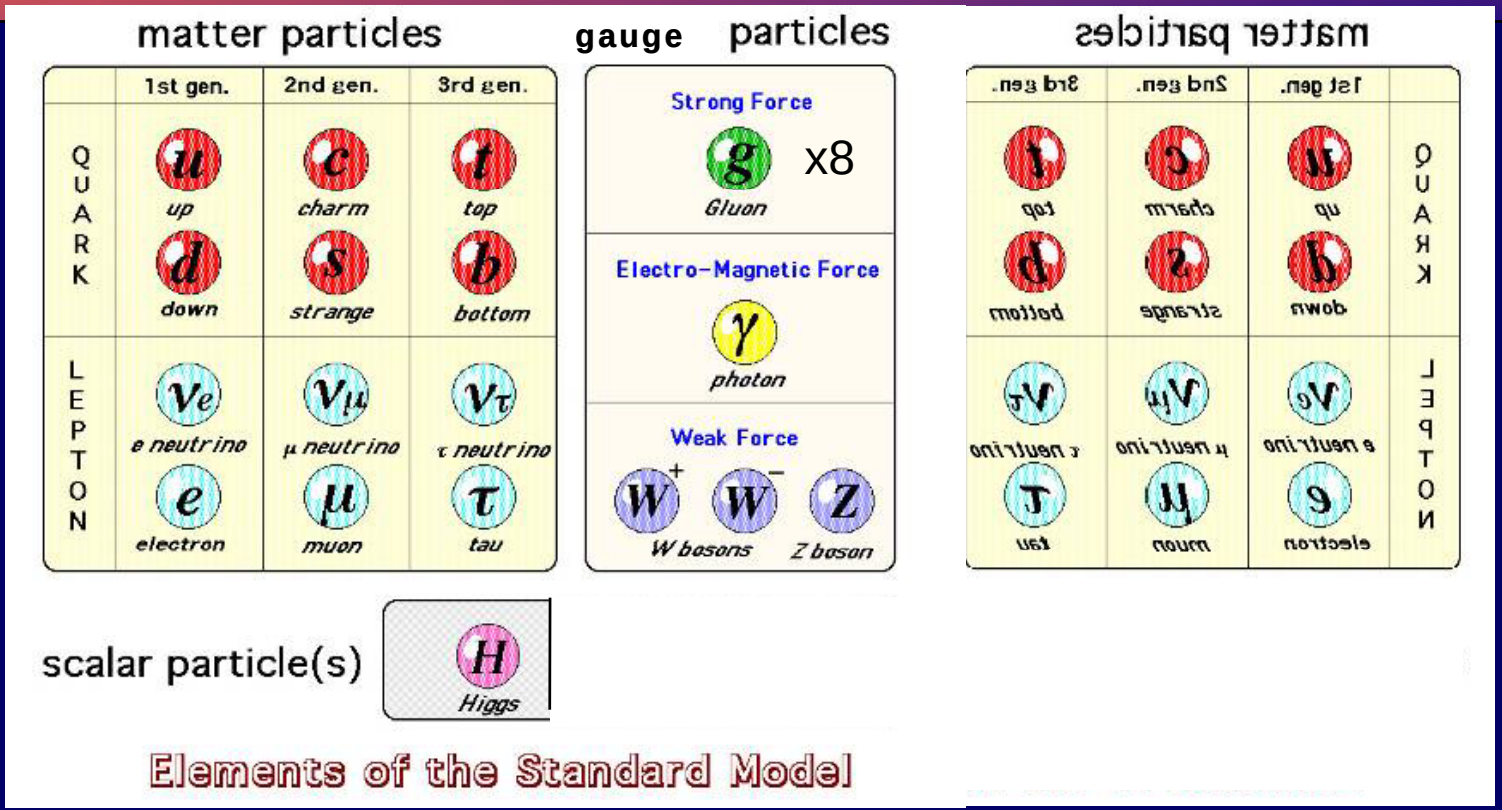




$$L_H = \frac{1}{2}(\partial_\mu H)^2 - m_H^2 H^2 - h\lambda H^3 - \frac{h}{4}H^4 + \frac{g^2}{4}(W_\mu^+ W^\mu + \frac{1}{2\cos^2\theta_W} Z_\mu Z^\mu)(\lambda^2 + 2\lambda H + H^2) + \sum_{l,q,q'}(\frac{m_l}{\lambda}\bar{l}l + \frac{m_q}{\lambda}\bar{q}q + \frac{m_{q'}}{\lambda}\bar{q}'q')H$$

The 'unknown'

Anti-Matter – also Supersymmetry?



The Supersymmetric world?

One supersymmetric partner for each ‘standard’ particle –

the Higgs sector becomes slightly more complicated: 5 supersymmetric Higgs bosons

The Large Hadron Collider

Proton – Proton collisions at 7 TeV + 7 TeV
Total energy = 14,000 times proton mass

1 billion collisions per second
Hundreds of particles produced per collision

'On line' selection of 100 events per second
'Off line' analysis to find the new physics

Higgs particle(s); supersymmetric particles;
'dark matter'; gravity...

a program of more than 10 years ahead of us!