Open questions in particle physics

Rolf Landua
CERN
Head of Education and Public Outreach
The Standard model is complete

The Higgs field gives all particles their mass
Its discovery opens a new era of physics
The evolution of the Universe is (rather) well understood

Standard Model + Gen. relativity = Universe?

No!

Less than 5% of the energy content of the universe are understood!

DARK MATTER? DARK ENERGY?

MERGE THE TWO ‘STANDARD MODELS’
What is behind?

Explain the parameters of the two Standard Models (Particle physics and cosmology)

- Their existence points to a deeper origin
- Look for new model with fewer numbers … or none
- Einstein: “there are no arbitrary constants …”

Two frontiers:

- Higher energy (‘direct production’) LHC - FCC - CLIC
- Higher precision (‘vacuum fluctuations’)

Open known problems

The pattern of the standard model:
- Origin of particles (‘periodic table’)
- Origin of forces (their number, strengths)
- Origin of parameters (particle masses, mixing angles)

The Higgs mass - why 126 GeV?

Neutrino masses
- Zero in the standard model
- Experiment: non-zero, but very small (~0.01-0.1 eV)
- Relevant physics may be at much higher energies

The cosmological antimatter mystery
1) Make sure this is “the” Higgs boson

Higgs boson decay

γγ (t-tbar)
Z^0Z^*, WW^*
tau
b

Higher energy at LHC
Higher intensity
—> better statistics
—> smaller error bars
2) Search for new phenomena at the LHC

a) Gravity and extra dimensions? *(Weakness of G)*

b) Supersymmetric particles? *(Dark matter particles)*

c) New fundamental interactions?

d) New generations of quarks/leptons?

e) Leptoquarks?

f) Something completely new?
Interlude: Why is the Planck scale fundamental?

Max Planck (1899): Boundary for quantum theory, gravity, and space time on small scales

System of units based on three fundamental constants (G, c, h)
Dimensionally independent - length, time, and mass (energy)

\[ \ell_P = \sqrt{\frac{\hbar G}{c^3}} = 1.6 \times 10^{-35} \text{ m} \]

\[ T_P = \sqrt{\frac{\hbar G}{c^5}} = 0.54 \times 10^{-43} \text{ s} \]

\[ M_P = \sqrt{\frac{\hbar c}{G}} = 2.2 \times 10^{-8} \text{ kg} \]

\[ E_P = M_P c^2 = 1.2 \times 10^{19} \text{ GeV} \]

Fig. 3. A light pulse is sent from A and reflected back from B. Its energy causes a distortion of the spacetime between A and B and hence affects the length \( \ell \).

Fig. 5. A region of space of size \( \ell \) to be measured in time \( \ell/c \). As the size approaches the Planck length, there can occur wild variations in the geometry, including such things as black holes and wormholes.

http://www.stat.physik.uni-potsdam.de/~pikovsky/teaching/stud_seminar/Planck_scale.pdf
Interlude: The hierarchy problem with the Planck scale

- Why is the scale of particle physics (Higgs mass!) so much smaller than the Planck Scale \(10^{-16}\)?
- Why is the observable Universe \(10^{60}\) so much bigger than the Planck Scale?
- Why is the amount of dark energy so much smaller than the Planck Scale \(10^{120}\)?

Are we asking the wrong question?
Planck scale not fundamental?
Stabilising mechanism (SUSY?)

Why is Nature so stable?
Example: Gravity and extra dimensions?

Probing gravity at the LHC?

Gravitational wave jet + $E_T$
Gravitational deflection dijet
Black hole multiparticle event

Gravitational phenomena into collider arena

from G. Giudice’s talk
Characteristic signatures of ‘missing energy/mass’

**Monophoton event**

**Monojet event**
How to go to increase collision energy of constituents?

CLIC: 3 TeV $e^+ e^-$ Collider?
Future circular collider (FCC)?

New study (Kickoff: February 2014)

Circular collider in new tunnel
80-100 km circumference (16-20 T magnets)

Circular proton-proton collider
**100 TeV** collision energy (p+p)

Also studied:

Circular electron-positron collider (VLEP)
(350 GeV c.m. energy, t-tbar threshold)

Lepton-Hadron collider (like HERA)
(50 TeV p + 100 GeV e)

Conceptual design report ~ 2018
Europeans Strategy: “CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines.”

Kick-off meeting: 11th Nov. 2013 (Daresbury)

Project

FCC Study: p-p towards 100 TeV

Thank you.