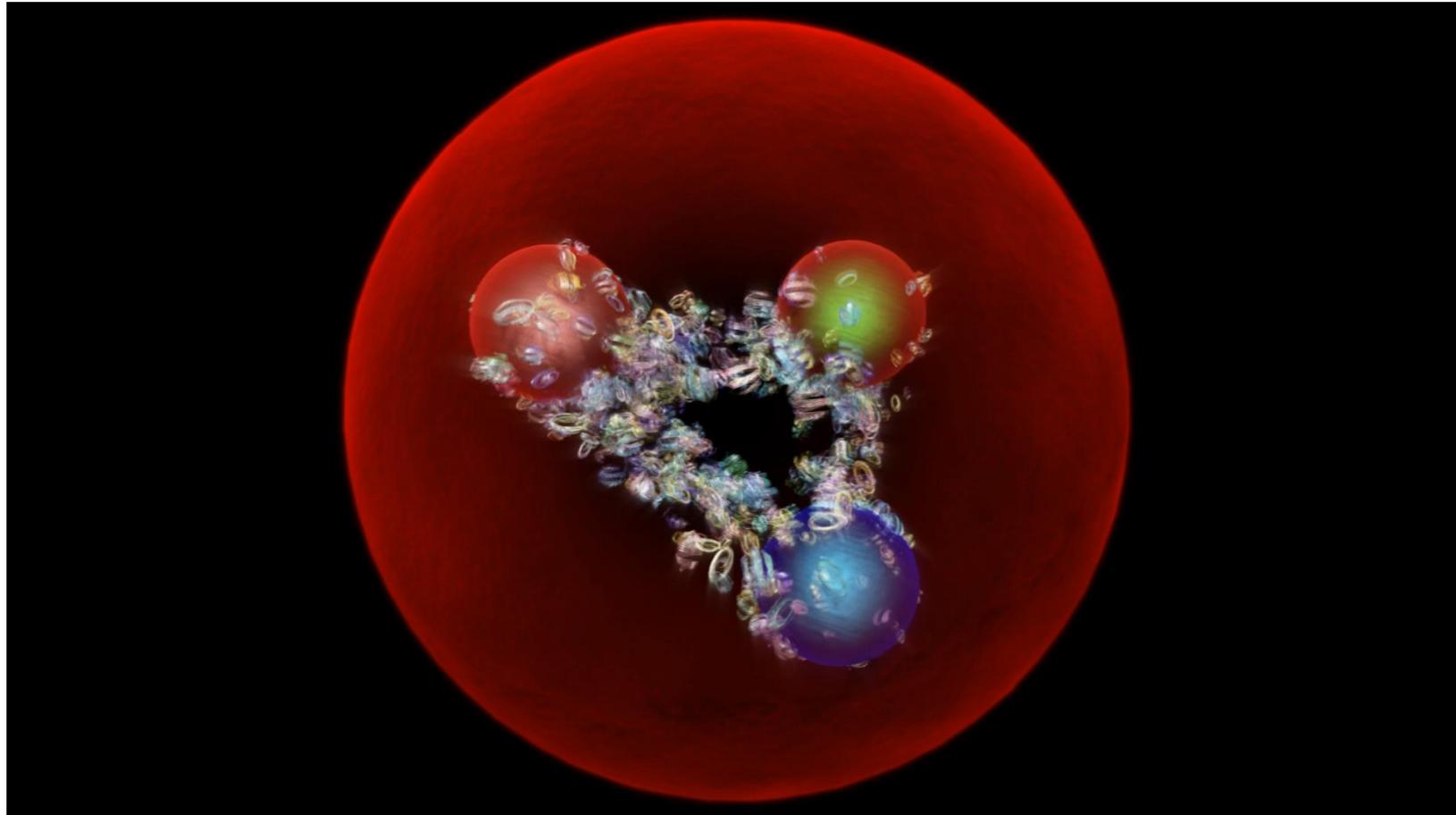




Open questions in particle physics

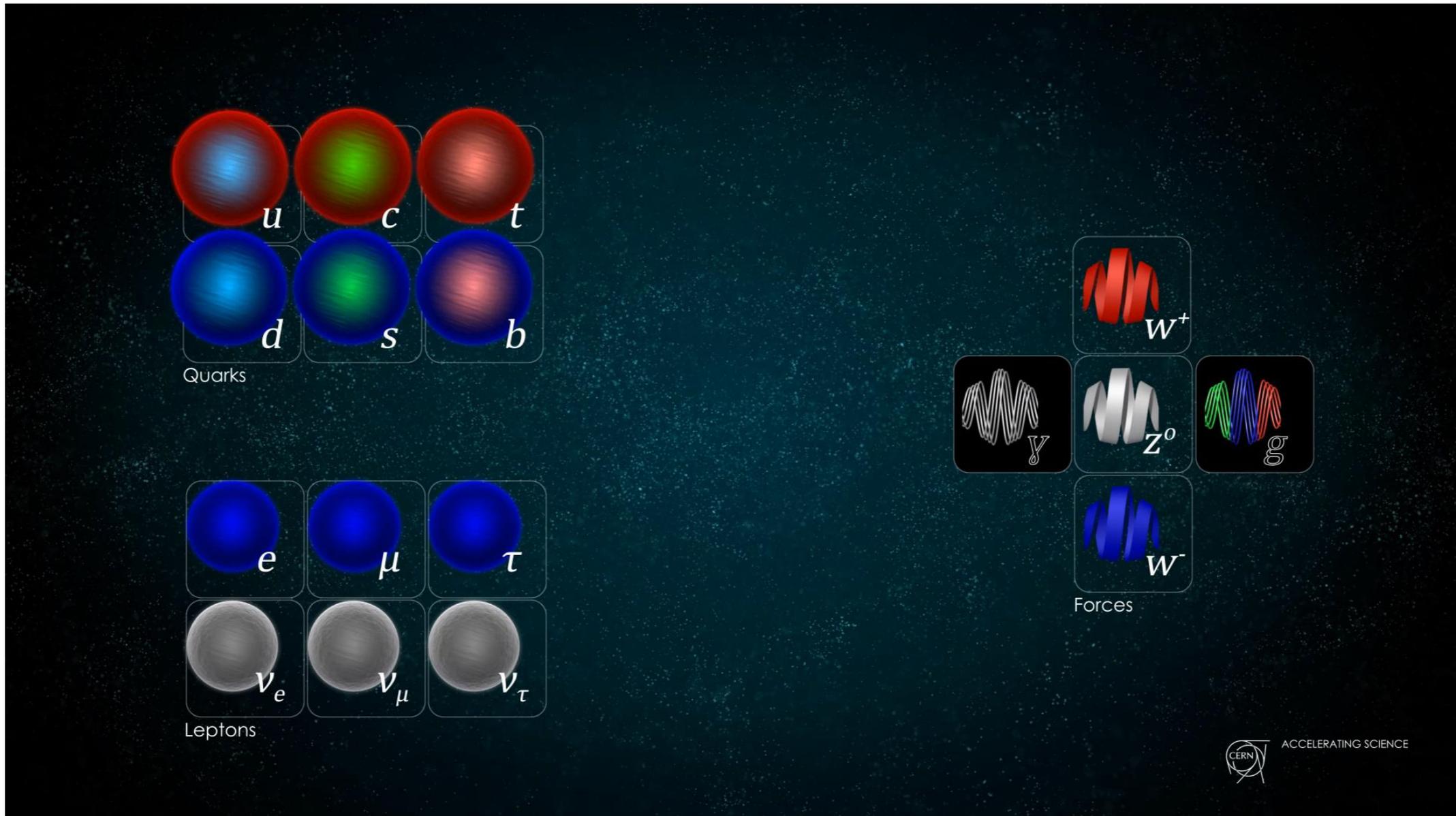


Rolf Landua

CERN

Head of Education and Public Outreach

The Standard model is complete

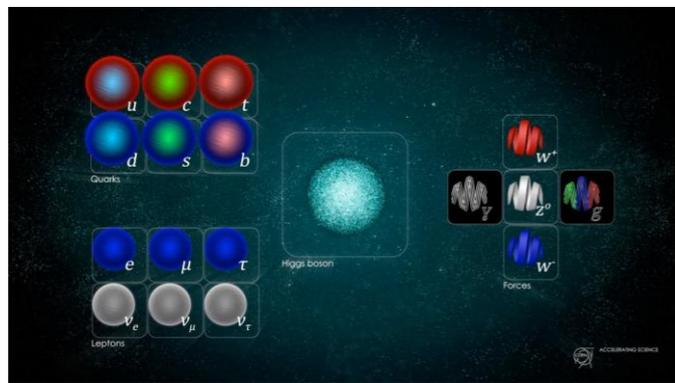


The Higgs field gives all particles their mass
Its discovery opens a new era of physics

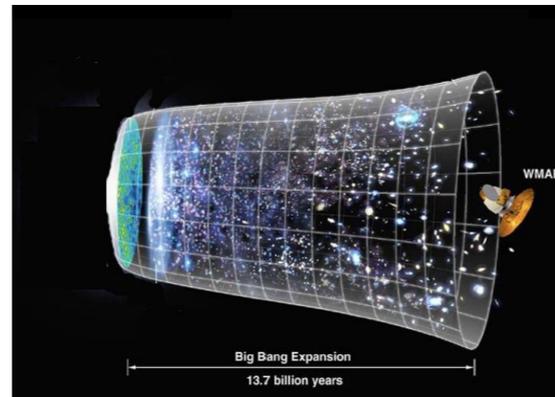
The evolution of the Universe is (rather) well understood

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

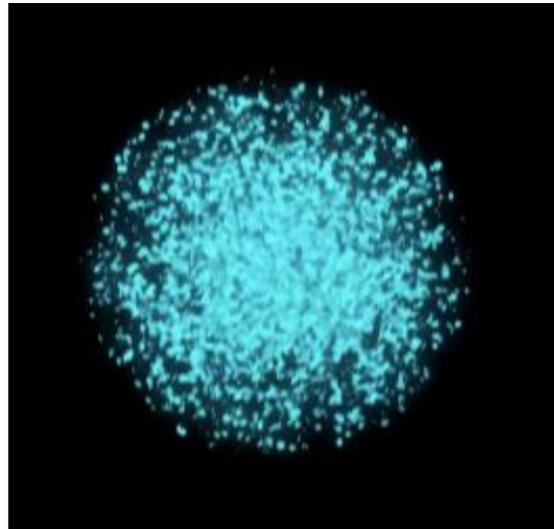
- Zero in the standard model
- Experiment: non-zero, but very small ($\sim 0.01-0.1$ eV)
- Relevant physics may be at much higher energies

The cosmological antimatter mystery



1) Make sure this is “the” Higgs boson

Higgs boson decay



$\gamma\gamma$ (t-tbar)

Z^0Z^* , WW^*

tau

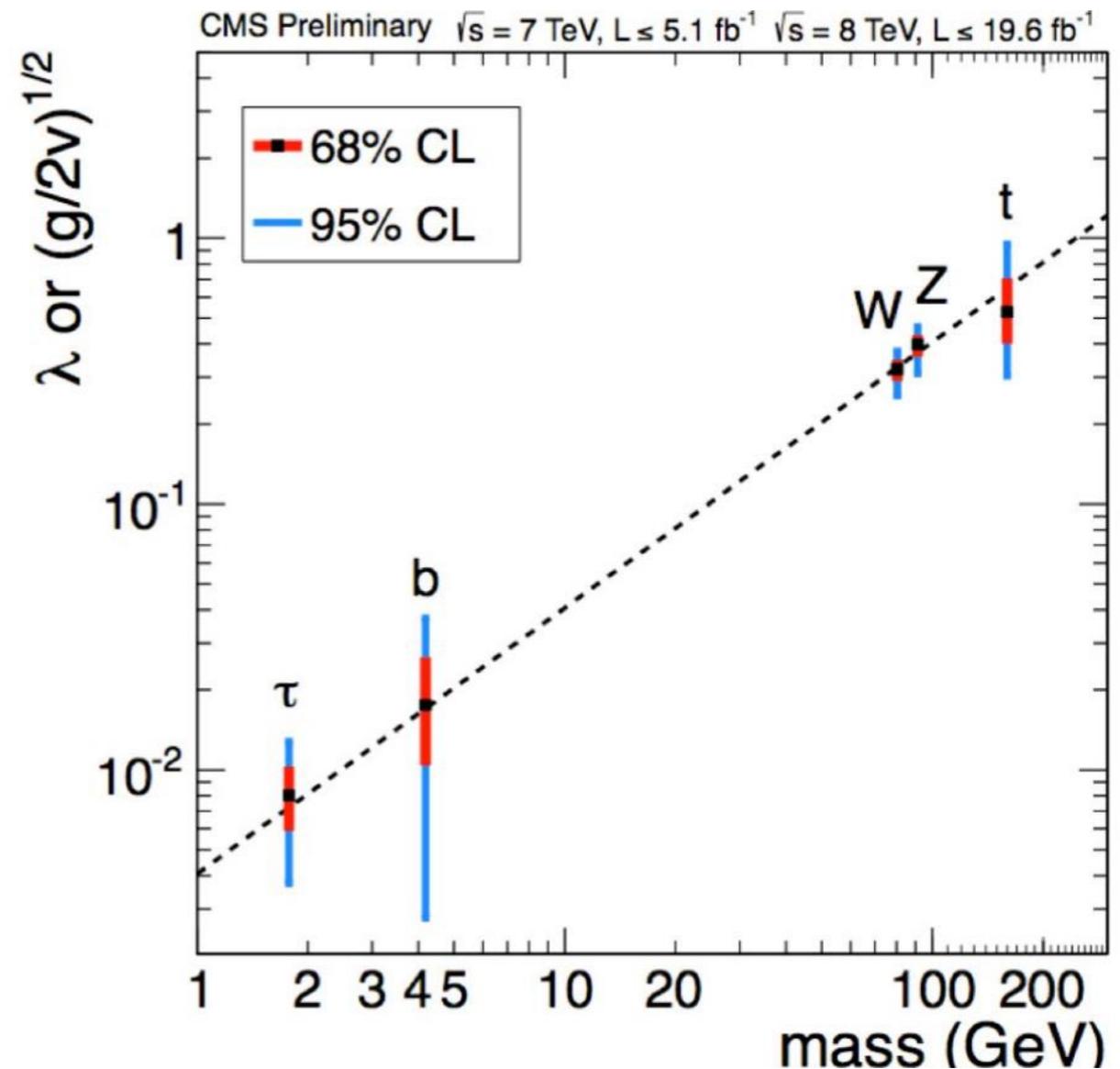
b

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 ℓ .

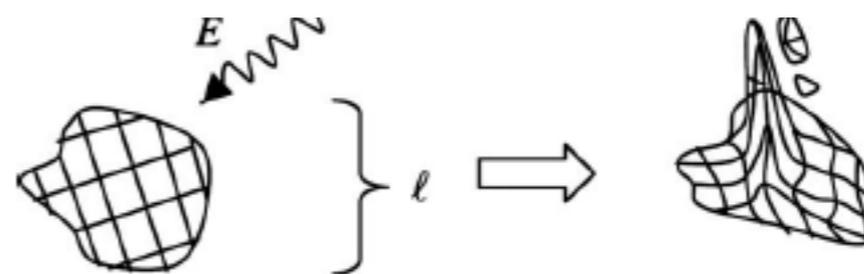


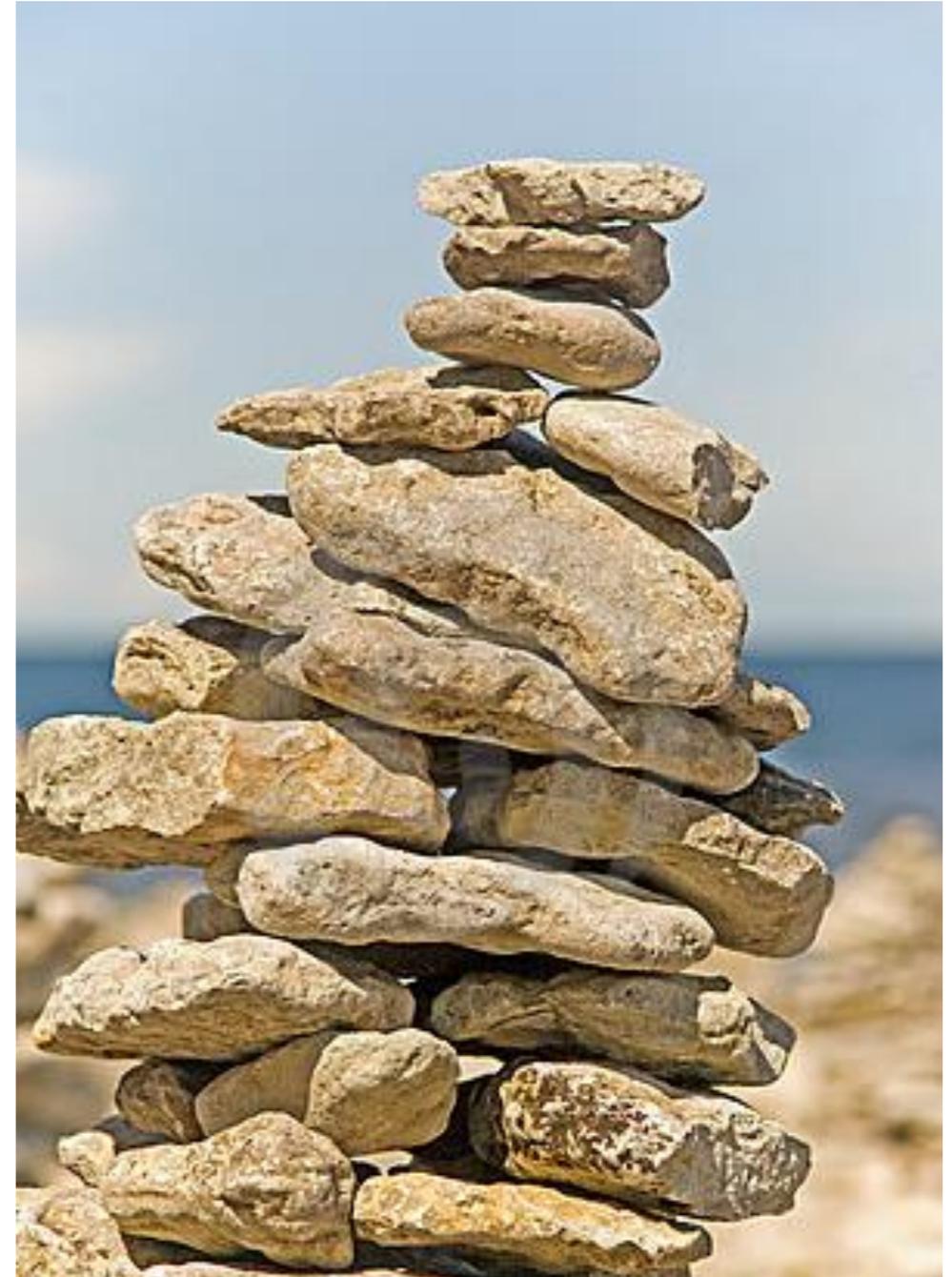
Fig. 5. A region of space of size ℓ to be measured in time ℓ/c . As the size approaches the Planck length, there can occur wild variations in the geometry, including such things as black holes and wormholes.

- 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?

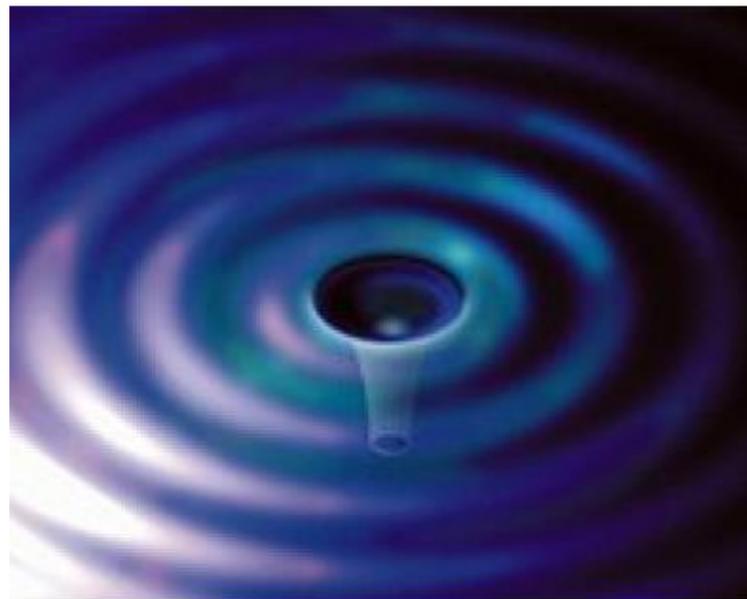
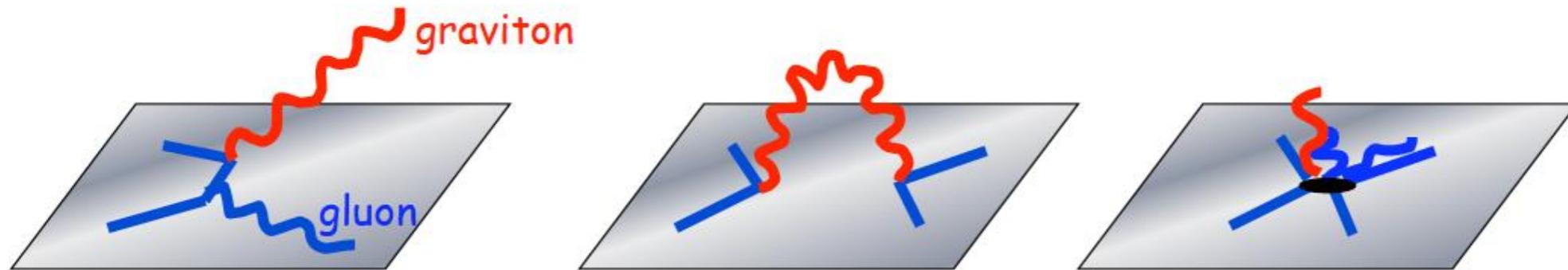
Stablising mechanism (SUSY?)



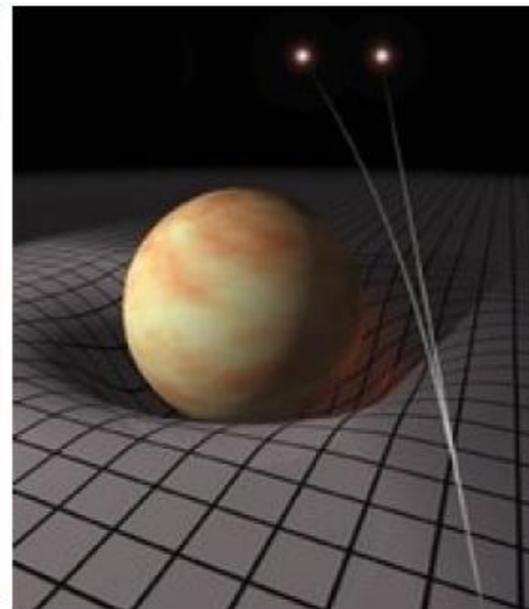
Why is Nature so stable?

Example: Gravity and extra dimensions ?

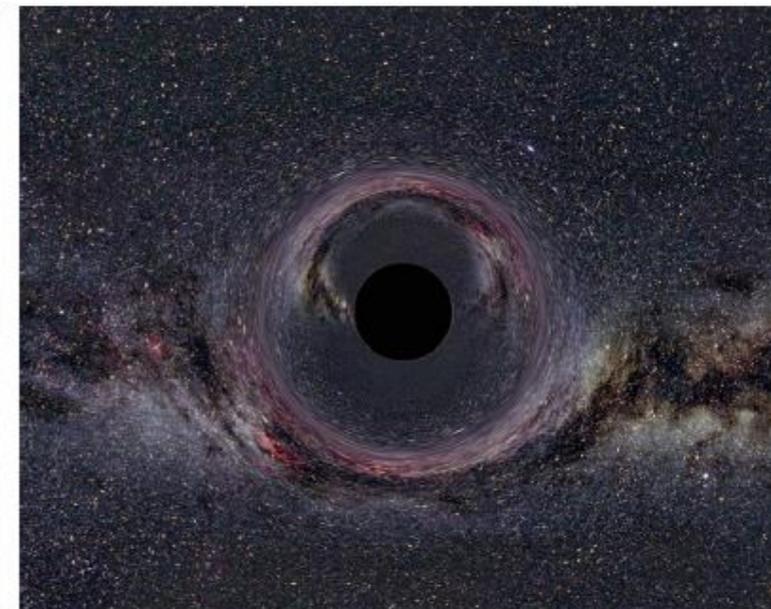
Probing gravity at the LHC?



Gravitational wave
jet + \cancel{E}_T



Gravitational deflection
dijet

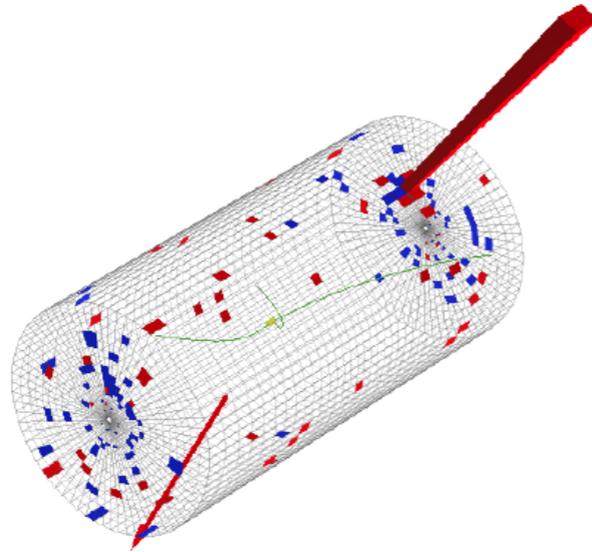


Black hole
multiparticle event

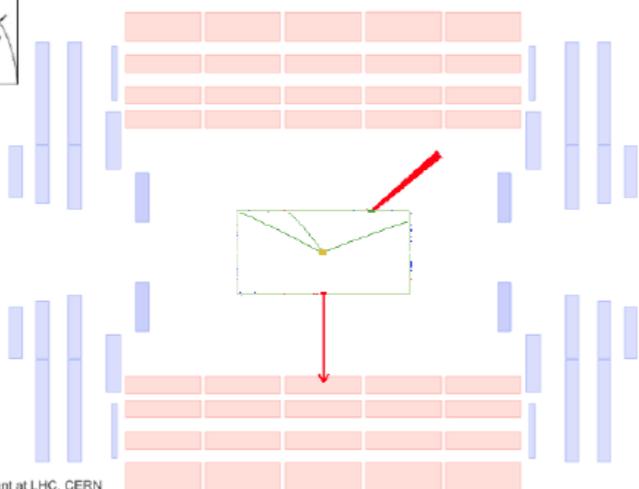
Gravitational phenomena into collider arena

from G. Giudice's talk

Monophoton event



CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

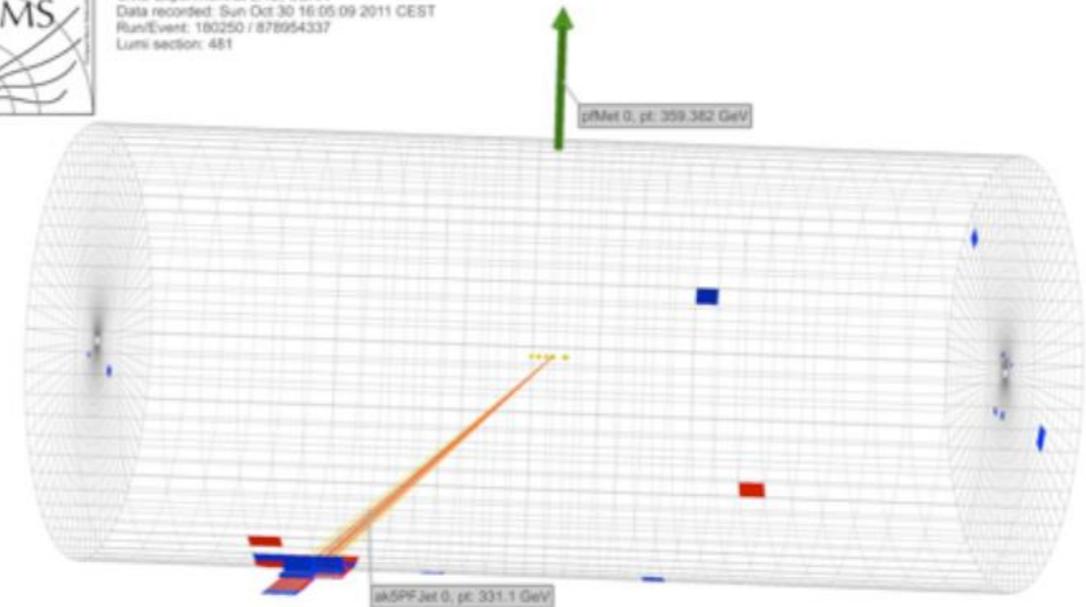


CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

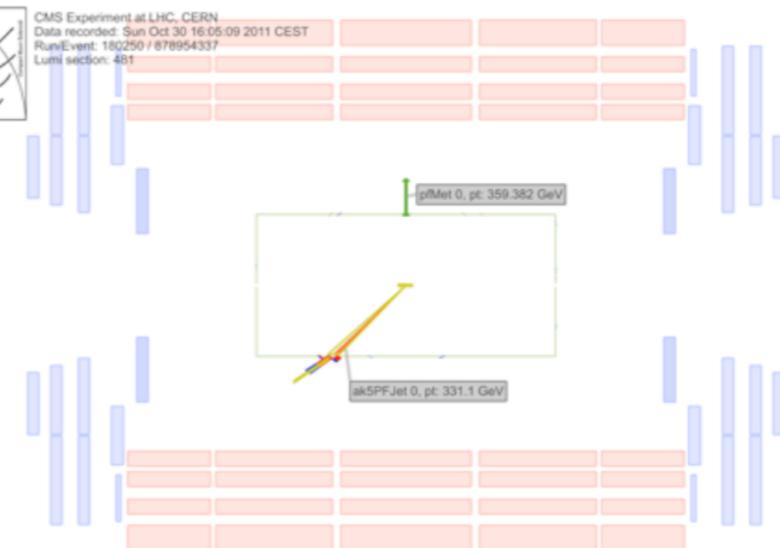
Monojet event



CMS Experiment at LHC, CERN
Data recorded: Sun Oct 30 16:05:09 2011 CEST
Run/Event: 180250 / 878954337
Lumi section: 481



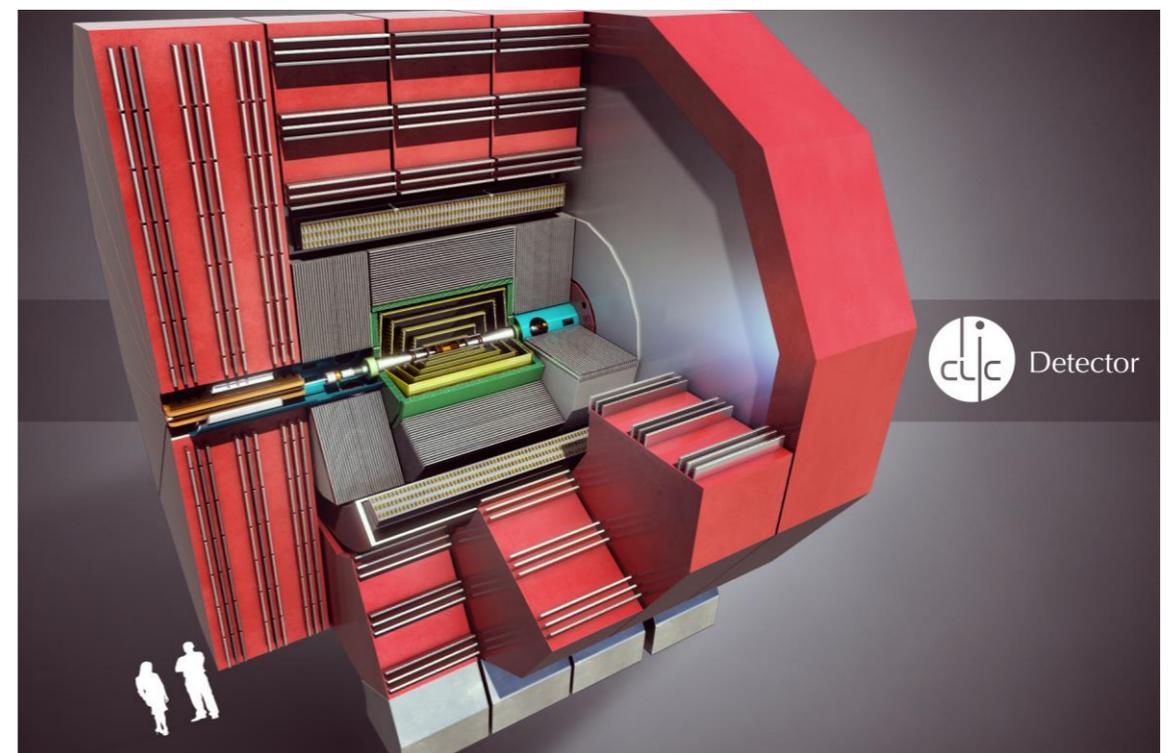
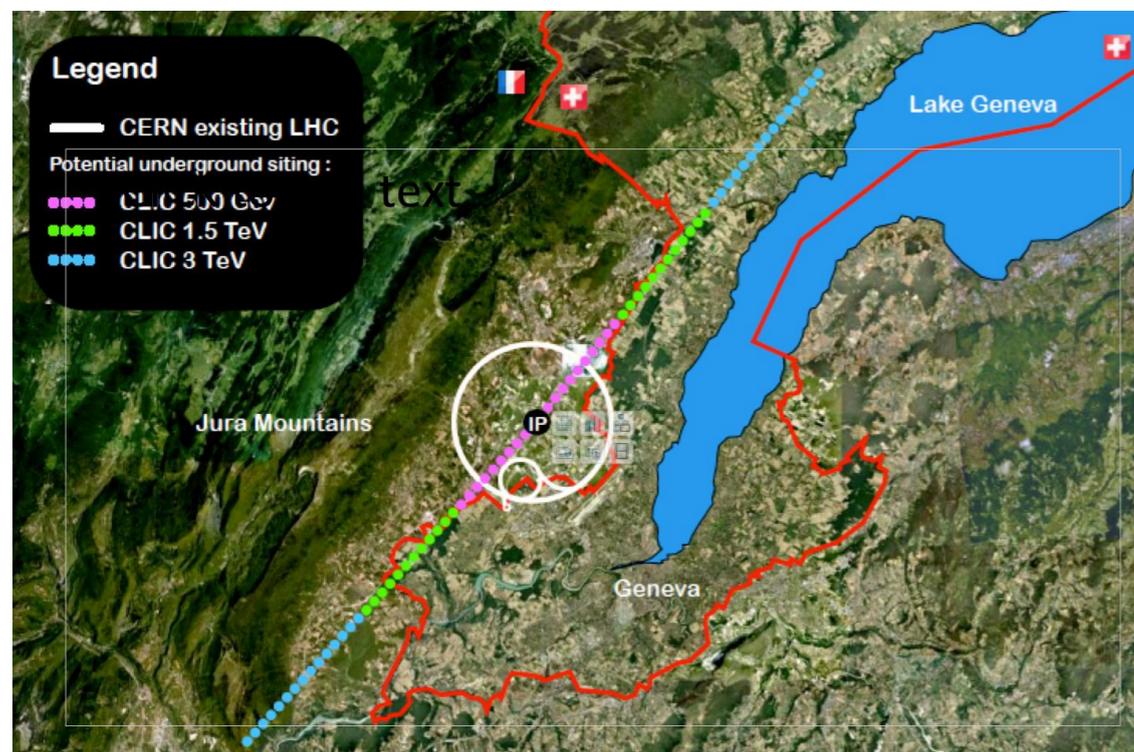
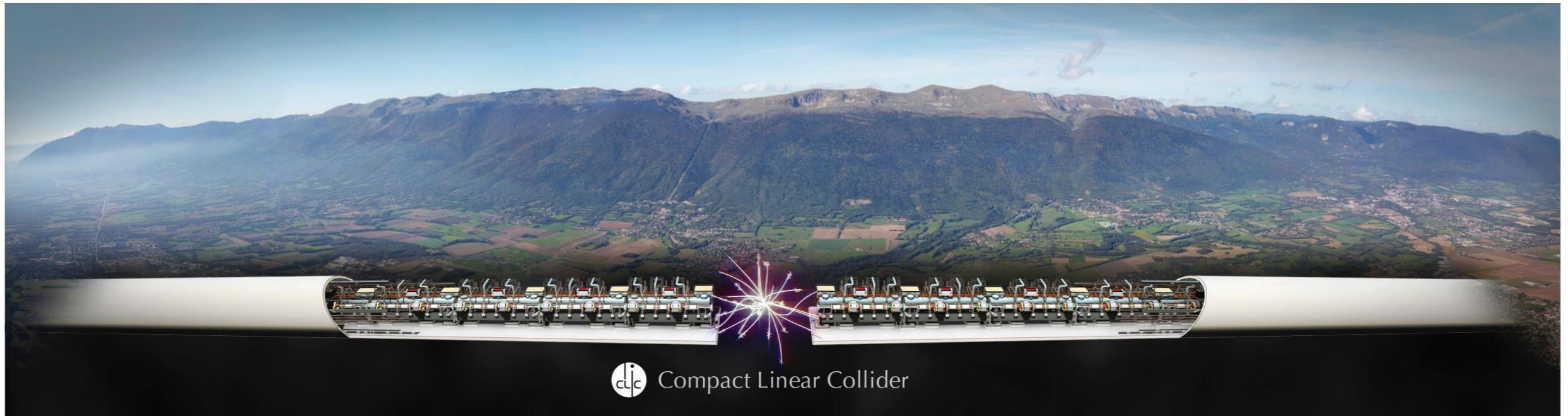
CMS Experiment at LHC, CERN
Data recorded: Sun Oct 30 16:05:09 2011 CEST
Run/Event: 180250 / 878954337
Lumi section: 481





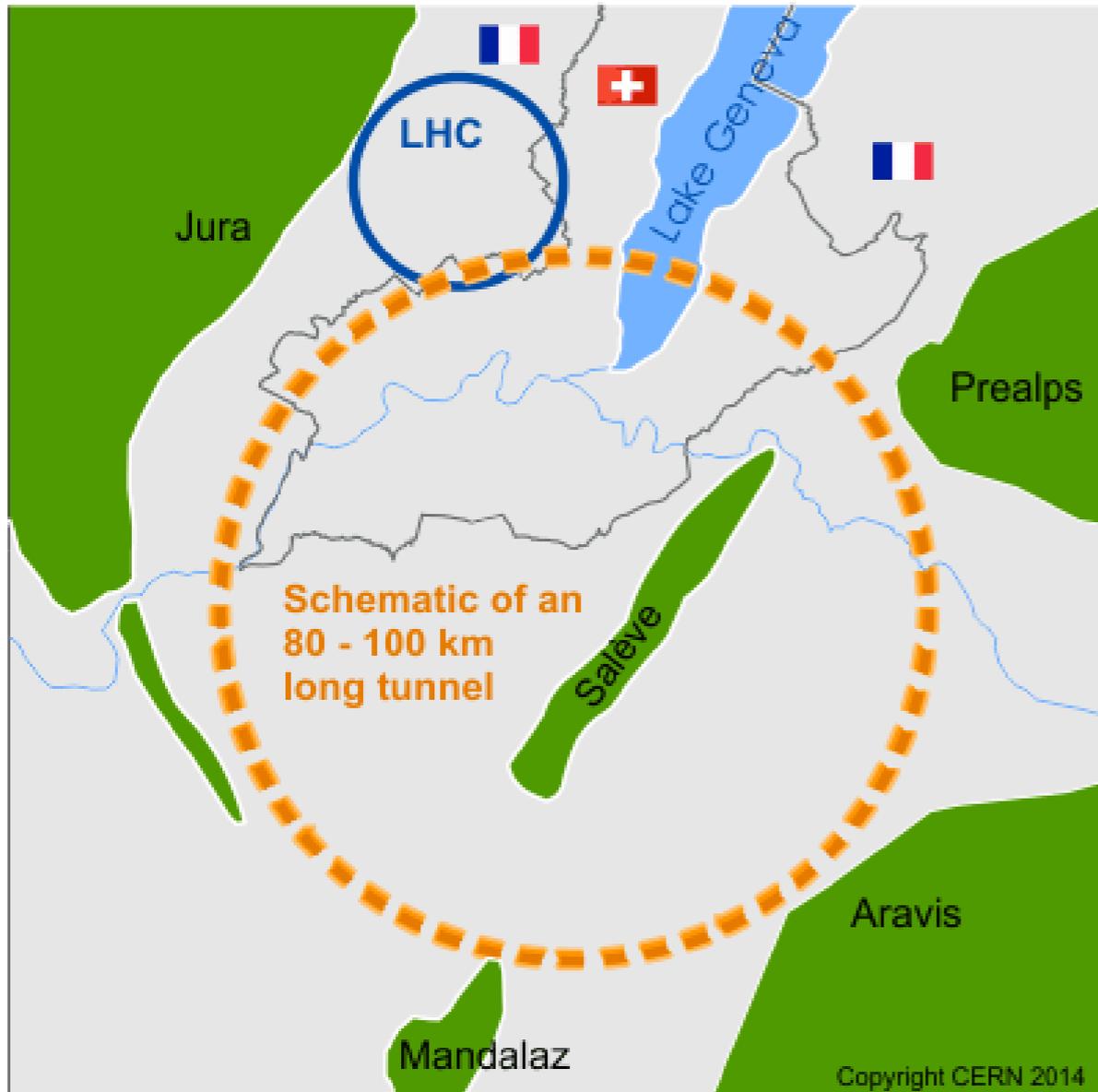
How to go to increase collision energy of constituents ?

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



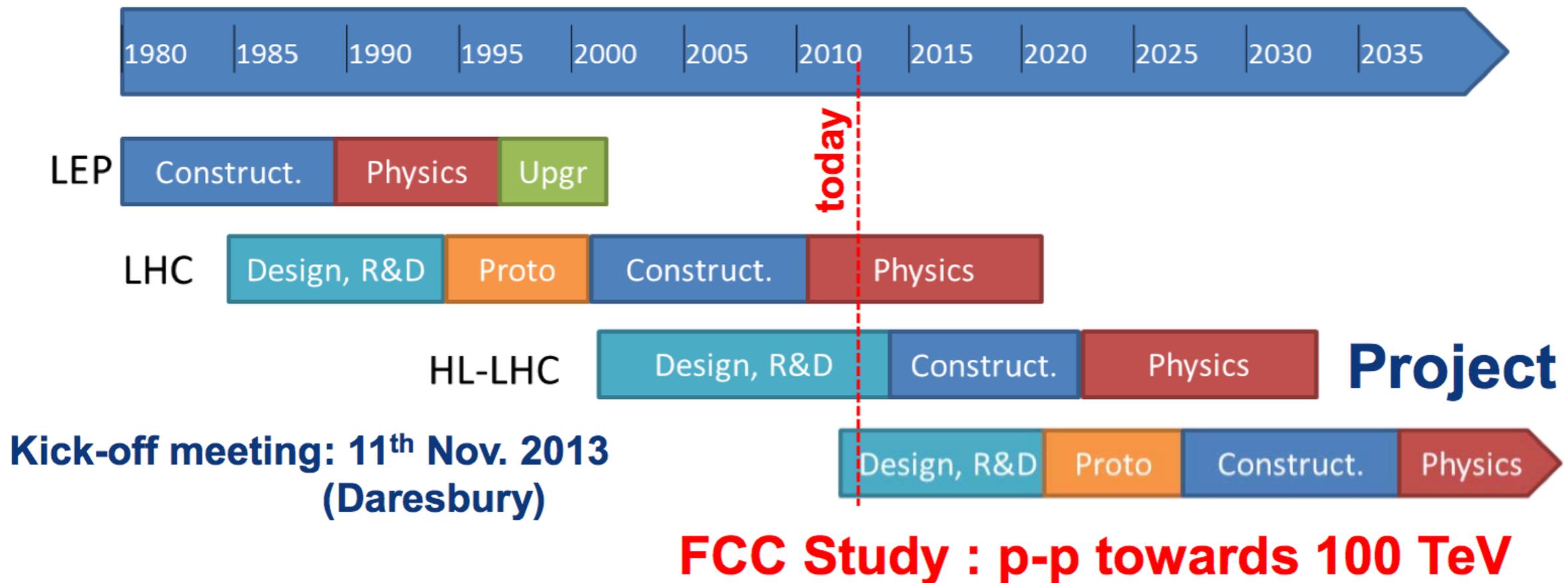
CERN Schedule 2015 - 2035





... and beyond

*European 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.**"*



Thank you.