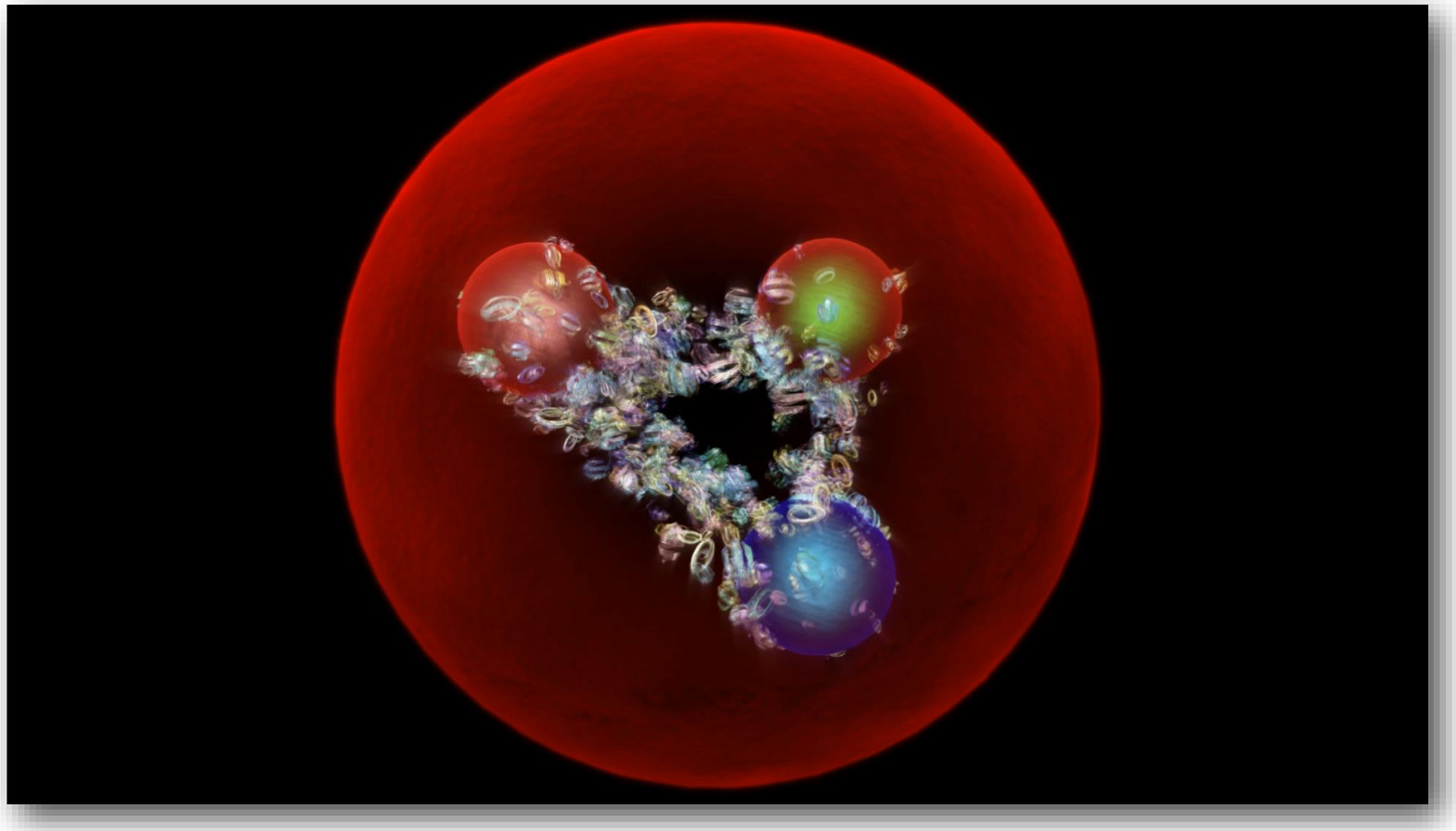
Open questions in particle physics

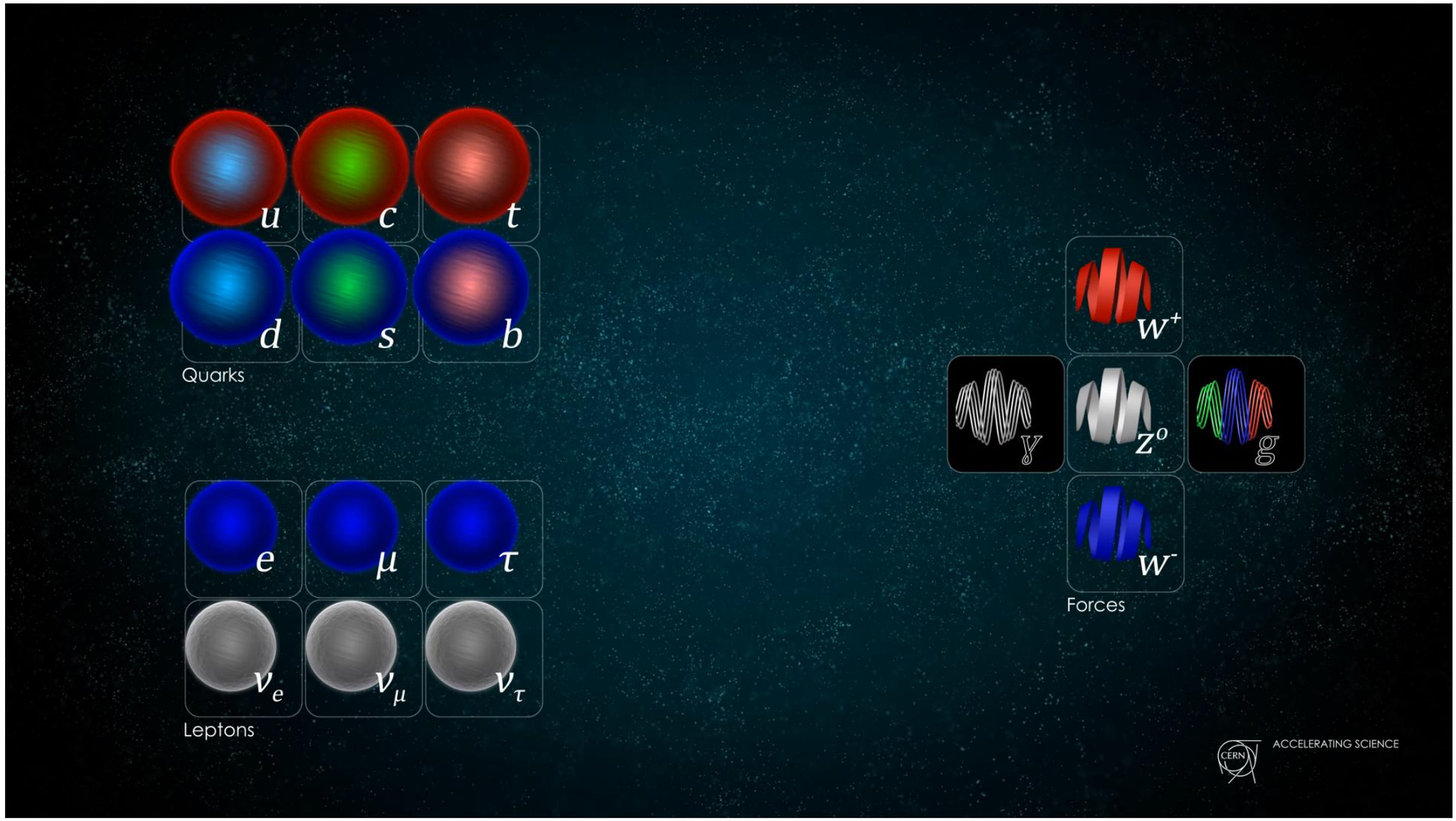


Rolf Landua

CERN

Head of Education and Public Outreach

The Standard model is complete

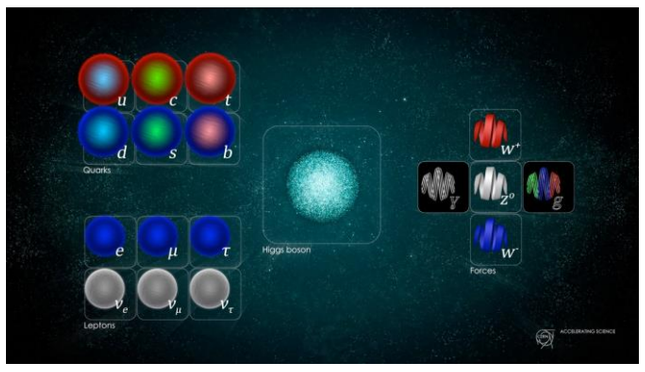


The Higgs field gives all particles their mass

Its discovery opens a new era of physics

The evolution of the Universe is (rather) well understood

Standard Model + Gen. relativity = Universe ?



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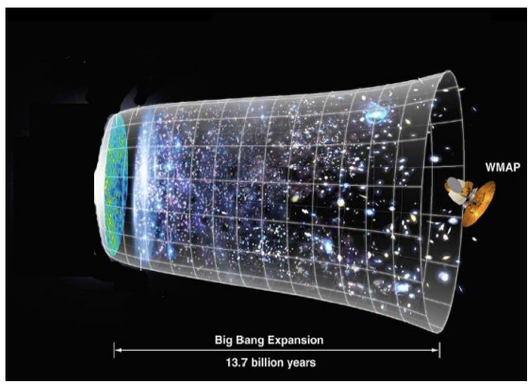

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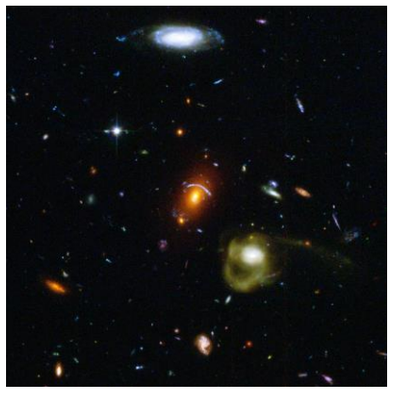


No !

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?

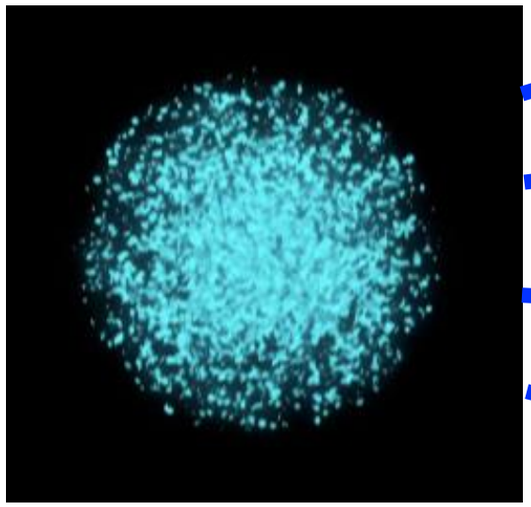
Neutrino masses

- 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

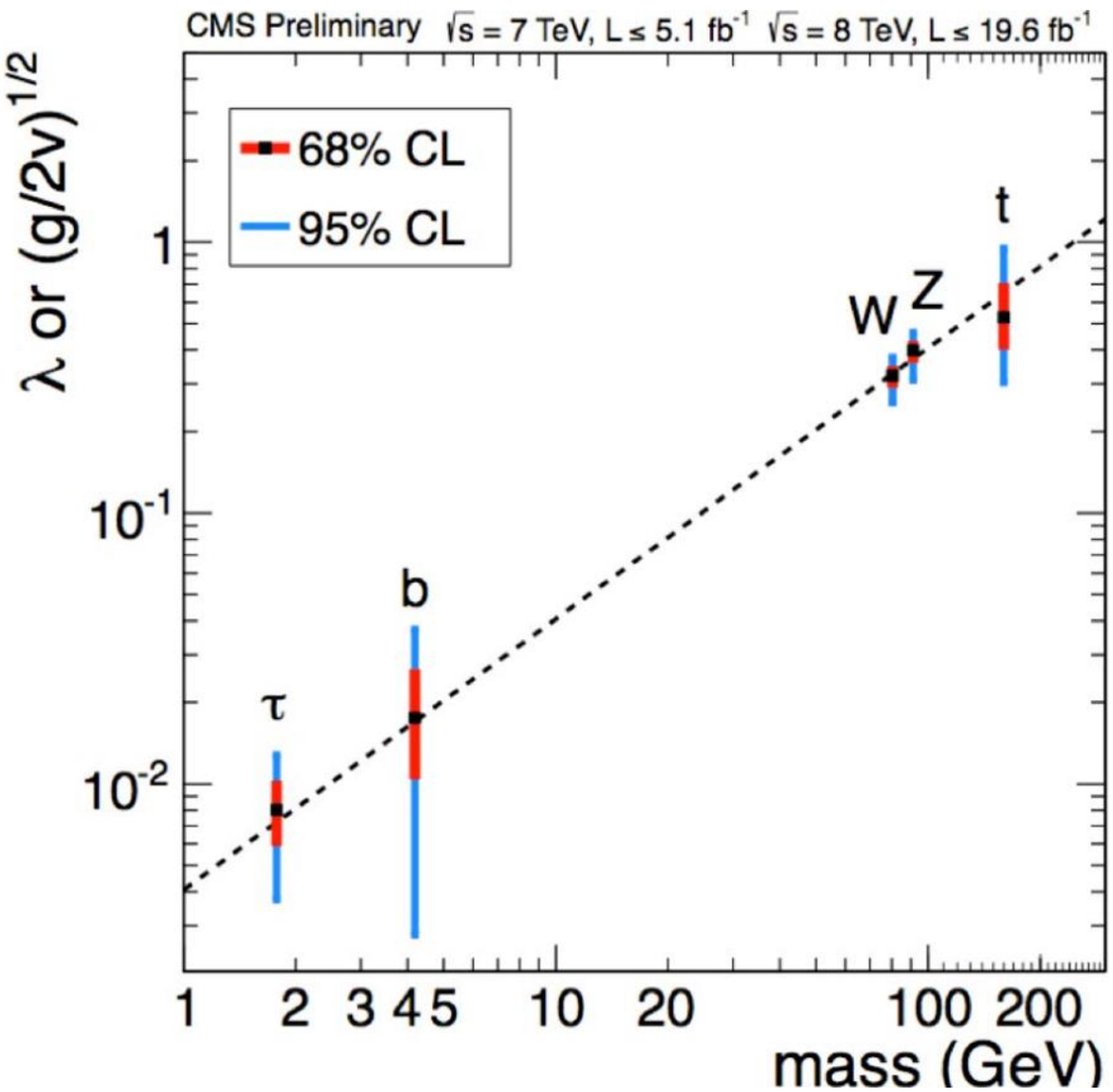


γγ (t-tbar)

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)

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

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

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

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

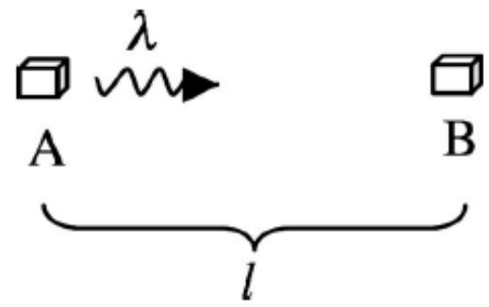


Fig. 3. A light pulse is sent from A and reflected back from B. Its energy causes a distortion of the spacetime between A and B and hence affects the length ℓ.

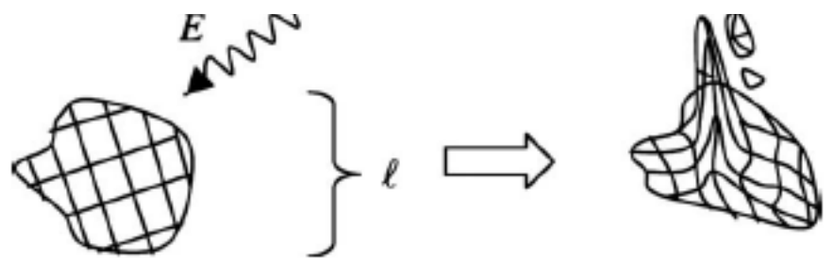


Fig. 5. A region of space of size ℓ to be measured in time ℓ/c. As the size approaches the Planck length, there can occur wild variations in the geometry, including such things as black holes and wormholes.

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?

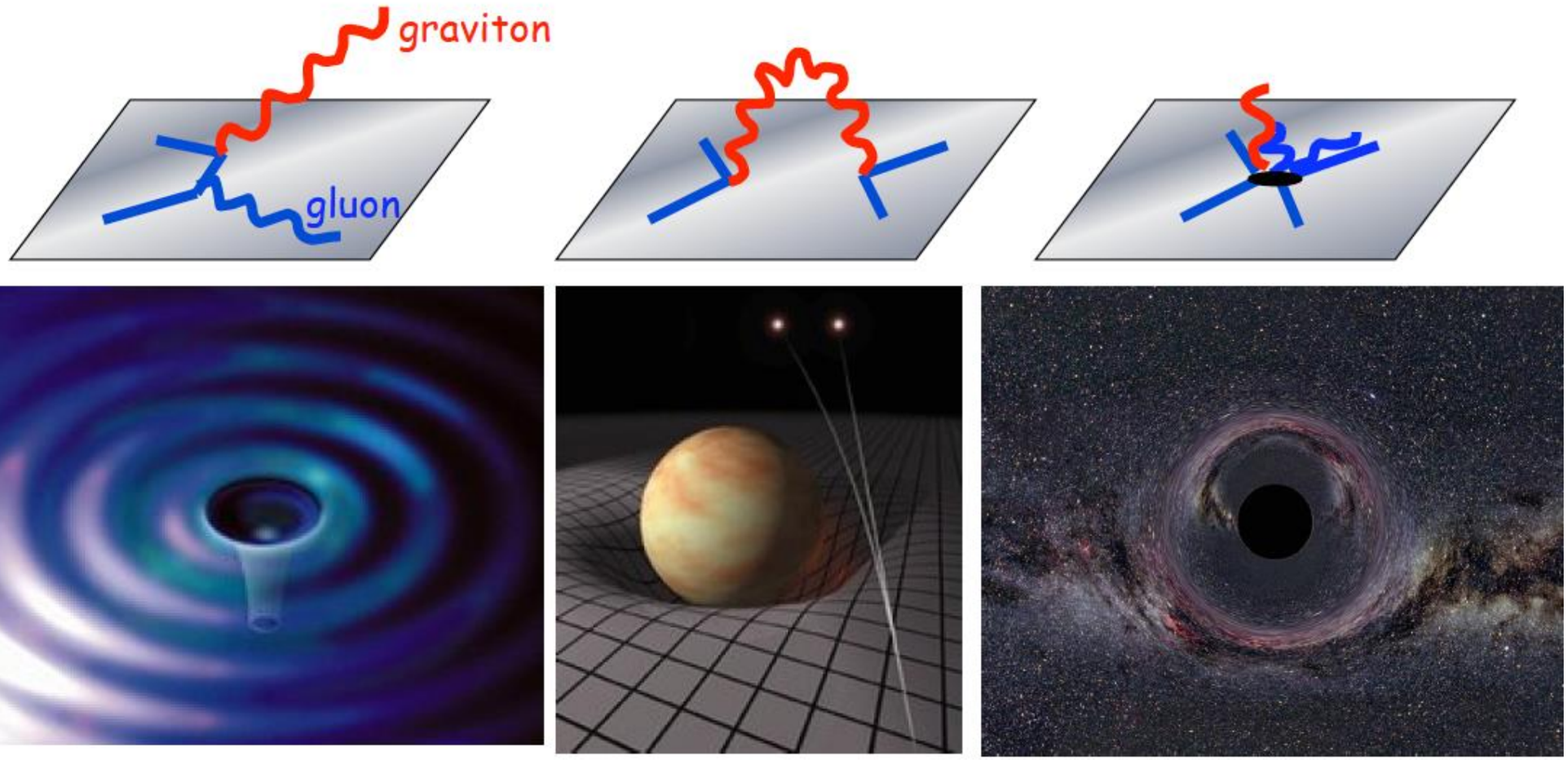
Planck scale **not** fundamental?

Stablising mechanism (SUSY?)

Why is Nature so stable?

Example: Gravity and extra dimensions ?

Probing gravity at the LHC?



Gravitational wave
jet + $\not{E}_T$

Gravitational deflection
dijet

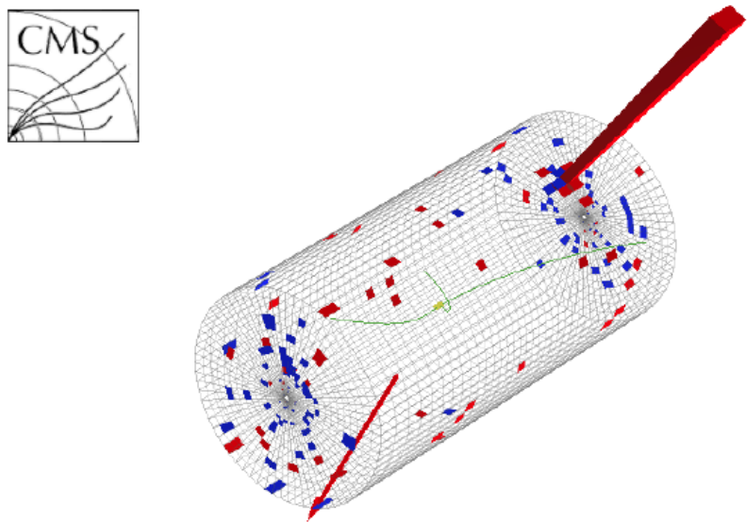
Black hole
multiparticle event

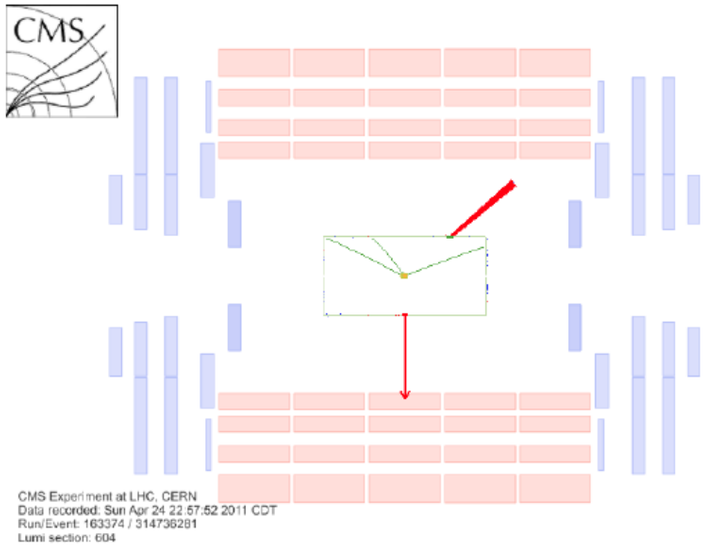
Gravitational phenomena into collider arena

from G. Giudice's talk

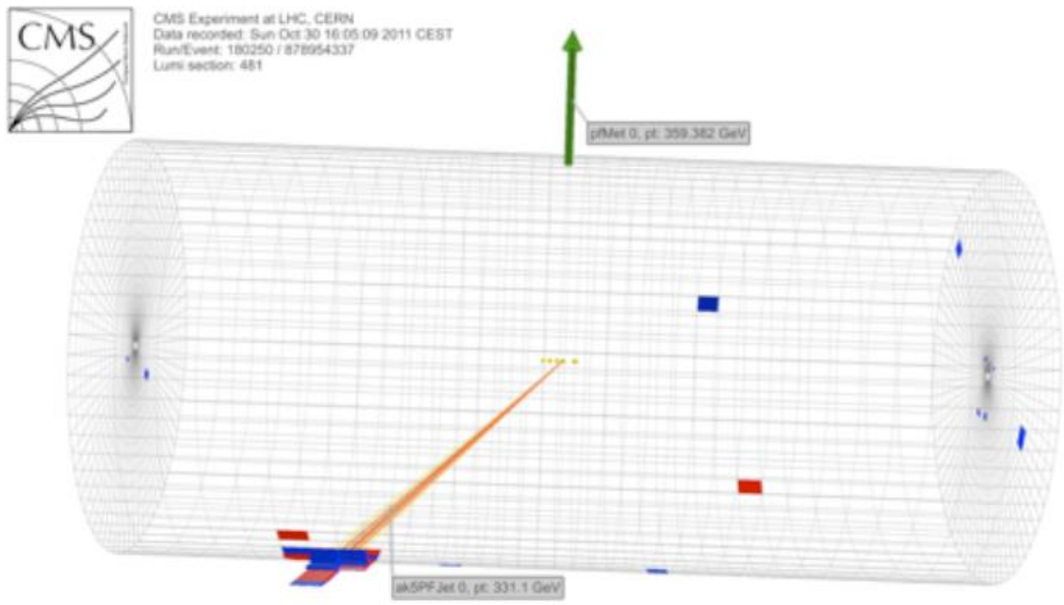
Characteristic signatures of ‘missing energy/mass’

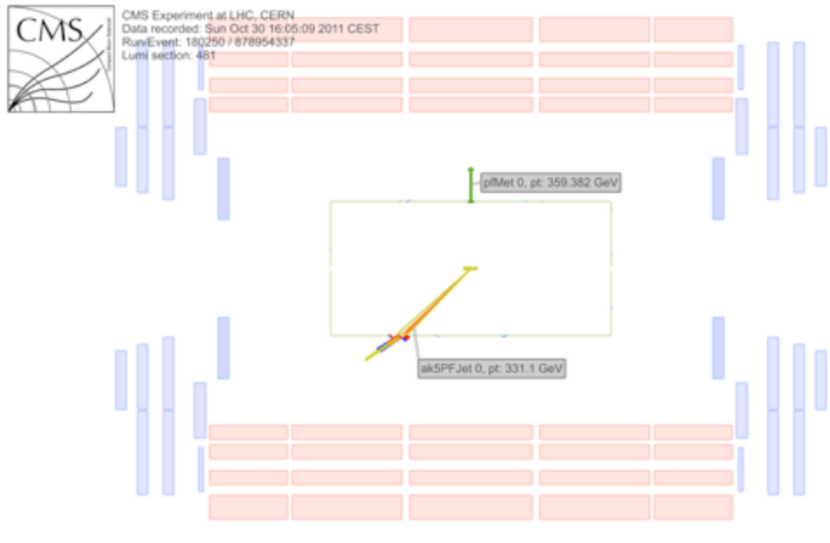
Monophoton event





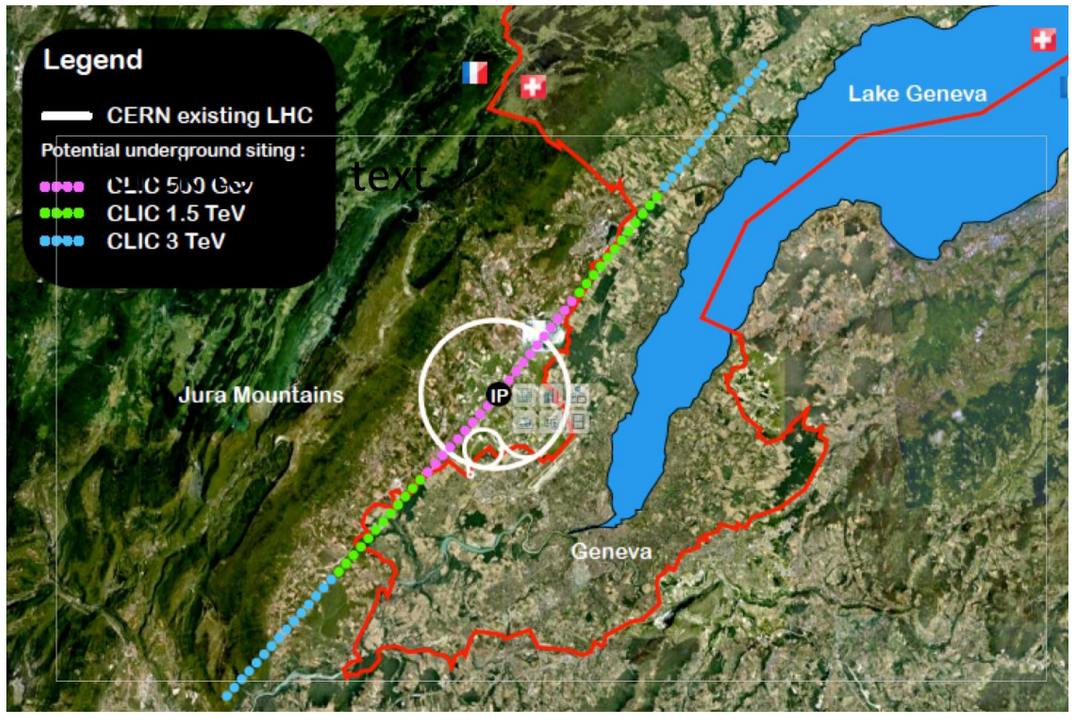
Monojet event

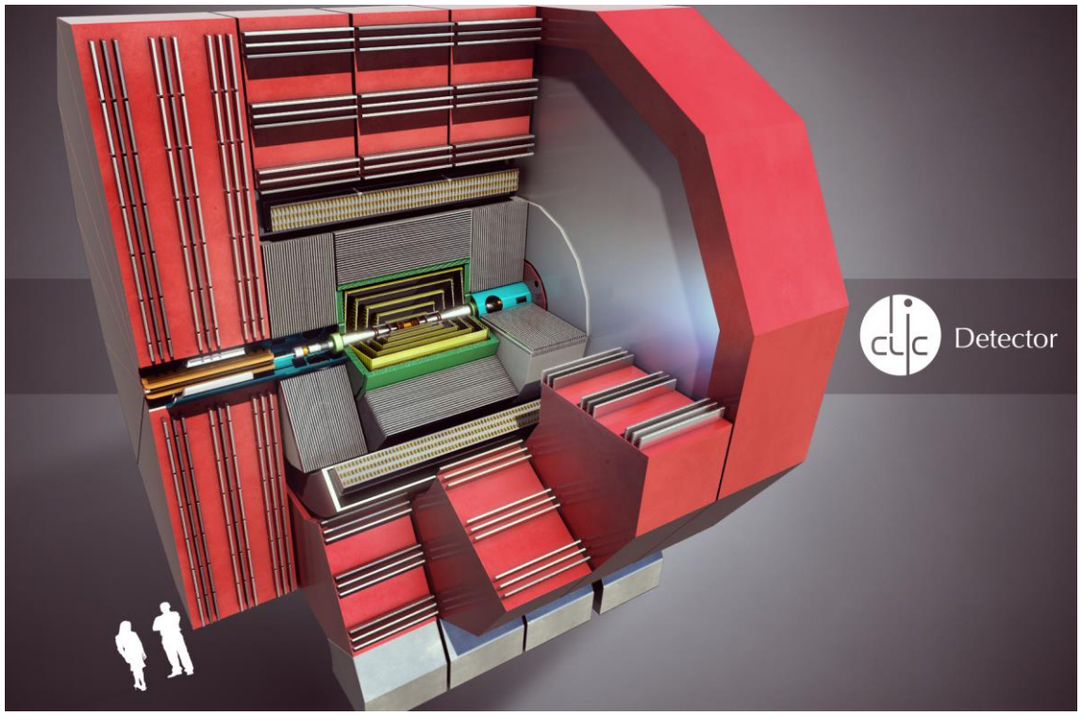




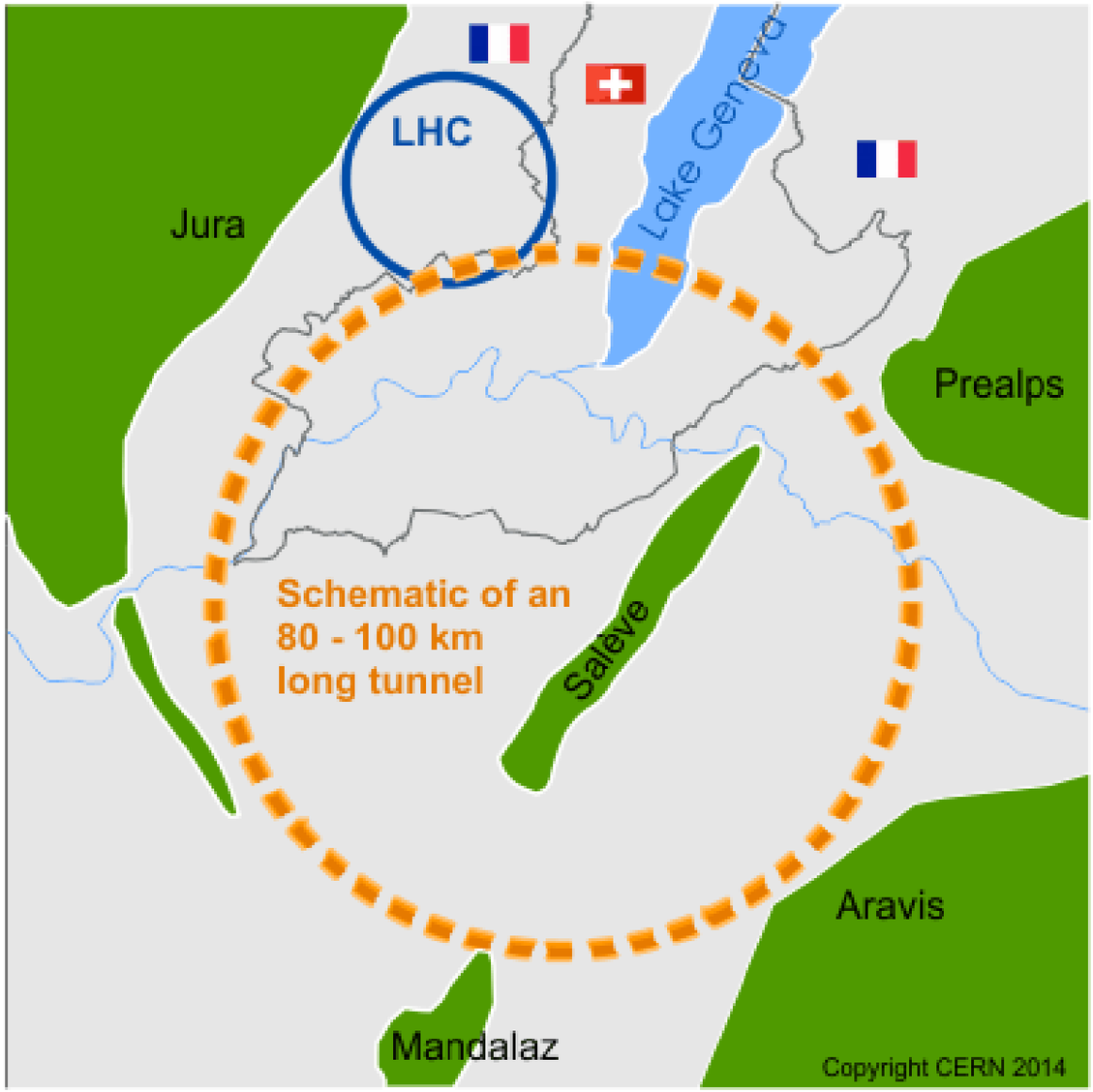
How to go to increase collision energy of constituents ?

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)

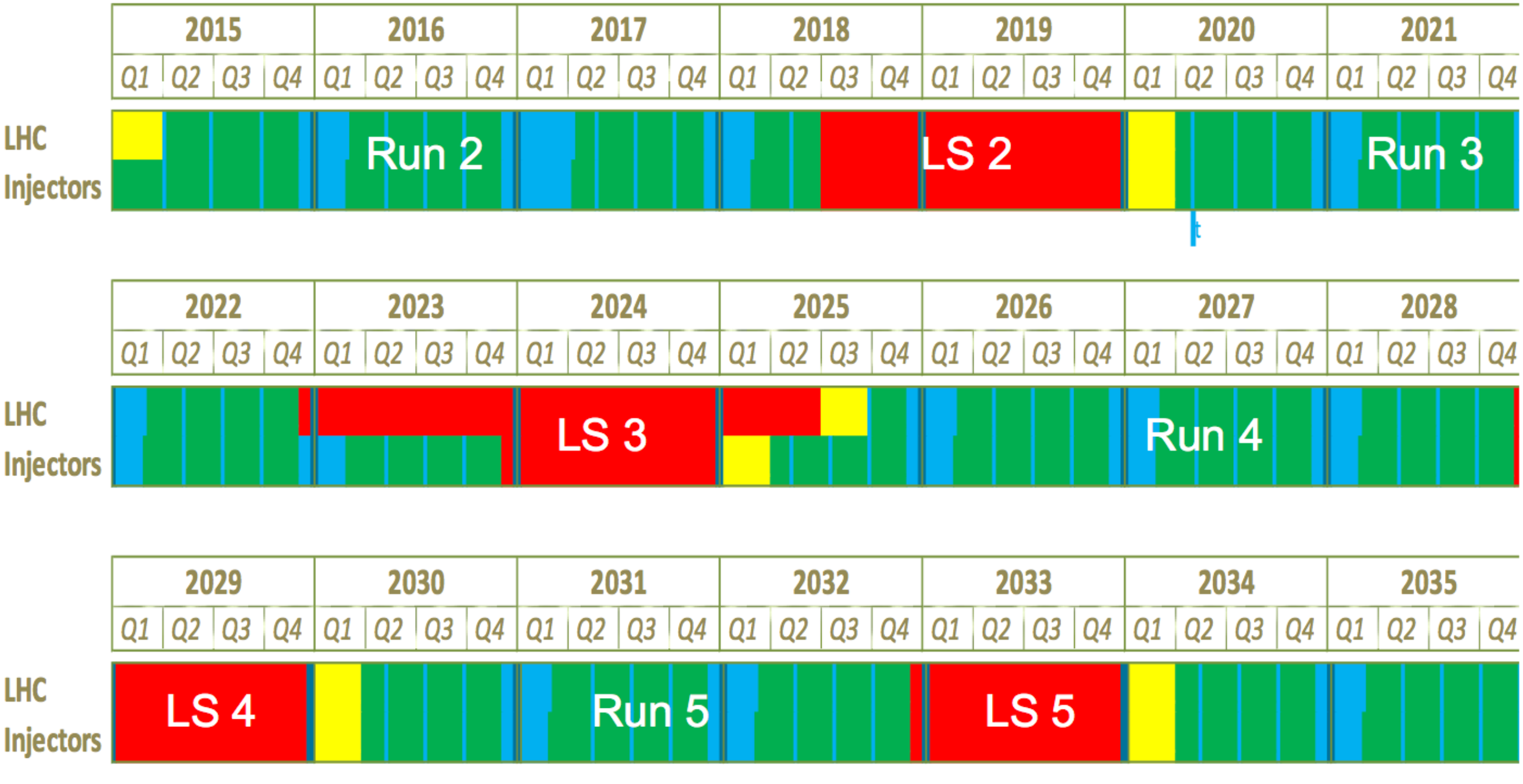
Also studied:

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

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

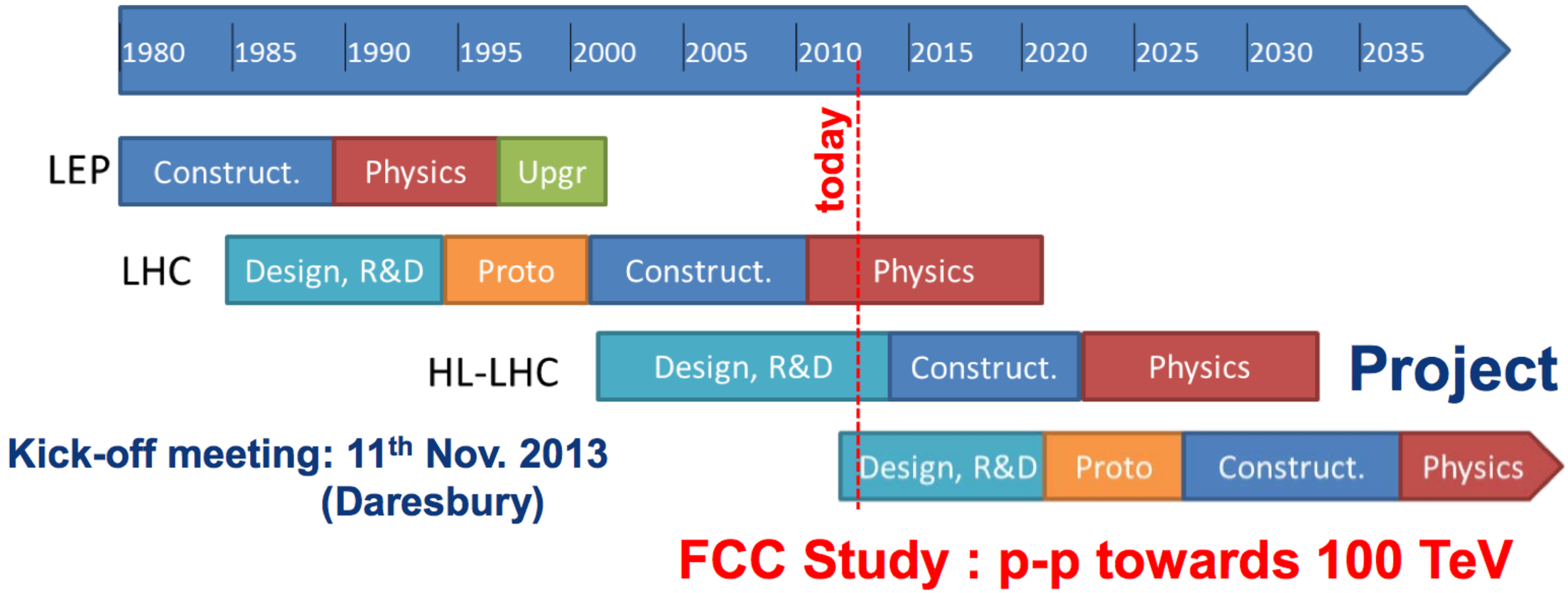
Conceptual design report ~ 2018

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.