Looking at the universe with particle colliders

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Pint of Science
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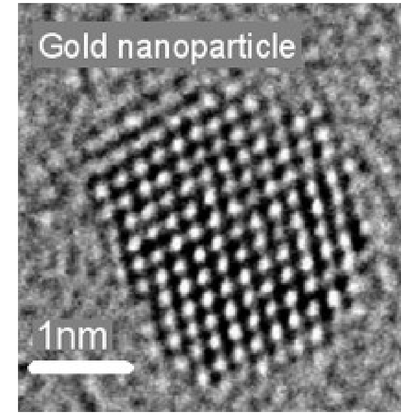
Microscopes

Scale that can be studied depends on
- magnification strength
- wavelength of light

Microscopes



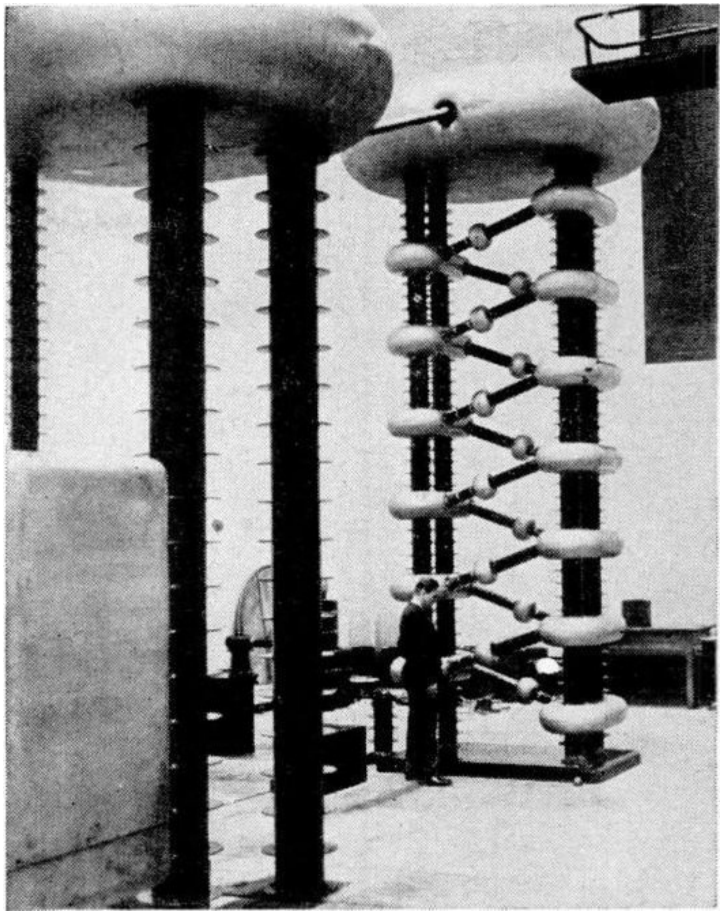
Scale that can be studied depends on

- magnification strength
- wavelength of light

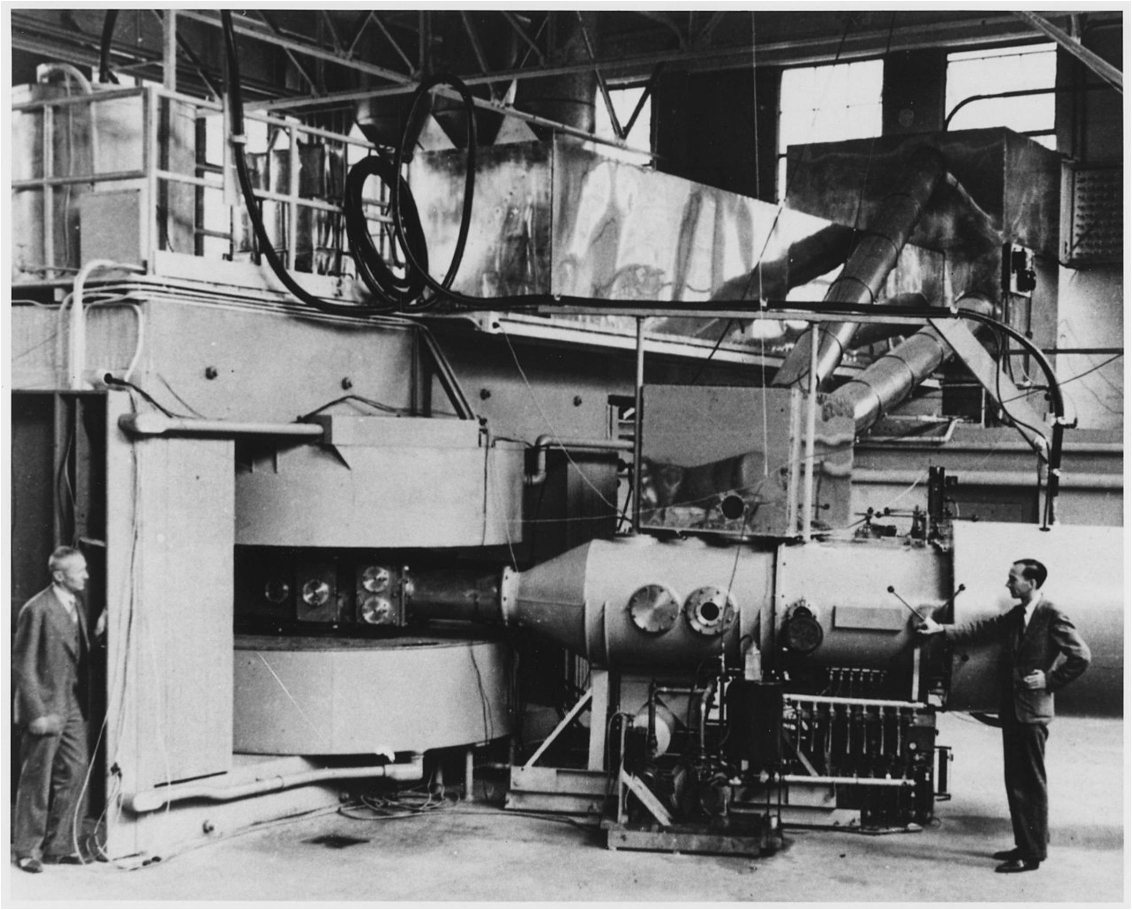
To look at smaller scales can use

- shorter wavelength light (X-ray microscopes)
- massive particles (electron microscopes)

To zoom in more …
accelerate particles



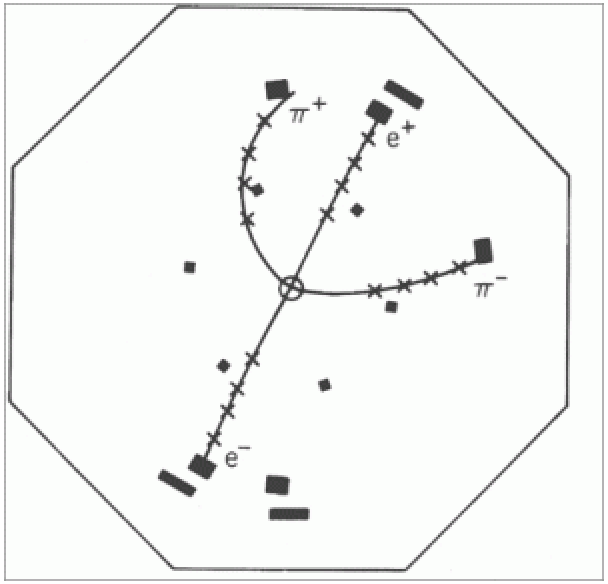
Cockcroft-Walton



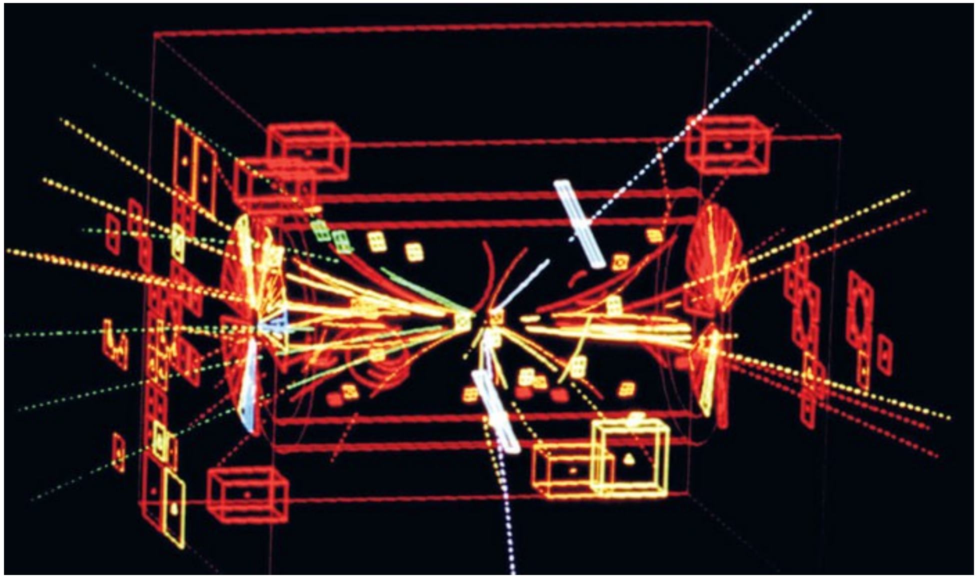
Cyclotron (Lawrence)

Discoveries with accelerators

- Just two examples of many

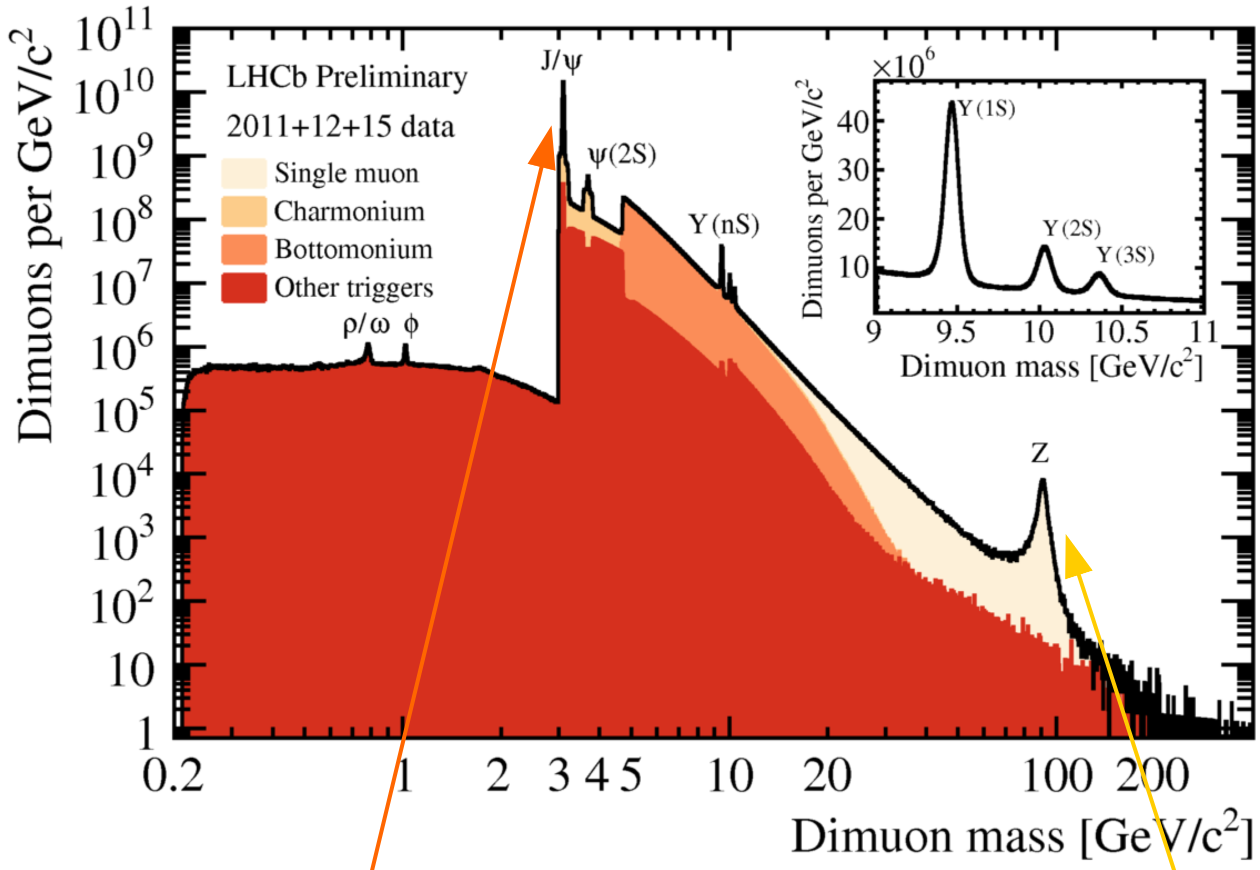


J/ψ particle (composed of charm quark + charm antiquark) discovered at SLAC e^+e^- collider 1974



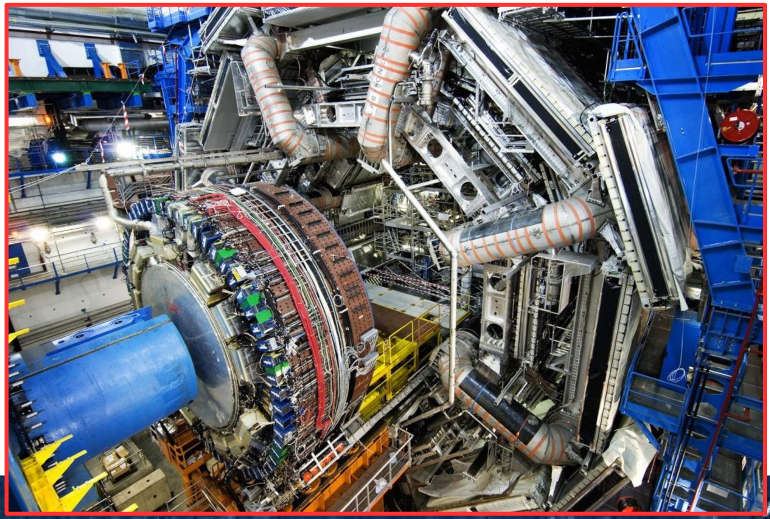
Z^0 particle (fundamental electroweak force carrier) discovered at CERN $p\bar{p}$ collider 1983

Standard Model particles today



Using data collected at the Large Hadron Collider, we can now see tens of billions of J/ψ particles and millions of Z^0 particles

The Large Hadron Collider

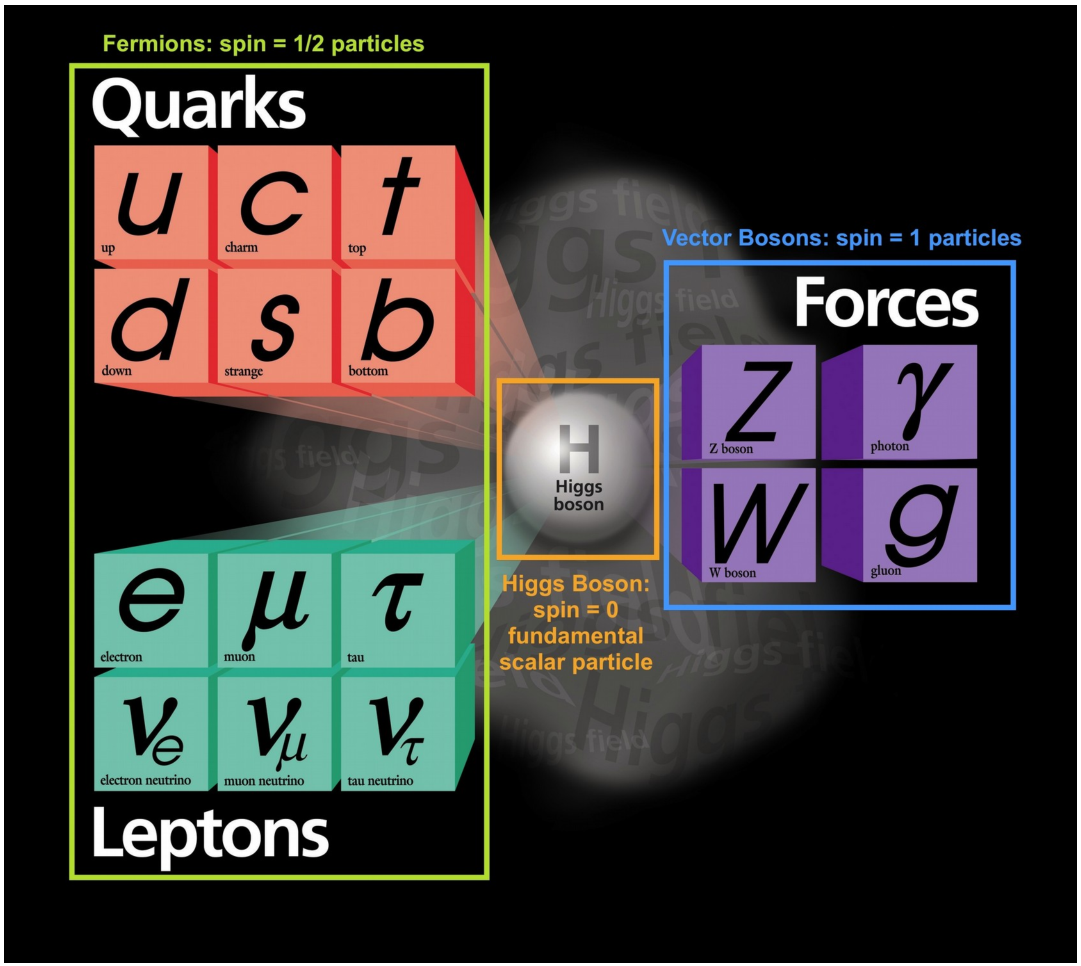


The Large Hadron Collider

- Based at CERN, near Geneva
- 27 km circumference
- 1232 main dipole magnets (8.3 T)
  - operating at 1.9 K (superconducting)
  - total stored energy around 10 GJ
- Data produced > total on the internet
  - only a fraction can be stored and analysed

Every new particle is a new type of microscope

(and some are new types of telescope, too!)

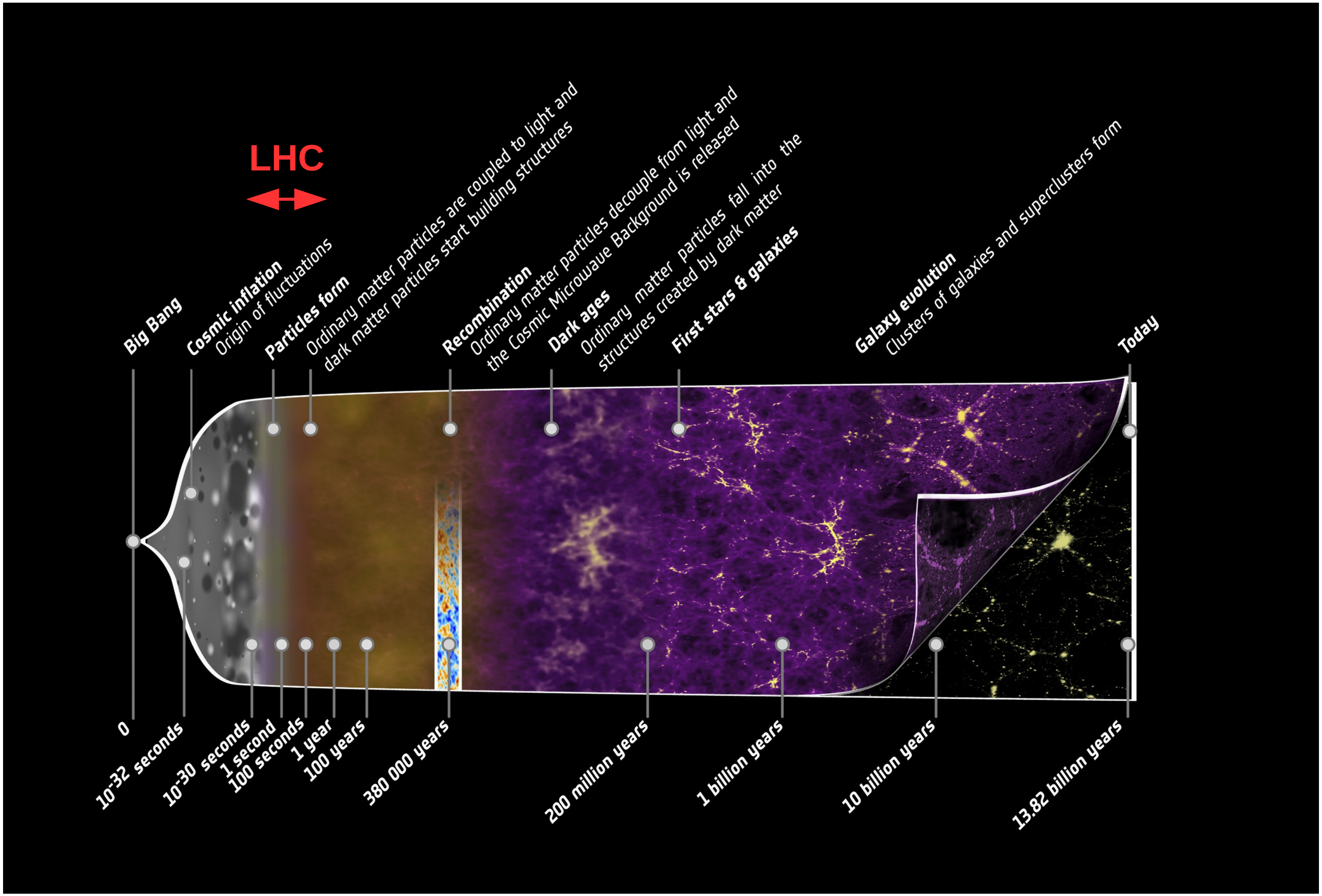


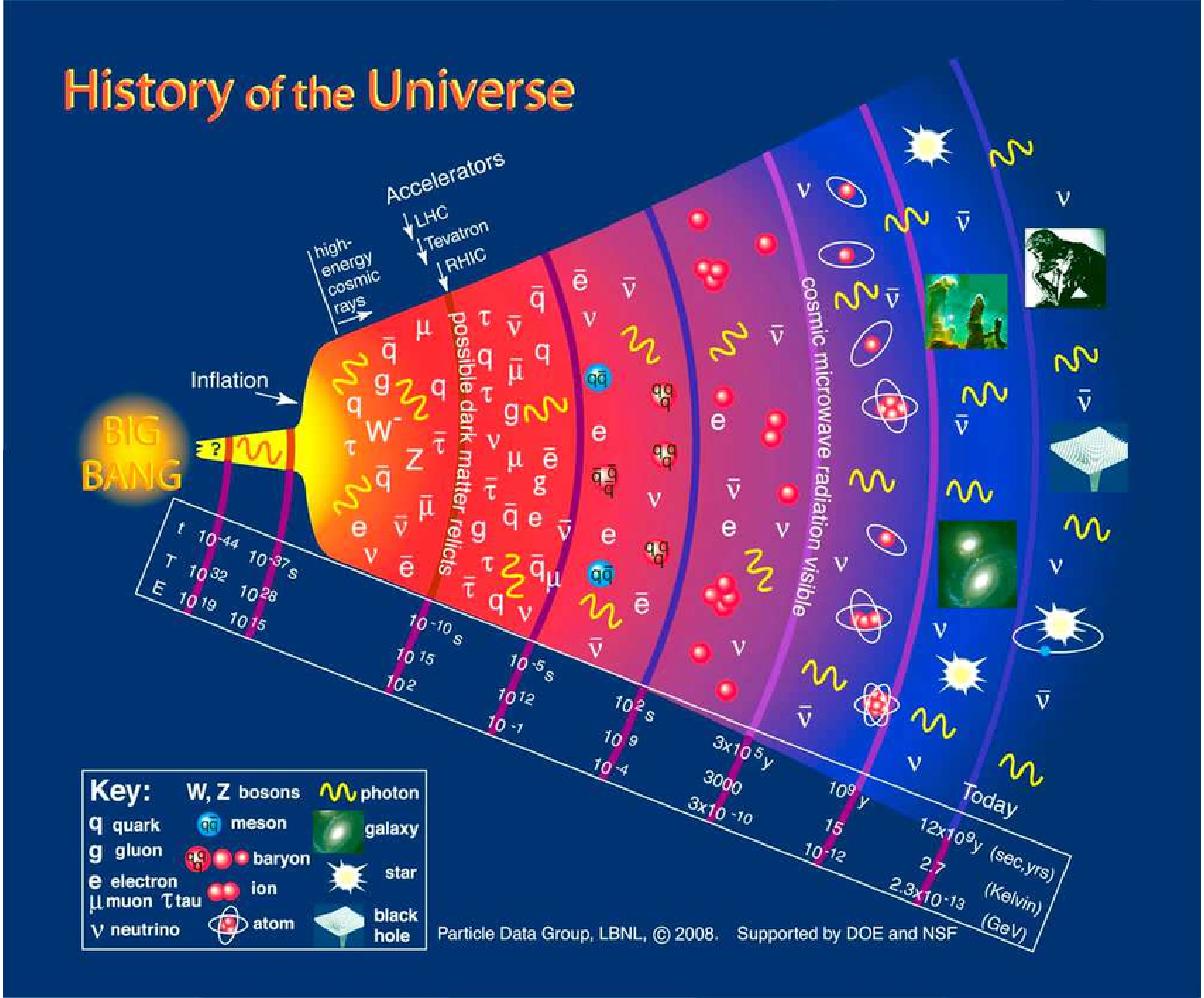
Studying these allows us to look at the Universe closer than ever before

Aim to answer some of the biggest open questions in science

- Why is there more matter than antimatter?
- What is dark matter?
- Why is the Higgs boson special?
- How do the forces behave at different scales?
- Are there new laws of nature?
- ...

Short distances ≡ High energies ≡ Early times



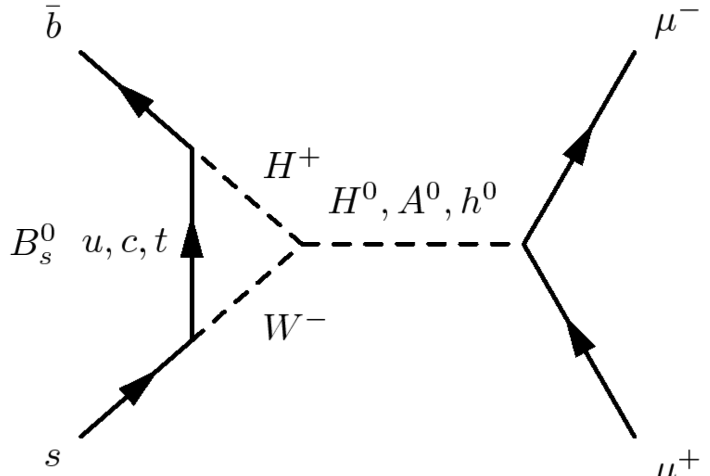


History of the Universe
BIG BANG
?
Inflation
high-energy cosmic rays
Accelerators
LHC
Tevatron
RHIC
possible dark matter relicts
cosmic microwave radiation visible
Today
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

Seeing further with quantum loops

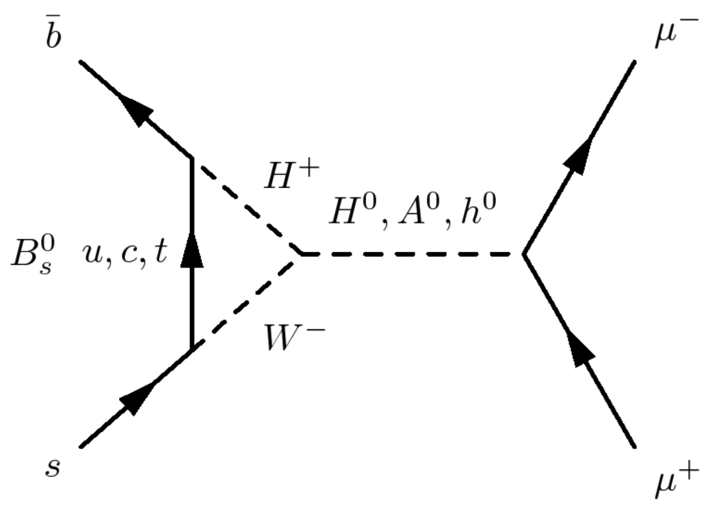
- Collision energy not the only important characteristic of a collider!
- Quantum effects probe effects of “virtual” particles
  - Heisenberg’s uncertainty principle:

$$\Delta E \Delta t > h/(4\pi)$$

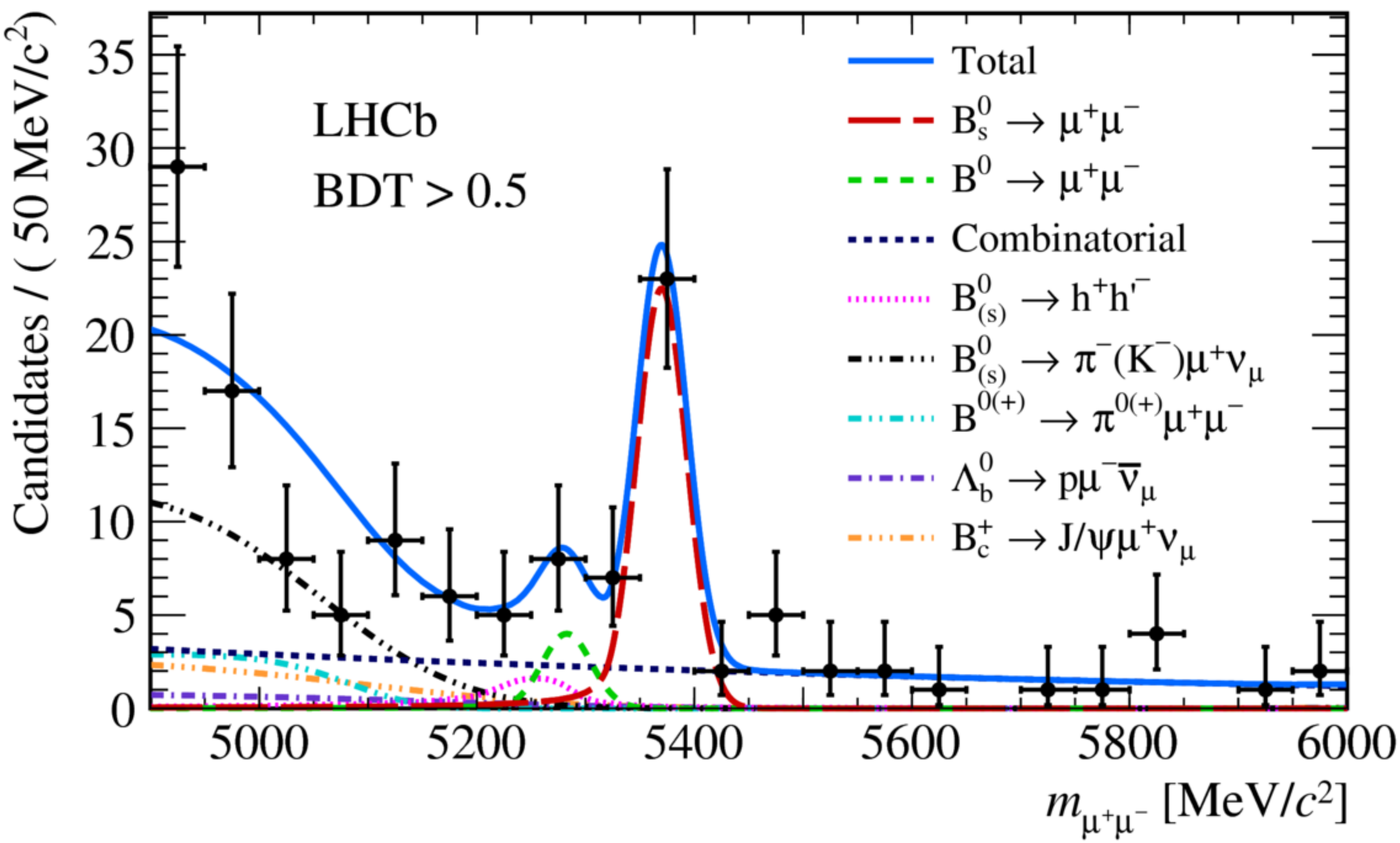


Seeing further with quantum loops

- Collision energy not the only important characteristic of a collider!
- Quantum effects probe effects of “virtual” particles
  - example: decay of B_s^0 meson to $\mu^+\mu^-$
    - forbidden in Standard Model without loop effects
    - small and precisely predicted rate once these effects included
- Require high precision & therefore large data samples



Measurement of $B_s^0 \rightarrow \mu^+\mu^-$



SM prediction: $B(B_s^0 \rightarrow \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$

Measured: $B(B_s^0 \rightarrow \mu^+\mu^-) = (3.0 \pm 0.6) \times 10^{-9}$

Consistent so far … but still much more to be done

Looking at the universe with particle colliders

- A tried and trusted method of making major discoveries about fundamental physics
- The Large Hadron Collider makes it especially exciting now
- Next few years may reveal insights into the early Universe, and help to address big unanswered questions