Looking at the universe with particle colliders

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Pint of Science
16\textsuperscript{th} May 2018
Microscopes

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

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- magnification strength
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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

$Z^0$ particle (fundamental electroweak force carrier) discovered at CERN pp collider 1983

$J/\psi$ particle (composed of charm quark + charm antiquark) discovered at SLAC $e^+e^-$ collider 1974
Using data collected at the Large Hadron Collider, we can now see tens of billions of $J/\psi$ 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 $\equiv$ High energies $\equiv$ Early times
History of the Universe

Key:
- W, Z bosons
- photon
- quark
- meson
- gluon
- electron
- baryon
- muon
- tau
- neutrino
- ion
- atom
- galaxy
- star
- black hole

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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:
    \[ \Delta E \Delta t > \frac{\hbar}{(4\pi)} \]
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: $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$

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

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