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A5 4 Trust Me, Bro, Just One More Particle Accelerator...

D. Booth, A. Friesner and C. Howitt

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

We consider the effects of increasingly large particle accelerators, approaching the ridiculous in scale, and how these could lead to pivotal discoveries. We find that accelerators using current magnet technology on a continental scale could be used to find Weakly Interacting Massive Particles (WIMPs), on an Earth-Moon system scale could be used to answer questions surrounding Supersymmetry, and on an interstellar scale could allow us to reach the Grand Unified Theory (GUT). We conclude that improving magnet technology is more important than scale.

Introduction

There are common jokes in scientific circles about constantly needing to justify increasingly large particle accelerators for high energy particle physics [1]. We consider the case where a research group has gone rogue after discovering a source of infinite money.

We propose three humorous cases:

Scale	Name & Acronym
Continental	"Massive Engineered Geo-Annular Loop (MEGA-L)"
Earth-Moon System	"Lunar Orbital Synchrotron Emission Radiator (LOSER)"
Interstellar	"Large Universal Device for Investigation of Cosmic Radii, Origins and Unknown Space-time (LUDICROUS)"

Theory

Each of these particle accelerators are giant synchrotrons which use a large ring of powerful magnets to confine particles to a circular path. To calculate the maximum attainable beam energy from a synchrotron, we begin by considering the Lorentz force:

$$\vec{F}_{\mathrm{B}} = q(\vec{v} \times \vec{B})$$

and the centripetal force,

$$\vec{F}_{\mathrm{c}} = \frac{m(\vec{v})^2}{R}\,.$$

When the magnetic field is perpendicular to the velocity (as is the case for an accelerator dipole magnet), the magnitudes are equal and we find:

$$F_{\mathrm{B}} = F_{\mathrm{c}} \Longrightarrow qvB = \frac{mv^2}{R}\,,$$

where in each of the above equations, the symbols take on their classical definitions.

This simplifies to:

$$p = qBR$$

as the momentum, p, is equal to mv.

In modern, high-energy colliders such as those at CERN, particles are accelerated at speeds close to the speed of light, c, which means we need to account for relativistic effects. At these speeds, the total energy of the particle is much greater than its rest mass, so we can approximate

$$E \approx pc$$

and therefore,

$$E \approx cqBR\,. \tag{1}$$

Given the apparent simplicity of this equation, the construction is clearly a question of engineering more than physics and each example could easily be the subject of an individual paper.

We also have to assume that the technology to build and operate synchrotrons on enormous scales exists which is rather unlikely. In each case, we will use the same 8.3 T magnets from the Large Hadron Collider (LHC) at CERN [2].

MEGA-L

We have identified Antarctica as a suitably circular landmass and have built a synchrotron with a circumference (length, L) of 1.6×10^7 m [3]. We can calculate the bending radius of our synchrotron using the following equation:

$$R = \frac{L}{2\pi}\,, \tag{2}$$

returning a value of $R \approx 2.5 \times 10^6$ m.

If we substitute this into Equation 1, we find a maximum attainable beam energy of 6.2×10^{15} eV, or 6.2 PeV. If we account for engineering challenges in Antarctica, even at 10% capacity the resulting energy far exceeds that of the LHC, a comparatively meagre 6.8 TeV [2]. If we managed to achieve a 100% efficiency then we could investigate the possibility of Weakly Interacting Massive Particles (WIMPs) since our collision energy (double the beam energy) would be nearly 40 PeV. At such large energies, WIMP signatures, which are identified by momentum imbalances in collisions, should be easily detectable [4].

LOSER

The average Earth-Moon distance is 3.844×10^8 m [5], which provides a minimum effective radius of $\sim 2 \times 10^8$ m. This returns a maximum attainable beam energy of 4.98×10^{17} eV, approximately 500 PeV which gives us a maximum collision energy of 1 EeV, capable of probing new mass creation limits that far exceed those of MEGA-L (25 times greater). There is also the chance of producing super-heavy particles that mediate forces beyond the standard model as we know it and this could lead to the first verifiable evidence of Supersymmetry (SUSY), where particles have supersymmetric partners with a half unit difference in spin. However, we do not know how far we would need to go in terms of collision energies to prove any SUSY models and it seems that hope is slowly fading for these theories [6].

LUDICROUS

If we wish to probe the Grand Unified Theory (GUT) and merge the theories of quantum mechanics with general relativity, then we need a collision energy equal to the Planck energy, 1.22×10^{28} eV (12.2 ReV) [7]. We can halve this value and rearrange Equation 1 to find a radius requirement of 2.45×10^{18} m, or approximately 260 ly which itself is around 1.4% the half-light radius of the Milky Way Galaxy [8]. With energies on these scales, we could also create micro black holes that evaporate via Hawking radiation [9] but they could temporarily swallow parts of the reactor which would be a problem.

Conclusion

While MEGA-L, LOSER and LUDICROUS provide humorous insights into current high-energy particle physics research, none of these particle accelerators would be feasible with current human engineering and they go to show that simply increasing the scale of particle colliders is not enough, there must be a better way of attaining collision energies greater than tens of TeV.

Perhaps focussing on drastically increasing the strength of electromagnets would be good idea, although, the proposed Future Circular Collider (FCC) could be taken to suggest that scale and magnets together can lead to faster discoveries [10].

References

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