Hi, this is Steve Nerlich from Cheap Astronomy, www.cheapastro.com and this is *Cheap Astronomy – Live at CERN.*

Here at Cheap Astronomy we occasionally report on an astronomy-related travel experience and since I recently went to Geneva and I visited CERN, that fit the bill nicely. CERN is an acronym for an old title in French, which the French don't use anymore, which roughly translates to the European Laboratory for Nuclear Research. But, it's actual title in English is now the European Organization for Nuclear Research and it's pretty much the same in French. Nonetheless, everyone remains happy to keep calling it CERN, even though it's an acronym that doesn't stand for anything now. Also, as soon as you as you start saying the European Organisation for Nuclear…, someone will quickly stop you and clarify that it's not really *nuclear* – since that sounds like it's about nuclear energy or even bombs. CERN is actually about particle physics and not much else.

CERN was established in 1954 and has hosted a number of particle colliders over the years, some of which have since become a part of the Large Hadron Collider, the LHC, which is currently the largest particle collider in the world. For example, the Proton Synchrotron, which began operation in 1959, can accelerate a proton beam up to 25 giga-electron volts. It feeds an already-accelerated proton beam to the SPS, the Super Proton Synchrotron, which began operation in 1976 and can accelerate proton beams up to 450 giga-electron volts The SPS then feeds beams into the LHC, which began operation in 2010 – and the LHC can accelerate that beam up to a world-record breaking energy level of 13 tera-electron volt range.

When you compare accelerator performance, it is best to talk in terms of electron volt energies, since you can accelerate particles quite close to the speed of light in a fairly modest accelerator. The extra energy of bigger accelerators contributes more to particle momentum than it does to speed – so the high energies of the LHC ensure that collisions of its accelerated particles are considerably more violent and hence more likely scatter debris, in the form of quarks and bosons. The term *luminosity* describes how many collisions per unit time and per unit cross-sectional area a particle collider can generate. Planned upgrades of the LHC are focused on increasing its luminosity through various tweaks and adjustments.

Of course, there are also longer-term plans for the next even bigger particle collider, which might have a 100 kilometre circuit as opposed to the LHC's current 27 kilometre circuit. This future machine is currently referred to as the FCC, the future circular collider, and is likely to be also built at CERN, and would hence likely be fed a particle beam that had already been sped up in the LHC. It's usually the case that bigger colliders are built on the shoulders of smaller colliders.

Within the LHC, as with most particle accelerators, the acceleration of charged particles is driven by mechanisms called radiofrequency cavities. Within those cavities, the polarity of an electromagnetic field is switched from positive to negative as positively-charged protons or other hadrons pass by. This process tends to bunch-up groups of particles – since, for any field-switch, some particles in the right position will be accelerated while others won't. This bunching-up is actually a good thing as it creates high-density packets of particles that will then produce higher luminosity collisions whenever two such bunches collide

The electromagnets you often hear about in particle accelerators are really just there to steer and shape the particle beam, rather than accelerating it. Steering is obviously important since the LHC is a big circle rather than a straight line. You can build linear accelerators, which do have straight-line beam paths, but the advantage of a circular accelerator is that you can run two beams in opposite directions before colliding them and you can keep giving those beams a repeated acceleration kick as they go round and around. The disadvantage of a circular accelerator is that particle beams lose energy when they are bent around curves. That energy loss is in the form of photons, called synchrotron radiation – and the more curvature that's in the beam path, the more synchrotron radiation that's lost. So, big circular accelerators are big because a larger diameter reduces the curviness of the path that particle beams have to follow.

So, to recap: the main components of an accelerator are the RF cavities that do the acceleration; the electromagnets that steer and shape the particle beam; and of course you need an evacuated beam tube so particles can keep moving at close to light speed without crashing into air molecules.

The LHC has 16 RF cavities and thousands of electromagnets, some of which guide the beam around the circle and some of which keep the beam narrow and focused and some of which can be activated to shift the two beams that are running in opposite directions so they collide. After an already-accelerated particle beam enters the LHC, it takes about 15 minutes to accelerate that beam to maximum energy, over which time particle bunches will have passed the 16 accelerating RF cavities around 1 million times each.

Beam collisions are directed to happen at four collision points around the LHC circuit and of course the LHC's main detectors are situated at those four points. There's Atlas, standing for A Toroidal LHC ApparatuS and the CMS, the compact muon solenoid – which are both generic detectors that collect generic collision data and it was Atlas that found the Higgs boson in 2012. Additionally, there's the LHCb detector that's investigating matter and antimatter physics and there's ALICE – A Large Ion Collider Experiment that's investigating quark-gluon physics.

Another key part of the LHC is its supercooling system. The high energy flow required for its electromagnets to work is only possible if the wiring is supercooled so that it will superconduct. In fact if you go down into the tunnel of the LHC, you'll see two tubes running alongside each other, one being the accelerator tube that houses the particle beams, the electromagnets and so on, while the other tube alongside it is the cryogenic system that keeps everything supercool.

Another key part of the LHC infrastructure is its IT system. When the LHC is running, collisions are going on all the time at the four beam cross-over points. This produces a ridiculous amount of non-stop data flow, so any kind of data storage device is going to fill up long before anyone's had a chance to sift through all that data. So, automated data processing filters out most routine collision events, reducing the data output by a factor of about 100,000. What's left is stored on local servers and copies of all of that is distributed around the world by what's now called the Grid, though no doubt you are familiar with its predecessor the World Wide Web, which was developed by Sir Tim Berners-Lee in 1989 at CERN.

Anyhow if you do go to Geneva for the CERN tour - and you go when the LHC is running, forget about most of the documentary visuals you might have seen showing all those long tunnels and huge detectors. If the LHC is running, no-one goes underground. The radiation arising from all the collisions, in the form of both gamma rays and high energy subatomic particles, could potentially kill you or at least shorten your life. And it's pretty cold down there too.

When the LHC is running it will run non-stop for months or even years at a stretch. The cool down and warm up processes that are needed between starts and stops take literally months to complete. So, as long as the LHC is running smoothly it's best just to keep it running. So, if you do want a tour of the underground bits, a shut-down for maintenance and upgrades is scheduled in 2019.

Whatever your plans are, be aware there is a bit of mucking-about required to book a CERN tour, which are all free and very popular. You have to book a tour online exactly fifteen days ahead of the day you want, although you might get lucky with the second round offer that's 3 days ahead. Alternatively, if you just rock up, you won't get the speaking tour but there are still self-guided exhibits on site that aren't half bad. There's the Microcosm exhibit – next to the visitors centre which has several walk-through rooms with animations and push-buttons that tell you about how the LHC works. And, on the other side of the tram lines, there's the Universe of Particles exhibit inside the Globe of Science and Innovation, which covers more of the theoretical side of particle physics – and actually gives string theory a lot more plausibility than you might have inferred from listening to some cheap podcast.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where you can always order the quark-gluon soup. No ads, no profit, just good science. Bye.