Guide Sheet: **Proton Express**

Overview and timing

Time	Task	Experiment/Slide	
Welcome (T0) 1 min	**Welcome** the audience. Introduce yourself and the show (title, language, duration) – (present translator)	Welcome slide: English or bilingual	
Intro 5 min	**Safety** *emergency exits* *Cryo liquids, magnetic fields and high voltage* *DO NOT COME ON STAGE unless invited* *Volunteer: no medical implant, heart condition, pregnancy*	Safety slide	
	Introduction Big Bang; fundamental questions of humankind	Proton Express slide Big Bang slide	
	IKEA accelerator Explain the important parts of particle accelerators	IKEA slide	**00:05**
Getting the Protons 10 min	**Wimshurst Machine: Plasma and Separation** Where can we find protons? Fire ~ plasma; volunteer *Safety: be careful with the candle, blow it off when demo over. Discharge*	Zoom into matter	
		Wimshurst with candle (Plan B: plasma ball + fluorescent tube)	
	Duoplasmatron Hydrogen gas; voltage	Duoplasmatron	**00:15**
No later than 15 min into the show: Accelerating protons			
Accelerating the Protons 10 min	**Van de Graaff generator** Electrons repel each other (same charge) *Safety: discharge*	Van de Graaff + saucers	
		RF cavity animation	**00:20**
	Further and further Particles need more space to reach almost the speed of light, cannot use a linear accelerator → circular	Optional: walking demo	
		Linac length slide Line to circle slide	**00:25**
No later than 25 min into the show: Steering the protons			
Steering the Protons 5 min	**Permanent magnet: Magnet and CRT TV** Curves the path of charged particles *Safety: be careful when handling the magnet. Turn off TV*	CRT TV with magnets	
	Electromagnetism: Electromagnet Electromagnet works with electricity; even copper has resistance; hot wires; possible volunteer *Safety: check the temperature with the back of your hand*	Electromagnet	
	Superconductors can conduct up to 13.000 A without melting – zero resistance but cooled down to -271°C	Show superconducting cable prop	**00:30**
No later than 35 min into the show: Cryogenics *Safety: no jewelry/watch, goggles, gloves, long pants, closed shoes*			
Cooling the magnets 10 min	**If you are low on time (>35 min), skip some or all liquid nitrogen experiments.**		
	Cryogenics: Fragility *Safety: knot outside to prevent fountain effect, hit carefully*	Rubber tube demo	
	Cryogenics: Pressure *Safety: do not touch the cold parts*	Kettle demo	
	Cryogenics: Shrinking	Ball and ring apparatus	**00:40**
Finale 5 min	**Cryogenics: Levitating superconducting train** Turn the track over; turn the track back and let it cool the right way up (try not to let the train fall).	Levitating train	
	Conclusion Accelerate and collide; more on detectors in the exhibitions; closer to answering the 3 questions	LHC animation Thank you slide	**00:45**
"Thank you, enjoy the exhibitions", individual Q&A possible in the first row (NOT ON STAGE)			

Show preparation

- Arrive at the auditorium at least **15 min before the show is due to start.**
- Say Hi to AV/Technical support, put on your microphone(s) and **check the sound** with them.
- Check the **emergency exit route** at the stage level: do the doors open, is the path to leave the building clear? If not, report to the technical team.
- **Remove the black cloth from the table and check the equipment.** If anything is missing, check whether it is in the flightcase or inform the person on duty or the technical team. If anything seems wrong with the equipment, inform the person on duty or the technical team.
- **Check that the Wimshurst machine is recharged**, if not, recharge it with the help of the plexiglass tube and fur provided in the flightcase (or ask the on duty person)
- Set up the **laptop** and the presentation.
- Wait at the stage level while the audience is coming in and make sure no one goes onto the stage area.
- If the show is translated, confirm final details with the translator.
- Any issues should be **communicated to the duty person or the technical team**, not the VTC.
- If you are performing the show during the weekend, you need to know how to use the Streamdeck with the Go Pros if the technicians have to leave for an emergency. You can find the explanations on Cernbox

End of the Show

- Stow the liquid **nitrogen dewar under the table** and out of sight. If the dewar is running low, ask the person on duty/technicians to bring a new one.
- For cryogenic materials, put back the remaining liquid nitrogen of the small dewar into the big one and lay any wet items out to dry, so they're ready for the next performance. Absorbent tissues for drying materials are provided under the table if needed.
- **Clean up the table**: leave the area as clean and tidy as you found it.
- **Cover** the table, the Wimshurst machine and CRT TV with the black cloth.
- Ensure that the **security bands** are in place around the stage.

Safety measures

PRESENTER

DO NOT PRESENT THE SHOW IF YOU ARE PREGNANT, HAVE A SENSITIVE MEDICAL DEVICE OR SUFFER FROM A HEART CONDITION

Thermodynamics

- Be careful when handling the **naked flame. Extinguish** it when experiment is over.
- Only touch the **electromagnet** with the back of the hand. **Switch it off** before it gets hot.

Static electricity

- Wilmshurst machine and Van de Graaff generator both produce high voltage (up to 10kV). While this is **static electricity**, make sure you do not touch the metal parts of the machines or the frame of the generator when charged. **Discharge** (by touching the two metal balls together) after demonstration and before touching.
- **Be careful when handling the TV**. Never remove the plastic casing at the back. **Turn it off** after the experiment.

Strong permanent magnet

- **Be careful when handling the strong magnet.** To avoid blunt injuries, keep a distance between the magnet and ferrous objects or sensitive electronics. Do not place the magnet directly on the screen as it scratches the screen – just hold it close to see the effect.

Liquid nitrogen

- **Remove** any watch and/or jewellery from hands. Wear **closed shoes and long pants.**
- Only handle the big liquid nitrogen dewar with **safety goggles AND gloves**.
- Never pour liquid nitrogen from the big dewar to the pot on the table – do it on the floor.
- Use **safety goggles at all times** when performing liquid nitrogen experiments (i.e. for the whole section of the show).
- **Do not touch liquid nitrogen** or any materials that were in direct contact with liquid nitrogen with your bare hands. Do not put your face over the liquid nitrogen.
- When handling the rubber tube, make sure that there is a knot on the outer part of the tube to avoid the fountain effect.
- Do not to touch the metal parts of the kettle as they can get very cold - use the handle.
- After you finish the liquid nitrogen experiments, **put the pot under the table, away from the public.** Similarly, move the big dewar under the table after the show.

Superconductors

- Be careful when handling the superconducting train. Do not let the train fall as this can cause the YBCO ceramic to break. Do not touch the ceramic directly; use nitril gloves.

AUDIENCE

- **Do not approach the stage** unless invited. Stay in the first row.
- **Do not touch** any equipment unless invited.
- The right side of the stage (next to the TV and the train) is **completely off limits** due to strong magnetic fields and liquid nitrogen risk.

VOLUNTEER

- Only participants with **no sensitive medical devices** (e.g. pacemakers), **no heart condition and no pregnancy** are allowed to volunteer.

In case of emergency, call the emergency services (fire department)
(+41 22 76) 74444

Show Overview

» **Duration:** 45 min + 15 min Q&A
Age group: 8+

AV support

Standard AV support	**Low AV support**
• Cameras and screens handled by AV team.	• If present, cameras handled by tech team • In case of emergency: Two GoPro cameras handled by the presenter using the Streamdeck to switch between laptop and camera view. Instructions
• Sound always handled by (AV) technical team. • General lights handled by (AV) technical team (ask for it, if needed).	

Key messages

- Same electric charges repel, opposite electric charges attract.
- Charged particles are accelerated (=increase in speed) by electric fields.
- Charged particles are steered (=change in direction) by magnetic fields.

Common pre-conceptions

- Charged particles are accelerated by magnets.
- Objects only get positively charged when they gain additional protons.
- Magnetic poles are electrically charged.

Equipment

Lighter, candle, candle stand, Wimshurst machine, plasma ball, fluorescent tube, Van de Graaff with discharge ball, aluminium saucers, CRT TV, strong neodymium magnet, power source, electromagnet, paperclips, safety goggles (x2), safety gloves, liquid nitrogen dewar, pot for liquid nitrogen, rubber tube (at least 20 cm with a knot at one end), hammer, chopping board, kettle, ring and ball apparatus, NbTi example cable, YBCO example superconducting block, superconducting train, magnetic track, coasters for distancing the train.

Example Script

Please use the **script below as an example**. You don't need to learn the script by heart, but you should also not stray too far away from the storyline so that you don't lose your audience or extend the show.

Please, do your best to **stick to the timeline**. This will allow the audience to keep their attention on you and the show, and you will be left with enough time to answer their questions after the show.

Most importantly, enjoy the show! The audience responds well to presenters who enjoy being on the stage with them. So, don't panic! ☺

Introduction [slide: Welcome – chose the correct one (EN or bilingual)]
Welcome to Science Gateway and welcome to today's science show **Proton Express**. This show will take you on a journey into the world of particle accelerators. It will last **around 45 minutes** and it will be **in [language(s)]**. There will be time for **questions after the show.**

My name is [name] and I am a [role at CERN]. Today, I will take you on a journey with our Proton Express (together with [name], who will translate this show).

[slide: Emergency exits] Before we start the show, I need to make a short **safety announcement**. In case of an emergency, this auditorium has **emergency exits** at the back, where you came in, and at the side(s) at the front of the room. After exiting the auditorium, please, follow the signs and meet us at the nearest emergency point. To reduce the risk of an accident, **please stay away from the stage** unless you are invited. This will make everyone's show more enjoyable. And finally, we are using **very strong magnets** on the stage, so if you have any **medical devices** (like a pacemaker), please do not come too close to the stage. We will also need a volunteer. As we are using strong magnet and high voltage equipment, please **do not volunteer if you are pregnant, have any sensitive medical device or suffer from heart condition**. Thank you for your attention and we hope you enjoy this show about particle accelerators at CERN.

[slide: Welcome abroad the Proton Express]
Before we start with particle accelerators, let's talk a bit about CERN. Does anyone know what CERN is?

[Maybe someone knows …]

CERN is the **largest particle physics research laboratory in the world**, with more than 18,000 scientists, engineers, technicians and so on. Now, what do all these people do? Let's have a show of hands to see what you think. I'll read out a few statements and you raise your hand if you think this is what people at CERN do.

(1) Raise your hand if you think people at CERN produce antimatter and investigate its properties.

(2) Raise your hand if you think people at CERN work in a hospital and develop medical devices.

(3) Raise your hand if you think people at CERN run the world's largest particle accelerator. [Wait for audience to raise hands after each statement].

All of you are correct! At CERN, thousands of people are trying to learn what we are made of, how the Universe began and how the universe will continue to evolve, by researching antimatter, medical applications, and much more! They are studying this with the help of the largest machine in the world: the **Large Hadron Collider, or, as we call it, the LHC**. The LHC is a 27km circle, 100m underground, where we can accelerate particles up to almost the speed of light! But why are we doing this?

[slide: Big Bang slide] To answer this, we need to return to the very beginning. **13.8 billion years ago**, there was something called the **Big Bang**. This was the very beginning of the Universe. While the theory of the Big Bang has been around for almost 100 years already, we still don't know exactly what happened in those first instants of the Universe. In fact, the very beginning of the Universe is still one of the three fundamental questions of humankind:

- Where do we come from? (how did the Universe begin?)
- What are we made of? (and what is all the stuff around us made of?)
- Where are we going? (what will happen to the Universe in the future?)

These three questions have been driving all fields of fundamental science in one way or another, including particle physics. To answer these three fundamental questions, particle physics uses sophisticated tools - which can sometimes be quite complicated. Who here thinks particle physics sounds complicated?

[Show of hands.]

Okay … Who would like me to make it a bit less complicated?

[Show of hands.]

Okay, I guess I can try.

[slide: IKEA slide] All Particle physics research can be more easily explained using a simple set of IKEA-like instructions. So, what do we need? We need some straight tracks, some circular tracks, about 2800 train wagons with 100 billion passengers (or protons) each, and, most importantly, approximately 18 thousand scientists, engineers, technicians, and so on.

As with real IKEA items, the most important instruction is this one: you should never work alone, always bring a friend. This is why all those 18 thousand CERN people need to work together to build and operate their research facilities. In the end, we should create something like this (point to the image of the CERN accelerator complex), the CERN accelerator complex. So let's begin…

Getting the Protons

The first thing we need for our proton express, is some protons!! Does anyone here know **what a proton is**? [Maybe an answer.]
Exactly, a proton is a **positively electrically charged particle**.
Did anyone bring any protons with them today? [Maybe some raised hands]

Protons can be found in **everything around us**, including our bodies. Let's see where we find protons in our bodies.

[slide: Zoom into matter animation]
Talk over the animation to explain what the audience is seeing

Okay, so now we know where we can *find* protons – in all atoms. But we don't yet know how we can *separate* them from the atoms and get them on their own. Well, for that, we need to do some experiments.

The first experiment will help us to see how we can get protons out of atoms. For this experiment, we need to first talk a bit about **different states of matter**. Which states of matter do you know? (prompt with 'There are 3 main states of matter' if the audience is slow to respond).

[Solid, liquid, gas.]

Exactly, usually we talk about three main states of matter: solid, liquid, and gas. However, these three are not the only states of matter around us. Does anyone know a fourth state of matter? (Prompt with it is the most common state of matter in the Universe, if audience doesn't respond)

[Plasma.]

Yes. **Plasma** is the most common state of matter in the Universe. Plasma is a state of matter in which the electrons, constituent particles of atoms, receive enough energy to escape the atom. Kind of like if I ran *super* fast and my nose fell off.
Does anyone know how to create plasma?

[Heat/High Voltage]

/// Plan B if Wimshurst Machine doesn't work: Plasma ball (create plasma by applying a high voltage to a gas) and fluorescent tube (to show the movement of electrons) ///

One way of creating plasma is by increasing the temperature of matter. At CERN we have a lot of very fancy technology. Here, I have a state-of-the-art hot plasma maker with me. Do you want to see it?

[Yes!] *shows the lighter dramatically*

Ok, I was joking – this is a regular lighter. With it, we can create fire (*lights the lighter*), which can be considered a plasma (*showing the flame*). Inside the flame, the electrons are moving freely in a soup of positively electrically charged particles. So, it is quite easy to create plasma. But, for our Proton Express, we need protons. So how do we remove some protons from this plasma?

Wimshurst Marchine and candle experiment

We can demonstrate how to do this with the next experiment. Here, I have a strange-looking machine (called a Wimshurst machine). This is made of two round plates, with metallic strips on them, and tiny metal brushes that brush against the metal strips when

we turn the plates. When the brushes brush against the metal strips, they "steal" electrons from them. These stolen electrons get onto one of these two balls, which makes it negative, while the other ball receives no new electrons and remains non-negative/neutral.

I'm going to light a candle and put it in between these two metal balls and then start the machine. Actually, I am going to ask a volunteer to help me with this. Would anyone like to help?

[Get a volunteer; name, applause.]

Okay, [name], you will have one very important task: you are now an engineer, so you need to turn the handle at the back of the machine to start the experiment.

Turn the handle clockwise and increase the speed at first. (Instruct volunteer to keep going until they have reached a good speed). Now, slow down a bit and maintain a steady speed.

Everyone else in the audience, you're the physics PhD students. Your task is to observe what is happening with the candle and describe the phenomenon.

Before we start with this, does anyone have any predictions about what might happen? In science, we call these predictions hypotheses. Any ideas?

[Take ideas from the audience, if there are any.]

Okay, so let's try it and see what happens… maybe nothing will happen. Audience, please make sure that you are good observers. Let's go in 3, 2, 1 …

[The volunteer spins the wheel.] *Ask the volunteer to stop and start again to see the difference in the flame when the wheels are moving or not.*

Did you see any change in the flame? [ask volunteer or audience]

[Answer(s).]

So, remember that these two balls have different charges. One is negatively electrically charged, and the other one is more positively electrically charged. Therefore, one ball attracts the positively electrically charged particles, protons, and the other ball attracts the negatively electrically charged particles, electrons. As the protons and electrons are both a bit freer in the flame, in the *plasma*, the flame gets stretched between the negative and (more) positive balls.

/// [Thank the volunteer, sit down, round of applause.]

A similar principle is also used at CERN, but with a slightly more sophisticated method! Instead of using *fire* to get plasma, we use ***high voltage***. High voltage has a similar effect – it frees electrons from the atoms. Once we create plasma, we need to pull the electrons in one direction and send the protons in a different direction – simple. We can see how this is done with this animation. At CERN, we do this using a machine called a **duoplasmatron**!

[slide: Duoplasmatron animation] *Explain what people see in the animation.*

In this animation, we see that at CERN, we always start with a bottle of **hydrogen**. As hydrogen is the simplest element with an atom that is only made of one proton and one electron, it is the simplest choice for getting protons. The hydrogen gas is directed into a duoplasmatron, where it first goes through a phase transition to become plasma, and then the electrons are stripped, as they are attracted to a positively charged part of the device, like in the animation. The protons continue, entering the next step of our proton express – the **linear accelerator.**

Accelerating the protons

Particle accelerators are huge machines that accelerate particles to speeds close to the speed of light, making them super energetic. Does anyone know how we can accelerate particles? [Prompt with: What can we use? if necessary].

[The answer is electric forces, but often the audience answers magnets]

[If magnets is answered:] This is almost correct[1], but we'll talk about magnets later. To increase the speed and the energy of particles, we need to use **electric forces**.

We've already seen one experiment that uses electric forces - *point back to the Wimshurst machine* - But now we will see how particles can be accelerated, using an even more impressive experiment.

Van de Graaff generator experiment

This is a world-famous experiment, called the Van de Graaff generator. It works in a similar way to the Wimshurst machine, but it is electrically powered, so I don't need to use manual power to turn a wheel. When I turn the Van de Graaff generator on, the rubber belt starts rotating and rubbing against a metal strip inside this ball. As that happens, electrons are scraped from the rubber belt and they collect on the metal ball. So, the whole outside of the metal ball becomes negatively charged. These electrons repel each other, and they want to be as far away from each other as possible.

Here I have some aluminium trays. What do you think will happen if I put them on top of the Van de Graff generator and then turn it on?

[They will fly off. Get compressed. Nothing…]

Let's try it and see what happens! (turn on the Van de Graaff)

Flying saucers

The aluminium trays are repelled from the top of the Van de Graaff generator, and they fly off individually. So they are accelerated away from the machine. We have shown that particles (in this case electrons) can be accelerated using **electric charge**. While this is an impressive experiment, the saucers were not flying anywhere near the speed that we want the protons to reach at CERN, which is almost the speed of light. This is only possible if we accelerate the protons again and again and again. We can see how we do this at CERN in this animation.

[Slide: radiofrequency cavity animation] *As animation is playing, describe what people are seeing – the blue and red colours are alternating, showing that the electric charge is alternating between positive and negative, thereby repelling and attracting the protons as they move through the accelerator.*

The positive and negative charges change at exactly the right time. When there is positive charge behind the proton and negative charge in front, the proton is accelerated; (it is repelled from the positive charge and attracted towards the negative charge). When the proton reaches the negative electric charge, the charge changes to a positive charge. The

[1] It is almost correct, as acceleration generally means changing the vector of velocity. As such, magnets accelerate by changing the direction of protons.

proton flies past, the positive charge repels the proton, and the story repeats again. If we switch it at exactly the right time, we can accelerate particles faster and faster and faster … But there's one problem - the particles are going faster and faster…!

[Optional demonstration] How is that a problem? Well, let's see how that works. Let's say I am a proton. (Step in front of the tables) Hi! I'm a proton. I am now being accelerated inside the particle accelerator. In the first second, I travel 1 step. Then, I am accelerated, so in the second second, I travel 2 steps. And in the third second, I … run out of the auditorium. And I'm still nowhere close to the speed of light!

As I mentioned before, at CERN we wish to accelerate protons to **99.9999991% speed of light.** If we want to accelerate a particle from a standstill to this extremely fast speed, we'd need a linear accelerator that would go from Switzerland to…

[Slide: Linear accelerator length]

… the edge of our Solar system. That's a problem. But there is a solution for this. Does any of you have any ideas how to make … basically, an infinite line with no start and no end?

[Circle.]

[Slide: Line to Circle] What a fantastic idea! That's also what particle physicists and engineers came up with, almost 100 years ago.

So how can we use a circle for particle acceleration? Well, the principle of accelerating particles in a **circular accelerator** is very similar to how we push someone on a swing. Who here has been on a swing before?

[Show of hands]

And who has pushed someone on a swing?

[Show of hands]

How do you push a swing? Do you push the swing all the way forwards and pull it all the way back again repeatedly? No, right? You just stand in one spot, and you wait for the swing to go forwards and back again… and when it's just in the right spot, you catch it and push again. We do the same with protons, but **we use electric force to give them the push**.

Steering the Protons

But if we give the protons a push, they will just travel in a straight line, and we need them to follow a circular path. Does anyone know what we can use to steer the protons? To bend their path?

[A magnet.]

Exactly, we can use a **magnet**! This next experiment will demonstrate how a magnet can affect the path of electrically charged particles. I'm going to show you something that will make some of you feel really old, if you remember this object, and some of you might be too young to know what it is!

CRT TV Experiment

This is a really old TV. It is called a **cathode ray tube TV, or CRT TV** and it is also a particle accelerator! You can see the accelerator nicely if you open up a TV – but beware, opening a

TV like this is something you should **never** do at home. The team that opened this TV are all trained professionals. Anyway, this particle accelerator is quite similar to what we use at CERN. First, by heating up the material at the very back, we free electrons from this part, then the electrons are accelerated towards the screen at the front. Finally, the electrons hit the screen, where they interact with the material and provide us with an image.

Here, we have also installed a magnet - this red thing on a stick *(point out the magnet)*. This magnet is connected to the knob at the front, so when I turn the knob, the magnet moves closer to the beam of particles or away from the beam.

Now, let me turn the TV on … Wow, the image quality is really not very good; you can see why new technology was developed. But you can probably still recognise the people on the screen. Wave if you see anyone you know! What do you think will happen if I turn the knob to bring the magnet closer to the electron beam in the CRT TV?

[The image will split/shift/change colour/brightness…]

Turn the knob/bring a magnet close and describe what we see *(don't touch the screen with the magnet!)*

So, when we bring a magnet close to the stream of electrically charged particles, the **particles deflect, their path curves**.

But the problem with this magnet is that it is a **permanent magnet**. It always has a magnetic field. In the LHC we need to use extremely strong magnets, but we need to be able to turn them on and off. Does anyone know what kind of magnet we can use to do that?

[Electromagnet.]

Yes, **electromagnets!** An electromagnet is a fantastic choice for a magnet that can be adjusted, turned on and off, and that is also super strong. But what is an electromagnet?

[Maybe someone answers.]

An electromagnet is a device that relies on the connection between electricity and magnetism. When we create electric current in a wire, a magnetic field appears around it. If we make that wire into a coil, with many, many turns, like this (show the electromagnet), we create an electromagnet. Let's try it out with this one.

Turn the electromagnet on and off*, use it to pick up some paper clips. Point out that it only acts as a magnet when it is turned on; when there is an electric current running in the wire. if it's turned on for about a minute, it becomes warm, which you can use to continue your storyline.*

So, the electromagnets are a fantastic solution. They're also great because the more electricity we send through the wire, the stronger the magnet is, so we can control the strength of the magnet. However, even with low currents, electromagnets like this **get very warm very quickly**. That's because the wires are made of copper, and although copper is a good conductor it still has some resistance to electrical current. Because of this resistance, when we send the electricity through, some of electrical energy is transformed into thermal energy. We can feel this if we touch the copper wire.

Feel the electromagnet to demonstrate this (when it is unplugged); you can also bring it to a volunteer near the front to test as well – they should use the back of their hand.

This experiment was done with a low electric current which creates a weak magnet. But the higher the current, the hotter the electromagnet would get. At CERN, we need our magnets to be incredibly strong, so we use **13,000 amps**. At this high a current, the copper wires would simply melt. And let me tell you – that's not good. So, we needed to find a better conductor – a *super*conductor!

Superconductors are super cool materials. There are different kinds of superconductor; for example, this is the cable that we use at the LHC, which consists of a superconducting material called **Niobium Titanium**.

Show the superconducting cable prop

Superconducting materials are great. When they become superconducting, they have **zero resistance**, so they don't heat up at all. This one is great for making extremely strong electromagnets, which can conduct up to 13,000 amps without melting! And yes, 13,000 amps is A LOT! This creates a very strong magnetic field, equal to the strength of several thousand fridge magnets!

However, we can't use this material today, as it needs to be cooled down to about **2 K (-271°C),** and we can't do that on the stage.

Cooling the magnets

We can explore a different superconducting material – a high-temperature superconductor called **YBCO (Yttrium Barium Copper Oxide)**. When I say a high-temperature superconductor, you might expect this material to work at a hot temperature?

[Optional: What temperature would you expect this to work at?]

In fact, it's only *high temperature* in comparison to other superconducting materials such as the Niobium Titanium inside the LHC. This material, YBCO, needs to be cooled down by something called liquid nitrogen.

Have you heard of liquid nitrogen before? What is it?

[Yes.] [Super cold nitrogen.]

Exactly, at room temperature, nitrogen is in a gaseous state of matter. But if it is cooled down to a very low temperature it becomes a liquid. This is **below -196°C**, so it's very cold.

*Pour out liquid nitrogen – **wear goggles and gloves**. As the audience to observe the colour and what they see when you pour it out. You can comment on the colour – transparent; and the fog – the condensation of water vapour in the air as you pour it.*

Before we can use superconductors, we need to cool them. But there are some risks associated with using super cold materials. Let's try to find out with an experiment. Here I have a rubber tube. Which state of matter is this tube in?

[Solid.]

Yes, it is a solid. What will happen when I use the liquid nitrogen to cool down a solid? Will it become solider? Let's see. Right now, the rubber tube is really bendy and flexible. It has elastic properties. If I hit it with a hammer, the hammer bounces back up (show the hammer hitting the tube). Let's see what happens when I put the rubber tube in the liquid nitrogen and cool it to almost minus 200 degrees.

Put the tube in liquid nitrogen. Check that the knot is on the outer end of the tube to avoid fountain effect!

Does anyone have a hypothesis?

[It will break / explode / disappear… etc]

Okay, let's check if any of those can be supported by our experiment.

Take the rubber tube out when it has finished boiling, and then smash it GENTLY with the hammer.

The tube became extremely **brittle**! And, just so you know, this would also happen to your finger if you'd put it into liquid nitrogen[2] for a few moments. Yikes! As you can imagine, this can also be a problem for the materials we use – we need to make sure that our materials can withstand these temperature changes and don't suddenly break.

This first problem of **fragility** is made even worse when we combine it with the second problem. If we want to keep the superconductors cool, we need to somehow trap the cooling liquid. But the cooling liquid would rather be in a gaseous form at room temperature – which is the temperature of everything around the device. So, the liquid boils – just like this liquid nitrogen. Usually, we boil water in a water kettle. Have you done this before?

[Yes.]

So, if liquid nitrogen boils at room temperature, what do you think will happen when we put it into this kettle?

[The kettle will explode.]

Let's try it.

Pour some liquid nitrogen into the kettle and close it.

It's whistling! Why is the kettle whistling?

[Pressure.]

Yes, it's the **pressure**. When nitrogen boils and changes from a liquid to a gaseous state of matter, it expands and takes up a lot more space. In fact, one litre of liquid nitrogen becomes almost **700 litres of gaseous nitrogen**! If the kettle were made of a more fragile material, or even worse if we closed it off completely, all that pressure would build up and result in a big BANG (explosion)! But not the cool one as we talked about in the beginning.

Optional: show the audience how the lid of the dewar is loose. It comes off easily and is never tightly sealed, so that if there is a build-up of pressure, the lid comes off and the gas (and pressure) is released.

And there's also another problem. Here, I have a metal ring and a metal ball. The ball fits into the ring. What do you think will happen if I cool the ring down in the liquid nitrogen?

[2] Of course, we know that we get the Leidenfrost effect protecting our fingers, but we don't want our audience to risk doing the experiment without proper training or proper precautions, so we do not mention this effect.

[It could shrink / the ball will no longer fit / it will melt, etc.]

Ok, let's try it and see what happens.

Ring and ball experiment. *Cool the ring down in the liquid nitrogen for about 20/30 seconds. Then remove the ring from the liquid nitrogen and test with the ball again.*

The ball no longer fits through the ring! This is because as the ring cooled down it contracted. Now the hole is smaller, so the ball doesn't fit through. When it warms up again the ball will fit through, as it did in the beginning. This **contraction** is another really important consideration when building a particle accelerator. The world's largest experiment, the Large Hadron Collider (or LHC) is in a 27km ring, 100m underground here at CERN. When this machine is cooled down, it also contracts. It is 27km long, any idea how much it contracts by? *(You can encourage the audience to make random guesses)*. It contracts by **80m**! If you think of a 100m running track, it is long… and you think of *most* of that track, that's how much distance we *lose* from the machine when we cool it down. So it's really important to account for this when building the machine.

Ok, so we have three important considerations to keep in mind. [1] We need to be careful about which materials we choose in case they become more fragile or brittle, and break; [2] we should not close the liquid nitrogen container completely, so that we do not have a dangerous build-up of pressure, and [3] we need to account for the fact that the machine will contract when it is cooled.

As I said, I cannot show you how the superconducting cables we use at CERN work, but we can explore the amazing property of superconductivity by using YBCO superconducting discs. I have installed a superconducting disc in this train. The train is on a magnetic rail, and I have used coasters to keep a small distance between the train and the magnets. I'm going to cool the train superconductor down by pouring liquid nitrogen into the train. I fill the superconducting train with liquid nitrogen … and then we wait.

Superconducting train *- Pour liquid nitrogen into the train – you will need to do this 2/3 times and wait about 2 minutes for the train to become cold enough to work (use the timer). During this time, you can continue to talk about the trains or superconductors*

The material needs a bit of time to cool down – but it is a cool experiment so it's worth it. What we will see will be, in some way, an interaction between magnetism and electricity. However, the physical principle behind this is really complex – it's quantum mechanics!

This demonstration does not exactly show what we use superconductors for at CERN, but it's a very cool demonstration for the show! And the technology used in this experiment is similar to the superconducting trains that are being developed in Japan and China. In fact, from 2034 there will be superconducting trains with passengers! They are, however, using niobium titanium, the same material we use in the LHC. Ok, so let's see what superconductors can do!

Check that the train is ready, otherwise leave it a little longer. Remove the coasters from under the train and push it gently along the track

Wow!! The train levitates above the magnets! So, what is happening? Well basically the superconductors "learned" the magnetic field they were in when they cooled down and turned into superconductors. So they are 'pinned' to this particular magnetic field and they don't let any other magnetic field through. It's really cool. Are you impressed?

[Yes.]

It sounds like some of you are not yet impressed by this – I don't know why! So maybe I can make it even better!

Hold the wheel while removing the pin from the track and carefully turn the track upside down. Do this towards the camera so that the audience can see it as it turns

Look! Even when it is upside down the train still levitates at the very same distance as it did before. This level of stability on the track is really useful for future trains, making our train rides safer, faster, and more energy efficient. Oh, and cooler of course!

Put back the train upside down so it doesn't fall

Conclusion

We have seen how we can separate charges from a plasma, to get a beam of protons (like in the Wimshurst machine); use electric charges to accelerate those protons (like with the Van de Graaff generator), steer the proton beam using a magnetic field (like in the CRT TV) and considered the safety issues.

[slide: LHC] If we put all of this science and technology together, we can build the largest particle accelerator in the world – the Large Hadron Collider, or the LHC. 100m under the ground, this is where we use electric fields to accelerate particles to almost to the speed of light, steer them in circles with superconducting magnets, and, finally, collide them in enormous particle detectors. We don't have time to explore particle detectors in the show today, but you can learn a lot about them in the Science Gateway exhibitions. A true collaboration between science and technology, and we do all this to get closer to answering the three fundamental questions we mentioned in the beginning of this show: where do we come from, what are we made of, and where are we going?

[Thank you slide] Thank you all for joining this science show today, I hope you had fun and maybe even learned something new. If you have any questions, feel free to stay and I will do my best to answer them – but please don't come on the stage. Otherwise, have a wonderful day in CERN Science Gateway! Thank you and goodbye!