



# Beam and detectors

## Beamline for schools 2018

### Preface

All the big discoveries in science have started by curious minds asking simple questions: How? Why? This is how you should start. Then you should investigate with the help of this document whether this question could be answered with the available equipment (or with material that you can provide) and the experimental setup of the Beamline for Schools at CERN. As your proposal takes shape, you will be learning a lot about particle physics, detectors, data acquisition, data analysis, statistics and much more. You will not be alone during this journey: there is a list of [volunteer physicists](#) who are happy to interact with you and to provide you with additional information and advice.

**Remember: It is not necessary to propose a very ambitious experiment to succeed in the Beamline for Schools competition. We are looking for exciting and original ideas!**

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## Introduction

### The Beamline for Schools

There are two types of setups for experiments with elementary particles: collider and fixed target configurations. In a [collider](#) (such as the Large Hadron Collider (LHC)), accelerated particle beams travel at close to the speed of light before they are made to collide. In a fixed-target experiment a beam of accelerated particles collides with a target, which can be a solid, liquid, or gas. The Beamline for Schools (BL4S) experiment is of the **fixed target** type.

The BL4S experiments will take place in a beam line (called [T9](#)) at CERN's [Proton Synchrotron](#) (PS). Fast moving protons from the PS hit a target called the "[North target](#)" or "[Production target](#)", generating particles. The stream of these particles is called the [secondary beam](#). You (the user of T9) can choose the charge, the focusing and the momentum of the secondary beam entering the experimental area by operating a series of bending and focusing magnets. The beam will contain either positively or negatively charged particles with a well-defined momentum. Neutral particles such as photons or neutral kaons are not available.

### Typical equipment

In a typical experiment commonly used elements to identify or measure the properties<sup>1</sup> of particles are:

- [Cherenkov](#) detectors for particle identification,
- [Scintillation counters](#) (or scintillation detectors or just scintillators) for recording the passage of a charged particle,
- [Tracking](#) chambers for measuring the position of a charged particle within the active volume of a detector,
- Electromagnetic [calorimeters](#) for measuring the energy of electrons, positrons and photons,
- Magnets for measuring the momentum of charged particles<sup>2</sup>.

These detectors are *electronic* detectors: when a particle interacts with the detector, an analogue electrical signal is produced in different ways. In a [Cherenkov](#) or a [scintillator](#), light is emitted and converted into an electrical pulse using a [photomultiplier](#). In a gaseous [tracking](#) chamber, ionization of the gas generates electrons that are multiplied in electric fields. The typical duration of the signals is 100 ns and the signal voltages are typically 100 mV to 1 V. The

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<sup>1</sup> Like their path or momentum.

<sup>2</sup> The bending magnets have to be used together with tracking detectors. The bending angle of a particle that passes through the magnet is inversely proportional to its momentum.

signals are sent to a readout system where they are digitized and eventually read out by a computer and stored to a hard disk.

Examples of detectors in the BL4S experiment are described in more detail in the following chapters. It should be emphasized that experiments can be conducted without making use of all of these detectors.

### Trigger and readout

Signals from some of the detectors are used to build the *trigger*. The trigger logic identifies interesting interactions (“events”) and instructs the computer to initiate the readout of the data from all the detectors. The trigger is a fundamental and complex component of LHC experiments, where collision rates are very high and only a very small fraction of the collisions are of interest<sup>3</sup>. In BL4S, the trigger is much simpler and might, for example, require coincident signals from two [scintillators](#) along the beam path to indicate the passage of a particle.

When a trigger occurs, data from all detectors are recorded by the readout system and a signal is sent to a computer that transfers the data to mass storage, usually a disk. This mechanism is very similar to when you take a picture with a digital camera. When the shutter-release button is pressed, data (light) is transferred to the charge coupled device (CCD) and recorded to memory. One difference is that in the case of BL4S, the exposure time is about 100 ns.

A large amount of software has been developed at CERN and elsewhere for the analysis of experimental data. The analysis software is based on a framework called [Root](#) which is used by many physics laboratories all over the world.

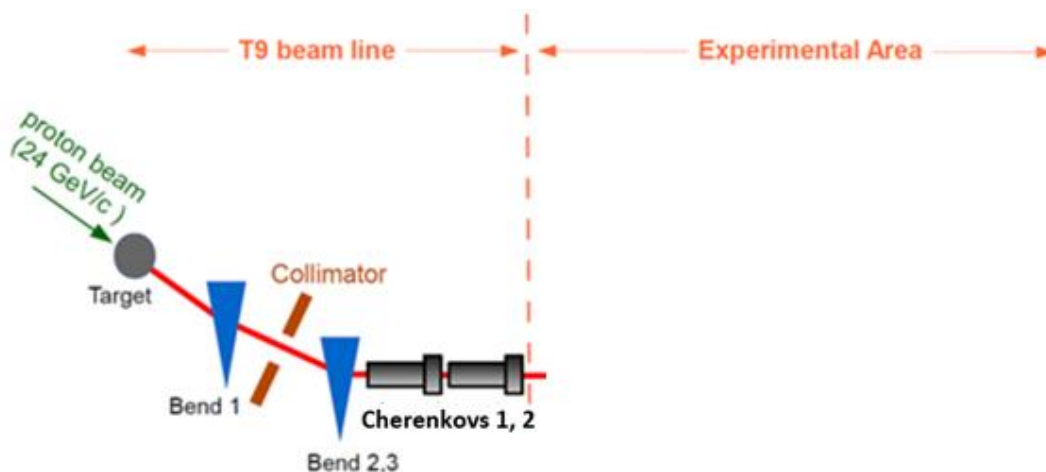
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<sup>3</sup> For example, the production of a Higgs [boson](#) occurs in one out of a trillion events (where one trillion is  $10^{12}$ ).

## The T9 Beam line

### Beam production

The proton beam exits the PS with a momentum<sup>4</sup> of 24 [GeV/c](#) and hits an aluminium or beryllium target. In some targets there is a tungsten plate which increases the production of electrons and positrons. Three bending magnets, one at each bend, and a collimator, all user-operated, filter and select the secondary beam (left part of Figure 1 - left). Then, the beam enters the fixed [Cherenkov detectors](#) that allow a first particle identification.



**Figure 1:** The proton beam from the [proton synchrotron](#) enters from the left and hits the [production target](#). The text gives detailed information about the various points along the beam-path

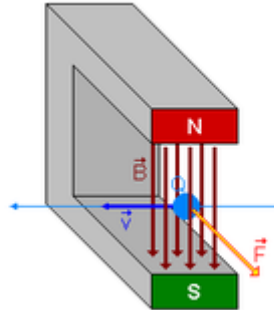
### Bending magnets

Bending magnets<sup>5</sup> are used in the beamline not only to guide the particles in a certain direction, but also to choose the particles' momenta (between 0.5 [GeV/c](#) and 10 [GeV/c](#)) by defining the magnet currents accordingly. A bending magnet is a dipole (Figure 2) with a vertically-orientated magnetic field. The particles that cross the field will be deflected horizontally.

<sup>4</sup> In high-energy physics, the units for energy, momentum and mass are [GeV](#), [GeV/c](#) and [GeV/c<sup>2</sup>](#), respectively, where  $c$  is the speed of light. In the world of particles, these units are more practical than the [MKS units](#): 1 [GeV](#) =  $1.6 \times 10^{-10}$  Joule, 1 [GeV/c<sup>2</sup>](#) =  $1.783 \times 10^{-27}$  kg. Time is usually measured in nanoseconds (ns), where 1 ns =  $10^{-9}$  s, which is the time it takes for light to move a distance of 30 cm.

For comparison, the maximum energy of the [proton](#) beam at the LHC is 6500 [GeV/c](#).

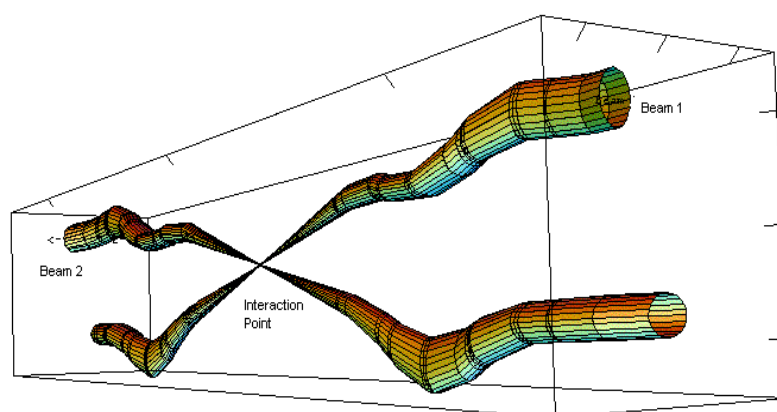
<sup>5</sup> You might consider watching this short instructional video, which shows how charged particles move when influenced by a magnetic field: [Particle movement in a magnetic field](#).



**Figure 2:** A dipole magnet with the vertical magnetic field and a charged particle moving horizontally into the field. The force is perpendicular to the magnetic field vector and the velocity vector, deflecting the charged particle horizontally. Image source: [https://hr.wikipedia.org/wiki/Portal:Fizika/Slika/37,\\_2007](https://hr.wikipedia.org/wiki/Portal:Fizika/Slika/37,_2007).

### Quadrupole magnets

Quadrupole magnets are used to control the beam size and to focus or defocus the particles in the beamline. Their role is similar to the role of lenses in your camera. However, contrary to an optical lens, a quadrupole will focus the beam in one plane but defocus the beam in the other plane. This means that a horizontally focussing quadrupole defocuses vertically and vice versa. To overcome this effect quadrupole magnets are usually used in pairs. These magnets are used to set the focus of the beam to a defined place in the experimental area. Figure 3 shows how the proton beams are squeezed in the LHC:

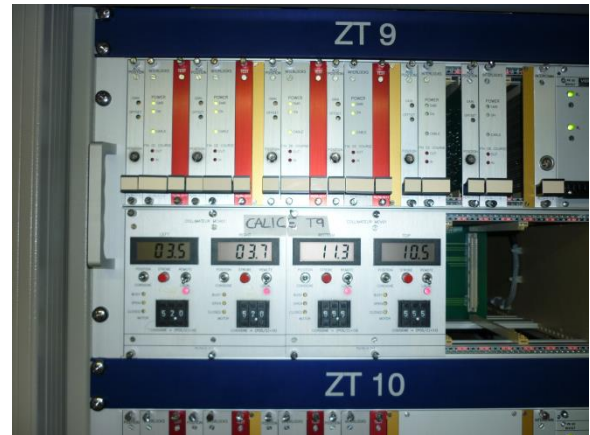


Relative beam sizes around IP1 (Atlas) in collision

**Figure 3:** The proton beams in the LHC are squeezed (made thinner) by quadrupole magnets, in order to increase the collision rate. Image source: <http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/collisions.htm>

## Collimator

A collimator is a tool used to filter the beam of particles. There are two collimators in the [T9 beamline](#). The horizontal collimator changes the width of the momentum distribution of the beam, depending on its opening. Thus, it rejects particles that have either a higher or lower momentum than a pre-determined range. The vertical collimator, on the other hand, filters particles according to their initial angle on leaving the target. Any particle with a larger angle than selected is rejected.



**Figure 4:** The collimator controls of the T9 experimental area.

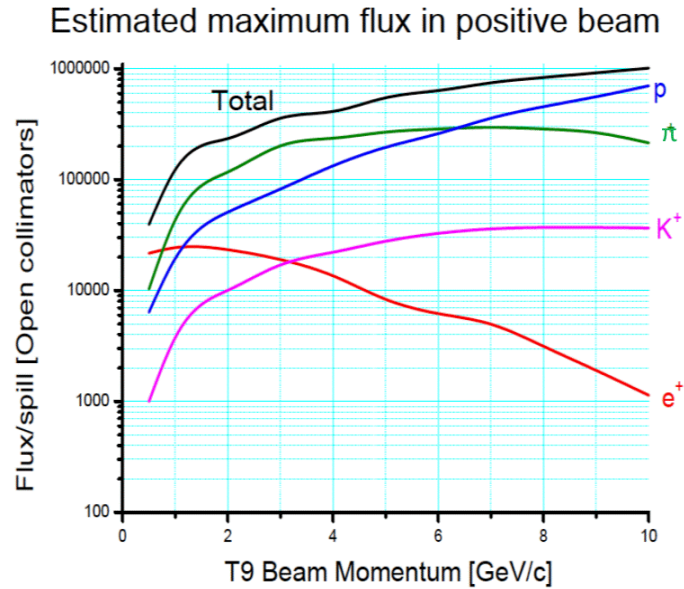
## Beam composition

The proportion of the particles in the beam depends on the primary target, the selected momentum and the polarity. Figure 5 and Figure 6 show the composition of the positive and negative beam respectively. It is not possible to have a beam of neutral particles (e.g. neutral kaons or gamma rays). The negative (positive) beam contains negatively (positively) charged particles: electrons (positrons), [antiprotons](#) (protons), [pions](#) and [kaons](#)<sup>6</sup>. Some of the pions and kaons decay to [muons](#) along their path to the experimental area, therefore there is also a large number of muons in T9. The particles of the secondary beam are relativistic. This means they are moving at almost the speed of light<sup>7</sup>. Because of the acceleration cycle of the PS, the particles arrive in [bursts](#): about one million ( $10^6$ ) particles in a 0.4 second burst, at a frequency of two bursts per 40 seconds. As an example if the magnets are set up to deliver a negative beam with a momentum of 4 GeV/c, each burst (spill) of 400 ms duration will deliver ~450 antiprotons, ~10.000 electrons and kaons, as well as ~150.000 pions<sup>8</sup>.

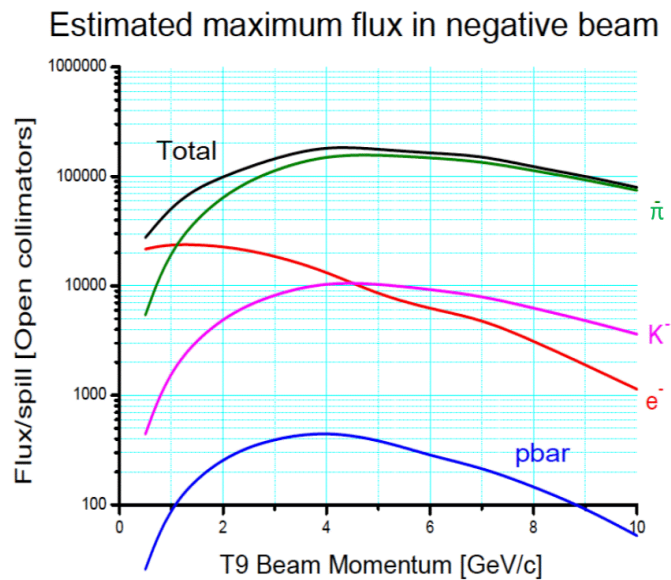
<sup>6</sup> You might consider watching a short introductory [video](#) about hadrons.

<sup>7</sup> As an example, the rest mass of a pion is  $0.140 \text{ GeV}/c^2$  and, with a momentum of  $3 \text{ GeV}/c$ , it will therefore have a velocity equal to  $0.99891 \times c$  (this can be computed from the relativistic formula for the momentum). The energy of a pion is  $3.0032 \text{ GeV}$ , so the kinetic energy is much larger than the rest energy of the pion.

<sup>8</sup> See also: <http://gatignon.web.cern.ch/gatignon/T9flux.pdf>



**Figure 5:** Positive beam which consists of positively charged particles. Flux/spill means the number of particles per spill, or equivalent, per burst. There are no [muons](#) present right after the production target, but they appear when [pions](#) or [kaons](#) decay.



**Figure 6:** The negative beam consists of negatively charged particles. The [pbar](#) graph describes the [antiprotons](#), which have the opposite electrical charge of a proton. As for the positive beam, there are no [muons](#) present at this stage, but they appear when [pions](#) or [kaons](#) decay.



## Beam profile

The beam has, more or less, a round cross section. In the focal plane, the beam spot has a diameter of about 2 cm. The further away the beam is from the focal plane, the larger the diameter. The position of the focal point can be adjusted.

## Background

In addition to the particles created by the interaction of the proton beam with the [production target](#), there is a background of other particles in the beamline ([T9](#)). Some of the [pions](#) of the [secondary beam](#), for example, decay into [muons](#). Other particles may be created by collisions of the beam with the air in the experimental zone. All of these “undesired” particles are called background. Depending on the experiment that you are going to propose, this background can mask the effect that you are looking for. Understanding the background is essential to almost every experiment we do at CERN. Please contact us if you need additional information.

## The T9 experimental area

The Beamline for Schools takes place in an area of about 5 m by 12 m, containing a number of detectors, which are fixed, along with the available equipment which can be laid out according to the needs of your experiment. Additionally, it may be possible to install devices that are brought by your team to the experimental area<sup>9</sup>. Each request will be reviewed individually and will need to respect health and safety guidelines. For example the installation of large amounts of combustible material (e.g. wood) is not possible for safety reasons. It is also not possible to expose any [biological material](#) to the beam.

## Example of an experimental setup

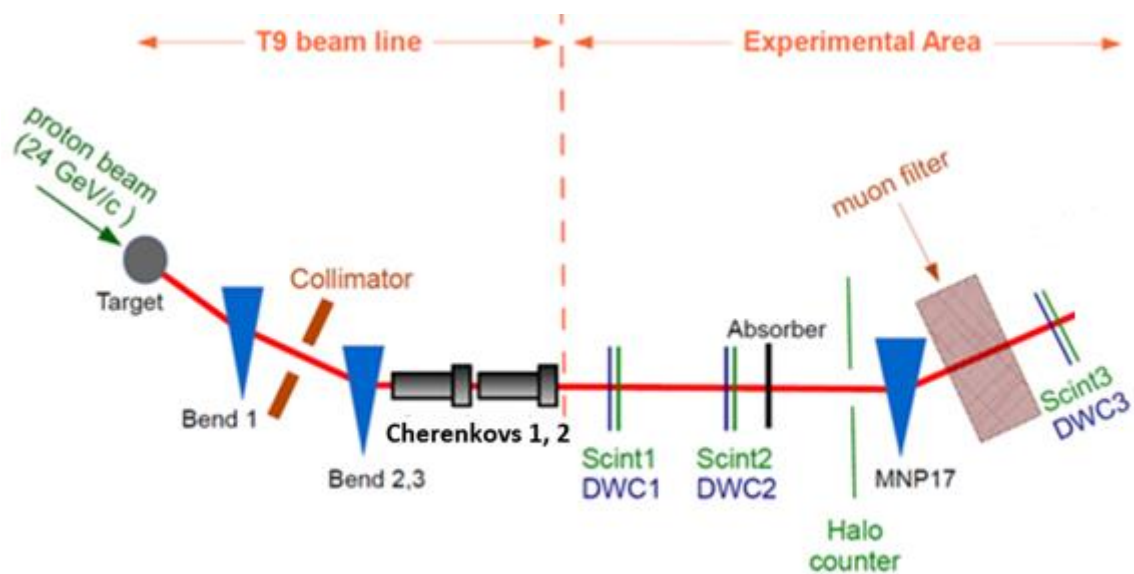
An example setup can be seen in Figure 7.

1. The proton beam from the [PS](#) hits the [production target](#), and generates the secondary particle beam.
2. The secondary beam goes through the [Cherenkov detectors](#). Depending on the choice of gas in the Cherenkov detectors, it may be possible to discriminate between electrons (or positrons), [pions](#) and [muons](#).
3. The beam enters the experimental area where in our example there are two [scintillators](#) (Scint1 and Scint2). The scintillators count the number of particles and it is possible to measure the time it takes for a particle to travel from one scintillator to the other.

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<sup>9</sup>Please note that CERN cannot guarantee the installation of all the suggested devices.

4. There are also two Delay Wire Chambers (DWC) that measure the positions of the particles that passed through their active area.
5. There is a lead absorber in the beam path. The lead absorbs electrons, but the heavy particles will go through practically without interacting with the lead.
6. The MNP17 is a strong magnet that bends the trajectory of the charged particles. The momentum of the particles can be determined from their tracks.
7. The muon filter is an iron block that stops all particles, except [muons](#) and neutrinos. The Scint3 scintillator will then count the number of muons that pass through.



**Figure 7:** Example setup of equipment in the T9 experimental area (right of the dashed line). PLEASE NOTE: the part of the set-up under "T9 beam line" (i.e. to the left of the dashed line) cannot be changed.

## The BL4S detectors

### Scintillation counter

A scintillator is a material that produces scintillation light – a property of luminescence – when excited by ionizing radiation<sup>10</sup>. Luminescent materials, when struck by an incoming particle, absorb the particle's energy and scintillate, i.e., re-emit the absorbed energy in the form of light. A scintillation counter is obtained when a scintillator slab is connected to an electronic light sensor, in our case a sensitive photomultiplier tube. Photomultiplier tubes absorb the light emitted by the scintillator and re-emit it in the form of electrons, via the photoelectric effect. The subsequent multiplication of these photoelectrons results in an amplified, electrical pulse that can then be analysed; yielding meaningful information about the particle that originally struck the scintillator.

One scintillator is part of the fixed setup of the beam line. Four additional scintillators are available for installation in the experiment. The scintillators can be used for counting particles or for setting up the trigger logic. Fast scintillators can be used for timing the particles (i.e. measuring the time it takes for a particle to travel from one scintillator to another).

### Delay Wire Chamber (DWC) / Tracking chamber

The Delay Wire Chamber (DWC) is a multi-wire chamber that can give the coordinates of the position of a particle that passed through the detector. It uses an array of wires at high voltage connected to a delay line. The chamber is filled with gas (a mixture of argon and CO<sub>2</sub>). Any ionizing particle that passes through the chamber will ionize the atoms of the gas. The resulting ions and electrons are accelerated by an electric field across the chamber, causing a localized cascade of ionization. The signal from the wires builds up two waves in the delay line, one in each direction. By using a reference signal as a common start and measuring the time delays for the waves to reach each end of the delay line, the impact point (where the first ionising took place) can be determined.

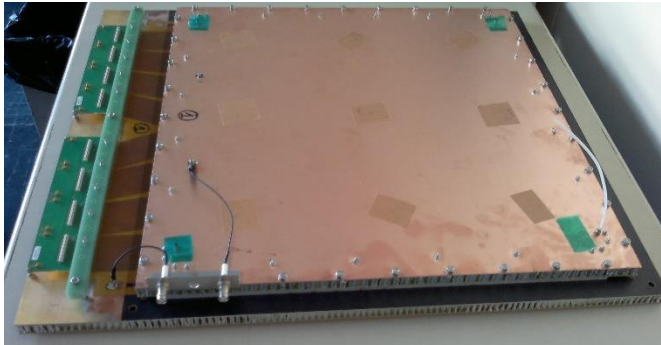
The active area is 10x10 cm<sup>2</sup> and position resolutions of 200 µm can be achieved. The unit “µm” represents a micrometre, one millionth of a metre. However, the chamber can measure only one particle inside a certain time window (100 ns approximately). One DWC is part of the fixed setup of the beamline. Two additional DWCs are available for the experiment, if required.

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<sup>10</sup> You can watch a simple animation here:

[https://upload.wikimedia.org/wikipedia/commons/2/22/Scintillation\\_Detector.gif](https://upload.wikimedia.org/wikipedia/commons/2/22/Scintillation_Detector.gif)

## MicroMegas detectors / Tracking chamber



MicroMegas detectors serve the same purpose as DWCs; they allow us to track particles. They are “better” than the DWCs because they have a larger surface and a higher resolution. The disadvantage is that they are not as fast. With the electronics that will be used to read them out we can at most track 500 particles per second.

Our MicroMegas detectors have a spatial resolution of about 200  $\mu\text{m}$  and an active area of 40 x 40 cm. They are 1D detectors and therefore able to record the position of a charged particle in the vertical or the horizontal plane. As we have four of them, we can build, by combining two of them, two 2D detectors. The MicroMegas, for example, can be used behind the MNP17 magnet (see below) to record the angle by which charged particles are deflected in the magnetic field. You may also be able to use them in order to measure the scattering of particles in a target that you install in the beamline.

See [Appendix 1](#) for background information.

## Multi Gap Resistive Plate Chamber (MRPC)

Our two MRPC detectors have a surface area of 30 x 30 cm. They provide, like the DWCs, [tracking](#) information but with a smaller resolution. Their main advantage is that they can provide very accurate time information for the passage of a particle. In a well-calibrated system, values as low as 100 ps<sup>11</sup> can be reached. Therefore, the MRPCs are very useful detectors for time-of-flight measurements.

The MRPC consists of a stack of resistive plates, where spacers between these plates define a series of gas gaps. Anode and cathode electrodes are placed on the outer surfaces of the outermost resistive plates while all interior plates are left electrically floating. The resistive plates are transparent to the fast signals generated by the avalanches inside each gas gap. The induced signal on the external electrodes is the *sum* of the activities of *all the gaps*.

## Cherenkov detector

Nothing is faster than the speed of light in vacuum. However, in other media, such as certain gasses, the velocity of particles can exceed the velocity of light in that medium. If that is the

<sup>11</sup> where ps stands for pico second, one trillionth of a second.

case, the particles emit [Cherenkov](#) radiation (also known as Cherenkov light<sup>12</sup>). Cherenkov radiation is emitted by a charged particle when it passes through a material with a speed greater than  $c/n$ , where  $n$  is the index of refraction of the material and  $c$  is the speed of light. The angle of the photons with respect to the charged particle direction depends on its velocity. By adjusting the pressure of the gas, the velocity threshold of the particles that emit Cherenkov light can be chosen. Since the momenta of all traversing particles are preselected, the different velocities can be assigned to different particle masses and, thus, different types of particles. Therefore, one could compute the mass of the particle by its momentum and velocity, hence identifying the particle. For example electrons will always emit light in any gas, unlike the other particles. At a given momentum range the discrimination between electrons, [muons](#) and [pions](#) is possible by tuning the pressure of the gas inside the detector. Identifying heavier particles ([kaons](#) or protons) is not possible in T9 for technical reasons.

Two Cherenkov detectors are part of the fixed setup. You can choose between carbon dioxide and nitrogen and tune the pressure of the gas according to what particles you would like to detect. If you choose not to use the Cherenkov detectors in your experiment, they will remain on the beam but can be emptied, so that they will not interfere with the properties of the beam.

### Timepix detector

The Timepix chip is designed as a universal readout chip for various types of radiation. It can be used in combination with a pixelated semiconductor detector with a gaseous Time Projection Chamber (TPC) or without any sensor (electrostatically collecting electrons)<sup>13</sup>.

The hybrid silicon pixel device [Timepix](#) was developed at [CERN](#) by the [Medipix](#) collaboration, with support by the [EUNET](#) project. It is based on its successful predecessor [Medipix2](#). The device consists of a semiconductor detector chip (usually containing a 300  $\mu\text{m}$  thick piece of silicon) bump-bonded to a readout chip. The detector chip is equipped with a single common backside electrode and a front side matrix of electrodes (256 x 256 square pixels with a pitch of 55  $\mu\text{m}$ ). Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip. The noise of the analogue circuitry is about 650 electrons. Each Timepix pixel can work in one of three modes:

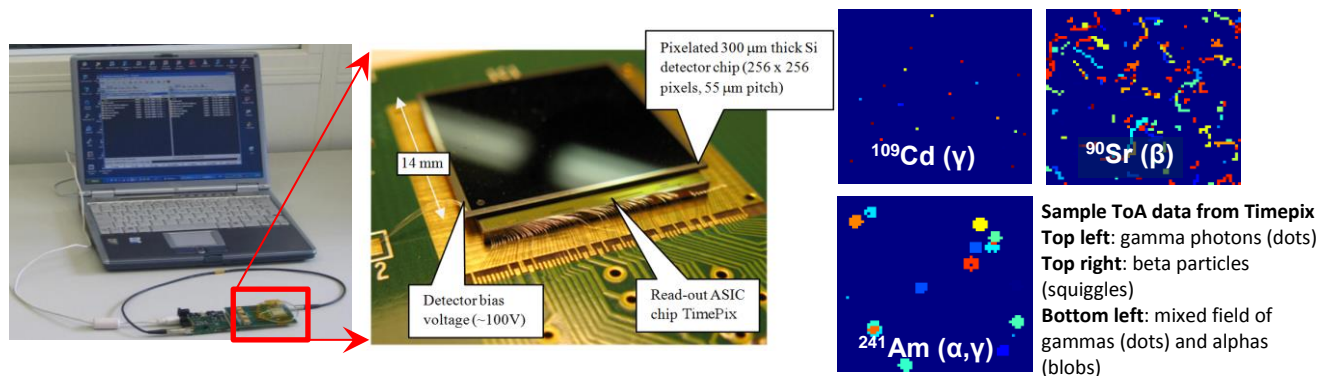
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<sup>12</sup> You might want to see these two instructional videos explaining Cherenkov light:  
[Particle physics and Cherenkov light](#)  
[Cherenkov light: What is it?](#)

<sup>13</sup> See also these videos:  
[Medipix 2 - See Through Science](#)  
[Material resolving CT using Timepix](#)

1. Medipix mode – The counter counts the incoming particles.
2. Timepix mode or ToA (Time of arrival mode) – The counter works as a timer, measuring time of the particle detection. This mode distinguishes between particles and/or reconstruct tracks of particles.
3. Time over threshold (TOT) mode – The counter is used as Wilkinson type ADC, allowing direct energy measurement in each pixel (this mode measures the energy of the detected particles).

Each individual pixel of the Timepix device in TOT mode is connected to its own analogue circuitry and AD converter. Thus, the device contains 65536 independent ADCs. All of them have to be [individually calibrated](#).



**Figure 8:** The timepix [pixel detector](#): This device consists of two chips connected by the bump-bonding technique. The upper chip is a pixelated semiconductor detector (usually silicon). The bottom chip is ASIC readout containing a matrix of 256 x 256 preamplifiers, comparators and counters. The chip can deliver up to 1000 frames per second.

### Lead Crystal Calorimeter



**Figure 9:** Stack of lead crystal calorimeters.

A [calorimeter](#) is a detector that measures the energy of impinging particles (therefore it is not a [tracking](#) detector). An electron hitting the calorimeter, for example, will produce a fully contained [electromagnetic shower](#), depositing all its energy in the calorimeter and, thus, allowing a very precise measurement of its energy. Although heavier particles produce a signal as well, the energy deposition is smaller than that of electrons. By measuring the deposited energy, signals induced by electrons can be distinguished from those induced by [muons](#) and [hadrons](#).



(here: [pions](#), [kaons](#) and protons) with a certain amount of overlap. The 16 available calorimeters each have a volume of  $10 \times 10 \times 37 \text{ cm}^3$  (Figure 9).

### Halo counter

The halo counter is a set of 4 [scintillators](#) that form a hole around the beam passage (Figure 10). Its purpose is to identify particles that are too far away from the beam axis. While a collimator immediately filters the beam by rejecting particles with a larger angle, the halo counter identifies them and thus makes it possible to choose to either reject or flag them. This is useful, e.g. for flagging particles that interacted with a certain absorber and underwent scattering. The opening of the BL4S halo counter can be adjusted between 1 cm and 15 cm.

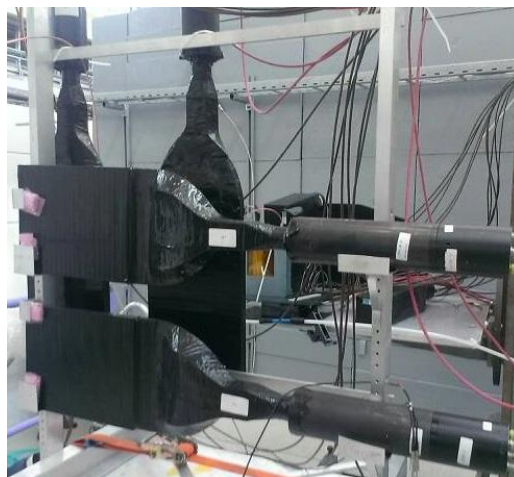


Figure 10: A Halo counter.

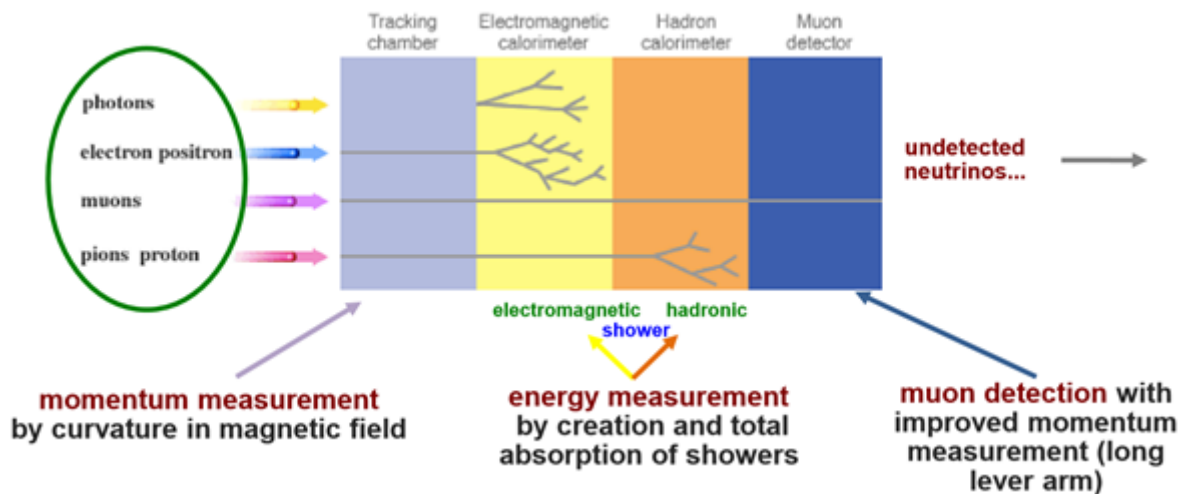
## Additional equipment

### Muon filter

[Muons](#) are charged particles that like electrons and [positrons](#) but are 200 times heavier. Unlike most of the particles, they are not stopped by [calorimeters](#) because muons can penetrate several metres of iron without interacting. That is why the muon detectors are placed at the very edge of a typical particle detector, for example ATLAS, where they are the only particles likely to leave a signal<sup>14</sup> (Figure 11).

A muon filter is a special absorber in the form of a massive, iron block. It will be installed by the crane operators, if needed. All particles of the beam that travel through the muon filter are absorbed completely, except for the muons; therefore the term “muon filter” is a bit misleading but it is the jargon we are using at CERN. By installing a detector such as a [scintillator](#) behind the muon filter, the muon content of the beam can be detected.

<sup>14</sup> See also this interactive animation of particles' passage through different detector parts:  
[Interactive animation of the ATLAS detector](#)



**Figure 11:** Schematic drawing of interaction of particles with typical detector components.

## MNP17 magnet



**Figure 12:** The MNP17 magnet positioned in T9.

CERN's large, polarity-changeable, horizontal dipole magnet (Figure 12) has a maximum field of 0.96 Tesla over a length of 52 cm. The gap height is 30 cm and the useful aperture width is 1 m. By adjusting the current, the field can be varied. This magnet can be installed inside the experimental area on request, in order to determine the momentum of the particles.

## Data acquisition

We will provide a complete data acquisition system for reading out the detectors and controlling the experiment. This system is fast enough to trace up to 2000 particles per second.

The data acquisition system provides tools for the on-line monitoring of the experiment in the form of histograms. In addition, a 3D tool will be available in order to look at selected events. This 3D event viewer is provided by National Instruments. You can create an account and download it freely [here](#). The S/W comes with a free LabView licence as well as some selected events from the 2014 BL4S experiment. This BL4S Event Software Display can be used on both Windows and Linux platforms. When you follow the link, you will find the installation instructions, LabVIEW source code and a tutorial. Don't hesitate to try it out in order to get an impression of how it works and what a BL4S detector setup may look like.



## Glossary

<a href="#">Antiproton</a>	A hadron made from three anti-quarks, also written as pbar.
Biological material	Living cells, human / animal tissue
<a href="#">Boson</a>	Particles can be categorized as bosons or fermions according to their intrinsic spin
Calorimeter	A detector that measures the energy of a particle
<a href="#">Cherenkov detector</a>	A gas volume that emits light when it gets penetrated by charged particles. The light emission depends on the type of particle and its momentum <a href="https://en.wikipedia.org/wiki/Cherenkov_detector">https://en.wikipedia.org/wiki/Cherenkov_detector</a>
Collider	An accelerator that collides two beams which are cruising in opposite directions as in the LHC
Electromagnetic shower	An avalanche of particles created from the interaction of a high-energetic particle with the material of a calorimeter
<a href="#">Electronvolt</a>	A unit of energy used in particle physics <a href="https://en.wikipedia.org/wiki/Electronvolt">https://en.wikipedia.org/wiki/Electronvolt</a>
GeV/c <a href="https://en.wikipedia.org/wiki/Electronvolt">https://en.wikipedia.org/wiki/Electronvolt</a>	A unit of momentum used in particle physics
GeV/c <sup>2</sup>	A unit of mass used in particle physics
<a href="#">Hadron</a>	A particle made up from quarks
<a href="#">Kaon</a> , K <sup>0</sup> , K <sup>+</sup> , K <sup>-</sup>	A hadron made up from a quark and an anti-quark <a href="https://en.wikipedia.org/wiki/Kaon">https://en.wikipedia.org/wiki/Kaon</a>
MKS units	Units expressed in meters, kilograms and seconds
<a href="#">Muon</a> , $\mu$	A particle like an electron but much heavier and not stable (decays into other particles)
North target	The <a href="#">target head</a> that serves the T9 beamline (CERN jargon)
Pbar	Another name for an antiproton
<a href="#">Photomultiplier</a>	A device that converts photons into electric signals <a href="https://en.wikipedia.org/wiki/Photomultiplier">https://en.wikipedia.org/wiki/Photomultiplier</a>
<a href="#">Pion</a> , $\pi^0$ , $\pi^+$ , $\pi^-$	A hadron made from a quark and an anti-quark <a href="https://en.wikipedia.org/wiki/Pion">https://en.wikipedia.org/wiki/Pion</a>
Pixel detector	A tracking detector with a 2-dimensional array of sensors; usually made from silicon

<a href="#"><u>Positron</u></a> , $e^+$	A particle that is the <a href="#"><u>antimatter</u></a> twin of the electron. <a href="https://en.wikipedia.org/wiki/Positron">https://en.wikipedia.org/wiki/Positron</a>
Production target	Same as North target, target that protons first collide with
PS, CERN <a href="#"><u>Proton Synchrotron</u></a>	The <a href="#"><u>Proton Synchrotron</u></a> is an accelerator with a circumference of 628 m. It is used to accelerate (mainly) protons, giving the primary beam of protons. <a href="https://en.wikipedia.org/wiki/Proton_Synchrotron">https://en.wikipedia.org/wiki/Proton_Synchrotron</a>
<a href="#"><u>Root</u></a>	A powerful software framework for the display and analysis of physics data. <a href="https://root.cern.ch/documentation">https://root.cern.ch/documentation</a>
<a href="#"><u>Scintillation counter</u></a>	A transparent material that emits light when penetrated by charges particles. <a href="https://en.wikipedia.org/wiki/Scintillation_counter">https://en.wikipedia.org/wiki/Scintillation_counter</a>
Secondary beam	Particles created from the interaction of the primary beam with the <a href="#"><u>target head</u></a>
T9 beamline	The beamline before the experimental area
Target head	The material at which the primary proton beam is directed; the choice of material influences the composition of the secondary beam
Tracking	The measurement of the trajectory of a particle
Trigger	It identifies interesting interactions (“events”) and instructs the computer to initiate the readout of the data from all the detectors.

## Appendix 1: More about Micromegas detectors

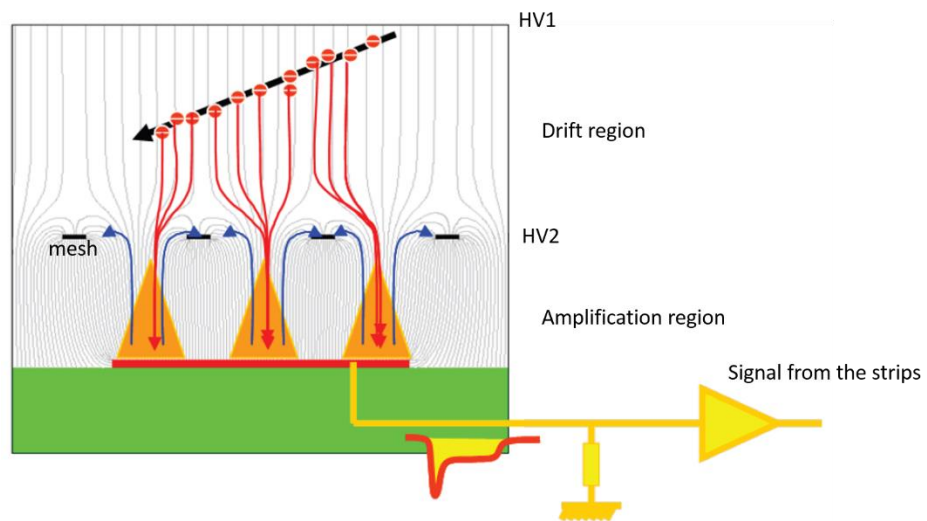
In 1996 Nobel Prize winner G. Charpak and Y. Giomataris presented a new approach to the micro strip gas counter (MSGC) concept. They replaced the wire plane with a thin electroformed nickel mesh. They called the new detector MICROMEAS (MICRO-Mesh Gaseous Structure).

The micromesh separates the two regions of the detector, the drift region (with a typical electric field of  $10^2 - 10^3$  V/cm) and the amplification region (with a typical field of  $10^4 - 10^5$  V/cm), as seen in Figure 1. It is stretched and glued on an insulating frame and placed above the anode plane. It is kept in position with precise spacers (pillars) at a distance of the order of 100  $\mu$ m from the readout. The pillars are fixed to the anode strips by a standard printed circuit technique.

Typically, the electric field of the drift region is achieved by applying a positive high voltage (HV2) to the micromesh and a higher positive voltage (HV1) to an electrode plane, the drift electrode, placed a few cm above the micromesh thus defining the drift region (Figure 1). The readout plane is kept grounded. The whole structure is placed in a leak tight chamber and operates with a gas mixture of a noble gas and a small amount of a polyatomic gas.

With sufficiently thin micromesh the amplification inside its holes is negligible. The shape of the field close to the micromesh is crucial for the transparency to electrons and the fast evacuation of the positive ions. The voltages are applied in a way that the amplification field is one order of magnitude higher than the drift field, so that the field lines coming from the drift region do not end at the bottom of the micromesh.

In the drift region ion-electron pairs are generated by the incident radiation in the gas and the electrons drift towards the mesh. The electrons pass through the holes of the mesh to the amplification region. In the presence of the strong electric field they initiate avalanches. The positive ions from the avalanches move quickly and induce fast signals to the strips. They are collected in the micromesh and only a small fraction, inversely proportional to the electric field ratio diffuses to the drift region and the transparency to the drift electrons is ensured.



**Figure 13:** Schematic representation of the MICROMEAS detector.