Measurement of Beam Composition

Suggestion 1: CERN's T9 beamline is meant to provide a beam of pure protons or electrons or muons through the accelerator. One of the ideas is to check whether this beam is pure, detect any impurities and isolate them from the beamline to make it pure.

Here's a list of particles which we will be using throughout the project -

	Name		Q	Mass [MeV/c²]	Mean life (τ) [s]	cτ [m]	Mean decay distance [m/GeV/c]	Decays
Leptons	Electron	e	±e	0.511	stable			
Leptons	Muon	μ	±e	105.6	2.2×10^{-6}	659.6	6.3×10^{3}	$\mu^+ \longrightarrow e^+ \bar{\nu}_e \nu_\mu$ (100%)
Hadrons / Mesons	Pion	π	±e	139.6	2.6×10^{-8}	7.8	56.4	$\pi^+ \longrightarrow \mu^+ \nu_\mu$ (100%)
Hadrons / Mesons	Kaon	K	±e	493.6	1.23×10^{-8}	3.7	8.38	$K^+ \longrightarrow \mu^+ \nu_\mu$ (63%) $\pi^0 e^+ \nu_e$ (5%) $\pi^0 \mu^+ \nu_\mu$ (3%) $\pi^+ \pi^0$ (...) (28.9%)
Hadrons / Mesons	Kaon	K^0	0	497.6	K^0_S: 8.9×10^{-11}	0.02	0.060	$K^0_S \longrightarrow \pi^0 \pi^0$ (30.7%) $\pi^+\pi^-$ (69.2%)
Hadrons / Mesons	Kaon	K^0	0	497.6	K^0_L: 5.12×10^{-8}	15.34	34.4	$K^0_L \longrightarrow \pi^\pm e^\mp \nu_e$ (40.5%) $\pi^\pm \mu^\mp \nu_\mu$ (27.0%) $3\pi^0$ (19.5%) $\pi^+\pi^-\pi^0$ (12.5%)
Hadrons / Baryons	Proton	p	±e	938	stable			
Hadrons / Baryons	Lambda	Λ	0	1115.6	2.63×10^{-10}	0.079	0.237*	$\Lambda^0 \longrightarrow p\ \pi^-$ (63.9%)
Hadrons / Baryons	Sigma Hyperons	Σ^+	+e	1189.3	8.02×10^{-11}	0.024	0.068*	$\Sigma^+ \longrightarrow p\ \pi^0$ (51.57%)
Hadrons / Baryons	Sigma Hyperons	Σ^-	-e	1197.4	1.48×10^{-10}	0.044	0.125*	$\Sigma^- \longrightarrow n\ \pi^-$ (99.84%)

(*) for 10 GeV/c

Important Properties of the beam:

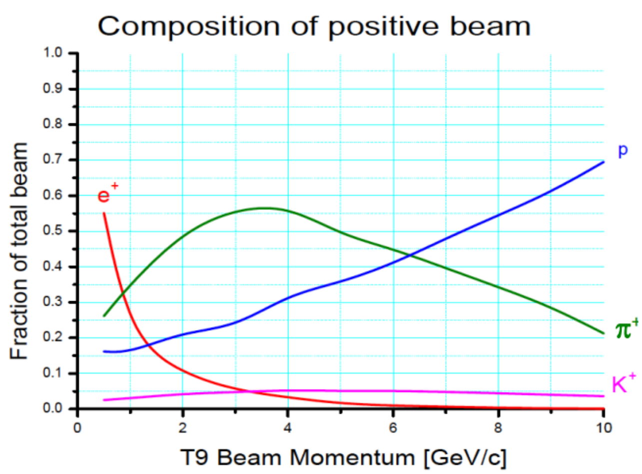
- Energy ranges between 0.2 GeV to 15 GeV (though energies below 0.5 GeV are sub-optimal)
    - At this energy, particles are relativistic (ie. rest mass of Pion - 0.140 GeV/c^2, w/ 3GeV/c momentum, will travel at 99.891% speed of light)
- Other particles may be created by collision of beam with air in experimental area "undesired particles"
    - These create unwanted backgrounds that can affect results.
- Beam is not continuous in time, but follows acceleration cycle of the PS, Thus particles arrive in bursts/spills
- Beam has more or less a "round" profile/cross section. In focal plane, beam spot has a diameter of ~2cm.

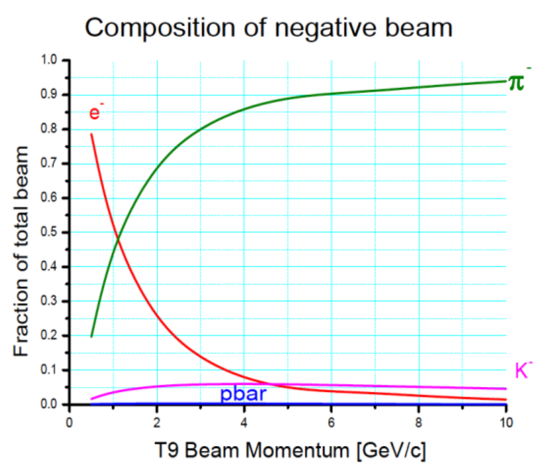
- The further away the beam is from the focal plane, the larger the diameter.
- Position of focal plane can be adjusted

The Primary Idea - (under construction)

1. Use previously determined data to find the detailed composition of CERN’s T9 proton/electron beamline. OR make it part of our own project to determine in depth the composition of the beam.
2. Find out the characteristics of the impurities which differ from the major particle of the beam, and look for physical methods of using this uniqueness in our favor.
3. Using some kind of device to detect the beam (before another device removes the “impurities”, while removing the impurities, and after removing the impurities) and finally once again determine the percentage purity of our beam (efficiency of our experiment).

The composition of the T9 beam, according to this source, is -





Beam rate in terms of estimated maximum flux is as follows:

9+

Some other characteristics of the T9 beam are mentioned below -

Parameter	T9
Maximum momentum (GeV/c)	12
Production angle (mrad)	0
Beam length to ref. focus (m)	55.8
Beam height above floor (m)	2.50
Ang.acceptance Horizotal (mrad) Vertical (mrad)	±4.8 ±5.8
Acc. Solid angle (μsterad)	87
Theor. momentum resol. (%)	0.24
Max. momentum band (%)	±10
Magnification at reference focus	1.0, 1.2
Protons on North target	~2.5 10^{11}
Max. flux (depending on p, Q)	10^6

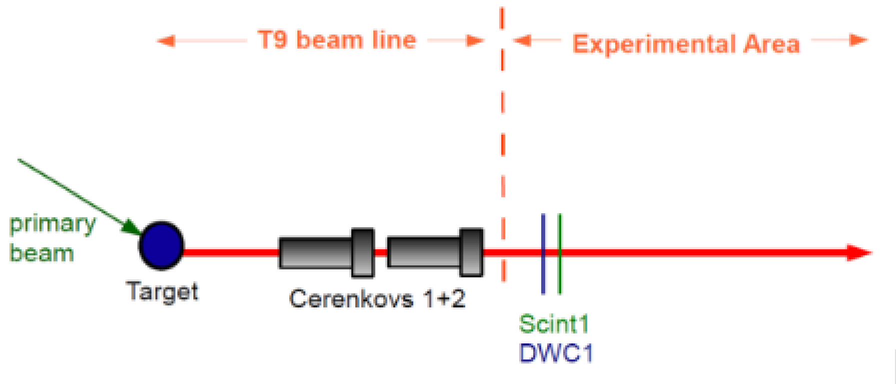
To identify the type of particles other than protons in a beam -

Cherenkov Detectors

- Answers "Did a particle pass through?" and "What kind of particle is it?"
- when different (charged) particles pass through a non-vacuum medium, i.e. gas, it can technically travel faster than the speed of light in that medium.
- Thus emitting cherenkov radiation in form of light (cherenkov radiation) if its speed is greater than c/n (n=refractive index of material)
- Cherenkov detectors detect cherenkov radiation
- This light is converted into electrical pulse using photomultiplier

- Angle of photons with respect to the direction of a charged particle depends on its velocity.
  - Thus by adjusting the pressure of gas, velocity threshold can be chosen.
- Since momentum of diff particles are preselected, diff velocities can be assigned to diff particle mass (thus diff types of particles) within the same pressure of gas.
  - Thus can compute particle mass by its momentum and velocity, hence identifying it.
  - At a given momentum range, the discrimination between electrons, muons, and pions is possible by tuning pressure of gas inside detector
- 2 are part of the fixed set up.

Illustration:



Some results so far -

There's also possibility of creating pure electron beam from neutral channel

1. Secondary beams of charged particles deflected away w/ 2 bending magnets = only neutral gammas rays (photons $>$0.5GeV) selected
2. Converter consisting of 5mm of lead placed in path = converts them into e^+/e^- pairs
3. Beamine tuned to select either e^+/e^- of energies ranging in between 0.5-4GeV.
4. At energies $<$3GeV, electron purity is $>$90%.

The curious case of muons; as explained [here]() -

Pions, muons and other particles are produced by firing protons onto a graphite target [3]. Liquid mercury targets were also considered [4]. The target is contained in a 20 T magnet which serves to confine both positively and negatively charged secondary particles, unlike a horn-type target. The field is tapered to a 2 T constant solenoid field.

High momentum impurities are removed from the beam by means of a chicane created using a bent solenoid field, which introduces vertical dispersion [5]. High momentum particles get proportionately more dispersion and are removed on scrapers. A reverse bend returns the surviving particles with remarkably little emittance growth despite the large transverse emittance and huge momentum spread.

Low momentum protons are removed by a thick Beryllium window [5]; low momentum protons lose much more energy than muons and electrons in the material. The window marks the end of the active handling area.

Muons are first captured longitudinally [6]. The muon beam contains all momenta up to the limit of the chicane. Fast muons migrate to the front of the bunch while slow muons migrate to the end of the bunch. RF cavities are placed successively with gradually increasing voltage to adiabatically introduce microbunches into the beam. Frequency of successive cavities is selected to match the increasing time spread in the beam. RF cavities towards the end of the section are dephased such that the earlier, faster bunches experience a decelerating gradient and the later, slower bunches experience an accelerating gradient. This is repeated until the energy of the later bunches matches the energy of the earlier bunches.

Consider a specific case of the **proton beam**. Simulations have shown almost 70% purity in this beam. Most of the impurity exists in the form of π^+ particles and very little amount of K^+ particles. Mass of a pion is ~ 139.6 GeV/c^2. Mass of a proton, on the other hand, is ~ 938 GeV/c^2. This significant difference in their masses can be used to our advantage.

Suggestion 2 - Using advanced and sensitive devices such as electromagnetic calorimeters to understand the quality and composition of the T9 beamline by measuring the electronic content of the beam with precision.

FOCUS ON - sensitive devices that interact electromagnetically with the beamline.

Another resource for reading about electromagnetic calorimeters.