8 The gas system

8.1 Introduction

The Transition Radiation Detector has an overall volume of 27.2 m^3 which surrounds the TPC and spans radii between 2.94 and 3.68 m. The detector follows the ALICE segmentation in φ of 20° and a 5-fold segmentation in the *z* direction. Each of these 18 supermodules consist of 6 layers (radiator, chamber and electronics) in radial direction, and 5 modules in *z* direction. A schematic cross section in the *r*φ plane of the TRD module arrangement is shown in Fig. 8.1. The total number of gas enclosures in the system is 540. The dimensions of the chambers vary according to their positions in *r* and *z*, and are typically of order 1 m in *r*φ, 1 m in *z*. The depth in *r* is always 3.7 cm. This results in a rather disadvantageous, from the gas tightness point of view, volume-to-surface ratio of 0.017 m. For this reason, special provisions are taken in order to minimise gas leakage (see Chapter 4).

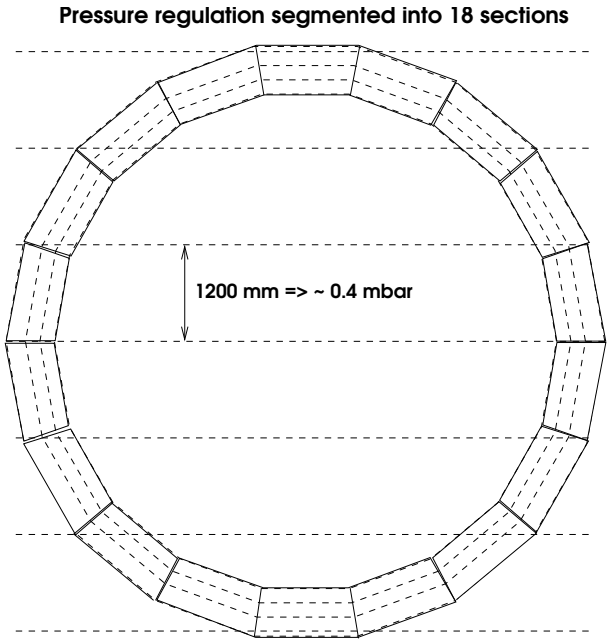

Figure 8.1: Schematic view of the TRD in the rφ plane, showing the 18-fold segmentation of individually pressure-regulated sections.

In addition, a low-mass construction of the detectors is needed for minimising electron multiple scattering and TR photon absorption in the materials. The light construction mechanically limits the absolute overpressure of the chambers to 2-3 mbar. In order to avoid electrostatic distortions due to deformation of the enclosing drift and pad electrodes, the overpressure at which the chambers are operated is limited at 1 mbar.

8.2 Gas choice

The traditional choice of xenon as the noble gas of the running mixture is determined by its large absorption, and subsequent ionisation, cross section for transition radiation X-rays produced in a suitable radiator material. This effect constitutes the principle of electron identification of such a detector. Because

xenon is a high-cost gas (11.66 CHF/l), the recirculation in a closed loop, the purification, and the recovery of the purged gas is mandatory.

In addition, xenon is a rather heavy gas (density 5.58 g/l). This means that the pressure gradient over a volume which extends over a height of 7.36 m is 2.5 mbar. For reasons of geometrical parallelism of the thin entrance foil and pad plane structure, and of uniformity of operation of the whole system in terms of E/p (see section 4.2), the maximum overpressure in each individual chamber should not be higher than 1 mbar. Thus, a suitable segmentation of the pressure regulation along slices in height of the detector is imposed by the choice of the noble gas.

The typical quencher used in other TRD systems is methane, since its well known transport and quenching properties makes it a rather convenient choice. However, safety, neutron interactions, and lifetime considerations make CH_4 a gas to be avoided. Therefore, the choice of the quencher is CO_2, because it is non-flammable, it contains no hydrogen, it is a low-cost gas, and it performs adequately. The concentration of quencher is 15% (see section 4.1).

Because the maximum drift distance in a TRD module is only 3 cm, problems associated with electron attachment due to oxygen contamination in the presence of CO_2 are expected to be negligible. Concentrations of O_2 as high as 100 ppm are therefore affordable, since such a contamination would only affect the signal by $< 10\%$. Other contaminants from air such as N_2 will be removed from the mixture in the recovery process (see section 8.3.4).

8.3 Layout

As explained in the previous section, the use of a high-cost gas component makes a closed loop circulation system mandatory. The proposed system will consist of functional modules that are designed as standardised units for all LHC gas systems. Table 8.1 indicates the location of these modules. The mixing, purifying, and gas recovery are located on the shielding plug in the pit PX24. The component sizes and ranges will be adapted to meet the specific requirements of the TRD gas system. An overview of the distribution system can be seen in Fig. 8.2. The basic function of the gas system is to mix the components in the appropiate proportions and circulate the gas through the TRD chambers at a pressure of ≤ 1 mbar above atmospheric pressure. Some of the basic parameters of the TRD gas system are given in Table 8.2.

Table 8.1: Functional modules of the TRD gas system and their location.

Functional module	Location
Primary gas supplies	SGX Building
Mixer	SGX Building
Circulation loop	
Distribution rack	PX24 Pit
Pump	UX24 Pit
Pressure regulation	UX25 Cavern
Recovery	SGX Building

8.3.1 Mixing unit

An LHC gas mixing unit, schematically shown in Fig. 8.3, will be used to mix the components in the appropriate proportions. The flows of component gases are metered by mass-flow controllers, which have an absolute stability of 0.3% over one year, and a medium term stability of 0.1% under steady state conditions. Flows are monitored by a process flow control computer, which continually calculates

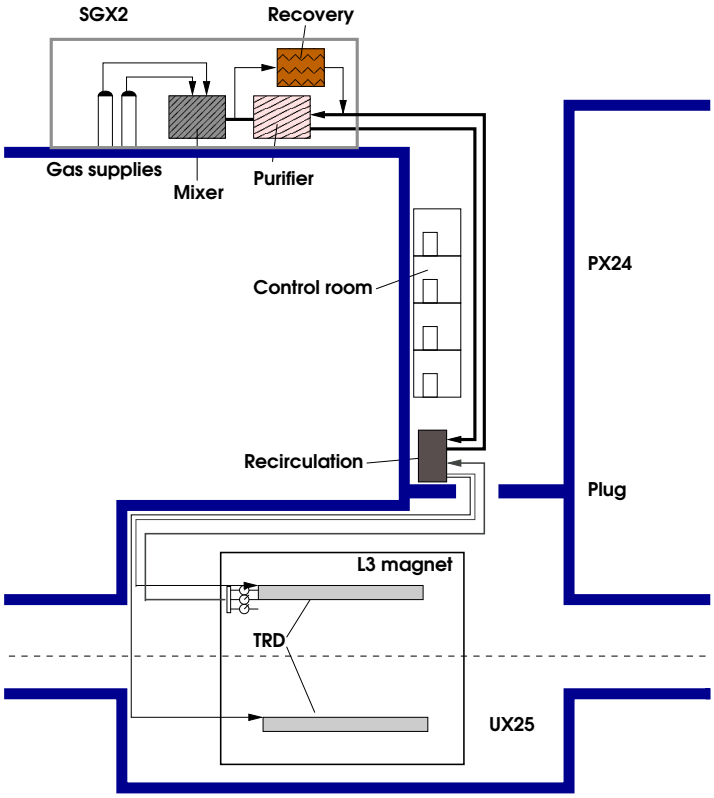

Figure 8.2: Schematic layout of the TRD gas system, showing the location of the different modules.

Table 8.2: Basic parameters of the TRD gas system.

Max. No. of modules	540
Maximum volume	27.2 m^3
Gas mixture	Xe,CO_2
Working overpressure	1 mbar
Filling rate	5 m^3/h
Circulation flow rate	5 m^3/h
Operation period per year	8 months

the mixture percentages supplied to the system. The anticipated fresh gas flow at operating conditions, which depends strongly on the leak rate, is expected to be not higher than 0.5 l/h.

Filling of the detector will be done in a closed loop circulation mode, where the purging N_2 gas is gradually replaced by the operation mixture. The separation and recovery of the Xe,CO_2 mixture will be done in the recovery plant. The start up period is estimated to take 11 days for a purification-injection rate of 20% of the total volume, i. e. 5 m^3/h. Under normal operating conditions the mixing unit will top up the gas which is removed from the system for purification purposes or by losses due to leaks within the circuit.

8.3.2 Circulation and purification system

The gas mixture is circulated in a closed loop as has been shown in Fig. 8.2. Return gas from the detector must be compressed well above atmospheric pressure to pump it back to the surface gas building where it will be recycled through the purifier. The pump itself will be located on the shielding plug in PX24.

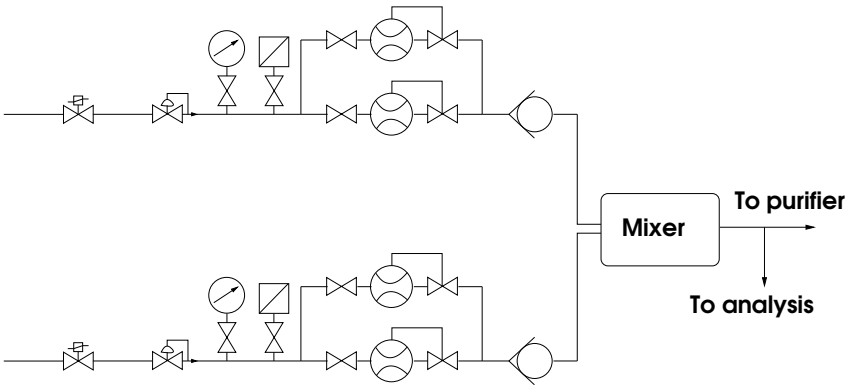

Figure 8.3: Gas mixing unit, located in the surface gas building. The substantially different gas flows in the filling and running modes are controlled by two different mass flowmeters per gas line.

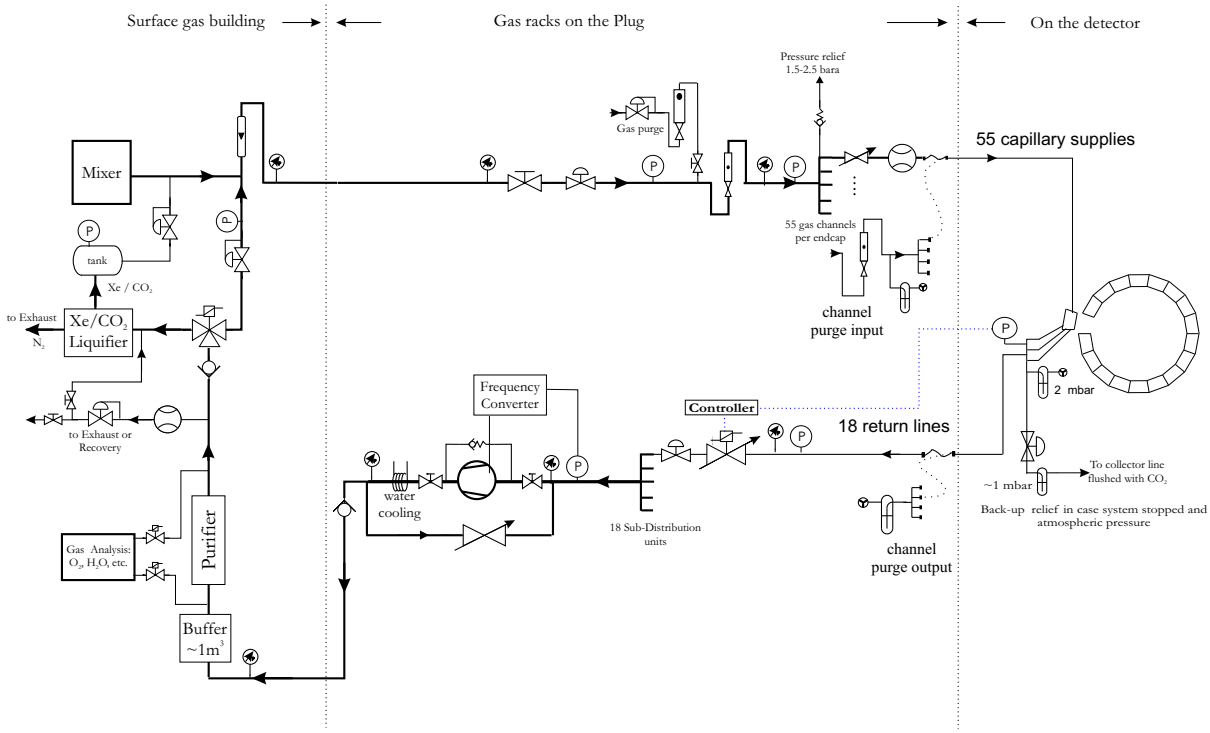

Figure 8.4: General layout of the circulation gas loop.

As already pointed out, the hydrostatic pressure over the total height of the detector is 2.5 mbar. Since the detector working pressure is limited, for mechanical reasons, to 1 mbar, a subdivision of the full detector into height sections is necessary. Furthermore, the flow and pressure regulation must be done in each section independently. In particular, the sensor for the pressure regulation must be as close as possible to the detector inlet or outlet, in order to minimise hydrostatical and hydrodynamical pressure differences between the chamber and the sensor. On the other hand, due to space limitations inside and around the L3 magnet, it is desirable to place as much hardware as possible in other areas.

Taking into account these considerations, the following gas distribution into the detectors is proposed and shown in Figs. 8.4 and 8.5: gas in the recirculation unit at the plug (see Fig. 8.2) is distributed through a 54-line manifold where the lines going to the detector are thin enough (4 mm inner diameter) in order

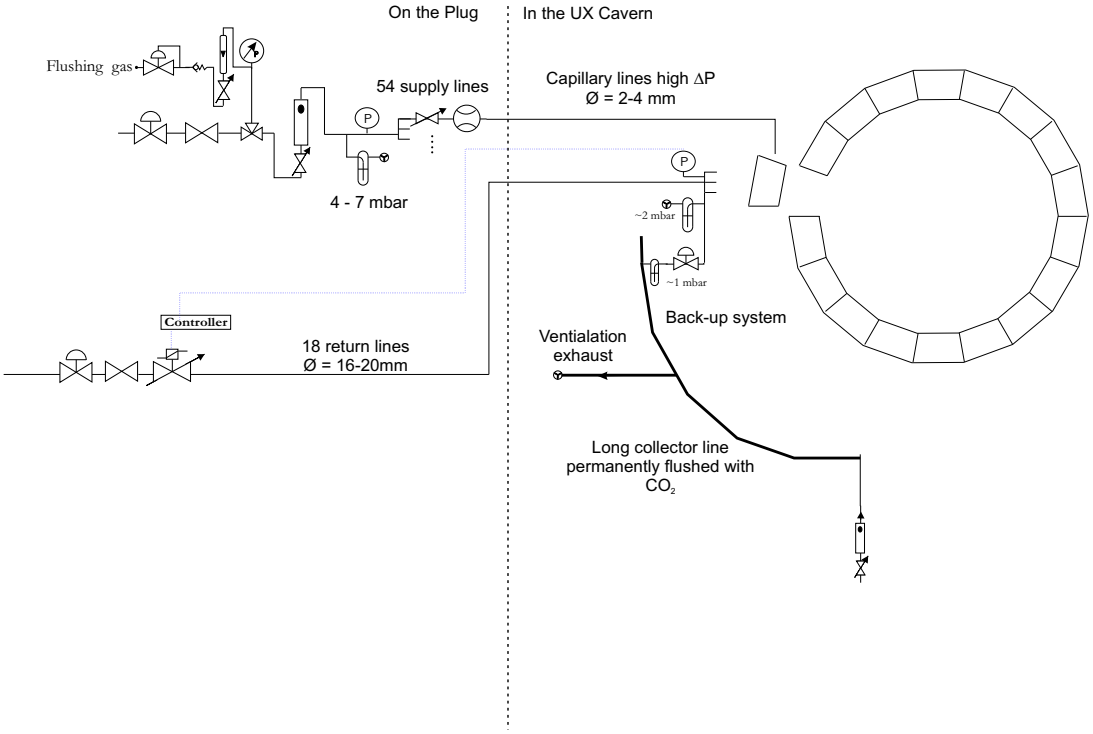

Figure 8.5: The distribution of the gas mixture into the 18 sectors of the detector by thin lines, with the flow and pressure regulation, and the back-up system

to achieve a uniform, substantial pressure drop of almost 100 mbar. If all the lines have the same length, the pressure drop in each line will be much larger than the hydrostatic differences between sectors. In this manner, the individual flow regulation can be skipped. Each line serves one set of 10 chambers (two layers back and forth in z direction) and the pressure regulation sensor is placed at the outlet, thus being the only component inside the L3 magnet. All the other components will be located at the plug.

The feedthrough from chamber to chamber will be a short (3 cm) pipe with an inner diameter of 18 mm, which results in a negligible (0.04 mbar) total impedance to the gas along the 10 served chambers. The pressure regulation will be performed at the outlet of each sub-circuit (three per sector) by placing the pressure sensor near the last chamber. Still inside the L3 magnet a 3-fold manifold will merge the lines from each sector into one 16 mm line. Therefore, a total of 18 outlet lines will run up to an accessible area at the plug, where the rest of the instruments for flow and pressure regulation will be installed. All of these circuits will route into the L3 magnet space from the RB26 side (the side of the muon arm).

The loop pressure regulation is performed by acting on the suction speed of the compressor. A pressure sensor located at the detector outlet drives the reaction mechanism. In addition, gas losses are compensated for by acting on the mixing unit flowmeters according to a pressure sensor located at the high pressure buffer after the compressor. In this manner, the regeneration rate can be chosen anywhere within the range of the mixing flowmeters, and the unrecoverable gas is limited to the leaks.

The purification system will remove, as usual, oxygen and water contamination in the gas. This will be done with cartridges filled with activated copper. A configuration in parallel allows one to run gas through one purification cylinder while the other one is being regenerated. Regeneration is done by heating the cartridges to 200° C under an Ar,H_2(7%) (Noxal) mixture.

8.3.3 Backup system

In case of a misfunctioning of the pressure regulation, for example due to a power failure, the two-way safety bubblers, located near the detectors, shall ensure that the maximum over- and underpressures that

the detectors can stand does not exceed 2-3 mbar. However, this mechanism should be regarded as the ultimate safety for the system. In case of an increase of the atmospheric pressure during such periods, the safety bubblers would allow air to be sucked into the detectors thus deteriorating the purity of the operating gas. The purifiers and the recovery station might therefore get rapidly saturated.

In order to prevent air to enter the gas loop, a backup system for cases of failure has been foreseen. It consists of a permanent flow of CO_2 that circulates to an exhaust which passes by one of the sides of a bubbler. In this manner, positive fluctuations of the ambient pressure results in an enrichment of CO_2 in the mixture, which can be gradually compensated for by the fresh gas injection mechanism as the experiment is restarted. Negative fluctuations of the ambient pressure will lead, in any case, to the loss of some precious xenon. The flow of backup CO_2, and the expected rate of xenon loss, is estimated from experience to be driven by short maximum pressure fluctuations of 5 mbar/h.

8.3.4 Recovery station

Nitrogen, which enters the recirculation loop through leaks, cannot be removed by the purification system. Thus, a separation station is needed in order to extract the N_2 from the system and recover the xenon for recycling. The precise gas purge rate into the recovery unit, estimated to be 0.1% of the detector volume per hour (2.4 l/h), will be determined by the actual leak rate of the system.

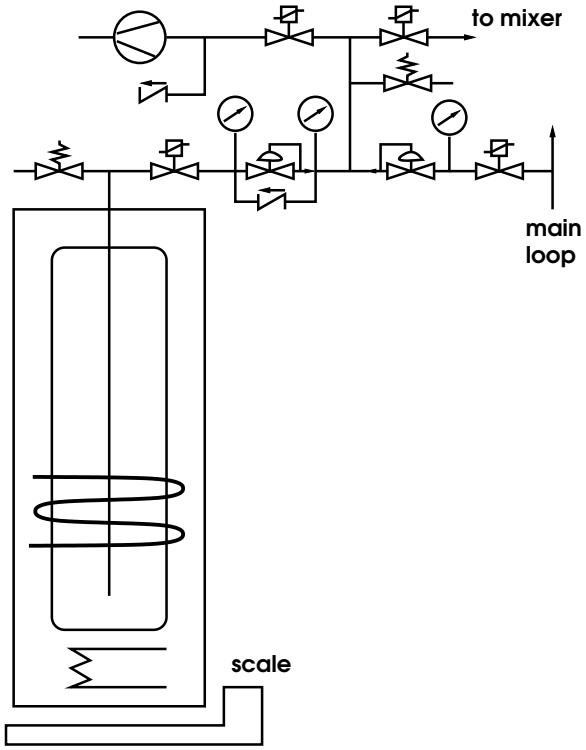

Figure 8.6: Schematic layout of the cryogenic plant used to separate the nitrogen from the components of the gas mixture.

The proposed cryogenic recovery unit is shown in Fig. 8.6. Similar concepts have already been used by the NOMAD [1] and ALEPH [2] experiments. The operating principle is based on the selective distillation of the gas by cooling it down to nearly the temperature of liquid nitrogen (LN_2). Because the freezing point of both the xenon and the CO_2 are above that of the nitrogen, as shown in Table 8.3, by cooling down with LN_2 a storage vessel, one can freeze both the xenon and the CO_2 as the gas enters the

vessel, while still keeping the nitrogen in the gas phase. A scale that weighs the vessel is used to control the amount of gas that enters the vessel. Once the desired amount - such that at room temperature the pressure would not exceed 200 bars - has been frozen, the gas left in the vessel is pumped and vented out until the pressure drops to essentially zero. Then, the vessel is brought back to room temperature. The time-pressure diagram corresponding to this operation is shown in Fig. 8.7. One can see the shoulders at which condensation and evaporation of the gas components take place as the temperature cycles down and up. The non-volatile component, namely the nitrogen, is pumped out at 60 min. This method, which accounts for no loss of xenon, results in a nitrogen-free mixture, although at some loss of CO_2. When the mixture in injected back into the loop, appropiate monitoring of and compensation for the loss of CO_2 will take place by injecting fresh quencher according to the reading of a dedicated CO_2 analyser.

This procedure will be carried out in parallel by doubling up the recovery vessel, such that while one vessel is being filled, the second one is used to feed gas into the loop. The frequency at which the recovery cycle has to be carried out depends strongly on the actual leak rate of the detector.

The recovery vessels will be filled up to the equivalent of 100 bars in a 9 m^3 bottle. For this purpose, the vessels will be cooled down with LN_2 as the gas enters it, such that a normal compressor can be used. This operation may require that the temperature cycle is repeated twice, since the freezing of the mixture in a turbulent regime may lead to trapping of some nitrogen into the condensed gas.

We consider the possibility to reuse an existing recovery plant which has been used in the ALEPH experiment for the same purpose and with the same gas mixture. We now have this plant in hand. Although conceived to work in a double temperature cycle for distilling the pure Xe, it has actually been used in exactly the same manner [3] as we propose in this document and have tested in a small set-up.

Table 8.3: Freezing and boiling points, in $^\circ$ C, of some gases relevant to the present gas system.

Gas	Freezing point	Boiling point
N_2	-209.86	-195.8
Xe	-111.9	-108.1
CO_2	-78.4 (subl.)	

8.4 Gas distribution pipework

All pipes and fittings in the TRD gas system will be made of stainless steel. The pipes will be butt-welded together to reduce the possibility of contamination and leaks to a minimum. Existing gas pipes at point 2 will be reused as far as possible. Table 8.4 shows an overall view of the main piping parameters. A total of 54 pipes run from the plug into the detectors, all on the RB26 side, left and right of the TRD.

Table 8.4: Main piping parameters.

	Number of pipes	Pipe inner diameter [mm]	Pipe length [m]	Nominal flow [m^3/h]	Reynolds number	Pressure drop [mbar]
SGX building to plug	1	73	90	5	5052	.12
Plug to RB26 side	54	4	100	0.1	1893	97
RB26 side to plug	18	16	100	0.28	1325	1.1
Plug SGX building	1	73	90	5	5052	.12

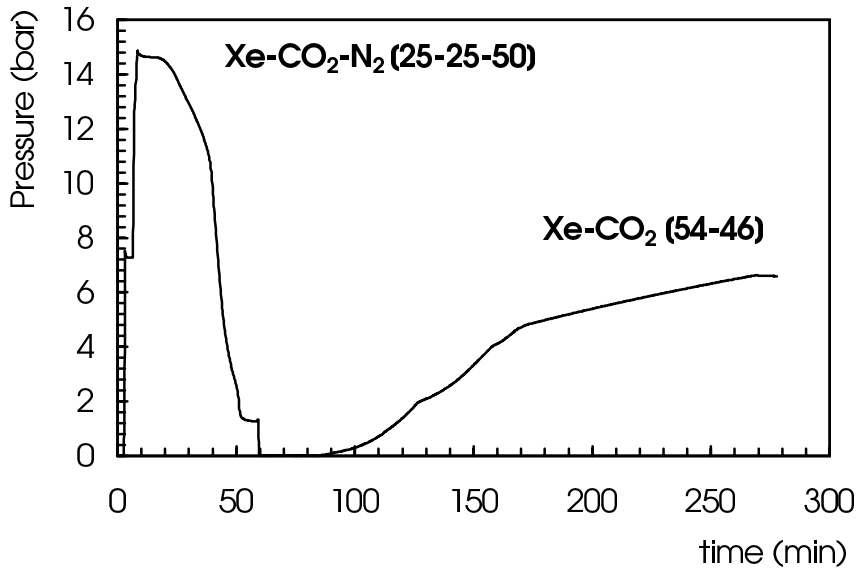

Figure 8.7: The evolution in time of the pressure of a Xe-CO_2-N_2 gas mixture as it is cooled with LN_2. At 40 min solidification of CO_2 takes place, followed by the xenon at 50 min. At 60 min the gas (nitrogen) left in the sample bottle is pumped out and the LN_2 flow stopped until the mixture returns to the gas phase. The gas was analysed with a mass spectrometer gas chromatograph system before and after the cryogenic treatment.

8.5 Prototype

A prototype gas system has been designed in collaboration with the CERN ST/CV group and built by Tecnodelta (Italy). The schematic layout in its present configuration is shown in Fig. 8.8. This gas system is being used in the current test beam experiments. Because the prototype chambers used so far have only a few liters gas volume, the gas is made to flow through the detector prior to entering the loop, where a higher circulation flow is best adapted to the strong pump of the system. The gas is then stored in a recovery bottle where the cryogenic cycle, described in section 8.3.4, takes place. The detectors under test can be included in the recirculation loop whenever their size and number increases. First operation of this gas system, at the test beam in spring 2001, has shown adequate performance both in terms of gas tightness and overpressure regulation of the gas in the test detector at the 0.1 mbar level.

It is intended to reuse both the principle of operation and most of the parts of this gas system for the final one. The manual valves will be replaced by remote-controlled ones (or completed with remote-controlled turning devices) and the manifolds and subsequent flow and pressure regulation hardware will be added, which will account for most of the cost. In addition, two more extra compressors, one of them being spare, will be added in order to be able to pump the gas from the plug to the surface and fill the recovery bottles at the required flow.

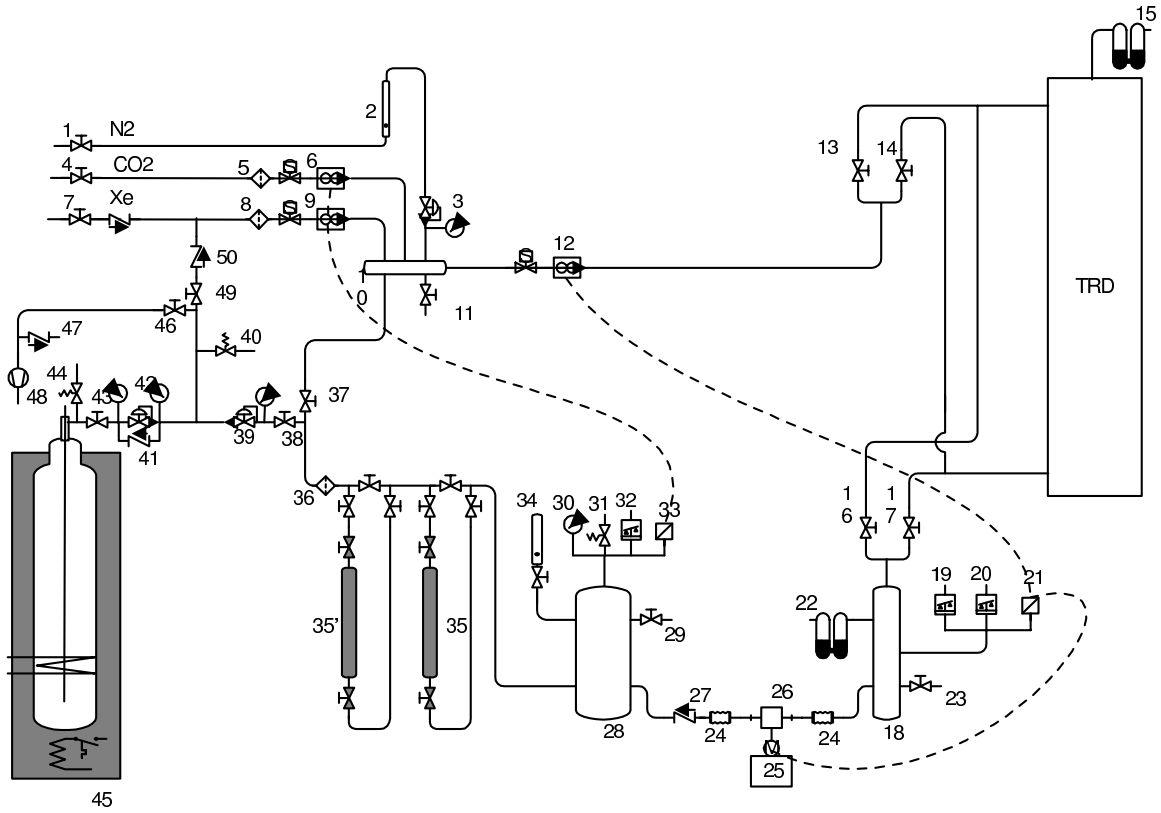

Figure 8.8: Layout of the gas system prototype used for the current TRD tests. For small detector volumes, the chamber is placed outside, upstream of the loop and the recirculation is regulated only by automatic tuning of the comrpessor speed. A fraction of the gas, equal to the fresh gas injected into the system, is pumped into the recovery bottle. The configuration shown in the figure corresponds to the case of larger detector volumes. The flow is regulated by acting both on the compressor speed (25) and on the loop main flowmeter (12) so as to keep the detector overpressure to the value set at the outlet pressure sensor (21). Leaks, if existing, are sensed at the high pressure vessel at the compressor output by the corresponding sensor (33), which opens the fresh gas injection flowmeters (6 and 9) whenever necessary. In order to keep the electrical complexity of the system low, all valves are manual.