Chapter 2

The experimental apparatus

In this chapter the NA38/NA50 experimental apparatus is described. The differences existing between the set-ups used to collect the pA, SU and PbPb data analysed in the present work are also pointed out.

2.1 Introduction

The NA50 experiment is located at CERN (European Laboratory for Particle Physics) and uses the SPS (Super Proton Synchroton) proton and lead beams. The aim of the experiment is the study of the dimuon production in ultra-relativistic Pb-Pb and proton-nucleus interactions.
The NA38/NA50 experimental apparatus is based on the upgraded NA10 spectrometer[1]. The NA50 apparatus has also been improved with respect to NA38 : two new detectors for the measurement of the centrality of the interaction (the multiplicity detector and the zero degree calorimeter) have been added, the Beam Hodoscope and the target detector have been rebuilt in quartz to be radiation resistant and the pseudo-rapidity coverage of the electro-magnetic calorimeter (EMCal) has been shifted to larger angles.
Since NA50 uses both the proton and the lead ion beam from the SPS, the target system can be correspondingly changed. When the experiment is running with a proton beam, the target is single and thick and no interaction vertex recognition is possible. On the other hand, the target used when running with lead ions, consists of a number of lead sub-targets with corresponding interaction vertex recognition system. During the NA38 S-U data taking period the target was also segmented. In the last section of the present chapter, the characteristics of the targets used during the NA50 1996-97 450 GeV/c p-A and 1996 158 A GeV/c Pb-Pb and the NA38 1992 200 A GeV/c S-U data taking periods are described.
In the following a detailed description of the NA38/NA50 spectrometers is given and the most important differences between the two apparata are pointed out.

2.2 The muon spectrometer

The NA38/NA50 muon spectrometer is used to reconstruct the dimuon events and the associated kinematic variables. It consists of a hadron absorber, a toroidal field magnet and of a system of MWPC's and scintillator hodoscopes placed both before and after the magnet as shown in fig.2.1
In NA38 muon pairs were detected in the pseudo-rapidity interval 2.8< η <4.1 whilst in NA50 muon pairs are detected in the pseudorapidity interval 2.8< η <4.0.

2.2.1 The hadron absorber

The hadron absorber, see fig.2.2, is composed by different layers of materials. In Tab.2.1 the characteristics of all the absorber materials are listed. In NA38 the very central part, the so called plug, was a cone of W-U which absorbed the beam which did not interact in the target. In NA50 the first 80 cm of W in the plug have been replaced by 65 cm of Ta corresponding to the zero degree calorimeter (see section 2.3.3.) followed by 15 cm of air. The plug is surrounded by carbon cylinders, for a total length of 4 m followed by 80 cm of iron at the very back of the absorber. Iron

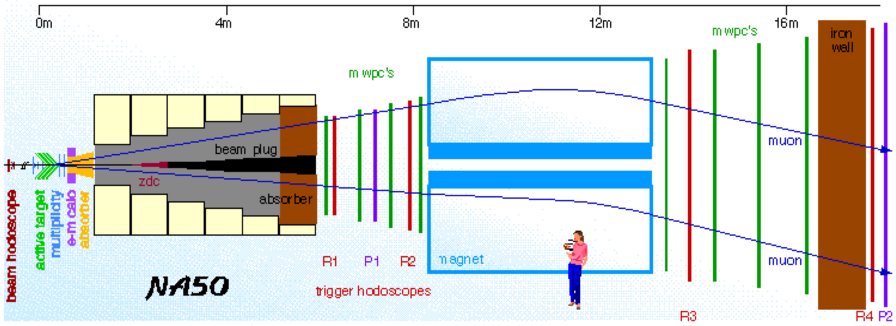

Figure 2.1: *The NA50 muon spectrometer.*

and concrete blocks are finally placed all around the carbon cylinders. The carbon cylinders and the last 80 cm of iron absorb hadrons coming from the interaction region but introduce small angular deflections on the muon track because of the multiple scattering effect : $\Delta\theta_\mu$ (C) $= \simeq$ 64 mrad/p(GeV) and $\Delta\theta_\mu$ (Fe) $= \simeq$ 101 mrad/p(GeV) if the Gaussian angular distribution is used[7]; the muon angle θ_μ is defined as

$$\theta_\mu = tan^{-1}(\frac{p_T}{p_l}) \tag{2.1}$$

where p_T and p_l are the transverse and longitudinal muon momenta in the laboratory frame.
Before the main absorber a preabsorber is placed to diminish the hadron (kaon and pion) disintegration : 59.1 cm BeO (p-W and Pb-Pb 96) or 60.8 cm Al_2O_3 (p-A 1997 with A=Al, Cu, Ag). The BeO preabsorber is placed in the innest EMCal part, and it is therefore used together with the EMCal. During the p-W 96 data taking period the BeO has also been used because the Al_2O_3 preabsorber was not yet available. During the following p-A NA50 data taking periods, the EMCal has been moved out of the spectrometer and the Al_2O_3 adopted. The BeO preabsorber covers the pseudo-rapidity range $2.42 < \eta < 4.43$, whilst the Al_2O_3 one covers the range $2.17 < \eta < 4.93$. A central hole along the beam axis allows the passage of the ions which did not interact in the target.
At the very end of the whole spectrometer, just before the last trigger hodoscope, a 1.2 m thick iron wall stops the surviving mesons to avoid the counting of fake triggers.

2.2.2 The toroidal field magnet

The hexagonally shaped magnet is 4.8 m long with an internal radius of 29.5 cm and an external one of 1.54 m, as shown in fig.2.3. It is placed at 1046.45 cm from the target centre, and covers the pseudo-rapidity interval $2.6 < \eta < 4.26$.

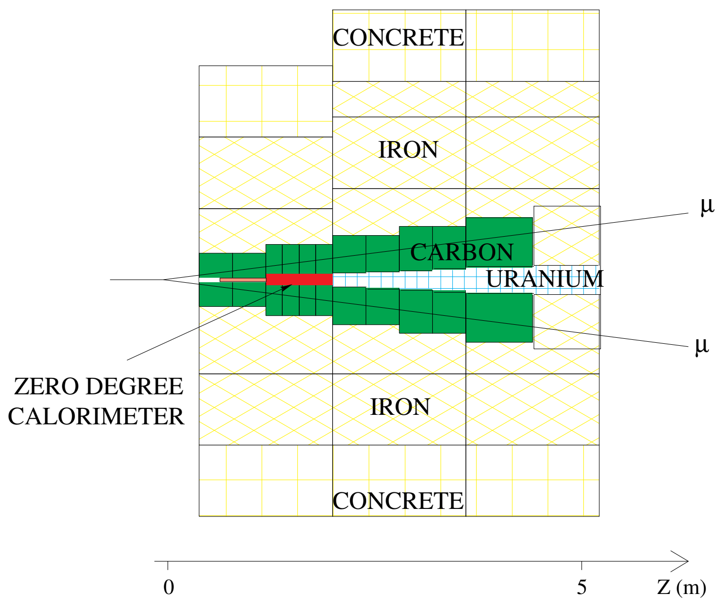

Figure 2.2: *The hadron absorber*

Material	Aim	Length (cm)	λ_i (g/cm^2)	ρ (g/cm^3)	X_0 (g/cm^2)
Al_2O_3	Pre-abs.	60.8	98.70	3.82	27.90
BeO	Pre-abs.	59.1	84.90	2.81	41.30
C	Main-abs.	400.0	86.30	1.93	42.70
Fe	Main-abs.	80.0	131.90	7.20	13.84
Air	Plug	80.0	84.40	38.30	36.66
Ta	ZDC(plug)	65.0	197.95	16.6	6.83
W	Plug	80.0	185.00	17.80	6.76
U	Plug	320.0	199.00	18.95	6.00

Table 2.1: *Characteristics of the absorber and pre-absorber materials.*

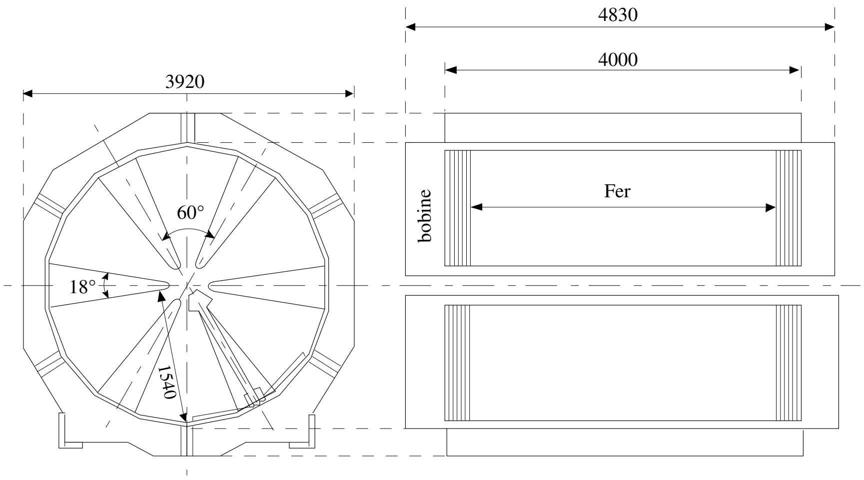

Figure 2.3: *The NA50 magnet*

The magnetic field is generated by a pulsed current circulating in 6 coils mounted on 6 iron supports occupying an azimuthal angle of 18^0. The generated azimuthal field, shown in fig.2.4, is characterised by a radial intensity, i.e.

$$\vec{B} = \frac{B_0}{r}\vec{e_\phi}$$

where B_0 depends on the current intensity, i.e., $B_0 = 0.383$ T m for 7000 A (NA50) and $B_0 = 0.550$ T m for the 10000 A current used in the NA38 p-A data taking. In NA38, for the S-U data taking period a 4000 A current was used corresponding to $B_0 = 0.219$ T m. In NA50 the current value has been raised to 7000 A in order to eliminate the soft muon background and have a good J/ψ mass resolution ($\simeq 3\%$ in NA50 and $\simeq 5\%$ in NA38).
Particles are deflected in the same azimuthal plane they belonged to when entering the magnetic field and the deflection can be calculated as[4]

$$\Delta\theta \simeq \frac{qB_0}{p_T} ln(\frac{z_2}{z_1}) = \frac{b}{p_T} \tag{2.2}$$

where z_1-z_2 is the magnet length, the z_i being computed from the target, and b = 0.023 rad GeV in NA38 for a 4000 A current and b = 0.0402 rad GeV in NA50.

2.2.3 The trigger hodoscopes

The 4 hodoscopes in the muon spectrometer provide the signal for the dimuon trigger and allow a first determination of the dimuon trajectory. They have the same hexagonal shape than the magnet and they consist of 6 azimuthal units of scintillator blades. They are organized in two sets, one placed between the main

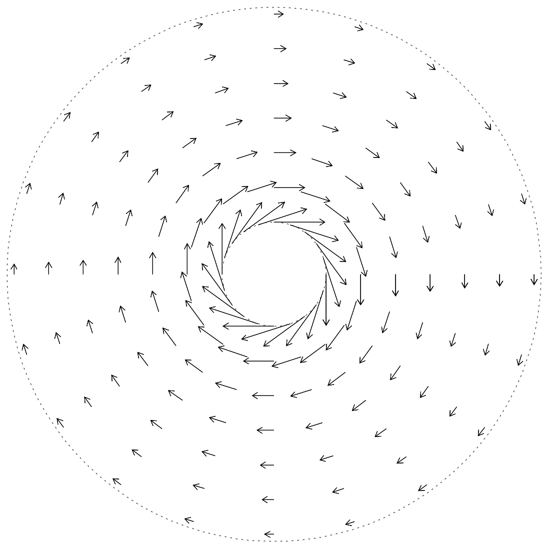

Figure 2.4: *The azimuthal magnetic field*

absorber and the magnet (R_1 and R_2) and one after the magnet, R_3 and R_4, as visible in fig.2.1.
R_1 and R_2 are homothetic copies of each other with respect to the central sub-target position. They consist of 30 blades for each sextant. Since the dimension of the blades grows with the radial distance from the beam axis, a particle coming from the interaction vertex will cross the blades R_{1i} and R_{2i} (or $R_{2(i+1)}$).
R_3 and R_4 have blades of identical dimension (23 blades for R_3 and 32 for R_4). R_3 is placed after the magnet and before the ending iron wall whilst R_4 comes just after it.

2.2.4 The proportional wire chambers

The two sets of 4 MWPC's, see fig.2.5, are used to precisely (some tenth of a mrad) reconstruct the muon tracks before and after the deflecting magnet. The first set of four chambers is placed just after the main absorber and reconstructs the part of the track which is pointing at the interaction vertex. The second set is placed after the magnet and reconstructs the track after it has been bent in the magnet. Each chamber is hexagonally shaped and consists of three independent planes rotated of 0^0, 60^0, 120^0 with respect to the vertical axis. The three planes are placed 2.2 cm from each other, the distance between the wires is 3 mm for all chambers and each wire has a diameter of 20 μm. The radius of the chambers in the first set is 1.3 m and each chamber consists of 749 wires, whereas the radius of the chambers in the second set is 3 m and each chamber consists of 1229 wires. The MWPC's are filled with a mixture of Argon (80%), ISO-butane (19.8%) and Freon (0.2%).

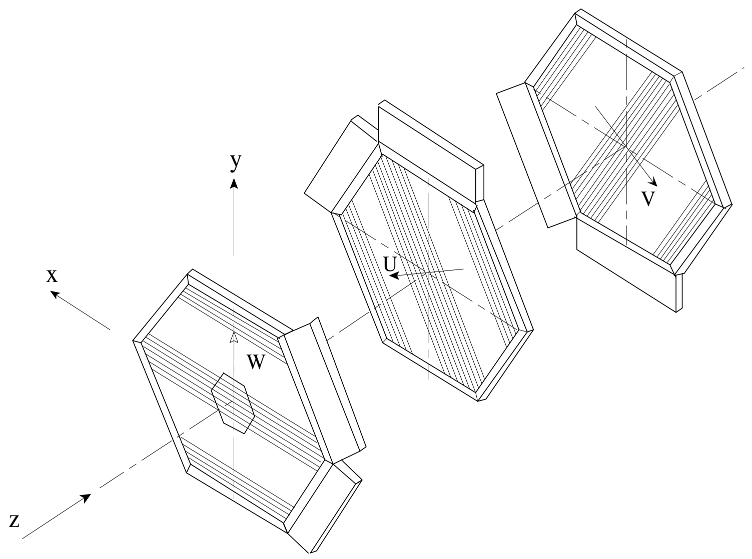

Figure 2.5: *The multi-wire proportional chambers.*

2.3 The centrality detectors

In order to search for threshold effects taking place when a certain temperature and/or energy density is created in the interaction volume, it is important to be able to select different ranges of centrality in the ion-ion collisions. In NA50, the centrality measurement is performed by three independent detectors in the experimental apparatus : the multiplicity detector (MD), the electro-magnetic calorimeter (EMC) and the zero degree calorimeter (ZDC). The MD measurement is strongly correlated with the EMC one and both are anti-correlated with the ZDC. In the NA38 S-U 1992 data taking period, the collision centrality was uniquely measured with the EMC[6].

2.3.1 The multiplicity detector

The MD measures the multiplicity of particles produced in a Pb-Pb collision. It consists of two silicon strip detectors organised in 2 discs each. Each detector consists of $\approx$ 7000 silicon micro-strips. In fig.2.6 one of the detector is shown.

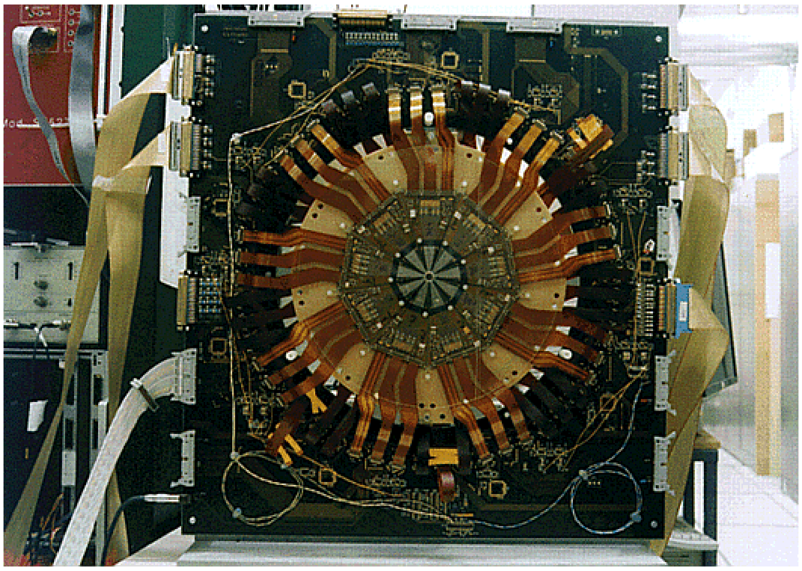

Figure 2.6: *One of the two Multiplicity Detector planes.*

The MD detector is placed after the target system and before the preabsorber, as shown in fig.2.7 and covers the pseudo-rapidity interval $1.5 < \eta < 3.9$. A very detailed description of the MD can be found in[2].

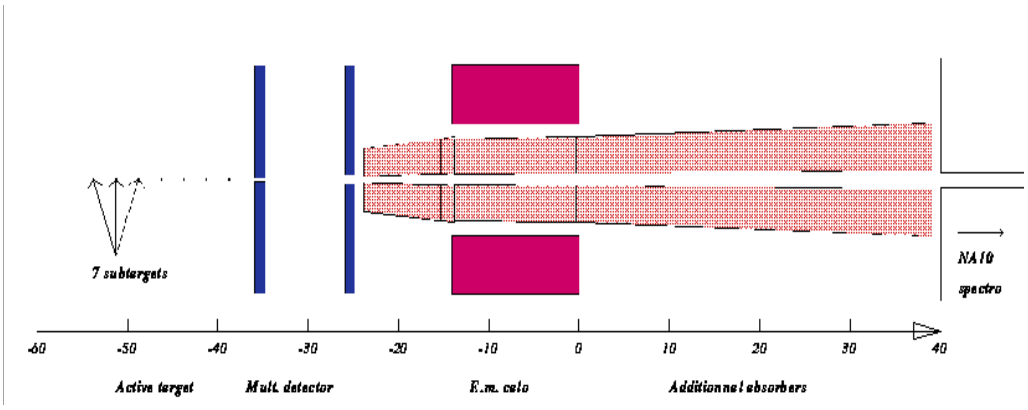

Figure 2.7: *View of the target region. The Multiplicity Detector and the Electro-magnetic Calorimeter are shown.*

2.3.2 The electro-magnetic calorimeter

The electro-magnetic calorimeter (EMCal) is 14 cm long, with an internal radius of 8.2 cm and an external one of 24.2 cm. It consists of polystyrene scintillating fibres ($\oslash = 2mm$) which are placed parallel to the beam axis and embedded in an alloy of lead and bismuth, for a fibres to alloy ratio of 1/2. The EMCal has the same hexagonal shape of all the detectors placed in the muon spectrometer and it is subdivided in four crowns, each of them covering a pseudo-rapidity interval $\Delta\eta = 0.34$. The calorimeter, positioned 32 cm downstream from the central sub-target as shown in fig.2.7, measures the neutral transverse energy produced in every nucleus-nucleus collision. The EMCal, which in NA38 covered the pseudo-rapidity interval $1.7 < \eta < 4.1$, in NA50 has been shifted to $1.1 < \eta < 2.3$ in order to reduce the amount of heavy material crossed by the muons and therefore improve the J/ψ and ψ' mass resolution.

2.3.3 The zero degree calorimeter

The zero degree calorimeter (ZDC), sketched in fig.2.8, measures the energy of the projectile nucleons which did not interact in the target, i.e., the projectile spectators. By subtraction the energy deposited in the collision can be obtained

$$E_{dep} = E_{beam} - E_{ZDC}$$

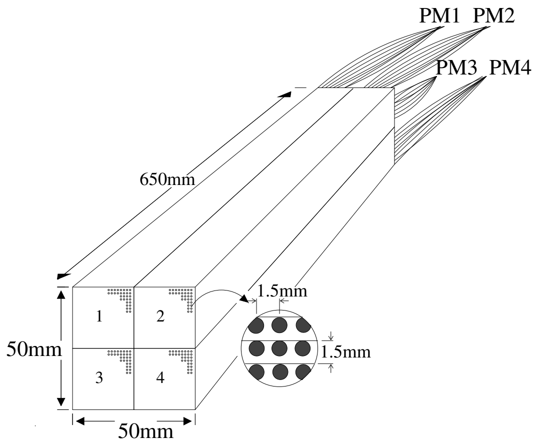

Figure 2.8: *The Zero Degree Calorimeter*

The ZDC is placed inside the main absorber, in the W-U internal cone of which it replaces the innest part, 165 cm downstream from the target. It has a cross section of 5X5 cm^2 for 65 cm of length. It consists of 900 quartz fibres ($\oslash = 365\mu$m for a length of 1.8 m) embedded in 30 tantalum blades (1.56 mm thick) for a Si/Ta ratio of 1/17. Since the ZDC has to stand extremely high radiation level, $\simeq 70$ MRaD on average during the 1996 158 A GeV/c Pb-Pb data taking period (corresponding to 4 GRaD in the ZDC central region), quartz fibres are used instead of the commonly adopted scintillating ones. The calorimeter reveals particles via the Cerenkov effect. The fibres are parallel to the beam axis for the first 65 cm, the active part, then they bend and guide the light to four photo-multipliers. To obtain a beam position sensitive device, the fibres are organised in four groups, each read by one of the four

PM's. The ZDC acceptance is delimited by a copper collimator 60 cm long and with a conical aperture of 3.5 mrad ($\eta \geq 6.3$).
The energy resolution of the ZDC has been measured with proton, deuteron, alpha and lead beams[3]. The ZDC energy resolution for a 158 A GeV/c Pb beam is 5% before and 7% after $\approx$ 40 days of data taking.

2.4 The beam

The NA50 experiment is located in the ECN3 hall where a high intensity beam is extracted. In fig.2.9 the beam line is shown[5].

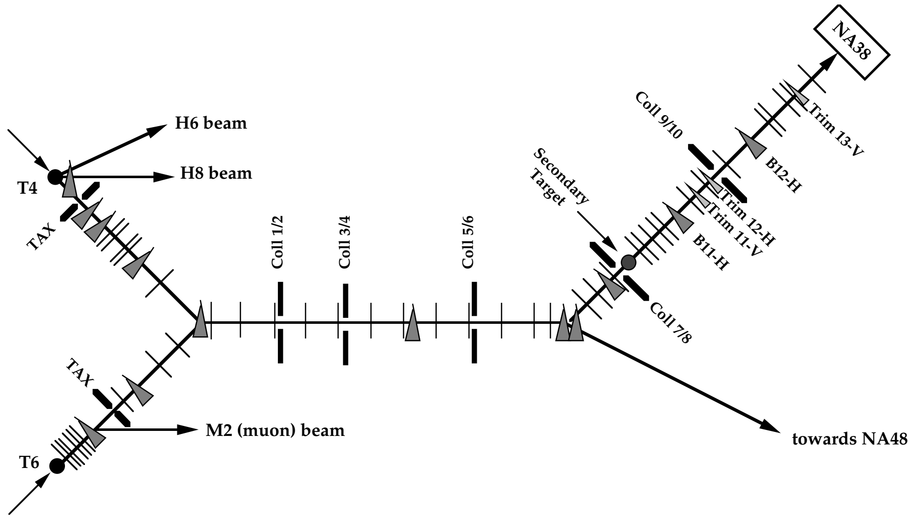

Figure 2.9: *Schematic view of NA38/NA50 beam line*

The primary beam, coming from the SPS, is either a proton or an ion beam. Protons are delivered with an energy of 450 GeV/c per charged particle whilst ions have 400 GeV/c per charged particle (158 GeV per nucleon for a Pb ion beam). The beam intensity is different in the case of proton and ion beam : the maximum number of particles (ions) per burst is 10^{11} for the former and around $5 \cdot 10^7$ for the latter. In NA38, during S-U data taking, the beam intensity was 10^8 S ions/burst. The beam intensity during ion-ion data taking periods has been chosen as a compromise between the safety and efficiency of the detectors which are directly placed on the beam line and the small J/ψ cross section in the $\mu\mu$ decay channel, $B_{\mu\mu}\sigma_{J/psi} = 2.10 \pm 0.15$ nb/nucleon in pp collisions at 200 GeV/c with

$$B_{\mu\mu}\sigma^{AB}_{J/psi} = B_{\mu\mu}\sigma^{pp}_{J/psi} \cdot (AB)^{\alpha} \tag{2.3}$$

where $\alpha = 0.920 \pm 0.015$[8]. As for the p-A data taking period, the maximum intensity is imposed by the chamber efficiency which is affected by a too high chamber

occupation level : in 450 GeV/c p-A the chamber reconstruction efficiency is 100% at low (10^8 protons/burst) intensity and falls down to 90-95% when higher ($\simeq$ 2.5 10^9 protons/burst) intensities are used.
The beam cycle is 20 s, for a 5 s effective spill.
A beam hodoscope (BH) placed 22 m upstream from the target counts the incoming ions and measures the luminosity during ion-ion data taking periods. The crossing ions produce Cerenkov light in the BH quartz blades. This same hodoscope is used to reject events where more than one ion have crossed the detector blades in the same trigger time window of 20 ns, as explained in the next chapter.
When running with the proton beam, the beam hodoscope can not be used because of the too high number of impinging projectiles and the too little produced Cerenkov light. Three independent Argon counters are therefore used to measure the luminosity and no pile-up rejection is possible.

2.4.1 The Beam Hodoscope

Placed 22 m upstream the target, the NA50 Beam Hodoscope (BH) consists of one plane of 16 quartz blades, detecting the incoming ions by Cerenkov effect. Each blade is associated with a photo-multiplier and the blade transverse size is adjusted so that each blade receives the same fraction of the total incoming number of ions. This is also possible because of the large cross section the beam has when crossing the BH, σ_x=0.8 mm and $\sigma_y = 6$ mm. The overall efficiency has been found to be better than 99% but the maximum intensity the BH can stand is 10^8 particles/burst. If more than one ion cross the BH in the same 20 ns trigger gate, the corresponding dimuon event is eventually rejected during off-line data analysis. This is the so called beam pile-up rejection. In fact during ion-ion data taking periods piling-up ions can lead to a wrong centrality measurement if more than one of the piling-up ions also interact in the target.
In NA38, where the radiation level was much lower, the BH was entirely built with plastic scintillator.

2.4.2 The BHI and BHIN

The BHI and BHIN are placed just after the BH in order to detect any interaction having taken place in the BH itself. The BHI consists of two scintillator blades of 1X3X8 cm^3 in z, x and y respectively, and is placed 17 cm from the BH, covering the pseudo-rapidity interval $2< \eta <3.1$.

The BHIN (or BHI new) is placed after the BHI. It consists of four scintillator blades organised around a central hole. The central hole is as wide as the BH in order to avoid the interaction of the incoming ions in the BHIN blades. The BHIN covers the pseudo-rapidity interval $3.3< \eta <5.1$, therefore complementing the BHI.

2.4.3 The Argon counters

Three ionisation chambers, filled with Argon, measure the proton beam intensity integrating over the current produced by ionisation in the gas. Once known the calibration constant, C_{argo}, which translates the number of argonium counts in number of incident protons, the luminosity measurement is straightforward. The Argon counters can properly work over a wide intensity range (10^6 to 10^{11} protons per second).

2.5 Trigger selection and data acquisition

The so called dimuon trigger selects events on the basis of the information given by the four R_i hodoscopes. If the two hodoscopes R_1 and R_2 have been hit in coincidence, i.e, on blades R_{1n} and R_{2n} (or $R_{2(n+1)}$), this makes a first positive selection of the muons which track points at the target region: this is called the V coincidence and defines the first half of the dimuon tracks. The dimuon is considered good if the hodoscopes R_3 and R_4, defining the last half of the dimuon tracks, are also in spatial and temporal coincidence with the first ones. This global hodoscopes coincidence is called VXR_3XR_4. This type of trigger allows a measurement of the bending of the muon tracks in the magnet, obtained extrapolating both half of the muon track up to the magnet middle plane. A good trigger is found when the extrapolated half of the track spatially coincide.
During Pb data taking periods, a maximum of 5000 events per burst can be recorded on tape (16Mbytes) within the 15 s inter-burst time. The data transfer takes place every burst; during the burst the data are kept in a temporary memory location. The maximum amount of events stored on a single tape defines the number of events per 'run'.

2.6 The target system

The NA38/NA50 target system used during heavy ion data taking periods has been designed in order to allow an easy determination of the interaction vertex. Therefore, the target is segmented and each sub-target is followed by two radiation resistant quartz blades whose signal identify the sub-target where the interaction took place. During p-A data taking periods the segmented target is replaced by a single thick one of the desired material.

In the present work, the 1996-1997 450 GeV/c p-A(A=Al, Cu, Ag, W), the 1996 158 A GeV/c Pb-Pb and the 1992 200 A GeV/c S-U sets of data are analysed. From now on those sets will be simply indicated as pA, PbPb and SU, otherwise specified when necessary.

2.6.1 PbPb 1996

During the 1996 PbPb data taking period, the target system consisted of 7 sub-targets each followed by two quartz blades, as shown in fig.2.10. This system allowed for the identification of the sub-target where the interaction took place and the one where eventually a projectile fragment had re-interacted. The radiation resistant quartz blades were placed on both sides of each sub-target and detected the Cerenkov light produced by the high energy secondary particles generated in the collision. The first and last sub-targets were 1 mm thick while the 5 middle ones had a thickness of 2 mm. This system corresponded to a total of 30% λ_i, where $\lambda_i(Pb)$= 194 gr cm^{-2}.
Just before the first sub-target, two quartz blades recognised when the interactions took place in the air before the target system. Since, at the target level, the cross section of the Pb beam is $\sigma_x \approx \sigma_y \approx 0.4$ mm, a couple of anti-halo detectors counted the number of ions arriving at the target out of a 3 mm diameter.

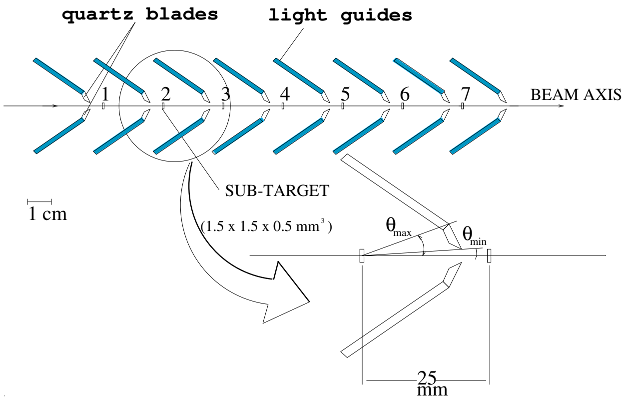

Figure 2.10: *The active target*

2.6.2 SU 1992

During the 1992 SU data taking period, the active target consisted of 12 sub-targets and 32 scintillating rings. The first sub-target had a x and y half-size of 5 mm and a thickness of 1 mm, whereas the following sub-targets were 0.5 mm in x and 1 mm in y for a thickness of 1 mm. The total interaction length was 20% $\lambda_i(U)$, where $\lambda_i(U) = 199\ g\ cm^-2$[6].

2.6.3 pA 1996-1997

During the 1996-1997 pA data taking periods the target was single and thick, not allowing for vertex recognition or re-interaction rejection. The characteristics of the 4 targets used between 1996 and 1997 are listed in tab.2.2.

Target	A (g)	L (cm)	λ_i $(\frac{gr}{cm^2})$	ρ $(\frac{gr}{cm^3})$	χ_0 (cm)
Al	26.98	12	106.4	2.70	8.9
Cu	63.54	7.5	134.9	8.960	12.86
Ag	107.87	7,5	156	10.5	6.37
W	183.85	4.5	185.0	17.80	0.35

Table 2.2: *Targets characteristics for the data taking periods p-A 1996-1997.*

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