Chapter 2. NA44 Experiment

2.1 Overview

NA44 experiment is one of the fixed target experiment using heavy-ion beams accelerated by the Super Proton Synchrotron (SPS) at CERN. 450GeV/c proton beam, 200AGeV/c sulphur beam and 160AGeV/c lead beam were used in this experiment with beryllium, sulphur, silver and lead targets in order to do the systematic study of the high-energy heavy-ion collisions. The NA44 focusing spectrometer is optimized to measure single and two particle distributions around the mid-rapidity in order to investigate the single particle productions and the space-time evolution of the colliding system with the two particle interferometry of hadrons [2-1,2,3,4].

This focusing spectrometer is shown in the figure 2-1, and consists of two dipole magnets for selecting particle momenta and three quadruple magnets to focus the secondary particles on the following detectors. By changing the current of the magnets and moving the spectrometer angle, the transverse momentum acceptance is covered up to around 1.5 GeV/c for pion, kaon and proton at around the mid-rapidity ($2 < y < 4$). Three scintillation hodoscopes [2-5] are used for tracking and time of flight measurement combining with Cherenkov beam counter [2-6]. The momentum resolution of this system is $\Delta P/P = 0.2\%$, time of flight resolution is σ_{TOF} = 100 *psec*. Two threshold gas Cherenkov detectors provide the particle identification for pion, kaon and proton up to 8 GeV/c in the laboratory momentum together with the time of flight measurement. For the lead beam experiment, we added one pad-chamber, two strip-chambers, Aerogel kaon trigger Cherenkov detector and the threshold imaging Cherenkov detector in order to help the tracking and the particle identification under the high multiplicity environment. The centrality trigger is given by a scintillation counter located just after the target, where the signal of the counter is roughly proportional to the charged multiplicity. The silicon pad detector gives the charged multiplicity in the pseudo-rapidity region of $1.5 < \eta < 3.3$, which is used in the off-line analysis. For both S+S and Pb+Pb collisions, the data are corrected at top 15% central collisions.

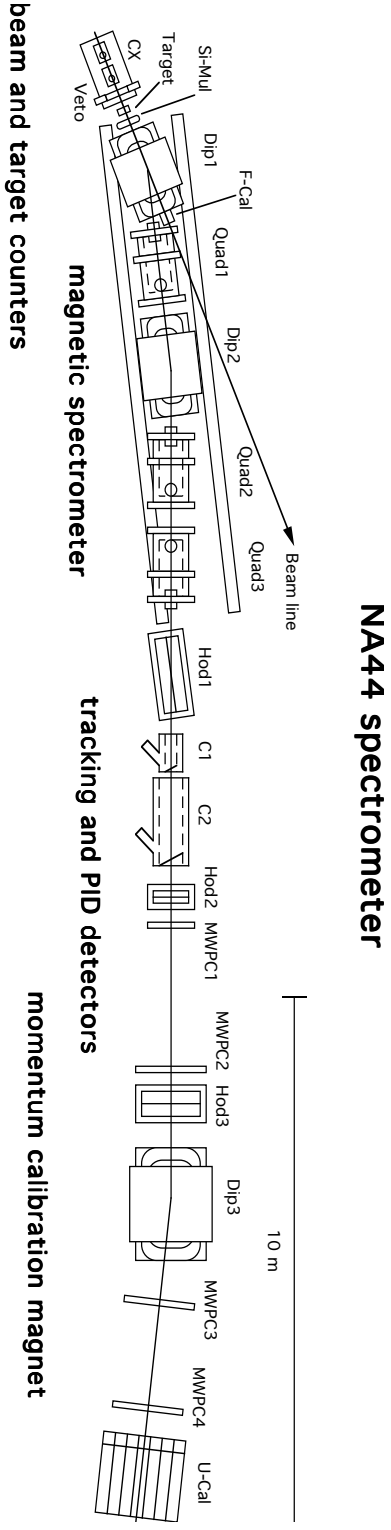

Figure 2-1: NA44 focusing spectrometer

2.2 Target area

Beam counter is located at 0.5m upstream from the target, and consists of two identical gas Cherenkov detectors (CX1,CX2). This detector is operated with the nitrogen gas radiator in atmospheric pressure. Radiated Cherenkov photons are reflected by the flat aluminum mirror and collected by the photomultiplier tube with UV glass window. This beam counter is optimized for the heavy-ion beam. Since 200AGeV/c sulphur beam and 160AGeV/c lead beam have enough velocity to fire the nitrogen gas radiator and the number of radiated photons is proportional to the charge-square z^2 of the beam particle, therefore the photomultiplier tube gives enough resolution of the ADC signal to eliminate the different charged beam, which can be contaminated as beam fragments from the upstream interactions. The characteristic of fast timing response of the Cherenkov radiation compared with the standard plastic scintillators and fast rise-time of the photomultiplier tube give about 40psec intrinsic timing resolution of the detector. Top two figures in the figure 2-2 show the CX detector ADC spectrum and TOF difference between 2 CX detectors.

Two veto counters are located between the CX beam counter and the target to reject the beam halo and upstream interactions. The CX veto counter is a scintillation counter with 1cm diameter hole on the beam with two photomultiplier tubes reading from both sides of the scintillator. The size of the hole is changed down to 0.5cm for the Pb beam experiment to eliminate large the background. The T0 veto counter has a hole of 0.5cm diameter, is located closer to the target, and has a readout photomultiplier tube from one side. The veto counters are used in the rejection mode in on-line trigger with requiring a good hit in the CX beam counter in order to make a clean definition of the beam going onto the target.

During the beam tuning by using the upstream magnets to change the focusing size and the position of the beam spot on the target, a blade target with 1mm width is used to find the center of the target position. The focused size of the beam on the target is about 1mm in horizontal direction and 3mm in vertical direction. In the normal experimental running condition, 1cm diameter disk target is used. Because one need to have the larger area of the target than the beam spot, all beam particles should have the same probability to collide with the target nuclei in order to calculate the cross section with the beam normalization. The target thickness is selected from 1mm to 10mm depending on the target material.

The trigger scintillation counter T0 is located just after the target. The T0 counter consists of two identical scintillator pieces (1cm width, 3cm height, 0.5cm thickness) located in right and left sides of the beam with a 3mm gap in the middle. The scintillation light collection is done by two light guides from top and bottom after connecting the scintillator pieces. Two photomultiplier tubes are attached to the both end of the light guides. The amount of the signal from the T0 scintillation counter is roughly corresponding to the number of the charged particles going through the geometrical acceptance of the T0 counter, which covers around back-

ward pseudo-rapidity region. Therefore this counter is used in the on-line trigger device to determine the centrality of each collision.

The silicon pad detector is located after the T0 counter, covers backward pseudo-rapidity region ($1.5 < \eta < 3.3$), the detector is segmented into 192 pads. The detector is counting the number of charged particle in its geometrical acceptance. The data from the detector is used in off-line analysis to get the centrality of the collision.

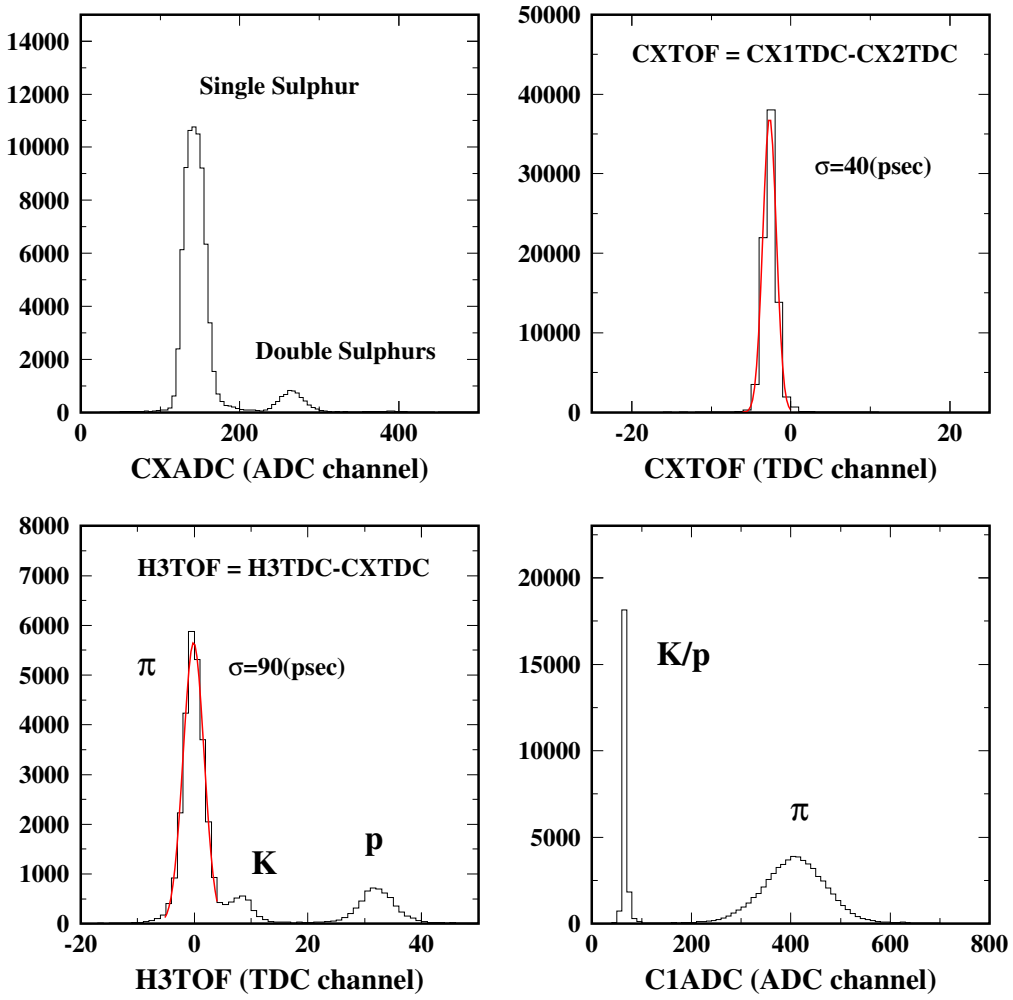

Figure 2-2: CX, H3 and C1 ADC and TOF spectra

2.3 Focusing spectrometer

First and second dipole magnets select the momentum, third dipole magnet is used for a momentum calibration with wire chambers. Three quadruple magnets focus secondary particles onto the tracking and particle identification detectors. This spectrometer is a single arm magnetic spectrometer, which has a narrow acceptance $\pm 20\%$ of the nominal momentum, therefore only the same charged particles can be measured at a time. Different charged particles will be measured by switching the polarity of the magnetic field.

By changing the currents of all magnets, the magnetic field strength can be changed to scan the different spectrometer acceptance in the space of the transverse momentum and the rapidity. To scan larger transverse momentum acceptance up to 1.5GeV/c, the magnetic spectrometer and the detectors are movable up to angle of 131mrad respect to the beam line for the 'large angle setting', while the normal spectrometer is located at 44mrad for the 'small angle setting'. The NA44 spectrometer acceptances at several settings is shown for each particle in the figure 2-3.

By changing the combination of the polarities of three quadruple magnets, the spectrometer acceptance can be changed between the 'horizontal setting' and the 'vertical setting', where two particle acceptance is different between these two settings.

Two particle acceptance is determined by a momentum difference between the two particles Q, which will be separated into the longitudinal component Q_L, which is parallel to the beam direction, and the transverse component Q_T, which is orthogonal to the beam direction. Transverse momentum difference Q_T of two particles is further separated into two orthogonal directions, Q_{TO} is parallel to the total transverse momentum of the particle pair, Q_{TS} is perpendicular to Q_{TO}. One can extract an time duration component of particle emitting source distribution with the difference between these two directions. The horizontal setting is optimized to maximize the Q_{TO} window, and the vertical setting maximizes the Q_{TS} window.

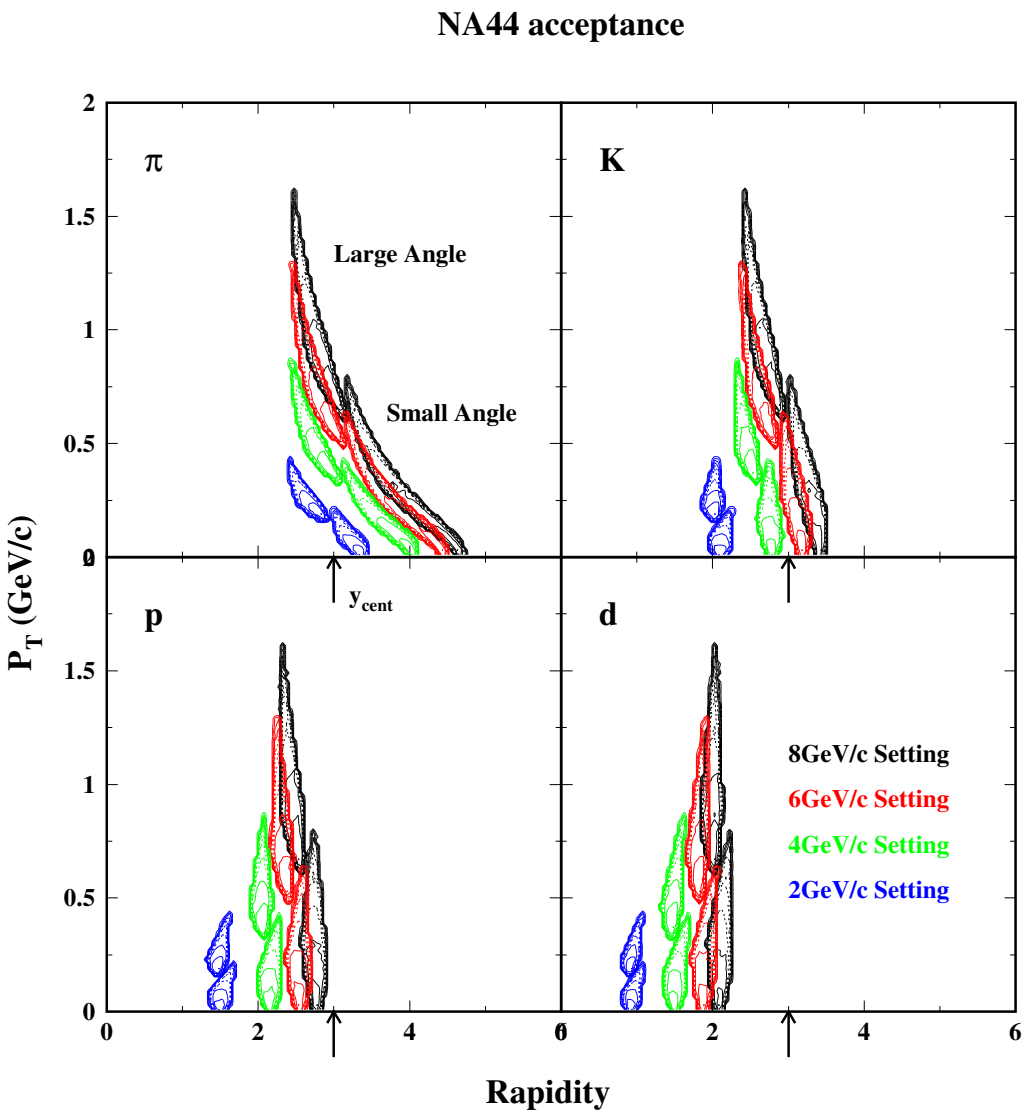

Figure 2-3: spectrometer acceptance for various settings

2.4 Tracking and TOF hodoscopes

Three scintillator hodoscopes give three 3-dimensional positions after the magnetic spectrometer in order to reconstruct the trajectories of the secondary particles in the magnetic-free space. Each highly segmented hodoscope consists of a row of 50 or 60 stick-type plastic scintillation detectors in order to know momenta of secondary particles with fine momentum resolution over a small momentum phase space described in the previous section. The specification of the hodoscope is tabled.

item	Hod1	Hod2	Hod3
elements	50	60	50
width (cm)	2.6	0.6	1.3
height (cm)	20	20	20
thickness (cm)	0.1	0.6	1.3
position (m)	10	13	18
angle (degrees)	5	90	90
X resolution (cm)	0.1	0.2	0.4
Y resolution (cm)	1.1	0.9	0.8
TOF resolution (ps)	150	130	80

The position is the distance from the target, angle is respected to a central ray of the spectrometer in horizontal plane. The each detector element has two photomultiplier tubes at both ends of the plastic scintillator. Horizontal position from the each hodoscope is given by the hitted detector element number. Vertical position will be calculated by using the timing difference between top and bottom photomultiplier tube. To calculate vertical position, one need to correct the scintillation light velocity, the difference of the rise time of the photomultiplier tubes, the timing response of the discriminator and the cable length for each element, therefore vertical offset and vertical gain are need to be calibrated. To calibrate vertical position, there are 3 horizontal scintillation counters, called finger counters, fixed at top, center and bottom of the geometrical acceptance of each hodoscope in order to make tagged events by the hits of those three counters. In off-line analysis, origin of vertical position and the scintillation light velocity inside the plastic scintillator will be calibrated in advance, using events tagged by the hits of these three scintillation counters. Momentum resolution of this system is 0.2% of the nominal momentum.

Another purpose of the hodoscope is to measure the time of flight (TOF) of the secondary particle. The TOF is calculated from the TDC difference between the hodoscopes and the CX beam counter for the heavy-ion beam experiment. On the other hand, the T0 scintillation counter is used instead of the CX beam counter for proton beam experiment. The different mass particles give the difference in TOF at the same momentum, therefore particle identification can be done combining with the measured momentum.

Because the leading-edge discriminators are used to make timing signal, the timing depends on the pulse height of the scintillation counter. Therefore both

timing information (TDC) and pulse height information (ADC) are read-out from CAMAC module for each detector element, in order to correct the effect of the pulse height dependence of the timing with 'slewing correction' technique, which will be mentioned further more in the following chapter. An intrinsic time of flight resolution of the last (H3) hodoscope is around 80psec, which is mainly used for the particle identification, because of the better separation between the different mass particles with the longest flight path. Overall time of flight resolution between CX beam counter and H3 hodoscope is about 100psec. At nominal 4GeV/c momentum setting, pion and kaon separation at H3 is around 4 sigma level in TOF. TOF spectrum between the H3 hodoscope and the CX beam counter is shown in the bottom left figure in the figure 2-2.

2.5 PID and trigger Cherenkov

Two gas threshold Cherenkov detectors are located between H1 and H2 hodoscopes. Each detector is filled with gas radiator for Cherenkov photon radiation and has a concave mirror to reflect and focus photons onto a photo cathode of a single photomultiplier tube to measure the amount of total photons emitted by particles passed through the aperture of the detector. By choosing an optimized threshold between the different particles for both Cherenkov detectors, a required particle species can be identified in on-line and off-line. Especially, rare particles can be triggered in on-line to get enough statistics for single and pair particle measurements. The first Cherenkov detector filled with freon gas radiator called C1 is fired by pions at lower pressure and is fired by pions and kaons at higher pressure depending on the nominal momentum setting. The second Cherenkov detector filled with nitrogen gas radiator called C2 is fired by electrons at lower pressure and is also fired by electrons and pions at higher pressure depending on the nominal momentum setting. The C1 Cherenkov detector ADC spectrum is shown in the bottom right figure in the figure 2-2. The figure 2-4 shown here is the normalized number of photon as a function of momentum for C1 and C2 both low and high pressure setting. At 4GeV/c setting, both C1 and C2 are used at low pressure, therefore one can select pion with requiring C1 hit and rejecting C2 hit, kaon and proton can be separated by TOF. At 8GeV/c setting, both C1 and C2 are used at high pressure, pion can be selected with requiring C2 hit, kaon can be collected with requiring small pulse height in C1, because the pulse height of C1 between pion and kaon is clearly different around 8GeV/c as seen in the figure, after rejecting C1 and C2 hit, proton or heavier particles can be collected.

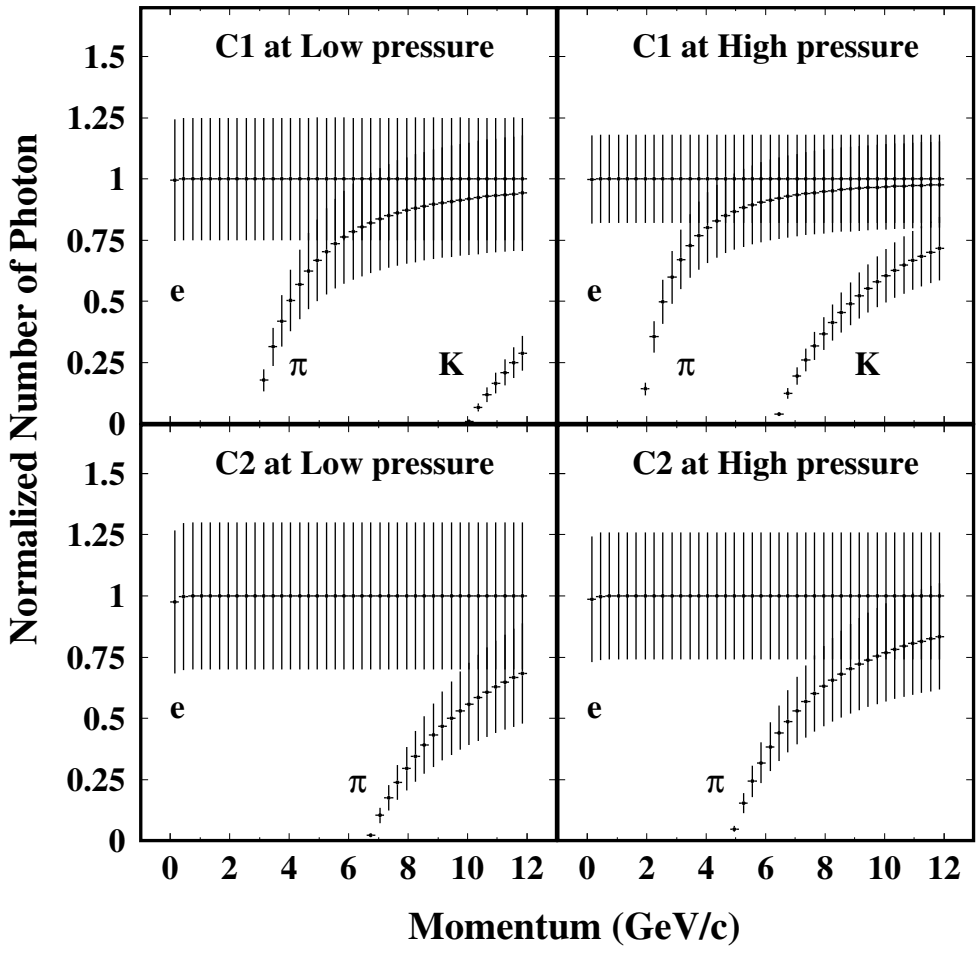

Figure 2-4: Cherenkov photon vs momentum

2.6 Trigger and DAQ

Main trigger is given by :

(1) a good beam definition (CX beam counter and veto counters),
(2) a required centrality depending the threshold of the T0 counter discriminator,
(3) at least one/two hits in each hodoscope for single/double tracks trigger selection respectively,
(4) two (C1 and C2) Cherenkov detectors trigger selection (requiring or rejecting or neglecting mode for each Cherenkov detector to select a particle species in on-line effectively).

NA44 DAQ (Data Acquisition) system is explained in this section. CAMAC (Computer Automated Modulation And Control, based on the ESONE/IEEE standard) readout and VME (Virtual Memory Extension) bus network and IBM tape driver are controlled by a Macintosh computer (32 bit 68040 CPU running at 40 MHz) to flow the data from CAMAC into VME and tape driver and to write the data onto an IBM tape. A tape writing speed is 200 Kbytes per second, For given burst of 10^7 sulphur ions, 400-500 single particle triggered events are written to the tape. The typical event size is about 800 4-byte integer words. 60,000 events per tape are written as one run corresponding to 200 Mbytes. Several monitoring Macintosh is looking for the data from VME to monitor and check the detector performance and data quality. To avoid false trigger from multiple beam particles, for 100 ns before and after each trigger the DAQ does not accept any triggers, this is called as before and after protection.