Nuclear Instruments and Methods in Physics Research A 383 (1996) 409-412

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

A gas Cherenkov beam counter with a timing resolution of 30 ps for relativistic heavy ion experiments

Tatsuya Chujo *, Kazuhiko Enosawa, Riko Higuchi, Kenji Kanoh, Mizuki Kurata, Kazuyoshi Kurita, Yasuo Miake, Yuko Miyamoto, Shunji Nishimura, Yasuo Okuma, Susumu Sato, Yukio Yokota, Kohsuke Yagi

Institute of Physics, University of Tsukuba, Tsukuba, Ibaraki 305, Japan

Received 28 May 1996

Abstract

We constructed gas a Cherenkov beam counter for a lead beam to obtain start signals of time of fight measurements for relativistic heavy ion experiments in WA98 at CERN-SPS. The intrinsic timing resolution of the gas Cherenkov counter was found to be ≤ 30 ps at a beam intensity up to 3×10^5 ions/s and the charge resolution ($\Delta Z/Z$) was 2.0% for lead ions of 160 GeV/c per nucleon. This counter has been successfully operated for more than $1\frac{1}{2}$ month of heavy ion run in 1995.

PACS: 29.40.Ka; 25.75.-q

1. Introduction

In the WA98 experiment at the CERN Super Proton Synchrotron (SPS), highly excited compressed nuclear matter, the degree of thermalization and a possible phase transition to the Quark Gluon Plasma (QGP) by means of high statistic measurements of hadrons and photons in Pb + Pb collisions at 160 GeV/c per nucleon has been studied [1]. In particular, we are interested in measurements of single-particle spectra, two-particle correlation and detection of ϕ mesons by the magnetic spectrometer.

For precise particle identification, there are two Time Of Flight detector walls (abbreviate as TOF hereafter), called TOF1 and TOF2, to obtain stop timing signals of both negative (π^-, K^- and $\bar{p}$) and positive charged particles (π^+, K^+ and p), respectively (see Fig. 1). For requiring 4σ separation between K^+'s and π^+'s at 4 GeV/c with a flight path of 17.8 m, a TOF resolution of 100 ps is needed. As the intrinsic timing resolution of TOF2 is 80 ps, the gas Cherenkov beam counter must have a timing resolution of < 50 ps as a start counter to fulfill this requirement.

At the NA44 experiment (CERN-SPS), a Cherenkov beam counter for the sulfur beam [2] is constructed. Following the concepts of this counter, we have optimized the design (size and material) for the lead ion beam to achieve the minimum interaction rate and the timing resolution. Since the intensity of Cherenkov emission is proportional to the Z^2 of the injected ions, for a lead ion ($Z = 82$), the thickness of the radiator can be much thinner than for the sulfur beam. The number of photoelectrons will be several thousands per cm in the case of lead ions.

We have examined the performance of the gas Cherenkov beam counter for lead ions with a beam energy of 160 GeV/c per nucleon at a beam intensity up to 3×10^5 ions/s during the beam time of $1\frac{1}{2}$ month in 1995.

2. Counter design and test configurations

For the design of the gas Cherenkov beam counter, there are four major requirements:

(1) a timing resolution less than 50 ps,

(2) a beam interaction rate of the lead ions in the counter of less than 0.5%,

(3) a high beam rate stability,

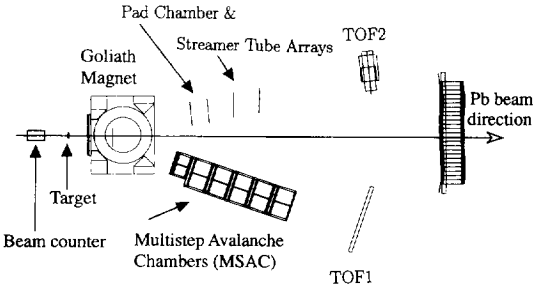

Fig. 1. Plan view of the WA98 experiment set up.

* Corresponding author. Tel. +81 289 53 6121, fax +81 298 53 4254, e-mail chujo@tac.tsukuba.ac.jp.

0168-9002/96/$15.00 Copyright © 1996 Elsevier Science B.V. All rights reserved
PII S0168-9002(96)00731-0

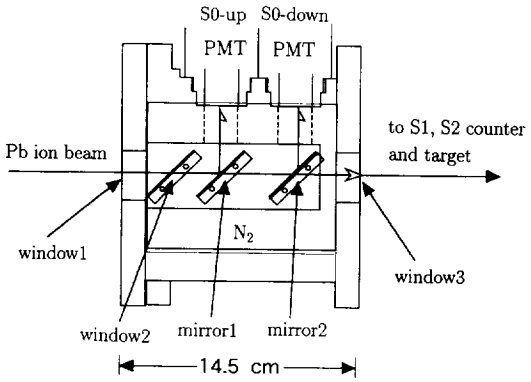

Fig. 2. Side view of the gas Cherenkov beam counter (S0).

(4) no radiation damage.

To fulfill requirement (1), we have adopted fast timing photomultiplier tubes (PMT) utilizing the prompt nature of Cherenkov light emission. For requirement (2), nitrogen gas, total thickness 7.5 cm at a pressure of 1 atm., has been used as a radiator of Cherenkov light emission. Also for separation of the vacuum before and after the counter, 50 μm thick alamide film[1] was used. Mirrors that reflect the Cherenkov light onto PMTs were made of 15 μm thick aluminum foil. The geometrical interaction rate P is calculated as follows:

$$P = \sigma_{geo} N_A \rho t / A, \quad (1)$$

$$\sigma_{geo} = \pi (R_{Pb} + R_m)^2, \quad (2)$$

$$R_A = 1.2 A^{1/3}, \quad (3)$$

where σ_{geo} is the geometrical cross section of the material of S0 counter with lead ions, N_A is the Avogadro constant, ρ is the density of each material of the S0 counter, t is the thickness of the material, A is the mass number, and R_{Pb} and R_m are the radius of the nuclei of the lead ions and the material, respectively (Eq. (3)). From Eq. (1), the total interaction rate of the gas Cherenkov counter was kept less than 0.5% for lead ions. For requirement (3), we applied boosters to the PMTs, which supply voltages to the last three dynodes. Finally, for requirement (4), we made the nitrogen gas flow at 1 atm. pressure. Fig. 2 shows the side view of the gas Cherenkov beam counter (abbreviated as S0 hereafter).

In addition to the S0 counter, a plastic scintillation counter (S1) and a solid (quartz) Cherenkov counter (S2) were implemented together with S0 in order to compare performances (Table 1).

2.1. S0 counter (gas Cherenkov)

As shown in Fig. 2, the S0 counter has two independent counter cells to evaluate their intrinsic timing resolution by themselves. Since the emission angle of the Cherenkov light is 1.4° in 1 atm. nitrogen gas, the Cherenkov light can be directly reflected onto the PMT with a mirror, tilted 45° against the beam direction. The length of the radiator is 3.0 cm for the up stream cell (S0-up), and 4.5 cm for the down stream cell (S0-down). Window 2 is equipped to maintain the same radiator thickness for beam particles vertically deviated.

We adopted a 1 in. type H5321-MOD (Hamamatsu Photonics K.K.) for the S0-up, and a 2 in. type H2431-02T (Hamamatsu photonics K.K.) for the S0-down. This PMT selection is not essential but just for the sake of convenience. Both PMTs have a fast rise time (0.7 ns), and a small transit time spread (S0-up: 0.16 ns, S0-down: 0.37 ns), a quartz window which is transparent for the UV light, and the booster (See Table 1) [3].

We adjusted the amount of photoelectrons on each PMT with the installation of neutral density filters (30% transmittance) in front of the photocathodes. For a high rate capability up to 10^6 ions/s, we connected the boosters to the last three stages of the dynodes of each PMT (for S0-up, dynode 8–10 and for S0-down, dynode 6–8).

2.2. S1 (plastic scintillator) and S2 (quartz) counter

A plastic scintillator of 0.5 mm thickness and a quartz counter of 0.2 mm thickness were installed in the S1 and S2 counter, respectively. These thicknesses were chosen to obtain a comparable number of photoelectrons and interaction rate. Both S1 and S2 counters had two PMTs on both ends to get the intrinsic timing resolution by themselves as S0 counter. Specifications of these counters are listed in Table 1.

3. Experimental results

We measured the intrinsic timing resolution and the light yield of the gas Cherenkov counter for lead ions of 160 GeV/c per nucleon at a beam intensity from 2.5×10^4 to 3×10^5 ions/s. At the same time, for comparison, the performance of the S1 and S2 counters was studied.

3.1. Performance of the S0 counter

We measured the intrinsic timing resolution at various beam intensities. Fig. 3a shows the typical timing differences between the PMTs of S0. On average, the intrinsic timing resolution was obtained as 30.4 ± 0.8 ps in σ with Gaussian fitting (the fitting error of the Gaussian distribution is included). In Fig. 4, the intrinsic timing resolutions are plotted as a function of the beam intensity. This indicates that the intrinsic timing resolution remains at the level of 30 ps up to 3×10^5 ions/s of the beam intensity.

In Fig. 5, the Cherenkov light yield is shown at a beam intensity of 3×10^5 ions/s. The clear peak corresponds to the passage of a single lead ion beam. The broader distri-

[1] The density of the alamide film is 1.50 g/cm^2, and its constituents are; N: 9%, C: 57%, H:3%, O: 11%, Cl: 21%.

Table 1
Specification and performance of each beam counter

	Name		
	S0	S1	S2
Type	gas Cherenkov counter	plastic scintillation counter	quartz Cherenkov counter
Description (n: refractive index)	N_2 gas 1 atm., n= 1.000297	scintillator: BICRON BC404	n = 1.45
Thickness	up: 3.0 cm down: 4.5 cm	0.5 mm	0.2 mm
Interaction rate	0.5%	0.6%	0.5%
PMT	up: H5321-MOD down: H2431-02T	H2431 (glass window)	H2431-02T
Timing resolution	30 ps	48–135 ps	55 ps
Charge resolution ($\Delta Z/Z$)	2.0%	> 5%	2.6%
Deterioration of PMT output[a]	9%	17%	18%

[a] Decrease of the PMT output during the exposure to 1.5×10^9 lead ions.

bution at around channel 700 was also seen, which might be due to the passage of two lead ions in the gate timing of 100 ns. The resolution of the light yield, σ/Y is found to be 4.0%, where σ and Y are the width of the fitted Gaussian distribution in Fig. 5 and the Cherenkov light yield, respectively. Considering that the Cherenkov light intensity is proportional to Z^2, the charge resolution ($\Delta Z/Z$) is 2.0%. The scatter plot of S0-up vs. S0-down is shown in Fig. 6, that indicates we can clearly reject the background events such as double hits of lead ions.

3.2. Performance of the S1 and S2 counter

Figs. 3b and 3c show the typical intrinsic timing resolution of the S1 and S2 counter, respectively. The S1 counter had 48 ps timing resolution at the beginning, but gradually got worse and it became 135 ps. This might be due to the radiation damage of the plastic scintillator by the lead ions. The timing resolution of S2 was 55.0 ± 1.7 ps on average.

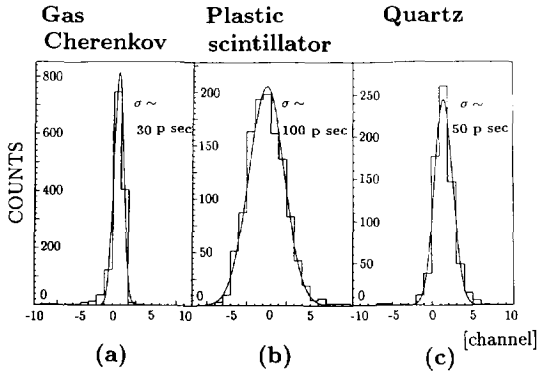

Fig. 3. Typical histograms of the timing difference of PMTs of (a) the gas Cherenkov beam counter (S0), (b) the scintillation counter (S1) and (c) the quartz Cherenkov counter (S2) with Gaussian fitting. The zero point on the abscissae are taken arbitrarily (45 ps/channel).

3.3. Deterioration of the PMT output

We measured the radiation damage of the quartz and plastic scintillator due to the lead ions by comparing the Cherenkov or scintillation light yield as a function of the total number of hit lead ions. During the exposure to 1.5×10^9 lead ions, for the gas Cherenkov beam counter, this change was 9%. This might be caused by the degradation of the PMTs themselves, because the PMTs were operated at the maximum dynode current. However, for the quartz and plastic scintillation counter, deterioration of the PMT outputs is much worse; 18% and 17% respectively (See Table 1). In addition to the PMT degradation, radiation damages might be the cause of this effect.

4. Conclusions

We constructed a gas Cherenkov beam counter for relativistic heavy ion experiments in WA98 at CERN-SPS for a lead beam. In addition to the gas Cherenkov counter, we also installed a plastic scintillation counter and a solid (quartz) Cherenkov counter in order to compare performances of these counters using lead ions of 160 GeV/c per nucleon at

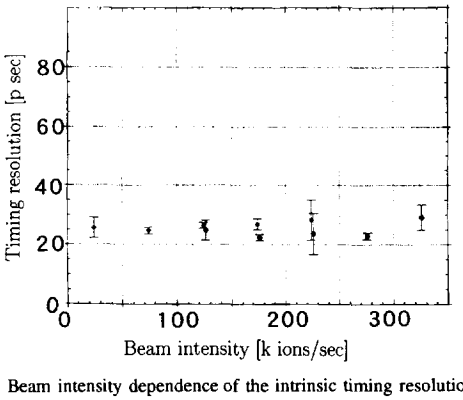

Fig. 4. Beam intensity dependence of the intrinsic timing resolution of the S0 counter. Error bars show the fitting error of the Gaussian distribution.

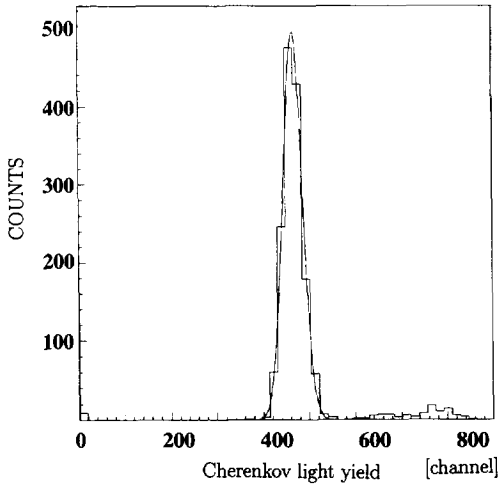

Fig. 5. Cherenkov light yield of the S0 counter.

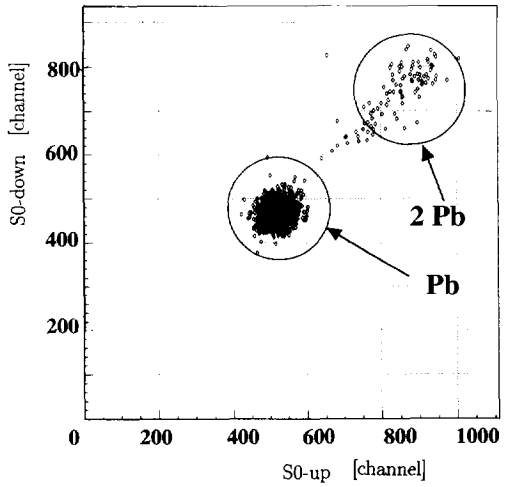

Fig. 6. Scatter plot of the light yield of S0-up vs. S0-down.

a beam intensity from 2.5×10^4 to 3×10^5 ions/s. The intrinsic timing resolution of the gas Cherenkov beam counter was $\sim$ 30 ps with a beam intensity up to 3×10^5 ions/s, the charge resolution ($\Delta Z/Z$) was 2.0%. On the other hand, for the quartz Cherenkov counter, the timing resolution was about 55 ps. The gas Cherenkov beam counter has been successfully operated for more than $1\frac{1}{2}$ month of heavy ion run in 1995.

Acknowledgements

We appreciate other WA98 collaborators and the CERN technical staff. This work is supported by the University of Tsukuba Special Research Projects and the Research-in-Aid for Scientific Research (Specially Promoted Research & International Scientific Research) of the Ministry of Education, Science and Culture.

References

[1] Proposal for a Large Acceptance Hadron and Photon Spectrometer, CERN/SPSLC 91-17/SPSLC/P260 May, 1991.
[2] N. Maeda et al., Nucl. Instr. and Meth. A 346 (1994) 132.
[3] Photomultiplier Tubes and Assemblies For Scintillation Counting & High Energy Physics, Hamamatsu Photonics Cat. No. TPMO, 0001E03, Mar. 94T.