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**A HIGH RESOLUTION FAST-RICH COUNTER FOR ON-LINE
TAGGING
OF HIGH ENERGY BEAM PARTICLES**

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ABSTRACT

The counter is equipped with a 6m focal length spherical mirror and a chromatic corrector. The Cerenkov ring size is reduced by means of a set of two conical mirrors to match the active area of an image intensifier whose output is read by a matrix of optical fibres partitioned in pixels, each pixel being coupled to a photomultiplier. The nominal overall angular resolution of the counter is better than $30\mu\text{rad}$, allowing a separation of the 270 GeV Σ^- and Ξ^- hyperons at the 4σ level. Results of test runs with 2 to 8 GeV electrons are reported. A brief updating of the resolution performances measured with 220 GeV pions showing a π/K separation better than 4σ is also given.

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The need for on-line tagging of high energy beam particles occurs from the use of secondary beams which contain different species of particles. The on-line identification of beam particles should allow events induced by different particle components of the beam population either to be tagged and then recorded, or to be rejected. This flexibility would be a noticeable improvement over the DISC type counters which can select only one type of particle at a time in a very low momentum spread ($\leq 1\%$) parallel beam.

In the new hyperon experiment at CERN, part of the physics program will require the 270 GeV hyperons to be properly identified at the trigger level [1]. None of the currently existing Cerenkov counter techniques could achieve the angular resolution required to separate Σ^- 's from Ξ^- 's in the hyperon beam. This contribution reports on the fast-Rich tagging Cerenkov counter dedicated to the needs of the WA89 experimental program.

1 Description of the counter

The purpose of the counter is to provide a clean enough Σ^-/Ξ^- separation to allow the rejection of a major fraction of the Σ^- induced events from the data acquisition at the second trigger level, while a better separation could be obtained from off-line data analysis of the collected sample. This requirement fixes the values of the angular resolution to be obtained together with the scale of the event processing time to be complied with.

1.0.1 The structure parameters

The basic parameters of the counter are given in table 1. The values of these parameters, and more generally the counter architecture and characteristics, have been fixed taking into account the following specific constraints of the WA89 experiment.

- The angular resolution must allow to separate the Σ^-/Ξ^- masses, i.e. the counter must have a velocity resolution better than $\frac{\Delta\beta}{\beta} \approx 2 \cdot 10^{-6}$.
- The radiator length must be as short as possible in order to limit the particle decay losses upstream the target.
- The detection must accept counting rates of the order of 10^5 events s^{-1} , or even 10^6 events s^{-1} if the pions are within the counter acceptance.
- The acceptable processing time should not be larger than about 5 μ sec (the above event rates being reduced by the first level trigger). These two latter constraints restrict the type of photodetector which can be used.

1.1 The counter architecture

A general (CAD) view of the counter is shown on figure 1. The optical elements encountered along a photon path are:

- The spherical mirror focussing the Cerenkov photons into a ring in the focal plane of the system.
- The plane mirror deflecting the light to right angle towards the detection system placed at a safe distance from the beam background.

Table 1: Counter parameters and characteristics

Parameter	value
Radiator length	4 m
Radiator gas	CF ₄ (38%)+Ne(62%)
Pressure of operation	1 atm.
Maximum Cerenkov angle θ_∞	20.6 mrad
Threshold velocity γ_{thr}	48.8
Tolerable beam divergence	$\leq \pm 150 \mu\text{rad}$
Useful range of wave-length	200 nm - 600 nm
Number of emitted Cerenkov Photons	235
Photoelectron multiplicity	17 (experimental, see text)
Photodetection quality factor N_0	95 (experimental) cm^{-1}
Focal length of spherical mirror	6.043 m
Overall angular resolution	$90/\sqrt{n} \mu\text{rad}$ (nominal value)
Chromatic corrector	
Natural chromatic spreading	900 μrad 200-600 nm
Type of corrector	2 fused silica lenses
Residual chromatic aberrations	90 μrad 200-600 nm
Photon detection	
Ring size reduction factor (adjustable)	≈ 6 to 12
- Image Intensifier:	
model	VARO, model 9732, type I
Type	proximity focussing, 1 microchannel plate
Entrance window type	fused silica
Exit window type	fibre optics (6 μm diameter)
Photocathode	multialkali
Phosphor layer :	
- type	P47
- decay time (to 10 % intensity)	80 nS
- average wave-length	(blue) 408 nm
- spectral width	60 nm FWHM
Active size	$\Phi=40$ mm
- optical fibre matrix:	
Useful detection area	$\Phi_{min}=20$ mm, $\Phi_{max}=40$ mm
Pixel number	8 sectors of 20 radial shells
Pixel size	45 deg. x 0.525 mm (0.025 mm glue)
- Photomultipliers:	
Type	XP2802 Philips

- A two silica lens chromatic corrector reducing the natural chromatic dispersion from $900 \mu\text{rad}$ (over 200-600 nm wave-length) down to about $90 \mu\text{rad}$ (full width).
- An image reductor consisting of two coaxial conical mirrors (fig 2) reducing the original ring diameter from about 24 cm down to a value matching the active size of an image intensifier, the reduced value being adjustable by moving the small conical mirror along its axis.

Figure 1: CAD view of the counter mechanical architecture and of its internal structure

The photon detector consists of an image intensifier with a cathode sensitivity extending to UV range 200-600 nm, equipped with a fast phosphor output layer radiating in the blue range (central wave-length 408 nm), and placed in the focal plane of the optics. The output of the image intensifier is coupled to a matrix of optical fibers partitioned in $160 \times (\frac{\pi}{4} \times 0.525 \text{ mm})$ pixels, each bundle of fibers corresponding to one pixel read by one photomultiplier (see figure 2). The pixel pattern choice was based on Monte-Carlo simulation.

Figure 2 shows the detector region. The optical fibre matrix is mechanically held in contact with the II exit window. The 160 bundles of fibres, defining the 160 sensitive pixels, have their end seen by the 160 photomultipliers through a few mm of air. Each bundle is equipped with a mechanical termination allowing its clamping into its mate photomultiplier socket. The sockets are fixed on a cylinder of the same diameter as the

Figure 2: CAD view of the detection region of the counter, showing conical mirrors, image intensifier, optical fibre matrix, and photomultipliers, mounted together in the detection body.

counter body. They receive the fibre bundle ends on one side, and the photomultipliers on the other side.

2 Performances in test beam

2.1 *test with electron beam*

The counter has been tested in a secondary electron beam from the CERN-PS at 2 GeV, 4 GeV, and 8 GeV. Even at the largest of these energies, the angular spread of the electron trajectory due to multiple scattering in the radiator is of the order of $300 \mu\text{rad}$, i.e. several times larger than the ultimate nominal resolution of the counter. These tests were undertaken to investigate the basic performances of the counter (photon yield, photon distribution) with beam particles for which the Cerenkov angle was θ_∞ , i.e., momentum independent, and to probe the optical system and the photon detection.

2.1.1 *Experimental set-up*

The tests were performed in the T9 beam line of the CERN-PS. The trigger was provided by two plastic scintillators $2.5 \times 2.5 \text{ cm}^2$ placed upstream and downstream of the counter respectively (about 5 m apart). However, because of the poor optical quality of the beam, the set-up had to be improved with two more plastic scintillators having 5 mm holes in their centre, and placed close to the first two beam counters respectively, in order to define a 2 mrad acceptance angle. This allowed the trigger logic to limit the

divergence of the accepted trajectories. The beam electrons were identified by means of two threshold Cerenkov counters available on the beam-line.

The associated electronics consisted of a set of 160 discriminators. Each photomultiplier output was fed both into a discriminator and into an encoder. The discriminator outputs were distributed to a set of pattern units used for trigger definition. For each valid trigger, the 160 encoded amplitudes were put on tape. For sampled events, the on-line analysis program displayed the measured hit pattern, and calculated the Cerenkov radius using the full regression and the simplified algorithms. It performed also the statistical analysis of samples of events, computing the radius distribution moments and the spatial resolution obtained for the treated sample.

2.1.2 Experimental results

Figure 3: Radial distributions of hits around the mean Cerenkov radius obtained by circular regression, for data samples measured at the three electron energies.

This section reports on the main results of the off-line analysis. The analysed data have been measured in the standard operating conditions for the detection, i.e., with the photomultipliers operated in saturated mode, and discriminator thresholds set at 150 mV, and with the beam divergence restricted as described above. Figure 3 shows the radial distributions of hits around the mean Cerenkov radius $r_i - \langle r \rangle$, where r_i means the hit radial distance from the reconstructed ring centre, and $\langle r \rangle$ is the mean ring radius obtained from fitting the hit pattern using the circular regression method. The distributions are shown for data samples measured at the three incident energies. A remarkable feature of these distributions is the absence of count outside the gaussian hit distribution. This shows that the amount of background photons is at most a few counts over a few thousands. The photon background is thus compatible with the requirements for a proper particle identification. In table 2, the first line provides the variance of

Table 2: Radial distribution of hits, measured with 2 GeV, 4 GeV, and 8 GeV electrons

e^- momentum	2 GeV/C	4 GeV/C	8 GeV/C
$r_i - \langle r \rangle$ (mm)	1.7	1.25	1.04
mul σ_{reg} (mm)	0.83	0.54	0.34
σ_{per} (mm)	0.98	0.60	0.35

the $r_i - \langle r \rangle$ distributions shown on figure 3, and the other two lines provide the corresponding radial resolutions obtained with the circular regression method (σ_{reg}) and the perimeter method (σ_{per}). The resolution follows approximately the trend expected from a multiple scattering dominance. From this set of numbers, we conclude that the resolution is better than $350\mu\text{m}$

Figure 4: Experimental distributions obtained for the raw hit multiplicity (1), for the number of hit sectors (2), and for hit clusters (3).

Figure 4 shows the experimental (solid line) raw hit multiplicity, (μ) the sector multiplicity (number of sectors containing at least one hit for a given event), and the hit cluster multiplicity (cluster: set of n contiguous pixels touched in a given sector) distributions. The dashed lines in figure 4 correspond to a simple Monte-Carlo simulation of the photon detection incorporating the discretization of the useful detection surface, using a gaussian radial distribution and an equiprobable azimuthal distribution. The gaussian photon distribution parameters deduced from this simulation are $\mu = 15$ and variance $\sigma = 3.7$. The μ value corresponds to a quality factor of the counter $N_0 = 95$.

Figure 5: Cerenkov radius distribution obtained with the 220 GeV pion beam, calculated with the circular regression method. The 3 peaks observed correspond to pions, kaons, and $\bar{p}$, respectively from right to left. The upper histogram shows the raw distribution, whereas for the lower one, background photons have been removed and 6 (out of 8) sectors have been required for each event, leaving 71% of the original sample.

2.2 test with pion beam

Here we briefly update the resolution performances with recent results obtained at Cern using a $50 \mu\text{rad}$ divergence 220 GeV pion beam. This beam also contained small components of kaons and $\bar{p}$. The $\pi/K/\bar{p}$ $\tilde{C}$ angle separations and relative intensities are similar to those expected for $\Sigma/\Xi/\Omega$ in the 270 GeV phase II hyperon beam, thus providing a realistic test of the identification performances of the counter.

Figure 5 shows the $\tilde{C}$ radius distribution obtained. The upper spectrum corresponds to the raw on-line results. In the lower spectrum, background photons have been removed and 6 azimuthal sectors have been required for the events, leaving 71% of the original sample. For the latter, the pion (Σ) contamination of the kaon (Ξ) sample is about $4 \cdot 10^{-5}$ for a cut-off radius of 14.9 mm assuming pure gaussian shapes. Taking into account the non gaussian tails increases this number to the 1% level. The $\bar{p}$ peak is free from any contamination, so would be the Ω sample in these conditions. The

spatial resolution obtained is $\sigma = 0.124$ mm, and the corresponding angular separation is $20.6 \mu\text{rad}$

The fast processing electronics to be associated to the counter is being tested. A complete report on this work is in preparation.

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