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THE SLOW PROTON POSITION-SENSITIVE TIME OF FLIGHT DETECTOR OF THE GAMS NA12/2 EXPERIMENT AT CERN

D. Alde³⁾, R. Bellazzini⁷⁾, F.G. Binon^{2,5)}, M. Boutemour⁶⁾*, A. Brez⁷⁾,
J. Ditta⁴⁾, S.V. Donskov¹⁾, M. Gouanère⁴⁾, S. Inaba⁸⁾, H. Kawai¹¹⁾,
G.V. Khaustov¹⁾, T. Kinash⁹⁾, E.A. Knapp³⁾, M. Kobayashi⁸⁾, T. Lopez³⁾,
M.M. Massai⁷⁾, T. Nakamura¹⁰⁾, J.P. Peigneux⁴⁾, V. Poliakov¹⁾, M. Poulet⁴⁾,
V.I. Rykalin¹⁾, V.D. Samoylenko¹⁾, P.M. Shagin¹⁾, A.V. Singovsky¹⁾,
J.P. Stroot²⁾**, K. Takamatsu⁸⁾, M.R. Torquati⁷⁾,
and T. Tsuru⁸⁾.

GAMS NA12/2 Collaboration

Abstract

A large Time of Flight detector has been built by the GAMS NA12/2 experiment at CERN. It surrounds a 60 cm long liquid hydrogen target. With a time resolution better than $\sigma = 350$ ps, pion/proton separation is achieved up to a 800 MeV/c momentum.

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- 1) Institute for High Energy Physics, Protvino, 142 284, Russia.
 - 2) Institut Interuniversitaire des Sciences Nucléaires, 1050 Brussels, Belgium.
 - 3) Los Alamos National Laboratory, Los Alamos, NM 87544, USA.
 - 4) LAPP-IN2P3, BP 110, 74941 Annecy-le-Vieux, France.
 - 5) Université Libre de Bruxelles, 1050 Belgium.
 - 6) CERN, 1211 Geneva 23, Switzerland.
 - 7) INFN, Pisa Univ., Piazza Torricelli, 2, 56100 Pisa, Italy.
 - 8) KEK, 1-1 oho, Tsukuba-Shi, Ibaraki-Ken305, Japan.
 - 9) Nagoya Univ., Nagoya 464, Japan.
 - 10) Miyazaki Univ., Miyazaki 889-21, Japan.
 - 11) Chiba Univ., Chiba, Japan.
 - *) Now at the Univ. of Montreal, present address : PPE, CERN, 1211 Geneva 23, Switzerland.
 - **) Mailing address : CERN-Div. PPE, 1211 Geneva 23, Switzerland.

1. Introduction

The GAMS NA12/2 programme is a fixed CERN target experiment. It looks for new mesons or exotic states which are centrally produced by 450 GeV/c protons in the exclusive reaction at 450 GeV/c :

$$pp \rightarrow p_F M_0 p_S \quad (1).$$

The symbols p_F and p_S refer to the fast (very forward direction) and the slow (spectator emitted at large angle) proton. The kinematics of this reaction is fully reconstructed using the experimental set-up of Fig.1.

Fig. 1 : GAMS NA12/2 experimental setup

A time of flight (TOF) system measures the momentum vector of the slow recoiling proton from a liquid hydrogen target and a forward magnetic spectrometer determines the momentum of the fast proton which is detected with two kind of chambers : multiwire proportional chambers (MWPC1, 2, 3, 4) of 2 mm pitch and new microstrip gas chambers [1] (MSGC 1, 2, 3, 4) with a 50 μ m resolution. The neutral M_0 state is observed through its decay into multi photons in a 4092 cells electromagnetic lead glass calorimeter GAMS-4000 [2]. The hadron calorimeters allow to reject muon background (HC-9) and charged hadrons (HC-240) which could escape from the AH anti-counter. Other detectors are scintillation counters (S), hodoscopes (H) or lead-scintillator sandwich vetos (SW). In this paper we present the position-sensitive time of flight (TOF) detector. If large TOF counters have been designed [3] in the past, each one has its own characteristics relevant to one specific experiment. The GAMS TOF requirements are as follows :

- 1) Ability to detect proton up to 1 GeV/c as well as to reject highly relativistic ($\beta \approx 1$) charged particles (electron or fast $\pi^\pm$).
- 2) Complete azimuthal (2π) covering with a polar θ angle compatible with the kinematical constraints, i. e. $50^\circ \leq \theta < 90^\circ$.
- 3) Primary vertex reconstruction (in the beam direction)
- 4) Momentum reconstruction of the proton.
- 5) Automatized time calibration system.
- 6) Inclusion of TOF information at the first GAMS trigger level.

2. The position-sensitive TOF detector

Figures 2a and 2b respectively show longitudinal and transverse sections of the detector. It consists of two rings A and B of scintillation counters surrounding the liquid hydrogen target (60 cm long, $\phi = 6$ cm). The inner layer -ring A- and the external layer -ring B- respectively are at 7 cm and 75 cm from the beam axis. The ring A is made of 6 scintillator slabs, the ring B of 24 slabs.

Fig.2 : Sketch of the TOF detector. Longitudinal section (a), transverse section (b)

Each scintillator is viewed by two PM's, one at both ends. The position along the scintillator axis of a crossing particle, is then determined by the arrival time difference between the two PM's signals. The ring A is made of 6 NE102A scintillator slabs ($65 \times 8.5 \times .5$ cm³) which are connected through optical guides to two Philips XP2020 PM's. The ring B consists of 24 extruded scintillating plates ($106 \times 20 \times 1$ cm³) produced at IHEP Protvino [4] with properties close to the NE110 ones (except absorption). They are directly connected to 2 Philips XP2262 PM's through their shaped end obtained by machining and remoulding the rectangular scintillator section in order to correspond to the round photomultiplier photocathode. The complete detector is housed in a 3 mm thick iron cylinder. This cylinder frame is provided with holes in front of the geometrical center of each B-layer scintillator slab allowing their irradiation with a collimated ⁹⁰Sr source for calibration and checking purposes. For the inner layer, a source can be slid along the A counters after removing the hydrogen target.

Identification of the slow proton of the reaction (1) requires one (and only one) fired counter of ring A in coincidence with one (and only one) geometrically correlated fired counter of the ring B. To each counter of the A ring are associated 5 counters of the ring B as shown Fig. 2b, giving in total 30 A-B combinations. The whole TOF apparatus can be viewed as 30 individual TOF detectors made of a single combination of one A and one B counter. This combination automatically gives the azimuthal ϕ position with a precision depending on the total number of B counters, i.e. $\Delta\phi = 360^\circ/24 = 15^\circ$. The impact points of the proton are denoted by a (ring A) and b (ring B) as shown in Fig. 3.

Fig. 3 : Sketch of one A-B combination

The middle of the respective scintillators (geometrical center) is taken the origin of the coordinates $X_A = X_A(a)$, $X_B = X_B(b)$. In order to define the momentum vector of the proton we need to calculate :

- 1) The impact coordinates X_A , X_B
- 2) T , the particle time of flight from a to b (between layers A and B).

The arrival times $t_1 = t_1(a)$, $t_2 = t_2(a)$ and $t_3 = t_3(b)$, $t_4 = t_4(b)$ of the PM pulses (measured with a Time to Digital Converter, or TDC) depend on X_A , X_B and T as follows :

$$t_1 = C_1 - X_A/V_A \quad (2)$$

$$t_2 = C_2 + X_A/V_A \quad (3)$$

$$t_3 = C_3 - X_B/V_B + T \quad (4)$$

$$t_4 = C_4 + X_B/V_B + T \quad (5)$$

V_A and V_B are the propagation velocities of scintillation light pulses in the counters A and B. C_1, C_2, C_3, C_4 are constants depending on cabling, electronic chain, PM high voltage, etc... If the two velocities V_A, V_B and the Constants are known it is very easy to calculate X_A from $(t_2 - t_1)$, X_B from $(t_4 - t_3)$ and T from $(t_3 + t_4) - (t_1 + t_2)$. The constants also depend on the stability of the electronic chain from the PM photocathode to the time readout. (For example a little change of the high voltage of a PM will change the transit time of the corresponding pulse). For that purpose a calibration system under computer control has been designed. From time to time, during the experiment, these constants are monitored and measured. A lamp flash illuminates the 30 scintillators (at $X_A = 0$ and $X_B = 0$) through a bundle of 30 light fibres, one fibre for each scintillator. The time

calibration (determination of C_1, C_2, C_3, C_4) consists at first order to run the time readout with synchronized light pulses arriving into the scintillators and to register the average value of each distribution (putting $X_A = X_B = T = 0$ in equations (2)-(5) one immediately gets the calibration constants). But to reach a good resolution, several corrections must be applied as discussed below.

3. Associated Electronics

The electronics logical diagram of the whole TOF detector is represented on Fig. 4. It shows the processing of the PM signals, the building of the TOF trigger and of the signals for the GAMS readout system. It is implemented in the experimental area, close to the detector. They are Camac controlled. Each PM has two outputs which are connected through 50 Ω cables to a Constant Fraction Discriminator and to an ADC readout. The interest of measuring the amplitude of each individual PM except the obvious reason of allowing a simple setting of the PM High Voltage will be explained in section 5. All the output signals (TCD, ADC, Triggers, Registers) are sent to the GAMS barak through 30 meter cables.

Fig. 4 : TOF electronics diagram (experimental area)

The Constant Fraction Discriminator (CFD) allows not only to handle the 1 to 100 dynamics but to protect the pulse rise time from long cabling damage. These devices were developed by CNRS at GANIL and are manufactured by GANELEC (France). Each Camac module includes 8 input channels with amplitude dynamical range from -10mV up to -5 Volts, which fits well with -25 mV up to -5 volts pulses of the detector. The internal delay is adjusted to the 5 ns rise time of the PM's input pulse and the intrinsic CFD jitter does not exceed 130 ps in our full dynamical range. The input threshold and the width outputs are under Camac control. The outputs are differential and are connected through flat twisted cables to a Camac Receiver Mask module. It has been built in LAPP. It has 64 ECL inputs and 2 groups of 64 ECL outputs (one group is connected to LRS 4418 Registers, the other one to the logic unit). Each input channel of the Receiver Mask can be enabled or disabled by Camac control. In physics mode all channels are open but, in Lamp-mode calibration

runs, all scintillators are simultaneously illuminated and the valid A_i - B_j correlated combinations are selected with appropriate mask loading, one after the other.

The Logic Unit (Camac LAPP module) generates two multiplicity signals M_1 and M_2 . M_1 is set if one and only one A counter (over 6) has its 2 PM's fired. M_2 is set if one and only one B counter (over 24) has its 2 PM's fired in coincidence with the space correlated A fired counter (Fig. 2). Mainly the logic unit is made of programmable exclusive "or" from PAL 22 V106 circuits. The internal delay time (input-output) of the logic unit is less than 55 ns. In addition the Logic Unit provides start-stop signal for TDC LRS 2228A modules. According to Fig. 2 and 4 they are defined as :

$$A_L = A_{\text{Left}} = \sum_{i=1}^6 A_{i,L} \quad B_L = B_{\text{Left}} = \sum_{j=1}^{24} B_{j,L}$$

$$A_R = A_{\text{Right}} = \sum_{i=1}^6 A_{i,R} \quad B_R = B_{\text{Right}} = \sum_{j=1}^{24} B_{j,R}$$

A_L is taken as the Start signal while A_R , B_L , B_R are used as Stop signals. The complete TOF decision is made as fast as possible but compatible with a maximum time of flight basis of 30 ns. The TOF logic transit time is kept less than 60 ns to allow the M_2 trigger condition to be put in coincidence with the other detectors at the first trigger level.

4. Characteristics and Time Calibration

The photoelectron number corresponding to a minimum ionizing particle (mip) entering perpendicularly in the scintillator plate A, at the center of the bar, is about 60. The left-right ($t_2 - t_1$) time resolution typically is $\sigma \sim 230$ ps. It includes the resolution of the CFD's of the electronic chain. The materials of the liquid hydrogen target (liquid + walls) and the scintillator A generate a proton detection threshold corresponding to a momentum of 270 MeV/c. The photoelectron number corresponding to a mip, crossing perpendicularly the scintillator bar B at $X_B = 0$, is 50 and the left-right time resolution ($t_4 - t_3$) is $\sigma \sim 340$ ps. This resolution is not very good but it is much better for slow protons. The deposited energy can be a factor 12 higher for very slow proton escaping from the scintillator A. Two other phenomena will enlarge the range of the proton spectrum amplitude which finally extends over a scale of two order of magnitude :

- the attenuation (amplification) of the collected light when the impact point (of the proton in the scintillator) is far from the center (~ 1.85),
- the statistical fluctuations of the number of photoelectrons.

The speed of scintillation light pulses has been thoroughly measured with a light induced by collimated ^{90}Sr source. They are respectively $V_A = 15.8 \pm 0.3$ cm/ns and $V_B = 16. \pm 0.4$ cm/ns. As an example Fig. 5 represents the peak position of the left-right time difference $\Delta t = t_2 - t_1$ as a function of X_A (the distance of the source from the center of the scintillator A). The linearity of the curve indicates a constant velocity along the scintillator axis. For a mip the position resolution is $\sigma = 1.8$ cm for A and 2.70 cm for B.

Fig.5 : Mean value of $\Delta t = t_2 - t_1$ measured as a function of X_A (scintillator A)

Fig. 6 : Lamp calibration design

A commercial lamp (Nanopulser N787B, Xenon Corporation), delivering short light pulses, with a rise time compatible with that of the scintillators, is used for time calibration purposes. Its light is distributed to all 30 scintillators by a bundle of optical fibers as shown Fig. 6. On the lamp side, the fibres are held mechanically so as to ensure good parallelism between them and they are illuminated through a depolished mylar foil located at 5 cm from the source. The distance bundle-foil is 30 cm. The other end of each 4.5 m long fibre is glued to the geometrical center of the scintillator. The light arrives perpendicularly to the slab and thanks to the defaults of its surface, a fraction of the incoming light is captured by the 2 PM's by internal reflection. The lamp light speed inside the scintillator is different from the speed of light generated by scintillations. The average angles of the light cones are not the same in scintillation mode and lamp mode. The measured propagation velocities of the lamp light inside the scintillators are

$V_A(\text{lamp}) = 12. \text{cm/ns}$ and $V_B(\text{lamp}) = 14.5 \text{ cm/ns}$, to be compared with the above quoted values. The best possible synchronization of the pulses at the exit of all fibres is achieved by putting a depolished mylar foil in front of the lamp, as shown in Fig. 6. In that case the synchronization dispersion has been reduced to 200 ps for all 30 fibres. Without the depolished mylar it reaches up to 700 ps. Different curvatures of the fibres do not give any sizeable contribution to this value. Finally corrections are applied to the lamp timing in order to reproduce the scintillation conditions: in the next we shall call scintillation mode the results obtained with scintillations generated at the center of the bars (simulated with a collimated ^{90}Sr source) and lamp mode the results obtained with the light pulses generated with the lamp.

For $X_A = 0$, $X_B = 0$ and $T = 0$, equations (2)-(5) become :

Scintillation mode		Lamp mode	
$t_1(0) = C_1$	 Fibre A	$t'_1(0) = C_1$	(6)
$t_2(0) = C_2$		$t'_2(0) = C_2 + K_2$	(7)
$t_3(0) = C_3$	 Fibre B	$t'_3(0) = C_3 + K_3$	(8)
$t_4(0) = C_4$		$t'_4(0) = C_4 + K_3 + K_4$	(9)

The constants C_i depend on electronics stability, including PM's high voltage and cabling. K_2, K_3, K_4 are corrections which depend on the scintillator geometry and optics (fibre-fibre synchronization, fibre-scintillator interfaces, speed of the lamp pulses and so on). They originate from the short comings of the lamp mode to simulate the scintillation mode.

K_2 and K_4 refer to the left-right "asymmetry" of the ring A and B respectively :

$$K_2 = [t'_2(0) - t'_1(0)] - [t_2(0) - t_1(0)] \quad (10)$$

$$K_4 = [t'_4(0) - t'_3(0)] - [t_4(0) - t_3(0)] \quad (11)$$

Non zero values of K_2 and K_4 mean that in lamp mode one gets results different from those obtained with the source. It is due to some small differences of the lamp light pulse velocity between left and right directions, but also to the light collection in lamp mode which is not isotropic. They only depend on the optics. These corrections have been measured for each of the 30 scintillator slabs. Following equations (10) or (11) they are just the difference of the right-left peak position obtained in the two working modes (lamp and scintillation). They are found to be small (< 250 ps).

The constant K_3 is related to the variation in arrival time of the PM pulses in two different fibres and scintillators, one in each layer A and B. It reflects the default of light pulse synchronization but also the differences in lamp light propagation through the scintillators A and B. The measurement of K_3 requests another constraint. It is given by the ($\beta = 1$) particles flying between A and B, mainly electron pairs of π^0 Dalitz decays or $\pi^\pm$ from N^* or Δ baryon decay. The physical trigger can be enriched with this type of events for calibration purposes. A typical calibration spectrum of an A-B combination (namely A3-B23) is shown on Fig. 7.

Fig. 7 : Typical normalized (flight length) TOF spectrum (T) obtained in a calibration run with a $\beta = 1$ particles, before any corrections. The $\beta = 1$ peak position is located at $T = 1.43$ ns, and $\sigma = .263$ ns (combination A6-B23)

This spectrum is the distribution of the T variable of equations (2) - (5), as obtained with $K_2 = K_3 = K_4 = 0$ (equations (6) - (9)). As the length of the flight basis (distance a-b of Fig. 3) varies, from one event to another event, the time of flight spectrum of Fig. 7 has been normalized to the 68 cm minimum distance between the two scintillator rings. The left side peak corresponds to the $\beta = 1$ particles. After correction the peak position should be at 2.25 ns. But it is not yet the case on Fig. 7. Its shifted position allows to determine the K_3 constant for the considered A3 - B23 combination.

$$K_3 = 2.25 - (\beta = 1 \text{ peak position}) + 0.5 * (K_2 - K_4) \quad (12)$$

The K_3 corrections have been measured for all 30 A-B combinations. They are not negligible and extend up to 1 ns.

Fig. 8 : Distribution of the ΔK_3 difference obtained over a 2-month (a) and 3-day (b) time interval. The 30 physical combinations are represented

As already mentioned the constants also depend on the stability of the electronics. They are regularly monitored and re-measured during the experiment. The experimental system has good time stability as shown for example on Fig. 8a. It indicates the difference ΔK_3 obtained for the K_3 parameter over a two month interval and all 30 physical A_i-B_j combinations. The mean value of the histogram is 65 ps with a 100 ps rms. Except for two combinations, corresponding to the left side of the figure, the electronic stability is better than $\approx \pm 200$ ps. As the constant parameters are rescaled from time to time the absolute errors of these TOF constants are smaller than ± 100 ps. This is illustrated Fig. 8b which shows the ΔK_3 difference over a 3-day interval. The 30 combinations are plotted with a 50 ps bin width. Enriched mip events also allow to calibrate the coefficients needed for amplitude analysis signals (ADC measurements [5]). The distribution of the amplitudes, as a function of the particle impact coordinates (obtained from time measurement) are well described by two exponential laws, one for each scintillator ring. The attenuation lengths are found to be $\lambda_A = 46$ cm (A ring) and $\lambda_B = 80$ cm (B ring).

5. Experimental Performances

In Physics mode it corresponds to the TOF type M_2 trigger as described in section 3 : one recoil particle (and only one) is detected in a geometrically correlated A-B coincidence. Fig. 9 illustrates a typical calibrated TOF spectrum of the whole detector obtained in the GAMS-NA12 central production conditions.

Fig. 9 : Calibrated TOF spectrum (T) obtained with the standard GAMS Central production trigger

Fig. 10 : Spectrum of the speed β (in c units) of the recoil particles (trigger level)

It is normalized to the 68 cm flight length.

$$T = T_0 / \beta = T_0 (1 + m^2 / P^2)^{1/2} \quad (13)$$

T_0 is the reference time of a $\beta = 1$ particle flying over 68 cm ($T_0 = 2.25$ ns), m and P are the mass and momentum of particle of speed β flying between A and B. Except for the small peak at the left side of the histogram, which corresponds to a small contribution of $\beta \sim 1$

particles, the whole spectrum is populated with slow particle. Fig. 10 represents the corresponding β distribution of the physical $\beta \leq 1$ events. The β spectrum is dominated by slow protons peaked at $\beta \sim 0.35$. But it also shows a contribution of $\pi^\pm$ with velocities extending up to $\beta = 1$.

Fig. 11 : Calibrated TOF spectrum (T) obtained in an enriched $\beta \sim 1$ run (whole detector)

The Fig. 11 represents the normalized (flight length) and calibrated TOF spectrum of the whole detector obtained with a trigger enriched with $\beta = 1$ particles. All the corrections have been made and the histogram is the superposition of the 30 individual combinations. The small discrepancy between the peak position (2.16 ns) and the expected value (2.25 ns) gives the limit of the absolute TOF measurement (± 100 ps) with the present detector. The resolution $\sigma(T) = 350$ ps is compatible with minimum ionizing particle crossing the scintillators with an angle θ of 65° . For an individual combination $\sigma(T)$ varies from 240 ns (minimum) to 420 ns (maximum) and reflects the fluctuations in PM's photocathode sensitivity. The TOF resolution improves for slow energetic protons (increase of the photoelectron number). At $P = 350$ MeV/c ($\beta = 0.35$) we estimate a resolution $\sigma P/P (\approx \sigma(T)/T)$ better than 5%. Coordinates can be determined from TOF measurements. The position resolutions (measured with a source is given in the section 4) or by the amplitude measurements (ADC). In the last case and assuming an exponential law of the attenuation as function of the position, the particle coordinate X_A in the scintillator A is given by the formula:

$$X_A = -\ell_n(A_2 / A_1) 2\lambda_A \quad (14)$$

The amplitudes A_1, A_2 correspond to the t_1, t_2 signals of the Fig. 3. X_B is given by a similar equation. The light attenuation lengths λ_A, λ_B are defined in section 4 (exponential law). The coordinates calculated from the amplitudes are in good agreement with the coordinates obtained from the TOF information. For a typical proton momentum range of 200 to 250 MeV/c the distributions of the coordinate differences ($\Delta X_A, \Delta X_B$) are shown in Fig. 12a, 12b. They are almost Gaussian with $\sigma(\Delta X_A) = 3.2$ cm for the A-layer and $\sigma(\Delta X_B) = 3.8$ cm for the B-layer. Obviously with increasing momentum the coordinate resolution, deduced from the amplitude, is getting worse. Nevertheless this agreement at low energy is a good test of the whole detector control.

Fig. 12 : Distribution of the difference of coordinates obtained from the amplitudes and from TOF information for protons in the 200-250 MeV/c momentum range.

- a) $\Delta X_A = X_A(\text{amp}) - X_A(\text{TOF})$, ring A.
- b) $\Delta X = X_B(\text{amp}) - X_B(\text{TOF})$, ring B

The π/p separation level depends first on the threshold value applied to the normalized TOF value T . A first selection consists to eliminate the residual $\beta \sim 1$ particles (Fig. 9) with a " 2σ " cut, i.e. at $T = T_0 + 2\sigma = 2.25 + 2 * (0.35) = 2.95$ ns. This corresponds to the events of the β spectrum (Fig. 10) with $\beta \leq 0.76$ ($P \leq 1.1$ GeV/c). In a second step the energy loss in the scintillators is taken into account. For the reconstruction of the primary amplitude the geometrical mean amplitudes from both PM's, $\Delta E_A = \sqrt{A_1 A_2}$, $\Delta E_B = \sqrt{A_3 A_4}$ are used. They do not depend on the particle impact point for a purely exponential light attenuation over the scintillator length. The distributions of the energy depositions are shown in Fig. 13 (90% of the experimental events are inside the shaded area).

Fig. 13: a) Normalized energy loss ΔE_A in the A ring in function of the proton momentum P_0 at the primary vertex.
 b) Normalized energy loss ΔE_B in the B ring in function of the proton momentum at the exit of the ring A. This curve has been obtained with the M_2 trigger.

They are normalized to a particle path length of 5 mm in layer A and 10 mm in layer B, respectively, in order to avoid the dependence on the impact angle. ΔE_A is the energy loss in ring A in function of the reconstructed proton momentum P_0 at the main reaction vertex. We observe the threshold at $P_0 \sim 270$ MeV/c. ΔE_B is the energy loss in ring B in function of the momentum P of protons leaving the scintillator A. P is the momentum used in equation (13). The minimum kinetic energy of the protons is about 7 MeV. They lose part of their energy in the (air, plastic scintillator envelopes) gap between A and B. Then they can be fully absorbed in the B scintillator (left part of the spectrum) or only partially (right part). Fig. 14 shows the calibrated energy loss ΔE_B distribution in the B ring for different momentum ranges. At low momentum the protons are well distinguishable from the charged pions. But with increasing momentum, the π/p separation is getting worse. A practical limit ($\Delta E_B > 3$ MeV) guarantees a very enriched proton sample if $P \leq 800$ MeV/c, ($\beta \leq 0.65$).

Fig. 14 : Histograms of the energy loss ΔE_B in the B ring for different momentum ranges.

Fig. 15 : Distribution of the $\Delta\phi = \phi_m - \phi_r$ difference of the azimuthal angles ϕ_m (TOF measurement) and ϕ_r (reconstructed from the other detectors).

Fig. 16 : Spectrum of the speed β_0 (in c units) of the recoil particles measured at the primary vertex (offline analysis)

If we suppose the slow particle (spectator p_s) is a proton, its momentum and angles (polar θ and azimuthal ϕ) can be reconstructed from other detectors and kinematical constraints. Obviously we assume to be right the central reaction process $pp \rightarrow p_F M_0 p_s$ (1) and in the following we have selected M_0 decaying into $2\pi_0$ (4γ 's). The Fig. 15 shows $\Delta\phi = \phi_m - \phi_r$ distribution. ϕ_m is the recoil proton azimuthal measured with the TOF detector and ϕ_r is the reconstructed azimuthal angle from the other detectors. The correlated events ($\Delta\phi = 0. \pm 15^\circ$) mainly correspond to the exclusive reaction (1) but the

distribution indicates a small uncorrelated background. Probably these events are due to π^+ from baryonic resonances. A similar background is also present in the β_0 distribution of Fig. 16. β_0 is the proton speed measured with the TOF detector at the primary vertex. A pion contribution for $\beta_0 > .65$ is not surprising as already shown previously (see Fig. 14 for example).

6. Conclusions

A large TOF detector, made of 30 scintillating counters, has been designed and installed in the GAMS NA12/2 experiment at CERN. Combining the performances of CFD discriminators and a computer-control time calibration system the whole detector time resolution is better than 350 ps over long running periods. The detector allows simultaneous reconstruction of coordinates, momentum and ionization of slow recoiling protons. The proton detection threshold is 270 MeV/c and a good π /proton separation is achieved up to 800 MeV/c.

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References

- [1] F. Angelini et al., Part. World 1-3 (1990) 85,
Nucl. Instr. and Meth. A315 (1992) 21.
- [2] D. Alde et al., Nucl. Instr. and Meth. A240 (1986) 343, Nucl. Phys. B269 (1986) 485,
Yad. Fiz. 44(1986) 120.
F. Binon et al., Cherenkov detectors and their applications in Science and Techniques
(Nauka, Moscow, 1990) p.149, Nucl. Instr. and Meth. A248 (1986) 86.
- [3] For example :
T. Petkovic et al., Nucl. Instr. and Meth. A273 (1988) 833.
S. Cierjacks et al., Nucl. Instr. and Meth. A238 (1985) 354.
G. D'Agostini et al., Nucl. Instr. and Meth. A219 (1984) 495.
- [4] T. Azimova et al., Preprint IHEP 86-35 (1986).
- [5] D. Alde et al., Nucl. Instr. and Meth. A240 (1985) 343.