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ISR-BT/BdeR/EEK

3rd February, 1971

ISR RUNNING-IN, Runs 15 and 16
First observation of colliding beam events

1. Instrumentation

For these runs two teams of physicists had set up counter telescopes to obsverve colliding beam events at crossing points I4 and I5.

The layout in I5 corresponded closely to the proposal *) made in November 1970 and is shown in Fig. 1. S_1 to S_4 are discs of scintillators with a hole of inner diameter 170 mm, so that they fit closely around the circular vacuum chamber of each Ring and an outer diameter of 800 mm. As shown in Fig. 2, the discs have been subdivided into 4 quadrants each of which is viewed by its own photomultiplier.

The signals from the four quadrants of each scintillator disc are added and a coincidence $S_1 + S_2$ occurring at the same time as a coincidence in $S_3 + S_4$ is registered as a possible colliding beam event.

The minimum and maximum half angles subtended by $S_1 + S_2$ or $S_3 + S_4$ at the crossing point are 17 mrad and 73 mrad respectively. In order that a colliding beam event is registered, it is necessary and sufficient that one charged secondary passes through $S_1 + S_2$ and another charged secondary passes through $S_3 + S_4$. Since the average multiplicity of secondaries for 15 GeV colliding beam events should be approximately 10 and since most secondaries are produced at relatively small angles, this arrangement has a quite good efficiency for counting colliding beam events. In fact, preliminary estimates indicate that the fraction of colliding beam events that satisfies the criterium of at least one charged secondary passing through

*) B. de Raad, The ISR luminosity monitor in crossing point I5, CERN-ISR-BT/70-58.

each branch is close to 50%.

The counters in I4 were built up in one day and one night after Ring 2 had been operated successfully for the first time on 25th January and the observation of colliding beam events looked probable on 27th January. The equipment consisted of three counters above the downstream arm of beam 1 and three counters below the downstream arm of beam 2. The scintillators had rectangular shapes ranging from 10 x 10 cm^2 to 10 x 20 cm^2 and were placed close against the ISR vacuum chamber which in I4 is oval with outer dimensions 165 x 60 mm^2.

2. Beam conditions and background considerations

With a circulating current of 1A in each ring and a guessed beam height of 1 cm in the crossing point,the number of colliding beam events should be about 400 per second.

During the previous runs with Ring 1 in November and January it had been found that the relative decay rate $\frac{1}{I}\frac{dI}{dt}$ of the stacked beam depended strongly on the vacuum, was reduced at least an order of magnitude by applying voltage to the clearing electrodes and usually increased rather strongly with increasing current. It had also been found that for nearly all the stacks which had been studied at the beginning of January, the background counting rate in I5 was between one and two orders of magnitude higher than would be expected from beam gas interactions at the pressure of 10^{-10} Torr that was measured in I5.

In fact, there was a strong correlation between the decay rate of a stack and the background radiation in I5. Stacks with a small dI/dt invariably gave a small background in I5 whereas stacks with a large dI/dt produced large amounts of background radiation.

At present the average vacuum in Ring 1 and Ring 2 is 10^{-10} Torr and 10^{-9} Torr respectively. Moreover, the clearing electrodes of Ring 1 can be powered, but those of Ring 2 not yet. In November, when Ring 1 had no power supplies for the clearing electrodes and a somewhat worse vacuum than Ring 2 now, it had been observed that circulating beams of the order of 10 mA had a good lifetime, whereas stacks in the range 100 mA to 200 mA had a reasonable decay rate only during the first few minutes, after which the decay rate increased enormously.

It appeared therefore that the best conditions for observing colliding beam events with a good signal to background ratio with the present status of the ISR would occur with a stack of the order of 1A in Ring 1 and at most 100 mA in Ring 2. The size of the scintillators in I5 had been chosen such that we would still obtain a good counting rate under these conditions. This would permit to explore rapidly the colliding beam event rate as a function of machine adjustments at the low beam currents at which we might be forced to work either by background conditions or by not yet known beam-beam interactions.

3. Observation of colliding beam events

On 27th January there were two successive runs, the first one with 4 bunches, the second with the full PS intensity of 20 bunches.

On the basis of measurements of the vertical orbit positions made with the pick-up electrodes, the horizontal field magnets were adjusted for maximum overlap of the beams in I4 and I5.

The first stack of 930 mA was made with 4 bunch operation in Ring 1 at 12.15 hr. After a few minutes it dropped suddenly, for unexplained reasons, to 586.6 mA but thereafter it behaved better than anything we had seen before. At 14.30 h. the current reading of that same stack was 586.5 mA. The background counting rate in I5 corresponded to true beam-gas interactions.

Since these conditions were so good, it was decided to inject a single shot of 4 bunches into Ring 2 and with 14.7 mA circulating beam in Ring 1 a search for colliding beam events was made. The coincidence counting rate observed in I5 was about 1 per second, and this corresponded to within a factor 2 with the previously made rough estimates of the expected counting rates. The rate of accidental coincidences was a factor 20 smaller.

After better adjustments if Ring 2, larger stacks were made in both rings and the colliding beam event rate was measured with much better statistics. Figure 3 shows the counting rate in I5 as a function of the product of the stacked beam currents $I_1 \ I_2$ in the two rings. The highest point of 110 counts per second was obtained with $I_1 = 2.19A$ and $I_2 = 0.33A$. The background due to the accidental counting rate in a coincidence circuit with a resolution of $\pm$ 10 nsec was about 10%. For the points lower down on the curve the accidentals were only a few per cent.

Independent confirmation that colliding beam events were indeed occurring was provided by the counter telescopes in I4. For instance, at a current of 2.5 A in Ring 1 and 23 mA in Ring 2, 105 coincidences were observed in 1400 sec, while the number rate of accidental coincidences counted in the same period was 11. After beam 2 had been dumped both rates went down to zero counts in 100 sec. Also these figures are in rough agreement with the rate expected from the currents in the two rings and the geometry of the equipment and varied approximately proportional to the product of the two circulating currents.

Further evidence about the correctness of the interpretation of the coincidences as colliding beam events is shown in Fig. 4, which was obtained with the colliding beam monitor in I5. To obtain this particular curve*) the pulses generated by any two coincidences between one quadrant of S_1S_2 and one quadrant of S_3S_4 occurring within ± 50 nsec of each other were fed into a time to pulse height converter, whose output pulses were then analyzed by a pulse height analyzer. The resulting pulse height spectrum is shown in Fig. 4. The peak in the centre is due to colliding beam events of which the secondaries pass at the same time through S_1S_2 and S_3S_4 respectively. The peak on the left hand side is caused by secondaries from protons of beam 1 which interact upstream of the crossing point with the residual gas or the vacuum chamber. If one secondary from such a background event passes through all four scintillators S_4 to S_1 or if, more likely, one secondary passes through S_1S_2 and another secondary of the same shower passes through S_3S_4, then the pulse from S_1S_2 which for background caused by beam 1 is 10.5 m downstream of S_3S_4, should occur 35 nsec after the pulse from S_3S_4 and this is precisely the time difference between the left hand side and the central peak. For background caused by Ring 2 the time difference has the opposite sign and this leads to a third peak at 35 nsec to the right of the central peak. Several of these time difference spectra were recorded in which the relative heights of the three peaks varied in the way that would be expected from the intensity and spillout rate of the two beams.

4. Some more comments on background counting rates

Since the background counting rate is such an important parameter for colliding beam experiments, we shall sum up here the information that has been collected on this subject during the runs in January.

In the present condition of Ring 1, the vacuum in the crossing regions is about 10^{-10} Torr. Under these circumstances the lowest background counting rate that has been obtained in a 10 cm x 10 cm

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*) Similar curves were obtained by adding the counts of all quadrants of S_1S_2 and S_3S_4 but since there was no time to equalize the delays of the pulses from all quadrants, the three peaks in these curves were broader.

counter telescope parallel to and immediately adjacent to the ISR vacuum chamber, is about 100 counts per second per ampère for a stack of moderate intensity, say 0.5 A. This figure corresponds roughly to what one would expect from beam-gas interactions. For most stacks that have been made in January and especially for those of higher current, the background counting rate caused by spilt out protons interacting in the vacuum chamber upstream of the crossing point was between one and two orders of magnitude larger. Up to now little systematic information has been collected about the important question what causes a stack to be "clean" or dirty. We only know that the best stacks up to now have been made when

i) A working point in the Q_H, Q_V diagram had been chosen which had been found to be free of resonances by scanning the aperture with a small beam.

ii) The shutter of the inflector was used during the stacking, so that the stacked beam was not disturbed by the stray field of the inflector.

iii) The stack was made with only 4 bunches per pulse for the PS.

Some modest attempts have been made to clean up a stack by scraping. Vertical scraping was done by reducing the vertical aperture by moving the dump block up or down. The total vertical aperture of the dump block is 32 mm whereas the scaled vertical ISR aperture at that location is 30 mm. On one occasion it was found that the background decreased almost an order of magnitude when the dump block was displaced vertically by 5 mm. A similar improvement was found on another occasion when the dump block was displaced vertically by 9 mm. It was also found that the background returned quite quickly to its previous high value when the dump block was centered again. Contrary to what one might expect, since scraping looks a rather dirty process,intermittant vertical scraping seems to be of little use with the beam conditions prevailing at present. It seems best to insert into the ISR a permanent aperture restriction in the form of a thick absorber.

An attempt was made to turn off the colliding beam events by making a local half wavelength bump of the vertical orbit of Ring 2 in I5. However, the background in I5 increased so much that useful measurements became impossible. This would tend to indicate that with the prevailing beam conditions the technique of distinguishing between colliding beam events and beam-gas background by turning off the colliding beam events by vertical separation of the beams is not so easy as it looks. Apparently the vertical dimension of the stack was such that a local bump with a vertical displacement of 5 mm in I5 and about 7.5 mm in the adjacent mid-D straight sections 456 and 508 was sufficient to cause heavy scraping of the beam. On the other hand the group in I4, which point for Ring 2 is 850 m downstream of I5 reported at the same time a substantial reduction of the background. This again confirms the beneficial effect of continuous vertical scraping, provided that the experiment is reasonably far downstream of the scraping point.

From the fact that the background rapidly becomes worse when the dump is centered again, one might tentatively conclude that the spill-out is not caused by a slow increase of the height of the whole stack but by small numbers of protons whose amplitude increases rather rapidly after they have become unstable. When looking at the rate meter which displays the background counting rate, one also sees quite often bursts of background radiation,especially at higher stacked currents and, of course, intermittant scraping is ineffective against these bursts.

One attempt has been made to clean up a 2 A stack by scraping off the horizontal edges with the normal ISR beam scrapers. This showed little improvement, but we consider that this experiment should be repeated with different combinations and sequence of horizontal and vertical scraping before meaningful conclusions can be drawn .

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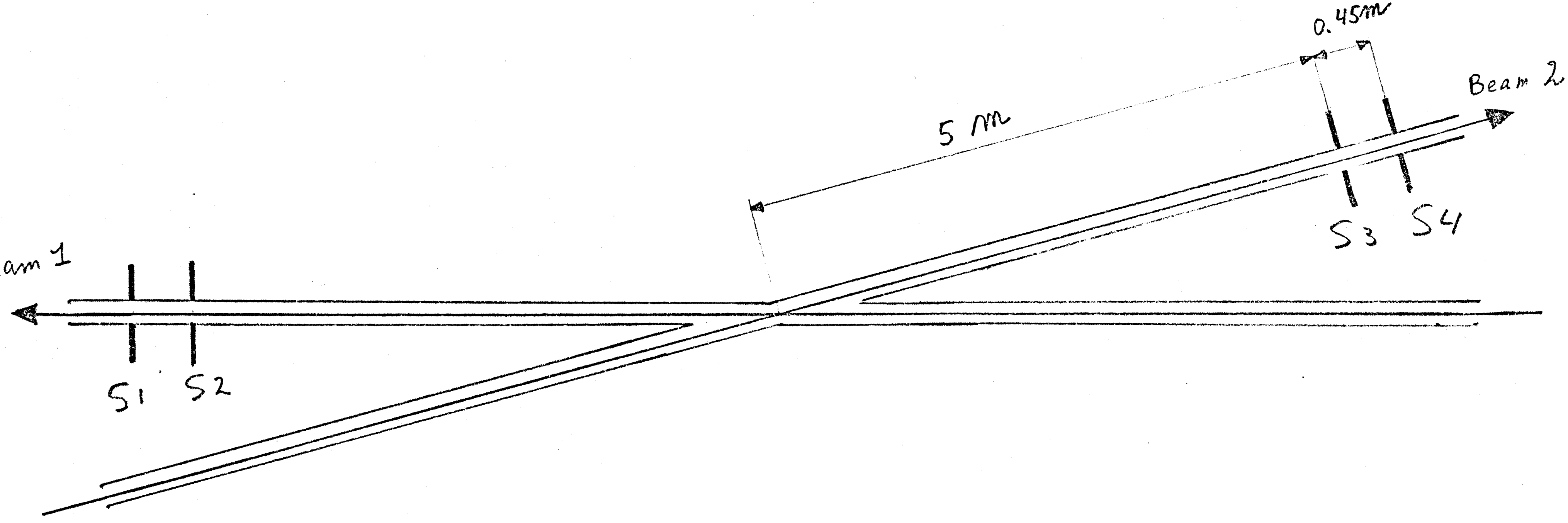

Fig 1. Layout of counters in I 5

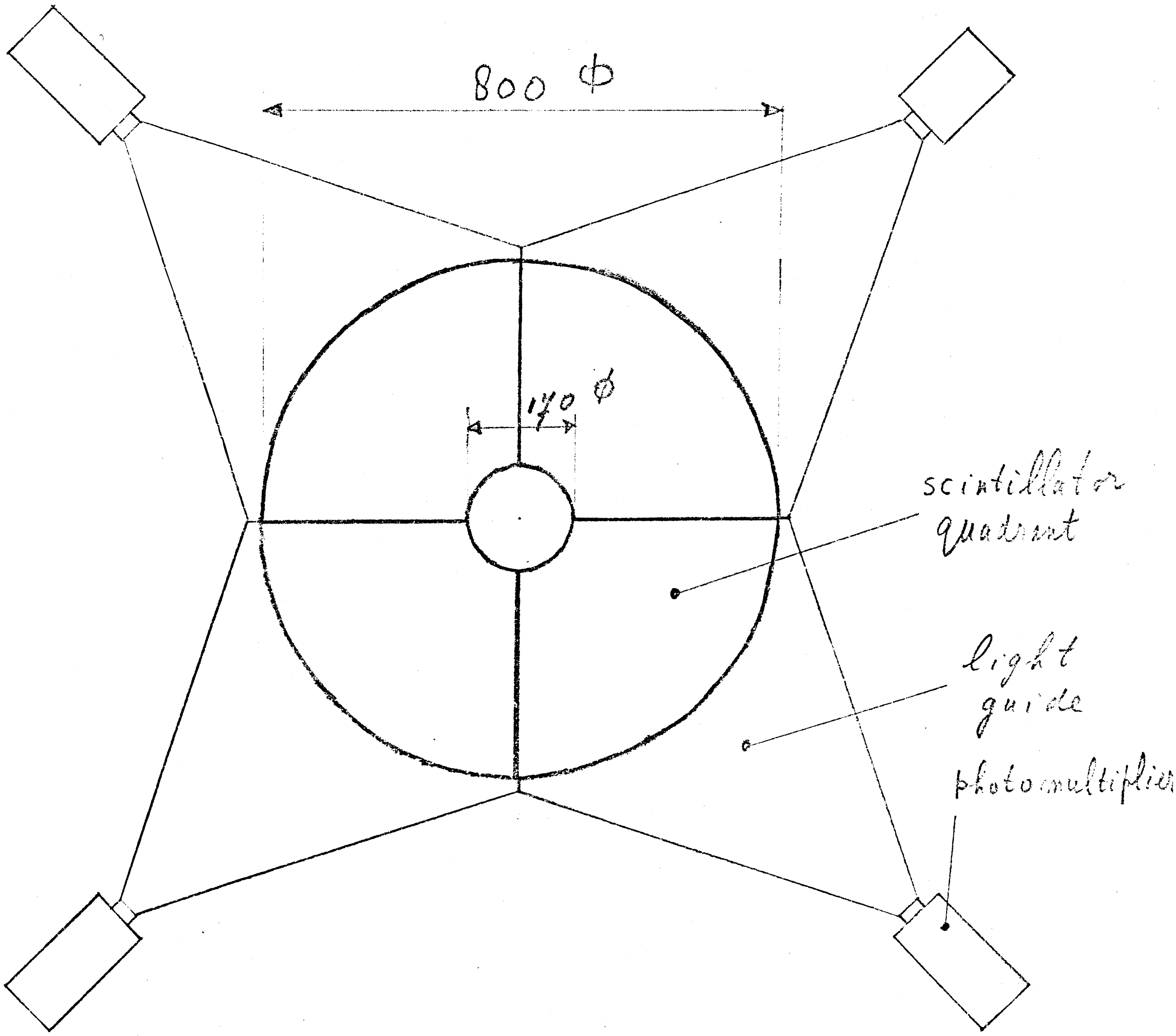

Fig 2. Subdivision of scintillator discs into quadrants.

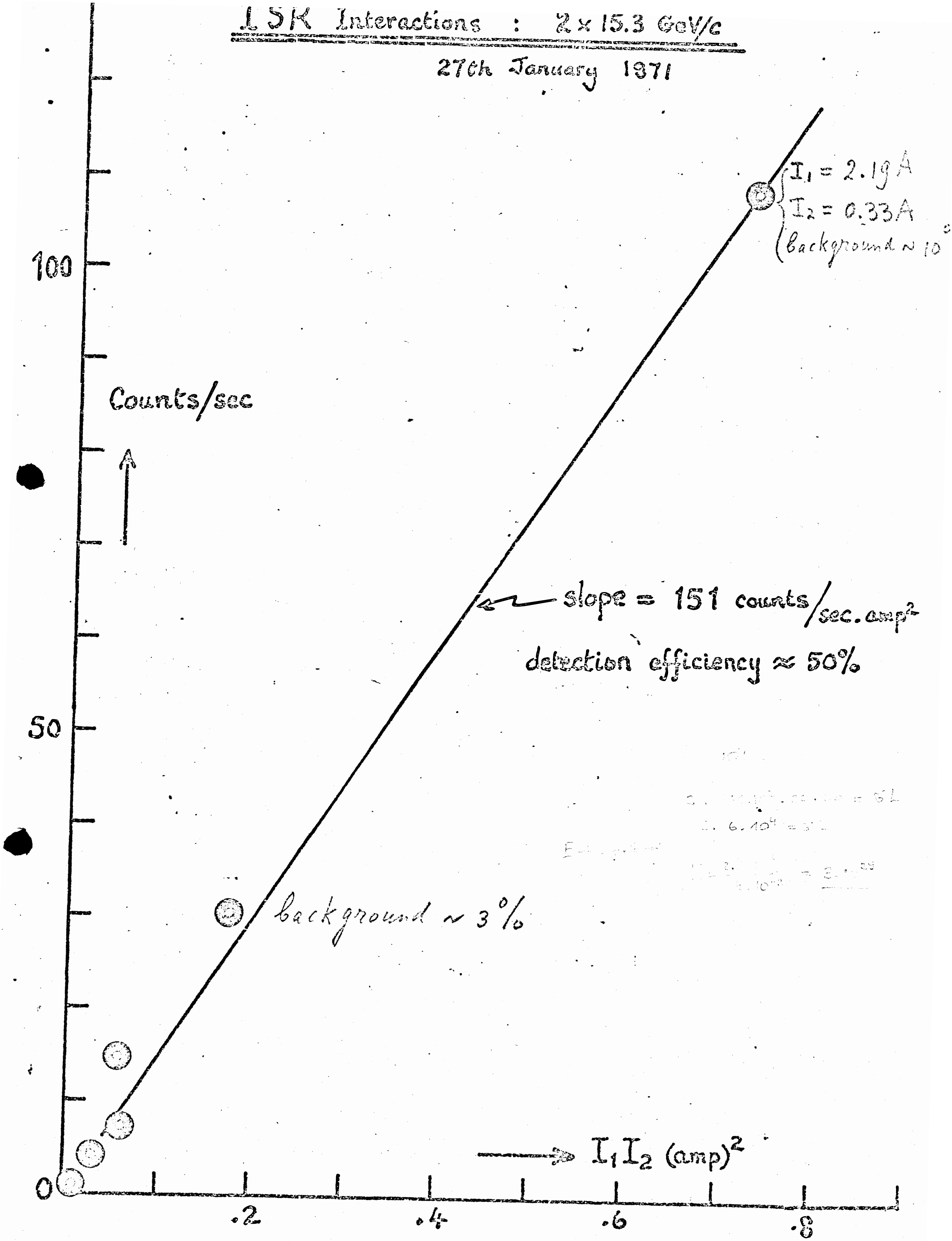

Fig 3. Counting rate in colliding beam monitor vs product of circulating currents

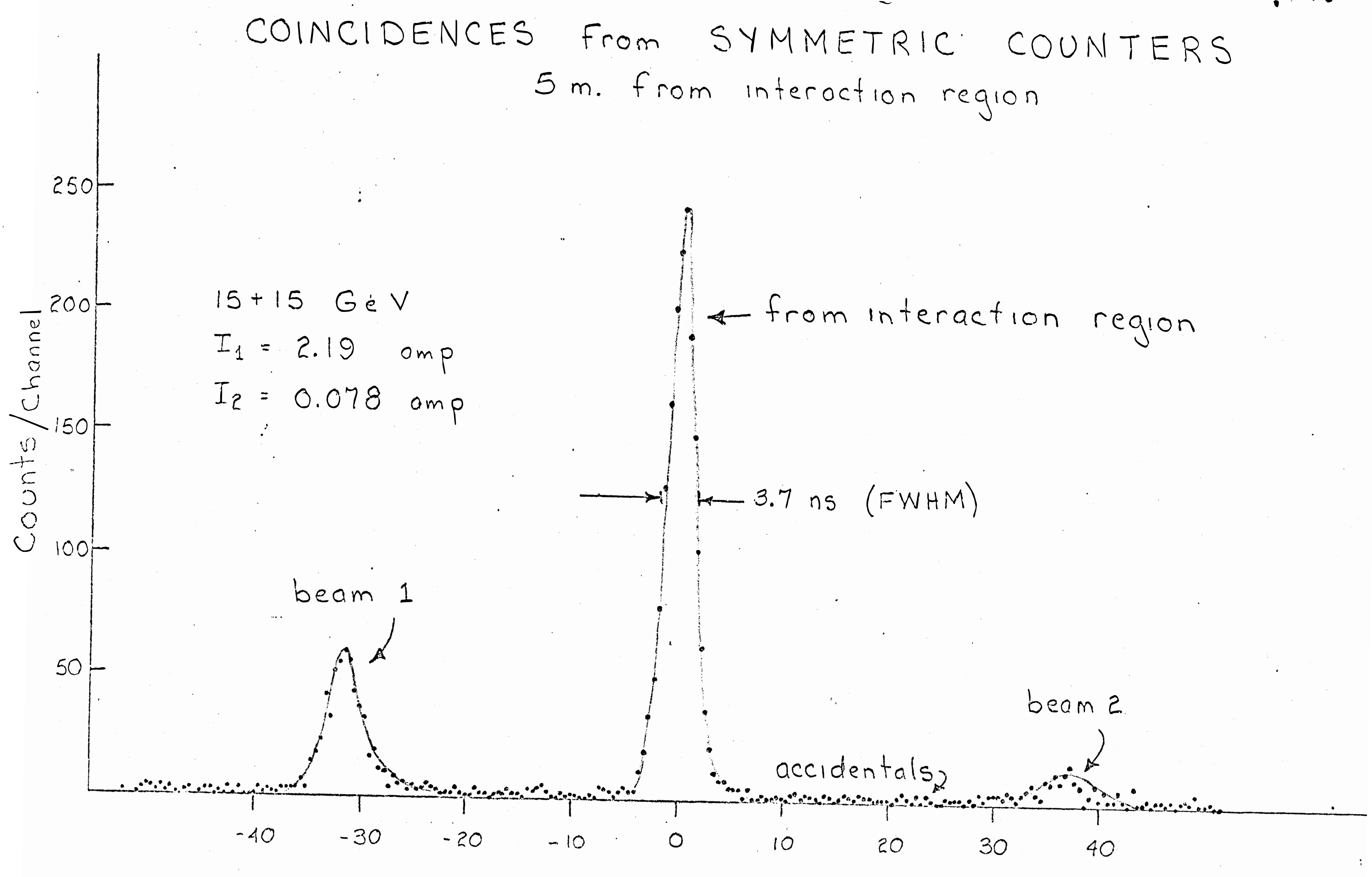

Fig. 4. Distribution of time differences of coincidences