A LARGE GENERAL-PURPOSE STREAMER CHAMBER
FOR THE ISR EXPERIMENTAL PROGRAMME

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Abstract:

The general-purpose nature of a large streamer chamber in the ISR experimental programme is outlined: as an instrument on its own for beam analysis; in experiments in combination with counter arrays; as a detector in direct contact with the ISR vacuum pipe - using the vacuum pipe as central electrode; as a self-contained particle identifier in a magnet. The extent of the research and development necessary before such an instrument can be constructed is emphasised, in view of the possibility that such an apparatus may be desirable for initial ISR experiments where visual techniques are particularly suitable.
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Introduction

With the opening up of a higher range of energies to accelerator particle physics, the ISR will introduce at the same time new problems of particle identification and event reconstruction in which a large high-precision streamer chamber can prove an invaluable complement to other detector techniques: such an apparatus has the unique potential of being able to provide both high-precision geometrical reconstruction and high-precision ionisation measurements for multi-track events covering a wide solid angle, giving the possibility of mass identification of individual particles up to high values of $E/mc^2$ using the relativistic increase of the primary ionisation. Streamer chambers of the necessary size combined with ionisation-measurement capability have not been made, or even designed. A one-litre chamber, designed and constructed in the CERN_ISR by the Schneider group, has demonstrated the operational feasibility of an apparatus of the required performance - over the limited dimensions $0.1 \times 0.1 \times 0.1 \text{m}^3$\(^{(1)}\). The principle research and development area in streamer chamber technology today is research and development in power supplies and photographic techniques for larger chambers, of the order of one metre cubed, having comparable performance to the one litre model. Some aspects of the further investigation required have been indicated in previous reports \(^{(2)}\). It is not yet possible to consider embarking on any construction programme for such a chamber: model work on a chamber of intermediate dimensions is only just beginning and further intensive research and development on short-pulse HV supplies and high-resolution image-intensifier photography are required in order to render feasible a design for a large chamber.

In this report, the general purpose nature of a cubic-metre ionisation measuring streamer chamber at the ISR is outline: as an instrument on its own for the analysis of momentum defined beams; in experiments in combination with counter arrays; as a detector in direct contact with the ISR vacuum pipe - using the vacuum pipe as central electrode; and as a self-contained particle identifier in a large magnet. It is seen that a chamber of dimensions $2.0 \times 0.8 \times 0.8 \text{m}^3$ is a feasible development objective which may be useful in these different configurations.
The utility of the streamer chamber will depend mainly on the development of its unique ionisation measuring capability - the only competing detector in this respect being the much slower Wilson cloud chamber. There are also the advantages of a fast visual technique in the digestion and interpretation of multiple track events in a new physics field. The extrapolation of the very short high-voltage pulse technique and the high resolution image intensifier photography required for good ionisation measurement, will be a technological feat of some magnitude. CERN is among the leaders in the field, with the first operational ionisation measuring streamer chamber (at the quark experiment \(^{(1)}\)) and the first separation of relativistic particles by ionisation measurement (in the cloud chamber \(^{(3)}\)). The coming into operation of the ISR for particle physics in 1971 - 1972 is a great incentive to try to reach the cubic metre chamber goal by this deadline.

2. Particle identification:

Relativistic particle identification by simultaneous measurement of momentum and ionisation was proposed by several cloud chamber workers \(^{(4)}\). The advantage of using primary rather than total or probable ionisation was pointed out by the CERN cloud chamber group and measurement of the relativistic increase of the specific primary ionisation in helium was made in CERN in post-expansion cloud chamber tracks \(^{(3,5)}\). A discussion of ionisation measurement improvement and particle identification is given in reference \(^{(5)}\). The importance of the relativistic increase has been recognised at the Moscow Engineering Physics Institute where it has been measured in pure helium in a streamer chamber \(^{(6)}\).

The error on the logarithm of the particle mass is given by \(^{(5)}\)

\[
\sigma_m = \sqrt{(s_p^2 + (I/a)^2 s_I^2)}
\]

where \(m\) is the particle mass, \(s_p\) is the fractional error on the momentum, \(I\) the relative ionisation, and \(a\) the slope of the relativistic increase. In practice, \(I/a\) has a value about 7, so that the mass error is seven times
more sensitive to ionisation than to momentum error. The ionisation error is given by \(1/\sqrt{n}\) where \(n\) is the number of countable primary events. Four countable events per cm have been measured in the CERN one-litre streamer chamber (1) and a factor two increase in this density is feasible with further development in spatial resolution. Assuming the fractional error on the ionisation measurement \(s_i\) to be the limiting error on \(s_m\), since a few percent error on \(p\) is not difficult to attain at PS momenta, one may take

\[ s_m = 7s_i\]

to show the essential dependence of the mass error on the ionisation error.

In considering the application to the identification of protons, kaons and pions (as an example) one notes that the separation between the masses \(m_k - m_p\), \(m_k - m_\pi\), and \(m_\pi - m_p\) are almost exactly in the ratio 1:2:3 on a logarithmic mass scale. The errors on the mass measurement corresponding to a given precision of identification are therefore in the ratio 1:2:3 for the three pairs, it being three times as difficult to separate kaons from protons and twice as difficult to separate kaons from pions as it is to separate pions from protons. The situation is illustrated in figure 1 from reference (5) where the error distributions are drawn in which the standard deviation on the mass measurement is equal to one third of the log-mass difference for each of the three cases. One may say that when on the average there are a similar number of each type of particle in a beam, mass measurements on single tracks can distinguish individual protons and kaons if \(s_m \leq 20\%\), pions and kaons if \(s_m \leq 40\%\) and pions and protons if \(s_m \leq 60\%.\) Statistical separation is feasible for mass errors of the order of twice as great as these. In figure 2 from the same reference, the clear separation of a relativistic pion-electron beam by ionisation measurement technique is illustrated. Further discussion of particle identification is given in references (7).
3. Track lengths necessary for useful ionisation measurement

The useful track lengths for good ionisation measurement, and hence the required dimensions of the streamer chamber, may be inferred from the discussion of the last section. (The use of ionisation measurement for detecting particles of unusual electromagnetic characteristics such as the quark (having much lower minimum ionisation than normal) and the monopole (having much higher) is a separate field where already one-litre chambers are in use. \(^{(1)}\). We consider here only track lengths for the discrimination of relativistic particles.

Figure 3 shows the relationship between measurable track length \(L\), countable ionisation density \(I_c\), precision obtained in ionisation measurement \(s_I\), momentum error \(s_p\), and the resulting error on the mass \(s_m\).

It can be seen that individual identification of \(k^{-}\) and of \(p^{-}\) is possible with currently attainable \(I_c = 4 \text{ cm}^{-1}\) and track lengths of up to one metre. Statistical separation of \(p^{-}-k\) is also possible with this track length. It should be remembered that the above considerations apply to the linear part of the \(I/\log(p)\) characteristic, which gives limits to the momentum

\[7 \leq p/mc \leq 350\]

The case of distinguishing electrons from other particles has to be treated separately since electrons of \(p \geq 0.5 \text{ Gev/c}\) are ionising at plateau level. A possible application \(^{(8)}\) has been suggested in the dilepton experiment proposed by Cool et al \(^{(9)}\). Again, track lengths of the order of one metre are necessary.

4. Practical limitations on the chamber dimensions

The strongest overall limitation on the chamber dimensions is the requirement to photograph it with a resolution of better than one mm using image intensifiers. Image resolution in the best intensifier tubes available today restrict the area coverable to one square metre in square
format, while the gain of the intensifier at this high resolution will restrict the obtainable depth of focus to about one metre. An estimate of the performance of these tubes is given in reference (8). A coverable volume of one cubic metre appears to be a feasible development objective.

The next limitation is the requirement to fill the chamber volume with a very high electric field of the order of 20 kV/cm for a very short time of the order of 4 nsec. The Schneider Group in CERN-ISCR is now developing a one megavolt, 4 nsec supply for a double gap chamber of 40 cm each gap. The width of the chamber can be 80 cm and the length several metres (10). These dimensions are regarded as a feasible development objective.

The image intensifiers thus limit the length and the high voltage supply limits the gap distance or depth of the chamber. Doubling the square format, and thus the number of image intensifiers, would appear to be the only way of reducing the length restriction and achieving an overall chamber volume of 2.0 x 0.8 x 0.8 m³.

A two-metre chamber length is necessary if the chamber is to give one-metre track lengths over a wide solid angle near the ISR interaction region. This can be seen in the suggested layout in reference (8) which also shows a possible camera system, figures 4 and 5.

Extension of the length of the chamber to take advantage of the 3 - 6 metres allowable from the high voltage aspect, may be envisaged by the use of multi-format techniques when the single and double format problems have been solved.

5. **Streamer chamber for the analysis of a momentum-defined beam**

This first case is the most straightforward: in which a two-metre streamer chamber is placed along or across a beam, or restricted cone, of particles whose momentum is defined upstream by some magnet system. The chamber then gives the number of beam particles, their spacial distribution to better than ± 0.2 mm and their mass distribution with a mass precision given by figure 3.
When the chamber is aligned along the beam, and the beam momentum is defined to better than 5%, the two-metre tracks obtainable give - 3.5% ionisation precision and - 27% error on the mass. Across the beam, with one-metre tracks, the corresponding figures are 5% and 40%. This is based on the already achieved counting density of 4 per cm. When 8 per cm becomes feasible, so does the individual identification of P-k - at $m_s = 20\%$.

In the limit of performance along the present line of development - if a 6.0 x 0.8 x 0.8 m$^3$ chamber becomes possible - one may obtain a mass precision 12 - 16%, sufficient to distinguish individual pions from muons.

6. **Streamer chamber with counter arrays**

A category of particle physics experiments at the ISR exists in which the beam-beam interaction is signalled by a coincidence of radially arranged counter arrays in opposite solid angle hemispheres around the interaction region - and the momentum of the triggering particles is determined by magnet spectrometer, total absorption counters or other technique. The fact that the streamer chamber is triggerable with a sensitive time of the order of only 1 μsec makes it an invaluable complement in such experiments where precise information is required on spacial distribution and especially on the mass of the triggering particles.

The dilepton experiment proposed by Cool et al. (9) is a case in point, where the triggering particles are an electron pair whose energies are determined with high precision in special lead-glass Cerenkov counters. The possible application of the streamer chamber as the electron detector has been outlined in a separate report (8).

7. **Streamer chamber in direct contact with the ISR Vacuum pipe**

The importance of just how near to the ISR interaction region and to the beam in the vicinity of the interaction region one can get, with the sensitive volume of one's detector, has been underlined in the ISR User Group meetings. The question relates both to the distance of the detector from the beam, and the amount of material separating them, including the
beam pipe wall and the detector wall.

With this in mind we have given some thought to the possibility of constructing a streamer chamber which uses the ISR vacuum pipe as part of the central electrode, so that the pipe is totally immersed in the sensitive volume. The simplest solution from the point of view of electric field homogeneity is to make the central electrode of plane parallel thin conducting sheets separated by the height of the vacuum pipe (figure 6a and b), but this loses a lot of solid angle for tracks near the horizontal plane - even when the 6 cm high elliptic section is used in place of the 16 cm circular section. And this loss of solid angle is important for a chamber photographed along vertical camera axes as dictated by this electrode disposition - both from the point of view of ionisation resolution which decreases with track angle to the horizontal, and precise measurement of track curvature in the case of a magnetic chamber. This solution also adds material in the region where it is least wanted and cuts off parts of the tracks just where they are most useful - near the vacuum pipe.

The next step is to consider a single thin central electrode on which the beam pipe is a conducting proturbation (figure 6c and d). The trouble here is the deformation of the high voltage pulse as it reaches this discontinuity: an effect increasing as the ratio of the pipe height to the chamber gap height increases. In order to reduce this ratio for a given overall chamber height, we have considered putting the vacuum pipe itself at high voltage - thus halving the ratio (figure 6e and f). Although suitable ceramic insulating materials and know-how exist with which to construct insulating pipe sections, this solution has been discarded for a first approximation because of possible interference with ISR operation.

One may guess (10) that a proturbation of less than 10% of the gap is supportable, though calculation and/or model testing will have to be done on this. With this assumption, solution (c) is ruled out and solution (d) becomes acceptable with 30 cm gaps. The chamber may therefore have
to be photographed from above and below because of restriction on focal depth.

The problem of constructing a vacuum pipe cross-over section using welded sections of standard 16 x 6 cm elliptic pipe is being studied by the ISR vacuum group and model work for this is under way. It looks as though a wall thickness of 0.25 cm throughout the section will be mechanically strong enough.

One can thus entertain the idea of building a double 2.0 x 0.8 x 0.8 m$^3$ streamer chamber which can be aligned along the intersection or across it (figure 6g and h). Such a chamber probably represents the limit in spacial proximity of such a large detector to the ISR beams.

An extension of this line of thought is followed up in the next section, in the planning of a streamer chamber to operate in a magnet. In this case, the pole gap of the magnet restricts the height of the chamber to 80 cm so the high voltage gap from the above argument would be 20 cm, putting a limit of 20 mm on the half height of the vacuum pipe. It will apparently be possible to install a pipe of elliptic section 40 mm by 130 mm in the intersection area when equipment designed to correct closed orbit distortions in this region has been put into operation (17).

8. Streamer chamber in a large magnet

The utility of a large streamer chamber in a magnetic field has been indicated by Hyams and O'Neill (11) in a study of the design of detector systems for a central field ISR magnet. In a discussion of the relative merits of different detectors for the ISR magnet, summarised by Winter (12), the performance data of large streamer chambers operating at SLAC and DESY (13) are quoted. One of the principal points of the present report is to stress, without prejudice to the excellent design of these chambers, that the possibility of very significant improvement in these figures has been established by the pioneering work of Schneider and his group at CERN-ISR. For example, already in 1963 the practic-
ability of reducing the sensitive time to $\leq 1$ usec by the controlled addition of electro-negative gases was demonstrated (14). The large streamer chamber now being built at NINA (15) is taking full advantage of this characteristic with the installation of precision gas-handling equipment. As another example, the spatial resolution obtained by Schneider is nearer $\pm 0.2$ mm than the quoted figure of $\pm 0.5$ mm. This is not to question the relevance of having used present-day large-chamber performance data in the big magnet discussions, but a mention of present-day small-chamber data might have put streamer chamber prospects in a fairer, brighter light.

The big central field magnet was decided against in favour of the split field system, and no other large magnet project for the ISR appears to be envisaged for the near future. However, there does exist now in CERN a 10 kgauss magnet (16) which could house quite a large streamer chamber ($1.7 \times 0.6 \times 0.8$ m$^3$) and which could be placed around one of the ISR intersections. We shall examine here what performance one could hope for from such a combination, in the light of the arguments developed in the previous sections. Such an arrangement has severe dimensional limitations, but the magnet does exist - and the streamer chamber could exist.

A possible layout is shown in figure 7, in which the streamer chamber is aligned across the ISR intersect. A chamber construction is envisaged with the ISR vacuum pipe as part of the central electrode, as discussed in the last section. The magnet is described by P. Astbury et al (16). It has a field of $10.5 \pm 0.9$ kgauss over the above quoted volume. From the diagram one can see that excluding $45^\circ$ half-angle cones about the vertical and similar cones about the long axis of the ISR intersection, a solid angle of about 5 steradians is available for precise ionisation and momentum measurement. The track lengths in this solid angle vary from -35 cm to -75 cm with a mean value -60 cm. The mean MDN corresponding to a sagitta error of $\pm 0.2$ mm is given by

$$MDN = p = 0.3TL^2/8s$$
with $T = 1.05$ tesla, $L = 0.6$ m, $s = 2 \times 10^{-4}$ m, giving an MDM -70 Gev/c.

From figure 3, with this MDM, $14$ Gev/c $\pi-p$ and $\pi-k$ could be individually identified from tracks of length 60 cm and countable ionisation density 8 per cm. This is quoted merely as an example: other possibilities may suggest themselves from the diagram.

9. Conclusions:

Intensive development in very high voltage pulse technique and image intensifier photography could yield a practical design for a large high-precision geometry and mass measuring streamer chamber, and possible experimental configurations for such a chamber have been sketched. It is hoped that the description of the possibilities given in this report may stimulate some discussion of the application of this apparatus in experimental particle physics. If such an instrument is thought to be useful in the ISR experimental programme, it will be difficult to reach the construction stage by the time the ISR is due to operate for particle physics in 1971.

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Figure Captions

1. Mass separation of pions, kaons and protons as a function of precision of mass measurement.

2. Experimental separation of relativistic pions and electrons.

3. Dependence of mass error on momentum error, ionisation error, ionisation density, and track length.

4. Plan view of camera layout for 2.0 x 0.8 x 0.6 m³ streamer chambers.

5. End elevation of same.

6. Streamer chamber in direct contact with the ISR vacuum pipe: electrode dispositions, plan view of chamber.

7. Streamer chamber in the CERN-EHT magnet.
Fig. 1
Relative primary ionisation for particles of momentum 235 MeV/c

\( \frac{p}{mc} = 1.81 \quad \frac{p}{mc} = 460 \)

\( \bar{j}_{rel} = 1.09 \pm 0.014 \quad \sigma = 0.10 \)

\( \bar{j}_{rel} = 1.55 \pm 0.018 \quad \sigma = 0.11 \)

Figure 2
Figure 3
ISR vacuum pipe

streamer chambers

50 cm

main lenses
image intensifiers
mirrors

70 mm film box
Figure 6a-f
Figure 6g-h