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SPIRAL PROJECTION CHAMBERS: EXPERIENCE and PROSPECTS

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Abstract

Spiral Projection Chambers (SPCs) and Radial Projection Chambers (RPCs) have been operating at CERN and FNAL in antiproton experiments at low energies. The SPC, besides its application in $\bar{p}$ physics, satisfies most of the properties required for the inner tracking detector at Φ factories and could be suitable for single-pass colliders, where the SPC magnification properties could be fully exploited. This paper compares the relative advantages of the TPC, JET, and SPC designs in terms of transparency, segmentation, distribution of massive materials, and safety of operation. Methods for localizing clusters of primary ionization and track points in the SPC are discussed, experience with operating chambers is summarized, and new applications of the SPC design are indicated.

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1. Introduction

Spiral Projection Chambers (SPCs) are cylindrical gas detectors with radial drift electric field and axial symmetry, which surround a coaxial target region [1]. The whole volume of the counter gas is active. The internal cathode of the SPC can have the shape of a cylinder, a cone, or even an elliptic cone [2, 3]. The target container can provide the support for this cathode; it may be extremely thin if the target is gas at the same pressure as the gas in the SPC [4, 5].

The SPC provides a tridimensional picture of the ionization produced in its active volume. Its geometrical configuration is different from that of the TPC [6] but its operation principles are similar.

Spiral Projection Chambers (or Radial Projection Chambers, RPCs, when no magnetic field parallel to the chamber axis is present) have been operating successfully and are in use in experiments with low-energy antiprotons at CERN, LEAR, [5, 7–10], and at the FNAL Antiproton Accumulator [3]. Chambers adopting the same geometry are also exploited in experiments at the PSI meson factory [11].

In this paper we discuss the properties of the SPC (geometry, architecture, logistics, and event reconstruction), making comparisons with other types of imaging chambers (JET [12, 13], TPC, multicell à la Mark III [14] and DM2 [15]); we recall the main characteristics of SPC detectors used with antiprotons; we discuss the advantages of using an SPC at a Φ factory such as DAΦNE, where its extreme transparency could be fully exploited; finally, we mention the advantages of the SPC geometry in terms of radiation hardness and security, trigger flexibility, and magnification for future single-pass collider facilities. An independent paper [16] describes a project at the LNL to develop a micro-SPC prototype, where the amplification region of the SPC will be instrumented with a microstrip structure similar to those used in planar microstrip chambers [17, 18], but bent to match the external radius of the SPC.

2. SPC properties and comparison with other detectors

2.1 Geometry, architecture, and logistics

The general structure of the SPC is described in Ref. [1]. Figure 1 shows an example of SPC cells with drift lines and isochronous curves. Figure 2 shows schematically TPC, JET, and SPC geometries and structures.

The main properties of the SPC design are:

- modularity: all drift cells are equal;
- transparency: the detector has the maximum transparency for all particles originating from the centre of the target region;
- symmetry: discrete axial symmetry modulo any angle integer multiple of $2\pi/n$, where n is the number of detector cells;
- magnification (and tower structure thrown in): the transverse size of the cells reduces when going towards the centre of the detector;
- granularity: the segmentation of the active volume is constant at all radii and in the longitudinal (z) direction;
- safety: all active parts of the detector, including the gas amplification regions and the front-end preamplifiers, are located in the most peripheric regions away from beam halo, beam-originated bremsstrahlung radiation, and accidental beam losses;
- efficiency: the SPC can instrument all the volume around a beam pipe or target, not only with cylindrical shape, but also with conic (and even elliptic cone) shape;

- triggering: since information on all ionizations at a given radius in the active volume is available at the same time, triggering on multiplicities, and variation of multiplicities as a function of radius, is simple.

The TPC design has the advantage over the JET and SPC designs of featuring parallel magnetic field B and drift electric fields E . This reduces transverse diffusion. In the JET and SPC designs, B and E are orthogonal. In the JET, E is constant in absolute value in the drift region of the active volume: the drift velocity and Lorenz drift angle are then constant. In the SPC, E is radial and its absolute value decreases in the drift region as $1/r$, where r is the radial distance from the chamber axis. In the presence of a constant magnetic field B , both the modulus of the drift velocity and the value of the drift angle vary with r . The complications in computing and measuring the SPC cell shape are overcompensated by the fact that the cells are all equal, whereas in JET chambers they become longer azimuthally with increasing radius, and in TPCs the shape of the drift cells depends on the segmentation of the amplification regions on the two end-caps of the chamber. The equality of the cells of the SPC permits a straightforward use of the detector for purposes of triggering on multiplicities and on secondary vertices, and simplifies the representation of the projection of the events on the transverse plane ($r\phi$ plane).

The distribution of structural materials in the three designs is indicated in Fig. 2.

The internal cathode of the SPC has to be set at constant negative HV. A conducting layer of a few tens of nanometres thickness is sufficient and its support may comfortably be a 6 μm thick Mylar foil. Figure 3 shows a cathode, 70 cm long and with diameter $D = 4$ cm, made of 2 μm thick aluminized Mylar. If the SPC surrounds a gas target at the same pressure, the Mylar of the cathode support also acts as target container. If an SPC were to surround a beam pipe, H_2 gas at the same pressure as the SPC active gas could be flushed between the internal cathode on the thin Mylar support and the beam pipe, for electrical insulation (see Fig. 4). The amount of insulation and window material in the radial direction can be below $2 \times 10^{-5} X_0$. In the JET design the internal window may be as thin as in the SPC case only if the field shaping in the azimuthal direction is made with wires. In the TPC case the internal window is thick since it has to contain the shaping of the electric field in the longitudinal direction.

The drift region of the active volume of an SPC is completely devoid of materials, apart from the counter gas. In the JET and in the multicell designs used, for instance, by Mark III and DM2, the chamber volume is filled with different configurations of sense and field wires parallel to the chamber axis. In the TPC, a central HV disk cathode divides the chamber volume into two parts. By using a He-based gas mixture [19] an SPC can instrument a cylindrical volume around a beam pipe or a gas target with less than $10^{-4} X_0$ per 10 cm radial extension.

The external cylindrical container cannot be extremely thin in any of the designs, as it has to provide the mechanical rigidity for the detector structure. The SPC's external container supports the cathode strips that provide good resolution in the z direction. The JET's external wall has to counteract the tension of all of the field-shaping wires positioned inside the active volume. The TPC's external wall has to contain the external field shaping.

The end-cap walls of the SPC can be rather thin from the internal cathode to the amplification region, since their functions are solely to support the end-cap field shaping (which can be provided by a thin coating of germanium deposited on a kapton foil), and the internal cathode. Massive material is present only at the extreme periphery of the

end-cap walls: the support of the wires, the boards with the preamplifiers for the sense wires and the strips, and the high-voltage distribution systems are situated there. Apart from the HV for the central cathode, which has to be fed at one of its two extremities, all cables to and from the SPC are connected in the two extreme regions at maximum distance from the centre of the detector and from its axis. This feature permits end-cap detectors to be inserted against the two extremities of the SPC without major difficulties. The chamber materials relevant for multiple scattering and gamma conversion are thin and are distributed evenly. The end-cap regions of TPC and JET chambers are covered with electronics and cables. The end-cap flanges of JET chambers must also be solid enough to withstand the tension and the torque generated by all the wires strung across the chamber.

2.2 Localization of isolated clusters

For isolated clusters, such as those generated by low-energy X-rays, the SPC angular resolution is set, in the transverse plane, by the number n of sense wires, and may improve at small radii if the primary electrons are generated in more than one cell, and centre-of-gravity techniques [20] can be applied. In the radial direction the resolution is controlled by the spacing of the sense wires, which determines the depth of the U-shaped equidrift curves. This depth is conserved right through to the chamber centre. The FADC electronics sampling time and the drift velocity determine the spacing between two successive U-shaped equidrift curves in the same drift cell. This spacing also affects the resolution in the radial direction. For isolated clusters the coordinate in the z direction is given by charge division with modest resolution, but without ambiguities, and with good resolution by the centre of gravity of the pulses induced on the cathode strips. Provided that the drift electric field E is effectively radial and that there are no distortions, the z resolution can be very good for all radii, since the centre-of-gravity technique applied to the signals of the strips averages out transverse-diffusion effects.

2.3 Localization of track points

Typically, tracks of particles emerging from the target cross several contiguous SPC drift cells at relatively small angles to the lateral boundaries of cells in the transverse plane. Primary-ionization electrons drifting to the same sense wire are normally generated in succession (apart from tracks at very low momentum or coming from secondary vertices, which can be tangent to equidrift curves in several contiguous cells). For tracks at small angles, there is therefore no front of clusters of primary ionization arriving together in the region of amplification and determining the leading edge of the pulse. The primary-ionization cluster generated near the exit boundary, and arriving at the sense wire of the same cell, initiates the signal on the wire. Transverse diffusion can cause primary electrons generated near the exit boundary of a cell to migrate either to the nearby cell (thus contributing to the pulse tail in that cell), or inside the cell (in this case arriving sooner). In the drift region of the SPC's active volume, for tracks crossing several contiguous wires at small (varying) angles, track points are given by the intersection points of the track with the exit boundaries of the cells. For each cell there are two candidate track points in the transverse plane, one on the left, the other on the right boundary of the cell. The pattern recognition can immediately discard one of the two by making use of the positive or negative inclination of the track relative to the cell direction at the radius of the hit, provided at least two contiguous cells are hit. The effect of transverse diffusion adds to

that of longitudinal diffusion and to the drift-time measurement error in smearing the leading edge of the pulse and causing the error dr in the determination of the intersection point of a track with a cell boundary. For a cell traversed, at large angles, by a track tangent to an equidrift curve, the reconstructible track point in the transverse plane is no longer on the boundary. It is given by the point of tangency of the track to the equidrift curve given by the drift time of the signal's leading edge.

Owing to the curved shape of the SPC cells, tracks sometimes traverse a cell twice, exiting once from one boundary, and the second time from the other one. Furthermore, in general, tracks traverse all cells but one in the elongated region, where errors in spatial reconstruction move track points mainly in the radial direction along the cell borders. For the cell traversed through the cylindrical region (i.e. that where the equidrift curves are almost circles around the sense wire), errors in the spatial reconstruction change the radius of the equidrift time circle to which the track is required to be tangent, thus moving the track point mainly orthogonally to the direction defined by the points in the elongated region of the other cells. This feature permits the imposition of an 'autofocus condition' individual for each track. The autofocus condition is very practical for the purposes of calibration and monitoring of the chamber, because all cells of the SPC are identical.

The cell traversed through its cylindrical region by a track coming out of the SPC provides the value of the z coordinate of the track point Z nearest to the sense wire. This value is given by the charge-division method, by calculating the average of the z values given by all drift-time bins between the one containing the leading edge of the signal and that corresponding to the maximum drift time in the cylindrical region (this corresponds to a drift distance of half the pitch between two sense wires). In this time window, the signal does not contain tails of earlier signals, which would spoil the measurement. The centre of gravity of the signals induced, in the same time window, on the strips facing the sense wire provides the above-mentioned z value with high resolution. (Ionization on pairs of segments of the track at equal distances from Z cause avalanches that occur at the same time. The signals induced on the cathodes by these pairs of avalanches have their centre of gravity at Z , where the tails of earlier inductions also have theirs; tails of symmetric pairs are cut in the same way, and there are no tails of pulses generated by the track in the internal region of the SPC.)

For a cell traversed by a particle only through the elongated region, charge-division averaging over all drift-time bins of the associated signal gives the z value of the centre of the track segment contained in the cell. The determination of the same z value by exploiting the centre of gravity of the signals induced on the strips in the same time window is disturbed by the tails of the ones caused by ionization of the track at larger radii in the SPC. However, clusters of primary ionization of L shells (in Ar, this corresponds to more than 400 eV energy loss) give signals that emerge above the continuous signal due to the convolution of the frequent pulses from small M-shell ionization clusters [21]. The larger clusters belonging to a track can be localized in the z direction eventually with the same accuracy as X-rays. They provide track points with a precise z value, which are localized in the $r\phi$ plane at the intercept of the track projection with the equidrift curve associated with the leading edge of their signal. Two points of a track with precise measurements of their z coordinate are sufficient to determine the inclination of the track, since the magnetic field is directed along the z axis. Therefore, the z values determined by the centre-of-gravity technique in the cylindrical region of the cells and for the large

clusters of ionization spread along the track corridors, enable a precise measurement of the track inclination.

3. Use of SPC detectors in $\bar{p}$ physics experiments

The SPC of the ASTERIX experiment [5, 7] was operating from 1983 to 1986, taking data for more than 600 h with $\bar{p}$ stopping in a H_2 gas target in the centre of the experiment. The beam intensity was in the range 10^4 – 10^5 $\bar{p}$ s $^{-1}$. The detector was exposed to about 10^{11} annihilations and more than 55×10^6 events were recorded on tape. The main use of the SPC of ASTERIX was as an X-ray drift chamber [22], for identifying and measuring X-rays of the $p\bar{p}$ atom in the energy range 1–15 keV. Several millions of L X-rays of protonium were present in the data. For a large fraction of the data taking, the experiment also used an X-ray trigger given by the SPC, in order to select annihilation events from the 2P sublevels of protonium, which are marked by the presence of an L X-ray in coincidence with the annihilation particles. The detector permitted the ground state of protonium to be discovered and measured [23, 24], the observation of the effect of angular momentum polarization in $p\bar{p}$ annihilations at rest [25–27], the discovery of the new meson AX(1565), which is a candidate exotic meson [28], and the determination of the $0^{-+} J^{PC}$ quantum numbers of the E/i(1420) meson from the dependence of its production branching ratio on the angular momentum of the initial $p\bar{p}$ state [29]. It has also initiated studies of annihilation dynamics [30–32], which are necessary for establishing parameters needed for differential measurements that could also enable the experimental observation of broad mesonic structures [27]. The main property of the SPC geometry exploited in the ASTERIX SPC was the transparency of the entrance window to soft X-rays. The advantages of the device for tracking and measuring charged particles was a bonus for the experiment. The device ($\phi_{\text{int}} = 16$ cm, $\phi_{\text{ext}} = 30$ cm, $\ell = 90$ cm, 90 sense wires, 32 ns sampling time of the FADC electronics) permitted the reconstruction of track points with an error $\sigma = 400$ μm in the transverse plane for typically 5 points per track. Neither was the signal in the cylindrical region of the wires exploited, nor the autofocus condition imposed. The z resolution of the ASTERIX SPC for the track point reconstruction of charged particles was not critical since the container of the detector was rather thin (500 μm aluminium) and surrounded by cylindrical multiwire proportional chambers equipped with cathodic strips with 3 mm pitch in the z direction. The detector provided 25% FWHM energy resolution for 5.5 keV X-rays and had a dE/dx resolution of $\sigma = 14\%$ for minimum ionizing prongs, permitting good π/K separation up to 300 MeV/c.

The central detector of the E760 experiment at FNAL is a radial projection chamber with conical internal cathode surface [3]. The experiment studies charmonium states in formation with very high resolution. The RPC provides tracking and dE/dx measurements. It exploits the property of the SPC geometry, which permits an active volume with conical internal shape and sense wires strung parallel to the beam direction. The device is positioned immediately downstream of the region of interaction of the $\bar{p}$ beam circulating in the accumulator with the H_2 beam of the jet target of the experiment. The conic shape of the internal cathode avoids flooding the detector with low-transverse-momentum prongs emitted in the bulk of interactions where charmonium states are not formed. The detector operates with $p\bar{p}$ interaction rates in excess of 10^6 s $^{-1}$.

The SPC constructed for the OBELIX experiment at LEAR [8–10] ($\phi_{\text{int}} = 6$ cm, $\phi_{\text{ext}} = 29$ cm, $\ell = 60$ cm, FADC sampling time 10 ns, 90 sense wires, 90 cathode strips) has cathode strips to get good z resolution and a central cathode with a smaller diameter than

in the ASTERIX experiment to instrument a region of space nearer to the annihilation vertex. From the beginning the detector was designed as an autonomous tracking device in order to measure, and eventually trigger on, multiplicities and secondary vertices, and to measure low-momentum recoil protons in $\bar{p}n$ annihilations in a gas D_2 target. It was also designed for detecting, identifying, measuring, and giving a trigger on X-rays of protonium or of antiprotonic deuterium atoms. It mainly exploits the property of transparency and of low-momentum threshold of the SPC geometry. It has been operated with a stopping $\bar{p}$ beam. The detector is in the phase of precalibration. The z resolution is $\sigma_z \simeq 1$ mm for X-rays; for track points the resolution in the transverse plane is better than $500 \mu\text{m}$. Typically, a track coming from the target region crosses more than 7 cells. An autonomous pattern recognition has been developed and reached a single-track efficiency exceeding 95% for minimum-bias events with $\bar{p}$'s stopped inside the target [33]. Work is in progress, along the lines mentioned in Section 2, to calibrate the detector, exploiting the autofocus property, and for measuring the track inclination in the longitudinal plane with good accuracy.

4. Prospects of applications of SPC detectors

The property of extremely high transparency of the SPC makes its use interesting at Φ factories to instrument a volume surrounding the beam pipe without introducing regeneration. Figure 4 illustrates schematically a possible detector configuration to be placed centrally in an apparatus intended to measure all detectable ϕ decay products. A thin (e.g. $6 \mu\text{m}$ thick aluminized Mylar) tube separates the counter gas based on a He mixture from H_2 gas at the same pressure. The H_2 layer electrically isolates the SPC central cathode from the beam pipe, which can have the smallest diameter compatible with safe machine operation and correspondingly the minimum thickness. The aluminized Mylar tube provides additional immunity against beam-induced electromagnetic noise on the sense wires and the cathode strips of the SPC. Regeneration in the beam pipe will be the dominant source of regeneration for all decays in the active volume of the SPC. Reduction of the beam-pipe diameter, which usually occurs after some years of operation of a storage ring, can be accompanied by instrumenting the liberated volume simply by a corresponding reduction of the Mylar tube, without any other change to the SPC, provided the electronics has enough memory depth to keep up with the increased maximum drift time. Since the event rate foreseen at all proposed Φ factories is below 10^4 s^{-1} , the rate capability is already proved by the operational experience of the ASTERIX SPC. A relatively short SPC would allow the insertion of end-cap gamma detectors near the interaction vertex. Alternatively, a long SPC would permit momentum measurement to be extended to very inclined tracks, which would have low transverse momentum.

At future single-pass colliders, the SPC geometry might prove very convenient because of the built-in safety against beam and bremsstrahlung losses and because, in view of the small beam pipe, the magnification properties of the detector could be fully exploited for double-track separation, resolution in the transverse plane, and for triggering.

For laboratory measurements with sources or active gases, the SPC geometry permits the subdivision of a given volume of gas into a large number of pixels. This offers the advantage of magnification if the source is deposited on a central cathode of small diameter (magnification factors of above 1000 appear practicable). If the source is the active gas itself, the subdivision into pixels would greatly help the identification of Auger and X-ray signals against background, and in defining a fiducial volume and calibration

volumes. Activities at LNL to miniaturize the SPC, increasing the spatial resolution and magnification, and reducing the gas volume, are presented in Ref. [16].

The use of the SPC geometry also appears to be interesting with small liquid- and solid-state imaging detectors. If solid-state detectors with bulk active volume of toroidal shape could be constructed with pixel readout located on the external periphery, extreme spatial resolutions could be achieved in the internal part of the toroidal active volume, in view of the very small pitches allowed by semiconductor technology and the magnification of the SPC geometry.

REFERENCES

- [1] U. Gastaldi, Nucl. Instrum. Methods **188** (1981) 459.
- [2] U. Gastaldi, 'Spiral projection chambers', Proc. Discussion Meeting on HERA experiments, Genoa, 1984 (Report DESY HERA 85/01, Hamburg, 1985), p. 695-722.
- [3] R. Calabrese et al., IEEE Trans. Nucl. Sci. **NS-36** (1989) 54.
- [4] U. Gastaldi et al., Nucl. Instrum. Methods **156** (1978) 267.
- [5] S. Ahmad et al., Nucl. Instrum. Methods **A286** (1990) 76.
- [6] D. Fancher et al., Nucl. Instrum. Methods **161** (1979) 383 and references therein.
- [7] U. Gastaldi et al., The X-ray drift chamber of the ASTERIX experiment at LEAR, to be submitted to Nucl. Instrum. Methods.
- [8] G. Bendiscioli et al., The Obelix SPC, Legnaro Report LNL INFN(REP) 034/90, to be published in Proc. Int. School of Physics with Low-Energy Antiprotons, Erice, January 1990.
- [9] G. Bendiscioli et al., IEEE Trans. Nucl. Sci. **NS-37** (1990) 762.
- [10] G. Bendiscioli et al., 'The Obelix central detector', Pavia Report FNT/BE 91-13, to be published in Proc. 6th Winter School on Hadronic Physics, Folgaria, 1991.
- [11] Paul-Scherrer Institut Jahresbericht (PSI, Villigen, 1989), p. 11, and H. Muheim, Dissertation, Univ. Zurich (1991).
- [12] H. Drumm et al., Nucl. Instrum. Methods **176** (1980) 333.
- [13] H. Gordon et al., Nucl. Instrum. Methods **196** (1982) 303.
- [14] D. Bernstein et al., Nucl. Instrum. Methods **226** (1984) 301.
- [15] J.E. Augustin et al., Phys. Scr. **23** (1981) 623.
- [16] U. Gastaldi et al., The micro Spiral Projection Chamber (μ SPC), these proceedings.
- [17] A. Oed, Nucl. Instrum. Methods **A263** (1988) 351.
- [18] F. Angelini et al., Nucl. Instrum. Methods **A283** (1989) 755.
- [19] S.M. Playfer et al., Studies of helium gas mixtures for low mass tracking detectors, these proceedings.
- [20] G. Charpak et al., Nucl. Instrum. Methods **167** (1979) 455.
- [21] B. Sadoulet, Proc. Int. Conf. on Instrumentation for Colliding Beam Physics, Stanford, 1982 (SLAC Rpt. 250, Stanford, 1982), p. 1.
- [22] U. Gastaldi, Nucl. Instrum. Methods **157** (1978) 441.
- [23] S. Ahmad et al. (ASTERIX Collab.), Phys. Lett. **B157** (1985) 333.
- [24] M. Ziegler et al. (ASTERIX Collab.), Phys. Lett. **B206** (1988) 151.
- [25] M. Doser et al. (ASTERIX Collab.), Nucl. Phys. **A486** (1988) 493.
- [26] M. Doser et al. (ASTERIX Collab.), Phys. Lett. **B215** (1988) 792.
- [27] U. Gastaldi, Meson spectroscopy at LEAR, invited talk at QCD '90, Montpellier, 1990; Legnaro Report LNL INFN(REP) 045/91 and CERN-PPE/91-57, to be published in Nucl. Phys. B, and references therein.
- [28] B. May et al. (ASTERIX Collab.), Phys. Lett. **B225** (1989) 450.
- [29] K.D. Duch et al. (ASTERIX Collab.), Z. Phys. **C45** (1989) 223.
- [30] B. May et al. (ASTERIX Collab.), Z. Phys. **C46** (1990) 191.
- [31] B. May et al. (ASTERIX Collab.), Z. Phys. **C46** (1990) 203.
- [32] P. Weidenauer et al. (ASTERIX Collab.), Z. Phys. **C47** (1990) 353.
- [33] L. Vannucci et al., Legnaro report in preparation.

Figure captions

Fig. 1 Transverse cut view of the SPC with spiral drift lines in the elongated region of the drift cells.

Fig. 2 Comparison of TPC, JET, and SPC geometries and structures. Dense structural material, front-end electronics, and cabling are marked in black. Light structural material is marked as hatched areas. Lines represent thin windows.

Fig. 3 Example of 2 μm thick aluminized Mylar central cathode prepared in the context of R&D for the ASTERIX SPC.

Fig. 4 Conceptual scheme of an SPC for a Φ factory.

Fig. 1

Fig. 2

Fig. 3

Fig. 4