**FIRST BEAM EXPOSURES OF A SCINTILLATING FIBRE TRACKER
READOUT BY AN ISPA-TUBE***

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Abstract

The ISPA (Imaging Silicon Pixel Array)-tube is a new position-sensitive photon detector. It represents a vacuum-sealed cylinder of 45 mm length and 35 mm diameter, which encloses a photocathode confronted at 30 mm distance with a silicon chip containing 1024 pixels of 75 μm x 500 μm edges bump bonded to their individual front-end electronics. The photoelectrons were accelerated by 20 kV potential difference towards this anode chip. Track patterns, emitted from a fibre tracker (composed of 60 μm diameter scintillating fibres) and exposed to 120 GeV/c negative pions, were readout with this tube. The Gaussian of the track residuals indicates 42 μm standard deviation σ . The centre-of-gravity precision $\varepsilon = \sigma / \sqrt{N}$ (N =number of hits) amounts to 15 μm and the angular precision of the tracks peaks at 8 mrad.

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As reported in a previous paper [1], we have developed [2,3,4] an Imaging Silicon Pixel Array (ISPA)-tube^{#1}, which replaces the commonly adopted optoelectronic chain of image intensifiers to readout track patterns from scintillating fibres. As shown in Fig. 1, it consists of a photocathode confronted at 30 mm distance by a 8 mm x 4.8 mm silicon chip^{#2} containing 1024 pixels of 75 μm x 500 μm edges. Each silicon pixel is bonded with Pb-Sn solder bumps to its proper electronic front-end channel. The electronics consist of preamplifier, comparator with adjustable threshold, delay line, coincidence logic and memory element [5,6]^{#3}. The ISPA-tube is readout in a line-parallel mode^{#4}, which is about thousand times faster than an equally sized CCD-chip. Via its pixel delay lines, the ISPA-tube can be triggered and its gating is provided by the strobed output. All its components are vacuum-sealed inside the ISPA-tube.

Fig. 1 displays the experimental arrangement with the ISPA-tube for the readout of track images from a fibre ribbon exposed to a 120 GeV/c negative pion beam in the CERN North-hall. The ribbon (5 mm thick, 250 mm long and 10 mm in beam direction) composed of eight plastic fibre bundles was closely attached to the optical fibre window preceeding the photocathode of the ISPA-tube. Each bundle^{#5} is of square cross-section with 2.5 mm edges [7] and contains about 1600 coherently aligned scintillating fibres of some 60 μm transverse dimensions, fused together by repeated drawing procedures. Each individual fibre is of hexagonal shape and separated from its next neighbours by a double cladding [8] of standard PMMA ($n=1.49$) and fluorinated polymethacrylate ($n=1.42$). All fibres were doped with the 1-component scintillator PMP420 [9,10], with its light emission peaking at 415 nm. Beam particles are selected with two scintillating fingers working in coincidence mode in front and behind the ribbon. An anticoincidence strip with a 3 mm diameter hole aligned with the two fingers, excludes tracks from the beam halo.

Our actual magnetic focussed^{#6} ISPA-tube was operated with 20 kV acceleration voltage over a photocathode-anode gap of 30 mm distance. We applied 0.05 Tesla magnetic flux density parallel to the electric field, in order to achieve one full spiral turn of the photoelectrons until they hit the anode chip at a position exactly opposite to their emission point. The oblong pixel dimensions (500 μm) were oriented parallel to the beam direction, whereas the 75 μm edges allow for spatial resolution perpendicular to the tracks.

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^{#1} Assembled and manufactured by BV Delft Electronische Producten (DEP), NL-9300 AB Roden, The Netherlands. The chip was wire bonded at U.C.I. Microélectronique, F-91946 Les Ulis, France.

^{#2} In front of the chip a diaphragm limits the active chip surface to 7 mm x 4 mm.

^{#3} We are indebted to E. H. M. Heijne, who kindly provided us with the silicon chip. The CERN-ECP Microelectronics group designed it and supervised its manufacturing at different places: Canberra Semiconductor NV, B-2430 Olen, Belgium (silicon pixel array); GEC-Marconi Materials Technology Ltd, Caswell Towchester NN 128 EQ, United Kingdom (bump bonding); Smart Silicon System SA, CH-1012 Lausanne, Switzerland (electronics).

^{#4} The 64 columns of 16 pixels can be readout at a frequency of 5 to 10 MHz, resulting in readout times of 6 to 12 μs .

^{#5} Produced by Kuraray Co. Ltd, Tokyo, Japan.

^{#6} ISPA-tube prototypes with electrostatic or proximity focussing are also envisaged, depending on the applications considered.

Typical fibre tracks are displayed in Fig. 2. They show the expected microvectors already supposed for track reconstruction [11] with the tracker layout proposed in ref. [12]. Fig. 3 shows tracks from another fibre ribbon, where two fibre bundles u and v , with fibres oblique (angle α) to the particle beam, are sandwiched between the bundles ϕ_1 and ϕ_2 , which run parallel to the beam. In this way the symmetric track displacements u and v with respect to ϕ_1 and ϕ_2 provide a stereo view of the track and indicate the track distance d from the readout face of the ribbon: $d = (u+v) / 2\text{tg}\alpha$.

The transverse hit distribution of 10^5 tracks is plotted in Fig. 4. The Gaussian with a background level of $\sim 1\%$ shows a residual standard deviation σ of $42\text{ }\mu\text{m}$, which corresponds to a two-track resolution (FWHM) of $2.4 \times \sigma = 100\text{ }\mu\text{m}$. These values are mostly due to the binary readout of the $75\text{ }\mu\text{m}$ wide pixels, which does not indicate the number of hits within one pixel. An analog readout would reduce the dominant contribution of the pixel width and result in smaller residuals. This can be improved by producing anode chips with smaller pixel widths. The measured values for the centre-of-gravity precisions ε and for the track directions (which correspond to the precisions of the generated microvectors [11,12]) are $15\text{ }\mu\text{m}$ (Fig. 5) and 8 mrad (Fig. 6) respectively^{#7}.

It should be stressed that, in contrast to other tracking devices, this arrangement produces microvectors with an average of ~ 10 pixel hits within 1.7% of radiation length rather than single hits like with silicon strips or micro strip gas chambers. Therefore, track directions are clearly indicated by a thin layer (cylindrical shell in ref. [12]) of scintillating fibres and can be used for track-extrapolations to the next fibre layers or shells [11].

During almost 1000 hours of operation, we could not notice any degradation of the tube performance and the leakage current of the detector chip stayed below 5 nA . Our future plans include the production of ISPA-tubes with larger anode area consisting of several silicon chips, the extension of the presently applied magnetic focussing of the ISPA-tubes to proximity and electrostatic ones and, in collaboration with RD19, the improvement of the present chip architecture.

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^{#7} The centre of gravity precision is related to the residual σ in fig. 4 via the number of hit pixels N :
 $\varepsilon = \sigma / \sqrt{N}$.

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FIGURE CAPTIONS

- Fig. 1 Experimental layout. The ISPA-tube digitizes with its pixel chip the track images from the fibre ribbon, which is composed of eight fused fibre bundles arranged in a double row of four. Each bundle contains 1600 fibres of $\sim 60\ \mu\text{m}$ transverse dimension. The negative pion beam traverses four bundles (10 mm). Two scintillating fingers wired in coincidence and an anticoincidence strip with its 3 mm diameter hole form a hodoscope, which is aligned with the beam and excludes most of the parasitic particles.
- Fig. 2 Typical track patterns from a 120 GeV/c negative pion beam traversing the fibre ribbon. The active frame size is 4 mm x 7 mm (along the beam). The pixel size is $75\ \mu\text{m} \times 500\ \mu\text{m}$ (along the beam). The firing pixels are clearly seen. Occasional hits aside the tracks are attributed to δ -rays.
- Fig. 3 Two examples of track patterns obtained with a stereoscopic bundle arrangement. The bundles u and v run with an angle $\pm\alpha = 7\ \text{mrad}$ oblique to the bundles ϕ_1 and ϕ_2 . The beam passes straight through all four bundles (a) and the ribbon end-face (patterns b, c) confronts the photocathode. There, its microvectors indicate the track distance from the photocathode: $d = (u+v) / 2\tan\alpha$. Note that the bundles ϕ_1 and ϕ_2 are only partly covered by the active chip frame (dashed area) and that the pixel lengths ($500\ \mu\text{m}$) do not exactly coincide with the bundle edges. The stereo angle is about ten times smaller than in ref. [11,12] in order to match the bundles u and v with the active chip frame.
- Fig. 4 Residuals from 10^5 beam tracks (circles) and their Gaussian fit. The values for the standard deviations σ and full widths at half maximum (FWHM) are due to the binary readout, which does not indicate the number of hits within one pixel. An analog readout would reduce the dominant contribution of the $75\ \mu\text{m}$ pixel width and improve σ and FWHM.
- Fig. 5 Measured centre-of-gravity precision ϵ . It is related to the residuals σ of Fig. 4 via the number of hit pixels N : $\epsilon = \sigma / \sqrt{N}$. The asymmetric shape is mainly due to the diminishing number of hit pixels at the right-hand part.
- Fig. 6 Measured direction precisions of 10^5 accumulated tracks. They indicate the accuracy with which the microvectors of a tracker plane or shell [11] can be projected to the next plane or shell.

Fig 1

Fig. 2

a

b

c

Fig. 3

Fig. 4

Fig. 5

Fig. 6