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IMAGING PERFORMANCE OBTAINED WITH FUSED BUNDLES OF SCINTILLATING FIBRES*

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Abstract

Fused bundles of 60 μm diameter scintillating fibres with square cross sections of 2.5 mm edge length, were illuminated through 2 m length and their exit faces magnified and then photographed with a highly resolving CCD-camera. Subsequent, rows of individual fibres were selected with an appropriate slit or grid in front of the entrance face. The pictures taken, stored in a McIntosh computer, were processed to determine the coherency, the intrinsic optical precision and the resolution of these bundles without distortions by optoelectronic readout systems: the precision (sigma) varied from 18.4 to 22 μm and the resolution from 42 to 55 μm , depending on the angular deviation from parallel slit orientation.

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1. INTRODUCTION

Small diameter scintillating fibres are indispensable to achieve high precision, excellent two track resolution, extremely low occupancy and therefore sufficiently small fractions of ambiguous tracks for central tracking [1] within the barrel regions of particle detectors at future colliders. Since fibre diameters below some 200 μm become difficult for individual handling and precise alignment, we developed what we call fused fibre bundles*. These are square or rectangular shaped strands of required length and geometrical cross-sections with edge dimensions between 1 mm and a few millimetres. The diameters of individual fibres are between 30 and 100 μm depending on the requirements on light attenuation and optical resolution.

Apart from measuring attenuation lengths and counting photons with such multibundles - these results will be published in a separate paper - we took photographs of patterns imaged through these bundles (see fig. 1). In this way, we wanted to establish the degree of fibre coherency, the precision (sigma) of single fibre rows, the optical resolution between two fibre rows and the impact of angular deviations from parallel slit arrangements. This latter would simulate particle tracks bent by solenoidal magnetic fields oriented parallel to the beam axis.

2. EXPERIMENTAL PROCEDURE

For our measurements we used fused fibre bundles of 2 m length with square cross-sections of 2.5 mm edges containing about 1600 individual fibres as shown in fig. 1. The individual fibres are of hexagonal shape and share their cladding accordingly with their adjacent neighbours. The relevant dimensions are indicated in fig. 2. The bundle end faces were machined with an appropriate diamond tool to achieve the required optical quality. This treatment was preferred to a grinding procedure, where the results varied by a large extent between various samples.

Photographs were taken with the arrangement shown in fig. 3. The Lamp illuminated uniformly the bundle entrance and its exit was magnified and focussed onto a CCD-camera containing 442000 pixels. The pictures were stored for further processing in a McIntosh computer. To select single fibre rows, a slit of 10 μm width could be placed between the lamp and the bundle entrance. To simulate slanting tracks this slit could be turned at different angles with respect to the vertical fibre rows. In order to confirm the coherency of the fibre bundles, a grid could be placed in front of the bundle entrance face. In this way it could be photographed through the whole bundle length and any distortions would show up on the pictures taken. To photograph a single fibre and his six closest

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neighbours (fig. 2), a microscope objective was placed in front of the bundle entrance face to focus the illuminating light directly on the fibre in question [2].

3. RESULTS

Firstly, pictures were taken without slit or grid in front of the bundle entrance face to check the transmission performance of the fibres contained in the bundle. A typical result of this procedure is shown in fig. 1. Slight variations of light intensities are caused by polishing defects or dust particles. Black spots only would indicate bad or no light transmission through the fibre in question. As can be seen, the bulk part of the fibres are accurately arranged within the bundle, apart from some cushion distortions close to the bundle edges. According to this picture it is already obvious, that there is not much room for fibre misalignments.

With the 10 μm slit in front of the bundle entrance face, we took photographs like the example shown in fig. 4a, which shows a single row of individual 60 μm fibres. In scanning across this row we determined the exposed light intensity via the charges deposited in the CCD-pixels. A typical result is plotted in fig. 4b versus the transverse fibre dimension. The average precision (σ) achieved in this way is 18 μm for 60 μm fibre diameter.

In a next step we increased the slit width to 80 μm in order to span two fibre rows. The result is shown in fig. 5, which shows a photograph (5a) together with the histogramme from the corresponding scanning procedure. The optical resolution amounts to 50 μm between the two fibre rows.

With the slit width reduced to 10 μm again, the slit was turned stepwise by 1.2, 17 and 30 degrees and typical results of this exercise are shown in figs 6 a, b, c, respectively, together with the corresponding histogrammes. The result is a small broadening of the line shape as compared to the single row with parallel slit (fig. 4) and therefore an increased sigma (precision).

Finally, we introduced the grid between the illuminating lamp and the entrance face of the fibre bundle. Since with a pitch of 100 μm the grid did not match completely the pitch of the fibre rows, we photographed four rows only, interspaced by three rows, which were covered by the struts of the grid. Typical results are shown in fig. 7a and 7b.

4. DISCUSSION

In a central tracker, the fibre bundles will be arranged in two or more cylindrical shells at distances between 0.5 m and 1.3 m from the collider axis as shown in figs 2 and 3 of reference [1]. Each shell is composed of layers with different fibre orientation. Fibre

bundles, stretched parallel to the collider axis and 1.5 to 3.5 mm thick, indicate the (r, φ) -coordinates, with r meaning the radial distance and φ the azimuth angle with respect to the collider axis. The two other layers with oblique fibre bundles, running at a few degrees with respect to the parallel ones, provide via their corresponding stereo view the z -coordinate of the particle track and are between 2 mm and 6 mm thick.

Only tracks of particles with transverse momenta exceeding some 10 GeV/c are of interest for further data acquisition, in contrast to the debris of minimum bias events with less than 1 GeV/c transverse momentum. In a solenoidal magnetic field, oriented parallel to the collider axis, the tracks of charged particles are bent in the (r, φ) -plane. These bents show up within the thin fibre layer of a shell as small stubs oriented according to the p_t momentum of the particle. Since we intend to orient our fibre bundles around the shells in such a way that the fibre rows point to the beam axis, as indicated in fig. 1 (arrow), the angular deviation of these stubs amount to $\tan \omega = (0.3 B r / p_t)$, with ω meaning the angle between stubs and fibre rows indicated in fig. 1, B [T] the magnetic flux density, r [m] the bundle distance from the beam and p_t [GeV/c] the transverse momentum. Angular deviations for three magnetic inductions are displayed versus p_t momentum in fig. 8.

The packing fractions, i.e. the ratio between the fibre core cross-sections and the total cross-section of the fibre bundle, are plotted in fig. 9 versus the individual fibre diameters. The two upper curves are for hexagonal fibres sharing their claddings between adjacent neighbours. Cladding thicknesses of 5 μm and 3.4 μm result in packing fractions of 0.85 and 0.90 respectively for 60 μm fibres. Circular capillaries filled with scintillating liquids achieve only 0.67 packing fraction for 60 μm diameter, since they cannot share their 5 μm claddings between their next neighbours and in addition form necessarily interstices.

To conclude, our measurements indicate the intrinsic optical precision and resolution of fibre bundles containing 60 μm diameter individual fibres, without any contributions of the opto-electronic readout. The measured values are 18.5 μm precision (sigma) and 42 μm resolution (full width at half maximum) for straight tracks parallel to the fibre rows. For tracks bent by the magnetic field these values become 22 μm (sigma) and 55 μm (full width half maximum), if we average between 1.2 and 30 degrees angular deviation. Finally, the fibre coherencies within these bundles turned out to match perfectly our requirements.

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REFERENCES

- [1] C. D'Ambrosio, T. Gys, H. Leutz, U. Gensch and S. Schlenstedt, to be published in Nucl. Instr. and Methods.
- [2] C. D'Ambrosio, H. Leutz, T. Shimizu, O. Shinji, J. Sun and M. Taufer, Nucl. Instr. and Methods in Physics Research, A306, (1991) 549

FIGURE CAPTIONS

- Fig. 1 Square fibre bundle with 2.5 mm edge length containing about 1600 individual fibres of 60 μm diameter. The photograph is taken through 2 m bundle length. The arrow indicates the bundle orientation to the normal to the beam axis and the angle ω .
- Fig. 2 An individual fibre surrounded by its six adjacent neighbours.
- Fig. 3 Experimental arrangement for the photographs. The lamp illuminated uniformly the bundle entrance. The bundle exit was focussed with a telescope onto a CCD-camera. The pictures were stored in a McIntosh computer. To select individual fibre rows, a slit or, for more rows, a grid could be placed alternatively in front of the bundle entrance.
- Fig. 4 Single fibre row photographed with the 10 μm slit in front of the bundle entrance (a). The transverse intensity distribution (b) yields not a Gaussian due to the hexagonal fibres. Therefore the usual 2.36-factor between sigma and the full width at half maximum does not hold.
- Fig. 5 Two adjacent fibre rows photographed with 80 μm slit width (a). The transverse intensity distribution (b) indicates a resolution between two tracks of 50 μm .
- Fig. 6 The 10 μm slit turned at 1.2 degrees (a), 17 degrees (b) and 30 degrees (c) with respect to the vertical row of fig. 4. Precisions σ and full width at half maximum are indicated at the corresponding histogrammes.
- Fig. 7 Photograph of a bundle region taken with the grid (fig. 3c) in front of the bundle entrance (a). The corresponding intensity distribution (a) is partly affected by the slight mismatch between fibre and grid period.
- Fig. 8 Angular deviations of particle tracks from radial directions due to various magnetic flux densities versus p_T -momenta.
- Fig. 9 Packing fractions of hexagonal shaped fibres (with claddings of 3.4 and 5 μm respectively) and circular capillaries (5 μm cladding) versus their diameter.

Fig. 1

Fig. 2

Experimental Set-up

Fig. 3

a)

b)

Fig. 4

a)

b)

Fig. 5

1.2°

a)

b)

Fig. 6a

a)

b)

Fig. 6b

a)

b)

Fig. 6c

a)

b)

Fig. 7

Fig. 8

Fig. 9