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A NOVEL APPROACH FOR AN INTEGRATED STRAW TUBE-MICROSTRIP DETECTOR

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Abstract

We report on a novel concept of silicon microstrips and straw tubes detector, where integration is accomplished by a straw module with straws not subjected to mechanical tension in a Rohacell lattice and carbon fiber reinforced plastic shell. Results on mechanical and test beam performances are reported on as well.

Index Term: Elementary Particles, Detectors, Tracking

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1 CONCEPT

Modern physics detectors are based on tracking subcomponents, such as silicon pixels and strips, straw tubes and drift chambers, which require high space resolution, large geometrical acceptance and extremely large-scale integration. Detectors are often requested with demanding requirements of hermeticity and compactness that must satisfy the minimization of materials. We have developed for the BTeV experiment[1] an integrated solution that accommodates straw tubes and silicon strips in a common structure. Our novel design utilizes glued straw tubes mechanically un-tensioned and embedded in a Rohacell lattice. The straw-Rohacell composite is enclosed in a carbon fiber reinforced plastic (CFRP) shell and supports the microstrip detector. Un-tensioned straw tubes have been used in the past [2]. The untensioned straws in the ATLAS TRT detector [3] at LHC need support dividers every 25cm of their lengths, and four sets of thin carbon fiber filaments each to provide required stiffness. The TOF detector [4] at COSY uses a very large gas overpressure (2bar) for straw stiffness. Our design avoids supports and filaments, operates straws in standard conditions of very small gas overpressure, and allows integration between straws and microstrip detectors.

2 BTEV DETECTOR

The BTeV experiment[1] at the Fermilab proton-antiproton collider (the Tevatron) will produce and study particles containing the beauty heavy quark, in order to investigate the phenomenon called CP violation, and understand if the Standard Model of particles and interactions is sufficient to describe the world we live in. BTeV is composed of tracking detectors (pixel, strips, straws) for detection of charged particles, a RICH Cerenkov detector for identification of pions, kaons and protons, a crystal EM calorimeter for detection of neutral particles (photons, π^0) and identification of electrons, and a muon detector. The experimental setup is shown in Fig. 1.

3 M0X CONCEPT

The M0X module is a special module to be placed closest to the beam, measuring the x-coordinate of tracks. It houses straw tubes and supports silicon strip detector planes. M0X is made of straw tubes embedded in a Rohacell IG50 foam, inside a CFRP shell. Straws are glued together and onto the foam, the foam is glued to the CFRP shell. CFRP is chosen to allow the fabrication of a rigid mechanical structure with high transparency to incoming particles. CFRP is also used for the M1 modules, conventional straw tubes sub-detectors that act as struts sustaining the mechanical tension of the remaining straw modules. Six straw-microstrip stations are deployed in BTeV, each station made of three views (X, U, V), each view made of two half-views. The X view (vertical straws) measures the X coordinate, while the two stereo views (U,V) are at $\pm 11.3°$ around the Y bend coordinate. Straw inner diameter is 4mm, straw lengths vary from 54cm in the first station to 231cm in the sixth station. Fig. 2 shows a conceptual design of M0X and M1X assembly (left), and a 60-cm-long prototype with straws embedded in Rohacell (right).

4 TOMOGRAPHY

A check of the eccentricity of the straws and of their positions in the grooves can be done with a tomography method. The tomography uses X-rays and can reconstruct sections of the scanned region. The technique determines location and geometry of straws by reconstructing images of their cross sections. Computed images are reconstructed from a large number of measurements of X-ray transmission. Reconstruction provides 2-dimensional and 3-dimensional images of straws. 2-dimensional images of 6-channel M0X prototype, 3-dimensional reconstruction, and 2-dimensional image of final assembly technique M0X prototype are shown in Figure 3 left, center, right, respectively. Preliminary results show that a precision of about 20μm can be reached on the measurement of straw radii. The maximum variation from circularity allowed is 100μm, in order not to change the straw gain by more than 10%.

5 FINITE ELEMENT ANALYSIS

A finite element analysis (FEA) [5],[6] allows to estimate the displacements of the M0X module under the loads of the microstrip detectors and straw tubes. Time stability and maximum displacements of the order of $10\,\mu$m are requested, in order not to spoil the space resolution of the microstrip detectors. The FEA analysis has been carried on the M0X of the sixth station, the longest straw length. A straw load of 12N in each corner of M0X has been simulated to reproduce the mechanical tension of wires. A straw load of 12N and a torque of 2Nm have been applied to simulate the weight of the micro-strip. The geometry and mechanical properties of materials used are reported in Tab.1. Fig. 4 shows the graphical output of FEA with isocurves of deformation under simulated load of microstrip detector and associated electronics. Maximum deformation is pointed to by arrow in Fig. 4. FEA shows a maximum displacement of about 15μm (4μm in the axial direction, 9μm x direction, 11μm y direction), close to the required specification. We have used shell elements for the simulation of the carbon fiber reinforced polyester structure and bricks for the Rohacell simulation. Beam elements were used for introducing glue between the CRFP module and the cylindrical plate where microstrips were placed. The geometry shown in Tab.1 and Fig. 4 corresponds to a $0.007X_0$ material thickness in radiation lengths units, which represents a 60% reduction in material with respect to a design with independent supports.

Table 1: *Geometrical arrangement (thicknesses), Young modules (E_{11}, E_{12}, E_{22}), and Poisson coefficient (ν_{12}) used in FEA simulation of M0X.*

	M0 and M1 Structure	Micro Strip Cylinder	Rohacell Foam Foam
Thickness [mm]	0.07 each ply with fibres disposition of 0/90/0	0.07 each ply (0/90/0) with a Rohacell foam of 5cm	2
$E_{11}[GPa]$	260	590	0.019
$E_{22}[GPa]$	10	10	-
$E_{12}[GPa]$	7.2	7.2	-
ν_{12}	0.3	0.3	0.3

6 FBG Sensors

Fiber Bragg Grating (FBG) sensors have been used so far as telecommunication filters, and as optical strain gauges in civil and aerospace engineering [7], and, only recently, in HEP detectors [8]. The BTeV detectors utilize Fiber Bragg Grating (FBG) sensors to monitor online the positions of the straws and microstrips. The optical fiber is used for monitoring displacements and strains in mechanical structures such as the straw tube-microstrip support presented here. A modulated refractive index along the FBG sensor produces Bragg reflection at a wavelength dependent on the strain in the fiber, permitting real-time monitoring of the support. According to these properties, an FBG sensor is going to be placed in the M0X structure between the Rohacell foam and the CFRP shell. Sensors will be located in spots of maximal deformation, as predicted by FEA simulation. Fig. 5 shows long-term behaviour of FBG sensors while monitoring micron-size displacements, compared to monitoring via photographic methods.

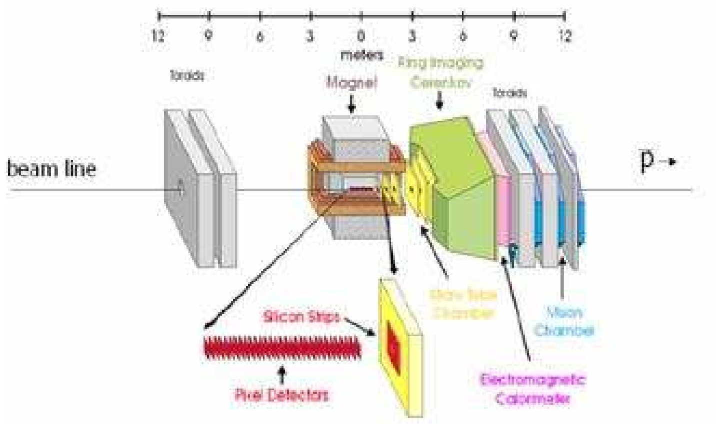

Figure 1: BTeV detector layout; the straw tube chamber are in yellow, the silicon strips in red.

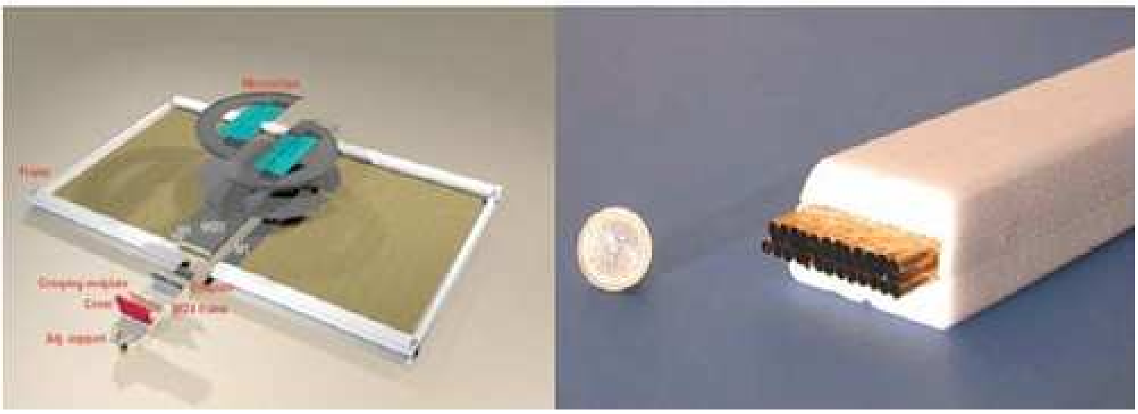

Figure 2: Exploded view of BTeV microstrip and straws tubes integration (left); M0X prototype with straw tubes embedded in Rohacell (right).

7 PROTOTYPE

M0X prototypes have been fabricated in order to study the construction procedures, mechanical properties, material characterization, and physical behaviour for detection of particles in test beam set-ups. Straw materials such as mylar and kapton have been studied and characterized for tensile properties under exposure to Ar-CO_2 mixtures [9]. The

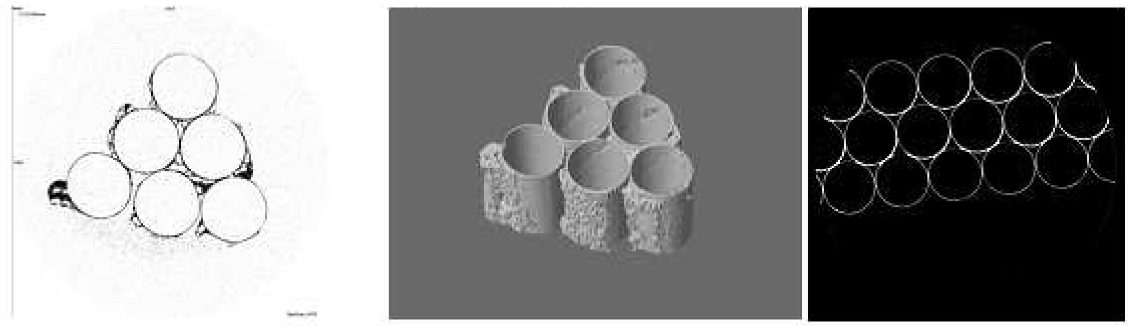

Figure 3: 2-dimensional images of 6-channel M0X prototype (left); 3-dimensional reconstruction (center); 2-dimensional image of final assembly technique M0X prototype (right). Tomographs are for straws at the foam-supported stage.

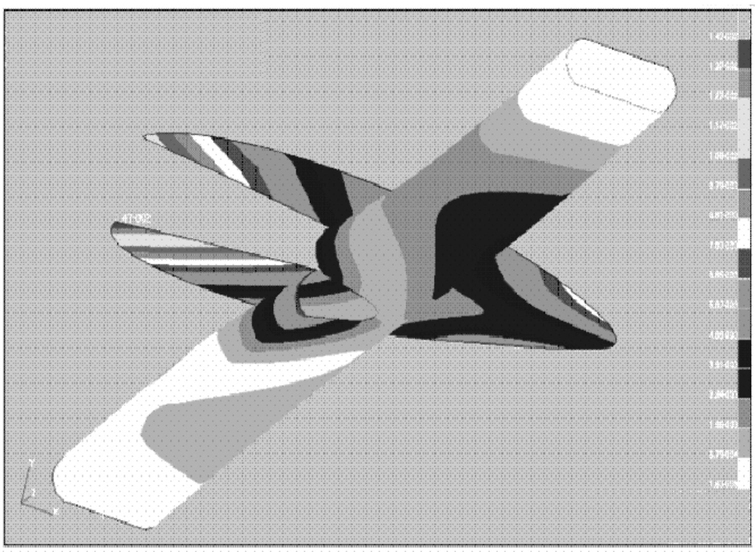

Figure 4: FEA results for the simulation of M0X (straws-Rohacell -CFRP) straw-microstrip detector. Geometry and materials are shown in Tab.1. Colour levels show curves of equal deformation under simulated load of microstrip detector and associated electronics. Units are micrometers. Maximum deformation is 14.7 μm (arrow).

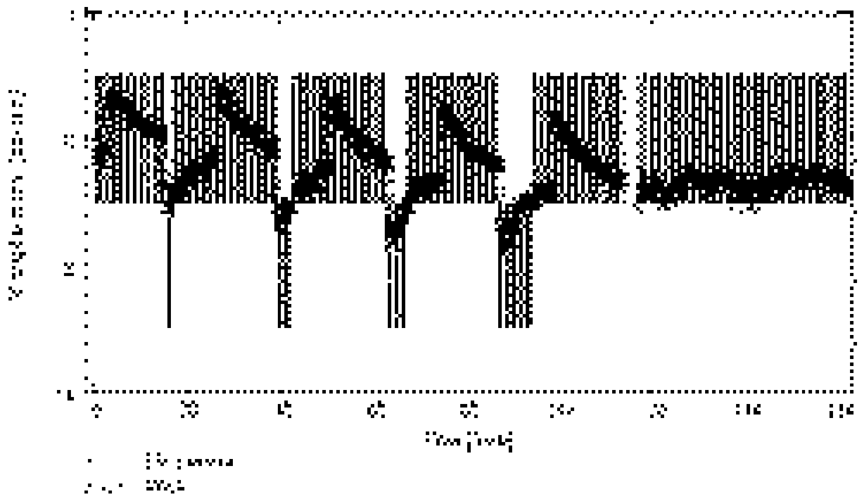

Figure 5: FBG long-term monitoring stability results. FBG output (crosses) is validated by TV camera (bars). The bar size indicates the best resolution of TV camera.

Figure 6: M0X module prototype during assembly. Straw tubes are glued together and positioned between end-plates (one shown) without mechanical tension. Rohacell foam and CFRP shell not shown.

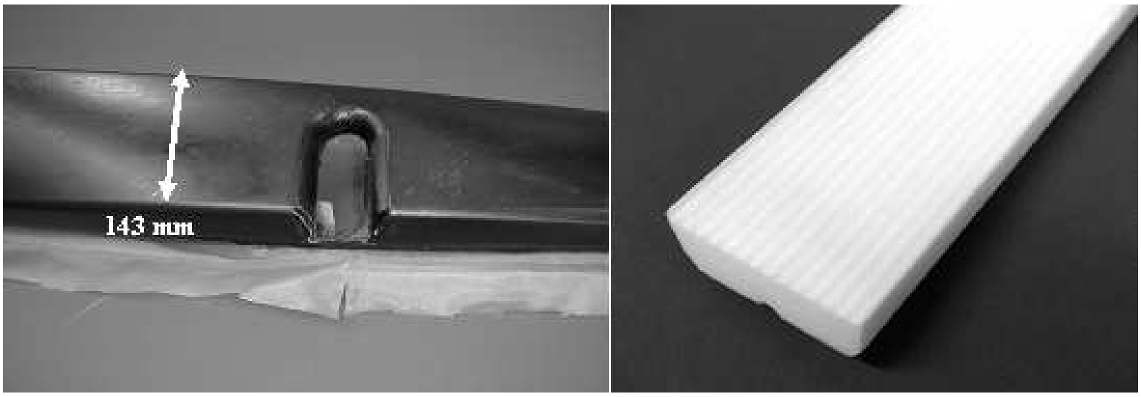

Figure 7: CFRP shell prototype immediately after fabrication (left); grooved Rohacell foam (right).

Figure 8: Cosmic rays signals in M0X prototype with (Ar-CO_2 80/20) gas mixture. High-voltage applied is 1400V, a transimpedance preamplifier provides a $2V/mA$ gain.

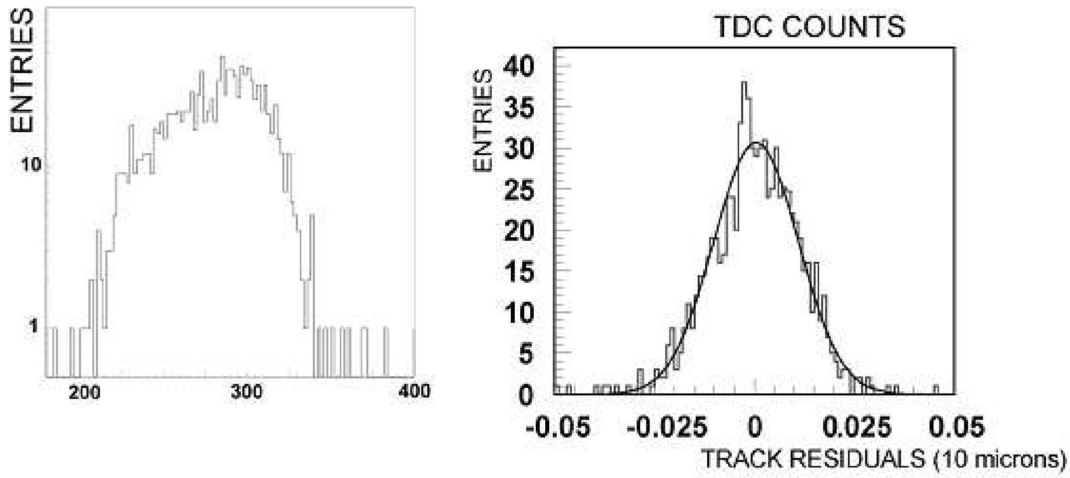

Figure 9: Distribution of drift times from beam particles. Times are expressed in time-to-digital-converter counts (300ps/count), Ar-CO_2 (80/20) gas mixture is used, with 10mV threshold (left); tracks residuals of beam particles tracks reconstructed by the M0X prototype, the distribution of residuals is well fitted by a Gaussian with a rms width of about 130μm (right).

most demanding design requirement is the assembly of straws in a close pack, with no mechanical tension applied. Several gluing techniques have been examined and tested to determine the optimal technique. Straw tubes are glued together in three layers, and the upper and lower layer are glued to the Rohacell foam. Glues with different viscosity, and several gluing techniques, have been used. Glues tested range from cyanoacrylate (Loctite 401) to epoxy (Eccobond series). Gluing techniques ranged from brush, to injection, to spray gluing. The most promising results have been obtained by using an Eccobond 45W and catalyst mixture (1:1 by weight), diluted with dimethylcheton solvent. For each 40g of glue-catalyst mixture, 40cm^3 of solvent was used.
The assembly process proceeds as follows. Stainless steel rods (4-mm-diameter) are inserted in each straw tube. A straw layer is formed by locating 16 straws on a machined grooved plate. The glue-solvent mixture described is sprayed, with 2bar air pressure, and 20cm distance between spray gun and straw layer. Mechanical pressure is applied to layers during curing. After curing at room temperature, the straw layers are sprayed again and more layers are superimposed. After additional curing, the stainless steel rods are removed from the straws. The mechanical pressure applied during curing allows loose (0.1%) requirements on rod straightness. Conductive contact between straw cathodes and aluminum endplate, is accomplished via spraying of Eccobond 57C. Fig. 6 shows a com-

plete prototype after gluing, with endplate for wiring on one side. The glued layers of straws provide excellent stiffness (see Sect. Tomography) for operation, without need of Rohacell foam which, instead, contributes to mechanical properties when used in integration with microstrip detector. Fig. 7 shows detail of the CFRP shell near the beam pipe region (left), and the grooved foam (right).

8 Cosmic Ray And Test Beam Results

Preliminary results with cosmic rays show very clean pulses (Fig. 8) in gas mixtures of interest for BTeV (Ar-CO_2 80/20), with shape parameters typical of operation with such mixtures. High-voltage applied is +1400V, a trans-impedance preamplifier [10] provides a 2V/mA gain, followed by a low-walk double-threshold discriminator [11]. Prototypes have been exposed to beam particles in the Frascati Test Beam Facility [12]. Preliminary results show the expected response of prototype to minimum ionizing particles. The distribution of drift time of the ionization electrons to the sense wire (Fig. 9 left) over the straw 2mm radius is compatible with the drift velocity in the Ar-CO_2 (80/20) gas mixture used. A 10mV threshold is applied. Beam particles tracks are reconstructed by the M0X prototype, tracks residuals are shown in Fig. 9 right. The distribution of residuals is well fitted by a Gaussian with a rms width of about 130μm.

9 Conclusions

We have developed a novel concept for integration of straw tubes tracking detectors and silicon microstrip detectors, for use in HEP experiments at hadron colliders. In our design, silicon microstrips are integrated to a special straw tube module M0X via a CFRP mechanical structure. M0X is realized via glued straws embedded in a Rohacell lattice with no need of mechanical tension. Detailed finite element analysis shows that deformations affect negligibly the tracking performance of the system. A complete system based on Fiber Bragg Grating sensors - acting as optical strain gauges - monitors the position of each sub detector with micron resolution. Test beam studies are underway to verify that M0X can provide the 200μm resolution needed by the BTeV tracking detector requirements.

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