

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/AE-95/09
10 Marzo 1995

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Presented at the

"4th International Conference on Advanced Technology and Particle Physics"
Como, Italy, 3-7 October 1994

To be Published on
"Nuclear Physics B Proceedings Supplement"

SIS-Pubblicazioni
dei Laboratori Nazionali di Frascati

THE SMALL ANGLE TILE CALORIMETER PROJECT IN DELPHI

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The new Small Angle Tile Calorimeter (STIC) covers the forward regions in DELPHI. The main motivation for its construction was to achieve a systematic error of 0.1% on the luminosity determination. This detector consists of a "shashlik" type calorimeter, equipped with two planes of silicon pad detectors placed respectively after 4 and 7.4 radiation lengths. A veto counter, composed of two scintillator planes, covers the front of the calorimeter to allow $e - \gamma$ separation and to provide a neutral energy trigger.

The physics motivations for this project, results from extensive testbeam measurements and the performance during the 1994 LEP run are reported here.

1. Introduction

The STIC project started in mid 1992 [1] to equip the DELPHI experiment at LEP with a new luminosity monitor, which was installed in time for the 1994 run. To match the statistical errors on the determination on the hadronic cross section at the Z^0 peak, the systematic contribution to the luminosity determination must be below 0.1%. The luminos-

ity is determined from the measurement of small-angle elastic (Bhabha) scattering (for which the theoretical cross-section is well known) into a precisely defined acceptance region. A better than 0.1% systematic error translates into the need of a precision of better than 50 μm in the total bias at the inner edge of the used acceptance region. This requires an hermetic calorimeter, with a projective structure and a uniform energy response. Good

energy resolution is also important in high precision luminosity measurements to separate background events from radiative Bhabha interactions.

When LEP will run above the Z^0 peak, the STIC will be essential for the detection of small angle γ 's in radiative events.

In addition, the STIC can tag the small angle scattered electrons in two photon physics and cover a gap in the forward regions that existed between the old luminosity monitor (SAT) and the Forward Electromagnetic Calorimeter (FEMC).

All these physics requirements have led to the construction of a new luminosity monitor for DELPHI (the STIC calorimeter), with the additional capability to trigger on isolated neutral showers (with the scintillator Veto Counter system). A shower maximum detector, consisting of two silicon pad planes inside the calorimeter, can be used to reconstruct the direction of the incoming shower axis and will provide a limited $e - \pi$ separation (for more details see [2]).

2. The STIC components

The STIC detector consists of two calorimeters located at ± 220 cm from the interaction point and these cover the angular regions between 29 and 185 mrad. One detector arm is shown in figure 1, with the scintillator planes in front (the Veto Counter), the silicon pad detector and the system of tungsten masks. One of these masks ("the Tungsten nose") is used to define the inner edge of the acceptance for Bhabha scattering in one arm of the STIC. The so-called outer and in-

ner shields protect the DELPHI detectors from synchrotron radiation. The STIC is mounted around the beampipe inside the 1.2 Tesla magnetic field of DELPHI.

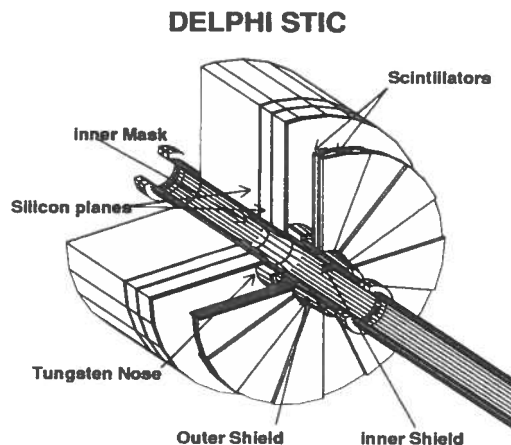


Figure 1. Layout of STIC, the Veto counters and the tungsten masks.

2.1. The STIC Calorimeter

Each STIC calorimeter is divided into two half-cylindrical modules. Longitudinally each detector is divided up into 47 sampling layers plus two silicon pad layers. Each sampling layer is made of 3.4 mm stainless steel laminated lead plates and 3.0 mm polystyrene based scintillator (doped with 1.5% PTP + .05% POPOP) as active media, for a total thickness of 27 radiation lengths. Layers 8 and 15 consist of the two planes of silicon pad detectors. To avoid cracks the lead absorber forms a continuous plate, while the scintillator planes are made of tiles. These

are optically separated by 120 μm thick white Tyvek¹ paper, which acts as a diffuser. The tiles are arranged into 8 azimuthal sectors (22.5° wide) and 10 radial sectors (see figure 2), for a total of 80 towers per module. The optical read-

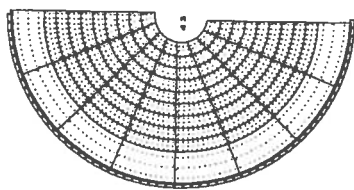


Figure 2. One scintillator plane in a STIC calorimeter module. Holes for WLS fibers are also shown.

out is made by 1 mm fibers² doped with Y7 green wavelength shifter, running orthogonal to the active planes and grouped together at the back of the calorimeter by a clamp fixed on a supporting plate. The fluctuations in energy response over the calorimeter surface [3] were minimized by choosing a suitable combination of continuous absorber plates and optimal WLS fiber density (about 1 fiber/cm²).

The end of the fiber bundle from each tower is seen by 1" phototetrodes³ after a 5 mm air gap. Phototetrodes were chosen as they can operate inside high magnetic fields. A charge preamplifier and a high voltage divider are mounted

inside a light-tight aluminium cylinder, which holds each tetrode. The differential output signal is fed into the shaper and ADC boards developed for the phototriode readout of the FEMC.

2.2. The Veto System

The STIC Veto System consists of 64 trapezoidal scintillation counters arranged into two planes in front of each calorimeter. The counters are made of 10 mm thick plastic scintillator⁴ and the scintillation light is collected at the edges by bundles of WLS fibers. The light is taken out of the magnetic field by 10 m long clear optical fibers⁵ and then collected by 10 stage photomultipliers⁶.

The response of the Veto counters is around 20 photoelectrons per MIP. Asking a MIP requirement on both counters, testbeam measurements give an efficiency $\geq 99.7\%$ for charge particle identification and a loss of neutral triggers around 5%, due to calorimeter albedo.

2.3. Quality Control of Components

The production of all the relevant parts of the detector (mechanics, WLS fibers, tetrode readout, etc) have been carefully studied and monitored during the construction.

The radius of the first and second ring has been measured for all the half cylinder sampling layers using an optical X-Y table (accuracy 5 μm) and the values obtained were within $\pm 50 \mu\text{m}$ from the nominal geometry [5]. A very precise positioning of

¹Tyvek[®] is Du Pont's registered trademark for its spunbonded olefin

²Kuraray fibers: polystyrene core, F-PMMA cladding

³R2149-03 phototetrodes from Hamamatsu

⁴BC-408 plastic scintillator from Bicon

⁵PST Kuraray fibers

⁶Hamamatsu H3165 photomultipliers

each scintillator tile on the lead plate was obtained by means of two alignment dowels in each tile. All precision mechanics has been made in a controlled temperature environment ($21^0 \pm 0.5^0$). The weight of each absorber plate was measured with a dispersion of 67 g around the nominal weight, corresponding to a variation in the lead thickness of 20 μm .

To obtain the best uniform response possible from the calorimeter, the light yield and attenuation length of each WLS fibre was also measured by using a computer controlled scanning table (with a precision of 20 μm) equipped with an EMI 9813KB photomultiplier and a scintillator excited by a ^{90}Sr source. In a total of ~ 10000 fibres, 10% have been rejected.

Extensive studies of the behaviour of the chosen phototetrodes inside high magnetic fields were performed, using a superconducting solenoid at LASA, INFN Milano. In particular the dependence of the gain of the tubes with respect to magnetic field intensity and orientation were measured [6]. The highest gain (~ 1.9) and the most stable operation were obtained with an angle of 15^0 between the phototube axis and the magnetic field, as shown in figure 3. As a consequence the tetrotodes were mounted with a 15^0 angle inside STIC.

3. Testbeam results

The X5 unseparated beam of the CERN West Area, which provides high purity electrons from 10 to 100 GeV/c, was used in November 1992 to test a small 3×4 cells prototype [4]. These measurements

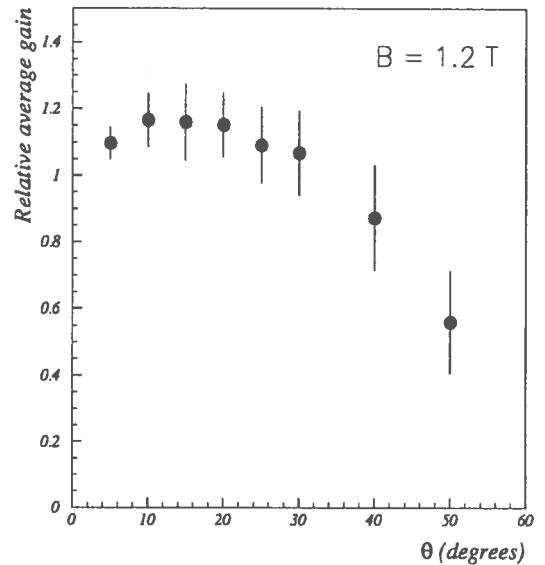


Figure 3. Average tetrotode gain inside a 1.2 T magnetic field, as a function of the angle of the tetrotode to the field (error bars show rms spread)

were repeated in 1993 with two different modules in the CERN West Area X3, X5 and X7 beamlines.

Data at 10, 20, 45, 60, 70 and 100 GeV were taken to measure the energy resolution and the uniformity of the response. Calibration runs obtained by injecting charge pulses at the preamplifier input and pedestal runs were also periodically taken.

In some of these runs the impact point of the beam particle was measured with an accuracy of $\pm 40 \mu\text{m}$ by using a silicon microstrip telescope.

3.1. Energy linearity and resolution

The deviation from linearity of the calorimeter response is within $\pm 1\%$. The results obtained for the energy resolution are shown in figure 4. The fit gives:

$$\sigma/E(\%) = (1.52 \pm 0.02) \oplus (13.5 \pm 0.1)/\sqrt{E}$$

This results in a resolution of 2.5% for 45 GeV electrons. The contribution of the electronics noise to the resolution is negligible ($\sigma \simeq 90$ MeV). The response to MIPs was satisfactory: about 4.5σ from the pedestal. A GEANT Monte Carlo sim-

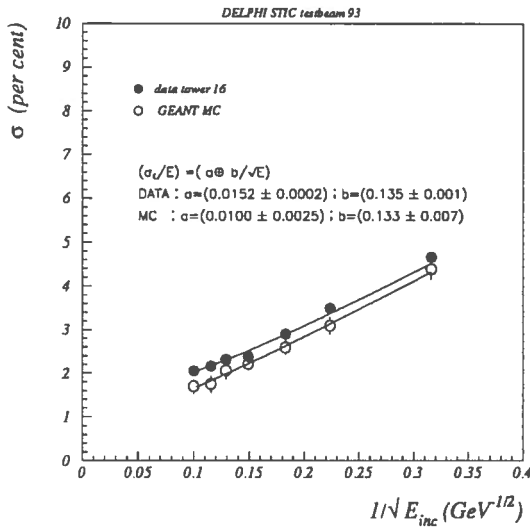


Figure 4. Energy resolution measured for a STIC module. The black points are the experimental data and the open dots a Monte Carlo simulation.

ulation [7] including an accurate description of the geometry, light collection of the

WLS fibres and the light attenuation has been performed. While the sampling term is well reproduced, there is a difference in the constant term which is most likely due to an imperfect simulation of the light collection mechanisms and fluctuations.

3.2. Spatial uniformity

Spatial scans have been made with 45 GeV electrons in several regions of the detector. The measured energy per tower is shown in figure 5 as a function of radius together with the total energy in all towers. The typical distribution given by the energy sharing between adjacent towers (1 to 4) is clearly visible. The spatial non-uniformities in the overall calorimeter response are less than 2% as shown in the same figure by the three lines, which show the 45 GeV value together with $\pm 2\%$ deviations.

3.3. Position reconstruction

In a luminosity monitor it is essential to have good definition of the inner edge of the acceptance. In DELPHI this is obtained by use of a precisely-machined tungsten mask that translates an energy cut into an acceptance cut [8]. The “mask” method used by DELPHI was studied scanning the border of a 6 cm thick piece of tungsten covering part of a module. The results, shown in figure 6, give a transition region of $\sim 90\mu\text{m}$, corresponding to $\sigma \sim 25\mu\text{m}$.

To reconstruct the radial impact position, with the calorimeter alone, the ratio of energy below and above a tower ring was measured as a function of the radial coordinate (as given by a silicon mi-

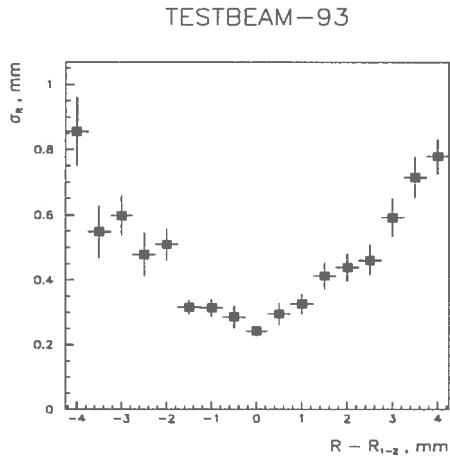


Figure 7. The STIC resolution (σ_r) in a radial scan close to the border between two towers (45 GeV electrons)

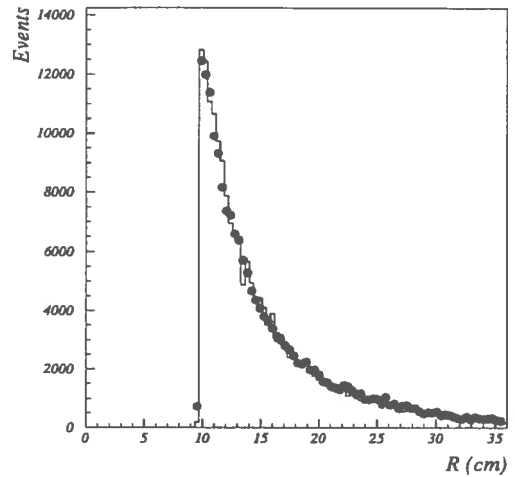


Figure 8. Radial distribution of Bhabha electrons reconstructed with STIC. Note the sharp cutoff at a radius of ~ 9.7 cm due to the tungsten nose. The points are from a Monte Carlo simulation and the histogram is data

5. Conclusions

The STIC detector is presently operating as the DELPHI luminosity monitor and already at this preliminary stage of the analysis is close to its design parameters. It extends the calorimetric coverage of DELPHI both at the inner edge, thus improving the statistical accuracy of the luminosity measurement, and at large impact radii thus closing a gap that existed between the old luminosity monitor (SAT) and the forward electromagnetic calorimeter (FEMC).

The Veto Counter System provides a trigger on single γ 's and adequate $e - \gamma$ separation, to be used for future runs at high energies at LEP.

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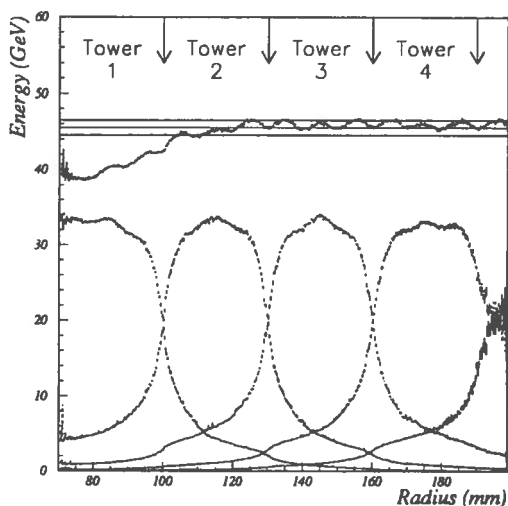


Figure 5. Spatial uniformity measured with 45 GeV electrons: total reconstructed energy (top curve) and energy deposited in each tower (bottom curves)

crostrip telescope). The response curve can be parametrized to provide an estimate of the radial impact point of the showering particle. Figure 7 shows the radial position resolution for 45 GeV electrons within ± 4 mm from a tower ring border. It varies from 250 μm at the border to about 1.2 mm at the tower center.

4. Performances at LEP

The STIC detector has been in operation in DELPHI since the beginning of the 1994 LEP run. After calibration (performed with collinear Bhabha events) and correction for non-uniformities, the energy resolution is 2.7% at 45 GeV, in good agreement with testbeam measure-

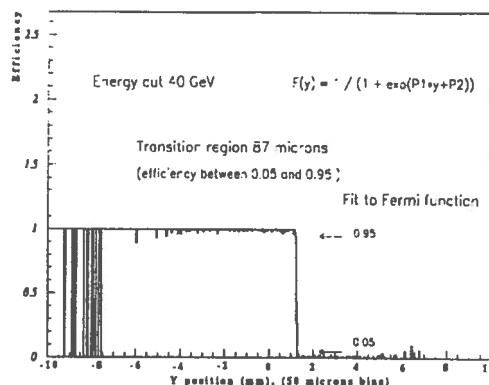


Figure 6. The average measured energy in the calorimeter (normalized to 45 GeV) as a function of the radial impact position (y). The region $y \geq 1$ mm was covered by a tungsten mask. A fit of the transition region at the mask border with a Fermi function is superimposed.

ments (2.5%).

For a 0.1% systematic error on the luminosity measurement, a precise simulation of the detector is essential. The simulation [7], based on the GEANT 3.21 package, takes into account the detailed structure of STIC and of the beampipe region and it is interfaced with the BHLUMI 2.01 Bhabha generator [9]. Figure 8 shows the radial impact point reconstruction and figure 9 the lowest of the cluster energies in the two STIC arms for Bhabha electrons in data and simulation. The data are well reproduced by the Montecarlo simulation.

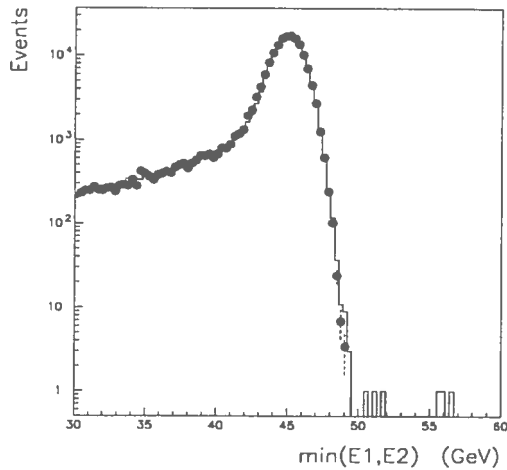


Figure 9. Minimum shower energy in the two STIC arms for Bhabha events. The points are from Monte Carlo simulation and the histogram is data.

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