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Measurement of pion showers longitudinal leakage in the TILECAL prototype

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1 Abstract

Punchthrough probability of showers induced by positive pions of momenta 20, 50, 100, 150, 180 and 300 GeV/c in the TILECAL prototype has been measured using scintillator detector plane placed behind the calorimeter.

Using a simple parametrization of RD5 [1] data we have found from the TILECAL prototype test beam results its thickness to be $(1.66 \pm 0.01_{stat} \pm 0.03_{syst})$ m of iron equivalent. This value agrees within two standard deviations with the value 1.58 m calculated from known sampling ratio of iron and scintillator.

2 Introduction

The probability of hadron shower leakage was extensively studied by CCFR [2] and especially by RD5 [1] collaboration in order to estimate the occupancy of muon detectors in high luminosity LHC experiments.

Because barrel hadron calorimeter of ATLAS experiment is based on innovative concept of longitudinal segmentation of active and passive layers, the measurement of longitudinal leakage from the TILECAL prototype was of special interest.

To compare the results with RD5 measurements [1] we have parametrized their data by a simple approximation. It allowed us to find the iron equivalent thickness of the TILECAL prototype.

3 The Measurement

Construction and performance of a scintillator tile hadron calorimeter prototype is described elsewhere [3].

Test beam measurements of the prototype was carried out in the H8 test beam of the CERN SPS North Area. The beam of energies 20, 50, 100, 150, 180 and 300 GeV was defined by three scintillating counters and its direction was measured by two drift chambers.

For the measurement of longitudinal hadronic shower leakage, "Backward muon wall" (77 x 73 cm^2) [4] was placed behind calorimeter modules. Backward muon wall consisted of eight plastic scintillator counters with dimensions of 40x20x2 cm^3 read-out by 2-inch PMTs.

The May and June 1995 test beam period data were taken with muon and pion beams. The muon data were used for scintillator wall calibration. Mean value ($\langle ADC \rangle_i$) and dispersion sigma(σ_i) were extracted from ADC spectra corresponding to the passage of muon through each scintillator counter. A number of photoelectrons estimated as

$$N_i^{pe} = (\langle ADC \rangle_i / \sigma_i)^2$$

was found to be at the level of 80 p.e. per mip.

The probability of the longitudinal leakage of pion induced shower from the TILECAL module is defined as the ratio of number of events with at least one hit in the "Backward muon wall" to the total number of events. We assume a hit in the i-th counter if its ADC_i fulfills the following condition:

$$ADC_i \;\; > \;\; (\langle ADC \rangle_i - 3\sigma_i \;\;)$$

Events with muon contamination in the pion beam were suppressed off line by using information about deposited energy measured by calorimeter modules. Muon background remaining after the cut was estimated to be $0.5 - 2.0$ % and it was subtracted from further analysis.

Scintillator wall is centered with respect to the backward plane of calorimeter modules but it does not cover the whole area. The acceptance was calculated assuming an exponential lateral distribution of leaking particles. The acceptance values from 0.65 to 0.87 for different beam energies were applied.

4 Results

Punchthrough probability p of hadronic shower with energy E having mean length $L_0(E)$ through material with thickness L can be simply described by the formula (lengths are expressed in the units of iron interaction length λ_{Fe})

$p(L, L_0(E)) = 1$ for $L \leq L_0(E)$

$p(L, L_0(E)) = exp(-(L - L_0(E)))$ for $L > L_0(E)$

If we describe fluctuations of actual shower length by the gaussian distribution with $\sigma_{L_0}(E)$

$G(L_0', L_0(E), \sigma_{L_0}(E)) = C exp(-(L_0' - L_0(E))^2/2\sigma_{L_0}^2(E))$

we can write the punch through probability as convolution of above two distributions

$$\pi_h(L) = \pi(L; L_0(E), \sigma_{L_0}(E)) = \int p(L, L_0')G(L_0', L_0(E), \sigma_{L_0}(E))dL_0' \qquad (1)$$

We have used the formula (1) to describe RD5 [1] data for pions with two free parameters $L_0(E)$ and $\sigma_{L_0}(E)$. We have found $\sigma_{L_0}(E)$ to be approximately equal to $2\lambda_{Fe} = 0.34$ m in the whole range of energies $30 \div 300 GeV$. The results of fits with formula (1) are shown on Fig.1 together with energy dependence of second fitted parameter

$$L_0(E) = 1.95 \cdot \ln(E(GeV)/3.44)$$

which was used in further analysis.
To describe our data we were interested in having good description of RD5 data up to $10\lambda_{Fe}$. For lowest energy $30 GeV$ we had to add another exponential description of muon tail in punchthrough probability (see Fig.1).

We have used modification of formula (1) to describe energy dependence of punchthrough probability for fixed absorber thickness L_{fix}

$$\pi_h(E) = \pi(L_{fix}; L_0(E), \sigma_{L_0}(E)) = \int p(L_{fix}, L_0^{'})G(L_0^{'}, L_0(E), \sigma_{L_0}(E))dL_0^{'} \quad (2)$$

where $\sigma_{L_0}(E) = 2\lambda_{Fe}$ and $L_0(E) = 1.95 \cdot \ln(E(GeV)/3.44)$.

The results of approximation (2) for RD5 data taken with L_{fix} equal to 1.58m and 1.69m of iron equivalent are shown on Fig.2. To describe our data we let $L_{fix}^{TILECAL}$ to be free parameter of the fit and we have found the value
$L_{fix}^{TILECAL} = (1.66 \pm 0.01_{stat} \pm 0.03_{syst})$ m of iron equivalent.

5 Conclusions

The iron equivalent length of the TILECAL prototype at $\theta = 10^o$ was calculated to be 1.58 m (see Appendix A). This value agrres within two standard deviations with the measured value
$L_{fix}^{TILECAL} = (1.66 \pm 0.01_{stat} \pm 0.03_{syst})$ m.

Therefore we can conclude that our measurement proved that the equivalent length of TILECAL prototype with innovative "longitudinal" tile configuration is the same as for more classical sandwich configuration of passive and active layers.

6 Acknowledgements

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References

[1] RD5 Collaboration Z.Phys.C60(1993)1-10
RD5 Collaboration CERN-PPE/95-61

[2] CCFR Collaboration NIM A245(1986) 27-34

[3] RD34 Collaboration NIM A349(1994)384-397

[4] M.Lokajíček et al., TILECAL-NO-063 (1995).

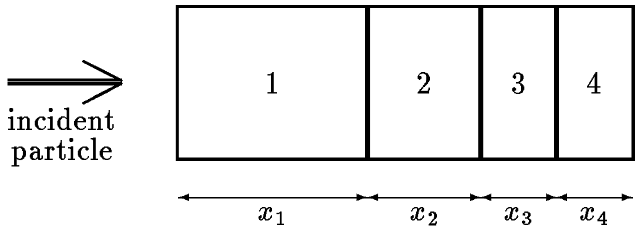

Figure A.1: *Scheme of the simple sample.*

A Equivalent Iron Length of the Test Module

In order to derive a formula for the equivalent iron length of a sampling calorimeter, let us consider a simple case of four different environments 1, 2, 3, 4 (see Fig. A.1).

Let us denominate the respective absorption lengths λ_1, λ_2 λ_3 and λ_4. Now we introduce a new quantity $\bar{\lambda}$, which describes the absorption of the incident beam in the above mentioned sample. For its definition we exploit the probability that the incident particle does not interact in the sample :

$$e^{-(x_1+x_2+x_3+x_4)/\bar{\lambda}} = e^{-x_1/\lambda_1} e^{-x_2/\lambda_2} e^{-x_3/\lambda_3} e^{-x_4/\lambda_4} \tag{A.1}$$

It yields

$$\bar{\lambda} = \frac{x_1 + x_2 + x_3 + x_4}{\frac{x_1}{\lambda_1} + \frac{x_2}{\lambda_2} + \frac{x_3}{\lambda_3} + \frac{x_4}{\lambda_4}} \tag{A.2}$$

So, the equivalent iron length of the sample is determined by the formula

$$d_{\text{Fe}}^{\text{eq.}}\,(sample) = (x_1 + x_2 + x_3 + x_4)\,\frac{\lambda_{\text{Fe}}}{\bar{\lambda}} \tag{A.3}$$

where λ_{Fe} stands for the absorption length in the iron.

Taking into account the relations (A.2), (A.3), the equivalent iron length of the calorimeter test module obeys

$$d_{\text{Fe}}^{\text{eq.}} = \frac{1}{\cos\theta} \left(l \left(\frac{x_{\text{Fe}}}{\lambda_{\text{Fe}}} + \frac{x_{\text{scint}}}{\lambda_{\text{scint}}} + \frac{x_{\text{Tyvek}}}{\lambda_{\text{Tyvek}}} + \frac{x_{\text{air}}}{\lambda_{\text{air}}} \right) \lambda_{\text{Fe}} + l_{\text{dead}} \right) \tag{A.4}$$

where l stands for the total length of the 18 alternating spacer plates and tiles ($l = 18 \times 10$ cm $= 180$ cm) and θ represents the entry angle of the incident beam into the calorimeter. The quantity l_{dead} describes the steel amount behind the calorimeter module[1] as well as the 2 cm thick iron spacers in the end of the calorimeter module.[2] Thus, this quantity fulfills

$$l_{\rm dead} = 2 \times 2 + 2.62 + 2 = 8.62 \text{ cm}$$

The parameters $x_{\rm Fe}$, $x_{\rm scint}$, $x_{\rm Tyvek}$, $x_{\rm air}$ describe the volume fractions of the respective materials in a period of the test module. As one period is 18 mm thick, the volume fractions equal :

$$\begin{aligned} x_{\rm Fe} &= 14/18 \\ x_{\rm scint} &= 3/18 \\ x_{\rm Tyvek} &= 0.2/18 \\ x_{\rm air} &= 0.8/18 \end{aligned}$$

Following values of the nuclear interaction lengths were used :

$$\begin{aligned} \lambda_{\rm Fe} &= 16.8 \text{ cm} \\ \lambda_{\rm scint} &= 79.5 \text{ cm} \\ \lambda_{\rm Tyvek} &\approx \lambda_{\rm scint} \\ \lambda_{\rm air} &= 747 \text{ m} \end{aligned}$$

Thus, for the angle $\theta = 10^\circ$ the formula (A.4) gets

$$d_{\rm Fe}^{\rm eq.} = 1.58 \text{ m}$$

[1]The support construction (2 plates of 2 cm thick steel) for PMTs fixing and the metallic shielding of PMTs (it represents in mean 2.62 cm).

[2]The master plates are 182 cm ($= l + 2$ cm) long. The small 2 cm spacers are present at the end of the layers with alternating spacer plates and tiles because of welding the submodules.

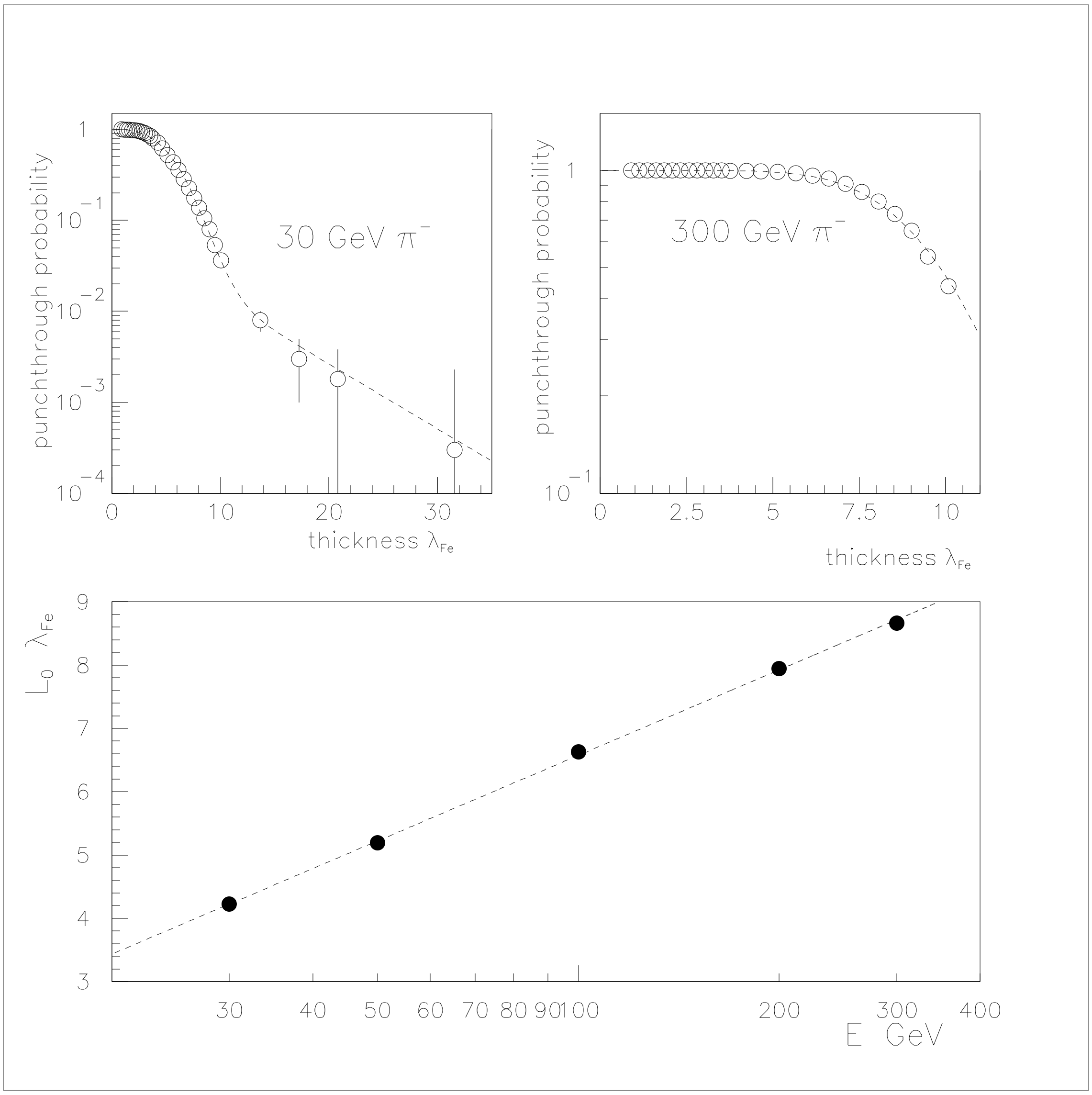

Figure 1: Upper figures show the quality of the fit of RD5 [1] data (open circles) with the formula (1) in the text. Bottom plot shows the energy dependence of fitted length L_0 of pion shower together with the approximation $L_0 = 1.95 \cdot \ln(E(GeV)/3.44)$ which was used in further calculations.

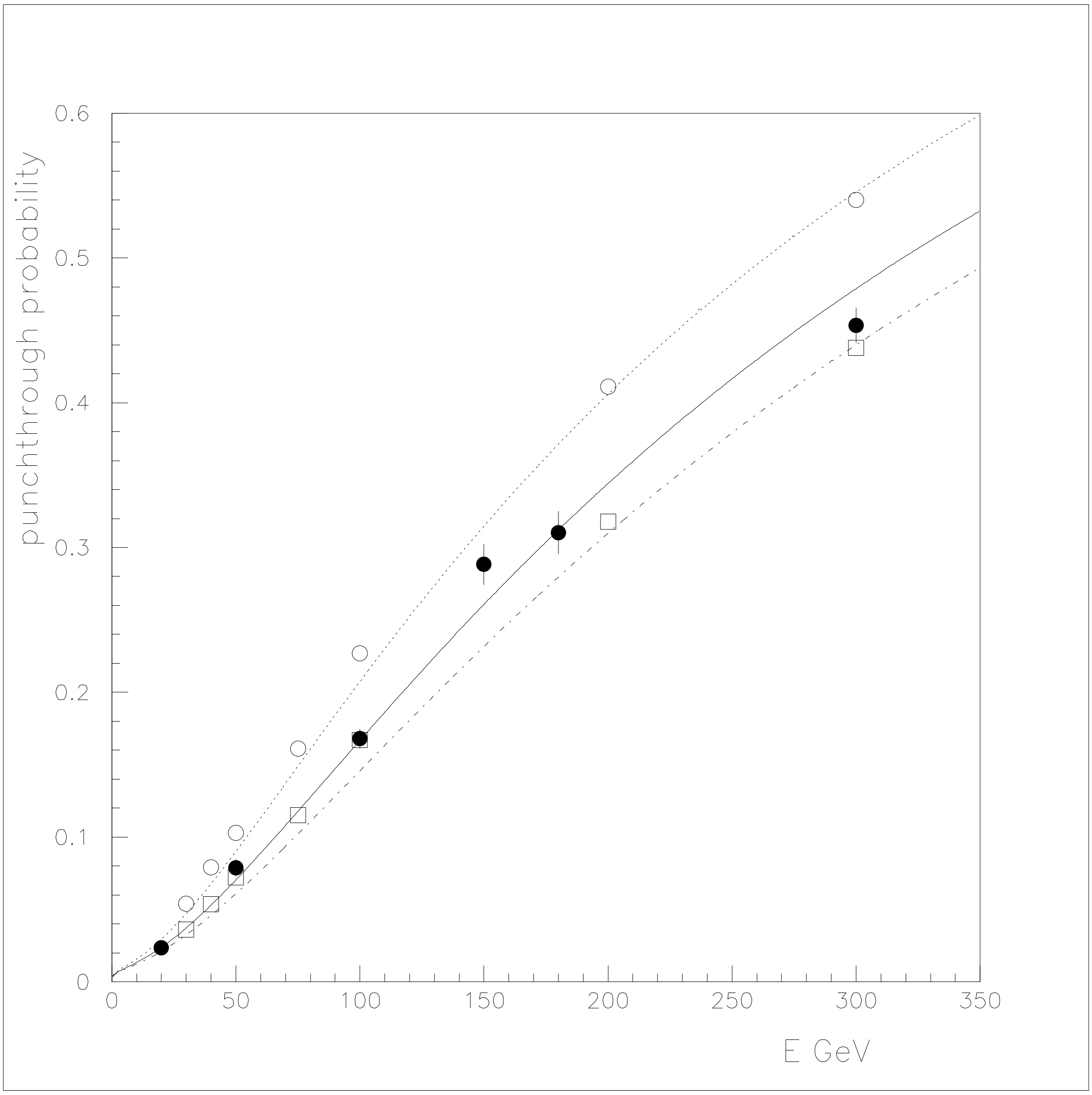

Figure 2: The energy dependence of punchthrough probability for fixed thickness of the absorber. Empty circles and squares are RD5 [1] data for 1.59 m and 1.69 m of iron equivalent respectively together with dotted and dot-dashed approximations according to formula (2). Full circles show TILECAL data measured at $\theta = 10^o$ and full curve is the fit (2) with $L_{fix}^{TILECAL} = (1.66 \pm 0.01_{stat} \pm 0.03_{syst})$ m of iron equivalent.