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LOW p_T MUONS IN b-JETS IN ATLAS TILECAL

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Мюоны с низким p_T в b-струях в тайл-калориметре АТЛАС

Исследованы возможности тайл-калориметра АТЛАС идентифицировать b-струи, которые содержат мюоны с низким p_T. Это сделано для того, чтобы расширить способность b-идентификации через полулептонные мюонные распады b-кварка вне пределов эффективной регистрации мюонного детектора. Результаты, полученные моделированием Монте Карло отдельных изолированных струй в детекторе АТЛАС, указывают, что для b-струй, которые содержат мюоны с низким p_T в диапазоне $2 < p_T < 5$ ГэВ, существует возможность их отделения от легкого кварка или глюонных струй.

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Low p_T Muons in b-Jets in ATLAS Tilecal

ATLAS Tile Calorimeter possibilities to identify b-jets that contain low p_T muons are investigated. This is made in order to extend the capability of b-tagging through muon b-quark semileptonic decays beyond the muon detector limits of efficient registration. Results obtained by Monte Carlo simulation of single isolated jets in ATLAS detector indicate that for b-jets that contain low p_T muons in the range $2 < p_T < 5$ GeV, one can separate them from light quark or gluon jets.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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1 Introduction

In order to identify b-quarks in an event (b-tagging), two different methods which don't exclude each other are used. One method consists in b-hadrons' decay vertices determination with inner detector and then imposing cuts in the impact parameter.

A second method is to search for charged leptons (e, μ) from semileptonic decays of b-hadrons, either directly $b \to l\nu_l X$, or by cascade $b \to c + ..(c \to l\nu_l X)$. The p_T distributions of leptons from b-quark decays indicate a significant fraction in the $p_T < 5GeV$ region. Efforts are made to increase b-tagging capability by lowering as much as possible the threshold of efficient lepton detection down in the low-p_T region. In both cases, either for electrons or for muons, one relies on the information provided by calorimeters. This task presents additional complications because the leptons are non-isolated and one has to detect their presence inside jets.

Muons and electrons have a different behaviour in calorimeter.

Electrons generate electromagnetic showers and the problem is to detect the presence of such a shower inside the jet.

Muons lose their energy mainly by ionisation. They penetrate behind the hadron calorimeter and are detected with a high efficiency by muon detector. But low p_T muons (in the ATLAS case $p_T < 5$ GeV) have a significant probability to be absorbed in the calorimeter. Nevertheless they can penetrate deep inside the hadron calorimeter, while the hadrons from the jet are absorbed. The b-jets contain high multiplicity low-p_T hadrons. The inner depths of hadron calorimeter will act as a filter for these hadrons. The idea is to look at the signal in the last depths of hadron calorimeter which has to be much smaller for jets without muons(light quark jets, gluon jets) than for jets which contain muons [1].

Questions which arise are:

- is the muon signal in the calorimeter strong enough (i.e. well separated from electronic noise and not affected by photoelectron statistics)?

- what is the lower limit for p_T of the muons where one can separate between the two kinds of jets and what is the contribution of this soft p_T region to the total number of semileptonic b-decay events?

- what is the rejection factor for light quark (or gluon) jets against the efficiency of b-quark jet identification?

A solution is possible due to ATLAS calorimeter good performances and fine segmentation [1] and some preliminary simulations have provided encouraging results [2]. Results of an investigation of tagging with low-p_T electrons from b decays with Atlas electromagnetic calorimeter have also been reported [3].

In this paper, results obtained studying the possibility to use the Tile Calorimeter to detect low-p_T muons inside b-jets are presented. It is shown that for muon p_T in the range $2 < p_T < 5$ GeV one can identify effectively b-jets through b muonic decays.

2 Low p_T muons inside b-jets: particle level results

In [2] we investigated the possibility to tag the channel $B_d^0 \rightarrow J/\psi K_S^0$ with $J/\psi \rightarrow \mu^+\mu^-$. It was shown that, for b-jets with $p_T = 20$ GeV at $\eta = 0.3$, if one relies only on detection possibilities of the muon detector, i.e. requiring both muons to have $p_T > 5$ GeV, only 13% of events will be registered. Now suppose that we are able to identify one of the muons in the event with lower p_T, using the calorimetric information. If this limit is $p_T > 3$ GeV, then the fraction increases to 34% and if the limit is lowered to $p_T > 2$ GeV, one attains 48%.

Soft muons are also important for other processes to be studied at LHC, containing b-jets at higher p_T. One can mention the search for Higgs in the intermediate mass region through the decay channel $H \rightarrow b\bar{b}$, where the typical transverse momentum of the jet is $p_T = 40$ GeV. Also b-jets with p_T around 70 GeV could serve to tag t-quarks through the decay $t \rightarrow Wb$.

In order to illustrate the importance of the soft region $2 < p_T < 5$ GeV, b-jets with $p_T = 20$, 40 and 70 GeV and $|\eta| < 0.6$ were generated with JETSET, imposing the semileptonic (muonic) decay of b-quark directly, or in cascade. The p_T spectrum of these muons is presented in Fig. 1. For the soft regions indicated by the hatched areas, the percentages of the total number of events which they represent in each case, are indicated also on the figure: 32.2% at $p_T = 20$ GeV, 27.9% at $p_T = 40$ GeV and 21.9% at 70 GeV. The corresponding percentages for hard muons (i.e. with $p_T > 5$ GeV), are 21%, 45.7% and 64.8%. One can observe that as p_T of the jet increases, the relative weight of the soft region over the hard region is decreasing, but it remains important for all processes.

3 Isolated π/μ separation

It was found useful to simulate firstly isolated particles: pions and muons at different values of p_T and η. From this study one can obtain some indications about which are the rejection factors for hadrons at different values of p_T and which is the efficiency we can expect for muon identification in Tile Calorimeter as a function of pseudorapidity. Combining these two, one can have an indication about the p_T range for soft muon tagging in ATLAS.

In DICE were generated single muons and pions with $p_T = 2$, 3, 5 and 10 GeV at $\eta = 0.3$ and 0.9.

For simulation, the Technical Proposal layout was used, where the Tile Calorimeter consisted of four longitudinal depths (on r axis in cilindrical coordinates). The reconstruction of deposited energy in each depth at the cell level was performed. In fact it was used only the energy that particles deposit in the last depth, refered as Depth4 and, because of decision to bring together the previous two depths, the sum of of the deposited energies in this combined depth, refered as Depth2+3.

The distribution of the energy deposited by $p_T = 2$, 3, 5 and 10 GeV muons and pions in Depth4 is presented in Fig. 2 for $\eta = 0.3$ and in Fig. 3 for $\eta = 0.9$. At $\eta = 0.3$ one can observe that for $p_T > 3$ GeV the muon signal is well separated from that of pions. For $p_T =$

2 GeV an appreciable fraction of muons (16%) don't reach Depth4. As η increases one have still a good separation from pions, but already at $p_T = 3$ GeV there is a loss of muon registration efficiency due to absorbtion in Depth2+3, which at $\eta = 0.9$ is about 4%. At $p_T = 2$ this fraction is 50%. In the Fig. 4, the rejection factors for pions and efficiency for muon registration are given in function of the cut we imposed in the deposited energy in Depth4. The energy cut is converted in the number of photoelectrons using a conversion factor of 30 pe/GeV. From the new measurements, the light yield in Tile Calorimeter is 50 pe/GeV and this figure is expected to be further improved. We see no influence of photostatistics even for 30 pe/GeV. In order to lower the p_T limit and to increase the efficiency of muon registration at higher values of η, one has to look at the deposited energy in Depth2+3. In Fig. 5 are shown the distributions for deposited energies of $p_T = 2$ GeV muons and pions at $\eta = 0.3$, in Depth4 and Depth2+3. One can see that the muon and pion signals are well separated in Depth2+3. The usefulness of looking at Depth2+3 can be observed in Fig. 6 were the same distributions are presented for $\eta = 0.9$.

One can conclude that a good separation was obtained for $2 < p_T < 5$ GeV isolated muons and pions in the barrel region, looking at their energy deposition in Depth4 and Depth2+3. The muon signal is well above the electronic noise. The separation is not affected by photostatistics. Due to the relative high multiplicity of hadrons that enter in the componence of jets, they are less energetic and thus the results obtained for isolated particles are expected to be preseved in the case of jets.

4 Results on soft μ b-tagging

For our study, two event samples were generated. The b sample consisted of b-jets and the background sample, of gluon jets. In fact, choosing the light quark jets as a background process one can obtain similar results. We generated single jets in DICE with $p_T = 20$ and 40 GeV, uniformly in η in the central region $|\eta| < 0.6$. In each case 500 events were generated. For b-jets some conditions

were imposed at particle level in the moment of generation, the number of events given above represented events which passed these conditions:

- only events containing one muon (accompanied by its own neutrino).
- transverse momentum of the muon in the soft region $2 < p_T < 5$ GeV.

For simulation, the Technical Proposal layout was used and as for isolated particle case we looked at deposited energies in Depth4 and Depth2+3.

In Fig. 7 is plotted the energy deposited per depth by b jets and gluon jets with $p_T = 20$ GeV and in Fig. 8 the same, for $p_T = 40$ GeV. The separation between b-jets and gluon jets was performed by imposing a cut in the deposited energy in Depth4 and Depth2+3. For a given value of this cut one can define the eficiency ϵ_b for b-jets and the rejection factor R_{gluon} for gluon jets. The dependence R_{gluon} versus ϵ_b is shown in Fig. 9. One can notice that the rejection factor decreases as the p_T of the jet is increasing. This is due to the fact that in higher p_T gluon jets there are more energetic hadrons which cannot deposit their whole energy in the inner depths of Tile Calorimeter. As expected, the largest contribution to the rejection comes from Depth4. In order to improve the separation, the information at the cell level has to be used. One idea was to corelate the deposited energies in cells from different depths and to take advantage that the muon signal will be distributed in a few cells, in general one or two. One considers the cell with the highest energy deposition in Depth4 and determines its position (η_m, ϕ_m). Then one looks in a 3×3 window in Depth2+3, centerd on (η_m, ϕ_m), for two adjacent cells with highest energy deposition. The sum of deposited energies in these two cells from Depth2+3 is plotted in Fig. 10. For b-jets one observes a peak which corresponds to what is expected for the energy which is deposited by a single muon, while for the gluon jets, this distribution is flat. For the comparison, we simulated the response to single muons, under the following requirements:

- uniformly in η in the range $|\eta| < 0.6$
- p_T in the range $2 < p_T < 5$ GeV

The η distribution of muons from b-quark decays in b-jets simulated previously, is not exactly uniform, but for comparison purposes, this is a good approximation. The reconstructed deposited energy in Depth2+3 for the single muons is shown in the Fig. 11, together with deposited energies in Depth2+3 of the two cells fron b-jets, as decribed previously. On the basis of similarity of these two kinds of distributions one can say that correlating cells form Depth4 and Depth2+3 one can isolate muons in b-jets. Applying some cuts to the deposited energies from Fig. 10, one can impose an additional rejection factor of the order of $3-4$ for gluon jets, for a loss of about 10% in the efficiency of b-jet identification. Therefore, combining the rejection conditions one can expect to obtain rejection factors for gluon jets in the range of $50 - 100$.

This technique could also provide useful in rejecting some fake muons registrated by muon detector, if one considers the 3×3 window in Depth2+3, centered on (η, ϕ) coordinate given by the muon detector.

5 Conclusions

In this paper, Tile Calorimeter capability to identify low p_T muons inside the b-jets is investigated. Applying cuts in jet deposited energy in last depths it was found possible to separate b-jets with a muon with p_T in the range $2 < p_T < 5$ GeV. By a Monte Carlo simulation of single b-jets in the central region $|\eta| < 0.6$ it was shown that they represent a significant fraction of semileptonic b-decay events. If the information at the cell level is used it was found that one can increase the rejection factor against the background (light quark, gluon) jets.

With the muon detector for high p_T muons ($p_T > 5$ GeV and with Tile Calorimeter for $2 < p_T < 5$ GeV, one can expect an overall efficiency $\epsilon_b \approx 10\%$ for b-jet tagging through muon semileptonic b-decays.

To enhance the b-tagging efficiency one has to use the information provided by the inner tracker in conjunction with the analysis based on correlating cells from Depth4 and Depth2+3 in Tile Calorimeter.

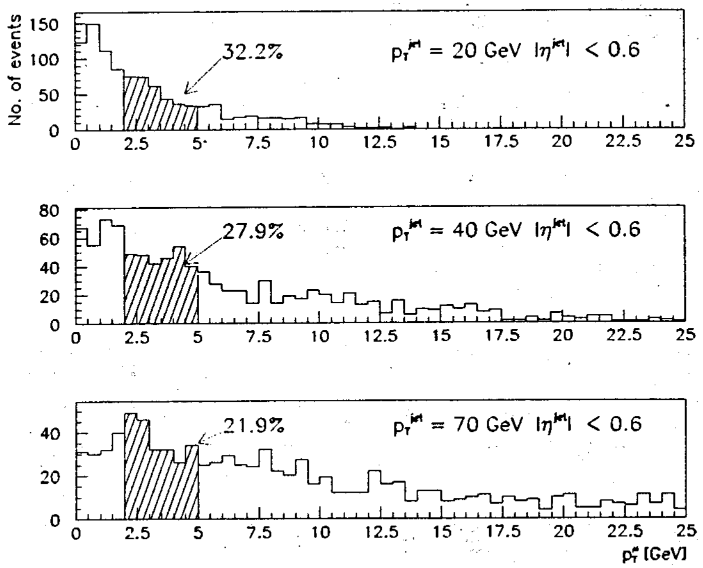

Figure 1: *p_T distributions of muons from b-jets with p_T = 20, 40, 70 GeV and $|\eta| < 0.6$. For soft muon region $2 < p_T < 5$ GeV (hatched area) is indicated the fraction which it represents in the total sample of muon semileptonic b-decay events.*

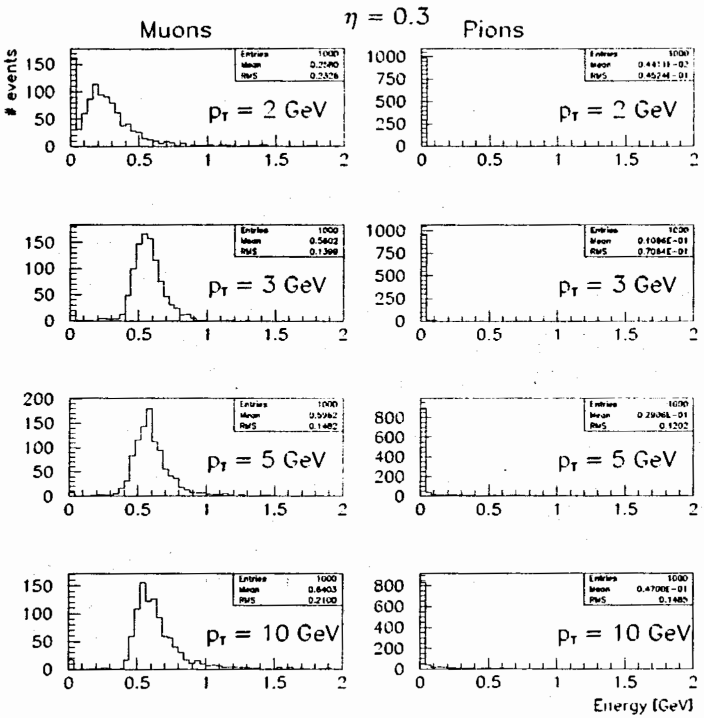

Figure 2: *The distribution of deposited energy in Depth4 by* p_T = 2, 3, 5 *and* 10 *GeV muons and pions at* $\eta = 0.3$

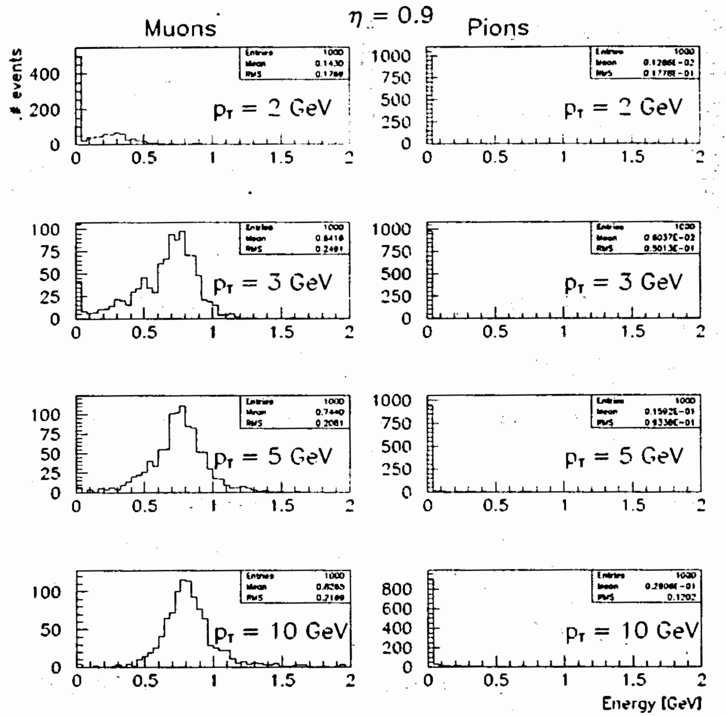

Figure 3: *The distribution of deposited energy in Depth4 by* p_T = 2, 3, 5 *and* 10 *GeV muons and pions at* $\eta = 0.9$

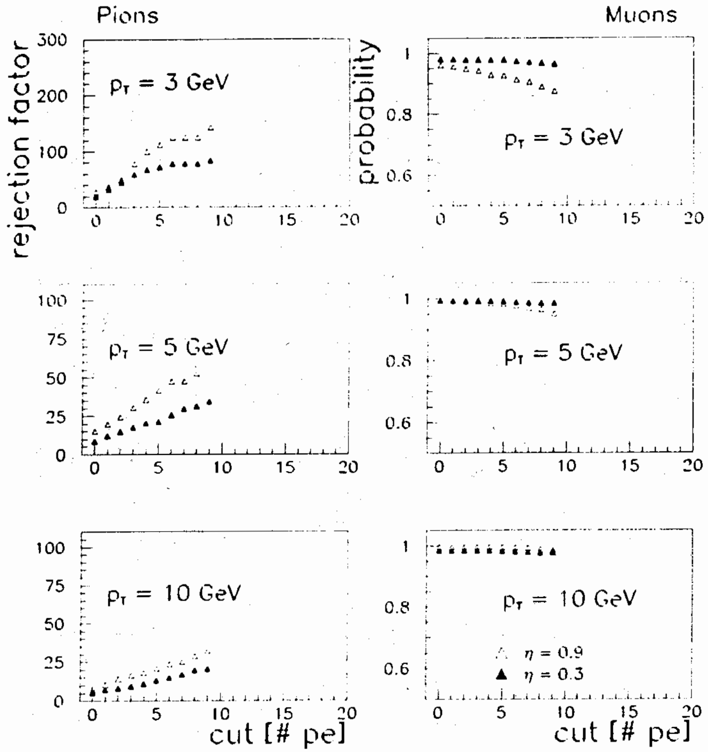

Figure 4: *Pion rejection factors and muon registration efficiency at p_T = 3, 5 and 10 GeV and η = 0.3, 0.9 as a function of the cut in deposited energy in Depth4, expressed in equivalent number of photoelectrons (conversion factor 30 pe/GeV)*

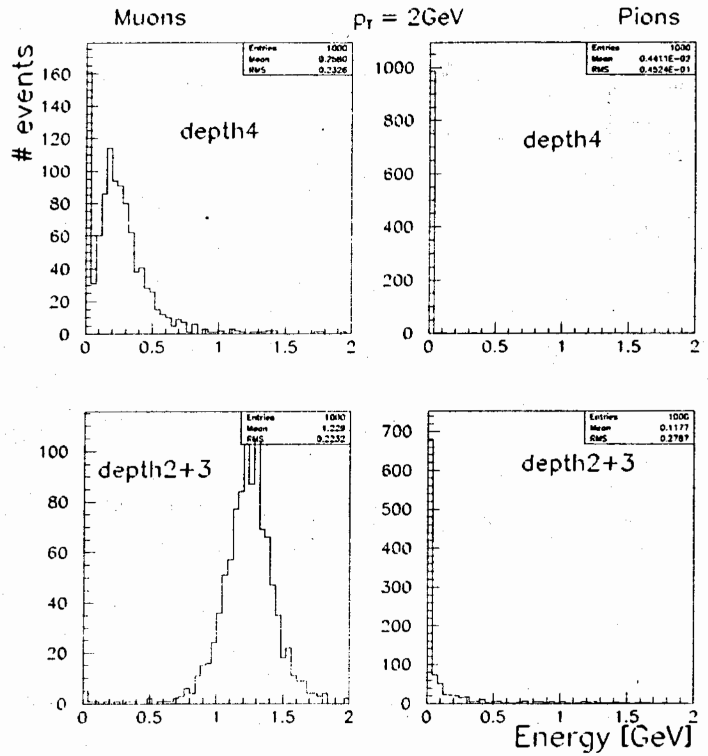

Figure 5: *Deposited energy distributions in Depth4 and Depth2+3 for p_T = 2 GeV isolated muons and pions at η = 0.3*

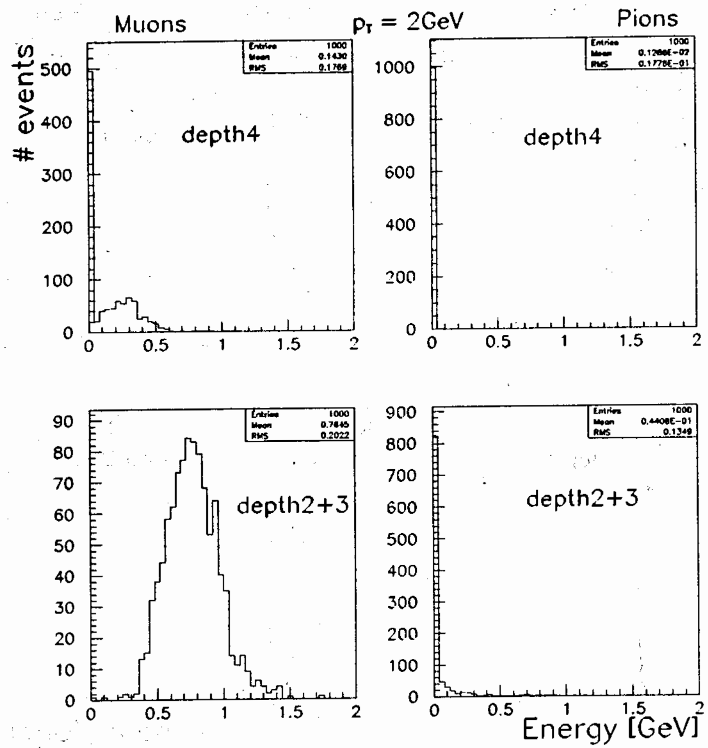

Figure 6: *Deposited energy distributions in Depth4 and Depth2+3 for $p_T = 2$ GeV isolated muons and pions at $\eta = 0.9$*

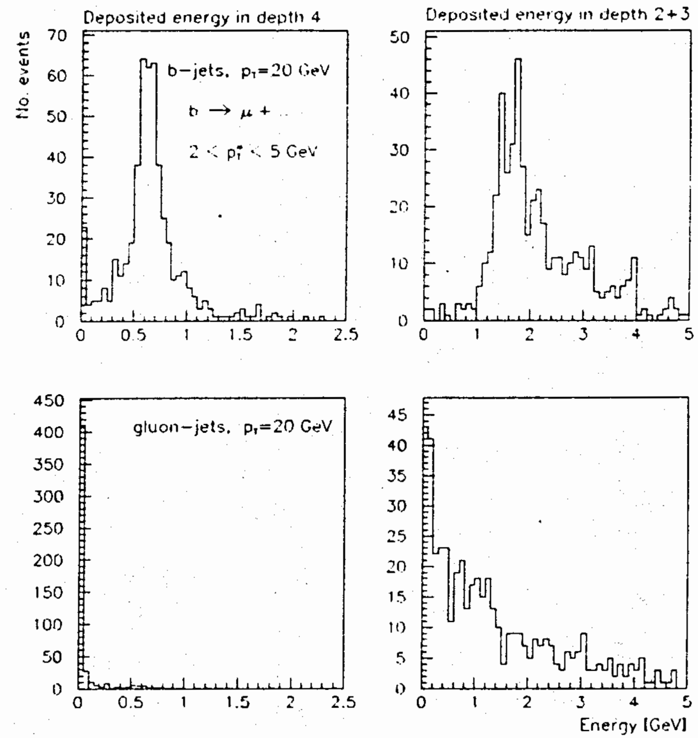

Figure 7: *Energy deposited in Depth4 and Depth 2+3 of the Tile Hadron Calorimeter by $p_T = 20$ GeV b-jets (top) and gluon-jets (bottom)*

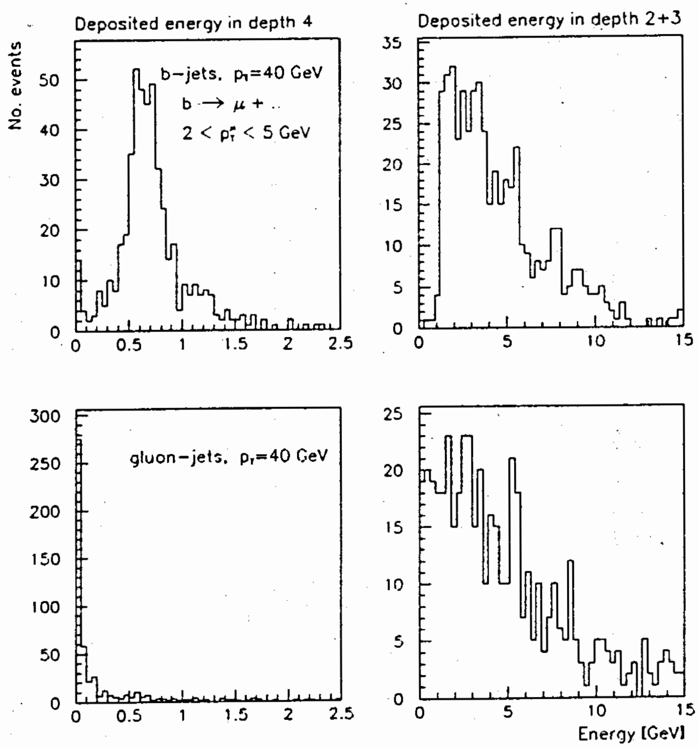

Figure 8: *Energy deposited Depth4 and Depth 2+3 of the Tile Hadron Calorimeter by $p_T = 40$ GeV b-jets (top) and gluon-jets (bottom)*

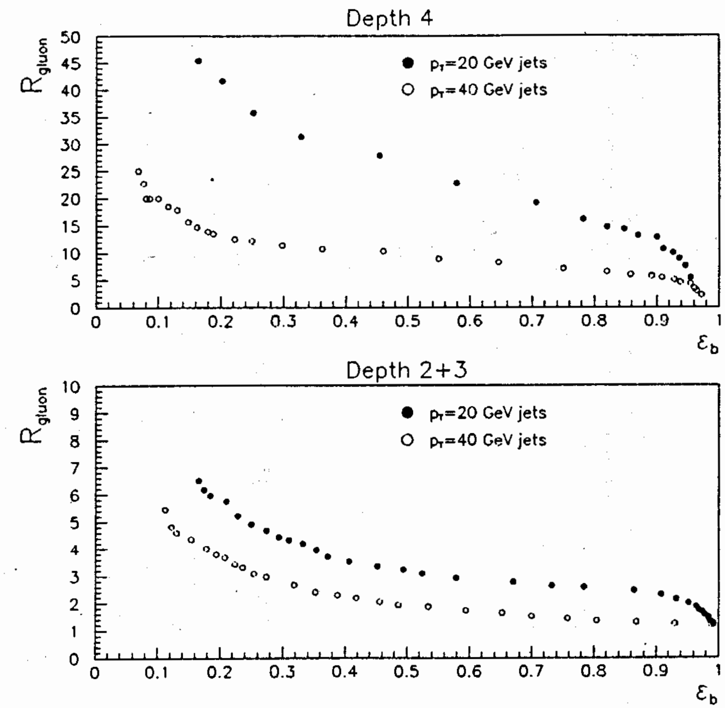

Figure 9: *Rejection factor R_{gluon} for gluon jets versus the efficiency ϵ_b for b=jets from Depth4 (top) and Depth2+3 (bottom)*

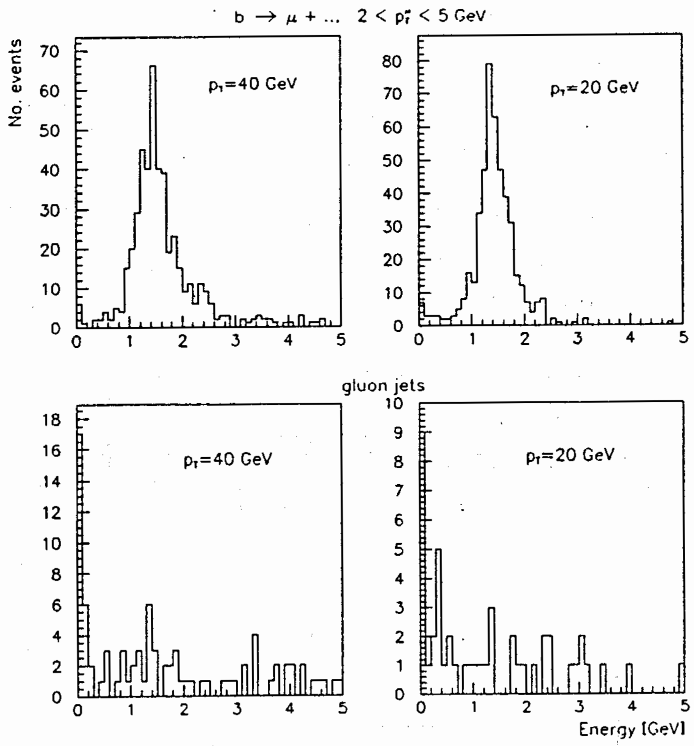

Figure 10: *Sum of deposited energies in depth2+3 in two adjacent cells with maximal deposit from a 3 × 3 window centered on the position of the cell with highest deposited energy in depth4, for b-jets (top) and for gluon-jet (bottom)*

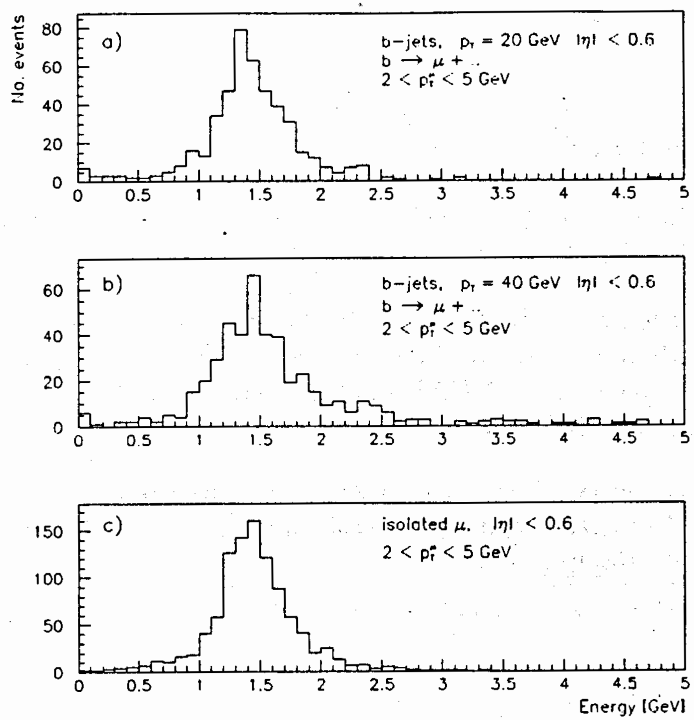

Figure 11: *Comparison between distribution of the sum of the highest deposited energies in two adjacent cells in Depth2+3 from a* 3×3 *window centered on the position of the cell with highest deposited energy in Depth4 by b-jets: a)* $p_T^{jet} = 20$*, b)* $p_T^{jet} = 40$ *GeV and the deposited energy by an isolated muon in Depth2+3 c).*

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References

[1] ATLAS Collaboration, ATLAS Technical Proposal, CERN/LHCC/94-43.

[2] J. Budagov, I. Chirikov-Zorin, A. Pantea, D. Pantea, O. Pukhov, M. Bosman, M. Nessi, B-meson Tagging improvement using HCAL information, ATLAS Internal Note TILECAL-NO-023 (1994).

[3] F. Gianotti, Tagging of low-p_T electrons from b decays with the ATLAS electromagnetic calorimeter, ATLAS Internal Note PHYS-No-49 (1995).

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