Joint Institute for Nuclear Research

VERY HIGH MULTIPLICITY PHYSICS

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Dubna, 7 April 2001

Calculation of the Correlators for Very High Multiplicity Events at LHC

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JINR, Dubna

1 Correlation functions

- $K_1(E,n) = \langle\varepsilon\rangle = \int \frac{d^3p}{(2\pi)^3 2\varepsilon(p)}\varepsilon(p)\frac{d^3\sigma_n}{dp^3} = \int d\varepsilon\ \varepsilon\ \frac{dN}{d\varepsilon}$

If $d\varepsilon \to 0$
than $K_1(E,n) = \langle\varepsilon\rangle = \frac{1}{N}\sum_{i=1}^{N} E_i$

where E_i is i-particle energy.

- $K_2(E,n) = \langle(\varepsilon_1 - \langle\varepsilon\rangle)\cdot(\varepsilon_2 - \langle\varepsilon\rangle)\rangle = $
$= \langle\varepsilon^2\rangle - \langle\varepsilon\rangle^2$

- $K_3(E,n) = \langle(\varepsilon_1 - \langle\varepsilon\rangle)\cdot(\varepsilon_2 - \langle\varepsilon\rangle)\cdot(\varepsilon_3 - \langle\varepsilon\rangle)\rangle = $
$= \langle\varepsilon^3\rangle - 2\langle\varepsilon^2\rangle\langle\varepsilon\rangle + 3\langle\varepsilon\rangle^3$

  - Sissakian-Manjavidze prediction for VHM $R = \frac{K_3^{2/3}}{K_2} \ll 1$

  - If $R = \frac{K_3^{2/3}}{K_2} \ll 1$

then the particle energy spectrum is Gaussian, with

— "temperature": $K_1^{-1}(E,n)$

— dispersion: $\sqrt{K_2(E,n)}$

2 PYTHIA Sub-processes:

— $q_i\ q_j \to q_i\ q_j$
— $q_i\ \bar{q}_i \to q_j\ \bar{q}_j$
— $q_i\ \bar{q}_i \to g\ g$
— $q_i\ g \to q_i\ g$
— $g\ g \to q_i\ \bar{q}_i$
— $g\ g \to g\ g$

2.1 PYTHIA prediction

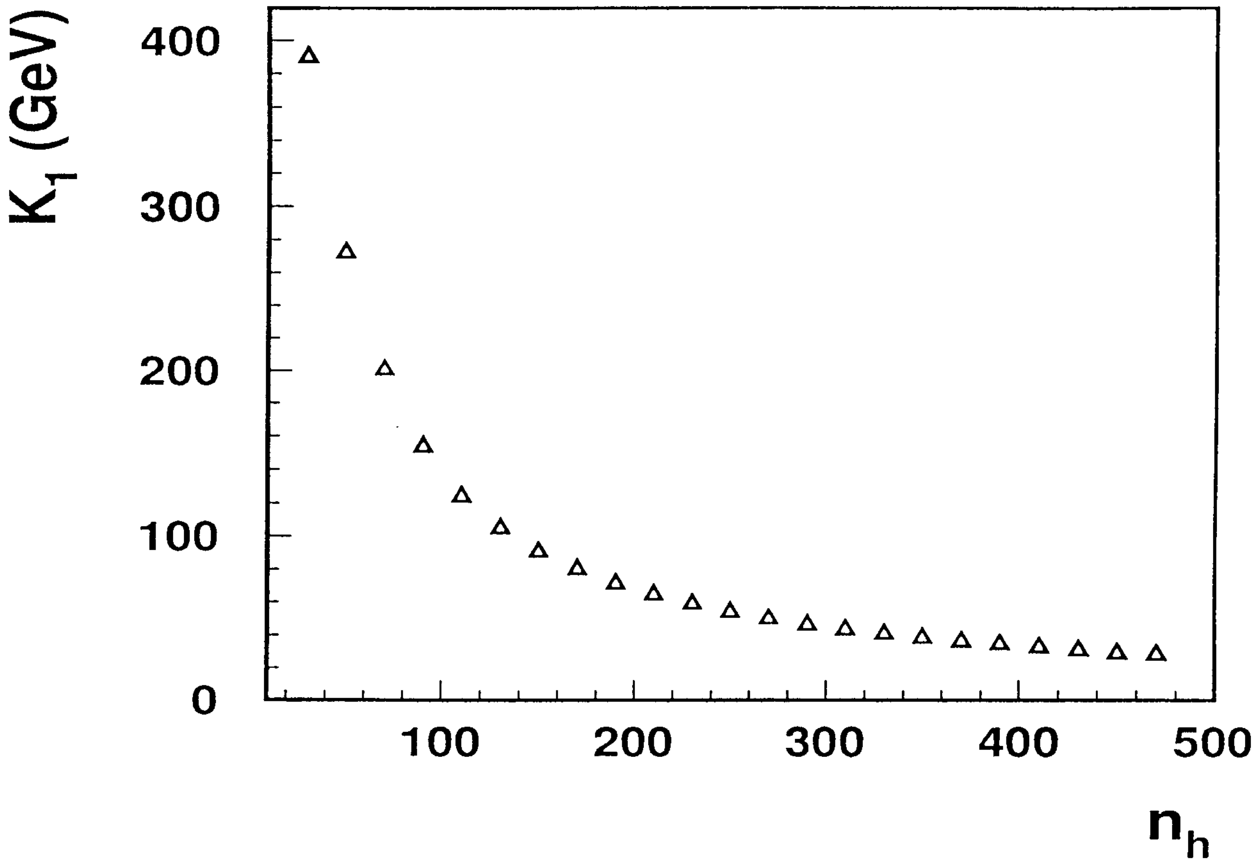


Figure 1: **Dependent of $K_1(\varepsilon, n_h)$ from number of hadrons without cut on the p_t**

$$K_1(\varepsilon, n_h) = \langle \varepsilon; n \rangle = \frac{1}{N_n} \int \varepsilon d\varepsilon \, \frac{dN_n(\varepsilon)}{d\varepsilon} = \frac{1}{N_n} \sum_{i=1}^{N_n} E_i$$

— n - number of particles (hadrons)

— ε - particles energy

— N_n - number of events with multiplicity n_h

— $dN_n(\varepsilon)/d\varepsilon$ - number of events with multiplicity n and particle with energy ε

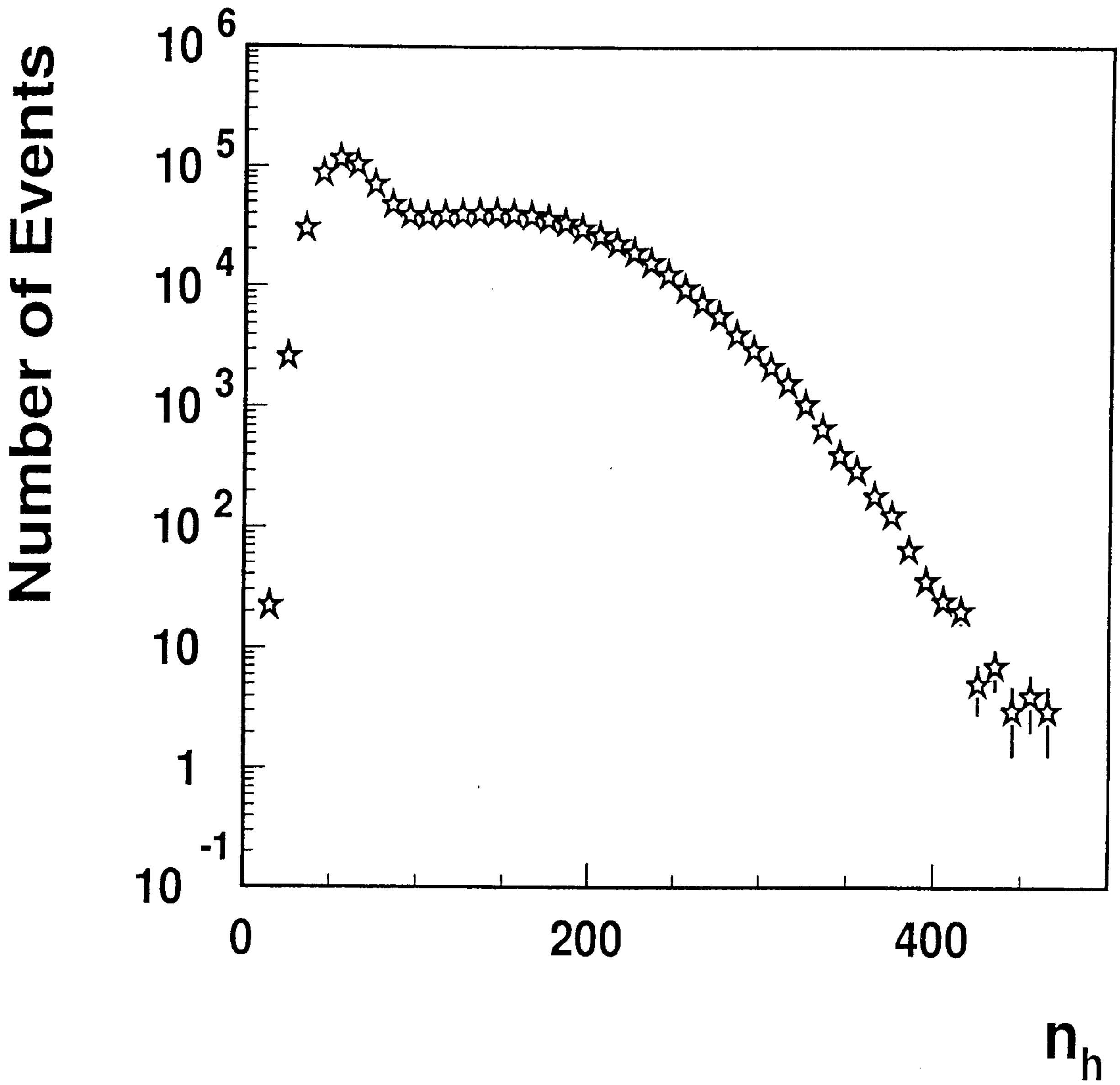


Figure 2: Multiplicity distribution. Without colored partons transverse momentum cutoff p_t

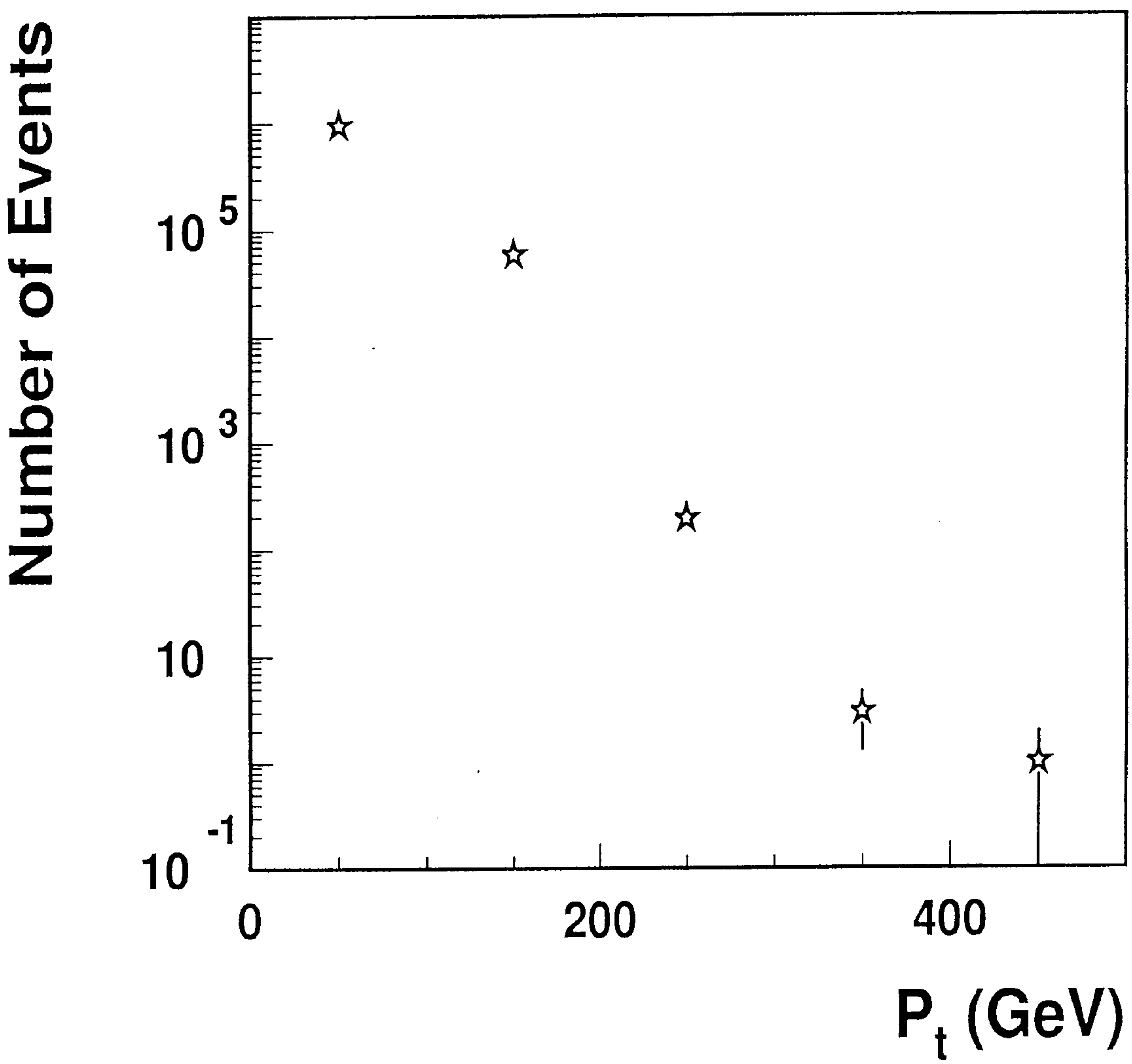


Figure 3: p_t distribution. Without colored partons transverse momentum cutoff p_t

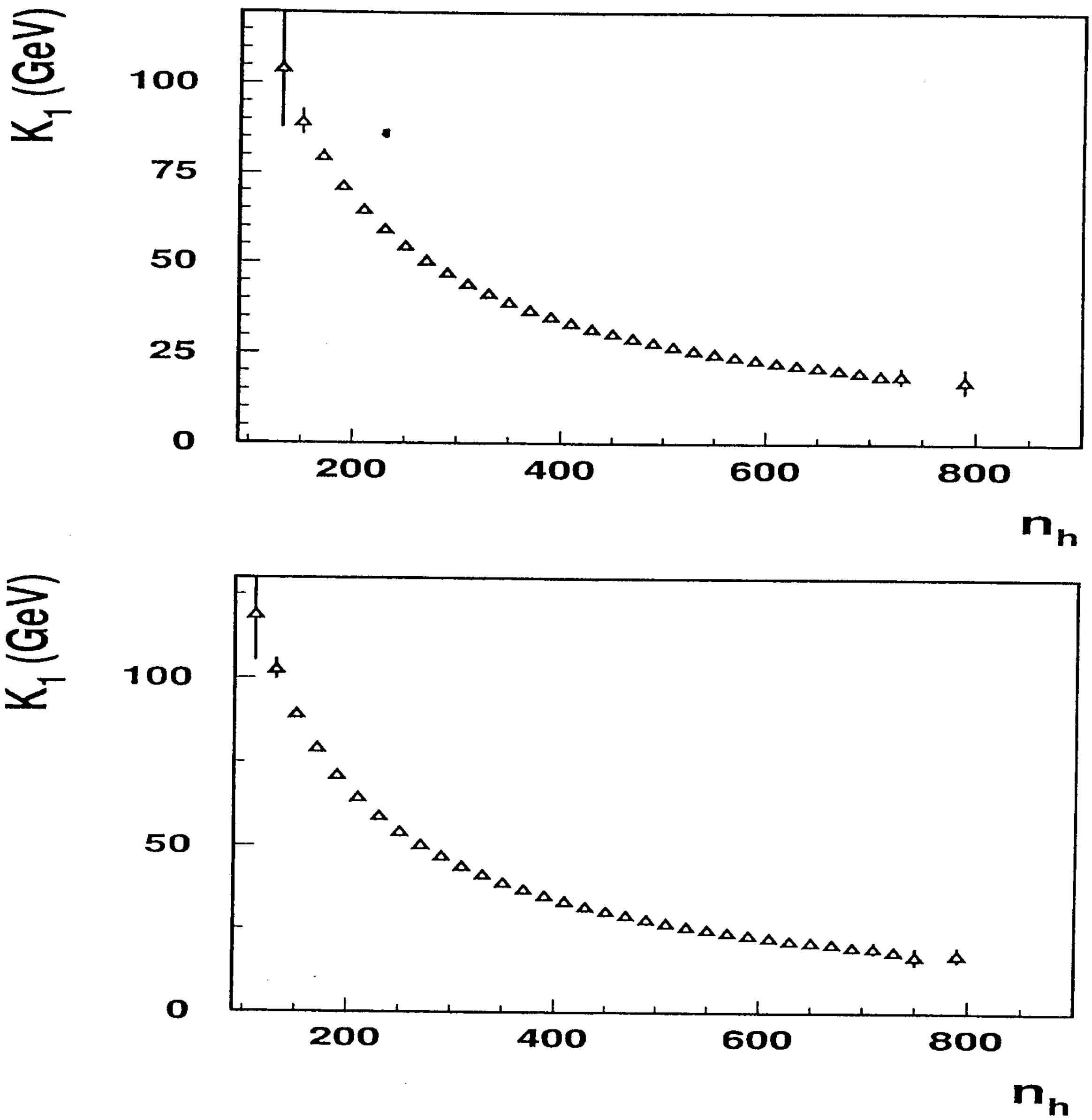


Figure 4: Dependent of $K_1(\varepsilon, n_h)$ from number of hadrons. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

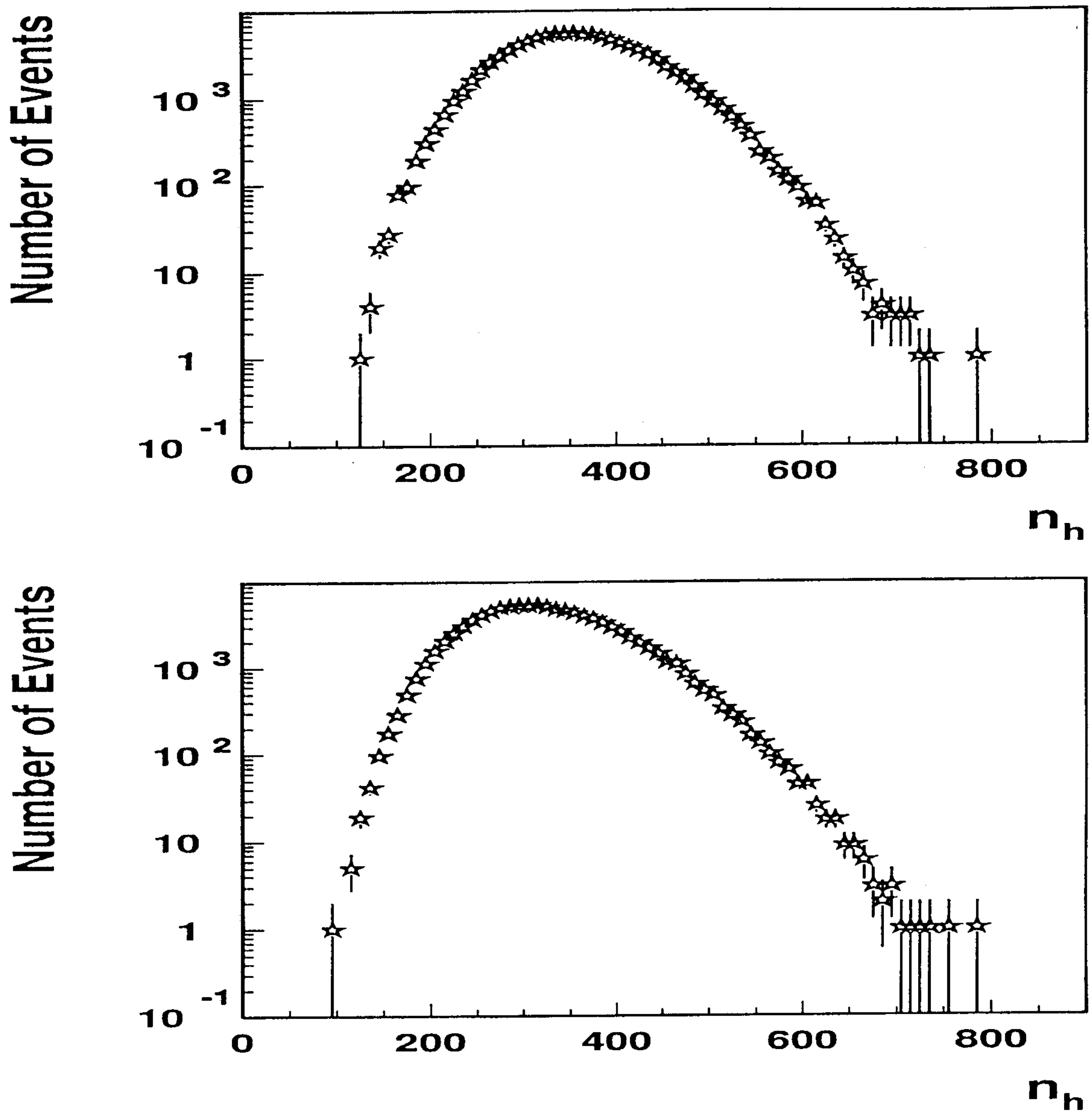
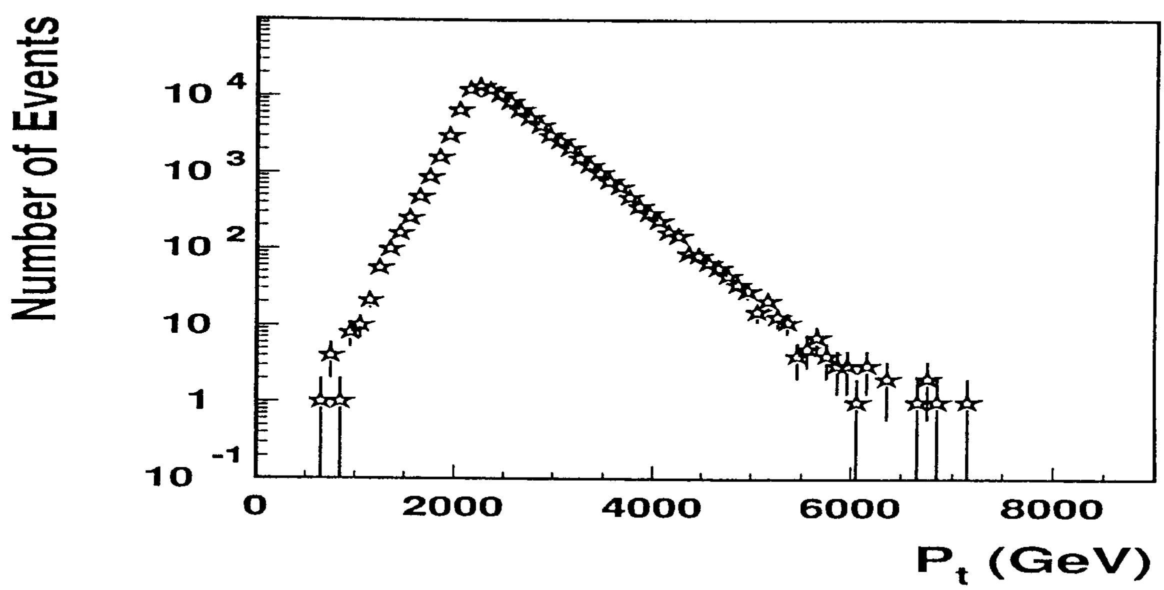


Figure 5: Multiplicity distribution. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)



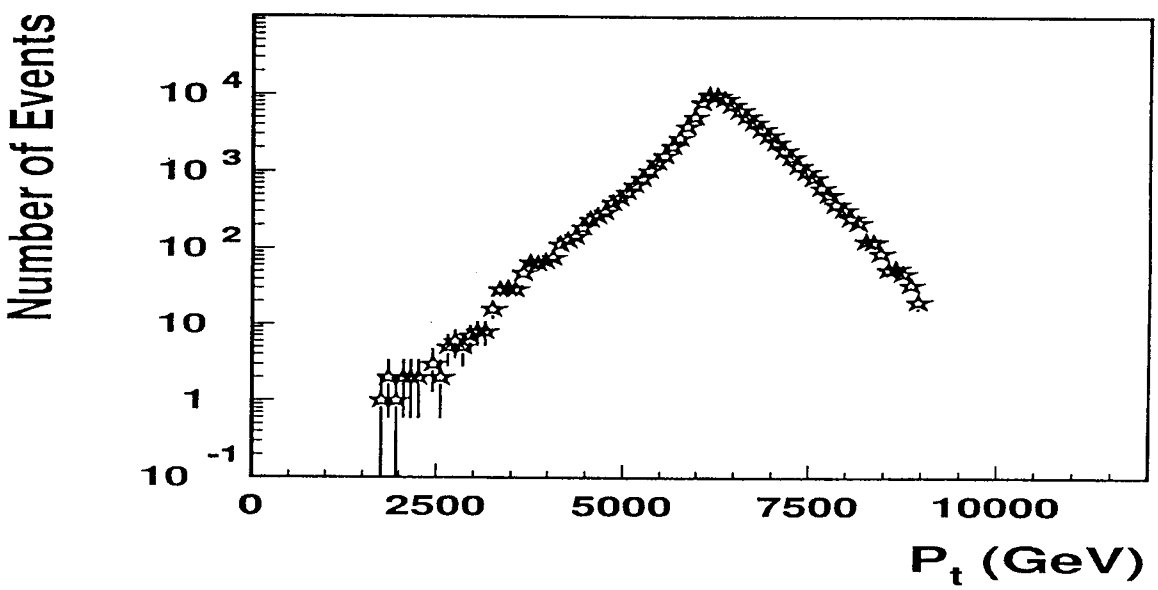


Figure 6: p_t distribution. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

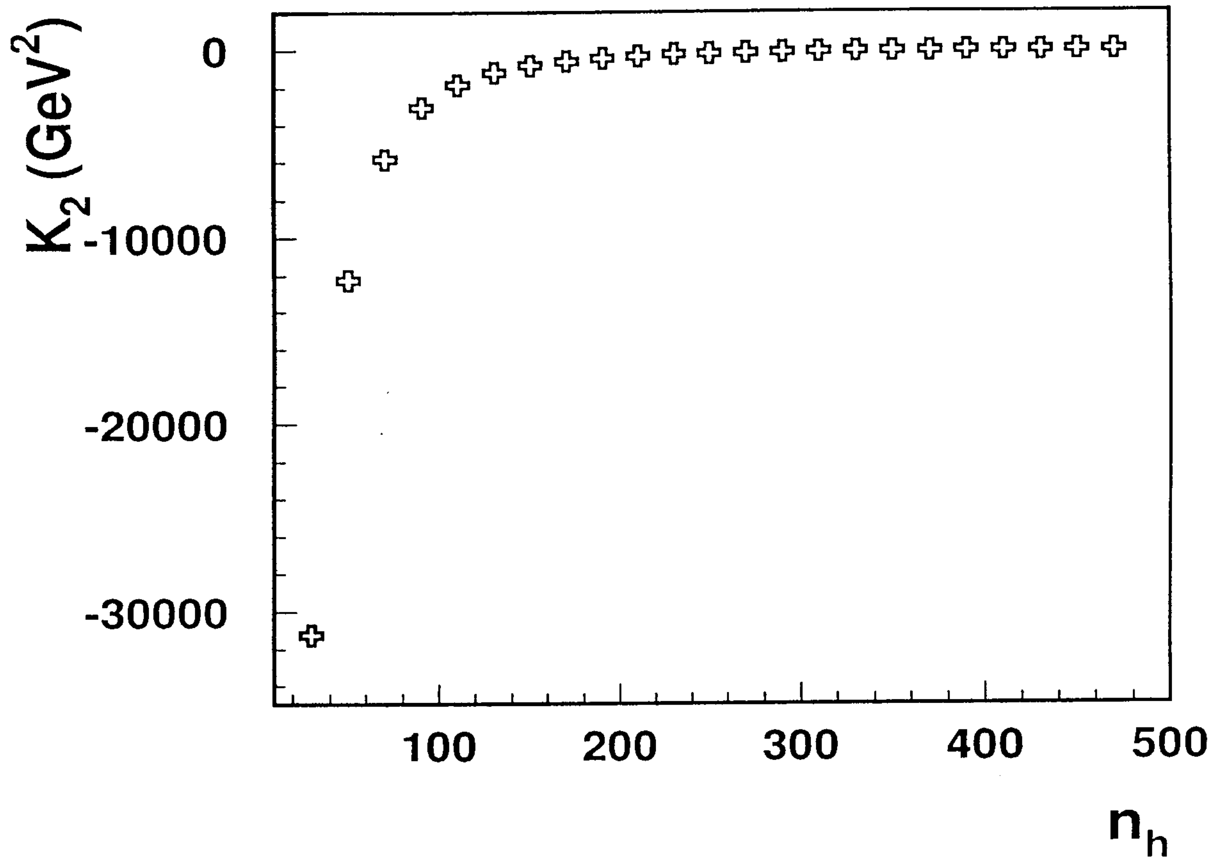


Figure 7: **Dependent of $K_2(\varepsilon, n_h)$ from number of hadrons without cut on the p_t**

$$K_2(\varepsilon_1, \varepsilon_2; n_h) = \langle[(\varepsilon_1; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_2; n_h) - \langle\varepsilon; n_h\rangle]\rangle$$
$$= \langle\varepsilon^2; n_h\rangle - \langle\varepsilon; n_h\rangle^2$$

$$\langle\varepsilon^2; n_h\rangle = \frac{1}{N_n}\int \varepsilon_1 d\varepsilon_1\ \varepsilon_2 d\varepsilon_2 \frac{d^2N_n}{d\varepsilon_1 d\varepsilon_2}$$

— $d^2N_n/d\varepsilon_1 d\varepsilon_2$ - number of events with multiplicity n_h and **particles** with energy ε_1 and ε_2

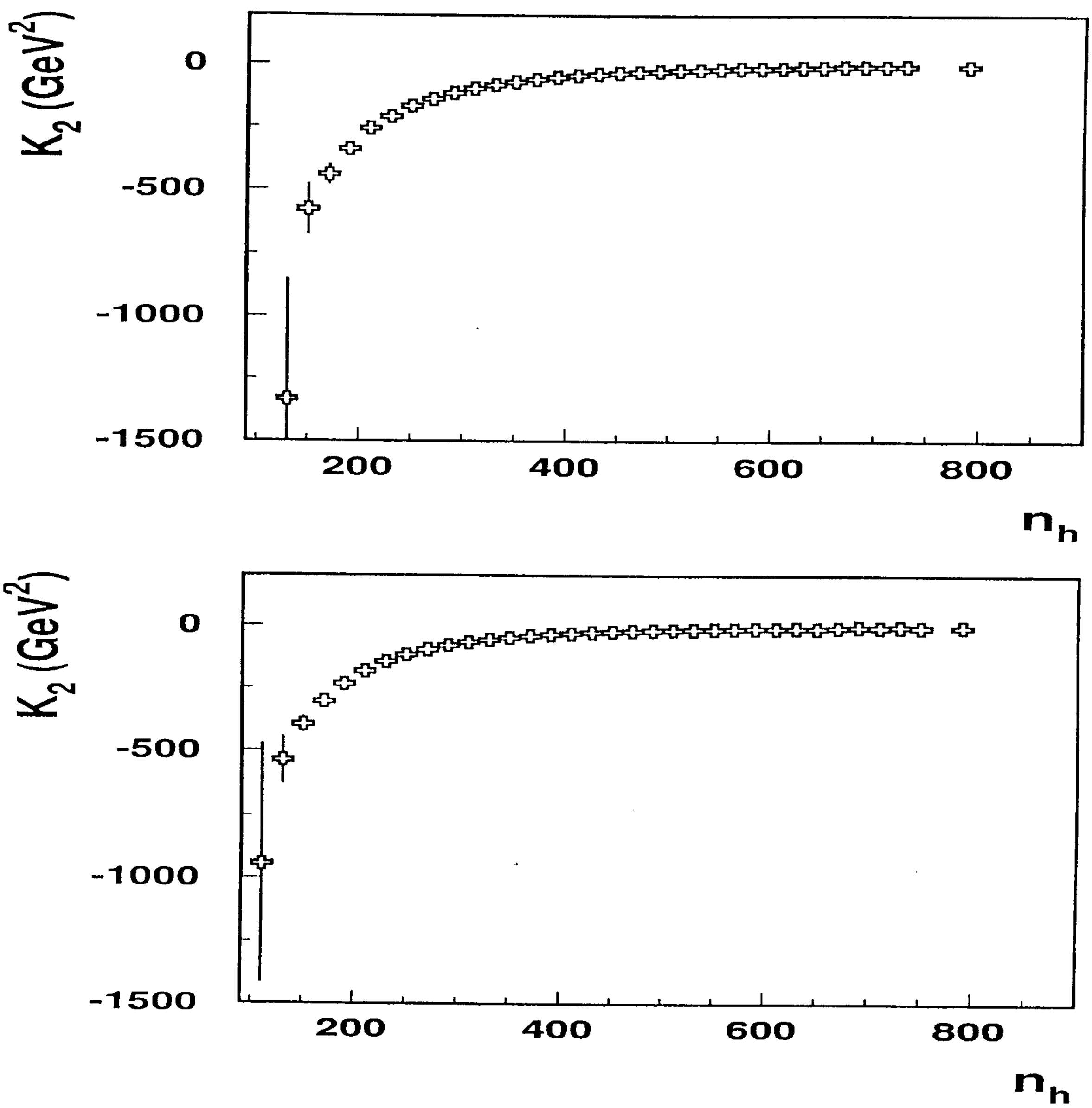


Figure 8: Dependent of $K_2(\varepsilon, n_h)$ from number of hadrons. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

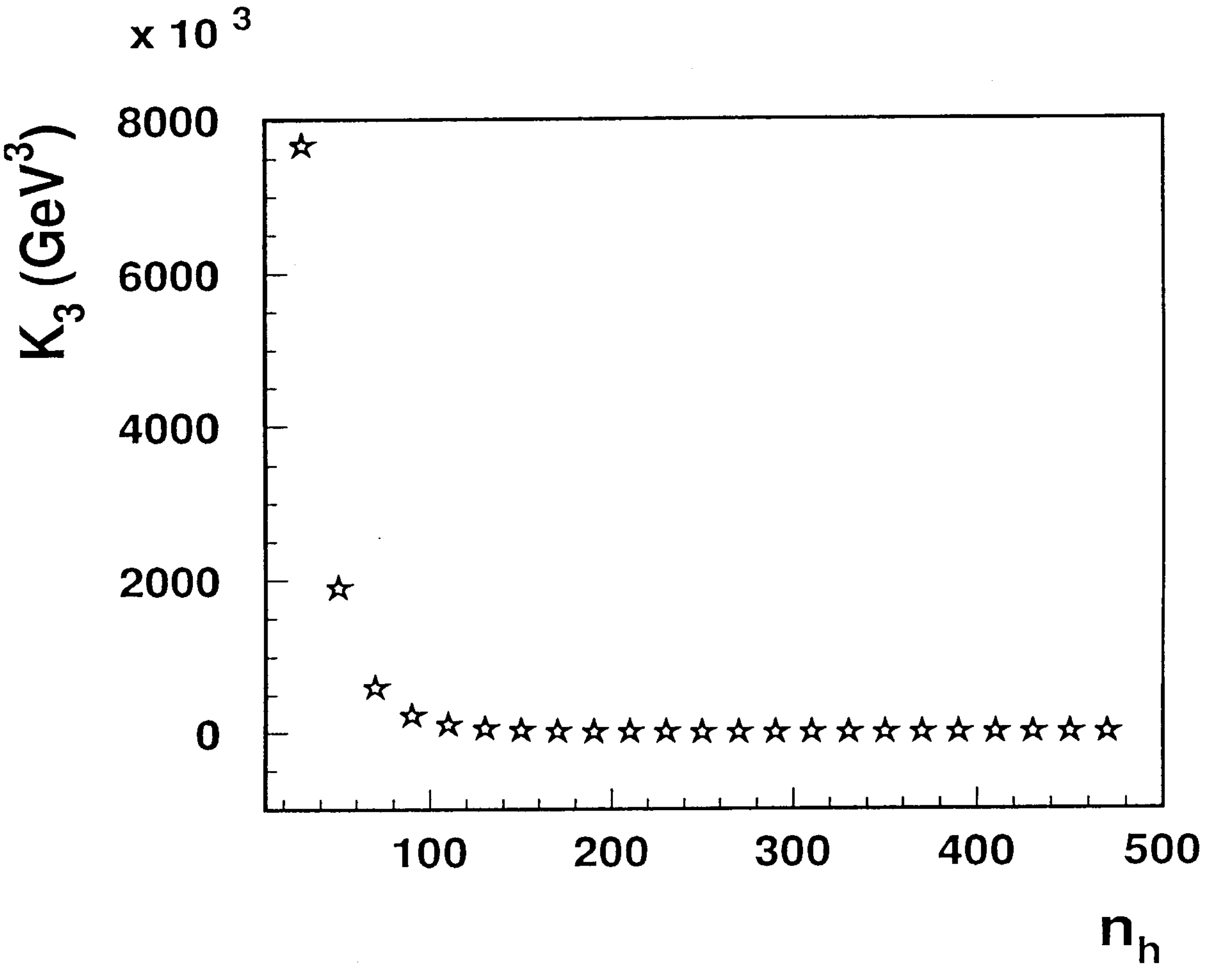


Figure 9: **Dependent of $K_3(\varepsilon, n_h)$ from number of hadrons without cut on the p_t**

$$
\begin{aligned}
&K_3(\varepsilon_1, \varepsilon_2, \varepsilon_3; n_h) = \\
&= \langle[(\varepsilon_1; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_2; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_3; n_h) - \langle\varepsilon; n_h\rangle]\rangle = \\
&= \langle\varepsilon^3; n_h\rangle - 2\langle\varepsilon^2; n_h\rangle\langle\varepsilon; n_h\rangle + \langle\varepsilon; n_h\rangle^3
\end{aligned}
$$

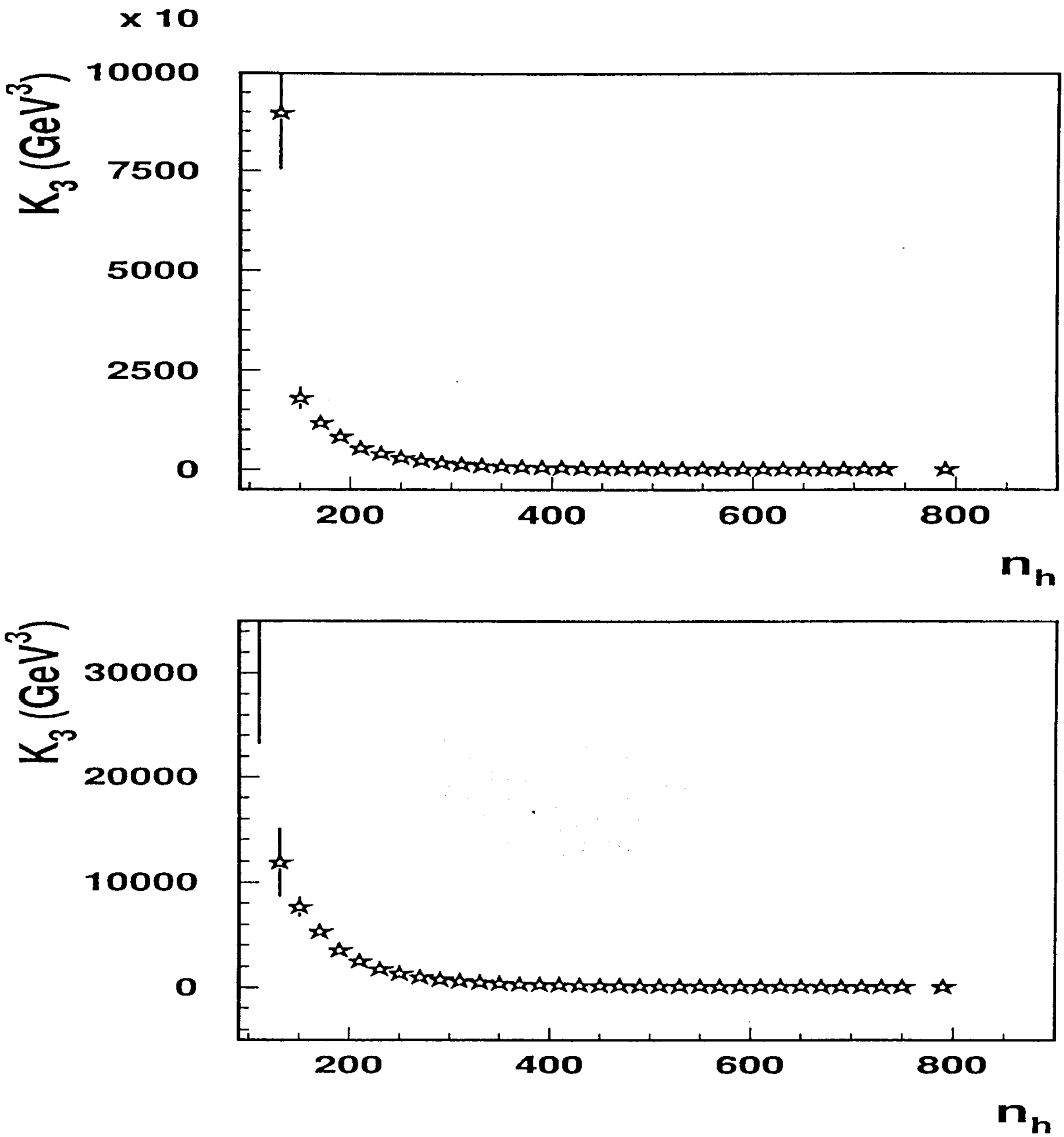


Figure 10: **Dependent of $K_3(\varepsilon, n_h)$ from number of hadrons. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)**

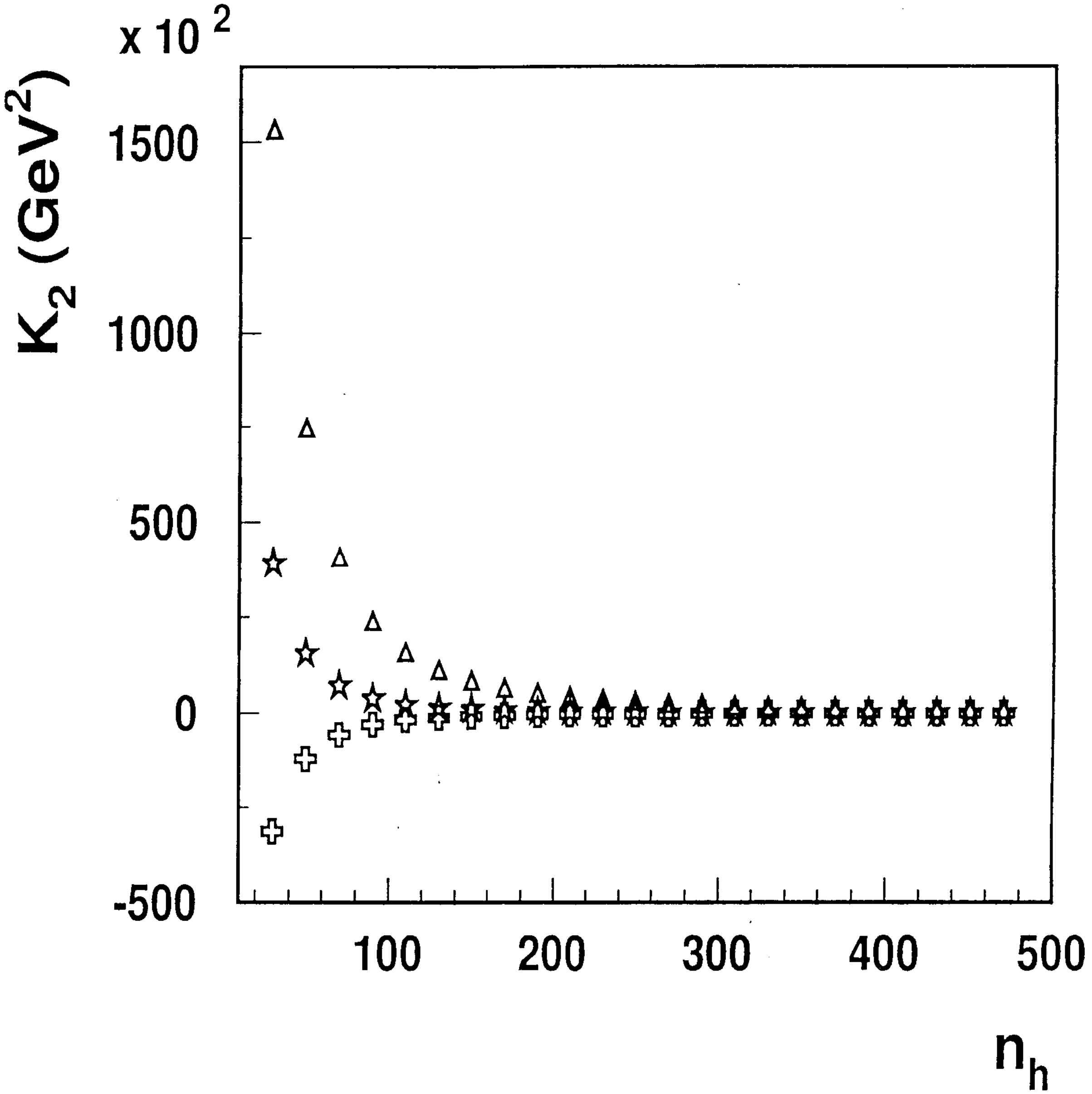


Figure 11: Dependent of K_1^2 (triangles), K_2 (crosses) and $K_3^{2/3}$ (stars) from number of hadrons without cut on the p_t

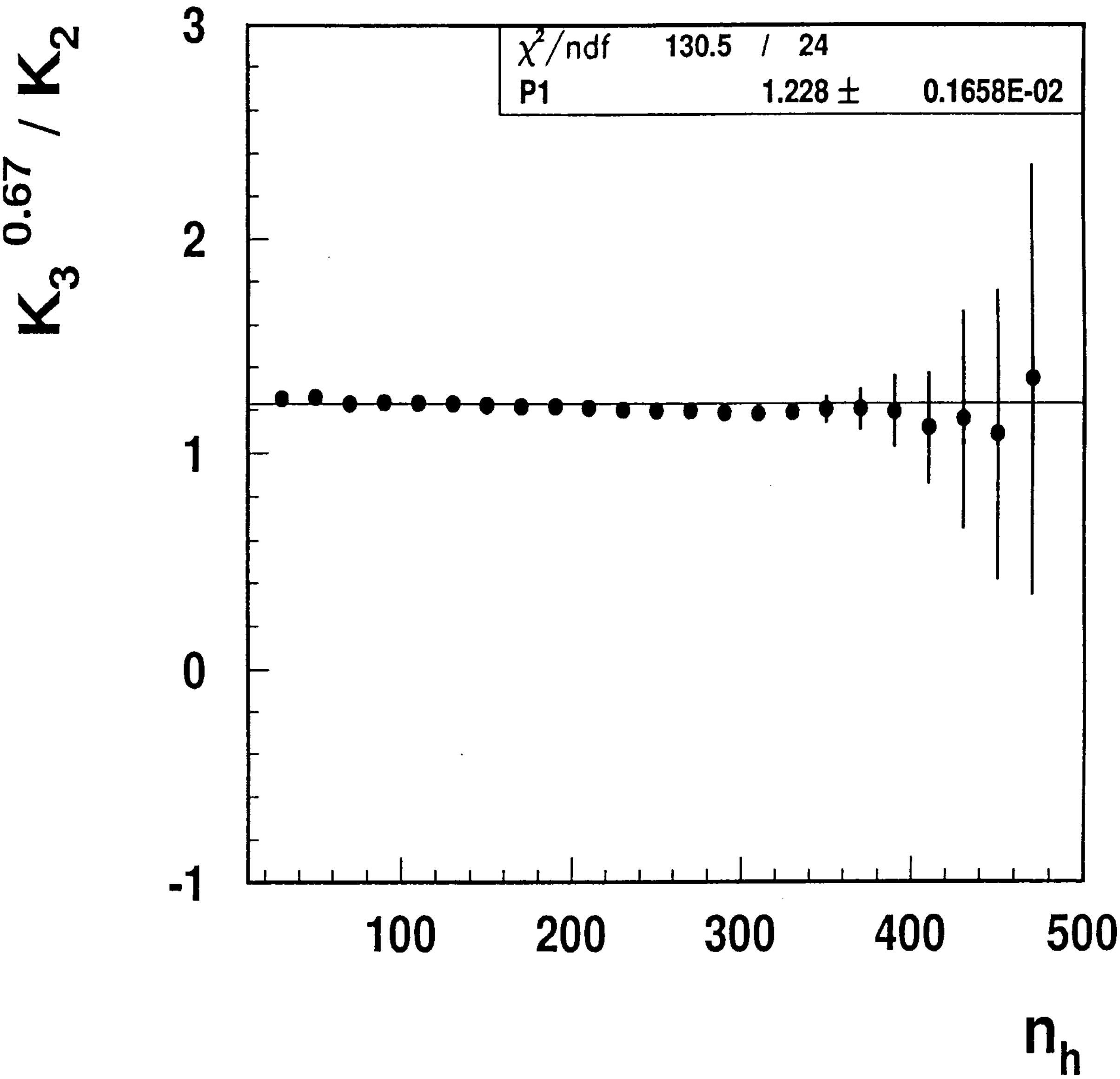


Figure 12: Dependent of Ratio $K_3^{2/3}/K_2$ from number of hadrons without cut on the p_t

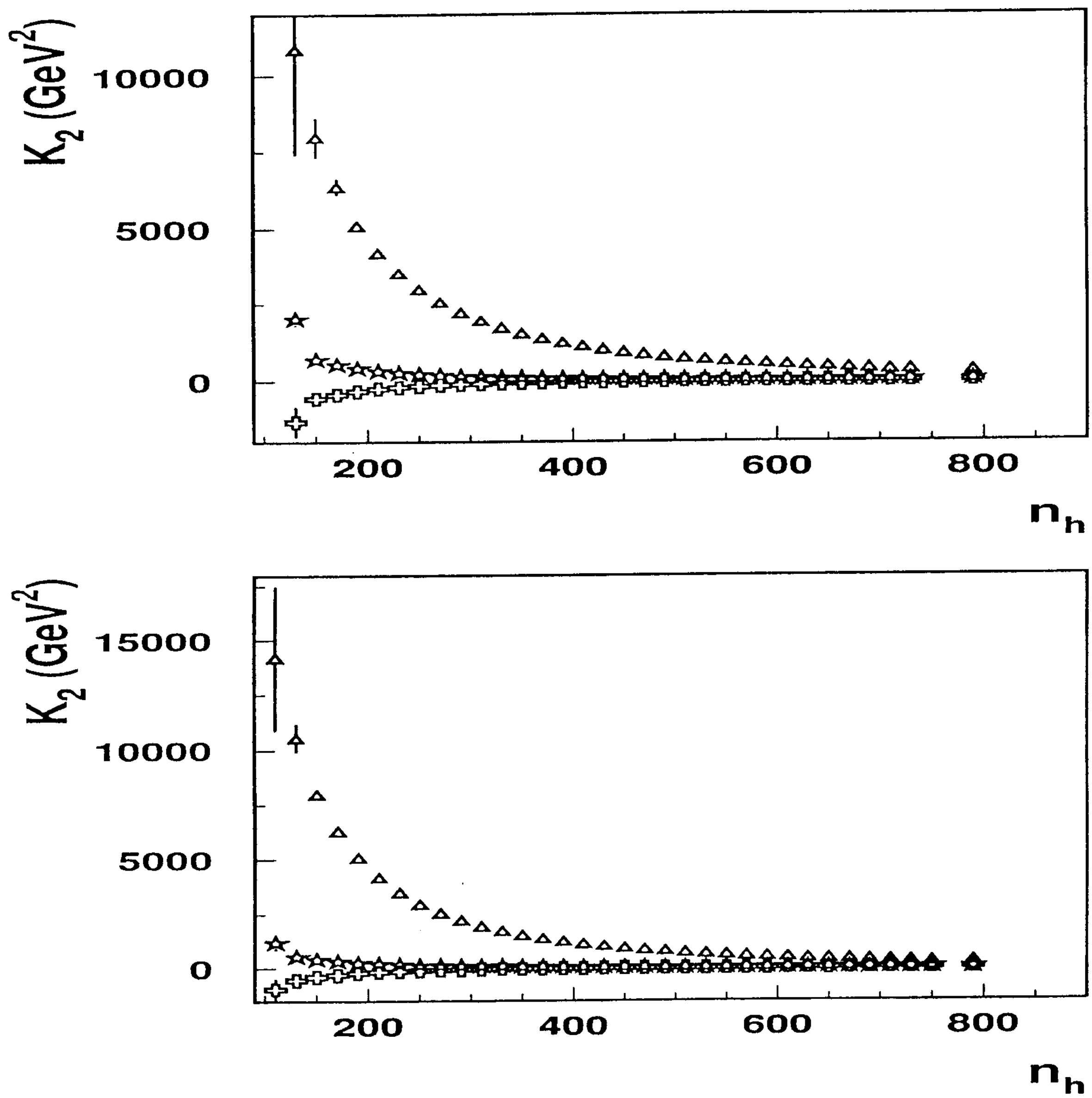


Figure 13: Dependent of K_1^2 (triangles), K_2 (crosses) and $K_3^{2/3}$ (stars) from number of hadrons. Colored partons transverse momentum cutoff is p_t = 1000 GeV (top) and p_t = 3000 GeV (bottom)

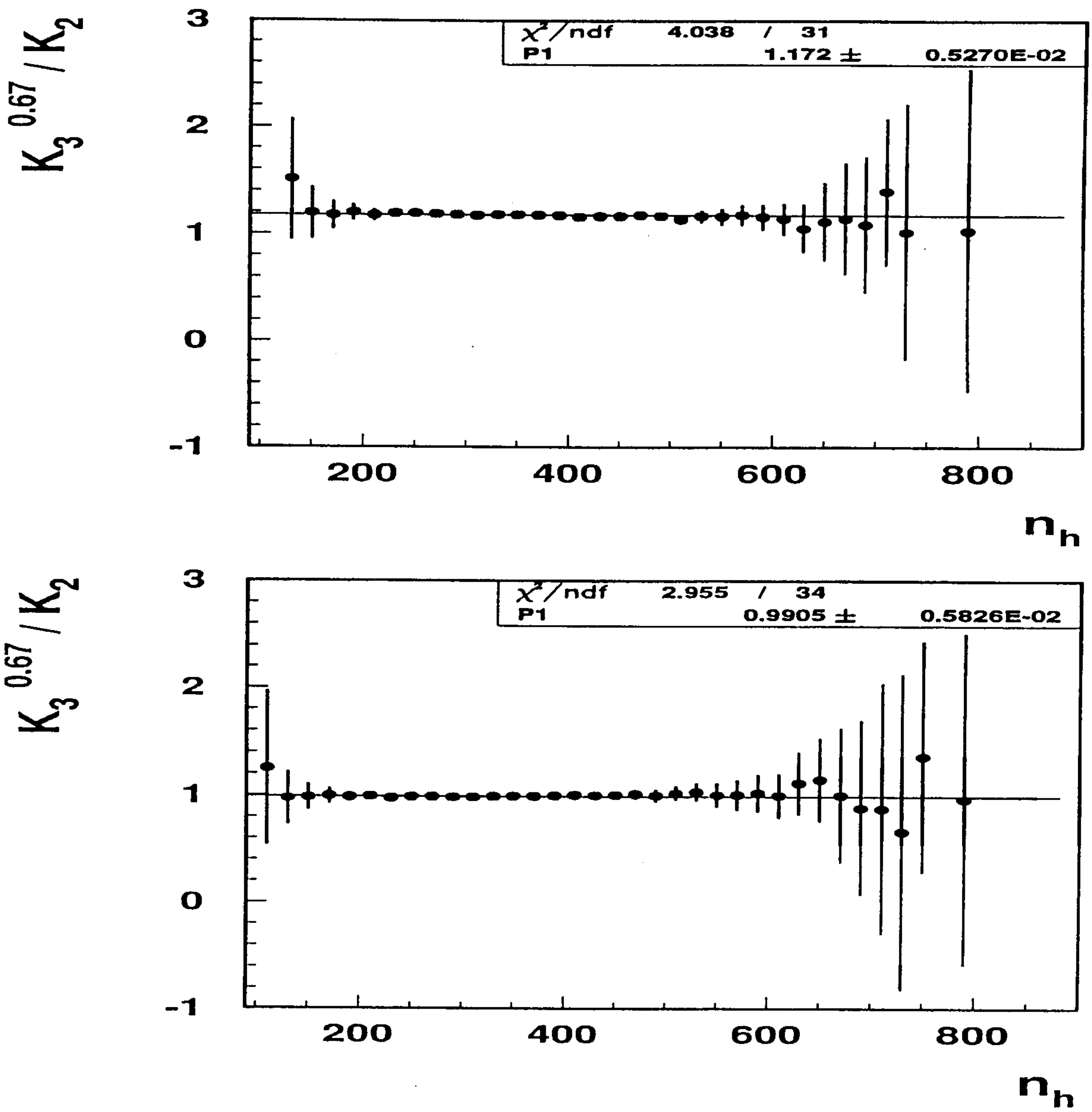


Figure 14: Dependent of ratio $K_3^{2/3}/K_2$ from number of hadrons. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

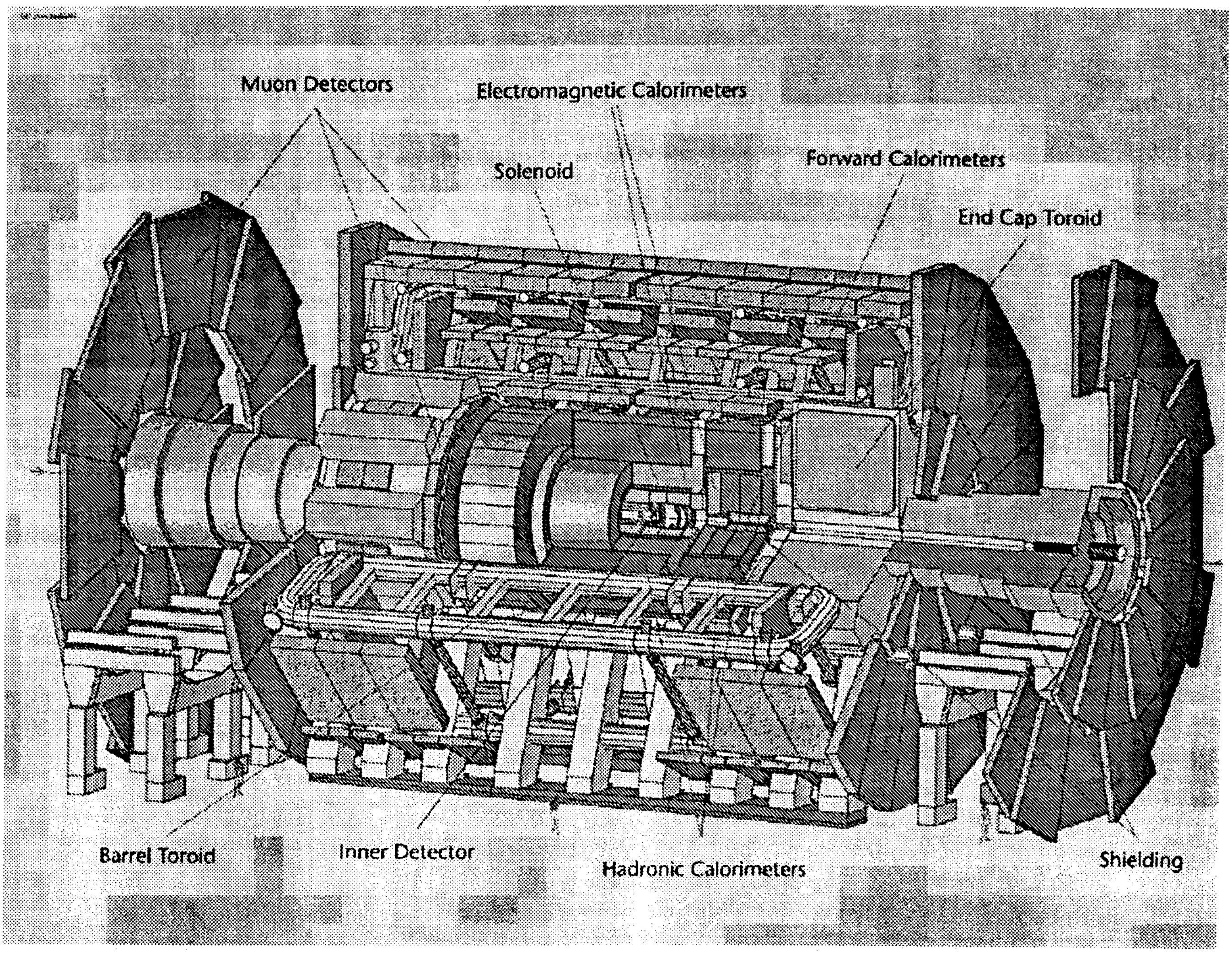


Figure 15: Overall layout of the ATLAS Detector

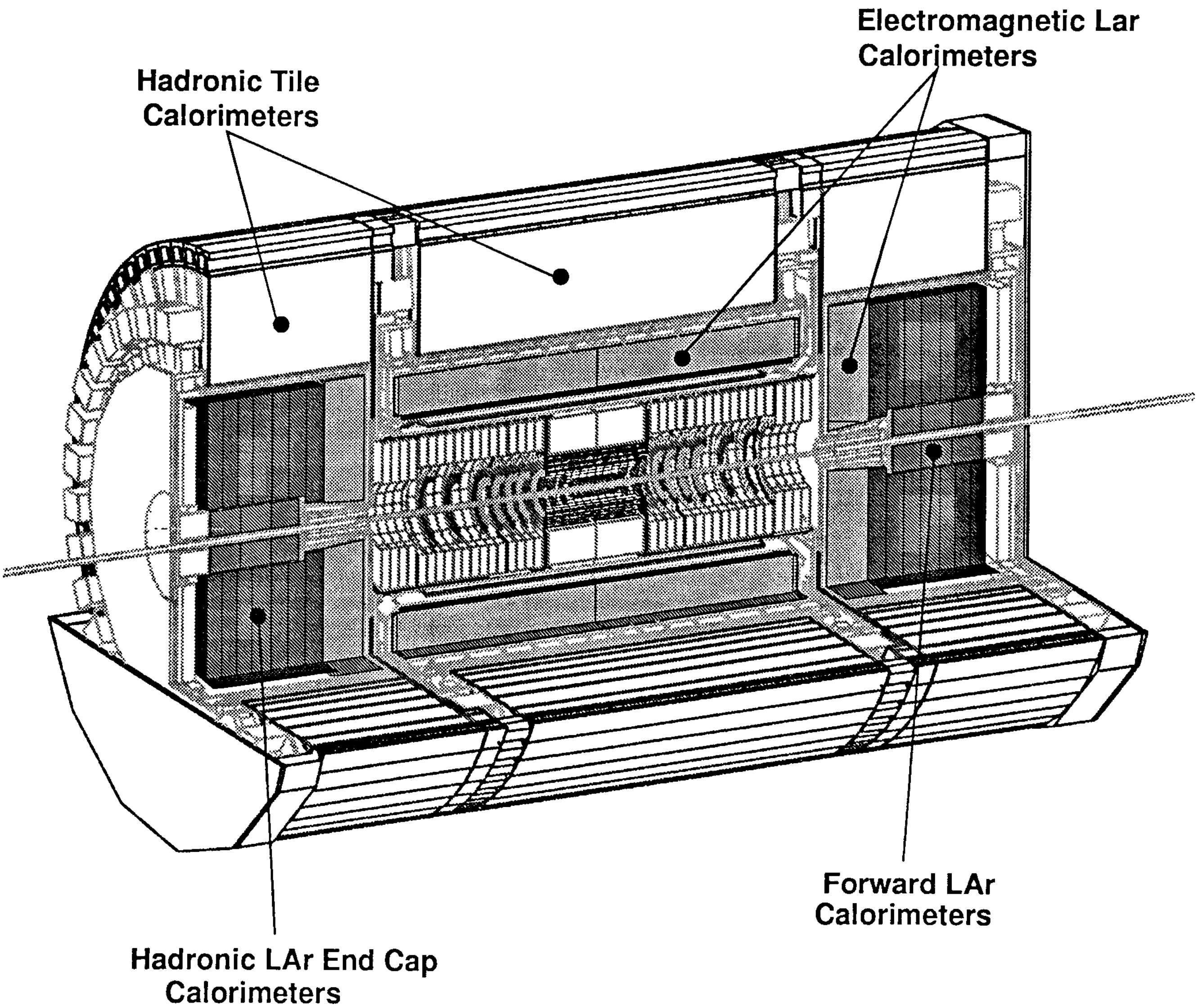


Figure 16: Three-dimensional view of the ATLAS Calorimetry

2.2 ATLFAST prediction for "tower" energy correlators

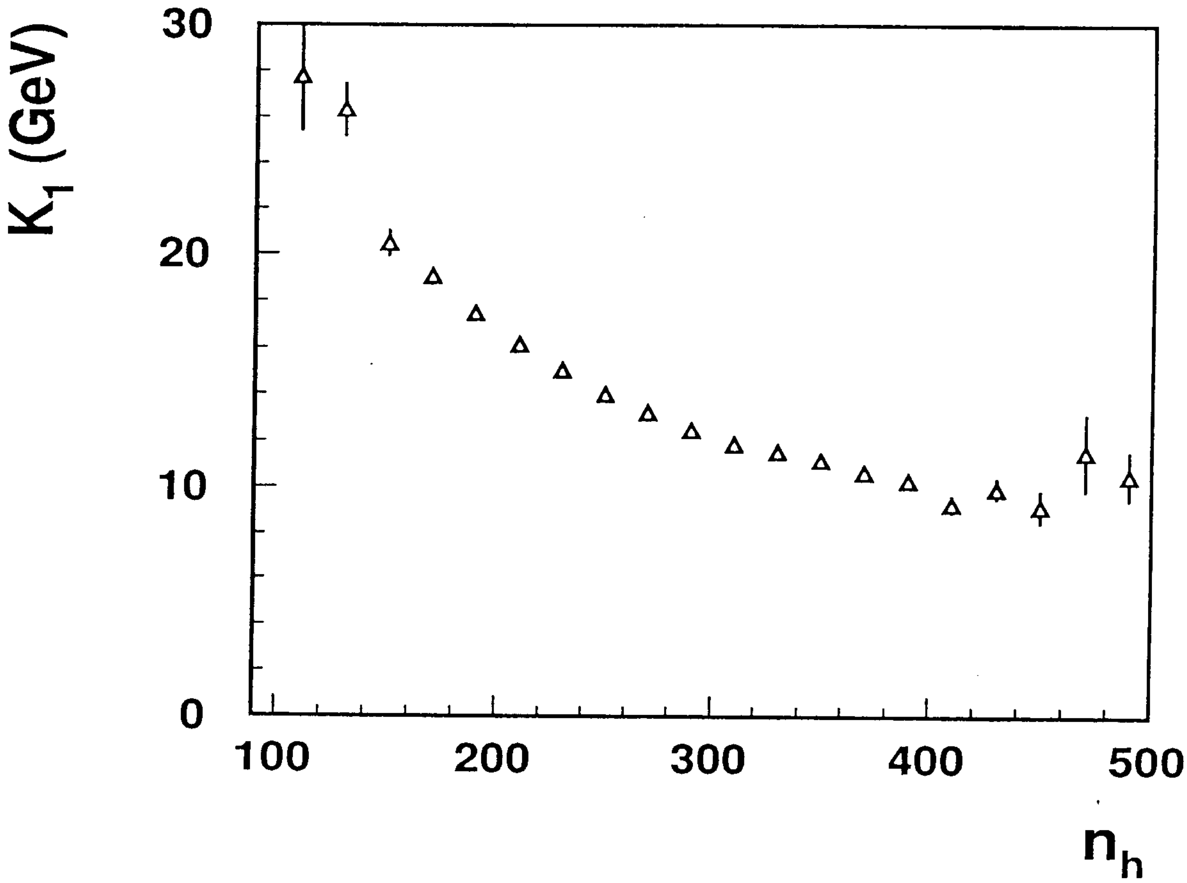


Figure 17: **Dependent of $K_1(\varepsilon, n_h)$ from number of hadrons with cut on the $p_t = 500$ GeV**

— ε - energy deposed in the "tower"
— $dN_n/d\varepsilon$ - number of events with energy ε in the "tower"

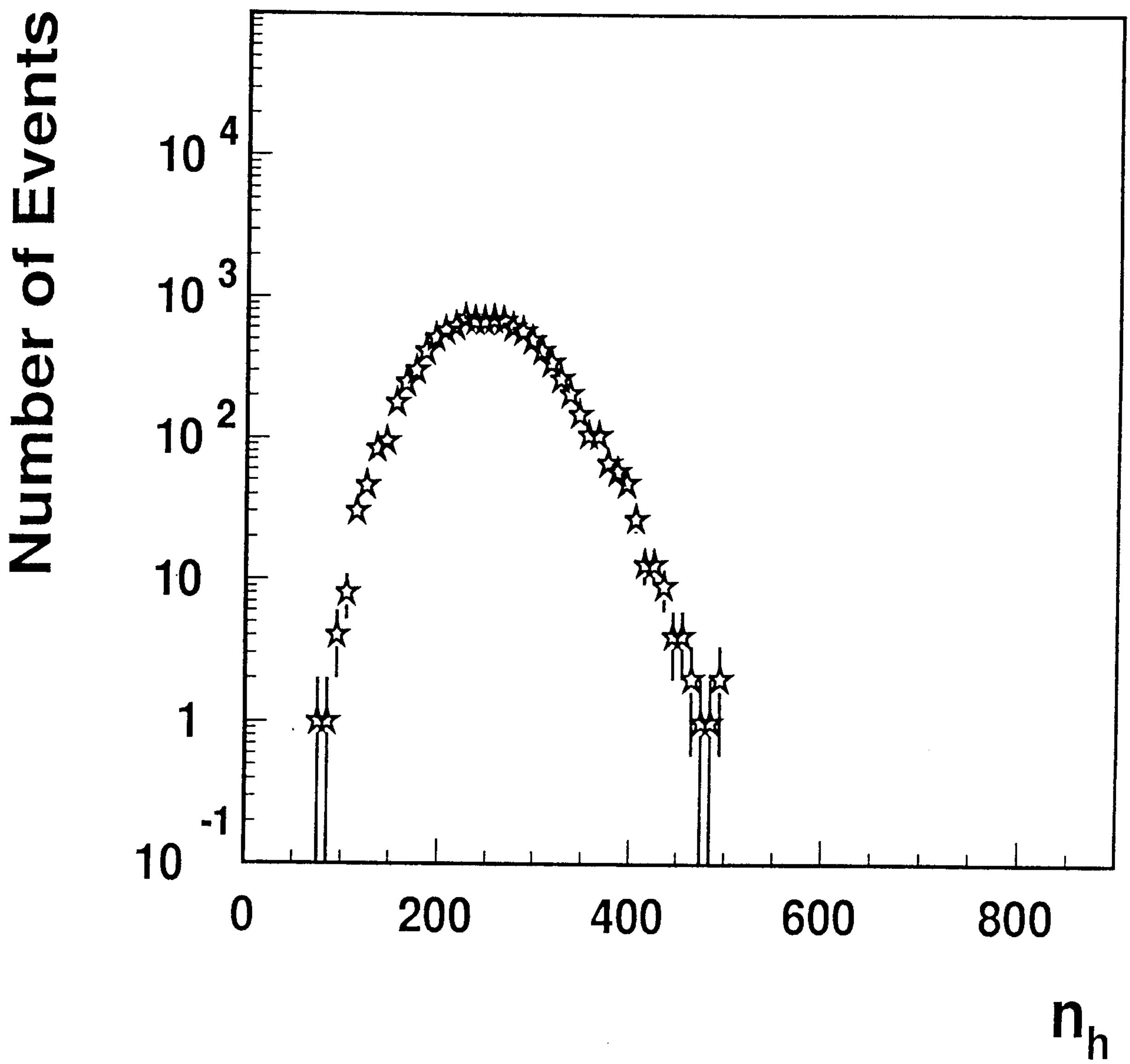


Figure 18: Multiplicity distribution. With colored partons transverse momentum cutoff $p_t = 500$ GeV

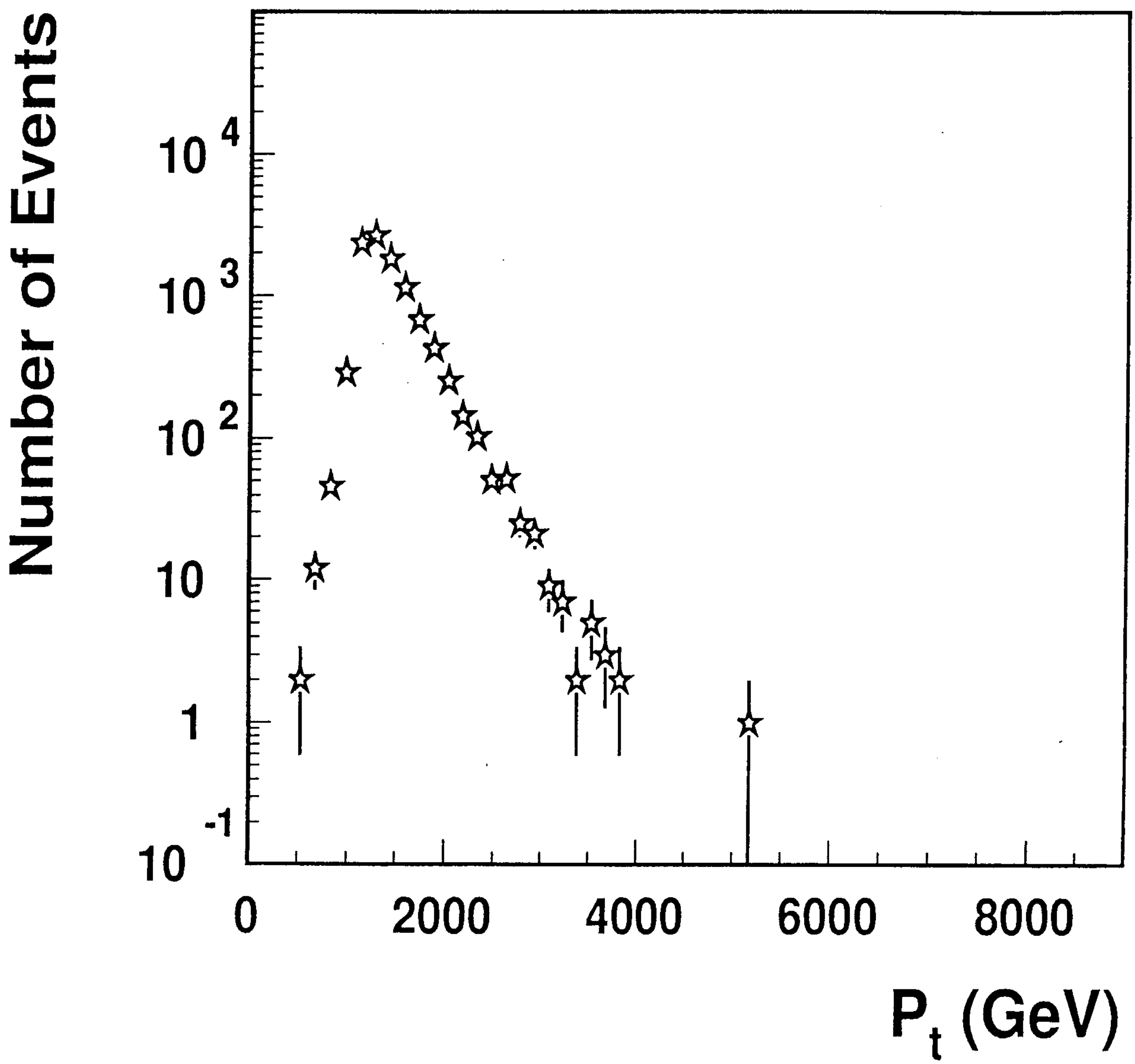


Figure 19: p_t distribution. With colored partons transverse momentum cutoff $p_t = 500$ GeV

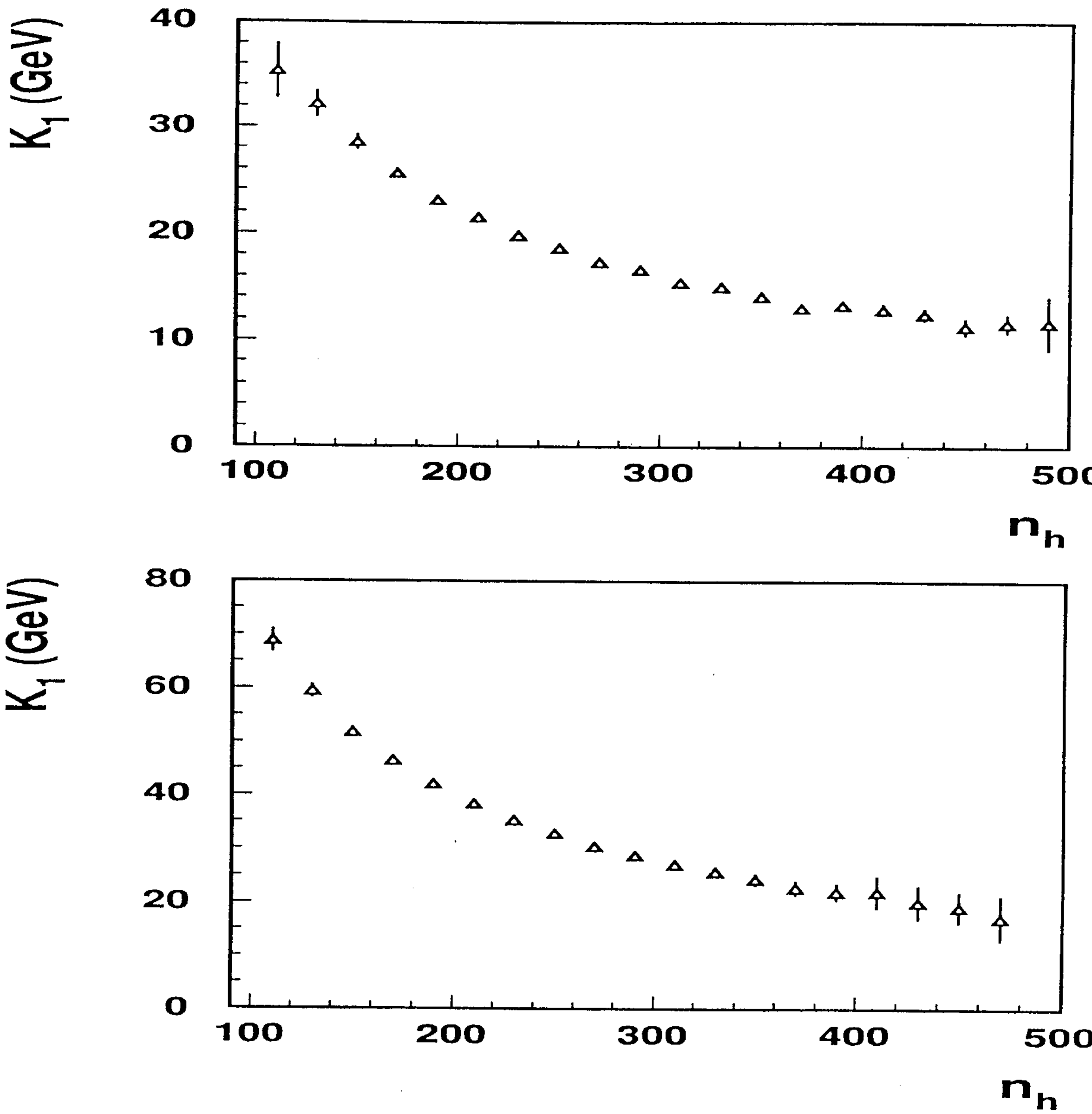


Figure 20: Dependent of $K_1(\varepsilon, n_h)$ from number of calorimeter towers. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

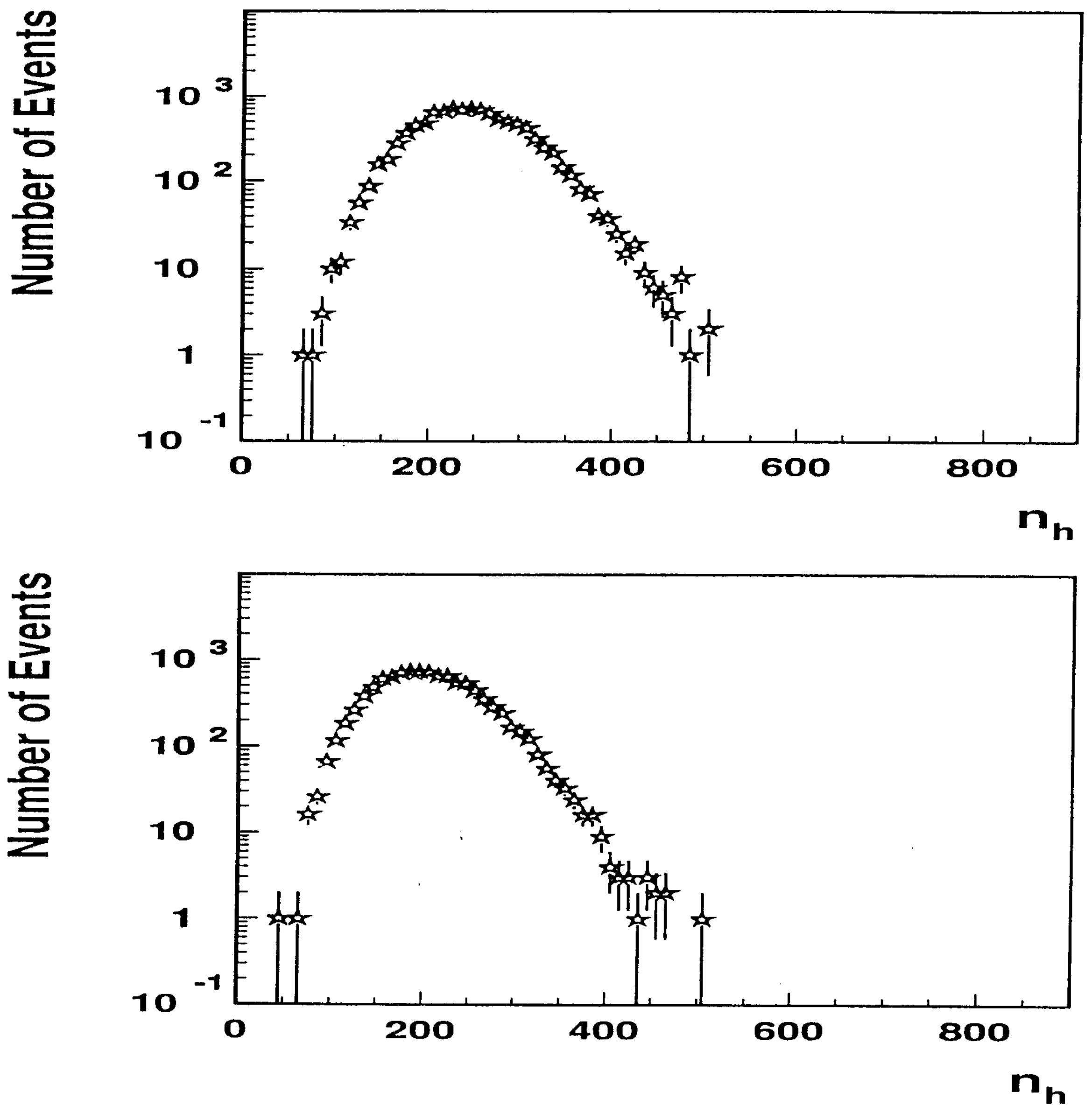


Figure 21: Multiplicity distribution. Colored partons transverse momentum cutoff is p_t = 1000 GeV (top) and p_t = 3000 GeV (bottom)

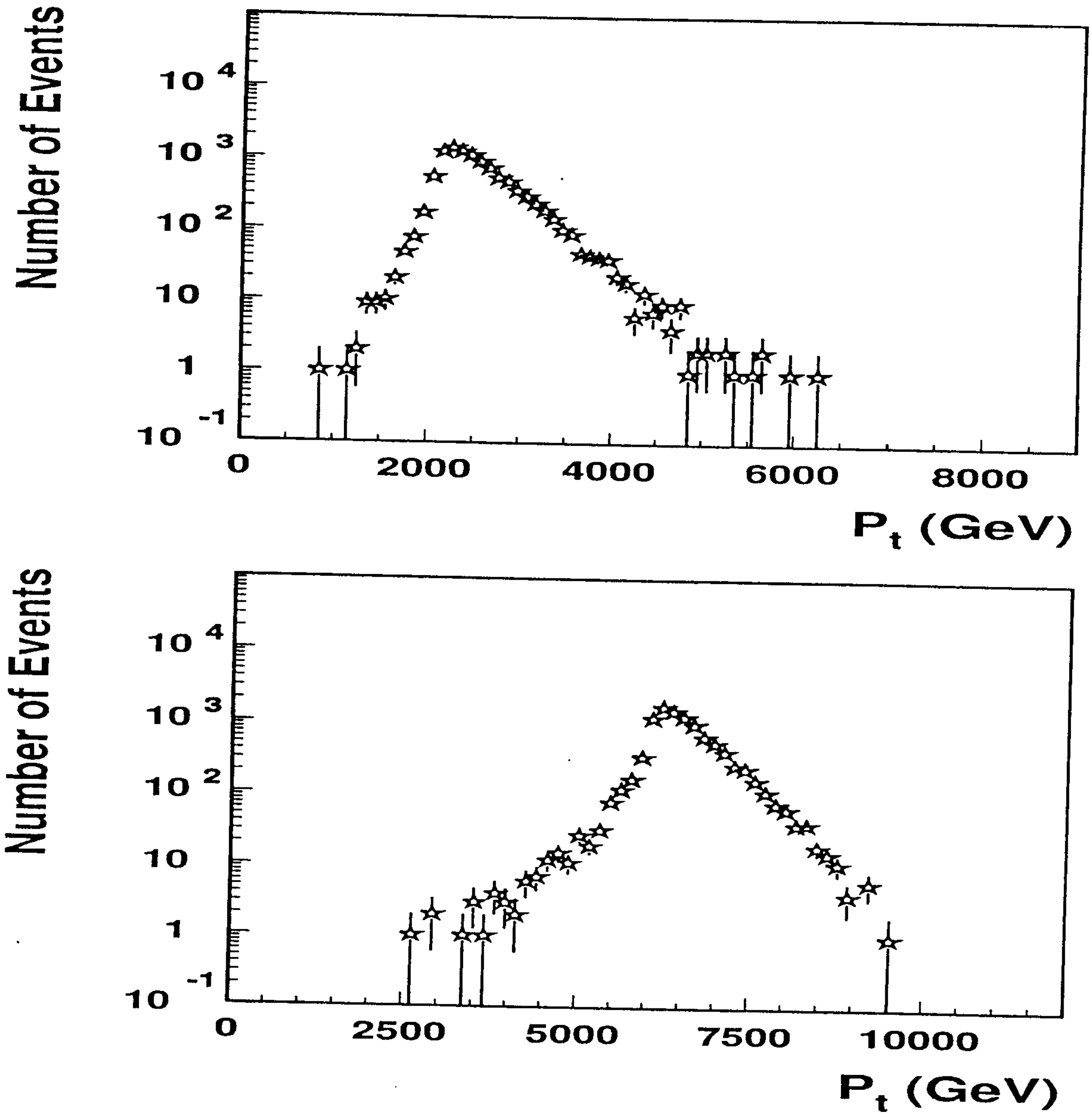


Figure 22: p_t distribution. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

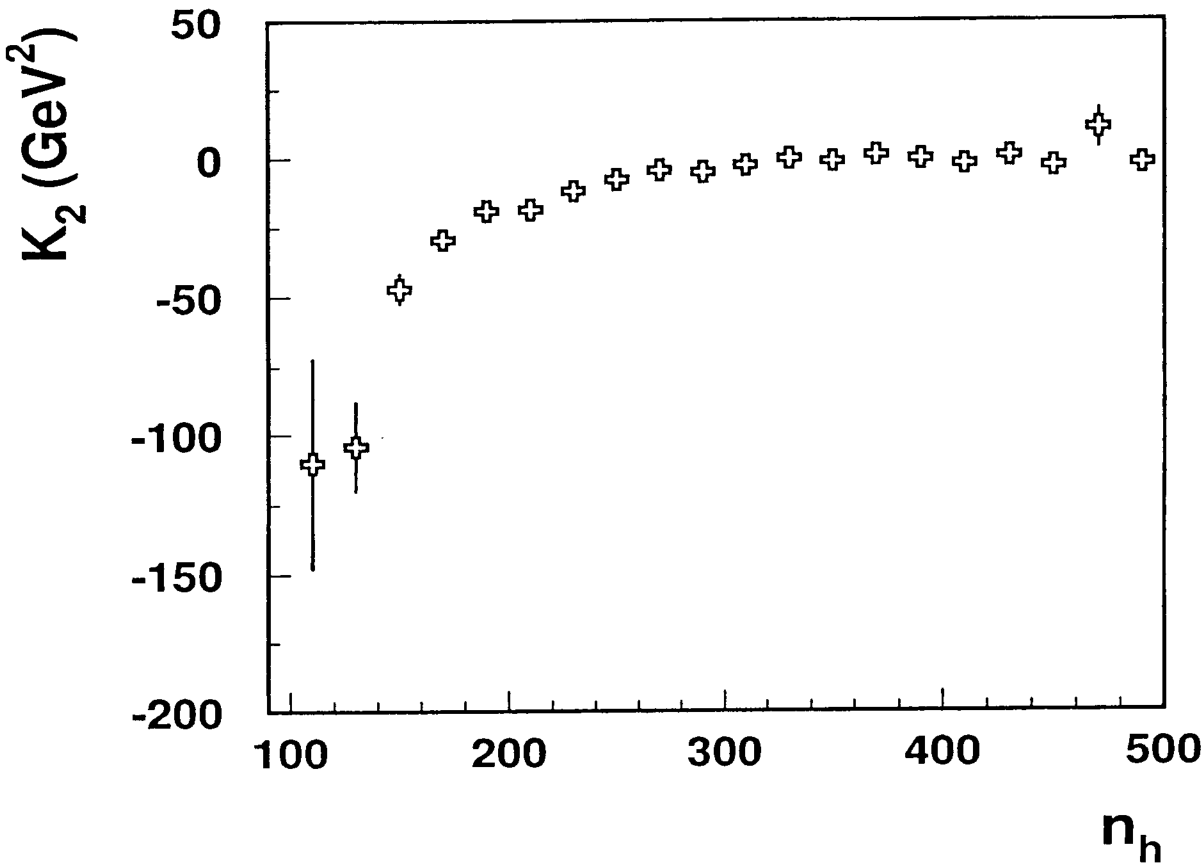


Figure 23: **Dependent of $K_2(\varepsilon, n_h)$ from number of calorimeter towers with cut on the $p_t = 500$ GeV**

$$K_2(\varepsilon_1, \varepsilon_2; n_h) = \langle[(\varepsilon_1; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_2; n_h) - \langle\varepsilon; n_h\rangle]\rangle$$
$$= \langle\varepsilon^2; n_h\rangle - \langle\varepsilon; n_h\rangle^2$$

$$\langle\varepsilon^2; n_h\rangle = \frac{1}{N_n}\int \varepsilon_1 d\varepsilon_1\ \varepsilon_2 d\varepsilon_2 \frac{d^2N_n}{d\varepsilon_1 d\varepsilon_2}$$

— $d^2N_n/d\varepsilon_1 d\varepsilon_2$ - number of events with multiplicity n_h and **particles** with energy ε_1 and ε_2

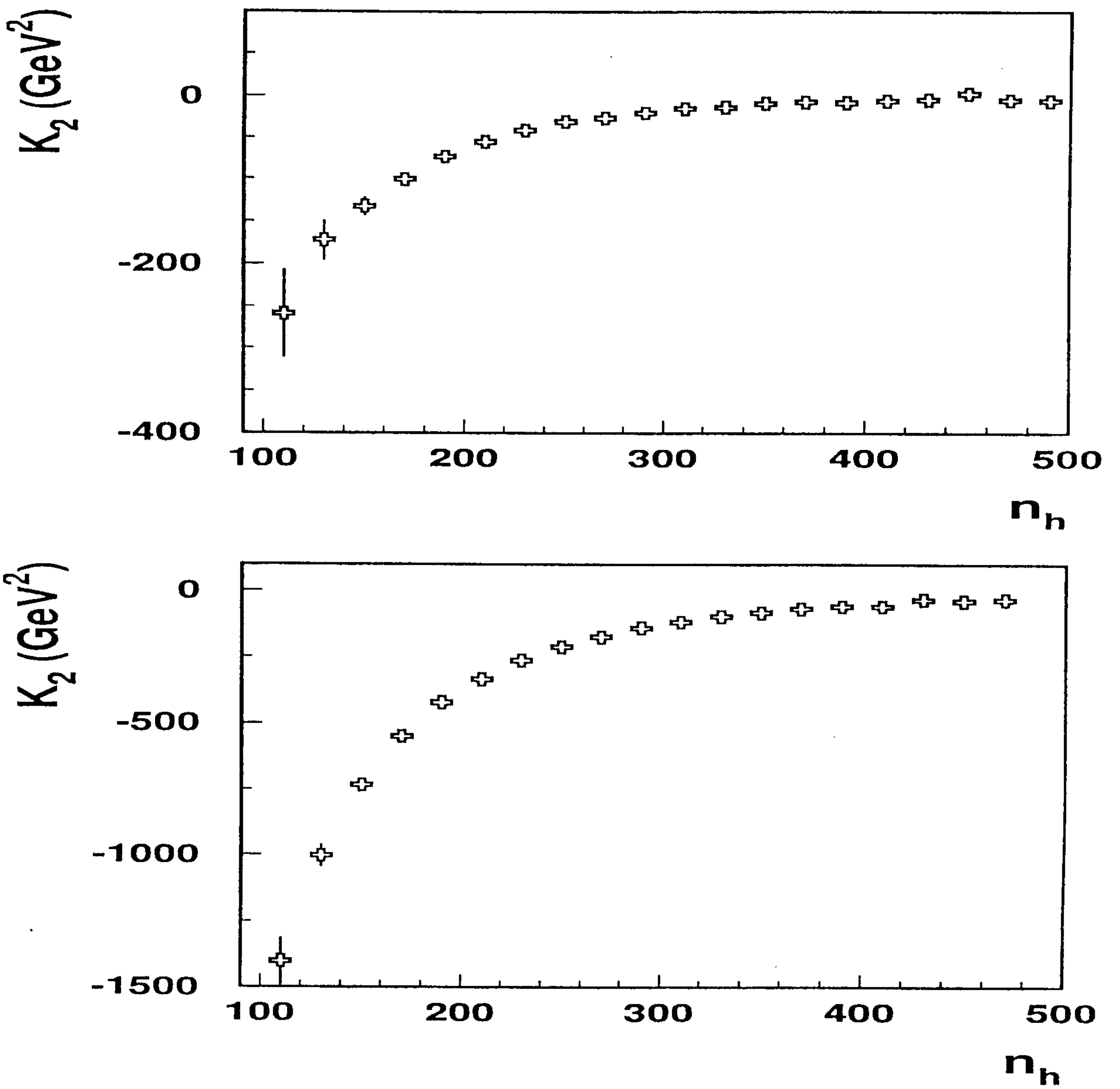


Figure 24: Dependent of $K_2(\varepsilon, n_h)$ from number of calorimeter towers. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

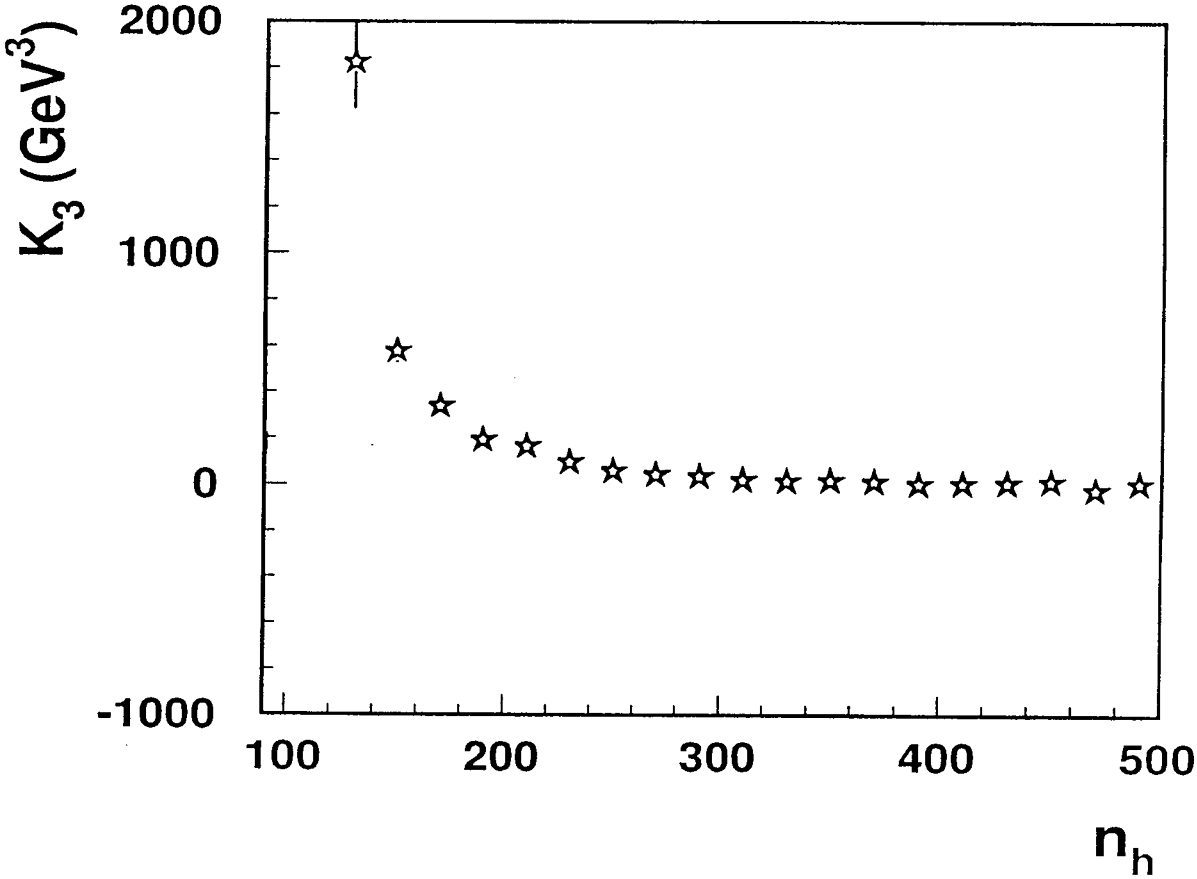
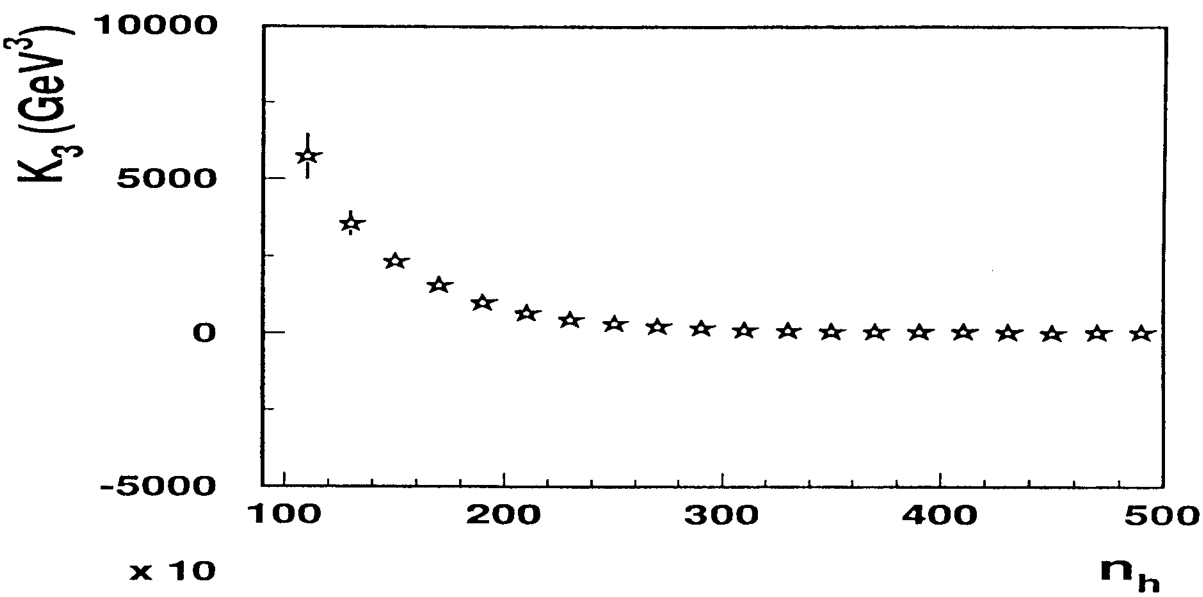


Figure 25: **Dependent of $K_3(\varepsilon, n_h)$ from number of calorimeter towers with cut on the $p_t = 500$ GeV**

$$K_3(\varepsilon_1, \varepsilon_2, \varepsilon_3; n_h) =$$
$$= \langle[(\varepsilon_1; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_2; n_h) - \langle\varepsilon; n_h\rangle][(\varepsilon_3; n_h) - \langle\varepsilon; n_h\rangle]\rangle =$$
$$= \langle\varepsilon^3; n_h\rangle - 2\langle\varepsilon^2; n_h\rangle\langle\varepsilon; n_h\rangle + \langle\varepsilon; n_h\rangle^3$$



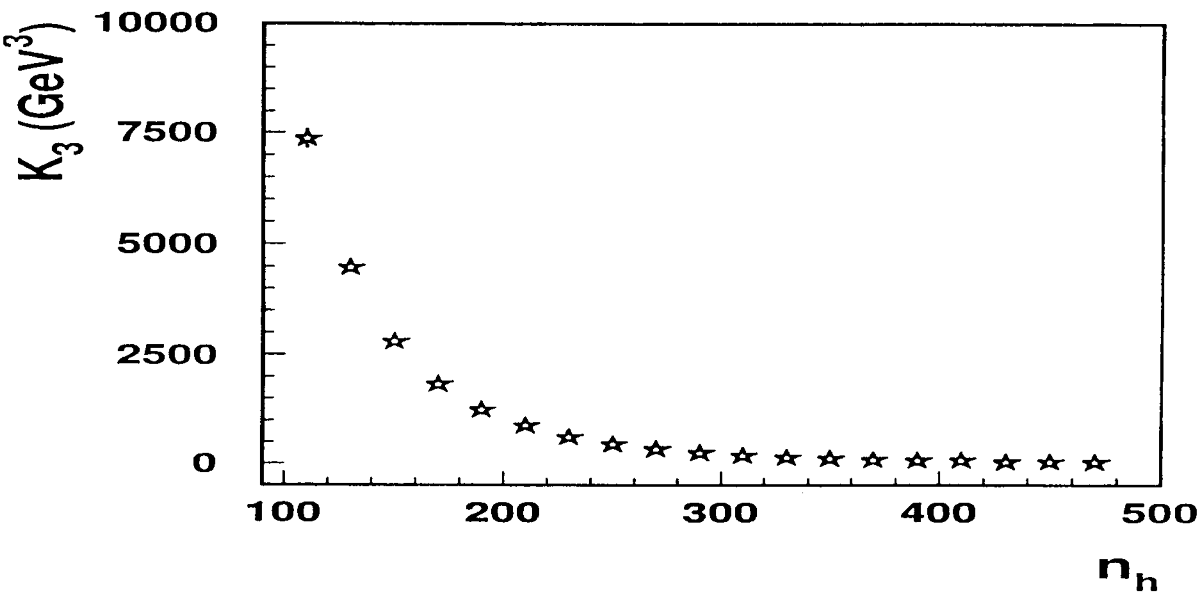


Figure 26: Dependent of $K_3(\varepsilon, n_h)$ from number of calorimeter towers. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

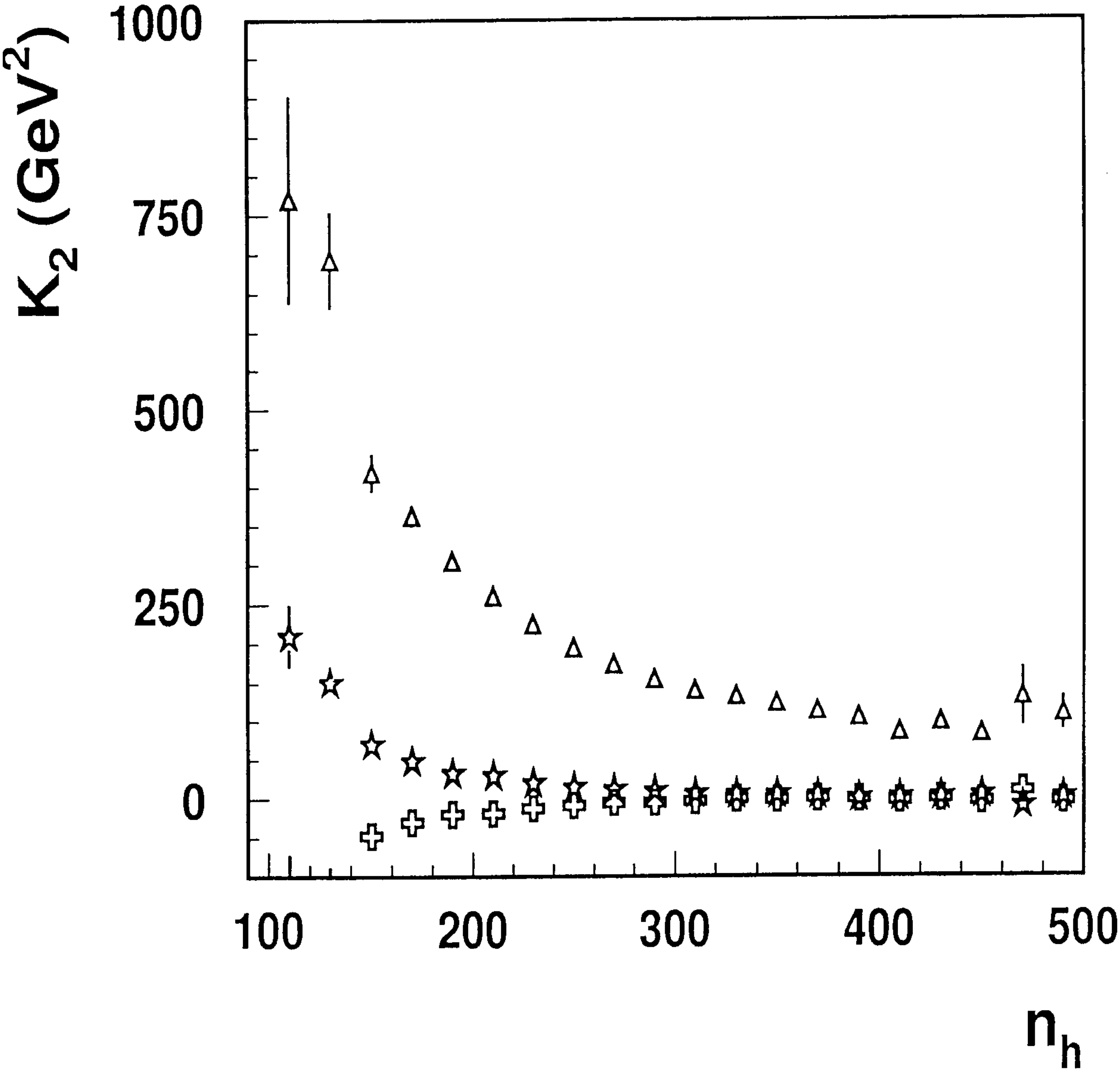


Figure 27: **Dependent of K_1^2 (triangles), K_2 (crosses) and $K_3^{2/3}$ (stars) from number of calorimeter towers with cut on the $p_t = 500$ GeV**

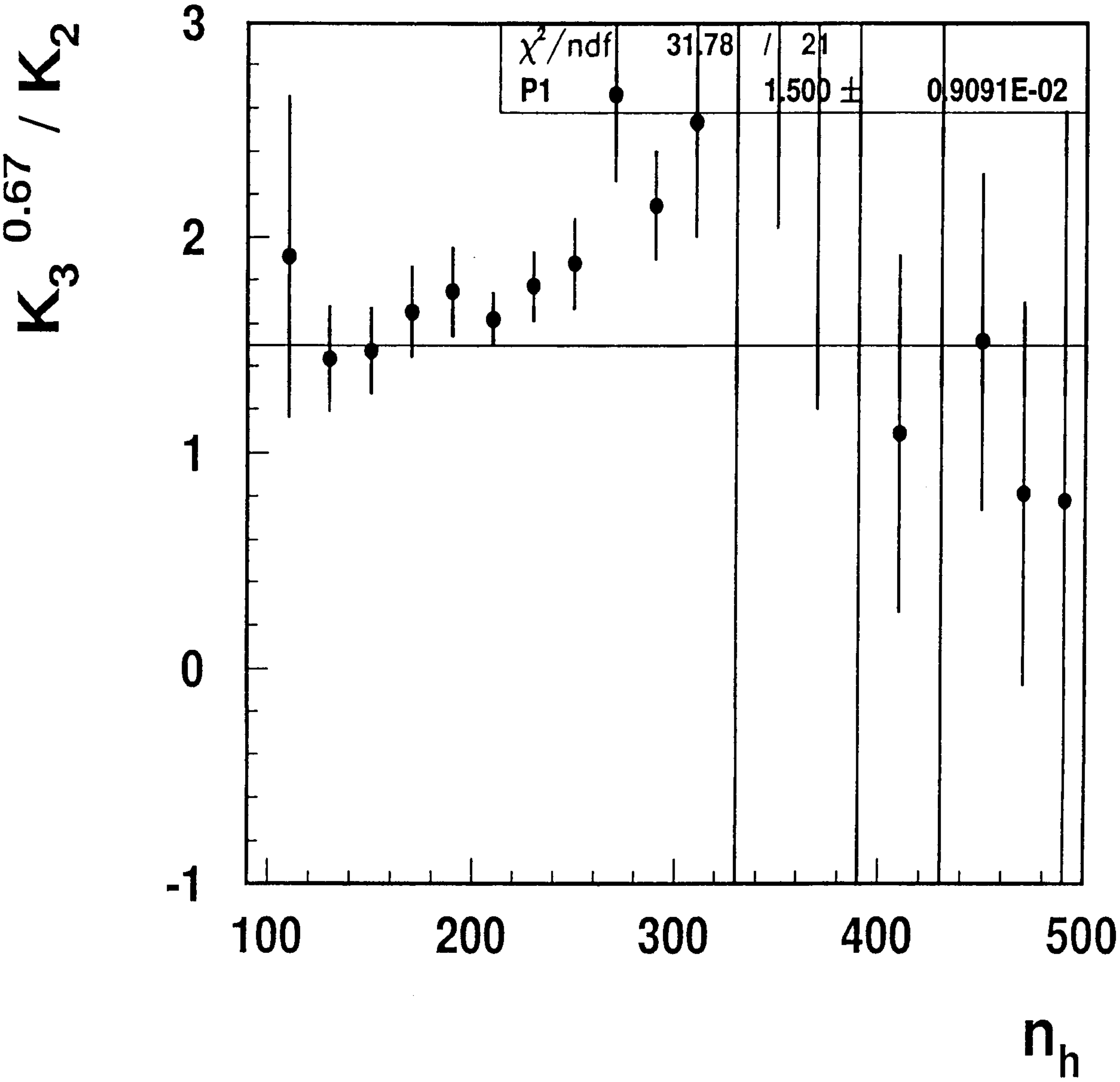
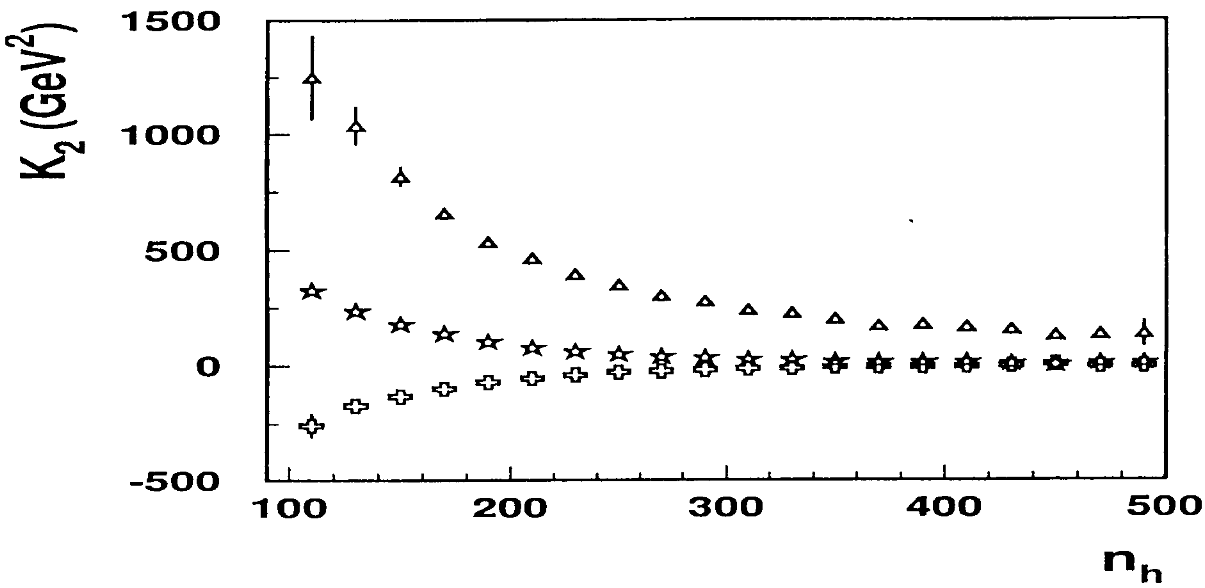


Figure 28: **Dependent of Ratio $K_3^{2/3}/K_2$ from number of calorimeter towers with cut on the $p_t = 500$ GeV**



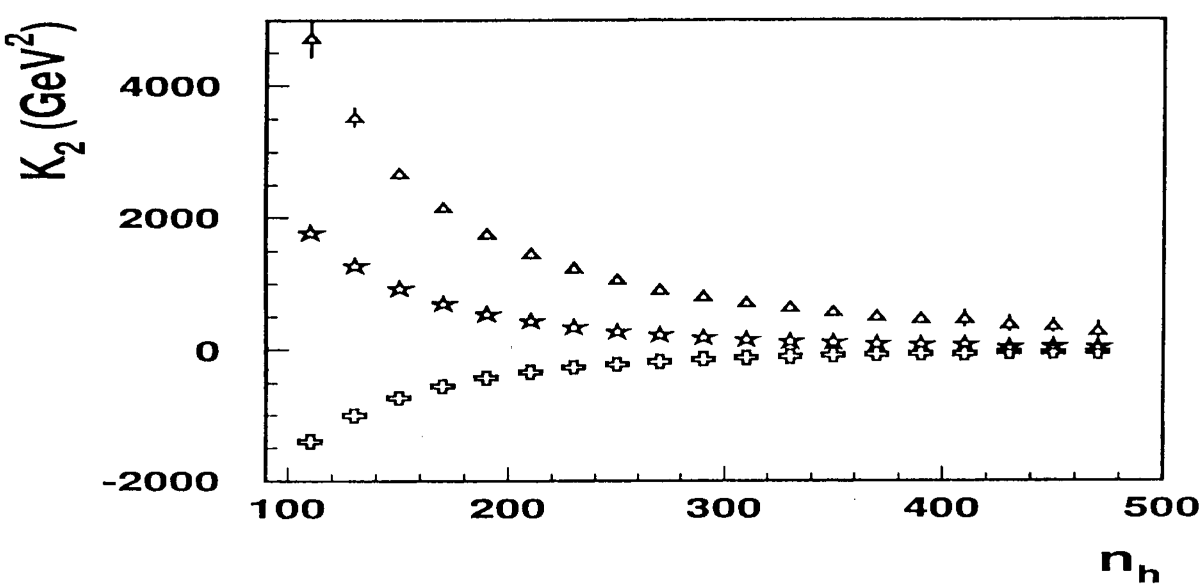
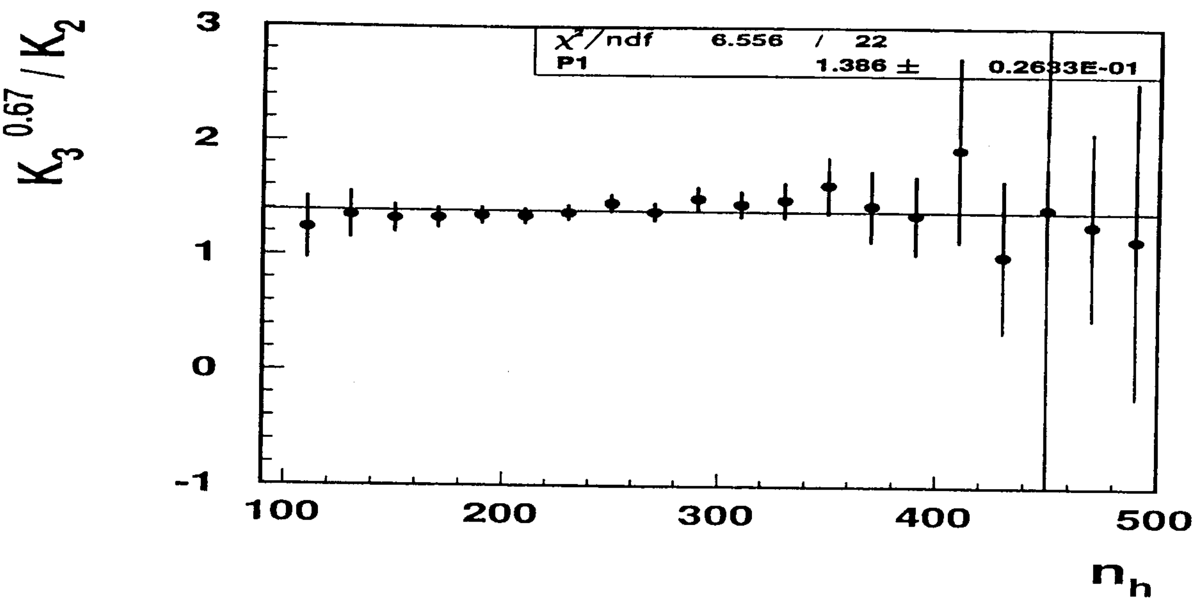


Figure 29: Dependent of K_1^2 (triangles), K_2 (crosses) and $K_3^{2/3}$ (stars) from number of towers. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)



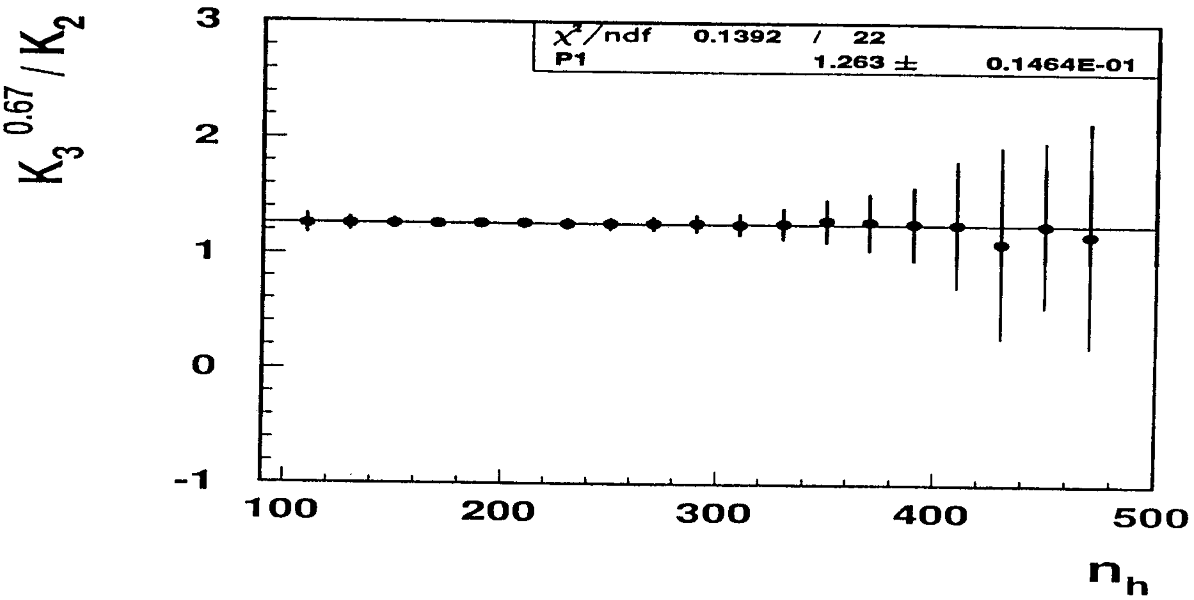


Figure 30: Dependent of ratio $K_3^{2/3}/K_2$ from number of towers. Colored partons transverse momentum cutoff is $p_t = 1000$ GeV (top) and $p_t = 3000$ GeV (bottom)

3 Conclusion

- We preset results of calculation in PYTHIA correlators K_1, K_2, K_3 and ratio $R = \frac{K_3^{2/3}}{K_2}$ versus number of hadrons.

- $R = \frac{K_3^{2/3}}{K_2} \simeq 1$ for all p_t cuts and does not agree with Sissakian-Manjavidze prediction for VHM $R = \frac{K_3^{2/3}}{K_2} \ll 1$. The PYTHIA can not predict the **tendency** to equilibrium.

- Using ATLFAST we calculated correlators K_1, K_2, K_3 and ratio $R = \frac{K_3^{2/3}}{K_2}$ versus number of ATLAS calorimeter towers with hit.

- The correlators K_1, K_2, K_3 have the same dependencies for hadrons and for ATLAS Calorimeter towers.
$R_{towers} \approx 1.1 \cdot R_{hadrons}$.